Aleutian Islands Golden King Crab Stock Assessment

May 2021 Crab SAFE REPORT

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Executive Summary

1. *Stock*

   Golden king crab, *Lithodes aequispinus,* Aleutian Islands, east of 174° W longitude (EAG) and west of 174° W longitude (WAG).

2. *Catches*

   The Aleutian Islands golden king crab (AIGKC) commercial fishery has been prosecuted every year since 1981/82. Retained catch peaked in 1986/87 at 2,686 t (5,922,425 lb) and 3,999 t (8,816,319 lb), respectively, for EAG and WAG, but the retained catch dropped sharply from 1989/90 to 1990/91. The fishery has been managed separately east (EAG) and west (WAG) of 174° W longitude since 1996/97, and Guideline Harvest Levels (GHLs) of 1,452 t (3,200,000 lb) for EAG and 1,225 t (2,700,000 lb) for WAG were introduced into management. The GHL was subsequently reduced to 1,361 t (3,000,000 lb) beginning in 1998/99 for EAG. The reduced harvest levels remained at 1,361 t (3,000,000 lb) for EAG and 1,225t (2,700,000 lb) for WAG through 2007/08, but were increased to 1,429 t (3,150,000 lb) for EAG and 1,294 t (2,835,000 lb) for WAG beginning with the 2008/09 fishing season following an Alaska Board of Fisheries (BOF) decision. The management specification changed from GHL to TAC (Total Allowable Catch) with adoption of the Crab Rationalization Program in 2005/06 (NPFMC 2007b). The TACs were increased by another BOF decision to 1,501 t (3,310,000 lb) for EAG and 1,352 t (2,980,000 lb) for WAG beginning with the 2012/13 fishing season. The below par fishery performance in WAG in 2014/15 and 2015/16 lead to reduction in TAC to 1,014 t (2,235,000 lb), which reflected a 25% reduction in the TAC for WAG, while the TAC for EAG was kept at the same level, 1,501 t (3,310,000 lb) for the 2016/17 through 2017/18 fishing seasons. With the improved fishery performance and stock status in 2017/18, the TACs were further increased to 1,134 t (2,500,000 lb) for WAG and 1,749 t (3,856,000 lb) for EAG beginning with the 2018/19 fishing season. With the implementation of a revised state harvest strategy in 2019, the TACs were further increased to 1,302 t (2,870,000 lb) for WAG and 1,955 t (4,310,000 lb) for EAG. Based on the model estimated abundances, the 2020/21 fishing season TACs were adjusted to 1,343 t (2,960,000 lb) for WAG and 1,656 t (3,650,000 lb) for EAG. The 2021/22 fishing season TACs were adjusted to 1,052 t (2,320,000 lb) for WAG and 1,637 t (3,610,000 lb) for EAG.

Catches have been regularly under the GHL/TAC and the fishery has harvested close to allowable levels since 1996/97. These TAC levels were set below the ABCs determined under Tier 5 criteria (considering 1991–1995 mean catch for the whole Aleutian Islands region, 3,145 t (6,933,822 lb), as the catch limit) under the most recent crab management plan. A new harvest strategy based on model estimated mature male abundance was accepted by the BOF in March 2019, specifying a 15% maximum harvest rate for EAG and 20% maximum harvest rate for WAG, and implemented during the 2019/20 fishery. In addition to the retained catch allotted as TAC, there was retained catch in a cost-recovery fishery towards a $300,000 goal in 2013/14 and 2014/15 to fund an onboard observer program, and towards a $500,000 goal in 2015/16 to 2020/21 to fund an onboard observer program and stock survey.

Total mortality of Aleutian Islands golden king crab includes retained catch in the directed and the cost recovery fisheries, mortality of discarded catch, and bycatch in fixed-gear and trawl groundfish fisheries, though bycatch in other fisheries is low compared to mortality in the directed fishery. Total retained catch in the post-rationalized fishery (2005/06–2020/21) has ranged from 2,387 t (5,262,000 lb) to 3,319 t (7,316,853 lb). Total mortality ranged from 2,506 t (5,525,000 lb) to 3,733 t (8,230,000 lb) for the same period. Total retained catch in 2020/21 was 3,000 t (6,613,953 lb): 1,733 t (3,821,118 lb) from the EAG fishery (which included cost-recovery catch), and 1,267 t (2,792,835 lb) from the WAG fishery. Discarded (non-retained) catch occurs mainly during the directed fishery. Although low levels of discarded catch can occur during other crab fisheries, there have been no such fisheries prosecuted locally since 2004/05, except as surveys for red king crab conducted under an Alaska Department of Fish and Game (ADF&G) Commissioner's Permit (and no golden king crab were caught during the cooperative red king crab survey performed by industry and ADF&G in the Adak area in September 2015; Hilsinger *et al.* 2016). Estimates of the bycatch mortality during crab fisheries decreased during 1995/96–2005/06, both in absolute value and relative to the retained catch weight and stabilized during 2005/06–2014/15. Total estimated bycatch mortality during crab fisheries in 2020/21 was 241 t (531,000 lb) for EAG and 147 t (323,302 lb) for WAG. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries but is small relative to the directed fishery. Groundfish fisheries are a minor contributor to total fishery discard mortality, 40 t (88,000 lb) for EAG and 17 t (37,000 lb) for WAG in 2020/21.

Catch per unit effort (CPUE, i.e., catch per pot lift) of retained legal males decreased from the 1980s into the mid-1990s, but increased after 1994/95, particularly with the initiation of the Crab Rationalization Program in 2005/06. Although CPUE for the two areas showed similar trends through 2010/11, during 2011/12–2014/15 CPUE trends have diverged (increasing for EAG and decreasing for WAG).

A cooperative golden king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G in the EAG and WAG (beginning in August 2018) fisheries, by vessels that were commercial fishing (i.e., each vessel fishing an allotted share of total allowable catch). The cooperative survey was not conducted in 2020/21 due to COVID-19. For catch accounting, it was assumed that bycatch mortality that occurred during any survey was accounted for by reported discards for the season's fishery.

3. *Stock biomass*

Estimated mature male biomass (MMB) for EAG under all scenarios decreased from the 1980s to the 1990s, then increased during the 2000s and systematically increased since 2014. Estimated MMB for WAG decreased during the late 1980s and 1990s, increased during the 2000s, decreased for several years since 2009 and has increased since 2014. The low levels of MMB for EAG were observed in 1995–1997 and in 1990s for WAG. Stock trends reflected the fishery standardized CPUE trends in both regions.

4. *Recruitment*

The numbers of recruits to the model size groups under all scenarios have fluctuated in both EAG and WAG. For EAG, model recruitment was high during 2017–2019, highest in 2018; and lowest in 1986. The model recruitment for WAG was high during 1984 to 1986, highest in 1985, and lowest in 2011. A slightly increasing trend in recruitment was observed since 2011 in WAG.

5. *Management performance*

The size-based assessment model was accepted at the September 2016 CPT and October 2016 SSC meetings for OFL determination for the 2017/18 fishery cycle. In addition, the CPT in January 2017 and SSC in February 2017 recommended using the Tier 3 method to compute OFL and ABC. The assessment model was first used for setting OFL and ABC for the 2017/18 fishing season. The CPT in May 2017 and SSC in June 2017 accepted the authors' recommendation of using scenario 9 (i.e., model using the knife-edge maturity to determine MMB) for OFL and ABC calculation. During the May 2017 meeting, the CPT noted that a single OFL and ABC are defined for Aleutian Islands golden king crab (AIGKC), however; separate models are available by area. Hence, following previous assessments, OFLs and ABCs by area were summed to calculate OFL and ABC for the entire stock.

The first two status and catch specification tables provide fishery and reference point estimates for completed fisheries except for the 2020/21 season. The rest of the executive summary tables and subsequent assessment results were derived from analysis of the previous season's completed fishery data. For the 2020/21 season, retained and total catch information was updated for the completed fishery; however, reference points and MMB projection were calculated by the approved model, 21.1a, with incomplete fishery data at the time of May CPT meeting. We recommended any one from three models for EAG and WAG: model 21.1a (selection of a fixed period, 1987–2017, for mean number of recruit calculation for reference points estimation; and standardization of observer and fishery CPUE by the negative binomial generalized linear model); model 21.1b (same as 21.1a but consideration of three total selectivity periods to reduce retrospective pattern in EAG); and 21.1c (same as 21.1a but consideration of year and area interaction factor for observer CPUE standardization).

We also proposed variants of the above three models: 21.1a1, 21.1b1, and 21.1c1 [knife-edge maturity size increased by one size bin to 116 mm carapace length for mature male biomass (MMB) estimation].

Model 19.1 is the base model (accepted model 19.1 in 2019) with the knife-edge male maturity at 111 mm CL, an M of 0.21yr^{-1}, selection of a fixed period, 1987–2012, for mean number of recruit calculation for reference points estimation; and addition of up to 2020/21 data. Models

21.1a, 21.1b, and 21.1c are modifications from the base model. We do not recommend selecting the base model 19.1 because different fixed period was considered for the mean recruit calculation.

The total catch, 3,444 t, at the end of 2020/21 fishing season did not exceed OFL, 4,798 t, in 2020/21; therefore, overfishing did not occur. The mature male biomass, 15,442 t, is above MSST, 6,014 t, in 2020/21; hence, the stock was not overfished.

Status and catch specifications (1000 t) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2019/20	5.915	16.386	3.257	3.319	3.735	5.249	3.937
2020/21	6.026[c]	16.207[c]	2.999	3.000	3.444	4.798	3.599
2021/22		14.816[c]				4.817[d]	3.372[d,e]

Status and catch specifications (million lb) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2019/20	13.041	36.124	7.180	7.317	8.234	11.572	8.679
2020/21	13.284[c]	35.730[c]	6.610	6.614	7.593	10.579	7.934
2021/22		32.662[c]				10.620[d]	7.434[d,e]

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. 25% buffer was applied to total catch OFL to determine ABC.
c. Accepted model 21.1a with incomplete fisheries data from WAG was used to estimate MSST, MMB, and 2021/22 MMB projection.
d. OFL and ABC were estimated in May 2021 assessment when the WAG fishery was not completed.
e. 30% buffer was applied to total catch OFL to determine ABC for the 2021/22 fishing season after SSC/Council's recommendation.

6. *Basis for the OFL*
   The length-based model developed for the Tier 3 analysis estimated mature male biomass (MMB) on February 15 each year for the period 1961 through 2021. The terminal year mature male biomass was projected by an additional year to determine OFL and ABC for the

2021/22 season. The Tier 3 approach uses a constant annual natural mortality (M), knife-edge maturity size/maturity curve, and the mean number of recruits for different time periods for OFL and ABC calculation. Previously derived M of 0.21 yr^{-1} from the combined data from the EAG and WAG data was used (Siddeek *et al.* 2018).

We provided OFL and ABC estimates for EAG and WAG separately and combined (i.e., for the entire Aleutian Islands; AI) from seven models, 19.1, 21.1a, 21.1b, and 21.1c (CPT/SSC suggested models); and 21.1a1, 21.1b1, and 21.1c1 for EAG, WAG, and AI in the following six tables. The stock statuses of all models were above MMB$_{35\%}$ (i.e., they were in Tier 3a) except the WAG model, 21.1c1, which was in Tier 3b. Therefore, the two regions' OFL and ABC were combined to get the total OFL and ABC for AI for all models except model 21.1c1.

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2022.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
EAG19.1	3a	14.761	19.325	1.31	0.61	1987–2012	0.61	6.496	6.459	4.872
EAG21.1a	3a	14.908	19.315	1.30	0.61	1987–2017	0.61	6.492	6.454	4.869
EAG21.1b	3a	14.657	1.7051	1.16	0.56	1987–2017	0.56	5.573	5.544	4.180
EAG21.1c	3a	14.889	19.151	1.29	0.61	1987–2017	0.61	6.431	6.399	4.823
EAG21.1a1	3a	14.354	18.606	1.30	0.55	1987–2017	0.55	5.979	5.944	4.484
EAG21.1b1	3a	14.201	16.336	1.15	0.50	1987–2017	0.50	5.089	5.063	3.817
EAG21.1c1	3a	14.465	18.519	1.28	0.54	1987–2017	0.54	5.836	5.807	4.377

Biomass, total OFL, and ABC for the next fishing season in 1000 t.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to Define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
EAG19.1	3a	6.69570	8.76585	1.31	0.61	1987–2012	0.61	2.946624	2.929637	2.209968
EAG21.1a	3a	6.7620	8.76118	1.30	0.61	1987–2017	0.61	2.944538	2.927552	2.208404
EAG21.1b	3a	6.64858	7.73415	1.16	0.56	1987–2017	0.56	2.527920	2.514936	1.895940
EAG21.1c	3a	6.7537	8.68665	1.29	0.61	1987–2017	0.61	2.917000	2.902360	2.187750
EAG21.1a1	3a	6.51095	8.43984	1.30	0.55	1987–2017	0.55	2.712089	2.696246	2.034067
EAG21.1b1	3a	6.44159	7.41012	1.15	0.50	1987–2017	0.50	2.308484	2.296511	1.731363
EAG21.1c1	3a	6.56116	8.40001	1.28	0.54	1987–2017	0.54	2.647321	2.634150	1.985491

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WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2022.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to Define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
WAG19.1	3a	11.685	12.336	1.06	0.57	1987–2012	0.57	3.494	3.480	2.620
WAG21.1a	3a	11.611	12.334	1.06	0.57	1987–2017	0.57	3.493	3.479	2.620
WAG21.1b	3a	11.611	12.538	1.08	0.57	1987–2017	0.57	3.524	3.510	2.643
WAG21.1c	3a	11.552	11.620	1.01	0.57	1987–2017	0.57	3.183	3.169	2.387
WAG21.1a1	3a	11.186	11.538	1.03	0.51	1987–2017	0.51	3.196	3.184	2.397
WAG21.1b1	3a	11.183	11.736	1.05	0.51	1987–2017	0.51	3.225	3.212	2.419
WAG21.1c1	3b	11.128	10.870	0.98	0.50	1987–2017	0.50	2.851	2.832	2.139

Biomass, total OFL and ABC for the next fishing season in 1000 t.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB / $MMB_{35\%}$	F_{OFL}	Recruitment Years to Define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
WAG19.1	3a	5.30021	5.59535	1.06	0.57	1987–2012	0.57	1.584739	1.578645	1.188554
WAG21.1a	3a	5.26657	5.59452	1.06	0.57	1987–2017	0.57	1.584342	1.578249	1.188257
WAG21.1b	3a	5.26651	5.68742	1.08	0.57	1987–2017	0.57	1.598415	1.591923	1.198812
WAG21.1c	3a	5.23987	5.27077	1.01	0.57	1987–2017	0.57	1.443667	1.437604	1.082751
WAG21.1a1	3a	5.0738	5.23351	1.03	0.51	1987–2017	0.51	1.449703	1.444151	1.087277
WAG21.1b1	3a	5.0726	5.32328	1.05	0.51	1987–2017	0.51	1.462895	1.456829	1.097171
WAG21.1c1	3b	5.04779	4.93078	0.98	0.50	1987–2017	0.50	1.293398	1.284589	0.970049

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in millions of pounds.

Model	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
19.1	9.990	9.939	7.492
21.1a	9.985	9.933	7.489
21.1b	9.097	9.054	6.823
21.1c	9.614	9.568	7.210
21.1a1	9.175	9.128	6.881
21.1b1	8.314	8.275	6.236

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in 1000 t.

Model	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
19.1	4.531	4.508	3.399
21.1a	4.529	4.506	3.397
21.1b	4.126	4.107	3.095
21.1c	4.361	4.340	3.271
21.1a1	4.162	4.140	3.121
21.1b1	3.771	3.753	2.829

7. Probability density functions of the OFL

Assuming a lognormal distribution of total OFL, we determined the cumulative distributions of OFL and selected the median as the OFL.

8. Basis for the ABC recommendation

> A x proportion buffer on the OFL; i.e., ABC = (1.0 - x) *OFL. The CPT recommended x = 0.25 but the SSC/Council recommended x = 0.3 for the 2021/22 season.

Please see also the section G on ABC.

9. A summary of the results of any rebuilding analysis:
   Not applicable.

A. Summary of Major Changes

1. *Changes (if any) to management of the fishery*
   - None.

2. *Changes to input data*
   - Commercial fisheries data were updated with values from the most recent observer and fish ticket data for 2020/21: retained catch for the directed fishery and discarded catch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries. Thus, the time series of data used in the model are retained catch (1981/82–2020/21), total catch (1990/91–2020/21), and groundfish bycatch (1989/90–2020/21) biomass and size compositions.
   - We detected some errors in preparing observer and fish ticket size composition data for 2016–2019 and rectified them in the current assessment.
   - Fish ticket retained CPUE were standardized by the generalized linear model (GLM) with the negative binomial link function for the 1985/86–1998/98 period.
   - Observer pot sample legal size crab CPUE data were standardized by the GLM with the negative binomial link function with variable selection by CAIC (modified AIC) followed by R square criterion, separately for 1995/96–2004/05 and 2005/06–2020/21 periods. A Year and Area interaction factor was considered in one model (21.1c) to estimate a set of CPUE indices. The habitat areas were determined from observer historical pot locations as fishing footprints (Appendix B).

3. *Changes to assessment methodology*
   None.

4. *Changes to assessment results*
   As expected, the addition of the 2020/21 data changed the OFL and ABC estimates, but changes in parameter or abundance estimates were not dramatic.

B. *Response to January 2021 CPT comments*

Comment#1: The current GMACS model has some unexpected behavior (e.g., an inability to fit the catch data and unrealistically good fits to the CPUE data) so is not viable for adoption. However, progress on a GMACS-based assessment should be included as an appendix to the assessment report.

Response: We continue to work with the GMACS *group to tailor the base model to implement EAG 19.1 model. We try to mimic the status quo model (relabeled as 19.1A) results with* GMACS *output. Once this is satisfactorily matched, we will be ready to apply* GMACS *on EAG and WAG assessment.*

Comparison of CPUE trends by EAG19.1A with GMACS *run#10AUpdate (most parameters were fixed to modified EAG19.1A estimated parameter values and* GMACS *employing the same formula as that of the status quo model for CPUE calculation) is depicted in the following figure (Figure CPT1).*

The GMACS *ctl, dat, and prj files for EAG 19.1 are included in Appendix F.*
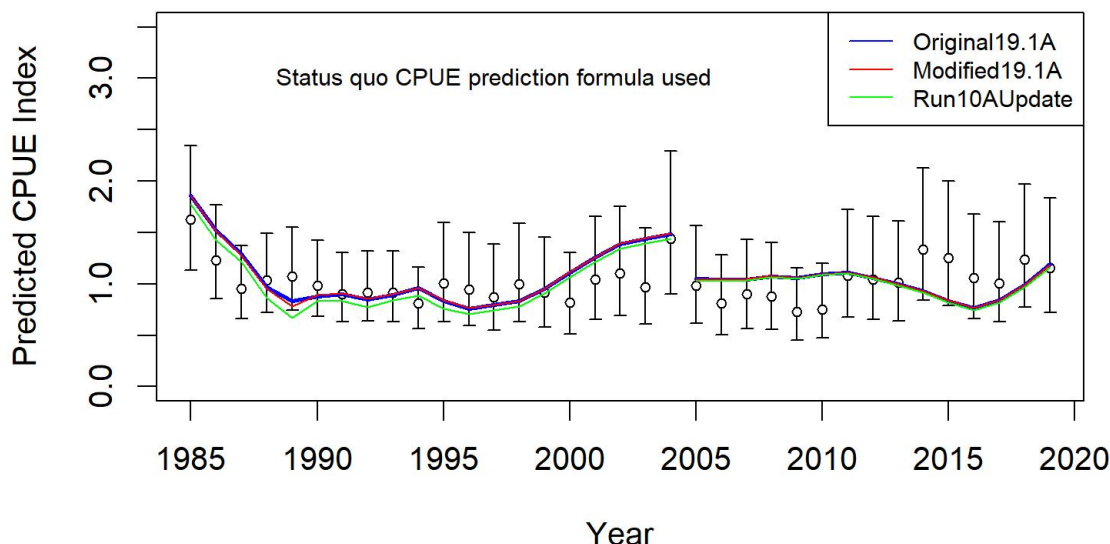
Figure CPT1. Comparison of input CPUE indices (open circles with +/- 2 SE for model 19.1A) with predicted CPUE indices (colored solid lines) under original model 19.1A, modified 19.1A to satisfy GMACS coding procedure, and GMACS Run#10AUpdate (most parameters were fixed to modified 19.1A model output) for EAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.

Comment# 2: During the January 2021 CPT meeting, authors presented the following model scenarios that include cooperative survey data: 19.1d: model 21.1a, but with the EAG cooperative survey CPUE indices for 2015–2019; 19.1e, as for 19.1d, but using the fish ticket CPUE data for the entire period. Model 19.1d had cooperative survey and CPUE data for same years (which could lead to double use of some data) and model 19.1e made no use of the observer CPUE data, even though these data are preferable to the fish ticket CPUE data. The CPT recommends that the results of an exploratory model in which model 21.1a is modified to use the EAG cooperative survey data, and the observer CPUE data from 2015 are ignored, be provided in an appendix to the assessment report. This model could be considered for use in the 2022 assessment.

Response: We provided results of an exploratory model (21.1d) in Appendix C in which model 21.1a was modified to use the EAG cooperative survey data for 2015–19, and the observer CPUE data from 2015–2019 were ignored.

Comment#3: The CPT was unclear why a predicted CPUE from the CPUE standardization with Year:Area interaction could be negative. Also, the formulae used to compute the variances for years*areas with no data should be provided and a bias correction factor should be applied to Equation A.15.

$$\widehat{B_{i,j}} = e^{A_i + C_j} \qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{A.15}$$

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Response: We provided the clarification and formula to compute the standard deviations (hence variances) for years*areas with no data *in Appendix B.*

Comment#4: The analysts should consider a range of alternative standardization models for the EAG cooperative survey data (including that suggested by the SSC) and provide a rationale (including model fit, whether the analysis converged, etc.) for the selected model.

Response: We provided a few alternative standardization models for EAG cooperative survey data and provided the rationale for the selected model in Appendix C. The limitations on time series of data and factor levels (for example, only a maximum of three vessels operate in EAG) prevent us exploring variants of the simple random slope model.

Comment# 5: The assessment should more clearly provide the rationale for separate EAG and WAG assessments, including consideration of differences in trends in CPUE and age-compositions between the EAG and the WAG.

Response: We provided a few reasons in the January 2021 CPT document. We added more reasons to justify separate stock assessments in the two regions in our response to February 2021 SSC comment#4.

Comment# 6: Model results should be presented only for the best fit (lowest objective function). If a best fit model exhibits unusual features (e.g., outlying *F* estimates or parameters on bounds), this can often be rectified by implementing bounds or smoothing penalties on some of the parameters.

Response: We detected some errors in input observer and fish ticket size measurement data for 2016–2019 and rectified them. This surprisingly eliminated multiple minima issues found earlier when jittering WAG parameter estimates.

Comment# 7: The runs used to create the retrospective plots should be checked as one run (1994 for WAG) appears to be a case where the minimizer has failed to converge.

Response: The minimizer did not fail in the retrospective run. The 1994 MMB jump was the result of an increase in total catch removal in the model (Figure CPT2):
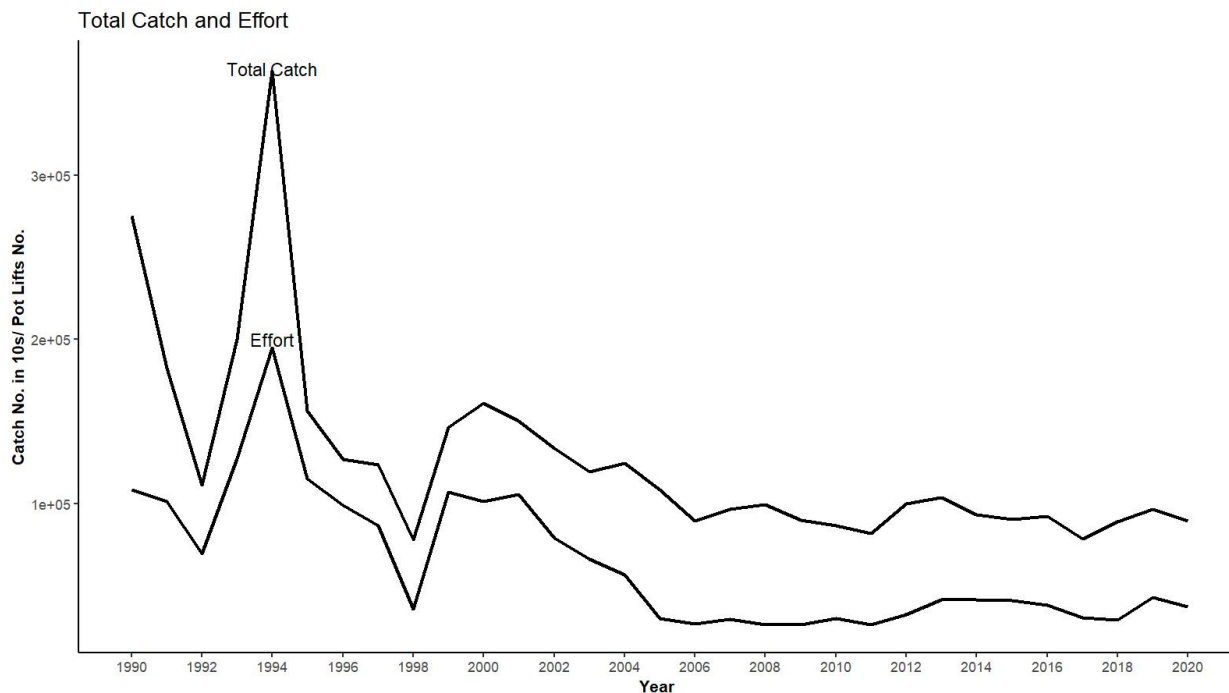
Figure CPT2. Estimated total catch (in 10s of crab) to the model size range (101 to 185+ mm CL) and effort (pot lifts) by year in WAG.

Comment # 8: Additional suggestions related to presentation:

a. Add the historical TACs to the plot of catches and CPUEs.

> *Response: done (Figure 6 in the main text).*

b. When plotting MMB, the x-axis value should be the second of the two years (e.g., the MMB for 2019/20 should be plotted against 2020, not 2019).

> *Response: done. Please see an example plot in Figure CPT3. We used the same procedure in constructing other plots.*
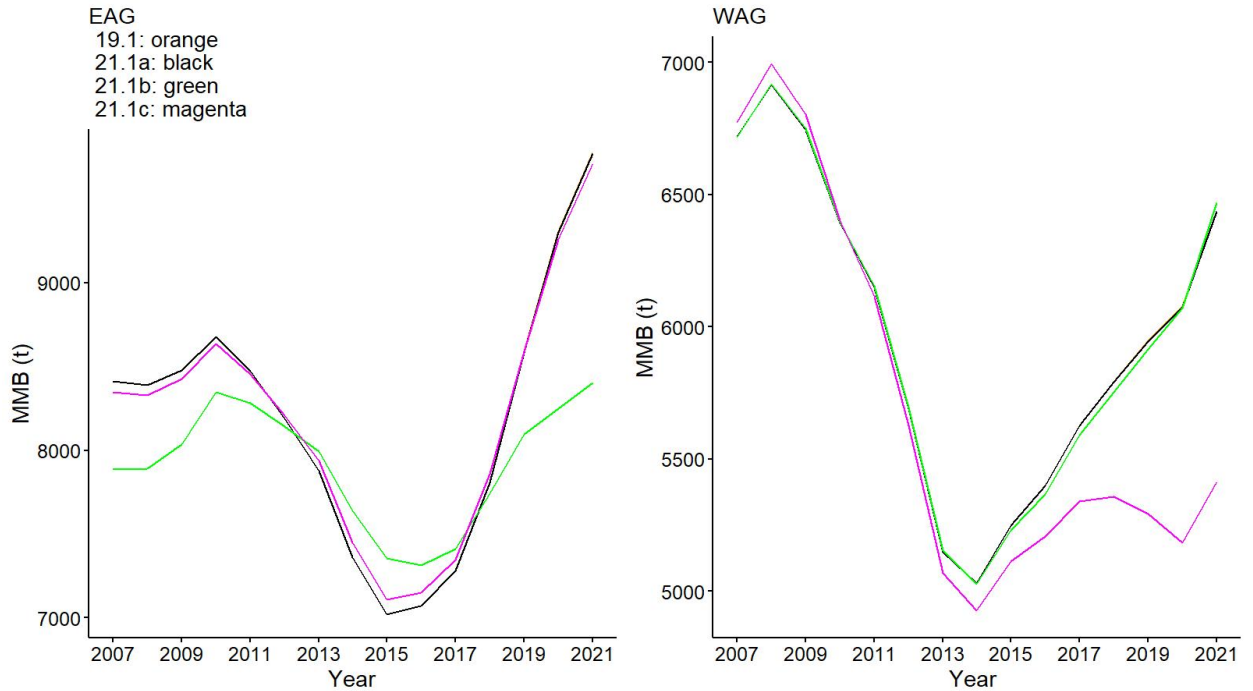
Figure CPT3. Trends in golden king crab mature male biomass for models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG (left) and WAG (right) data, 2007–2021. Year 2021 refers to 2020/21 fishing season.

c. Provide a figure that shows the size composition data for the fleet with time-varying selectivity in a vertical manner (e.g., Figure 12 in the snow crab assessment) to see changes in the data over time. This can be done using the R package ggridges.

   Response: done (Figures 9 to 11 for EAG and 27 to 29 for WAG in the main text).

d. Additionally, a plot that shows the fits to the aggregate size-composition data would be useful.

   Response: done (Figure CPT4). Cumulative size compositions of retained catch fitted well for all models but total catch fits slightly differ.
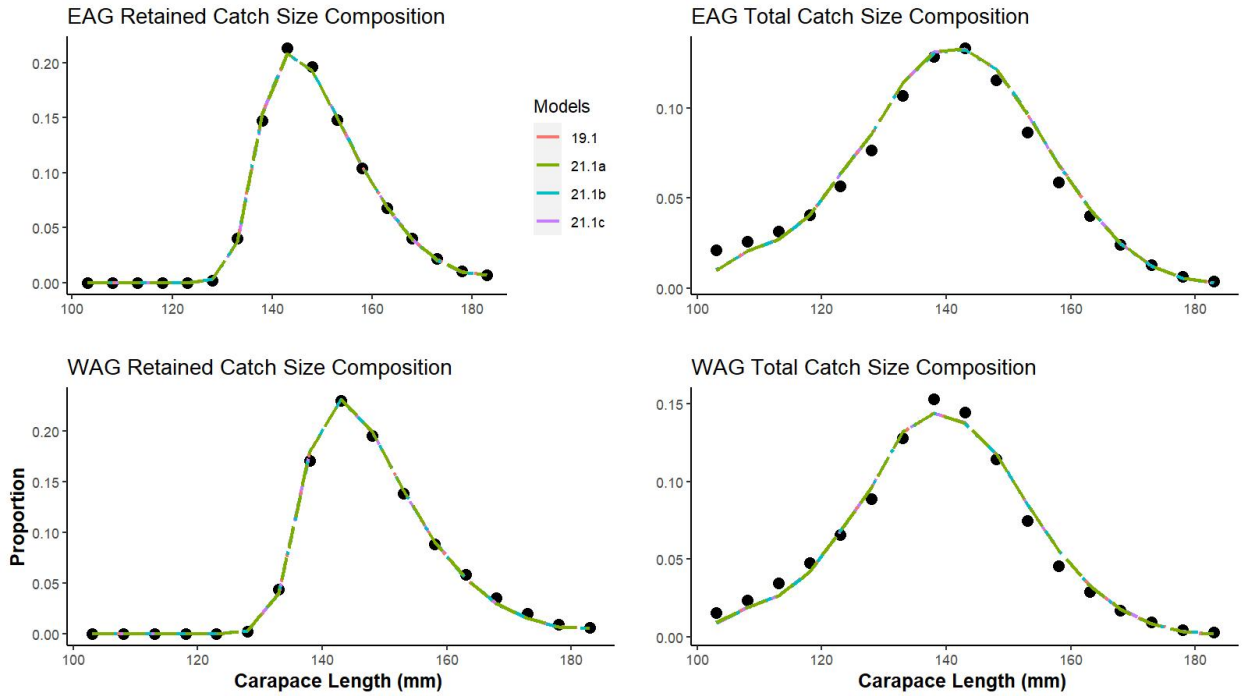
Figure CPT4. Cumulative size compositions vs carapace length for retained catch (left panels) and total catch (right panels) for EAG (top) and WAG (bottom). Observed proportions are marked by solid circles and predicted proportions by different models' (19.1, 21.1a, 21.1b, and 21.1c) are shown by different colored lines.

e. Include plots of the estimates of the smoothing functions (soak for the observer CPUE; depth and soak for the cooperative survey data) when conducting the CPUE and survey standardizations to check that these behave sensibly.

Response: We have addressed the soak time and depth effects on CPUE in the next section (f). We have not addressed the smoothing functions output because of time limitation. We will address this in the next run.

f. Also plot the data on CPUE vs. depth and CPUE vs. soak time to allow the underlying patterns to be identified.

Response: done. We plotted annual observer nominal legal male CPUE against annual mean soak time and annual mean depth (Figure CPT5). Soak time appears to positively influence CPUE (adjusted R square for EAG and WAG: 0.81); but not depth (adjusted R square for EAG: -0.02, WAG: 0.25). Please note that their effects were already modelled in CPUE standardization.
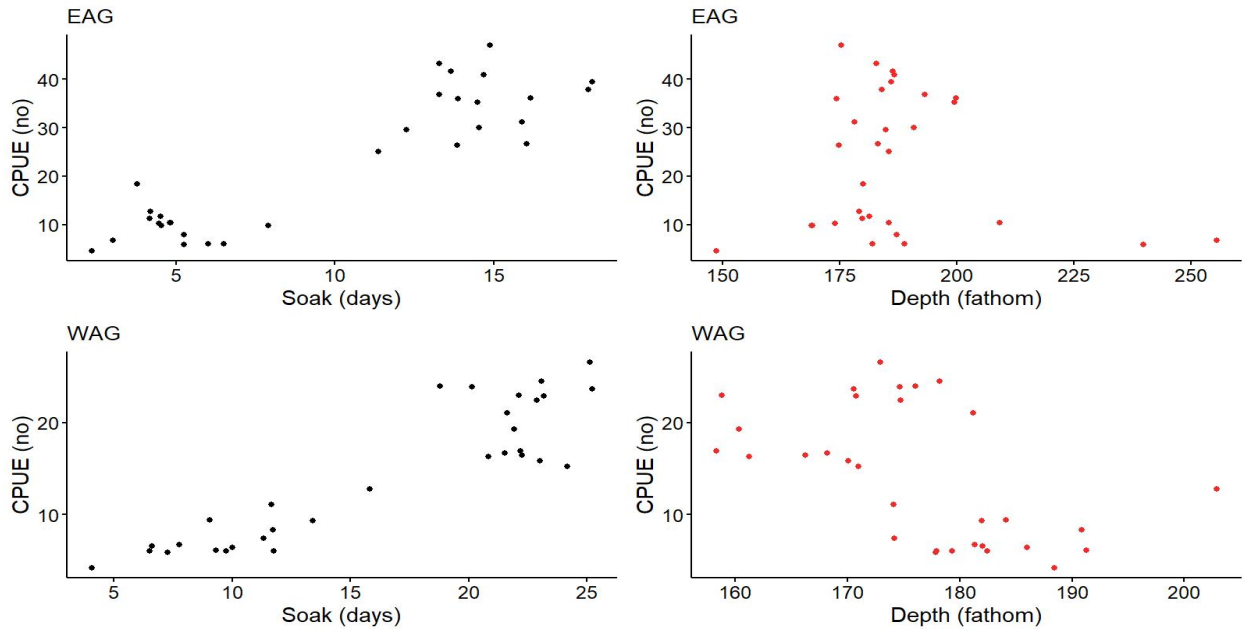
14

Figure CPT5. Annual observer nominal legal male CPUE vs annual mean soak time and annual mean depth in EAG (top) and WAG (bottom).

Response to one of June 2020 SSC comments:

Comment 4: The SSC recommends that, if this approach [i.e., 0.7 Sigma approach] were used, the CV would be a better choice. This is because the standard deviations of high recruitments with the same CV might be higher than a cutoff and would result in reference points that are biased lower. The SSC also recommends exploring choosing a reasonable lag from the current year that would include most crabs that have recruited into the fishery. For example, if most crabs are observed by age 6, the 2020 assessment would use recruitments from 1987–2014, and the 2021 assessment would use 1987– 2015, and so on.

Response: We did not adequately address the above comment earlier. We try to address the points below.

First point: Considering CV instead of standard deviation of rec_dev provided mixed results for choosing an appropriate year range for different levels of CV (e.g., CV 100%: 1985–2011; CV 125%: 1984–2013; and CV 150%: 1984–2016). Furthermore, years in the selected ranges were non-contiguous. We provide the case for 150% CV cutoff level below (Figure SSC1). Although CV standardizes different magnitudes of variability for a comparison, they appeared to be not useful here.

Second point: The fixed period 1987–2012 for mean number of recruit calculation used in the base model 19.1 considers an 8-year time lag from the terminal year, which appears to be the recruitment age for golden king crab. However, it is necessary to locate cut off points on both ends of the time range to choose an appropriate fixed period for mean recruit calculation. The method used in our selection process takes care of this.
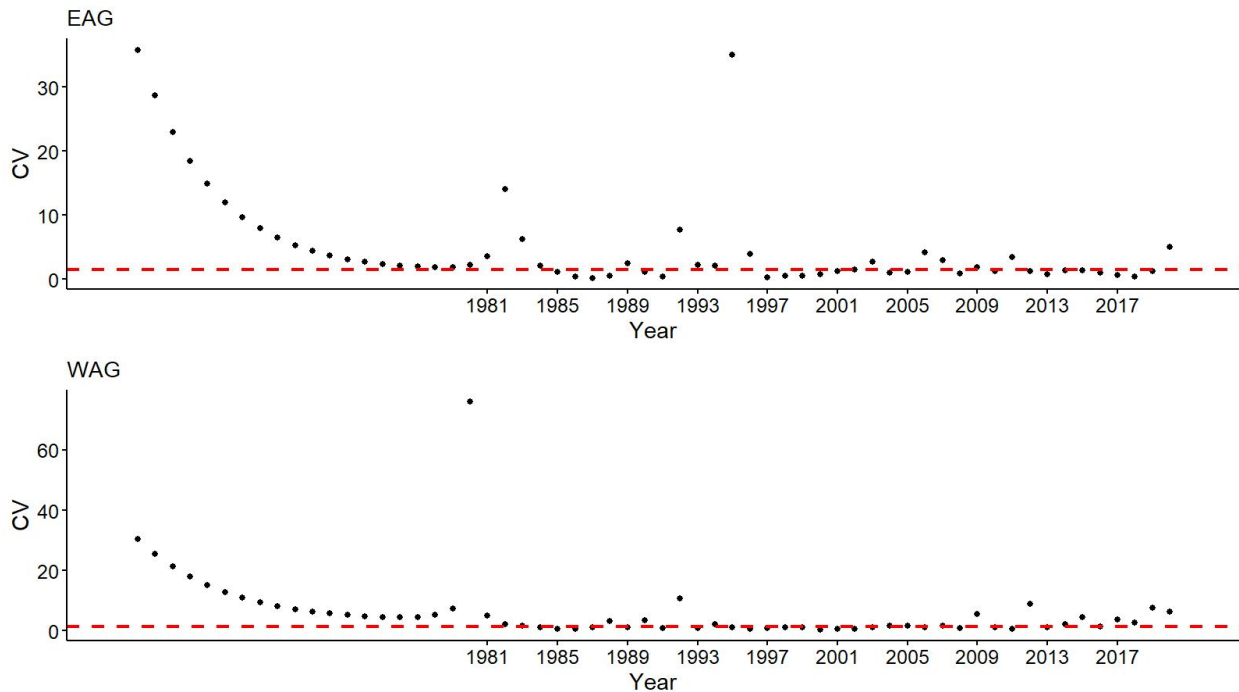
15

Figure SSC1. Coefficient of variation (CV) of recruit_dev vs. year for EAG (top) and WAG (bottom) for model 21.1a. The 1981–2020 marked years have input information for model fitting.

Response to February 2021 SSC comments

Comment#1: With respect to Model 21.1b (Same structure and data inputs as M21.1a, but with three-time blocks for selectivity (1960–2004, 2005–2015, and 2016+), the SSC agrees that justification will need to be provided as to why allowing time-varying selectivity based on these time blocks is appropriate, relative to other time-varying parameterizations.

Response: The first block, 1960–2004, pertains to the pre-rationalization period, which was the feature of all models. In the new model scenario (21.1b), the post-rationalization period was divided into two, 2005–2015 and 2016+, to create two selectivity blocks based on observed different fishing patterns (total size distribution shifted to small size groups, please see reduced proportions in large size groups in Figure SSC2) between the two post-rationalization periods in EAG. The visualization of shift is clear in Figures 10a, b, and c in the main text. This pattern was not seen in WAG though. A three-selectivity-block design was created specifically to reduce the retrospective pattern in MMB in EAG (please see the reduction in Mohn rho value for model 21.1b in EAG in Figure 23). Although several other factors separately or in combination may contribute to retrospective patterns (e.g., change in growth, change in catchability, etc.), change in selectivity was the most easily explained by data available.
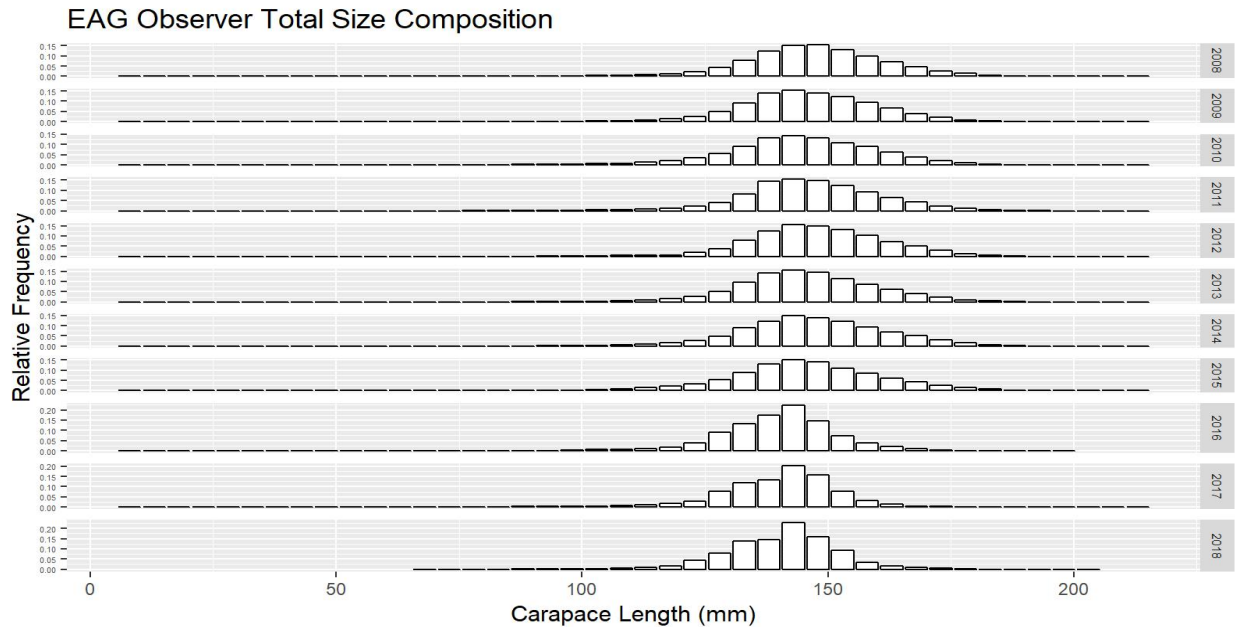
16

Figure SSC2. Observer total size composition for 2008–2018 in the EAG.

Comment#2: The SSC supports continued efforts to recreate existing operational model structures and explore novel structures, within the standardized GMACS platform.

Response: We continue effort to implement golden king crab stock assessment models in GMACS. Appendix F provides preliminary comparison of our model results with GMACS results for EAG19.1. Please see our response to CPT comment#1 as well.

Comment#3: An exploratory model in which M21.1a ignores 2015– observer CPUE data but incorporates estimates from the cooperative survey for EAG. The SSC encourages exploration of whether overlapping these indices may help in estimating catchability.

Response: We explored this issue but did not observe much difference in the post-rationalization catchability estimates.

Comment#4: The SSC would also like to reiterate its support for several previous suggestions:

a. Exploration of a single-area model, or possibly a two-area model with larval connectivity, for the AIGKC crab stock.

Response: We expanded the list of justifications that were presented at the January 2021 CPT and February 2021 SSC meetings, for assessing EAG and WAG separately below:

We modelled EAG and WAG stocks separately for several reasons:
(a) Fishery catch data (e.g., CPUE magnitude and CPUE temporal trends) suggest that the productivity is different between the two areas.

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(b) WAG has wider area of stock distribution compared to limited area distribution in EAG.

(c) The fishing areas are spatially separated with an area gap between EAG and WAG (Figure 8 in the main text). Regions of low fishery catch suggest that availability of suitable habitat may vary longitudinally.

(d) Tagging studies have shown little mixing between the two areas (Watson and Gish 2002).

(e) Currents are known to be strong around the Aleutian Islands, thus larval mixing between the two regions may occur. Yet needed data to confirm larval drift trajectories or horizontal displacement are lacking. Unlike other king crabs, golden king crab females carry large, yolk-rich, eggs, which hatch into lecithotrophic (non-feeding) larvae that do not require a pelagic distribution for encountering food items. Depth at larval release, the lecithotrophic nature of larvae, and swimming inactivity in lab studies implies benthic distributions, which may limit larval drift between areas if horizontal current velocities are reduced at depth.

(f) Integrating contrasting data in one single model may provide parameter estimates in between the two extremes which would not be applicable to either (Richards 1991; Schnute and Hilborn 1993).

(g) Area specific assessment is superior to a holistic approach for this stock because of patchy nature of golden king crab distribution.

h) Alaska Board of Fisheries decided to manage the two areas with separate total allowable catches.

i) Genetic analysis shows no significant differentiation between areas within the Aleutian Island population (Grant and Siddon 2018), thus there is no genetic support for subdividing this population; however, above listed factors support separate stock assessments in the two regions.

b. Evaluation of whether catches of AIGKC caught in the NMFS Aleutian Island trawl survey could be utilized as an additional index of abundance.

Response: We have not looked at the NMFS trawl data for AIGKC catches. We will explore any feasibility of including AIGKC caught in the NMFS Aleutian Island trawl survey as an additional index of abundance in the future.

c. Continued exploration of the Year:Area effect in the CPUE standardization, specifically by fitting two area models and combining the results and comparing to the Year:Area model. Diagnostic plots of the data and model predictions of time trends by area (holding all other predictors at their median or mean value) might shed light on the nature of the interaction and aid interpretation.

Response: We addressed the Year:Area effect in the CPUE standardization including some of SSC's suggestions in Appendix B. We have not made SSC suggested diagnostic plots in this report because of time limitation. We will address this in the next run.

C. Introduction

1. Scientific name:

Golden king crab, *Lithodes aequispinus* J.E. Benedict, 1895.

2. Distribution:

General distribution of golden king crab is summarized by NMFS (2004). Golden king crab, also called brown king crab, occur from the Sea of Japan to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, generally in high-relief habitat such as inter-island passes, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett *et al.* 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom.

The Aleutian Islands king crab stock boundary is defined by the boundaries of the Aleutian Islands king crab Registration Area O (Figure 1). In this chapter, "Aleutian Islands Area" means the area described by the current definition of Aleutian Islands king crab Registration Area O. Nichols *et al.* (2021) define the boundaries of Aleutian Islands king crab Registration Area O:

The Aleutian Islands king crab Registration Area O eastern boundary is the longitude of Scotch Cap Light (164°44.72'W long); the northern boundary is a line from Cape Sarichef (54°36'N lat) to 171°W long, north to 55°30'N lat; and the western boundary the United States–Russia Maritime Boundary Line of 1990.

During 1984/85–1995/96, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas, which were divided at 171° W longitude (Figure 2), but from the 1996/97 season to present the fishery has been managed using a division at 174° W longitude (Figure 1). In March 1996, the Alaska Board of Fisheries (BOF) replaced the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and directed ADF&G to manage the golden king crab fishery in the areas east and west of 174°W longitude as two distinct stocks. That re-designation of management areas was intended to reflect golden king crab stock distribution, congruent with the longitudinal pattern in fishery production prior to 1996/97 (Figure 3). The longitudinal pattern in fishery production relative to 174° W longitude since 1996/97 is like that observed prior to the change in management area definition, although there have been some changes in the longitudinal pattern in fishery production within the areas east and west of 174° W longitude (Figure 4).

Commercial fishing for golden king crab in the Aleutian Islands Area typically occurs at depths of 100–275 fathoms (183–503 m). Pots sampled by at-sea fishery observers in 2013/14 were fished at an average depth of 176 fathoms (322 m; N=499) in the area east of 174° W longitude and 158 fathoms (289 m; N=1,223) for the area west of 174° W longitude (Gaeuman 2014).

3. Evidence of stock structure:

Given the expansiveness of the Aleutian Islands Area and the existence of deep (>1,000 m) canyons between some islands, at least some weak structuring of the stock within the area would be expected. Data for making inferences on stock structure of golden king crab within the Aleutian Islands are largely limited to the geographic distribution of commercial fishery catch and effort. Catch data by statistical area from fish tickets and catch data by location from pots sampled by observers suggest that habitat for legal-sized males may be continuous throughout the waters adjacent to the islands in the Aleutian chain. However, regions of low fishery catch suggest that availability of suitable habitat, in which golden king crab are present at only low densities, may vary longitudinally. Catch has been low in the fishery in the area between 174° W longitude and 176° W longitude (the Adak Island area, Figures 3 and 4) in comparison to adjacent areas, a pattern that is consistent with low CPUE for golden king crab between 174° W longitude and 176° W longitude (Figure 5) during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys (von Szalay *et al*. 2011). In addition to longitudinal variation in density, there is also a gap in fishery catch and effort between the Petrel Bank-Petrel Spur area and the Bowers Bank area; both of those areas, which are separated by Bowers Canyon, have reported effort and catch. Recoveries during commercial fisheries of golden king crab tagged during ADF&G surveys (Blau and Pengilly 1994; Blau *et al.* 1998; Watson and Gish 2002; Watson 2004, 2007) provided no evidence of substantial movements by crab in the size classes that were tagged (males and females ≥90-mm carapace length [CL]). Maximum straight-line distance between release and recovery location of 90 golden king crab released prior to the 1991/92 fishery and recovered through the 1992/93 fishery was 61.2 km (Blau and Pengilly 1994). Of the 4,567 recoveries reported through April 12, 2016 for the male and female golden king crab tagged and released between 170.5° W longitude and 171.5° W longitude during the 1991, 1997, 2000, 2003, and 2006 ADF&G Aleutian Island golden king pot surveys, none of the 3,807 with recovery locations specified by latitude and longitude were recovered west of 173° W longitude and only fifteen were recovered west of 172° W longitude (V. Vanek, ADF&G, Kodiak, pers. comm.). Similarly, of 139 recoveries in which only the statistical area of recovery was reported, none were recovered in statistical areas west of 173° W longitude and only one was in a statistical area west of 172° W longitude.

4. **Life history characteristics relevant to management:**

There is a paucity of information on golden king crab life history characteristics due in part to the deep depth distribution (~200–1000 m) and the asynchronous nature of life history events (Otto and Cummiskey 1985; Somerton and Otto 1986). The reproductive cycle is thought to last approximately 24 months and at any time of year ovigerous females can be found carrying egg clutches in highly disparate developmental states (Otto and Cummiskey 1985). Females carry large, yolk-rich, eggs, which hatch into lecithotrophic (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997) larvae that are negatively phototactic (Adams and Paul 1999). Molting and mating are also asynchronous and protracted (Otto and Cummiskey 1985; Shirley and Zhou 1997) with some indications of seasonality (Hiramoto 1985). Molt increment for large males (adults) in Southeast Alaska is 16.3 mm CL per molt (Koeneman and Buchanan 1985) and was

estimated at 14.4 mm CL for legal males in the EAG (Watson *et al.* 2002). Annual molting probability of males decreases with increasing size, which results in a protracted inter-molt period and creates difficulty in determining annual molt probability (Watson *et al.* 2002). Male size-at-maturity varies among stocks (Webb 2014) and declines with increasing latitude from about 130 mm CL in the Aleutian Islands to 92 mm CL in Saint Matthew Island section (Somerton and Otto 1986). Along with a lack of annual survey data, limited stock-specific life history stock information prevents development of the standard length-based assessment model.

5. **Summary of management history:**
    A complete summary of the management history through 2015/16 is provided in Leon *et al.* (2017). The first commercial landing of golden king crab in the Aleutian Islands was in 1975/76 but directed fishing did not occur until 1981/82.

    The Aleutian Islands golden king crab fishery was restructured beginning in 1996/97 to replace the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and golden king crab in the areas east and west of 174° W longitude were managed separately as two stocks (ADF&G 2002). Hereafter, the east of 174° W longitude stock segment is referred to as EAG and the west of 174° W longitude stock segment is referred to as WAG. Table 1 provides the historical summary of number of vessels, GHL/TAC, harvest, effort, CPUE and average weight in the Aleutian Islands golden king crab fishery.

    The fisheries in 1996/97–1997/98 were managed with GHLs of 1,452 t (3,200,000 lb) in EAG and 1,225 t (2,700,000 lb) in WAG (Table 1). During 1998/99–2004/05 the fisheries were managed with GHLs of 1,361 t (3,000,000 lb) for EAG and 1,225 t (2,700,000 lb) for WAG. During 2005/06–2007/08 the fisheries were managed with a total allowable catch (TAC) of 1,361 t (3,000,000 lb) for EAG and a TAC of 1,225 t (2,700,000 lb) for WAG. By state regulation (*5 AAC 34.612*), TAC for the Aleutian Islands golden king crab fishery during 2008/09–2011/12 was 1,429 t (3,150,000 lb) for EAG and 1,286 t (2,835,000 lb) for WAG. In March 2012, the BOF changed *5 AAC 34.612* so that the TAC beginning in 2012/13 would be 1,501 t (3,310,000 lb) for the EAG and 1,352 t (2,980,000 lb) for WAG. Additionally, the BOF added a provision to *5 AAC 34.612* that allows ADF&G to lower the TAC below the specified level if conservation concerns arise. The TAC for 2016/17 (and 2017/18) was reduced by 25% for WAG to 1,014 t (2,235,000 lb) while keeping the TAC for EAG at the same level as the previous season.

    During 1996/97–2020/21 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2020/21) has averaged 2% below the annual GHL/TACs. During 1996/97–2020/21, the retained catch has been as much as 13% below (1998/99) and as much as 6% above (2000/01) the GHL/TAC.

    A summary of other relevant State of Alaska fishery regulations and management actions pertaining to the Aleutian Islands golden king crab fishery is provided below:

Beginning in 2005/06 the Aleutian Islands golden king crab fishery has been prosecuted under the Crab Rationalization Program. Accompanying the adoption of crab rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., EAG) and the Adak Community Allocation (ACA) fishery for golden king crab in the western Aleutians (i.e., WAG; Hartill 2012; Nichols *et al*. 2021). The CDQ fishery in the eastern Aleutians is allocated 10% of the golden king crab TAC for the area east of 174° W longitude and the ACA fishery in the western Aleutians is allocated 10% of the golden king crab TAC for the area west of 174° W longitude. The CDQ fishery and the ACA fishery are managed by ADF&G and prosecuted concurrently with the individual fishing quota (IFQ) fishery.

Golden king crab may be commercially fished only with king crab pots (defined in state regulation *5 AAC 34.050*). Pots used to fish for golden king crab in the Aleutian Islands Area must be longlined and, since 1996, each pot must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (*5 AAC 34.625 (b)*). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139 mm [5.5 inches]) into their gear or, more rarely, included panels with escape mesh (Beers 1992). Regarding the gear used since the establishment of *5 AAC 34.625 (b)* in 1996, Linda Kozak, a representative of the industry, reported in a 19 September 2008 email to the Crab Plan Team, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9[-inch] escape web on the door of over 95% of Golden Crab pot orders we manufactured." A study to estimate the contact-selection curve for male golden king crab was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season and found gear and fishing practices used by that vessel were highly effective in reducing bycatch of sublegal-sized males and females (Vanek *et al.* 2013). In March 2011 (effective for 2011/12), the BOF amended *5 AAC 34.625 (b)* to relax the "biotwine" specification for pots used in the Aleutian Islands golden king crab fishery relative to the requirement *in 5 AAC 39.145* that "(1) a sidewall ...of all shellfish and bottom fish pots must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." Regulation *5 AAC 34.625 (b)(1)* allows the opening described in *5 AAC 39.145 (1)* to be "laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 60 [rather than 30] thread."

Regulation (*5 AAC 34.610 (b)*) sets the commercial fishing season for golden king crab in the Aleutian Islands Area as 1 August through 30 April. That regulatory fishing season became effective in 2015/16 (the commercial fishing season was set in regulation as 15 August through 15 May during 2005/06–2014/15).

Current regulations (*5 AAC 39.645 (d)(4)(A)*) stipulate that onboard observers are required on catcher vessels during the time that at least 50% of the retained catch is captured in each of the three trimesters of the 9-month fishing season. Onboard observers are required for 100% of fishing activity on catcher-processor vessels during the crab fishing season.

In addition, the commercial golden king crab fishery in the Aleutian Islands Area may only retain males at least 6.0-inches (152.4 mm) carapace width (CW), including spines (*5 AAC 34.620 (b)*), which is at least one annual molt increment larger than the 50% maturity length of 120.8 mm CL for males estimated by Otto and Cummiskey (1985). A carapace length (CL) $\geq$136 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007b). Note that the size limit for golden king crab has been 6-inches (152.4 mm) CW for the entire Aleutian Islands Area since the 1985/86 season. Prior to the 1985/86 season, the legal-size limit was 6.5-inches (165.1 mm) CW for at least one of the now-defunct Adak or Dutch Harbor Registration Areas.

We re-evaluated the male maturity size using 1991 pot survey measurements of carapace length and chela height in EAG and 1984 NMFS measurements in WAG (Siddeek *et al*. 2018). Bootstrap analysis of chela height and carapace length data provided the median 50% male maturity length estimates of 107.02 mm CL in EAG and 107.85 mm CL in WAG. We used a knife-edge 50% maturity length of 111.0 mm CL, which is the lower limit of the next upper size bin, for mature male biomass (MMB) estimation. We analyzed the recently collected (2018 to 2020) chela height and carapace length data and proposed a higher 50% maturity length of 116.0 mm CL (Appendix D).

Daily catch and catch-per-unit effort (CPUE) are determined in-season to monitor fishery performance and progress towards the respective TACs. Figures 6 to 8 provide the 1985/86–2020/21 time series of catches, CPUE, and the geographic distribution of catch during the 2020/21 fishing season. Increases in CPUE were observed during the late 1990s through the early 2000s, and with the implementation of crab rationalization in 2005. This is likely due to changes in gear configurations in the late 1990s (crab harvesters, personal communication, 1 July 2008) and, after rationalization due to increased soak time (Siddeek *et al.* 2015), and decreased competition owing to the reduced number of vessels fishing. Decreased competition could allow crab vessels to target only the most productive fishing areas. Trends in fishery nominal CPUE within the areas EAG and WAG generally paralleled each other during 1985/86–2010/11 but diverged thereafter (EAG CPUE exceeded one and half times of that in WAG). A moderate decreasing trend in CPUE was observed since 2014 in EAG. A sharp drop in CPUE was detected in 2020/21 for WAG (Figures 6 and 7).

6. **Brief description of the annual ADF&G harvest strategy:**
   In March 2019, the BOF adopted a revised harvest strategy (Daly *et al.* 2019). The annual TAC is set by state regulation, *5 AAC 34.612* (Harvest Levels for Golden King Crab in Registration Area O), per:

(a) In that portion of the Registration Area O east of 174° W. long., the total allowable catch level shall be established as follows:

    (1) if MMA_E is less than 25 percent of $MMA_{E,(1985-2017)}$, the fishery will not open;

    (2) if MMA_E is at least 25 percent but not greater than 100 percent of $MMA_{E,(1985-2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.15) \times (MMA_E/MMA_{E,(1985-2017)}) \times (MMA_E)$ or 25 percent of LMA_E, whichever is less; and

    (3) if MMA_E is greater than 100 percent of $MMA_{E,(1985-2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.15) \times (MMA_E)$ or 25 percent of LMA_E, whichever is less.

(b) In that portion of the Registration Area O west of 174° W. long., the total allowable catch level shall be established as follows:

    (1) if MMA_W is less than 25 percent of $MMA_{W,(1985-2017)}$, the fishery will not open

    (2) if MMA_W is at least 25 percent but not greater than 100 percent of $MMA_{W,(1985-2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.20) \times (MMA_W/MMA_{W,(1985-2017)}) \times (MMA_W)$ or 25 percent of LMA_W, whichever is less; and

    (3) if MMA_W is greater than 100 percent of $MMA_{W,(1985-2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.20) \times (MMA_W)$ or 25 percent of LMA_W, whichever is less.

(c) In implementing this harvest strategy, the department shall consider the reliability of estimates of golden king crab, the manageability of the fishery, and other factors the department determines necessary to be consistent with sustained yield principles and to use the best scientific information available and consider all sources of uncertainty as necessary to avoid overfishing.

(d) In this section,

    (1) MMA_E means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery;

    (2) $MMA_{E,(1985-2017)}$ means the mean value of the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery for the period 1985 – 2017;

    (3) LMA_E means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 136 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery;

    (4) MMA_W means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O west of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery;

    (5) $MMA_{W,(1985-2017)}$ means the mean value of the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O west of 174° W. long that are greater than or equal to 111 millimeters in carapace length

estimated by the stock assessment model for the time prior to the start of the fishery for the period 1985 – 2017; and

(6) LMA_W means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O west of 174° W. long that are greater than or equal to 136 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery.

In addition to the retained catch that is limited by the TAC established by ADF&G under *5 AAC 34.612*, ADF&G has authority to annually receive receipts up to $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually established TAC.

7. **Summary of the history of the basis and estimates of MMB_{MSY} or proxy MMB_{MSY}:**
We estimated the proxy MMB_{MSY} as $MMB_{35\%}$ using the Tier 3 estimation procedure, which is explained in a subsequent section.

D. Data
1. **Summary of new information:**
   (a) Commercial fishery retained catch by size, estimated total catch by size, groundfish male discard catch by size, observer CPUE index, and commercial fishery CPUE index were updated to include 2020/21 information. Available data by year are shown below.

2. Data presented as time series:

a. **Total Catch**:

Fish ticket data on retained catch weight, catch numbers, effort (pot lifts), CPUE, and average weight of retained catch for 1981/82–2020/21 (Table 1). Estimated total catch weight for 1990/91–2020/21 (Table 2a).

b. **Bycatch and discards**:

Retained catch, bycatch mortality (male and female) separated by the crab fishery and groundfish fishery, and total fishery mortality for 1981/82–2020/21 (Table 2). Crab fishery discards are available after observer sampling was established in 1988/89. Observer data for the 1988/89–1989/90 seasons are not considered reliable. Table 2 provides crab fishery discards and groundfish fishery bycatch for 1991/92–2020/21 seasons.

c. **Catch-per-unit-effort:**

- Pot fishery and observer nominal retained and total CPUE, pot fishery effort, observer sample size, and estimated observer CPUE index delineated by EAG and WAG for 1985/86–2020/21 (Table 3).

- Estimated commercial fishery CPUE index with coefficient of variation (Table 4 for EAG and Table 14 for WAG). The estimation methods, and CPUE fits are described in Appendix B.

d. **Catch-at-length:**

Information on length compositions is provided (Figures 9a, b, c to 11a, b, c for EAG; and 27a, b, c to 29a, b, c for WAG for models 21.1a, 21.1b, and 21.1c, respectively.

e. **Survey biomass estimates:**

Estimates are not available for the area because no systematic surveys, covering the entire fishing area, have occurred.

f. **Survey catch–at–length:**

Not available.

g. **Other time series data**: None.

3. **Data which may be aggregated over time:**

- **Molt and size transition matrix:** Tag release – recapture –time at liberty records from 1991, 1997, 2000, 2003, and 2006 male tag crab releases were aggregated by year at liberty to determine the molt increment and size transition matrix by the integrated model.
- **Weight-at-length**: Male length-weight relationship: $W = aL^b$ where $a = 1.445*10^{-4}$, $b = 3.28113$ [$\sigma = 0.00737$ (bias correction for a was not required because of the very small value of σ); updated estimates from WAG data].
- **Natural mortality**: A previous model estimated fixed natural mortality value of 0.21 yr^{-1}, was used in the assessment.

4. **Information on any data sources that were available, but were excluded from the assessment:**

   Data from triennial ADF&G pot surveys for Aleutian Islands golden king crab in a limited area in EAG (between 170° 21' and 171° 33' W longitude) that were performed during 1997 (Blau *et al.* 1998), 2000 (Watson and Gish 2002), 2003 (Watson 2004), and 2006 (Watson 2007) are available, but were not used in this assessment. However, the tag release and recapture data from these surveys were used.

   Data from the cooperative pot surveys conducted during 2015 to 2019 are available but is limited in the time series. The EAG survey covers the full time series but WAG survey started only in 2018. We incorporated the EAG data in a model scenario (21.1d) as a test run in this assessment (Appendix C).

E. *Analytic Approach*

1. **History of modeling approaches for this stock:**

   A size structured assessment model based on only fisheries data was under development for several years for the EAG and WAG golden king crab stocks and accepted in 2016 for OFL and ABC setting for the 2017/18 season. The CPT in January 2017 and SSC in February 2017 recommended using the Tier 3 procedure to set the OFL and ABC. They also suggested using the maturity data to estimate the male mature biomass (MMB). We followed these suggestions in this report to estimate the model based OFL and ABC.

2. **Model Description:**

   a. **Description of overall modeling approach:**

   The underlying population dynamics model is male-only and length-based (Appendix A). This model combines commercial retained catch, total catch, groundfish fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, and tag recaptures by release-recapture length to estimate stock assessment parameters. The tagging data were used to calculate the size transition matrix. To estimate the MMB, we used the knife-edge 50% maturity based on the chela height and carapace length data analysis. To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized fishery CPUE indices as a separate likelihood component in all scenarios (Table T1).

   There were significant changes in fishing practice associated with changes in management regulations (e.g., constant TAC since 1996/97 and crab rationalization since 2005/06), pot configuration (escape web on the pot door increased to 9-inch since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86–2004/05 and 2005/06–2020/21. We also considered a model (21.1b) with three total selectivity curves to reduce the retrospective pattern of EAG MMB.

We fitted the observer and commercial fishery CPUE indices with standard errors (estimated by GLM) and an additional assessment model estimated constant variance. The assessment model predicted total and retained CPUEs. However, we compared only the predicted retained CPUE with the observer legal size crab CPUE indices in the likelihood function because observer recordings of legal-size crabs are reliable.

The data series ranges used for the WAG are the same as those for EAG.

b. **Software**:
AD Model Builder (Fournier *et al.* 2012), ver 12.3.

c.–f. Details are given in Appendix A.

g. **Critical assumptions and consequences of assumption failures**:
Because of the lack of an annual stock survey, we relied heavily on standardized CPUE indices (Appendix B) and catch and size composition information to determine the stock abundance trends in both regions. We assumed that the observer and fish ticket CPUE indices are linearly related to exploitable abundance. We kept M constant at 0.21 yr^{-1} and knife-edge maturity size at 111 mm CL (Siddeek *et al.* 2018). We also considered a higher knife-edge maturity size of 116 mm CL for MMB estimation in different model scenarios. We assumed directed pot fishery discard mortality at 0.20 yr^{-1}, overall groundfish fishery mortality at 0.65 yr^{-1} (mean of groundfish pot fishery mortality [0.5 yr^{-1}] and groundfish trawl fishery mortality [0.8 yr^{-1}]), groundfish fishery selectivity at full selection for all length classes (selectivity = 1.0). Any discard of legal-size males in the directed pot fishery was not considered in this analysis. These fixed values invariably reduced the number of model parameters to be estimated and helped in convergence. We assumed different q's (scaling parameter for standardized CPUE in the model, Equation A.13) and logistic selectivity patterns (Equation A.9) for different periods for the pot fishery.

h. **Changes to any of the above since the previous assessment:**
None.

i. **Model code has been checked and validated**.
The codes have been checked at various times by independent reviewers and the current codes are available from the first author.

3. **Model Selection and Evaluation**

a. **Description of alternative model configurations:**
We considered seven models for EAG and WAG (Table T1). We presented OFL and ABC results for all models separately for EAG, WAG, and the entire AI in the executive summary tables. We considered model 19.1 as the base model. It considers:

i) Initial abundance by the equilibrium condition considering the mean number of recruits for 1987–2012: The equilibrium abundance was determined for 1960 (Equations A.4 and A.5), projected forward with only M and annual recruits until 1980, then retained catches removed during 1981–1984 and projected to obtain the initial abundance in 1985.

ii) Observer CPUE indices for 1995/96–2020/21.

iii) Fishery CPUE indices for 1985/86–1998/99.

iv) Initial (Stage-1) weighting of effective sample sizes: number of vessel-days for retained and total catch size compositions, and number of fishing trips for groundfish discard size composition (the groundfish size composition was not used in model fitting); and (Stage-2) iterative re-weighting of effective sample sizes by the Francis method.

v) Two catchabilities and two sets of logistic total selectivities for the periods 1985/86–2004/05 and 2005/06–2020/21, and a single set of logistic retention curve parameters.

vi) Full selectivity (selectivity =1.0) for groundfish fishery bycatch.

vii) Knife-edge 50% maturity size of 111 mm CL.

viii) Stock dynamics $M = 0.21$ yr^{-1}, pot fishery handling mortality = 0.2 yr^{-1}, and mean groundfish bycatch handling mortality = 0.65 yr^{-1}.

ix) Size transition matrix using tagging data estimated by the normal probability function with the logistic molt probability sub-model. The tag-recaptures were treated as Bernoulli trials (i.e., Stage-1 weighting).

x) The period, 1987–2012, was used to determine the mean number of recruits for $MMB_{35\%}$ (a proxy for MMB_{MSY}) estimation under Tier 3.

The salient features and variations from the base scenario of all other scenarios are listed in Table T1. The list of fixed and estimable parameters is provided in Table A1 and detail weights with coefficient of variations (CVs) assigned to each type of data are listed in Table A2.

Best estimates of parameter values for the selected model 21.1a were jittered to confirm model global convergence. The results indicated that global convergence was achieved for most runs (Appendix E).

Table T1. Features of all model scenarios: Initial condition was estimated in year 1960 by the equilibrium condition; two catchability and two sets of logistic total selectivity curves were used for the pre- and post-rationalization periods; a single retention curve was used for the whole period; and a common M of 0.21 yr^{-1} was used. The effective sample sizes for size compositions were estimated in two stages: Stage-1: as the number of vessel days/trips and Stage-2: as the Francis re-iteration method. Changes in base model specifications are highlighted by the shaded text.

Model	CPUE Data Type and Maturity Option	Period for Mean Number of Recruit Calculation for (a) Initial Equilibrium Abundance and (b) Reference Points Estimations and Remarks
19.1 (accepted model in May 2019, implemented with up to 2020/21 data)	Observer data from 1995/96–2020/21 Fish ticket data from 1985/86–1998/99; Observer and fish ticket CPUE standardization by negative binomial model; a knife-edge minimum maturity size of 111 mm CL.	1987–2012; CPT/SSC suggested base model.
21.1a	19.1+	1987–2017; CPT/SSC suggested model.
21.1b	21.1a+ three total selectivity periods (1960–2004; 2005–2015; 2016+).	CPT/SSC suggested model.
21.1c	21.1a+ the observer CPUE data standardized including Year:Area interactions.	CPT/SSC suggested model.
21.1a1	21.1a+ a knife-edge minimum maturity size of 116 mm CL.	Authors proposed additional model.
21.1b1	21.1b+ a knife-edge minimum maturity size of 116 mm CL.	Authors proposed additional model.
21.1c1	21.1c+ a knife-edge minimum maturity size of 116 mm CL.	Authors proposed additional model.

b. **Progression of results:**
   The OFL and ABC estimates are like those estimates made in 2020.

c. **Label the approved model from the previous year as model:**
   We used the notation 19.1 for the base model which came from the last season (2019/20) accepted assessment model, 19.1.

d. **Evidence of search for balance between realistic and simpler models**:
   Unlike annually surveyed stocks, Aleutian Islands golden king crab stock biomass is difficult to track, and several biological parameters are assumed based on knowledge from red king crab (e.g., handling mortality rate of 0.2 yr-1) due to a lack of species/stock specific information. We fixed several model parameters after initially running the model with free parameters to reduce the number of parameters to be estimated (e.g., groundfish bycatch selectivity parameters were fixed). In CPUE standardization, instead of using the traditional AIC we used the Consistent Akaike Information Criteria (Bozdogan 1987) that considers number of parameters and data points used for fitting models when selecting the final model. The models also considered different configuration of parameters to select parsimonious models. The detailed results of all models are provided in tables and figures.

e. **Convergence status and criteria**:
   ADMB default convergence criteria were used.

f. **Table of the sample sizes assumed for the size compositional data:**
   We estimated the initial input effective sample sizes (i.e., Stage-1) either as number of vessel-days for retained and total catch compositions or number of fishing trips for groundfish size composition (note: we did not use the groundfish size composition in model fitting) for all model scenarios. Then we estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes using the Francis' (2011, 2017) mean length-based method.

   We provide the initial input sample sizes (Stage-1) and Stage-2 effective sample sizes for models 21.1a, 21.1b, and 21.1c in Tables 5 to 7 for EAG and Tables 15 to 17 for WAG.

g. **Provide the basis for data weighting, including whether the input effective sample sizes are tuned, and the survey CV adjusted:**
   Described previously (f).

h. **Do parameter estimates make sense and are they credible?**
   The estimated parameter values are within the bounds and various plots suggest that the parameter values are reasonable for a fixed M value for the golden king crab stocks.

i. **Model selection criteria:**
   We used several diagnostic criteria to select appropriate models for our recommendation: CPUE fits, observed vs. predicted tag recapture numbers by time at

large and release size, retained and total catch, and groundfish bycatch fits. Figures are provided for all model scenarios in the Results section.

j. **Residual analysis:**

We illustrated residual fits by bubble plots for retained and total catch size composition predictions in various figures in the Results section.

k. **Model evaluation:**

Only one base model with several model variations is presented and the evaluations are presented in the Results section below.

4. Results

1. **List of effective sample sizes and weighting factors:**

The Stage-1 and Stage-2 effective sample sizes are listed for various models in Tables 5 to 7 for EAG and Tables 15 to 17 for WAG. The weights, with the corresponding coefficient of variations specifications, for different data sets are provided in Table A2 for various models for both EAG and WAG. These weights (with the corresponding coefficient of variations) adequately fitted the length compositions, and no further changes were examined.

We used weighting factors for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. We set the retained catch biomass weight to an arbitrarily large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass weight in accordance with the observer annual sample sizes (number of pots) with a maximum of 250.0. The total catches were derived from observer nominal total CPUE and effort. In some years, observer sample sizes were low (Tables 3). We chose a small groundfish bycatch weight (0.2) based on the September 2015 CPT suggestion for a lower its weight. We used the best fit criteria to choose the lower weight for the groundfish bycatch. Groundfish bycatch of Aleutian Islands golden king crab is very low (Table 2). We set the CPUE weights to 1.0 for all models. We included a constant (model estimated) variance in addition to input CPUE variance for the CPUE fit. We used the Burnham *et al.* (1987) suggested formula for ln(CPUE) (and ln(MMB)) variance estimation (Equation A.14). However, the estimated additional variance values were small for both observer and fish ticket CPUE indices for the two regions. Nevertheless, the CPUE index variances estimated from the negative binomial GLM were adequate to fit the model, as confirmed by the fit diagnostics (Fox and Weisberg 2011). Parameter estimates are provided in Tables 8 for EAG and 18 for WAG for models 19.1, 21.1a, 21.1b, and 21.1c. The numbers of estimable parameters are listed in Table A1.

2. **Include tables showing differences in likelihood:**

Tables 13 and 23 list the total and component negative log likelihood values for EAG and WAG, respectively.

3. **Tables of estimates:**

   a. The parameter estimates with coefficient of variation for models 19.1, 21.1a, 21.1b, and 21.1c are summarized in Tables 8 and 18 for EAG and WAG, respectively. We have also provided the boundaries for parameter searches in those tables. All parameter estimates were within the bounds.

   b. All models considered molt probability parameters in addition to the linear growth increment and normally distributed growth variability parameters to determine the size transition matrix.

   c. The mature male and legal male abundance time series for selected models (19.1, 21.1a, 21.1b, and 21.1c) are summarized in Tables 9 to 12 for EAG and Tables 19 to 22 for WAG.

   d. The recruitment estimates for those models are summarized in Tables 9 to 12 for EAG and Tables 19 to 22 for WAG.

   e. The negative log-likelihood component values and total negative log-likelihood values for models 19.1, 21.1a, 21.1b, and 21.1c are summarized in Table 13 for EAG and Table 23 for WAG. Although loglikelihood values of different models are not comparable because of data weighting (i.e., different magnitude of effective sample sizes), nevertheless, model 21.1c has the minimum total negative log likelihood for EAG and WAG. However, the total negative log likelihood values for the four models were not widely different. We may conclude that the input observer CPUE indices with Year and Area interaction appears to have positively influenced the overall fit.

4. **Graphs of estimates:**

   a. **Selectivity**:
   Total selectivity and retention curves of the pre- and post-rationalization periods for selected models are illustrated in Figures 12a and 12b for EAG and Figures 30a and 30b for WAG. Figures 12b and 30b correspond to second part (2016–2020) of the post-rationalization period in the three total selectivity model. Total selectivity for the pre-rationalization period was used in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis, indicating that all size groups were vulnerable to the gear. This is also shown in the size compositions of groundfish bycatch (Figures 11 and 29 for model 21.1a for EAG and WAG, respectively). Thus, we set the groundfish bycatch selectivity to 1.0 for all length-classes in the subsequent analysis.

   b. **Mature male biomass**:
   The mature male biomass time series for models 19.1, 21.1a, 21.1b, and 21.1c are depicted in Figure 26 for EAG and WAG. Mature male biomass tracked the CPUE trends well for selected models for EAG and WAG. The biomass variance was estimated using the Burnham *et al.* (1987) suggested formula (Equation A.14). We

determined the mature male biomass values on 15 February each year and considered a fixed period time series of recruits (Table T1) for estimating mean number of recruits for the $MMB_{35\%}$ calculation under a Tier 3 approach.

c. **Fishing mortality**:

The full selection pot fishery F values over time for models 19.1, 21.1a, 21.1b, and 21.1c are shown in Figure 25 for EAG and WAG. The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. Slight increases in F were observed from 2014 to 2016, followed by a decline in the EAG. On the other hand, the F in the WAG peaked in late 1980s, 1990s, and early 2000s, declined in late 2000s, and slightly increased in 2013–2014 before declining.

d. **F vs. MMB:**

We provide these plots for models 21.1a, 21.1b, and 21.1c for EAG and WAG in Figure 42. The 2020/21 F was below the overfishing levels in both regions.

e. **Stock-Recruitment relationship:** None.

f. **Recruitment**:

Temporal changes in total number of recruits to the modeled (19.1, 21.1a, 21.1b, and 21.1c) population are illustrated in Figure 14 for EAG and in Figure 32 for WAG. The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 15 and 33 for EAG and WAG, for the respective models.

5. **Evaluation of the fit to the data:**

g. **Fits to catches:**

The fishery retained and total catch, and groundfish bycatch (observed vs. estimated) plots are illustrated in Figure 17 for EAG and in Figure 35 for WAG for models 19.1, 21.1a, 21.1b, and 21.1c. The 1981/82–1984//85 retained catch plots for respective models are depicted in Figures 18 and 36 for EAG and WAG, respectively. All predicted fits were very close to observed values, especially for retained catch and groundfish bycatch mortality. However, pre-1995 total catch data did not fit well.

h. **Survey data plot:**

We provide some cooperative pot survey data plots in Appendix C.

i. **CPUE index data:**

The comparison of predicted CPUE with input indices (open circles with 95% confidence intervals) for models 19.1, 21.1a, 21.1b, and 21.1c are shown in Figure 24 for EAG and Figure 41 for WAG. The CPUE variance was estimated using the Burnham *et al.* (1987) suggested formula (Equation A.14). These figures illustrate varying matches of CPUE predictions with input values by different models.

j. **Tagging data:**
The predicted vs. observed tag recaptures by length-class for years 1 to 6 post tagging are depicted in Figure 13 for EAG and Figure 31 for WAG. The predictions appear reasonable. Note that we used the EAG tagging information for a fixed size transition matrix estimation for both stocks (EAG and WAG). The size transition matrices estimated using EAG tagging data in the EAG and WAG models were similar.

k. **Molt probability**:
The predicted molt probabilities vs. CL are depicted for models 19.1, 21.1a, 21.1b, and 21.1c in Figures 16 for EAG and in Figure 34 for WAG. The fitted curves appear to be satisfactory.

l. **Fit to catch size compositions:**
Retained and total length compositions are shown in Figures 9a, b, c and 10a, b, c for EAG and 27a, b, c and 28a, b, c for WAG for models 21.1a, 21.1b, and 21.1c, respectively. The groundfish discard length compositions for model 21.1a are shown in Figures 11 for EAG and 29 for WAG. The retained and total catch size composition fits appear satisfactory. But the fits to groundfish bycatch size compositions are bad. Note that we did not use the groundfish size compositions in any of the model fits.

We illustrate the standardized residual plots as bubble plots of size composition over time for retained catch (Figures 19 and 20 for EAG, and 37 and 38 for WAG) and for total catch (Figures 21 and 22 for EAG, and 39 and 40 for WAG) for two models (21.1a and 21.1c). The retained catch bubble plots do not appear to exhibit major pronounced patterns among residuals for the selected models.

m. **Marginal distributions for the fits to the composition data:**
We did not provide this plot in this report.

n. **Plots of implied versus input effective sample sizes and time series of implied effective sample sizes:**
We did not provide the plots or table values of implied vs. input effective sample sizes in this report. However, we provide the Stage-1 and the optimized re-weighted Stage-2 effective sample sizes in Tables 5 to 7 for EAG and in Tables 15 to 17 for WAG, respectively for models 21.1a, 21.1b, and 21.1c.

o. **Tables of RMSEs for the indices:**
We did not provide this table in this report.

p. **Quantile-quantile (Q–Q) plots:**
We did not provide these plots for model fits in this report. However, we provide a Q-Q plot for cooperative survey CPUE fit in Appendix C.

6. **Retrospective and historical analysis:**
   The retrospective fits for scenarios 21.1a, 21.1b, and 21.1c are shown in Figure 23 for EAG and WAG. The retrospective fits for the whole time series, 1961 to 2020, did not show severe departure when nine terminal years' data were sequentially removed, especially for WAG, and hence the current formulation of the model appears stable. The modified Mohn rho (1999) values are also given in the figure.

   The Mohn rho (ρ) formula, modified by Deroba (2014), is:

   $$Mohn\ \rho = \frac{\sum_{n=1}^{x} \frac{\left[\widehat{MMB}_{y=T-n,T-n} - \widehat{MMB}_{y=T-n,T}\right]}{\widehat{MMB}_{y=T-n,T}}}{x}$$

   where, $\widehat{MMB}_{y=T-n,T-n}$ is the MMB estimated for terminal year T-n (left subscript) using data up to T-n years (right subscript), T is the terminal year of the entire data, x is the total number of peels, most recent year's data is "peeled off" recursively n times, where n =1, 2, 3. …x. We used nine peels (x=9) and our T =2020.

   The low values (rule of thumb: closer to zero / between -0.2 to 0.2) of Mohn rho indicate no severe model misspecification. The Mohn rho values show no severe model misspecification for WAG. The model 21.1b for EAG shows some reduction in the Mohn rho value compared to that of either model 21.1a or model 21.1c.

   A severe drop in modeled biomass from initial MMB occurred when the fishery time series started in 1981 in both regions.

7. **Uncertainty and sensitivity analysis:**
   The main task was to determine a plausible size transition matrix to project the population over time. In a previous study, we investigated the sensitivity of the model to determining the size transition matrix by using or not using a molt probability function (Siddeek *et al.* 2016a). The model fit improved when a molt probability model was included. Therefore, we included a molt probability sub-model for size transition matrix calculation in all model scenarios.

8. **Conduct 'jitter analysis':**
   We conducted jitter analysis on the selected model 21.1a (Appendix E). The results indicated that global convergence was achieved for most runs.

F. Calculation of the OFL

1. **Specification of the Tier level:**
   In the following section, we provide the Tier 3 method to determine OFL and ABC.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:**

The critical assumptions for MMB_{MSY} reference point estimation of Aleutian Islands golden king crab are:
  a. Natural mortality is constant.
  b. A fixed growth transition matrix is adequately estimated from tagging data and a molt probability sub-model.
  c. Total fishery selectivity and retention curves are length-dependent and the 2005/06–2020/21 period selectivity estimates are applicable.
  d. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
  e. Model estimated recruits (in millions of crab) are valid for different periods considered in selected models.
  f. Model estimated groundfish bycatch mortality values are appropriately averaged for the period 2011/12–2020/21 (10 years).
  g. The knife-edge 50% maturity size used for MMB estimation is correct.

Method:
We simulated the population abundance starting from the model estimated terminal year stock size by length, model estimated parameter values, a fishing mortality value (F), and a constant number of annual recruits. Once stock dynamics were stabilized (we used the 99th year estimates) for an F, we calculated the MMB/R for that F. We computed the relative MMB/R in percentage, $\left(\frac{MMB}{R}\right)_{x\%}$

(where $x\% = \frac{\frac{MMB_F}{R}}{\frac{MMB_0}{R}} \times 100$ and MMB_0/R is the virgin MMB/R) for different F values.

$F_{35\%}$ is the F value producing an MMB/R value equal to 35% of MMB_0/R.
$MMB_{35\%}$ is estimated using the following formula:
$$MMB_{35\%} = \left(\frac{MMB}{R}\right)_{35\%} \times \bar{R},$$
where $\bar{R}$ is the mean number of model estimated recruits for a selected period.

3. **Specification of the OFL:**
  a. **Provide the equations (from Amendment 24) on which the OFL is to be based:**

   F_{OFL} uses Equation A.28. The OFL is estimated by an iterative procedure accounting for intervening total removals (Appendix A).

  b. **Basis for projecting MMB to the time of mating:**
   We followed the NPFMC (2007a) guideline.

  c. **Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:**

The 2020/21 fishery data indicated that overfishing did not occur (Total Catch < OFL) and the stock did not reach an overfished status (MMB > MSST). Please see Management Performance table below. The OFL and ABC values for 2021/22 in the table below are the authors-recommended values.

Status and catch specifications (1000 t) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2019/20	5.915	16.386	3.257	3.319	3.735	5.249	3.937
2020/21	6.026[c]	16.207[c]	2.999	3.000	3.444	4.798	3.599
2021/22		14.816[c]				4.817[d]	3.372[d,e]

Status and catch specifications (million lb) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2019/20	13.041	36.124	7.180	7.317	8.234	11.572	8.679
2020/21	13.284[c]	35.730[c]	6.610	6.614	7.593	10.579	7.934
2021/22		32.662[c]				10.620[d]	7.434[d,e]

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. 25% buffer was applied to total catch OFL to determine ABC.
c. Accepted model 21.1a with incomplete fisheries data for WAG was used to calculate MSST, MMB, and 2021/22 MMB projection.
d. OFL and ABC were estimated in May 2021 assessment when the WAG fishery was not completed.
e. 30% buffer was applied to total catch OFL to determine ABC for the 2021/22 fishery after SSC/Council's recommendation.

4. Specification of the retained portion of the total catch OFL:
The retained catch portions of the total-catch OFL for EAG, WAG, and the entire Aleutian Islands (AI = EAG + WAG) stock were calculated for the three models (21.1a, 21.1b, and 21.1c):

Model 21.1a:
EAG: 2,812 t (6.200 million lb)
WAG: 1,491 t (3.287 million lb)
 AI: 4,303 t (9.487 million lb).

Model 21.1b:
EAG: 2,398 t (5.286 million lb)

WAG: 1,505 t (3.319 million lb)
AI: 3,903 t (8.605 million lb).

Model 21.1c:
EAG: 2,785 t (6.140 million lb)
WAG: 1,355 t (2.987 million lb)
AI: 4,140 t (9.127 million lb).

G. Calculation of ABC

We estimated the cumulative probability distribution of OFL assuming a log normal distribution of OFL. We calculated the OFL at the 0.5 probability and the maximum ABC at the 0.49 probability and considered an additional buffer by setting ABC =0.75*OFL.

We provide the ABC estimates with the 25% buffer for EAG, WAG, and AI considering models 21.1a, 21.1b, and 21.1c:

Model 21.1a:
EAG: ABC = 2,208 t (4.869 million lb)
WAG: ABC = 1,188 t (2.620 million lb)
AI: ABC = 3,396 t (7.489 million lb).

Model 21.1b:
EAG: ABC = 1,896 t (4.180 million lb)
WAG: ABC = 1,199 t (2.643 million lb)
AI: ABC = 3,095 t (6.823 million lb).

Model 21.1c:
EAG: ABC = 2,188 t (4.825 million lb)
WAG: ABC = 1,083 t (2.568 million lb)
AI: ABC = 3.353 t (7.393 million lb).

1. **List of variables related to scientific uncertainty:**
   - Models rely largely on fisheries data.
   - Observer and fisheries CPUE indices played a major role in the assessment model.
   - Natural mortality, 0.21 yr^{-1}, was estimated in the previous model and not independently estimated here.
   - The period to compute the average number of recruits relative to the assumption that this represents "a period determined to be representative of the production potential of the stock."
   - Fixed bycatch mortality rates were used in each fishery (crab fishery and the groundfish fishery) that discarded golden king crab.

- Discarded catch and bycatch mortality for each fishery in which bycatch occurred during 1981/82–1989/90 were not available.

2. **List of additional uncertainties for alternative sigma-b.**
   We recommend a buffer of 25% to account for additional uncertainties.

3. **Author recommended ABC:**
   Authors recommend three ABC options based on 25% buffer on the OFL under models 21.1a, 21.1b, and 21.1c.

H. *Rebuilding Analysis*
Not applicable. This stock has not been declared overfished.

I. *Data Gaps and Research Priorities*
1. Recruit abundances were tied to commercial catch sampling data. The implicit assumption in the analysis was that the estimated recruits come solely from the same exploited stock through growth and mortality. The current analysis did not consider that additional recruitment may occur through immigration from neighboring areas and possibly separate sub-stocks. The analysis also did not consider emigration from the study area, which would result in an assumption of increased M or a reduced estimate of recruits. Extensive tagging experiments or resource surveys are needed to investigate stock distributions.
2. We estimated M in the model. However, an independent estimate of M is needed for comparison, which could be achieved with tagging experiments.
3. An extensive tagging study may provide independent estimates of molting probability and growth. We used historical tagging data to determine the size transition matrix.
4. An arbitrary 20% handling mortality rate on discarded males was used, which was obtained from the red king crab literature (Kruse *et al.* 2000; Siddeek 2002). An experimentally based independent estimate of handling mortality is needed for Aleutian Islands golden king crab.
5. The Aleutian King Crab Research Foundation recently initiated crab survey programs in the Aleutian Islands. This program needs to be strengthened and continued for golden king crab research to address some of the data gaps and establish a fishery independent data source.
6. It is unclear how the recent changes in environmental conditions in the Bering Sea will affect golden king crab growth and survival. Limited length-weight data from the cooperative survey and independent biological sampling in 2018 and 2020 from WAG were used in the current assessment; however, more measurements are needed from both regions to increase the sample size to refine the length-weight model.
7. We used male maturity information to determine MMB. The ADF&G observer sampling, dock side sampling, and cooperative survey programs collected male maturity data during 2018/19 through 2020/21. Preliminary analysis on these data

is presented in this assessment. The CPT previously recommended to collect additional data on small size crab (sublegal) to improve maturity fit. The maturity data collection needs to be continued to accumulate more measurements on small crab.

8. Morphometric measurements provide size at maturity. Ideally, an experimental study under natural environment conditions is needed to collect male size at functional maturity data to determine functional maturity size.

J. Acknowledgments

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Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2020/21: number of vessels, guideline harvest level (GHL; established in lb, converted to t) for 1996/97 – 2004/05, total allowable catch (TAC; established in lb, converted to t) for 2005/06– 2020/21, weight of retained catch (harvest; t), number of retained crab, pot lifts, fishery catch-per-unit-effort (CPUE; retained crab per pot lift), and average weight (kg) of landed crab. The values are separated by EAG and WAG beginning in 1996/97.

Crab Fishing Season	Vessels	GHL/TAC	Harvest[a]	Crab	Pot Lifts	CPUE[b]	Average Weight[c]
1981/82	14–20	–	599	240,458	27,533	9	2.5[d]
1982/83	99–148	–	4,169	1,737,109	179,472	10	2.4[d]
1983/84	157–204	–	4,508	1,773,262	256,393	7	2.5[d]
1984/85	38–51	–	2,132	971,274	88,821	11	2.2[e]
1985/86	53	–	5,776	2,816,313	236,601	12	2.1[f]
1986/87	64	–	6,685	3,345,680	433,870	8	2.0[f]
1987/88	66	–	4,199	2,177,229	307,130	7	1.9[f]
1988/89	76	–	4,820	2,488,433	321,927	8	1.9[f]
1989/90	68	–	5,453	2,902,913	357,803	8	1.9[f]
1990/91	24	–	3,153	1,707,618	215,840	8	1.9[f]
1991/92	20	–	3,494	1,847,398	234,857	8	1.9[f]
1992/93	22	–	2,854	1,528,328	203,221	8	1.9[f]
1993/94	21	–	2,518	1,397,530	234,654	6	1.8[f]
1994/95	35	–	3,687	1,924,271	386,593	5	1.9[f]

Crab Fishing Season	Vessels		GHL/TAC		Harvest[a]		Crab		Pot Lifts		CPUE[b]		Average Weight[c]	
1995/96	28		–		3,157		1,582,333		293,021		5		2.0[f]	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1996/97	14	13	1,452	1,225	1,493	1,145	731,909	602,968	113,460	99,267	7	6	2.04[f]	1.91[f]
1997/98	13	9	1,452	1,225	1,588	1,109	780,610	569,550	106,403	86,811	7	7	2.04[f]	1.95[f]
1998/99	14	3	1,361	1,225	1,473	768	740,011	410,018	83,378	35,975	9	11	2.00[f]	1.86[f]
1999/00	15	15	1,361	1,225	1,392	1,256	709,332	676,558	79,129	107,040	9	6	1.95[f]	1.86[f]
2000/01	15	12	1,361	1,225	1,422	1,308	704,702	705,613	71,551	101,239	10	7	2.00[f]	1.86[f]
2001/02	19	9	1,361	1,225	1,442	1,243	730,030	686,738	62,639	105,512	12	7	2.00[f]	1.81[f]
2002/03	19	6	1,361	1,225	1,280	1,198	643,886	664,823	52,042	78,979	12	8	2.00[f]	1.81[f]
2003/04	18	6	1,361	1,225	1,350	1,220	643,074	676,633	58,883	66,236	11	10	2.09[f]	1.81[f]
2004/05	19	6	1,361	1,225	1,309	1,219	637,536	685,465	34,848	56,846	18	12	2.04[f]	1.77[f]
2005/06	7	3	1,361	1,225	1,300	1,204	623,971	639,368	24,569	30,116	25	21	2.09[f]	1.91[f]
2006/07	6	4	1,361	1,225	1,357	1,030	650,587	527,734	26,195	26,870	25	20	2.09[f]	1.95[f]
2007/08	4	3	1,361	1,225	1,356	1,142	633,253	600,595	22,653	29,950	28	20	2.13[f]	1.91[f]
2008/09	3	3	1,361	1,286	1,426	1,150	666,946	587,661	24,466	26,200	27	22	2.13[f]	1.95[f]
2009/10	3	3	1,429	1,286	1,429	1,253	679,886	628,332	29,298	26,489	26	24	2.09[f]	2.00[f]
2010/11	3	3	1,429	1,286	1,428	1,279	670,983	626,246	25,851	29,994	26	21	2.13[f]	2.04[f]

Crab Fishing Season	Vessels		GHL/TAC		Harvest[a]		Crab		Pot Lifts		CPUE[b]		Average Weight[c]	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
2011/12	3	3	1,429	1,286	1,429	1,276	668,828	616,118	17,915	26,326	37	23	2.13[f]	2.09[f]
2012/13	3	3	1,501	1,352	1,504	1,339	687,666	672,916	20,827	32,716	33	21	2.18[f]	2.00[f]
2013/14	3	3	1,501	1,352	1,546	1,347	720,220	686,883	21,388	41,835	34	16	2.13[f]	1.95[f]
2014/15	3	2	1,501	1,352	1,554	1,217	719,064	635,312	17,002	41,548	42	15	2.18[f]	1.91[f]
2015/16	3	2	1,501	1,352	1,590	1,139	763,604	615,355	19,376	41,108	39	15	2.09[f]	1.85[f]
2016/17	3	3	1,501	1,014	1,578	1,015	793,983	543,796	24,470	38,118	32	14	1.99[f]	1.87[f]
2017/18	3	3	1,501	1,014	1,571	1,014	802,610	519,051	25,516	30,885	31	17	1.96[f]	1.95[f]
2018/19	3	3	1,749	1,134	1,830	1,135	940,336	578,221	25,553	29,156	37	20	1.95[f]	1.96[f]
2019/20	3	3	1,955	1,302	2,031	1,288	1,057,464	649,832	30,998	42,924	34	15	1.92[f]	1.98[f]
2020/21	3	3	1,656	1,343	1,733	1,267	902,122	682,107	30,072	46,701	30	15	1.92[f]	1.86[f]

Note:
[a.] Includes deadloss.
[b.] Number of crab per pot lift.
[c.] Average weight of landed crab, including dead loss.
[d.] Managed with 6.5" carapace width (CW) minimum size limit.
[e.] Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.
[f.] Managed with 6.0" minimum size limit.
Catch and effort data include cost recovery fishery.

Table 2. Annual weight of total fishery mortality to Aleutian Islands golden king crab, 1981/82 – 2020/21, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries. For bycatch in the federal groundfish fisheries, historical data (1991–2008) are not available for areas east and west of 174W, and are listed for federal groundfish reporting areas 541, 542, and 543 combined. The 2009– present data are available by separate EAG and WAG fisheries and are listed as such. A mortality rate of 20% was applied for crab fisheries bycatch, and a mortality rate of 50% for groundfish pot fisheries and 80% for the trawl fisheries were applied.

Season	Retained Catch (t)		Bycatch Mortality by Fishery Type (t) Crab		Groundfish		Total Fishery Mortality (t)		
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	Entire AI
1981/82	490	95							585
1982/83	1,260	2,655							3,914
1983/84	1,554	2,991							4,545
1984/85	1,839	424							2,263
1985/86	2,677	1,996							4,673
1986/87	2,798	4,200							6,998
1987/88	1,882	2,496							4,379
1988/89	2,382	2,441							4,823
1989/90	2,738	3,028							5,766
1990/91	1,623	1,621							3,244
1991/92	2,035	1,397	515	344	0				4,291
1992/93	2,112	1,025	1,206	373	0				4,716
1993/94	1,439	686	383	258	4				2,770
1994/95	2,044	1,540	687	823	1				5,095
1995/96	2,259	1,203	725	530	2				4,719
1996/97	1,738	1,259	485	439	5				3,926
1997/98	1,588	1,083	441	343	1				3,455
1998/99	1,473	955	434	285	1				3,149
1999/00	1,392	1,222	313	385	3				3,316
2000/01	1,422	1,342	82	437	2				3,285
2001/02	1,442	1,243	74	387	0				3,146
2002/03	1,280	1,198	52	303	18				2,850
2003/04	1,350	1,220	53	148	20				2,792
2004/05	1,309	1,219	41	143	1				2,715
2005/06	1,300	1,204	22	73	2				2,601
2006/07	1,357	1,022	28	81	18				2,506
2007/08	1,356	1,142	24	114	59				2,695
2008/09	1,426	1,150	61	102	33				2,772
2009/10	1,429	1,253	111	108	18	5	1,558	1,366	2,923
2010/11	1,428	1,279	123	124	49	3	1,600	1,407	3,006
2011/12	1,429	1,276	106	117	25	4	1,560	1,398	2,957
2012/13	1,504	1,339	118	145	9	6	1,631	1,491	3,122
2013/14	1,546	1,347	113	174	5	7	1,665	1,528	3,192

2014/15	1,554	1,217	127	175	9	5	1,691	1,397	3,088
2015/16	1,590	1,139	165	157	23	2	1,778	1,298	3,076
2016/17	1,578	1,015	203	145	101	4	1,882	1,164	3,046
2017/18	1,571	1,014	219	126	47	2	1,837	1,142	2,979
2018/19	1,830	1,135	240	140	24	3	2,094	1,278	3,372
2019/20	2,031	1,288	275	112	18	6	2,327	1,406	3,733
2020/21	1,733	1,267	241	147	40	17	2,014	1,431	3,444

Table 2a. Time series of estimated total male catch (weight of crabs on the deck without applying any handling mortality) for the EAG and WAG golden king crab stocks (1990/91–2020/21). The crab weights are for the size range ≥ 101mm CL and a length-weight formula was used to predict weight at the mid-point of each size bin. NA: no observer sampling to compute catch.

Year	Total Catch Biomass (t) EAG	Total Catch Biomass (t) WAG
1990/91	1,405	3,657
1991/92	5,861	2,555
1992/93	5,532	1,508
1993/94	NA	2,804
1994/95	1,971	4,911
1995/96	3,711	2,115
1996/97	2,052	1,754
1997/98	2,540	1,789
1998/99	2,783	1,079
1999/00	2,275	2,079
2000/01	2,554	2,215
2001/02	2,099	2,123
2002/03	1,806	1,880
2003/04	1,825	1,856
2004/05	1,629	1,871
2005/06	1,737	1,793
2006/07	1,636	1,553
2007/08	1,818	1,610
2008/09	1,815	1,733
2009/10	1,771	1,687
2010/11	1,755	1,597
2011/12	1,770	1,523
2012/13	1,948	1,831
2013/14	1,839	1,916
2014/15	1,966	1,593
2015/16	2,125	1,558
2016/17	2,234	1,568
2017/18	2,376	1,435
2018/19	2,724	1,632
2019/20	3,026	1,709
2020/21	2,597	1,840

Table 3. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), total pot fishing effort (number of pot lifts), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index (for non-interaction model) for the EAG and WAG golden king crab stocks, 1985/86–2020/21. Observer retained CPUE includes retained and non-retained legal-size crabs.

Year	Pot Fishery Nominal Retained CPUE		Obs. Nominal Retained CPUE		Obs. Nominal Total CPUE		Pot Fishery Effort (no.pot lifts)		Obs. Sample Size (no.pot lifts)		Obs. CPUE Index	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1985/86	11.90	11.90					117,718	118,563				
1986/87	8.42	7.32					155,240	277,780				
1987/88	7.03	7.15					146,501	160,229				
1988/89	7.52	7.93					155,518	166,409				
1989/90	8.49	7.83					155,262	202,541				
1990/91	8.90	7.00	6.84	8.34	13.00	26.67	106,281	108,533	138	340		
1991/92	8.20	7.40	9.84	6.14	36.91	19.17	133,428	101,429	377	857		
1992/93	8.40	5.90	10.44	4.26	38.52	16.83	133,778	69,443	199	690		
1993/94	7.80	4.40	5.91	12.75	20.81	17.23	106,890	127,764	31	174		
1994/95	5.90	4.10	4.66	6.62	12.91	19.23	191,455	195,138	127	1,270		
1995/96	5.90	4.70	6.03	6.03	16.98	14.28	177,773	115,248	6,388	5,598	1.00	1.16
1996/97	6.50	6.10	6.02	5.90	13.81	13.54	113,460	99,267	8,360	7,194	0.94	0.98
1997/98	7.30	6.60	7.99	6.72	18.25	15.03	106,403	86,811	4,670	3,985	0.87	0.98
1998/99	8.90	11.40	9.82	9.43	25.77	23.09	83,378	35,975	3,616	1,876	1.00	1.09
1999/00	9.00	6.30	10.28	6.09	20.77	14.49	79,129	107,040	3,851	4,523	0.92	0.91
2000/01	9.90	7.00	10.40	6.46	25.39	16.64	71,551	101,239	5,043	4,740	0.82	0.84
2001/02	11.70	6.50	11.73	6.04	22.48	14.66	62,639	105,512	4,626	4,454	1.04	0.82
2002/03	12.40	8.40	12.70	7.47	22.59	17.37	52,042	78,979	3,980	2,509	1.10	0.91
2003/04	10.90	10.20	11.34	9.33	19.43	18.17	58,883	66,236	3,960	3,334	0.97	1.16
2004/05	18.30	12.10	18.34	11.14	28.48	22.45	34,848	56,846	2,206	2,619	1.44	1.25
2005/06	25.40	21.20	29.52	23.89	38.55	36.23	24,569	30,116	1,193	1,365	0.98	1.16
2006/07	24.80	19.60	25.13	23.93	33.39	33.47	26,195	26,870	1,098	1,183	0.80	1.10
2007/08	28.00	20.00	31.10	21.01	40.38	32.46	22,653	29,950	998	1,082	0.89	1.02
2008/09	27.30	22.40	29.97	24.50	38.23	38.16	24,466	26,200	613	979	0.87	1.13
2009/10	25.90	23.70	26.60	26.54	35.88	34.08	26,298	26,489	408	892	0.72	1.20
2010/11	26.00	20.90	26.40	22.43	37.10	29.05	25,851	29,994	436	867	0.75	1.06
2011/12	37.30	23.40	39.48	23.63	52.04	31.13	17,915	26,326	361	837	1.07	1.10
2012/13	33.02	20.57	37.82	22.88	47.57	30.76	20,827	32,716	438	1,109	1.03	1.11
2013/14	33.67	16.42	35.94	16.89	46.16	25.01	21,388	41,835	499	1,223	1.01	0.82
2014/15	42.29	15.29	47.01	15.25	60.00	22.67	17,002	41,548	376	1,137	1.33	0.77
2015/16	39.41	14.97	43.27	15.81	58.68	22.14	19,376	41,108	478	1,296	1.26	0.76
2016/17	32.45	14.29	36.89	16.65	52.82	24.41	24,470	38,118	617	1,060	1.06	0.88
2017/18	31.46	16.81	35.18	19.30	54.62	25.54	25,516	30,885	585	760	1.01	1.00
2018/19	36.80	19.83	41.57	22.90	62.97	30.69	25,553	29,156	475	688	1.24	1.23
2019/20	34.11	15.10	40.88	16.30	57.46	22.73	30,998	42,963	540	967	1.15	0.95
2020/21	30.00	14.61	36.15	15.71	57.21	22.82	30,072	46,701	567	1,137	1.05	0.89

Table 4. Time series of negative binomial GLM estimated CPUE indices and coefficient of variation (CV) for the fish ticket based retained catch-per-pot lift for the EAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data.

Year	CPUE Index	CV
1985/86	1.63	0.03
1986/87	1.23	0.04
1987/88	0.96	0.05
1988/89	1.04	0.04
1989/90	1.08	0.03
1990/91	0.99	0.05
1991/92	0.90	0.05
1992/93	0.92	0.05
1993/94	0.91	0.05
1994/95	0.81	0.05
1995/96	0.78	0.06
1996/97	0.78	0.06
1997/98	1.05	0.04
1998/99	1.21	0.04

Table 5. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 21.1a fit to EAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	57	49				
1986/87	11	9				
1987/88	61	53				
1988/89	352	304				
1989/90	792	683			9	4
1990/91	163	141	22	13	13	6
1991/92	140	121	48	29	NA	NA
1992/93	49	42	41	24	2	1
1993/94	340	293	NA	NA	2	1
1994/95	319	275	34	20	4	2
1995/96	879	758	1,117	665	5	2
1996/97	547	472	509	303	4	2
1997/98	538	464	711	423	8	4
1998/99	541	467	574	342	15	7
1999/00	463	399	607	361	14	7
2000/01	436	376	495	295	16	8
2001/02	488	421	510	303	13	6
2002/03	406	350	438	261	15	7
2003/04	405	349	416	248	17	8
2004/05	280	242	299	178	10	5
2005/06	266	230	232	138	12	6
2006/07	234	202	143	85	14	7
2007/08	199	172	134	80	17	8
2008/09	197	170	113	67	15	7
2009/10	170	147	95	57	16	8
2010/11	183	158	108	64	26	13
2011/12	160	138	107	64	13	6
2012/13	187	161	99	59	18	9
2013/14	193	167	122	73	17	8
2014/15	168	145	99	59	16	8
2015/16	190	164	125	74	10	5
2016/17	223	192	155	92	12	6
2017/18	213	184	133	79	12	6
2018/19	218	188	234	139	9	4
2019/20	214	185	148	88	8	4
2020/21	227	196	155	92	6	3

Table 6. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 21.1b fit to EAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	57	47				
1986/87	11	9				
1987/88	61	50				
1988/89	352	291				
1989/90	792	654			9	4
1990/91	163	135	22	13	13	6
1991/92	140	116	48	28	NA	NA
1992/93	49	40	41	24	2	1
1993/94	340	281	NA	NA	2	1
1994/95	319	264	34	20	4	2
1995/96	879	726	1,117	653	5	2
1996/97	547	452	509	298	4	2
1997/98	538	445	711	416	8	4
1998/99	541	447	574	336	15	7
1999/00	463	383	607	355	14	7
2000/01	436	360	495	290	16	8
2001/02	488	403	510	298	13	6
2002/03	406	335	438	256	15	7
2003/04	405	335	416	243	17	8
2004/05	280	231	299	175	10	5
2005/06	266	220	232	136	12	6
2006/07	234	193	143	84	14	7
2007/08	199	164	134	78	17	8
2008/09	197	163	113	66	15	7
2009/10	170	140	95	56	16	8
2010/11	183	151	108	63	26	12
2011/12	160	132	107	63	13	6
2012/13	187	155	99	58	18	9
2013/14	193	159	122	71	17	8
2014/15	168	139	99	58	16	8
2015/16	190	157	125	73	10	5
2016/17	223	184	155	91	12	6
2017/18	213	176	133	78	12	6
2018/19	218	180	234	137	9	4
2019/20	214	177	148	87	8	4
2020/21	227	188	155	91	6	3

Table 7. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 21.1c fit to EAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	57	48				
1986/87	11	9				
1987/88	61	52				
1988/89	352	298				
1989/90	792	670			9	4
1990/91	163	138	22	13	13	6
1991/92	140	119	48	29	NA	NA
1992/93	49	41	41	24	2	1
1993/94	340	288	NA	NA	2	1
1994/95	319	270	34	20	4	2
1995/96	879	744	1,117	665	5	2
1996/97	547	463	509	303	4	2
1997/98	538	455	711	423	8	4
1998/99	541	458	574	342	15	7
1999/00	463	392	607	361	14	7
2000/01	436	369	495	295	16	8
2001/02	488	413	510	304	13	6
2002/03	406	344	438	261	15	7
2003/04	405	343	416	248	17	8
2004/05	280	237	299	178	10	5
2005/06	266	225	232	138	12	6
2006/07	234	198	143	85	14	7
2007/08	199	168	134	80	17	8
2008/09	197	167	113	67	15	7
2009/10	170	144	95	57	16	8
2010/11	183	155	108	64	26	13
2011/12	160	135	107	64	13	6
2012/13	187	158	99	59	18	9
2013/14	193	163	122	73	17	8
2014/15	168	142	99	59	16	8
2015/16	190	161	125	74	10	5
2016/17	223	189	155	92	12	6
2017/18	213	180	133	79	12	6
2018/19	218	185	234	139	9	4
2019/20	214	181	148	88	8	4
2020/21	227	192	155	92	6	3

Table 8. Parameter estimates and coefficient of variations (CV) with the 2020 MMB (MMB estimated on 15 Feb 2021) for models 19.1, 21.1a, 21.1b, and 21.1c for the golden king crab data from the EAG, 1985/86–2020/21. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

Parameter	Model 19.1		Model 21.1a		Model 21.1b		Model 21.1c		
	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
$\log\_\omega_1$ (growth incr. intercept)	2.538	0.01	2.538	0.01	2.539	0.01	2.538	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-8.175	0.21	-8.175	0.21	-8.079	0.21	-8.166	0.21	-12.0-5.0
$\log\_a$ (molt prob. slope)	-2.508	0.02	-2.508	0.02	-2.520	0.02	-2.509	0.02	-4.61-1.39
$\log\_b$ (molt prob. L50)	4.949	0.001	4.949	0.001	4.949	0.001	4.949	0.001	3.869,5.05
σ (growth variability std)	3.676	0.03	3.676	0.03	3.679	0.03	3.676	0.03	0.1,12.0
$\log\_$total sel deltaθ, 1985–04	3.384	0.02	3.384	0.02	3.397	0.02	3.390	0.02	0.,4.4
$\log\_$ total sel deltaθ, 2005–20	2.989	0.02	2.989	0.02	3.070	0.03	2.989	0.02	0.,4.4
$\log\_$ total sel deltaθ, 2016–20					2.909	0.04			0.,4.4
$\log\_$ ret. sel deltaθ, 1985–20	1.859	0.02	1.859	0.02	1.857	0.02	1.860	0.02	0.,4.4
$\log\_$tot sel θ_{50}, 1985–04	4.835	0.002	4.835	0.002	4.838	0.003	4.836	0.002	4.0,5.0
$\log\_$tot sel θ_{50}, 2005–20	4.919	0.002	4.919	0.002	4.934	0.002	4.918	0.002	4.0,5.0
$\log\_$tot sel θ_{50}, 2016–20					4.899	0.002			4.0,5.0
$\log\_$ret. sel θ_{50}, 1985–20	4.915	0.0003	4.915	0.0003	4.915	0.0003	4.915	0.0003	4.0,5.0
$\log\_\beta_r$ (rec.distribution par.)	-1.080	0.17	-1.080	0.17	-1.076	0.17	-1.079	0.17	-12.0, 12.0
logq2 (catchability 1995–04)	-0.547	0.13	-0.547	0.13	-0.530	0.13	-0.557	0.12	-9.0, 2.25
logq3 (catchability 2005–20)	-0.743	0.16	-0.743	0.16	-0.691	0.17	-0.713	0.15	-9.0, 2.25
$\log\_$mean_rec (mean rec.)	0.840	0.05	0.840	0.05	0.825	0.05	0.840	0.05	0.01, 5.0
$\log\_$mean_Fpot (Pot fishery F)	-0.959	0.07	-0.959	0.07	-0.921	0.08	-0.958	0.07	-15.0, -0.01
$\log\_$mean_Fground (GF byc. F)	-9.155	0.08	-9.155	0.08	-9.128	0.08	-9.155	0.08	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.058	0.36	0.058	0.36	0.035	0.38	0.018	0.64	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.033	0.44	0.033	0.44	0.034	0.44	0.034	0.44	0.0,1.0
2020 MMB	9,778	0.22	9,819	0.22	8,450	0.20	9,721	0.19	

Table 9. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 19.1 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB_{eq} =22,976			
		$MMB_{35\%}$=6,696			
1985	1.71	9,543	0.04	9,694	0.05
1986	1.01	7,321	0.04	8,224	0.04
1987	4.31	6,730	0.05	6,447	0.04
1988	3.60	6,762	0.05	5,392	0.05
1989	2.02	5,910	0.06	4,854	0.07
1990	2.90	6,003	0.05	4,389	0.06
1991	3.50	6,067	0.04	4,673	0.06
1992	2.25	5,985	0.04	4,485	0.05
1993	2.15	6,130	0.03	4,499	0.05
1994	2.44	5,658	0.04	4,917	0.03
1995	2.322	5,076	0.04	4,470	0.04
1996	2.25	5,196	0.04	3,865	0.04
1997	3.04	5,465	0.05	4,006	0.04
1998	2.80	6,047	0.05	4,122	0.05
1999	2.91	6,731	0.06	4,565	0.05
2000	2.71	7,341	0.06	5,235	0.06
2001	2.04	7,689	0.06	5,864	0.06
2002	2.53	7,956	0.07	6,396	0.07
2003	2.18	8,191	0.07	6,727	0.07
2004	1.89	8,215	0.07	6,944	0.07
2005	2.81	8,233	0.07	7,087	0.08
2006	2.17	8,411	0.07	6,974	0.08
2007	2.10	8,389	0.07	7,068	0.08
2008	3.04	8,476	0.07	7,174	0.08
2009	1.98	8,676	0.06	7,104	0.08
2010	1.84	8,472	0.06	7,305	0.07
2011	2.15	8,188	0.06	7,353	0.06
2012	1.86	7,876	0.06	7,092	0.06
2013	1.60	7,360	0.06	6,775	0.06
2014	2.71	7,019	0.06	6,374	0.06
2015	2.73	7,074	0.07	5,870	0.06
2016	2.92	7,280	0.08	5,654	0.07
2017	3.46	7809	0.10	5,755	0.08
2018	4.27	8,588	0.14	6,114	0.10
2019	3.19	9,307	0.19	6,571	0.13
2020	2.56	9,778	0.22	7,291	0.19
2021	2.32				

Table 10. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1a for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,203 $MMB_{35\%}$=6,762			
1985	1.71	9,543	0.04	9,695	0.05
1986	1.01	7,321	0.04	8,224	0.04
1987	4.31	6,730	0.05	6,447	0.04
1988	3.60	6,762	0.05	5,392	0.05
1989	2.02	5,911	0.06	4,854	0.07
1990	2.90	6,003	0.05	4,389	0.06
1991	3.50	6,067	0.04	4,673	0.06
1992	2.25	5,985	0.04	4,486	0.05
1993	2.15	6,130	0.03	4,499	0.05
1994	2.44	5,658	0.04	4,917	0.03
1995	2.32	5,076	0.04	4,470	0.04
1996	2.25	5,196	0.04	3,865	0.04
1997	3.04	5,465	0.05	4,006	0.04
1998	2.80	6,048	0.05	4,122	0.05
1999	2.91	6,731	0.06	4,565	0.05
2000	2.71	7,341	0.06	5,235	0.06
2001	2.04	7,689	0.06	5,864	0.06
2002	2.53	7,956	0.07	6,396	0.07
2003	2.18	8,191	0.07	6,727	0.07
2004	1.89	8,215	0.07	6,944	0.07
2005	2.81	8,233	0.07	7,088	0.08
2006	2.17	8,411	0.07	6,974	0.08
2007	2.10	8,389	0.07	7,068	0.08
2008	3.04	8,476	0.07	7,174	0.08
2009	1.98	8,676	0.06	7,104	0.08
2010	1.84	8,472	0.06	7,305	0.07
2011	2.15	8,188	0.06	7,353	0.06
2012	1.86	7,876	0.06	7,091	0.06
2013	1.59	7,360	0.06	6,775	0.06
2014	2.71	7,018	0.06	6,374	0.06
2015	2.73	7,073	0.07	5,870	0.06
2016	2.92	7,279	0.08	5,653	0.07
2017	3.46	7,807	0.10	5,754	0.08
2018	4.27	8,584	0.14	6,113	0.10
2019	3.19	9,301	0.19	6,568	0.13
2020	2.56	9,771	0.22	7,287	0.19
2021	2.32				

Table 11. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1b for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMBeq and MMB$_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB$_{eq}$ =22,944			
		MMB$_{35\%}$=6,649			
1985	1.70	9,509	0.04	9,650	0.06
1986	1.01	7,290	0.04	8,186	0.04
1987	4.30	6,703	0.05	6,412	0.04
1988	3.62	6,737	0.05	5,363	0.05
1989	2.01	5,890	0.06	4,818	0.07
1990	2.92	5,985	0.05	4,355	0.07
1991	3.49	6,053	0.04	4,641	0.06
1992	2.25	5,971	0.04	4,460	0.05
1993	2.15	6,119	0.03	4,474	0.05
1994	2.43	5,645	0.03	4,895	0.03
1995	2.29	5,051	0.04	4,450	0.04
1996	2.21	5,145	0.04	3,841	0.04
1997	2.96	5,372	0.05	3,963	0.04
1998	2.69	5,887	0.05	4,050	0.05
1999	2.79	6,489	0.05	4,441	0.05
2000	2.56	7,005	0.06	5,039	0.06
2001	1.93	7,260	0.06	5,586	0.06
2002	2.41	7,452	0.07	6,026	0.06
2003	2.12	7,636	0.07	6,280	0.07
2004	1.85	7,654	0.07	6,433	0.07
2005	2.77	7,686	0.07	6,551	0.08
2006	2.12	7,885	0.07	6,448	0.08
2007	2.07	7,889	0.07	6,565	0.08
2008	3.11	8,033	0.07	6,696	0.08
2009	2.09	8,349	0.07	6,658	0.08
2010	1.93	8,283	0.06	6,936	0.07
2011	2.30	8,140	0.06	7,108	0.07
2012	2.04	7,991	0.06	6,981	0.06
2013	1.77	7,641	0.06	6,808	0.06
2014	2.51	7,355	0.06	6,563	0.06
2015	2.67	7,313	0.07	6,197	0.07
2016	2.79	7,414	0.07	5,947	0.07
2017	3.11	7,743	0.09	5,937	0.08
2018	3.43	8,097	0.12	6,153	0.09
2019	2.70	8,248	0.17	6,349	0.11
2020	2.51	8,402	0.20	6,561	0.16
2021	2.28				

Table 12. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1c for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMBeq and MMB$_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB$_{eq}$ =23,190			
		MMB$_{35\%}$=6,754			
1985	1.71	9,557	0.04	9,718	0.06
1986	1.02	7,332	0.04	8,241	0.04
1987	4.32	6,744	0.05	6,456	0.04
1988	3.58	6,776	0.05	5,401	0.05
1989	2.03	5,918	0.06	4,865	0.07
1990	2.89	6,008	0.05	4,396	0.06
1991	3.49	6,064	0.04	4,678	0.06
1992	2.22	5,973	0.04	4,485	0.05
1993	2.14	6,105	0.03	4,491	0.05
1994	2.44	5,628	0.03	4,898	0.03
1995	2.32	5,050	0.04	4,440	0.04
1996	2.25	5,173	0.04	3,837	0.04
1997	3.03	5,443	0.05	3,980	0.04
1998	2.80	6,024	0.05	4,100	0.05
1999	2.92	6,713	0.05	4,541	0.05
2000	2.70	7,327	0.06	5,212	0.06
2001	2.05	7,675	0.06	5,848	0.06
2002	2.55	7,950	0.06	6,380	0.06
2003	2.14	8,186	0.07	6,714	0.06
2004	1.86	8,193	0.07	6,940	0.07
2005	2.78	8,188	0.07	7,076	0.07
2006	2.17	8,348	0.07	6,944	0.07
2007	2.11	8,330	0.07	7,013	0.07
2008	3.03	8,424	0.07	7,111	0.07
2009	2.00	8,634	0.06	7,048	0.07
2010	1.87	8,454	0.06	7,257	0.07
2011	2.21	8,205	0.06	7,320	0.06
2012	1.90	7,937	0.05	7,085	0.06
2013	1.60	7,447	0.06	6,810	0.06
2014	2.70	7,107	0.06	6,445	0.06
2015	2.73	7,149	0.07	5,957	0.06
2016	2.94	7,347	0.07	5,732	0.07
2017	3.41	7,859	0.09	5,817	0.08
2018	4.20	8,587	0.12	6,170	0.09
2019	3.17	9,258	0.16	6,595	0.11
2020	2.56	9,711	0.19	7,263	0.16
2021	2.32				

Table 13. Negative log-likelihood values of the fits for models 19.1 (last year's accepted model with additional 2020/21 data), 20.1a, 21.1b, and 21.1c for golden king crab in the EAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB = retained catch biomass.

Likelihood Component	Model 19.1	Model 21.1a	Model 21.1b	Model 21.1c	21.1a-19.1	21.1b-19.1	21.1c-19.1
Number of free parameters	152	152	154	152			
Retlencomp	-1334.9600	-1335.0100	-1325.3100	-1331.2300	-0.0500	9.6500	3.7300
Totallencomp	-1486.6000	-1486.4300	-1481.24000	-1486.8700	0.1700	5.3600	-0.2700
Observer cpue	0.1376	0.1459	-6.6334	-6.3334	0.0083	-6.7710	-6.471
RetdcatchB	7.6797	7.6806	7.5861	7.8856	0.0009	-0.0936	0.2059
TotalcatchB	23.7070	23.7333	23.5648	23.7643	0.0263	-0.1422	0.0573
GdiscdcatchB	0.0003	0.0003	0.0003	0.0003	0	0	0
Rec_dev	6.8557	6.8828	5.7494	6.7044	0.0271	-1.1063	-0.1513
Pot F_dev	0.0128	0.0128	0.0120	0.0128	0	-0.0008	0
Gbyc_F_dev	0.0267	0.0267	0.0261	0.0265	0	-0.0006	-0.0002
Tag	2692.6000	2692.6000	2692.9000	2692.5700	0	0.3000	-0.0300
Fishery cpue	-3.5625	-3.5620	-3.3091	-3.2836	0.0005	0.2534	0.2789
RetcatchN	0.0062	0.0062	0.0058	0.0061	0	-0.0004	-0.0001
Total	-94.0875	-93.9058	-86.6354	-96.7234	0.1817	7.4521	-2.6359

Table 14. Time series of negative binomial GLM estimated CPUE indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data. GLM predictor variables were selected by R square criteria.

Year	CPUE Index	CV
1985/86	2.07	0.02
1986/87	1.59	0.03
1987/88	1.22	0.04
1988/89	1.41	0.02
1989/90	1.15	0.02
1990/91	0.87	0.04
1991/92	0.76	0.05
1992/93	0.61	0.07
1993/94	0.76	0.07
1994/95	0.83	0.04
1995/96	0.90	0.04
1996/97	0.84	0.04
1997/98	0.76	0.04
1998/99	1.06	0.03

Table 15. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 21.1a model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	24				
1986/87	23	12				
1987/88	8	4				
1988/89	286	153				
1989/90	513	275			7	5
1990/91	205	110	190	93	6	4
1991/92	102	55	104	51	1	1
1992/93	76	41	94	46	3	2
1993/94	378	203	62	30	NA	NA
1994/95	367	197	119	58	2	1
1995/96	705	378	907	444	5	3
1996/97	817	438	1,061	520	8	5
1997/98	984	528	1,116	547	6	4
1998/99	613	329	638	312	14	9
1999/00	915	491	1,155	566	18	12
2000/01	1,029	552	1,205	590	11	7
2001/02	898	482	975	477	11	7
2002/03	628	337	675	331	16	10
2003/04	688	369	700	343	8	5
2004/05	449	241	488	239	9	6
2005/06	337	181	220	108	6	4
2006/07	337	181	321	157	14	9
2007/08	276	148	257	126	17	11
2008/09	318	171	258	126	19	12
2009/10	362	194	292	143	24	16
2010/11	328	176	222	109	13	8
2011/12	295	158	252	123	14	9
2012/13	288	155	241	118	18	12
2013/14	327	176	236	116	17	11
2014/15	305	164	219	107	18	12
2015/16	287	154	243	119	10	6
2016/17	392	210	253	124	12	8
2017/18	299	160	222	109	10	6
2018/19	328	176	318	156	5	3
2019/20	338	11	224	110	6	4
2020/21	462	248	302	148	7	5

Table 16. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 21.1b model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	24				
1986/87	23	12				
1987/88	8	4				
1988/89	286	154				
1989/90	513	276			7	5
1990/91	205	110	190	94	6	4
1991/92	102	55	104	51	1	1
1992/93	76	41	94	46	3	2
1993/94	378	203	62	31	NA	NA
1994/95	367	198	119	59	2	1
1995/96	705	379	907	447	5	3
1996/97	817	440	1,061	523	8	5
1997/98	984	530	1,116	550	6	4
1998/99	613	330	638	315	14	9
1999/00	915	492	1,155	569	18	12
2000/01	1,029	554	1,205	594	11	7
2001/02	898	483	975	481	11	7
2002/03	628	338	675	333	16	10
2003/04	688	370	700	345	8	5
2004/05	449	242	488	241	9	6
2005/06	337	181	220	108	6	4
2006/07	337	181	321	158	14	9
2007/08	276	149	257	127	17	11
2008/09	318	171	258	127	19	12
2009/10	362	195	292	144	24	16
2010/11	328	177	222	109	13	8
2011/12	295	159	252	124	14	9
2012/13	288	155	241	119	18	12
2013/14	327	176	236	116	17	11
2014/15	305	164	219	108	18	12
2015/16	287	154	243	120	10	6
2016/17	392	211	253	125	12	8
2017/18	299	161	222	109	10	6
2018/19	328	177	318	157	5	3
2019/20	338	182	224	110	6	4
2020/21	462	249	302	149	7	5

Table 17. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 21.1c model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	24				
1986/87	23	12				
1987/88	8	4				
1988/89	286	154				
1989/90	513	276			7	5
1990/91	205	110	190	96	6	4
1991/92	102	55	104	52	1	1
1992/93	76	41	94	47	3	2
1993/94	378	203	62	31	NA	NA
1994/95	367	197	119	60	2	1
1995/96	705	379	907	456	5	3
1996/97	817	439	1,061	534	8	5
1997/98	984	529	1,116	562	6	4
1998/99	613	330	638	321	14	9
1999/00	915	492	1,155	581	18	12
2000/01	1,029	553	1,205	606	11	7
2001/02	898	483	975	491	11	7
2002/03	628	338	675	340	16	10
2003/04	688	370	700	352	8	5
2004/05	449	241	488	246	9	6
2005/06	337	181	220	111	6	4
2006/07	337	181	321	162	14	9
2007/08	276	148	257	129	17	11
2008/09	318	171	258	130	19	12
2009/10	362	195	292	147	24	16
2010/11	328	176	222	112	13	8
2011/12	295	159	252	127	14	9
2012/13	288	155	241	121	18	12
2013/14	327	176	236	119	17	11
2014/15	305	164	219	110	18	12
2015/16	287	154	243	122	10	7
2016/17	392	211	253	127	12	8
2017/18	299	161	222	112	10	7
2018/19	328	176	318	160	5	3
2019/20	338	182	224	113	6	4
2020/21	462	248	302	152	7	5

Table 18. Parameter estimates and coefficient of variations (CV) with the 2020 MMB (MMB estimated on 15 Feb 2021) for models 19.1, 21.1a, 21.1b, and 21.1c for the golden king crab data from the WAG, 1985/86–2020/21. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

Parameter	Model 19.1		Model 21.1a		Model 21.1b		Model 21.1c		
	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.539	0.01	2.539	0.01	2.539	0.01	2.539	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-7.451	0.23	-7.451	0.23	-7.445	0.23	-7.425	0.23	-12.0-5.0
log_a (molt prob. slope)	-2.646	0.03	-2.646	0.03	-2.647	0.03	-2.648	0.03	-4.61-1.39
log_b (molt prob. L50)	4.948	0.00	4.948	0.001	4.948	0.001	4.948	0.001	3.869,5.05
σ (growth variability std)	3.691	0.03	3.691	0.03	3.691	0.03	3.692	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.405	0.01	3.405	0.01	3.406	0.01	3.408	0.01	0.,4.4
log_ total sel deltaθ, 2005–20	2.883	0.02	2.883	0.02	2.901	0.03	2.885	0.02	0.,4.4
log_ total sel deltaθ, 2016–20					2.853	0.03			0.,4.4
log_ ret. sel deltaθ, 1985–20	1.784	0.02	1.784	0.02	1.784	0.02	1.785	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.870	0.002	4.870	0.002	4.870	0.002	4.870	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–20	4.901	0.001	4.901	0.001	4.901	0.002	4.901	0.001	4.0,5.0
log_tot sel θ_{50}, 2016–20					4.902	0.002			4.0,5.0
log_ret. sel θ_{50}, 1985–20	4.915	0.0002	4.915	0.0002	4.915	0.0002	4.915	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.031	0.16	-1.031	0.16	-1.031	0.16	-1.029	0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.031	2.24	-0.031	2.24	-0.030	2.32	-0.036	1.89	-9.0, 2.25
logq3 (catchability 2005–20)	-0.405	0.21	-0.405	0.21	-0.402	0.21	-0.387	0.22	-9.0, 2.25
log_mean_rec (mean rec.)	0.714	0.05	0.714	0.05	0.715	0.06	0.706	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.709	0.09	-0.709	0.09	-0.707	0.09	-0.700	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.370	0.09	-8.370	0.09	-8.371	0.09	-8.361	0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.018	0.34	0.018	0.34	0.018	0.34	0.021	0.37	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.025	0.60	0.025	0.60	0.026	0.59	0.025	0.57	0.0,1.0
2020 MMB	5,624	0.15	5,662	0.15	5,770	0.17	5,175	0.16	

Table 19. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 19.1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB_{eq}=18,253 $MMB_{35\%}$=5,300			
1985	4.00	10,945	0.05	9,025	0.10
1986	3.45	8,906	0.04	8,474	0.08
1987	2.65	7,945	0.04	5,994	0.06
1988	1.86	6,843	0.04	5,601	0.05
1989	2.54	4,965	0.04	4,942	0.04
1990	1.93	4,421	0.04	3,107	0.06
1991	1.62	4,137	0.04	2,845	0.05
1992	2.02	4,201	0.04	2,793	0.05
1993	1.59	4,703	0.03	2,947	0.05
1994	1.95	4,187	0.03	3,524	0.03
1995	1.89	4,089	0.03	2,842	0.03
1996	1.73	3,966	0.04	2,776	0.04
1997	1.85	4,028	0.04	2,813	0.04
1998	1.89	4,329	0.03	2,893	0.04
1999	2.24	4,328	0.04	3,174	0.03
2000	2.50	4,430	0.04	3,108	0.04
2001	2.56	4,867	0.05	3,108	0.04
2002	2.51	5,426	0.05	3,432	0.05
2003	1.77	5,762	0.05	3,956	0.05
2004	2.29	5,880	0.06	4,456	0.05
2005	2.33	6,178	0.06	4,657	0.06
2006	2.46	6,712	0.05	4,839	0.06
2007	1.73	6,903	0.05	5,292	0.06
2008	1.52	6,730	0.05	5,597	0.06
2009	1.97	6,373	0.05	5,662	0.05
2010	1.66	6,124	0.05	5,318	0.05
2011	1.19	5,658	0.05	5,039	0.05
2012	1.99	5,108	0.05	4,730	0.05
2013	2.42	4,968	0.06	4,148	0.05
2014	1.82	5,162	0.06	3,732	0.06
2015	1.89	5,278	0.06	3,886	0.06
2016	1.66	5,459	0.06	4,109	0.06
2017	1.86	5,574	0.07	4,368	0.06
2018	2.08	5,653	0.08	4,506	0.07
2019	1.87	5,635	0.11	4,495	0.08
2020	2.29	5,624	0.15	4,446	0.11
2021	2.04				

Table 20. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1a for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB_{eq} =18,137			
		$MMB_{35\%}$=5,267			
1985	4.00	10,945	0.05	9,025	0.10
1986	3.45	8,905	0.04	8,474	0.08
1987	2.65	7,945	0.04	5,994	0.06
1988	1.86	6,843	0.04	5,601	0.05
1989	2.54	4,965	0.04	4,942	0.04
1990	1.93	4,421	0.04	3,107	0.06
1991	1.62	4,137	0.04	2,845	0.05
1992	2.02	4,201	0.04	2,793	0.05
1993	1.59	4,703	0.03	2,947	0.05
1994	1.95	4,187	0.03	3,524	0.03
1995	1.89	4,089	0.03	2,842	0.03
1996	1.73	3,966	0.04	2,776	0.04
1997	1.85	4,028	0.04	2,813	0.04
1998	1.89	4,329	0.03	2,893	0.04
1999	2.24	4,328	0.04	3,174	0.03
2000	2.50	4,430	0.04	3,108	0.04
2001	2.56	4,867	0.05	3,108	0.04
2002	2.51	5,426	0.05	3,432	0.05
2003	1.77	5,762	0.05	3,955	0.05
2004	2.29	5,880	0.06	4,456	0.05
2005	2.33	6,178	0.06	4,657	0.06
2006	2.46	6,712	0.05	4,839	0.06
2007	1.73	6,903	0.05	5,292	0.06
2008	1.52	6,730	0.05	5,597	0.06
2009	1.97	6,373	0.05	5,662	0.05
2010	1.66	6,124	0.05	5,318	0.05
2011	1.19	5,658	0.05	5,039	0.05
2012	1.99	5,108	0.05	4,730	0.05
2013	2.42	4,968	0.06	4,148	0.05
2014	1.82	5,162	0.06	3,732	0.06
2015	1.89	5,277	0.06	3,886	0.06
2016	1.66	5,459	0.06	4,109	0.06
2017	1.86	5,573	0.07	4,367	0.06
2018	2.08	5,652	0.08	4,506	0.07
2019	1.87	5,634	0.11	4,495	0.08
2020	2.29	5,622	0.15	4,445	0.11
2021	2.04				

Table 21. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1b for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB_{eq} =18,133 $MMB_{35\%}$=5,267			
1985	3.99	10,949	0.05	9,029	0.10
1986	3.46	8,908	0.04	8,478	0.08
1987	2.65	7,946	0.04	5,996	0.06
1988	1.86	6,844	0.04	5,601	0.05
1989	2.54	4,966	0.04	4,942	0.04
1990	1.93	4,422	0.04	3,107	0.06
1991	1.62	4,138	0.04	2,844	0.05
1992	2.02	4,202	0.04	2,793	0.05
1993	1.59	4,703	0.03	2,947	0.05
1994	1.95	4,186	0.03	3,523	0.03
1995	1.89	4,088	0.03	2,840	0.03
1996	1.73	3,965	0.04	2,774	0.03
1997	1.85	4,027	0.04	2,811	0.04
1998	1.89	4,329	0.03	2,891	0.04
1999	2.24	4,328	0.04	3,173	0.03
2000	2.51	4,432	0.04	3,107	0.04
2001	2.56	4,869	0.05	3,107	0.04
2002	2.51	5,429	0.05	3,432	0.05
2003	1.77	5,768	0.05	3,956	0.05
2004	2.29	5,888	0.06	4,458	0.05
2005	2.32	6,184	0.06	4,662	0.06
2006	2.46	6,715	0.05	4,846	0.06
2007	1.74	6,909	0.05	5,295	0.06
2008	1.52	6,737	0.05	5,599	0.06
2009	1.97	6,379	0.05	5,667	0.05
2010	1.66	6,129	0.05	5,324	0.05
2011	1.19	5,663	0.05	5,043	0.05
2012	1.99	5,111	0.05	4,733	0.05
2013	2.40	4,965	0.06	4,151	0.05
2014	1.79	5,141	0.06	3,733	0.06
2015	1.91	5,247	0.06	3,877	0.06
2016	1.65	5,432	0.06	4,083	0.07
2017	1.87	5,549	0.07	4,339	0.07
2018	2.10	5,641	0.09	4,479	0.07
2019	1.96	5,656	0.13	4,475	0.09
2020	2.34	5,700	0.17	4,441	0.12
2021	3.99				

Table 22. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1c for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2021 are restricted to 1985–2021. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB_{eq} =18,036			
		$MMB_{35\%}$=5,240			
1985	3.99	10,953	0.05	9,026	0.10
1986	3.46	8,915	0.04	8,479	0.08
1987	2.65	7,956	0.04	5,999	0.06
1988	1.86	6,852	0.04	5,607	0.05
1989	2.53	4,970	0.04	4,949	0.04
1990	1.92	4,423	0.04	3,112	0.05
1991	1.62	4,136	0.04	2,847	0.05
1992	2.00	4,195	0.04	2,791	0.05
1993	1.57	4,685	0.03	2,943	0.05
1994	1.96	4,165	0.03	3,512	0.03
1995	1.89	4,074	0.03	2,819	0.03
1996	1.72	3,954	0.04	2,757	0.03
1997	1.87	4,020	0.04	2,799	0.04
1998	1.90	4,332	0.03	2,881	0.04
1999	2.24	4,339	0.04	3,169	0.03
2000	2.51	4,446	0.04	3,113	0.04
2001	2.54	4,878	0.05	3,118	0.04
2002	2.49	5,423	0.05	3,443	0.05
2003	1.75	5,743	0.05	3,958	0.05
2004	2.31	5,857	0.06	4,444	0.05
2005	2.39	6,180	0.06	4,633	0.06
2006	2.51	6,758	0.05	4,821	0.06
2007	1.72	6,978	0.05	5,304	0.06
2008	1.45	6,789	0.05	5,650	0.05
2009	1.92	6,388	0.05	5,730	0.05
2010	1.64	6,102	0.05	5,359	0.05
2011	1.18	5,616	0.05	5,036	0.05
2012	1.99	5,058	0.05	4,696	0.05
2013	2.41	4,917	0.06	4,099	0.05
2014	1.80	5,106	0.06	3,682	0.06
2015	1.85	5,207	0.06	3,835	0.06
2016	1.57	5,349	0.06	4,052	0.06
2017	1.73	5,394	0.07	4,289	0.06
2018	1.93	5,375	0.09	4,381	0.07
2019	1.74	5,253	0.12	4,293	0.08
2020	2.25	5,175	0.17	4,146	0.12
2021	2.03				

Table 23. Negative log-likelihood values of the fits for models 19.1 (last year's accepted model with additional 2020/21 data), 20.1a, 21.1b, and 21.1c for golden king crab in the WAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB = retained catch biomass.

Likelihood Component	Model 19.1	Model 21.1a	Model 21.1b	Model 21.1c	21.1a-19.1	21.1b-19.1	21.1c-19.1
Number of free parameters	152	152	154	152			
Retlencomp	-1302.9100	-1302.9200	-1303.5800	-1302.9900	-0.0100	-0.6700	-0.0800
Totallencomp	-1610.3300	-1610.3300	-1611.5700	-1616.1400	0	-1.2400	-5.8100
Observer cpue	-14.5204	-14.5207	-14.4723	-10.9203	-0.0003	0.0481	3.6001
RetdcatchB	5.0638	5.0636	5.0752	5.2114	-0.0002	0.0114	0.1476
TotalcatchB	45.2926	45.2930	45.3808	45.3805	0.0004	0.0882	0.0879
GdiscdcatchB	0.0014	0.0014	0.0014	0.0013	0	0	-0.0001
Rec_dev	4.5425	4.5426	4.5407	4.8163	0.0001	-0.0018	0.2738
Pot F_dev	0.0265	0.0265	0.0265	0.0265	0	0	0
Gbyc_F_dev	0.0434	0.0434	0.0435	0.0434	0	0001	0
Tag	2695.0800	2695.0800	2695.1200	2695.1700	0	0.0400	0.0900
Fishery cpue	-5.3819	-5.3821	-5.3481	-5.5096	-0.0002	0.0338	-0.1277
RetcatchN	0.0022	0.0022	0.0022	0.0020	0	0	-0.0002
Total	-183.0910	-183.0960	-184.7750	-184.9090	-0.0050	-1.6840	-1.8180
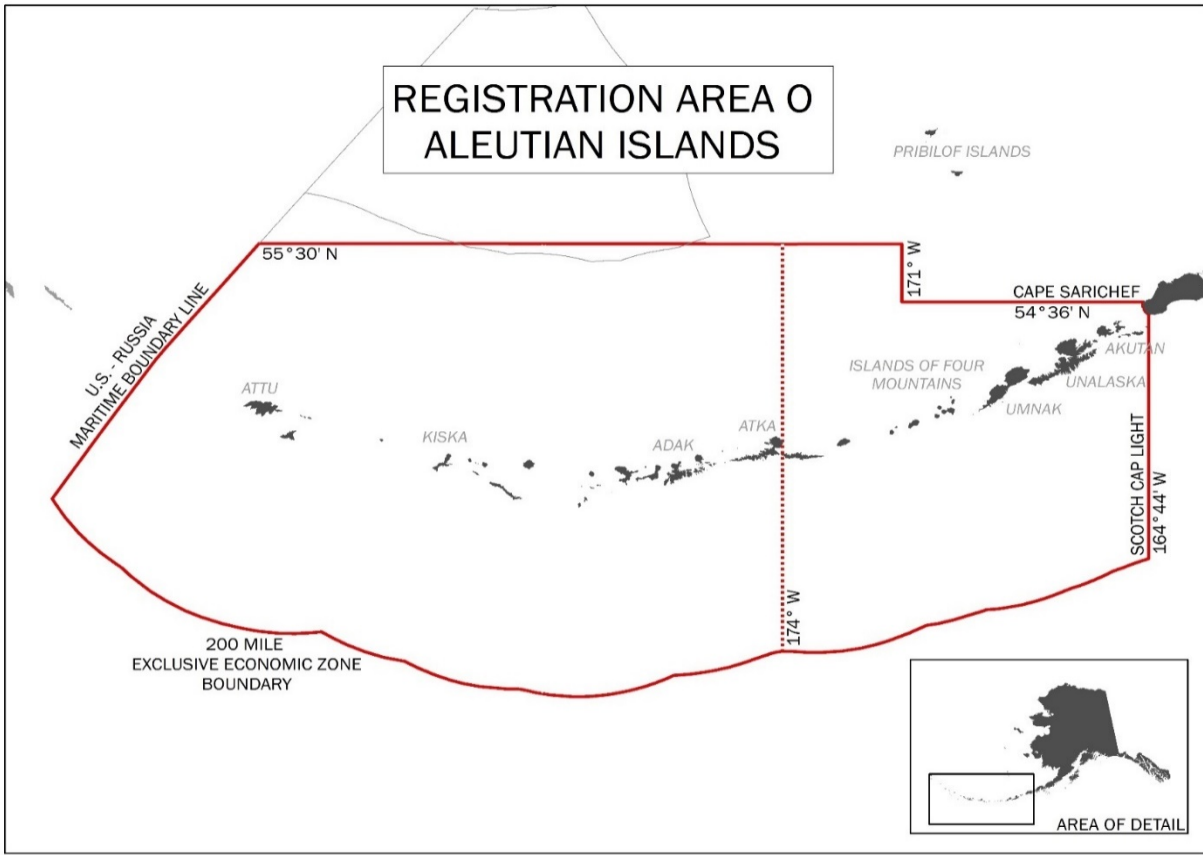
Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Nichols *et al.* 2021).
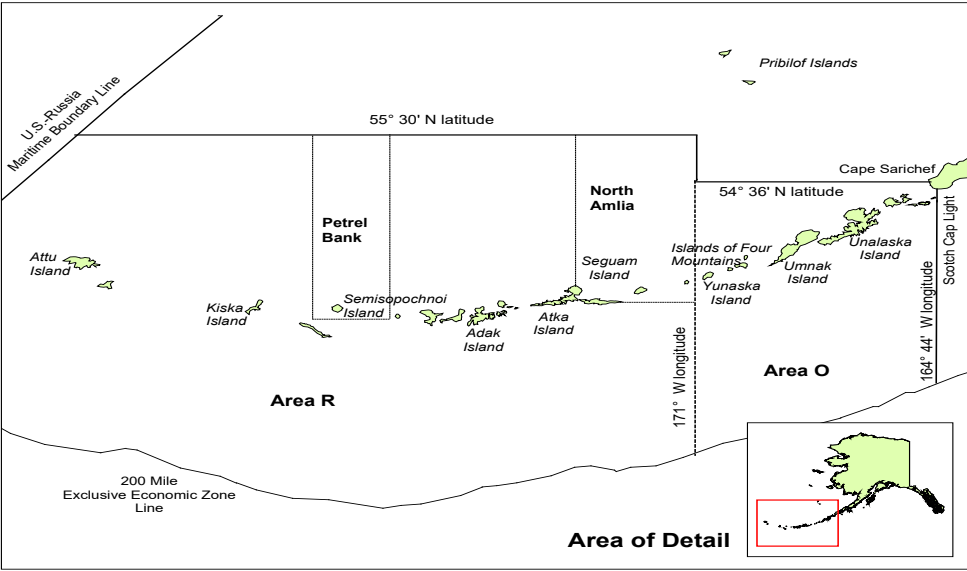
Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon *et al.* 2017).
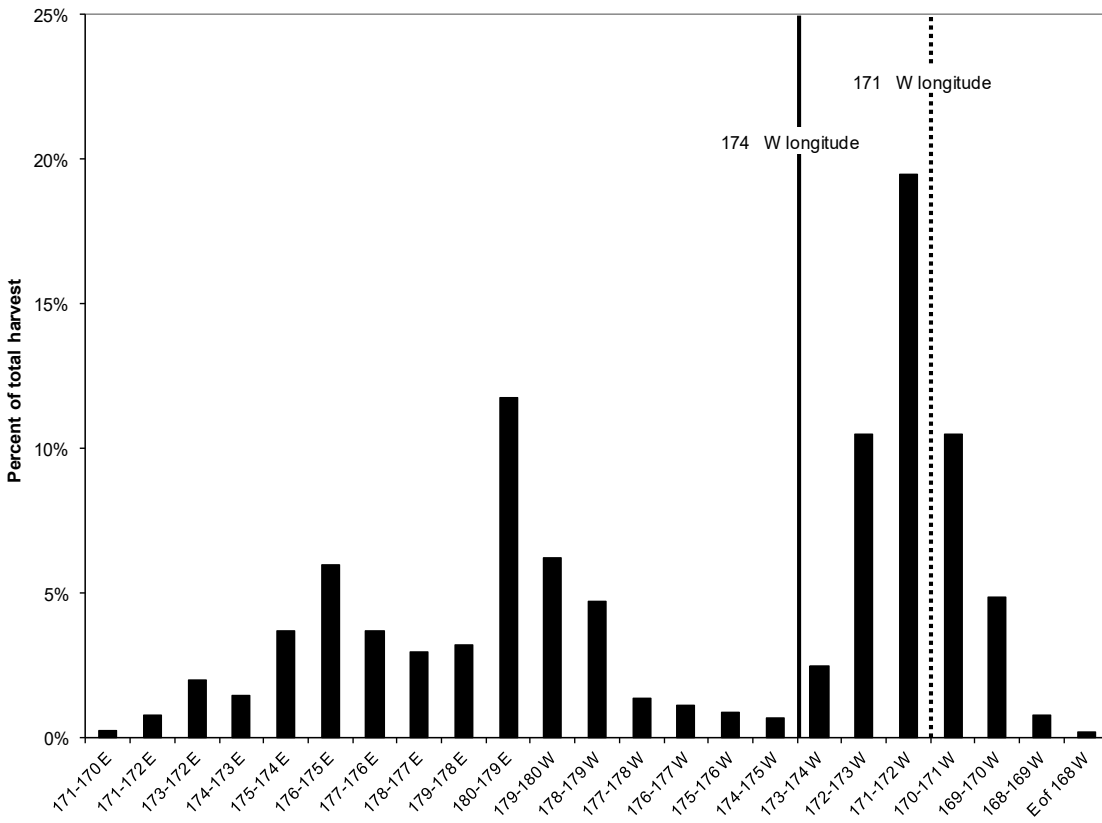
Figure 3. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude used since the 1996/97 season to manage crab east and west of 174° W longitude (adapted from Figure 4-2 in Morrison *et al.* 1998).
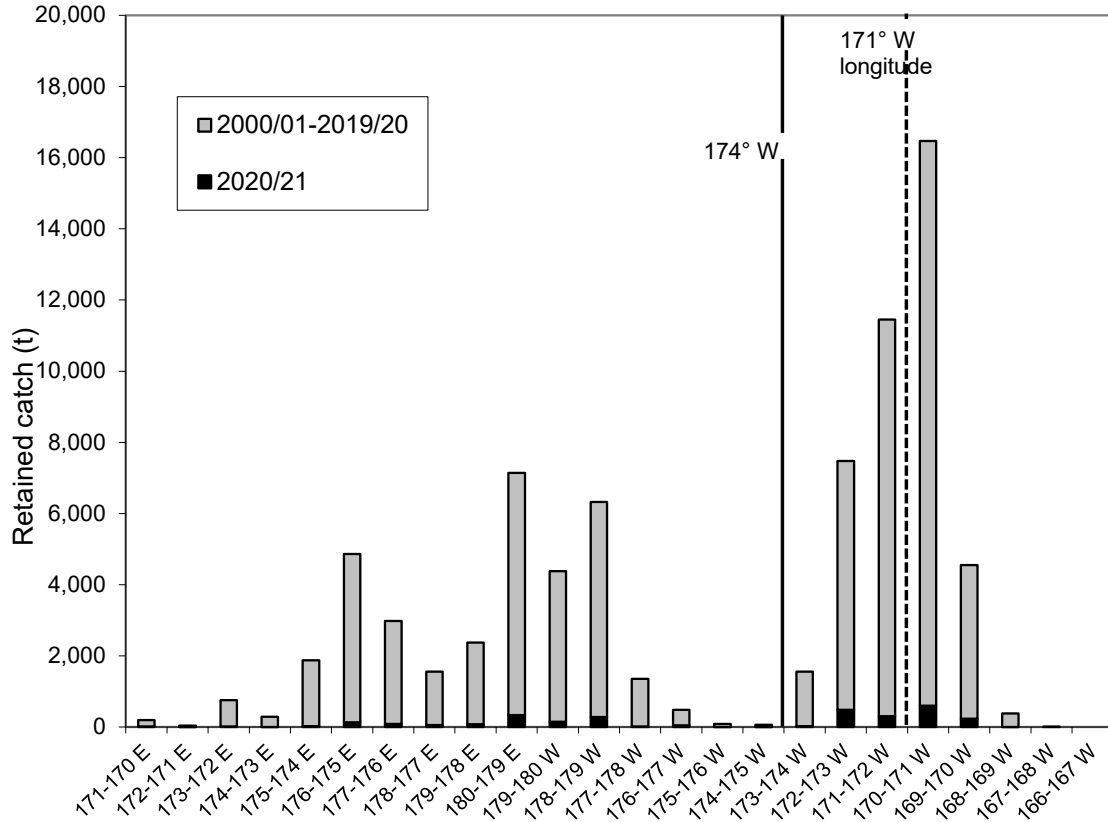
Figure 4. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2020/21 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude and dashed line denotes the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude).
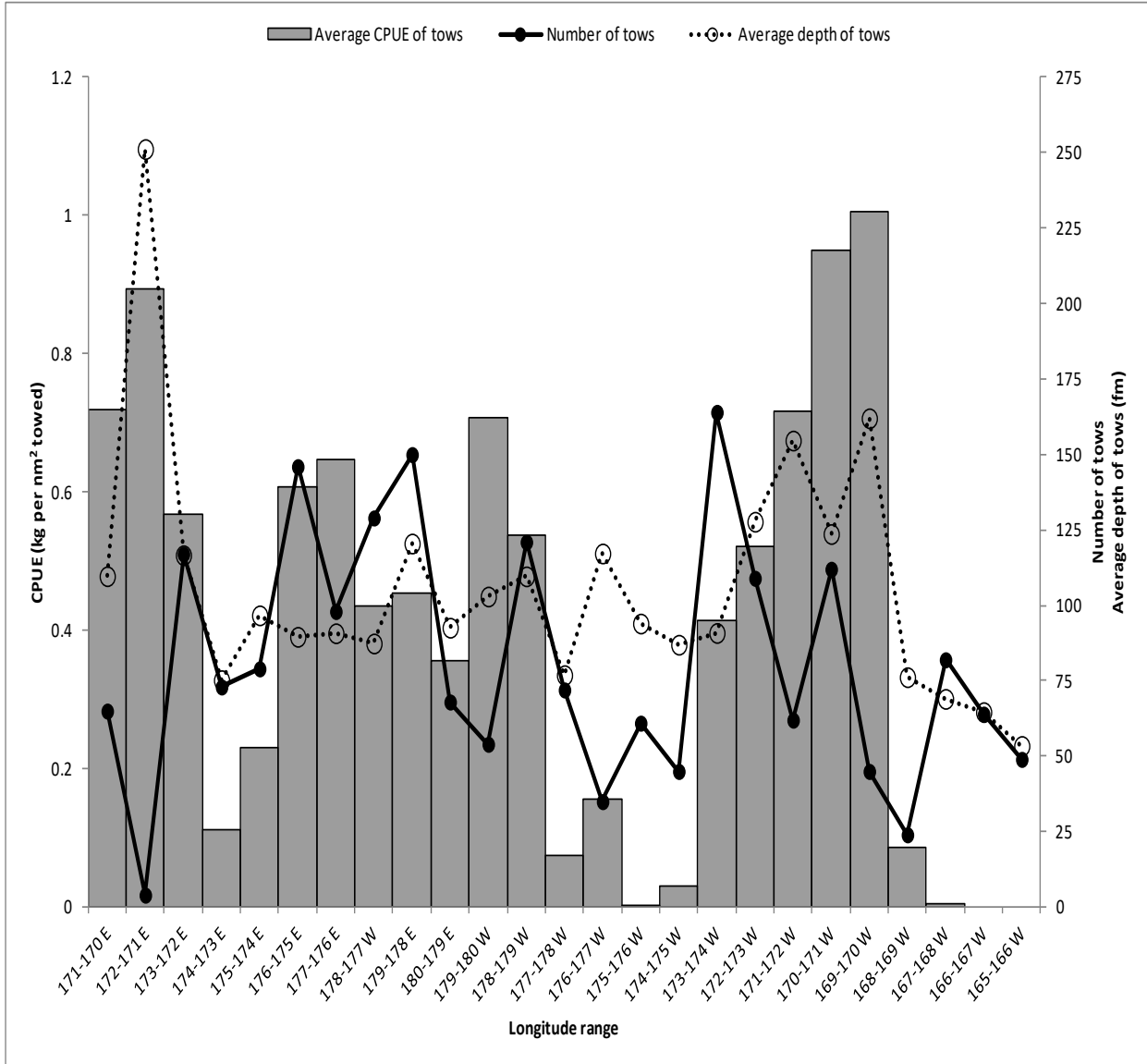
Figure 5. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.
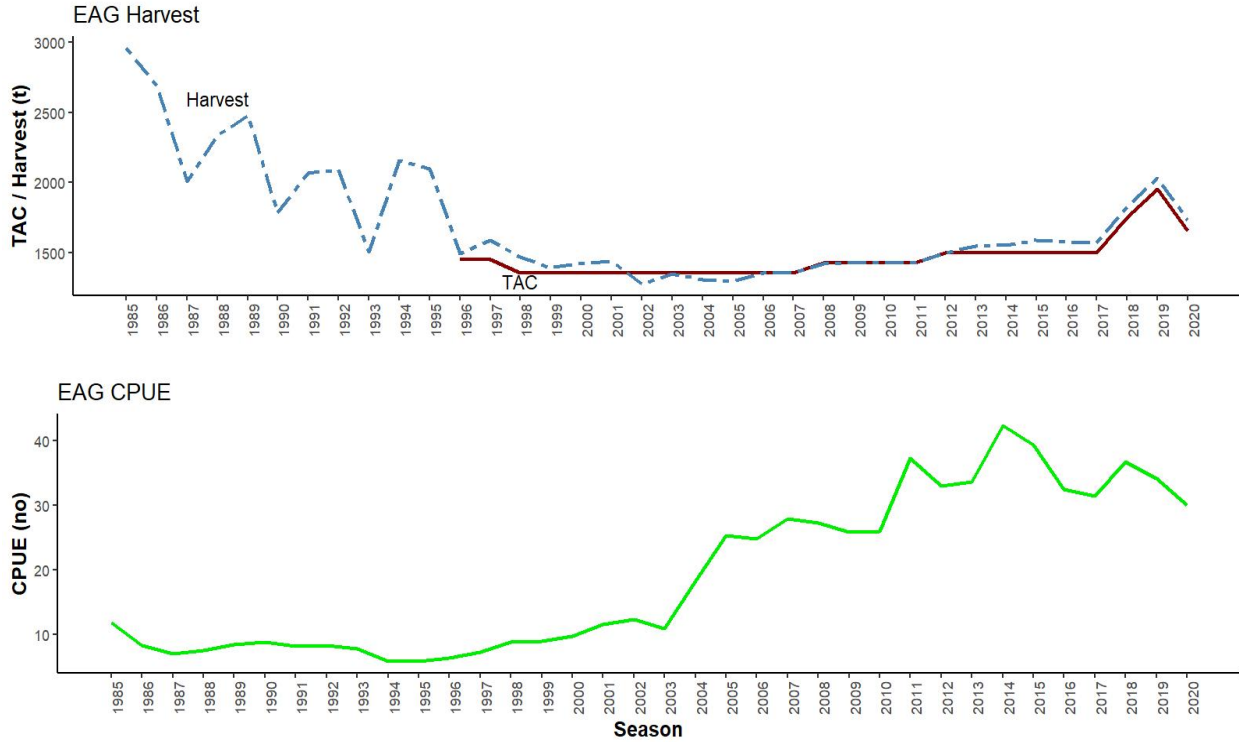
Figure 6. Historical commercial harvest (from fish tickets; metric tons), total allowable catch (TAC), and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the EAG, 1985/86–2020/21 fisheries (note: 1985 refers to the 1985/86 fishing year).
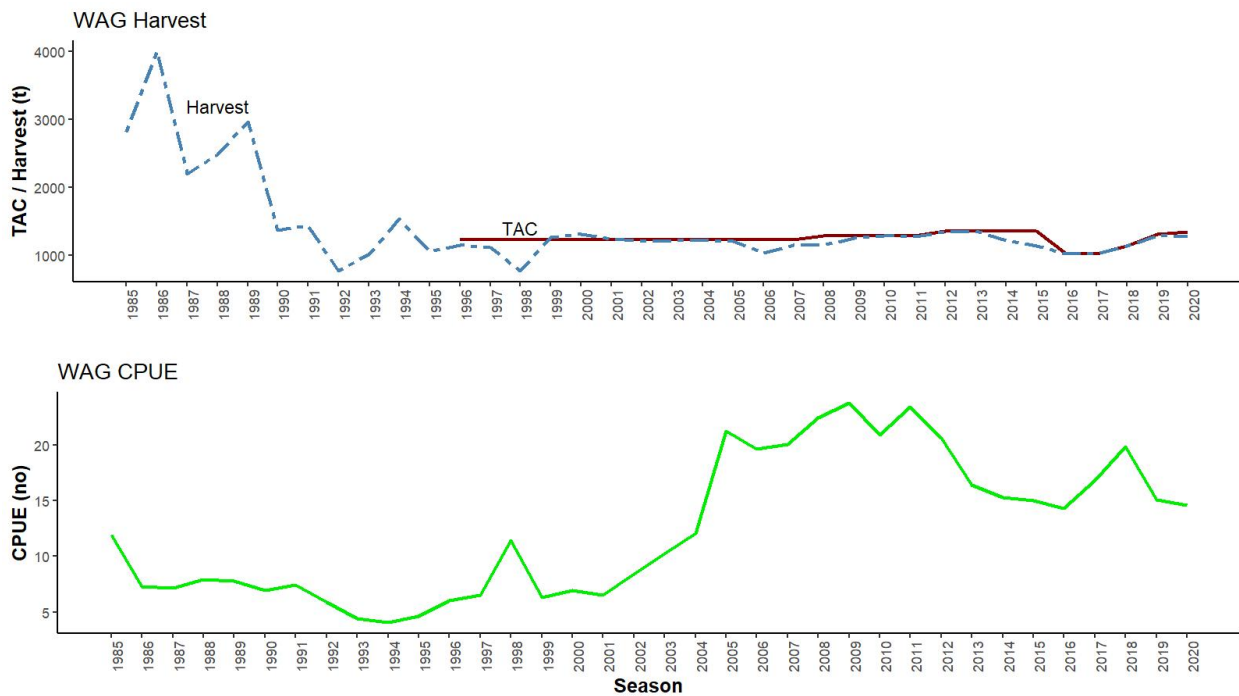
Figure 7. Historical commercial harvest (from fish tickets; metric tons)), total allowable catch (TAC), and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the WAG, 1985/86–2020/21 fisheries (note: 1985 refers to the 1985/86 fishing year).
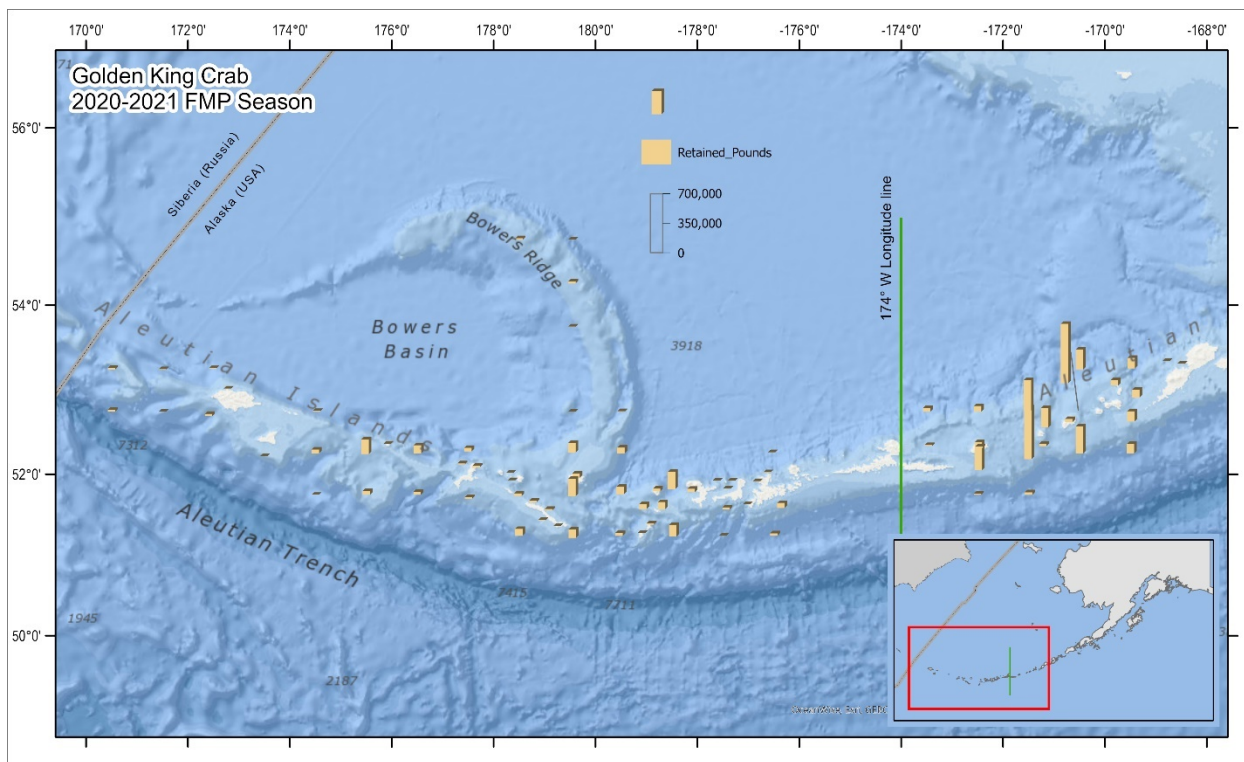
Figure 8. Catch distribution by statistical area.in 2020/21.
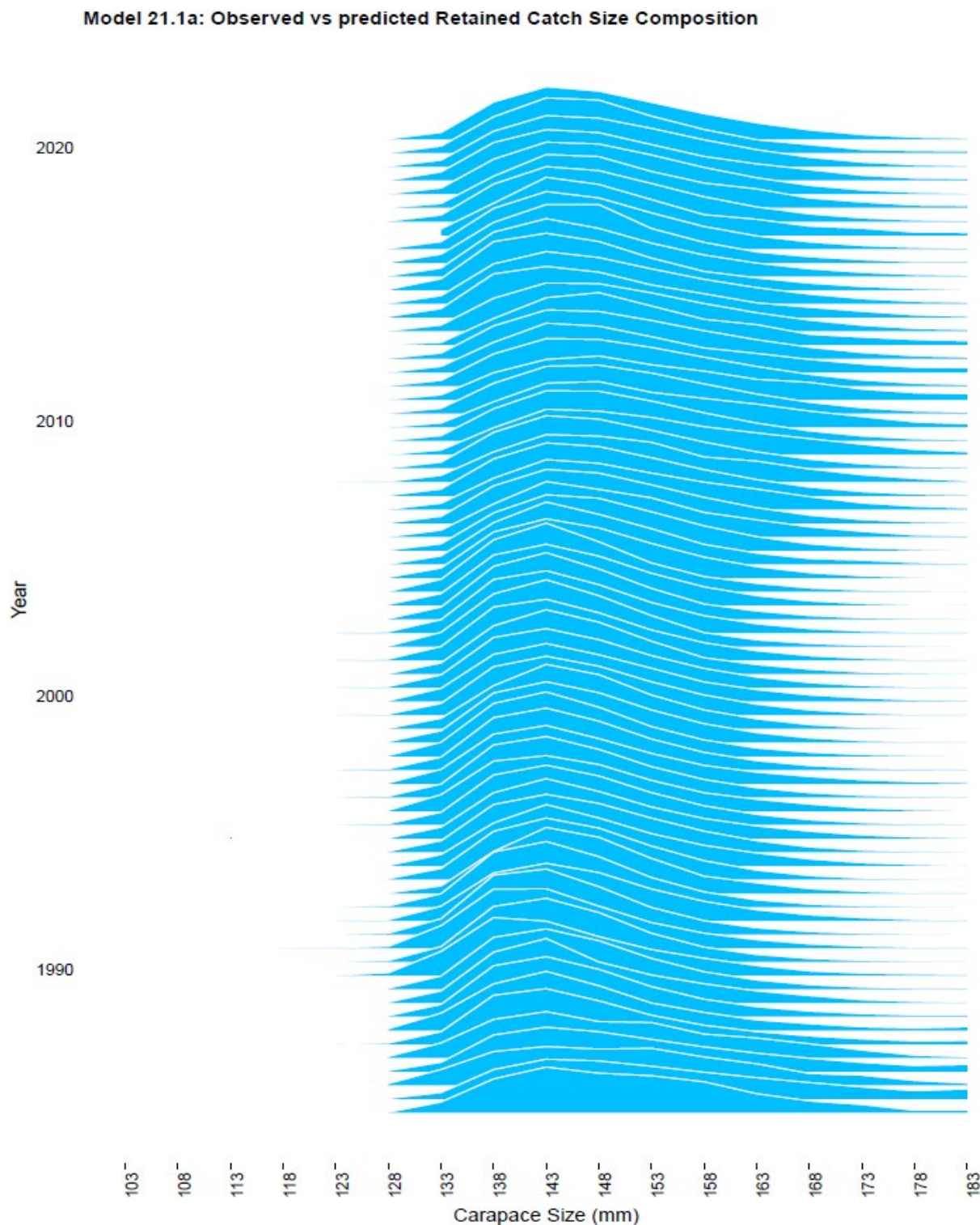
Figure 9a. Predicted vs. observed retained catch relative length frequency distributions under model 21.1a for golden king crab in the EAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.
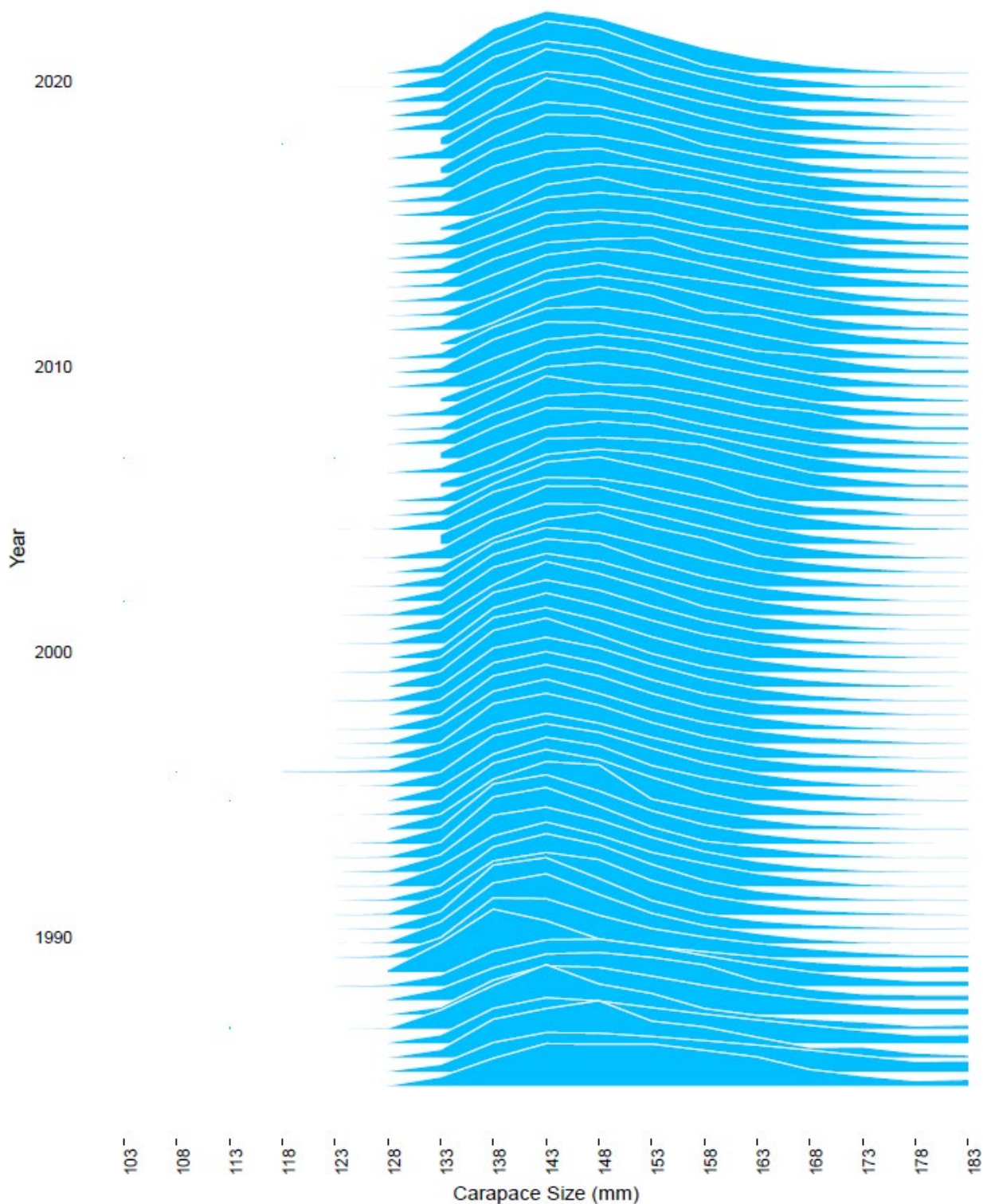
Figure 9b. Predicted vs. observed retained catch relative length frequency distributions under model 21.1b for golden king crab in the EAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1c: Observed vs predicted Retained Catch Size Composition
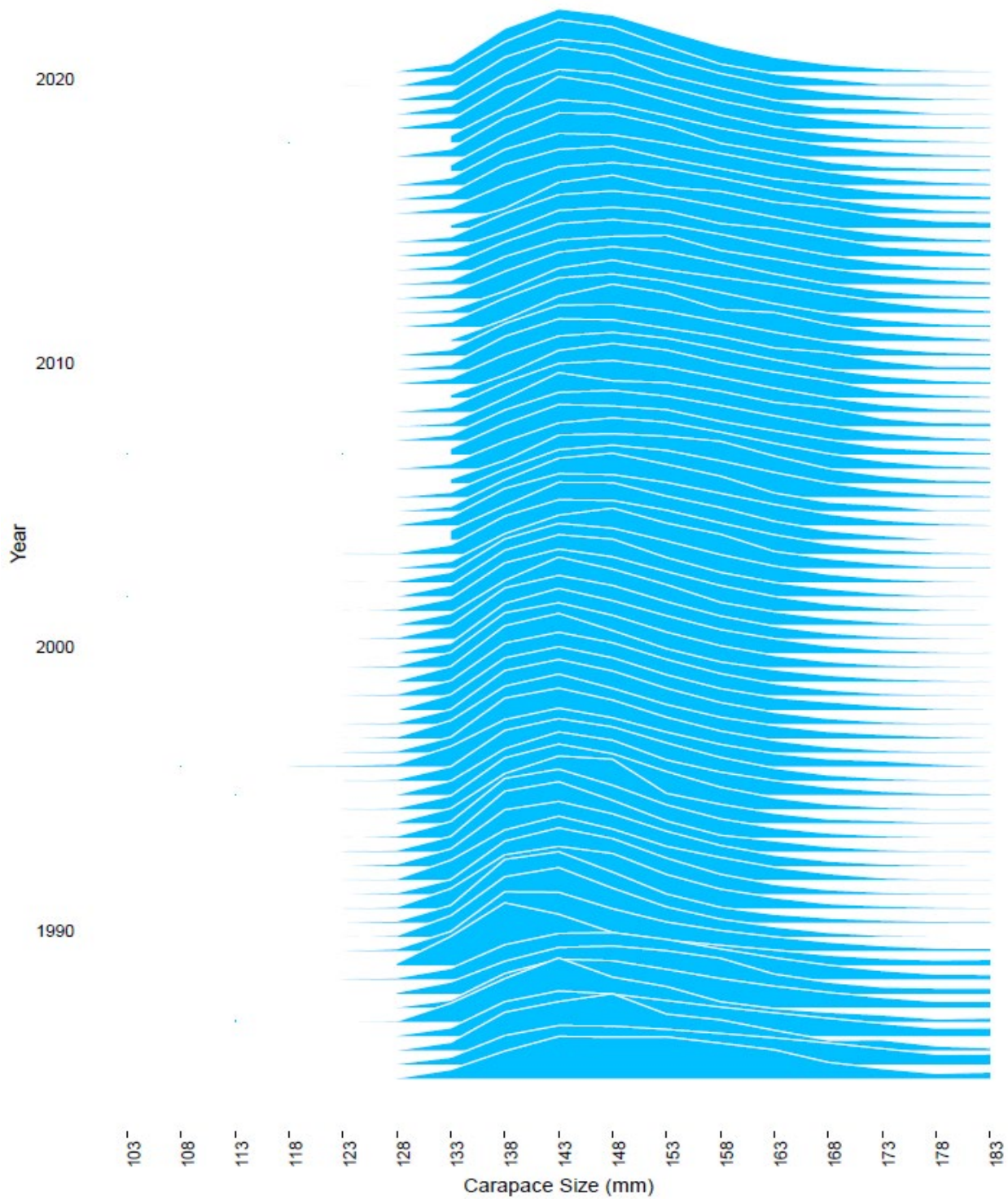
Figure 9c. Predicted vs. observed retained catch relative length frequency distributions under model 21.1c for golden king crab in the EAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.
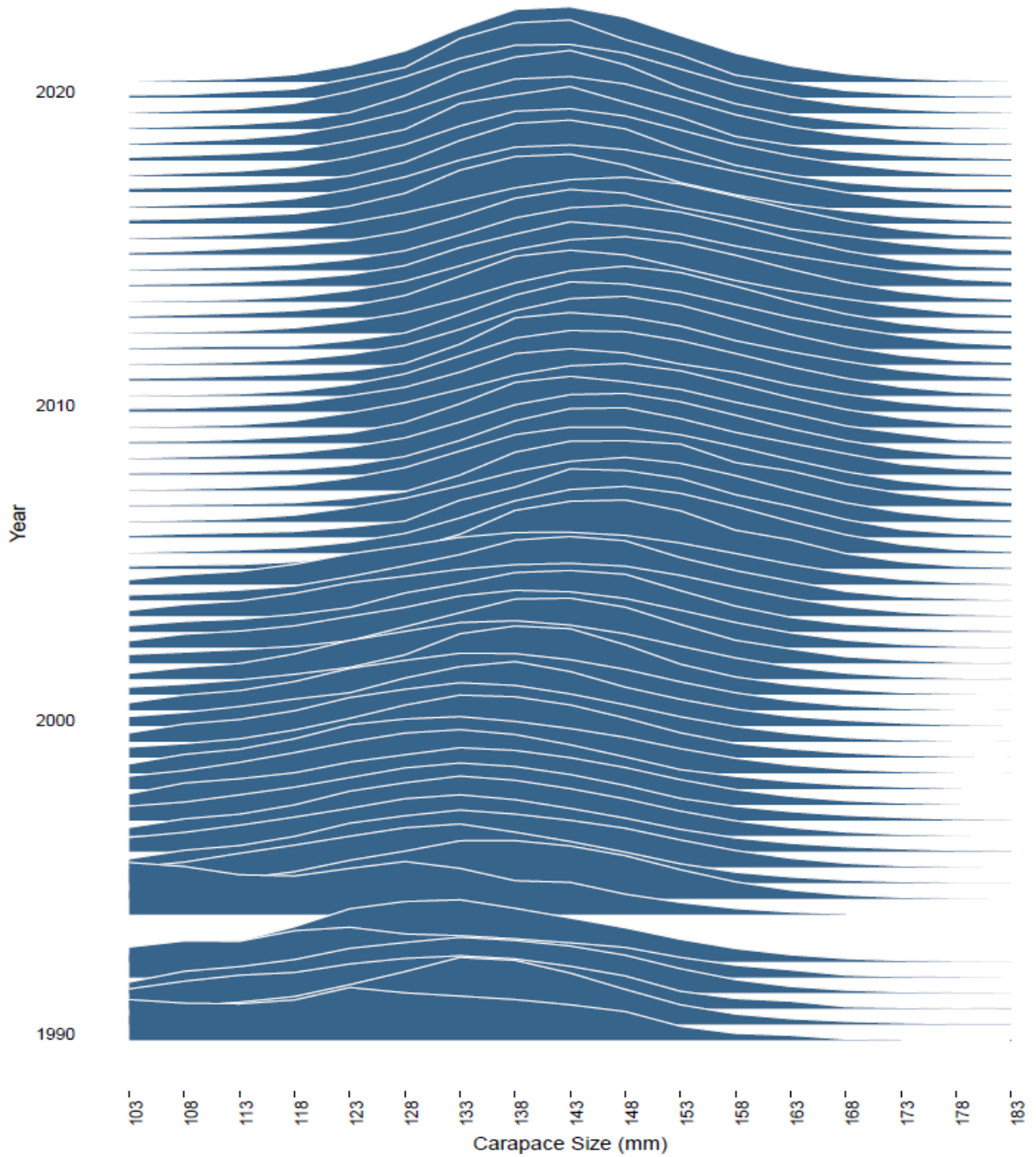
Figure 10a. Predicted vs. observed total catch relative length frequency distributions under model 21.1a for golden king crab in the EAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1b: Observed vs predicted Total Catch Size Composition
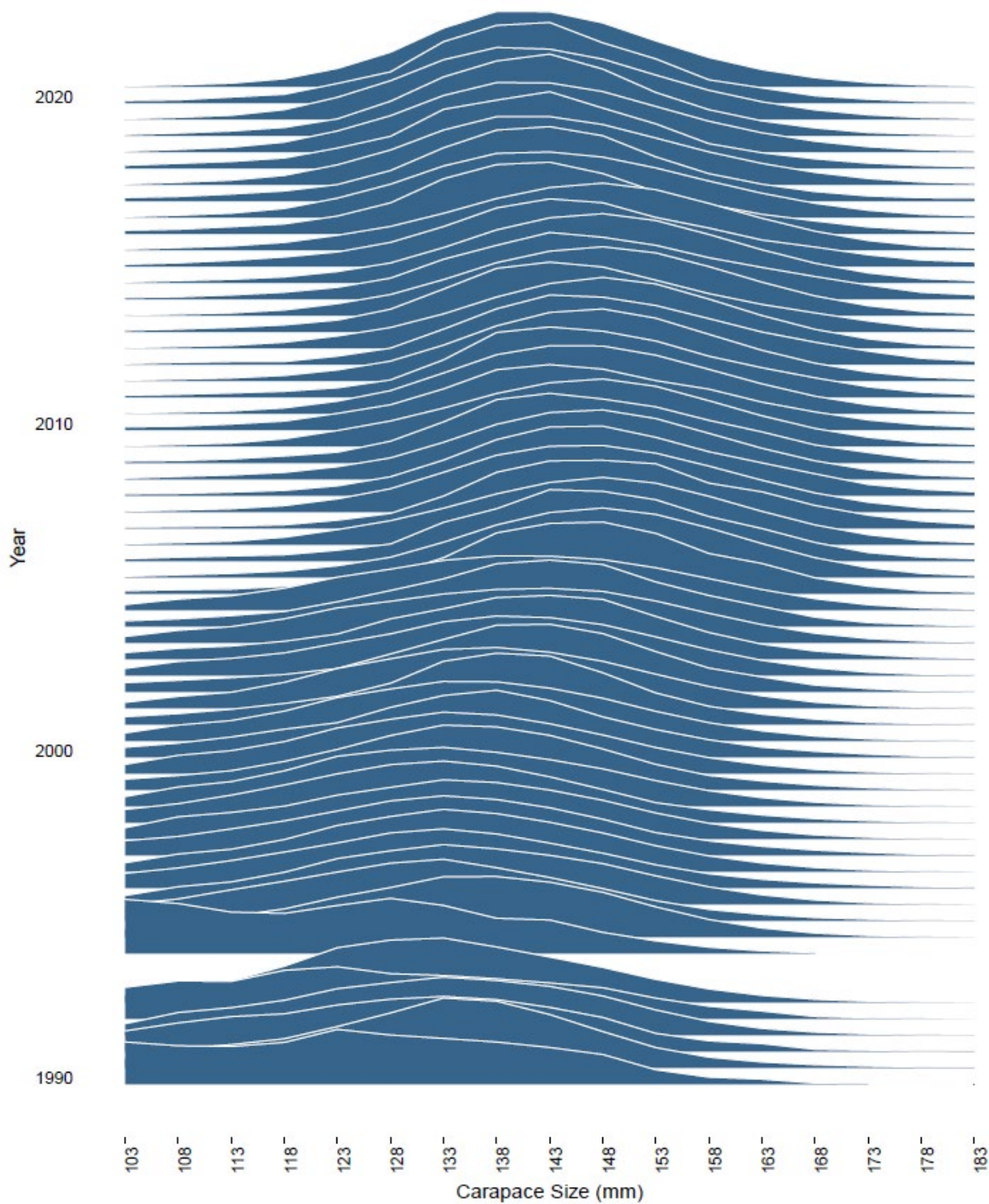
Figure 10b. Predicted vs. observed total catch relative length frequency distributions under model 21.1b for golden king crab in the EAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1c: Observed vs predicted Total Catch Size Composition
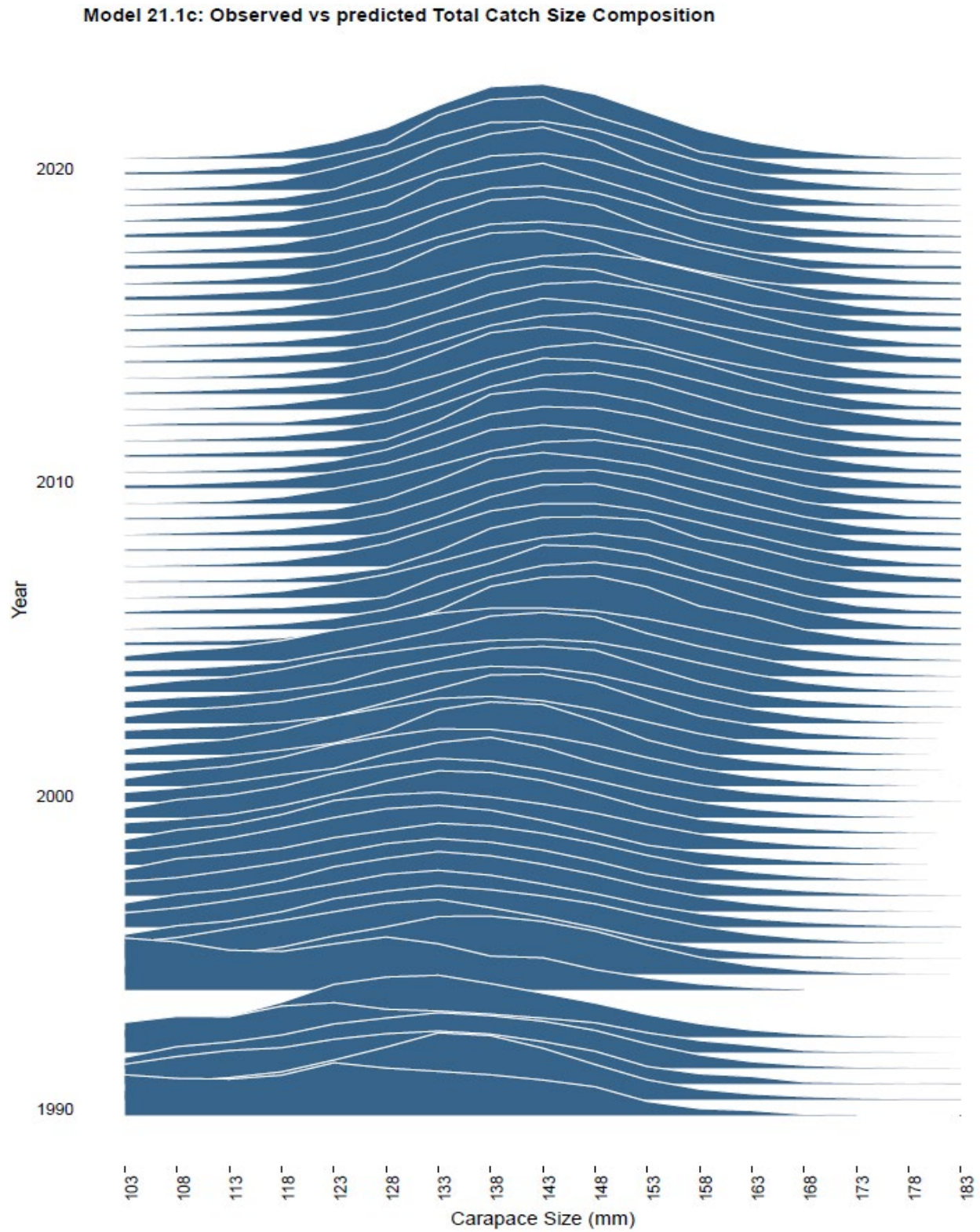
Figure 10c. Predicted vs. observed total catch relative length frequency distributions under model 21.1c for golden king crab in the EAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1a: Observed vs predicted Groundfish Bycatch Size Composition
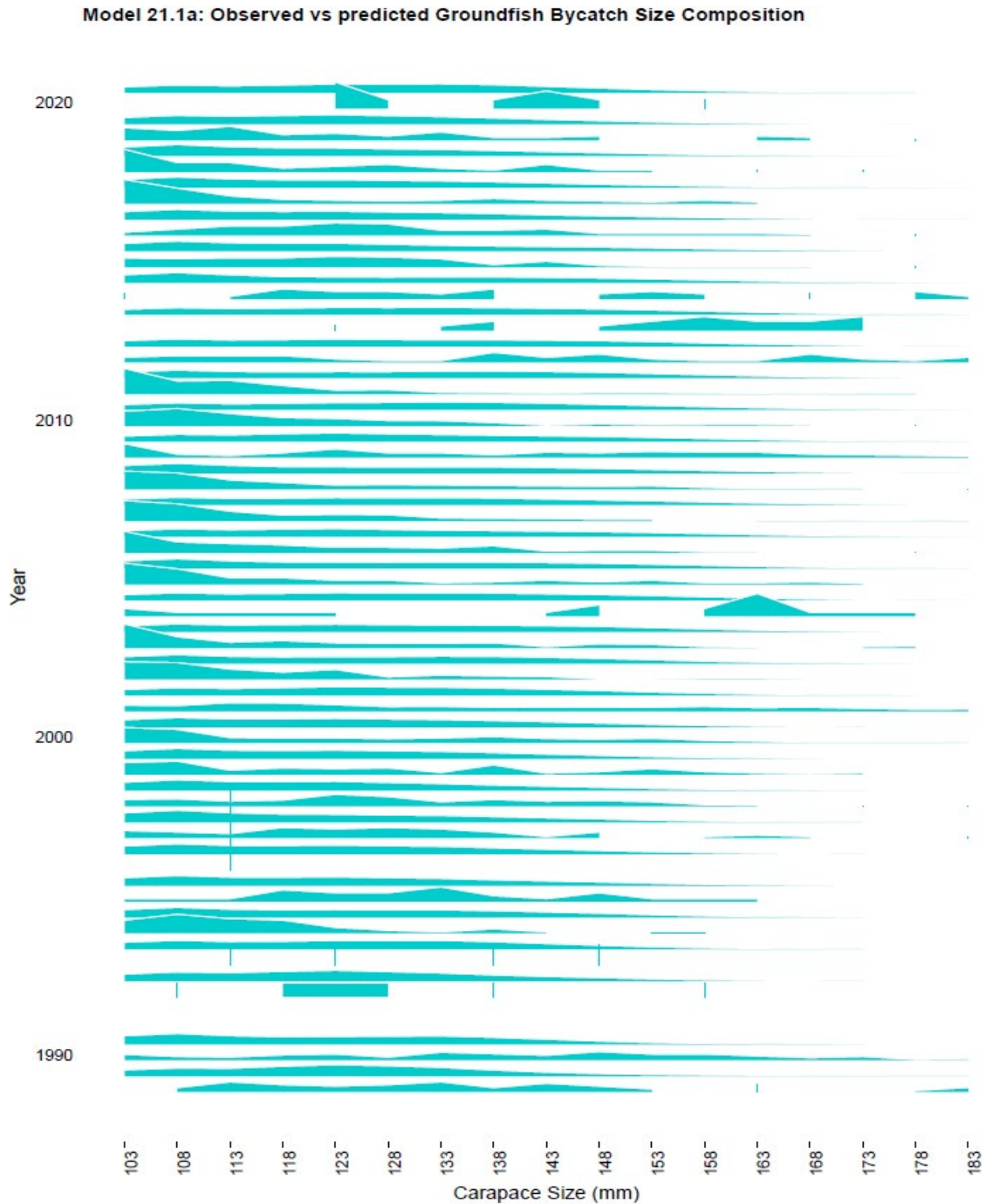
Figure 11. Predicted vs. observed groundfish discarded bycatch relative length frequency distributions under model 21.1a for golden king c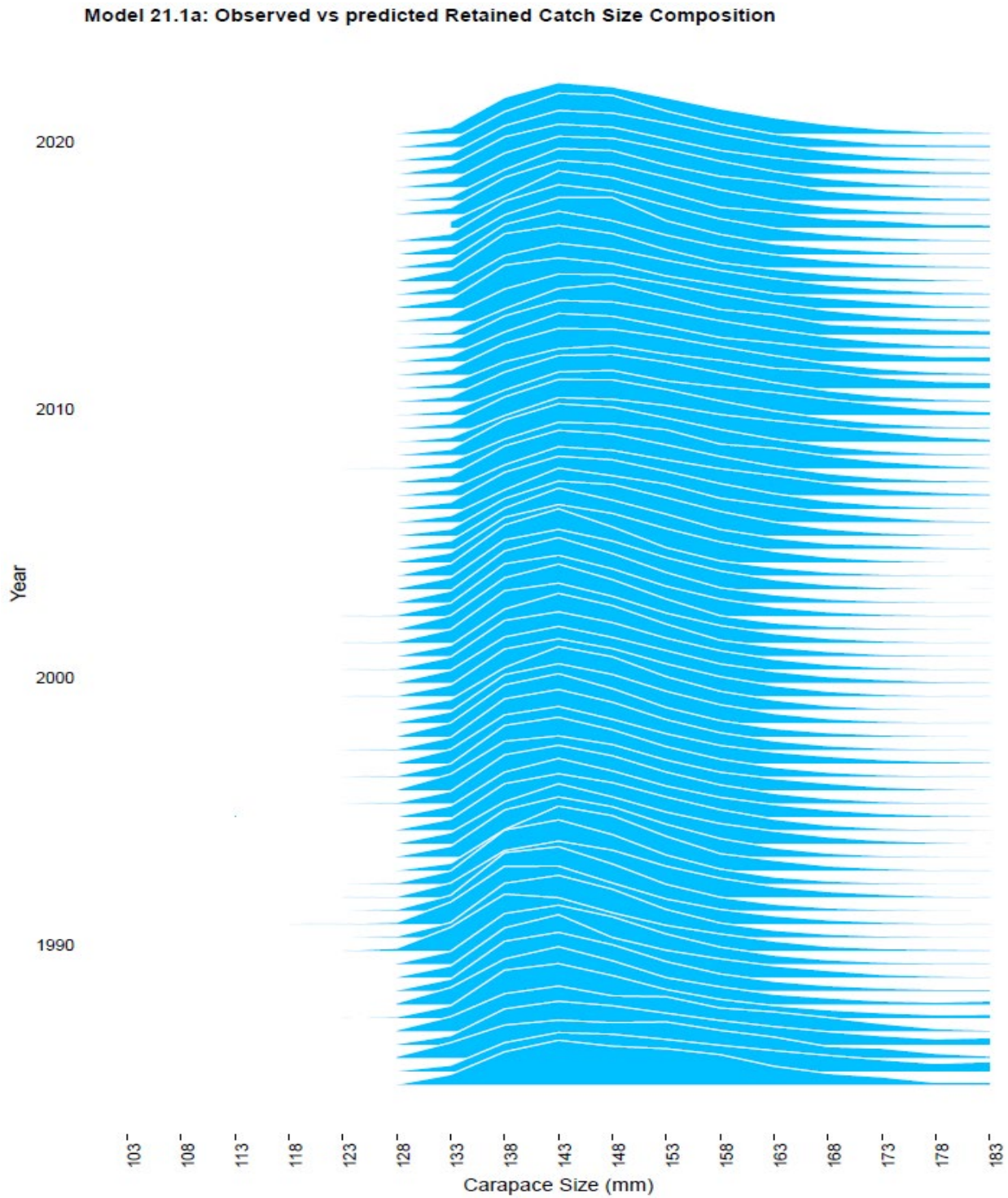rab in the EAG, 1989/90 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.
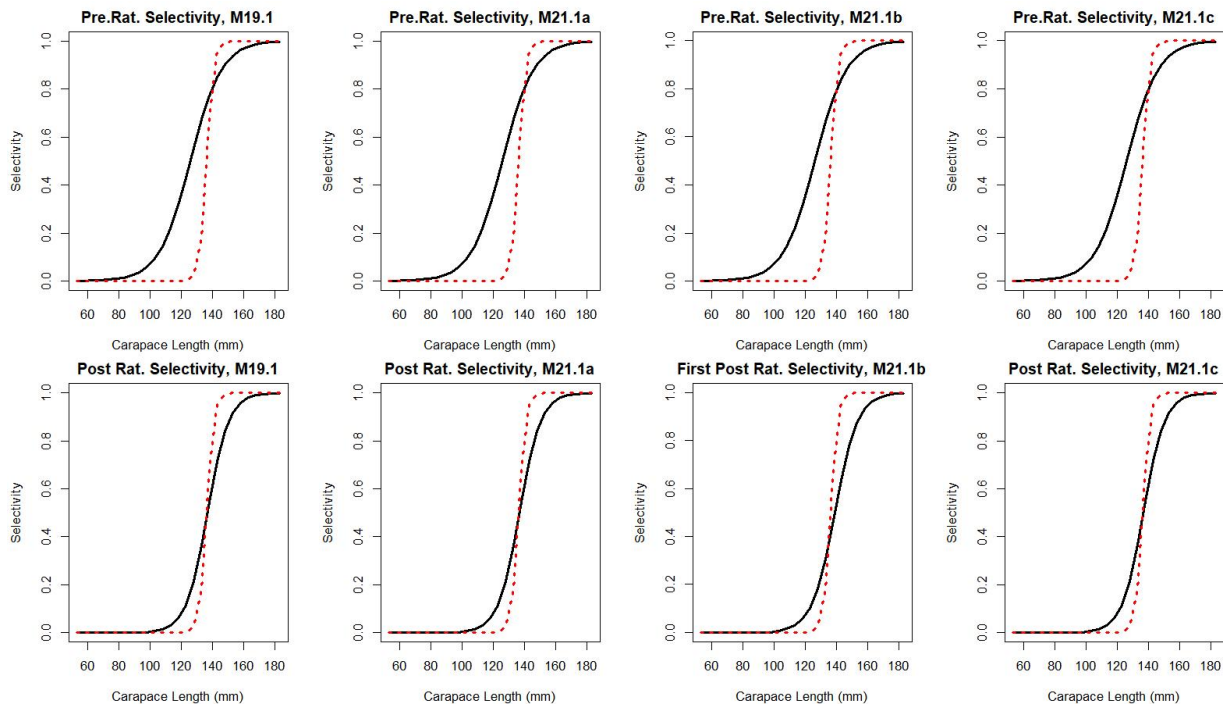
Figure 12a. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under models 19.1, 21.1a, 21.1b, and 21.1c fits to golden king crab data in the EAG. The post-rationalization total selectivity for 21.1b corresponds to first part (2005–2015) of the post-rationalization period.
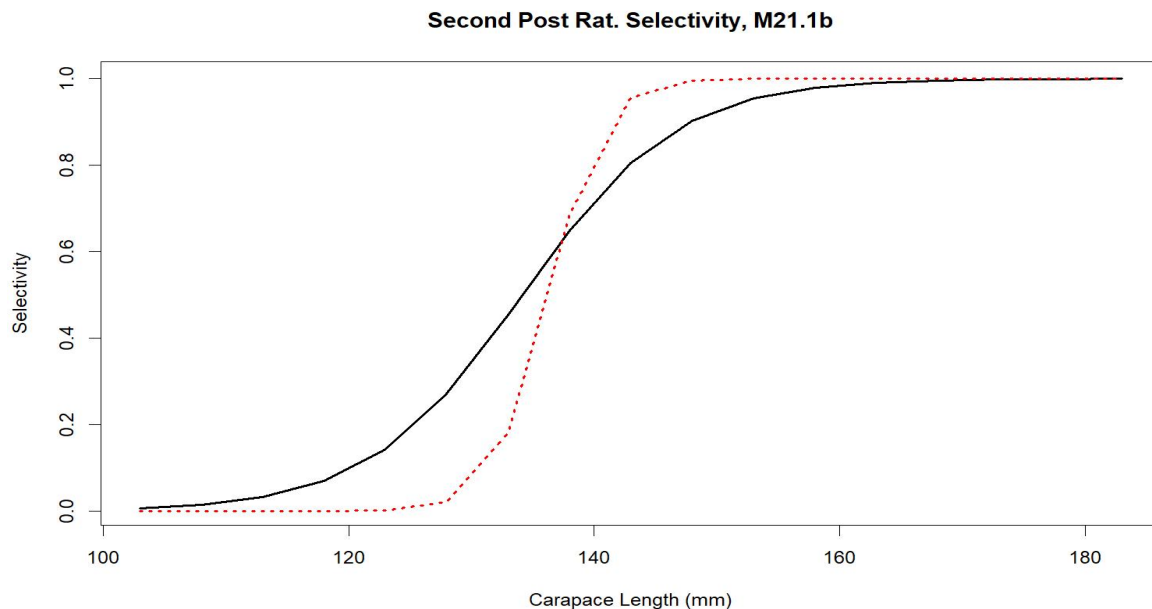
Figure 12b. Estimated total (black solid line) and retained selectivity (red dotted line) for second part (2016–2020) of the post- rationalization period under model 21.1b fit to golden king crab data in the EAG.
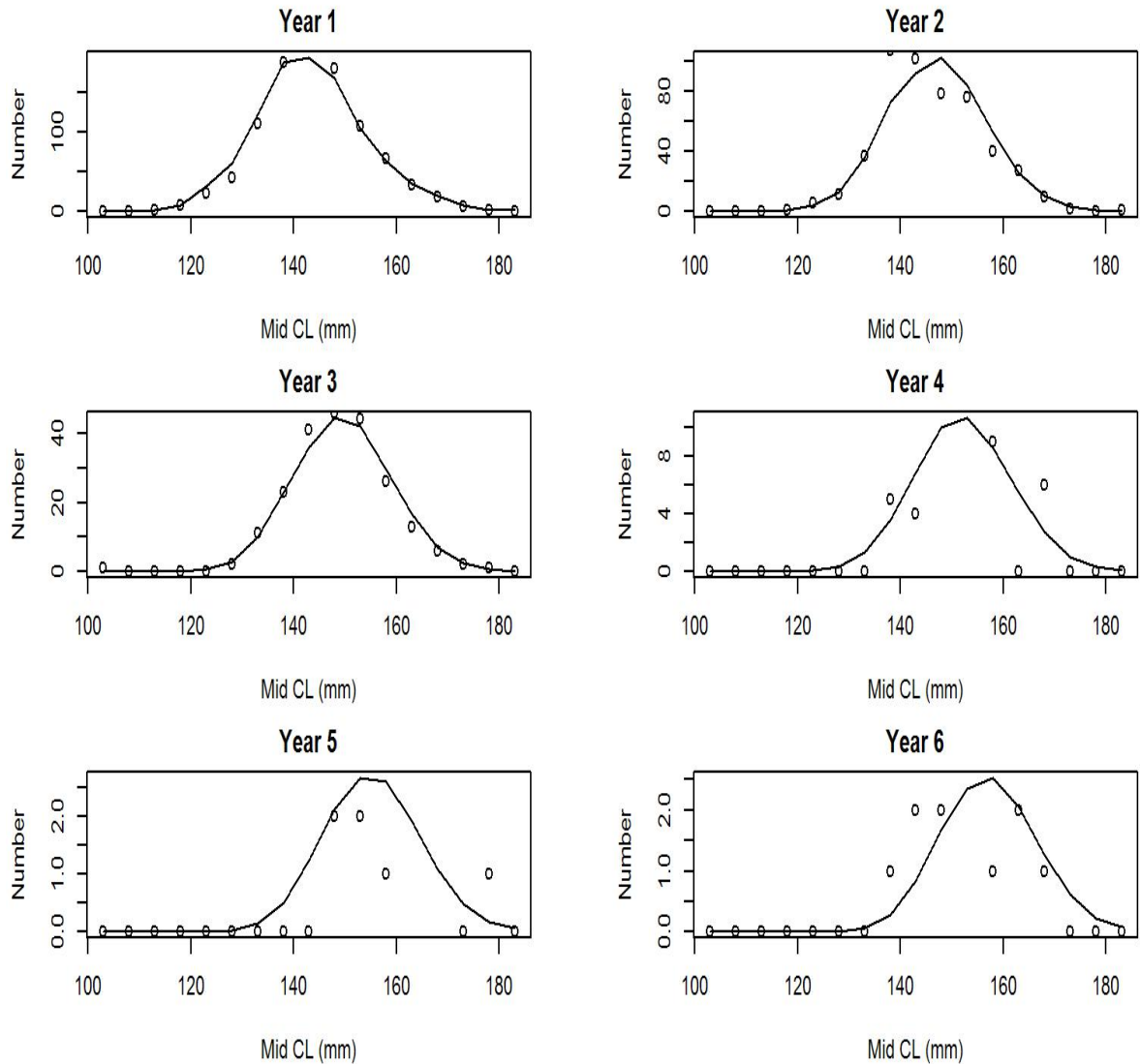
Figure 13. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under model 21.1a for EAG golden king crab.
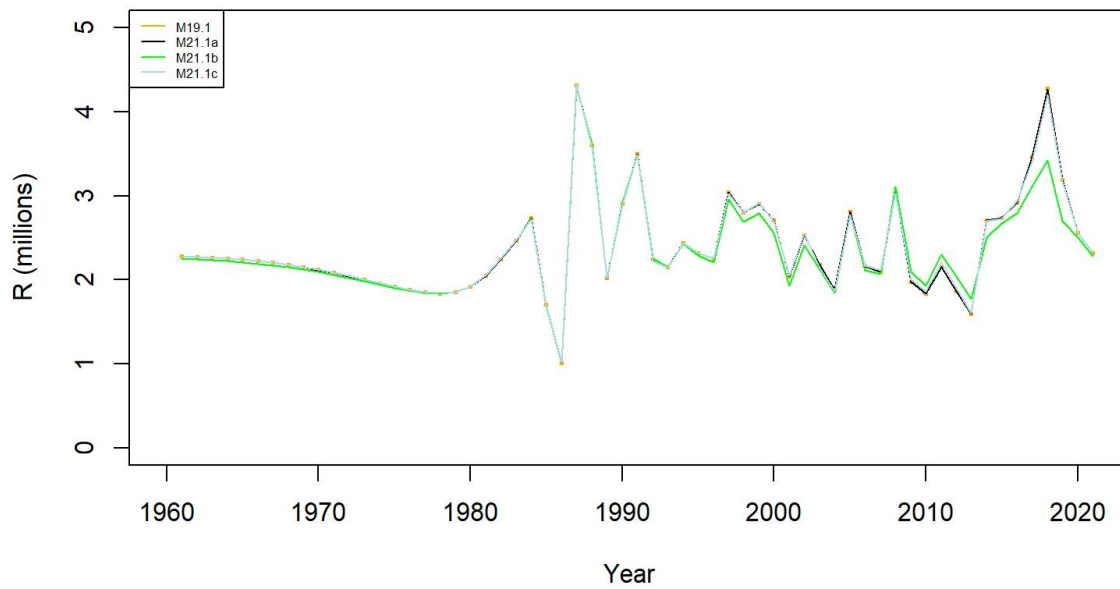
Figure 14. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG golden king crab data, 1961–2021.
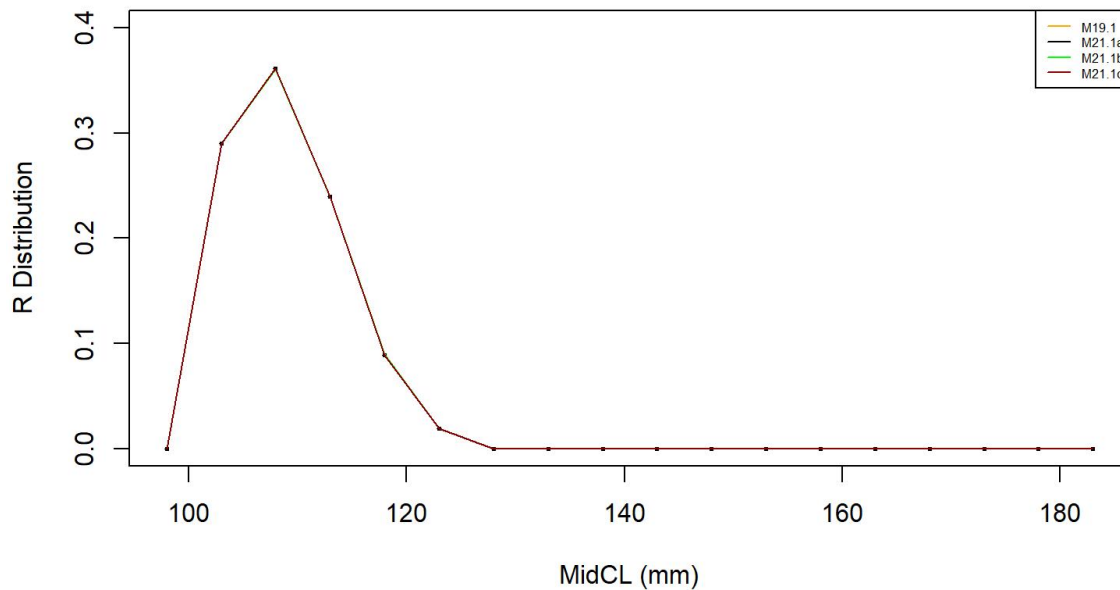
Figure 15. Recruit size distribution to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG golden king crab data.
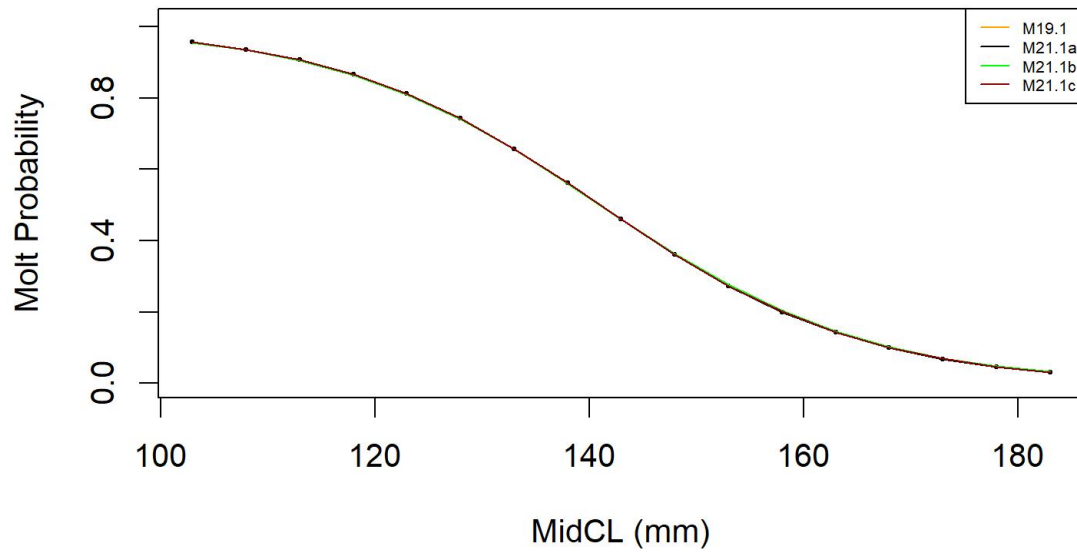
Figure 16. Estimated molt probability vs. carapace length of golden king crab under models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG golden king crab data.
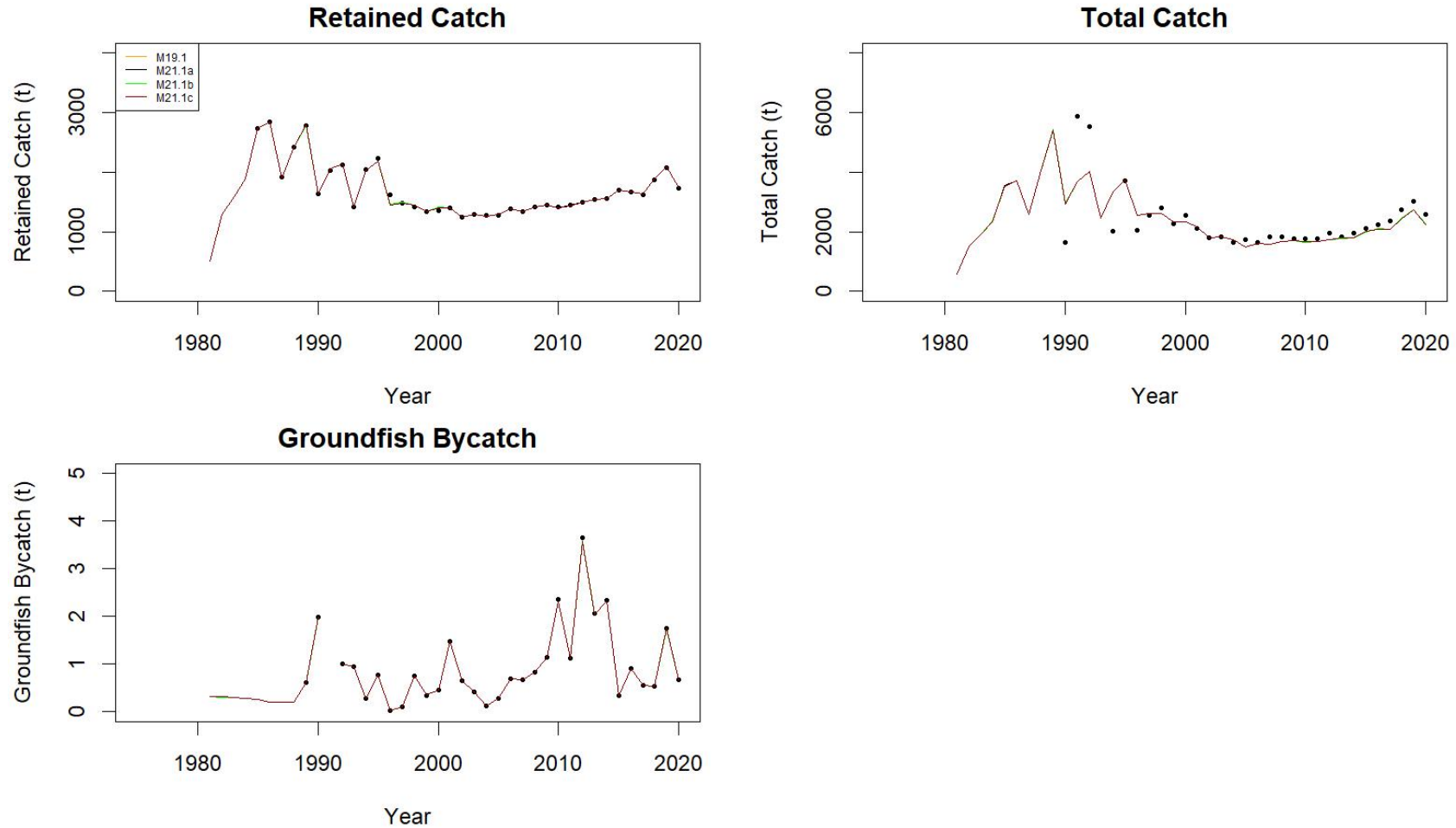
Figure 17. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab under models 19.1, 21.1a, 21.1b, and 21.1c fits in EAG, 1981/82–2020/21.
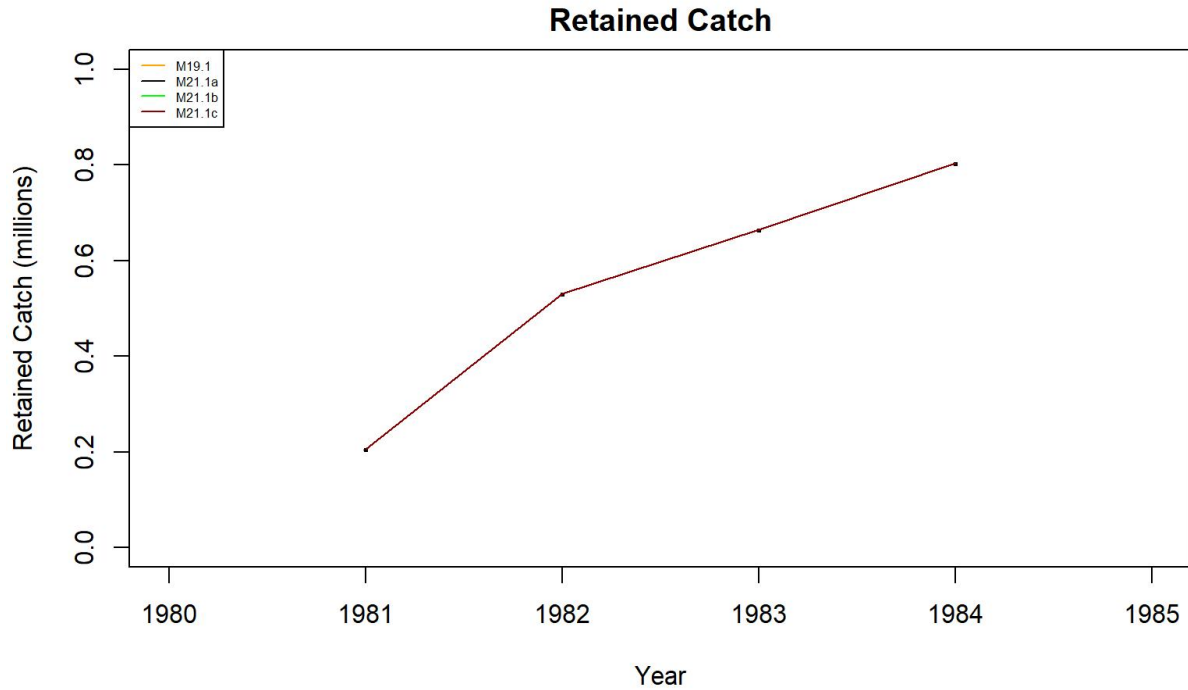
Retained Catch

Figure 18. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.
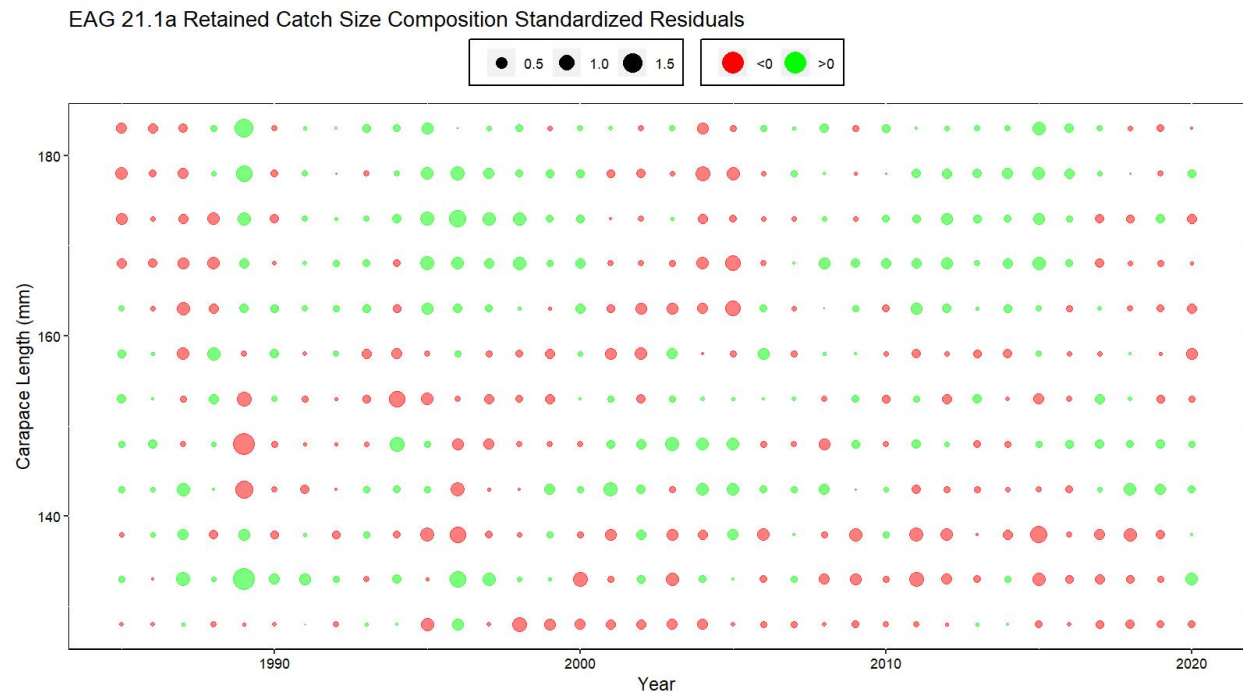
Figure 19. Bubble plot of standardized residuals of retained catch length composition for model 21.1a fit for EAG golden king crab, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
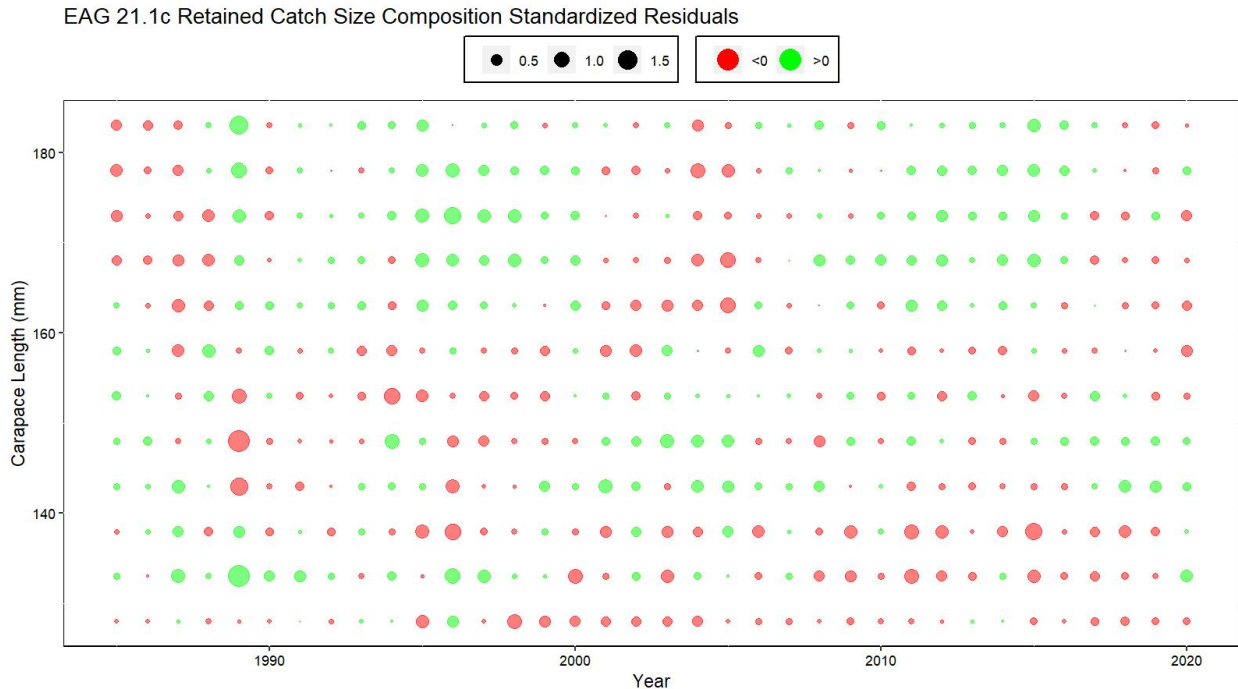
Figure 20. Bubble plot of standardized residuals of retained catch length composition for model 21.1c fit for EAG golden king crab, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
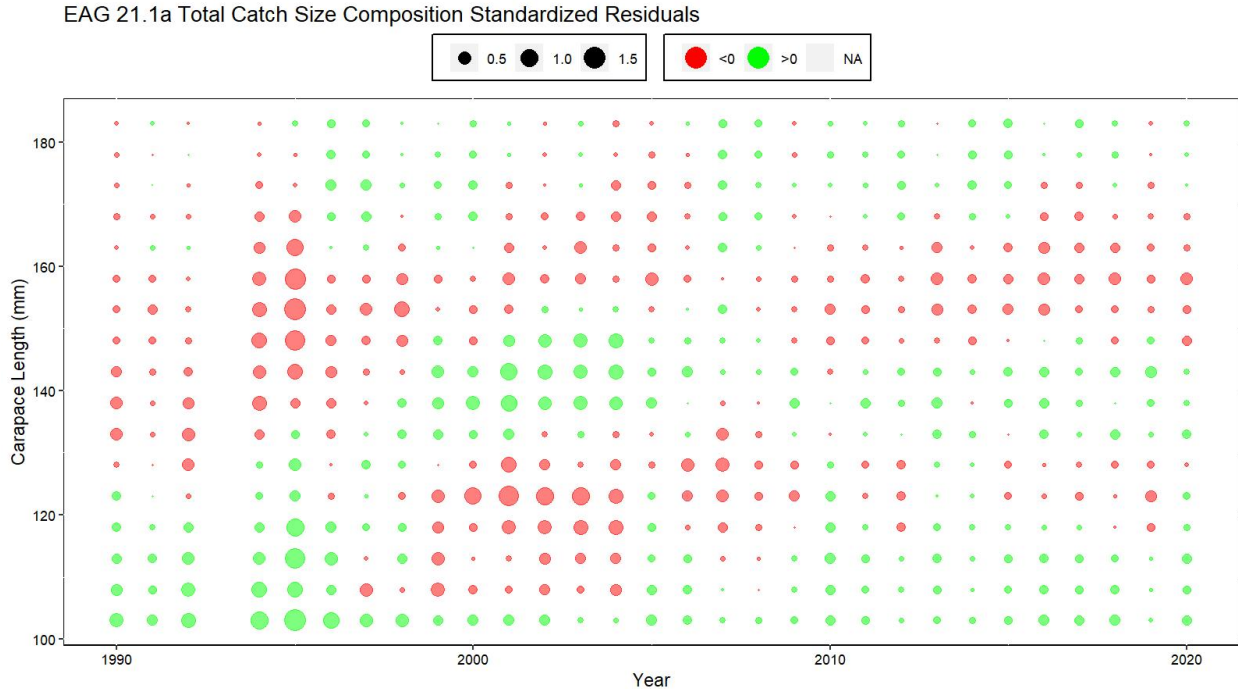
Figure 21. Bubble plot of standardized residuals of total catch length composition for model 21.1a fit for EAG golden king crab, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
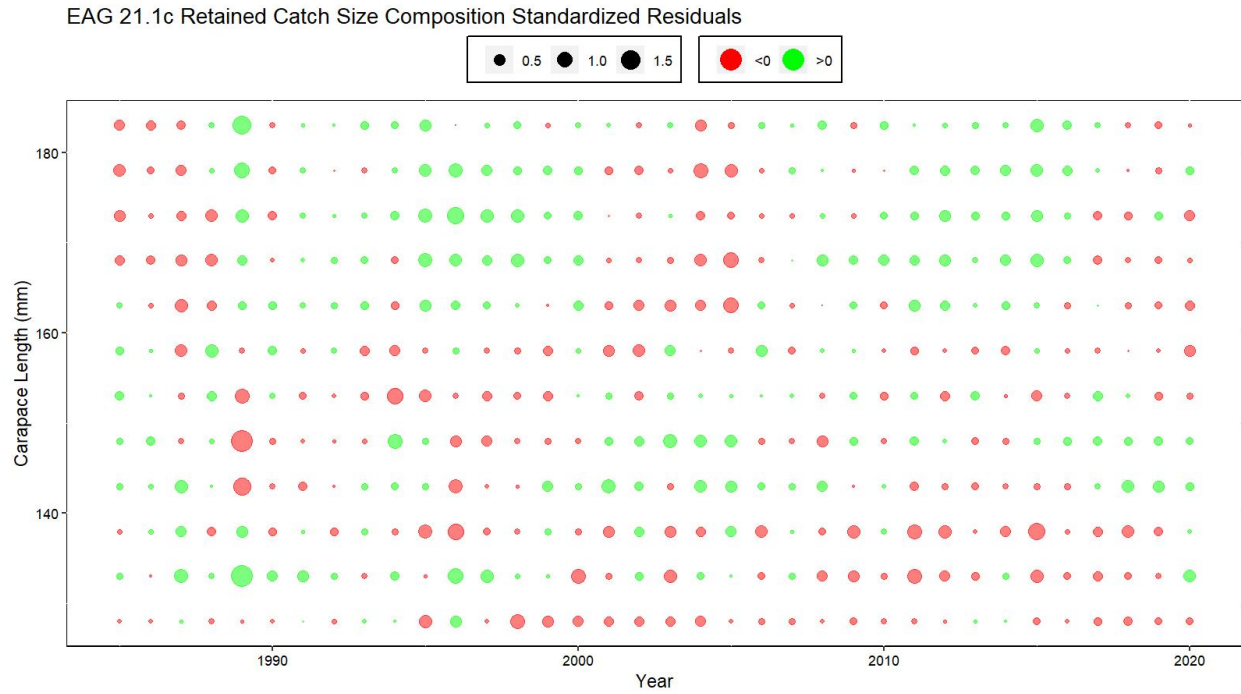
Figure 22. Bubble plot of standardized residuals of total catch length composition for model 21.1c fit for EAG golden king crab, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
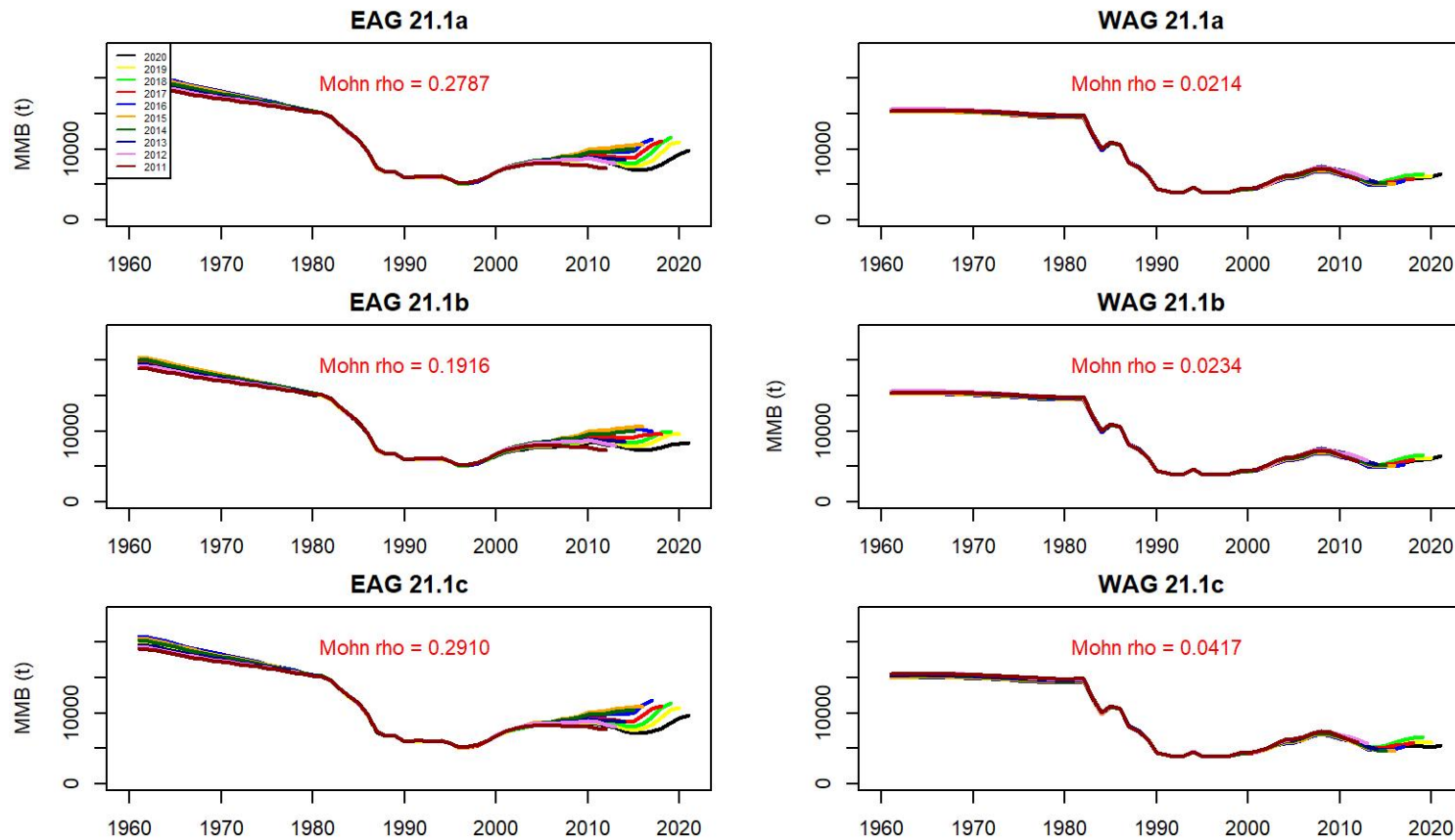
Figure 23. Retrospective fits of MMB by the model following removal of terminal year data under models 21.1a, 21.1b, and 21.1c for golden king crab in the EAG (left) and WAG (right), 1960/61–2020/21.
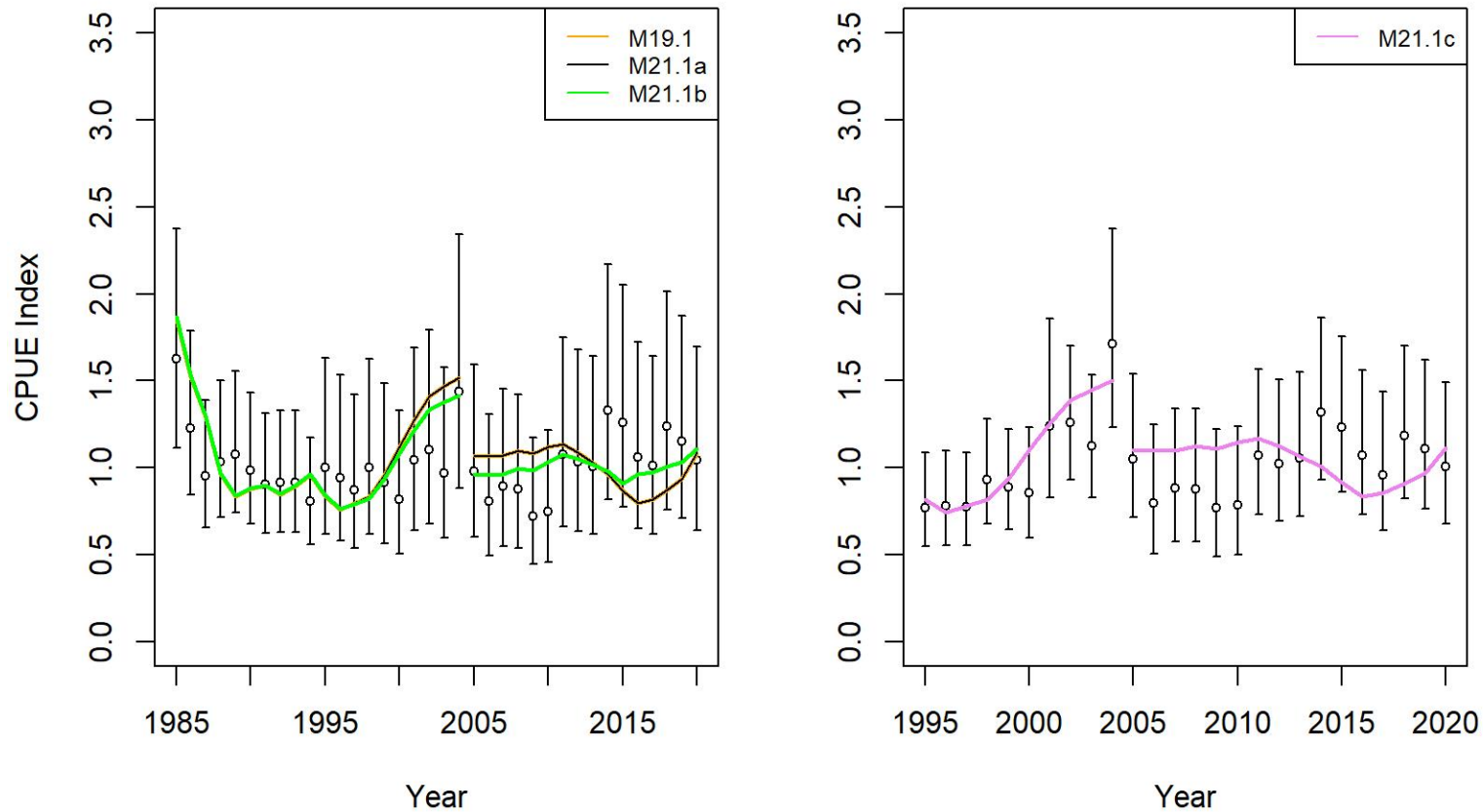
Figure 24. Comparison of input CPUE indices [open circles with +/- 2 SE for model 21.1a (left) and model 21.1c (right)] with predicted CPUE indices (colored solid lines) under 19.1, 21.1a, and 21.1b (left), and 21.1c (right) for EAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.
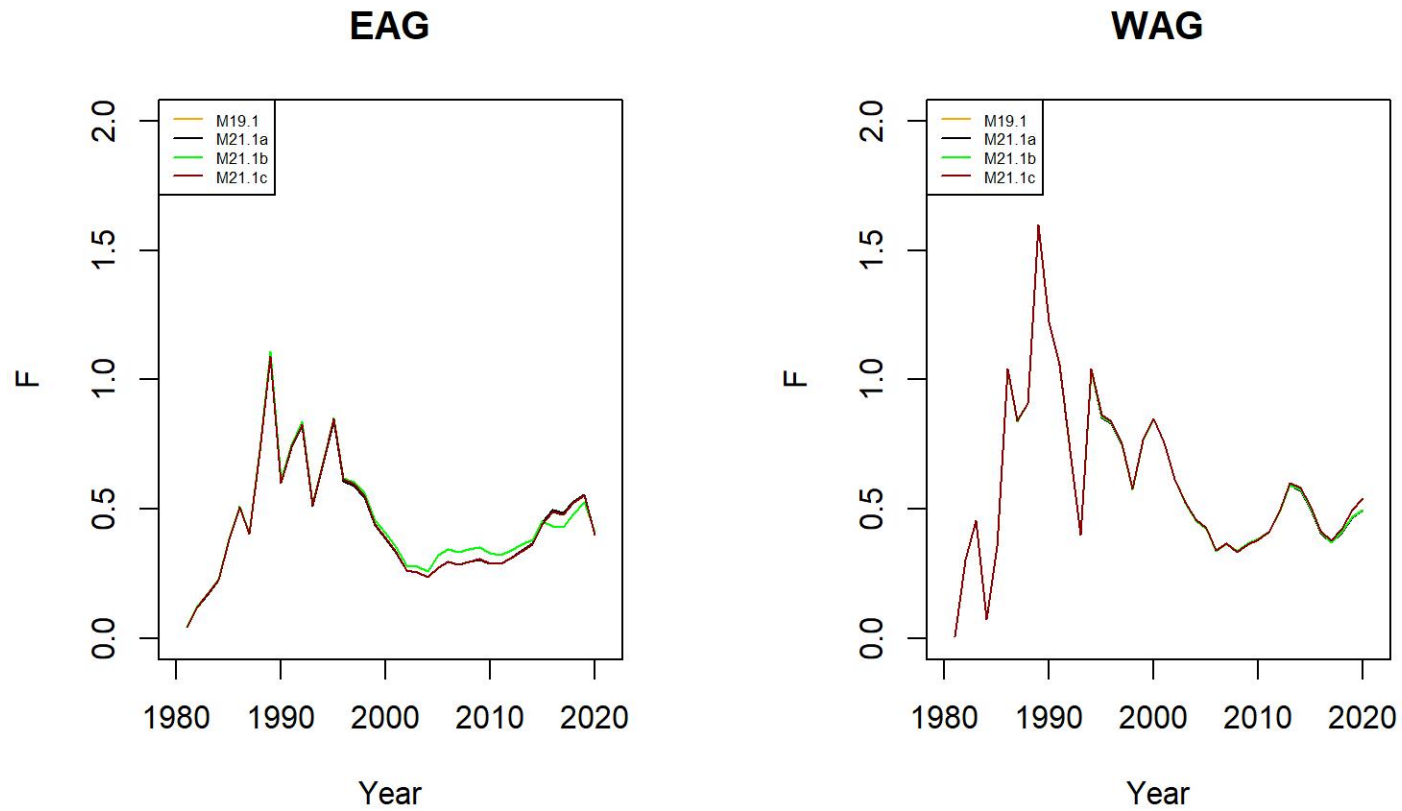
Figure 25. Trends in pot fishery full selection total fishing mortality of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits in the EAG (left) and WAG (right) data, 1981/82–2020/21.
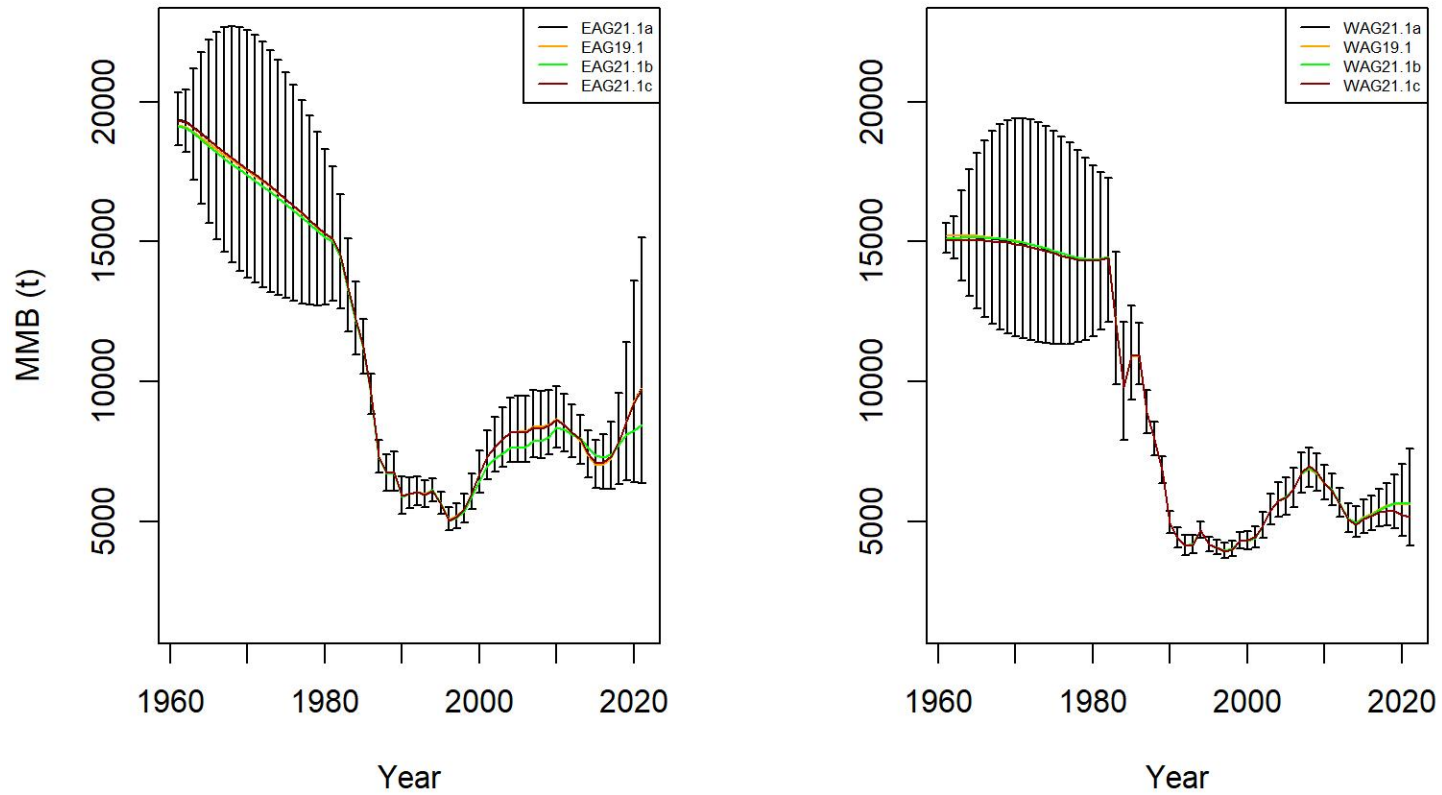
Figure 26. Trends in golden king crab mature male biomass for models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG (left) and WAG (right) data, 1961–2021. Model 21.1a estimate has two standard error confidence limits. Year 2020 refers to 2019/20 fishing season.

Model 21.1a: Observed vs predicted Retained Catch Size Composition

Figure 27a. Predicted vs. observed retained catch relative length frequency distributions under model 21.1a for golden king crab in the WAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1b: Observed vs predicted Retained Catch Size Composition
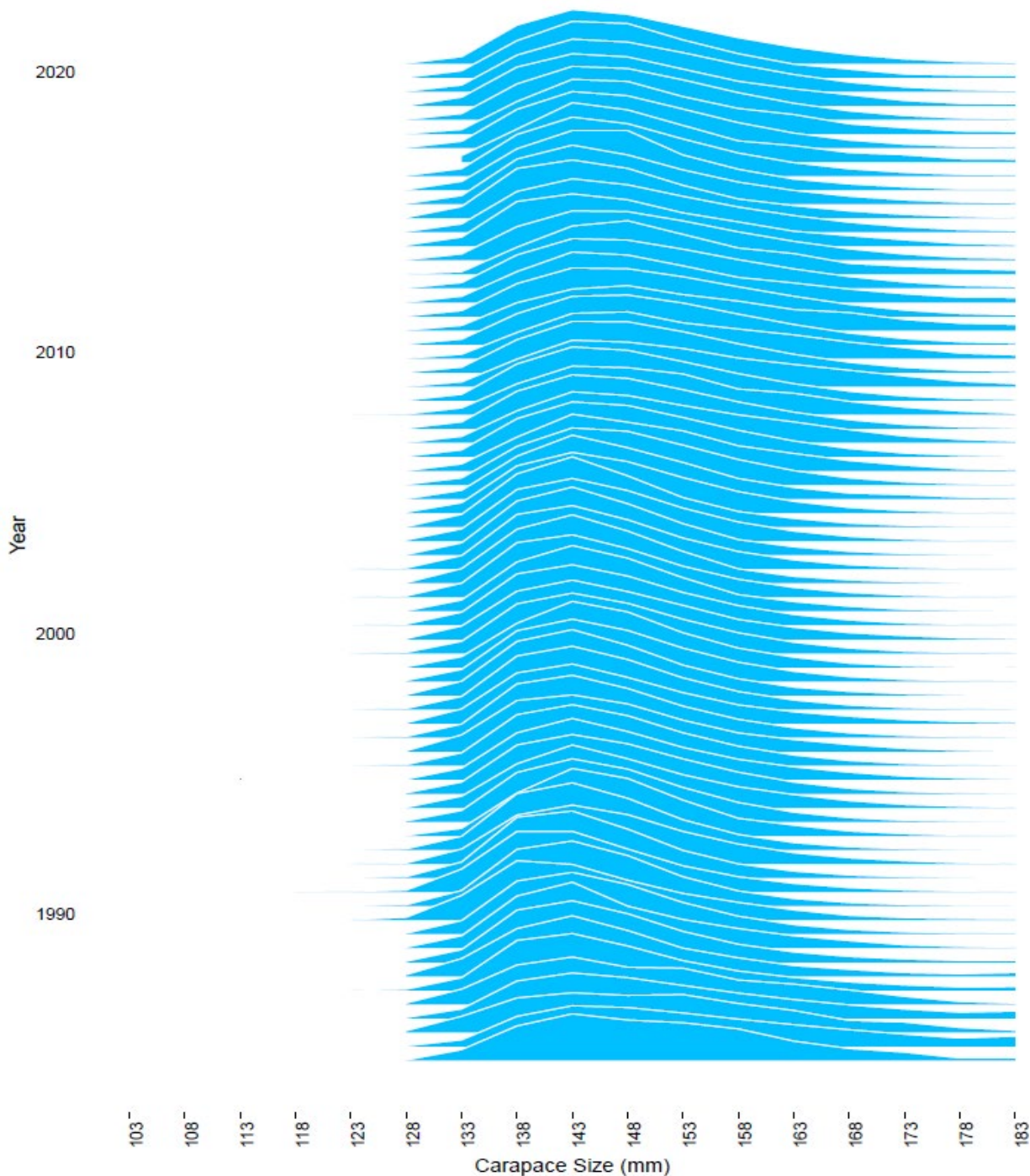
Figure 27b. Predicted vs. observed retained catch relative length frequency distributions under model 21.1b for golden king crab in the WAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.
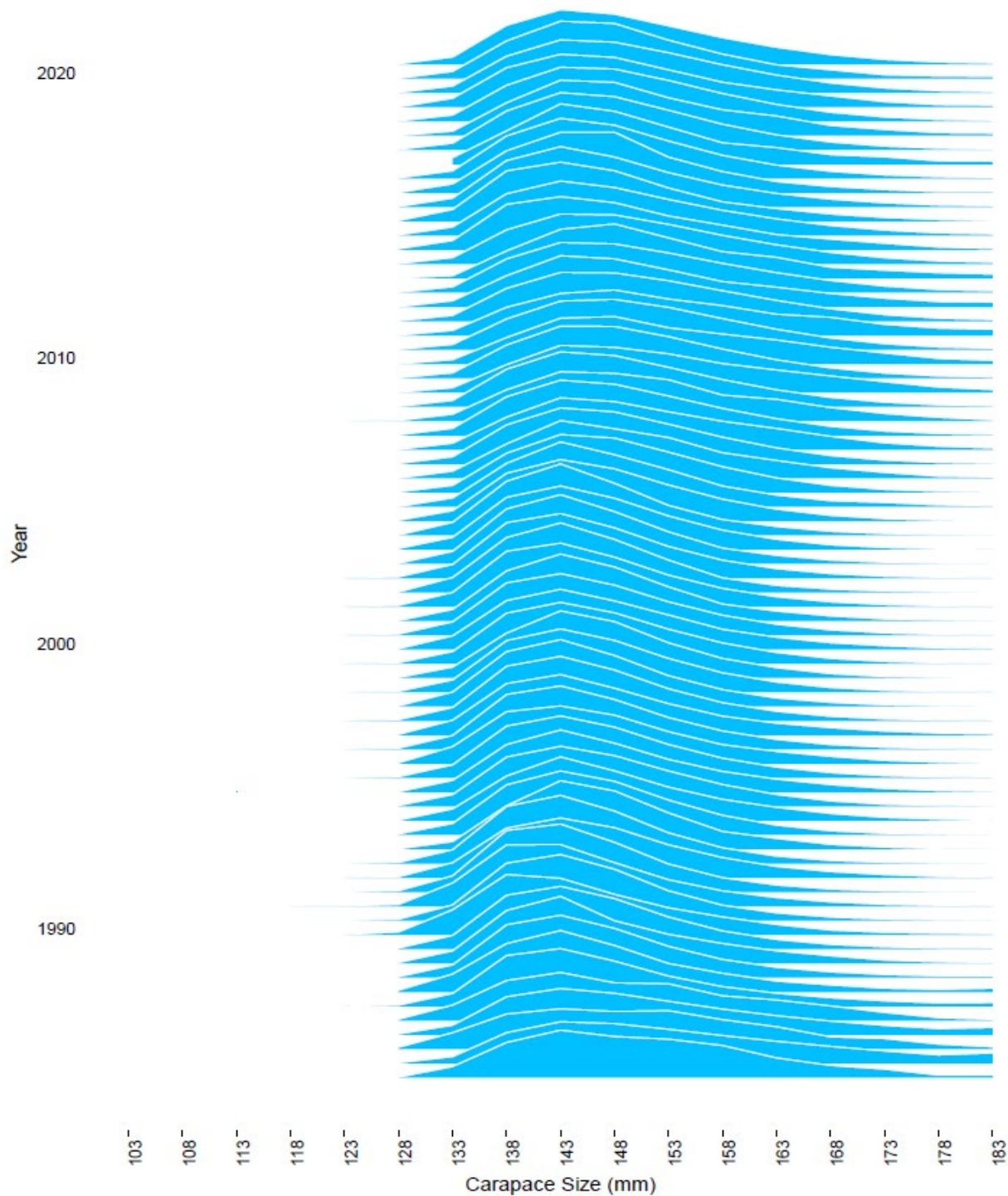
Figure 27c. Predicted vs. observed retained catch relative length frequency distributions under model 21.1c for golden king crab in the WAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1a: Observed vs predicted Total Catch Size Composition
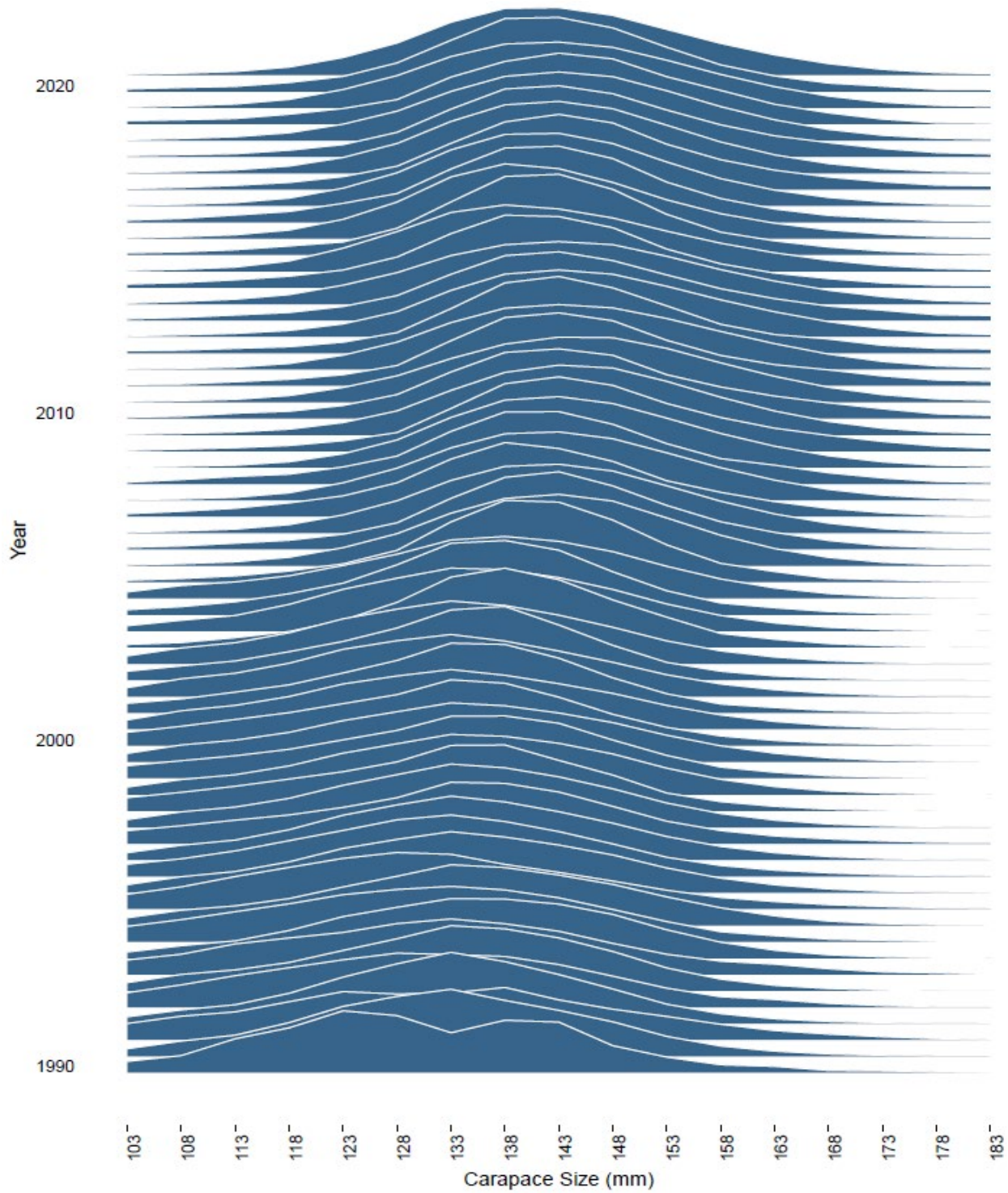
Figure 28a. Predicted vs. observed total catch relative length frequency distributions under model 21.1a for golden king crab in the WAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1b: Observed vs predicted Total Catch Size Composition
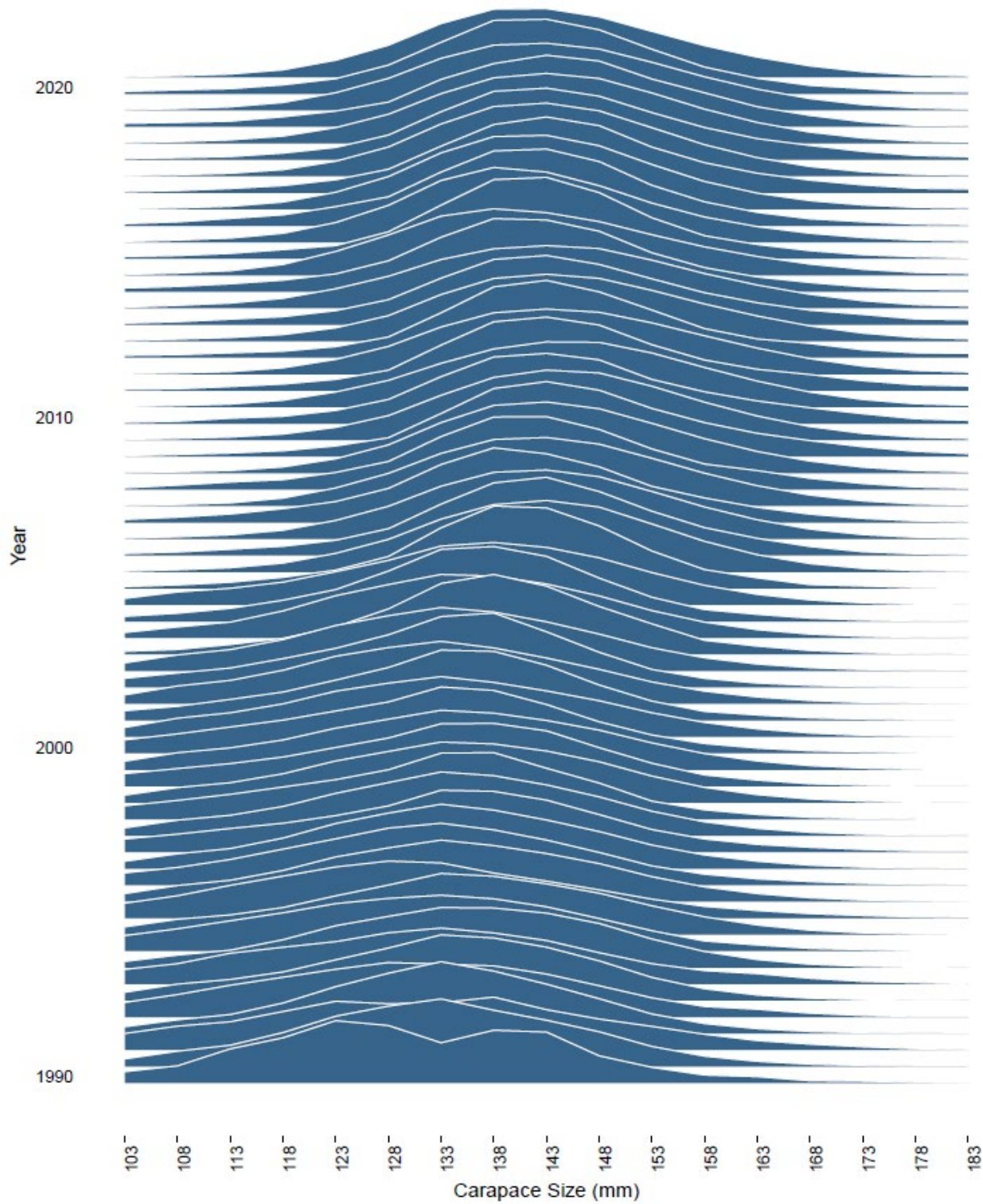
Figure 28b. Predicted vs. observed total catch relative length frequency distributions under model 21.1b for golden king crab in the WAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Model 21.1c: Observed vs predicted Total Catch Size Composition
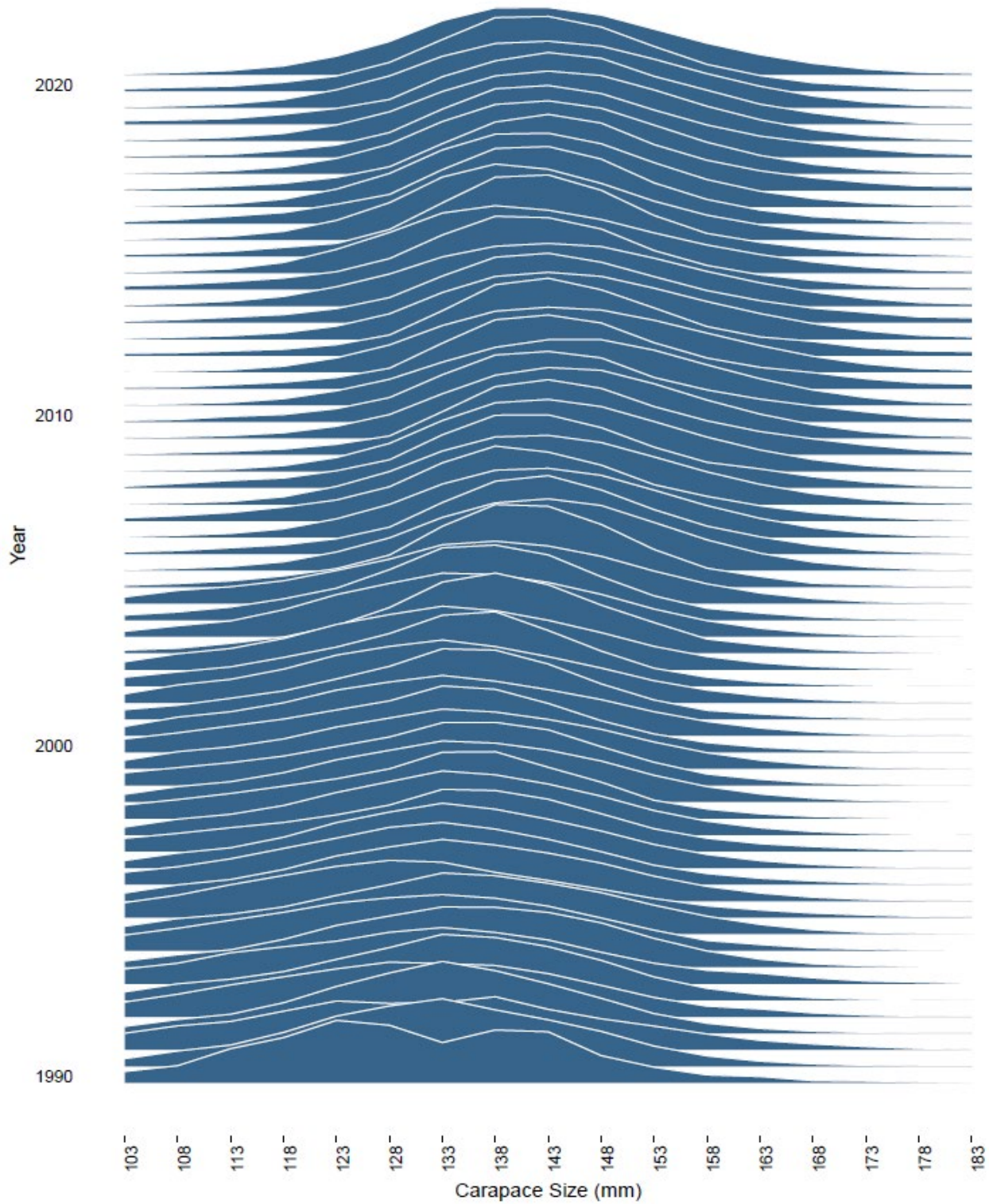
Figure 28c. Predicted vs. observed total catch relative length frequency distributions under model 21.1c for golden king crab in the WAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

Figure 29. Predicted vs. observed groundfish discarded bycatch relative length frequency distributions under model 21.1a for golden king crab in the WAG, 1989/90 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.
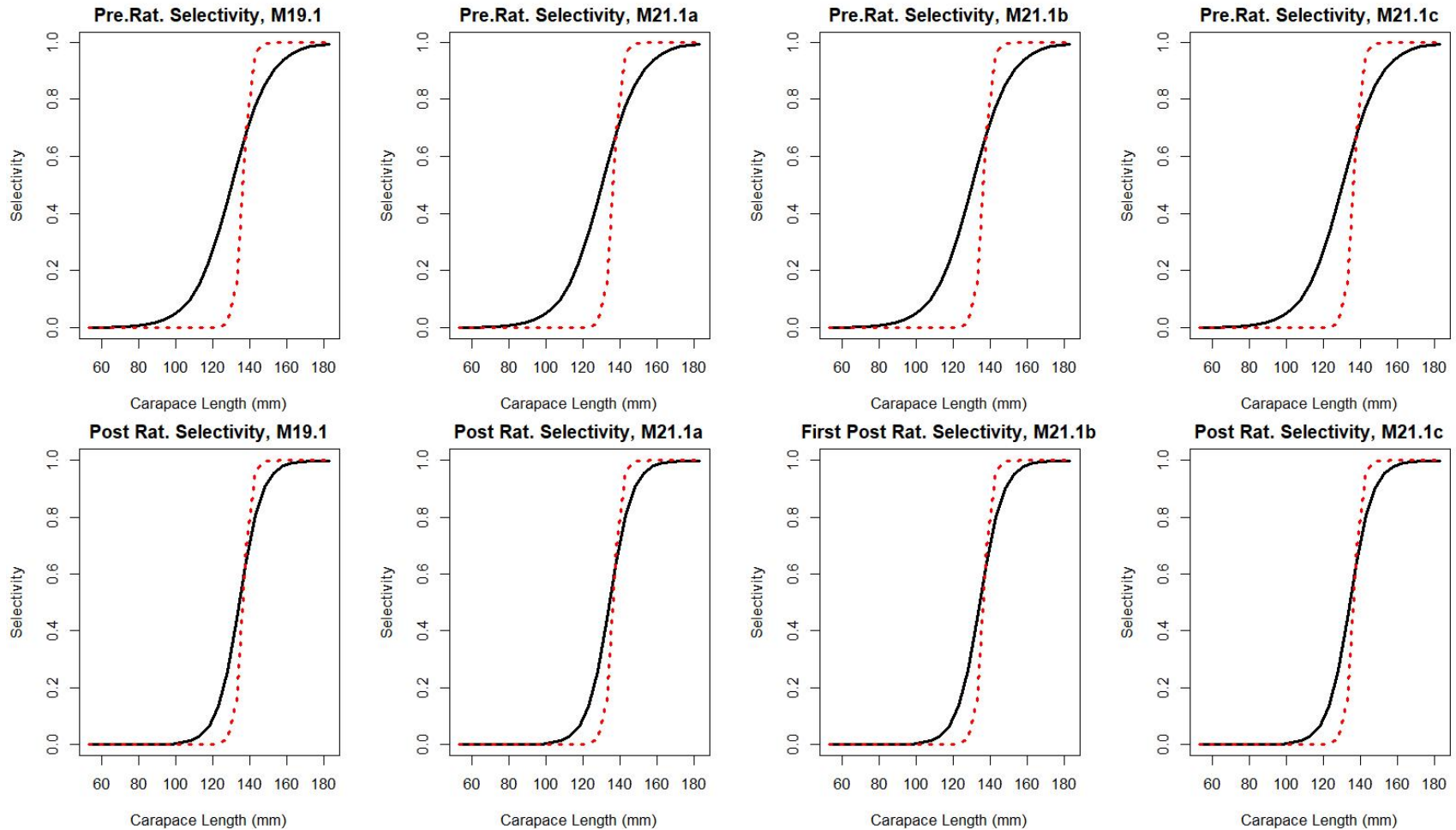
Figure 30a. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under models 19.1, 21.1a, 21.1b, and 21.1c fits to golden king crab data in the WAG. The post-rationalization total selectivity for 21.1b corresponds to first part (2005–2015) of the post-rationalization period.

Second Post Rat. Selectivity, M21.1b
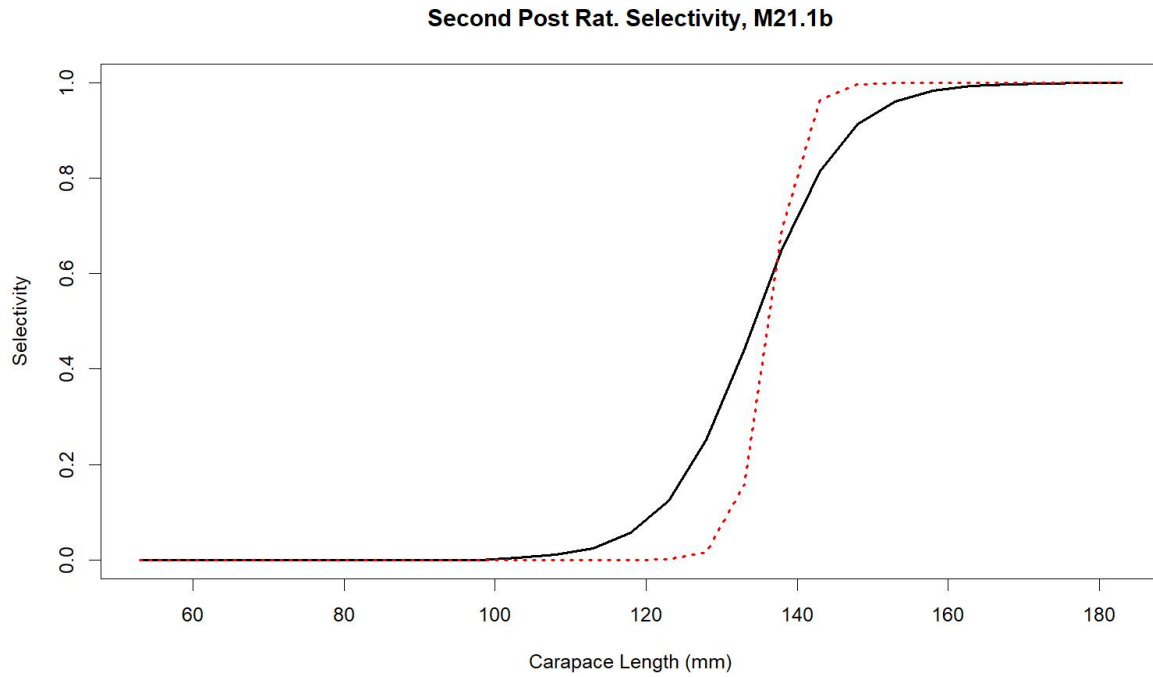
Figure 30b. Estimated total (black solid line) and retained selectivity (red dotted line) for second part (2016–2020) of the post- rationalization period under model 21.1b fit to golden king crab data in the WAG.
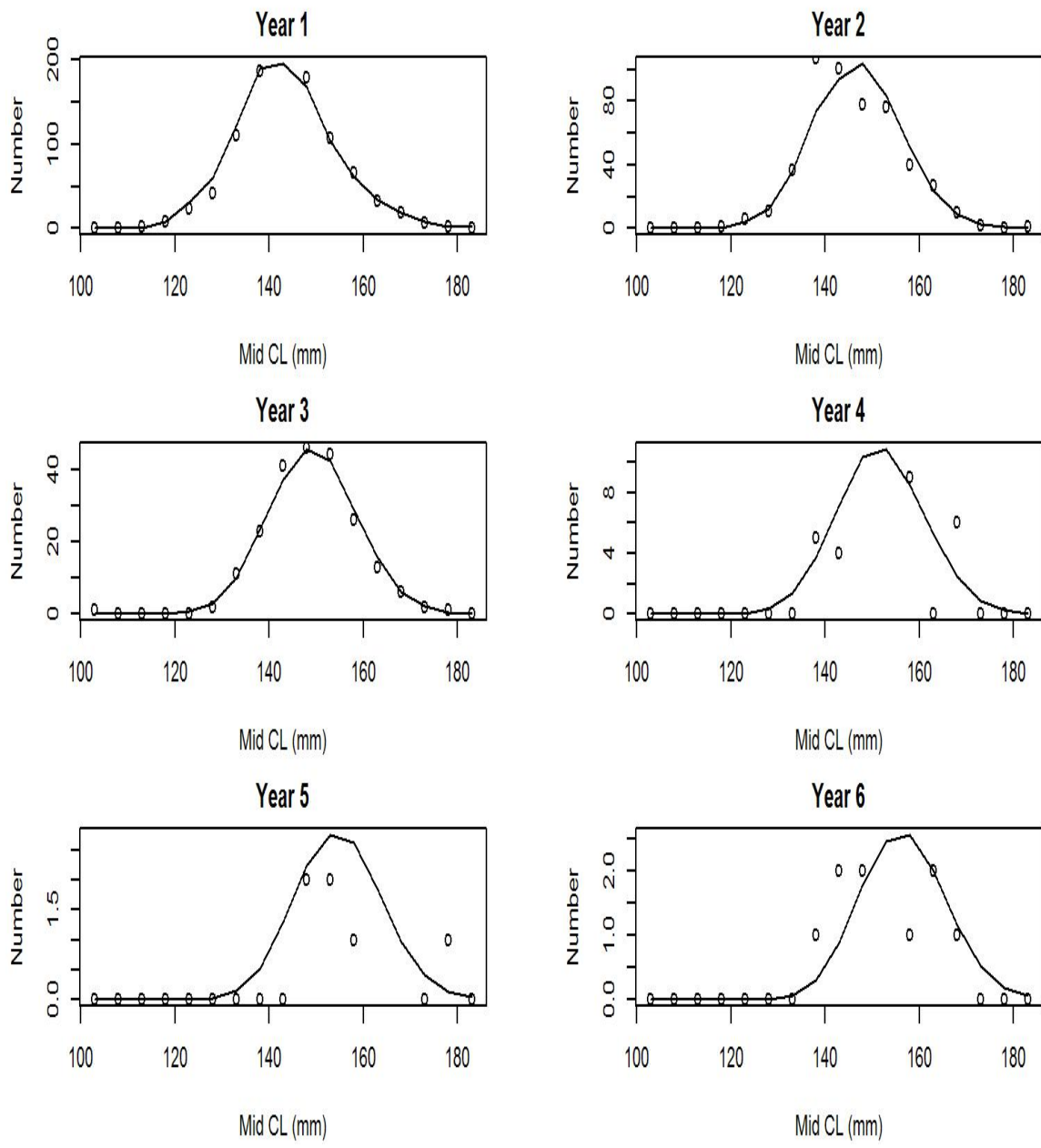
Figure 31. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under model 21.1a fit to WAG golden king crab data.
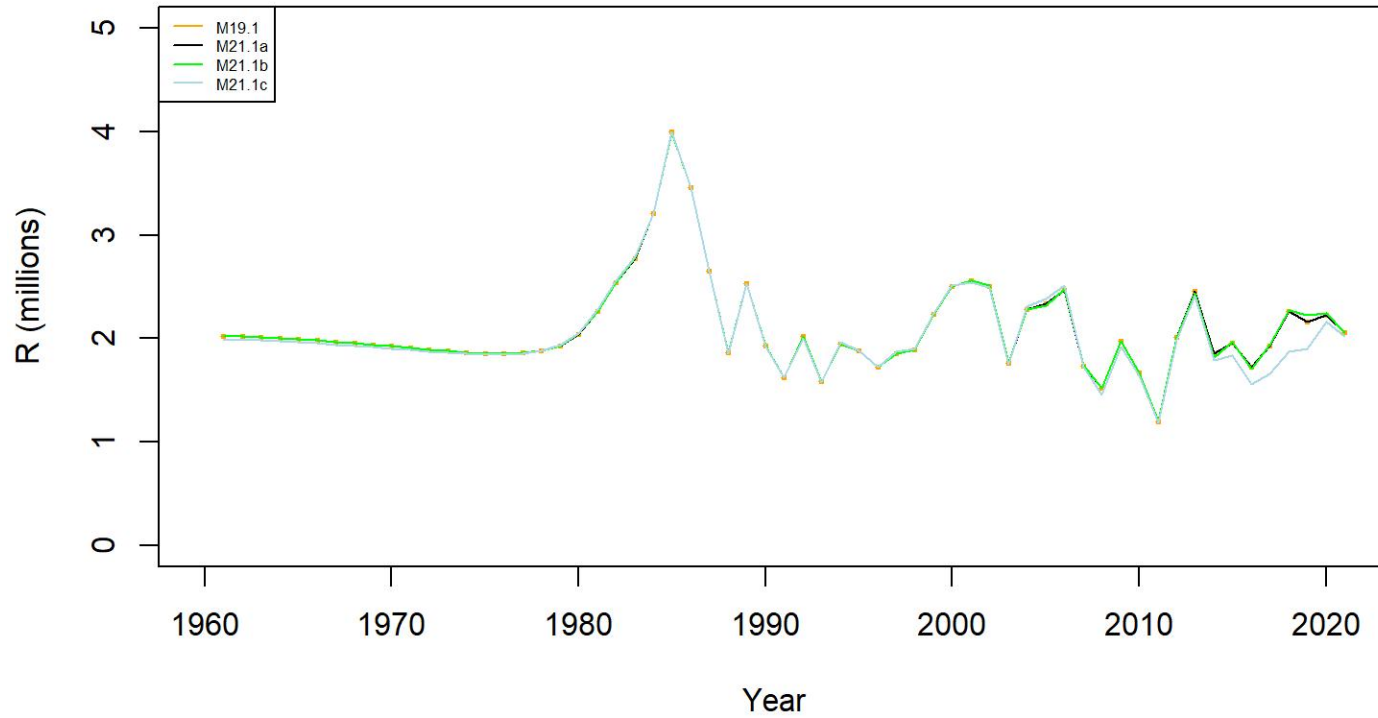
Figure 32. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data, 1961–2021.
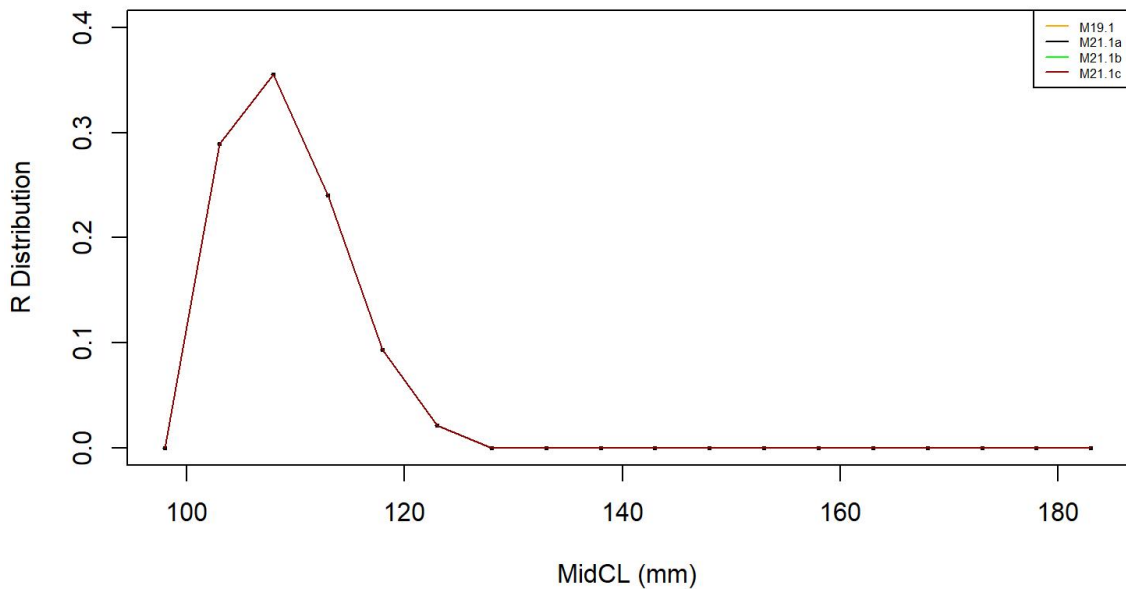
Figure 33. Recruit size distribution to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data.
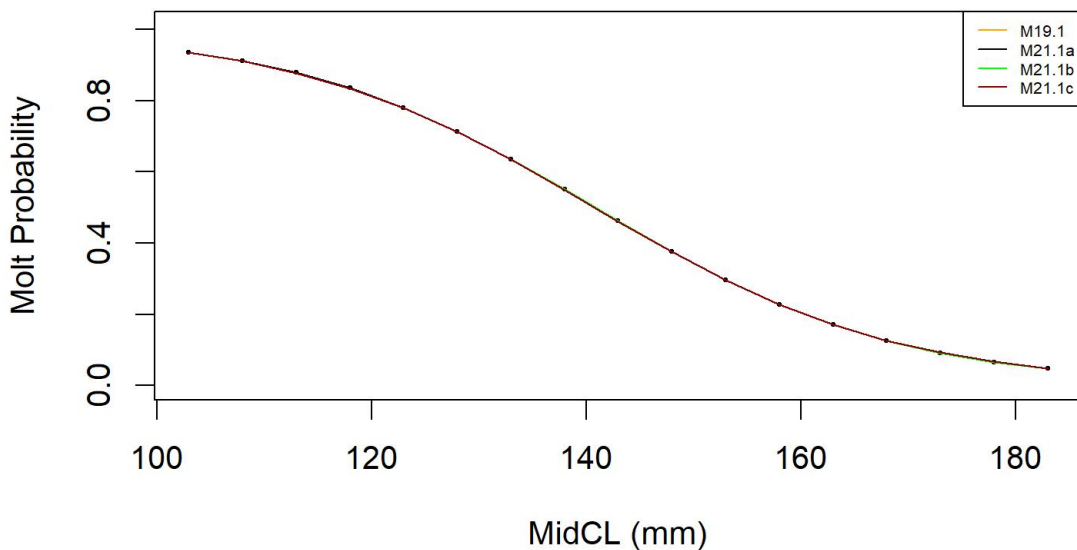
Figure 34. Estimated molt probability vs. carapace length of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data.
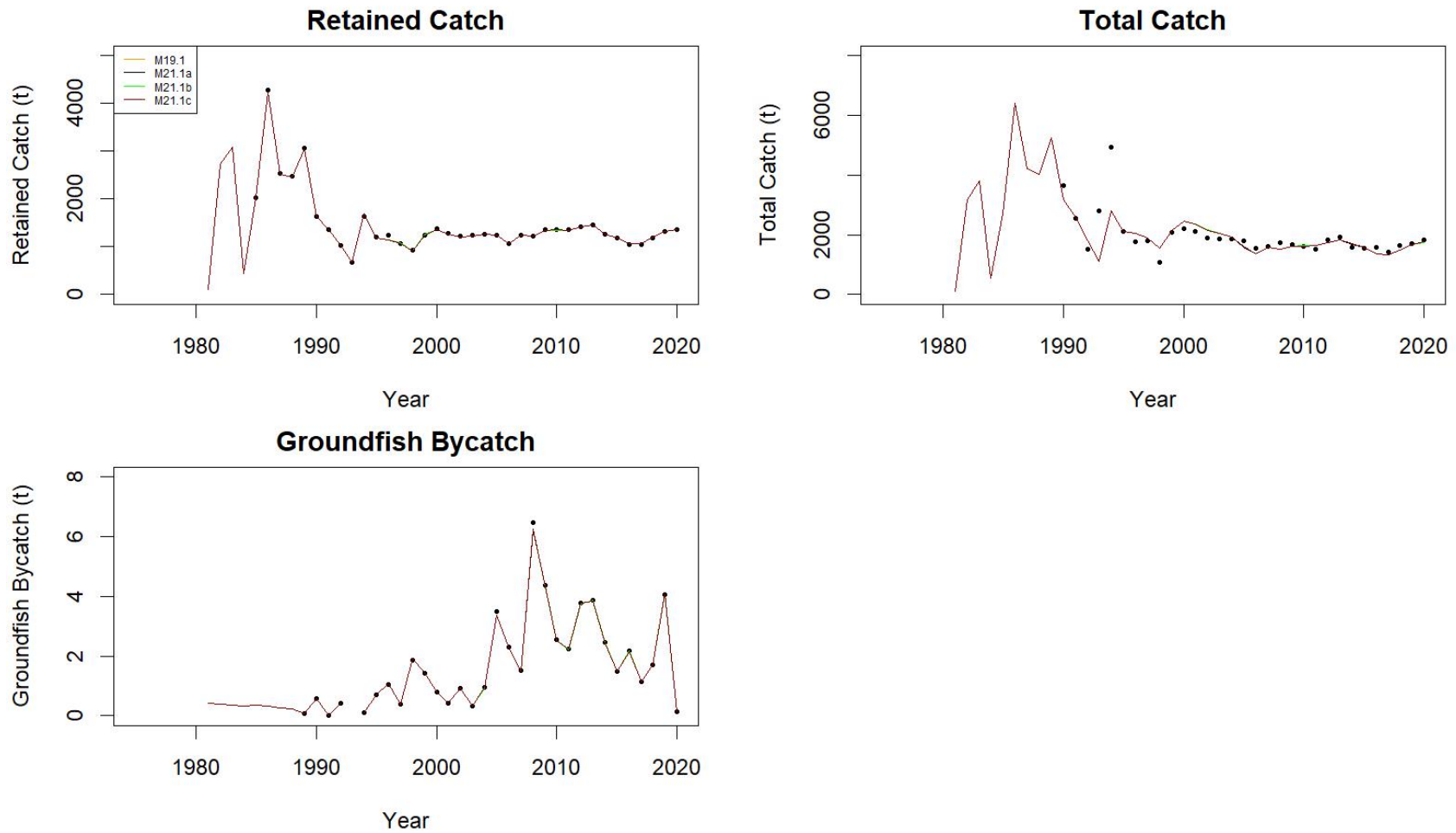
Figure 35. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG data, 1981/82–2020/21.
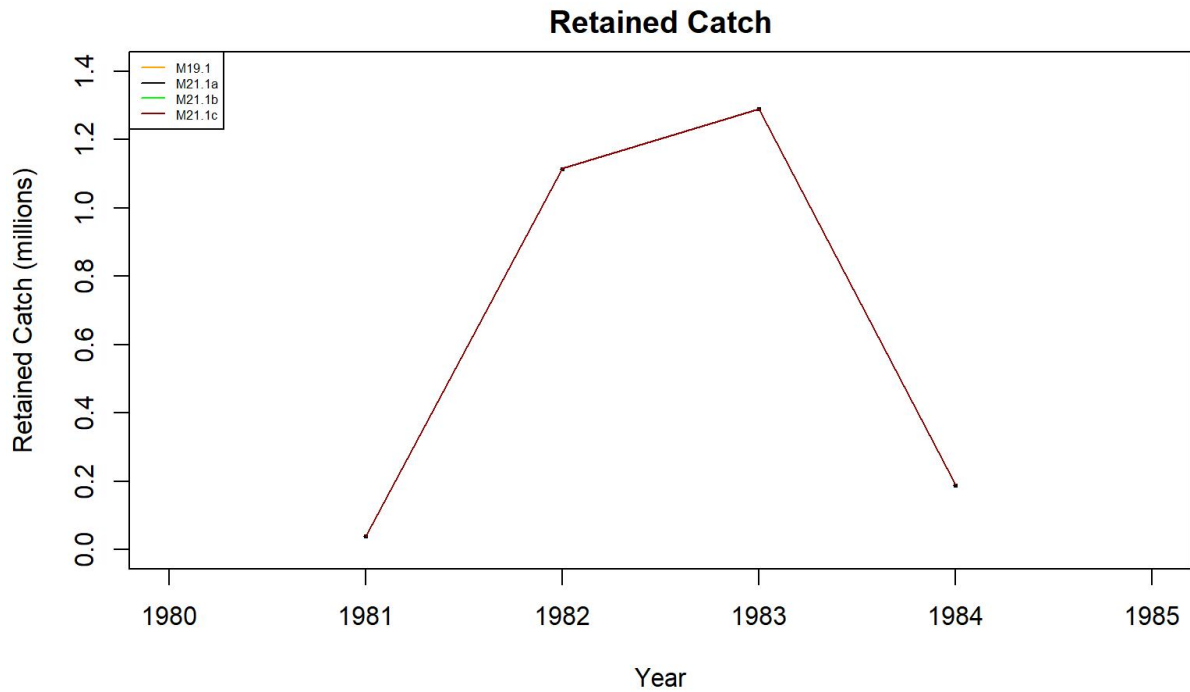
Retained Catch

Figure 36. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG data, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.
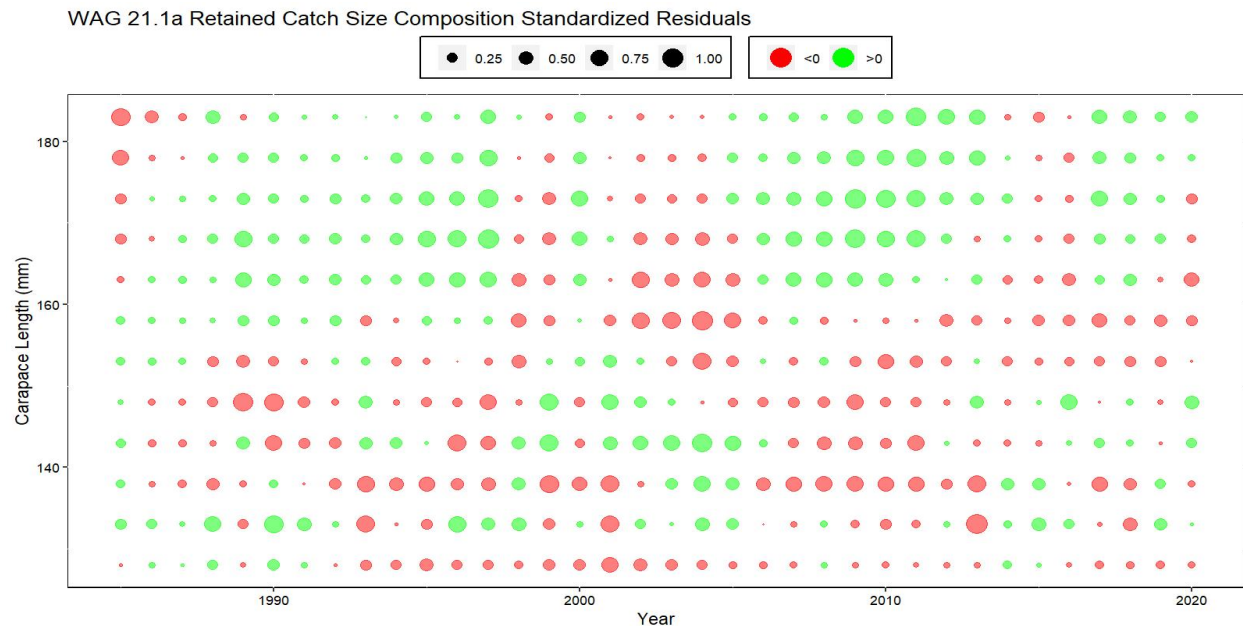
Figure 37. Bubble plot of standardized residuals of retained catch length composition for model 21.1a fit to WAG golden king crab data, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
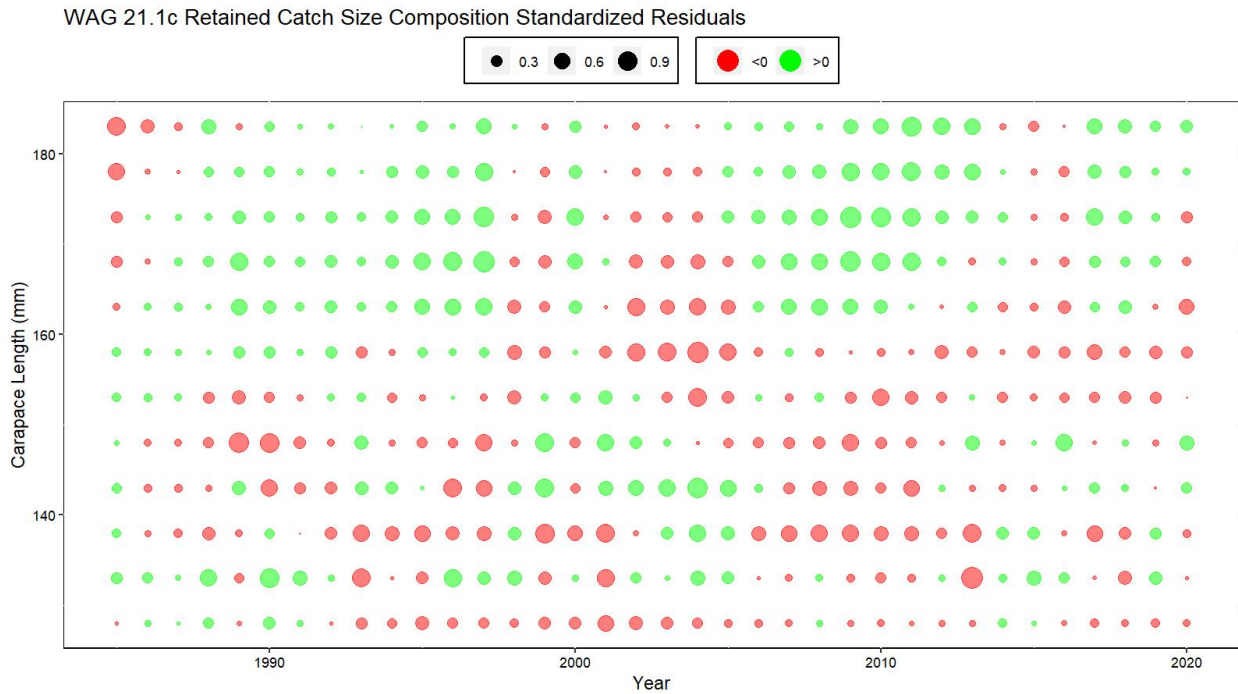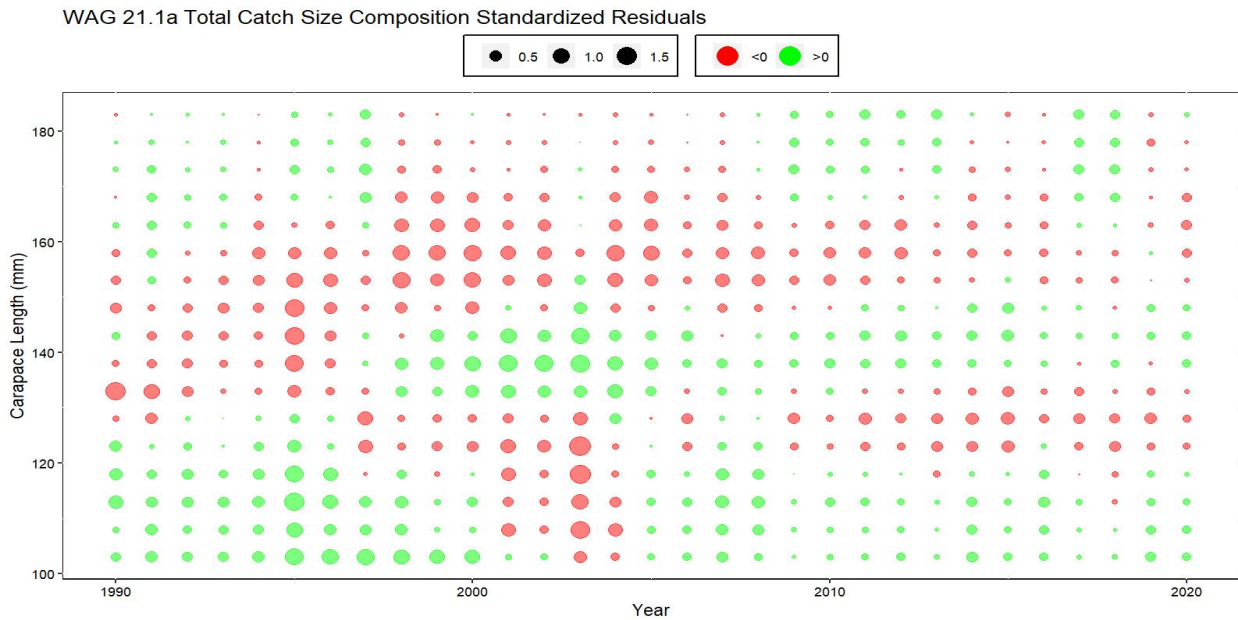
Figure 38. Bubble plot of standardized residuals of retained catch length composition for model 21.1c fit to WAG golden king crab data, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
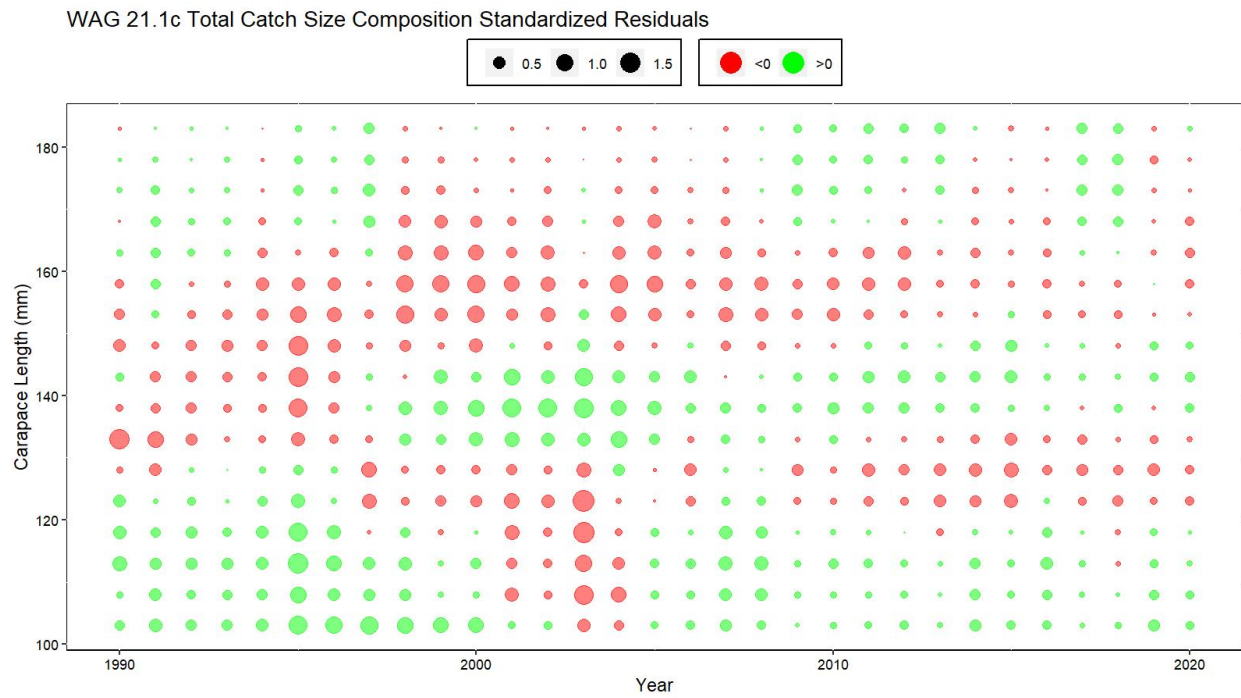

Figure 39. Bubble plot of standardized residuals of total catch length composition for model 21.1a fit to WAG golden king crab data, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

Figure 40. Bubble plot of standardized residuals of total catch length composition for model 21.1c fit to WAG golden king crab data, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.
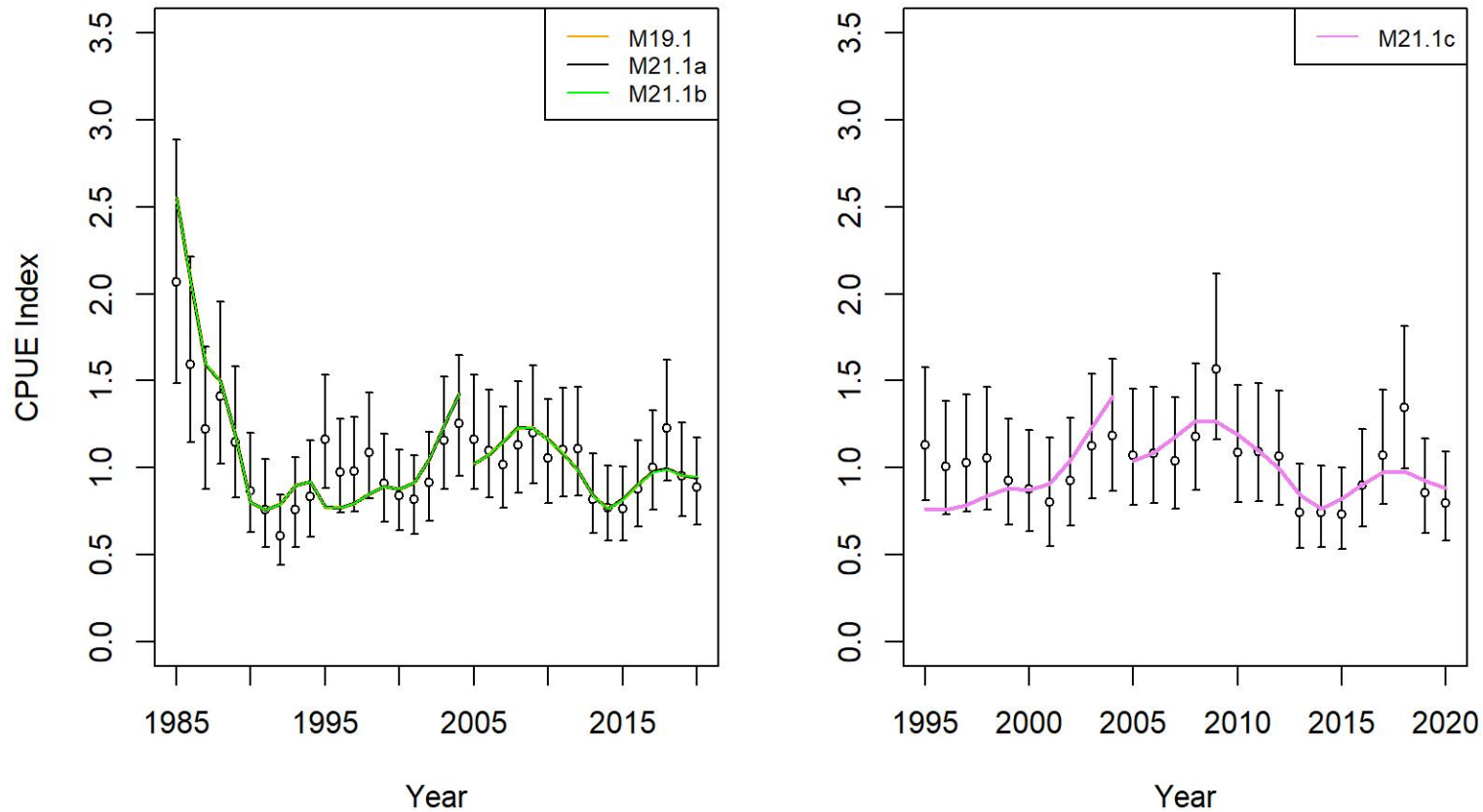
Figure 41. Comparison of input CPUE indices [open circles with +/- 2 SE for model 21.1a (left) and model 21.1c (right)] with predicted CPUE indices (colored solid lines) under 19.1, 21.1a, and 21.1b (left), and 21.1c (right) for WAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.
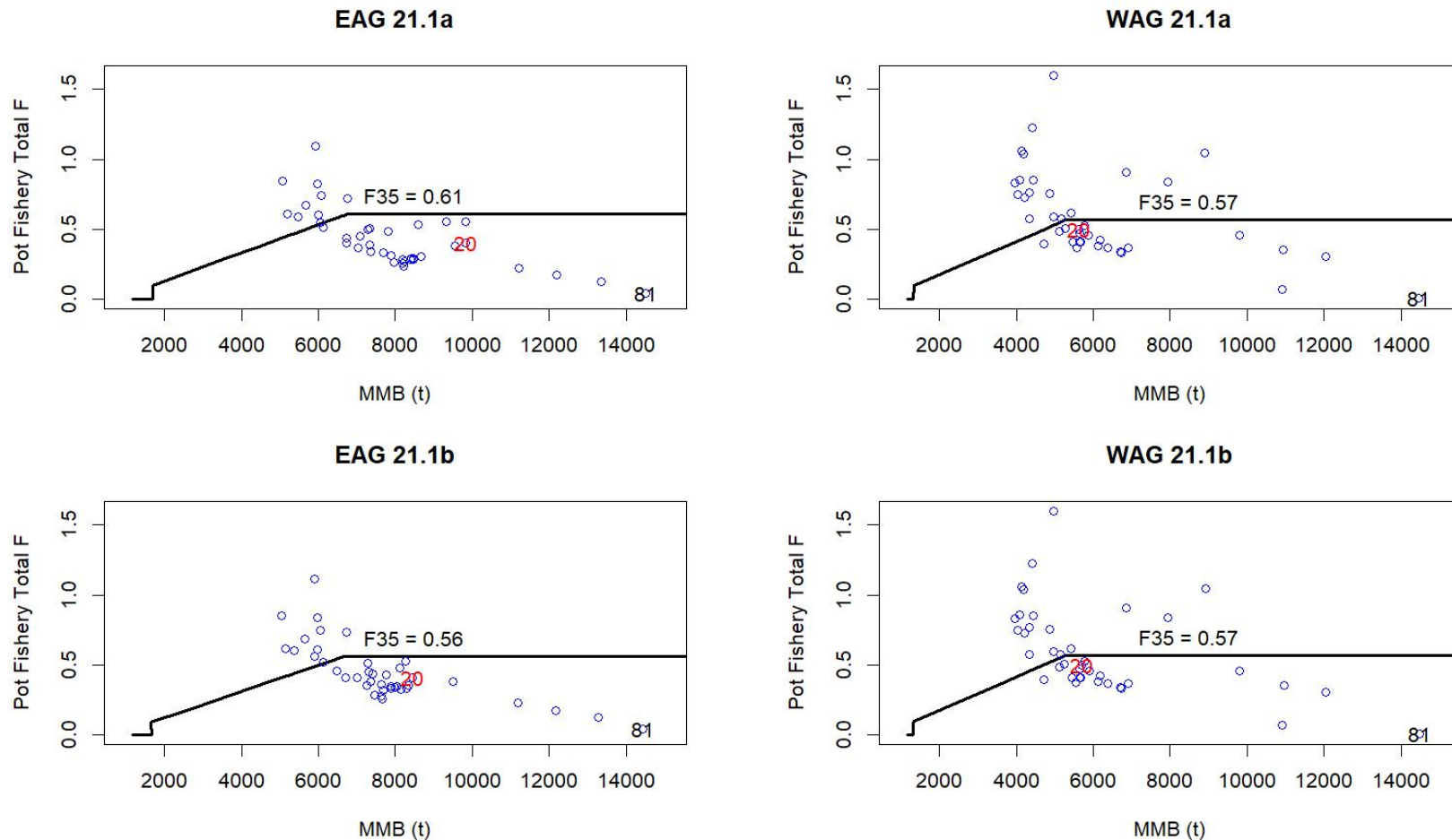
Figure 42. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass during 1981/82–2020/21 under models, 21.1a, 21.1b, and 21.1c fits to EAG and WAG data. *F* in 2020/21 (red) and 1981/82 (black) are shown in the plots.