BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2022

K.J. Palof, and M.S.M. Siddeek
Alaska Department of Fish and Game
Division of Commercial Fisheries
P.O. Box 115526
Juneau, AK 99811-5526, USA
Phone: (907) 465-4226
Fax: (907) 465-2604
Email: katie.palof@alaska.gov

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 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 abundances 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 2022 is approximately 43% of the estimate mean survey biomass for the entire time series. The estimated mature female biomass has also been very low during the last four years, with the 2022 values begin approximately 42% of the mean. The estimated mature female abundance was below the state of Alaska harvest strategy threshold of 8.4 million of crab for a fishery opening in 2022.
4. Recruitment: Estimated recruitment was high during the 1970s and early 1980s and has generally been low since 1985 (1979-year class). During 1984-2020, estimated recruitment was above the historical average (1976-2019 reference years) only in 1984, 1986, 1990, 1995, 1999, 2002, and 2005. Estimated recruitment was extremely low during the last 12 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:

Status and catch specifications (1,000 t) (model 21.1b):

Year	**MSST**	**Biomass (MMB)**	**TAC**	**Retained Catch**	**Total Catch**	**OFL**	**ABC**
2018/19	10.62^{B}	16.92^{B}	1.95	2.03	2.65	5.34	4.27
2019/20	12.72^{C}	14.24^{C}	1.72	1.78	2.22	3.40	2.72
2020/21	12.12^{D}	13.96^{D}	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		16.95				3.04	2.43

The stock was above MSST in 2021/22 (69% of BMSY) and hence was not overfished. Since total catch was below OFL, overfishing did not occur. The projection using the lowest recruitment periods during 2013-2021 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 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 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 CPT and SSC for ABC estimation for 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), in addition to low mature female biomass the last two years, all contribute to a recommended 20% buffer for 2022/23.

Status and catch specifications (million lb, model 21.1b):

Year	**MSST**	**Biomass (MMB)**	**TAC**	**Retained Catch**	**Total Catch**	**OFL**	**ABC**
2018/19	23.4^{B}	37.3^{B}	4.31	4.31	5.85	11.76	9.41
2019/20	28.0^{C}	31.4^{C}	3.80	3.91	4.89	7.50	6.00
2020/21	26.7^{D}	30.8^{D}	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		37.4				6.70	5.35

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2018

B – Calculated from the assessment reviewed by the Crab Plan Team in September 2019
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2020
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2021

6. Basis for the OFL: Values are in 1,000 t (model 21.1b):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2018/19	3b	25.5	20.8	0.82	0.25	1984-2017	0.18
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

Basis for the OFL: Values are in million lb:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2018/19	3b	56.2	45.9	0.82	0.25	1984-2017	0.18
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

A. Summary of Major Changes

1. Changes to management of the fishery: None.

2. Changes to the input data:

a. Updated groundfish fisheries bycatch data during 1986-2021.

b. Updated NMFS survey data for 2022, biomass and length compositions

c. Updated length composition data for directed and non-directed fisheries.

3. Changes to the assessment methodology:

a. Updated version of GMACS (version 2.01.E, Feb. 6, 2022) 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):

21.1b: model 21.1a + updated groundfish fisheries bycatch data.

22.0: model 21.1b + starting in 1985.

22.0a: model 22.0 + estimating a constant *M* for males.

These models are designed for evaluating starting the model in 1985 and estimating M for males.

4. Changes to assessment results:

Three model scenarios are compared in this report. In the May 2022 draft report small updates were made to the accepted model in 2021 (21.1), which included an updated GMACS version 2.01.E (finalized on Feb. 6, 2022) and groundfish bycatch that was updated when the AKFIN database was updated in spring of 2022, resulting in a new “base” - model 21.1b. These updates are minor and considered appropriate to replace the base mofel of 21.1 (refer to CPT May minutes and SSC June minutes 2022). Model 21.1b was used to compare to the other model scenarios.

The two additional models considered starting the model in 1985, rather that the 1975 start date of the base model (21.1b). These models were used to evaluate model starting year and estimating a base *M* for males. 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 $B_{35\%}$ (22,896 t vs 24,026 t) and NMFS survey catchability (0.94 vs 0.97), and higher MMB in the terminal year (2022) (17,158 t vs 16,953 t) and higher OFL (3,482 t vs 3,036 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. Estimating *M* for males (0.23 compared to fixing at 0.18 for the base model) in model 22.0a significantly increases likelihood values, slightly increases annual mature male biomass, except for the terminal year projection, and results in an estimated $B_{35\%}$ about 10% lower than model 22.0. A higher *M* also results in higher $F_{35\%}$ and OFL for model 22.0a.

Based on the model results, it appears that the choice of preferred models depends on two factors: model starting year and estimation of *M*. 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. 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 22.0 (the base model that starts in 1985). The concern with estimating a base *M* for males for the whole time series is potential confounding with estimating trawl survey catchability.

Based on the above considerations, we recommend model 21.b or 22.0 as the base model for overfishing definition determination in September 2022 due their simple approach: a fixed base *M* of 0.18 for males, less confounding between estimating *M* and survey catchability, and acceptable data fittings. Model 22.0 has an additional advantage of avoiding the dramatic abundance decline during the early 1980s and not including the recruitment associated with an extremely high *M* being used for estimating $B_{35\%}$. If estimating a base *M* value for males in the model is acceptable, then model 22.0a is also a good alternative, which fits the data well and greatly reduces retrospective bias from model 22.0. Model 21.1b results are presented in the specification tables in the executive summary but values for management-related quantities for all models are summarized in likelihood Tables 5b.

B. Responses to SSC and CPT Comments

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

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.

2. Responses to the most recent two sets of SSC and CPT comments specific to this 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: M was explored in May 2022. 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 three models in September 2022, one estimates a base M for males (22.0a).

"The CPT recommended presenting Models 19.3d, 19.3e, and 19.3g in September with updated data."

Response: We ran these three models as well as another model suggested by the SSC for September 2021.

"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 make 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 results in lower biomass estimates in 2020 and 2021. The biases for total abundance are much smaller than mature male biomass.

In May 2022, we examined the retrospective patterns further. It appears that adding a time block of M during 2015-2018 and dropping BSFRF survey data reduces retrospective bias but these changes were not considered to be biologically or scientifically acceptable.

"Model 19.3c probably should have been labeled model 21.0, given the large change in inputs?"

Response: To avoid confusion, we do not change the model label this time. The year in the model label will be changed when the major model changes, such as the model suggested by the SSC in June 2021, which is named as model 21.0 in the draft SAFE report in September 2021.

"When calculating the probability of being overfished via MCMC, it is necessary to calculate $B_{35\%}$ *for each draw to compare the MMB from that draw. If this is not done, the comparison is not consistent."*

Response: We have followed this recommendation.

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: we list uncertainties in the projection section.

"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 follow this recommendation.

"Consider a model with constant M, but estimated separately for males and females (i.e., similar to Model 21.0, but with sex-specific M's) for May 2022."

Response: Models 22.0, 22.0a, 22.0b, 22.0c and 22.0d with starting year of 1985 in May 2022 are constant *M* and estimated separately for males and females.

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

Response: Models 22.0, 22.0a, 22.0b, 22.0c, 22.0d, and 22.0e in May 2022 start in 1985. Of these models 22.0 and 22.0a were recommended to bring forth in September 2022 for consideration. They are included in this report.

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

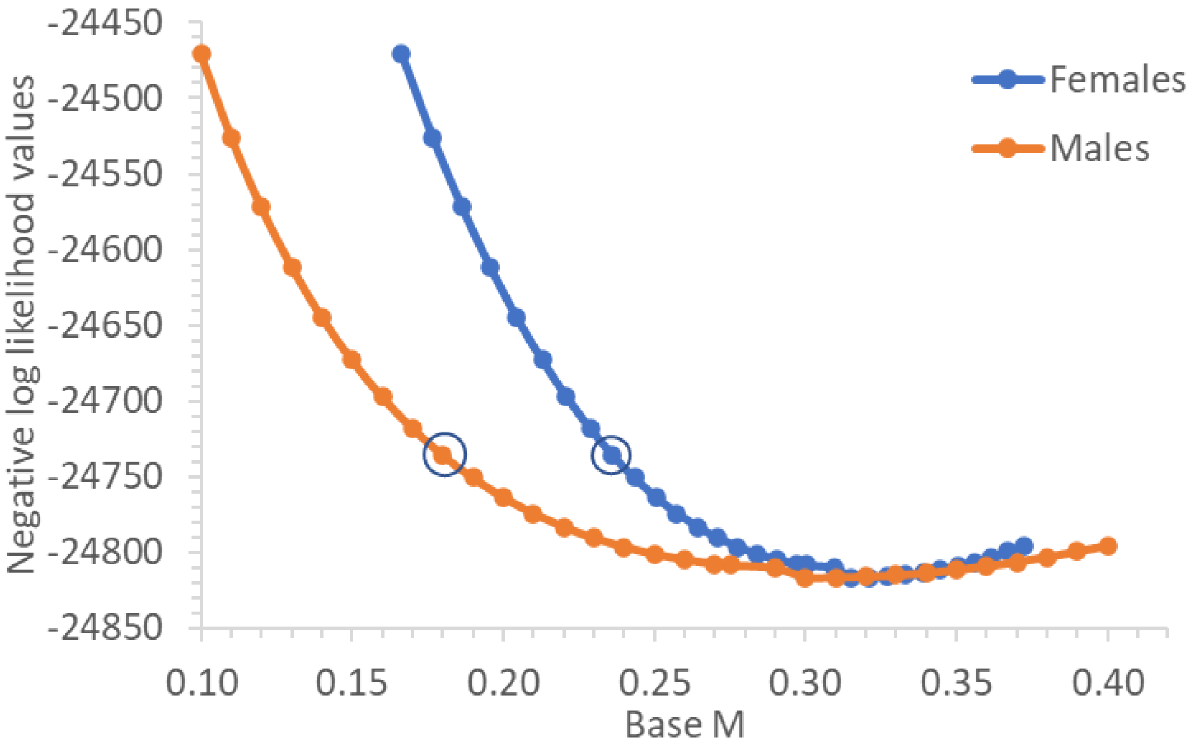
"The SSC supports exploring more modern methods for estimating natural mortality, but notes that this method still relies strongly on the maximum age for BBRKC. The SSC recommends continued research to validate the ages for this stock."

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 like 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:



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 2022, instead of continuing to examine model 19.6, we examine new models starting in 1985 with constant *M* over time: models 22.0, 22.0a, 22.0b, 22.0c, and 22.0d. Model 22.0a with model estimated *M* of 0.226 for males and 0.261 for females is close to model 19.6. Bubble plots are illustrated for models 22.0, 22.0a, and 22.0d in Figures 25c, 25d, 25e, 26c, 26d, and 26e. Higher base *M* values do improve the plus group fittings somewhat for model 22.0a.

"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.

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 is doing evaluation of re-tow survey protocol. Probabilities in the overfished condition for some models were estimated in September 2021 and are estimated in this report for the base model (21.1b).

"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. We plot 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 agree and have urged tagging studies for a few years.

"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, 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. We prefer 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. Hopefully, we will be able to use the VAST results in the models soon.

C. Introduction

1. Species

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

2. General 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 1a and 1b). 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. Fisheries Management

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) frameworked 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 ≥6.5-in carapace width (equivalent to 135-mm 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 (≥120-mm CL) males with a maximum 60% harvest rate cap of legal (≥135-mm CL) males (Pengilly and Schmidt 1995). In addition, a minimum threshold of 8.4 million mature-sized females (≥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 1.

D. Data

1. Summary of New Information

a. Updated groundfish fisheries bycatch data during 1986-2021.

b. Updated survey data for 2022

c. Updated length-frequencies distributions for all data sets for 2021/2022

Data types and availability periods are illustrated in Figure 2.

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 1a and 1b). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013) (Table 2). Sample sizes for catch by length and shell condition are summarized in Table 3a. 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.

(i). Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Tables 1a and 1b and illustrated in Figure 3. 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 1a and 1b 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 since 2018 (B. Daly, ADF&G, personal communication).

(ii). 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.

(iii). 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 1b). 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

4). 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. 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 ≈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 1975-2021 were provided by NMFS. Due to survey data quality issue, 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 (Figures 5a and 5b). 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 4, 5a, and 5b 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 2021. The VAST estimated biomasses were not considered in this year’s assessment but may be considered in the future (Figure 6).

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 these resurvey years.

4. Bering Sea Fisheries Research Foundation Survey Data

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 Figure 7a, and ratios of NMFS survey abundances/BSFRF side-by-side trawl survey abundances are shown in Figures 7b and 7c.

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

$$q = \sum_{y=2013,l=135mm}^{y=2016,l=\infty} r_{y,l}\ n_{y,l} \Big/ \sum_{y=2013,l=135mm}^{y=2016,l=\infty} n_{y,l} \qquad (1)$$

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

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 1). 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 2022.

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 0.18yr^{-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) 1982-2021, 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 1994-2022) based on sizes at maturity. Once mature, female red king crab have a much smaller growth increment per molt.

  iv. Molting probabilities are an inverse logistic function of length for males. Females 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 ≥135 mm CL across four years of side-by-side NMFS and BSFRF survey data (Figure 7c).

  vii. Males mature at sizes ≥120 mm CL. For convenience, female abundance is summarized at sizes ≥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 first author.

3. Model Selection and Evaluation

a. Alternative model configurations (models):

21.1b:**:** the base model for September 2021 with accepted updates May 2022 (12,13). 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.

(12) using the recently updated version of GMACS (version 2.01.E).

(13) updated groundfish fisheries bycatch data

22.0: model 21.1b + starting in 1985.

22.0a: model 22.0 + estimating a constant M for males.

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 3a.
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:

$$temp = 0.5\ rdev\ Jitter\ \ln\left(\frac{P_{\max} - P_{\min} + 0.0000002}{P_{val} - P_{\min} + 0.0000001} - 1\right), \tag{6}$$

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

$$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0\ temp)}, \tag{7}$$

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.

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 22.0a are summarized in Table 4.

b. Tables of estimates.

   i. Negative log-likelihood values and parameter estimates are summarized in Tables 5a, 5b, 6a, 6b, and 6c for all three models.
   ii. Natural mortality estimates are shown in Table 7 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 8.
   iv. Abundance and biomass time series are provided in Tables 9a, 9b, and 9c for models 21.1b, 22.0, and 22.0a.
   v. Recruitment time series for models 21.1b, 22.0, 22.0a are provided in Tables 9a, 9b, and 9c.
   vi. Time series of catch biomass is provided in Tables 1a and 1b.

   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 9a, 9b, and 9c). 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 6a, 6b, and 6c for models 21.1b, 22.0, and 22.0a).

c. Graphs of estimates.

   i. Estimated selectivities by length are provided in Figures 8a, 8b, 8c, and 8d and estimated molting probabilities by length are illustrated in Figures 9a and 9b.

   One of the most important results is estimated trawl survey selectivity (Figures 8a). 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 1975-2021 (Figures 9a, 9b, and 9c) 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 10a and 10b) and BSFRF surveys (Figure 10c). Absolute mature male biomasses are illustrated in Figures 11a and 11b.

The survey male biomass estimates in 2022 are slightly higher than those in 2018, 2019, and 2021, but the survey female biomass estimates are lower than 2018 and 2019, and up slightly from 2021. 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 10a-10b, 11a, 11b, and 11c). Absolute mature male biomasses for all models have a similar trend over time (Figures 11a and 11b). Among the three models, model estimated relative NMFS survey biomasses are similar for two models 21.1b and 22.0. Model 22.0a estimates a constant M for males, resulting in slightly higher NMFS survey biomass estimates from the early 2000s 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 10c-10d, but are all similar in their results.

iii. Estimated recruitment time series are plotted in Figure 12a and recruitment length distributions in Figure 12b for models 21.1b, 22.0, and 22.0a. 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 22.0a 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 28c).

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figures 13a, 13.b, and 13c for models 21.1b, 22.0, and 22.0e, and estimated M and directed pot fishing mortality values over time are illustrated in Figure 13d for models 21.1b, 22.0, and 22.0a.

The average of estimated male recruits from 1984 to 2021 for models starting in 1975 and from 1986 to 2021 for models starting in 1985 (Figure 12a) 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 13a, 13.b and 13c). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figures 13a and 13b). 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 for models 21.1b and 22.0, 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 6a, Figure 13a). 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 0.88 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 13c). 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 22.0a, estimates 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 0.26, 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 7.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with model 21.1b (Figure 14a). Annual stock productivities are illustrated in Figure 14b.

Stock productivity (recruitment/mature male biomass) is generally lower during the last 20 years (Figure 14b). 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 15a, b). 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 15a). The high 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 15a). The average clutch fullness is similar for these two periods (Figure 15). Egg clutch fullness during 2016-2018 was relatively low, then increased in 2019, and declined again in 2021.

d. Graphic evaluation of the fit to the data.

   i. Observed vs. estimated catches are plotted in Figure 16a, with bycatch mortalities from different sources shown in Figure 16b for all models.

   ii. Model fits to NMFS survey biomass are shown in Figure 10 with a standardized residual plot in Figure 17 for models 21.1b, 22.0, and 22.0a.

   iii. Model fits to catch and survey proportions by length are illustrated in Figures 18-24 and residual bubble plots are shown in Figures 25-26.

All models fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 16). 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 (Figure 10a).

All models also fit the length composition data well (Figures 18-24). Modal progressions are tracked well in the trawl survey data, particularly beginning in mid-1990s (Figures 18 and 19). 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 21), 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 (Figures 23 and 24).

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 17). Generally, residuals of proportions of survey males and females appear to be random over length and year for all models (Figures 25a-25e and 26a-26e). Models with higher base *M* values like model 22.0a improve the plus group fittings slightly.

e. Retrospective and historic analyses.

Retrospective analyses were conducted for this report using the 2022 models. The 2022 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 2022 model includes sequentially excluding one-year of data. Model 21.1b produces some upward biases during 2012-2022 with higher terminal year estimates of mature male biomass in 2014-2022 (Figure 27a). 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. Models 22.0 and 22.0a with starting year of 1985 have similar results (Figures 27a-27c). Mohn's rho calculations for these retrospective runs were high (0.329 to 0.453) but were reduced some in model 22.0a, which estimates a base *M* for males in the model.

Ratios of estimated retrospective recruitments to terminal estimates in 2021 as a function of number of years estimated in the model show converging to 1.0 as the number of years increases (Figure 28b). Standard deviations of the ratios drop sharply from one year estimated in the model to two years (Figure 28c), 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 6a-6c for models 21.1b, 22.0, and 22.0a. Estimated standard deviations of mature male biomass are listed in Table 9.

   ii. Probabilities for mature male biomass and OFL in 2023 were illustrated in Figures 30a-30b 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 31 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.

g. Comparison of alternative models

These 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.

In this report (September 2022), three models are compared. For negative likelihood value comparisons (Table 5b), models 22.0a has a higher negative likelihood value. High base M values estimated inside the models generally result in significantly higher total likelihood values.

The first model, 21.1b, has very close results to the base model in 2021 and was considered to be the “base” for this assessment as of May 2022. The GMACS update and the groundfish fisheries bycatch update hardly affected the results. Model 21.1b was used to compare the other two model scenarios, both of which were presented in May 2022 and chosen as potential candidates for specification setting.

The other models presented here both start in 1985 and were used to evaluate model starting year and estimating a M value for males in the model. Model 22.0 is the short data version of model 21.1b and the overall results are similar. The notable differences are smaller $B_{35\%}$ (21,896 t vs 24,026 t) and NMFS survey catchability (0.94 vs 0.97), and higher MMB in the terminal year (2022) (17,158 t vs 16,953 t) and higher OFL (3,482 t vs 3,036 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. Estimating a base M for males for model 22.0a significantly increases likelihood values, slightly increases annual mature male biomass, and results in an estimated $B_{35\%}$ about 10% lower than model 22.0. A high M also results in higher $F_{35\%}$ and OFL for model 22.0a.

Based on the model results, it appears that the choice of preferred models depends on two factors: preferred starting year and 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. Either of these two approaches reduces the retrospective bias considerably. Concern of estimating a base M for males for the whole time series is potential confounding with estimating trawl survey catchability.

Based on the above considerations, we recommend model 21.1b (a fixed base M of 0.18 for males, less confounding between estimating M and survey catchability) or model 22.0 (avoiding dramatic abundance decline during the early 1980s, no recruitment associated with an extremely high M being used for estimating $B_{35\%}$, and acceptable data fittings) for specification setting for September 2022. The base model is considered a good option if moving the starting date is not a desired change this assessment cycle. Values for management-related quantities for all models are summarized in likelihood Tables 5b.

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 control rule formula is as follows:

a) $\frac{B}{B^*} > 1$ $\quad F_{OFL} = F^*$

b) $\beta < \frac{B}{B^*} \le 1$ $\quad F_{OFL} = F^*\left(\frac{B/B^* - \alpha}{1-\alpha}\right)$ (2)

c) $\frac{B}{B^*} \le \beta$ $\quad$ directed pot fishery $F = 0$ and $F_{OFL} \le F^*$

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 of F_{MSY}, which is a full selection instantaneous F that will produce MSY at the MSY producing biomass.

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

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

α = a parameter with a restriction that $0 \le \alpha \le \beta$. 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 2017 to 2021 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 2016-2021 are used for per recruit analysis and projections. For the models in 2022, the averages are the same since they are constant over time during at least the last 15 years.

Average recruitments during 1984-2021 for models starting in 1975 and during 1986-2021 for models starting in 1985 are used to estimate $B_{35\%}$ (Figure 12a). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 14a. The period of 1984-2021 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 0.5 B_{MSY} (i.e., MSST), the stock is "overfished." If B/B_{MSY} or B/B_{MSY}-proxy 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 2023 are illustrated in Figure 30 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 close to an overfished condition 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.

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 31). The probability (converted to a percentage) is estimated to be about 0% for model 21.1b (Figure 31).

Status and catch specifications (1,000 t) (model 21.1b):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2018/19	10.62B	16.92B	1.95	2.03	2.65	5.34	4.27
2019/20	12.72C	14.24C	1.72	1.78	2.22	3.40	2.72
2020/21	12.12D	13.96D	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		16.95				3.04	2.43

The stock was above MSST in 2021/22 and hence was not overfished. Since total catch was below OFL, overfishing did not occur. The relatively low MSST in 2018/19 and B_{MSY} in 2019/20 below was caused by a problem of the previous GMACS 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 much more stable sex ratio (about 50%) for the reference point calculation.

Status and catch specifications (million lb) (model 21.1b):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2018/19	23.4B	37.3B	4.31	4.31	5.85	11.76	9.41
2019/20	28.0C	31.4C	3.80	3.91	4.89	7.50	6.00
2020/21	26.7D	30.8D	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		37.4				6.70	5.35

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2018
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2019
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2020
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2021

Basis for the OFL: Values are in 1,000 t (model 21.1b):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2018/19	3b	25.5	20.8	0.82	0.25	1984-2017	0.18
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

Basis for the OFL: Values are in million lb (model 21.1b):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2018/19	3b	56.2	45.9	0.82	0.25	1984-2017	0.18
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

Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2021, the biological reference points and OFL are illustrated in Table 5b.

Based on the CPT/SSC recommendation of 20% buffer rule in May 2018 and an additional buffer of 5% by the CPT for 2020 due to the lack of a 2020 survey, ABC = 0.75*OFL (Table 4). A 20% buffer was recommended by the CPT for ABC estimation for 2021/22. A 20% buffer is also recommended for 2022/23 for similar reasoning as 2021/22.

G. Rebuilding Analyses

NA

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 Future 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 2013-2021, 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 0.173 in 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 (Figure 32). 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 is not overfished in 2021/22, 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 0.167 for the directed pot fishery in the 2022/2023and 2023/2024 seasons, the projection using the lowest recruitment periods during 2013-2021 would not likely result in “approaching an overfished condition” for model 21.1b (Figure 33). With additional low recruitment estimate used to compute $B_{35\%}$, the estimated MSST would decline further in 2023.

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 (Figure 34). 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 5a, b). However, no additional strong cohorts were observed in the survey data after this cohort through 2010 (Figure 5a, 5b, and 34). A huge tow of juvenile crab of size 45-55 mm in 2011 was not tracked during 2012-2022 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 (Figure 34). Due to lack of recruitment, mature and legal crab may continue to decline next year in the presence of fishing pressure. However, this past year suggests that lack of a directed fishery and a small increase in recruitment contributed to an increase in abundance. 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.

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 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 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 1a. Bristol Bay red king crab annual catch and bycatch mortality biomass (t) from July 1 to June 30. A handling mortality rate of 20% for the directed pot, 25% for the Tanner fishery, 80% for trawl, and 50% or 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, ADF&G, personal communication). 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 2021.

Year	Retained Catch				Pot Bycatch	Trawl Bycatch	Fixed Bycatch	Tanner Fishery Bycatch
	U.S.	Cost-Recovery	Foreign	Total	Females			
1953	1331.3		4705.6	6036.9				
1954	1149.9		3720.4	4870.2				
1955	1029.2		3712.7	4741.9				
1956	973.4		3572.9	4546.4				
1957	339.7		3718.1	4057.8				
1958	3.2		3541.6	3544.8				
1959	0.0		6062.3	6062.3				
1960	272.2		12200.7	12472.9				
1961	193.7		20226.6	20420.3				
1962	30.8		24618.7	24649.6				
1963	296.2		24930.8	25227.0				
1964	373.3		26385.5	26758.8				
1965	648.2		18730.6	19378.8				
1966	452.2		19212.4	19664.6				
1967	1407.0		15257.0	16664.1				
1968	3939.9		12459.7	16399.6				
1969	4718.7		6524.0	11242.7				
1970	3882.3		5889.4	9771.7				
1971	5872.2		2782.3	8654.5				
1972	9863.4		2141.0	12004.3				
1973	12207.8		103.4	12311.2				
1974	19171.7		215.9	19387.6				
1975	23281.2		0	23281.2				
1976	28993.6		0	28993.6		682.8		
1977	31736.9		0	31736.9		1249.9		
1978	39743.0		0	39743.0		1320.6		
1979	48910.0		0	48910.0		1331.9		
1980	58943.6		0	58943.6		1036.5		
1981	15236.8		0	15236.8		219.4		
1982	1361.3		0	1361.3		574.9		
1983	0.0		0	0.0		420.4		
1984	1897.1		0	1897.1		1094.0		
1985	1893.8		0	1893.8		390.1		
1986	5168.2		0	5168.2		200.6		
1987	5574.2		0	5574.2		186.4		
1988	3351.1		0	3351.1		598.4		
1989	4656.0		0	4656.0		175.2		
1990	9236.2	36.6	0	9272.8	639.2	259.9		
1991	7791.8	93.4	0	7885.1	46.8	349.4		1401.8

1992	3648.2	33.6	0	3681.8	395.3	293.5		244.4
1993	6635.4	24.1	0	6659.6	628.3	401.4		54.6
1994	0.0	42.3	0	42.3	0.4	87.3		10.8
1995	0.0	36.4	0	36.4	0.3	82.1		0.0
1996	3812.7	49.0	0	3861.7	1.0	90.8	41.4	0.0
1997	3971.9	70.2	0	4042.1	36.5	57.5	22.5	0.0
1998	6693.8	85.4	0	6779.2	553.9	186.1	18.5	0.0
1999	5293.5	84.3	0	5377.9	5.6	150.5	50.1	0.0
2000	3698.8	39.1	0	3737.9	164.4	81.7	4.7	0.0
2001	3811.5	54.6	0	3866.2	120.8	192.8	35.3	0.0
2002	4340.9	43.6	0	4384.5	9.1	151.2	29.2	0.0
2003	7120.0	15.3	0	7135.3	356.9	136.9	12.7	0.0
2004	6915.2	91.4	0	7006.7	171.8	173.5	15.2	0.0
2005	8305.0	94.7	0	8399.7	405.4	124.7	19.9	0.0
2006	7005.3	137.9	0	7143.2	37.5	151.7	19.6	3.8
2007	9237.9	66.1	0	9303.9	159.9	154.1	32.3	1.8
2008	9216.1	0.0	0	9216.1	144.8	136.6	15.6	4.0
2009	7226.9	45.5	0	7272.5	88.3	94.9	5.8	1.6
2010	6728.5	33.0	0	6761.5	118.5	83.2	2.4	0.0
2011	3553.3	53.8	0	3607.1	25.0	56.2	10.9	0.0
2012	3560.6	61.1	0	3621.7	11.2	34.1	18.4	0.0
2013	3901.1	89.9	0	3991.0	98.1	66.9	55.1	28.5
2014	4530.0	8.6	0	4538.6	84.9	34.5	118.7	42.0
2015	4522.3	91.4	0	4613.7	239.1	45.1	77.4	84.2
2016	3840.4	83.4	0	3923.9	123.4	67.3	29.7	0.0
2017	2994.1	99.6	0	3093.7	53.4	91.7	130.0	0.0
2018	1954.1	72.4	0	2026.5	150.1	78.0	154.7	0.0
2019	1719.8	55.5	0	1775.3	43.3	80.7	45.1	0.0
2020	1200.6	56.4	0	1257.0	15.2	80.7	37.6	0.0
2021	0.0	17.4	0	17.4	5.9	34.4	40.3	0.0

Table 1b. Annual retained catch (millions of crab) and catch per unit effort of the Bristol Bay red king crab fishery.

Year	Japanese Tanglenet		Russian Tanglenet		U.S. Pot		Standardized Crab/tan
	Catch	Crab/tan	Catch	Crab/tan	Catch	Crab/Potlift	
1960	1.949	15.2	1.995	10.4	0.088		15.8
1961	3.031	11.8	3.441	8.9	0.062		12.9
1962	4.951	11.3	3.019	7.2	0.010		11.3
1963	5.476	8.5	3.019	5.6	0.101		8.6
1964	5.895	9.2	2.800	4.6	0.123		8.5
1965	4.216	9.3	2.226	3.6	0.223		7.7
1966	4.206	9.4	2.560	4.1	0.140	52	8.1
1967	3.764	8.3	1.592	2.4	0.397	37	6.3
1968	3.853	7.5	0.549	2.3	1.278	27	7.8
1969	2.073	7.2	0.369	1.5	1.749	18	5.6
1970	2.080	7.3	0.320	1.4	1.683	17	5.6
1971	0.886	6.7	0.265	1.3	2.405	20	5.8
1972	0.874	6.7			3.994	19	
1973	0.228				4.826	25	
1974	0.476				7.710	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					2.100	12	
1987					2.122	10	
1988					1.236	8	
1989					1.685	8	
1990					3.130	12	
1991					2.661	12	
1992					1.208	6	
1993					2.270	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					2.510	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					2.410	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					0.630	20	
2019					0.549	16	
2020					0.455	21	
2021					No directed	fishery	

Table 2. 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 2021.

	Directed Pot Total		Trawl	Fixed	Tanner
Year	Males	Females	Bycatch	Bycatch	Bycatch
1975			0.000		
1976			853.494		
1977			1,562.313		
1978			1,650.775		
1979			1,664.925		
1980			1,295.625		
1981			274.229		
1982			718.610		
1983			525.554		
1984			1,367.550		
1985			487.576		
1986			250.758		
1987			233.045		
1988			747.996		
1989			219.023		
1990	11621.800	3196.200	324.883		
1991	9792.900	233.900	436.783		5,580.843
1992	5916.200	1976.300	366.816		962.846
1993	9516.800	3141.500	501.770		218.112
1994	62.300	1.877	109.129		39.395
1995	52.800	1.612	102.623		0.000
1996	3845.200	5.100	113.495	82.859	0.000
1997	3758.800	182.700	71.862	44.979	0.000
1998	15644.800	2769.300	232.580	36.916	0.000
1999	12112.300	28.000	188.101	100.242	0.000
2000	6579.700	821.900	102.161	9.446	0.000
2001	5711.500	604.000	241.011	70.553	0.000
2002	6961.400	45.600	189.018	58.382	0.000
2003	12166.500	1784.400	171.114	25.351	0.000
2004	10692.000	859.200	216.889	30.422	0.000
2005	13615.900	2027.100	155.924	39.802	0.000
2006	9254.000	187.400	189.660	39.134	15.217
2007	13871.900	799.400	192.571	64.655	7.142
2008	14894.900	724.200	170.754	31.158	16.070
2009	12218.800	441.300	118.672	11.614	6.499
2010	10095.400	592.600	104.005	4.944	0.000
2011	5665.300	124.800	70.286	21.726	0.000
2012	4495.500	55.900	42.641	36.897	0.000
2013	5305.900	490.700	83.613	110.208	113.063
2014	8113.800	424.300	43.129	237.374	137.786
2015	6726.800	1195.600	56.410	154.775	639.573
2016	5651.800	617.200	84.127	59.418	0.000
2017	4077.200	266.900	114.624	260.011	0.000
2018	3423.200	750.400	97.561	309.415	0.000
2019	3144.600	218.000	100.915	90.291	0.000
2020	2299.700	76.100	100.842	75.130	0.000
2021	33.800	29.400	42.99	80.602	0.000

Table 3a. 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. These include recently updated estimates from the pot fisheries observer data and are used for models 2022.

Year	Trawl Survey		Retained Catch	Pot Total	Pot Bycatch	Trawl Bycatch	Fixed G. Bycatch	Tanner Fishery Bycatch
	Males	Females		Males	Females	Combined	Combined	Combined
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						

Table 3b. Comparison of area-swept and VAST-based male Bristol Bay red king crab biomass estimates from the NMFS trawl survey. Difference = (area-swept – VAST)/[(area-swept + VAST)/2]. Reduction = (area-swept – VAST)/area-swept. VAST estimates were not computed for 2022 or included in models in 2022.

	Area-swept		VAST		Biomass	CV
Year	Biomass	CV	Biomass	CV	Differ.%	Reduction%
1975	133.084	0.171	148.119	0.099	-10.69	42.37
1976	256.362	0.222	243.853	0.089	5.00	59.74
1977	232.539	0.176	239.346	0.080	-2.89	54.39
1978	199.542	0.200	196.698	0.090	1.44	54.94
1979	102.448	0.239	96.579	0.101	5.90	57.79
1980	166.524	0.240	141.622	0.096	16.16	59.90
1981	68.294	0.144	73.903	0.081	-7.89	44.07
1982	72.296	0.263	60.766	0.096	17.33	63.40
1983	34.762	0.210	34.590	0.088	0.50	58.16
1984	96.418	0.549	47.590	0.108	67.81	80.41
1985	26.819	0.154	29.607	0.090	-9.88	41.62
1986	40.549	0.481	27.200	0.098	39.41	79.62
1987	46.769	0.225	42.384	0.095	9.84	57.78
1988	35.374	0.168	37.874	0.092	-6.83	45.42
1989	42.358	0.222	40.527	0.094	4.42	57.83
1990	38.728	0.227	37.492	0.099	3.24	56.50
1991	66.528	0.543	36.916	0.149	57.25	72.63
1992	25.096	0.178	26.546	0.099	-5.62	44.19
1993	35.671	0.210	36.554	0.109	-2.45	48.32
1994	23.003	0.173	25.230	0.105	-9.23	39.35
1995	27.252	0.327	23.646	0.103	14.17	68.56
1996	26.816	0.187	28.476	0.104	-6.01	44.62
1997	59.638	0.244	55.682	0.101	6.86	58.76
1998	46.209	0.162	50.277	0.092	-8.43	43.25
1999	44.529	0.210	46.095	0.109	-3.46	48.10
2000	38.391	0.164	46.505	0.101	-19.12	38.40
2001	27.943	0.146	31.181	0.088	-10.95	39.84
2002	45.140	0.195	48.796	0.101	-7.78	48.09
2003	74.641	0.406	60.035	0.101	21.69	75.04
2004	90.354	0.395	64.126	0.104	33.96	73.78
2005	54.790	0.181	55.097	0.098	-0.56	46.06
2006	51.215	0.197	54.277	0.088	-5.80	55.27
2007	58.144	0.184	62.256	0.091	-6.83	50.34
2008	67.214	0.302	61.024	0.103	9.65	65.93
2009	43.170	0.365	39.091	0.113	9.92	69.05
2010	39.021	0.237	40.329	0.101	-3.30	57.57
2011	27.385	0.207	29.640	0.106	-7.91	48.65
2012	30.655	0.255	34.232	0.117	-11.02	54.08
2013	39.650	0.207	42.819	0.105	-7.68	49.11
2014	60.649	0.192	64.111	0.097	-5.55	49.56
2015	37.085	0.174	42.030	0.093	-12.50	46.41
2016	27.185	0.148	30.230	0.091	-10.61	38.84
2017	25.335	0.174	26.252	0.086	-3.56	50.61
2018	16.034	0.138	18.270	0.091	-13.03	33.75
2019	15.170	0.163	16.262	0.093	-6.95	42.65
2021	18.235	0.202	17.185	0.133	5.93	34.14
Mean	61.631	0.234	58.942	0.099	2.69	53.24
Min					-19.12	33.75
Max					67.81	80.41

Table 3c. Comparison of area-swept and VAST-based female Bristol Bay red king crab biomass estimates from the NMFS trawl survey. Difference = (area-swept – VAST)/[(area-swept + VAST)/2]. Reduction = (area-swept – VAST)/area-swept. VAST estimates were not computed for 2022 or included in models in 2022.

	Area-swept		VAST		Biomass	CV
Year	Biomass	CV	Biomass	CV	Differ.%	Reduction%
1975	66.559	0.301	58.081	0.127	13.60	57.79
1976	71.252	0.235	68.255	0.106	4.30	55.08
1977	138.684	0.188	134.450	0.097	3.10	48.60
1978	143.647	0.196	125.444	0.099	13.53	49.30
1979	63.001	0.179	53.741	0.091	15.86	49.34
1980	80.701	0.327	67.448	0.118	17.89	63.92
1981	62.850	0.257	55.937	0.107	11.64	58.30
1982	69.601	0.251	61.728	0.103	11.99	58.91
1983	13.714	0.247	11.953	0.106	13.72	56.95
1984	56.189	0.710	19.191	0.154	98.16	78.28
1985	7.319	0.251	6.680	0.116	9.12	53.59
1986	6.885	0.331	5.835	0.122	16.51	63.20
1987	22.476	0.320	17.208	0.125	26.55	61.01
1988	19.224	0.411	13.843	0.153	32.55	62.72
1989	12.778	0.347	9.644	0.121	27.95	65.03
1990	20.723	0.401	14.301	0.138	36.67	65.47
1991	17.364	0.415	11.900	0.124	37.34	70.14
1992	12.238	0.247	10.797	0.116	12.51	53.03
1993	17.235	0.248	15.702	0.127	9.31	48.83
1994	9.102	0.219	8.425	0.126	7.72	42.42
1995	10.816	0.247	9.454	0.117	13.44	52.54
1996	17.143	0.270	14.672	0.126	15.54	53.41
1997	24.392	0.352	19.315	0.131	23.23	62.79
1998	37.893	0.250	31.954	0.113	17.01	54.82
1999	20.225	0.339	19.950	0.138	1.37	59.28
2000	28.991	0.330	31.734	0.143	-9.04	56.73
2001	24.513	0.294	21.338	0.123	13.85	58.20
2002	23.947	0.289	20.469	0.122	15.66	57.63
2003	41.119	0.221	37.258	0.114	9.85	48.58
2004	40.202	0.255	32.518	0.109	21.13	57.43
2005	50.937	0.205	44.651	0.109	13.15	46.93
2006	43.262	0.200	54.154	0.113	-22.36	43.48
2007	45.183	0.223	53.047	0.105	-16.01	53.10
2008	45.867	0.322	47.268	0.124	-3.01	61.57
2009	47.377	0.327	45.385	0.120	4.29	63.32
2010	41.480	0.271	42.706	0.119	-2.91	56.21
2011	39.023	0.256	41.777	0.121	-6.82	52.62
2012	30.042	0.334	30.582	0.150	-1.78	55.21
2013	22.567	0.359	22.856	0.145	-1.27	59.51
2014	52.486	0.227	65.939	0.129	-22.72	43.09
2015	27.090	0.295	30.854	0.133	-12.99	54.81
2016	33.773	0.259	36.498	0.114	-7.75	55.92
2017	27.599	0.250	29.231	0.106	-5.74	57.70
2018	12.771	0.224	14.247	0.117	-10.93	47.79
2019	13.369	0.185	15.989	0.100	-17.85	46.11
2021	10.241	0.244	10.576	0.109	-3.23	55.17
Mean	37.475	0.285	34.674	0.120	9.22	56.00
Min					-22.72	42.42
Max					98.16	78.28

Table 4. Comparison of harmonic means of implied sample sizes and maximum caps (N) of effective sample sizes for models 21.1b, 22.0, and 22.0a.

		Models		
		21.1b	22.0	22.0a
	N	Harm.S	Harm.S	Harm.S
Retained catch	150	156.6	161.5	171.0
Pot total males	150	216.9	218.1	221.0
Pot total females	50	29.4	29.4	29.4
Trawl bycatch	50	58.8	57.4	61.5
Tanner fishery bycatch	50	25.4	25.2	25.6
Fixed gear bycatch	50	42.0	41.8	42.5
NMFS survey	200	175.1	201.6	210.2
BSFRF survey	200	118.8	115.3	124.4

Table 5a. Number of parameters for the model (Models 21.1b, 22.0, and 22.0a). Red values indicate different values among models.

Parameter counts	**21.1b**	**22.0**	**22.0a**
Fixed growth parameters	0	0	0
Fixed recruitment parameters	2	2	2
Fixed length-weight relationship parameters	6	6	6
Fixed mortality parameters	5	5	4
Fixed survey catchability parameter	1	1	1
Fixed high grading parameters	0	0	0
Total number of fixed parameters	14	14	13
Free survey catchability parameter	1	1	1
Free growth parameters	6	4	4
Initial abundance (1975 or 1985)	1	1	1
Recruitment-distribution parameters	2	2	2
Mean recruitment parameters	1	1	1
Male recruitment deviations	47	37	37
Female recruitment deviations	47	37	37
Natural mortality parameters	2	1	2
Mean & offset fishing mortality parameters	6	6	6
Pot male fishing mortality deviations	47	37	37
Bycatch mortality from Tanner crab fishery	50	30	30
Pot female bycatch fishing mortality devia.	32	32	32
Trawl bycatch fishing mortality deviations	47	37	37
Fixed gear bycatch fishing mortality devia.	26	26	26
Initial (1975 or 1985) length compositions	35	35	35
Survey extra CV	1	1	1
Free selectivity parameters	22	20	20
Total number of free parameters	372	308	309
Total number of fixed and free parameters	386	322	323

Table 5b. Negative log likelihood components and their differences for Models 21.1b. 22.0, 22.0a, and some management quantities. Highlighted cells in yellow color show prior density values and total negative likelihood values without prior density. Biomass is in metric ton, and abundance is in millions of crab.

	Model			
	21.1b	22.0	22.0a	22.0a-22.0
Pot-ret-catch	-60.88	-34.88	-35.81	-0.93
Pot-totM-catch	26.54	26.55	25.62	-0.93
Pot-F-discC	-55.69	-55.70	-55.28	0.42
Trawl-discC	-63.74	-51.28	-51.28	0
Tanner-M-discC	-43.54	-26.12	-26.12	0
Tanner-F-discC	-43.48	-26.08	-26.10	-0.02
Fixed-discC	-36.04	-36.04	-36.04	0
Trawl-suv-bio	-35.47	-44.09	-47.68	-3.59
BSFRF-sur-bio	-2.94	-3.33	-4.73	-1.4
Pot-ret-comp	-3932.20	-3131.80	-3134.52	-2.72
Pot-totM-comp	-2369.46	-2370.52	-2371.39	-0.87
Pot-discF-comp	-1449.36	-1449.09	-1450.22	-1.13
Trawl-disc-comp	-5836.10	-4681.05	-4685.50	-4.45
TC-disc-comp	-1274.28	-1273.40	-1276.25	-2.85
Fixed-disc-comp	-3393.50	-3394.74	-3392.59	2.15
Trawl-sur-comp	-6984.67	-5503.89	-5516.02	-12.13
BSFRF-sur-comp	-843.53	-842.35	-844.98	-2.63
Recruit-dev	70.56	41.28	41.83	0.55
Recruit-sex-R	76.98	60.67	60.63	-0.04
Log_fdev=0	0.00	0.00	0.00	0
M-deviation	43.83	0.00	0.00	
Sex-specific-R	0.01	0.15	0.18	0.03
Ini-size-struct.	30.88	50.88	55.77	4.89
PriorDensity	267.30	233.94	221.50	-12.44
Tot-likelihood	-25908.79	-22510.90	-22549.41	-38.51
Tot-likeli-no-PD	-25641.5	-22276.96	-22317.91	-40.95
Tot-parameter	372	308	309	1
$MMB_{35\%}$	24026.11	21896.23	19512.93	-2383.3
MMB-terminal	16952.82	17157.89	15713.76	-1444.13
$F_{35\%}$	0.298	0.299	0.395	0.096
F_{ofl}	0.200	0.227	0.309	0.082
OFL	3035.63	3481.84	4319.04	837.2
ABC	2428.50	2785.47	3455.23	669.76
NMFS Q	0.967	0.940	0.922	-0.018
Mature females	10.20	10.99	11.688	0.698
Mohn's rho, 10yr	0.373	0.453	0.329	

Table 6a. Summary of estimated model parameter values and standard deviations for model 21.1b for Bristol Bay red king crab.

index	name	value	std.dev	index	name	value	std.dev
1	theta[2]	0.281	0.014	47	log_slx_pars[1]	4.759	0.008
2	theta[4]	19.823	0.049	48	log_slx_pars[2]	2.264	0.046
3	theta[5]	16.213	0.138	49	log_slx_pars[3]	4.507	0.016
4	theta[7]	0.680	0.127	50	log_slx_pars[4]	2.020	0.113
5	theta[9]	-0.472	0.230	51	log_slx_pars[5]	5.153	0.056
6	theta[13]	0.959	0.420	52	log_slx_pars[6]	2.852	0.045
7	theta[14]	0.651	0.469	53	log_slx_pars[7]	4.720	0.220
8	theta[15]	0.858	0.333	54	log_slx_pars[8]	2.164	0.306
9	theta[16]	0.707	0.305	55	log_slx_pars[9]	4.746	0.078
10	theta[17]	0.544	0.295	56	log_slx_pars[10]	0.900	0.304
11	theta[18]	0.499	0.277	57	log_slx_pars[11]	4.790	0.023
12	theta[19]	0.342	0.278	58	log_slx_pars[12]	2.340	0.086
13	theta[20]	0.376	0.264	59	log_slx_pars[13]	4.106	0.176
14	theta[21]	0.408	0.259	60	log_slx_pars[14]	2.234	0.378
15	theta[22]	0.181	0.282	61	log_slx_pars[15]	3.773	0.604
16	theta[23]	0.158	0.277	62	log_slx_pars[16]	3.290	0.409
17	theta[24]	0.053	0.287	63	log_slx_pars[17]	4.427	0.029
18	theta[25]	0.169	0.263	64	log_slx_pars[18]	2.435	0.072
19	theta[26]	-0.010	0.204	65	log_slx_pars[19]	4.923	0.002
20	theta[27]	-0.239	0.196	66	log_slx_pars[20]	0.673	0.053
21	theta[28]	-0.390	0.198	67	log_slx_pars[21]	4.932	0.002
22	theta[29]	-0.738	0.211	68	log_slx_pars[22]	0.727	0.099
23	theta[30]	-1.198	0.233	69	log_fbar[1]	-1.574	0.042
24	theta[31]	-1.243	0.235	70	log_fbar[2]	-4.306	0.075
25	theta[52]	1.294	0.679	71	log_fbar[3]	-5.599	0.289
26	theta[53]	1.454	0.462	72	log_fbar[4]	-6.514	0.072
27	theta[54]	1.395	0.367	73	log_fdev[1]	0.818	0.119
28	theta[55]	1.170	0.336	74	log_fdev[1]	0.776	0.090
29	theta[56]	1.083	0.295	75	log_fdev[1]	0.688	0.074
30	theta[57]	0.600	0.318	76	log_fdev[1]	0.781	0.060
31	theta[58]	0.214	0.353	77	log_fdev[1]	0.993	0.054
32	theta[59]	-0.025	0.362	78	log_fdev[1]	1.861	0.056
33	theta[60]	-0.214	0.355	79	log_fdev[1]	2.394	0.119
34	theta[61]	-0.545	0.374	80	log_fdev[1]	0.816	0.177
35	theta[62]	-0.932	0.386	81	log_fdev[1]	-8.897	0.126
36	theta[63]	-1.190	0.390	82	log_fdev[1]	1.143	0.112
37	theta[64]	-1.421	0.389	83	log_fdev[1]	1.217	0.089
38	theta[65]	-1.791	0.377	84	log_fdev[1]	1.386	0.073
39	theta[66]	-1.897	0.373	85	log_fdev[1]	0.920	0.064
40	theta[67]	-1.838	0.352	86	log_fdev[1]	-0.018	0.053
41	Grwth[21]	0.972	0.185	87	log_fdev[1]	0.097	0.047
42	Grwth[42]	1.454	0.122	88	log_fdev[1]	0.745	0.039
43	Grwth[85]	142.500	1.727	89	log_fdev[1]	0.758	0.041
44	Grwth[86]	0.058	0.010	90	log_fdev[1]	0.242	0.046
45	Grwth[87]	139.890	0.596	91	log_fdev[1]	0.910	0.051

46	Grwth[88]	0.071	0.003	92	log_fdev[1]	-4.242	0.049
93	log_fdev[1]	-4.651	0.042	143	log_fdev[2]	-0.222	0.104
94	log_fdev[1]	-0.181	0.041	144	log_fdev[2]	-0.981	0.103
95	log_fdev[1]	-0.132	0.041	145	log_fdev[2]	-0.211	0.103
96	log_fdev[1]	0.783	0.044	146	log_fdev[2]	-0.511	0.103
97	log_fdev[1]	0.426	0.043	147	log_fdev[2]	-0.604	0.102
98	log_fdev[1]	-0.160	0.041	148	log_fdev[2]	-0.371	0.102
99	log_fdev[1]	-0.239	0.041	149	log_fdev[2]	-0.646	0.102
100	log_fdev[1]	-0.128	0.040	150	log_fdev[2]	-0.477	0.102
101	log_fdev[1]	0.337	0.038	151	log_fdev[2]	-0.399	0.102
102	log_fdev[1]	0.294	0.038	152	log_fdev[2]	-0.426	0.102
103	log_fdev[1]	0.585	0.039	153	log_fdev[2]	-0.784	0.102
104	log_fdev[1]	0.339	0.038	154	log_fdev[2]	-0.932	0.102
105	log_fdev[1]	0.704	0.038	155	log_fdev[2]	-1.394	0.102
106	log_fdev[1]	0.874	0.040	156	log_fdev[2]	-1.914	0.102
107	log_fdev[1]	0.690	0.041	157	log_fdev[2]	-1.199	0.102
108	log_fdev[1]	0.560	0.040	158	log_fdev[2]	-1.762	0.103
109	log_fdev[1]	-0.075	0.039	159	log_fdev[2]	-1.378	0.103
110	log_fdev[1]	-0.151	0.038	160	log_fdev[2]	-0.852	0.105
111	log_fdev[1]	0.036	0.038	161	log_fdev[2]	-0.418	0.107
112	log_fdev[1]	0.366	0.038	162	log_fdev[2]	-0.483	0.110
113	log_fdev[1]	0.438	0.041	163	log_fdev[2]	-0.389	0.113
114	log_fdev[1]	0.437	0.046	164	log_fdev[2]	-0.421	0.115
115	log_fdev[1]	0.347	0.054	165	log_fdev[2]	-1.414	0.115
116	log_fdev[1]	0.156	0.064	166	log_fdev[3]	-0.116	0.068
117	log_fdev[1]	0.095	0.072	167	log_fdev[3]	0.670	0.068
118	log_fdev[1]	-0.342	0.076	168	log_fdev[3]	1.228	0.068
119	log_fdev[1]	-4.797	0.075	169	log_fdev[3]	1.093	0.068
120	log_fdev[2]	0.195	0.125	170	log_fdev[3]	1.383	0.068
121	log_fdev[2]	0.634	0.116	171	log_fdev[3]	1.424	0.068
122	log_fdev[2]	0.614	0.111	172	log_fdev[3]	0.993	0.068
123	log_fdev[2]	0.690	0.109	173	log_fdev[3]	0.476	0.068
124	log_fdev[2]	1.406	0.112	174	log_fdev[3]	-0.987	0.068
125	log_fdev[2]	1.176	0.131	175	log_fdev[3]	-0.579	0.068
126	log_fdev[2]	2.458	0.132	176	log_fdev[3]	-1.099	0.068
127	log_fdev[2]	2.178	0.119	177	log_fdev[3]	-0.256	0.068
128	log_fdev[2]	3.398	0.116	178	log_fdev[3]	0.940	0.068
129	log_fdev[2]	2.192	0.111	179	log_fdev[3]	1.418	0.068
130	log_fdev[2]	1.129	0.111	180	log_fdev[3]	3.239	0.075
131	log_fdev[2]	0.676	0.109	181	log_fdev[3]	1.284	0.095
132	log_fdev[2]	1.452	0.104	182	log_fdev[3]	0.581	0.119
133	log_fdev[2]	0.022	0.104	183	log_fdev[3]	-0.757	0.082
134	log_fdev[2]	0.475	0.104	184	log_fdev[3]	-2.137	0.073
135	log_fdev[2]	0.899	0.105	185	log_fdev[3]	-2.991	0.093
136	log_fdev[2]	0.735	0.105	186	log_fdev[3]	-2.412	0.112
137	log_fdev[2]	1.212	0.108	187	log_fdev[3]	-3.494	0.075
138	log_fdev[2]	-0.556	0.105	188	log_fdev[3]	-0.845	0.094
139	log_fdev[2]	-0.842	0.103	189	log_fdev[3]	-0.119	0.111
140	log_fdev[2]	-0.774	0.104	190	log_fdev[3]	1.064	0.133

141	log_fdev[2]	-1.240	0.103
142	log_fdev[2]	0.058	0.104
193	log_fdev[4]	-0.314	0.102
194	log_fdev[4]	0.606	0.102
195	log_fdev[4]	-1.822	0.101
196	log_fdev[4]	0.133	0.101
197	log_fdev[4]	-0.124	0.100
198	log_fdev[4]	-0.957	0.100
199	log_fdev[4]	-0.783	0.100
200	log_fdev[4]	-0.509	0.100
201	log_fdev[4]	-0.555	0.100
202	log_fdev[4]	-0.008	0.100
203	log_fdev[4]	-0.707	0.100
204	log_fdev[4]	-1.703	0.100
205	log_fdev[4]	-2.538	0.099
206	log_fdev[4]	-1.057	0.099
207	log_fdev[4]	-0.501	0.099
208	log_fdev[4]	0.639	0.099
209	log_fdev[4]	1.491	0.099
210	log_fdev[4]	1.175	0.100
211	log_fdev[4]	0.345	0.101
212	log_fdev[4]	1.949	0.102
213	log_fdev[4]	2.207	0.103
214	log_fdev[4]	1.005	0.105
215	log_fdev[4]	0.795	0.107
216	log_fdev[4]	0.771	0.109
217	log_foff[1]	-2.781	0.039
218	log_foff[3]	-0.095	0.414
219	log_fdov[1]	1.969	0.083
220	log_fdov[1]	-0.701	0.083
221	log_fdov[1]	1.973	0.084
222	log_fdov[1]	1.810	0.086
223	log_fdov[1]	-0.421	0.084
224	log_fdov[1]	-0.191	0.082
225	log_fdov[1]	-3.696	0.081
226	log_fdov[1]	-0.328	0.082
227	log_fdov[1]	1.457	0.082
228	log_fdov[1]	-2.773	0.081
229	log_fdov[1]	1.155	0.081
230	log_fdov[1]	0.881	0.080
231	log_fdov[1]	-1.866	0.080
232	log_fdov[1]	1.218	0.080
233	log_fdov[1]	0.425	0.080
234	log_fdov[1]	0.958	0.079
235	log_fdov[1]	-1.226	0.079
236	log_fdov[1]	-0.187	0.079
237	log_fdov[1]	-0.450	0.079
238	log_fdov[1]	-0.714	0.079
239	log_fdov[1]	-0.233	0.079
191	log_fdev[4]	0.562	0.103
192	log_fdev[4]	-0.100	0.102
243	log_fdov[1]	-0.226	0.078
244	log_fdov[1]	0.834	0.079
245	log_fdov[1]	0.287	0.080
246	log_fdov[1]	-0.364	0.083
247	log_fdov[1]	0.964	0.087
248	log_fdov[1]	-0.106	0.091
249	log_fdov[1]	-0.626	0.093
250	log_fdov[1]	2.972	0.094
251	log_fdov[3]	0.000	0.096
252	log_fdov[3]	0.000	0.096
253	log_fdov[3]	0.000	0.096
254	log_fdov[3]	0.000	0.096
255	log_fdov[3]	0.000	0.096
256	log_fdov[3]	0.000	0.096
257	log_fdov[3]	0.000	0.096
258	log_fdov[3]	0.000	0.096
259	log_fdov[3]	0.000	0.096
260	log_fdov[3]	0.000	0.096
261	log_fdov[3]	0.000	0.096
262	log_fdov[3]	0.000	0.096
263	log_fdov[3]	0.000	0.096
264	log_fdov[3]	0.001	0.096
265	log_fdov[3]	1.546	0.169
266	log_fdov[3]	1.804	0.120
267	log_fdov[3]	0.573	0.141
268	log_fdov[3]	-3.440	0.108
269	log_fdov[3]	-2.134	0.145
270	log_fdov[3]	-0.775	0.126
271	log_fdov[3]	0.043	0.132
272	log_fdov[3]	0.387	0.102
273	log_fdov[3]	0.943	0.167
274	log_fdov[3]	0.162	0.152
275	log_fdov[3]	0.889	0.167
276	rec_dev_est	1.066	0.269
277	rec_dev_est	0.627	0.295
278	rec_dev_est	1.073	0.240
279	rec_dev_est	1.658	0.207
280	rec_dev_est	1.921	0.216
281	rec_dev_est	1.127	0.257
282	rec_dev_est	2.396	0.165
283	rec_dev_est	1.442	0.179
284	rec_dev_est	1.072	0.166
285	rec_dev_est	-0.768	0.250
286	rec_dev_est	0.322	0.163
287	rec_dev_est	-0.843	0.245
288	rec_dev_est	-1.269	0.277
289	rec_dev_est	-1.008	0.223

240	log_fdov[1]	-1.129	0.078
241	log_fdov[1]	-1.845	0.078
242	log_fdov[1]	0.178	0.078
293	rec_dev_est	-0.886	0.197
294	rec_dev_est	-2.023	0.424
295	rec_dev_est	0.994	0.147
296	rec_dev_est	-0.936	0.260
297	rec_dev_est	-1.599	0.339
298	rec_dev_est	-0.573	0.198
299	rec_dev_est	0.423	0.155
300	rec_dev_est	-0.568	0.225
301	rec_dev_est	-0.534	0.239
302	rec_dev_est	0.850	0.154
303	rec_dev_est	-0.627	0.265
304	rec_dev_est	-0.698	0.265
305	rec_dev_est	0.586	0.156
306	rec_dev_est	-0.150	0.182
307	rec_dev_est	-0.542	0.189
308	rec_dev_est	-1.124	0.236
309	rec_dev_est	-0.992	0.236
310	rec_dev_est	-0.010	0.178
311	rec_dev_est	-0.557	0.227
312	rec_dev_est	-1.103	0.233
313	rec_dev_est	-1.421	0.222
314	rec_dev_est	-1.890	0.268
315	rec_dev_est	-1.428	0.225
316	rec_dev_est	-0.756	0.174
317	rec_dev_est	-1.619	0.257
318	rec_dev_est	-0.816	0.196
319	rec_dev_est	-1.425	0.277
320	rec_dev_est	-1.335	0.279
321	rec_dev_est	-1.203	0.273
322	rec_dev_est	-0.893	0.316
323	logit_rec_prop_est	-0.093	0.433
324	logit_rec_prop_est	-0.844	0.513
325	logit_rec_prop_est	-0.235	0.357
326	logit_rec_prop_est	-0.439	0.266
327	logit_rec_prop_est	0.078	0.255
328	logit_rec_prop_est	0.273	0.336
329	logit_rec_prop_est	0.343	0.140
330	logit_rec_prop_est	0.395	0.231
331	logit_rec_prop_est	-0.095	0.175
332	logit_rec_prop_est	0.462	0.463
333	logit_rec_prop_est	-0.497	0.165
334	logit_rec_prop_est	0.206	0.419
335	logit_rec_prop_est	-0.106	0.458
336	logit_rec_prop_est	0.433	0.389
337	logit_rec_prop_est	-0.091	0.167
338	logit_rec_prop_est	0.167	0.242
290	rec_dev_est	-0.054	0.164
291	rec_dev_est	-0.518	0.184
292	rec_dev_est	-1.985	0.357
339	logit_rec_prop_est	0.751	0.737
340	logit_rec_prop_est	0.231	0.284
341	logit_rec_prop_est	-0.222	0.692
342	logit_rec_prop_est	-0.298	0.087
343	logit_rec_prop_est	1.317	0.660
344	logit_rec_prop_est	0.431	0.646
345	logit_rec_prop_est	0.498	0.324
346	logit_rec_prop_est	-0.049	0.141
347	logit_rec_prop_est	0.193	0.363
348	logit_rec_prop_est	-0.531	0.373
349	logit_rec_prop_est	-0.489	0.124
350	logit_rec_prop_est	-0.419	0.426
351	logit_rec_prop_est	0.009	0.444
352	logit_rec_prop_est	-0.393	0.139
353	logit_rec_prop_est	-0.091	0.237
354	logit_rec_prop_est	0.360	0.280
355	logit_rec_prop_est	-0.185	0.370
356	logit_rec_prop_est	-0.429	0.359
357	logit_rec_prop_est	-0.786	0.194
358	logit_rec_prop_est	-0.460	0.317
359	logit_rec_prop_est	-0.522	0.346
360	logit_rec_prop_est	-0.228	0.332
361	logit_rec_prop_est	-0.287	0.428
362	logit_rec_prop_est	-0.314	0.327
363	logit_rec_prop_est	0.331	0.218
364	logit_rec_prop_est	0.537	0.474
365	logit_rec_prop_est	0.800	0.308
366	logit_rec_prop_est	0.187	0.467
367	logit_rec_prop_est	0.662	0.523
368	logit_rec_prop_est	0.194	0.444
369	logit_rec_prop_est	-0.755	0.513
370	m_dev_est[1]	1.594	0.029
371	survey_q[1]	0.967	0.025
372	log_add_cv[2]	-0.775	0.273

Table 6b. Summary of estimated model parameter values and standard deviations for model 22.0 for Bristol Bay red king crab.

index	name	value	std.dev	index	name	value	std.dev
1	theta[2]	0.253	0.016	47	log_slx_pars[3]	4.501	0.016
2	theta[4]	17.851	0.041	48	log_slx_pars[4]	1.993	0.116
3	theta[5]	15.817	0.156	49	log_slx_pars[5]	5.208	0.093
4	theta[7]	0.648	0.123	50	log_slx_pars[6]	2.932	0.054
5	theta[9]	-0.456	0.250	51	log_slx_pars[7]	4.731	0.223
6	theta[13]	0.759	0.497	52	log_slx_pars[8]	2.165	0.306
7	theta[14]	0.778	0.475	53	log_slx_pars[9]	4.718	0.091
8	theta[15]	1.131	0.350	54	log_slx_pars[10]	0.903	0.302
9	theta[16]	1.320	0.285	55	log_slx_pars[11]	4.787	0.023
10	theta[17]	1.255	0.265	56	log_slx_pars[12]	2.339	0.088
11	theta[18]	0.989	0.272	57	log_slx_pars[13]	3.946	0.380
12	theta[19]	0.945	0.259	58	log_slx_pars[14]	2.956	0.384
13	theta[20]	1.202	0.222	59	log_slx_pars[15]	4.435	0.033
14	theta[21]	1.194	0.216	60	log_slx_pars[16]	2.425	0.090
15	theta[22]	1.011	0.223	61	log_slx_pars[17]	4.924	0.002
16	theta[23]	0.958	0.215	62	log_slx_pars[18]	0.672	0.070
17	theta[24]	0.815	0.218	63	log_slx_pars[19]	4.932	0.002
18	theta[25]	0.486	0.223	64	log_slx_pars[20]	0.734	0.099
19	theta[26]	0.044	0.194	65	log_fbar[1]	-1.645	0.048
20	theta[27]	-0.427	0.197	66	log_fbar[2]	-4.694	0.082
21	theta[28]	-1.082	0.220	67	log_fbar[3]	-5.973	0.307
22	theta[29]	-1.662	0.253	68	log_fbar[4]	-6.548	0.073
23	theta[30]	-2.340	0.276	69	log_fdev[1]	1.030	0.119
24	theta[31]	-2.004	0.361	70	log_fdev[1]	1.250	0.079
25	theta[52]	-0.099	0.599	71	log_fdev[1]	0.857	0.063
26	theta[53]	0.396	0.656	72	log_fdev[1]	0.005	0.052
27	theta[54]	0.869	0.546	73	log_fdev[1]	0.153	0.046
28	theta[55]	1.077	0.428	74	log_fdev[1]	0.809	0.037
29	theta[56]	1.224	0.336	75	log_fdev[1]	0.821	0.039
30	theta[57]	1.049	0.314	76	log_fdev[1]	0.305	0.043
31	theta[58]	0.830	0.311	77	log_fdev[1]	0.969	0.047
32	theta[59]	0.368	0.348	78	log_fdev[1]	-4.182	0.045
33	theta[60]	-0.372	0.393	79	log_fdev[1]	-4.591	0.039
34	theta[61]	-0.822	0.386	80	log_fdev[1]	-0.120	0.038
35	theta[62]	-1.523	0.376	81	log_fdev[1]	-0.074	0.038
36	theta[63]	-1.616	0.373	82	log_fdev[1]	0.842	0.040
37	theta[64]	-1.546	0.373	83	log_fdev[1]	0.482	0.039
38	theta[65]	-1.769	0.363	84	log_fdev[1]	-0.106	0.038
39	theta[66]	-1.907	0.353	85	log_fdev[1]	-0.185	0.038
40	theta[67]	-1.874	0.344	86	log_fdev[1]	-0.071	0.037
41	Grwth[21]	0.897	0.192	87	log_fdev[1]	0.394	0.036

42	Grwth[42]	1.488	0.134	88	log_fdev[1]	0.351	0.037
43	Grwth[64]	139.700	0.612	89	log_fdev[1]	0.641	0.037
44	Grwth[65]	0.071	0.003	90	log_fdev[1]	0.395	0.036
45	log_slx_pars[1]	4.759	0.008	91	log_fdev[1]	0.759	0.036
46	log_slx_pars[2]	2.266	0.046	92	log_fdev[1]	0.928	0.037
93	log_fdev[1]	0.743	0.037	143	log_fdev[3]	-0.727	0.066
94	log_fdev[1]	0.612	0.037	144	log_fdev[3]	0.116	0.066
95	log_fdev[1]	-0.024	0.036	145	log_fdev[3]	1.312	0.066
96	log_fdev[1]	-0.100	0.035	146	log_fdev[3]	1.790	0.066
97	log_fdev[1]	0.088	0.035	147	log_fdev[3]	3.616	0.076
98	log_fdev[1]	0.416	0.035	148	log_fdev[3]	1.665	0.095
99	log_fdev[1]	0.486	0.038	149	log_fdev[3]	0.960	0.127
100	log_fdev[1]	0.482	0.043	150	log_fdev[3]	-0.383	0.080
101	log_fdev[1]	0.387	0.051	151	log_fdev[3]	-1.764	0.074
102	log_fdev[1]	0.192	0.061	152	log_fdev[3]	-2.614	0.091
103	log_fdev[1]	0.129	0.069	153	log_fdev[3]	-2.036	0.116
104	log_fdev[1]	-0.309	0.073	154	log_fdev[3]	-3.123	0.077
105	log_fdev[1]	-4.762	0.073	155	log_fdev[3]	-0.479	0.096
106	log_fdev[2]	2.366	0.114	156	log_fdev[3]	0.243	0.114
107	log_fdev[2]	1.339	0.112	157	log_fdev[3]	1.422	0.137
108	log_fdev[2]	0.944	0.109	158	log_fdev[4]	0.578	0.103
109	log_fdev[2]	1.778	0.104	159	log_fdev[4]	-0.086	0.102
110	log_fdev[2]	0.381	0.103	160	log_fdev[4]	-0.305	0.103
111	log_fdev[2]	0.847	0.103	161	log_fdev[4]	0.614	0.102
112	log_fdev[2]	1.271	0.104	162	log_fdev[4]	-1.814	0.101
113	log_fdev[2]	1.108	0.104	163	log_fdev[4]	0.142	0.101
114	log_fdev[2]	1.579	0.106	164	log_fdev[4]	-0.115	0.100
115	log_fdev[2]	-0.183	0.104	165	log_fdev[4]	-0.949	0.100
116	log_fdev[2]	-0.468	0.102	166	log_fdev[4]	-0.775	0.100
117	log_fdev[2]	-0.403	0.103	167	log_fdev[4]	-0.501	0.100
118	log_fdev[2]	-0.874	0.102	168	log_fdev[4]	-0.547	0.100
119	log_fdev[2]	0.417	0.103	169	log_fdev[4]	-0.001	0.100
120	log_fdev[2]	0.138	0.103	170	log_fdev[4]	-0.702	0.100
121	log_fdev[2]	-0.620	0.102	171	log_fdev[4]	-1.700	0.100
122	log_fdev[2]	0.150	0.102	172	log_fdev[4]	-2.536	0.099
123	log_fdev[2]	-0.149	0.102	173	log_fdev[4]	-1.055	0.099
124	log_fdev[2]	-0.243	0.102	174	log_fdev[4]	-0.500	0.099
125	log_fdev[2]	-0.011	0.102	175	log_fdev[4]	0.639	0.099
126	log_fdev[2]	-0.289	0.101	176	log_fdev[4]	1.488	0.099
127	log_fdev[2]	-0.118	0.101	177	log_fdev[4]	1.168	0.100
128	log_fdev[2]	-0.043	0.101	178	log_fdev[4]	0.334	0.101
129	log_fdev[2]	-0.074	0.101	179	log_fdev[4]	1.932	0.102
130	log_fdev[2]	-0.431	0.101	180	log_fdev[4]	2.187	0.104
131	log_fdev[2]	-0.577	0.101	181	log_fdev[4]	0.981	0.105
132	log_fdev[2]	-1.037	0.101	182	log_fdev[4]	0.771	0.107
133	log_fdev[2]	-1.557	0.101	183	log_fdev[4]	0.751	0.109
134	log_fdev[2]	-0.843	0.101	184	log_foff[1]	-2.787	0.039
135	log_fdev[2]	-1.410	0.102	185	log_foff[3]	-0.208	0.425
136	log_fdev[2]	-1.029	0.102	186	log_fdov[1]	2.000	0.084

137	log_fdev[2]	-0.507	0.104	187	log_fdov[1]	-0.674	0.083
138	log_fdev[2]	-0.078	0.106	188	log_fdov[1]	1.995	0.084
139	log_fdev[2]	-0.148	0.108	189	log_fdov[1]	1.830	0.086
140	log_fdev[2]	-0.059	0.111	190	log_fdov[1]	-0.408	0.084
141	log_fdev[2]	-0.089	0.113	191	log_fdov[1]	-0.183	0.082
142	log_fdev[2]	-1.077	0.114	192	log_fdov[1]	-3.692	0.081
193	log_fdov[1]	-0.323	0.082	243	rec_dev_est	-0.556	0.265
194	log_fdov[1]	1.462	0.082	244	rec_dev_est	-1.183	0.334
195	log_fdov[1]	-2.767	0.081	245	rec_dev_est	-0.172	0.208
196	log_fdov[1]	1.161	0.080	246	rec_dev_est	0.807	0.171
197	log_fdov[1]	0.884	0.080	247	rec_dev_est	-0.179	0.234
198	log_fdov[1]	-1.866	0.080	248	rec_dev_est	-0.124	0.246
199	log_fdov[1]	1.219	0.080	249	rec_dev_est	1.218	0.171
200	log_fdov[1]	0.428	0.080	250	rec_dev_est	-0.225	0.271
201	log_fdov[1]	0.963	0.079	251	rec_dev_est	-0.300	0.268
202	log_fdov[1]	-1.223	0.079	252	rec_dev_est	0.967	0.172
203	log_fdov[1]	-0.183	0.079	253	rec_dev_est	0.231	0.195
204	log_fdov[1]	-0.447	0.079	254	rec_dev_est	-0.131	0.201
205	log_fdov[1]	-0.713	0.079	255	rec_dev_est	-0.739	0.249
206	log_fdov[1]	-0.233	0.079	256	rec_dev_est	-0.574	0.244
207	log_fdov[1]	-1.132	0.078	257	rec_dev_est	0.364	0.194
208	log_fdov[1]	-1.852	0.078	258	rec_dev_est	-0.131	0.236
209	log_fdov[1]	0.168	0.078	259	rec_dev_est	-0.730	0.248
210	log_fdov[1]	-0.238	0.078	260	rec_dev_est	-1.007	0.233
211	log_fdov[1]	0.821	0.079	261	rec_dev_est	-1.458	0.272
212	log_fdov[1]	0.272	0.080	262	rec_dev_est	-1.020	0.231
213	log_fdov[1]	-0.380	0.083	263	rec_dev_est	-0.328	0.187
214	log_fdov[1]	0.948	0.088	264	rec_dev_est	-1.182	0.262
215	log_fdov[1]	-0.126	0.091	265	rec_dev_est	-0.398	0.209
216	log_fdov[1]	-0.650	0.093	266	rec_dev_est	-0.986	0.282
217	log_fdov[1]	2.939	0.093	267	rec_dev_est	-0.917	0.285
218	log_fdov[3]	0.000	0.093	268	rec_dev_est	-0.778	0.286
219	log_fdov[3]	0.000	0.093	269	rec_dev_est	-0.442	0.330
220	log_fdov[3]	0.000	0.093	270	logit_rec_prop_est	-0.452	0.150
221	log_fdov[3]	0.001	0.093	271	logit_rec_prop_est	0.248	0.420
222	log_fdov[3]	1.546	0.142	272	logit_rec_prop_est	-0.070	0.459
223	log_fdov[3]	1.829	0.119	273	logit_rec_prop_est	0.463	0.371
224	log_fdov[3]	0.598	0.145	274	logit_rec_prop_est	-0.061	0.163
225	log_fdov[3]	-3.425	0.108	275	logit_rec_prop_est	0.234	0.244
226	log_fdov[3]	-2.181	0.144	276	logit_rec_prop_est	0.580	0.665
227	log_fdov[3]	-0.801	0.117	277	logit_rec_prop_est	0.313	0.287
228	log_fdov[3]	0.026	0.136	278	logit_rec_prop_est	-0.463	0.653
229	log_fdov[3]	0.376	0.104	279	logit_rec_prop_est	-0.239	0.088
230	log_fdov[3]	0.961	0.151	280	logit_rec_prop_est	1.304	0.604
231	log_fdov[3]	0.168	0.145	281	logit_rec_prop_est	0.416	0.602
232	log_fdov[3]	0.901	0.174	282	logit_rec_prop_est	0.542	0.320
233	rec_dev_est	0.742	0.175	283	logit_rec_prop_est	-0.018	0.142
234	rec_dev_est	-0.478	0.253	284	logit_rec_prop_est	0.219	0.364
235	rec_dev_est	-0.901	0.285	285	logit_rec_prop_est	-0.503	0.369

236	rec_dev_est	-0.583	0.227	286	logit_rec_prop_est	-0.444	0.128
237	rec_dev_est	0.327	0.178	287	logit_rec_prop_est	-0.417	0.422
238	rec_dev_est	-0.132	0.197	288	logit_rec_prop_est	0.046	0.434
239	rec_dev_est	-1.581	0.363	289	logit_rec_prop_est	-0.350	0.139
240	rec_dev_est	-0.481	0.209	290	logit_rec_prop_est	-0.069	0.239
241	rec_dev_est	-1.543	0.410	291	logit_rec_prop_est	0.381	0.279
242	rec_dev_est	1.377	0.164	292	logit_rec_prop_est	-0.184	0.377
293	logit_rec_prop_est	-0.451	0.356				
294	logit_rec_prop_est	-0.724	0.200				
295	logit_rec_prop_est	-0.511	0.313				
296	logit_rec_prop_est	-0.461	0.358				
297	logit_rec_prop_est	-0.237	0.332				
298	logit_rec_prop_est	-0.306	0.422				
299	logit_rec_prop_est	-0.278	0.321				
300	logit_rec_prop_est	0.327	0.212				
301	logit_rec_prop_est	0.516	0.456				
302	logit_rec_prop_est	0.811	0.307				
303	logit_rec_prop_est	0.122	0.454				
304	logit_rec_prop_est	0.587	0.488				
305	logit_rec_prop_est	0.096	0.448				
306	logit_rec_prop_est	-0.969	0.567				
307	survey_q[1]	0.941	0.027				
308	log_add_cv[2]	-0.816	0.276				

Table 6c. Summary of estimated model parameter values and standard deviations for model 22.0a for Bristol Bay red king crab.

index	name	value	std.dev	index	name	value	std.dev
1	theta[1]	0.228	0.007	47	log_slx_pars[2]	2.275	0.043
2	theta[2]	0.135	0.020	48	log_slx_pars[3]	4.548	0.019
3	theta[4]	18.053	0.053	49	log_slx_pars[4]	2.177	0.099
4	theta[5]	16.129	0.162	50	log_slx_pars[5]	5.176	0.070
5	theta[7]	0.684	0.127	51	log_slx_pars[6]	2.857	0.049
6	theta[9]	-0.433	0.248	52	log_slx_pars[7]	4.724	0.239
7	theta[13]	0.907	0.505	53	log_slx_pars[8]	2.168	0.305
8	theta[14]	0.941	0.477	54	log_slx_pars[9]	4.701	0.104
9	theta[15]	1.263	0.352	55	log_slx_pars[10]	0.905	0.302
10	theta[16]	1.419	0.288	56	log_slx_pars[11]	4.809	0.023
11	theta[17]	1.336	0.266	57	log_slx_pars[12]	2.345	0.079
12	theta[18]	1.052	0.272	58	log_slx_pars[13]	4.008	0.335
13	theta[19]	0.981	0.258	59	log_slx_pars[14]	3.375	0.502
14	theta[20]	1.199	0.221	60	log_slx_pars[15]	4.480	0.033
15	theta[21]	1.156	0.216	61	log_slx_pars[16]	2.565	0.105
16	theta[22]	0.944	0.224	62	log_slx_pars[17]	4.924	0.002
17	theta[23]	0.863	0.217	63	log_slx_pars[18]	0.673	0.070
18	theta[24]	0.687	0.222	64	log_slx_pars[19]	4.933	0.002
19	theta[25]	0.344	0.227	65	log_slx_pars[20]	0.737	0.097
20	theta[26]	-0.102	0.196	66	log_fbar[1]	-1.678	0.049
21	theta[27]	-0.582	0.198	67	log_fbar[2]	-4.707	0.082
22	theta[28]	-1.236	0.221	68	log_fbar[3]	-6.067	0.344
23	theta[29]	-1.812	0.252	69	log_fbar[4]	-6.553	0.078
24	theta[30]	-2.483	0.275	70	log_fdev[1]	1.080	0.123
25	theta[31]	-2.110	0.352	71	log_fdev[1]	1.291	0.083
26	theta[52]	-0.079	0.608	72	log_fdev[1]	0.873	0.066
27	theta[53]	0.446	0.691	73	log_fdev[1]	0.003	0.054
28	theta[54]	0.990	0.566	74	log_fdev[1]	0.148	0.048
29	theta[55]	1.213	0.431	75	log_fdev[1]	0.802	0.038
30	theta[56]	1.350	0.336	76	log_fdev[1]	0.806	0.040
31	theta[57]	1.152	0.314	77	log_fdev[1]	0.291	0.044
32	theta[58]	0.910	0.309	78	log_fdev[1]	0.949	0.048
33	theta[59]	0.434	0.342	79	log_fdev[1]	-4.216	0.046
34	theta[60]	-0.326	0.387	80	log_fdev[1]	-4.617	0.040
35	theta[61]	-0.798	0.380	81	log_fdev[1]	-0.131	0.039
36	theta[62]	-1.534	0.372	82	log_fdev[1]	-0.068	0.039
37	theta[63]	-1.635	0.368	83	log_fdev[1]	0.853	0.041
38	theta[64]	-1.560	0.365	84	log_fdev[1]	0.469	0.041
39	theta[65]	-1.802	0.356	85	log_fdev[1]	-0.124	0.039
40	theta[66]	-1.957	0.346	86	log_fdev[1]	-0.189	0.039
41	theta[67]	-1.928	0.336	87	log_fdev[1]	-0.067	0.038
42	Grwth[21]	0.888	0.192	88	log_fdev[1]	0.391	0.037

43	Grwth[42]	1.460	0.138	89	log_fdev[1]	0.348	0.037
44	Grwth[64]	141.050	0.637	90	log_fdev[1]	0.641	0.038
45	Grwth[65]	0.068	0.003	91	log_fdev[1]	0.387	0.037
46	log_slx_pars[1]	4.779	0.009	92	log_fdev[1]	0.749	0.037
93	log_fdev[1]	0.918	0.038	143	log_fdev[2]	-0.990	0.114
94	log_fdev[1]	0.720	0.039	144	log_fdev[3]	-0.727	0.066
95	log_fdev[1]	0.575	0.038	145	log_fdev[3]	0.116	0.066
96	log_fdev[1]	-0.063	0.037	146	log_fdev[3]	1.312	0.066
97	log_fdev[1]	-0.129	0.036	147	log_fdev[3]	1.790	0.066
98	log_fdev[1]	0.071	0.036	148	log_fdev[3]	3.619	0.076
99	log_fdev[1]	0.403	0.037	149	log_fdev[3]	1.661	0.107
100	log_fdev[1]	0.472	0.039	150	log_fdev[3]	0.932	0.133
101	log_fdev[1]	0.475	0.043	151	log_fdev[3]	-0.394	0.085
102	log_fdev[1]	0.398	0.050	152	log_fdev[3]	-1.751	0.075
103	log_fdev[1]	0.229	0.059	153	log_fdev[3]	-2.609	0.099
104	log_fdev[1]	0.189	0.067	154	log_fdev[3]	-2.043	0.122
105	log_fdev[1]	-0.241	0.071	155	log_fdev[3]	-3.136	0.077
106	log_fdev[1]	-4.689	0.071	156	log_fdev[3]	-0.470	0.099
107	log_fdev[2]	2.414	0.116	157	log_fdev[3]	0.256	0.123
108	log_fdev[2]	1.369	0.114	158	log_fdev[3]	1.443	0.152
109	log_fdev[2]	0.951	0.110	159	log_fdev[4]	0.556	0.103
110	log_fdev[2]	1.771	0.105	160	log_fdev[4]	-0.094	0.102
111	log_fdev[2]	0.367	0.104	161	log_fdev[4]	-0.314	0.103
112	log_fdev[2]	0.825	0.103	162	log_fdev[4]	0.592	0.102
113	log_fdev[2]	1.241	0.104	163	log_fdev[4]	-1.836	0.101
114	log_fdev[2]	1.079	0.104	164	log_fdev[4]	0.126	0.101
115	log_fdev[2]	1.542	0.107	165	log_fdev[4]	-0.128	0.101
116	log_fdev[2]	-0.215	0.104	166	log_fdev[4]	-0.965	0.101
117	log_fdev[2]	-0.494	0.103	167	log_fdev[4]	-0.789	0.100
118	log_fdev[2]	-0.422	0.103	168	log_fdev[4]	-0.516	0.100
119	log_fdev[2]	-0.878	0.103	169	log_fdev[4]	-0.565	0.100
120	log_fdev[2]	0.416	0.103	170	log_fdev[4]	-0.018	0.100
121	log_fdev[2]	0.126	0.103	171	log_fdev[4]	-0.720	0.100
122	log_fdev[2]	-0.638	0.102	172	log_fdev[4]	-1.724	0.100
123	log_fdev[2]	0.138	0.102	173	log_fdev[4]	-2.565	0.100
124	log_fdev[2]	-0.153	0.102	174	log_fdev[4]	-1.082	0.099
125	log_fdev[2]	-0.249	0.102	175	log_fdev[4]	-0.517	0.099
126	log_fdev[2]	-0.019	0.102	176	log_fdev[4]	0.631	0.099
127	log_fdev[2]	-0.297	0.102	177	log_fdev[4]	1.485	0.100
128	log_fdev[2]	-0.129	0.101	178	log_fdev[4]	1.173	0.100
129	log_fdev[2]	-0.058	0.102	179	log_fdev[4]	0.350	0.101
130	log_fdev[2]	-0.091	0.102	180	log_fdev[4]	1.965	0.102
131	log_fdev[2]	-0.452	0.102	181	log_fdev[4]	2.238	0.104
132	log_fdev[2]	-0.606	0.102	182	log_fdev[4]	1.046	0.105
133	log_fdev[2]	-1.065	0.102	183	log_fdev[4]	0.844	0.107
134	log_fdev[2]	-1.577	0.102	184	log_fdev[4]	0.828	0.109
135	log_fdev[2]	-0.852	0.102	185	log_foff[1]	-2.815	0.044
136	log_fdev[2]	-1.409	0.102	186	log_foff[3]	-0.269	0.480
137	log_fdev[2]	-1.023	0.103	187	log_fdov[1]	1.972	0.084

138	log_fdev[2]	-0.491	0.104	188	log_fdov[1]	-0.689	0.083
139	log_fdev[2]	-0.046	0.106	189	log_fdov[1]	1.976	0.084
140	log_fdev[2]	-0.094	0.108	190	log_fdov[1]	1.812	0.086
141	log_fdev[2]	0.015	0.111	191	log_fdov[1]	-0.410	0.084
142	log_fdev[2]	-0.005	0.113	192	log_fdov[1]	-0.193	0.082
193	log_fdov[1]	-3.696	0.081	243	rec_dev_est	1.368	0.163
194	log_fdov[1]	-0.344	0.082	244	rec_dev_est	-0.441	0.255
195	log_fdov[1]	1.420	0.083	245	rec_dev_est	-1.147	0.332
196	log_fdov[1]	-2.793	0.082	246	rec_dev_est	-0.171	0.209
197	log_fdov[1]	1.146	0.081	247	rec_dev_est	0.820	0.171
198	log_fdov[1]	0.860	0.081	248	rec_dev_est	-0.134	0.231
199	log_fdov[1]	-1.898	0.080	249	rec_dev_est	-0.170	0.255
200	log_fdov[1]	1.199	0.080	250	rec_dev_est	1.239	0.170
201	log_fdov[1]	0.407	0.081	251	rec_dev_est	-0.187	0.266
202	log_fdov[1]	0.929	0.080	252	rec_dev_est	-0.284	0.268
203	log_fdov[1]	-1.244	0.079	253	rec_dev_est	0.942	0.173
204	log_fdov[1]	-0.199	0.079	254	rec_dev_est	0.291	0.192
205	log_fdov[1]	-0.462	0.080	255	rec_dev_est	-0.111	0.199
206	log_fdov[1]	-0.713	0.080	256	rec_dev_est	-0.696	0.243
207	log_fdov[1]	-0.215	0.080	257	rec_dev_est	-0.542	0.240
208	log_fdov[1]	-1.096	0.079	258	rec_dev_est	0.331	0.191
209	log_fdov[1]	-1.813	0.078	259	rec_dev_est	-0.108	0.227
210	log_fdov[1]	0.201	0.078	260	rec_dev_est	-0.722	0.243
211	log_fdov[1]	-0.203	0.079	261	rec_dev_est	-1.031	0.233
212	log_fdov[1]	0.864	0.079	262	rec_dev_est	-1.506	0.274
213	log_fdov[1]	0.318	0.081	263	rec_dev_est	-1.071	0.227
214	log_fdov[1]	-0.338	0.083	264	rec_dev_est	-0.408	0.186
215	log_fdov[1]	0.975	0.087	265	rec_dev_est	-1.226	0.256
216	log_fdov[1]	-0.109	0.090	266	rec_dev_est	-0.471	0.204
217	log_fdov[1]	-0.630	0.092	267	rec_dev_est	-1.072	0.281
218	log_fdov[1]	2.963	0.093	268	rec_dev_est	-0.954	0.282
219	log_fdov[3]	0.000	0.093	269	rec_dev_est	-0.839	0.283
220	log_fdov[3]	0.000	0.093	270	rec_dev_est	-0.510	0.322
221	log_fdov[3]	0.000	0.093	271	logit_rec_prop_est	-0.441	0.148
222	log_fdov[3]	0.001	0.093	272	logit_rec_prop_est	0.216	0.403
223	log_fdov[3]	1.494	0.120	273	logit_rec_prop_est	-0.075	0.450
224	log_fdov[3]	1.809	0.130	274	logit_rec_prop_est	0.450	0.371
225	log_fdov[3]	0.604	0.151	275	logit_rec_prop_est	-0.072	0.166
226	log_fdov[3]	-3.435	0.114	276	logit_rec_prop_est	0.207	0.233
227	log_fdov[3]	-2.230	0.149	277	logit_rec_prop_est	0.648	0.658
228	log_fdov[3]	-0.825	0.122	278	logit_rec_prop_est	0.308	0.285
229	log_fdov[3]	0.021	0.142	279	logit_rec_prop_est	-0.490	0.671
230	log_fdov[3]	0.385	0.103	280	logit_rec_prop_est	-0.299	0.090
231	log_fdov[3]	1.010	0.143	281	logit_rec_prop_est	1.198	0.569
232	log_fdov[3]	0.214	0.151	282	logit_rec_prop_est	0.451	0.607
233	log_fdov[3]	0.951	0.194	283	logit_rec_prop_est	0.536	0.324
234	rec_dev_est	0.753	0.174	284	logit_rec_prop_est	-0.057	0.140
235	rec_dev_est	-0.429	0.247	285	logit_rec_prop_est	0.217	0.354
236	rec_dev_est	-0.864	0.281	286	logit_rec_prop_est	-0.462	0.385

237	rec_dev_est	-0.574	0.227	287	logit_rec_prop_est	-0.500	0.127
238	rec_dev_est	0.324	0.178	288	logit_rec_prop_est	-0.388	0.410
239	rec_dev_est	-0.068	0.194	289	logit_rec_prop_est	-0.004	0.431
240	rec_dev_est	-1.509	0.352	290	logit_rec_prop_est	-0.365	0.142
241	rec_dev_est	-0.460	0.208	291	logit_rec_prop_est	-0.126	0.225
242	rec_dev_est	-1.601	0.427	292	logit_rec_prop_est	0.451	0.280
293	logit_rec_prop_est	-0.106	0.365				
294	logit_rec_prop_est	-0.451	0.347				
295	logit_rec_prop_est	-0.652	0.197				
296	logit_rec_prop_est	-0.490	0.292				
297	logit_rec_prop_est	-0.440	0.346				
298	logit_rec_prop_est	-0.207	0.332				
299	logit_rec_prop_est	-0.307	0.424				
300	logit_rec_prop_est	-0.300	0.312				
301	logit_rec_prop_est	0.319	0.211				
302	logit_rec_prop_est	0.553	0.453				
303	logit_rec_prop_est	0.792	0.301				
304	logit_rec_prop_est	0.148	0.454				
305	logit_rec_prop_est	0.536	0.481				
306	logit_rec_prop_est	0.171	0.448				
307	logit_rec_prop_est	-0.967	0.552				
308	survey_q[1]	0.922	0.028				
309	log_add_cv[2]	-0.971	0.289				

Table 7. Natural mortality estimates for three model scenarios during different year blocks.

Model	Sex	1975-1979, 1985-2022	1980-1984	1985-2022
21.1b	Males	0.180	0.886	
	Females	0.238	1.174	
22.0	Males			0.180
	Females			0.232
22.0a	Males			0.228
	Females			0.261

Table 8. Area-swept estimates of mature female abundance (million crab) and model estimates of effective spawning biomass (ESB, Zheng et al. 1995b) (1000 t) during 2011-2022 for groundfish fisheries bycatch (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
2011	28.520	19.541
2012	21.121	20.029
2013	15.694	22.382
2014	38.580	23.272
2015	18.666	21.098
2016	22.633	19.147
2017	18.497	18.042
2018	9.106	15.093
2019	8.587	12.705
2020	9.668*	11.394
2021	6.432	9.463
2022	8.004	8.894

Table 9a. Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) for red king crab in Bristol Bay estimated by length-based model 21.1b during 1975-2022. MMB for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	55.540	28.226	83.213	0.050	54.794	NA	235.861	199.643
1976	65.221	35.521	99.070	3.381	83.134	63.885	275.709	327.615
1977	72.440	41.304	113.031	3.817	110.373	41.197	297.013	371.223
1978	77.709	46.495	119.799	3.719	114.468	64.349	300.165	343.189
1979	68.280	47.420	99.943	3.121	109.505	115.470	288.724	165.449
1980	50.101	37.749	30.332	1.572	111.469	150.262	273.367	247.226
1981	14.471	8.026	6.551	1.017	48.863	67.936	109.145	131.145
1982	6.784	2.164	6.563	0.850	21.395	241.558	65.174	141.898
1983	6.175	2.171	7.407	0.590	14.199	93.067	57.646	48.476
1984	6.151	2.291	5.230	0.351	13.980	64.266	50.624	152.607
1985	7.558	1.884	9.676	0.376	9.730	10.204	34.842	34.138
1986	12.174	4.646	15.064	0.558	13.636	30.361	45.545	47.434
1987	14.360	6.686	20.405	0.701	17.029	9.473	51.326	69.245
1988	14.454	8.458	25.123	0.724	21.453	6.184	54.700	54.597
1989	15.546	9.750	27.979	0.701	20.233	8.033	57.355	55.136
1990	15.014	10.437	24.139	0.724	18.058	20.848	57.416	59.451
1991	11.547	8.652	18.449	0.760	17.435	13.111	52.333	83.892
1992	9.280	6.463	17.241	0.750	18.579	3.023	47.662	37.334
1993	10.499	6.160	15.852	0.826	17.269	9.070	47.203	52.906
1994	10.350	6.016	21.696	0.806	14.681	2.910	42.628	32.104
1995	10.862	7.892	24.839	0.730	13.574	59.439	48.696	38.068
1996	11.145	8.548	23.323	0.698	19.693	8.630	58.051	43.959
1997	10.587	7.787	22.063	0.688	28.739	4.446	64.180	84.030
1998	15.903	7.751	24.944	0.811	25.234	12.405	68.062	84.101
1999	16.967	9.732	28.678	0.875	21.317	33.581	66.662	64.754
2000	14.654	10.648	28.897	0.869	22.735	12.468	68.283	67.381
2001	14.471	10.216	29.284	0.838	25.762	12.893	71.897	52.455
2002	17.318	10.409	33.344	0.802	25.010	51.478	76.960	69.086
2003	18.144	12.050	32.898	0.816	30.661	11.755	83.108	115.760
2004	16.357	11.629	30.409	0.817	37.823	10.951	84.595	130.556
2005	18.229	10.845	30.944	0.821	35.026	39.536	85.554	105.727
2006	17.344	11.425	31.316	0.808	35.327	18.930	85.403	94.477
2007	15.638	11.175	26.310	0.828	39.205	12.793	86.951	103.327
2008	16.023	9.509	24.990	0.876	36.751	7.149	83.339	113.082
2009	15.870	9.465	25.857	0.906	32.183	8.156	77.330	90.547
2010	14.749	9.692	25.141	0.887	28.167	21.789	72.264	80.501
2011	12.486	9.152	24.850	0.822	27.729	12.611	67.802	66.408
2012	11.131	8.608	23.277	0.758	29.488	7.303	66.173	60.697
2013	11.042	7.865	22.213	0.704	27.879	5.315	63.453	62.217
2014	10.759	7.568	20.208	0.674	24.647	3.324	58.710	113.135
2015	9.238	6.891	17.223	0.664	21.092	5.278	51.909	64.175
2016	7.483	5.797	14.188	0.668	17.965	10.332	45.238	60.958
2017	5.936	4.699	11.595	0.673	16.325	4.358	40.299	52.935
2018	5.173	3.797	10.342	0.679	14.911	9.732	37.304	28.805
2019	5.919	3.519	11.240	0.742	13.124	5.294	36.024	28.539
2020	6.489	4.032	12.859	0.804	12.066	5.793		
2021	7.671	4.652	16.637	0.830	10.982	6.606	36.141	28.476
2022	8.658	5.963	16.953	1.180	10.201	9.006	38.016	36.198

Table 9b. Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) 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. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1985	8.557	2.350	11.651	0.007	8.440	NA	34.983	34.138
1986	12.986	5.351	17.143	0.505	11.908	31.070	44.854	47.434
1987	14.402	7.309	21.340	0.677	15.698	9.169	50.338	69.245
1988	14.418	8.689	25.552	0.704	20.545	6.011	53.589	54.597
1989	15.533	9.777	28.169	0.696	19.574	8.255	56.086	55.136
1990	15.089	10.459	24.356	0.739	17.604	20.523	56.080	59.451
1991	11.608	8.711	18.620	0.785	17.115	12.964	51.198	83.892
1992	9.366	6.515	17.426	0.776	18.263	3.043	46.836	37.334
1993	10.616	6.219	16.093	0.855	17.056	9.144	46.525	52.906
1994	10.513	6.101	22.010	0.830	14.609	3.161	42.186	32.104
1995	10.986	8.007	25.120	0.748	13.638	58.618	47.973	38.068
1996	11.305	8.643	23.651	0.719	19.628	8.485	57.278	43.959
1997	10.662	7.906	22.290	0.708	28.458	4.532	63.631	84.030
1998	16.156	7.799	25.401	0.838	25.175	12.459	67.618	84.101
1999	17.270	9.916	29.280	0.907	21.402	33.141	66.212	64.754
2000	14.880	10.863	29.431	0.900	22.783	12.372	67.855	67.381
2001	14.670	10.391	29.770	0.867	25.786	13.073	71.515	52.455
2002	17.558	10.556	33.871	0.830	25.156	49.985	76.328	69.086
2003	18.387	12.227	33.442	0.845	30.609	11.816	82.352	115.760
2004	16.544	11.810	30.880	0.846	37.556	10.964	83.936	130.556
2005	18.450	10.978	31.431	0.854	35.019	38.925	84.824	105.727
2006	17.553	11.590	31.797	0.842	35.322	18.643	84.702	94.477
2007	15.802	11.330	26.723	0.864	39.147	12.975	86.364	103.327
2008	16.242	9.630	25.461	0.918	36.866	7.063	83.001	113.082
2009	16.095	9.624	26.353	0.951	32.483	8.334	77.219	90.547
2010	14.996	9.858	25.679	0.933	28.616	21.279	72.204	80.501
2011	12.713	9.340	25.376	0.865	28.161	12.983	67.831	66.408
2012	11.310	8.780	23.735	0.798	29.908	7.126	66.312	60.697
2013	11.238	8.006	22.677	0.742	28.489	5.404	63.718	62.217
2014	10.954	7.718	20.672	0.713	25.260	3.443	59.092	113.135
2015	9.414	7.039	17.660	0.705	21.759	5.334	52.412	64.175
2016	7.648	5.935	14.603	0.710	18.643	10.655	45.840	60.958
2017	6.089	4.830	11.990	0.715	17.006	4.536	41.040	52.935
2018	5.319	3.918	10.721	0.719	15.634	9.940	38.162	28.805
2019	6.122	3.635	11.695	0.781	13.838	5.520	36.977	28.539
2020	6.713	4.187	13.370	0.840	12.782	5.916		
2021	7.939	4.820	17.230	0.862	11.737	6.793	37.146	28.476
2022	8.922	6.167	17.158	1.204	10.992	9.513	38.940	36.198

Table 9c. Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) for red king crab in Bristol Bay estimated by length-based model 22.0a during 1975-2022. MMB for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1985	8.837	2.375	11.771	0.007	10.572	NA	34.058	34.138
1986	13.669	5.465	17.699	0.527	14.890	42.936	44.651	47.434
1987	15.464	7.611	22.496	0.717	19.678	13.167	50.907	69.245
1988	15.613	9.197	27.056	0.749	25.738	8.523	54.866	54.597
1989	16.905	10.330	29.968	0.755	24.215	11.387	57.743	55.136
1990	16.338	11.099	26.071	0.821	21.462	27.952	57.729	59.451
1991	12.521	9.272	19.972	0.870	20.935	18.883	52.802	83.892
1992	10.235	6.932	18.686	0.858	22.567	4.469	48.624	37.334
1993	11.773	6.649	17.712	0.958	21.033	12.766	48.605	52.906
1994	11.889	6.737	24.062	0.954	17.867	4.077	44.562	32.104
1995	12.148	8.741	26.941	0.871	16.446	79.363	50.163	38.068
1996	12.243	9.191	25.037	0.820	24.647	13.010	58.696	43.959
1997	11.440	8.283	23.274	0.786	35.915	6.420	65.015	84.030
1998	17.674	8.133	27.168	0.948	31.183	17.044	69.465	84.101
1999	18.935	10.690	31.490	1.034	26.102	45.925	68.566	64.754
2000	16.129	11.684	31.266	1.012	28.030	17.680	70.155	67.381
2001	15.878	10.945	31.406	0.978	31.953	17.060	73.747	52.455
2002	19.212	11.096	35.944	0.977	30.762	69.824	78.686	69.086
2003	19.968	12.999	35.497	0.997	38.074	16.776	84.520	115.760
2004	17.833	12.511	32.579	0.986	47.217	15.214	86.324	130.556
2005	20.144	11.557	33.583	1.031	43.367	51.883	87.429	105.727
2006	19.081	12.405	33.875	1.029	43.515	27.054	87.195	94.477
2007	17.021	12.023	28.418	1.029	48.035	18.089	88.725	103.327
2008	17.708	10.193	27.435	1.107	44.885	10.079	85.576	113.082
2009	17.732	10.371	28.684	1.172	38.807	11.759	80.075	90.547
2010	16.634	10.721	28.194	1.174	33.698	28.137	74.998	80.501
2011	14.082	10.203	27.633	1.103	33.038	18.150	70.140	66.408
2012	12.392	9.463	25.515	1.013	34.946	9.825	67.981	60.697
2013	12.312	8.516	24.274	0.952	33.078	7.208	64.879	62.217
2014	11.975	8.223	22.134	0.903	28.918	4.484	59.788	113.135
2015	10.200	7.512	18.804	0.845	24.450	6.930	52.626	64.175
2016	8.174	6.276	15.345	0.792	20.625	13.442	45.504	60.958
2017	6.380	5.022	12.314	0.741	18.657	5.932	40.089	52.935
2018	5.500	3.975	10.766	0.711	16.967	12.628	36.765	28.805
2019	6.325	3.631	11.645	0.755	14.864	6.919	35.247	28.539
2020	6.883	4.181	13.195	0.794	13.645	7.788		
2021	8.101	4.774	16.927	0.804	12.461	8.740	34.992	28.476
2022	8.912	6.060	15.714	1.051	11.688	12.138	36.458	36.198

Figures

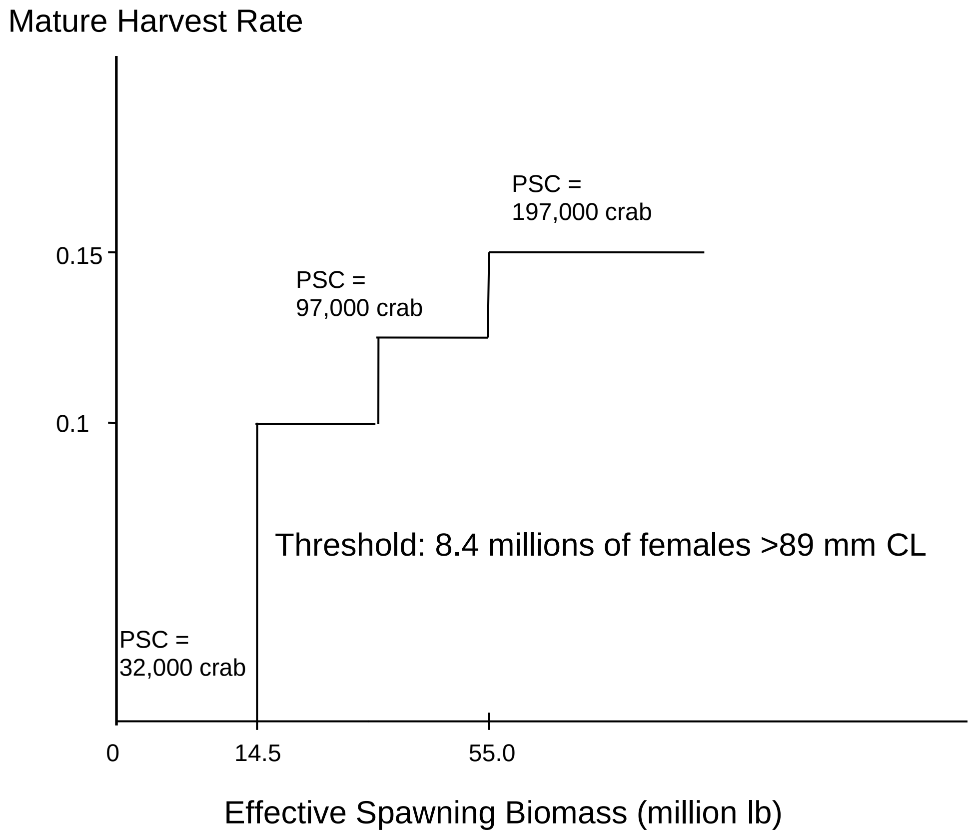


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and the associated annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year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

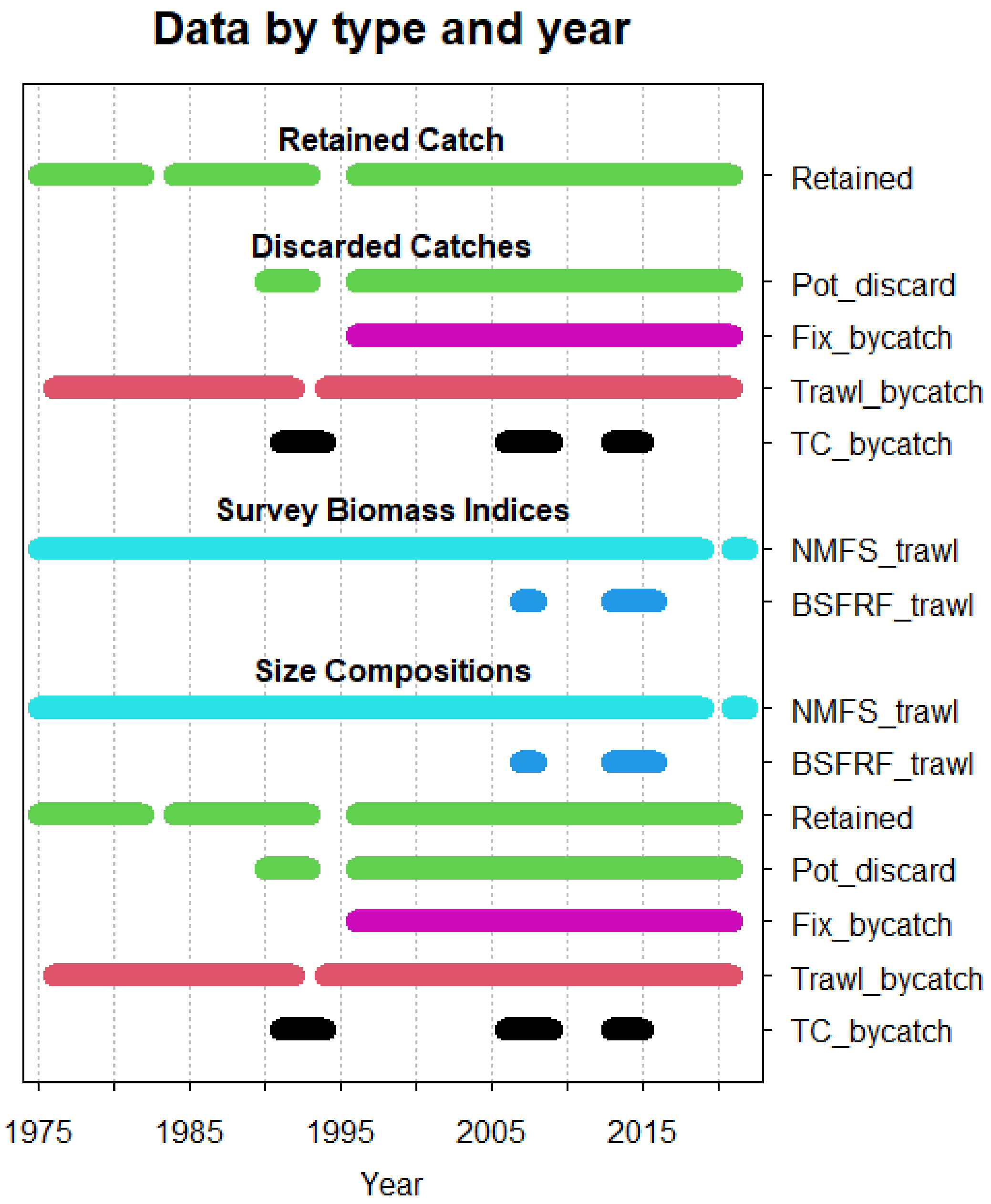


Figure 2. Data types and ranges used for the stock assessment.

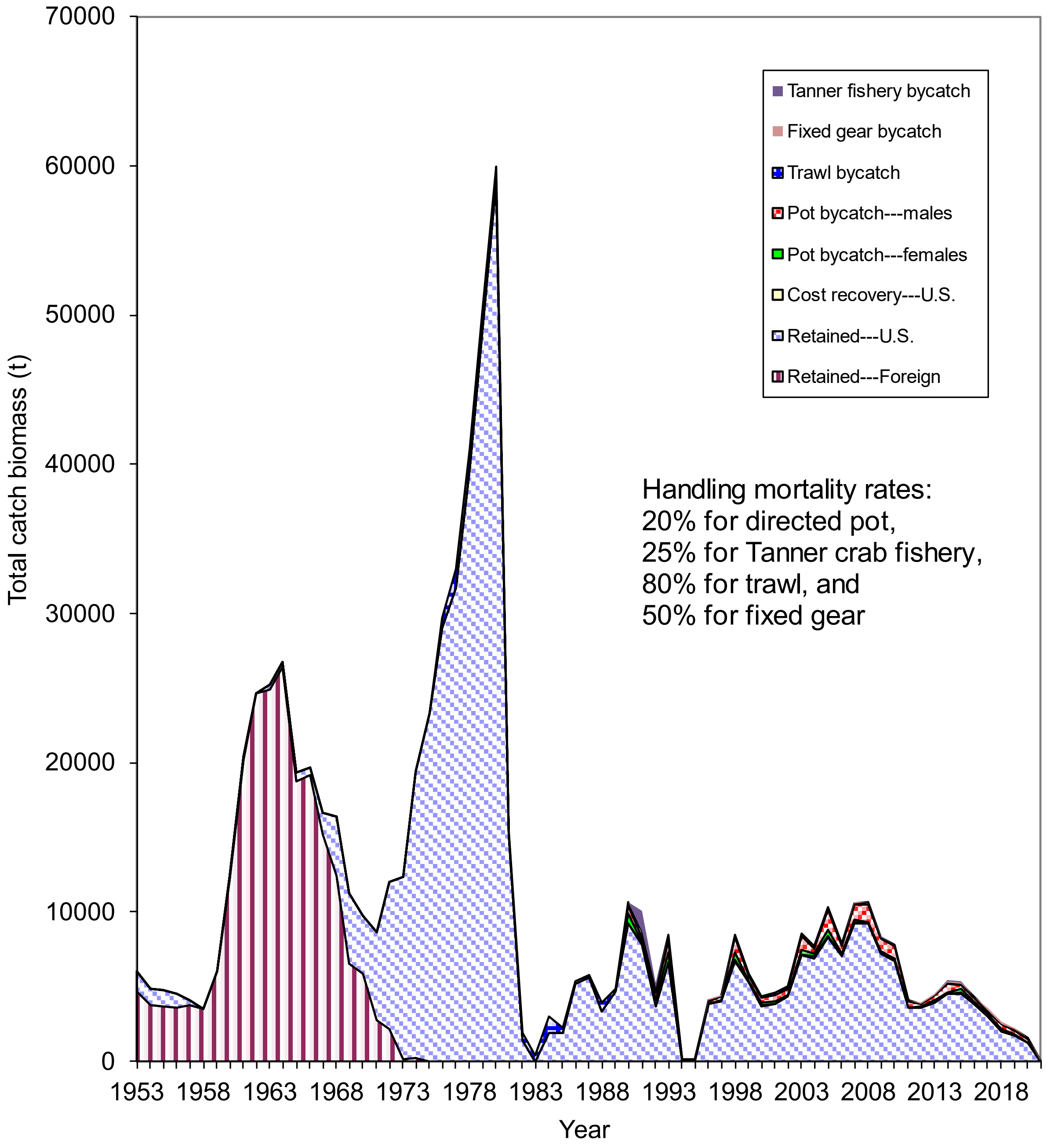


Figure 3. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2021. Directed pot bycatch data were not available from the observer program before 1990 and are not included in this figure.

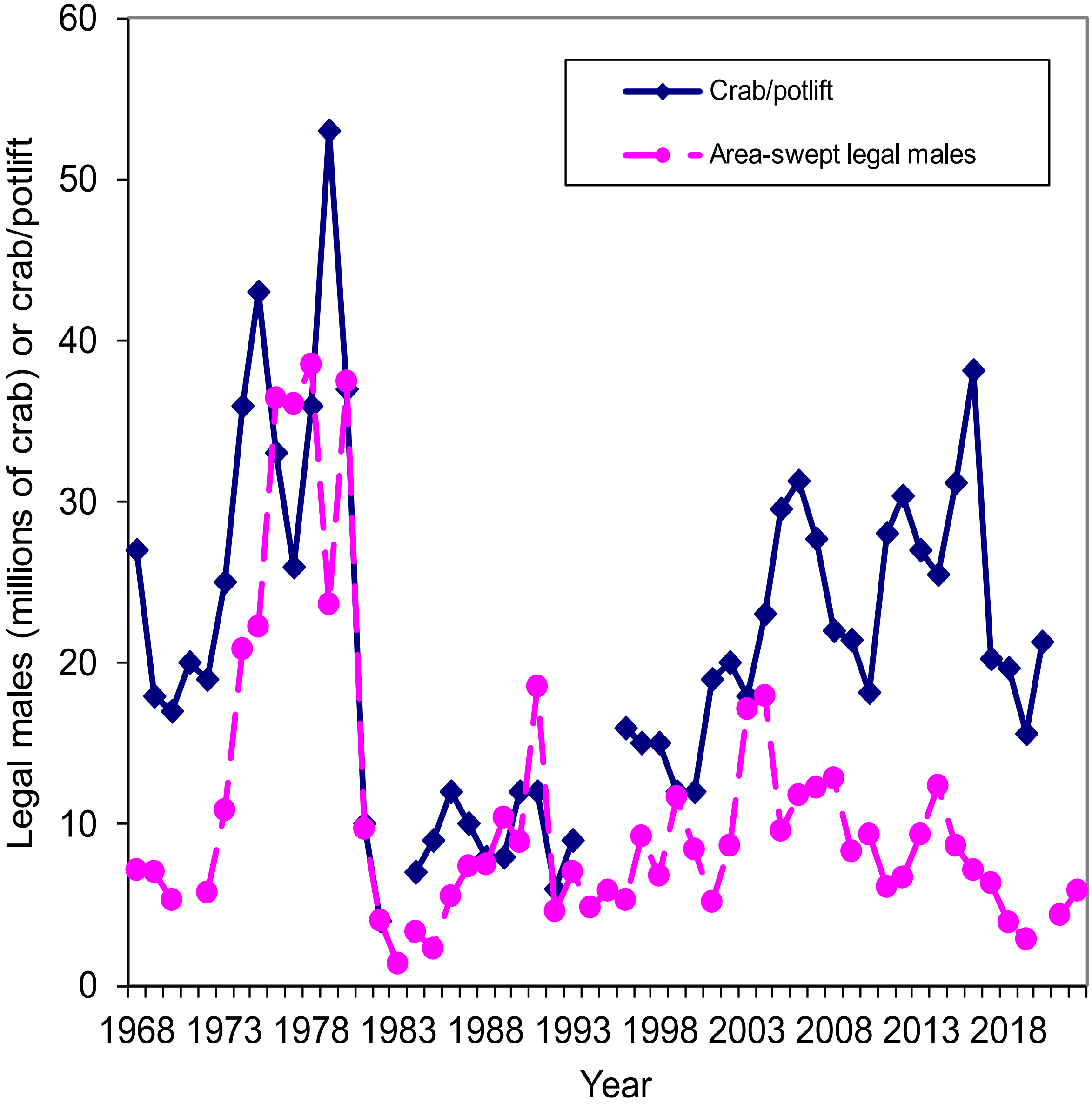


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2022.

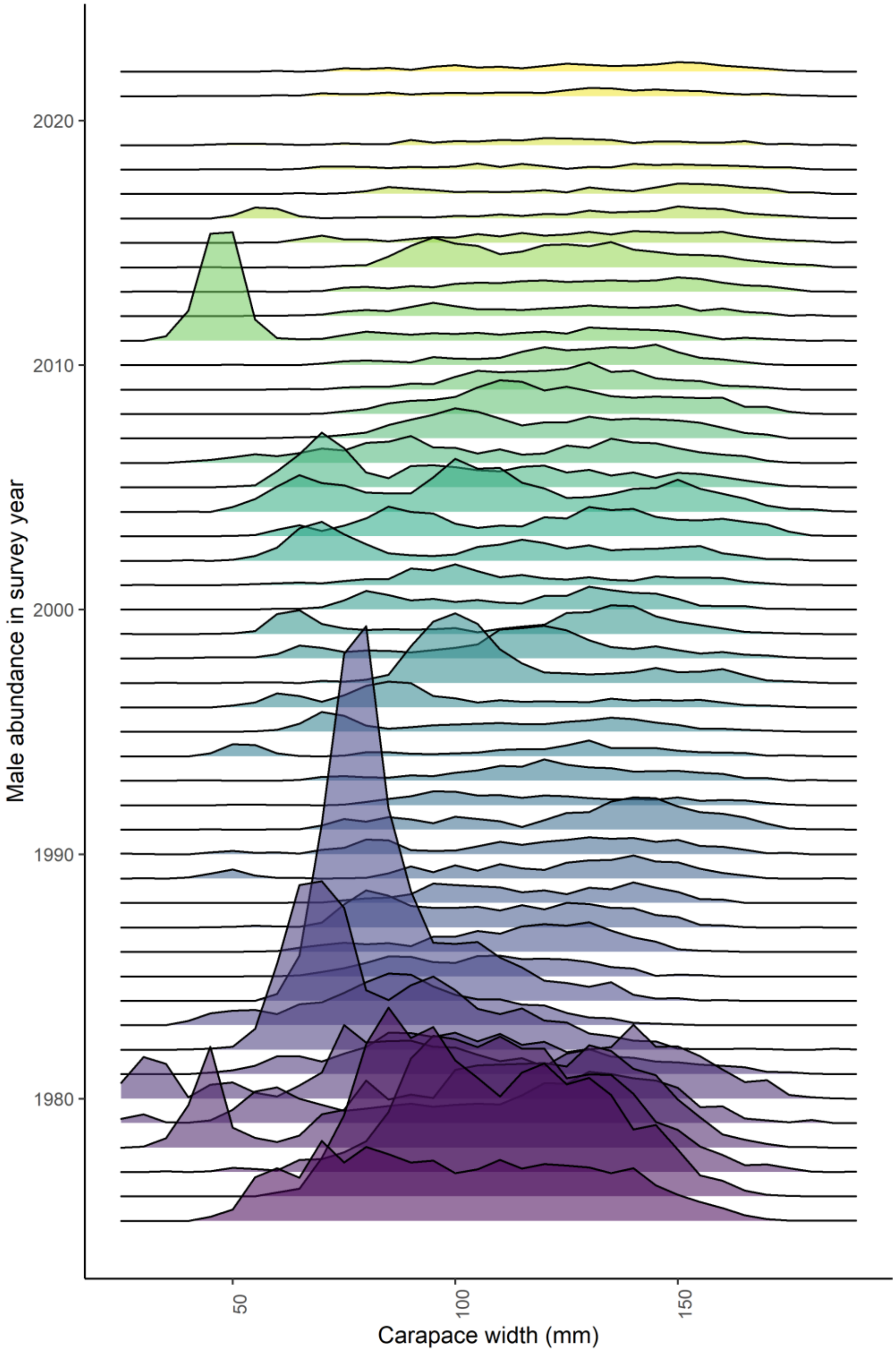


Figure 5a. Survey abundances by 5-mm carapace length bin for ***male*** Bristol Bay red king crab from 1975 to 2022.

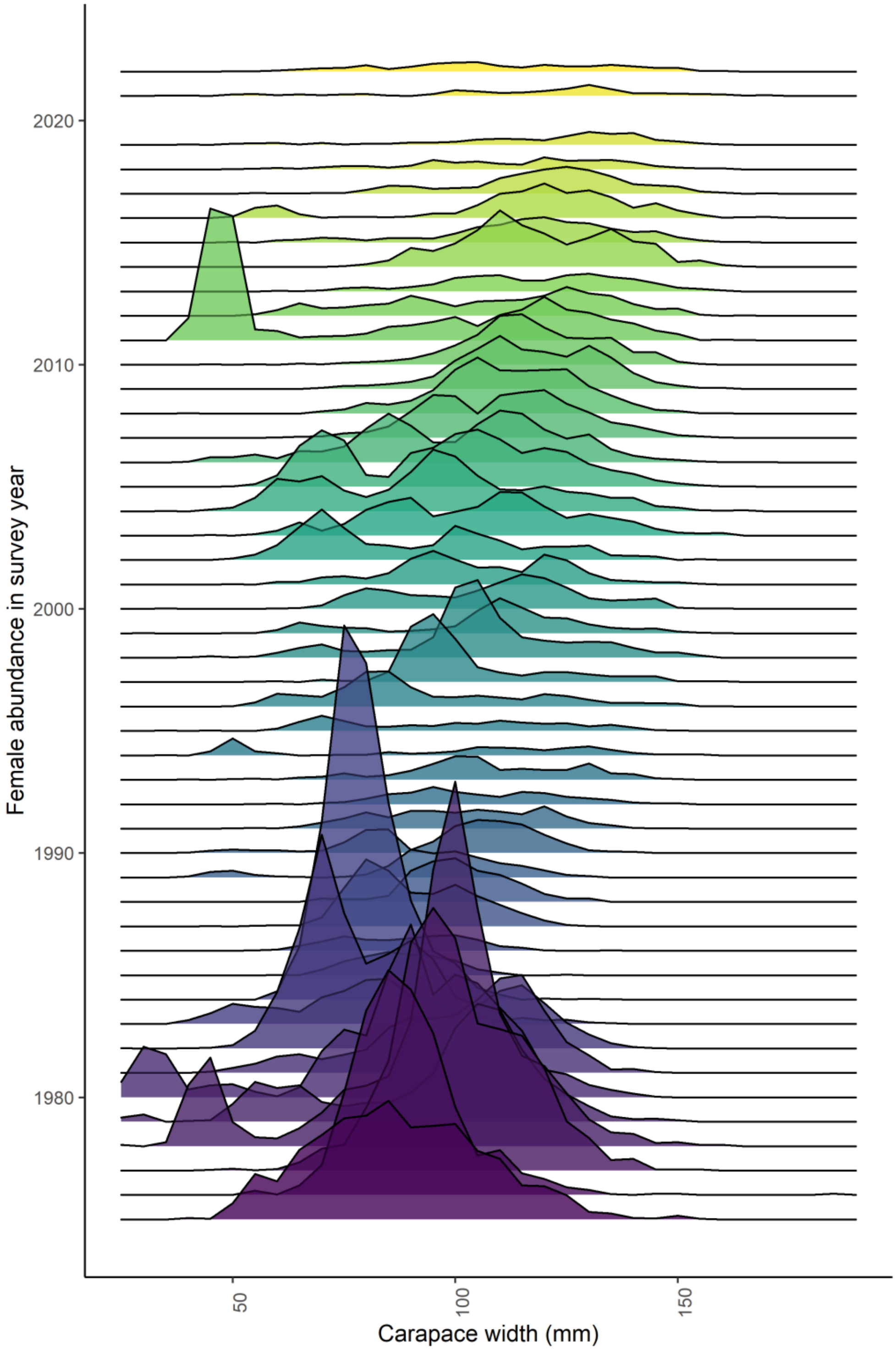


Figure 5b. Survey abundances by 5 mm carapace length bin for ***female*** Bristol Bay red king crab from 1975 to 2022.

Figure 6. Holding spot for VAST results in future assessments.

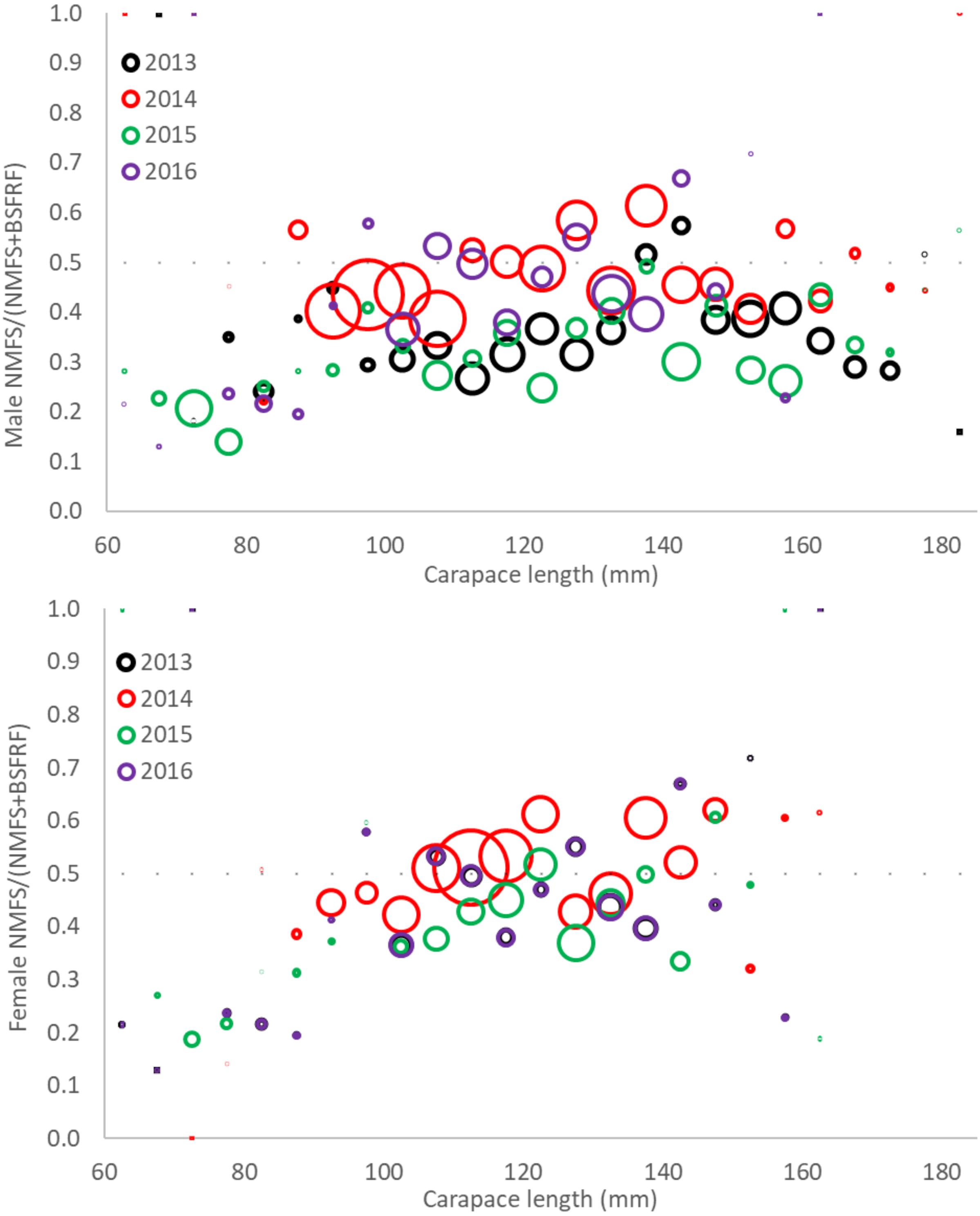
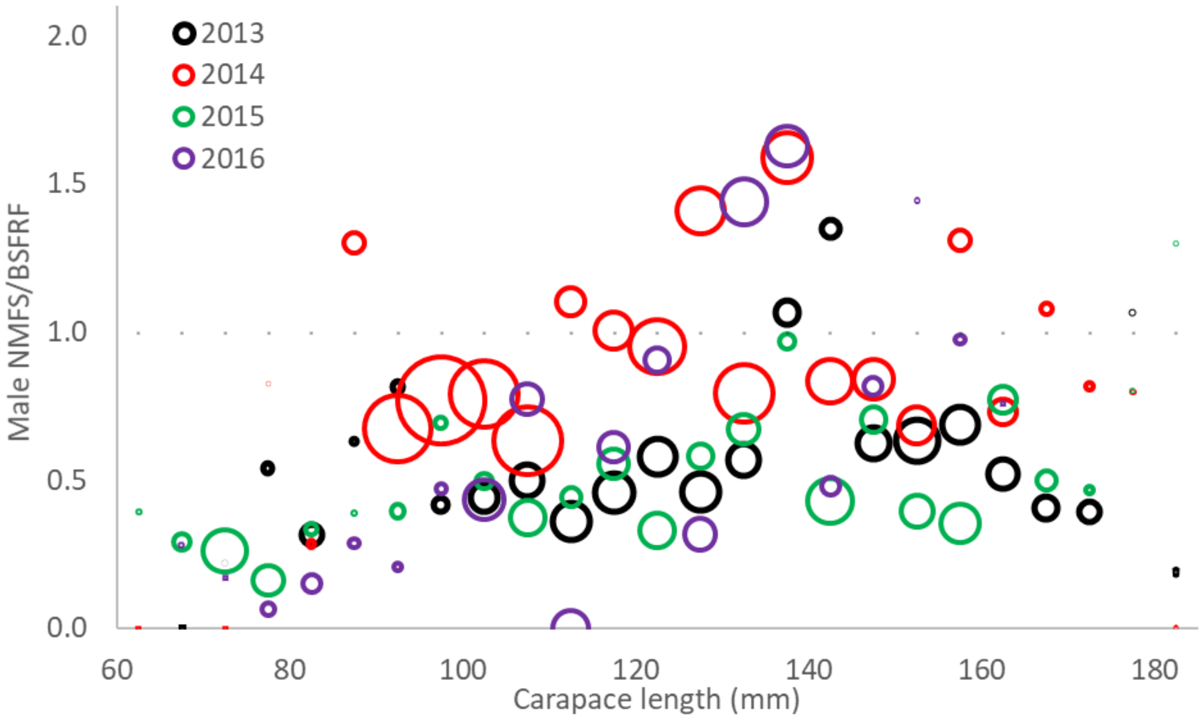


Figure 7a. Comparison of NMFS survey abundance proportions of total NMFS and BSFRF side-by-side trawl surveys during 2013-2016 for Bristol Bay red king crab. Sizes of circles are proportional to total abundances.



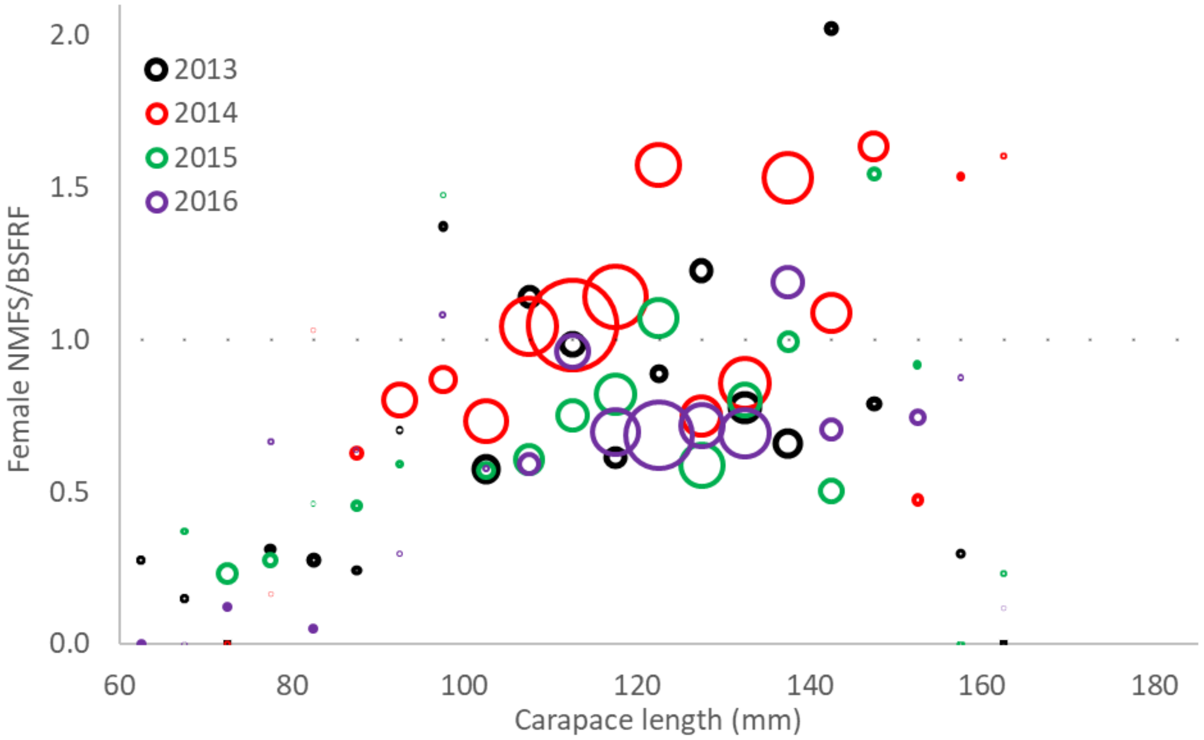


Figure 7b. Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for Bristol Bay red king crab. Sizes of circles are proportional to total abundances.

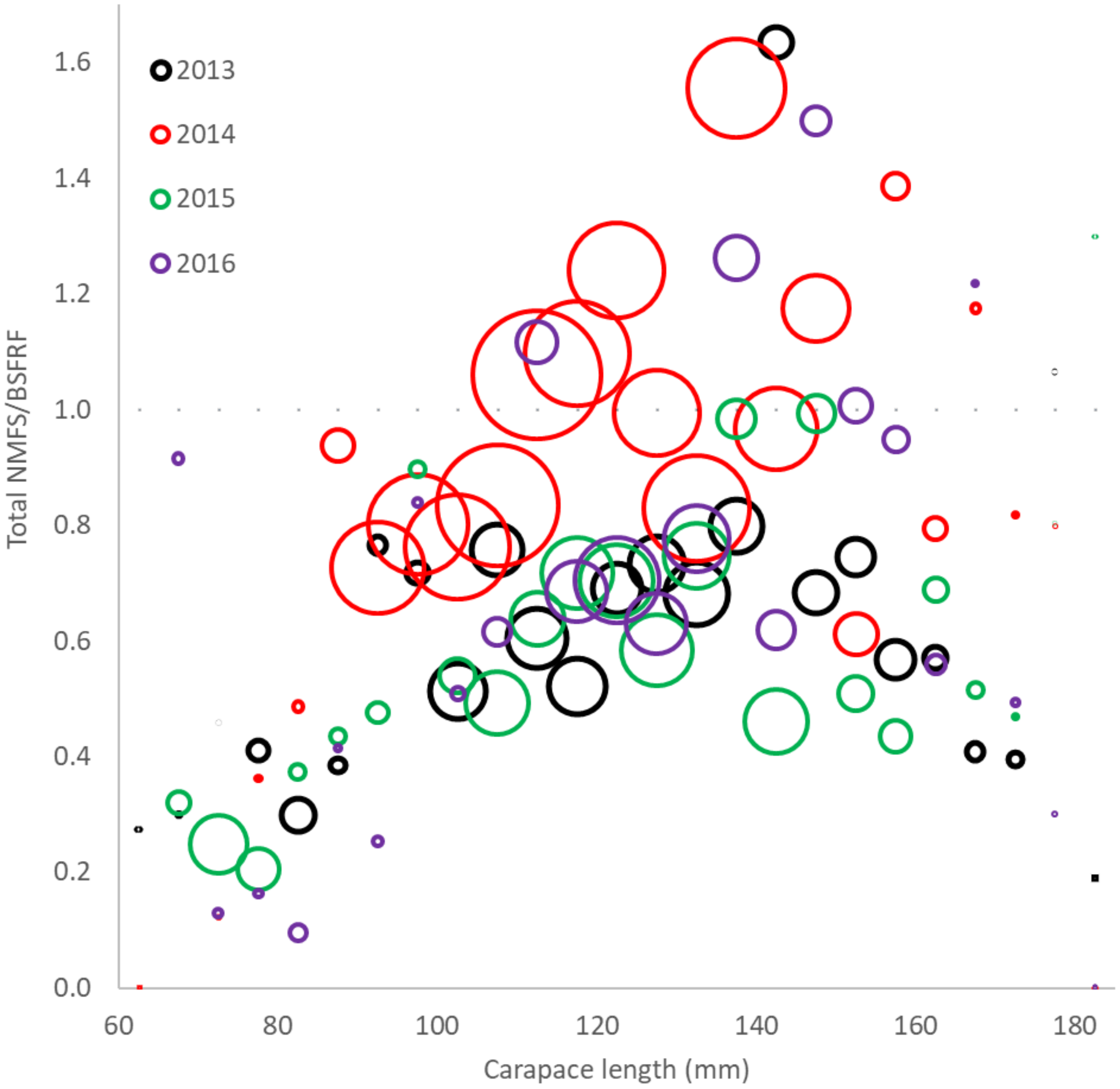


Figure 7c. Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for Bristol Bay red king crab. Sizes of circles are proportional to total abundances. The abundance-weighted average ratio is 0.891 for crab ≥135 mm carapace length from all four years of data. The approach to compute this overall ratio is documented in section D. Data, 4. Bering Sea Fisheries Research Foundation Survey Data.

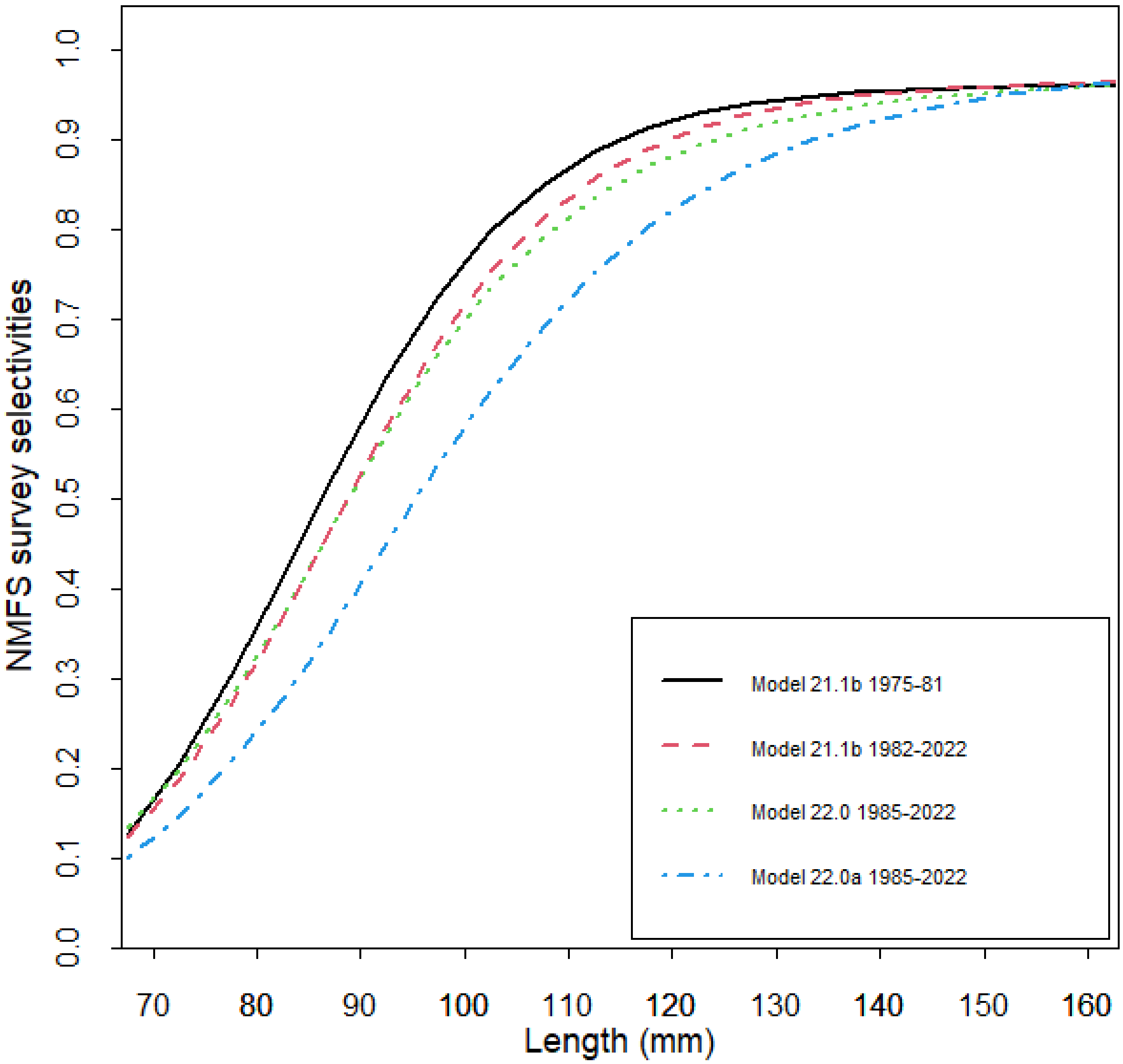


Figure 8a. Estimated NMFS trawl survey selectivities under models 21.1b, 22.0, and 22.0a

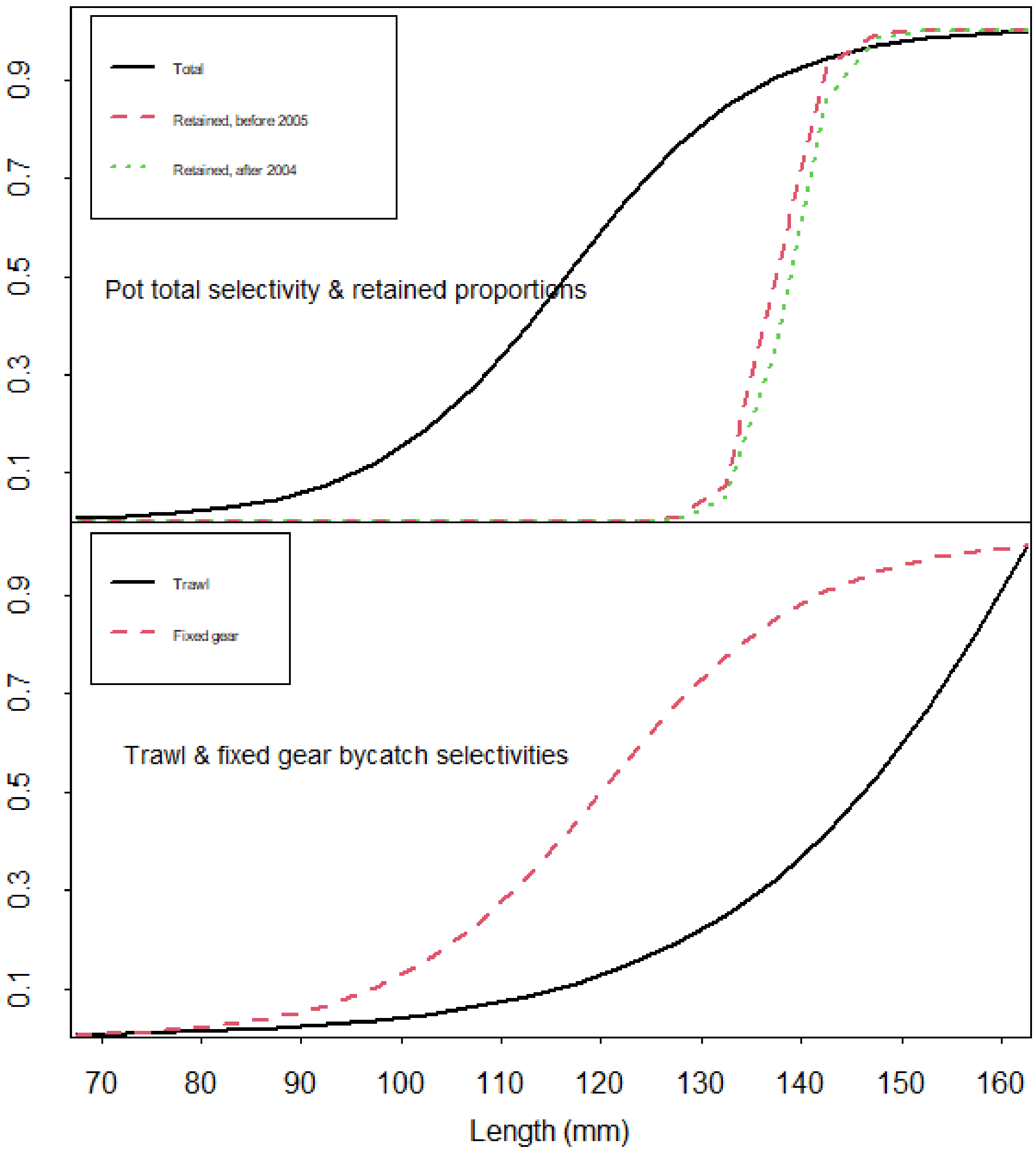


Figure 8b. Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 21.1b.

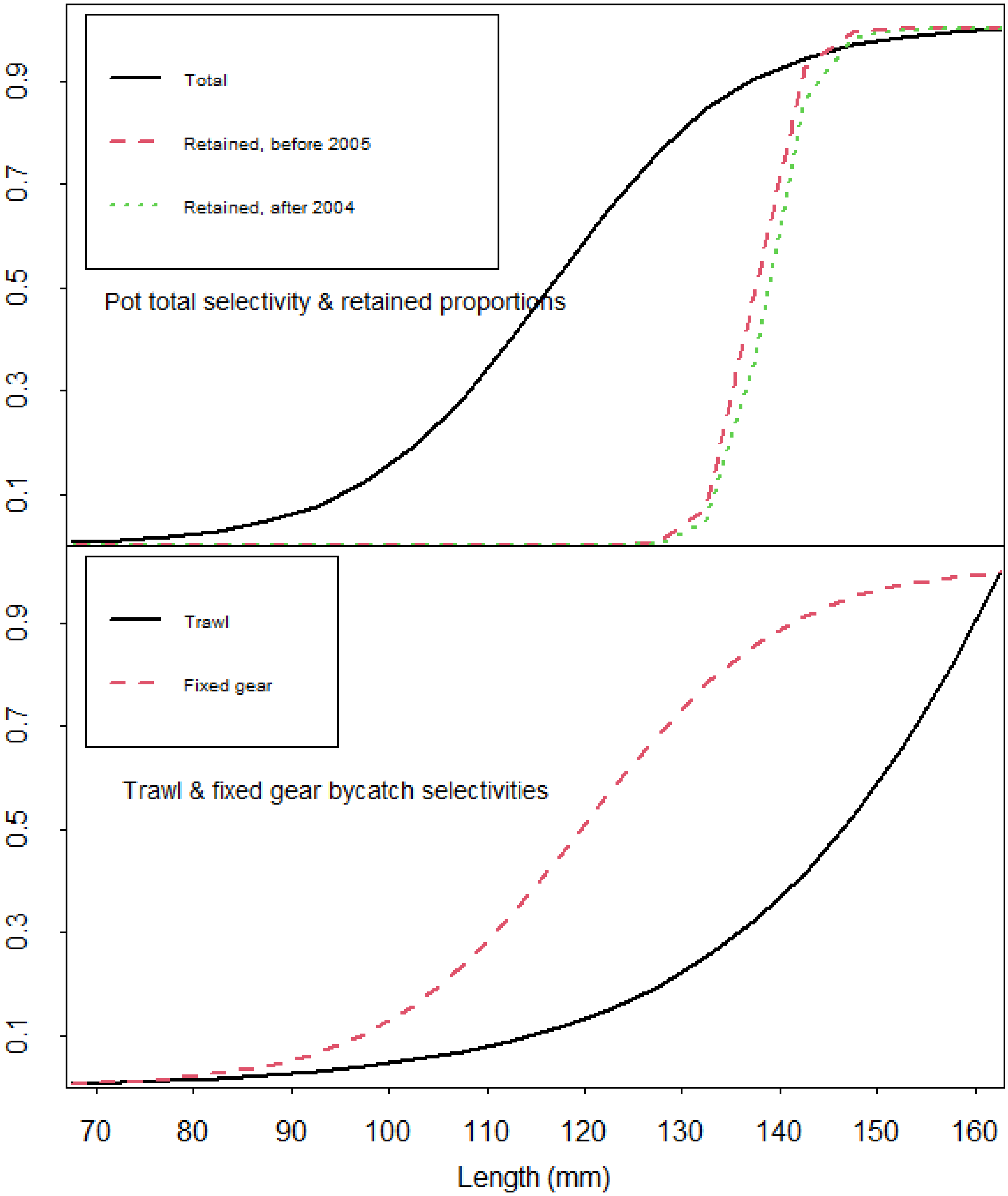


Figure 8c. Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 22.0.

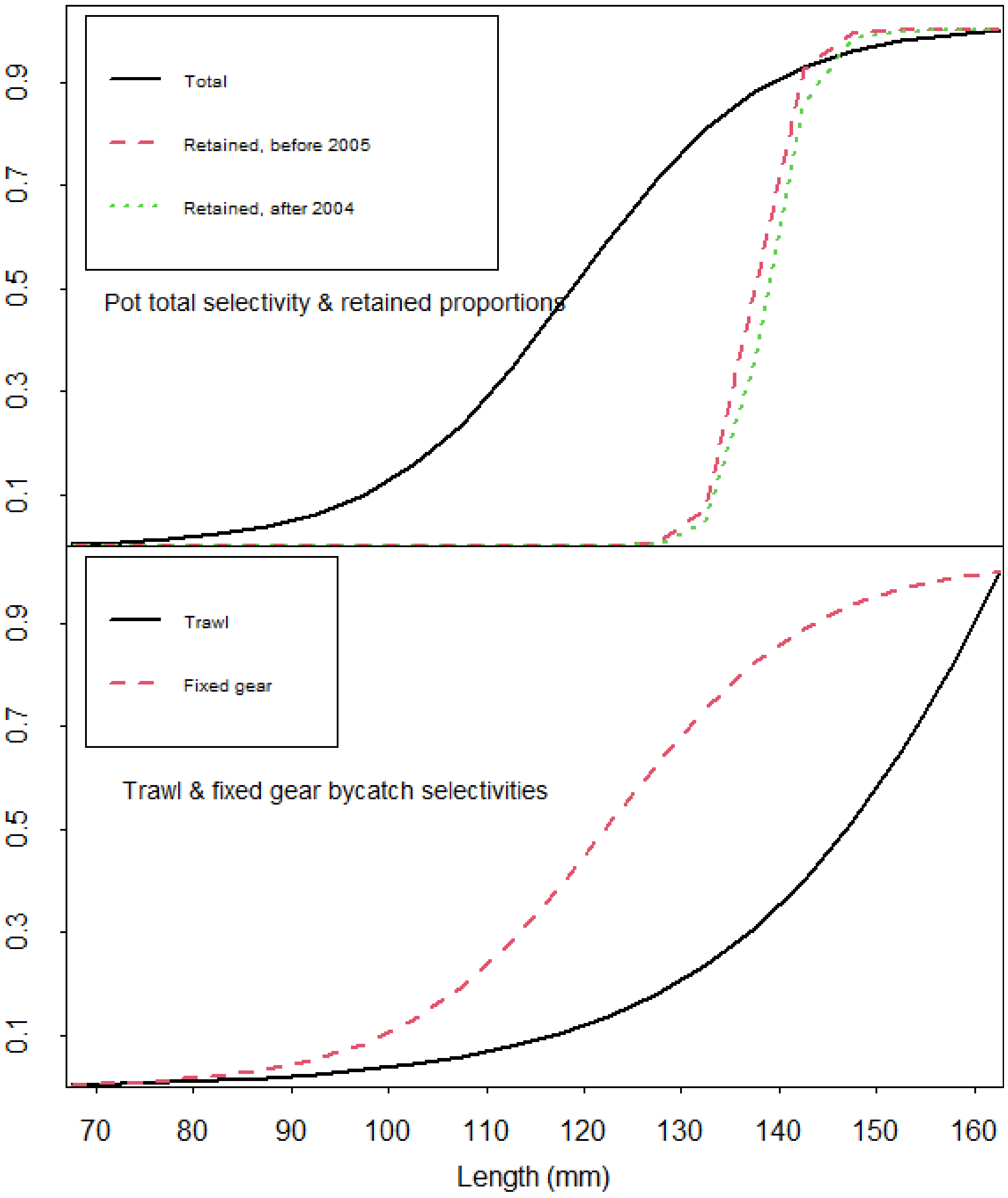


Figure 8d. Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 22.0a.

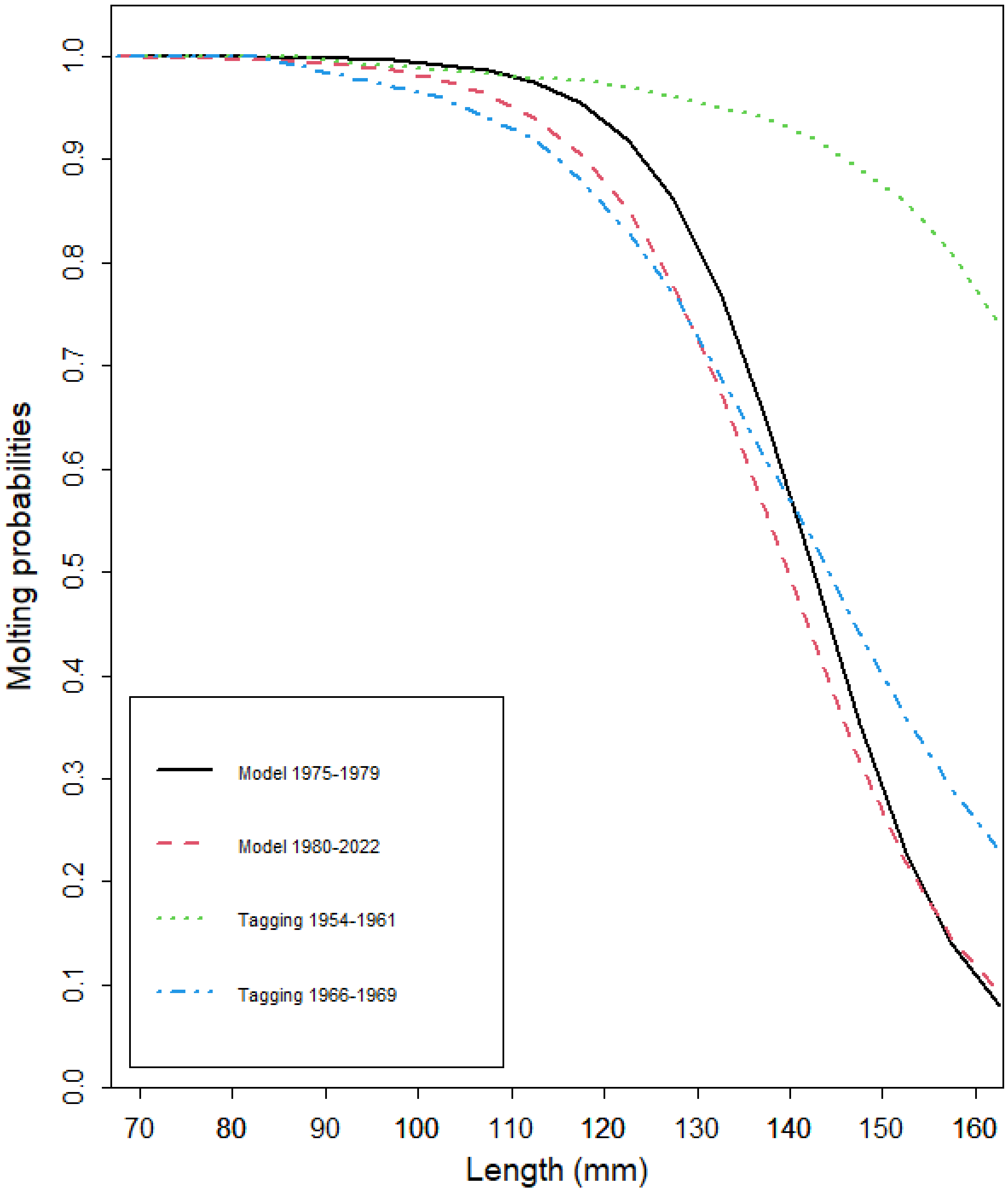


Figure 9a. Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 21.1b. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-1979 and 1980-2022 were estimated with a length-based model.

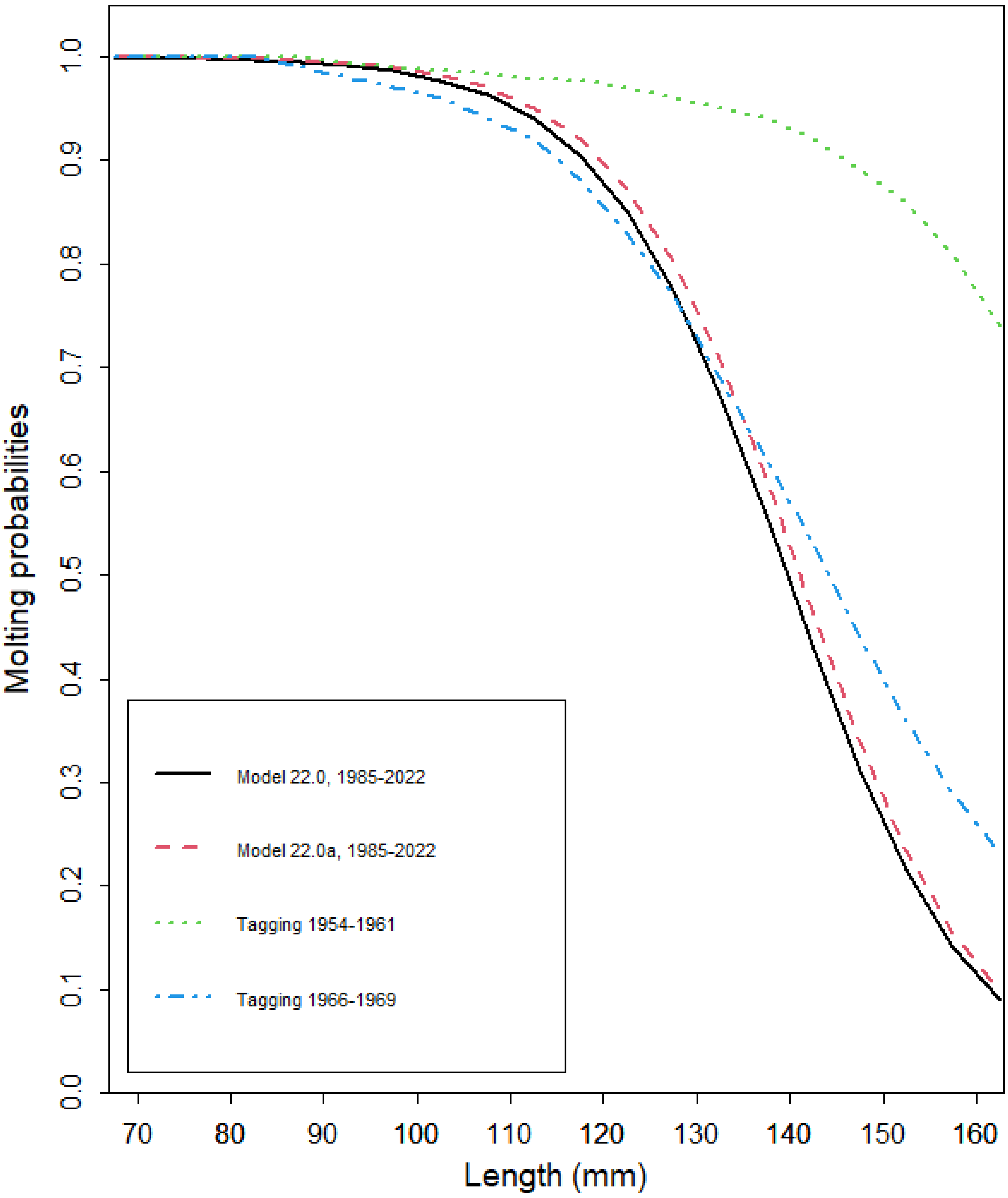


Figure 9b. Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with models 22.0 and 22.0a during 1985-2022. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data.

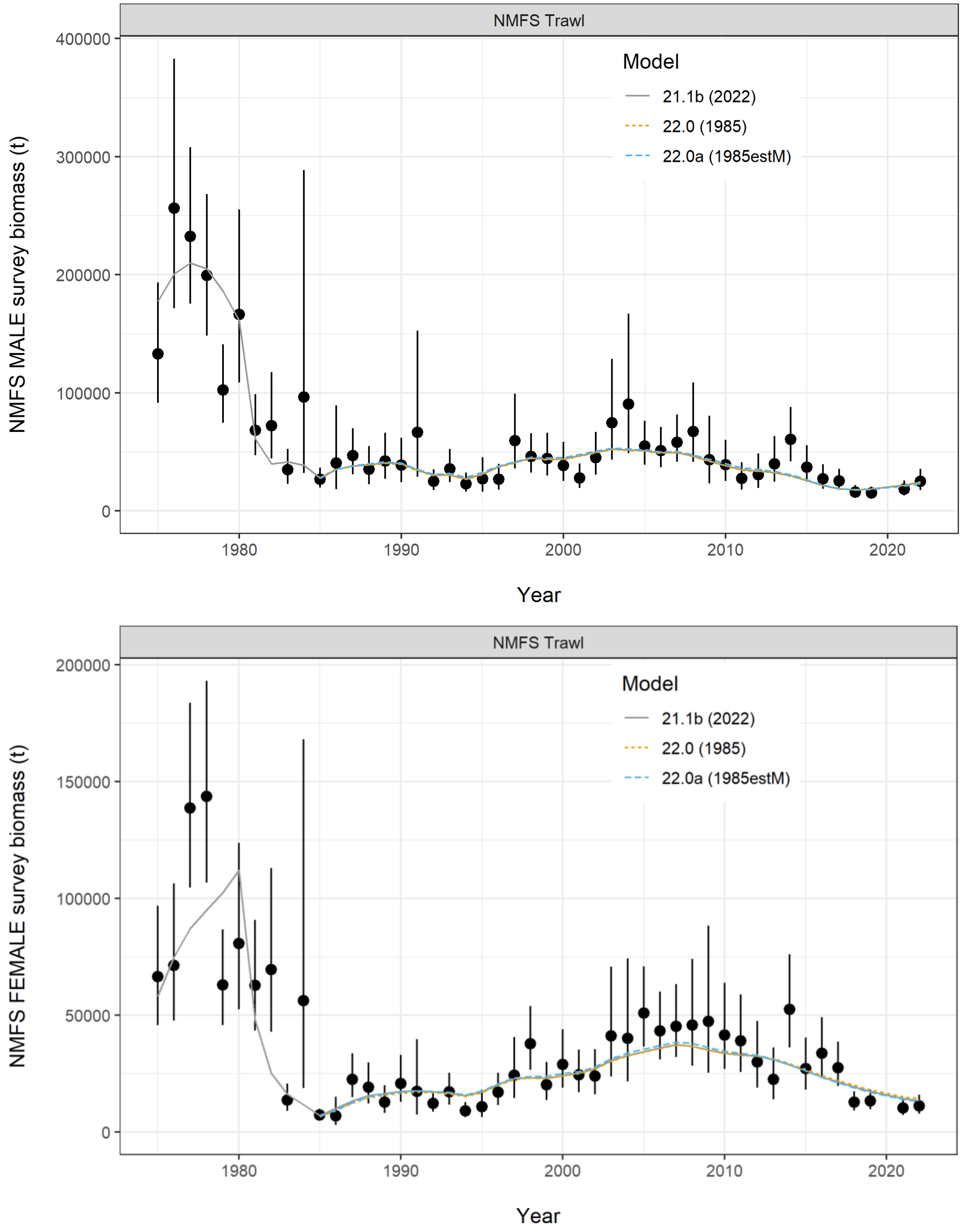


Figure 10a. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates in 2022 under models 21.1, 22.0, and 22.0a. The error bars are plus and minus 2 standard deviations of model 21.1b.

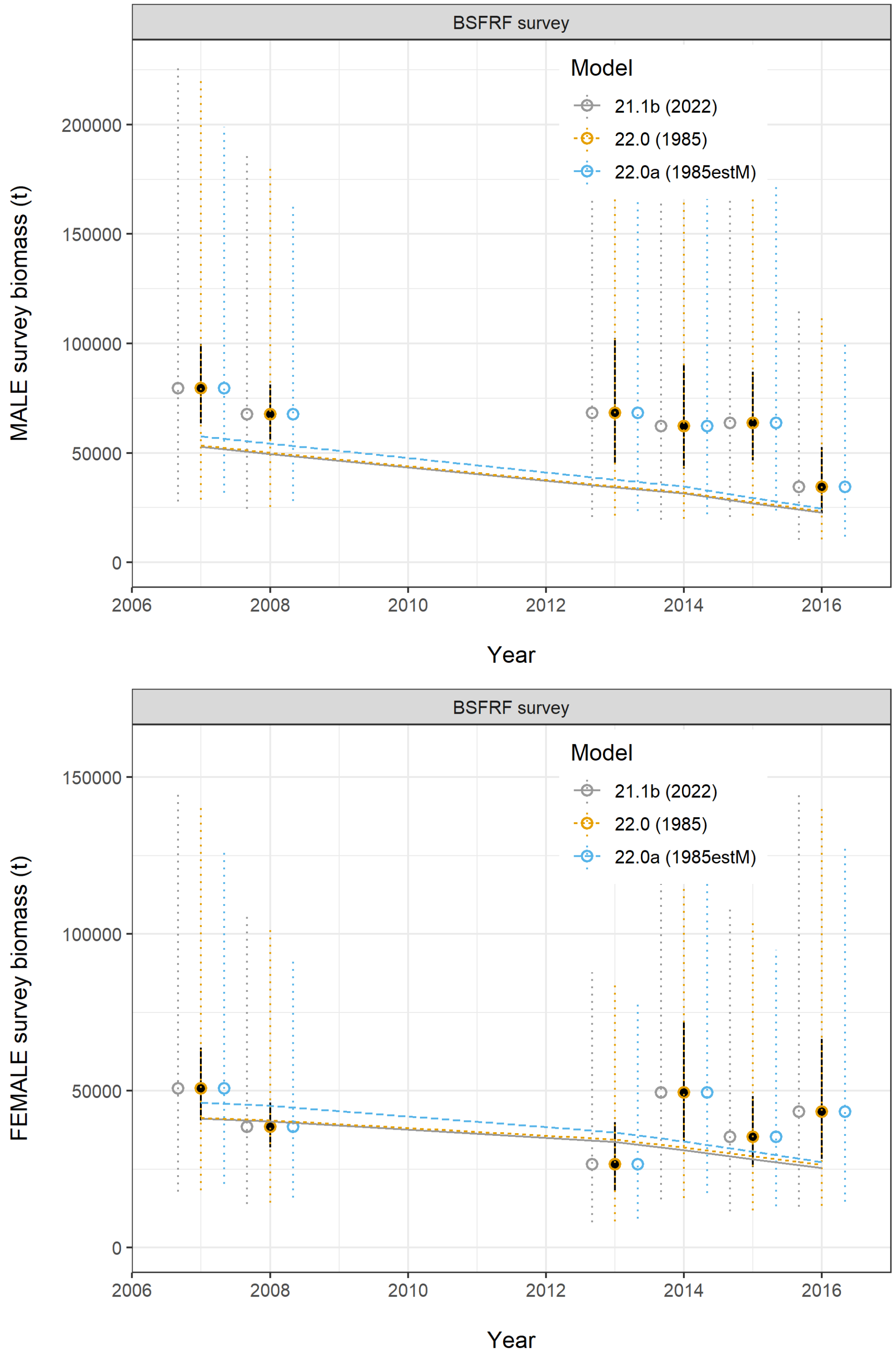


Figure 10b. Comparisons of survey biomass estimates by sex (upper plot for males and lower plot for females) by the BSFRF survey and the model for model estimates in 2022 (models 21.1b, 22.0, 22.0a). The error bars are plus and minus 2 standard deviations of model 21.1b. The BSFRF survey catchability is assumed to be 1.0 for all models.

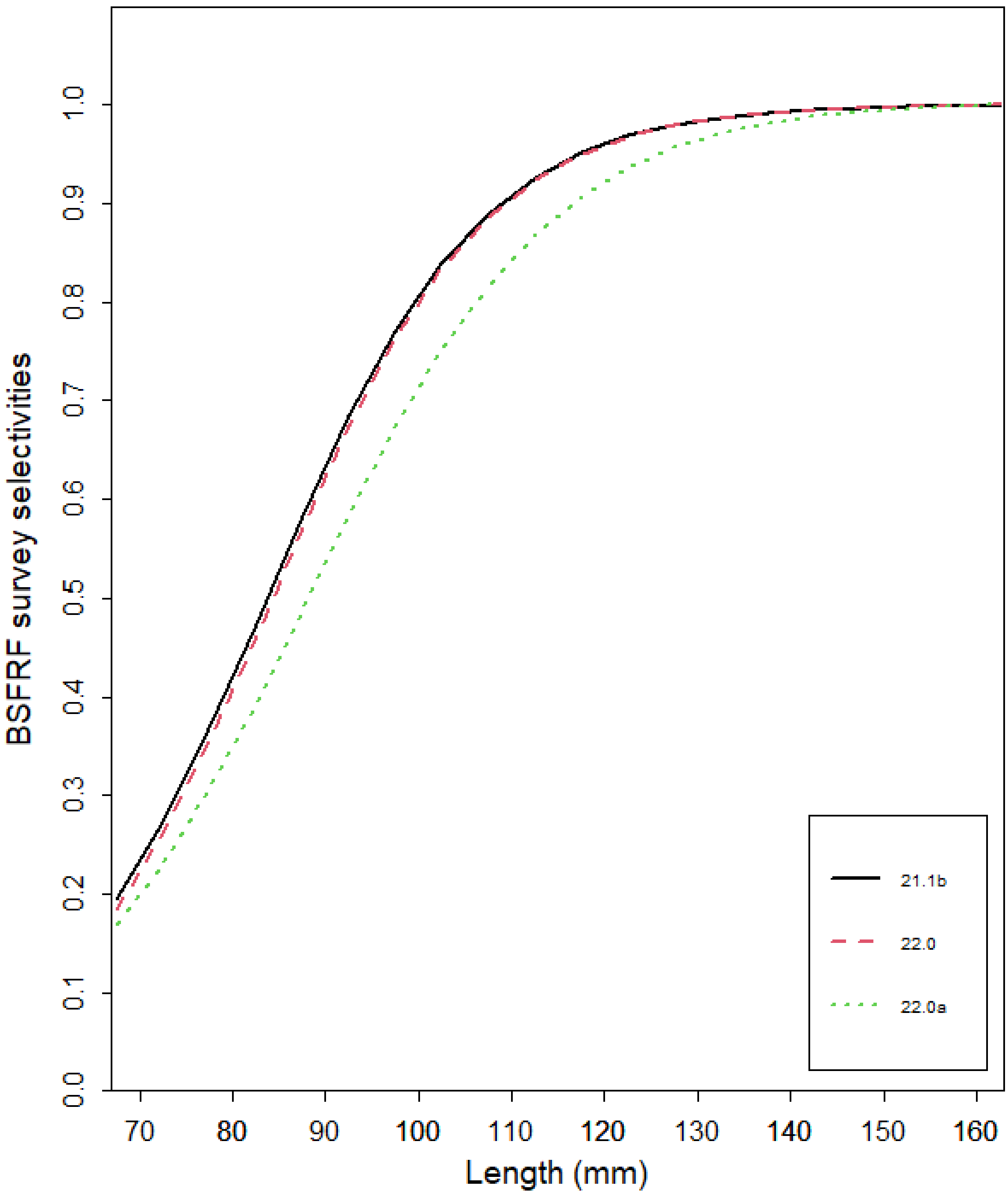


Figure 10c. Comparisons of estimated BSFRF survey selectivities with models 21.1b, 22.0, and 22.0a. The BSFRF survey catchability is assumed to be 1.0 for all models.

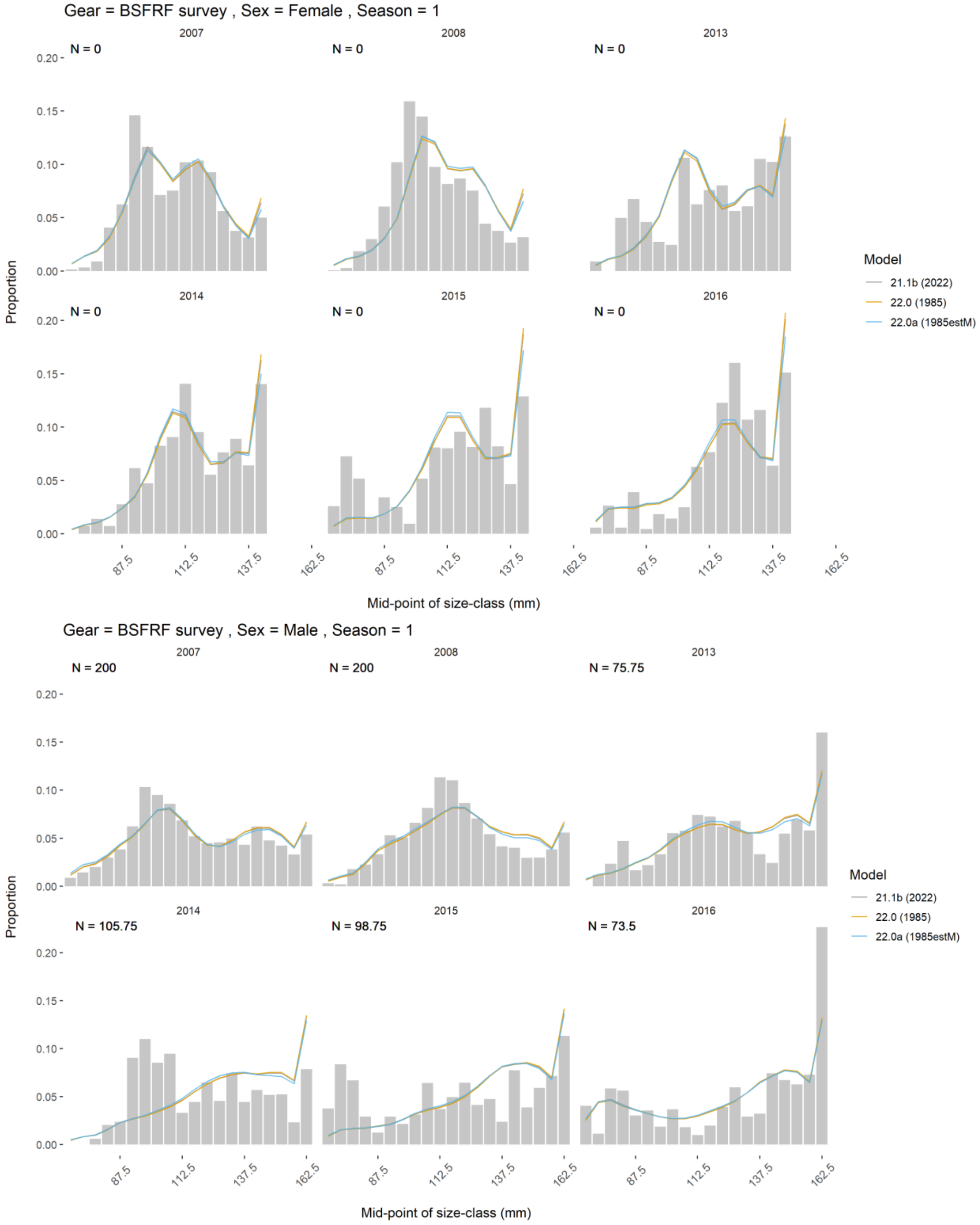


Figure 10d. Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with models 21.1b, 22.0, and 22.0a.

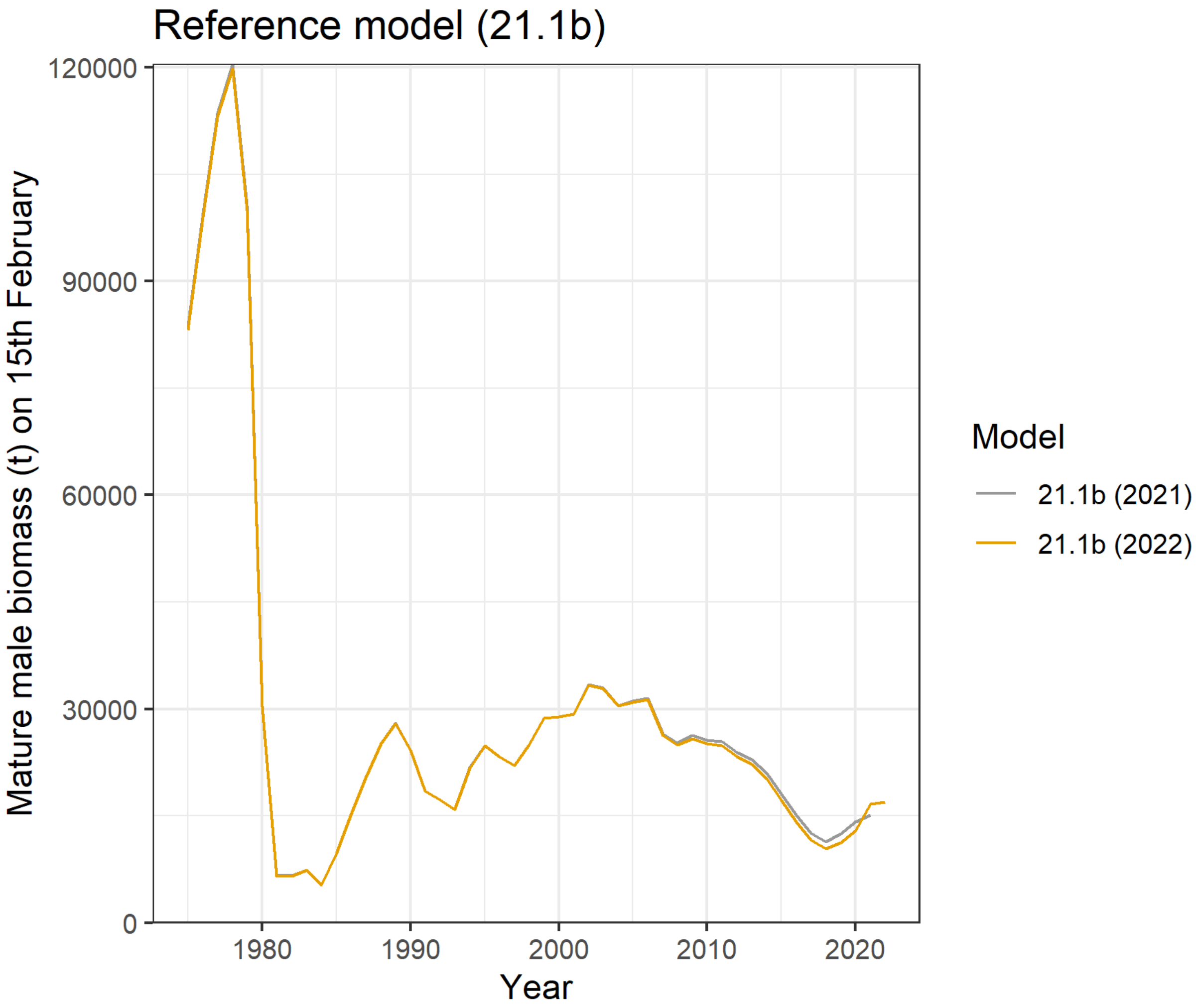


Figure 11a. Estimated absolute mature male biomasses during 1975-2022 for the base model (21.1b) in 2021 and 2022 model years. Mature male biomass is estimated on Feb. 15, year+1.

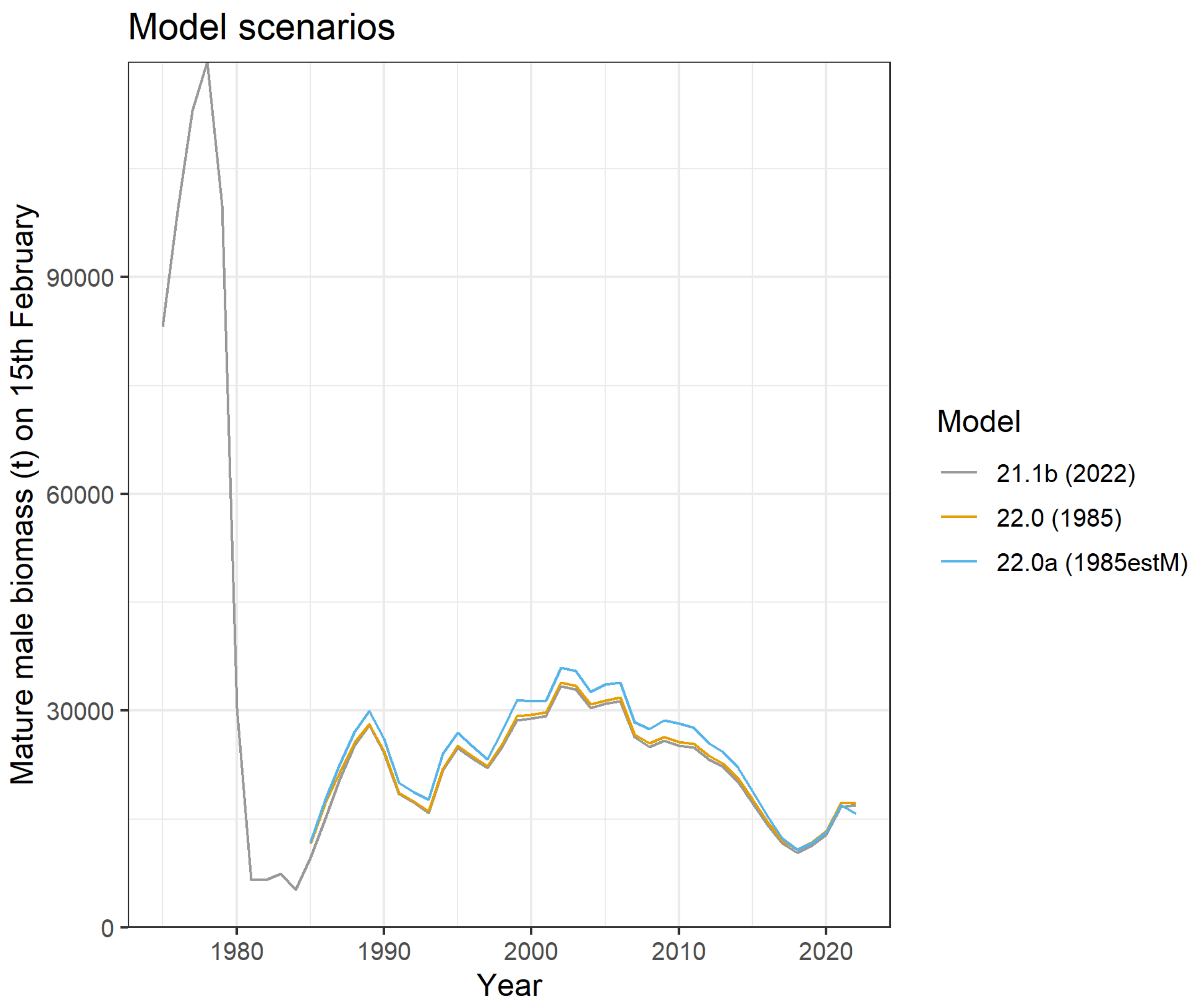


Figure 11b. Estimated absolute mature male biomasses during 1975-2022 for models 21.1b, 22.0, and 22.0a. Mature male biomass is estimated on Feb. 15, year+1.

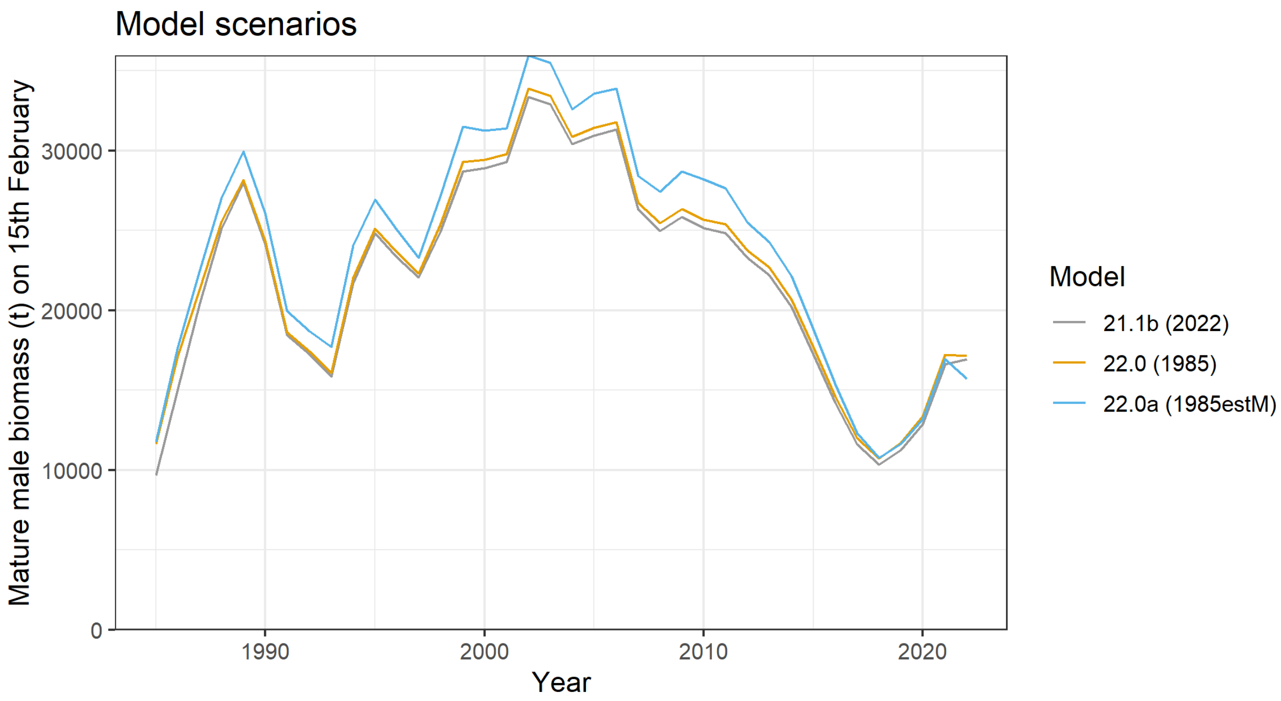


Figure 11c. Estimated absolute mature male biomasses during 1985-2022 for models 21.1b, 22.0, and 22.0a. Mature male biomass is estimated on Feb. 15, year+1.

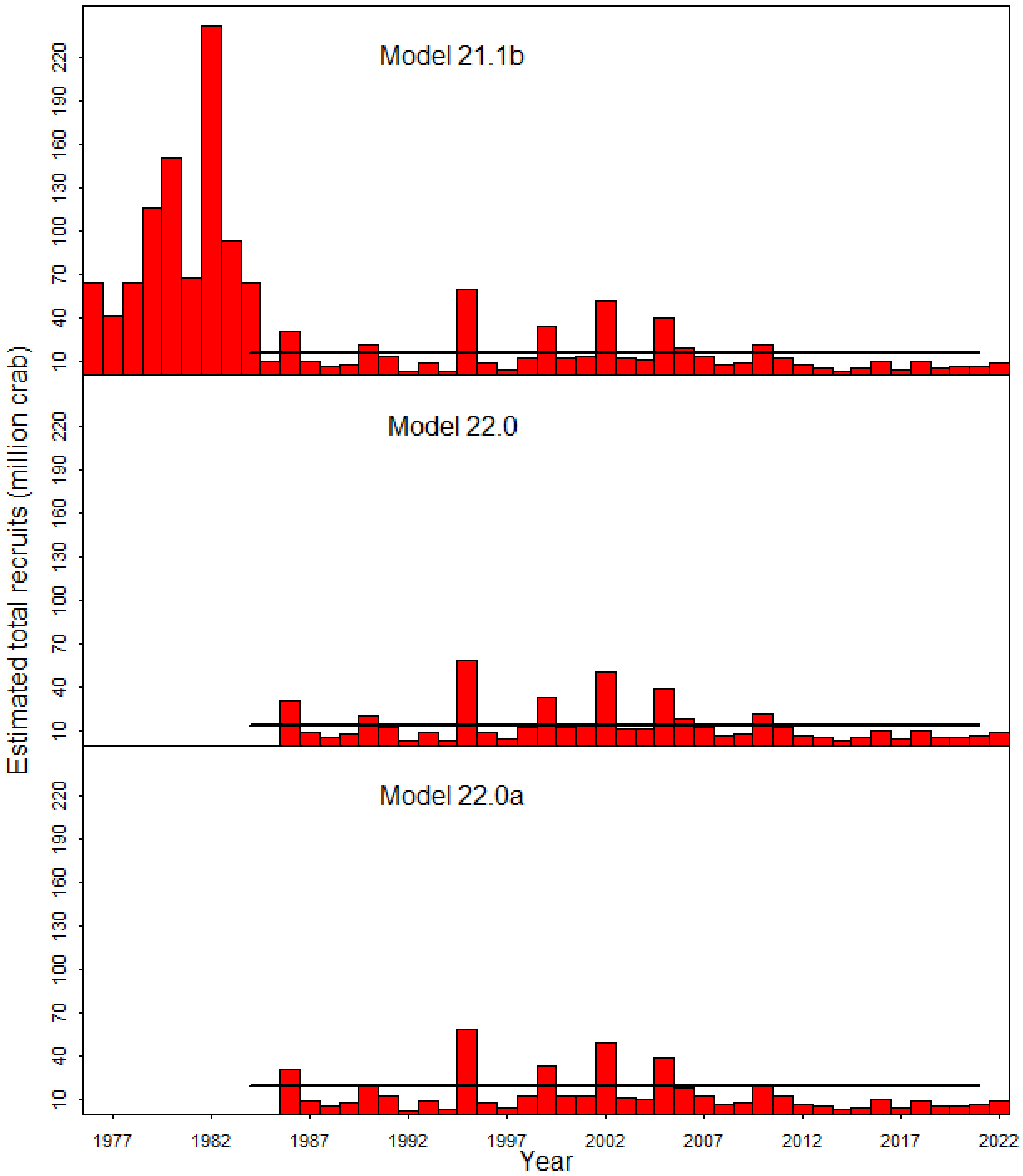


Figure 12a. Estimated recruitment time series during 1976-2022 with models 21.1b, 22.0 and 22.0a. Mean male recruits during 1984-2021 was used to estimate $B_{35\%}$. Recruitment estimates in the terminal year (2022) are unreliable.

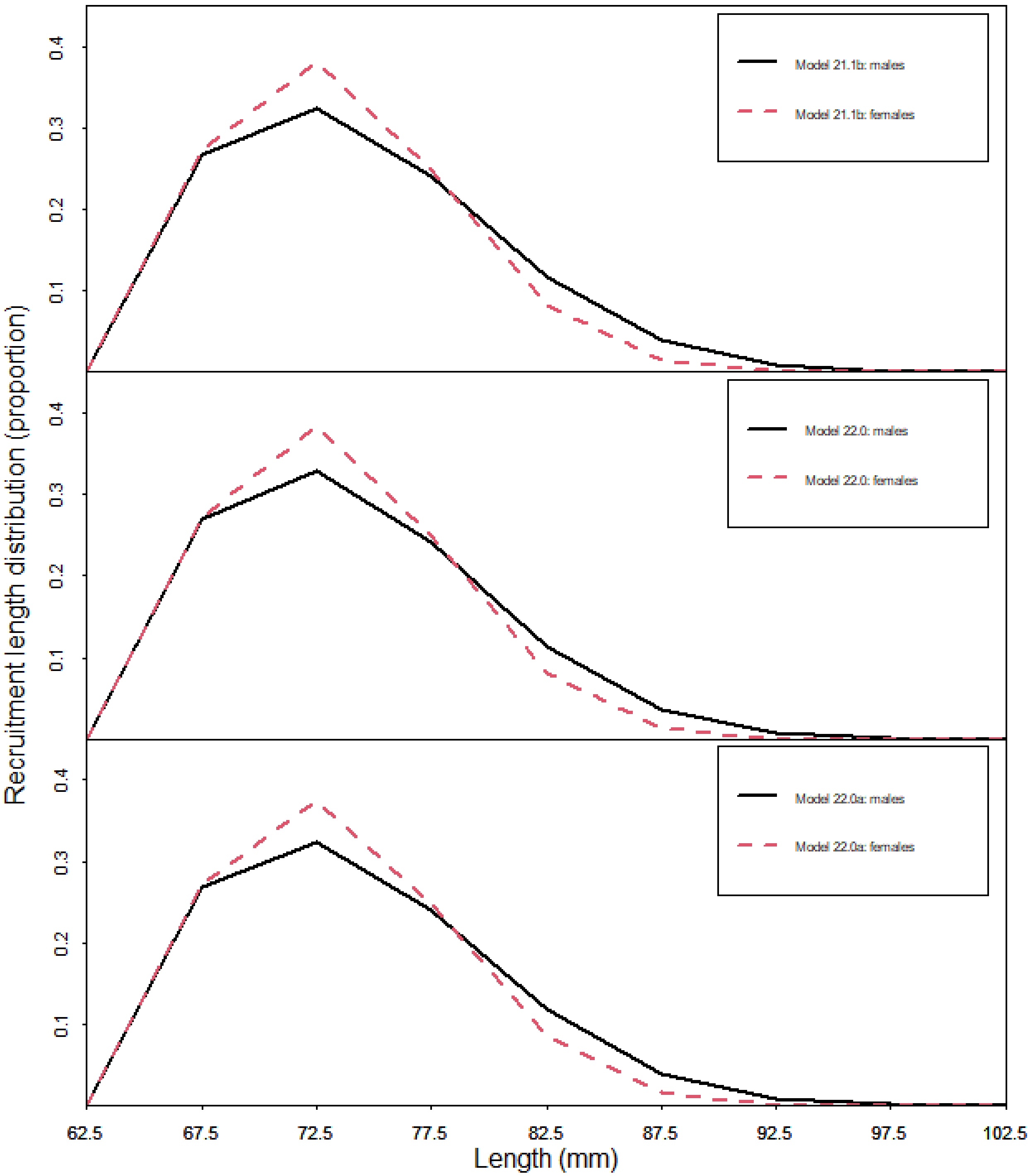


Figure 12b. Estimated recruitment length distributions with models 21.1b, 22.0, and 22.0a.

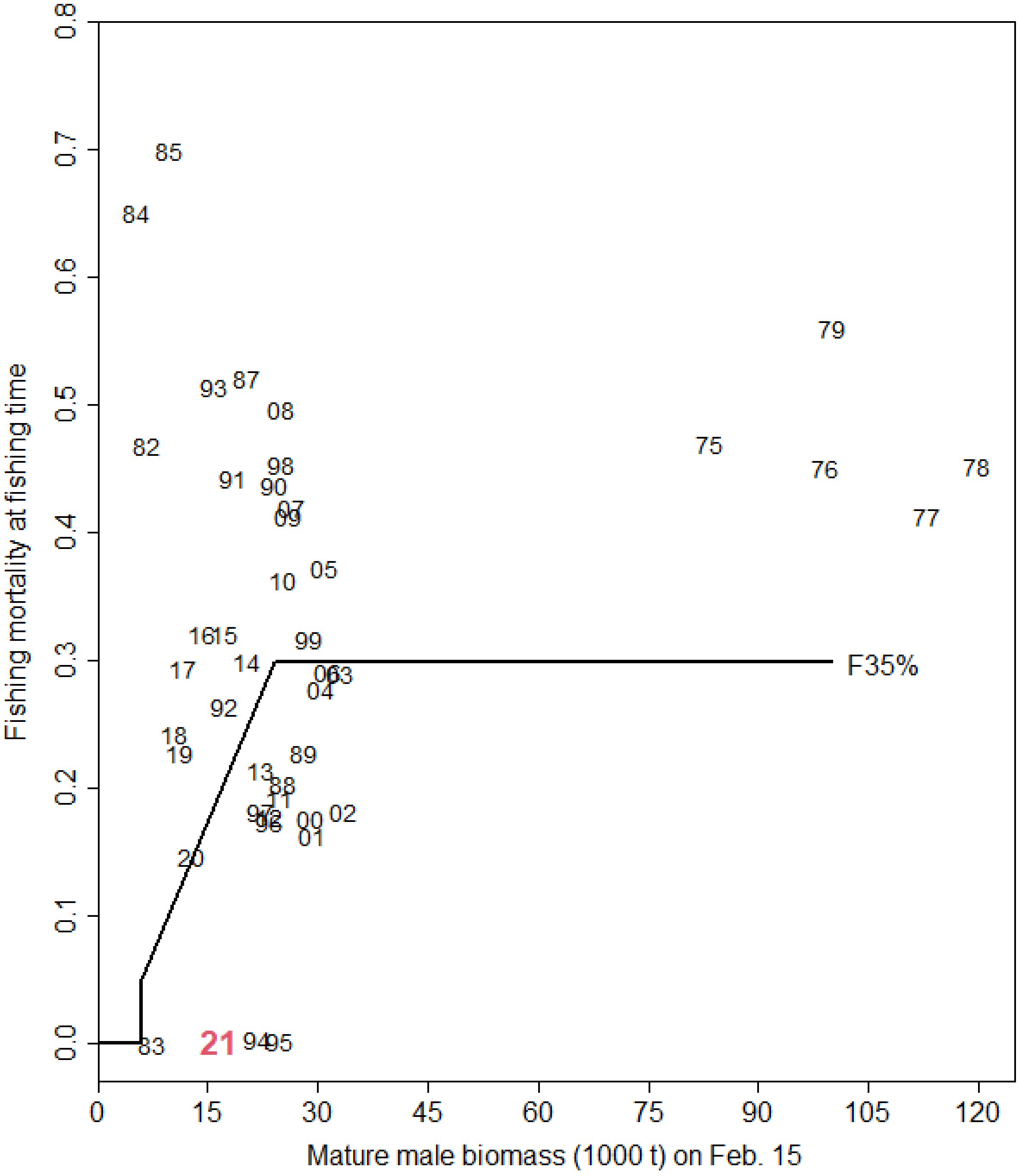


Figure 13a. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2021 under model 21.1b. Average of recruitment from 1984 to 2020 was used to estimate $B_{35\%}$.

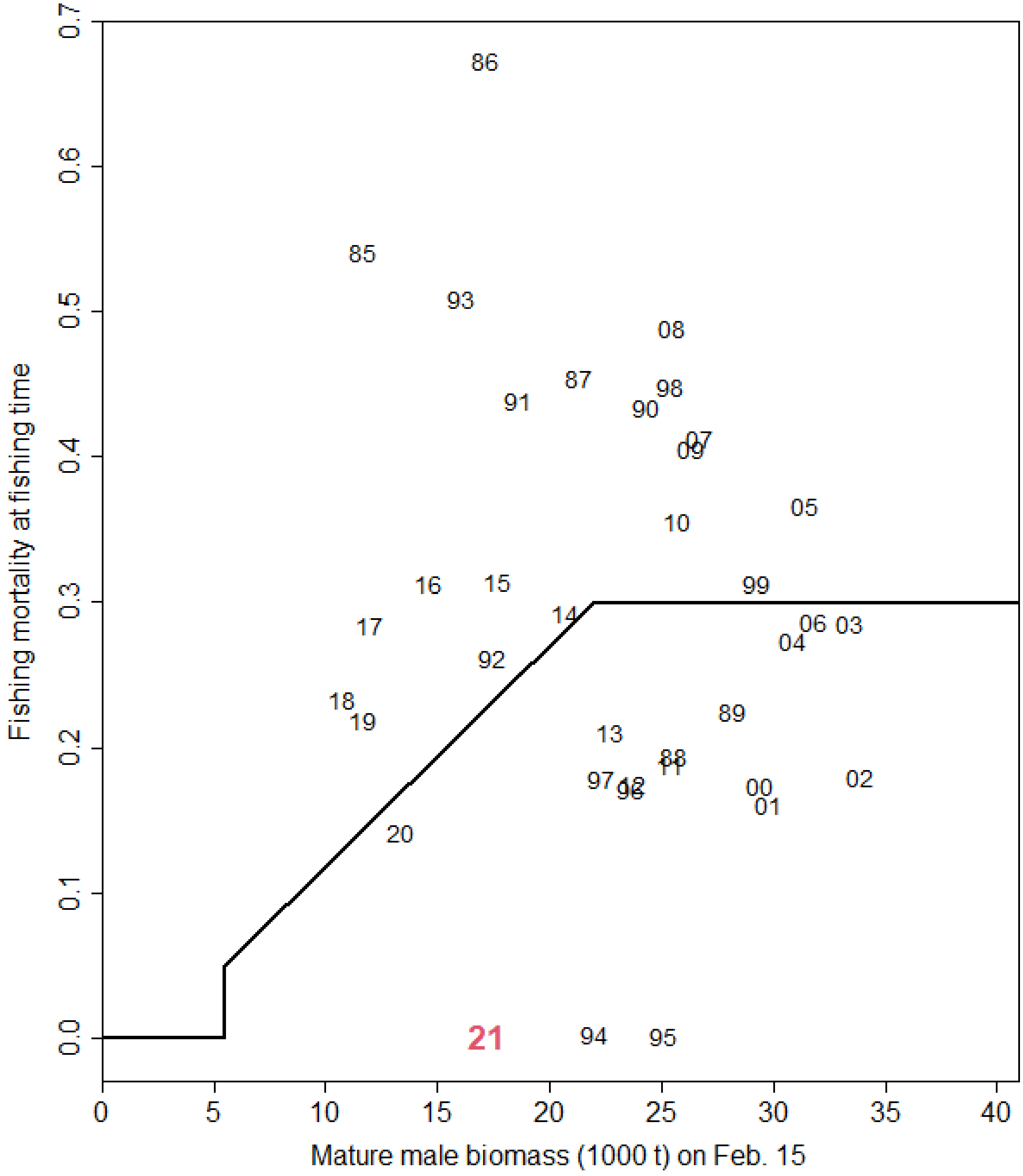


Figure 13b. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985-2021 under model 22.0. Average of recruitment from 1984 to 2020 was used to estimate $B_{35\%}$.

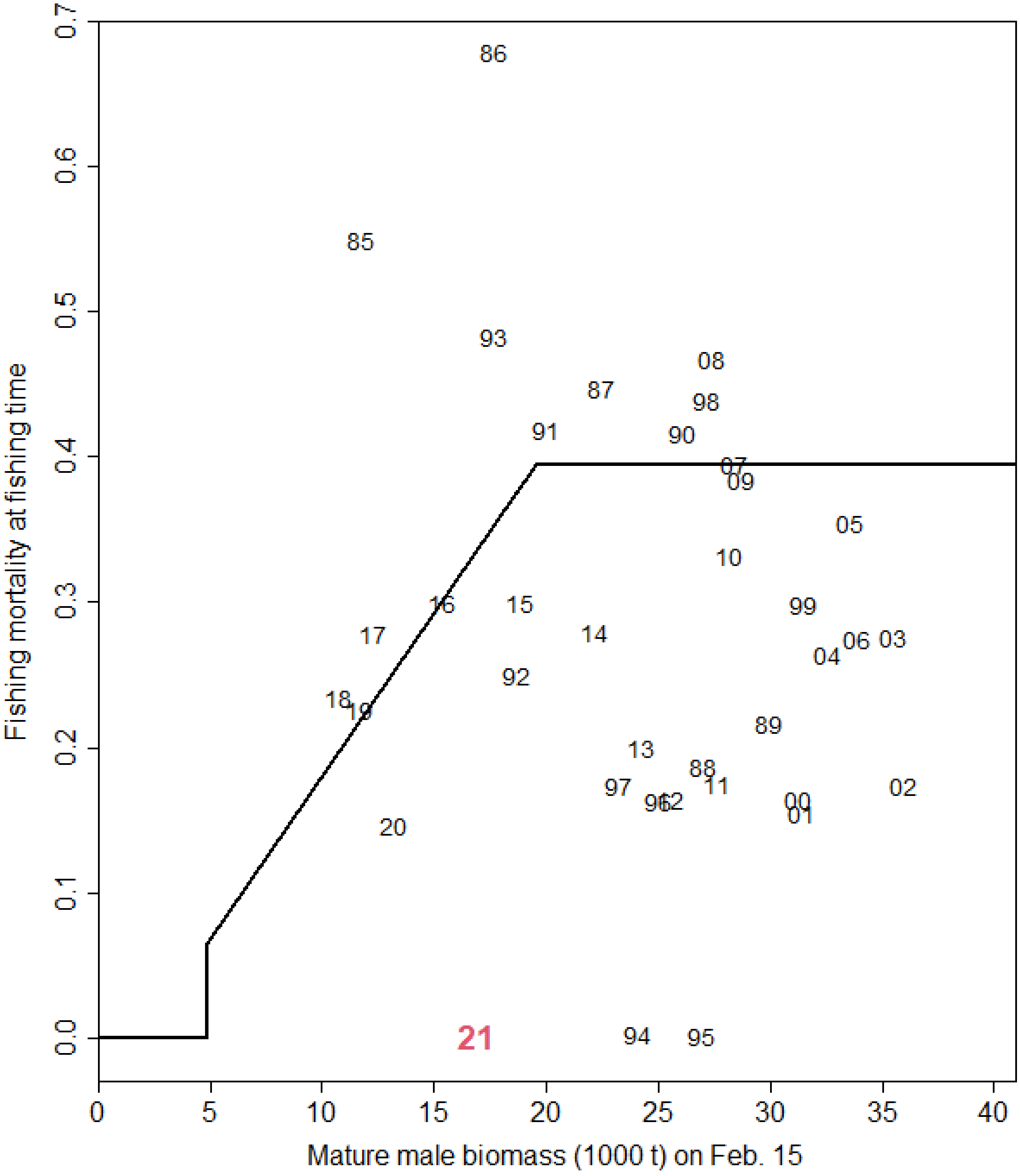


Figure 13c. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985-2021 under model 22.0a. Average of recruitment from 1986 to 2021 was used to estimate $B_{35\%}$.

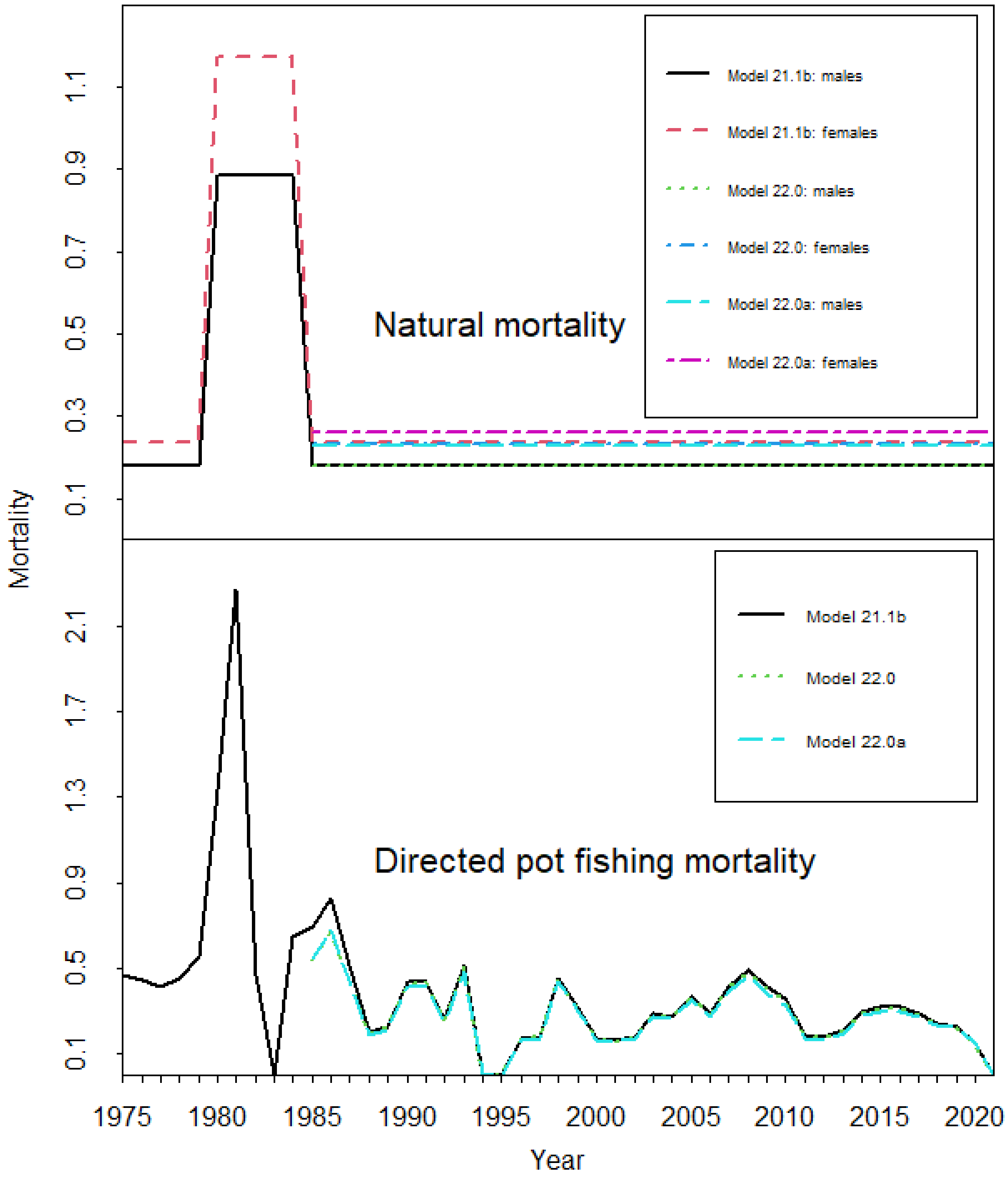


Figure 13d. Comparison of estimated natural mortality and directed pot fishing mortality for models 21.1b, 22.0, and 22.0a.

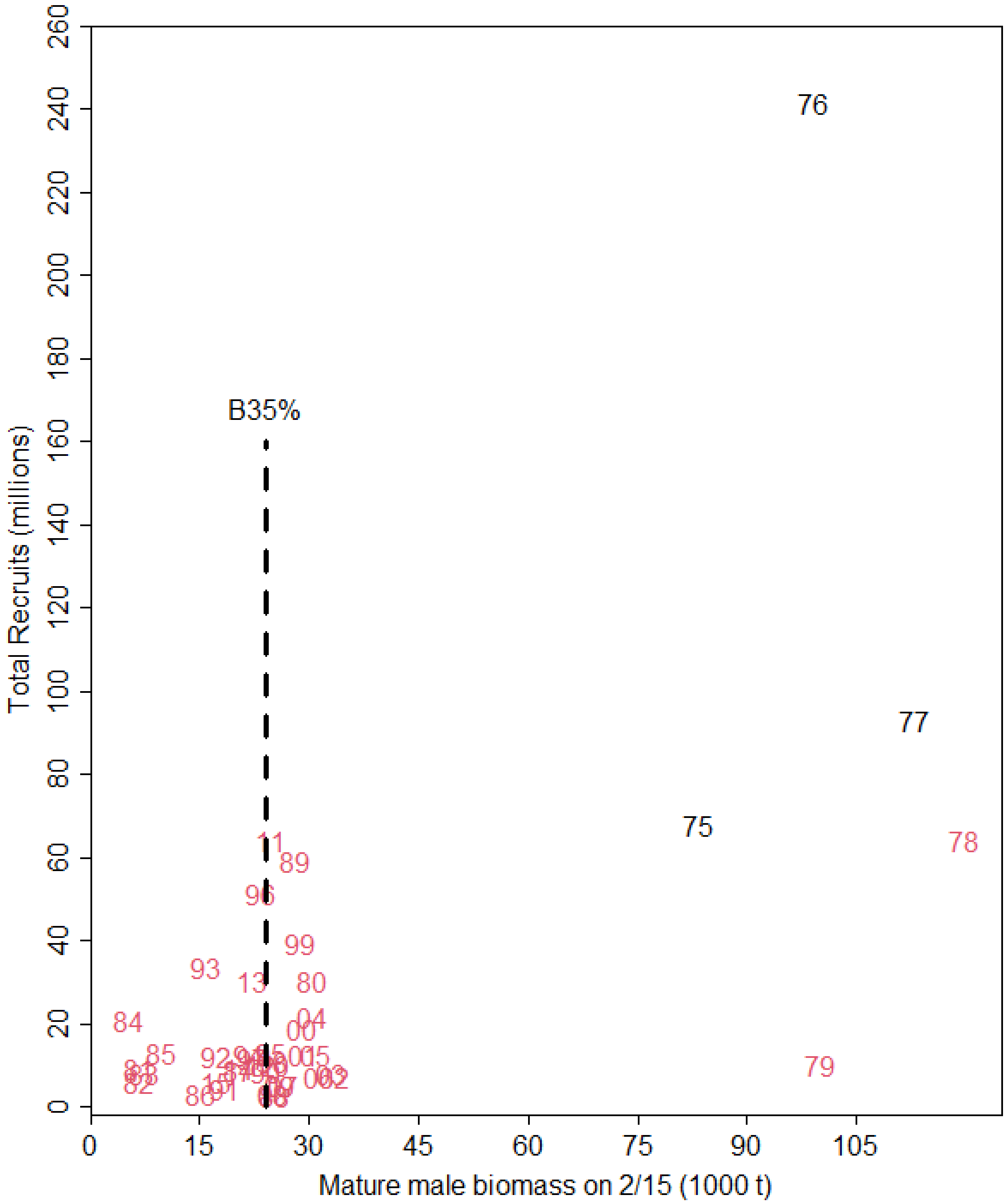


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab under model 21.1b. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2021.

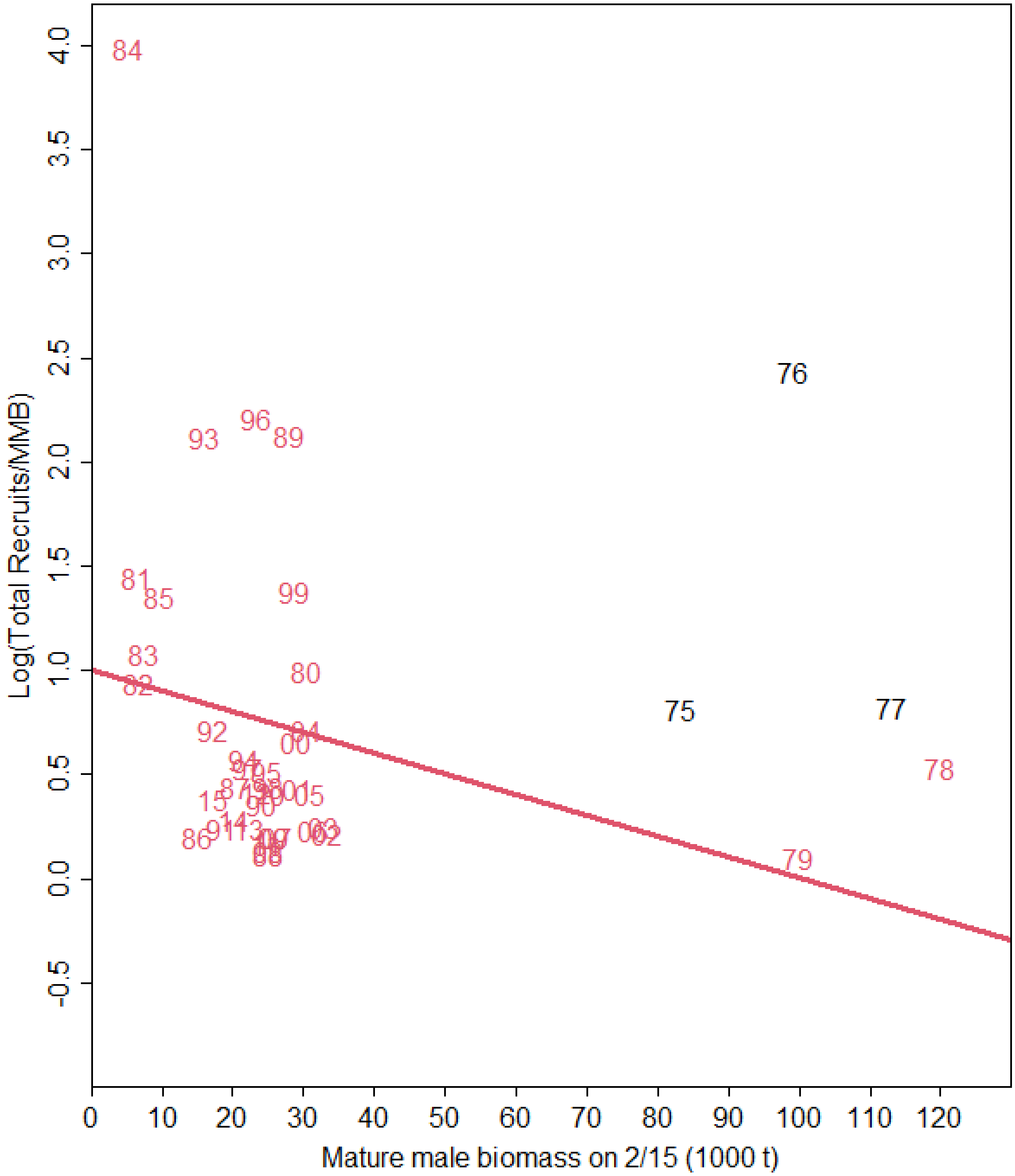


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab under model 21.1b. Numerical labels are years of mating, and the line is the regression line for data of 1978-2015.

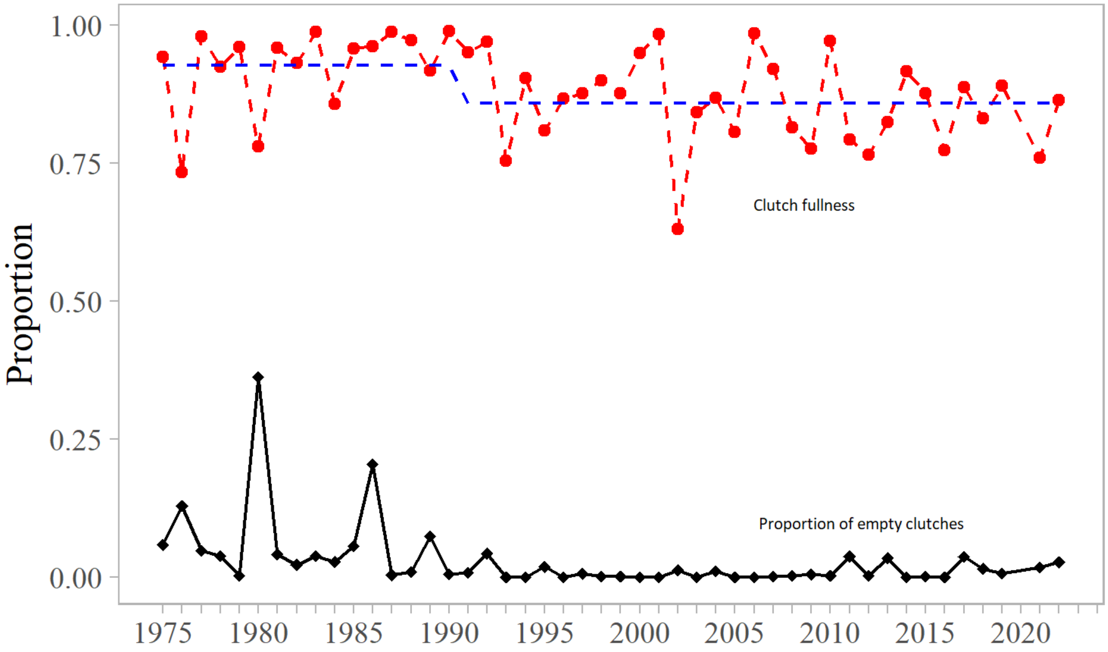


Figure 15a. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2022 from survey data. Oldshell females were excluded. The blue dashed line is the mean clutch fullness during two periods before 1992 and after 1991.

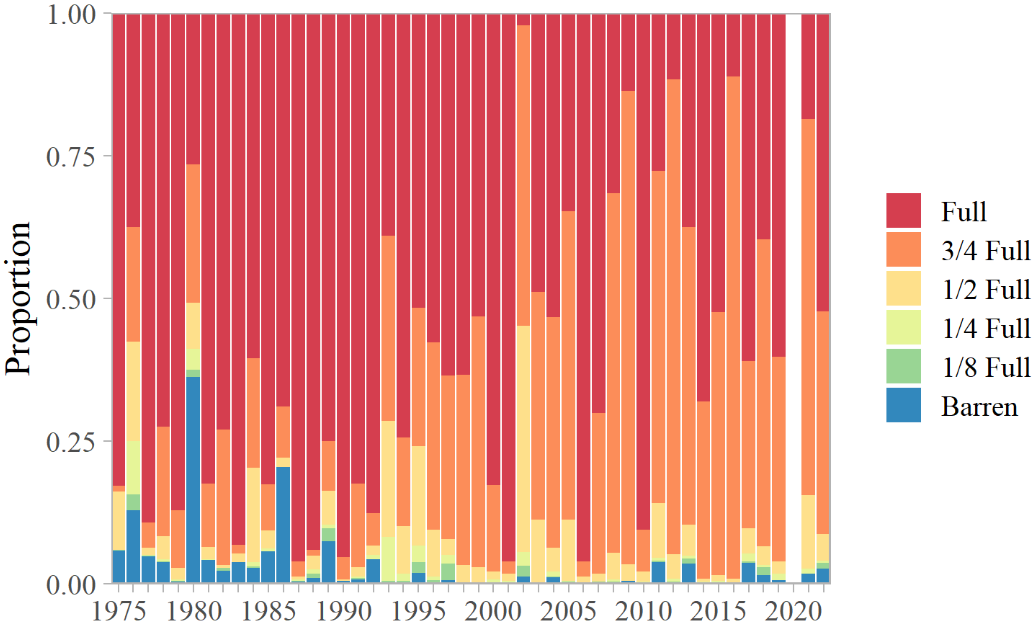


Figure 15b. Clutch fullness distribution of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2022 from survey data. Oldshell females were excluded.

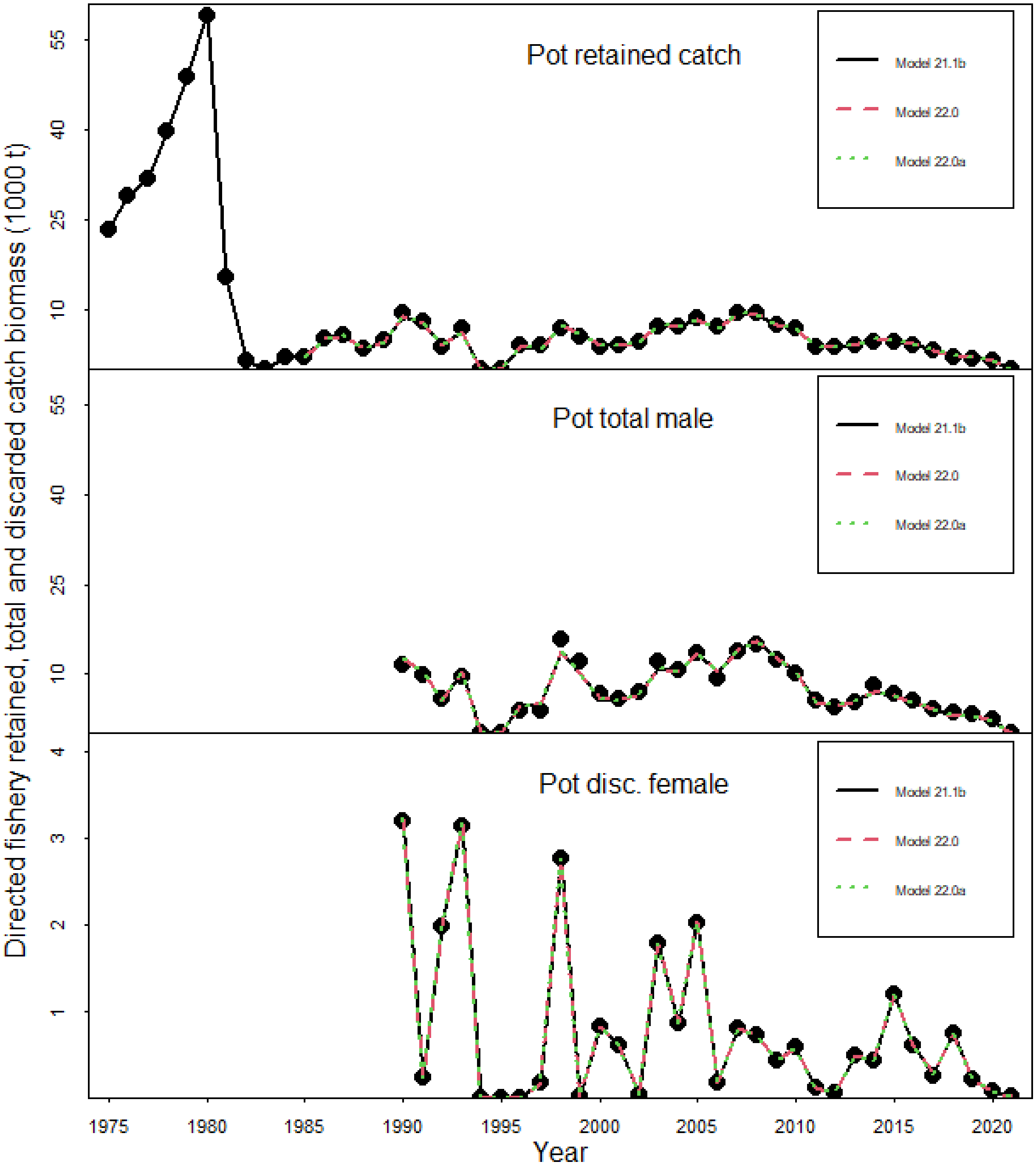


Figure 16a. Observed (dots) and predicted (lines) RKC catch and bycatch biomass under models 21.1b, 22.0, and 22.0a.

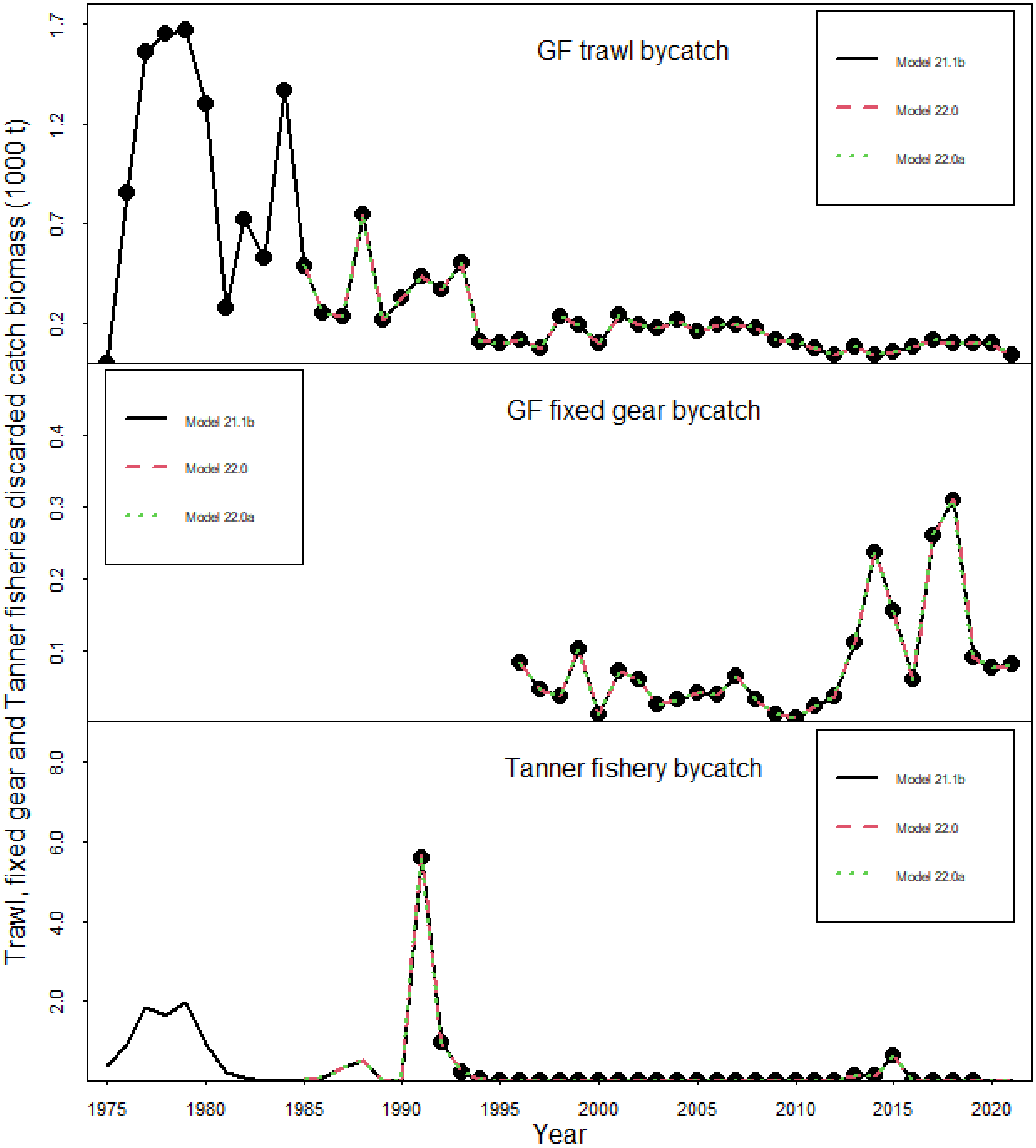


Figure 16b. Observed (dots) and predicted (lines) RKC bycatch biomass from groundfish fisheries and the Tanner crab fishery under models 21.1b, 22.0, and 22.0a. Trawl bycatch biomass was 0 before 1976.

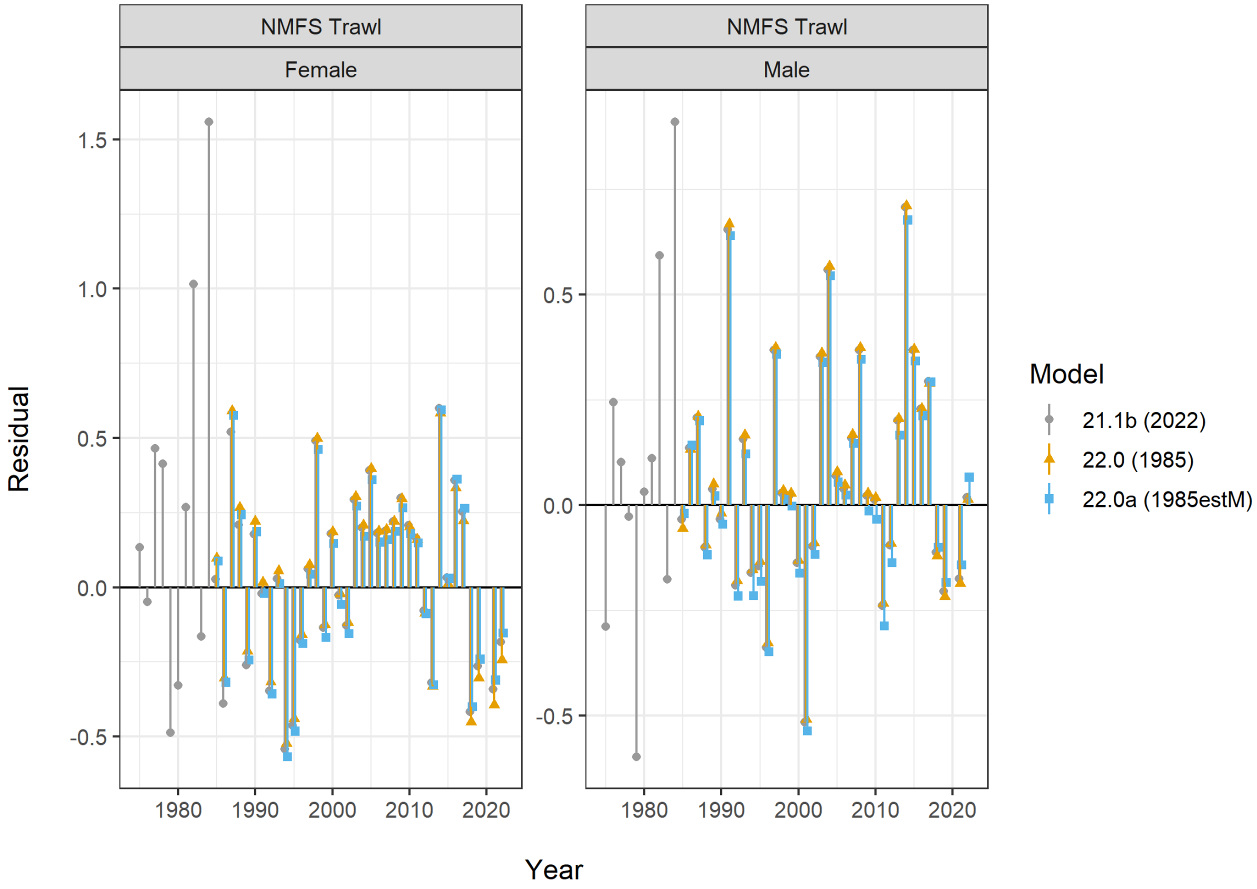


Figure 17. Standardized residuals of NMFS survey biomass under model 21.1b, 22.0 and 22.0a.

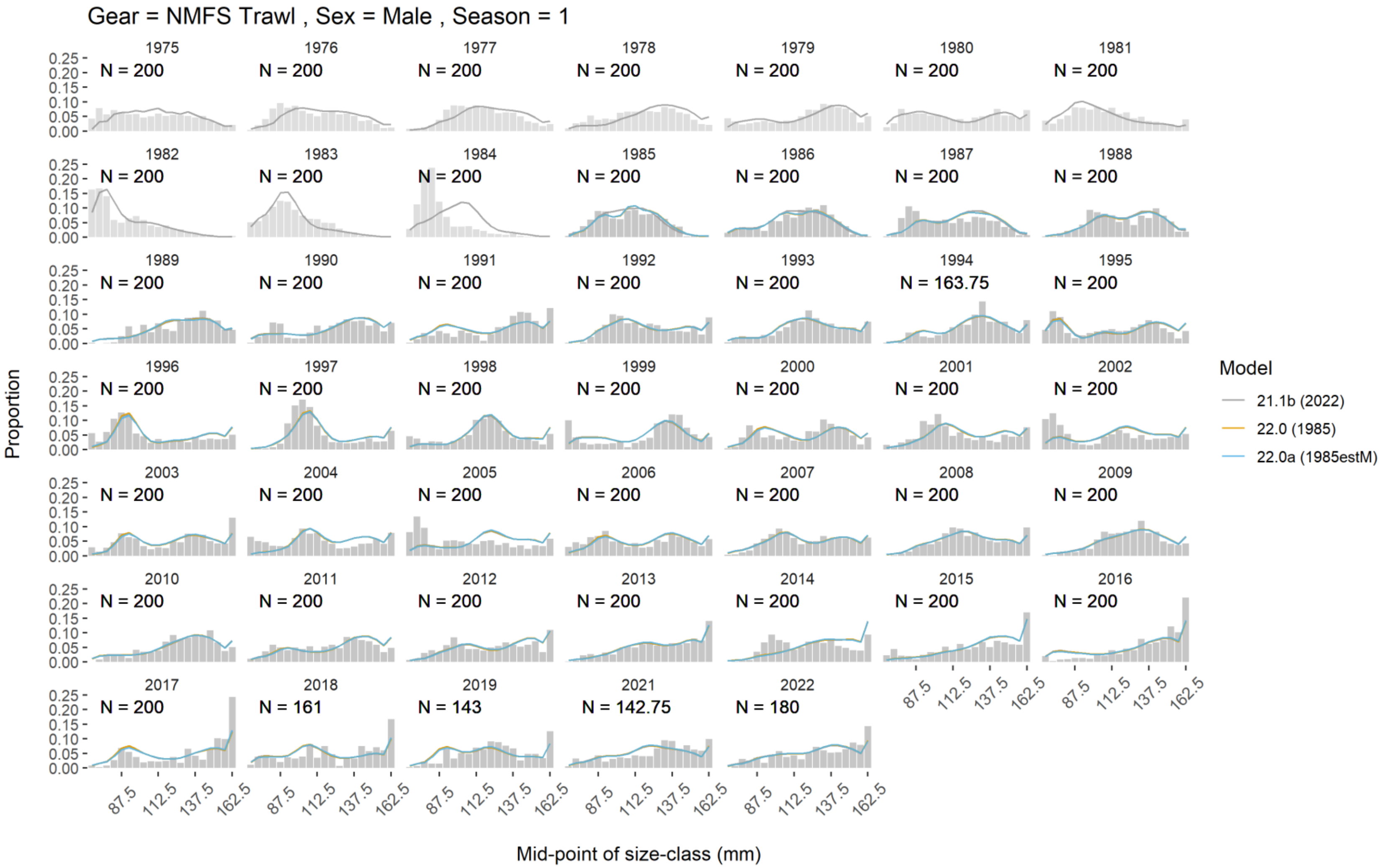


Figure 18. Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year under models 21.1b, 22.0, and 22.0a.

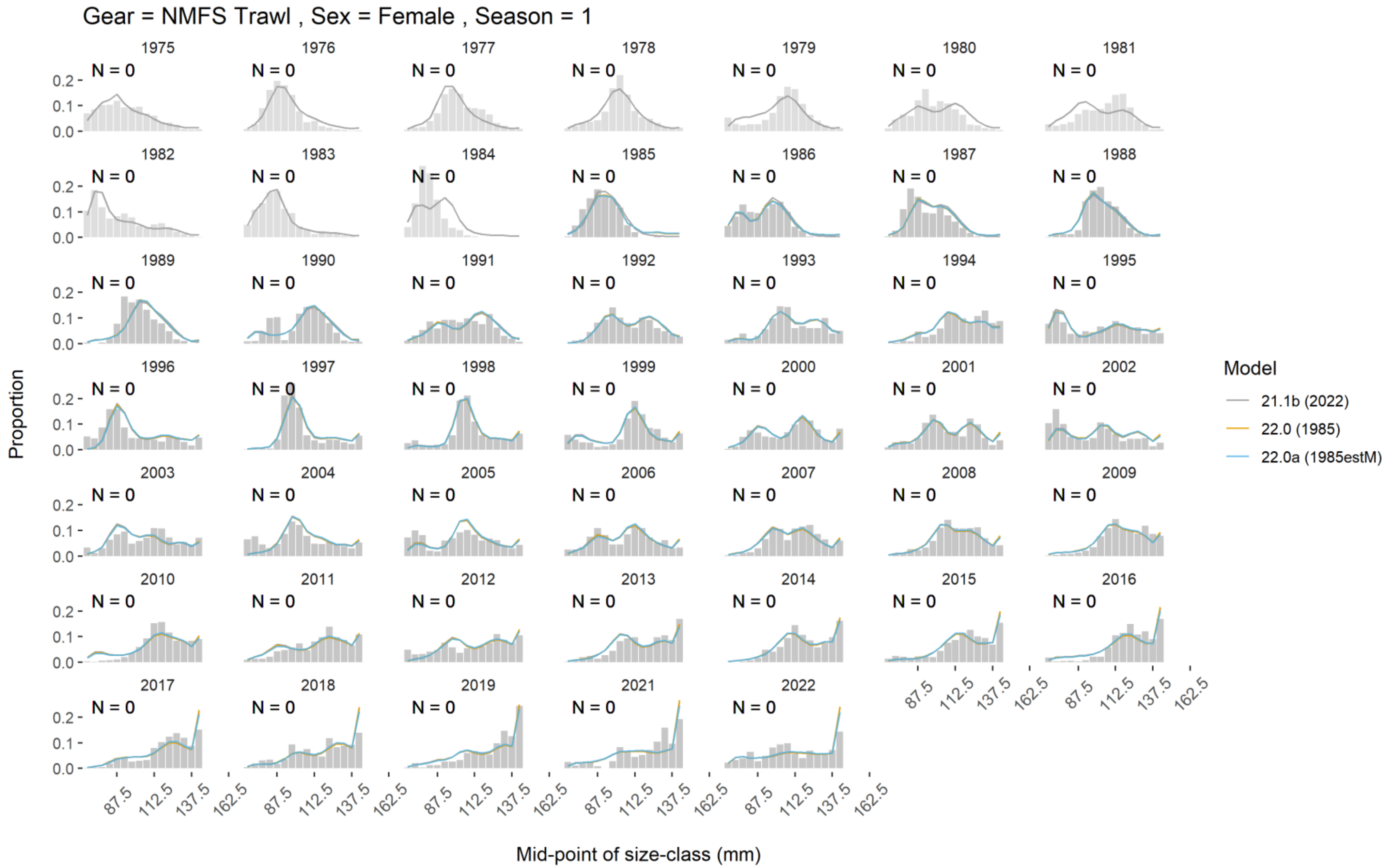
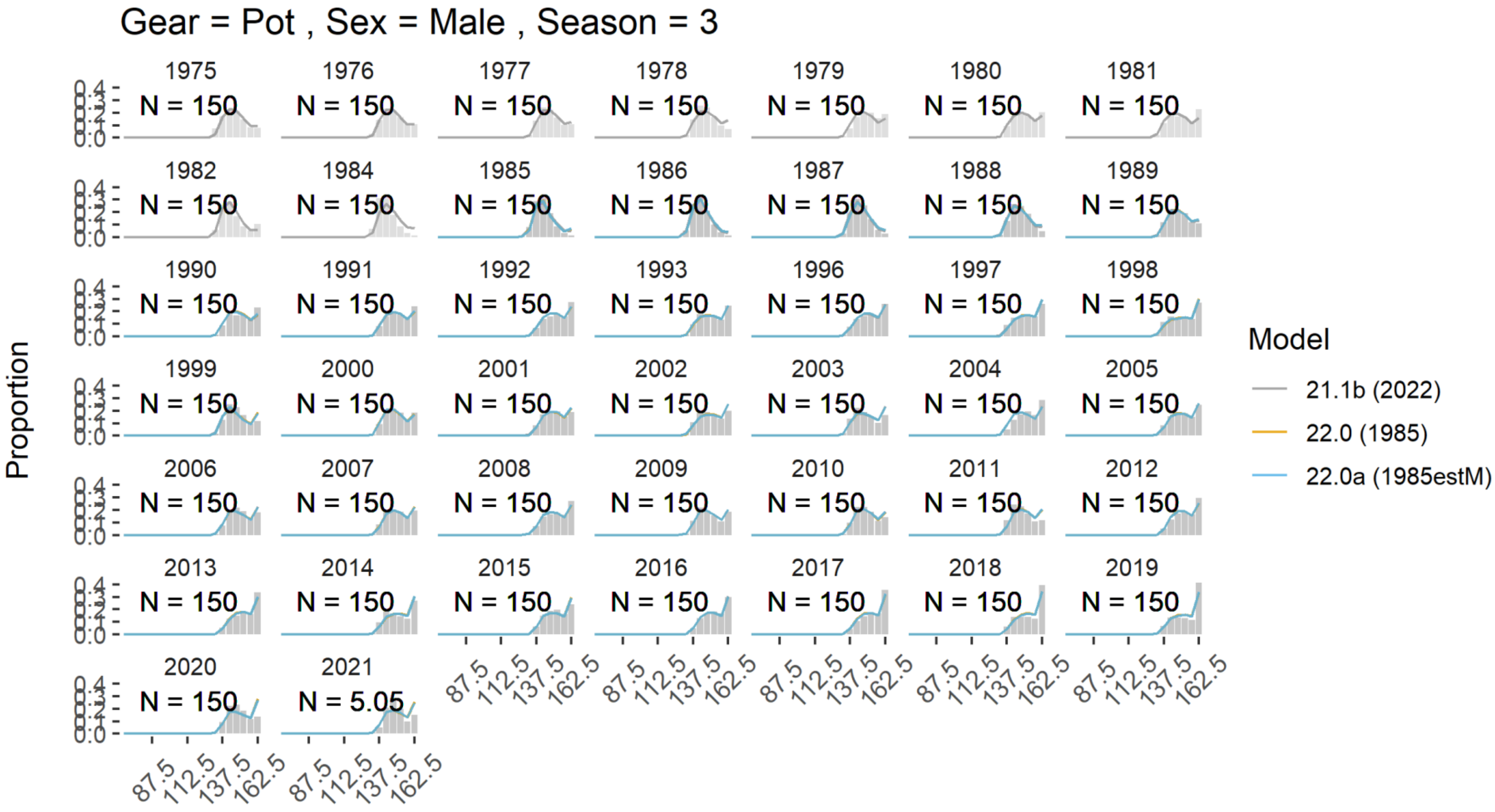


Figure 19. Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay female red king crab by year under models 21.1b, 22.0, and 22.0a.



Mid-point of size-class (mm)

Figure 20. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 21.1b, 22.0, and 22.0a.

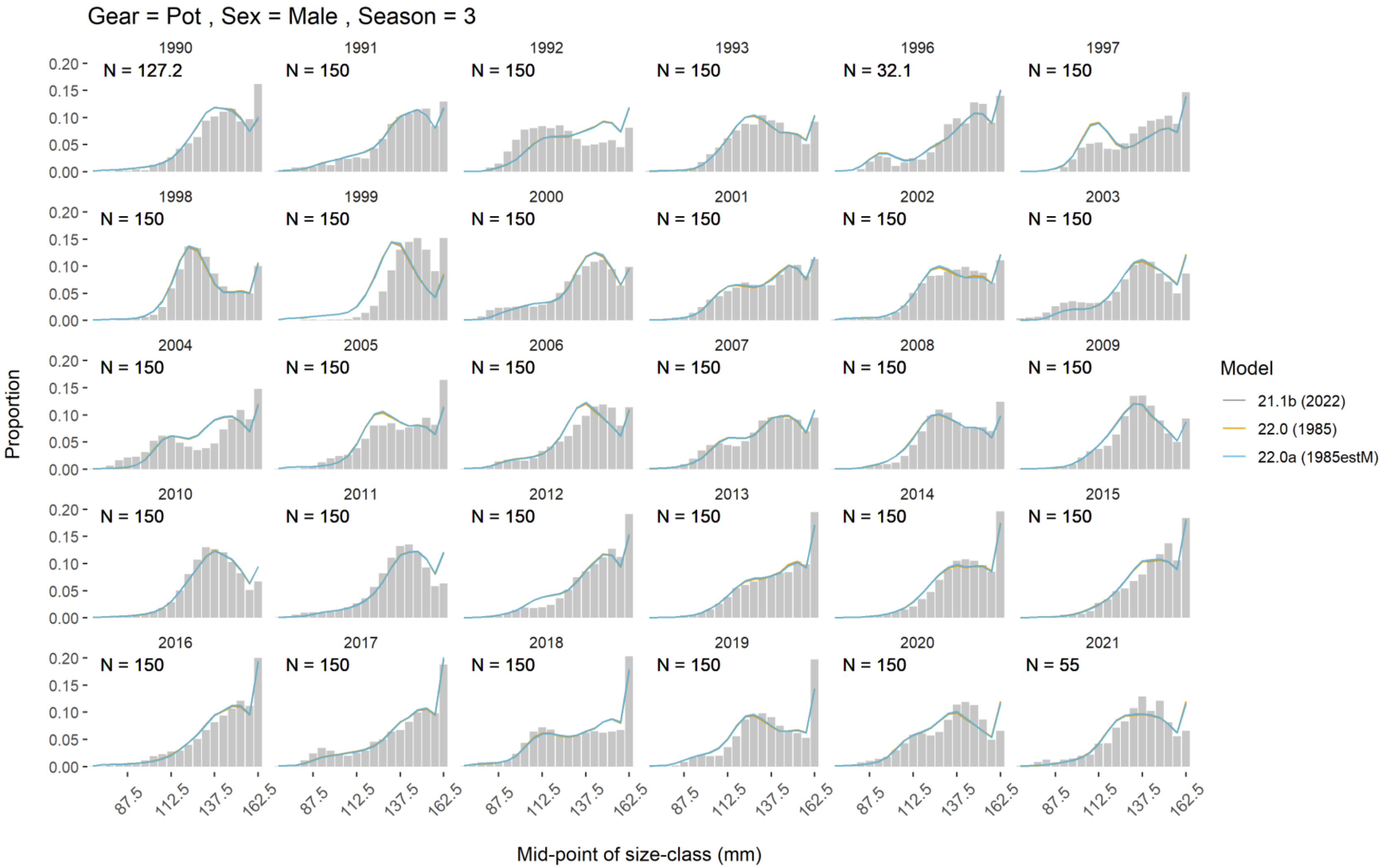


Figure 21. Comparison of observer and model estimated total observer length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 21.1b, 22.0, and 22.0a.

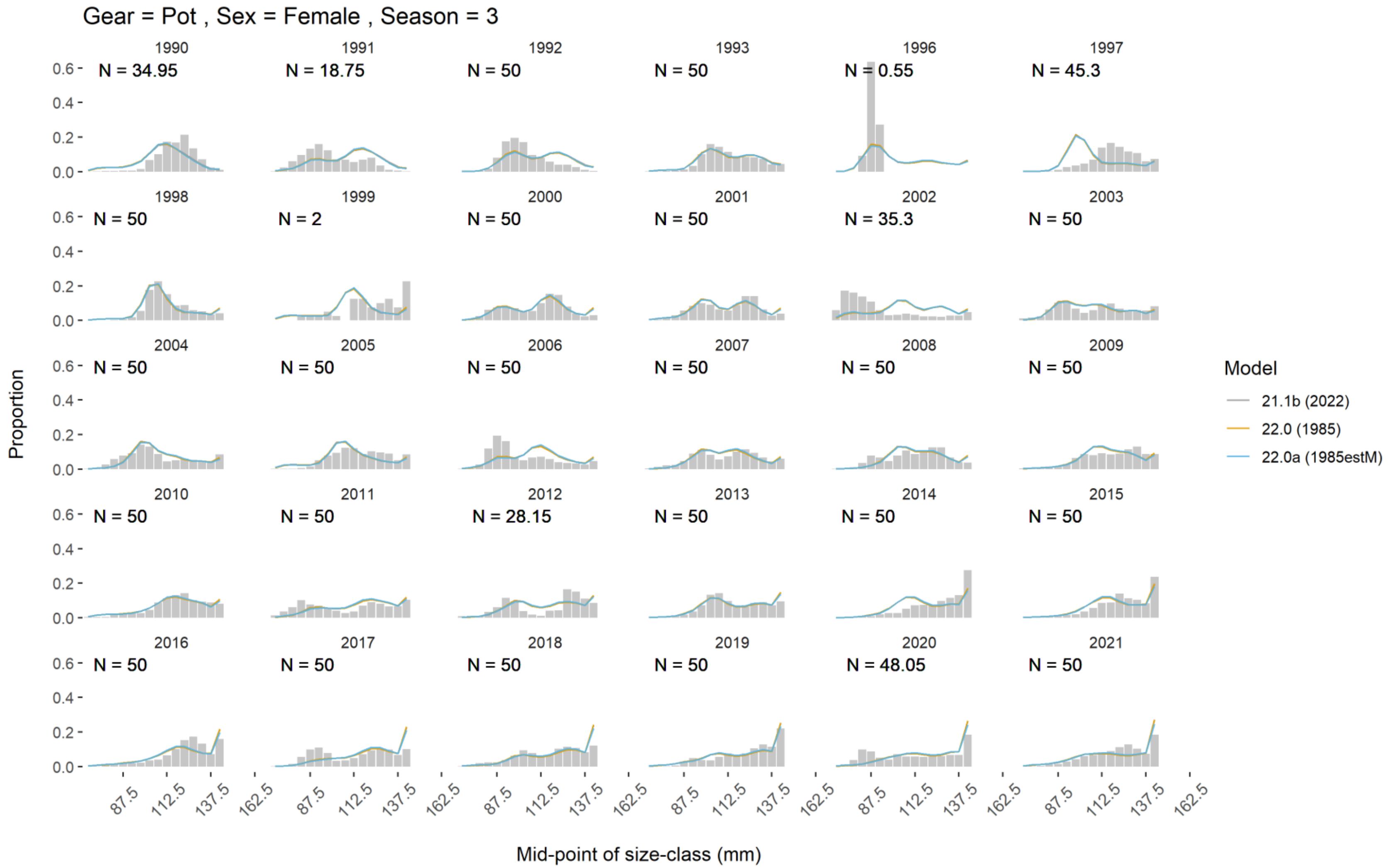


Figure 22. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under models 21.1b, 22.0, and 22.0aretro.

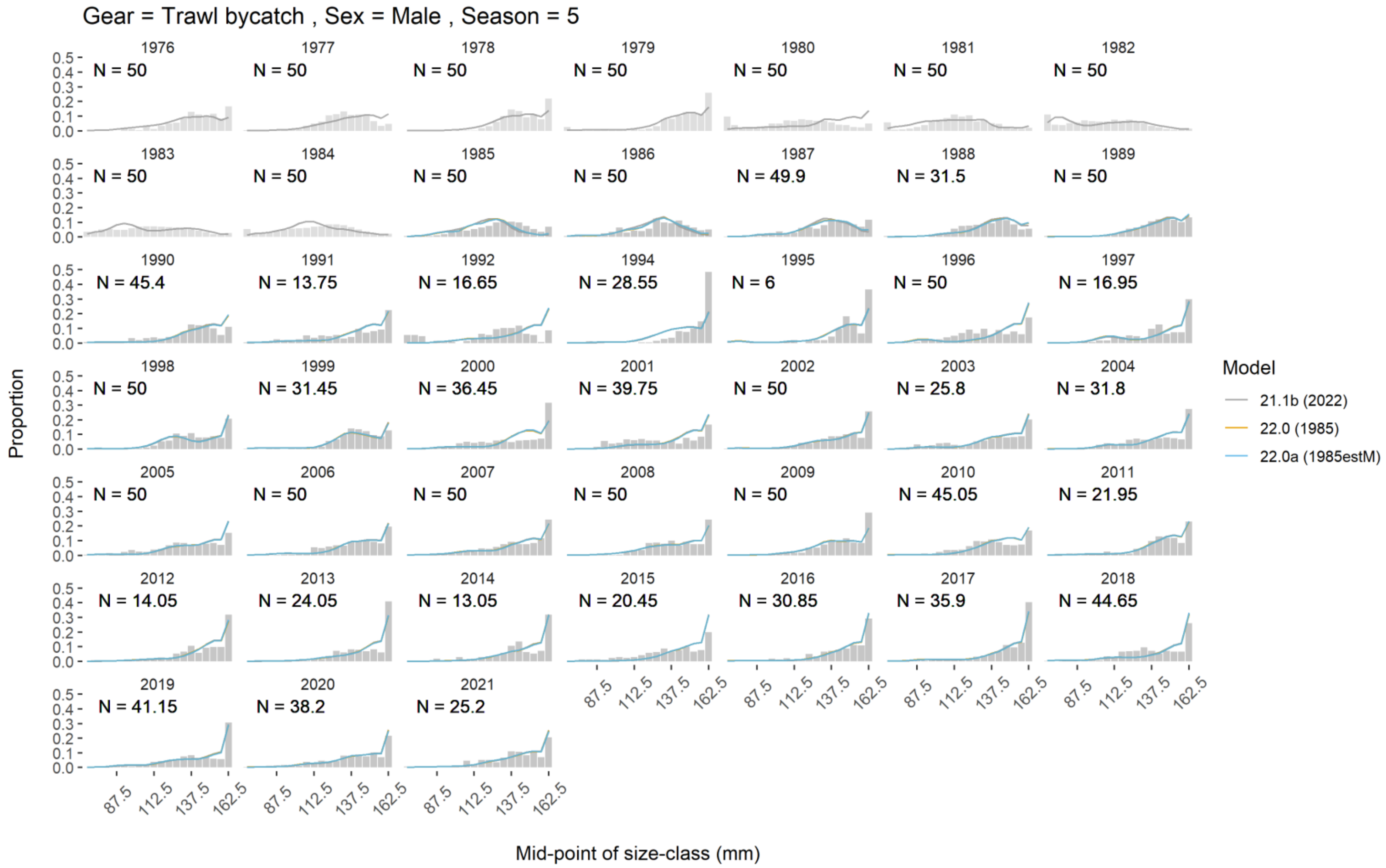


Figure 23a. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under models 21.1b, 22.0, and 22.0a.

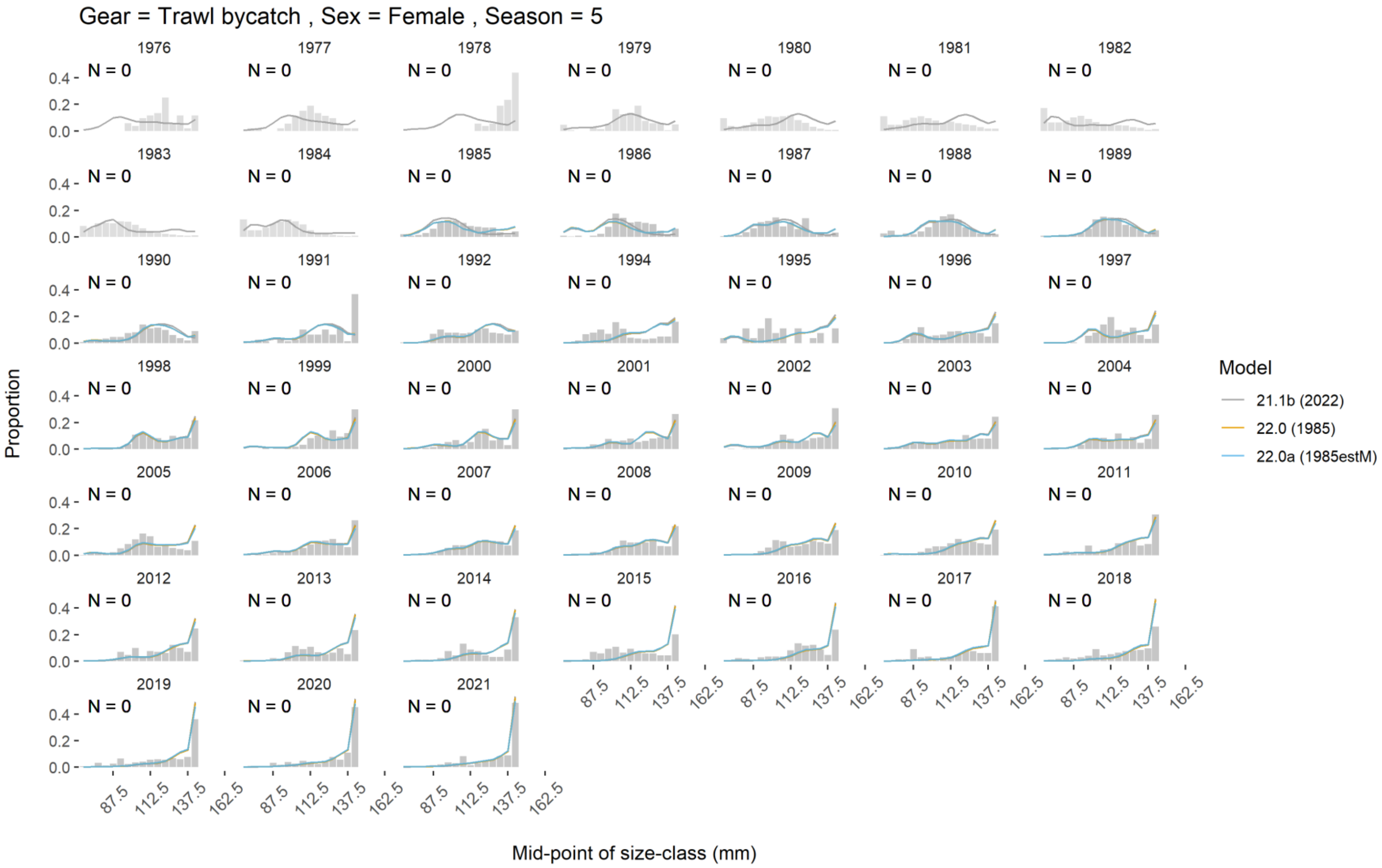


Figure 23b. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under models 21.1b, 22.0, and 22.0a.

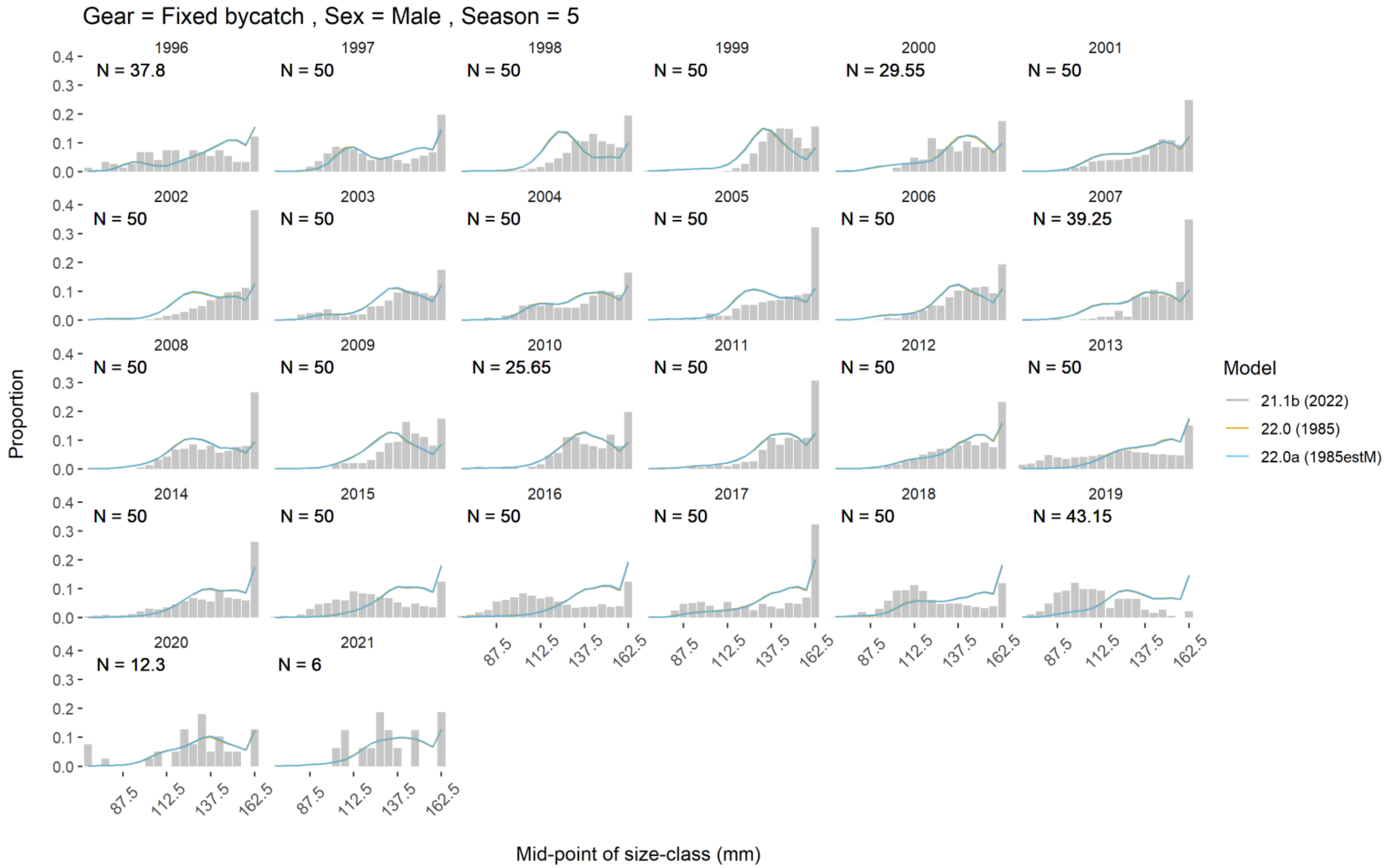


Figure 24a. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries under models 21.1b, 22.0, and 22.01.

Figure 24b. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries under models 21.1b, 22.0, and 22.0a.

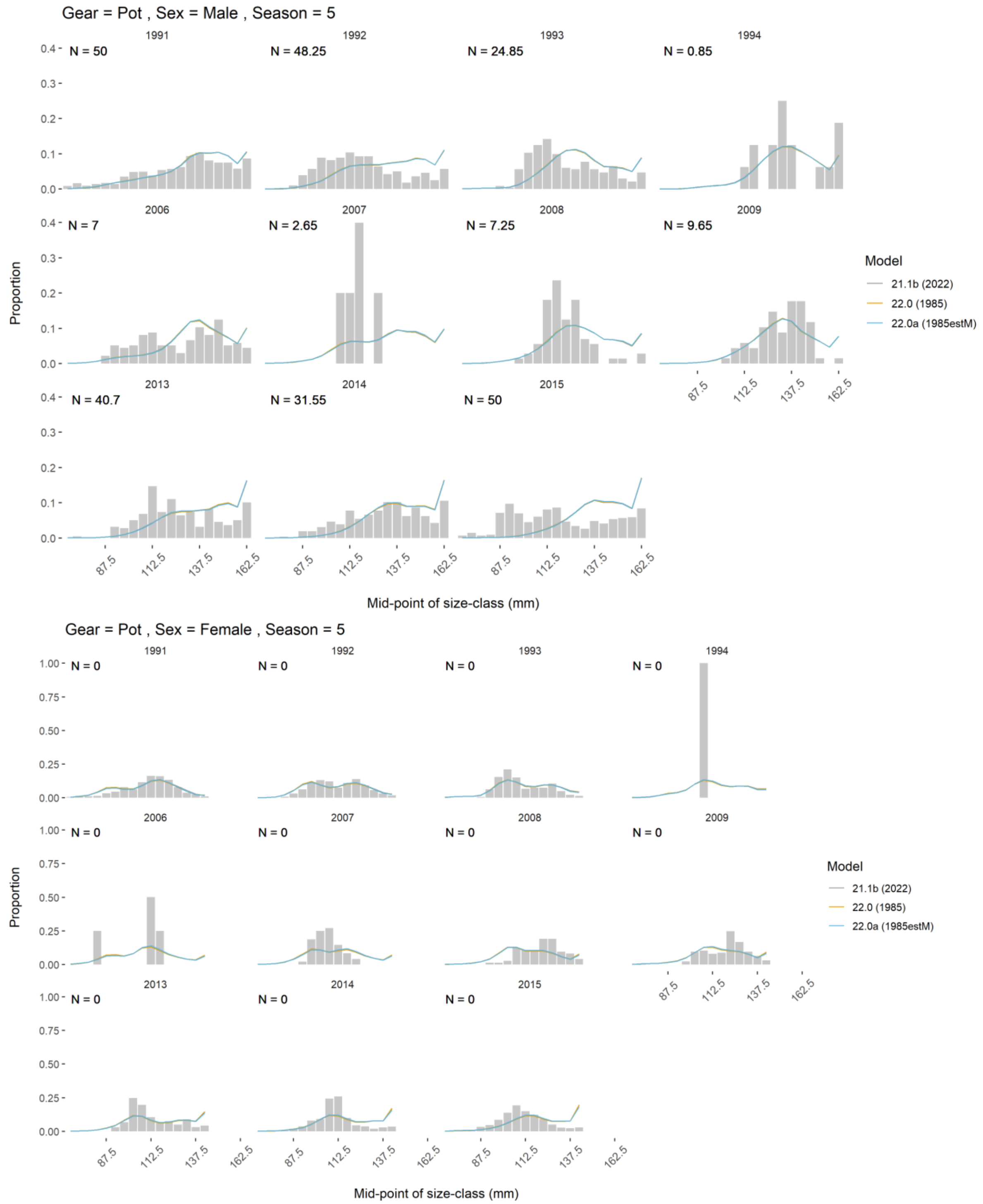


Figure 24c. Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under models 21.1b, 22.0, and 22.0a. Length composition data during 1994-2009 were not used before 2021.

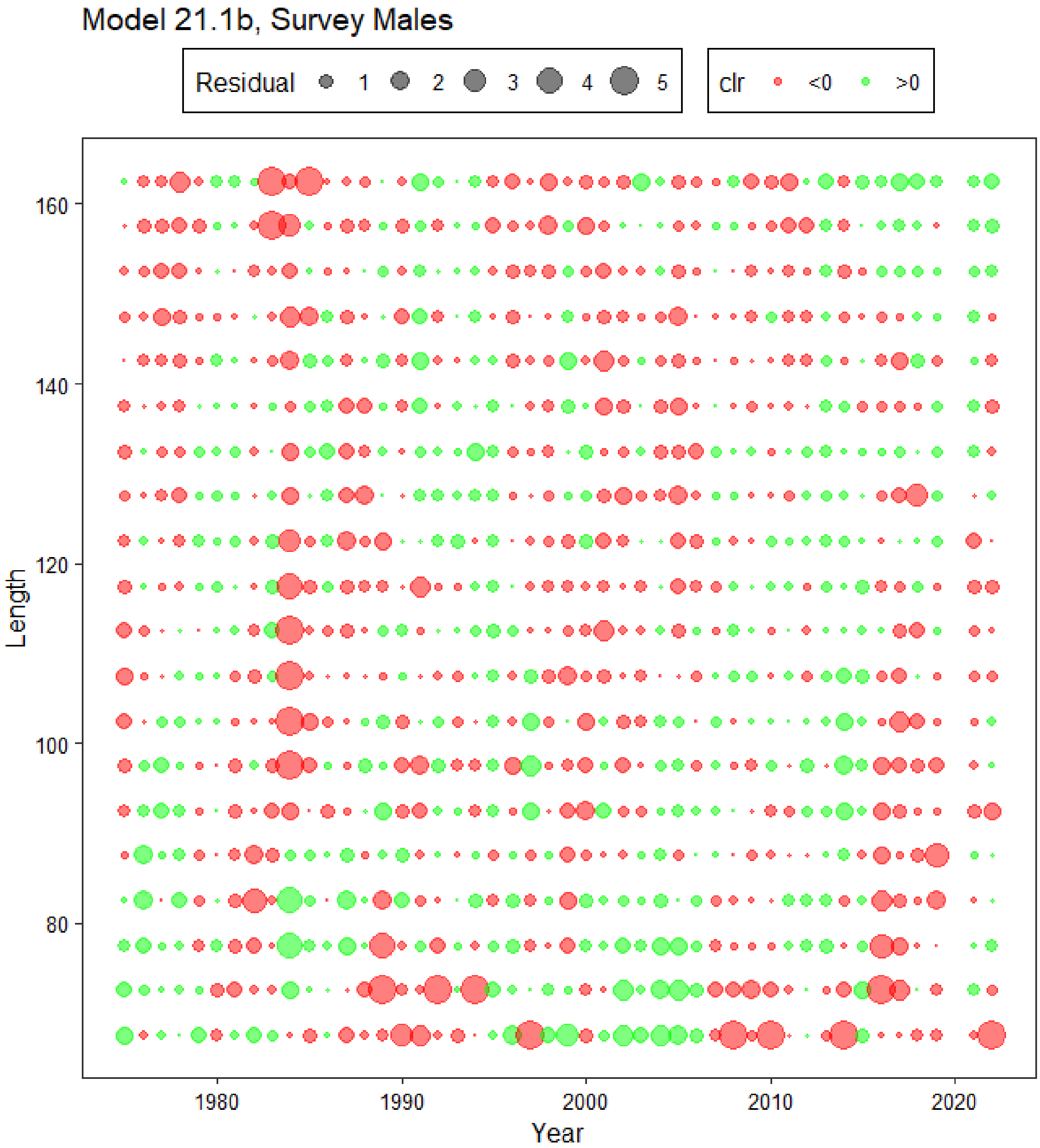


Figure 25a. Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 21.1b. Green circles are positive residuals, and red circles are negative residuals.

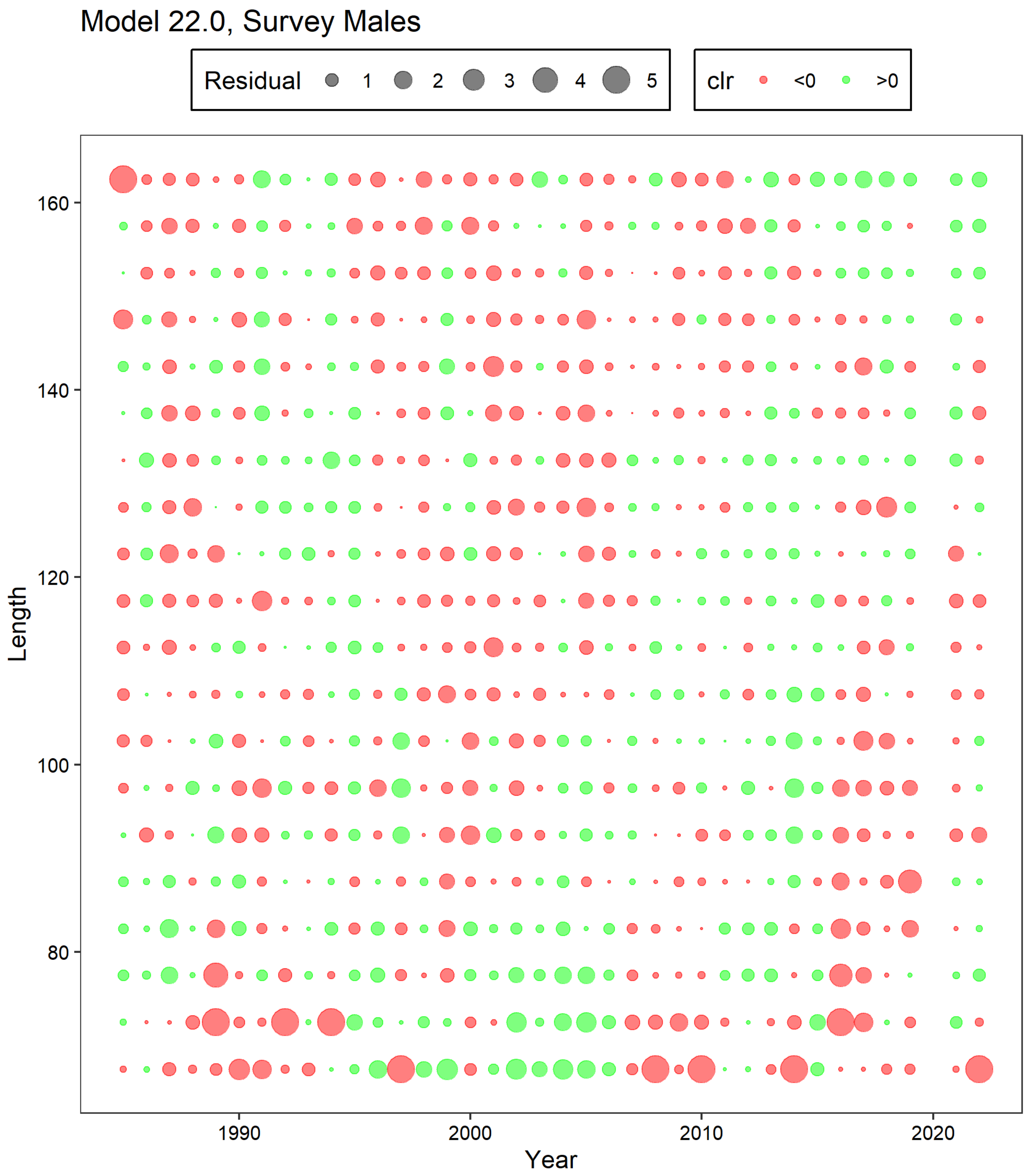


Figure 25b. Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 22.0. Green circles are positive residuals, and red circles are negative residuals.

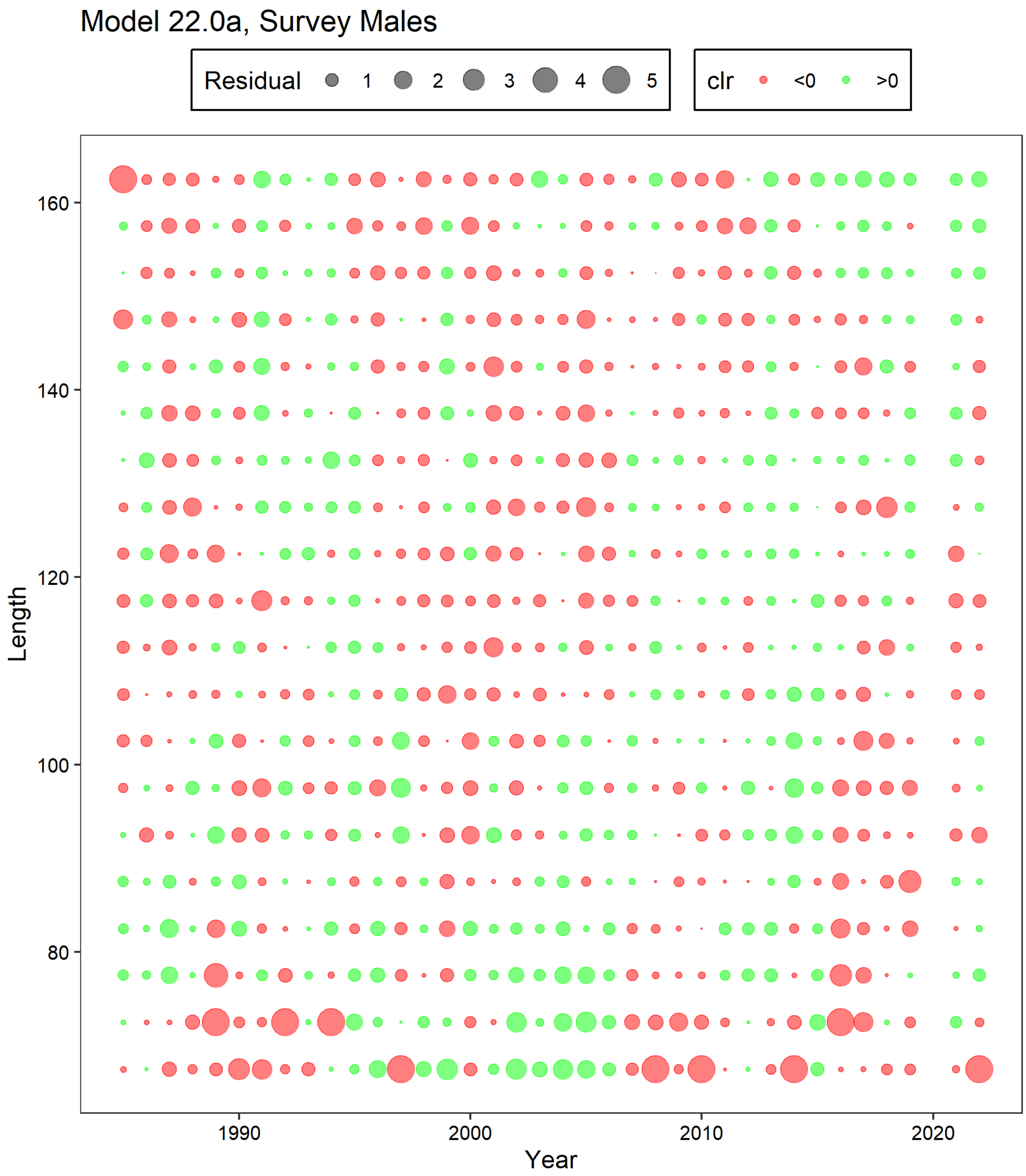


Figure 25c. Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 22.0a. Green circles are positive residuals, and red circles are negative residuals.

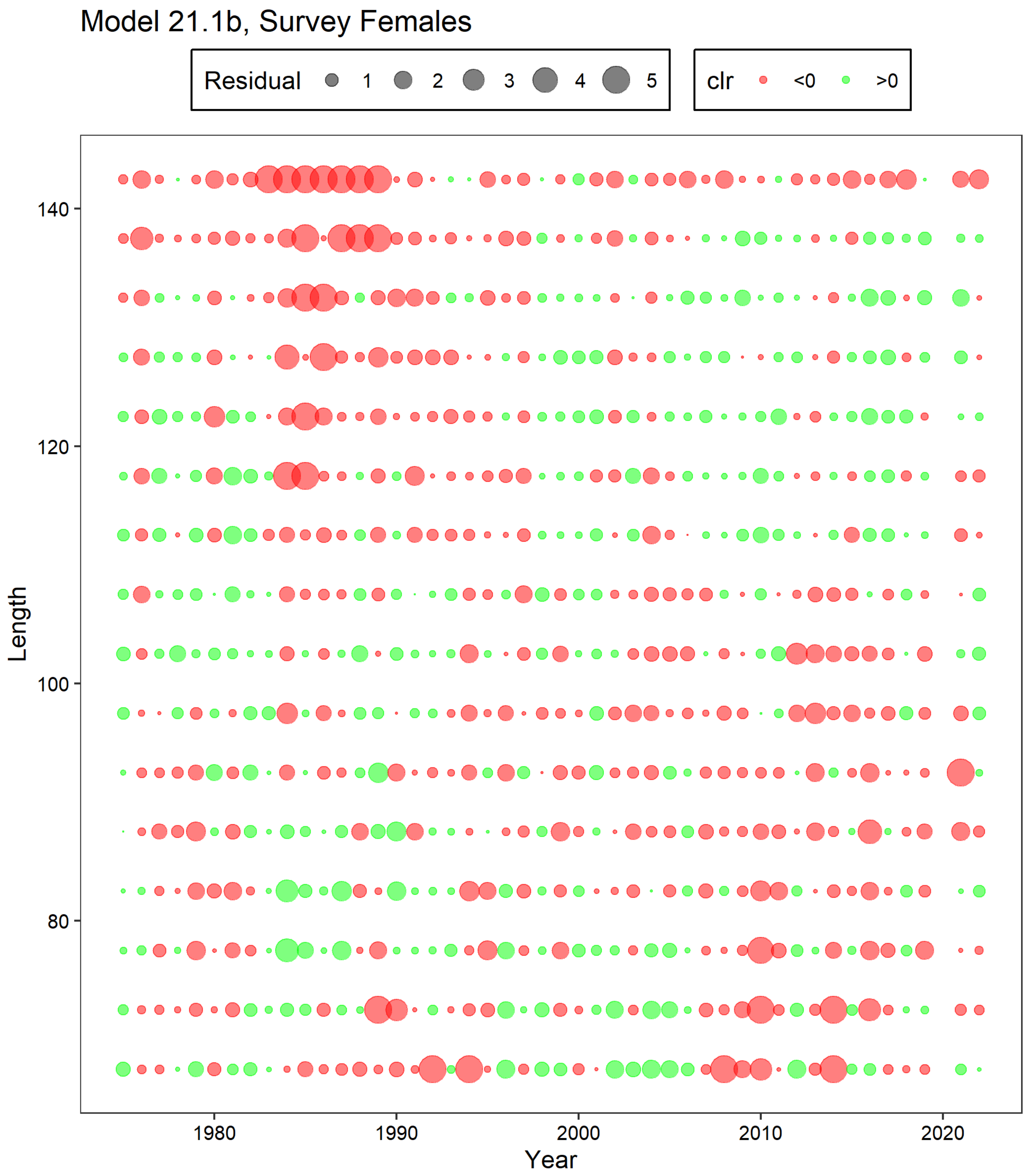


Figure 26a. Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 21.1b. Green circles are positive residuals, and red circles are negative residuals.

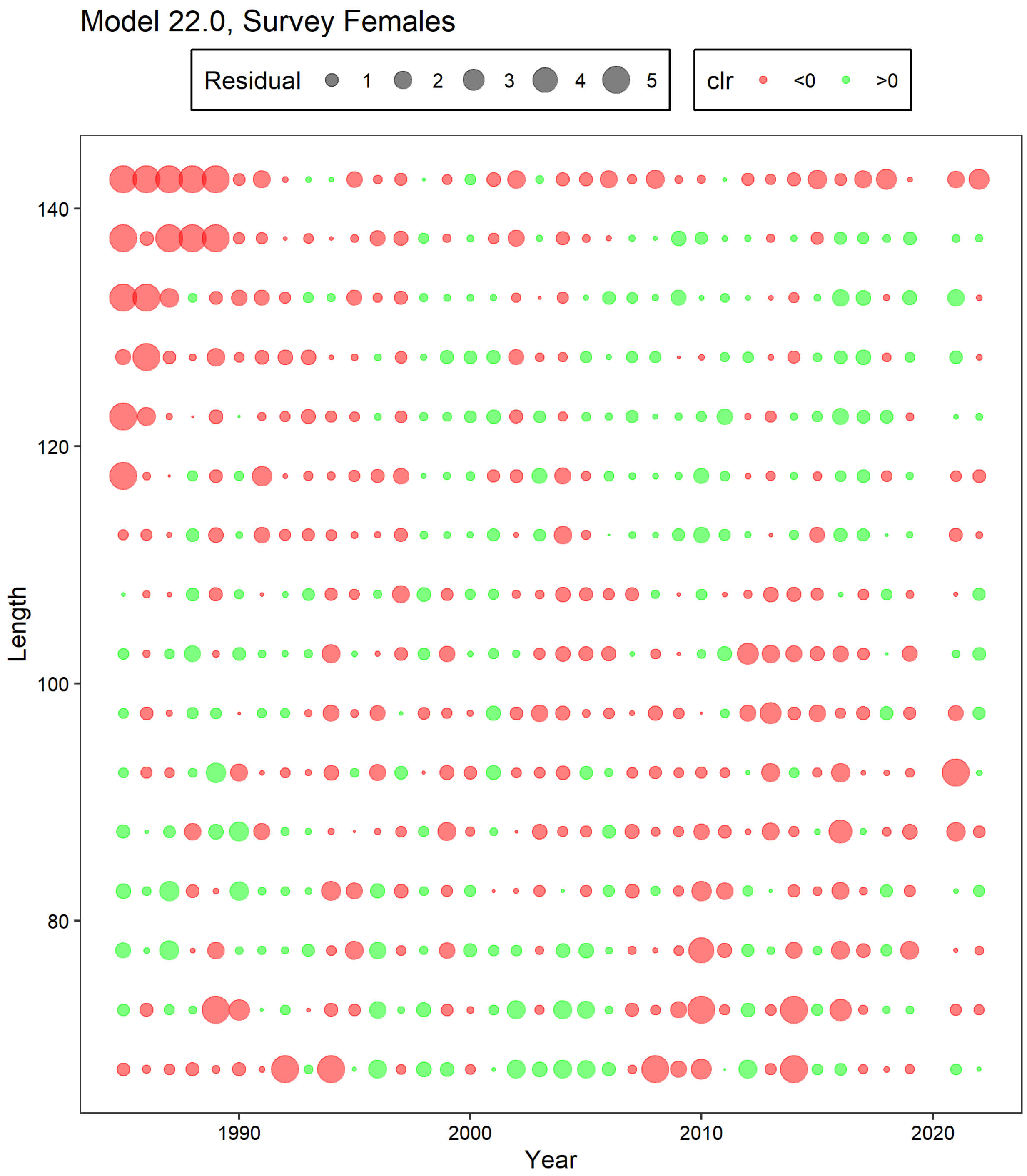


Figure 26b. Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 22.0. Green circles are positive residuals, and red circles are negative residuals.

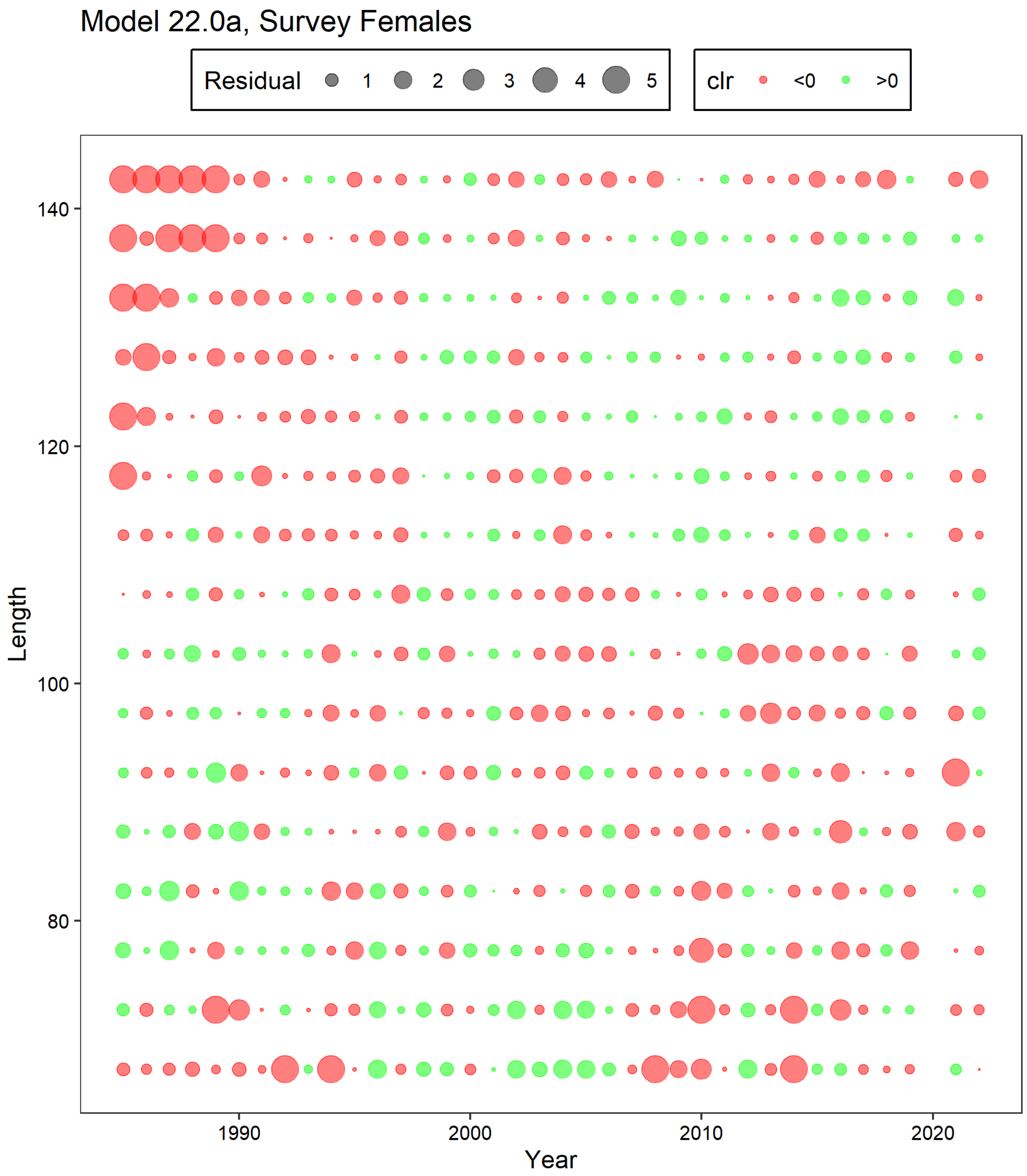


Figure 26c. Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 22.0a. Green circles are positive residuals, and red circles are negative residuals.

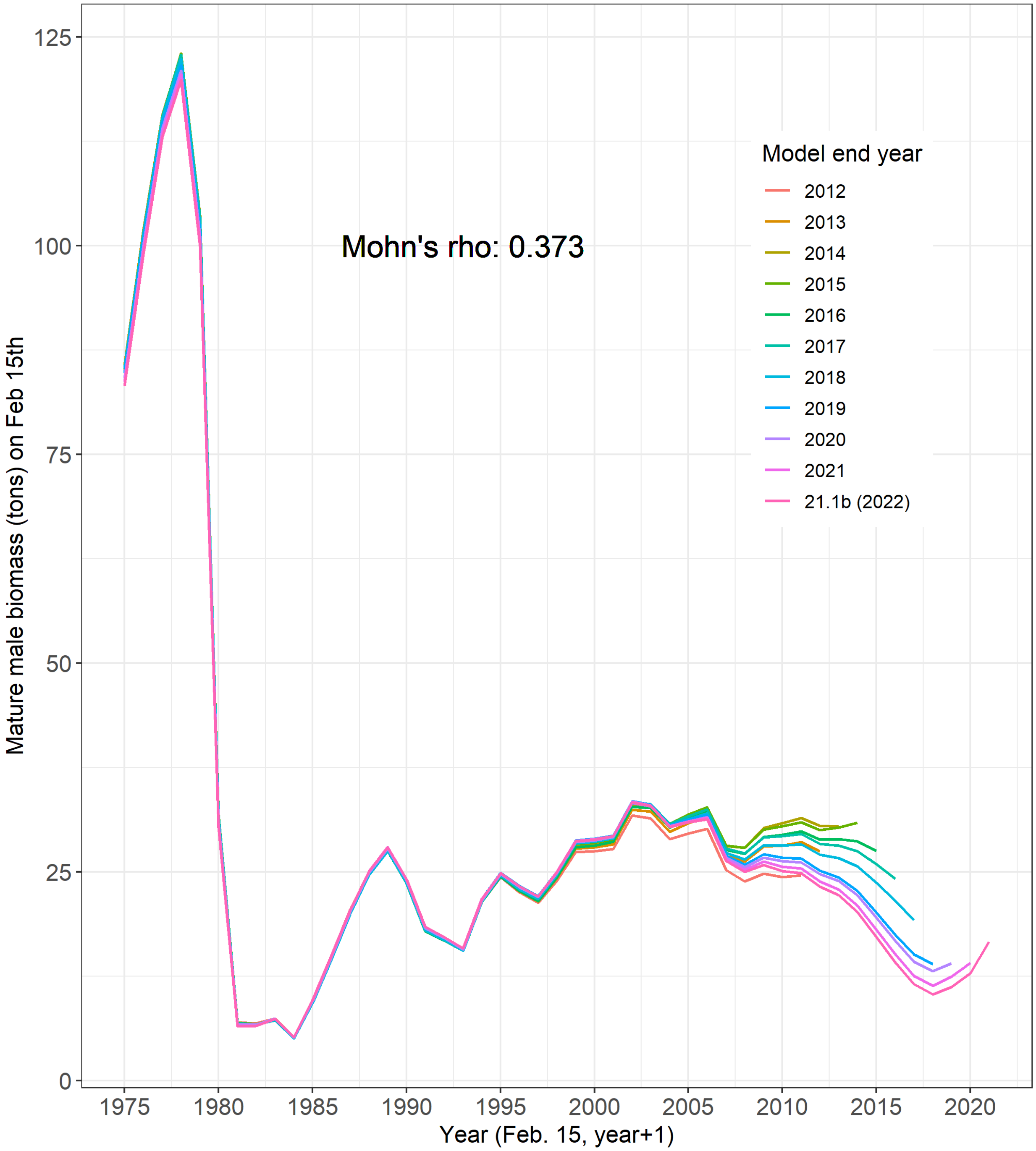


Figure 27a. Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab from 1975 to 2021 made with terminal years 2012-2022 with model 21.1b. These are results of the 2022 model. Legend shows the terminal year.

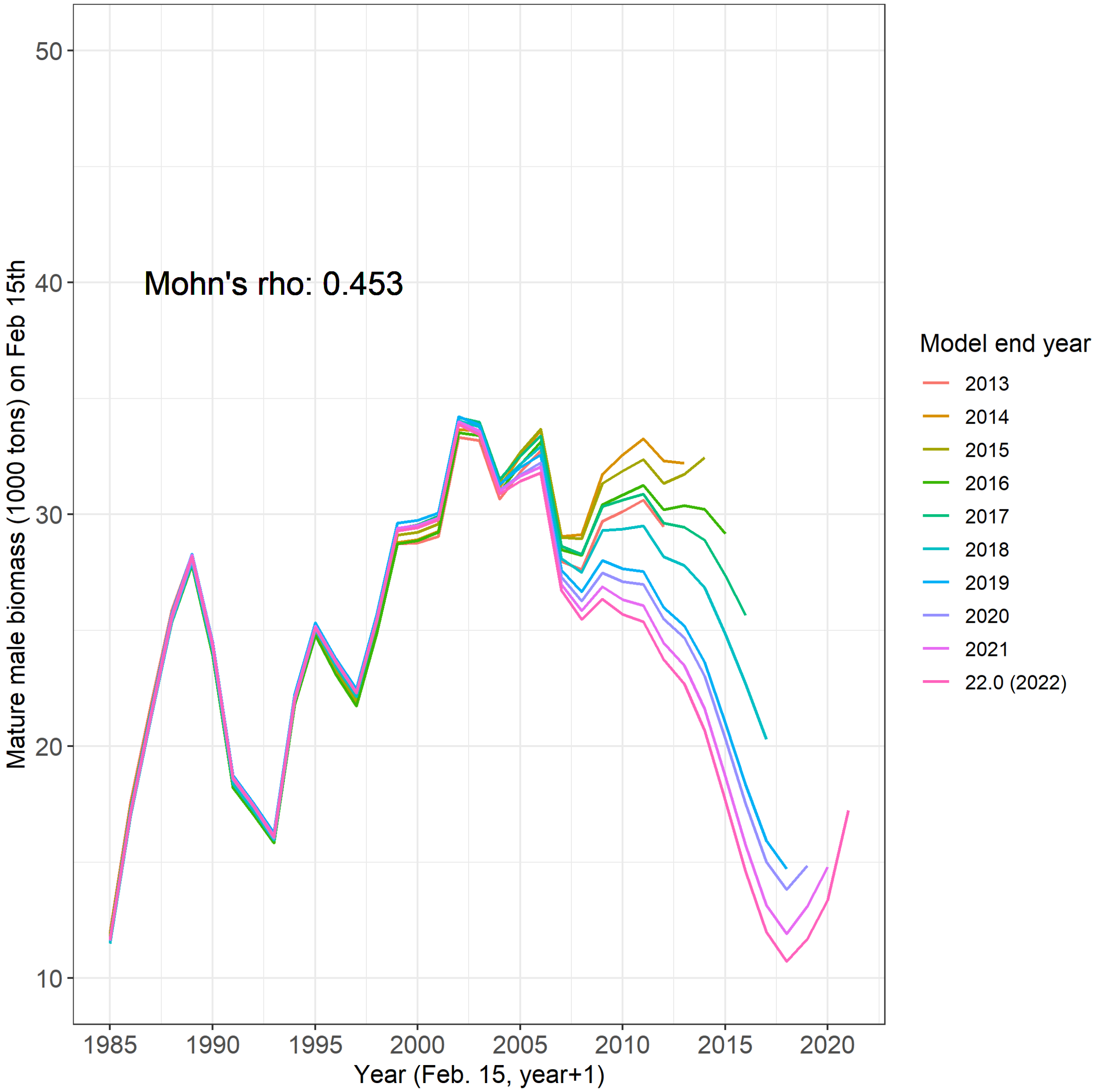


Figure 27b. Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab from 1975 to 2021 made with terminal years 2013-2022 with **model 22.0**. These are results of the 2022 model. Legend shows the terminal year.

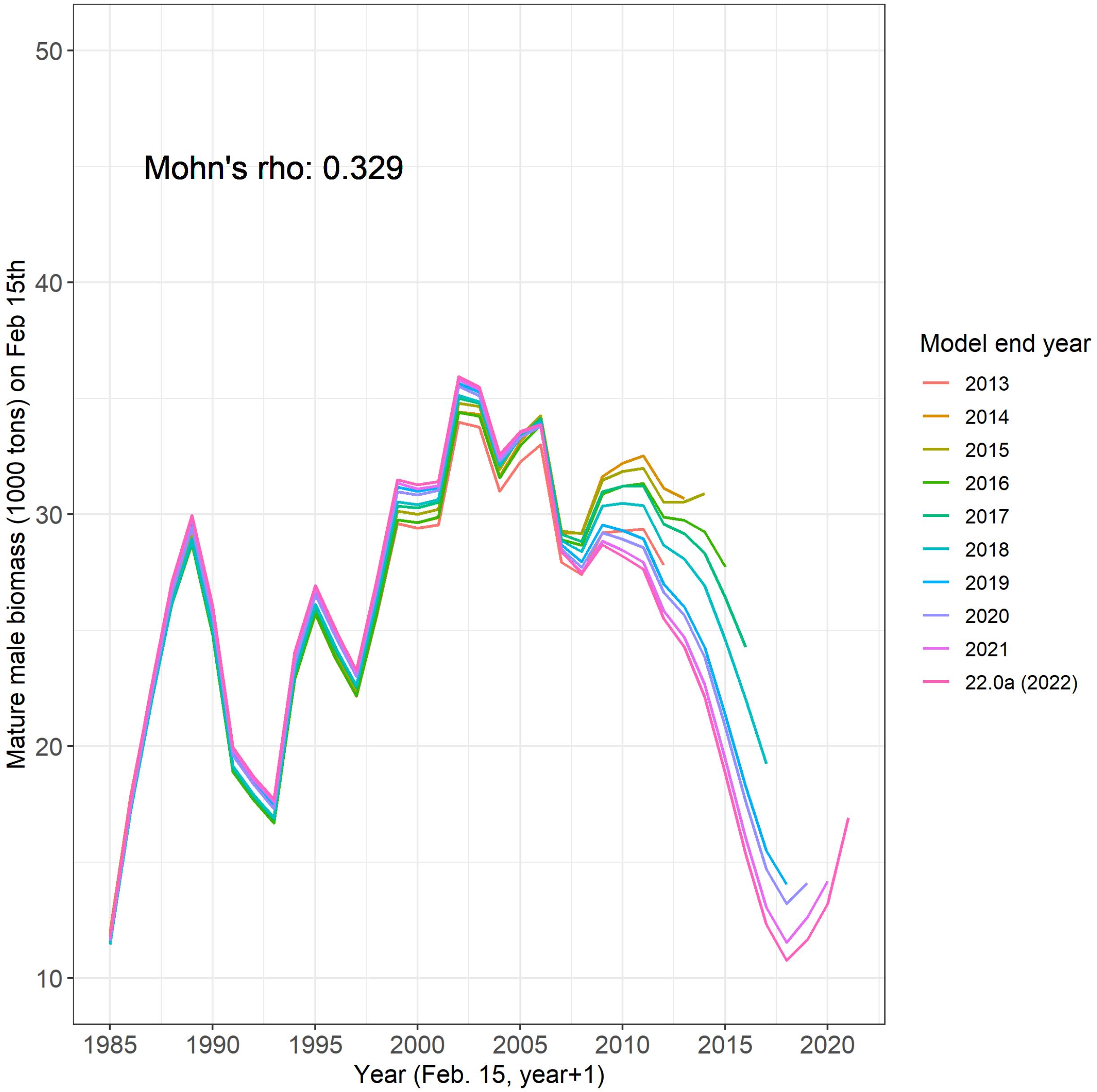


Figure 27c. Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab from 1975 to 2021 made with terminal years 2013 to 2022 with **model 22.0a**. These are results of the 2022 model. Legend shows the terminal year.

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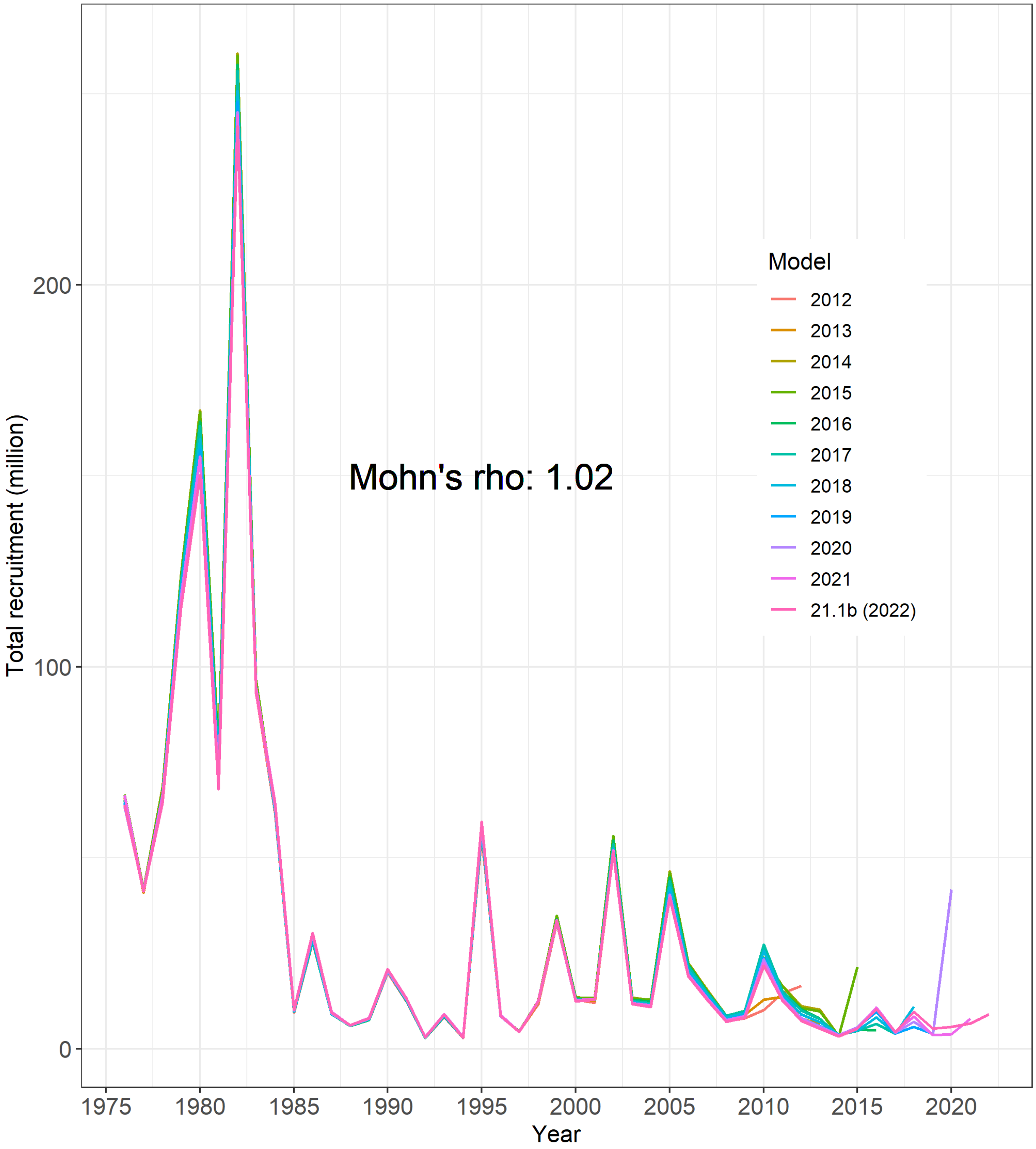


Figure 28a. Comparison of hindcast estimates of total recruitment for model 21.1b of Bristol Bay red king crab from 1976 to 2022 made with terminal years 2012-2022. These are results of the model 21.1b. Legend shows the terminal year.

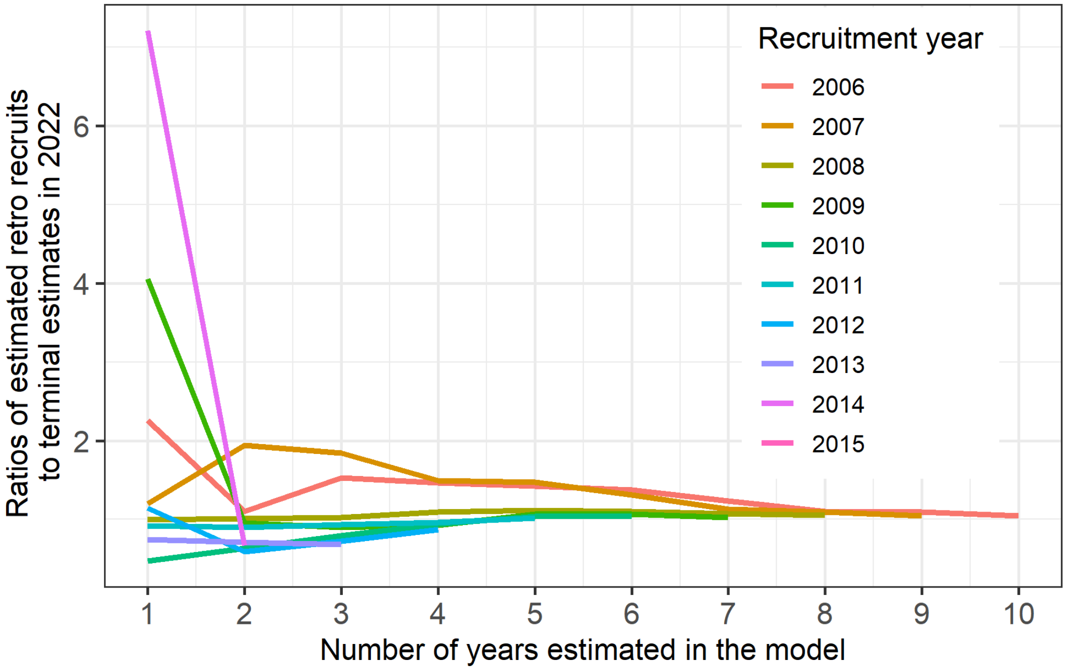


Figure 28b. Evaluation of Bristol Bay red king crab retrospective errors on recruitment estimates as a function of the number of years in the model for model 21.1b.

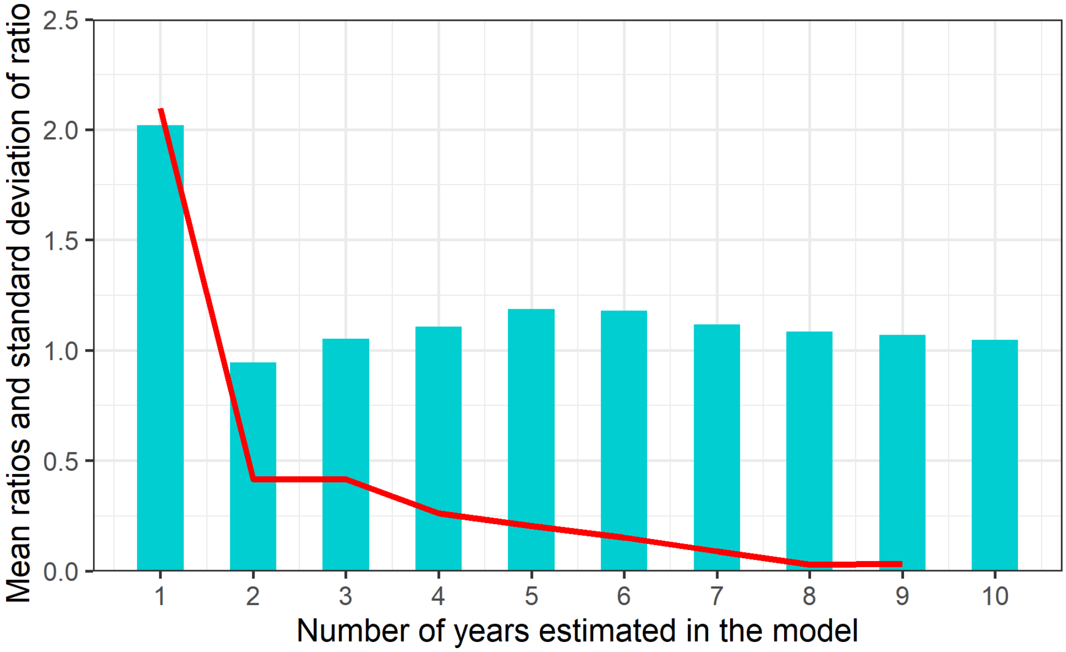


Figure 28c. Mean ratios of retrospective estimates of recruitments to those estimated in the most recent year (2022) and standard deviations (red line) of the ratios as a function of the number of years in the model for model 21.1b.

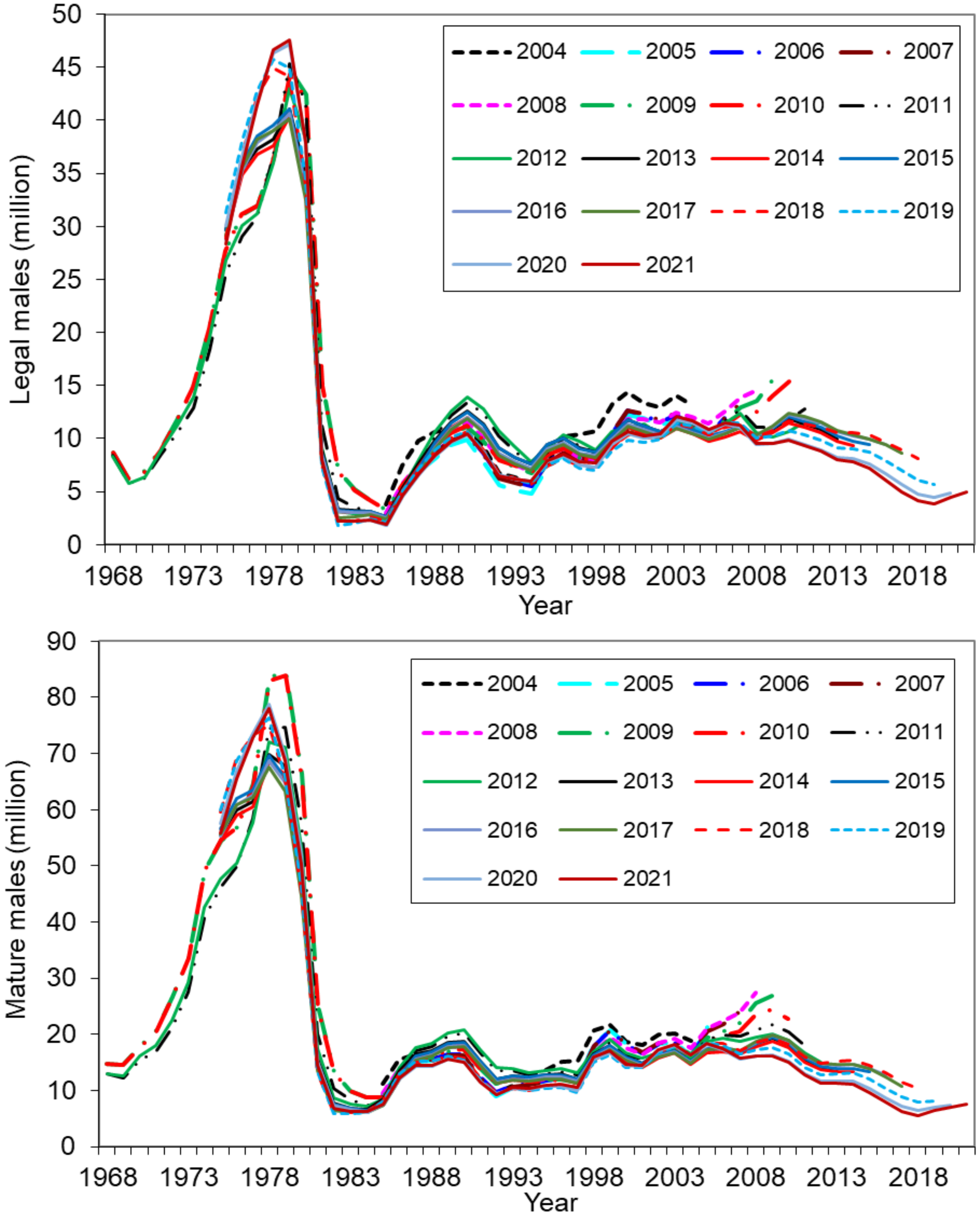


Figure 29a. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2021 made with terminal years 2004-2021 with the base models. Model 21.1b is used for 2021. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

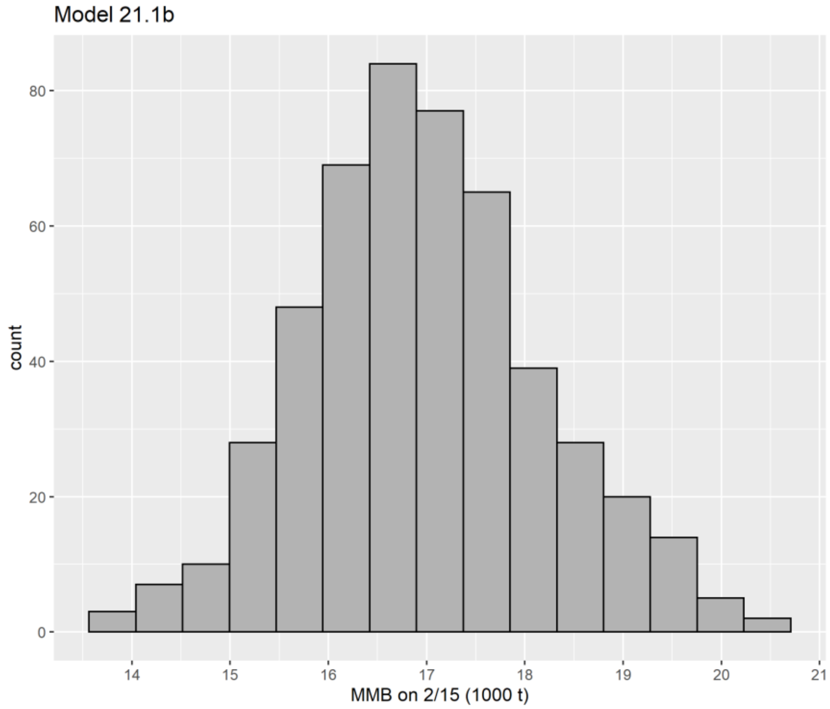


Figure 30a. Histogram of estimated mature male biomass on Feb. 15, 2022, under model 21.1b with the MCMC approach.

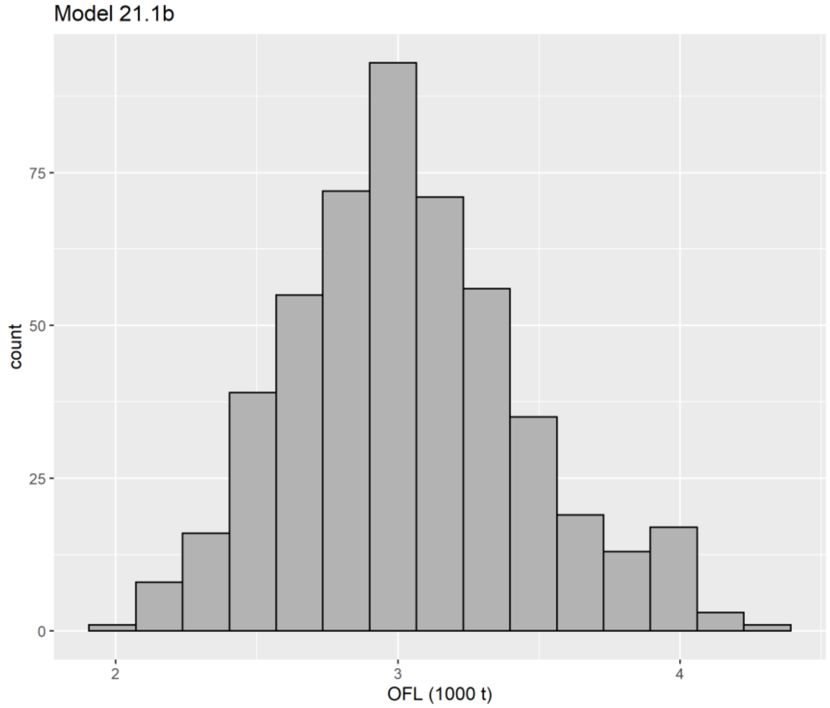


Figure 30b. Histogram of the 2021 estimated OFL under model 21.1b with the MCMC approach.

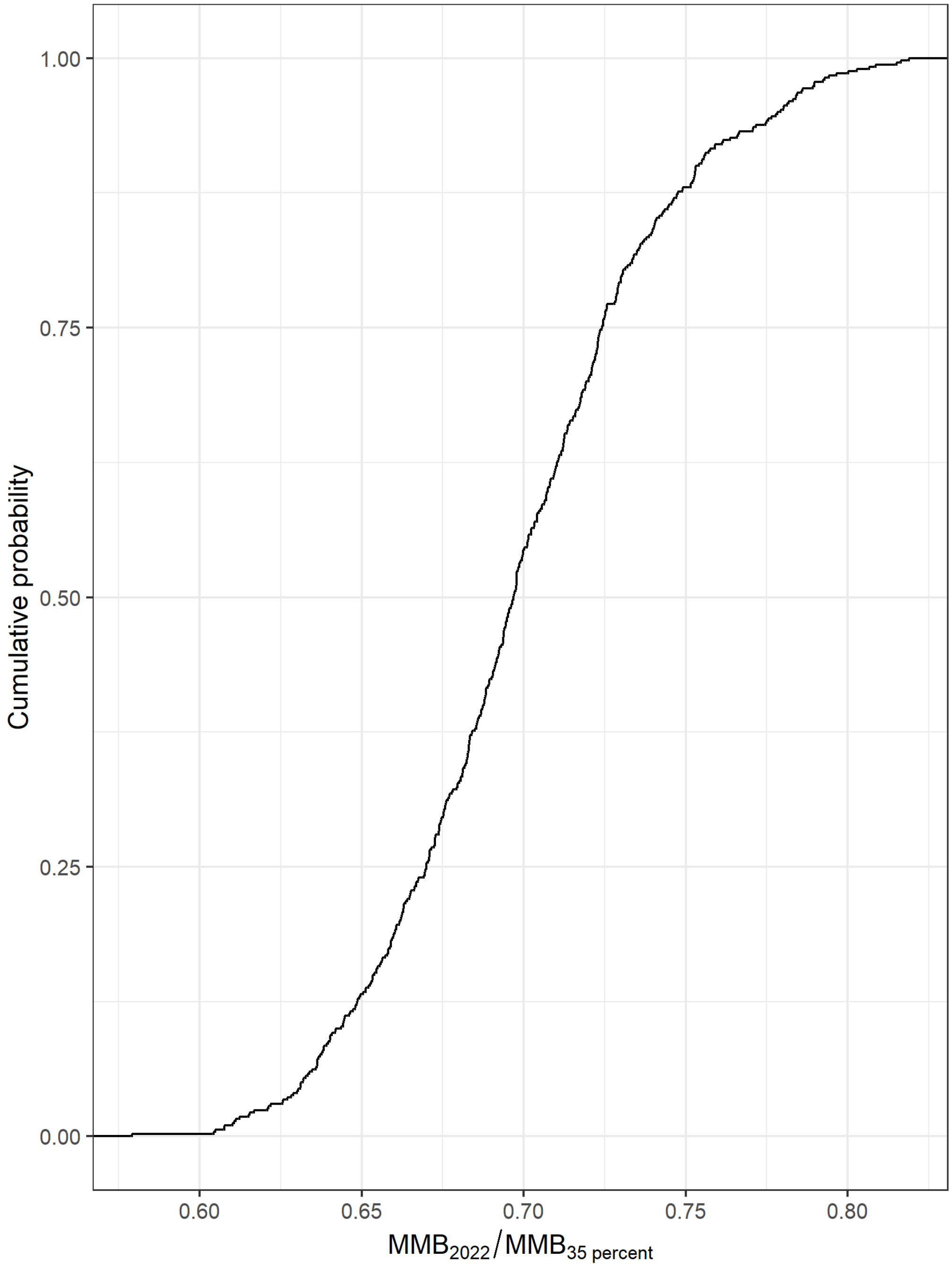


Figure 31. Cumulative probabilities of estimated ratios of MMB on Feb. 15, 2023, to corresponding estimated $B_{35\%}$ values under model 21.1b with the MCMC approach. Zero probability is below the estimated minimum thresholds.

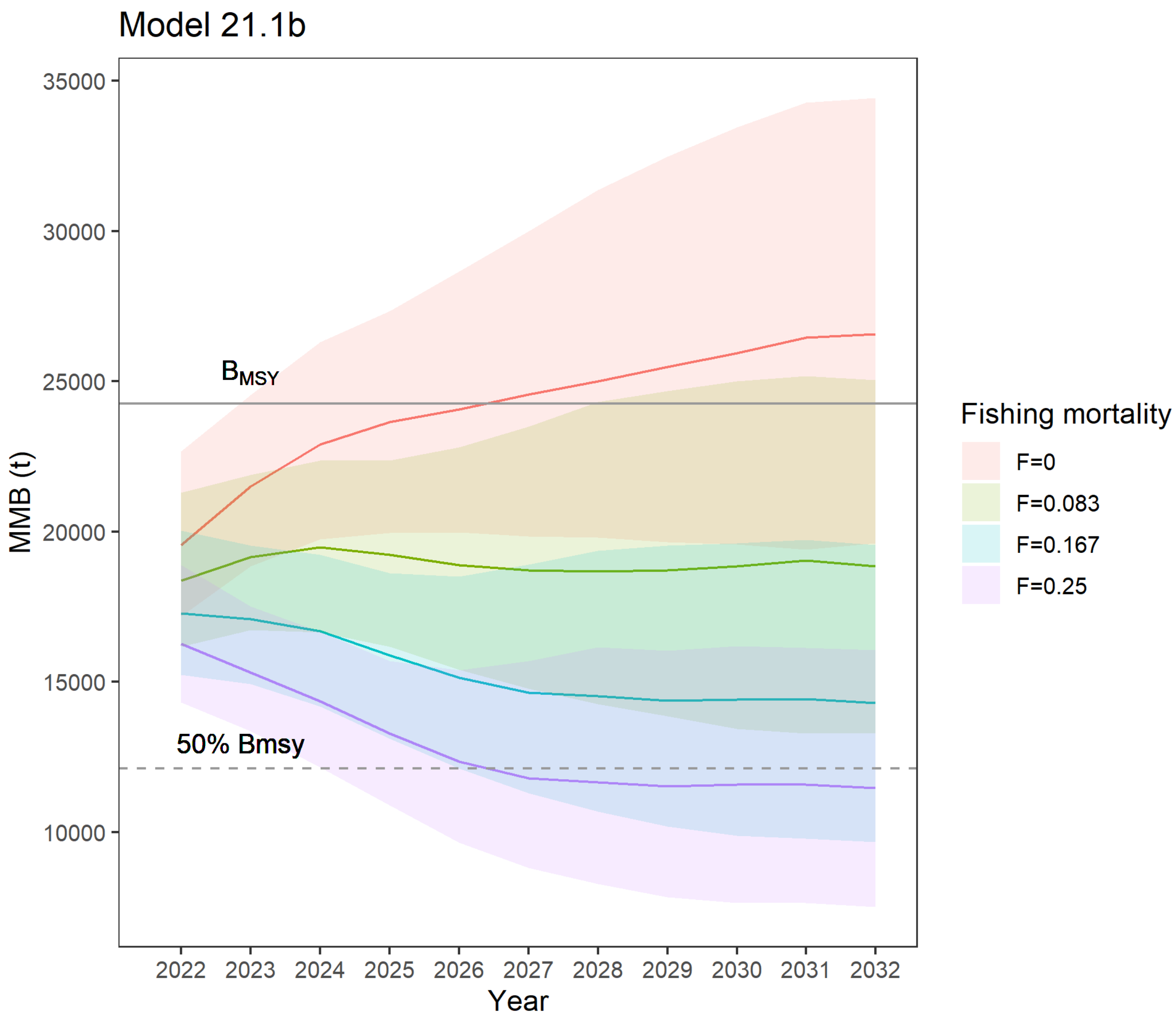


Figure 32. Projected mature male biomass on Feb. 15 with four fishing mortalities in the directed fishery - *F* = 0, F = 0.083, F = 0.167, and F = 0.25, during 2022-2032. Input parameter estimates are based on model 21.1b. Crab year “2022” represents Feb. 15, 2023. Shaded areas represent a 5% to 95% limits.

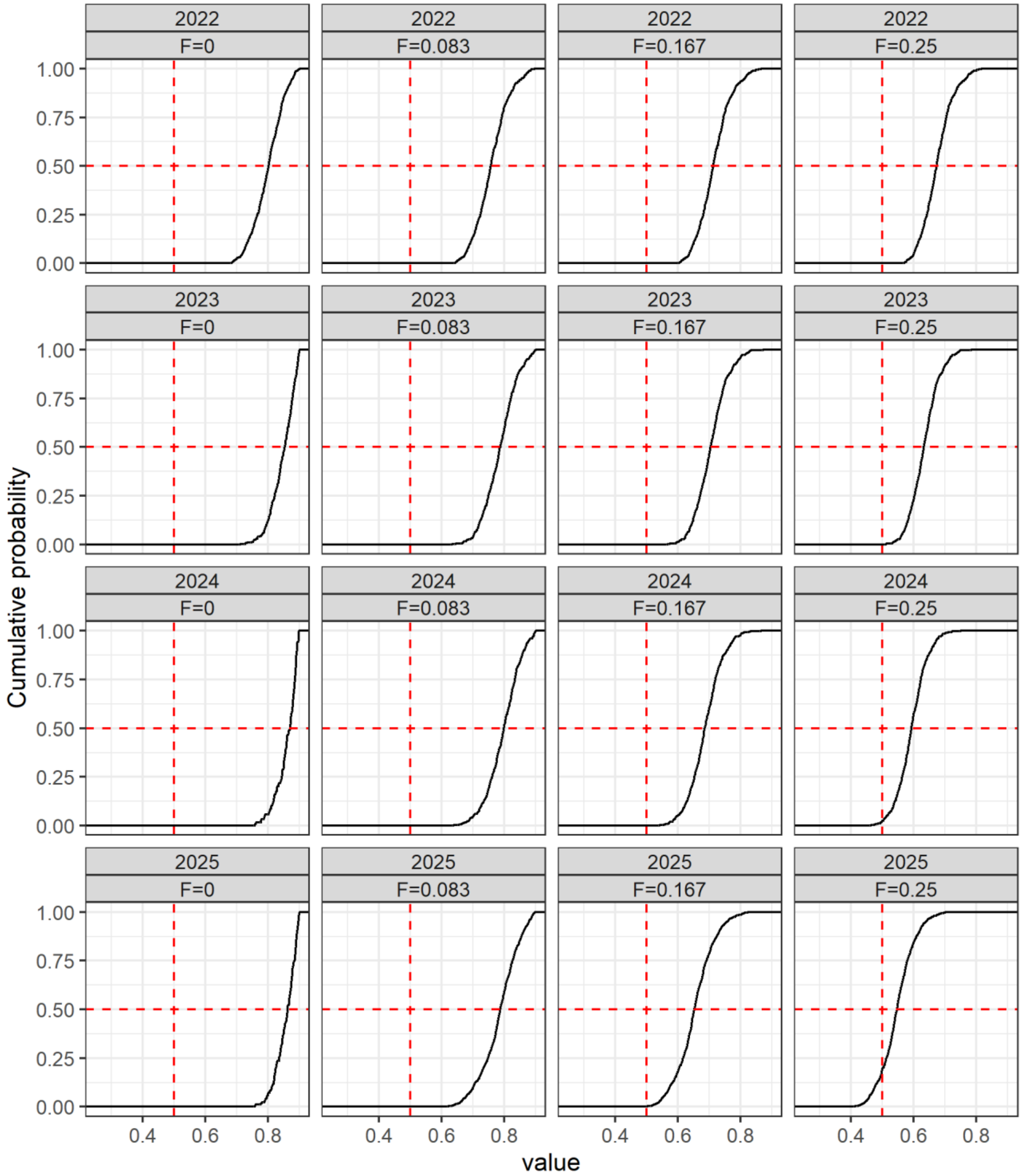


Figure 33. Cumulative probabilities of estimated ratios of MMB during 2022-2025 to corresponding estimated $B_{35\%}$ values under model 21.1b with the MCMC approach and four fishing mortality values. Crab year "2022" represents Feb. 15, 2023.

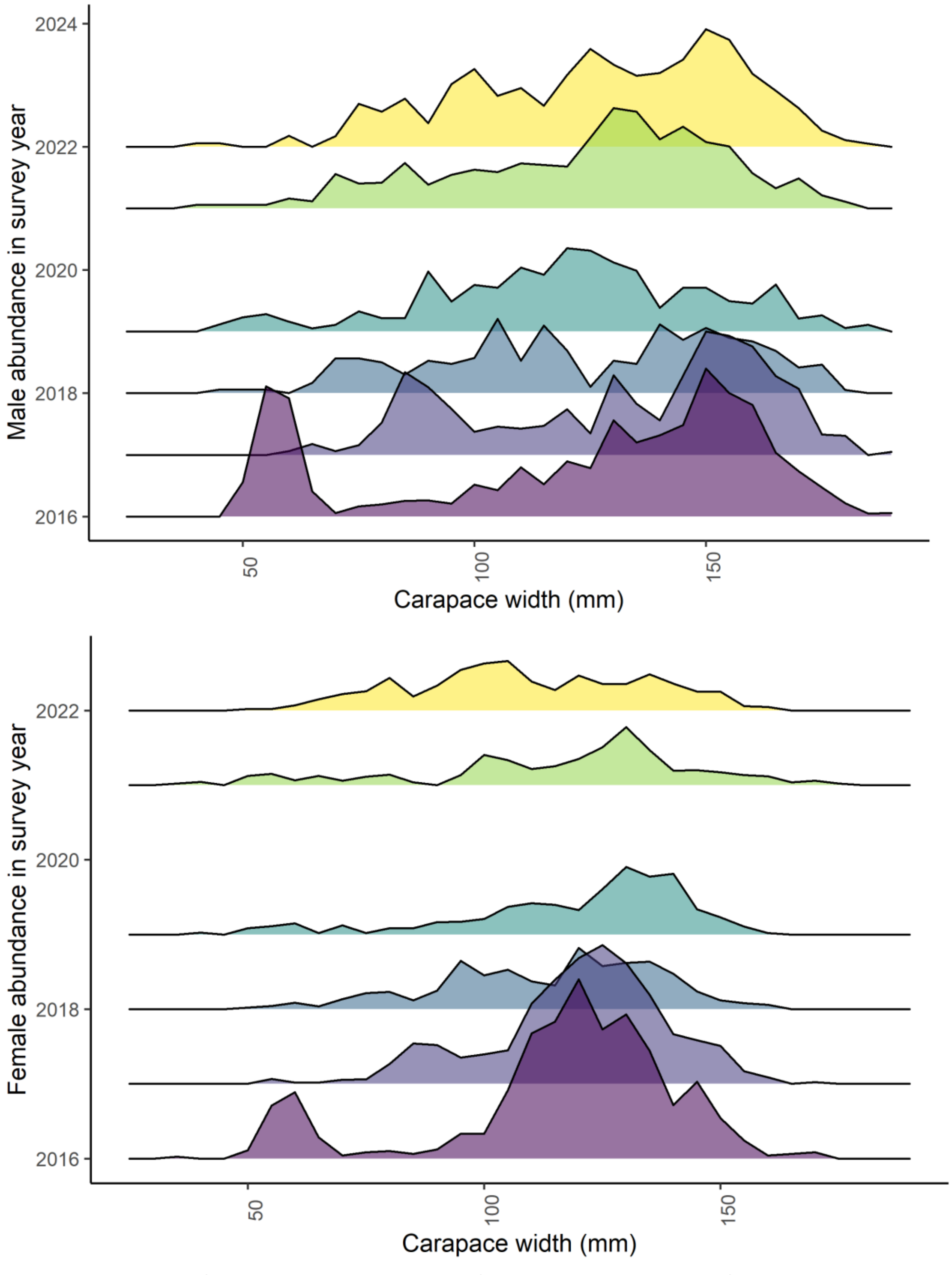


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2016-2022. For purposes of these graphs, abundance estimates are based on area-swept methods.

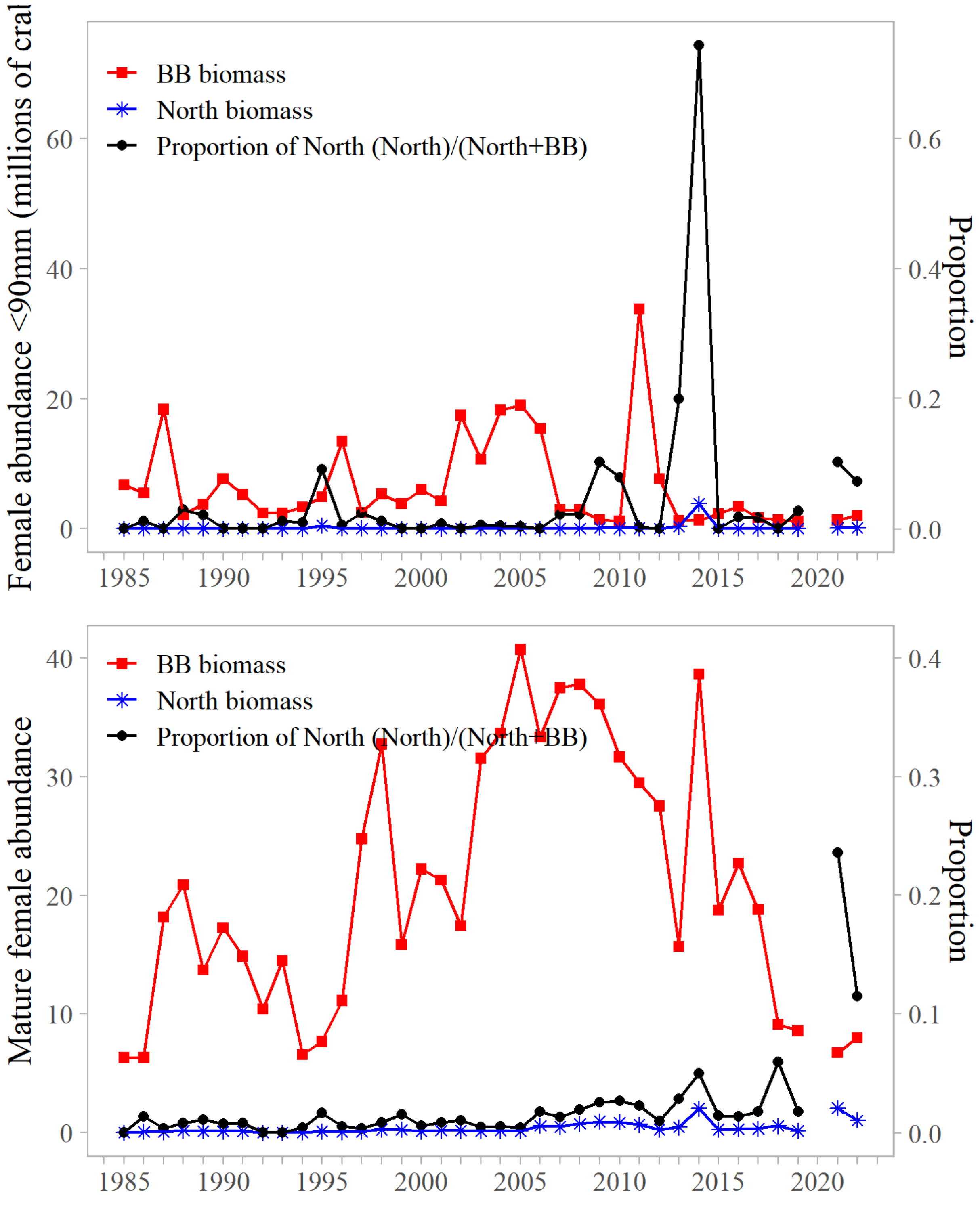
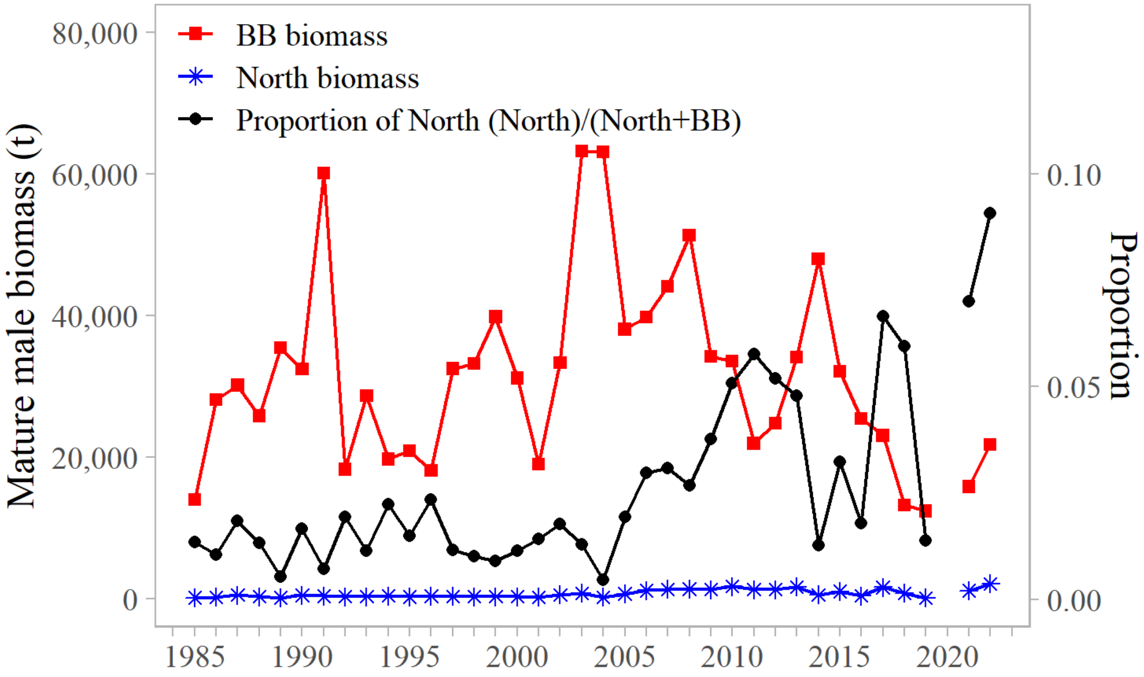


Figure 35a. Comparisons of NMFS survey area-swept estimates of total crab <90 mm CL and mature female abundances in Bristol Bay area (BB) and north of Bristol Bay area (North) during 1985-2022.



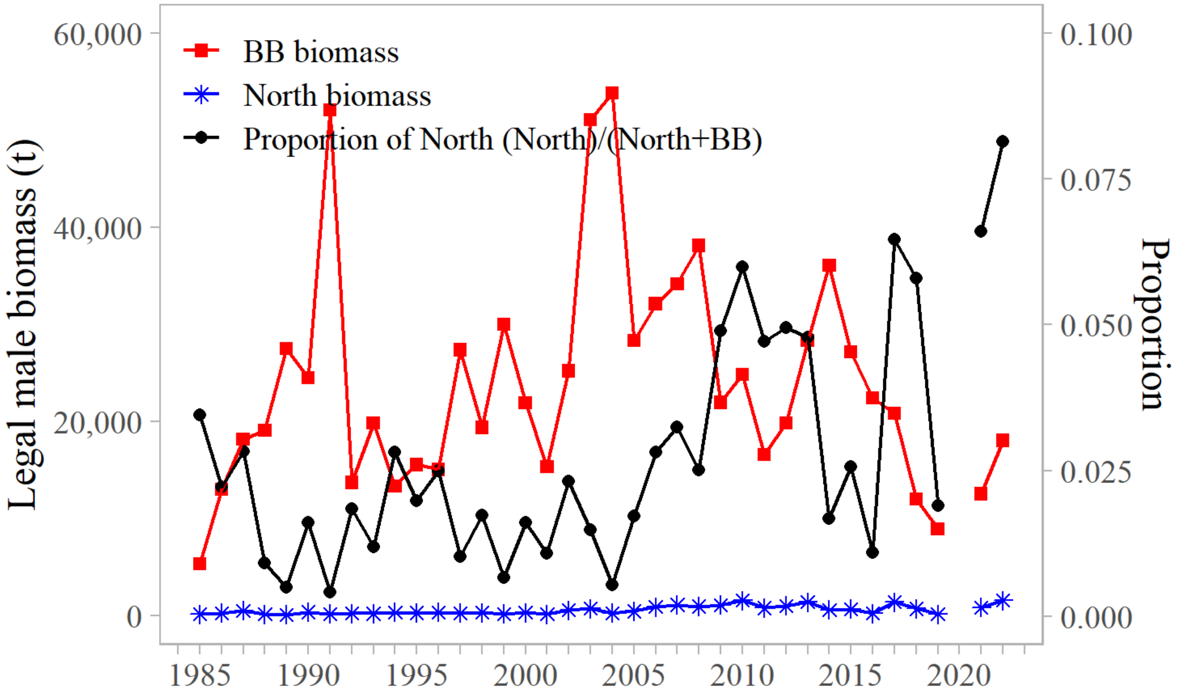


Figure 35b. Comparisons of NMFS survey area-swept estimates of mature and legal male abundances in Bristol Bay area (BB) and north of Bristol Bay area (North) during 1985-2022.

Appendix A. Description of GMACS with Bristol Bay Red King Crab Options (mainly from the GMACS document)

A. Model Description

a. Population model

The basic dynamics account for growth, mortality, maturity state and shell condition (although most of the equations below do not explicitly refer to maturity state and shell condition). For the case in which shell condition is not distinguished:

$$\underline{N}^g_{y,t} = ((\mathbf{I} - \mathbf{P}^g_{y,t-1}) + \mathbf{X}^g_{y,t-1}\mathbf{P}^g_{y,t-1})\mathbf{S}^g_{y,t-1}\,\underline{N}^g_{y,t-1} + \underline{\tilde{R}}^g_{y,t} \qquad \text{(A.1)}$$

where $\underline{N}^g_{y,t}$ is the number of animals by size-class of gender *g* at the start of season *t* of year *y*, $\mathbf{P}^g_{y,t}$ is a matrix with diagonals given by vector of molting probabilities for animals of gender *g* at the start of season *t* of year *y*, $\mathbf{S}^g_{y,t}$ is a matrix with diagonals given by the vector of probabilities of surviving for animals of gender *g* during time-step *t* of year *y* (which may be of zero duration):

$$S^g_{y,t,l,l} = \exp\left(-Z^g_{y,t,l}\right) \qquad \text{(A.2)}$$

$\mathbf{X}^g_{y,t}$ is the size-transition matrix (probability of growing from one size-class to each of the other size-classes or remains in the same size class) for animals of gender *g* during season *t* of year *y*, $\underline{\tilde{R}}^g_{y,t}$ is the recruitment (by size-class) to gear *g* during season *t* of year *y* (which will be zero except for one season – the recruitment season), and $Z^g_{y,t,l}$ is the total mortality for animals of gender *g* in size-class *l* during season *t* of year *y*. Note that mortality is continuous across a time-step.

The initial conditions for the model (i.e., the numbers-at-size at the start of the first year, y_1) is specified with an overall total recruitment multiplied by offsets for each size-class, i.e.:

$$N^g_{y_1,l} = R_{\text{Init}} e^{\delta^g_{y_1,l}} \Big/ \sum_{g'}\sum_{l'} e^{\delta^{g'}_{y_1,l'}} \qquad \text{(A.3)}$$

The minimum carapace length for both males and females is set at 65 mm, and crab abundance is modeled with a length-class interval of 5 mm. The last length class includes all crab ≥160-mm CL for males and ≥140-mm CL for females. Thus, length classes/groups are 20 for males and 16 for females.

b. Recruitment

Recruitment occurs once during each year. Recruitment by sex and size-class is the product of total recruitment, the split of the total recruitment to sex and the assignment of sex-specific recruitment to size-classes, i.e.:

$$\tilde{R}^{g}_{y,t,l} = \bar{R}e^{\varepsilon_y} \begin{cases} (1+e^{\phi_y})^{-1}\, p_l^{\mathrm{r,mal}} & \text{if } g\text{=males} \\ \phi_y (1+e^{\phi_y})^{-1}\, p_l^{\mathrm{r,fem}} & \text{if } g\text{=females} \end{cases} \tag{A.4}$$

where $\bar{R}$ is median recruitment, ϕ_y determines the sex ratio of recruitment during year *y*, and $p_l^{r,g}$ is the proportion of the recruitment (by gender and year) that recruits to size-class *l*:

$$p_l^{r,g} = \int_{L_l^{\mathrm{low}}}^{L_l^{\mathrm{hi}}} \frac{1}{\Gamma(\alpha^{r,g}/\beta^{r,g})} (l/\beta^{r,g})^{((\alpha^{r,g}/\beta^{r,g})-1)} e^{-l/\beta^{r,g}}\, dl \tag{A.5}$$

where $\alpha^{r,g}$ and $\beta^{r,g}$ are the parameters that define a gamma function for the distribution of recruits to size-class. Equation A.5 can be restricted to a subset of size-classes, in which case the results from Equation A.5 are normalized to sum to 1 over the selected size-classes.

c. Total mortality / probability of encountering the gear

Total mortality is the sum of fishing mortality and natural mortality, i.e.:

$$Z^{g}_{y,t,l} = \rho^{\mathrm{M}}_{y,t} M^{g}_{y} \tilde{M}_l + \sum_f S^{f,g}_{y,t,l} (\lambda^{f,g}_{y,t,l} + \Omega^{f,g}_{y,t,l} (1-\lambda^{f,g}_{y,t,l})) F^{f,g}_{y,t} \tag{A.6}$$

where $\rho^{\mathrm{M}}_{y,t}$ is the proportion of natural mortality that occurs during season *t* for year *y*, M^{g}_{y} is the rate of natural mortality for year *y* for animals of gender *g* (applies to animals for which $\tilde{M}_l = 1$), $\tilde{M}_l$ is the relative natural mortality for size-class *l* , $S^{f,g}_{y,t,l}$ is the (capture) selectivity for animals of gender *g* in size-class *l* by fleet *f* during season *t* of year *y*, $\lambda^{f,g}_{y,t,l}$ is the probability of retention for animals of gender *g* in size-class *l* by fleet *f* during season *t* of year *y*, $\Omega^{f,g}_{y,t,l}$ is the mortality rate for discards of gender *g* in size-class *l* by fleet *f* during season *t* of year *y*, and $F^{f,g}_{y,t}$ is the fully-selected fishing mortality for animals of gender *g* by fleet *f* during season *t* of year *y*.

The probability of encountering the gear (occurs instantaneously) is given by:

$$\tilde{Z}^{g}_{y,t,l} = \sum_f S^{f,g}_{y,t,l}\, F^{f,g}_{y,t} \tag{A.7}$$

Note that Equation A.7 is computed under the premise that fishing is instantaneous and hence that there is no natural mortality during season *t* of year *y*.

The logarithms of the fully-selected fishing mortalities by season are modelled as:

$$\ell\mathrm{n} F^{f,\mathrm{mal}}_{y,t} = \ell\mathrm{n} F^{f,\mathrm{mal}} + \xi^{f,\mathrm{mal}}_{y,t} \tag{A.8}$$

$$\ell\mathrm{n} F^{f,\mathrm{fem}}_{y,t} = \ell\mathrm{n} F^{f,\mathrm{mal}}_{y,t} + \phi^{f} + \xi^{f,\mathrm{fem}}_{y,t} \tag{A.9}$$

where $F^{f,\text{mal}}$ is the reference fully-selected fishing mortality rate for fleet *f*, ϕ^f is the offset between female and male fully-selected fishing mortality for fleet *f*, and $\xi^{f,g}_{y,t}$ are the annual deviation of fully-selected fishing mortality for fleet *f* (by gender).

Natural mortality can depend on time with blocked natural mortality (individual parameters). This option estimates natural mortality as parameters by block, i.e.:

$$M^g_y = e^{\psi^g_y} \tag{A.10}$$

where $M^g_{y_1}$ is the rate of natural mortality for gender *g* for the first year of the model, and ψ^g_y is the annual change in natural mortality and changes in blocks of years.

It is possible to 'mirror' the values for the ψ^g_y parameters (between genders and between blocks), which allows male and female natural mortality to be the same, and for natural mortality to be the same for discontinuous blocks (based on Equation A.10). It is also possible to estimate a ratio of natural mortality between genders. The deviations in natural mortality can also be penalized to avoid unrealistic changes in natural mortality to fit 'quirks' in the data.

d. Landings, discards, total catch

The model keeps track of (and can be fitted to) landings, discards, total catch by fleet in season with continuous mortality:

Landed catch

$$C^{\text{Land},f,g}_{y,t,l} = \frac{\lambda^{f,g}_{y,t,l} S^{f,g}_{y,t,l} F^{f,g}_{y,t}}{Z^g_{y,t,l}} N^{f,g}_{y,t,l} (1 - e^{-Z^g_{y,t,l}}) \tag{A.11}$$

Discards

$$C^{\text{Disc},f,g}_{y,t,l} = \frac{(1 - \lambda^{f,g}_{y,t,l}) S^{f,g}_{y,t,l} F^{f,g}_{y,t}}{Z^g_{y,t,l}} N^{f,g}_{y,t,l} (1 - e^{-Z^g_{y,t,l}}) \tag{A.12}$$

Total catch

$$C^{\text{Total},f,g}_{y,t,l} = \frac{S^{f,g}_{y,t,l} F^{f,g}_{y,t}}{Z^g_{y,t,l}} N^{f,g}_{y,t,l} (1 - e^{-Z^g_{y,t,l}}) \tag{A.13}$$

Landings, discards, and total catches by fleet can be aggregated over gender (e.g., when fitting to removals reported as gender-combined). Equations A.11-13 are extended naturally for the case in which the population is represented by shell condition and/or maturity status (given the assumption that fishing mortality, retention and discard mortality depend on gender and time, but not on shell condition nor maturity status).

Landings, discards, and total catches by fleet can be reported in numbers (Equations A.11–13) or in terms of weight. For example, the landings, discards, and total catches by fleet, season, year, and gender for the total (over size-class) removals are computed as:

$$C^{\text{Land},g,f}_{y,t} = \sum_l C^{\text{Land},g,f}_{y,t,l} w^g_{y,l}\ ;\ C^{\text{Disc},g,f}_{y,t} = \sum_l C^{\text{Disc},g,f}_{y,t,l} w^g_{y,l}\ ;\ C^{\text{Total},g,f}_{y,t} = \sum_l C^{\text{Total},g,f}_{y,t,l} w^g_{y,l} \tag{A.14}$$

where $C_{y,t}^{\mathrm{Land},g,f}$, $C_{y,t}^{\mathrm{Disc},g,f}$, and $C_{y,t}^{\mathrm{Total},g,f}$ are respectively the landings, discards, and total catches in weight by fleet, season, year, and gender for the total (over size-class) removals, and $w_{y,l}^{g}$ is the weight of an animal of gender *g* in size-class *l* during year *y*.

e. Selectivity / retention

Selectivity (the probability of encountering the gear) and retention (the probability of being landed given being captured) are logistic function:

$$S_l = 1 - \left(1 + \frac{exp((\bar{L}_l - S_{50})}{\sigma^S}\right))^{-1} \tag{A.15}$$

where S_{50} is the size corresponding to 50% selectivity, σ^S is the "standard deviation" of the selectivity curve, and $\bar{L}_l$ is the midpoint of size-class *l*.

It is possible to assume that selectivity for one fleet is the product of two of the selectivity patterns. This option is used to model cases in which one survey (NMFS trawl survey) is located within the footprint of another survey (BSFRF trawl survey).

The options to model retention are the same as those for selectivity, except that it is possible to estimate an asymptotic parameter, which allows discard of animals that would be "fully retained" according to the standard options for (capture) selectivity.

Selectivity and retention can be defined for blocks of contiguous years. Two blocks are used for NMFS survey selectivity (before 1982 and after 1981) due to gear modifications and two blocks are used for the directed pot fishery retention (before 2005 and after 2004) due to the fishery rationalization.

f. Growth

Growth is a key component of any size-structured model. It is modelled in terms of molt probability and the size-transition matrix (the probability of growing from each size-class to each of the other size-classes, constrained to be zero for sizes less than the current size). Note that the size-transition matrix has entries on its diagonal, which represent animals that molt but do not change size-classes.

(1) Molt probability

There are two options for modelling the probability of molting as a function of size, $P_{l,l}$:

- Constant probability (1 for females)
- Logistic probability (for males), i.e.:

$$P_{l,l} = 1 - (1 + \exp((\bar{L}_l - P_{50}) / \sigma^P))^{-1} \tag{A.16}$$

where P_{50} is the size at which the probability of molting is 0.5, and σ^S is the "standard deviation" of the molt probability function.

Molt probability is specified by gender and can change in blocks (one block before 1981 and one block after 1980 for males).

(2) Size-transition

The proportion of animals in size-class *j* that grow to be in size-class *i* ($X_{i,j}$) can be pre-specified as gamma-distributed size-increments:

$$X_{i,j} = \int_{L_j^{\text{low}}}^{L_j^{\text{hi}}} \frac{1}{\Gamma(I_i/\tilde{\beta})}((l-\bar{L}_i)/\tilde{\beta})^{(I_i/\tilde{\beta})-1} e^{-(l-\bar{L}_i)/\tilde{\beta}} dl \tag{A.17}$$

> where I_i is the 'expected' growth increment for an animal in size-class *i* (a linear function of the mid-point of size-class *i*), $\tilde{\beta}$ determines the variation in growth among individuals, and L_j^{low} and L_j^{hi} are respectively the lower and upper bounds of size-class *j*.

The size-transition matrix is specified by gender and can change in blocks (one block for males and three blocks for females (1975-1982, 1983-1993, and 1994-present based on changes in sizes at maturity).

B. Outputs, Projections and OFL Calculation

a. Core model outputs

The core model outputs are the N-matrix, the matrix of fully-selected fishing mortalities, the time-series of spawning stock biomass, mature male biomass (SSB), the values for the model parameters, and the predictions related to the observations. The spawning stock biomass (and hence mature male biomass) is defined according to:

$$SSB_y = \sum_g p^{\text{SSB},g} \sum_l N^g_{y,t^*,l} \tag{A.18}$$

where $p^{\text{SSB},g}$ is the relative contribution of gender *g* to spawning biomass ($p^{\text{SSB,mal}} = 1;\ p^{\text{SSB,fem}} = 0$ corresponds to spawning stock biomass equating to mature male biomass), and *t** is the season in which spawning takes place (spawning occurs at the start of the season).

Definition of model outputs:

(1) Biomass: two population biomass measurements are used in this report: total survey biomass (crab >64 mm CL) and mature male biomass (males >119 mm CL). Mating time is assumed to Feb. 15.
(2) Recruitment: new entry of number of males in the 1st seven length classes (65- 99 mm CL) and new entry of number of females in the 1st five length classes (65-89 mm CL).
(3) Fishing mortality: full-selected instantaneous annual fishing mortality rate at the time of fishery.

b. Biological reference points

The key biological reference points are the proxy for F_{MSY}, the proxy for B_{MSY} and the Overfishing Level (OFL).

(1) The proxy for F_{MSY}

The specification for the proxy for F_{MSY} depends on the tier in which the stock is placed. BBRKC belongs to Tier 3, and the proxy for F_{MSY} is $F_{35\%}$, the value of a multiplier on the fully-selected fishing mortality rates for directed fisheries in the final year of the assessment such that spawning biomass-per-recruit is 35% of the unfished level. The fully-selected fishing mortality rates for non-directed fisheries are set to recent averages (recent 5 years for BBRKC). The unfished spawning biomass-per-recruit, $SSBPR(\underline{0})$, is calculated by projecting the population model forward where fishing mortality is zero for all fleets, and recruitment is constant (and ideally equal to 1). $F_{35\%}$ is then computed (using Newtons' method) such that:

$$SSBPR(\underline{\alpha}\underline{\bar{F}}) = 0.35\, SSBPR(\underline{0}) \tag{A.19}$$

where $\underline{\bar{F}}$ is the vector of recent average fully-selected fishing mortalities, and $\underline{\alpha}$ is a vector with 1 for the non-directed fisheries and a calculated constant for the directed fisheries.

(2) The proxy for B_{MSY}

The specification for the proxy for B_{MSY} depends on the tier in which the stock is placed. For stocks in Tier 4, the proxy for B_{MSY} is the average spawning stock biomass over a pre-specified number of years. For Tier 3, the proxy for B_{MSY} is $0.35\,SSBPR(\underline{0})$ multiplied by the mean recruitment over a pre-specified number of years. GMACS estimates annual recruitments by sex through estimating annual recruitment deviations and annual recruitment proportions by sex. Pre-specified numbers of years are needed in the control file for recruitment average and for mean recruitment sex ratio, respectively.

(3) Calculating the OFL

The OFL is the total catch (in weight) encountered by the gear that dies either due to being landed or due to being discarded when fully-selected fishing mortality is computed using the OFL control rule. The total catch

$$OFL = \sum_g \sum_t w^g_{y_2,l} \frac{S^{f,g}_{y_2,t,l}(\lambda^{f,g}_{y_2,t,l} + \Omega^{f,g}_{y_2,t,l}(1-\lambda^{f,g}_{y_2,t,l})S^{f,g}_{y_2,t,l})\alpha^{*,f}\bar{F}^{f,g}_t}{Z^g_{y_2+1,t,l}} N^{f,g}_{y_2+1,t,l}(1-e^{-Z^g_{y_2+1,t,l}}) \tag{A.20}$$

where y_2 is the final year of the assessment, $\alpha^{*,f}$ is the multiplier on average fully-selected fishing mortality for fleet f (1 for non-directed fisheries and a value computed from the OFL control rule for the directed fisheries), $\bar{F}^{f,g}_t$ is recent average fully-selected fishing mortality for fleet f and gender g during season t, and $Z^g_{y_2+1,t,l}$ is the total mortality on animals of gender g in size-class l during season t of year y_2+1:

$$Z^g_{y_2+1,t,l} = \rho^{\mathrm{M}}_{y_2,t} M^g_{y_2} \tilde{M}_l + \sum_f S^{f,g}_{y_2,t,l} (\lambda^{f,g}_{y_2,t,l} + \Omega^{f,g}_{y_2,t,l} (1-\lambda^{f,g}_{y_2,t,l})) \alpha^{*,f} \bar{F}^{f,g}_t \tag{A.21}$$

The values for entries of the vector α^* for the directed fisheries are determined using the OFL control rule:

- If the projected spawning stock biomass in year y_2+1 when $\underline{\alpha}^* = \underline{\alpha}$ exceeds the proxy for B_{MSY}, then $\alpha^{*,f} = \alpha^f$.
- If the projected spawning stock biomass in year y_2+1 when $\underline{\alpha}^* = \underline{\alpha}$ is less than 25% of the proxy for B_{MSY}, then $\alpha^{*,f} = 0$.
- If the projected spawning stock biomass in year y_2+1, $SSB^*_{y_2}$ when $\underline{\alpha}^* = \underline{\alpha}$ lies between less than 25% and 100% of the proxy for B_{MSY}, then $\alpha^{*,f}$ is tuned according to $\alpha^{*,f} = \frac{\alpha^f\left(\frac{SSB^*_{y_2}}{B_{MSY}}-0.1\right)}{0.9}$ until convergence.

c. Projections

The specifications for the projections relate to:

- The duration of the projection.
- Whether the fully-selected fishing mortalities for the non-directed fisheries are set to zero or to recent averages by fleet.
- The way in which future recruitment is generated. The options available are:
    - Select a recruitment from a set of historical recruitments at random.
    - Generate a future recruitment from a Ricker stock-recruitment relationship, i.e.:

      $$R^g_y = SSB_{y-a*} / SSB_0 e^{-1.25 \ell n h (SSB_{y-a*}/SSB_0 - 1)} e^{\varepsilon_y - \sigma^2_R/2} \; ; \; \varepsilon_y \sim N(0;\sigma^2) \tag{A.22}$$

      where $a*$ is the time-lag between spawning and entering the first size-class in the model, SSB_0 is unfished spawning stock biomass, h is the steepness of the stock-recruitment relationship, σ_R is the variation in recruitment about the stock-recruitment relationship.
    - Generate a future recruitment from a Beverton-Holt stock-recruitment relationship, i.e.:

      $$R^g_y = \frac{4R_0 \, SSB_{y-a*} / SSB_0}{(1-h) + (5h-1) SSB_{y-a*} / SSB_0} e^{\varepsilon_y - \sigma^2_R/2} \quad \varepsilon_y \sim N(0;\sigma^2) \tag{A.23}$$

      where R_0 is unfished recruitment (i.e.. $SSB_0 / SSBPR(\underline{0})$).

- The control rule used to set fully-selected fishing mortality for the directed fisheries. The options are available
    - Pre-specified values for fully-selected fishing mortality for each fishery.
    - Pre-specified values subject to the dead catch not exceeding that corresponding to the OFL.
    - Pre-specified values subject to the dead catch not exceeding that corresponding to the OFL and the landed catch not exceeding that corresponding to the State of Alaska harvest control rule.

The value for the steepness of the stock-recruitment relationship is computed such that the maximum sustainable yield occurs at $F_{35\%}$, i.e.:

$$\left. \frac{dC(\underline{F})}{dF} \right|_{\underline{F}=\underline{\alpha}^{*}\bar{F}} \tag{A.24}$$

where $C(\underline{F})$ is the equilibrium landed catch when the population model is projected forward deterministically under one of the two stock-recruitment relationships.

C. Parameter Estimation

a. *Estimating Bycatch Fishing Mortalities for Years without Observer Data*

Observer data are not available for the directed pot fishery before 1990 and the Tanner crab fishery before 1991. There are also extremely low observed bycatches in the Tanner crab fishery in 1994 and during 2006-2009. Bycatch fishing mortalities for male and females during 1975-1989 in the directed pot fishery were estimated as

$$F_t^{disc,s} = r^s \; F_t^{dir} \tag{A.25}$$

where r^s is the mean ratio of estimated bycatch discard fishing mortalities to the estimated directed pot fishing mortalities during 1990-2004 for sex s. Directed pot fishing practice has changed after 2004 due to fishery rationalization.

We used pot fishing effort (potlifts) east of 163° W in the Tanner crab fishery to estimate red king crab bycatch discard fishing mortalities in that fishery when observer data are not available (1975-1990, 1994, 2006-2009):

$$F_t^{Tanner,s} = a^s \; E_t \tag{A.26}$$

where a^s is the mean ratio of estimated Tanner crab fishery bycatch fishing mortalities to fishing efforts during 1991-1993 for sex s, and E_t is Tanner crab fishery fishing efforts east of 163° W in year *t*. Due to fishery rationalization after 2004, we used the data only during 1991-1993 to estimate the ratio.

b. Likelihood Components

A maximum likelihood approach was used to estimate parameters. For length compositions ($p_{l,t,s,sh}$), the likelihood functions are :

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\coprod_{s=1}^{2}\prod_{sh=1}^{2}\frac{\left\{exp\left[-\frac{\left(p_{l,t,s,sh}-\hat{p}_{l,t,s,sh}\right)^2}{2\sigma_{l,t,s,sh}^2}\right]+0.01\right\}}{\sqrt{2\pi\sigma_{l,t,s,sh}^2}} \qquad \text{(A.27)}$$

$$\sigma_{l,t,s,sh}^2 = \frac{\left[p_{l,t,s,sh}\left(1-p_{l,t,s,sh}\right)+\frac{0.1}{L}\right]}{n_t}$$

where L is the number of length groups, T the number of years, and n_t the effective sample size in year t, which was estimated for trawl survey, pot retained catch, total directed pot male catch, directed pot female discard, groundfish trawl discard, groundfish fixed gear discard, and Tanner crab fishery discard length composition data. $p_{l,t,s,sh}$ is the observed proportion of crab in length-class l, year t, sex s and shell condition sh, and $\hat{p}_{l,t,s,sh}$ is the model-estimate corresponding to $p_{l,t,s,sh}$.

The weighted negative log likelihood functions are:

$$\begin{aligned}
&Length\ compositions\text{: } -\sum \ln\left(Rf_i\right)\\
&Catch\ and\ bycatch\ biomasses\text{: } \sum\left[ln\left(\frac{C_t}{\hat{C}_t}\right)^2/\left(2\ln\left(cv_t^2+1\right)\right)\right]\\
&NMFS\ survey\ biomass\text{: } \sum\left[ln\left(ln\left(CV_t^{\,2}+1\right)\right)^{0.5}+\frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{\left(2ln\left(CV_t^{\,2}+1\right)\right)}\right]\\
&BSFRF\ survey\ biomass\text{: } \sum\left[ln\left(ln\left(CV_t^{\,2}+AV^2+1\right)\right)^{0.5}+\frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{\left(2ln\left(CV_t^{\,2}+AV^2+1\right)\right)}\right]\\
&R\ variation\text{: } \lambda_R\sum\left[ln\left(\frac{R_t}{\bar{R}}\right)^2\right] \qquad \text{(A.28)}\\
&R\ sex\ ratio\text{: } \lambda_s\sum\left[ln\left(\frac{\bar{R}_M}{\bar{R}_F}\right)^2\right]\\
&Groundfish\ bycatch\ fishing\ mortalities\text{: } \lambda_t\sum\left[ln\left(\frac{F_{t,gf}}{\bar{F}_{gf}}\right)^2\right]\\
&Pot\ female\ bycatch\ fishing\ mortalities\text{: } \lambda_p\sum\left[ln\left(\frac{F_{t,f}}{\bar{F}_f}\right)^2\right]\\
&Trawl\ survey\ catchability\text{: } \frac{\left(Q-\hat{Q}\right)^2}{2\sigma^2}
\end{aligned}$$

where R_t is the recruitment in year t, $\bar{R}$ the mean recruitment, $\bar{R}_M$ the mean male recruitment, $\bar{R}_F$ the mean female recruitment, AV is additional CV and estimated in the model, $\bar{F}_{gf}$ the mean groundfish bycatch fishing mortality (this is separated into trawl and fixed gear fishery bycatch), $\bar{F}_f$ the mean pot female bycatch fishing mortality, Q summer trawl survey catchability, and σ the estimated standard deviation of Q (all models).

Weights λ_j are assumed to be 2 for recruitment variation, 10 for recruitment sex ratio, 0.2 for pot female bycatch fishing mortality, and 0.1 for trawl bycatch fishing mortality. These λ_j values correspond to CV values of 0.53, 0.23, 3.34, and 12.14, respectively.

c. Population State in Year 1.

The total abundance and proportions for the first year are estimated in the model.

d. Parameter estimation framework:

(1) Parameters estimated independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 0.5 for the groundfish fixed gear fishery, and 0.8 for the groundfish trawl fishery.

i. Natural Mortality

Based on an assumed maximum age of 25 years and the 1% rule (Zheng 2005), a base M was estimated to be 0.18 for males.

ii. Length-weight Relationship

Length-weight relationships for males and females were as follows:

$$\begin{aligned}
&\text{Immature Females:} && W = 0.000408\,L^{3.127956} \\
&\text{Ovigerous Females:} && W = 0.003593\,L^{2.666076} \qquad \text{(A.29)} \\
&\text{Males:} && W = 0.0004031\,L^{3.141334}
\end{aligned}$$

where W is weight in grams, and L CL in mm.

iii. Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1975-1993 and 1994-2020, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for model scenarios (Figure A2). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of 70% and 30% at 92.5 mm CL pre-molt length and 90% and 10% at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1975-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2021, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crab (Figure A2). Once mature, the growth increment per molt for male crab decreases slightly and annual molting probability decreases, whereas the growth increment for female crab decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

iv. Sizes at Maturity for Females

The NMFS collected female reproductive condition data during the summer trawl surveys. Mature females are separated from immature females by a presence of egg clutches or egg cases. Proportions of mature females at 5-mm length intervals were summarized and a logistic curve was fitted to the data each year to estimate sizes at 50% maturity. Sizes at 50% maturity are illustrated in Figure A3 with mean values for three different periods (1975-82, 1983-93, and 1994-2021).

v. Sizes at Maturity for Males

Although size at sexual maturity for Bristol Bay red king crab males has been estimated (Paul et al. 1991), there are no data for estimating size of functional maturity collected in the natural environment. Sizes at functional maturity for Bristol Bay male RKC have been assumed to be 120 mm CL (Schmidt and Pengilly 1990). This is based on mating pair data collected off Kodiak Island (Figure A4). Sizes at maturity for Bristol Bay female RKC are about 90 mm CL, about 15 mm CL less than Kodiak female RKC (Pengilly et al. 2002). The size ratio of mature males to females is 1.3333 at sizes at maturity for Bristol Bay RKC, and since mature males grow at much larger increments than mature females, the mean size ratio of mature males to females is most likely larger than this ratio. Size ratios of the large majority of Kodiak mating pairs were less than 1.3333, and in some bays, only a small proportion of mating pairs had size ratios above 1.3333 (Figure A4).

In the laboratory, male RKC as small as 80 mm CL from Kodiak and Southeast Alaska can successfully mate with females (Paul and Paul 1990). But few males less than 100 mm CL were observed to mate with females in the wild. Based on the size ratios of males to females in the Kodiak mating pair data, setting 120 mm CL as a minimum size of functional maturity for Bristol Bay male RKC is proper in terms of managing the fishery.

vi. Potential Reasons for High Mortality during the Early 1980s

Bristol Bay red king crab abundance had declined sharply during the early 1980s. Many factors have been speculated for this decline: (i) completely wiped out by fishing: the directed pot fishery, the other directed pot fishery (Tanner crab fishery), and bottom trawling; and (ii) high fishing and natural mortality. With the survey abundance, harvest rates in 1980 and 1981 were among the highest, thus the directed fishing definitely had a big impact on the stock decline, especially legal and mature males. However, for the sharp decline during 1980-1984 for males, 3 out of 5 years had low mature harvest rates. During the 1981-1984 decline for females, 3 out of 4 years had low mature harvest rates. Also pot catchability for females and immature males are generally much lower than for legal males, so the directed pot fishing alone cannot explain the sharp decline for all segments of the stock during the early 1980s.

Red king crab bycatch in the eastern Bering Sea Tanner crab fishery is another potential factor (Griffin et al. 1983). The main overlap between Tanner crab and Bristol Bay red king crab is east of 163^{o} W. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Tanner crab retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab bycatch in the Tanner crab fishery during 1991-2015 and total potlifts east of 166^{o} W during 1975 to 2015 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

Several factors may have caused increases in natural mortality. Crab diseases in the early 1980s were documented by Sparks and Morado (1985), but inadequate data were collected to examine their effects on the stock. Stevens (1990) speculated that senescence may be a factor because many crab in the early 1980s were very old due to low temperatures in the 1960s and early 1970s. The biomass of the main crab predator, Pacific cod, increased about 10 times during the late 1970s and early 1980s. Yellowfin sole biomass also increased substantially during this period. Predation is primarily on juvenile and molting/softshell crab. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crab molt. Also cannibalism occurs during molting periods for red king crab. High crab abundance in the late 1970s and early 1980s may have increased the occurrence of cannibalism.

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch, and predation on females and juvenile and sublegal males, senescence for older crab, and disease for all crab. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of 0.18yr^{-1}, all directed fishing mortality, and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters than without them.

(2) Parameters estimated conditionally

The following model parameters were estimated for male and female crab: total recruits for each year (year class strength R_t for t = 1975 to 2020), total abundance in the first year (1975), growth parameter β, and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crab. Estimated parameters also include different sets of β and L_{50} for total selectivity and retained proportions, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl and fixed gear discarded selectivities, and different sets of β and L_{50} for NMFS trawl survey male and female selectivities separately. The NMFS survey catchabilities Q for some models were also estimated. Different sets of β and L_{50} for selectivity parameters were estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2020), pot-discarded females from the directed fishery (1990-2020), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-15), groundfish trawl discarded males and females (1976-2020), and groundfish fixed gear discarded males and females (1996-2020). One additional mortality parameter for years 1980-1984 for males and a constant to multiply male natural mortality for estimating female natural mortality were also estimated. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

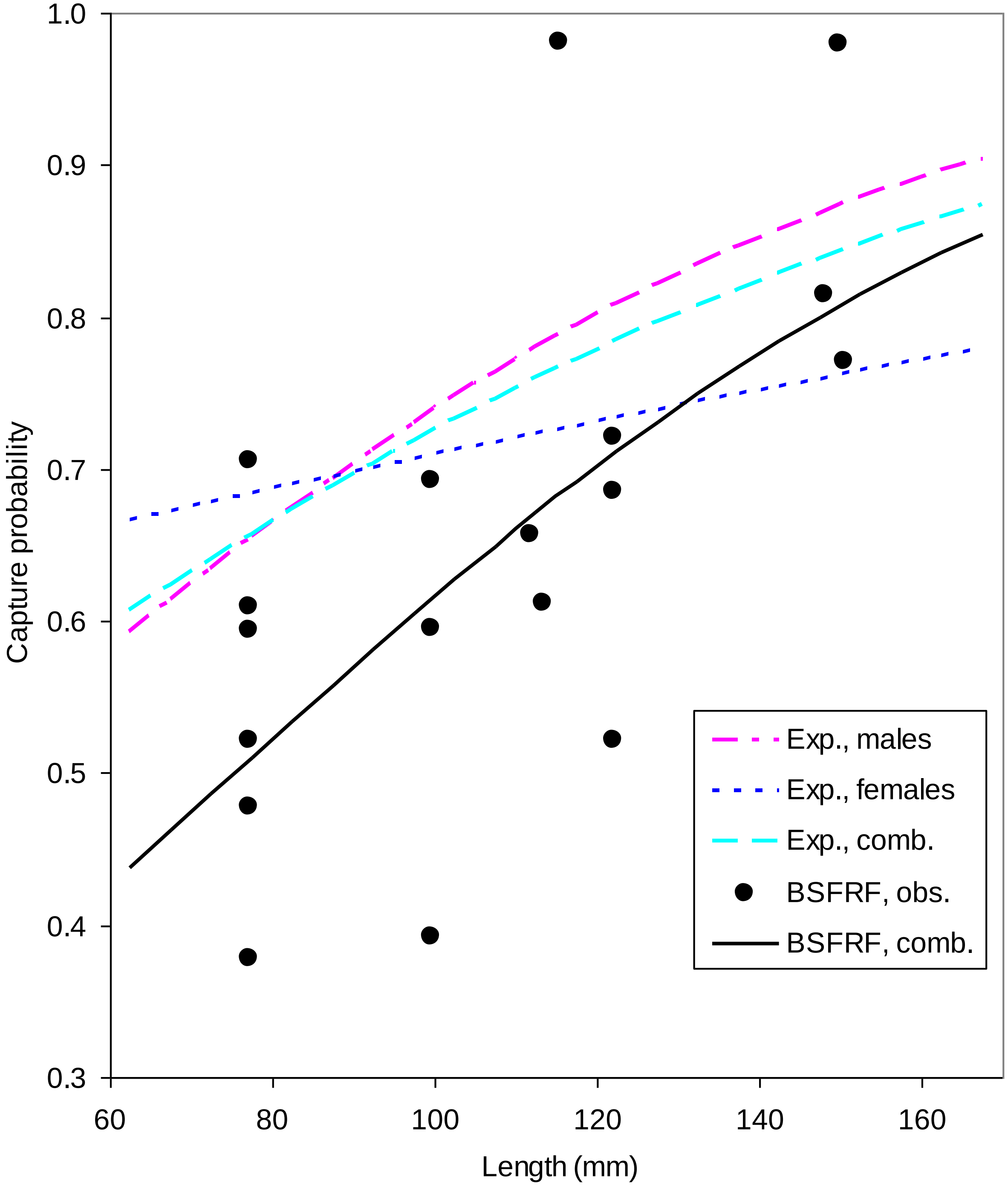


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.

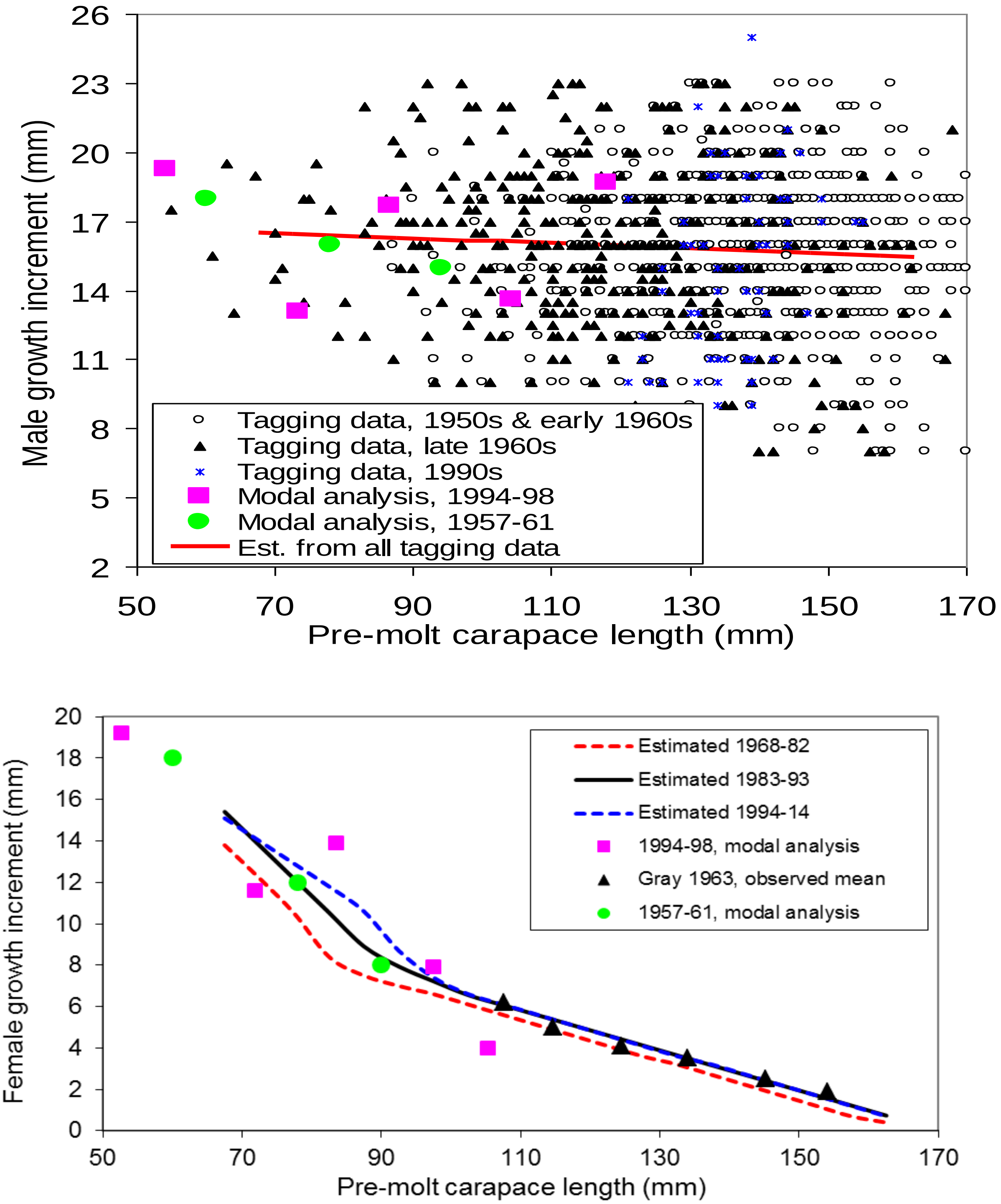


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis. The female growth increments per molt are for different model scenarios.

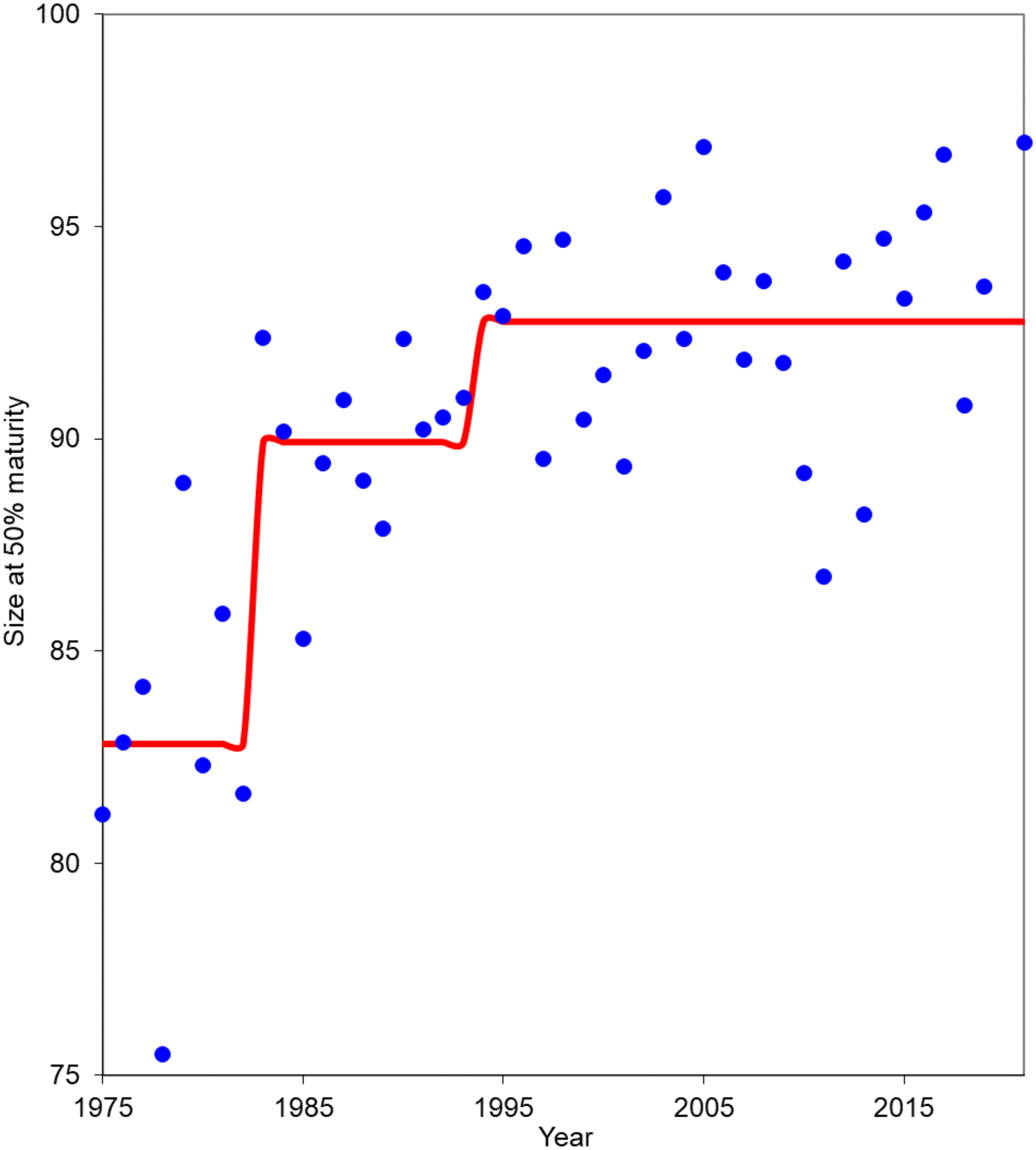


Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2021. Averages for three periods (1975-82, 1983-93, and 1994-2021) are plotted with a line.

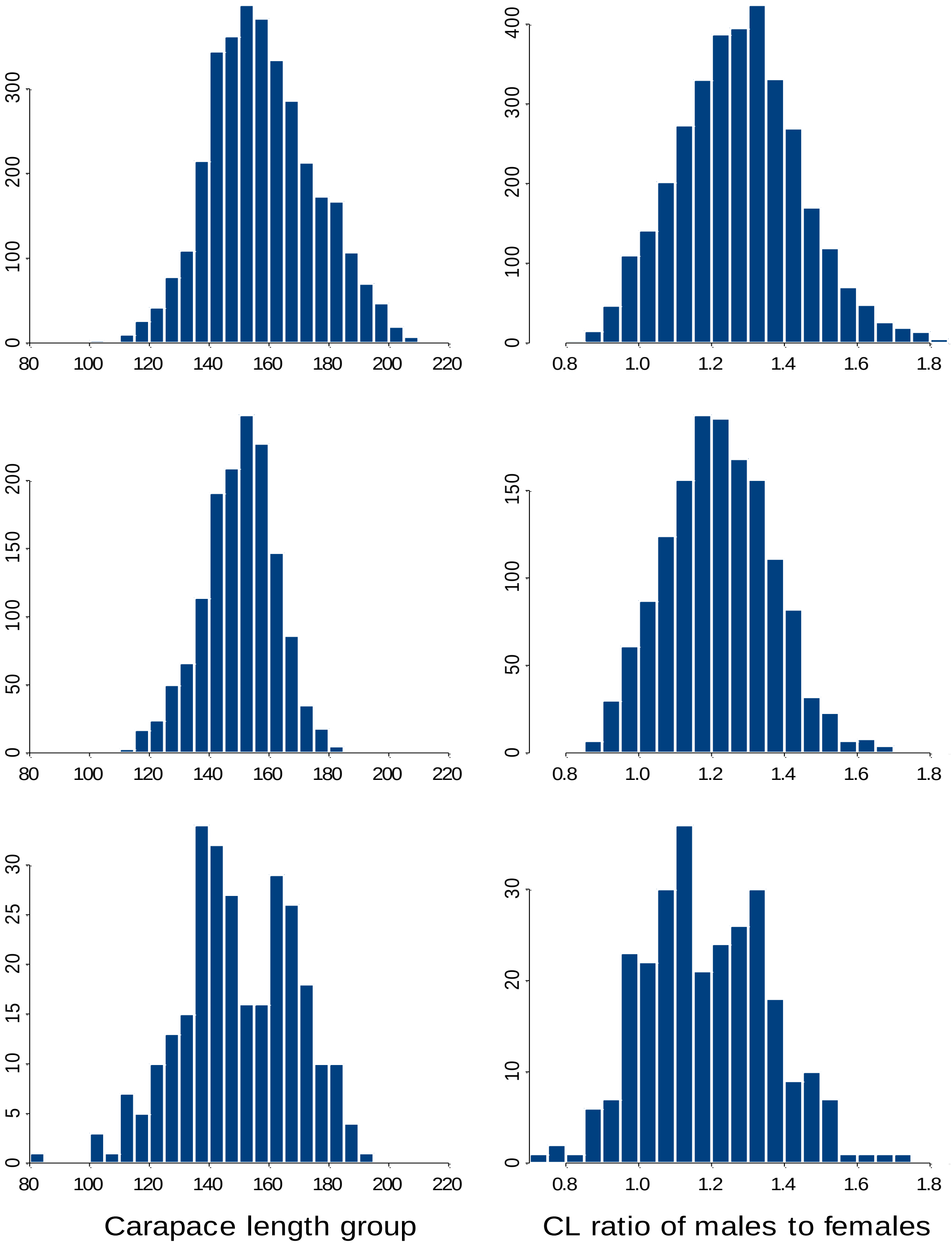


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak red king crab are about 15 mm larger than those for Bristol Bay red king crab. (Doug Pengilly, ADF&G, pers. comm.).

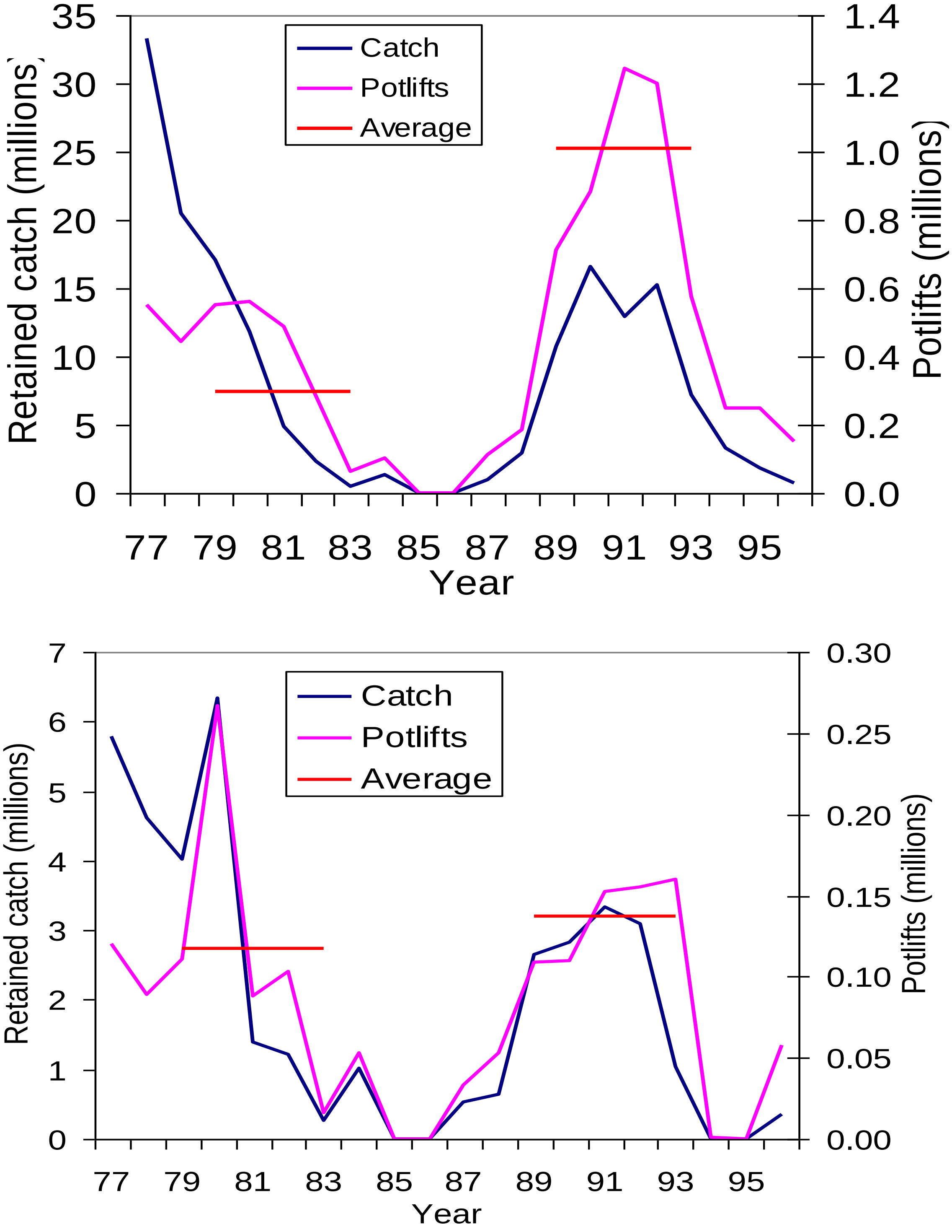


Figure A5. Tanner crab retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163º W (bottom).

Appendix B. Data Files for Model 21.1b

See pdf posted.

Appendix C. Summary of the CIE Review of BBRKC in 2021

The virtual CIE review of the stock assessments for Bristol Bay red king crab and eastern Bering Sea snow crab was held online during March 22-26, 2021. The review was conducted by three independent experts: Drs. Yong Chen, Nick Caputi, and Billy Ernst. The review reports are at the end of this SAFE report. The followings are a brief summary of recommendations and plan to address these recommendations.

1. *Identifying the possible sources of the large retrospective patterns and/or develop alternative approaches to provide catch advice if retrospective patterns persistent and biased errors are too large for the assessments to be considered reliable. Conducted more studies to identify temporal trends and/or time blocks of parameters, such as natural mortality and survey catchability, to be incorporated in future stock assessments.*

   Reply: Temporal changes in parameters may play an important role for the large retrospective patterns, and some data conflict between NMFS surveys and 2007-2008 and 2013-2016 BSFRF surveys also contributes to them. We used model 21.2 to add another time block (2018-2019) of natural mortality. The Mohn's rho value for mature male biomass decreases from 0.347 for model 19.3d to 0.223 for model 21.2. We will further examine the retrospective patterns and develop alternative model scenarios to reduce the retrospective patterns for the CPT meeting in January/May 2022. Potential changes in natural mortality over time play a big role for the large retrospective patterns during recent years, and additional time blocks of parameters for recent years will be further evaluated.

2. *Survey performance/efficacy and selectivity curve evaluations in term of changes in distributions over time, and the stock area evaluation.*

   Reply: We would like to examine red king crab north of the management area of Bristol Bay sometime in the future to see whether they are part of the BBRKC stock. Hopefully, a tagging study can be conducted to examine the link between red king crab in these two areas. We have not seen the need for evaluating different kinds of survey selectivity curves now since large-size crab are generally inside the survey area. Some limited genetic and larval transport studies were conducted on the stock area in the past.

3. *Surveying the red king crab juvenile crab abundance in nearshore locations may provide an estimate of younger juvenile abundance where the year-class is better defined.*

   Reply: We second this and have advocated this for a long time.

4. *Examining VAST results on effects on the stock assessment model.*

   Reply: We will continue to use VAST results as a model scenario to compare it to the other model scenarios.

5. *Evaluating commercial catch, effort, and CPUE for crab distributions, fishery performance, and population abundance relative to the trawl survey results and on impacts on survey timing and survey availability, and standardizing the CPUE for improvement, and conducting a depletion analysis.*

   Reply: Catch and bycatch are used in the model, the commercial CPUE is used to compare to the survey legal male abundance but not in the model, and fishing distributions and CPUE are often examined by ADF&G. The fishing season has been very short in the most years, so the depletion analysis may not be much useful. Trawl surveys generally cover all red king crab distribution areas except for nearshore areas. We just started CPUE standardization work and will try to incorporate the standardized CPUE in the assessment model in 2022.

6. *Extending estimates of sizes-at-50% maturity for females and examining the impacts of changes on mature female biomass estimates. Conducting a sensitivity study to examine impacts of changes at sizes-at-maturity for males on mature male biomass estimates.*

   Reply: We will update the estimates of sizes-at-50% maturity for females. Since the harvest strategy defines the sizes of mature females and males and the growth increments of males is not affected by changes in sizes-at-maturity, impacts of changes at sizes-at-maturity for males on mature male biomass estimates do not occur for the harvest strategy. The current defined size-at-maturity for males is for functional maturity and is much larger than the physiological mature sizes.

7. *A model run just using data from 1985 to avoid high natural mortality during the early 1980s.*

   Reply: We have planned to do this in 2022.

8. *Examining biological, environmental, and vessel performance data on the 2014 NMFS trawl survey to assess the survey abundance outlier and conducting a sensitivity study without the 2014 NMFS trawl survey data.*

   Reply: During the CIE review, we conducted this sensitivity study. The NMFS and BSFRF have examined biological, environmental, and vessel performance data on the 2014 NMFS trawl survey extensively. It is unlikely that we would drop this data point in the stock assessments since there are several data points in the survey time series that are as unexpected as the 2014 data.

9. *Important to continue environmental SAFE reports.*

   Reply: We agree and hopefully it will be updated annually.

10. *Besides overfished and overfishing, using MMB, recruitment, trends in commercial catch and CPUE, legal-size abundance and total survey biomass, and the projections and near future outlook to summarize the stock status.*

    Reply: We will add these in our summary of the stock status.

11. *Modeling double bag experiment and BSFRF side-by-side survey data to improve the catchability prior.*

    Reply: This is a good suggestion. However, we do not use BSFRF side-by-side survey data to estimate the NMFS trawl catchability prior because we do not want to use these data twice since they are used in the model already.

12. *Conducting new tagging study to update the outdated tagging/return data used in the assessments.*

    Reply: We agree with this recommendation. Hopefully, tagging study will be conducted for BBRKC in the future.