Aleutian Islands Golden King Crab

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A. *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.

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 2,770 t (6,106,746 lb): 1,733 t (3,821,118 lb) from the EAG fishery (which included cost-recovery catch), and 1,037 t (2,285,628 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 81 t (179,000 lb) for WAG (WAG fishery on-going). 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.

All models for EAG and WAG used the previous season's fishery information (i.e., 2020/21 fishery, concluded in EAG and 77% of TAC achieved in WAG). We recommend 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]; and 21.1a2, 21.1b2, and 21.1c2 (logistic maturity curve for MMB estimation) for evaluation.

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 $0.21 yr^{-1}$, 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. Although we list the references points of model 19.1, we do not recommend selecting this model because different fixed period was considered for the mean recruit calculation.

The data for the EAG are complete through the 2020/21 season. The fishery in the WAG was still operating when the assessment was conducted, with 77% of the TAC taken (as of the 26 March 2021 reported summary). In a hypothetical scenario when the WAG fishery were to achieve the whole TAC by end of the 2020/21 fishing season, based on current retained to total fishing mortality ratio in WAG, it would result in a total catch of 3,482 t, which would be less than 2020/21 ABC.

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[d]	5.998[d,c]	16.215[d,c]	2.999	2.770[c]	3.148[c]	4.798	3.599
2020/21[e]	6.026	16.207					
2020/21[f]	5.964	14.871					
2020/21[g]	5.991	15.124					
2021/22[d]		14.821				4.796	3.615
2021/22[e]		14.816				4.817	3.613
2021/22[f]		13.832				4.407	3.305
2021/22[g]		14.048				4.471	3.353

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[d]	13.223[d,c]	35.748[d,c]	6.610	6.107[c]	6.940[c]	10.579	7.934
2020/21[e]	13.284	35.730					
2020/21[f]	13.148	32.784					
2020/21[g]	13.207	33.341					
2021/22[d]		32.675				10.573	7.969
2021/22[e]		32.662				10.620	7.965
2021/22[f]		30.494				9.715	7.287
2021/22[g]		30.971				9.857	7.393

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. WAG fishery was still being prosecuted when the assessment was conducted.
d. Model 19.1(base model)
e. Model 21.1a.
f. Model 21.1b.
g. Model 21.1c.

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 ten models, 19.1, 21.1a, 21.1b, and 21.1c (CPT/SSC suggested models); and 21.1a1, 21.1b1, 21.1c1, 21.1a2, 21.1b2, and 21.1c2 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 two WAG models, 21.1c1 and 21.1c2. The mean recruitment estimation period for those WAG models was reduced to 1993–1997 to bring up the current stock statuses above $MMB_{35\%}$ for combining the two regions' OFL and ABC (following Siddeek, *et al*. 2017). The modified forms of WAG models were labeled as 21.1c1Ver2 and 21.1c2Ver2 and reference points only for those models are listed in the tables.

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	14.762	19.229	1.30	0.61	1987–2012	0.61	6.470	6.432	4.853
EAG21.1a	3a	14.907	19.219	1.29	0.61	1987–2017	0.61	6.466	6.429	4.850
EAG21.1b	3a	14.658	16.960	1.16	0.56	1987–2017	0.56	5.545	5.516	4.159
EAG21.1c	3a	14.893	19.111	1.28	0.61	1987–2017	0.61	6.433	6.401	4.825
EAG21.1a1	3a	14.353	18.510	1.29	0.55	1987–2017	0.55	5.956	5.921	4.467
EAG21.1a2	3a	13.068	16.047	1.23	0.48	1987–2017	0.48	5.330	5.299	3.998
EAG21.1b1	3a	14.202	16.245	1.14	0.50	1987–2017	0.50	5.063	5.037	3.798
EAG21.1b2	3a	12.928	14.124	1.09	0.44	1987–2017	0.44	4.559	4.535	3.419
EAG21.1c1	3a	14.468	18.480	1.28	0.54	1987–2017	0.54	5.838	5.809	4.379
EAG21.1c2	3a	13.055	15.955	1.22	0.48	1987–2017	0.48	5.303	5.276	3.977

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	6.69585	8.72217	1.30	0.61	1987–2012	0.61	2.935086	2.918135	2.201314
EAG21.1a	3a	6.76171	8.71756	1.29	0.61	1987–2017	0.61	2.932993	2.916042	2.199745
EAG21.1b	3a	6.64877	7.69293	1.16	0.56	1987–2017	0.56	2.515111	2.502109	1.886333
EAG21.1c	3a	6.75540	8.66857	1.28	0.61	1987–2017	0.61	2.918103	2.903490	2.188577
EAG21.1a1	3a	6.51066	8.39605	1.29	0.55	1987–2017	0.55	2.701414	2.685591	2.026060
EAG21.1a2	3a	5.92744	7.27904	1.23	0.48	1987–2017	0.48	2.417822	2.403729	1.813367
EAG21.1b1	3a	6.44179	7.36860	1.14	0.50	1987–2017	0.50	2.296729	2.284992	1.722546
EAG21.1b2	3a	5.86180	6.40658	1.09	0.44	1987–2017	0.44	2.067846	2.057141	1.550884
EAG21.1c1	3a	6.56279	8.38248	1.28	0.54	1987–2017	0.54	2.648313	2.635166	1.986235
EAG21.1c2	3a	5.92153	7.23736	1.22	0.48	1987–2017	0.48	2.405558	2.393397	1.804168

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	11.684	13.446	1.15	0.57	1987–2012	0.57	4.155	4.140	3.116
WAG21.1a	3a	11.662	13.444	1.15	0.57	1987–2017	0.57	4.154	4.138	3.115
WAG21.1b	3a	11.638	13.534	1.16	0.57	1987–2017	0.57	4.171	4.155	3.128
WAG21.1c	3a	11.521	11.860	1.03	0.57	1987–2017	0.57	3.424	3.410	2.568
WAG21.1a1	3a	11.346	12.750	1.12	0.50	1987–2017	0.50	3.741	3.728	2.806
WAG21.1a2	3a	10.297	11.108	1.08	0.44	1987–2017	0.44	3.308	3.291	2.481
WAG21.1b1	3a	11.319	12.837	1.13	0.50	1987–2017	0.50	3.757	3.742	2.818
WAG21.1b2	3a	10.270	11.165	1.09	0.44	1987–2017	0.44	3.384	3.371	2.538
WAG21.1c1Ver2	3a	10.097	11.082	1.10	0.51	1993–1997	0.51	3.135	3.122	2.351
WAG21.1c2Ver2	3a	9.145	9.655	1.06	0.45	1993–1997	0.45	2.830	2.818	2.122

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	5.29998	6.09902	1.15	0.57	1987–2012	0.57	1.884520	1.877668	1.413390
WAG21.1a	3a	5.28969	6.09798	1.15	0.57	1987–2017	0.57	1.884023	1.877172	1.413017
WAG21.1b	3a	5.27901	6.13891	1.16	0.57	1987–2017	0.57	1.891769	1.884480	1.418827
WAG21.1c	3a	5.22569	5.37973	1.03	0.57	1987–2017	0.57	1.553061	1.546571	1.164796
WAG21.1a1	3a	5.14652	5.78336	1.12	0.50	1987–2017	0.50	1.697025	1.690875	1.272768
WAG21.1a2	3a	4.67050	5.03845	1.08	0.44	1987–2017	0.44	1.528387	1.522805	1.146290
WAG21.1b1	3a	5.13443	5.82280	1.13	0.50	1987–2017	0.50	1.704275	1.697558	1.278206
WAG21.1b2	3a	4.65828	5.06458	1.09	0.44	1987–2017	0.44	1.534941	1.529012	1.151206
WAG21.1c1Ver2	3a	4.57997	5.02675	1.10	0.51	1993–1997	0.51	1.422027	1.416168	1.066520
WAG21.1c2Ver2	3a	4.14813	4.37926	1.06	0.45	1993–1997	0.45	1.283679	1.278425	0.962759

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	10.625	10.573	7.969
21.1a	10.620	10.567	7.965
21.1b	9.715	9.671	7.287
21.1c	9.857	9.811	7.393
21.1a1	9.697	9.648	7.273
21.1a2	8.700	8.656	6.525
21.1b1	8.821	8.780	6.615
21.1b2	7.943	7.906	5.957
21.1c1 (with Ver 2 model for WAG)	8.973	8.932	6.730
21.1c2(with Ver 2 model for WAG)	8.133	8.095	6.100

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	4.81961	4.79580	3.61470
21.1a	4.81702	4.79321	3.61276
21.1b	4.40688	4.38659	3.30516
21.1c	4.47116	4.45006	3.35337
21.1a1	4.39844	4.37647	3.29883
21.1a2	3.94621	3.92653	2.95966
21.1b1	4.00100	3.98255	3.00075
21.1b2	3.60279	3.58615	2.70209
21.1c1 (with Ver 2 model for WAG)	4.07034	4.05133	3.05276
21.1c2(with Ver 2 model for WAG)	3.68924	3.67182	2.76693

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.

Please see also the section G on ABC.

9. A summary of the results of any rebuilding analysis:

Not applicable.

10. 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. Responses to SSC and CPT Comments

1. 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.*

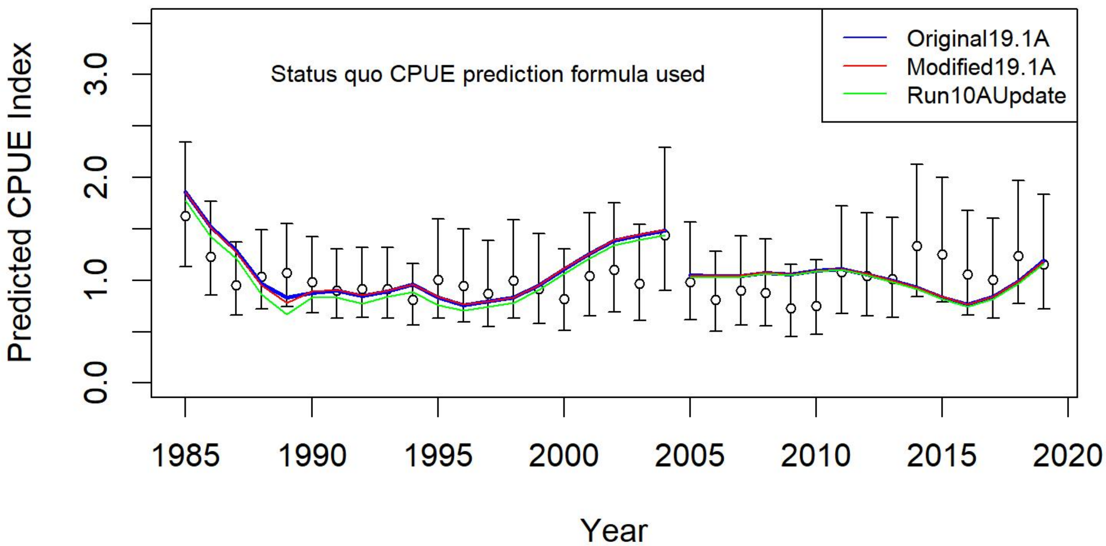


Figure CPT1. Comparison of input CPUE indices (open circles with +/- 2 SE for model 19.1A) with predicted CPUE indices (colored solid lines) under original model 19.1A, modified 19.1A to satisfy GMACS coding procedure, and GMACS Run#10AUpdate (most parameters were fixed to modified 19.1A model output) 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.

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

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.

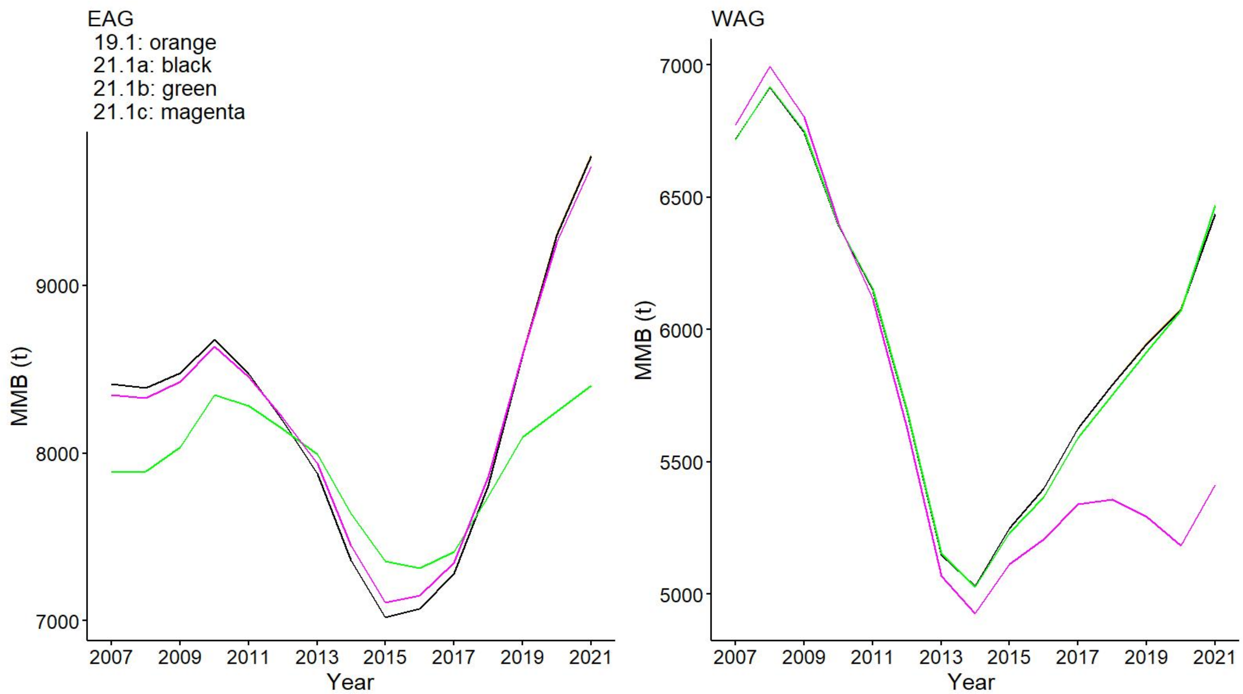


Figure CPT3. Trends in golden king crab mature male biomass for models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG (left) and WAG (right) data, 2007–2021. Year 2021 refers to 2020/21 fishing season.

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.

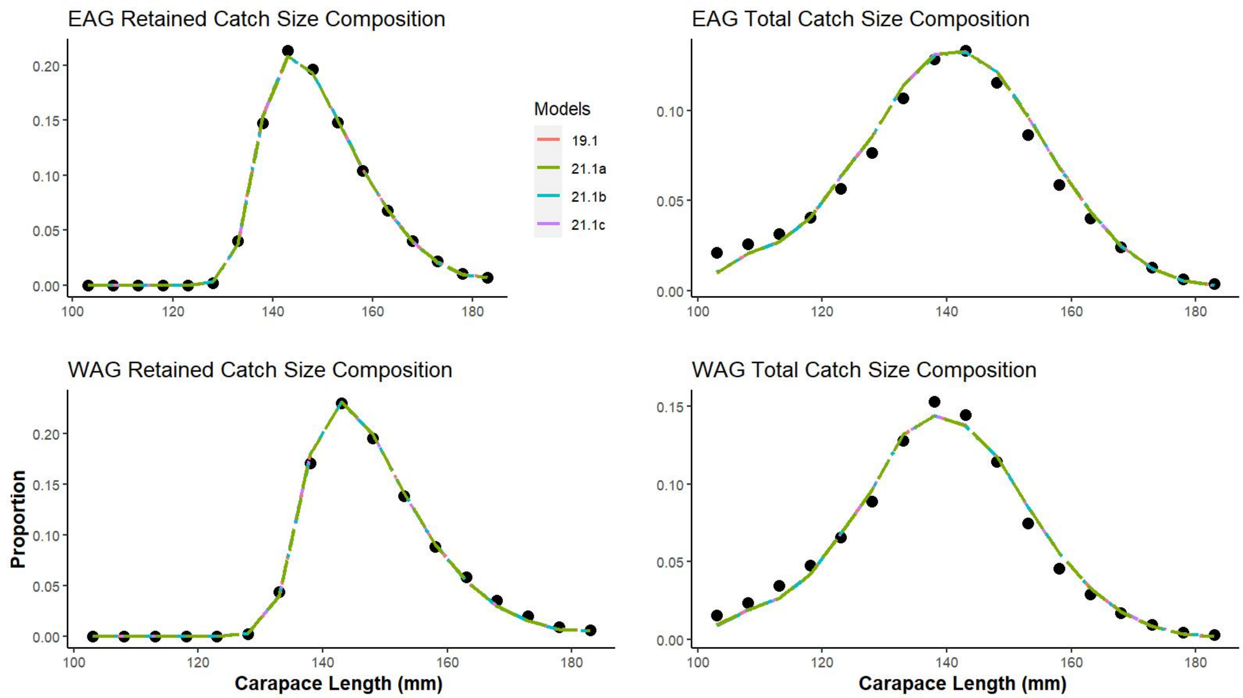


Figure CPT4. Cumulative size compositions vs carapace length for retained catch (left panels) and total catch (right panels) for EAG (top) and WAG (bottom). Observed proportions are marked by solid circles and predicted proportions by different models' (19.1, 21.1a, 21.1b, and 21.1c) are shown by different 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.

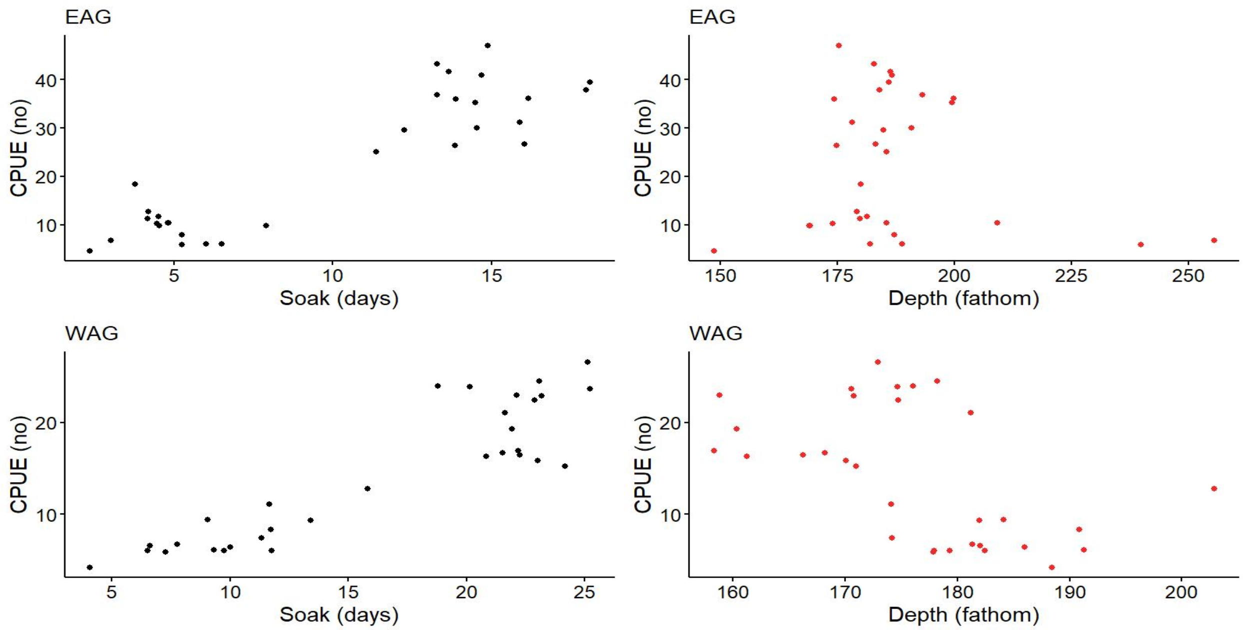


Figure CPT5. Annual observer nominal legal male CPUE vs annual mean soak time and annual mean depth in EAG (top) and WAG (bottom).

2. 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.*

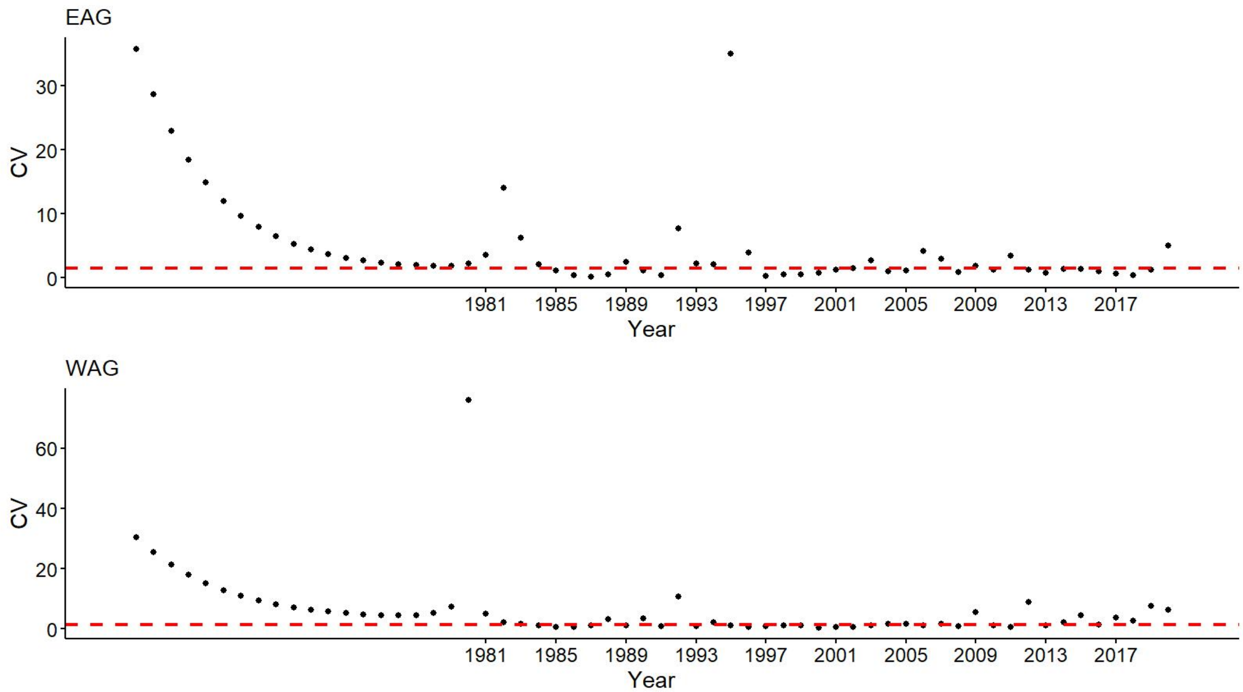


Figure SSC1. Coefficient of variation (CV) of recruit_dev vs. year for EAG (top) and WAG (bottom) for model 21.1a. The 1981–2020 marked years have input information for model fitting.

3. 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.

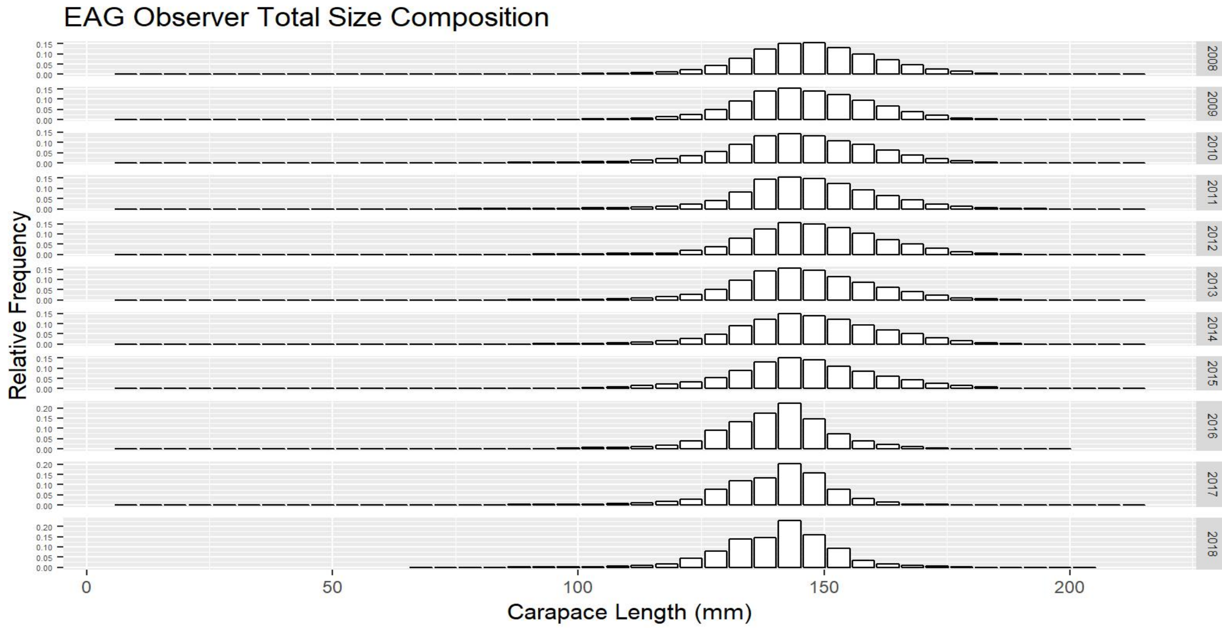


Figure SSC2. Observer total size composition for 2008–2018 in the EAG.

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.

(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 90 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) ≥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 and a maturity curve for MMB estimation (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 $MMA_{E,(1985\text{-}2017)}$, the fishery will not open;
   (2) if MMA_E is at least 25 percent but not greater than 100 percent of $MMA_{E,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.15)x(MMA_E/MMA_{E,(1985\text{-}2017)})x(MMA_E)$ or 25 percent of LMA_E, whichever is less; and
   (3) if MMA_E is greater than 100 percent of $MMA_{E,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.15)x(MMA_E)$ 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 $MMA_{W,(1985\text{-}2017)}$, the fishery will not open
   (2) if MMA_W is at least 25 percent but not greater than 100 percent of $MMA_{W,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.20)x(MMA_W/MMA_{W,(1985\text{-}2017)})x(MMA_W)$ or 25 percent of LMA_W, whichever is less; and
   (3) if MMA_W is greater than 100 percent of $MMA_{W,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.20)x(MMA_W)$ 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) $MMA_{E,(1985\text{-}2017)}$ 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) $MMA_{W,(1985\text{-}2017)}$ 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 MMBMSY or proxy MMBMSY:

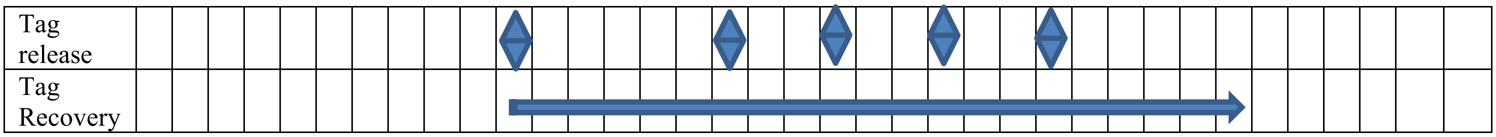
We estimated the proxy MMB_{MSY} as $MMB_{35\%}$ using the Tier 3 estimation procedure, which is explained in a subsequent section.

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.

Year	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	..	..	..	17	18	19	20
Ret.C. & Size Comp.																																					
Total C. & Size Comp.																																					
Ground fish ByC. & Size Comp.																																					
Observ. CPUE																																					
Fishery CPUE																																					



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 [σ = 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).

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 and maturity curves 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 ten 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 base model 19.1 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.
21.1a2	21.1a+ maturity curve.	Authors proposed additional model.
21.1b1	21.1b+ a knife-edge minimum maturity size of 116 mm CL.	Authors proposed additional model.
21.1b2	21.1b+ maturity curve.	Authors proposed additional model.
21.1c1	21.1c+ a knife-edge minimum maturity size of 116 mm CL.	Authors proposed additional model.
21.1c2	21.1c+ maturity curve.	Authors proposed additional model.

b. **Progression of results:**
The OFL and ABC estimates are like those estimates made in 2019.

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 year 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 base model 19.1 (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[d]	5.998[d,c]	16.215[d,c]	2.999	2.770[c]	3.148[c]	4.798	3.599
2020/21[e]	6.026	16.207					
2020/21[f]	5.964	14.871					
2020/21[g]	5.991	15.124					
2021/22[d]		14.821				4.796	3.615
2021/22[e]		14.816				4.817	3.613
2021/22[f]		13.832				4.407	3.305
2021/22[g]		14.048				4.471	3.353

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[d]	13.223[d,c]	35.748[d,c]	6.610	6.107[c]	6.940[c]	10.579	7.934
2020/21[e]	13.284	35.730					
2020/21[f]	13.148	32.784					
2020/21[g]	13.207	33.341					
2021/22[d]		32.675				10.573	7.969
2021/22[e]		32.662				10.620	7.965
2021/22[f]		30.494				9.715	7.287
2021/22[g]		30.971				9.857	7.393

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. WAG fishery was still operating when the assessment was conducted.
d. Model 19.1(base model)
e. Model 21.1a.
f. Model 21.1b.

g. Model 21.1c.

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: 2,801 t (6.176 million lb)
WAG: 1,782 t (3.928 million lb)
AI: 4,583 t (10.104 million lb).

Model 21.1b:
EAG: 2,386 t (5.260 million lb)
WAG: 1,790 t (3.947 million lb)
AI: 4,176 t (9.207 million lb).

Model 21.1c:
EAG: 2,787 t (6.143 million lb)
WAG: 1,461 t (3.222 million lb)
AI: 4,248 t (9.365 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 = 2,200 t (4.850 million lb)
WAG: ABC = 1,413 t (3.115 million lb)
AI: ABC = 3,613 t (7.965 million lb).

Model 21.1b:
EAG: ABC = 1,886 t (4.159 million lb)
WAG: ABC = 1,419 t (3.128 million lb)
AI: ABC = 3,305 t (7.287 million lb).

Model 21.1c:
EAG: ABC = 2,188 t (4.825 million lb)
WAG: ABC = 1,165 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.

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Tables

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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	1,037*	902,122	560,519*	30,072	37,478*	30	15*	1.92[f]	1.85[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.
*As of March 26, 2021, WAG fishery is ongoing.
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.

			Bycatch Mortality by Fishery Type (t)						
	Retained Catch (t)		**Crab**		**Groundfish**		**Total Fishery Mortality (t)**		
Season	**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	1,037*	241	81	40	17	2,014	1,134	3,148

*As of March 26, 2021, WAG fishery is ongoing.

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	2,584	1,561*

*As of March 26, 2021, WAG fishery is ongoing.

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	1.14
2006/07	24.80	19.60	25.13	23.93	33.39	33.47	26,195	26,870	1,098	1,183	0.80	1.07
2007/08	28.00	20.00	31.10	21.01	40.38	32.46	22,653	29,950	998	1,082	0.89	0.99
2008/09	27.30	22.40	29.97	24.50	38.23	38.16	24,466	26,200	613	979	0.88	1.11
2009/10	25.90	23.70	26.60	26.54	35.88	34.08	26,298	26,489	408	892	0.72	1.18
2010/11	26.00	20.90	26.40	22.43	37.10	29.05	25,851	29,994	436	867	0.75	1.04
2011/12	37.30	23.40	39.48	23.63	52.04	31.13	17,915	26,326	361	837	1.08	1.08
2012/13	33.02	20.57	37.82	22.88	47.57	30.76	20,827	32,716	438	1,109	1.03	1.10
2013/14	33.67	16.42	35.94	16.89	46.16	25.01	21,388	41,835	499	1,223	1.01	0.81
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	0.77
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	1.01
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	0.97
2020/21	30.00	14.96*	36.15	16.44*	57.21	24.12*	30,072	37,478*	552	672*	1.04	1.02*

*As of March 26, 2021, WAG fishery is ongoing.

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.

	Model 19.1		**Model 21.1a**		**Model 21.1b**		**Model 21.1c**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_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_β_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	9,771	0.22	8,402	0.20	9,711	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 (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 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} =23,202			
		$MMB_{35\%}$=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 (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =22,941 $MMB_{35\%}$=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 (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =23,196			
		$MMB_{35\%}$=6,755			
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	-1334.9600	-1325.3100	-1331.1500	0	9.65	3.81
Totallencomp	-1486.6000	-1486.6000	-1481.4000	-1487.0300	0	5.2	-0.43
Observer cpue	0.1376	0.1441	-6.5913	-6.3306	0.0065	-6.7289	-6.4682
RetdcatchB	7.6797	7.6795	7.5856	7.8838	-0.0002	-0.0941	0.2041
TotalcatchB	23.7070	23.7071	23.5424	23.7389	0.00010	-0.1646	0.0319
GdiscdcatchB	0.0003	0.0003	0.0003	0.0003	0	0	0
Rec_dev	6.8557	6.8548	5.7315	6.6954	-0.0009	-1.1242	-0.1603
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	0.3	-0.03
Fishery cpue	-3.5625	-3.5628	-3.3106	-3.2839	-0.0003	0.2519	0.2786
RetcatchN	0.0062	0.0062	0.0058	0.0061	0	-0.0004	-0.00010
Total	-94.0875	-94.0851	-86.8140	-96.8547	0.0024	7.2735	-2.7672

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	152				
1989/90	513	274			7	5
1990/91	205	109	190	93	6	4
1991/92	102	54	104	51	1	1
1992/93	76	41	94	46	3	2
1993/94	378	202	62	30	NA	NA
1994/95	367	196	119	58	2	1
1995/96	705	376	907	445	5	3
1996/97	817	436	1,061	520	8	5
1997/98	984	525	1,116	547	6	4
1998/99	613	327	638	313	14	9
1999/00	915	488	1,155	567	18	12
2000/01	1,029	549	1,205	591	11	7
2001/02	898	479	975	478	11	7
2002/03	628	335	675	331	16	10
2003/04	688	367	700	343	8	5
2004/05	449	239	488	239	9	6
2005/06	337	180	220	108	6	4
2006/07	337	180	321	157	14	9
2007/08	276	147	257	126	17	11
2008/09	318	170	258	127	19	12
2009/10	362	193	292	143	24	15
2010/11	328	175	222	109	13	8
2011/12	295	157	252	124	14	9
2012/13	288	154	241	118	18	12
2013/14	327	174	236	116	17	11
2014/15	305	163	219	107	18	12
2015/16	287	153	243	119	10	6
2016/17	392	209	253	124	12	8
2017/18	299	159	222	109	10	6
2018/19	328	175	318	156	5	3
2019/20	338	180	224	110	6	4
2020/21	372	198	176	86	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	153				
1989/90	513	275			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	202	62	31	NA	NA
1994/95	367	197	119	59	2	1
1995/96	705	377	907	448	5	3
1996/97	817	437	1,061	524	8	5
1997/98	984	527	1,116	551	6	4
1998/99	613	328	638	315	14	9
1999/00	915	490	1,155	570	18	12
2000/01	1,029	551	1,205	595	11	7
2001/02	898	481	975	481	11	7
2002/03	628	336	675	333	16	10
2003/04	688	368	700	346	8	5
2004/05	449	240	488	241	9	6
2005/06	337	180	220	109	6	4
2006/07	337	180	321	158	14	9
2007/08	276	148	257	127	17	11
2008/09	318	170	258	127	19	12
2009/10	362	194	292	144	24	15
2010/11	328	176	222	110	13	8
2011/12	295	158	252	124	14	9
2012/13	288	154	241	119	18	12
2013/14	327	175	236	116	17	11
2014/15	305	163	219	108	18	12
2015/16	287	154	243	120	10	6
2016/17	392	210	253	125	12	8
2017/18	299	160	222	110	10	6
2018/19	328	176	318	157	5	3
2019/20	338	181	224	111	6	4
2020/21	372	199	176	87	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	275			7	5
1990/91	205	110	190	96	6	4
1991/92	102	55	104	53	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	378	907	458	5	3
1996/97	817	439	1,061	536	8	5
1997/98	984	528	1,116	564	6	4
1998/99	613	329	638	322	14	9
1999/00	915	491	1,155	583	18	12
2000/01	1,029	552	1,205	609	11	7
2001/02	898	482	975	492	11	7
2002/03	628	337	675	341	16	10
2003/04	688	369	700	354	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	130	17	11
2008/09	318	171	258	130	19	12
2009/10	362	194	292	147	24	16
2010/11	328	176	222	112	13	8
2011/12	295	158	252	127	14	9
2012/13	288	155	241	122	18	12
2013/14	327	176	236	119	17	11
2014/15	305	164	219	111	18	12
2015/16	287	154	243	123	10	7
2016/17	392	210	253	128	12	8
2017/18	299	161	222	112	10	7
2018/19	328	176	318	161	5	3
2019/20	338	181	224	113	6	4
2020/21	372	200	176	89	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.

	Model 19.1		Model 21.1a		Model 21.1b		Model 21.1c		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.538	0.01	2.538	0.01	2.538	0.01	2.539	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-7.479	0.23	-7.479	0.23	-7.469	0.23	-7.441	-0.23	-12.0-5.0
log_a (molt prob. slope)	-2.644	0.03	-2.644	0.03	-2.645	0.03	-2.647	-0.03	-4.61-1.39
log_b (molt prob. L50)	4.948	0.001	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	2.878	0.02	2.878	0.02	2.898	0.03	2.882	0.02	0.,4.4
log_ total sel deltaθ, 2016–20					2.841	0.03			0.,4.4
log_ ret. sel deltaθ, 1985–20	1.783	0.02	1.783	0.02	1.783	0.02	1.784	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.869	0.002	4.869	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					4.901	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.)	-1.029	0.16	-1.029	0.16	-1.030	0.16	-1.028	-0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.032	2.12	-0.032	2.12	-0.031	2.23	-0.038	-1.80	-9.0, 2.25
logq3 (catchability 2005–20)	-0.430	0.20	-0.430	0.20	-0.426	0.20	-0.392	-0.22	-9.0, 2.25
log_mean_rec (mean rec.)	0.722	0.05	0.722	0.05	0.722	0.06	0.706	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.726	0.08	-0.726	0.08	-0.724	0.08	-0.709	-0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.383	0.09	-8.383	0.09	-8.382	0.09	-8.362	-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	0.022	0.36	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.025	0.60	0.025	0.60	0.025	0.60	0.025	0.57	0.0,1.0
2020 MMB	6,438	0.15	6,436	0.15	6,469	0.17	5,413	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 (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,279 $MMB_{35\%}$=6,696			
1985	4.00	10,590	0.05	9,037	0.10
1986	3.46	8,141	0.05	8,478	0.08
1987	2.65	7,472	0.04	5,995	0.06
1988	1.87	6,390	0.04	5,602	0.05
1989	2.53	4,397	0.04	4,943	0.04
1990	1.93	4,102	0.05	3,109	0.06
1991	1.62	3,871	0.05	2,846	0.05
1992	2.02	4,008	0.04	2,793	0.05
1993	1.59	4,578	0.03	2,947	0.05
1994	1.95	3,876	0.03	3,525	0.03
1995	1.89	3,863	0.04	2,843	0.03
1996	1.73	3,871	0.04	2,778	0.04
1997	1.85	3,940	0.04	2,815	0.04
1998	1.89	4,256	0.04	2,896	0.04
1999	2.24	4,282	0.04	3,177	0.03
2000	2.51	4,433	0.04	3,111	0.04
2001	2.56	4,871	0.05	3,112	0.04
2002	2.51	5,432	0.05	3,438	0.05
2003	1.76	5,769	0.05	3,962	0.05
2004	2.28	5,886	0.06	4,464	0.05
2005	2.34	6,183	0.06	4,666	0.06
2006	2.47	6,720	0.05	4,847	0.06
2007	1.74	6,916	0.05	5,299	0.06
2008	1.52	6,746	0.05	5,608	0.06
2009	1.97	6,393	0.05	5,677	0.05
2010	1.67	6,150	0.05	5,336	0.05
2011	1.20	5,691	0.05	5,061	0.05
2012	2.01	5,150	0.05	4,757	0.05
2013	2.46	5,029	0.06	4,182	0.05
2014	1.86	5,249	0.06	3,778	0.06
2015	1.96	5,400	0.06	3,954	0.06
2016	1.73	5,627	0.07	4,203	0.07
2017	1.93	5,791	0.07	4,499	0.07
2018	2.27	5,947	0.09	4,682	0.07
2019	2.16	6,077	0.12	4,722	0.09
2020	2.23	6,438	0.15	4,767	0.11
2021	2.06				

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 (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,243 $MMB_{35\%}$=5,290			
1985	4.00	10,589	0.05	9,037	0.10
1986	3.46	8,140	0.05	8,478	0.08
1987	2.65	7,472	0.04	5,995	0.06
1988	1.87	6,390	0.04	5,602	0.05
1989	2.53	4,397	0.04	4,943	0.04
1990	1.93	4,102	0.05	3,109	0.06
1991	1.62	3,871	0.05	2,846	0.05
1992	2.02	4,008	0.04	2,793	0.05
1993	1.59	4,578	0.03	2,947	0.05
1994	1.95	3,876	0.03	3,525	0.03
1995	1.89	3,863	0.04	2,843	0.03
1996	1.73	3,871	0.04	2,778	0.04
1997	1.85	3,940	0.04	2,815	0.04
1998	1.89	4,256	0.04	2,896	0.04
1999	2.24	4,282	0.04	3,177	0.03
2000	2.51	4,433	0.04	3,111	0.04
2001	2.56	4,871	0.05	3,112	0.04
2002	2.51	5,432	0.05	3,438	0.05
2003	1.76	5,769	0.05	3,962	0.05
2004	2.28	5,886	0.06	4,464	0.05
2005	2.34	6,183	0.06	4,666	0.06
2006	2.47	6,720	0.05	4,846	0.06
2007	1.74	6,916	0.05	5,299	0.06
2008	1.52	6,746	0.05	5,608	0.06
2009	1.97	6,393	0.05	5,676	0.05
2010	1.67	6,150	0.05	5,336	0.05
2011	1.20	5,691	0.05	5,061	0.05
2012	2.01	5,150	0.05	4,757	0.05
2013	2.46	5,029	0.06	4,181	0.05
2014	1.86	5,249	0.06	3,778	0.06
2015	1.96	5,399	0.06	3,953	0.06
2016	1.73	5,626	0.07	4,203	0.07
2017	1.93	5,790	0.07	4,499	0.07
2018	2.27	5,945	0.09	4,682	0.07
2019	2.16	6,076	0.12	4,721	0.09
2020	2.23	6,436	0.15	4,765	0.11
2021	2.06				

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 (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,232 $MMB_{35\%}$=5,279			
1985	3.99	10,594	0.05	9,040	0.10
1986	3.46	8,143	0.05	8,482	0.08
1987	2.65	7,473	0.04	5,997	0.06
1988	1.86	6,390	0.04	5,602	0.05
1989	2.53	4,398	0.04	4,942	0.04
1990	1.93	4,103	0.05	3,108	0.06
1991	1.62	3,872	0.05	2,845	0.05
1992	2.02	4,009	0.04	2,793	0.05
1993	1.59	4,578	0.03	2,947	0.05
1994	1.95	3,875	0.03	3,524	0.03
1995	1.89	3,862	0.03	2,841	0.03
1996	1.73	3,870	0.04	2,776	0.04
1997	1.85	3,939	0.04	2,813	0.04
1998	1.89	4,255	0.03	2,894	0.04
1999	2.24	4,281	0.04	3,175	0.03
2000	2.51	4,433	0.04	3,109	0.04
2001	2.56	4,870	0.05	3,110	0.04
2002	2.51	5,431	0.05	3,436	0.05
2003	1.77	5,770	0.05	3,960	0.05
2004	2.29	5,890	0.06	4,462	0.05
2005	2.32	6,185	0.06	4,666	0.06
2006	2.47	6,719	0.05	4,849	0.06
2007	1.74	6,918	0.05	5,298	0.06
2008	1.52	6,750	0.05	5,607	0.06
2009	1.98	6,397	0.05	5,678	0.05
2010	1.67	6,153	0.05	5,339	0.05
2011	1.20	5,694	0.05	5,063	0.05
2012	2.01	5,154	0.05	4,760	0.05
2013	2.44	5,028	0.06	4,184	0.05
2014	1.82	5,230	0.06	3,780	0.06
2015	1.97	5,366	0.06	3,947	0.06
2016	1.71	5,591	0.07	4,177	0.07
2017	1.94	5,752	0.07	4,466	0.07
2018	2.27	5,915	0.09	4,644	0.07
2019	2.23	6,071	0.13	4,686	0.09
2020	2.24	6,469	0.17	4,740	0.12
2021	2.06				

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 (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =18,014 $MMB_{35\%}$=5,226			
1985	3.99	10,599	0.05	9,028	0.10
1986	3.46	8,152	0.05	8,481	0.08
1987	2.65	7,486	0.04	6,001	0.06
1988	1.86	6,401	0.04	5,609	0.05
1989	2.53	4,404	0.04	4,951	0.04
1990	1.92	4,106	0.04	3,114	0.05
1991	1.62	3,872	0.05	2,848	0.05
1992	2.00	4,002	0.04	2,792	0.05
1993	1.57	4,559	0.03	2,943	0.05
1994	1.97	3,852	0.03	3,512	0.03
1995	1.89	3,847	0.03	2,819	0.03
1996	1.72	3,858	0.04	2,757	0.03
1997	1.87	3,932	0.04	2,799	0.04
1998	1.90	4,259	0.03	2,881	0.04
1999	2.25	4,294	0.04	3,171	0.03
2000	2.51	4,451	0.04	3,115	0.04
2001	2.54	4,887	0.05	3,122	0.04
2002	2.49	5,436	0.05	3,450	0.05
2003	1.75	5,759	0.05	3,968	0.05
2004	2.31	5,875	0.06	4,458	0.05
2005	2.39	6,198	0.06	4,650	0.06
2006	2.52	6,775	0.05	4,839	0.06
2007	1.72	6,994	0.05	5,321	0.06
2008	1.46	6,804	0.05	5,667	0.05
2009	1.92	6,402	0.05	5,745	0.05
2010	1.64	6,115	0.05	5,372	0.05
2011	1.19	5,627	0.05	5,049	0.05
2012	1.99	5,069	0.05	4,707	0.05
2013	2.41	4,927	0.06	4,110	0.05
2014	1.80	5,113	0.06	3,692	0.06
2015	1.84	5,207	0.06	3,843	0.06
2016	1.55	5,339	0.06	4,056	0.06
2017	1.66	5,357	0.07	4,287	0.07
2018	1.88	5,294	0.09	4,366	0.07
2019	1.90	5,184	0.13	4,244	0.09
2020	2.16	5,413	0.16	4,063	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	-1300.4500	-1300.4200	-1301.3600	-1301.5800	0.03	-0.91	-1.13
Totallencomp	-1606.4100	-1606.4300	-1607.5300	-1612.6400	-0.02	-1.12	-6.23
Observer cpue	-14.6181	-14.6180	-14.6192	-10.6439	0.00010	-0.0011	3.9742
RetdcatchB	5.0494	5.0493	5.0588	5.2239	-0.0001	0.0094	0.1745
TotalcatchB	45.3462	45.3465	45.4377	45.4480	0.0003	0.0915	0.1018
GdiscdcatchB	0.0014	0.0014	0.0014	0.0013	0	0	-0.0001
Rec_dev	4.4273	4.4274	4.4465	4.8170	0.00010	0.0192	0.3897
Pot F_dev	0.0266	0.0266	0.0266	0.0265	0	0	-0.00010
Gbyc_F_dev	0.0435	0.0435	0.0435	0.0436	0	0	0.0001
Tag	2694.9900	2694.9900	2695.0400	2695.1300	0	0.05	0.14
Fishery cpue	-5.4124	-5.4131	-5.3625	-5.5391	-0.0007	0.0499	-0.1267
RetcatchN	0.0024	0.0024	0.0024	0.0019	0	0	-0.0005
Total	-177.0030	-177.0010	-178.8120	-179.7090	0.002	-1.809	-2.706

Figures

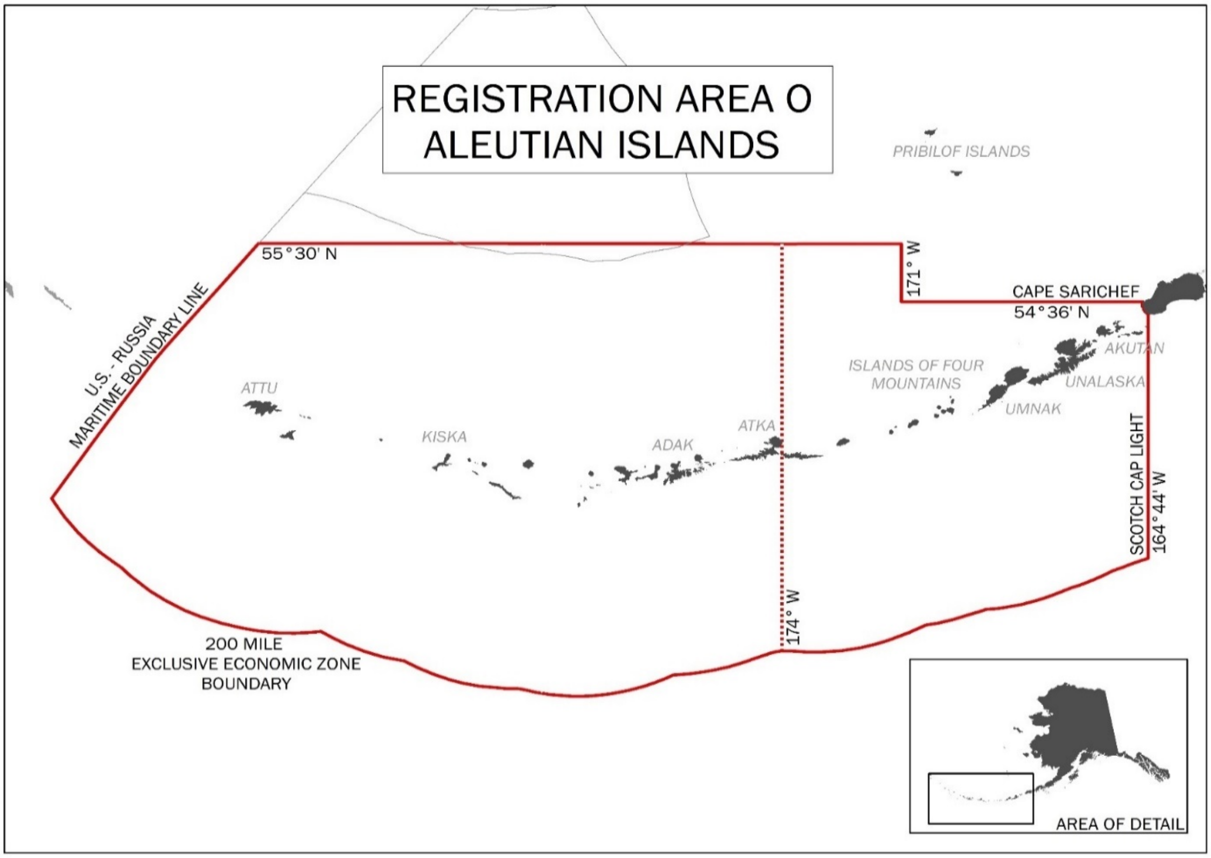


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Nichols *et al.* 2021).

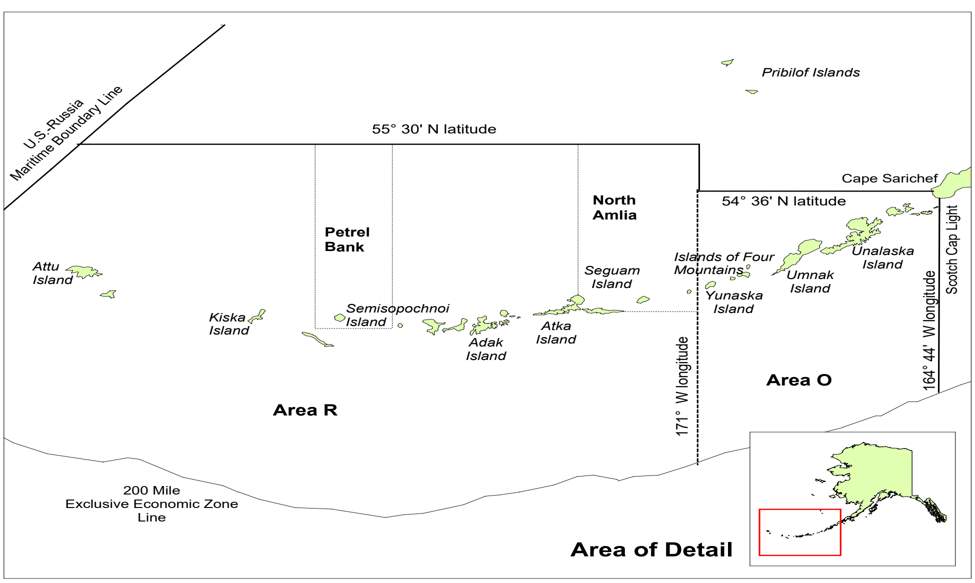


Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon *et al.* 2017).

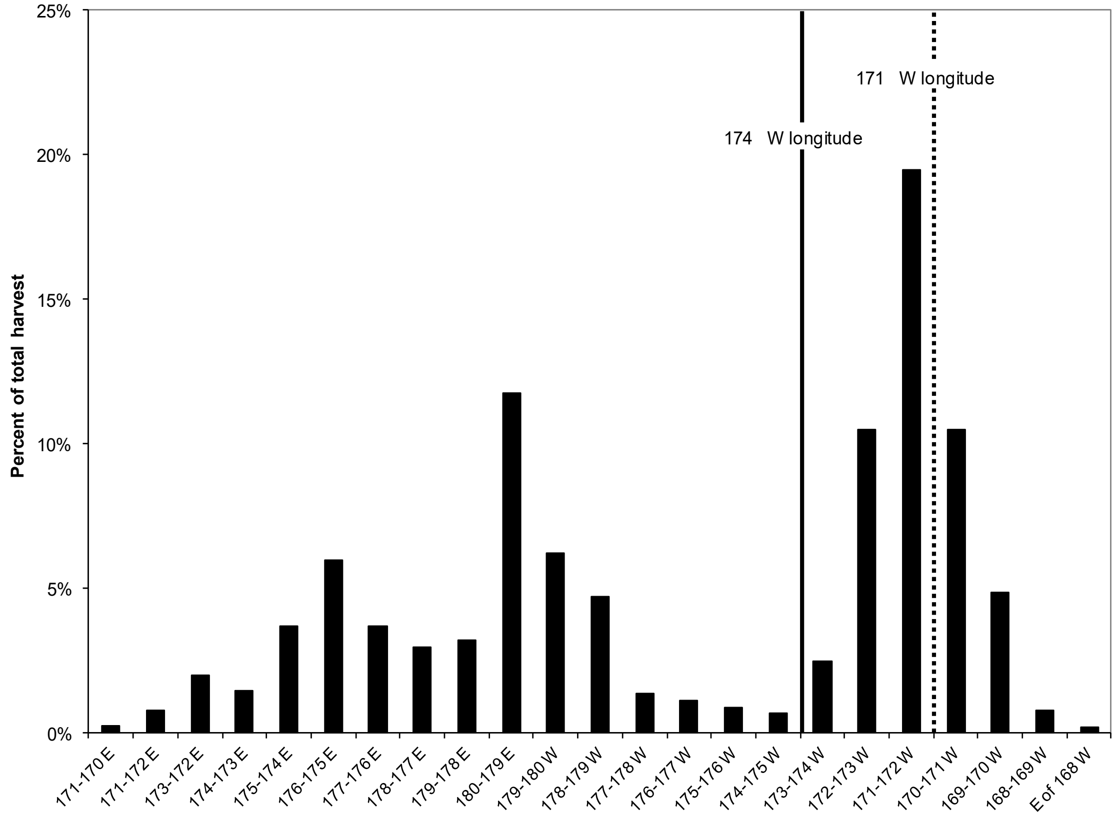


Figure 3. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor 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).

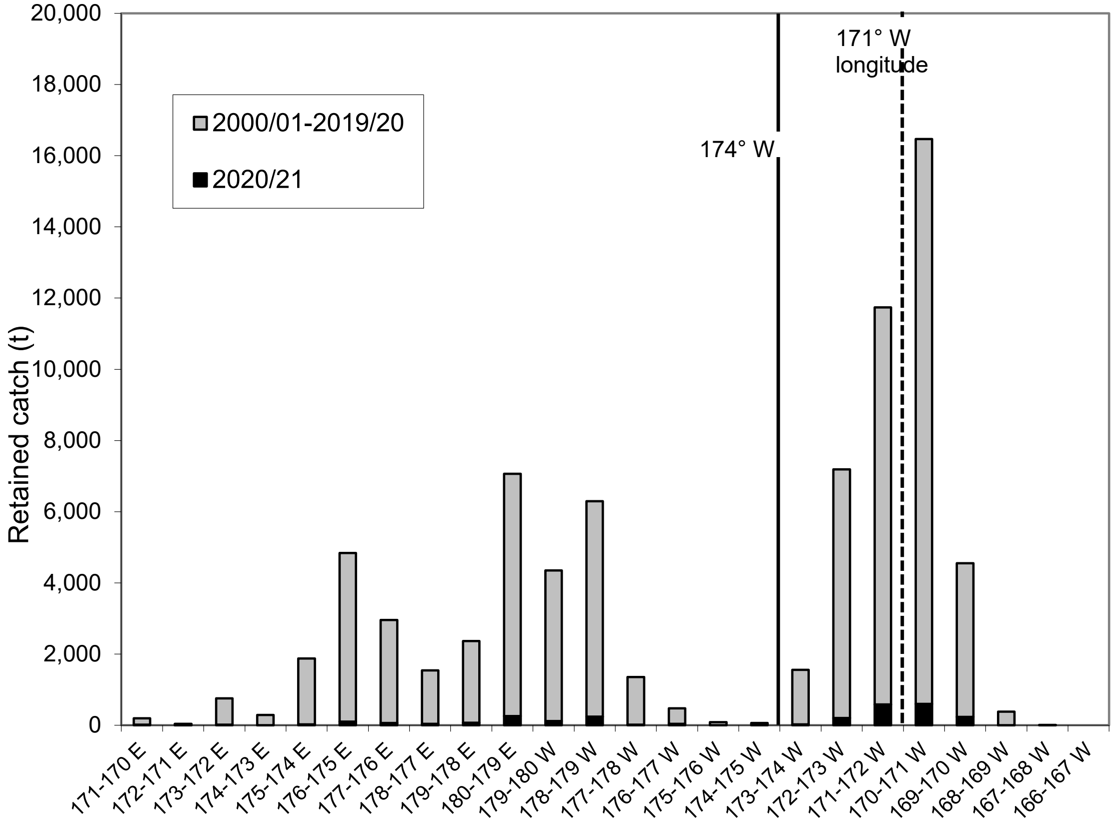


Figure 4. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2020/21 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden 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).

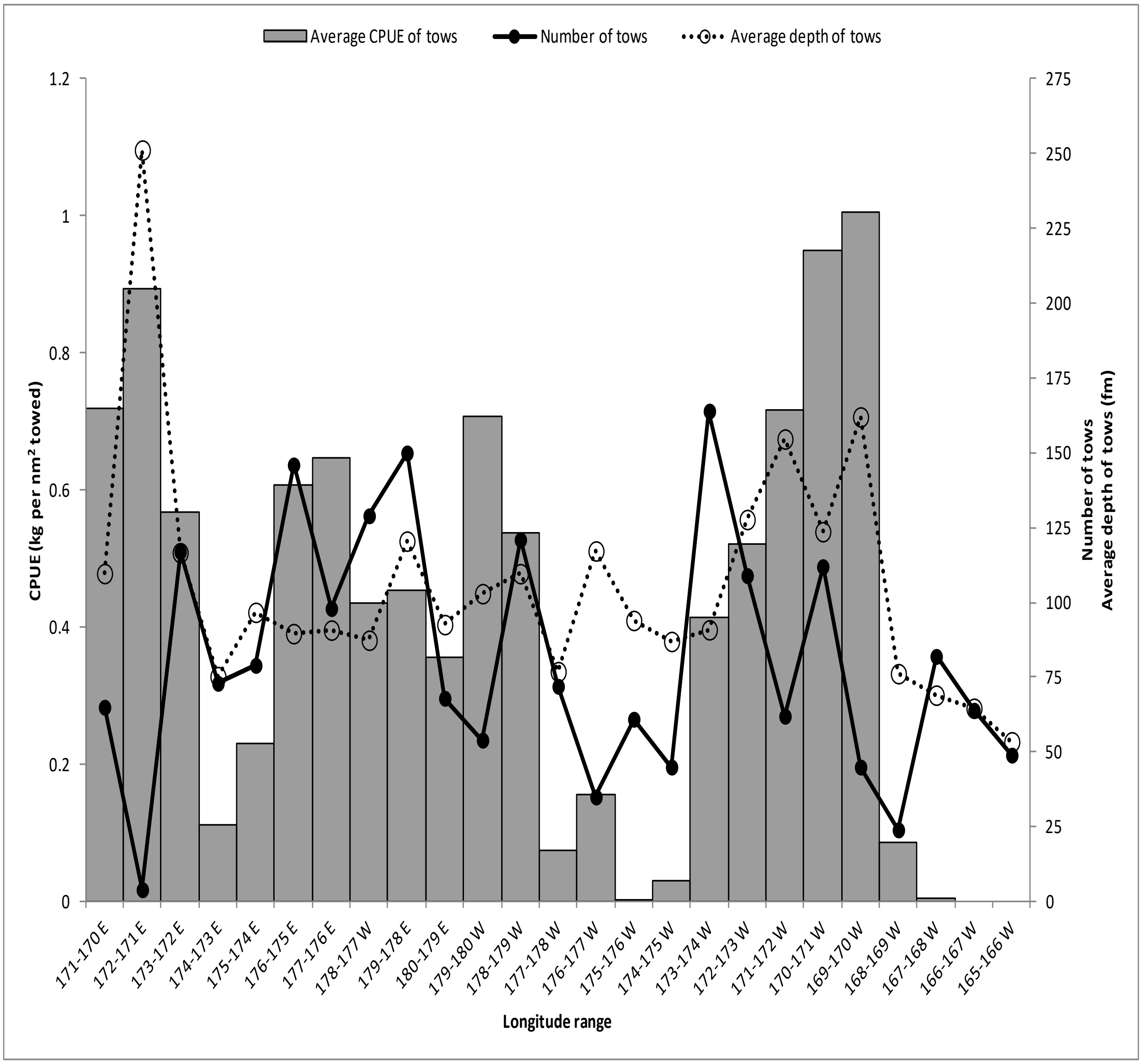


Figure 5. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

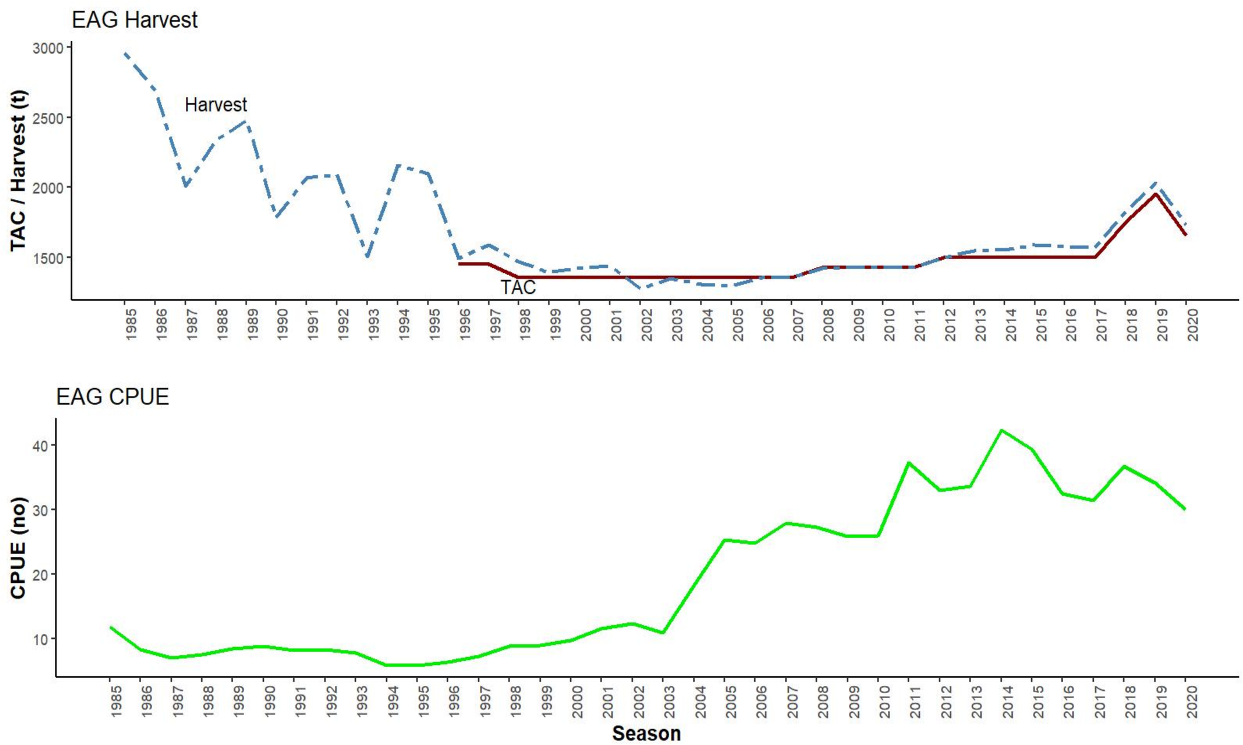


Figure 6. Historical commercial harvest (from fish tickets; metric tons), total allowable catch (TAC), and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the EAG, 1985/86–2020/21 fisheries (note: 1985 refers to the 1985/86 fishing year).

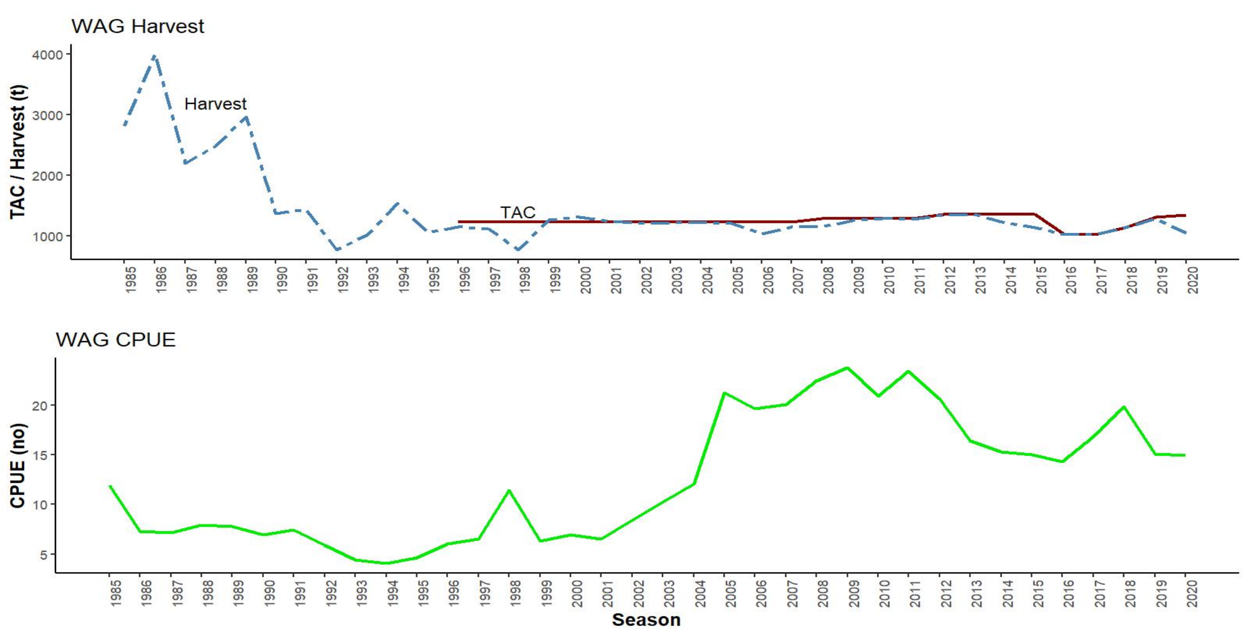


Figure 7. Historical commercial harvest (from fish tickets; metric tons)), total allowable catch (TAC), and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the WAG, 1985/86–2019/20 fisheries (note: 1985 refers to the 1985/86 fishing year).

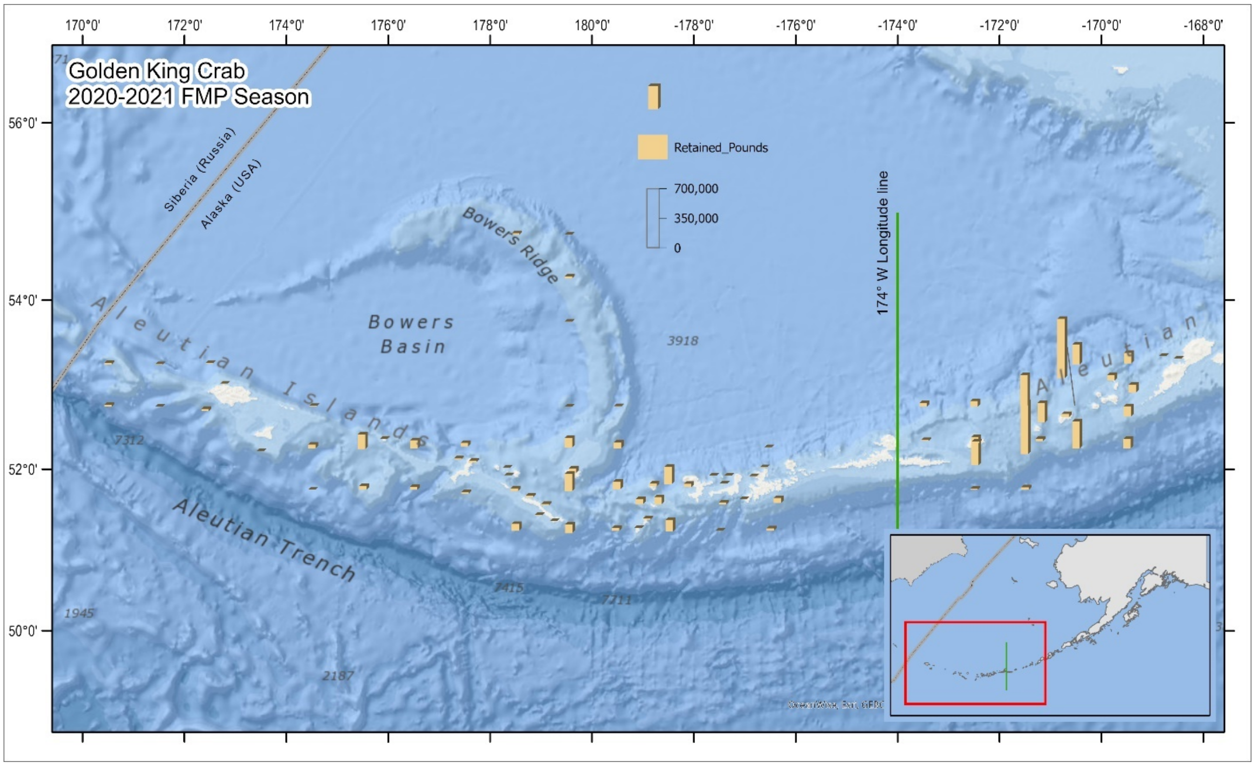


Figure 8. Catch distribution by statistical area.in 2020/21.

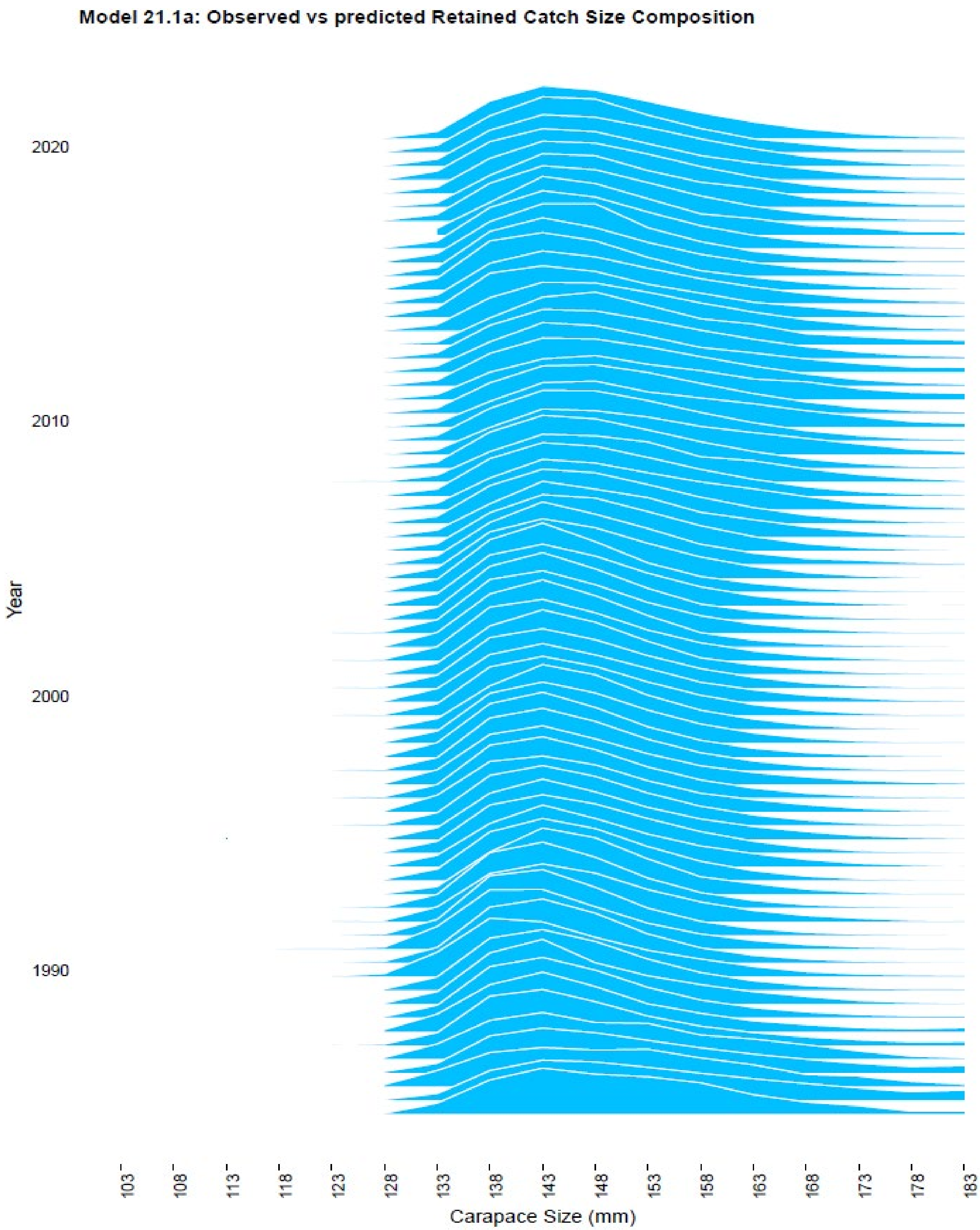


Figure 9a. Predicted vs. observed retained catch relative length frequency distributions under model 21.1a for golden king crab in the EAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

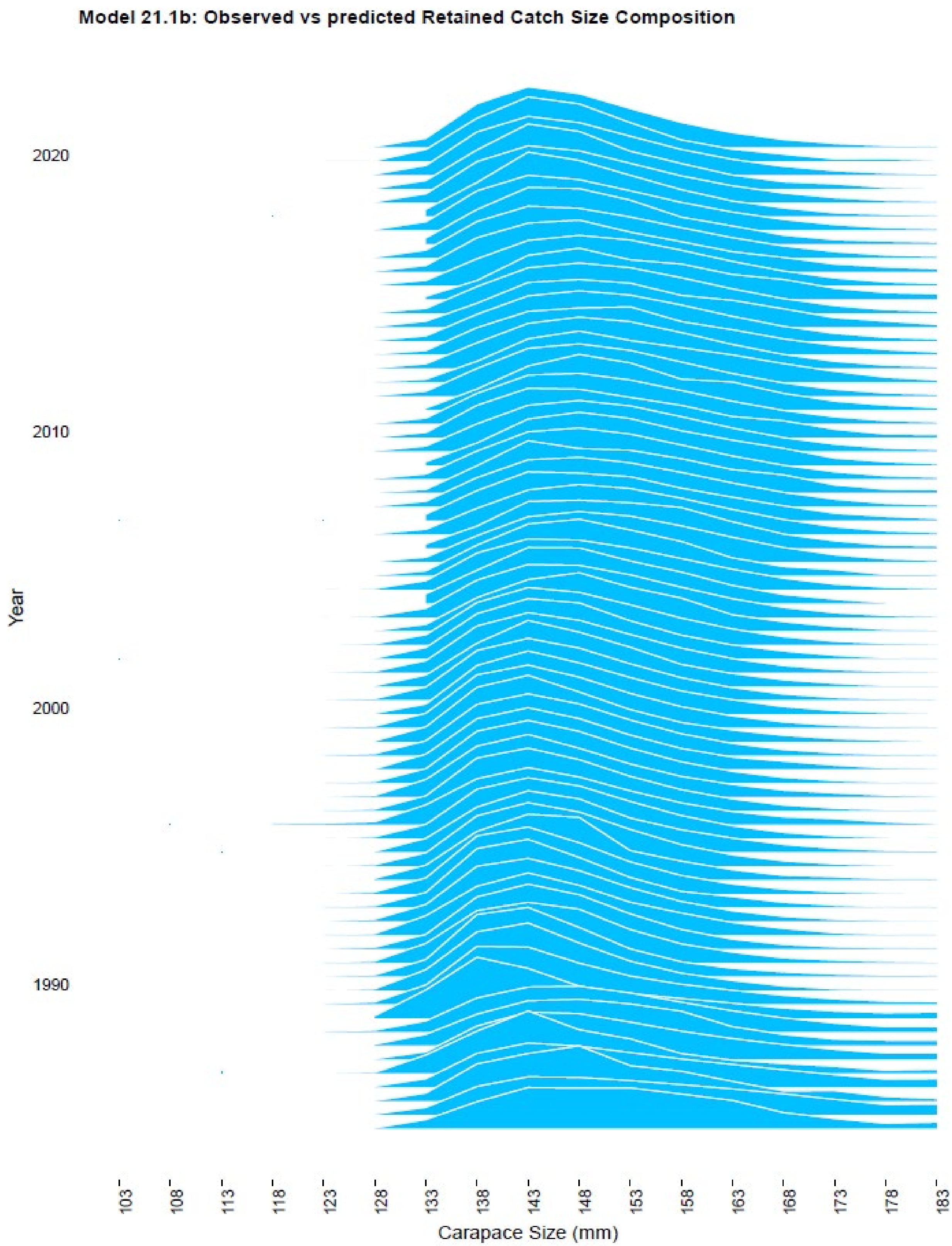


Figure 9b. Predicted vs. observed retained catch relative length frequency distributions under model 21.1b for golden king crab in the EAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

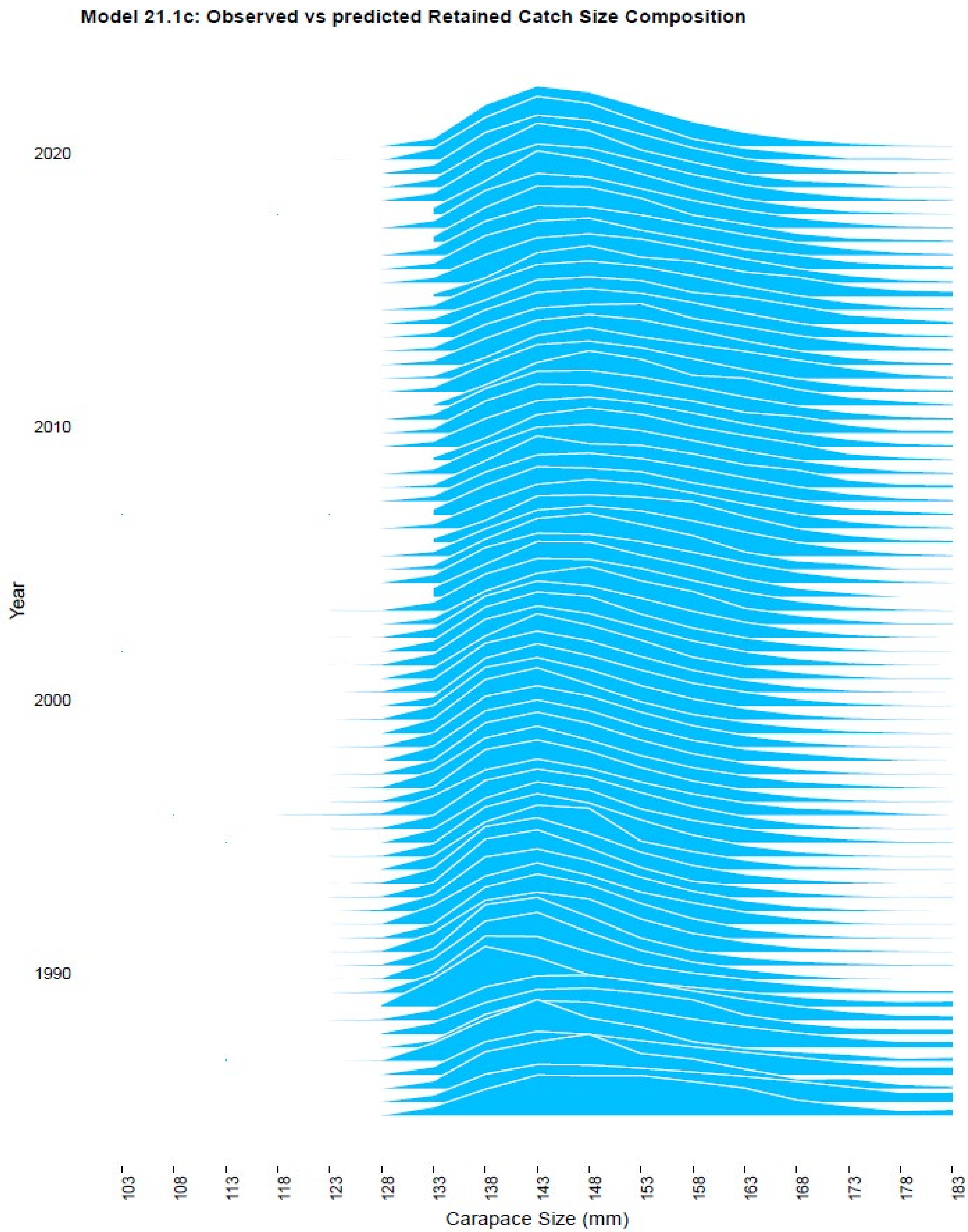


Figure 9c. Predicted vs. observed retained catch relative length frequency distributions under model 21.1c for golden king crab in the EAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

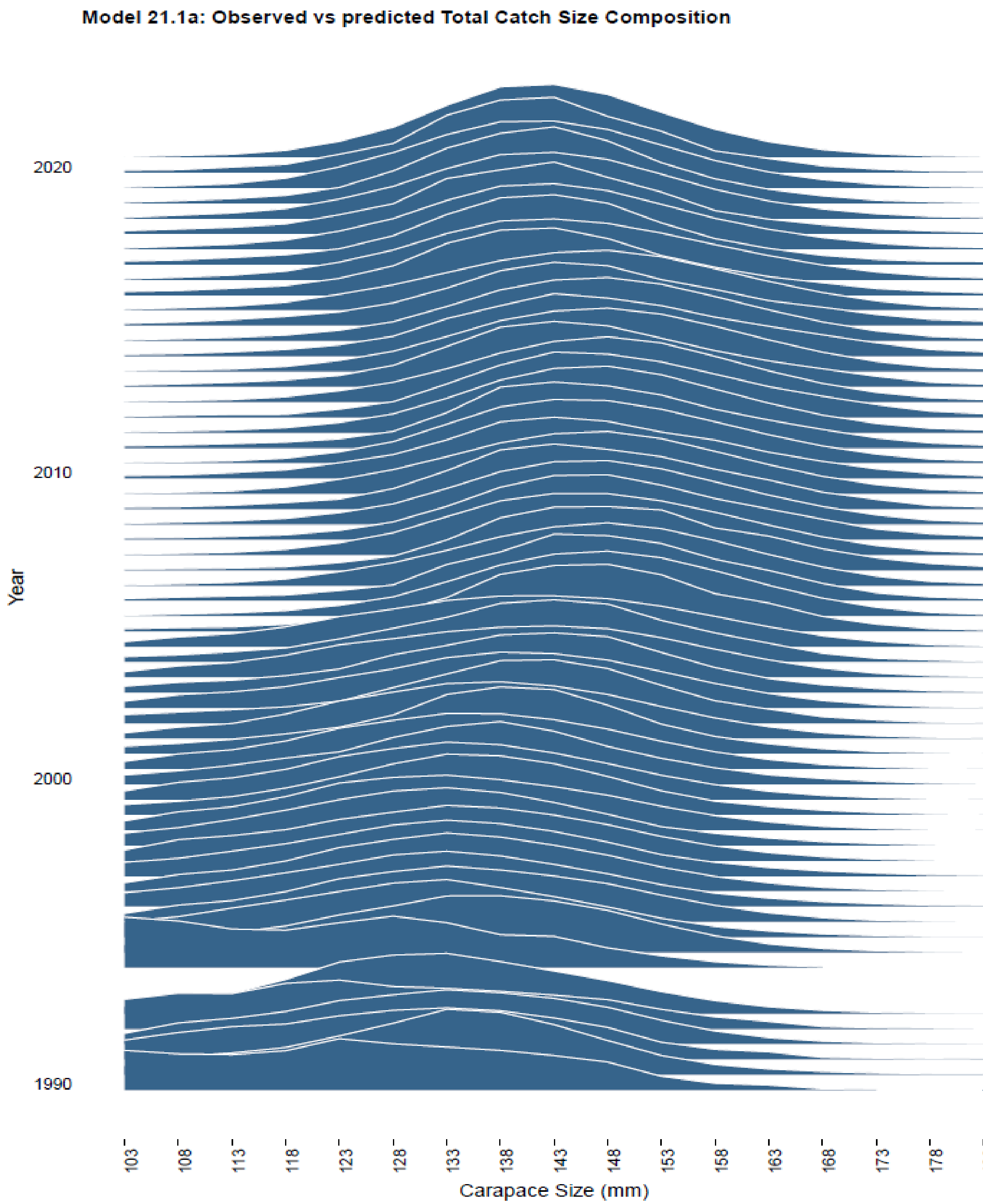


Figure 10a. Predicted vs. observed total catch relative length frequency distributions under model 21.1a for golden king crab in the EAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

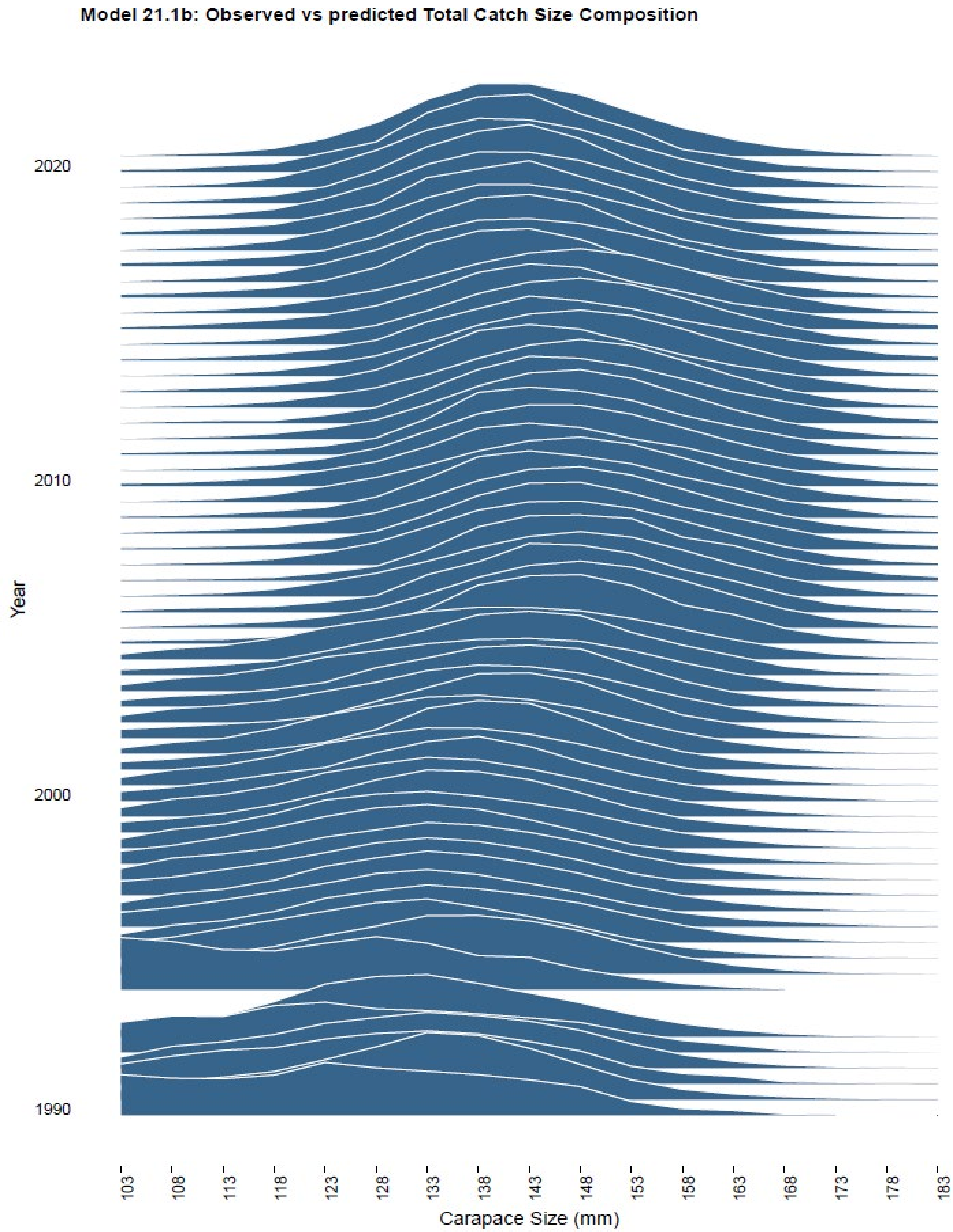


Figure 10b. Predicted vs. observed total catch relative length frequency distributions under model 21.1b for golden king crab in the EAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

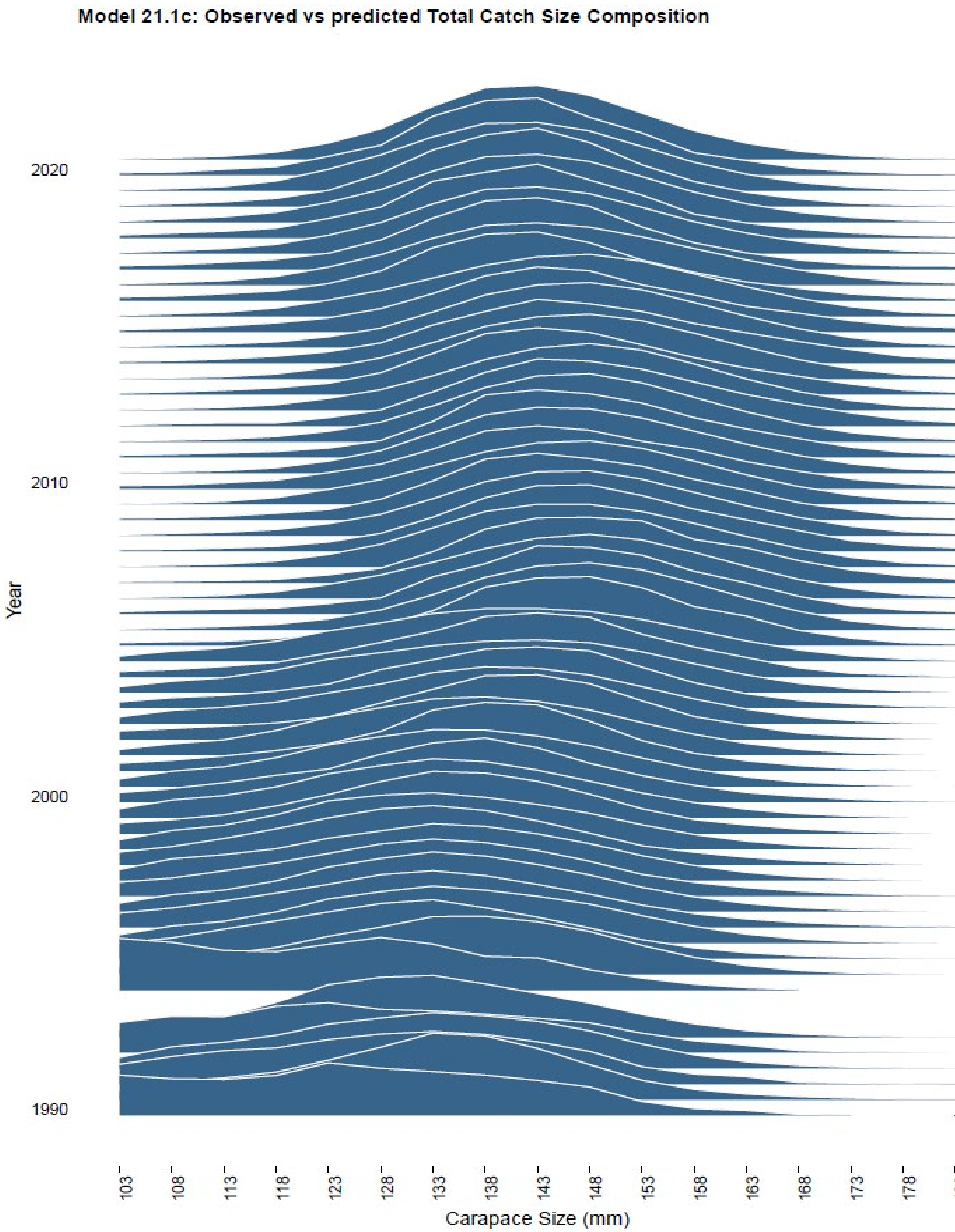


Figure 10c. Predicted vs. observed total catch relative length frequency distributions under model 21.1c for golden king crab in the EAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

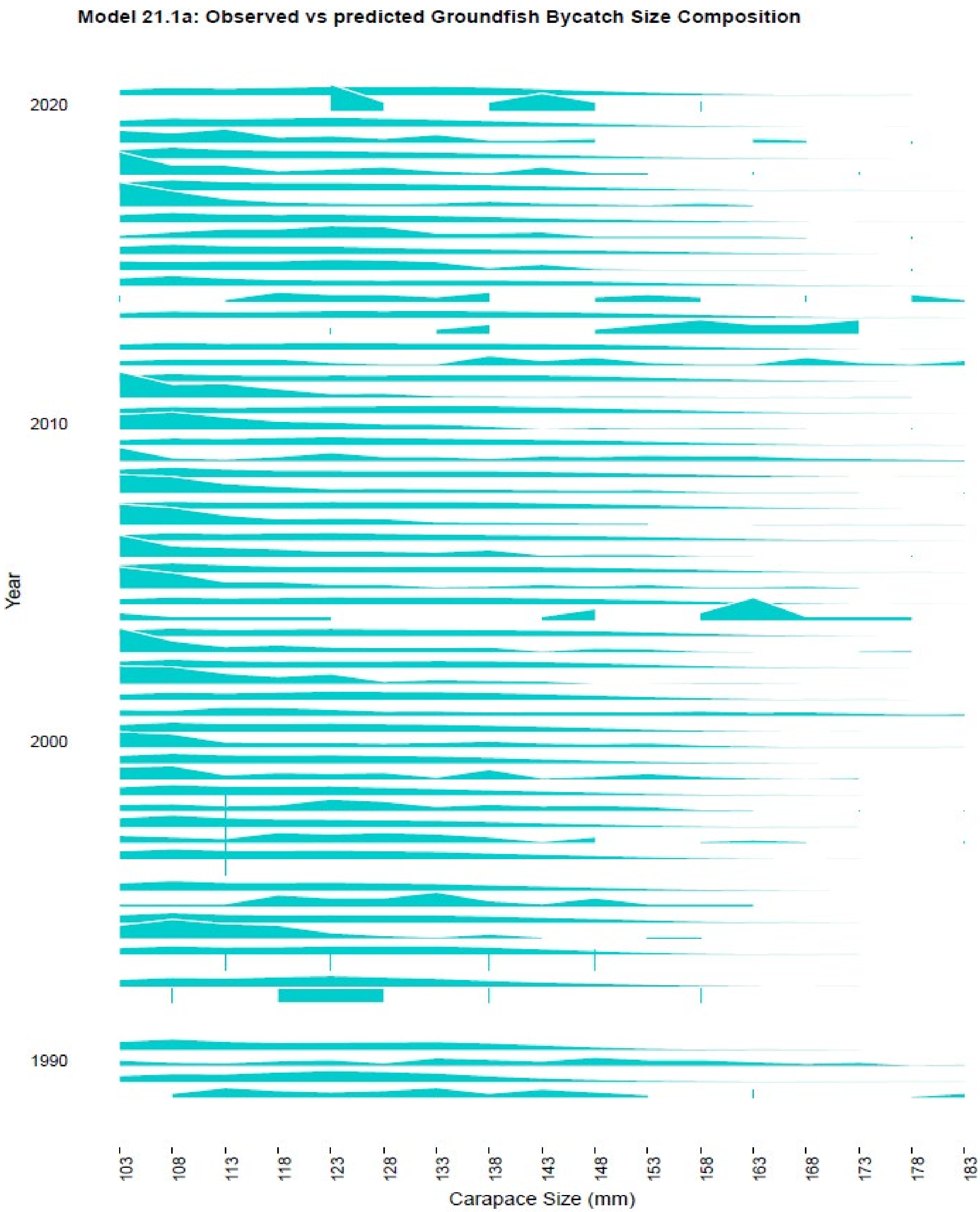


Figure 11. Predicted vs. observed groundfish discarded bycatch relative length frequency distributions under model 21.1a for golden king crab in the EAG, 1989/90 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

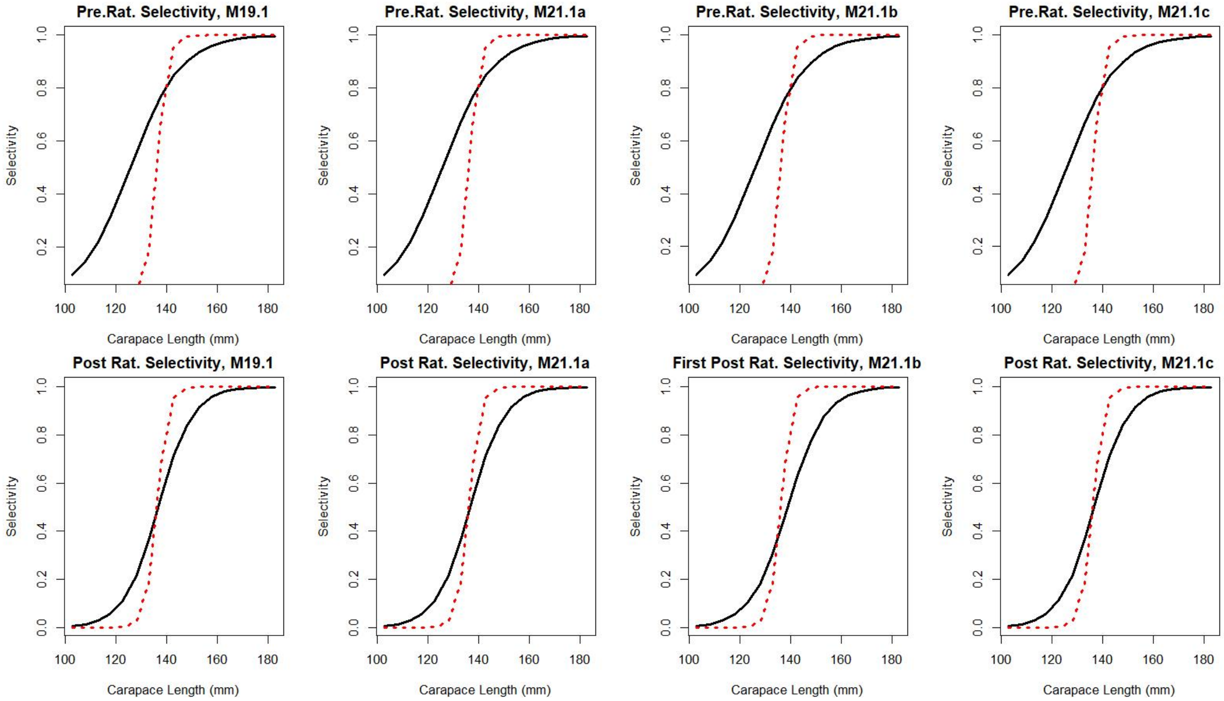


Figure 12a. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under models 19.1, 21.1a, 21.1b, and 21.1c fits to golden king crab data in the EAG. The post-rationalization total selectivity for 21.1b corresponds to first part (2005–2015) of the post-rationalization period.

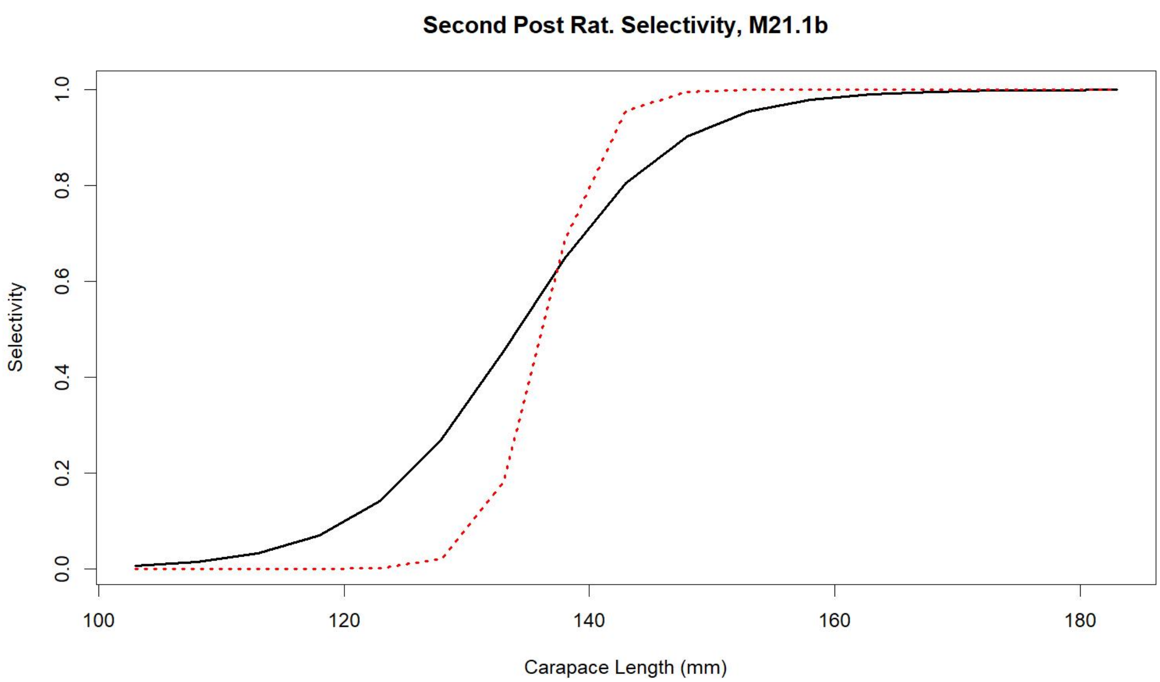


Figure 12b. Estimated total (black solid line) and retained selectivity (red dotted line) for second part (2016–2020) of the post- rationalization period under model 21.1b fit to golden king crab data in the EAG.

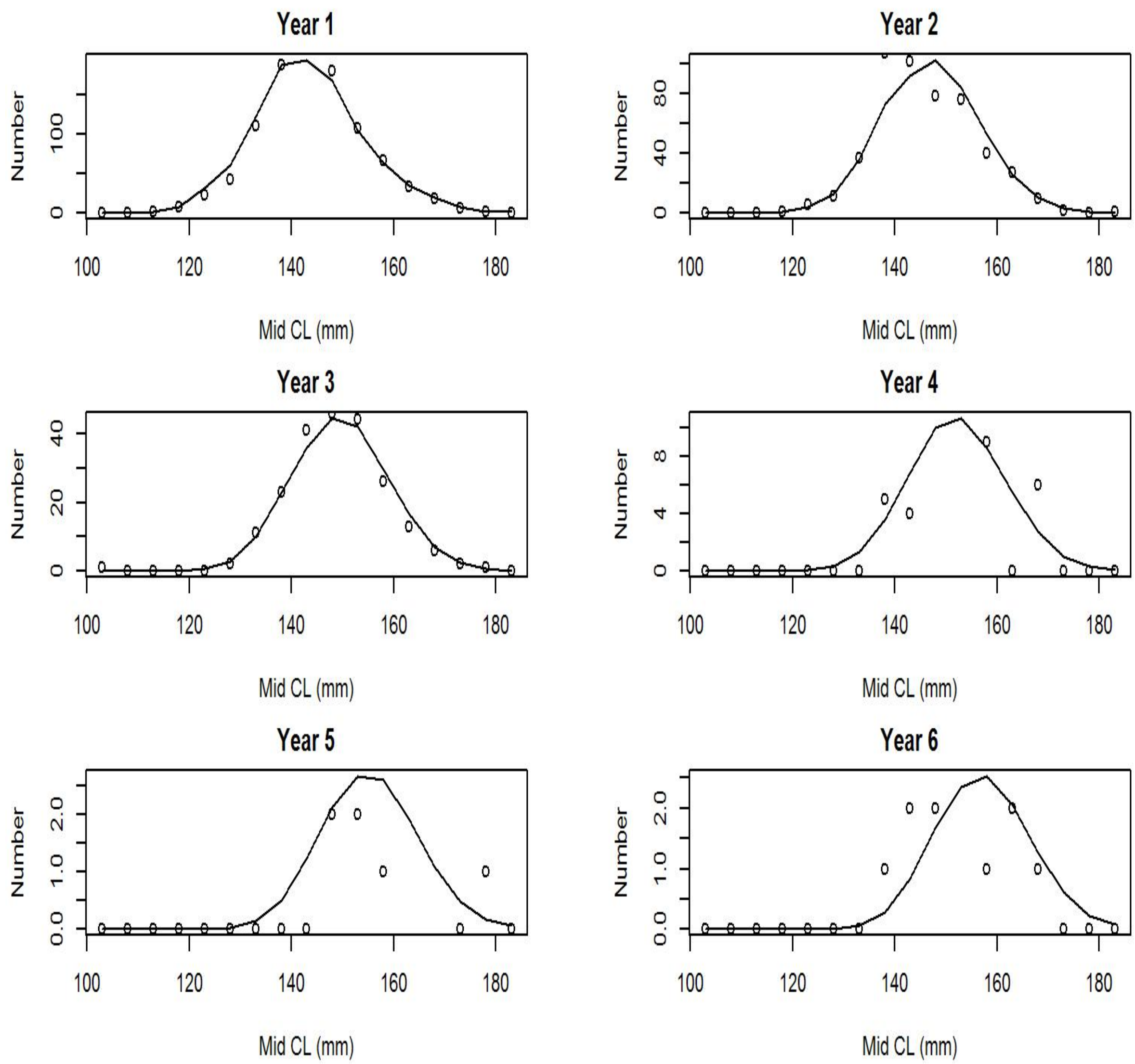


Figure 13. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under model 21.1a for EAG golden king crab.

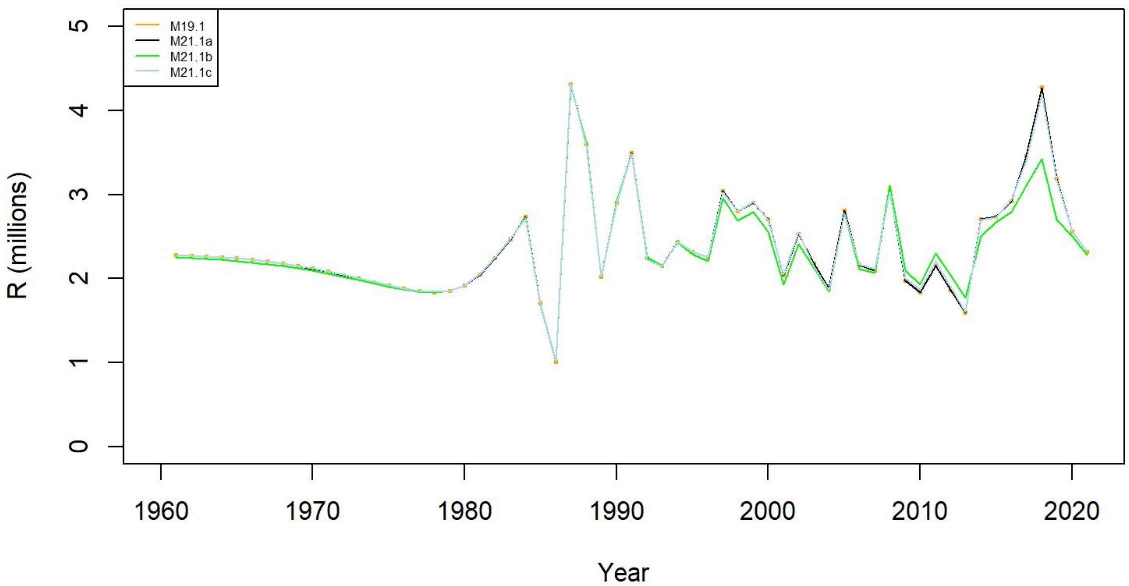


Figure 14. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG golden king crab data, 1961–2021.

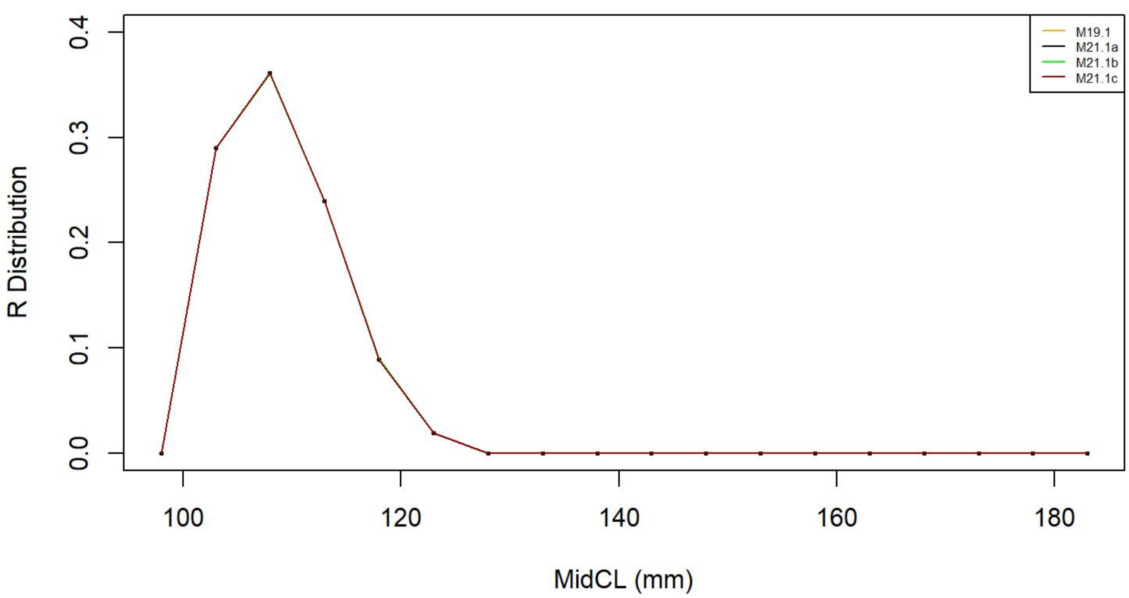


Figure 15. Recruit size distribution to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG golden king crab data.

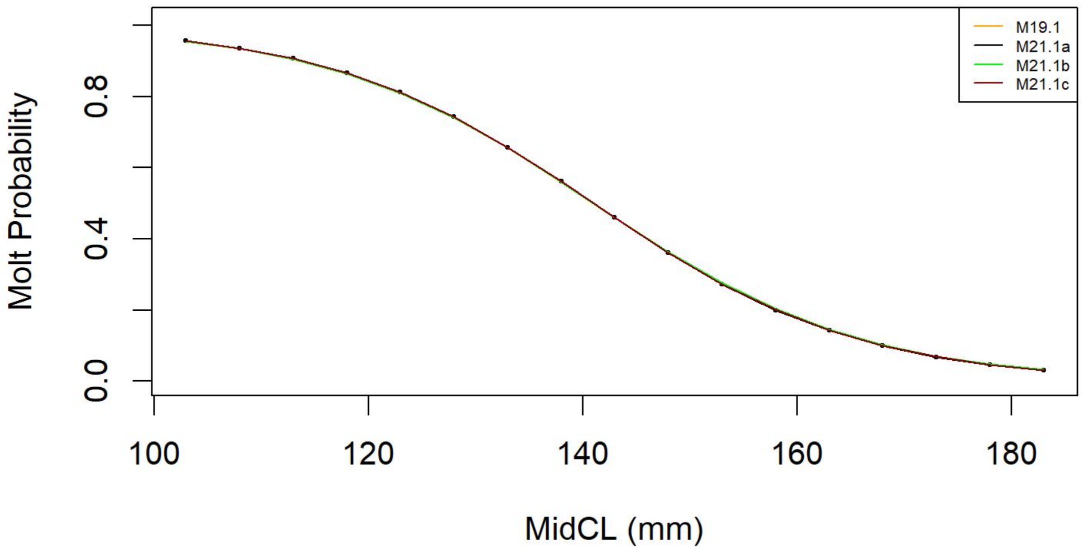


Figure 16. Estimated molt probability vs. carapace length of golden king crab under models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG golden king crab data.

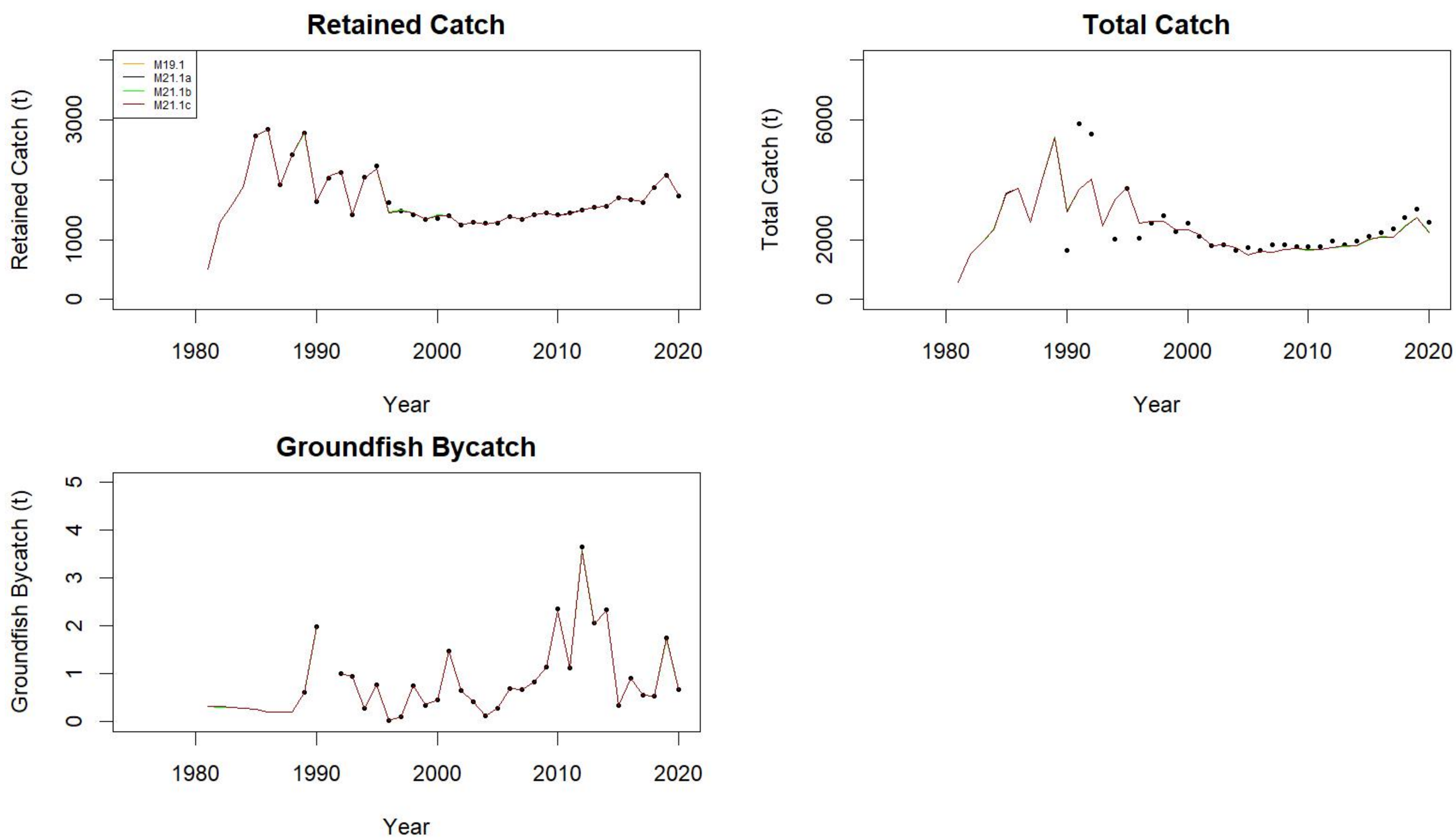


Figure 17. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab under models 19.1, 21.1a, 21.1b, and 21.1c fits in EAG, 1981/82–2020/21.

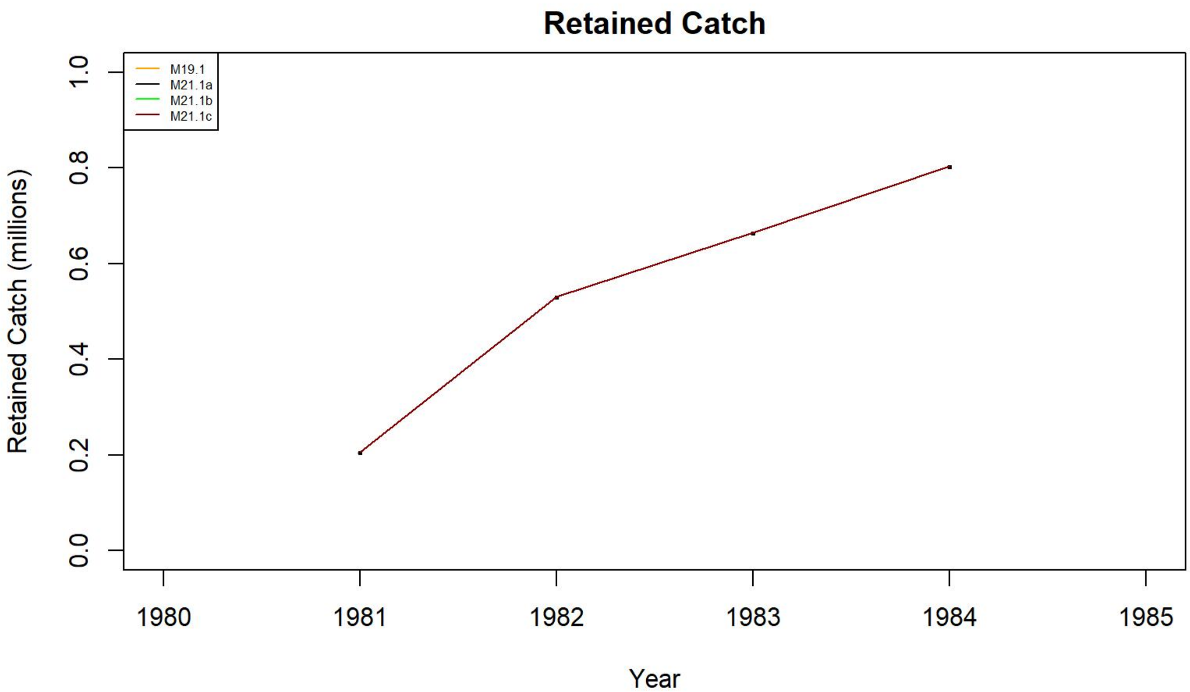


Figure 18. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.

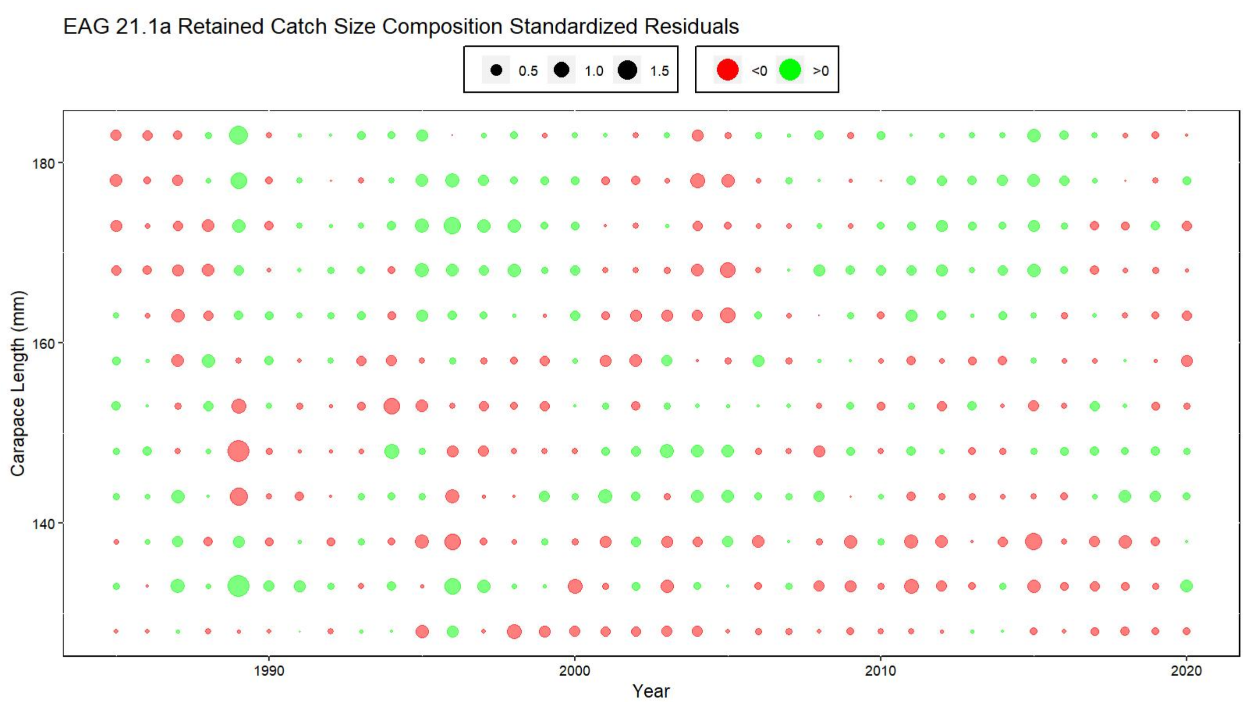


Figure 19. Bubble plot of standardized residuals of retained catch length composition for model 21.1a fit for EAG golden king crab, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

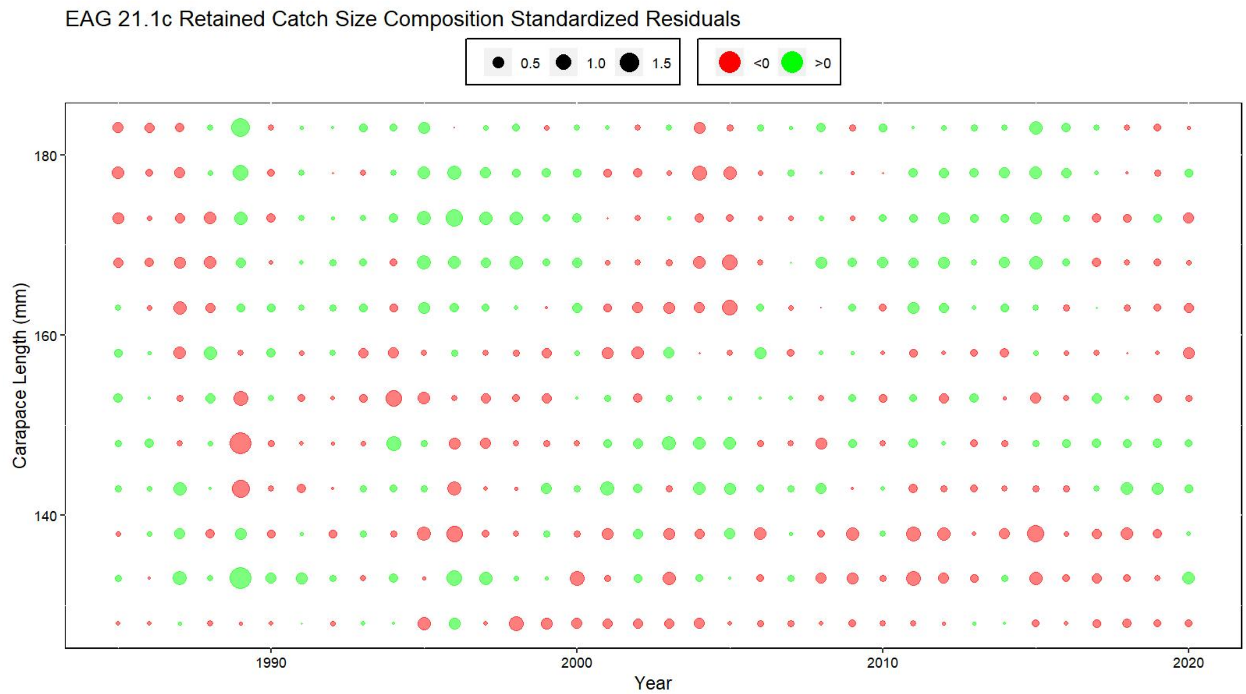


Figure 20. Bubble plot of standardized residuals of retained catch length composition for model 21.1c fit for EAG golden king crab, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

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.

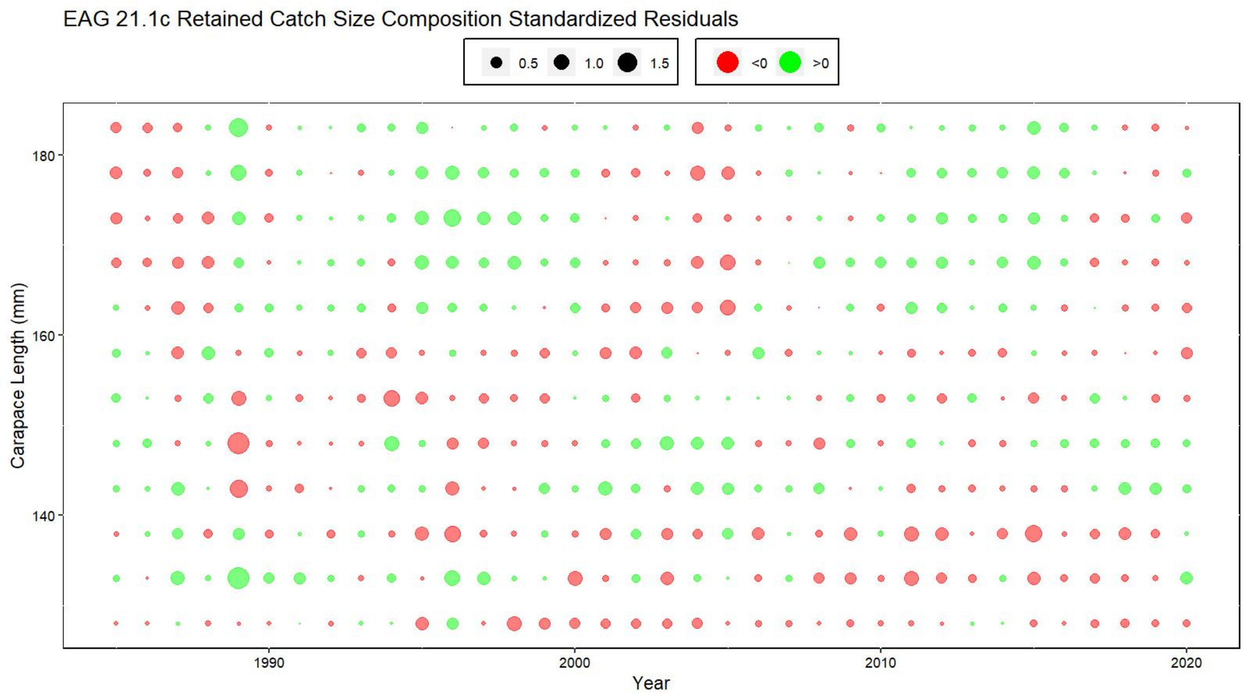


Figure 22. Bubble plot of standardized residuals of total catch length composition for model 21.1c fit for EAG golden king crab, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

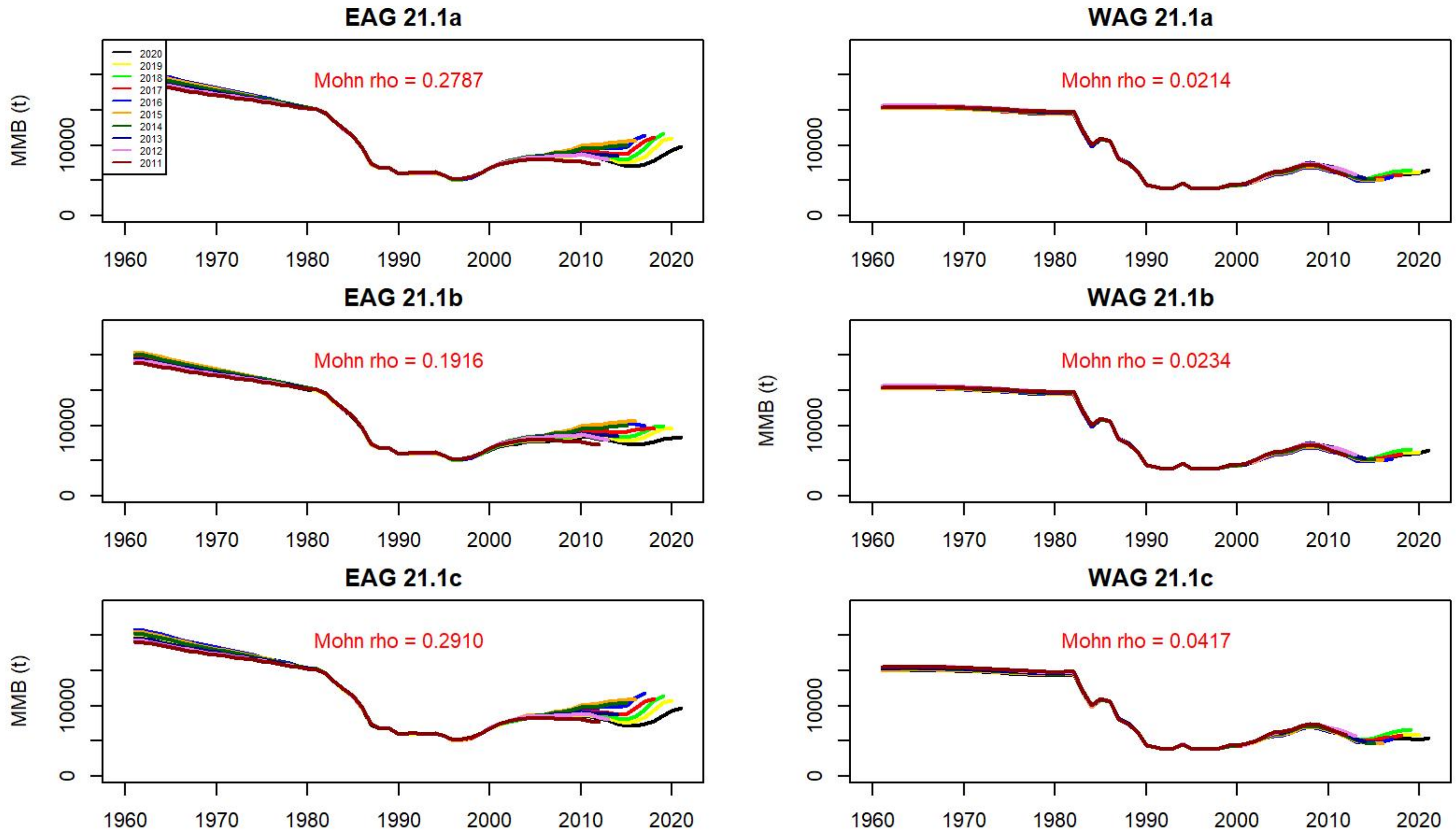


Figure 23. Retrospective fits of MMB by the model following removal of terminal year data under models 21.1a, 21.1b, and 21.1c for golden king crab in the EAG (left) and WAG (right), 1960/61–2020/21.

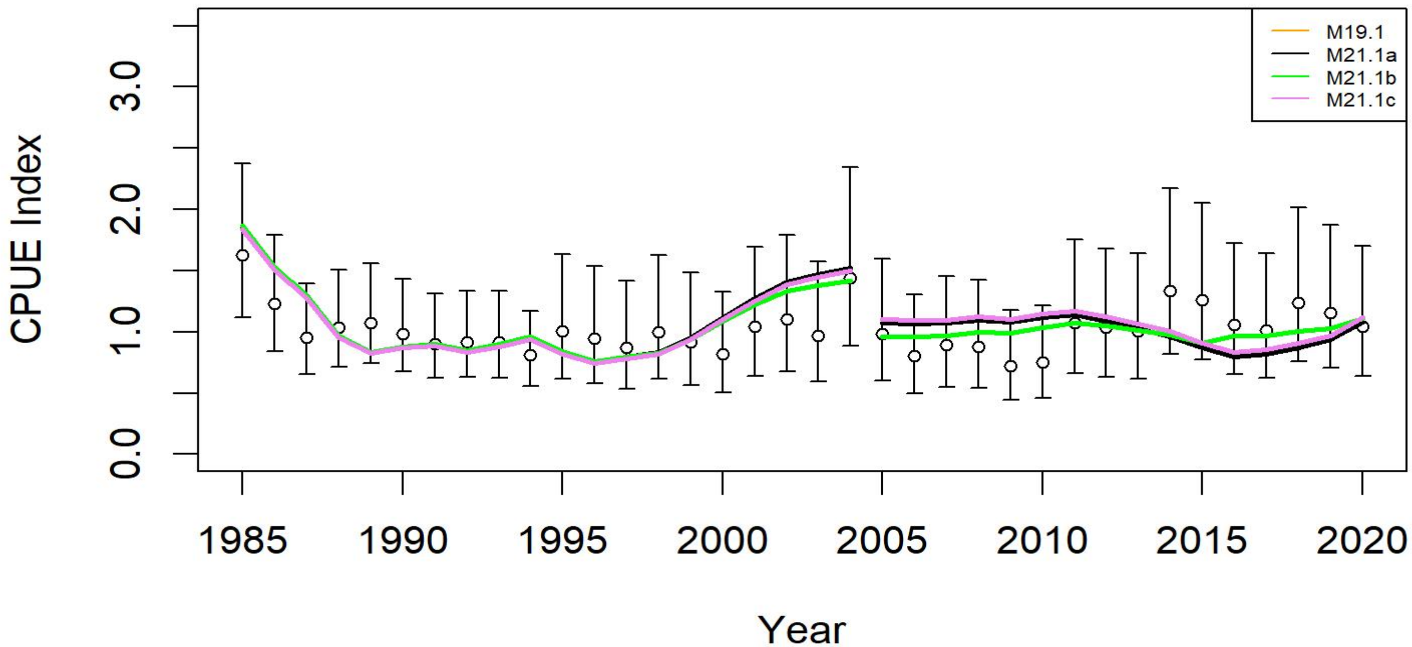


Figure 24. Comparison of input CPUE indices (open circles with +/- 2 SE for model 19.1) with predicted CPUE indices (colored solid lines) under 19.1, 21.1a, 21.1b, and 21.1c for EAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.

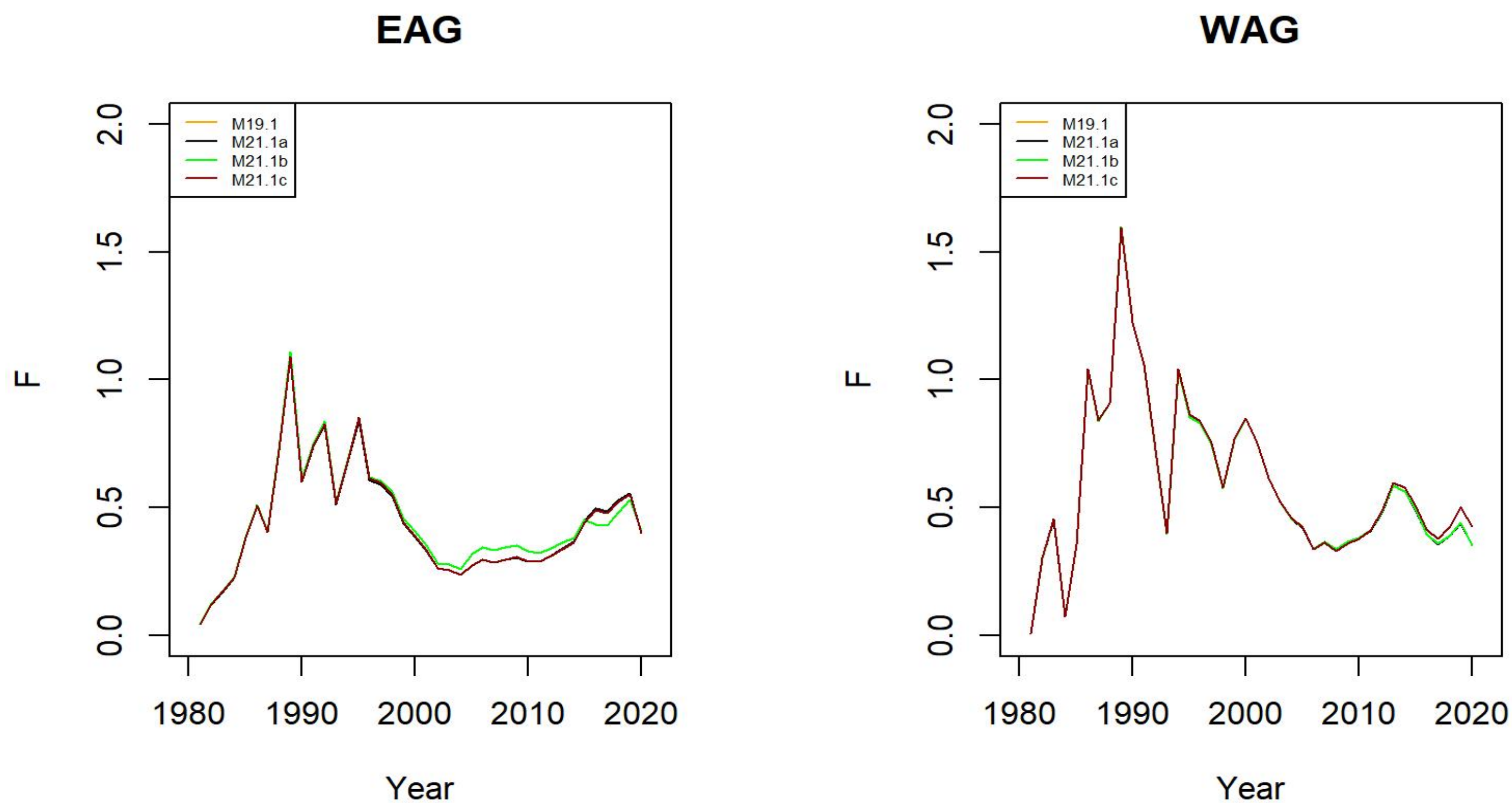


Figure 25. Trends in pot fishery full selection total fishing mortality of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits in the EAG (left) and WAG (right) data, 1981/82–2020/21.

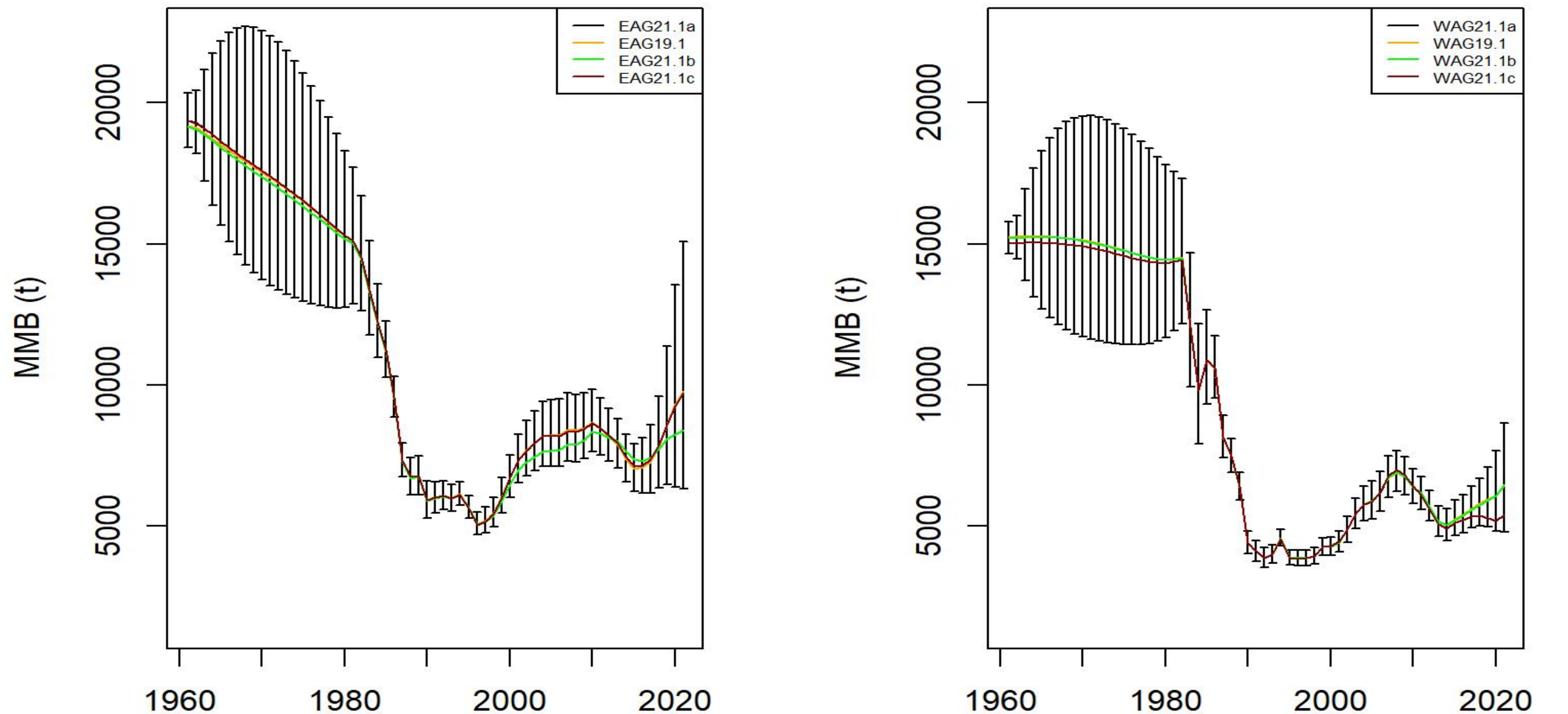


Figure 26. Trends in golden king crab mature male biomass for models 19.1, 21.1a, 21.1b, and 21.1c fits to EAG (left) and WAG (right) data, 1961–2021. Model 21.1a estimate has two standard error confidence limits. Year 2021 refers to 2020/21 fishing season.

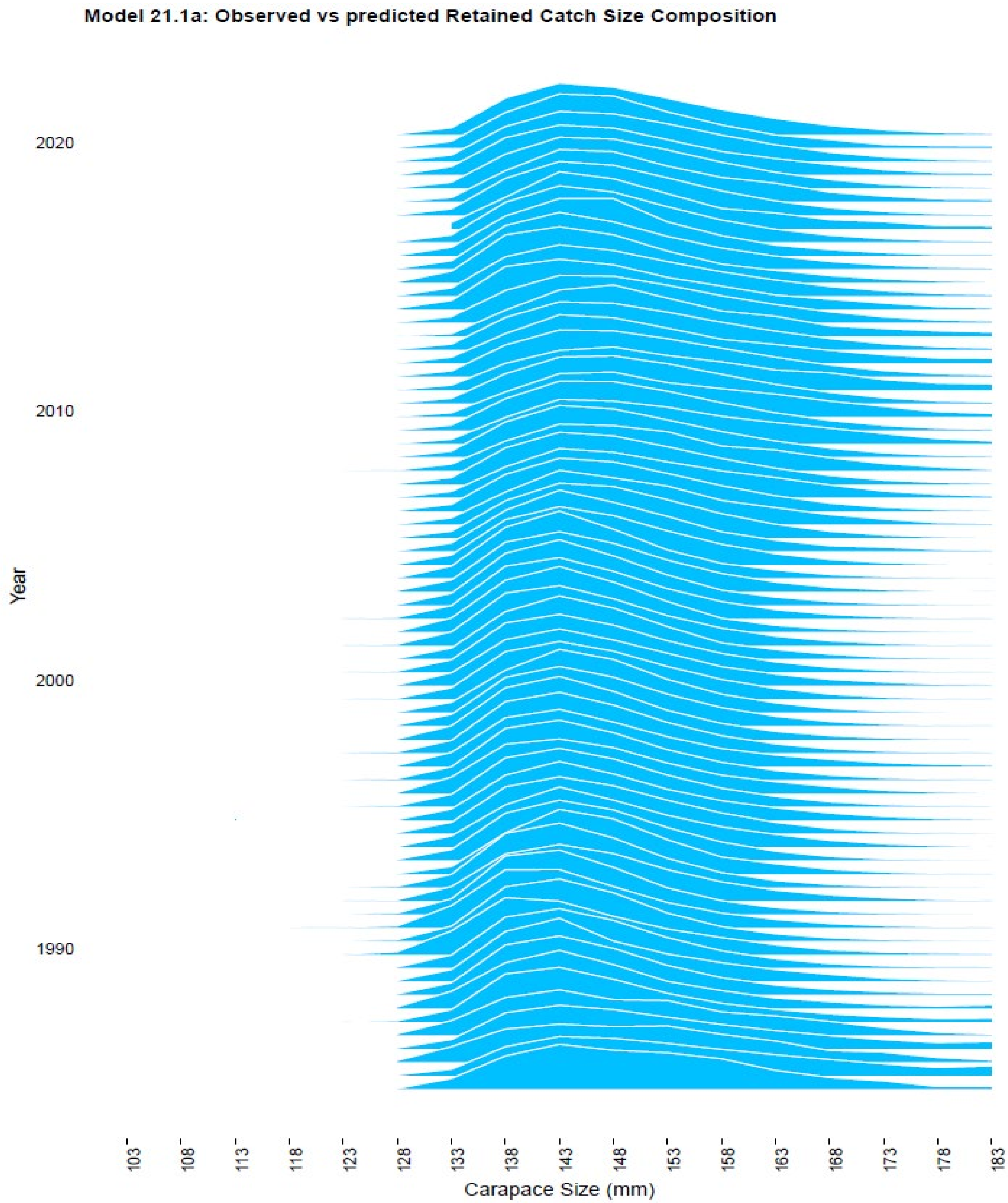


Figure 27a. Predicted vs. observed retained catch relative length frequency distributions under model 21.1a for golden king crab in the WAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

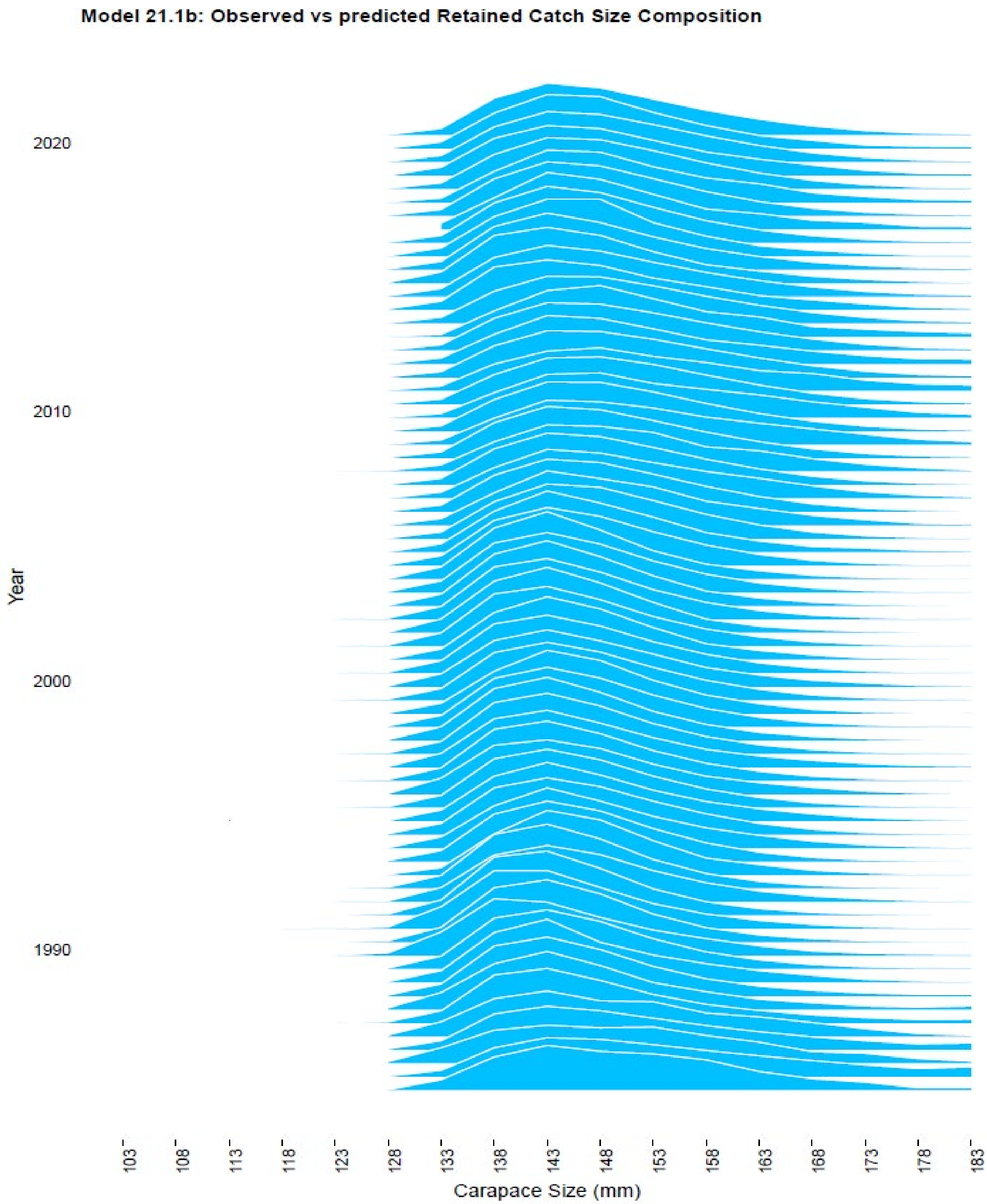


Figure 27b. Predicted vs. observed retained catch relative length frequency distributions under model 21.1b for golden king crab in the WAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

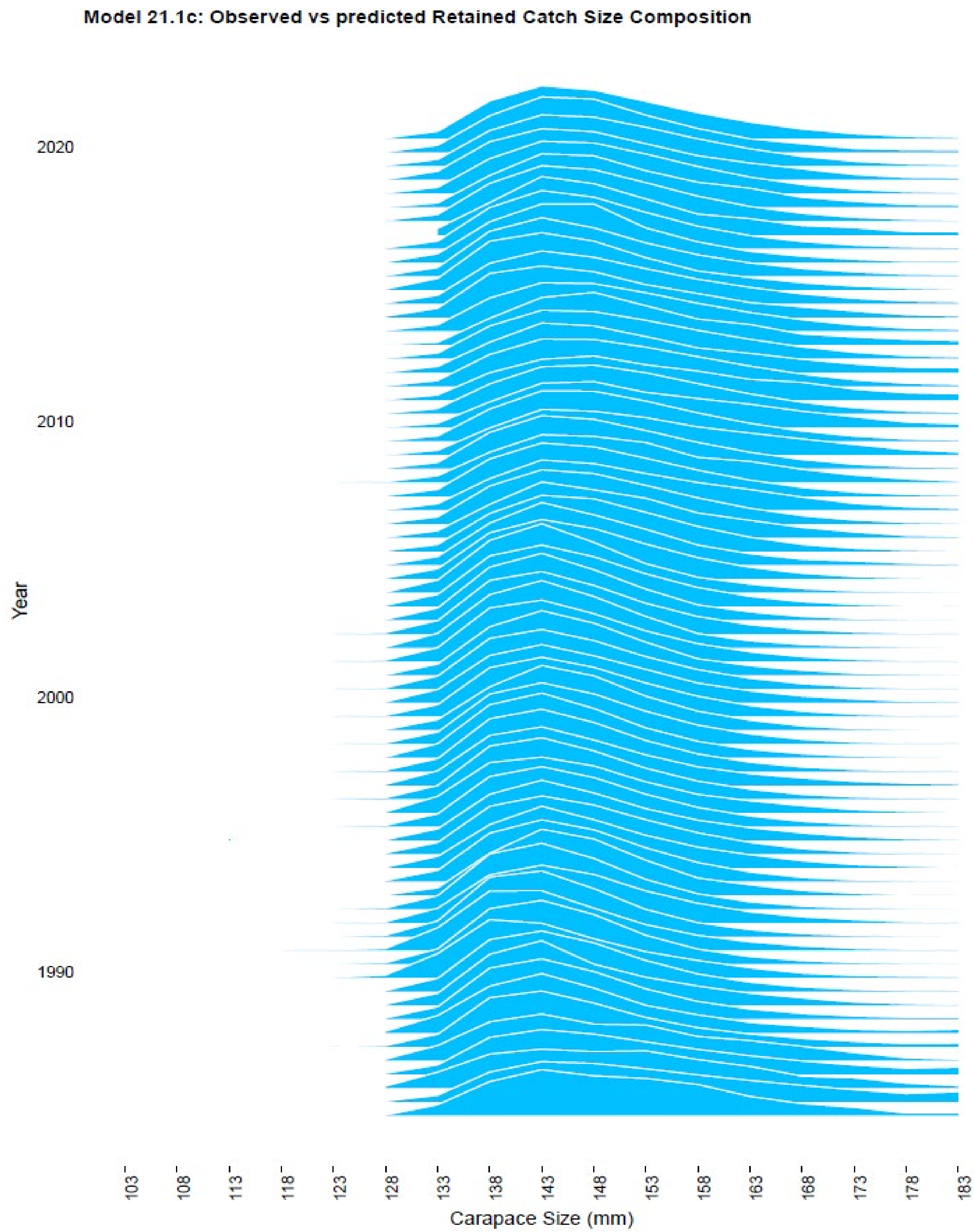


Figure 27c. Predicted vs. observed retained catch relative length frequency distributions under model 21.1c for golden king crab in the WAG, 1985/86 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

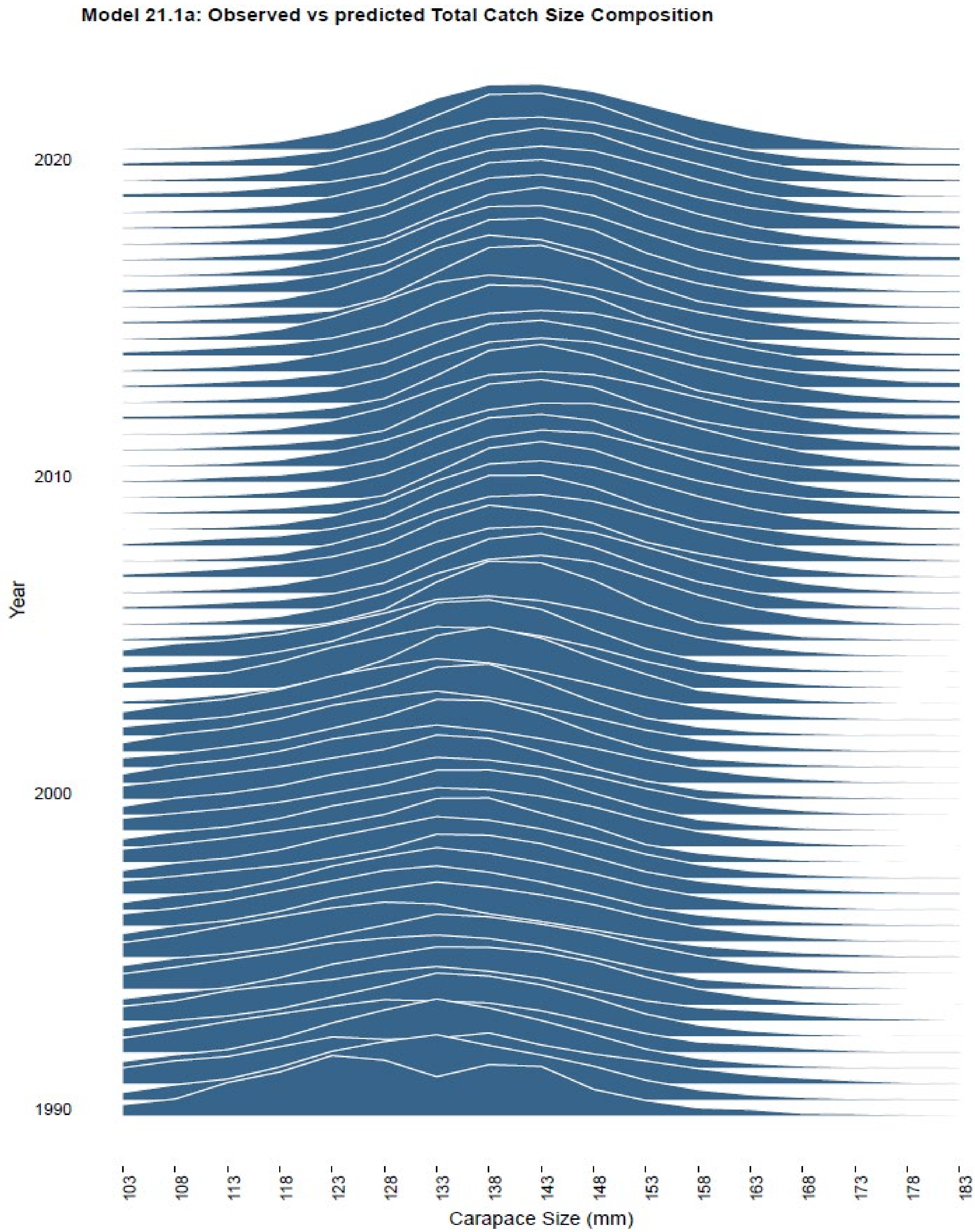


Figure 28a. Predicted vs. observed total catch relative length frequency distributions under model 21.1a for golden king crab in the WAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

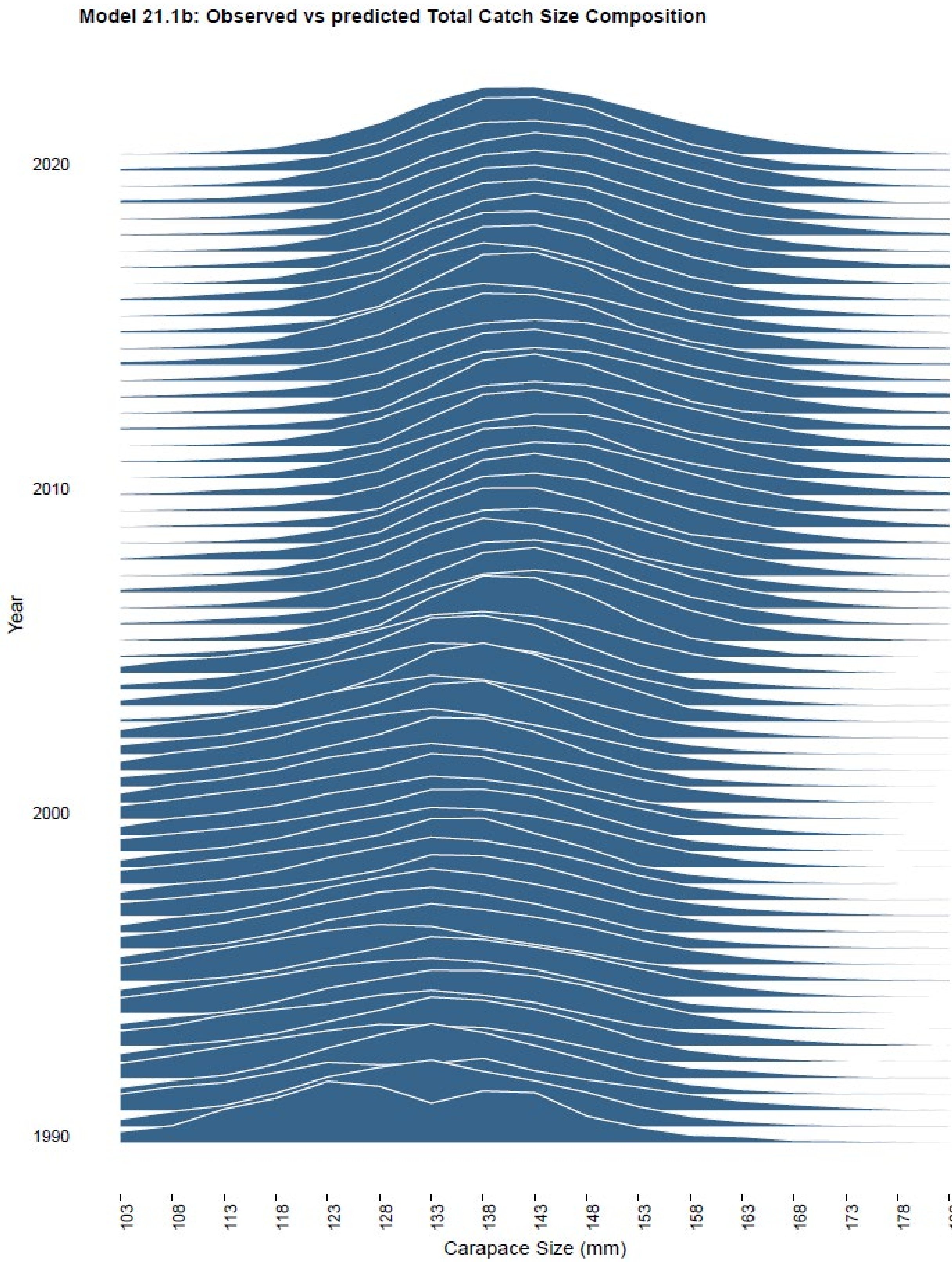


Figure 28b. Predicted vs. observed total catch relative length frequency distributions under model 21.1b for golden king crab in the WAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

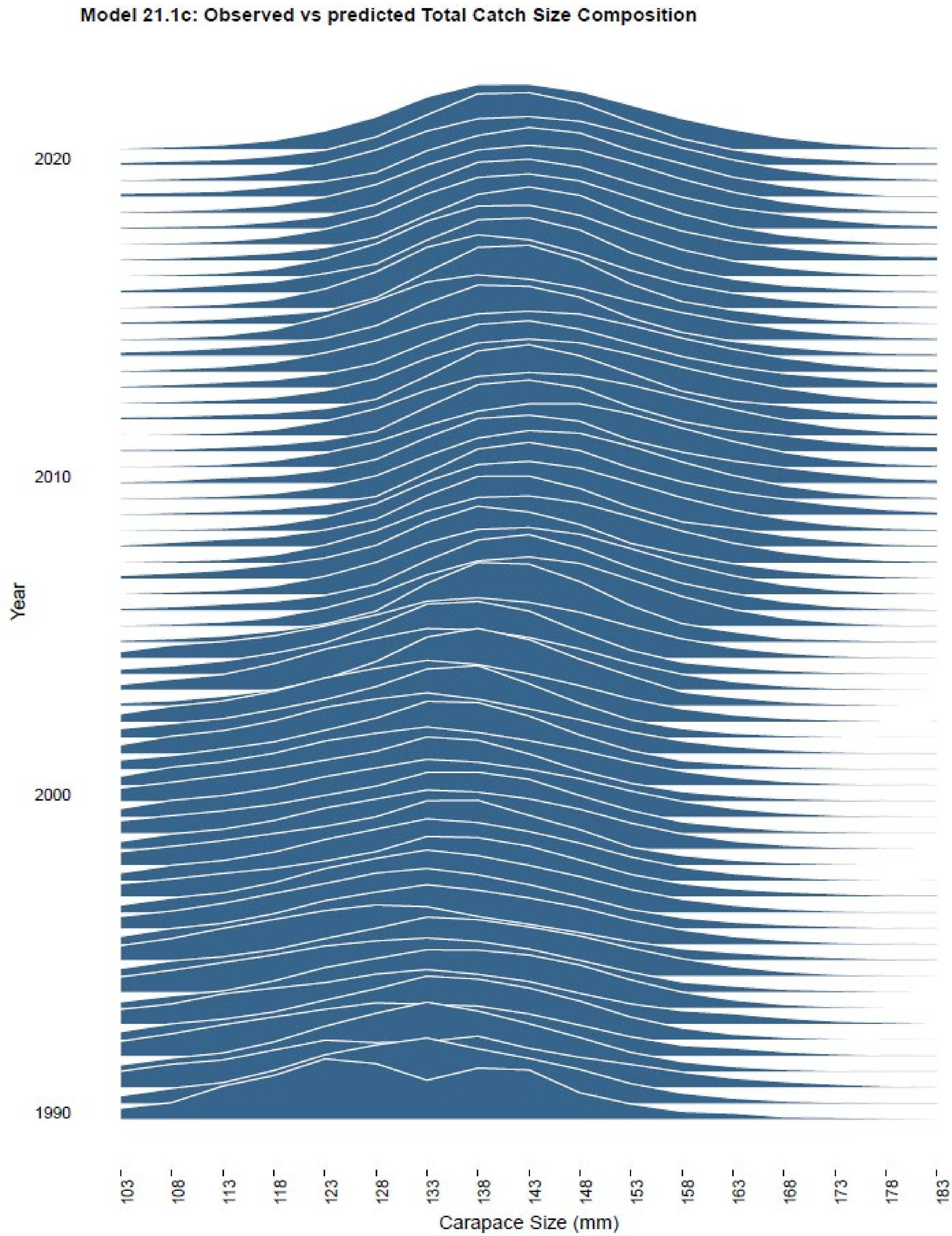


Figure 28c. Predicted vs. observed total catch relative length frequency distributions under model 21.1c for golden king crab in the WAG, 1990/91 to 2020/21. Each year has a pair of plots with the front plot for observed and the back plot for predicted proportions.

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.

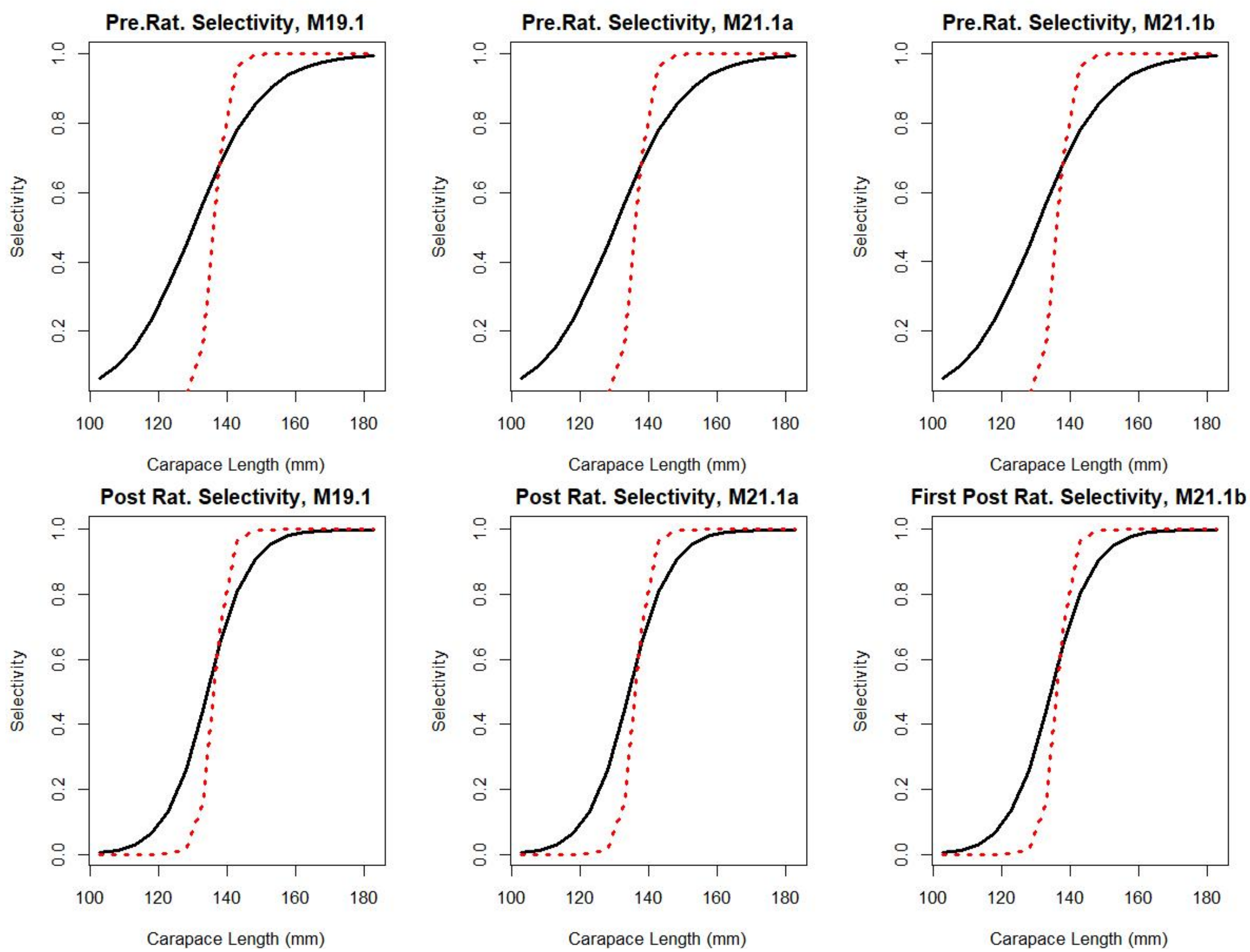


Figure 30a. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under models 19.1, 21.1a, 21.1b, and 21.1c fits to golden king crab data in the WAG. The post-rationalization total selectivity for 21.1b corresponds to first part (2005–2015) of the post-rationalization period.

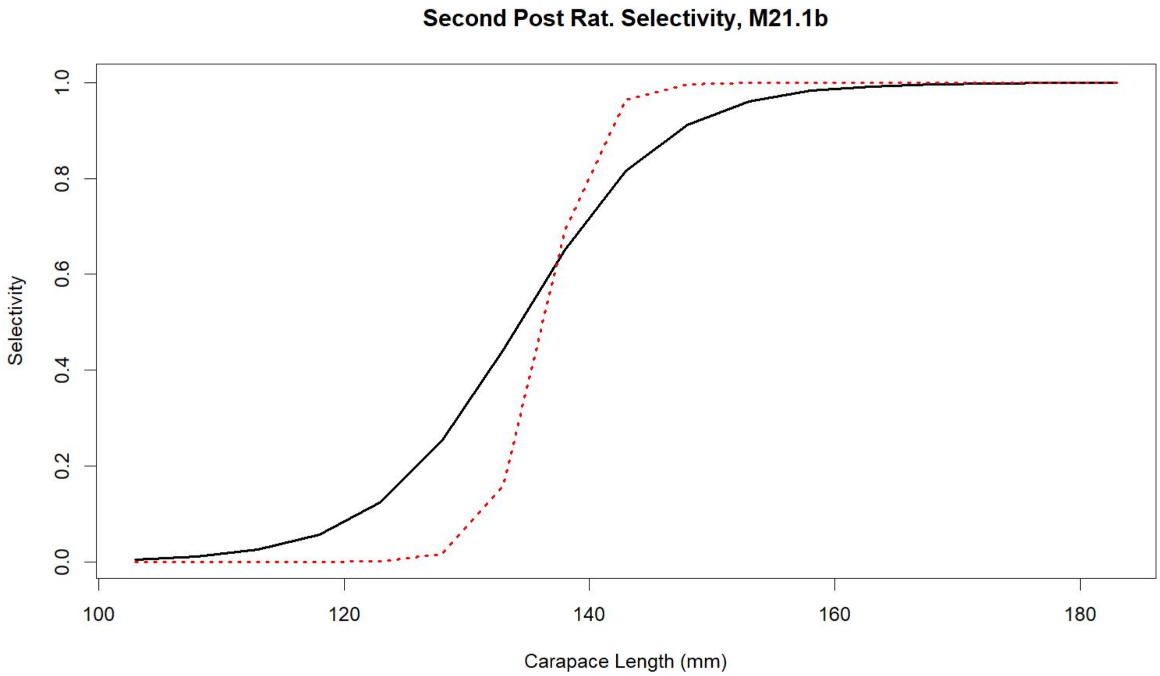


Figure 30b. Estimated total (black solid line) and retained selectivity (red dotted line) for second part (2016–2020) of the post- rationalization period under model 21.1b fit to golden king crab data in the WAG.

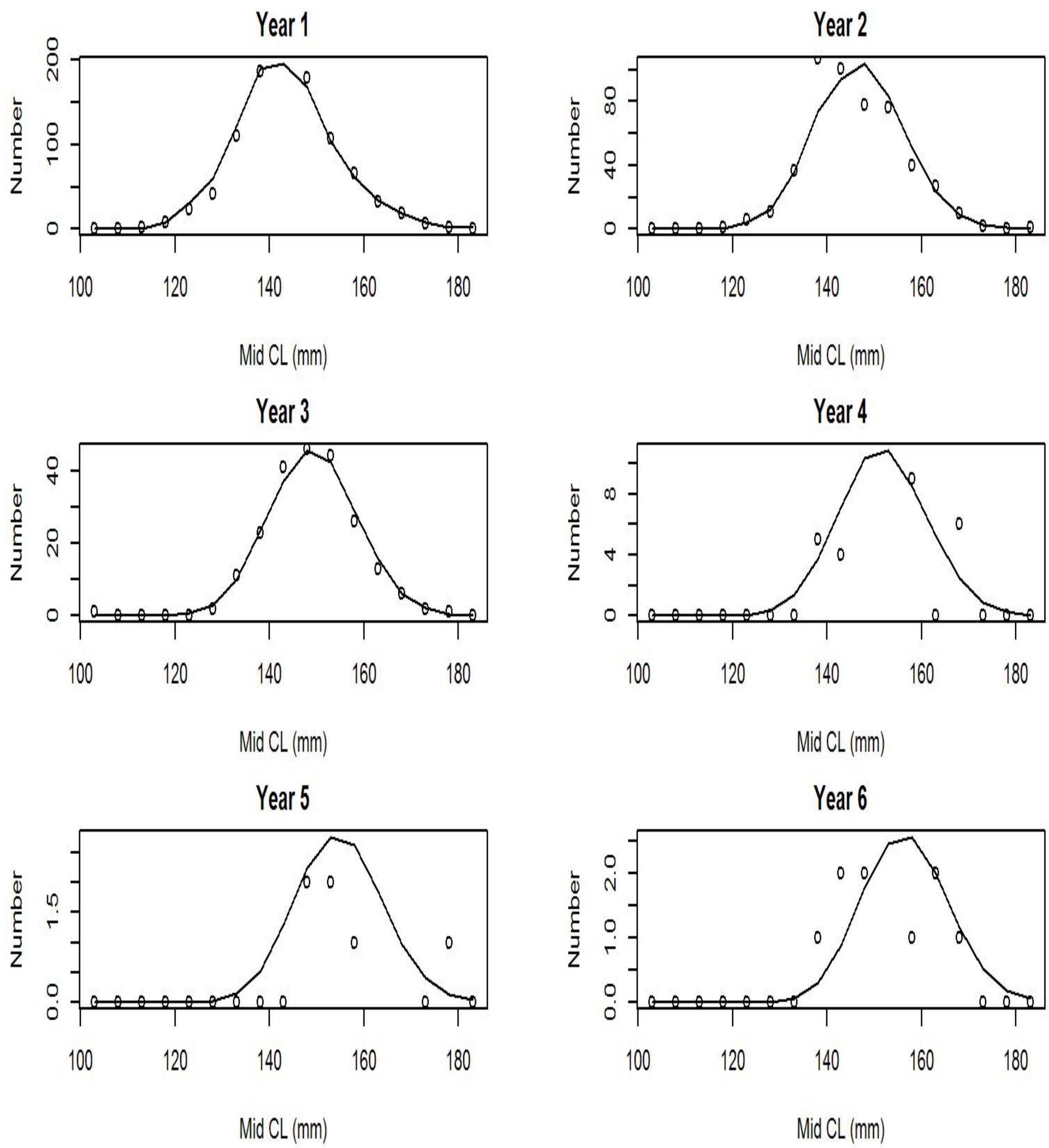


Figure 31. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under model 21.1a fit to WAG golden king crab data.

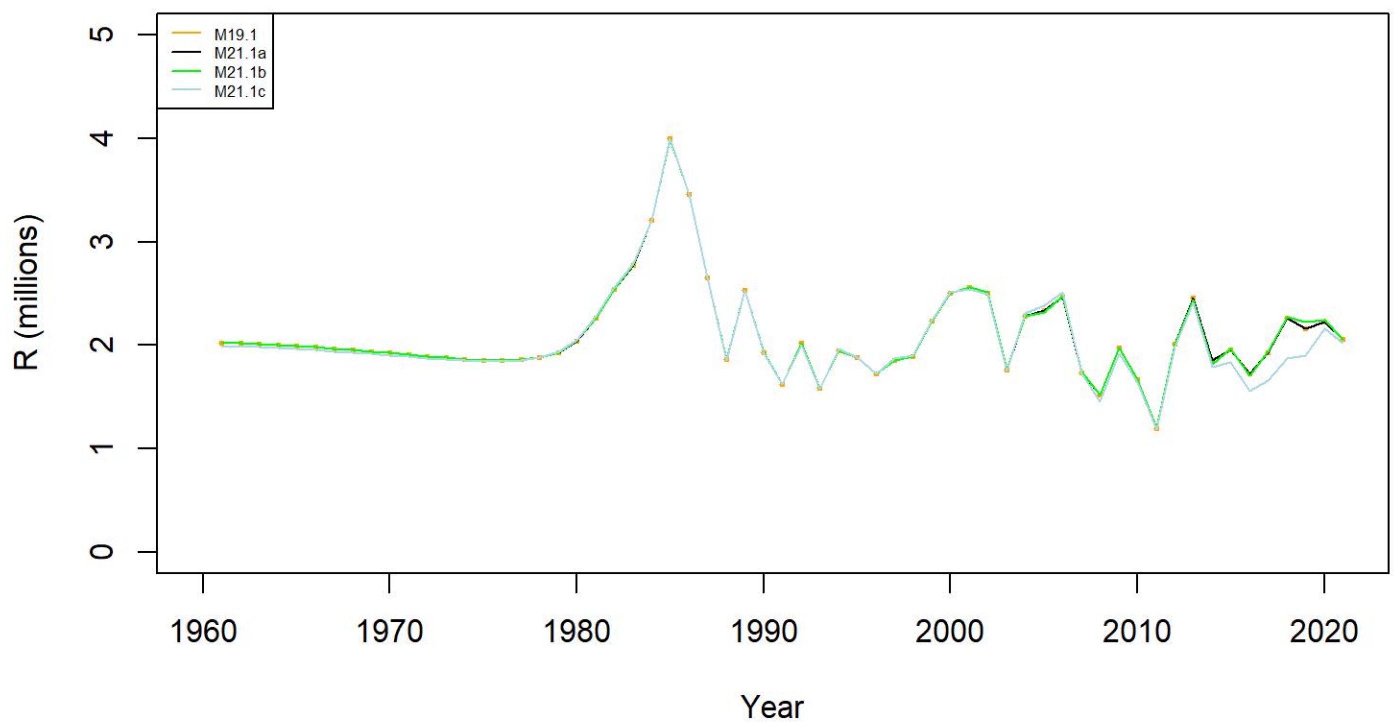


Figure 32. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data, 1961–2021.

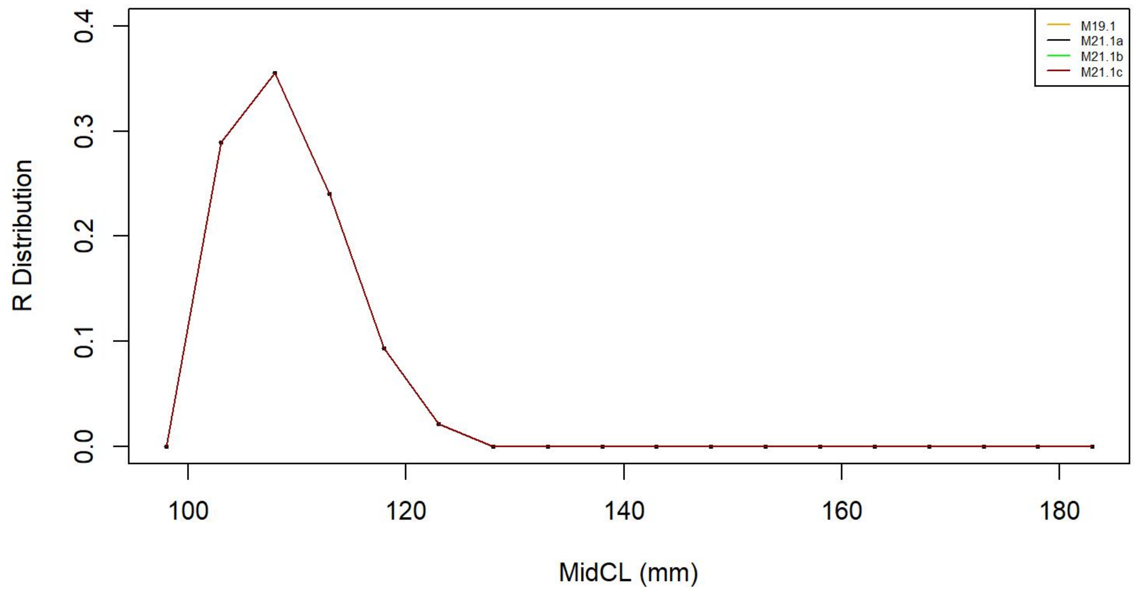


Figure 33. Recruit size distribution to the assessment model under models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data.

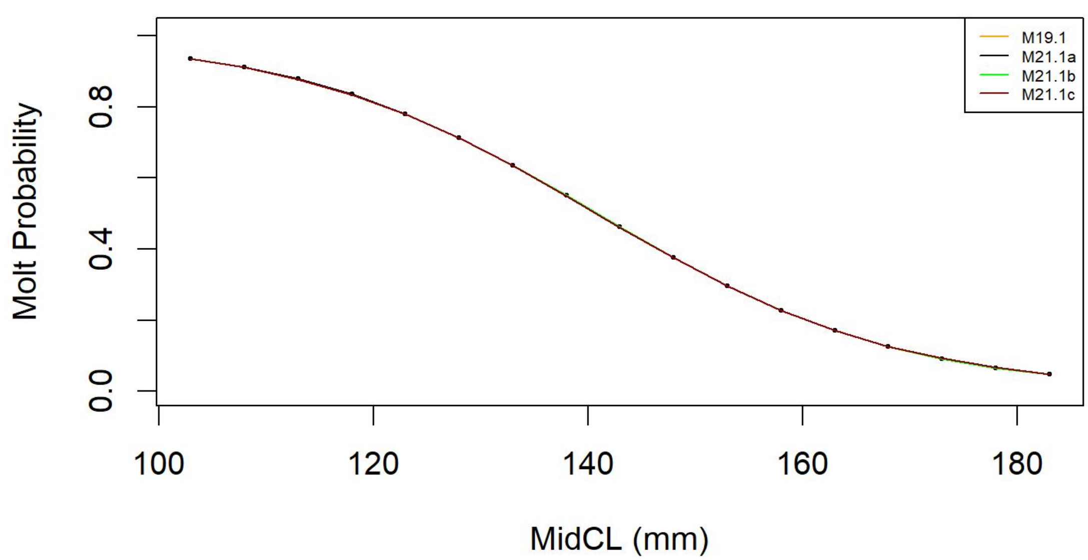


Figure 34. Estimated molt probability vs. carapace length of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data.

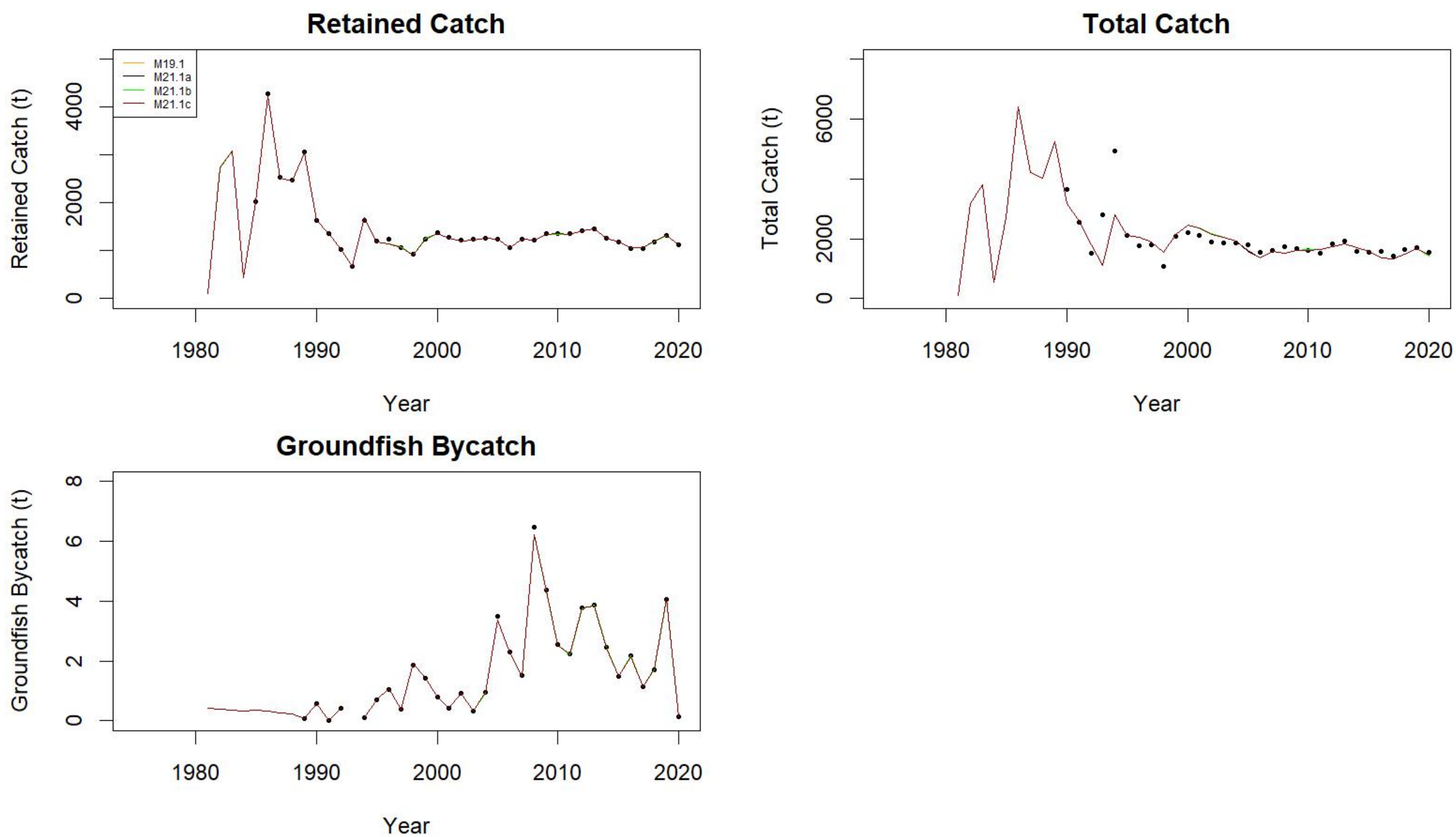


Figure 35. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG data, 1981/82–2020/21.

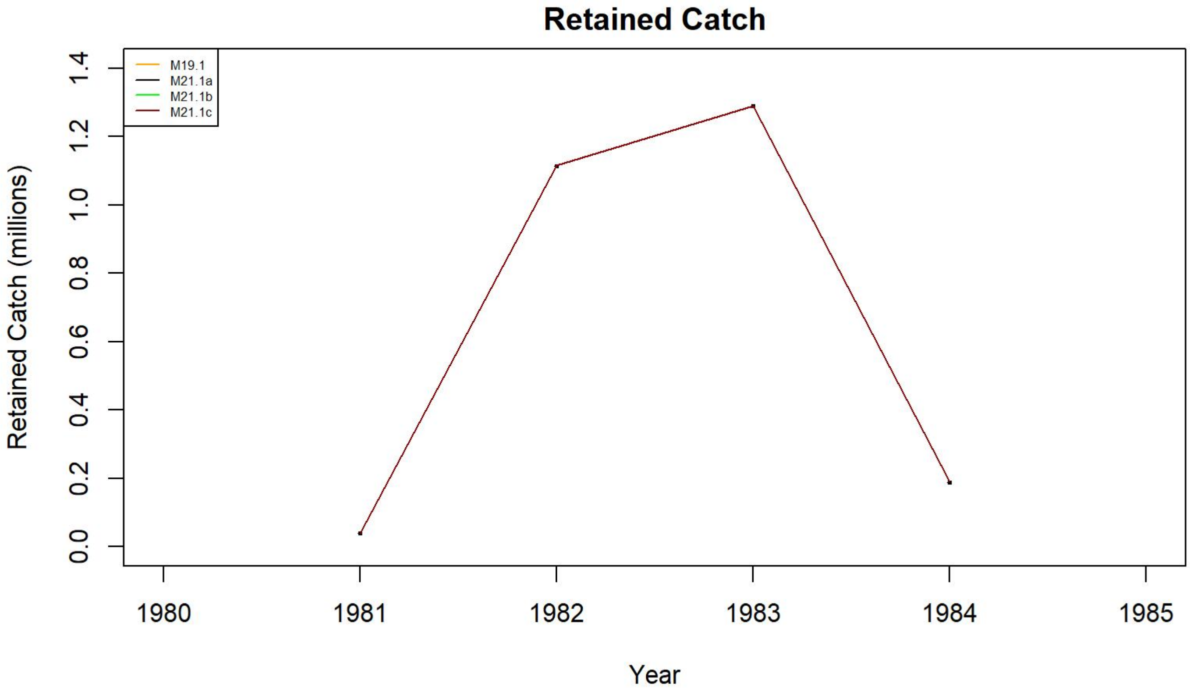


Figure 36. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG data, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.

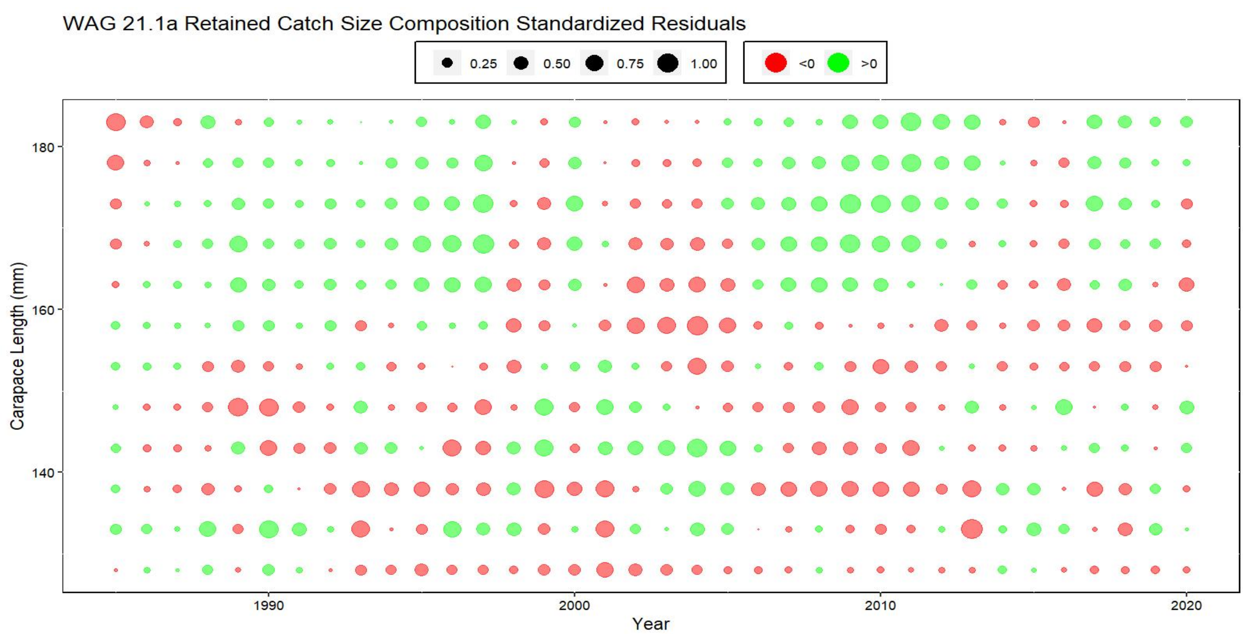


Figure 37. Bubble plot of standardized residuals of retained catch length composition for model 21.1a fit to WAG golden king crab data, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

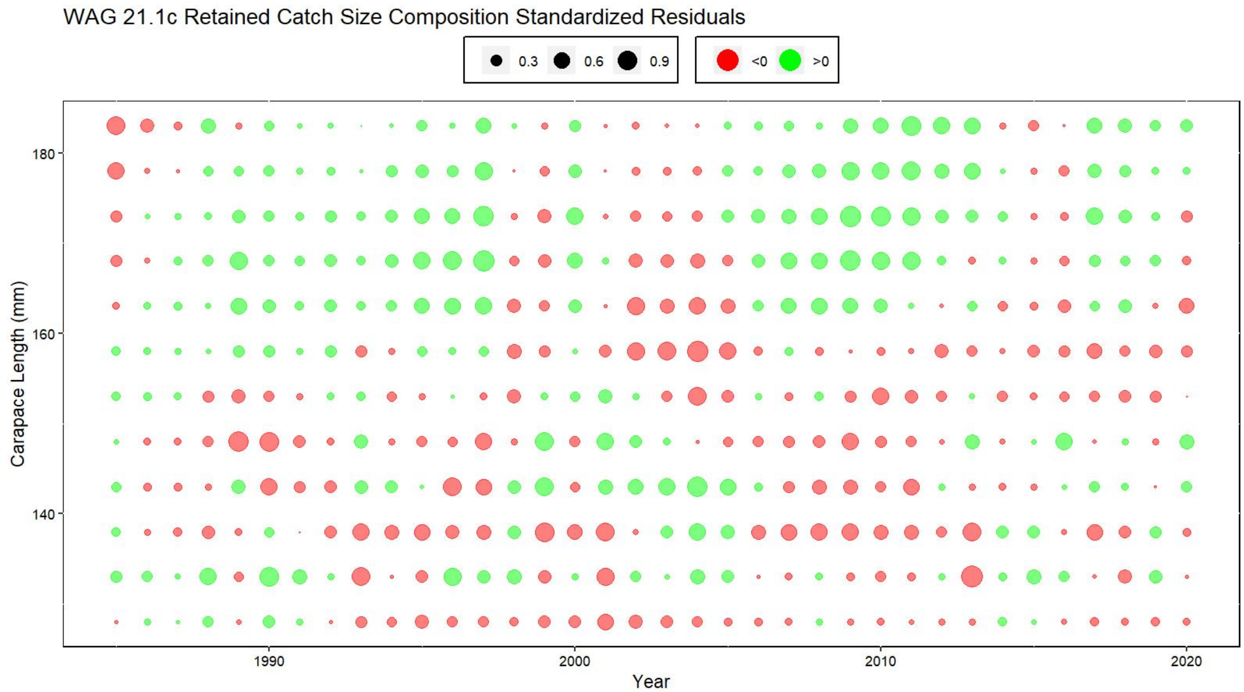


Figure 38. Bubble plot of standardized residuals of retained catch length composition for model 21.1c fit to WAG golden king crab data, 1985/86–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

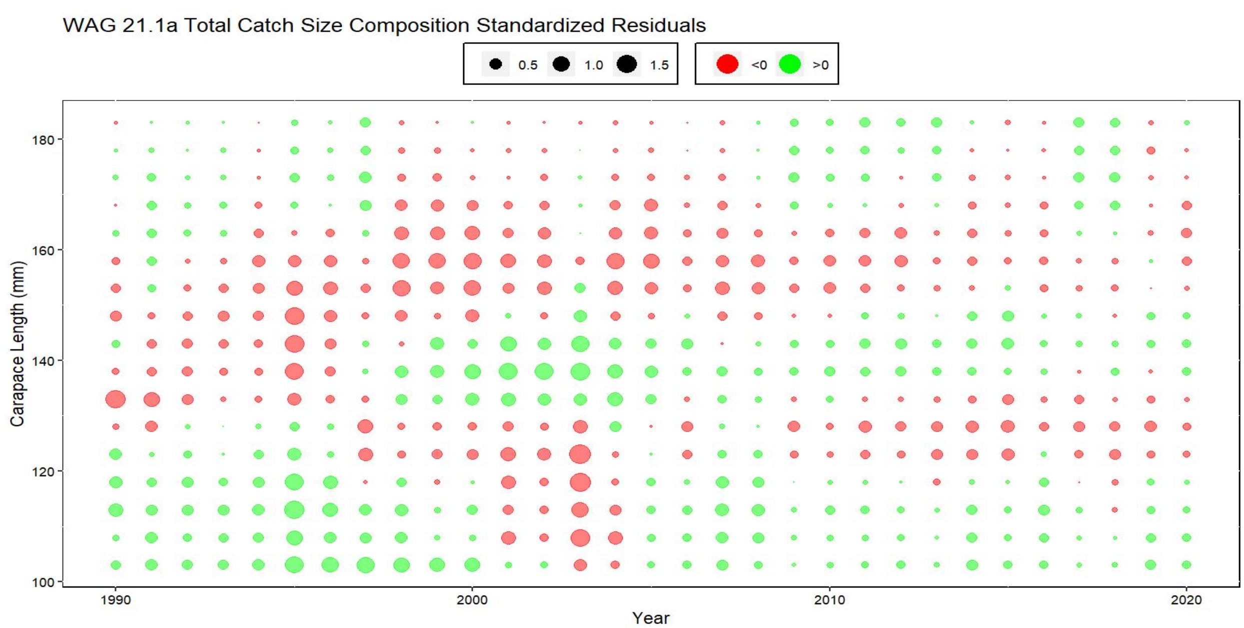


Figure 39. Bubble plot of standardized residuals of total catch length composition for model 21.1a fit to WAG golden king crab data, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

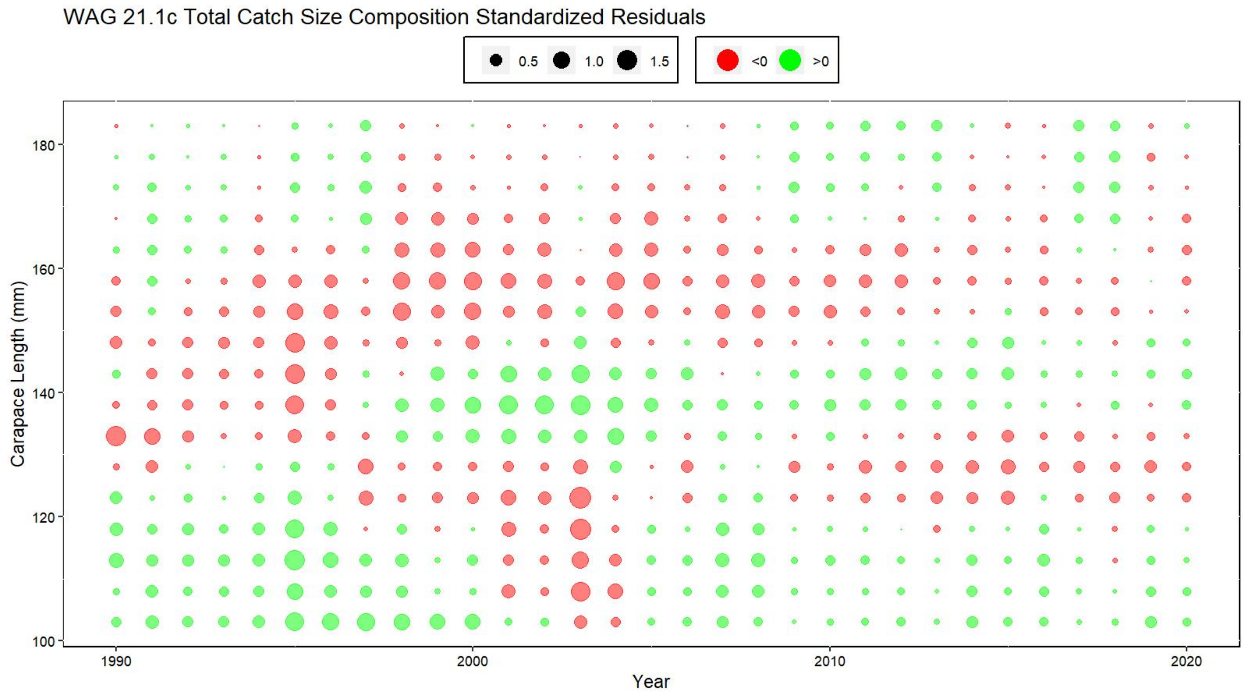


Figure 40. Bubble plot of standardized residuals of total catch length composition for model 21.1c fit to WAG golden king crab data, 1990/91–2020/21. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

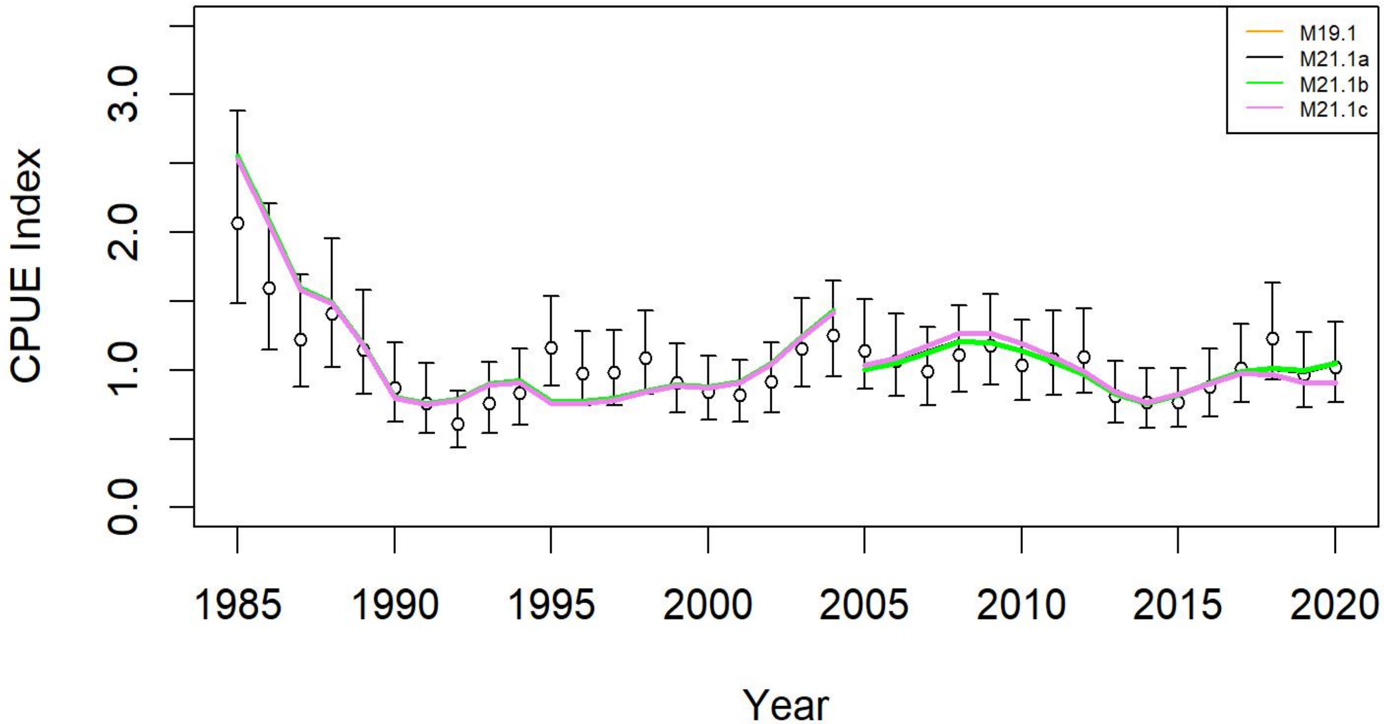


Figure 41. Comparison of input CPUE indices (open circles with +/- 2 SE for model 19.1) with model predicted CPUE indices (colored solid lines) under models 19.1, 21.1a, 21.1b, and 21.1c fits to WAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.

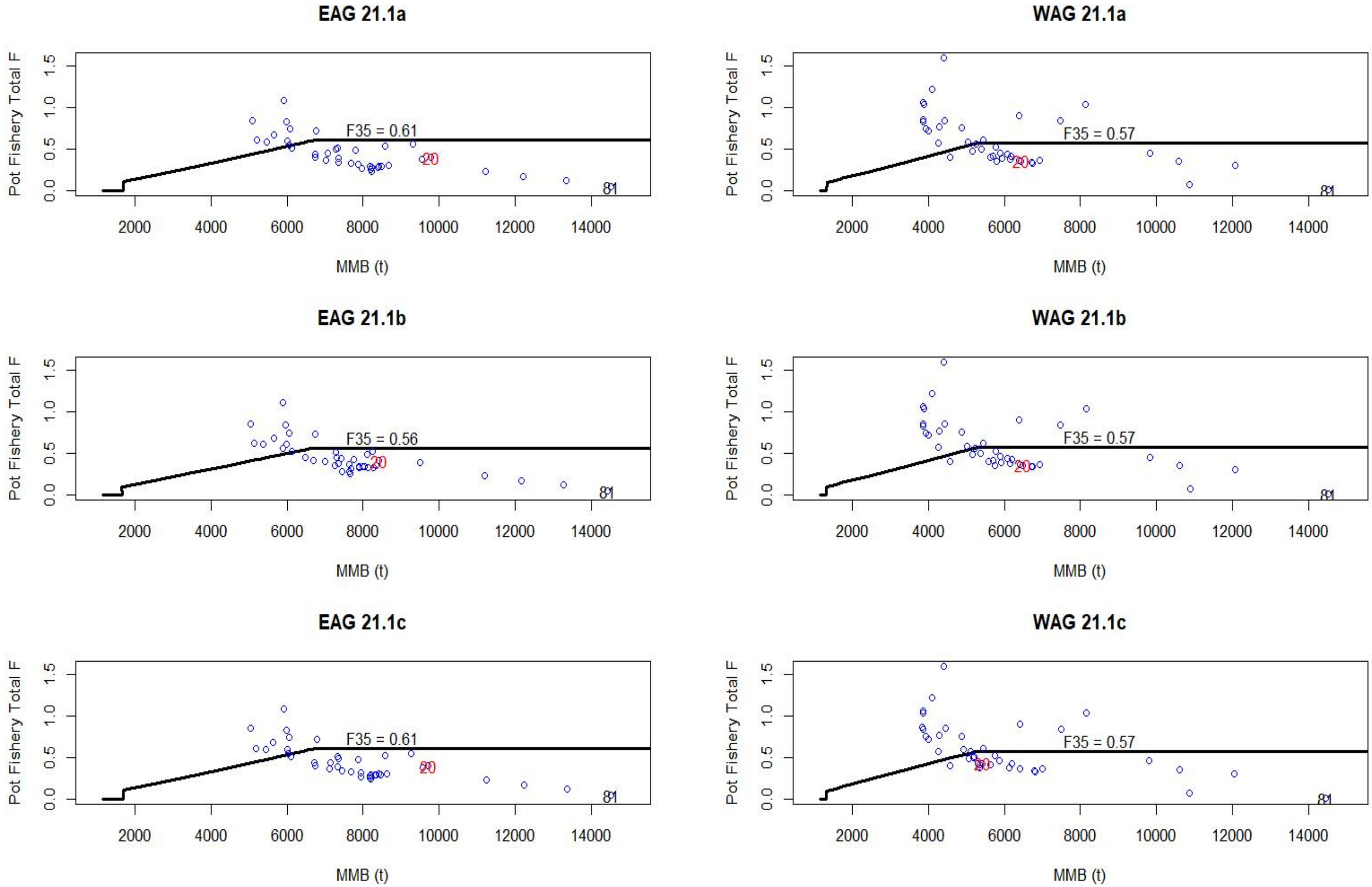


Figure 42. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass during 1981/82–2020/21 under models, 21.1a, 21.1b, and 21.1c fits to EAG and WAG data. *F* in 2020/21 (red) and 1981/82 (black) are shown in the plots.

Appendix A: Integrated model

Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Stock Assessment Model Development- east of 174° W (EAG) and west of 174° W (WAG) Aleutian Island stocks

Basic population dynamics

The annual [male] abundances by size are modeled using the equation:

$$N_{t+1,j} = \sum_{i=1}^{j}[N_{t,i}e^{-M} - (\hat{C}_{t,i} + \widehat{D}_{t,i} + \widehat{Tr}_{t,i})e^{(y_t-1)M}]X_{i,j} + R_{t+1,j} \quad \text{(A.1)}$$

where $N_{t,i}$ is the number of [male] crab in length class *i* on 1 July (start of fishing year) of year *t*; $\hat{C}_{t,i}$, $\widehat{D}_{t,i}$, and $\hat{T}r_{t,i}$ are respectively the predicted fishery retained, pot fishery discard dead, and groundfish fishery discard dead catches in length class *i* during year *t*; $\widehat{D}_{t,i}$ is estimated from the intermediate total $(\hat{T}_{t,i\,temp})$ catch and the retained $(\hat{C}_{t,i})$ catch by Equation A.2c. $X_{i,j}$ is the probability of length-class *i* growing into length-class *j* during the year; y_t is elapsed time period from 1 July to the midpoint of fishing period in year *t*; *M* is instantaneous rate of natural mortality; and $R_{t+1,j}$ recruitment to length class *j* in year *t+1*.

The catches are predicted using the equations

$$\hat{T}_{t,j,temp} = \frac{F_t s_{t,j}^T}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \quad \text{(A.2a)}$$

$$\hat{C}_{t,j} = \frac{F_t s_{t,j}^T s_{t,j}^r}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \quad \text{(A.2b)}$$

$$\widehat{D}_{t,j} = 0.2(\hat{T}_{t,j,temp} - \hat{C}_{t,j}) \quad \text{(A.2c)}$$

$$\widehat{Tr}_{t,j} = 0.65\frac{F_t^{Tr} s_j^{Tr}}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \quad \text{(A.2d)}$$

$$\hat{T}_{t,j} = \hat{C}_{t,j} + \widehat{D}_{t,j} \quad \text{(A.2e)}$$

where $Z_{t,j}$ is total fishery-related mortality on animals in length-class *j* during year *t*:

$$Z_{t,j} = F_t s_{t,j}^T s_{t,j}^r + 0.2F_t s_{t,j}^T(1 - s_{t,j}^r) + 0.65\, F_t^{Tr} s_j^{Tr} \quad \text{(A.3)}$$

F_t is the full selection fishing mortality in the pot fishery, F_t^{Tr} is the full selection fishing mortality in the trawl fishery, $s_{t,j}^T$ is the total selectivity for animals in length-class *j* by the pot fishery during year *t*, s_j^{Tr} is the selectivity for animals in length-class *j* by the trawl fishery, $s_{t,j}^r$ is the probability of retention for animals in length-class *j* by the pot fishery during year *t*. Pot bycatch mortality of

0.2 and groundfish bycatch mortality of 0.65 (average of trawl [0.8] and groundfish pot [0.5] mortality) were assumed.

Initial abundance

The initial conditions are computed as the equilibrium initial condition using the following relations:

The equilibrium stock abundance is

$$N = X.S.N + R \tag{A.4}$$

The equilibrium abundance in 1960, N_{1960}, is

$$\underline{N}_{1960} = (I - XS)^{-1}\underline{R} \tag{A.5}$$

where X is the growth matrix, S is a matrix with diagonal elements given by e^{-M}, I is the identity matrix, and $\underline{R}$ is the product of average recruitment and relative proportion of total recruitment to each size-class.

We used the mean number of recruits from 1987 to 2012 in equation (A.5) to obtain the equilibrium solution under only natural mortality in year 1960, and then projected the equilibrium abundance under natural mortality with recruitment estimated for each year after 1960 up to 1985 with removal of retained catches during 1981/82–1984/85.

Growth Matrix

The growth matrix X is modeled as follows:

$$X_{i,j} = \begin{cases} 0 & if\ j < i \\ P_{i,j} + (1 - m_i) & if\ j = i \\ P_{i,j} & if\ j > i \end{cases} \tag{A.6}$$

where:

$$P_{i,j} = m_i \begin{cases} \int_{-\infty}^{j_2 - L_i} N\,(x\,|\mu_i, \sigma^2)\,dx & if\ \ j = i \\ \int_{j_1 - L_i}^{j_2 - L_i} N\,(x\,|\mu_i, \sigma^2)\,dx & if\ \ i < j < n\ , \\ \int_{j_1 - L_i}^{\infty} N\,(x\,|\mu_i, \sigma^2)\,dx & if\ \ \ i = n \end{cases}$$

$$N(x|\mu_i, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(\frac{x-\mu_i}{\sqrt{2}\sigma})^2},\ and$$

μ_i is the mean growth increment for crab in size-class i:

$$\mu_i = \omega_1 + \omega_2 * \bar{L}_i. \tag{A.7}$$

ω_1, ω_2, and σ are estimable parameters, j_1 and j_2 are the lower and upper limits of the receiving length-class j (in mm CL), and $\bar{L}_i$ is the mid-point of the contributing length interval i. The quantity m_i is the molt probability for size-class i:

$$m_i = \frac{1}{1 + e^{c(\tau_i - d)}} \tag{A.8}$$

where τ_i is the mid-length of the *i*-th length-class, *c* and *d* are parameters.

Selectivity and retention

Selectivity and retention are both assumed to be logistic functions of length. Selectivity depends on the fishing period for the directed pot fishery:

$$S_i = \frac{1}{1 + e^{\left[-ln\,(19)\frac{\tau_i - \theta_{50}}{\theta_{95} - \theta_{50}}\right]}} \tag{A.9}$$

where θ_{95} and θ_{50} are the parameters of the selectivity/ retention pattern (Mark Maunder, unpublished generic crab model). In our program, we re-parameterized the denominator (θ_{95} - θ_{50}) to $log(delta\theta)$ so that the difference is always positive and transformed θ_{50} to $log(\theta_{50})$ to keep the estimate always positive.

Recruitment

Recruitment to length–class i during year *t* is modeled as $R_{t,i} = \bar{R}e^{\epsilon_i}\Omega_i$ where Ω_i is a normalized gamma function

$$gamma(x|\alpha_r, \beta_r) = \frac{x^{\alpha_r - 1}e^{\frac{x}{\beta_r}}}{\beta_r{}^{\alpha_r}\,\Gamma_{(\alpha_r)}} \tag{A.10}$$

with α_r and β_r (restricted to the first five length classes).

Parameter estimation

Table A1 lists the parameters of the model indicating which are estimated and which are pre-specified. The objective function includes contributions related to the fit of the model to the available data and penalties (priors on various parameters).

Tables A2 lists parameter values (with the corresponding coefficient of variations in parentheses) used to weight the components of the objective functions for EAG and WAG.

Likelihood components

Catches

The contribution of the catch data (retained, total, and groundfish discarded) to the objective function is given by:

$$LL_r^{catch} = \lambda_r \sum_t \{\ell n(\sum_j \hat{C}_{t,j} w_j + c) - \ell n(\sum_j C_{t,j} w_j + c)\}^2 \tag{A.11a}$$

$$LL_T^{catch} = \lambda_T \sum_t \{ln\,(\sum_j \hat{T}_{t,j} w_j + c) - ln\,(\sum_j T_{t,j} w_j + c)\}^2 \tag{A.11b}$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{ln\,(\sum_j \widehat{Tr}_{t,j} w_j + c) - ln\,(\sum_j Tr_{t,j} w_j + c)\}^2 \tag{A.11c}$$

where λ_r, λ_T, and λ_{GD} are weights assigned to likelihood components for the retained, pot total, and groundfish discard catches; w_j is the average mass of a crab is length-class j; $C_{t,j}$, $T_{t,j}$, and $Tr_{t,j}$ are, respectively, the observed numbers of crab in size class j for retained, pot total, and groundfish fishery discarded crab during year t, and c is a small constant value. We assumed c = 0.001.

An additional retained catch likelihood (using Equation A.11a without w) for the retained catch in number of crabs during 1981/82–1984/85 was also considered in all scenarios.

Catch-rate indices

The catch-rate indices are assumed to be lognormally distributed about the model prediction. Account is taken of variation in addition to that related to sampling variation:

$$LL_r^{CPUE} = \lambda_{r,CPUE}\left\{0.5\sum_t ln\left[2\pi\left(\sigma_{r,t}^2+\sigma_e^2\right)\right]+\sum_t\frac{\left(ln(CPUE_t^r+c)-ln\,(\widehat{CPUE}_t^r+c)\right)^2}{2(\sigma_{r,t}^2+\sigma_e^2)}\right\} \quad \text{(A.12)}$$

where $CPUE_t^r$ is the standardized retain catch-rate index for year t, $\sigma_{r,t}$ is standard error of the logarithm of $CPUE_t^r$,and $\widehat{CPUE}_t^r$ is the model-estimate of $CPUE_t^r$:

$$\widehat{CPUE}_t^r = q_k\sum_j S_j^T\, S_j^r\left(N_{t,j}-0.5\left[\widehat{C_{t,J}}+\widehat{D_{t,J}}+\widehat{Tr_{t,J}}\right]\right)e^{-y_tM} \quad \text{(A.13)}$$

in which q_k is the catchability coefficient during the k-th period (e.g., pre- and post-rationalization time periods), σ_e is the extent of over-dispersion, c is a small constant to prevent zero values (we assumed c = 0.001), and $\lambda_{r,CPUE}$ is the weight assigned to the catch-rate data. We used the same likelihood formula (A.12) for fish ticket and cooperative survey retained catch rate indices. However, for cooperative survey catch rate prediction we used a different catchability parameter.

Following Burnham *et al.* (1987), we computed the ln(CPUE) variance by:

$$\sigma_{r,t}^2 = ln\left(1+CV_{r,t}^2\right) \quad \text{(A.14)}$$

Length-composition data

The length-composition data are included in the likelihood function using the robust normal for proportions likelihood, i.e., generically:

$$LL_r^{LF} = 0.5\sum_t\sum_j \ell n(2\pi\sigma_{t,j}^2)-\sum_t\sum_j \ell n\left[\exp\left(-\frac{(P_{t,j}-\hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right)+0.01\right] \quad \text{(A.15)}$$

where $P_{t,j}$ is the observed proportion of crabs in length-class j in the catch during year t, $\hat{P}_{t,j}$is the model-estimate corresponding to $P_{t,j}$, i.e.:

$$\hat{L}_{t,j}^{r} = \frac{\hat{C}_{t,j}}{\sum_j^n \hat{C}_{t,j}}$$

$$\hat{L}_{t,j}^{T} = \frac{\hat{T}_{t,j}}{\sum_j^n \hat{T}_{t,j}}$$

$$\hat{L}_{t,j}^{GF} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \quad \text{(A.16)}$$

$\sigma_{t,j}^2$ is the variance of $P_{t,j}$:

$$\sigma_{t,j}^2 = \left[(1-P_{t,j})P_{t,j} + \frac{0.1}{n}\right] / S_t \tag{A.17}$$

and S_t is the effective sample size for year *t* and *n* is the number of size classes.

Note: The likelihood calculation for retained length composition starts from length-class 6 (mid length 128 mm CL) because the length-classes 1 to 5 mostly contain zero data.

Tagging data

Let $V_{j,t,y}$ be the number of tagged male crab that were released during year *t* that were in size-class *j* when they were released and were recaptured after *y* years, and $\rho_{j,t,y}$ be the vector of recaptures by size-class from the males that were released in year *t* that were in size-class *j* when they were released and were recaptured after *y* years. The log-likelihood corresponding to the multinomial distribution for the tagging data is then:

$$lnL = \lambda_{y,tag} \sum_j \sum_t \sum_y \sum_i \rho_{j,t,y,i} ln\hat{\rho}_{j,t,y,i} \tag{A18}$$

where $\lambda_{y,tag}$ is the weight assigned to the tagging data for recapture year *y*, $\hat{\rho}_{j,t,y,i}$ is the proportion in size-class *i* of the recaptures of males that were released during year *t* that were in size-class *j* when they were released and were recaptured after *y* years:

$$\underline{\hat{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{Z}^{(j)} \tag{A19}$$

where $Z^{(j)}$ is a vector with $V_{j,t,y}$ at element *j* and 0 otherwise, and S^T is the vector of total selectivity for tagged male crab by the pot fishery. This log-likelihood function is predicated on the assumption that all recaptures are in the pot fishery and the reporting rate is independent of the size of crab.

Penalties

Penalties are imposed on the deviations of annual pot fishing mortality about mean pot fishing mortality, annual trawl fishing mortality about mean trawl fishing mortality, recruitment about mean recruitment, and the posfunction (fpen):

$$P_1 = \lambda_F \sum_t (\ell n F_t - \ell n \overline{F})^2 \tag{A.20}$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ell n F_t^{Tr} - \ell n \overline{F}^{Tr})^2 \tag{A.21}$$

$$P_3 = \lambda_R \sum_t (\ell n \varepsilon_t)^2 \tag{A.22}$$

$$P_5 = \lambda_{posfn} * fpen \tag{A.23}$$

Standardized Residual of Length Composition

$$Std.Res_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma_{t,j}^2}} \tag{A.24}$$

Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n}(\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \tag{A.25}$$

Exploited legal male biomass at the start of year t:

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \tag{A.26}$$

where w_j is the weight of an animal in length-class j.

Mature male biomass on 15 February spawning time (NPFMC 2007a, b) in the following year:

$$MMB_t = \sum_{j=mature\ size}^{n}\{N_{j,t}e^{-y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t})e^{(y_t - y')M}\}w_j \tag{A.27}$$

where y' is the elapsed time from 1 July to 15 February in the following year.

For estimating the next year limit harvest levels from current year stock abundances, an F_{OFL} value is needed. The current crab management plan specifies five different Tier formulas for different stocks depending on the strength of information available for a stock, for computing F_{OFL} (NPFMC 2007a, b). For the golden king crab, the following Tier 3 formula is applied to compute F_{OFL}:

If,
$MMB_{current} > MMB_{35\%}, F_{OFL} = F_{35\%}$

If,
$MMB_{current} \leq MMB_{35\%}\ and\ MMB_{current} > \beta MMB_{35\%}$,

$$F_{OFL} = F_{35\%}\ \frac{\left(\frac{MMB_{current}}{MMB_{35\%}} - \alpha\right)}{(1-\alpha)} \tag{A.28}$$

If,
$MMB_{current} \leq \beta MMB_{35\%}$,

$F_{OFL} = 0.$

where
β = a parameter with a restriction that $0 \leq \beta < 1$. A default value of 0.25 is used,
α = a parameter with a restriction that $0 \leq \alpha \leq \beta$. A default value of 0.1 is used,

$\mathrm{MMB_{current}}$ = the mature male biomass in the current year, and
$MMB_{35\%}$ = a proxy MMB_{MSY} for Tier 3 stocks.

Because projected $\mathrm{MMB_t}$ (i.e., $\mathrm{MMB_{current}}$) depends on the intervening retained and discard catch (i.e., $\mathrm{MMB_t}$ is estimated after the fishery), an iterative procedure is applied using Equations A.27 and A.28 with retained and discard catch predicted from Equations A.2b-d. The next year limit harvest catch is estimated using Equations A.2b-d with the estimated F_{OFL} value.

Table A1. Pre-specified and estimated parameters of the population dynamics model

Parameter	Number of parameters
Fishing mortalities:	
Pot fishery, F_t	1981–2020 (estimated)
Mean pot fishery fishing mortality, $\overline{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2020 (the mean F for 1989 to 1994 was used to estimate groundfish discards back to 1981 (estimated)
Mean groundfish fishery fishing mortality, $\overline{F}^{Tr}$	1 (estimated)
Selectivity and retention:	
Pot fishery total selectivity, θ_{50}^{T}	2 (1981–2004; 2005+) (estimated)
Pot fishery total selectivity difference, deltaθ^{T}	2 (1981–2004; 2005+) (estimated)
Pot fishery retention, θ_{50}^{r}	1 (1981+) (estimated)
Pot fishery retention selectivity difference, deltaθ^{r}	1 (1981+) (estimated)
Groundfish fishery selectivity	fixed at 1 for all size-classes
Growth:	
Expected growth increment, ω_1, ω_2	2 (estimated)
Variability in growth increment, σ	1 (estimated)
Molt probability (size transition matrix with tag data), a	1 (estimated)
Molt probability (size transition matrix with tag data), b	1 (estimated)
Natural mortality, *M*	1 (pre-specified, 0.21yr^{-1})
Recruitment:	
Number of recruiting length-classes	5 (pre-specified)
Mean recruit length	1 (pre-specified, 110 mm CL)
Distribution to length-class, β_r	1 (estimated)
Median recruitment, $\overline{R}$	1 (estimated)
Recruitment deviations, ε_t	61 (1961–2021) (estimated)
Fishery catchability, q	2 (1985–2004; 2005+) (estimated)
Additional CPUE indices standard deviation, σ_e	1 (estimated)
Likelihood weights (coefficient of variation)	Pre-specified, varies by scenario

Table A2. Specifications for the weights with corresponding coefficient of variations* in parentheses for each model for EAG and WAG.

Weight	Models 19.1, 21.1a, 21.1b, and 21.1c
Catch:	
Retained catch for 1981–1984 and/or 1985–2020, λ_r	500 (0.032)
Total catch for 1990–2020, λ_T	Number of sampled pots scaled to a max 250
Groundfish bycatch for 1989 –2020, λ_{GD}	0.2 (3.344)
Catch-rate:	
Observer legal size crab catch-rate for 1995–2020, $\lambda_{r,CPUE}$	1 (0.805)
Fish ticket retained crab catch-rate for 1985–1998, $\lambda_{r,CPUE}$	1 (0.805)
Penalty weights:	
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2 (0.533)
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)
Tagging likelihood	EAG individual tag returns

$*$ Coefficient of Variation, $CV = \sqrt{\exp\left[\frac{1}{2W}\right] - 1}$, w =weight

Appendix B: Catch and CPUE data

The commercial catch and length frequency distribution were estimated from ADF&G landing records and dockside sampling (Bowers *et al.* 2008, 2011). The annual retained catch, total catch, and groundfish (or trawl) discarded mortality are provided in Tables 1, 2, and 2b for EAG and WAG. The weighted length frequency data were used to distribute the catch into 5-mm size intervals. The length frequency data for a year were weighted by each sampled vessel's catch as follows. The *i*-th length-class frequency was estimated as:

$$\sum_{j=1}^{k} C_j \frac{LF_{j,i}}{\sum_{i=1}^{n} LF_{j,i}} \qquad \text{(B.1)}$$

where k = number of sampled vessels in a year, $LF_{j,i}$ = number of crabs in the *i*-th length-class in the sample from *j*-th vessel, n = number of size classes, C_j = number of crabs caught by *j*-th vessel. Then the relative frequency for the year was calculated and applied to the annual retained catch (in number of crabs) to obtain retained catch by length-class.

The annual total catch (in number of crabs) was estimated by the observer nominal (unstandardized) total CPUE considering all vessels multiplied by the total fishing effort (number of pot lifts). The weighted length frequency of the observer samples across the fleet was estimated using Equation B.1. Observer measurement of crab ranged from 20 to 220 mm CL. To restrict the total number of crabs to the model assumed size range (101–185+ mm CL), the proportion of observer total relative length frequency corresponding to this size range was multiplied by the total catch (number of crabs). This total number of crabs was distributed into length-classes using the weighted relative length frequency. Thus, crab sizes < 101 mm CL were excluded from the model. In addition, all crab >185 mm CL were pooled into a plus length class. Note that the total crab catches by size that went into the model did not consider retained and discard components separately. However, once the model estimated the annual total catch, then retained catch was deducted from this total and multiplied by handling mortality [we used a 20% handling mortality (Siddeek *et al.* 2005) to obtain the directed fishery discarded (dead) catch].

Observer data have been collected since 1988 (Moore *et al.* 2000; Barnard *et al.* 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91–2020/21 was selected for this analysis. During 1990/91–1994/95, observers were only deployed on catcher-processor vessels. During 1995/96–2004/05, observers were deployed on all fishing vessels during fishing activity. Observers have been deployed on all fishing vessels since 2005/06, but catcher-only vessels are only required to carry observers for a minimum of 50% of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity. Onboard observers sample seven pots per day (may be different numbers of pots per string) and count and measure all crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season (Table 3). The observer CPUE data collection improved over the years and the data since 1995/96 are more reliable. Thus, for model fitting, the observer CPUE time series was restricted to 1995/96–2020/21. The 1990/91–2020/21 observer database consists of 118,025 records and that of 1995/96–2020/21 contains 113,746 records, For CPUE standardization, these data were further reduced by 5% cutoff of Soak time and 1% cutoff of Depth on both ends of the variable range to remove unreliable data or data from dysfunctional pot operations and restricting to vessels which have made five trips per year for at least three years during 1985/86 –2020/21.

We detected some computational errors in raw size frequency summary data preparation (observer and fish ticket sampling) for 2016–2019 and rectified errors in relative retained and total size frequency computations in the current analysis. The correction of errors did not affect retained catch crab distribution by size bins but caused minor changes to allocation of total catch crab into size bins.

Length-specific CPUE data collected by observers provides information on a wider size range of the stock than did the commercial catch length frequency data obtained from mostly legal-sized landed males.

There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9” since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two separate observer CPUE time series, 1995/96–2004/05 and 2005/06–2020/21, to estimate CPUE indices for model input.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE as a separate likelihood component in all scenarios. Because of the lack of soak time data before 1990, we estimated the CPUE index considering a limited set of explanatory variables (e.g., vessel, captain, area, month) and fitting the negative binomial GLM model to fish ticket data (Tables 4 and 14).

When using CPUE indices in the model fit, we compared the predicted with the observed legal male CPUE in the observer CPUE likelihoods because legal male (retained plus non-retained) data are more reliable than total in the observer samples.

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek *et al*. 2018). Following a suggestion from the CIE reviewers in June 2018 we reduced the number of gear codes in the database after consulting with the fishing industry (Rip Carlton, Chad Hoefer, and Scott Goodman, personal communication December 2018; Table B1). Following an SSC suggestion in October 2018, we used a hybrid procedure: First, we selected a scope of variables set by Akike Information Criterion, AIC (Burnham and Anderson 2002). An increase of more than 2 units in the AIC was used to identify the variable to be included successively (stepAIC program, R Core Team 2020). Then, the model parsimony was improved further by successively removing the term that explained the least proportion of deviance ($R^2 < 0.01$) (stepCPUE R function was used, Siddeek *et al*. 2018). Feenstra, *et al*. (2019) used a similar hybrid approach.

Table B.1. Updated gear codes for observer data analysis. Only gear code # 5, 6, 7, 8, and 13 were considered following crab industry suggestion. Note: Identical codes were given to those gear codes with similar catchability/selectivity. X indicates gear codes that were ignored.

Original Gear code	Pot gear description	Mark X against the code that can be ignored	Number encountered by observers during 1990–2016	Updated gear code
1	Dungeness crab pot, small & round	X	2	X
2	Pyramid pot, tunnel openings usually on sides, stackable	X	2121	X
3	Conical pot, opening at top of cone, stackable	X	2000	X
4	4' X 4' rectangular pot		60	X
5	5' X 5' rectangular pot		18032	5
6	6' X 6' rectangular pot		17508	6
7	7' X 7' rectangular pot		23806	7
8	8' X 8' rectangular pot		1936	8
9	5 1/2' X 5 1/2' rectangular pot		6934	5
10	6 1/2' X 6 1/2' rectangular pot		22085	6
11	7 1/2' X 7 1/2' rectangular pot		387	7
12	Round king crab pot, enlarged version of Dungeness crab pot		8259	X
13	10' X 10' rectangular pot		466	13
14	9' X 9' rectangular pot	X	1	X
15	8 1/2' X 8 1/2' rectangular pot	X	1	X
16	9 1/2' X 9 1/2' rectangular pot	X	Not used	X
17	8' X 9' rectangular pot	X	1	X
18	8' X 10' rectangular pot	X	1	X
19	9' X 10' rectangular pot		Not used	X
20	7' X 8' rectangular pot	X	252	X
21	Hair crab pot, longlined and small, stackable		Not used	X
22	snail pot	X	1	X
23	Dome-shaped pot, tunnel opening on top, often longlined in deep-water fisheries	X	6756	X
24	ADF&G shellfish research 7' X 7' X34" rectangular pot with 2.75" stretch mesh and no escapement rings or mesh		Research pot	X
80	Historical: Cod pot, any shape pot targeting cod, usually with tunnel fingers	X	711	X
81	Historical: Rectangular pot, unknown size, with escape rings	X	1123	X

All scenarios used CPUE indices estimated by the hybrid GLM method. Following a January 2019 CPT request, we considered a Year:Area interaction factor as a special case for a CPUE standardization scenario.

Thus we estimated two sets of observer CPUE indices for model input, 19.1 (reduced number of gear codes), and 21.1c (reduced number of gear codes and Year:Area interaction).

Observer CPUE index by GLM

a. Non-interaction GLM model

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek *et al*. 2016b). We considered the negative binomial GLM on positive and zero catches to select the explanatory variables. The response variable CPUE is the observer sample catch record for a pot haul. The negative binomial model uses the log link function for the GLM fit.

For the non-interaction model, we assumed the null model to be:

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \qquad \text{(B.2)}$$

where Year is a factorial variable.
The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln(\mathrm{CPUE_I}) = \mathrm{Year_{y_i}} + \mathrm{ns(Soak_{si}, df)} + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns(Depth_{di}, df)}, \qquad \text{(B.3)}$$

where Soak is in unit of days and is numeric; Month, Area (Block) code, Vessel code, Captain code, and Gear code are factorial variables; Depth in fathom is a numeric variable; ns=cubic spline, and df = degree of freedom.

We used a log link function and a dispersion parameter (θ) in the GLM fitting process. We used the R^2 criterion for predictor variable selection (Siddeek *et al*. 2016b).

We calculated appropriate degrees of freedom and dispersion parameters by calculating AICs for a range of values and locating the best values at the minimum AIC (Figures B1 and B.2, respectively).

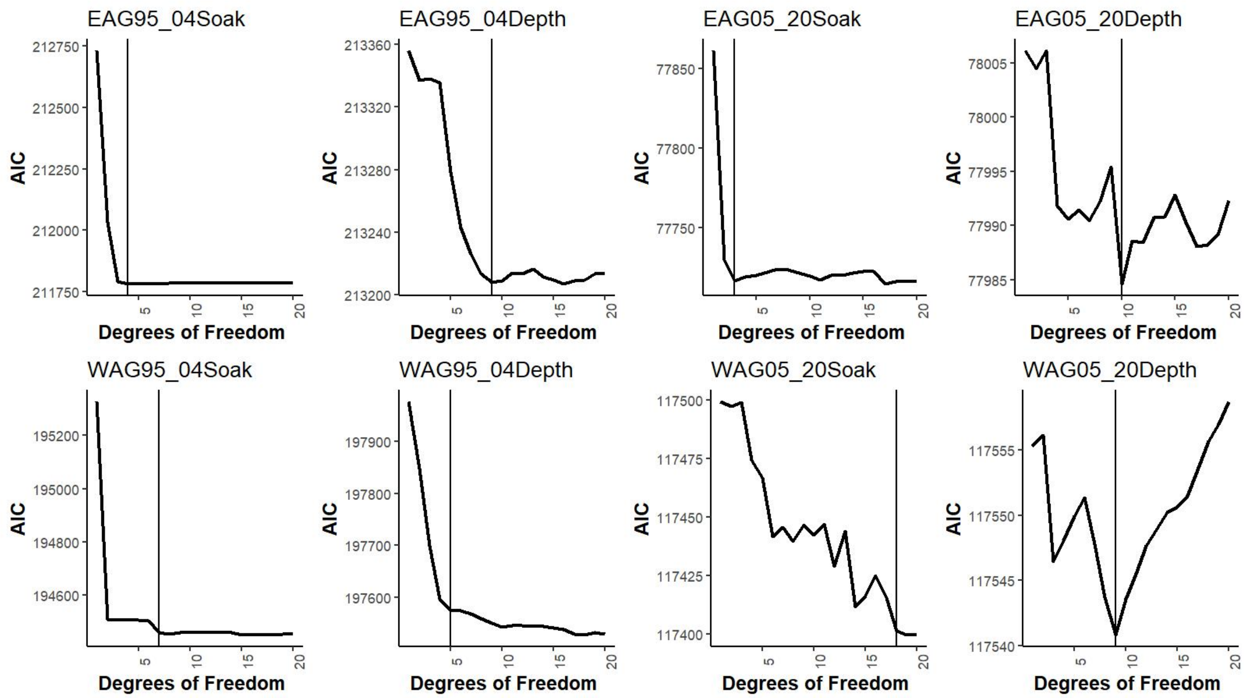


Figure B.1. AIC vs degrees of freedom for soak time and depth during pre- and post-rationalization periods for EAG (top) and WAG (bottom). Vertical lines identify the optimum degrees of freedom values chosen for CPUE standardization.

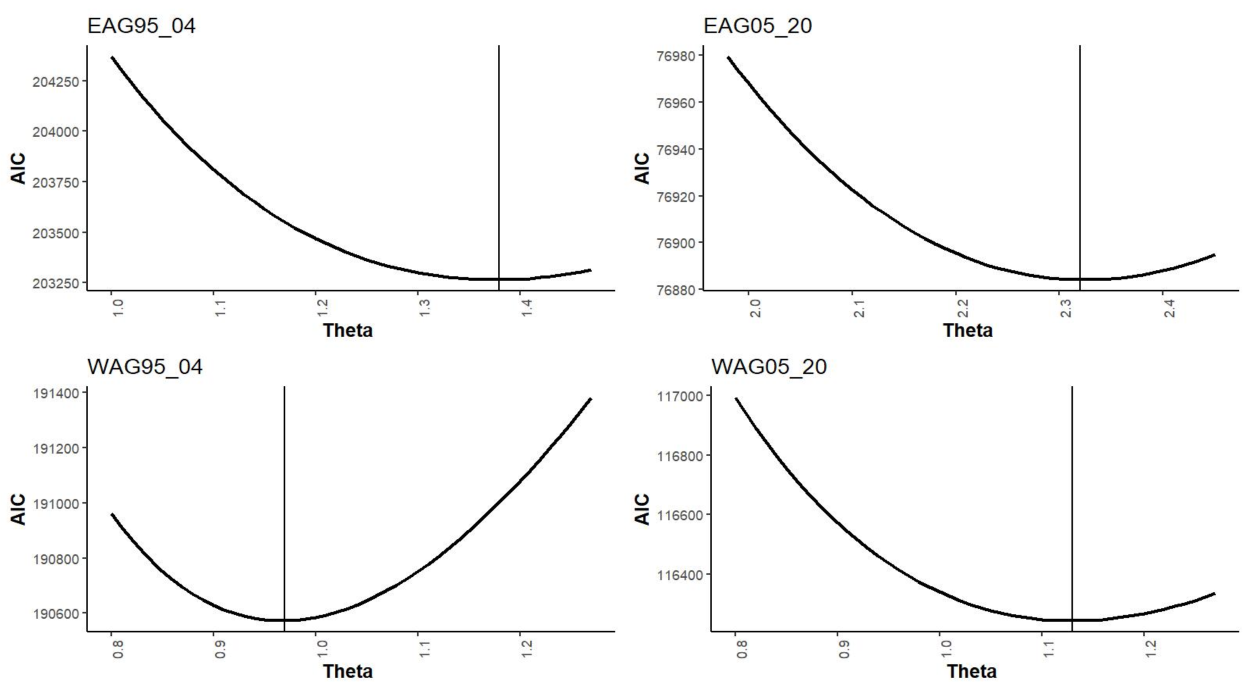


Figure B.2. AIC vs theta (dispersion parameter) during pre- and post-rationalization periods for EAG (top) and WAG (bottom). Vertical lines identify the optimum theta values chosen for CPUE standardization.

Instead of using the traditional AIC (-2log_likelihood+2p) we used the Consistent Akaike Information Criteria (CAIC) (Bozdogan 1987) {-2log_likelihood+[ln(n)+1]*p} for variable selection by StepAIC, where n=number of observations and p= number of parameters to be estimated. The number of selected variables were further reduced for parsimony, if feasible, by the R^2 criterion using the StepCPUE function. i.e., a hybrid selection procedure (Feenstra *et al.* 2019).

Example R codes used for main effect GLM fitting are as follows:

For EAG 1995_04 CPUE indices:

library(MASS)

library(splines)

Step 1:

glm.object<- glm(Legals~Year,family = negative.binomial(1.38),data=datacore)

epotsampleoutAIC<-stepAIC(glm.object,scope=list(upper= ~(Year+ns(SoakDays,df=4)+Month+Vessel+Captain+Area+Gear+ns(Depth,df=9)),lower= ~Year),family=negative.binomial(1.38),direction="forward",trace=9,k=log(nrow(datacore)) +1.0)

Step 2:

glm.object<- glm(Legals~Year,family = negative.binomial(1.38),data=datacore)

epotsampleout<- stepCPUE(glm.object,scope=list(upper=~(Year+Gear+Captain+ns(SoakDays,df=4)+ Month+Area),lower=~Year),family=negative.binomial(1.38),direction="forward",trace=9,r 2.change=0.01)

The final main effect models for EAG were:

Model 19.1:
Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + Month + Block$
AIC=203,808

Final selection by stepCPUE:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 4) + Month$ (B.4)
for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2205$]

Initial selection by stepAIC:

$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 3) + Month$
AIC=77,173

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 3)$ (B.5)
for the 2005/06–2020/21 period [$\theta = 2.32,\ R^2 = 0.1082$].

The final models for WAG were:

Model 19.1:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 7) + \mathrm{Gear} + Area + Month + \mathrm{ns}(\mathrm{Depth}, 5) + Vessel$
AIC=190,897

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 7) + Gear$ (B.6)
for the 1995/96–2004/05 period [θ=0.97, $R^2 = 0.1681$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{Month} + \mathrm{ns}(\mathrm{Soak}, 18)$
AIC=116,552

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 18)$ (B.7)
for the 2005/06–2020/21 period [$\theta = 1.13,\ R^2 = 0.0776$, Soak forced in].

b. Year:Area interaction GLM:

For year and area interaction analysis, we designed the areas in to 1 nmi x 1 nmi grids enmeshed in 10 larger blocks as follows. The number of blocks was restricted to a few to prevent GLM fitting problems (Figure B.3 and Table B.2).

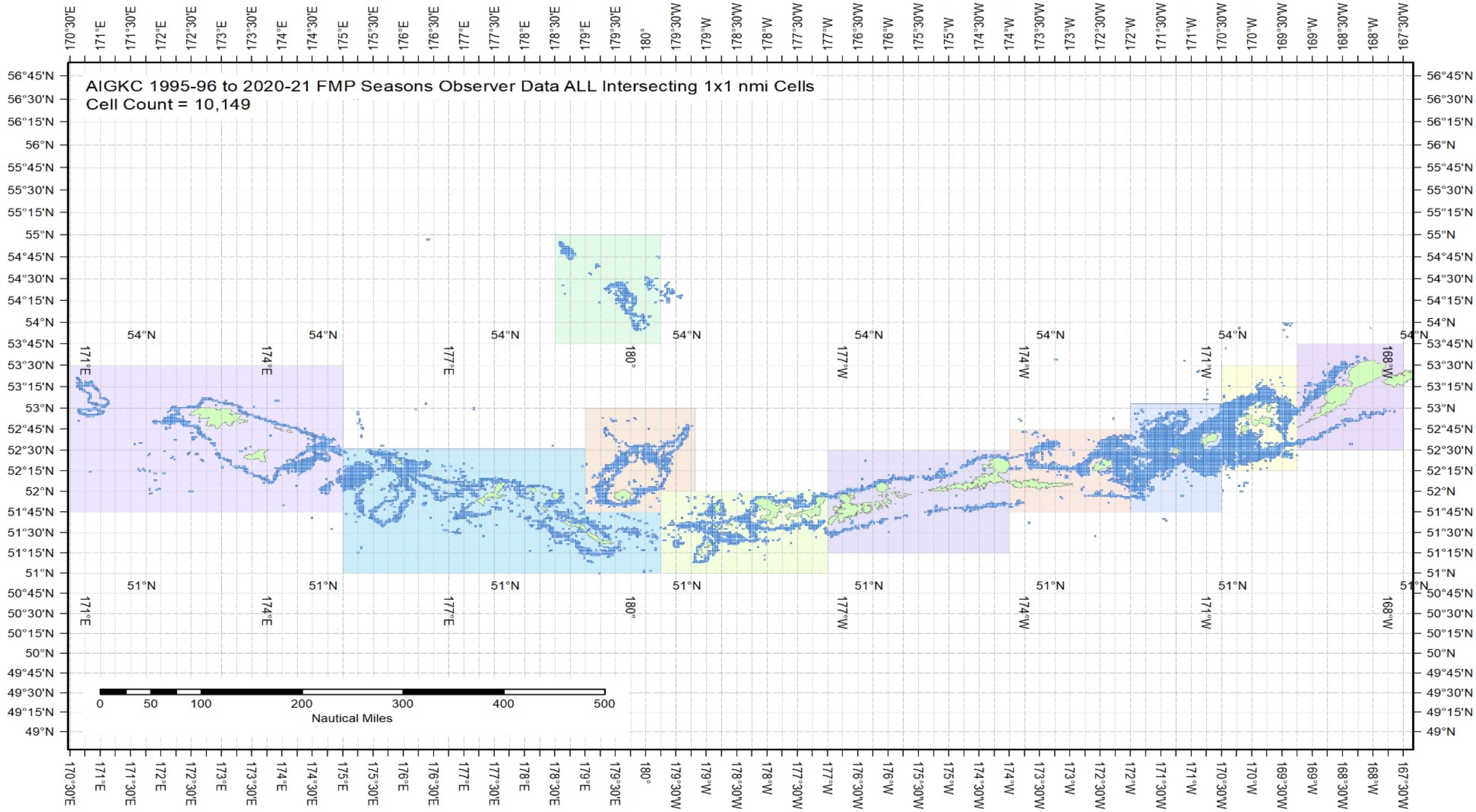


Figure B.3. The 1995/96–2020/21 observer pot samples enmeshed in 10 blocks for the Aleutian Islands golden king crab. The blocks were determined from visually exploring each year's pot distribution locations (available with the first author). The blocks contain observed patches of crab distribution during this period.

Table B.2. Number of 1 nmi x 1 nmi grids containing observer sample locations within each block by fishing year for the Aleutian Islands golden king crab, 1995/96–2020/21 data. Blocks 1–4 belong to EAG and 5–10 to WAG. Sum of ever fished number of grids for each block is listed at the bottom row.

FMP Season	Block_1	Block_2	Block_3	Block_4	Block_5	Block_6	Block_7	Block_8	Block_9	Block_10
1995	125	529	748	379	218	373	112	722	166	122
1996	149	814	761	372	89	473	359	799	200	35
1997	116	530	755	257	202	443	104	568	274	0
1998	78	581	453	236	18	318	157	251	132	0
1999	123	593	454	231	163	476	182	627	193	145
2000	72	540	754	301	187	440	195	555	547	47
2001	123	507	507	329	45	369	288	634	256	9
2002	97	387	584	271	71	341	205	335	242	37
2003	43	492	530	299	111	347	212	465	150	61
2004	81	289	377	216	77	319	150	359	172	116
2005	0	205	221	118	8	220	83	261	54	0
2006	0	154	248	122	15	191	58	220	39	0
2007	0	111	177	110	24	228	78	173	20	0
2008	0	111	203	93	12	181	67	196	0	0
2009	0	59	146	60	6	137	95	220	25	0
2010	0	81	141	85	1	115	73	260	39	0
2011	0	126	117	33	3	83	73	266	9	0
2012	0	146	110	56	7	91	85	312	53	0
2013	2	149	129	51	12	144	105	293	86	0
2014	1	138	96	41	39	120	114	319	37	0
2015	0	135	147	61	46	163	106	280	16	48
2016	0	145	231	63	26	134	89	210	106	0
2017	0	97	170	110	11	87	79	198	118	0
2018	0	91	158	95	7	69	82	204	121	0
2019	1	112	171	101	0	0	89	316	138	0
2020	4	109	193	95	0	0	76	287	91	36

Ever Fished: AIGKC All Seasons	Block_1	Block_2	Block_3	Block_4	Block_5	Block_6	Block_7	Block_8	Block_9	Block_10
1995–2020 - Sum of 1x1 cells	381	1402	1792	917	459	1028	796	2012	1021	334

We assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}}{:}\mathrm{Area_{ai}} \tag{B.8}$$

The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln\,(\mathrm{CPUE_I}) \;= \mathrm{Year_{y_i}}{:}\,Area_{ai} + \mathrm{ns(Soak_{si}, df)} + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns(Depth_{di}, df)}. \tag{B.9}$$

Example R codes used for interaction effect GLM fitting are as follows:

For WAG 1995_04 CPUE indices:

library(MASS)

library(splines)

Step 1:

```
glm.object<- glm(Legals~Year:Area,family = negative.binomial(0.97),data=datacore)

 wpotsampleoutAIC<-stepAIC(glm.object,scope=list(upper=
~(Year:Area+ns(SoakDays,df=7)+Month+Vessel+Captain+Area+Gear +
ns(Depth,df=5)),lower=~Year:Area),family=
negative.binomial(0.97),direction="forward",trace=9,k=log(nrow(datacore))+1.0)
```

Step 2:

```
glm.object<- glm(Legals~Year:Area,family = negative.binomial(0.97),data=datacore)

 wpotsampleout<-stepCPUE(glm.object,scope=list(upper=
~(Captain+ns(SoakDays,df=7)+Gear+Area+Month+Year:Area),lower= ~Year:Area),family=
negative.binomial(0.97),direction="forward",trace=9,r2.change=0.01)
```

The final interaction effect models for EAG were:

Model 21.1c:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \;\mathrm{Gear} + \mathrm{Captain} + \mathrm{ns(Soak, 4)} + \mathrm{Month} + Year{:}\,Area$
AIC=203,851

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Year{:}Area$ (B.10)
for the 1995/96–2004/05 period [θ=1.38, $\mathrm{R}^2 = 0.2235$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 3) + Month + Year{:}Area$
AIC=72,343

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + Gear + \mathrm{ns}(\mathrm{Soak}, 3) + Year{:}Area$ (B.11)
for the 2005/06–2020/21 period [$\theta = 2.32,\ \mathrm{R}^2 = 0.1169$].

The final interaction effect models for WAG were:

Model 21.1c:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + \mathrm{ns}(\mathrm{Soak}, 7) + Gear + Month + Year{:}Area$
AIC=191,018

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + \mathrm{ns}(\mathrm{Soak}, 7) + \mathrm{Gear} + Year{:}Area$ (B.12)
for the 1995/96–2004/05 period [θ=0.97, $\mathrm{R}^2 = 0.1719$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Gear} + \mathrm{Vessel} + \mathrm{Month} + Year{:}Area + ns(Soak, 18)$
AIC=116,859

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Gear} + Year{:}Area + ns(Soak, 18)$ (B.13)
for the 2005/06–2020/21 period [$\theta = 1.13,\ \mathrm{R}^2 = 0.0818, \mathrm{Soak\ forced\ in}$].

Steps:
1. *Block-scale analysis*:

   The bias corrected estimate of CPUE index for each Year-Area (Area=Block) interaction was first obtained as:
   $CPUE_{ij} = e^{YB_{ij} + \sigma_{ij}^2/2}$ (B.14)

   where $CPUE_{ij}$ is the CPUE index in the ith year and jth block, YB_{ij} is the coefficient of the *i*th year and *j*th block interaction, and σ_{ij} is the biased correction standard error for expected CPUE value.

The number of 1 nmi x 1 nmi grids in each block can change from year to year; so, we considered using the number of grids **ever fished** in a block, N_{everj} [this is equivalent to assuming that the grids fished in any year randomly sample the stock in that block (Campbell, 2004)].

The abundance index for *j*th block in *i*th year is

$$B_{ij} = N_{ever_j} CPUE_{ij} \tag{B.15}$$

Notice in Table B.2 that no or very few observer samplings occurred in certain years for a whole block. We filled the B_{ij} index gaps resulting from Year:Area CPUE standardization model fit as follows:

$$\widehat{B_{i,j}} = e^{A_i + C_j}$$

fitted by GLM [i.e., fitting a log-linear model, $ln\left(\hat{B}_{i,j}\right) = A_i + C_j$], (B.16)
where $B_{i,j}$ is the available index of biomass for year i and block j, A_i is a year factor, and C_j is a block factor, and used this model to predict the unavailable biomass index for blocks x years with no (or very limited) data.

An example set of R codes used to predict the missing biomass index is as follows:

library(MASS)

To fit the log-linear model (Equation B.16):

glm.fit<- glm(log(B_{ij})~Year$_i$ + Block$_j$, data=Bindex)

where the data frame "Bindex" contains available B_{ij},Year$_i$, and Block$_j$ column values.

To predict the missing biomass index Y:

Y<- predict.glm (glm.fit, BindexFillpredict, se.fit=TRUE)

where the new data frame "BindexFillpredict" contains Year$_i$ and Block$_j$ column values for which B_{ij} indices are needed and contains an empty B_{ij} column for fill in.

By setting se.fit=TRUE, the standard errors, σ_{ij}, of predictions are also estimated.

Bias correction was made to each predicted biomass index by $B_{i,j} = e^{\hat{Y}_{i,j} + \sigma_{ij}^2/2}$
where σ_{ij} is the standard error of predicted $Y_{i,j}$value, which is on the scale of the linear predictor (i.e., log transformed B_{ij}). The standard error for each year and area combination is estimated as follows.

If we denote the covariance matrix of the fitted "glm.fit" as Σ and write the coefficients for linear combination of a set of predictors in a vector form as C, then the standard error of prediction for that combination is $\sqrt{C'\Sigma C}$, where C' is the transpose of vector C.

Annual biomass index, B_i , was estimated as,

$$B_i = \sum_j B_{ij} \qquad \text{(B.17)}$$

The variance of the total biomass index was computed as:

$$\boldsymbol{Var\ (B_i) = \sum_j N_{ever,j}{}^2\ var(CPUE_{i,j})} \qquad \text{(B.18)}$$

where $\boldsymbol{N_{ever,j}}$ is the total number of 1mni x 1 mni cells ever fished in block j, and $CPUE_{i,j}$ is the CPUE index for year i and block j.

To compare with other CPUE index estimates (Figures 24 for EAG and 41 for WAG) as well as to use in the assessment model 21.1c, we rescaled the B_i indices by the geometric mean of estimated B_i values (Equation B.17) separately for the pre- and post-rationalization periods. The corresponding standard error (~CV) of B_i was estimated by

$$\sqrt{\frac{Var(B_i)}{(B_i)^2}} \qquad \text{(B.19)}$$

The rescaled biomass indices with standard errors are listed in Table B.3 for EAG and Table B.4 for WAG.

Table B.3. Steps to estimate biomass-based abundance indices with standard errors for 1995/96–2020/21 in EAG. GMScaled B_index and B_Index SE were used as CPUE index and its standard error.

Year	B_Index	GMScaled B_Index	Var(B_index)	Var(B_Index)/(B_Index)^2	B_Index SE
1995	1646.045	0.772	31119.811	0.011	0.107
1996	1664.192	0.781	30961.039	0.011	0.106
1997	1657.073	0.777	26973.953	0.010	0.099
1998	1983.401	0.930	28416.977	0.007	0.085
1999	1889.406	0.886	26998.598	0.008	0.087
2000	1829.271	0.858	48321.122	0.014	0.120
2001	2644.434	1.240	159513.439	0.023	0.151
2002	2685.133	1.260	33738.827	0.005	0.068
2003	2403.298	1.127	33864.001	0.006	0.077
2004	3651.543	1.713	114213.956	0.009	0.093
2005	11479.919	1.051	2445608.389	0.019	0.136
2006	8686.932	0.796	2442560.854	0.032	0.180
2007	9615.569	0.881	2441515.275	0.026	0.163
2008	9592.846	0.879	2445626.553	0.027	0.163
2009	8430.385	0.772	2454692.100	0.035	0.186

2010	8569.358	0.785	2452577.255	0.033	0.183
2011	11695.405	1.071	2455608.856	0.018	0.134
2012	11150.360	1.021	2451865.327	0.020	0.140
2013	11544.882	1.057	2516532.727	0.019	0.137
2014	14396.446	1.319	2451276.698	0.012	0.109
2015	13446.866	1.232	2445059.570	0.014	0.116
2016	11681.802	1.070	2443192.818	0.018	0.134
2017	10484.499	0.960	2447524.594	0.022	0.149
2018	12931.639	1.184	2447048.616	0.015	0.121
2019	12126.070	1.111	2569011.349	0.017	0.132
2020	10966.012	1.004	2507915.925	0.021	0.144

Table B.4. Steps to estimate biomass-based abundance indices with standard errors for 1995/96–2020/21 in WAG. GMScaled B_index and B_Index SE were used as CPUE index and its standard error.

Year	B_Index	GMScaled B_Index	Var(B_index)	Var(B_Index)/(B_Index)^2	B_Index SE
1995	4171.339	1.133	108954.723	0.006	0.079
1996	3700.400	1.005	59000.363	0.004	0.066
1997	3793.778	1.030	62175.636	0.004	0.066
1998	3890.218	1.056	83518.738	0.006	0.074
1999	3419.423	0.928	56573.751	0.005	0.070
2000	3235.253	0.878	57888.952	0.006	0.074
2001	2947.962	0.800	130461.360	0.015	0.123
2002	3411.078	0.926	62878.499	0.005	0.074
2003	4145.339	1.126	56898.996	0.003	0.058
2004	4371.503	1.187	63567.812	0.003	0.058
2005	12519.564	1.069	336101.196	0.002	0.046
2006	12648.627	1.080	262528.825	0.002	0.041
2007	12145.212	1.037	276246.442	0.002	0.043
2008	13834.526	1.182	294798.093	0.002	0.039
2009	18360.125	1.568	423396.136	0.001	0.035
2010	12742.844	1.088	271918.180	0.002	0.041
2011	12819.358	1.095	325347.368	0.002	0.044
2012	12472.968	1.065	247042.061	0.002	0.040
2013	8698.067	0.743	308718.510	0.004	0.064
2014	8667.031	0.740	250151.136	0.003	0.058
2015	8566.046	0.732	262916.058	0.004	0.060
2016	10509.029	0.898	247759.318	0.002	0.047
2017	12543.516	1.071	258282.878	0.002	0.041
2018	15738.039	1.344	298711.438	0.001	0.035
2019	10006.568	0.855	292689.921	0.003	0.054
2020	9330.912	0.797	300658.131	0.003	0.059

c. Commercial fishery CPUE index by non-interaction model

We fitted the negative binomial GLM model for fish ticket retained CPUE time series 1985/86 – 1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables and applying the hybrid selection method. Reduced area resolution (grouped ADF&G codes to AreaGP) was used for model fitting.

The final model for EAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + Month$
AIC=16,996

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month} \quad \text{(B.20)}$$
for the 1985/86–1998/99 period [θ=10.40, $R^2 = 0.3327$]

and that for WAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + Area$
AIC=31,701

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area} \quad \text{(B.21)}$$
for the 1985/86–1998/99 period [θ=6.67, $R^2 = 0.3569$]

Appendix C. Cooperative Survey

1. Summary of the survey method

The ADF&G and industry collaborative pot survey was initiated in 2015 in the EAG and has continued since then. The survey was extended to WAG in 2018. A stratified two-stage sampling design has been implemented in a 2 nmi x 2 nmi grids within 1000 m depth covering the entire golden king crab fishing area. The 2 nmi x 2 nmi choice was the best compromise between scale of fishing gear, accuracy of defining habitat, and number of possible stations (Figure C1).

Figure C.1. Survey design: 2 nmi x 2 nmi grids overlaid on observer pot sample locations (green squares) in EAG.

There are nearly 1100 grids in the EAG divided into three equal size strata for selecting random pot sampling locations (Figures C.2 and C.3).

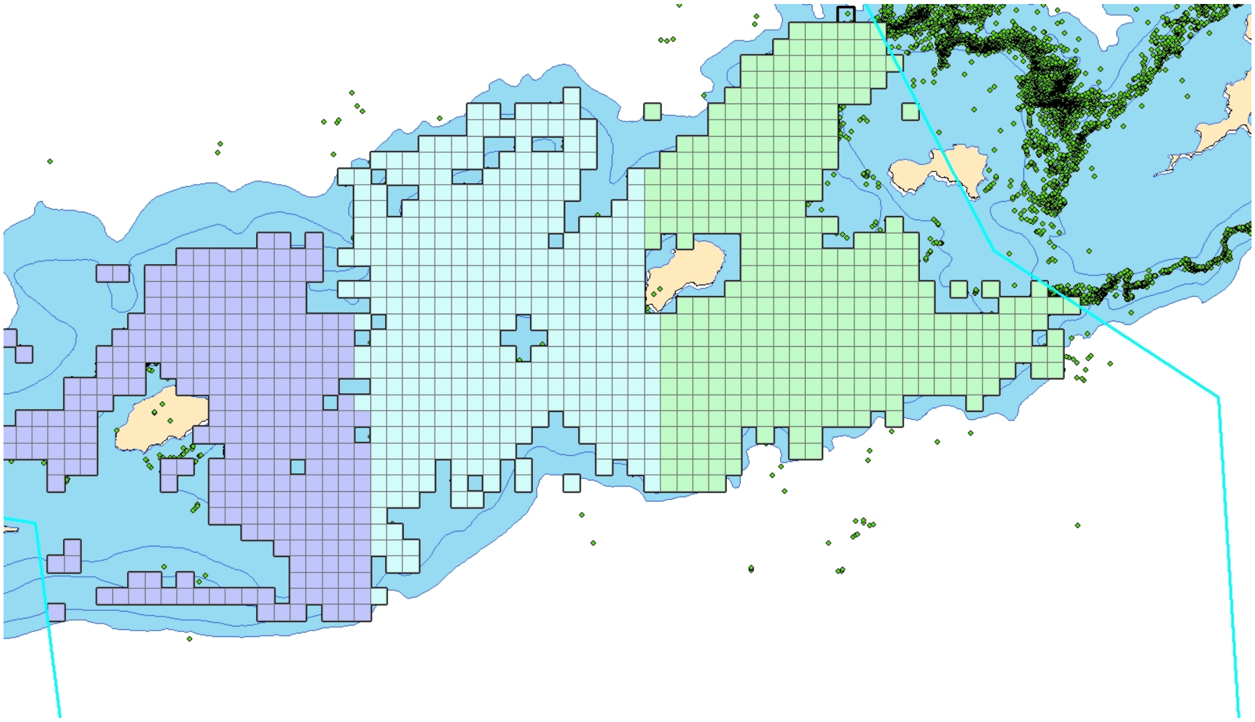


Figure C.2. Survey design: 2 nmi x 2 nmi grids stratified by three equal sizes for selecting random pot sampling locations in EAG.

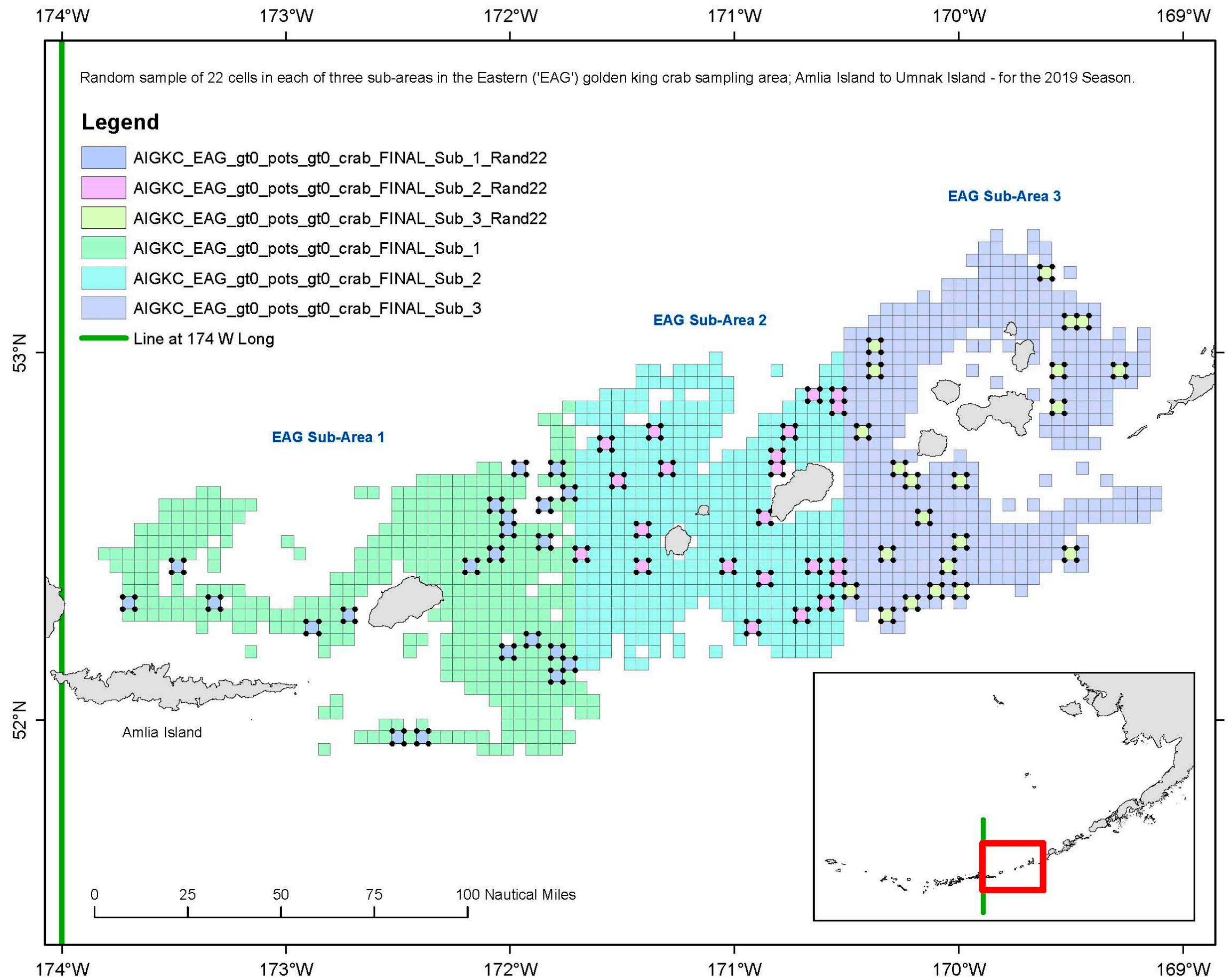


Figure C.3. Random sample of 22 cells selected in each of three sub strata in EAG during the 2019 fishery.

Surveys occur during the first month of each fishing season with one to two ADF&G biologists onboard the fishing vessel to collect fishery and biological data. Fishing operation takes place in a randomly selected set of grids in each stratum with long-line pots. The number of pots per string ranges from 30 to 40, 200 m apart, and a vessel carries on average 35 strings. Pot sizes range from 5.5 ft x 5.5 ft to 7 ft x 7 ft with large mesh sizes for retention of legal-sized king crab. A few small mesh size research pots are also deployed for special studies. Fishing operation is not standardized for depth or soak time to allow normal fishing practices.

There are multiple pots (typically about 5 pots) sampled for each long-line string with approximately 35 crab measurement made per pot. For example, if 100 crabs are caught in a sampled pot, the biologist measures every third crab. The following snapshot of an observation record provides an example of what stock assessment data are collected.

fishery	year	vessel	skipper	String#	pot_size	mesh_size	bait	subsample_rate	species_code	sex	size	legal
EAG	2015	20556	Chad_Hoefer	1	5x5	king(large)	halibut	2	923	1	187	1

Pot#	date_in	time_in	depth_start	start_lat	start_lon	depth_out	end_lat	end_lon	date_out	time_out	comments	soak_time
1	8/4/2015	17:00	132	52.74133	-170.692	133	52.7515	-170.675	8/17/2015	3:00		12.41667

2. Standardization of cooperative survey CPUE

Data

A unique property of the cooperative survey is that multiple pots from multiple strings are sampled. All sample measurements were taken in EAG except for 2018/19, during which measurements were also taken from WAG. There was no survey during 2020/21 due to COVID related restriction.

There are 27,255 records from five years (2015–2019) of surveys. After cleaning up for missing entries, the number of records reduced to 27,122 golden king crab.

Method

Data preparation for CPUE standardization:

i.) Created two new columns by concatenating Vessel Code with String# as well as with String# and Pot# because String# and Pot# are not unique numbers to each vessel. The new column names were identified as VesString and VesStingPot. For example, a Vessel Code 20556 with a String# 3 was concatenated to be 205563 in a new column VesString, and a Vessel Code 20556 with a String#17 and a Pot# 5 was concatenated to be 20556175 in a new column VesStringPot.

ii.) Raised the Catch in each record by the Sample Rate.

iii.) Subset the data by large mesh king crab pot [Mesh ID not equal to 2 (i.e., small mesh pot)], legal size (> 135 mm CL), and EAG (EAGWAG=1). The female (Sex=2) and unclassified catch without any male crab (Sex=1) in a crab pot was set to 0 to account for the possibility of zero catch for expected male CPUE determination.

iv.) Further subset the data by 5% to 95%, trimmed Soak time, and 1% to 99% trimmed Depth. This is to exclude catches from any unusual pot operations.

v.) Summed up the catch across sizes for each Pot# and labelled it as SumCatch. Thus, each Pot# has a single catch number.

The sampling design (sampling crab from a pot within a string within a vessel) begged for application of a mixed effects model to analyze data, which was recommended by the CPT. However, we explored different model structures before finalizing on a model: a fixed effect model and two versions of a random effects model. The dispersion parameter value for the negative binomial error model and the degrees of freedom for cubic splines for soak time and depth were borrowed from the observer final GLM model estimates for EAG for the post rationalization period, 2005–2020.

Results

1. Fixed effect model:

Sum Catch = Y, family= negative binomial (θ=2.32)

The maximum set of model terms offered to the stepwise selection procedure was:

Sum Catch= Y+ns(Soak,df=3)+VesselStringPot+Captain+Block+ns(Depth, df=10), family= negative binomial (θ=2.32).

Final model:
Sum Catch= Y + VesselStringPot + ns(Depth, df=10) + Block + ns(Soak, df=3) (C.1)
$R^2 = 0.6088$ (Soak forced in).

2. Random intercept model (model 1):

Sum Catch = Y + ns(Depth, df=10) +ns(Soak, df=3) + (1|Vessel/VesStringPot)+(1|Block/VesselString) family= negative binomial (θ=2.32). (C.2)

We selected relevant fixed effect components from the final fixed effect model for the random intercept models 1 and 2. We used the "lme4" library in R (R Core Team, 2020) with the "glmer()" function for model fitting. The glmer() function allows use of any type of error model to fit the data. The random intercept model 1 resulted in a singular fit (i.e., Vessel and VesStringPot:Vessel group variances were (very close to) zero):

Table C.1. Random intercept model 1 output.

Groups	Name	Variance	Std.Dev.
VesStringPot:Vessel	(Intercept)	0.00000	0.00000
VesString:Block	(Intercept)	0.35685	0.59737
Block	(Intercept)	0.00059	0.02439
Vessel	(Intercept)	0.00000	0.00000

3. Therefore, we used the following simpler form of the random intercept model (model 2):

Sum Catch = Y + ns(Depth, df=10) + ns(Soak, df=3) + (1|Block/VesselString) (C.3)
family= negative binomial (θ=2.32).

The random intercept model 2 converged with the following output:

Table C.2. Random intercept model 2 parameter estimates.

Random Effects:				
Groups	Name	Variance	Std.Dev.	
VesString:Block	(Intercept)	0.3569	0.5974	
Block	(Intercept)	0.0006	0.0244	
Fixed Effects:				
	Estimate	Std. Error	z_value	Pr(|z|)
Intercept	3.0426	0.2776	10.959	0.0000
Year2016	-0.2952	0.1005	-2.937	0.0033
Year2017	-0.0621	0.1107	-0.561	0.5748

Year2018	0.0963	0.1060	0.909	0.3634
Year2019	-0.3591	0.1052	-3.415	0.0006
ns(Depth, DF=10)1	0.6944	0.2399	2.895	0.0038
ns(Depth, DF=10)2	0.3130	0.3152	0.993	0.3206
ns(Depth, DF=10)3	0.0967	0.2740	0.353	0.7241
ns(Depth, DF=10)4	0.4526	0.3268	1.385	0.1661
ns(Depth, DF=10)5	0.0541	0.3188	0.170	0.8653
ns(Depth, DF=10)6	0.0146	0.3219	0.045	0.9639
ns(Depth, DF=10)7	0.7676	0.3270	2.348	0.0189
ns(Depth, DF=10)8	-0.0894	0.2574	-0.347	0.7285
ns(Depth, DF=10)9	0.3136	0.6123	0.512	0.6085
ns(Depth, DF=10)10	0.9769	0.2983	3.275	0.0011
ns(Soak, DF=3)1	0.2857	0.1638	1.744	0.0811
ns(Soak, DF=3)2	0.3628	0.4337	0.836	0.4029
ns(Soak, DF=3)3	0.7725	0.2448	3.156	0.0016

Inadequate time series (2015–2019) with fewer random effect levels (only three levels for Vessel and, somewhat better, four levels for Block) prevented us from exploring expanded model structures, such as a random intercept with random slope model. Categorical variable levels above 5 is recommended to be ideal for determining variances of the distribution of random effect factors (Gelman and Hill 2007). Comparison of the random intercept model 2 (C.3) with that of the fixed effects model (C.1) by the Hausman's (1978) model selection test resulted in rejecting the null hypothesis that random effect model is consistent with the data (Chi Square = 1124.4, df = 18, $p < 2.2e^{-16}$). However, because of limiting factors discussed above that could spoil any statistical test, we based our selection of random effects model 2 on the sampling design (i.e., multi-level sampling) implemented in data collection.

There is a plan to continue the cooperative survey in 2021/22, which will increase the time series of data to 6 years. Note that we do not have a flexibility to increase the number of Vessel levels from three but do have flexibility to increase the number of Block levels from four. Therefore, we intend to increase the number of Block levels by defining smaller areas in EAG for the next round of analysis.

Diagnostic test

The QQ plot for the fit assured that model 2 assumptions were correct (Figure C.4).

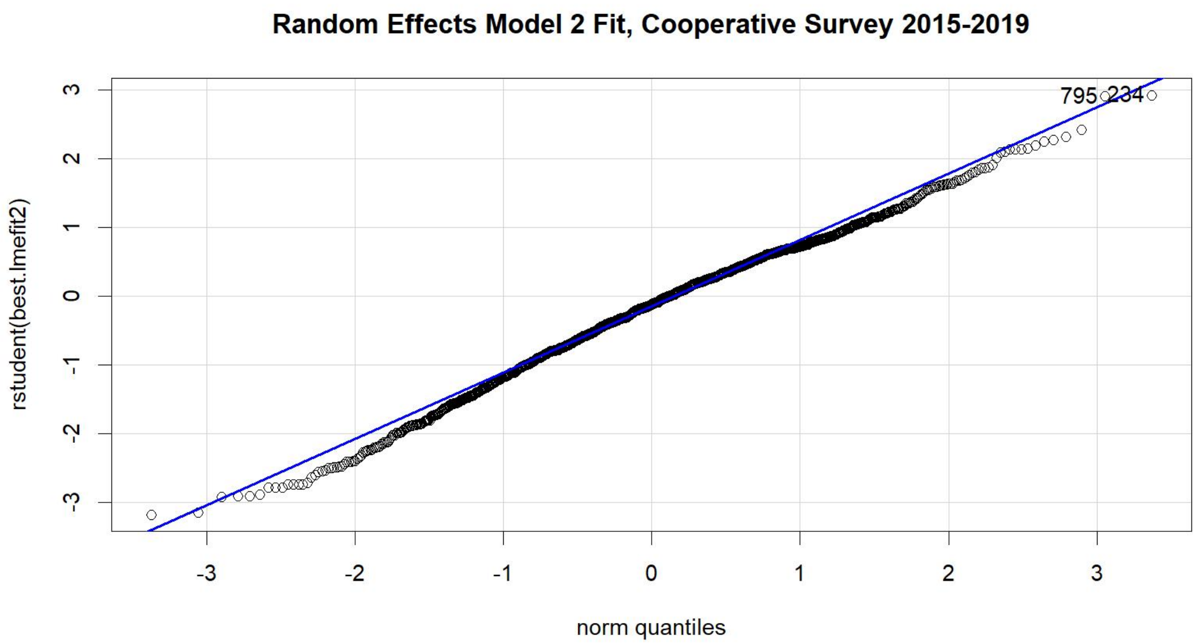


Figure C.4. Studentized residual plot for the mixed random effects model fit using the 2015–2019 EAG data.

Comparison of standardized CPUE from cooperative survey data (2015–19) for EAG and the corresponding years' observer CPUE indices indicated a similar pattern except for 2019 (Figure C.5).

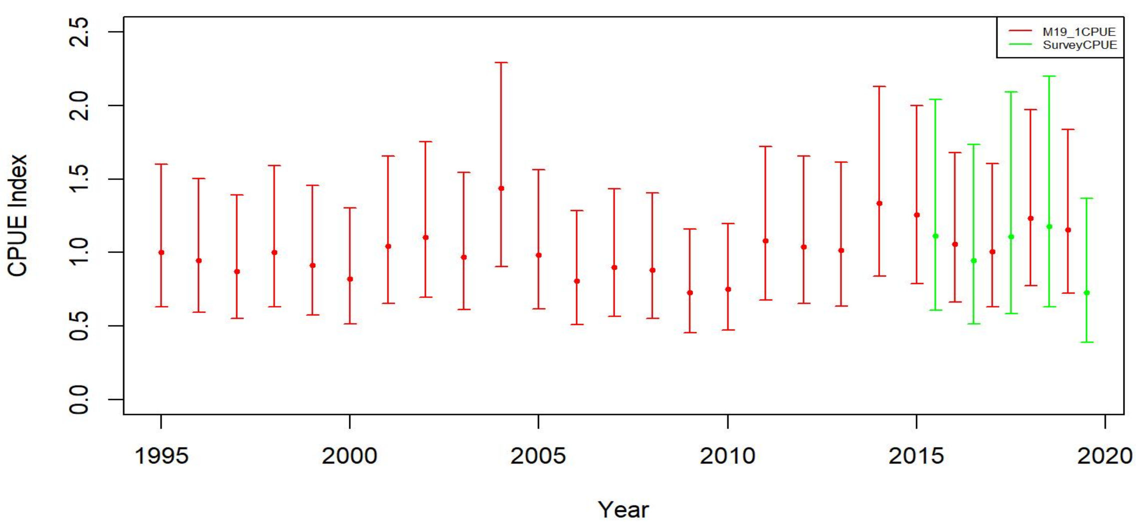


Figure C.5. Comparison of cooperative survey random effects model 2 CPUE indices (green) and observer non interaction factor model CPUE indices (red, 19.1) for EAG. The confidence limits are determined with ±2SE. Model estimated additional standard error was added to SE.

We standardized the yearly mean of predicted survey CPUEs for 2015–2019 by the geometric mean to obtain the CPUE indices for input to the assessment model (Table C.3).

Table C.3. The cooperative survey predicted legal male standardized (by geometric mean) CPUE indices by the mixed random effects model 2, standard errors (SE), and lower- and upper- 95% confidence limits with added model estimated additional standard error for EAG, 2015–2019 data.

Year	Predicted CPUE index	SE	Lower Limit	Upper Limit	Sample size
2015	1.11164	0.02666	0.60593	2.03943	335
2016	0.94664	0.02656	0.51610	1.73636	304
2017	1.10698	0.04148	0.58576	2.09200	206
2018	1.17588	0.03565	0.62952	2.19642	199
2019	0.73004	0.03749	0.38940	1.36867	289

We added a likelihood function with the 2015–2019 survey indices using Equations A.12 and A.13 to the likelihoods of observer indices (1995–2014) and fishery indices (1985–1998) and formulated a new model 21.1d. We maintained the same post-rationalization fishery catchability, total and retained selectivity for fitting survey indices. The reference points estimates were like those of 21.1a but a little lower.

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)
EAG21.1d	3a	14.686	17.823	1.21	0.62	1987–2017	0.62	5.822	5.791	4.367

Biomass in 1000 t; total OFL and ABC for the next fishing season in 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)*
EAG21.1d	3a	6661.73	8084.57	1.21	0.62	1987–2017	0.62	2,641.064	2,626.844	1,980.798

Figure C.6 provides the long-term trends in MMB by model 21.1d with the state quo knife-edge maturity size of 111 mm CL.

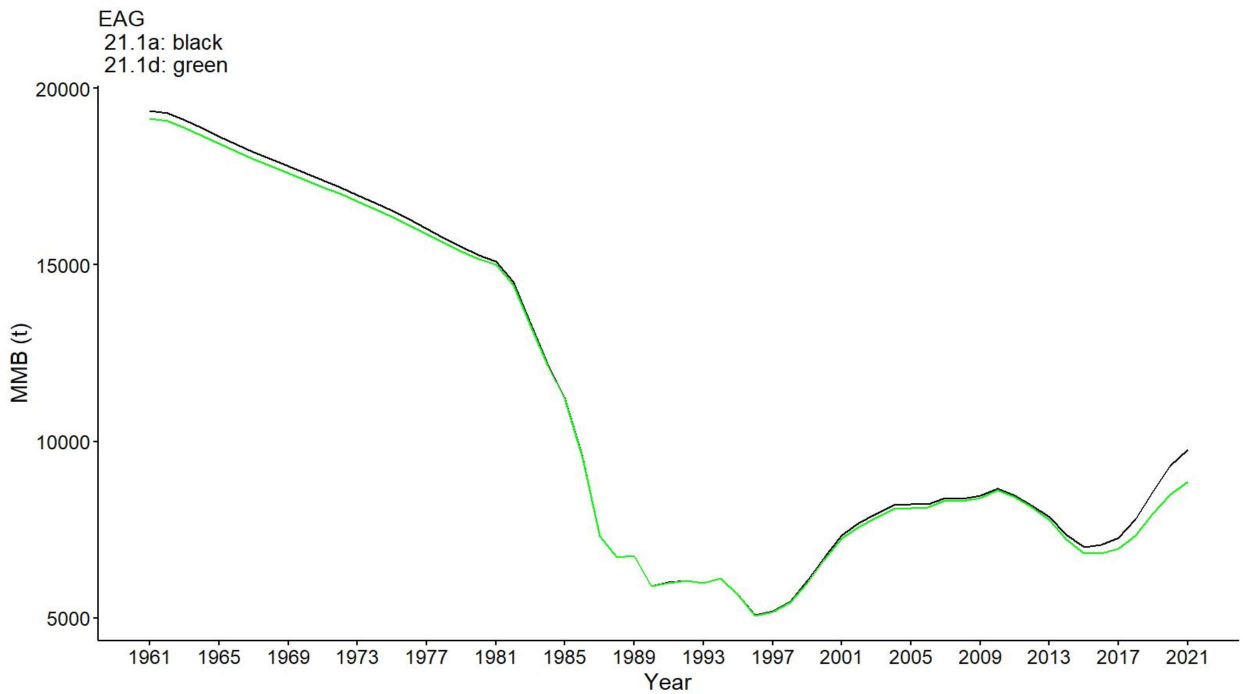


Figure C.6. Comparison of trends in golden king crab mature male biomass between models 21.1a and 21.1d for EAG, 1961–2021. Year 2021 refers to 2020/21 fishing season.

Appendix D: Male Maturity

Introduction

Sexual maturity is associated with alterations in both external morphology and internal physiology, on which bases different types of maturity can be defined: physiological, morphometric, and functional maturity. Although functional maturity is the true way of determining maturity, it requires elaborate lab or field experiments. Hence, crab researchers often adapt an indirect detection technique via morphometric measurement for maturity determination. Chelae allometry has been used to determine morphometric male size-at-maturity among several king crab (*Lithodidae*) stocks. Male golden king crab provides a better discrimination of chelae height against size at onset of maturity than other king crab stocks (Somerton and Otto 1986). Table D.1 lists the literature reported estimates of size-at-maturity of male golden king crab (*Lithodes aequispins*) stocks in Alaska. Breakpoint analysis has been used to estimate maturity in majority of cases.

Table D.1. Review of estimates of male size-at-maturity of golden (*Lithodes aequispins*) king crabs by regions in Alaska. Numbers in parentheses are standard errors (SE).

Species	Sex	Size-at-Maturity (mm CL)	Method	Area	Sources
Lithodes aequispins	Male	114 (11.4)	Breakpoint analysis on log(chela height) vs. log(carapace length)	British Columbia, Canada	Jewett *et al*. 1985
		92 (2.4) 107 (4.6) 130 (4.0)	Breakpoint analysis on log(chela height) vs. log(carapace length)	St. Matthew Is. District Pribilof Is District Eastern Aleutian Is	Somerton and Otto 1986
		117.9 to 158.0	Breakpoint analysis on log(chela height) vs. log(carapace length)	Various water inlets in southeast Alaska	Olson 2016
		108.6 (2.6) 120.8 (2.9)	Breakpoint analysis on log(chela height) vs. log(carapace length)	Bowers Ridge Seguam Pass	Otto and Cummiskey 1985
		110	Minimum size of successful mating (lab observation)	Prince William Sound	Paul and Paul 2001

Method

We used the carapace length (mm CL) and chela height (up to one-tenth of a mm CH) data collected by the observer, retained catch, and cooperative surveys sampling during the 2018/19, 2019/20, and 2020/21 fishing seasons for male maturity investigation. We determined bend points and corresponding two segmented lines for different groups of data outside the assessment model using the ‘segmented regression’ package available in R version 3.6.3 (R Core Team 2020).

First, we fitted a linear regression model to the data pair using the R package as follows:

$$ln(CH/CL) = \beta_0 + \beta_1 CL \quad \text{(D.1)}$$

where β_0 and β_1 are regression parameters

The procedure of 'segmented regression' uses maximum likelihood to fit a somewhat different parameterization of the linear model. It can be approximated as

$$ln(CH/CL) = \beta_0 + \beta_1 CL + \beta_2[CL - c] + \gamma I[CL > c] \quad \text{(D.2)}$$

where β_2 is a regression parameter and c is the break-point, and $\gamma I[CL > c]$ is a dummy variable. When $CL < c$, the model reduces to,

$$ln(CH/CL) = \beta_0 + \beta_1 CL + \beta_2[CL - c] \quad \text{(D.3)}$$

The γ term is a measure of the distance between the end of the first segment and the beginning of the next. The model converges when γ is minimized, thus this method constrains the segments to be (nearly) continuous.

We further refined the estimates by bootstrapping each data set (ln (CH/CL), CL pairs) 1000 times and applying 'segmented regression' to each bootstrapped sample. We used the bootstrap median bend point, intercept, and slope estimates to establish the two segmented lines (i.e., left hand line 1 was for immature and right-hand line 2 was for mature crab).

Finally, we categorized the observed ln (CH/CL) vs CL pair in to mature (code 1) if the ln (CH/CL) value was on or above line 2 or immature (code 0) if this value was below line 2 for a given CL. Then we fitted the following logistic model by GLM to the response variable (mature 1, immature 0, converted to mature proportion *P*) vs. the independent variable (CL) to obtain a maturity curve.

$$P_i = \frac{e^{\alpha+\beta CL_i}}{1+ e^{\alpha+\beta CL_i}} \quad \text{(D.4)}$$

where *P* is the proportion mature, α and β are intercept and slope parameters of the maturity curve, and CL is carapace length.

Data

We used the following data sets (Table D.2) for current maturity analysis. We restricted the size range to 85.0 mm CL to 142.0 mm CL (a plausible morphometric male maturity size range for golden king crab in the Bering Sea and Aleutian Islands (i.e., 92.0 mm CL – 3SE to 130 mm CL+3SE, Table D.1) for 'segmented regression' fit and maturity determination from segmented line 2 for subsequent logistic model fit.

Table D.2. Golden king crab male carapace length and chela height data collected during 2018/19 – 2020/21 fishing seasons in the Aleutian Islands.

Measurement type	Source and season of data collection	Group		
		Aleutian Islands (AI) 2018/19–2020/21	EAG 2018/19–2019/20	WAG 2018/19–2020/21
	Co-operative survey (2018/19, 2019/20) Observer sampling (2018/19, 2019/20) Retained catch sampling (2018/19, 2019/20) Special sampling WAG (2020/21)			
Carapace length and chela height records (all sizes)		10760	5433	5327
Carapace length and chela height records (85 mm CL–142 mm CL)		4025	1901	2124

Results

The median breakpoint ranged from 117.800 to 119.984 mm CL for the three 2018– 2020 data sets (AI, EAG, and WAG). These values are one to two 5 mm CL bins higher than the WAG 1984 and EAG 1991 estimates considered previously (Table D.3). The focus of the current analysis is to establish separate maturity curves for AI, EAG, and WAG for MMB determination. Table D.4 lists the logistic maturity curve parameter estimates for AI, EAG, and WAG. The estimates for the three data sets are highly significant. We considered three options for MMB estimation: ≥111 mm CL (status quo knife edge maturity), ≥116 mm CL (a cautionary choice based on the current determination of 50% maturity length by the logistic model for AI), and the AI logistic maturity curve common to both EAG and WAG.

Figures D.1, D.2, and D.3 show the fitted segmented regression lines overlayed on observed log (CH/CL) vs CL data for AI, EAG, and WAG, respectively. Figures D.4, D.5, and D.6 show the fitted logistic curves overlayed on observed maturity proportion vs CL for AI, EAG, and WAG, respectively. The observed mature (1) and immature (0) counts at each 2 mm CL interval were used to calculate the observed mature proportion by size. The observed maturity data were hard cutoff to be immature below 85 mm CL and mature above 142 mm CL (i.e., outside the data range considered for segmented regression fitting) for logistic model fitting. Although arbitrary, but reasonable, data massaging occurred before logistic model fitting. We considered that the fitted logistic curve (with highly significant parameter estimates) was appropriate for MMB determination.

Table D.3. Segment regression fit to 2018–2020 log (CH/CL) vs. CL data pairs and median estimates from 1000 bootstrap samples including breakpoints for EAG, WAG, and combined (AI) data sets. The data sets were truncated to 85.0–142.0 mm CL range for segmented regression fits. We also provide re-estimated parameters for the 1991 EAG and 1984 WAG data with the same size restriction for comparison. Intercept of line 2 was determined for each data set by solving the two lines at the bend point.

	Estimate	SE	t-value	Pr(>|t|)	Breakpoint (mm CL)	SE	Remarks
AI 2018–20:							Fit to original data, 85.0–142.0 mm CL range
Intercept line 1	-1.76273	0.04974	-35.43610	0.00000	118.900	1.760	
Slope line 1	0.00183	0.00046	3.96526	0.00007			
Slope to add	0.00465	0.00053	8.70356	0.00000			
Slope line 2	0.00648						
Intercept line 1	-1.78187	0.00185			119.984	0.104	Bootstrap median estimates
Slope line 1	0.00200	0.00002					
Slope line 2	0.00663	0.00002					
EAG 2018–20:							Fit to original data, 85.0–142.0 mm CL range
Intercept line 1	-1.74671	0.15258	-11.44750	0.00000	112.574	4.125	
Slope line 1	0.00146	0.00149	0.98016	0.32713			
Slope to add	0.00515	0.00154	3.35423	0.00081			
Slope line 2	0.00661						
Intercept line 1	-1.81430	0.01115			117.800	0.317	Bootstrap median estimates
Slope line 1	0.00216	0.00012					
Slope line 2	0.00698	0.00230					
WAG 2018–20:							Fit to original data, 85.0–142.0 mm CL range
Intercept line 1	-1.73808	0.05330	-32.60763	0.00000	119.330	2.115	
Slope line 1	0.00164	0.00049	3.33148	0.00088			
Slope to add	0.00440	0.00061	7.19722	0.00000			
Slope line 2	0.00604						
Intercept line 1	-1.74555	0.00188			119.603	0.124	Bootstrap median estimates
Slope line 1	0.00171	0.00002					
Slope line 2	0.00620	0.00005					

EAG 1991:							Fit to 85.0–142.0 mm CL range
Intercept line 1	-1.60166	0.02286	-70.04911	0.00000	107.000	1.915	Estimates from 2457 measurements
Slope line 1	0.00070	0.00026	2.71486	0.00668			
Slope to add	0.00424	0.00029	14.45235	0.00000			
Slope line 2	0.00494						
WAG 1984:							Fit to 85.0–142.0 mm CL range
Intercept line 1	-1.67570	0.09222	-18.17129	0.00000	105.824	4.650	Estimates from 341 measurements
Slope line 1	0.00126	0.00097	1.29613	0.19582			
Slope to add	0.00332	0.00106	3.12254	0.00195			
Slope line 2	0.00458						

Table D.4. Logistic fit to 2018–2020 maturity data for AI, EAG, and WAG.

	Estimate	SE	z-value	Pr(>|z|)	L_{50} (mm CL)	Remarks
AI 2018–20:						Logistic model fit to 52.6–198.7 mm CL range, 10760 measurements
	-7.68092	0.29230	-26.28000	0.00000	116.879	
	0.06572	0.00209	31.43000	0.00000		
EAG 2018–20:						Logistic model fit to 57.6–197.3 mm CL range, 5433 measurements
Intercept (α)	-13.45746	0.63635	-21.15000	0.00000	126.403	
Slope (β)	0.10647	0.00453	23.49000	0.00000		
WAG 2018–20:					110.363	Logistic model fit to 52.6–198.7 mm CL range, 5327 measurements
Intercept (α)	-5.64641	0.32860	-17.18000	0.00000		
Slope (β)	0.05116	0.00237	21.59000	0.00000		

Figures D.1, D.2 and D.3 provide the segment regression lines fitted to the log (CH/CL) vs. CL data pairs and D.4, D.5, and D.6 depict the logistic curves fitted to mature proportion vs. CL data pairs for 2018–2020 in AI, EAG, and WAG, respectively:

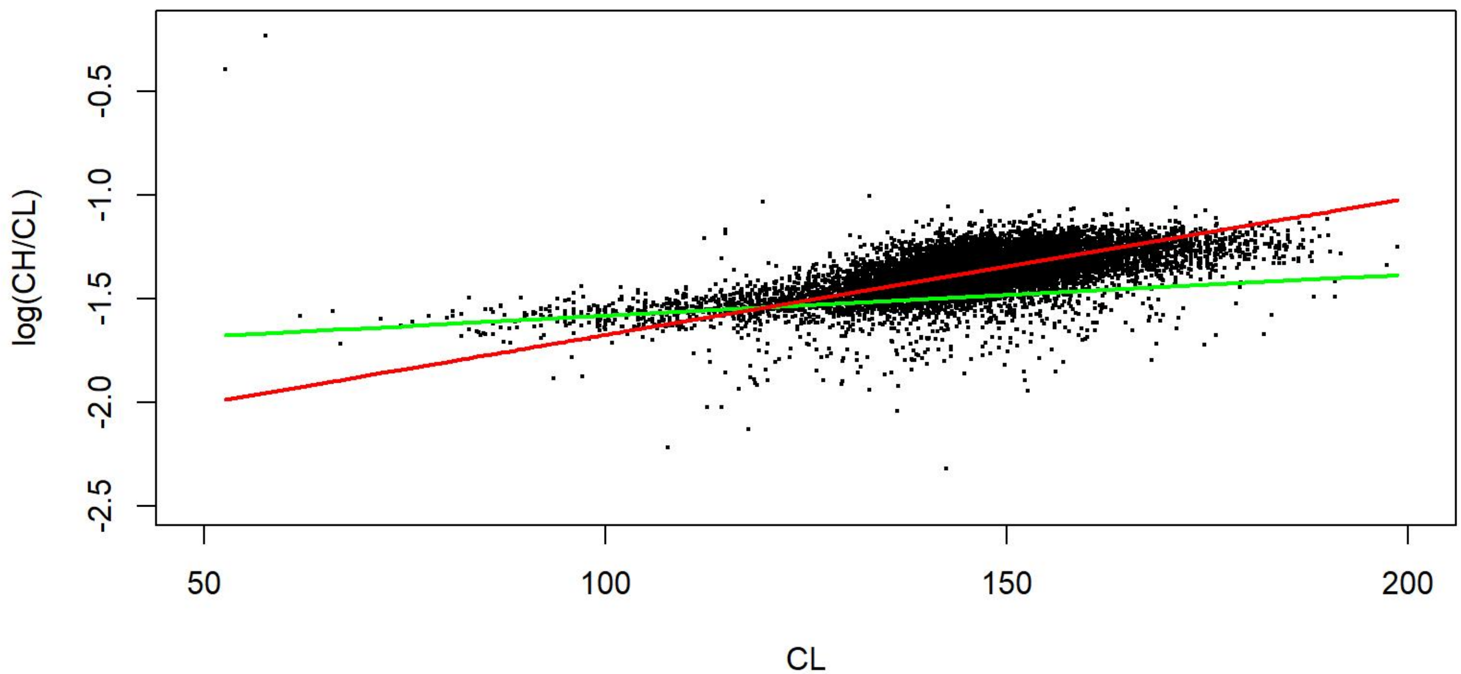


Figure D.1. Segmented linear regression fit to log(CH/CL) vs. CL data of male golden king crab for 2018–2020 in AI.

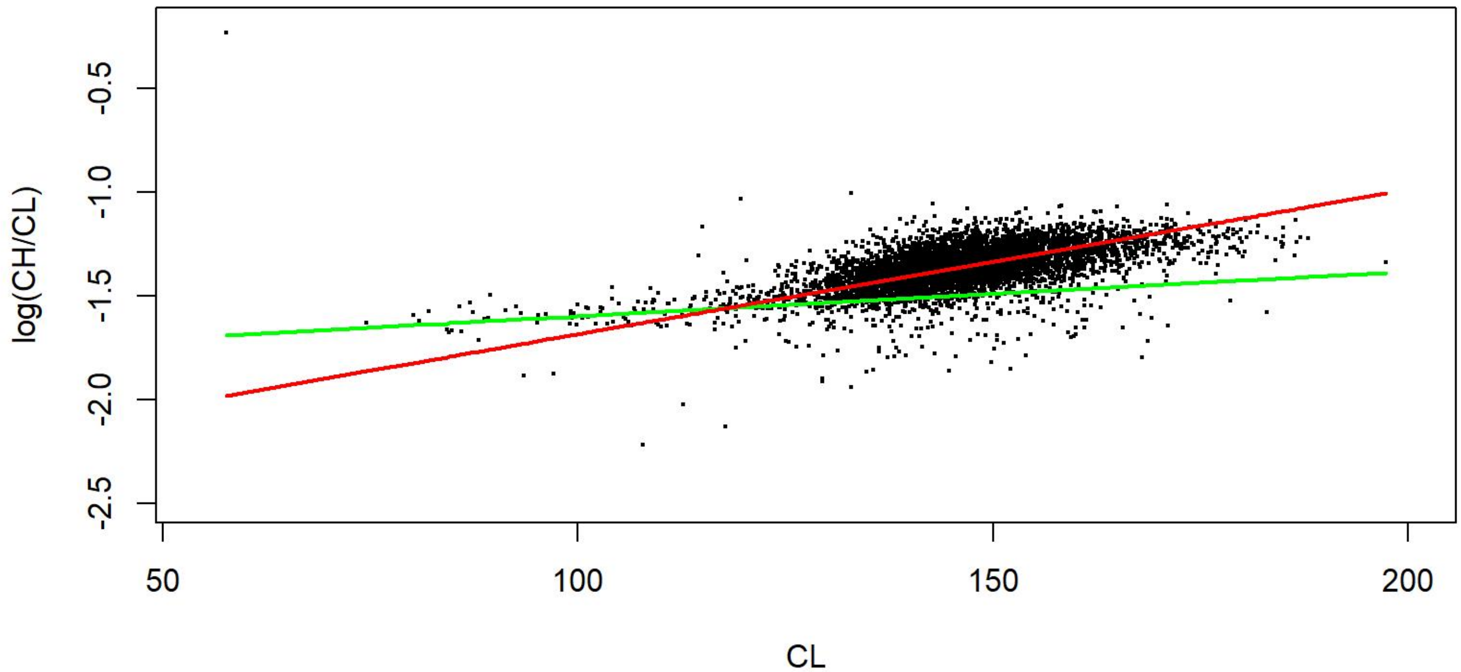


Figure D.2. Segmented linear regression fit to log(CH/CL) vs. CL data of male golden king crab for 2018–2020 in EAG.

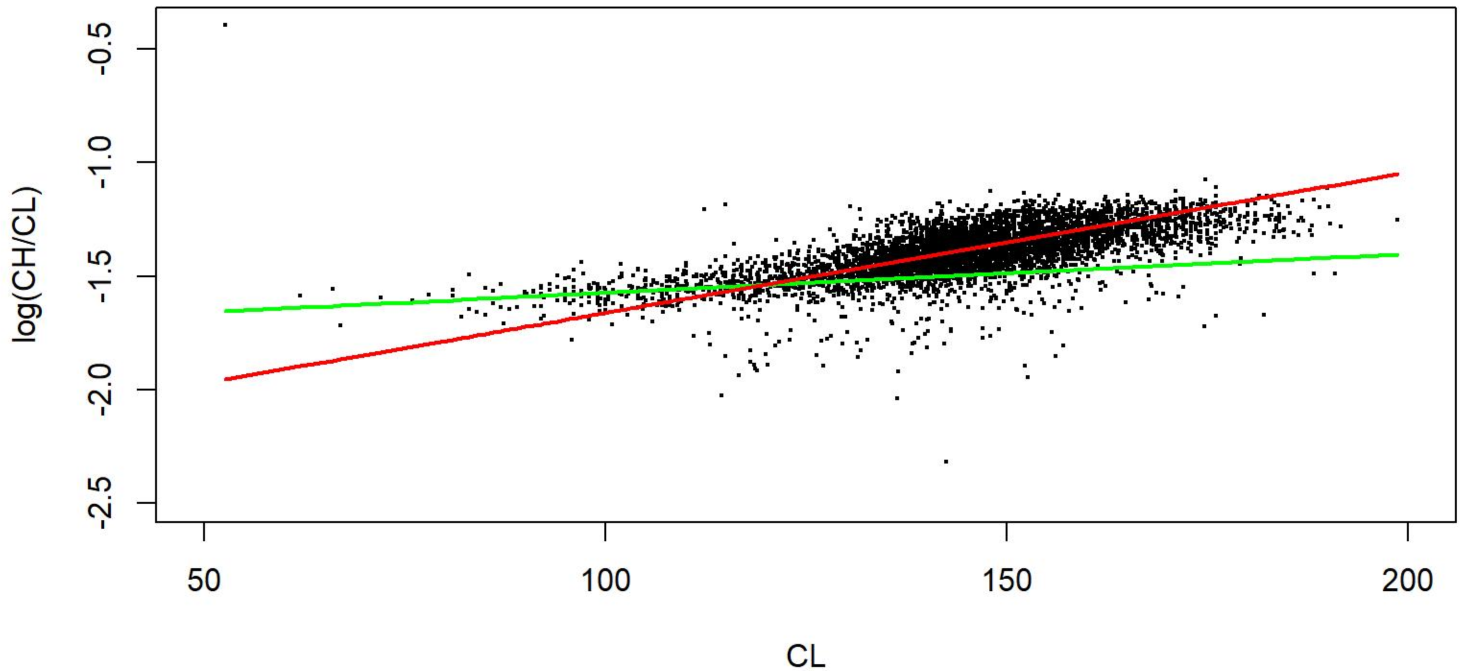


Figure D.3. Segmented linear regression fit to log(CH/CL) vs. CL data of male golden king crab for 2018–2020 in WAG.

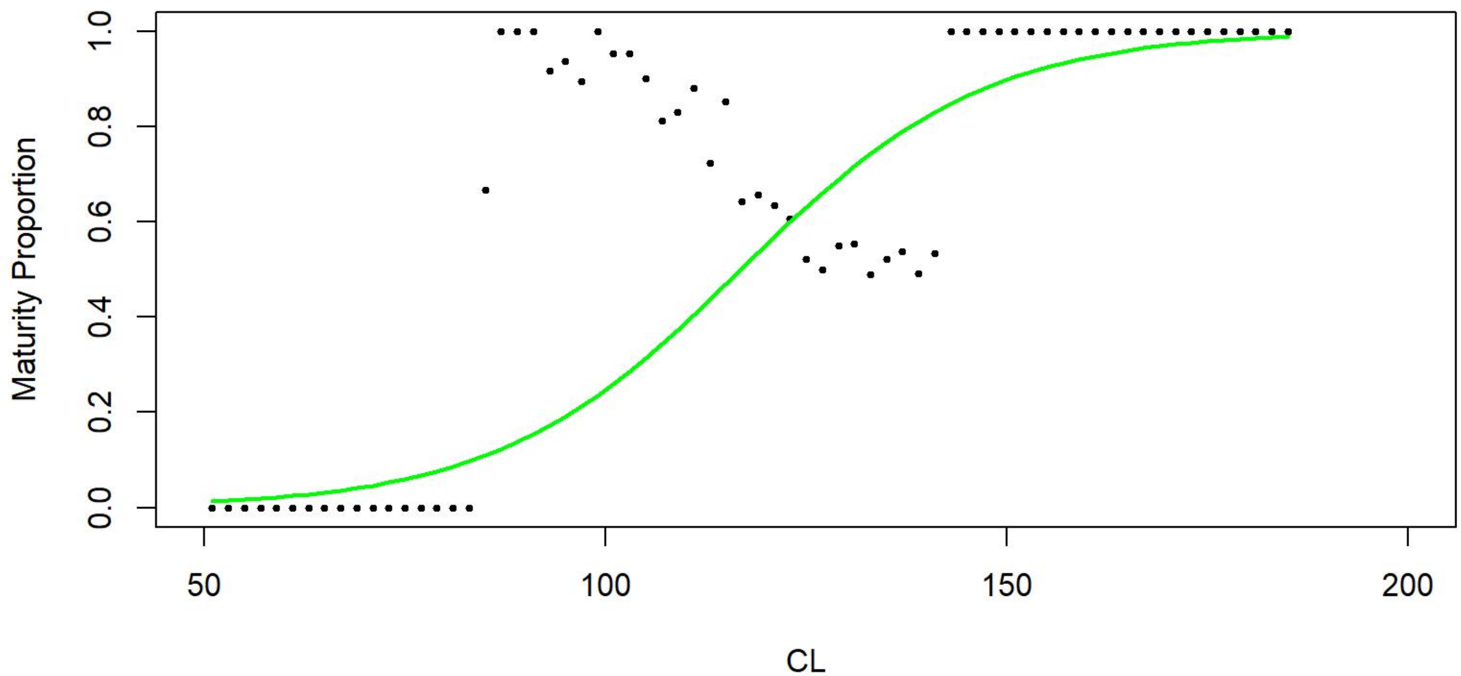


Figure D.4. Logistic fit to mature proportion of male golden king crab for 2018–2020 in AI.

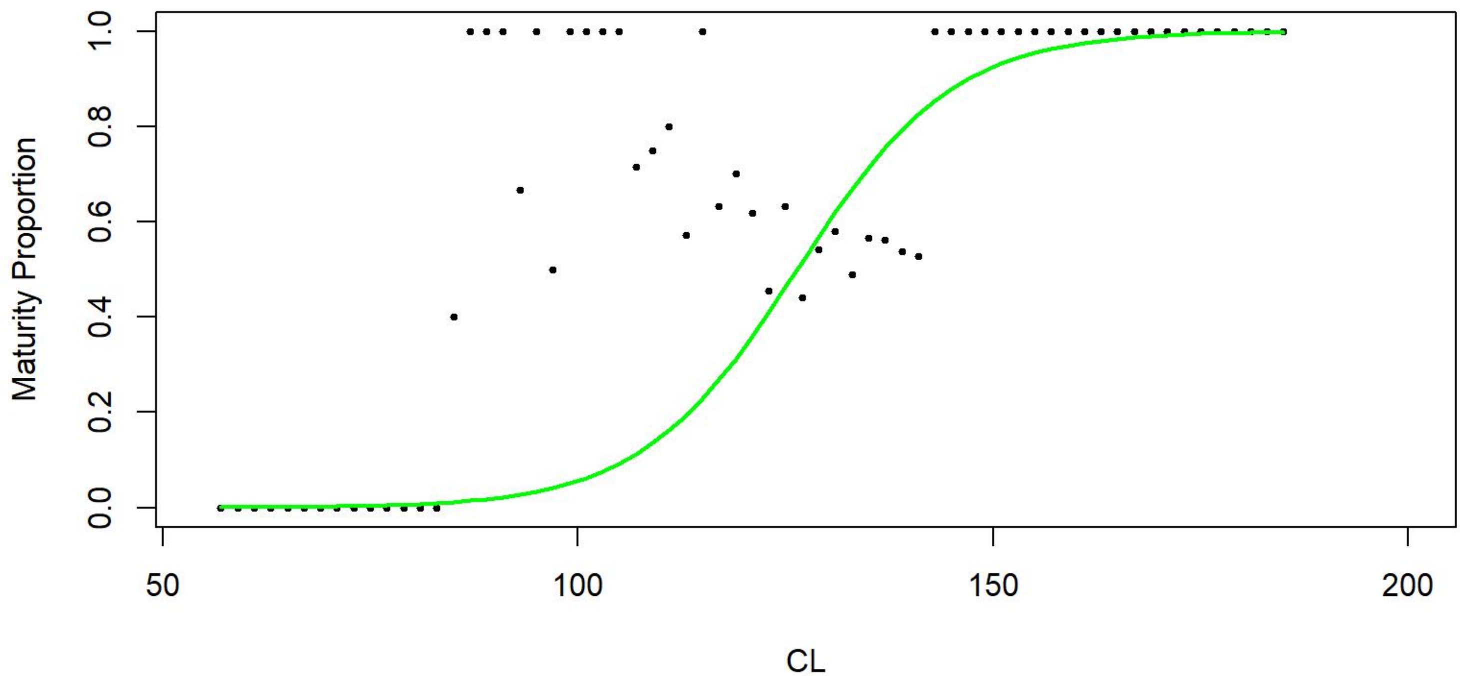


Figure D.5. Logistic fit to mature proportion of male golden king crab for 2018–2020 in EAG.

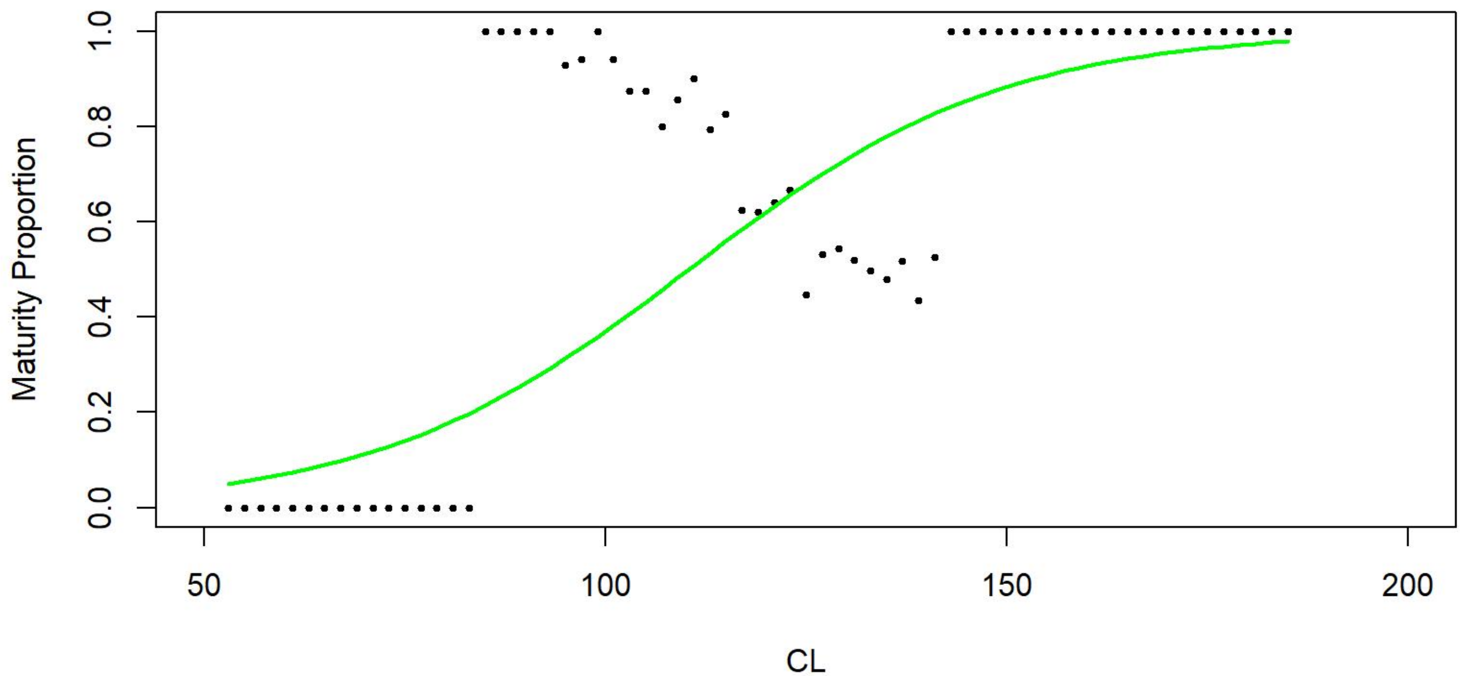


Figure D.6. Logistic fit to mature proportion of male golden king crab for 2018–2020 in WAG.

Implication on mature male biomass estimation:

Figure D.7 provides the long-term trends in MMB by models 21.1a, 21.1b, and 21.1c with varying maturity assumptions: status quo knife-edge maturity size of 111 mm CL (...1a, …1b, …1c), higher maturity size of 116 mm CL (…1a1, …1b1, …1c1), and logistic maturity curve (...1a2, …1b2, …1c2). Changes from status quo maturity assumption generally result in lower MMB values.

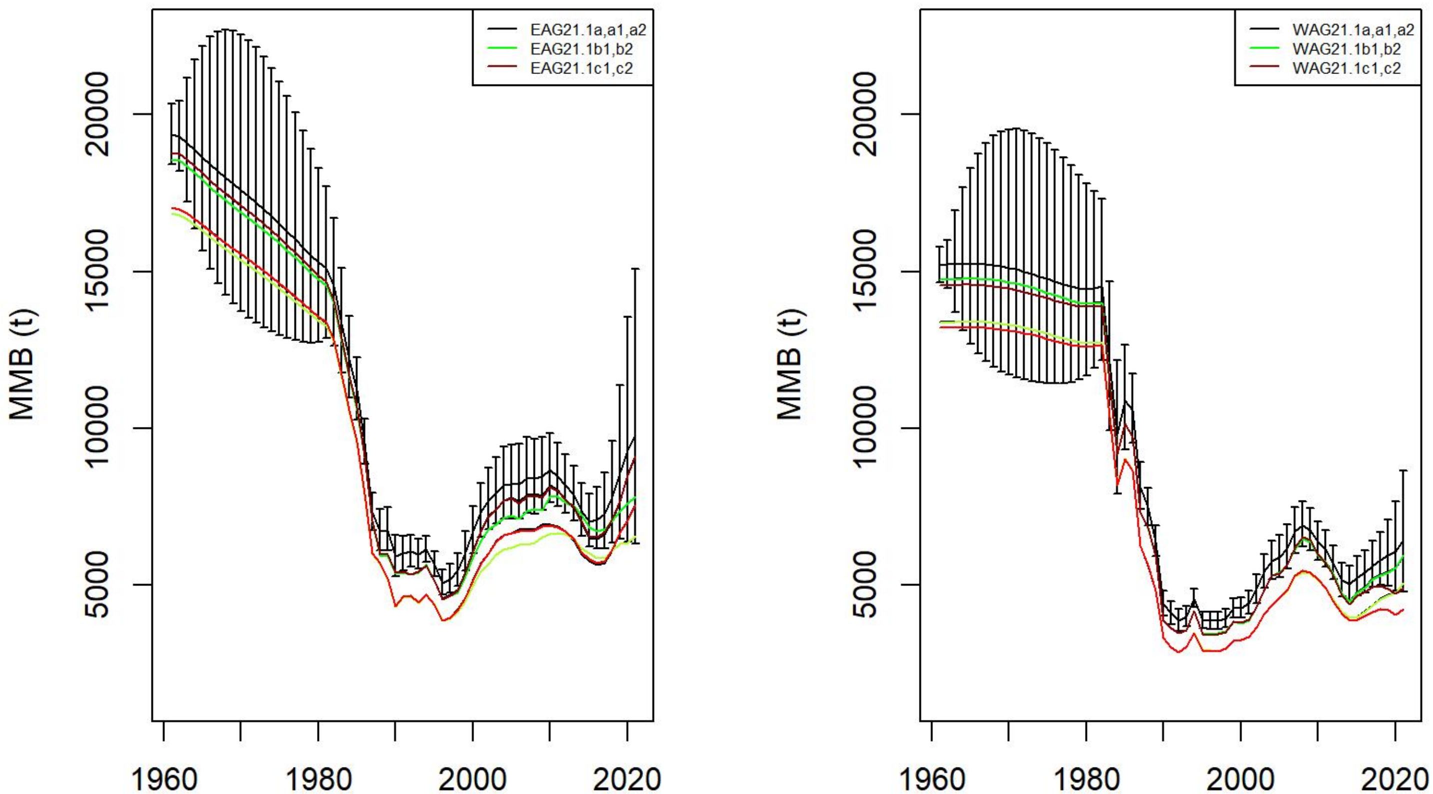


Figure D.7. Trends in golden king crab mature male biomass for models 21.1a, 21.1a1, 21.1a2, 21.1b1, 21.1b2, 21.1c1, and 21.1c2 fits to EAG (left) and WAG (right) data, 1961–2021. Model 21.1a estimate has two standard error confidence limits. Year 2021 refers to 2020/21 fishing season.

Appendix E: Jittering

Jittering of model 19.1 parameter estimates

We followed the Stock Synthesis approach to do 100 jitter runs of model 19.1 parameter estimates to use as initial parameter values (as .PIN file in ADMB) to assess model stability and to determine whether a global, as opposed to local, minima has been reached by the search algorithm:

Following CPT suggestion, we increased the jittering to 50% from previously used 30%. A *Jitter* factor of 0.5 was multiplied by a random normal deviation *rdev*=*N*(0,1) to create a transformed parameter value based upon the predefined parameter:

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

with the final jittered initial parameter value back transformed as:

$$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0\, temp)}, \tag{E.2}$$

where P_{max} and P_{min} are upper and lower bounds of parameter search space and P_{val} is the estimated parameter value before the jittering.

The jitter results are summarized for scenario 19.1 in Tables E.1 and E.2 for EAG and WAG, respectively. All runs converged to the highest log likelihood values except for nonconvergent runs. We concluded from jitter results that optimization of 19.1 model achieved global minima for both EAG and WAG.

Table E.1. Results from 100 jitter runs for scenario 19.1 for EAG. Jitter run 0 corresponds to the original optimized estimates. NA: model did not converge for run#3.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-94.08746**	**0.000155**	**6,696**	**2,935**	**8,722**
1	-94.08746	0.000155	6,696	2,935	8,722
2	-94.08746	0.000155	6,696	2,935	8,722
3	NA	NA	NA	NA	NA
4	-94.08746	0.000066	6,696	2,935	8,722
5	-94.08746	0.000015	6,696	2,935	8,722
6	-94.08746	0.000022	6,696	2,935	8,722
7	-94.08746	0.000370	6,696	2,935	8,722
8	-94.08746	0.000181	6,696	2,935	8,722
9	-94.08746	0.000131	6,696	2,935	8,722
10	-94.08746	0.000160	6,696	2,935	8,722
11	-94.08746	0.000050	6,696	2,935	8,722
12	-94.08746	0.000105	6,696	2,935	8,722

13	-94.08746	0.000152	6,696	2,935	8,722
14	-94.08746	0.000075	6,696	2,935	8,722
15	-94.08746	0.000166	6,696	2,935	8,722
16	-94.08746	0.000060	6,696	2,935	8,722
17	-94.08746	0.000024	6,696	2,935	8,722
18	-94.08746	0.000153	6,696	2,935	8,722
19	-94.08746	0.000202	6,696	2,935	8,722
20	-94.08746	0.000020	6,696	2,935	8,722
21	-94.08746	0.000078	6,696	2,935	8,722
22	-94.08746	0.001453	6,696	2,935	8,722
23	-94.08746	0.000478	6,696	2,935	8,722
24	-94.08746	0.000241	6,696	2,935	8,722
25	-94.08746	0.000309	6,696	2,935	8,722
26	-94.08746	0.000128	6,696	2,935	8,722
27	-94.08746	0.000054	6,696	2,935	8,722
28	-94.08746	0.000259	6,696	2,935	8,722
29	-94.08746	0.000169	6,696	2,935	8,722
30	-94.08746	0.000145	6,696	2,935	8,722
31	-94.08746	0.000079	6,696	2,935	8,722
32	-94.08746	0.000033	6,696	2,935	8,722
33	-94.08746	0.001445	6,696	2,935	8,722
34	-94.08746	0.000158	6,696	2,935	8,722
35	-94.08746	0.000159	6,696	2,935	8,722
36	-94.08746	0.000389	6,696	2,935	8,722
37	-94.08746	0.000111	6,696	2,935	8,722
38	-94.08746	0.000243	6,696	2,935	8,722
39	-94.08746	0.000041	6,696	2,935	8,722
40	-94.08746	0.000098	6,696	2,935	8,722
41	-94.08746	0.000045	6,696	2,935	8,722
42	-94.08746	0.000689	6,696	2,935	8,722
43	-94.08746	0.000013	6,696	2,935	8,722
44	-94.08746	0.000250	6,696	2,935	8,722
45	-94.08746	0.000222	6,696	2,935	8,722
46	-94.08746	0.000114	6,696	2,935	8,722
47	-94.08746	0.000306	6,696	2,935	8,722
48	-94.08746	0.000029	6,696	2,935	8,722
49	-94.08746	0.000175	6,696	2,935	8,722
50	-94.08746	0.000231	6,696	2,935	8,722
51	-94.08746	0.000163	6,696	2,935	8,722
52	-94.08746	0.000145	6,696	2,935	8,722
53	-94.08746	0.000192	6,696	2,935	8,722
54	-94.08746	0.000051	6,696	2,935	8,722
55	-94.08746	0.000281	6,696	2,935	8,722
56	-94.08746	0.000124	6,696	2,935	8,722

57	-94.08746	0.000162	6,696	2,935	8,722
58	-94.08746	0.000141	6,696	2,935	8,722
59	-94.08746	0.000254	6,696	2,935	8,722
60	-94.08746	0.000045	6,696	2,935	8,722
61	-94.08746	0.000005	6,696	2,935	8,722
62	-94.08746	0.000354	6,696	2,935	8,722
63	-94.08746	0.000068	6,696	2,935	8,722
64	-94.08746	0.000124	6,696	2,935	8,722
65	-94.08746	0.000057	6,696	2,935	8,722
66	-94.08746	0.000015	6,696	2,935	8,722
67	-94.08746	0.000088	6,696	2,935	8,722
68	-94.08746	0.000195	6,696	2,935	8,722
69	-94.08746	0.000204	6,696	2,935	8,722
70	-94.08746	0.000623	6,696	2,935	8,722
71	-94.08746	0.000090	6,696	2,935	8,722
72	-94.08746	0.000083	6,696	2,935	8,722
73	-94.08746	0.000031	6,696	2,935	8,722
74	-94.08746	0.000336	6,696	2,935	8,722
75	-94.08746	0.000113	6,696	2,935	8,722
76	-94.08746	0.000029	6,696	2,935	8,722
77	-94.08746	0.000065	6,696	2,935	8,722
78	-94.08746	0.000238	6,696	2,935	8,722
79	-94.08746	0.000034	6,696	2,935	8,722
80	-94.08746	0.000134	6,696	2,935	8,722
81	-94.08746	0.000152	6,696	2,935	8,722
82	-94.08746	0.000230	6,696	2,935	8,722
83	-94.08746	0.000141	6,696	2,935	8,722
84	-94.08746	0.000142	6,696	2,935	8,722
85	-94.08746	0.000147	6,696	2,935	8,722
86	-94.08746	0.000151	6,696	2,935	8,722
87	-94.08746	0.000146	6,696	2,935	8,722
88	-94.08746	0.000093	6,696	2,935	8,722
89	-94.08746	0.000118	6,696	2,935	8,722
90	-94.08746	0.000073	6,696	2,935	8,722
91	-94.08746	0.000041	6,696	2,935	8,722
92	-94.08746	0.000050	6,696	2,935	8,722
93	-94.08746	0.000034	6,696	2,935	8,722
94	-94.08746	0.000038	6,696	2,935	8,722
95	-94.08746	0.000108	6,696	2,935	8,722
96	-94.08746	0.000006	6,696	2,935	8,722
97	-94.08746	0.000079	6,696	2,935	8,722
98	-94.08746	0.000236	6,696	2,935	8,722
99	-94.08746	0.000039	6,696	2,935	8,722
100	-94.08746	0.000179	6,696	2,935	8,722

Table E.2 Results from 100 jitter runs for scenario 19.1 for WAG. Jitter run 0 corresponds to the original optimized estimates. NA: model did not converge for runs #9 and 30.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-177.0032**	**0.000280**	**5,300**	**1,884**	**6,099**
1	-177.0032	0.000280	5,300	1,884	6,099
2	-177.0032	0.000280	5,300	1,884	6,099
3	-177.0032	0.000280	5,300	1,884	6,099
4	-177.0032	0.000280	5,300	1,884	6,099
5	-177.0032	0.000280	5,300	1,884	6,099
6	-177.0032	0.000280	5,810	1,964	6,334
7	-177.0032	0.000280	5,300	1,884	6,099
8	-177.0032	0.000280	5,300	1,884	6,099
9	NA	NA	NA	NA	NA
10	-177.0032	0.000280	5,300	1,884	6,099
11	-177.0032	0.000280	5,300	1,884	6,099
12	-177.0032	0.000280	5,300	1,884	6,099
13	-177.0032	0.000280	5,300	1,884	6,099
14	-177.0032	0.000280	5,300	1,884	6,099
15	-177.0032	0.000280	5,872	1,962	6,378
16	-177.0032	0.000280	5,300	1,884	6,099
17	-177.0032	0.000280	5,300	1,884	6,099
18	-177.0032	0.000280	5,300	1,884	6,099
19	-177.0032	0.000280	5,300	1,884	6,099
20	-177.0032	0.000280	5,300	1,884	6,099
21	-177.0032	0.000280	5,300	1,884	6,099
22	-177.0032	0.000280	5,300	1,884	6,099
23	-177.0032	0.000280	5,300	1,884	6,099
24	-177.0032	0.000280	5,300	1,884	6,099
25	-177.0032	0.000280	5,300	1,884	6,099
26	-177.0032	0.000280	5,300	1,884	6,099
27	-177.0032	0.000280	5,300	1,884	6,099
28	-177.0032	0.000280	5,300	1,884	6,099
29	-177.0032	0.000280	5,300	1,884	6,099
30	NA	NA	NA	NA	NA
31	-177.0032	0.000280	5,300	1,884	6,099
32	-177.0032	0.000280	5,300	1,884	6,099
33	-177.0032	0.000280	5,300	1,884	6,099
34	-177.0032	0.000280	5,300	1,884	6,099
35	-177.0032	0.000280	5,300	1,884	6,099
36	-177.0032	0.000280	5,872	1,962	6,378
37	-177.0032	0.000280	5,300	1,884	6,099
38	-177.0032	0.000280	5,300	1,884	6,099

39	-177.0032	0.000280	5,300	1,884	6,099
40	-177.0032	0.000280	5,300	1,884	6,099
41	-177.0032	0.000280	5,300	1,884	6,099
42	-177.0032	0.000280	5,300	1,884	6,099
43	-177.0032	0.000280	5,300	1,884	6,099
44	-177.0032	0.000280	5,300	1,884	6,099
45	-177.0032	0.000280	5,300	1,884	6,099
46	-177.0032	0.000280	5,300	1,884	6,099
47	-177.0032	0.000280	5,782	1,960	6,331
48	-177.0032	0.000280	5,300	1,884	6,099
49	-177.0032	0.000280	5,300	1,884	6,099
50	-177.0032	0.000280	5,300	1,884	6,099
51	-177.0032	0.000280	5,300	1,884	6,099
52	-177.0032	0.000280	5,300	1,884	6,099
53	-177.0032	0.000280	5,300	1,884	6,099
54	-177.0032	0.000280	5,810	1,964	6,334
55	-177.0032	0.000280	5,300	1,884	6,099
56	-177.0032	0.000280	5,300	1,884	6,099
57	-177.0032	0.000280	5,300	1,884	6,099
58	-177.0032	0.000280	5,300	1,884	6,099
59	-177.0032	0.000280	5,300	1,884	6,099
60	-177.0032	0.000280	5,300	1,884	6,099
61	-177.0032	0.000280	5,300	1,884	6,099
62	-177.0032	0.000280	5,300	1,884	6,099
63	-177.0032	0.000280	5,300	1,884	6,099
64	-177.0032	0.000280	5,300	1,884	6,099
65	-177.0032	0.000280	5,300	1,884	6,099
66	-177.0032	0.000280	5,300	1,884	6,099
67	-177.0032	0.000280	5,300	1,884	6,099
68	-177.0032	0.000280	5,300	1,884	6,099
69	-177.0032	0.000280	5,782	1,960	6,331
70	-177.0032	0.000280	5,300	1,884	6,099
71	-177.0032	0.000280	5,872	1,962	6,378
72	-177.0032	0.000280	5,300	1,884	6,099
73	-177.0032	0.000280	5,300	1,884	6,099
74	-177.0032	0.000280	5,300	1,884	6,099
75	-177.0032	0.000280	5,901	1,958	6,338
76	-177.0032	0.000280	5,300	1,884	6,099
77	-177.0032	0.000280	5,300	1,884	6,099
78	-177.0032	0.000280	5,872	1,962	6,378
79	-177.0032	0.000280	5,872	1,962	6,378
80	-177.0032	0.000280	5,300	1,884	6,099
81	-177.0032	0.000280	5,300	1,884	6,099
82	-177.0032	0.000280	5,300	1,884	6,099

83	-177.0032	0.000280	5,300	1,884	6,099
84	-177.0032	0.000280	5,300	1,884	6,099
85	-177.0032	0.000280	5,872	1,962	6,378
86	-177.0032	0.000280	5,300	1,884	6,099
87	-177.0032	0.000280	5,300	1,884	6,099
88	-177.0032	0.000280	5,300	1,884	6,099
89	-177.0032	0.000280	5,300	1,884	6,099
90	-177.0032	0.000280	5,300	1,884	6,099
91	-177.0032	0.000280	5,300	1,884	6,099
92	-177.0032	0.000280	5,300	1,884	6,099
93	-177.0032	0.000280	5,300	1,884	6,099
94	-177.0032	0.000280	5,782	1,960	6,331
95	-177.0032	0.000280	5,300	1,884	6,099
96	-177.0032	0.000280	5,300	1,884	6,099
97	-177.0032	0.000280	5,300	1,884	6,099
98	-177.0032	0.000280	5,300	1,884	6,099
99	-177.0032	0.000280	5,300	1,884	6,099
100	-177.0032	0.000280	5,872	1,962	6,378

Appendix F: Progress in Gmacs

Introduction

Implementation of Aleutian Islands golden king crab stock assessment in gmacs started in 2020 and the effort is continuing.

Method

As a first step, we tried to compare EAG19.1 assessment results with that of gmacs. Estimated parameters from a modified EAG19.1 model (known as modifiedEAG19.1) that was reparametrized for gmacs computational formulas were input to gmacs ctl file. Parallel EAG19.1 data and projection files were also created for gmacs runs (gmacsEAG19.1CatchNo.ctl, gmacsEAG19.1CatchNo.dat, and gmacsEAG19.1CatchNo.prj). We compared time series of abundance composition (N- matrix), retained catch composition, and CPUE indices among originalEAG19.1, modifiedEAG19.1, and gmacsEAG19.1 for two options: (1) fixed parameters of modifiedEAG19.1 for gmacs run (run#10) and (2) free parameters of modifiedEAG19.1 for gmacs run (run#9).

Results

The gmacs ctl, dat, and prj files for EAG19.1 are provided in Tables F.1, F.2, and F.3, respectively. The abundance and retained catch compositions compare well among the three versions of EAG19.1 (originalEAG19.1, modifiedEAG19.1, and gmacsEAG19.1) in Figures F1, and F.2). The CPUE trends also compare well among the three versions (Figure F.3).

We found some differences in likelihood and reference points estimates between the original EAG19.1 model and its gmacs version. We will address those discrepancies before going into gmacs full implementation.

Table F1. gmacsEAG19.1.ctl file.

#	EAG19_1							
#								
#	Controls	for	leading	parameter	vector	theta		
#								
#	ntheta							
	9							
#								
#	ival	lb	ub	phz	prior	p1	p2	parameter
#								
	0.21	0.01	1	-3	2	0.18	0.04	M
	7.704441838	-10	20	-1	0	-10	20	R0
	12	-10	20	-3	0	-10	20	Rini
	8	-10	20	-1	0	-10	20	Rbar
	110	103	165	-2	1	72.5	7.25	R expected
	0.375940107	0.001	5.65	-3	0	0.1	5	R scale
	-0.05129329	-10	0.75	-1	0	-10	0.75	SigmaR
	0.73	0.2	1	-2	3	3	2	steepness
	0.001	0	1	-3	3	1.01	1.01	autocorrelation
#								
#	weight-at-length							
1								
#a,	in	kg						
	1.10E-07							
#b								
	3.335923							
#	Male	weight-at-length						
#								
#	Proportion	mature	by	sex,	males			
	0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1							
#	Proportion	legal	by	sex,	males			

	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1							
#								
##	GROWTH	PARAM	CONTROLS	##				
##	Two	lines	for	each	parameter			
#								
#	option	8	is	normal	distributed			
8								
#	growth increment		model					
1								
#	molt probability	function						
2								
#	maximum	size-class						
#	Maximum	size-class		recruitment				
5								
##	number	of	size-increment	periods				
1								
##	Year(s)	size-increment	period	changes				
##	number	of	molt	periods				
1								
##	Year(s)	molt	period	changes				
##	Beta	parameters						
1								
#		Growth	parameters					
#								
#	ival	lb	ub	phz	prior	p1	p2	parameter
#								
	22.456186	10	50	-3	0	0	20	alpha,
	0.069134986	-0.4	20	-3	0	0	10	beta,

```
3.65852444 0.01 5 -3 0 0 3 growth scale
141.1264139 65 165 -2 0 0 999 moult mu
0.08898126 -0.1 2 -2 0 0 2 moult cv
#
# The custom growth-increment matrix

# custom molt probability matrix

#
## SELECTIVITY CONTROLS
#
## ivector for number of year blocks or nodes
## Gear-1 Gear-2
## PotFishery Trawl Byc
2 1 # selectivity periods
0 0 # male only fishery,
2 5 # male selectivity type
0 0 # within another gear
0 0 # extra
## Gear-1 Gear-2
1 1 # retention periods
0 0 # male only fishery,
2 6 # male retention type
1 0 # male retention
0 0 # extra
##
## Selectivity P(capture of all sizes)
#
## gear par sel phz start end
# index index par sex ival lb ub prior p1 p2 mirror period
#
## Gear-1
```

	1	1	1	0	125.5	105	180	0	100	190	-3	1960	2004
	1	2	2	0	10.35	0.01	20	0	0.1	50	-3	1960	2004
	1	3	1	0	137.1	105	180	0	100	190	-3	2005	2019
	1	4	2	0	6.556	0.01	20	0	0.1	50	-3	2005	2019
#	Gear-2												
	2	5	1	0	1	0.99	1.02	0	10	200	-3	1960	2019
#													
##	Retained												
##	gear	par	sel	phz	start	end							
#	index	index	par	sex	ival	lb	ub	prior	p1	p2	mirror	period	
#	Gear-1												
	-1	6	1	0	136.3	105	180	0	100	190	-3	1960	2019
	-1	7	2	0	2.161	1E-04	20	0	0.1	50	-3	1960	2019
#	Gear-2												
	-2	8	1	0	1	0.99	1.01	0	10	200	-3	1960	2019
#	Number	of	asyptotic	parameters									
1													
#	Fleet	Sex	Year	ival	lb	ub	phz						
	1	1	1960	1E-06	0	1	-3						
#													
##	PRIORS	FOR	CATCHABILITY										
#													
##	SURVEYS/INDICES	ONLY											
##	observer	and	fishery	CPUE									
##	ival	lb	ub	phz	prior	p1	p2	Analytic?	LAMBDA	Emphasis			
	0.000585278	1E-07	0.01	1	0	0.1	1	0	1	1			
	0.000483222	1E-07	0.01	1	0	0.1	1	0	1	1			
#													
##	ADDITIONAL	CV	FOR	SURVEYS/INDICES									

#												
##	ival	lb	ub	phz	prior	p1	p2					
	0.000235	1E-07	0.01	-1	4	0.5	100	Fish cticket	CPUE	additional	var	
	0.000189	1E-07	0.01	-1	4	0.5	100	obs	CPUE	additional	var	
##												
##PENALTIES		FOR	AVERAGE	FISHING	MORTALITY	RATE	FOR	EACH	GEAR			
#												
##	Trap	Trawl										
##	Mean_F	Fema-Offset	STD_PHZ1	STD_PHZ2	PHZ_M	PHZ_F	Lb	Ub	Lb	Ub	Lb	Ub
	0.388745475	0	3	15	-1	-1	-12	4	-10	10	-10	10
	0.000109758	0	4	15	-1	-1	-12	4	-10	10	-10	10
##	OPTIONS	FOR	SIZE	COMPOSTION	DATA	##						
#	ret	tot										
#												
	2	2	Type	of	likelihood							
	0	0	Auto	tail	compression							
	1	1	effective	sample	size	multiplier						
	-4	-4	Phz	for	estimating	effective	sample	size				
	1	2	Composition		aggregator							
	1	1	LAMBDA									
	1	1	Emphasis		Dritchlet							
#												
##	TIME	VARYING	NATURAL	MORTALIIY	RATES							
#												
	0	#	M	type								
##	M	is	relative	(YES=1;	NO=0)							
##	Phase	of	estimation									
3												

```
##      STDEV      in        m_dev        for      Random   walk
    0.25
##      Number     of        nodes        for      cubic    spline
       1

##      Year       position  of           the      knots
    1960
##      number     of        breakpoints  in       M        by       size
       0
#       line       groups    for          breakpoint
       8
##      Specific   initial   values       for      the      natural  mortality devs

##      ival       lb        ub           phz      extra
##                 3         0.5          5        4        0

#
##      OTHER      CONTROLS
#
#
    1960 #         #start    rec_dev
    2019 #         #last     rec_dev
                -1 Estimated rec_dev      phase
                -2 Estimated sex-ratio    phase
               0.5 Expected  sex-ratio
                -3 Estimated rec_ini      phase
                 1 VERBOSE
                 0 Initial   conditions
                 1 Lambda
                 0 Stock-Recruit-Relationship
                10 Maximum                phase
                -1
```

##	EMPHASIS	FACTORS	(CATCH)				
#ret_male	tot_male	Groundfish					
	4	2	1				
##	EMPHASIS	FACTORS	(Priors)				
##							
#	Log_fdevs	meanF	Mdevs	Rec_devs	Initial_devs	Fst_dif_dev	Mean_sex-Ratio
	10000	0	1	2	0	0	1
##	EOF						
9999							

Table F2. gmacs EAG19.1. dat file.

#	EAG19.1							
#	Gmacs	Main	Data	File				
#	GEAR_	INDEX	DESCRIPTION					
#	1	:	Pot	fishery	Retained	catch		
#	2	:	Pot	fishery	total	catch		
#	3	:	Trawl	bycatch				
#	4	:	Observer	CPUE				
#	5	:	Fishery	CPUE				
#	Fisheries:	1	Pot	Fishery,	2	Pot	Total	
#	Cooperative	Survey:						
#								
1960	#	start	year)					
2019	#	terminal	year					
#2020	#	Projection	year					
6	#	Number	of	seasons:				
2	#	Number	of	distinct	data	groups		
1	#	Number	of	sexes				

1 # Number of shell condition types
1 # Number of maturity types
17 # Number of size-classes
6 # Season when recruitment occurs
6 # Season when molting and growth occur
5 # Season to calculate MMB
1 # Season for N output
maximum size-class
17
size_breaks
100.5 105.5 110.5 115.5 120.5 125.5 130.5 135.5 140.5 145.5 150.5 155.5 160.5
165.5 170.5 175.5 180.5 185.5
Natural mortality per season
2
Proportion of the total natural mortality
1 Start biological year (Jul 1) instantaneous N estimation
2 to mid fishing time
3 instantanous C removal
4 to spawning time
5 instantaneous byc removal and estimate MMB
6 Rest of the period of non fishing
from Feb 15 to June 30

#Ins	N	Jul1-MidFish	Inst	C	Jul1-15Feb	Ins
0	0.16667	0	0.463	0	0.3699	#1960
0	0.16667	0	0.463	0	0.3699	#1961
0	0.16667	0	0.463	0	0.3699	#1962
0	0.16667	0	0.463	0	0.3699	#1963
0	0.16667	0	0.463	0	0.3699	#1964
0	0.16667	0	0.463	0	0.3699	#1965
0	0.16667	0	0.463	0	0.3699	#1966
0	0.16667	0	0.463	0	0.3699	#1967
0	0.16667	0	0.463	0	0.3699	#1968

0	0.16667	0	0.463	0	0.3699	#1969
0	0.16667	0	0.463	0	0.3699	#1970
0	0.16667	0	0.463	0	0.3699	#1971
0	0.16667	0	0.463	0	0.3699	#1972
0	0.16667	0	0.463	0	0.3699	#1973
0	0.16667	0	0.463	0	0.3699	#1974
0	0.16667	0	0.463	0	0.3699	#1975
0	0.16667	0	0.463	0	0.3699	#1976
0	0.16667	0	0.463	0	0.3699	#1977
0	0.16667	0	0.463	0	0.3699	#1978
0	0.16667	0	0.463	0	0.3699	#1979
0	0.16667	0	0.463	0	0.3699	#1980
0	0.43973	0	0.19	0	0.3699	#1981
0	0.48082	0	0.149	0	0.3699	#1982
0	0.48082	0	0.149	0	0.3699	#1983
0	0.3137	0	0.316	0	0.3699	#1984
0	0.16575	0	0.464	0	0.3699	#1985
0	0.24932	0	0.381	0	0.3699	#1986
0	0.08493	0	0.545	0	0.3699	#1987
0	0.29726	0	0.333	0	0.3699	#1988
0	0.31233	0	0.318	0	0.3699	#1989
0	0.26301	0	0.367	0	0.3699	#1990
0	0.27123	0	0.359	0	0.3699	#1991
0	0.27397	0	0.356	0	0.3699	#1992
0	0.46027	0	0.17	0	0.3699	#1993
0	0.24795	0	0.382	0	0.3699	#1994
0	0.22192	0	0.408	0	0.3699	#1995
0	0.3274	0	0.303	0	0.3699	#1996
0	0.28493	0	0.345	0	0.3699	#1997
0	0.26301	0	0.367	0	0.3699	#1998
0	0.24521	0	0.385	0	0.3699	#1999
0	0.17808	0	0.452	0	0.3699	#2000

0	0.1589	0	0.471	0	0.3699	#2001
0	0.15479	0	0.475	0	0.3699	#2002
0	0.15616	0	0.474	0	0.3699	#2003
0	0.14247	0	0.488	0	0.3699	#2004
0	0.43288	0	0.197	0	0.3699	#2005
0	0.33151	0	0.299	0	0.3699	#2006
0	0.36849	0	0.262	0	0.3699	#2007
0	0.30274	0	0.327	0	0.3699	#2008
0	0.3274	0	0.303	0	0.3699	#2009
0	0.29315	0	0.337	0	0.3699	#2010
0	0.26301	0	0.367	0	0.3699	#2011
0	0.27534	0	0.355	0	0.3699	#2012
0	0.2726	0	0.358	0	0.3699	#2013
0	0.24795	0	0.382	0	0.3699	#2014
0	0.22877	0	0.401	0	0.3699	#2015
0	0.42055	0	0.21	0	0.3699	#2016
0	0.40959	0	0.221	0	0.3699	#2017
0	0.34932	0	0.281	0	0.3699	#2018
0	0.3274	0	0.303	0	0.3699	#2019

#
Fishing fleet names
Pot_Fishery Trawl_Bycatch
Survey names

Are the seasons discrete-instantaneous
1 1 1 1 1 1
Number of catch data frames
3
Number of rows in each data frame
1993 total catch is missing,
retained catch 1981/82-2019/20
39 29 31

##	CATCH	DATA	in	t							
##	Type	of	catch:	1	=	retained,		2	=	discard,	0= total
##	Units	of	catch:	1	=	biomass,		2	=	numbers	
#	Mult:	1=	use	data	as	thy	are,		2	=	multiply
##	Retained	Catch	(in	1000	crab)						
#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality	
1981	3	1	1	204	0.032	1	2	1	0	0.2	
1982	3	1	1	529.8	0.032	1	2	1	0	0.2	
1983	3	1	1	662.3	0.032	1	2	1	0	0.2	
1984	3	1	1	801.1	0.032	1	2	1	0	0.2	
1985	3	1	1	1251	0.032	1	2	1	0	0.2	
1986	3	1	1	1375	0.032	1	2	1	0	0.2	
1987	3	1	1	968.6	0.032	1	2	1	0	0.2	
1988	3	1	1	1156	0.032	1	2	1	0	0.2	
1989	3	1	1	1420	0.032	1	2	1	0	0.2	
1990	3	1	1	892.7	0.032	1	2	1	0	0.2	
1991	3	1	1	1083	0.032	1	2	1	0	0.2	
1992	3	1	1	1127	0.032	1	2	1	0	0.2	
1993	3	1	1	767.9	0.032	1	2	1	0	0.2	
1994	3	1	1	1087	0.032	1	2	1	0	0.2	
1995	3	1	1	1150	0.032	1	2	1	0	0.2	
1996	3	1	1	848	0.032	1	2	1	0	0.2	
1997	3	1	1	780.6	0.032	1	2	1	0	0.2	
1998	3	1	1	740	0.032	1	2	1	0	0.2	
1999	3	1	1	709.3	0.032	1	2	1	0	0.2	
2000	3	1	1	704.7	0.032	1	2	1	0	0.2	
2001	3	1	1	730	0.032	1	2	1	0	0.2	
2002	3	1	1	643.9	0.032	1	2	1	0	0.2	
2003	3	1	1	643.1	0.032	1	2	1	0	0.2	
2004	3	1	1	637.5	0.032	1	2	1	0	0.2	
2005	3	1	1	624	0.032	1	2	1	0	0.2	

2006	3	1	1	650.6	0.032	1	2	1	0	0.2
2007	3	1	1	633.3	0.032	1	2	1	0	0.2
2008	3	1	1	666.9	0.032	1	2	1	0	0.2
2009	3	1	1	679.9	0.032	1	2	1	0	0.2
2010	3	1	1	671	0.032	1	2	1	0	0.2
2011	3	1	1	668.8	0.032	1	2	1	0	0.2
2012	3	1	1	687.7	0.032	1	2	1	0	0.2
2013	3	1	1	720.2	0.032	1	2	1	0	0.2
2014	3	1	1	719.1	0.032	1	2	1	0	0.2
2015	3	1	1	763.6	0.032	1	2	1	0	0.2
2016	3	1	1	794	0.032	1	2	1	0	0.2
2017	3	1	1	802.6	0.032	1	2	1	0	0.2
2018	3	1	1	940.3	0.032	1	2	1	0	0.2
2019	3	1	1	1057	0.032	1	2	1	0	0.2

Total Catch (in 1000 crab, no mortality applied)

#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality
1990	3	1	1	1149	0.045	0	2	1	0	0.2
1991	3	1	1	4385	0.045	0	2	1	0	0.2
1992	3	1	1	4332	0.045	0	2	1	0	0.2
1994	3	1	1	1713	0.045	0	2	1	0	0.2
1995	3	1	1	2743	0.045	0	2	1	0	0.2
1996	3	1	1	1452	0.045	0	2	1	0	0.2
1997	3	1	1	1788	0.045	0	2	1	0	0.2
1998	3	1	1	2012	0.045	0	2	1	0	0.2
1999	3	1	1	1556	0.045	0	2	1	0	0.2
2000	3	1	1	1707	0.045	0	2	1	0	0.2
2001	3	1	1	1353	0.045	0	2	1	0	0.2
2002	3	1	1	1120	0.045	0	2	1	0	0.2
2003	3	1	1	1111	0.045	0	2	1	0	0.2
2004	3	1	1	965.4	0.045	0	2	1	0	0.2
2005	3	1	1	929.3	0.045	0	2	1	0	0.2

2006	3	1	1	857.3	0.045	0	2	1	0	0.2
2007	3	1	1	911.3	0.045	0	2	1	0	0.2
2008	3	1	1	931	0.045	0	2	1	0	0.2
2009	3	1	1	936.7	0.045	0	2	1	0	0.2
2010	3	1	1	944.2	0.045	0	2	1	0	0.2
2011	3	1	1	927	0.045	0	2	1	0	0.2
2012	3	1	1	986.8	0.045	0	2	1	0	0.2
2013	3	1	1	978.6	0.045	0	2	1	0	0.2
2014	3	1	1	1013	0.045	0	2	1	0	0.2
2015	3	1	1	1129	0.045	0	2	1	0	0.2
2016	3	1	1	1284	0.045	0	2	1	0	0.2
2017	3	1	1	1239	0.045	0	2	1	0	0.2
2018	3	1	1	1599	0.045	0	2	1	0	0.2
2019	3	1	1	1778	0.045	0	2	1	0	0.2

Trawl fishery discards (in 1000 crab, handling mortality rate applied)

#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality
1989	5	2	1	0.388	1.58	2	2	1	0	1
1990	5	2	1	1.19	1.58	2	2	1	0	1
1991	5	2	1	0	1.58	2	2	1	0	1
1992	5	2	1	0.779	1.58	2	2	1	0	1
1993	5	2	1	0.719	1.58	2	2	1	0	1
1994	5	2	1	0.311	1.58	2	2	1	0	1
1995	5	2	1	0.569	1.58	2	2	1	0	1
1996	5	2	1	0.046	1.58	2	2	1	0	1
1997	5	2	1	0.076	1.58	2	2	1	0	1
1998	5	2	1	0.587	1.58	2	2	1	0	1
1999	5	2	1	0.284	1.58	2	2	1	0	1
2000	5	2	1	0.387	1.58	2	2	1	0	1
2001	5	2	1	0.934	1.58	2	2	1	0	1
2002	5	2	1	0.707	1.58	2	2	1	0	1
2003	5	2	1	0.392	1.58	2	2	1	0	1

2004	5	2	1	0.059	1.58	2	2	1	0	1
2005	5	2	1	0.252	1.58	2	2	1	0	1
2006	5	2	1	0.679	1.58	2	2	1	0	1
2007	5	2	1	0.697	1.58	2	2	1	0	1
2008	5	2	1	0.808	1.58	2	2	1	0	1
2009	5	2	1	0.718	1.58	2	2	1	0	1
2010	5	2	1	2.415	1.58	2	2	1	0	1
2011	5	2	1	1.208	1.58	2	2	1	0	1
2012	5	2	1	2.058	1.58	2	2	1	0	1
2013	5	2	1	0.894	1.58	2	2	1	0	1
2014	5	2	1	1.327	1.58	2	2	1	0	1
2015	5	2	1	0.303	1.58	2	2	1	0	1
2016	5	2	1	0.717	1.58	2	2	1	0	1
2017	5	2	1	0.538	1.58	2	2	1	0	1
2018	5	2	1	0.495	1.58	2	2	1	0	1
2019	5	2	1	1.468	1.58	2	2	1	0	1

```
## RELATIVE ABUNDANCE DATA
## Units of abundance: 1 = biomass, 2 = numbers
## Number of relative abundance indicies
## sex:1=male;2=female; 0=both
## maturity: 1=immature;2=mature;0 = both)

# Fishery CPUE index, Observer CPUE index2
2
# Index Type (1=Selecivity; 2=retention)
# AEPAEP
2 2
## Number of rows in each index
39
# Fishery CPUE index NB error in GLM fits Obs &FishTicket
#Index Year Seas fleet Sex maturity index cv abundance unit timing
```

1	1985	3	1	1	0	1.6287	0.051	2	0.5
1	1986	3	1	1	0	1.2289	0.047	2	0.5
1	1987	3	1	1	0	0.9552	0.049	2	0.5
1	1988	3	1	1	0	1.0358	0.041	2	0.5
1	1989	3	1	1	0	1.0765	0.034	2	0.5
1	1990	3	1	1	0	0.9868	0.045	2	0.5
1	1991	3	1	1	0	0.9046	0.043	2	0.5
1	1992	3	1	1	0	0.9172	0.043	2	0.5
1	1993	3	1	1	0	0.9145	0.049	2	0.5
1	1994	3	1	1	0	0.8086	0.042	2	0.5
1	1995	3	1	1	0	0.7798	0.043	2	0.5
1	1996	3	1	1	0	0.7791	0.044	2	0.5
1	1997	3	1	1	0	1.0505	0.045	2	0.5
1	1998	3	1	1	0	1.2141	0.051	2	0.5

Observer CPUE index

1	1995	3	1	1	0	1.0034	0.032	2	0.5
1	1996	3	1	1	0	0.9444	0.021	2	0.5
1	1997	3	1	1	0	0.8742	0.021	2	0.5
1	1998	3	1	1	0	1.0004	0.019	2	0.5
1	1999	3	1	1	0	0.9154	0.018	2	0.5
1	2000	3	1	1	0	0.8196	0.016	2	0.5
1	2001	3	1	1	0	1.0429	0.018	2	0.5
1	2002	3	1	1	0	1.1029	0.021	2	0.5
1	2003	3	1	1	0	0.9714	0.019	2	0.5
1	2004	3	1	1	0	1.4394	0.027	2	0.5
2	2005	3	1	1	0	0.9829	0.026	2	0.5
2	2006	3	1	1	0	0.8087	0.023	2	0.5
2	2007	3	1	1	0	0.9017	0.022	2	0.5
2	2008	3	1	1	0	0.8819	0.026	2	0.5
2	2009	3	1	1	0	0.7266	0.031	2	0.5
2	2010	3	1	1	0	0.7518	0.031	2	0.5

2	2011	3	1	1	0	1.0808	0.033	2	0.5
2	2012	3	1	1	0	1.0407	0.03	2	0.5
2	2013	3	1	1	0	1.0141	0.028	2	0.5
2	2014	3	1	1	0	1.3351	0.032	2	0.5
2	2015	3	1	1	0	1.2551	0.029	2	0.5
2	2016	3	1	1	0	1.056	0.027	2	0.5
2	2017	3	1	1	0	1.0065	0.03	2	0.5
2	2018	3	1	1	0	1.2361	0.032	2	0.5
2	2019	3	1	1	0	1.1534	0.027	2	0.5

Number of length frequency matrices
#3
2
Number of rows in each matrix
35 29
#30
Number of bins in each matrix (columns of size data)
17 17
#17
SIZE COMPOSITION DATA FOR ALL FLEETS
SIZE COMP LEGEND
Sex: 1 = male, 2 = female, 0 = sexes combined
Type of composition: 1 = retained, 2 = discard, 0 = total
Maturity state: 1 = immature, 2 = mature, 0 = both states
Shell condition: 0 = both shell types combined
Type 1 effective sample: Nsamp
Retain catch size comp

##Year,	Seas,	Fleet,	Sex,	Type,	Shell,	Maturity,	Nsamp,	DataVec					
1985	3	1	1	1	0	0	47	0	0	0	0	0	0.002
1986	3	1	1	1	0	0	9	0	0	0	0	0	0.001
1987	3	1	1	1	0	0	50	0	0	0.004	0	0.00055	0.003

1988	3	1	1	1	0	0	291	0	0	0	0	0.00025	0.005
1989	3	1	1	1	0	0	655	0	0	0	0.000	0.00019	0.008
1990	3	1	1	1	0	0	135	0	0.000	0.000	0	0.00034	0.006
1991	3	1	1	1	0	0	116	0	0	0	0	0.00029	0.006
1992	3	1	1	1	0	0	41	0	0	0.000	0.000	0.00045	0.005
1993	3	1	1	1	0	0	281	0	0	0	0	0.00127	0.006
1994	3	1	1	1	0	0	264	0	0	0	0	0	0.005
1995	3	1	1	1	0	0	727	0	0	0.000	0	0.00013	0.003
1996	3	1	1	1	0	0	452	0	0.001	0	0.003	0.00446	0.011
1997	3	1	1	1	0	0	445	0	0	0	0	0.00055	0.006
1998	3	1	1	1	0	0	447	0	0	0	0	0.00015	0.002
1999	3	1	1	1	0	0	383	0	0	0	0	0	0.003
2000	3	1	1	1	0	0	360	0	0	0	0	0	0.002
2001	3	1	1	1	0	0	403	0	0.000	0	0	0	0.002
2002	3	1	1	1	0	0	336	0.0004	0	0	0	0	0.001
2003	3	1	1	1	0	0	335	0	0	0	0	0.0001	0.001
2004	3	1	1	1	0	0	231	0	0	0	0	0	0.000
2005	3	1	1	1	0	0	220	0	0	0	0	0	0.001
2006	3	1	1	1	0	0	193	0	0	0	0	0	0.000
2007	3	1	1	1	0	0	165	0.0003	0	0	0	0.00062	0
2008	3	1	1	1	0	0	163	0	0	0	0	0	0.001
2009	3	1	1	1	0	0	141	0	0	0	0	0	0
2010	3	1	1	1	0	0	151	0	0	0	0	0	0.000
2011	3	1	1	1	0	0	132	0	0	0	0	0	0.000
2012	3	1	1	1	0	0	155	0	0	0	0	0	0.001
2013	3	1	1	1	0	0	160	0	0	0	0	0	0.002
2014	3	1	1	1	0	0	139	0	0	0	0	0	0.001
2015	3	1	1	1	0	0	157	0	0	0	0	0	0.000
2016	3	1	1	1	0	0	184	0	0	0	0	0	0.002
2017	3	1	1	1	0	0	176	0	0	0	0.000	0	0.000
2018	3	1	1	1	0	0	180	0	0	0	0.001	0	0.000
2019	3	1	1	1	0	0	177	0	0	0	0	0	0.001

##	Total	catch	size	comp											
##Year,	Seas,	Fleet,	Sex,	Type,	Shell,	Maturity,	Nsamp,	DataVec							
		1990	3	1	1	0	0	0	13	0.0942	0.086	0.084	0.093	0.12217	0.11
		1991	3	1	1	0	0	0	28	0.0462	0.064	0.078	0.084	0.10383	0.117
		1992	3	1	1	0	0	0	24	0.0703	0.085	0.084	0.108	0.11602	0.101
		1994	3	1	1	0	0	0	20	0.1205	0.111	0.092	0.089	0.10685	0.123
		1995	3	1	1	0	0	0	649	0.0365	0.049	0.069	0.088	0.10852	0.128
		1996	3	1	1	0	0	0	296	0.033	0.045	0.061	0.08	0.1005	0.123
		1997	3	1	1	0	0	0	413	0.0327	0.042	0.059	0.077	0.09885	0.121
		1998	3	1	1	0	0	0	333	0.0296	0.042	0.061	0.084	0.1087	0.129
		1999	3	1	1	0	0	0	352	0.0242	0.032	0.043	0.064	0.09039	0.121
		2000	3	1	1	0	0	0	287	0.0222	0.032	0.045	0.063	0.07697	0.111
		2001	3	1	1	0	0	0	296	0.0175	0.024	0.034	0.047	0.06295	0.092
		2002	3	1	1	0	0	0	254	0.0204	0.026	0.032	0.039	0.05208	0.084
		2003	3	1	1	0	0	0	242	0.0147	0.024	0.029	0.04	0.05596	0.09
		2004	3	1	1	0	0	0	174	0.0127	0.017	0.024	0.033	0.055	0.08
		2005	3	1	1	0	0	0	135	0.0066	0.009	0.01	0.016	0.02939	0.042
		2006	3	1	1	0	0	0	83	0.005	0.009	0.011	0.014	0.02415	0.038
		2007	3	1	1	0	0	0	78	0.0028	0.004	0.005	0.008	0.01826	0.033
		2008	3	1	1	0	0	0	66	0.0039	0.005	0.008	0.012	0.02182	0.042
		2009	3	1	1	0	0	0	55	0.004	0.005	0.009	0.015	0.02396	0.048
		2010	3	1	1	0	0	0	63	0.0074	0.009	0.014	0.02	0.03743	0.057
		2011	3	1	1	0	0	0	62	0.0049	0.007	0.01	0.014	0.02171	0.039
		2012	3	1	1	0	0	0	57	0.0023	0.005	0.007	0.007	0.01942	0.037
		2013	3	1	1	0	0	0	71	0.0038	0.007	0.01	0.016	0.0268	0.051
		2014	3	1	1	0	0	0	57	0.0042	0.006	0.01	0.016	0.02694	0.047
		2015	3	1	1	0	0	0	73	0.0053	0.009	0.014	0.022	0.03282	0.054
		2016	3	1	1	0	0	0	90	0.0087	0.008	0.014	0.019	0.04065	0.066
		2017	3	1	1	0	0	0	77	0.0058	0.007	0.013	0.02	0.03253	0.085
		2018	3	1	1	0	0	0	136	0.0038	0.006	0.01	0.017	0.04301	0.08
		2019	3	1	1	0	0	0	86	0.0007	0.002	0.005	0.009	0.02372	0.079

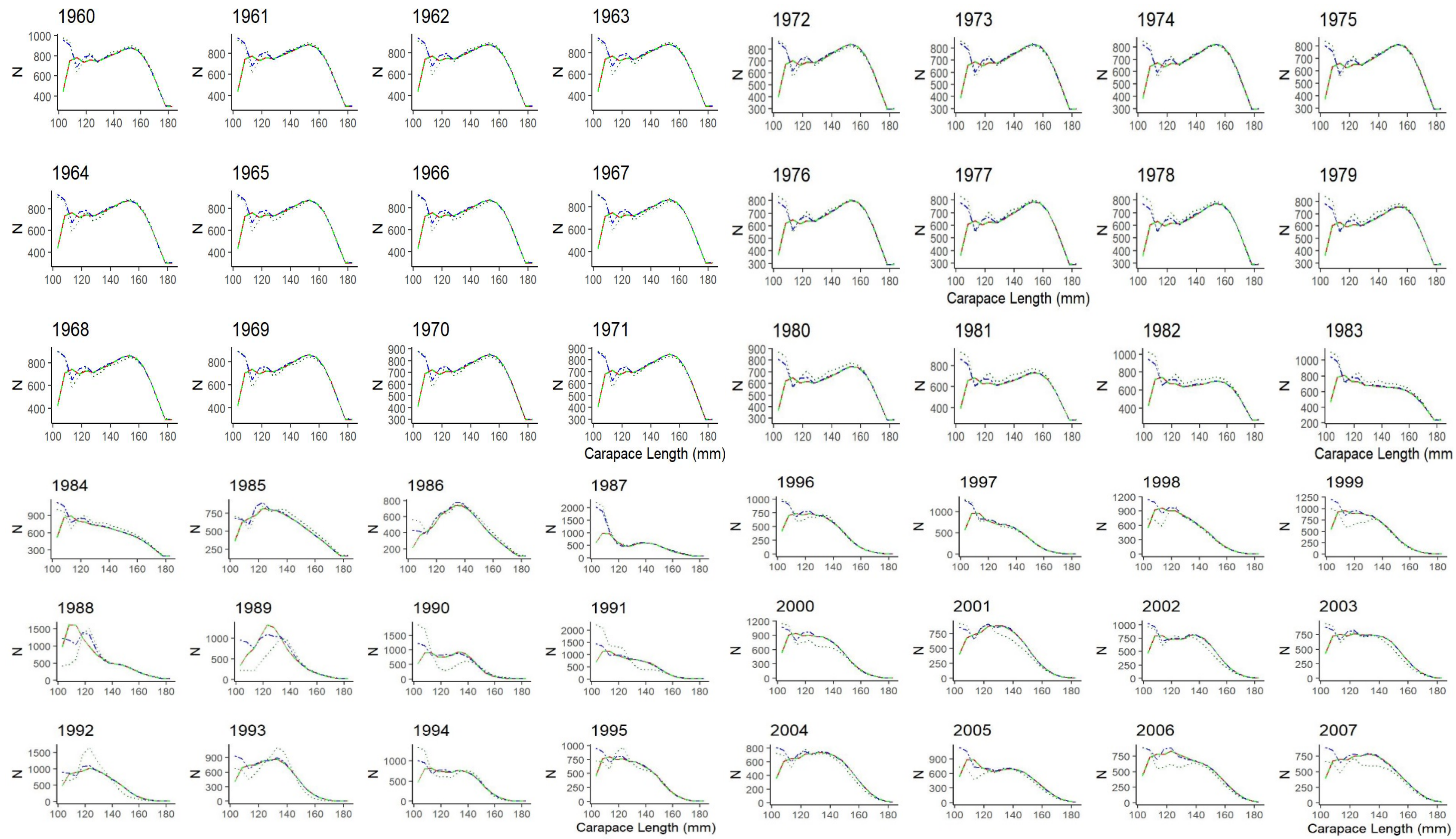
#														
##	Trawl	byc	size	comp										
##Year,	Seas,	Fleet,	Sex,	Type,	Shell,	Maturity,	Nsamp,	DataVec						
#1989	5	2	1	2	0	0	4	0	0.0545	0.127	0.091	0.073	0.09091	0.127
#1990	5	2	1	2	0	0	6	0.074	0.0465	0.039	0.066	0.078	0.03876	0.101
#1992	5	2	1	2	0	0	1	0	0.1667	0	0.167	0.167	0.16667	0
#1993	5	2	1	2	0	0	1	0	0	0.25	0	0.25	0	0
#1994	5	2	1	2	0	0	2	0.167	0.2407	0.185	0.167	0.074	0.03704	0.019
#1995	5	2	1	2	0	0	2	0.037	0.037	0.037	0.148	0.111	0.11111	0.185
#1996	5	2	1	2	0	0	2	0	0	1	0	0	0	0
#1997	5	2	1	2	0	0	4	0.096	0.0769	0.058	0.135	0.115	0.13462	0.115
#1998	5	2	1	2	0	0	7	0.088	0.0949	0.066	0.08	0.153	0.12409	0.058
#1999	5	2	1	2	0	0	7	0.152	0.1714	0.057	0.086	0.076	0.08571	0.029
#2000	5	2	1	2	0	0	8	0.197	0.171	0.068	0.063	0.063	0.05386	0.063
#2001	5	2	1	2	0	0	6	0.076	0.0714	0.107	0.103	0.083	0.05804	0.06
#2002	5	2	1	2	0	0	7	0.225	0.2143	0.132	0.093	0.126	0.03297	0.055
#2003	5	2	1	2	0	0	8	0.301	0.1399	0.07	0.091	0.063	0.05594	0.056
#2004	5	2	1	2	0	0	5	0.095	0.0476	0.048	0.048	0.048	0	0
#2005	5	2	1	2	0	0	6	0.268	0.1959	0.082	0.082	0.052	0.05155	0.021
#2006	5	2	1	2	0	0	7	0.269	0.1346	0.115	0.096	0.067	0.06731	0.058
#2007	5	2	1	2	0	0	8	0.257	0.2163	0.122	0.073	0.082	0.07755	0.037
#2008	5	2	1	2	0	0	7	0.229	0.2048	0.117	0.083	0.052	0.05714	0.052
#2009	5	2	1	2	0	0	8	0.174	0.0413	0.025	0.058	0.107	0.05785	0.058
#2010	5	2	1	2	0	0	12	0.184	0.2175	0.154	0.103	0.091	0.06647	0.063
#2011	5	2	1	2	0	0	6	0.324	0.1639	0.172	0.107	0.049	0.05328	0.02
#2012	5	2	1	2	0	0	9	0.063	0.0833	0.083	0.083	0.042	0.02083	0.021
#2013	5	2	1	2	0	0	8	0	0	0	0	0.059	0	0.059
#2014	5	2	1	2	0	0	8	0.063	0	0.031	0.125	0.094	0.09375	0.063
#2015	5	2	1	2	0	0	5	0.116	0.1053	0.116	0.116	0.137	0.12632	0.105
#2016	5	2	1	2	0	0	6	0.039	0.0789	0.118	0.118	0.158	0.14474	0.066
#2017	5	2	1	2	0	0	6	0.304	0.1957	0.098	0.054	0.043	0.03261	0.043
#2018	5	2	1	2	0	0	4	0.286	0.119	0.119	0.048	0.071	0.09524	0.048

#2019	5	2	1	2	0	0	4	0.158	0.1228	0.175	0.07	0.088	0.05263	0.105
#														
##	Growth	data	(increment)											
#	Type	of	growth	increment										
0														
#	nobs_growth													
0														
#	Class-at-release;	Sex;	Class-at-recapture;	Years-at-liberty;	number	transition	matrix;							
	RecaptureFleet	Recapture	Year											
#not considered														
##	eof													
9999														

Table F3. gmacs EAG19.1. prj file.

	0		Do	not	compute	MSY	(1=Yes)			
	1	1	if	future	F	is	to	be	fixed	
	1987	2017	for	Rbar		calc,				
	1985	2019	First	and	last	year	for	average	sex	ratio
	2010	2019	First	and	last	year	for	average	F	for discards
#	OFL	specifications								
	0.35	Target	SPR	ratio	for	Bmsy	proxy.			
	3	Tier								
	0.1	Alpha								
	0.25	Beta								
	1	Gamma								
	0.75	ABC-OFL	buffer							
	0	Produce	a	yield	curve or not					

#	Projection	material								
	2020	#	Last	year	of	projection	from	the	terminal	year
	1	#	Number	of	strategies					
	0	0.7	Range	of	F	values				
	1	mortality	for	non-directed						
	2	Mcmc	replicates	per	draw					
	-3423.8	Fixed	BMSY	(negative	number	for	replicate-specific)			
	1	Stock-recruitment		option	(1=Mean	Rec;2=Ricker;3=BH;4=Mean	and	CV)		
	8	age-at-recruitment								
#										
	1960	2019	First	and	last	years	for	generating	future	recruitment
	2294	Mean	recruitment	for	projections					
	0.6	SigmaR	only	used	if	Stock_recruitment	option	2		
	0.2	ProwR								
	-999	first	rec_dev,	set	to	-999	to	generate	it	
#	State	strategy								
	0	Apply	strategies	[OFL,	ABC]	(1=yes;0=no)				
	0.00135303	#	Mean	weight	(mature	in	t)			
	0.00196451	#	Mean	weight	(legal	in	t)			
#	Stop	after	XX	mcdraws						
	10000									
##	eof									
9999										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Carapace Length (mm)

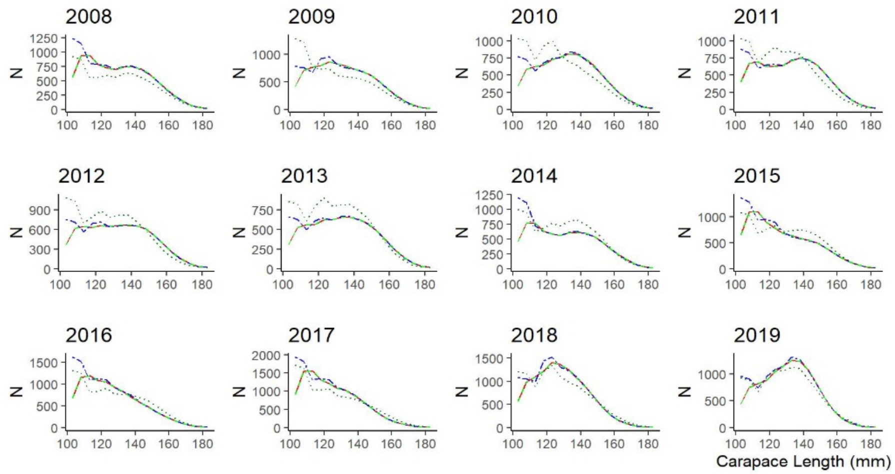

Figure F1. Comparison of time series of abundance by size (N-matrix) of EAG golden king crab, 1960–2019 [blue: OrignalEAG19.1; red: ModifiedEAG19.1; dark green: gmacs run#9 (free parameters); green: gmacs run#10(fixed parameters)]

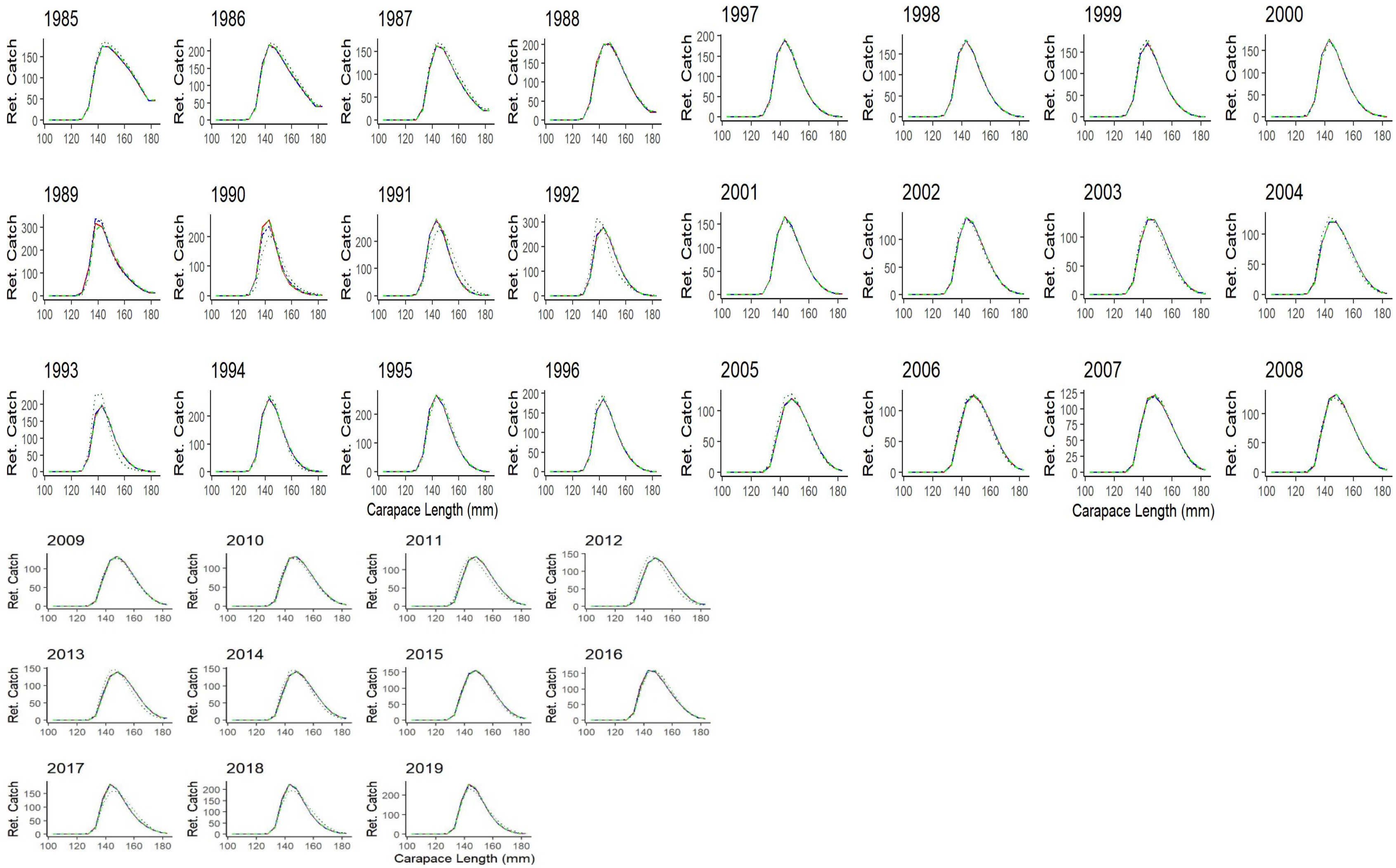

Figure F2. Comparison of time series of retained catch by size of EAG golden king crab, 1985–2019 (blue: OrignalEAG19.1; red: ModifiedEAG19.1; dark green: gmacs run#9; green: gmacs run#10)

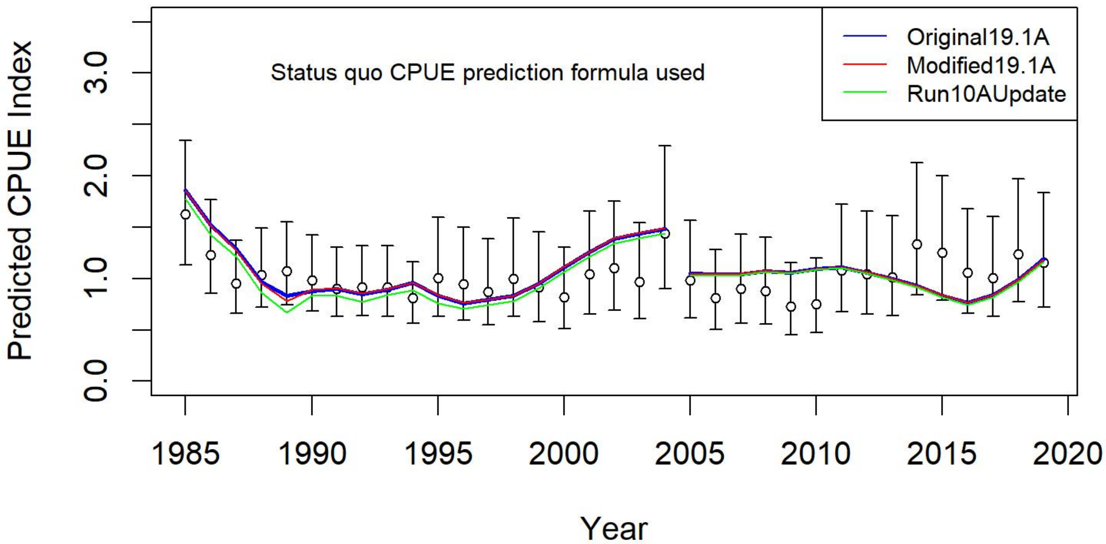

Figure F3. Comparison of time series of CPUE indices for EAG golden king crab, 1995–2019 (blue: OrignalEAG19.1A; red: ModifiedEAG19.1A; green: gmacs run#10AUpdate). For this comparison, the gmacs base model was slightly modified (update) to instantaneously remove catches at the middle of the fishing period.