Aleutian Islands Golden King Crab Model-Based Stock Assessment

May 2018 Crab SAFE DRAFT REPORT

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Executive Summary

1. *Stock*

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

2. *Catches*

   The Aleutian Islands golden king crab 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 acronym changed from GHL to TAC (Total Allowable Catch) since 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 on 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. 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, and towards a $500,000 goal in 2015/16 and 2016/17.

   Catch per pot lift (CPUE) 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 2011/12–2014/1 5 CPUE trends have diverged (increasing EAG and decreasing WAG). Total retained catch in 2016/17 was 2,593 t (5,716,180 lb): 1,578 t (3,479,529 lb) from the EAG fishery, which included cost-recovery catch, 1,015 t (2,236,651 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 2016/17 was 138 t (303,832 lb) for EAG and 92 t (202,815 lb) for WAG. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries, but is small relative to that during the directed fishery and the groundfish fisheries are a minor contributor to total fishery mortality. Estimated bycatch mortality during groundfish fisheries in 2016/17 was 3 t (6,245 lb) for EAG and 3 t (6,800 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 2016, 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 2016/17, it was assumed that bycatch mortality that occurred during the survey was accounted for by reported discards for the 2016/17 EAG fishery. The cooperative survey was also conducted in August 2017 during the 2017/18 EAG fishery.

3. *Stock biomass*

Estimated mature male biomass (MMB) for EAG under all scenarios decreased from high levels during the 1990s, then systematically increased during the 2000s and 2010s. Estimated MMB for WAG decreased during the late 1980s and 1990s, systematically increased during the 2000s, and decreased for a number of years since 2009. The low levels of MMB for EAG were observed in 1995–1997 and in 1990s for WAG. Slightly increasing trends in MMB were observed since 2014 in both regions. 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 1987, 1988, 2008, 2015, 2017, and highest in 2014; and lowest in 1986. An increasing trend in recruitment was observed since the early-1990s in EAG. The model recruitment for WAG was high during 1983 to 1987 and highest in 2015; and lowest in 2011. After 1983 to 1987 peaks, the recruitment trend was low except the 2015 highest recruitment.

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. 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. Following last year's approach, we added OFLs and ABCs by area to calculate OFL and ABC for the entire stock. We could add them together without any modification because the stock status in the two areas after 2016/17 fishery was similar.

Among the six common scenarios for EAG and WAG, we recommend three scenarios (17_0 (base), 17_0d (three catchability and total selectivity), and 17_0e (McAllister and Ianelli method of re-weighting) for consideration and provide the status and catch specifications for the AIGKC stock. Scenario 17_0 is the base scenario with an updated M of 0.21yr^{-1} and the addition of 2016/17 data. The model formulation is the same as that was accepted in 2017. Scenario 17_0d fits the recent three years' CPUE indices well for EAG, but the OFL and ABC are very low among the three selected scenarios. Scenario 17_0e is an alternative to the base scenario with McAllister and Ianelli method of size composition data weighting instead of Francis' method of reweighting. The OFL and ABC differences between 17_0e and 17_0 are small. The rest of the scenarios have some shortcomings either on adequacy of data or on model diagnostics; hence, are not considered. All scenarios assume the knife-edge maturity selection.

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]**
2013/14	N/A	N/A	2.853	2.894	3.192	5.69	5.12
2014/15	N/A	N/A	2.853	2.771	3.088	5.69	4.26
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				5.514	4.136
2018/19[d]	5.898	14.665				3.963	2.972
2018/19[e]	6.107	17.793				5.581	4.186

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

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]
2013/14	N/A	N/A	6.290	6.38	7.038	12.54	11.28
2014/15	N/A	N/A	6.290	6.11	6.807	12.53	9.40
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				12.157	9.118
2018/19[d]	13.002	32.331				8.737	6.553
2018/19[e]	13.464	39.227				12.305	9.228

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

Since the 2017/18 total catch of 2,942 t (6.487 million lb) is below the OFL catch of 6,048 t (13.333 million lb), "overfishing" did not occur in the Aleutian Islands golden king crab fishery in 2017/18.

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 2016 and projected to February 15, 2018 for OFL and ABC determination. 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 was used.

We provide the OFL and ABC estimates for EAG, WAG, and the two regions pooled together (i.e., for the entire Aleutian Islands, AI) for seven scenarios [17_0, 17_0a, 17_0b, 17_0c, 17_0d, 17_0e, and 17_0f (the last is only for EAG)] in the following six tables. As per September 2017 CPT suggestion, we also provide estimates for May 2017 CPT accepted scenario 9 (modified as 9** for WAG) in these tables. We treat scenario 17_0 as the base scenario for EAG and WAG. **We provide three options of OFL and ABC estimates based on scenarios 17_0, 17_0d, and 17_0e for CPT consideration and selection. Since the OFL and ABC have been set for the entire AI before, we suggest implementing the combined OFL and ABC for AI.**

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2018. Current MMB for May2017Sc9 =MMB on 15 Feb. 2017.

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)
EAG17_0	3a	15.332	25.474	1.66	0.64	1987–2012	0.64	8.637	8.601	6.478
EAG17_0a	3a	15.570	25.645	1.65	0.62	1987–2012	0.62	8.729	8.683	6.547
EAG17_0b	3a	14.979	22.949	1.53	0.65	1987–2012	0.65	7.529	7.492	5.646
EAG17_0c	3a	15.633	25.869	1.65	0.62	1987–2012	0.62	8.920	8.872	6.690
EAG17_0d	3a	14.745	17.986	1.22	0.64	1987–2012	0.64	5.469	5.435	4.102
EAG17_0e	3a	15.462	25.045	1.62	0.64	1987–2012	0.64	8.761	8.725	6.570
EAG17_0f	3a	15.312	25.340	1.65	0.64	1987–2012	0.64	8.581	8.545	6.436
May2017Sc9	3a	15.539	20.515	1.32	0.75	1987–2012	0.75	9.890	9.852	7.417

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)
EAG17_0	3a	6.954	11.555	1.66	0.64	1987–2012	0.64	3,917.776	3,901.317	2,938.332
EAG17_0a	3a	7.063	11.633	1.65	0.62	1987–2012	0.62	3,959.351	3,938.754	2,969.513
EAG17_0b	3a	6.794	10.409	1.53	0.65	1987–2012	0.65	3,414.981	3,398.458	2,561.235
EAG17_0c	3a	7.091	11.734	1.65	0.62	1987–2012	0.62	4,046.121	4,024.483	3,034.590
EAG17_0d	3a	6.688	8.158	1.22	0.64	1987–2012	0.64	2,480.617	2,465.170	1,860.463
EAG17_0e	3a	7.014	11.360	1.62	0.64	1987–2012	0.64	3,973.77	3,957.468	2,980.334
EAG17_0f	3a	6.946	11.494	1.65	0.64	1987–2012	0.64	3,892.238	3,876.174	2,919.178
May2017Sc9	3a	7.048	9.306	1.32	0.75	1987–2012	0.75	4,486.052	4,468.684	3,364.539

WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB= MMB on 15 Feb. 2018. Current MMB for May2017Sc9 =MMB on 15 Feb. 2017.

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)
WAG17_0	3a	11.327	14.103	1.25	0.60	1987–2012	0.60	3.520	3.505	2.640
WAG17_0a	3a	11.405	14.148	1.24	0.59	1987–2012	0.59	3.503	3.489	2.627
WAG17_0b	3a	11.252	13.391	1.19	0.60	1987–2012	0.60	3.289	3.270	2.466
WAG17_0c	3a	11.294	13.947	1.23	0.60	1987–2012	0.60	3.418	3.395	2.564
WAG17_0d	3a	11.260	14.345	1.27	0.68	1987–2012	0.68	3.268	3.248	2.451
WAG17_0e	3a	11.466	14.182	1.24	0.59	1987–2012	0.59	3.544	3.529	2.658
May2017Sc9	3a	9.937	10.800	1.09	0.68	1993–1997	0.68	3.443	3.428	2.582

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)
WAG17_0	3a	5.138	6.397	1.25	0.60	1987–2012	0.60	1,596.535	1,589.834	1,197.401
WAG17_0a	3a	5.173	6.417	1.24	0.59	1987–2012	0.59	1,588.903	1,582.813	1,191.677
WAG17_0b	3a	5.104	6.074	1.19	0.60	1987–2012	0.60	1,491.700	1,483.331	1,118.775
WAG17_0c	3a	5.123	6.326	1.23	0.60	1987–2012	0.60	1,550.509	1,540.027	1,162.882
WAG17_0d	3a	5.108	6.507	1.27	0.68	1987–2012	0.68	1,482.383	1,473.365	1,111.787
WAG17_0e	3a	5.201	6.433	1.24	0.59	1987–2012	0.59	1,607.523	1,600.637	1,205.642
May2017Sc9	3a	4.507	4.899	1..09	0.68	1993–1997	0.68	1,561.668	1,554.794	1,171.251

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)
17_0	12.157	12.106	9.118
17_0a	12.232	12.172	9.174
17_0b	10.818	10.762	8.112
17_0c	12.338	12.267	9.254
17_0d	8.737	8.683	6.553
17_0e	12.305	12.254	9.228
May2017Sc9	13.333	13.280	9.999

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

Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
17_0	5,514.311	5,491.151	4,135.733
17_0a	5,548.254	5,521.567	4,161.190
17_0b	4,906.681	4,881.789	3,680.010
17_0c	5,596.630	5,564.510	4,197.472
17_0d	3,963.000	3,938.535	2,972.250
17_0e	5,581.293	5,558.105	4,185.976
May2017Sc9	6,047.720	6,023.478	4,535.790

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% buffer on the OFL; i.e., ABC = (1.0 - x/100)*OFL. We considered x = 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 has been updated with the catches during 2016/17: 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 (1981/82–2016/17), total catch (1990/91–2016/17), and groundfish bycatch (1989/90–2016/17) 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 2005/06–2015/16 periods.
   - For scenario 17_0a, observer data were standardized by VAST. The work is still preliminary.
   - For scenario 17_0f for EAG, independent pot survey data from 2015 to 2017 were standardized by GLM and a likelihood component with this set of indices was added.
   - Chela height with carapace length data from ADFG (1991) and NMFS (1984) surveys were analyzed outside the assessment model to determine the knife-edge maturity for mature male biomass calculation.

3. *Changes to assessment methodology*
   - The equilibrium initial population and Tier 3 MMB_{MSY} reference point estimation procedures used the mean number of recruits for 1987–2012.

- Francis re-weighting method was used to update the input effective sample sizes for length composition data for most scenarios, including *M* profiling and retrospective analysis except scenario 17_0e in which we applied the McAllister and Ianelli re-weighting method (McAllister and Ianelli, 1997; Siddeek et al. 2016c, 2017).
- We also added a stock projection part (Appendix F) to assess the viability of the stock under Tier 3 OFL and ABC control rule and a dynamic B0 analysis part (Appendix H) to assess the biomass dynamics under no fishery.

4. *Changes to assessment results*
   Expectedly, addition of one more year data changed the OFL and ABC estimates, but no dramatic changes were observed.

B. Response to September 2017 CPT comments

Comment 1: The CPT recommended moving forward with the modeling convention adopted by the Groundfish Plan Teams. Naming conventions in groundfish SAFE guidelines:
When a model constituting a "major change" from the original version of the base model is introduced, it is given a label of the form "Model *yy.j*," where *yy* is the year (designated by the last two digits) that the model was introduced, and *j* is an integer distinguishing this particular "major change" model from other "major change" models introduced in the same year.

When a model constituting only a "minor change" from the original version of the base model is introduced, it is given a label of the form "Model *yy.jx*," where "*x*" is a letter distinguishing this particular "minor change" model from other "minor change" models derived from the original version of the same base model.

The distinction between "major" and "minor" model changes is determined subjectively by the author on the basis of qualitative differences in model

Response:
We followed this naming convention in labeling model scenarios: 17_0 refers to model was established in 2017 and carried forward to 2018; no major changes occurred in 2018 and remain at the 0-level. 17_0a refers to a minor change to 17_0; for example, CPUE indices were determined by spatio-temporal delta generalized linear mixed model (deltaGLMM) instead of GLM in this case.

Comment 2: a) Reconsider what crabs are mature vs immature via breakpoint analysis; b) Repeat the breakpoint analysis using log (CH/CL) vs CL, rather than the logCH vs. logCL; c) Because it was based on an inappropriate analysis, there is no need to show models with a logistic maturity curve, unless an improved approach can be found.

Response:
As suggested by Steve Martel, we used the log(CH/CL) vs. CL plot to get a better delineation of points for breakpoint analysis (see Appendix C figures). We used the breakpoint 50% maturity length for maturity determination in all scenarios. Sizes ≥ 111 mm CL were treated as mature and below this breakpoint immature.

Comment 3: It is appropriate to use only the equilibrium abundance as a starting point.

Response:
We used the equilibrium starting point in 1960 in all scenarios.

Comment 4: Moving forward, do not look at the core data.

Response:
We are not using the core data, but we have analyzed the independent pot survey data to estimate CPUE indices and incorporated them in a separate model scenario (17_0f). In the future we intend to use a spatio-temporal model to analyze the independent pot survey data.

Comment 5: Continue analysis of spatio-temporal variation of the fishery using a program like VAST.

Response:
We did a preliminary analysis of observer data using a spatio-temporal deltaGLMM (VAST, Thorson et al. 2015) and estimated an additional set of CPUE indices (see Appendix B) for scenario 17_0a. VAST requires spatially explicit catch data and some measure of ‘area fished’. This type of information is available from the observer data, which include soak time, lat. and long., and depth. The necessary data for a spatio-temporal detlaGLMM are not available from dock side sampling; therefore, observer data are more suitable (see West coast SSC’s March 2017 groundfish subcommittee report on the review of assessment methodologies proposed for use in 2017 groundfish assessments).

However, unlike the open West Coast Sea or Bering Sea, the Aleutian Islands areas provide additional constraints for spatial analysis due to the edge effects from the many islands. More work is needed to improve the use of spatio-temporal models in this region.

Comment 6: Show a scenario with the McAllister and Ianelli re-weighting for comparison when choosing preferred model.

Response:
We provide scenario 17_0e, which considers McAllister and Ianelli method of re-weighting (see Appendix D for detail).

Comment 7: Consider interaction terms, specifically area x year interaction for CPUE standardization.

Response:
We standardized the CPUE considering the year: area interaction for scenario 17_0c (see Appendix B for details). The problem with this interaction analysis is that a lot of NAs occurred for many missing factor levels over the years. Anyway, we used the resulting CPUE indices in scenario 17_0c.

Comment 8: Consider scenarios with catchability and/or total selectivity breaking at a third point in 2010 (or a better year).

Response:
We considered scenario 17_0d with different sets of catchability and total selectivity for 1985/86–2004/05; 2005/06–2012/13; and 2013/14–2016/17.

Comment 9: Provide a comparison between the previous CPUE standardization and any new standardization methods that are applied.

Response:

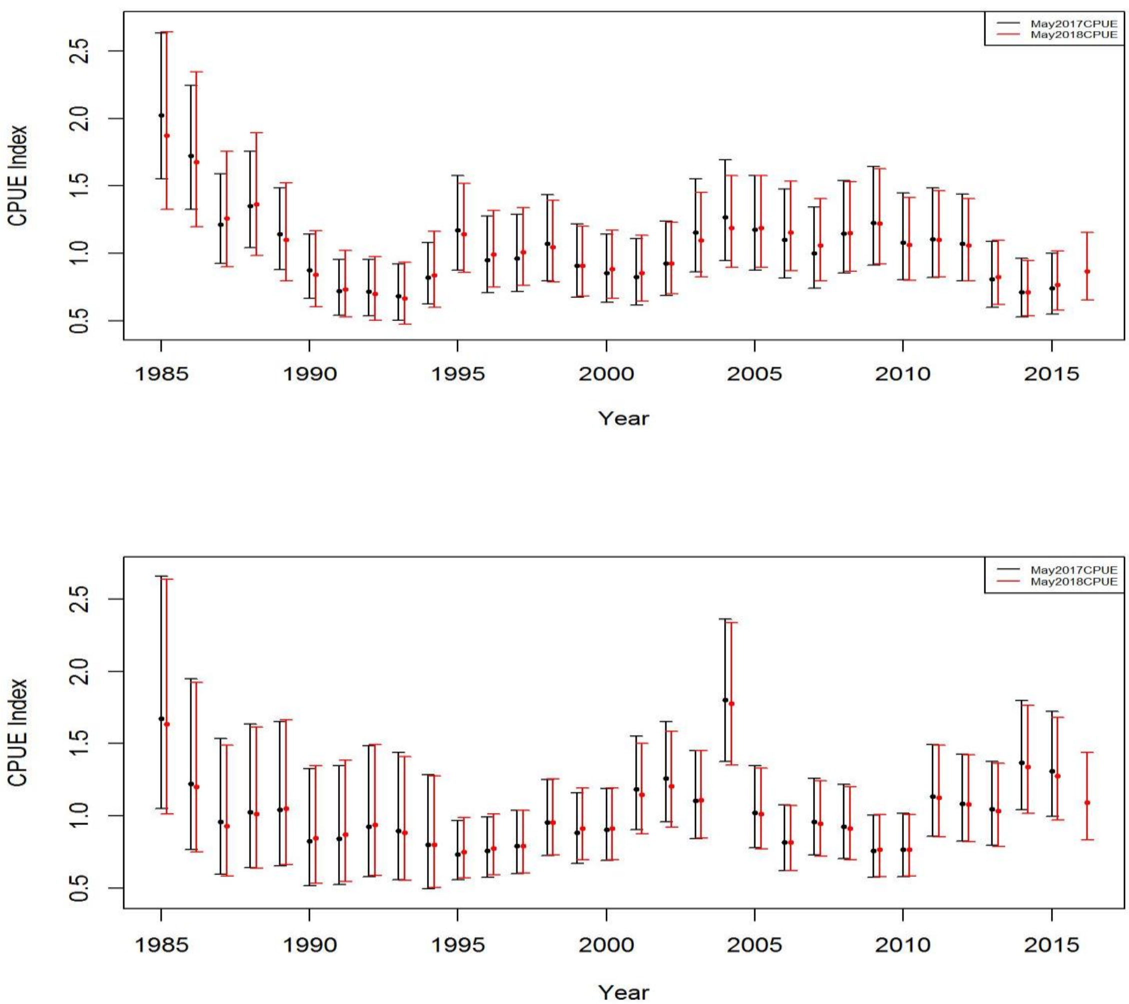


Figure Comm.9. Comparison between May 2017 and May 2018 CPUE indices (top: WAG, bottom: EAG). In 2017 we categorized the area broadly into 10 longitudinally separated regions whereas in 2018 we used individual ADFG coded statistical area. The confidence intervals are +/- 2SE. Model estimated additional standard error was added to each input standard error.

Comment 10: Include last year's model as a scenario for consideration.

Response:
We have included last year's model as scenario May17Sc9 to reflect scenario 9 with knife-edge maturity selectivity, which was accepted last year.

Comment 11: Overall model recommendation for May 2018: base model from last year (equilibrium initial abundance, knife edge maturity, both CPUE analyses with any significant interaction terms).

Response:
Done.

Response to October 2017 SSC comments

Comment 1: The SSC appreciates the CPT's consideration of model number convention and their recommendation to move forward with the modelling convention adopted by the Groundfish Plan Teams.

Response:
Done.

Comment 2: Although the use of chela height-carapace size regression lines has been validated for *Chionoecetes* crabs (snow, Tanner), the SSC expressed concern that the use of this approach to determine maturity may not be appropriate for lithodid (king) crabs. The SSC recommends that efforts be made to verify this relationship in lab or field experiments, as well as to review the available literature and application of this approach for other non-*Chionoecetes* species.

Response:

After analyzing a number of lithodid (king) crab stocks for size at maturity, Somerton and Otto (1986) observed that golden king crab provided a better separation of chela height growth at the onset of maturity than either red or blue king crabs (see Appendix C). We have also provided a literature review on king crab maturity determination in Appendix C, which supports the breakpoint type of analysis for male 50% maturity determination.

Comment 3: The SSC supports the exploration of the VAST geospatial model for investigation of fishery catch rate data, but cautions that the nonrandom nature of fisheries data adds an additional challenge to the standard assumptions of independence between the underlying density and the process of observation beyond that of standard statistically-designed survey programs.

Response:
We did a preliminary run of VAST for observer CPUE standardization and described its advantage and limitation (see response to CPT comment 5).

Comment 4: The SSC encourages the author to explore observer data and to discuss with the participants in the fishery potential changes in fisher behavior that may influence the relationship between fishery catch rates and crab abundance.

Response:
This is an ongoing process. We continue to explore this with the industry input and external experts.

Comment 5:The SSC reiterates previous concerns that this stock assessment relies solely on fishery data, and therefore carries a higher degree of uncertainty than other model-based assessments for crab stocks. The SSC encourages recent and future efforts by the industry to include survey pots in their fishing activity in order to generate additional data to inform this analysis. The SSC extends its appreciation to the industry for their generous cooperative research efforts on this important crab stock.

Response:
We recognized the higher degree of uncertainty in the assessment and therefore set the ABC using 25% buffer level. For the first time, we used the independent pot survey data in the model even though the time series is short (2015 to 2017).

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 2). 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 3), 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 4). 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 5).

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 4 and 5) 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 6) 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 1996/97–2016/17 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2016/17) has averaged 2% below the annual GHL/TACs. During 1996/97–2016/17, 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 required on catcher-processors at all times 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) ≥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 7 to 9 provide the 1985/86–2016/17 time series of catches, CPUE, and the geographic distribution of catch during the 2016/17 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 2011/12–2016/17 (an increasing trend in EAG and a decreasing trend in WAG).

6. **Brief description of the annual ADF&G harvest strategy:**
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 2012:

(a) Until the Aleutian Islands golden king crab stock assessment model and a state regulatory harvest strategy are established, the harvest levels for the Registration Area O golden king crab fishery are as follows:

(1) east of 174° W long. (EAG): 3.31 million pounds; and
(2) west of 174° W long. (WAG): 2.98 million pounds;

(b) The department may reduce the harvest levels based on the best scientific information available and considering the reliability of estimates and performance measures, sources of uncertainty as necessary to avoid overfishing, and any other factors necessary to be consistent with sustained yield principles.

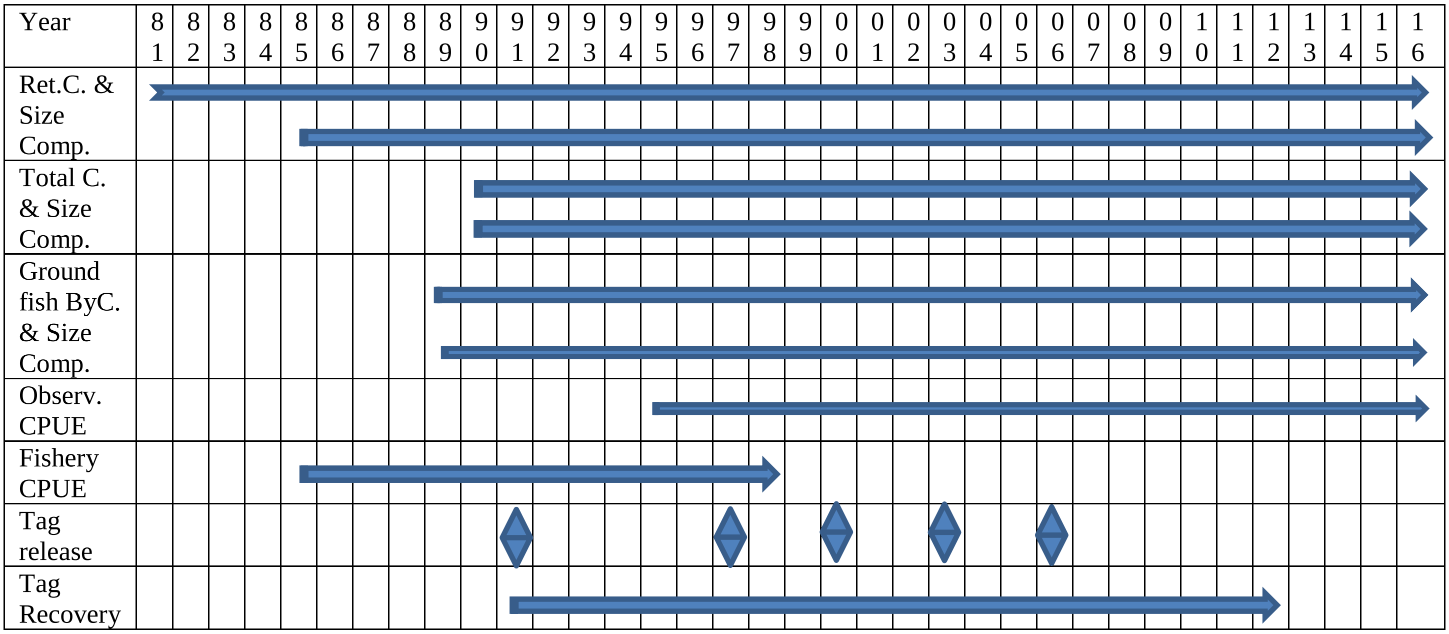
In addition to the retained catch that is limited by the TAC established by ADF&G under 5 AAC 34.612, ADF&G also has authority to annually receive receipts of $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually-established TAC.
At the March 2018 meeting, The BOF decided to amend the phrase “may reduce to “may modify” in (b).

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 2016/17 information. The details are given in the pictorial table below.



2. Data presented as time series:

a. **Total Catch**:

Fish ticket data on retained catch weight, catch numbers, effort (pot lifts), CPUE, and average weight of retained catch for 1981/82–2016/17 (Table 1). Estimated total catch weight for 1990/91–2016/17 (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 1981/82–2016/17 (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 1991/92–2016/17 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 1985/86–2016/17 (Table 3).

- Estimated commercial fishery CPUE index with coefficient of variation (Table 4 for EAG and Table 22 for WAG). The estimation methods, CPUE fits and diagnostic plots are described in Appendixes B and G.

d. Catch-at-length:

Information on length compositions (Figures 11 to 13 for length compositions for EAG; and 29 to 31 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.

E. Analytic Approach

1. History of modeling approaches for this stock:

A size structured assessment model based on only fisheries data has been under development for several years for the EAG and WAG golden king crab stocks. The model was accepted in 2016 for OFL and ABC setting for the 2017/18 season. The CPT in January 2017 and SSC in February 2017 recommended to 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. This is the second fishing season we are proposing to use the model-based OFL and ABC setting.

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). As a first attempt, we used VAST to estimate a separate set of observer CPUE indices for the model scenario 17_0a and also used the 2015-2017 fishery independent pot survey CPUE indices for the model scenario 17_0f.
There were significant changes in fishing practice due to 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 2005/06–2016/17. However, in order to respond to the September 2017 CPT comment, we considered three catchabilities, three sets of total selectivity, and one set of retention curves in one scenario (scenario 17_0d).

We fitted the observer and commercial fishery CPUE indices with estimated (by GLM or VAST) 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 (Figure 1). 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 7 scenarios for EAG and 6 scenarios for 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 17_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 1995/96–2016/17.
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 and McAllister and Ianelli methods (Appendix D).
v) Two catchability and two sets of logistic total selectivity for the periods 1985/86–2004/05 and 2005/06–2016/17, 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.
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 are 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.

As per CPT and SSC requests, initial parameter values for scenario 17_0 were jittered to confirm model global convergence. The results indicated that global convergence was achieved for almost all the runs (Appendix E).

Table T1. Features of model scenarios. Initial condition was estimated by the equilibrium condition for all scenarios. Changes from scenario 17_0 specifications are highlighted by the light blue shade.

Scenario	**Size-composition weighting**	**Catchability and logistic total selectivity sets**	**Maturity**	**Standardized CPUE data type**	**Treatment of *M* and Tier 3 MMB_{MSY} reference points**	**Natural mortality (M yr^{-1})**
0b	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer from 1995/96–2016/17 & Fish Ticket from 1985/86–1998/99; GLM variable selection by R square criterion	Estimate a common *M* using the combined EAG and WAG data without an *M* prior	0.2254; Individual component's estimate: EAG: 0.2142 WAG: 0.2142
17_0	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer from 1995/96–2016/17 & Fish Ticket from 1985/86–1998/99; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0a	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer CPUE by VAST & Fish Ticket CPUE by GLM; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0b	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer & Fish Ticket CPUE by GLM; GLM variable selection by CAIC	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21

17_0c	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer & Fish Ticket CPUE standardization considering Year:Area interaction; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0d	Stage-1:Number of boat_days/trips Stage-2: Francis method	3	Knife-edge, 111 mm CL	Observer & Fish ticket; GLM variable selection by R square criterion	Three different total selectivity curves and catchability coefficients for 1985–2004, 2005–2012, and 2013–2016; single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0e	Stage-1:Number of boat_days/trips Stage-2: McAllister and Ianelli method	2	Knife-edge, 111 mm CL	Observer & Fish ticket; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0f (only for EAG)	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer, Fish ticket, & fishery independent pot survey (2015–2016) in EAG; GLM variable selection by R square criterion	Fishery independent pot survey standardized CPUE are considered as a separate likelihood component for EAG; single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21

b. **Progression of results:**
The OFL and ABC estimates are similar to those estimated by the 2017 model.

c. **Label the approved model from the previous year as model 0:**
Following the September CPT suggestion we used the notation 17_0 for the base model which came from the previous assessment.

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 a number of 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 seven scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the seven scenarios are provided in tables and figures. The total catch OFLs and the reduction in terminal (2016) MMB from the initial condition (i.e., virgin MMB in 1960) for all scenarios for EAG and WAG are provided in Table 38. We also included the results of the accepted 2017 model scenario, Sc9, in this table for comparison. The reduction in terminal MMB from the initial condition is higher for WAG than EAG.

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 and McAllister and Ianelli method (McAllister and Ianelli, 1997) (Appendix D).

We provide the initial input sample sizes (Stage-1) and Stage-2 effective sample sizes for scenarios 17_0 to 17_0f in Tables 5 to 11 for EAG and Tables 23 to 28 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) and details are in Appendix D.

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 a number of 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 a number of 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 11 for EAG and Tables 23 to 28 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 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 12 and 13 for EAG and 29 and 30 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 21 and 37 list the total and component negative log likelihood values and their differences between scenarios of similar sample sizes and free parameters 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 12 and 13 for EAG and 29 and 30 for WAG. 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 14 to 20 for EAG and Tables 31 to 36 for WAG.

   d. The recruitment estimates for those scenarios are summarized in Tables 14 to 20 for EAG and Tables 31 to 36 for WAG.

   e. The negative log-likelihood component values and total negative log-likelihood values for all scenarios are summarized in Table 21 for EAG and Table 37 for WAG. Scenario 17_0d has the minimum total negative log likelihood for EAG whereas scenario 17_0e has the minimum for WAG. Among the scenarios with equal data components (base) and number of free parameters, scenario 17_0e has the lowest total negative log likelihoods for both EAG and WAG. Thus, we chose scenarios 17_0 (base), 17_0d, and 17_0e for OFL and ABC options for consideration.

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 14 for EAG and Figure 32 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 13 and 31 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 nine (a subset of 11) scenarios are depicted in Figures 28 and 46 for EAG and WAG, respectively. 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 27 and 45 for EAG and WAG, respectively. The F peaked in late 1980s and early to mid-1990s and systematically declined 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. The increase in F in recent years may be due to a decline in abundance under constant high harvest allocation to WAG.

d. **F vs. MMB:**
We provide these plots for scenarios 17_0 and 17_0d for EAG and WAG in Figure 47.

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 16 for EAG and in Figure 34 for WAG. The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 17 and 35 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 19 and 37 for EAG and WAG, respectively. The 1981/82–1984//85 retained catch plots for all scenarios are depicted in Figures 20 and 38 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 predicted vs. input CPUE indices for all scenarios are shown in Figure 26 for EAG and Figure 44 for WAG. Scenario 17_0d fit the recent three years' CPUE indices well for EAG; on the other hand, scenario 17_0c did not fit the post rationalization period CPUE indices well for WAG. 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 15 for EAG and Figure 33 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 18 and 36 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 11 to 13 for EAG and 29 to 31 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 21 and 23 for EAG, and 39 and 41 for WAG) and for total catch (Figures 22 and 24 for EAG, and 40 and 42 for WAG) for two scenarios (17_0 and 17_0d). 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 11 for EAG and in Tables 23 to 28 for WAG, respectively.

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

p. **Quantile-quantile (Q–Q) plots:**
We did not provide these plots for model fits in this report. However, we provided these plots in a separate Appendix F for CPUE standardization diagnostic.

6. **Retrospective and historical analysis:**
The retrospective fits for scenarios 17_0 and 17_0d are shown in Figure 25 for EAG and in Figure 43 for WAG. The retrospective fits were prepared for the whole time series 1961 to 2017. The retrospective patterns did not show severe departure when four terminal years' data were removed systematically, especially for WAG and

hence the current formulation of the model appears stable. The 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.

   - We also determined likelihood values at different M and plotted component negative likelihood against M (Figure 1).

8. **Conduct 'jitter analysis':**
   We conducted the (random) jitter analysis on scenario 17_0 (base) model fitted parameters. This analysis indicated that the base model achieved the global convergence (details in Appendix E).

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 2005/06–2016/17 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 2007/08 – 2016/17 (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 TACs for 2013/14–2015/16 in the table below do not include landings towards a cost-recovery fishery goal, but the catches towards cost-recovery fishing in 2013/14–2014/15 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]
2013/14	N/A	N/A	2.853	2.894	3.192	5.69	5.12
2014/15	N/A	N/A	2.853	2.771	3.088	5.69	4.26
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				5.514	4.136
2018/19[d]	5.898	14.665				3.963	2.972
2018/19[e]	6.107	17.793				5.581	4.186

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

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]
2013/14	N/A	N/A	6.290	6.38	7.038	12.54	11.28
2014/15	N/A	N/A	6.290	6.11	6.807	12.53	9.40
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			13.333	10.000
2018/19[c]	13.329	39.577				12.157	9.118
2018/19[d]	13.002	32.331				8.737	6.553
2018/19[e]	13.464	39.227				12.305	9.228

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

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) stock were calculated for the three recommended scenario options (17_0, 17_0d, and 17_0e):

Scenario 17_0:
EAG: 3,756 t (8.280 million lb)
WAG: 1,473 t (3.248 million lb)
AI: 5,229 t (11.528 million lb).

Scenario 17_0d:
EAG: 2,355 t (5.191 million lb)
WAG: 1,375 t (3.031 million lb)
AI: 3,730 t (8.222 million lb).

Scenario 17_0e:
EAG: 3,817 t (8.415 million lb)
WAG: 1,484 t (3.271 million lb)
AI: 5,301 t (11.686 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 17_0, 17_0d, and 17_0e:

   Scenario 17_0:
   EAG: ABC = 2,938 t (6.478 million lb)
   WAG: ABC = 1,197 t (2.640 million lb)
   AI: ABC = 4,136 t (9.118 million lb).

   Scenario 17_0d:
   EAG: ABC = 1,860 t (4.102 million lb)
   WAG: ABC = 1,112 t (2.451 million lb)
   AI: ABC = 2,972 t (6.553 million lb).

   Scenario 17_0e:
   EAG: ABC = 2,980 t (6.570 million lb)
   WAG: ABC = 1,206 t (2.658 million lb)
   AI: ABC = 4,186 t (9.228 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 was estimated in the 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 in during 1981/82–1989/90 were not available.

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

4. **Author recommended ABC:**
   Authors recommended three ABC options based on 25% buffer on the OFL under scenarios 17_0, 17_0d, and 17_0e.

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.
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.
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.

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K. *Literature Cited*

Adams, C.F., and A.J. Paul. 1999. Phototaxis and geotaxis of light-adapted zoeae of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae) in the laboratory. Journal of Crustacean Biology. 19(1): 106-110.

ADF&G (Alaska Department of Fish and Game). 2002. Annual management report for the shellfish fisheries of the Westward Region, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02–54, Kodiak, Alaska.

Barnard, D.R., and R. Burt. 2004. Summary of the 2002 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04–27, Kodiak, Alaska.

Barnard, D.R., R. Burt, and H. Moore. 2001. Summary of the 2000 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K01–39, Kodiak, Alaska.

Beers, D.E. 1992. Annual biological summary of the Westward Region shellfish observer database, 1991. Alaska Department of Fish and game, Division of Commercial Fisheries, Regional Information Report 4K92-33, Kodiak.

Blau, S.F., and D. Pengilly. 1994. Findings from the 1991 Aleutian Islands golden king crab survey in the Dutch Harbor and Adak management areas including analysis of recovered tagged crabs. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K94-35, Kodiak.

Blau, S.F., L.J. Watson, and I. Vining. 1998. The 1997 Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K98-30, Kodiak.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B.J. Failor-Rounds, K. Milani, K. Herring, M. Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 08-02, Anchorage, Alaska.

Bowers, F.R., M. Schwenzfeier, K. Herring, M. Salmon, J. Shaishnikoff, H. Fitch, J. Alas, and B. Baechler. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Region's shellfish observer program, 2009/10. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 11-05, Anchorage, Alaska.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society, Monograph 5, 437p.

Deroba, J.J. 2014. Evaluating the consequences of adjusting fish stock assessment estimates of biomass for retrospective patterns using Mohn's rho. *North American Journal of Fisheries Management* 34:380-390.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optim. Methods Softw*. 27:233-249.

Fox, J., and S. Weisberg. 2011. An R Companion to Applied Regression. Second edition. Sage Publications, Inc. 449 p.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. *Canadian Journal of. Fisheries and Aquatic Sciences* 68: 1124–1138.

Francis, R.I.C.C. (2017). Revisiting data weighting in fisheries stock assessment models. *Fisheries Research* 192: 5-15.

Gaeuman, W.B. 2014. Summary of the 2013/2014 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 14-49, Anchorage.

Gaeuman, W.B. 2011. Summary of the 2009/10 mandatory crab observer program database for the BSAI commercial crab fisheries. Fishery Data Series No. 11-04. Alaska Department of Fish and Game, Kodiak.

Hartill, T. 2012. Annual management report for the community development quota and Adak Community Allocation crab fisheries in the Bering Sea and Aleutian Islands, 2010/11. Pages 177–194 in Fitch, H., M. Schwenzfeier, B. Baechler, T. Hartill, M. Salmon, M. Deiman, E. Evans, E. Henry, L. Wald, J. Shaishnikoff, and K. Herring. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2010/11. Alaska Department of Fish and Game, Fishery Management Report No. 12-22, Anchorage.

Hilsinger, J., C. Siddon and L. Hulbert. 2016. Cooperative red king crab survey in the Adak area, 2015. Anchorage., Alaska Department of Fish and Game, Fishery Data Series No. 16-18.

Hiramoto, K. 1985. Overview of the golden king crab, *Lithodes aequispina*, fishery and its fishery biology in the Pacific waters of Central Japan. Pages 297-315, In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Jewett, S.C., N.A. Sloan, and D.A. Somerton. 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from northern British Columbia. *Journal of Crustacean Biology* 5: 377–385.

Koeneman, T.M., and D.V. Buchanan. 1985. Growth of the golden king crab, *Lithodes aequispina*, in Southeast Alaskan waters. Pages 281-297, In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Kruse, G.H., L.C. Byrne, F.C. Funk, S.C. Matulich, and J. Zheng. 2000. Analysis of minimum size limit for the red king crab fishery in Bristol Bay, Alaska. *N. Am. J. Fish. Manage.* 20:307-319.

Leon, J. M., J. Shaishnikoff, E. Nichols, and M. Westphal. 2017. Annual management report for shellfish fisheries of the Bering Sea–Aleutian Islands management area, 2015/16. Alaska Department of Fish and Game, Fishery Management Report No. 17-10, Anchorage.

Maunder, M.N., and A.E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70: 141-159.

McAllister, M.K., and J.N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling/importance resampling algorithm. *Canadian Journal of. Fisheries and Aquatic Sciences* 54: 284–300.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. *ICES Journal of Marine Science* 56:473-488.

Moore, H., L.C. Byrne, and M.C. Schwenzfeier. 2000. Summary of the 1999 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K00–50, Kodiak, Alaska.

Morrison, R., R.K. Gish, and M. Ruccio. 1998. Annual management report for the shellfish fisheries of the Aleutian Islands. Pages 82–139 in ADF&G. Annual management report for the shellfish fisheries of the Westward Region. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K98-39, Kodiak.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. National Marine Fisheries Service, Alaska Region, Juneau, August 2004.

North Pacific Fishery Management Council (NPFMC). 2007a. Initial Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 17 January 2007. North Pacific Fishery Management Council, Anchorage.

North Pacific Fishery Management Council (NPFMC). 2007b. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Otto, R.S., and P.A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. Pages 123-135 In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Pengilly, D. 2016. Aleutian Islands golden king crab – 2016 Tier 5 assessment. 2016 Crab SAFE report chapter (September 2016). North Pacific Fishery Management Council, Anchorage, Alaska.

Punt, A.E., Kennedy, R.B., Frusher, S.D., 1997. Estimating the size-transition matrix for Tasmanian rock lobster, *Jasus edwardsii*. *Mar. Freshw. Res* 48, 981–982.

Punt, A.E. (2017). Some insights into data weighting in integrated stock assessments. *Fisheries Research* 192:52-65.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Runnebaum, J., Guan, L., Cao, J., O'Brien, L., Chen, Y. 2017. Habitat suitability modeling based on a spatio-temporal model: an example for Cusk in the Gulf of Maine. *Canadian Journal of. Fisheries and Aquatic Sciences* (in press).

Shirley, T.C., and S. Zhou. 1997. Lecithotrophic development of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). *J. Crust. Biol.* 17(2):207-216.

Siddeek, M.S.M. 2002. Review of biological reference points used in Bering Sea and Aleutian Islands (king and Tanner) crab management. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J02-06, Juneau, Alaska.

Siddeek, M.S.M., D.R. Barnard, L.J. Watson, and R.K. Gish. 2005. A modified catch-length analysis model for golden king crab (*Lithodes aequispinus*) stock assessment in the eastern Aleutian Islands. Pages 783-805 in Fisheries assessment and management in data limited situations, Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, Alaska.

Siddeek, M.S.M., J. Zheng, and D. Pengilly. 2015. Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment in Fall 2015. Draft report submitted for the September 2015 Crab Plan Team Meeting. North Pacific Fishery Management Council, Anchorage, Alaska.

Siddeek, M.S.M., J. Zheng, A.E. Punt, and Vicki Vanek. 2016a. Estimation of size-transition matrices with and without moult probability for Alaska golden king crab using tag–recapture data. *Fisheries Research* 180:161-168.

Siddeek, M.S.M., Jie Zheng, and Doug Pengilly 2016b. Standardizing CPUE from the Aleutian Islands golden king crab observer data. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks, Alaska, USA, pp. 97-116.

Siddeek, M.S.M., J. Zheng, and D. Pengilly. 2016c. Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment in Spring 2016. Draft report submitted for the May 2016 Crab Plan Team Meeting. North Pacific Fishery Management Council, Anchorage, Alaska.

Siddeek, M.S.M., J. Zheng, A.E. Punt, and D. Pengilly 2017. Effect of data weighting on the mature male biomass estimate for Alaskan golden king crab. CAPAM Data weighting Workshop, San Diego, California. *Fisheries Research* 142: 103-113.

Somerton, D.A., and R.S. Otto. 1986. Distribution and reproductive biology of the golden king crab, *Lithodes aequispina*, in the Eastern Bering Sea. *Fishery Bulletin* 81(3): 571-584.

Starr, P.J. 2012. Standardized CPUE analysis exploration: using the rock lobster voluntary logbook and observer catch sampling programmes. New Zealand Fisheries Assessment Report 2012/34, 75 p.

Thorson, J.T., Shelton A.O., Ward, E.J., and Skaug, H.J. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES Journal of Marine Sciences* 72(5):1297-1310.

Thorson, J.T., and Barnett, L.A.K. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multi-species models of fishes and biogenic habitat. *ICES Journal of Marine Sciences* 74(5):1311-1321.

Thorson, J.T., Ianelli, J.N., and Kotwicki, S. 2017. Relative influence of temperature and size-structure on fish distribution shifts. A case study on Walleye Pollock in the Bering Sea. *Fish and Fisheries* 2017; 1-12.

Vanek, V., Pengilly, D., and Siddeek, M.S.M.. 2013. A study of commercial fishing gear selectivity during the 2012/13 Aleutian Islands Golden King Crab Fishery East of 174° W

Longitude. Fishery Data Series No. 13-41. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1565.

Von Szalay, P.G., C.N. Roper, N.W. Raring, and M.H. Martin. 2011. Data report: 2010 Aleutian Islands bottom trawl survey. U.S. Dep. Commerce., NOAA Technical Memorandum NMFS-AFSC-215.

Watson, L.J. 2004. The 2003 triennial Aleutian Islands golden king crab survey and comparisons to the 1997 and 2000 surveys (revised October 17, 2005). Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04-42, Kodiak. [Revised 10/17/2005].

Watson, L.J. 2007. The 2006 triennial Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Fishery Management Report No. 07-07, Anchorage.

Watson, L.J., and R.K. Gish. 2002. The 2000 Aleutian Islands golden king crab survey and recoveries of tagged crabs in the 1997–1999 and 2000–2002 fishing seasons. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02-6, Kodiak.

Watson, L.J., D. Pengilly, and S.F. Blau. 2002. Growth and molting of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169-187 *in* Crabs in cold water regions: biology, management, and economics, Alaska Sea Grant College Program, AK-SG-02-01, Fairbanks, Alaska.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 *in* B.G. Stevens (ed.). King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery1981/82–2015/16: 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 2005/06–2016/17, 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]

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 – 2016/17, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries. For bycatch in the federal groundfish fisheries, historical data (1991–2008) are not available for areas east and west of 174W, and are listed for federal groundfish reporting areas 541, 542, and 543 combined. The 2009– present data are available by separate EAG and WAG fisheries and are listed as such. A mortality rate of 20% was applied for crab fisheries bycatch, and a mortality rate of 50% for groundfish pot fisheries and 80% for the trawl fisheries were applied.

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

2013/14	1,546	1,347	113	174	5	7	1,665	1,528	3,192
2014/15	1,554	1,217	127	175	9	5	1,691	1,397	3,088
2015/16	1,590	1,139	165	157	23	2	1,778	1,298	3,076
2016/17	1,578	1,015	203	145	3	3	1,785	1,163	2,947
2017/18	1,571	1,014	219	126	10	2	1,801	1,142	2,942

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 (1990/91–2016/17). 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	3,672	3,736
1991/92	3,946	2,275
1992/93	5,570	1,500
1993/94	NA	2,800
1994/95	2,020	4,945
1995/96	3,724	2,125
1996/97	2,035	1,766
1997/98	2,534	1,794
1998/99	2,797	1,083
1999/00	2,272	2,085
2000/01	2,551	2,225
2001/02	2,107	2,131
2002/03	1,796	1,889
2003/04	1,819	1,853
2004/05	1,618	1,873
2005/06	1,713	1,786
2006/07	1,621	1,542
2007/08	1,790	1,602
2008/09	1,796	1,719
2009/10	1,750	1,667
2010/11	1,719	1,580
2011/12	1,736	1,504
2012/13	1,927	1,811
2013/14	1,818	1,890
2014/15	1,939	1,583
2015/16	2,104	1,547
2016/17	2,104	1,425

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 the EAG and WAG golden king crab stocks, 1985/86–2016/17. Observer retained CPUE includes retained and non-retained legal size crabs.

Year	Pot Fishery Nominal Retained CPUE		Obs. Nominal Retained CPUE		Obs. Nominal Total CPUE		Pot Fishery Effort (no.pot lifts)		Obs. Sample Size (no.pot lifts)		Obs. CPUE Index	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1985/86	11.90	11.90					117,718	118,563				
1986/87	8.42	7.32					155,240	277,780				
1987/88	7.03	7.15					146,501	160,229				
1988/89	7.52	7.93					155,518	166,409				
1989/90	8.49	7.83					155,262	202,541				
1990/91	8.90	7.00	6.84	8.00	33.60	27.04	106,281	108,533	138	340		
1991/92	8.20	7.40	8.11	6.83	24.69	17.01	133,428	101,429	377	857		
1992/93	8.40	5.90	10.42	6.35	38.46	16.64	133,778	69,443	199	690		
1993/94	7.80	4.40	5.07	6.51	20.81	17.14	106,890	127,764	31	174		
1994/95	5.90	4.10	2.54	6.71	12.91	19.25	191,455	195,138	127	1,270		
1995/96	5.90	4.70	5.03	4.96	16.94	14.26	177,773	115,248	6,388	5,598	0.75	1.14
1996/97	6.50	6.10	5.11	5.43	13.65	13.56	113,460	99,267	8,360	7,194	0.77	0.99
1997/98	7.30	6.60	7.11	6.53	18.15	15.03	106,403	86,811	4,670	3,985	0.79	1.01
1998/99	8.90	11.40	9.10	9.41	25.76	23.05	83,378	35,975	3,616	1,876	0.96	1.05
1999/00	9.00	6.30	9.21	5.92	20.70	14.47	79,129	107,040	3,851	4,523	0.91	0.91
2000/01	9.90	7.00	9.90	6.39	25.35	16.63	71,551	101,239	5,043	4,740	0.91	0.89
2001/02	11.70	6.50	11.19	5.99	22.59	14.64	62,639	105,512	4,626	4,454	1.15	0.86
2002/03	12.40	8.40	11.94	7.47	22.54	17.37	52,042	78,979	3,980	2,509	1.21	0.93
2003/04	10.90	10.20	11.03	9.28	19.46	18.15	58,883	66,236	3,960	3,334	1.11	1.10
2004/05	18.30	12.10	17.71	11.13	28.47	22.43	34,848	56,846	2,206	2,619	1.78	1.19
2005/06	25.40	21.20	29.44	23.89	38.47	36.23	24,569	30,116	1,193	1,365	1.01	1.19
2006/07	24.80	19.60	25.21	24.01	33.52	33.47	26,195	26,870	1,098	1,183	0.82	1.16
2007/08	28.00	20.00	31.09	21.07	40.37	32.48	22,653	29,950	998	1,082	0.95	1.06
2008/09	27.30	22.40	29.92	24.54	38.36	38.12	24,466	26,200	613	979	0.92	1.15
2009/10	25.90	23.70	26.64	26.54	35.89	34.07	26,298	26,489	408	892	0.77	1.22
2010/11	26.00	20.90	26.05	22.35	36.76	29.05	25,851	29,994	436	867	0.77	1.06
2011/12	37.30	23.40	38.79	23.76	51.69	31.09	17,915	26,326	361	837	1.13	1.10
2012/13	33.02	20.57	38.00	22.81	47.74	30.73	20,827	32,716	438	1,109	1.08	1.06
2013/14	33.67	16.42	35.83	16.93	46.16	24.95	21,388	41,835	499	1,223	1.04	0.83
2014/15	42.29	15.29	46.96	15.28	60.00	22.67	17,002	41,548	376	1,137	1.34	0.71
2015/16	39.41	14.97	43.17	15.75	58.81	22.13	19,376	41,108	478	1,296	1.28	0.77
2016/17	32.45	14.29	37.01	16.63	52.78	24.25	24,470	38,118	617	1,060	1.09	0.87

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. GLM predictor variables selected by R square criteria.

Year	**CPUE Index**	**CV**
1985/86	1.63	0.05
1986/87	1.20	0.05
1987/88	0.93	0.06
1988/89	1.02	0.05
1989/90	1.05	0.04
1990/91	0.85	0.06
1991/92	0.87	0.06
1992/93	0.94	0.06
1993/94	0.89	0.06
1994/95	0.80	0.06
1995/96	0.77	0.07
1996/97	0.82	0.07
1997/98	1.19	0.05
1998/99	1.39	0.05

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 17_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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	293				
1989/90	792	660			9	4
1990/91	163	136	22	11	13	6
1991/92	140	117	48	24	NA	NA
1992/93	49	41	41	21	2	1
1993/94	340	283	NA	NA	2	1
1994/95	319	266	34	17	4	2
1995/96	879	733	1,117	568	5	2
1996/97	547	456	509	259	4	2
1997/98	538	449	711	362	8	4
1998/99	541	451	574	292	15	7
1999/00	463	386	607	309	14	6
2000/01	436	363	495	252	16	7
2001/02	488	407	510	259	13	6
2002/03	406	338	438	223	15	7
2003/04	405	338	416	212	17	8
2004/05	280	233	299	152	10	4
2005/06	266	222	232	118	12	5
2006/07	234	195	143	73	14	6
2007/08	199	166	134	68	17	8
2008/09	197	164	113	57	15	7
2009/10	170	142	95	48	16	7
2010/11	183	153	108	55	26	12
2011/12	160	133	107	54	13	6
2012/13	187	156	99	50	18	8
2013/14	193	161	122	62	17	8
2014/15	168	140	99	50	16	7
2015/16	190	158	125	64	10	4
2016/17	223	186	155	79	12	5

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 17_0a 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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	294				
1989/90	792	661			9	4
1990/91	163	136	22	12	13	6
1991/92	140	117	48	26	NA	NA
1992/93	49	41	41	22	2	1
1993/94	340	284	NA	NA	2	1
1994/95	319	266	34	18	4	2
1995/96	879	733	1,117	598	5	2
1996/97	547	456	509	272	4	2
1997/98	538	449	711	380	8	4
1998/99	541	451	574	307	15	7
1999/00	463	386	607	325	14	6
2000/01	436	364	495	265	16	7
2001/02	488	407	510	273	13	6
2002/03	406	339	438	234	15	7
2003/04	405	338	416	223	17	8
2004/05	280	234	299	160	10	4
2005/06	266	222	232	124	12	5
2006/07	234	195	143	76	14	6
2007/08	199	166	134	72	17	8
2008/09	197	164	113	60	15	7
2009/10	170	142	95	51	16	7
2010/11	183	153	108	58	26	12
2011/12	160	133	107	57	13	6
2012/13	187	156	99	53	18	8
2013/14	193	161	122	65	17	8
2014/15	168	140	99	53	16	7
2015/16	190	158	125	67	10	4
2016/17	223	186	155	83	12	5

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 17_0b 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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	294				
1989/90	792	662			9	4
1990/91	163	136	22	11	13	6
1991/92	140	117	48	24	NA	NA
1992/93	49	41	41	21	2	1
1993/94	340	284	NA	NA	2	1
1994/95	319	266	34	17	4	2
1995/96	879	734	1,117	566	5	2
1996/97	547	457	509	258	4	2
1997/98	538	449	711	360	8	4
1998/99	541	452	574	291	15	7
1999/00	463	387	607	307	14	6
2000/01	436	364	495	251	16	7
2001/02	488	408	510	258	13	6
2002/03	406	339	438	222	15	7
2003/04	405	338	416	211	17	8
2004/05	280	234	299	151	10	4
2005/06	266	222	232	118	12	5
2006/07	234	195	143	72	14	6
2007/08	199	166	134	68	17	8
2008/09	197	165	113	57	15	7
2009/10	170	142	95	48	16	7
2010/11	183	153	108	55	26	12
2011/12	160	134	107	54	13	6
2012/13	187	156	99	50	18	8
2013/14	193	161	122	62	17	8
2014/15	168	140	99	50	16	7
2015/16	190	159	125	63	10	4
2016/17	223	186	155	79	12	5

Table 8. 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 17_0c 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	50				
1988/89	352	288				
1989/90	792	648			9	4
1990/91	163	133	22	12	13	6
1991/92	140	115	48	26	NA	NA
1992/93	49	40	41	22	2	1
1993/94	340	278	NA	NA	2	1
1994/95	319	261	34	18	4	2
1995/96	879	719	1,117	602	5	2
1996/97	547	447	509	274	4	2
1997/98	538	440	711	383	8	4
1998/99	541	443	574	309	15	7
1999/00	463	379	607	327	14	6
2000/01	436	357	495	267	16	7
2001/02	488	399	510	275	13	6
2002/03	406	332	438	236	15	7
2003/04	405	331	416	224	17	8
2004/05	280	229	299	161	10	4
2005/06	266	218	232	125	12	5
2006/07	234	191	143	77	14	6
2007/08	199	163	134	72	17	8
2008/09	197	161	113	61	15	7
2009/10	170	139	95	51	16	7
2010/11	183	150	108	58	26	12
2011/12	160	131	107	58	13	6
2012/13	187	153	99	53	18	8
2013/14	193	158	122	66	17	8
2014/15	168	137	99	53	16	7
2015/16	190	155	125	67	10	4
2016/17	223	182	155	84	12	5

Table 9. 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 17_0d 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	48				
1986/87	11	9				
1987/88	61	52				
1988/89	352	298				
1989/90	792	669			9	4
1990/91	163	138	22	12	13	6
1991/92	140	118	48	25	NA	NA
1992/93	49	41	41	22	2	1
1993/94	340	287	NA	NA	2	1
1994/95	319	270	34	18	4	2
1995/96	879	743	1,117	593	5	2
1996/97	547	462	509	270	4	2
1997/98	538	455	711	378	8	4
1998/99	541	457	574	305	15	7
1999/00	463	391	607	322	14	6
2000/01	436	369	495	263	16	7
2001/02	488	412	510	271	13	6
2002/03	406	343	438	233	15	7
2003/04	405	342	416	221	17	8
2004/05	280	237	299	159	10	4
2005/06	266	225	232	123	12	5
2006/07	234	198	143	76	14	6
2007/08	199	168	134	71	17	8
2008/09	197	167	113	60	15	7
2009/10	170	144	95	50	16	7
2010/11	183	155	108	57	26	12
2011/12	160	135	107	57	13	6
2012/13	187	158	99	53	18	8
2013/14	193	163	122	65	17	8
2014/15	168	142	99	53	16	7
2015/16	190	161	125	66	10	4
2016/17	223	188	155	82	12	5

Table 10. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by McAllister and Ianelli method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0e 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	72				
1986/87	11	14				
1987/88	61	77				
1988/89	352	443				
1989/90	792	997			9	7
1990/91	163	205	22	8	13	10
1991/92	140	176	48	18	NA	NA
1992/93	49	62	41	16	2	1
1993/94	340	428	NA	NA	2	1
1994/95	319	402	34	13	4	3
1995/96	879	1,106	1,117	424	5	4
1996/97	547	689	509	193	4	3
1997/98	538	677	711	270	8	6
1998/99	541	681	574	218	15	11
1999/00	463	583	607	230	14	10
2000/01	436	549	495	188	16	12
2001/02	488	614	510	194	13	10
2002/03	406	511	438	166	15	11
2003/04	405	510	416	158	17	13
2004/05	280	352	299	113	10	7
2005/06	266	335	232	88	12	9
2006/07	234	295	143	54	14	10
2007/08	199	250	134	51	17	13
2008/09	197	248	113	43	15	11
2009/10	170	214	95	36	16	12
2010/11	183	230	108	41	26	19
2011/12	160	201	107	41	13	10
2012/13	187	235	99	38	18	13
2013/14	193	243	122	46	17	13
2014/15	168	211	99	38	16	12
2015/16	190	239	125	47	10	7
2016/17	223	281	155	59	12	9

Table 11. 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 17_0f 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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	294				
1989/90	792	661			9	4
1990/91	163	136	22	11	13	6
1991/92	140	117	48	24	NA	NA
1992/93	49	41	41	21	2	1
1993/94	340	284	NA	NA	2	1
1994/95	319	266	34	17	4	2
1995/96	879	734	1,117	569	5	2
1996/97	547	457	509	259	4	2
1997/98	538	449	711	362	8	4
1998/99	541	452	574	292	15	7
1999/00	463	386	607	309	14	6
2000/01	436	364	495	252	16	7
2001/02	488	407	510	260	13	6
2002/03	406	339	438	223	15	7
2003/04	405	338	416	212	17	8
2004/05	280	234	299	152	10	4
2005/06	266	222	232	118	12	5
2006/07	234	195	143	73	14	6
2007/08	199	166	134	68	17	8
2008/09	197	164	113	58	15	7
2009/10	170	142	95	48	16	7
2010/11	183	153	108	55	26	12
2011/12	160	134	107	55	13	6
2012/13	187	156	99	50	18	8
2013/14	193	161	122	62	17	8
2014/15	168	140	99	50	16	7
2015/16	190	159	125	64	10	4
2016/17	223	186	155	79	12	5

Table 12. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0, 17_0a, 17_0b, and 17_0c for the golden king crab data from the EAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0		**Scenario 17_0a**		**Scenario 17_0b**		**Scenario 17_0c**		
Parameter	Estimate	CV	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	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-8.20	0.21	-8.22	0.21	-8.22	0.21	-8.26	0.21	-12.0,-5.0
log_a (molt prob. slope)	-2.50	0.02	-2.48	0.02	-2.50	0.02	-2.48	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.00	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	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.38	0.020	3.38	0.02	3.37	0.020	3.38	0.019	0.,4.4
log_ total sel deltaθ, 2005–16	2.97	0.030	2.93	0.030	2.98	0.030	2.92	0.031	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.85	0.023	1.85	0.023	1.85	0.0234	1.85	0.0233	0.,4.4
log_tot sel θ_{50}, 1985–04	4.83	0.003	4.84	0.003	4.83	0.003	4.84	0.003	4.0,5.0
log_tot sel θ_{50}, 2005–16	4.92	0.002	4.91	0.002	4.92	0.0021	4.91	0.0019	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.91	0.0003	4.91	0.00	4.91	0.0003	4.91	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.09	0.18	-1.08	0.18	-1.09	0.18	-1.06	0.18	-12.0, 12.0
logq2 (catchability 1995–04)	-0.59	0.12	-0.61	0.13	-0.57	0.13	-0.69	0.15	-9.0, 2.25
logq3 (catchability 2005–16)	-0.97	0.13	-1.06	0.13	-0.89	0.15	-1.09	0.13	-9.0, 2.25
log_mean_rec (mean rec.)	0.874	0.05	0.890	0.05	0.855	0.05	0.893	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.060	0.06	-1.108	0.06	-1.032	0.07	-1.119	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.244	0.09	-9.278	0.09	-9.210	0.09	-9.289	0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.018	0.37	0.029	0.43	0.032	0.39	0.031	0.47	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.051	0.43	0.051	0.44	0.040	0.432	0.173	0.58	0.0,1.0
2016 MMB	13,455	0.17	13,579	0.20	11,842	0.19	13,767	0.21	

Table 13. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0d, 17_0e, and 17_0f for the golden king crab data from the EAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0d		**Scenario 17_0e**		**Scenario 17_0f**		
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	0.21	-7.94	0.21	-8.20	0.21	-12.0,-5.0
log_a (molt prob. slope)	-2.50	0.02	-2.51	0.02	-2.50	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.00	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	3.34	0.02	3.38	0.02	0.,4.4
log_ total sel deltaθ, 2005–12	2.93	0.04			2.97	0.03	0.,4.4
log_ total sel deltaθ, 2013–16 or 2005–16	3.02	0.05	2.96	0.03	1.85	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.85	0.02	1.85	0.02	4.83	0.003	0.,4.4
log_tot sel θ_{50}, 1985–04	4.83	0.002	4.83	0.002	4.92	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–12	4.92	0.002			4.91	0.0003	4.0,5.0
log_tot sel θ_{50}, 2013–16 or 2005–16	4.92	0.004	4.92	0.002	-1.09	0.18	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.91	0.0003	4.91	0.0003	-0.59	0.12	4.0,5.0
log_β_r (rec.distribution par.)	-1.08	0.18	-1.15	0.17	-0.97	0.13	-12.0, 12.0
Logq1 (catchability 1985–04)	-0.60	0.12	-0.60	0.12	0.873	0.05	-9.0, 2.25
Logq3 (catchability 2005–12)	-0.99	0.11			-1.060	0.06	-9.0, 2.25
Logq2 (catchability 2013–16 or 2005–16)	-0.57	0.36	-1.01	0.12	-9.242	0.09	-9.0, 2.25
log_mean_rec (mean rec.)	0.83	0.06	0.872	0.05	0.018	0.38	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.02	0.07	-1.080	0.06	0.051	0.43	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.18	0.09	-9.259	0.09	2.54	0.006	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.02	0.36	0.018	0.37	-8.20	0.21	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.05	0.43	0.052	0.42	-2.50	0.02	0.0,1.0
σ_e^2 (survey CPUE additional var)					0.0000003	1001.0	0.0,1.0
2016 MMB	8,833	0.23	13,440	0.17	13,368	0.17	

Table 14. 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 17_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 2017 are restricted to 1985–2017. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =23,950 $MMB_{35\%}$=6,954			
1985	1.67			9,618	0.05
1986	1.00	9,534	0.04	8,147	0.04
1987	4.12	7,286	0.04	6,353	0.04
1988	3.77	6,652	0.05	5,274	0.05
1989	2.20	6,706	0.05	4,698	0.07
1990	2.71	5,973	0.06	4,287	0.07
1991	3.52	6,078	0.05	4,647	0.06
1992	2.27	6,116	0.04	4,466	0.05
1993	2.13	6,058	0.04	4,471	0.05
1994	2.45	6,195	0.03	4,889	0.04
1995	2.29	5,716	0.04	4,442	0.04
1996	2.25	5,139	0.04	3,850	0.04
1997	3.03	5,253	0.04	3,987	0.05
1998	2.78	5,529	0.05	4,100	0.05
1999	2.96	6,118	0.05	4,542	0.05
2000	2.78	6,811	0.05	5,202	0.06
2001	2.11	7,463	0.06	5,847	0.06
2002	2.70	7,848	0.06	6,414	0.06
2003	2.26	8,179	0.06	6,787	0.07
2004	1.95	8,507	0.07	7,089	0.07
2005	2.95	8,577	0.07	7,304	0.07
2006	2.25	8,649	0.07	7,233	0.08
2007	2.17	8,903	0.08	7,390	0.08
2008	3.52	8,910	0.08	7,543	0.08
2009	2.39	9,127	0.08	7,509	0.09
2010	2.19	9,630	0.08	7,914	0.09
2011	2.82	9,685	0.08	8,235	0.08
2012	2.74	9,708	0.08	8,229	0.09
2013	2.36	9,885	0.09	8,273	0.09
2014	5.63	9,913	0.10	8,368	0.10
2015	4.76	10,626	0.11	8,432	0.11
2016	2.59	12,484	0.14	9,623	0.13
2017	4.70	13,455	0.17		

Table 15. 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 17_0a 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 1985–2017. 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} =24,335 $MMB_{35\%}$=7,063			
1985	1.67			9,713	0.05
1986	1.01	9,594	0.04	8,206	0.04
1987	4.14	7,331	0.04	6,389	0.04
1988	3.75	6,696	0.05	5,303	0.05
1989	2.20	6,751	0.05	4,732	0.07
1990	2.70	6,013	0.06	4,321	0.07
1991	3.51	6,116	0.05	4,678	0.06
1992	2.23	6,146	0.04	4,492	0.05
1993	2.11	6,069	0.04	4,488	0.05
1994	2.49	6,179	0.03	4,881	0.04
1995	2.36	5,695	0.04	4,414	0.04
1996	2.32	5,152	0.04	3,836	0.04
1997	3.17	5,321	0.05	4,016	0.05
1998	2.94	5,673	0.05	4,185	0.05
1999	3.12	6,369	0.05	4,711	0.06
2000	2.97	7,180	0.06	5,476	0.06
2001	2.26	7,954	0.06	6,231	0.06
2002	2.83	8,457	0.07	6,914	0.07
2003	2.35	8,870	0.07	7,381	0.07
2004	2.02	9,248	0.08	7,747	0.08
2005	2.96	9,328	0.08	7,988	0.08
2006	2.41	9,369	0.08	7,907	0.09
2007	2.32	9,594	0.08	8,018	0.09
2008	3.46	9,635	0.08	8,168	0.09
2009	2.27	9,840	0.09	8,162	0.09
2010	2.23	10,218	0.09	8,513	0.09
2011	2.81	10,143	0.09	8,698	0.10
2012	2.68	10,095	0.10	8,594	0.10
2013	2.42	10,186	0.11	8,567	0.11
2014	5.58	10,143	0.13	8,582	0.13
2015	4.78	10,821	0.15	8,606	0.15
2016	2.63	12,627	0.18	9,754	0.18
2017	4.70	13,579	0.20		

Table 16. 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 17_0b 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 1985–2017. 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
		MMBeq =23,449 MMB35%=6,794			
1985	1.68			9,583	0.06
1986	1.00	9,536	0.04	8,138	0.04
1987	4.17	7,300	0.04	6,364	0.04
1988	3.73	6,683	0.05	5,295	0.05
1989	2.13	6,751	0.05	4,738	0.07
1990	2.72	5,991	0.06	4,325	0.07
1991	3.54	6,066	0.05	4,652	0.06
1992	2.28	6,107	0.04	4,455	0.05
1993	2.15	6,060	0.04	4,466	0.05
1994	2.43	6,209	0.03	4,896	0.04
1995	2.27	5,735	0.04	4,462	0.04
1996	2.23	5,145	0.04	3,864	0.04
1997	3.01	5,242	0.04	3,987	0.05
1998	2.74	5,498	0.05	4,082	0.05
1999	2.90	6,064	0.05	4,506	0.05
2000	2.71	6,720	0.06	5,140	0.06
2001	2.05	7,327	0.06	5,747	0.06
2002	2.60	7,667	0.07	6,270	0.07
2003	2.24	7,946	0.07	6,601	0.07
2004	1.92	8,231	0.07	6,852	0.08
2005	2.92	8,294	0.08	7,044	0.08
2006	2.27	8,364	0.08	6,971	0.08
2007	2.17	8,633	0.08	7,133	0.09
2008	3.32	8,676	0.08	7,313	0.09
2009	2.20	8,873	0.08	7,306	0.09
2010	2.08	9,261	0.08	7,650	0.09
2011	2.59	9,207	0.08	7,855	0.08
2012	2.45	9,126	0.08	7,753	0.09
2013	2.18	9,143	0.09	7,678	0.09
2014	4.97	9,019	0.11	7,618	0.11
2015	4.39	9,511	0.13	7,548	0.12
2016	2.54	11,020	0.16	8,450	0.16
2017	4.70	11,842	0.19		

Table 17. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with coefficient of variation (CV) for scenario 17_0c 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 1985–2017. 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} =24,526 $MMB_{35\%}$=7,091			
1985	1.59			9,750	0.06
1986	0.98	9,598	0.04	8,236	0.04
1987	3.98	7,282	0.04	6,372	0.04
1988	3.99	6,587	0.05	5,241	0.05
1989	2.18	6,625	0.06	4,601	0.07
1990	2.73	5,964	0.06	4,239	0.07
1991	3.52	6,080	0.05	4,634	0.06
1992	2.22	6,136	0.04	4,474	0.05
1993	2.09	6,069	0.04	4,487	0.05
1994	2.48	6,175	0.03	4,884	0.04
1995	2.35	5,682	0.04	4,409	0.04
1996	2.34	5,129	0.04	3,820	0.05
1997	3.24	5,300	0.05	3,995	0.05
1998	3.02	5,684	0.05	4,176	0.06
1999	3.15	6,445	0.06	4,749	0.06
2000	3.00	7,314	0.06	5,577	0.07
2001	2.27	8,117	0.07	6,375	0.07
2002	2.85	8,630	0.07	7,075	0.08
2003	2.38	9,044	0.08	7,545	0.08
2004	2.04	9,420	0.08	7,908	0.09
2005	3.03	9,502	0.09	8,147	0.09
2006	2.38	9,561	0.09	8,070	0.09
2007	2.30	9,795	0.09	8,202	0.10
2008	3.52	9,803	0.09	8,342	0.10
2009	2.37	9,997	0.09	8,307	0.10
2010	2.22	10,407	0.10	8,662	0.10
2011	2.81	10,360	0.10	8,886	0.10
2012	2.72	10,295	0.11	8,788	0.11
2013	2.41	10,377	0.12	8,745	0.12
2014	5.59	10,332	0.14	8,758	0.14
2015	4.85	10,995	0.16	8,773	0.16
2016	2.65	12,801	0.18	9,910	0.18
2017	4.70	13,767	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 17_0d 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 1985–2017. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,043 $MMB_{35\%}$=6,688			
1985	1.66			9,599	0.06
1986	0.99	9,538	0.04	8,146	0.04
1987	4.14	7,286	0.04	6,356	0.04
1988	3.79	6,653	0.05	5,272	0.05
1989	2.18	6,719	0.05	4,698	0.07
1990	2.70	5,989	0.06	4,296	0.07
1991	3.53	6,087	0.05	4,654	0.06
1992	2.26	6,126	0.04	4,470	0.05
1993	2.13	6,067	0.04	4,475	0.05
1994	2.46	6,200	0.03	4,890	0.04
1995	2.30	5,721	0.04	4,442	0.04
1996	2.26	5,150	0.04	3,853	0.04
1997	3.04	5,271	0.04	3,997	0.05
1998	2.79	5,553	0.05	4,115	0.05
1999	2.97	6,149	0.05	4,562	0.05
2000	2.79	6,849	0.05	5,229	0.06
2001	2.12	7,504	0.06	5,879	0.06
2002	2.69	7,894	0.06	6,449	0.06
2003	2.23	8,224	0.06	6,824	0.07
2004	1.92	8,539	0.07	7,123	0.07
2005	2.89	8,584	0.07	7,319	0.07
2006	2.16	8,619	0.07	7,221	0.07
2007	2.06	8,813	0.07	7,334	0.08
2008	3.21	8,743	0.07	7,424	0.08
2009	2.04	8,824	0.07	7,307	0.08
2010	1.78	9,087	0.08	7,538	0.08
2011	2.15	8,861	0.08	7,617	0.08
2012	2.11	8,518	0.09	7,326	0.09
2013	1.82	8,233	0.10	6,976	0.11
2014	3.58	7,848	0.12	6,651	0.12
2015	3.43	7,832	0.15	6,312	0.15
2016	2.42	8,486	0.19	6,546	0.19
2017	4.70	8,833	0.23		

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 17_0e 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 1985–2017. 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} =24,217 $MMB_{35\%}$=7,014			
1985	1.75			9,489	0.05
1986	0.99	9,601	0.04	8,137	0.04
1987	4.25	7,417	0.04	6,449	0.04
1988	3.36	6,806	0.04	5,406	0.04
1989	2.38	6,813	0.05	4,854	0.06
1990	2.63	5,974	0.05	4,325	0.06
1991	3.69	6,109	0.04	4,662	0.06
1992	2.26	6,148	0.04	4,471	0.04
1993	2.07	6,158	0.04	4,522	0.04
1994	2.37	6,286	0.03	4,977	0.03
1995	2.28	5,760	0.03	4,514	0.03
1996	2.22	5,130	0.04	3,860	0.04
1997	3.05	5,218	0.04	3,961	0.04
1998	2.69	5,473	0.05	4,048	0.05
1999	2.99	6,042	0.05	4,479	0.05
2000	2.88	6,701	0.05	5,105	0.06
2001	2.06	7,391	0.06	5,747	0.06
2002	2.87	7,821	0.06	6,364	0.06
2003	2.41	8,181	0.06	6,759	0.07
2004	1.92	8,631	0.07	7,136	0.07
2005	3.12	8,776	0.07	7,458	0.07
2006	2.40	8,879	0.07	7,426	0.08
2007	2.11	9,240	0.07	7,645	0.08
2008	3.84	9,295	0.08	7,886	0.08
2009	2.17	9,547	0.08	7,862	0.08
2010	2.26	10,114	0.08	8,353	0.08
2011	2.99	10,069	0.08	8,635	0.08
2012	2.77	10,108	0.08	8,581	0.09
2013	2.27	10,327	0.09	8,653	0.09
2014	5.75	10,317	0.10	8,764	0.10
2015	4.33	10,957	0.11	8,763	0.11
2016	2.55	12,709	0.14	9,910	0.13
2017	2.39	13,440	0.17		

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 17_0f 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 1985–2017. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =23,924 $MMB_{35\%}$=6,946			
1985	1.67			9,618	0.05
1986	1.00	9,534	0.04	8,146	0.04
1987	4.12	7,286	0.04	6,353	0.04
1988	3.77	6,652	0.05	5,274	0.05
1989	2.20	6,706	0.05	4,698	0.07
1990	2.71	5,973	0.06	4,287	0.07
1991	3.52	6,078	0.05	4,647	0.06
1992	2.27	6,116	0.04	4,466	0.05
1993	2.13	6,058	0.04	4,471	0.05
1994	2.45	6,195	0.03	4,889	0.04
1995	2.29	5,716	0.04	4,442	0.04
1996	2.25	5,139	0.04	3,849	0.04
1997	3.04	5,253	0.04	3,987	0.05
1998	2.78	5,530	0.05	4,100	0.05
1999	2.96	6,120	0.05	4,543	0.05
2000	2.78	6,814	0.05	5,204	0.06
2001	2.11	7,466	0.06	5,850	0.06
2002	2.70	7,853	0.06	6,417	0.06
2003	2.26	8,183	0.06	6,791	0.07
2004	1.95	8,511	0.07	7,093	0.07
2005	2.95	8,581	0.07	7,307	0.07
2006	2.25	8,653	0.07	7,237	0.08
2007	2.17	8,907	0.08	7,394	0.08
2008	3.51	8,914	0.08	7,547	0.08
2009	2.38	9,128	0.08	7,513	0.09
2010	2.18	9,625	0.08	7,913	0.09
2011	2.80	9,670	0.08	8,226	0.08
2012	2.70	9,683	0.08	8,212	0.09
2013	2.34	9,841	0.09	8,243	0.09
2014	5.66	9,845	0.10	8,317	0.10
2015	4.71	10,553	0.11	8,362	0.11
2016	2.59	12,415	0.13	9,560	0.13
2017	4.70	13,368	0.17		

Table 21. Negative log-likelihood values of the fits for scenarios (Sc) 17_0 (base), 17_0a (observer CPUE by VAST), 17_0b (observer and fishtick CPUE variable selection by CAIC), 17_0c (Year:Area interaction for observer and fishtick CPUE), 17_0d (three total selectivity and catchability for 1985–04, 2005–12, and 2013–16 time periods), 17_0e (Stage 2 effective sample sizes by McAllister and Ianelli method), and 17_0f (independent pot survey CPUE as an additional likelihood component) for golden king crab in the EAG. Differences in likelihood values are given for scenarios with the same number of data points (base) and free parameters. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 17_0**	**Sc 17_0a**	**Sc 17_0b**	**Sc 17_0c**	**Sc 17_0d**	**Sc 17_0e**	**Sc 17_0f**	**Sc17_0a– Sc 17_0**	**Sc 17_0b – Sc 17_0**	**Sc 17_0c – Sc 17_0**	**Sc 17_0e – Sc 17_0**
Number of free parameters	140	140	140	140	143	140	141				
Data	Base	Base	Base	Base	Base	Base					
Retlencomp	-1177.540	-1177.110	-1178.030	-1174.470	-1180.060	-1235.080	-1177.740	0.43	-0.490	3.070	-57.540
Totallencomp	-1249.120	-1260.300	-1248.190	-1261.890	-1258.200	-1192.770	-1249.490	-11.18	0.930	-12.770	56.350
Observer cpue	-12.551	-5.466	-6.545	-3.945	-12.776	-12.429	-12.364	7.085	6.006	8.606	0.122
RetdcatchB	7.502	8.109	7.283	8.009	7.581	7.034	7.501	0.607	-0.219	0.507	-0.468
TotalcatchB	18.260	18.609	18.199	18.611	18.419	17.723	18.267	0.349	-0.061	0.351	-0.537
GdiscdcatchB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
Rec_dev	7.571	7.435	6.880	7.804	5.937	7.966	7.552	-0.136	-0.691	0.233	0.395
Pot F_dev	0.013	0.014	0.013	0.015	0.013	0.013	0.013	0.001	0	0.002	0
Gbyc_F_dev	0.026	0.026	0.026	0.026	0.028	0.026	0.026	0	0	0	0
Tag	2692.200	2691.860	2692.350	2691.730	2692.220	2692.450	2692.200	-0.34	0.150	-0.470	0.250
Fishery cpue	-0.460	-0.565	-2.206	10.74300	-0.461	-0.347	-0.463	-0.105	-1.745	11.203	0.113
RetcatchN	0.007999	0.007584	0.007019	0.007569	0.005034	0.010917	0.0079	-0.00042	-0.00098	-0.00043	0.002918
Total	285.910	282.618	289.789	296.634	272.703	284.602	285.765	-3.292	3.879	10.724	-1.308

Table 22. 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	1.87	0.03
1986/87	1.68	0.03
1987/88	1.26	0.04
1988/89	1.37	0.03
1989/90	1.10	0.03
1990/91	0.84	0.04
1991/92	0.73	0.06
1992/93	0.70	0.06
1993/94	0.67	0.08
1994/95	0.84	0.05
1995/96	0.87	0.05
1996/97	0.85	0.04
1997/98	0.84	0.04
1998/99	1.12	0.03

Table 23. 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 17_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	23				
1986/87	23	12				
1987/88	8	4				
1988/89	286	148				
1989/90	513	265			7	5
1990/91	205	106	190	89	6	5
1991/92	102	53	104	49	1	1
1992/93	76	39	94	44	3	2
1993/94	378	196	62	29	NA	NA
1994/95	367	190	119	56	2	2
1995/96	705	365	907	426	5	4
1996/97	817	423	1,061	498	8	6
1997/98	984	509	1,116	524	6	5
1998/99	613	317	638	300	14	11
1999/00	915	473	1,155	542	18	14
2000/01	1,029	532	1,205	566	11	8
2001/02	898	464	975	458	11	8
2002/03	628	325	675	317	16	12
2003/04	688	356	700	329	8	6
2004/05	449	232	488	229	9	7
2005/06	337	174	220	103	6	5
2006/07	337	174	321	151	14	11
2007/08	276	143	257	121	17	13
2008/09	318	164	258	121	19	14
2009/10	362	187	292	137	24	18
2010/11	328	170	222	104	13	10
2011/12	295	153	252	118	14	11
2012/13	288	149	241	113	18	14
2013/14	327	169	236	111	17	13
2014/15	305	158	219	103	18	14
2015/16	287	148	243	114	10	8
2016/17	392	203	253	119	12	9

Table 24. 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 17_0a 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	23				
1986/87	23	12				
1987/88	8	4				
1988/89	286	148				
1989/90	513	266			7	5
1990/91	205	106	190	89	6	5
1991/92	102	53	104	49	1	1
1992/93	76	39	94	44	3	2
1993/94	378	196	62	29	NA	NA
1994/95	367	190	119	56	2	2
1995/96	705	365	907	427	5	4
1996/97	817	423	1,061	499	8	6
1997/98	984	510	1,116	525	6	5
1998/99	613	318	638	300	14	11
1999/00	915	474	1,155	543	18	14
2000/01	1,029	533	1,205	567	11	8
2001/02	898	465	975	459	11	8
2002/03	628	325	675	318	16	12
2003/04	688	357	700	329	8	6
2004/05	449	233	488	230	9	7
2005/06	337	175	220	104	6	5
2006/07	337	175	321	151	14	11
2007/08	276	143	257	121	17	13
2008/09	318	165	258	121	19	14
2009/10	362	188	292	137	24	18
2010/11	328	170	222	104	13	10
2011/12	295	153	252	119	14	11
2012/13	288	149	241	113	18	14
2013/14	327	169	236	111	17	13
2014/15	305	158	219	103	18	14
2015/16	287	149	243	114	10	8
2016/17	392	203	253	119	12	9

Table 25. 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 17_0b 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	23				
1986/87	23	12				
1987/88	8	4				
1988/89	286	145				
1989/90	513	261			7	5
1990/91	205	104	190	92	6	5
1991/92	102	52	104	50	1	1
1992/93	76	39	94	45	3	2
1993/94	378	192	62	30	NA	NA
1994/95	367	187	119	57	2	2
1995/96	705	358	907	438	5	4
1996/97	817	415	1,061	513	8	6
1997/98	984	500	1,116	539	6	5
1998/99	613	312	638	308	14	11
1999/00	915	465	1,155	558	18	14
2000/01	1,029	523	1,205	582	11	8
2001/02	898	456	975	471	11	8
2002/03	628	319	675	326	16	12
2003/04	688	350	700	338	8	6
2004/05	449	228	488	236	9	7
2005/06	337	171	220	106	6	5
2006/07	337	171	321	155	14	11
2007/08	276	140	257	124	17	13
2008/09	318	162	258	125	19	15
2009/10	362	184	292	141	24	18
2010/11	328	167	222	107	13	10
2011/12	295	150	252	122	14	11
2012/13	288	146	241	116	18	14
2013/14	327	166	236	114	17	13
2014/15	305	155	219	106	18	14
2015/16	287	146	243	117	10	8
2016/17	392	199	253	122	12	9

Table 26. 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 17_0c 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	142				
1989/90	513	255			7	5
1990/91	205	102	190	91	6	5
1991/92	102	51	104	50	1	1
1992/93	76	38	94	45	3	2
1993/94	378	188	62	30	NA	NA
1994/95	367	183	119	57	2	2
1995/96	705	351	907	433	5	4
1996/97	817	407	1,061	506	8	6
1997/98	984	490	1,116	533	6	5
1998/99	613	305	638	305	14	11
1999/00	915	456	1,155	551	18	14
2000/01	1,029	512	1,205	575	11	8
2001/02	898	447	975	465	11	8
2002/03	628	313	675	322	16	12
2003/04	688	343	700	334	8	6
2004/05	449	224	488	233	9	7
2005/06	337	168	220	105	6	5
2006/07	337	168	321	153	14	11
2007/08	276	137	257	123	17	13
2008/09	318	158	258	123	19	14
2009/10	362	180	292	139	24	18
2010/11	328	163	222	106	13	10
2011/12	295	147	252	120	14	11
2012/13	288	143	241	115	18	14
2013/14	327	163	236	113	17	13
2014/15	305	152	219	105	18	14
2015/16	287	143	243	116	10	8
2016/17	392	195	253	121	12	9

Table 27. 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 17_0d 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	25				
1986/87	23	13				
1987/88	8	4				
1988/89	286	160				
1989/90	513	286			7	5
1990/91	205	114	190	92	6	5
1991/92	102	57	104	50	1	1
1992/93	76	42	94	45	3	2
1993/94	378	211	62	30	NA	NA
1994/95	367	205	119	57	2	2
1995/96	705	393	907	438	5	4
1996/97	817	456	1,061	512	8	6
1997/98	984	549	1,116	539	6	5
1998/99	613	342	638	308	14	11
1999/00	915	510	1,155	557	18	14
2000/01	1,029	574	1,205	582	11	8
2001/02	898	501	975	471	11	8
2002/03	628	350	675	326	16	12
2003/04	688	384	700	338	8	6
2004/05	449	250	488	236	9	7
2005/06	337	188	220	106	6	5
2006/07	337	188	321	155	14	11
2007/08	276	154	257	124	17	13
2008/09	318	177	258	125	19	14
2009/10	362	202	292	141	24	18
2010/11	328	183	222	107	13	10
2011/12	295	165	252	122	14	11
2012/13	288	161	241	116	18	14
2013/14	327	182	236	114	17	13
2014/15	305	170	219	106	18	14
2015/16	287	160	243	117	10	8
2016/17	392	219	253	122	12	9

Table 28. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by McAllister and Ianelli method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0e 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	45				
1986/87	23	23				
1987/88	8	8				
1988/89	286	285				
1989/90	513	512			7	5
1990/91	205	204	190	82	6	4
1991/92	102	102	104	45	1	1
1992/93	76	76	94	41	3	2
1993/94	378	377	62	27	NA	NA
1994/95	367	366	119	51	2	1
1995/96	705	703	907	392	5	3
1996/97	817	815	1,061	459	8	6
1997/98	984	981	1,116	483	6	4
1998/99	613	611	638	276	14	10
1999/00	915	913	1,155	500	18	13
2000/01	1,029	1,026	1,205	521	11	8
2001/02	898	896	975	422	11	8
2002/03	628	626	675	292	16	11
2003/04	688	686	700	303	8	6
2004/05	449	448	488	211	9	6
2005/06	337	336	220	95	6	4
2006/07	337	336	321	139	14	10
2007/08	276	275	257	111	17	12
2008/09	318	317	258	112	19	13
2009/10	362	361	292	126	24	17
2010/11	328	327	222	96	13	9
2011/12	295	294	252	109	14	10
2012/13	288	287	241	104	18	13
2013/14	327	326	236	102	17	12
2014/15	305	304	219	95	18	13
2015/16	287	286	243	105	10	7
2016/17	392	391	253	109	12	8

Table 29. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0, 17_0a, 17_0b, and 17_0c for the golden king crab data from the WAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0		**Scenario 17_0a**		**Scenario 17_0b**		**Scenario 17_0c**		
Parameter	Estimate	CV	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	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-7.81	0.22	-7.84	0.22	-7.74	0.22	-7.74	0.22	-12.0,-5.0
log_a (molt prob. slope)	-2.61	0.03	-2.61	0.03	-2.61	0.03	-2.61	0.03	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.00	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.69	0.03	3.68	0.03	3.69	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.40	0.02	3.40	0.02	3.40	0.01	3.40	0.01	0.,4.4
log_ total sel deltaθ, 2005–16	2.90	0.02	2.89	0.02	2.89	0.02	2.89	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.78	0.02	1.77	0.02	1.78	0.02	1.78	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.86	0.002	4.86	0.002	4.87	0.002	4.87	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–16	4.90	0.002	4.90	0.002	4.90	0.002	4.90	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.92	0.0002	4.92	0.00	4.92	0.0002	4.92	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.05	0.16	-1.06	0.16	-1.05	0.16	-1.05	0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.06	1.18	-0.06	1.16	-0.09	0.75	-0.09	0.75	-9.0, 2.25
logq3 (catchability 2005–16)	-0.38	0.24	-0.39	0.22	-0.37	0.29	-0.37	0.29	-9.0, 2.25
log_mean_rec (mean rec.)	0.725	0.06	0.727	0.06	0.720	0.06	0.720	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.699	0.09	-0.709	0.09	-0.692	0.09	-0.692	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.371	0.10	-8.376	0.10	-8.364	0.10	-8.364	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.019	0.38	0.012	0.47	0.054	0.34	0.054	0.34	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.025	0.60	0.025	0.62	0.013	0.58	0.013	0.58	0.0,1.0
2016 MMB	6,269	0.17	6,280	0.16	5,884	0.22	5,884	0.22	

Table 30. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0d and 17_0e for the golden king crab data from the WAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0d		**Scenario 17_0e**		
Parameter	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.006	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-7.74	0.22	-7.29	0.23	-12.0,-5.0
log_a (molt prob. slope)	-2.62	0.03	-2.67	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.00	3.869,5.05
σ (growth variability std)	3.68	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.39	0.01	3.36	0.01	0.,4.4
log_ total sel deltaθ, 2005–12	2.90	0.03			0.,4.4
log_ total sel deltaθ, 2013–16 or 2005–16	2.92	0.03	2.89	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.78	0.02	1.78	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.87	0.002	4.87	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–12	4.89	0.002			4.0,5.0
log_tot sel θ_{50}, 2013–16 or 2005–16	4.92	0.003	4.90	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.92	0.00	4.92	0.00	4.0,5.0
log_β_r (rec.distribution par.)	-1.06	0.15	-1.10	0.15	-12.0, 12.0
Logq1 (catchability 1985–04)	-0.067	1.02	-0.04	1.62	-9.0, 2.25
Logq3 (catchability 2005–12)	-0.424	0.21			-9.0, 2.25
Logq2 (catchability 2013–16 or 2005–16)	-0.098	1.80	-0.41	0.20	-9.0, 2.25
log_mean_rec (mean rec.)	0.719	0.06	0.717	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.681	0.09	-0.710	0.08	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.364	0.10	-8.390	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.023	0.38	0.020	0.39	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.026	0.57	0.037	0.53	0.0,1.0
2016 MMB	6,136	0.23	6,355	0.17	

Table 31. 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 17_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 1985–2017. 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} =17,827 $MMB_{35\%}$=5,138			
1985	3.75			8,812	0.11
1986	3.41	10,641	0.05	8,387	0.08
1987	2.69	8,164	0.05	5,971	0.06
1988	1.92	7,496	0.04	5,553	0.05
1989	2.55	6,432	0.04	4,896	0.04
1990	1.85	4,468	0.05	3,106	0.06
1991	1.56	4,172	0.05	2,870	0.05
1992	2.07	3,906	0.05	2,810	0.05
1993	1.60	4,025	0.04	2,923	0.05
1994	1.96	4,613	0.03	3,493	0.03
1995	1.88	3,924	0.03	2,833	0.04
1996	1.72	3,925	0.04	2,785	0.04
1997	1.84	3,934	0.04	2,828	0.04
1998	1.90	4,002	0.04	2,909	0.04
1999	2.23	4,318	0.04	3,184	0.04
2000	2.49	4,351	0.04	3,122	0.04
2001	2.54	4,507	0.04	3,129	0.04
2002	2.48	4,943	0.05	3,451	0.05
2003	1.78	5,489	0.05	3,961	0.05
2004	2.27	5,810	0.06	4,442	0.06
2005	2.29	5,913	0.06	4,626	0.06
2006	2.41	6,194	0.06	4,797	0.06
2007	1.71	6,698	0.06	5,224	0.06
2008	1.48	6,863	0.05	5,502	0.06
2009	1.89	6,658	0.05	5,539	0.05
2010	1.59	6,263	0.05	5,173	0.05
2011	1.14	5,972	0.05	4,864	0.05
2012	1.80	5,465	0.05	4,521	0.05
2013	2.29	4,850	0.05	3,903	0.05
2014	1.59	4,627	0.07	3,421	0.07
2015	3.63	4,719	0.09	3,491	0.08
2016	2.23	5,204	0.13	3,650	0.12
2017	2.06	6,269	0.17		

Table 32. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 17_0a 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 1985–2017. 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
		MMBeq =17,862 *MMB35%*=5,173			
1985	3.76			8,815	0.11
1986	3.41	10,646	0.05	8,388	0.08
1987	2.69	8,170	0.05	5,974	0.06
1988	1.92	7,499	0.04	5,556	0.05
1989	2.55	6,435	0.04	4,898	0.04
1990	1.85	4,471	0.04	3,108	0.06
1991	1.56	4,175	0.05	2,873	0.05
1992	2.06	3,908	0.05	2,812	0.05
1993	1.60	4,022	0.04	2,924	0.05
1994	1.99	4,605	0.03	3,487	0.03
1995	1.89	3,921	0.03	2,826	0.04
1996	1.72	3,940	0.04	2,791	0.04
1997	1.85	3,957	0.04	2,846	0.04
1998	1.91	4,026	0.04	2,931	0.04
1999	2.23	4,344	0.04	3,206	0.04
2000	2.54	4,379	0.04	3,147	0.04
2001	2.59	4,544	0.04	3,154	0.04
2002	2.50	5,013	0.05	3,495	0.05
2003	1.81	5,592	0.05	4,038	0.05
2004	2.26	5,932	0.05	4,543	0.05
2005	2.21	6,044	0.06	4,744	0.06
2006	2.42	6,295	0.06	4,913	0.06
2007	1.69	6,755	0.05	5,299	0.06
2008	1.48	6,898	0.05	5,545	0.06
2009	1.91	6,668	0.05	5,557	0.05
2010	1.61	6,268	0.05	5,175	0.05
2011	1.13	5,987	0.05	4,867	0.05
2012	1.81	5,488	0.05	4,536	0.05
2013	2.28	4,872	0.05	3,922	0.05
2014	1.59	4,650	0.06	3,443	0.06
2015	3.62	4,739	0.08	3,510	0.08
2016	2.23	5,218	0.11	3,666	0.10
2017	2.07	6,280	0.16		

Table 33. 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 17_0b 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 1985–2017. 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**
		MMBeq =17,730 *MMB₃₅%*=5,104			
1985	3.89			8,932	0.09
1986	3.57	10,650	0.05	8,419	0.07
1987	2.65	8,254	0.05	5,995	0.06
1988	1.80	7,644	0.04	5,650	0.04
1989	2.36	6,540	0.04	5,019	0.04
1990	1.84	4,474	0.04	3,175	0.05
1991	1.65	4,091	0.05	2,841	0.05
1992	2.08	3,828	0.05	2,725	0.05
1993	1.56	3,985	0.04	2,857	0.05
1994	1.97	4,575	0.03	3,451	0.03
1995	1.87	3,879	0.03	2,792	0.03
1996	1.73	3,885	0.03	2,745	0.03
1997	1.85	3,895	0.04	2,787	0.04
1998	1.91	3,974	0.04	2,874	0.04
1999	2.25	4,301	0.04	3,158	0.04
2000	2.51	4,346	0.04	3,107	0.04
2001	2.55	4,519	0.04	3,126	0.04
2002	2.48	4,971	0.05	3,463	0.05
2003	1.76	5,525	0.05	3,985	0.05
2004	2.29	5,840	0.06	4,468	0.06
2005	2.33	5,937	0.06	4,645	0.06
2006	2.42	6,235	0.06	4,818	0.07
2007	1.70	6,758	0.06	5,264	0.06
2008	1.47	6,918	0.05	5,551	0.06
2009	1.85	6,698	0.05	5,581	0.05
2010	1.58	6,282	0.05	5,201	0.05
2011	1.13	5,965	0.05	4,867	0.05
2012	1.78	5,444	0.05	4,503	0.05
2013	2.16	4,817	0.06	3,876	0.06
2014	1.48	4,546	0.08	3,377	0.08
2015	3.43	4,547	0.12	3,382	0.11
2016	2.19	4,921	0.17	3,455	0.16
2017	2.05	5,884	0.22		

Table 34. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 17_0c 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 1985–2017. 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} =17,720 $MMB_{35\%}$=5,123			
1985	3.03			8,932	0.09
1986	3.64	10,650	0.05	8,419	0.07
1987	2.56	8,254	0.05	5,995	0.06
1988	1.87	7,644	0.04	5,650	0.04
1989	2.59	6,540	0.04	5,019	0.04
1990	1.87	4,474	0.04	3,175	0.05
1991	1.57	4,091	0.05	2,841	0.05
1992	1.86	3,828	0.05	2,725	0.05
1993	1.57	3,985	0.04	2,857	0.05
1994	1.97	4,575	0.03	3,451	0.03
1995	1.85	3,879	0.03	2,792	0.03
1996	1.71	3,885	0.03	2,745	0.03
1997	1.87	3,895	0.04	2,787	0.04
1998	1.89	3,974	0.04	2,874	0.04
1999	2.23	4,301	0.04	3,158	0.04
2000	2.48	4,346	0.04	3,107	0.04
2001	2.52	4,519	0.04	3,126	0.04
2002	2.45	4,971	0.05	3,463	0.05
2003	1.75	5,525	0.05	3,985	0.05
2004	2.32	5,840	0.06	4,468	0.06
2005	2.40	5,937	0.06	4,645	0.06
2006	2.37	6,235	0.06	4,818	0.07
2007	1.71	6,758	0.06	5,264	0.06
2008	1.49	6,918	0.05	5,551	0.06
2009	1.84	6,698	0.05	5,581	0.05
2010	1.61	6,282	0.05	5,201	0.05
2011	1.18	5,965	0.05	4,867	0.05
2012	1.80	5,444	0.05	4,503	0.05
2013	2.20	4,817	0.06	3,876	0.06
2014	1.55	4,546	0.08	3,377	0.08
2015	3.60	4,547	0.12	3,382	0.11
2016	2.23	4,921	0.17	3,455	0.16
2017	2.08	5,884	0.22		

Table 35. 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 17_0d 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 1985–2017. 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**
		MMBeq =17,710 $MMB_{35\%}$=5,108			
1985	3.68			8,888	0.10
1986	3.43	10,707	0.05	8,462	0.07
1987	2.68	8,202	0.05	6,010	0.06
1988	1.91	7,530	0.04	5,574	0.05
1989	2.56	6,457	0.04	4,911	0.04
1990	1.85	4,489	0.04	3,116	0.06
1991	1.56	4,198	0.04	2,882	0.05
1992	2.05	3,934	0.05	2,826	0.05
1993	1.58	4,047	0.04	2,941	0.05
1994	1.97	4,619	0.03	3,501	0.03
1995	1.89	3,920	0.03	2,828	0.03
1996	1.74	3,922	0.04	2,774	0.04
1997	1.86	3,936	0.04	2,818	0.04
1998	1.91	4,012	0.04	2,906	0.04
1999	2.26	4,336	0.04	3,188	0.04
2000	2.54	4,382	0.04	3,135	0.04
2001	2.62	4,564	0.04	3,156	0.04
2002	2.60	5,042	0.05	3,506	0.05
2003	1.83	5,654	0.05	4,061	0.05
2004	2.30	6,040	0.06	4,608	0.06
2005	2.21	6,171	0.06	4,843	0.06
2006	2.40	6,428	0.06	5,029	0.06
2007	1.64	6,871	0.05	5,411	0.06
2008	1.39	6,979	0.05	5,634	0.05
2009	1.71	6,688	0.05	5,606	0.05
2010	1.37	6,176	0.04	5,154	0.05
2011	1.08	5,723	0.04	4,720	0.05
2012	1.80	5,082	0.05	4,224	0.05
2013	2.09	4,424	0.06	3,513	0.06
2014	1.57	4,169	0.08	3,014	0.08
2015	4.05	4,211	0.11	3,039	0.11
2016	2.26	4,829	0.18	3,195	0.16
2017	2.05	6,136	0.23		

Table 36. 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 17_0e 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 1985–2017. 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
		MMBeq =18,001 $MMB_{35\%}$=5,201			
1985	3.33			9,215	0.08
1986	3.56	10,884	0.04	8,762	0.06
1987	2.62	8,250	0.04	6,106	0.04
1988	1.91	7,581	0.04	5,590	0.04
1989	2.68	6,476	0.04	4,903	0.04
1990	1.89	4,534	0.04	3,106	0.05
1991	1.54	4,296	0.04	2,908	0.05
1992	2.00	4,046	0.04	2,895	0.05
1993	1.54	4,139	0.04	3,022	0.04
1994	1.90	4,675	0.03	3,558	0.03
1995	1.86	3,931	0.03	2,848	0.03
1996	1.86	3,884	0.03	2,743	0.03
1997	1.77	3,906	0.04	2,753	0.03
1998	1.88	4,003	0.03	2,865	0.03
1999	2.20	4,285	0.03	3,140	0.03
2000	2.51	4,297	0.04	3,057	0.04
2001	2.67	4,437	0.04	3,035	0.04
2002	2.76	4,905	0.05	3,347	0.05
2003	1.95	5,573	0.05	3,907	0.05
2004	2.34	6,071	0.05	4,531	0.06
2005	2.25	6,289	0.05	4,875	0.06
2006	2.30	6,598	0.05	5,137	0.06
2007	1.65	7,039	0.05	5,561	0.05
2008	1.44	7,104	0.05	5,758	0.05
2009	1.86	6,820	0.04	5,710	0.05
2010	1.66	6,363	0.04	5,277	0.05
2011	1.02	6,048	0.04	4,914	0.04
2012	1.90	5,522	0.04	4,563	0.04
2013	2.48	4,868	0.05	3,910	0.05
2014	1.58	4,714	0.06	3,426	0.06
2015	3.58	4,878	0.09	3,561	0.08
2016	2.21	5,336	0.13	3,756	0.12
2017	2.05	6,355	0.17		

Table 37. Negative log-likelihood values of the fits for scenarios (Sc) 17_0 (base), 17_0a (observer CPUE by VAST), 17_0b (observer and fishtick CPUE variable selection by CAIC), 17_0c (Year:Area interaction for observer and fishtick CPUE), 17_0d (three total selectivity and catchability for 1985–04, 2005–12, and 2013–16 time periods), and 17_0e (Stage 2 effective sample sizes by McAllister and Ianelli method) for golden king crab in the WAG. Differences in likelihood values are given for scenarios with the same number of data points (base) and free parameters. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 17_0**	**Sc 17_0a**	**Sc 17_0b**	**Sc 17_0c**	**Sc 17_0d**	**Sc 17_0e**	**Sc17_0a– Sc 17_0**	**Sc 17_0b – Sc 17_0**	**Sc 17_0c – Sc 17_0**	**Sc 17_0e – Sc 17_0**
Number of free parameters	140	140	140	140	143	140				
Data	Base	Base	Base	Base	Base	Base				
Retlencomp	-1146.700	-1147.140	-1143.350	-1142.310	-1161.250	-1243.980	-0.440	3.350	4.390	-97.280
Totallencomp	-1389.720	-1389.680	-1395.850	-1396.210	-1396.220	-1370.230	0.040	-6.130	-6.490	19.490
Observer cpue	-11.773	-14.747	-0.680	15.078	-10.040	-11.199	-2.974	11.093	26.851	0.574
RetdcatchB	4.721	4.854	4.853	5.858	4.846	4.956	0.133	0.132	1.137	0.235
TotalcatchB	43.783	43.745	43.936	44.348	43.849	47.086	-0.038	0.153	0.565	3.303
GdiscdcatchB	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
Rec_dev	5.243	5.248	5.254	4.797	6.091	6.103	0.005	0.011	-0.446	0.860
Pot F_dev	0.026	0.026	0.026	0.027	0.027	0.026	0.000	0.000	0.001	0.000
Gbyc_F_dev	0.037	0.037	0.037	0.037	0.038	0.037	0.000	0.000	0.000	0.000
Tag	2693.630	2693.450	2693.710	2693.780	2693.910	2695.840	-0.180	0.080	0.150	2.210
Fishery cpue	-5.155	-5.207	-9.456	17.685	-5.004	-2.783	-0.052	-4.301	22.840	2.371
RetcatchN	0.002129	0.002068	0.001757	0.000874	0.002098	0.005553	-0.000061	-0.000372	-0.001255	0.003424
Total	194.090	190.591	198.490	243.086	176.255	125.863	-3.499	4.400	48.996	-68.227

Table 38. Predicted total catch OFL (t), $MMB_{35\%}$, and terminal MMB ratio for various scenarios for EAG and WAG, respectively. Sc = scenario; MMB_{2016}/ $MMB_{initial}$ = ratio of terminal MMB relative to initial MMB (= MMB_{1960}). Note: MMB_{2016} is estimated on Feb 15, 2017.

	EAG			WAG				
Sc	**Tier 3 Total Catch OFL (t)**	**$MMB_{35\%}$ (t)**	**MMB_{2016} / $MMB_{initial}$**	**Tier 3 Total Catch OFL (t)**	**$MMB_{35\%}$ (t)**	**MMB_{2016} / $MMB_{initial}$**	**M yr^{-1}**	**Remarks**
17_0	3,918	6,954	0.68	1,597	5,138	0.42	0.21	Base scenario: 1960 equilibrium initial size composition, 1995/96–2016/17 observer CPUE, 1985/86–1998/99 Fishery CPUE, time period for mean R calculation for equilibrium initial abundance and MMB_{MSY} reference point calculations 1987–2012, knife-edge maturity≥111 mm CL, Francis re-weighting,
17_0a	3,959	7,063	0.67	1,589	5,173	0.42	0.21	Observer CPUE standardization by VAST
17_0b	3,415	6,794	0.61	1,492	5,104	0.40	0.21	Variable selection for CPUE standardization by CAIC
17_0c	4,046	7,091	0.67	1,551	5,123	0.40	0.21	Year:Area interaction for CPUE standardization
17_0d	2,481	6,688	0.46	1,482	5,108	0.42	0.21	Three catchability and asymptotic total selectivity for 1985/86–2004/05, 2005/06–2012/13, and 2013/14–2016/17
17_0e	3,974	7,014	0.67	1,608	5,201	0.43	0.21	McAllister and Ianelli method of re-weighting
17_0f	3,892	6,946	0.67				0.21	EAG fishery independent pot survey (2015/16-2016/17) CPUE indices as an additional likelihood component.
May 2017 Sc9	4,486	7,048	0.60	1,562	4,507	0.34	0.224	2017 assessment. Knife-edge maturity ≥111 mm CL

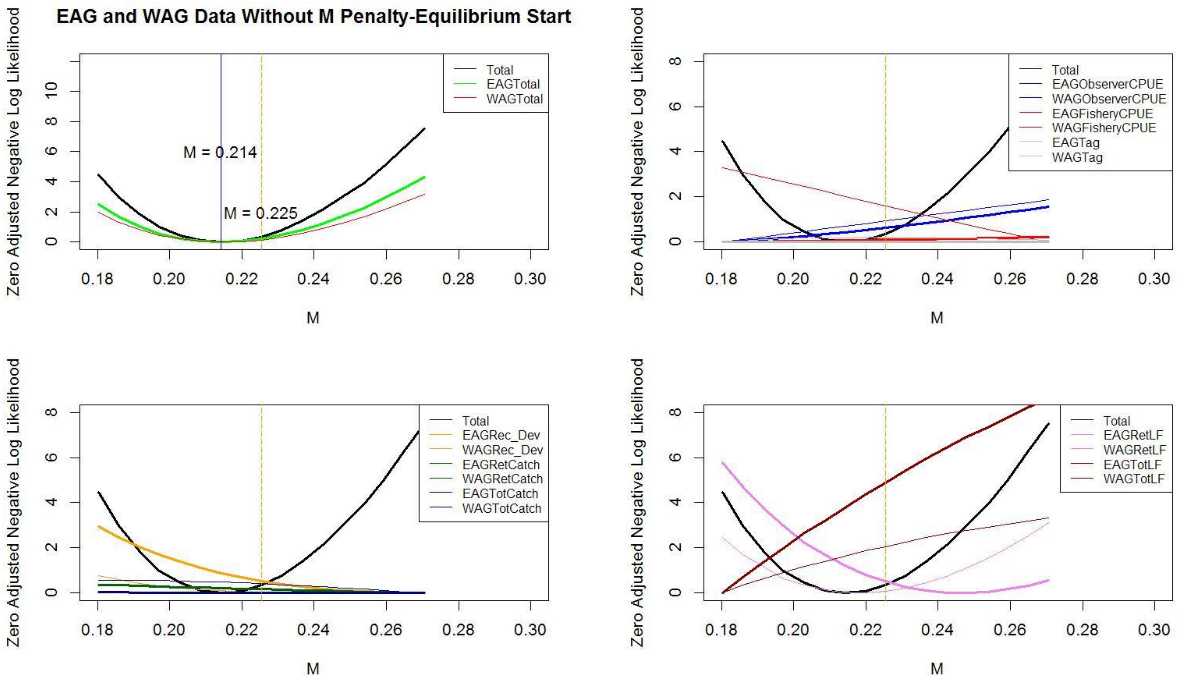


Figure 1. Total and components negative log-likelihoods vs. *M* for **scenario 0b** model fit for EAG and WAG combined data. The *M* estimate was obtained without any *M* penalty. The *M* estimate was 0.2254 yr^{-1} ($\pm$ 0.0199 yr^{-1}). The negative log likelihood values were estimated for fixed proportions of estimated *M* without using an *M* penalty and they were zero adjusted. The *M* profile indicates an *M* value of 0.2142 yr^{-1} at the minima of negative total likelihood for combined data as well as individual date sets. Hence an *M* value of 0.21 yr^{-1} was used in all scenarios.

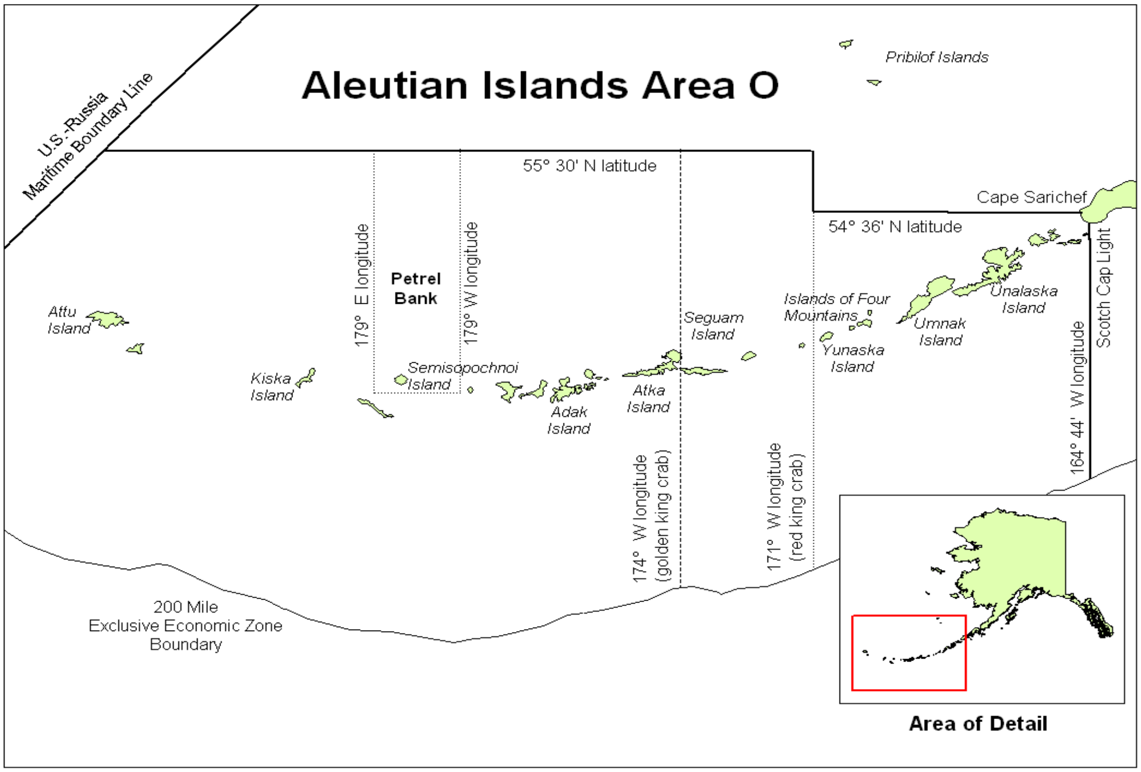


Figure 2. Aleutian Islands, Area O, red and golden king crab management area (from Leon et al. 2017).

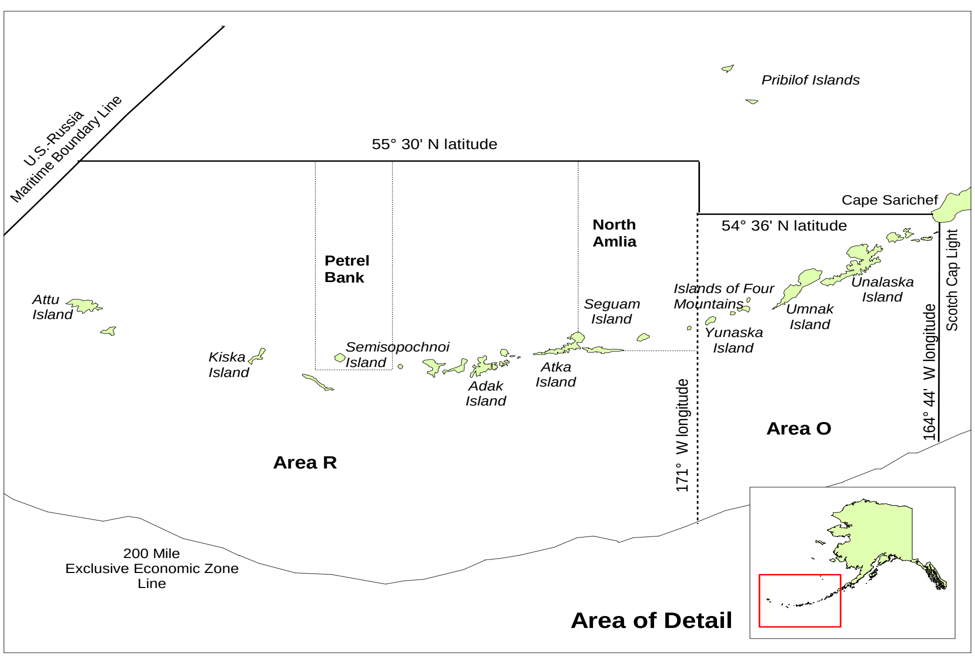


Figure 3. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon et al., 2017).

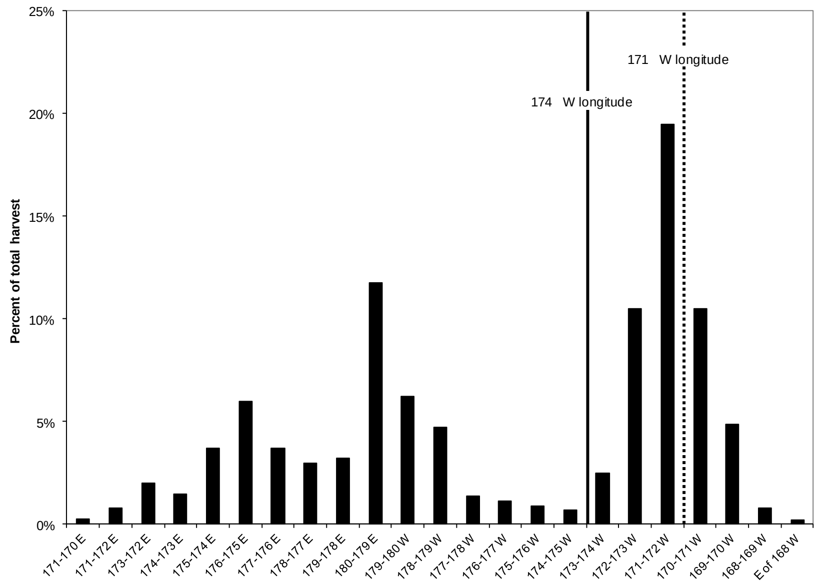


Figure 4. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor 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).

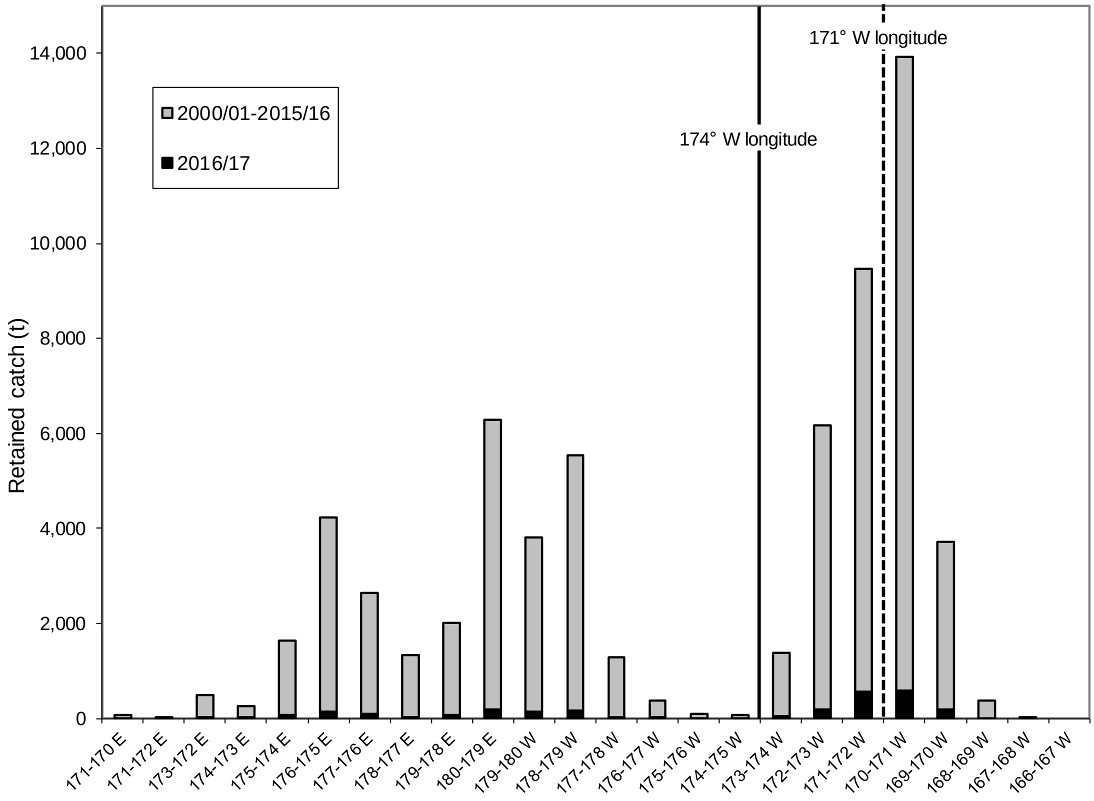


Figure 5. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2016/17commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king 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).

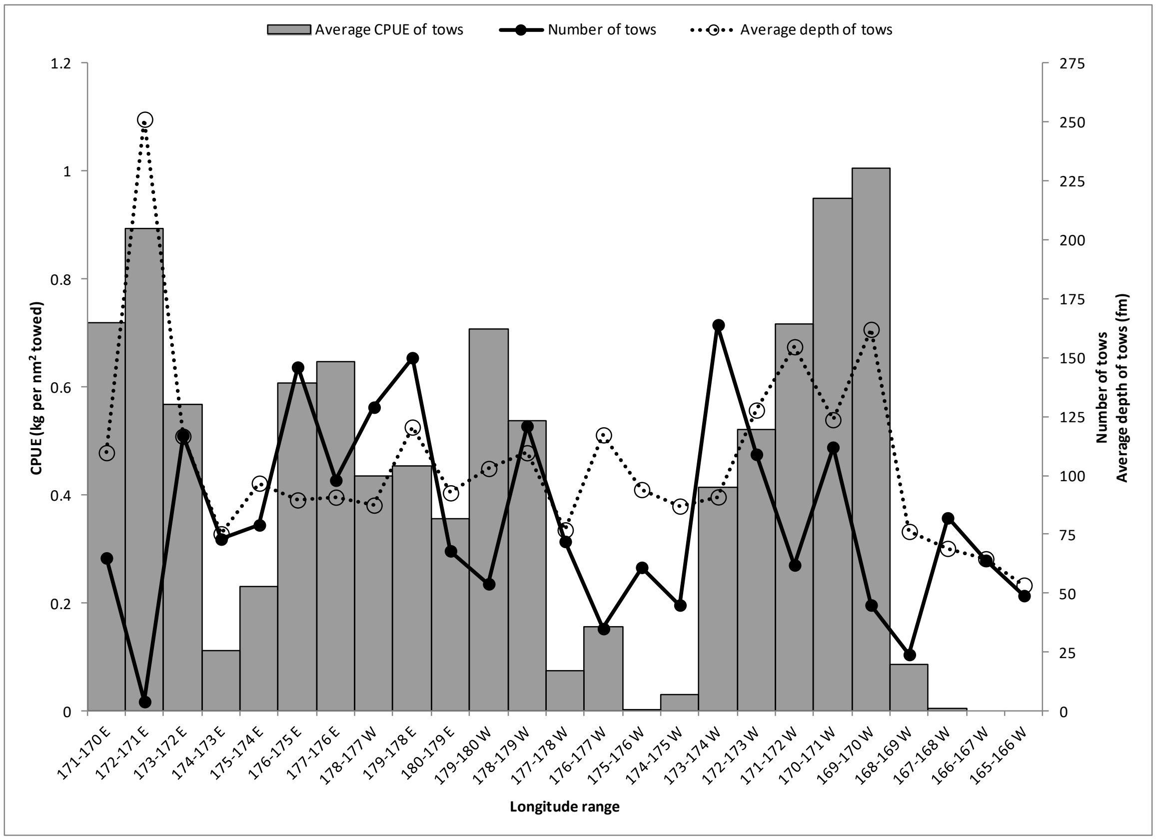


Figure 6. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

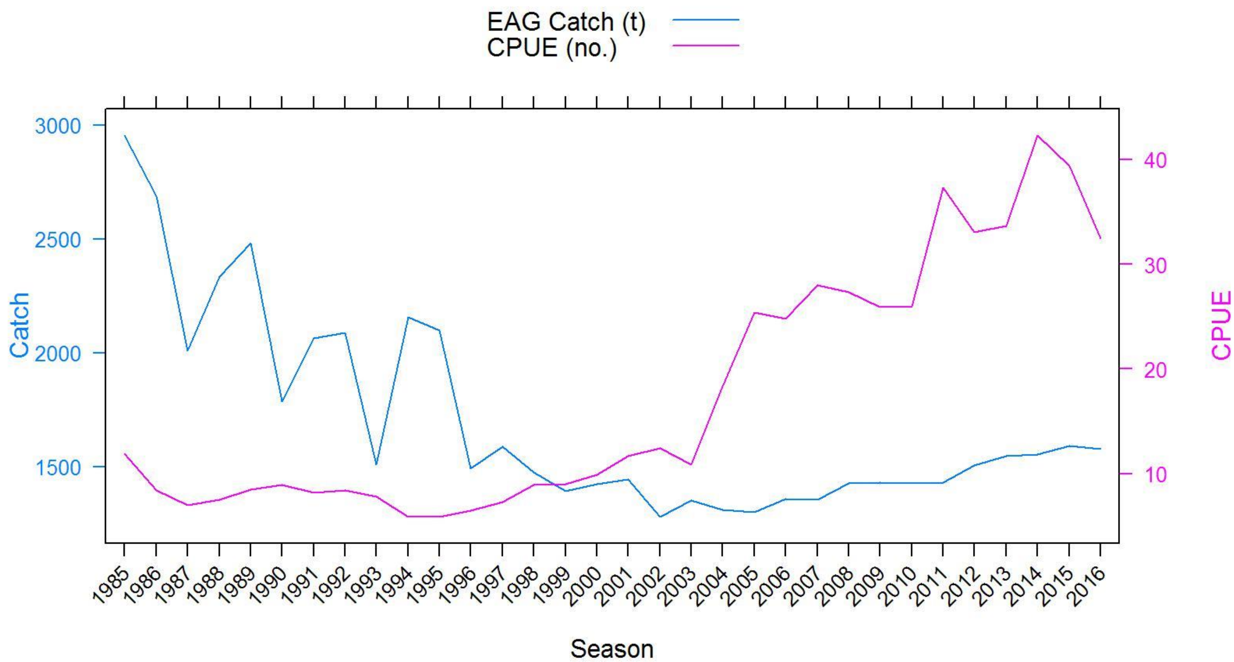


Figure 7. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2016/17 fisheries (note: 1985 refers to the 1985/86 fishing year).

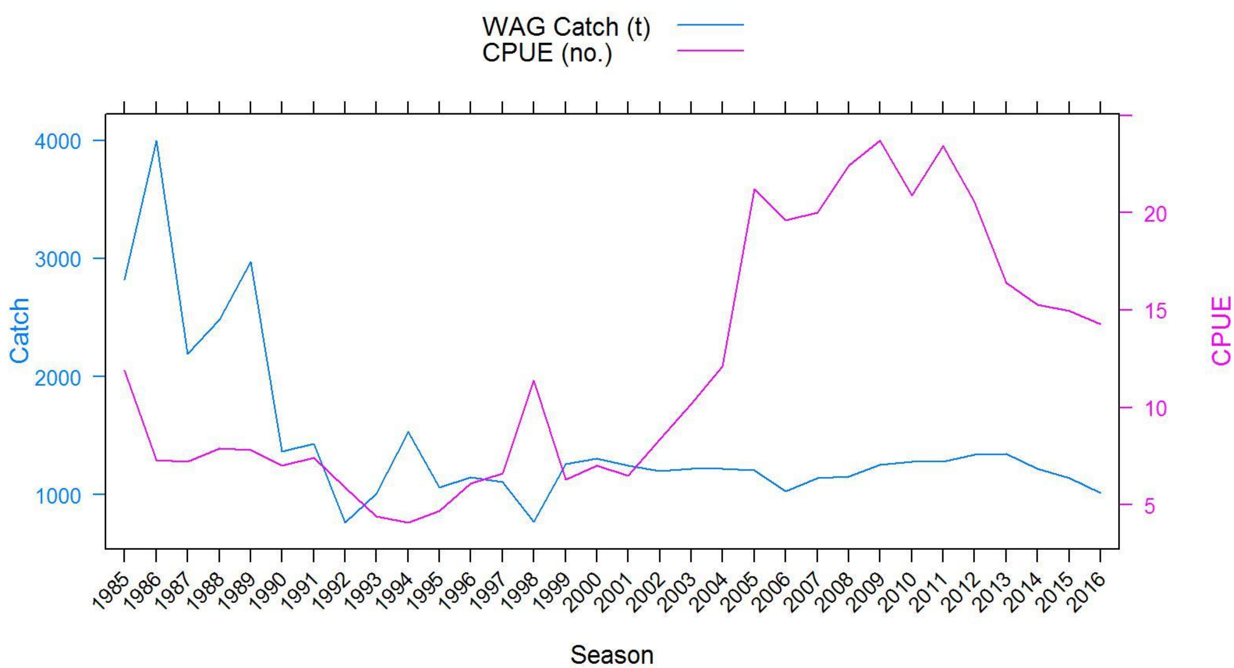


Figure 8. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2016/17 fisheries (note: 1985 refers to the 1985/86 fishing year).

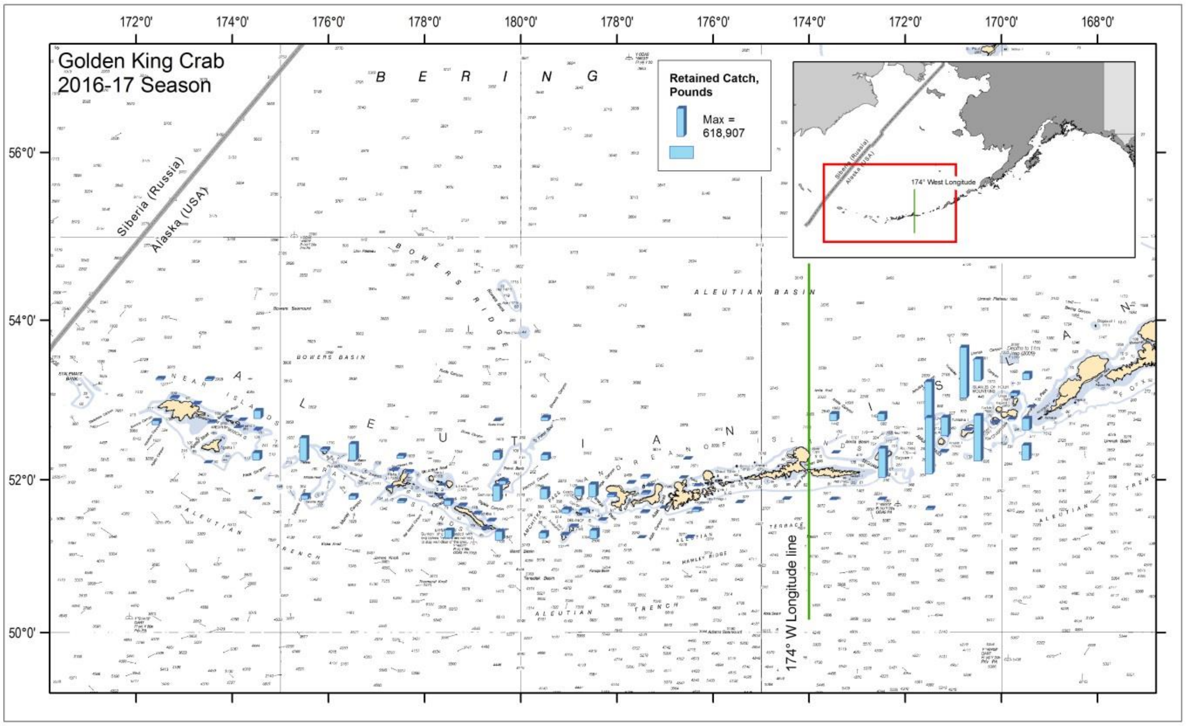


Figure 9. Catch distribution by statistical area.in 2016/17.

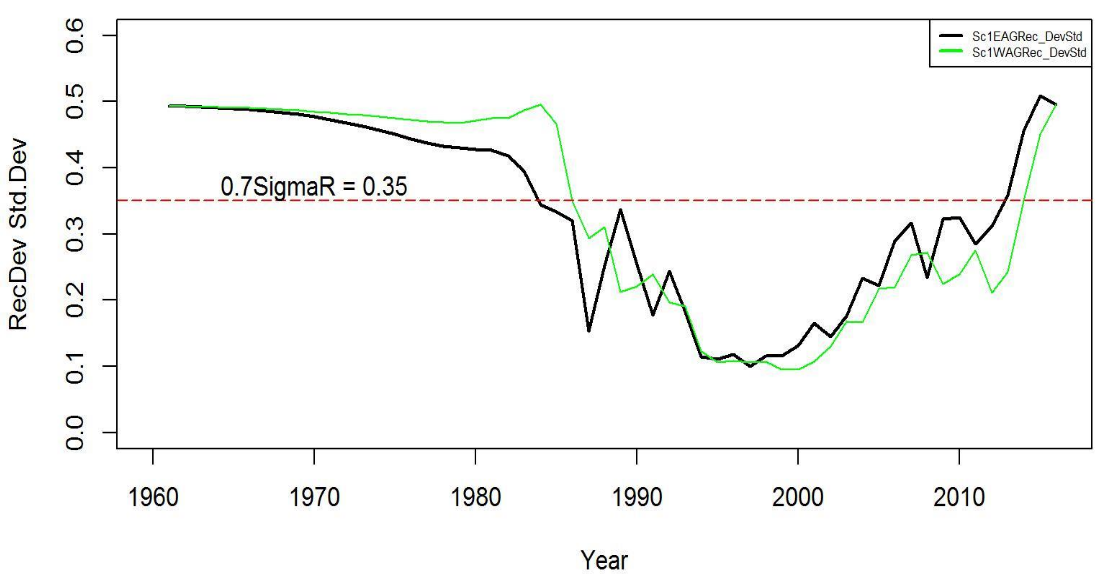


Figure 10. Standard deviation of recruit_dev plot for EAG and WAG. The mean recruit for years with standard deviation less than 0.7 sigma R was used to initialize model. We selected the 1987–2012 period for mean recruit estimation.

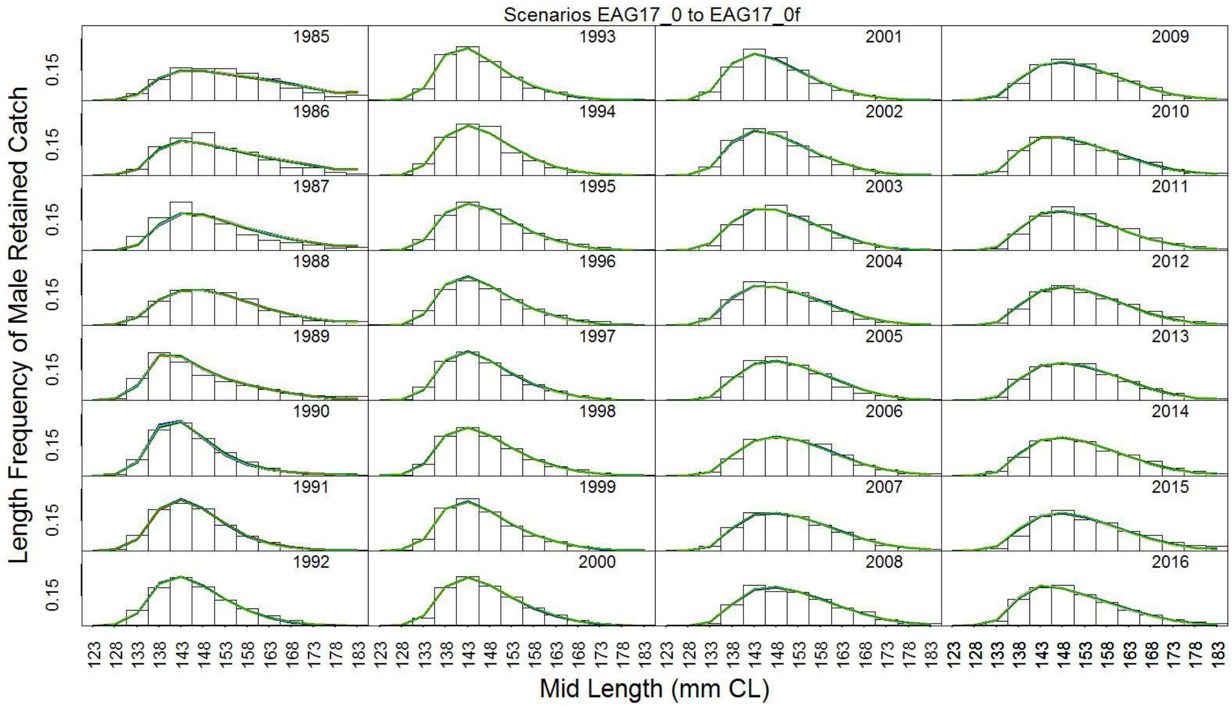


Figure 11. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 17_0 (black line), 17_0a (orange line), 17_0b (red line), 17_0c (blue line), 17_0d (violet line), 17_0e (dark green line), and 17_0f (green line) for golden king crab in the EAG, 1985/86 to 2016/17. This color scheme is used in all other graphs.

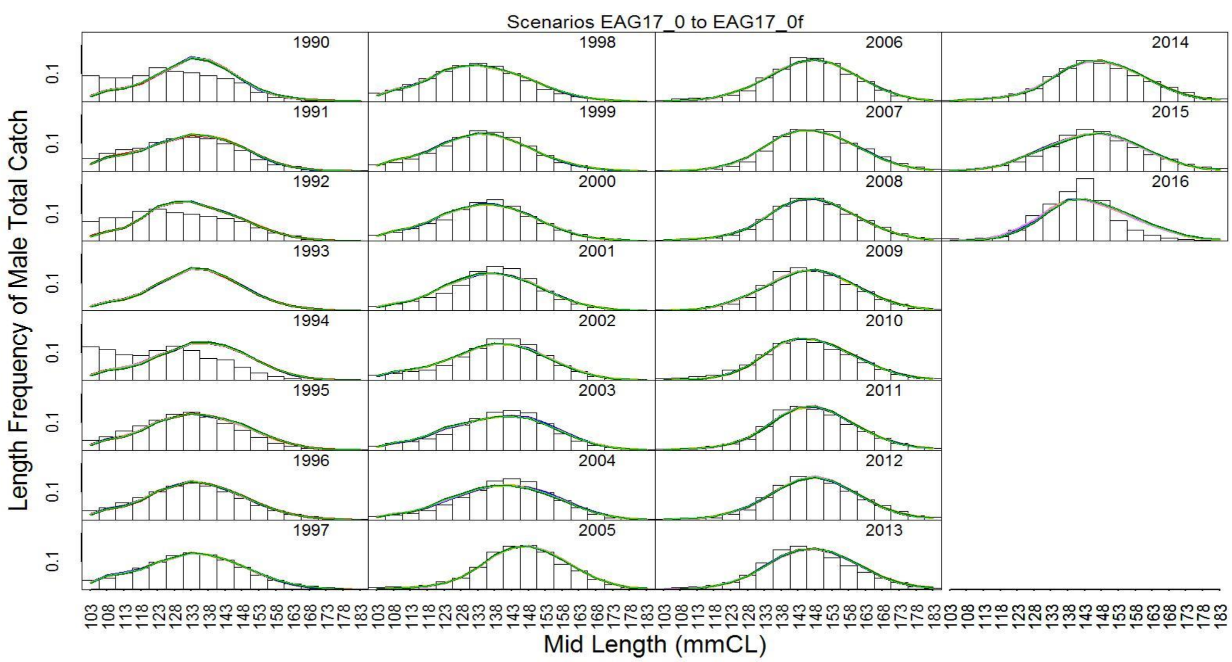


Figure 12. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 17_0 to 17_0f for golden king crab in the EAG, 1990/91 to 2016/17.

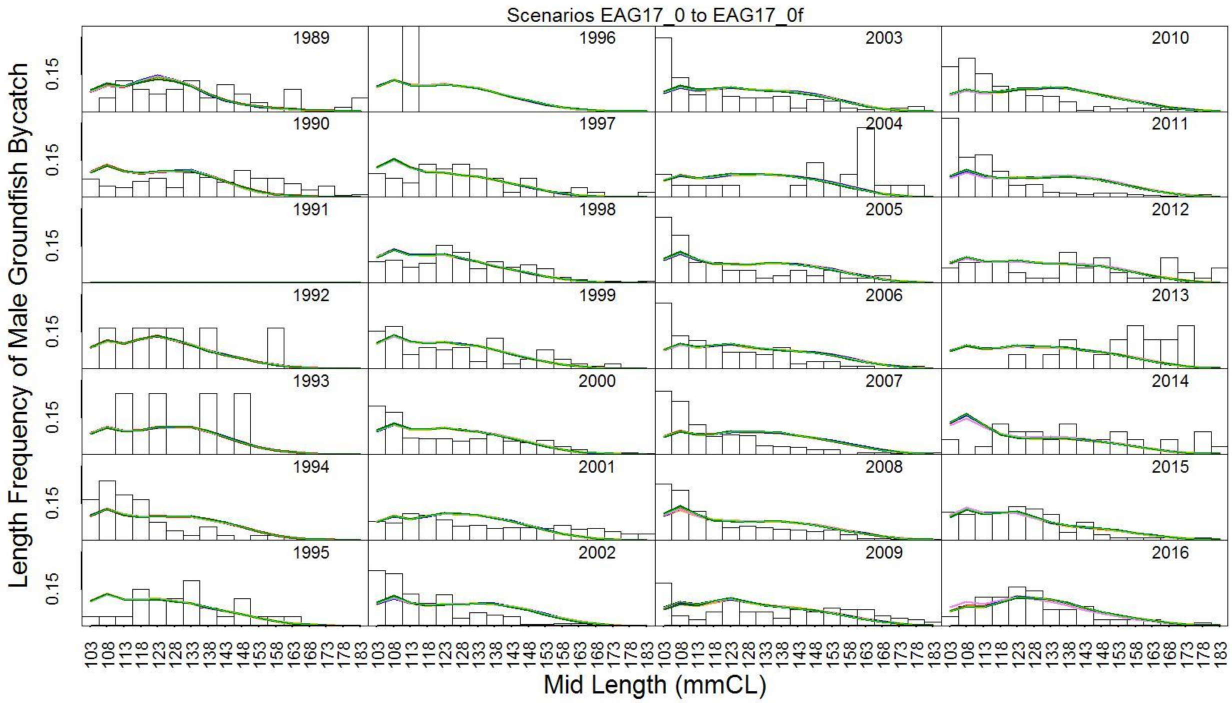
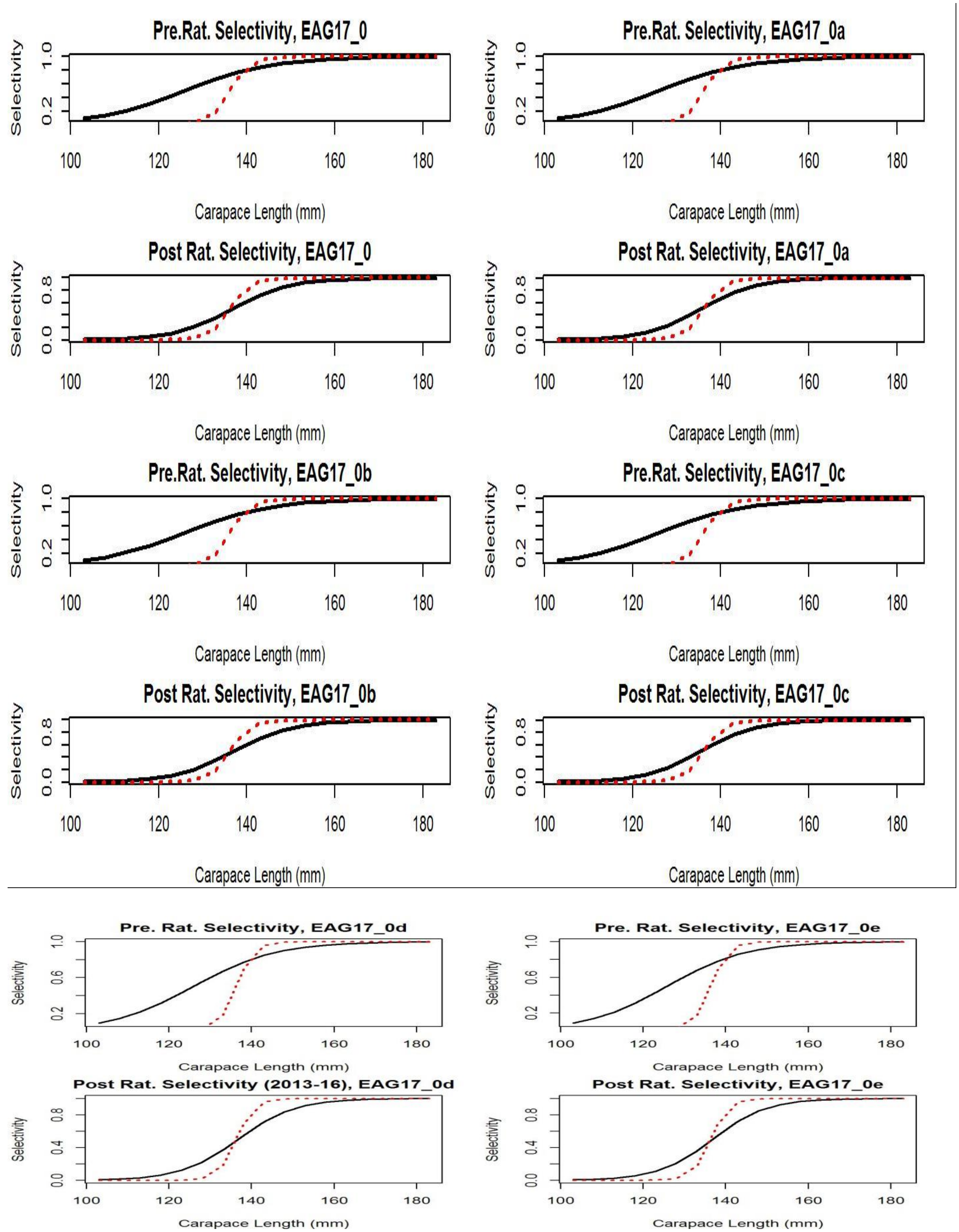


Figure 13. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 17_0 to 17_0f for golden king crab in the EAG, 1989/90 to 2016/17. Note that this data set was not used in the model fitting.


Pre.Rat. Selectivity, EAG17_0
Pre.Rat. Selectivity, EAG17_0a
Post Rat. Selectivity, EAG17_0
Post Rat. Selectivity, EAG17_0a
Pre.Rat. Selectivity, EAG17_0b
Pre.Rat. Selectivity, EAG17_0c
Post Rat. Selectivity, EAG17_0b
Post Rat. Selectivity, EAG17_0c
Pre. Rat. Selectivity, EAG17_0d
Pre. Rat. Selectivity, EAG17_0e
Post Rat. Selectivity (2013-16), EAG17_0d
Post Rat. Selectivity, EAG17_0e
Selectivity
Carapace Length (mm)
100
120
140
160
180
0.0
0.2
0.4
0.6
0.8
1.0

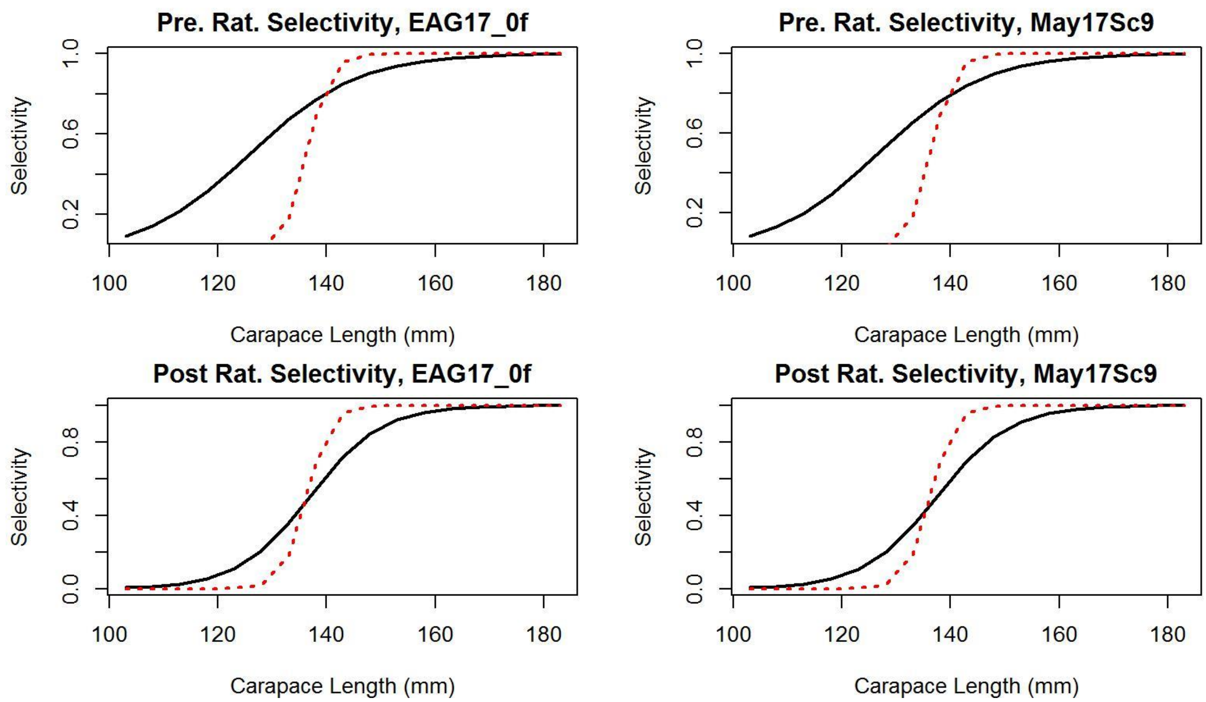


Figure 14. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 17_0 to May 2017 Sc9 model fits to golden king crab data in the EAG.

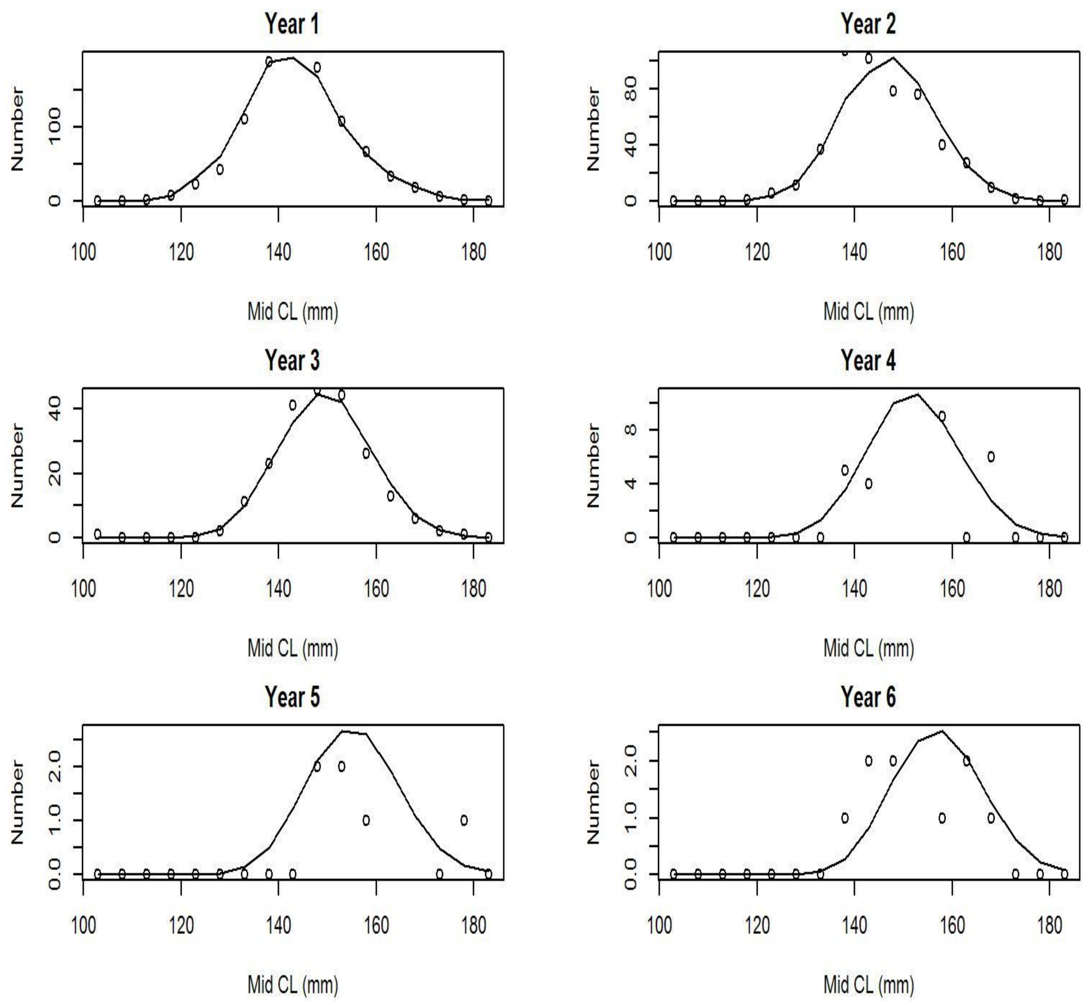


Figure 15. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 17_0 for EAG golden king crab.

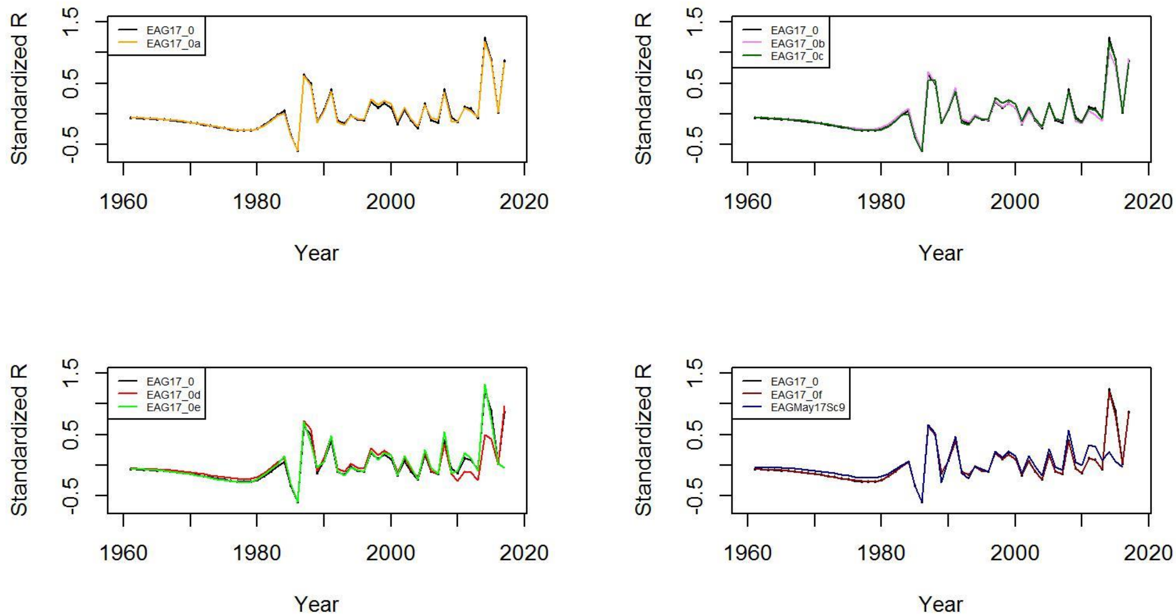


Figure 16. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 17_0 to May 2017 Sc9 for EAG golden king crab data, 1961–2017. Top left: scenarios 17_0 and 17_0a; top right: scenarios 17_0, 17_0b, and 17_0c; bottom left: scenarios 17_0, 17_0d, and 17_0e; and bottom right: scenarios 17_0, 17_0f, and May 2017 Sc9. This grouping scheme was used in a number of subsequent figures. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

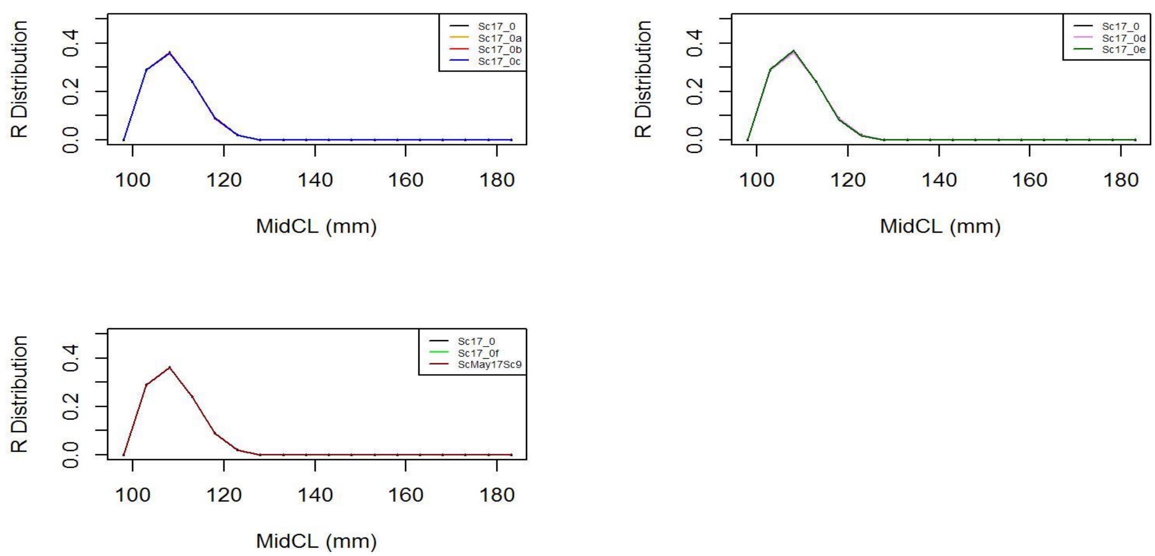


Figure 17. Recruit size distribution to the assessment model under scenarios (Sc) 17_0 to May 2017 Sc9 for EAG golden king crab.

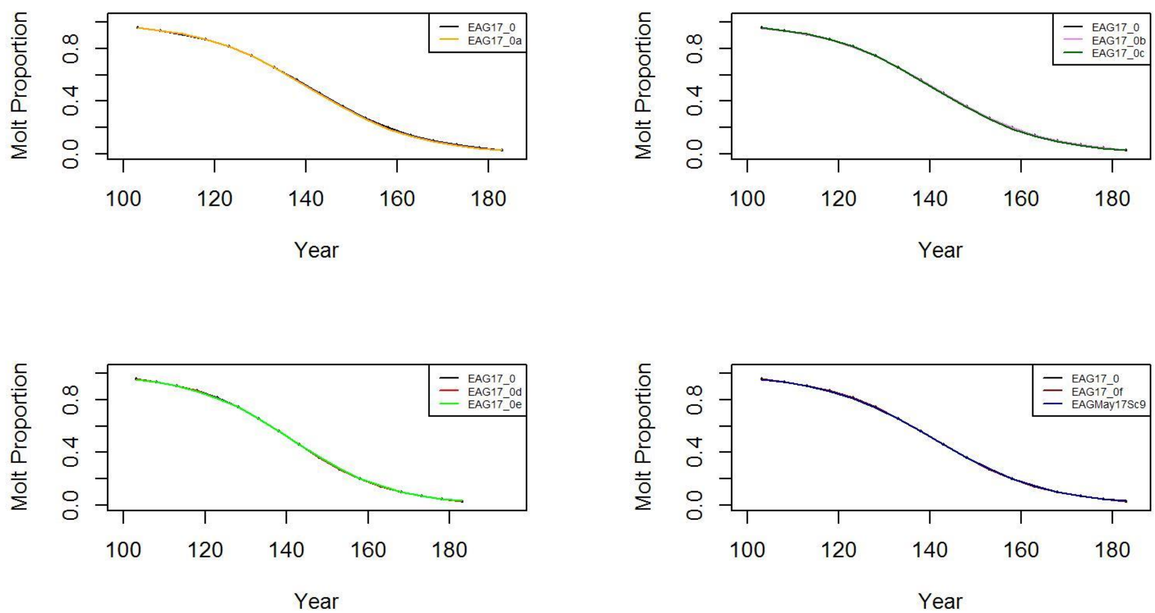
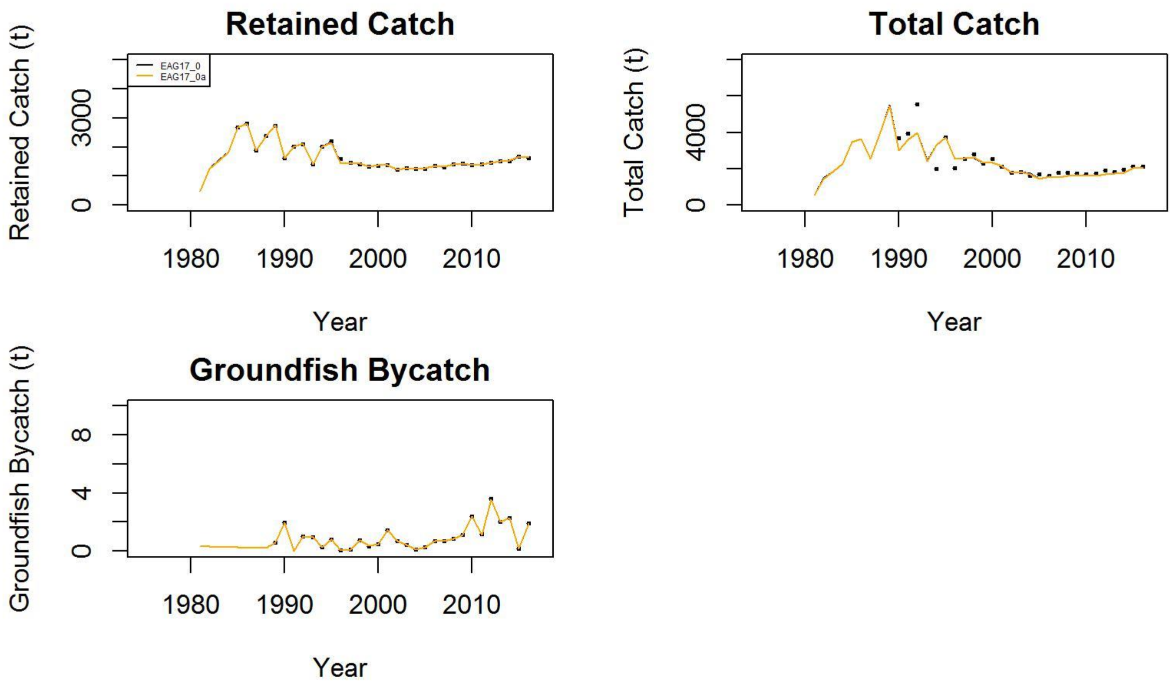
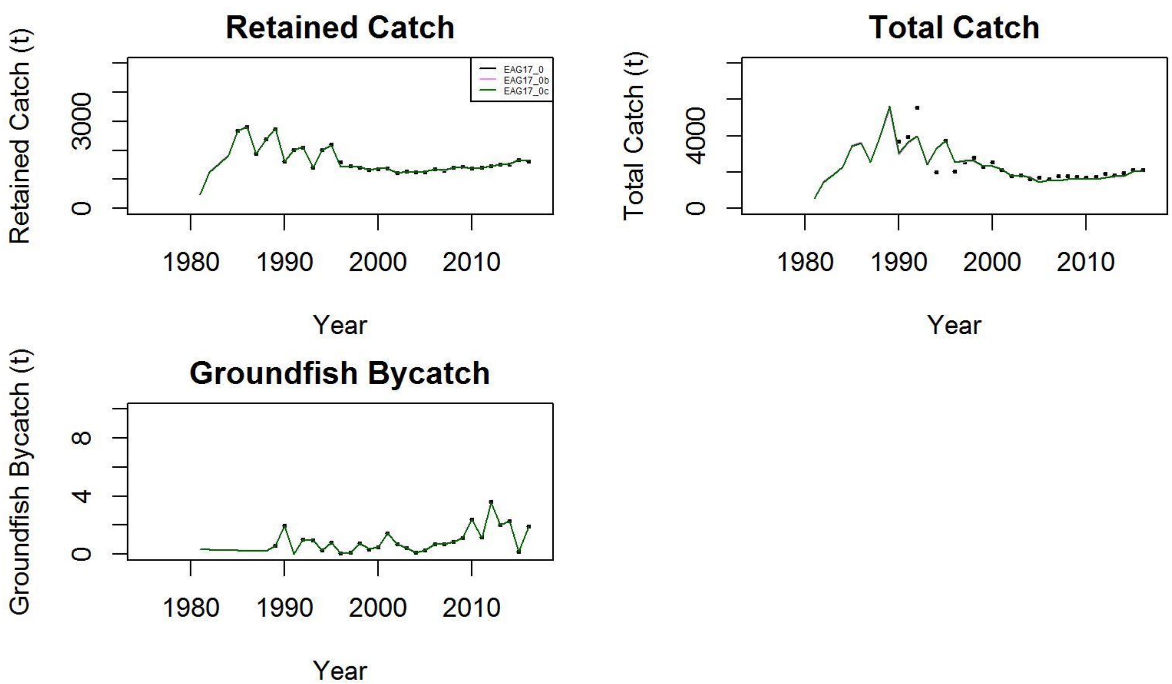


Figure 18. Estimated molt probability vs. carapace length of golden king crab for scenarios 17_0 to May 2017 Sc9 in the EAG.


Retained Catch
Retained Catch (t)
0
3000
EAG17_0
EAG17_0a
1980
1990
2000
2010
Year
Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year
Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year


Retained Catch
Retained Catch (t)
0
3000
EAG17_0
EAG17_0b
EAG17_0c
1980
1990
2000
2010
Year
Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year
Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year

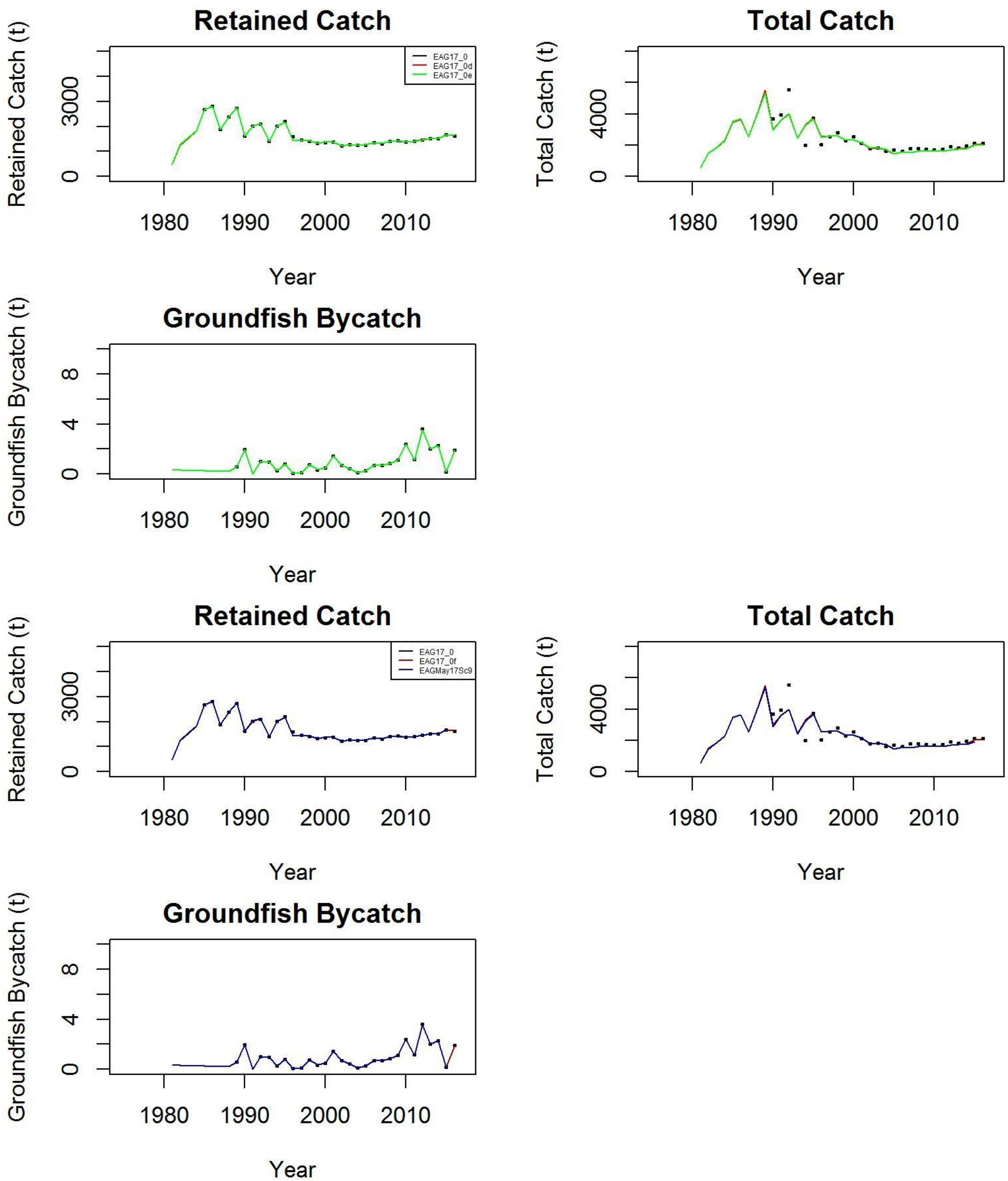


Figure 19. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios 17_0 to May 2017 Sc9, in EAG, 1981/82–2016/17.

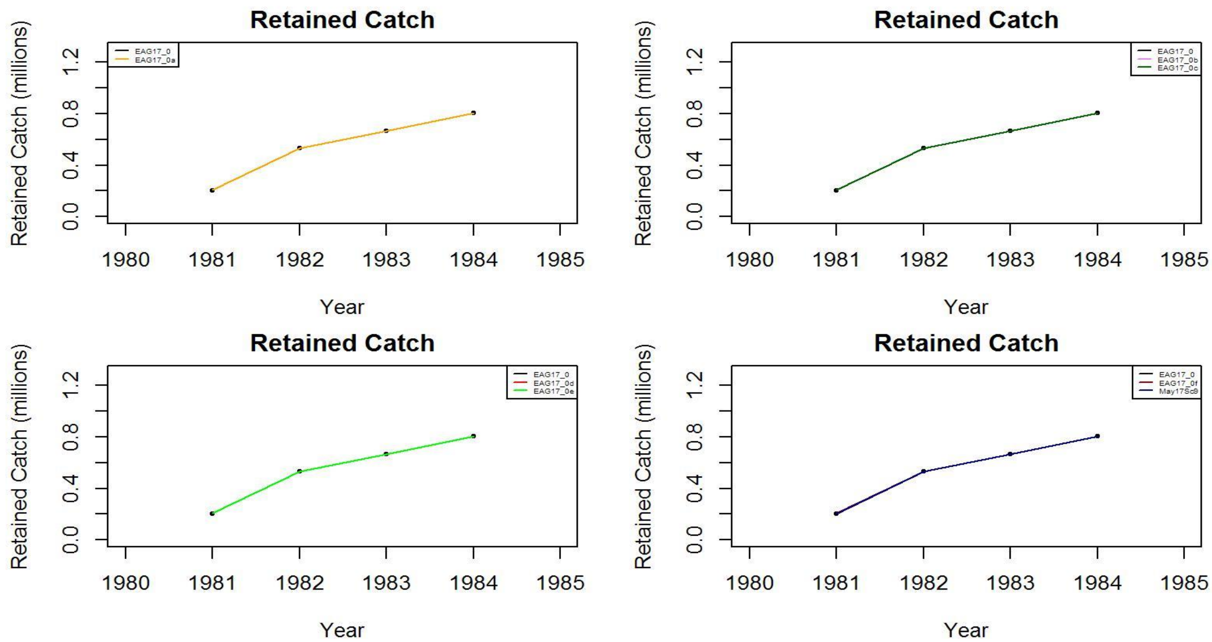


Figure 20. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 17_0 to May 2017 Sc9 fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

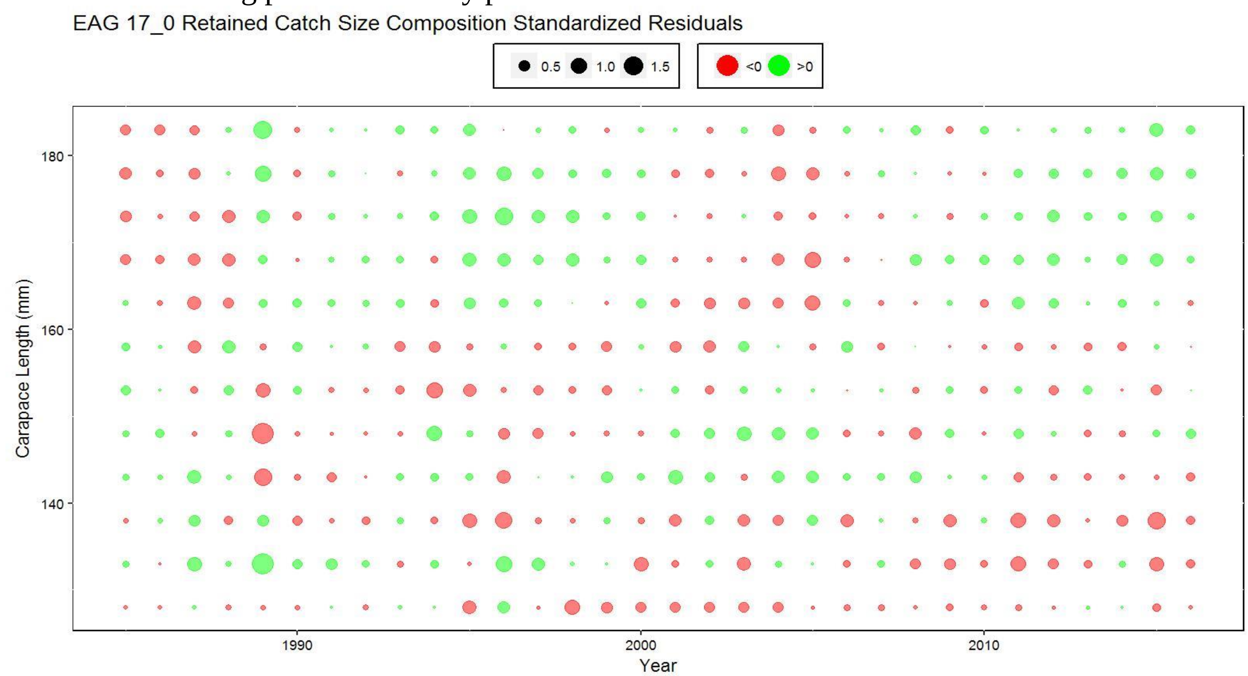


Figure 21. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0 fit for EAG golden king crab, 1985/86–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

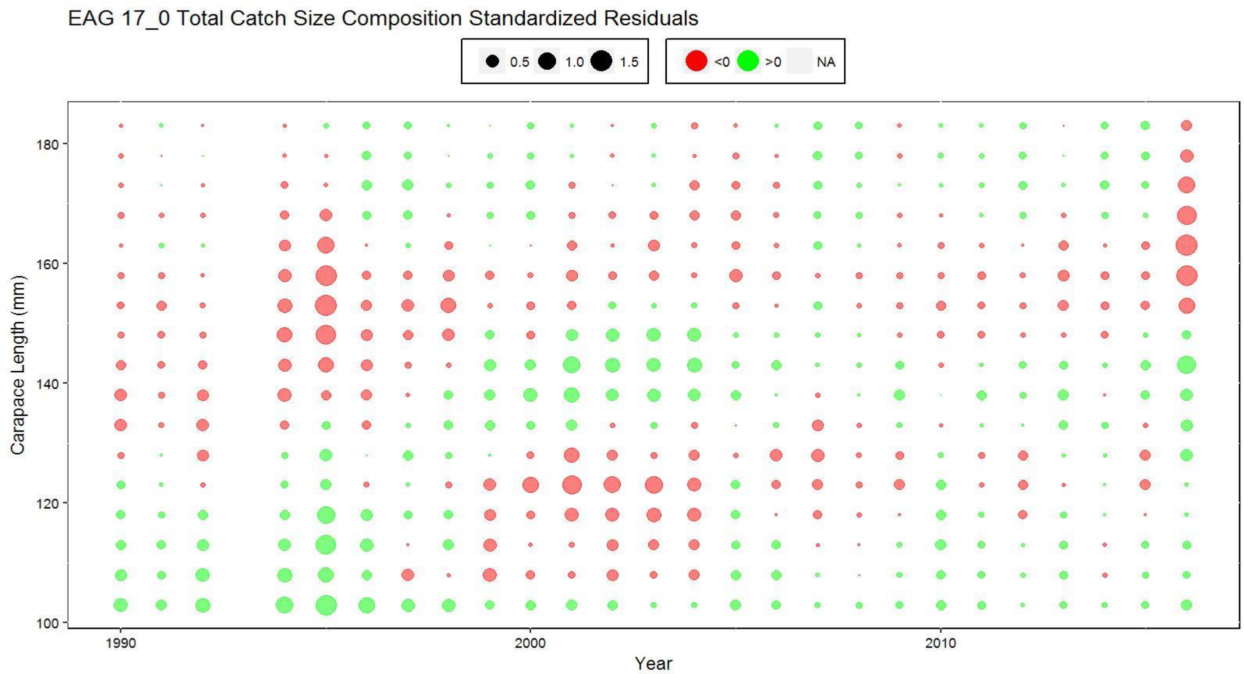


Figure 22. Bubble plot of standardized residuals of total catch length composition for scenario 17_0 fit for EAG golden king crab, 1990/91–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

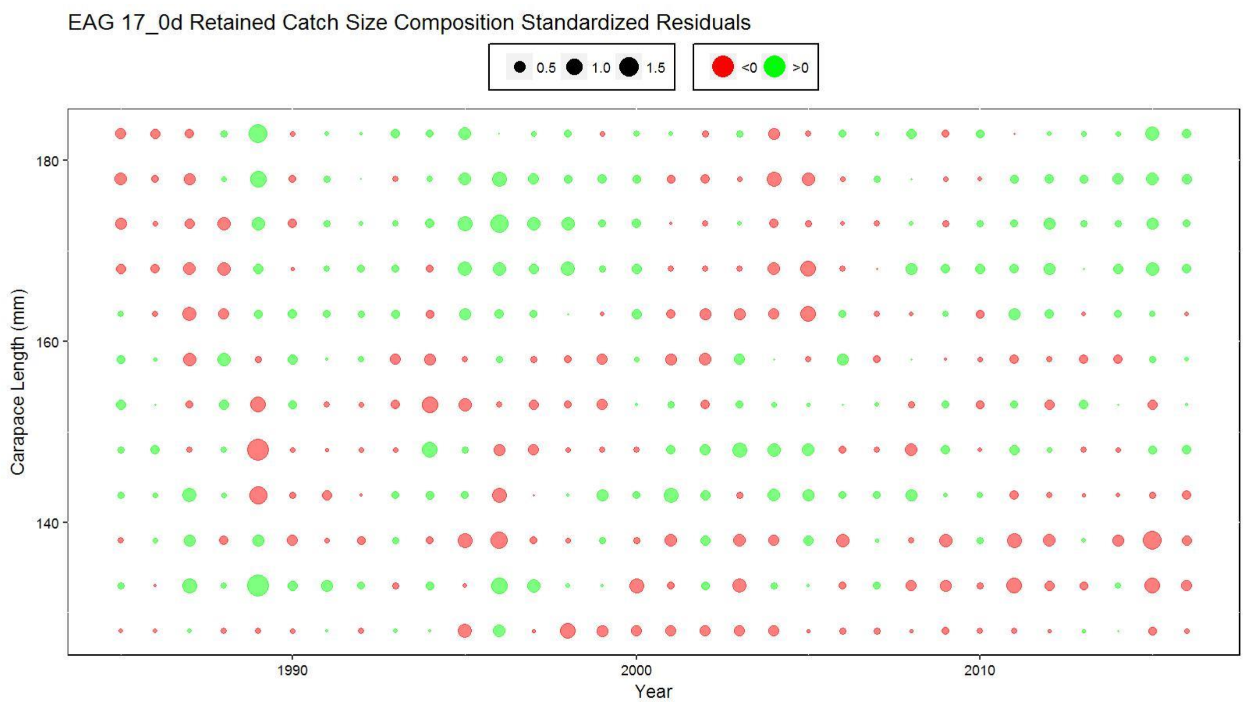


Figure 23. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0d fit for EAG golden king crab, 1985/86–2015/16. Blue circles are the positive and

pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

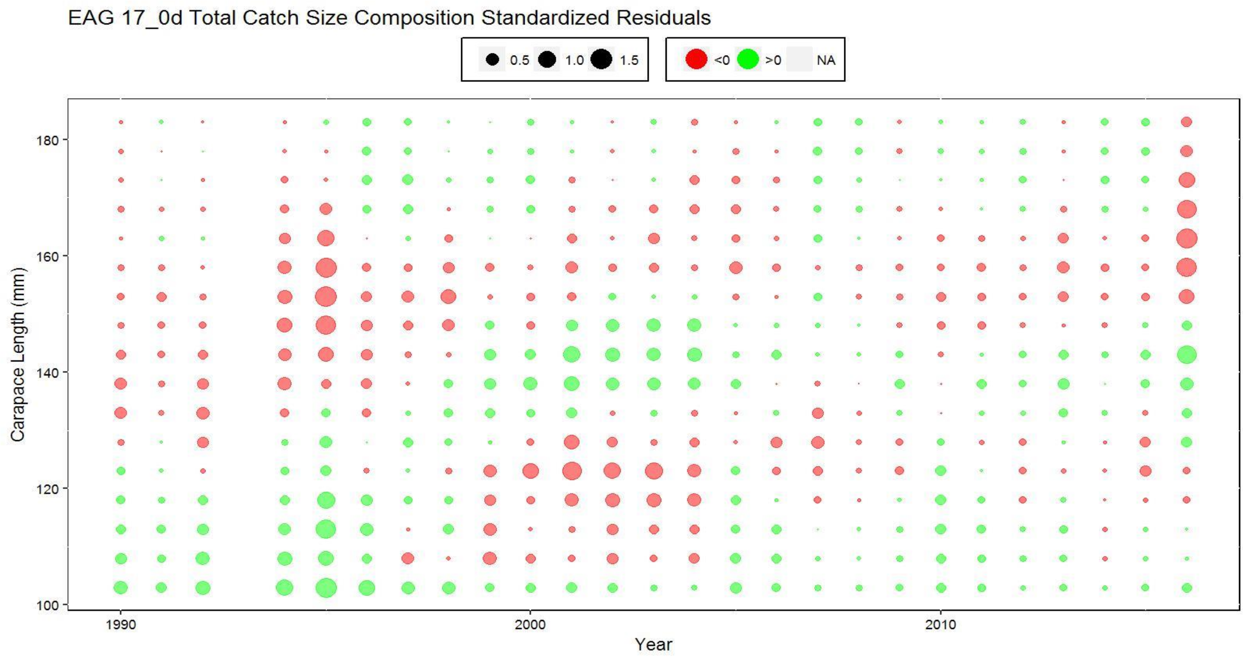


Figure 24. Bubble plot of standardized residuals of total catch length composition for scenario 9 fit for EAG golden king crab, 1990/91–2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

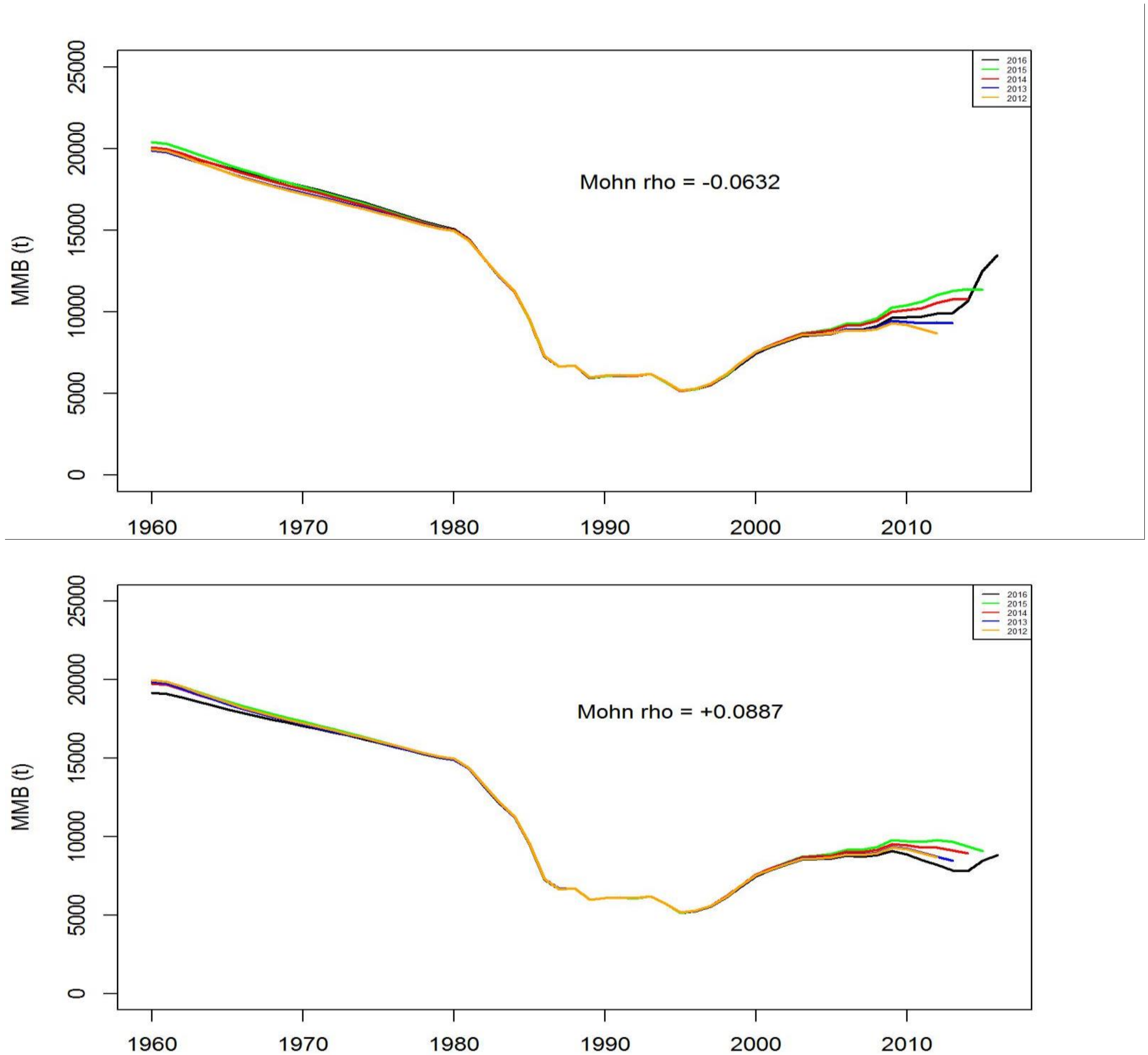


Figure 25. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 17_0 (top) and 17_0d (bottom) for golden king crab in the EAG, 1960/61–2016/17.

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 four peels (x=4) and our T =2016.

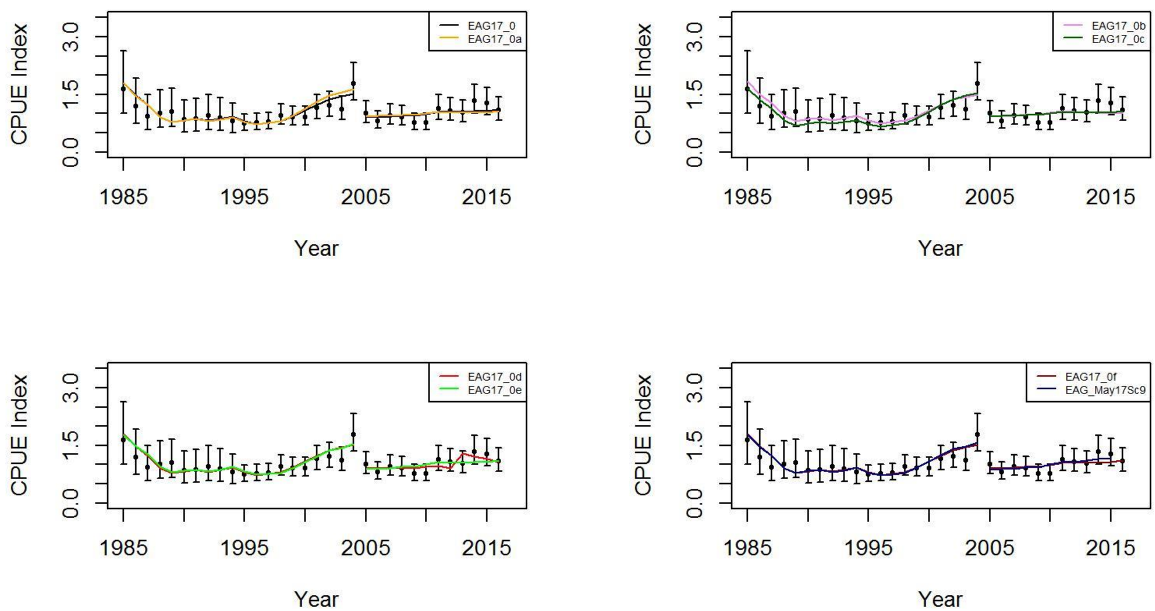


Figure 26. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) under scenarios 17_0 to May 2017 Sc9 for EAG golden king crab data, 1985/86–2016/17. Model estimated additional standard error was added to each input standard error.

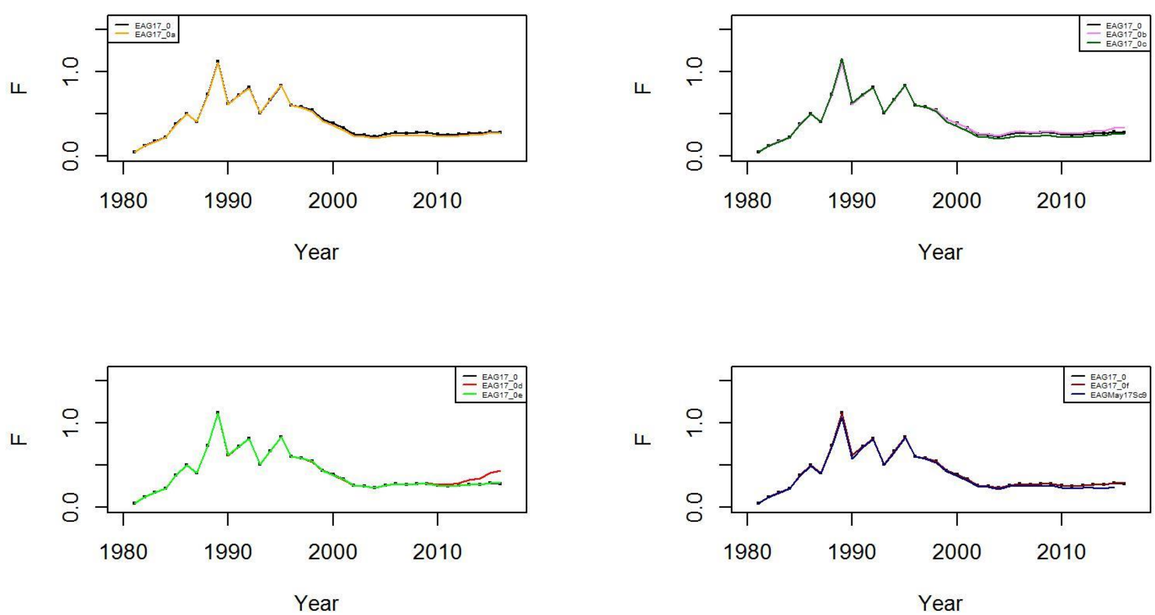


Figure 27. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 17_0 to May 2017 Sc9 model fits in the EAG, 1981/82–2016/17.

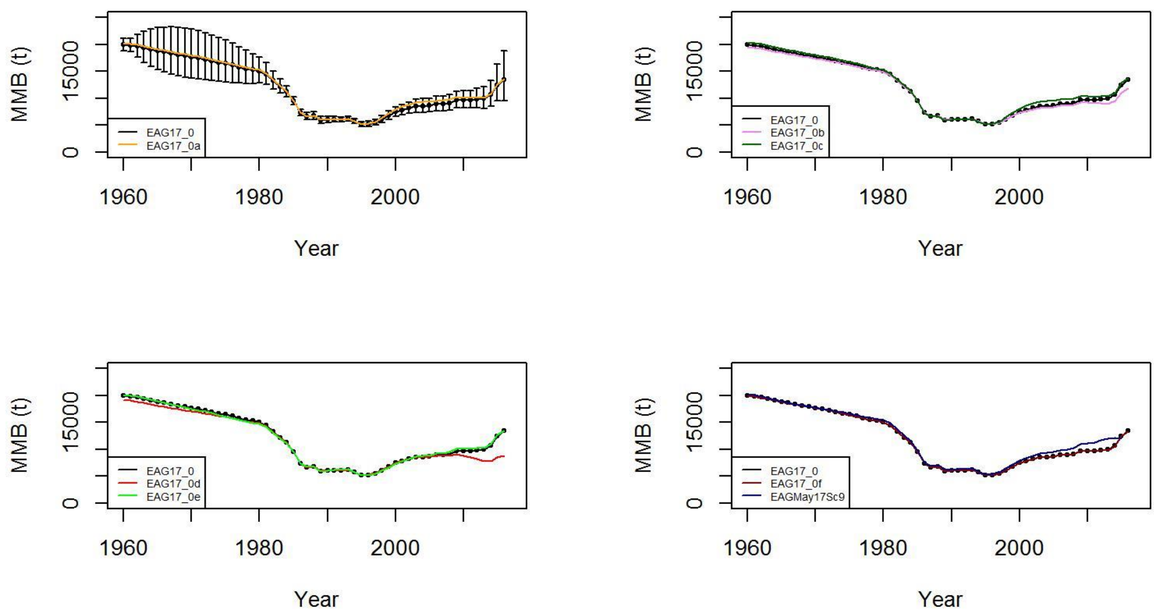


Figure 28. Trends in golden king crab mature male biomass for scenarios 17_0 to May 2017 Sc9 fits in the EAG, 1960/61–2016/17. Scenario 17_0 estimates have two standard errors confidence limits.

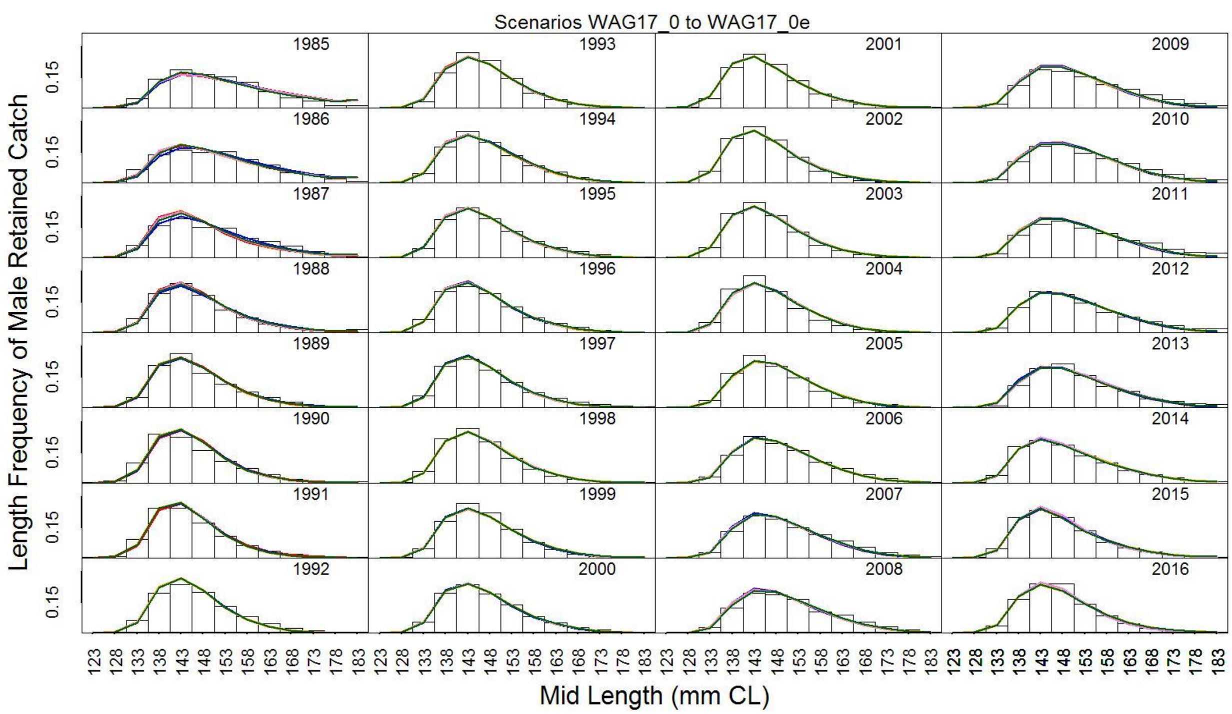


Figure 29. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 17_0 (black line), 17_0a (orange line), 17_0b (red line), 17_0c (blue line), 17_0d (violet line), and 17_0e (dark green line) for golden king crab in the WAG, 1985/86 to 2016/17. This color scheme is used in all other graphs.

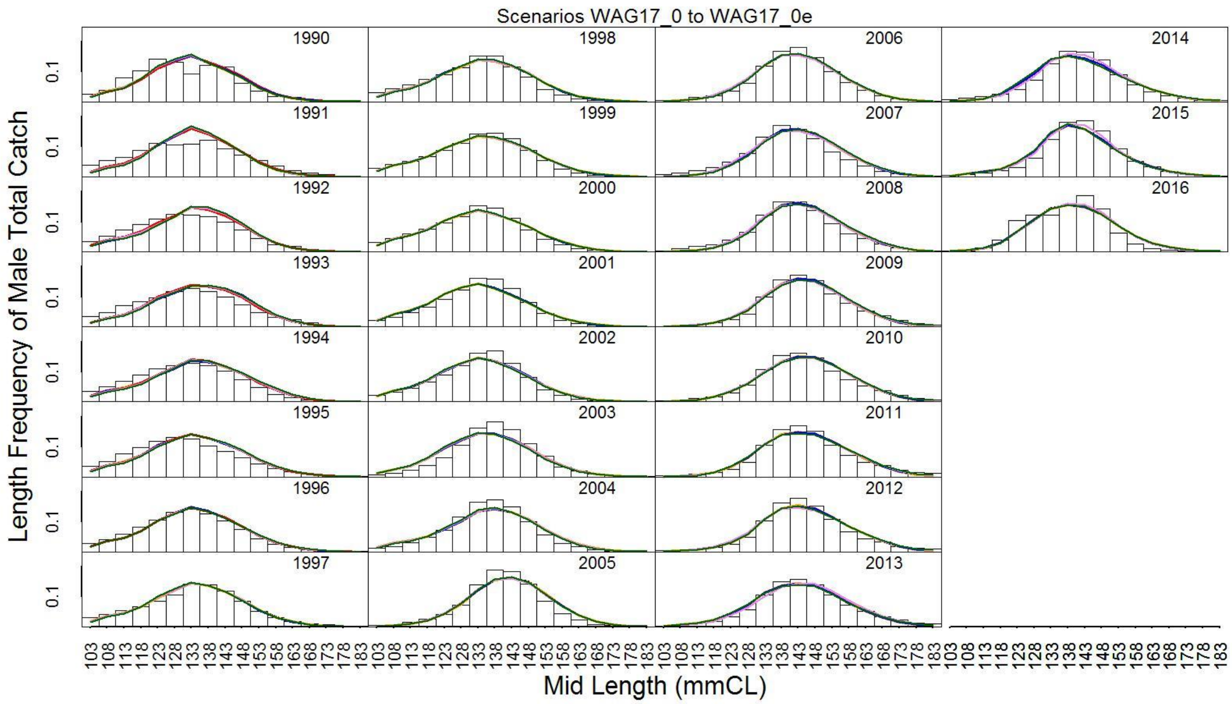


Figure 30. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 17_0 to 17_0e for golden king crab in the WAG, 1990/91 to 2016/17.

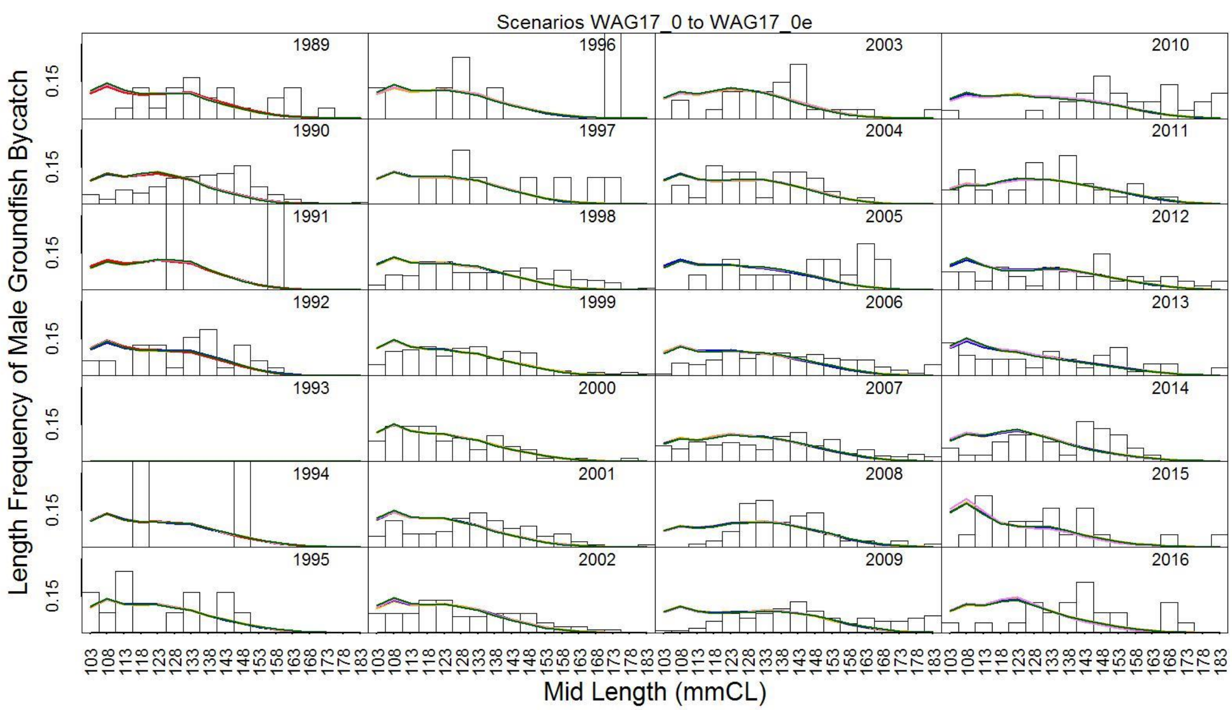
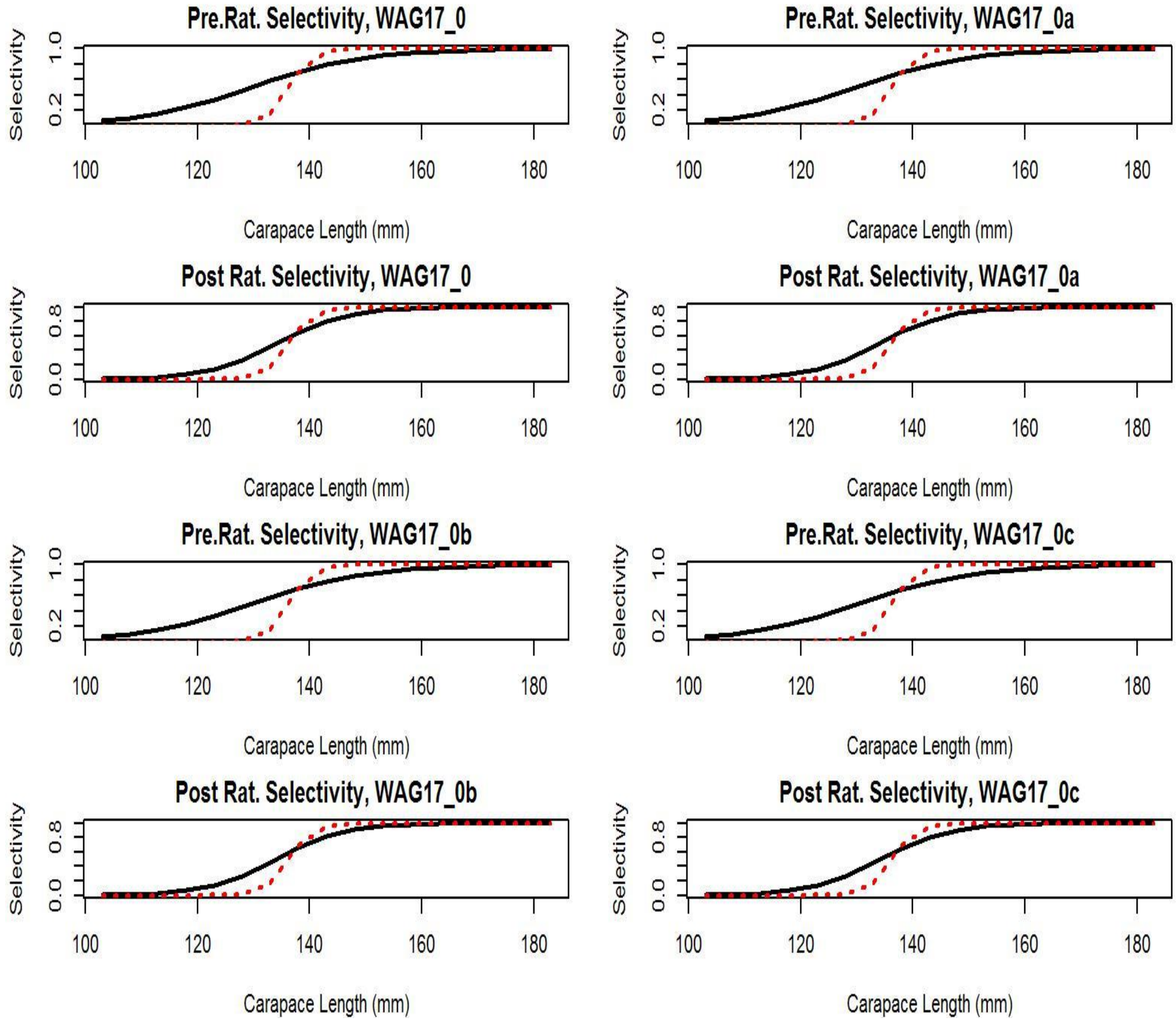


Figure 31. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 17_0 to 17_0e for golden king crab in the WAG, 1989/90 to 2016/17. Note that this data set was not used in the model fitting.


Pre.Rat. Selectivity, WAG17_0
Pre.Rat. Selectivity, WAG17_0a
Post Rat. Selectivity, WAG17_0
Post Rat. Selectivity, WAG17_0a
Pre.Rat. Selectivity, WAG17_0b
Pre.Rat. Selectivity, WAG17_0c
Post Rat. Selectivity, WAG17_0b
Post Rat. Selectivity, WAG17_0c
Selectivity
Carapace Length (mm)
100
120
140
160
180

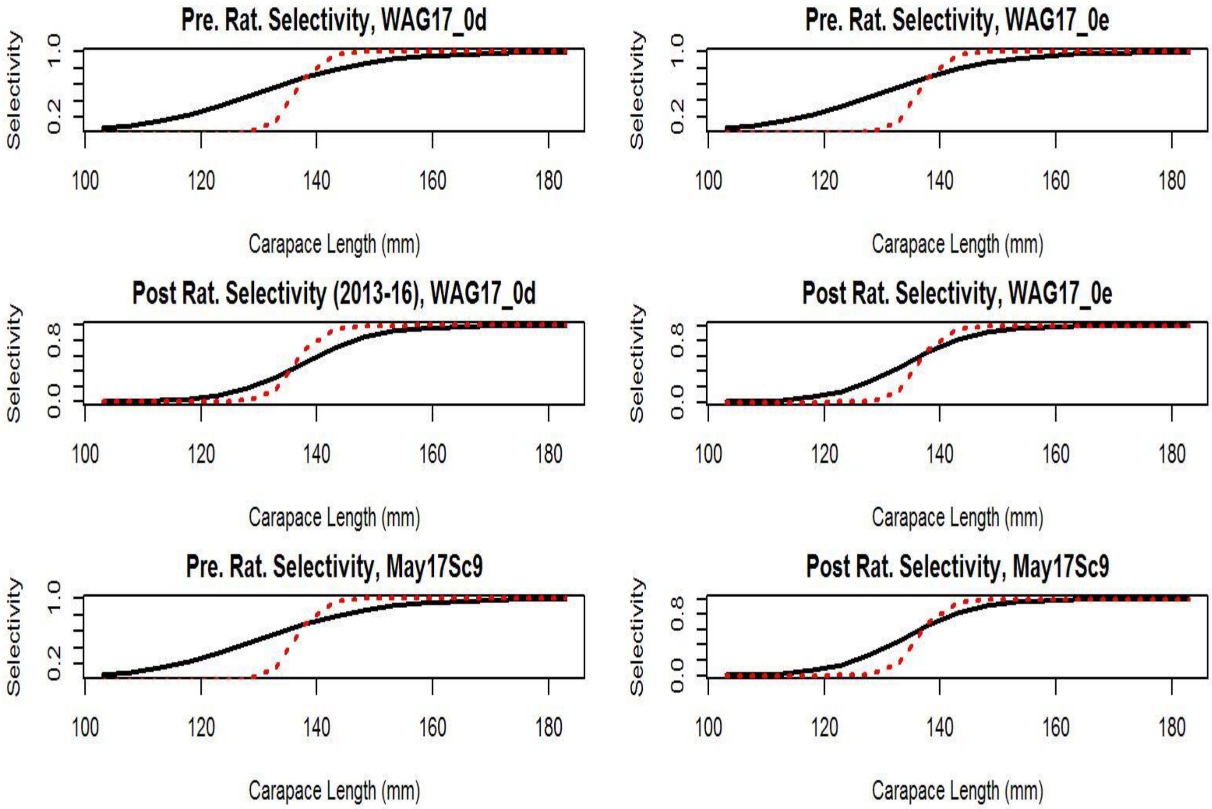


Figure 32. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 17_0 to May 2017 Sc9 fits to golden king crab data in the WAG.

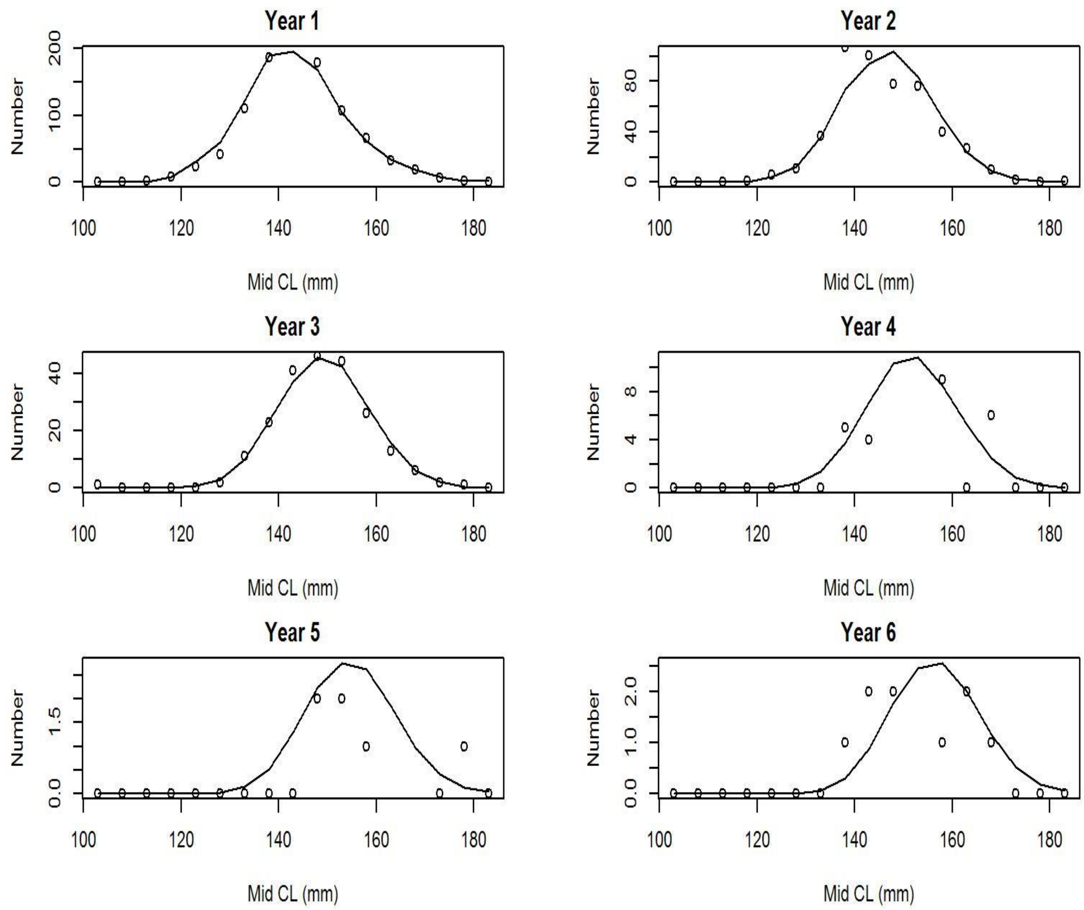


Figure 33. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 17_0 for WAG golden king crab.

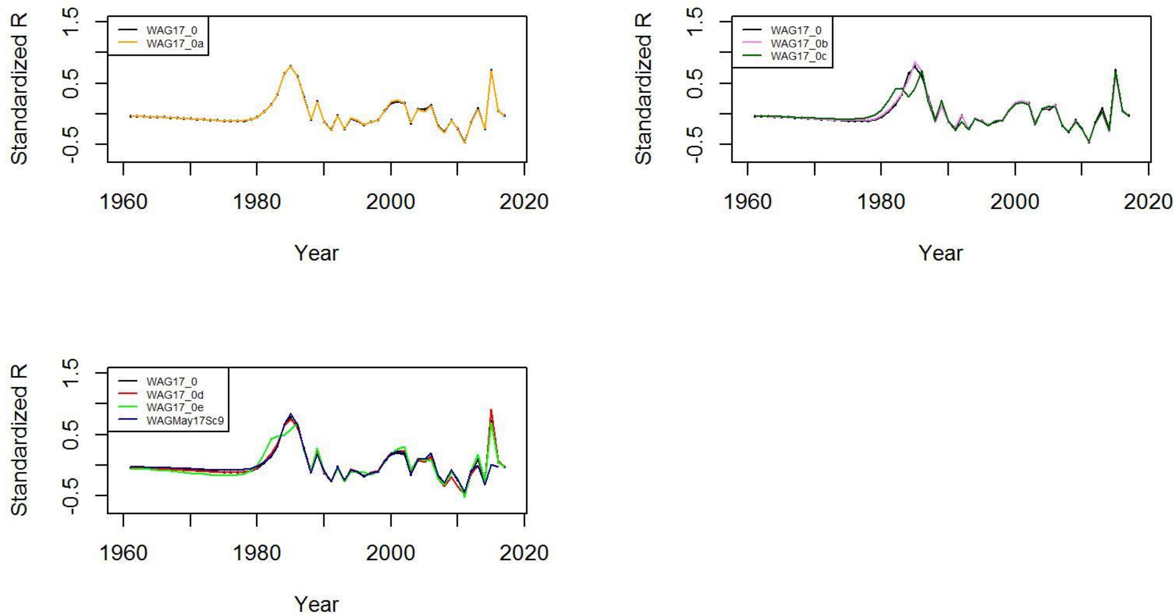


Figure 34. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios 17_0 to May 2017 Sc9 for WAG golden king crab data, 1961–2017. Top left: scenarios 17_0 and 17_0a; top right: scenarios 17_0, 17_0b, and 17_0c; and bottom left: scenarios 17_0, 17_0d, and 17_0e and May 2017 Sc9. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

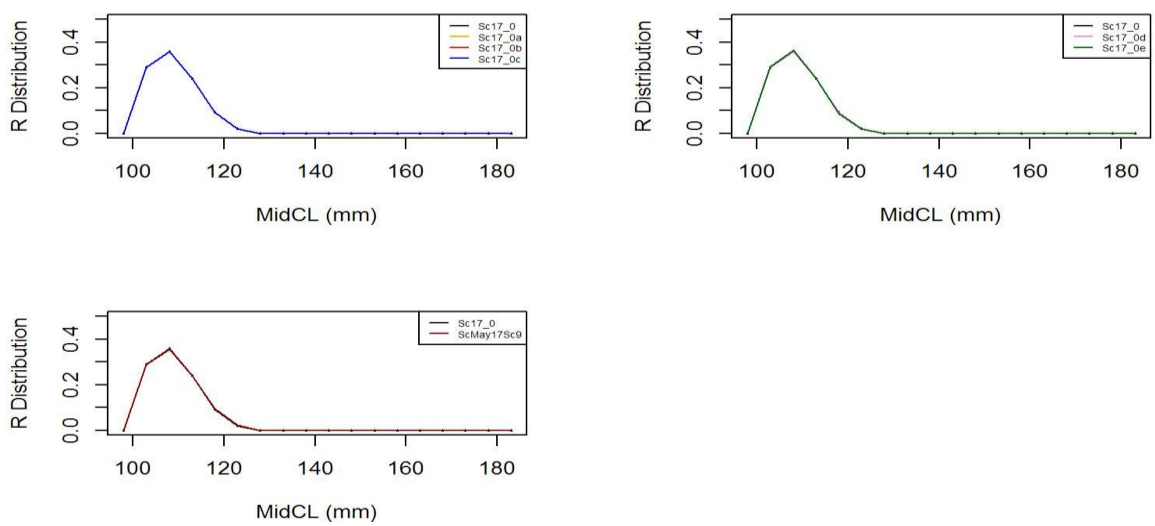


Figure 35. Recruit size distribution to the assessment model under scenarios (Sc) 17_0 to May 2017 Sc9 for WAG golden king crab.

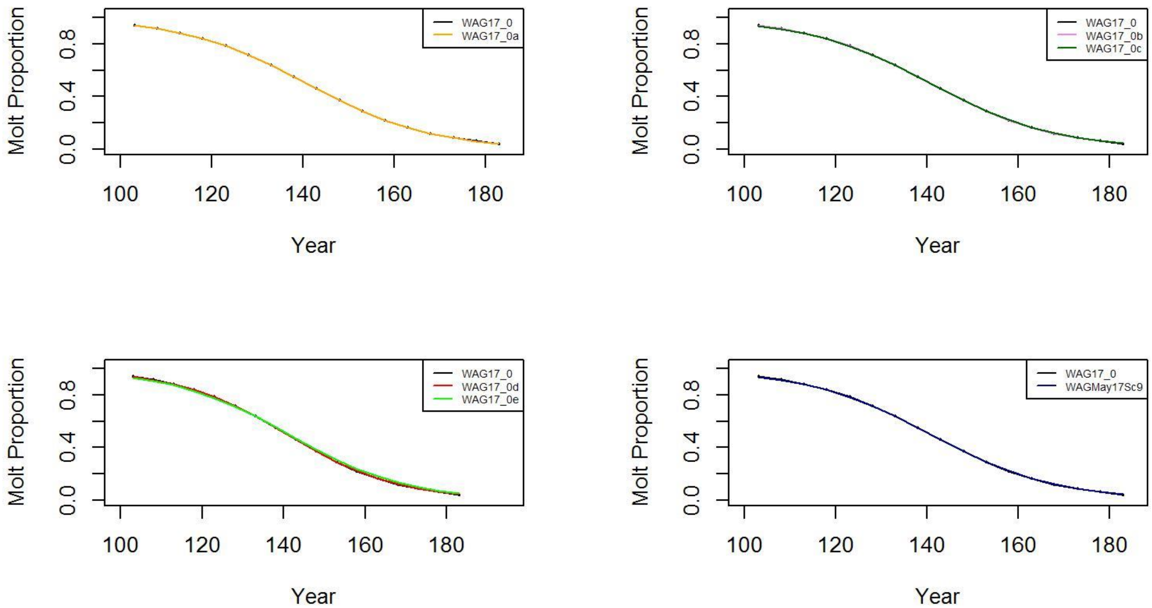
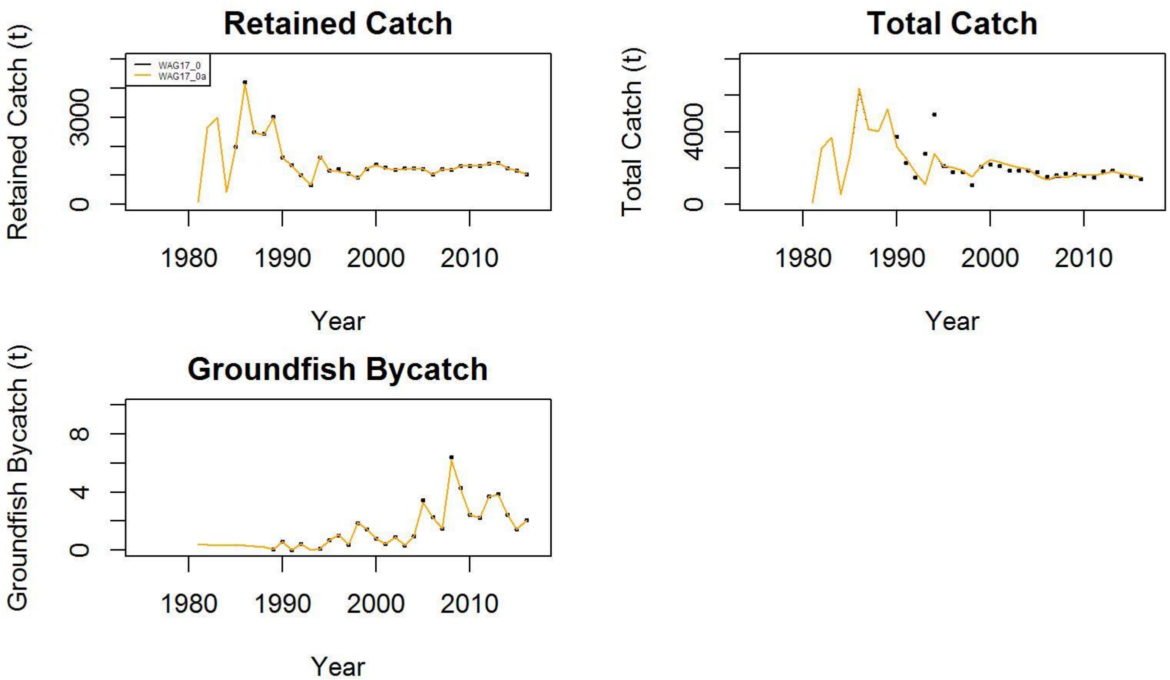
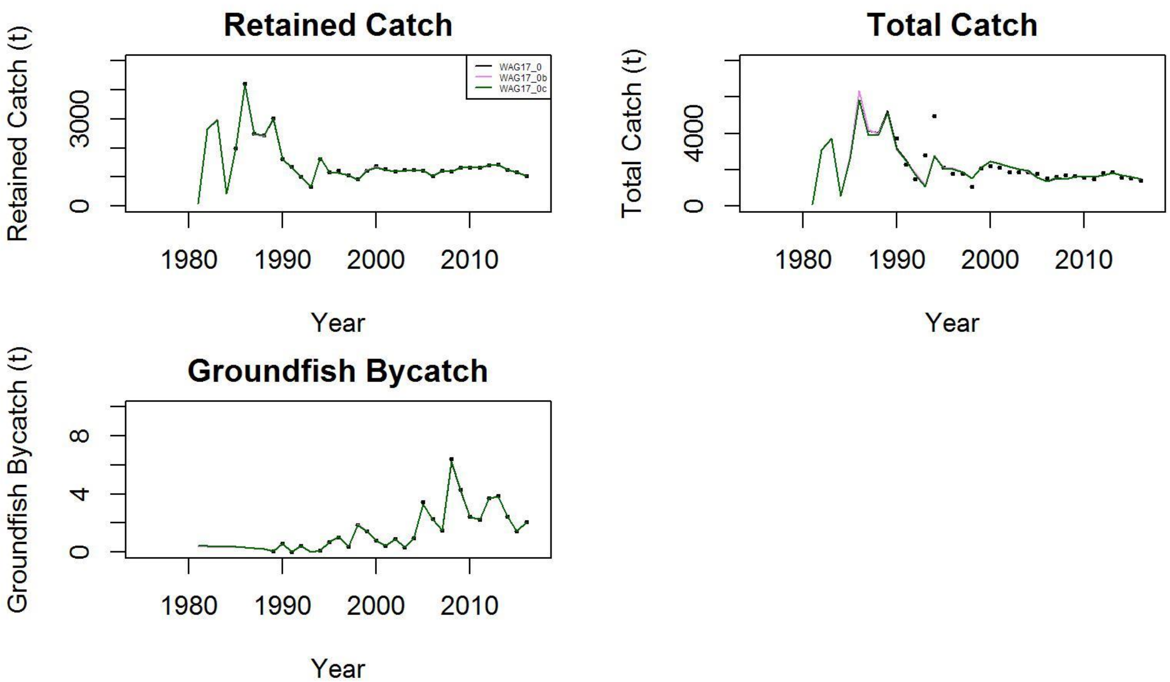


Figure 36. Estimated molt probability vs. carapace length of golden king crab for scenarios 17_0 to May 2017 Sc9 in the WAG.


Retained Catch
Retained Catch (t)
0
3000
WAG17_0
WAG17_0a
1980
1990
2000
2010
Year
Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year
Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year


Retained Catch
Retained Catch (t)
0
3000
WAG17_0
WAG17_0b
WAG17_0c
1980
1990
2000
2010
Year
Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year
Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year

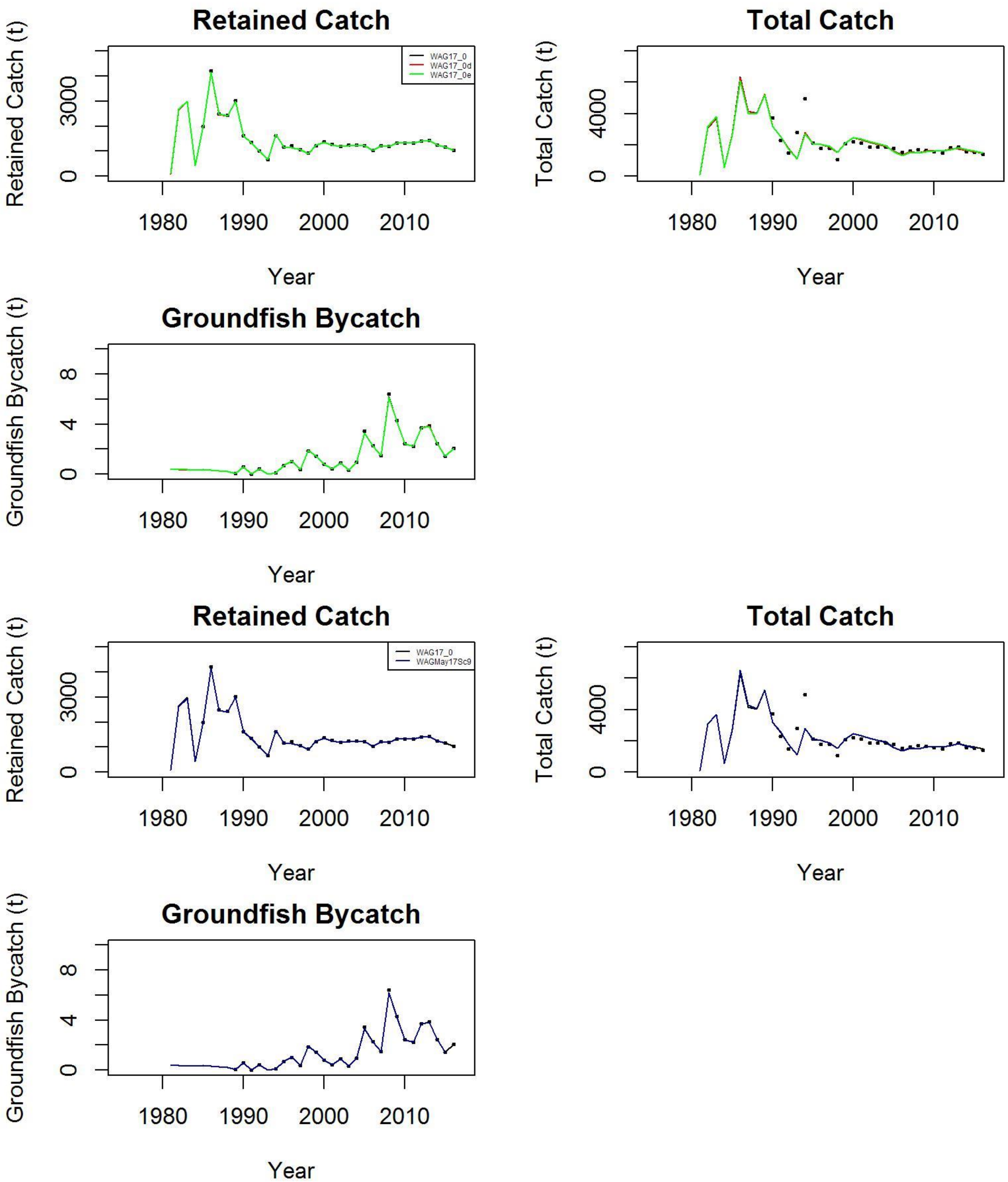


Figure 37. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios 17_0 to May 2017 Sc9 fits in the WAG, 1981/82–2016/17.

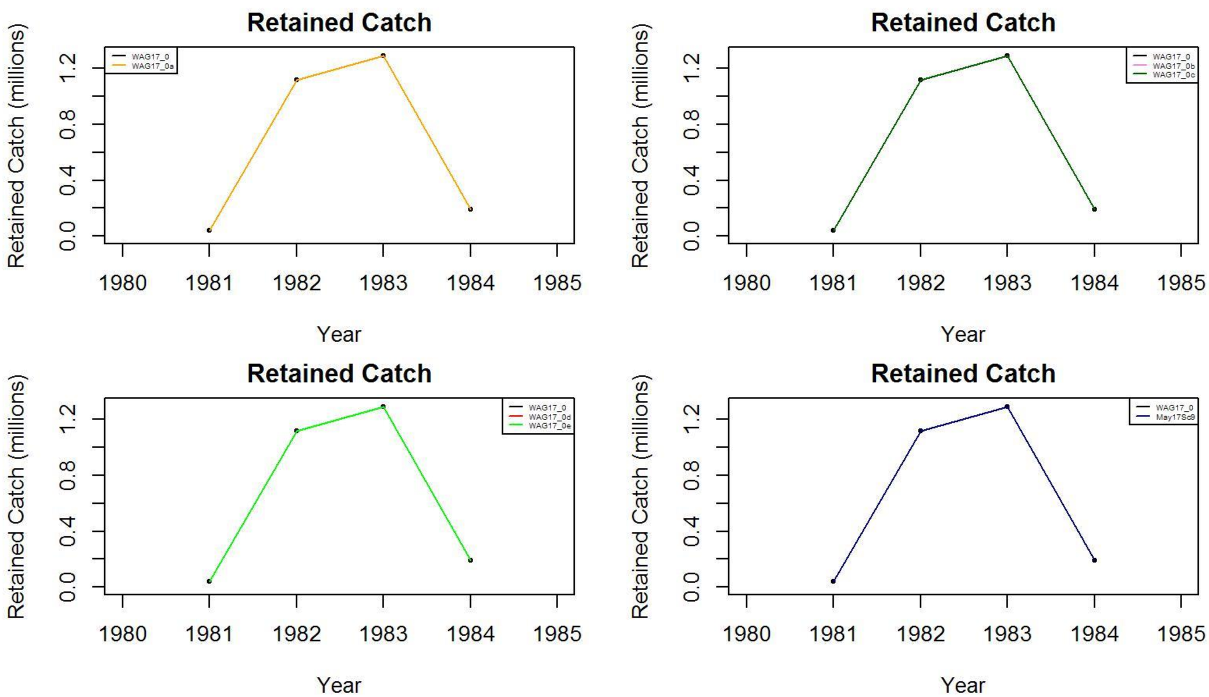


Figure 38. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 17_0 to May 2017 Sc9 fits in the WAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

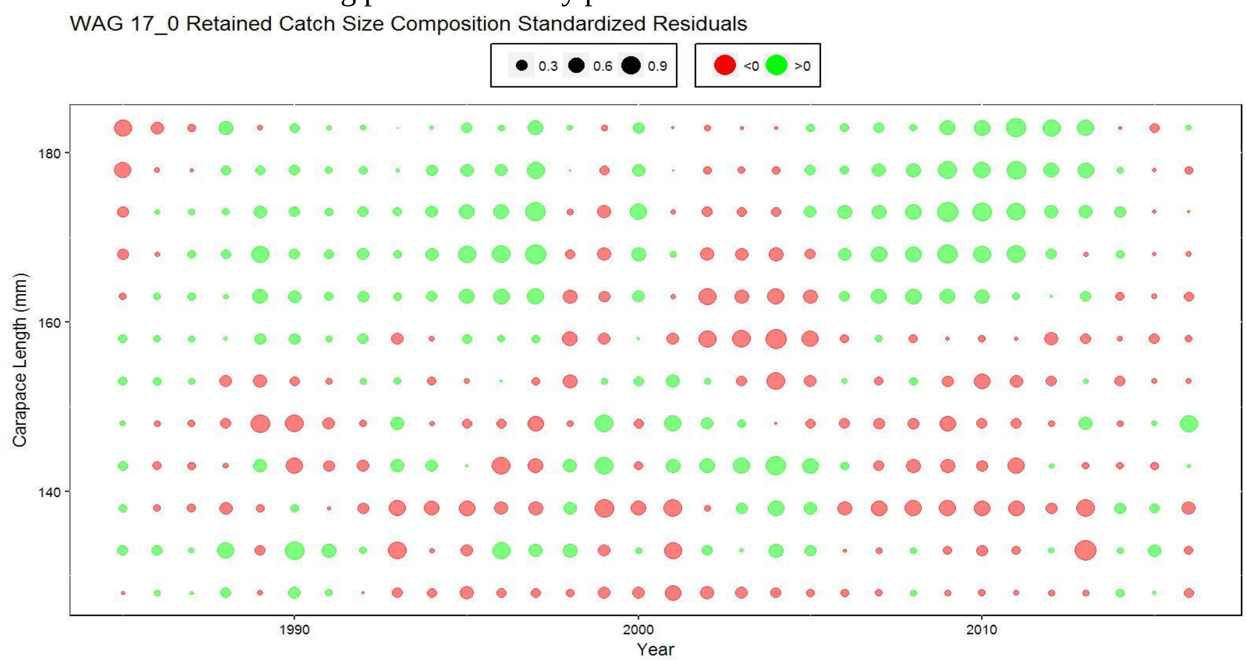


Figure 39. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0 fit for WAG golden king crab, 1985/86–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

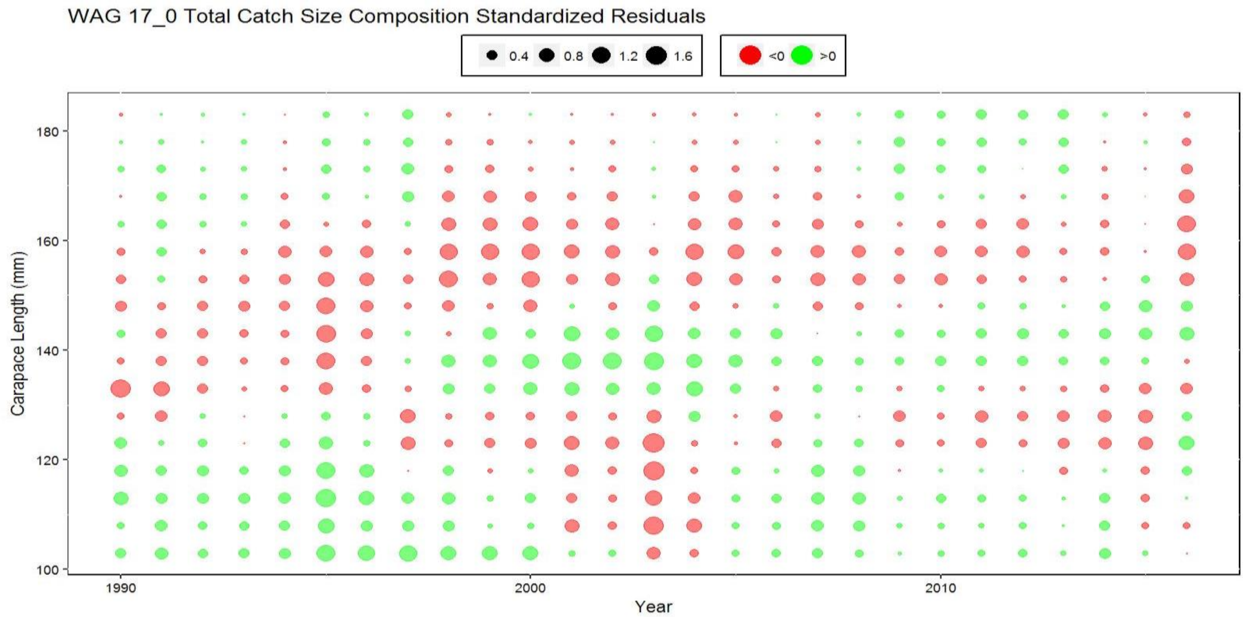


Figure 40. Bubble plot of standardized residuals of total catch length composition for scenario 17_0 fit for WAG golden king crab, 1990/91–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

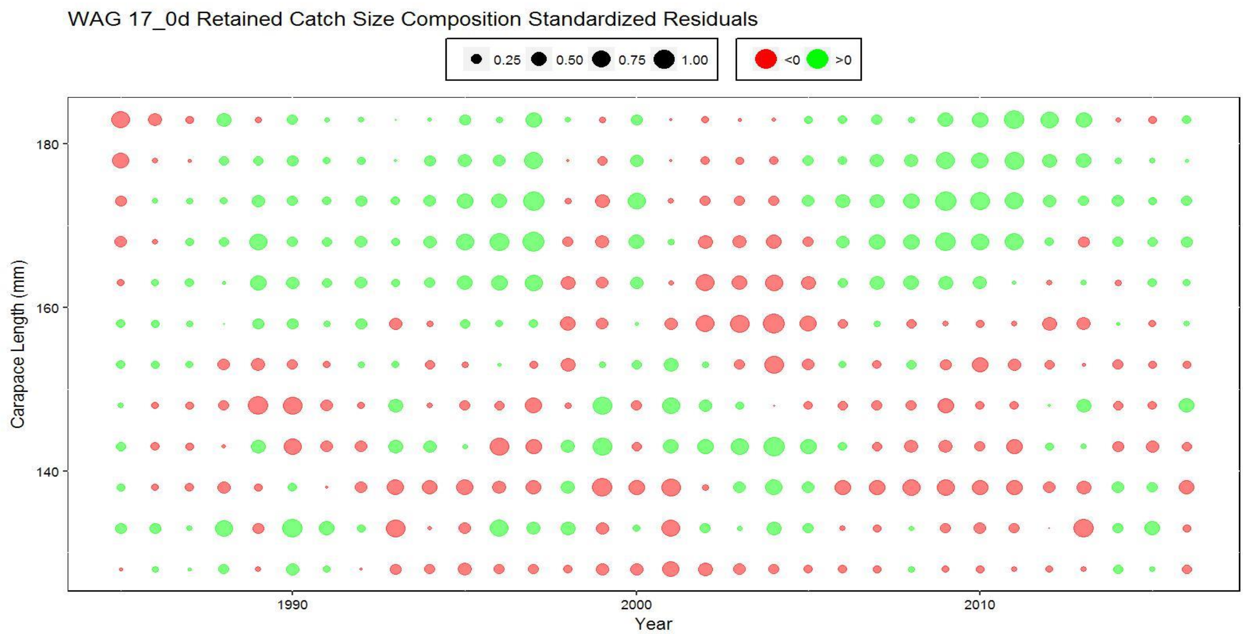


Figure 41. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0d fit for WAG golden king crab, 1985/86–2016/17. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

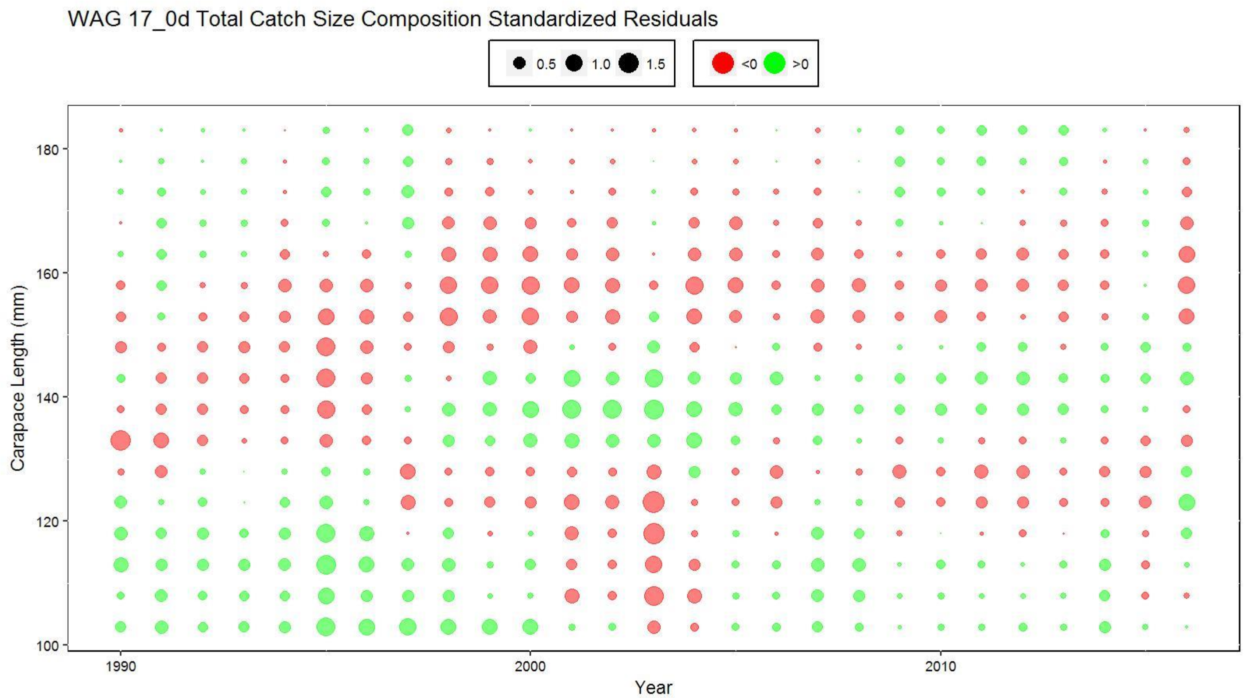


Figure 42. Bubble plot of standardized residuals of total catch length composition for scenario 17_0d fit for WAG golden king crab, 1990/91–2016/17. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

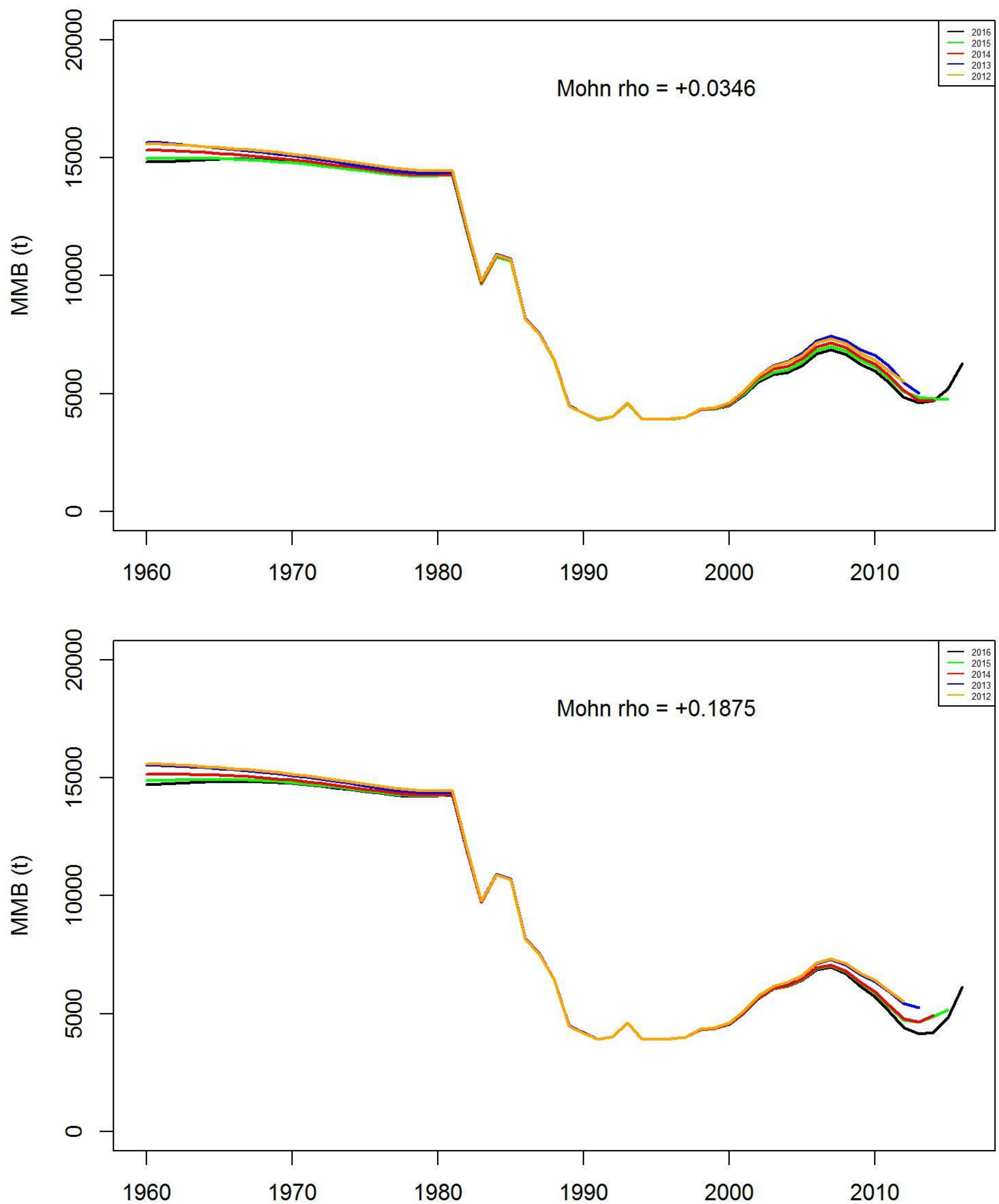


Figure 43. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 17_0 (top) and 17_0d (bottom) for golden king crab in the WAG, 1960/61–2016/17.

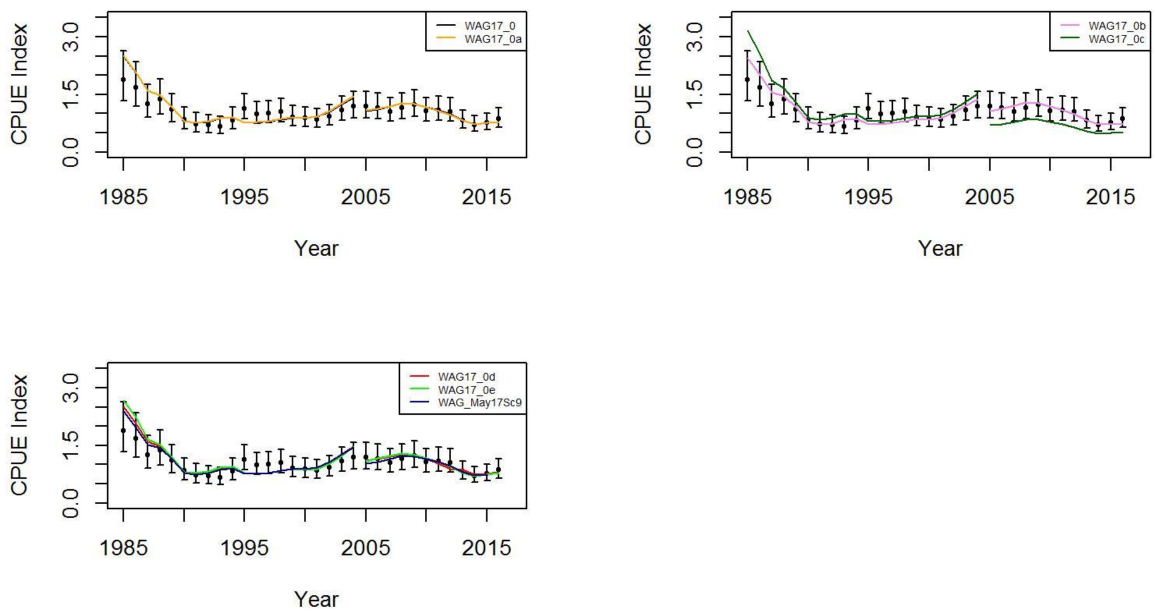


Figure 44. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) under scenarios 17_0 to May 2017 Sc9 for WAG golden king crab data, 1985/86–2016/17. Model estimated additional standard error was added to each input standard error.

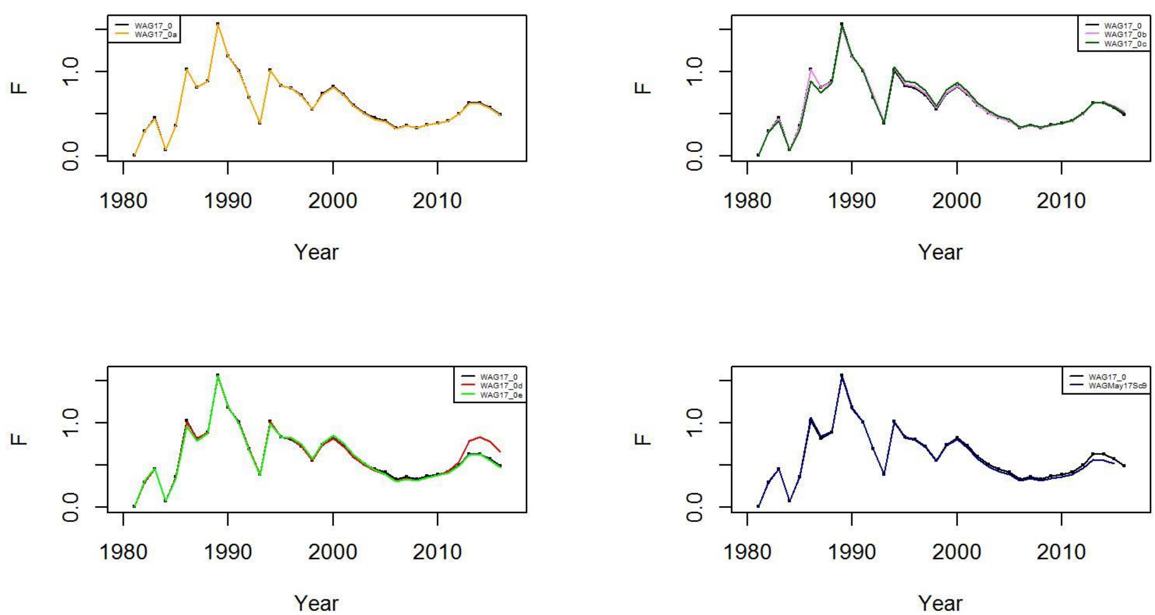


Figure 45. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 17_0 to May 2017 Sc9 model fits in the WAG, 1981/82–2016/17.

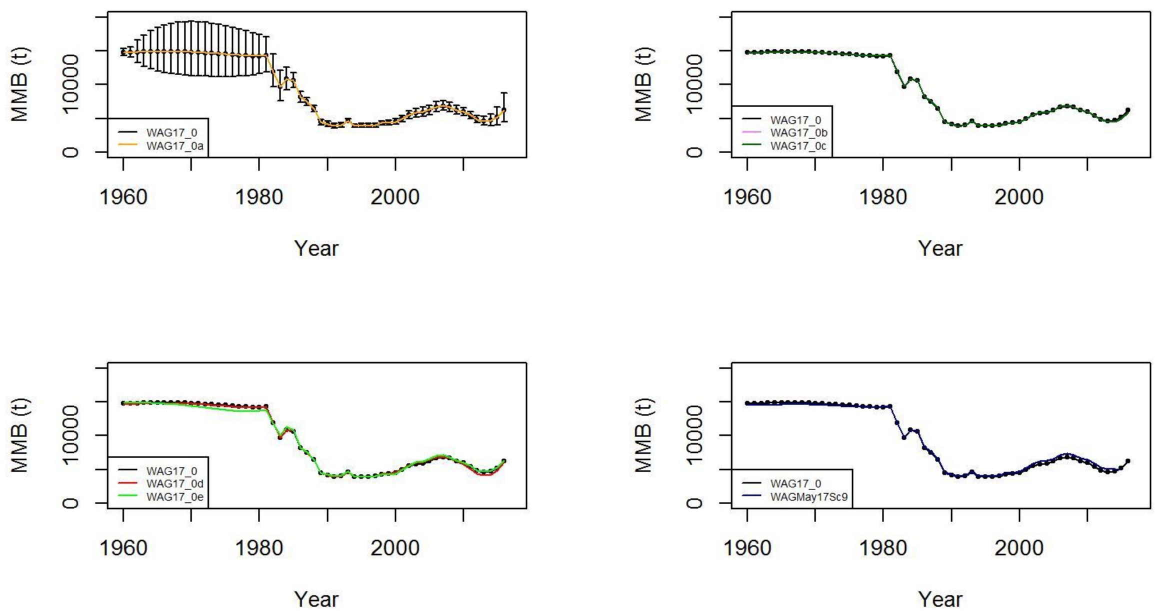


Figure 46. Trends in golden king crab mature male biomass for scenarios 17_0 to May 2017 Sc9 model fits in the WAG, 1960/61–2016/17. Scenario 17_0 estimates have two standard errors confidence limits.

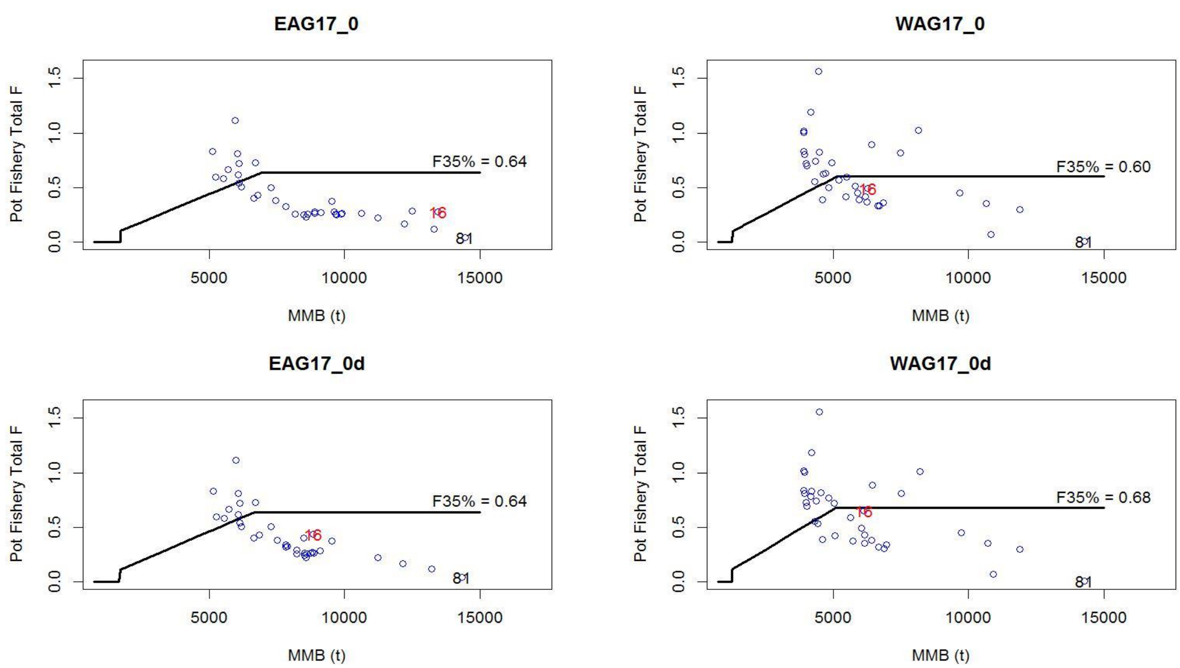


Figure 47. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985/86–2016/17 under scenarios 17_0 and 17_0d for EAG and WAG. Average recruitment from 1987 to 2012 was used to estimate $MMB_{35\%}$. Pot and groundfish handling mortality rates were assumed to be 0.2 and 0.65, respectively.

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 $\widehat{Tr}_{t,i}$ 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 ($\widehat{T}_{t,i\ temp}$) 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

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

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

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

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

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

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

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

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

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

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

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

Growth Matrix

The growth matrix X is modeled as follows:

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

where:

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

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

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

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

ω_1 , ω_2 , and σ are estimable parameters, 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:

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

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:

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

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

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

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:

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

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.:

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

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

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

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

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

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:

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

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:

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

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 selectivities 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):

$$P_1 = \lambda_F \sum_t (\ln F_t - \ln \bar{F})^2 \quad (A.20)$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ln F^{Tr}_t - \ln \bar{F}^{Tr})^2$$

(A.21)

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

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

Standardized Residual of Length Composition

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

Output Quantities

Harvest rate

Total pot fishery harvest rate:

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

Exploited legal male biomass at the start of year t:

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

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

Mature male biomass on 15 February spawning time (NPFMC 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* $MMB_{current} > 0.25 MMB_{35\%}$,

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

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	1981–2016 (estimated)
Mean pot fishery fishing mortality, $\bar{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2016 (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+) or 3 (1981–2004, 2005–2012, 2013+) (estimated)
Pot fishery total selectivity difference, deltaθ^{T}	2 (1981–2004; 2005+) or 3 (1981–2004; 2005–2012; 2013+) (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, $0.21 yr^{-1}$)
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	57 (1961–2017) (estimated)

Fishery catchability, q	2 (1985–2004; 2005+) or 3 (1981–2004; 2005–2012; 2013+) (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. select. phase = selectivity phase. Scenario 17_0f is for the independent survey and applicable only to EAG.

Weight	Value						
	Scenario 17_0	Scenario 17_0a	Scenario 17_0b	Scenario 17_0c	Scenario 17_0d	Scenario 17_0e	Scenario 17_0f
Catch:							
Retained catch for 1981–1984 and/or 1985–2016, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch for 1990–2016, 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	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	Number of sampled pots scaled to a max 250
Groundfish bycatch for 1989 –2016, λ_{GD}	0.2 (3.344)	0.2	0.2	0.2	0.2	0.2	0.2
Catch-rate:							
Observer legal size crab catch-rate for 1995–2016, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	1	1
Independent survey catch-rate for 2015–2017, $\lambda_{r,CPUE}$							1(0.805)
Fish ticket retained crab catch-rate for 1985–1998 , $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	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	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	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	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	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2 (0.533)	2	2	2	2	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000	1000	1000	1000	1000

Tagging likelihood	EAG individual tag returns	EAG tag data	EAG tag data	EAG tag data	EAG tag data	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:

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

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 1990/91–2016/17 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 1995/96–2016/17. The 1990/91–2016/17 observer database consists of 112,510 records and that of 1995/96–2016/17 contains 108,231 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 –2016/17.

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 2005/06–2016/17, 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 previous to 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 26).

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.

Most scenarios used CPUE indices estimated by the GLM method. One scenario (17_0a) used the deltaGLMM spatio-temporal method (VAST, Thorson et al., 2015) to estimate observer CPUE indices. We describe both below:

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. Therefore, 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:

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

where Soak is in unit of days and is numeric; Month, Area code, Vessel code, Captain code, and Gear code are factorial variables; Depth in fathom is a numeric variable; VesSoak is a numeric variable computed as annual number of vessels times annual mean soak days (to account for other vessels' effect on CPUE); 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).

The R^2 formula for explanatory variable selection is as follows:

$$R^2 = \frac{(null\ model\ deviance - added\ parameter\ model\ deviance)}{null\ model\ deviance} \quad (B.4)$$

An arbitrary R^2 minimum increment of 0.01 was set to select the model terms.

First we determined the dispersion parameter (θ) by a grid search method (Fox and Weisberg, 2011). The best θ value was obtained at the minimum AIC:

Table B.1. Dispersion parameter search.

	Time Period	θ	AIC
EAG	1995/96–2004/05	1.37	223,933
	2005/06–2016/17	2.30	59,284
WAG	1995/96–2004/05	1.00	196,290
	2005/06–2016/17	1.17	94,190

Then we used the optimized dispersion parameter value in the GLM model for individual predictor variable fit to determine appropriate df value based on the minimum AIC:

Table B.2. Predictor variable degree of freedom search.

	Time Period	Predictor Variable	Df	AIC
EAG	1995/96–2004/05	Soak	4	235,222
		Depth	2	237,098
		VesSoak	9	232,152
	2005/06–2016/17	Soak	11	59,988
		Depth	6	60,215
		VesSoak	4	59,982
WAG	1995/96–2004/05	Soak	10	201,755
		Depth	9	205,398
		VesSoak	7	204,841
	2005/06–2016/17	Soak	5	95,181
		Depth	2	95,202
		VesSoak	4	94,954

We also used the "stepAIC" package (R Core Team, 2018) for forward selection of predictor variables for CPUE standardization for scenarios EAG17_0b and WAG17_0b, respectively. Instead of using the traditional AIC (-2log_likelihood+2p) we used CAIC {-2log_likelihood+[ln(n)+1]p} for variable selection, where n=number of observations and p= number of parameters to be estimated.

The final main effect models for EAG were:

Under R square selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{Area} + \text{ns}(\text{Soak}, 4)$ (B.5)
for the 1995/96–2004/05 period [θ=1.37, $R^2 = 0.2473$, AIC=223,933]

Under CAIC selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + \text{Month} + \text{Area}$ (B.6)
for the 1995/96–2004/05 period [θ=1.37, $R^2 = 0.2563$, AIC=224,707]

Under R square selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 11)$ (B.7)
for the 2005/06–2016/17 period ($\theta = 2.30$, $R^2 = 0.1177$, $\text{AIC} = 59{,}284$).

Under CAIC selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Gear} + \text{ns}(\text{Soak}, 11)$ (B.8)
for the 2005/06–2016/17 period ($\theta = 2.30$, $R^2 = 0.1143$, $\text{AIC} = 59{,}610$).

The final models for WAG were:

Under R square selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 10) + \text{Area}$ (B.9)
for the 1995/96–2004/05 period [θ=1.00, $R^2 = 0.2031$, AIC=196,290]

Under CAIC selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 10) + \text{Month} + \text{Vessel} + \text{ns}(\text{Depth}, 9)$ (B.10)
for the 1995/96–2004/05 period [θ=1.00, $R^2 = 0.1948$, AIC=197,640]

Under R square selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Area} + \text{Gear} + \text{ns}(\text{Soak}, 5)$ (B.11)
for the 2005/06–2016/17 period
[θ=1.17, $R^2 = 0.0831$, $\text{AIC} = 94{,}190$ with $\text{ns}(\text{Soak}, 5)$ forced in]

Under CAIC selection criteria:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Vessel} + \text{ns}(\text{Depth}, 2) + \text{Month} + \text{ns}(\text{Soak}, 5)$ (B.12)
for the 2005/06–2016/17 period
[θ=1.17, $R^2 = 0.0684$, $\text{AIC} = 94{,}699$ with $\text{ns}(\text{Soak}, 5)$ forced in]

The final model after adding the Year:Area interaction term in the scope of variables for EAG were:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{Area} + \mathrm{Year{:}Area} + \mathrm{ns}(\mathrm{Soak}, 4) \quad \text{(B.13)}$$

for the 1995/96–2004/05 period
[θ=1.37, $R^2 = 0.2684$, AIC=223,164 with $\mathrm{ns}(\mathrm{Soak}, 4)$ forced in]

Note: A number of indeterminate parameter values for interaction factors were observed. However, as per January 2018 CPT request, we used the resulting CPUE indices in scenario EAG17_0c.

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 11) \quad \text{(B.14)}$$

for the 2005/06–2016/17 period [$\theta = 2.30$, $R^2 = 0.1177$, $\mathrm{AIC} = 59{,}284$].

Note: The Year:Area interaction term was not selected.

The final model after adding Year:Area interaction term in the scope of variables for WAG were:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 10) + \mathrm{Area} \quad \text{(B.15)}$$

for the 1995/96–2004/05 period [θ=1.00, $R^2 = 0.2031$, AIC=196,290]

Note: The Year:Area interaction term was not selected.

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Area} + \mathrm{Year{:}Area} + \mathrm{ns}(\mathrm{Soak}, 5) \quad \text{(B.16)}$$

for the 2005/06–2016/17 period
[θ=1.17, $R^2 = 0.1356$, $\mathrm{AIC} = 94{,}273$ with $\mathrm{ns}(\mathrm{Soak}, 5)$ forced in]

Note: A number of indeterminate parameter values for interaction factors were observed. However, as per January 2018 CPT request, we used the resulting CPUE indices in scenario WAG17_0c.

Figures B.1 to B.4 depict the trends in nominal and standardized CPUE indices for the two CPUE time series for EAG and WAG, respectively.

b. *Fishery independent survey CPUE index by GLM*:

The fishing industry and ADF&G cooperative fishery independent surveys have been conducted during the first month of each fishing season (i.e., August) for the last three years, 2015-2017 in the EAG, and this project is expected to continue. The sampling procedure is different from the observer sampling design. Fishing operations are conducted in a randomly selected grids (2km X 2km) and five pots per string are sampled for fishery and biological data collection (e.g., date, vessel, captain, soak time, depth, Lat. Long., pot number, string number, species, sex, size, legal status, catch, etc.). There are 7294 records for EAG golden king crab. 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.

The GLM followed the same procedure as that for observer data for standardizing CPUE. Only R^2 criterion was used for variable selection. The null model was

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year}_{\mathrm{y_i}} \quad \text{(B.17)}$$

where Year is a factorial variable.

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

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year}_{\mathrm{y_i}} + \mathrm{ns}(\mathrm{Soak_{si}}, \mathrm{df}) + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{VesStrPot_{Si}} + Lat_i + \mathrm{Long}Long_i + \mathrm{ns}(\mathrm{Depth_{di}}, \mathrm{df})$$

(B.18)

where Soak is in unit of days and is numeric; Depth in fathom is a numeric variable; Vessel code, Captain code, VesStrPot , Lat, and Long are factorial variables; ns=cubic spline, and df = degree of freedom. To make a unique factor level for vessel, string, and pot, we concatenated the Vessel code, string ID, and PotID (VesStrPot)..

The final model was

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{VesStrPot} + \mathrm{Lat} + \mathrm{ns}(\mathrm{Soak}, 11) \quad \text{(B.19)}$$

for the 2015/16–2017/18 period

$[\theta = 2.30,\ R^2 = 0.55695, \mathrm{AIC} = 30{,}481$ with $\mathrm{ns}(\mathrm{Soak}, 11)$ forced in$]$.

Because the assessment model considered fisheries data up to 2016/17, we used CPUE indices for 2015/16 – 2016/17 in the fitting of scenario EAG17_0f.

Figure B.5 shows the trends in nominal and standardized CPUE indices for the two CPUE time series for the independent survey in EAG.

c. *Observer CPUE index by VAST*:

We used a spatio-temporal deltaGLMM (Thorson et al., 2015; Thorson et al., 2017; Thorson and Barnett, 2017) to develop separate sets of CPUE indices based on the observer data for the pre- (1995/96–2004/05) and post- rationalization (2005/06–2016/17) periods. This is a two-stage model that first estimates the probability of presence (B.20) then estimates positive catch rates in the second stage (B.21). To account for the spatial dependence of crab density within the model, spatial and spatio-temporal autocorrelation are incorporated into the model as random effects. Positive catch rates in the model are a function of area fished. Since area swept is difficult to define for a pot gear, we used soak time as the area fished proxy. The number of knots is user defined and derived over the spatial domain based on the relative sampling density. Based on the fishing locations recorded during 1995/96-2016/17, one hundred knots were selected for each of EAG and WAG (Thorson et al., 2015; Runnebaum et al., 2017) (Figure B.6).

The final models applied to each period for EAG and WAG data are:

$$P_i = logit^{-1}\,[d^{(p)}_{T_{(i)}} + r^{(p)}_{v_i} + \omega^{(p)}_{J_{(i)}} + \varepsilon^{(p)}_{J_{(i)},T_{(i)}}\,] \tag{B.20}$$

$$\lambda_i = w_i exp[d^{(\lambda)}_{T_{(i)}} + r^{(\lambda)}_{v_i} + \omega^{(\lambda)}_{J_{(i)}} + \varepsilon^{(\lambda)}_{J_{(i)},T_{(i)}}\,] \tag{B.21}$$

where
P_i and λ_i are the expected probabilities of an occupied habitat and positive catches given occupied habitat for sample i at a given location; $d_{T_{(i)}}$ is the average annual density in year $T_{(i)}$; J_i is the nearest knot to sample i; w_i is the soak time for sample i; $\omega_{J_{(i)}}$ is a random field accounting for spatially correlated variability at knot $J_{(i)}$ that is persistent among years; $\varepsilon_{J_{(i)},T_{(i)}}$ is the random field accounting for spatio-temporal correlation at knot $J_{(i)}$ in year $T_{(i)}$; and r_{v_i} is a random effect accounting for differences in catch between vessels.

Figure B.7 compares the CPUE index trends between GLM and deltaGLMM estimates for EAG and WAG. The CPUE trends are similar, in particular during the post rationalization period. The confidence intervals for deltaGLMM estimated CPUE indices are wider than those of GLM estimated CPUE indices. Spatio-temporal models have been shown to provide more precision compared to design sampling of stock distribution because they are able to account for the spatial variation in density, thereby minimizing unexplained variability (Thorson et al., 2015). However, this was not the case when using a spatio-temporal deltaGLMM for golden king crab along the Aleutian Islands. There are likely two contributing factors to the increased variability in CPUE estimates. 1) Currently the VAST modeling framework is not able to account for an 'edge effect' when extrapolating species density to a given grid cell. In essence, there is no recognition of a land existing between density distributions, it appears density estimates from a given knot are being extrapolated over land. 2) Standard abundance surveys use a pre-designed grid and sample all grid cells consistently; on the other hand, commercial fishery samples the stock area opportunistically. Consequently, there are some years where there are large gaps in coverage, resulting in large areas being assigned density estimates with no direct observations for that area. This is leading to likely uncertainty in the spatial variability in density estimates. These are the two likely causes of increased variability in standard error estimates when using the deltaGLMM for Aleutian Islands golden king crab.

Fish Ticket CPUE index:

We also fitted the lognormal GLM for the fish ticket retained CPUE time series 1985/86–1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables. The fitting procedure was similar to that followed for observer data analysis. There were 20,435 records for 1985/86 –2016/17. The number of records was reduced by considering only those for 1985/86 – 1998/99, positive catches, and Vessels with five trips per year for at least three years.

The final model for EAG was:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Area} + \text{Vessel} + \text{Month},\ R^2 = 0.5037, \text{AIC} = 4{,}957 \quad (\text{B.22})$$

Under CAIC selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month},\ R^2 = 0.3700,\ \text{AIC} = 5{,}345 \quad (\text{B.23})$$

and those for WAG was:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel} + \text{Area},\ R^2 = 0.4971,\ \text{AIC} = 9{,}923 \quad (\text{B.24})$$

Under CAIC selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel},\ R^2 = 0.3679,\ \text{AIC} = 10{,}670 \quad (\text{B.25})$$

The final model after adding the Year:Area interaction term in the scope of variables for EAG were:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Area} + \text{Vessel} + \text{Month} + \text{Year:Area},\ R^2 = 0.6086,\ \text{AIC} = 4{,}783 \quad (\text{B.26})$$

The final model after adding the Year:Area interaction term in the scope of variables for WAG were:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel} + \text{Area} + \text{Year:Area},\ R^2 = 0.6105,\ \text{AIC} = 9{,}802 \quad (\text{B.27})$$

Note:

1. A number of indeterminate parameter values for Year:Area interaction factors were observed. However, as per January 2018 CPT request, we used the resulting CPUE indices in scenarios EAG17_0c and WAG17_0c.

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

Figures B.8 and B.9 depict the trends in nominal and standardized CPUE indices for the 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.

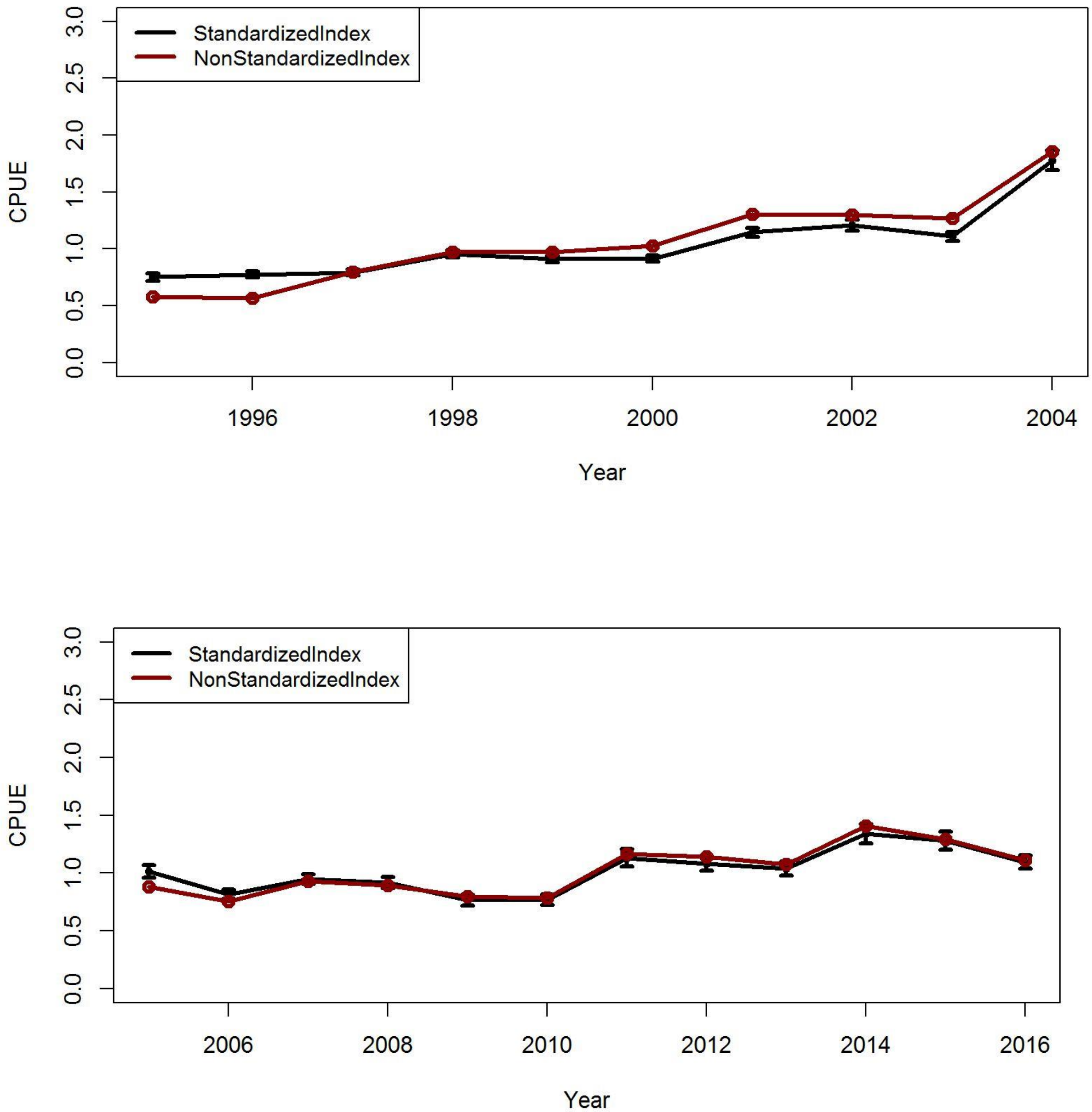


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by R^2 criteria.

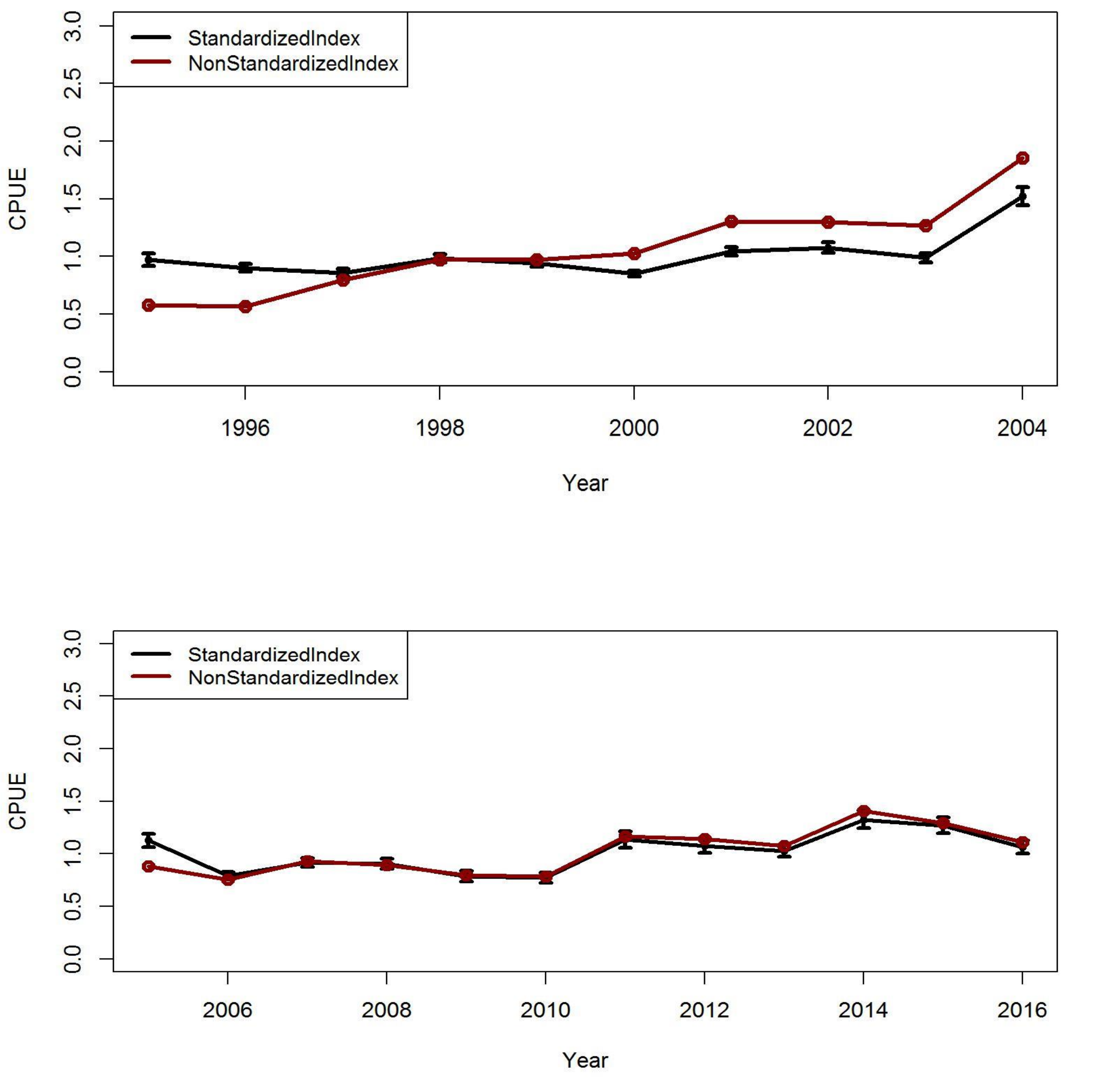


Figure B.2. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by CAIC criteria.

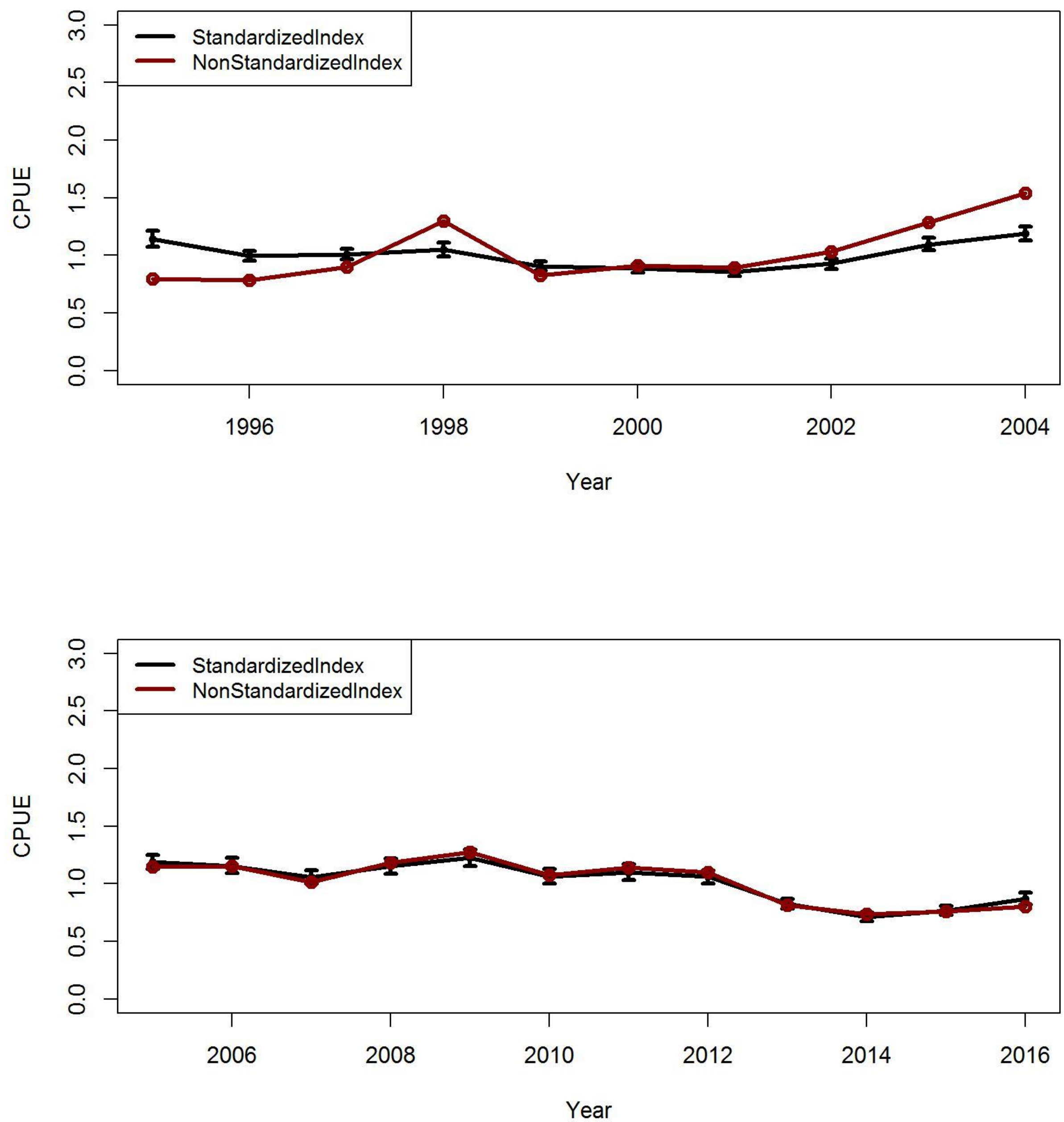


Figure B.3. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by R^2 criteria.

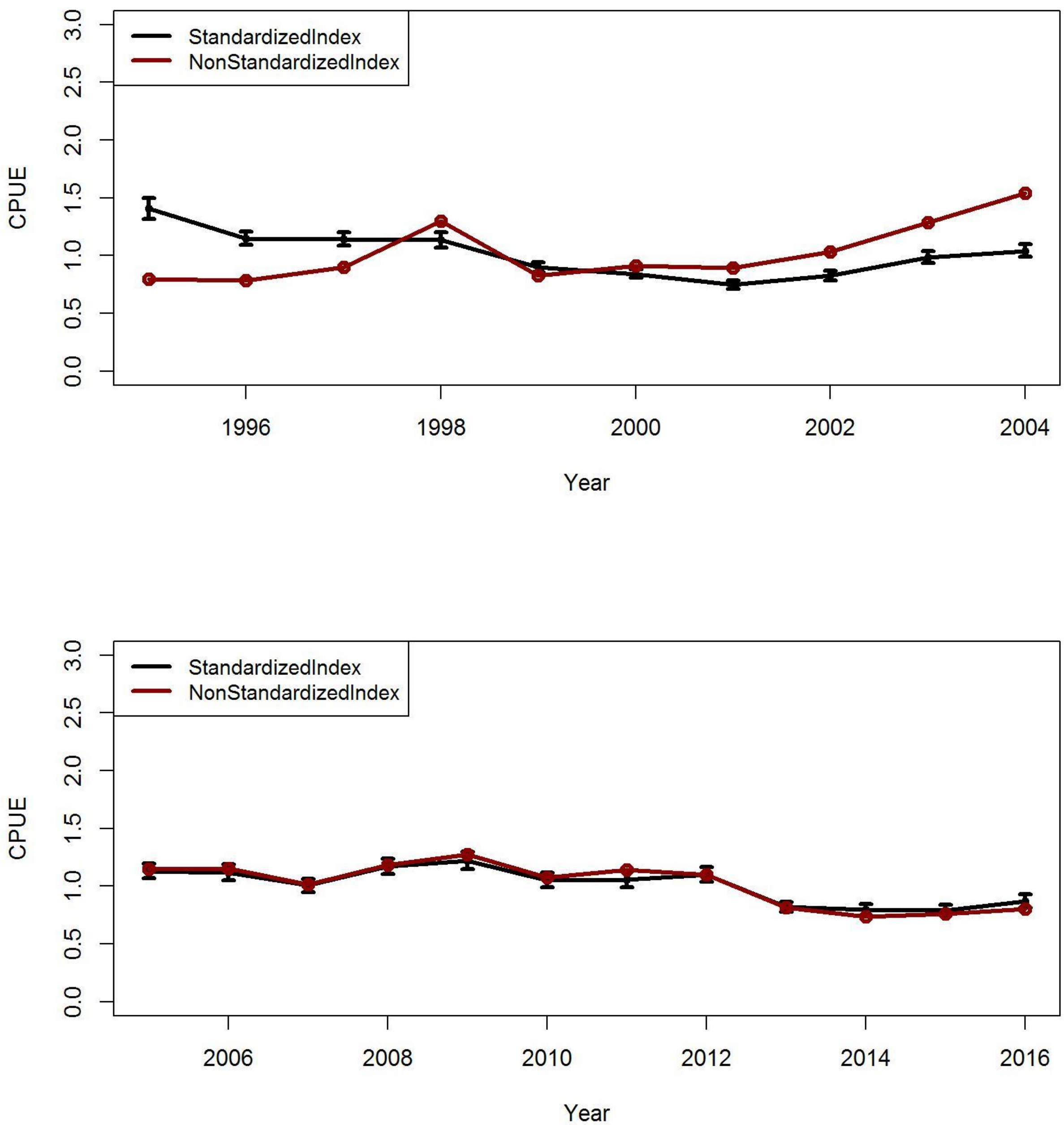


Figure B.4. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by CAIC criteria.

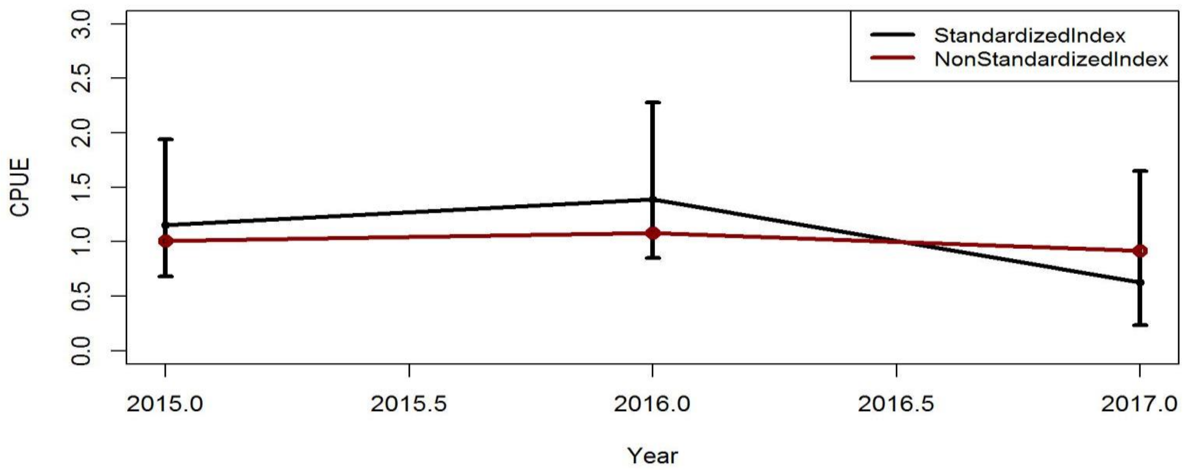


Figure B.5. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab independent survey data from EAG (east of 174 ° W longitude) during 2015–2017. Standardized indices: black line and non-standardized indices: red line. Variable selection by R^2 criteria.

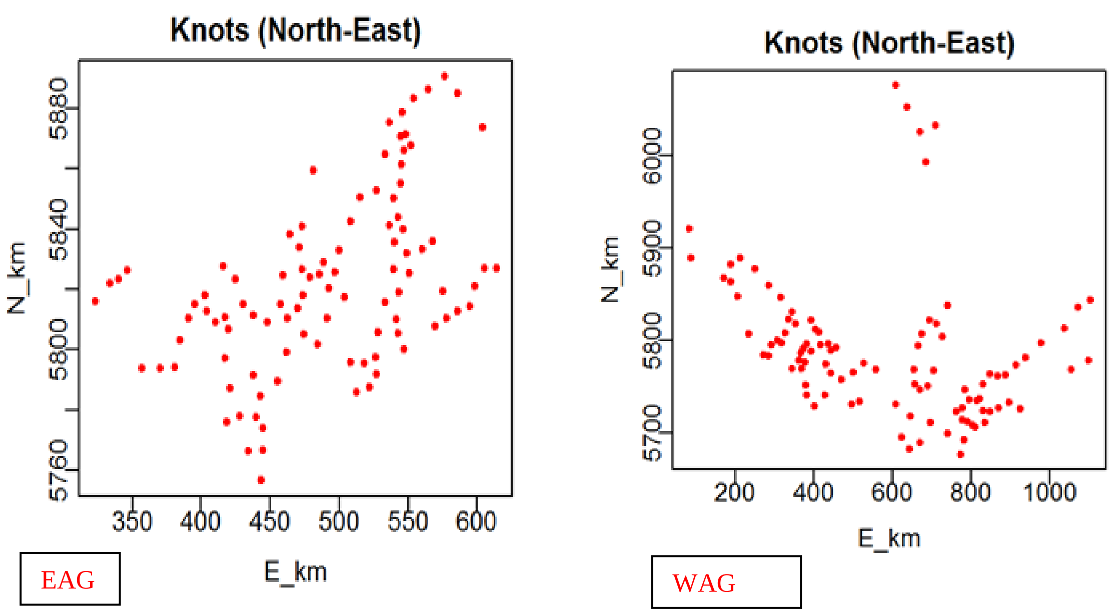


Figure B6. One hundred knots selected each for EAG (left panel) and WAG (right panel) for spatio-temporal delta GLMM model fitting for CPUE indices estimation.

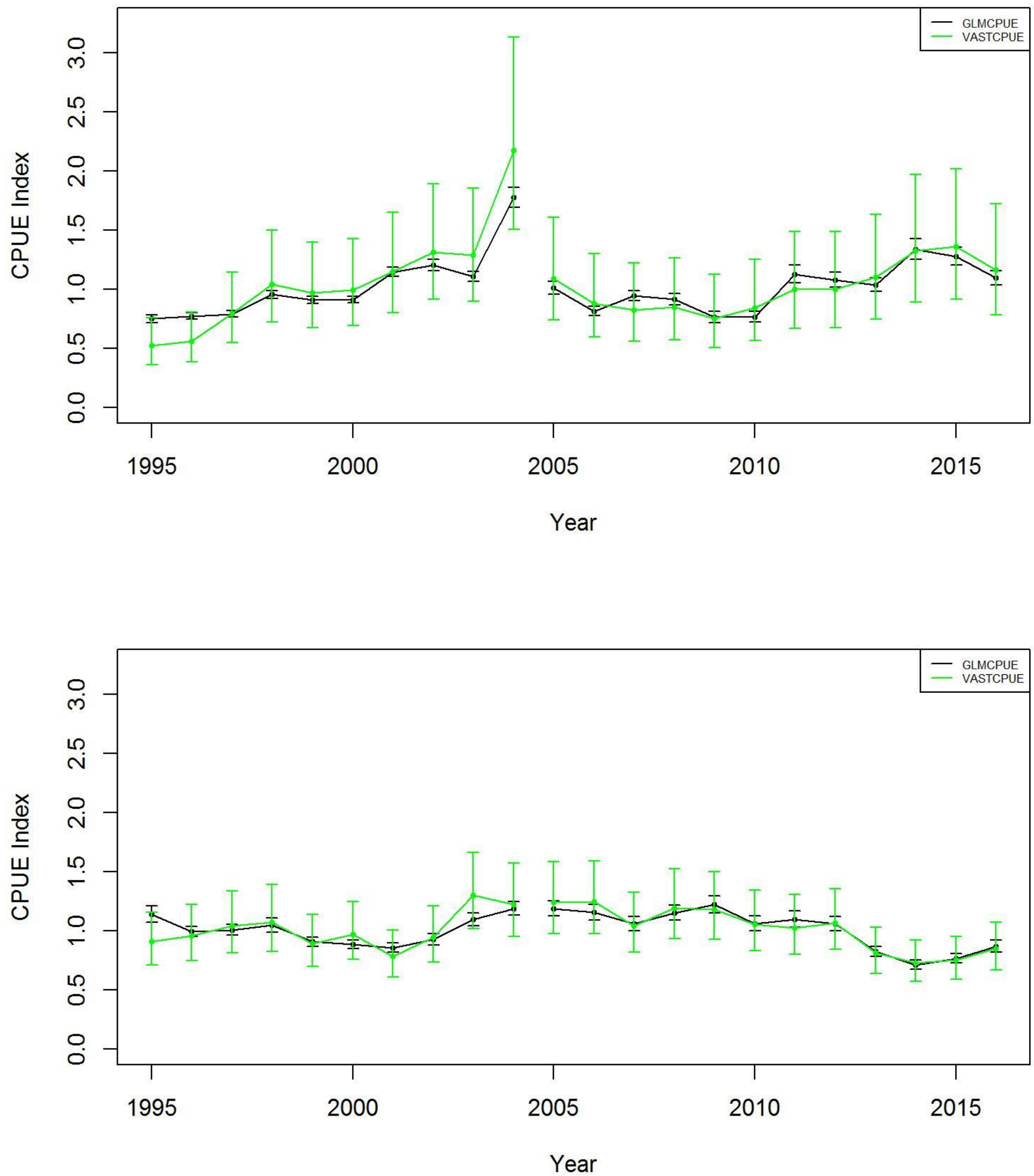


Figure B.7. Comparison of GLM (black) and VAST (green) estimated CPUE indices with +/- 2 SE for Aleutian Islands golden king crab in EAG (top panel) and WAG (bottom panel) for 1995/96–2016/17. GLM variable selection by R^2 criteria.

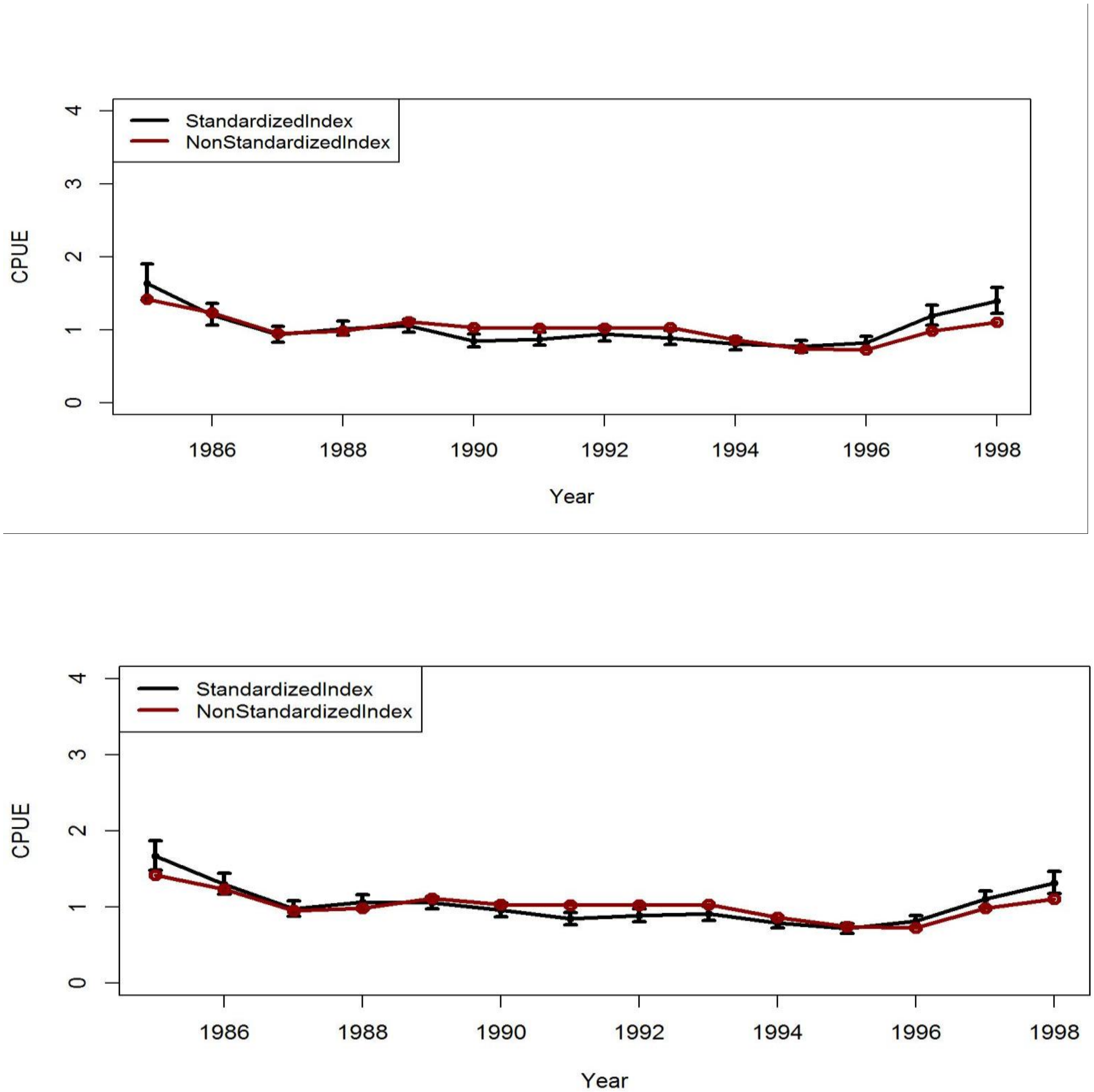
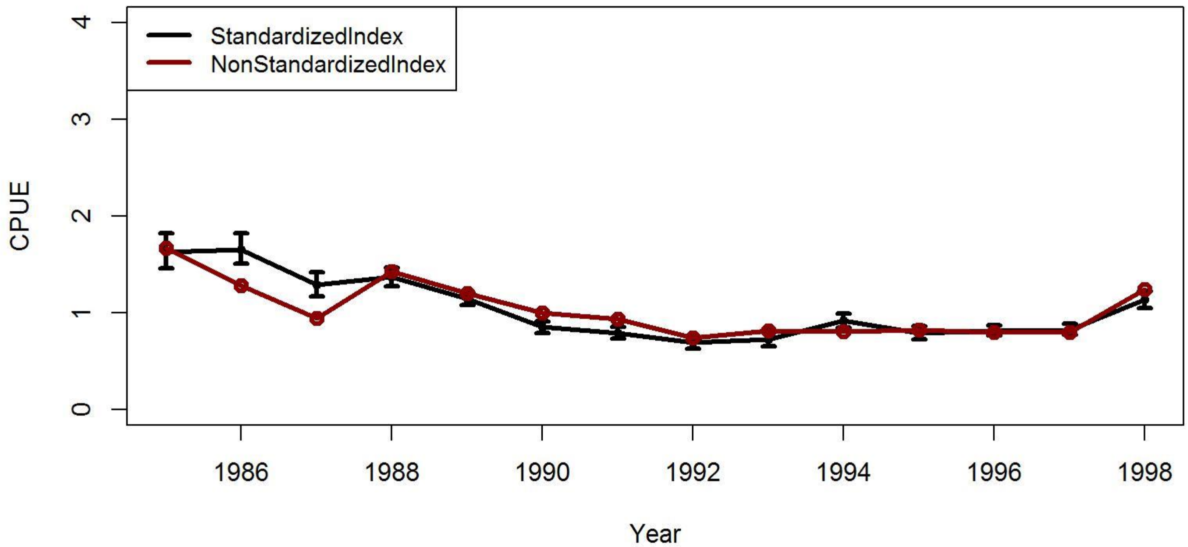


Figure B.8. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line. Top panel: variable selection by R^2 criteria; bottom panel: variable selection by CAIC square criteria.



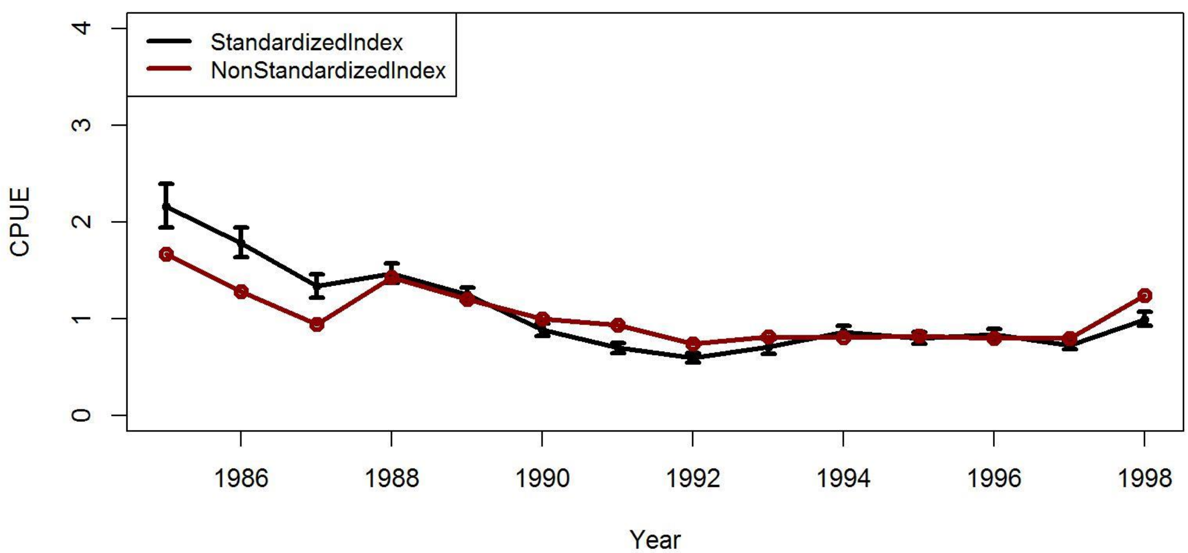


Figure B.9. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line. Top panel: variable selection by R^2 criteria; bottom panel: variable selection by CAIC criteria.

Appendix C: Male maturity

Male maturity:

Method:

We used the 1991 EAG pot survey collected 2457 carapace length (mm CL) and chela height (up to one-tenth of a mm CH) measurements in the EAG and NMFS survey collected 508 same measurements in Bowers Ridge, WAG for male 50% maturity length determination. We determined the 50% maturity length outside the assessment model using the ‘segmented regression’ package available in R (R Core Team 2017). We used the 50% maturity length as the break point for categorizing immature and mature crab for mature male biomass (MMB) determination for EAG and WAG.

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

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

where β_0 and β_1 are regression parameters

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

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

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

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

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

Results:

Table C1. Breakpoint analysis results for EAG:

Breakpoint Estimate, CL:	107.015	Standard Error (SE):	1.916	
Meaningful coefficients of the linear terms:				
	Estimate	SE	t value	Pr(>|t|)
Intercept	-1.60175	0.02286	-70.05	<2e-16 ***
CL	0.00070	0.00026	2.72	0.00657 **
U1.CL	0.00424	0.00029	14.45	NA

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Adjusted R-squared: 0.4551, df = 2453

Thus, the break point estimate of male CL (i.e., 50% maturity length) = 107.015 mm CL.

Table C2. Breakpoint analysis results for WAG:

Breakpoint Estimate, CL:	107.482	Standard Error (SE):	2.747	
Meaningful coefficients of the linear terms:				
	Estimate	SE	t value	Pr(>|t|)
Intercept	-1.63672	0.05592	-29.271	<2e-16 ***
CL	0.00086	0.00059	1.446	0.149
U1.CL	0.00441	0.00063	7.035	NA
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Adjusted R-squared: 0.7389, df=504				

Thus, the break point estimate of male CL (i.e., 50% maturity length) = 107.482 mm CL.

Figures C.1 and C.2 provide the segment regression fit to the log (CH/CL) vs. CL data pair for EAG and WAG, respectively:

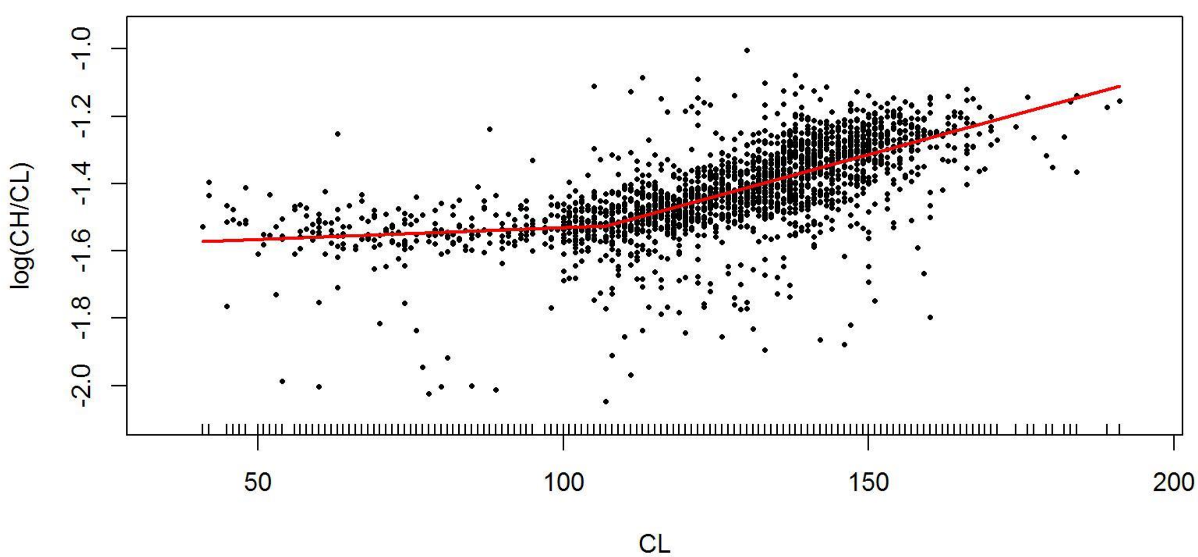


Figure C.1. Segmented linear regression fit to ln(CH/CL) vs. CL data of male golden king crab in EAG.

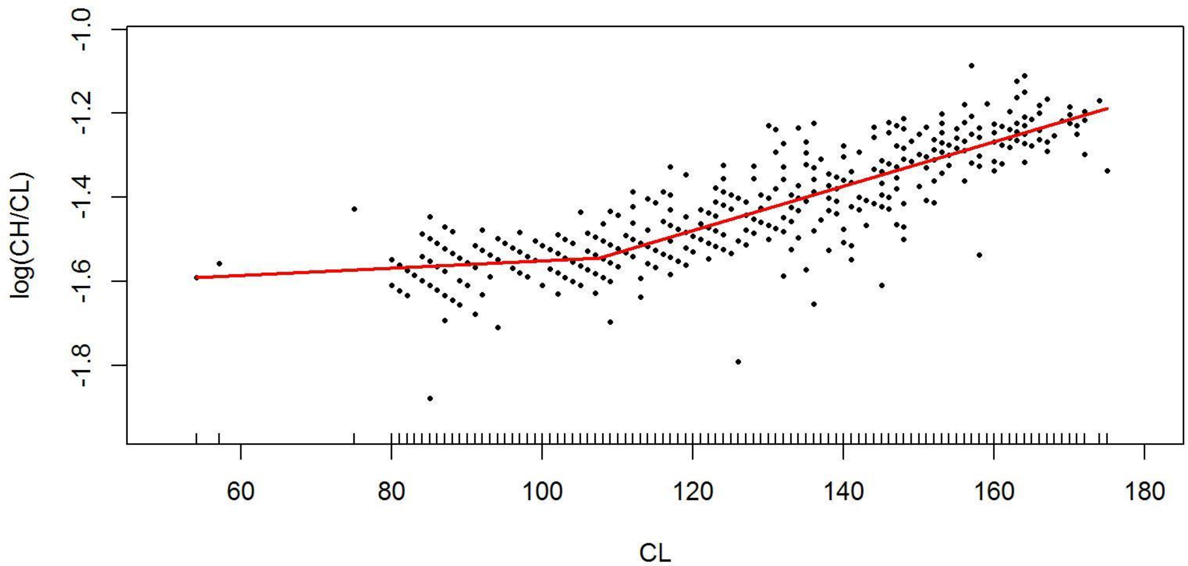


Figure C.2. Segmented linear regression fit to ln(CH/CL) vs. CL data of male golden king crab in WAG.

Bootstrap estimate of breakpoint with 95% confidence limits:

We created 1000 bootstrap samples of the ln(CH/CL) and CL pair and fitted the segmented regression to each sample [ln(CH/CL) vs CL] and estimated the median and the 95% confidence interval (2.5% and 97.5% percentiles of CL of the breakpoints) for EAG and WAG.

Table C.3. Median and 95% confidence limits of 1000 bootstrap estimates of male maturity by breakpoint analysis of chela height and carapace length data of golden king crab in EAG (1991 data) and WAG (1984 data).

Males	Median	Lower 95% Limit	Upper 95% Limit
EAG			
Maturity Breakpoint (mm CL)	107.02	85.12	111.02
WAG			
Maturity Breakpoint (mm CL)	107.85	103.46	126.03

We considered one bin above the median maturity size falling bin as the knife edge breakpoint of maturity. Thus all sizes equal and above 111 mmCL were considered to be fully mature and below this size immature for MMB calculation.

Essential R steps:
 # Segmented regression:
 # fit a single linear regression first then apply segmented
library(segmented)
singleline.mod<- lm(log(CH/CL)~CL)
segmented.mod<- segmented(singleline.mod,seg.Z=~CL)

Review of king crab male maturity:

Chelae allometry has been used to determine morphometric male size-at-maturity among a number of king crab (*Lithodidae*) stocks. Golden king crab provides a better discrimination of chelae height against size at the onset of maturity than other king crab stocks (Somerton and Otto, 1986). Table C.4 lists the literature reported estimates of size-at-maturity of males and females of different king crab stocks in the northern hemisphere including golden king crab. Breakpoint analysis has been used to estimate maturity on king crabs in majority of cases (Table C.4 and Webb, 2014).

Table C.4. Review of estimates of male and female size-at-maturity of golden (*Lithodes aequispins*), blue (*Paralithodes platypus*), and red (*Paralithodes camtschatica*) king crabs by area and stocks. Numbers in parentheses are standard deviations estimated by the bootstrap sampling method.

Species	**Sex**	**Size-at-Maturity (mm CL)**	**Method**	**Area**	**Sources**
Lithodes aequispins	Male	114 (11.4)	Breakpoint analysis on log(chela height) vs. log(carapace length)	British Columbia, Canada	Jewett *et al*., 1985
		92 (2.4) 107 (4.6) 130 (4.0)	Breakpoint analysis on log(chela height) vs. log(carapace length)	St. Matthew Is. District Pribilof Is District Eastern Aleutian Is	Somerton and Otto, 1986
		117.9 to 158.0	Breakpoint analysis on log(chela height) vs. log(carapace length)	Various water inlets in southeast Alaska	Olson, 2016
		108.6 (2.6) 120.8 (2.9)	Breakpoint analysis on log(chela height) vs. log(carapace length)	Bowers Ridge Seguam Pass	Otto and Cummiskey, 1985
		107.8 (5.2) 107.0 (6.2)	Breakpoint analysis on log (chela height/carapace length) vs. carapace length; median estimates	Bowers Ridge Seguam Pass	Current analysis
		110	Minimum size of successful mating (lab observation)	Prince William Sound	Paul and Paul, 2001
	Female	105.5 (0.7)	Size at 50% ovigerity – logistic regression	British Columbia, Canada	Jewett *et al*., 1985

Species	**Sex**	**Size-at-Maturity (mm CL)**	**Method**	**Area**	**Sources**
		97.7 (0.5) 99.9 (0.2) 110.7 (0.8)	Size at 50% ovigerity – logistic regression	St. Matthew Is. District, Pribilof Is District, Eastern Aleutian Is	Somerton and Otto, 1986
		106.4 (0.5) 113.2 (0.3) 102.2 (0.3)	Size at 50% ovigerity – logistic regression	Bowers Ridge Seguam Pass Petrel Bank	Otto and Cummiskey, 1985
Paralithodes platypus	Male	77 (9.8) 108 (12.8) 87 (7.2) 93 (13.9)	Breakpoint analysis on log(chela height) vs. log(carapace length)	St. Matthew Is. Pribilof Is. Olga Bay Prince William Sound	Somerton and MacIntosh, 1983
		~100	Lab study: Asymptote of the spermatophore diameter vs. carapace length	St. Matthew Is.	Paul *et al.*, 1991
	Female	80.6 (0.6) 96.3 (0.3) 93.7 (0.4) 87.4 (0.5)	Size at 50% ovigerity – logistic regression	St. Matthew Is. Pribilof Is. Olga Bay Prince William Sound	Somerton and MacIntosh, 1983
Paralithodes camtschatica	Male	102.8	Breakpoint analysis on log(chela height) vs. log(carapace length)	Eastern Bering Sea	Somerton, D.A., 1980
		120	Smallest male grasping female (in situ observation on mating pairs)	Kodiak	Powell *et al.*, 2002
		104.3	Breakpoint analysis on log(chela height) vs. log(carapace length)	Barents Sea, Norway	Rafter *et al.*, 1996
		105	Lab study: Asymptote of the spermatophore diameter vs. carapace length	Bristol Bay	Paul *et al.*, 1991
	Female	101.9	Breakpoint analysis on log(chela height) vs. log(carapace length)	Eastern Bering Sea	Somerton, D.A., 1980
		88.8 (0.5)	Size at 50% ovigerity – logistic regression	Bristol Bay	Otto *et al.*, 1990
		89 (1.3)	Size at 50% ovigerity – logistic regression	Adak Island	Blau *et al.*, 1990

References:

Blau, S.F. 1990. Size at maturity of female red king crabs (Paralithodes camtschatica) in the Adak Management Area, Alaska. In proceedings of the international symposium on king and

Tanner crabs. Alaska Sea Grant College Program Report No. 90-04. University of Alaska Fairbanks, Fairbanks, AK, pp. 105-116.

Jewett, S.C., N.A. Sloan, and D.A. Somerton, 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from northern British Columbia. Journal of Crustacean Biology, 5(3): 377-385.

Olson, A.P. 2016. Spatial variability in size at maturity and reproductive timing of golden king crab (*Lithodes aequispina*) in Southeast Alaska. MSc thesis, University of Alaska Fairbanks, Fairbanks, Alaska.

Otto, R.S. and P.A. Cummiskey, 1985. Observations on the reproductive biology of the golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. In Proceedings of the International king crab symposium, Edited by B. R. Melteff. University of Alaska Sea Grant, Anchorage, Alaska. pp. 123-136.

Otto, R.S., R.A. Macintosh, and P.A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (*Paralithodes camtschatica*) in Bristol Bay and Norton Sound, Alaska. In Proceedings of the International Symposium on King and Tanner Crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, Fairbanks, AK, pp. 65-90.

Paul, A.J. and J.M. Paul, 2001. Size of maturity in male golden king crab, *Lithodes aequispinus* (Anomura: Lithodidae). Journal of Crustacean Biology, 21(2): 384-387.

Somerton, D.A. 1980. A computer technique for estimating the size of sexual maturity in crabs. *Can.J.Fish.Aquat.Sci.*, 37:1488-1494.

Paul, J.M, A.J. Paul, R.S. Otto, and R. Macintosh. 1991. Spermatophore presence in relation to carapace length for eastern Bering Sea blue king crab (*Paralithodes platypus*, Brandt, 1850) and red king crab (*P. camtschaticus*, Tilesius, 1815) . Journal of Shellfish Research 10(1): 157-163.

Powell, G.C., D. Pengilly, and S.F Blau. 2002. Mating pairs of red king crab (*Paralithodes camtschaticus*) in the Kodiak Archipelago, Alaska, 1960-1984. In A.J. Paul, E.G. Dawe, R. Elner, G.S. Jameison, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.), Crab in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant College Program AK-SG-02-01, University of Alaska Fairbanks, Fairbanks, AK, pp 225-245.

Rafter E.E., M.Nilssen, and J.H. Sundet. 1996. Stomach content, life history, maturation, and morphometric parameters of red king crab, *Paralithodes camtschaticus*, from Varangerfjord area, North Norway, ICES CM 1996/K:10.

Somerton, D.A. and R.S. Otto, 1986. Distribution and reproductive biology of the golden king crab, *Lithodes aequispina*, in the Eastern Bering Sea. *Fishery Bulletin*, 84(3): 571-584.

Somerton, D.A. and MacIntosh, R.A. 1983. The size at sexual maturity of blue king crab, *Paralithodes platypus*, in Alaska. *Fishery Bulletin*, 81:621-628.

Webb, J., 2014. Reproductive ecology of commercially important lithodid crabs. In King crabs of the world: biology and fisheries management, Edited by B. G. Stevens. CRC Press, Boca Raton, FL. pp. 285-314.

Appendix D: Francis and McAllister and Ianelli re-weighting methods

Stage-1 effective sample size:

We considered number of vessel-days as the initial input annual effective sample sizes (i.e., Stage-1) for retained and total size compositions and number of trips for groundfish discard catch size composition without enforcing any upper limit. The number of vessel-days was calculated using,

$$Vessel - days_t = mean\ trip\ day_t \times number\ of\ trips\ made\ by\ all\ vessels_t \quad \text{(D.1)}$$

The groundfish bycatch of golden king crab comes from bottom trawlers, fish pot, and longlines. Vessel-days are difficult to calculate for the groundfish bycatch and hence we used annual number of trips as the Stage-1 effective sample size. Please note that we did not use the groundfish discard size compositions in any of the scenario's optimization although the predicted effective sample sizes were produced as a byproduct. We refer to the Stage-1 effective samples sizes for the size-composition of the retained catch, total catch, and the groundfish crab bycatch for year t as $\tau^{r}_{1,t}, \tau^{T}_{1,t}$, and $\tau^{Tr}_{1,t}$ respectively.

We estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes. The reiterated effective sample sizes' subscripts replace 1 by 2.

Francis' method:

The Francis' (2011) mean length based method [i.e., Francis TA1.8 method, Punt (2017)] uses the following formulas:

Observed mean length for year *t*,

$$\overline{l_t} = \sum_{i=1}^{n} l_{t,i} \times P_{t,i} \quad \text{(D.2)}$$

Predicted mean length for year *t*,

$$\hat{\bar{l}}_t = \sum_{i=1}^{n} l_{t,i} \times \hat{P}_{t,i} \quad \text{(D.3)}$$

Variance of the predicted mean length in year *t*,

$$var\left(\hat{\bar{l}}_t\right) = \frac{\sum_{i=1}^{n} \hat{P}_{t,i}\left(l_{t,i} - \hat{\bar{l}}_t\right)^2}{S_t} \quad \text{(D.4)}$$

Francis' re-weighting parameter *W*,

$$W = \frac{1}{var\left\{\frac{\bar{l}_t - \hat{\bar{l}}_t}{\sqrt{var\left(\hat{\bar{l}}_t\right)}}\right\}} \quad \text{(D.5)}$$

where $\hat{P}_{t,i}$ and $P_{t,i}$ are the estimated and observed proportions of the catch during year t in length-class i, $l_{t,i}$ is the mid length of the length-class i during year t, S_t is the effective sample size in year t, $\hat{\bar{l}}_t$ and $\bar{l}_t$ are predicted and observed mean lengths of the catch during year t, n is the number of length bins, and W is the re-weighting multiplier of Stage-1 sample sizes.

Francis (2017) suggested that a good stopping criterion for the iteration process is when there are no appreciable changes in the key outputs. Hence, we considered a stopping criterion of no appreciable change (<0.01%) in W and terminal year MMB (Equation A.27).

S_t is related to the initial input (Stage-1) effective sample size according to:

$$S_{t,i} = W_i \tau_{1,t} \tag{D.6}$$

where $S_{t,i}$ is the effective sample size for year t in iteration i and W_i is the Francis weight calculated using Equation D.5 during iteration i.

We did the re-weighting for combined data (for *M* estimation), individual scenarios, and MMB profiles. For brevity, we provide the iteration process for Francis Stage-2 weight calculation for individual scenarios for EAG and WAG respectively in Table D.1.

McAllister's and Ianelli's method:

Based on the assumption that the size-composition data are a multinomial sample, McAllister and Ianelli (1997) provided an estimator for the Stage-2 effective sample sizes based on the ratio of the theoretical variance of expected proportions to the actual variance of proportions,

$$\tau_{2,t} = \frac{\sum_l \hat{P}_{t,l}(1-\hat{P}_{t,l})}{\sum_l (P_{t,l}-\hat{P}_{t,l})^2} \tag{D.7}$$

McAllister and Ianelli (1997) set the effective sample size for each size-composition data set for eastern Bering Sea yellowfin sole (*Limanda aspera*) as the arithmetic mean of $\tau_{2,t}$ over years *t* (i.e., a year-invariant effective sample size) and iterated the model fitting, updating the effective sample sizes, until convergence occurred. Equation D.7 ignores correlation among the residuals for the catch proportions so likely overestimates effective sample sizes (Francis, 2011). Punt (2015) suggests using the harmonic mean of $\tau_{2,t}$ if the McAllister and Ianelli formula is used. A harmonic mean (constant) multiplier was consequently used to update the effective sample sizes at each iteration of model fitting until convergence occurred; i.e.

$$\tau_{2,t,i} = \left\{ \frac{1}{n_t} \sum_t \left[\frac{\dot{\tau}_{2,t,i-1}}{\tau_{2,t,i-1}} \right]^{-1} \right\}^{-1} \tau_{2,t,i-1} \tag{D.8}$$

where $\tau_{2,t,i}$ is the Stage-2 effective sample size for year *t* in iteration *i* ($\tau_{2,t,0} = \tau_{1,t}$) and $\dot{\tau}_{2,t,i}$ is the result of applying Equation D.7. Convergence of the process of setting the Stage-2 effective sample sizes using Equation D.8 was assessed similar to Francis' procedure, but the weight (*W*) at the final iteration was allowed to reach 1. We considered this re-weighting process for scenarios EAG17_0e and WAG17_0e (Table D.1).

Table D.1. Iteration process for Stage-2 effective sample size re-weighting multiplier, *W*, by Francis' (scenarios 17b0, 17_0, 17_0a, 17_0b, 17_0c, 17_0d, and 17_0f) and McAllister and Ianelli (scenario 17_0e) methods for retained, total, and groundfish discard catch size compositions of golden king crab for EAG and WAG. Sc. =scenario. Note: For certain scenarios we have done over six iterations, but we provide only the last three iteration results.

Area	Sc.	Iteration No.	Retained Catch Size Comp Effective Sample Size Multiplier (W)	Total Catch Size Comp Effective Sample Size Multiplier (W)	Groundfish Discard Catch Size Comp Effective Sample Size Multiplier (W)	Terminal MMB (t)	*M* yr^{-1}
EAGpart	17b0	1	0.8384	0.5053	0.4469	14,342	0.2274
		2	0.8384	0.5066	0.4458	14,142	0.2254
		3	0.8384	0.5053	0.4469	14,141	0.2254
WAGpart	17b0	1	0.5176	0.4685	0.7542	6,646	0.2274
		2	0.5175	0.4684	0.7584	6,603	0.2254
		3	0.5176	0.4685	0.7542	6,603	0.2254
EAG	17_0	1	0.8343	0.5084	0.4476	13,455	0.21
		2	0.8339	0.5086	0.4476	13,455	
		3	0.8338	0.5086	0.4476	13,455	
WAG	17_0	1	0.5171	0.4698	0.7596	6,269	0.21
		2	0.5172	0.4697	0.7598	6,269	
		3	0.5173	0.4697	0.7597	6,269	
EAG	17_0a	1	0.8343	0.5349	0.4488	13,579	0.21
		2	0.8340	0.5349	0.4487	13,579	
		3	0.8340	0.5349	0.4488	13,579	
WAG	17_0a	1	0.5180	0.4707	0.7625	6,280	0.21
		2	0.5183	0.4706	0.7627	6,280	
		3	0.5183	0.4705	0.7627	6,280	
EAG	17_0b	1	0.8351	0.5066	0.4498	11,842	0.21
		2	0.8353	0.5066	0.4497	11,842	
		3	0.8354	0.5065	0.4497	11,842	
WAG	17_0b	1	0.5084	0.4831	0.7643	5,884	0.21
		2	0.5083	0.4831	0.7643	5,884	
		3	0.5082	0.4832	0.7642	5,884	
EAG	17_0c	1	0.8182	0.5387	0.4468	13,766	0.21
		2	0.8181	0.5388	0.4467	13,767	
		3	0.8181	0.5388	0.4467	13,767	
WAG	17_0c	1	0.4979	0.4774	0.7581	6,154	0.21
		2	0.4979	0.4774	0.7579	6,154	
		3	0.4979	0.4774	0.7581	6,154	
EAG	17_0d	1	0.8450	0.5311	0.4495	8,833	0.21
		2	0.8452	0.5310	0.4495	8,833	
		3	0.8452	0.5310	0.4495	8,833	

WAG	17_0d	1	0.5582	0.4830	0.7604	6,136	0.21
		2	0.5578	0.4826	0.7611	6,136	
		3	0.5577	0.4826	0.7610	6,136	
EAG	17_0e	1	1.4025	0.7873	1.6475	13,453	0.21
		2	1.0640	0.9582	1.0022	13,444	
		3	1.0100	0.9908	1.0001	13,440	
WAG	17_0e	1	1.1639	0.9202	0.9948	6,348	0.21
		2	1.0384	0.9526	0.9989	6,353	
		3	1.0097	0.9817	0.9997	6,355	
EAG	17_0f	1	0.8396	0.5065	0.4487	12,484	0.21
		2	0.8410	0.5060	0.4488	12,485	
		3	0.8411	0.5060	0.4488	12,485	

Appendix E: Jittering

Jittering of scenario 17_0 parameter estimates:
We followed the Stock Synthesis approach to do 100 jitter runs of scenarios EAG17_0 and WAG17_0 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 found 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:

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

with the final jittered initial parameter value back transformed as:

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

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

The jitter results are summarized for scenario 17_0 in Tables E.1 and E.2 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 produced smaller objective function values compared to the base estimate (run 0). However, those fits predicted extremely large groundfish bycatches in certain years, consequently we ignored those runs. Thus we selected scenario 17_0 as the base scenario for EAG and WAG.

Table E.1. Results from 100 jitter runs for scenario 17_0 for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1986–2016.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**285.91650**	**0.0000222934**	**6,954.48**	**3,917.74**	**11,554.70**
1	285.91650	0.0000174504	6,954.48	3,917.74	11,554.70
2	285.91650	0.0001631845	6,954.48	3,917.74	11,554.70
3	285.91650	0.0000062988	6,954.48	3,917.74	11,554.70
4	285.91650	0.0002805318	6,954.48	3,917.74	11,554.70
5	285.91650	0.0001137684	6,954.48	3,917.74	11,554.70
6	285.91650	0.0001572297	6,954.48	3,917.74	11,554.70
7	285.91650	0.0001488496	6,954.48	3,917.74	11,554.70
8	285.91650	0.0003391617	6,954.48	3,917.74	11,554.70
9	285.91650	0.0001285458	6,954.48	3,917.74	11,554.70

10	285.91650	0.0000977588	6,954.48	3,917.74	11,554.70
11	285.91650	0.0001231468	6,954.48	3,917.74	11,554.70
12	285.91650	0.0000890800	6,954.48	3,917.74	11,554.70
13	285.91650	0.0000399059	6,954.48	3,917.74	11,554.70
14	285.91650	0.0002567647	6,954.48	3,917.74	11,554.70
15	285.91650	0.0000064600	6,954.48	3,917.74	11,554.70
16	285.91650	0.0002346045	6,954.48	3,917.74	11,554.70
17	285.91650	0.0002820026	6,954.48	3,917.74	11,554.70
18	285.91650	0.0000241932	6,954.48	3,917.74	11,554.70
19	285.91650	0.0000365975	6,954.48	3,917.74	11,554.70
20	285.91650	0.0003771734	6,954.48	3,917.74	11,554.70
21	285.91650	0.0001375338	6,954.48	3,917.74	11,554.70
22	285.91650	0.0001120951	6,954.48	3,917.74	11,554.70
23	285.91650	0.0000285661	6,954.48	3,917.74	11,554.70
24	285.91650	0.0006714663	6,954.48	3,917.74	11,554.70
25	285.91650	0.0001187696	6,954.48	3,917.74	11,554.70
26	285.91650	0.0000138714	6,954.48	3,917.74	11,554.70
27	285.91650	0.0000495531	6,954.48	3,917.74	11,554.70
28	285.91650	0.0005756958	6,954.48	3,917.74	11,554.70
29	285.91650	0.0000373670	6,954.48	3,917.74	11,554.70
30	285.91650	0.0001517096	6,954.48	3,917.74	11,554.70
31	285.91650	0.0003618456	6,954.48	3,917.74	11,554.70
32	285.91650	0.0013670960	6,954.48	3,917.74	11,554.70
33	285.91650	0.0000539773	6,954.48	3,917.74	11,554.70
34	285.91650	0.0000154992	6,954.48	3,917.74	11,554.70
35	285.91650	0.0000760394	6,954.48	3,917.74	11,554.70
36	285.91650	0.0000046526	6,954.48	3,917.74	11,554.70
37	285.91650	0.0002455134	6,954.48	3,917.74	11,554.70
38	285.91650	0.0001081487	6,954.48	3,917.74	11,554.70
39	285.91650	0.0001221035	6,954.48	3,917.74	11,554.70
40	285.91650	0.0001775793	6,954.48	3,917.74	11,554.70
41	285.91650	0.0000850537	6,954.48	3,917.74	11,554.70
42	285.91650	0.0000655746	6,954.48	3,917.74	11,554.70
43	285.91650	0.0001097075	6,954.48	3,917.74	11,554.70
44	285.91650	0.0005359162	6,954.48	3,917.74	11,554.70
45	285.91650	0.0000582206	6,954.48	3,917.74	11,554.70
46	285.91650	0.0001263718	6,954.48	3,917.74	11,554.70
47	285.91650	0.0001669157	6,954.48	3,917.74	11,554.70
48	285.91650	0.0001184376	6,954.48	3,917.74	11,554.70
49	285.91650	0.0001850153	6,954.48	3,917.74	11,554.70
50	285.91650	0.0001171299	6,954.48	3,917.74	11,554.70
51	285.91650	0.0000927041	6,954.48	3,917.74	11,554.70
52	285.91650	0.0001977530	6,954.48	3,917.74	11,554.70

53	285.91650	0.0000502208	6,954.48	3,917.74	11,554.70
54	285.91650	0.0002810899	6,954.48	3,917.74	11,554.70
55	285.91650	0.0002931756	6,954.48	3,917.74	11,554.70
56	285.91650	0.0001466994	6,954.48	3,917.74	11,554.70
57	285.91650	0.0001492200	6,954.48	3,917.74	11,554.70
58	285.91650	0.0000375202	6,954.48	3,917.74	11,554.70
59	285.91650	0.0004659215	6,954.48	3,917.74	11,554.70
60	285.91650	0.0000479571	6,954.48	3,917.74	11,554.70
61	285.91650	0.0000159505	6,954.48	3,917.74	11,554.70
62	285.91650	0.0000466713	6,954.48	3,917.74	11,554.70
63	285.91650	0.0001467107	6,954.48	3,917.74	11,554.70
64	285.91650	0.0003362615	6,954.48	3,917.74	11,554.70
65	285.91650	0.0003528916	6,954.48	3,917.74	11,554.70
66	285.91650	0.0001518528	6,954.48	3,917.74	11,554.70
67	285.91650	0.0000965183	6,954.48	3,917.74	11,554.70
68	285.91650	0.0001700814	6,954.48	3,917.74	11,554.70
69	285.91650	0.0001150075	6,954.48	3,917.74	11,554.70
70	285.91650	0.0001708935	6,954.48	3,917.74	11,554.70
71	285.91650	0.0000843366	6,954.48	3,917.74	11,554.70
72	285.91650	0.0000147518	6,954.48	3,917.74	11,554.70
73	285.91650	0.0000711309	6,954.48	3,917.74	11,554.70
74	285.91650	0.0000831972	6,954.48	3,917.74	11,554.70
75	285.91650	0.0001249322	6,954.48	3,917.74	11,554.70
76	285.91650	0.0000950038	6,954.48	3,917.74	11,554.70
77	285.91650	0.0000930142	6,954.48	3,917.74	11,554.70
78	285.91650	0.0005069687	6,954.48	3,917.74	11,554.70
79	285.91650	0.0001041060	6,954.48	3,917.74	11,554.70
80	285.91650	0.0000268403	6,954.48	3,917.74	11,554.70
81	285.91650	0.0001235642	6,954.48	3,917.74	11,554.70
82	285.91650	0.0001945769	6,954.48	3,917.74	11,554.70
83	285.91650	0.0004412037	6,954.48	3,917.74	11,554.70
84	285.91650	0.0000976698	6,954.48	3,917.74	11,554.70
85	285.91650	0.0000551057	6,954.48	3,917.74	11,554.70
86	285.91650	0.0000495026	6,954.48	3,917.74	11,554.70
87	285.91650	0.0005078082	6,954.48	3,917.74	11,554.70
88	285.91650	0.0001855834	6,954.48	3,917.74	11,554.70
89	285.91650	0.0001687559	6,954.48	3,917.74	11,554.70
90	285.91650	0.0000065286	6,954.48	3,917.74	11,554.70
91	285.91650	0.0000599673	6,954.48	3,917.74	11,554.70
92	285.91650	0.0003389603	6,954.48	3,917.74	11,554.70
93	285.91650	0.0000402791	6,954.48	3,917.74	11,554.70
94	285.91650	0.0002217916	6,954.48	3,917.74	11,554.70
95	285.91650	0.0000923698	6,954.48	3,917.74	11,554.70

96	285.91650	0.0000245177	6,954.48	3,917.74	11,554.70
97	285.91650	0.0001364416	6,954.48	3,917.74	11,554.70
98	285.91650	0.0001427303	6,954.48	3,917.74	11,554.70
99	285.91650	0.0000980820	6,954.48	3,917.74	11,554.70
100	285.91650	0.0000929987	6,954.48	3,917.74	11,554.70

Table E.2. Results from 100 jitter runs for scenario 17_0 for WAG. Jitter run 0 corresponds to the original optimized estimates. Since there were differences in the objective function estimates, we sorted out the jitter results from lowest to the highest objective function values. Note: B_{MSY} reference points were based on average recruitment for 1986–2017.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**194.09019**	**0.0001417655**	**5,137.94**	**1,596.46**	**6,397.24**
3	188.28830	0.0000977034	5,711.55	1,730.50	6,854.65
76	188.28830	0.0000794244	5,711.55	1,730.50	6,854.65
98	188.28830	0.0002341052	5,711.55	1,730.49	6,854.65
16	190.76970	0.0005141899	5,715.07	1,694.36	6,775.36
18	190.76970	0.0001464585	5,715.07	1,694.36	6,775.36
32	190.76970	0.0000894627	5,715.07	1,694.36	6,775.36
39	190.76970	0.0000800169	5,715.07	1,694.36	6,775.36
62	190.76970	0.0002638217	5,715.07	1,694.36	6,775.36
90	190.76970	0.0004216969	5,715.07	1,694.36	6,775.36
84	193.67430	0.0002215062	5,684.40	1,708.01	6,745.06
1	194.09020	0.0000999658	5,137.94	1,596.46	6,397.24
2	194.09020	0.0001227291	5,137.94	1,596.46	6,397.24
4	194.09020	0.0000671676	5,137.94	1,596.46	6,397.24
5	194.09020	0.0001882438	5,137.94	1,596.46	6,397.24
6	194.09020	0.0000723657	5,137.94	1,596.46	6,397.24
7	194.09020	0.0000858417	5,137.94	1,596.46	6,397.24
8	194.09020	0.0001479368	5,137.94	1,596.46	6,397.24
9	194.09020	0.0000540315	5,137.94	1,596.46	6,397.24
10	194.09020	0.0002584561	5,137.94	1,596.46	6,397.24
11	194.09020	0.0001629403	5,137.94	1,596.46	6,397.24
12	194.09020	0.0000882497	5,137.94	1,596.46	6,397.24
13	194.09020	0.0003632097	5,137.94	1,596.46	6,397.24
14	194.09020	0.0001908709	5,137.94	1,596.46	6,397.24
15	194.09020	0.0000972293	5,137.94	1,596.46	6,397.24
17	194.09020	0.0000796912	5,137.94	1,596.46	6,397.24
19	194.09020	0.0000362523	5,137.94	1,596.46	6,397.24
20	194.09020	0.0000699955	5,137.94	1,596.46	6,397.24
21	194.09020	0.0000281890	5,137.94	1,596.46	6,397.24

22	194.09020	0.0001078193	5,137.94	1,596.46	6,397.24
23	194.09020	0.0002701639	5,137.94	1,596.46	6,397.24
24	194.09020	0.0004094629	5,137.94	1,596.46	6,397.24
25	194.09020	0.0001398647	5,137.94	1,596.46	6,397.24
26	194.09020	0.0001581441	5,137.94	1,596.46	6,397.24
27	194.09020	0.0000172173	5,137.94	1,596.46	6,397.24
28	194.09020	0.0002431567	5,137.94	1,596.46	6,397.24
29	194.09020	0.0001333304	5,137.94	1,596.46	6,397.24
30	194.09020	0.0001117535	5,137.94	1,596.46	6,397.24
31	194.09020	0.0001606068	5,137.94	1,596.46	6,397.24
33	194.09020	0.0004427428	5,137.94	1,596.46	6,397.24
34	194.09020	0.0001611413	5,137.94	1,596.46	6,397.24
35	194.09020	0.0000631701	5,137.94	1,596.46	6,397.24
36	194.09020	0.0000459606	5,137.94	1,596.46	6,397.24
37	194.09020	0.0001064168	5,137.94	1,596.46	6,397.24
38	194.09020	0.0000172059	5,137.94	1,596.46	6,397.24
40	194.09020	0.0000038408	5,137.94	1,596.46	6,397.24
41	194.09020	0.0000859666	5,137.94	1,596.46	6,397.24
42	194.09020	0.0000537521	5,137.94	1,596.46	6,397.24
43	194.09020	0.0001620099	5,137.94	1,596.46	6,397.24
44	194.09020	0.0000315661	5,137.94	1,596.46	6,397.24
45	194.09020	0.0000738932	5,137.94	1,596.46	6,397.24
46	194.09020	0.0001887252	5,137.94	1,596.46	6,397.24
47	194.09020	0.0000429643	5,137.94	1,596.46	6,397.24
48	194.09020	0.0000776832	5,137.94	1,596.46	6,397.24
49	194.09020	0.0003267544	5,137.94	1,596.46	6,397.24
50	194.09020	0.0003924007	5,137.94	1,596.46	6,397.24
51	194.09020	0.0001833688	5,137.94	1,596.46	6,397.24
52	194.09020	0.0002360240	5,137.94	1,596.46	6,397.24
53	194.09020	0.0000717775	5,137.94	1,596.46	6,397.24
54	194.09020	0.0001178624	5,137.94	1,596.46	6,397.24
55	194.09020	0.0002562605	5,137.94	1,596.46	6,397.24
56	194.09020	0.0001003891	5,137.94	1,596.46	6,397.24
57	194.09020	0.0002306516	5,137.94	1,596.46	6,397.24
58	194.09020	0.0001687052	5,137.94	1,596.46	6,397.24
59	194.09020	0.0001481354	5,137.94	1,596.46	6,397.24
60	194.09020	0.0000907526	5,137.94	1,596.46	6,397.24
61	194.09020	0.0002972557	5,137.94	1,596.46	6,397.24
63	194.09020	0.0001718722	5,137.94	1,596.46	6,397.24
64	194.09020	0.0000443092	5,137.94	1,596.46	6,397.24
65	194.09020	0.0004282920	5,137.94	1,596.46	6,397.24
66	194.09020	0.0000609887	5,137.94	1,596.46	6,397.24
69	194.09020	0.0000496104	5,137.94	1,596.46	6,397.24

70	194.09020	0.0001474220	5,137.94	1,596.46	6,397.24
71	194.09020	0.0000817530	5,137.94	1,596.46	6,397.24
72	194.09020	0.0002925135	5,137.94	1,596.46	6,397.24
74	194.09020	0.0000172826	5,137.94	1,596.46	6,397.24
75	194.09020	0.0001158849	5,137.94	1,596.46	6,397.24
77	194.09020	0.0000685658	5,137.94	1,596.46	6,397.24
78	194.09020	0.0000642759	5,137.94	1,596.46	6,397.24
79	194.09020	0.0002103009	5,137.94	1,596.46	6,397.24
80	194.09020	0.0000927951	5,137.94	1,596.46	6,397.24
82	194.09020	0.0000092932	5,137.94	1,596.46	6,397.24
83	194.09020	0.0002106457	5,137.94	1,596.46	6,397.24
85	194.09020	0.0002154777	5,137.94	1,596.46	6,397.24
86	194.09020	0.0002772188	5,137.94	1,596.46	6,397.24
87	194.09020	0.0000738715	5,137.94	1,596.46	6,397.24
88	194.09020	0.0000222923	5,137.94	1,596.46	6,397.24
89	194.09020	0.0000501345	5,137.94	1,596.46	6,397.24
91	194.09020	0.0004448138	5,137.94	1,596.46	6,397.24
92	194.09020	0.0000542747	5,137.94	1,596.46	6,397.24
93	194.09020	0.0002043152	5,137.94	1,596.46	6,397.24
94	194.09020	0.0000163931	5,137.94	1,596.46	6,397.24
95	194.09020	0.0001567686	5,137.94	1,596.46	6,397.24
97	194.09020	0.0000887919	5,137.94	1,596.46	6,397.24
99	194.09020	0.0001385326	5,137.94	1,596.46	6,397.24
100	194.09020	0.0004455103	5,137.94	1,596.46	6,397.24
68	194.56190	0.0002346658	5,667.26	1,710.85	6,808.70
96	1575.75000	8813.9550000000	11,642.10	5,338.79	18,099.20
67	1755.93500	7572.1610000000	112,920.00	185,340.00	446,363.00
73	1783.22200	2679.4760000000	6,571.68	1,390.86	6,177.96
81	2018.62300	5380.9700000000	11,434.00	7,879.87	29,661.80

Appendix F: Projection

Simulations on future projection and outlook of Aleutian Islands golden king crab under Tier 3 harvest control rule

Simulation Method

We simulated the future male abundances from the 2018 model scenarios 17_0 and 17_0d estimated abundances by length-class and recruitment. We projected the abundances for 30 years with 100 random replicates and estimated various management parameters: legal male biomass (LMB), mature male biomass (MMB), OFL (total) catch, retained catch, CPUE indices, and probability of overfishing under federal overfishing control rule. Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was selected by a random selection from estimated recruitments during 1987– 2012 (CPT and SSC agreed time period, Siddeek et al., 2017). Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2016 (terminal year). The estimated recruitments were randomly selected using a uniform random distribution whereas the 2016 abundance was randomized by a lognormal random error.

The simulation steps are as follows:

1) Run the assessment model scenario 17_0 and 17_0d from the start year to the terminal year of the data (1981/82 - 2016/17 fishing seasons). Model equations are provided in Appendix A.

2) After estimating the abundances and parameters, run the forecast function (at the standard deviation phase of the ADMB optimization).

a) Randomize the recruitment:

Random selection of model estimated recruits for 1987 to 2012 was done as follows:

$$R_i = e^{[logMeanRec\ +rec_{dev(1987+uniform\ random\ error\ selected\ year\ incrment)}]} \quad \text{(F.1)}$$

where i = 2 to 30 years

b) Randomize the abundance:

The lognormal random error to abundance is added in the following steps:

We first scaled the standard error based on the terminal year abundance (number of crabs) on its standard error (i.e., CV= $\frac{Std.Error\ of\ terminal\ year\ mature\ male\ abundance}{terminal\ year\ mature\ male\ abundance}$). Then we added the lognormal random error to abundance as follows:

$$N_i = N_i e^{\varepsilon_i - \frac{\sigma_\varepsilon^2}{2}} \quad \text{(F.2)}$$

where $\sigma_{\varepsilon} = \frac{Std.Error\ of\ terminal\ year\ mature\ male\ abundance}{terminal\ year\ mature\ male\ abundance}$

N = abundance, and *i* = projection year.

The scaled standard error estimates (CV) are:

Scenario 17_0:

WAG: σ_{ε} = 0.18108
EAG: σ_{ε} = 0.18726

Scenario 17_0d:

WAG: σ_{ε} = 0.23771
EAG: σ_{ε} = 0.23674

3. Projection.

Two scenarios of fishing mortality for the directed pot fishery were used in the projections under Tier 3 control rule (i.e., Federal overfishing control rule):

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

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

The groundfish bycatch mortality was kept constant at the last 10-year mean fishing mortality level.

Each scenario was replicated 100 times and projections made over 30 years beginning in 2016

At each time step in the future:

a) Calculated legal male biomass (LMB) and mature male biomass (MMB).

b) Calculated the overfishing level total catch (OFL), acceptable biological catch (ABC), retained catch (RETC), and catch-per-unit effort (CPUE) indices using the Tier 3 OFL control rule.

c) Implemented the fishery under Tier 3 OFL control rule and removed the OFL catch from the simulated population.

d) Drew new recruitment numbers from historical distribution.

e) Updated the number-at-length.

4) Repeated step-3 for 30 years into the future.

5) Repeated steps 3 and 4 for 100s of Monte Carlo trials, randomizing recruitment and abundance.

6) Used the annual distribution of simulated OFL catch, ABC catch, RETC, CPUE, LMB, and MMB to calculate performance statistics:

a) Median and mean annual MMB, LMB, OFL, ABC, RETC, and CPUE with standard errors and 95% confidence limits (by Efron's and Tibshirani's (1986) method: 2.5% and 97.5% percentile points).

b) Probability that the median MMB remains above the threshold reference points ($0.25MMB_{35\%,2016}$), median ABC and median OFL exceeding ABC_{2016} and OFL_{2016} respectively during the 30-yr projection period. The subscript 2016 refers to estimates by the respective assessment model scenarios.

The state harvest control rule simulation procedures are under development; therefore, we are not presenting any results of the state harvest strategy in this report.

Results

The simulations compared the projection outputs for 17_0 and 17_0d scenarios and also investigated the probability of the stock being overfished (median $MMB < 0.25MMB_{35\%,2016}$) and overfishing occurred [i.e., median OFL catch (i.e., median total catch under F_{OFL}) exceeded OFL_{2016} or ABC_{2016} estimates] during the 30yr projection time horizon. The standard deviation of the total catch (OFL), retained catch (RETC), and CPUE are provided to assess the variability of the harvest under Tier 3 control rule.

We provide the results in the subsequent tables for the Tier 3 control rule for both scenarios. Tables F.1 and F.2 compare the 30-yr projected OFL catches with that of the model estimated OFL and ABC and provide the probability of overfishing and overfished under Tier 3 control rule for 17_0 and 17_0d scenarios for EAG and WAG, respectively. Subsequent tables (Tables F.3 to F.14) provide the mean, median, standard deviation, and 95% confidence intervals for projected OFL, ABC, RETC, CPUE, LMB, and MMB during time horizon. We can make the following general conclusion from the simulation results:

If the Tier 3 control rule were directly applied as the harvest strategy, the probability of median MMB declining below the threshold (overfished) would be zero for both scenarios for EAG and WAG. However, probability of median OFL (total) catch exceeding ABC would be 0.067 for scenario 17_0, but zero for scenario 17_0d for EAG. On the other hand, probability of median OFL exceeding ABC would be 1.0 for both scenarios (17_0 and 17_0d) for WAG (Tables F.1 and F.2).

Reference

Efron, B., and Tibshirani, R. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science, 1(1): 54-75.

M.S.M. Siddeek, J. Zheng, C. Siddon, B. Daly. 2017. Aleutian Islands golden king crab (*Lithodes aequispinus*) model-based stock assessment in Spring 2017. Draft report for the May 2017 CPT meeting, Juneau.

Table F.1. Comparison of projected median OFL (i.e., total catch under Tire 3 F_{OFL}) with OFL_{2016} and ABC_{2016} in metric tons (t) for scenario (Sc) 17_0 and 17_0d with F=$F_{35\%}$ (0.64yr^{-1}) and F=0 for EAG. Probability of projected median OFL exceeding OFL_{2016} and ABC_{2016} and projected median MMB (t) depleting below the threshold MMB_{2016} are also listed. $Thresh_{2016}$= threshold MMB in 2016.

Projection Year	Sc17_0			Sc 17_0, F=0			Sc 17_0, F=$F_{35\%}$			Sc17_0d			Sc 17_0d, F=0			Sc 17_0d, F=$F_{35\%}$		
	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB
2016	3,918	2,938	1738.615	1.974	1.480	14,832	3,359	2,519	11,445	2,481	1,860	1672.03	1.672	1.254	10,201	2,262	1,696	7,922
2017				2.157	1.618	16,281	3,194	2,395	10,017				1.911	1.434	11,708	2,170	1,628	7,470
2018				2.252	1.689	17,228	2,909	2,182	8,790				2.090	1.567	13,021	2,074	1,555	7,191
2019				2.361	1.771	17,851	2,559	1,919	7,889				2.272	1.704	13,957	1,975	1,481	6,957
2020				2.407	1.805	18,401	2,256	1,692	7,416				2.376	1.782	15,000	1,907	1,430	6,804
2021				2.460	1.845	18,660	2,073	1,555	7,092				2.506	1.879	15,573	1,884	1,413	6,716
2022				2.471	1.854	18,959	1,951	1,463	7,064				2.598	1.949	16,324	1,832	1,374	6,736
2023				2.507	1.880	19,082	1,937	1,453	7,014				2.674	2.005	16,848	1,831	1,373	6,747
2024				2.548	1.911	19,380	1,899	1,424	7,019				2.763	2.072	17,381	1,819	1,365	6,705
2025				2.547	1.910	19,483	1,904	1,428	6,877				2.805	2.104	17,715	1,835	1,376	6,667
2026				2.544	1.908	19,434	1,893	1,420	6,884				2.844	2.133	17,969	1,831	1,373	6,653
2027				2.560	1.920	19,527	1,877	1,407	6,881				2.877	2.158	18,051	1,814	1,361	6,675
2028				2.587	1.940	19,632	1,871	1,403	6,828				2.923	2.192	18,398	1,813	1,360	6,723
2029				2.563	1.923	19,701	1,872	1,404	6,882				2.930	2.198	18,507	1,817	1,363	6,657
2030				2.571	1.928	19,630	1,883	1,413	6,930				2.947	2.210	18,649	1,818	1,363	6,743
2031				2.576	1.932	19,694	1,883	1,412	6,881				2.962	2.221	18,770	1,814	1,360	6,604
2032				2.564	1.923	19,639	1,889	1,417	6,845				2.968	2.226	18,733	1,836	1,377	6,656
2033				2.577	1.933	19,657	1,882	1,411	6,913				2.974	2.231	18,869	1,814	1,360	6,682
2034				2.571	1.928	19,676	1,875	1,406	6,945				2.978	2.233	18,846	1,818	1,364	6,674
2035				2.585	1.939	19,709	1,885	1,414	6,921				2.991	2.243	18,909	1,816	1,362	6,664
2036				2.582	1.936	19,710	1,881	1,411	6,920				2.985	2.239	19,008	1,806	1,355	6,690
2037				2.595	1.947	19,715	1,885	1,413	6,895				3.002	2.252	18,942	1,838	1,378	6,644
2038				2.596	1.947	19,804	1,880	1,410	6,983				3.017	2.262	19,059	1,812	1,359	6,768
2039				2.615	1.962	19,894	1,896	1,422	7,008				3.048	2.286	19,206	1,823	1,367	6,823
2040				2.617	1.962	19,979	1,905	1,429	7,025				3.038	2.278	19,305	1,831	1,374	6,870
2041				2.629	1.972	20,013	1,924	1,443	7,098				3.065	2.299	19,363	1,856	1,392	6,856
2042				2.623	1.967	20,115	1,915	1,436	6,976				3.045	2.284	19,400	1,857	1,393	6,716
2043				2.613	1.959	20,005	1,925	1,444	6,861				3.060	2.295	19,346	1,851	1,389	6,685
2044				2.605	1.953	19,920	1,898	1,423	6,871				3.060	2.295	19,359	1,842	1,381	6,695
2045				2.606	1.955	19,945	1,871	1,404	6,876				3.045	2.284	19,300	1,810	1,358	6,653
Prob OFL> ABC_{2016}				0			0.067						0			0		
Prob OFL> OFL_{2016}				0			0						0			0		
Prob MMB< $Thresh_{2016}$						0			0						0			0

Table F.2. Comparison of projected median OFL (i.e., total catch under Tire 3 F_{OFL}) with OFL_{2016} and ABC_{2016} in metric tons (t) for scenario (Sc) 17_0 and 17_0d with F=$F_{35\%}$ (0.6yr^{-1} and 0.68yr^{-1} for Sc 17_0 and Sc 17_0d, respectively) and F=0 for WAG. Probability of projected median OFL exceeding OFL_{2016} and ABC_{2016} and projected median MMB (t) depleting below the threshold MMB_{2016} are also listed. $Thresh_{2016}$= threshold MMB in 2016.

Projection Year	Sc17_0			Sc 17_0, F=0			Sc 17_0, F=$F_{35\%}$		
	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB
2016	1,597	1,197	1,284.485	3.367	2.526	7,243	1,297	973	5,934
2017				3.955	2.966	8,745	1,489	1,116	6,057
2018				4.335	3.251	9,814	1,614	1,211	5,778
2019				4.765	3.574	10,647	1,605	1,204	5,550
2020				5.091	3.818	11,457	1,525	1,143	5,425
2021				5.369	4.027	12,153	1,475	1,106	5,229
2022				5.566	4.174	12,666	1,443	1,082	5,195
2023				5.786	4.339	13,127	1,407	1,055	5,175
2024				5.883	4.413	13,532	1,404	1,053	5,277
2025				5.999	4.499	13,725	1,410	1,057	5,272
2026				6.074	4.555	13,941	1,410	1,057	5,192
2027				6.136	4.602	14,080	1,415	1,061	5,145
2028				6.179	4.634	14,154	1,395	1,047	5,121
2029				6.216	4.662	14,253	1,381	1,036	5,136
2030				6.234	4.676	14,348	1,384	1,038	5,117
2031				6.318	4.738	14,406	1,391	1,043	5,148
2032				6.333	4.749	14,574	1,389	1,041	5,244
2033				6.330	4.747	14,570	1,402	1,051	5,189
2034				6.389	4.791	14,631	1,406	1,054	5,204
2035				6.412	4.809	14,695	1,406	1,054	5,213
2036				6.410	4.808	14,774	1,401	1,051	5,273
2037				6.452	4.839	14,750	1,411	1,058	5,174
2038				6.468	4.851	14,872	1,403	1,052	5,177
2039				6.424	4.818	14,825	1,407	1,055	5,188
2040				6.431	4.823	14,754	1,399	1,049	5,160
2041				6.428	4.821	14,756	1,390	1,043	5,180
2042				6.430	4.823	14,814	1,393	1,045	5,150
2043				6.458	4.843	14,766	1,392	1,044	5,212
2044				6.467	4.850	14,828	1,391	1,043	5,266
2045				6.507	4.880	14,951	1,407	1,056	5,274
Prob OFL> ABC_{2016}				0			1.000		
Prob OFL> OFL_{2016}				0			0.067		
Prob MMB< $Thresh_{2016}$						0			0

Projection Year	Sc17_0d			Sc 17_0d, F=0			Sc 17_0d, F=$F_{35\%}$		
	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB
2016	1,482	1,112	1,276.905	3.434	2.576	7,015	1,119	840	5,886
2017				4.065	3.048	8,565	1,416	1,062	6,132
2018				4.491	3.368	9,717	1,625	1,219	5,811
2019				4.945	3.709	10,565	1,636	1,227	5,584
2020				5.298	3.973	11,415	1,548	1,161	5,475
2021				5.581	4.186	12,089	1,483	1,113	5,243
2022				5.811	4.358	12,637	1,449	1,087	5,138
2023				6.032	4.524	13,059	1,406	1,055	5,131
2024				6.121	4.591	13,437	1,394	1,045	5,238
2025				6.266	4.699	13,633	1,398	1,048	5,214
2026				6.326	4.745	13,888	1,409	1,057	5,152
2027				6.400	4.800	14,001	1,411	1,058	5,122
2028				6.447	4.835	14,104	1,391	1,043	5,111
2029				6.470	4.853	14,194	1,384	1,038	5,117
2030				6.500	4.875	14,230	1,386	1,039	5,106
2031				6.608	4.956	14,359	1,381	1,036	5,102
2032				6.602	4.952	14,512	1,384	1,038	5,207
2033				6.611	4.958	14,461	1,393	1,045	5,189
2034				6.650	4.987	14,508	1,409	1,057	5,234
2035				6.676	5.007	14,590	1,401	1,051	5,201
2036				6.709	5.032	14,728	1,408	1,056	5,256
2037				6.724	5.043	14,711	1,413	1,059	5,146
2038				6.714	5.035	14,802	1,406	1,055	5,135
2039				6.674	5.005	14,730	1,395	1,046	5,110
2040				6.696	5.022	14,647	1,392	1,044	5,151
2041				6.698	5.023	14,659	1,392	1,044	5,121
2042				6.691	5.018	14,745	1,394	1,046	5,164
2043				6.716	5.037	14,703	1,390	1,043	5,223
2044				6.770	5.078	14,726	1,394	1,045	5,223
2045				6.795	5.096	14,871	1,408	1,056	5,229
Prob OFL> ABC_{2016}				0			1.000		
Prob OFL> OFL_{2016}				0			0.133		
Prob MMB< $Thresh_{2016}$						0			0

Table F.3. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for EAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	9,433	9,400	1,737	6,595	13,218	14,883	14,832	2,740	10,405	20,855
2017	12,587	12,543	2,317	8,800	17,637	16,313	16,281	2,879	11,472	22,419
2018	14,564	14,507	2,665	10,191	20,352	17,318	17,228	2,765	12,462	22,966
2019	15,658	15,592	2,660	11,087	21,174	17,972	17,851	2,547	13,564	23,105
2020	16,274	16,134	2,483	11,898	21,322	18,445	18,401	2,267	14,667	22,953
2021	16,686	16,579	2,208	12,937	21,095	18,764	18,660	2,036	15,385	22,643
2022	16,951	16,865	1,936	13,656	20,784	19,051	18,959	1,885	16,157	22,485
2023	17,171	17,116	1,753	14,400	20,388	19,259	19,082	1,742	16,473	22,652
2024	17,366	17,243	1,618	14,781	20,347	19,375	19,380	1,619	16,511	22,420
2025	17,493	17,327	1,513	14,933	20,420	19,432	19,483	1,497	16,608	22,483
2026	17,553	17,605	1,405	14,934	20,344	19,470	19,434	1,389	16,841	22,141
2027	17,573	17,560	1,309	15,118	20,291	19,532	19,527	1,273	17,123	21,747
2028	17,600	17,568	1,213	15,298	19,926	19,598	19,632	1,168	17,154	21,722
2029	17,654	17,645	1,103	15,492	19,590	19,630	19,701	1,132	17,275	21,915
2030	17,699	17,785	1,037	15,537	19,733	19,643	19,630	1,088	17,308	21,718
2031	17,718	17,723	1,013	15,618	19,809	19,658	19,694	1,027	17,590	21,531
2032	17,724	17,743	963	15,725	19,467	19,674	19,639	1,006	17,599	21,354
2033	17,738	17,788	922	15,861	19,497	19,713	19,657	998	17,616	21,727
2034	17,746	17,646	914	15,906	19,499	19,778	19,676	1,015	17,712	21,734
2035	17,810	17,732	923	15,948	19,565	19,789	19,709	1,037	17,929	21,948
2036	17,838	17,778	945	16,047	19,809	19,818	19,710	1,088	17,836	21,972
2037	17,864	17,785	978	16,167	19,867	19,833	19,715	1,110	17,931	22,094
2038	17,875	17,752	1,027	15,999	19,970	19,870	19,804	1,100	17,973	22,222
2039	17,901	17,835	1,021	16,166	19,971	19,898	19,894	1,152	17,873	22,330
2040	17,928	17,902	1,033	16,176	20,238	19,951	19,979	1,214	18,010	22,393
2041	17,961	17,984	1,092	16,044	20,048	20,007	20,013	1,207	18,006	22,526
2042	18,018	18,011	1,128	16,214	20,399	20,012	20,115	1,153	17,988	22,093
2043	18,053	18,078	1,099	16,200	20,182	19,987	20,005	1,115	17,941	22,148
2044	18,042	18,095	1,051	16,167	20,096	19,952	19,920	1,100	18,168	21,959
2045	18,012	18,009	1,020	16,199	19,887	19,941	19,945	1,114	18,181	22,370

$F_{35\%}$ (0.64yr^{-1})										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	9,433	9,400	1,737	6,595	13,218	11,485	11,445	2,114	8,029	16,093
2017	9,210	9,178	1,696	6,439	12,905	10,054	10,017	1,731	7,096	13,655
2018	8,346	8,309	1,518	5,842	11,637	8,841	8,790	1,261	6,536	11,281
2019	7,275	7,264	1,135	5,304	9,522	7,968	7,889	885	6,497	9,837
2020	6,435	6,374	795	5,123	8,085	7,466	7,416	677	6,471	8,855
2021	5,943	5,923	561	5,148	7,087	7,180	7,092	592	6,206	8,342
2022	5,665	5,570	445	5,095	6,591	7,095	7,064	643	6,092	8,546
2023	5,563	5,509	438	4,915	6,516	7,063	7,014	658	6,042	8,493
2024	5,548	5,415	473	4,884	6,721	7,005	7,019	649	5,976	8,352
2025	5,526	5,456	459	4,870	6,508	6,939	6,877	635	5,932	8,313
2026	5,481	5,417	453	4,832	6,552	6,901	6,884	594	5,933	8,260
2027	5,434	5,383	431	4,826	6,452	6,919	6,881	562	6,129	8,227
2028	5,421	5,350	416	4,823	6,491	6,955	6,828	543	6,123	7,865
2029	5,449	5,348	388	4,909	6,390	6,957	6,882	555	6,067	8,016
2030	5,466	5,402	388	4,929	6,245	6,939	6,930	511	6,098	7,974
2031	5,455	5,383	385	4,874	6,272	6,931	6,881	471	6,104	7,756
2032	5,439	5,407	329	4,925	6,037	6,933	6,845	539	6,057	8,148
2033	5,446	5,388	348	4,928	6,245	6,964	6,913	582	6,030	8,224
2034	5,447	5,365	406	4,875	6,442	7,020	6,945	611	6,111	8,336
2035	5,500	5,377	428	4,924	6,437	7,007	6,921	614	6,049	8,323
2036	5,503	5,378	446	4,933	6,486	7,011	6,920	626	6,025	8,452
2037	5,507	5,386	441	4,901	6,459	7,005	6,895	634	6,041	8,437
2038	5,498	5,376	456	4,859	6,683	7,026	6,983	618	6,101	8,368
2039	5,507	5,430	450	4,875	6,508	7,038	7,008	630	6,076	8,276
2040	5,520	5,453	432	4,927	6,452	7,074	7,025	679	6,090	8,398
2041	5,536	5,493	474	4,887	6,436	7,109	7,098	665	6,100	8,294
2042	5,570	5,488	492	4,881	6,509	7,083	6,976	628	6,086	8,478
2043	5,571	5,505	465	4,884	6,562	7,027	6,861	622	6,085	8,636
2044	5,534	5,426	452	4,899	6,669	6,982	6,871	612	6,077	8,428
2045	5,498	5,358	448	4,919	6,586	6,978	6,876	605	6,036	8,197

Table F.4. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for EAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1.981	1.974	0.365	1.385	2.775	0	0	0	0	0
2017	2.163	2.157	0.363	1.533	2.907	0	0	0	0	0
2018	2.279	2.252	0.349	1.667	2.995	0	0	0	0	0
2019	2.367	2.361	0.316	1.841	2.993	0	0	0	0	0
2020	2.419	2.407	0.283	1.932	2.973	0	0	0	0	0
2021	2.466	2.460	0.262	2.048	2.943	0	0	0	0	0
2022	2.501	2.471	0.239	2.127	2.955	0	0	0	0	0
2023	2.523	2.507	0.223	2.157	2.959	0	0	0	0	0
2024	2.536	2.548	0.205	2.158	2.930	0	0	0	0	0
2025	2.542	2.547	0.190	2.177	2.951	0	0	0	0	0
2026	2.550	2.544	0.176	2.218	2.878	0	0	0	0	0
2027	2.560	2.560	0.159	2.240	2.837	0	0	0	0	0
2028	2.566	2.587	0.151	2.246	2.852	0	0	0	0	0
2029	2.569	2.563	0.147	2.263	2.862	0	0	0	0	0
2030	2.570	2.571	0.138	2.284	2.818	0	0	0	0	0
2031	2.574	2.576	0.134	2.296	2.829	0	0	0	0	0
2032	2.574	2.564	0.130	2.295	2.833	0	0	0	0	0
2033	2.587	2.577	0.131	2.319	2.832	0	0	0	0	0
2034	2.586	2.571	0.132	2.325	2.870	0	0	0	0	0
2035	2.592	2.585	0.137	2.352	2.859	0	0	0	0	0
2036	2.593	2.582	0.145	2.334	2.881	0	0	0	0	0
2037	2.598	2.595	0.140	2.344	2.879	0	0	0	0	0
2038	2.601	2.596	0.145	2.347	2.915	0	0	0	0	0
2039	2.606	2.615	0.155	2.331	2.901	0	0	0	0	0
2040	2.615	2.617	0.158	2.367	2.952	0	0	0	0	0
2041	2.619	2.629	0.152	2.356	2.922	0	0	0	0	0
2042	2.616	2.623	0.147	2.357	2.909	0	0	0	0	0
2043	2.614	2.613	0.143	2.358	2.862	0	0	0	0	0
2044	2.609	2.605	0.144	2.385	2.930	0	0	0	0	0
2045	2.614	2.606	0.147	2.383	2.909	0	0	0	0	0

$F_{35\%}$ (0.64yr^{-1})										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	3,371	3,359	621	2,357	4,723	3,198	3,187	589	2,236	4,481
2017	3,205	3,194	589	2,241	4,488	3,051	3,042	564	2,134	4,278
2018	2,925	2,909	526	2,052	4,058	2,796	2,788	517	1,878	3,906
2019	2,566	2,559	401	1,877	3,372	2,447	2,449	405	1,714	3,247
2020	2,274	2,256	281	1,801	2,856	2,154	2,143	292	1,657	2,734
2021	2,092	2,073	196	1,813	2,500	1,964	1,964	213	1,641	2,390
2022	1,991	1,951	153	1,802	2,312	1,853	1,823	177	1,571	2,201
2023	1,949	1,937	145	1,740	2,266	1,806	1,791	170	1,504	2,137
2024	1,939	1,899	155	1,720	2,321	1,792	1,776	185	1,494	2,202
2025	1,931	1,904	152	1,718	2,268	1,781	1,781	184	1,469	2,142
2026	1,917	1,893	149	1,704	2,257	1,769	1,741	179	1,455	2,138
2027	1,902	1,877	142	1,700	2,231	1,758	1,753	165	1,493	2,108
2028	1,896	1,871	135	1,708	2,250	1,753	1,738	156	1,529	2,119
2029	1,904	1,872	127	1,732	2,219	1,760	1,734	151	1,504	2,097
2030	1,909	1,883	126	1,733	2,158	1,768	1,743	152	1,508	2,036
2031	1,906	1,883	125	1,720	2,172	1,766	1,756	149	1,510	2,060
2032	1,901	1,889	108	1,734	2,123	1,757	1,747	131	1,504	2,006
2033	1,903	1,882	112	1,737	2,156	1,759	1,741	136	1,529	2,031
2034	1,905	1,875	130	1,723	2,224	1,763	1,733	153	1,509	2,110
2035	1,919	1,885	140	1,730	2,230	1,777	1,752	163	1,496	2,108
2036	1,923	1,881	146	1,732	2,254	1,779	1,749	171	1,489	2,135
2037	1,924	1,885	146	1,728	2,243	1,780	1,773	170	1,507	2,128
2038	1,922	1,880	149	1,716	2,314	1,780	1,749	173	1,503	2,192
2039	1,924	1,896	148	1,720	2,253	1,779	1,763	174	1,503	2,133
2040	1,929	1,905	144	1,732	2,247	1,785	1,782	172	1,518	2,138
2041	1,935	1,924	154	1,729	2,230	1,793	1,808	178	1,522	2,105
2042	1,944	1,915	161	1,728	2,258	1,805	1,784	183	1,511	2,141
2043	1,945	1,925	154	1,726	2,263	1,803	1,782	177	1,515	2,135
2044	1,934	1,898	149	1,733	2,300	1,790	1,761	171	1,516	2,175
2045	1,922	1,871	147	1,731	2,289	1,777	1,749	170	1,518	2,174

Table F.5. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0 for EAG, 2016–2045.

	$F_{35\%}$ (0.64yr^{-1})				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.997	0.993	0.183	0.697	1.396
2017	0.977	0.974	0.180	0.683	1.369
2018	0.894	0.890	0.162	0.631	1.245
2019	0.781	0.779	0.121	0.573	1.023
2020	0.691	0.684	0.084	0.553	0.866
2021	0.638	0.636	0.059	0.555	0.759
2022	0.609	0.597	0.046	0.549	0.705
2023	0.598	0.592	0.045	0.533	0.697
2024	0.597	0.586	0.049	0.533	0.719
2025	0.595	0.588	0.047	0.528	0.699
2026	0.591	0.585	0.047	0.524	0.701
2027	0.585	0.579	0.045	0.524	0.692
2028	0.584	0.578	0.043	0.524	0.697
2029	0.587	0.578	0.040	0.533	0.685
2030	0.589	0.580	0.040	0.536	0.669
2031	0.587	0.579	0.040	0.529	0.673
2032	0.586	0.583	0.034	0.533	0.649
2033	0.587	0.580	0.036	0.534	0.667
2034	0.587	0.578	0.042	0.528	0.691
2035	0.592	0.580	0.044	0.533	0.690
2036	0.593	0.579	0.046	0.537	0.697
2037	0.593	0.580	0.046	0.533	0.693
2038	0.592	0.577	0.047	0.527	0.716
2039	0.593	0.584	0.047	0.529	0.697
2040	0.595	0.587	0.045	0.535	0.694
2041	0.596	0.589	0.049	0.528	0.690
2042	0.599	0.590	0.051	0.527	0.699
2043	0.600	0.593	0.048	0.531	0.702
2044	0.596	0.586	0.047	0.529	0.713
2045	0.592	0.578	0.047	0.533	0.707

Table F.6. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for EAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	6,380	6,317	1,492	4,036	9,720	10,303	10,201	2,410	6,517	15,696
2017	8,560	8,476	2,002	5,415	13,042	11,798	11,708	2,604	7,590	17,467
2018	10,234	10,117	2,373	6,490	15,526	13,110	13,021	2,533	8,872	18,403
2019	11,540	11,427	2,419	7,551	16,666	14,156	13,957	2,346	10,271	19,084
2020	12,560	12,405	2,290	8,730	17,353	15,033	15,000	2,094	11,533	19,428
2021	13,400	13,345	2,041	10,045	17,723	15,743	15,573	1,905	12,803	19,627
2022	14,066	14,004	1,804	11,079	17,776	16,385	16,324	1,787	13,789	19,940
2023	14,643	14,507	1,655	12,140	17,967	16,917	16,848	1,679	14,335	20,394
2024	15,150	15,076	1,552	12,825	18,258	17,331	17,381	1,587	14,705	20,452
2025	15,560	15,517	1,476	13,189	18,526	17,647	17,715	1,498	15,057	20,612
2026	15,873	15,903	1,395	13,550	18,569	17,894	17,969	1,422	15,326	20,455
2027	16,102	16,185	1,329	13,784	18,564	18,129	18,051	1,321	15,632	20,465
2028	16,296	16,311	1,255	13,967	18,635	18,336	18,398	1,228	15,841	20,412
2029	16,487	16,473	1,160	14,221	18,403	18,480	18,507	1,194	16,107	20,815
2030	16,641	16,671	1,097	14,440	18,678	18,578	18,649	1,160	16,190	20,835
2031	16,743	16,802	1,078	14,591	18,980	18,666	18,770	1,112	16,481	20,835
2032	16,812	16,905	1,036	14,719	18,805	18,749	18,733	1,090	16,680	20,769
2033	16,886	16,976	1,003	14,950	18,922	18,836	18,869	1,067	16,746	20,946
2034	16,944	16,978	987	15,039	18,916	18,942	18,846	1,063	16,902	20,851
2035	17,043	17,010	977	15,185	18,859	18,999	18,909	1,073	16,939	20,976
2036	17,109	17,018	981	15,220	19,041	19,056	19,008	1,139	16,994	21,238
2037	17,171	17,079	1,016	15,281	19,027	19,088	18,942	1,177	17,131	21,443
2038	17,196	17,107	1,080	15,291	19,465	19,154	19,059	1,177	17,201	21,705
2039	17,242	17,141	1,091	15,448	19,480	19,194	19,206	1,225	17,118	21,872
2040	17,289	17,194	1,105	15,403	19,809	19,250	19,305	1,296	17,135	21,839
2041	17,325	17,357	1,160	15,458	19,682	19,324	19,363	1,305	17,086	22,242
2042	17,391	17,377	1,210	15,319	20,080	19,337	19,400	1,249	17,209	21,814
2043	17,437	17,530	1,190	15,452	19,940	19,323	19,346	1,189	17,243	21,651
2044	17,433	17,426	1,134	15,472	19,561	19,314	19,359	1,145	17,356	21,601
2045	17,418	17,423	1,073	15,548	19,448	19,332	19,300	1,148	17,505	21,690

	$F_{35\%}$ ($0.64yr^{-1}$)									
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	6,380	6,317	1,492	4,036	9,720	8,001	7,922	1,871	5,061	12,189
2017	6,314	6,215	1,418	4,237	9,563	7,556	7,470	1,585	5,035	10,977
2018	6,068	5,930	1,305	4,234	9,084	7,254	7,191	1,184	5,386	9,669
2019	5,783	5,651	1,010	4,299	7,907	7,004	6,957	846	5,772	8,950
2020	5,550	5,422	732	4,538	7,199	6,865	6,804	656	5,887	8,205
2021	5,416	5,374	517	4,682	6,620	6,773	6,716	594	5,751	7,937
2022	5,323	5,245	425	4,730	6,200	6,783	6,736	666	5,800	8,264
2023	5,306	5,228	446	4,636	6,330	6,802	6,747	684	5,760	8,404
2024	5,331	5,189	497	4,684	6,583	6,787	6,705	669	5,685	8,226
2025	5,336	5,258	482	4,651	6,458	6,746	6,667	665	5,727	8,092
2026	5,318	5,239	473	4,619	6,401	6,709	6,653	649	5,673	8,157
2027	5,281	5,158	464	4,650	6,293	6,723	6,675	618	5,769	8,189
2028	5,264	5,184	458	4,611	6,434	6,751	6,723	599	5,782	7,855
2029	5,287	5,208	433	4,702	6,286	6,742	6,657	606	5,749	7,852
2030	5,298	5,204	428	4,684	6,199	6,711	6,743	561	5,785	7,775
2031	5,279	5,185	422	4,662	6,178	6,698	6,604	523	5,814	7,689
2032	5,254	5,244	369	4,705	5,924	6,707	6,656	571	5,745	8,044
2033	5,261	5,190	384	4,667	6,165	6,734	6,682	607	5,869	8,116
2034	5,264	5,189	427	4,652	6,382	6,789	6,674	646	5,798	8,073
2035	5,315	5,201	452	4,724	6,296	6,789	6,664	657	5,794	8,084
2036	5,324	5,182	477	4,695	6,315	6,791	6,690	685	5,817	8,413
2037	5,336	5,261	481	4,697	6,379	6,776	6,644	695	5,809	8,323
2038	5,318	5,170	502	4,691	6,679	6,808	6,768	672	5,760	8,295
2039	5,328	5,229	498	4,696	6,487	6,815	6,823	669	5,771	8,214
2040	5,345	5,271	470	4,662	6,455	6,839	6,870	720	5,662	8,357
2041	5,352	5,314	498	4,647	6,415	6,883	6,856	719	5,749	8,302
2042	5,386	5,327	530	4,601	6,494	6,858	6,716	669	5,847	8,387
2043	5,391	5,273	507	4,664	6,545	6,806	6,685	646	5,932	8,428
2044	5,352	5,257	483	4,721	6,534	6,778	6,695	636	5,862	8,344
2045	5,322	5,185	469	4,755	6,561	6,794	6,653	634	5,820	8,047

Table F.7. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for EAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1.689	1.672	0.395	1.068	2.573	0	0	0	0	0
2017	1.929	1.911	0.397	1.267	2.758	0	0	0	0	0
2018	2.115	2.090	0.386	1.473	2.933	0	0	0	0	0
2019	2.278	2.272	0.350	1.707	3.016	0	0	0	0	0
2020	2.403	2.376	0.317	1.882	3.051	0	0	0	0	0
2021	2.517	2.506	0.297	2.057	3.099	0	0	0	0	0
2022	2.613	2.598	0.275	2.206	3.175	0	0	0	0	0
2023	2.690	2.674	0.261	2.277	3.222	0	0	0	0	0
2024	2.750	2.763	0.244	2.346	3.218	0	0	0	0	0
2025	2.795	2.805	0.232	2.402	3.244	0	0	0	0	0
2026	2.836	2.844	0.218	2.429	3.250	0	0	0	0	0
2027	2.874	2.877	0.200	2.472	3.203	0	0	0	0	0
2028	2.902	2.923	0.191	2.527	3.248	0	0	0	0	0
2029	2.921	2.930	0.187	2.544	3.296	0	0	0	0	0
2030	2.936	2.947	0.179	2.569	3.262	0	0	0	0	0
2031	2.953	2.962	0.175	2.614	3.300	0	0	0	0	0
2032	2.962	2.968	0.170	2.623	3.298	0	0	0	0	0
2033	2.984	2.974	0.167	2.664	3.285	0	0	0	0	0
2034	2.991	2.978	0.165	2.668	3.318	0	0	0	0	0
2035	3.005	2.991	0.172	2.686	3.309	0	0	0	0	0
2036	3.007	2.985	0.184	2.676	3.382	0	0	0	0	0
2037	3.019	3.002	0.181	2.726	3.379	0	0	0	0	0
2038	3.026	3.017	0.186	2.708	3.450	0	0	0	0	0
2039	3.032	3.048	0.199	2.714	3.429	0	0	0	0	0
2040	3.046	3.038	0.205	2.696	3.501	0	0	0	0	0
2041	3.052	3.065	0.199	2.701	3.484	0	0	0	0	0
2042	3.050	3.045	0.192	2.719	3.433	0	0	0	0	0
2043	3.050	3.060	0.182	2.726	3.389	0	0	0	0	0
2044	3.049	3.060	0.181	2.744	3.421	0	0	0	0	0
2045	3.059	3.045	0.182	2.782	3.474	0	0	0	0	0

$F_{35\%}$ (0.64yr^{-1})										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	2,284	2,262	534	1,445	3,480	2,124	2,137	556	1,116	3,289
2017	2,206	2,170	493	1,487	3,336	2,046	2,052	519	1,148	3,157
2018	2,126	2,074	446	1,500	3,154	1,981	1,966	467	1,209	3,012
2019	2,027	1,975	351	1,521	2,782	1,887	1,855	373	1,299	2,657
2020	1,947	1,907	254	1,595	2,523	1,809	1,778	276	1,406	2,397
2021	1,897	1,884	178	1,652	2,316	1,756	1,752	201	1,459	2,206
2022	1,865	1,832	144	1,675	2,154	1,721	1,709	169	1,441	2,043
2023	1,857	1,831	147	1,641	2,195	1,712	1,691	170	1,424	2,068
2024	1,863	1,819	162	1,647	2,268	1,717	1,686	187	1,429	2,134
2025	1,864	1,835	159	1,645	2,244	1,715	1,703	188	1,401	2,105
2026	1,859	1,831	156	1,634	2,227	1,710	1,688	185	1,400	2,106
2027	1,848	1,814	153	1,641	2,165	1,704	1,676	177	1,407	2,034
2028	1,842	1,813	149	1,636	2,227	1,699	1,689	171	1,418	2,102
2029	1,847	1,817	142	1,652	2,193	1,702	1,686	166	1,425	2,073
2030	1,851	1,818	140	1,650	2,151	1,708	1,695	167	1,406	2,021
2031	1,846	1,814	137	1,641	2,136	1,703	1,691	161	1,409	2,018
2032	1,838	1,836	121	1,653	2,076	1,695	1,683	143	1,434	1,952
2033	1,839	1,814	124	1,658	2,128	1,694	1,678	145	1,429	2,008
2034	1,842	1,818	137	1,645	2,199	1,698	1,677	159	1,454	2,081
2035	1,856	1,816	147	1,667	2,176	1,712	1,687	169	1,439	2,049
2036	1,861	1,806	157	1,652	2,191	1,716	1,673	182	1,420	2,066
2037	1,864	1,838	160	1,655	2,217	1,717	1,706	183	1,431	2,081
2038	1,861	1,812	166	1,653	2,313	1,718	1,690	187	1,424	2,182
2039	1,862	1,823	164	1,649	2,244	1,717	1,691	188	1,403	2,118
2040	1,868	1,831	156	1,640	2,238	1,721	1,706	185	1,422	2,115
2041	1,872	1,856	163	1,645	2,213	1,728	1,741	187	1,405	2,086
2042	1,881	1,857	173	1,624	2,255	1,741	1,730	192	1,422	2,125
2043	1,882	1,851	168	1,644	2,254	1,742	1,721	187	1,458	2,126
2044	1,871	1,842	159	1,666	2,258	1,729	1,702	177	1,478	2,139
2045	1,861	1,810	155	1,678	2,254	1,719	1,685	173	1,464	2,134

Table F.8. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0d for EAG, 2016–2045.

	$F_{35\%}$ (0.64yr^{-1})				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.661	0.652	0.151	0.432	1.004
2017	0.657	0.644	0.144	0.455	0.991
2018	0.636	0.619	0.134	0.455	0.947
2019	0.606	0.591	0.104	0.457	0.829
2020	0.583	0.571	0.075	0.477	0.753
2021	0.568	0.565	0.053	0.497	0.692
2022	0.559	0.551	0.043	0.498	0.649
2023	0.557	0.549	0.045	0.491	0.662
2024	0.560	0.545	0.050	0.495	0.687
2025	0.561	0.553	0.049	0.492	0.676
2026	0.559	0.551	0.048	0.490	0.670
2027	0.555	0.544	0.047	0.493	0.657
2028	0.553	0.546	0.047	0.487	0.673
2029	0.556	0.548	0.044	0.494	0.660
2030	0.557	0.546	0.043	0.498	0.647
2031	0.555	0.545	0.043	0.494	0.646
2032	0.552	0.551	0.037	0.497	0.622
2033	0.553	0.546	0.039	0.493	0.643
2034	0.553	0.545	0.043	0.494	0.668
2035	0.558	0.546	0.046	0.500	0.658
2036	0.560	0.544	0.048	0.498	0.662
2037	0.561	0.552	0.049	0.495	0.667
2038	0.559	0.544	0.051	0.494	0.699
2039	0.560	0.549	0.050	0.496	0.678
2040	0.562	0.555	0.047	0.497	0.676
2041	0.562	0.559	0.050	0.491	0.671
2042	0.565	0.558	0.054	0.488	0.680
2043	0.566	0.555	0.052	0.492	0.684
2044	0.563	0.552	0.049	0.499	0.684
2045	0.559	0.544	0.048	0.503	0.685

Table F.9. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for WAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,581	3,571	637	2,534	4,964	7,263	7,243	1,292	5,141	10,070
2017	5,526	5,511	983	3,911	7,662	8,749	8,745	1,452	6,428	11,840
2018	7,292	7,253	1,284	5,191	10,074	9,898	9,814	1,403	7,709	12,874
2019	8,572	8,561	1,349	6,452	11,405	10,815	10,647	1,312	8,797	13,603
2020	9,502	9,311	1,277	7,554	12,218	11,541	11,457	1,222	9,518	13,945
2021	10,211	10,095	1,167	8,321	12,665	12,115	12,153	1,130	10,264	14,185
2022	10,752	10,731	1,074	8,956	12,782	12,602	12,666	1,035	10,879	14,553
2023	11,195	11,267	979	9,618	13,002	13,025	13,127	967	11,284	14,629
2024	11,567	11,645	900	9,982	13,232	13,398	13,532	893	11,684	14,808
2025	11,909	12,028	843	10,346	13,211	13,681	13,725	799	12,083	15,031
2026	12,192	12,286	768	10,682	13,403	13,902	13,941	730	12,413	15,167
2027	12,408	12,481	691	10,977	13,601	14,076	14,080	703	12,709	15,225
2028	12,574	12,550	639	11,283	13,678	14,210	14,154	717	12,847	15,469
2029	12,702	12,659	636	11,495	13,806	14,306	14,253	706	13,035	15,594
2030	12,796	12,752	658	11,545	13,971	14,382	14,348	683	13,082	15,585
2031	12,863	12,834	635	11,773	14,045	14,471	14,406	722	12,990	15,833
2032	12,923	12,862	644	11,715	14,092	14,561	14,574	733	13,329	15,953
2033	13,004	12,980	669	11,654	14,311	14,612	14,570	704	13,303	16,015
2034	13,066	13,072	670	11,871	14,304	14,655	14,631	672	13,403	16,083
2035	13,107	13,078	630	11,950	14,389	14,705	14,695	656	13,459	16,069
2036	13,143	13,138	610	11,963	14,475	14,745	14,774	647	13,540	15,999
2037	13,187	13,209	593	12,086	14,331	14,761	14,750	656	13,465	15,747
2038	13,208	13,203	597	12,045	14,247	14,780	14,872	667	13,502	16,029
2039	13,225	13,255	607	12,032	14,221	14,778	14,825	709	13,322	16,210
2040	13,232	13,300	626	11,973	14,443	14,775	14,754	765	13,298	15,976
2041	13,225	13,223	675	11,890	14,471	14,773	14,756	780	13,281	16,113
2042	13,223	13,198	711	11,855	14,335	14,764	14,814	784	13,091	16,148
2043	13,214	13,227	720	11,735	14,536	14,784	14,766	785	13,351	16,114
2044	13,214	13,261	724	11,863	14,509	14,828	14,828	776	13,538	16,103
2045	13,240	13,274	716	12,022	14,462	14,880	14,951	782	13,420	16,134

$F_{35\%}$ (0.6yr^{-1})										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,581	3,571	637	2,534	4,964	5,951	5,934	1,059	4,212	8,251
2017	4,237	4,208	727	3,117	5,851	6,061	6,057	961	4,582	8,101
2018	4,619	4,575	777	3,445	6,341	5,849	5,778	713	4,731	7,379
2019	4,546	4,531	623	3,646	5,907	5,597	5,550	543	4,544	6,679
2020	4,334	4,262	451	3,635	5,246	5,395	5,425	473	4,472	6,244
2021	4,160	4,135	346	3,554	4,858	5,258	5,229	420	4,438	6,005
2022	4,031	4,030	306	3,503	4,611	5,205	5,195	396	4,405	5,872
2023	3,967	3,937	268	3,506	4,459	5,209	5,175	415	4,496	5,911
2024	3,949	3,907	271	3,476	4,438	5,246	5,277	393	4,567	5,888
2025	3,973	3,951	283	3,499	4,516	5,243	5,272	345	4,581	5,859
2026	3,983	3,962	253	3,595	4,442	5,222	5,192	335	4,663	5,945
2027	3,971	3,962	230	3,554	4,500	5,200	5,145	389	4,550	6,031
2028	3,960	3,924	239	3,621	4,446	5,183	5,121	445	4,389	6,116
2029	3,954	3,890	283	3,524	4,622	5,164	5,136	427	4,373	5,867
2030	3,943	3,891	300	3,456	4,542	5,152	5,117	414	4,408	5,930
2031	3,927	3,895	271	3,468	4,454	5,174	5,148	440	4,240	5,997
2032	3,925	3,888	288	3,405	4,485	5,210	5,244	415	4,376	5,993
2033	3,952	3,945	291	3,470	4,554	5,204	5,189	373	4,586	5,960
2034	3,959	3,927	272	3,472	4,525	5,197	5,204	369	4,446	5,865
2035	3,952	3,927	244	3,529	4,457	5,207	5,213	371	4,465	5,907
2036	3,949	3,930	247	3,510	4,430	5,214	5,273	397	4,454	5,873
2037	3,965	3,955	254	3,490	4,399	5,200	5,174	422	4,448	6,031
2038	3,960	3,946	278	3,523	4,475	5,198	5,177	420	4,457	6,055
2039	3,956	3,939	288	3,494	4,571	5,179	5,188	432	4,323	6,002
2040	3,950	3,926	281	3,486	4,617	5,167	5,160	452	4,271	6,004
2041	3,938	3,885	295	3,426	4,539	5,164	5,180	442	4,300	5,915
2042	3,938	3,907	299	3,402	4,543	5,157	5,150	438	4,283	5,912
2043	3,930	3,901	292	3,442	4,486	5,180	5,212	420	4,404	5,889
2044	3,932	3,892	290	3,381	4,477	5,226	5,266	403	4,436	5,911
2045	3,954	3,947	274	3,536	4,410	5,266	5,274	415	4,412	6,051

Table F.10. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for WAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	3.377	3.367	0.601	2.390	4.682	0	0	0	0	0
2017	3.949	3.955	0.603	2.998	5.223	0	0	0	0	0
2018	4.416	4.335	0.585	3.520	5.656	0	0	0	0	0
2019	4.796	4.765	0.549	3.902	5.943	0	0	0	0	0
2020	5.085	5.091	0.517	4.241	6.051	0	0	0	0	0
2021	5.332	5.369	0.472	4.555	6.220	0	0	0	0	0
2022	5.532	5.566	0.439	4.785	6.356	0	0	0	0	0
2023	5.721	5.786	0.411	4.977	6.388	0	0	0	0	0
2024	5.864	5.883	0.369	5.149	6.482	0	0	0	0	0
2025	5.978	5.999	0.335	5.307	6.557	0	0	0	0	0
2026	6.068	6.074	0.312	5.459	6.595	0	0	0	0	0
2027	6.139	6.136	0.308	5.537	6.676	0	0	0	0	0
2028	6.192	6.179	0.314	5.605	6.735	0	0	0	0	0
2029	6.230	6.216	0.289	5.684	6.787	0	0	0	0	0
2030	6.265	6.234	0.306	5.680	6.822	0	0	0	0	0
2031	6.314	6.318	0.314	5.726	6.919	0	0	0	0	0
2032	6.339	6.333	0.315	5.761	6.896	0	0	0	0	0
2033	6.361	6.330	0.293	5.847	6.993	0	0	0	0	0
2034	6.381	6.389	0.291	5.811	6.992	0	0	0	0	0
2035	6.407	6.412	0.280	5.893	6.942	0	0	0	0	0
2036	6.412	6.410	0.283	5.859	6.905	0	0	0	0	0
2037	6.426	6.452	0.282	5.864	6.882	0	0	0	0	0
2038	6.429	6.468	0.292	5.831	6.993	0	0	0	0	0
2039	6.426	6.424	0.321	5.789	7.014	0	0	0	0	0
2040	6.430	6.431	0.333	5.803	6.972	0	0	0	0	0
2041	6.422	6.428	0.335	5.748	7.030	0	0	0	0	0
2042	6.425	6.430	0.340	5.775	7.013	0	0	0	0	0
2043	6.440	6.458	0.336	5.825	7.002	0	0	0	0	0
2044	6.462	6.467	0.336	5.872	7.017	0	0	0	0	0
2045	6.480	6.507	0.341	5.858	7.031	0	0	0	0	0

	F$_{35\%}$ (0.6yr^{-1})									
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1,301	1,297	232	921	1,804	1,177	1,188	235	726	1,652
2017	1,500	1,489	256	1,106	2,069	1,372	1,371	251	939	1,906
2018	1,629	1,614	267	1,232	2,219	1,514	1,506	264	1,116	2,087
2019	1,614	1,605	218	1,303	2,091	1,505	1,500	223	1,165	1,977
2020	1,546	1,525	158	1,301	1,864	1,433	1,412	171	1,136	1,767
2021	1,485	1,475	121	1,271	1,725	1,372	1,374	137	1,112	1,623
2022	1,440	1,443	104	1,264	1,636	1,325	1,336	120	1,080	1,538
2023	1,417	1,407	91	1,261	1,591	1,300	1,298	107	1,079	1,487
2024	1,411	1,404	92	1,254	1,577	1,296	1,281	105	1,115	1,474
2025	1,417	1,410	95	1,265	1,597	1,306	1,309	106	1,118	1,497
2026	1,420	1,410	86	1,288	1,572	1,310	1,314	96	1,144	1,465
2027	1,416	1,415	78	1,282	1,592	1,300	1,297	89	1,153	1,485
2028	1,413	1,395	82	1,300	1,587	1,291	1,269	100	1,127	1,482
2029	1,410	1,381	96	1,266	1,641	1,289	1,271	115	1,076	1,535
2030	1,407	1,384	101	1,246	1,606	1,286	1,272	118	1,076	1,512
2031	1,402	1,391	93	1,249	1,580	1,282	1,276	112	1,070	1,471
2032	1,402	1,389	97	1,238	1,593	1,285	1,283	113	1,074	1,488
2033	1,409	1,402	98	1,248	1,623	1,295	1,291	110	1,083	1,514
2034	1,412	1,406	91	1,255	1,595	1,297	1,296	106	1,111	1,492
2035	1,410	1,406	82	1,265	1,582	1,296	1,294	98	1,099	1,481
2036	1,409	1,401	83	1,264	1,575	1,293	1,293	101	1,092	1,468
2037	1,413	1,411	86	1,256	1,565	1,295	1,302	104	1,088	1,464
2038	1,413	1,403	93	1,268	1,595	1,297	1,302	110	1,091	1,488
2039	1,411	1,407	97	1,263	1,615	1,292	1,296	116	1,084	1,511
2040	1,409	1,399	96	1,253	1,631	1,288	1,296	118	1,053	1,528
2041	1,405	1,390	99	1,233	1,606	1,284	1,277	119	1,035	1,496
2042	1,405	1,393	101	1,222	1,611	1,283	1,284	121	1,067	1,511
2043	1,403	1,392	99	1,239	1,593	1,283	1,279	117	1,041	1,488
2044	1,404	1,391	98	1,220	1,595	1,289	1,284	113	1,097	1,490
2045	1,411	1,407	93	1,270	1,570	1,298	1,307	108	1,083	1,469

Table F.11. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0 for WAG, 2016–2045.

	$F_{35\%}$ (0.6yr^{-1})				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.753	0.749	0.131	0.546	1.041
2017	0.887	0.880	0.151	0.661	1.223
2018	0.970	0.960	0.161	0.725	1.328
2019	0.954	0.950	0.129	0.766	1.237
2020	0.908	0.893	0.092	0.772	1.095
2021	0.871	0.864	0.070	0.753	1.015
2022	0.844	0.845	0.062	0.738	0.964
2023	0.831	0.823	0.055	0.739	0.935
2024	0.827	0.818	0.056	0.727	0.927
2025	0.832	0.825	0.058	0.733	0.944
2026	0.834	0.829	0.052	0.754	0.930
2027	0.833	0.831	0.048	0.744	0.942
2028	0.831	0.823	0.049	0.759	0.932
2029	0.830	0.818	0.058	0.742	0.968
2030	0.827	0.819	0.062	0.728	0.949
2031	0.824	0.819	0.055	0.728	0.932
2032	0.823	0.814	0.059	0.717	0.939
2033	0.828	0.825	0.060	0.723	0.953
2034	0.830	0.823	0.056	0.724	0.945
2035	0.828	0.822	0.050	0.746	0.933
2036	0.828	0.822	0.050	0.739	0.928
2037	0.831	0.827	0.052	0.739	0.920
2038	0.831	0.829	0.057	0.736	0.937
2039	0.830	0.824	0.059	0.739	0.957
2040	0.829	0.825	0.057	0.738	0.966
2041	0.826	0.819	0.060	0.723	0.951
2042	0.826	0.819	0.061	0.725	0.949
2043	0.824	0.820	0.060	0.719	0.939
2044	0.824	0.818	0.060	0.710	0.936
2045	0.829	0.827	0.056	0.740	0.924

Table F.12. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for WAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,114	3,082	731	1,966	4,751	7,086	7,015	1,664	4,473	10,813
2017	5,231	5,179	1,229	3,302	7,982	8,653	8,565	1,897	5,747	12,848
2018	7,156	7,068	1,664	4,553	10,877	9,840	9,717	1,837	7,101	13,857
2019	8,514	8,461	1,771	5,843	12,382	10,778	10,565	1,706	8,248	14,532
2020	9,472	9,275	1,675	7,021	13,147	11,512	11,415	1,567	9,062	14,823
2021	10,190	10,001	1,513	7,874	13,523	12,083	12,089	1,431	9,855	14,907
2022	10,729	10,690	1,369	8,596	13,491	12,560	12,637	1,291	10,420	15,125
2023	11,162	11,189	1,228	9,209	13,492	12,975	13,059	1,184	10,983	15,295
2024	11,522	11,572	1,108	9,640	13,807	13,346	13,437	1,076	11,528	15,238
2025	11,857	11,918	1,017	10,115	13,710	13,624	13,633	955	11,823	15,302
2026	12,137	12,211	917	10,487	13,766	13,836	13,888	857	12,253	15,430
2027	12,347	12,367	815	10,812	13,810	14,005	14,001	801	12,511	15,313
2028	12,506	12,515	738	11,145	13,852	14,133	14,104	790	12,770	15,557
2029	12,629	12,587	712	11,343	13,832	14,222	14,194	758	12,864	15,647
2030	12,717	12,676	713	11,442	14,008	14,292	14,230	735	12,931	15,650
2031	12,778	12,765	679	11,586	14,050	14,379	14,359	782	12,929	15,883
2032	12,834	12,767	694	11,589	14,120	14,468	14,512	796	13,067	15,984
2033	12,913	12,933	725	11,546	14,342	14,515	14,461	770	13,146	16,056
2034	12,974	12,993	729	11,661	14,334	14,556	14,508	736	13,248	16,009
2035	13,012	13,001	690	11,836	14,390	14,604	14,590	721	13,224	15,910
2036	13,046	13,041	669	11,811	14,325	14,641	14,728	711	13,185	15,965
2037	13,088	13,120	652	11,800	14,262	14,651	14,711	724	13,144	15,807
2038	13,105	13,213	656	11,753	14,196	14,669	14,802	736	13,219	16,065
2039	13,119	13,203	669	11,748	14,269	14,661	14,730	785	13,079	16,111
2040	13,123	13,196	691	11,762	14,479	14,651	14,647	852	12,886	15,926
2041	13,110	13,122	750	11,557	14,376	14,651	14,659	867	12,829	16,081
2042	13,106	13,115	792	11,440	14,339	14,645	14,745	867	12,909	16,137
2043	13,098	13,171	799	11,350	14,481	14,666	14,703	859	13,009	16,142
2044	13,100	13,192	796	11,517	14,491	14,717	14,726	847	13,374	16,156
2045	13,130	13,179	781	11,737	14,429	14,775	14,871	857	13,271	16,112

					$F_{35\%}$ ($0.68yr^{-1}$)					
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,114	3,082	731	1,966	4,751	5,946	5,886	1,396	3,754	9,073
2017	4,116	4,051	930	2,738	6,244	6,187	6,132	1,300	4,262	9,067
2018	4,701	4,611	1,042	3,189	7,086	5,966	5,811	947	4,567	8,085
2019	4,652	4,571	843	3,482	6,545	5,664	5,584	669	4,407	6,948
2020	4,397	4,288	579	3,525	5,678	5,419	5,475	536	4,391	6,376
2021	4,182	4,150	406	3,466	4,969	5,251	5,243	464	4,352	6,075
2022	4,024	4,011	341	3,435	4,678	5,177	5,138	435	4,300	5,925
2023	3,944	3,903	294	3,435	4,487	5,174	5,131	459	4,381	6,014
2024	3,918	3,848	299	3,404	4,495	5,218	5,238	439	4,455	5,938
2025	3,943	3,909	315	3,432	4,541	5,218	5,214	388	4,486	5,899
2026	3,957	3,928	285	3,513	4,462	5,193	5,152	379	4,499	5,995
2027	3,945	3,925	259	3,484	4,507	5,170	5,122	429	4,479	6,055
2028	3,931	3,889	269	3,524	4,472	5,151	5,111	480	4,259	6,153
2029	3,924	3,871	308	3,475	4,666	5,129	5,117	465	4,251	5,881
2030	3,911	3,871	323	3,370	4,562	5,116	5,106	463	4,242	5,997
2031	3,895	3,842	297	3,380	4,463	5,140	5,102	490	4,156	6,064
2032	3,893	3,829	323	3,311	4,529	5,178	5,207	460	4,287	6,095
2033	3,922	3,897	324	3,390	4,561	5,173	5,189	419	4,478	6,009
2034	3,931	3,906	303	3,404	4,535	5,166	5,234	408	4,309	5,858
2035	3,923	3,903	270	3,450	4,443	5,175	5,201	408	4,258	5,849
2036	3,919	3,919	271	3,415	4,394	5,179	5,256	438	4,300	5,880
2037	3,934	3,941	278	3,407	4,371	5,162	5,146	476	4,329	6,099
2038	3,928	3,924	308	3,423	4,483	5,161	5,135	476	4,299	6,101
2039	3,923	3,892	326	3,413	4,608	5,138	5,110	487	4,100	6,016
2040	3,917	3,876	317	3,374	4,628	5,122	5,151	508	4,073	6,076
2041	3,901	3,857	331	3,290	4,587	5,125	5,121	489	4,151	5,903
2042	3,900	3,881	331	3,273	4,568	5,122	5,164	481	4,130	5,994
2043	3,896	3,880	320	3,330	4,481	5,148	5,223	458	4,316	5,948
2044	3,900	3,877	316	3,294	4,511	5,199	5,223	446	4,346	5,975
2045	3,924	3,918	302	3,465	4,446	5,244	5,229	461	4,336	6,093

Table F.13. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for WAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	3.469	3.434	0.815	2.190	5.293	0	0	0	0	0
2017	4.094	4.065	0.825	2.846	5.883	0	0	0	0	0
2018	4.599	4.491	0.798	3.423	6.348	0	0	0	0	0
2019	5.006	4.945	0.742	3.853	6.633	0	0	0	0	0
2020	5.311	5.298	0.692	4.228	6.737	0	0	0	0	0
2021	5.568	5.581	0.624	4.560	6.782	0	0	0	0	0
2022	5.773	5.811	0.571	4.831	6.990	0	0	0	0	0
2023	5.970	6.032	0.523	5.072	6.943	0	0	0	0	0
2024	6.119	6.121	0.467	5.242	6.949	0	0	0	0	0
2025	6.233	6.266	0.417	5.471	6.978	0	0	0	0	0
2026	6.325	6.326	0.379	5.633	7.010	0	0	0	0	0
2027	6.398	6.400	0.364	5.747	7.011	0	0	0	0	0
2028	6.450	6.447	0.358	5.810	7.071	0	0	0	0	0
2029	6.487	6.470	0.326	5.877	7.147	0	0	0	0	0
2030	6.522	6.500	0.347	5.872	7.152	0	0	0	0	0
2031	6.572	6.608	0.357	5.945	7.276	0	0	0	0	0
2032	6.597	6.602	0.360	5.931	7.239	0	0	0	0	0
2033	6.618	6.611	0.336	6.046	7.321	0	0	0	0	0
2034	6.638	6.650	0.334	6.005	7.264	0	0	0	0	0
2035	6.665	6.676	0.323	6.041	7.233	0	0	0	0	0
2036	6.667	6.709	0.327	6.019	7.245	0	0	0	0	0
2037	6.681	6.724	0.326	6.004	7.246	0	0	0	0	0
2038	6.683	6.714	0.337	6.003	7.328	0	0	0	0	0
2039	6.674	6.674	0.375	5.930	7.320	0	0	0	0	0
2040	6.680	6.696	0.388	5.880	7.305	0	0	0	0	0
2041	6.673	6.698	0.390	5.819	7.354	0	0	0	0	0
2042	6.676	6.691	0.391	5.871	7.341	0	0	0	0	0
2043	6.693	6.716	0.384	6.008	7.317	0	0	0	0	0
2044	6.719	6.770	0.384	6.074	7.328	0	0	0	0	0
2045	6.741	6.795	0.393	6.020	7.378	0	0	0	0	0

	$F_{35\%}$ (0.68yr^{-1})									
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1,131	1,119	266	714	1,725	1,017	1,029	275	516	1,586
2017	1,440	1,416	323	964	2,181	1,322	1,314	321	784	2,025
2018	1,656	1,625	360	1,143	2,480	1,553	1,532	358	1,028	2,356
2019	1,664	1,636	302	1,250	2,342	1,569	1,557	308	1,131	2,240
2020	1,584	1,548	211	1,281	2,066	1,487	1,457	225	1,129	1,978
2021	1,508	1,483	146	1,255	1,805	1,410	1,399	164	1,108	1,729
2022	1,452	1,449	118	1,249	1,684	1,350	1,351	135	1,062	1,601
2023	1,421	1,406	101	1,240	1,610	1,316	1,300	119	1,068	1,525
2024	1,410	1,394	100	1,238	1,607	1,309	1,299	116	1,092	1,517
2025	1,416	1,398	105	1,254	1,618	1,319	1,307	119	1,111	1,534
2026	1,420	1,409	97	1,269	1,588	1,323	1,322	109	1,123	1,502
2027	1,417	1,411	88	1,263	1,599	1,314	1,305	101	1,135	1,510
2028	1,413	1,391	91	1,278	1,603	1,305	1,276	111	1,119	1,509
2029	1,410	1,384	103	1,269	1,658	1,302	1,286	126	1,072	1,568
2030	1,406	1,386	108	1,231	1,628	1,298	1,284	130	1,070	1,551
2031	1,401	1,381	101	1,234	1,598	1,294	1,300	124	1,068	1,506
2032	1,400	1,384	107	1,220	1,620	1,296	1,293	125	1,071	1,531
2033	1,408	1,393	109	1,230	1,635	1,306	1,300	124	1,087	1,547
2034	1,412	1,409	102	1,238	1,624	1,310	1,314	120	1,114	1,539
2035	1,410	1,401	91	1,260	1,584	1,309	1,318	110	1,086	1,502
2036	1,409	1,408	90	1,244	1,568	1,305	1,302	113	1,072	1,484
2037	1,413	1,413	93	1,234	1,565	1,306	1,318	116	1,075	1,482
2038	1,412	1,406	102	1,240	1,604	1,307	1,310	123	1,061	1,508
2039	1,410	1,395	110	1,239	1,638	1,302	1,300	133	1,033	1,554
2040	1,408	1,392	108	1,224	1,644	1,298	1,303	135	1,011	1,559
2041	1,403	1,392	111	1,199	1,626	1,294	1,284	134	1,006	1,535
2042	1,402	1,394	111	1,195	1,634	1,293	1,292	135	1,048	1,548
2043	1,401	1,390	108	1,216	1,599	1,294	1,287	129	1,032	1,509
2044	1,402	1,394	106	1,204	1,622	1,301	1,304	124	1,099	1,536
2045	1,410	1,408	102	1,258	1,590	1,310	1,326	120	1,084	1,509

Table F.14. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0d for WAG, 2016–2045.

	$F_{35\%}$ (0.68yr^{-1})				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.562	0.554	0.128	0.369	0.855
2017	0.733	0.719	0.163	0.499	1.109
2018	0.846	0.828	0.185	0.576	1.272
2019	0.841	0.825	0.152	0.628	1.184
2020	0.795	0.778	0.104	0.645	1.029
2021	0.755	0.746	0.071	0.638	0.894
2022	0.726	0.723	0.059	0.628	0.843
2023	0.711	0.706	0.051	0.622	0.808
2024	0.706	0.697	0.052	0.613	0.805
2025	0.710	0.703	0.055	0.621	0.815
2026	0.713	0.707	0.050	0.634	0.801
2027	0.712	0.709	0.045	0.635	0.808
2028	0.710	0.703	0.046	0.643	0.807
2029	0.708	0.697	0.052	0.635	0.839
2030	0.706	0.695	0.056	0.614	0.820
2031	0.703	0.693	0.051	0.615	0.801
2032	0.702	0.693	0.056	0.607	0.813
2033	0.707	0.703	0.057	0.608	0.820
2034	0.709	0.705	0.053	0.611	0.813
2035	0.707	0.702	0.047	0.629	0.797
2036	0.707	0.704	0.046	0.622	0.787
2037	0.710	0.706	0.047	0.616	0.786
2038	0.709	0.708	0.053	0.621	0.804
2039	0.708	0.701	0.056	0.619	0.826
2040	0.707	0.699	0.054	0.625	0.831
2041	0.705	0.698	0.057	0.602	0.822
2042	0.704	0.700	0.057	0.605	0.821
2043	0.703	0.698	0.055	0.599	0.805
2044	0.703	0.701	0.055	0.597	0.814
2045	0.707	0.707	0.052	0.626	0.799

Appendix H. 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 base assessment model 17_0 and setting all directed and bycatch fishing mortality to zero. Figure H.1 compares the time series of estimated B0 and MMB with fishing and MMB ratio (MMB/B0) for scenario 17_0 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.

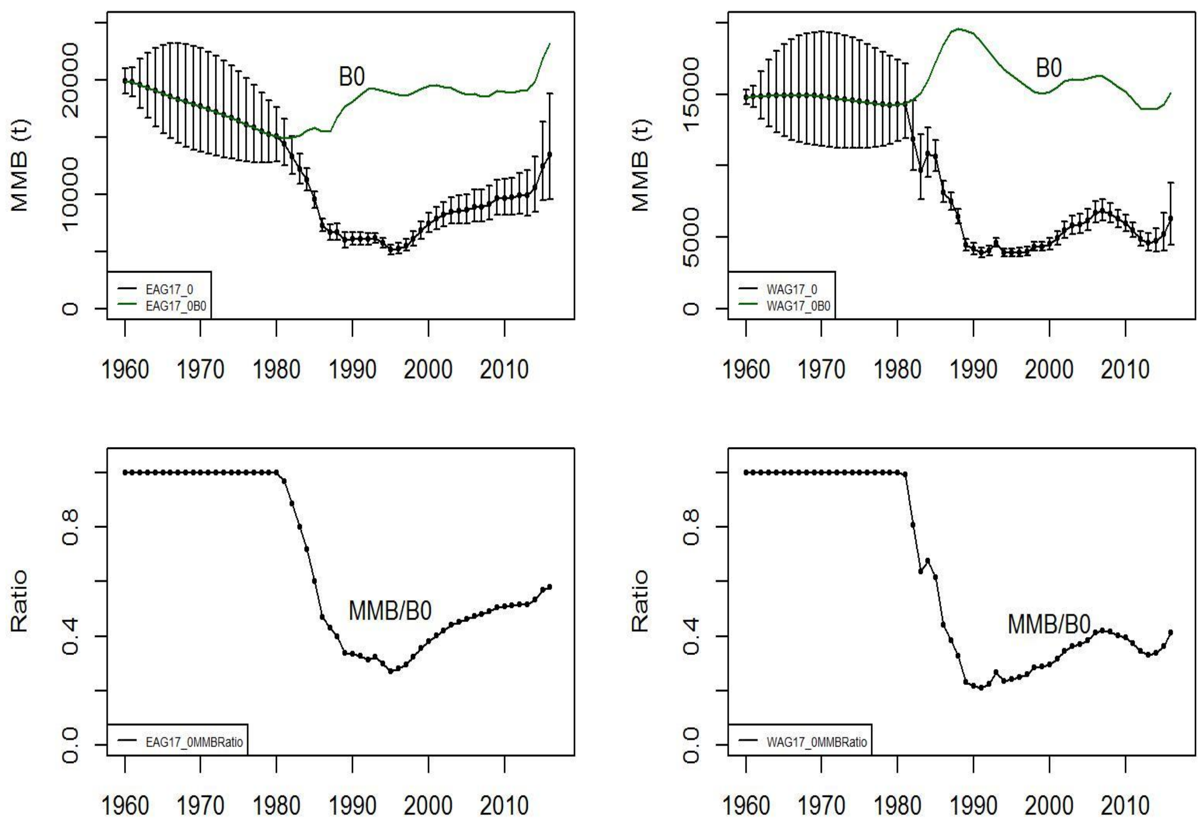


Figure H.1. Estimated B0 (t) (dark green curve) and MMB (t) with fishing (black curve with +/- 2SE) (top panel); and MMB/B0 ratio (bottom panel) from 1960 to 2016 for scenario 17_0 for Aleutian Islands golden king crab in EAG (left) and WAG (right). (Note: 2016 MMB= MMB estimated on 15 February 2017).