Aleutian Islands Golden King Crab Model-Based Stock Assessment

May 2019 Crab SAFE DRAFT REPORT

M.S.M. Siddeek[1,] J. Zheng[1], C. Siddon[1], B. Daly[2], M.J. Westphal[3], and L. Hulbert[1]
[1]Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 115526, Juneau, Alaska 99811
[2]Alaska Department of Fish and Game, Division of Commercial Fisheries, 351 Research Ct., Kodiak, Alaska 99615
[3]Alaska Department of Fish and Game, Division of Commercial Fisheries, PO Box 920587, Dutch Harbor, Alaska 99692.

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 commercial fishery has been prosecuted since 1981/82 and opened every year since then. 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 for the first time in 1996/97. The GHL was subsequently reduced to 1,361 t (3,000,000 lb beginning in 1998/99 for EAG. The reduced GHLs remained at 1,361 t (3,000,000 lb) for EAG and 1,225 t (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 regime changed from GHL to TAC (Total Allowable Catch) with crab rationalization in 2005/06. The TACs were further 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.

   Catches have been steady since the introduction of GHL/TAC and the fishery has harvested close to TAC levels since 1996/97. These TAC levels were 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 limit catch) under the most recent crab management plan. The below par fishery performance in WAG in recent years 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 2015/16 through 2017/18 fishing seasons. Following the BOF recommendation in March 2018 to change the TAC based on stock status and fishery performance, the TACs were increased to 1,134 t (2,500,000 lb) for WAG and 1,749 t (3,856,000lb) for EAG beginning with the 2018/19 fishing season. A new harvest strategy based on model estimated mature male abundance was accepted by the BOF in March 2019, 15% maximum harvest rate for EAG and 20% maximum harvest rate for WAG and is expected to be implemented for the 2019/20 fishery. In addition to the retained catch that is 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 on-board observer program, and towards a $500,000 goal in 2015/16 to 2018/19 in order to fund an on-board observer program and golden king crab in-fishery stock survey..

Catch per unit effort (CPUE, i.e., pot lift) of retained legal males decreased from the 1980s into the mid-1990s but increased steadily after 1994/95 and increased markedly at 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). Total retained catch in 2018/19 was 2,965 t (6,535,586 lb): 1,830 t (4,034,242 lb) from the EAG fishery, which included cost-recovery catch, 1,135 t (2,501,344 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 since 2004/05, except as surveys for red king crab conducted under a commissioner's permit (and there were none 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 2018/19 was 240 t (528,954 lb) for EAG and 140 t (309,038 lb) for WAG. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries but is relatively small relative to that during the directed fishery. Groundfish fisheries are a minor contributor to total fishery mortality. Estimated bycatch mortality during groundfish fisheries in 2018/19 was 8 t (17,275 lb) for EAG and 2 t (5,046 lb) for WAG. A cooperative golden king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G during the EAG fishery in August 2018, by vessels that were simultaneously fishing. During the survey work, adjustments were made to a portion of the gear so escape mechanisms were no longer functional. However, for the purpose of catch accounting for 2018/19, it was assumed that bycatch mortality that occurred during the survey was accounted for by reported discards for the 2018/19 EAG fishery.

3. *Stock biomass*

Estimated mature male biomass (MMB) for EAG under all scenarios decreased from high levels during the 1980s to the 1990s, then systematically increased during the 2000s and sharply increased since 2014. Estimated MMB for WAG decreased during the late 1980s and 1990s, systematically increased during the 2000s, and decreased for several years since 2009 and started to increase 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, the model recruitment was high in 2014 and 2015, and highest in 2015-2016; and lowest in 1986. The model recruitment for WAG was high during 1984 to

1986 and highest in 1985; and lowest in 2011. A reducing trend in recruitment was observed since the early-1990s in WAG.

5. *Management performance*

The 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. This was followed for the second season in 2018/19. The CPT in May 2017 and SSC in June 2017 accepted author's 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 added to calculate OFL and ABC for the entire stock.

Among the three common scenarios for EAG and WAG, we recommend two scenarios [19_1 (re-evaluation of observer CPUE indices after reducing the number of gear codes) and 19_2a (Year and Area interaction factor considered in the observer CPUE standardization) for EAG or 19_2 for WAG. Scenario 19_0 is the base scenario with the knife edge male maturity at 111 mm CL, an M of 0.21yr^{-1} and the addition of 2018/19 data. Scenarios 19_1 and 19_2a or 19_2 are modifications from the base scenario.

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]
2015/16	N/A	N/A	2.853	2.729	3.076	5.69	4.26
2016/17	N/A	N/A	2.515	2.593	2.947	5.69	4.26
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19[c]	6.046	17.952	2.883	2.965	3.355	5.514	4.136
2019//20[d]	5.976	16.095				5.264	3.948.
2019/20[e]	5.990	16.000				5.189	3.892
2019/20[f]	5.881	15.978				5.263	3.947
2019/20[g]	**5.880**	**15.944**				**5.249**	**3.937**
2019/20[h]	**5.904**	**13.861**				**4.380**	**3.285**

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]
2015/16	N/A	N/A	6.290	6.016	6.782	12.53	9.40
2016/17	N/A	N/A	5.545	5.716	6.497	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19[c]	13.329	39.577	6.356	6.536	7.396	12.157	9.118
2019//20[d]	13.174	35.483				11.606	8.704
2019/20[e]	13.204	35.274				11.440	8.580
2019/20[f]	12.965	35.225				11.603	8.702
2019/20[g]	**12.964**	**35.150**				**11.572**	**8.679**
2019/20[h]	**13.018**	**30.558**				**9.656**	**7.242**

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. 2018/19 accepted scenario (up to 2016/17 data, includes Francis method of re-weighting).
d. 18_0 base scenario (up to 2017/18 data, includes Francis method of re-weighting).
e. 18_1 scenario: 18_0 modified with number of gear code reduced for observer CPUE standardization.
f. 19_0 scenario: same as 18_0 with 2018/19 data.
g. 19_1 scenario: same as 18_1 with 2018/19 data.
h. 19_2 scenario: same as 19_1 with Year and Area interaction in the observer CPUE standardization.

6. *Basis for the OFL*

The length-based model developed for the Tier 3 analysis estimated MMB on February 15 each year for the period 1986 through 2019. The terminal year mature male biomass was projected by an additional year to determine OFL and ABC for the 2019/20 season. The Tier 3 approach uses a constant annual natural mortality (*M*) and the mean number of recruits for the period 1987 – 2012 for OFL and ABC calculation. An *M* of 0.21 yr^{-1} derived from the combined data (Siddeek et al., 2018) was used.

We provide the OFL and ABC estimates for EAG and WAG separately and combined (i.e., for the entire Aleutian Islands, AI) for three scenarios 18_0, 18_1, 19_0, 19_1, and 19_2 (or 19_2a) in the following six tables. We treat scenario 19_0 as the base scenario for EAG and WAG.

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. For 18_... scenarios, Current MMB = MMB on 15 Feb. 2019; and for 19_... scenarios, Current MMB = MMB on 15 Feb. 2020.

Scenario	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)
EAG18_0	3a	14.982	23.682	1.58	0.644	1987–2012	0.644	8.141	7.978	6.106
EAG18_1	3a	14.958	23.327	1.56	0.644	1987–2012	0.644	7.928	7.770	5.946
EAG19_0	3a	14.517	22.561	1.55	0.660	1987–2012	0.660	7.564	7.522	5.673
EAG19_1	3a	14.516	22.494	1.55	0.660	1987–2012	0.660	7.536	7.494	5.652
EAG19_2a	3a	14.629	18.587	1.27	0.640	1987–2012	0.640	5.856	5.811	4.392

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

Scenario	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)
EAG18_0	3a	6.796	10.742	1.58	0.644	1987–2012	0.644	3,692.810	3,618.954	2,769.608
EAG18_1	3a	6.785	10.581	1.56	0.644	1987–2012	0.644	3,596.260	3,524.335	2,697.195
EAG19_0	3a	6.585	10,234	1.55	0.660	1987–2012	0.660	3,430.984	3,412.054	2,573.238
EAG19_1	3a	6.584	10.203	1.55	0.660	1987–2012	0.660	3,418.287	3,399.176	2,563.715
EAG19_2a	3a	6.635	8.431	1.27	0.640	1987–2012	0.640	2,656.254	2,635.769	1,992.190

WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. For 18_... scenarios, Current MMB = MMB on 15 Feb. 2019; and for 19_ … scenarios, Current MMB = MMB on 15 Feb. 2020.

Scenario	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)
WAG18_0	3a	11.365	11.801	1.04	0.596	1987–2012	0.596	3.465	3.395	2.598
WAG18_1	3a	11.451	11.947	1.04	0.596	1987–2012	0.596	3.512	3.442	2.634
WAG19_0	3a	11.412	12.664	1.11	0.600	1987–2012	0.600	4.039	4.024	3.029
WAG19_1	3a	11.412	12.656	1.11	0.600	1987–2012	0.600	4.036	4.021	3.027
WAG19_2	3a	11.406	11.971	1.05	0.600	1987–2012	0.600	3.800	3.779	2.850

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

Scenario	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)
WAG18_0	3a	5.155	5.353	1.04	0.596	1987–2012	0.596	1,571.490	1,540.060	1,178.618
WAG18_1	3a	5.194	5.419	1.04	0.596	1987–2012	0.596	1,593.020	1,561.160	1,194.765
WAG19_0	3a	5.176	5.744	1.11	0.600	1987–2012	0.600	1,831.940	1,825.151	1,373.955
WAG19_1	3a	5.176	5.741	1.11	0.600	1987–2012	0.600	1,830.847	1,823.914	1,373.135
WAG19_2	3a	5.174	5.430	1.05	0.600	1987–2012	0.600	1,723.882	1,714.360	1,292.912

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

Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
18_0	11.606	11.373	8.704
18_1	11.440	11.212	8.580
19_0	11.603	11.546	8.702
19_1	11.572	11.515	8.679
19_2	9.656	9.590	7.242

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

Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
18_0	5,264.30	5,159.01	3,948.23
18_1	5,189.28	5,085.50	3,891.96
19_0	5,262.92	5,237.21	3,947.19
19_1	5,249.13	5,223.09	3,936.85
19_2	4,380.14	4,350.13	3,285.10

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*
   An x proportion buffer on the OFL; i.e., ABC = (1.0 - x) *OFL. We considered x = 0.25.

See also the section G on ABC.

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

Not applicable.

A. *Summary of Major Changes*

1. *Changes (if any) to management of the fishery*
   - In 2017, proposed changes to OFL and ABC calculation under model–based Tier 3 assessment were accepted.
2. *Changes to input data*
   - Commercial fisheries data were updated with values from the most recent ADF&G Area Management report (Leon et al., 2017) and most recent fish ticket data. Fishery data have been updated with the catches during 2018/19: 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

(1981/82–2018/19), total catch (1990/91–2018/19), and groundfish bycatch (1989/90–2018/19) biomass and size compositions.
- Fish ticket retained CPUE were standardized by the GLM with the lognormal link function for the 1985/86–1998/98 period.
- Observer pot sample legal size crab CPUE data were standardized by the generalized linear model (GLM) with the negative binomial link function with variable selection by R square criterion and CAIC (modified AIC), separately for 1995/96–2004/05 and 2005/06–2018/19 periods. A Year and Area interaction factor was considered in one scenario to estimate a set of CPUE indices.

3. *Changes to assessment methodology*
None

4. *Changes to assessment results*
As expected, the addition of the 2018/19 data changed the OFL and ABC estimates, but changes in parameter or abundance estimates were not dramatic.

B. Response to May 2018 CPT comments

Selected Comments relevant for this assessment:

Comment 2: Reanalyze chela measurement data for AIGKC using new analytical techniques developed for snow crab and Tanner crab.

Response:
We are currently collecting more chela measurement data from the Observer, dockside retained catch, and independent survey (in EAG) sampling. The first set of extended data will not be available for completing the revised analysis for the May 2019 CPT meeting. However, we will complete the re-analysis for May CPT 2020 presentation.

We are also collecting additional length-weight data during the 2018/19 fishing season from the independent survey sampling which covers all sizes and both regions. These data will enable us to update the length-weight relationship separately for EAG and WAG. We will complete this analysis for the May 2020 CPT presentation.

Comment 3: Work on appropriate statistical models for analysis of ADF&G cooperative pot survey that reflect the nested sampling design of vessels, strings within vessel, and pots within strings and consider the use of random effects as appropriate.

Response:
We have completed the cooperative survey for four fishing seasons (2015/16, 2016/17, 2017/18, and 2018/19) in the EAG region. We also extended the survey for the first time in the WAG region in 2018/19. However, the time series is not long enough to provide meaningful results. We will follow the random effect approach and present preliminary results at the 2020 CPT meeting as per CPT recommendation.

Comment 5: Continue exploration of year-area interactions using appropriate analytical methods and develop area weights using fishing footprint calculations.

Response:
We investigated the Year and Area interaction effect on observer CPUE indices calculation in this report. Scenarios 19_2 (WAG) and 19_2a (EAG) considered the interaction term in the CPUE standardization. Appendix B provides the details.

Comment 6: A standard set of plots should be prepared to summarize the B0 calculations for each model-based crab assessment, including AIGKC. Plot 1 should compare dynamic B0 and the estimated time series of mature male biomass. Plot 2 should plot the B0 depletion ratio, MMB/B0. Plot 3 should plot the estimated recruitment time series. These plots should be collated and used to develop recommendations on the use of B0 in Bering Sea crab assessments at the September 2018 CPT meeting for subsequent SSC review. This should be flagged as a general recommendation applicable to all assessed stocks.

Response:
B0 analysis is done for the three scenarios, 19_0, 19_1, and 19_2 (or 19_2a). See Figures C.1 (EAG) and C.2 (WAG) in Appendix C.

Response to June 2018 SSC comments:

Selected Comments relevant for this assessment:

Comment 1: The SSC reminds all stock assessment authors to implement the guidelines for model numbering for consistency and easier version tracking over time. The authors should use their best estimate of catch for current and future years to get the best estimate of projected ABC/OFLs. The groundfish stock assessment authors have adopted methods to do this, such as using the 3-year average ratio of catch/TAC.

Response:

We followed CPT suggested model numbering. For example, When the base scenario 18_0, which is the 2018 model with up to 2017/18 data, is used with up to 2018/19 data, we labeled the model as 19_0.

Because we are using the currently completed fishery data (2018/19) this time, the recommended approach is not needed.

Comment 2: There is continued high uncertainty about maturity. Using knife-edge maturity, as currently implemented, was an interim fix due to problems with estimating maturity at size. We support and encourage efforts to obtain additional chela measurements to improve the parameterization of maturity in the model as a probabilistic function of size (e.g., logistic).

Response:
We will be developing a logistic maturity curve with the additional data analysis (see our response to CPT comment #2).

Comment 3: We encourage the co-operative survey to be continued and endorse further work to include this independent survey into the model. The SSC specifically endorses the CPT recommendation to use nested random effects for strings within vessels and for pots within strings in a mixed-effects model.

The SSC also requests the authors to include a brief description of the cooperative survey in the document, including the area sampled, size composition, and a summary of trends in CPUE.

Response:
We will provide a description of the survey in consultation with the independent survey project leader.

Comment 5: The CPT noted that the year effect is not appropriate as an abundance index in the presence of interactions and recommended use of the "fishing footprint" as a measure of area, then use of area weights to compute the annual abundance index. The SSC supports this recommendation but notes that, like the VAST analyses, the 'fishing footprint' needs to be clearly defined and a rationale for how it is quantified needs to be developed before further pursuing year-area interactions in the model.

Response:
We identified the fishing footprints based on the observer pot sampling locations in the 1995/96 to 2018/19 database. We used a geostatistical package in R to allocate the fishing footprints to 30X30 nmi cell grids for Year and Area interaction investigation (see Appendix B). Please see our response to CPT comment #5.

Response to January 2019 CPT comments

Comment 1:
The projection for the 2018/19 fishing year should be based on setting the retained catch to the 2018/19 TAC (because catches closely mimic the TACs for AIGKC) and assuming that groundfish bycatch for 2018/19 equals the recent three-year mean groundfish bycatch. The assumed removals should be listed in Table 2 (with annotations that the catches concerned are assumed). No catch composition data for the 2018/19 fishing year should be generated based on averaged past data.

Response:
Because we are using the currently completed fishery data (2018/19), this recommendation is no longer needed.

Comment 2:

Scenario 18_1a should be dropped because the suggested approach for adjusting pot bycatch is plausible at the individual pot level, but not at the total bycatch level.

Response:
We have dropped this scenario in the current analysis.

Comment 3:

Add a new scenario based on a revised definition of "area" when conducting the CPUE standardization – consideration should be given to including an interaction between year and the revised area definition in the standardization model. If an area*year interaction is supported, the final index should be an area-weighted index

Response:
We investigated the Year and Area interaction effect on observer CPUE indices calculation. We identified scenarios 19_2 (WAG) and 19_2a (EAG) that include observer CPUE indices estimated considering Year and Area interaction. Appendix B provides the details.

In relation to the results presented, the CPT requested the following:

Comment 4:

The next assessment should report results from the May 2017, September 2017, and May 2018 assessments as well as those from the new scenarios to enable an evaluation of the impact of changes to the model and the data.

Response:

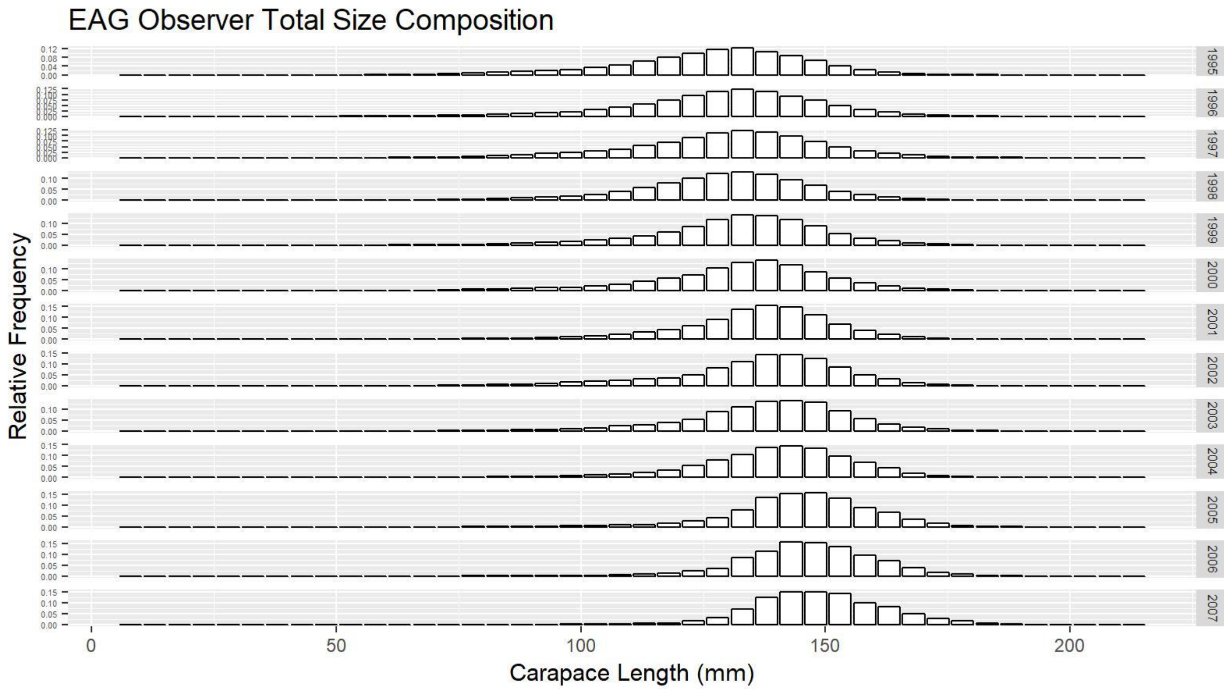
We have identified the progression of years in the previous and current model scenarios appropriately. For example, see Figure 26 for comparison of MMB time series estimates that include up to 2016/17, 2017/18, and 2018/19 data and Figures B.2 and B.3 in Appendix B for input CPUE indices based on up to 2015/16, 2016/17, 2017/18, and 2018/19 data.

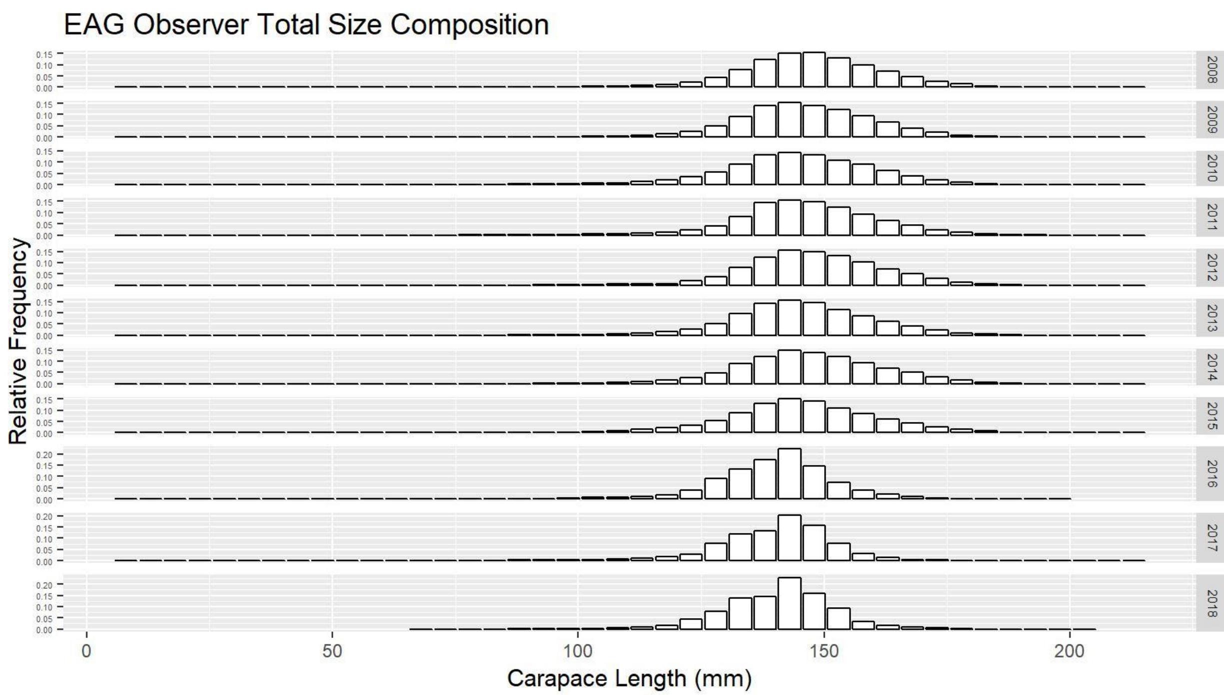
Comment 5:

The increase in MMB in the last year of the assessment for the EAG is caused by a large recruitment three years ago, but this increase is not reflected in the standardized CPUE – the analysts should identify what in the data (e.g. the length-compositions) are the cause of the increased recruitment. Showing the fits to the length-composition data may help identify whether there is a basis in the data for higher estimated recruitment.

Response:

We provide the observer collected relative total size compositions to justify the possibility of high recruitment to wider size groups until 2015 in EAG and then the total catch size range narrowing down during 2016 to 2018.





Comment 6:

The results of the three scenarios are hard to distinguish in the figures. Whether they are actually different needs to be checked.

Response:
Scenarios 19_0 and 19_1 result are largely indistinguishable because only the gear codes were reduced in the CPUE standardization. Therefore, we identified scenario 19_1 with orange points for differentiation in most of the plots.

Comment 7:

The time-trajectories for dynamic B_0 should be clearly labelled in figures such as 17 and 18.

Response:
Done. See Figures C.1 (EAG) and C.2 (WAG) in Appendix C.

Comment 8:

The survey data will not be included in the assessment formally until the 2020 assessment. However, there would be value in plotting the length-composition data from the survey as it may provide evidence in support of the large estimated recent recruitment.

Response:

We have not yet analyzed the survey data.

Response to February 2019 SSC comments

Comment 1:
exploration of geostatistical models (e.g., VAST) for spatial analysis of the NMFS and ADF&G survey information,

Response:
We have postponed analysis of observer data using VAST pending the presentation by the developer on applicability of VAST to crab stocks in May 2019 CPT.

Comment 2:
removing one dataset at a time from the model to identify the source of the large estimated recruitment three years ago; the CPUE time series does not show this increase and the source of information for this large recruitment estimate should be identified,

Response:
We have done the retrospective analysis on MMB (Figure 23 for EAG and Figure 41 for WAG). Peeling off the data set year-by-year show some spread on MMB time series for EAG but not for WAG, which may suggest influx of large recruitment in recent years! When we added the new data set 2018/19, the recruitment pulse did not disappear (see Figure14).

Comment 3:

exploring the use of the industry survey for purposes other than stock assessment modeling, such as length compositions

Response:
Please see our response to January 2019 CPT comment #8.

Comment 4:

pursuing other CPT recommendations, including a comparison with the May 2017, September 2017, and May 2018 assessments to assess the impact of incremental model and data changes. This type of retrospective comparison among assessment results has been reported in some groundfish assessments and, if routinely reported, would provide useful information on the development of the assessment model.

Response:
Please see our responses to January 2019 CPT comments #4.

Response to some of the June 2018 CIE comments:

We have not completely addressed all the comments made by the reviewers. We addressed some in this report.

A. Comment by Yong Chen:

Specific recommendations:

Short Term:

Comment A.1: More in-depth and structured diagnosis of relative importance of different likelihood functions for different input data sets and how they should be weighted in model fitting. A careful examination of potential temporal trends in residual distribution may be also needed.

Response:

Because size frequency likelihoods consume large part of the total likelihood, for all scenarios we objectively weighted the length composition data by Francis' re-weighting method. We also examined the temporal trends in size compositions fit by bubble plots (Figures 19, 20, 37, and 38). We validated the error model used in the CPUE standardization by the QQ plot.

Comment A.2: Multiple model configurations were used over the time, which reflect different assumptions on the fishery dynamics. I recommend analyzing among-model variations to better understand the structural uncertainty and possible management implications of making changes to the models over the time.

Response:

Because AIGKC model was recently approved for OFL and ABC calculations, the model has not been changed during the last three years of its implementation. Only new data points have been added. Therefore, the comment is not strictly applicable to the AIGKC model.

Comment A.3: I suggest that the assessment model structure be kept relatively stable over time. If a new model or new model configurations/parametrizations need to be used, it should be run in parallel to the old model to identify changes in stock assessment outcomes resulting from changes in model configurations. i.e., New scenarios should be run in parallel to the old one.

Response:
We have kept the assessment model structure relatively stable since the acceptance of the model. We are showing the time trends in input CPUE indices (Figures B.2 and B.3), recruitment (Figures 14 and 32), fishing mortality (Figures 25 and 43), and mature male biomasses (Figure 26) in parallel as a result of changes in model configurations and expansion of input data sources over time.

Comment A.4: Retrospective analysis should be done for all scenarios.

Response:
We did the retrospective analysis for all scenarios: 19_0, 19_1, and 19_2 (or 19_2a).

Comment A.5: The current models estimate model parameters using maximum likelihood function and is not a full Bayesian model. Uncertainty estimates may not be reliable (tend to be under-estimated), which limits the full consideration of uncertainty in stock assessment and management. A full Bayesian model may be more desirable.

Response:
This is debatable for the length-based models. We have not undertaken this step yet.

Comment A.6: VAST type analysis should be carried out for index estimation to capture autocorrelation over space and time of independent survey data.

Response:
The VAST developer will present the applicability of VAST to crab stocks at the May 2019CPT meeting. We will discuss its applicability at the CPT meeting and follow the CPT guidance.

Comment A.7: Jittering should be done to evaluate the sensitivity of model convergence.

Response:
Done for scenarios 19_1 and 19_2 (or 19_2a).

Long-term:

Comment A.8: Given strong seasonality of fishery and life history, a model with season as its time step may better capture the dynamics of fishery and life history. A comparative study may be needed for evaluating possible differences in stock assessments using "year" and "season" as time steps.

Response:
A good suggestion. We will investigate this in the near future.

Comment A.9: Given the importance of the survey data in the assessment, I suggest conducting an extensive computer simulation study based on past data to evaluate the effectiveness of the current survey designs capturing the spatio-temporal dynamics of the stocks.

Response:

A good suggestion. We have not looked into this aspect yet.

Comment A.10: There is a need to evaluate temporal ad spatial variability in key life history parameters such as weight-at-length and maturity-at-length. Mixed-effect model can be used for analysis.

Response:
A good suggestion. We are currently collecting data on weight-at-length and maturity-at-length over time and space. We will consider using appropriate model to analyze these data.

Comment A.11: Constant discard mortality over time and space may not be biologically realistic.

Response:
We will investigate how best to capture this aspect. We presented our first thought at the January 2019 CPT meeting by weighting the mortality rate by overall landing and was not accepted by the CPT.

Comment A.12: Survey for AIGKC should be extended to WAG and more information on small crab need to be collected, in particular for the WAG area.

Response:
We extended the survey to WAG in 2018.

Comment A.13: It is likely that outliers may exist I fisheries data, which may introduce biases in stock assessment results because of log-normal and multinomial likelihood functions tend to be sensitive to outliers in data. Using robust likelihood functions may be more appropriate. Some simulation studies can be done to evaluate possible impacts of using different likelihood functions in the absence and presence of outliers in various input data sets.

Response:
A good thought. We used the robust likelihood function for the length composition data sets. We will investigate its applicability to other likelihood components.

B. Comments by John Neilson:

Comment B.1: Bycatch mortality may vary over season.

Response:
See our response to comment #A.11.

Comment B.2: Past models' projections should have been compared with the current estimates and trends of MMB.

Response:
Yes, we did in this report. See our response to comment #A.3.

Comment B.3: However, there are so many degrees of freedom associated with Gear in the CPUE standardization. Consulting with fishing industry could help obtain realistic and sensible ways of combining gear types that have essentially similar selectivity.

Response:

We reduced the number of gear codes in scenarios 18_1, 19_1, and 19_2 (or 19_2a) with the industry consultation.

Comment B.4: The CPUE standardization attempts to deal with the issue of reduction in number of vessels by considering vessels stayed in the fishery for a long time period.

Response:
Agree.

Comment B.5: The fishery independent survey is not truly independent index because the survey does not standardize for soak time and depth. But useful for the model and sampling young crabs. The industry survey offers the best hope to avoid problems with the changes in the area fished or number of vessels over time. Can test the gear power as well. The coverage should also expand to WAG.

Response:
Agree. We extended the independent survey to WAG in 2018.

Comment B.6: Estimate maturity outside the model.

Response:
We did.

C. Comments by Rauf Kalida:

Comment C.1: Breakpoint analysis is a good approach. Spatial and temporal changes in maturity should also be investigated to improve maturity breakpoint.

Response:
With the additional data currently being collected we will investigate spatio-temporal changes in maturity.

Several other recommendations, such as tagging experiments with DST and PIT tags, larval distribution study, crab ageing, have been made by Rauf in the CIE report, which will be addressed in the future.

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 Japan Sea 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. Leon et al. (2017) define the boundaries of Aleutian Islands king crab Registration Area O:

The Aleutian Islands king crab management area's 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 Maritime Boundary Agreement Line as described in the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990 (Figure 1-1 in Leon et al. 2017). Area O encompasses territorial waters of the state of Alaska (0–3 nautical miles) and waters of the Exclusive Economic Zone (3–200 nautical miles).

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 2). 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 the Alaska Department of Fish and Game (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 more accurately reflect golden king crab stock distribution, coherent 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 similar to 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 12 April 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 one time, 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. **Brief summary of management history:**
   A complete summary of the management history through 2015/16 is provided in Leon et al. (2017, pages 9–14). 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 1,452 t (3,200,000 lb) for EAG and 1,225 t (2,700,000 lb) for WAG (Table 1). During 1998/99–2004/05 the fisheries were managed with 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 with 1,014 t (2,235,000 lb) while keeping the TAC for EAG at the same level as that in the previous season.

During 1996/97–2018/19 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2018/19) has averaged 2% below the annual GHL/TACs. During 1996/97–2018/19, 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 SOA 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 implementation of the 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). 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 IFQ fishery.

Golden king crab may be commercially fished only with king crab pots (defined in 5 AAC 34.050). Pots used to fish for golden king crab in the Aleutian Islands Area must be operated from a shellfish longline and, since 1996, 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 or 5.5 inches) into their gear or, more rarely, included panels with escape mesh (Beers 1992). With regard to 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 that, "… 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 that was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season showed that 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 bottomfish 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 always required on catcher-processor vessels during the fishing season.

Additional management measures include only males of a minimum size may be retained by the commercial golden king crab fishery in the Aleutian Islands Area. By SOA regulation (5 AAC 34.620 (b)), the minimum legal-size limit is 6.0-inches (152.4 mm) carapace width (CW), including spines, which is at least one annual molt increment larger than the 50% maturity length of 120.8 mm CL for males estimated by Otto and Cummiskey (1985). A carapace length (CL) $\geq$136 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007b). Note that 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 (Appendix C). 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.

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 1985/86–2018/19 time series of catches, CPUE, and the geographic distribution of catch during the 2018/19 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 fishermen, personal communication, July 1, 2008) and, after rationalization, 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 CPUE within the areas EAG and WAG generally paralleled each other during 1985/86–2010/11 but diverged during 2011/12–2018/19 (an increasing trend in EAG and a decreasing trend in WAG). Sharp increases in CPUE were observed since 2016 in WAG and 2017 in EAG.

6. Brief description of the annual ADF&G harvest strategy:

In March 2019, the BOF accepted 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), as approved by the BOF in March 2019:

(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/$MMA_{W,(1985-2017)}$)x(MMA_W) or 25 percent of LMA_W, whichever is less; and

(3) if MMA_W is greater than 100 percent of $MMA_{W,(1985-2017)}$, 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) $MMA_{E,(1985-2017)}$ means the mean value of the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery for the period 1985 – 2017;

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

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

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

(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 also has authority to annually receive receipts of $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually-established TAC.

7. Summary of the history of the basis and estimates of MMB_{MSY} or proxy MMB_{MSY}:

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

D. Data

1. Summary of new information:

(a) Commercial fishery retained catch by size, estimated total catch by size, groundfish male discard catch by size, observer CPUE index, commercial fishery CPUE index, and tag-recapture data were updated to include 2018/19 information. The details are given in the pictorial table 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	11	12	..	..	17	18
Ret.C. & Size Comp.																																				
Total C. & Size Comp.																																				
Ground fish ByC. & Size Comp.																																				
Observ. CPUE																																				
Fishery CPUE																																				
Tag release																																				
Tag Recovery																																				

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 1981/82–2018/19 (Table 1). Estimated total catch weight for 1990/91–2018/19 (Table 2a).

b. **Bycatch and discards**:

Retained catch, bycatch mortality (male and female of all sizes included) separated by the crab fishery and groundfish fishery, and total fishery mortality for 1981/82–2018/19 (Table 2). Crab fishery discards are available after observer sampling was established in 1988/89. Some observer data exists for the 1988/89–1989/90 seasons, but those data are not considered reliable. Table 2 provides crab fishery discards and groundfish fishery bycatch for 1991/92–2018/19 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 1985/86–2018/19 (Table 3).

- Estimated commercial fishery CPUE index with coefficient of variation (Table 4 for EAG and Table 13 for WAG). The estimation methods, and CPUE fits are described in Appendix B.

d. Catch-at-length:

Information on length compositions (Figures 9 to 11 for length compositions for EAG; and 27 to 29 for length compositions for WAG).

e. Survey biomass estimates:

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

f. Survey catch–at–length:

They are 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 $a = 3.7255*10^{-4}$, $b = 3.0896$ (updated estimates).
- **Natural mortality**: Model estimated fixed natural mortality value 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 recapture data from these surveys were used.

   Data from the independent pot surveys conducted during 2015 to 2017 in EAG and 2018 in both EAG and WAG were not used in the current assessment. We plan to use them in 2020 model.

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 to using the maturity data to estimate MMB. We followed these suggestions in this report to use the model-based OFL and ABC settings for the third fishing season.

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 male mature biomass (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 CPUE indices as a separate likelihood component in all scenarios (see 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 2005/06–2018/19.

We fitted the observer and commercial fishery CPUE indices with estimated (by GLM) standard errors and an additional 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}. The *M* value was the combined estimates for EAG and WAG (Siddeek et al., 2018). 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 in Appendix A) and logistic selectivity patterns (Equation A.9 in Appendix A) 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 code is available from the authors.

3. Model Selection and Evaluation

a. Description of alternative model configurations:

We considered 5 scenarios for EAG and WAG (Table T1). We presented OFL and ABC results for all scenarios separately for EAG, WAG, and the entire AI in the executive summary tables. We considered scenario 19_0 as the base scenario. 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, 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 (see Equations A.4 and A.5 in Appendix A).

ii) Observer CPUE indices for 1995/96–2018/19.

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 the model fitting); and (Stage-2) iterative re-weighting of effective sample sizes by the Francis method.

v) Two catchability and two sets of logistic total selectivity for the periods 1985/86–2004/05 and 2005/06–2018/19, and a single set of logistic retention curve parameters.

vi) Full selectivity (selectivity =1.0) for groundfish (trawl) 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 time 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 of Appendix A.

Best estimate of parameter values for scenarios 19_1 and 19_2 (or 19_2a) were jittered to confirm model global convergence. The results indicated that global convergence was achieved for almost all the runs (Appendix D).

Table T1. Features of all model scenarios: Initial condition was estimated in year 1960 by the equilibrium condition; a constant 50% knife-edge maturity size of 111 mm CL was used for MMB calculation; two catchability and two sets of logistic total selectivity curves were used for the pre- and post-rationalization periods; and a common *M* based on the estimate from the combined EAG and WAG data was used . Changes from scenario 19_0 specifications are highlighted by the purple shade.

Scenario	**Size-composition weighting**	**CPUE data type**	Natural mortality (M yr^{-1})
18_0	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2017/18; Fish Ticket data from 1985/86–1998/99; and number of gear codes were not reduced for CPUE standardization.	0.21
18_1	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2017/18; Fish Ticket data from 1985/86–1998/99; and number of gear codes were reduced for CPUE standardization	0.21
19_0	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2018/19; Fish Ticket data from 1985/86–1998/99; and number of gear codes were not reduced for CPUE standardization.	0.21
19_1	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2018/19; Fish Ticket data from 1985/86–1998/99; and number of gear codes were reduced for CPUE standardization.	0.21
19_2a (EAG) or 19_2 (WAG)	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2018/19; Fish Ticket data from 1985/86–1998/99; Year and Area interaction factor was considered & number of gear codes were reduced for CPUE standardization.	

b. **Progression of results:**
The OFL and ABC estimates are similar to those estimated by the 2018 model.

c. **Label the approved model from the previous year as model 0:**
Following the September CPT suggestion, we used the notation 19_0 for the base model which came from the previous assessment, 18_0.

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). The five scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the five scenarios 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 and number of fishing trips for groundfish size composition (note: we did not use the groundfish size composition in the model fit) for all 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 scenarios 19_0, 19_1, and 19_2 (or 19_2a) in Tables 5 to 7 for EAG and Tables 14 to 16 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 the 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 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 model with several scenarios 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 scenarios in Tables 5 to 7 for EAG and Tables 14 to 16 for WAG. The weights for different data sets are provided in Table A2 for various scenarios, respectively, for EAG and WAG (Appendix A). 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 to a large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass 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 to 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. We set the CPUE weights to 1.0 for all scenarios. 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 of Appendix A). 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 and lognormal GLMs 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 17 for WAG for all scenarios. The numbers of estimable parameters are listed in Table A1 of Appendix A. The weights with the corresponding coefficient of variations specifications are detailed in Tables A2 of Appendix A for EAG and WAG.

2. **Include tables showing differences in likelihood:**
Tables 12 and 21 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 all scenarios are summarized respectively in Tables 8 and 17 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 scenarios 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 all scenarios are summarized in Tables 9 to 11 for EAG and Tables 18 to 20 for WAG.

d. The recruitment estimates for those scenarios are summarized in Tables 9 to 11 for EAG and Tables 18 to 20 for WAG.

e. The negative log-likelihood component values and total negative log-likelihood values for all scenarios are summarized in Table 12 for EAG and Table 21 for WAG. Scenario 19_2a has the minimum total negative log likelihood for EAG whereas scenario 19_2 has the minimum for WAG. Thus, the input observer CPUE indices with Year and Area interaction appears to have had an effect on the overall fit.

4. **Graphs of estimates:**

a. **Selectivity**:
Total selectivity and retention curves of the pre- and post-rationalization periods for all scenarios are illustrated in Figure 12 for EAG and Figure 30 for WAG. 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 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 six scenarios (2017 assessment time series of MMB estimates were included for comparison) are depicted in Figures 26 for EAG and WAG. Mature male biomass tracked the CPUE trends well for all scenarios for EAG and WAG. The biomass variance was estimated using Burnham et al. (1987) suggested formula (Equation A.14 in Appendix A). We determined the mature male biomass values on 15 February each year and considered the 1987–2012 time series of recruits for estimating mean number of recruits for $MMB_{35\%}$ calculation under Tier 3 approach.

c. **Fishing mortality**:
The full selection pot fishery F over time for all scenarios is shown in Figures 25 and 43 for EAG and WAG, respectively. The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. Slight increases in F were observed since 2014 in the EAG. On the other hand, the F in the WAG peaked in late 1980s, 1990s and early 2000s, then declined in late 2000s and slightly increased since 2010 and decreased since 2014.

d. **F vs. MMB:**
We provide these plots for scenarios 19_1 and 19_2 (or 19_2a) for EAG and WAG in Figure 44. The 2018 F is below the overfishing levels in both regions.

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

f. **Recruitment**:
The temporal changes in total number of recruits to the modeled population for all scenarios 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, respectively for all scenarios.

5. Evaluation of the fit to the data:

g. **Fits to catches:**
The fishery retained, total, and groundfish bycatch (observed vs. estimated) plots for all scenarios are illustrated in Figures 17 and 35 for EAG and WAG, respectively. The 1981/82–1984//85 retained catch plots for all scenarios 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 did not consider the pot survey data for the analysis.

i. **CPUE index data:**
The model predicted CPUE vs. input CPUE indices for all scenarios are shown in Figure 24 for EAG and Figure 42 for WAG. Scenario 19_2 (or 19_2a) predictions dipped lower than other predictions in recent three years. The CPUE variance was estimated using Burnham et al. (1987) suggested formula (Equation A.14 in Appendix A).

j. **Tagging data:**
The predicted vs. observed tag recaptures by length-class for years 1 to 6 recaptures 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 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 for all scenarios are depicted in Figures 16 and 34 for EAG and WAG, respectively. The fits appear to be satisfactory.

l. **Fit to catch size compositions:**

Retained, total, and groundfish discard length compositions are shown in Figures 9 to 11 for EAG and 27 to 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 composition in any of the model scenario fits.

We illustrate the standardized residual plots as bubble plots of size composition over time for retained catch (Figures 19 and 21 for EAG, and 37 and 39 for WAG) and for total catch (Figures 20 and 22 for EAG, and 38 and 40 for WAG) for two scenarios [19_1 and 19_2a (EAG) and 19_2 (WAG)]. The retained catch bubble plots appear random for the selected scenarios.

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 but provided the estimated values in Tables 5 to 7 for EAG and in Tables 14 to 16 for WAG, respectively. The three respective figures are for scenarios 19_0, 19_1, and 19_2 (or 19_2a).

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.

6. **Retrospective and historical analysis:**
The retrospective fits for scenarios 19_0, 19_1, and 19_2 (or 19_2a) are shown in Figure 23 for EAG and in Figure 41 for WAG. The retrospective fits were prepared for the whole time series 1961 to 2018. The retrospective patterns did not show severe departure when five terminal years' data were removed systematically, especially for WAG and hence the current formulation of the model appears stable. The modified Mohn rho values are also given in the figures, which indicate no severe model misspecification (i.e., small rho) (Mohn, 1999; Deroba, 2014). A severe drop in modeled biomass from the initial MMB occurred when the fishery time series started in 1981.

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 is better when the molt probability model is included. Therefore, we included a molt probability sub-model for the size transition matrix calculation in all scenarios.

8. **Conduct 'jitter analysis':**
   We conducted jitter analysis on scenarios 19_1 and 19_2 (or 19_2a). The results indicated that global convergence was achieved for almost all the runs

F. Calculation of the OFL

1. **Specification of the Tier level:**

Aleutian Islands golden king crab has been elevated to Tier 3 level in 2017 for OFL and ABC determination. In the following section, we provide the 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 $MMBB_{MSY}$ reference point estimation are:

a. Natural mortality is constant.
b. Growth transition matrix is fixed and estimated using tagging data with the molt probability sub-model.
c. Total fishery selectivity and retention curves are length dependent and the 2005/06–2018/19 period selectivity estimates are used.
d. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated recruits (in millions of crab) are averaged for the time period 1987– 2012.
f. Model estimated groundfish bycatch mortality values are averaged for the period 2009/10 – 2018/19 (10 years).
g. A knife-edge 50% maturity size is used for MMB estimation.

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 adding a constant number of annual recruits. Once the 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 that produces the 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} is determined using Equation A.28 in Appendix A. The OFL is estimated by an iterative procedure accounting for intervening total removals (see Appendix A for the formulas).

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:

See Management Performance table, below. The OFL and ABC values for 2018/19 in the table below are the recommended values. The TAC for 2015/16-2016/17 in the table below do not include landings towards a cost-recovery fishery goal, but the catches towards cost-recovery fishing are included in the retained and total catch.

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]
2015/16	N/A	N/A	2.853	2.729	3.076	5.69	4.26
2016/17	N/A	N/A	2.515	2.593	2.947	5.69	4.26
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19[c]	6.046	17.952	2.883	2.965	3.355	5.514	4.136
2019//20[d]	5.976	16.095				5..264	3.948.
2019/20[e]	5.990	16.000				5.189	3.892
2019/20[f]	5.881	15.978				5.263	3.947
2019/20[g]	5.880	15.944				5.249	3.937
2019/20[h]	5.904	13.861				4.380	3.285

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]
2015/16	N/A	N/A	6.290	6.016	6.782	12.53	9.40
2016/17	N/A	N/A	5.545	5.716	6.497	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19[c]	13.329	39.577	6.356	6.536	7.396	12.157	9.118
2019//20[d]	13.174	35.483				11.606	8.704
2019/20[e]	13.204	35.274				11.440	8.580
2019/20[f]	12.965	35.225				11.603	8.702
2019/20[g]	12.964	35.150				11.572	8.679
2019/20[h]	13.018	30.558				9.656	7.242

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. 2018/19 accepted scenario (up to 2016/17 data, includes Francis method of re-weighting).
d. 18_0 base scenario (up to 2017/18 data, includes Francis method of re-weighting).
e. 18_1 scenario: 18_0 modified with number of gear code reduced for observer CPUE standardization.
f. 19_0 scenario: same as 18_0 with 2018/19 data.
g. 19_1 scenario: same as 18_1 with 2018/19 data.
h. 19_2 scenario: same as 19_1 with Year and Area interaction in the observer CPUE standardization.

4. Specification of the retained portion of the total catch OFL:

The retained catch portion of the total-catch OFL for EAG, WAG, and the entire Aleutian Islands (AI: EAG + WAG) stock were calculated for the three scenarios [19_0, 19_1, and 19_2 (& 19_2a)]:

Scenario 19_0:
EAG: 3,279 t (7.229 million lb)
WAG: 1,739 t (3.834 million lb)
AI: 5,018 t (11.063 million lb).

Scenario 19_1:
EAG: 3,267 t (7.202 million lb)
WAG: 1,738 t (3.831 million lb)
AI: 5,005 t (11.033 million lb).

Scenario 19_2a (EAG) & 19_2 (WAG):
EAG: 2,522 t (5.560 million lb)

WAG: 1,633 t (3.600 million lb)
AI: 4,155 t (9.160 million lb).

G. Calculation of ABC

1. 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 additional buffer by setting ABC =0.75*OFL
   We provide the ABC estimates with the 25% buffer for EAG, WAG, and AI considering scenarios 19_0, 19_1, and 19_2 (& 19_2a):

   Scenario 19_0:
   EAG: ABC = 2,573 t (5.673 million lb)
   WAG: ABC = 1,374 t (3.029 million lb)
   AI: ABC = 3,947 t (8.702 million lb).

   Scenario 19_1:
   EAG: ABC = 2,564 t (5.652 million lb)
   WAG: ABC = 1,373 t 3.027 million lb)
   AI: ABC = 3,937 t (8.679 million lb).

   Scenario 19_2a (EAG) & 19_2 (WAG):
   EAG: ABC = 1,992 t (4.392 million lb)
   WAG: ABC = 1,293 t (2.850 million lb)
   AI: ABC = 3.285 t (7.242 million lb).

2. **List of variables related to scientific uncertainty:**
   - Model relied 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 independent estimate is not available.
   - The time period to compute the average number of recruits (1987–2012) relative to the assumption that this represents “a time 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 that bycatch occurred during 1981/82–1989/90 were not available.

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

4. **Author recommended ABC:**
   Authors recommend two ABC options based on 25% buffer on the OFL under scenarios 19_1 and 19_2 (or 19_2a).

H. Rebuilding Analysis

Not applicable. This stock has not been declared overfished.

I. Data Gaps and Research Priorities

1. The recruit abundances were estimated from 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 the possibility that additional recruitment may occur through immigration from neighboring areas and possibly separate sub-stocks. 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 will also provide independent estimates of molting probability and growth. We used the 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. We have been using the length-weight relationship established based on late 1990s data for golden king crab. The Aleutian King Crab Research Foundation program can help us to update this relationship by collecting new length weight information. The independent survey has collected length weight data during 2018, which will be analyzed during the next assessment cycle.
7. We have recently included male maturity data in the model to determine a maturity curve for MMB estimation. The maturity data available to us were collected in 1984 and 1991. More data and recent data are needed. ADF&G observer sampling, dock side sampling, and the independent survey programs have collected male maturity data during the 2018/19 fishery. We will analyze the additional data and plan to continue data collection for another season before deciding on continuing this type of data collection.
8. Morphometric measurements provide morphometric maturity size. Ideally, an experimental study under natural environment condition is needed to collect male size at functional maturity data to determine functional maturity size.

J. Acknowledgments

We thank Ethan Nichols, Bo Whiteside, Vicki Vanek, and Andrew Nault for preparing/providing various fisheries and biological data and plots for this assessment; We appreciate the technical and editorial help at various time from Andre Punt, Martin Dorn, William Stockhausen, Steve Martel, Paul Starr, Sherri Dressel, Katie Palof, Hamazaki Hamachan, Karla Bush, William Bechtol, CPT and SSC members, and industry personnel.

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Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2018/19: 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– 2018/19, 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 1996/97.

Crab Fishing Season	***Vessels***	**GHL/TAC**	**Harvest**[a]	**Crab**[b]	**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[b]		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[b]		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]

Note:

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

Table 2. Annual weight of total fishery mortality to Aleutian Islands golden king crab, 1981/82 – 2018/19, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries. For bycatch in the federal groundfish fisheries, historical data (1991–2008) are not available for areas east and west of 174W, and are listed for federal groundfish reporting areas 541, 542, and 543 combined. The 2009– present data are available by separate EAG and WAG fisheries and are listed as such. A mortality rate of 20% was applied for crab fisheries bycatch, and a mortality rate of 50% for groundfish pot fisheries and 80% for the trawl fisheries were applied.

Season	Retained Catch (t)		Bycatch Mortality by Fishery Type (t)				Total Fishery Mortality (t)		
			Crab		Groundfish				
	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	3	3	1,785	1,163	2,947
2017/18	1,571	1,014	219	126	10	2	1,801	1,142	2,942
2018/19	1,830	1,135	240	140	8	2	2,078	1,277	3,355

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 (1990/91–2018/19). The crab weights are for the size range ≥ 101mm CL and 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	1,623	3,684
1991/92	5,899	2,565
1992/93	5,580	1,517
1993/94	NA	2,814
1994/95	2,017	4,942
1995/96	3,734	2,128
1996/97	2,059	1,763
1997/98	2,548	1,793
1998/99	2,797	1,085
1999/00	2,280	2,087
2000/01	2,555	2,228
2001/02	2,097	2,133
2002/03	1,800	1,889
2003/04	1,816	1,855
2004/05	1,619	1,874
2005/06	1,717	1,786
2006/07	1,615	1,542
2007/08	1,791	1,602
2008/09	1,790	1,721
2009/10	1,750	1,667
2010/11	1,735	1,580
2011/12	1,748	1,506
2012/13	1,919	1,812
2013/14	1,818	1,895
2014/15	1,939	1,583
2015/16	2,099	1,548
2016/17	2,218	1,545
2017/18	2,035	1,155
2018/19	2,643	1,507

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 Scenario19_1) for the EAG and WAG golden king crab stocks, 1985/86–2018/19. 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	2.17	11.83	13.00	26.67	106,281	108,533	138	340		
1991/92	8.20	7.40	17.56	7.07	42.16	17.26	133,428	101,429	377	857		
1992/93	8.40	5.90	10.44	4.24	34.84	11.35	133,778	69,443	199	690		
1993/94	7.80	4.40	5.91	12.75	23.50	21.25	106,890	127,764	31	174		
1994/95	5.90	4.10	4.66	6.62	18.43	19.52	191,455	195,138	127	1,270		
1995/96	5.90	4.70	6.03	6.03	20.36	17.30	177,773	115,248	6,388	5,598	1.00	1.16
1996/97	6.50	6.10	6.02	5.90	16.71	14.85	113,460	99,267	8,360	7,194	0.94	1.01
1997/98	7.30	6.60	7.99	6.72	20.66	15.54	106,403	86,811	4,670	3,985	0.87	1.03
1998/99	8.90	11.40	9.82	9.43	28.27	23.09	83,378	35,975	3,616	1,876	1.00	1.08
1999/00	9.00	6.30	10.28	6.09	23.27	14.83	79,129	107,040	3,851	4,523	0.92	0.93
2000/01	9.90	7.00	10.40	6.46	26.77	16.76	71,551	101,239	5,043	4,740	0.82	0.87
2001/02	11.70	6.50	11.73	6.04	23.60	14.70	62,639	105,512	4,626	4,454	1.04	0.83
2002/03	12.40	8.40	12.70	7.47	23.54	17.37	52,042	78,979	3,980	2,509	1.10	0.90
2003/04	10.90	10.20	11.34	9.33	20.04	18.21	58,883	66,236	3,960	3,334	0.97	1.09
2004/05	18.30	12.10	18.34	11.14	29.36	22.44	34,848	56,846	2,206	2,619	1.44	1.17
2005/06	25.40	21.20	29.52	23.83	38.44	36.16	24,569	30,116	1,193	1,365	0.99	1.17
2006/07	24.80	19.60	25.13	24.01	33.41	33.47	26,195	26,870	1,098	1,183	0.81	1.14
2007/08	28.00	20.00	31.10	21.04	40.38	32.46	22,653	29,950	998	1,082	0.91	1.00
2008/09	27.30	22.40	29.97	24.50	38.36	38.11	24,466	26,200	613	979	0.90	1.14
2009/10	25.90	23.70	26.60	26.55	35.78	34.08	26,298	26,489	408	892	0.73	1.25
2010/11	26.00	20.90	26.40	22.41	36.95	29.12	25,851	29,994	436	867	0.76	1.06
2011/12	37.30	23.40	39.48	23.69	52.25	31.04	17,915	26,326	361	837	1.09	1.10
2012/13	33.02	20.57	37.82	22.86	47.49	30.80	20,827	32,716	438	1,109	1.05	1.07
2013/14	33.67	16.42	35.94	16.94	46.34	25.00	21,388	41,835	499	1,223	1.03	0.82
2014/15	42.29	15.29	47.01	15.28	59.91	22.64	17,002	41,548	376	1,137	1.34	0.72
2015/16	39.41	14.97	43.19	15.80	58.77	22.23	19,376	41,108	478	1,296	1.27	0.76
2016/17	32.45	14.29	36.89	16.75	52.58	24.43	24,470	38,118	617	1,060	1.06	0.85
2017/18	31.46	16.81	35.18	19.28	53.40	25.53	25,516	30,885	585	760	1.02	0.96
2018/19	36.80	19.83	41.57	22.85	62.97	30.61	25,553	29,156	475	688	1.25	1.16

Table 4. Time series of GLM estimated CPUE indices and coefficient of variations (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	1.66	0.06
1986/87	1.30	0.06
1987/88	0.97	0.06
1988/89	1.06	0.05
1989/90	1.05	0.04
1990/91	0.96	0.05
1991/92	0.84	0.05
1992/93	0.89	0.05
1993/94	0.91	0.06
1994/95	0.78	0.05
1995/96	0.71	0.05
1996/97	0.81	0.05
1997/98	1.10	0.05
1998/99	1.31	0.06

Table 5. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 19_0 model 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	51				
1988/89	352	293				
1989/90	792	659			9	4
1990/91	163	136	22	12	13	6
1991/92	140	117	48	26	NA	NA
1992/93	49	41	41	23	2	1
1993/94	340	283	NA	NA	2	1
1994/95	319	266	34	19	4	2
1995/96	879	732	1,117	613	5	2
1996/97	547	455	509	280	4	2
1997/98	538	448	711	390	8	4
1998/99	541	450	574	315	15	7
1999/00	463	386	607	333	14	6
2000/01	436	363	495	272	16	7
2001/02	488	406	510	280	13	6
2002/03	406	338	438	241	15	7
2003/04	405	337	416	228	17	8
2004/05	280	233	299	164	10	5
2005/06	266	221	232	127	12	6
2006/07	234	195	143	79	14	6
2007/08	199	166	134	74	17	8
2008/09	197	164	113	62	15	7
2009/10	170	142	95	52	16	7
2010/11	183	152	108	59	26	12
2011/12	160	133	107	59	13	6
2012/13	187	156	99	54	18	8
2013/14	193	161	122	67	17	8
2014/15	168	140	99	54	16	7
2015/16	190	158	125	69	10	5
2016/17	223	186	155	85	12	6
2017/18	213	177	133	73	12	6
2018/19	218	182	234	128	9	4

Table 6. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 19_1 model 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	51				
1988/89	352	293				
1989/90	792	659			9	4
1990/91	163	136	22	12	13	6
1991/92	140	117	48	26	NA	NA
1992/93	49	41	41	23	2	1
1993/94	340	283	NA	NA	2	1
1994/95	319	266	34	19	4	2
1995/96	879	732	1,117	614	5	2
1996/97	547	455	509	280	4	2
1997/98	538	448	711	391	8	4
1998/99	541	450	574	316	15	7
1999/00	463	385	607	334	14	6
2000/01	436	363	495	272	16	7
2001/02	488	406	510	280	13	6
2002/03	406	338	438	241	15	7
2003/04	405	337	416	229	17	8
2004/05	280	233	299	164	10	5
2005/06	266	221	232	128	12	6
2006/07	234	195	143	79	14	6
2007/08	199	166	134	74	17	8
2008/09	197	164	113	62	15	7
2009/10	170	142	95	52	16	7
2010/11	183	152	108	59	26	12
2011/12	160	133	107	59	13	6
2012/13	187	156	99	54	18	8
2013/14	193	161	122	67	17	8
2014/15	168	140	99	54	16	7
2015/16	190	158	125	69	10	5
2016/17	223	186	155	85	12	6
2017/18	213	177	133	73	12	6
2018/19	218	181	234	129	9	4

Table 7. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 19_2a model 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	51				
1988/89	352	292				
1989/90	792	658			9	4
1990/91	163	135	22	13	13	6
1991/92	140	116	48	28	NA	NA
1992/93	49	41	41	24	2	1
1993/94	340	282	NA	NA	2	1
1994/95	319	265	34	20	4	2
1995/96	879	730	1,117	661	5	2
1996/97	547	454	509	301	4	2
1997/98	538	447	711	421	8	4
1998/99	541	449	574	340	15	7
1999/00	463	384	607	359	14	6
2000/01	436	362	495	293	16	7
2001/02	488	405	510	302	13	6
2002/03	406	337	438	259	15	7
2003/04	405	336	416	246	17	8
2004/05	280	232	299	177	10	5
2005/06	266	221	232	137	12	6
2006/07	234	194	143	85	14	6
2007/08	199	165	134	79	17	8
2008/09	197	164	113	67	15	7
2009/10	170	141	95	56	16	7
2010/11	183	152	108	64	26	12
2011/12	160	133	107	63	13	6
2012/13	187	155	99	59	18	8
2013/14	193	160	122	72	17	8
2014/15	168	139	99	59	16	7
2015/16	190	158	125	74	10	5
2016/17	223	185	155	92	12	6
2017/18	213	177	133	79	12	6
2018/19	218	181	234	138	9	4

Table 8. Parameter estimates and coefficient of variations (CV) with the 2018 MMB (MMB estimated on 15 Feb 2019) for scenarios 19_0, 19_1, and 19_2a for the golden king crab data from the EAG, 1985/86–2018/19. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 19_0		**Scenario 19_1**		**Scenario 19_2a**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.006	2.54	0.006	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-8.24	0.208	-8.24	0.21	-8.25	0.21	-12.0-5.0
log_a (molt prob. slope)	-2.51	0.023	-2.51	0.02	-2.49	0.02	-4.61-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.68	0.03	3.68	0.03	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.38	0.02	3.38	0.02	3.39	0.02	0.,4.4
log_ total sel deltaθ, 2005–18	2.98	0.03	2.98	0.03	2.96	0.03	0.,4.4
log_ ret. sel deltaθ, 1985–18	1.86	0.02	1.86	0.02	1.86	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.834	0.00	4.834	0.003	4.83	0.003	4.0,5.0
log_tot sel θ_{50}, 2005–18	4.923	0.002	4.923	0.002	4.92	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–18	4.915	0.0003	4.915	0.0003	4.92	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.077	0.17	-1.077	0.17	-1.06	0.17	-12.0, 12.0
logq2 (catchability 1995–04)	-0.55	0.13	-0.550	0.13	-0.52	0.15	-9.0, 2.25
logq3 (catchability 2005–18)	-0.77	0.16	-0.766	0.16	-0.79	0.19	-9.0, 2.25
log_mean_rec (mean rec.)	0.85	0.05	0.847	0.05	0.84	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.97	0.07	-0.973	0.07	-1.00	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.21	0.09	-9.207	0.09	-9.21	0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.04	0.39	0.043	0.39	0.05	1.01	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.04	0.43	0.040	0.43	0.04	0.44	0.0,1.0
2018 MMB	11,562	0.21	11,520	0.21	9,126	0.29	

Table 9. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 19_0 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 2019 are restricted to 1985–2019. 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} =22,467 $MMB_{35\%}$=6,585			
1985	1.69	9,527	0.04	9,563	0.06
1986	1.01	7,295	0.04	8,122	0.04
1987	4.23	6,702	0.05	6,352	0.04
1988	3.60	6,760	0.05	5,292	0.05
1989	2.01	5,914	0.06	4,755	0.07
1990	2.96	6,006	0.05	4,296	0.07
1991	3.49	6,108	0.04	4,566	0.06
1992	2.26	6,040	0.04	4,406	0.05
1993	2.16	6,180	0.03	4,445	0.05
1994	2.43	5,707	0.03	4,865	0.04
1995	2.29	5,121	0.04	4,427	0.04
1996	2.22	5,219	0.04	3,832	0.04
1997	3.00	5,470	0.05	3,957	0.04
1998	2.73	6,027	0.05	4,052	0.05
1999	2.86	6,670	0.06	4,468	0.05
2000	2.65	7,240	0.06	5,093	0.06
2001	1.99	7,535	0.06	5,679	0.06
2002	2.48	7,757	0.07	6,164	0.07
2003	2.152	7,967	0.07	6,451	0.07
2004	1.88	7,980	0.07	6,638	0.07
2005	2.81	8,016	0.07	6,766	0.08
2006	2.16	8,228	0.07	6,659	0.08
2007	2.085	8,224	0.07	6,781	0.08
2008	3.09	8,349	0.07	6,912	0.08
2009	2.03	8,614	0.07	6,863	0.08
2010	1.89	8,458	0.07	7,110	0.07
2011	2.25	8,241	0.06	7,211	0.07
2012	2.01	8,037	0.07	7,009	0.07
2013	1.75	7,646	0.07	6,777	0.07
2014	3.16	7,518	0.09	6,488	0.08
2015	4.03	8,157	0.11	6,121	0.09
2016	4.77	9,392	0.14	6,199	0.11
2017	4.05	10,933	0.18	6,942	0.14
2018	2.57	11,562	0.21	8,382	0.18
2019	2.33				

Table 10. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 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 2017 are restricted to 1985–2019. 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} =22,465 $MMB_{35\%}$=6,584			
1985	1.69	9,527	0.04	9,564	0.06
1986	1.01	7,295	0.04	8,122	0.04
1987	4.23	6,702	0.05	6,351	0.04
1988	3.60	6,760	0.05	5,292	0.05
1989	2.01	5,914	0.06	4,755	0.07
1990	2.96	6,006	0.05	4,296	0.07
1991	3.49	6,108	0.04	4,565	0.06
1992	2.26	6,039	0.04	4,406	0.05
1993	2.15	6,179	0.03	4,444	0.05
1994	2.43	5,706	0.03	4,865	0.04
1995	2.29	5,120	0.04	4,426	0.04
1996	2.22	5,219	0.04	3,831	0.04
1997	3.00	5,471	0.05	3,957	0.04
1998	2.74	6,030	0.05	4,052	0.05
1999	2.86	6,675	0.06	4,469	0.05
2000	2.65	7,247	0.06	5,097	0.06
2001	2.00	7,545	0.06	5,685	0.06
2002	2.48	7,767	0.07	6,172	0.07
2003	2.15	7,977	0.07	6,460	0.07
2004	1.88	7,990	0.07	6,648	0.07
2005	2.80	8,023	0.07	6,775	0.08
2006	2.16	8,231	0.07	6,668	0.08
2007	2.08	8,225	0.07	6,785	0.08
2008	3.09	8,349	0.07	6,913	0.08
2009	2.03	8,613	0.07	6,863	0.08
2010	1.89	8,458	0.07	7,109	0.07
2011	2.25	8,243	0.06	7,210	0.07
2012	2.00	8,036	0.07	7,009	0.07
2013	1.75	7,639	0.07	6,777	0.07
2014	3.15	7,506	0.09	6,485	0.08
2015	4.02	8,139	0.11	6,113	0.09
2016	4.76	9,365	0.14	6,185	0.11
2017	4.04	10,898	0.18	6,921	0.14
2018	2.57	11,520	0.21	8,353	0.18
2019	2.33				

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 19_2a 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 2017 are restricted to 1985–2019. Equilibrium MMBeq and MMB35% 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} =22,596 $MMB_{35\%}$=6,635			
1985	1.68	9,532	0.04	9,589	0.06
1986	1.01	7,289	0.04	8,122	0.04
1987	4.21	6,691	0.05	6,339	0.04
1988	3.63	6,751	0.05	5,275	0.05
1989	2.01	5,913	0.06	4,736	0.07
1990	2.99	6,013	0.05	4,285	0.07
1991	3.48	6,124	0.04	4,558	0.06
1992	2.24	6,044	0.04	4,410	0.05
1993	2.15	6,171	0.03	4,450	0.05
1994	2.47	5,702	0.04	4,856	0.04
1995	2.34	5,151	0.04	4,410	0.04
1996	2.29	5,298	0.05	3,834	0.04
1997	3.14	5,626	0.05	3,998	0.05
1998	2.91	6,301	0.06	4,146	0.05
1999	3.02	7,073	0.06	4,650	0.06
2000	2.83	7,763	0.06	5,393	0.06
2001	2.13	8,160	0.07	6,094	0.07
2002	2.60	8,449	0.07	6,687	0.07
2003	2.23	8,690	0.08	7,052	0.08
2004	1.94	8,698	0.08	7,286	0.08
2005	2.82	8,696	0.08	7,424	0.08
2006	2.18	8,843	0.08	7,298	0.09
2007	2.14	8,785	0.07	7,365	0.08
2008	3.01	8,844	0.07	7,433	0.08
2009	1.91	8,977	0.07	7,337	0.08
2010	1.81	8,677	0.07	7,496	0.07
2011	2.11	8,322	0.07	7,463	0.07
2012	1.83	7,953	0.07	7,131	0.07
2013	1.63	7,404	0.08	6,761	0.07
2014	2.85	7,109	0.10	6,318	0.08
2015	3.41	7,432	0.13	5,817	0.10
2016	3.59	8,058	0.18	5,700	0.13
2017	3.38	8,855	0.24	6,063	0.17
2018	2.53	9,126	0.29	6,817	0.24
2019	2.31				

Table 12. Negative log-likelihood values of the fits for scenarios (Sc) 19_0 (base), 19_1 (observer CPUE with reduced number of gear codes), and 19_2a (observer CPUE with Year an Area interaction factor) for golden king crab in the EAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 19_0**	**Sc 19_1**	**Sc 19_2a**
Number of free parameters	146	146	146
Retlencomp	-1251.82	-1251.74	-1250.70
Totallencomp	-1363.48	-1363.84	-1380.79
Observer cpue	-3.88	-3.55	4.03
RetdcatchB	7.35	7.36	7.82
TotalcatchB	22.53	22.53	22.80
GdiscdcatchB	0.00	0.00	0.00
Rec_dev	7.55	7.53	6.42
Pot F_dev	0.01	0.01	0.01
Gbyc_F_dev	0.03	0.03	0.03
Tag	2692.49	2692.48	2692.15
Fishery cpue	-2.2896	-2.2935	-2.835
RetcatchN	0.0065	0.0065	0.0048
Total	108.50	108.52	98.94

Table 13. Time series of 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 selected by R square criteria.

Year	**CPUE Index**	**CV**
1985/86	2.16	0.06
1986/87	1.78	0.04
1987/88	1.33	0.05
1988/89	1.47	0.03
1989/90	1.25	0.03
1990/91	0.88	0.04
1991/92	0.70	0.04
1992/93	0.59	0.04
1993/94	0.71	0.06
1994/95	0.86	0.04
1995/96	0.80	0.04
1996/97	0.84	0.03
1997/98	0.72	0.03
1998/99	0.99	0.04

Table 14. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 19_0 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	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	139				
1989/90	513	249			7	5
1990/91	205	100	190	98	6	4
1991/92	102	50	104	54	1	1
1992/93	76	37	94	48	3	2
1993/94	378	184	62	32	NA	NA
1994/95	367	178	119	61	2	1
1995/96	705	343	907	467	5	4
1996/97	817	397	1061	546	8	6
1997/98	984	478	1116	574	6	4
1998/99	613	298	638	328	14	10
1999/00	915	445	1155	594	18	13
2000/01	1029	500	1205	620	11	8
2001/02	898	436	975	502	11	8
2002/03	628	305	675	347	16	12
2003/04	688	334	700	360	8	6
2004/05	449	218	488	251	9	7
2005/06	337	164	220	113	6	4
2006/07	337	164	321	165	14	10
2007/08	276	134	257	132	17	12
2008/09	318	155	258	133	19	14
2009/10	362	176	292	150	24	17
2010/11	328	159	222	114	13	9
2011/12	295	143	252	130	14	10
2012/13	288	140	241	124	18	13
2013/14	327	159	236	121	17	12
2014/15	305	148	219	113	18	13
2015/16	287	139	243	125	10	7
2016/17	392	191	253	130	12	9
2017/18	299	145	222	114	10	7
2018/19	328	159	318	164	5	4

Table 15. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 19_1 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	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	139				
1989/90	513	249			7	5
1990/91	205	100	190	98	6	4
1991/92	102	50	104	54	1	1
1992/93	76	37	94	48	3	2
1993/94	378	184	62	32	NA	NA
1994/95	367	178	119	61	2	1
1995/96	705	342	907	468	5	4
1996/97	817	397	1061	547	8	6
1997/98	984	478	1116	575	6	4
1998/99	613	298	638	329	14	10
1999/00	915	444	1155	596	18	13
2000/01	1029	500	1205	621	11	8
2001/02	898	436	975	503	11	8
2002/03	628	305	675	348	16	12
2003/04	688	334	700	361	8	6
2004/05	449	218	488	252	9	7
2005/06	337	164	220	113	6	4
2006/07	337	164	321	166	14	10
2007/08	276	134	257	133	17	12
2008/09	318	154	258	133	19	14
2009/10	362	176	292	151	24	17
2010/11	328	159	222	114	13	9
2011/12	295	143	252	130	14	10
2012/13	288	140	241	124	18	13
2013/14	327	159	236	122	17	12
2014/15	305	148	219	113	18	13
2015/16	287	139	243	125	10	7
2016/17	392	190	253	130	12	9
2017/18	299	145	222	114	10	7
2018/19	328	159	318	164	5	4

Table 16. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 19_2 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	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	139				
1989/90	513	249			7	5
1990/91	205	99	190	102	6	4
1991/92	102	49	104	56	1	1
1992/93	76	37	94	50	3	2
1993/94	378	183	62	33	NA	NA
1994/95	367	178	119	64	2	1
1995/96	705	342	907	485	5	4
1996/97	817	396	1061	568	8	6
1997/98	984	477	1116	597	6	4
1998/99	613	297	638	341	14	10
1999/00	915	444	1155	618	18	13
2000/01	1029	499	1205	645	11	8
2001/02	898	435	975	522	11	8
2002/03	628	305	675	361	16	12
2003/04	688	334	700	375	8	6
2004/05	449	218	488	261	9	7
2005/06	337	163	220	118	6	4
2006/07	337	163	321	172	14	10
2007/08	276	134	257	138	17	12
2008/09	318	154	258	138	19	14
2009/10	362	176	292	156	24	18
2010/11	328	159	222	119	13	10
2011/12	295	143	252	135	14	10
2012/13	288	140	241	129	18	13
2013/14	327	159	236	126	17	12
2014/15	305	148	219	117	18	13
2015/16	287	139	243	130	10	7
2016/17	392	190	253	135	12	9
2017/18	299	145	222	119	10	7
2018/19	328	159	318	170	5	4

Table 17. Parameter estimates and coefficient of variations (CV) with the 2018 MMB (MMB estimated on 15 Feb 2019) for scenarios 19_0, 19_1, and 19_2 for the golden king crab data from the WAG, 1985/86–2018/19. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 19_0		**Scenario 19_1**		**Scenario 19_2**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.01	2.54	0.01	2.54	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-7.63	0.22	-7.63	0.22	-7.67	0.22	-12.0-5.0
log_a (molt prob. slope)	-2.63	0.03	-2.63	0.03	-2.63	0.03	-4.61-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.69	0.03	3.69	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.41	0.01	3.41	0.01	3.42	0.01	0.,4.4
log_ total sel deltaθ, 2005–18	2.86	0.02	2.86	0.02	2.85	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–18	1.79	0.02	1.79	0.02	1.79	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.868	0.002	4.868	0.002	4.871	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–18	4.902	0.001	4.902	0.001	4.899	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985–18	4.916	0.0002	4.916	0.0002	4.916	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.024	0.16	-1.024	0.16	-1.019	0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.046	1.40	-0.047	1.36	-0.062	1.04	-9.0, 2.25
logq3 (catchability 2005–18)	-0.387	0.23	-0.387	0.23	-0.409	0.28	-9.0, 2.25
log_mean_rec (mean rec.)	0.718	0.06	0.718	0.06	0.717	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.693	0.09	-0.693	0.09	-0.702	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.356	0.10	-8.356	0.10	-8.358	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.021	0.34	0.022	0.34	~0.000	387.19	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.013	0.66	0.013	0.65	0.014	0.58	0.0,1.0
2018 MMB	6,332	0.15	6,328	0.15	5,947	0.21	

Table 18. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 19_0 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 2017 are restricted to 1985–2019. 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} =17,941 *$MMB_{35\%}$*=5,176			
1985	4.03	10,539	0.05	8,712	0.09
1986	3.57	8,206	0.05	8,238	0.07
1987	2.66	7,606	0.04	5,888	0.06
1988	1.76	6,497	0.04	5,582	0.04
1989	2.37	4,418	0.04	4,964	0.04
1990	1.91	4,049	0.05	3,113	0.05
1991	1.66	3,801	0.05	2,772	0.05
1992	2.11	3,975	0.04	2,668	0.06
1993	1.57	4,581	0.03	2,821	0.05
1994	1.97	3,895	0.03	3,434	0.03
1995	1.88	3,905	0.03	2,792	0.03
1996	1.72	3,914	0.04	2,749	0.03
1997	1.87	3,986	0.04	2,794	0.04
1998	1.90	4,310	0.03	2,875	0.04
1999	2.24	4,345	0.04	3,156	0.03
2000	2.49	4,504	0.04	3,098	0.04
2001	2.51	4,929	0.05	3,106	0.04
2002	2.44	5,450	0.05	3,424	0.05
2003	1.72	5,733	0.05	3,918	0.05
2004	2.25	5,804	0.06	4,371	0.05
2005	2.34	6,092	0.06	4,523	0.06
2006	2.46	6,638	0.05	4,674	0.06
2007	1.71	6,832	0.05	5,120	0.06
2008	1.50	6,643	0.05	5,434	0.06
2009	1.92	6,276	0.05	5,499	0.05
2010	1.61	6,012	0.05	5,156	0.05
2011	1.18	5,531	0.05	4,871	0.05
2012	1.90	4,965	0.05	4,551	0.05
2013	2.40	4,816	0.06	3,965	0.05
2014	1.88	5,038	0.07	3,536	0.06
2015	2.32	5,307	0.08	3,680	0.07
2016	2.48	5,855	0.09	3,942	0.08
2017	1.79	6,323	0.12	4,360	0.09
2018	1.86	6,332	0.15	4,913	0.11
2019	2.05				

Table 19. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 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 2017 are restricted to 1985–2019. 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} =17,940			
		$MMB_{35\%}$=5,176			
1985	4.03	10,544	0.05	8,719	0.09
1986	3.57	8,210	0.05	8,243	0.07
1987	2.66	7,610	0.04	5,892	0.06
1988	1.76	6,500	0.04	5,585	0.04
1989	2.37	4,420	0.04	4,968	0.04
1990	1.91	4,050	0.05	3,115	0.05
1991	1.66	3,802	0.05	2,774	0.05
1992	2.10	3,975	0.04	2,669	0.06
1993	1.56	4,579	0.03	2,822	0.05
1994	1.98	3,893	0.03	3,433	0.03
1995	1.88	3,904	0.03	2,789	0.03
1996	1.71	3,914	0.04	2,747	0.03
1997	1.87	3,985	0.04	2,794	0.04
1998	1.90	4,309	0.03	2,874	0.04
1999	2.24	4,344	0.04	3,155	0.03
2000	2.49	4,504	0.04	3,097	0.04
2001	2.51	4,931	0.05	3,105	0.04
2002	2.44	5,452	0.05	3,425	0.05
2003	1.72	5,734	0.05	3,919	0.05
2004	2.25	5,805	0.06	4,372	0.05
2005	2.34	6,095	0.06	4,523	0.06
2006	2.46	6,643	0.05	4,674	0.06
2007	1.71	6,836	0.05	5,123	0.06
2008	1.50	6,647	0.05	5,438	0.06
2009	1.92	6,278	0.05	5,502	0.05
2010	1.61	6,013	0.05	5,159	0.05
2011	1.18	5,534	0.05	4,872	0.05
2012	1.90	4,970	0.05	4,553	0.05
2013	2.40	4,822	0.06	3,968	0.05
2014	1.88	5,041	0.07	3,541	0.06
2015	2.32	5,308	0.08	3,684	0.07
2016	2.48	5,854	0.10	3,944	0.08
2017	1.79	6,320	0.12	4,359	0.09
2018	1.86	6,328	0.15	4,911	0.12
2019	2.05				

Table 20. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 19_2 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 2017 are restricted to 1985–2019. 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} =17,932 $MMB_{35\%}$=5,174			
1985	3.91	10,658	0.05	8,868	0.09
1986	3.60	8,275	0.05	8,374	0.07
1987	2.64	7,667	0.04	5,966	0.06
1988	1.75	6,538	0.04	5,632	0.04
1989	2.38	4,452	0.04	5,000	0.04
1990	1.91	4,086	0.05	3,138	0.05
1991	1.66	3,836	0.05	2,799	0.05
1992	2.04	3,987	0.04	2,694	0.05
1993	1.54	4,552	0.03	2,842	0.05
1994	2.01	3,853	0.03	3,424	0.03
1995	1.88	3,876	0.03	2,748	0.03
1996	1.71	3,890	0.04	2,708	0.03
1997	1.89	3,971	0.04	2,764	0.04
1998	1.92	4,315	0.04	2,848	0.04
1999	2.28	4,378	0.04	3,141	0.03
2000	2.55	4,579	0.04	3,104	0.04
2001	2.553	5,048	0.05	3,142	0.04
2002	2.49	5,603	0.05	3,500	0.05
2003	1.72	5,901	0.06	4,029	0.05
2004	2.29	5,973	0.06	4,510	0.06
2005	2.393	6,276	0.06	4,667	0.06
2006	2.43	6,824	0.06	4,823	0.07
2007	1.70	6,987	0.05	5,282	0.06
2008	1.50	6,771	0.05	5,583	0.06
2009	1.90	6,375	0.05	5,620	0.05
2010	1.61	6,081	0.05	5,251	0.05
2011	1.20	5,589	0.05	4,938	0.05
2012	1.90	5,021	0.05	4,597	0.05
2013	2.35	4,850	0.07	4,007	0.06
2014	1.80	5,015	0.08	3,573	0.07
2015	2.22	5,207	0.10	3,686	0.08
2016	2.30	5,649	0.14	3,887	0.10
2017	1.68	6,001	0.18	4,225	0.13
2018	1.83	5,947	0.21	4,669	0.17
2019	2.05				

Table 21. Negative log-likelihood values of the fits for scenarios (Sc) 19_0 (base), 19_1 (observer CPUE with reduced number of gear codes), and 19_2 (observer CPUE with Year an Area interaction factor) for golden king crab in the WAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 19_0**	**Sc 19_1**	**Sc 19_2**
Number of free parameters	146	146	146
Retlencomp	-1204.90	-1204.75	-1205.02
Totallencomp	-1511.17	-1511.61	-1518.91
Observer cpue	-12.08	-11.23	-6.10
RetdcatchB	4.90	4.93	5.51
TotalcatchB	45.31	45.31	45.56
GdiscdcatchB	0.00	0.00	0.00
Rec_dev	4.65	4.65	4.62
Pot F_dev	0.03	0.03	0.03
Gbyc_F_dev	0.04	0.04	0.04
Tag	2694.37	2694.36	2694.14
Fishery cpue	-9.6898	-9.7218	-9.2786
RetcatchN	0.0022	0.0021	0.0017
Total	11.45	12.00	10.60

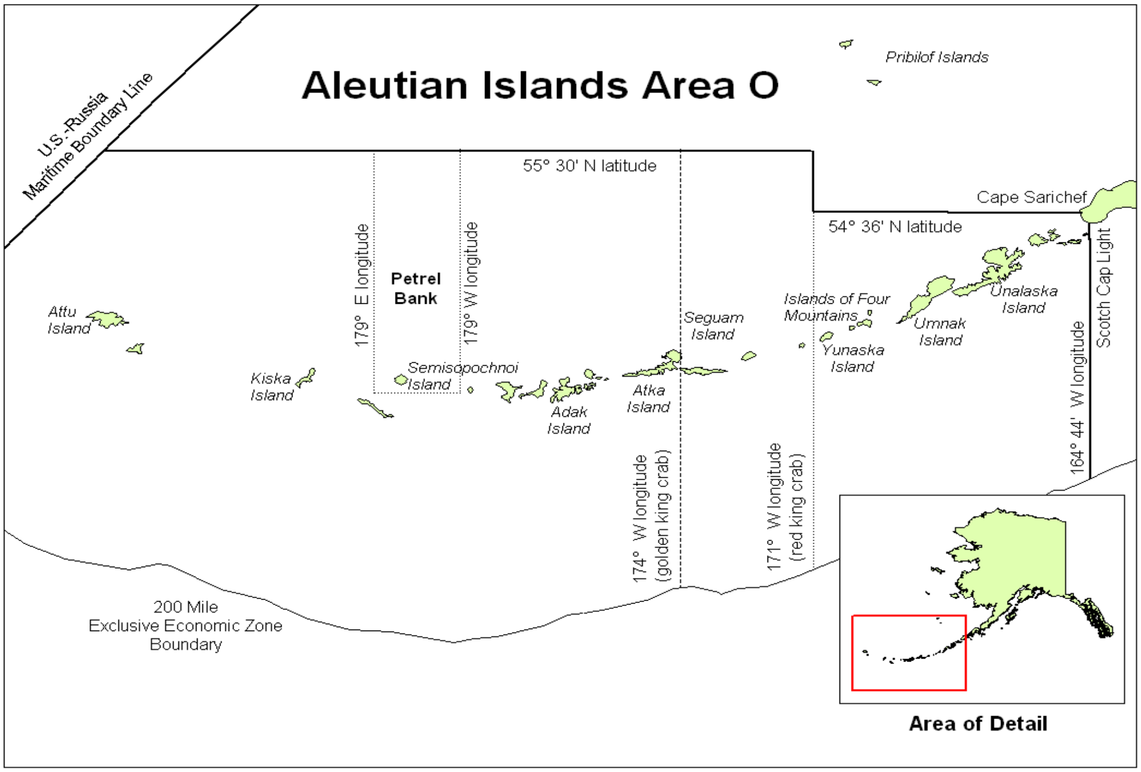


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Leon et al. 2017).

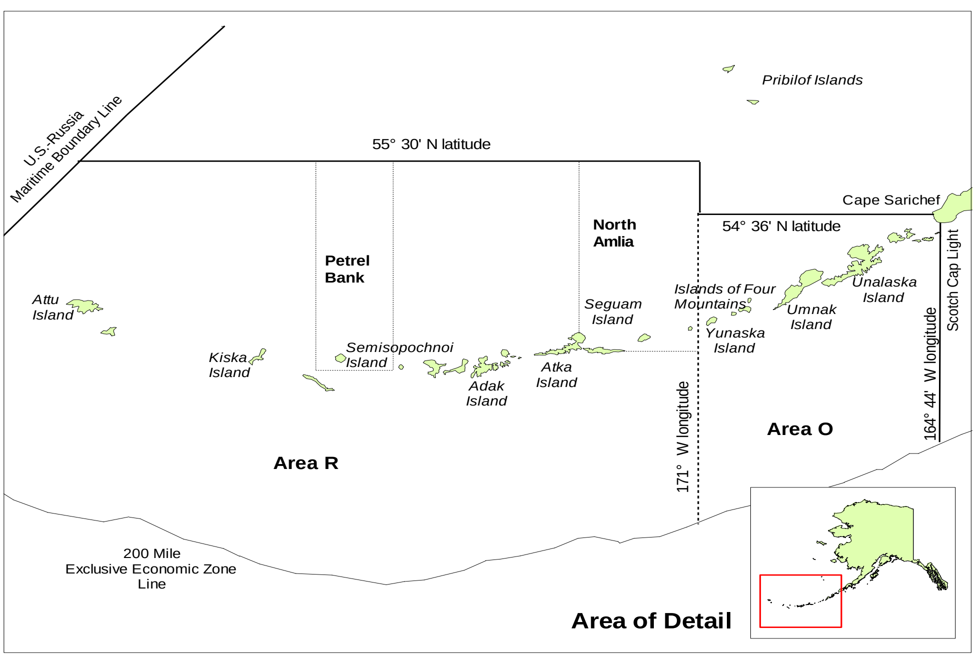


Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon et al., 2017).

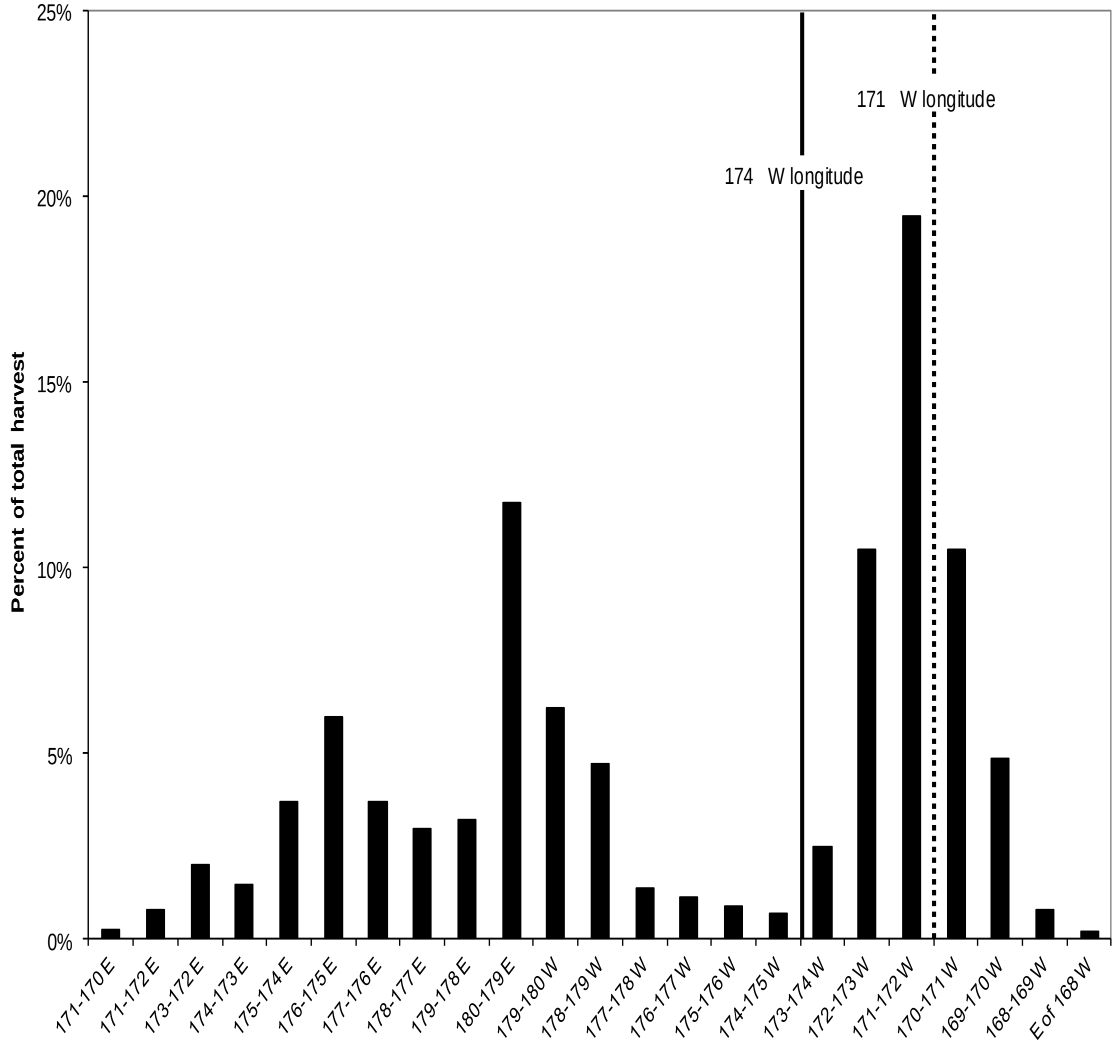


Figure 3. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor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

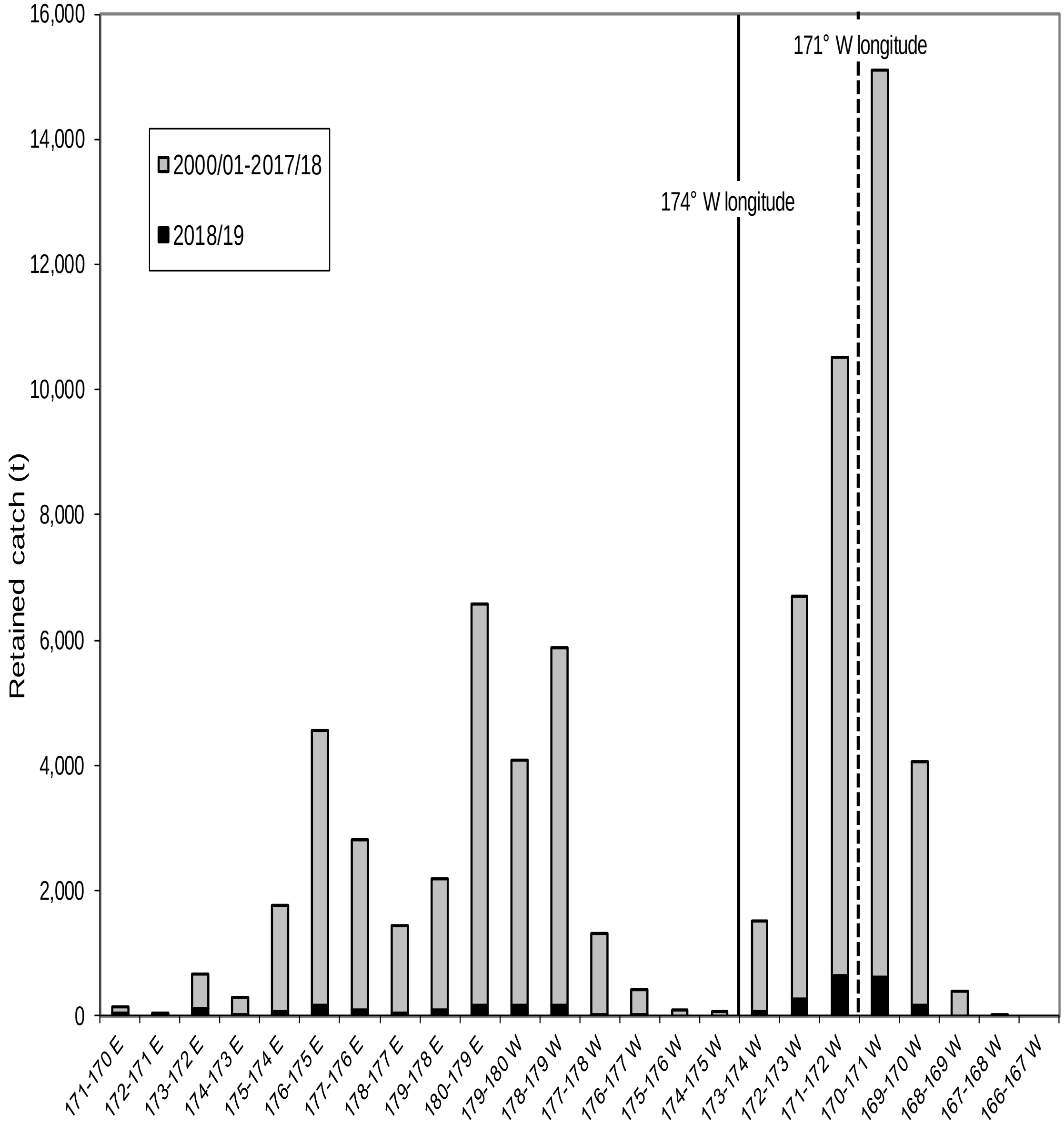


Figure 4. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2018/19commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king 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).

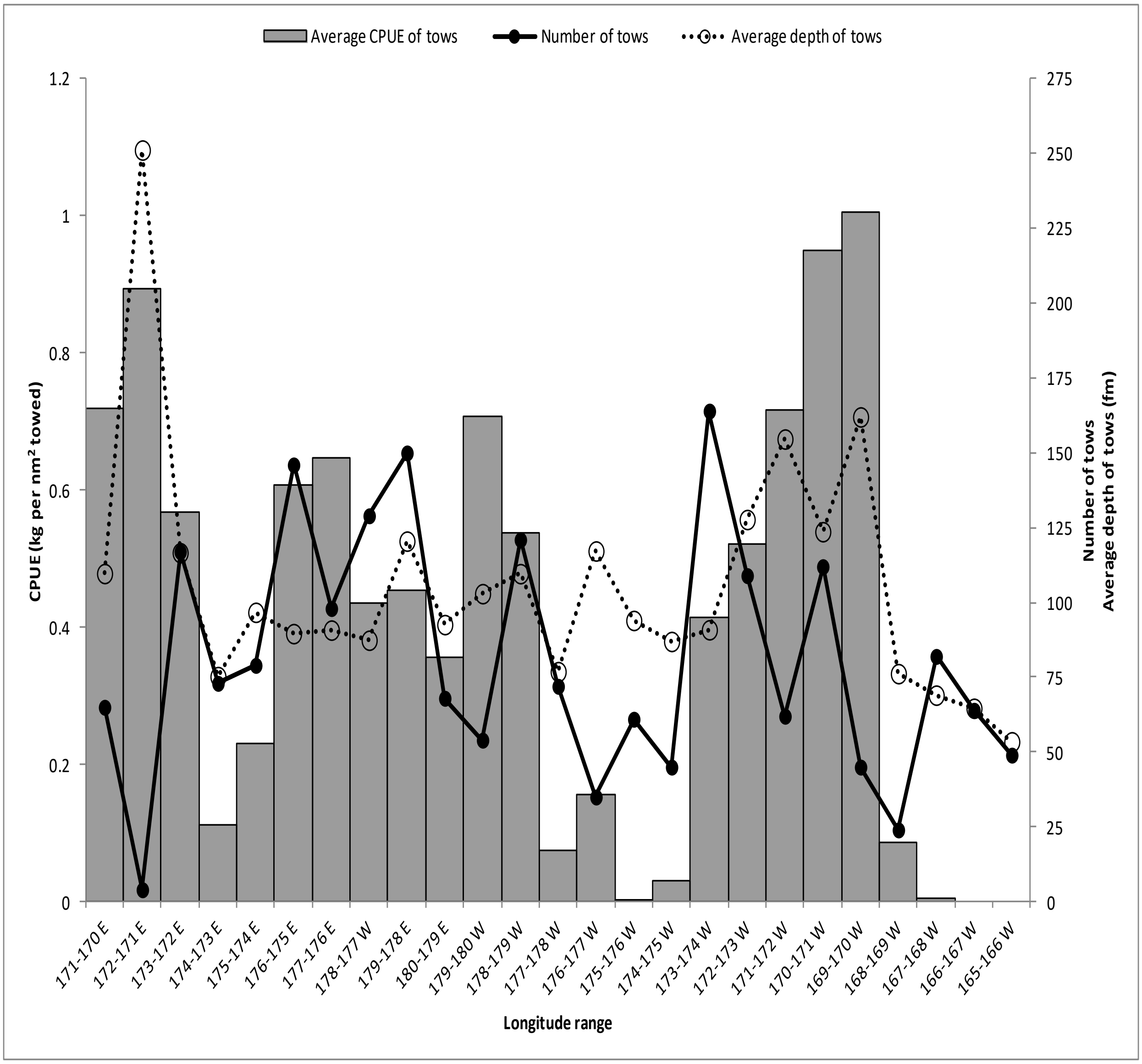


Figure 5. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

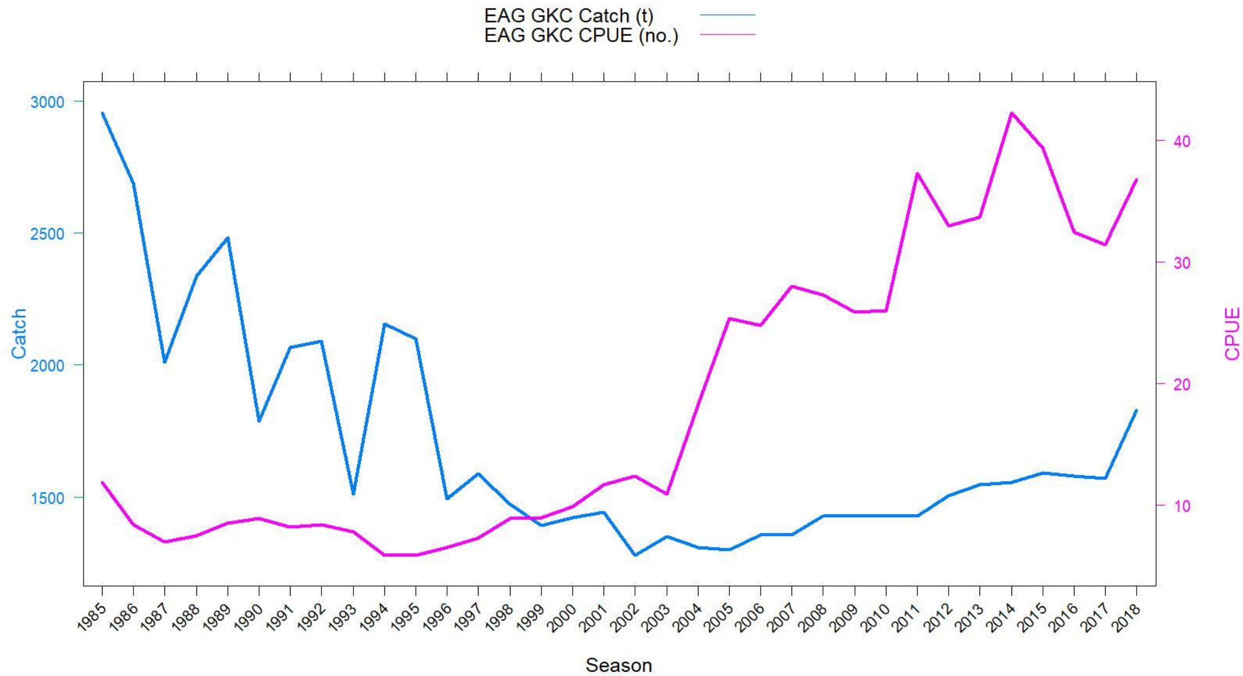


Figure 6. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2018/19 fisheries (note: 1985 refers to the 1985/86 fishing year).

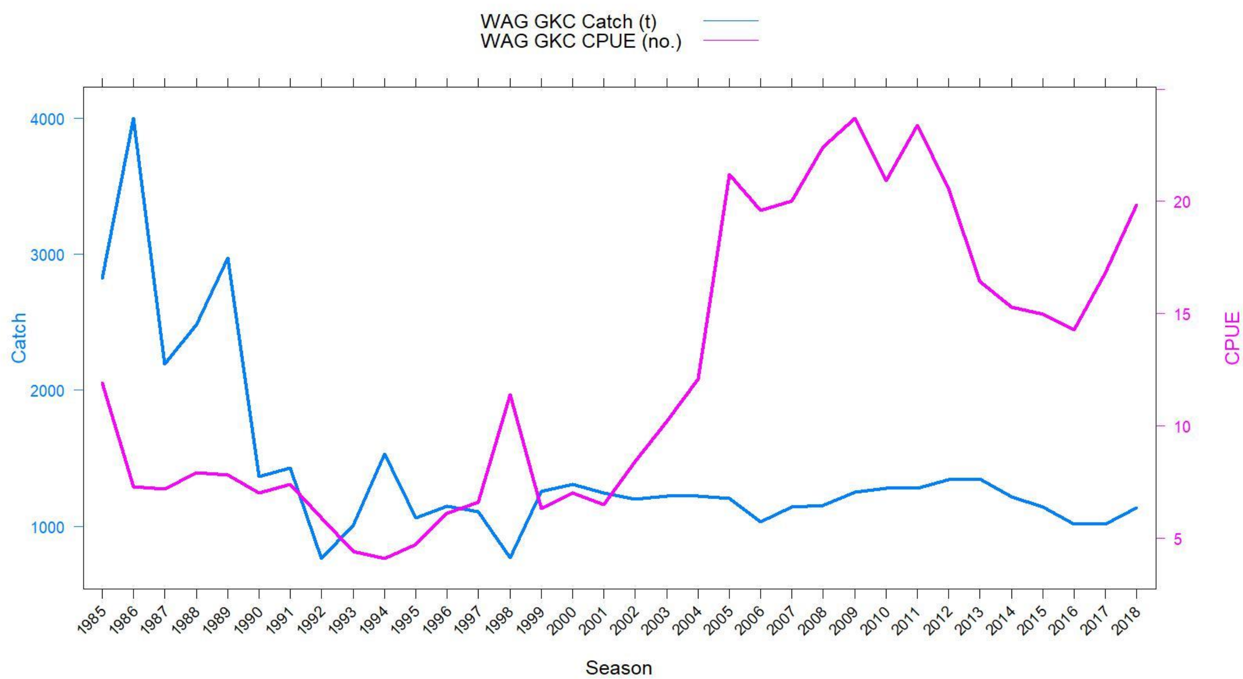


Figure 7. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2018/19 fisheries (note: 1985 refers to the 1985/86 fishing year).

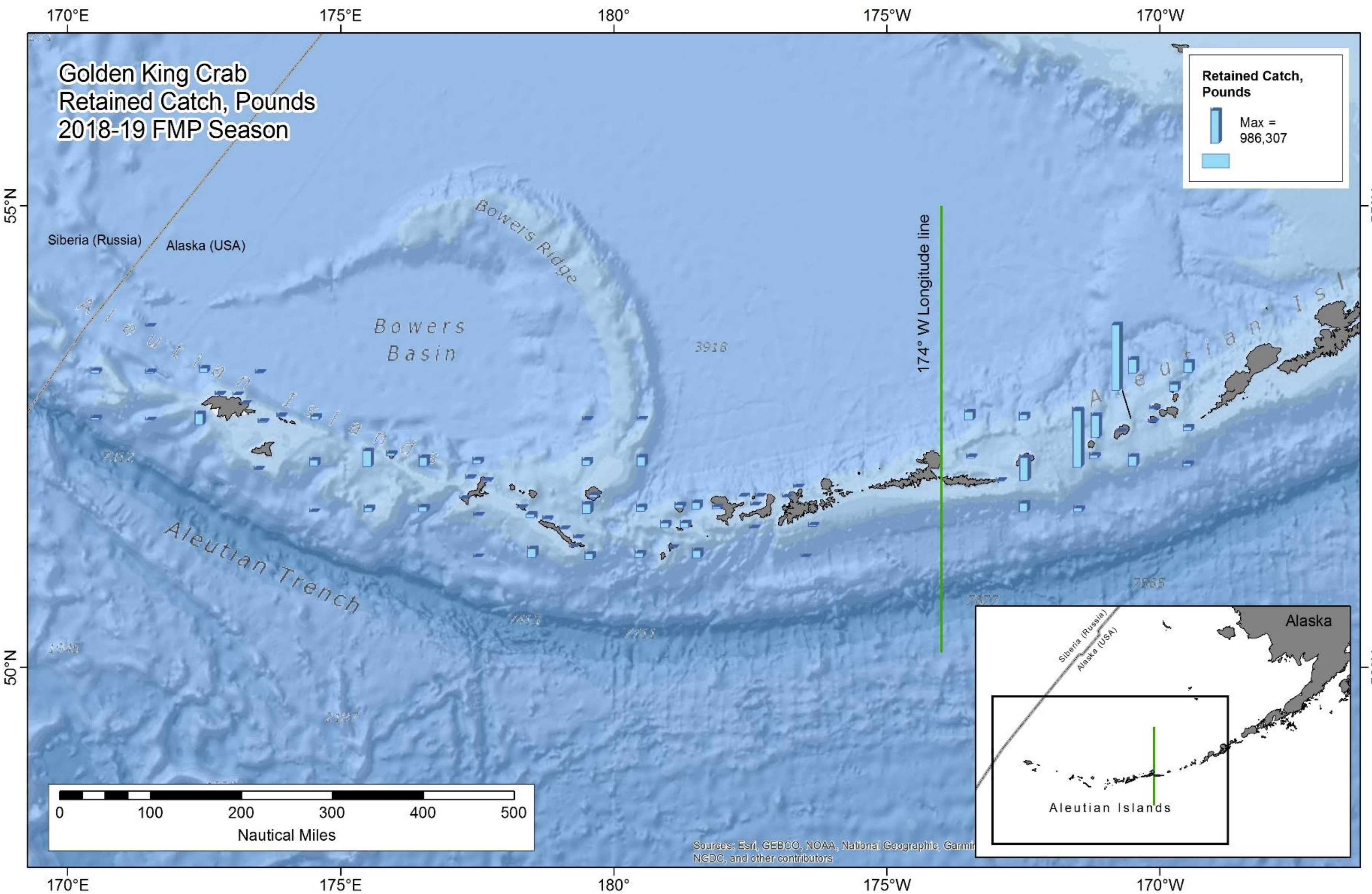


Figure 8. Catch distribution by statistical area.in 2018/19.

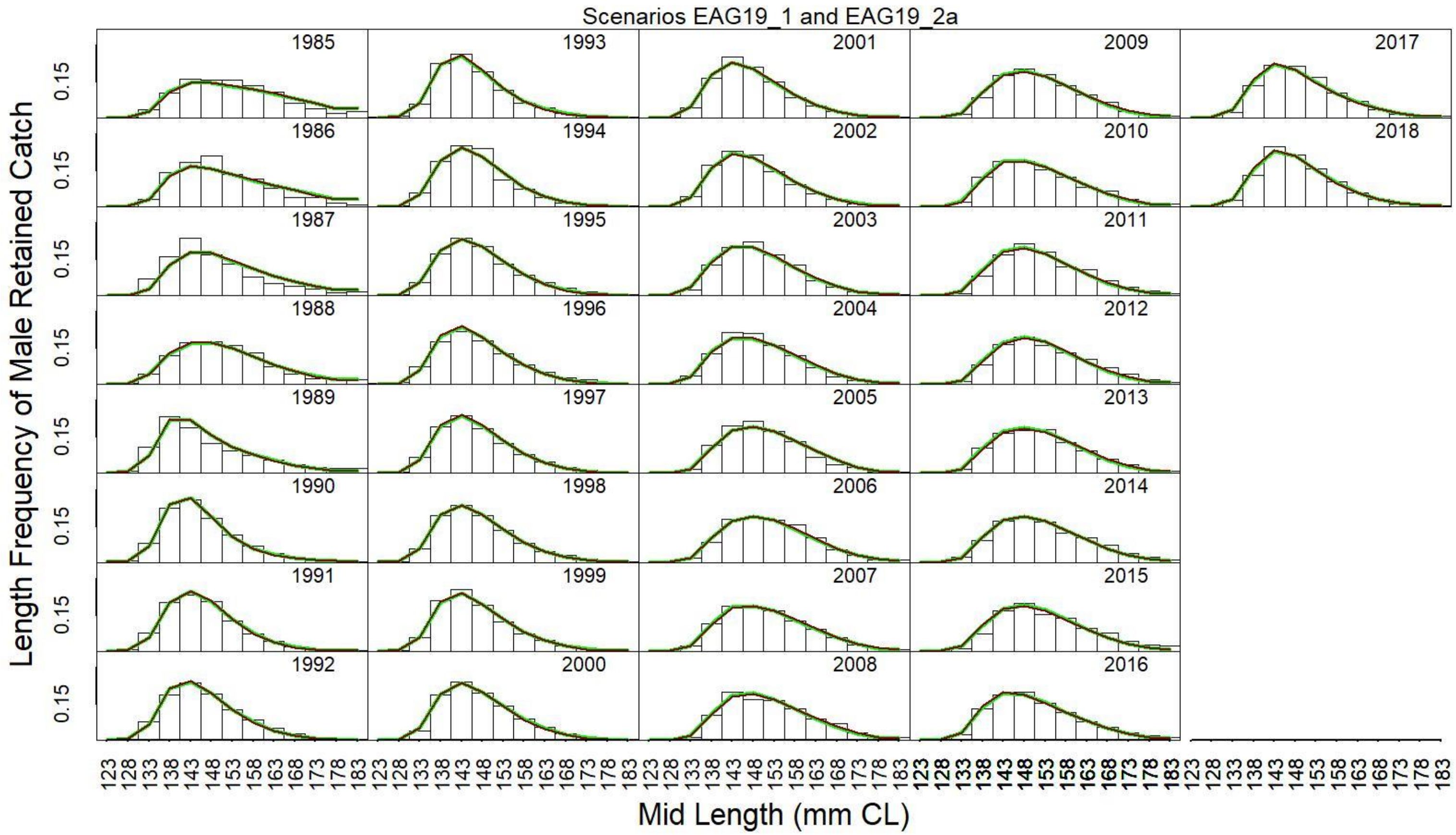


Figure 9. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2a (dark red line) for golden king crab in the EAG, 1985/86 to 2018/19. This color scheme is used in all other figures.

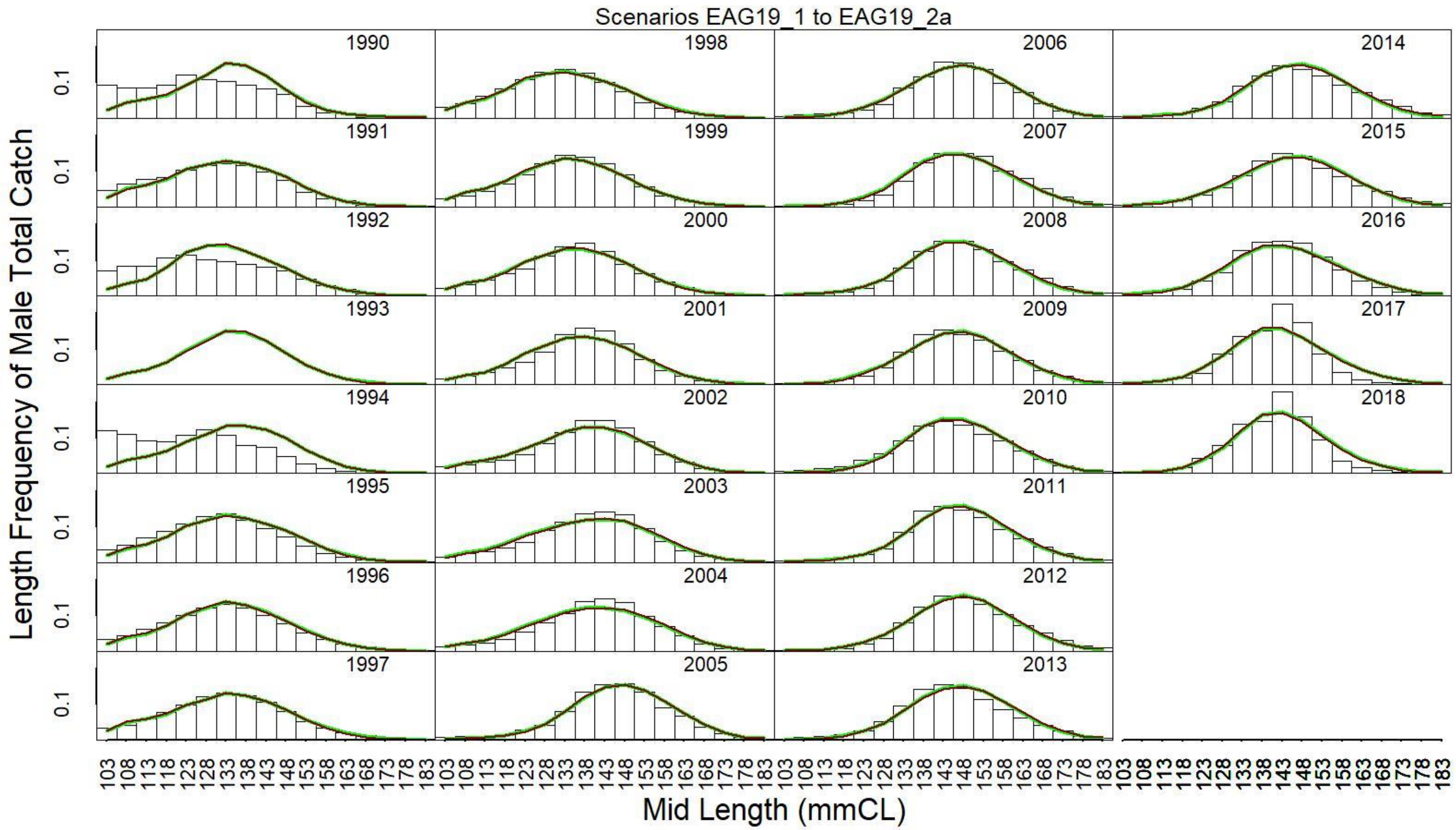


Figure 10. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2a (dark red line) for golden king crab in the EAG, 1990/91 to 2018/19.

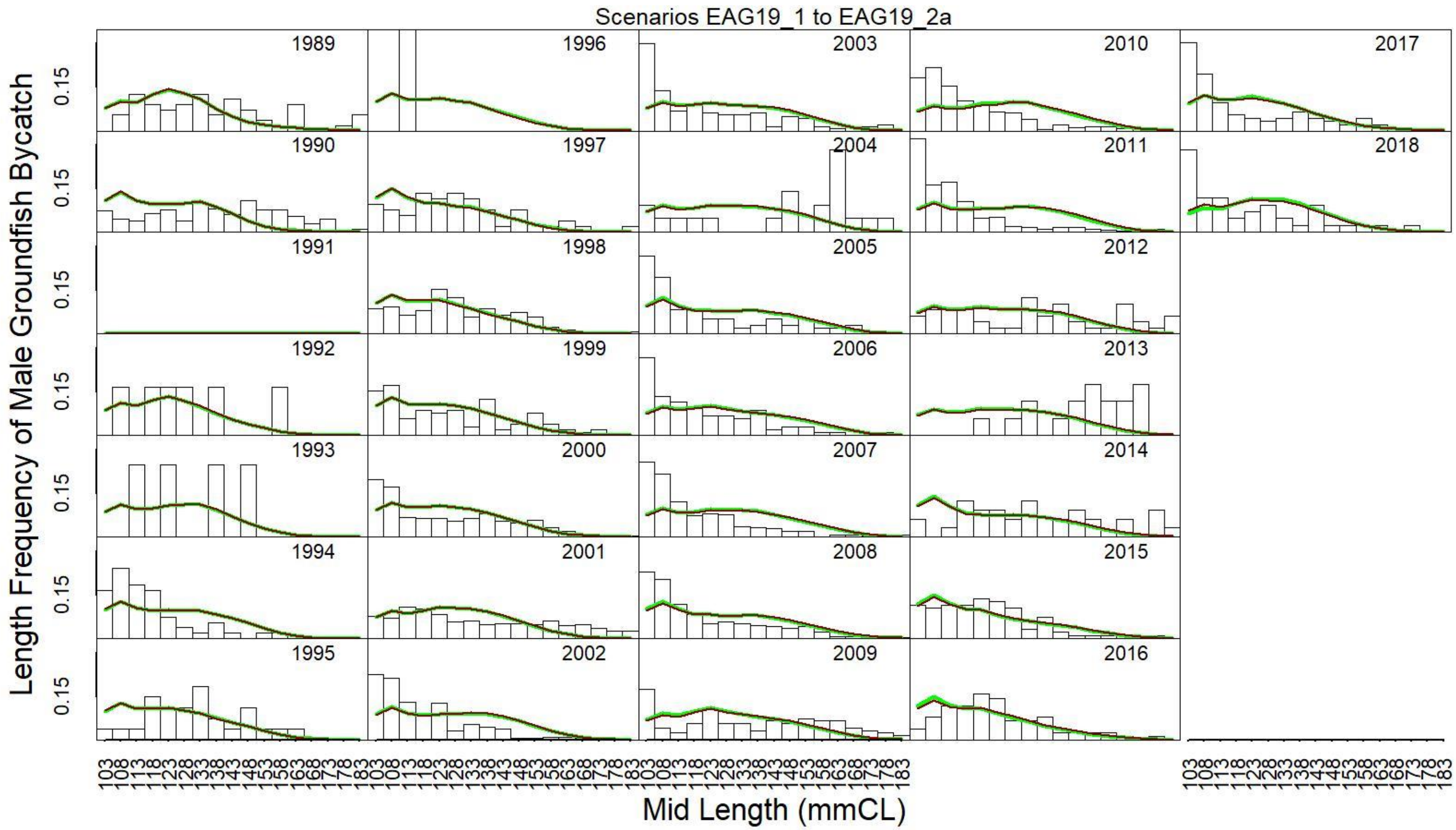


Figure 11. Predicted (line) vs. observed (bar) groundfish discarded bycatch relative length frequency distributions under scenarios 19_1 (green line) and 19_2a (dark red line) for golden king crab in the EAG, 19989/90 to 2018/19.

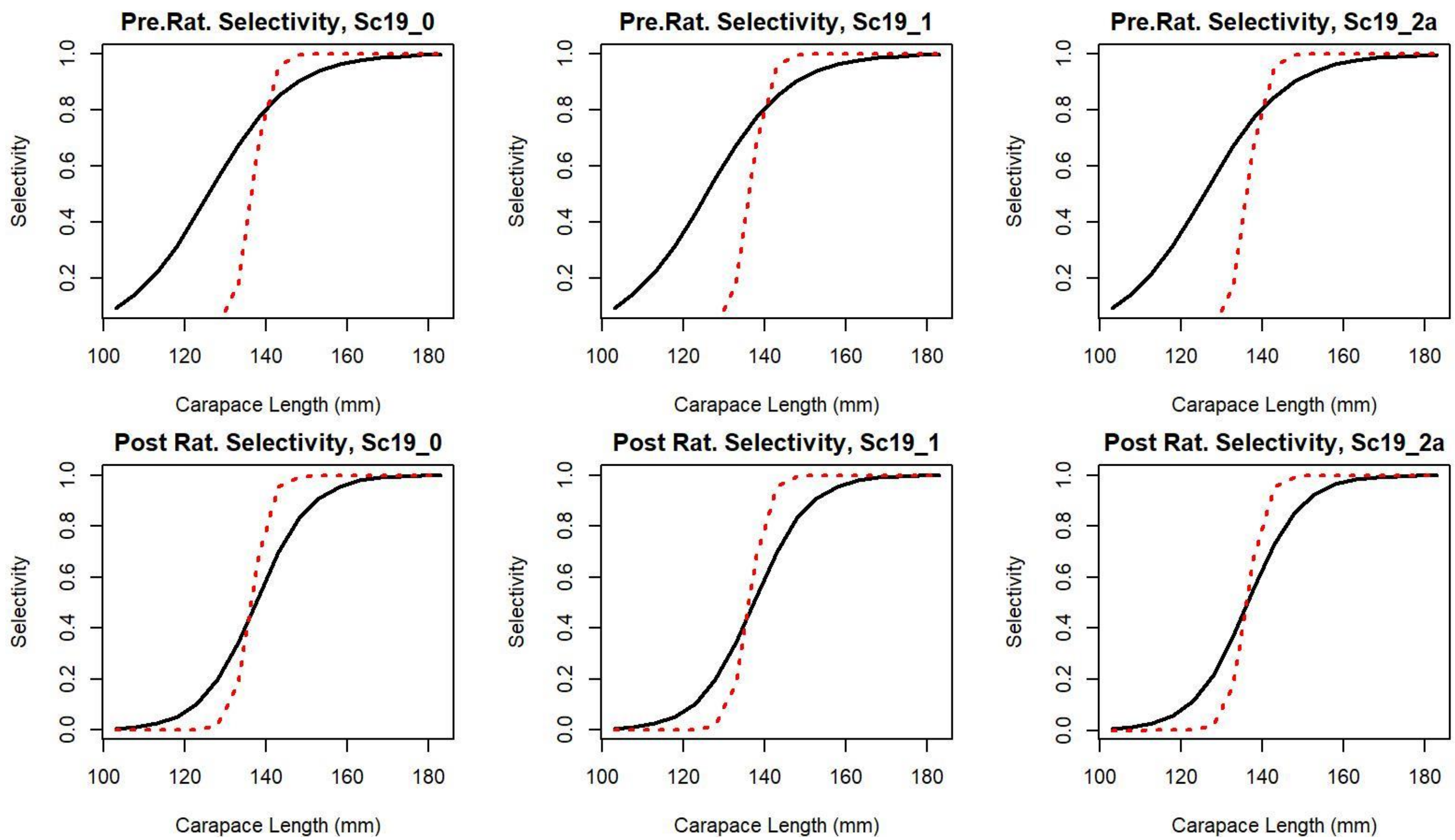


Figure 12. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 19_0, 19_1, and 19_2a model fits to golden king crab data in the EAG.

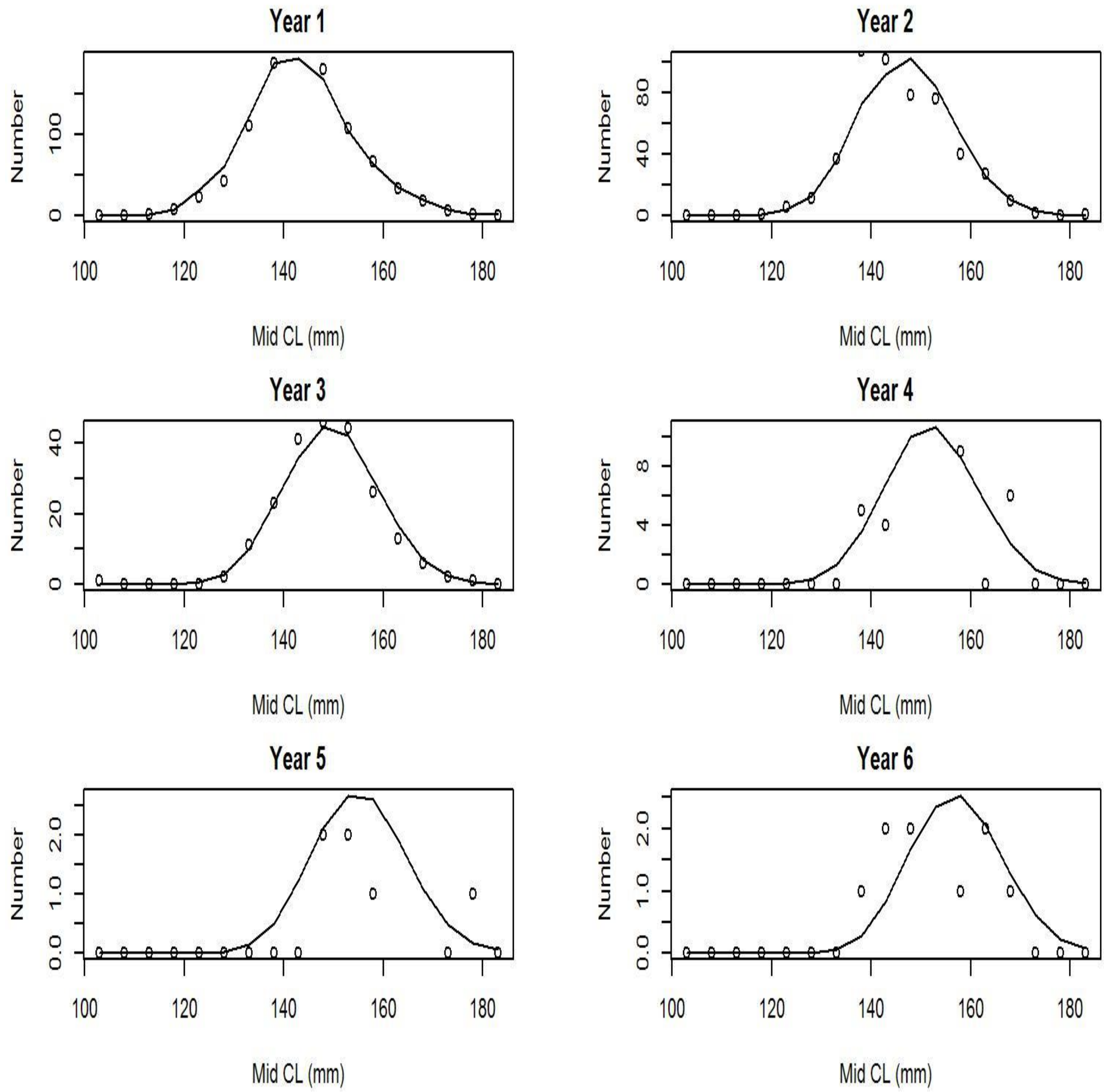


Figure 13. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 19_1 for EAG golden king crab.

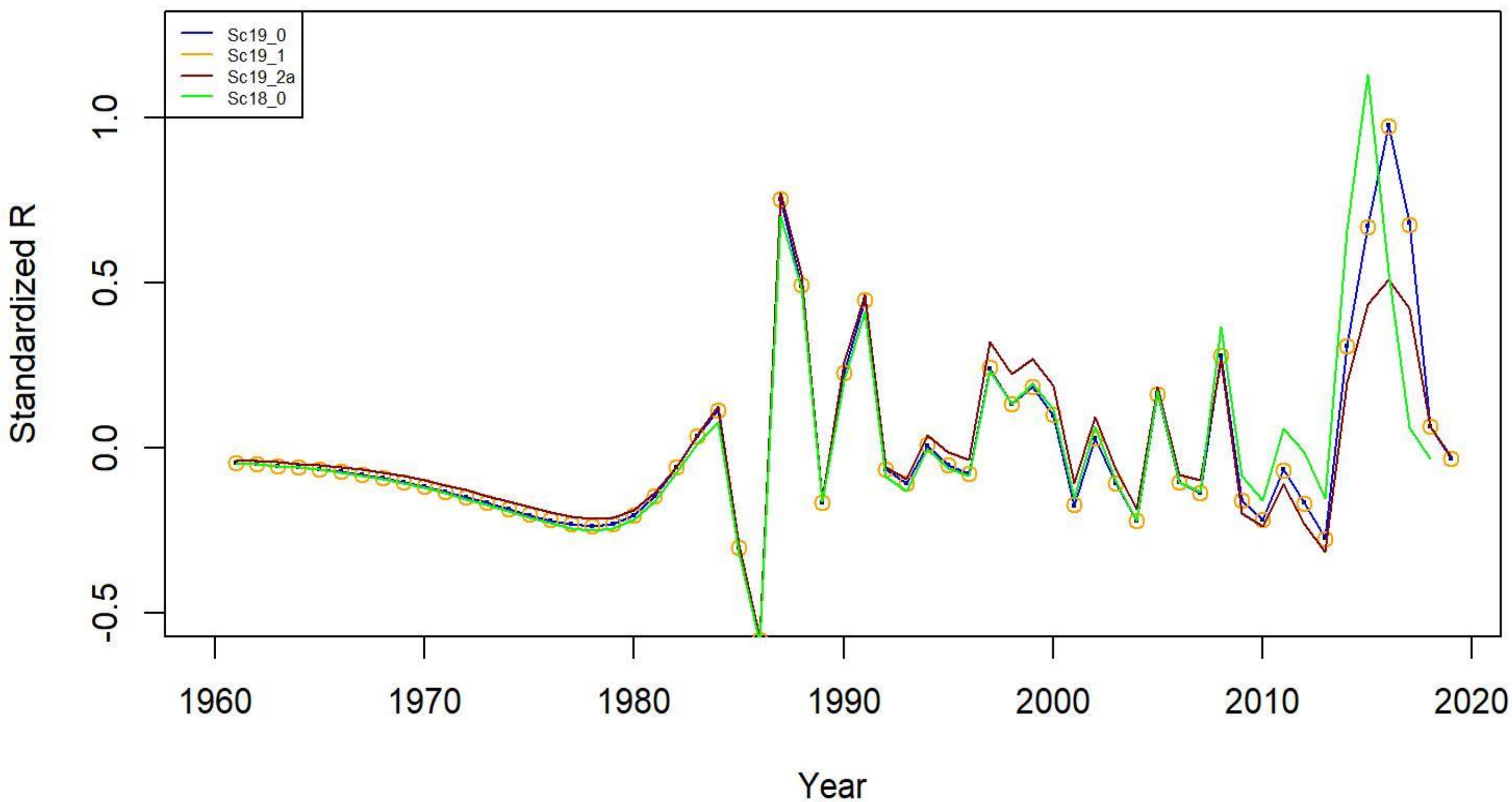


Figure 14. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for EAG golden king crab data, 1961–2019. The numbers of recruits are standardized using (R-mean R)/mean R for comparing different scenarios' results.

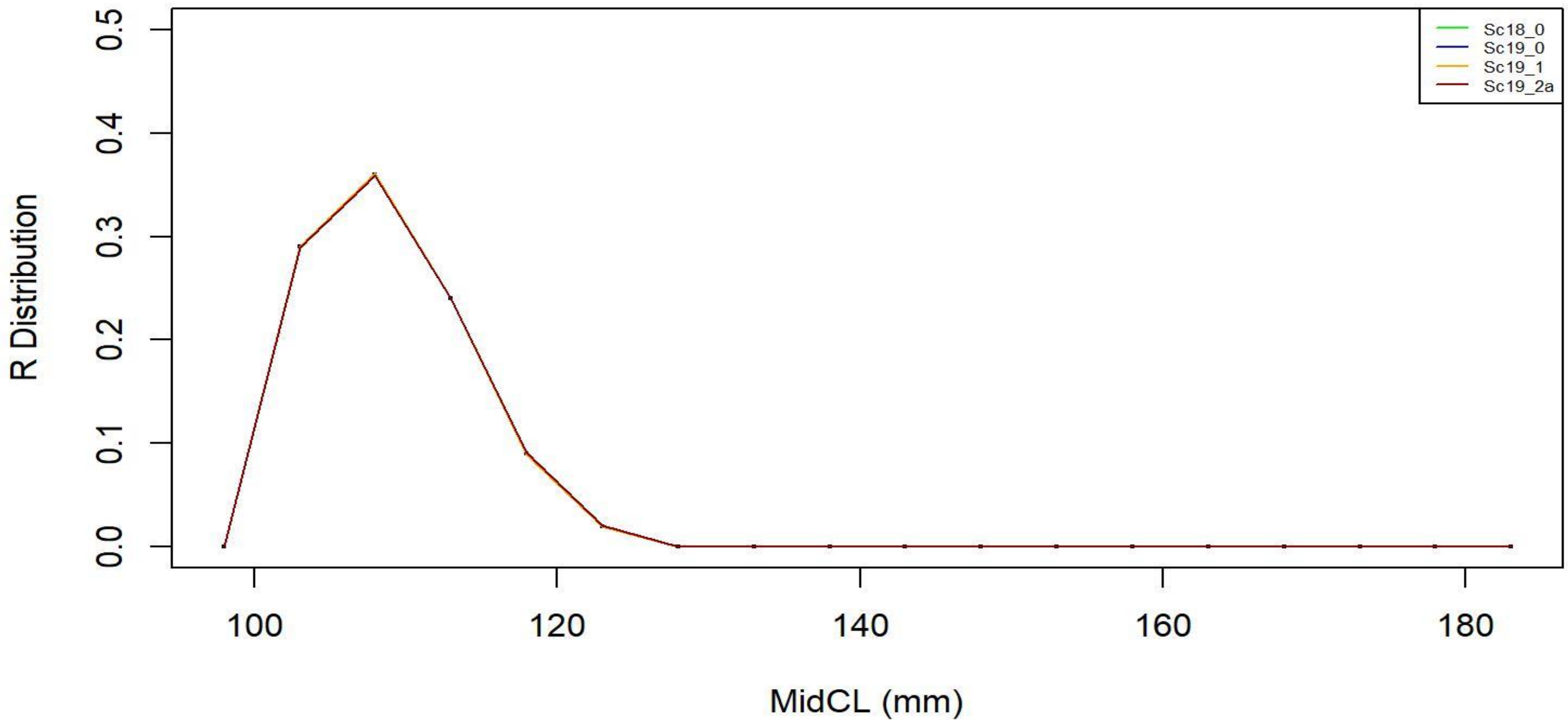


Figure 15. Recruit size distribution to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for EAG golden king crab.

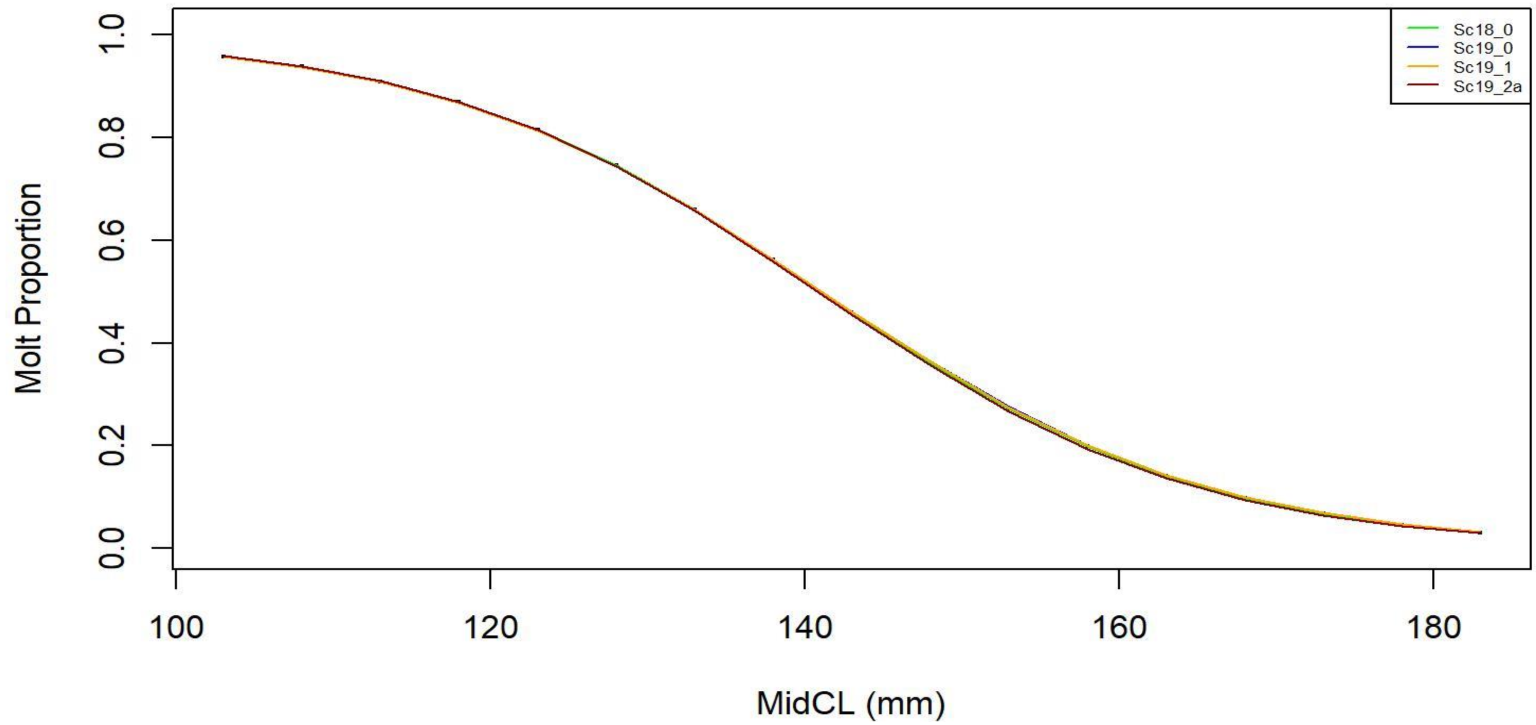


Figure 16. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for EAG golden king crab.

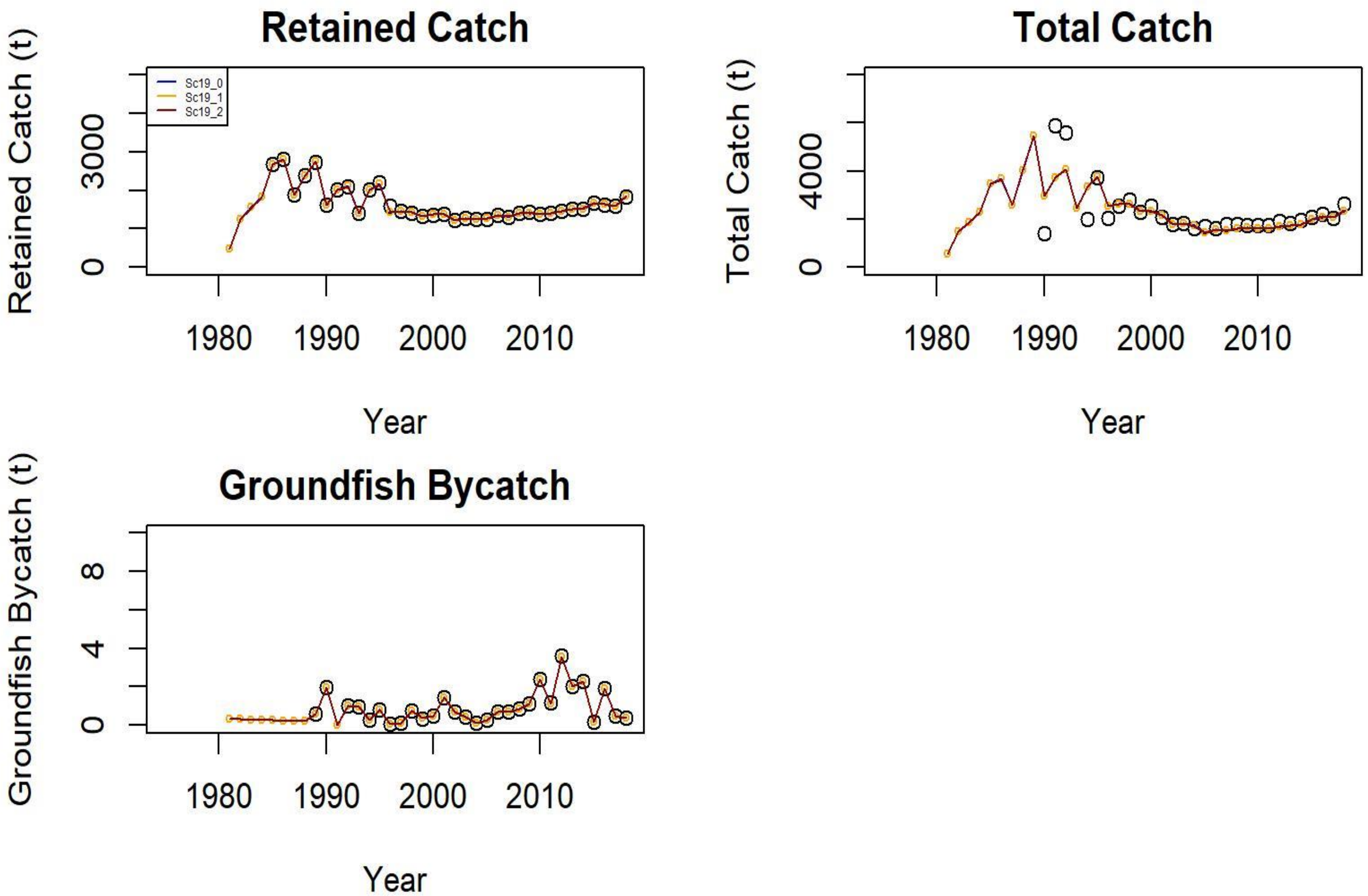


Figure 17. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for scenarios 19_0, 19_1, and 19_2a fits in EAG, 1981/82–2018/19.

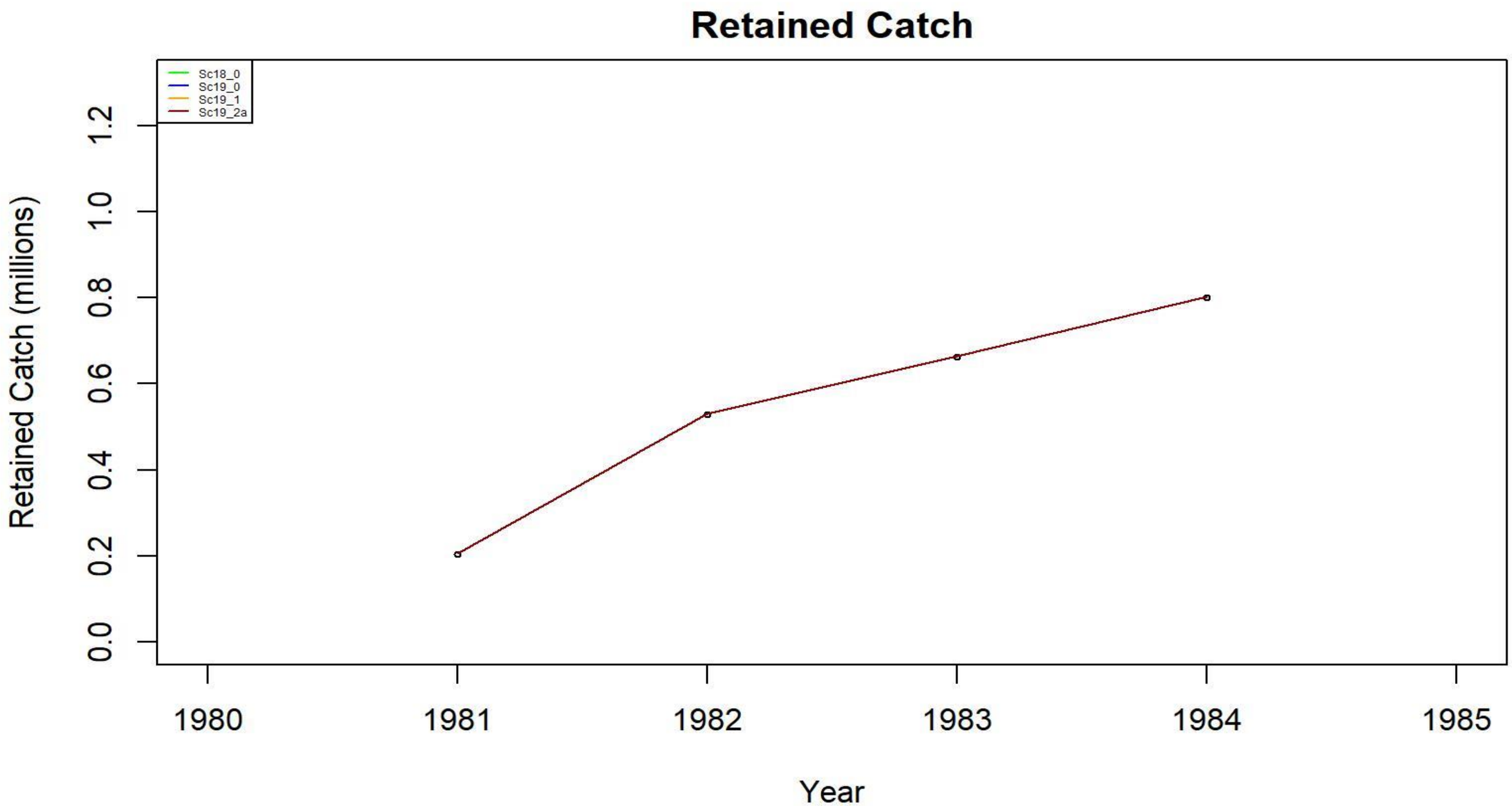


Figure 18. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for golden king crab fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

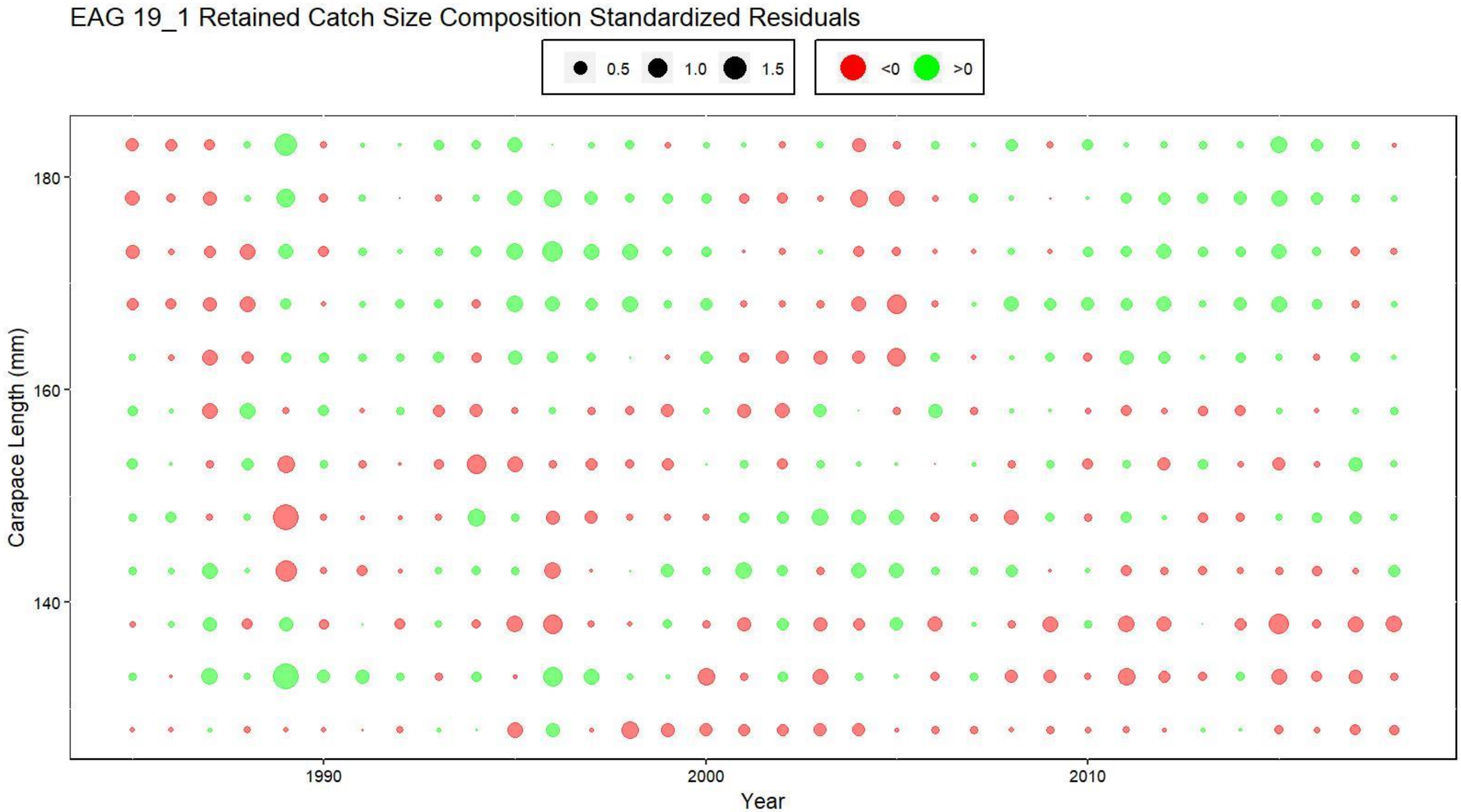


Figure 19. Bubble plot of standardized residuals of retained catch length composition for scenario 19_1 fit for EAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

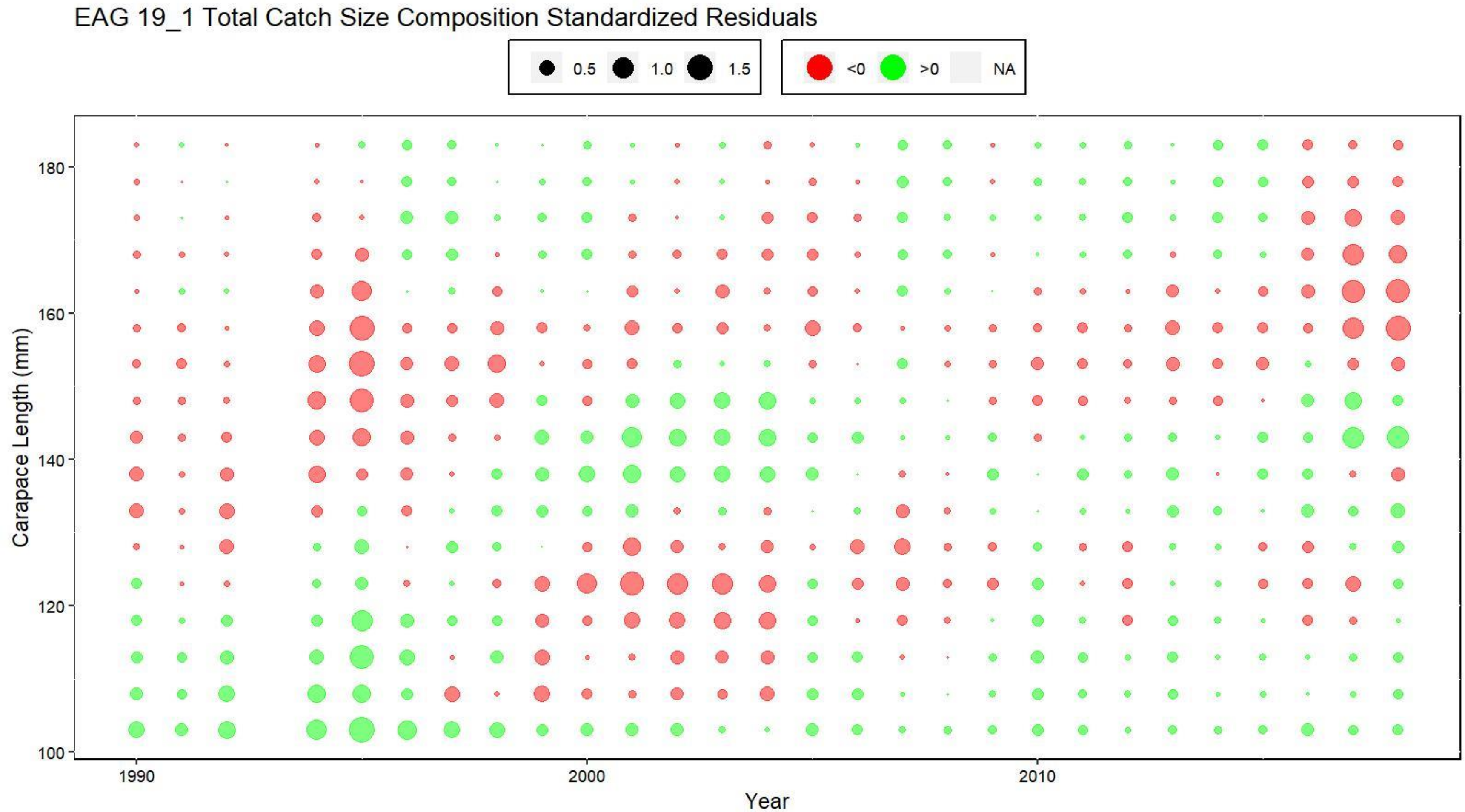


Figure 20. Bubble plot of standardized residuals of total catch length composition for scenario 19_1 fit for EAG golden king crab, 1990/91–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

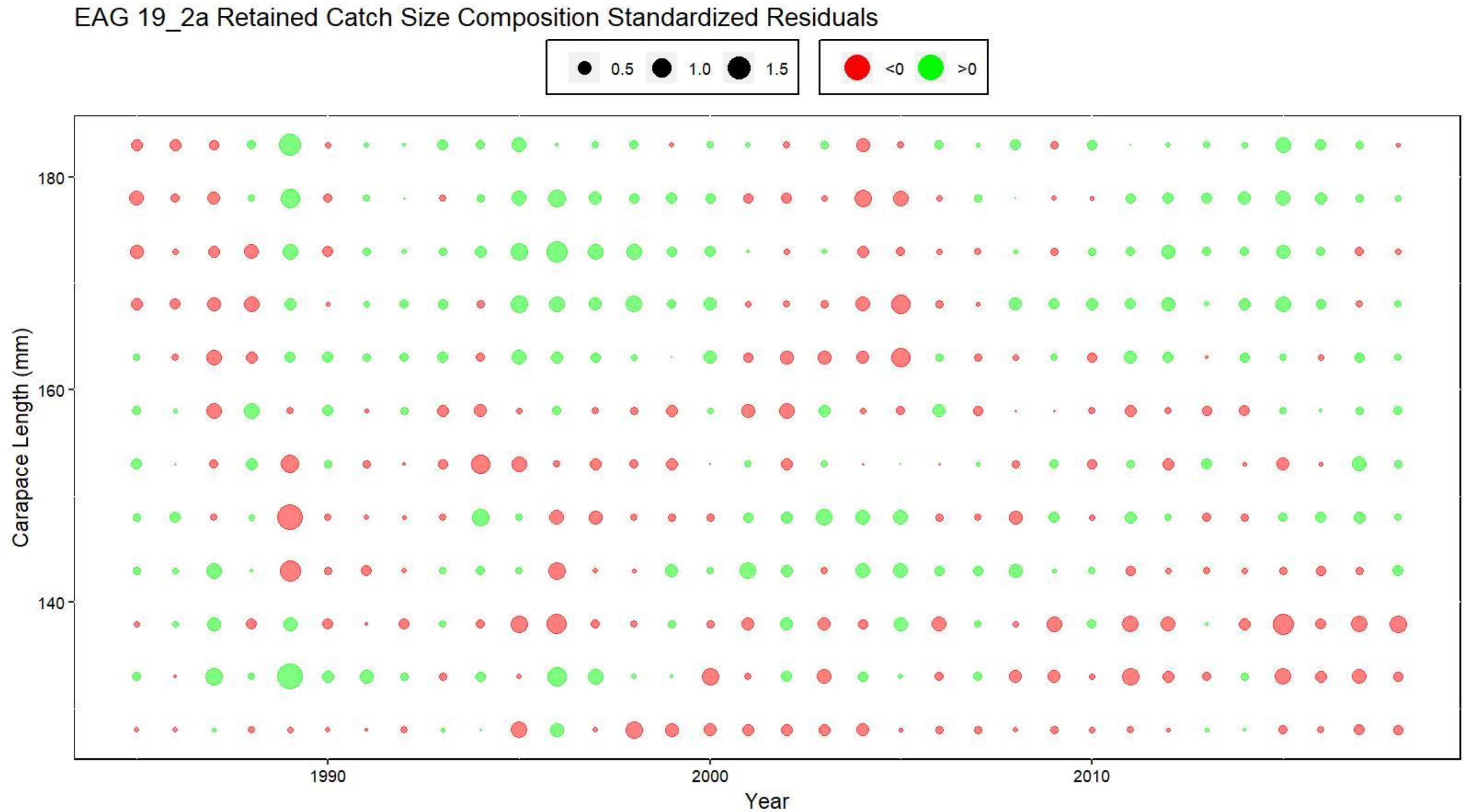


Figure 21. Bubble plot of standardized residuals of retained catch length composition for scenario 19_2a fit for EAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

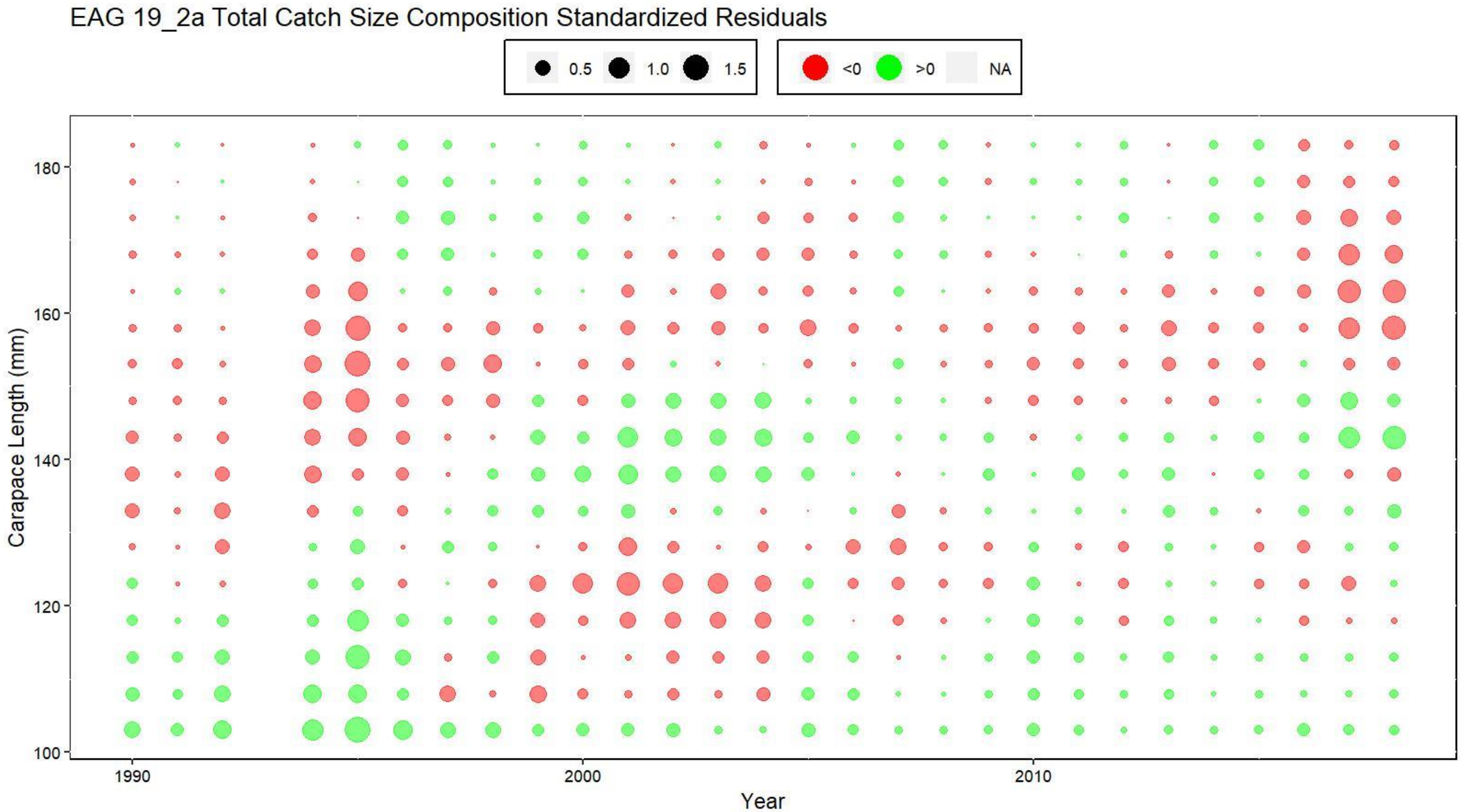
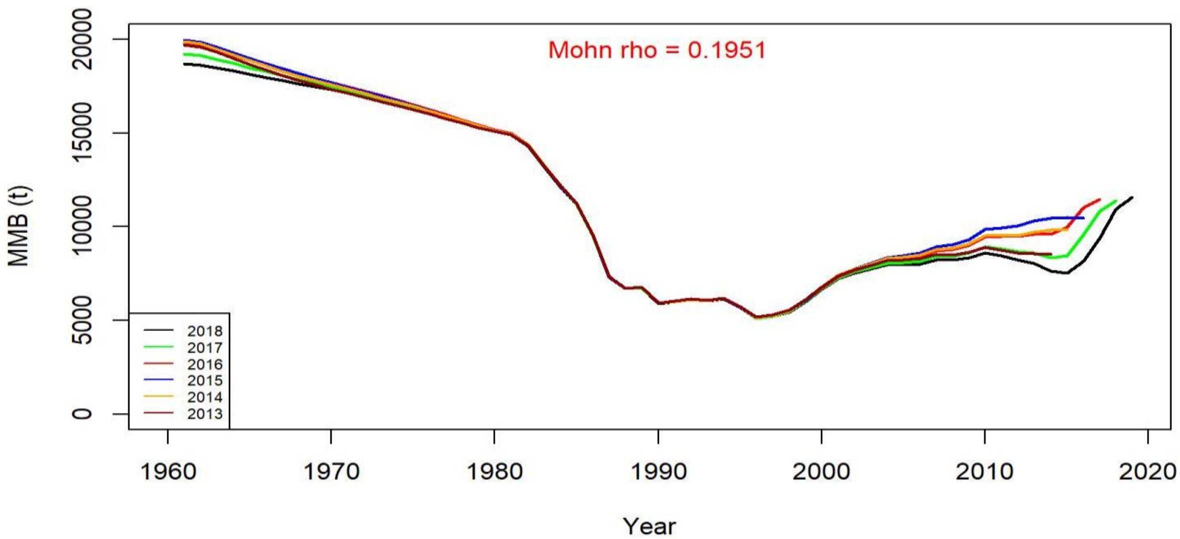
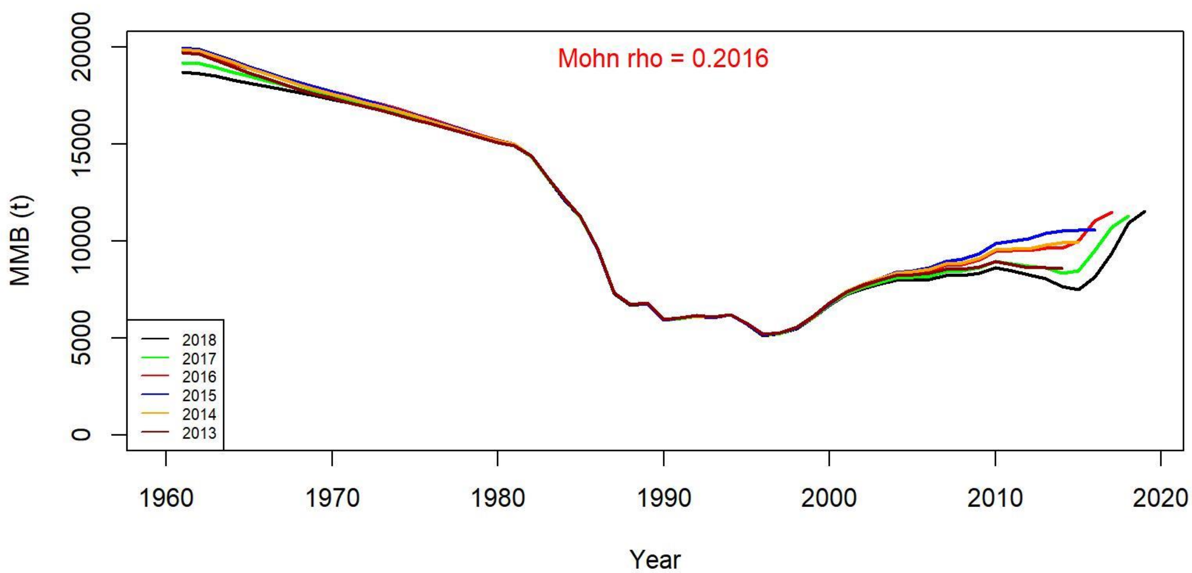


Figure 22. Bubble plot of standardized residuals of total catch length composition for scenario 19_2a fit for EAG golden king crab, 1990/91–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

Sc19_0


Mohn rho = 0.1951
MMB (t)
Year
2018
2017
2016
2015
2014
2013

Sc19_1


Mohn rho = 0.2016
MMB (t)
Year
2018
2017
2016
2015
2014
2013

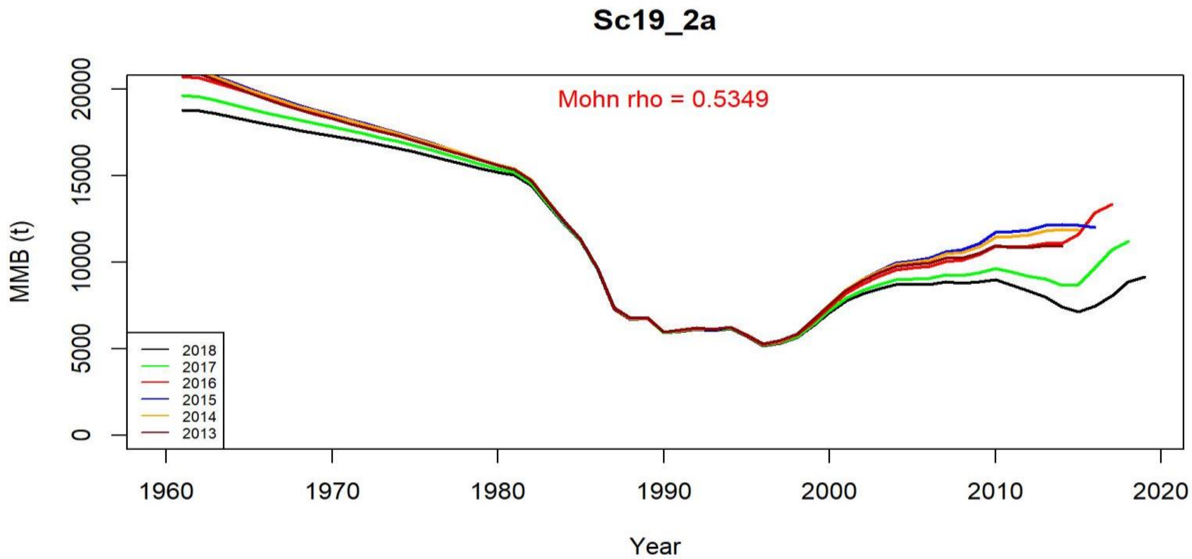


Figure 23. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 19_0, 19_1 and 19_2a for golden king crab in the EAG, 1960/61–2018/19.

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

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

where, $\widehat{MMB}_{y=T-n,T-n}$ is the MMB estimated for 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 five peels (x=5) and our T =2018.

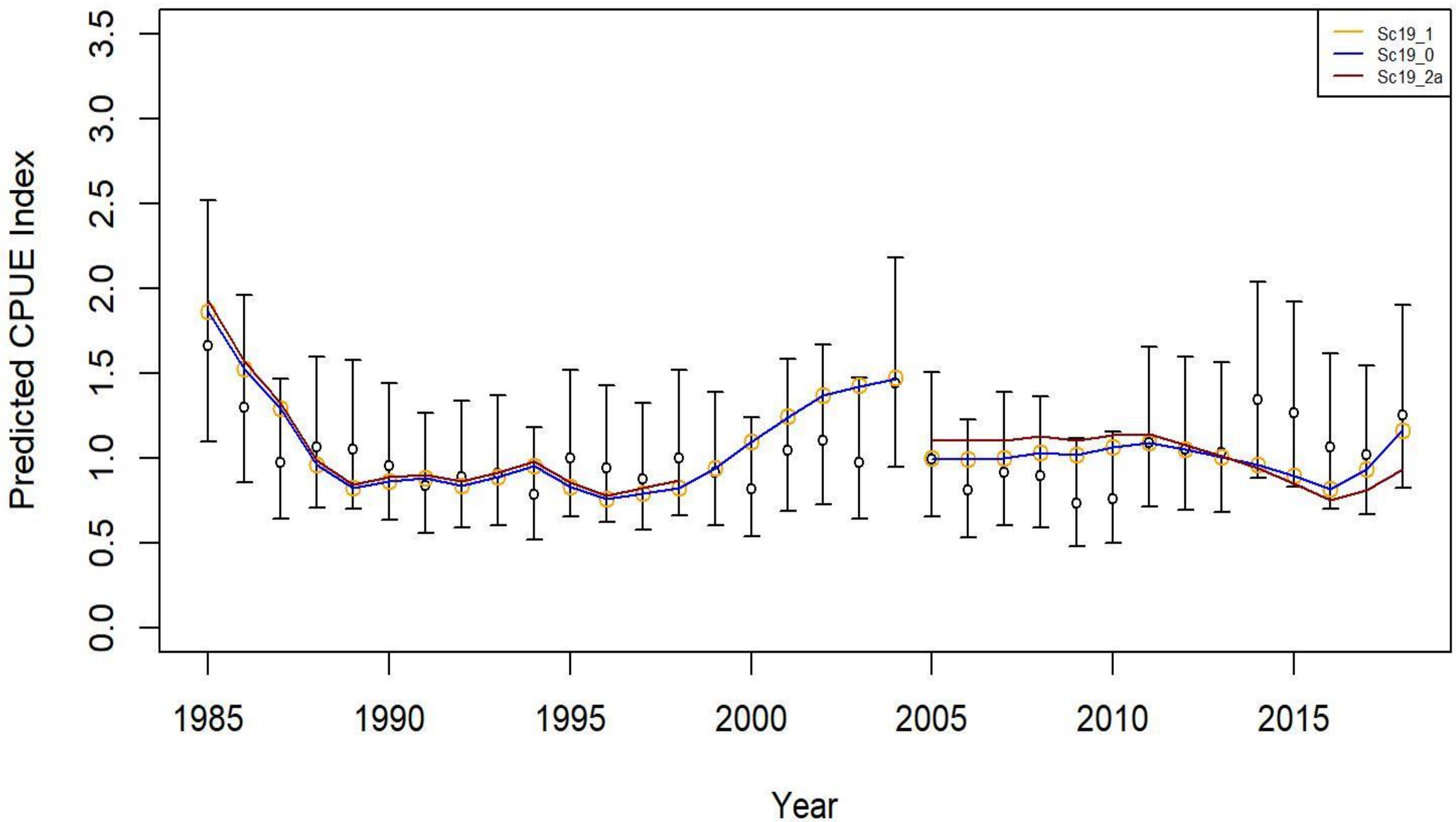


Figure 24. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) under scenarios 19_0, 19_1 (orange points), and 19_2a for EAG golden king crab data, 1985/86–2018/19. Model estimated additional standard error was added to each input standard error.

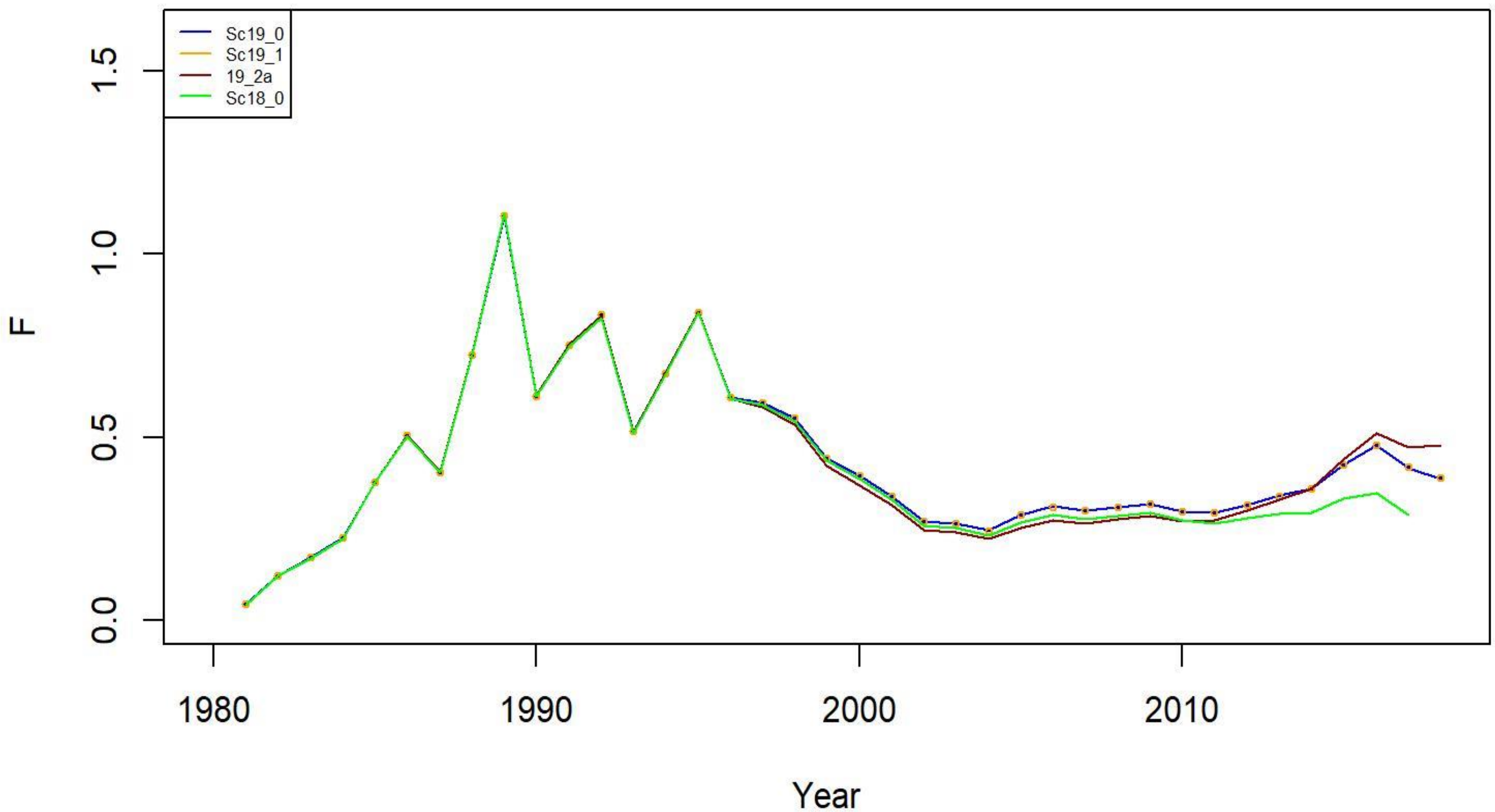


Figure 25. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 18_0 (green line), 19_0, 19_1, and 19_2a model fits in the EAG, 1981/82–2018/19.

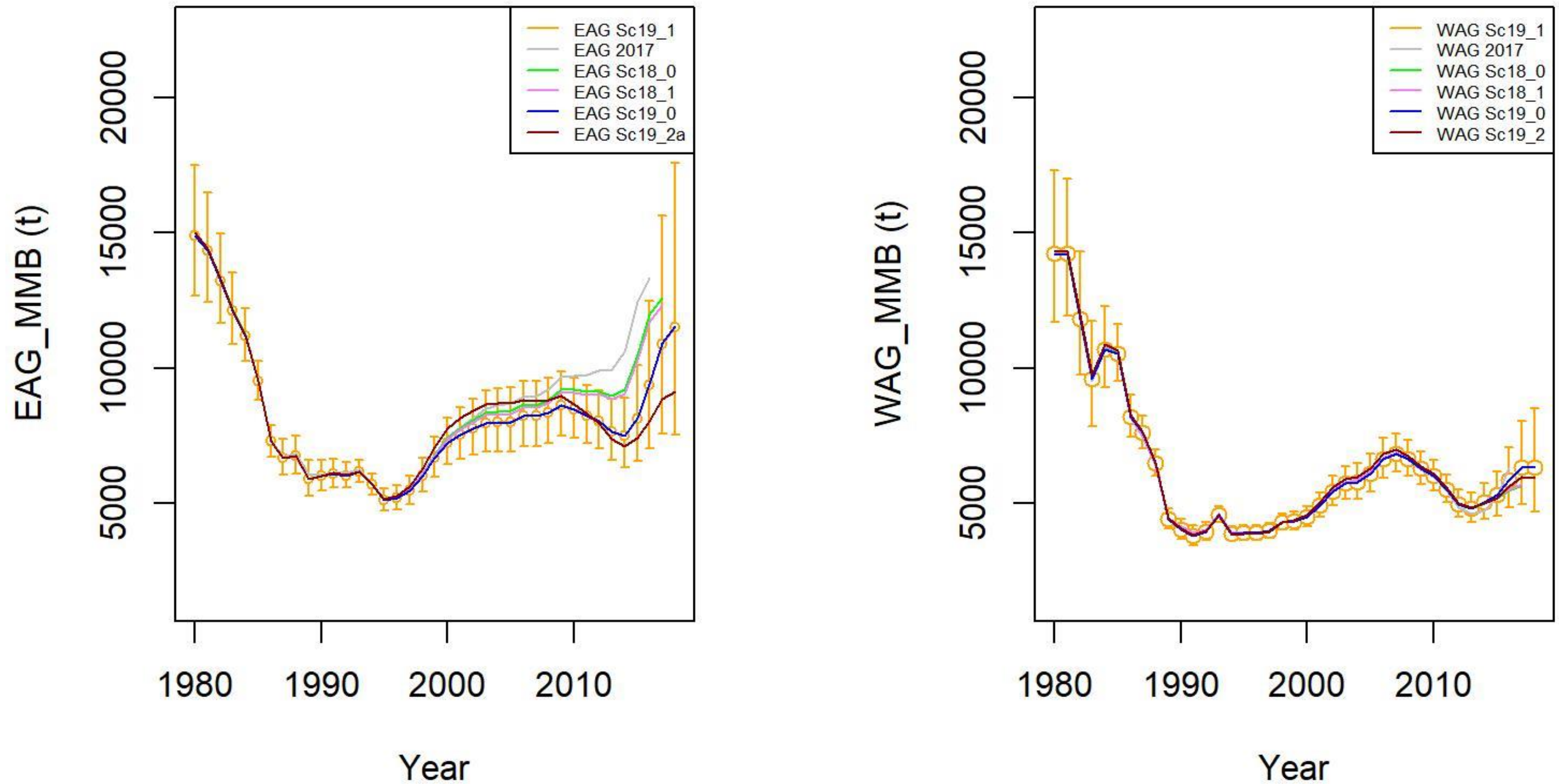


Figure 26. Trends in golden king crab mature male biomass for scenarios EAG 2017 (up to 2016/17 data), 18_0 and 18_1 (up to 2017/18 data), and 19_0, 19_1, 19_2a (EAG), or 19_2 (WAG) (up to 2018/19 data) fits to EAG (left) and WAG (right) data, 1960/61–2018/19. Scenario 19_1 estimate have two standard error confidence limits.

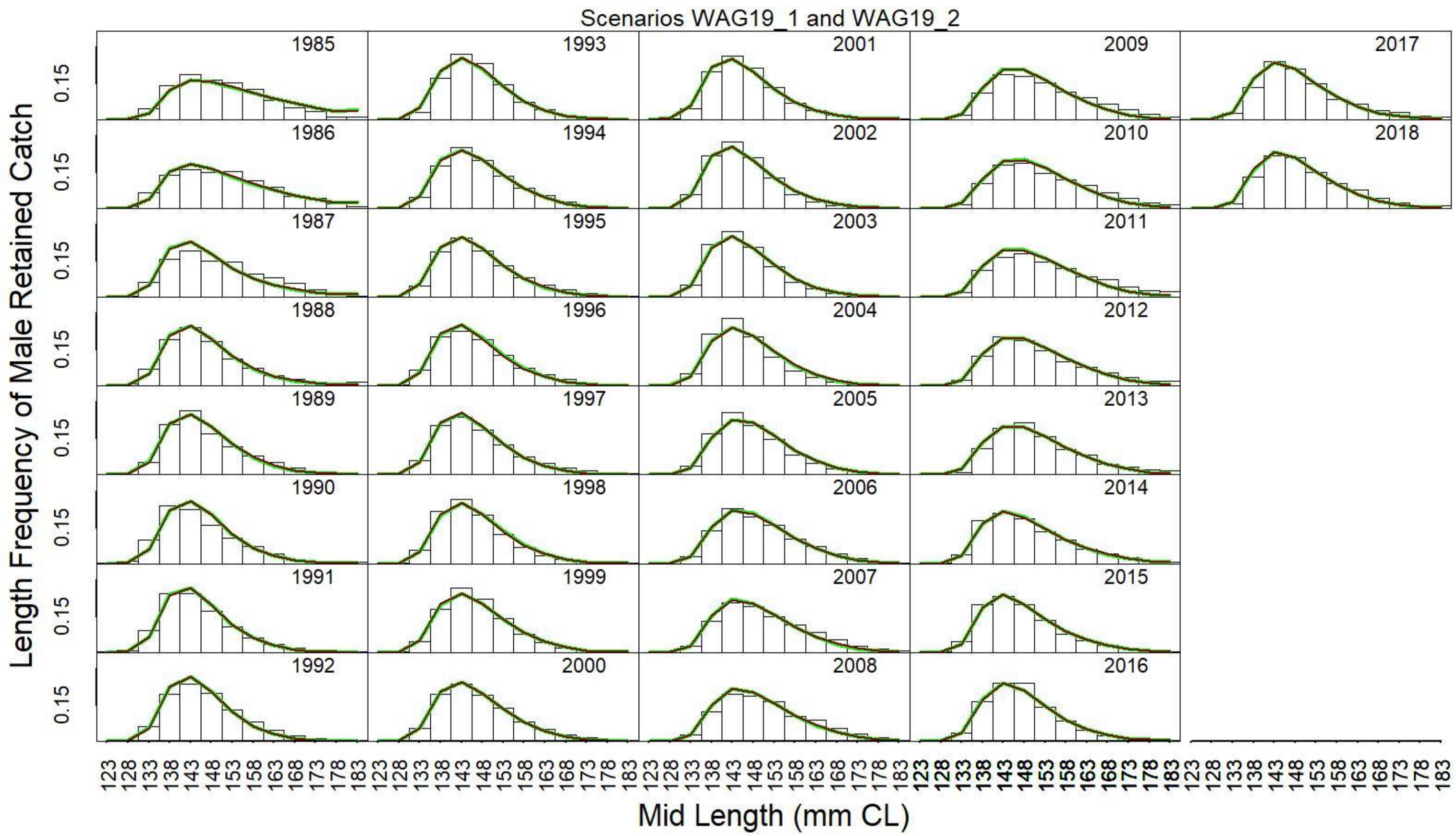


Figure 27. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2 (dark red line) for golden king crab in the WAG, 1985/86 to 2018/19. This color scheme is used in all other graphs.

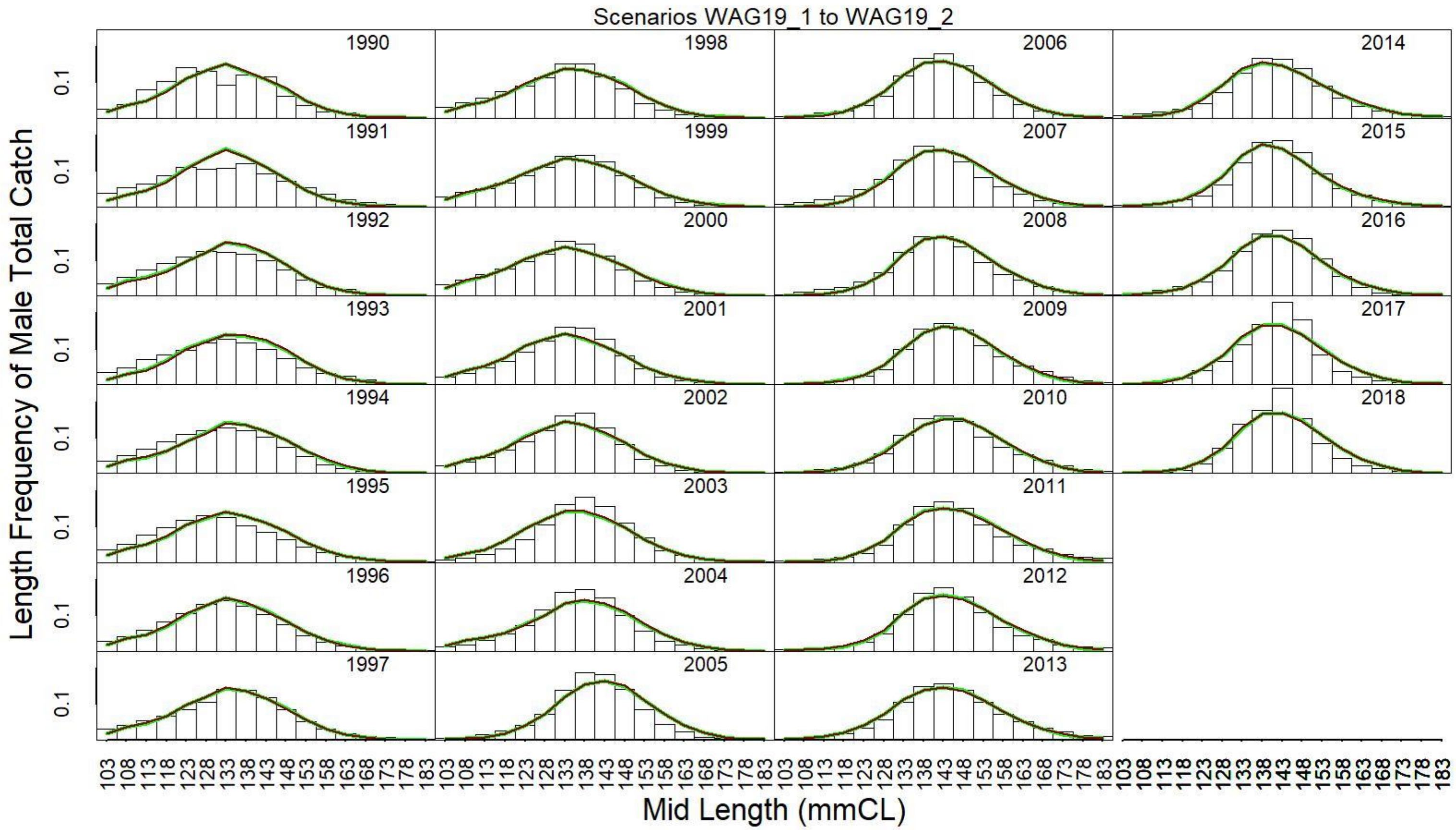


Figure 28. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2 (dark red line) for golden king crab in the WAG, 1990/91 to 2018/19.

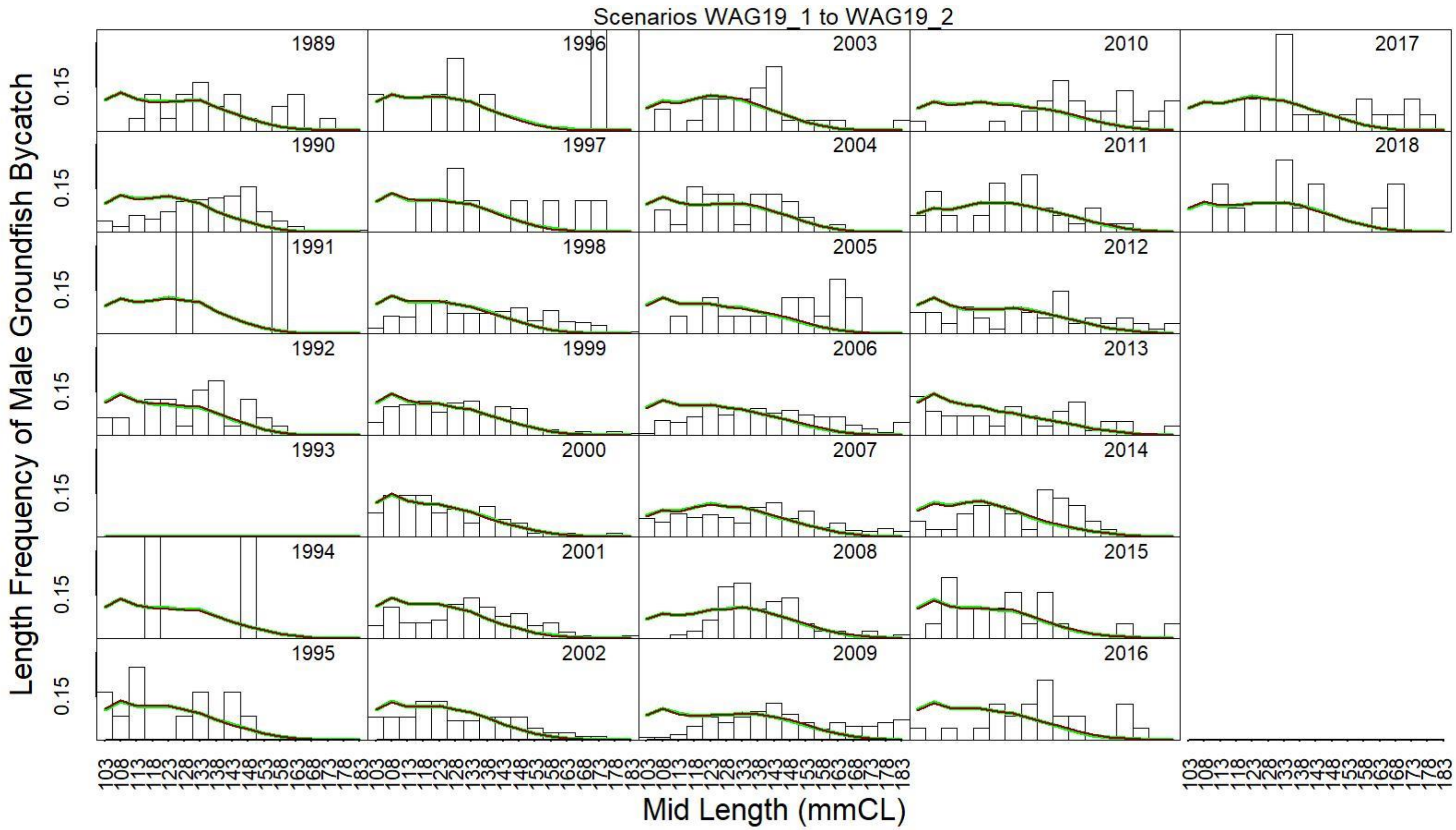


Figure 29. Predicted (line) vs. observed (bar) groundfish discarded bycatch relative length frequency distributions under scenarios 19_1 (green line) and 19_2 (dark red line) for golden king crab in the WAG, 19989/90 to 2018/19.

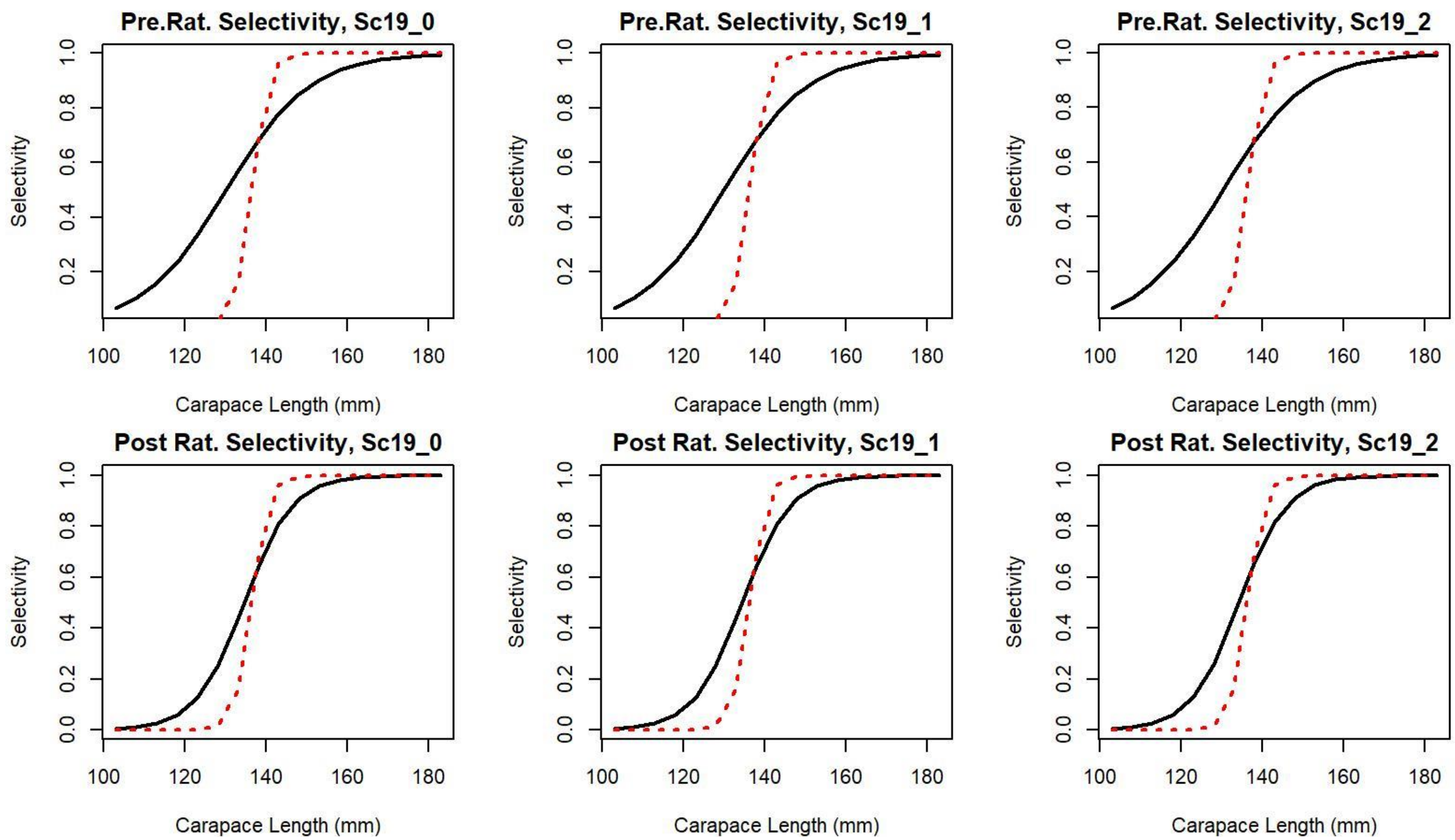


Figure 30. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 19_0, 19_1, and 19_2 model fits to golden king crab data in the WAG.

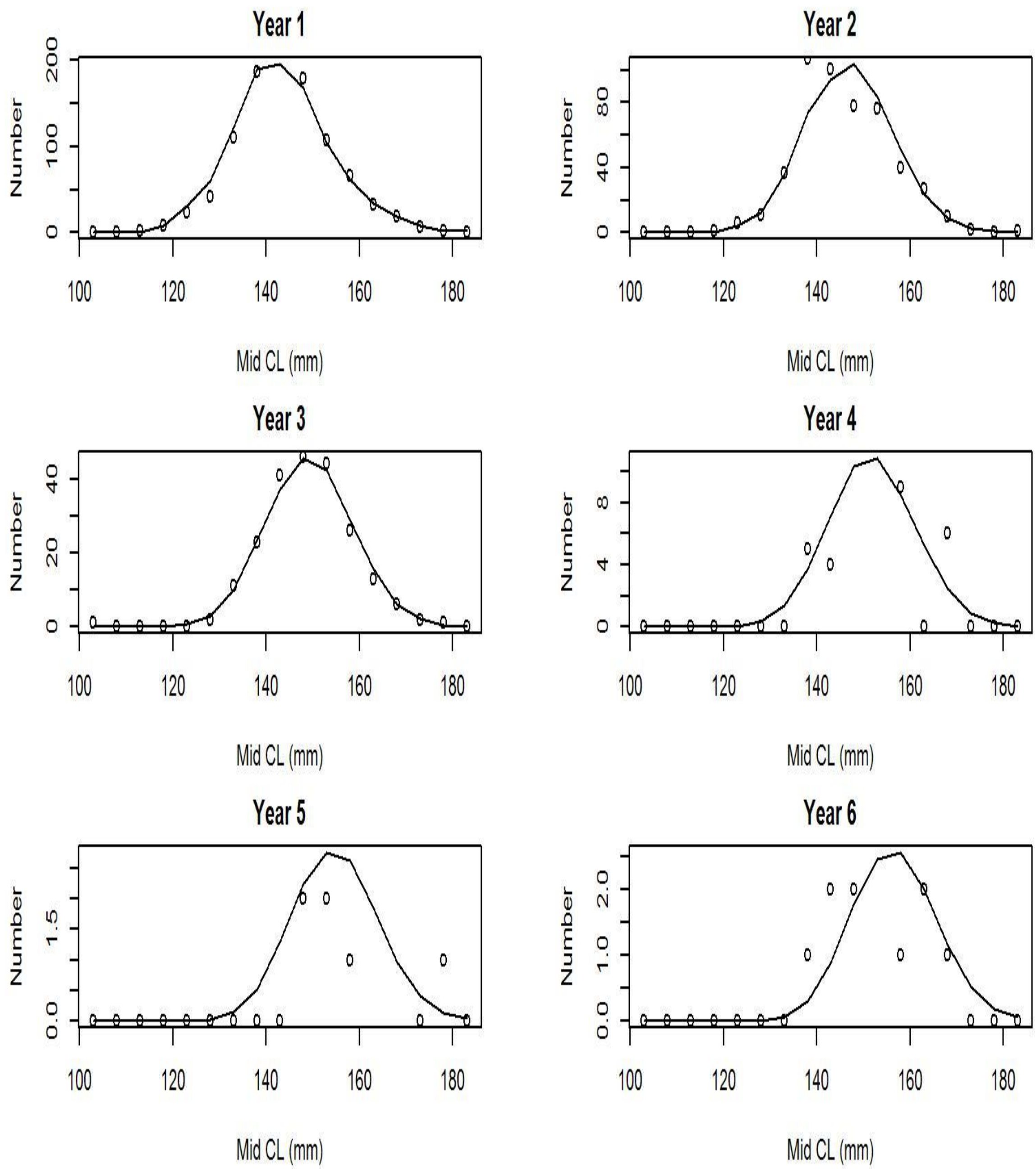


Figure 31. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 19_1 for WAG golden king crab.

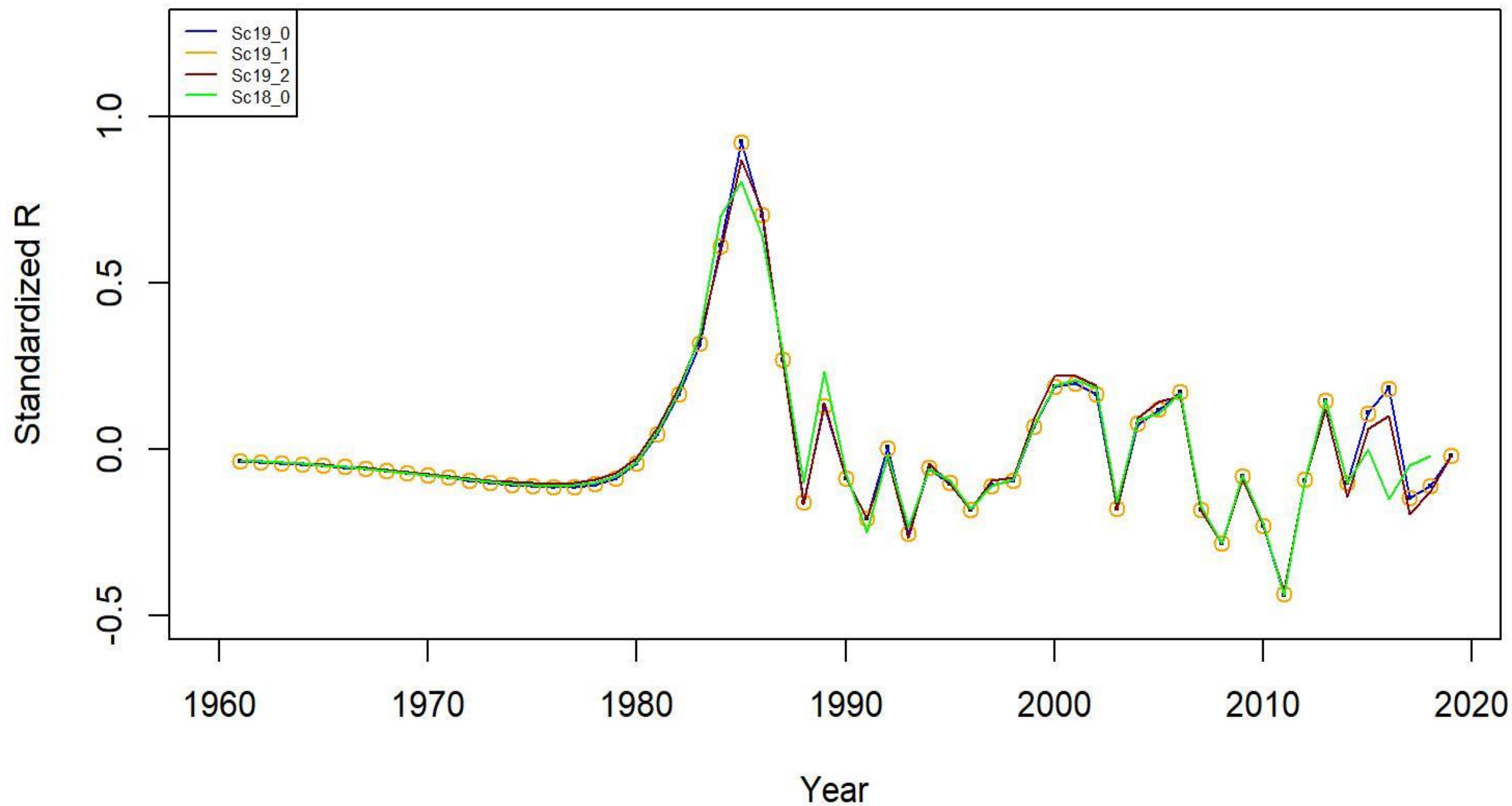


Figure 32. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for WAG golden king crab data, 1961–2019. The numbers of recruits are standardized using (R-mean R)/mean R for comparing different scenarios' results.

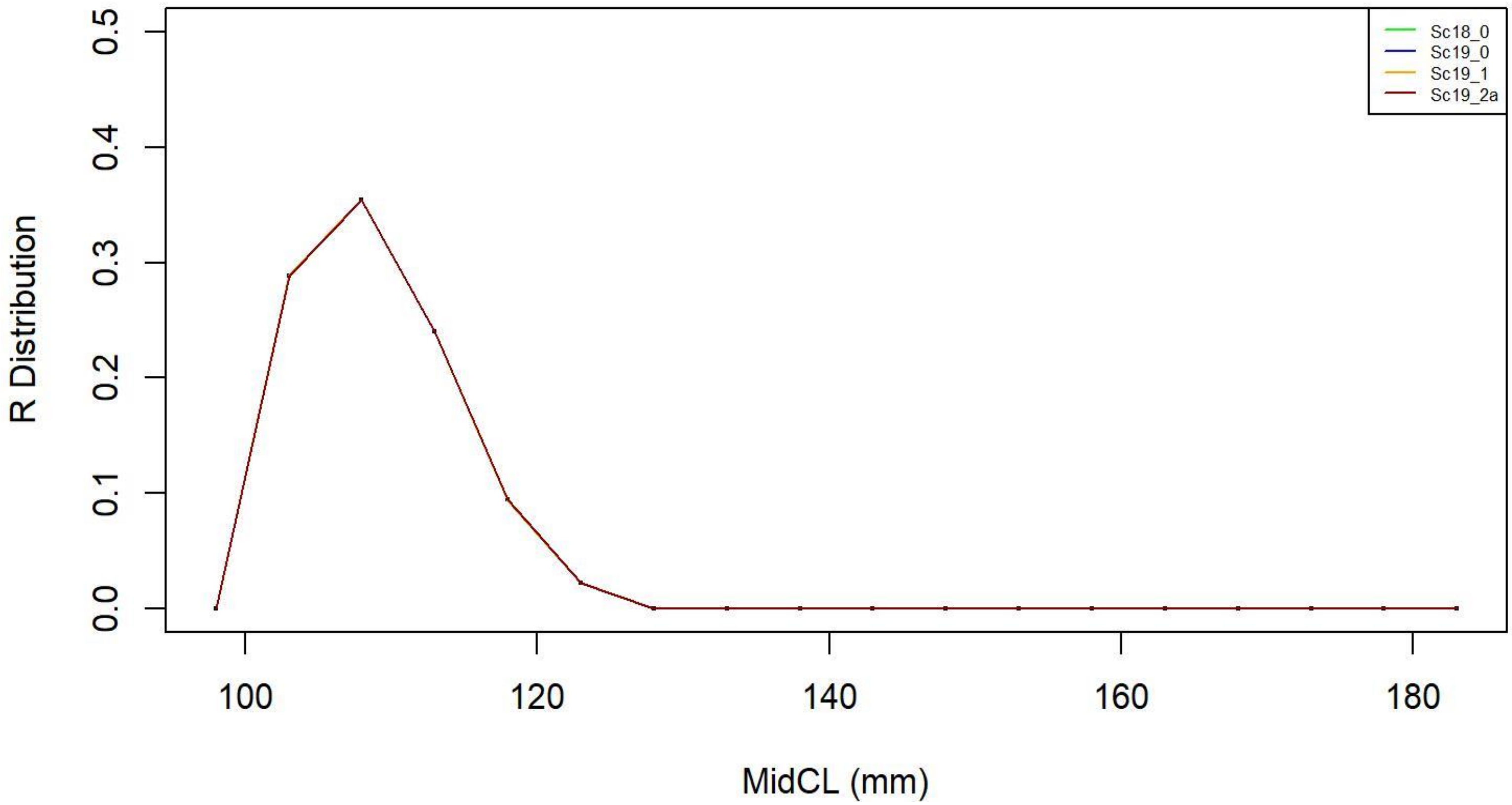


Figure 33. Recruit size distribution to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for WAG golden king crab.

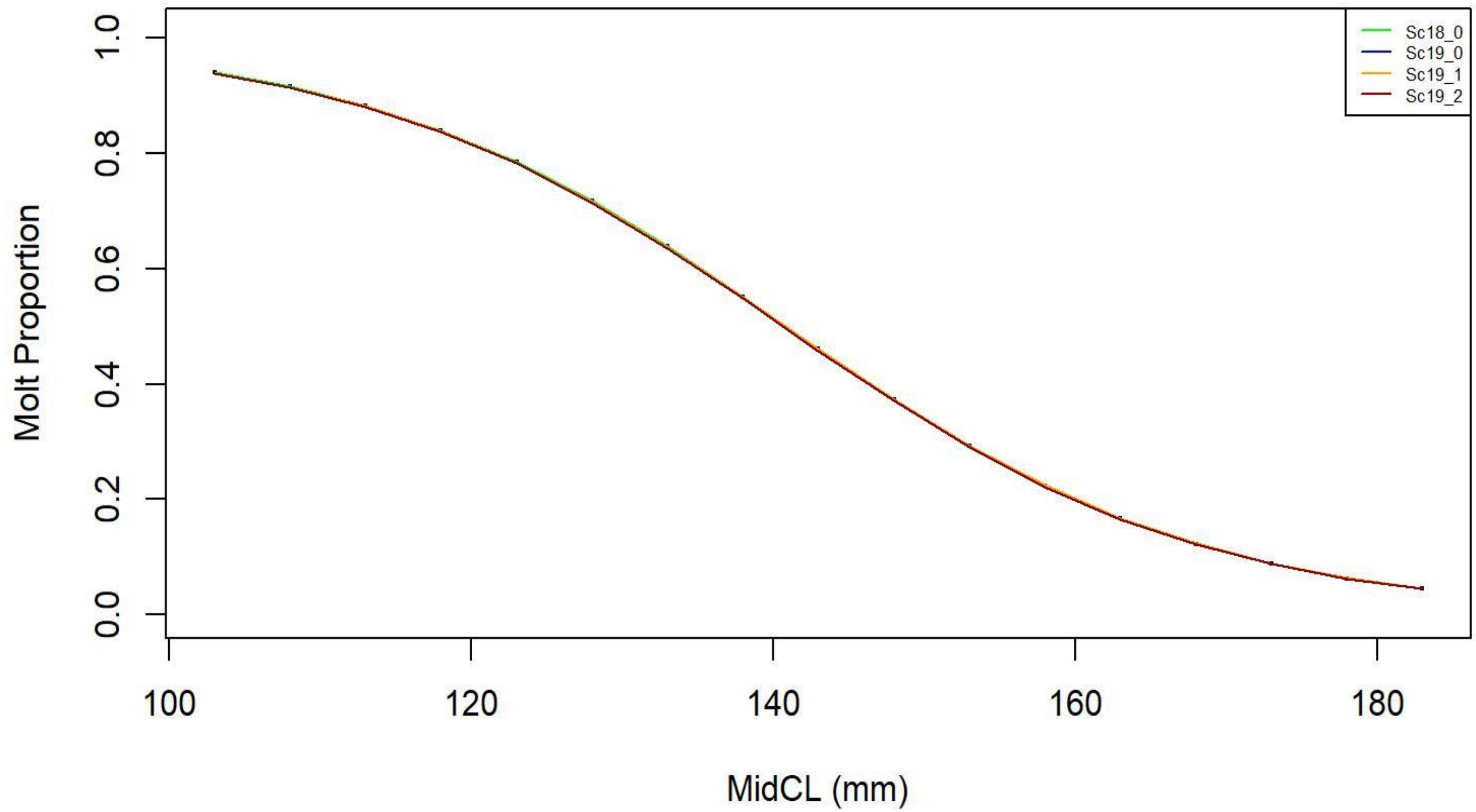


Figure 34. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for WAG golden king crab.

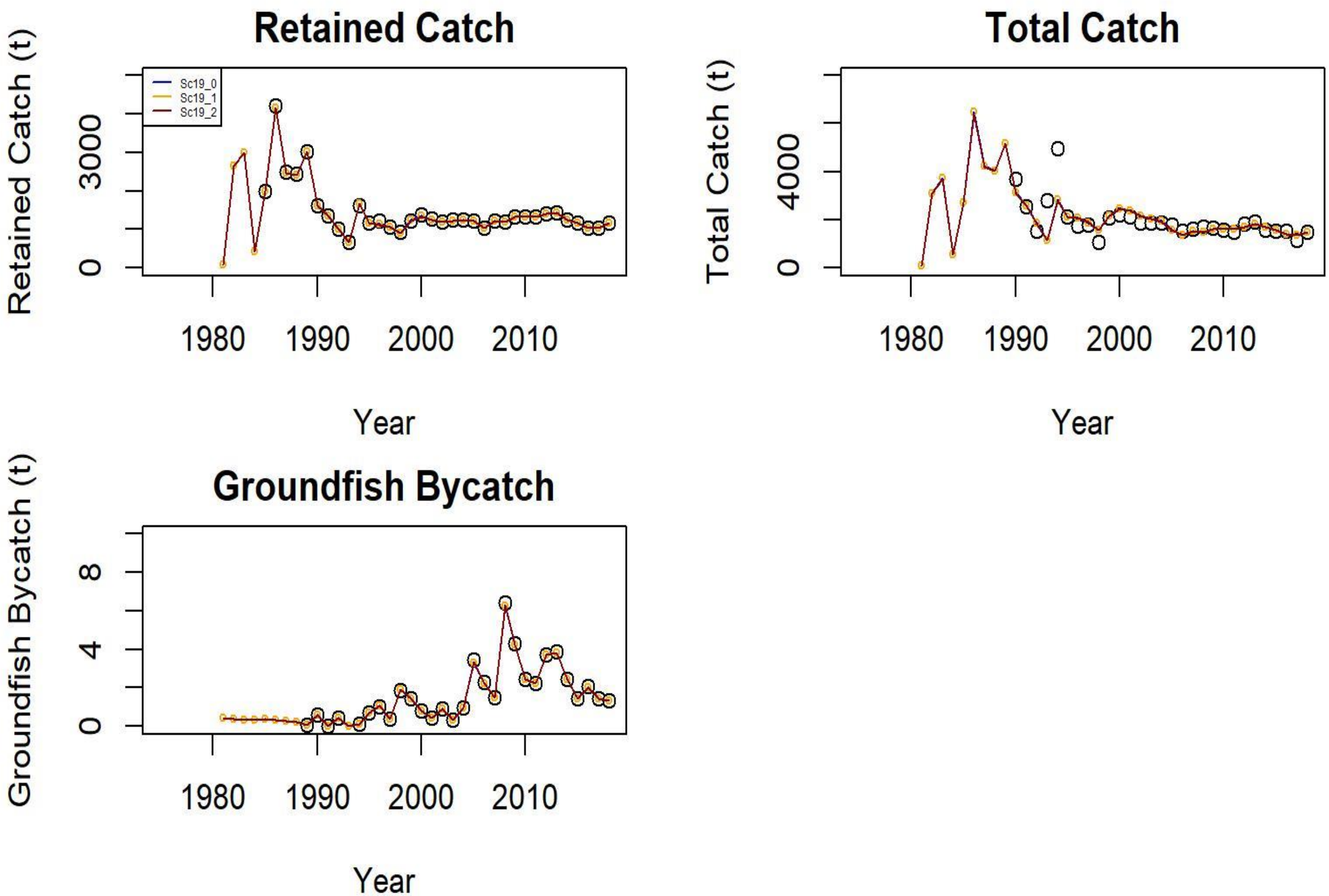


Figure 35. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for scenarios 19_0, 19_1, and 19_2 fits in WAG, 1981/82–2018/19.

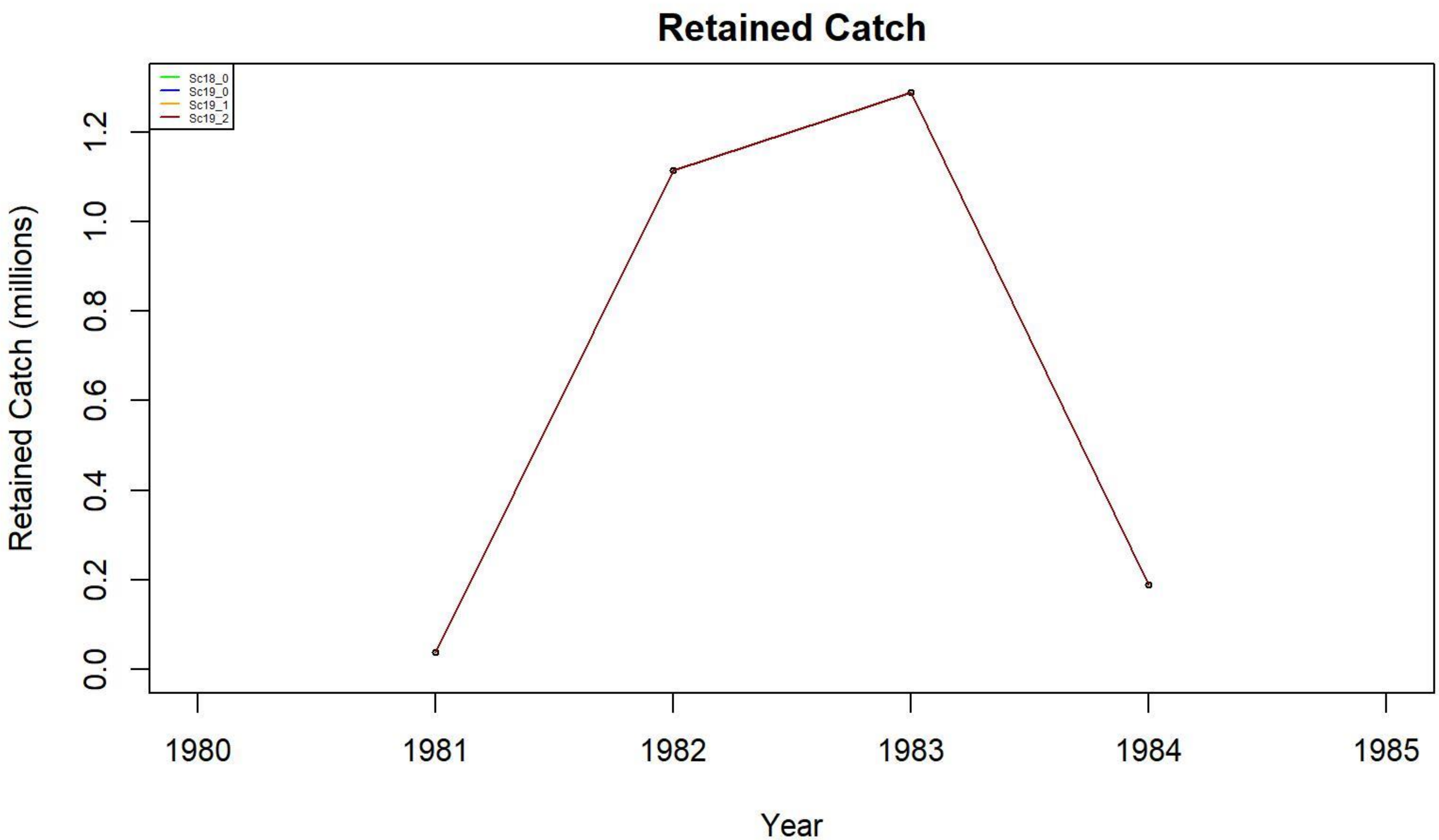


Figure 36. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for golden king crab fits in the WAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

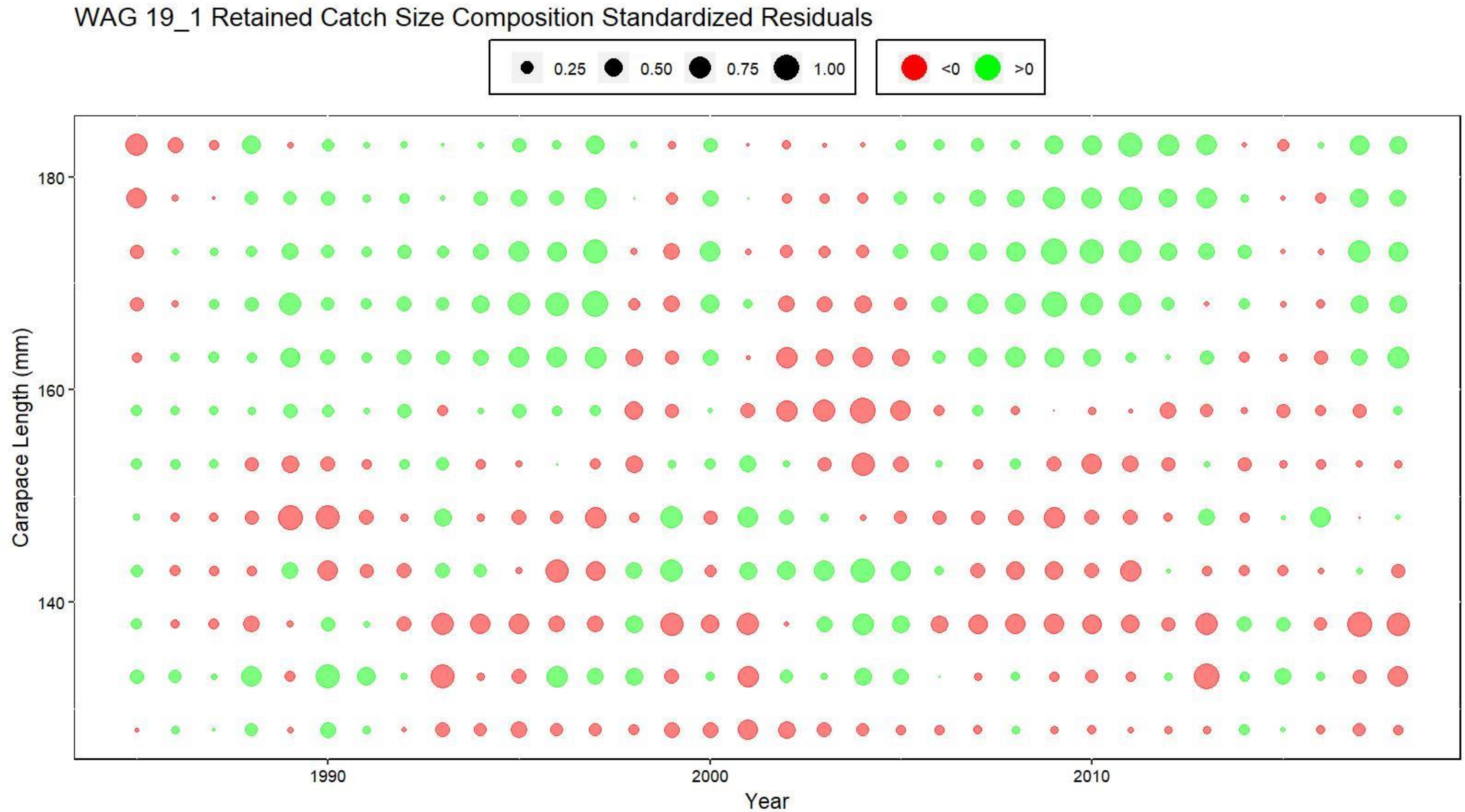


Figure 37. Bubble plot of standardized residuals of retained catch length composition for scenario 19_1 fit for WAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

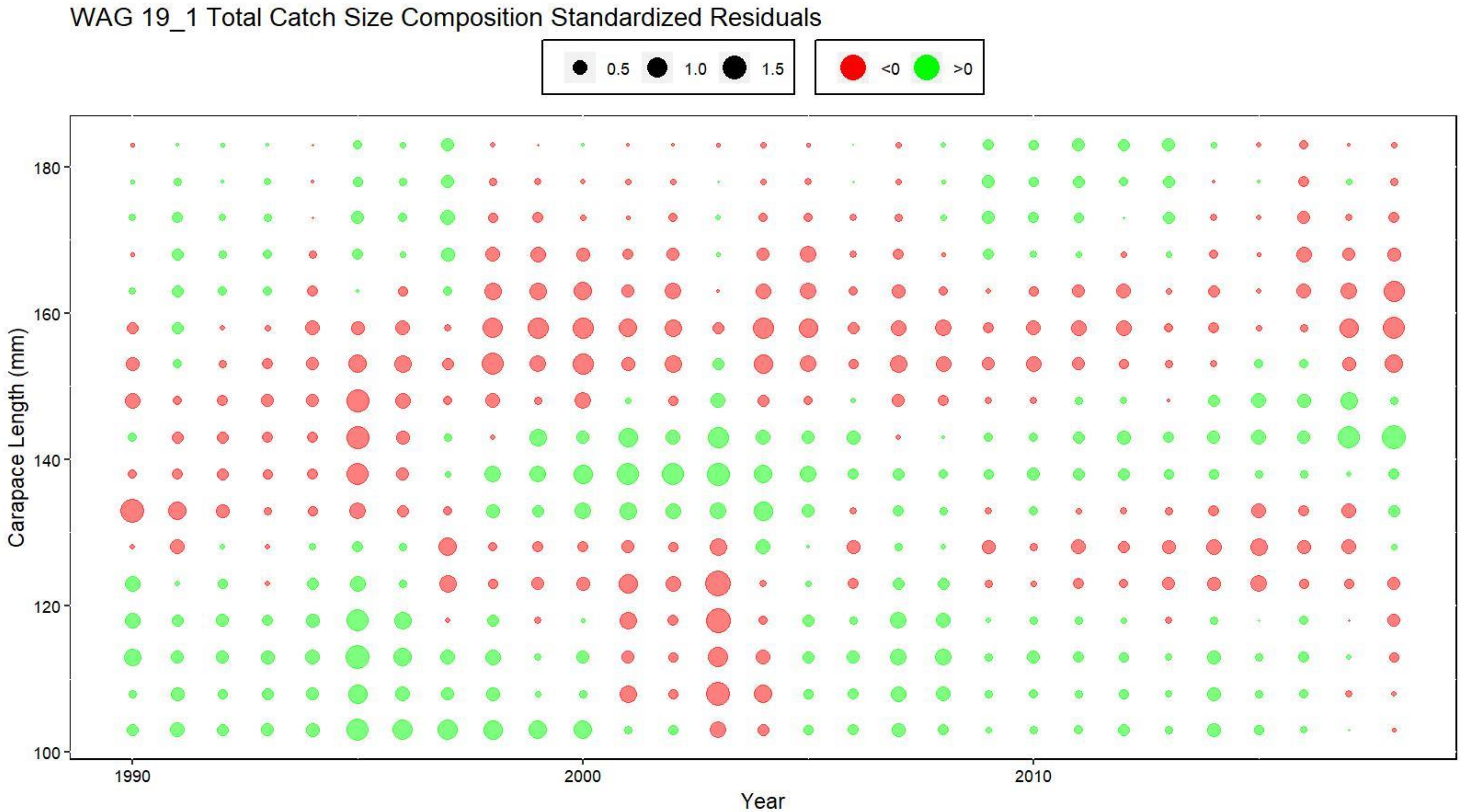


Figure 38. Bubble plot of standardized residuals of total catch length composition for scenario 19_1 fit for WAG golden king crab, 1990/91–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

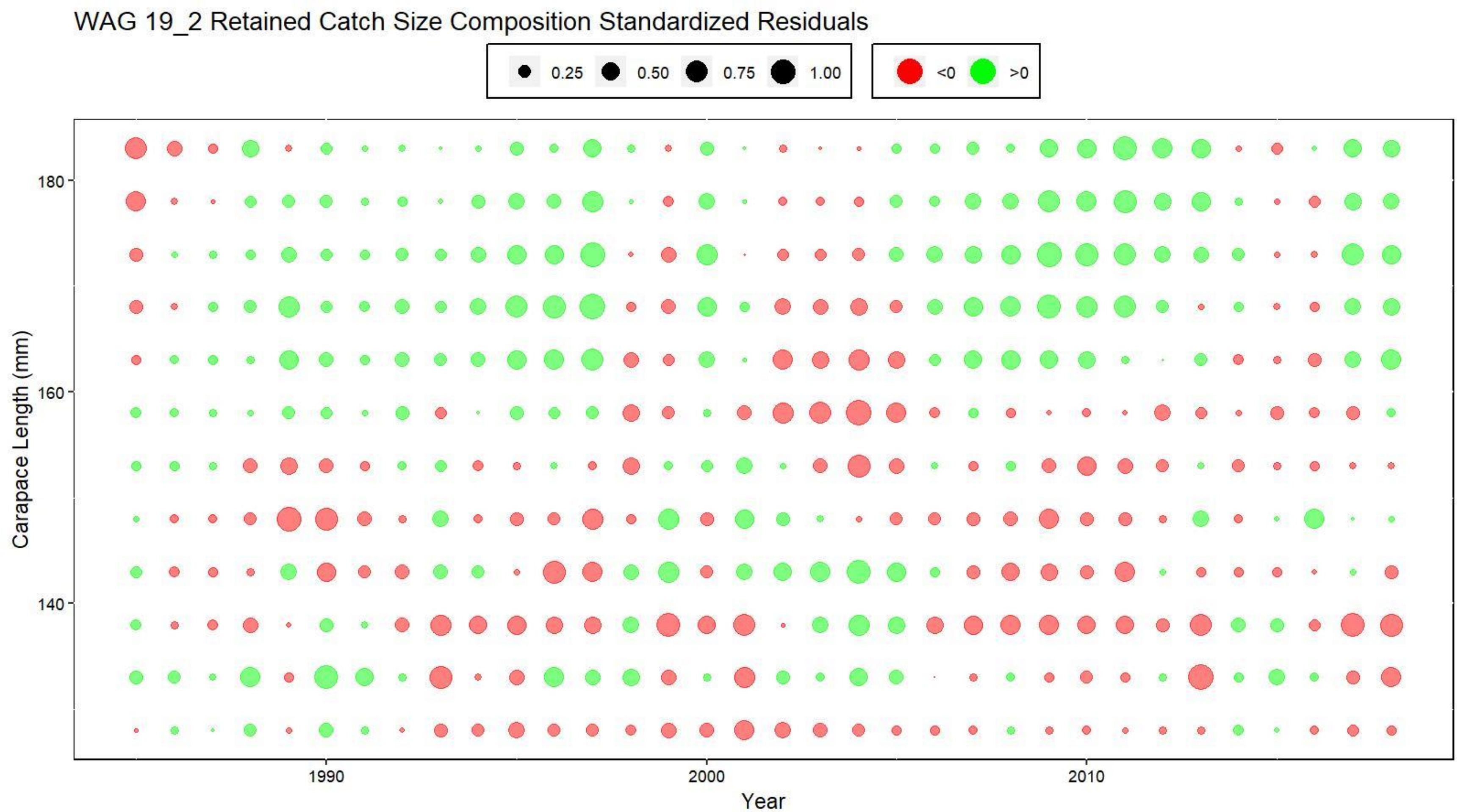
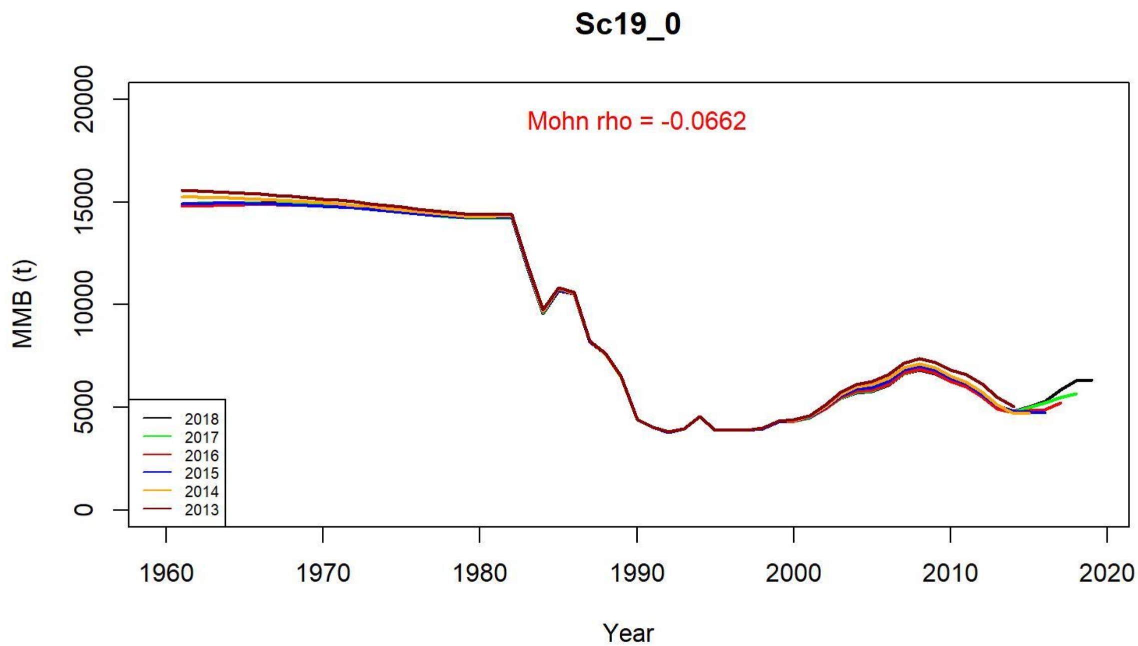
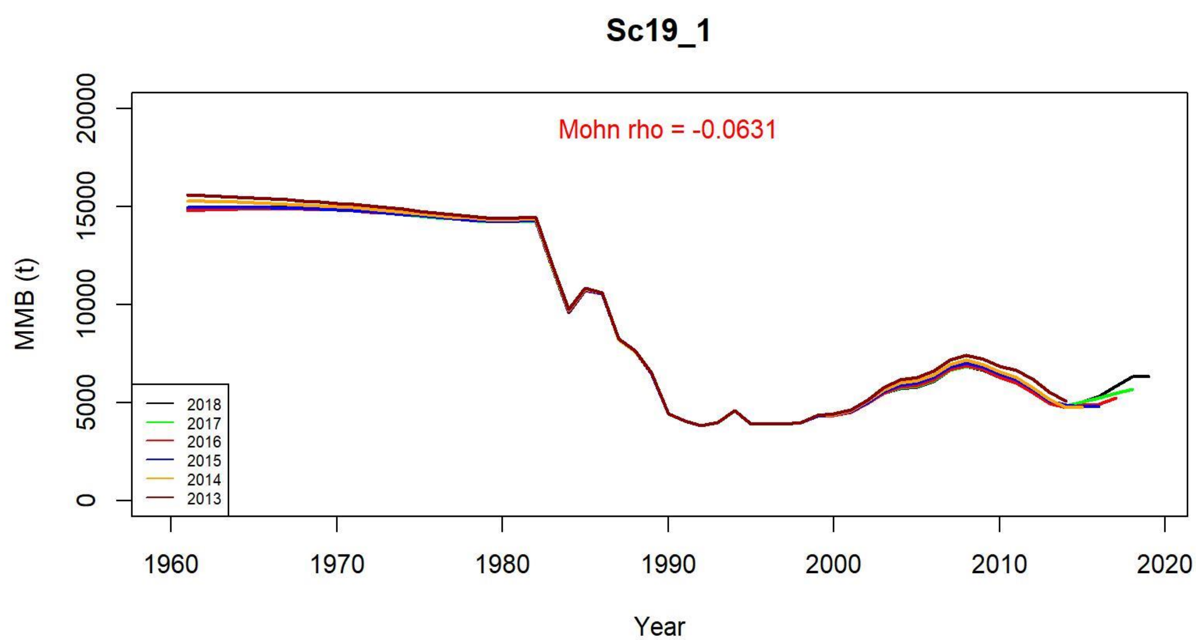


Figure 39. Bubble plot of standardized residuals of retained catch length composition for scenario 19_2 fit for WAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

Figure 40. Bubble plot of standardized residuals of total catch length composition for scenario 19_2 fit for WAG golden king crab, 1990/91–2018/19. 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.



Sc19_0
Mohn rho = -0.0662
MMB (t)
Year
2018
2017
2016
2015
2014
2013



Sc19_1
Mohn rho = -0.0631
MMB (t)
Year
2018
2017
2016
2015
2014
2013

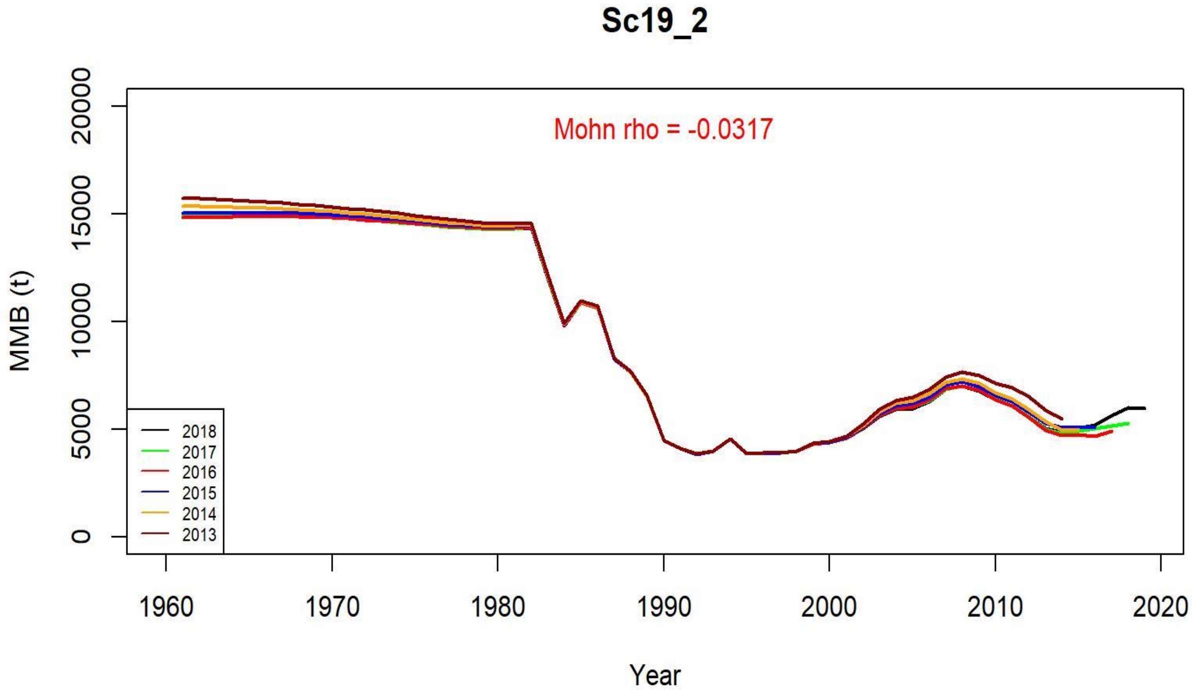


Figure 41. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 19_0, 19_1 and 19_2 for golden king crab in the WAG, 1960/61–2018/19.

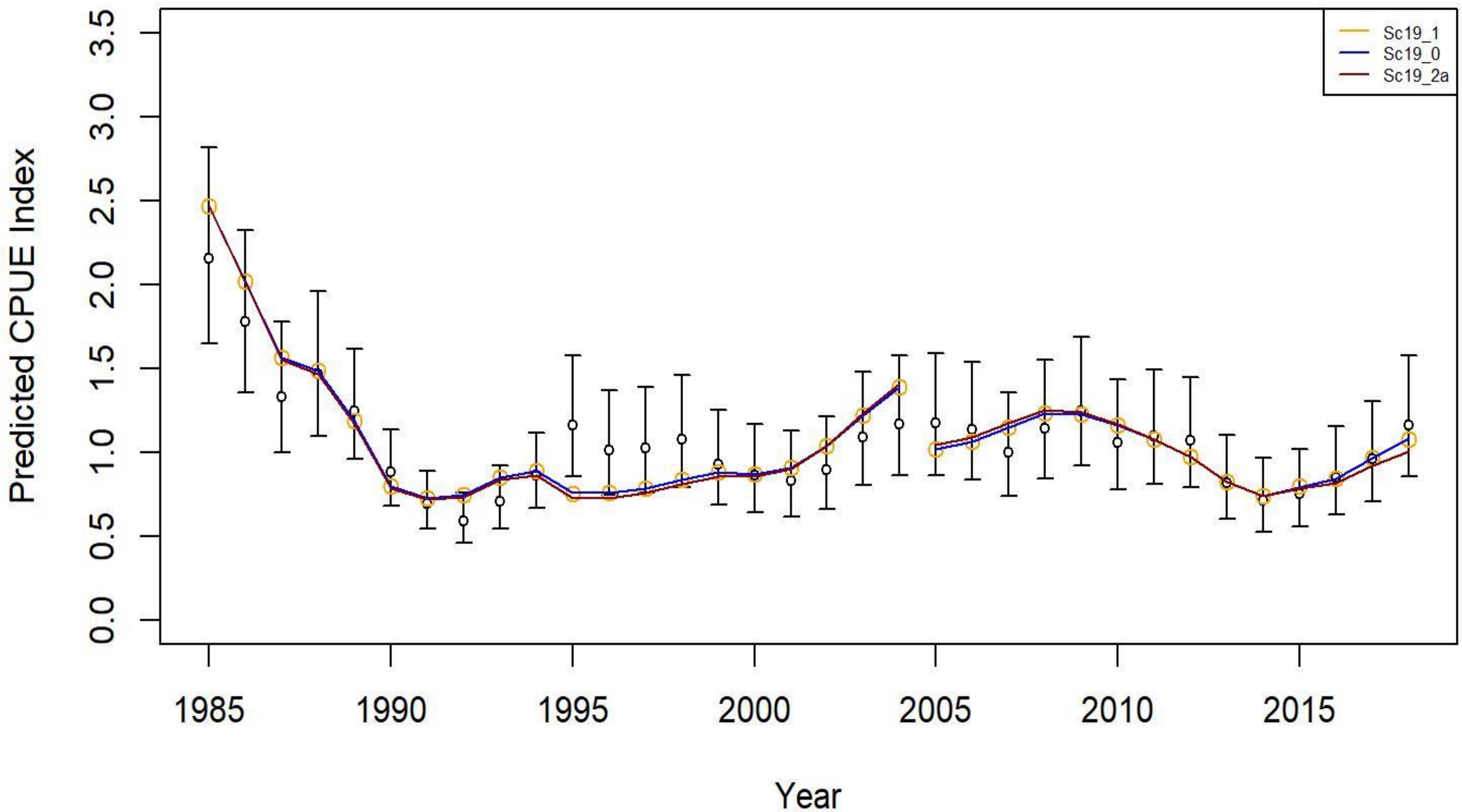


Figure 42. Comparison of input CPUE indices (open circles with +/- 2 SE) with model predicted CPUE indices (colored solid lines) under scenarios 19_0, 19_1 (orange points), and 19_2 for WAG golden king crab data, 1985/86–2018/19. Model estimated additional standard error was added to each input standard error.

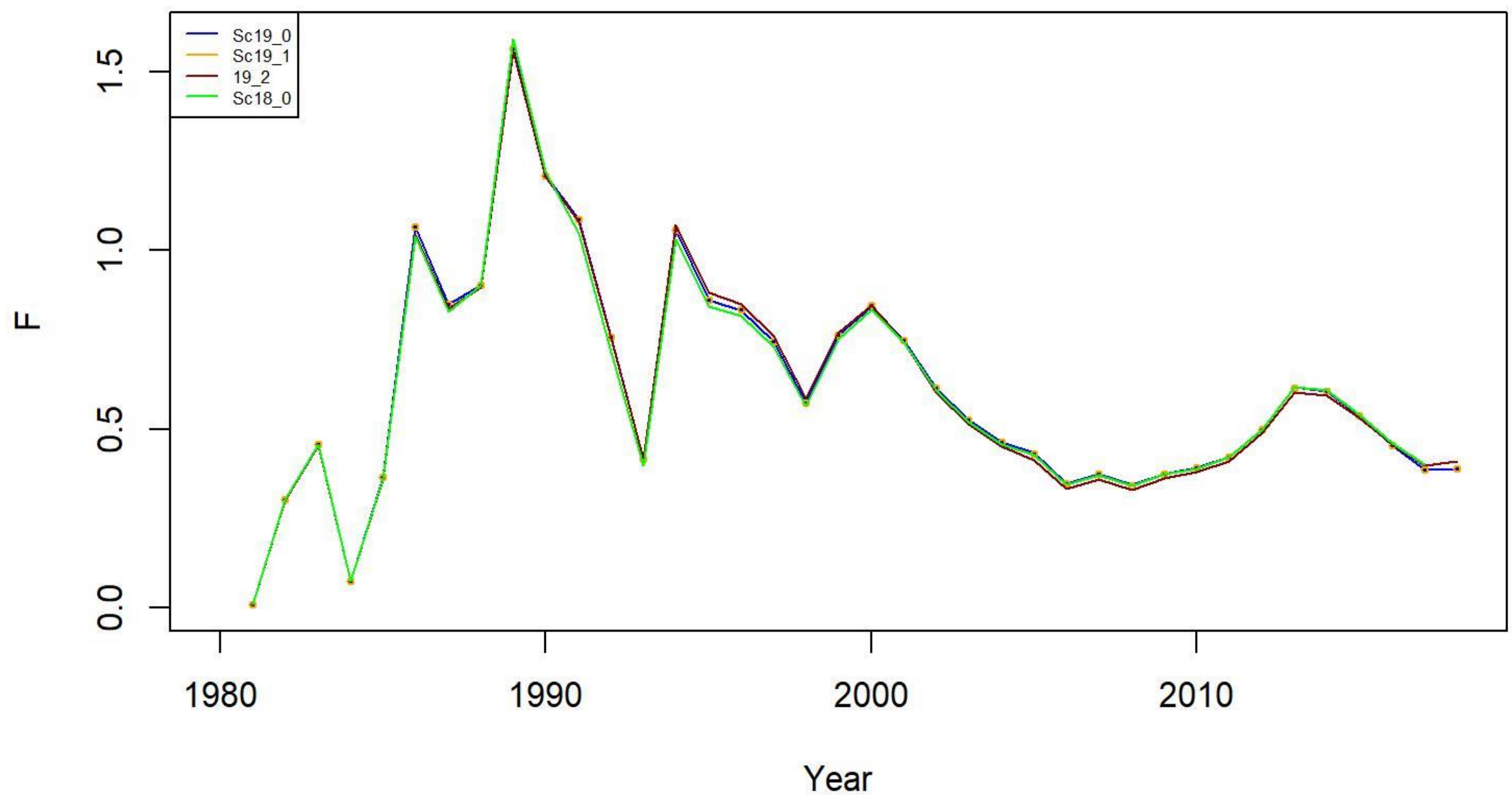


Figure 43. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 18_0 (green line), 19_0, 19_1, and 19_2 model fits in the WAG, 1981/82–2018/19.

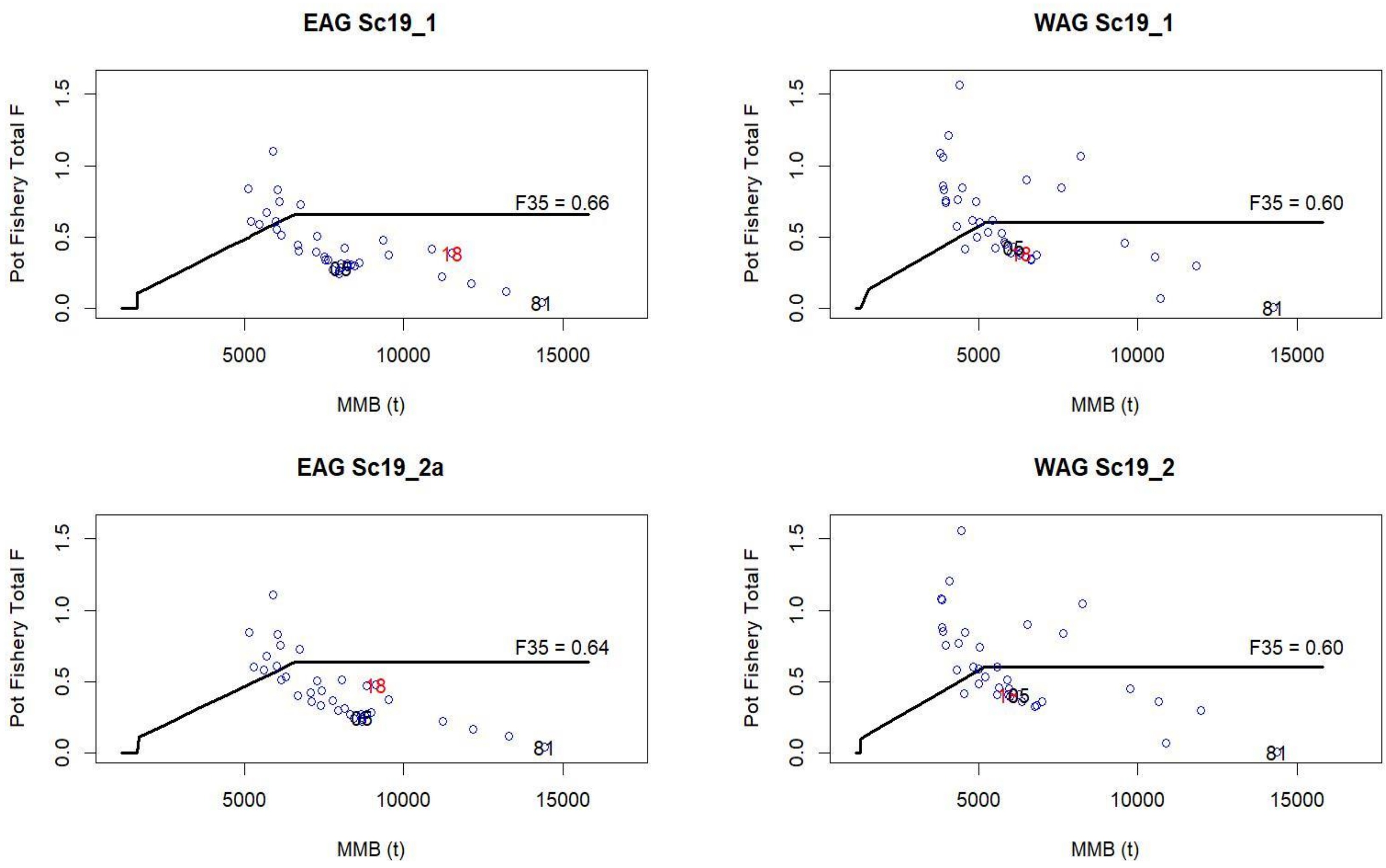


Figure 44. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985/86–2018/19 under scenarios 19_1 and 19_2a (or19_2) for EAG and WAG. Average recruitment from 1987 to 2012 was used to estimate $MMB_{35\%}$.

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; $\hat{C}_{t,i}$, $\hat{D}_{t,i}$, 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 mid –point 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

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

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

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

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

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

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 fish 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

$$N = X.S.N + R \quad \text{(A.4)}$$

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

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

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 to 1984/85.

Growth Matrix

The growth matrix X is modeled as follows:

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

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:

$$\mu_i = \omega_1 + \omega_2 * \bar{L}_i. \quad \text{(A.7)}$$

ω_1 , ω_2 , and σ are estimable parameters, and 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:

$$m_i = \frac{1}{1 + e^{c(\bar{L}_i - d)}} \quad \text{(A.8)}$$

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 pot fishery:

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

where θ_{95} and θ_{50} are the parameters of the selectivity/ retention pattern (Mark Maunder, unpublished generic crab model). In the 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

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

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:

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

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

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

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 to 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:

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

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 $CPUE_t^r$:

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

in which q_k is the catchability coefficient during the *k*-th time 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 retained catch rate indices.

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

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

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 $\underline{\rho}_{j,t,y}$ 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):

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

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

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

$$\text{P}_5 = \lambda_{\text{posfn}} * \text{fpen} \tag{A.23}$$

Standardized Residual of Length Composition

$$\text{Std. Res}_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma^2_{t,j}}} \tag{A.24}$$

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 2007) 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, a F_{OFL} value is needed. 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 2007). 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* $MMB_{current} > 0.25MMB_{35\%}$,

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

If,
$MMB_{current} \leq 0.25MMB_{35\%}$,

$F_{OFL} = 0.$

where α is a parameter, $MMB_{current}$ is the mature male biomass in the current year and $MMB_{35\%}$ is the proxy MMB_{MSY} for Tier 3 stocks. We assumed $\alpha = 0.1$.

Because projected MMB_t (i.e., $MMB_{current}$) depends on the intervening retained and discard catch (i.e., 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
Initial conditions:	
Length specific equilibrium abundance	17 (estimated)
Fishing mortalities:	
Pot fishery, F_t	1981–2018 (estimated)
Mean pot fishery fishing mortality, $\bar{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2018 (the mean F for 1989 to 1994 was used to estimate groundfish discards back to 1981 (estimated)
Mean groundfish fishery fishing mortality, $\bar{F}^{Tr}$	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 mmCL)
Distribution to length-class, β_r	1 (estimated)
Median recruitment, $\bar{R}$	1 (estimated)
Recruitment deviations, ε_t	59 (1961–2019) (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 scenario for EAG and WAG.

Weight	Scenario 19_0	Scenario 19_1	Scenario 19_2 (or 19_2a)
Catch:			
Retained catch for 1981–1984 and/or 1985–2018, λ_r	500 (0.032)	500	500
Total catch for 1990–2018, λ_T	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250
Groundfish bycatch for 1989 –2018, λ_{GD}	0.2 (3.344)	0.2	0.2
Catch-rate:			
Observer legal size crab catch-rate for 1995–2018, $\lambda_{r,CPUE}$	1(0.805)	1	1
Fish ticket retained crab catch-rate for 1985–1998 , $\lambda_{r,CPUE}$	1(0.805)	1	1
Penalty weights:			
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	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	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2 (0.533)	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000
Tagging likelihood	EAG individual tag returns	EAG tag data	EAG tag data

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

$$\sum_{j=1}^{k} C_j \frac{LF_{j,i}}{\sum_{i=1}^{n} LF_{j,i}} \tag{B.1}$$

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 catch 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 1990/91–2018/19 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 (it can be different number 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 1995/96–2018/19. The 1990/91–2018/19 observer database consists of 115,118 records and that of 1995/96–2018/19 contains 110,843 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 –2018/19.

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 2005/06–2018/19, 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 lognormal GLM to fish ticket data (Tables 4 and 13).

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 made by the CIE reviewers (CIE, 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 SSC (October 2018) suggestion, we used a hybrid procedure: First, 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, 2018). 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. (unpublished, 2019) used a similar hybrid approach.

Table B.1. Updated Gear code 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 stands for the 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 January 2019 CPT request, we considered an Year:Area interaction factor as a special case for a CPUE standardization scenario.

Thus we estimated three sets of CPUE indices for model input scenarios, 19_0 (original gear codes), 19_1 (reduced number of gear codes), and 19_2 (WAG) or 19_2a (EAG) [reduced number of gear codes and Year:Area interaction].

For year and area interaction analysis, we designed the areas in to 30X30nmi grids as follows:

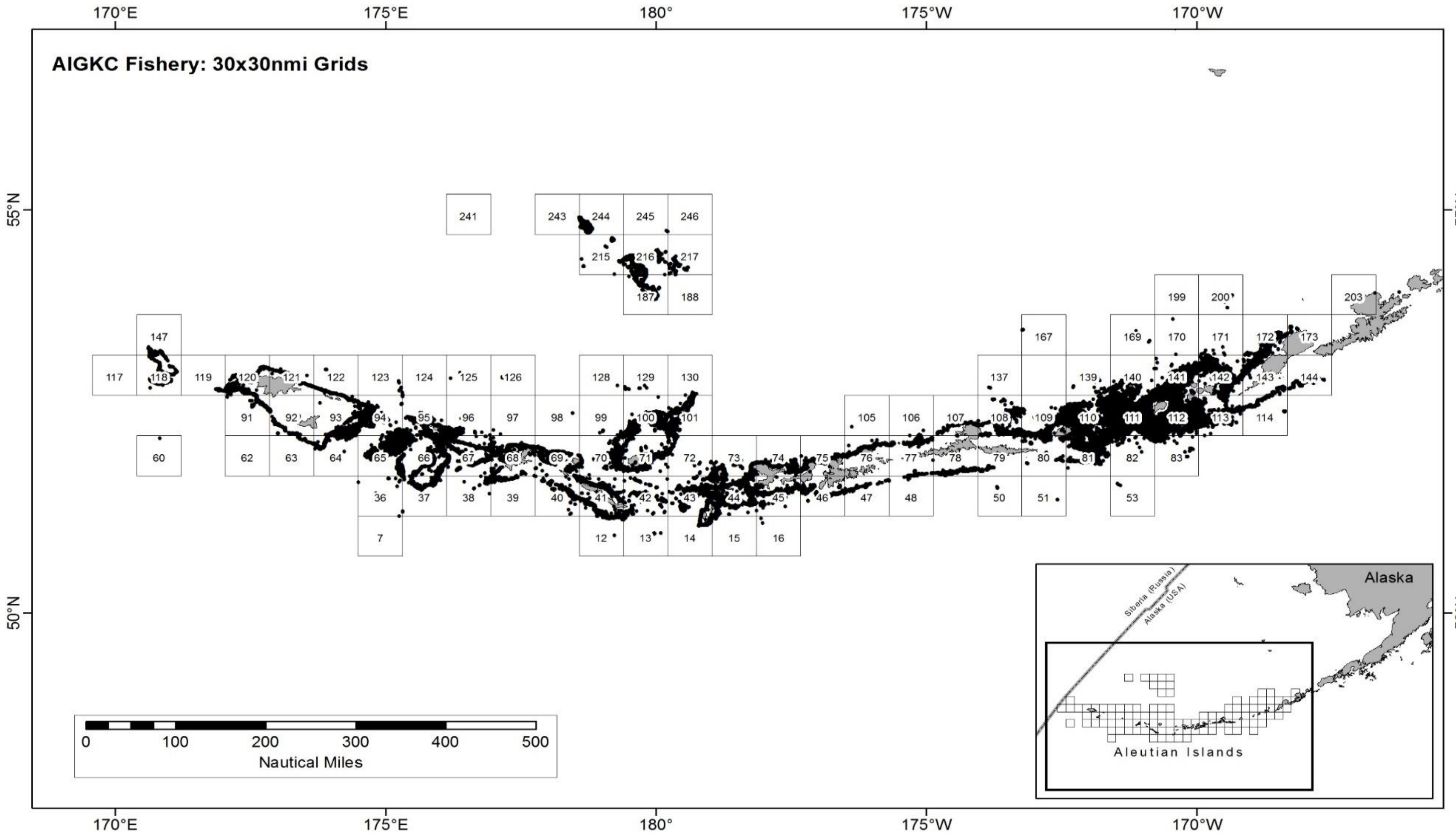


Figure B.1. The 1995/96 to 2018/19 observer pot samples enmeshed with 30X30nmi grids for the Aleutian Islands golden king crab.

To add a column of actual fishing location cell (i.e., foot print) in the 1995/96 to 2018/19 observer database, we used a geostatistical software available in R with the following lines of codes. It allocates an observer sampled pot location with a given Latitude and Longitude to the nearest Cell.

```
distancem<- vector(mode = "numeric", length = 106)
 library(geosphere)
  for(i  in 1:length(potsample1$Latitude))
   {distancem<- distGeo(potsample1[i,12:11],potsample2[,6:5])
   potsample1$GridCell[i]<- potsample2$FID[which.min(distancem)]   }
```

where "potsample1" is the original observer data base and "potsample2" is a set of Lat and Long centroids of 30X30nmi grids based on 1995_2017 observer data foot prints, and FID is a Cell number identified by a grid.

In the observer CPUE standardization, we identified the Area by the fishing foot print Cell ID#.

a. *Observer CPUE index by GLM*:

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

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

where Year is a factorial variable.

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

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

where Soak is in unit of days and is numeric; Month, Area (GridCell) 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).

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.

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=5)),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, r2.change=0.01)

The final main effect models for EAG were:

Scenario 19_0:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Area$
AIC=205012

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month$ (B.4)
for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2201$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) + Month + Vessel$
AIC=68144

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) \qquad (B.5)$$
for the 2005/06–2018/19 period [$\theta = 2.33$, $R^2 = 0.1157$].

Scenario 19_1:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Area$
AIC=204999

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month \qquad (B.6)$$
for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2203$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) + Month$
AIC=68132

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) \qquad (B.7)$$
for the 2005/06–2018/19 period [$\theta = 2.33$, $R^2 = 0.1135$].

The final models for WAG were:

Scenario 19_0:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 8) + \mathrm{Gear} + Area + Month$
AIC=179337

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 8) + Gear + Area \qquad (B.8)$$
for the 1995/96–2004/05 period [θ=1.0, $R^2 = 0.1874$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Vessel} + \mathrm{ns}(\mathrm{Depth}, 2) + \mathrm{Month} + \mathrm{ns}(\mathrm{Soak}, 9)$
AIC=96308

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 5) \qquad (B.9)$$
for the 2005/06–2018/19 period [$\theta = 1.15$, $R^2 = 0.0470$, Soak forced in].

Scenario 19_1:
Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + \text{Gear} + Area + Month$
AIC=179340

Final selection by stepCPUE:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + \text{Gear} + \text{Area}$ (B.10)
for the 1995/96–2004/05 period [θ=1.0, $R^2 = 0.1864$]

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Vessel} + \text{ns}(\text{Depth}, 2) + \text{Month} + \text{ns}(\text{Soak}, 5)$ AIC=96286

Final selection by stepCPUE:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{ns}(\text{Soak}, 5)$ (B.11)
for the 2005/06–2018/19 period [$\theta = 1.15$, $R^2 = 0.0468$, Soak forced in].

Year and Area interaction GLM:

We assumed the null model to be

$$\ln(\text{CPUE}_i) = \text{Year}_{y_i}\text{:Area}_{ai} \quad \text{(B.12)}$$

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

$$\ln(\text{CPUE}_I) = \text{Year}_{y_i}: Area_{ai} + \text{ns}(\text{Soak}_{si}, \text{df}) + \text{Month}_{m_i} + \text{Vessel}_{vi} + \text{Captain}_{ci} + \text{Area}_{ai} + \text{Gear}_{gi} + \text{ns}(\text{Depth}_{di}, \text{df}), \quad \text{(B.13)}$$

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(1.0),data=datacore)

 wpotsampleoutAIC<-stepAIC(glm.object,scope=list(upper=
~(Year:Area+ns(SoakDays,df=8)+Month+Vessel+Captain+Area+Gear+ns(Depth,df=10
)),lower=~Year:Area),family=
negative.binomial(1.0),direction="forward",trace=9,k=log(nrow(datacore))+1.0)
```

Step 2:

```
glm.object<- glm(Legals~Year:Area,family = negative.binomial(1.0),data=datacore)

 wpotsampleout<-stepCPUE(glm.object,scope=list(upper=
~(Captain+ns(SoakDays,df=8)+Gear+Area+Month+Year:Area),lower=
~Year:Area),family=
negative.binomial(1.0),direction="forward",trace=9,r2.change=0.01)
```

The final interaction effect models for EAG were:

Scenario 19_2:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \ \mathrm{Gear} + \mathrm{Captain} + \mathrm{Month} + \mathrm{ns}(\mathrm{Soak}, 4) + Area + Year{:}Area$

AIC=205530

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \ \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Year{:}Area$ (B.14)
for the 1995/96–2004/05 period [θ=1.38, $\mathrm{R}^2 = 0.2368$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \ \mathrm{Vessel} + \mathrm{Gear} + \ \mathrm{ns}(\mathrm{Soak}, 9) + Year{:}Area$
AIC=69116

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \ \mathrm{ns}(\mathrm{Soak}, 9) + Gear + Year{:}Area$ (B.15)
for the 2005/06–2018/19 period [$\theta = 2.33, \ \mathrm{R}^2 = 0.1463$].

The final interaction effect models for WAG were:

Scenario 19_2:
Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Captain} + \text{ns}(\text{Soak}, 8) + Gear + Area + Month + Year{:}Area$

AIC=181206

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Captain} + \text{ns}(\text{Soak}, 8) + \text{Gear} + Year{:}Area \qquad \text{(B.16)}$$

for the 1995/96–2004/05 period [θ=1.0, $R^2 = 0.2103$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Vessel} + \text{Area} + \text{Gear} + \text{ns}(\text{Depth}, 2) + ns(Soak, 5) + Year{:}Area$

AIC=98649

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Vessel} + Year{:}Area + ns(Soak, 5) \qquad \text{(B.17)}$$

for the 2005/06–2018/19 period [$\theta = 1.15$, $R^2 = 0.1125$, Soak forced in].

Steps:

1. We removed the zero interaction factor cells based on the estimated bivariate correlation matrix (Zeros and NAs producing interaction factor levels were removed. Information is available with the first author).
2. We did not include the Year factor on its own in the GLM.
3. The Year coefficient (as CPUE index for an Year) was determined from the Year:Area coefficients as follows:

   $$Index_{yi} = \sum_i e^{coefficient\ (Year_i\ X\ Area_i)}\ X\ Area_i \qquad \text{(B.18)}$$

   Where *i* is the number of Grid Cell (fishing footprints) in $Year_i$

   The indices were rescaled by the geometric mean of estimated Index_{yi} values separately for the pre- and post-rationalization periods. The variance of ln(indexi) was estimated as the mean value of GLM estimated standard deviation ^2 for each year (this is because we assumed each Cell has the same area, 30X30nmi).

4. For EAG, the estimated variances were substantially high for the pre-rationalization period (Table B.2). Therefore, we modified Scenario 19_2 to 19_2a where pre-rationalization period's indices were omitted; instead, used the extended Fish Ticket CPUE indices (1985-1998).

Table B.2. Comparison of CPUE indices and variances of log CPUE between EAG and WAG for scenario 19_2.

Year	EAG CPUE Index 19_2	Variance (ln(CPUE))	WAG CPUE Index 19_2	Variance (ln(CPUE))
1995	0.8796	0.9656	0.9291	0.0725
1996	0.6943	0.9651	1.0757	0.0645
1997	0.7232	0.9045	0.9771	0.0283
1998	0.9321	0.9045	0.9623	0.0918
1999	0.8269	0.9275	0.8855	0.0384
2000	0.8824	0.9170	0.8203	0.0358
2001	1.3353	0.9591	0.8227	0.0275
2002	1.2385	0.9623	1.1716	0.0523
2003	1.1646	0.9049	1.0789	0.0328
2004	1.7285	0.8996	1.4085	0.0574
2005	0.9103	0.0539	1.1771	0.0649
2006	0.7970	0.0457	1.1095	0.0782
2007	0.9785	0.0589	1.0932	0.0764
2008	0.7926	0.0540	1.1148	0.0899
2009	0.5490	0.0630	1.2306	0.0695
2010	0.9999	0.0571	0.9935	0.0686
2011	1.1685	0.0709	1.2384	0.1084
2012	0.9646	0.0520	0.9521	0.1160
2013	1.3463	0.0491	0.9121	0.0893
2014	1.3650	0.0572	0.7339	0.1101
2015	1.2458	0.0639	0.7906	0.0769
2016	1.2662	0.0434	0.7636	0.0788
2017	0.9440	0.0371	0.8403	0.0958
2018	1.0498	0.0420	1.2837	0.1020

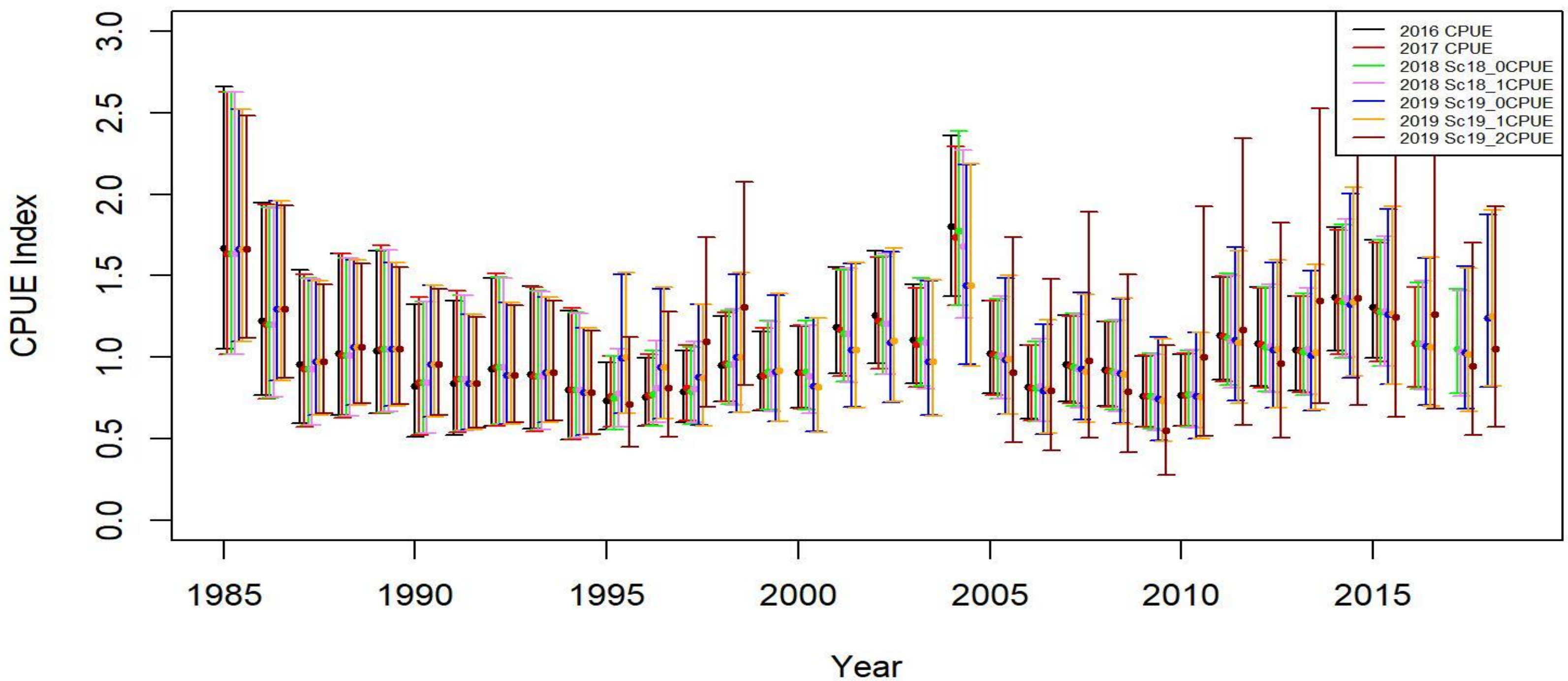


Figure B.2. Comparison of input CPUE indices for scenarios 2016 (ADF&G area codes grouped into 10 groups, up to 2015/16 data), 2017 (ADF&G area codes not grouped, up to 2016/17 data), 2018 Sc 18_0 (Lat and Long position of observed pot, up to 2017/18 data), 2018 Sc18_1 (Lat and Long position of observed pot, reduced number of gear codes, , up to 2017/18 data), 2019 Sc 19_0 (Grid Cell position of observed pot, up to 2018/19 data), 2019 Sc 19_1 (Grid Cell position of observed pot, reduced number of gear codes, up to 2018/19 data), and 2019 Sc 19_2a (Grid Cell position of observed pot, reduced number of gear codes, fish ticket CPUE indices extended up to 1998/99, pre rationalization period observer CPUE indices ignored, up to 2018/19 data) for EAG golden king crab. Model estimated additional standard error was added to each input standard error for 2-standard error confidence interval determination.

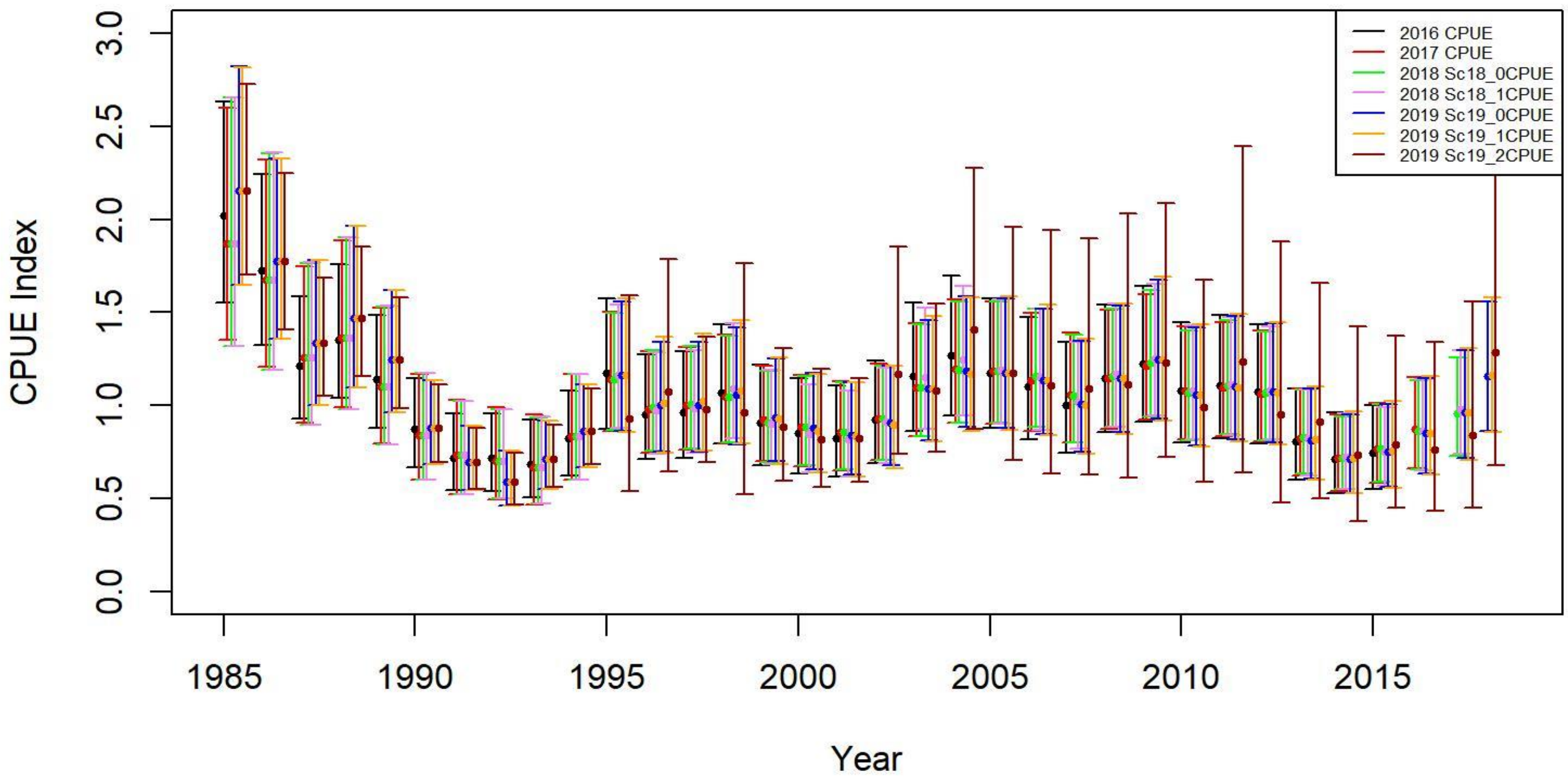


Figure B.3. Comparison of input CPUE indices for scenarios 2016 (ADF&G area codes grouped into 10 groups, up to 2015/16 data), 2017 (ADF&G area codes not grouped, up to 2016/17 data), 2018 Sc 18_0 (Lat and Long position of observed pot, up to 2017/18 data), 2018 Sc18_1 (Lat and Long position of observed pot, reduced number of gear codes, , up to 2017/18 data), 2019 Sc 19_0 (Grid Cell position of observed pot, up to 2018/19 data), 2019 Sc 19_1 (Grid Cell position of observed pot, reduced number of gear codes, up to 2018/19 data), and 2019 Sc 19_2 (Grid Cell position of observed pot, reduced number of gear codes, up to 2018/19 data) for WAG golden king crab. Model estimated additional standard error was added to each input standard error for 2-standard error confidence interval determination.

Fish Ticket CPUE index:

We also fitted the lognormal GLM 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 code- AreaGP) was used for model fitting. The final model for EAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month}$
AIC=25805

Final selection by stepCPUE:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month}$ (B.19)
for the 1985/86–1998/99 period [$R^2 = 0.3700$]

and that for WAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area}$
AIC= 11110

Final selection by stepCPUE
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel}, \ R^2 = 0.3679$ (B.20)

The R^2 for the fish ticket data fits are much higher compared to that for observer data fits

Figures B.6 and B.7 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively.

Figures B.4 and B.7 depict the trends in nominal and standardized CPUE indices for the observer and Fish Ticket CPUE time series for EAG and WAG, respectively.

Note: For brevity we did not present the diagnostic figures for the fits in this document. They are available with the first author.

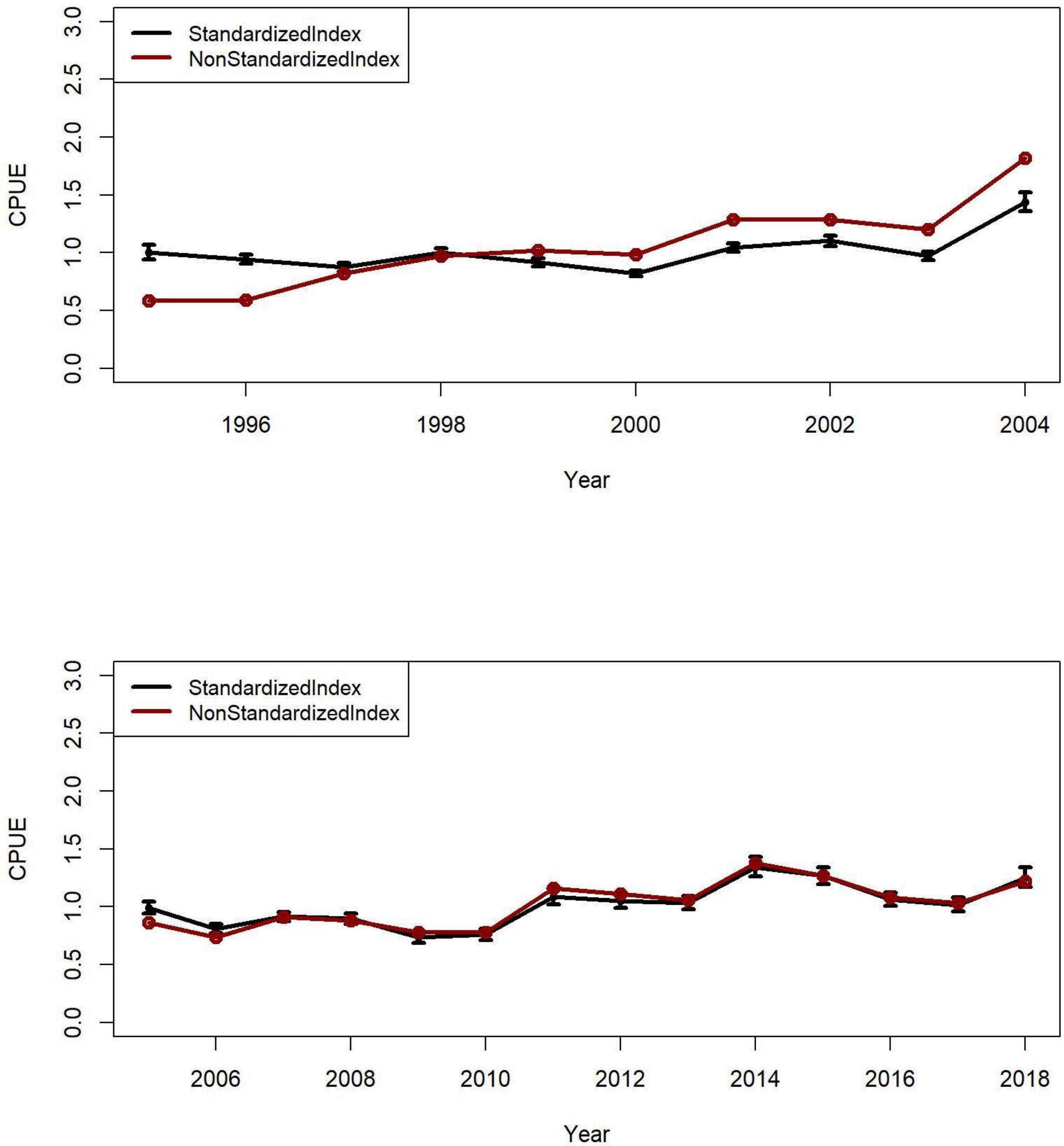


Figure B.4. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2018/19. Standardized indices: black line and non-standardized indices: red line. Scenario 19_1.

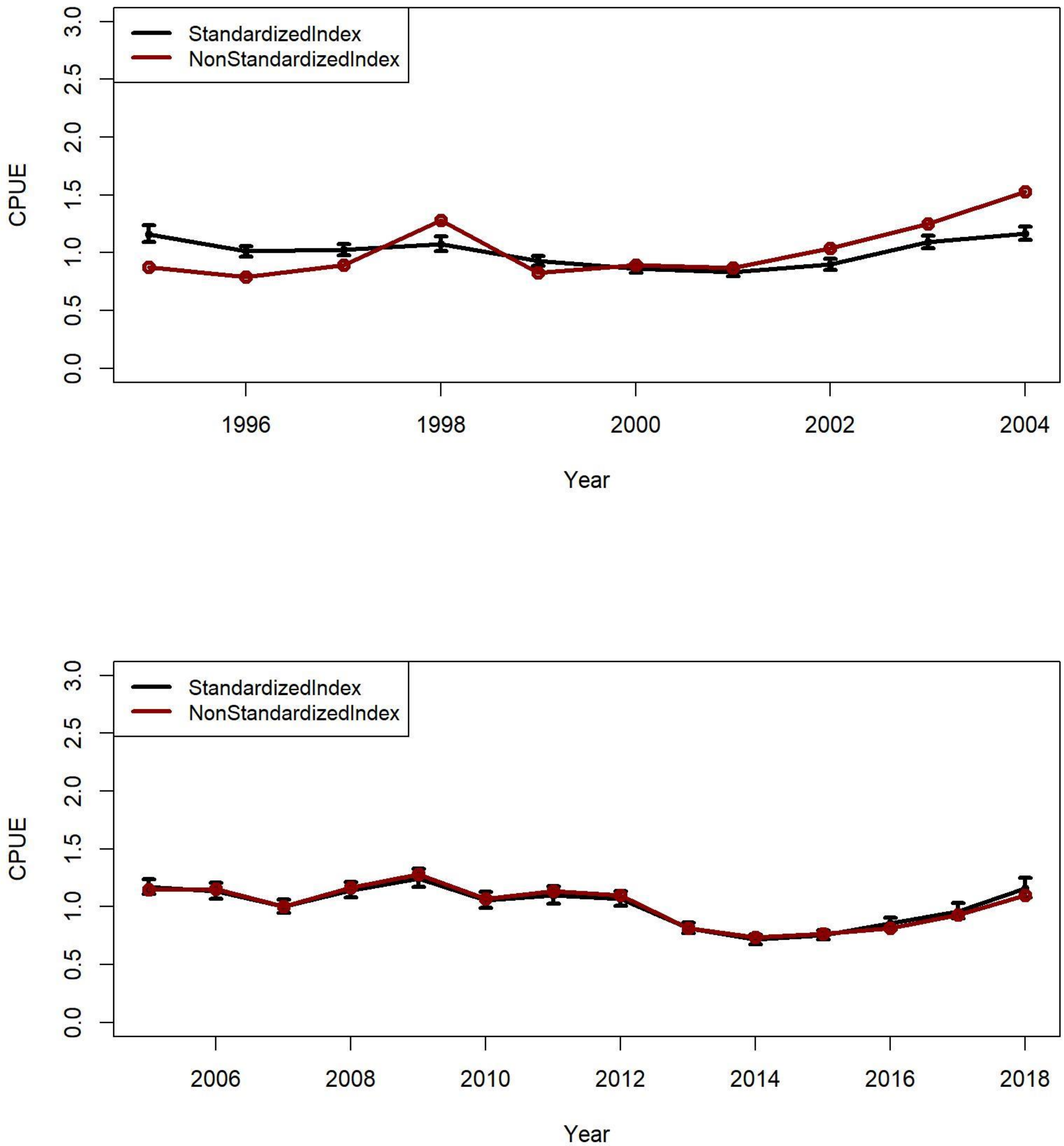


Figure B.5. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2018/19. Standardized indices: black line and non-standardized indices: red line. Scenario 19_1.

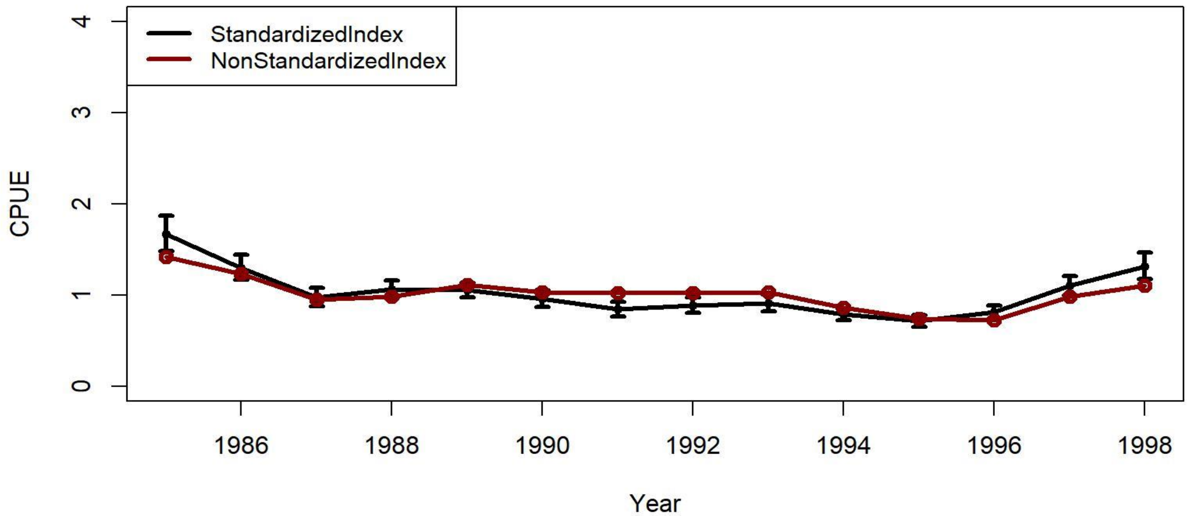


Figure B.6. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

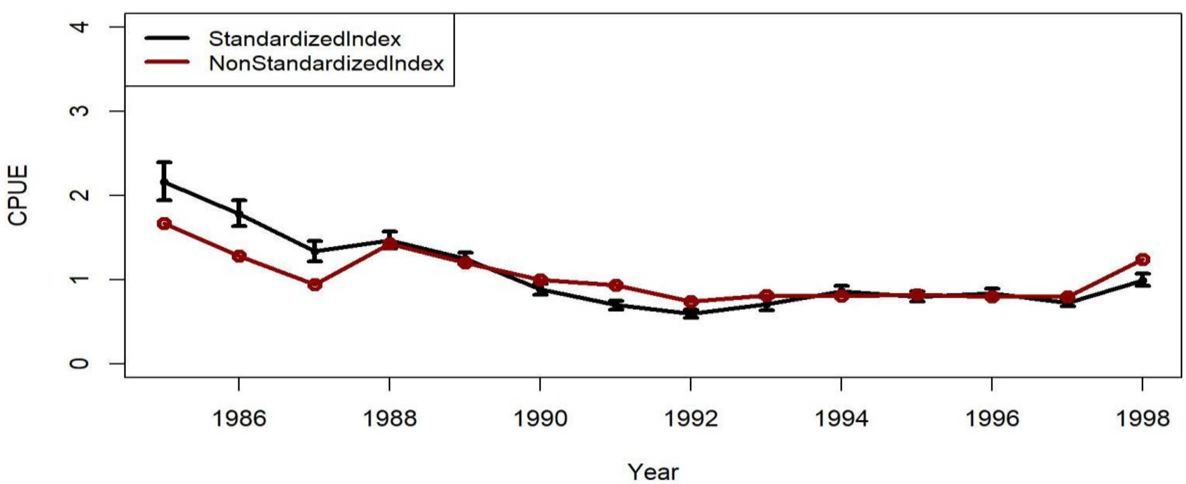


Figure B.7. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

Appendix C. B0 Analysis

For proper B0 analysis, a stock-recruitment relationship and impacts of environmental factors on recruitment are needed. We did not establish a stock-recruitment relationship for Aleutian Islands golden king crab. Furthermore, the impacts of environmental factors on recruitment have not been studied in the Aleutian Islands areas. Therefore, we approached the B0 analysis in a simple way. We computed the time series of B0 values using the same recruitment time series estimated by the assessment model scenarios (Sc.) 19_0, 19_1, and 19_2a (for EAG) or 19_2 (for WAG) and setting all directed and bycatch fishing mortality to zero. Following figures compare the time series of estimated B0 and MMB with fishing, MMB ratio (MMB/B0), and number of recruits for the three scenarios separately for EAG and WAG. It is clear that the fishery has a great impact on the biomass dynamics with MMB dropping precipitously with the onset of significant fishery removals in 1981:

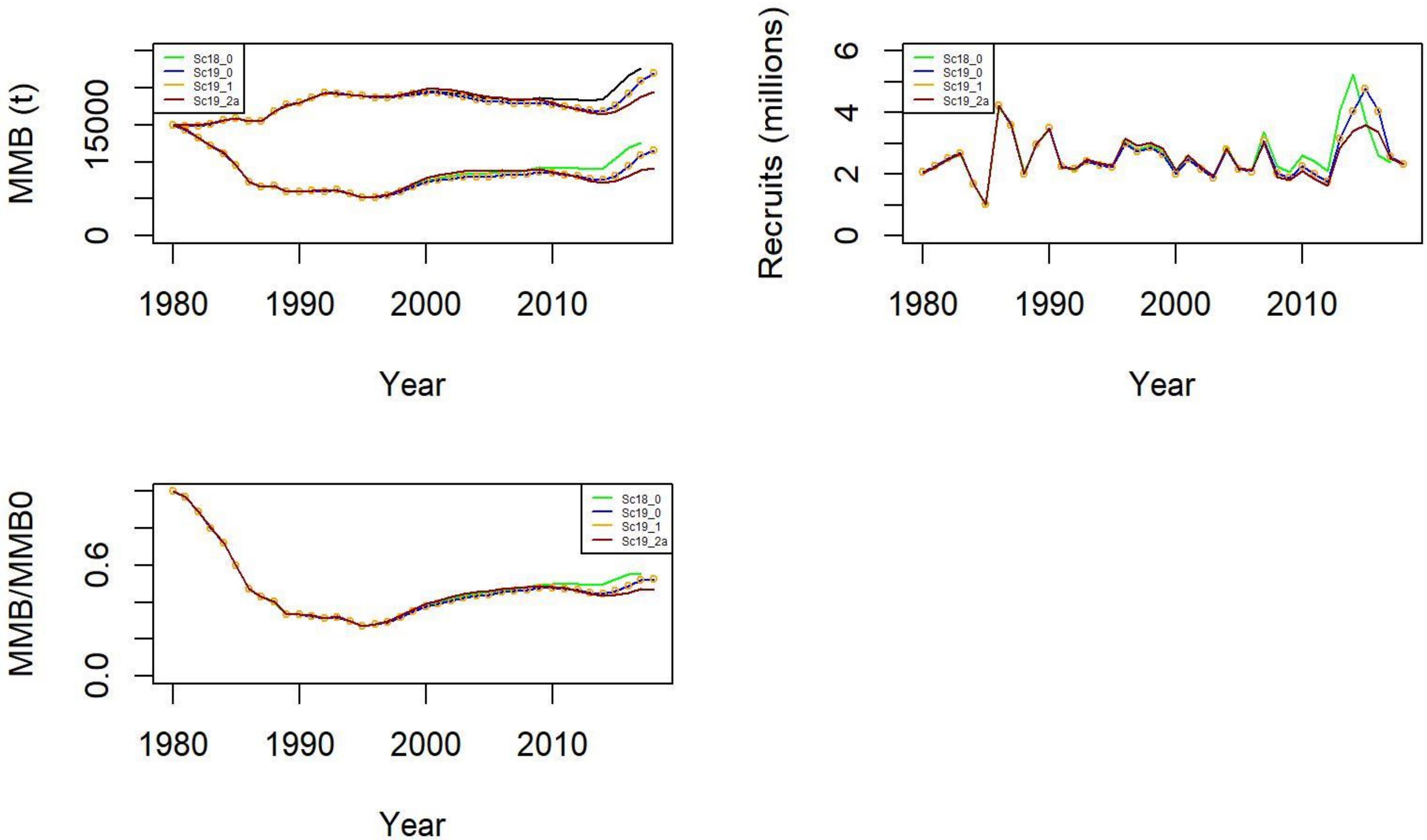


Figure C.1. Comparison of estimated B0 (t) with MMB (top left), estimated number of recruits (top right), and MMB/B0 ratio for scenarios (Sc.) 18_0 (green line, up to 2017/18 data), 19_0 (up to 2018/19 data), 19_1, and 19_2a model fits in the EAG.

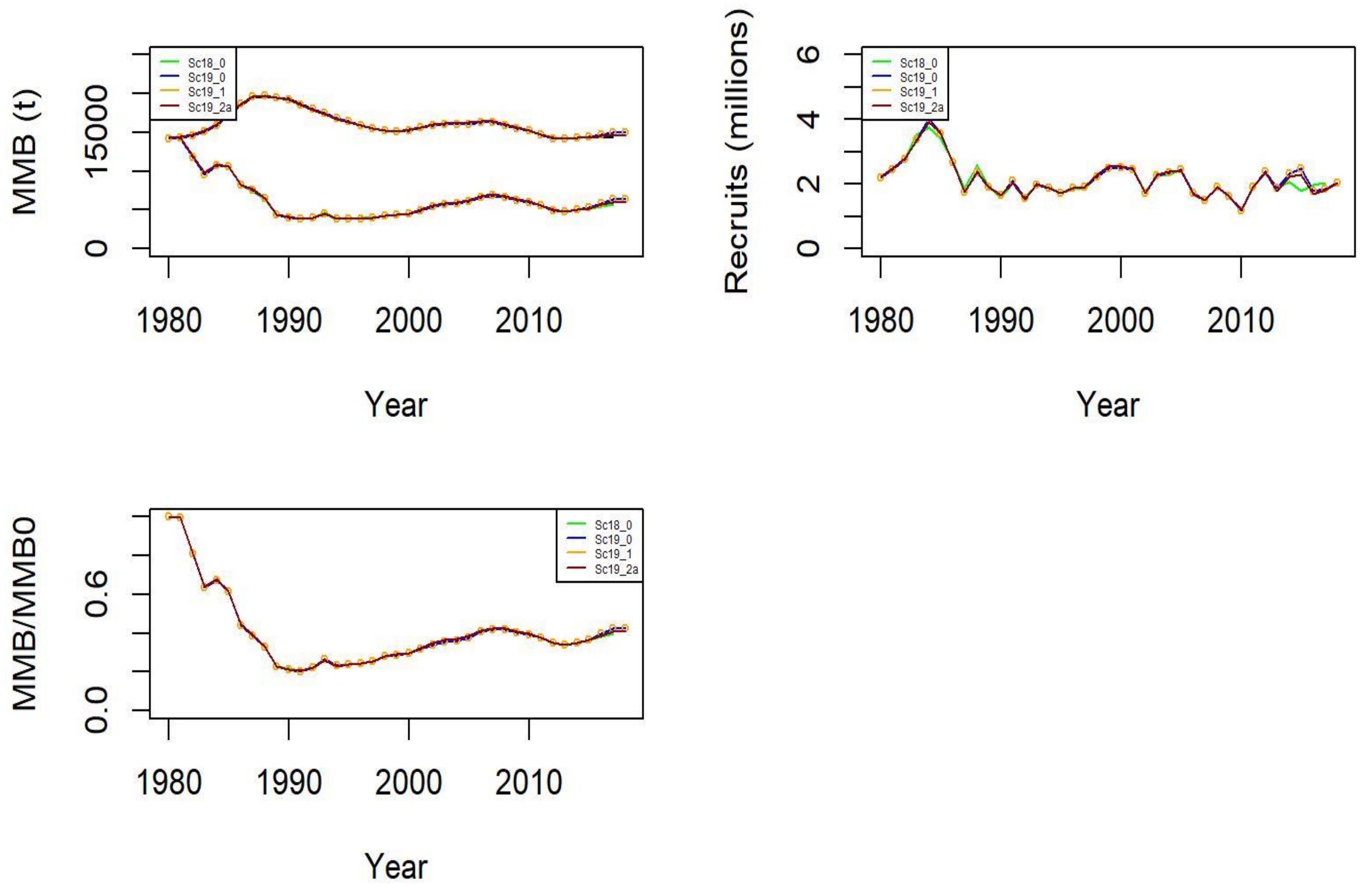


Figure C.2. Comparison of estimated B0 (t) with MMB (top left), estimated number of recruits (top right), and MMB/B0 ratio for scenarios (Sc.) 18_0 (green line, up to 2017/18 data), 19_0 (up to 2018/19 data), 19_1, and 19_2a model fits in the WAG.

Appendix D: Jittering

Jittering of scenarios 19_1 and 19_2 (or 19_2a) parameter estimates:
We followed the Stock Synthesis approach to do 100 jitter runs of scenarios *19_1 and 19_2 or 19_2a* 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:

The *Jitter* factor of 0.3 was multiplied by a random normal deviation $rdev$=N(0,1), to a transformed parameter value based upon the predefined parameter:

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

with the final jittered initial parameter value back transformed as:

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

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 scenarios 19_1 in Tables D.1 and D.2; and 19_2a and 19_2 in Tables D.3 and D.4 for EAG and WAG, respectively. Almost all runs converged to the highest log likelihood values for EAG. On the other hand, some jitter runs for WAG scenario 19_1 produced smaller objective function value whereas some runs for WAG scenario 19_2 produced larger objective function values compared to the base estimate (run 0). However, those fits with smaller objective function values predicted extremely large groundfish bycatches in certain years, consequently we ignored those runs. We concluded from jitter results that optimization of 19_1 and 19_2 (or 19_2a) models achieved global minima.

Table D.1. Results from 100 jitter runs for scenario 19_1 for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**108.5244**	**0.00019844**	**6,584**	**3,418**	**10,203**
1	108.5244	0.00003765	6,584	3,418	10,203
2	108.5244	0.00006024	6,584	3,418	10,203
3	108.5244	0.00006469	6,584	3,418	10,203
4	108.5244	0.00085722	6,584	3,418	10,203
5	108.5244	0.00010202	6,584	3,418	10,203
6	108.5244	0.00002813	6,584	3,418	10,203
7	108.5244	0.00007841	6,584	3,418	10,203
8	108.5244	0.00002810	6,584	3,418	10,203

9	108.5244	0.00010359	6,584	3,418	10,203
10	108.5244	0.00019743	6,584	3,418	10,203
11	108.5244	0.00010534	6,584	3,418	10,203
12	108.5244	0.00020649	6,584	3,418	10,203
13	108.5244	0.00023738	6,584	3,418	10,203
14	108.5244	0.00008070	6,584	3,418	10,203
15	108.5244	0.00074843	6,584	3,418	10,203
16	108.5244	0.00013616	6,584	3,418	10,203
17	108.5244	0.00011527	6,584	3,418	10,203
18	108.5244	0.00003540	6,584	3,418	10,203
19	108.5244	0.00003587	6,584	3,418	10,203
20	108.5244	0.00023851	6,584	3,418	10,203
21	108.5244	0.00009878	6,584	3,418	10,203
22	108.5244	0.00002835	6,584	3,418	10,203
23	108.5244	0.00007482	6,584	3,418	10,203
24	108.5244	0.00020804	6,584	3,418	10,203
25	108.5244	0.00008940	6,584	3,418	10,203
26	108.5244	0.00046323	6,584	3,418	10,203
27	108.5244	0.00018521	6,584	3,418	10,203
28	108.5244	0.00020666	6,584	3,418	10,203
29	108.5244	0.00002508	6,584	3,418	10,203
30	108.5244	0.00010483	6,584	3,418	10,203
31	108.5244	0.00012694	6,584	3,418	10,203
32	108.5244	0.00006304	6,584	3,418	10,203
33	108.5244	0.00011522	6,584	3,418	10,203
34	108.5244	0.00013291	6,584	3,418	10,203
35	108.5244	0.00001389	6,584	3,418	10,203
36	108.5244	0.00001315	6,584	3,418	10,203
37	108.5244	0.00000710	6,584	3,418	10,203
38	108.5244	0.00009928	6,584	3,418	10,203
39	108.5244	0.00017745	6,584	3,418	10,203
40	108.5244	0.00009716	6,584	3,418	10,203
41	108.5244	0.00025232	6,584	3,418	10,203
42	108.5244	0.00015306	6,584	3,418	10,203
43	108.5244	0.00004956	6,584	3,418	10,203
44	108.5244	0.00019774	6,584	3,418	10,203
45	108.5244	0.00001779	6,584	3,418	10,203
46	108.5244	0.00003405	6,584	3,418	10,203
47	108.5244	0.00009371	6,584	3,418	10,203
48	108.5244	0.00012506	6,584	3,418	10,203
49	108.5244	0.00010105	6,584	3,418	10,203
50	108.5244	0.00005369	6,584	3,418	10,203
51	108.5244	0.00003462	6,584	3,418	10,203

52	108.5244	0.00013454	6,584	3,418	10,203
53	108.5244	0.00037256	6,584	3,418	10,203
54	108.5244	0.00004734	6,584	3,418	10,203
55	108.5244	0.00006217	6,584	3,418	10,203
56	108.5244	0.00010582	6,584	3,418	10,203
57	108.5244	0.00027120	6,584	3,418	10,203
58	108.5244	0.00009683	6,584	3,418	10,203
59	108.5244	0.00007260	6,584	3,418	10,203
60	108.5244	0.00101527	6,584	3,418	10,203
61	108.5244	0.00033784	6,584	3,418	10,203
62	108.5244	0.00008491	6,584	3,418	10,203
63	108.5244	0.00001370	6,584	3,418	10,203
64	108.5244	0.00003530	6,584	3,418	10,203
65	108.5244	0.00005301	6,584	3,418	10,203
66	108.5244	0.00007408	6,584	3,418	10,203
67	108.5244	0.00040697	6,584	3,418	10,203
68	108.5244	0.00007171	6,584	3,418	10,203
69	108.5244	0.00000551	6,584	3,418	10,203
70	108.5244	0.00016844	6,584	3,418	10,203
71	108.5244	0.00001833	6,584	3,418	10,203
72	108.5244	0.00014056	6,584	3,418	10,203
73	108.5244	0.00007077	6,584	3,418	10,203
74	108.5244	0.00002829	6,584	3,418	10,203
75	108.5244	0.00003979	6,584	3,418	10,203
76	108.5244	0.00018708	6,584	3,418	10,203
77	108.5244	0.00028434	6,584	3,418	10,203
78	108.5244	0.00048770	6,584	3,418	10,203
79	108.5244	0.00006920	6,584	3,418	10,203
80	108.5244	0.00005676	6,584	3,418	10,203
81	108.5244	0.00010013	6,584	3,418	10,203
82	108.5244	0.00016680	6,584	3,418	10,203
83	108.5244	0.00000654	6,584	3,418	10,203
84	108.5244	0.00018383	6,584	3,418	10,203
85	108.5244	0.00006973	6,584	3,418	10,203
86	108.5244	0.00012976	6,584	3,418	10,203
87	108.5244	0.00000915	6,584	3,418	10,203
88	108.5244	0.00015539	6,584	3,418	10,203
89	108.5244	0.00009303	6,584	3,418	10,203
90	108.5244	0.00054451	6,584	3,418	10,203
91	108.5244	0.00008850	6,584	3,418	10,203
92	108.5244	0.00055446	6,584	3,418	10,203
93	108.5244	0.00022993	6,584	3,418	10,203
94	108.5244	0.00004575	6,584	3,418	10,203

95	108.5244	0.00056284	6,584	3,418	10,203
96	108.5244	0.00015610	6,584	3,418	10,203
97	108.5244	0.00016861	6,584	3,418	10,203
98	108.5244	0.00010544	6,584	3,418	10,203
99	108.5244	0.00010761	6,584	3,418	10,203
100	108.5244	0.00003920	6,584	3,418	10,203

Table D.2 Results from 100 jitter runs for scenario 19_1 for WAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**12.0048**	**0.00018382**	**5,176**	**1,831**	**5,741**
1	12.0048	0.00020306	5,176	1,831	5,741
2	12.0048	0.00022315	5,176	1,831	5,741
3	12.0048	0.00006551	5,176	1,831	5,741
4	14.2432	0.00046758	5,532	1,912	5,910
5	12.0048	0.00012866	5,176	1,831	5,741
6	12.0048	0.00000595	5,176	1,831	5,741
7	9.9980	0.00015851	5,670	1,929	5,997
8	12.0048	0.00001447	5,176	1,831	5,741
9	9.9980	0.00017029	5,670	1,929	5,997
10	12.0048	0.00072925	5,176	1,831	5,741
11	12.0048	0.00054967	5,176	1,831	5,741
12	12.0048	0.00010234	5,176	1,831	5,741
13	12.0048	0.00005552	5,176	1,831	5,741
14	12.0048	0.00015787	5,176	1,831	5,741
15	12.0048	0.00012732	5,176	1,831	5,741
16	12.0048	0.00001726	5,176	1,831	5,741
17	12.0048	0.00009354	5,176	1,831	5,741
18	12.0048	0.00020537	5,176	1,831	5,741
19	12.0048	0.00008776	5,176	1,831	5,741
20	12.0048	0.00010251	5,176	1,831	5,741
21	12.0048	0.00004000	5,176	1,831	5,741
22	12.0048	0.00015839	5,176	1,831	5,741
23	12.0048	0.00019508	5,176	1,831	5,741
24	12.0048	0.00018912	5,176	1,831	5,741
25	12.0048	0.00014118	5,176	1,831	5,741
26	12.0048	0.00009186	5,176	1,831	5,741
27	12.0048	0.00003851	5,176	1,831	5,741
28	12.0048	0.00003228	5,176	1,831	5,741

29	12.0048	0.00009755	5,176	1,831	5,741
30	12.0048	0.00004661	5,176	1,831	5,741
31	12.0048	0.00001021	5,176	1,831	5,741
32	12.0048	0.00047176	5,176	1,831	5,741
33	14.2432	0.00001721	5,532	1,912	5,910
34	NA	NA	NA	NA	NA
35	12.0048	0.00034421	5,176	1,831	5,741
36	12.0048	0.00008064	5,176	1,831	5,741
37	12.0048	0.00031788	5,176	1,831	5,741
38	12.0048	0.00020530	5,176	1,831	5,741
39	12.0048	0.00032915	5,176	1,831	5,741
40	12.0048	0.00015036	5,176	1,831	5,741
41	12.0048	0.00003404	5,176	1,831	5,741
42	NA	NA	NA	NA	NA
43	8.9832	0.00003104	5,760	1,909	5,985
44	9.9980	0.00005094	5,670	1,929	5,997
45	12.0048	0.00008802	5,176	1,831	5,741
46	12.0048	0.00020453	5,176	1,831	5,741
47	8.9832	0.00038883	5,760	1,909	5,985
48	12.0048	0.00006047	5,176	1,831	5,741
49	NA	NA	NA	NA	NA
50	12.0048	0.00005564	5,176	1,831	5,741
51	12.0048	0.00031332	5,176	1,831	5,741
52	12.0048	0.00016600	5,176	1,831	5,741
53	12.0048	0.00006754	5,176	1,831	5,741
54	12.0048	0.00011545	5,176	1,831	5,741
55	12.0048	0.00026613	5,176	1,831	5,741
56	12.0048	0.00015730	5,176	1,831	5,741
57	12.0048	0.00011702	5,176	1,831	5,741
58	12.0048	0.00008183	5,176	1,831	5,741
59	12.0048	0.00035406	5,176	1,831	5,741
60	12.0048	0.00008772	5,176	1,831	5,741
61	12.0048	0.00007139	5,176	1,831	5,741
62	12.0048	0.00004616	5,176	1,831	5,741
63	12.0048	0.00019302	5,176	1,831	5,741
64	12.0048	0.00007680	5,176	1,831	5,741
65	14.0510	0.00000970	5,669	1,935	5,970
66	12.0048	0.00008575	5,176	1,831	5,741
67	8.9832	0.00005520	5,760	1,909	5,985
68	12.0048	0.00008454	5,176	1,831	5,741
69	12.0048	0.00016487	5,176	1,831	5,741
70	12.0048	0.00001696	5,176	1,831	5,741
71	12.0048	0.00010773	5,176	1,831	5,741

72	12.0048	0.00044903	5,176	1,831	5,741
73	12.0048	0.00005129	5,176	1,831	5,741
74	12.0048	0.00013604	5,176	1,831	5,741
75	12.0048	0.00000918	5,176	1,831	5,741
76	9.9980	0.00022635	5,670	1,929	5,997
77	12.0048	0.00011279	5,176	1,831	5,741
78	8.9832	0.00002840	5,760	1,909	5,985
79	12.0048	0.00017031	5,176	1,831	5,741
80	9.9980	0.00007145	5,670	1,929	5,997
81	9.9980	0.00002225	5,670	1,929	5,997
82	12.0048	0.00032589	5,176	1,831	5,741
83	12.0048	0.00023430	5,176	1,831	5,741
84	12.0048	0.00024683	5,176	1,831	5,741
85	12.0048	0.00009399	5,176	1,831	5,741
86	12.0048	0.00015281	5,176	1,831	5,741
87	12.0048	0.00019518	5,176	1,831	5,741
88	12.0048	0.00012389	5,176	1,831	5,741
89	12.0048	0.00017609	5,176	1,831	5,741
90	12.0048	0.00004449	5,176	1,831	5,741
91	12.0048	0.00017768	5,176	1,831	5,741
92	12.0048	0.00004224	5,176	1,831	5,741
93	12.0048	0.00001789	5,176	1,831	5,741
94	12.0048	0.00010999	5,176	1,831	5,741
95	9.9980	0.00005282	5,670	1,929	5,997
96	12.0048	0.00005739	5,176	1,831	5,741
97	12.0048	0.00000249	5,176	1,831	5,741
98	12.0048	0.00010971	5,176	1,831	5,741
99	12.0048	0.00012626	5,176	1,831	5,741
100	12.0048	0.00008679	5,176	1,831	5,741

Table D.3. Results from 100 jitter runs for scenario 19_2a for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**98.9350**	**0.00220451**	**6,635**	**2,656**	**8,431**
1	98.9350	0.00005061	6,635	2,656	8,431
2	98.9350	0.00025215	6,635	2,656	8,431
3	98.9350	0.00001897	6,635	2,656	8,431
4	98.9350	0.00047266	6,635	2,656	8,431
5	98.9350	0.00008656	6,635	2,656	8,431
6	98.9350	0.00026322	6,635	2,656	8,431

7	98.9350	0.00001076	6,635	2,656	8,431
8	98.9350	0.00014052	6,635	2,656	8,431
9	98.9350	0.00027672	6,635	2,656	8,431
10	98.9350	0.00025903	6,635	2,656	8,431
11	98.9350	0.00010192	6,635	2,656	8,431
12	98.9350	0.00005431	6,635	2,656	8,431
13	98.9350	0.00013773	6,635	2,656	8,431
14	98.9350	0.00062415	6,635	2,656	8,431
15	98.9350	0.00030986	6,635	2,656	8,431
16	98.9350	0.00012384	6,635	2,656	8,431
17	98.9350	0.00010802	6,635	2,656	8,431
18	98.9350	0.00000473	6,635	2,656	8,431
19	98.9350	0.00008735	6,635	2,656	8,431
20	98.9350	0.00017034	6,635	2,656	8,431
21	98.9350	0.00009046	6,635	2,656	8,431
22	98.9350	0.00006774	6,635	2,656	8,431
23	98.9350	0.00004319	6,635	2,656	8,431
24	98.9350	0.00016437	6,635	2,656	8,431
25	98.9350	0.00008285	6,635	2,656	8,431
26	98.9350	0.00014131	6,635	2,656	8,431
27	98.9350	0.00005240	6,635	2,656	8,431
28	98.9350	0.00008080	6,635	2,656	8,431
29	98.9350	0.00003179	6,635	2,656	8,431
30	98.9350	0.00032008	6,635	2,656	8,431
31	98.9350	0.00008112	6,635	2,656	8,431
32	98.9350	0.00027994	6,635	2,656	8,431
33	98.9350	0.00027537	6,635	2,656	8,431
34	98.9350	0.00004613	6,635	2,656	8,431
35	98.9350	0.00027592	6,635	2,656	8,431
36	98.9350	0.00009002	6,635	2,656	8,431
37	98.9350	0.00005911	6,635	2,656	8,431
38	98.9350	0.00098377	6,635	2,656	8,431
39	98.9350	0.00025026	6,635	2,656	8,431
40	98.9350	0.00007010	6,635	2,656	8,431
41	98.9350	0.00050483	6,635	2,656	8,431
42	98.9350	0.00020079	6,635	2,656	8,431
43	98.9350	0.00007397	6,635	2,656	8,431
44	98.9350	0.00001915	6,635	2,656	8,431
45	98.9350	0.00002672	6,635	2,656	8,431
46	98.9350	0.00002425	6,635	2,656	8,431
47	98.9350	0.00011851	6,635	2,656	8,431
48	98.9350	0.00015965	6,635	2,656	8,431
49	98.9350	0.00035529	6,635	2,656	8,431

50	98.9350	0.00001112	6,635	2,656	8,431
51	98.9350	0.00004687	6,635	2,656	8,431
52	98.9350	0.00013227	6,635	2,656	8,431
53	98.9350	0.00025765	6,635	2,656	8,431
54	98.9350	0.00004983	6,635	2,656	8,431
55	98.9350	0.00004199	6,635	2,656	8,431
56	98.9350	0.00042957	6,635	2,656	8,431
57	98.9350	0.00005388	6,635	2,656	8,431
58	98.9350	0.00004797	6,635	2,656	8,431
59	98.9350	0.00021588	6,635	2,656	8,431
60	98.9350	0.00035240	6,635	2,656	8,431
61	98.9350	0.00015409	6,635	2,656	8,431
62	98.9350	0.00004914	6,635	2,656	8,431
63	98.9350	0.00002380	6,635	2,656	8,431
64	98.9350	0.00007796	6,635	2,656	8,431
65	98.9350	0.00001817	6,635	2,656	8,431
66	98.9350	0.00005540	6,635	2,656	8,431
67	98.9350	0.00016910	6,635	2,656	8,431
68	98.9350	0.00011864	6,635	2,656	8,431
69	98.9350	0.00014533	6,635	2,656	8,431
70	98.9350	0.00003525	6,635	2,656	8,431
71	98.9350	0.00023926	6,635	2,656	8,431
72	98.9350	0.00002570	6,635	2,656	8,431
73	98.9350	0.00006938	6,635	2,656	8,431
74	98.9350	0.00004828	6,635	2,656	8,431
75	98.9350	0.00001484	6,635	2,656	8,431
76	98.9350	0.00007852	6,635	2,656	8,431
77	98.9350	0.00012094	6,635	2,656	8,431
78	98.9350	0.00002564	6,635	2,656	8,431
79	98.9350	0.00015410	6,635	2,656	8,431
80	98.9350	0.00003088	6,635	2,656	8,431
81	98.9350	0.00003733	6,635	2,656	8,431
82	98.9350	0.00002000	6,635	2,656	8,431
83	98.9350	0.00032593	6,635	2,656	8,431
84	98.9350	0.00019526	6,635	2,656	8,431
85	98.9350	0.00021407	6,635	2,656	8,431
86	98.9350	0.00032090	6,635	2,656	8,431
87	98.9350	0.00012003	6,635	2,656	8,431
88	98.9350	0.00015566	6,635	2,656	8,431
89	98.9350	0.00007121	6,635	2,656	8,431
90	98.9350	0.00002203	6,635	2,656	8,431
91	98.9350	0.00005271	6,635	2,656	8,431
92	98.9350	0.00037249	6,635	2,656	8,431

93	98.9350	0.00009763	6,635	2,656	8,431
94	98.9350	0.00033723	6,635	2,656	8,431
95	98.9350	0.00015707	6,635	2,656	8,431
96	98.9350	0.00022095	6,635	2,656	8,431
97	98.9350	0.00005962	6,635	2,656	8,431
98	98.9350	0.00015658	6,635	2,656	8,431
99	98.9350	0.00011312	6,635	2,656	8,431
100	98.9350	0.00001896	6,635	2,656	8,431

Table D.4 Results from 100 jitter runs for scenario 19_2 for WAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**10.5983**	**0.00082425**	**5,174**	**1,724**	**5,430**
1	10.5983	0.00011058	5,174	1,724	5,430
2	10.5983	0.00010558	5,174	1,724	5,430
3	10.5983	0.00026167	5,174	1,724	5,430
4	10.5983	0.00040994	5,174	1,724	5,430
5	10.5983	0.00011106	5,174	1,724	5,430
6	10.5983	0.00010598	5,174	1,724	5,430
7	10.5983	0.00014270	5,174	1,724	5,430
8	10.5983	0.00004026	5,174	1,724	5,430
9	10.5983	0.00024259	5,174	1,724	5,430
10	15.2881	0.00011151	5,471	1,770	5,584
11	10.5983	0.00024071	5,174	1,724	5,430
12	10.5983	0.00002014	5,174	1,724	5,430
13	10.5983	0.00021256	5,174	1,724	5,430
14	10.5983	0.00007823	5,174	1,724	5,430
15	10.5983	0.00006527	5,174	1,724	5,430
16	10.5983	0.00013656	5,174	1,724	5,430
17	12.2552	0.00010209	5,542	1,791	5,650
18	10.5983	0.00029437	5,174	1,724	5,430
19	12.2552	0.00010219	5,542	1,791	5,650
20	12.2552	0.00008522	5,542	1,791	5,650
21	10.5983	0.00011096	5,174	1,724	5,430
22	10.5983	0.00018497	5,174	1,724	5,430
23	10.5983	0.00006415	5,174	1,724	5,430
24	10.5983	0.00007716	5,174	1,724	5,430
25	10.5983	0.00012036	5,174	1,724	5,430
26	10.5983	0.00003911	5,174	1,724	5,430

27	10.5983	0.00011934	5,174	1,724	5,430
28	10.5983	0.00012605	5,174	1,724	5,430
29	10.5983	0.00019706	5,174	1,724	5,430
30	15.2881	0.00002597	5,471	1,770	5,584
31	10.5983	0.00004627	5,174	1,724	5,430
32	10.5983	0.00005286	5,174	1,724	5,430
33	10.5983	0.00013577	5,174	1,724	5,430
34	10.5983	0.00018601	5,174	1,724	5,430
35	10.5983	0.00041979	5,174	1,724	5,430
36	10.5983	0.00015026	5,174	1,724	5,430
37	10.5983	0.00020795	5,174	1,724	5,430
38	10.5983	0.00020491	5,174	1,724	5,430
39	10.5983	0.00034183	5,174	1,724	5,430
40	10.5983	0.00035498	5,174	1,724	5,430
41	10.5983	0.00062835	5,174	1,724	5,430
42	10.5983	0.00006200	5,174	1,724	5,430
43	10.5983	0.00016800	5,174	1,724	5,430
44	10.5983	0.00005308	5,174	1,724	5,430
45	10.5983	0.00003170	5,174	1,724	5,430
46	10.5983	0.00024692	5,174	1,724	5,430
47	10.5983	0.00007671	5,174	1,724	5,430
48	10.5983	0.00022411	5,174	1,724	5,430
49	10.5983	0.00013150	5,174	1,724	5,430
50	10.5983	0.00009045	5,174	1,724	5,430
51	15.6088	0.00004377	5,596	1,824	5,681
52	10.5983	0.00003371	5,174	1,724	5,430
53	10.5983	0.00022699	5,174	1,724	5,430
54	12.2552	0.00014177	5,542	1,791	5,650
55	10.5983	0.00032630	5,174	1,724	5,430
56	10.5983	0.00029168	5,174	1,724	5,430
57	10.5983	0.00035747	5,174	1,724	5,430
58	10.5983	0.00002259	5,174	1,724	5,430
59	10.5983	0.00030140	5,174	1,724	5,430
60	10.5983	0.00006033	5,174	1,724	5,430
61	10.5983	0.00017884	5,174	1,724	5,430
62	12.2552	0.00009428	5,542	1,791	5,650
63	10.5983	0.00012856	5,174	1,724	5,430
64	10.5983	0.00008975	5,174	1,724	5,430
65	10.5983	0.00035089	5,174	1,724	5,430
66	10.5983	0.00038820	5,174	1,724	5,430
67	10.5983	0.00011772	5,174	1,724	5,430
68	10.5983	0.00013030	5,174	1,724	5,430
69	10.5983	0.00005639	5,174	1,724	5,430

70	10.5983	0.00014941	5,174	1,724	5,430
71	10.5983	0.00049187	5,174	1,724	5,430
72	10.5983	0.00008074	5,174	1,724	5,430
73	10.8981	0.00017206	5,674	1,826	5,695
74	10.5983	0.00000739	5,174	1,724	5,430
75	10.5983	0.00013654	5,174	1,724	5,430
76	10.5983	0.00002294	5,174	1,724	5,430
77	10.5983	0.00019720	5,174	1,724	5,430
78	10.5983	0.00007537	5,174	1,724	5,430
79	10.5983	0.00040316	5,174	1,724	5,430
80	10.5983	0.00016887	5,174	1,724	5,430
81	10.5983	0.00012809	5,174	1,724	5,430
82	10.5983	0.00017558	5,174	1,724	5,430
83	10.5983	0.00011734	5,174	1,724	5,430
84	10.5983	0.00008249	5,174	1,724	5,430
85	10.5983	0.00026630	5,174	1,724	5,430
86	10.5983	0.00026680	5,174	1,724	5,430
87	10.5983	0.00022976	5,174	1,724	5,430
88	10.5983	0.00077521	5,174	1,724	5,430
89	10.5983	0.00012832	5,174	1,724	5,430
90	10.5983	0.00013345	5,174	1,724	5,430
91	10.8981	0.00049018	5,674	1,826	5,695
92	10.8981	0.00032380	5,674	1,826	5,695
93	10.5983	0.00024174	5,174	1,724	5,430
94	10.5983	0.00013448	5,174	1,724	5,430
95	10.5983	0.00023735	5,174	1,724	5,430
96	10.5983	0.00019920	5,174	1,724	5,430
97	10.5983	0.00005063	5,174	1,724	5,430
98	10.5983	0.00010792	5,174	1,724	5,430
99	10.5983	0.00033559	5,174	1,724	5,430
100	10.5983	0.00060659	5,174	1,724	5,430