BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2019

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Executive Summary

1. Stock: Red king crab (RKC), *Paralithodes camtschaticus*, in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. Catches during recent years until 2010/11 were among the high catches in last 15 years. The retained catch in 2018/19 was approximately 4.5 million lbs (2,027 t), below the catch in 2017/18 (6.8 million lbs, 3,094 t). 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.
3. Stock biomass: Estimated mature biomass increased dramatically in the mid-1970s and decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about three times more abundant in 2009 than in 1985 and mature males being about two times more abundant in 2009 than in 1985. Estimated mature abundance has steadily declined since 2009.
4. Recruitment: Estimated recruitment was high during 1970s and early 1980s and has generally been low since 1985 (1979-year class). During 1984-2019, only in 1984, 1986, 1995, 1999, 2002 and 2005 were estimated recruitments above the historical average for 1976-2019. Estimated recruitment was extremely low during the last 12 years.
5. Management performance:

Status and catch specifications (1,000 t) (model 19.0):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	12.89[A]	27.68[A]	4.52	4.61	5.30	6.73	6.06
2016/17	12.53[B]	25.81[B]	3.84	3.92	4.37	6.64	5.97
2017/18	12.74[C]	24.86[C]	2.99	3.09	3.60	5.60	5.04
2018/19	10.62[D]	16.92D	1.95	2.03	2.65	5.34	4.27
2019/20		15.96[D]				3.40	2.72

The stock was above MSST in 2018/19 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	28.4[A]	61.0[A]	9.97	10.17	11.69	14.84	13.36
2016/17	27.6[B]	56.9[B]	8.47	8.65	9.63	14.63	13.17
2017/18	28.1[C]	54.8[C]	6.60	6.82	7.93	12.35	11.11
2018/19	23.4[D]	37.3[D]	4.31	4.31	5.85	11.76	9.41
2019/20		35.2[D]				7.5	6.00

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2016

B – Calculated from the assessment reviewed by the Crab Plan Team in September 2017

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

D – Calculated from the assessment reviewed by the Crab Plan Team in September 2019

6. Basis for the OFL: Values in 1,000 t (model 19.0):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	26.1	24.7	0.95	0.27	1984-2015	0.18
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18
2017/18	3b	25.1	21.3	0.85	0.24	1984-2017	0.18
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

Basis for the OFL: Values in million lbs:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	57.5	54.4	0.95	0.27	1984-2015	0.18
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18
2017/18	3b	55.2	47.0	0.85	0.24	1984-2017	0.18
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

A. Summary of Major Changes

1. Changes to management of the fishery: None.

2. Changes to the input data:

a. Updated NMFS trawl survey data through 2019.

b. Updated the directed pot fishery catch and bycatch data through 2018 (i.e., completed 2018/19 fishery).

c. Updated groundfish fisheries bycatch data during 1991-2018.

3. Changes to the assessment methodology:

a. Estimated recruitment in the terminal year is not used for estimating $B_{35\%}$. That is, the mean recruitment from 1984-2018 is used for estimating $B_{35\%}$.

b. For the directed pot fishery, the model fits total observer male biomass and length compositions, instead of discarded male biomass and length compositions. Observers have not separated retained and discarded legal males in the directed pot fishery starting in 2018.

c. The analyses of terminal years of recruitment is updated.

d. Three models are compared in this report (See Section E.3.a for details):

18.0d: The model rk18A.D18a from May 2019 with the 2019 data, also the model 18.0a in the SAFE report from September 2018 with the 2019 data and separating the groundfish fisheries bycatch data into trawl and fixed gear during 1996-2018, the period the data are available (model 18.0a separated the groundfish data only during 2009-2017). This model assumes that Bering Sea Fisheries Research Foundation (BSFRF) survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities. A survey capture probability for a length group is simply defined as the proportion of the crab in the length group within the area-swept that is caught by the survey net.

Changes since May 2018 include: (1) the total observer male biomass and total observer male length composition data in the directed pot fishery are used to replace discarded male biomass and discarded male length composition data, (2) total male selectivity and retained proportions in the directed pot fishery are used to replace retained selectivity and discarded male selectivity, (3) due to high grading problems in some years since rationalization, two logistic curves are estimated for retained proportions: one before rationalization (before 2005) and another after 2004, and (4) equal annual effective sample sizes of male and female length compositions are considered.

18.0e: The same as model 18.0d except for the sum of length composition data for Tanner crab fishery bycatch each year is equal to 1.0 for both sexes combined (model 18.0d has the sum equal to 1.0 for each sex). This change treats the Tanner crab fishery bycatch length compositions the same way as the groundfish fisheries bycatch.

19.0: This is the Gmacs version of model 18.0e. This model uses the same input data as model 18.0e and the same approach as much as possible. Some differences are: (1) likelihood values for catch and bycatch biomasses include constant terms under Gmacs while constant terms are not included in the likelihood values under model 18.0e, (2) penalties and prior-densities are much more extensively used with Gmacs than model 18.0e, (3) model 18.0e restricts the estimated survey selectivities to be equal for the smallest length group for both sexes for a given survey (two logistic curves with three parameters) while no such a restriction for Gmacs (two logistic curves with four parameters), (4) model 18.0e uses the smoothed trawl survey length compositions in the initial year divided by the estimated survey selectivities as estimated population length compositions in the initial year before the phase of estimating the population length composition parameters while model 19.0 uses the initial length composition parameters to estimate population length compositions before the estimating phase, and (5) Gmacs uses the BSFRF survey selectivities as a limit to the NMFS trawl survey selectivities while model 18.0e assumes the BSFRF survey selectivities as availabilities to the NMFS trawl survey.

4. Changes to assessment results:

The population biomass estimates in 2019 are lower than those in 2018. Among the three models, model estimated relative NMFS survey biomasses and mature biomasses are very similar. Estimated results are extremely similar for models 18.0d and 18.0e, indicating that normalizing combined sex or single sex length compositions of Tanner crab fishery bycatch has little impacts on the results. Gmacs (model 19.0) results in slightly high relative female biomass estimates after 2004 and slightly low relative male biomasses during the last 30 years. Models 18.0d and 18.0e fit the BSFRF survey biomasses better than model 19.0 (gmacs) while Gmacs fits NMFS survey biomasses better than the other two models. The Gmacs model (19.0) results in lower mature male biomass estimates (thus lower recruitment estimates) than the other two models during the last 30 years, which may be explained by a weaker link between NMFS and BSFRF surveys by Gmacs, resulting in a lower weight for BSFRF survey data through higher estimated additional CV for BSFRF survey biomass. Lower recruitment estimates in the 1970s for models 18.0d and 18.0e than for model 19.0 (gmacs) may be caused by the restriction of equal survey selectivity value of the smallest length group. Also higher recruitment estimates in the 1970s result in higher high M estimates for model 19.0. All three models fit the catch and bycatch biomass extremely well. Since the results are extremely similar for models 18.0d and 18.0e, we prefer 18.0e and recommend either model 18.0e or model 19.0 (gmacs) for overfishing definition determination for September 2019. The Gmacs model (19.0) is preferred due to better fits of NMFS survey biomass during recent years. The Gmacs generally runs well and maybe it is time for it to take over the BBRKC assessments. The CPT adopted Gmacs for overfishing definition determination for September 2019.

Like the results of model 18.0a (rk18A.D18a) in May 2019, terminal year recruitment analysis with model 19.0 (gmacs) also suggests the estimated recruitment in the last year should not be used for estimating $B_{35\%}$.

There are a few areas with the Gmacs model that may need some improvement or further examination: (1) documentation (the current documentation is limited); (2) more options are needed for relationships between NMFS survey and BSFRF survey (the current options are no relationships or NMFS survey selectivity values cannot be larger than BSFRF survey); (3) a jittering option for Gmacs; (4) equations for instantaneous seasons may be problematic and need to be checked (we used continuous seasons, which are fine); and (5) output and R plot scripts need to be further developed for more complex assessments like BBRKC (we revised output and used our R functions and scripts for this report). We will work on (2) for the BBRKC assessment updates before the next CPT meeting in January or May 2020.

B. Responses to SSC and CPT Comments

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

None.

2. Responses to the most recent two sets of SSC and CPT comments specific to this assessment:

Response to CPT Comments (from May 2019):

"Explain why the likelihoods for size-compositions differ given the fits are very similar."

Response: four reasons: (1) Gmacs does not include the constant term whereas we had a constant term in the robust normal for proportion likelihoods, (2) for sex combined normalized length compositions, the effective sample sizes were doubled for Gmacs (Gmacs adds them together), (3) for sex combined normalized length compositions, the robust constant for variance estimation is 1/36 for both males and females with Gmacs, while our past assessment program in May 2019 or earlier used 1/20 for males and 1/16 for females, and (4) although it is an extremely small value, our past program did not compute likelihood for the first several length groups for retained catch due to zero proportions while Gmacs computes it.

We made all length composition likelihoods comparable in this report: models 18.0d and 18.0e drop the constant term; for sex combined normalized length compositions, effective sample sizes in data file are reduced to half for Gmacs and the robust constant 1/36 is used for all models; and for retained length compositions, all groups are used to compute likelihood for models 18.0d and 18.0e.

Also, NMFS survey biomass likelihood was not comparable in the report in May 2019 between models 18.0e and 19.0 (gmacs). Gmacs had an extra term, 0.5σ, in the likelihood function and a constant term. We deleted the extra term from Gmacs and added the constant term to models 18.0d and 18.0e. Now the likelihood function values for both NMFS and BSFRF survey biomass are comparable among the three models in this report.

"Document how the two models penalize parameter values, in particular, differences in the sex ratio of recruits from 1:1, and explore whether the difference in results is due to difference in this penalty."

Response: model 18.0e doesn't have priors on parameters except NMFS survey catchability. Most of penalties of model 18.0e are on recruitment: sex ratio of recruits from 1:1 and recruitment variation over time. Model 18.0e also has a very small penalty on bycatch fishing mortality deviations to make sure that they make sense, and this small penalty generally does not affect the results. Model 19.0 has the same prior on NMFS survey catchability and tried to have the same penalties as model 18.0e on recruitment. However, model 19.0 has further penalty on recruitment, such as sigmaR. Besides sigmaR, model 19.0 has many prior-densities and a penalty on natural mortality (M) deviations. Based on penalty values in negative likelihood components, prior-densities have the highest value, recruitment has the second, and M deviations have the third. Since prior-densities in Gmacs are mostly constants, we examined penalties from sigmaR, recruitment sex ratio, and M deviations on the results of model 19.0.

At first, sigmaR seems to have a huge impact (it was the case in May 2019); however, we found out that the impacts were caused by the interaction of female fishing mortality offset values in the groundfish bycatch. Therefore, we set the offsets for the groundfish bycatch female mortality to be zero for model 19.0, consistent with model 18.0e, the impacts by sigmaR on results are very small. See the following table for sigmaR (the default sigmaR is 0.9):

Gmacs' sensitivity on sigmaR:

SigmaR	0.5	0.7	0.88	1	1.2
Neg. log likelihood	-23550.3	-23549.9	-23548.6	-23547.5	-23545.5
$B_{35\%}$(t)	21389.8	21535.1	21662.2	21724.9	21786.8
$F_{35\%}$	0.299	0.299	0.299	0.299	0.299
MMB_{2019}(t)	15978.2	16043.7	16090.7	16115.5	16148.4
OFL_{2019}(t)	3386.9	3390.2	3389.2	3389.4	3394.2
ABC_{2019}(t)	2709.5	2712.2	2711.4	2711.6	2715.4
$F_{ofl2019}$	0.215	0.214	0.214	0.213	0.213
Q	0.925	0.924	0.925	0.925	0.925

Surprisingly, the weighting factor (emphasis factor/prior) for recruitment ratios does not have large impacts on the results for model 19.0 (the default factor is 10):

Gmacs' sensitivity on mean R sex ratio:

W.factor	1	5	10	20	50
Neg. log likelihood	-23551.2	-23550.8	-23550.3	-23549.5	-23547.6
$B_{35\%}$(t)	21751.2	21518.4	21247.2	20759.3	19601.0
F35%	0.299	0.299	0.299	0.299	0.299
MMB_{2019}(t)	16015.4	15988.1	15956.6	15895.4	15741.6
OFL_{2019}(t)	3336.8	3367.3	3403.4	3469.8	3636.2
ABC_{2019}(t)	2669.4	2693.8	2722.7	2775.8	2908.9
$F_{ofl2019}$	0.211	0.214	0.216	0.221	0.234
Q	0.925	0.925	0.925	0.924	0.924

Finally, the penalty on M deviations has some impacts on the results for model 19.0, but the impacts are not very large (the default factor is 1.0):

Gmacs' sensitivity on M penalty:

W. factor	0.1	0.5	1.0	2.0	5.0
Neg. log likelihood	-23598.2	-23576.6	-23550.3	-23500.2	-23365.1
$B_{35\%}$(t)	21793.0	21531.3	21247.2	20698.5	19462.7
$F_{35\%}$	0.298	0.299	0.299	0.300	0.303

MMB_{2019}(t)	16133.4	16051.6	15956.6	15675.0	15147.8
OFL_{2019}(t)	3374.3	3389.4	3403.4	3384.4	3410.6
ABC_{2019}(t)	2699.5	2711.5	2722.7	2707.5	2728.5
$F_{ofl2019}$	0.212	0.214	0.216	0.219	0.228
Q	0.925	0.925	0.925	0.928	0.922

"Check whether GMACS is fitting to length-composition for males and females combined rather than by sex, and ensure that observed and predicted length-compositions are correctly plotted."

Response: Gmacs has options whether to fit length-composition for males and females combined, or by sex. It is the Gmacs output that causes confusion. Gmacs normalizes all length composition output by sex even fitting to length-composition for males and females combined in the program. We changed Gmacs output to match what are fitted in the program, and all plots are correct.

"Further examine the difference in OFL values from the two models, in particular check the inputs into the OFL calculation such as mean recruitment corresponding to MSY."

Response: we compared mean recruitment, $B_{35\%}$, and OFL between Gmacs and model 18.0e for a lot of runs. The mean male recruitment (50% of total recruitment) for model 18.0e and Gmacs (19.0) are 8.63 and 7.80 million, so Gmacs has a lower $B_{35\%}$ as it should be.

"Explain why the number of estimated parameters in GMACS differs from 18.0e (some of the additional parameters are the fully selected fishing mortalities due to bycatch in the Tanner crab fishery)."

Response: the extra number of estimated parameters for Gmacs is 38 from the fully selected fishing mortalities due to bycatch in the Tanner crab fishery (deriving from fishing effort and model 18.0e does not count them as parameters), 3 for survey selectivity (model 18.0e uses three parameters for two sets of male and female logistic selectivity curves due to assuming the smallest length group has the same selectivity value for both sexes), and 2 for mean fishing mortality and female offset for Tanner crab fishery bycatch (model 18.0e estimates Tanner crab fishing mortalities without mean F and female offset).

"Report fits to biomass indices (NMFS and BSFRF) and residuals by sex rather than aggregated over sex because that is how the data are included in the model likelihood."

Response: done.

"Include the fits by GMACS and 18.0e on the same plot to ease comparisons."

Response: done.

"Evaluate whether the two models have converged using a jitter analysis."

Response: we did jitter analysis for model 18.0d and 18.0e. We tried to do the same for model 19.0 (gmacs); however, our approach (doing in R) does not work for Gmacs (when taking in initial values from a parameter file, Gmacs tried to estimate M, which should be fixed to 0.18). It may need to change initial parameter values from the control file for Gmacs, and we have not figured out how to automate it. We tried many runs with Gmacs, which seems quite robust.

"Apply the CPT-approved naming conventions for the model scenarios."

Response: hopefully we got it right this time.

Response to CPT Comments (from September 2018):

"The CPT requested that the author consider a scenario based on 18.0a in which the asymptote to the retention function is estimated after 2004, rather than fixing it to 1 as it now is."

Response: Done for all scenarios.

Response to SSC Comments specific to this assessment (from June 2019):

"The authors identified seven areas for which the GMACS scenario needs some improvement or additional examination on the bottom of page 4 and top of page 5 of the assessment report. One of these issues includes an unbelievably high estimate of fishing mortality in 1981. The SSC supports the authors' intentions to investigate these issues for the September assessment. Additionally, the SSC supports the CPT's recommendations to the authors to provide additional diagnostics to facilitate comparisons among the base model with better bycatch data and GMACS model so that outcomes can be better understood. It is important to understand what drives differences among these models, and such an evaluation is critical before GMACS can be accepted. Finally, the SSC reiterates its request that model names should follow approved conventions."

Response: we tried to understand Gmacs as much as we could. The Gmacs results in May 2019 and earlier were impacted by one parameter that seems not important at all. It is the offset female mortality for the trawl bycatch, that is, estimating separate mean fishing mortalities for male and female trawl bycatch. Due to unusual conditions for BBRKC in the early 1980s, this parameter causes confoundings among other parameters, especially estimated high natural mortality in the early 1980s. After fixing this parameter to be 0 (no difference between male and female mean trawl bycatch fishing mortalities; the same approach as models 18.0d and 18.0e), Gmacs results are better understood than before. Besides the Gmacs penalty and prior-densities, we believe that the assumption of equal survey selectivity value for the smallest length group for both sexes and different treatments of the relationship between NMFS and BSFRF surveys can explain the differences in results between models 18.0e and 19.0. The difference of estimated NMFS survey selectivity values for small length groups are quite larger for these two models (Figure 8a (18.0e) and Figure 8a (19.0 (gmacs))) due to this survey selectivity assumption. More options are needed for different treatments of the relationship between NMFS and BSFRF surveys in Gmacs; current options are unlikely to work for other stocks: snow and Tanner crabs.

The extremely high estimated fishing mortality in 1981 is a concern for all models. It is caused by a huge decrease of crab abundance. We watched this parameter all the time to make sure it does not cause any convergence problem.

Model names have been changed in this report. We also changed word "scenarios" to "models".

Response to SSC Comments specific to this assessment (from October 2018):

"The SSC also agreed with the Team's recommendation that the buffer be raised from 10% to 20%. Justification for this raise is (1) the over-prediction of 2018 observed survey biomass, (2) 20% is the buffer recommended for other crab stocks with similar uncertainty"

Response: We will use a 20% buffer from now on.

"The SSC notes that a reduction of structural fauna providing protection for small crabs and increase in mobile predators of small crabs was reported from current ecosystem studies. The SSC encourages the author to investigate whether these ecosystem changes are linked to changes in natural mortality or reproductive success."

Response: This is a good idea. We will look at this issue in the future.

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 (Alaska Department of Fish and Game (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 several tens of thousands to a few 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 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 fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (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, historical guideline harvest levels (GHL) were changed to a total allowable catch (TAC). Before rationalization, the implementation errors were quite high for some years and total actual catch 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 carapace length, 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, and 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 lbs and 15% when ESB is at or above 55.0 million lbs (Zheng et al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. A threshold of 14.5 million lbs of ESB was also added. In 1997, a minimum threshold of 4.0 million lbs was established as the minimum GHL for opening the fishery and maintaining fishery 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 lbs 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 NMFS trawl survey data through 2019.

b. Updated the directed pot fishery catch and bycatch data through 2018 (2018/19 completed fishery).

c. Updated groundfish fisheries bycatch data during 1991-2018.

Data types and ranges 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 ADF&G from 1974 to 2017. Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013). Sample sizes for catch by length and shell condition are summarized in Table 2. 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 Table 1a 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. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1a are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as July 1 to June 30; e.g., year 2002 in Table 1a for trawl bycatch corresponds to what is reported for year 2003 in the NMFS database. 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.

(ii). Catch Size Composition

Retained catch by length and shell condition and bycatch 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 performed 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 1975-2017 were provided by NMFS.

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 for 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 2019.

In addition to standard surveys, NMFS also conducted some surveys after the standard surveys to better assess mature female abundance. 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 re-surveyed in 1999, 2000, 2006-2012, and 2017. 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 and 2012) with high female densities. The resurveys were necessary because a high proportion of mature females had not yet molted or mated when sampled by the standard survey. 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. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 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. 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 in 2007 and 19.747 million in 2008 with respective CVs of 0.0634 and 0.0765. 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.

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 LBA (research model) was developed in 2004 to include small size crab for 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 1976-1993. In this report, we present only the research model that was fit to the data from 1975 to 2019.

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, selectivities, catches, and bycatch of the commercial pot fisheries and groundfish trawl fisheries. 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 constant at 0.18yr^{-1} over sex, 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 are also 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) 1982-2019, based on modifications to the trawl gear used in the assessment survey.

iii. Growth is a function of length and is assumed to not change over time for males. For females, growth-per-molt increments as a function of length are estimated for three periods (1975-1982, 1983-1993, and 1994-2019) based on sizes at maturity. Once mature, female red king crab grow with 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 of 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.

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. 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: The code is available with the first author.

3. Model Selection and Evaluation

a. Alternative model configurations (models):

18.0d: The model rk18A.D18a from May 2019 with the 2019 data, also the model 18.0a in the SAFE report from September 2018 with the 2019 data and separating the groundfish fisheries bycatch data into trawl and fixed gear during 1996-2018, the period data are available (model 18.0a separated the groundfish data only during 2009-2017). This model assumes that BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities. A survey capture probability for a length group is simply defined as the proportion of the crab in the length group within the area-swept that is caught by the survey net.

Model 18.0d includes:

(1) Base $M = 0.18\text{yr}^{-1}$, with an additional mortality level during 1980-1984 for males and two additional mortality levels (one for 1980-1984 and the other for 1976-1979 and 1985-1993) for females. Additional mortalities are estimated in the model.

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

(3) NMFS survey catchability is estimated in the model and is assumed to be constant over time. BSFRF survey catchability is assumed to be 1.0.

(4) 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.

(5) 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, 100 for males from the pot fishery and 50 for females from pot fishery and both males and females from the 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). The effective sample sizes are plotted against the implied effective sample sizes in Figures 6 and 7, where the implied effective sample sizes are estimated as follows:

$$n_y = \sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l}) / \sum_l (P_{y,l} - \hat{P}_{y,l})^2 \qquad (1)$$

where $\hat{P}_{y,l}$ and $P_{y,l}$ are estimated and observed size compositions in year y and length group l, respectively.

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

(7) Estimating initial year length compositions.

(8) The total observer male biomass and total observer male length composition data in the directed pot fishery are used to replace discarded male biomass and discarded male length composition data.

(9) Total male selectivity and retained proportions in the directed pot fishery are used to replace retained selectivity and discarded male selectivity, and due to high grading problems in some years since rationalization, two logistic curves are estimated for retained proportions: one before rationalization (before 2005) and another after 2004.

(10) Equal annual effective sample sizes of male and female length compositions.

For model 18.0d, survey abundances $\hat{N}^b_{s,y,l}$ (BSFRF survey) and $\hat{N}^n_{s,y,l}$ (NMFS survey) by sex s and in year y and length group l are computed as follows:

$$\begin{aligned} \hat{N}^b_{s,y,l} &= N_{s,y,l}\, s^b_{s,l}, \\ \hat{N}^n_{s,y,l} &= N_{s,y,l}\, s^n_{s,l}, \end{aligned} \qquad (2)$$

where $s^b_{s,l}$ and $s^n_{s,l}$ are survey selectivities for BSFRF and NMFS surveys by sex s and in length group l, respectively, and $N_{s,y,l}$ is the population abundance by sex s and in year y and length group l. BSFRF survey selectivities are computed as

$$s^b_{s,l} = \frac{1}{1+e^{-\beta^b_s\,(\iota - L^b_{50,s})}}, \qquad (3)$$

where β and L_{50} are parameters. Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, *L50* for females, and *L50* for males) were estimated in the model for each survey. The BSFRF survey catchability is assumed to be 1.0.

Model 18.0d assumes that the BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities (*p*):

$$s_{s,l}^{n} = p_{s,l}\, s_{s,l}^{b}. \tag{4}$$

Therefore, the model estimates NMFS survey capture probabilities and BSFRF survey selectivities and computes NMFS survey selectivities from these estimates. NMFS survey capture probabilities are computed as

$$p_{s,l} = \frac{Q}{1 + e^{-\beta_s \; (\iota - L_{50,s})}}, \tag{5}$$

where β and *L50* are parameters and like the survey selectivities, only three parameters (β, *L50* for females and *L50* for males) were estimated in the model for each sex. Q is the NMFS survey catchability and is estimated in the model with or without a prior from the double-bag experiment, depending on models.

Since fishing times for both Tanner crab fishery and groundfish fishery are assumed to occur at the same time, the fraction separation of fishing mortality rates for both fisheries is used to divide the total fishing mortality rate to individual fisheries, that is, $F_i/F_{tot}*(1\text{-exp}(-F_{tot}))$ for fishery i, and the sum of $F_i = F_{tot}$.

18.0e: The same as model 18.0d except the sum of length composition data for Tanner crab fishery bycatch each year is equal to 1.0 for both sexes combined (model 18.0d has the sum equal to 1.0 for each sex). This change treats the Tanner crab fishery bycatch length compositions the same way as the groundfish fisheries bycatch.

19.0: This is the Gmacs version of model 18.0e. This model uses the same input data as model 18.0e and the same approach as much as possible. Some differences are: (1) likelihood values for catch and bycatch biomasses include constant terms under Gmacs while constant terms are not included in the likelihood values under model 18.0e, (2) penalties and prior-densities are much more extensively used with Gmacs than model 18.0e, (3) model 18.0e restricts the estimated survey selectivities to be equal for the smallest length group for both sexes for a given survey (two logistic curves with three parameters) while no such a restriction for Gmacs (two logistic curves with four parameters), (4) model 18.0e uses the smoothed trawl survey length compositions in the initial year divided by the estimated survey selectivities as estimated population length compositions in the initial year before the phase of estimating the population length composition parameters while model 19.0 uses the initial length composition parameters to estimate population length compositions before the estimating phase, and (5) Gmacs uses the BSFRF survey selectivities as a limit to the NMFS trawl survey selectivities while model 18.0e assumes the BSFRF survey selectivities as availabilities to the NMFS trawl survey.

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 2 and estimated implied sample sizes and effective sample sizes are illustrated in Figures 6 and 7.

f. Credible parameter estimates: All estimated parameters seem to be credible.

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. Due to technical issues for model 19.0 (gmacs), the jittering approach is used for models 18.0d and 18.0e in this report. About half of the jittered runs converged, and a few runs converged to the highest log likelihood values (Table 3).

4. Results

a. Effective sample sizes and weighting factors.

i. For model 18.0e, effective sample sizes are illustrated in Figures 6 and 7.

ii. 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, 0.53 for recruitment variation, and 0.23 for recruitment sex ratio for models 18.0d and 18.0e. Model 19.0 has the same CVs except for using sigmaR for recruitment variation and having a penalty M variation and many prior-densities.

iii. 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 as a prior for estimating Q in all models.

b. Tables of estimates.

i. Parameter estimates for models 18.0d, 18.0e, and 19.0 are summarized in Table 5.

ii. Abundance and biomass time series are provided in Table 6 for models 18.0d, 18.0e, and 19.0.

iii. Recruitment time series for models 18.0d, 18.0e, and 19.0 are provided in Table 6.

iv. Time series of catch biomass is provided in Table 1.

Negative log-likelihood values and parameter estimates are summarized in Tables 4 and 5, respectively. Length-specific fishing mortality is equal to selectivity-at-length times the full fishing mortality. Estimated full pot fishing mortalities for females and full fishing mortalities for groundfish fisheries bycatch are very low due to low bycatch as well as handling mortality rates less than 1.0. Estimated recruits varied greatly among years (Table 6). 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 for male retained catch and bycatch (Table 5).

c. Graphs of estimates.

i. Selectivities and molting probabilities by length are provided in Figures 8 and 9 for models 18.0d, 18.0e, and 19.0.

One of the most important results is estimated trawl survey selectivity (Figure 8). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 8 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. Information about crab availability to the survey area at survey times will help estimate the survey selectivities.

For all models, estimated molting probabilities during 1975-2019 (Figure 9) 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 total survey biomass and mature male and female abundances are plotted in Figure 10. Absolute mature male biomasses are illustrated in Figure 11.

The population biomass estimates in 2019 are lower than those in 2018. Among the three models, model estimated relative survey biomasses and mature biomasses are very similar. Estimated results are extremely similar for models 18.0d and 18.0e, indicating that normalizing combined sex or single sex length compositions of Tanner crab fishery bycatch has little impacts on the results. Gmacs (model 19.0) results in slightly high relative female biomass estimates after 2004 and slightly low relative male biomasses during the last 30 years. Models 18.0d and 18.0e fit the BSFRF survey biomasses better than model 19.0 (gmacs) while Gmacs fits NMFS survey biomasses better than the other two models. Like model estimated NMFS survey biomasses, the Gmacs model (19.0) results in lower mature male biomass estimates (thus lower recruitment estimates) than the other two models during the last 30 years.

Although the model did not fit the mature crab abundances directly, trends in the mature abundance estimates agree well with observed survey values (Figure 10b). Estimated mature crab abundance increased dramatically in the mid-1970s then decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about 3 times more abundant in 2009 than in 1985 and mature males being about 2 times more abundant in 2009 than in 1985. Estimated mature abundance has declined since 2009 (Figure 10b). Model estimates of both male and female mature abundances have steadily declined since the late 2000s. Absolute mature male biomasses for all models have a similar trend over time (Figure 11).

The fit to BSFRF survey data and estimated survey selectivities are illustrated in Figures 10c-e.

The recruitment breakpoint analysis done in May 2019 (Appendix B) has similar results to the analysis done in May 2017, estimating 1984 as the breakpoint brood year, or 1990 recruitment year with a Beverton-Holt model, and 1986 as the breakpoint brood year, or 1992 recruitment year with a Ricker model. No recruitment breakpoint is seen in brook year of 2006. Terminal year recruitment analysis suggests the estimated recruitment in the last terminal year should not be used for estimating $B_{35\%}$.

iii. Estimated recruitment time series are plotted in Figure 12 for models 18.0e and 19.0.

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figure 13 for models 18.0d, 18.0e, and 19.0. Recruitment is estimated at the end of year for model 19.0 while at the beginning of year for models 18.0d and 18.0e. Therefore, recruitment year is moved up one year for model 19.0 to match those for models 18.0d and 18.0e.

The average of estimated male recruits from 1984 to 2018 (Figure 12) and mature male biomass per recruit are used to estimate $B_{35\%}$. Alternative periods of 1976-present and 1976-1983 are compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing are plotted against mature male biomass on Feb. 15 (Figure 13). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figure 13). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, and 2007-2009 for models 18.0d and 18.0e and 1998-1999, 2003, 2005, 2007-2009, and 2010 for model 19.0, but below the $F_{35\%}$ limits in the other post-1995 years.

For model 18.0e, estimated full pot fishing mortalities ranged from 0.00 to 3.91 during 1975-2018. Estimated values were greater than 0.40 during 1975-1982, 1984-1987, 1990-1991, 1993, 1998 and 2007-2008 (Table 5, Figure 13). For model 19.0 (gmacs), estimated full pot fishing mortalities ranged from 0.00 to 2.95 during 1975-2018, with estimated values over 0.40 during 1975-1976, 1978-1982, 1984-1987, 1990-1991, 1993, 1998, and 2007-2008 (Figure 13). Estimated fishing mortalities for pot female and groundfish fisheries bycatches are generally less than 0.07.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with model 18.0e (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).

Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions. 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 15). The highest proportion of empty clutches (0.2) was in 1986, and primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 15). The average clutch fullness is similar for these two periods (Figure 15). Egg clutch fullness during the last three years is relatively low.

d. Graphic evaluation of the fit to the data.

i. Observed vs. estimated catches are plotted in Figure 16.

ii. Model fits to total survey biomass are shown in Figure 10 with a standardized residual plot in Figure 17.

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.

The models (three 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, trawl and fixed gear bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.

The model 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).

Standardized 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. Standardized residuals of survey biomasses did not show any consistent patterns (Figure 17). Standardized residuals of proportions of survey males appear to be random over length and year (Figure 25). There is an interesting pattern for residuals of proportions of survey females. Residuals are generally negative for large-sized mature females during 1975-1987 for the three models

(Figure 26). Also, there are large negative residuals for the last length group during the last 17 years for model 19.0. Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors or with improved growth data.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2019 model (model 19.0) hindcast results and (2) historical results. The 2019 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Treating the 2019 estimates as the baseline values, we can evaluate how well the model had done in the past.

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

The performance of the 2019 model includes sequentially excluding one-year of data. Model 19.0 produced some upward biases during 2009-2018 with higher terminal year estimates of mature male biomass in 2009-2010 and 2014-2017 (Figures 27-28). 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 2019.

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

The model first fit the data from 1985 to 2004 in the terminal year of 2004. Thus, sequentially incrementing the terminal year provided 16 historical assessments for comparison with the 2019 assessment model results (Figure 29). The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1,000 for survey biomass, 2,000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also respectively applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).

In 2005, to improve the fit for retained catch data, the weight for retained catch biomass was increased to 3,000 and the weight for retained catch proportions was increased to 6. All other weights were not changed. In 2006, all weights were re-configured. No weights were used for proportion data, and instead, effective sample sizes were set to 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for bycatch. The weights in 2007 were the same as 2006. Generally, estimates of time series of abundance in 2005 were slightly lower than in 2006 and 2007, and there were few differences between estimates in 2006 and 2007 (Figure 29).

In 2008, estimated coefficients of variation for survey biomass were used to compute likelihood values as suggested by the CPT in 2007. Thus, weights were re-configured to: 500 for retained catch biomass, 50 for survey biomass, and 20 for bycatch biomasses. Effective sample size was lowered to 400 for the retained catch data. These changes were necessary for the estimation to converge and for a relatively good balanced fit to both biomasses and proportion data. Also, sizes at 50% selectivities for all fisheries data were allowed to change annually, subject to a random walk pattern, for all assessments before 2008. The 2008 model does not allow annual changes in any fishery selectivities. Except for higher estimates of abundance during the late 1980s and early 1990s, estimates of time series of abundance in 2008 were generally close to those in 2006 and 2007 (Figure 29).

During 2009-2013, the model was extended to the data through 1968. No weighting factors were used for the NMFS survey biomass during 2009-2013 assessments. Since 2013, the model has fitted the data only back to 1975 for consistence of trawl survey data. Two levels of molting probabilities over time were used, shell conditions for males were combined, and length composition data of the BSFRF survey were used as well. In 2014 and 2015, the trawl survey time series were re-estimated and a trawl survey catchability was estimated for some models.

Overall, both historical results (historic analysis) and the 2019 model results (retrospective analysis) performed reasonably well. No great overestimates or underestimates occurred as was observed in assessments for Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) and some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002; Ianelli et al. 2003). Since the most recent model was not used to set TAC or overfishing limits until 2009, historical implications for management from the stock assessment errors cannot be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002).

Ratios of estimated retrospective recruitments to terminal estimates in 2019 as a function of number of years estimated in the model show converging to 1.0 as the number of years increase (Figure 28). Standard deviations of the ratios drop sharply from one year estimated in the model to two years (Figure 28), 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 Table 5 for models 18.0d, 18.0e, and 19.0. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for NMFS trawl survey catchability Q are illustrated in Figure 30 for model 18.0e using the mcmc approach; estimated Qs are less than 1.0. Probabilities for mature male biomass and OFL in 2019 are illustrated in Figure 31 for model 18.0e using the mcmc approach. The confidence intervals are quite narrow.

iii. Sensitivity analysis for handling mortality rate was reported 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 abundance and mature male biomass were small among these handling mortality rates.

iv. 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 also reduced or increased. Overall, estimated biomasses were very close 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) results 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 are similar between models. Using only standard survey data (scenario 1b) results 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 has the lowest likelihood value. Although the likelihood value is 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 are almost identical. The higher likelihood value for scenario 1 over scenario 1c is due to trawl bycatch length compositions.

In this report (September 2019), three models are compared. The population biomass estimates in 2019 are lower than those in 2018. Among the three models, model estimated relative NMFS survey biomasses and mature biomasses are very similar. Estimated results are extremely similar for models 18.0d and 18.0e, indicating that normalizing combined sex or single sex length compositions of Tanner crab fishery bycatch has little impact on the results. Gmacs (model 19.0) results in slightly high relative female biomass estimates after 2004 and slightly low relative male biomasses during the last 30 years. Models 18.0d and 18.0e fit the BSFRF survey biomasses better than model 19.0 (gmacs) while Gmacs fits NMFS survey biomasses better than the other two models. The Gmacs model (19.0) results in lower mature male biomass estimates (thus lower recruitment estimates) than the other two models during the last 30 years, which may be explained by a weaker link between NMFS and BSFRF surveys by Gmacs, resulting in a lower weight for BSFRF survey data through higher estimated additional CV for BSFRF survey biomass. Lower recruitment estimates in the 1970s for models 18.0d and 18.0e than for model 19.0 (gmacs) may be caused by the restriction of the survey selectivity value of the smallest length group. Also, higher recruitment estimates in the 1970s result in higher high M estimates for model 19.0. All three models fit the catch and bycatch biomass extremely well.

For negative likelihood value comparisons (Table 4b), models 18.0d and 18.0e have almost the same likelihood value except for the difference of Tanner crab fishery bycatch length composition component due to different normalizations. Model 19.0 (gmacs) has many more penalties and prior-densities than models 18.0d and 18.0e and thus a lower likelihood value. Generally speaking, model 18.0e fits all length compositions better than model 19.0 except for the directed pot fishery female discard. Model 19.0 fits the NMFS survey biomass much better than model 18.0e while model 18.0e fits the BSFRF survey biomass slightly better.

Since the results are extremely similar for models 18.0d and 18.0e, we prefer 18.0e and recommend either model 18.0e or model 19.0 (gmacs) for an overfishing definition determination for September 2019. The Gmacs model (19.0) is preferred due to better fits of NMFS survey biomass during recent years. The Gmacs generally runs well and maybe it is time for it to take over the BBRKC assessments.

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) $\beta < \frac{B}{B^*} \le 1$ $\quad F_{OFL} = F^* \left(\frac{B/B^* - \alpha}{1 - \alpha} \right)$ (8)

c) $\frac{B}{B^*} \le \beta$ $\quad$ directed 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 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 restriction that $0 \le \beta < 1$. A default value of 0.25 is used.

α = a parameter with 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 2009 to 2018 is used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality is set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2018. Some discards of legal males occurred since 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. For models 18.0d and 18.0e, the averages of retained proportions and total male selectivities during 2017-2018 are used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2009-2018 are used for per recruit analysis and projections. For model 19.0, averages of values during the last five year are used for per recruit analysis. For the models in 2019, the averages are the same since they are constant over time during at least last 14 years.

Average recruitments during three periods are used to estimate $B_{35\%}$: 1976-2018, 1984-2018, and 1991-2018 (Figure 12). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1984-2018, corresponding to the 1976/77 regime shift. Note that 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 current spawning stock is mainly in the middle of Bristol Bay. The 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.

If we believe that differences in productivity and other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1976-1983 (corresponding to brood years before 1978) as the baseline to estimate $B_{35\%}$. If we believe that the regime shift during 1976/77 caused the productivity differences, then we should select the recruitments from period 1984-2018 as the baseline.

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 fishery is closed.

The estimated probability distribution of MMB in 2019 is illustrated in Figure 30. Based on SSC suggestions in 2011, ABC = 0.9*OFL and in October 2018, ABC = 0.8*OFL. The CPT also recommended ABC = 0.8*OFL in May 2018, which is used to estimate ABC in this report.

Status and catch specifications (1,000 t) (model 19.0):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	12.89[A]	27.68[A]	4.52	4.61	5.30	6.73	6.06
2016/17	12.53[B]	25.81[B]	3.84	3.92	4.37	6.64	5.97
2017/18	12.74[C]	24.86[C]	2.99	3.09	3.60	5.60	5.04
2018/19	10.62[D]	16.92D	1.95	2.03	2.65	5.34	4.27
2019/20		15.96[D]				3.40	2.72

The stock was above MSST in 2018/19 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	28.4[A]	61.0[A]	9.97	10.17	11.69	14.84	13.36
2016/17	27.6[B]	56.9[B]	8.47	8.65	9.63	14.63	13.17
2017/18	28.1[C]	54.8[C]	6.60	6.82	7.93	12.35	11.11
2018/19	23.4[D]	37.3[D]	4.31	4.31	5.85	11.76	9.41
2019/20		35.2[D]				7.5	6.00

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2016

B – Calculated from the assessment reviewed by the Crab Plan Team in September 2017

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

D – Calculated from the assessment reviewed by the Crab Plan Team in September 2019

6. Basis for the OFL: Values in 1,000 t (model 19.0):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	26.1	24.7	0.95	0.27	1984-2015	0.18
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18
2017/18	3b	25.1	21.3	0.85	0.24	1984-2017	0.18
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

Basis for the OFL: Values in million lbs:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	57.5	54.4	0.95	0.27	1984-2015	0.18
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18
2017/18	3b	55.2	47.0	0.85	0.24	1984-2017	0.18
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

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2018, the biological reference points and OFL are illustrated in Table 4.
5. Based on the CPT/SSC recommendation of 20% buffer rule in May 2018, ABC = 0.8*OFL (Table 4).

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.
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 1984-2019. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2019. The 2019 abundance is randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three models of fishing mortality for the directed pot fishery are used in the projections:

(1) No directed fishery. This was used as a base projection.

(2) $F_{40\%}$. This fishing mortality creates a buffer between the limits and target levels.

(3) $F_{35\%}$. This is the maximum fishing mortality allowed under the current overfishing definitions.

Each model is replicated 1,000 times and projections made over 10 years beginning in 2019 (Table 7).

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under the other models. At the end of 10 years, projected mature male biomass is above $B_{35\%}$ for all models (Table 7; Figure 32). Projected retained catch for the $F_{35\%}$ model is higher than those for the $F_{40\%}$ model (Table 7, Figure 33). Due to the poor recruitment in recent years, the projected biomass and retained catch are expected to decline during the next few years.

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a 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 (Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011, but these juveniles were not tracked during 2012-2019 surveys. This single tow is unlikely to be an indicator for a strong cohort. The high survey abundance 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 2016-2019 survey results (Figure 34). Due to lack of recruitment, mature and legal crab should continue to decline next year. 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.

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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.

Year	Retained Catch				Pot Bycatch		Trawl Bycat.	Fixed Bycat.	Tanner Fishery Bycat.	Total Catch
	U.S.	Cost-Recovery	Foreign	Total	Males	Females				
1953	1331.3		4705.6	6036.9						6036.9
1954	1149.9		3720.4	4870.2						4870.2
1955	1029.2		3712.7	4741.9						4741.9
1956	973.4		3572.9	4546.4						4546.4
1957	339.7		3718.1	4057.8						4057.8
1958	3.2		3541.6	3544.8						3544.8
1959	0.0		6062.3	6062.3						6062.3
1960	272.2		12200.7	12472.9						12472.9
1961	193.7		20226.6	20420.3						20420.3
1962	30.8		24618.7	24649.6						24649.6
1963	296.2		24930.8	25227.0						25227.0
1964	373.3		26385.5	26758.8						26758.8
1965	648.2		18730.6	19378.8						19378.8
1966	452.2		19212.4	19664.6						19664.6
1967	1407.0		15257.0	16664.1						16664.1
1968	3939.9		12459.7	16399.6						16399.6
1969	4718.7		6524.0	11242.7						11242.7
1970	3882.3		5889.4	9771.7						9771.7
1971	5872.2		2782.3	8654.5						8654.5
1972	9863.4		2141.0	12004.3						12004.3
1973	12207.8		103.4	12311.2						12311.2
1974	19171.7		215.9	19387.6						19387.6
1975	23281.2		0	23281.2						23281.2
1976	28993.6		0	28993.6			682.8			29676.4
1977	31736.9		0	31736.9			1249.9			32986.8
1978	39743.0		0	39743.0			1320.6			41063.6
1979	48910.0		0	48910.0			1331.9			50241.9
1980	58943.6		0	58943.6			1036.5			59980.1
1981	15236.8		0	15236.8			219.4			15456.2
1982	1361.3		0	1361.3			574.9			1936.2
1983	0.0		0	0.0			420.4			420.4
1984	1897.1		0	1897.1			1094.0			2991.1
1985	1893.8		0	1893.8			390.1			2283.8
1986	5168.2		0	5168.2			200.6			5368.8
1987	5574.2		0	5574.2			186.4			5760.7
1988	3351.1		0	3351.1			598.4			3949.4
1989	4656.0		0	4656.0			175.2			4831.2
1990	9236.2	36.6	0	9272.8	526.9	648.0	259.9			10707.6
1991	7791.8	93.4	0	7885.1	407.8	47.3	349.4		1401.8	10091.5
1992	3648.2	33.6	0	3681.8	552.0	400.2	293.5		244.4	5172.0
1993	6635.4	24.1	0	6659.6	763.2	634.9	401.4		54.6	8513.6
1994	0.0	42.3	0	42.3	3.8	1.9	87.3		10.8	146.2
1995	0.0	36.4	0	36.4	3.3	1.6	82.1		0.0	123.3
1996	3812.7	49.0	0	3861.7	164.6	1.0	90.8	41.4	0.0	4159.6
1997	3971.9	70.2	0	4042.1	244.7	37.0	57.5	22.5	0.0	4403.7
1998	6693.8	85.4	0	6779.2	959.7	579.4	186.1	18.5	0.0	8522.8
1999	5293.5	84.3	0	5377.9	314.2	5.6	150.5	50.1	0.0	5898.3
2000	3698.8	39.1	0	3737.9	360.8	166.7	81.7	4.7	0.0	4351.9
2001	3811.5	54.6	0	3866.2	417.9	122.3	192.8	35.3	0.0	4634.4
2002	4340.9	43.6	0	4384.5	442.7	9.2	151.2	29.2	0.0	5016.8
2003	7120.0	15.3	0	7135.3	918.9	360.9	136.9	12.7	0.0	8564.7
2004	6915.2	91.4	0	7006.7	345.5	174.6	173.5	15.2	0.0	7715.5

2005	8305.0	94.7	0	8399.7	1359.5	410.3	124.7	19.9	0.0	10314.1
2006	7005.3	137.9	0	7143.2	563.8	37.5	151.7	19.6	3.8	7919.6
2007	9237.9	66.1	0	9303.9	1001.3	163.3	154.1	32.3	1.8	10656.8
2008	9216.1	0.0	0	9216.1	1165.5	146.9	136.6	15.6	4.0	10684.6
2009	7226.9	45.5	0	7272.5	888.1	93.7	95.1	5.8	1.6	8356.9
2010	6728.5	33.0	0	6761.5	797.5	121.8	83.3	2.4	0.0	7766.5
2011	3553.3	53.8	0	3607.1	395.0	24.7	56.3	10.9	0.0	4093.9
2012	3560.6	61.1	0	3621.7	205.2	12.0	34.2	18.4	0.0	3891.5
2013	3901.1	89.9	0	3991.0	310.6	102.9	67.1	55.5	28.5	4555.5
2014	4530.0	8.6	0	4538.6	584.7	72.4	34.2	118.8	42.0	5390.8
2015	4522.3	91.4	0	4613.7	266.1	216.3	45.4	77.4	84.2	5303.1
2016	3840.4	83.4	0	3923.9	237.4	105.4	71.1	29.3	0.0	4367.1
2017	2994.1	99.6	0	3093.7	225.2	53.3	96.1	11.0	0.0	3598.7
2018	1954.1	72.4	0	2026.5	279.6	114.8	84.3	148.1	0.0	2653.3

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
	Catch	Crab/tan	Catch	Crab/tan	Catch	Crab/Potlift	Crab/tan
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					0.000		
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					0.015		
1995					0.014		
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	

Table 2. 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.

Year	Trawl Survey		Retained Catch	Pot Total	Pot Bycatch	Trawl & Fixed Gear Bycatch		Tanner Fishery Bycatch	
	Males	Females		Males	Females	Males	Females	Males	Females
1975	2,815	2,042	29,570						
1976	2,699	1,466	26,450			676	2,327		
1977	2,734	2,424	32,596			689	14,014		
1978	2,735	2,793	27,529			1,456	8,983		
1979	1,158	1,456	27,900			2,821	7,228		
1980	1,917	1,301	34,747			39,689	47,463		
1981	591	664	18,029			49,634	42,172		
1982	1,911	1,948	11,466			47,229	84,240		
1983	1,343	733	0			104,910	204,464		
1984	1,209	778	4,404			147,134	357,981		
1985	790	414	4,582			30,693	169,767		
1986	959	341	5,773			1,199	927		
1987	1,123	1,011	4,230			723	275		
1988	708	478	9,833			437	194		
1989	764	403	32,858			3,140	1,566		
1990	729	535	7,218	2,571	1,416	756	375		
1991	1,180	490	36,820	5,024	366	236	90	885	2,198
1992	509	357	23,552	4,769	3,238	212	228	280	685
1993	725	576	32,777	10,334	6,187			232	265
1994	416	239	0	0	0	327	245		
1995	685	407	0	0	0	120	40		
1996	755	753	8,896	1,778	11	1,035	971		
1997	1,280	702	15,747	11,089	939	1,200	445		
1998	1,067	1,123	16,131	31,432	10,236	1,623	913		
1999	765	618	17,666	13,519	57	2,025	843		
2000	734	730	14,091	32,711	8,470	957	661		
2001	599	736	12,854	26,460	5,474	3,444	2,406		
2002	972	826	15,932	32,612	714	3,262	1,435		
2003	1,360	1,250	16,212	45,583	12,971	1,518	1,008		
2004	1,852	1,271	20,038	38,782	6,667	1,656	1,508		
2005	1,198	1,563	21,938	94,794	26,824	1,814	1,871		
2006	1,178	1,432	18,027	66,529	3,646	1,461	1,979		
2007	1,228	1,305	22,387	111,575	12,457	1,018	1,099		
2008	1,228	1,183	14,567	90,331	8,737	1,794	979		
2009	837	941	16,708	92,616	6,050	1,443	853		
2010	708	1,004	20,137	66,659	6,862	624	843		
2011	531	912	10,706	40,226	1,752	566	1,071		
2012	585	707	8,956	20,161	562	1,508	1,752		
2013	647	569	10,197	30,261	6,070	4,809	4,198	218	596
2014	1,107	1,257	9,618	28,540	1,953	1,975	2,584	256	381
2015	615	681	11,746	22,022	5,927	1,154	3,734	726	2163
2016	378	812	10,811	26,510	4,315	1,946	3,020		
2017	385	508	9,867	27,219	3,834	1,031	1,168		
2018	285	359	7,626	22,480	7,386	2,820	3,470		
2019	273	299							

Table 3(18.0d). Summary of jittering results for model 18.0d. Run 80 is used for initial conditions. Runs with “NA” did not converge. The jittering factor is 0.1. Biomass and OFL are in t. The R scripts (100 runs each time) were run twice for total 200 runs; about 100 runs converged. This table has the second 100 runs.

Run	Neg.log.liklihood	Max gradient	$B_{35\%}$	B_{2019}	OFL_{2019}
1	NA	NA	NA	NA	NA
2	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA
4	-23551.2	0.00007	24922.1	17613.9	3555.0
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	-23555.1	0.00002	24675.6	17795.4	3665.6
9	NA	NA	NA	NA	NA
10	-23551.2	0.00013	24922.1	17613.9	3555.0
11	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA
13	NA	NA	NA	NA	NA
14	NA	NA	NA	NA	NA
15	-23570.3	0.00002	24977.9	17867.6	3643.6
16	NA	NA	NA	NA	NA
17	NA	NA	NA	NA	NA
18	NA	NA	NA	NA	NA
19	NA	NA	NA	NA	NA
20	-23558.5	0.00004	24803.0	17802.3	3645.6
21	NA	NA	NA	NA	NA
22	-23570.3	0.00007	24977.9	17867.6	3643.6
23	NA	NA	NA	NA	NA
24	NA	NA	NA	NA	NA
25	NA	NA	NA	NA	NA
26	NA	NA	NA	NA	NA
27	-23551.2	0.00004	24922.1	17613.9	3555.0
28	-23570.3	0.00005	24977.9	17867.6	3643.6
29	-23551.2	0.00002	24922.1	17613.9	3555.0
30	-23551.2	0.00002	24922.1	17613.9	3555.0
31	NA	NA	NA	NA	NA
32	NA	NA	NA	NA	NA
33	NA	NA	NA	NA	NA
34	-23570.0	0.00025	24912.9	17814.5	3632.1
35	NA	NA	NA	NA	NA
36	NA	NA	NA	NA	NA
37	NA	NA	NA	NA	NA
38	NA	NA	NA	NA	NA
39	-23558.5	0.00006	24803.0	17802.3	3645.6
40	NA	NA	NA	NA	NA
41	NA	NA	NA	NA	NA
42	-23551.2	0.00003	24922.1	17613.9	3555.0
43	NA	NA	NA	NA	NA
44	NA	NA	NA	NA	NA
45	NA	NA	NA	NA	NA
46	NA	NA	NA	NA	NA
47	-23570.2	0.00017	24906.9	17818.4	3634.9
48	-23570.3	0.00005	24977.9	17867.6	3643.6
49	-23558.5	0.00004	24803.0	17802.3	3645.6
50	NA	NA	NA	NA	NA
51	NA	NA	NA	NA	NA
52	-23570.3	0.00021	24977.9	17867.6	3643.6
53	-23549.5	0.00008	24841.1	17576.7	3536.1
54	NA	NA	NA	NA	NA
55	-23551.2	0.00001	24922.1	17613.9	3555.0
56	NA	NA	NA	NA	NA
57	-23551.2	0.00007	24922.1	17613.9	3555.0
58	NA	NA	NA	NA	NA
59	NA	NA	NA	NA	NA
60	-23570.3	0.00017	24977.9	17867.6	3643.6
61	NA	NA	NA	NA	NA
62	NA	NA	NA	NA	NA
63	NA	NA	NA	NA	NA
64	-23551.2	0.00007	24922.1	17613.9	3555.0
65	-23570.3	0.00015	24977.9	17867.6	3643.6

66	NA	NA	NA	NA	NA
67	NA	NA	NA	NA	NA
68	-23570.3	0.00004	24977.9	17867.6	3643.6
69	-23549.5	0.00001	24841.1	17576.7	3536.1
70	-23570.3	0.00008	24977.9	17867.6	3643.6
71	NA	NA	NA	NA	NA
72	NA	NA	NA	NA	NA
73	-23551.2	0.00006	24922.1	17613.9	3555.0
74	-23549.5	0.00004	24841.1	17576.7	3536.1
75	NA	NA	NA	NA	NA
76	-23549.5	0.00010	24841.1	17576.7	3536.1
77	NA	NA	NA	NA	NA
78	-23570.0	0.00023	24912.9	17814.5	3632.1
79	NA	NA	NA	NA	NA
80	-23570.3	0.00008	24977.9	17867.6	3643.6
81	-23570.0	0.00010	24912.9	17814.5	3632.1
82	NA	NA	NA	NA	NA
83	NA	NA	NA	NA	NA
84	NA	NA	NA	NA	NA
85	NA	NA	NA	NA	NA
86	NA	NA	NA	NA	NA
87	-23551.2	0.00009	24922.1	17613.9	3555.0
88	NA	NA	NA	NA	NA
89	NA	NA	NA	NA	NA
90	-23551.2	0.00007	24922.1	17613.9	3555.0
91	-23558.5	0.00003	24803.0	17802.3	3645.6
92	NA	NA	NA	NA	NA
93	-23551.2	0.00004	24922.1	17613.9	3555.0
94	-23549.5	0.00001	24841.1	17576.7	3536.1
95	NA	NA	NA	NA	NA
96	-23551.2	0.00012	24922.1	17613.9	3555.0
97	NA	NA	NA	NA	NA
98	-23551.2	0.00005	24922.1	17613.9	3555.0
99	-23570.3	0.00006	24977.9	17867.6	3643.6
100	NA	NA	NA	NA	NA

Table 3(18.0e). Summary of jittering results for model 18.0e. Run 62 is used for initial conditions. Runs with "NA" did not converge. The jittering factor is 0.1. Biomass and OFL are in t. The R scripts (100 runs each time) were run twice for total 200 runs; about 100 runs converged. This table has the second 100 runs.

Run	Neg.log.liklihood	Max gradient	$B_{35\%}$	B_{2019}	OFL_{2019}
1	NA	NA	NA	NA	NA
2	NA	NA	NA	NA	NA
3	-23649.0	0.00005	24985.0	17480.4	3480.6
4	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	-23667.7	0.00006	24990.3	17671.5	3550.7
9	-23655.1	0.00008	24810.2	17674.9	3587.0
10	-23649.0	0.00007	24985.0	17480.4	3480.6
11	NA	NA	NA	NA	NA
12	-23649.0	0.00004	24985.0	17480.4	3480.6
13	NA	NA	NA	NA	NA
14	-23667.9	0.00034	25054.1	17723.9	3562.1
15	NA	NA	NA	NA	NA
16	-23667.9	0.00008	25054.1	17723.9	3562.1
17	NA	NA	NA	NA	NA
18	NA	NA	NA	NA	NA
19	-23649.0	0.00017	24985.0	17480.4	3480.6
20	-23649.0	0.00004	24985.0	17480.4	3480.6
21	-23649.0	0.00003	24985.0	17480.4	3480.6
22	-23649.0	0.00005	24985.0	17480.4	3480.6
23	NA	NA	NA	NA	NA
24	-23667.7	0.00130	24990.3	17671.5	3550.7
25	NA	NA	NA	NA	NA
26	NA	NA	NA	NA	NA
27	NA	NA	NA	NA	NA
28	NA	NA	NA	NA	NA
29	NA	NA	NA	NA	NA
30	-23649.0	0.00017	24985.0	17480.4	3480.6
31	NA	NA	NA	NA	NA
32	NA	NA	NA	NA	NA
33	-23649.0	0.00021	24985.0	17480.4	3480.6
34	-23649.0	0.00007	24985.0	17480.4	3480.6
35	NA	NA	NA	NA	NA
36	NA	NA	NA	NA	NA
37	NA	NA	NA	NA	NA
38	-23641.9	0.00008	24485.5	17009.8	3344.5
39	NA	NA	NA	NA	NA
40	-23647.2	0.00002	24906.8	17443.9	3462.0
41	-23649.0	0.00003	24985.0	17480.4	3480.6
42	-23649.0	0.00002	24985.0	17480.4	3480.6
43	-23667.9	0.00005	25054.1	17723.9	3562.1
44	-23649.0	0.00004	24985.0	17480.4	3480.6
45	-23649.0	0.00028	24985.0	17480.4	3480.6
46	NA	NA	NA	NA	NA
47	-23667.9	0.00025	25054.1	17723.9	3562.1
48	NA	NA	NA	NA	NA
49	NA	NA	NA	NA	NA
50	-23649.0	0.00004	24985.0	17480.4	3480.6
51	-23666.3	0.00058	24980.2	17734.0	3583.8
52	-23649.0	0.00002	24985.0	17480.4	3480.6
53	-23647.2	0.00002	24906.8	17443.9	3462.0
54	NA	NA	NA	NA	NA
55	-23649.0	0.00008	24985.0	17480.4	3480.6
56	NA	NA	NA	NA	NA
57	-23649.0	0.00005	24985.0	17480.4	3480.6
58	-23666.4	0.00005	24994.5	17681.7	3555.5
59	NA	NA	NA	NA	NA
60	NA	NA	NA	NA	NA
61	NA	NA	NA	NA	NA
62	-23667.9	0.00001	25054.1	17723.9	3562.1
63	-23647.2	0.00002	24906.8	17443.9	3462.0
64	NA	NA	NA	NA	NA
65	-23649.0	0.00001	24985.0	17480.4	3480.6

66	-23649.0	0.00007	24985.0	17480.4	3480.6
67	-23665.7	0.00015	24994.8	17675.3	3552.5
68	NA	NA	NA	NA	NA
69	NA	NA	NA	NA	NA
70	NA	NA	NA	NA	NA
71	-23649.0	0.00002	24985.0	17480.4	3480.6
72	-23667.7	0.00009	24990.3	17671.5	3550.7
73	-23649.0	0.00004	24985.0	17480.4	3480.6
74	NA	NA	NA	NA	NA
75	NA	NA	NA	NA	NA
76	-23647.2	0.00001	24906.8	17443.9	3462.0
77	-23649.0	0.00005	24985.0	17480.4	3480.6
78	NA	NA	NA	NA	NA
79	-23649.0	0.00006	24985.0	17480.4	3480.6
80	NA	NA	NA	NA	NA
81	-23647.2	0.00001	24906.8	17443.9	3462.0
82	NA	NA	NA	NA	NA
83	-23656.0	0.00004	24868.4	17651.1	3562.5
84	-23649.0	0.00003	24985.0	17480.4	3480.6
85	-23649.0	0.00003	24985.0	17480.4	3480.6
86	-23649.0	0.00001	24985.0	17480.4	3480.6
87	NA	NA	NA	NA	NA
88	NA	NA	NA	NA	NA
89	NA	NA	NA	NA	NA
90	-23649.0	0.00004	24985.0	17480.4	3480.6
91	NA	NA	NA	NA	NA
92	NA	NA	NA	NA	NA
93	-23655.1	0.00000	24810.2	17674.9	3587.0
94	NA	NA	NA	NA	NA
95	NA	NA	NA	NA	NA
96	-23649.0	0.00002	24985.0	17480.4	3480.6
97	-23649.0	0.00002	24985.0	17480.4	3480.6
98	NA	NA	NA	NA	NA
99	NA	NA	NA	NA	NA
100	NA	NA	NA	NA	NA

Table 4a. Number of parameters and the list of likelihood components for the model (Models 18.0d, 18.0e, and 19.0 (gmacs)).

Parameter counts	**18.0d**	**18.0e**	**19.0**
Fixed growth parameters	9	9	9
Fixed recruitment parameters	2	2	2
Fixed length-weight relationship parameters	6	6	6
Fixed mortality parameters	4	4	4
Fixed survey catchability parameter	1	1	1
Fixed high grading parameters	0	0	0
Total number of fixed parameters	22	22	22
Free survey catchability parameter	1	1	1
Free growth parameters	6	6	6
Initial abundance (1975)	1	1	1
Recruitment-distribution parameters	2	2	2
Mean recruitment parameters	1	1	1
Male recruitment deviations	44	44	44
Female recruitment deviations	44	44	44
Natural mortality parameters	3	3	3
Mean & offset fishing mortality parameters	4	4	6
Pot male fishing mortality deviations	44	44	44
Bycatch mortality from the Tanner crab fishery	12	12	50
Pot female bycatch fishing mortality deviations	29	29	29
Trawl bycatch fishing mortality deviations	43	43	43
Fixed gear bycatch fishing mortality deviations	23	23	23
Initial (1975) length compositions	35	35	35
BSFRF survey extra CV	1	1	1
Free selectivity parameters	25	25	28
Total number of free parameters	318	318	361
Total number of fixed and free parameters	340	340	383

Table 4b. Negative log likelihood components for Models 18.0d, 18.0e, and 19.0 (gmacs), their differences and some management quantities. Highlighted cells in yellow color are not comparable between model 19.0 and the other two models due to different constants in likelihood functions and between model 18.0d and the other two models due to sex-specific length compositions and sex combined length compositions for Tanner crab fishery bycatch. Red values show large differences from the other models.

	Model			Difference	
Negative log likelihood	18.0d	18.0e	19.0	18.0d – 18.0e	18.0e – 19.0
R-variation	68.81	69.41	136.83	-0.60	-67.42
Length-like-retained	-3553.66	-3553.84	-3551.90	0.18	-1.94
Length-like-tot male	-2071.65	-2072.02	-2065.00	0.37	-7.02
Length-like-discfemale	-1293.43	-1292.83	-1304.17	-0.60	11.34
Length-like-survey	-6734.97	-6734.48	-6730.33	-0.49	-4.15
Length-like-disctrawl	-5461.31	-5461.65	-5446.30	0.34	-15.35
Length-like-discfix	-3057.86	-3056.94	-3004.06	-0.92	-52.88
Length-like-discTanner	-691.89	-790.47	-780.75	98.58	-9.72
Length-like-bsfrfsurvey	-854.88	-855.28	-846.14	0.40	-9.13
Catchbio_retained	17.32	17.42	-62.26	-0.10	79.68
Catchbio_tot/discmale	60.42	60.55	22.53	-0.13	38.02
Catchbio-discfemale	0.05	0.04	-50.49	0.00	50.53
Catchbio-disctrawl	0.02	0.02	-59.58	0.00	59.60
Catchbio-discfix	0.00	0.00	-87.08	0.00	87.08
Catchbio-discTanner	0.01	0.00	-31.88	0.00	31.88
Biomass-trawl survey	-7.96	-8.67	-22.06	0.71	13.39
Biomass-bsfrfsurvey	-8.90	-8.85	-7.75	-0.05	-1.10
Q-trawl survey	0.59	0.67		-0.09	
Others	19.00	19.01	340.03	-0.01	-321.02
Total	-23570	-23668	-23550	97.60	-118
Free parameters	318	318	361	0	-43
$B_{35\%}(t)$	24978	25054	21247	-76.200	3807
$F_{35\%}$	0.304	0.304	0.299	0.000	0.005
$MMB_{2019}(t)$	17868	17724	15957	143.700	1767.282
OFL_{2019}	3643.6	3562.1	3403.4	81.450	158.763
$ABC_{2019}(t)$	2914.9	2849.7	2722.7	65.160	127.010
$F_{ofl2019}$	0.208	0.205	0.216	0.003	-0.011
Q	0.923	0.925	0.925	-0.002	0.000

Table 5(18.0d). Summary of estimated model parameter values and standard deviations and limits for model 18.0d for Bristol Bay red king crab. All values are on a log scale. Male recruit in year t is exp($mean$+$males_t$), and female recruit in year t is exp($mean$+$males_t$+$females_t$).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.905	0.034	15.905	0.034	-1.570	0.041	0.013	0.001	-4.521	0.074
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.93		-6.0,3.5		-10,10	
1975					0.755	0.136				
1976	0.216	0.572	0.402	0.414	0.726	0.096			0.215	0.129
1977	0.565	0.405	0.567	0.257	0.658	0.075			0.688	0.118
1978	0.582	0.377	0.763	0.232	0.825	0.062			0.734	0.112
1979	0.830	0.284	1.157	0.197	1.130	0.056			0.915	0.110
1980	0.353	0.290	1.636	0.166	2.110	0.059			1.789	0.112
1981	0.174	0.354	0.939	0.249	2.925	0.014			1.648	0.115
1982	0.074	0.150	2.373	0.109	1.381	0.120			2.812	0.119
1983	0.207	0.222	1.464	0.142	-9.999	0.054			2.345	0.113
1984	0.765	0.172	1.118	0.125	1.026	0.096			3.349	0.115
1985	-0.233	0.410	-0.289	0.222	0.945	0.096			2.051	0.114
1986	0.735	0.172	0.425	0.124	1.191	0.074			1.005	0.113
1987	-0.089	0.377	-0.344	0.187	0.765	0.065			0.577	0.110
1988	-0.054	0.401	-0.808	0.211	-0.126	0.054			1.387	0.105
1989	-0.293	0.346	-0.517	0.176	0.010	0.049			-0.025	0.105
1990	0.243	0.179	0.268	0.111	0.703	0.044	1.947	0.088	0.439	0.105
1991	0.018	0.247	-0.111	0.134	0.693	0.046	-0.647	0.089	0.857	0.106
1992	-0.432	0.460	-1.264	0.244	0.104	0.051	2.128	0.090	0.685	0.106
1993	-0.259	0.265	-0.362	0.141	0.823	0.057	1.937	0.093	1.176	0.110
1994	-0.089	0.434	-1.198	0.249	-4.313	0.054	1.285	0.121	-0.564	0.107
1995	-0.032	0.089	1.266	0.068	-4.725	0.045	1.443	0.123	-0.846	0.105
1996	-1.051	0.442	-0.617	0.260	-0.186	0.044	-3.656	0.140	-0.782	0.105
1997	-0.889	0.435	-0.880	0.241	-0.100	0.044	-0.332	0.087	-1.248	0.105
1998	-0.610	0.308	-0.008	0.146	0.683	0.047	1.579	0.086	0.024	0.104
1999	0.023	0.150	0.721	0.096	0.299	0.045	-2.708	0.093	-0.261	0.104
2000	-0.155	0.353	-0.243	0.193	-0.275	0.044	1.179	0.083	-1.020	0.104
2001	0.186	0.353	-0.341	0.212	-0.319	0.044	0.858	0.083	-0.255	0.103
2002	0.378	0.128	0.949	0.093	-0.192	0.043	-1.937	0.088	-0.547	0.103
2003	-0.306	0.453	-0.448	0.252	0.274	0.042	1.156	0.082	-0.632	0.103
2004	-0.191	0.382	-0.185	0.206	0.259	0.042	0.360	0.083	-0.395	0.103
2005	0.128	0.154	0.868	0.095	0.555	0.044	0.859	0.083	-0.674	0.103
2006	-0.200	0.279	0.261	0.137	0.349	0.043	-1.384	0.083	-0.503	0.103
2007	-0.526	0.312	-0.074	0.148	0.662	0.043	-0.278	0.082	-0.448	0.103
2008	-0.002	0.341	-0.725	0.202	0.810	0.046	-0.548	0.084	-0.508	0.103
2009	0.234	0.323	-0.568	0.188	0.582	0.047	-0.761	0.084	-0.893	0.104
2010	0.701	0.193	0.080	0.121	0.412	0.047	-0.318	0.084	-1.073	0.104
2011	0.191	0.350	-0.336	0.165	-0.280	0.046	-1.225	0.085	-1.557	0.105
2012	0.171	0.326	-0.613	0.177	-0.337	0.046	-1.897	0.087	-2.099	0.106
2013	-0.302	0.331	-0.687	0.161	-0.191	0.047	0.116	0.083	-1.423	0.106
2014	-0.181	0.411	-1.292	0.215	0.041	0.049	-0.433	0.085	-2.054	0.108
2015	0.120	0.293	-0.799	0.177	0.080	0.053	0.672	0.087	-1.722	0.109
2016	-0.132	0.275	-0.384	0.167	-0.015	0.059	0.110	0.090	-1.224	0.110
2017	-0.312	0.402	-0.846	0.238	-0.191	0.065	-0.335	0.093	-0.877	0.112
2018	-0.284	0.398	-0.547	0.262	-0.527	0.070	0.829	0.095	-1.068	0.113
2019	-0.275	0.474	-0.773	0.317						

Table 5(18.0d) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0d for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.478	0.031	0.184, 1.0	68	1.030	0.422	-4.2. 4.2
Mf80-84	0.843	0.040	0.276, 1.5	73	0.700	0.589	-4.2, 4.2
Mf76-79,85-93	0.090	0.012	0.0, 0.108	78	0.510	0.427	-4.2, 4.2
log_betal, females	0.693	0.130	-0.67, 1.32	83	0.697	0.289	-4.2, 4.2
log_betal, males	-0.050	0.214	-0.67, 1.32	88	0.558	0.270	-4.2, 4.2
log_betar, females	-0.509	0.207	-1.14, 0.5	93	0.445	0.269	-4.2, 4.2
log_betar, males	-0.494	0.173	-1.14, 0.5	98	0.472	0.255	-4.2, 4.2
Bsfrf_CV	0.130	0.066	0.00, 0.40	103	0.334	0.271	-4.2, 4.2
moltp_slope, 75-78	0.109	0.017	0.01, 0.259	108	0.425	0.255	-4.2, 4.2
moltp_slope, 79-19	0.093	0.005	0.01, 0.259	113	0.487	0.248	-4.2, 4.2
log_moltp_L50, 75-78	4.951	0.013	4.445, 5.52	118	0.269	0.286	-4.2, 4.2
log_moltp_L50, 79-19	4.938	0.005	4.445, 5.52	123	0.281	0.281	-4.2, 4.2
log_N75	19.927	0.055	15.0, 22.0	128	0.138	0.309	-4.2, 4.2
log_avg_L50_tot	4.754	0.010	4.38, 5.45	133	0.271	0.263	-4.2, 4.2
tot_fish_slope	0.104	0.006	0.05, 0.57	138	0.080	0.198	-4.2, 4.2
Log_ret_L50, 75-04	4.922	0.002	4.6, 5.1	143	-0.185	0.196	-4.2, 4.2
Ret_fish_slope, 75-04	0.498	0.032	0.05, 0.87	148	-0.362	0.200	-4.2, 4.2
Log_ret_L50, 05-19	4.929	0.003	4.6, 5.1	153	-0.725	0.227	-4.2, 4.2
Ret_fish_slope, 05-19	0.503	0.065	0.05, 0.7	158	-1.257	0.284	-4.2, 4.2
pot disc.fema., slope	0.092	0.016	0.05, 0.43	163	-1.295	0.286	-4.2, 4.2
log_pot disc.fema., L50	4.552	0.038	4.20, 4.666	68	1.620	0.436	-4.2, 4.2
trawl disc slope	0.059	0.003	0.01, 0.20	73	1.513	0.437	-4.2, 4.2
log_trawl disc L50	5.171	0.061	4.50, 5.40	78	1.508	0.357	-4.2, 4.2
log_srv_L50, m, bsfrf	4.362	0.033	3.359, 5.48	83	1.352	0.319	-4.2, 4.2
srv_slope, f, bsfrf	0.044	0.008	0.01, 0.134	88	1.261	0.268	-4.2, 4.2
log_srv_L50, f, bsfrf	4.514	0.049	3.471, 5.539	93	0.763	0.308	-4.2, 4.2
log_srv_L50, m, 75-81	4.343	0.025	3.551, 5.864	98	0.376	0.372	-4.2, 4.2
srv_slope, f, 75-81	0.102	0.013	0.01, 0.303	103	0.103	0.428	-4.2, 4.2
log_srv_L50, f, 75-81	4.444	0.027	3.709, 4.80	108	-0.058	0.426	-4.2, 4.2
log_srv_L50, m, 82-19	4.066	0.279	3.709, 5.10	113	-0.265	0.453	-4.2, 4.2
srv_slope, f, 82-19	0.086	0.029	0.01, 0.43	118	-0.891	0.678	-4.2, 4.2
log_srv_L50, f, 82-19	4.172	0.063	3.709, 4.90	123	-1.093	0.751	-4.2, 4.2
TC_slope, females	0.339	0.104	0.02, 0.40	128	-1.465	0.917	-4.2, 4.2
log_TC_L50, females	4.530	0.015	4.24, 4.90	133	-2.561	1.950	-4.2, 4.2
TC_slope, males	0.212	0.068	0.05, 0.90	138	-2.916	2.403	-4.2, 4.2
log_TC_L50, males	4.567	0.020	4.25, 5.14	143	NA	NA	
Q	0.923	0.022	0.59, 1.2				
log_TC_F, males, 91	-4.011	0.091	-10.0, 1.00				
log_TC_F, males, 92	-5.992	0.093	-10.0, 1.00				
log_TC_F, males, 93	-6.715	0.097	-10.0, 1.00				
log_TC_F, males, 13	-8.208	0.092	-10.0, 1.00				
log_TC_F, males, 14	-7.331	0.091	-10.0, 1.00				
log_TC_F, males, 15	-6.897	0.093	-10.0, 1.00				
log_TC_F, females, 91	-2.897	0.096	-10.0, 1.00				
log_TC_F, females, 92	-4.538	0.099	-10.0, 1.00				
log_TC_F, females, 93	-6.436	0.102	-10.0, 1.00				
log_TC_F, females, 13	-7.724	0.090	-10.0, 1.00				
log_TC_F, females, 14	-7.586	0.090	-10.0, 1.00				
log_TC_F, females, 15	-6.562	0.089	-10.0, 1.00				

Table 5(18.0d) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0d for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

Fixed gear bycatch			
Parameter	Value	SD	Limits
log_avg_fmortf	-7.318	0.105	-8.5, -0.5
fmortf_96dev	0.793	0.107	-10, 10
fmortf_97dev	0.149	0.107	-10, 10
fmortf_98ev	-0.038	0.108	-10, 10
fmortf_99dev	0.862	0.104	-10, 10
fmortf_00dev	-1.596	0.121	-10, 10
fmortf_01dev	0.358	0.104	-10, 10
fmortf_02dev	0.113	0.104	-10, 10
fmortf_03dev	-0.724	0.108	-10, 10
fmortf_04dev	-0.548	0.106	-10, 10
fmortf_05dev	-0.265	0.105	-10, 10
fmortf_06dev	-0.321	0.105	-10, 10
fmortf_07ev	0.207	0.103	-10, 10
fmortf_08dev	-0.503	0.107	-10, 10
fmortf_09dev	-1.526	0.117	-10, 10
fmortf_10dev	-2.446	0.139	-10, 10
fmortf_11ev	-0.967	0.108	-10, 10
fmortf_12dev	-0.448	0.105	-10, 10
fmortf_13dev	0.666	0.102	-10, 10
fmortf_143dev	1.465	0.102	-10, 10
fmortf_15dev	1.086	0.103	-10, 10
fmortf_16dev	0.169	0.106	-10, 10
fmortf_17dev	1.719	0.105	-10, 10
fmortf_18dev	1.795	0.106	-10, 10
Fix_slo	0.079	0.007	0, 0.2
log_l50	4.876	0.037	4.5, 5.4

Table 5(18.0e). Summary of estimated model parameter values and standard deviations and limits for model 18.0e for Bristol Bay red king crab. All values are on a log scale. Male recruit in year *t* is exp(*mean*+$males_t$), and female recruit in year *t* is exp(*mean*+$males_t$+$females_t$).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.901	0.034	15.901	0.034	-1.561	0.041	0.013	0.001	-4.509	0.074
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.93		-6.0,3.5		-10,10	
1975					0.752	0.135				
1976	0.168	0.578	0.402	0.415	0.724	0.096			0.220	0.129
1977	0.532	0.412	0.571	0.257	0.659	0.075			0.691	0.118
1978	0.555	0.382	0.772	0.231	0.823	0.062			0.735	0.112
1979	0.811	0.286	1.170	0.197	1.127	0.056			0.913	0.110
1980	0.332	0.292	1.654	0.166	2.107	0.059			1.788	0.112
1981	0.143	0.358	0.956	0.247	2.925	0.017			1.646	0.115
1982	0.085	0.149	2.383	0.109	1.378	0.120			2.811	0.118
1983	0.208	0.224	1.467	0.142	-9.999	0.053			2.347	0.113
1984	0.789	0.172	1.110	0.125	1.028	0.096			3.357	0.115
1985	-0.261	0.419	-0.300	0.222	0.951	0.096			2.064	0.114
1986	0.772	0.173	0.402	0.125	1.200	0.074			1.021	0.113
1987	-0.025	0.381	-0.374	0.188	0.777	0.065			0.594	0.110
1988	0.003	0.408	-0.839	0.213	-0.112	0.054			1.402	0.105
1989	-0.269	0.360	-0.549	0.181	0.024	0.049			-0.011	0.105
1990	0.263	0.188	0.296	0.111	0.720	0.044	1.927	0.088	0.455	0.105
1991	0.041	0.264	-0.142	0.140	0.716	0.047	-0.679	0.089	0.872	0.106
1992	-0.468	0.464	-1.225	0.243	0.119	0.052	2.089	0.090	0.693	0.107
1993	-0.254	0.269	-0.353	0.142	0.839	0.058	1.897	0.093	1.185	0.110
1994	-0.110	0.442	-1.188	0.249	-4.303	0.054	1.251	0.121	-0.560	0.107
1995	-0.015	0.090	1.271	0.068	-4.722	0.045	1.420	0.123	-0.846	0.105
1996	-1.057	0.446	-0.614	0.260	-0.184	0.044	-3.671	0.140	-0.784	0.105
1997	-0.914	0.440	-0.873	0.240	-0.101	0.044	-0.341	0.087	-1.252	0.105
1998	-0.617	0.315	-0.005	0.146	0.681	0.047	1.574	0.086	0.020	0.104
1999	0.046	0.151	0.724	0.096	0.295	0.045	-2.709	0.093	-0.267	0.104
2000	-0.145	0.357	-0.238	0.193	-0.281	0.044	1.181	0.083	-1.028	0.104
2001	0.172	0.362	-0.336	0.211	-0.326	0.044	0.863	0.083	-0.263	0.103
2002	0.408	0.127	0.950	0.093	-0.199	0.043	-1.931	0.088	-0.555	0.103
2003	-0.334	0.462	-0.445	0.252	0.267	0.042	1.163	0.082	-0.641	0.103
2004	-0.201	0.390	-0.181	0.205	0.252	0.042	0.368	0.083	-0.403	0.103
2005	0.149	0.156	0.871	0.095	0.548	0.044	0.867	0.083	-0.682	0.103
2006	-0.180	0.283	0.265	0.137	0.342	0.043	-1.375	0.083	-0.510	0.103
2007	-0.534	0.318	-0.071	0.148	0.656	0.043	-0.269	0.082	-0.455	0.103
2008	-0.005	0.345	-0.720	0.201	0.803	0.046	-0.539	0.084	-0.514	0.104
2009	0.233	0.328	-0.559	0.187	0.576	0.048	-0.752	0.084	-0.898	0.104
2010	0.709	0.205	0.060	0.125	0.405	0.047	-0.308	0.084	-1.079	0.105
2011	0.166	0.360	-0.297	0.165	-0.287	0.046	-1.213	0.085	-1.563	0.105
2012	0.120	0.342	-0.599	0.181	-0.344	0.046	-1.882	0.087	-2.106	0.107
2013	-0.238	0.340	-0.748	0.172	-0.198	0.047	0.133	0.084	-1.430	0.106
2014	-0.171	0.420	-1.315	0.216	0.035	0.049	-0.415	0.085	-2.059	0.108
2015	0.132	0.294	-0.798	0.175	0.075	0.054	0.690	0.087	-1.727	0.109
2016	-0.132	0.278	-0.390	0.166	-0.023	0.059	0.132	0.090	-1.230	0.110
2017	-0.312	0.406	-0.847	0.237	-0.197	0.065	-0.315	0.093	-0.882	0.112
2018	-0.290	0.402	-0.550	0.261	-0.528	0.070	0.845	0.095	-1.070	0.114
2019	-0.304	0.478	-0.770	0.316						

Table 5(18.0e) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0e for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.484	0.031	0.184, 1.0	68	1.034	0.423	-4.0,4.0
Mf80-84	0.844	0.040	0.276, 1.5	73	0.703	0.592	-4.0,4.0
Mf76-79,85-93	0.089	0.012	0.0, 0.108	78	0.512	0.430	-4.0,4.0
log_betal, females	0.749	0.133	-0.67, 1.32	83	0.704	0.291	-4.0,4.0
log_betal, males	-0.042	0.213	-0.67, 1.32	88	0.563	0.271	-4.0,4.0
log_betar, females	-0.470	0.213	-1.14, 0.5	93	0.449	0.270	-4.0,4.0
log_betar, males	-0.501	0.173	-1.14, 0.5	98	0.476	0.255	-4.0,4.0
Bsfrf_CV	0.131	0.067	0.00, 0.40	103	0.337	0.271	-4.0,4.0
moltp_slope, 75-78	0.109	0.017	0.01, 0.259	108	0.429	0.255	-4.0,4.0
moltp_slope, 79-19	0.093	0.005	0.01, 0.259	113	0.491	0.248	-4.0,4.0
log_moltp_L50, 75-78	4.951	0.013	4.445, 5.52	118	0.273	0.286	-4.0,4.0
log_moltp_L50, 79-19	4.939	0.005	4.445, 5.52	123	0.285	0.282	-4.0,4.0
log_N75	19.916	0.054	15.0, 22.0	128	0.142	0.309	-4.0,4.0
log_avg_L50_tot	4.754	0.010	4.38, 5.45	133	0.275	0.263	-4.0,4.0
tot_fish_slope	0.104	0.006	0.05, 0.57	138	0.085	0.198	-4.0,4.0
Log_ret_L50, 75-04	4.922	0.002	4.6, 5.1	143	-0.179	0.195	-4.0,4.0
Ret_fish_slope, 75-04	0.498	0.032	0.05, 0.87	148	-0.356	0.200	-4.0,4.0
Log_ret_L50, 05-19	4.929	0.003	4.6, 5.1	153	-0.719	0.227	-4.0,4.0
Ret_fish_slope, 05-19	0.504	0.066	0.05, 0.7	158	-1.251	0.284	-4.0,4.0
pot disc.fema., slope	0.092	0.016	0.05, 0.43	163	-1.289	0.286	-4.0,4.0
log_pot disc.fema., L50	4.553	0.039	4.20, 4.666	68	1.634	0.427	-4.0,4.0
trawl disc slope	0.059	0.003	0.01, 0.20	73	1.513	0.431	-4.0,4.0
log_trawl disc L50	5.175	0.062	4.50, 5.40	78	1.492	0.354	-4.0,4.0
log_srv_L50, m, bsfrf	4.360	0.033	3.359, 5.48	83	1.333	0.318	-4.0,4.0
srv_slope, f, bsfrf	0.042	0.008	0.01, 0.134	88	1.250	0.270	-4.0,4.0
log_srv_L50, f, bsfrf	4.528	0.052	3.471, 5.539	93	0.760	0.307	-4.0,4.0
log_srv_L50, m, 75-81	4.344	0.025	3.551, 5.864	98	0.374	0.372	-4.0,4.0
srv_slope, f, 75-81	0.103	0.013	0.01, 0.303	103	0.098	0.432	-4.0,4.0
log_srv_L50, f, 75-81	4.441	0.027	3.709, 4.80	108	-0.067	0.432	-4.0,4.0
log_srv_L50, m, 82-19	4.085	0.264	3.709, 5.10	113	-0.259	0.454	-4.0,4.0
srv_slope, f, 82-19	0.086	0.028	0.01, 0.43	118	-0.899	0.686	-4.0,4.0
log_srv_L50, f, 82-19	4.175	0.063	3.709, 4.90	123	-1.090	0.752	-4.0,4.0
TC_slope, females	0.375	0.149	0.02, 0.40	128	-1.475	0.928	-4.0,4.0
log_TC_L50, females	4.510	0.017	4.24, 4.90	133	-2.571	1.971	-4.0,4.0
TC_slope, males	0.146	0.072	0.05, 0.90	138	-2.936	2.452	-4.0,4.0
log_TC_L50, males	4.614	0.041	4.25, 5.14	143	NA	NA	
Q	0.925	0.022	0.59, 1.2				
log_TC_F, males, 91	-5.193	0.100	-10.0, 1.00				
log_TC_F, males, 92	-7.155	0.109	-10.0, 1.00				
log_TC_F, males, 93	-7.411	0.115	-10.0, 1.00				
log_TC_F, males, 13	-9.490	0.117	-10.0, 1.00				
log_TC_F, males, 14	-8.213	0.101	-10.0, 1.00				
log_TC_F, males, 15	-8.250	0.103	-10.0, 1.00				
log_TC_F, females, 91	-3.302	0.095	-10.0, 1.00				
log_TC_F, females, 92	-4.961	0.098	-10.0, 1.00				
log_TC_F, females, 93	-7.133	0.102	-10.0, 1.00				
log_TC_F, females, 13	-8.056	0.092	-10.0, 1.00				
log_TC_F, females, 14	-8.112	0.092	-10.0, 1.00				
log_TC_F, females, 15	-6.860	0.089	-10.0, 1.00				

Table 5(18.0e) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0e for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

Fixed gear bycatch			
Parameter	Value	SD	Limits
log_avg_fmortf	-7.321	0.109	-8.5, -0.5
fmortf_96dev	0.794	0.107	-10, 10
fmortf_97dev	0.149	0.107	-10, 10
fmortf_98ev	-0.040	0.108	-10, 10
fmortf_99dev	0.860	0.104	-10, 10
fmortf_00dev	-1.598	0.121	-10, 10
fmortf_01dev	0.356	0.104	-10, 10
fmortf_02dev	0.112	0.104	-10, 10
fmortf_03dev	-0.725	0.108	-10, 10
fmortf_04dev	-0.550	0.106	-10, 10
fmortf_05dev	-0.266	0.105	-10, 10
fmortf_06dev	-0.322	0.105	-10, 10
fmortf_07ev	0.206	0.103	-10, 10
fmortf_08dev	-0.504	0.107	-10, 10
fmortf_09dev	-1.527	0.117	-10, 10
fmortf_10dev	-2.447	0.139	-10, 10
fmortf_11ev	-0.968	0.108	-10, 10
fmortf_12dev	-0.447	0.105	-10, 10
fmortf_13dev	0.668	0.102	-10, 10
fmortf_143dev	1.466	0.102	-10, 10
fmortf_15dev	1.087	0.103	-10, 10
fmortf_16dev	0.171	0.106	-10, 10
fmortf_17dev	1.723	0.105	-10, 10
fmortf_18dev	1.802	0.106	
Fix_slo	0.079	0.007	0, 0.2
log_l50	4.876	0.038	4.5, 5.4

Table 5(19.0 (gmacs)). Summary of estimated model parameter values and standard deviations for model 19.0 for Bristol Bay red king crab.

index	name	value	std.dev	index	name	value	std.dev
1	theta[4]	19.8860	0.0541	47	log_slx_pars[2]	2.2279	0.0601
2	theta[5]	15.8870	0.0357	48	log_slx_pars[3]	4.4324	0.0158
3	theta[7]	0.6174	0.1108	49	log_slx_pars[4]	1.3801	0.2385
4	theta[9]	-0.6054	0.2492	50	log_slx_pars[5]	5.1654	0.0622
5	theta[13]	0.9618	0.3275	51	log_slx_pars[6]	2.8603	0.0458
6	theta[14]	0.5115	0.3800	52	log_slx_pars[7]	4.7531	0.1952
7	theta[15]	0.6825	0.2992	53	log_slx_pars[8]	2.7840	0.6570
8	theta[16]	0.5458	0.2856	54	log_slx_pars[9]	4.5120	0.0189
9	theta[17]	0.3997	0.2844	55	log_slx_pars[10]	0.9697	0.4020
10	theta[18]	0.3918	0.2726	56	log_slx_pars[11]	4.7388	0.0193
11	theta[19]	0.2547	0.2794	57	log_slx_pars[12]	2.2370	0.1008
12	theta[20]	0.3117	0.2700	58	log_slx_pars[13]	4.1055	0.2218
13	theta[21]	0.3607	0.2659	59	log_slx_pars[14]	1.9086	0.9221
14	theta[22]	0.1665	0.2875	60	log_slx_pars[15]	4.1919	0.1679
15	theta[23]	0.1792	0.2830	61	log_slx_pars[16]	3.2211	0.3563
16	theta[24]	0.0680	0.2956	62	log_slx_pars[17]	4.2620	0.0776
17	theta[25]	0.1355	0.2777	63	log_slx_pars[18]	2.2824	0.2724
18	theta[26]	0.0404	0.2197	64	log_slx_pars[19]	3.7585	437.38
19	theta[27]	-0.1844	0.2132	65	log_slx_pars[20]	0.3462	705.80
20	theta[28]	-0.3530	0.2156	66	log_slx_pars[21]	4.3311	0.0392
21	theta[29]	-0.6881	0.2306	67	log_slx_pars[22]	2.2613	0.1368
22	theta[30]	-1.1358	0.2519	68	log_slx_pars[23]	4.4430	0.0120
23	theta[31]	-1.1660	0.2538	69	log_slx_pars[24]	2.3198	0.0678
24	theta[52]	0.4016	0.8919	70	log_slx_pars[25]	4.9221	0.0016
25	theta[53]	1.7498	0.5125	71	log_slx_pars[26]	0.6971	0.0658
26	theta[54]	1.7336	0.4210	72	log_slx_pars[27]	4.9285	0.0022
27	theta[55]	1.3695	0.3630	73	log_slx_pars[28]	0.6875	0.1266
28	theta[56]	1.1422	0.3196	74	log_fbar[1]	-1.5107	0.0444
29	theta[57]	0.6046	0.3435	75	log_fbar[2]	-4.2908	0.0793
30	theta[58]	0.2403	0.3631	76	log_fbar[3]	-5.3966	0.2026
31	theta[59]	0.0141	0.3652	77	log_fbar[4]	-6.8678	0.0621
32	theta[60]	-0.1622	0.3523	78	log_fdev[1]	0.6155	0.1227
33	theta[61]	-0.4977	0.3726	79	log_fdev[1]	0.6255	0.0905
34	theta[62]	-0.8844	0.3846	80	log_fdev[1]	0.5777	0.0722
35	theta[63]	-1.1433	0.3900	81	log_fdev[1]	0.7350	0.0604
36	theta[64]	-1.3765	0.3888	82	log_fdev[1]	1.0144	0.0557
37	theta[65]	-1.7565	0.3775	83	log_fdev[1]	1.9643	0.0661
38	theta[66]	-1.8673	0.3735	84	log_fdev[1]	2.5926	0.2089
39	theta[67]	-1.8070	0.3523	85	log_fdev[1]	0.9540	0.2505
40	Grwth[21]	0.9626	0.1940	86	log_fdev[1]	-8.9290	0.1417
41	Grwth[42]	1.4708	0.1303	87	log_fdev[1]	0.9397	0.1057
42	Grwth[85]	139.9700	1.6684	88	log_fdev[1]	0.9554	0.0977
43	Grwth[86]	0.0624	0.0094	89	log_fdev[1]	1.1917	0.0777
44	Grwth[87]	139.1200	0.7011	90	log_fdev[1]	0.7571	0.0674
45	Grwth[88]	0.0773	0.0043	91	log_fdev[1]	-0.1530	0.0556
46	log_slx_pars[1]	4.7552	0.0093	92	log_fdev[1]	-0.0138	0.0502
93	log_fdev[1]	0.6557	0.0422	143	log_fdev[2]	-1.1511	0.1042
94	log_fdev[1]	0.6747	0.0445	144	log_fdev[2]	0.1750	0.1047

95	log_fdev[1]	0.1602	0.0484	145	log_fdev[2]	-0.1168	0.1044
96	log_fdev[1]	0.8438	0.0525	146	log_fdev[2]	-0.8987	0.1036
97	log_fdev[1]	-4.2843	0.0504	147	log_fdev[2]	-0.1523	0.1034
98	log_fdev[1]	-4.6742	0.0439	148	log_fdev[2]	-0.4695	0.1030
99	log_fdev[1]	-0.1833	0.0428	149	log_fdev[2]	-0.5752	0.1028
100	log_fdev[1]	-0.1125	0.0439	150	log_fdev[2]	-0.3584	0.1027
101	log_fdev[1]	0.8635	0.0473	151	log_fdev[2]	-0.6603	0.1026
102	log_fdev[1]	0.4649	0.0465	152	log_fdev[2]	-0.5177	0.1023
103	log_fdev[1]	-0.1397	0.0450	153	log_fdev[2]	-0.4748	0.1024
104	log_fdev[1]	-0.2347	0.0444	154	log_fdev[2]	-0.5454	0.1027
105	log_fdev[1]	-0.1348	0.0431	155	log_fdev[2]	-0.9367	0.1030
106	log_fdev[1]	0.3228	0.0418	156	log_fdev[2]	-1.1173	0.1033
107	log_fdev[1]	0.2714	0.0419	157	log_fdev[2]	-1.5942	0.1034
108	log_fdev[1]	0.5351	0.0422	158	log_fdev[2]	-2.1316	0.1038
109	log_fdev[1]	0.2559	0.0414	159	log_fdev[2]	-1.4479	0.1043
110	log_fdev[1]	0.5998	0.0414	160	log_fdev[2]	-2.0697	0.1051
111	log_fdev[1]	0.7377	0.0435	161	log_fdev[2]	-1.7339	0.1066
112	log_fdev[1]	0.5134	0.0446	162	log_fdev[2]	-1.2293	0.1087
113	log_fdev[1]	0.3531	0.0448	163	log_fdev[2]	-0.8725	0.1111
114	log_fdev[1]	-0.2887	0.0447	164	log_fdev[2]	-0.9585	0.1134
115	log_fdev[1]	-0.3695	0.0448	165	log_fdev[3]	-0.0389	0.0685
116	log_fdev[1]	-0.2139	0.0459	166	log_fdev[3]	-0.0389	0.0685
117	log_fdev[1]	0.0891	0.0484	167	log_fdev[3]	1.7534	0.0685
118	log_fdev[1]	0.0901	0.0531	168	log_fdev[3]	1.4486	0.0685
119	log_fdev[1]	0.0036	0.0600	169	log_fdev[3]	1.6752	0.0685
120	log_fdev[1]	-0.1669	0.0677	170	log_fdev[3]	2.5536	0.0685
121	log_fdev[1]	-0.4594	0.0746	171	log_fdev[3]	1.4425	0.0685
122	log_fdev[2]	0.1107	0.1243	172	log_fdev[3]	1.6004	0.0685
123	log_fdev[2]	0.6006	0.1154	173	log_fdev[3]	-0.2471	0.0685
124	log_fdev[2]	0.6425	0.1105	174	log_fdev[3]	0.9281	0.0685
125	log_fdev[2]	0.7947	0.1100	175	log_fdev[3]	0.4544	0.0685
126	log_fdev[2]	1.6043	0.1183	176	log_fdev[3]	0.9396	0.0685
127	log_fdev[2]	1.3880	0.1535	177	log_fdev[3]	1.6528	0.0685
128	log_fdev[2]	2.6138	0.1518	178	log_fdev[3]	1.6604	0.0685
129	log_fdev[2]	2.2314	0.1267	179	log_fdev[3]	3.0526	0.0718
130	log_fdev[2]	3.3382	0.1194	180	log_fdev[3]	1.1358	0.0730
131	log_fdev[2]	2.0779	0.1145	181	log_fdev[3]	0.4561	0.0883
132	log_fdev[2]	1.0265	0.1130	182	log_fdev[3]	-2.9934	0.0685
133	log_fdev[2]	0.5915	0.1099	183	log_fdev[3]	-3.9509	0.0685
134	log_fdev[2]	1.3964	0.1053	184	log_fdev[3]	-3.7277	0.0685
135	log_fdev[2]	-0.0157	0.1043	185	log_fdev[3]	-3.7277	0.0685
136	log_fdev[2]	0.4572	0.1044	186	log_fdev[3]	-4.6440	0.0685
137	log_fdev[2]	0.9000	0.1056	187	log_fdev[3]	-1.1889	0.0726
138	log_fdev[2]	0.7557	0.1059	188	log_fdev[3]	-0.3115	0.0736
139	log_fdev[2]	1.2731	0.1087	189	log_fdev[3]	0.1158	0.0797
140	log_fdev[2]	-0.4836	0.1056	190	log_fdev[4]	0.9289	0.1026
141	log_fdev[2]	-0.7720	0.1041	191	log_fdev[4]	0.2325	0.1017
142	log_fdev[2]	-0.6946	0.1043	192	log_fdev[4]	-0.0097	0.1023
193	log_fdev[4]	0.9084	0.1013	243	log_fdov[1]	0.9102	0.0911
194	log_fdev[4]	-1.5264	0.1008	244	log_fdov[3]	0.0003	0.0967
195	log_fdev[4]	0.4067	0.1003	245	log_fdov[3]	0.0001	0.0967
196	log_fdev[4]	0.1346	0.0999	246	log_fdov[3]	0.0003	0.0967

197	log_fdev[4]	-0.7100	0.0997	247	log_fdov[3]	0.0009	0.0967
198	log_fdev[4]	-0.5622	0.0995	248	log_fdov[3]	0.0008	0.0967
199	log_fdev[4]	-0.3183	0.0994	249	log_fdov[3]	-0.0015	0.0966
200	log_fdev[4]	-0.3793	0.0991	250	log_fdov[3]	-0.0002	0.0967
201	log_fdev[4]	0.1302	0.0991	251	log_fdov[3]	-0.0001	0.0967
202	log_fdev[4]	-0.6114	0.0993	252	log_fdov[3]	0.0000	0.0967
203	log_fdev[4]	-1.6296	0.0991	253	log_fdov[3]	0.0000	0.0967
204	log_fdev[4]	-2.5230	0.0990	254	log_fdov[3]	-0.0002	0.0966
205	log_fdev[4]	-1.0074	0.0991	255	log_fdov[3]	0.0001	0.0967
206	log_fdev[4]	-0.4714	0.0993	256	log_fdov[3]	-0.0010	0.0966
207	log_fdev[4]	0.6424	0.0996	257	log_fdov[3]	0.0004	0.0967
208	log_fdev[4]	1.4444	0.1002	258	log_fdov[3]	0.5920	0.0990
209	log_fdev[4]	1.0746	0.1012	259	log_fdov[3]	0.8809	0.0979
210	log_fdev[4]	0.1743	0.1025	260	log_fdov[3]	-0.2725	0.1096
211	log_fdev[4]	1.7446	0.1041	261	log_fdov[3]	0.0000	0.0967
212	log_fdev[4]	1.9272	0.1055	262	log_fdov[3]	0.0000	0.0967
213	log_foff[1]	-2.9047	0.0389	263	log_fdov[3]	0.0000	0.0967
214	log_foff[3]	0.4411	0.1912	264	log_fdov[3]	0.0000	0.0967
215	log_fdov[1]	2.1181	0.0843	265	log_fdov[3]	0.0000	0.0967
216	log_fdov[1]	-0.5204	0.0840	266	log_fdov[3]	-0.1086	0.0977
217	log_fdov[1]	2.2075	0.0847	267	log_fdov[3]	-0.8455	0.0978
218	log_fdov[1]	2.1379	0.0870	268	log_fdov[3]	-0.2463	0.1007
219	log_fdov[1]	-0.0764	0.0871	269	rec_dev_est	1.6057	0.2177
220	log_fdov[1]	0.0929	0.0843	270	rec_dev_est	1.1328	0.2703
221	log_fdov[1]	-3.5509	0.0846	271	rec_dev_est	1.4406	0.2157
222	log_fdov[1]	-0.2319	0.0813	272	rec_dev_est	2.0024	0.1698
223	log_fdov[1]	1.5432	0.0822	273	rec_dev_est	2.1532	0.1867
224	log_fdov[1]	-2.7062	0.0816	274	rec_dev_est	1.4204	0.2183
225	log_fdov[1]	1.1940	0.0810	275	rec_dev_est	2.4533	0.1020
226	log_fdov[1]	0.9071	0.0807	276	rec_dev_est	1.7026	0.1147
227	log_fdov[1]	-1.8467	0.0800	277	rec_dev_est	1.5312	0.0962
228	log_fdov[1]	1.2166	0.0803	278	rec_dev_est	-0.2839	0.1992
229	log_fdov[1]	0.4402	0.0797	279	rec_dev_est	0.8487	0.0959
230	log_fdov[1]	1.0067	0.0799	280	rec_dev_est	-0.3309	0.2053
231	log_fdov[1]	-1.2075	0.0789	281	rec_dev_est	-0.7010	0.2792
232	log_fdov[1]	-0.1519	0.0789	282	rec_dev_est	-0.8406	0.1952
233	log_fdov[1]	-0.4046	0.0795	283	rec_dev_est	0.4051	0.0983
234	log_fdov[1]	-0.6073	0.0798	284	rec_dev_est	-0.3699	0.1419
235	log_fdov[1]	-0.1566	0.0797	285	rec_dev_est	-1.6763	0.2988
236	log_fdov[1]	-1.1315	0.0788	286	rec_dev_est	-0.7517	0.1451
237	log_fdov[1]	-1.7937	0.0786	287	rec_dev_est	-1.8760	0.3490
238	log_fdov[1]	0.2206	0.0790	288	rec_dev_est	1.1290	0.0572
239	log_fdov[1]	-0.3855	0.0798	289	rec_dev_est	-0.6753	0.1897
240	log_fdov[1]	0.7779	0.0815	290	rec_dev_est	-1.3762	0.2777
241	log_fdov[1]	0.2223	0.0842	291	rec_dev_est	-0.2849	0.1319
242	log_fdov[1]	-0.2250	0.0875	292	rec_dev_est	0.5601	0.0809
293	rec_dev_est	-0.3057	0.1626	336	logit_rec_prop_est	0.2585	0.1512
294	rec_dev_est	-0.2522	0.1781	337	logit_rec_prop_est	0.6368	0.3684
295	rec_dev_est	0.9736	0.0807	338	logit_rec_prop_est	-0.4041	0.3532
296	rec_dev_est	-0.4218	0.2205	339	logit_rec_prop_est	0.0362	0.1364
297	rec_dev_est	-0.4082	0.2059	340	logit_rec_prop_est	-0.2141	0.4344
298	rec_dev_est	0.8933	0.0777	341	logit_rec_prop_est	0.4569	0.4442

299	rec_dev_est	0.0825	0.1280	342	logit_rec_prop_est	-0.1929	0.1355
300	rec_dev_est	-0.2140	0.1314	343	logit_rec_prop_est	0.4468	0.2792
301	rec_dev_est	-0.8396	0.1999	344	logit_rec_prop_est	0.3874	0.2764
302	rec_dev_est	-0.6482	0.1844	345	logit_rec_prop_est	0.0264	0.3914
303	rec_dev_est	0.2996	0.1036	346	logit_rec_prop_est	-0.0992	0.3579
304	rec_dev_est	-0.1679	0.1455	347	logit_rec_prop_est	-0.5159	0.1872
305	rec_dev_est	-0.6478	0.1741	348	logit_rec_prop_est	0.0047	0.2806
306	rec_dev_est	-0.9285	0.1704	349	logit_rec_prop_est	-0.1722	0.3350
307	rec_dev_est	-1.5382	0.2471	350	logit_rec_prop_est	0.3882	0.3480
308	rec_dev_est	-1.0039	0.1735	351	logit_rec_prop_est	-0.0192	0.4778
309	rec_dev_est	-0.5503	0.1469	352	logit_rec_prop_est	0.2204	0.3377
310	rec_dev_est	-1.3767	0.2872	353	logit_rec_prop_est	0.2387	0.2801
311	rec_dev_est	-0.9514	0.2801	354	logit_rec_prop_est	0.5659	0.5737
312	rec_dev_est	-1.2133	0.4045	355	logit_rec_prop_est	0.3806	0.5224
313	logit_rec_prop_est	-0.6920	0.3714	356	logit_rec_prop_est	-0.1638	0.7338
314	logit_rec_prop_est	-1.1781	0.4992	357	m_dev_est[1]	1.4105	0.0492
315	logit_rec_prop_est	-0.7408	0.3643	358	m_dev_est[3]	0.5628	0.0388
316	logit_rec_prop_est	-1.0340	0.2759	359	m_dev_est[4]	1.8791	0.0353
317	logit_rec_prop_est	-0.5971	0.2758	360	survey_q[1]	0.9247	0.0246
318	logit_rec_prop_est	-0.6504	0.3470	361	log_add_cv[2]	-1.2996	0.3189
319	logit_rec_prop_est	0.1114	0.1575	362	sd_rbar	15607000	434050
320	logit_rec_prop_est	-0.0593	0.2092	363	sd_ssbF0	60706.0	24341.0
321	logit_rec_prop_est	-0.5666	0.1771	364	sd_Bmsy	21247.0	8519.3
322	logit_rec_prop_est	-0.0358	0.3901	365	sd_depl	0.7510	0.2551
323	logit_rec_prop_est	-0.7848	0.1778	366	sd_fmsy	0.2990	0.0051
324	logit_rec_prop_est	-0.1967	0.3894	367	sd_fmsy	0.0038	0.0004
325	logit_rec_prop_est	-0.5111	0.4979	368	sd_fmsy	0.0017	0.0003
326	logit_rec_prop_est	0.8451	0.4901	369	sd_fmsy	0.0044	0.0003
327	logit_rec_prop_est	-0.4149	0.1724	370	sd_fmsy	0.0000	0.0000
328	logit_rec_prop_est	0.4282	0.3097	371	sd_fmsy	0.0000	0.0000
329	logit_rec_prop_est	0.4718	0.6161	372	sd_fofl	0.2163	0.0848
330	logit_rec_prop_est	0.3344	0.2944	373	sd_fofl	0.0038	0.0004
331	logit_rec_prop_est	-0.5598	0.6403	374	sd_fofl	0.0017	0.0003
332	logit_rec_prop_est	0.1098	0.0834	375	sd_fofl	0.0044	0.0003
333	logit_rec_prop_est	1.9895	0.6395	376	sd_fofl	0.0000	0.0000
334	logit_rec_prop_est	0.6947	0.5815	377	sd_fofl	0.0000	0.0000
335	logit_rec_prop_est	0.7705	0.3058	378	sd_ofl	3403.4	1211.0

Table 6(18.0d). 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 analysis (model 18.0d) from 1975-2019. Mature male biomass 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	60.031	29.488	87.311	9.288	61.746		254.789	202.731
1976	69.275	36.952	102.099	8.245	98.922	27.072	290.871	331.868
1977	72.498	42.178	109.316	6.572	122.581	39.315	296.211	375.661
1978	73.932	44.272	107.789	4.732	117.258	48.334	282.262	349.545
1979	63.591	42.902	84.055	3.072	103.569	84.667	255.690	167.627
1980	43.303	32.196	20.017	0.787	97.763	100.486	222.204	249.322
1981	12.192	6.733	3.314	0.344	46.200	45.250	92.560	132.669
1982	4.881	1.364	4.023	0.464	21.841	180.012	47.927	143.740
1983	5.407	1.658	6.195	0.507	16.642	77.943	46.066	49.320
1984	6.207	2.367	5.372	0.501	17.408	77.817	46.872	155.311
1985	8.630	2.221	11.243	0.799	15.317	10.849	37.452	34.535
1986	13.643	5.195	17.199	1.153	20.986	38.143	48.057	48.158
1987	15.759	7.429	22.355	1.328	24.785	10.972	53.251	70.263
1988	15.796	9.195	26.816	1.382	28.180	7.017	55.674	55.372
1989	16.735	10.461	29.296	1.333	25.562	8.411	57.424	55.941
1990	16.370	11.068	25.506	1.275	21.494	24.044	56.949	60.321
1991	12.875	9.342	20.169	1.222	19.971	14.599	51.241	85.055
1992	10.279	7.233	18.893	1.187	20.443	3.765	45.966	37.687
1993	11.246	6.787	16.882	1.213	18.746	9.973	44.995	53.703
1994	11.059	6.353	22.462	1.279	15.799	4.672	40.190	32.335
1995	11.693	8.248	25.598	1.274	15.489	56.406	47.164	38.396
1996	12.033	9.022	24.061	1.225	21.338	5.881	55.815	44.649
1997	11.559	8.285	22.850	1.214	28.840	4.732	60.793	85.277
1998	16.872	8.146	26.033	1.389	27.247	12.366	64.458	85.176
1999	18.139	10.134	30.141	1.566	24.168	33.605	64.281	65.604
2000	15.770	11.299	30.262	1.563	26.339	11.771	66.438	68.102
2001	15.320	10.926	30.228	1.518	30.027	12.663	69.980	53.188
2002	17.758	10.833	33.430	1.514	30.202	51.313	75.199	69.786
2003	18.613	12.132	32.903	1.494	36.251	8.961	80.561	116.794
2004	16.951	11.797	30.450	1.433	42.993	12.263	81.979	131.910
2005	18.800	11.012	30.796	1.404	41.117	41.140	84.116	107.341
2006	18.452	11.520	31.622	1.405	42.233	19.076	85.210	95.676
2007	16.926	11.590	27.371	1.357	46.143	11.941	87.600	104.841
2008	17.782	10.147	26.911	1.421	44.567	7.824	85.630	114.430
2009	18.257	10.367	29.039	1.526	40.562	10.366	81.532	91.673
2010	17.122	11.060	28.819	1.532	37.170	26.395	78.826	81.642
2011	14.805	10.678	28.941	1.486	38.061	12.760	76.276	67.053
2012	13.616	10.285	27.827	1.427	40.705	9.577	76.212	61.248
2013	13.764	9.651	27.401	1.402	39.424	7.068	74.994	62.410
2014	13.719	9.513	26.299	1.410	36.202	4.072	71.898	114.103
2015	12.571	9.111	24.192	1.421	32.206	7.728	67.046	64.240
2016	11.157	8.318	22.115	1.432	28.730	10.334	61.908	61.231
2017	9.681	7.502	20.025	1.421	26.873	6.007	57.679	52.922
2018	8.793	6.678	18.984	1.414	25.180	8.195	54.449	28.932
2019	9.040	6.333	17.868	1.257	23.196	6.562	52.381	28.744

Table 6(18.0e). 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 analysis (model 18.0e) from 1975-2019. Mature male biomass 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	59.708	29.357	86.794	9.288	60.901		253.555	202.731
1976	68.850	36.736	101.362	8.245	97.382	26.264	289.362	331.868
1977	72.022	41.881	108.769	6.572	120.490	38.495	294.618	375.661
1978	73.648	44.072	107.463	4.732	115.766	47.767	281.477	349.545
1979	63.458	42.791	84.008	3.072	102.577	84.296	255.554	167.627
1980	43.342	32.195	20.032	0.787	97.257	100.718	222.907	249.322
1981	12.233	6.738	3.304	0.344	46.243	45.065	93.241	132.669
1982	4.881	1.361	4.014	0.464	21.824	182.201	48.027	143.740
1983	5.399	1.654	6.161	0.507	16.891	77.868	46.141	49.320
1984	6.169	2.353	5.308	0.501	17.529	78.203	46.770	155.311
1985	8.533	2.195	11.083	0.799	15.458	10.554	37.153	34.535
1986	13.469	5.131	16.896	1.153	21.079	38.069	47.599	48.158
1987	15.495	7.308	21.899	1.328	24.976	10.932	52.594	70.263
1988	15.497	9.019	26.274	1.382	28.397	6.966	54.890	55.372
1989	16.395	10.260	28.713	1.333	25.903	8.197	56.598	55.941
1990	16.028	10.854	24.875	1.275	21.900	24.902	56.285	60.321
1991	12.553	9.117	19.715	1.222	20.524	14.259	50.724	85.055
1992	10.074	7.078	18.456	1.187	21.223	3.846	45.964	37.687
1993	11.142	6.648	16.573	1.213	19.416	10.036	45.089	53.703
1994	10.961	6.268	22.188	1.279	16.362	4.649	40.307	32.335
1995	11.596	8.172	25.337	1.274	15.954	56.942	47.335	38.396
1996	11.967	8.951	23.859	1.225	21.905	5.870	56.017	44.649
1997	11.511	8.232	22.694	1.214	29.361	4.709	60.995	85.277
1998	16.838	8.109	25.916	1.389	27.773	12.327	64.665	85.176
1999	18.115	10.111	30.061	1.566	24.610	33.962	64.496	65.604
2000	15.748	11.285	30.203	1.563	26.807	11.835	66.642	68.102
2001	15.298	10.914	30.180	1.518	30.502	12.576	70.161	53.188
2002	17.734	10.822	33.384	1.514	30.655	52.111	75.405	69.786
2003	18.593	12.123	32.863	1.494	36.872	8.847	80.750	116.794
2004	16.932	11.789	30.415	1.433	43.657	12.209	82.119	131.910
2005	18.770	11.004	30.747	1.404	41.753	41.545	84.242	107.341
2006	18.419	11.508	31.566	1.405	42.891	19.243	85.317	95.676
2007	16.894	11.574	27.313	1.357	46.809	11.891	87.681	104.841
2008	17.748	10.130	26.848	1.421	45.228	7.816	85.689	114.430
2009	18.226	10.350	28.978	1.526	41.129	10.405	81.574	91.673
2010	17.093	11.045	28.763	1.532	37.648	25.902	78.815	81.642
2011	14.781	10.663	28.894	1.486	38.408	13.040	76.183	67.053
2012	13.594	10.273	27.785	1.427	40.847	9.407	76.040	61.248
2013	13.700	9.637	27.306	1.402	39.508	6.811	74.757	62.410
2014	13.687	9.478	26.236	1.410	36.207	3.981	71.607	114.103
2015	12.587	9.097	24.211	1.421	32.194	7.760	66.717	64.240
2016	11.121	8.330	22.069	1.432	28.736	10.225	61.548	61.231
2017	9.588	7.480	19.882	1.421	26.872	5.976	57.261	52.922
2018	8.694	6.620	18.799	1.414	25.149	8.121	53.989	28.932
2019	8.938	6.263	17.724	1.257	23.157	6.475	51.898	28.744

Table 6(19.0 (gmacs)). 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 analysis (model 19.0) from 1975-2019. Mature male biomass 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	60.013	31.266	89.668	9.026	59.402		245.609	199.643
1976	68.767	37.982	103.099	8.150	101.748	79.100	286.741	327.615
1977	73.301	42.737	111.413	6.758	127.694	49.292	297.867	371.223
1978	76.290	45.682	112.315	5.184	122.553	67.057	288.972	343.189
1979	65.780	44.876	88.970	3.893	110.496	117.610	265.792	165.449
1980	46.428	34.324	22.284	1.449	107.015	136.747	237.289	247.226
1981	13.282	7.357	4.406	1.000	48.577	65.721	95.769	131.145
1982	5.844	1.798	5.002	0.853	22.574	184.622	56.314	141.898
1983	5.827	2.023	6.485	0.624	14.163	87.142	51.163	48.476
1984	6.089	2.425	5.002	0.482	13.672	73.417	48.779	152.607
1985	8.160	2.119	10.494	0.779	10.874	11.954	37.092	34.138
1986	13.016	5.016	16.119	1.122	15.728	37.103	47.952	47.434
1987	15.244	7.162	21.384	1.297	19.162	11.406	53.809	69.245
1988	15.147	8.928	25.688	1.324	23.539	7.877	56.368	54.597
1989	16.078	10.112	28.107	1.245	21.216	6.851	57.494	55.136
1990	15.426	10.675	24.071	1.148	17.598	23.809	56.091	59.451
1991	11.850	8.810	18.388	1.071	15.844	10.969	49.885	83.892
1992	9.431	6.593	16.988	1.026	16.274	2.970	43.918	37.334
1993	10.368	6.181	15.120	1.065	13.681	7.488	41.818	52.906
1994	9.981	5.804	20.284	1.138	10.628	2.433	36.021	32.104
1995	10.389	7.509	22.954	1.121	10.526	49.105	41.818	38.068
1996	10.480	8.083	21.040	1.065	15.191	8.082	50.924	43.959
1997	9.696	7.185	19.337	1.040	22.961	4.010	56.929	84.030
1998	15.080	6.984	21.774	1.248	21.144	11.942	61.268	84.101
1999	16.300	8.808	25.643	1.423	18.714	27.801	60.442	64.754
2000	14.183	9.877	26.160	1.438	20.209	11.696	62.886	67.381
2001	14.087	9.649	26.795	1.415	23.118	12.340	67.141	52.455
2002	16.781	9.912	30.610	1.440	23.367	42.039	72.670	69.086
2003	17.806	11.439	30.459	1.423	27.869	10.414	79.331	115.760
2004	16.258	11.166	28.517	1.358	33.605	10.556	81.671	130.556
2005	18.610	10.587	29.917	1.360	32.486	38.793	84.149	105.727
2006	17.982	11.452	30.976	1.358	34.000	17.244	86.136	94.477
2007	16.516	11.446	26.773	1.311	39.312	12.820	89.784	103.327
2008	17.324	10.018	26.378	1.381	37.971	6.858	88.219	113.082
2009	17.616	10.254	28.203	1.476	35.000	8.305	84.053	90.547
2010	16.550	10.806	27.986	1.478	31.940	21.424	80.599	80.501
2011	14.173	10.382	27.772	1.427	31.872	13.424	77.823	66.408
2012	12.836	9.842	26.402	1.361	34.208	8.308	77.765	60.697
2013	12.981	9.149	25.863	1.335	33.254	6.275	76.588	62.217
2014	13.187	9.033	24.778	1.349	30.592	3.410	73.272	113.135
2015	11.990	8.679	22.755	1.372	27.207	5.818	67.561	64.175
2016	10.455	7.881	20.503	1.398	24.032	9.158	61.615	60.958
2017	8.816	6.976	18.163	1.396	22.168	4.008	56.695	52.935
2018	7.901	6.052	16.932	1.398	20.652	6.132	52.748	28.805
2019	8.125	5.673	15.957	1.496	18.570	4.720	49.822	28.539

Table 7(18.0e). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2018-2027. Parameter estimates with model 18.0e are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
No Directed Fishery						
2019	20.911	17.712	23.932	0.000	0.000	0.000
2020	22.863	19.365	26.166	0.000	0.000	0.000
2021	24.595	20.832	28.149	0.000	0.000	0.000
2022	26.250	22.328	30.138	0.000	0.000	0.000
2023	29.361	23.989	39.509	0.000	0.000	0.000
2024	33.884	25.578	52.244	0.000	0.000	0.000
2025	38.730	27.121	61.231	0.000	0.000	0.000
2026	43.296	28.544	70.041	0.000	0.000	0.000
2027	47.428	30.699	77.976	0.000	0.000	0.000
2028	51.265	32.069	84.474	0.000	0.000	0.000
$F_{40\%}$						
2019	18.287	15.823	20.552	2.678	1.928	3.448
2020	17.992	15.792	19.981	2.518	1.883	3.148
2021	17.796	15.769	19.612	2.445	1.876	2.998
2022	17.785	15.891	19.590	2.417	1.898	2.941
2023	19.193	16.083	27.580	2.607	1.959	3.699
2024	21.686	16.276	36.240	3.046	2.010	5.078
2025	24.081	16.406	40.001	3.650	2.046	6.730
2026	25.897	16.834	44.376	4.212	2.152	7.530
2027	27.174	17.548	46.821	4.647	2.290	8.384
2028	28.209	17.872	48.426	4.952	2.402	8.975
$F_{35\%}$						
2019	17.798	15.458	19.941	3.175	2.300	4.070
2020	17.212	15.187	19.033	2.852	2.156	3.536
2021	16.841	15.007	18.477	2.689	2.089	3.267
2022	16.726	15.016	18.330	2.612	2.076	3.152
2023	18.024	15.125	25.831	2.807	2.113	4.147
2024	20.330	15.235	34.276	3.312	2.149	5.751
2025	22.455	15.322	37.051	3.998	2.169	7.621
2026	23.969	15.740	40.553	4.606	2.275	8.397
2027	24.961	16.363	43.313	5.047	2.409	9.320
2028	25.750	16.680	44.114	5.338	2.534	9.887

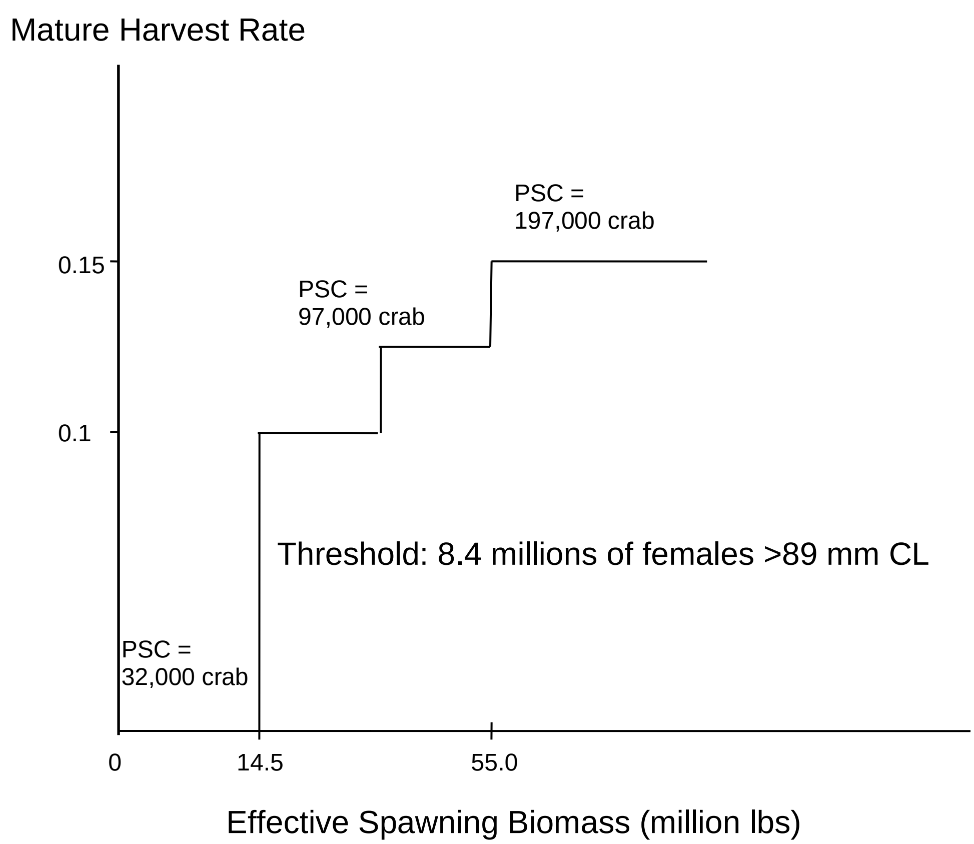


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of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

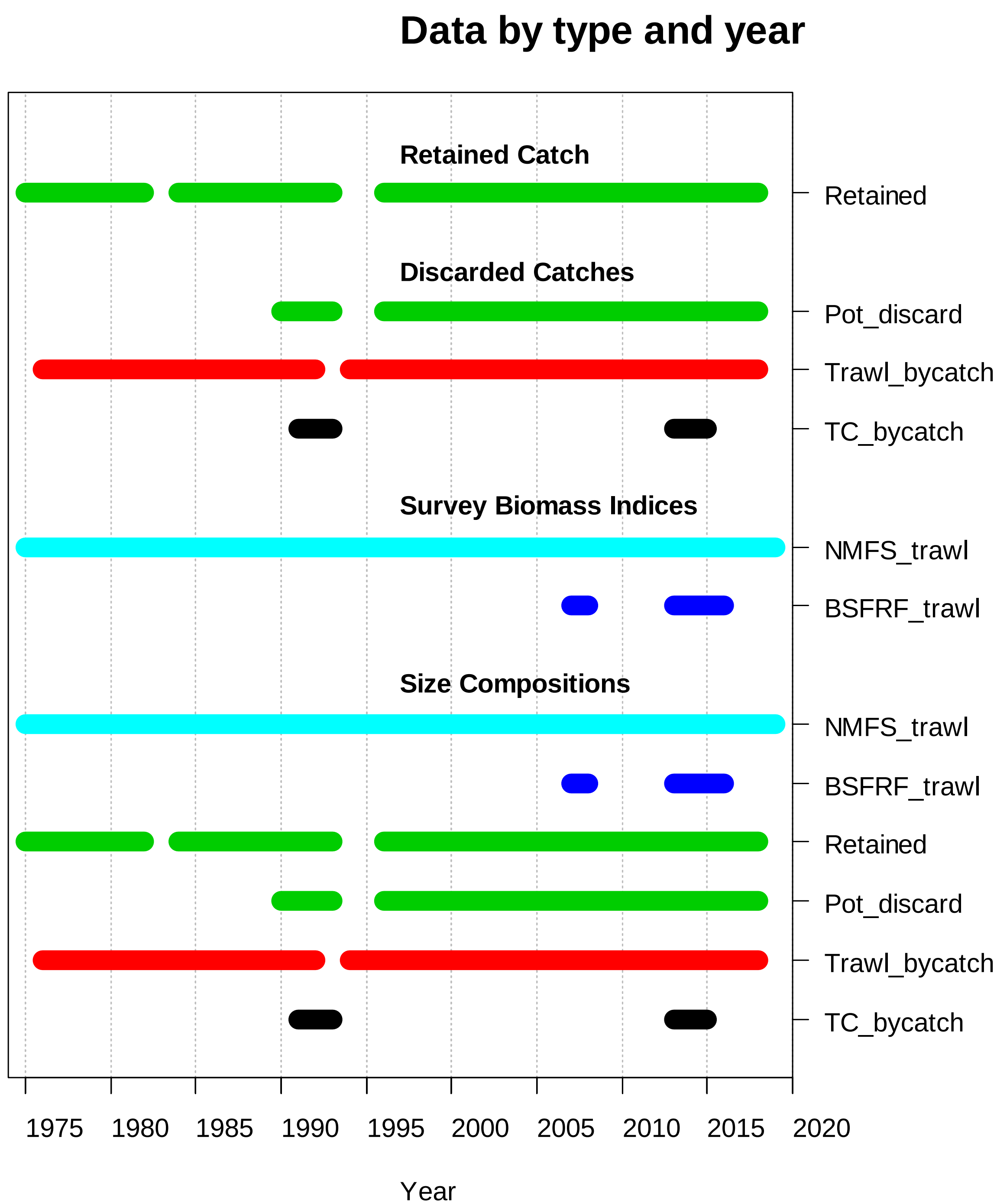


Figure 2. Data types and ranges used for the stock assessment.

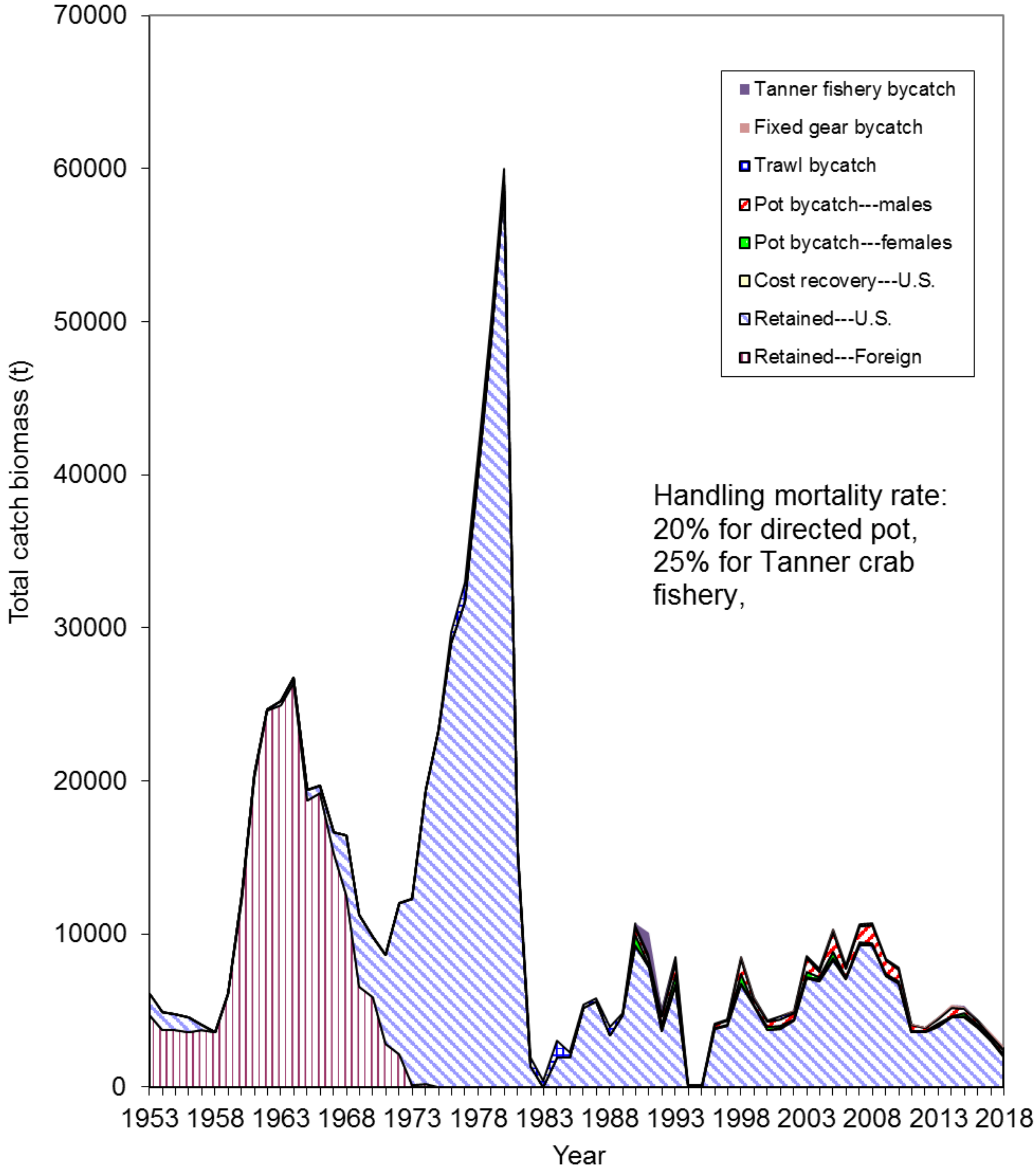


Figure 3. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2018. Handling mortality rates were assumed to be 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 0.8 for the trawl fisheries, and 50% for the fixed gear fisheries.

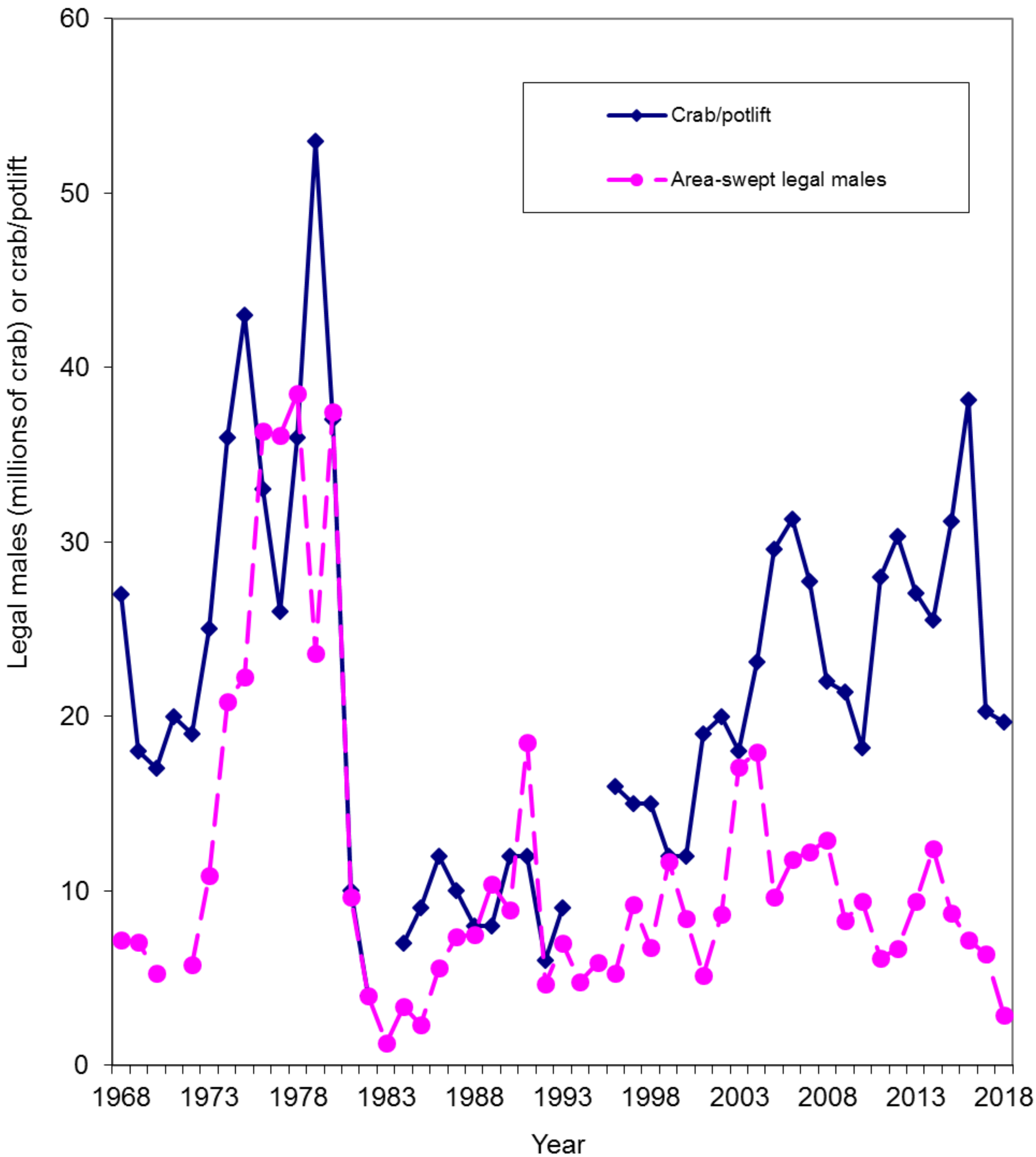


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2018.

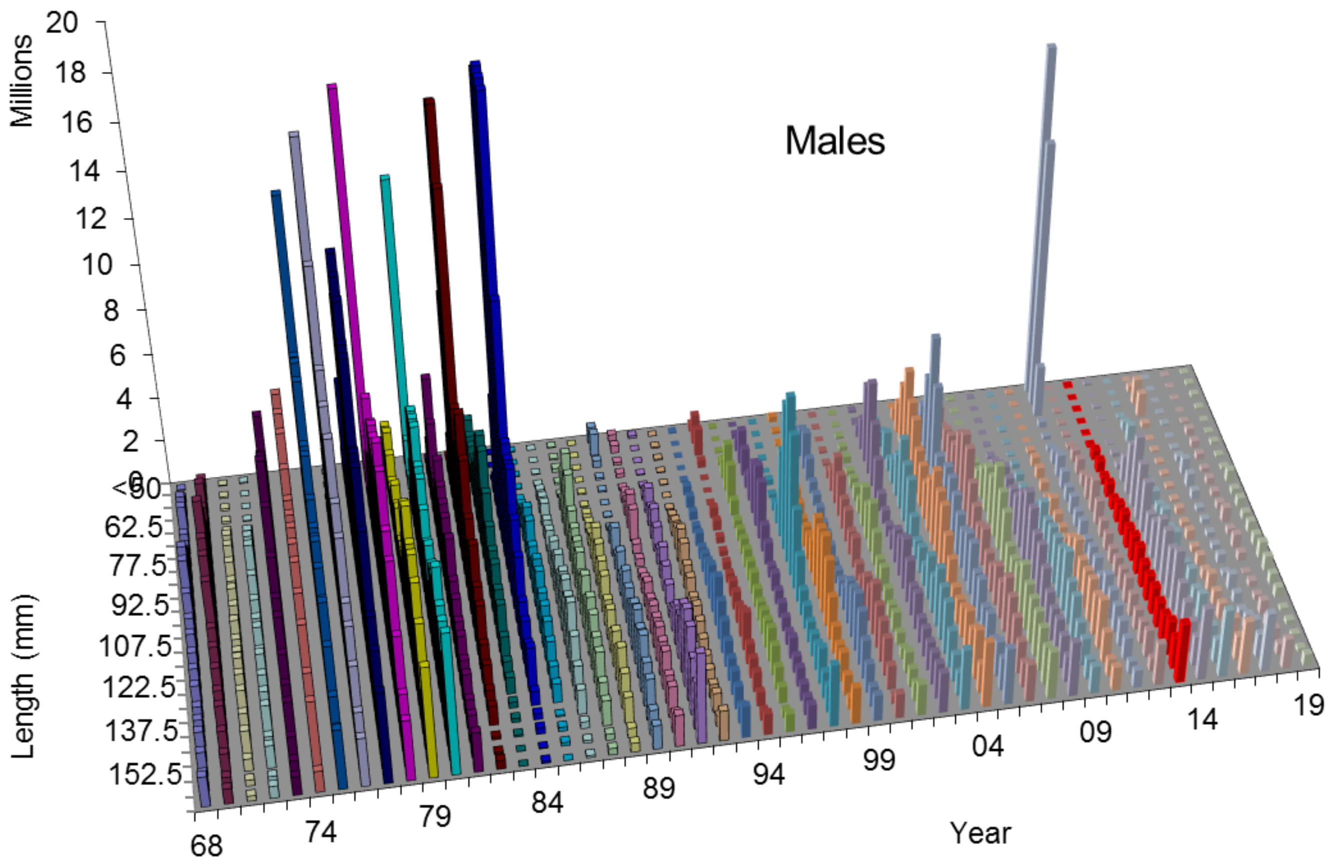


Figure 5a. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2019.

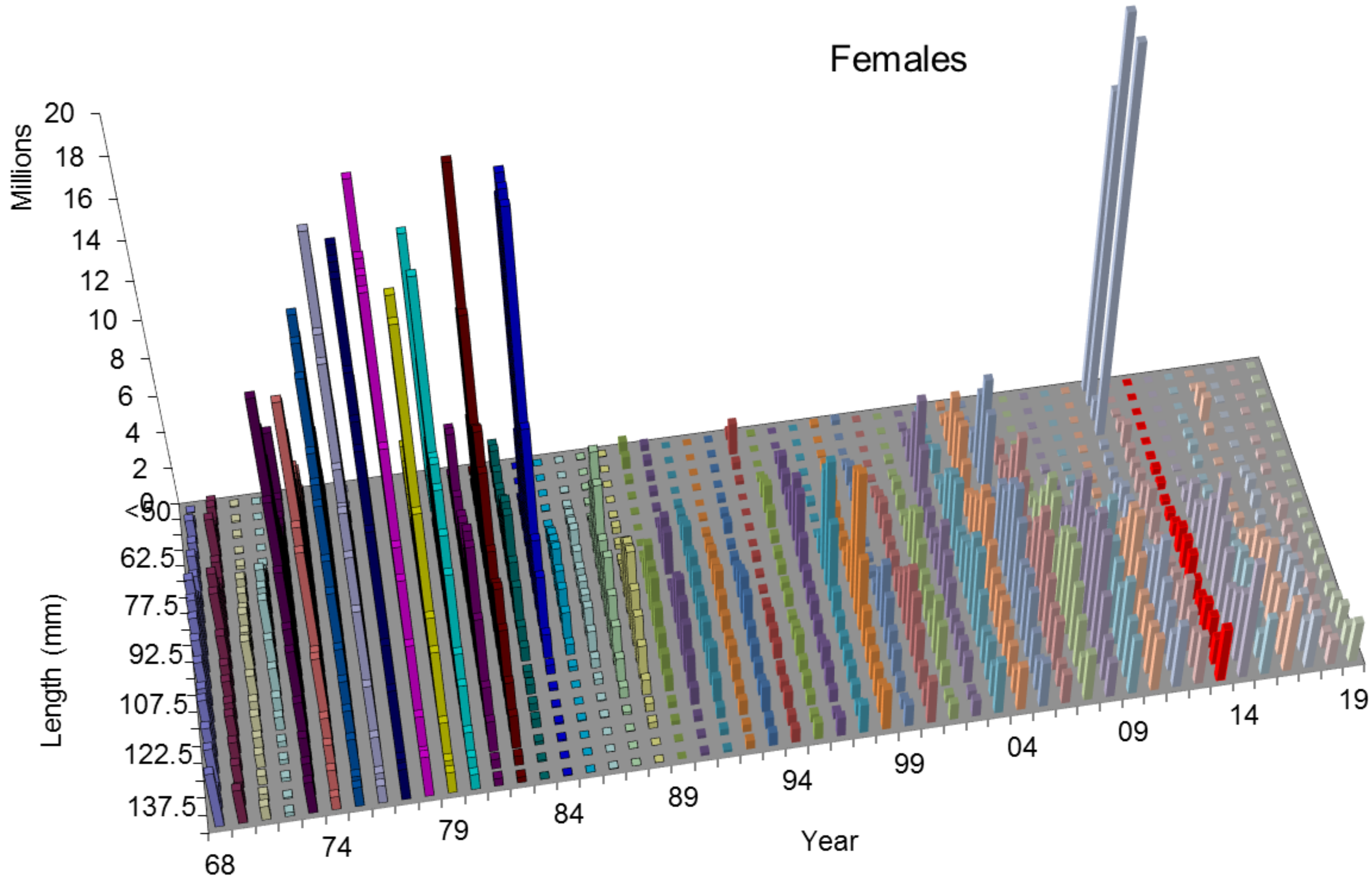


Figure 5b. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2019.

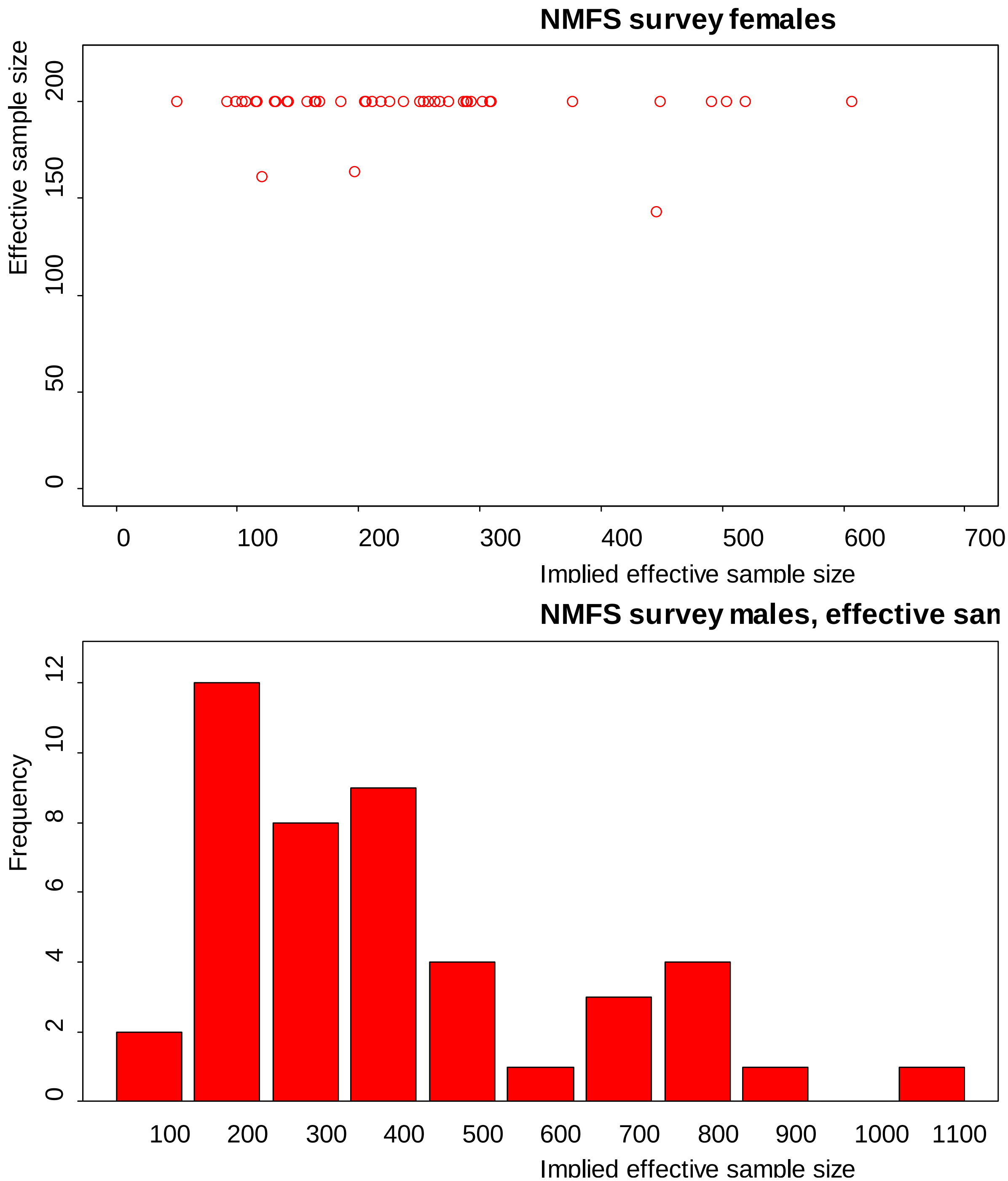


Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes for length/sex composition data with model 18.0e: trawl survey data.

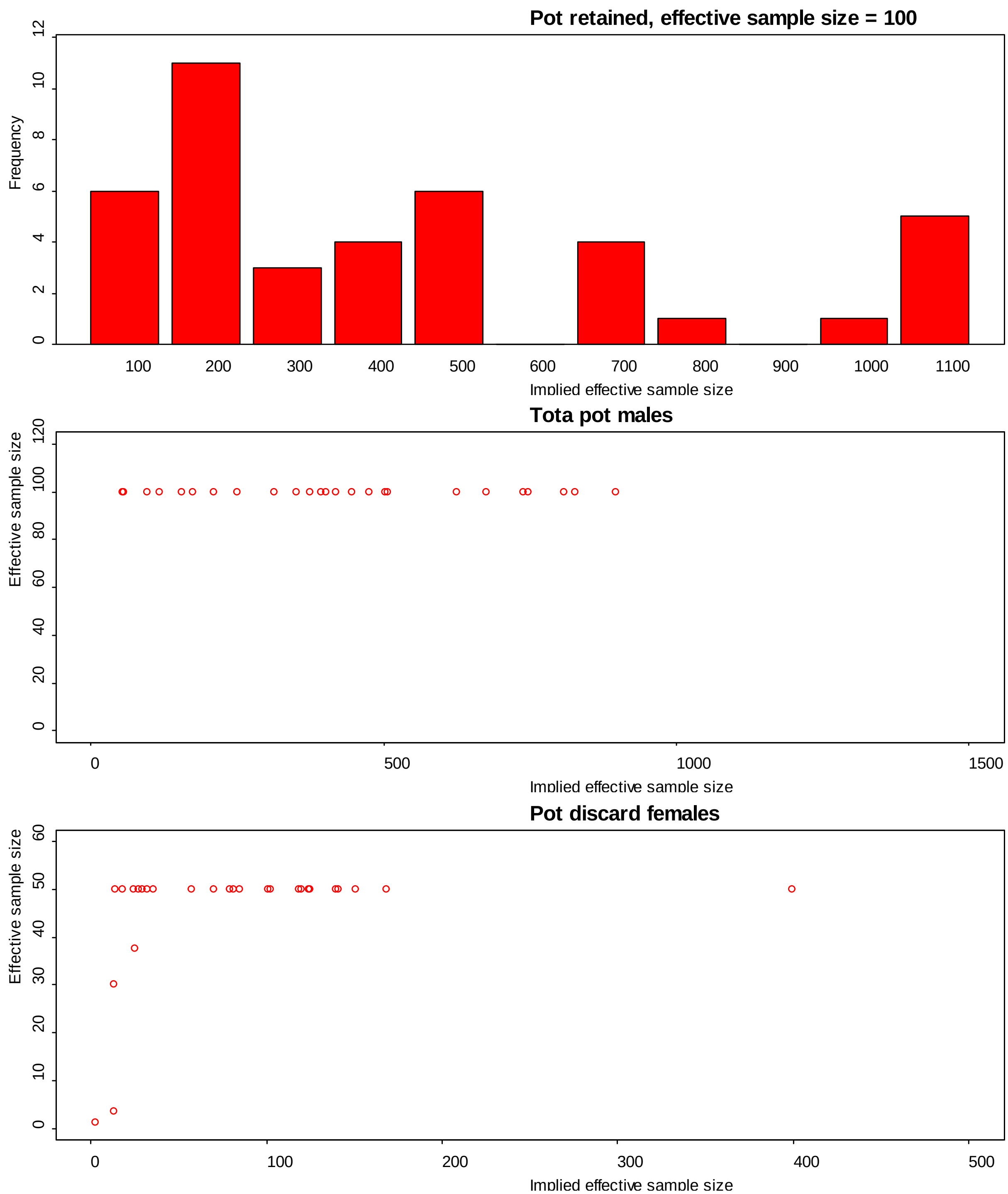


Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes for length/sex composition data with model 18.0e: directed pot fishery data.

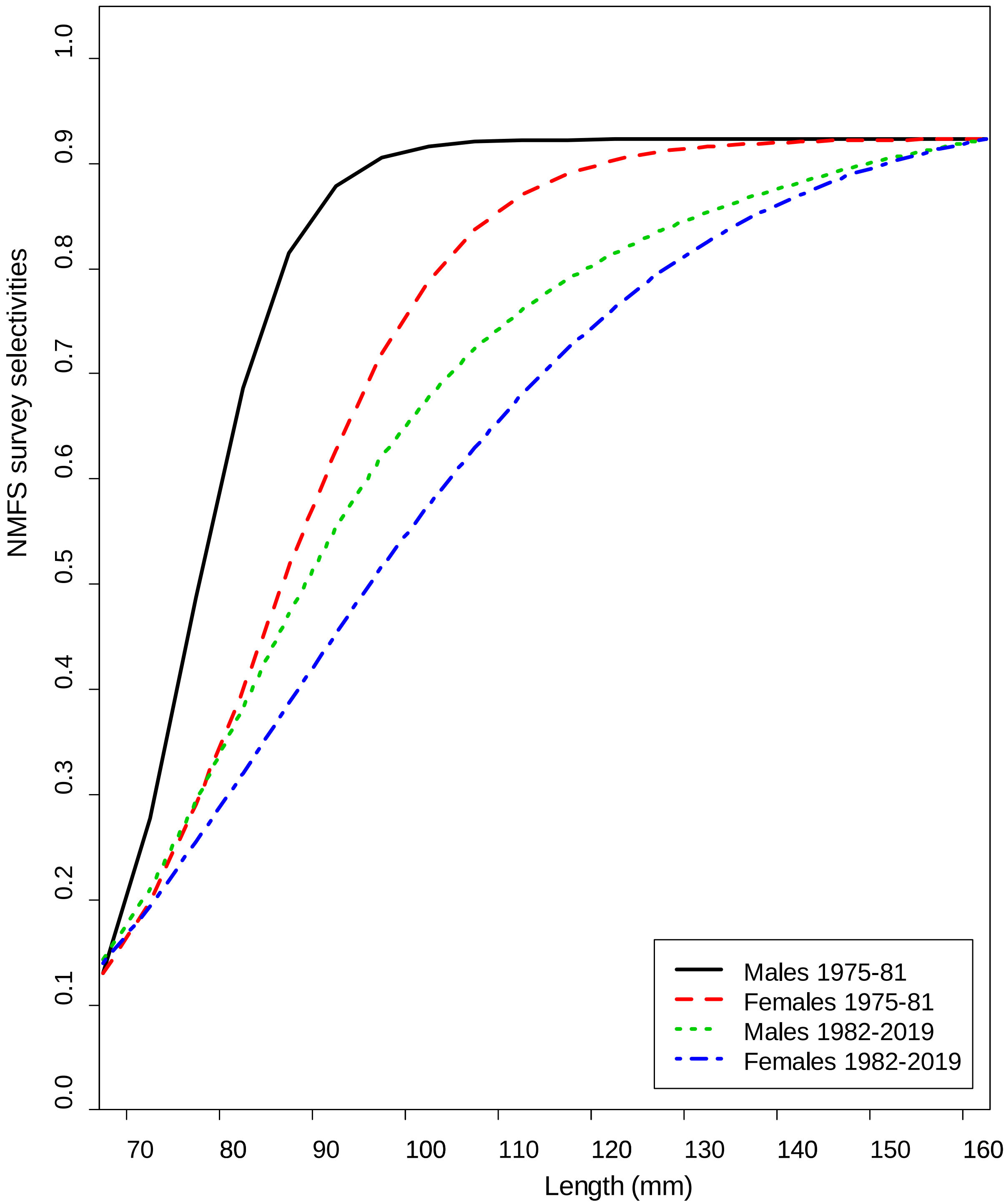


Figure 8a(18.0d). Estimated NMFS trawl survey selectivities under model 18.0d. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

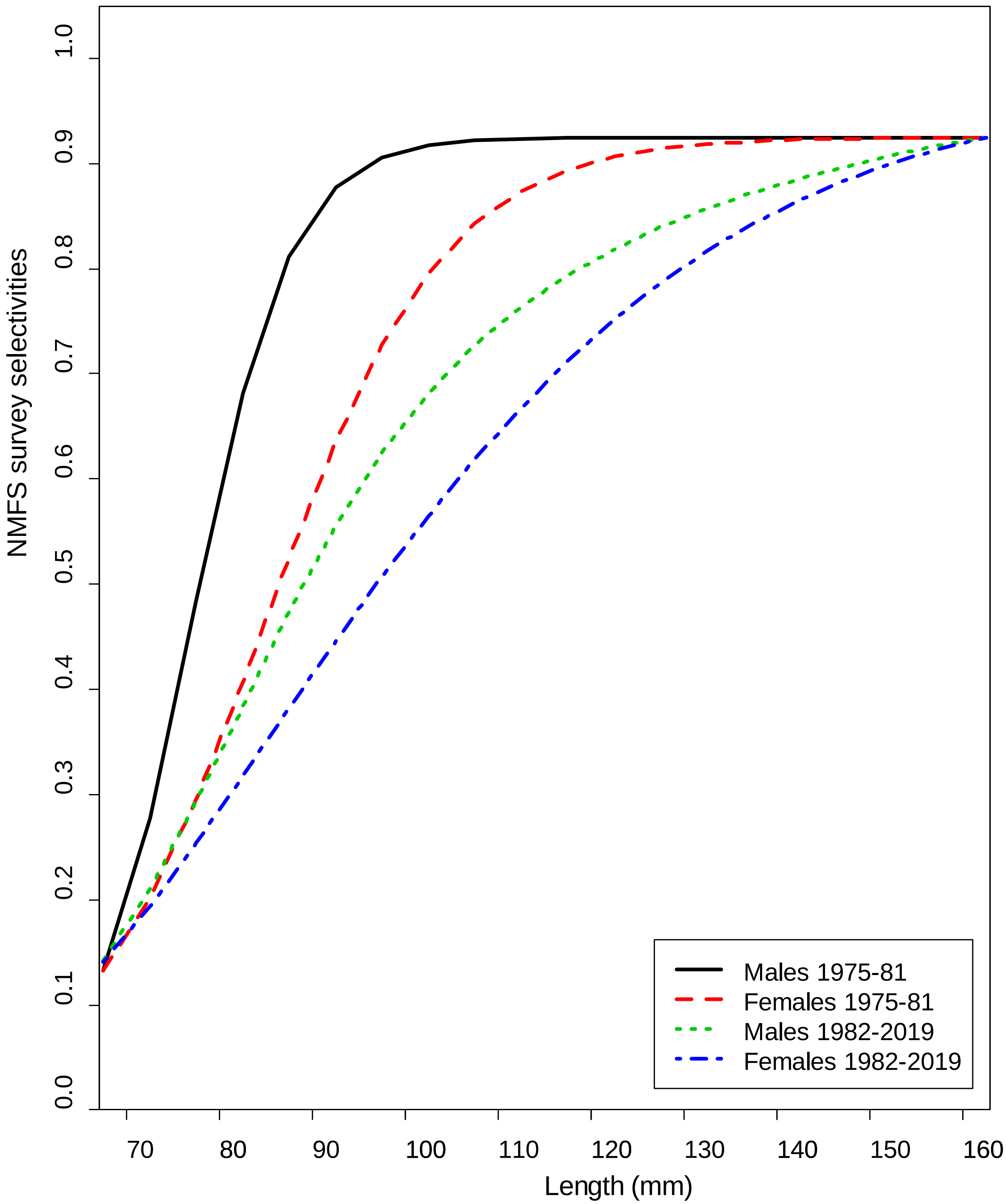


Figure 8a(18.0e). Estimated NMFS trawl survey selectivities under model 18.0e. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

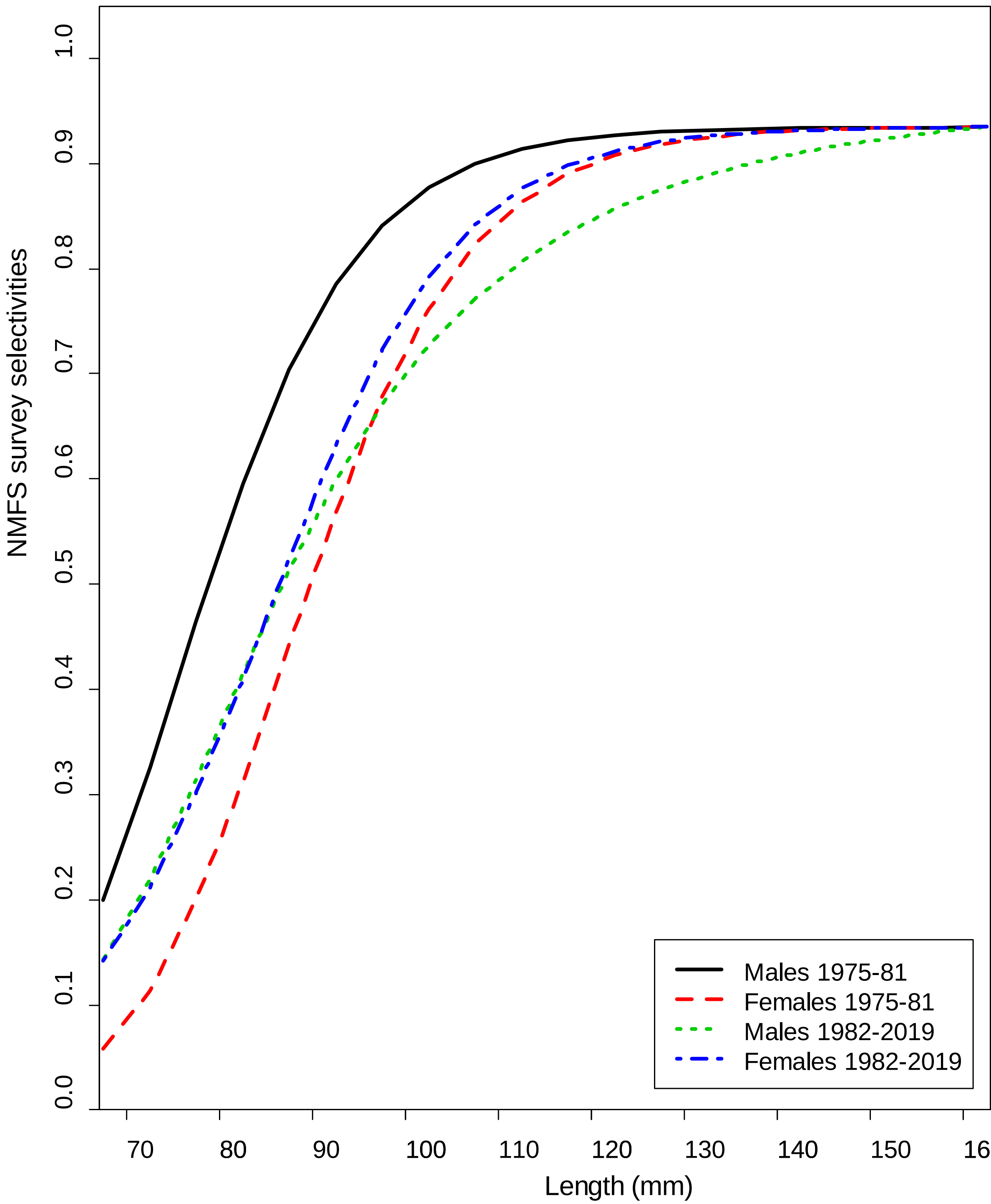


Figure 8a(19.0(gmacs)). Estimated NMFS trawl survey selectivities under model 19.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

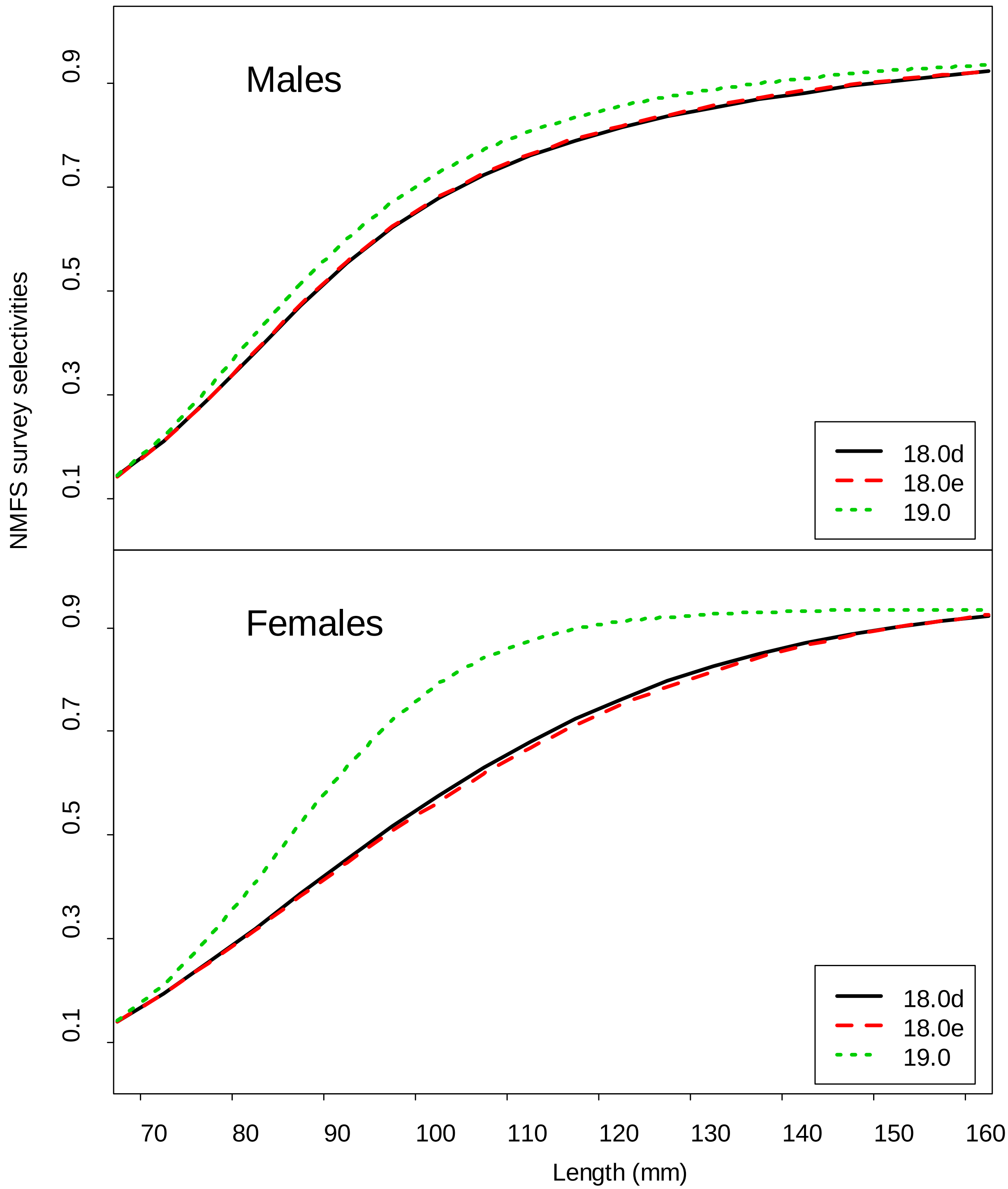


Figure 8b. Comparisons of estimated NMFS trawl survey selectivities for period 1982-2019 under models 18.0d, 18.0e, and 19.0 (gmacs). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

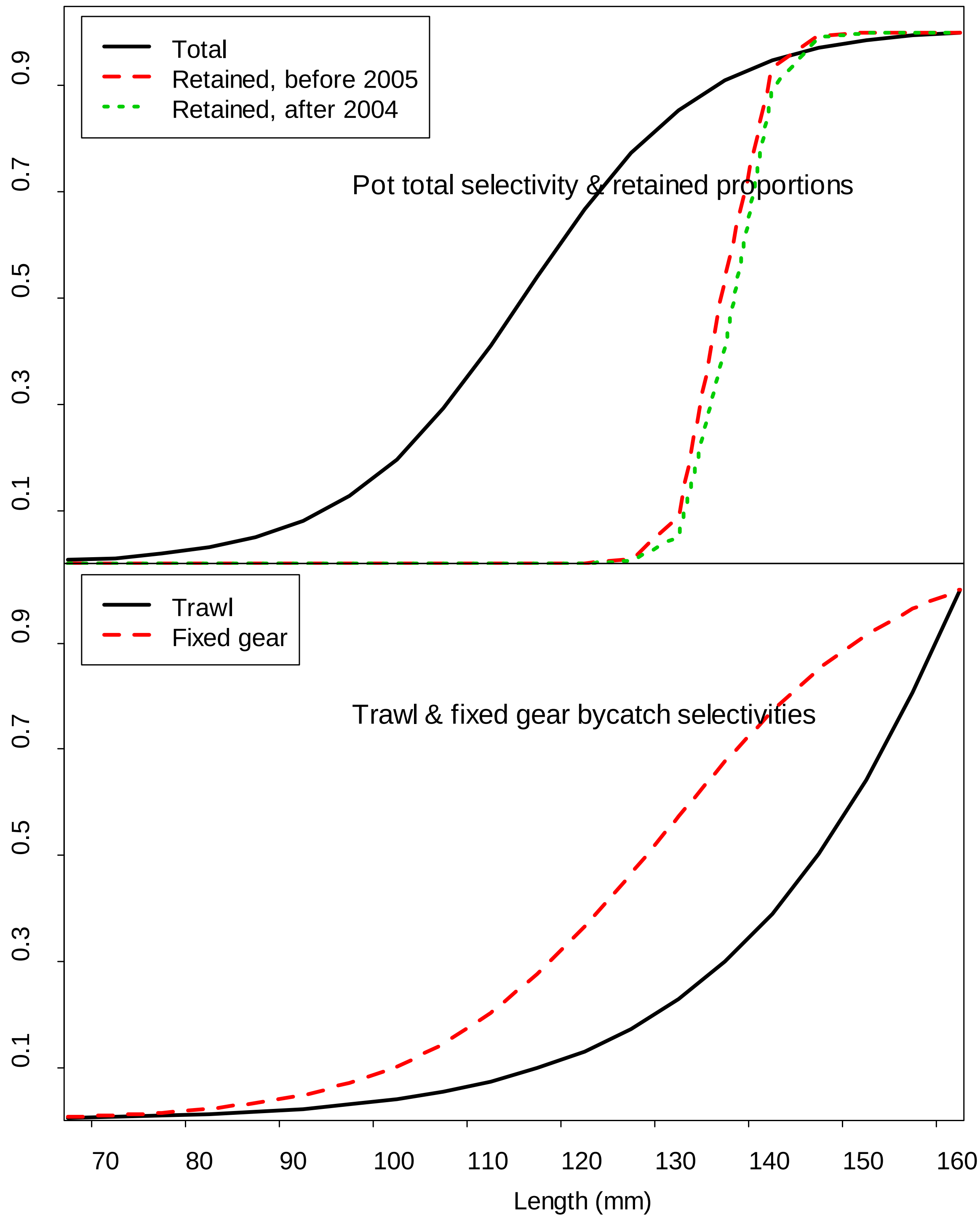


Figure 8c(18.0e). Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 18.0e. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

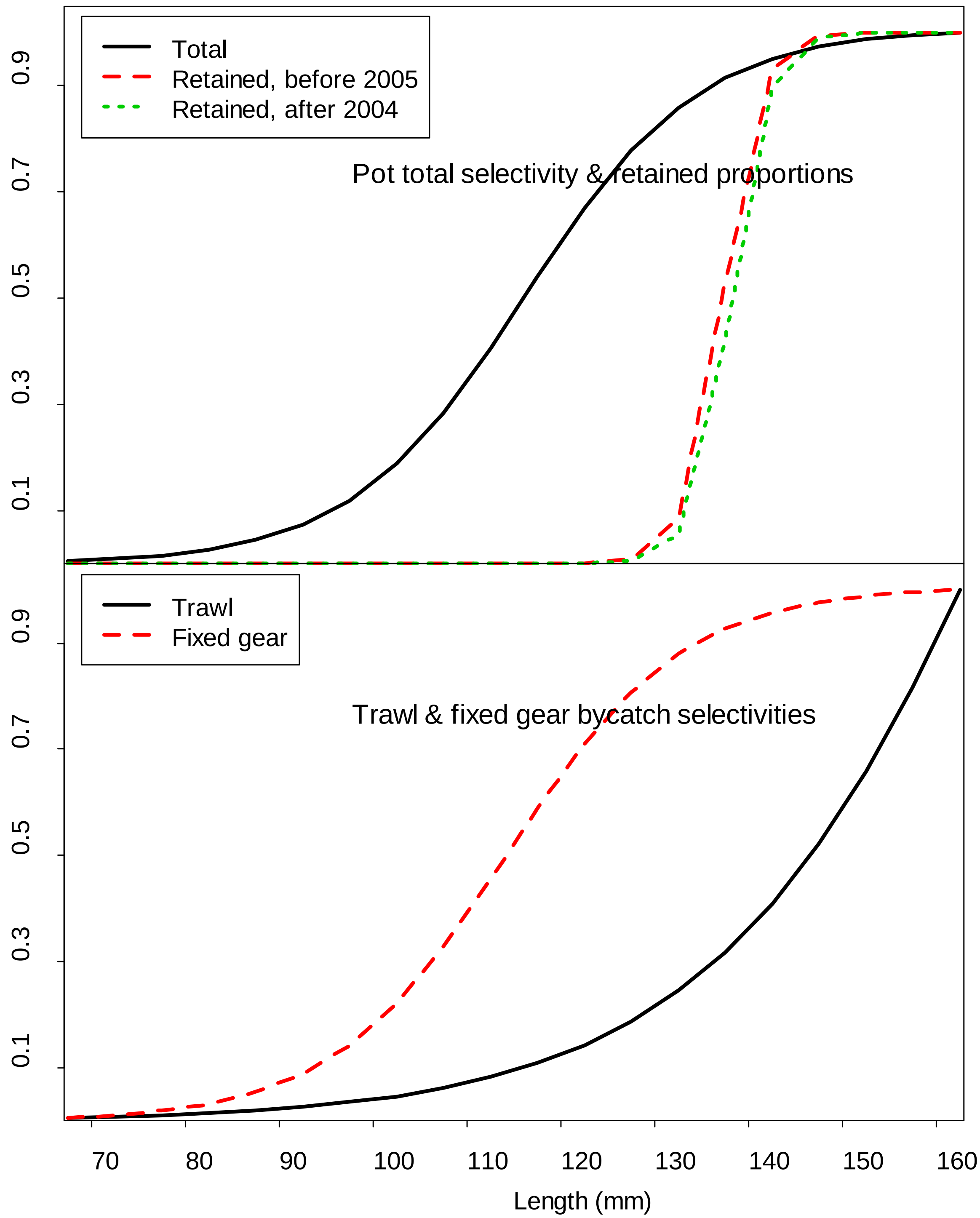


Figure 8c(19.0). Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 19.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

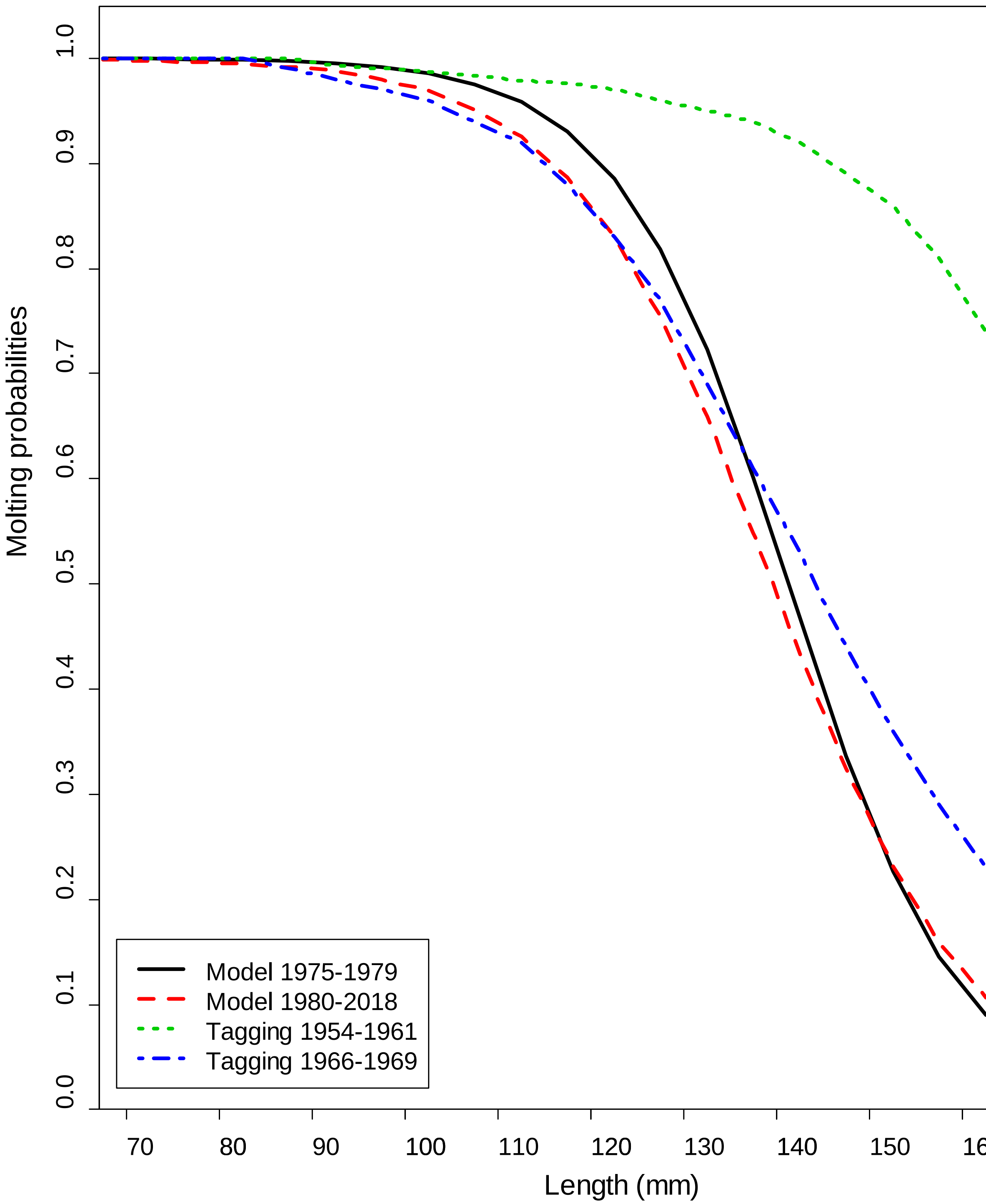


Figure 9(18.0e). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 18.0e. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2019 were estimated with a length-based model.

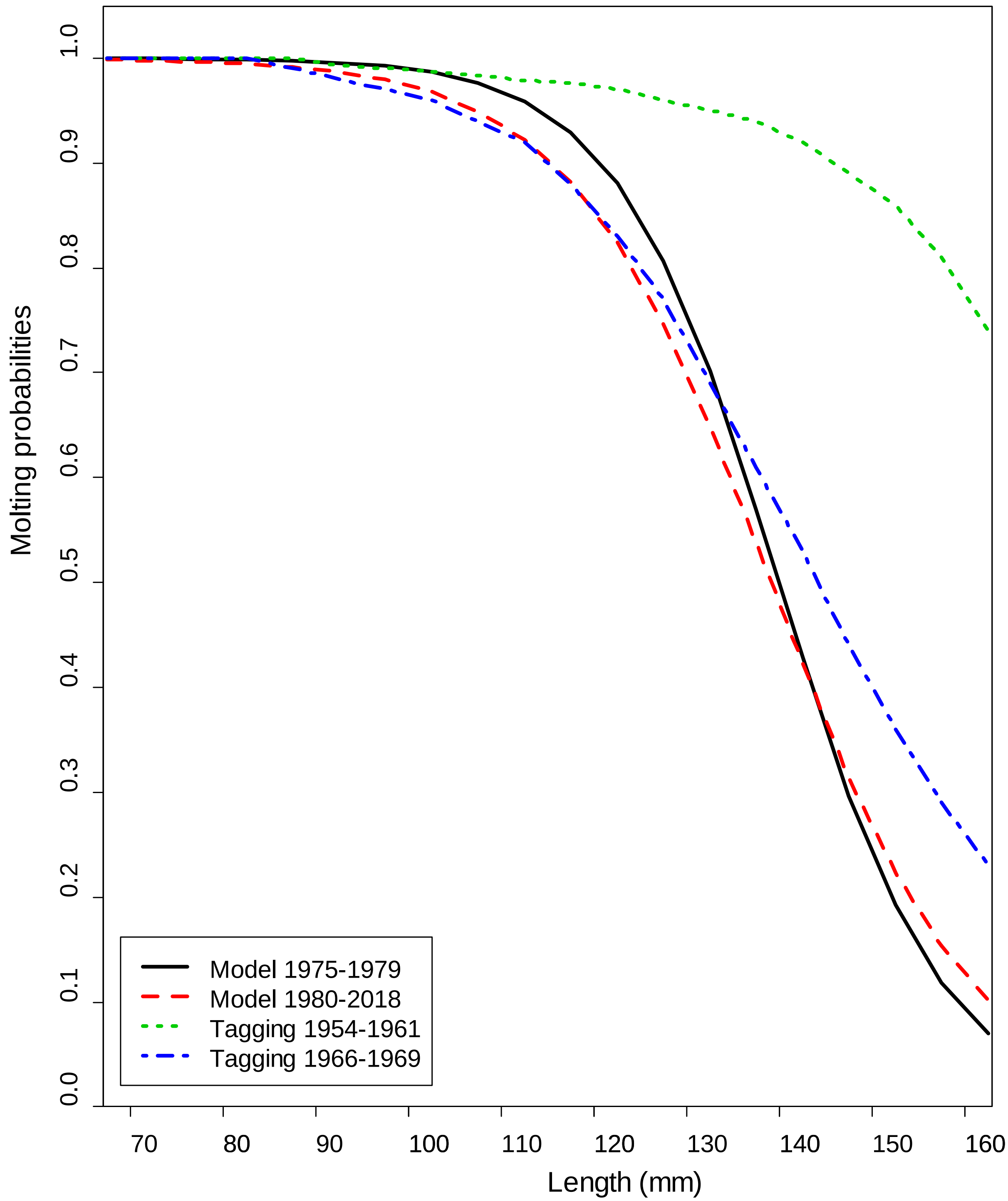


Figure 9(19.0). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 19.0. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2019 were estimated with a length-based model.

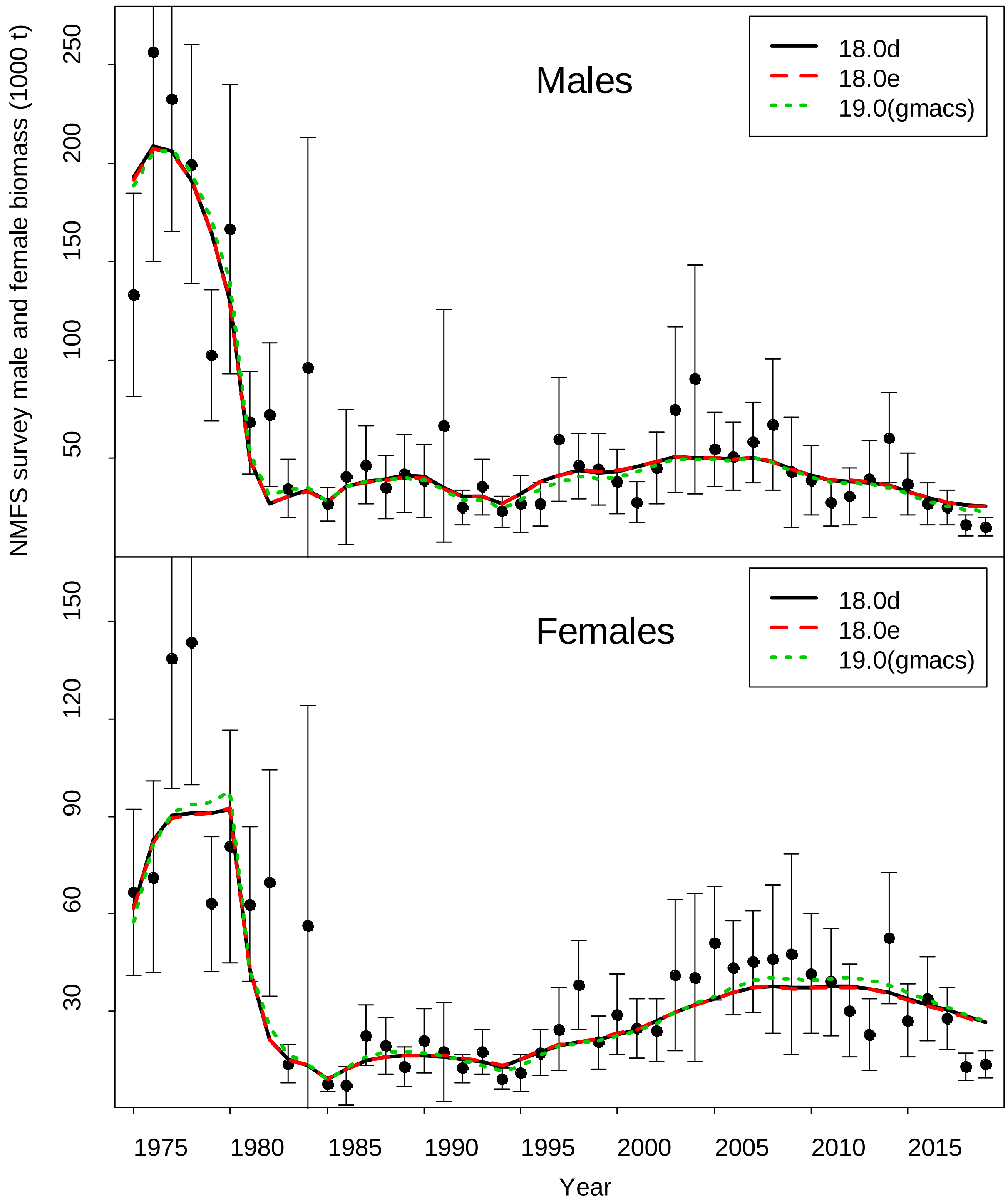


Figure 10a. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates in 2019 under models 18.0d, 18.0e, and 19.0 (gmacs). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

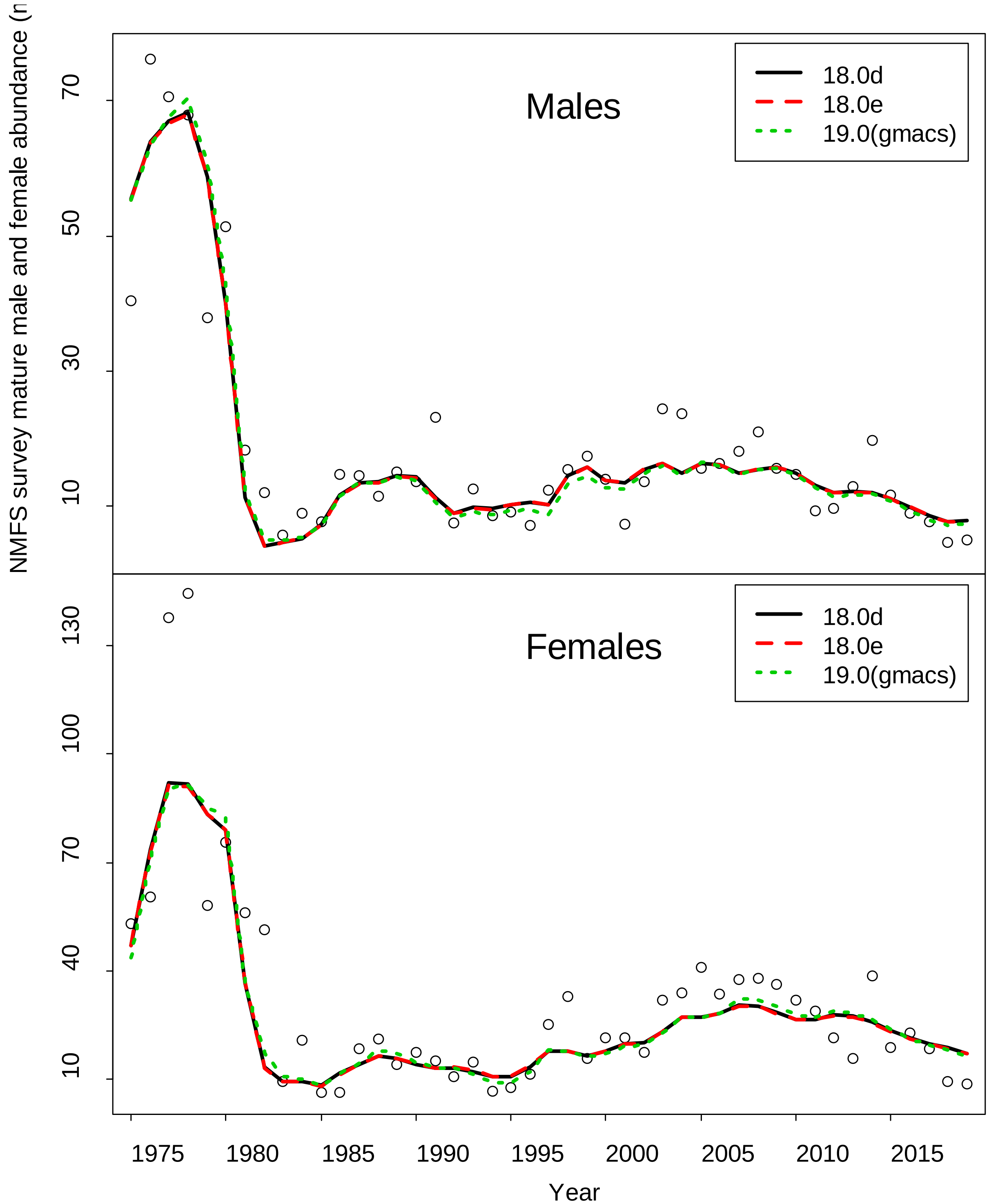


Figure 10b. Comparisons of NMFS survey area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2019 under models 18.0d, 18.0e, and 19.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

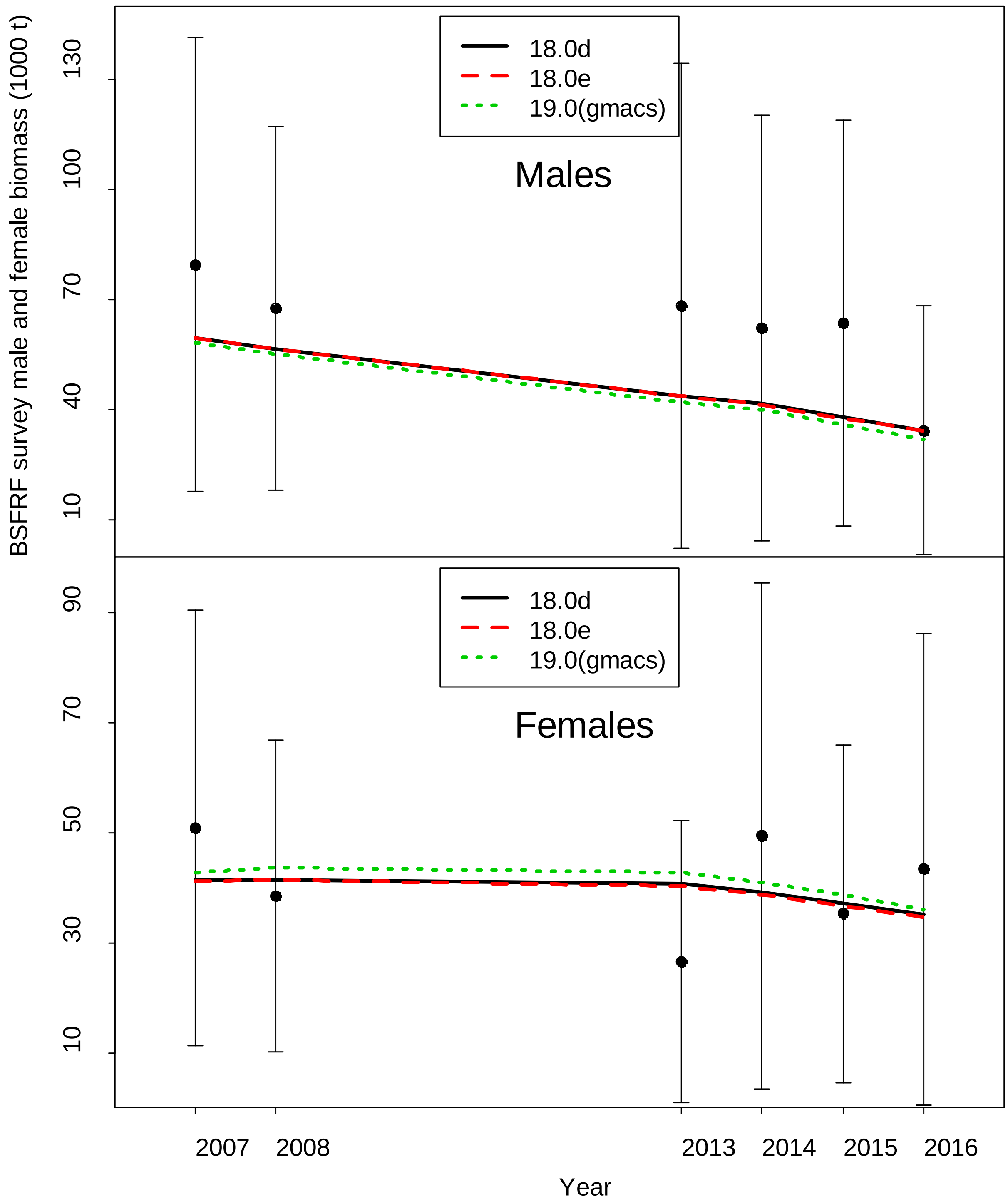


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2019 (models 18.0d, 18.0e, and 19.0). The error bars are plus and minus 2 standard deviations of model 19.0.

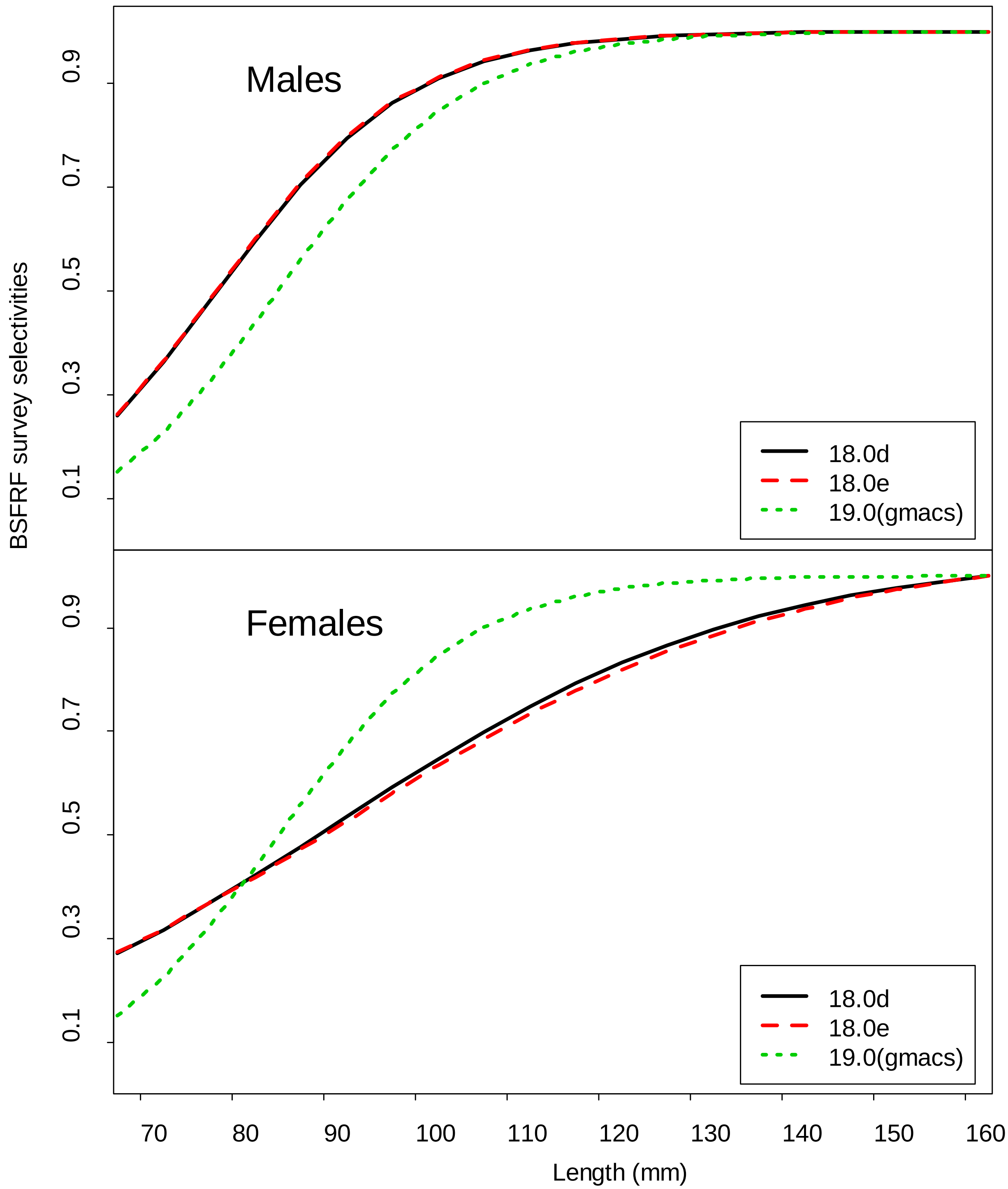


Figure 10d. Comparisons of estimated BSFRF survey selectivities with models 18.0d, 18.0e, and 19.0. The catchability is assumed to be 1.0.

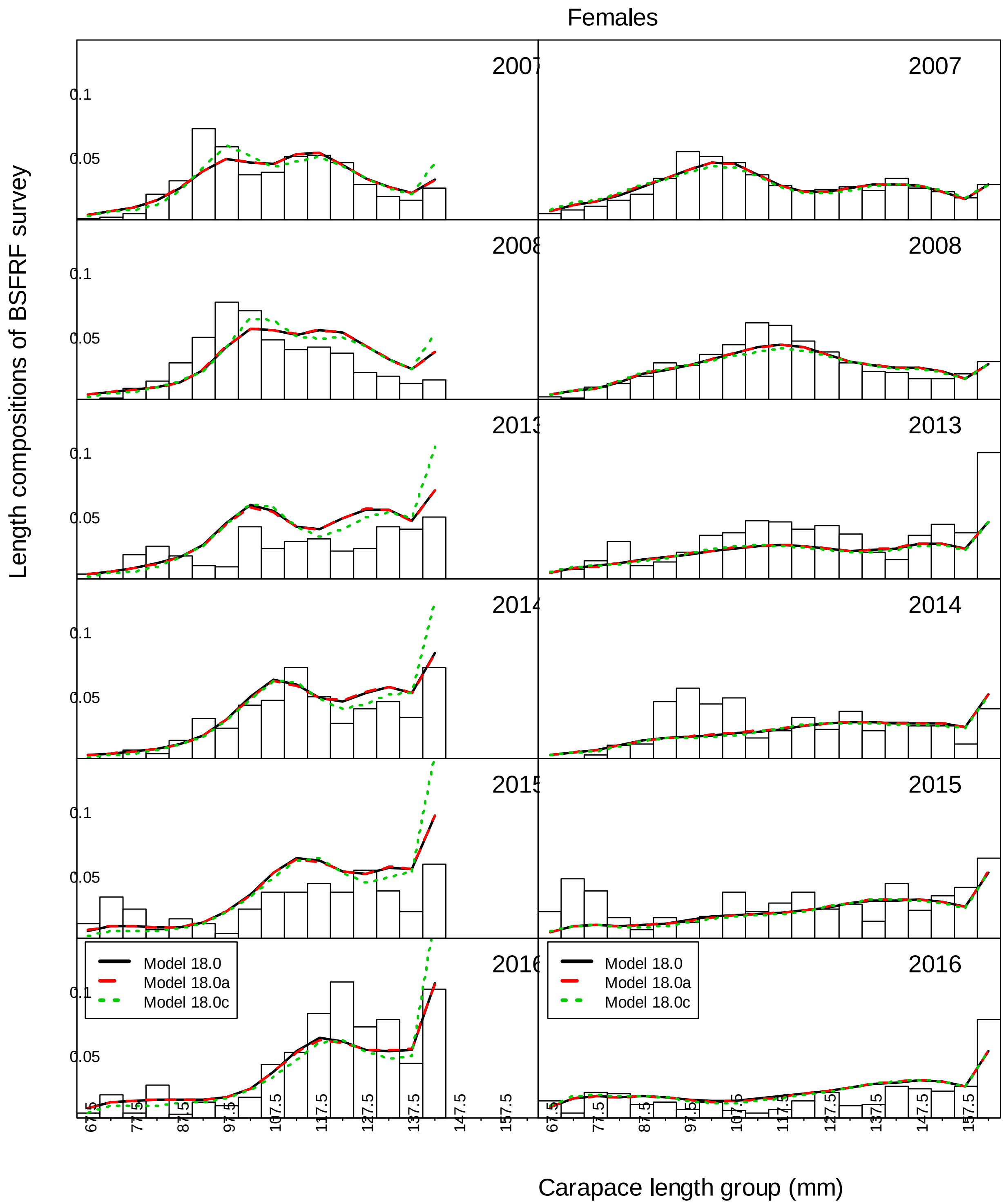


Figure 10e(18.0d, 18.0e & 19.0). Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with models 18.0d (solid black), 18.0e (dashed red) and 19.0 (green lines).

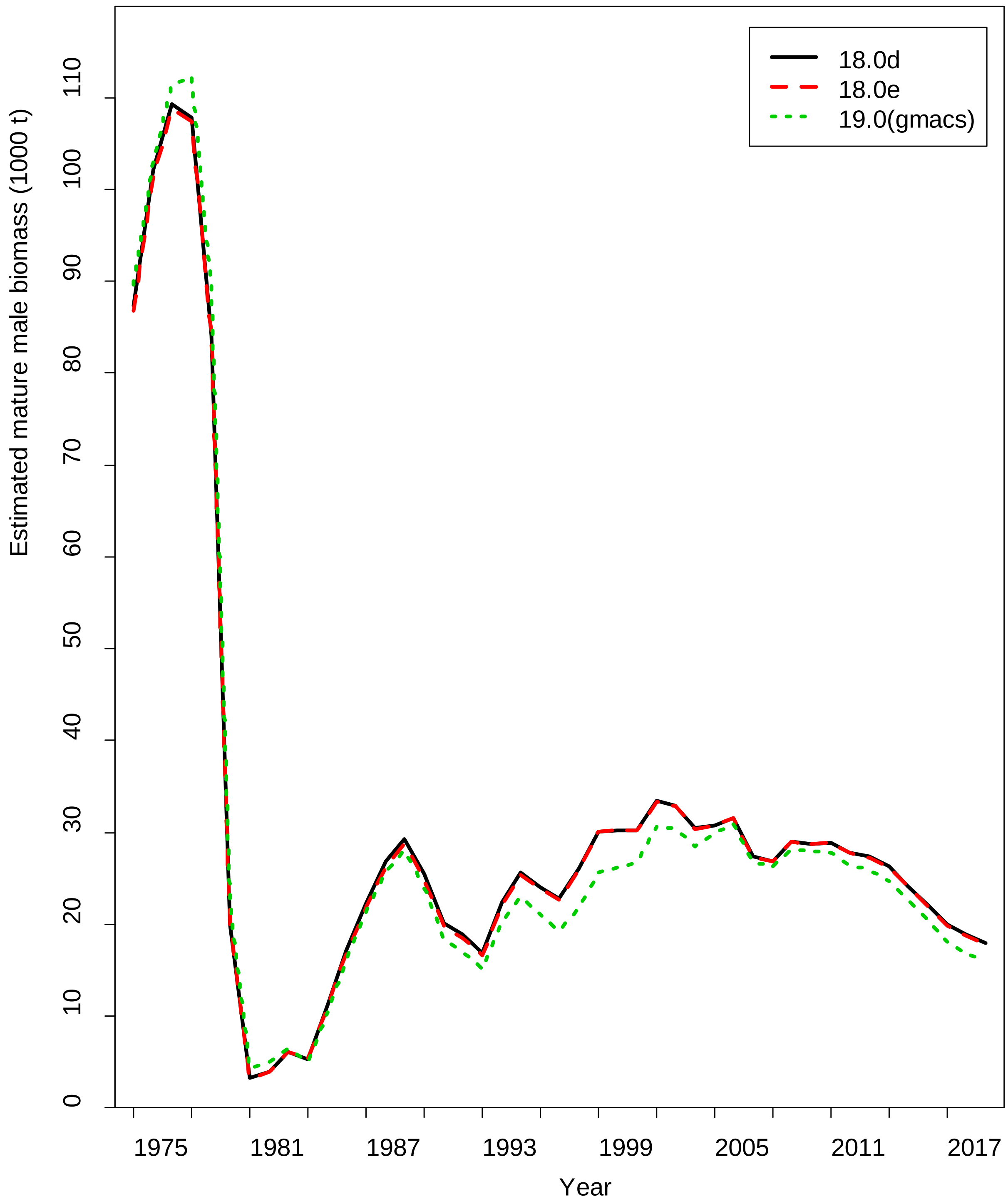


Figure 11. Estimated absolute mature male biomasses during 1975-2019 for models 18.0d, 18.0e, and 19.0.

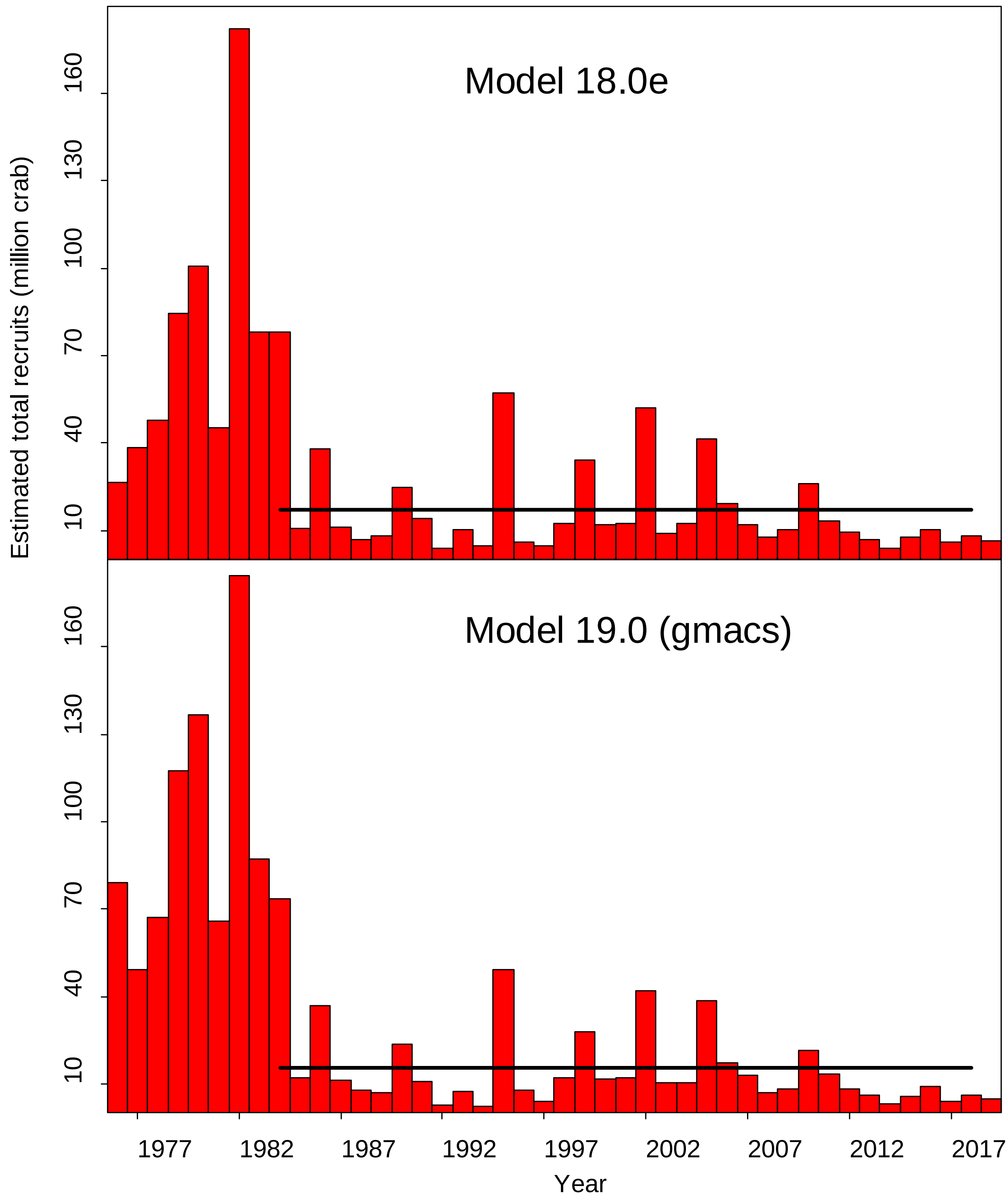


Figure 12(18.0e & 19.0). Estimated recruitment time series during 1976-2019 with models 18.0e and 19.0 (gmacs). Mean male recruits during 1984-2018 was used to estimate $B_{35\%}$.

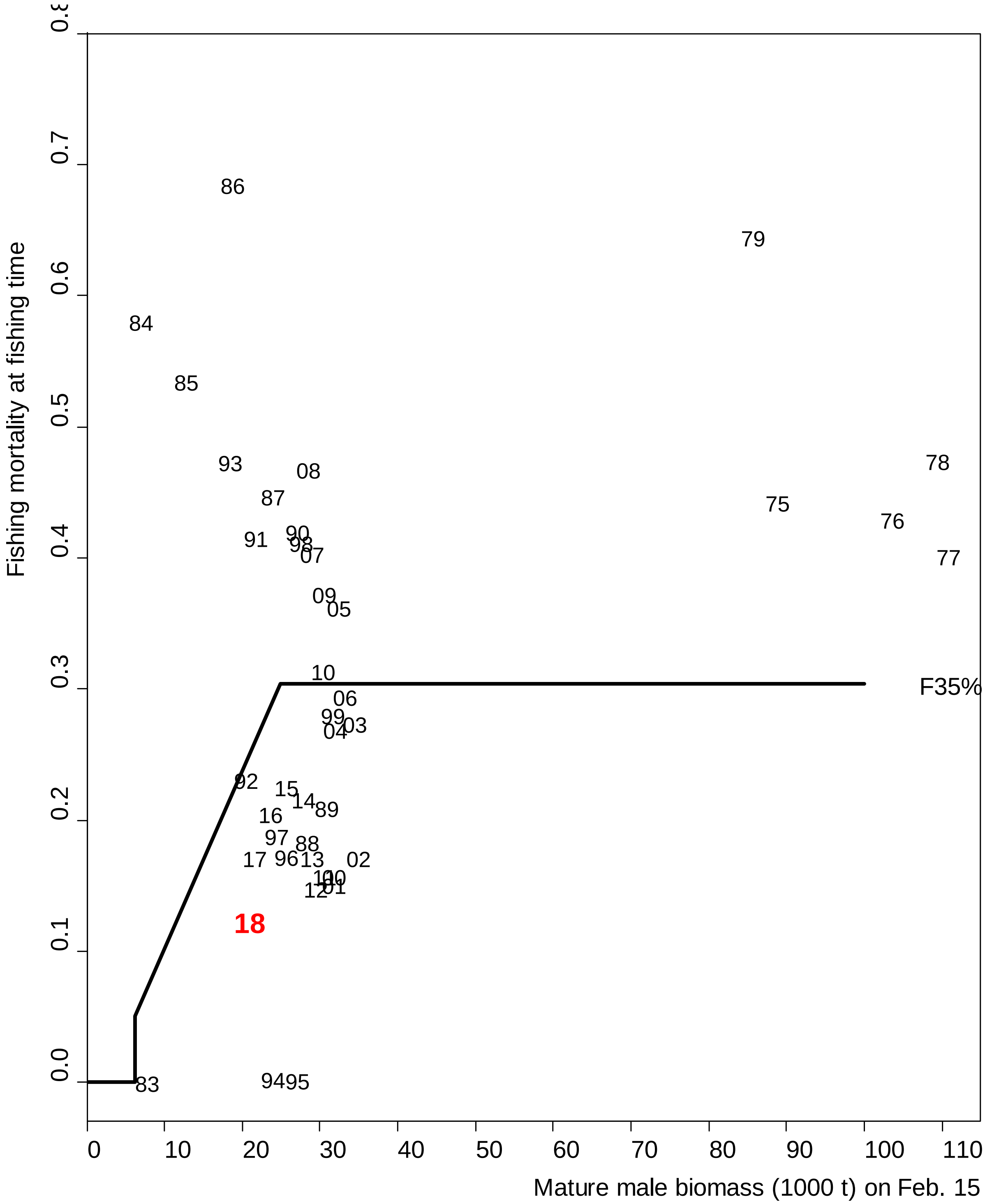


Figure 13a(18.0d). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 18.0d. Average of recruitment from 1984 to 2018 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

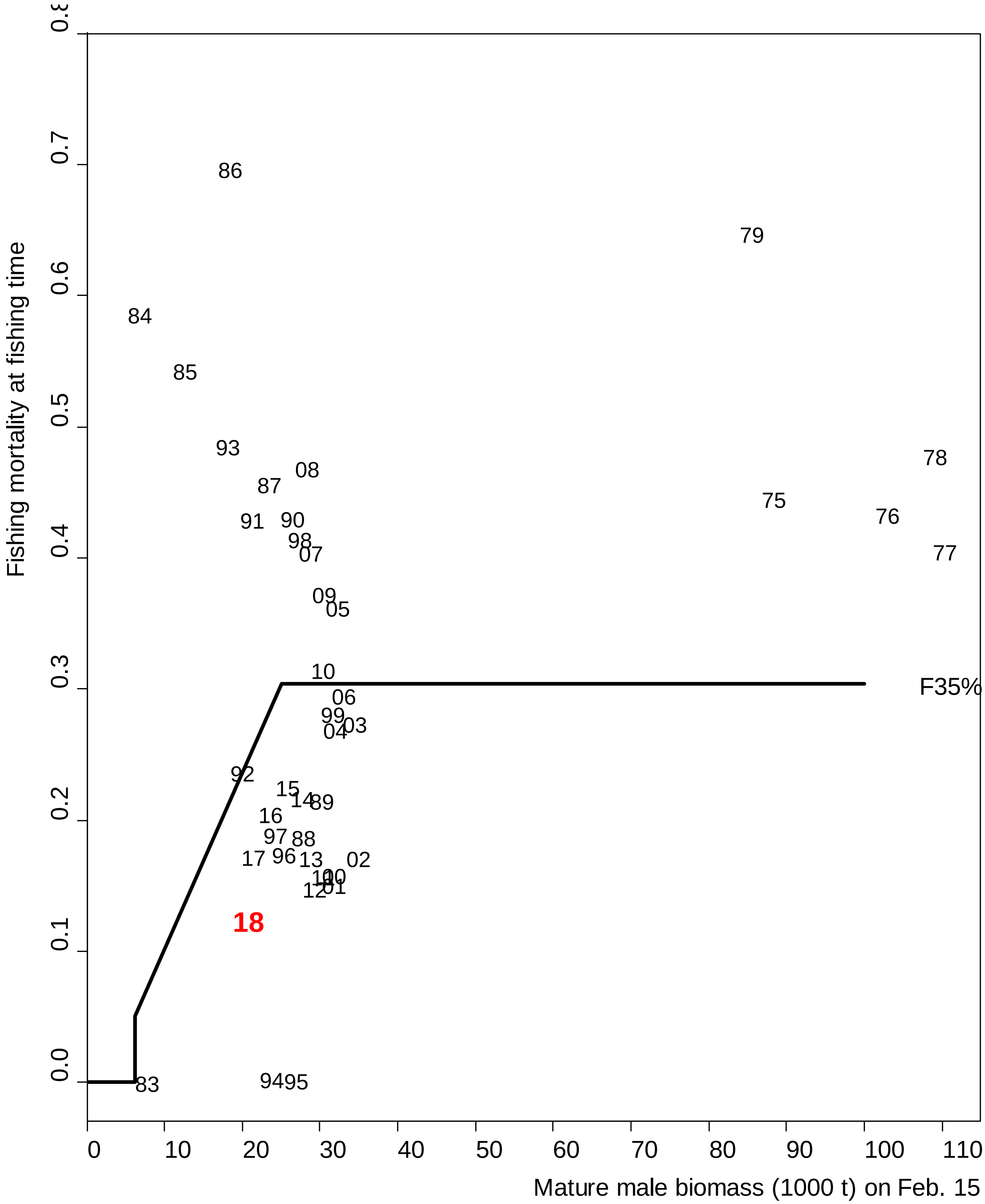


Figure 13a(18.0e). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 18.0e. Average of recruitment from 1984 to 2018 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

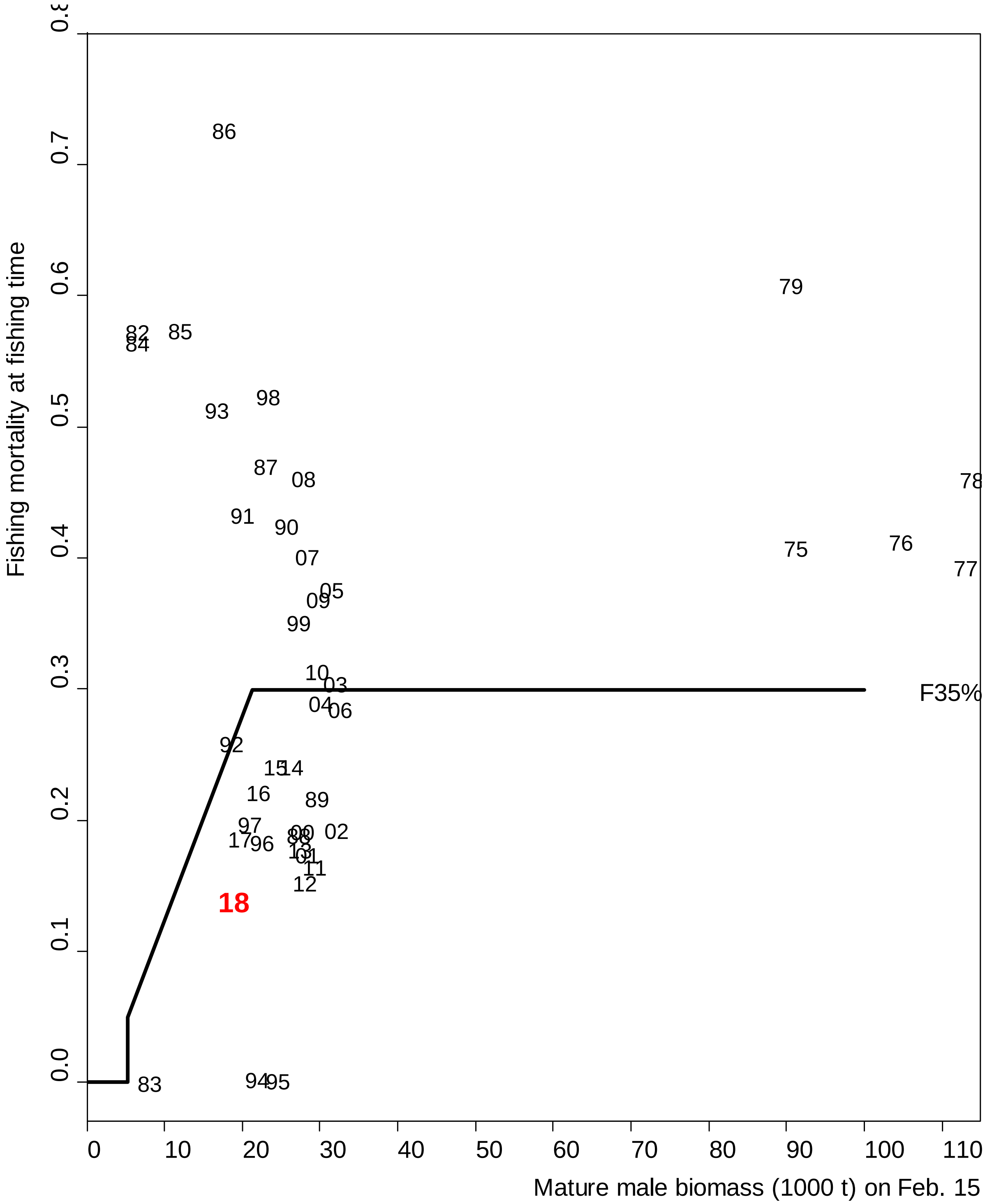


Figure 13a(19.0). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 19.0. Average of recruitment from 1984 to 2017 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

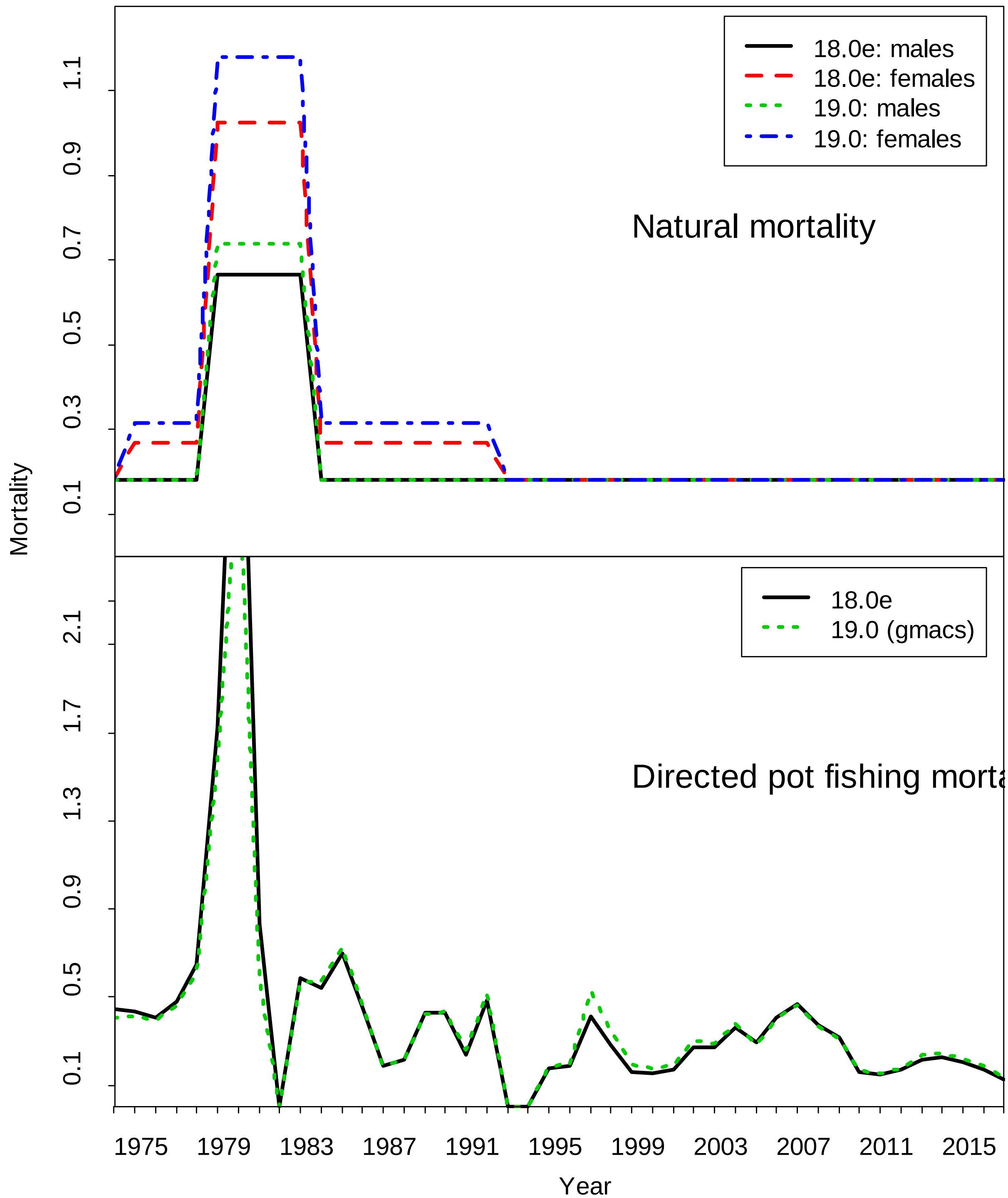


Figure 13b. Comparison of estimated natural mortality and directed pot fishing mortality for models models 18.0e and 19.0. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

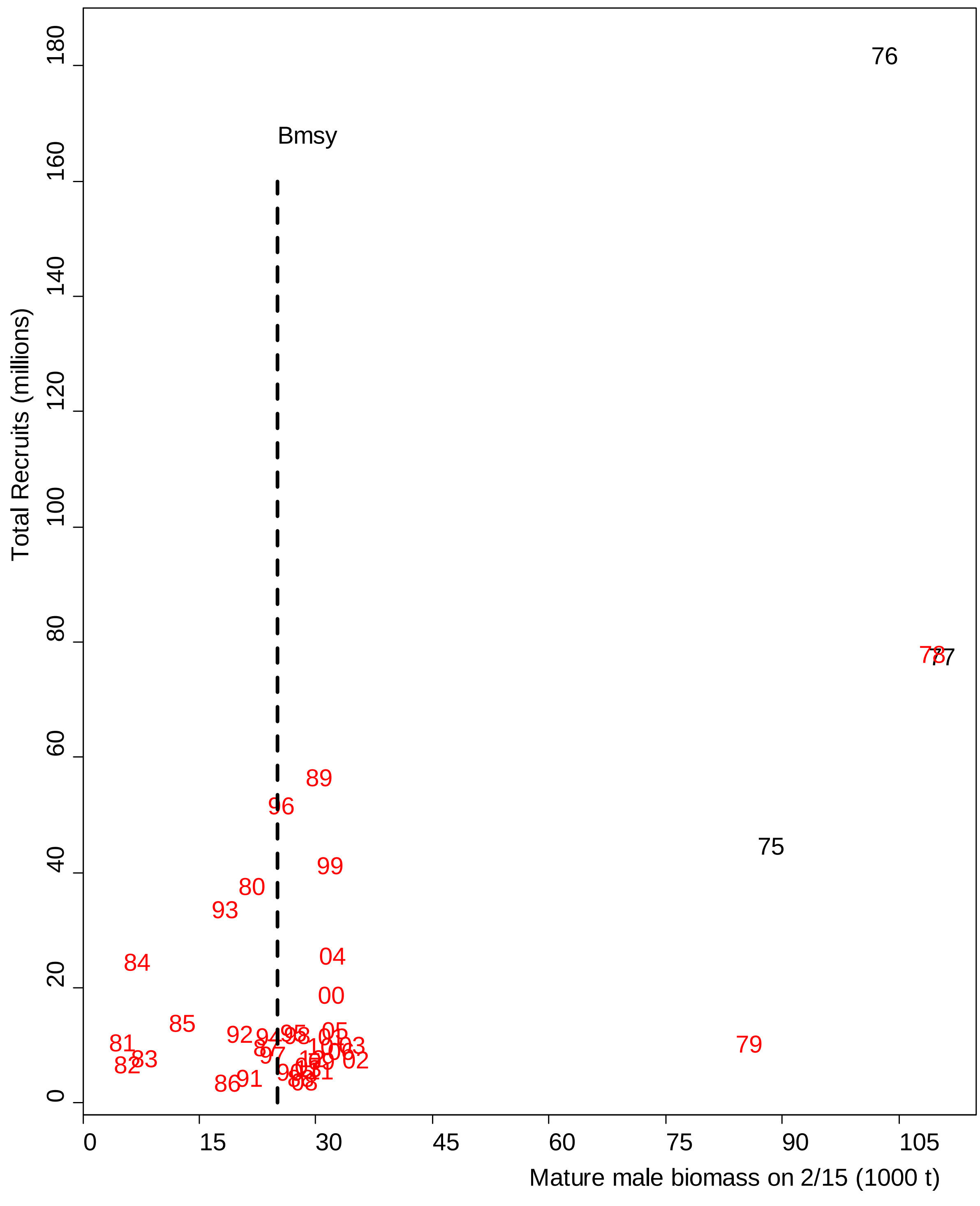


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate of 0.2 under model 18.0e. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2018.

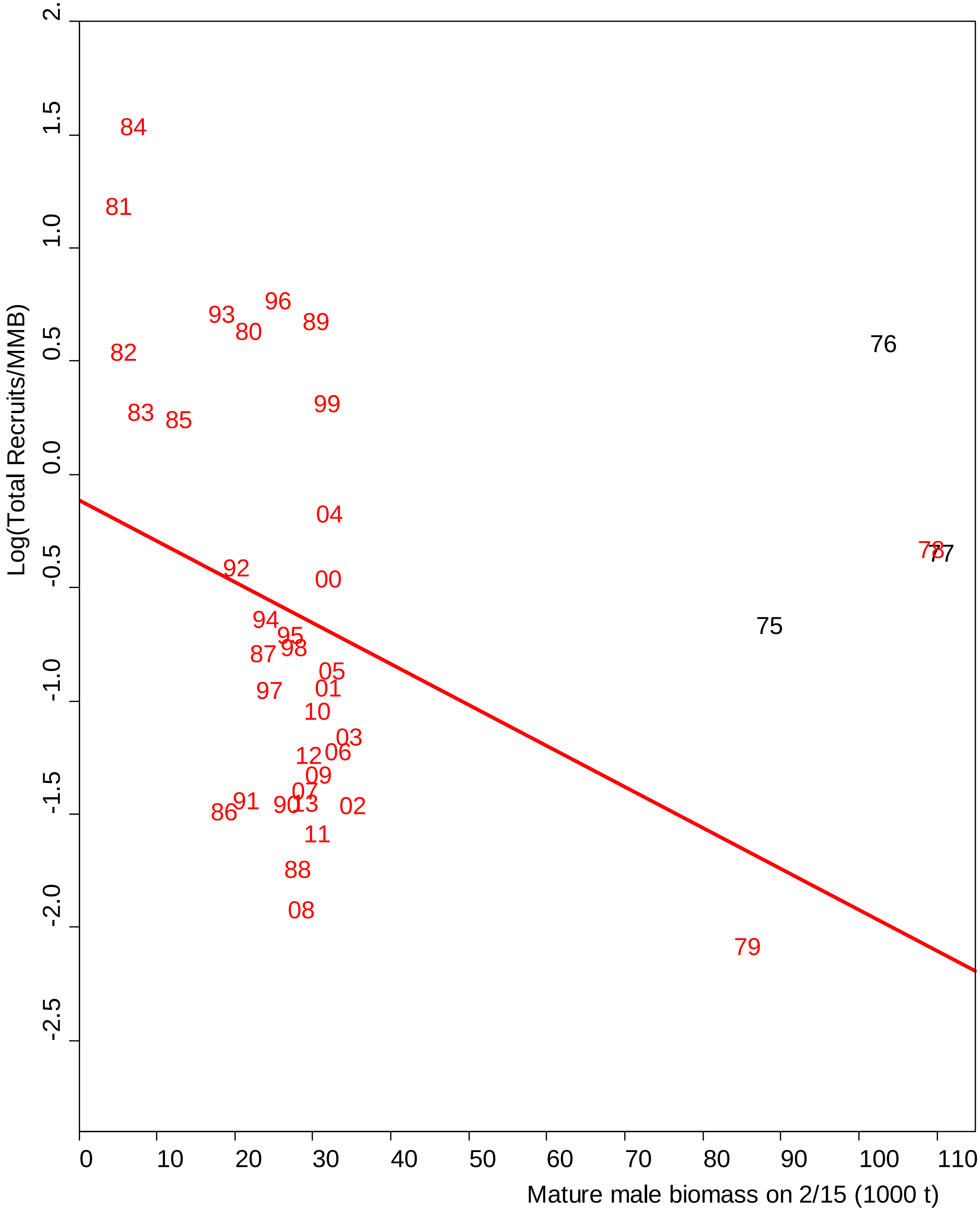


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under model 18.0e. Numerical labels are years of mating, and the line is the regression line for data of 1978-2013.

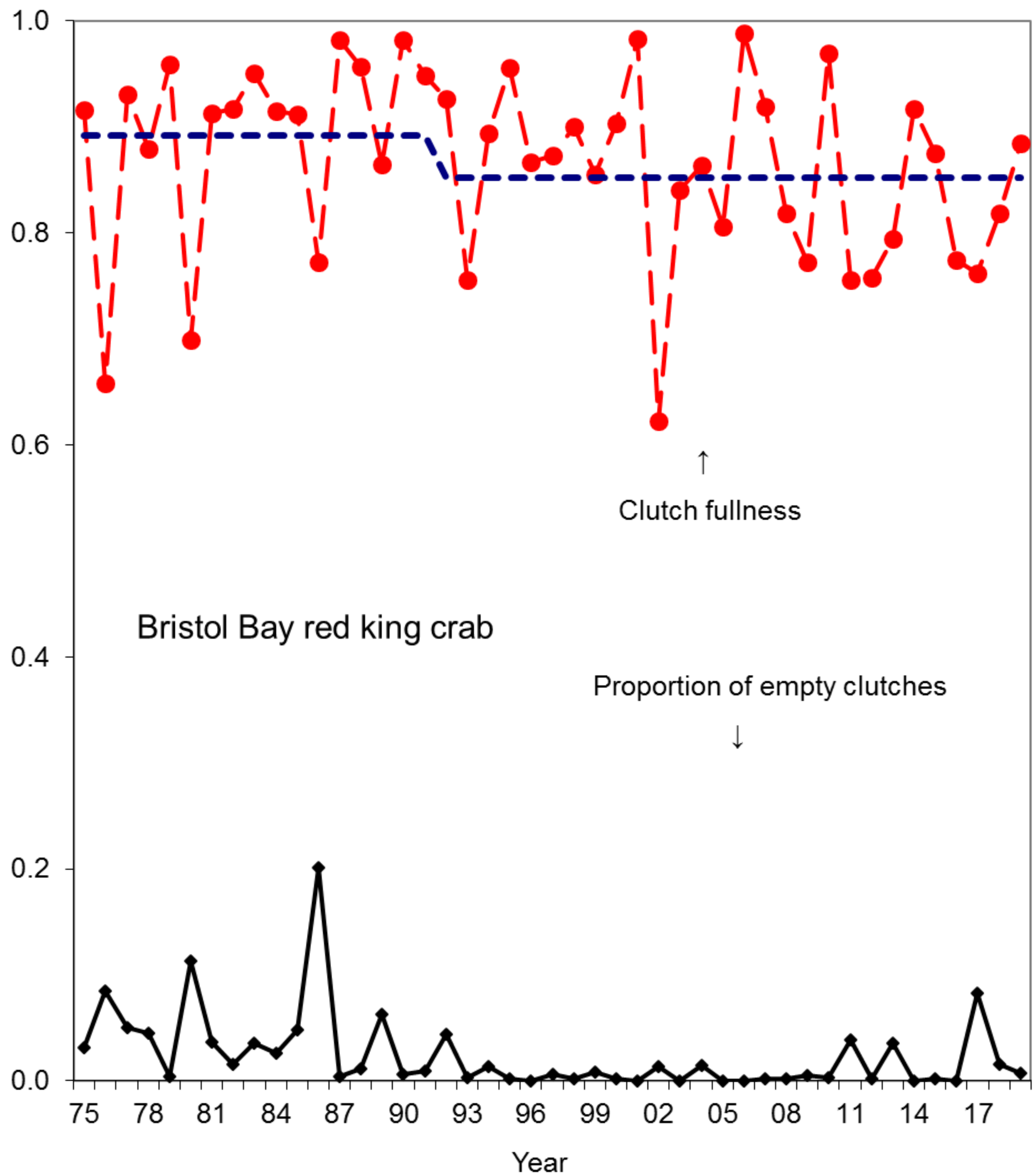


Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2019 from survey data. Oldshell females were excluded. The blue dashed line is the mean clutch fullness during two periods before 1992 and after 1991.

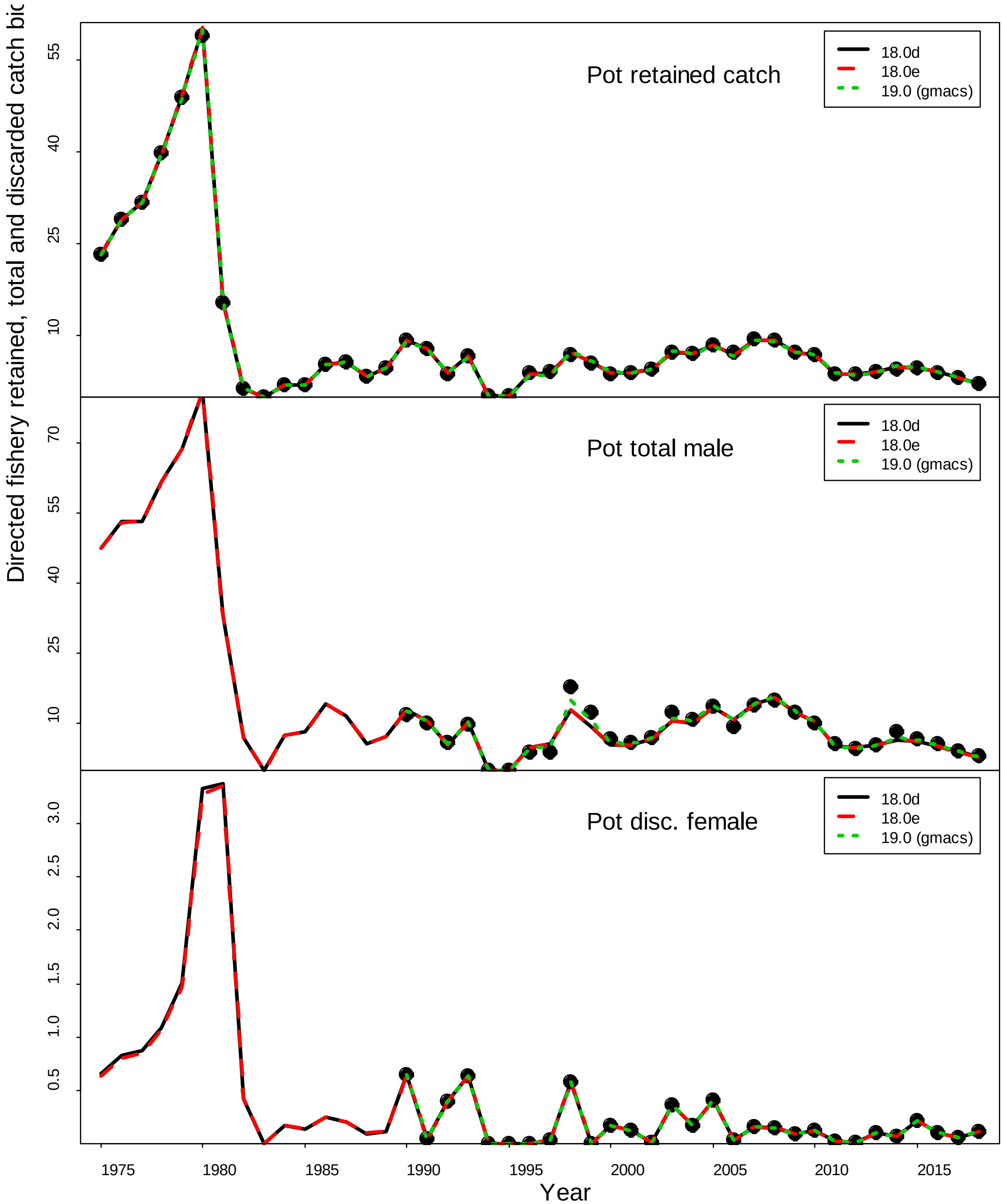


Figure 16a. Observed and predicted RKC catch mortality biomass under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate.

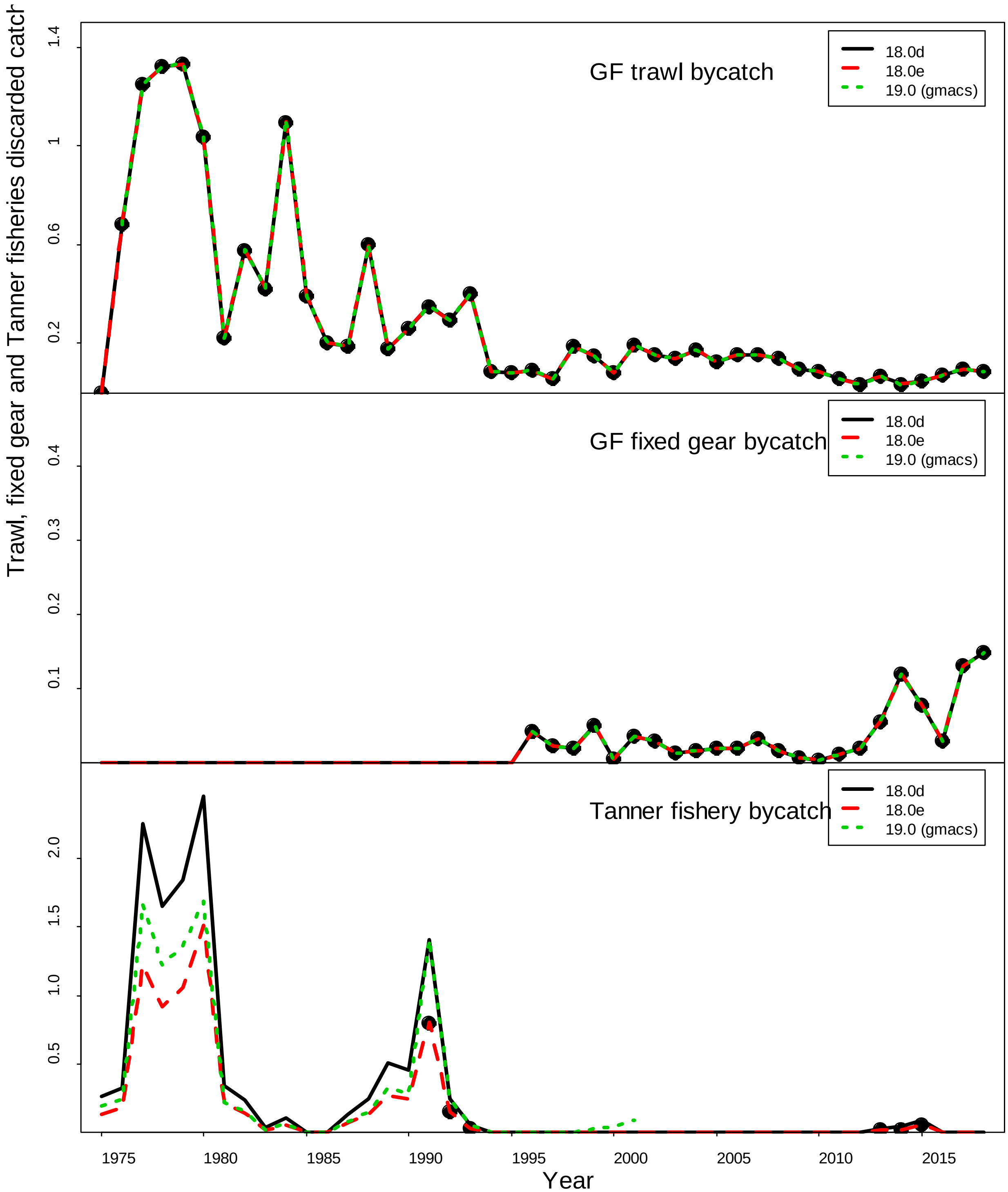


Figure 16b. Observed and predicted RKC bycatch mortality biomass from groundfish fisheries and the Tanner crab fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively. Trawl bycatch biomass was 0 before 1976.

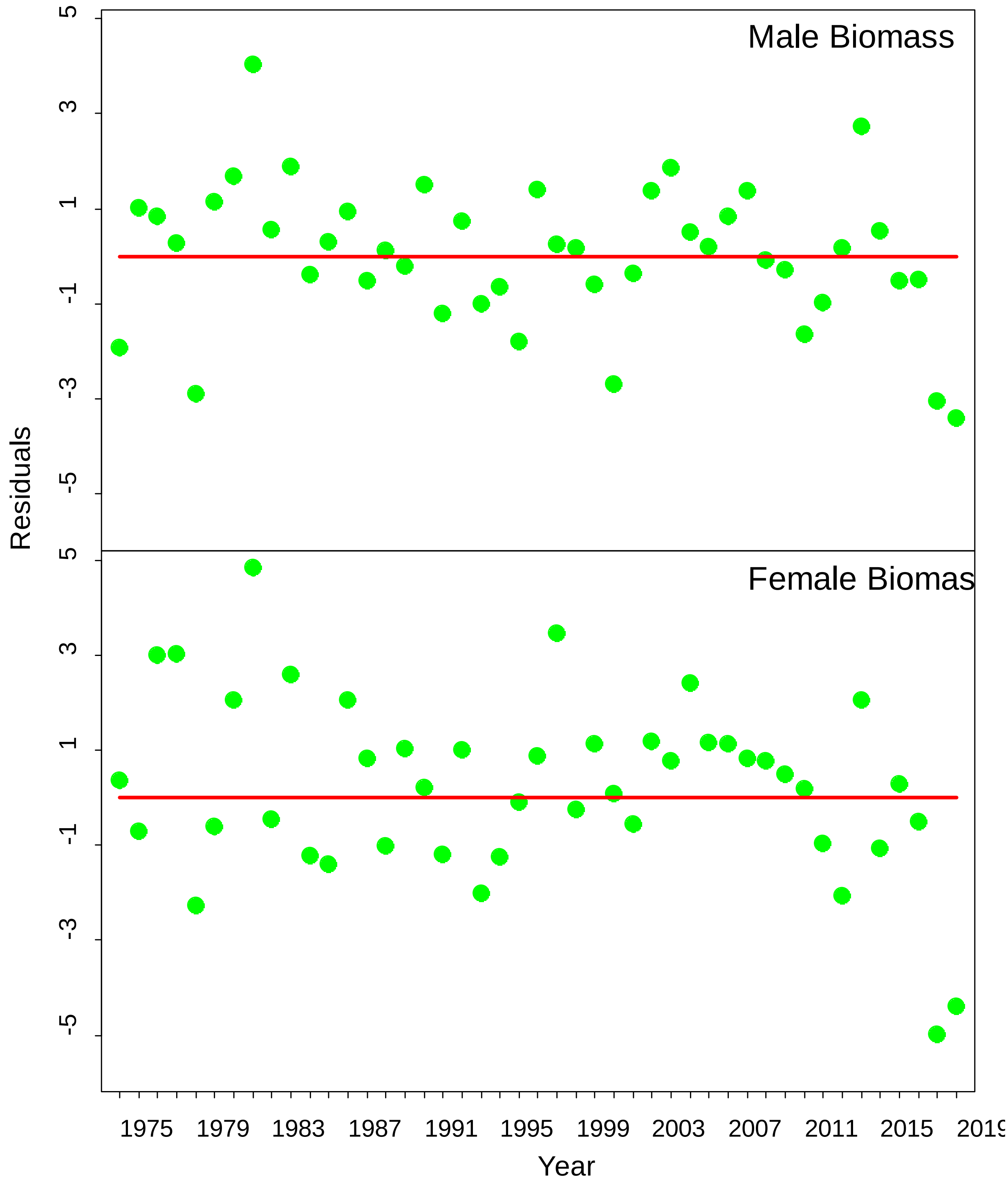


Figure 17(18.0d). Standardized residuals of NMFS survey biomass under model 18.0d. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

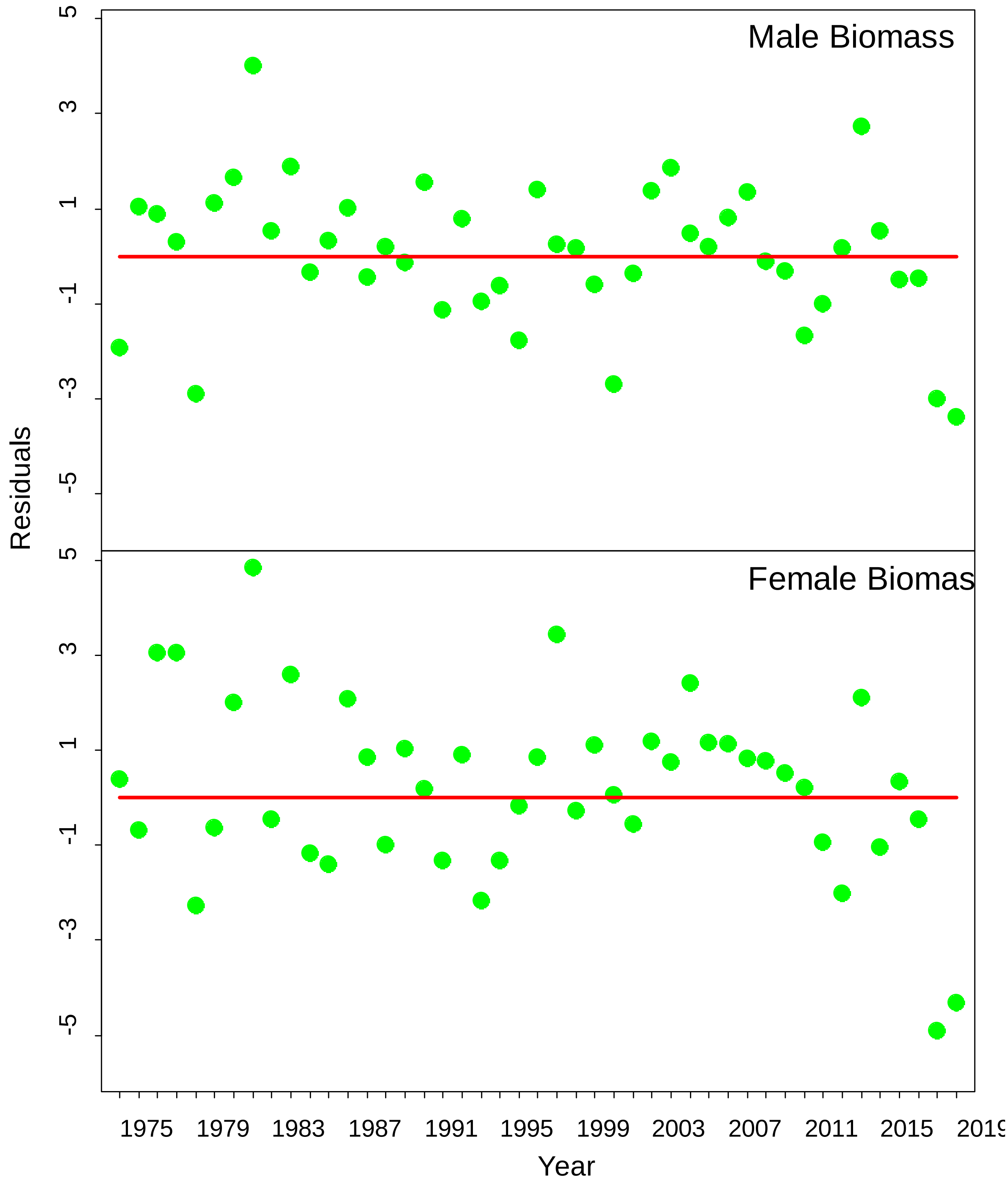


Figure 17(18.0e). Standardized residuals of NMFS survey biomass under model 18.0e. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

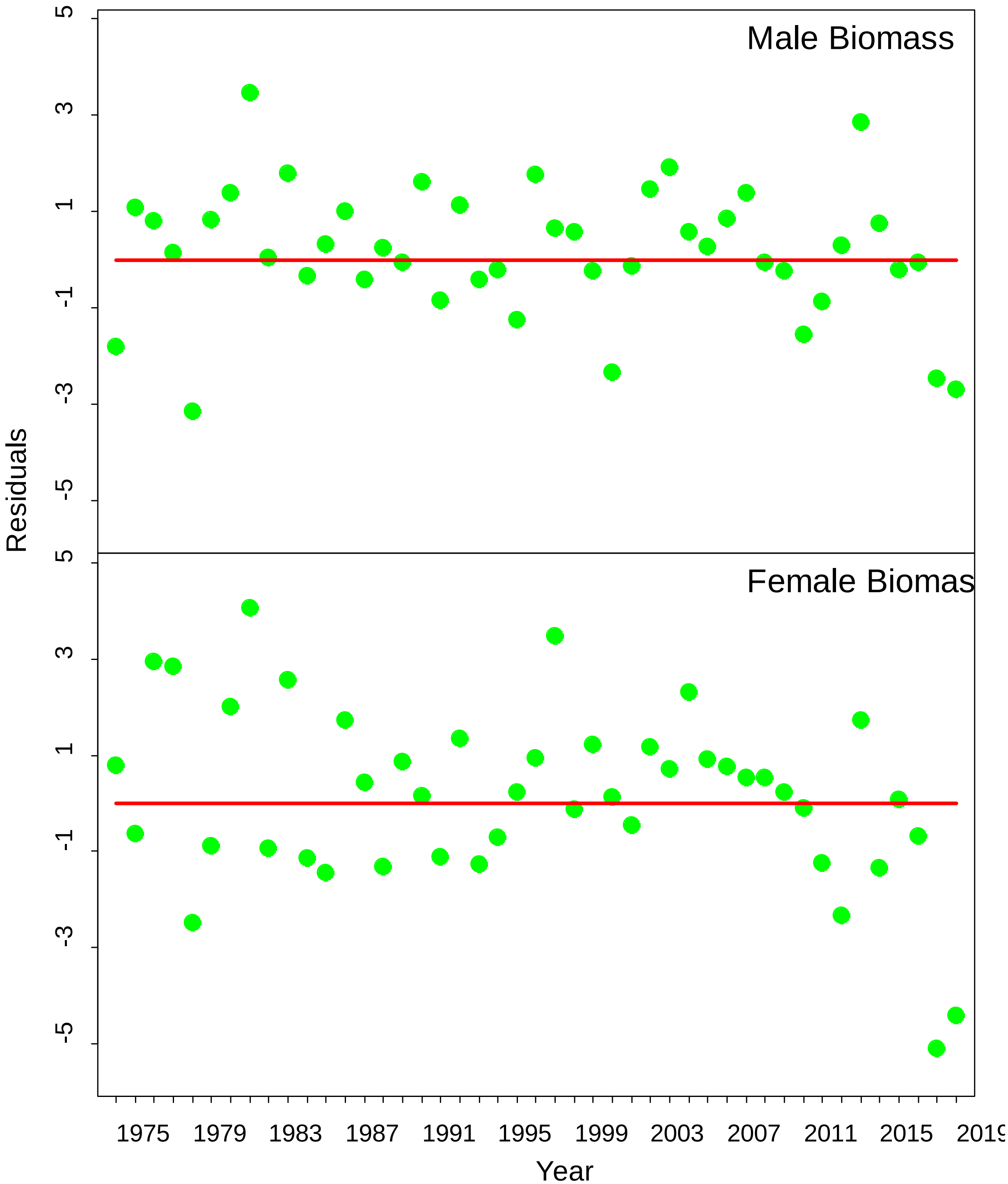


Figure 17(19.0). Standardized residuals of NMFS survey biomass under model 19.0. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

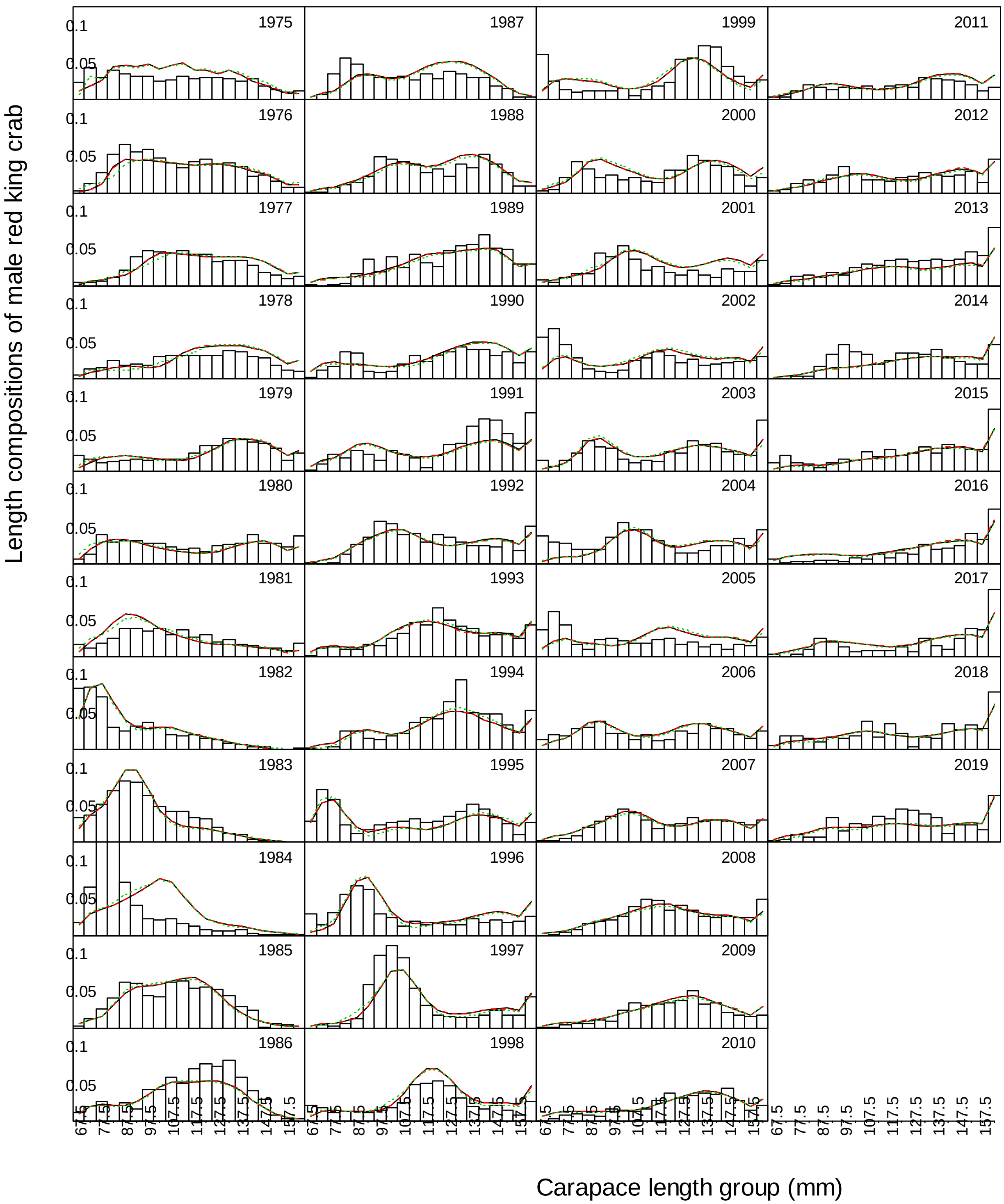


Figure 18(18.0d, 18.0e & 19.0 (gmacs)). Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

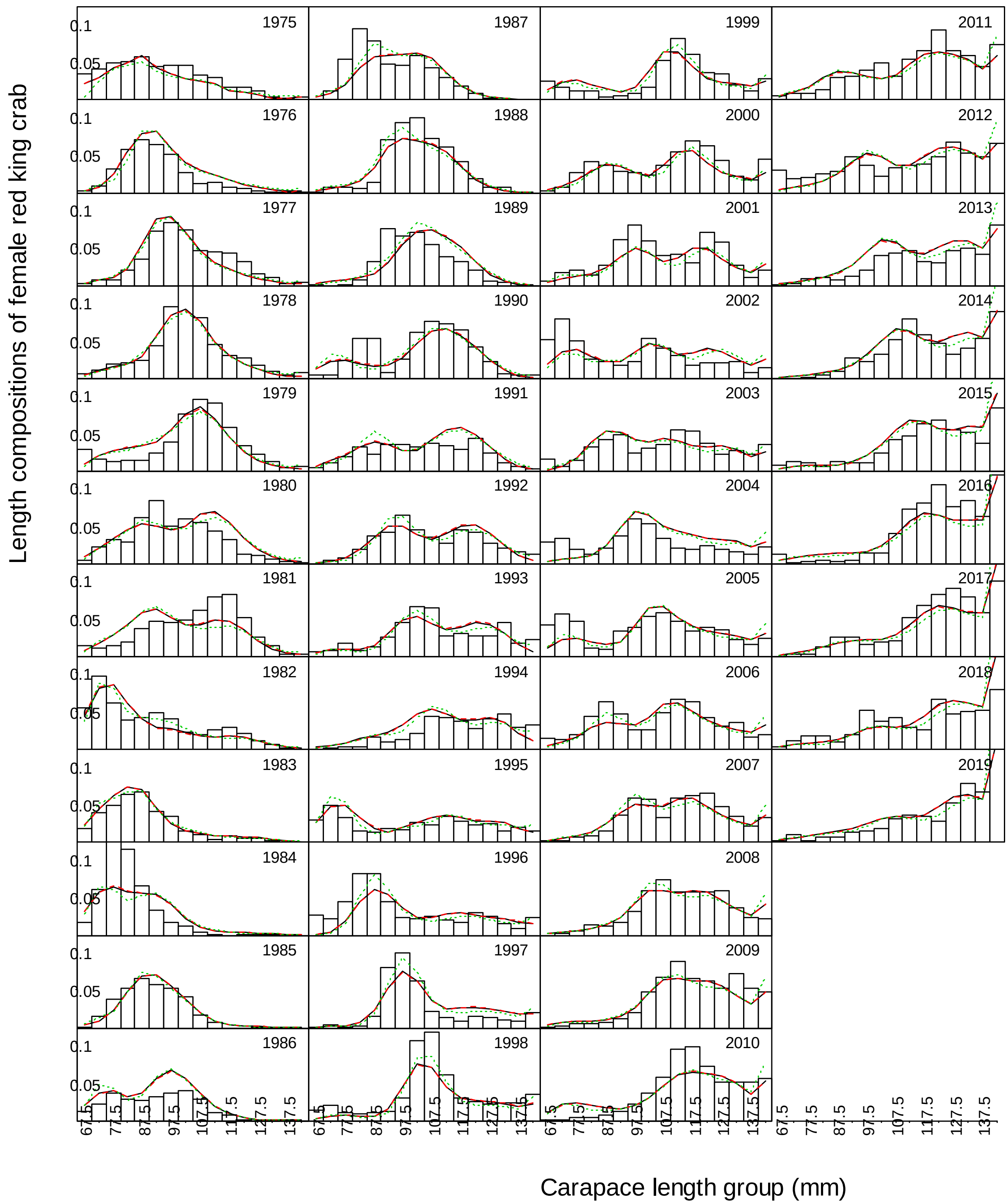


Figure 19(18.0d, 18.0e & 19.0 (gmacs)). Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay female red king crab by year under models 18.0d (solid black), 18.0e (dashed red), and 19.0 (green lines).

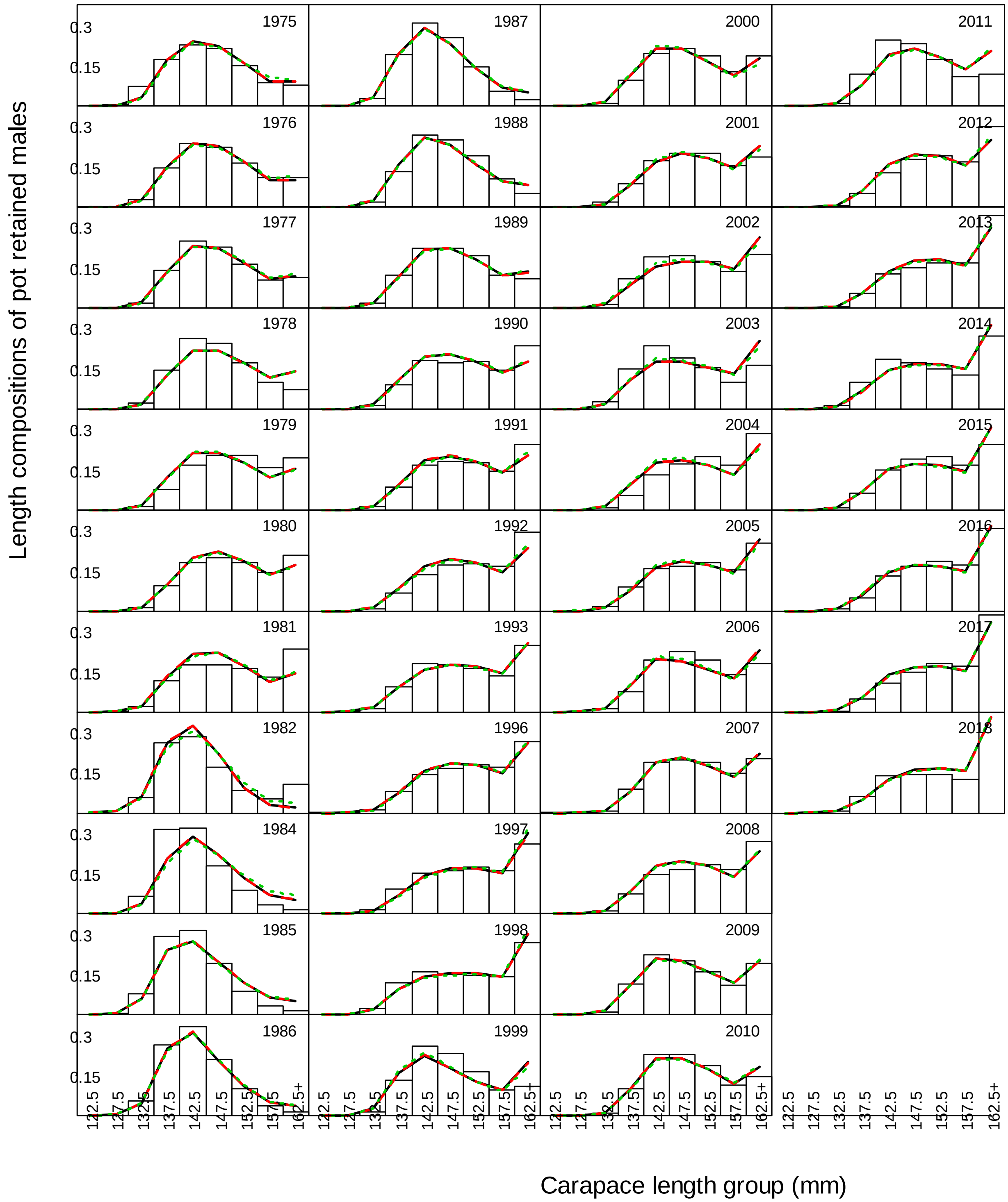


Figure 20(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

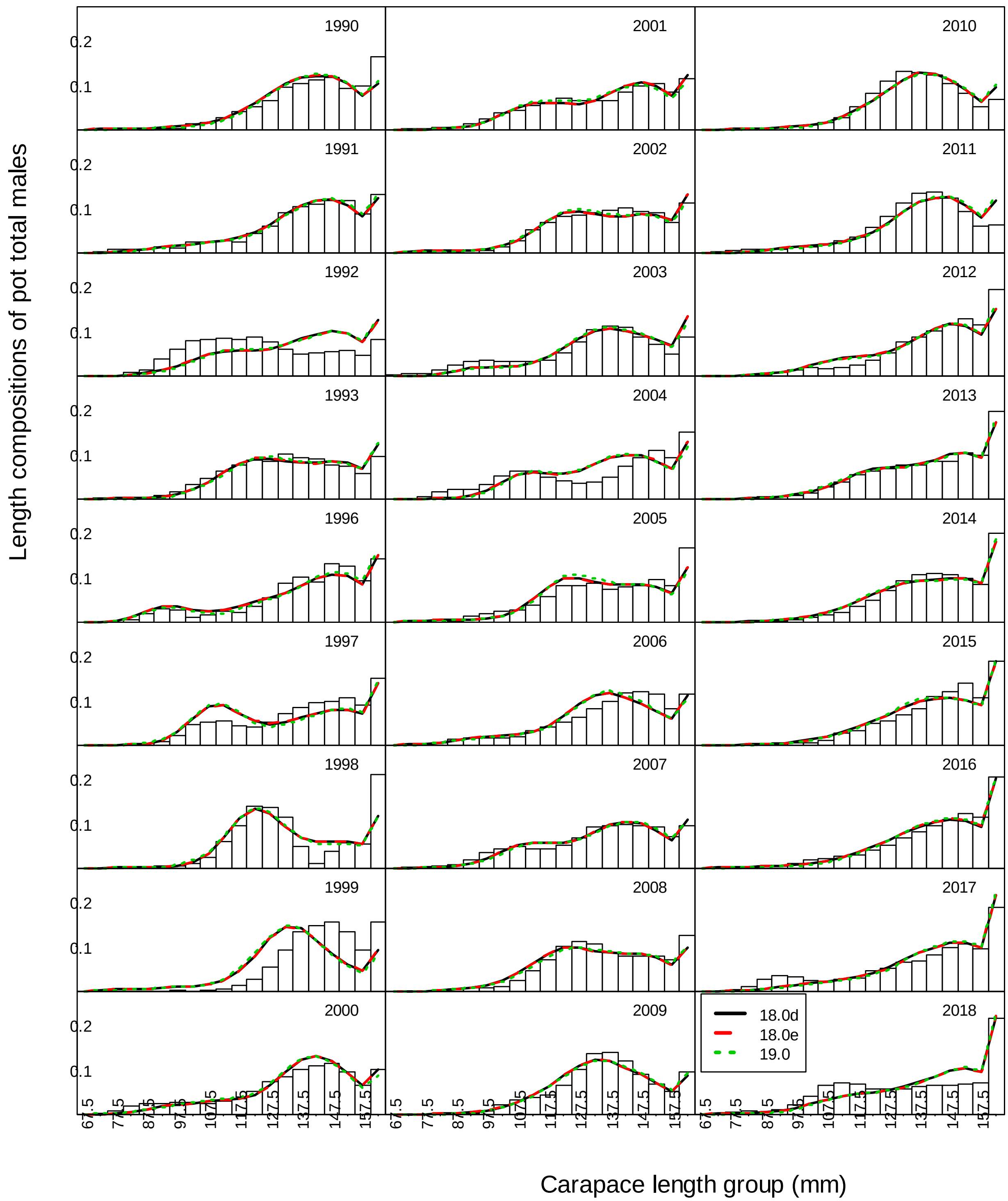


Figure 21(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated total observer length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

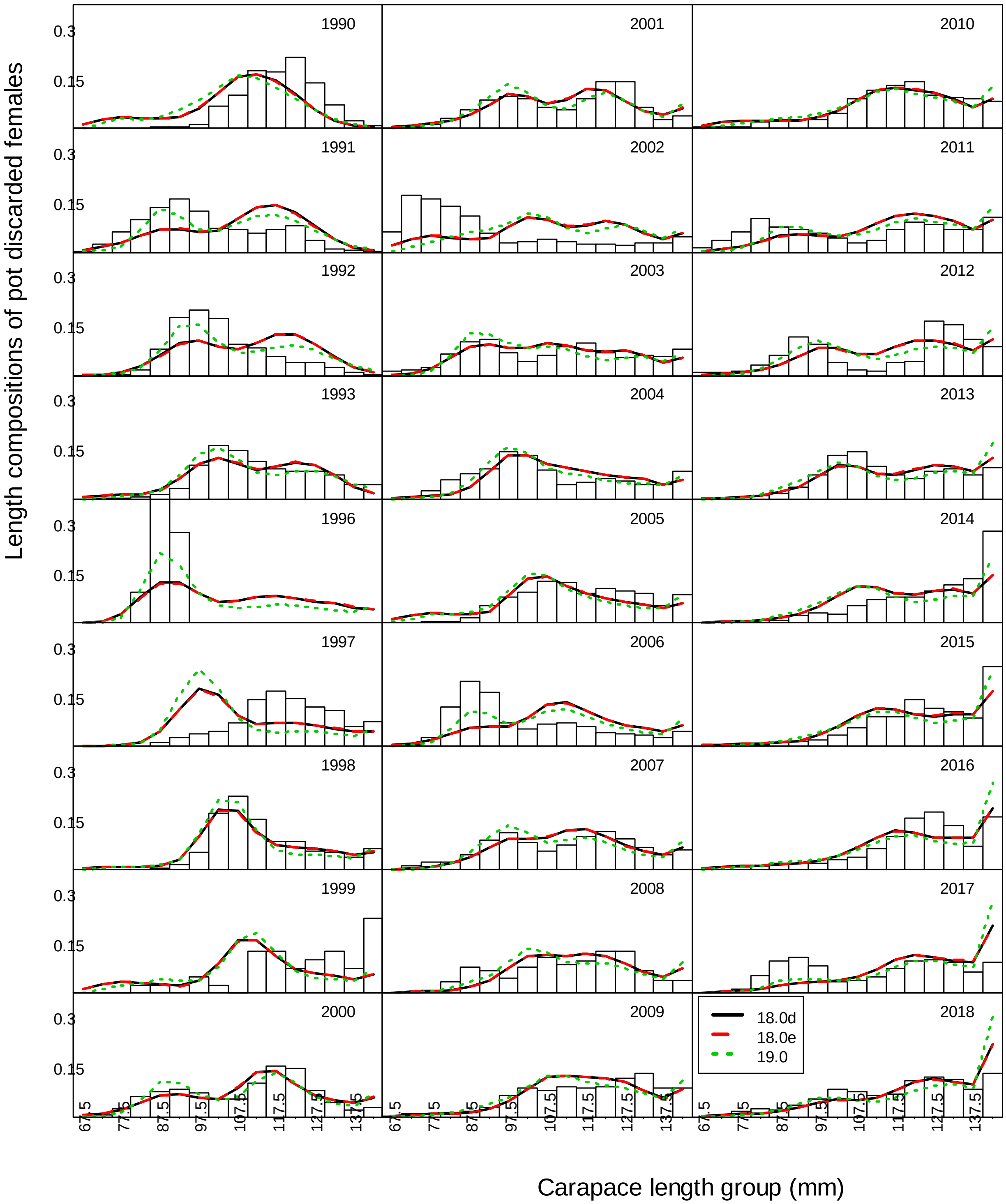


Figure 22(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

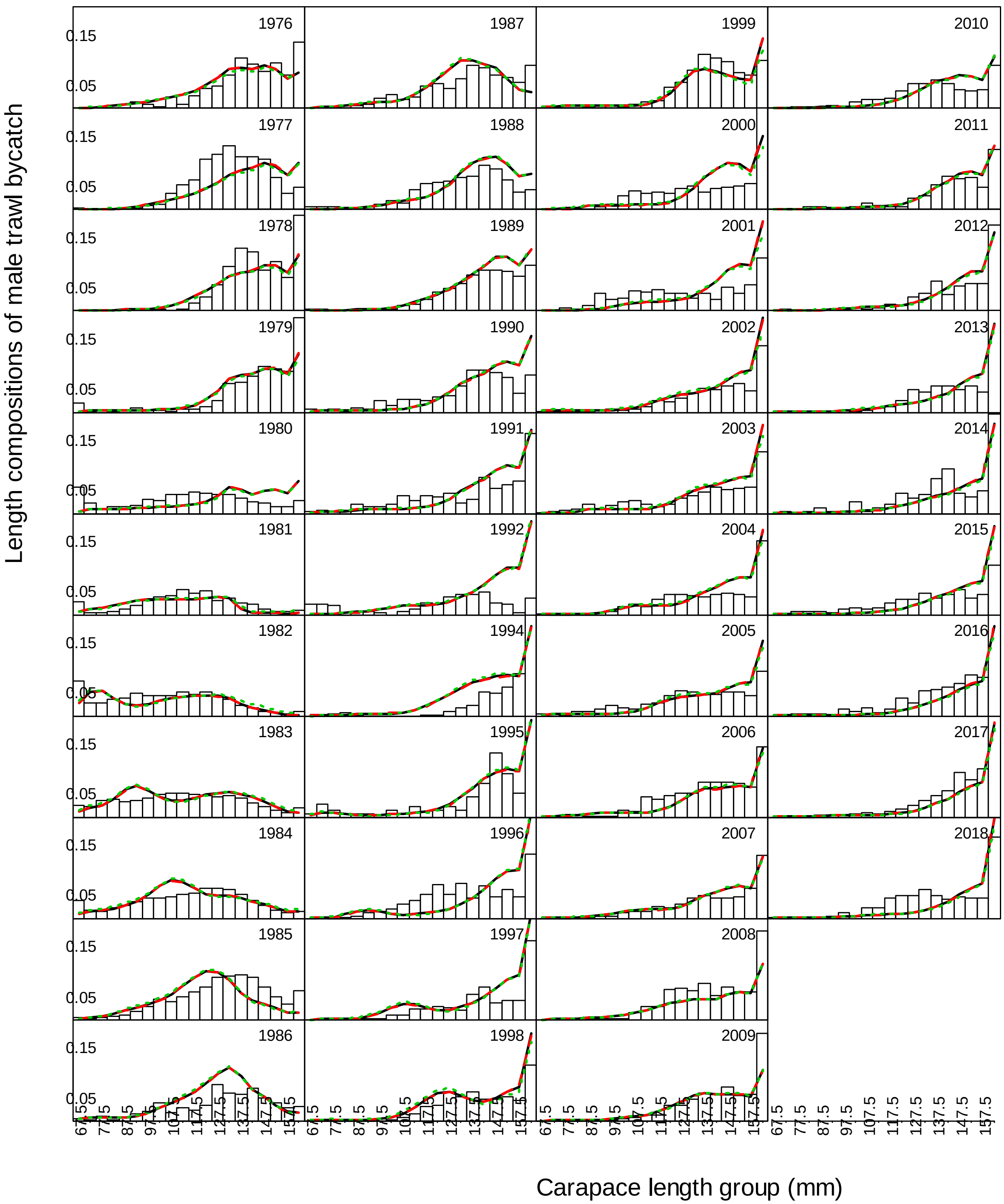


Figure 23(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

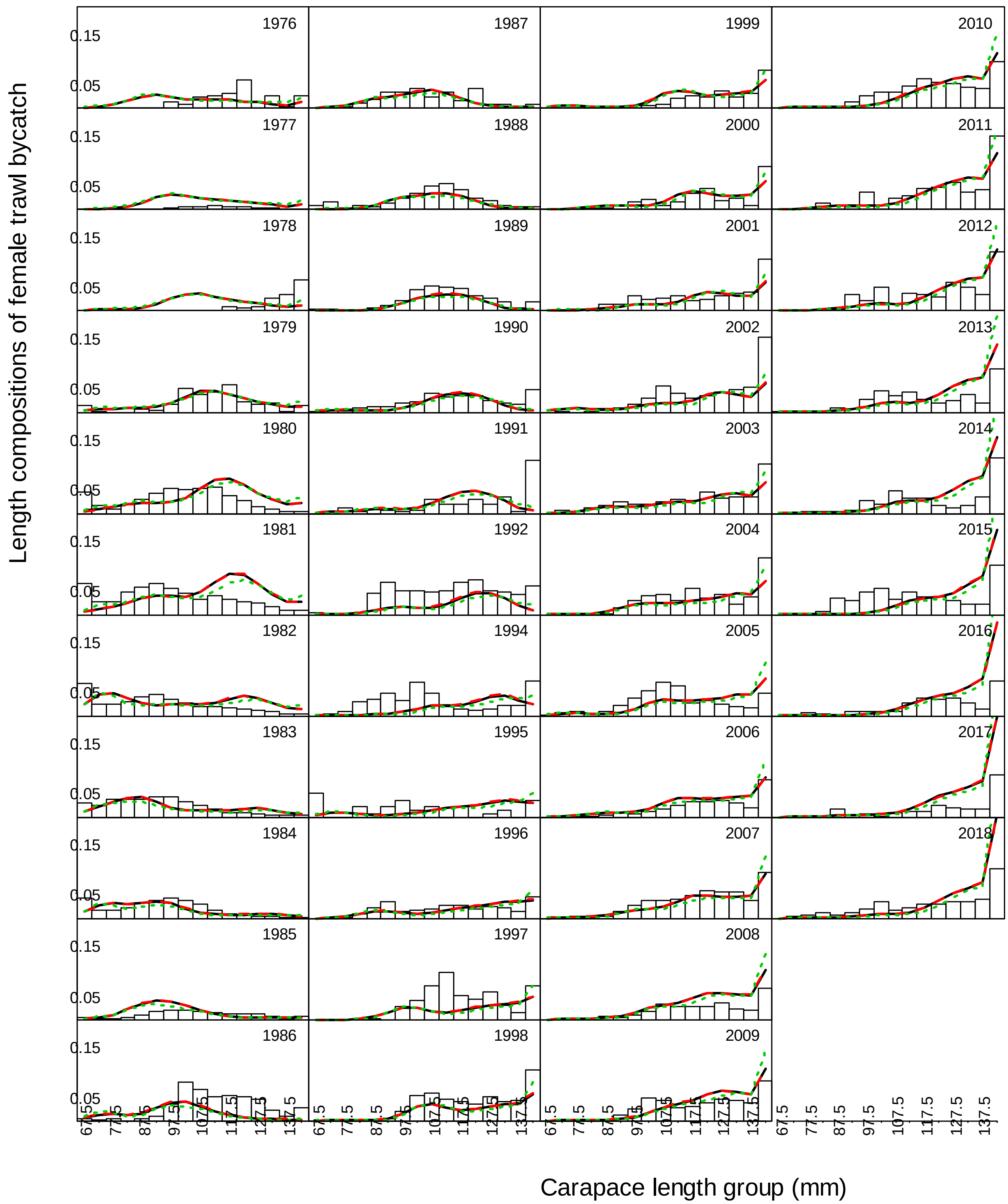


Figure 23(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

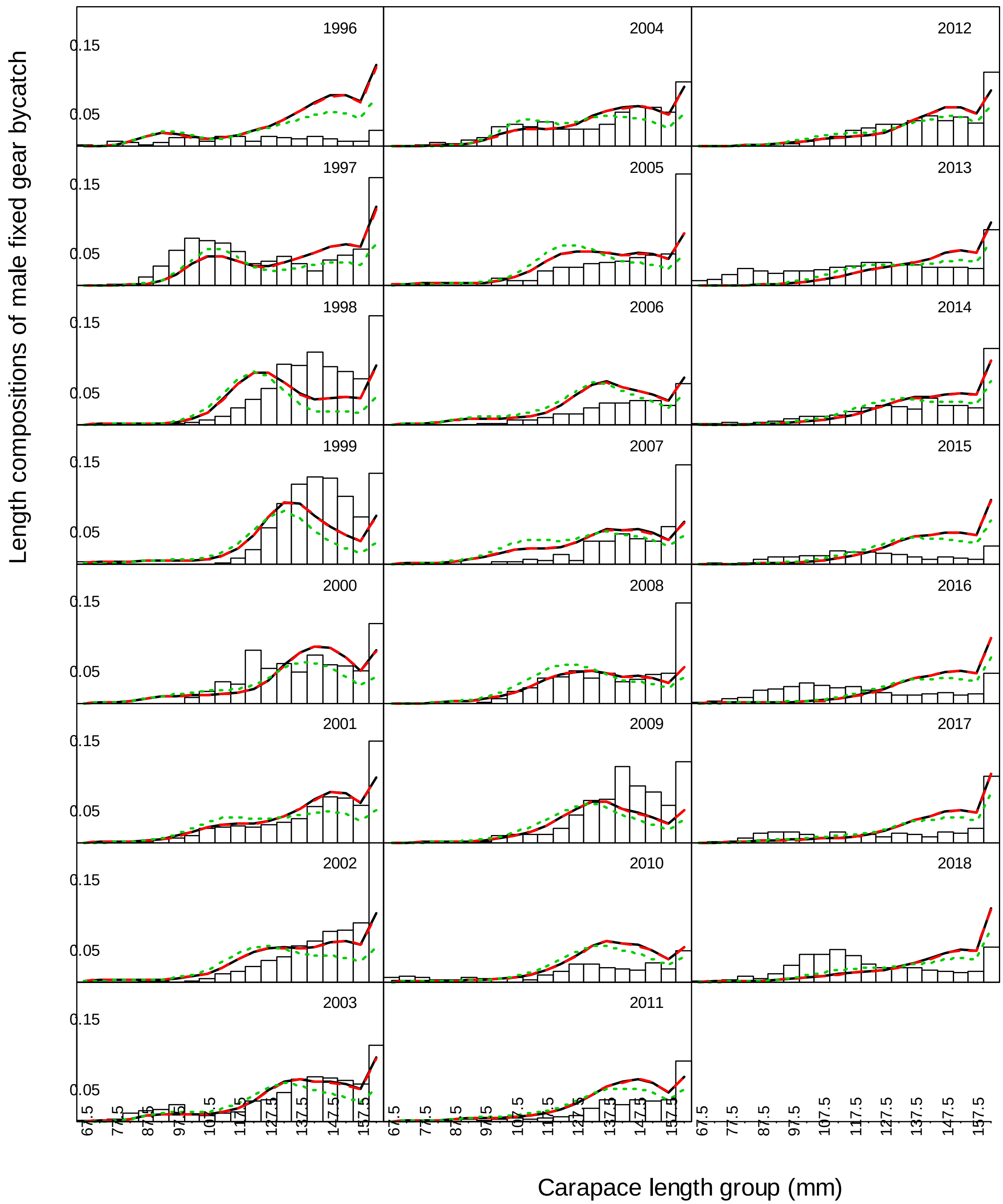


Figure 24(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

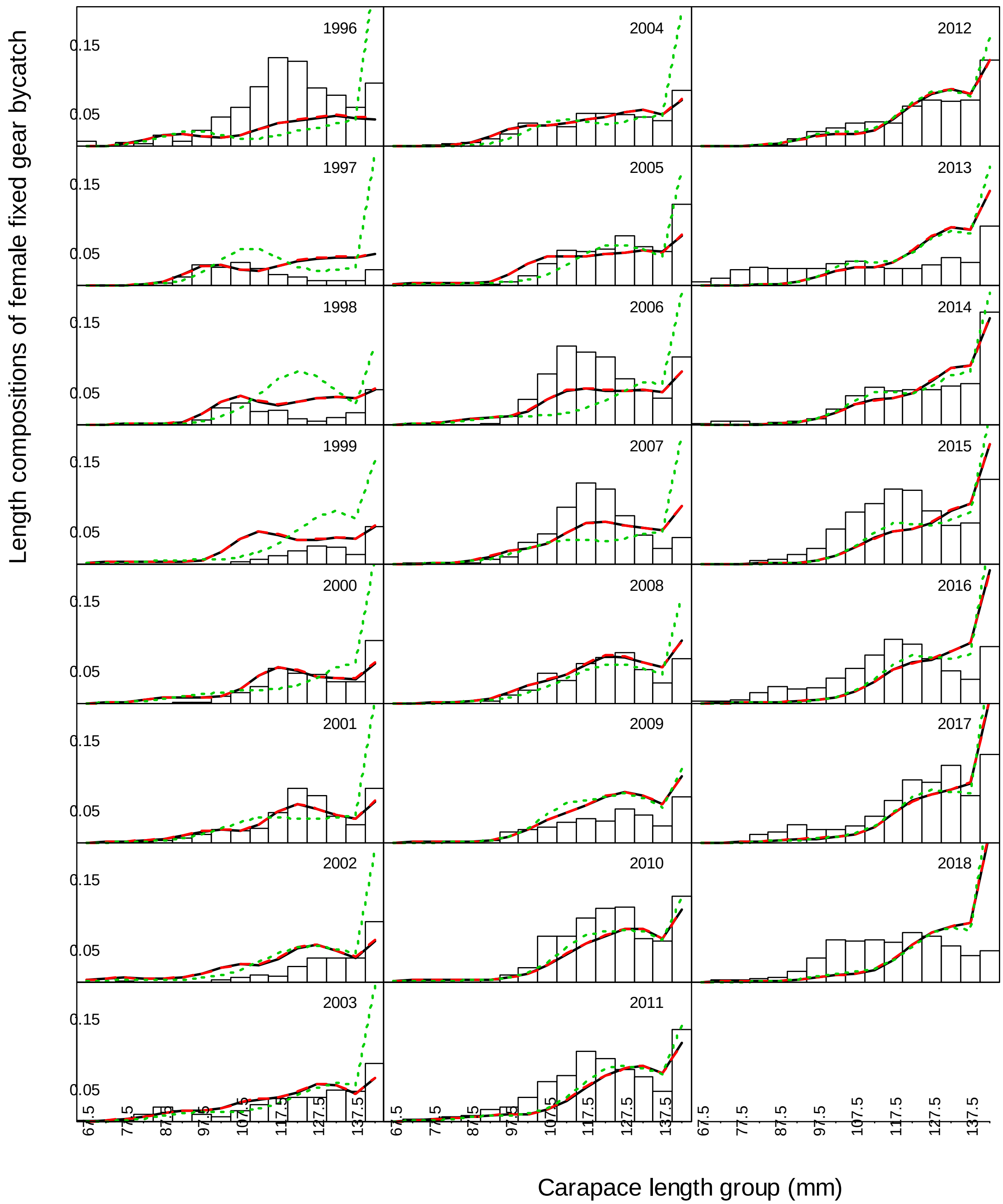


Figure 24(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

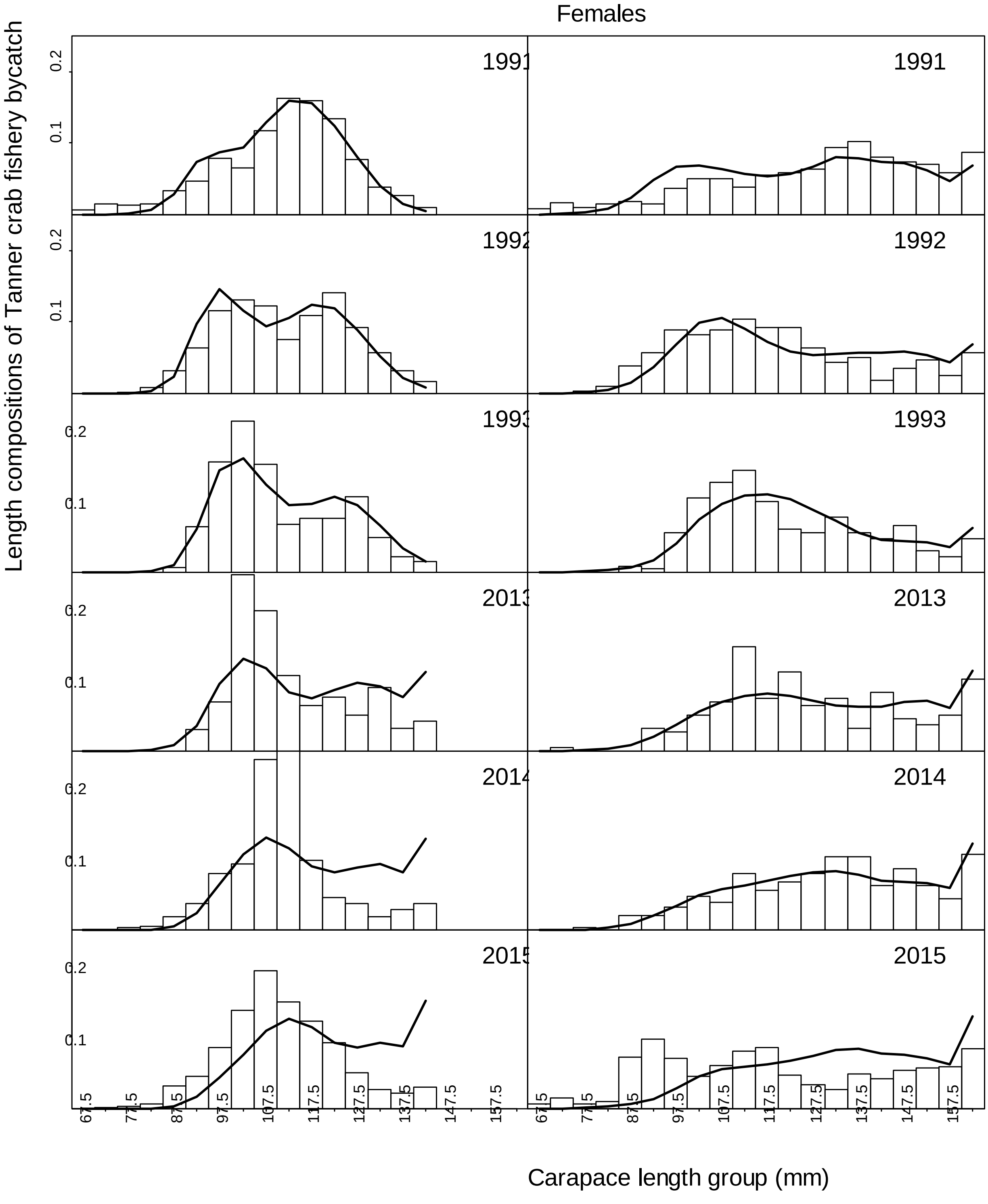


Figure 24(18.0d). Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under model 18.0d. The sum of each sex length composition for each year is 1.0.

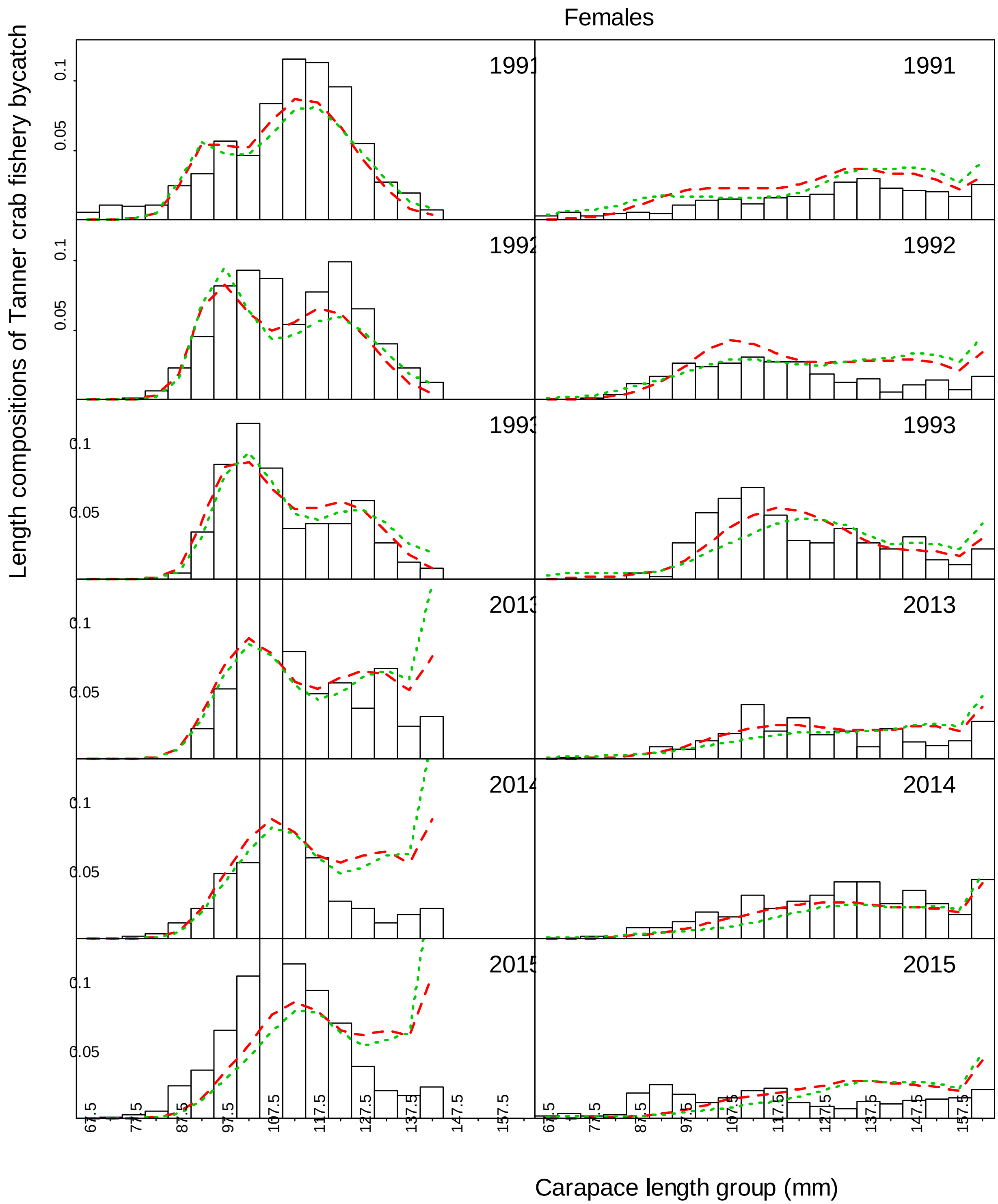


Figure 24(18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under models 18.0e (dashed red) and 19.0 (green lines).

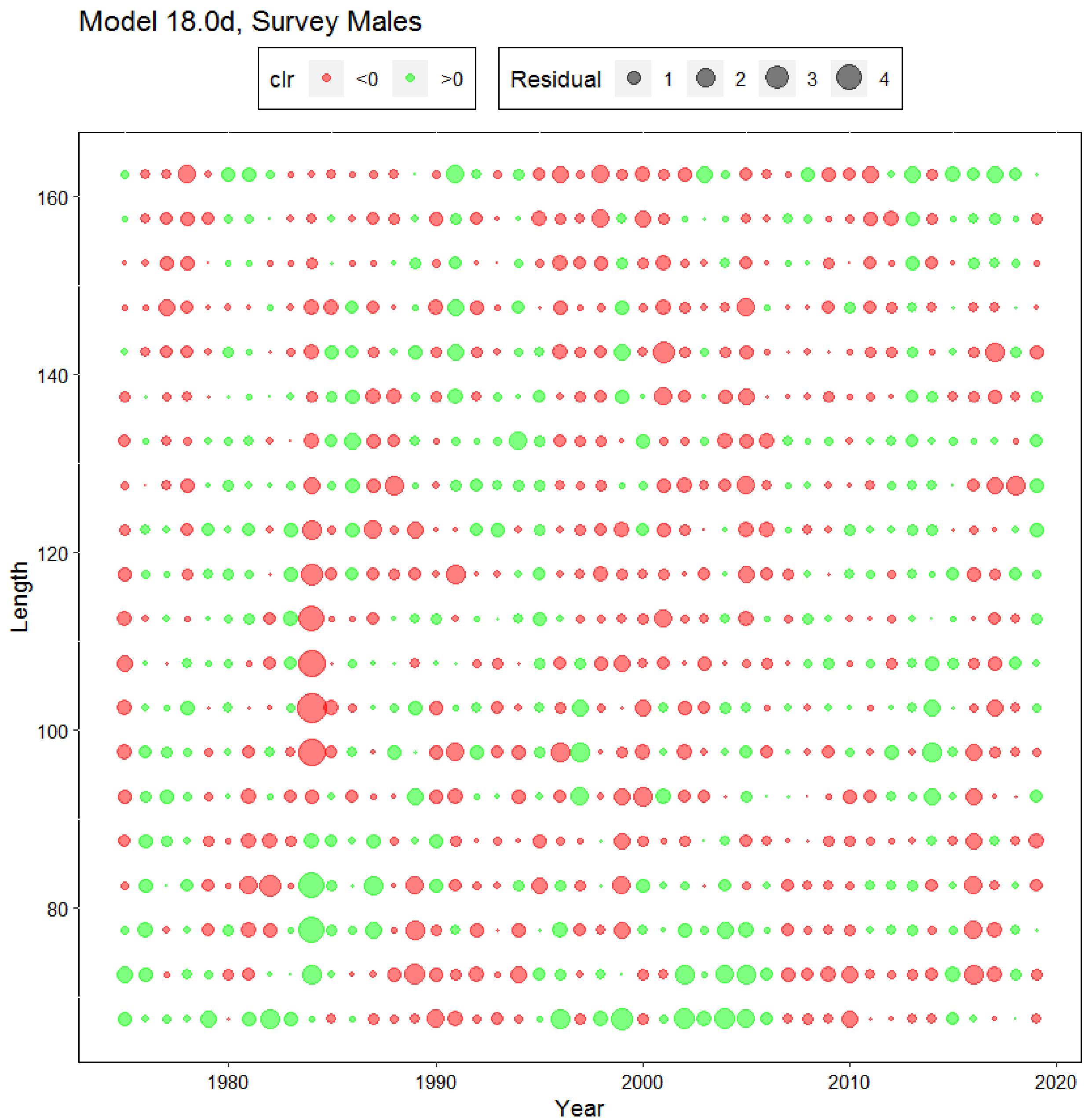


Figure 25(18.0d). Standardized residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 18.0d. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

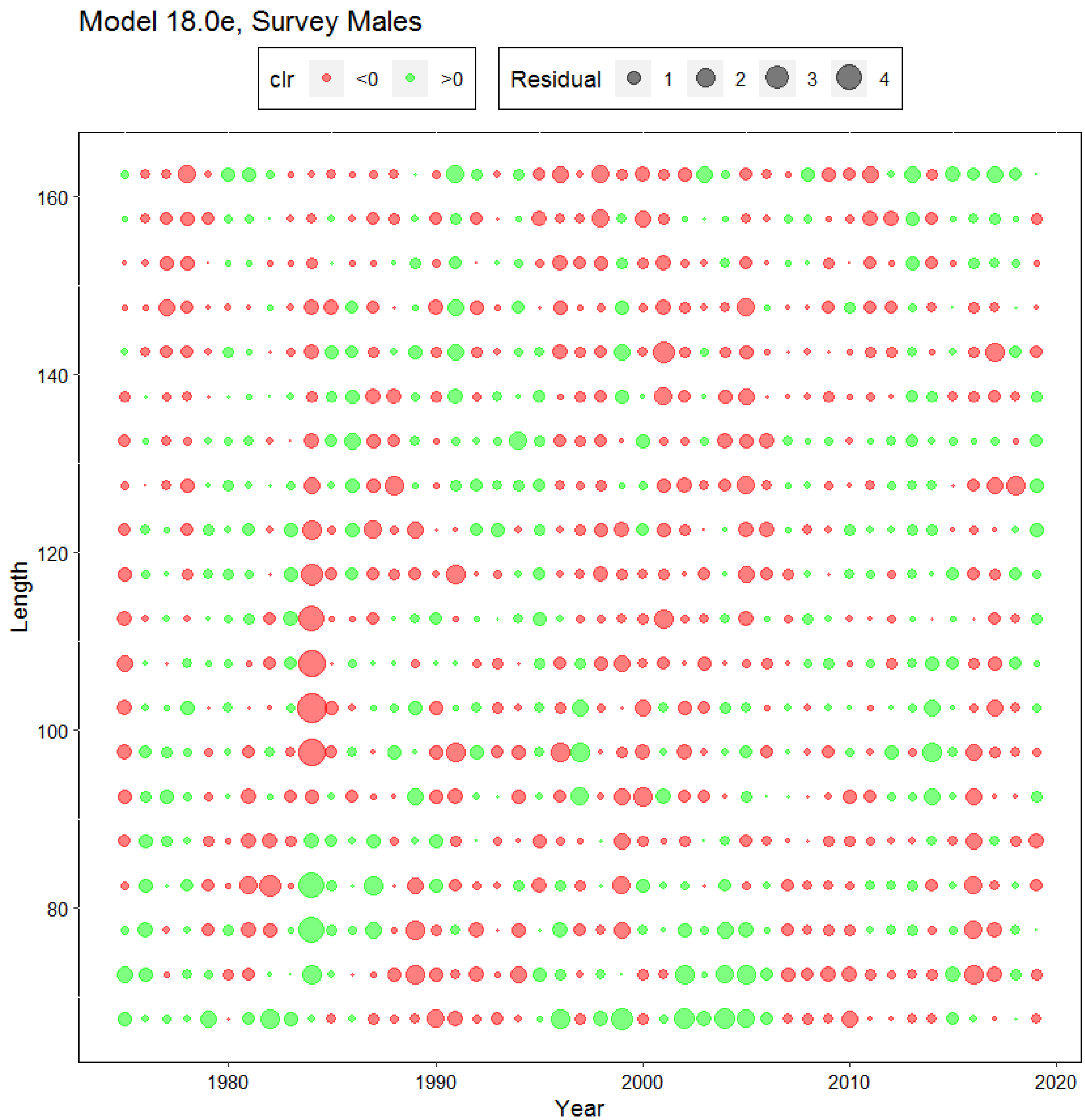


Figure 25(18.0e). Standardized residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 18.0e. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

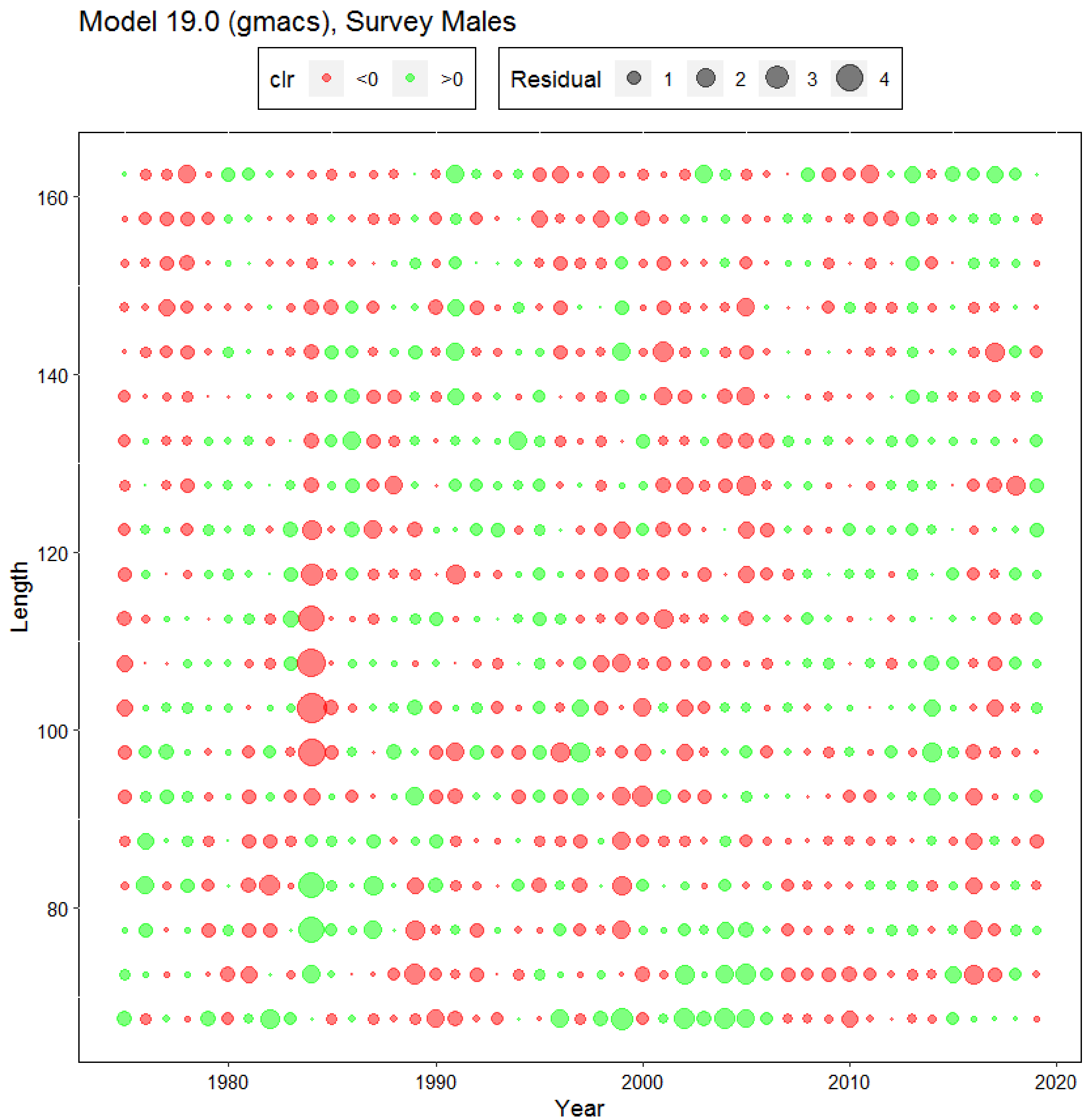


Figure 25(19.0 (gmacs)). Standardized residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 19.0. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

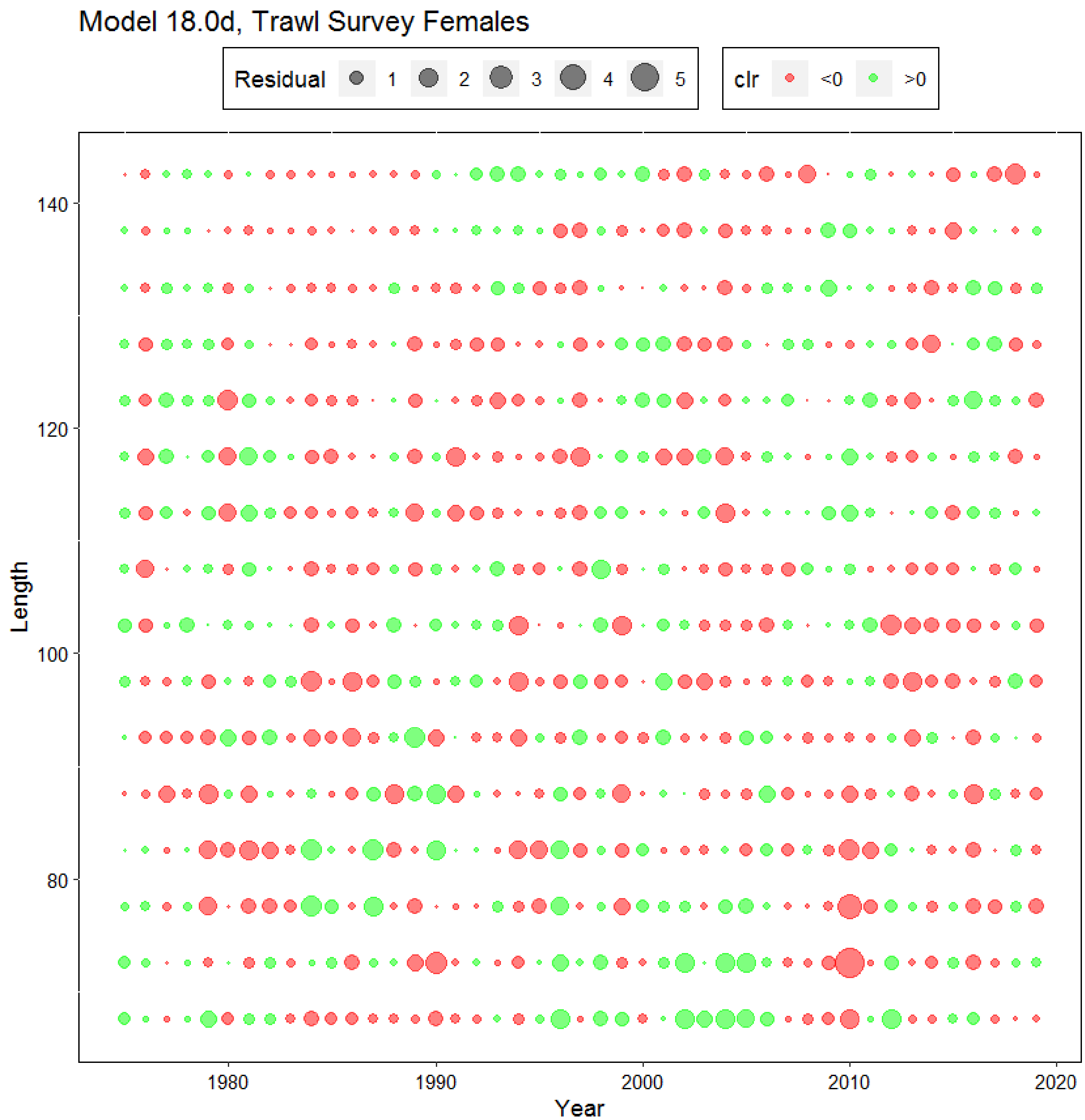


Figure 25(18.0d). Standardized residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 18.0d. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

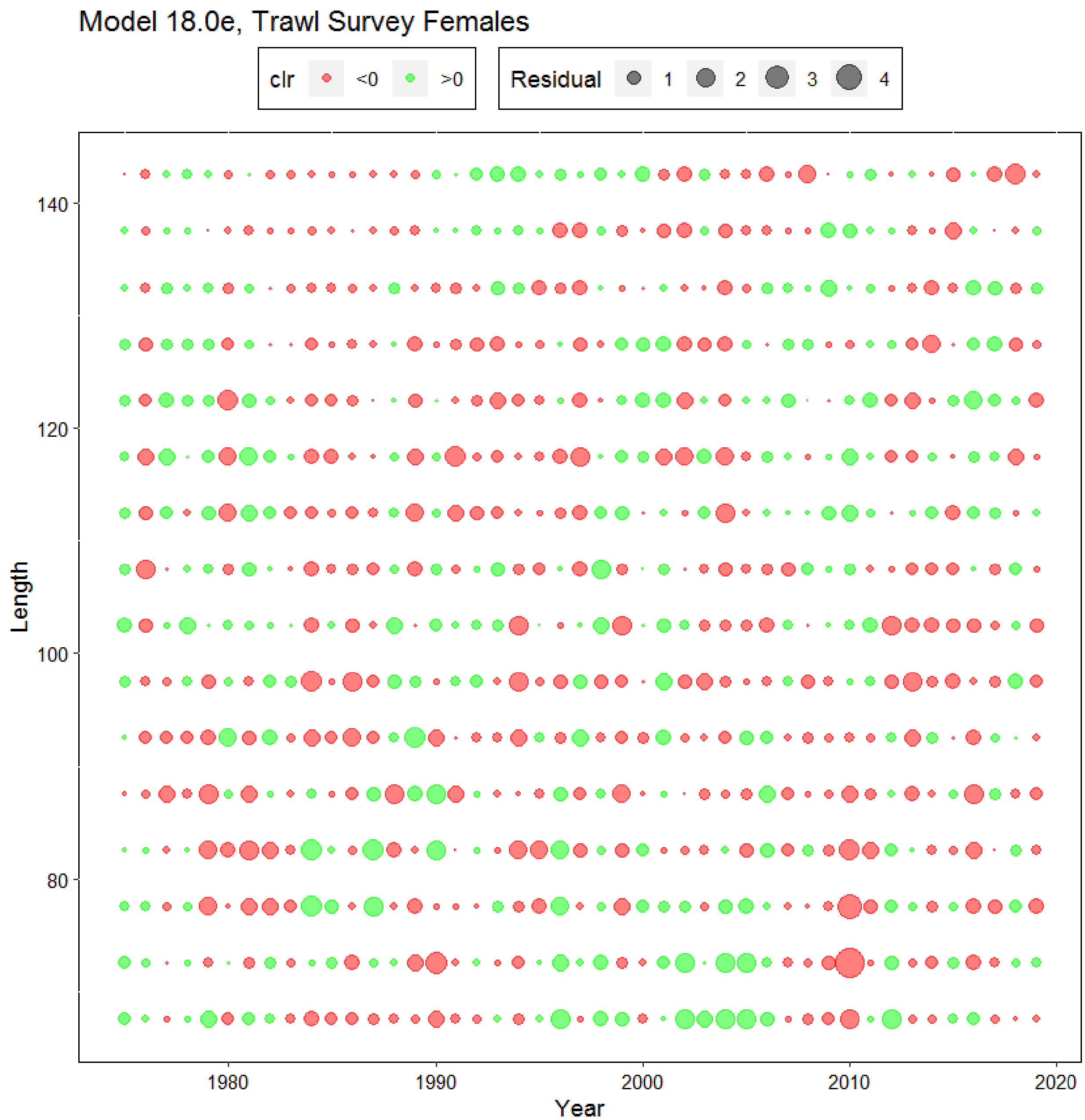


Figure 25(18.0e). Standardized residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 18.0e. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

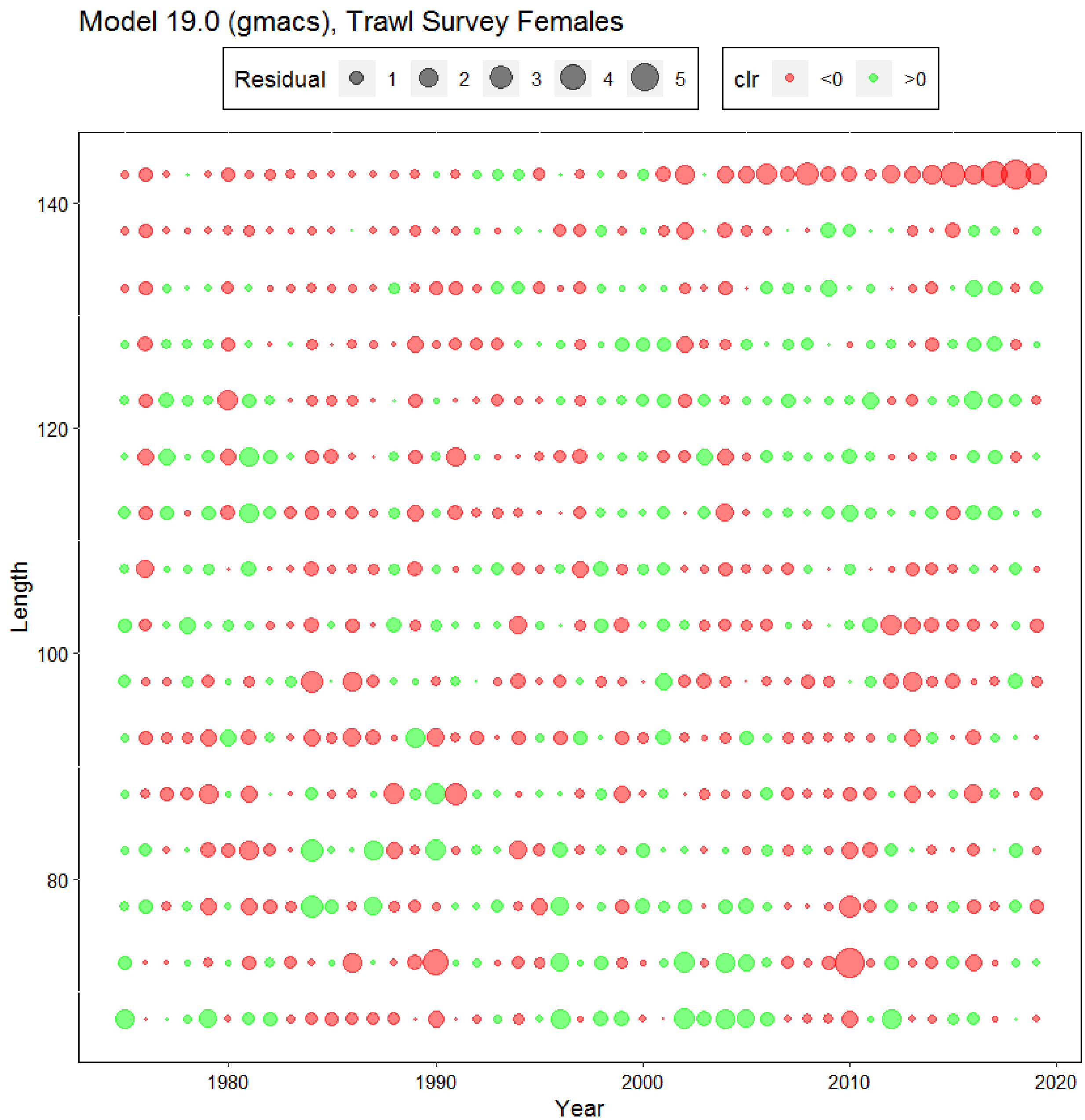


Figure 25(19.0 (gmacs)). Standardized residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 19.0. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

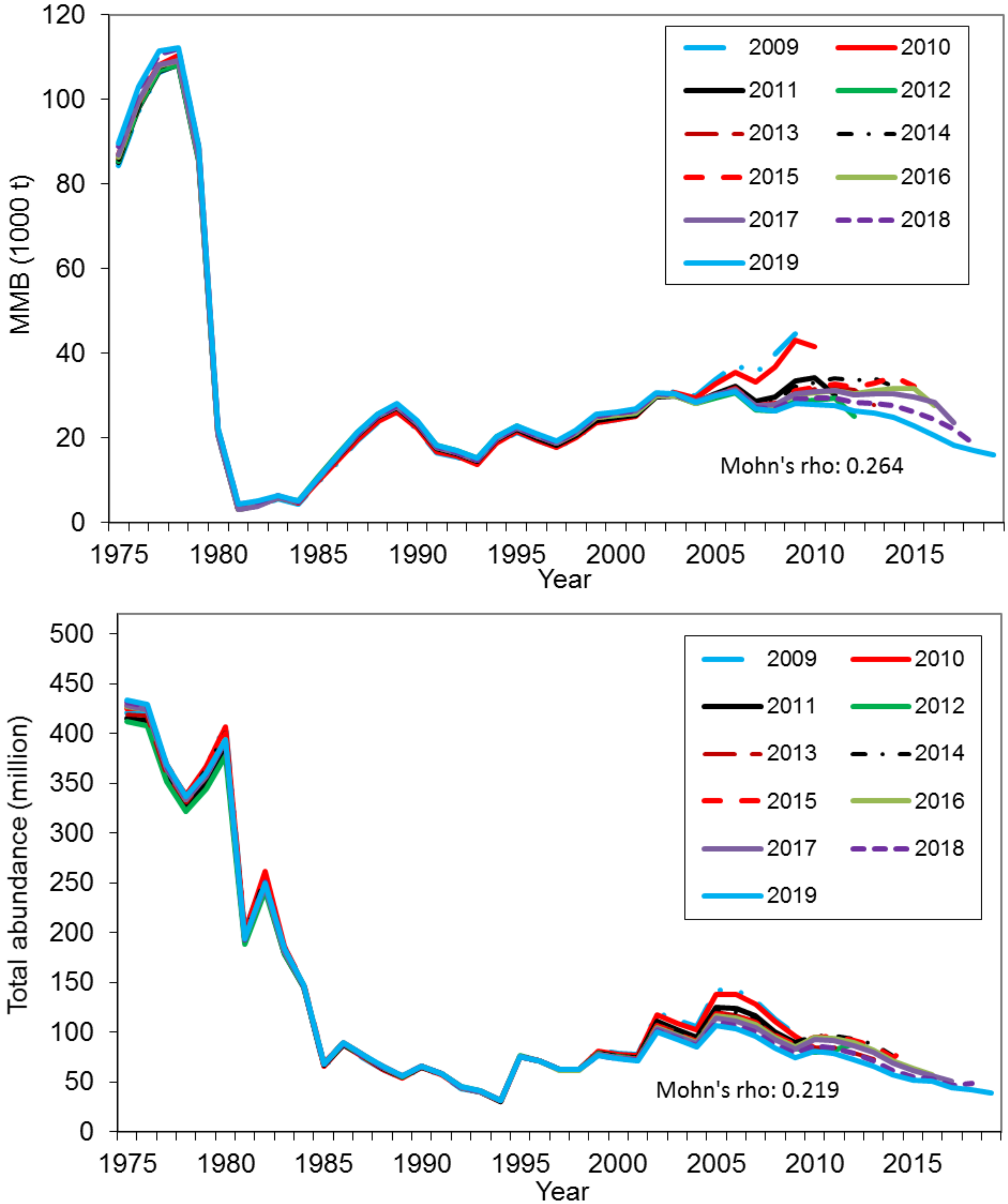


Figure 27. Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2019 made with terminal years 2009-2019 with model 19.0 (gmacs). These are results of the 2019 model. Legend shows the terminal year. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

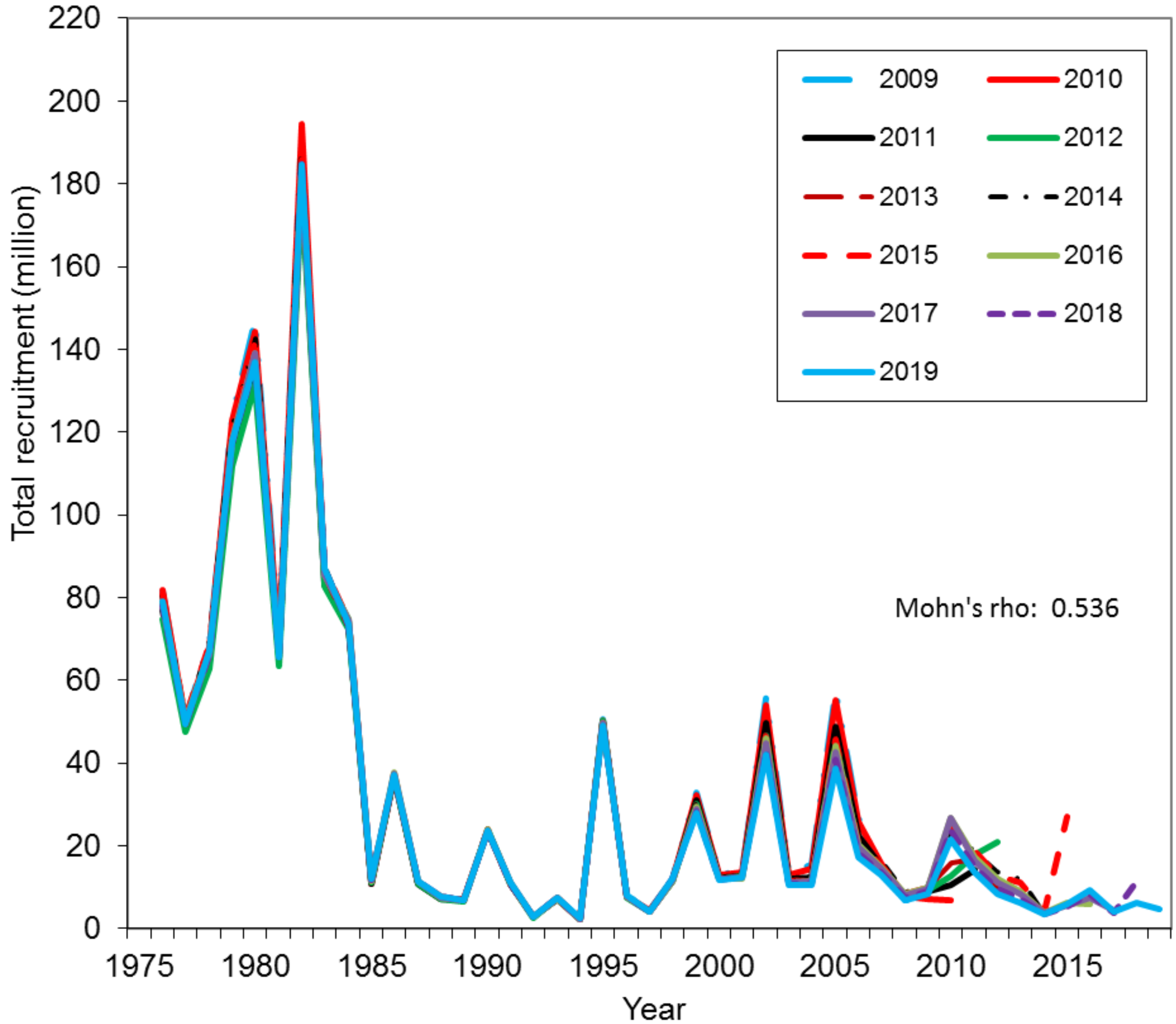


Figure 28a. Comparison of hindcast estimates of total recruitment for model 19.0 (gmacs) of Bristol Bay red king crab from 1976 to 2019 made with terminal years 2009-2019. These are results of the 2019 model. Legend shows the terminal year. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

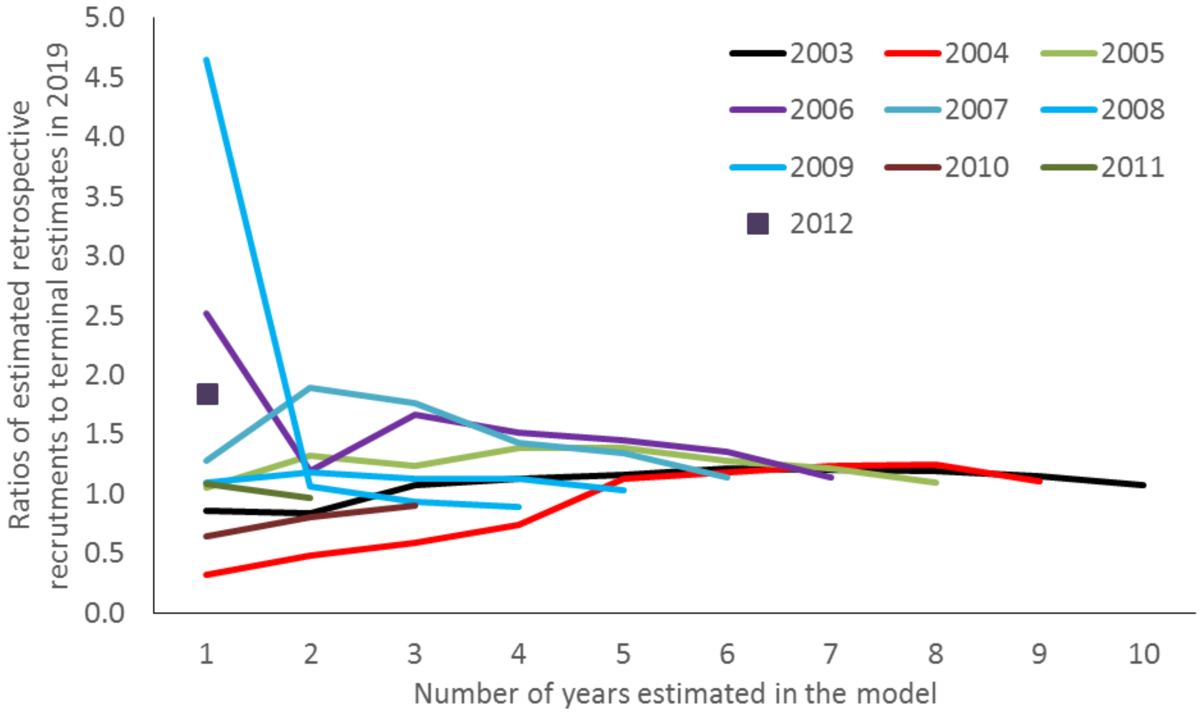


Figure 28b. Evaluation of Bristol Bay red king crab retrospective errors on recruitment estimates as a function of the number of years in the model for model 19.0 (gmacs).

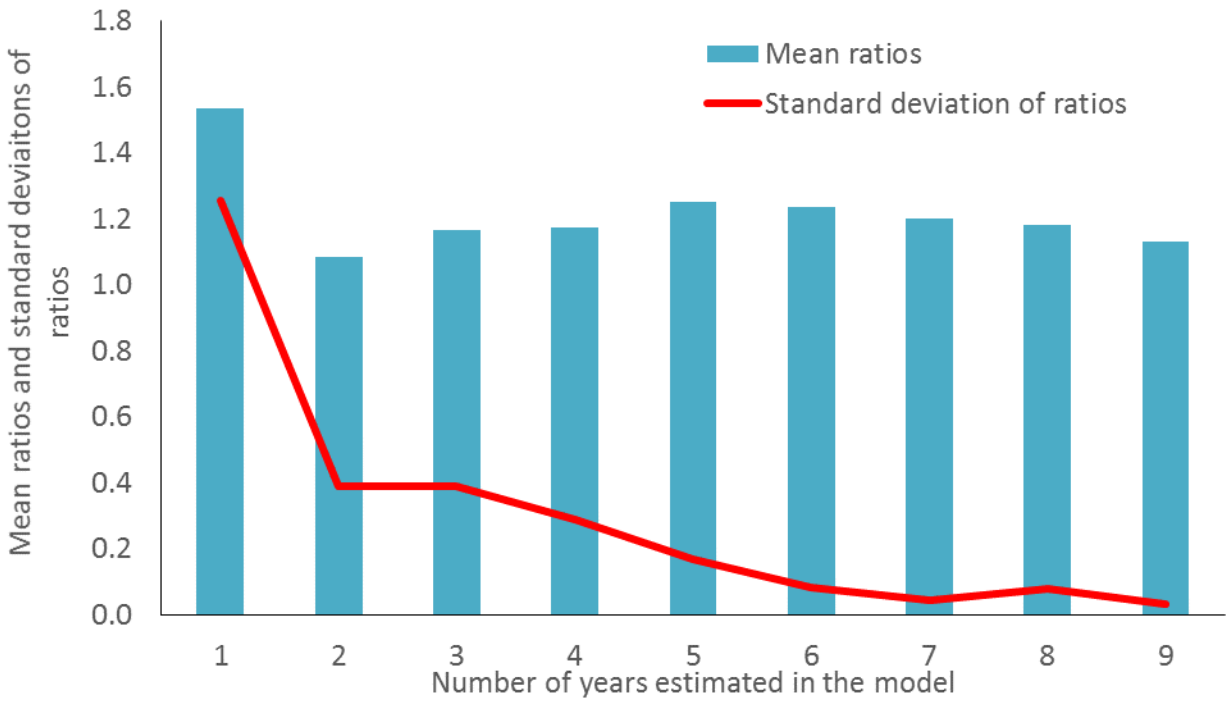
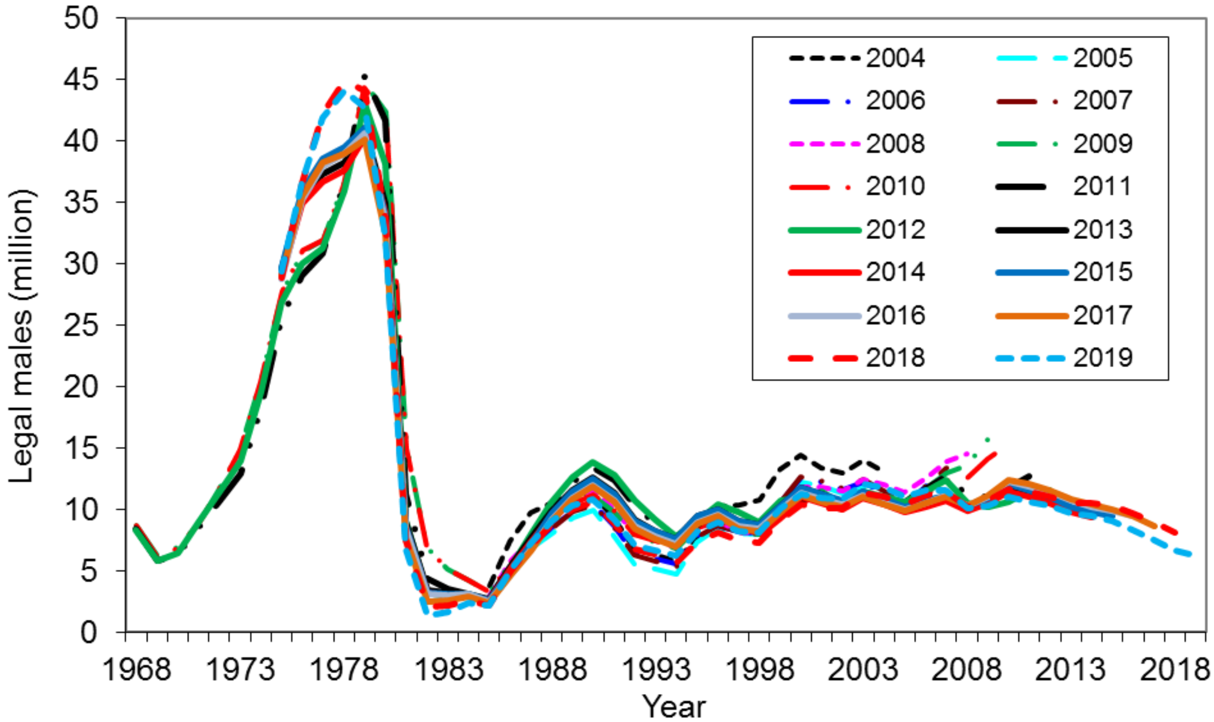


Figure 28c. Mean ratios of retrospective estimates of recruitments to those estimated in the most recent year (2019) and standard deviations of the ratios as a function of the number of years in the model for model 19.0 (gmacs).



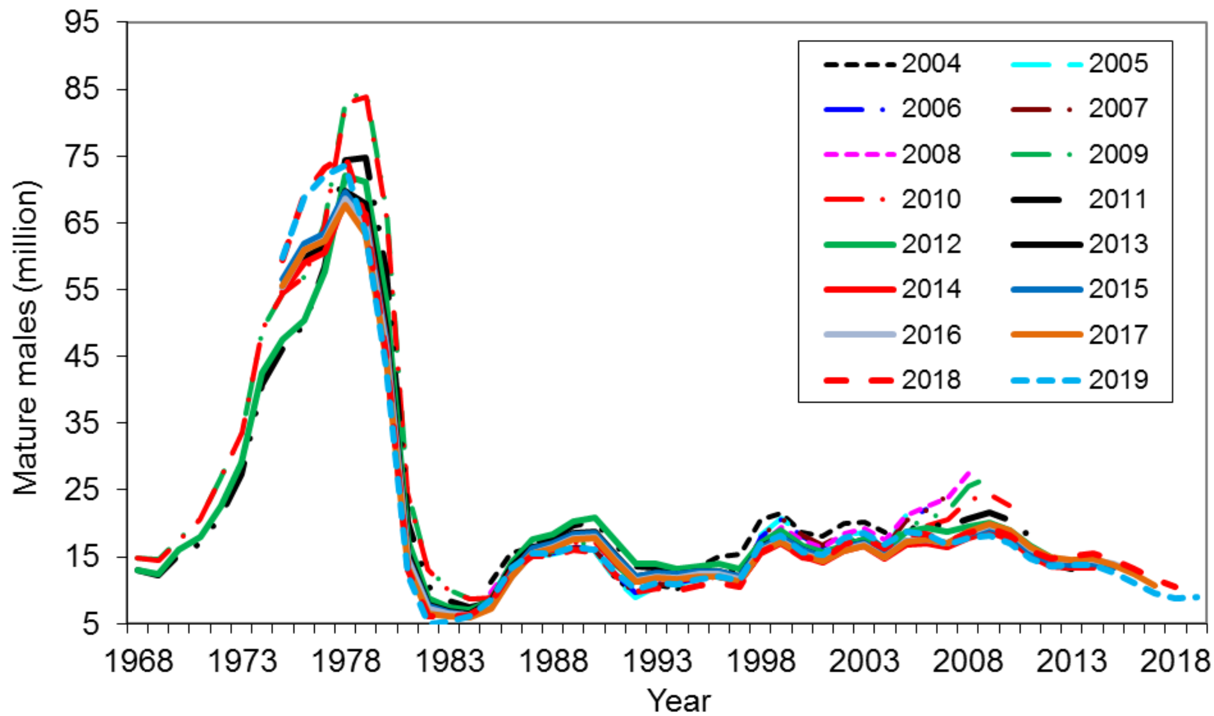


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2019 made with terminal years 2004-2019 with the base models. Model 18.0e is used for 2019. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

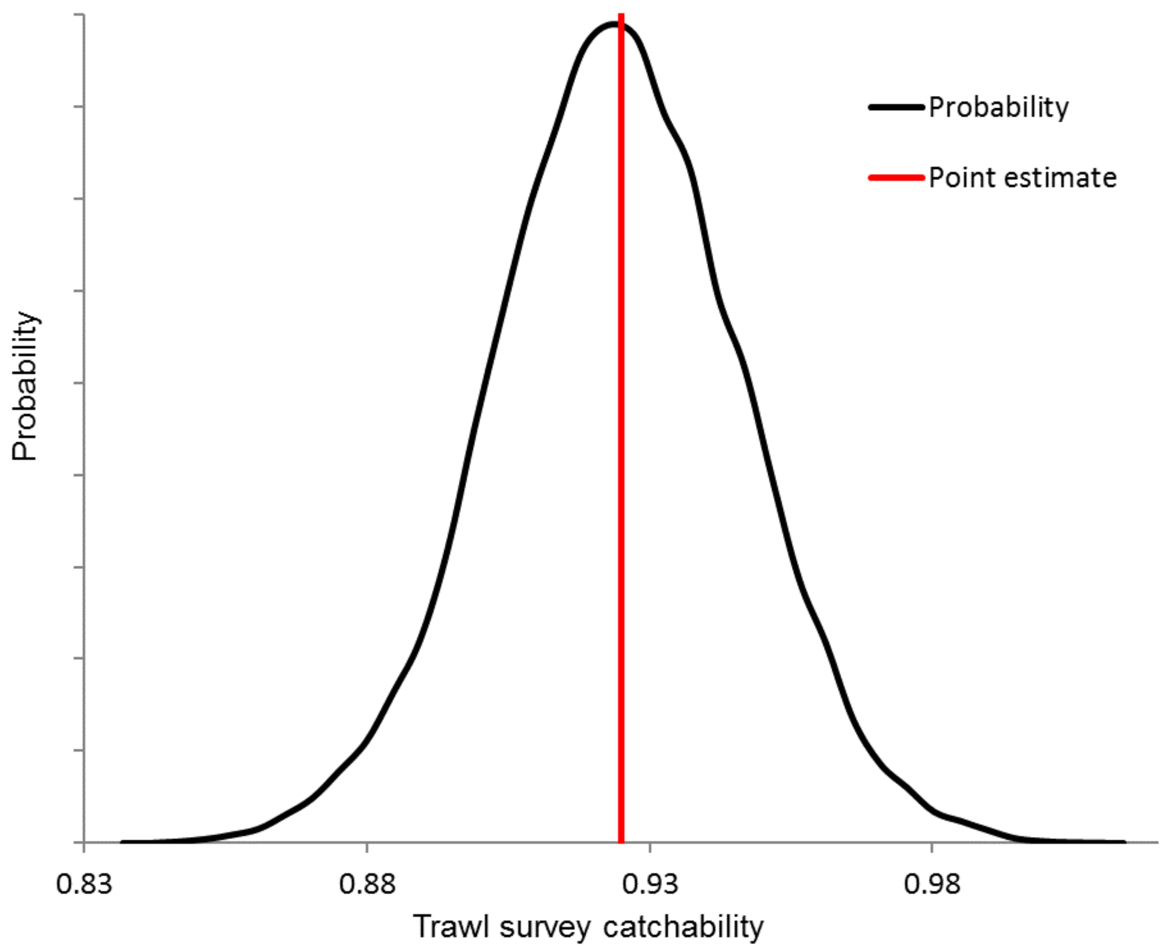


Figure 30. Probability distributions of estimated trawl survey catchability (*Q*) under model 18.0e with the mcmc approach. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

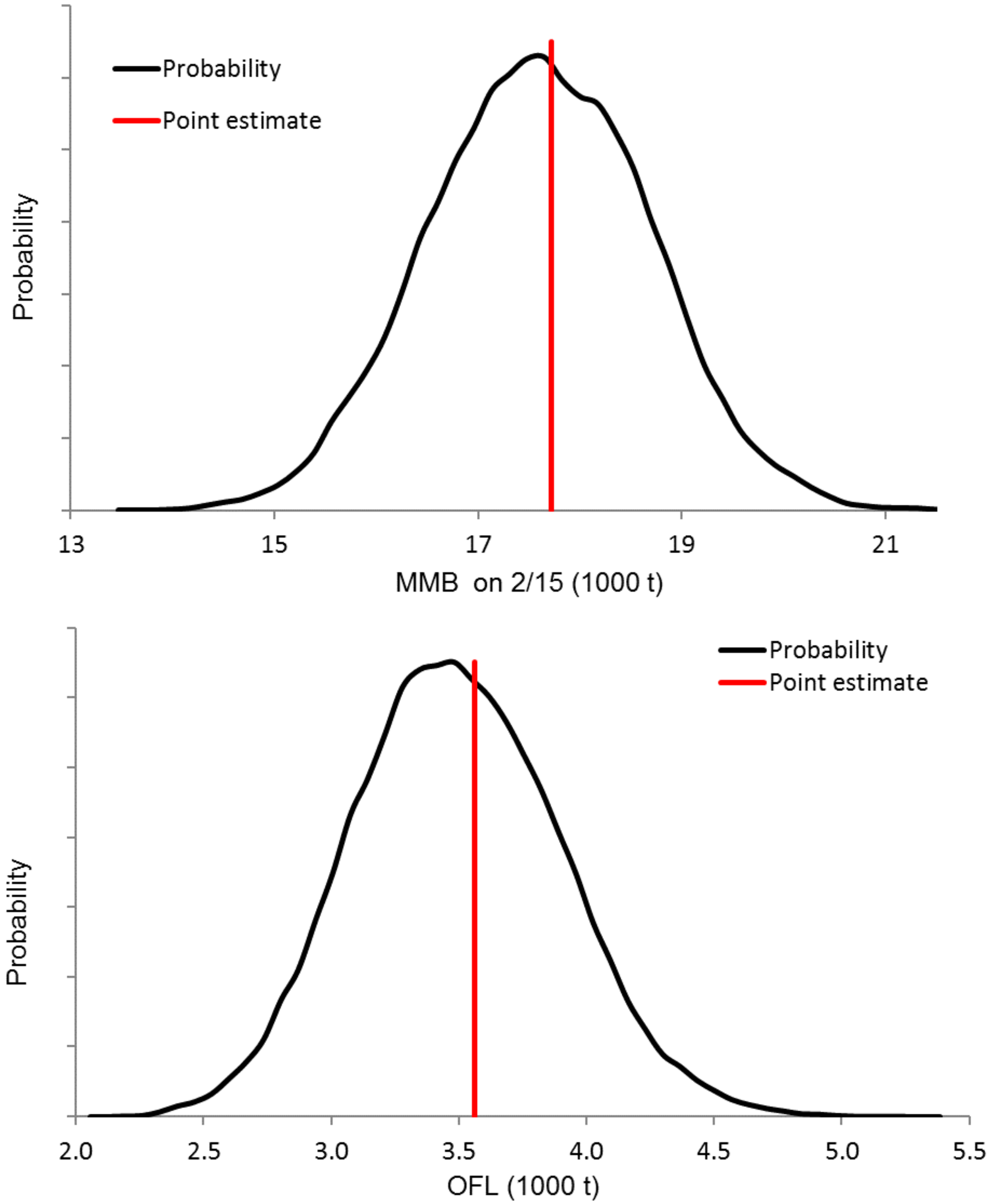


Figure 31. Probability distributions of estimated mature male biomass on Feb. 15, 2019 (upper panel) and probability distributions of the 2019 estimated OFL (lower panel) under model 18.0e with the mcmc approach. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

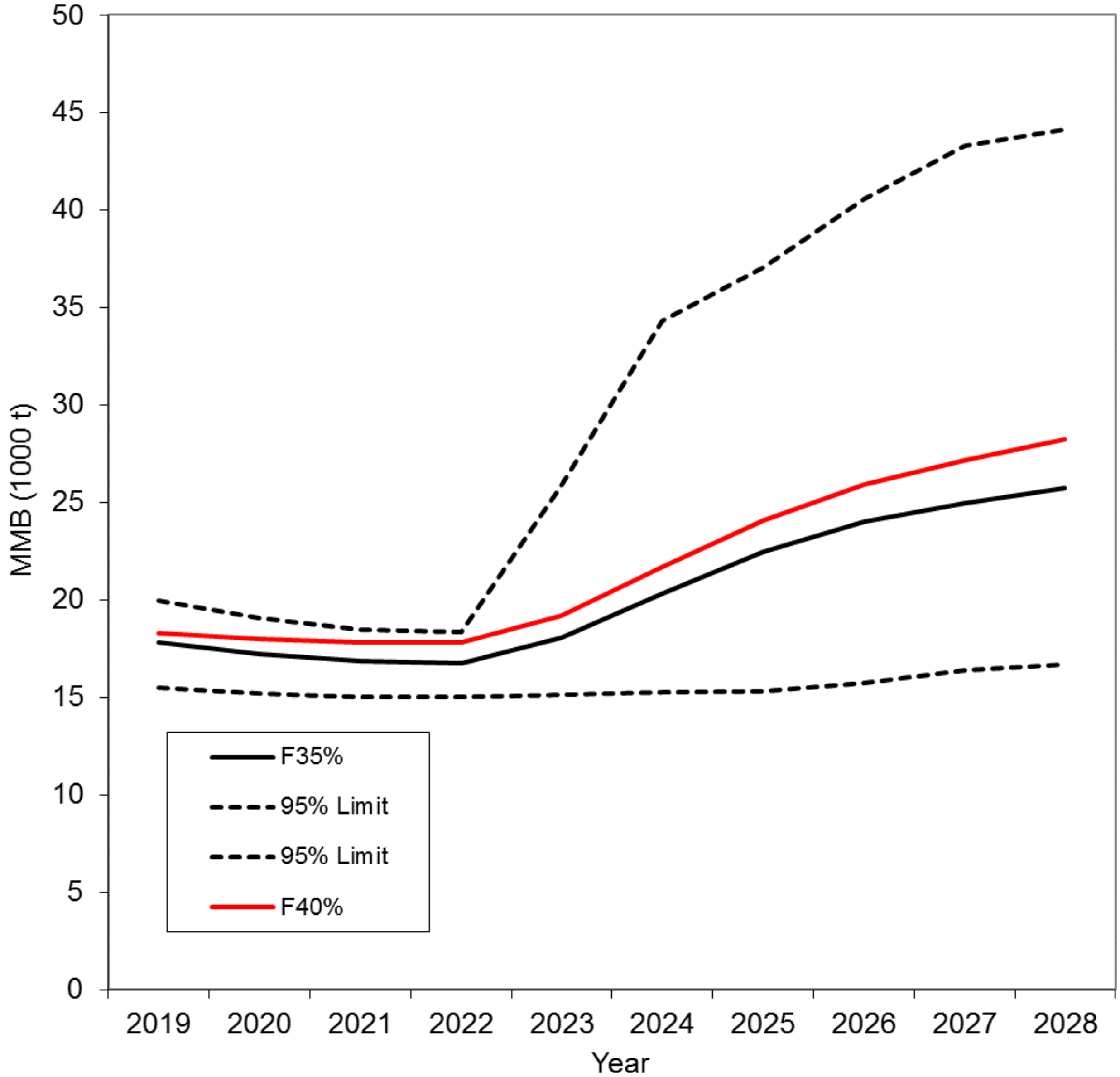


Figure 32. Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2019-2029. Input parameter estimates are based on model 18.0e. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

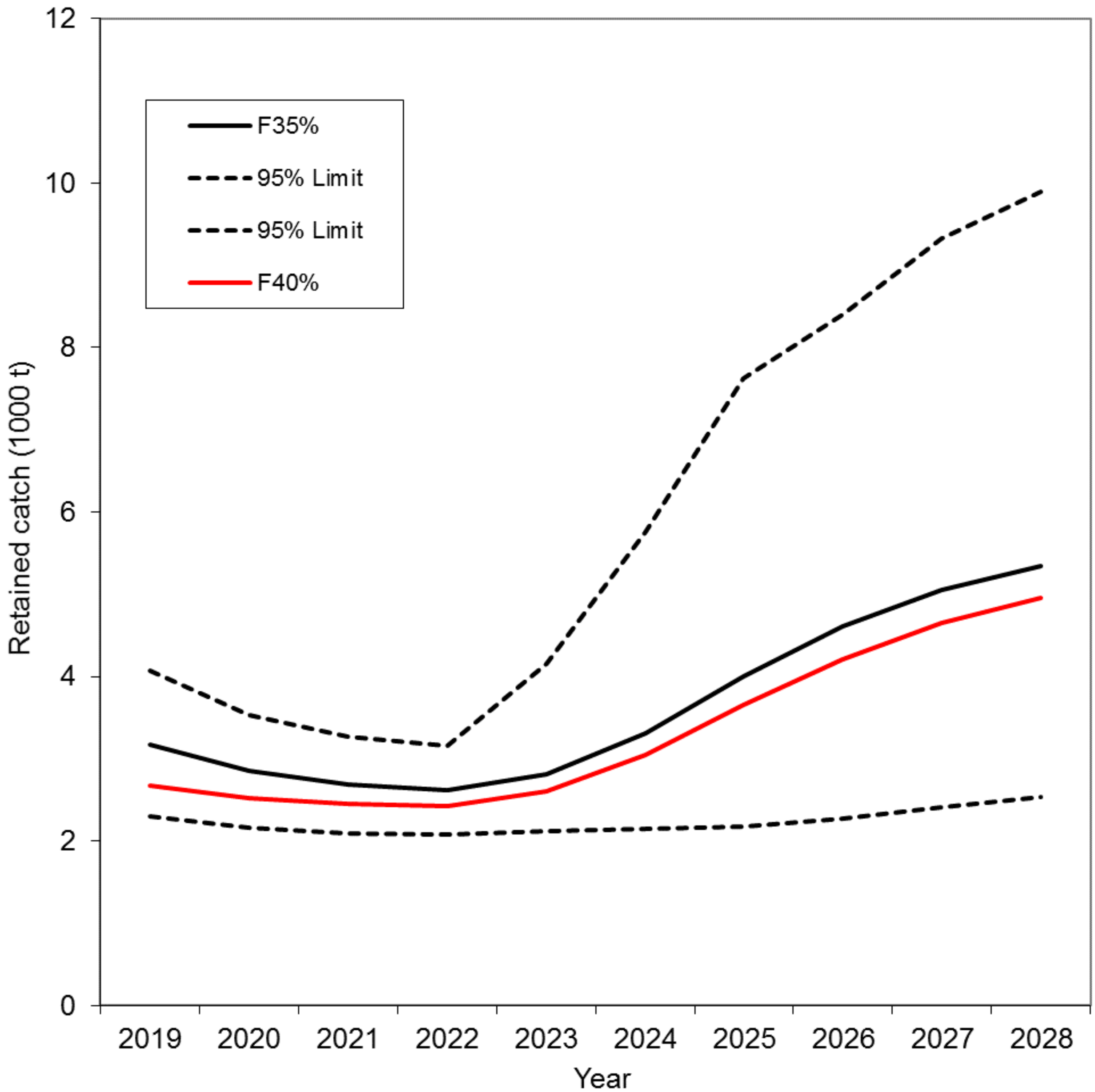


Figure 33. Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2019-2128. Input parameter estimates are based on model 18.0e. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

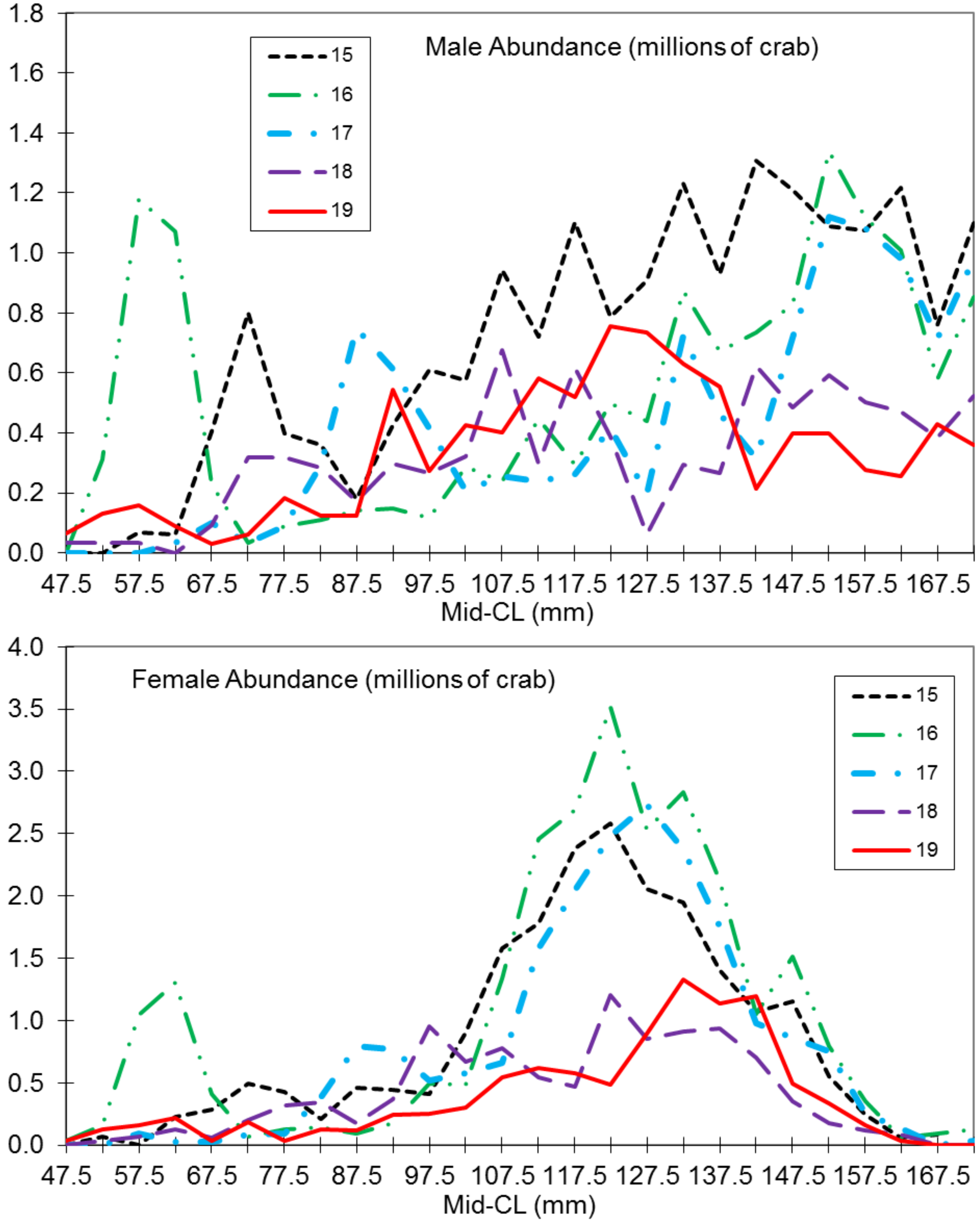


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2015-2019. For purposes of these graphs, abundance estimates are based on area-swept methods.

Appendix A. Description of the Bristol Bay Red King Crab Model

a. Model Description

i. Population model

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). Crab abundances by carapace length and shell condition in any one year are modeled to result from abundances in the previous year minus catch and handling and natural mortalities, plus recruitment, and additions to or losses from each length class due to growth:

$$N^s_{l,t+1} = \sum_{l'=1}^{l}\{P^s_{l',l,t}[(N^s_{l',t}+O^s_{l',t})e^{-M^s_t} - (C^s_{l',t}+D^s_{l',t})e^{(y_t-1)M^s_t} - T^s_{l',t}\ e^{(j_t-1)M^s_t}]m^s_{l',t}\} + R^s_{t+1}U^s_l$$
$$O^s_{l,t+1} = [(N^s_{l,t}+O^s_{l,t})e^{-M^s_t} - (C^s_{l,t}+D^s_{l,t})e^{(y_t-1)M^s_t} - T^s_{l,t}\ e^{(j_t-1)M^s_t}](1-m^s_{l,t}) \quad \text{(A1)}$$

where $N^s_{l,t}$ is the number of new shell crab of sex *s* in length-class *l* at the start of year *t*, $O^s_{l,t}$ the number of old shell crab of sex *s* in length-class *l* at the start of year *t*, $P^s_{l',l,s}$ the proportion during year *t* of an animals of sex *s* in length-class *l'* which grow into length-class *l* given that they moulted, M^s_t the rate of natural mortality on animals of sex *s* during year *t*, $m^s_{l,t}$ the probability that an animal of sex *s* in length-class *l* will moult during year *t*, R^s_{t+1} the recruitment [to the model] of animals of sex *s* during year *t*, U^s_l the proportion of recruits of sex *s* which recruit to length-class *l*, $C^s_{l,t}$ the retained catch (in numbers) of animals of sex *s* in length-class *l* during year *t*, $D^s_{l,t}$ the discarded catch of animals of sex *s* in length-class *l* during year *t* in the directed fishery, $T^s_{l,t}$ the discarded catch of animals of sex *s* in length-class *l* during year *t* in the Tanner crab fishery and the groundfish fisheries, y_t the time in years between survey and the directed pot fishery during year *t*, and j_t the time in years between survey and the Tanner and groundfish fisheries during year *t*.

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. Since females moult annually (Powell 1967), females have only the first part of the equation (A1).

The growth increment is assumed to be gamma distributed with mean which depends linearly on pre-moult length, i.e.:

$$P^s_{l,l',t} = \int_{L_l-\Delta L/2}^{L_l+\Delta L/2} \frac{x^{\alpha^s_{L_{l'},t}} e^{x/\beta^s}}{(\beta^s)^{\alpha^s_{L_{l'},t}}\,\Gamma(\alpha^s_{L_{l'},t})}dx \qquad \alpha^s_{L_l,t}\beta^s = a^s_t + b^s_t L_l \quad \text{(A2)}$$

where L_l is the mid-point of length-class *l*, ΔL the width of each size-class (5 mm carapace length), a^s_t, b^s_t the parameters of the length–growth increment relationship for sex *s* and year *t*, and

β^s the parameter determining the variance of the growth increment. Growth is time-invariant for males, and specified for three time-blocks for females (1968-82; 1983-93; 1994-2019) based on changes to the size at maturity for females. The probability of moulting as a function of length for males is given by an inverse logistic function, i.e.:

$$m_l = \frac{1}{1+e^{\tilde{\beta}(L_l - L_{50})}} \qquad \text{(A3)}$$

where $\tilde{\beta}, L_{50}$ are the parameters which determine the relationship between length and the probability of moulting.

Recruitment is defined as recruitment to the model and survey gear rather than recruitment to the fishery. Recruitment is separated into a time-dependent variable, R^s_{t+1}, and size-dependent variables, U^s_l, representing the proportion of recruits belonging to each length class. R^s_{t+1} is assumed to consist of crab at the recruiting age with different lengths and thus represents year class strength for year *t*. The proportion of recruits by length-class, U^s_l, is described using a gamma distribution with parameters α^s_l and β^s_l. Because of different growth rates, recruitment is estimated separately for males and females under a constraint of approximately equal sex ratios of recruitment over time.

ii. Catches and Fisheries Selectivities

Before 1990, no observed bycatch data were available in the directed pot fishery; the crab that were discarded and died in those years were estimated as the product of handling mortality rate, legal harvest rates, and mean length-specific selectivities. It is difficult to estimate bycatch from the Tanner crab fishery before 1991. A reasonable index to estimate bycatch fishing mortalities is potlifts of the Tanner crab fishery within the distribution area of Bristol Bay red king crab. Thus, bycatch fishing mortalities from the Tanner crab fishery before 1991 were estimated to be proportional to the smoothing average of potlifts east of 163^o W. The smoothing average is equal to (P_{t-2}+2P_{t-1}+3P_t)/6 for the potlifts in year t. The smoothing process not only smoothes the annual number of potlifts, it also indexes the effects of lost pots during the previous years. All bycatches are death catches because the model fits the estimated observed death bycatches.

The catch (by sex) in numbers by the directed fishery is:

$$G^s_{l,t} = (N^s_{l,t} + O^s_{l,t}) e^{-y_t M^s_t} (1 - e^{-F^s_{l,t}}) \qquad \text{(A4)}$$

where $F^s_{l,t}$ is the fishing mortality rate during year *t* on animals of sex *s* in length-class *l* due to the directed pot fishery:

$$F^s_{l,t} = \begin{cases} \left[S^{tot,mal}_l S^{ret}_{l,t} + S^{tot,mal}_l \left(1 - S^{ret}_{l,t}\right)\emptyset\right] F^{dir}_t & if\ s = mal \\ S^{dir,disc,fem}_l F^{disc,fem}_t & if\ s = fem \end{cases} \qquad \text{(A5)}$$

where $S^{tot,mal}_l$ is the total male selectivity in the directed fishery, $S^{ret}_{l,t}$ the retained proportions of males in the directed fishery, F^{dir}_t the fully-selected fishing mortality during year *t* (on males),

$S_l^{\text{dir,disc},s}$ the selectivity pattern for the discards in the directed fishery by sex, $F_t^{disc,fem}$ the fully-selected fishing mortality on female animals during year *t* related to discards in the directed fishery, and ϕ the handling mortality (the proportion of animals which die due to being returned to the water following capture).

There are no landings of females in a male-only fishery, while the landings *C* of males in the directed fishery and discards *D* of males in the directed fishery are:

$$C_{l,t}^{mal} = \left(N_{l,t}^{mal} + O_{l,t}^{mal}\right) e^{-y_t M_t^{mal}} \left(1 - e^{-S_l^{tot,mal} S_{l,t}^{ret} F_t^{dir}}\right) \quad \text{(A6)}$$

$$D_{l,t}^{mal} = G_{l,t}^{mal} - C_{l,t}^{mal} \quad \text{(A7)}$$

The catch (by sex) in numbers by the Tanner crab and groundfish fisheries in length-class *l* during year *t* is given by:

$$T_{l,t}^s = (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) \quad \text{(A8)}$$

where $\tilde{F}_{l,t}^s$ is the fishing mortality rate during year *t* on animals of sex *s* in length-class *l* due to the Tanner crab and groundfish fisheries:

$$\tilde{F}_{l,t}^s = S_l^{Tanner,s} F_t^{Tanner,s} + S_l^{trawl} F_t^{trawl} + S_l^{fix} F_t^{fix} \quad \text{(A9)}$$

where $S_l^{\text{Tanner},s}$ is the selectivity pattern for the discards in the Tanner crab fishery by sex, $F_t^{\text{Tanner},s}$ the fully-selected fishing mortality during year *t* on animals of sex *s* during year *t* due to this fishery, S_l^{trawl} the selectivity pattern for the bycatch in the groundfish trawl fishery, F_t^{trawl} the fully-selected fishing mortality due to the groundfish trawl fishery, S_l^{fix} the selectivity pattern for the bycatch in the groundfish fixed gear fishery, and F_t^{fix} the fully-selected fishing mortality due to the groundfish fixed gear fishery.

The bycatches by sex are estimated from the Tanner crab fishery, $TC_{l,t}^s$, groundfish trawl fishery, $GT_{l,t}^s$, and groundfish fixed gear fishery, $GF_{l,t}^s$, as follow:

$$\begin{aligned}
TC_{l,t}^s &= (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) S_l^{Tanner,s} F_t^{Tanner,s} / \tilde{F}_{l,t}^s \\
GT_{l,t}^s &= (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) S_l^{trawl} F_t^{trawl} / \tilde{F}_{l,t}^s \qquad \text{(A10)} \\
GF_{l,t}^s &= (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) S_l^{fixed} F_t^{fixed} / \tilde{F}_{l,t}^s
\end{aligned}$$

For models separating mature and immature crab, discarded female bycatch in numbers is separated into immature and mature bycatches. The female bycatches in the directed fishery in length-class *l* and during year *t*, $D_{l,t}^i$ and $D_{l,t}^m$, and $T_{l,t}^i$ and $T_{l,t}^m$, are:

$$\begin{aligned}
D_{l,t}^i &= N_{l,t}^i e^{-y_t M_t^{fem}} (1 - e^{-F_{l,t}^{fem}}) \\
D_{l,t}^m &= N_{l,t}^m e^{-y_t M_t^{fem}} (1 - e^{-F_{l,t}^{fem}})
\end{aligned} \qquad \text{(A11)}$$

The female bycatches (by maturity) in numbers by the Tanner crab and groundfish fisheries in length-class l during year t for scenario 2 are given by:

$$T^{i}_{l,t} = N^{i}_{l,t}\, e^{-j_t M^{fem}_t} e^{-F^{fem}_{l,t}} (1 - e^{-\tilde{F}^{fem}_{l,t}})$$
$$T^{m}_{l,t} = N^{m}_{l,t}\, e^{-j_t M^{fem}_t} e^{-F^{fem}_{l,t}} (1 - e^{-\tilde{F}^{fem}_{l,t}}) \quad \text{(A12)}$$

Selectivity for females in the directed fishery, $S^{\text{dir,disc,fem}}$, total male selectivity, $S_l^{tot,mal}$, retained proportions, $S_{l,t}^{ret}$, selectivities for males and females in the groundfish trawl and fixed gear fisheries, S^{trawl} and S^{fix}, and selectivity for males and females in the Tanner crab fishery, $S^{\text{Tanner},s}$, are all assumed to be logistic functions of length:

$$S_l^{type} = \frac{1}{1 + e^{-\beta^{type}\,(l - L_{50}^{type})}} \quad \text{(A13)}$$

Different sets of parameters (β, L_{50}) are estimated for retained males, female pot bycatch, male and female trawl bycatch, and discarded males and females from the Tanner crab fishery.

iii. Trawl Survey Selectivities

Trawl survey selectivities are estimated as

$$S_{l,t}^{s} = \frac{Q}{1 + e^{-\beta_t^{s}\,(l - L_{50,t}^{s})}} \quad \text{(A14)}$$

with different sets of parameters (β, L_{50}) estimated for males and females as well as two different periods (1975-81 and 1982-19). Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, L_{50} for females and L_{50} for males) were estimated in the model for each of the four periods. Parameter Q was called the survey catchability that was estimated based on a trawl experiment by Weinberg et al. (2004; Figure A1). Q was assumed to be constant over time.

Assuming that the BSFRF survey caught all crab within the area-swept, the ratio between NMFS abundance and BSFRF abundance is a capture probability for the NMFS survey net. The Delta method was used to estimate the variance for the capture probability. A maximum likelihood method was used to estimate parameters for a logistic function as an estimated capture probability curve (Figure A1). For a given size, the estimated capture probability is smaller based on the BSFRF survey than from the trawl experiment, but the Q value is similar between the trawl experiment and the BSFRF surveys (Figure A1). Because many small-sized crab are likely in the shallow water areas that are not accessible for the trawl survey, NMFS trawl survey selectivity consists of capture probability and crab availability.

iv. *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

$$F_t^{disc,s} = r^s \; F_t^{dir} \tag{A15}$$

where r^s is the median 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):

$$F_t^{Tanner,s} = a^s \; E_t \tag{A16}$$

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. Software Used: AD Model Builder (Fournier et al. 2012).

c. Likelihood Components

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

$$Rf = \prod_{l=1}^{L} \prod_{t=1}^{T} \coprod_{s=1}^{2} \prod_{sh=1}^{2} \frac{\left\{ exp\left[-\frac{\left(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh}\right)^2}{2\sigma_{l,t,s,sh}^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma_{l,t,s,sh}^2}} \tag{A17}$$

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

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:

$$
\begin{aligned}
&Length\ compositions:\ -\sum \ln(Rf_i)\\
&Catch\ and\ bycatch\ biomasses:\ \lambda_j \sum\left[ln\left(\frac{C_t}{\hat{C}_t}\right)^2\right]\\
&NMFS\ survey\ biomass:\ \sum\left[ln\left(ln\left(CV_t^{\ 2}\ +1\right)\right)^{0.5} + \frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{2ln\left(\left(CV_t^{\ 2}+1\right)\right)}\right]\\
&BSFRF\ survey\ biomass:\ \sum\left[ln\left(ln\left(CV_t^{\ 2}\ +AV^2+1\right)\right)^{0.5} + \frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{\left(2ln\left(CV_t^{\ 2}+AV^2+1\right)\right)}\right]\\
&R\ variation:\ \lambda_R \sum\left[ln\left(\frac{R_t}{\bar{R}}\right)^2\right]\\
&R\ sex\ ratio:\ \lambda_s \sum\left[ln\left(\frac{\bar{R}_M}{\bar{R}_F}\right)^2\right]\\
&Groundfish\ bycatch\ fishing\ mortalities:\ \lambda_t \sum\left[ln\left(\frac{F_{t,gf}}{\bar{F}_{gf}}\right)^2\right]\\
&Pot\ female\ bycatch\ fishing\ mortalities:\ \lambda_p \sum\left[ln\left(\frac{F_{t,f}}{\bar{F}_f}\right)^2\right]\\
&Trawl\ survey\ catchability:\ \frac{(Q-\hat{Q})^2}{2\sigma^2}
\end{aligned}
\qquad (A18)
$$

where R_t is the recruitment in year t, $\overline{R}$ 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 500 for retained catch biomass, 300 for total directed pot fishery male biomass, 100 for all pot bycatch biomasses, and 50 for groundfish bycatch biomasses (trawl and fixed gear fisheries), 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 0.03, 0.04, 0.07, 0.1, 0.53, 0.23, 3.34, and 12.14, respectively, representing prior assumptions about the accuracy of the observed catch biomass data.

d. Population State in Year 1.

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

e. Parameter estimation framework:

i. 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.

(1). Natural Mortality

Based on an assumed maximum age of 25 years and the 1% rule (Zheng 2005), basic M was estimated to be 0.18 for both males and females. Natural mortality in a given year, M_t, equals to $M + Mm_t$ (for males) or $M + Mf_t$ (females). One value of Mm_t during 1980-1985 was estimated and two values of Mf_t during 1980-1984 and 1976-79, 1985-93 were estimated in the model for models.

(2). Length-weight Relationship

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

Immature Females: $W = 0.000408\, L^{3.127956}$

Ovigerous Females: $W = 0.003593\, L^{2.666076}$ (A18)

Males: $W = 0.0004031\, L^{3.141334}$

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

(3). 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 1994-2019, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for scenarios 1, 1n and 2 (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 1994-2019, 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).

(4). 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 1994-2019).

(5). 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.

(6). 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. 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 1991-1993 and total potlifts east of 163^o W during 1968 to 2005 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 $0.18 yr^{-1}$, 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.

ii. 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 = 1976 to 2019), 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 β and L_{50} for retained selectivity, 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 discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. The NMFS survey catchabilities Q for some models were also estimated. Three 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 (1975-2018), pot-discarded females from the directed fishery (1990-2018), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-15), groundfish trawl discarded males and females (1976-2019), and groundfish fixed gear discarded males and females (1996-2018). Three additional mortality parameters for Mm_t and Mf_t 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.

f. Definition of model outputs.

i. 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.

ii. 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).

iii. Fishing mortality: full-selected instantaneous annual fishing mortality rate at the time of fishery.

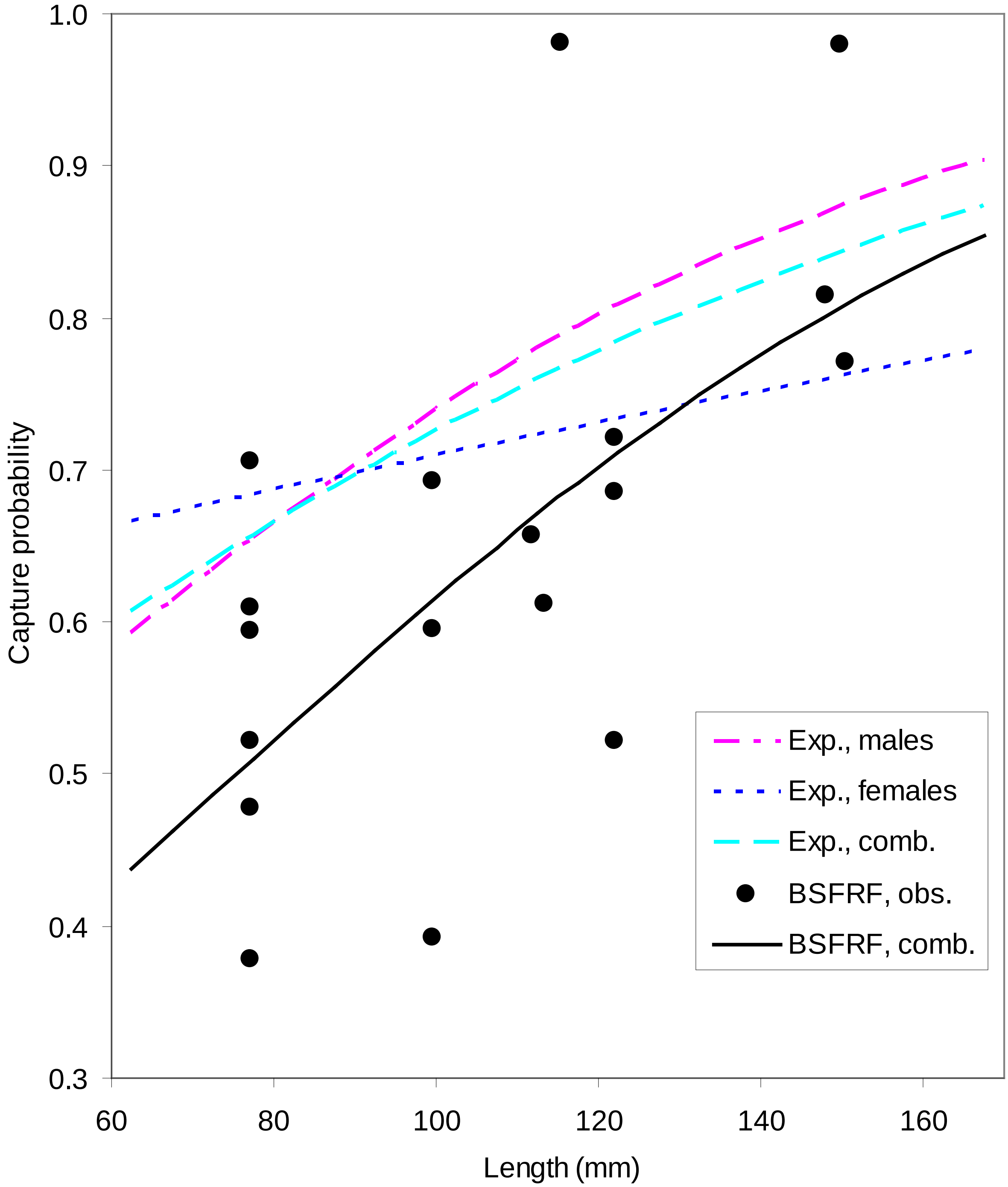


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.

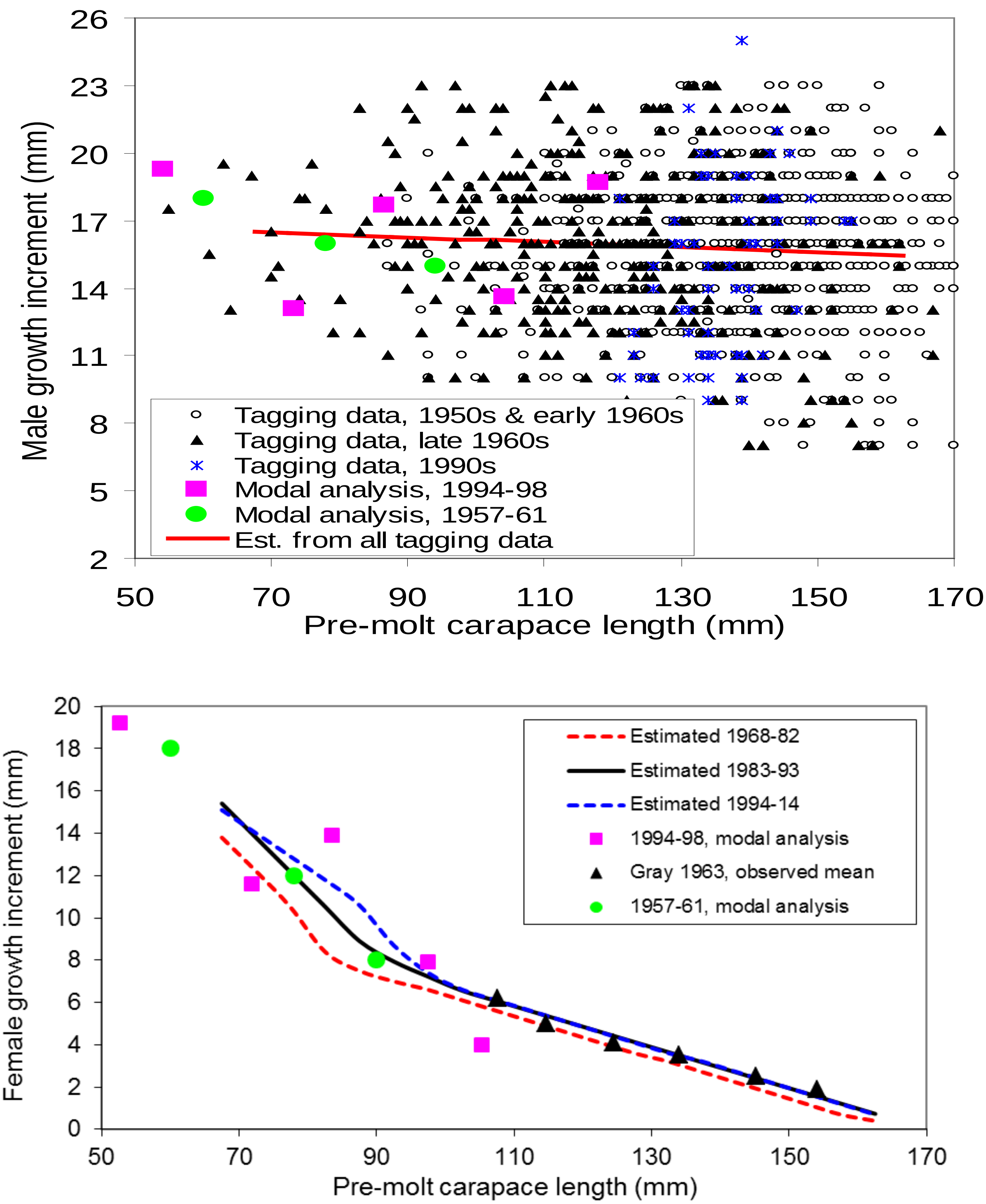


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: “tagging”---based on tagging data; “mode”---based on modal analysis. The female growth increments per molt are for models 18.0d, 18.0e and 19.0.

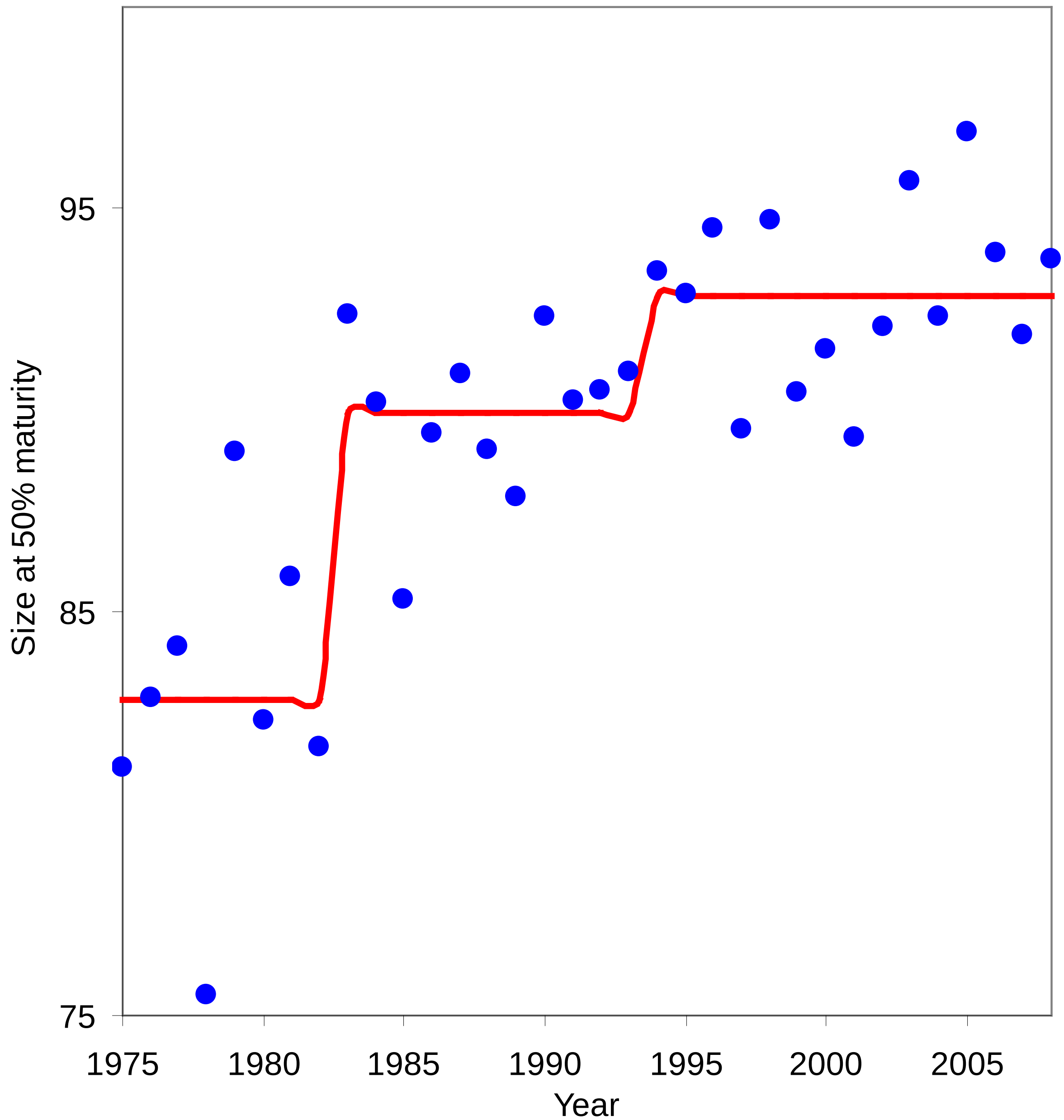


Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

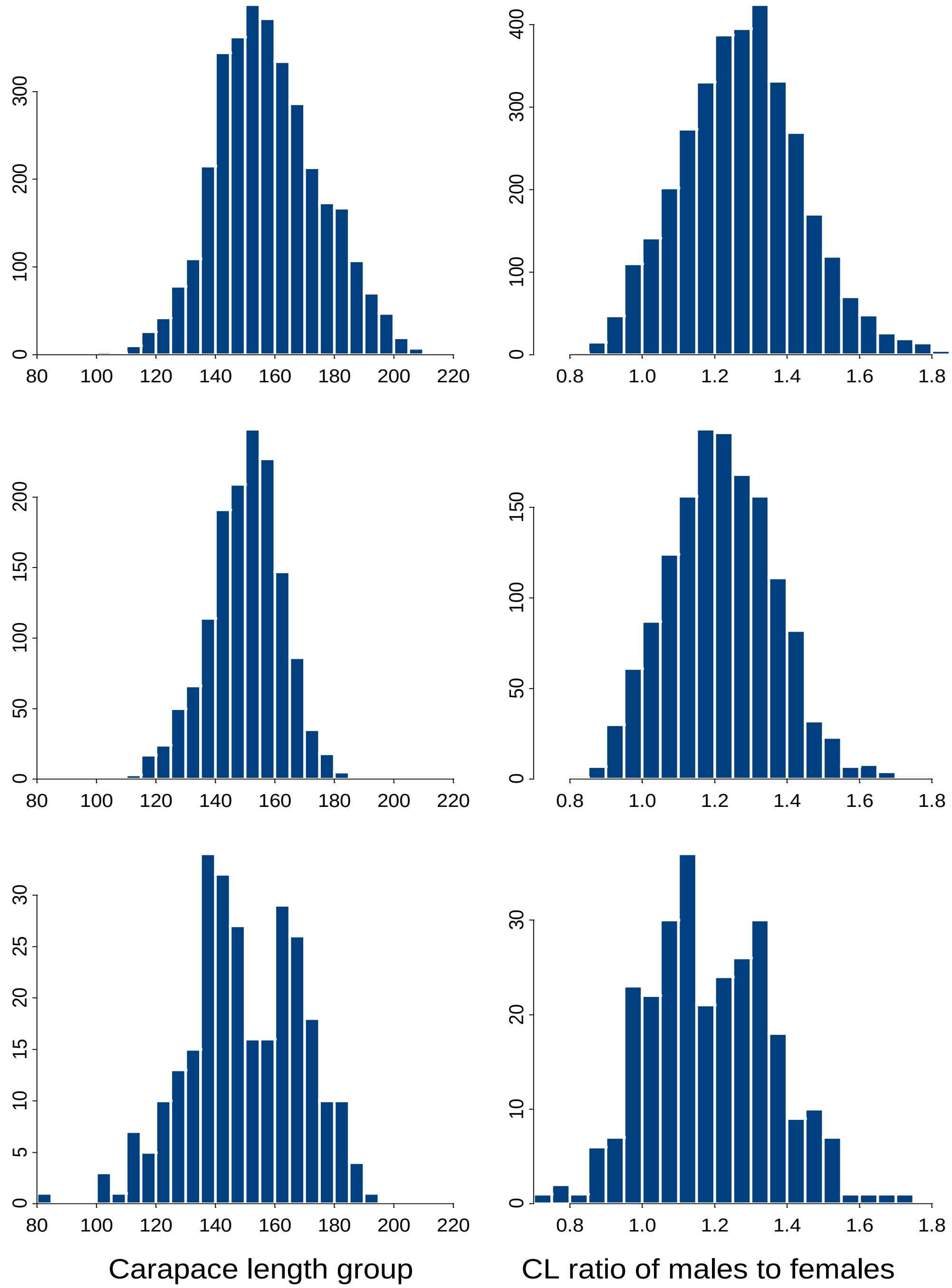
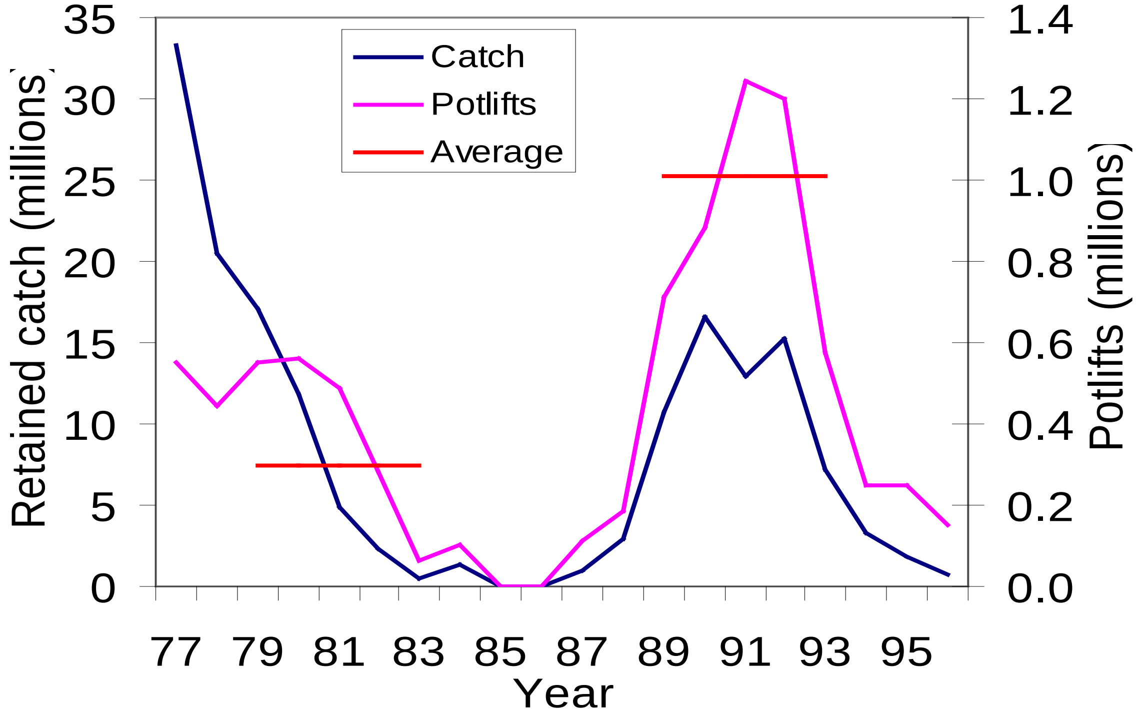


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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



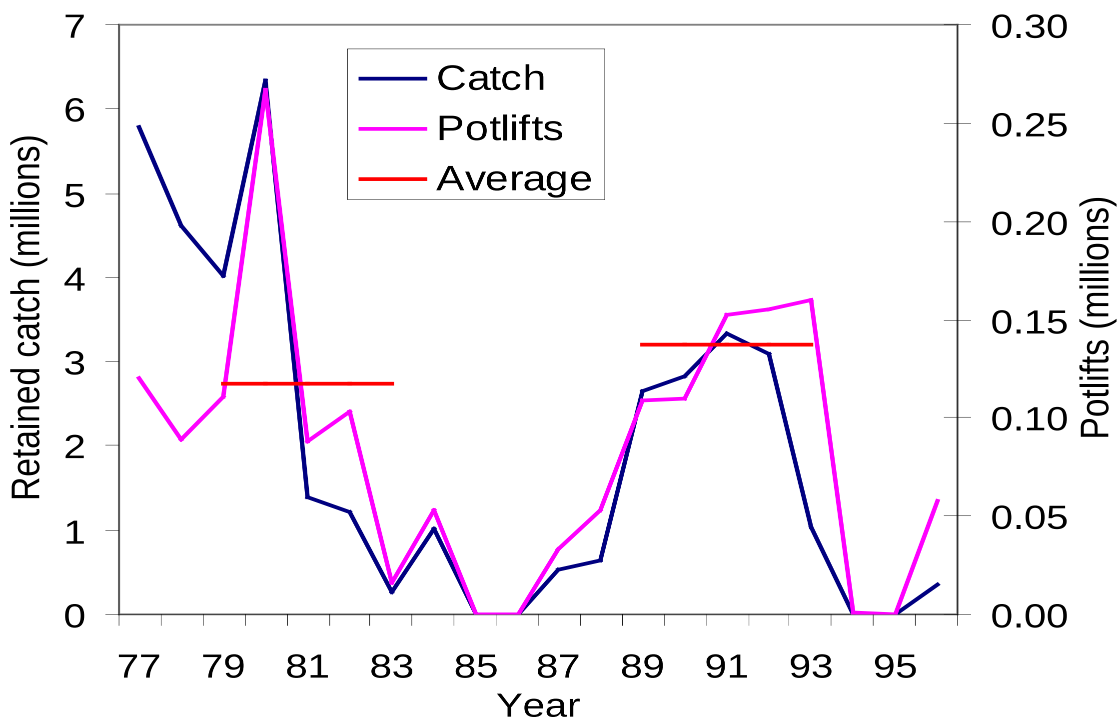


Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163º W (bottom).

Appendix B. Recruitment Breakpoint Analysis in May 2019

Introduction

SSC asked authors to conduct a recruitment breakpoint analysis similar to that conducted for eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). We obtained the R codes from Dr. William (Buck) Stockhausen of NMFS and slightly modified them to conduct the analysis for Bristol Bay red king crab for better understanding the temporal change of stock productivity and the recruitment time series used for overfishing/overfished definitions. Results from assessment model model 18.0a are used for this analysis. We are very grateful for the help of Dr. Stockhausen for this analysis.

Methods

The methods are the same as Punt et al. (2014) and Stockhausen (2013). Stock productivity is represented by ln(*R/MMB*), where *R* is recruitment and *MMB* is mature male biomass, with recruitment lagging to the brood year of mature biomass. Let y_t = ln(*R/MMB*) and y_t can be estimated directly from the stock assessment model as observed values or from a stock-recruitment model as $\hat{y}_t$. For Ricker stock-recruitment models,

$$
\begin{aligned}
\hat{y}_t &= \alpha_1 + \beta_1 \cdot MMB \qquad t < b, \\
\hat{y}_t &= \alpha_2 + \beta_2 \cdot MMB \qquad t \geq b,
\end{aligned}
\tag{1}
$$

where α_1 and β_1 are the Ricker stock-recruit function parameters for the early time period before the potential breakpoint in year *b* and α_2 and β_2 are the parameters for the time period after the breakpoint in year *b*. For Beverton-Holt stock-recruitment models,

$$
\begin{aligned}
\hat{y}_t &= \alpha_1 - \log(1 + e^{\beta_1} \cdot MMB) \qquad t < b, \\
\hat{y}_t &= \alpha_2 + \log(1 + e^{\beta_2} \cdot MMB) \qquad t \geq b,
\end{aligned}
\tag{2}
$$

where α_1 and β_1 are the Beverton-Holt stock-recruit function log-transformed parameters for the early time period before the potential breakpoint in year *b* and α_2 and β_2 are the log-transformed parameters for the time period after the breakpoint in year *b*.

A maximum likelihood approach is used to estimate stock-recruitment model and error parameters. Because y_t is measured with error, the negative log-likelihood function is

$$
-\ln(L) = 0.5 \cdot \ln(|\mathbf{\Omega}|) + 0.5 \cdot \sum_t \sum_j (y_t - \hat{y}_t) \cdot \left[\mathbf{\Omega}^{-1}\right]_{t,j} \cdot (y_j - \hat{y}_j), \tag{3}
$$

where Ω contains observation and process error as

$$
\mathbf{\Omega} = \mathbf{O} + \mathbf{P}, \tag{4}
$$

where **O** is the observation error covariance matrix estimated from the stock assessment model and **P** is the process error matrix and is assumed to reflect a first-order autoregressive process to have σ^2 on the diagonal and $\sigma^2 \rho^{|t-j|}$ on the off-diagonal elements. σ^2 represents process error variance and ρ represents the degree of autocorrelation.

For each candidate breakpoint year *b*, the negative log likelihood value of equation (3) is minimized with respect to the six model parameters: α_1, β_1, α_2, β_2, $\ln(\sigma)$ and $\tan(\rho)$. The minimum time span considered as a potential regime is 5 years. Each brood year from 1980 to 2007 is evaluated as a potential breakpoint *b* using time series of ln(R/MMB) and MMB for brood years 1975-2012. A model with no breakpoint is also evaluated. Models with different breakpoints are then ranked using AICc (AIC corrected for small sample size; Burnham and Anderson 2004),

$$AIC_c = -2 \cdot \ln(L) + \frac{2 \cdot k \cdot (k+1)}{n-k-1}, \tag{5}$$

where *k* is the number of parameters and *n* is the number of observations. Using AICc, the model with the smallest AICc is regarded as the "best" model among the set of models evaluated. Different models can be compared in terms of θ_m, the relative probability (odds) that the model with the minimum AICc score is a better model than model *m*, where

$$\theta_m = \exp([(AICc_m - AICc_{\min})/2]. \tag{6}$$

Results

Results are summarized in Tables B1-B4 and Figures B1-B6. Discarding the implausible breakpoint year of 1980 for the Ricker model due to implausible stock-recruitment model parameters, the Ricker model has a breakpoint of brood year of 1986 (recruitment year of 1992), and the Beverton-Holt model results in the same breakpoint brood year of 1984, which corresponds to recruitment year of 1990. The model with no breakpoint (i.e., a single time period) is about 18 times less probable than the 1984 breakpoint model for Beverton-Holt stock-recruitment models and about 17 times less probable for Ricker stock-recruitment relationships, which may suggest a possible change in stock productivity from the early high period to the recent low period. Alternative breakpoint brood years of 1980-1986 for both Ricker and Beverton-Holt models are also reasonably reported. Both Ricker and Beverton-Holt stock-recruitment models fit the data poorly.

Discussion

A recruitment breakpoint analysis was conducted on Bristol Bay red king crab by Punt et al. (2014) with data from 1968 to 2010 to estimate a breakpoint brood year of 1984, corresponding to recruitment year of 1990, which is the same as our estimate with the Beverton-Holt model. Our data start in 1975 and have only two brood-year data points before the regime shift of 1976/77 and thus we cannot detect any stock productivity changes due to the 1976/77 regime shift because of lack of data. Without the early data, the fits of stock-recruitment models to the data are also more poorly.

Time series of estimated recruitment during 1984-present have been used to compute Bmsy proxy. The mean recruitment with model 18.0e during 1984-present is 17.70 million of crab, compared to the mean recruitment of 16.21 million of crab during 1990-present, about 8.4% reduction (Figure 12(18.0a). If the estimated breakpoint year is used to set the new recruitment time series, estimated Bmsy proxy will be correspondingly lower than the current estimated value.

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Punt, A.E., C.S. Szuwalski, and W. Stockhausen. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fisheries Research 157:28-40.

Stockhausen, W.T. 2013 Recruitment Analysis for Stock Status Determination and Harvest Recommendations. Appendix to: 2013 Stock Asssessment and Fishery Evaluation Report for the Tanner Crab Fisheries in the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage. pp.450-478.

Table B1. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Ricker stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The “best” model is shaded with a plausible stock-recruitment model. Years are brood year.

Year	AICc	Odds
NA	30.9238	22.6194
1980	24.6862	1.0000
1981	26.0669	1.9944
1982	26.1803	2.1107
1983	26.1267	2.0549
1984	26.1003	2.0280
1985	25.6051	1.5832
1986	25.3132	1.3682
1987	28.6416	7.2259
1988	29.9626	13.9875
1989	32.4417	48.3160
1990	29.2430	9.7607
1991	31.1066	24.7833
1992	31.1349	25.1368
1993	30.8432	21.7255
1994	31.8353	35.6785
1995	32.0101	38.9364
1996	32.2674	44.2836
1997	30.7012	20.2369
1998	31.6248	32.1144
1999	32.0321	39.3669
2000	29.4065	10.5927
2001	28.6866	7.3904
2002	29.3953	10.5332
2003	30.9657	23.0977
2004	31.5810	31.4179
2005	30.1676	15.4974
2006	29.9998	14.2502
2007	31.0384	23.9530

Table B2. Parameter estimates and standard deviations for the Ricker stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			-0.319	0.260			0.006	0.006	-0.224	0.127	0.367	0.304
1980	-4.927	3.085	0.825	0.358	-0.043	0.030	0.057	0.014	-0.406	0.123	-0.021	0.282
1981	0.215	0.869	0.789	0.353	0.007	0.009	0.056	0.014	-0.388	0.124	-0.082	0.279
1982	0.527	0.563	0.734	0.394	0.010	0.007	0.054	0.016	-0.387	0.124	-0.056	0.275
1983	0.406	0.440	0.818	0.436	0.009	0.006	0.057	0.017	-0.388	0.124	-0.066	0.271
1984	0.397	0.376	0.858	0.498	0.009	0.005	0.059	0.019	-0.389	0.124	-0.060	0.271
1985	0.623	0.333	0.336	0.608	0.011	0.005	0.040	0.023	-0.395	0.124	-0.059	0.273
1986	0.581	0.307	0.087	0.728	0.011	0.005	0.031	0.027	-0.398	0.124	-0.047	0.277
1987	0.337	0.300	0.555	0.820	0.009	0.005	0.047	0.030	-0.354	0.124	-0.043	0.270
1988	0.223	0.308	0.645	0.912	0.008	0.005	0.050	0.033	-0.335	0.123	0.058	0.271
1989	0.057	0.302	0.727	0.929	0.007	0.005	0.052	0.034	-0.302	0.123	0.037	0.274
1990	0.172	0.309	0.809	0.949	0.008	0.005	0.057	0.035	-0.347	0.125	0.169	0.282
1991	0.036	0.298	0.946	0.971	0.007	0.005	0.061	0.035	-0.320	0.125	0.152	0.274
1992	-0.083	0.288	1.514	1.041	0.006	0.005	0.080	0.037	-0.320	0.125	0.159	0.276
1993	-0.097	0.275	1.800	1.140	0.006	0.005	0.089	0.041	-0.325	0.125	0.149	0.274
1994	-0.002	0.275	0.929	1.586	0.007	0.005	0.060	0.055	-0.309	0.124	0.156	0.286
1995	-0.046	0.261	1.410	1.784	0.006	0.005	0.076	0.061	-0.308	0.124	0.129	0.273
1996	-0.080	0.253	1.675	1.881	0.006	0.005	0.084	0.064	-0.305	0.124	0.116	0.272
1997	0.009	0.256	-0.664	2.251	0.007	0.005	0.008	0.076	-0.324	0.125	0.182	0.287
1998	-0.048	0.241	-0.088	3.178	0.006	0.005	0.027	0.106	-0.315	0.124	0.114	0.271
1999	-0.079	0.233	-0.453	4.442	0.006	0.005	0.015	0.146	-0.309	0.124	0.078	0.276
2000	-0.047	0.219	-1.902	4.333	0.006	0.004	-0.029	0.142	-0.350	0.125	0.049	0.275
2001	-0.060	0.206	-2.645	4.313	0.006	0.004	-0.052	0.141	-0.360	0.125	-0.016	0.277
2002	-0.086	0.211	-2.603	4.317	0.006	0.004	-0.050	0.141	-0.348	0.124	0.023	0.271
2003	-0.126	0.215	-4.313	5.199	0.006	0.005	-0.108	0.172	-0.325	0.124	0.038	0.273
2004	-0.150	0.215	-5.235	6.326	0.006	0.005	-0.139	0.211	-0.315	0.123	0.039	0.276
2005	-0.142	0.211	-4.701	6.169	0.006	0.005	-0.118	0.206	-0.336	0.124	0.056	0.274
2006	-0.155	0.209	-3.551	6.362	0.006	0.005	-0.077	0.213	-0.337	0.124	0.051	0.272
2007	-0.181	0.210	-3.992	9.066	0.006	0.005	-0.093	0.308	-0.322	0.123	0.059	0.277

Table B3. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Beverton-Holt stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The “best” model is shaded. Years are brood year.

Year	AICc	Odds
NA	29.7727	18.4149
1980	25.7843	2.5066
1981	24.5863	1.3770
1982	24.5910	1.3803
1983	24.1006	1.0801
1984	23.9464	1.0000
1985	24.8023	1.5341
1986	24.7628	1.5041
1987	27.9016	7.2254
1988	29.2177	13.9523
1989	31.7329	49.0694
1990	28.6093	10.2928
1991	30.6450	28.4827
1992	31.5624	45.0590
1993	31.6181	46.3324
1994	31.3514	40.5480
1995	31.7759	50.1358
1996	32.1970	61.8866
1997	30.0083	20.7162
1998	31.0013	34.0360
1999	31.4110	41.7743
2000	28.8322	11.5062
2001	28.1772	8.2927
2002	28.8375	11.5366
2003	30.5744	27.4948
2004	31.1698	37.0289
2005	29.6270	17.1211
2006	29.2277	14.0223
2007	30.1635	22.3878

Table B4. Parameter estimates and standard deviations for the Beverton-Holt stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			0.224	0.851			-3.290	1.684	-0.236	0.129	0.403	0.324
1980	-0.556	0.310	2.686	3.333	-10.91	35.202	0.094	3.500	-0.388	0.125	-0.146	0.282
1981	0.672	1.635	2.762	3.782	-3.736	2.500	0.203	3.952	-0.409	0.124	-0.052	0.296
1982	0.799	0.787	2.882	4.945	-3.551	1.225	0.326	5.129	-0.409	0.124	-0.045	0.282
1983	0.538	0.526	8.307	57.004	-3.945	0.992	5.768	57.013	-0.416	0.124	-0.068	0.275
1984	0.501	0.436	9.152	68.364	-4.003	0.889	6.604	68.368	-0.418	0.124	-0.064	0.273
1985	0.776	0.421	2.594	11.533	-3.580	0.785	0.026	11.994	-0.406	0.124	-0.051	0.275
1986	0.727	0.393	0.795	2.881	-3.643	0.777	-1.978	3.689	-0.405	0.124	-0.041	0.278
1987	0.482	0.385	8.354	122.464	-3.906	0.876	5.793	122.479	-0.364	0.124	-0.035	0.273
1988	0.394	0.421	8.228	111.591	-3.939	0.996	5.652	111.606	-0.344	0.123	0.079	0.274
1989	0.249	0.434	7.025	61.785	-4.023	1.107	4.410	61.814	-0.312	0.123	0.060	0.278
1990	0.370	0.452	7.051	52.894	-3.911	1.065	4.513	52.916	-0.354	0.125	0.187	0.288
1991	0.237	0.452	7.762	72.745	-4.018	1.157	5.185	72.760	-0.326	0.125	0.164	0.279
1992	0.084	0.433	7.678	54.671	-4.237	1.267	5.051	54.684	-0.311	0.124	0.178	0.279
1993	0.058	0.419	7.628	51.998	-4.281	1.277	4.996	52.011	-0.310	0.124	0.180	0.280
1994	0.206	0.450	5.852	54.545	-4.008	1.204	3.282	54.618	-0.313	0.125	0.199	0.288
1995	0.145	0.426	6.347	56.553	-4.097	1.219	3.763	56.599	-0.309	0.124	0.165	0.280
1996	0.100	0.411	6.545	58.063	-4.156	1.234	3.954	58.102	-0.304	0.124	0.132	0.280
1997	0.212	0.430	-0.690	2.493	-4.005	1.178	-4.849	13.254	-0.333	0.126	0.196	0.296
1998	0.130	0.391	0.233	9.064	-4.143	1.176	-2.668	13.428	-0.324	0.125	0.119	0.276
1999	0.094	0.380	-0.473	6.417	-4.193	1.186	-4.029	18.286	-0.318	0.124	0.081	0.281
2000	0.113	0.352	-1.011	0.284	-4.231	1.113	-9.764	109.299	-0.358	0.125	0.065	0.272
2001	0.098	0.336	-1.063	0.260	-4.258	1.083	-9.645	77.507	-0.368	0.125	0.012	0.272
2002	0.088	0.356	-1.074	0.349	-4.211	1.121	-8.571	46.119	-0.357	0.125	0.041	0.272
2003	0.087	0.401	-1.046	0.280	-4.085	1.186	-9.606	63.896	-0.331	0.124	0.073	0.275
2004	0.086	0.425	-1.051	0.334	-4.022	1.217	-8.858	47.684	-0.321	0.124	0.082	0.278
2005	0.089	0.411	-1.171	0.310	-4.033	1.179	-9.685	77.778	-0.344	0.124	0.081	0.277
2006	0.080	0.407	-1.248	0.398	-4.032	1.168	-8.833	63.349	-0.349	0.124	0.056	0.277
2007	0.082	0.440	-1.261	0.596	-3.954	1.211	-8.167	60.765	-0.336	0.124	0.075	0.281

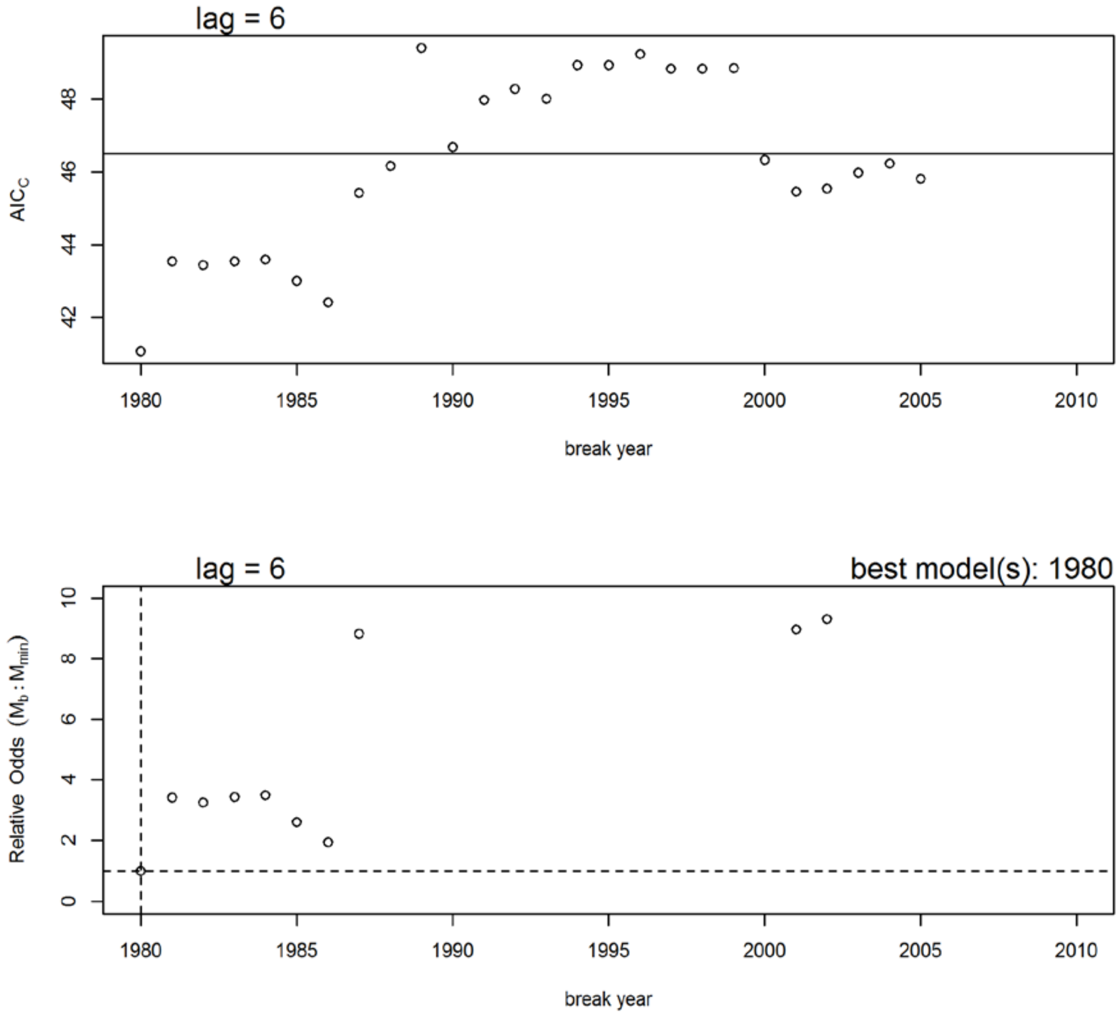


Figure B1. Results from the Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score. Not shown are 1-breakpoint models with high odds (>10) of being incorrect.

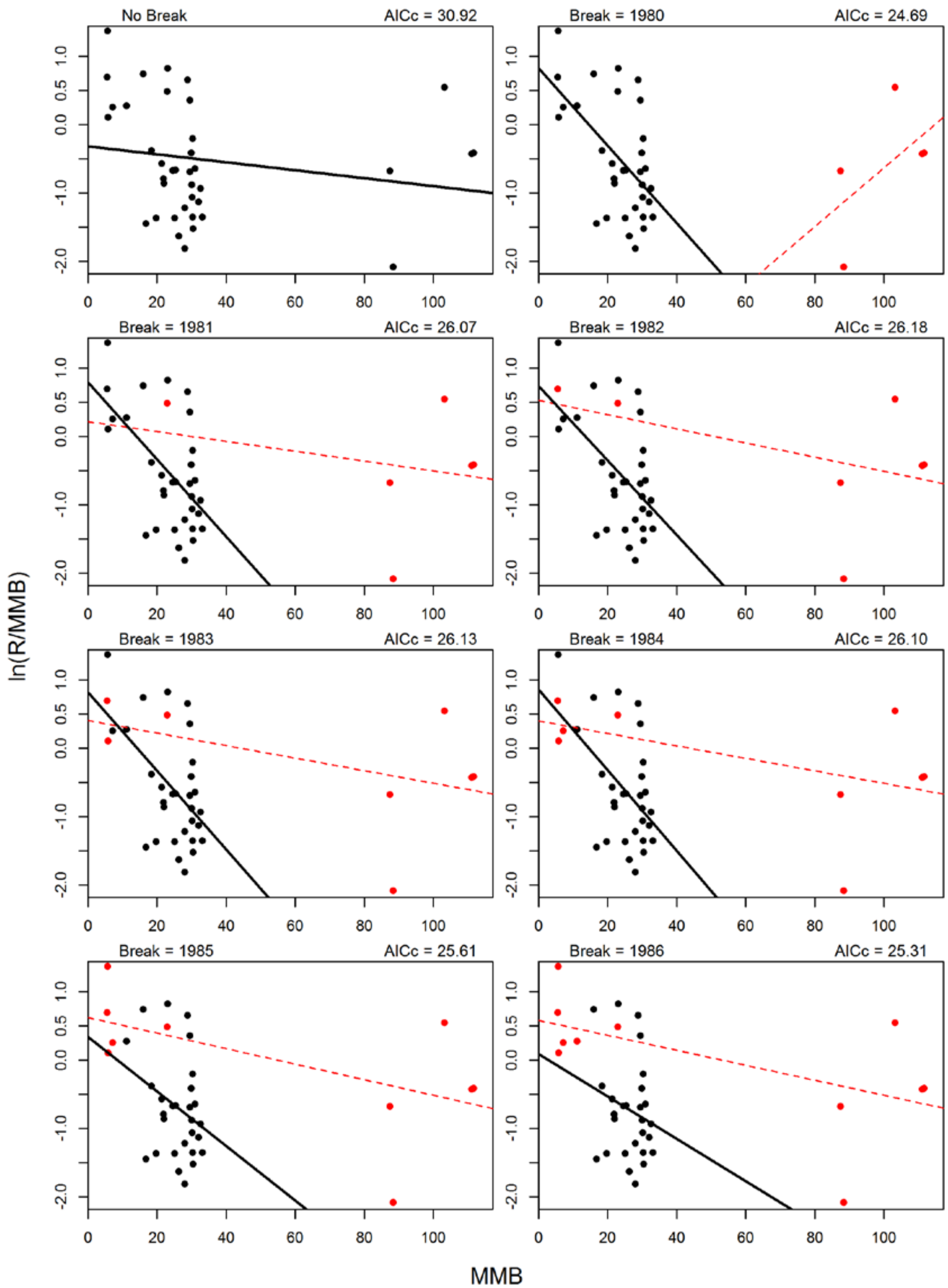
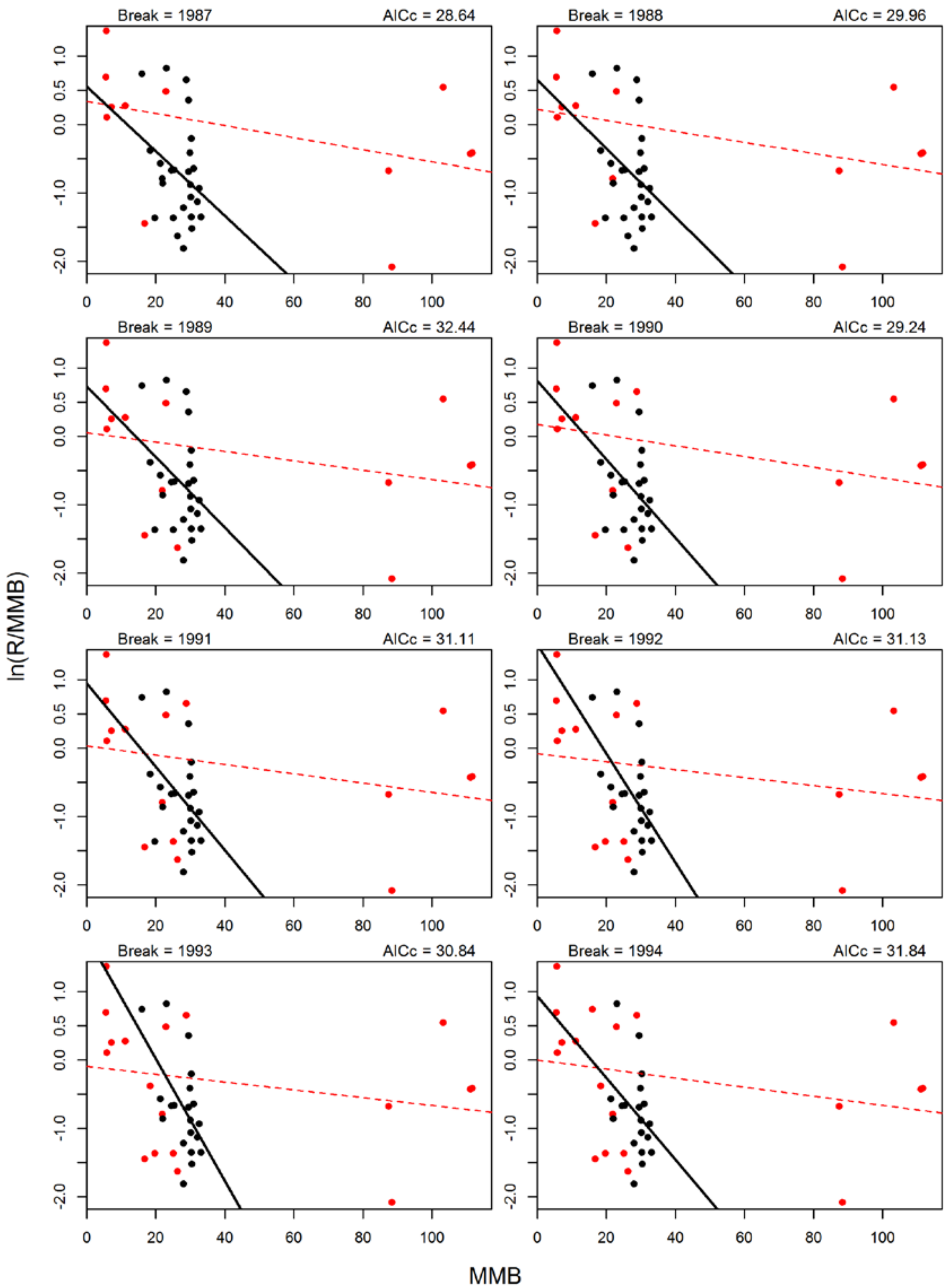


Figure B2. Fits for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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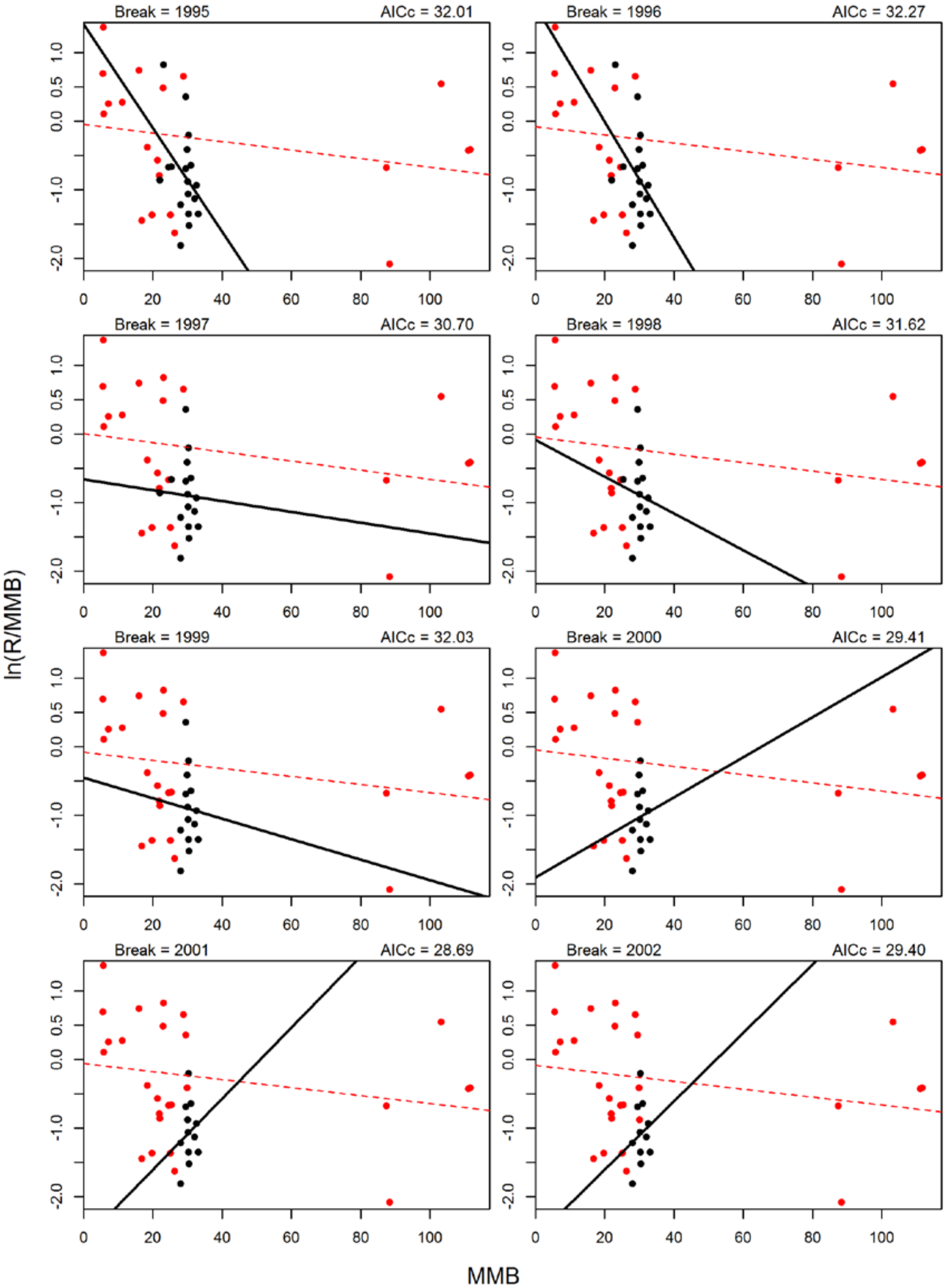


Figure B2. Continue.

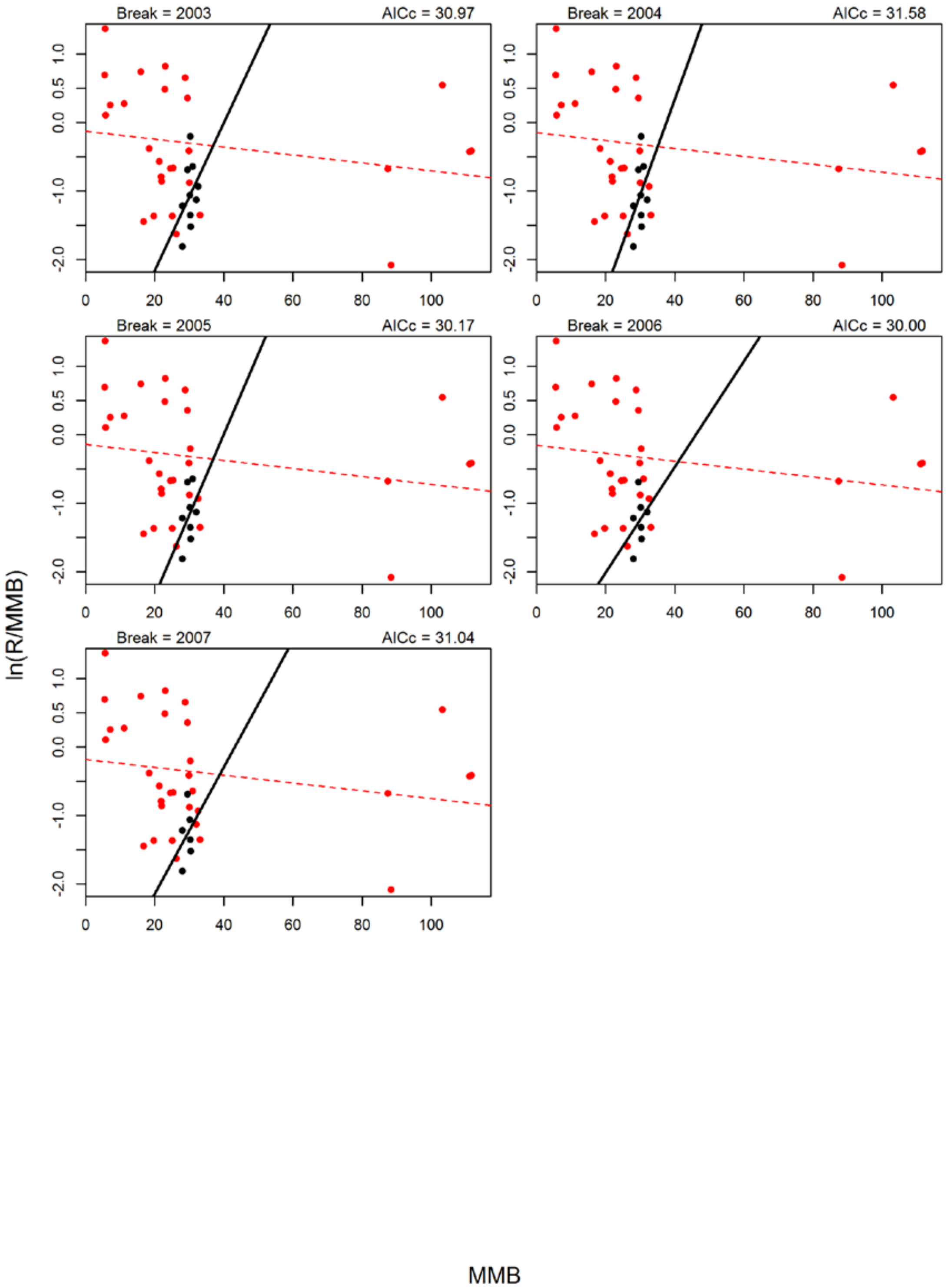


Figure B2. Continue.

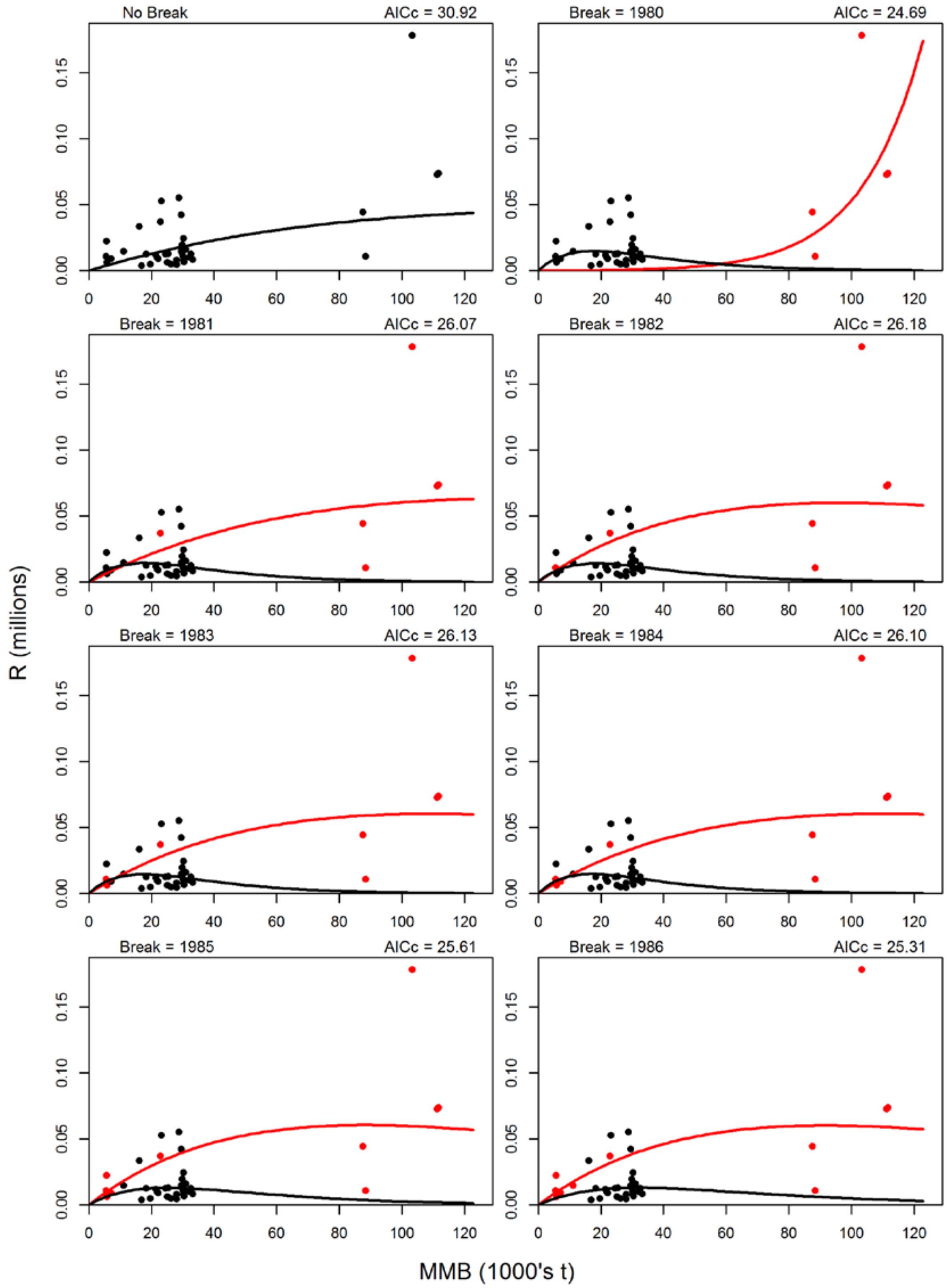
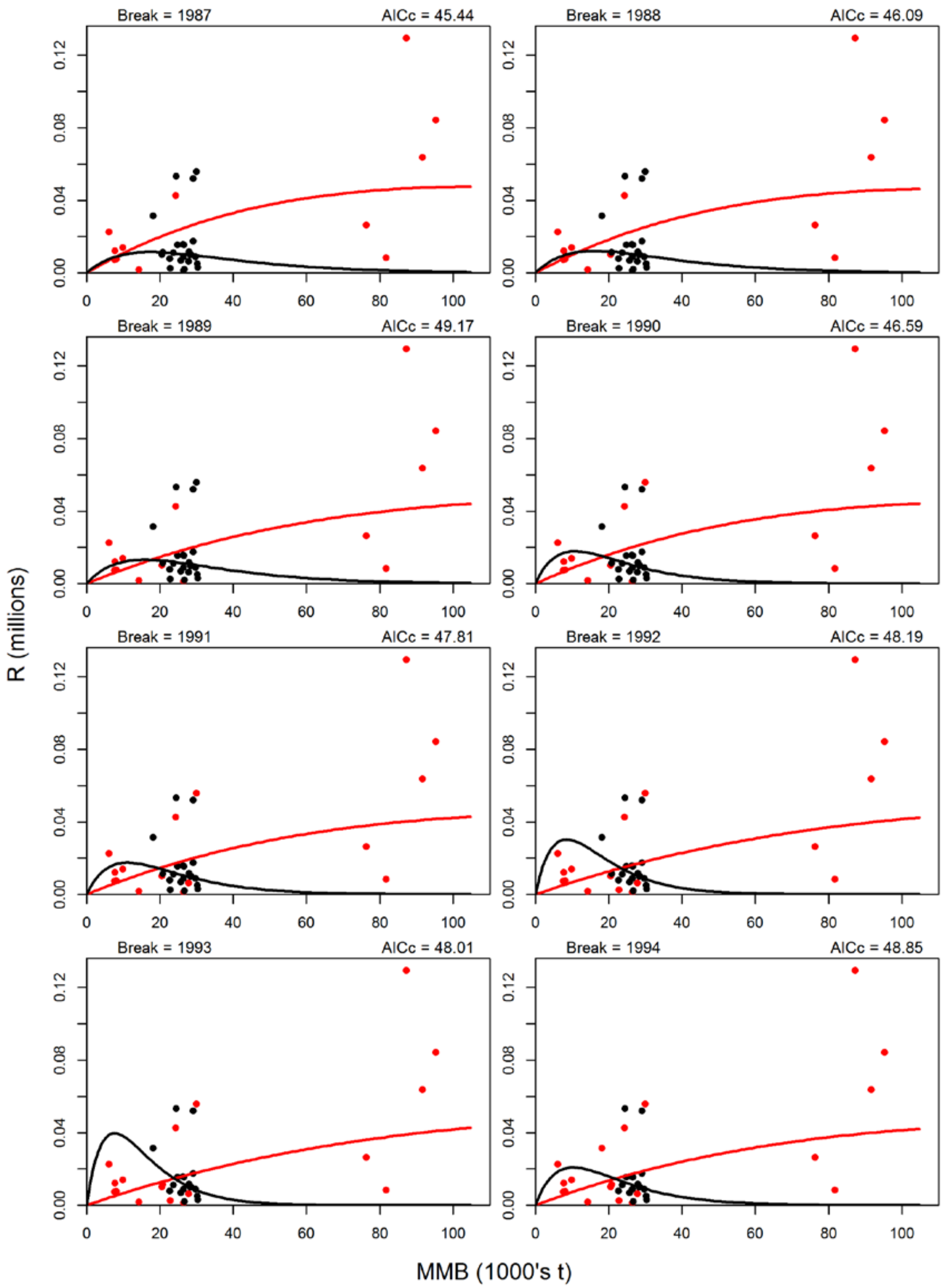


Figure B3. Fits on the arithmetic scale for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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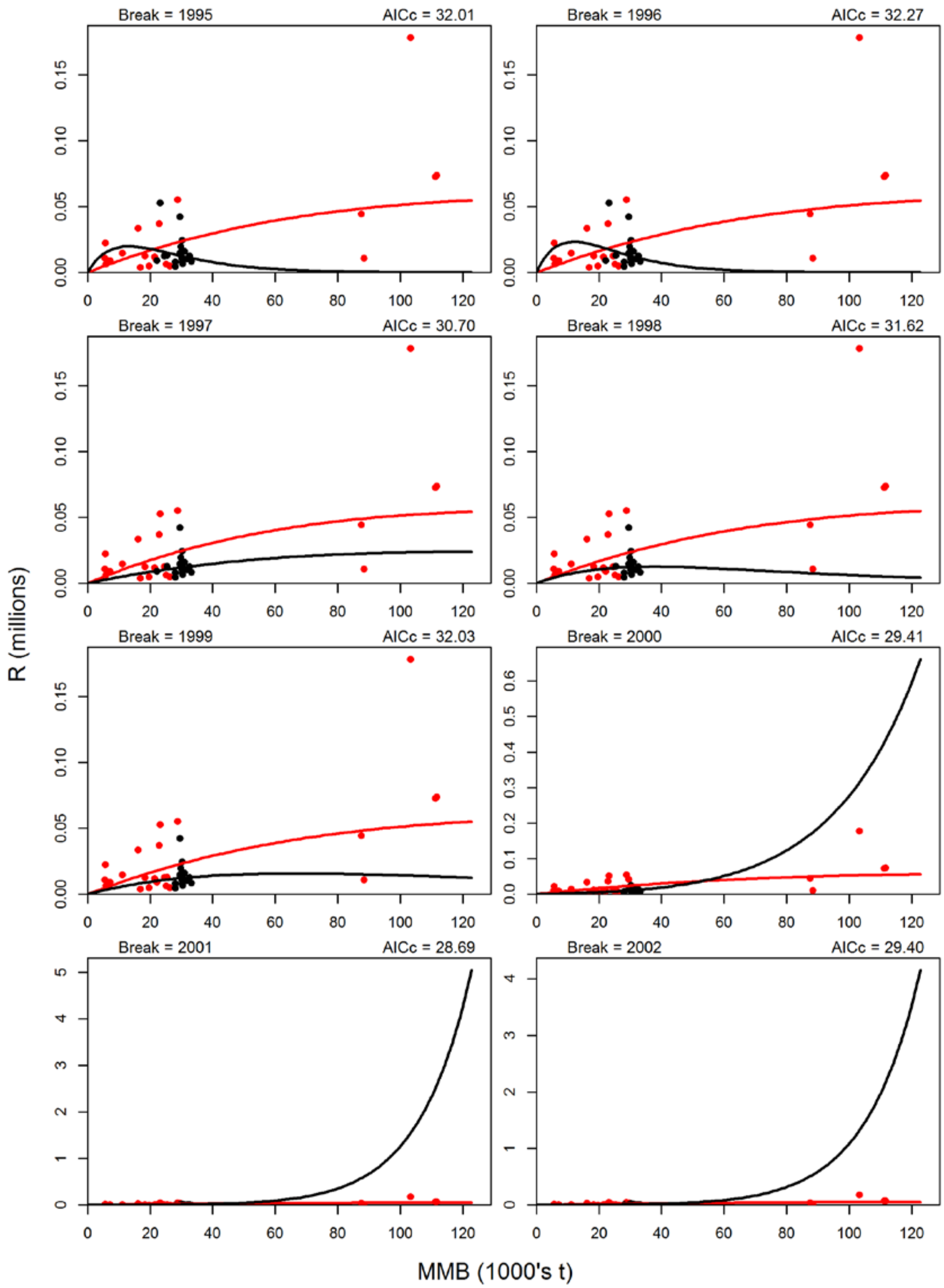

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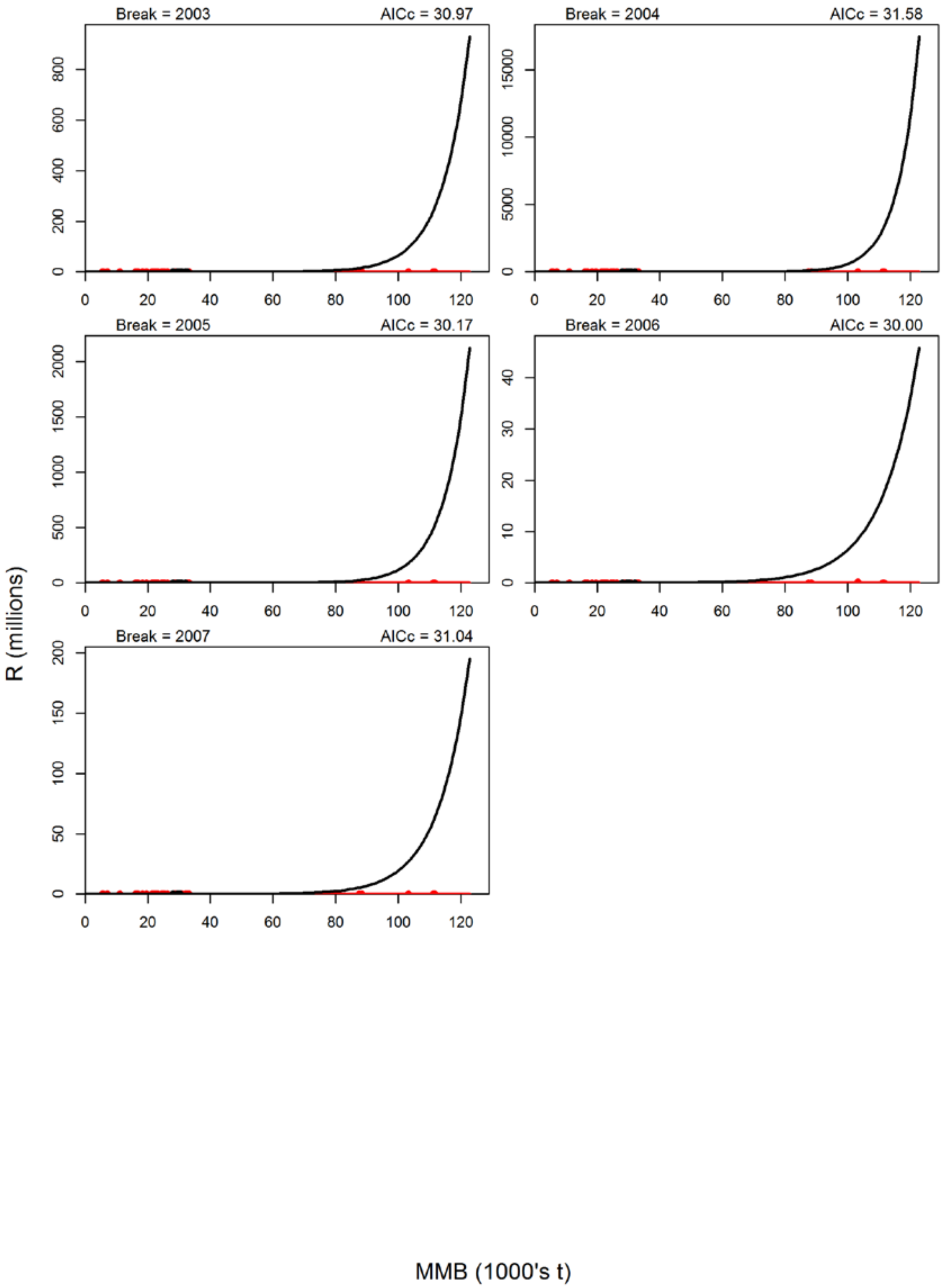

Figure B3. Continue.

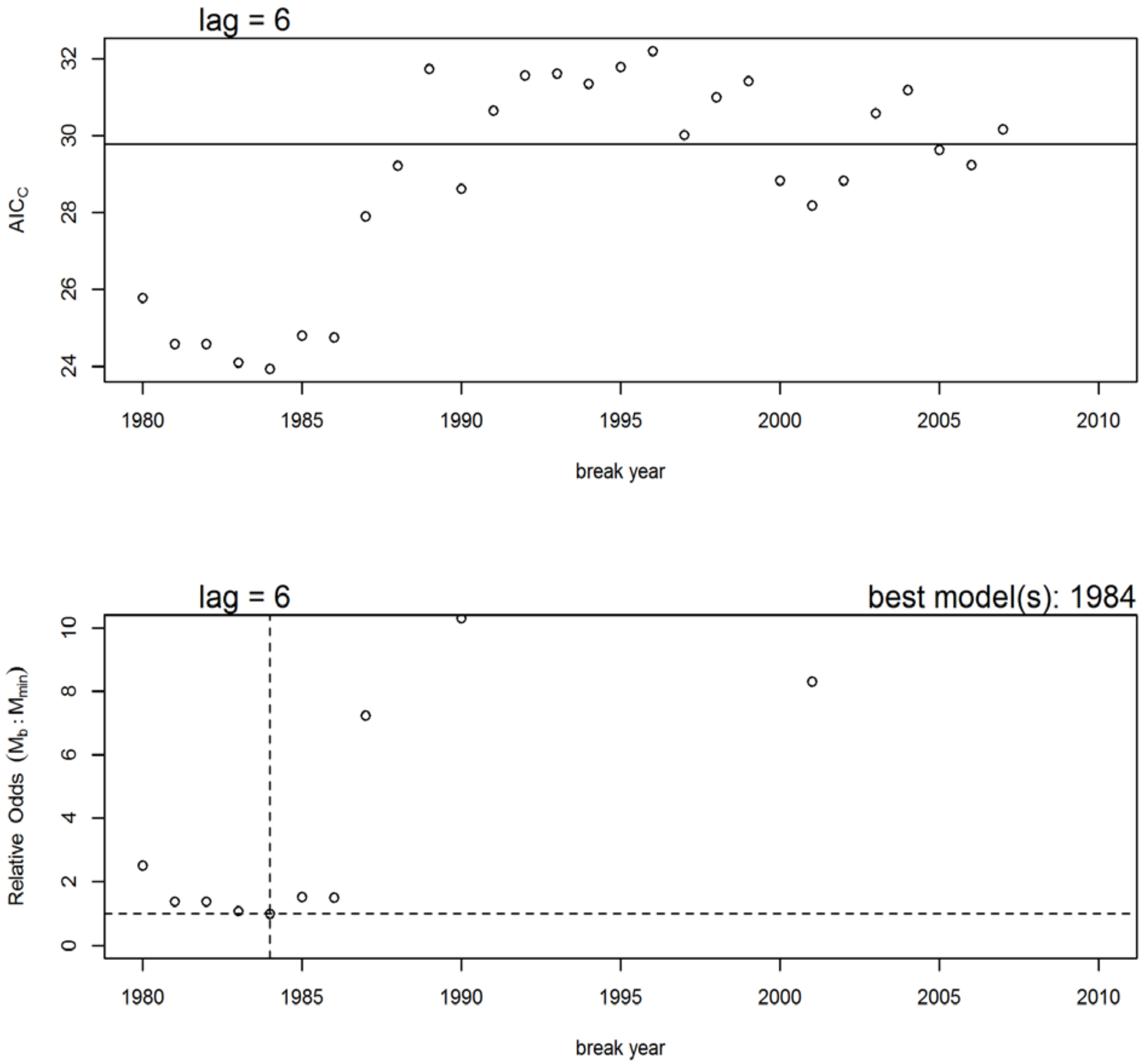

Figure B4. Results from the B-H stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1984). Not shown are 1-breakpoint models with high odds (>10) of being incorrect.

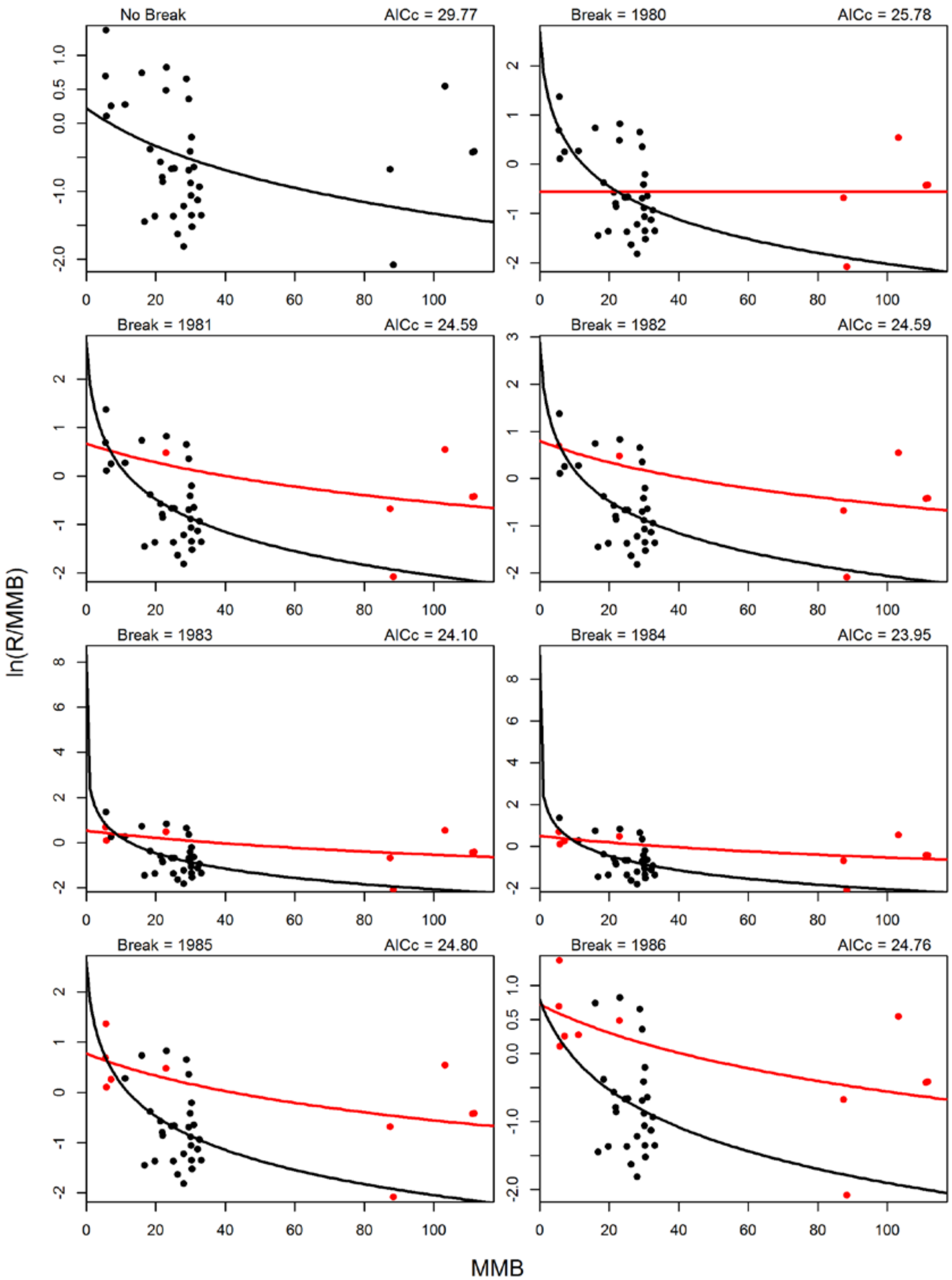

Figure B5. Fits for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

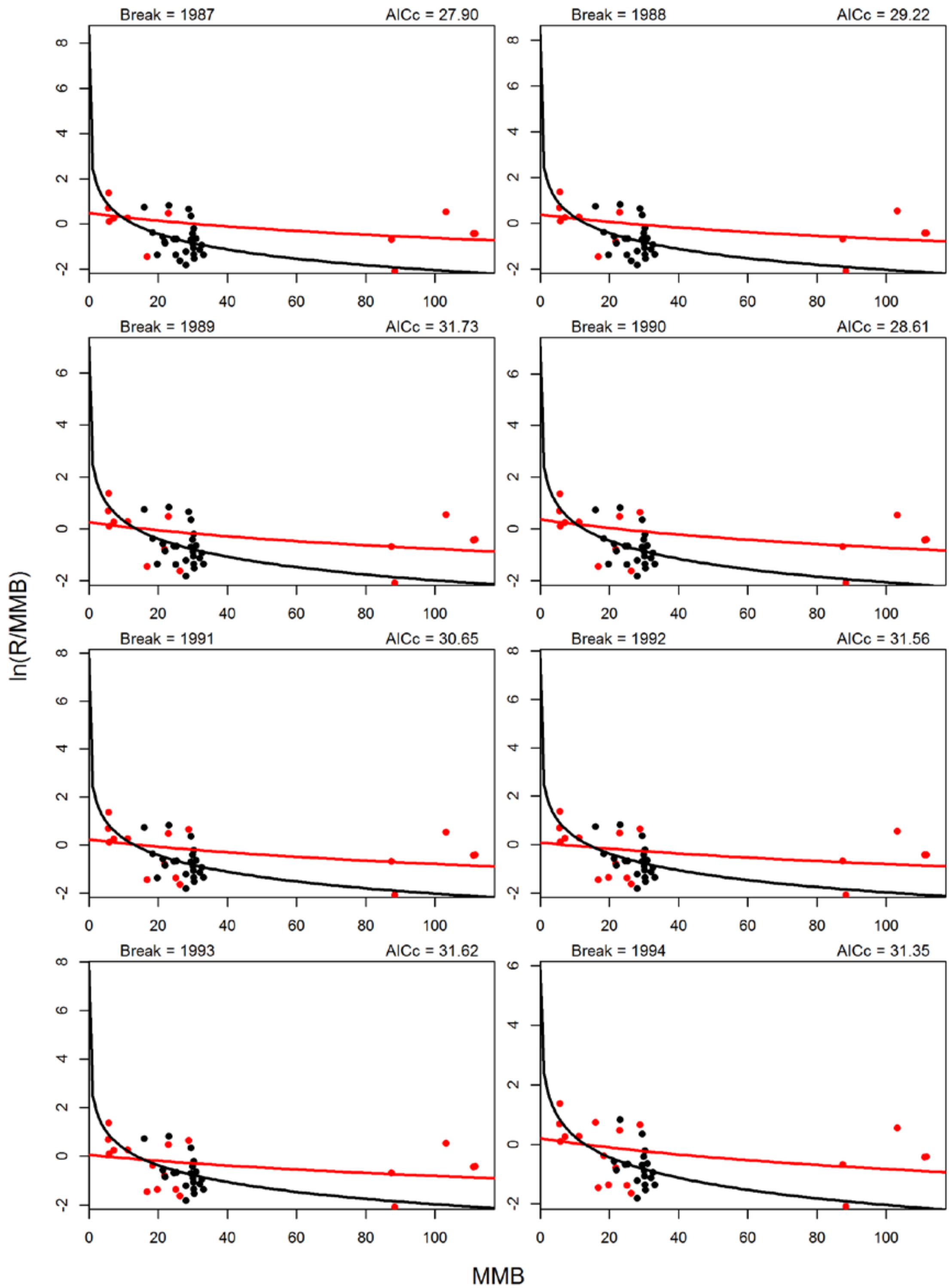

Figure B5. Continue.

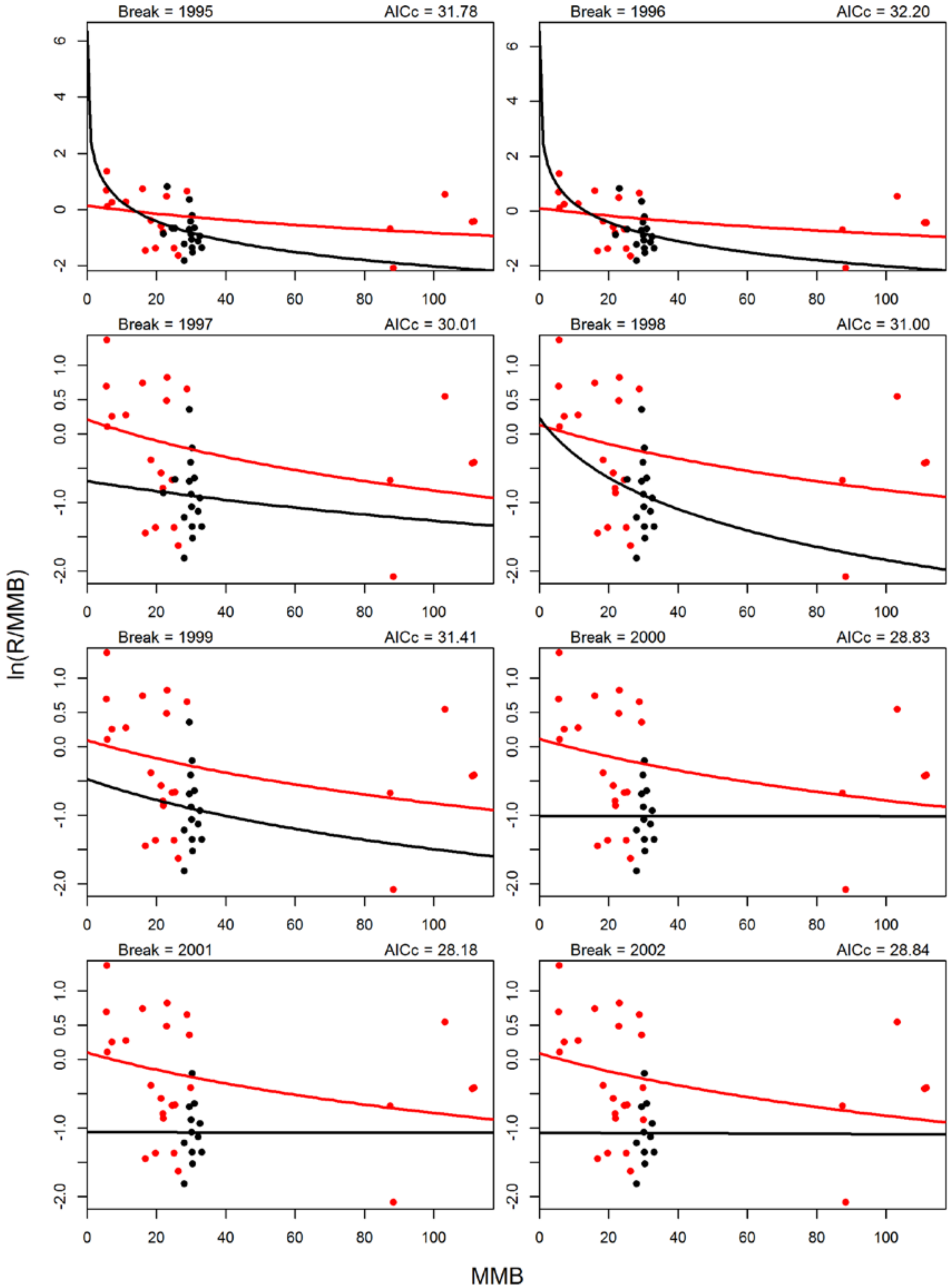

Figure B5. Continue.

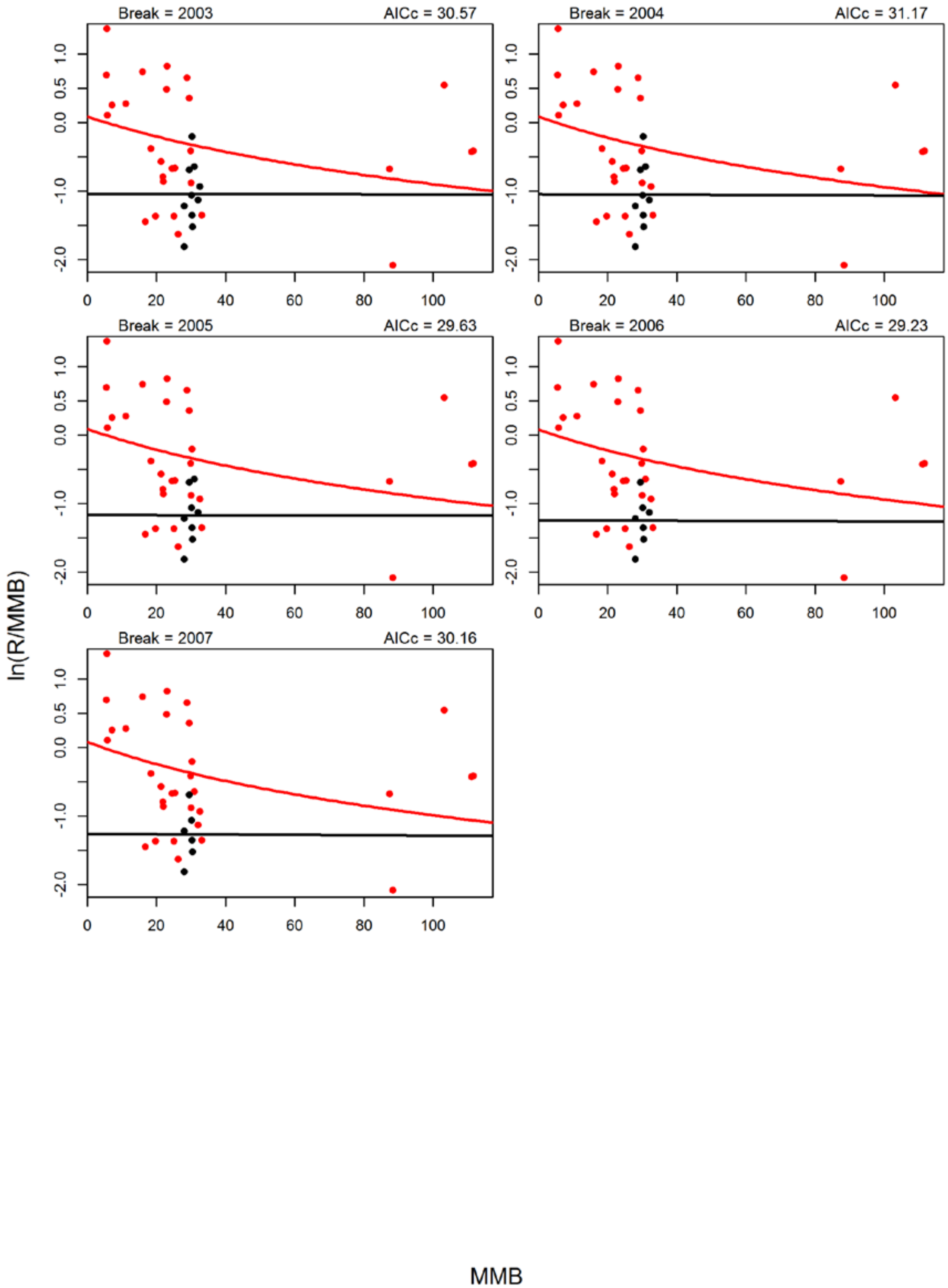

Figure B5. Continue.

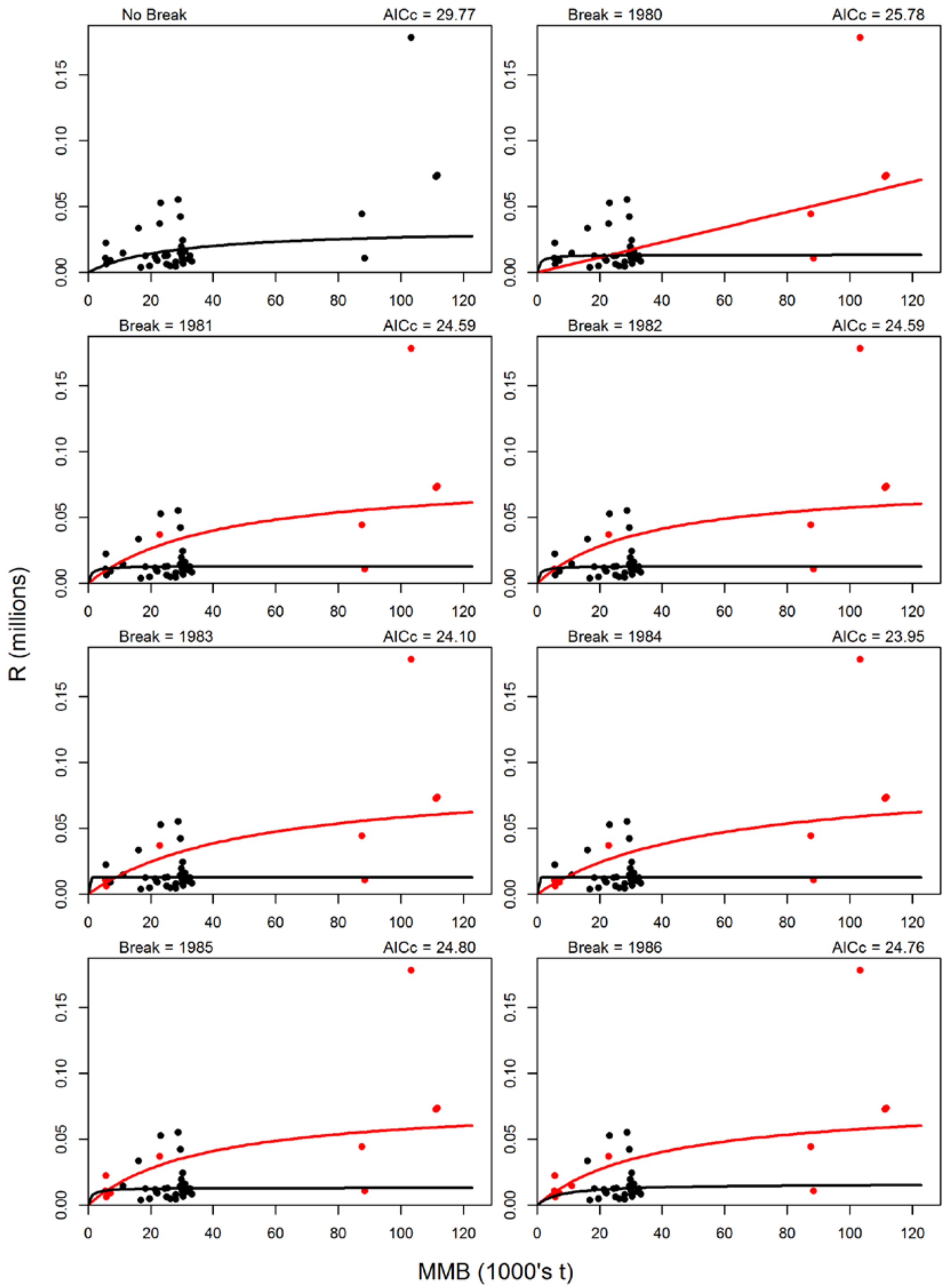

Figure B6. Fits on the arithmetic scale for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

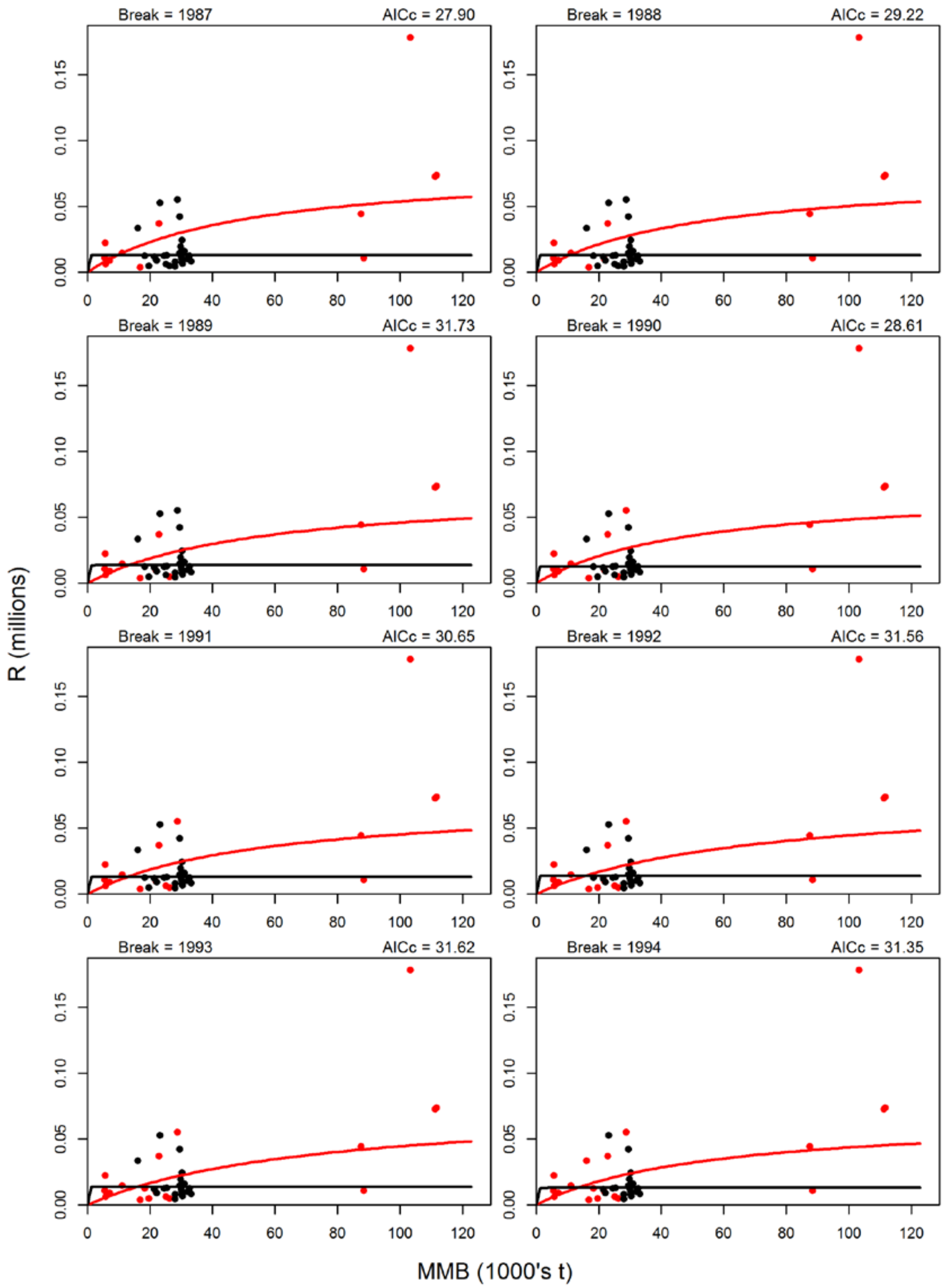

Figure B6. Continue.

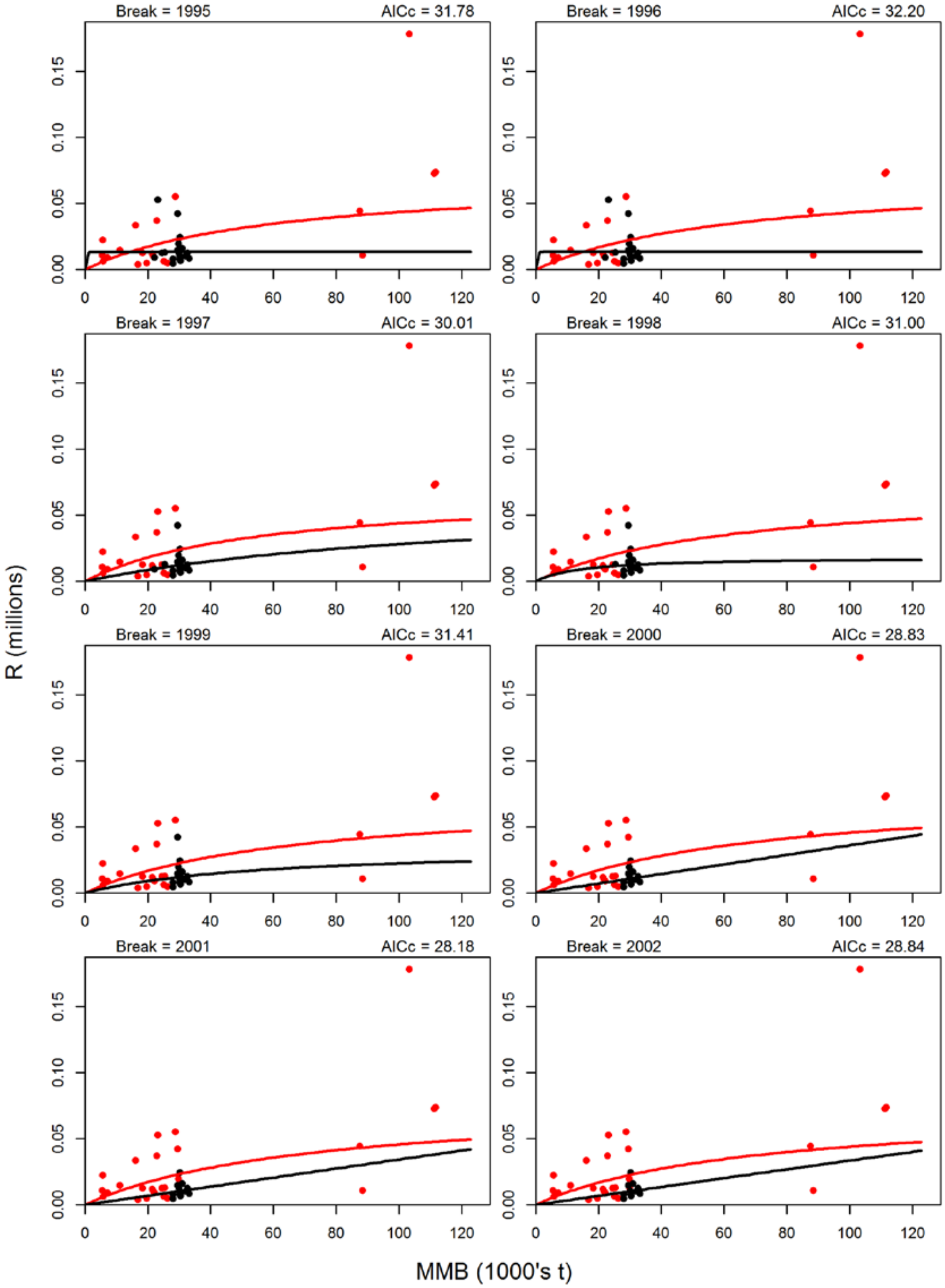

Figure B6. Continue.

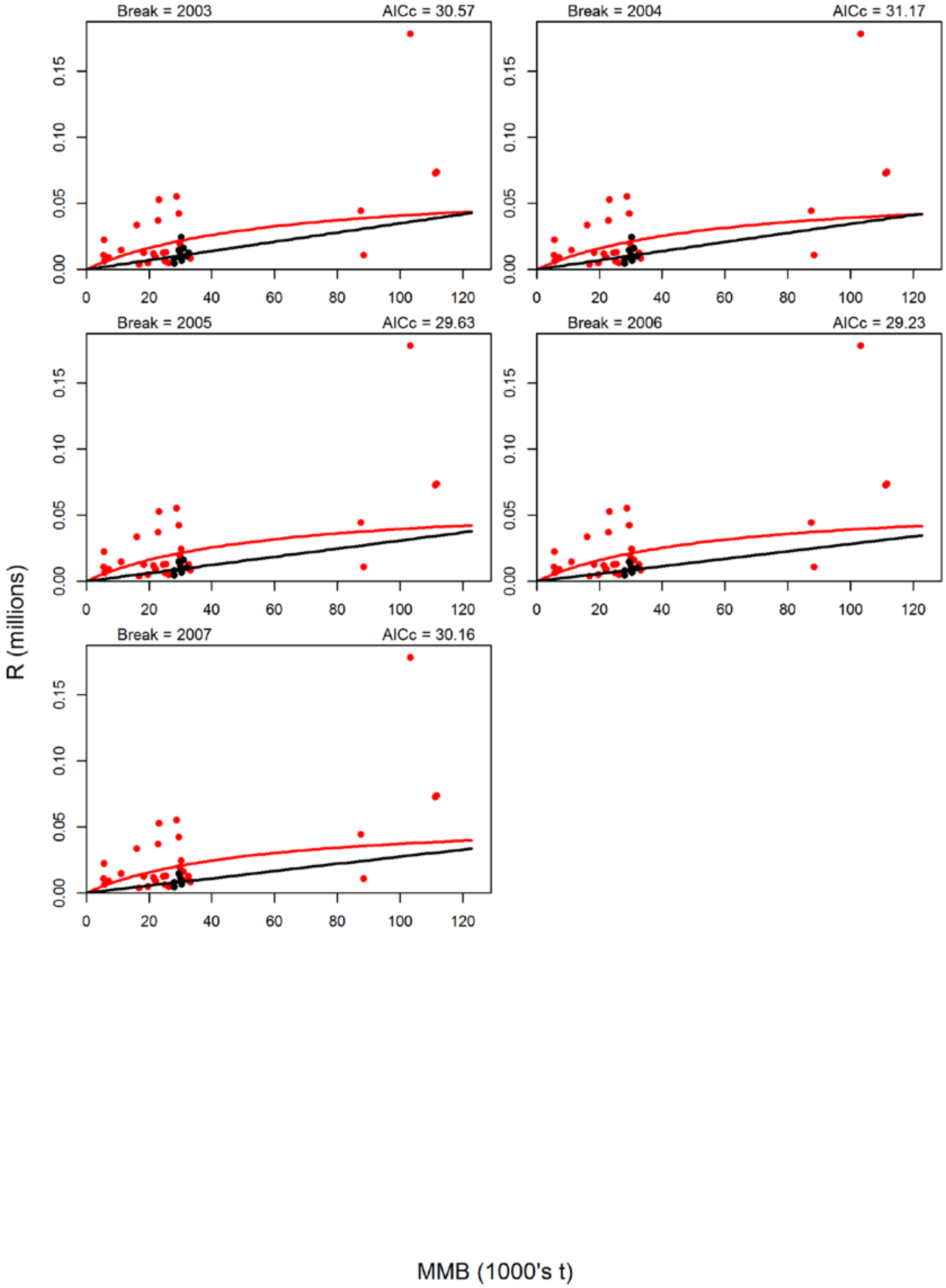

Figure B6. Continue.

Appendix C. Simple B0 Analysis

Ideally, a stock-recruitment relationship and impacts of environmental factors on recruitment are developed before doing B0 analysis. For Bristol Bay red king crab, there is hardly any relationship between estimated recruits and MMB (Figure 14a). The impacts of environmental factors on recruitment have not been quantified. We simply computed B0 values over time using the same recruitment time series estimated from the assessment model through setting all directed and bycatch fishing mortality to be zero. Figure C1 shows the time series of estimated B0, MMB with fishing, and ratios of MMB to B0 for model 18.0e. As expected, estimated B0 values change greatly over time.

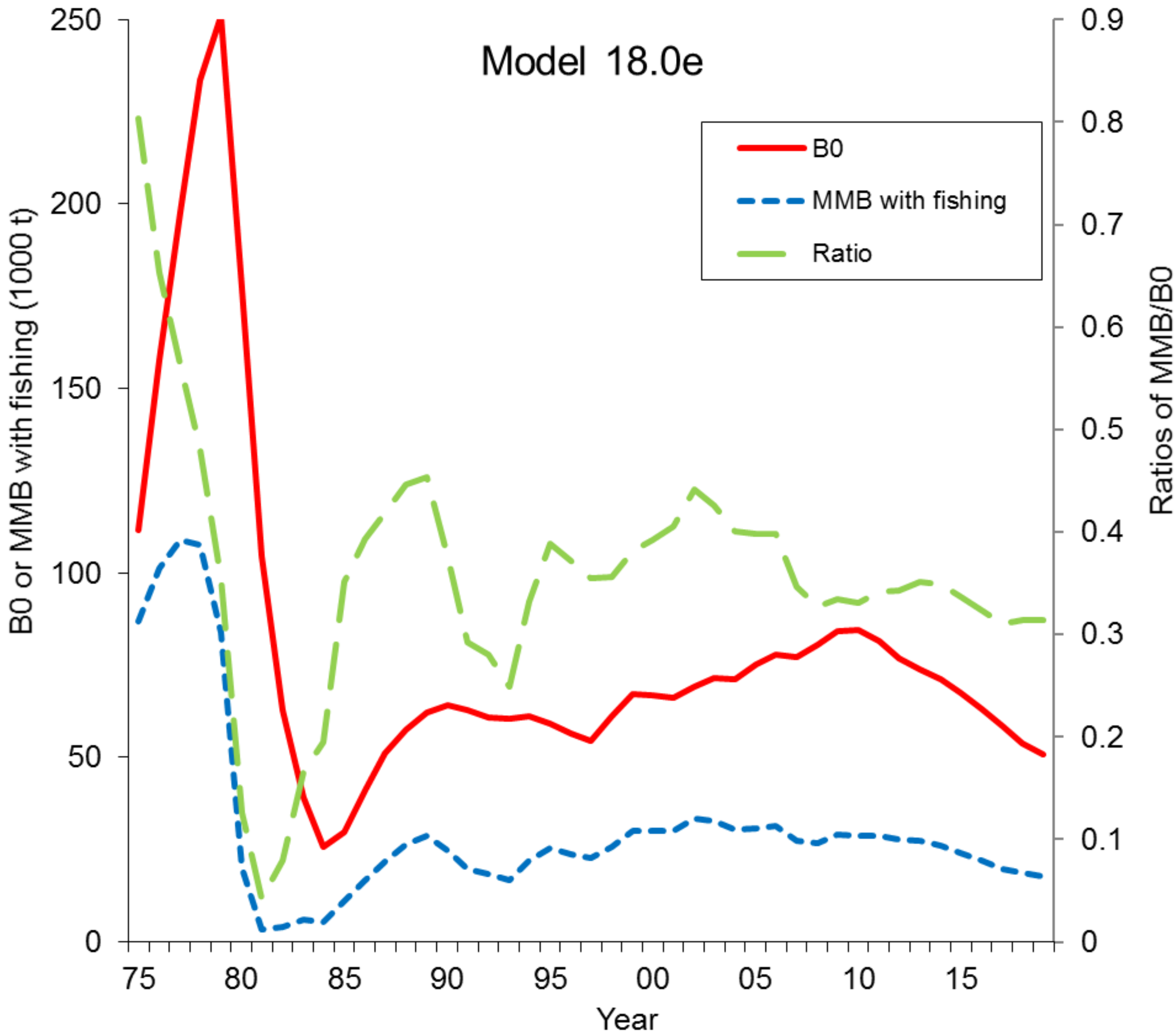

Figure C1. Estimated B0, MMB with fishing, and ratios of MMB/B0 from 1975 to 2019 for model 18.0e for Bristol Bay red king crab.

Appendix D. Control File for Model 19.0 (Gmacs)

```
##                                                              ##
## LEADING PARAMETER CONTROLS                                   ##
##     Controls for leading parameter vector (theta)            ##
## LEGEND                                                       ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma   ##
##                                                              ##
## ntheta
  91
## ------------------------------------------------------------------------ ##
## ival     lb     ub     phz  prior   p1     p2      # parameter      ##
## ------------------------------------------------------------------------ ##
   0.18     0.15   0.2     -4    2   0.18   0.04     # M
   0.18     0.15   0.2     -4    2   0.18   0.04     # M
  16.5     -10     18      -2    0  -10.0   20.0     # logR0
  19.5     -10     25       3    0   10.0   25.0     # logRini, to estimate if NOT initialized at unfished (n68)
  16.5     -10     25       1    0   10.0   20.0  #1   # logRbar, to estimate if NOT initialized at unfished     #1
  72.5      55    100      -4    1   72.5   7.25     # recruitment expected value (males or combined)
   0.726149  0.32   1.64    3    0    0.1    5.0     # recruitment scale (variance component) (males or combined)
   0.00     -5      5      -4    0    0.0   20.00    # recruitment expected value (females)
   0.00     -1.69   0.40    3    0    0.0   20.0     # recruitment scale (variance component) (females)
  -0.10536   -10    0.75   -4    0  -10.0   0.75     # ln(sigma_R)
   0.75     0.20   1.00    -2    3    3.0   2.00     # steepness
   0.01     0.00   1.00    -3    3   1.01   1.01     # recruitment autocorrelation
#  0.00     -10     4       2    0   10.0   20.00    # Deviation for size-class 1 (normalization class)
   1.107962885630    -10    4    9    0   10.0   20.00    # Deviation for size-class 2
   0.563229168219    -10    4    9    0   10.0   20.00    # Deviation for size-class 3
   0.681928313426    -10    4    9    0   10.0   20.00    # Deviation for size-class 4
   0.491057364532    -10    4    9    0   10.0   20.00    # Deviation for size-class 5
   0.407911777560    -10    4    9    0   10.0   20.00    # Deviation for size-class 6
   0.436516142684    -10    4    9    0   10.0   20.00    # Deviation for size-class 7
   0.40612675395550  -10    4    9    0   10.0   20.00    # Deviation for size-class 8
   0.436145974880    -10    4    9    0   10.0   20.00    # Deviation for size-class 9
   0.40494522852708  -10    4    9    0   10.0   20.00    # Deviation for size-class 10
   0.30401970466854  -10    4    9    0   10.0   20.00    # Deviation for size-class 11
   0.2973752673022   -10    4    9    0   10.0   20.00    # Deviation for size-class 12
   0.1746800712364   -10    4    9    0   10.0   20.00    # Deviation for size-class 13
   0.0845298456942   -10    4    9    0   10.0   20.00    # Deviation for size-class 14
   0.0107462399193   -10    4    9    0   10.0   20.00    # Deviation for size-class 15
   -0.190468322904   -10    4    9    0   10.0   20.00    # Deviation for size-class 16
   -0.376312503735   -10    4    9    0   10.0   20.00    # Deviation for size-class 17
   -0.699162895473   -10    4    9    0   10.0   20.00    # Deviation for size-class 18
   -1.15881771530    -10    4    9    0   10.0   20.00    # Deviation for size-class 19
   -1.17311583316    -10    4    9    0   10.0   20.00    # Deviation for size-class 20
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 1
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 2
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 3
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 4
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 5
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 6
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 7
 -100.00    -101    5      -2    0   10.0   20.00    # Deviation for size-class 8
```

```
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 9
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 10
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 11
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 12
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 13
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 14
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 15
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 16
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 17
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 18
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 19
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 20
  0.425704202053    -10    4    9    0  10.0   20.00     # Deviation for size-class 1
  2.268408592660    -10    4    9    0  10.0   20.00     # Deviation for size-class 2
  1.810451373080    -10    4    9    0  10.0   20.00     # Deviation for size-class 3
  1.37035725111    -10    4    9    0  10.0   20.00     # Deviation for size-class 4
  1.158258087990    -10    4    9    0  10.0   20.00     # Deviation for size-class 5
  0.596196784439    -10    4    9    0  10.0   20.00     # Deviation for size-class 6
  0.225756761257    -10    4    9    0  10.0   20.00     # Deviation for size-class 7
  -0.0247857565368    -10    4    9    0  10.0   20.00     # Deviation for size-class 8
  -0.214045895269    -10    4    9    0  10.0   20.00     # Deviation for size-class 9
  -0.560539577780    -10    4    9    0  10.0   20.00     # Deviation for size-class 10
  -0.974218300021    -10    4    9    0  10.0   20.00     # Deviation for size-class 11
  -1.24580072031    -10    4    9    0  10.0   20.00     # Deviation for size-class 12
  -1.49292897450    -10    4    9    0  10.0   20.00     # Deviation for size-class 13
  -1.94135821253    -10    4    9    0  10.0   20.00     # Deviation for size-class 14
  -2.05101560679    -10    4    9    0  10.0   20.00     # Deviation for size-class 15
  -1.94956606430    -10    4    9    0  10.0   20.00     # Deviation for size-class 16
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 17
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 18
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 19
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 20
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 1
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 2
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 3
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 4
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 5
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 6
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 7
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 8
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 9
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 10
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 11
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 12
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 13
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 14
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 15
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 16
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 17
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 18
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 19
-100.00    -101    5    -2    0  10.0   20.00     # Deviation for size-class 20

# Use custom natural mortality (0=no, 1=yes, by sex and year)
0
#          weight-at-length input    method  (1 = allometry     [w_l = a*l^b],     2 = vector by sex)
```

```
2
##	Males
0.000224781	0.000281351	0.000346923	0.000422209	0.000507927	0.000604802 0.000713564
	0.00083495	0.0009697	0.00111856	0.00128229	0.00146163	0.00165736
	0.00187023	0.00210101	0.00235048	0.00261942	0.00290861	0.00321882
	0.0039059
##	Females
0.0002151 0.00026898	0.00033137	0.00040294	0.00048437	0.00062711	0.0007216
	0.00082452	0.00093615	0.00105678	0.00118669	0.00132613	0.00147539
	0.00163473	0.00180441	0.00218315	0.00218315	0.00218315	0.00218315
	0.0021831
# Proportion mature by sex
0	0	0	0	0	0	0	0	0	0	0	1	1
	1	1	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
# Proportion legal by sex
0	0	0	0	0	0	0	0	0	0	0	1	1
	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
## ———————————————————————————————————————— ##

## ———————————————————————————————————————— ##
## GROWTH PARAMETER CONTROLS	##
##	Two lines for each parameter if split sex, one line if not	##
## ———————————————————————————————————————— ##
# Use growth transition matrix option (1=read in growth-increment matrix; 2=read in size-transition; 3=gamma distribution for size-increment; 4=gamma distribution for size after increment)
3
# growth increment model (1=alpha/beta; 2=estimated by size-class;3=pre-specified/emprical)
3
# molt probability function (0=pre-specified; 1=flat;2=declining logistic)
2
# maximum size-class (males then females)
20 16
# Maximum size-class for recruitment(males then females)
7 5
## number of size-increment periods
1 3
## Year(s) size-incremnt period changes (blank if no changes)
1983 1994
## number of molt periods
2 2
## Year(s) molt period changes (blank if no changes)
1980 1980
## Beta parameters are relative (1=Yes;0=no)
1

## ———————————————————————————————————————— ##
## ival	lb	ub	phz	prior	p1	p2	# parameter	##
## ———————————————————————————————————————— ##
16.5	0	20	-33	0	0	999	# Males
16.5	0	20	-33	0	0	999	# Males
16.4	0	20	-33	0	0	999	# Males
16.3	0	20	-33	0	0	999	# Males
```

16.3	0	20	-33	0	0	999	# Males
16.2	0	20	-33	0	0	999	# Males
16.2	0	20	-33	0	0	999	# Males
16.1	0	20	-33	0	0	999	# Males
16.1	0	20	-33	0	0	999	# Males
16	0	20	-33	0	0	999	# Males
16	0	20	-33	0	0	999	# Males
15.9	0	20	-33	0	0	999	# Males
15.8	0	20	-33	0	0	999	# Males
15.8	0	20	-33	0	0	999	# Males
15.7	0	20	-33	0	0	999	# Males
15.7	0	20	-33	0	0	999	# Males
15.6	0	20	-33	0	0	999	# Males
15.6	0	20	-33	0	0	999	# Males
15.5	0	20	-33	0	0	999	# Males
15.5	0	20	-33	0	0	999	# Males
#1.38403	0.5	3.7	7	0	0	999	# Males (beta)
1.0	0.5	3.0	6	0	0	999	# Males (beta)
13.8	0	20	-33	0	0	999	# Females
12.2	0	20	-33	0	0	999	# Females
10.5	0	20	-33	0	0	999	# Females
8.4	0	20	-33	0	0	999	# Females
7.5	0	20	-33	0	0	999	# Females
7	0	20	-33	0	0	999	# Females
6.6	0	20	-33	0	0	999	# Females
6.1	0	20	-33	0	0	999	# Females
5.6	0	20	-33	0	0	999	# Females
5.1	0	20	-33	0	0	999	# Females
4.6	0	20	-33	0	0	999	# Females
4.1	0	20	-33	0	0	999	# Females
3.6	0	20	-33	0	0	999	# Females
3.2	0	20	-33	0	0	999	# Females
2.7	0	20	-33	0	0	999	# Females
2.2	0	20	-33	0	0	999	# Females
1.7	0	20	-33	0	0	999	# Females
1.2	0	20	-33	0	0	999	# Females
0.7	0	20	-33	0	0	999	# Females
0.4	0	20	-33	0	0	999	# Females
#1.38403	0.5	3.0	7	0	0	999	# Females (beta)
1.5	0.5	3.0	6	0	0	999	# Females (beta)
15.4	0	20	-33	0	0	999	# Females
13.8	0	20	-33	0	0	999	# Females
12.2	0	20	-33	0	0	999	# Females
10.5	0	20	-33	0	0	999	# Females
8.9	0	20	-33	0	0	999	# Females
7.9	0	20	-33	0	0	999	# Females
7.2	0	20	-33	0	0	999	# Females
6.6	0	20	-33	0	0	999	# Females
6.1	0	20	-33	0	0	999	# Females
5.6	0	20	-33	0	0	999	# Females
5.1	0	20	-33	0	0	999	# Females
4.6	0	20	-33	0	0	999	# Females
4.1	0	20	-33	0	0	999	# Females
3.6	0	20	-33	0	0	999	# Females
3.2	0	20	-33	0	0	999	# Females
2.7	0	20	-33	0	0	999	# Females

```
2.2        0     20     -33     0     0     999          # Females
1.7        0     20     -33     0     0     999          # Females
1.2        0     20     -33     0     0     999          # Females
0.7        0     20     -33     0     0     999          # Females
0.0   -1.0 1.0    -7      0     0     999          # Females (beta)
#1.38403   0.5   3.7     -7     0     0     999          # Females (beta)
15.1       0     20     -33     0     0     999          # Females
14         0     20     -33     0     0     999          # Females
12.9       0     20     -33     0     0     999          # Females
11.8       0     20     -33     0     0     999          # Females
10.6       0     20     -33     0     0     999          # Females
8.7        0     20     -33     0     0     999          # Females
7.4        0     20     -33     0     0     999          # Females
6.6        0     20     -33     0     0     999          # Females
6.1        0     20     -33     0     0     999          # Females
5.6        0     20     -33     0     0     999          # Females
5.1        0     20     -33     0     0     999          # Females
4.6        0     20     -33     0     0     999          # Females
4.1        0     20     -33     0     0     999          # Females
3.6        0     20     -33     0     0     999          # Females
3.2        0     20     -33     0     0     999          # Females
2.7        0     20     -33     0     0     999          # Females
2.2        0     20     -33     0     0     999          # Females
1.7        0     20     -33     0     0     999          # Females
1.2        0     20     -33     0     0     999          # Females
0.7        0     20     -33     0     0     999          # Females
0.0   -1.0 1.0    -7      0     0     999          # Females (beta)
#1.38403   0.5   3.7     -7     0     0     999          # Females (beta)
## ------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------ ##
## MOLTING PROBABILITY CONTROLS                                      ##
##    Two lines for each parameter if split sex, one line if not     ##
## ------------------------------------------------------------------------ ##
## ival     lb     ub     phz   prior    p1     p2     # parameter    ##
## ------------------------------------------------------------------------ ##
## males and combined
  145.0386    100.    500.0    3    0   0.0   999.0     # molt_mu males
    0.053036    0.02    2.0    3    0   0.0   999.0     # molt_cv males
  145.0386    100.    500.0    3    0   0.0   999.0     # molt_mu males
    0.053036    0.02    2.0    3    0   0.0   999.0     # molt_cv males
## females
  300.0000      5.    500.0   -4    0   0.0   999.0     # molt_mu females (molt every year)
    0.01      0.001   9.0    -4    0   0.0   999.0     # molt_cv females (molt every year)
  300.0000      5.    500.0   -4    0   0.0   999.0     # molt_mu females (molt every year)
    0.01      0.001   9.0    -4    0   0.0   999.0     # molt_cv females (molt every year)
## ------------------------------------------------------------------------ ##
# The custom growth-increment matrix
# custom molt probability matrix
## ------------------------------------------------------------------------ ##
## SELECTIVITY CONTROLS                                              ##
##    Selectivity P(capture of all sizes). Each gear must have a selectivity and a    ##
##    retention selectivity. If a uniform prior is selected for a parameter then the  ##
##    lb and ub are used (p1 and p2 are ignored)                      ##
## LEGEND                                                            ##
##    sel type: 0 = parametric, 1 = coefficients (NIY), 2 = logistic, 3 = logistic95,  ##
```

```
##           4 = double normal (NIY)                              ##
##    gear index: use +ve for selectivity, -ve for retention          ##
##    sex dep: 0 for sex-independent, 1 for sex-dependent              ##
## ------------------------------------------------------------------ ##
## Gear-1   Gear-2   Gear-3   Gear-4   Gear-5   Gear-6
## PotFshry TrawlByc TCFshry  FixedGr  NMFS     BSFRF
  1      1      1      1      2      1       # selectivity periods
  1      0      1      0      1      1       # sex specific selectivity
  2      2      2      2      2      2       # male selectivity type
  2      2      2      2      2      2       # female selectivity type
  0      0      0      0      6      0   #6     # within another gear
## Gear-1   Gear-2   Gear-3   Gear-4   Gear-5   Gear-6
  2      1      1      1      1      1       # retention periods
  1      0      0      0      0      0       # sex specific retention
  2      6      6      6      6      6       # male   retention type
  6      6      6      6      6      6       # female retention type
  1      0      0      0      0      0       # male   retention flag (0 = no, 1 = yes)
  0      0      0      0      0      0       # female retention flag (0 = no, 1 = yes)

## -------------------------------------------------------------------##
## gear  par   sel                                    start  end       ##
## index index par sex  ival  lb    ub     prior   p1   p2     phz   period period     ##
## -------------------------------------------------------------------- ##
# Gear-1
  1     1    1   1    125.0000    5    190    0      1    999    4     1975   2018  #4
  1     2    2   1      8.0     0.1   20    0      1    999    4     1975   2018  #4
  1     3    1   2     84.00     5    150    0      1    999    4     1975   2018
  1     4    2   2     4.0000    0.1   20    0      1    999    4     1975   2018
# Gear-2
  2     5    1   0    165.0       5    190    0      1    999    4     1975   2018
  2     6    2   0     15.0000    0.1   25    0      1    999    4     1975   2018
# Gear-3-
  3     7    1   1    115.0       5    190    0      1    999    4     1975   2018
  3     8    2   1     15.0      0.1   25    0      1    999    4     1975   2018
  3     9    1   2     95.0       5    190    0      1    999    4     1975   2018
  3    10    2   2     2.5       0.1   25    0      1    999    4     1975   2018
# Gear-4
  4    11    1   0    115.0       5    190    0      1    999    4     1975   2018
  4    12    2   0    9.0        0.1   25    0      1    999    4     1975   2018
# Gear-5
  5    13    1   1     75.0      30   190    0      1    999    5     1975   1981  #5
  5    14    2   1      5.0       1     50    0      1    999    5     1975   1981  #5
  5    15    1   1     80.0      30   190    0      1    999    5     1982   2019  #5
  5    16    2   1     10.0       1     50    0      1    999    5     1982   2019  #5
  5    17    1   2     70.0      30   180    0      1    999    5     1975   1981  #5
  5    18    2   2      9.0       1     50    0      1    999    5     1975   1981  #5
  5    19    1   2     70.0      30   180    0      1    999    5     1982   2019  #5
  5    20    2   2     4.00      1.0    50    0      1    999    5     1982   2019  #5
# Gear-6
  6    21    1   1     75.0       1    180    0      1    999    5     1975   2019  # 5
  6    22    2   1      8.5       1     50    0      1    999    5     1975   2019  # 5
  6    23    1   2     85.0       1    180    0      1    999    5     1975   2019  # 5
  6    24    2   2     10.0       1     50    0      1    999    5     1975   2019  # 5
## ---------------------------------------------------------------------- ##
## Retained                                                      ##
## gear  par   sel                                    start  end       ##
```

```
## index index par sex  ival  lb    ub     prior   p1    p2     phz   period period      ##
## ------------------------------------------------------------------------------------ ##
# Gear-1
  -1    25    1   1    135    1    999    0      1    999    4     1975   2004
  -1    26    2   1    2.0    1     20    0      1    999    4     1975   2004
  -1    27    1   1    140    1    999    0      1    999    4     2005   2018
  -1    28    2   1    2.5    1     20    0      1    999    4     2005   2018
  -1    29    1   2    591    1    999    0      1    999   -3     1975   2003
  -1    30    1   2    591    1    999    0      1    999   -3     2004   2018
# Gear-2
  -2    31    1   0    595    1    999    0      1    999   -3     1975   2018
# Gear-3
  -3    32    1   0    595    1    999    0      1    999   -3     1975   2018
# Gear-4
  -4    33    1   0    595    1    999    0      1    999   -3     1975   2018
# Gear-5
  -5    34    1   0    590    1    999    0      1    999   -3     1975   2019
# Gear-6
  -6    35    1   0    580    1    999    0      1    999   -3     1975   2019
## ------------------------------------------------------------------------------------ ##
# Number of asyptotic parameters
1
# Fleet   Sex     Year       ival  lb   ub    phz
      1     1     1975   0.000001   0    1     -3
#     1     1     2006   0.044000   0    1     -3
#     1     1     2007   0.019700   0    1     -3
#     1     1     2008   0.019875   0    1     -3
#     1     1     2009   0.032750   0    1     -3
#     1     1     2010   0.015320   0    1     -3
#     1     1     2011   0.011250   0    1     -3
#     1     1     2012   0.024045   0    1     -3
#     1     1     2013   0.063200   0    1     -3
#     1     1     2014   0.160500   0    1     -3
#     1     1     2015   0.070950   0    1     -3
#     1     1     2016   0.082600   0    1     -3


## ------------------------------------------------------------------------------------ ##
## PRIORS FOR CATCHABILITY
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                            ##
## LEGEND                                                                               ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ------------------------------------------------------------------------------------ ##
## ival     lb       ub    phz   prior  p1       p2     Analytic?   LAMBDA Emphasis
   0.896     0        2     6    1      0.896    0.03   0           1           1
   1.0       0        5    -6    0      0.001    5.00   0           1           1   # BSFRF
## ------------------------------------------------------------------------------------ ##
## ------------------------------------------------------------------------------------ ##
## ADDITIONAL CV FOR SURVEYS/INDICES                                                    ##
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                            ##
## LEGEND                                                                               ##
##     prior type: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma          ##
## ------------------------------------------------------------------------------------ ##
```

```
## ival       lb       ub       phz   prior    p1     p2
  0.0001     0.00001   10.0     -4    4        1.0    100   # NMFS
 0.25     0.00001   10.0       9    0        0.001   1.00   # BSFRF
## ———————————————————————————————————————————————————— ##
## ———————————————————————————————————————————————————— ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ———————————————————————————————————————————————————— ##
## Mean_F   Female Offset STD_PHZ1   STD_PHZ2   PHZ_M   PHZ_F
  0.22313        0.0505     0.5      45.50      1       1   # Pot
  0.0183156        1.0      0.5      45.50      1      -1   # Trawl
  0.011109         1.0      0.5      45.50      1       1   # Tanner (-1 -5)
  0.011109         1.0      0.5      45.50      1      -1   # Fixed
  0.00             0.0     2.00      20.00     -1      -1   # NMFS trawl survey (0 catch)
  0.00             0.0     2.00      20.00     -1      -1   # BSFRF (0)
  2.95                                      # Upper bound value for male directed fishig mortality deviations
## ——————————————————————————————————————————————————— ##
## ——————————————————————————————————————————————————— ##
## OPTIONS FOR SIZE COMPOSTION DATA                                  ##
##     One column for each data matrix                           ##
## LEGEND                                                  ##
##     Likelihood: 1 = Multinomial with estimated/fixed sample size        ##
##               2 = Robust approximation to multinomial               ##
##               3 = logistic normal (NIY)                         ##
##               4 = multivariate-t (NIY)                         ##
##               5 = Dirichlet                                  ##
## AUTO TAIL COMPRESSION                                         ##
##     pmin is the cumulative proportion used in tail compression          ##
## ———————————————————————————————————————————————————— ##
#  Pot        Trawl   Tanner  Fixed   NMFS    BSFRF
  2  2  2  2  2  2  2  2  2  2  2  2  2  # Type of likelihood
  0  0  0  0  0  0  0  0  0  0  0  0  0  # Auto tail compression (pmin)
  1  1  1  1  1  1  1  1  1  1  1  1  1  # Initial value for effective sample size multiplier
 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4 -4  # Phz for estimating effective sample size (if appl.)
  1  2  3  4  4  5  5  6  6  7  7  8  8  # Composition aggregator
  1  1  1  1  1  1  1  1  1  1  1  1  1  # LAMBDA
  1  1  1  1  1  1  1  1  1  1  1  1  1  # Emphasis AEP
## ———————————————————————————————————————————————— ##
## ——————————————————————————————————————————————— ##
## TIME VARYING NATURAL MORTALIIY RATES                              ##
## LEGEND                                                  ##
## Type: 0 = constant natural mortality                            ##
##      1 = Random walk (deviates constrained by variance in M)          ##
##      2 = Cubic Spline (deviates constrained by nodes & node-placement)      ##
##      3 = Blocked changes (deviates constrained by variance at specific knots)    ##
##      4 = Time blocks                                         ##
## ———————————————————————————————————————————————— ##
## Type
6
## M is relative (YES=1; NO=0)
0
## Phase of estimation
3
## STDEV in m_dev for Random walk
0.25
## Number of nodes for cubic spline or number of step-changes for option 3
2
```

```
4
## Year position of the knots (vector must be equal to the number of nodes)
1980 1985
1976 1980 1985 1994
# number of breakpoints in M by size
0
## Specific initial values for the natural mortality devs (0-no, 1=yes)
1
## ——————————————————————————————————————— ##
## ival       lb       ub       phz   extra    prior    p1     p2       # parameter     ##
## ——————————————————————————————————————— ##
 1.5342575      0        2         8      0
 0.000000     -2         2       -99      0
 0.262792      0         2         8      0
 1.780586      0         2         8      0
 9.262792      0         2         8     -3
 0.000000     -2         2       -99      0
## ——————————————————————————————————————— ##
## ——————————————————————————————————————— ##
## OTHER CONTROLS
## ——————————————————————————————————————— ##
1975      # First rec_dev
2018      # last rec_dev
   2       # Estimated rec_dev phase
  -3       # Estimated rec_ini phase
   1       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func; 3 diagnostics)
   3       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters, 3 = Free parameters (revised))
   1       # Lambda (proportion of mature male biomass for SPR reference points).
   0       # Stock-Recruit-Relationship (0 = none, 1 = Beverton-Holt)
   10      # Maximum phase (stop the estimation after this phase).
   -1      # Maximum number of function calls

## ——————————————————————————————————————— ##
## EMPHASIS FACTORS (CATCH)
## ——————————————————————————————————————— ##
#Ret_male Disc_male Disc_female Disc_trawl Disc_Tanner_male Disc_Tanner_female Disc_fixed
      1        1          1         1              1                1         1
## ——————————————————————————————————————— ##
## EMPHASIS FACTORS (Priors)
## ——————————————————————————————————————— ##
# Log_fdevs   meanF      Mdevs  Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio
     10000        0          1.0            2             0             0                  1
## EOF
9999
```