Aleutian Islands Golden King Crab Model Scenarios for May 2020 Assessment

January 2020 DRAFT REPORT

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Preamble

In this report, we provide a set of model scenarios that could be selected for May 2020 assessment, and OFL and ABC determination for the Aleutian Islands golden king crab. The scenarios are based on May 2019 CPT and June 2019 SSC recommendations. This document does not follow the standard SAFE document format. Standard SAFE document will be presented at the May 2020 CPT meeting.

Highlights:

1. Observer catch-per-unit-effort (CPUE) data were standardized with Year:Area interaction, measuring area from observer samples' fishing footprints (see Appendix A).

   Inclusion of Year:Area interaction addressed the area shrinkage issue as a result of reduction in number of vessels during post-rationalization period and provided improved CPUE estimates.

2. The 2015–2019 cooperative survey CPUE data were standardized by a mixed random effects model. A random slope procedure was applied to account for strings' random effects. The "depth," "soak time," and "pot ID" were considered as fixed effects based on fixed effect GLM fit. Various random structures, including String:Block interaction term, were considered (see Appendix A).

   The best random structure for CPUE standardization included a String:Block interaction term addressing area shrinkage. However, the data series is not long enough to use it exclusively in the model fit for OFL and ABC calculation.

3. The 2018/19 chela height (CH)-carapace length (CL) data from observer, fish ticket, and cooperative survey samples were pooled to determine maturity probability curves separately for EAG, WAG, and both regions combined. The Segmented regression (Bent-Point) and Cut-Line (implemented in Tanner and snow crab maturity analysis) methods were applied to determine maturity probability. The ADF&G 1991 and NMFS 1984 chela height and carapace length data were also analyzed by the two methods (see Appendix B).

After evaluating various results, the logistic maturity curves fitted to combined 2018/19 data were used for mature male biomass (MMB) estimation.

4. A new weight-length relationship was established from 2018 cooperative survey data and used for biomass calculation. Crab weight-at-size was estimated not as a point estimate at the mid-point of a size-interval but as an area integral estimate in a size-interval (see equation (1) in the main text).

   The revised weight-length relation provided similar biomass estimates to previous estimates.

5. The time period for mean number of recruit estimation for initialization of equilibrium abundance and for estimation of management reference points (e.g., F_{35} and MMB_{35}) was re-evaluated by the R_sigma procedure (see main text).

   This analysis provided an extended time series 1985–2016 for EAG and 1987–2016 for WAG than previously used 1987–2012 time period for mean recruitment estimation.

6. The probable cause(s) for retrospective patterns of MMB in EAG was investigated. After removing some years' size compositions and catch biomasses, the retrospective bias was reduced (see main text).

   We are open to discussion whether to remove some years' data or down weight them in the model fit.

7. The causes for recent recruitment pulses in the EAG recruitment were investigated. The cooperative survey size frequency distribution provides a probable cause for recent recruitment increases. The recruitment pulses disappeared when 2015–2018 size compositions and catch biomasses were removed from the fit (see main text).

   Since the cooperative survey size compositions indicated probable recruitment pulses in recent years in EAG, we treat this as a theoretical exercise to identify the subset of data causing those pulses.

8. A total of 13 Model scenarios were formulated considering different CPUE standardization procedures, maturity estimation methods, and time periods for mean number of recruit determination. The May 2019 accepted model scenario 19.1 was considered as the base scenario (see Table A).

   We identify model 19.2c as an appropriate model for final OFL and ABC calculation in May 2020. This model considers (a) Year:Area interaction for observer CPUE standardization, (b) Cut-Line maturity analysis for MMB determination, and (c) uses the extended time period 1985–2016 for EAG and 1987–2016 for WAG for mean recruitment estimation.

For detailed accounts of the Aleutian Islands golden king crab model formulation, fisheries, and biology, we direct you to the stock assessment report presented at the May 2019 CPT and June 2019 SSC meetings (Siddeek *et al*., 2019).

Input Data

1. *Changes to input data*
   - No changes to the data presented at the May 2019 CPT meeting. Thus, the time series of data used in the model are: retained catch (1981/82–2018/19), total catch (1990/91–2018/19), and groundfish bycatch (1989/90–2018/19) biomass and size compositions.
   - Fish ticket retained CPUE were standardized by the generalized linear model (GLM) with the lognormal as well as negative binomial link functions for the 1985/86–1998/98 period. Negative binomial model described the errors better than that of the lognormal (see Appendix A).
   - Observer pot sample legal size crab CPUE data were standardized by the GLM with the negative binomial link function with variable selection by first CAIC (modified AIC) and followed by R square criterion, separately for 1995/96–2004/05 (pre-rationalization) and 2005/06–2018/19 (post-rationalization) periods.
   - A Year and Area interaction was considered in one scenario to estimate a set of observers CPUE indices. Area was defined based on observer sample locations within 1nmi x 1nmi grids to reflect fishing footprints.
   - A mixed random effects model was used to standardize CPUE from the cooperative survey data for 2015/16–2018/19. We present this analysis as to get feedback but not used in the current model fit likelihood function.
   - Chela height and carapace length data collected during the 2018/19 fishing season by observer, retained catch, and cooperative pot survey samplings were pooled and analyzed to determine maturity probability curves.

   Figure Intro1 justifies selection of different time periods for mean number of recruit estimation to initialize the models. Table A lists brief description of various model scenarios considered in this report.

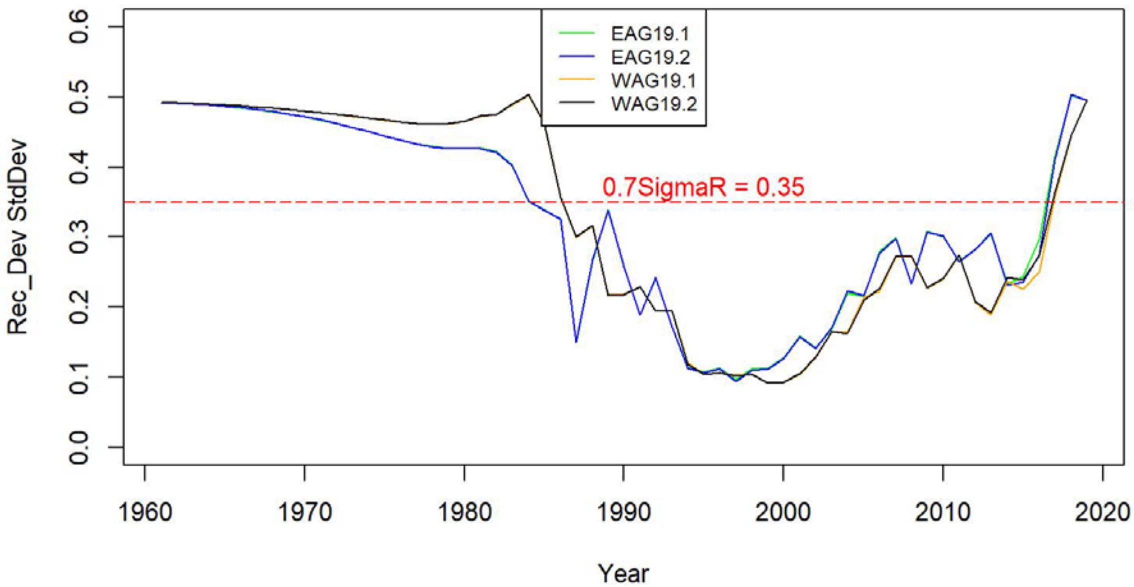


Figure Intro1. Standard deviation of recruit_dev plot for models 19.1 and 19.2 for EAG and WAG. The mean recruit for years with standard deviation less than 0.7 Sigma R was used to initialize models. Time periods 1985–2016 for EAG and 1987–2016 for WAG were selected for mean recruit estimation. For the recruit likelihood weight of 2, $SigmaR = \sqrt{\frac{1}{2 \times 2}} = 0.5$.

Table A. Features of all model scenarios: Initial condition was estimated in year 1960 by the equilibrium condition; two catchability and two sets of logistic total selectivity curves were used for the pre- and post-rationalization periods; and a common M of 0.21 yr^{-1} based on the estimate from the combined EAG and WAG data was used . The effective sample sizes for size compositions were estimated in two stages: Stage-1: number of vessel days/trips and Stage-2: Francis re-iteration method.

Model	CPUE Data Type	Maturity Analysis Method	Maturity Curve Type Used or MMB	Time Period for Mean Number of Recruit
19.1 (accepted model in May 2019)	Observer data from 1995/96–2018/19; Fish ticket data from 1985/86–1998/99. Observer CPUE standardization by negative binomial and Fish ticket by lognormal	Segmented regression on log(CH/CL) vs CL (EAG: 1991 data and WAG: 1984 data) for maturity determination	Knife-edge maturity 111 mm CL for EAG and WAG	1987-2012
19.1a	19.1+	ditto	ditto	EAG:1985-2016; WAG:1987-2016
19.1b	19.1a+ Fish ticket CPUE standardization by negative binomial	Segmented regression on log(CH/CL) vs CL (2018 combined data) for maturity determination	Logistic curve fitted to Segmented regression estimated maturity proportions	ditto
19.1ba	ditto	25% below the fitted segmented regression line for maturity determination	ditto	ditto
19.1c	19.1b+	Cut-Line on ln(CH) vs. ln(CL) (2018 combined data) for maturity determination	Logistic curve fitted to Cut-Line estimated maturity proportions	ditto

19.1ca	ditto		10% below the fitted Cut-Line for maturity determination	ditto	ditto
19.1d	19.1c+ EAG 2015–2018 Cooperative Survey CPUE index		Cut-Line on ln(CH) vs. ln(CL) (2018 combined data) for maturity determination	ditto	EAG:1985-2016;
19.2	Year:Area interaction for observer CPUE standardization. Fish ticket CPUE standardization by lognormal	Segmented regression on log(CH/CL) vs CL (EAG: 1991 data and WAG: 1984 data)	Knife-edge maturity 111 mm CL for EAG and WAG	1987-2012	
19.2a	19.2+	ditto	ditto	EAG:1985-2016; WAG:1987 -2016	
19.2b	19.2a+Fish ticket CPUE standardization by negative binomial	Segmented regression on log(CH/CL) vs CL (2018 combined data) for maturity determination	Logistic curve fitted to Segmented regression estimated maturity proportions	ditto	
19.2ba	ditto	25% below the fitted segmented regression line for maturity determination	ditto	ditto	

19.2c	19.2b+	Cut-Line analysis on ln(CH) vs. ln(CL) (2018 combined data) for maturity determination	Logistic curve fitted to Cut-Line estimated maturity proportions	ditto
19.2ca	ditto	10% below the fitted Cut-Line for maturity determination	ditto	ditto

Response to May 2019 CPT comments

Comment 1:
Model 19_1 should be used as the base model for OFL ad ABC determination for the 2019/20 season.

Response:
Done.

Comment 2:
Additional development is needed for fishery CPUE standardization, including further development in year-area interactions, focusing on estimating fishing footprints for each 30X30 block as area weights.

Response:
We followed Campbell's (2004) approach to address Year:Area interaction for CPUE standardization. Observer sampling locations over the years were used to create finer 1.0 X 1.0 nmi mesh and 10 larger blocks created over the entire Aleutian Islands. These blocks identify golden king crab distribution patches based on historical observer sampling locations. Model scenarios 19.2, 19.2a, 19.2b, 19.2ba, 19.2c, and 19.2ca considered Year:Area interaction for observer CPUE standardization (see Appendix A).

Comment 3:
Additional work is needed to obtain an index using the cooperative pot survey data for use in the EAG assessment model. Before the survey data can be used in the model, analyze the survey length composition data to check for cohort progress over time to support recent high recruitment estimates for EAG.

Response:
1. So far, we have five years of cooperative pot survey data (2015–2019). We provide the survey length composition plots to support recent high recruitment estimate for EAG below:

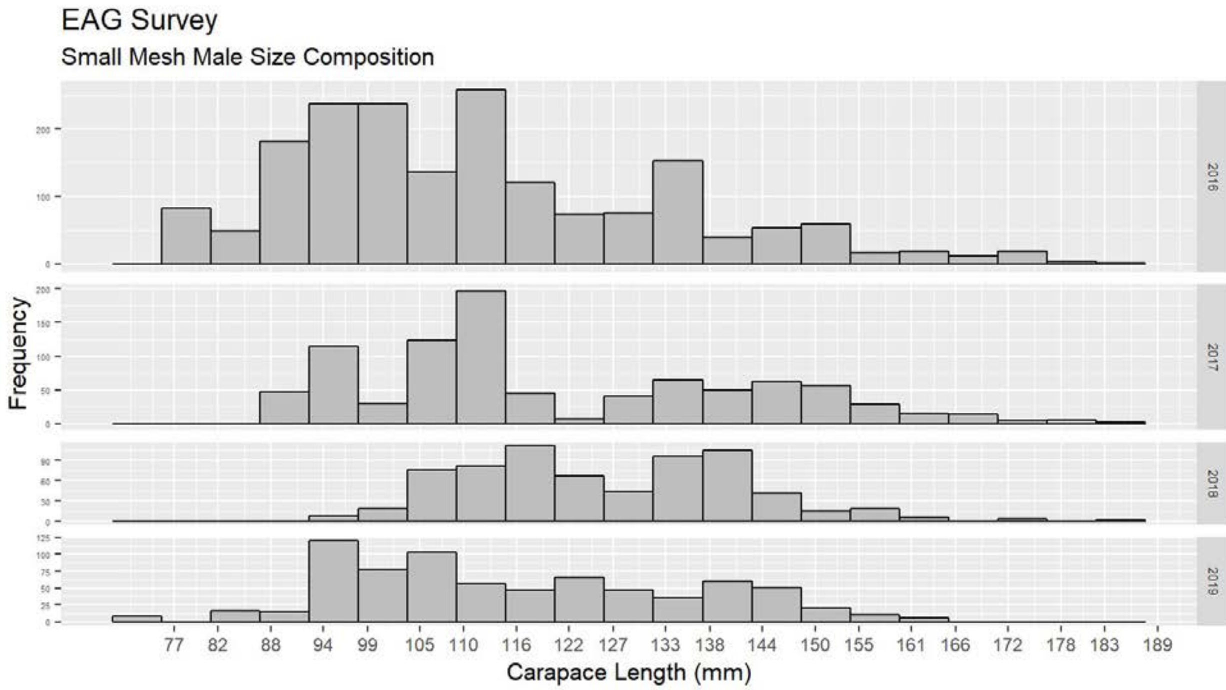


Figure Intro2. Male size composition from the small mesh size pots deployed in the cooperative survey during 2016–2019 in EAG.

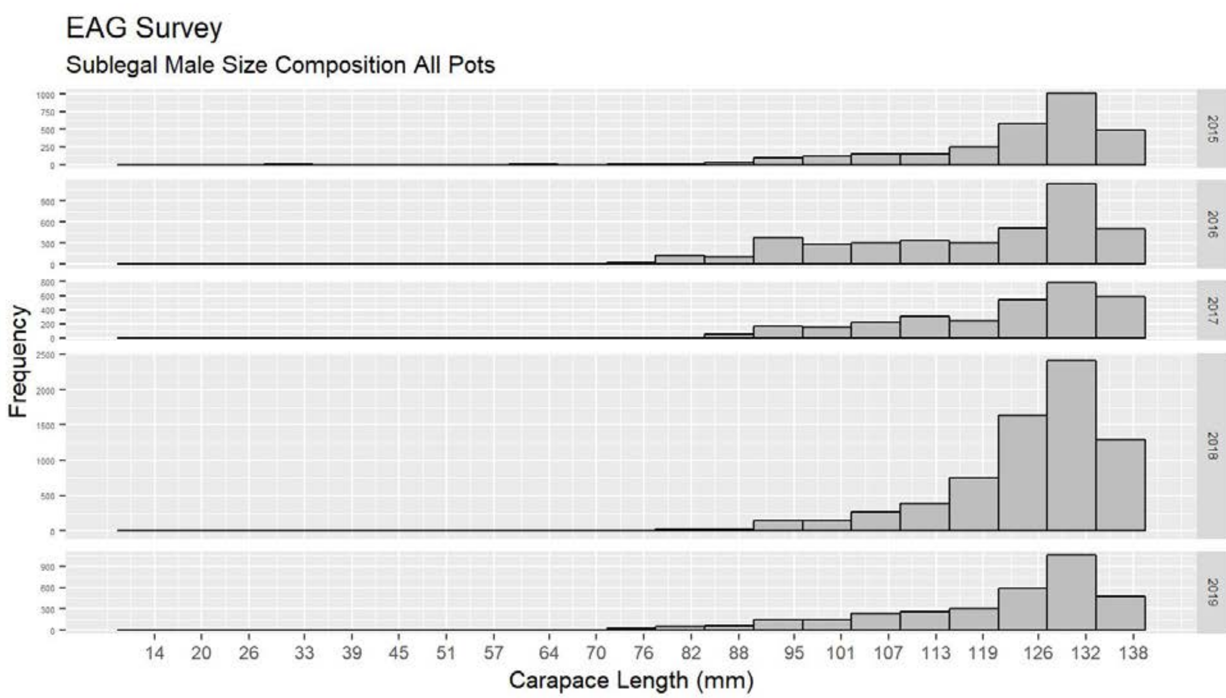


Figure Intro3. Sublegal male size composition from king crab pots deployed in the cooperative survey during 2015–2019 in EAG.

Figures Intro2 and 3 depict high frequency entry of smaller size crab in 2016 and justify EAG model prediction of high number of recruits during 2016–17.

2. We fitted a mixed random effects model to 2015–2019 EAG cooperative survey data. We used the random intercept model considering Strings as the random component, which means that each String has a different (random) baseline value to predict CPUE. We also investigated different random structures and based on AIC value selected String:Block interaction random effects term as appropriate for CPUE standardization. We used the fixed effect variables, "depth," "soak time," and "pot ID", which were identified form fitting a fixed effect GLM for standardization (see Appendix A).

3. We fitted the new length-weight data collected during the 2018/19 fishing season from the cooperative survey sampling, which covered all sizes. We used this relationship to estimate biomasses in the current models.

Comment 4:
The chela measurement data should be reanalyzed using recently collected fishery and survey data to better estimate the maturity of AIGKC.

Response:
We analyzed the chela height data collected during the 2018/19 fishing season from retained catch, observer, and cooperative survey samplings. We used the Bent-Point and Cut-Line approaches to determine maturity proportions by size and fitted logistic maturity curves. Then we used the logistic curves to estimate mature male biomass (MMB) for different model scenarios for EAG and WAG (see Appendix B).

Comment 5:
The bias of retrospective estimates for EAG needs to be checked and investigated for any model misspecifications

Response:
Likely culprit for this bias was incorporation of full time series of length compositions. To investigate this, we removed some early years' retained size compositions (1985–1987) and terminal years (2015–2018) retained and total catches and size compositions, and then performed the retrospective analysis. This resulted in eliminating the retrospective pattern (Figure Intro4):

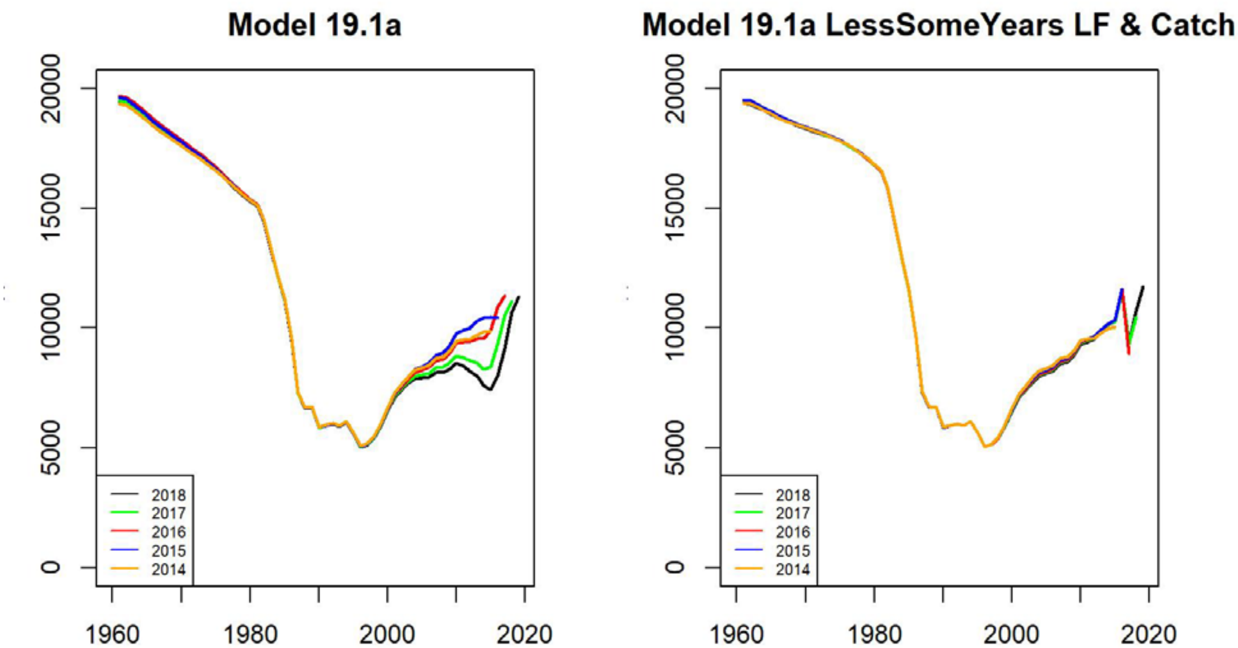


Figure Intro4. Comparison of retrospective patterns of Model 19.1a (left) and 19.1a (right) after removing 1985–1987 retained size compositions and 2015–2018 retained and total catches and size compositions, EAG.

Comment 6:
Uncertainty of recruitment estimates in the terminal years should be assessed in each assessment to determine how many years of recruitment estimates in the terminal years should be excluded for B35% estimation. The range of years to be used to estimate B35% should not be considered fixed.

Response:
We compared the standard deviations of Rec_Dev with a fixed proportion (0.7) of Sigma_R, $SigmaR = \sqrt{\frac{1}{2 \times W}}$., and considered the time period during which standard deviations were below 0.7SigmaR for mean recruit calculation (see Figure Intro1). This analysis determined the time periods 1985–2016 for EAG and 1987–2016 for WAG for mean calculation. We used these two periods in the current model fits.

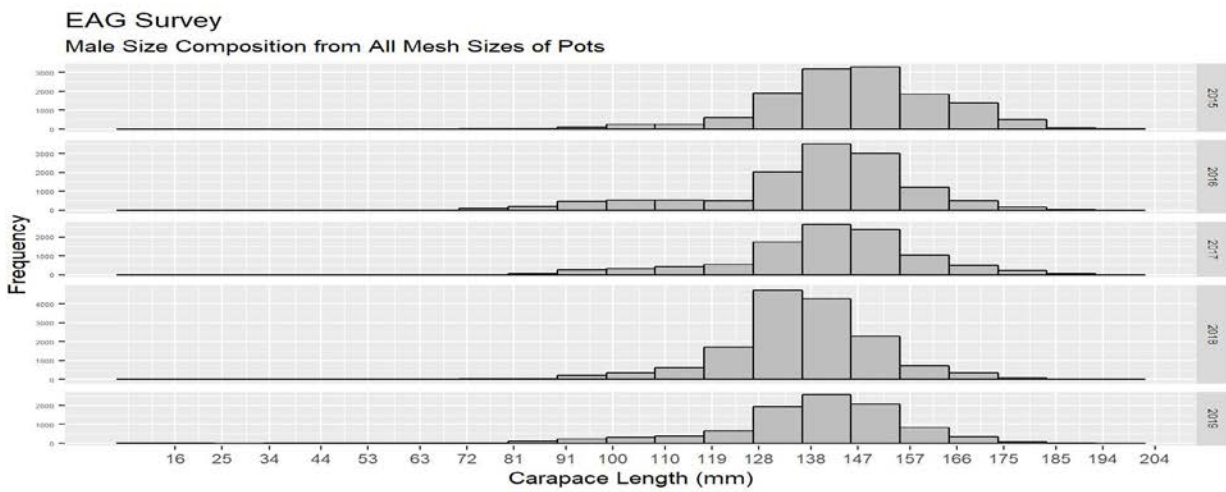
Comment 7:
Use of GMACS for the AIGKC assessment should be explored.

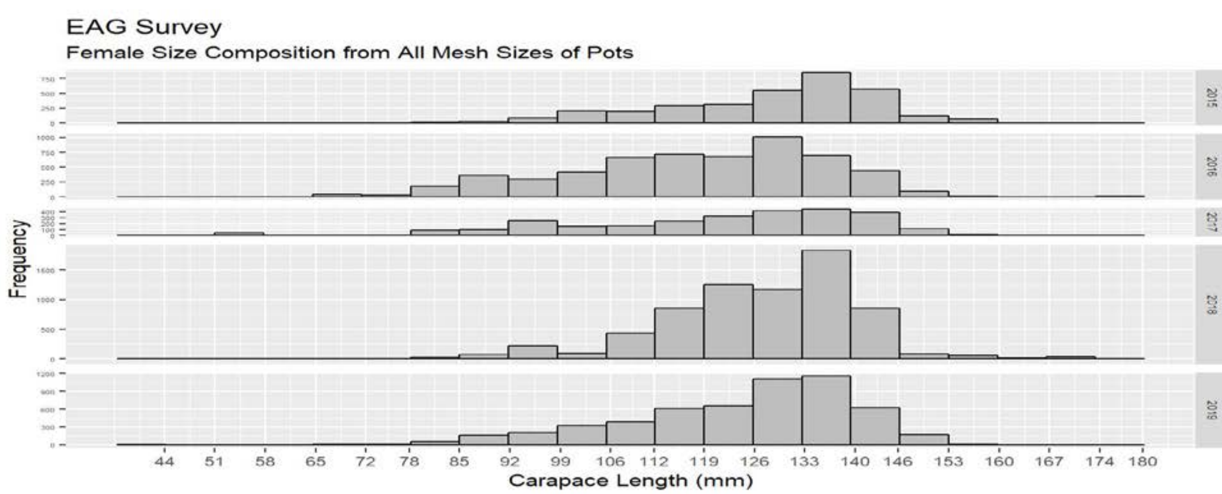
Response:
We will present our first attempt to apply GMACS on AIGKC at the May 2020 CPT meeting.

Response to June 2019 SSC comments:

Comment 1:
The SSC reiterates its request for a brief description of the cooperative survey in the assessment document, including the area sampled, size composition, and a summary of trends in CPUE.

Response:
The survey design and activities was presented at the September 2019 CPT meeting which was reported in the CPT minutes to SSC. We are yet to include the description of the survey design in the assessment report because it continues to evolve and recently extended to WAG. However, we present the preliminary results of size compositions (Figure Intro5) and CPUE indices (Tables A.4 and A.5 in Appendix A) from the cooperative surveys.





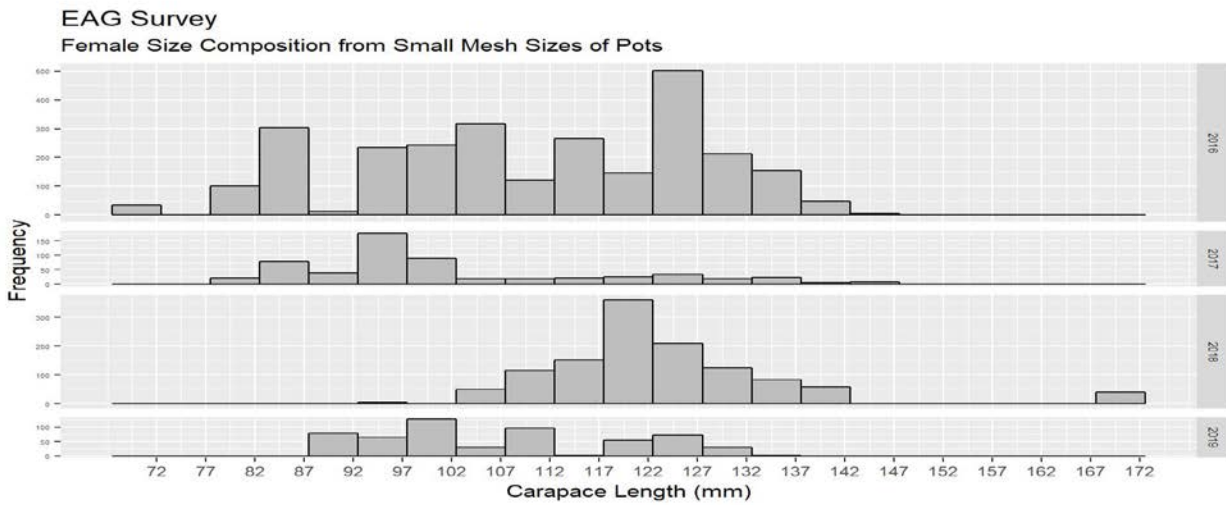


Figure Intro5. Male (top) and female (center) size compositions from all mesh sizes of crab pots; and female (bottom) size composition from small mesh crab pots deployed in the cooperative survey during 2015–2019 in EAG. Bottom figure only covers 2016–2019 data.

Comment 2:

The SSC suggests the authors to continue to look for the source of large estimated recruitment in recent years (in EAG) and reiterates the request that the authors remove one data set at a time from the model as one way to potentially identify the source.

Response:
Please refer to our response to the CPT comment#3.

We also investigated the sources of estimated recruitment pulses as per your suggestion:
We removed terminal year retained and total catch biomasses and length compositions one-year-at a time until 2014 for model 19.1a. This removed the 2015 to 2017 recruitment pulses (Figure Intro6).

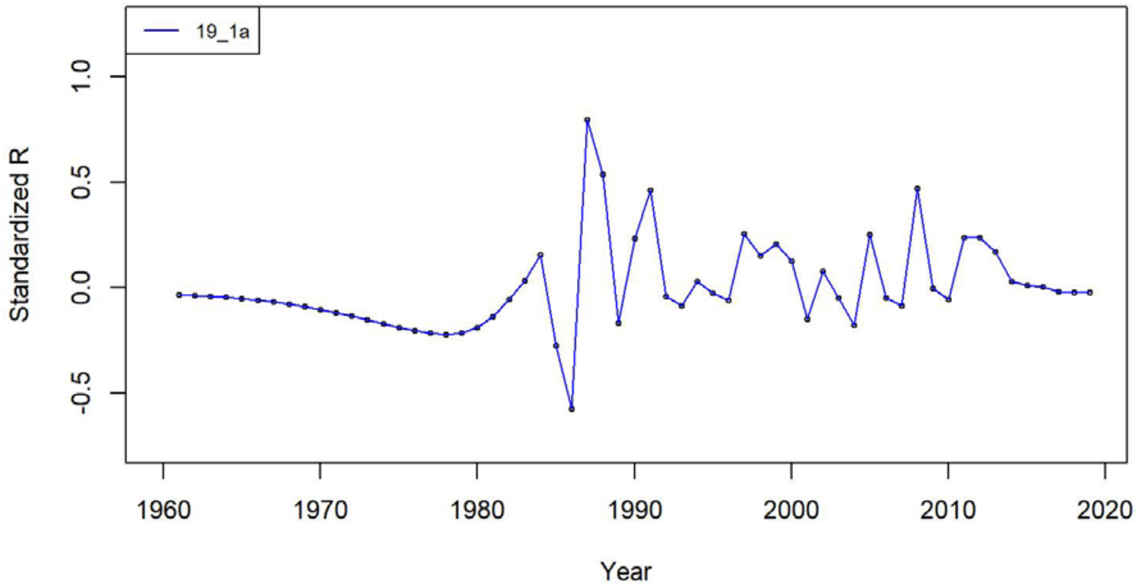


Figure Intro6. Estimated number of male recruits (crab size ≥ 101 mm CL) for 19.1a model fit for EAG golden king crab data, 1961–2019. The 2015 to 2018 retained and total catch biomasses and length compositions were removed for this fit. The number of recruits is standardized using (R-mean R)/mean R.

Comment 3:

The SSC noted that the 30X30 nmi grid cell size appears rather large and may exaggerate the fishery footprint for Year:Area interaction analysis. The authors might consider the use of a smaller grid cell size, which may better represent the spatial distribution of the fishery footprint. Other geostatistical tools might be explored, as well. Perhaps data products and analyses from the recent EFH 5-yr review can be used to estimate the AIGKC fishery footprint (SSC listed several references in connection with this comment).

Response:

We identified fishing footprints at a finer scale 1 x 1nmi grids based on observer pot sampling locations in the 1995/96 to 2018/19 database. We grouped them into 10 large blocks for the entire Aleutian Islands considering observer sampling intensity over the years, assumed to reflect abundance patches. We standardized CPUE considering Year:Area interaction. Effective area was measured as distribution of fishing footprints (number of 1 x 1nmi cells) in different blocks by year (details in Appendix A).

Introduction

Genetic studies did not show any evidence for separate golden king stocks in the Aleutian Islands. CPUE trends suggest different factors may influence stock productivity in EAG and WAG, which are separated by the 174° W longitude meridian. Since 1996, the Alaska Department of Fish and

Game (ADF&G) has divided management of the Aleutian Islands golden king fishery into EAG and WAG (ADF&G 2002). The stocks in the two areas are managed with annual total allowable (retained) catches. Additional management measures include a male-only fishery and a minimum legal-size limit (152.4 mm CW, or approximately 136 mm CL), 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).

There is a paucity of information on golden king crab life history characteristics due in part to the deep depth (~300–1000 m) and extremely rough bottom distribution on the slopes and trenches and the asynchronous nature of life history events, growth and reproduction (Otto and Cummiskey 1985; Somerton and Otto 1986; Watson et al., 2002).

Figures 1 and 2 provide the historical time series of catch and CPUE for EAG and WAG, respectively. Increases in CPUE were observed during the late 1990s through the early 2000s, and with the implementation of crab rationalization in 2005. In 2012, the Board of Fisheries of Alaska (BOF) increased the TAC levels to 3.310 million pounds for EAG and 2.980 million pounds for WAG beginning with the 2012/13 fishing year. The below par fishery performance in WAG in middle 2010 years lead to reduction in TAC to 2.235 million pounds, which reflected a 25% reduction in the TAC for WAG, while the TAC for EAG was kept at the same level 3.31 million pounds for the 2015/16 through 2017/18 fishing seasons. With the improved fishery performance and stock status since 2017/18, the TACs were further increased to 2.5 million pounds for WAG and 3.856 million pounds for EAG in 2018/19 and 2.87 million pounds for WAG and 4.31 million pounds for EAG in 2019/20 fishing years.

A new harvest strategy based on model estimated mature male abundance was accepted by the BOF in March 2019, specifying a 15% maximum harvest rate for EAG and 20% maximum harvest rate for WAG, and was implemented first time for the 2019/20 fishery (Daly, *et al.*, 2019).

Analytic Approach

The underlying population dynamics model is male-only and length-based (Siddeek *et al.*, 2019). This model combines commercial retained catch, total catch, groundfish (trawl and pot) fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) and commercial fishery 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.

We fitted the observer and commercial fishery CPUE indices with GLM estimated standard errors and an additional constant variance. The additional constant variance was estimated by the model fit. 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 coverage in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86–2004/05 and 2005/06–2018/19.

We projected the equilibrium abundance in 1960 with natural mortality and annual recruitment to create the initial abundance by size at the start of the (available) fishery in 1981. The R0 for equilibrium abundance was determined using the average model estimated number of recruits for a selected period. We used standardized CPUE indices (Appendix A) 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}. We assumed directed pot fishery discard mortality proportion at 0.20 yr^{-1}, overall groundfish fishery mortality proportion 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 (i.e., selectivity = 1.0). we did not model any discard of legal-size males in the directed pot fishery.

We considered number of vessel-days as the initial input 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. We did not fit the groundfish size composition following an earlier CPT suggestion in all model scenarios. We estimated the stage-2 effective sample sizes iteratively from stage-1 input effective sample sizes by the Francis (2011) method for all scenarios.

We used weighting factors for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. We set the retained catch biomass weight to an arbitrarily large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass weight in accordance with the observer annual sample sizes (number of pots) with a maximum of 250.0. The total catches were derived from observer nominal total CPUE and effort. In some years, observer sample sizes were low (Tables 3). We chose a small groundfish bycatch weight (0.2) based on the September 2015 CPT suggestion 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 (Table 2). 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 (formula in Siddeek *et al*., 2019)). 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).

We used the AD Model Builder (Fournier *et al.,* 2012) for model fitting.

Results

Model equations and weights for different data sets were provided in Siddeek *et al*. (2019). These weights (with the corresponding coefficient of variations) adequately fitted various data under integrated model setting. All scenarios considered molt probability parameters in addition to the linear growth increment and normal growth variability parameters to determine the size transition matrix.

In May 2019 assessment and before, the length-weight relationship of $W = aL^b$, based on 1991 weight vs. CL data, where a= $3.725*10^{-4}$, b = 3.0896, was used for biomass calculation from number of crabs by length. We updated the length-weight relationship parameters using cooperative survey collected data during 2018/19 with a = $1.095*10^{-4}$, b = 3.35923. Furthermore, we calculated the crab weight in a size bin using Beyer's (1987) formula, which considers integration through lower (CL_l) - to upper (CL_u)- limit of a size bin:

$$W_l = \left(\frac{1}{CL_u - CL_l}\right)\left(\frac{a}{1+b}\right)\left(CL_u^{b+1} - CL_l^{b+1}\right) \quad (1)$$

Tables of input values and parameter estimates

a. Historical GHL, TAC, catch, effort, CPUE, and mean crab weight are summarized in Table 1 for EAG and WAG.
b. Time series of retained and total catch and groundfish fishery discard mortality are summarized in Table 2 for EAG and WAG.
c. Time series of pot fishery and observer nominal retained and total CPUE, annual pot fishing effort, observer sample size, estimated observer CPUE indices are listed in Table 3 for EAG and WAG.
d. The estimated commercial fishery CPUE indices are provided in Table 4 for EAG and WAG. The CPUE index estimation methods, fits, and diagnostic plots are described in Appendix A.
e. The parameter estimates with coefficient of variation for four model scenarios 19.1(base), 19.1a, 19.2, and 19.2a are summarized respectively in Tables 5 for EAG and 15 for WAG. We have also provided the boundaries for parameter searches in those tables, and the estimates were within the bounds.
f. The mature male and legal male abundance time series for model scenarios 19.1 (base), 19.1a, 19.1b, 19.1c, 19.2, 19.2a, 19.2b, 19.2c are summarized in Tables 6 to 13 for EAG and Tables 16 to 23 for WAG.
g. The recruitment estimates for those model scenarios are summarized in Tables 6 to 13 for EAG and Tables 16 to 23 for WAG.
h. The likelihood component values and the total likelihood values for four model scenarios 19.1, 19.1a, 19.2, and 19.2a are summarized in Table 14 for EAG and Table 24 for WAG.
i. The Tier level, MMB35%, current MMB, current $MMB/MMB_{35\%}$, F_{OFL}, $F_{35\%}$, OFL, and ABC (under 25% buffer) for EAG, WAG, and the entire Aleutian Islands (AI) are listed in Table 25 for all model scenarios.

Graphs of estimates

a. We provide the retained length composition fits in Figure 3 for EAG and Figure 13 for WAG, total length composition fits in Figure 4 for EAG and Figure 14 for WAG, and groundfish discarded catch length composition fits in Figure 5 for EAG and Figure 15for WAG for 19.1, 19.1a, 19.2, and 19.2a model scenarios. The retained and total catch size composition fits appear satisfactory. But, the fits to groundfish bycatch size compositions are bad.

b. We provide the pre- and post-rationalization periods' total and retained selectivity curves in Figures 6 for EAG and Figures 16 for WAG for 19.1, 19.1a, 19.2, and 19.2a model scenarios. 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 5 and 15).
c. We provide the CPUE fits by 19.1, 19.1a, 19.2, and 19.2a model scenarios in Figure 7 for EAG and Figure 17 for WAG. All scenarios appear to fit the CPUE indices satisfactorily for both management areas. The Year:Area interaction effect produced higher confidence intervals than that of fixed effect.
d. We show the recruitment trends for 19.1, 19.1a, 19.2, and 19.2a model scenarios in Figure 8 for EAG and Figure 18 for WAG. The recruitment pulse peaked in recent years in EAG.
e. We provide the fits to retained catch, total catch, and groundfish discarded catch by 19.1, 19.1a, 19.2, and 19.2a model scenarios in Figure 9 for EAG and Figure 19 for WAG. The retained and groundfish bycatch fits are adequate, but the total catch fits showed some discrepancy.
f. We provide the fits to pre–1985 retained catches (in number of crabs) by 19.1, 19.1a, 19.2, and 19.2a model scenarios in Figure 10 for EAG and Figure 20 for WAG. All scenarios adequately fitted the 1981/82–1984/85 retained catches in both areas.
g. We provide the pot fishery total fishing mortality (F) plots for 19.1, 19.1a, 19.2, and 19.2a model scenarios in Figure 11 for EAG and Figure 21 for WAG. The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. Slight increases in F were observed from 2014 to 2016, followed by a decline in the EAG. On the other hand, the F in the WAG peaked in late 1980s, 1990s and early 2000s, declined in late 2000s, and slightly increased in 2013–2014 before declining.
h. We provide MMB trends for 19.1, 19.1a, 19.1b, 19.1c, 19.2, 19.2a, 19.2b, and 19.2c model scenarios in Figure 12 for EAG and Figure 22 for WAG. Mature male biomass tracked the CPUE trends well for all scenarios for EAG and WAG. We determined the mature male biomass values on 15 February each year after the fishery.

Specification of the Tier level

The OFL and ABC for Aleutian Islands golden king crab stocks are determined under Tier 3 level. The calculation procedures are described below:

The critical assumptions for MMB_{MSY} reference point estimation of Aleutian Islands golden king crab are:

a. Natural mortality is constant.
b. Growth transition matrix is fixed and estimated using tagging data with the molt probability sub-model.
c. Total fishery selectivity and retention curves are length dependent and the 2005/06–2018/19 period selectivity estimates are used.
d. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated recruits (in millions of crab) are averaged for the time periods 1987–2012, 1985– 2016, or 1987– 2016 depending on the region and model scenario.

f. Model estimated groundfish bycatch mortality values are averaged for the period 2009/10 – 2018/19 (10 years).
g. Knife-edge 50% maturity size and various maturity curves are used for MMB estimation depending on different model scenarios.

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.

Specification of the OFL:
F_{OFL} was determined using the following equation with an iterative procedure accounting for intervening total removals. The formulas for removal catches and groundfish discards are given in Siddeek et al. (2019).

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

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

$$F_{OFL} = F_{35\%} \frac{\left(\frac{MMB_{current}}{MMB_{35\%}} - \alpha\right)}{(1-\alpha)} \quad (2)$$

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

$F_{OFL} = 0.$

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 $\alpha = 0.1$.

Calculation of the ABC:
We estimated the cumulative probability distribution of OFL assuming a log normal distribution of OFL. We calculated the OFL at the 0.5 probability and the ABC using a 25% buffer on OFL.

The OFL and ABC estimates for various scenarios under Tier 3 are summarized separately for EAG, WAG, and the entire Aleutian Islands (AI) in Table 25.

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Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2018/19: number of vessels, guideline harvest level (GHL; established in lb, converted to t) for 1996/97 – 2004/05, total allowable catch (TAC; established in lb, converted to t) for 2005/06– 2018/19, weight of retained catch (harvest; t),number of retained crab, pot lifts, fishery catch-per-unit- effort (CPUE; retained crab per pot lift), and average weight (kg) of landed crab. The values are separated by EAG and WAG beginning in 1996/97.

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

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

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

Note:

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

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

			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
2018/19	1,830	1,135	240	140	8	2	2,078	1,277	3,355

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 model19.1) for the EAG and WAG golden king crab stocks, 1985/86–2018/19. Observer retained CPUE includes retained and non-retained legal-size crabs.

Year	Pot Fishery Nominal Retained CPUE		Obs. Nominal Retained CPUE		Obs. Nominal Total CPUE		Pot Fishery Effort (no.pot lifts)		Obs. Sample Size (no.pot lifts)		Obs. CPUE Index	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1985/86	11.90	11.90					117,718	118,563				
1986/87	8.42	7.32					155,240	277,780				
1987/88	7.03	7.15					146,501	160,229				
1988/89	7.52	7.93					155,518	166,409				
1989/90	8.49	7.83					155,262	202,541				
1990/91	8.90	7.00	2.17	11.83	13.00	26.67	106,281	108,533	138	340		
1991/92	8.20	7.40	17.56	7.07	42.16	17.26	133,428	101,429	377	857		
1992/93	8.40	5.90	10.44	4.24	34.84	11.35	133,778	69,443	199	690		
1993/94	7.80	4.40	5.91	12.75	23.50	21.25	106,890	127,764	31	174		
1994/95	5.90	4.10	4.66	6.62	18.43	19.52	191,455	195,138	127	1,270		
1995/96	5.90	4.70	6.03	6.03	20.36	17.30	177,773	115,248	6,388	5,598	1.00	1.16
1996/97	6.50	6.10	6.02	5.90	16.71	14.85	113,460	99,267	8,360	7,194	0.94	0.98
1997/98	7.30	6.60	7.99	6.72	20.66	15.54	106,403	86,811	4,670	3,985	0.87	0.98
1998/99	8.90	11.40	9.82	9.43	28.27	23.09	83,378	35,975	3,616	1,876	1.00	1.09
1999/00	9.00	6.30	10.28	6.09	23.27	14.83	79,129	107,040	3,851	4,523	0.92	0.91
2000/01	9.90	7.00	10.40	6.46	26.77	16.76	71,551	101,239	5,043	4,740	0.82	0.84
2001/02	11.70	6.50	11.73	6.04	23.60	14.70	62,639	105,512	4,626	4,454	1.04	0.82
2002/03	12.40	8.40	12.70	7.47	23.54	17.37	52,042	78,979	3,980	2,509	1.10	0.91
2003/04	10.90	10.20	11.34	9.33	20.04	18.21	58,883	66,236	3,960	3,334	0.97	1.16
2004/05	18.30	12.10	18.34	11.14	29.36	22.44	34,848	56,846	2,206	2,619	1.44	1.25
2005/06	25.40	21.20	29.52	23.83	38.44	36.16	24,569	30,116	1,193	1,365	0.99	1.17
2006/07	24.80	19.60	25.13	24.01	33.41	33.47	26,195	26,870	1,098	1,183	0.81	1.13
2007/08	28.00	20.00	31.10	21.04	40.38	32.46	22,653	29,950	998	1,082	0.91	1.00

2008/09	27.30	22.40	29.97	24.50	38.36	38.11	24,466	26,200	613	979	0.90	1.16
2009/10	25.90	23.70	26.60	26.55	35.78	34.08	26,298	26,489	408	892	0.73	1.24
2010/11	26.00	20.90	26.40	22.41	36.95	29.12	25,851	29,994	436	867	0.76	1.07
2011/12	37.30	23.40	39.48	23.69	52.25	31.04	17,915	26,326	361	837	1.09	1.10
2012/13	33.02	20.57	37.82	22.86	47.49	30.80	20,827	32,716	438	1,109	1.05	1.06
2013/14	33.67	16.42	35.94	16.94	46.34	25.00	21,388	41,835	499	1,223	1.03	0.82
2014/15	42.29	15.29	47.01	15.28	59.91	22.64	17,002	41,548	376	1,137	1.35	0.72
2015/16	39.41	14.97	43.19	15.80	58.77	22.23	19,376	41,108	478	1,296	1.27	0.74
2016/17	32.45	14.29	36.89	16.75	52.58	24.43	24,470	38,118	617	1,060	1.06	0.85
2017/18	31.46	16.81	35.18	19.28	53.40	25.53	25,516	30,885	585	760	1.02	0.97
2018/19	36.80	19.83	41.57	22.85	62.97	30.61	25,553	29,156	475	688	1.25	1.17

Table 4. Time series of GLM estimated CPUE indices and standard errors [standard error of ln(CPUE index)] for fish ticket based retained catch-per-pot lift (CPUE) for the EAG and WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data.

Year	**EAG Lognormal CPUE Index**	**Standard Error of ln (CPUE)**	**EAG Negative Binomial CPUE Index**	**Standard Error of ln (CPUE)**	**WAG Lognormal CPUE Index**	**Standard Error of ln (CPUE)**	**WAG Negative Binomial CPUE Index**	**Standard Error of ln (CPUE)**
1985/86	1.66	0.06	1.63	0.05	2.16	0.05	2.07	0.05
1986/87	1.30	0.05	1.23	0.05	1.78	0.04	1.59	0.04
1987/88	0.97	0.05	0.96	0.05	1.33	0.05	1.22	0.04
1988/89	1.06	0.04	1.04	0.04	1.47	0.03	1.41	0.03
1989/90	1.05	0.04	1.08	0.03	1.25	0.03	1.15	0.03
1990/91	0.96	0.05	0.99	0.05	0.88	0.03	0.87	0.03
1991/92	0.84	0.05	0.90	0.04	0.70	0.04	0.76	0.04
1992/93	0.89	0.05	0.92	0.04	0.59	0.04	0.61	0.04
1993/94	0.91	0.05	0.91	0.05	0.71	0.05	0.76	0.05
1994/95	0.78	0.04	0.81	0.04	0.86	0.04	0.83	0.04
1995/96	0.71	0.04	0.78	0.04	0.80	0.04	0.90	0.04
1996/97	0.81	0.04	0.78	0.04	0.84	0.03	0.84	0.03
1997/98	1.10	0.05	1.05	0.05	0.72	0.03	0.76	0.03
1998/99	1.31	0.06	1.21	0.05	0.99	0.04	1.06	0.03

Table 5. Parameter estimates and coefficient of variations (CV) with the 2018 MMB (MMB estimated on 15 Feb 2019) for models 19.1, 19.1a, 19.2, and 19.2a for the golden king crab data from the EAG, 1985/86–2018/19. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Model 19.1		Model 19.1a		Model 19.2		Model 19.2a		
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)	-8.23	0.208	-8.26	0.21	-8.22	0.21	-8.24	0.21	-12.0-5.0
log_a (molt prob. slope)	-2.51	0.023	-2.51	0.02	-2.50	0.02	-2.50	0.02	-4.61-1.39
log_b (molt prob. L50)	4.96	0.001	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.68	0.03	3.68	0.03	3.68	0.03	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.38	0.02	3.38	0.02	3.39	0.02	3.38	0.02	0.,4.4
log_ total sel deltaθ, 2005–18	2.98	0.03	2.98	0.03	2.98	0.03	2.98	0.03	0.,4.4
log_ ret. sel deltaθ, 1985–18	1.86	0.02	1.86	0.02	1.86	0.02	1.86	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.83	0.00	4.83	0.002	4.84	0.003	4.84	0.003	4.0,5.0
log_tot sel θ_{50}, 2005–18	4.92	0.002	4.92	0.002	4.92	0.002	4.92	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–18	4.92	0.0003	4.92	0.0003	4.92	0.0003	4.92	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.08	0.17	-1.08	0.17	-1.077	-0.17	-1.078	-0.17	-12.0, 12.0
logq2 (catchability 1995–04)	-0.55	0.13	-0.55	0.13	-0.56	-0.13	-0.56	-0.12	-9.0, 2.25
logq3 (catchability 2005–18)	-0.77	0.16	-0.77	0.16	-0.80	-0.15	-0.80	-0.15	-9.0, 2.25
log_mean_rec (mean rec.)	0.85	0.05	0.85	0.05	0.85	0.05	0.85	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.97	0.07	-0.98	0.07	-0.99	-0.07	-0.99	-0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.21	0.09	-9.21	0.09	-9.22	-0.09	-9.22	-0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.04	0.39	0.04	0.39	0.02	0.47	0.02	0.47	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.04	0.43	0.03	0.44	0.04	0.43	0.03	0.44	0.0,1.0
2018 MMB	11,323	0.21	11,317	0.21	11,598	0.19	11,577	0.19	

Table 6. 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 model 19.1 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =22,924 $MMB_{35\%}$=6,650			
1985	1.69	9,501	0.04	9,742	0.05
1986	1.01	7,274	0.04	8,251	0.04
1987	4.24	6,656	0.05	6,447	0.04
1988	3.60	6,636	0.05	5,379	0.05
1989	2.02	5,779	0.06	4,806	0.07
1990	2.96	5,888	0.05	4,319	0.07
1991	3.49	5,975	0.04	4,599	0.06
1992	2.26	5,903	0.04	4,438	0.05
1993	2.15	6,065	0.03	4,469	0.05
1994	2.43	5,602	0.04	4,899	0.04
1995	2.29	5,014	0.04	4,461	0.04
1996	2.23	5,116	0.04	3,856	0.04
1997	2.99	5,360	0.05	3,982	0.04
1998	2.74	5,904	0.05	4,082	0.05
1999	2.86	6,547	0.06	4,499	0.05
2000	2.65	7,120	0.06	5,133	0.06
2001	2.00	7,437	0.06	5,728	0.06
2002	2.48	7,681	0.07	6,226	0.07
2003	2.16	7,901	0.07	6,530	0.07
2004	1.88	7,933	0.07	6,726	0.07
2005	2.81	7,968	0.07	6,865	0.08
2006	2.17	8,165	0.07	6,765	0.08
2007	2.09	8,169	0.07	6,879	0.08
2008	3.09	8,285	0.07	7,011	0.08
2009	2.03	8,542	0.07	6,962	0.08
2010	1.89	8,404	0.07	7,206	0.07
2011	2.25	8,196	0.07	7,311	0.07
2012	2.00	7,985	0.07	7,111	0.07
2013	1.75	7,592	0.07	6,874	0.07
2014	3.15	7,441	0.09	6,576	0.08
2015	4.02	8,013	0.11	6,197	0.09
2016	4.75	9,177	0.14	6,250	0.11
2017	4.03	10,675	0.18	6,971	0.14
2018	2.57	11,323	0.21	8,400	0.18
2019	2.33				

Table 7. 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 model 19.1a for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,273 $MMB_{35\%}$=6,749			
1985	1.72	9,471	0.04	9,691	0.06
1986	1.02	7,264	0.04	8,208	0.04
1987	4.28	6,666	0.05	6,429	0.04
1988	3.63	6,678	0.05	5,379	0.05
1989	2.01	5,838	0.06	4,833	0.07
1990	2.90	5,933	0.05	4,372	0.07
1991	3.50	5,995	0.04	4,658	0.06
1992	2.26	5,919	0.04	4,472	0.05
1993	2.16	6,078	0.03	4,488	0.05
1994	2.42	5,613	0.04	4,913	0.04
1995	2.30	5,020	0.04	4,474	0.04
1996	2.23	5,121	0.04	3,864	0.04
1997	3.00	5,365	0.05	3,989	0.04
1998	2.74	5,908	0.05	4,087	0.05
1999	2.86	6,551	0.06	4,505	0.05
2000	2.65	7,124	0.06	5,139	0.06
2001	2.00	7,440	0.06	5,734	0.06
2002	2.48	7,683	0.07	6,232	0.07
2003	2.16	7,902	0.07	6,534	0.07
2004	1.88	7,934	0.07	6,729	0.07
2005	2.81	7,969	0.07	6,867	0.08
2006	2.17	8,167	0.07	6,766	0.08
2007	2.09	8,171	0.07	6,882	0.08
2008	3.09	8,287	0.07	7,014	0.08
2009	2.03	8,545	0.07	6,965	0.08
2010	1.89	8,407	0.07	7,211	0.07
2011	2.25	8,199	0.07	7,316	0.07
2012	2.01	7,988	0.07	7,115	0.07
2013	1.75	7,595	0.07	6,878	0.07
2014	3.15	7,444	0.09	6,581	0.08
2015	4.02	8,015	0.11	6,201	0.09
2016	4.74	9,176	0.14	6,254	0.11
2017	4.03	10,671	0.18	6,975	0.14
2018	2.57	11,317	0.21	8,401	0.18
2019	2.33				

Table 8. 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 model 19.1b for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Bent-Point fit: logistic maturity curve fitted to Bent-Point lines determined maturity proportion.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (Bent-Point fit)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,273 $MMB_{35\%}$=5,228			
1985	1.72	7,114	0.04	9,691	0.06
1986	1.02	5,368	0.04	8,208	0.04
1987	4.28	5,447	0.05	6,429	0.04
1988	3.63	5,152	0.05	5,379	0.05
1989	2.01	4,227	0.05	4,833	0.07
1990	2.90	4,493	0.04	4,372	0.07
1991	3.50	4,621	0.04	4,658	0.06
1992	2.26	4,338	0.04	4,472	0.05
1993	2.16	4,482	0.03	4,488	0.05
1994	2.42	4,224	0.03	4,913	0.04
1995	2.30	3,776	0.04	4,474	0.04
1996	2.23	3,838	0.04	3,864	0.04
1997	3.00	4,133	0.05	3,989	0.04
1998	2.74	4,448	0.05	4,087	0.05
1999	2.86	4,925	0.05	4,505	0.05
2000	2.65	5,309	0.06	5,139	0.06
2001	2.00	5,460	0.06	5,734	0.06
2002	2.48	5,769	0.07	6,232	0.07
2003	2.16	5,892	0.07	6,534	0.07
2004	1.88	5,900	0.07	6,729	0.07
2005	2.81	6,090	0.07	6,867	0.08
2006	2.17	6,091	0.07	6,766	0.08
2007	2.09	6,090	0.07	6,882	0.08
2008	3.09	6,342	0.07	7,014	0.08
2009	2.03	6,315	0.07	6,965	0.08
2010	1.89	6,229	0.07	7,211	0.07
2011	2.25	6,170	0.07	7,316	0.07
2012	2.01	5,975	0.07	7,115	0.07
2013	1.75	5,653	0.08	6,878	0.07
2014	3.15	5,767	0.09	6,581	0.08
2015	4.02	6,222	0.11	6,201	0.09
2016	4.74	7,057	0.15	6,254	0.11
2017	4.03	7,937	0.18	6,975	0.14
2018	2.57	8,197	0.21	8,401	0.18
2019	2.33				

Table 9. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 19.1c for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Cut-Line fit: logistic maturity curve fitted to Cut- Line determined maturity proportion.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (Cut-Line fit)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =23,273			
		$MMB_{35\%}$=6,899			
1985	1.72	9,638	0.03	9,691	0.06
1986	1.02	7,332	0.04	8,208	0.04
1987	4.28	7,399	0.05	6,429	0.04
1988	3.63	7,192	0.05	5,379	0.05
1989	2.01	6,031	0.05	4,833	0.07
1990	2.90	6,343	0.04	4,372	0.07
1991	3.50	6,509	0.04	4,658	0.06
1992	2.26	6,173	0.04	4,472	0.05
1993	2.16	6,340	0.03	4,488	0.05
1994	2.42	5,942	0.03	4,913	0.04
1995	2.30	5,327	0.04	4,474	0.04
1996	2.23	5,416	0.04	3,864	0.04
1997	3.00	5,808	0.05	3,989	0.04
1998	2.74	6,276	0.05	4,087	0.05
1999	2.86	6,937	0.05	4,505	0.05
2000	2.65	7,464	0.06	5,139	0.06
2001	2.00	7,657	0.06	5,734	0.06
2002	2.48	8,016	0.07	6,232	0.07
2003	2.16	8,165	0.07	6,534	0.07
2004	1.88	8,151	0.07	6,729	0.07
2005	2.81	8,378	0.07	6,867	0.08
2006	2.17	8,424	0.07	6,766	0.08
2007	2.09	8,421	0.07	6,882	0.08
2008	3.09	8,741	0.07	7,014	0.08
2009	2.03	8,758	0.07	6,965	0.08
2010	1.89	8,618	0.06	7,211	0.07
2011	2.25	8,497	0.06	7,316	0.07
2012	2.01	8,233	0.07	7,115	0.07
2013	1.75	7,796	0.07	6,878	0.07
2014	3.15	7,929	0.09	6,581	0.08
2015	4.02	8,623	0.11	6,201	0.09
2016	4.74	9,872	0.15	6,254	0.11
2017	4.03	11,178	0.18	6,975	0.14
2018	2.57	11,545	0.21	8,401	0.18
2019	2.33				

Table 10. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 19.2 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =23,060 $MMB_{35\%}$=6,706			
1985	1.68	9,531	0.04	9,786	0.05
1986	1.02	7,297	0.04	8,281	0.04
1987	4.25	6,681	0.05	6,466	0.04
1988	3.58	6,661	0.05	5,396	0.05
1989	2.03	5,797	0.06	4,827	0.07
1990	2.94	5,904	0.05	4,336	0.07
1991	3.487	5,981	0.04	4,614	0.06
1992	2.23	5,898	0.04	4,446	0.05
1993	2.14	6,042	0.03	4,469	0.05
1994	2.44	5,572	0.04	4,883	0.04
1995	2.299	4,990	0.04	4,431	0.04
1996	2.24	5,101	0.04	3,826	0.04
1997	3.02	5,362	0.05	3,960	0.04
1998	2.80	5,935	0.05	4,072	0.05
1999	2.93	6,624	0.05	4,508	0.05
2000	2.68	7,243	0.06	5,178	0.06
2001	2.04	7,587	0.06	5,820	0.06
2002	2.54	7,861	0.06	6,352	0.06
2003	2.15	8,096	0.07	6,681	0.07
2004	1.86	8,109	0.07	6,903	0.07
2005	2.79	8,109	0.07	7,040	0.07
2006	2.19	8,280	0.07	6,912	0.08
2007	2.11	8,277	0.07	6,990	0.08
2008	3.13	8,396	0.07	7,104	0.08
2009	2.07	8,667	0.07	7,052	0.08
2010	1.92	8,546	0.07	7,307	0.07
2011	2.31	8,358	0.07	7,429	0.07
2012	2.05	8,176	0.07	7,245	0.07
2013	1.77	7,801	0.07	7,032	0.07
2014	3.19	7,658	0.08	6,760	0.08
2015	4.04	8,233	0.10	6,392	0.09
2016	4.82	9,404	0.13	6,449	0.10
2017	4.10	10,931	0.16	7,169	0.12
2018	2.59	11,598	0.19	8,616	0.16
2019	2.35				

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 19.2a for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2017 are restricted to 1985–2019. Equilibrium MMB_{eq} and MMB35% are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =23,416 $MMB_{35\%}$=6,808			
1985	1.71	9,501	0.04	9,737	0.06
1986	1.02	7,288	0.04	8,240	0.04
1987	4.29	6,691	0.05	6,449	0.04
1988	3.61	6,702	0.05	5,396	0.05
1989	2.02	5,855	0.06	4,853	0.07
1990	2.89	5,947	0.05	4,388	0.07
1991	3.49	6,001	0.04	4,671	0.06
1992	2.23	5,914	0.04	4,479	0.05
1993	2.14	6,055	0.03	4,487	0.05
1994	2.43	5,582	0.04	4,897	0.04
1995	2.30	4,994	0.04	4,443	0.04
1996	2.24	5,104	0.04	3,834	0.04
1997	3.02	5,364	0.05	3,965	0.04
1998	2.79	5,937	0.05	4,076	0.05
1999	2.93	6,626	0.05	4,512	0.05
2000	2.68	7,243	0.06	5,181	0.06
2001	2.04	7,587	0.06	5,824	0.06
2002	2.54	7,859	0.06	6,355	0.06
2003	2.15	8,093	0.07	6,682	0.07
2004	1.86	8,106	0.07	6,902	0.07
2005	2.79	8,107	0.07	7,039	0.07
2006	2.19	8,279	0.07	6,910	0.08
2007	2.11	8,276	0.07	6,990	0.08
2008	3.13	8,396	0.07	7,105	0.08
2009	2.06	8,667	0.07	7,054	0.08
2010	1.92	8,545	0.07	7,309	0.07
2011	2.31	8,356	0.07	7,431	0.07
2012	2.05	8,175	0.07	7,245	0.07
2013	1.77	7,800	0.07	7,033	0.07
2014	3.19	7,655	0.08	6,760	0.08
2015	4.03	8,228	0.10	6,391	0.09
2016	4.81	9,393	0.13	6,448	0.10
2017	4.09	10,915	0.16	7,165	0.12
2018	2.59	11,577	0.19	8,607	0.16
2019	2.35				

Table 12. 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 model 19.2b for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Bent-Point fit: logistic maturity curve fitted to Bent-Point lines determined maturity proportion.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (Bent-Point fit)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,416 $MMB_{35\%}$=5,278			
1985	1.71	7,137	0.04	9,737	0.06
1986	1.02	5,387	0.04	8,240	0.04
1987	4.29	5,468	0.05	6,449	0.04
1988	3.61	5,165	0.05	5,396	0.05
1989	2.02	4,241	0.05	4,853	0.07
1990	2.89	4,501	0.04	4,388	0.07
1991	3.49	4,625	0.04	4,671	0.06
1992	2.23	4,330	0.04	4,479	0.05
1993	2.14	4,465	0.03	4,487	0.05
1994	2.43	4,204	0.03	4,897	0.04
1995	2.30	3,757	0.04	4,443	0.04
1996	2.24	3,827	0.04	3,834	0.04
1997	3.02	4,134	0.05	3,965	0.04
1998	2.79	4,473	0.05	4,076	0.05
1999	2.93	4,984	0.05	4,512	0.05
2000	2.68	5,392	0.06	5,181	0.06
2001	2.04	5,568	0.06	5,824	0.06
2002	2.54	5,901	0.06	6,355	0.06
2003	2.15	6,026	0.07	6,682	0.07
2004	1.86	6,022	0.07	6,902	0.07
2005	2.79	6,192	0.07	7,039	0.07
2006	2.19	6,182	0.07	6,910	0.08
2007	2.11	6,174	0.07	6,990	0.08
2008	3.13	6,429	0.07	7,105	0.08
2009	2.06	6,410	0.07	7,054	0.08
2010	1.92	6,333	0.07	7,309	0.07
2011	2.31	6,293	0.07	7,431	0.07
2012	2.05	6,115	0.07	7,245	0.07
2013	1.77	5,803	0.07	7,033	0.07
2014	3.19	5,925	0.09	6,760	0.08
2015	4.03	6,379	0.10	6,391	0.09
2016	4.81	7,228	0.13	6,448	0.10
2017	4.09	8,123	0.16	7,165	0.12
2018	2.59	8,387	0.19	8,607	0.16
2019	2.35				

Table 13. 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 model 19.2c for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Cut-Line fit: logistic maturity curve fitted to Cut- Line determined maturity proportion.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (Cut-Line fit)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,416 $MMB_{35\%}$=6,910			
1985	1.71	9,668	0.03	9,737	0.06
1986	1.02	7,357	0.04	8,240	0.04
1987	4.29	7,427	0.05	6,449	0.04
1988	3.61	7,210	0.05	5,396	0.05
1989	2.02	6,050	0.05	4,853	0.07
1990	2.89	6,354	0.04	4,388	0.07
1991	3.49	6,514	0.04	4,671	0.06
1992	2.23	6,162	0.03	4,479	0.05
1993	2.14	6,315	0.03	4,487	0.05
1994	2.43	5,914	0.03	4,897	0.04
1995	2.30	5,302	0.04	4,443	0.04
1996	2.24	5,402	0.04	3,834	0.04
1997	3.02	5,811	0.05	3,965	0.04
1998	2.79	6,314	0.05	4,076	0.05
1999	2.93	7,023	0.05	4,512	0.05
2000	2.68	7,584	0.06	5,181	0.06
2001	2.04	7,808	0.06	5,824	0.06
2002	2.54	8,199	0.06	6,355	0.06
2003	2.15	8,351	0.07	6,682	0.07
2004	1.86	8,317	0.07	6,902	0.07
2005	2.79	8,512	0.07	7,039	0.07
2006	2.19	8,541	0.07	6,910	0.08
2007	2.11	8,529	0.07	6,990	0.08
2008	3.13	8,855	0.07	7,105	0.08
2009	2.06	8,886	0.07	7,054	0.08
2010	1.92	8,759	0.06	7,309	0.07
2011	2.31	8,664	0.06	7,431	0.07
2012	2.05	8,425	0.07	7,245	0.07
2013	1.77	8,001	0.07	7,033	0.07
2014	3.19	8,143	0.08	6,760	0.08
2015	4.03	8,835	0.10	6,391	0.09
2016	4.81	10,100	0.13	6,448	0.10
2017	4.09	11,429	0.16	7,165	0.12
2018	2.59	11,805	0.19	8,607	0.16
2019	2.35				

Table 14. Negative log-likelihood values of the fits for models 19.1 (base), 19.1a, 19.2, and 19.2a for golden king crab in the EAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**19.1**	**19.1a**	**19.2**	**19.2a**
Number of free parameters	146	146	146	146
Retlencomp	-1251.89	-1252.15	-1250.70	-1251.04
Totallencomp	-1363.66	-1362.35	-1365.49	-1364.13
Observer cpue	-3.49	-3.51	-8.11	-8.07
RetdcatchB	7.46	7.41	7.65	7.59
TotalcatchB	22.74	22.80	22.77	22.83
GdiscdcatchB	0.00	0.00	0.00	0.00
Rec_dev	7.52	7.52	7.55	7.54
Pot F_dev	0.01	0.01	0.01	0.01
Gbyc_F_dev	0.03	0.03	0.03	0.03
Tag	2692.49	2692.48	2692.33	2692.33
Fishery cpue	-2.3197	-3.4794	-2.0787	-3.2168
RetcatchN	0.0066	0.0067	0.0066	0.0067
Total	108.90	108.76	103.96	103.87

Table 15. Parameter estimates and coefficient of variations (CV) with the 2018 MMB (MMB estimated on 15 Feb 2019) for models 19.1, 19.1a, 19.2, and 19.2a for the golden king crab data from the WAG, 1985/86–2018/19. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Model 19.1		Model 19.1a		Model 19.2		Model 19.2a		
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)	-7.63	0.22	-7.66	0.22	-7.62	0.22	-7.65	0.22	-12.0-5.0
log_a (molt prob. slope)	-2.63	0.03	-2.63	0.03	-2.63	0.03	-2.63	0.03	-4.61-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.69	0.03	3.69	0.03	3.69	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.41	0.01	3.41	0.01	3.41	0.01	3.41	0.01	0.,4.4
log_ total sel deltaθ, 2005–18	2.86	0.02	2.86	0.02	2.86	0.02	2.86	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–18	1.79	0.02	1.79	0.02	1.79	0.02	1.79	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.87	0.002	4.87	0.002	4.87	0.002	4.87	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–18	4.90	0.001	4.90	0.001	4.90	0.001	4.90	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985–18	4.92	0.0002	4.92	0.0002	4.92	0.0002	4.92	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.03	0.16	-1.03	0.16	1.02	0.16	-1.03	0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.04	1.43	-0.03	1.97	-0.05	1.41	-0.04	1.90	-9.0, 2.25
logq3 (catchability 2005–18)	-0.40	0.22	-0.40	0.22	-0.40	0.23	-0.40	0.23	-9.0, 2.25
log_mean_rec (mean rec.)	0.72	0.06	0.72	0.06	0.72	0.06	0.72	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.70	0.09	-0.70	0.09	-0.70	0.09	-0.70	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.34	0.10	-8.34	0.10	-8.34	0.10	-8.34	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.02	0.35	0.02	0.35	0.01	0.63	0.01	0.68	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.01	0.66	0.02	0.61	0.01	0.65	0.02	0.60	0.0,1.0
2018 MMB	6,336	0.14	6,343	0.14	6,393	0.16	6,403	0.16	

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 model 19.1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,038 $MMB_{35\%}$=5,247			
1985	4.00	10,486	0.05	8,929	0.09
1986	3.57	8,073	0.05	8,413	0.07
1987	2.66	7,458	0.04	5,971	0.06
1988	1.77	6,373	0.04	5,628	0.04
1989	2.38	4,317	0.04	4,998	0.04
1990	1.92	3,957	0.05	3,128	0.05
1991	1.66	3,724	0.05	2,790	0.05
1992	2.10	3,897	0.04	2,692	0.05
1993	1.56	4,501	0.03	2,850	0.05
1994	1.97	3,813	0.03	3,470	0.03
1995	1.88	3,813	0.03	2,816	0.03
1996	1.72	3,823	0.04	2,764	0.03
1997	1.86	3,893	0.04	2,808	0.04
1998	1.90	4,214	0.03	2,888	0.04
1999	2.24	4,243	0.04	3,172	0.03
2000	2.50	4,394	0.04	3,112	0.04
2001	2.53	4,822	0.05	3,117	0.04
2002	2.47	5,359	0.05	3,444	0.05
2003	1.73	5,670	0.05	3,959	0.05
2004	2.26	5,766	0.06	4,437	0.05
2005	2.34	6,052	0.06	4,612	0.06
2006	2.47	6,590	0.05	4,773	0.06
2007	1.72	6,789	0.05	5,222	0.06
2008	1.51	6,619	0.05	5,537	0.06
2009	1.93	6,254	0.05	5,604	0.05
2010	1.62	5,983	0.05	5,256	0.05
2011	1.18	5,504	0.05	4,961	0.05
2012	1.90	4,932	0.05	4,631	0.05
2013	2.41	4,757	0.06	4,034	0.05
2014	1.91	4,971	0.07	3,589	0.06
2015	2.35	5,256	0.07	3,731	0.07
2016	2.51	5,816	0.09	4,008	0.08
2017	1.81	6,302	0.11	4,449	0.09
2018	1.88	6,335	0.14	5,024	0.11
2019	2.06				

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 CV for model 19.1a for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =18,447 $MMB_{35\%}$=5,369			
1985	4.05	10,473	0.05	9,005	0.10
1986	3.46	8,041	0.05	8,427	0.08
1987	2.67	7,385	0.04	5,959	0.06
1988	1.86	6,323	0.04	5,578	0.05
1989	2.52	4,339	0.04	4,931	0.04
1990	1.92	4,039	0.05	3,101	0.06
1991	1.63	3,810	0.05	2,834	0.05
1992	2.03	3,952	0.04	2,775	0.05
1993	1.59	4,525	0.03	2,928	0.05
1994	1.95	3,830	0.03	3,510	0.03
1995	1.89	3,820	0.04	2,834	0.03
1996	1.71	3,828	0.04	2,773	0.04
1997	1.86	3,893	0.04	2,814	0.04
1998	1.89	4,210	0.04	2,891	0.04
1999	2.23	4,236	0.04	3,171	0.04
2000	2.50	4,381	0.04	3,107	0.04
2001	2.53	4,807	0.05	3,109	0.04
2002	2.47	5,345	0.05	3,432	0.05
2003	1.74	5,661	0.05	3,945	0.05
2004	2.26	5,763	0.06	4,426	0.05
2005	2.33	6,051	0.06	4,606	0.06
2006	2.46	6,588	0.05	4,772	0.06
2007	1.72	6,786	0.05	5,222	0.06
2008	1.51	6,616	0.05	5,536	0.06
2009	1.93	6,252	0.05	5,602	0.05
2010	1.62	5,982	0.05	5,254	0.05
2011	1.18	5,503	0.05	4,960	0.05
2012	1.90	4,930	0.05	4,631	0.05
2013	2.42	4,756	0.06	4,033	0.05
2014	1.91	4,974	0.06	3,588	0.06
2015	2.35	5,262	0.07	3,733	0.07
2016	2.51	5,822	0.09	4,013	0.08
2017	1.81	6,308	0.11	4,455	0.09
2018	1.88	6,343	0.14	5,031	0.11
2019	2.06				

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 model 19.1b for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Bent-Point fit: logistic maturity curve fitted to Bent-Point lines determined maturity proportion.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (Bent-Point fit)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,447 $MMB_{35\%}$=4,141			
1985	4.05	8,088	0.05	9,005	0.10
1986	3.46	6,063	0.05	8,427	0.08
1987	2.67	5,434	0.04	5,959	0.06
1988	1.86	4,581	0.04	5,578	0.05
1989	2.52	3,306	0.04	4,931	0.04
1990	1.92	2,996	0.04	3,101	0.06
1991	1.63	2,805	0.05	2,834	0.05
1992	2.03	2,989	0.04	2,775	0.05
1993	1.59	3,333	0.03	2,928	0.05
1994	1.95	2,901	0.03	3,510	0.03
1995	1.89	2,876	0.03	2,834	0.03
1996	1.71	2,850	0.04	2,773	0.04
1997	1.86	2,926	0.04	2,814	0.04
1998	1.89	3,158	0.04	2,891	0.04
1999	2.23	3,224	0.04	3,171	0.04
2000	2.50	3,348	0.04	3,107	0.04
2001	2.53	3,635	0.05	3,109	0.04
2002	2.47	4,000	0.05	3,432	0.05
2003	1.74	4,123	0.05	3,945	0.05
2004	2.26	4,320	0.06	4,426	0.05
2005	2.33	4,541	0.06	4,606	0.06
2006	2.46	4,943	0.05	4,772	0.06
2007	1.72	4,968	0.05	5,222	0.06
2008	1.51	4,858	0.05	5,536	0.06
2009	1.93	4,698	0.05	5,602	0.05
2010	1.62	4,452	0.05	5,254	0.05
2011	1.18	4,043	0.05	4,960	0.05
2012	1.90	3,757	0.05	4,631	0.05
2013	2.42	3,670	0.06	4,033	0.05
2014	1.91	3,696	0.07	3,588	0.06
2015	2.35	3,966	0.08	3,733	0.07
2016	2.51	4,380	0.09	4,013	0.08
2017	1.81	4,616	0.11	4,455	0.09
2018	1.88	4,690	0.14	5,031	0.11
2019	2.06				

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 model 19.1c for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Cut-Line fit: logistic maturity curve fitted to Cut- Line determined maturity proportion.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (Cut-Line fit)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,447 $MMB_{35\%}$=5,427			
1985	4.05	11,056	0.04	9,005	0.10
1986	3.46	8,491	0.04	8,427	0.08
1987	2.67	7,693	0.04	5,959	0.06
1988	1.86	6,508	0.04	5,578	0.05
1989	2.52	4,692	0.04	4,931	0.04
1990	1.92	4,279	0.04	3,101	0.06
1991	1.63	4,007	0.05	2,834	0.05
1992	2.03	4,235	0.04	2,775	0.05
1993	1.59	4,715	0.03	2,928	0.05
1994	1.95	4,100	0.03	3,510	0.03
1995	1.89	4,075	0.03	2,834	0.03
1996	1.71	4,048	0.04	2,773	0.04
1997	1.86	4,144	0.04	2,814	0.04
1998	1.89	4,463	0.03	2,891	0.04
1999	2.23	4,552	0.04	3,171	0.04
2000	2.50	4,737	0.04	3,107	0.04
2001	2.53	5,155	0.05	3,109	0.04
2002	2.47	5,672	0.05	3,432	0.05
2003	1.74	5,846	0.05	3,945	0.05
2004	2.26	6,067	0.06	4,426	0.05
2005	2.33	6,364	0.06	4,606	0.06
2006	2.46	6,916	0.05	4,772	0.06
2007	1.72	6,963	0.05	5,222	0.06
2008	1.51	6,774	0.05	5,536	0.06
2009	1.93	6,509	0.05	5,602	0.05
2010	1.62	6,176	0.04	5,254	0.05
2011	1.18	5,618	0.05	4,960	0.05
2012	1.90	5,203	0.05	4,631	0.05
2013	2.42	5,114	0.06	4,033	0.05
2014	1.91	5,212	0.06	3,588	0.06
2015	2.35	5,585	0.07	3,733	0.07
2016	2.51	6,163	0.09	4,013	0.08
2017	1.81	6,504	0.11	4,455	0.09
2018	1.88	6,569	0.14	5,031	0.11
2019	2.06				

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 model 19.2 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMBeq =18,030 *$MMB_{35\%}$*=5,248			
1985	3.99	10,487	0.05	8,931	0.09
1986	3.57	8,074	0.05	8,415	0.07
1987	2.66	7,460	0.04	5,972	0.06
1988	1.77	6,374	0.04	5,630	0.04
1989	2.38	4,317	0.04	4,999	0.04
1990	1.92	3,956	0.05	3,129	0.05
1991	1.66	3,722	0.05	2,789	0.05
1992	2.09	3,892	0.04	2,690	0.05
1993	1.56	4,490	0.03	2,847	0.05
1994	1.98	3,803	0.03	3,463	0.03
1995	1.88	3,809	0.03	2,805	0.03
1996	1.71	3,820	0.04	2,758	0.03
1997	1.87	3,891	0.04	2,806	0.04
1998	1.89	4,215	0.03	2,885	0.04
1999	2.23	4,244	0.04	3,171	0.03
2000	2.50	4,389	0.04	3,113	0.04
2001	2.52	4,809	0.05	3,115	0.04
2002	2.44	5,333	0.05	3,437	0.05
2003	1.72	5,630	0.05	3,942	0.05
2004	2.28	5,728	0.06	4,407	0.05
2005	2.41	6,044	0.06	4,572	0.06
2006	2.46	6,617	0.05	4,744	0.06
2007	1.70	6,819	0.05	5,230	0.06
2008	1.49	6,640	0.05	5,566	0.06
2009	1.91	6,258	0.05	5,633	0.05
2010	1.61	5,970	0.05	5,271	0.05
2011	1.18	5,483	0.05	4,957	0.05
2012	1.92	4,914	0.05	4,613	0.05
2013	2.42	4,747	0.06	4,014	0.05
2014	1.92	4,968	0.07	3,575	0.06
2015	2.38	5,267	0.08	3,724	0.07
2016	2.53	5,846	0.10	4,010	0.08
2017	1.82	6,349	0.13	4,466	0.10
2018	1.88	6,393	0.16	5,059	0.13
2019	2.06				

Table 21. 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 model 19.2a 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 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 111 mm CL)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMBeq =18,461 *MMB35%*=5,376			
1985	4.05	10,473	0.05	9,005	0.10
1986	3.47	8,042	0.05	8,427	0.08
1987	2.67	7,387	0.04	5,959	0.06
1988	1.86	6,324	0.04	5,579	0.05
1989	2.51	4,339	0.04	4,932	0.04
1990	1.92	4,037	0.05	3,102	0.06
1991	1.63	3,807	0.05	2,833	0.05
1992	2.01	3,946	0.04	2,772	0.05
1993	1.59	4,513	0.03	2,925	0.05
1994	1.97	3,819	0.03	3,502	0.03
1995	1.89	3,817	0.04	2,822	0.03
1996	1.71	3,826	0.04	2,767	0.04
1997	1.87	3,892	0.04	2,812	0.04
1998	1.89	4,212	0.03	2,888	0.04
1999	2.23	4,237	0.04	3,171	0.04
2000	2.49	4,378	0.04	3,109	0.04
2001	2.51	4,795	0.05	3,108	0.04
2002	2.45	5,319	0.05	3,426	0.05
2003	1.73	5,620	0.05	3,929	0.05
2004	2.29	5,724	0.06	4,395	0.06
2005	2.41	6,044	0.06	4,565	0.06
2006	2.46	6,618	0.05	4,743	0.06
2007	1.70	6,819	0.05	5,232	0.06
2008	1.48	6,640	0.05	5,568	0.06
2009	1.90	6,257	0.05	5,634	0.05
2010	1.61	5,970	0.05	5,271	0.05
2011	1.18	5,482	0.05	4,957	0.05
2012	1.92	4,912	0.05	4,613	0.05
2013	2.42	4,747	0.06	4,013	0.05
2014	1.92	4,973	0.07	3,574	0.06
2015	2.38	5,274	0.08	3,727	0.07
2016	2.53	5,854	0.10	4,016	0.08
2017	1.83	6,357	0.13	4,474	0.10
2018	1.88	6,403	0.16	5,067	0.12
2019	2.06				

Table 22. 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 model 19.2b 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 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Bent-Point fit: logistic maturity curve fitted to Bent-Point lines determined maturity proportion.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (Bent-Point fit)**	**CV**	**Legal Size Male Biomass (≥ 136 mm CL)**	**CV**
		MMBeq =18,461 $MMB_{35\%}$=4,146			
1985	4.05	8,088	0.05	9,005	0.10
1986	3.47	6,064	0.05	8,427	0.08
1987	2.67	5,435	0.04	5,959	0.06
1988	1.86	4,581	0.04	5,579	0.05
1989	2.51	3,305	0.04	4,932	0.04
1990	1.92	2,994	0.04	3,102	0.06
1991	1.63	2,802	0.05	2,833	0.05
1992	2.01	2,983	0.04	2,772	0.05
1993	1.59	3,324	0.03	2,925	0.05
1994	1.97	2,896	0.03	3,502	0.03
1995	1.89	2,872	0.03	2,822	0.03
1996	1.71	2,847	0.04	2,767	0.04
1997	1.87	2,926	0.04	2,812	0.04
1998	1.89	3,159	0.04	2,888	0.04
1999	2.23	3,224	0.04	3,171	0.04
2000	2.49	3,344	0.04	3,109	0.04
2001	2.51	3,624	0.05	3,108	0.04
2002	2.45	3,979	0.05	3,426	0.05
2003	1.73	4,094	0.05	3,929	0.05
2004	2.29	4,297	0.06	4,395	0.06
2005	2.41	4,546	0.06	4,565	0.06
2006	2.46	4,957	0.05	4,743	0.06
2007	1.70	4,987	0.05	5,232	0.06
2008	1.48	4,871	0.05	5,568	0.06
2009	1.90	4,700	0.05	5,634	0.05
2010	1.61	4,444	0.05	5,271	0.05
2011	1.18	4,030	0.05	4,957	0.05
2012	1.92	3,746	0.05	4,613	0.05
2013	2.42	3,663	0.06	4,013	0.05
2014	1.92	3,695	0.07	3,574	0.06
2015	2.38	3,978	0.08	3,727	0.07
2016	2.53	4,404	0.11	4,016	0.08
2017	1.83	4,652	0.13	4,474	0.10
2018	1.88	4,732	0.16	5,067	0.12
2019	2.06				

Table 23. 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 model 19.2c 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 2019 are restricted to 1985–2019. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed. Cut-Line fit: logistic maturity curve fitted to Cut- Line determined maturity proportion.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (Cut-Line fit)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,461 $MMB_{35\%}$=5,434			
1985	4.05	11,056	0.04	9,005	0.10
1986	3.47	8,492	0.04	8,427	0.08
1987	2.67	7,694	0.04	5,959	0.06
1988	1.86	6,508	0.04	5,579	0.05
1989	2.51	4,691	0.04	4,932	0.04
1990	1.92	4,276	0.04	3,102	0.06
1991	1.63	4,004	0.05	2,833	0.05
1992	2.01	4,226	0.04	2,772	0.05
1993	1.59	4,702	0.03	2,925	0.05
1994	1.97	4,093	0.03	3,502	0.03
1995	1.89	4,071	0.03	2,822	0.03
1996	1.71	4,044	0.04	2,767	0.04
1997	1.87	4,144	0.04	2,812	0.04
1998	1.89	4,465	0.03	2,888	0.04
1999	2.23	4,551	0.04	3,171	0.04
2000	2.49	4,732	0.04	3,109	0.04
2001	2.51	5,140	0.05	3,108	0.04
2002	2.45	5,642	0.05	3,426	0.05
2003	1.73	5,805	0.05	3,929	0.05
2004	2.29	6,035	0.06	4,395	0.06
2005	2.41	6,371	0.06	4,565	0.06
2006	2.46	6,941	0.05	4,743	0.06
2007	1.70	6,993	0.05	5,232	0.06
2008	1.48	6,792	0.05	5,568	0.06
2009	1.90	6,509	0.05	5,634	0.05
2010	1.61	6,163	0.04	5,271	0.05
2011	1.18	5,599	0.05	4,957	0.05
2012	1.92	5,188	0.05	4,613	0.05
2013	2.42	5,105	0.06	4,013	0.05
2014	1.92	5,212	0.07	3,574	0.06
2015	2.38	5,602	0.08	3,727	0.07
2016	2.53	6,197	0.10	4,016	0.08
2017	1.83	6,555	0.13	4,474	0.10
2018	1.88	6,628	0.16	5,067	0.12
2019	2.06				

Table 24. Negative log-likelihood values of the fits for models 19.1 (base), 19.1a, 19.2, and 19.2a for golden king crab in the WAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**19.1**	**19.1a**	**19.2**	**19.2a**
Number of free parameters	146	146	146	146
Retlencomp	-1207.43	-1211.77	-1207.24	-1211.50
Totallencomp	-1509.29	-1506.14	-1511.22	-1508.28
Observer cpue	-12.09	-13.72	-11.27	-11.93
RetdcatchB	5.03	5.14	5.08	5.19
TotalcatchB	45.38	45.51	45.38	45.51
GdiscdcatchB	0.00	0.00	0.00	0.00
Rec_dev	4.61	4.51	4.66	4.56
Pot F_dev	0.03	0.03	0.03	0.03
Gbyc_F_dev	0.04	0.04	0.04	0.04
Tag	2694.36	2694.34	2694.41	2694.40
Fishery cpue	-9.3215	-5.6533	-9.3566	-5.6998
RetcatchN	0.0021	0.0020	0.0021	0.0021
Total	10.42	12.29	10.51	12.31

Table 25. Stock status, reference biomass and fishing mortality, OFL (total catch), and ABC for various models for EAG, WAG, and AI golden king crab stock.

EAG:

Biomass, OFL, and ABC are in t. Current MMB = MMB on 15 Feb. 2020.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	$F_{35\%}$	OFL	ABC (0.75*OFL)
19.1	3a	6,650	9,834	1.48	0.62	0.62	3,276	2,457
19.1a	3a	6,749	9,827	1.46	0.62	0.62	3,277	2,458
19.1b	3a	5,228	7,337	1.40	0.57	0.57	3,066	2,300
19.1ba	3a	7.085	10,115	1.43	0.75	0.75	3,789	2,842
19.1c	3a	6,899	9,913	1.44	0.66	0.66	3,440	2,580
19.1ca	3a	7,102	10,145	1.43	0.76	0.76	3,826	2,870
19.1d	3a	6,644	8,247	1.24	0.66	0.66	2,641	1,981
19.2	3a	6,706	10,031	1.50	0.61	0.61	3,352	2,514

19.2a	3a	6,808	10,015	1.47	0.61	0.61	3,347	2,510
19.2b	3a	5,278	7,482	1.42	0.56	0.56	3,128	2,346
19.2ba	3a	7,135	10,287	1.44	0.74	0.74	3,879	2,909
19.2c	3a	6,910	10,054	1.46	0.66	0.66	3,558	2,668
19.2ca	3a	7,151	10,317	1.44	0.75	0.75	3,918	2,939

WAG:

Biomass, OFL, and ABC are in t. Current MMB = MMB on 15 Feb. 2020.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	$F_{35\%}$	OFL	ABC (0.75*OFL)
19.1	3a	5,247	5,821	1.11	0.56	0.56	1,783	1,337
19.1a	3a	5,369	5,829	1.09	0.56	0.56	1,784	1,249
19.1b	3a	4,141	4,439	1.07	0.52	0.52	1,682	1,262
19.1ba	3a	5,591	6,230	1.11	0.69	0.69	2,094	1,570
19.1c	3a	5,427	5,978	1.10	0.61	0.61	1,907	1,431
19.1ca	3a	5,634	6,274	1.11	0.69	0.69	2,094	1,570
19.2	3a	5,248	5,866	1.12	0.56	0.56	1,798	1,349
19.2a	3a	5,376	5,876	1.09	0.56	0.56	1,800	1,350
19.2b	3a	4,146	4,472	1.08	0.52	0.52	1,697	1,273
19.2ba	3a	5,598	6,274	1.12	0.69	0.69	2,113	1,584
19.2c	3a	5,434	6,023	1.11	0.61	0.61	1,924	1,443
19.2ca	3a	5,641	6,318	1.12	0.69	0.69	2,113	1,584

AI:

OFL and ABC are in t.

Model	OFL	ABC (0.75*OFL)
19.1	5,059	3,794
19.1a	5,061	3,707
19.1b	4,748	3,562
19.1ba	5,883	4,412
19.1c	5,347	4,011
19.1ca	5,920	4,440

19.2	5,150	3,863
19.2a	5,147	3,860
19.2b	4,825	3,619
19.2ba	5,992	4,493
19.2c	5,482	4,111
19.2ca	6,031	4,523

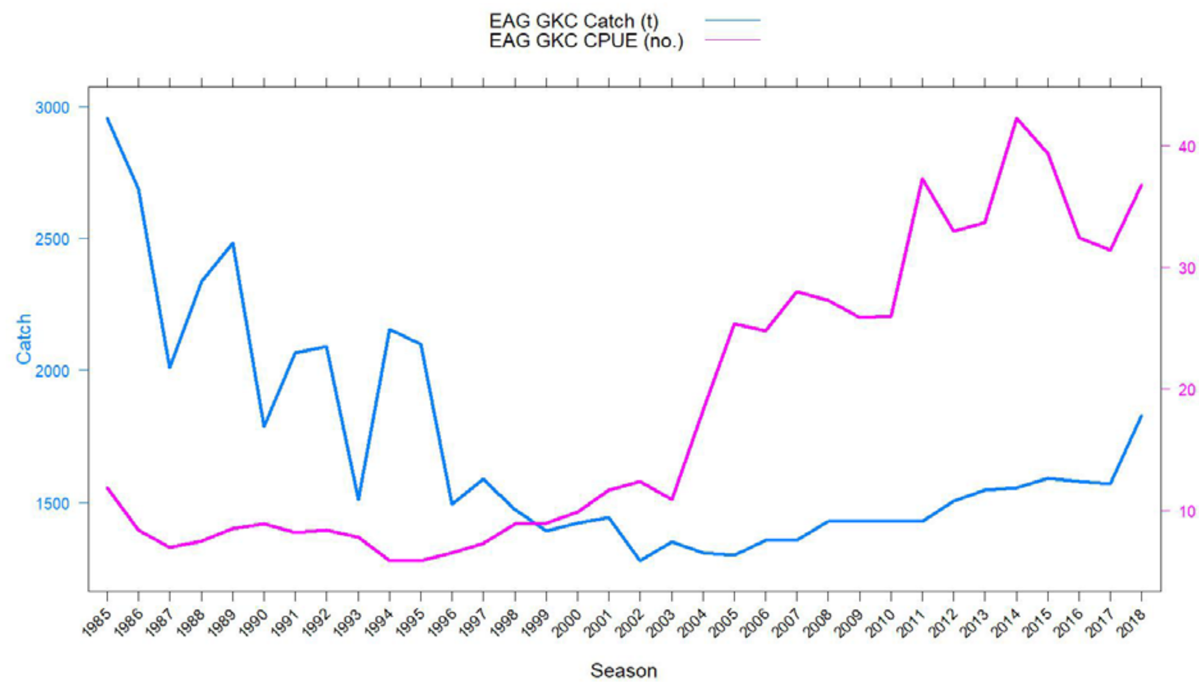


Figure 1. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2018/19 fisheries (note: 1985 refers to the 1985/86 fishing year).

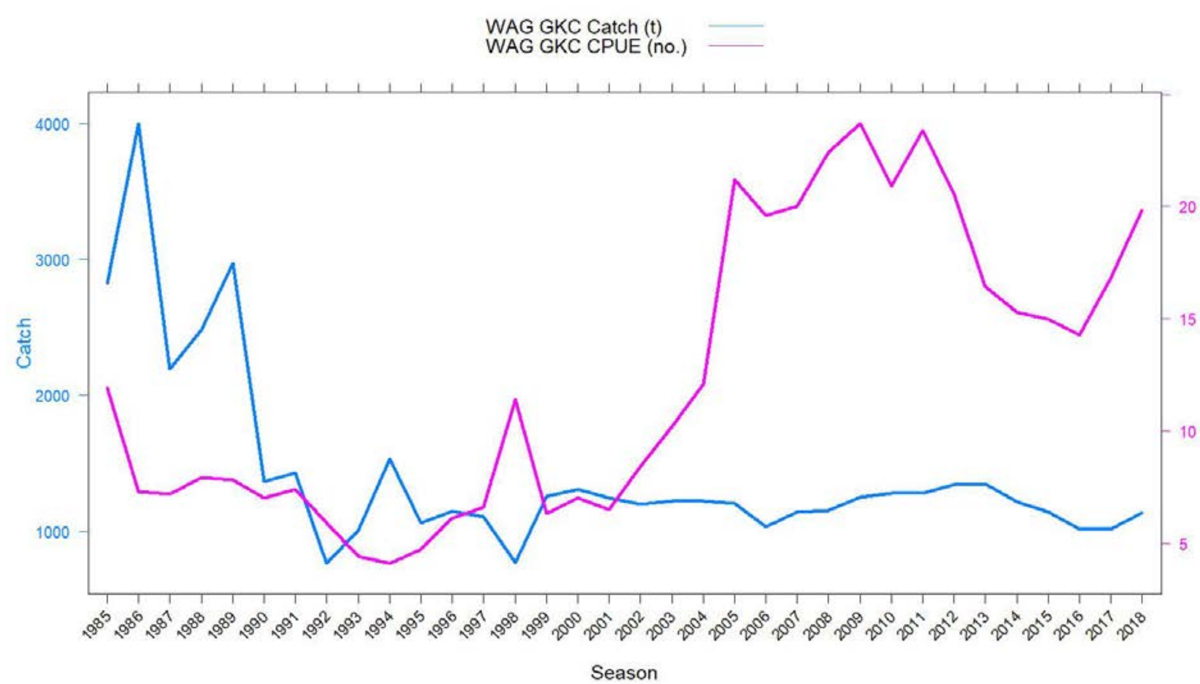


Figure 2. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2018/19 fisheries (note: 1985 refers to the 1985/86 fishing year).

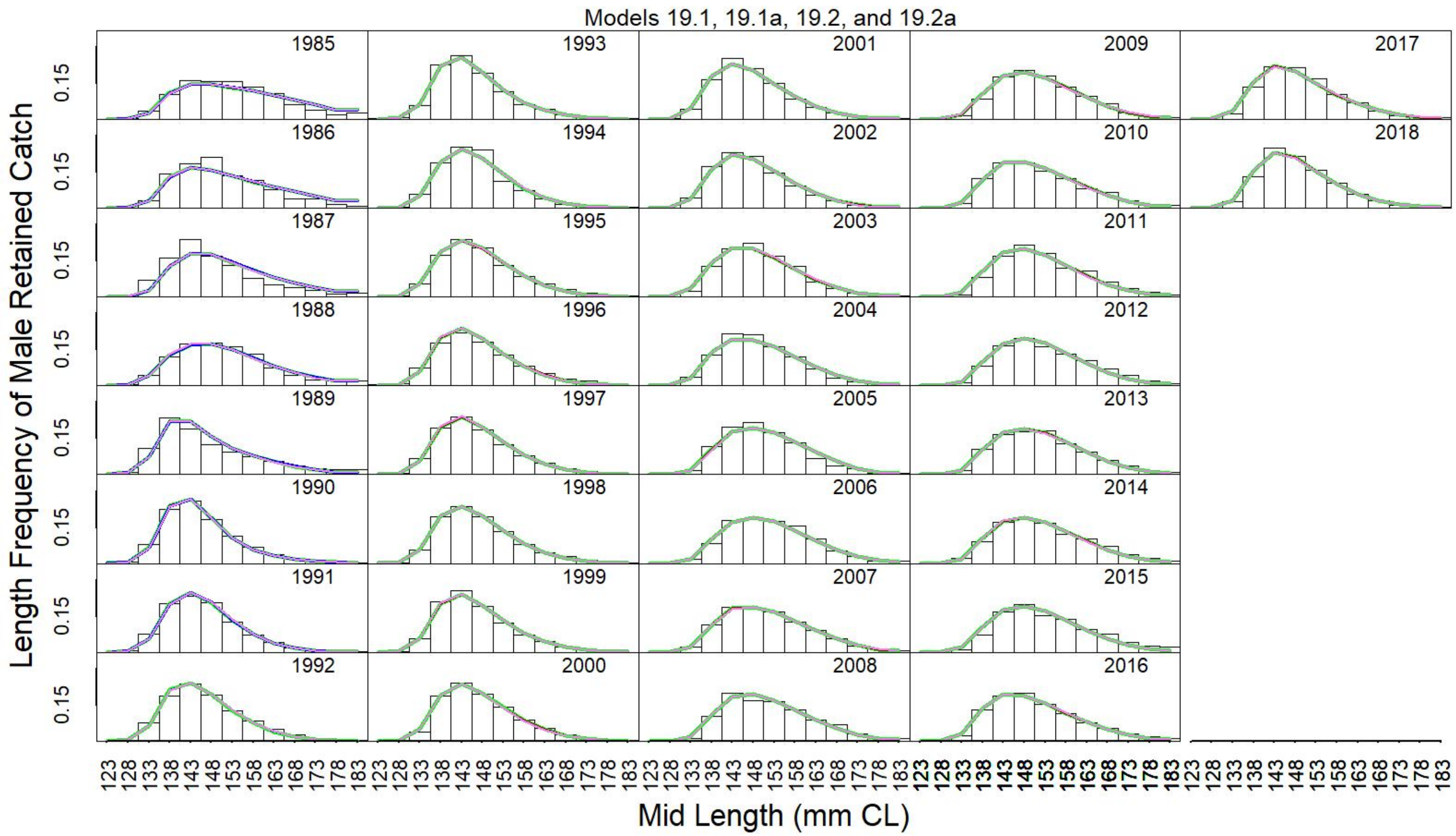


Figure 3. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for models 19.1 (green line), 19.1a (dark red line), 19.2 (blue line), and 19.2a (violet line) for golden king crab in the EAG, 1985/86 to 2018/19. This color scheme is used in all other figures.

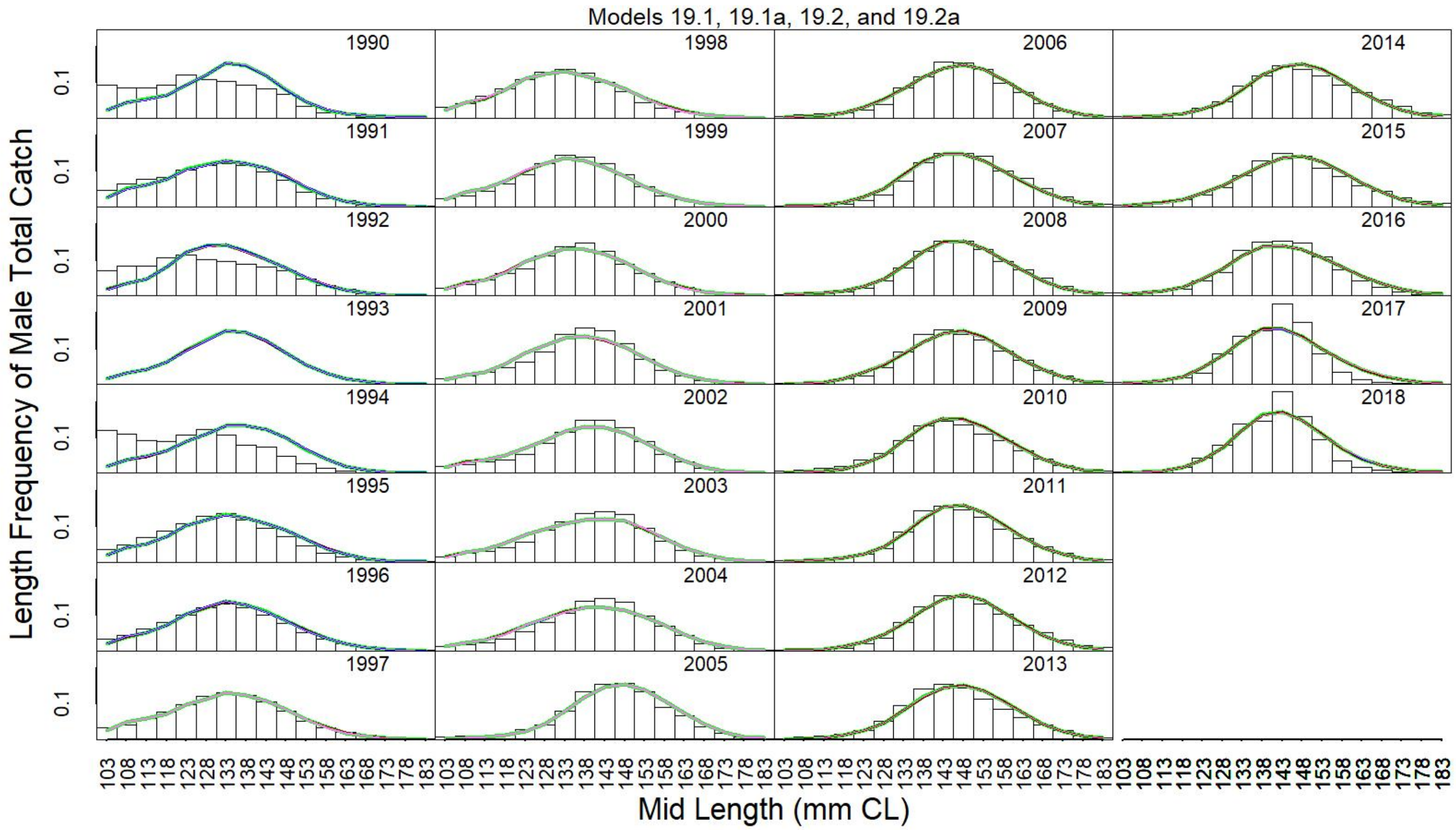


Figure 4. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for models 19.1, 19.1a, 19.2, and 19.2a for golden king crab in the EAG, 1990/91 to 2018/19.

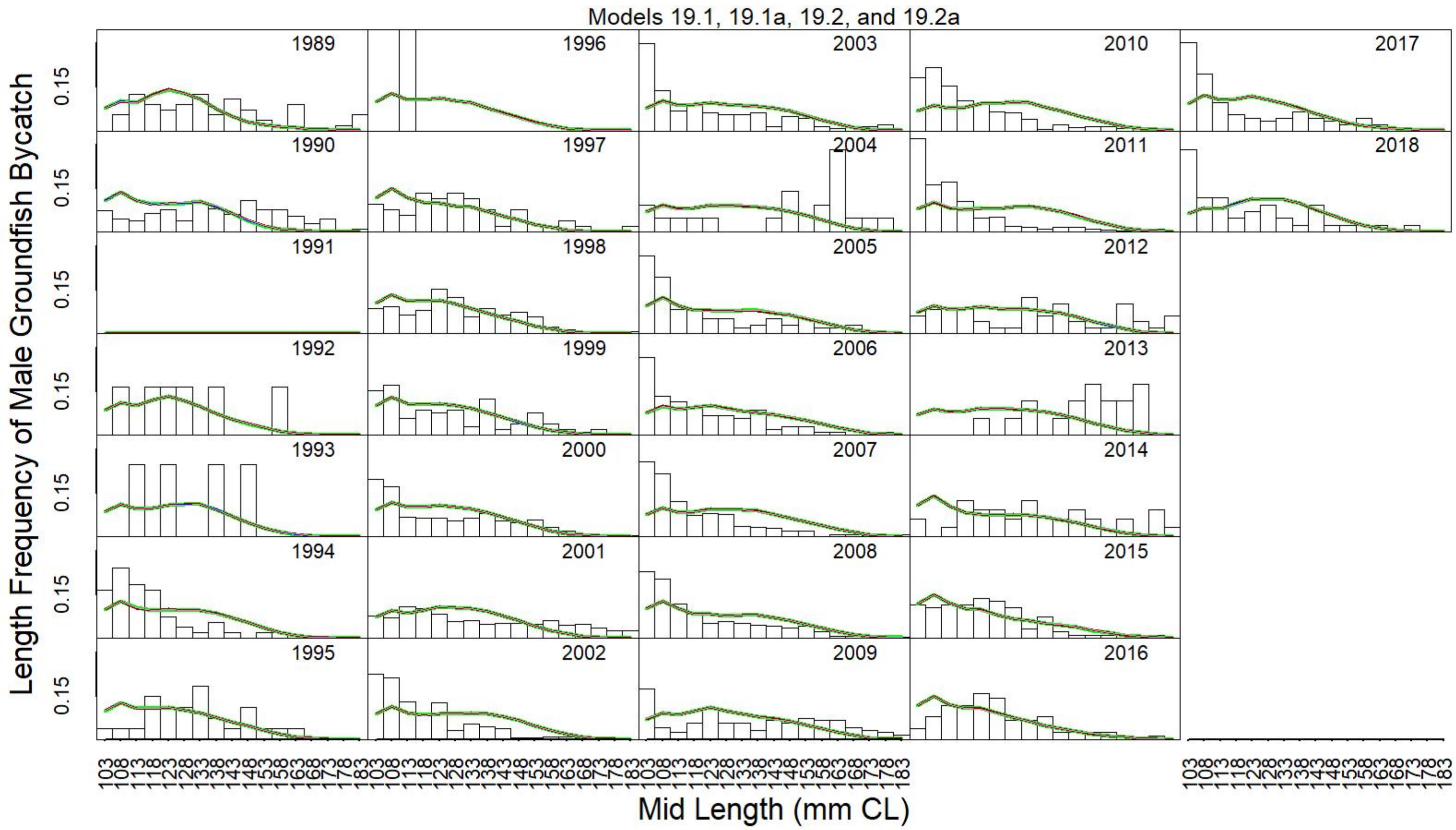


Figure 5. Predicted (line) vs. observed (bar) groundfish discard catch relative length frequency distributions for models 19.1, 19.1a, 19.2, and 19.2a for golden king crab in the EAG, 1989/90 to 2018/19.

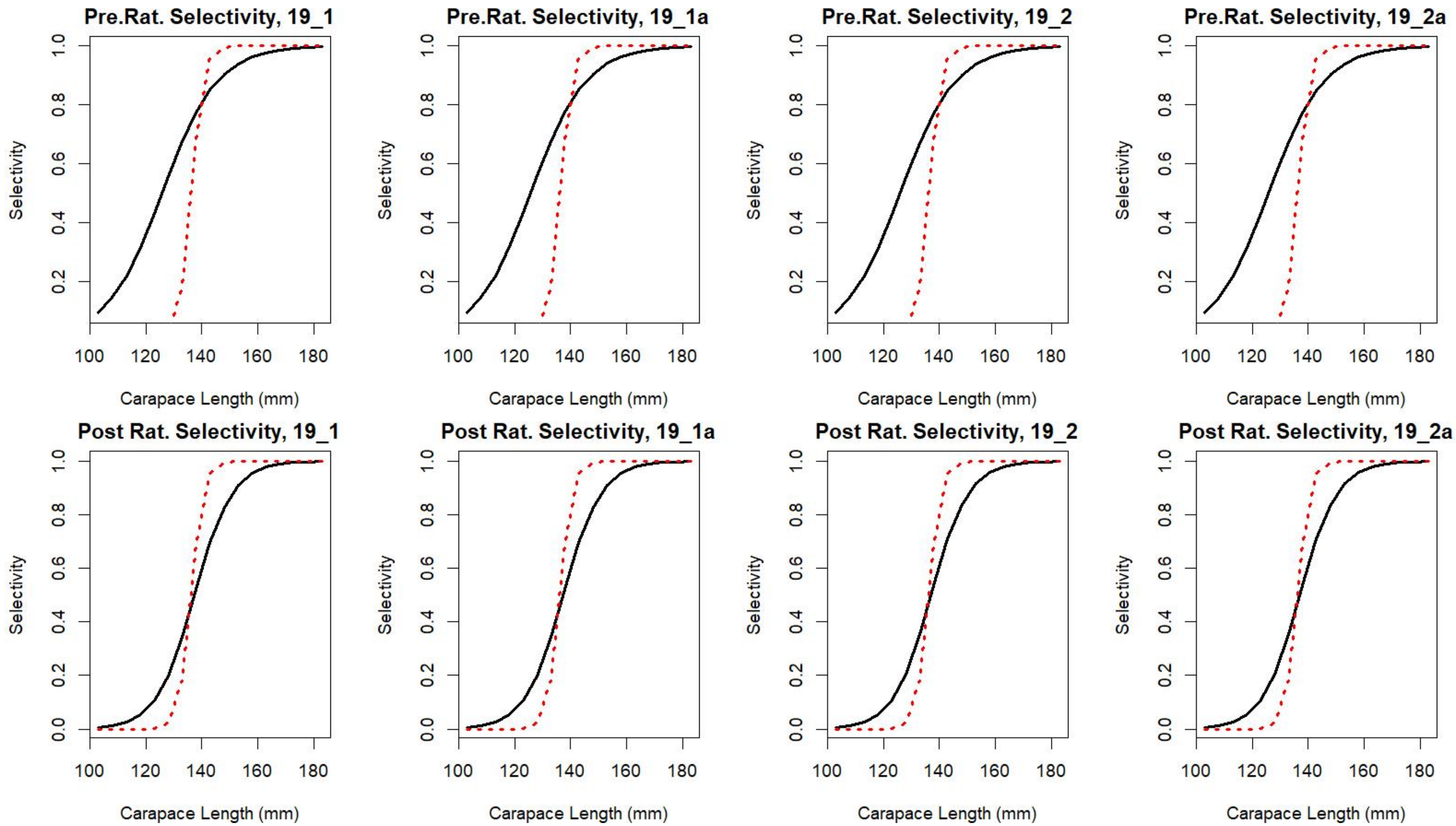


Figure 6. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods for models 19.1, 19.1a, 19.2, and 19.2a fits to golden king crab data in the EAG.

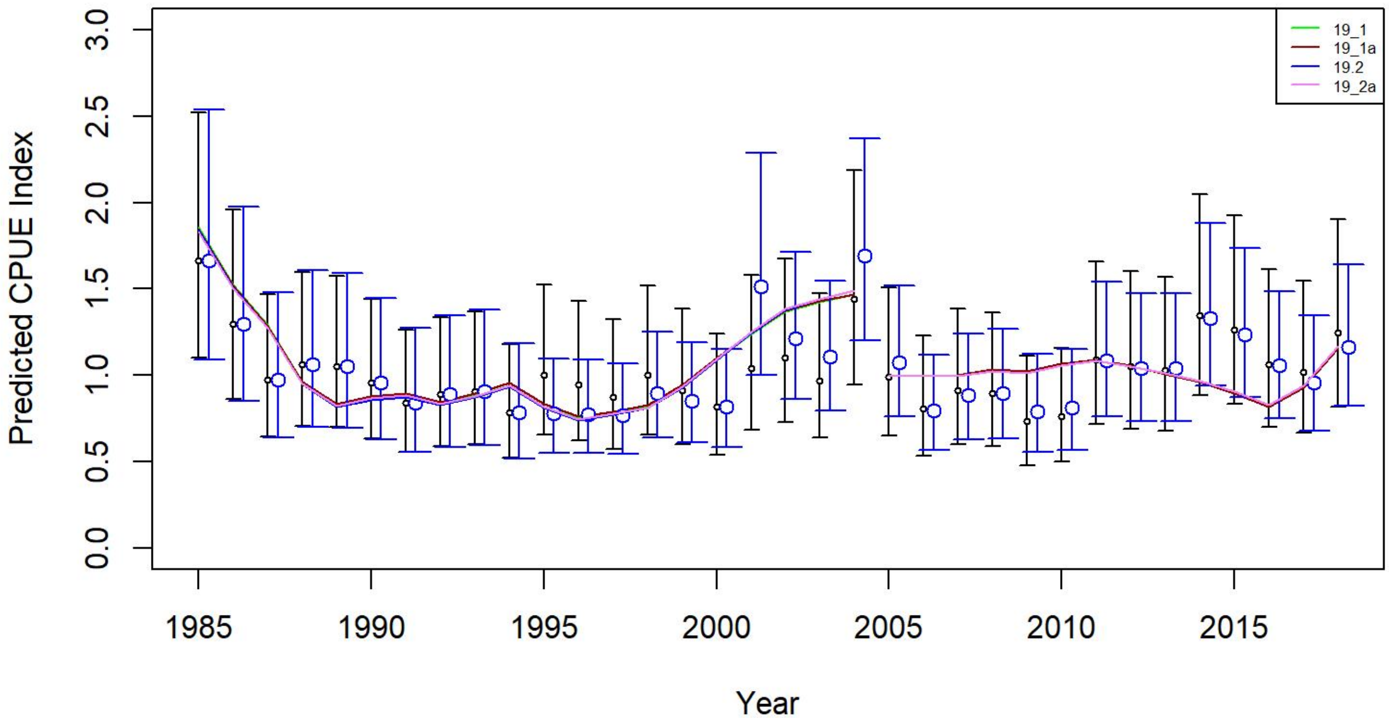


Figure 7. Comparison of input CPUE indices [with +/- 2 SE for model 19.1 (black small circles) and model 19.2 (blue large circles)] with predicted CPUE indices (colored solid lines) by 19.1, 19.1a, 19.2, and 19.2a model fits for EAG golden king crab data, 1985/86–2018/19. Model estimated additional standard error was added to each input standard error.

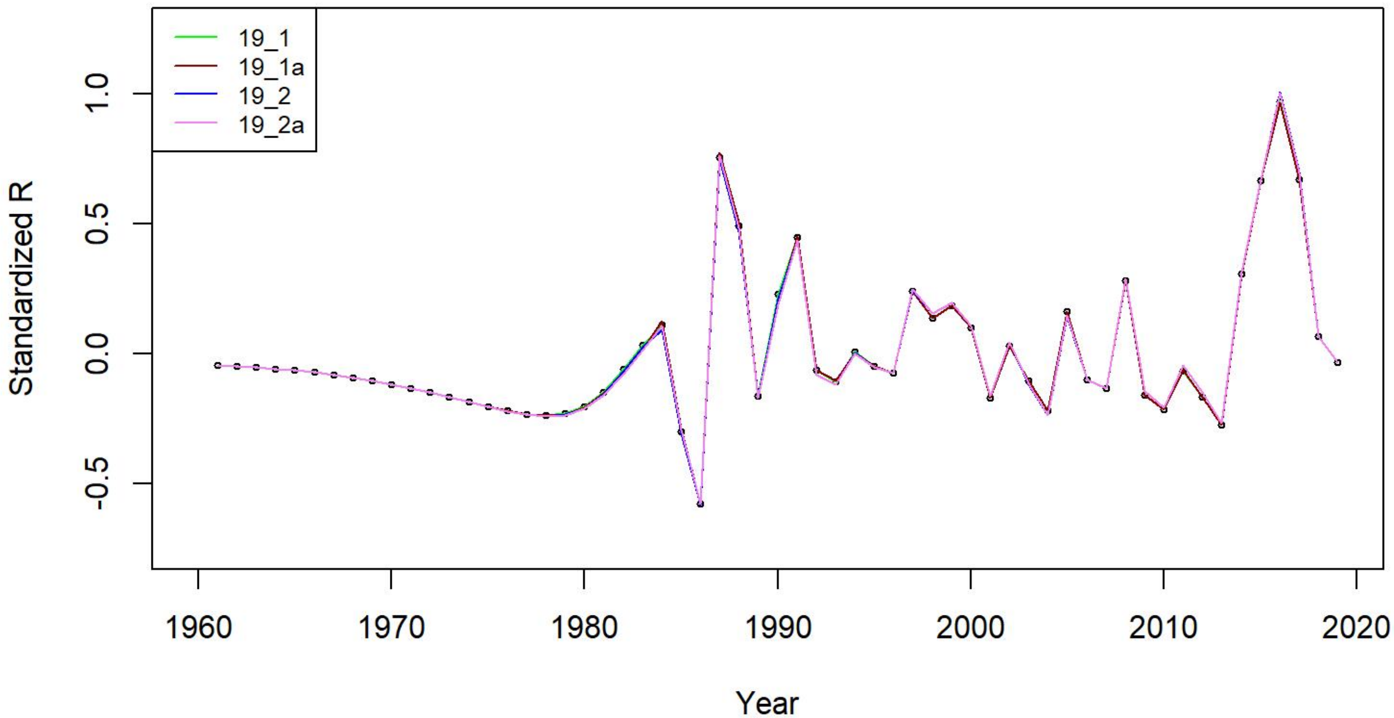


Figure 8. Estimated number of male recruits (crab size ≥ 101 mm CL) for 19.1, 19.1a, 19.2, and 19.2a model fits for EAG golden king crab data, 1961–2019. The number of recruits is standardized using (R-mean R)/mean R for comparing different models' results.

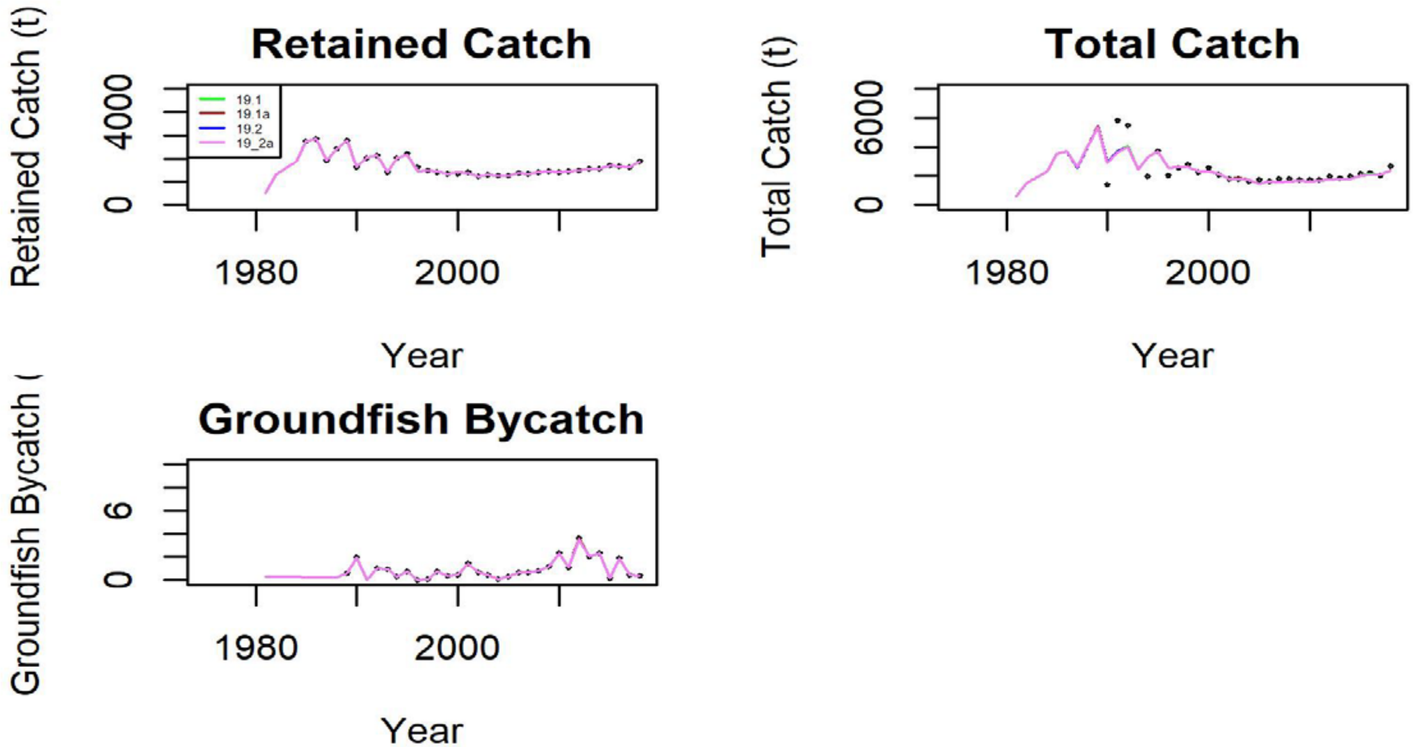


Figure 9. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for 19.1, 19.1a, 19.2, and 19.2a model fits in EAG, 1981/82–2018/19.

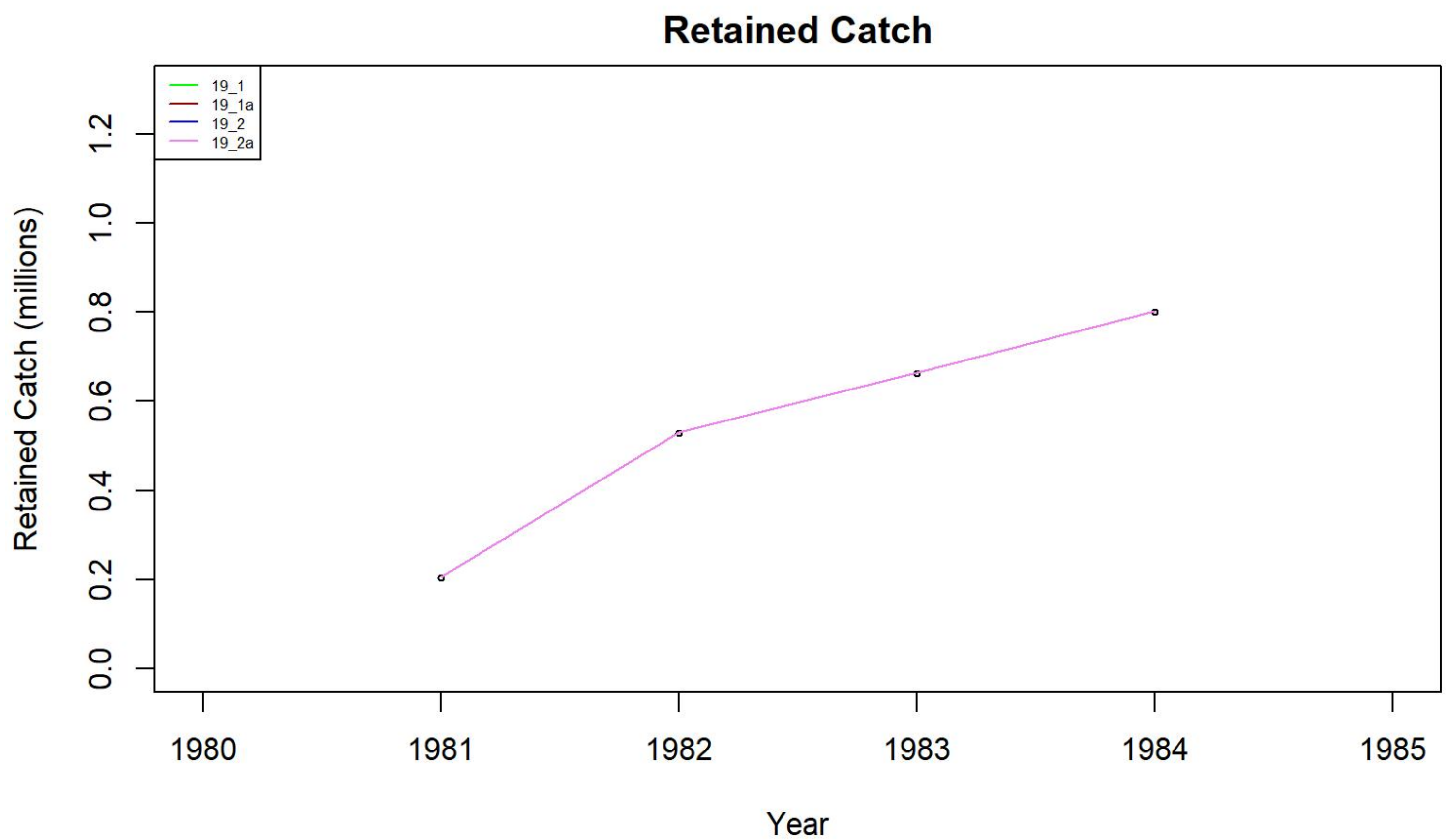


Figure 10. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for 19.1, 19.1a, 19.2, and 19.2a model fits in EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.

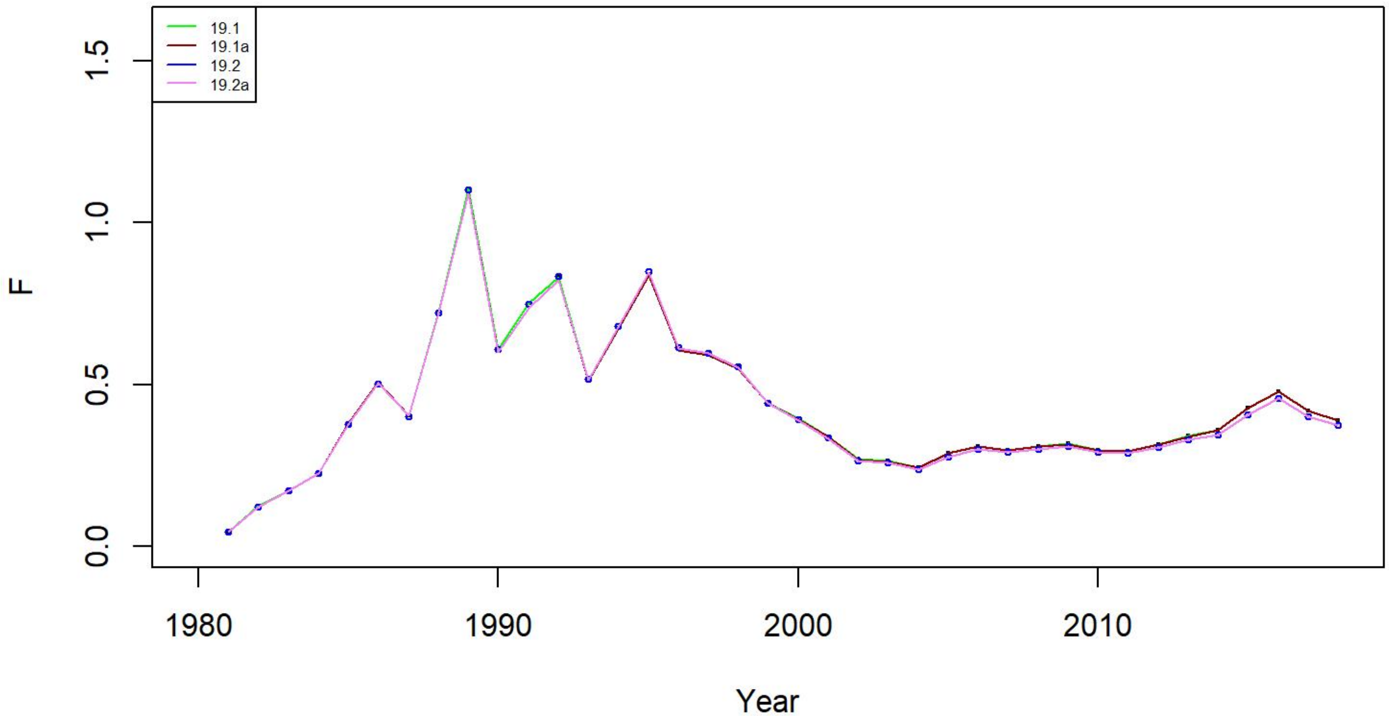


Figure 11. Trends in pot fishery full selection total fishing mortality of golden king crab for 19.1, 19.1a, 19.2, and 19.2a model fits in the EAG, 1981/82–2018/19.

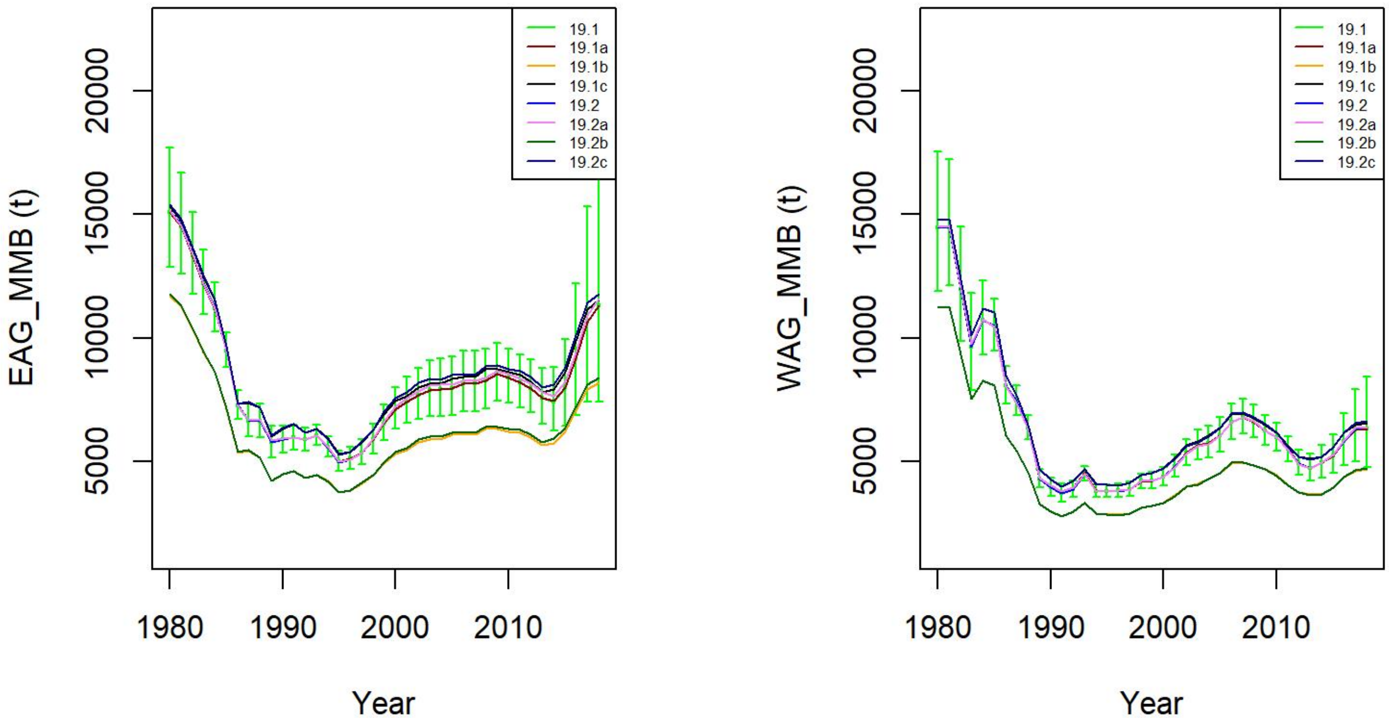


Figure 12. Trends in golden king crab mature male biomass for 19.1, 19.1a, 19.1b, 19.1c, 19.2, 19.2a, 19.2b, and 19.2c model fits to EAG (left) and WAG (right) data, 1980/81–2018/19. Model19.1 estimate has two standard error confidence limits.

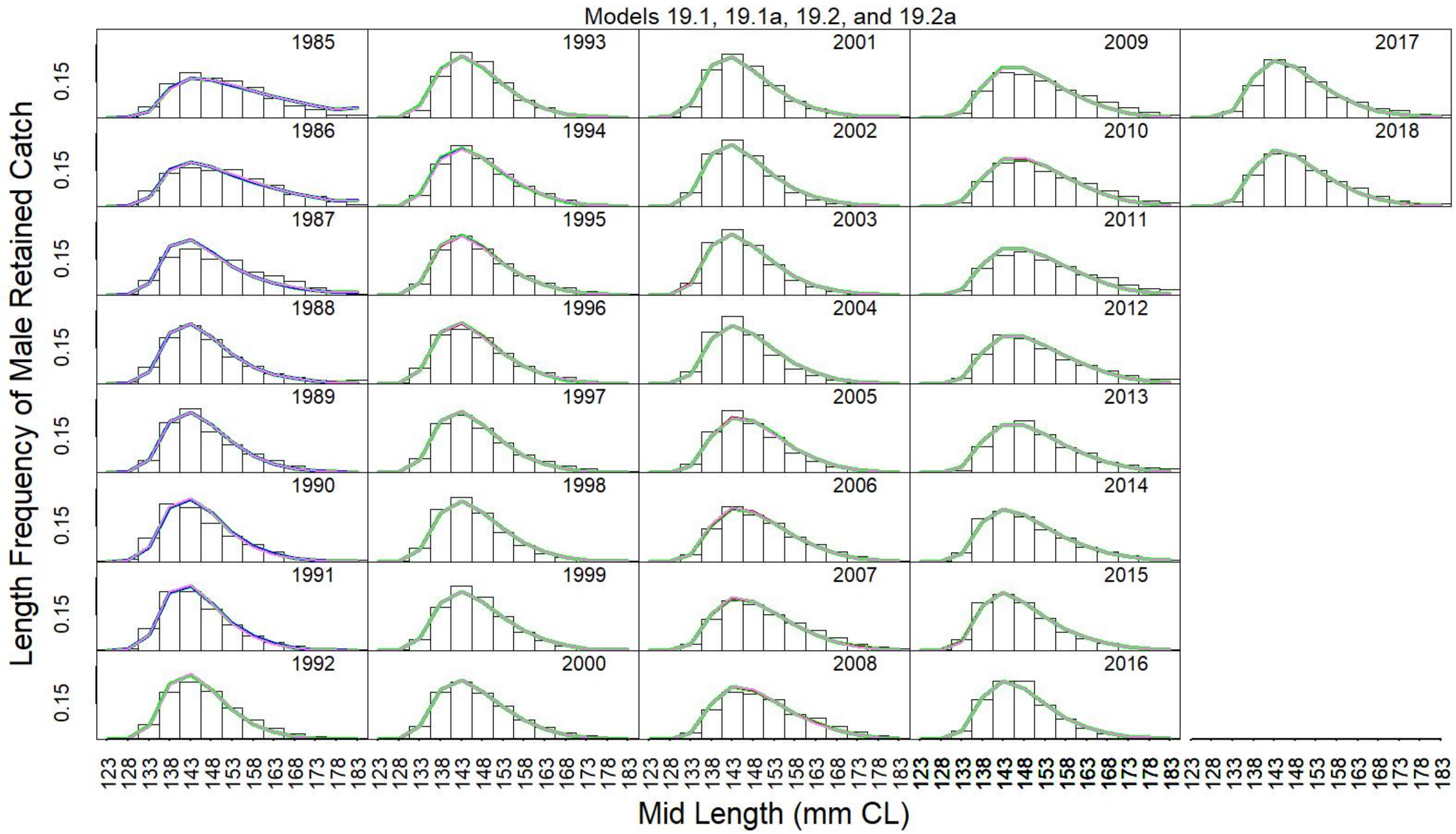


Figure 13. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for models 19.1 (green line), 19.1a (dark red line), 19.2 (blue line), and 19.2a (violet line) for golden king crab in the WAG, 1985/86 to 2018/19. This color scheme is used in all other figures.

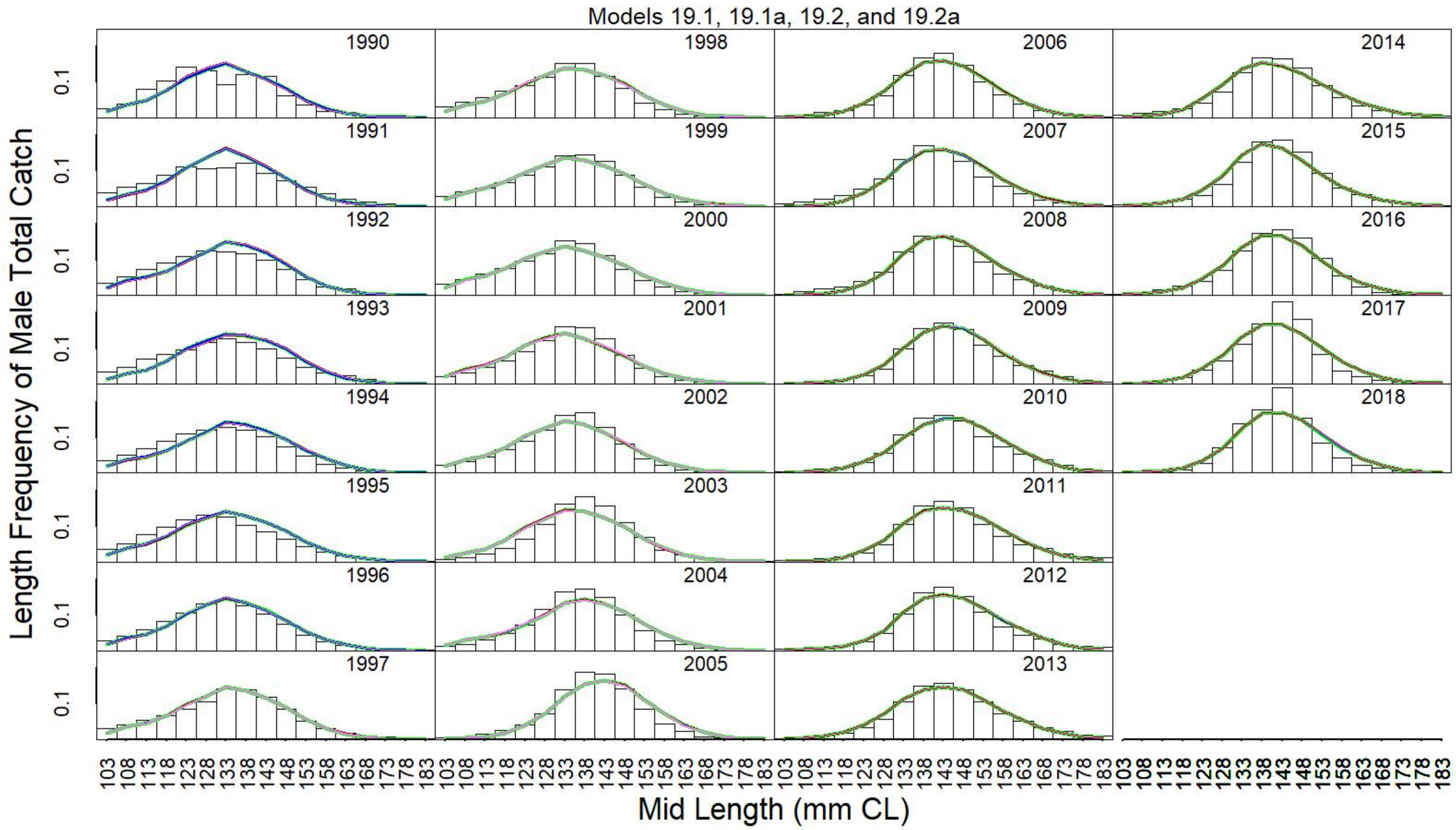


Figure 14. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for models 19.1, 19.1a, 19.2, and 19.2a for golden king crab in the WAG, 1990/91 to 2018/19.

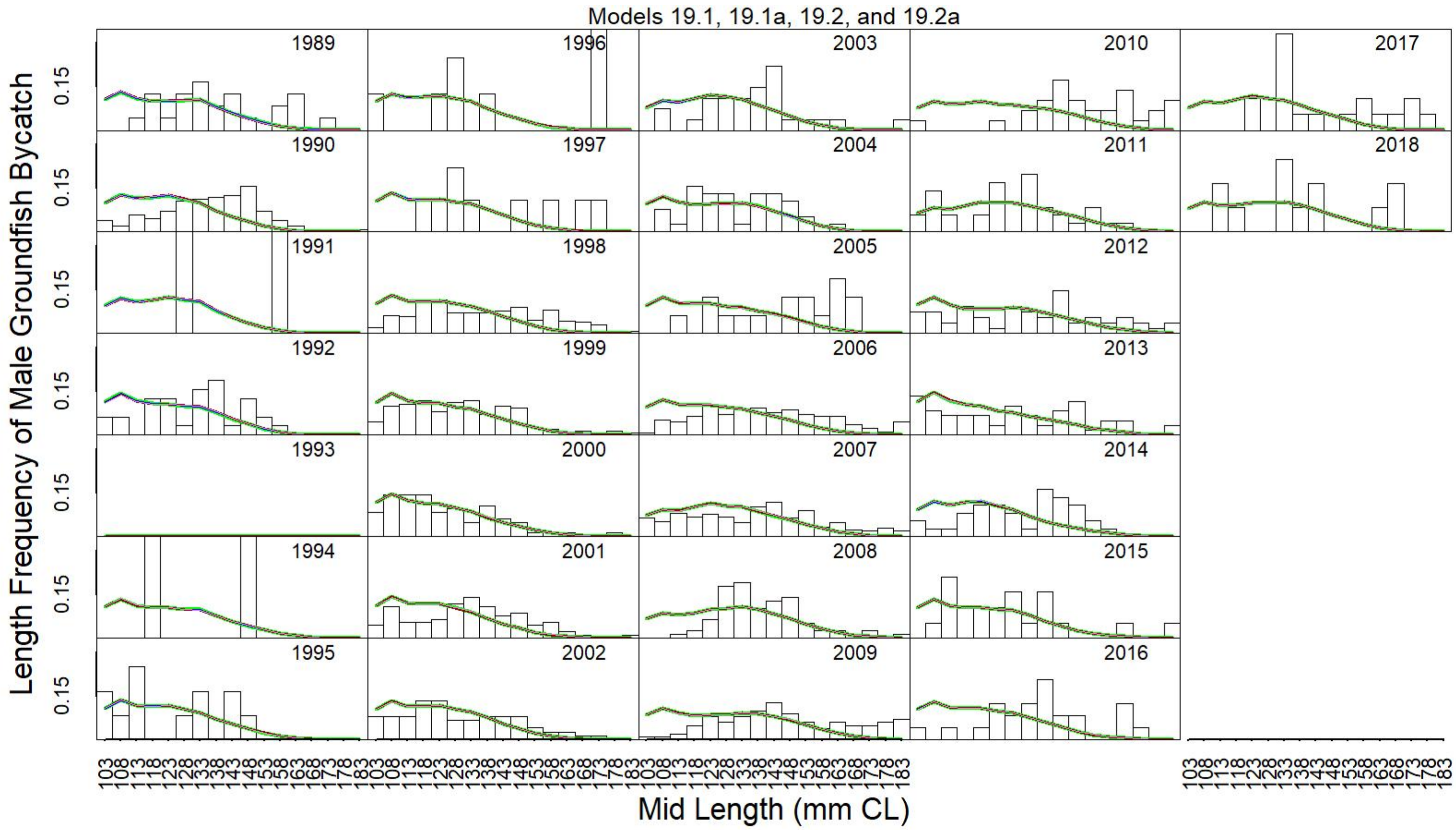


Figure 15. Predicted (line) vs. observed (bar) groundfish discard catch relative length frequency distributions for models 19.1, 19.1a, 19.2, and 19.2a for golden king crab in the WAG, 1989/90 to 2018/19.

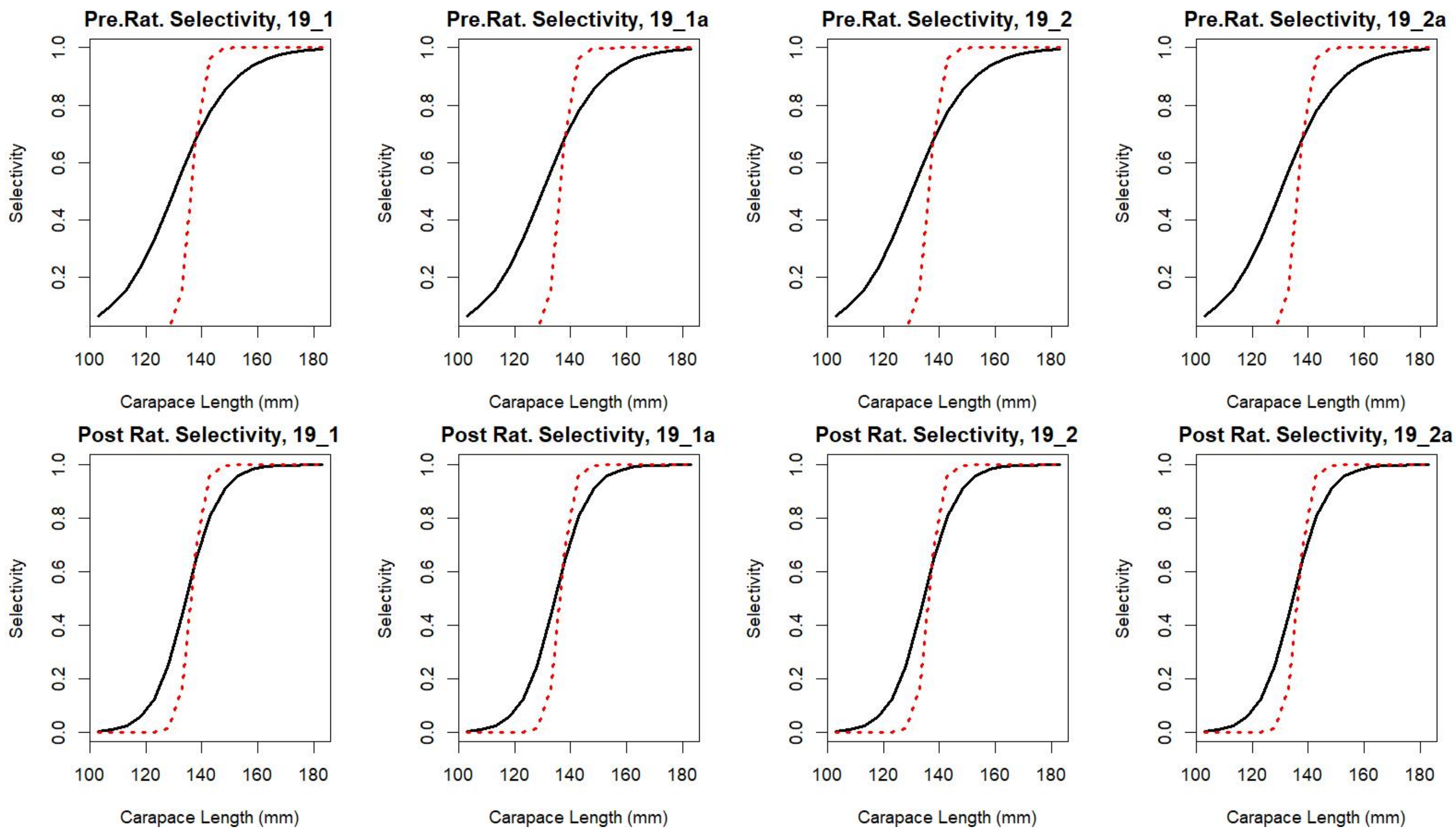


Figure 16. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods for models 19.1, 19.1a, 19.2, and 19.2a fits to golden king crab data in the WAG.

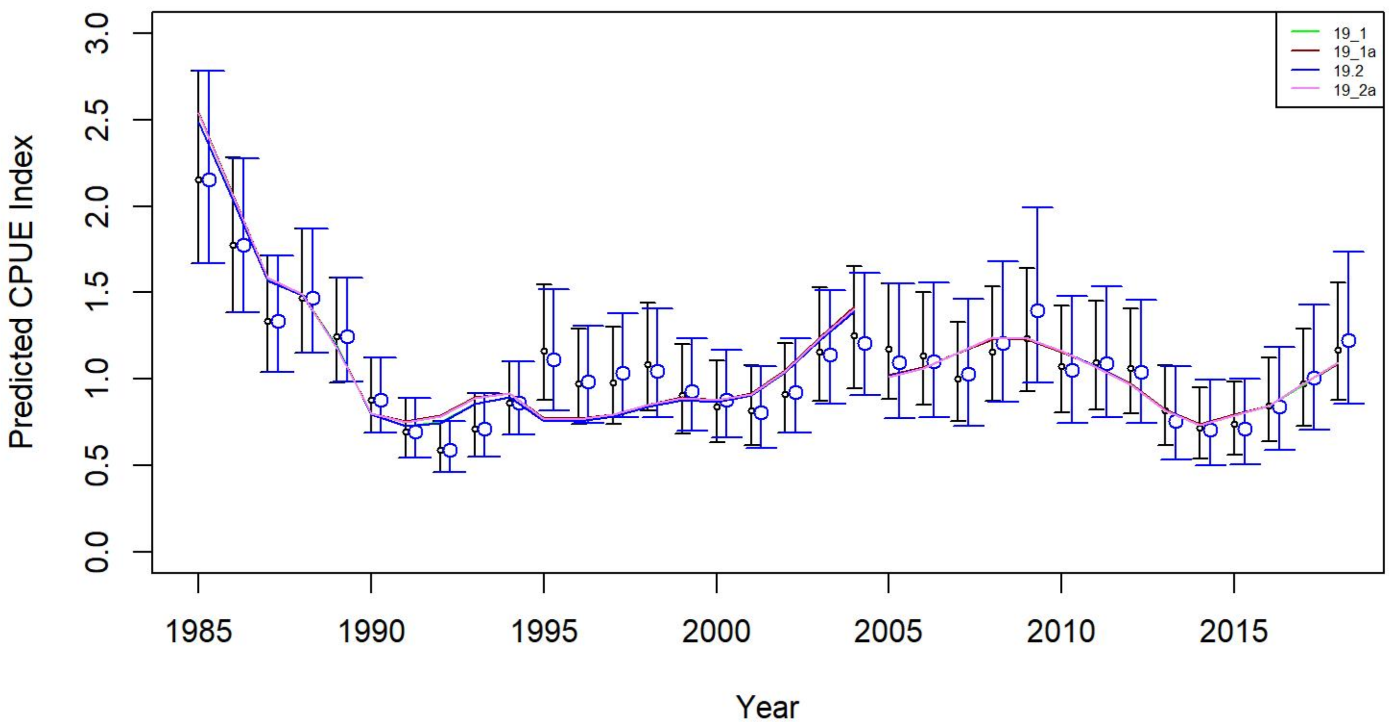


Figure 17. Comparison of input CPUE indices [with +/- 2 SE for model 19_1 (black small circles) and model 19_2 (blue large circles)] with predicted CPUE indices (colored solid lines) by 19.1, 19.1a, 19.2, and 19.2a model fits for WAG golden king crab data, 1985/86–2018/19. Model estimated additional standard error was added to each input standard error.

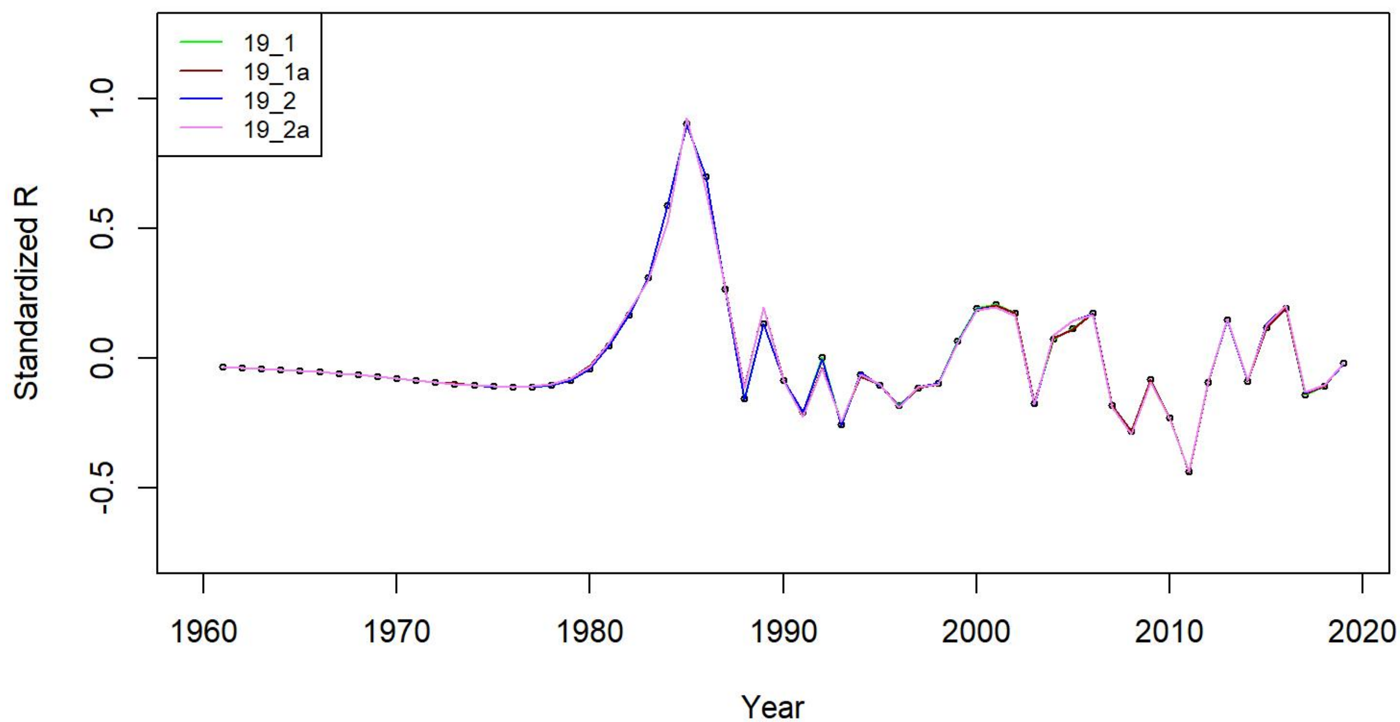


Figure 18. Estimated number of male recruits (crab size ≥ 101 mm CL) for 19.1, 19.1a, 19.2, and 19.2a model fits for WAG golden king crab data, 1961–2019. The number of recruits is standardized using (R-mean R)/mean R for comparing different models' results.

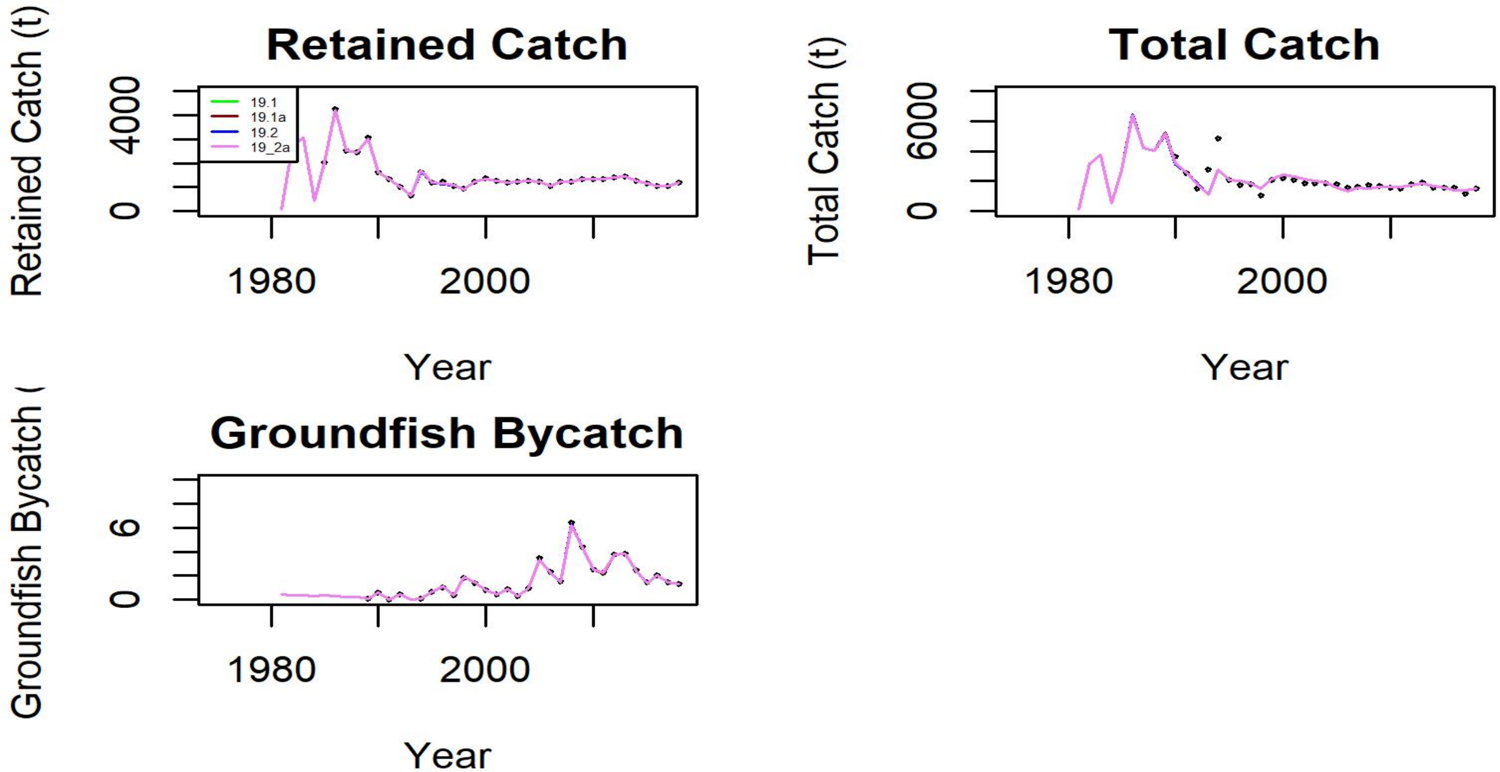


Figure 19. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for 19.1, 19.1a, 19.2, and 19.2a model fits in WAG, 1981/82–2018/19.

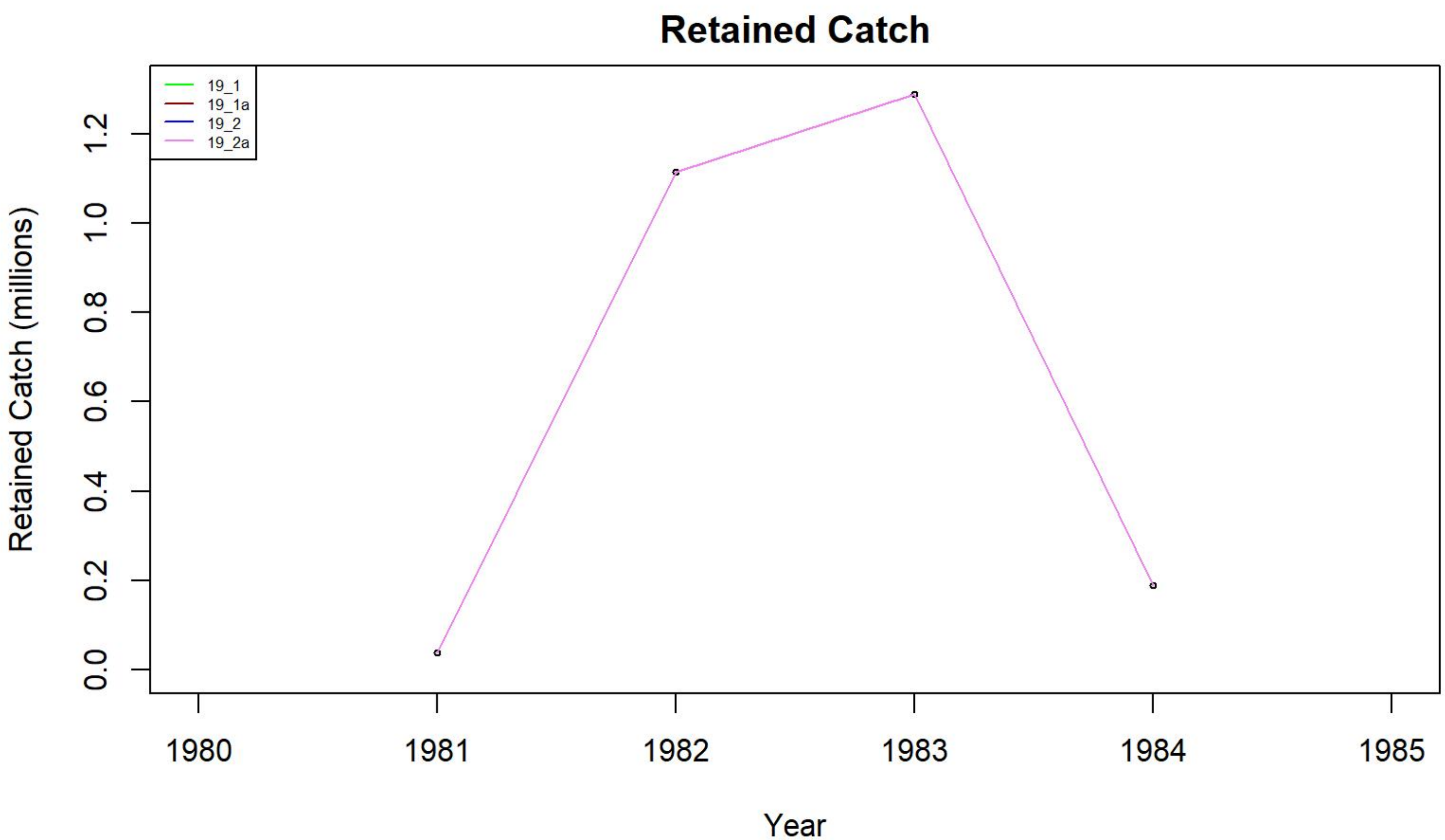


Figure 20. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for 19.1, 19.1a, 19.2, and 19.2a model fits in WAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.

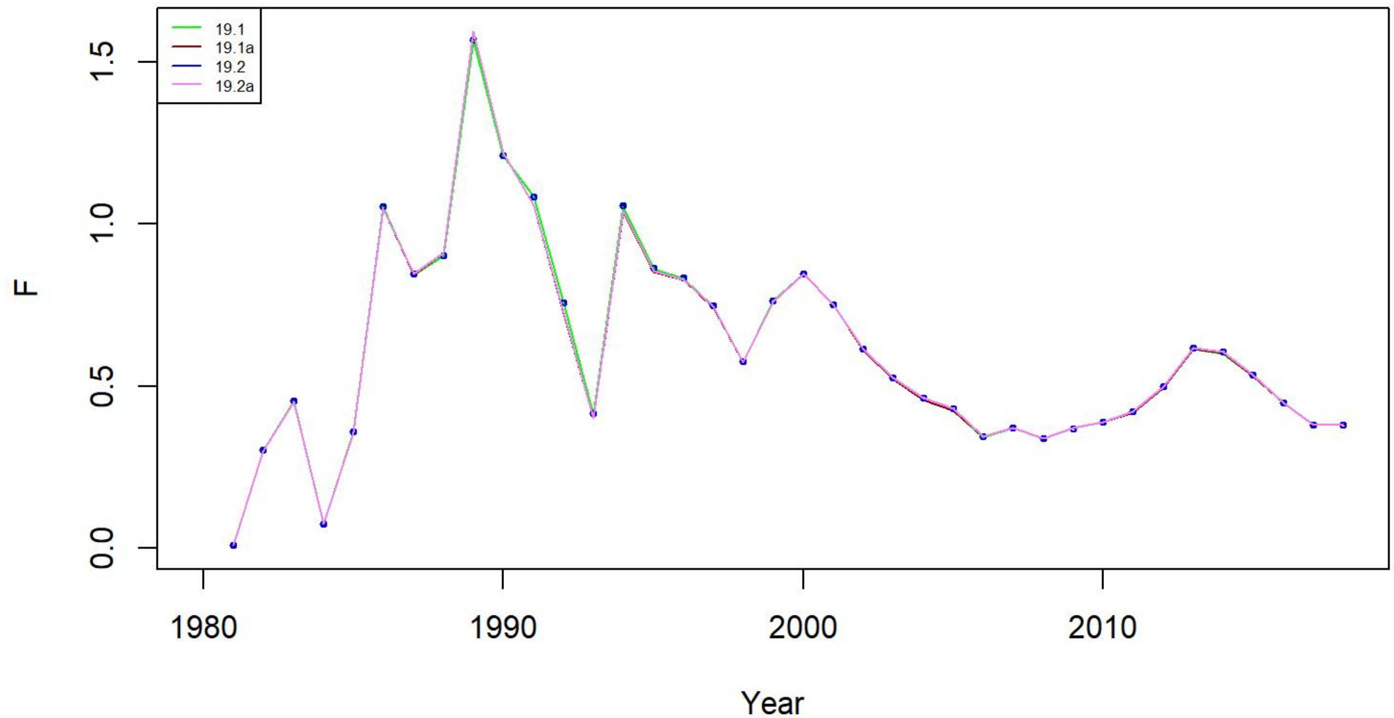


Figure 21. Trends in pot fishery full selection total fishing mortality of golden king crab for 19.1, 19.1a, 19.2, and 19.2a model fits in the WAG, 1981/82–2018/19.

Appendix A: CPUE standardization

This section is restricted to new analyses for standardization of observer, fisheries, and cooperative survey CPUE data. Siddeek *et al.* (2019) provides details of data preparation for catch, size composition, and CPUE computations.

All models used CPUE indices estimated by the hybrid method (i.e., initial selection of predictor variables by AIC followed by R^2 criterion (at least 0.01 increase in R^2 for inclusion of a new variable to already selected set of predictor variables) to select the final model. This section is subdivided in to three:

1. CPUE standardization of observer and commercial fisheries CPUE by GLM with non-interaction predictor variables.
2. CPUE standardization of observer CPUE by GLM including Year:Area interaction term in the fixed effect predictor variables.
3. CPUE standardization of cooperative survey CPUE by a mixed random effects model.

We estimated two sets of CPUE indices for models input, 19.1, 19.1a, 19.1b, and 19.1c: (fixed effect predictors), and 19.2, 19.2a, 19.2b, 19.2c (Year:Area interaction included to fixed effect predictors).

1.1 Observer CPUE index by non-interaction model:

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012). 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.

We assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \qquad \text{(A.1)}$$

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

$$\ln\,(\mathrm{CPUE_I}) = \mathrm{Year_{y_i}} + \mathrm{ns(Soak_{si}, df)} + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns(Depth_{di}, df)}, \qquad \text{(A.2)}$$

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

We used a log link function and a dispersion parameter (θ) in the GLM fitting process.

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

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

For EAG 1995_04 CPUE indices:

library(MASS)

library(splines)

Step 1:

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

epotsampleoutAIC<-stepAIC(glm.object,scope=list(upper= ~(Year + ns(SoakDays,df=4) + Month + Vessel + Captain + Area + Gear + ns(Depth,df=5)), lower=~Year), family=negative.binomial(1.38), direction="forward", trace=9, k=log(nrow(datacore)) + 1.0)

Step 2:

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

epotsampleout<- stepCPUE(glm.object, scope=list(upper= ~(Year + Gear + Captain + ns(SoakDays, df=4) + Month + Area), lower=~Year), family=negative.binomial(1.38), direction="forward", trace=9, r2.change=0.01)

The final main effect models for EAG were:

Model 19.1:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Area$
AIC=203808

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month \tag{A.3}$$
for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2205$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) + Month$
AIC=67891

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) \tag{A.4}$$
for the 2005/06–2018/19 period [$\theta = 2.33$, $R^2 = 0.1133$].

The final models for WAG were:

Model 19.1:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 8) + \mathrm{Gear} + Area + Month + Vessel$

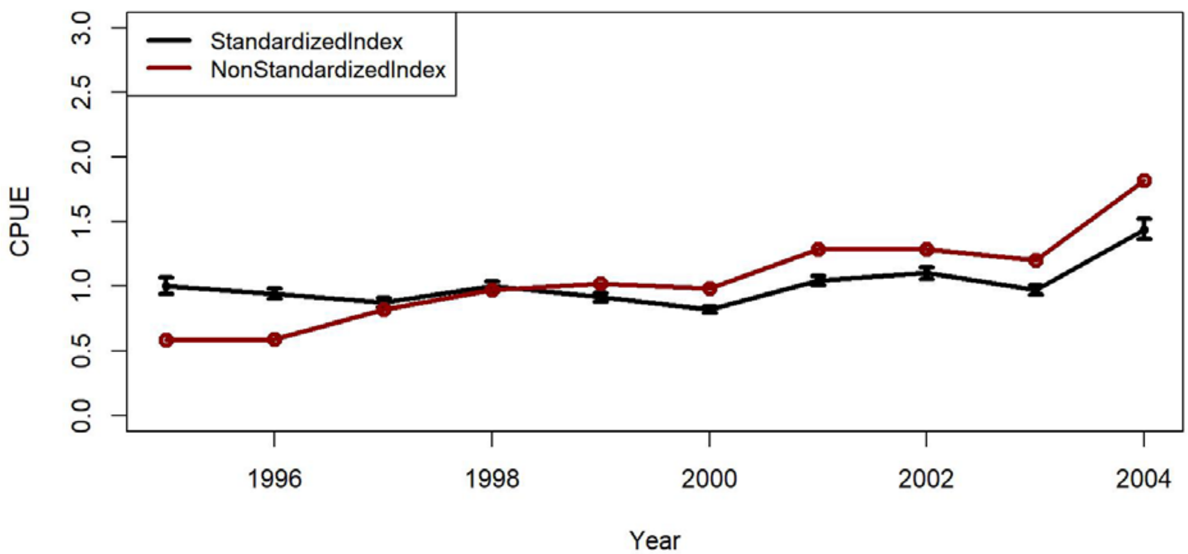
AIC=190,953

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 8) + \mathrm{Gear}$ (A.5)
for the 1995/96–2004/05 period [θ=0.97, $\mathrm{R}^2 = 0.1682$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Depth}, 2) + \mathrm{Month} + \mathrm{ns}(\mathrm{Soak}, 5)$
AIC=104,340

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 5)$ (A.6)
for the 2005/06–2018/19 period [$\theta = 1.12$, $\mathrm{R}^2 = 0.0485$, Soak forced in].

Fitted observer CPUE figures and diagnostic Q_Q plots are given below:



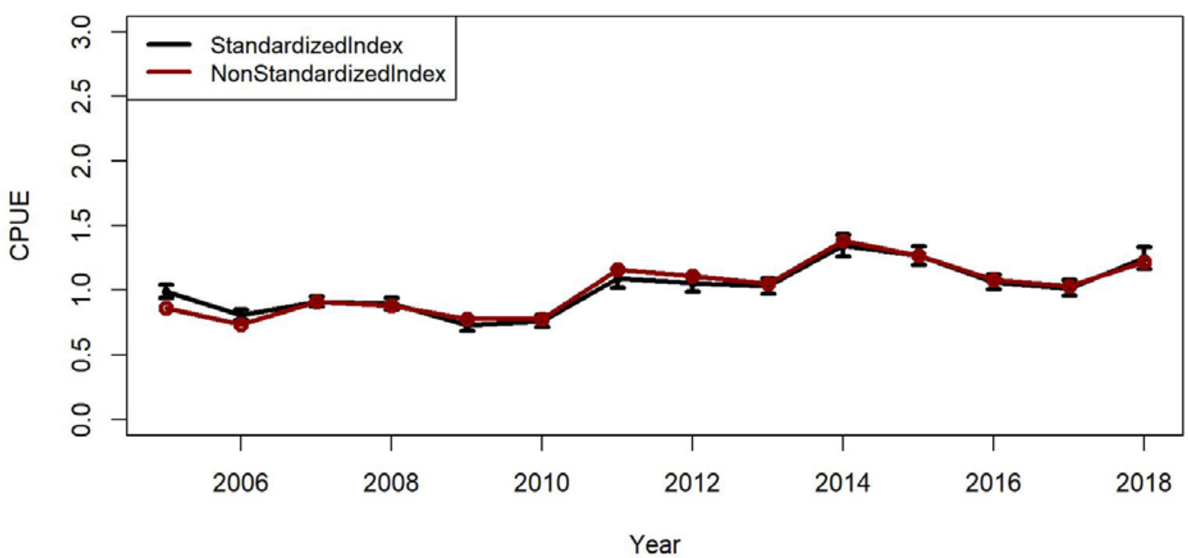


Figure A.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2018/19. Standardized indices: black line and non-standardized indices: red line. Model 19.1.

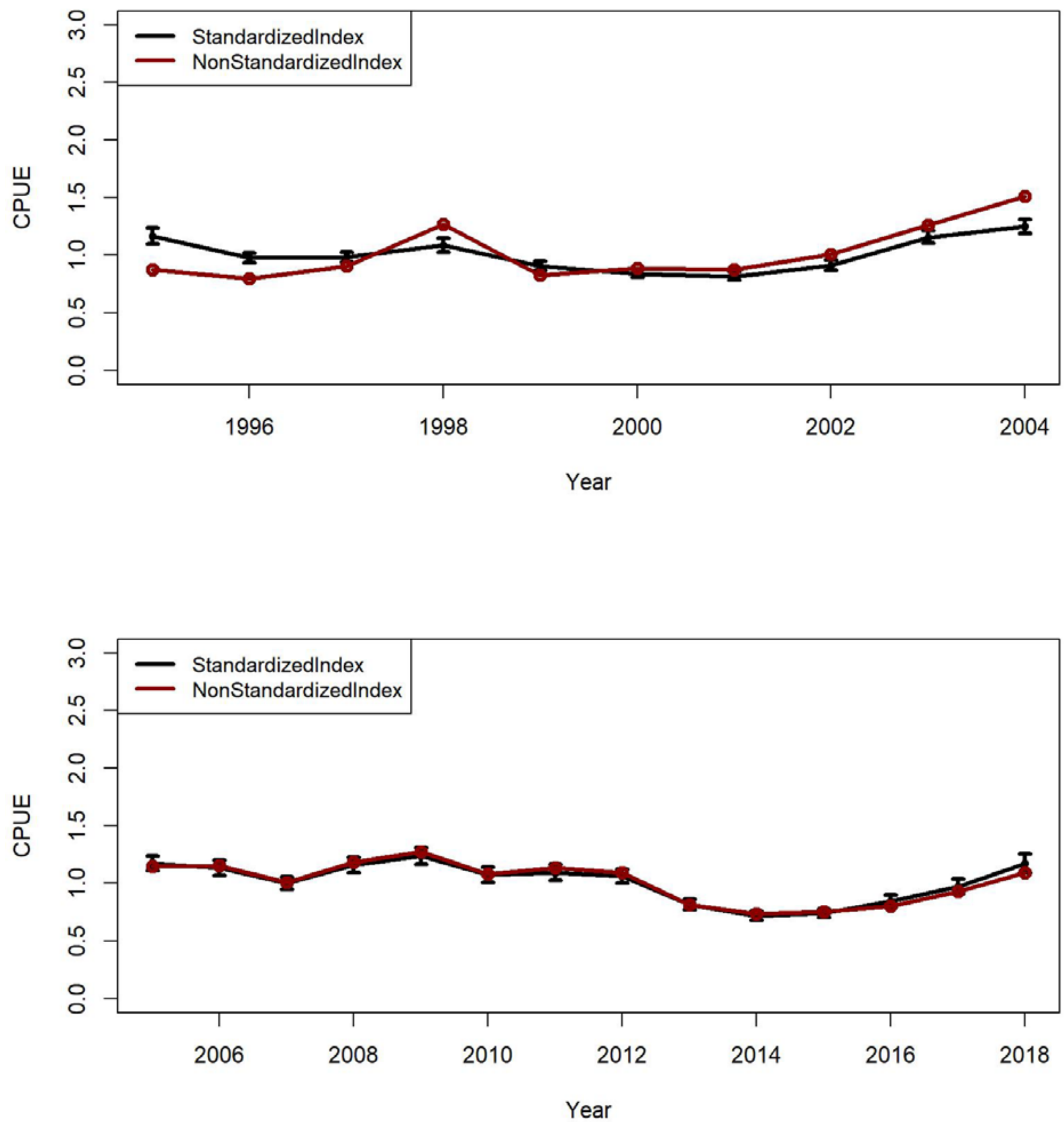


Figure A.2. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2018/19. Standardized indices: black line and non-standardized indices: red line. Model 19.1.

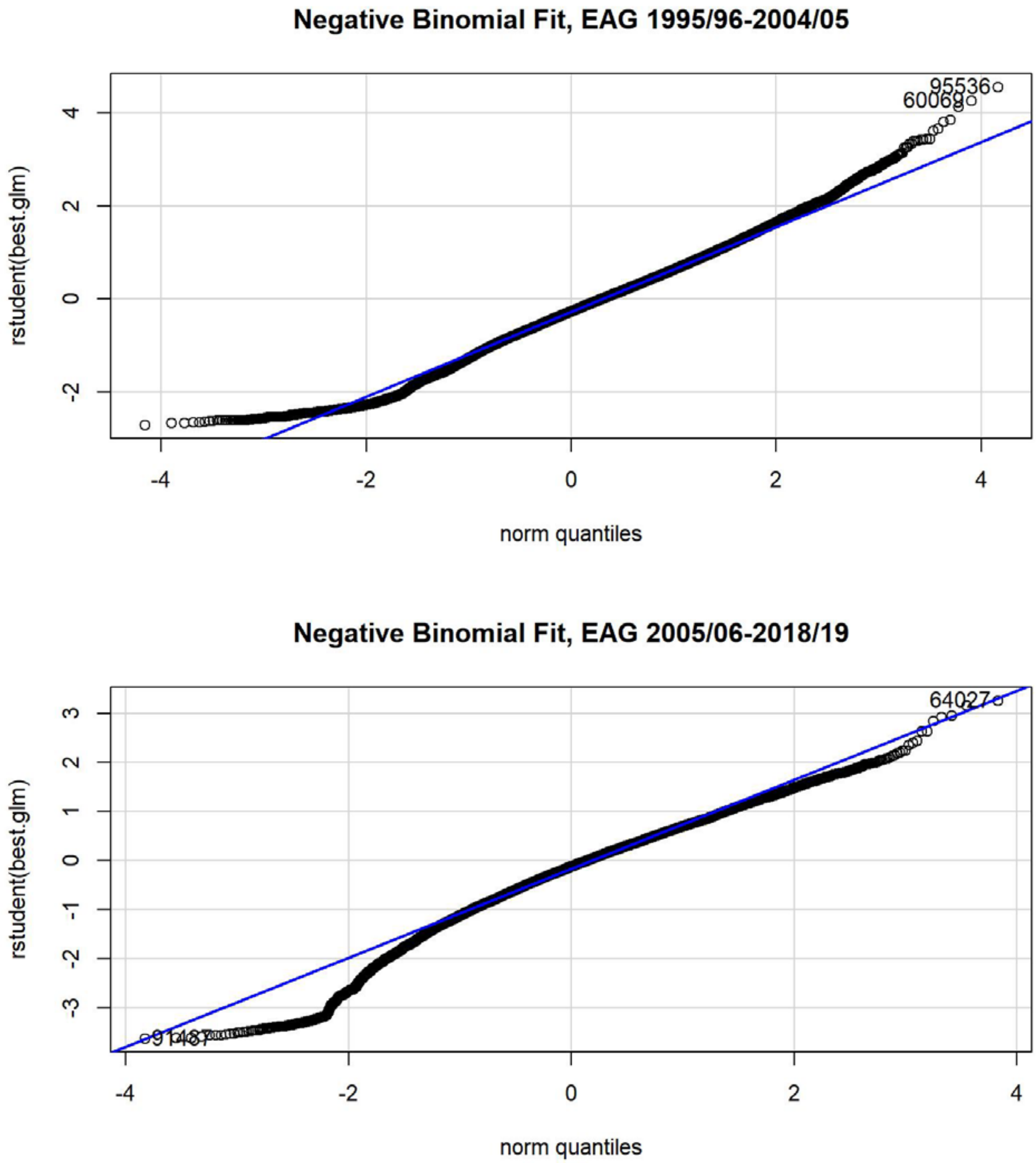


Figure A.3. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1995/96–2004/05 and bottom panel is for 2005/06–2018/19.

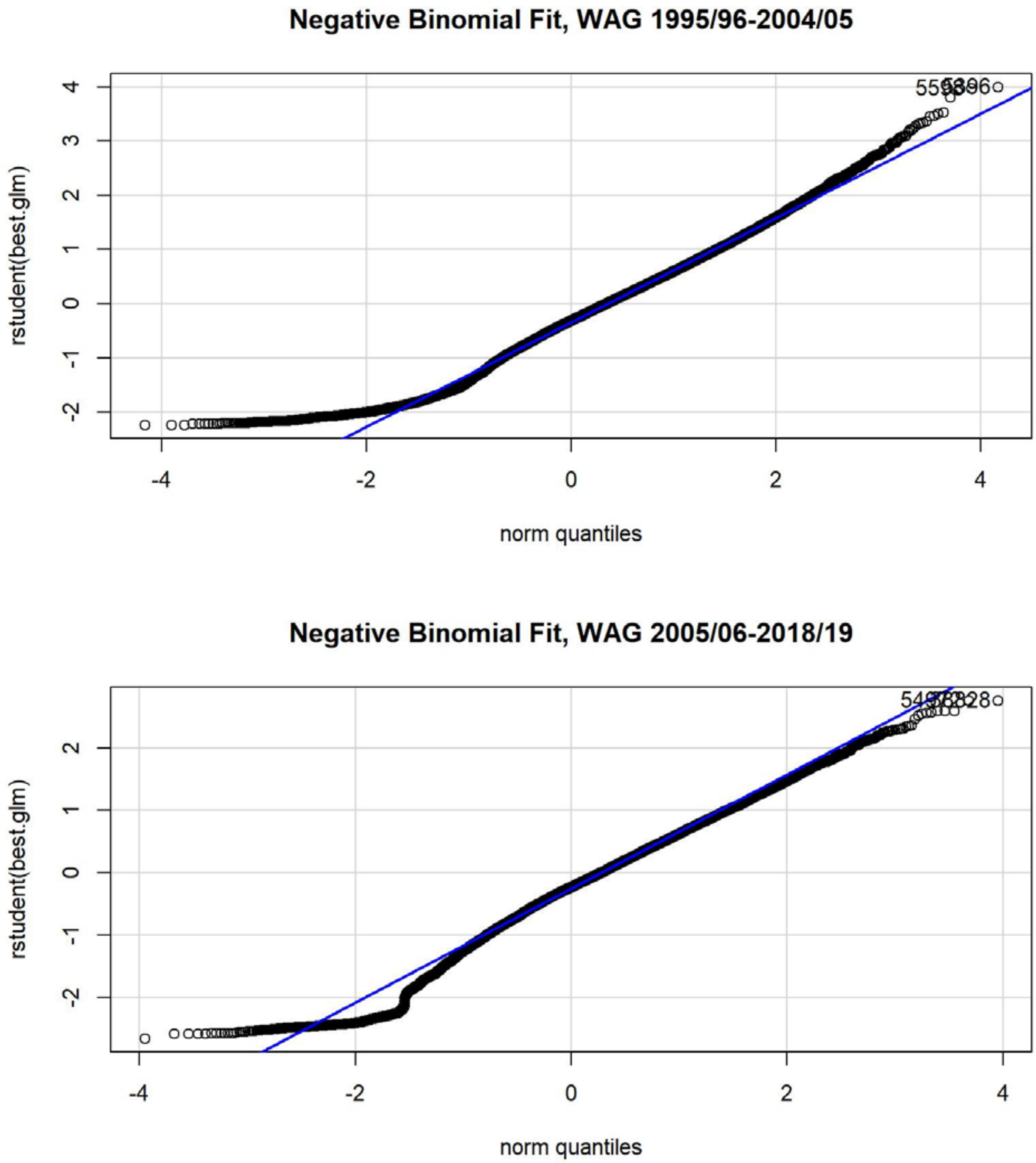


Figure A.4. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1995/96–2004/05 and bottom panel is for 2005/06–2018/19.

1.2 Commercial fishery CPUE index by non-interaction model:

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

The final model under lognormal error structure for EAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month}$
AIC=25,805

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month} \tag{A.7}$$
for the 1985/86–1998/99 period [$R^2 = 0.3700$]

and that for WAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area}$
AIC= 11,110

Final selection by stepCPUE
$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel},\ R^2 = 0.3679 \tag{A.8}$$

The final model under negative binomial error structure for EAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + Month$
AIC=16,997

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month} \tag{A.9}$$
for the 1985/86–1998/99 period [θ=10.45, $R^2 = 0.3328$]

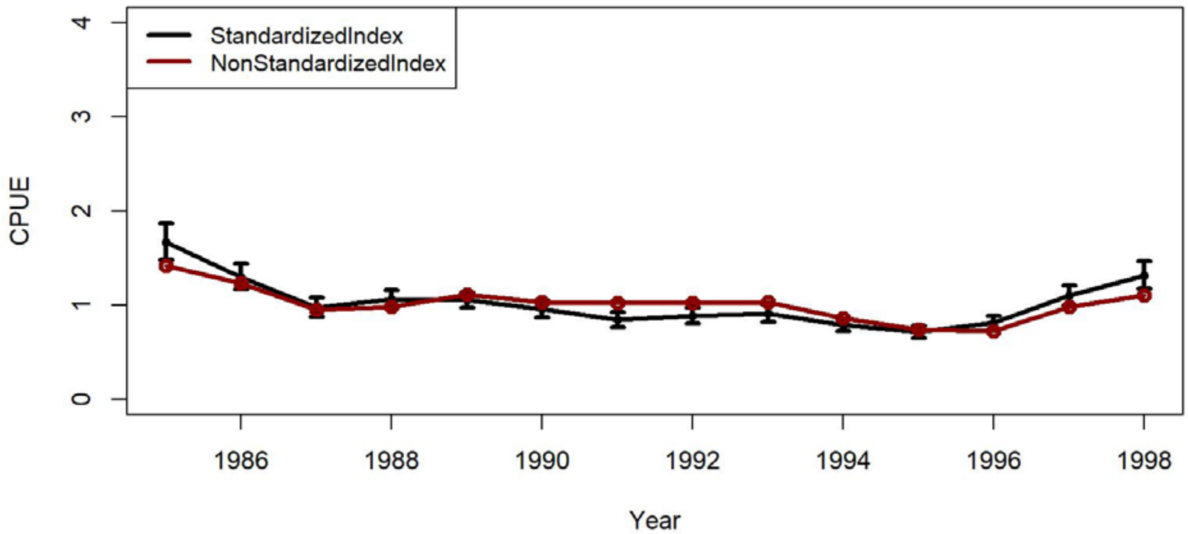
and that for WAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + Area$
AIC=30,586

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area} \tag{A.10}$$
for the 1985/86–1998/99 period [θ=6.67, $R^2 = 0.4475$]

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

Fitted commercial fishery CPUE figures and diagnostic Q_Q plots are given below:



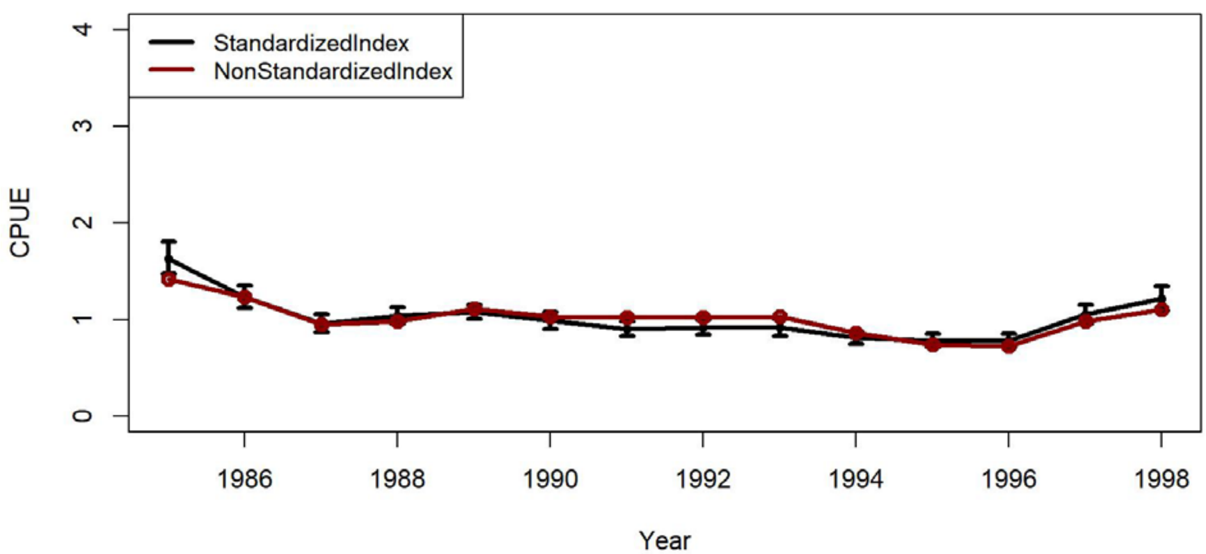
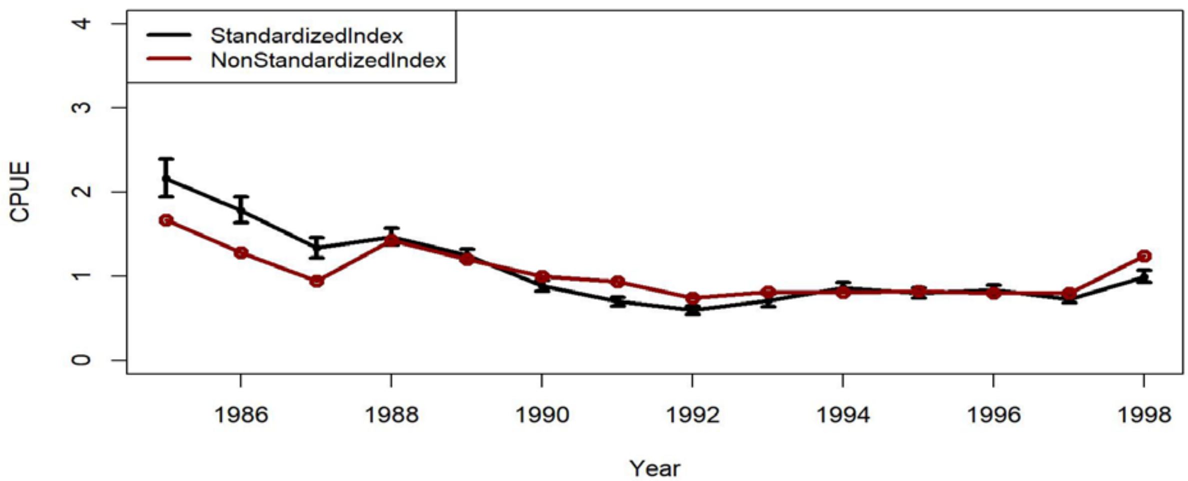


Figure A.5. Trends in non-standardized [arithmetic (nominal)] and standardized CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. Top: lognormal error and bottom: negative binomial error. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.



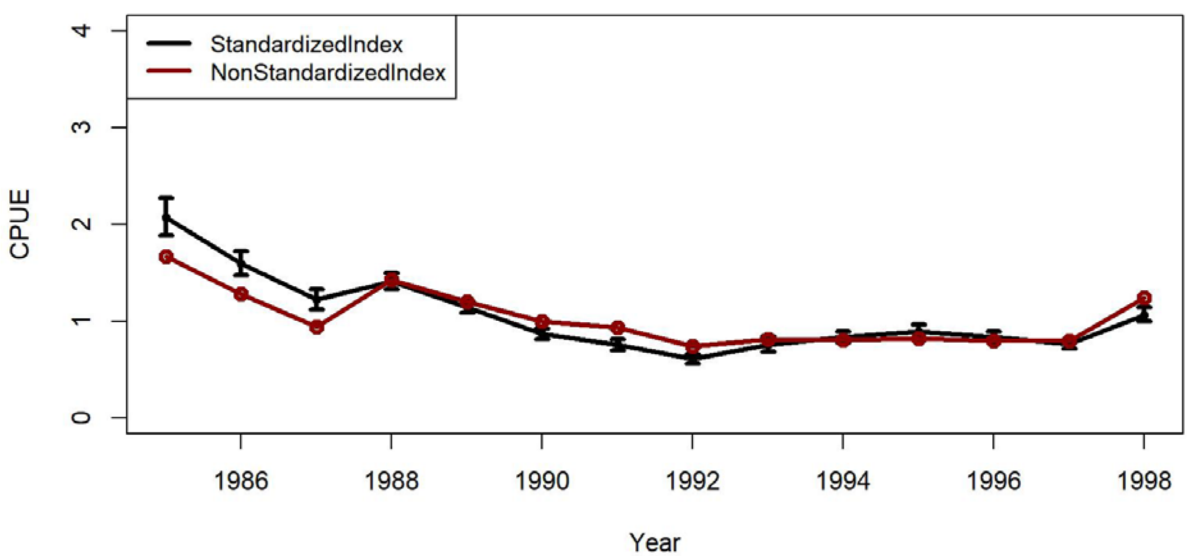
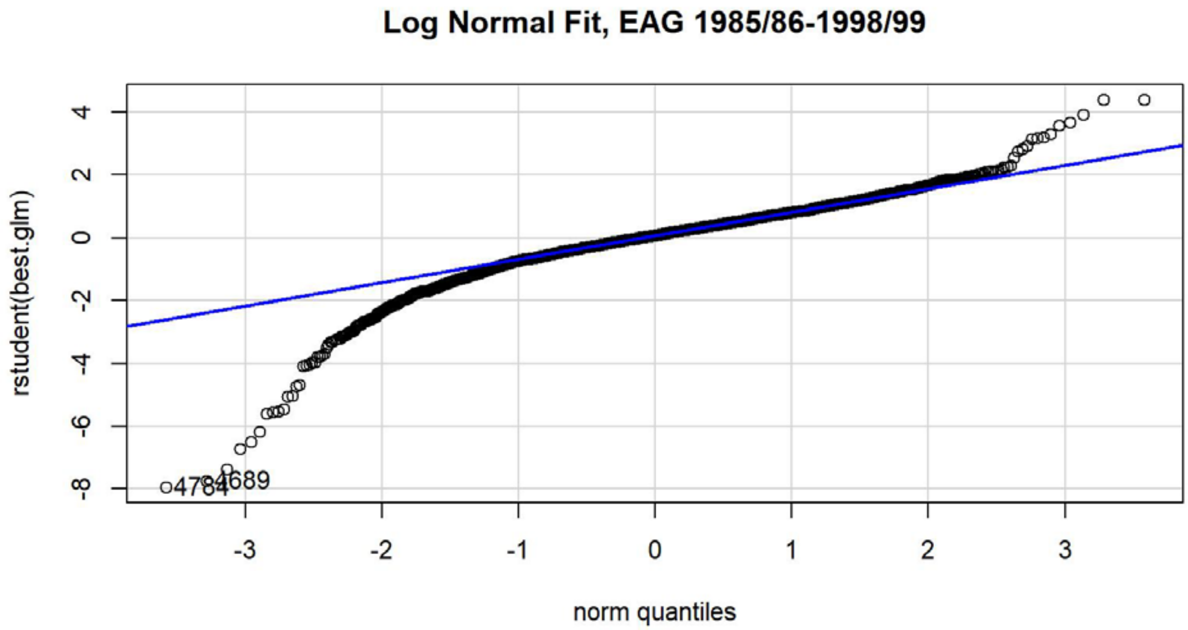


Figure A.6. Trends in non-standardized [arithmetic (nominal)] and standardized CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG. Top: lognormal error and bottom: negative binomial error. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized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



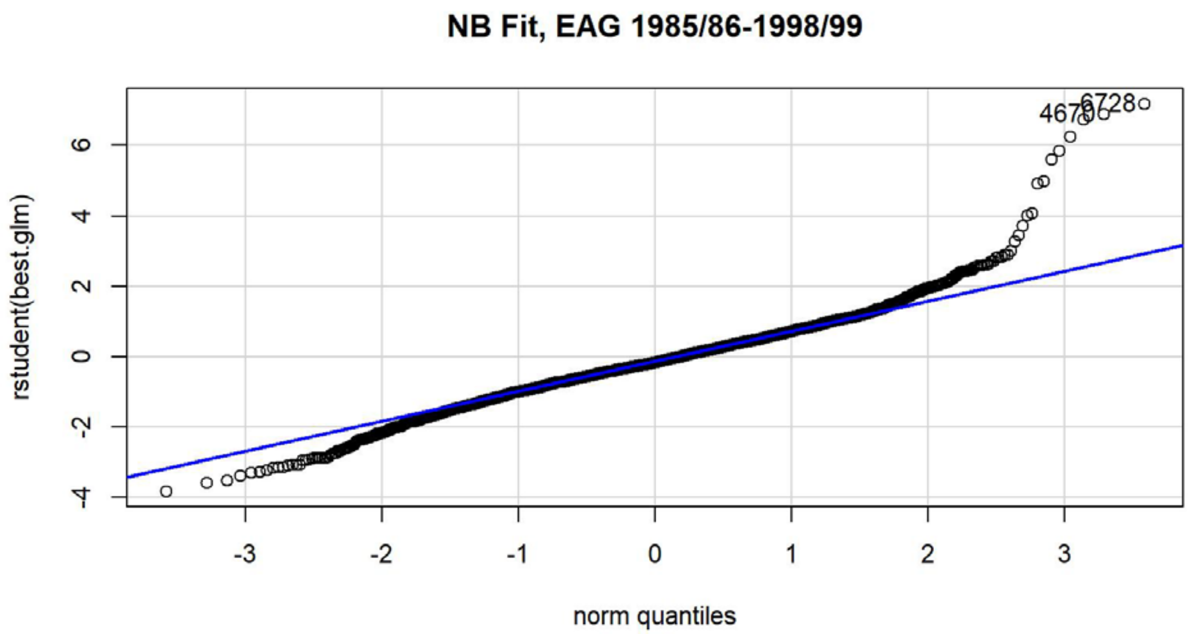
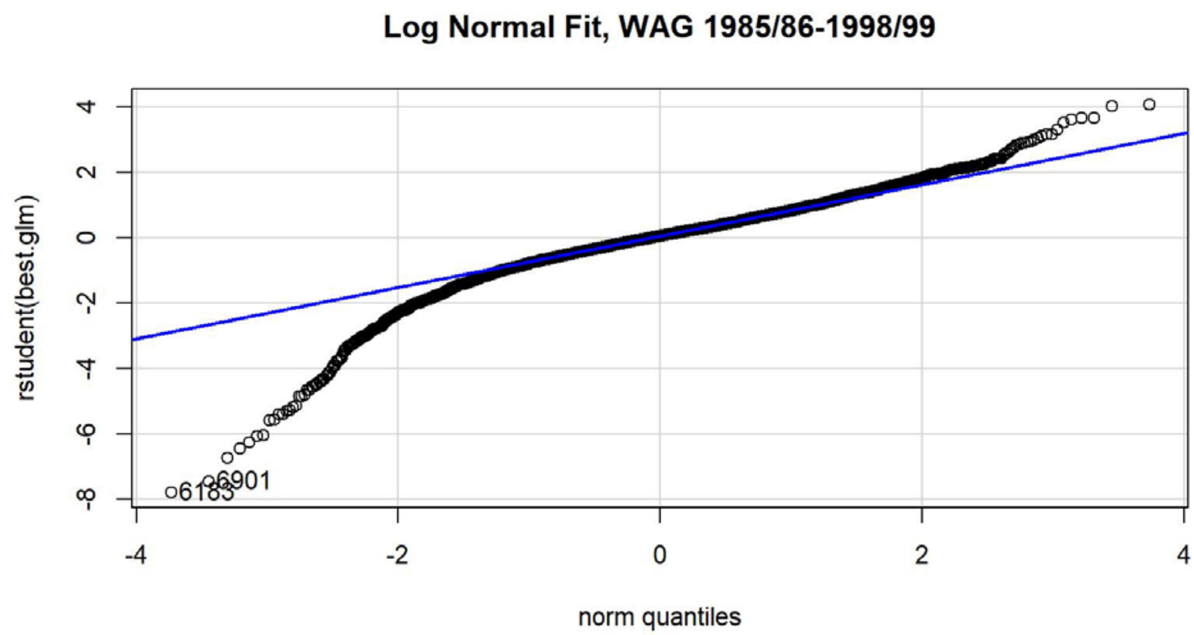


Figure A.7. Studentized residual plots for GLM fit to EAG golden king crab fisheries CPUE data. Top panel is for lognormal error and bottom panel is for negative binomial error. The 1985/86–1998/99 fish ticket data set was used.



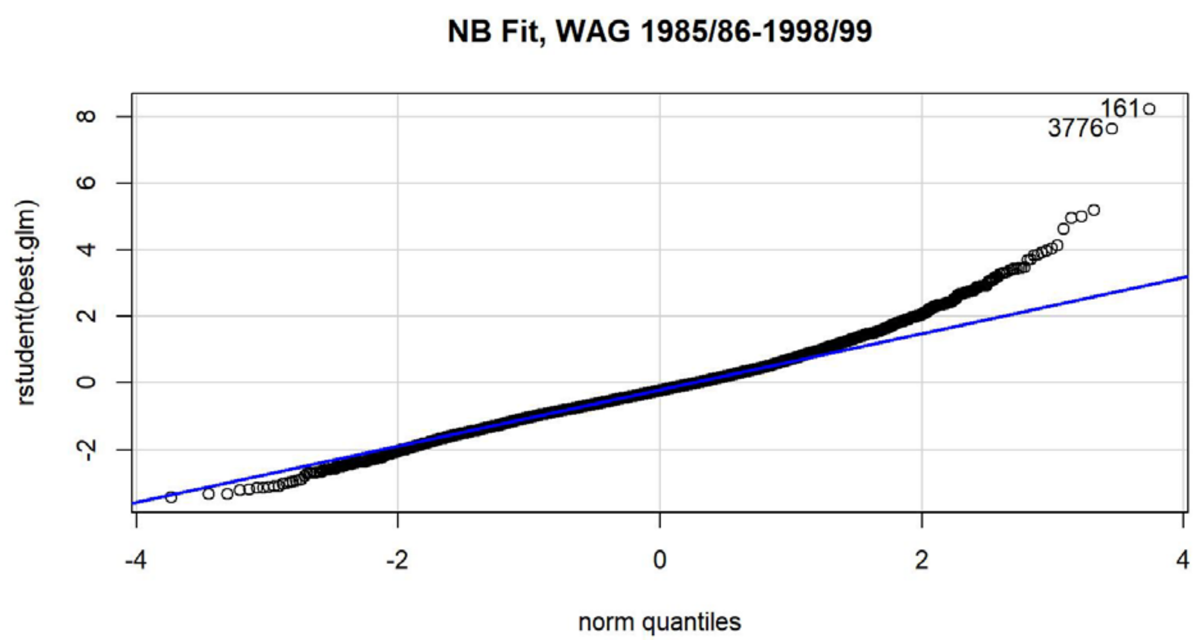


Figure A.8. Studentized residual plots for GLM fit to WAG golden king crab fisheries CPUE data. Top panel is for lognormal error and bottom panel is for negative binomial error. The 1985/86–1998/99 fish ticket data set was used.

2. *Observer CPUE index by Year:Area interaction model:*

We explored a number of studies to identify fishing footprints [e.g., extent of bait smell plume, Jocelyn Runnebaum, personal communication]. Because of variation in current direction and viability of bait smell over a long time period, this type of approach is unrealistic for this stock. Therefore, we designed the areas in to 1 x 1 nautical mile (nmi) small grids and grouped them into larger blocks based on intensity of pot sampling locations over the years. We considered these blocks would reflect golden king crab habitat patches (fishing footprints) for interaction analysis (Figure A.9). Number of small grids in each block by fishing year are listed in Table A.1.

Methods to determine year index in the presence of interaction of another variable(s) with year were discussed in Maunder and Punt (2004), Punt *et al*. (2000), and Campbell (2004). We estimated observer yearly CPUE index following Campbell's (2004) procedure for accounting for Year:Area interaction.

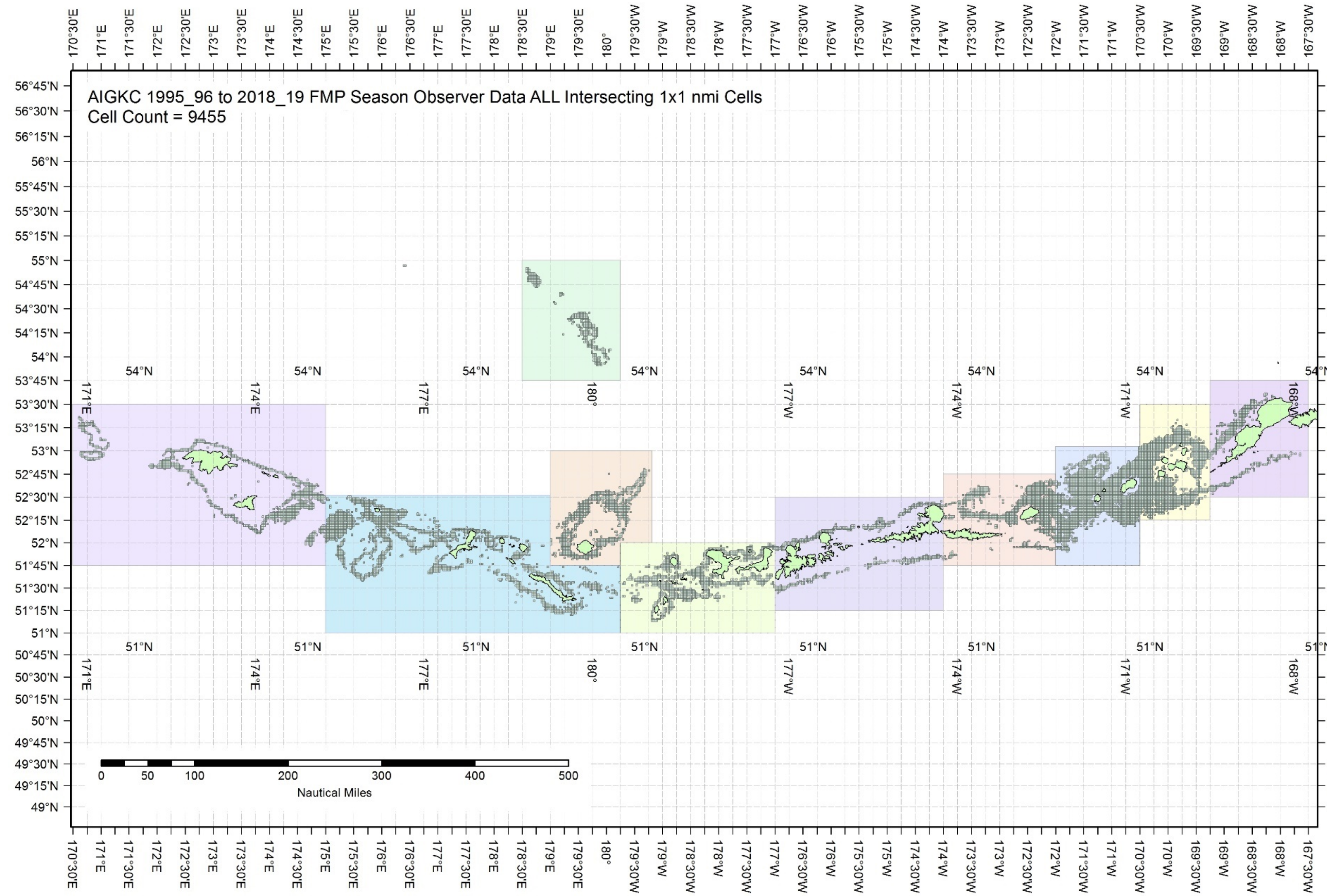


Figure A.9. The 1995/96–2018/19 observer pot samples enmeshed in 10 blocks for the Aleutian Islands golden king crab.

Table A.1. Number of 1 x 1 nmi grids containing observer sample locations within each block by fishing year for the Aleutian Islands golden king crab, 1995/96–2018/19 data. Blocks 1–4 belong to EAG and 5 – 10 to WAG.

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

Year:Area interaction GLM model:

We assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}}: \mathrm{Area_{ai}} \qquad \text{(A.11)}$$

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

$$\ln\,(\mathrm{CPUE_I}) \;= \mathrm{Year_{y_i}}: Area_{ai} + \mathrm{ns}(\mathrm{Soak_{si}}, \mathrm{df}) + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns}(\mathrm{Depth_{di}}, \mathrm{df}). \qquad \text{(A.12)}$$

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

For WAG 1995_04 CPUE indices:

library(MASS)

library(splines)

Step 1:

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

 wpotsampleoutAIC<-stepAIC(glm.object,scope=list(upper=
~(Year:Area+ns(SoakDays,df=8)+Month+Vessel+Captain+Area+Gear+ns(Depth,df=10
)),lower=~Year:Area),family=negative.binomial(0.97),direction="forward",trace=9,
k=log(nrow(datacore))+1.0)
```

Step 2:

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

 wpotsampleout<-stepCPUE(glm.object,scope=list(upper=
~(Vessel+ns(SoakDays,df=8)+Gear+Month+Year:Area),lower=~Year:Area),family=
negative.binomial(0.97),direction="forward",trace=9,r2.change=0.01)
```

The final interaction effect models for EAG were:

Model 19.2:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Year: Area$
AIC=203,851

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + Year{:}Area \qquad \text{(A.13)}$$
for the 1995/96–2004/05 period [θ=1.38, $\text{R}^2 = 0.2235$]

Initial selection by stepAIC:
$$\ln(\text{CPUE}) = \text{Vessel} + \text{Gear} + \text{ns}(\text{Soak}, 9) + Month + Year{:}Area$$
AIC=68,015

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Vessel} + \text{ns}(\text{Soak}, 9) + Gear + Year{:}Area \qquad \text{(A.14)}$$

for the 2005/06–2018/19 period [$\theta = 2.33,\ \text{R}^2 = 0.1242$].

The final interaction effect models for WAG were:

Model 19.2:
Initial selection by stepAIC:
$$\ln(\text{CPUE}) = \text{Vessel} + \text{ns}(\text{Soak}, 8) + Gear + Month + Year{:}Area$$
AIC=191,070

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Vessel} + \text{ns}(\text{Soak}, 8) + \text{Gear} + Year{:}Area \qquad \text{(A.15)}$$
for the 1995/96–2004/05 period [θ=0.97, $\text{R}^2 = 0.1719$]

Initial selection by stepAIC:
$$\ln(\text{CPUE}) = \text{Gear} + \text{ns}(\text{Depth}, 2) + ns(Soak, 5) + Month + Year{:}Area$$
AIC=104,594

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Gear} + Year{:}Area + ns(Soak, 5) \qquad \text{(A.16)}$$
for the 2005/06–2018/19 period [$\theta = 1.12,\ \text{R}^2 = 0.0681, \text{Soak forced in}$].

Steps:

1. *Block-scale analysis*:

   The estimate of the CPUE index in each Year-Block was first obtained:
   $$CPUE_{ij} = e^{YB_{ij} + \sigma_{ij}^2/2} \qquad \text{(A.17)}$$

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

The number of 1 x 1 nmi grids in each block can change from year to year; so, we assumed of using the maximum number of grids fished in a block across all years, N_{max_j} (this is equivalent to assuming that the grids fished in any year randomly sample the stock in that block (see Campbell, 2004).

The abundance index for jth block in ith year is

$$B_{ij} = N_{max_j} CPUE_{ij} \tag{A.18}$$

As you noticed in Table A.1 that there are no-observer samplings took place in certain years for a whole block. We filled the B_{ij} index gaps following Campbell (2004) as follows:

i) Find the maximum block index for each year, B_{max_i}

ii) For each year, calculate the relative index for each fished block, $B_{rel_{ij}} = \frac{B_{ij}}{B_{max_i}}$

iii) For each block, calculate the mean relative index, $\overline{B_{rel_j}}$, across those years when all blocks were fished

iv) For those blocks with either no observer sampling observations or NAs for YB_{ij} coefficients, the likely abundance index is set to $B_{modefied_{ij}} = B_{max_i} \overline{B_{rel_j}}$

Annual biomass index, B_i , was estimated as,

$$B_i = \sum_j B_{ij} \tag{A.19}$$

Following Helser *et al.* (2004), variance of annual biomass index was estimated weighting by area. In order to do that, standard deviation of ln (B_i) was first calculated as the area weighted average of $Standard\ deviation\ of\ ln(B_{ij})$. i.e.,

$$Standard\ deviation\ ln(B_i) = \frac{\sum_j Block\_Area_{ij} \times Standard\ deviation\ ln(B_{ij})}{\sum_j Block\_Area_{ij}} \tag{A.20}$$

where $Block\_Area_{ij}$ is the number of 1 x 1nmi cells sampled by observers in $Block_j$ in year *i*; and $Standard\ deviation$ ln (B_{ij}) is the GLM estimated standard error of the $Year_i$: $Block_j$ coefficient.

Then,

$$Variance\ \ln(B_i) = [Standard\ deviation\ ln(B_i)]^2 \tag{A.21}$$

To compare with other CPUE index estimates as well as to input into the assessment model, we rescaled the B_i indices by the geometric mean of estimated B_i values separately for the pre- and post-rationalization periods.

We compare the estimated indices between non-interaction (19.1) and interaction (19.2) GLM models in Table A.2, and Figures A.10 and A.11.

Table A.2. Comparison of observer CPUE indices and variances between models 19.1 and 19.2 for EAG and WAG. The 19.2 model variances are fishing footprint area weighted averages.

Year	EAG CPUE Index 19.1	Variance (ln(CPUE))	EAG CPUE Index 19.2	Variance (ln(CPUE))	WAG CPUE Index 19.1	Variance (ln(CPUE))	WAG CPUE Index 19.2	Variance (ln(CPUE))
1995	1.0034	0.0010	0.7784	0.0055	1.1650	0.0009	1.1155	0.0117
1996	0.9444	0.0004	0.7766	0.0055	0.9759	0.0004	0.9860	0.0078
1997	0.8742	0.0004	0.7658	0.0047	0.9825	0.0005	1.0356	0.0085
1998	1.0004	0.0004	0.8948	0.0048	1.0872	0.0008	1.0466	0.0100
1999	0.9154	0.0003	0.8539	0.0044	0.9076	0.0005	0.9313	0.0083
2000	0.8196	0.0003	0.8196	0.0058	0.8397	0.0004	0.8793	0.0083
2001	1.0429	0.0003	1.5148	0.0189	0.8177	0.0005	0.8047	0.0087
2002	1.1029	0.0004	1.2149	0.0060	0.9143	0.0006	0.9240	0.0090
2003	0.9714	0.0004	1.1097	0.0039	1.1562	0.0006	1.1389	0.0083
2004	1.4394	0.0008	1.6893	0.0052	1.2499	0.0006	1.2095	0.0087
2005	0.9912	0.0007	1.0762	0.0059	1.1736	0.0007	1.0966	0.0180
2006	0.8097	0.0006	0.7980	0.0054	1.1332	0.0009	1.1041	0.0179
2007	0.9132	0.0005	0.8842	0.0053	1.0015	0.0008	1.0315	0.0185
2008	0.8966	0.0007	0.8990	0.0061	1.1591	0.0008	1.2067	0.0154
2009	0.7327	0.0010	0.7901	0.0073	1.2354	0.0009	1.3982	0.0194
2010	0.7629	0.0010	0.8107	0.0073	1.0735	0.0009	1.0498	0.0176
2011	1.0903	0.0011	1.0867	0.0073	1.0952	0.0010	1.0930	0.0170
2012	1.0538	0.0009	1.0402	0.0069	1.0618	0.0008	1.0432	0.0161
2013	1.0309	0.0008	1.0427	0.0067	0.8170	0.0007	0.7581	0.0184
2014	1.3456	0.0010	1.3315	0.0065	0.7192	0.0007	0.7078	0.0170
2015	1.2660	0.0009	1.2342	0.0058	0.7419	0.0007	0.7153	0.0169
2016	1.0631	0.0007	1.0586	0.0054	0.8465	0.0009	0.8394	0.0183
2017	1.0162	0.0009	0.9568	0.0061	0.9718	0.0011	1.0067	0.0189
2018	1.2488	0.0012	1.1654	0.0060	1.1713	0.0012	1.2226	0.0190

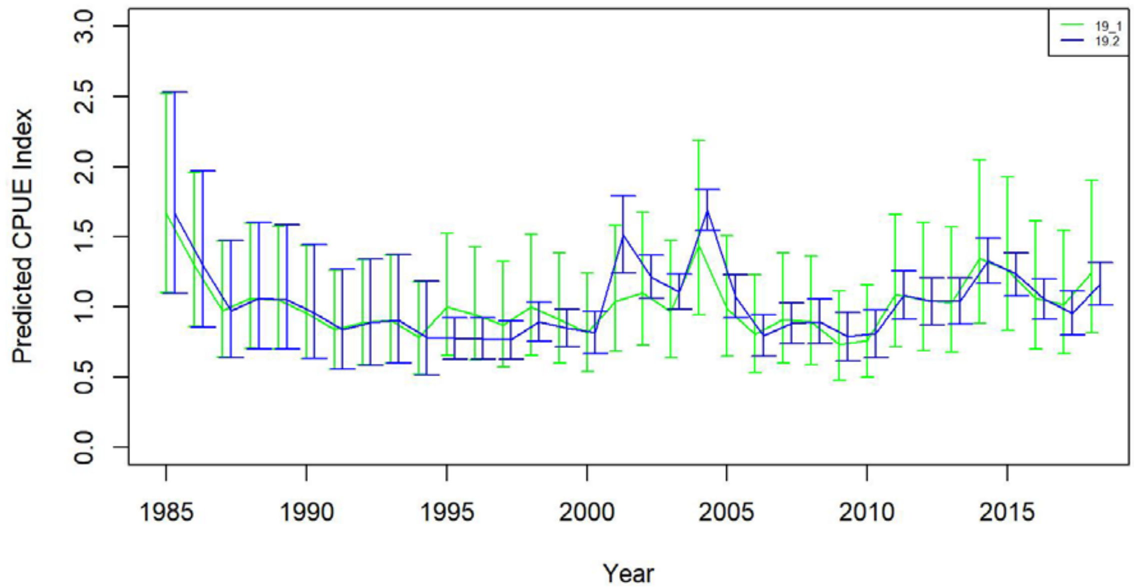


Figure A.10. Comparison of standardized (negative binomial GLM) CPUE indices with +/- 2 SE between no interaction (green line, 19.1) and Year:Area interaction (blue line, 19.2) models for golden king crab observer data from EAG.

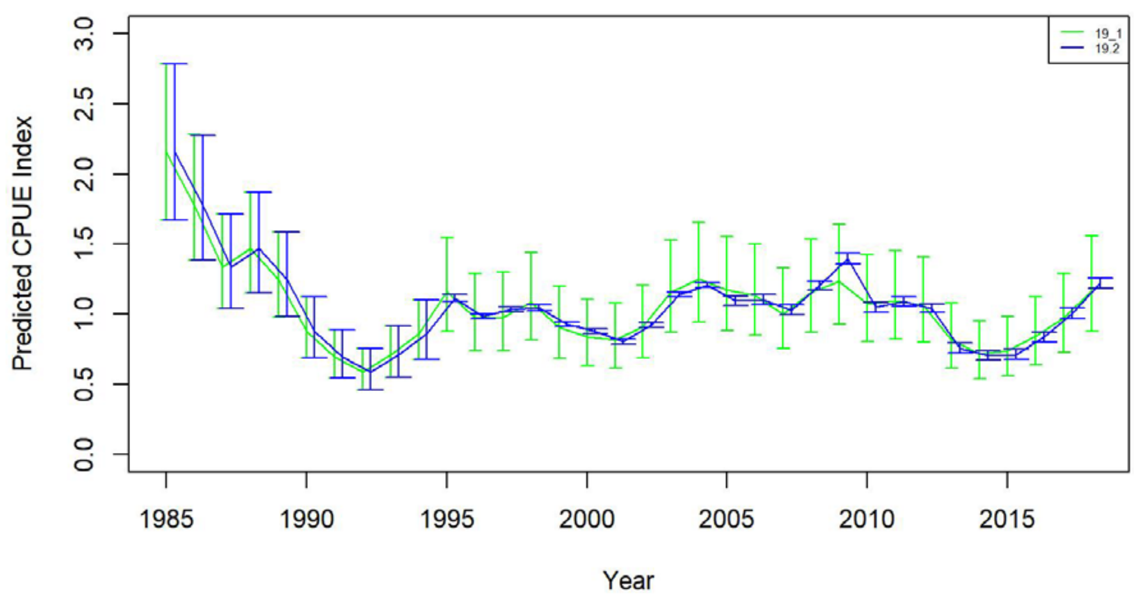


Figure A.11. Comparison of standardized (negative binomial GLM) CPUE indices with +/- 2 SE between no interaction (green line, 19.1) and Year:Area interaction (blue line, 19.2) models for golden king crab observer data from WAG.

3. *Standardization of cooperative survey CPUE by mixed random effects model:*

The unique property of cooperative survey is that multiple pots from multiple strings are sampled. Survey is done during the first month of each fishing season. All sample measurements were taken in EAG except for 2018 and 2019, during which measurements were also taken from WAG. The CPT and SSC suggested to use the random effect model to standardize the survey CPUE.

Data:
There are 27,255 records from four-year (2015–2019) cooperative surveys.

Each record consists of:
Year, Vessel Code, Captain Code, String ID, Mesh ID, Sub Sample Rate, Sex, Carapace Length, Catch (count at each size), Legal ID, Latitude, Longitude, Depth, Soak Time, and EAG_WAG ID.

Data preparation for CPUE standardization:

i.) Created two new columns by concatenating Vessel Code with String ID as well as Pot ID because String ID and Pot ID are not unique numbers to each vessel. The new column names were identified as VesStringID and VesPotID. For example, a Vessel Code 20556 with a String ID 3 was concatenated to be 205563 in column VesStringID, and a Vessel Code 20556 with a Pot ID 5 was concatenated to be 205565 in column VesPotID.

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

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

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

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

The mixed random effects model considered a random intercept procedure by randomizing the String ID (i.e., VesStringID) to analyze the 2015–2019 data. So, each string has a different (random) baseline value to predict CPUE. Following Helser *et al*. (2004), we also used different random structures to explore the fits (see Table A.3). We used the "lme4" library in R (version 3.5.1, R Core Team, 2018) with the "glmer()" function to perform the mixed random effects model on the data. The glmer() function allows to use any type of error model (we used the negative binomial model) to fit the data:

library(MASS)

library(splines)

library(Matrix)

library(lme4)

best.lmefit<- glmer(SumCatch~ Year+VesPotID+ns(SoakDays, df=9)+ns(Depth, df=6)+(1|VesStringID), family = negative.binomial(2.33),control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)), data=eSurvey15_19Subtrim)

where SumCatch= observed CPUE, best.lmefit = expected CPUE, Year and VesPotID are factorial variables. The fixed effect variables (Year, VesPotID, Depth, and SoakDays) were selected from fit of a fixed effect model on the survey data. The dispersion parameter value for the negative binomial error model and the degrees of freedom for cubic splines were borrowed from the observer final GLM model estimate for EAG for the post rationalization period.

The best model based on lowest AIC value is the String:Block interaction model (Table A3):

best.lmefit2<- glmer(SumCatch~ Year+VesPotID+ns(SoakDays, df=9)+ns(Depth, df=6)+(1|VesStringID:Block), family = negative.binomial(2.33), control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)), data=eSurvey15_19Subtrim)

Table A.3. Diagnostic table for the mixed effects models with different random effects structures for 2015–2019 data. σ_{RE} is the standard deviation of the random effects.

Model Type	Final Model	AIC	σ_{RE}
Fixed effect, no random	$SumCatch \sim Year + VesStringID + VesPotID + ns(SoakDays, df = 9) + ns(Depth, df = 6)$	11,399	-
String random	$SumCatch \sim Year + VesPotID + ns(SoakDays, df = 9) + ns(Depth, df = 6) + (1 \mid VesStringID)$	11,526	0.4803
$Year : Block$ random	$SumCatch \sim VesPotID + ns(SoakDays, df = 9) + ns(Depth, df = 6) + (1 \mid Year{:}\,Block)$	11,663	0.3876
$String : Block$ random	$SumCatch \sim Year + ns(Depth, df = 6) + ns(SoakDays, df = 9) + VesPotID + (1 \mid VesStringID{:}\,Block)$	11,370	0.6021

The QQ plot for the mixed effect model fits assured model assumptions were correct for various random effects structures (Figure A.12). Table A.4 provides random effects model (with String:Block random) predicted and observed CPUE estimates for EAG 2015–2019 data.

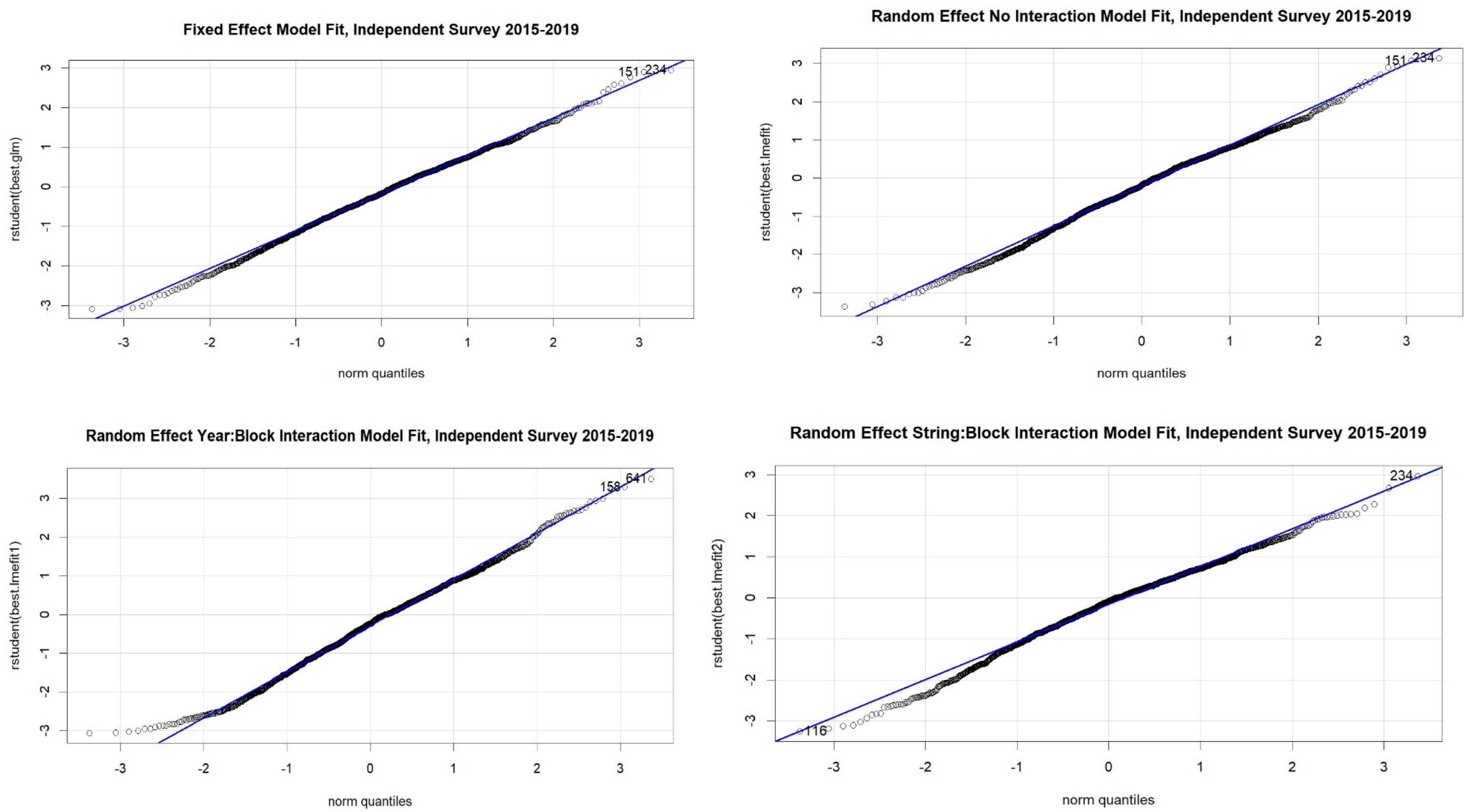


Figure A.12. Studentized residual plots for various mixed random effects model structures. Top left: Fixed Effects; top right: String random, no interaction; bottom left: Year:Block random; and bottom right: String:Block random. The 2015–2019 data were used.

Table A.4. The cooperative survey expected and observed legal size male (> 135 mm CL) mean CPUE by the mixed random effects model with String:Block interaction, standard errors (SE), and upper- and lower- 95% confidence limits for EAG, 2015–2019 data. n = sample size; Legal size = crab size > 135 mm CL.

Year	Predicted CPUE	SE	Lower Limit	Upper Limit	Observed CPUE	SE	Lower Limit	Upper Limit	n
2015	31.5537	0.8520	29.8498	33.2577	32.4494	1.3981	29.6532	35.2456	336
2016	27.2278	0.7287	25.7704	28.6852	28.5230	1.3279	25.8673	31.1788	304
2017	31.3232	1.1380	29.0472	33.5991	32.9854	1.9275	29.1303	36.8405	206
2018	33.4100	1.1660	31.0779	35.7420	36.4121	2.3918	31.6285	41.1957	199
2019	20.9275	0.6945	19.5385	22.3165	20.8304	1.0094	18.8117	22.8492	289

We standardized the expected CPUE for 2015–2018 by the geometric mean to obtain the CPUE indices for input to the assessment model (19.1d) (Table A.5). Figure A.13 compares the model 19.1d (with cooperative survey data) prediction of CPUE with the 19.1 model estimates. The cooperative survey estimates are more precise than the observer estimates (Figure A.13). However, the number of data points are not large enough to make reliable conclusion from stock assessment model.

Table A.5. The cooperative survey expected legal size male standardized (by geometric mean) CPUE indices by the mixed random effects model with String:Block interaction, standard errors (SE), and upper- and lower- 95% confidence limits for assessment model input for EAG, 2015–2018 data.

Year	Predicted CPUE index	SE	Lower Limit	Upper Limit
2015	1.0247	0.0277	0.9694	1.0800
2016	0.8842	0.0237	0.8369	0.9316
2017	1.0172	0.0370	0.9433	1.0911
2018	1.0850	0.0379	1.0093	1.1607

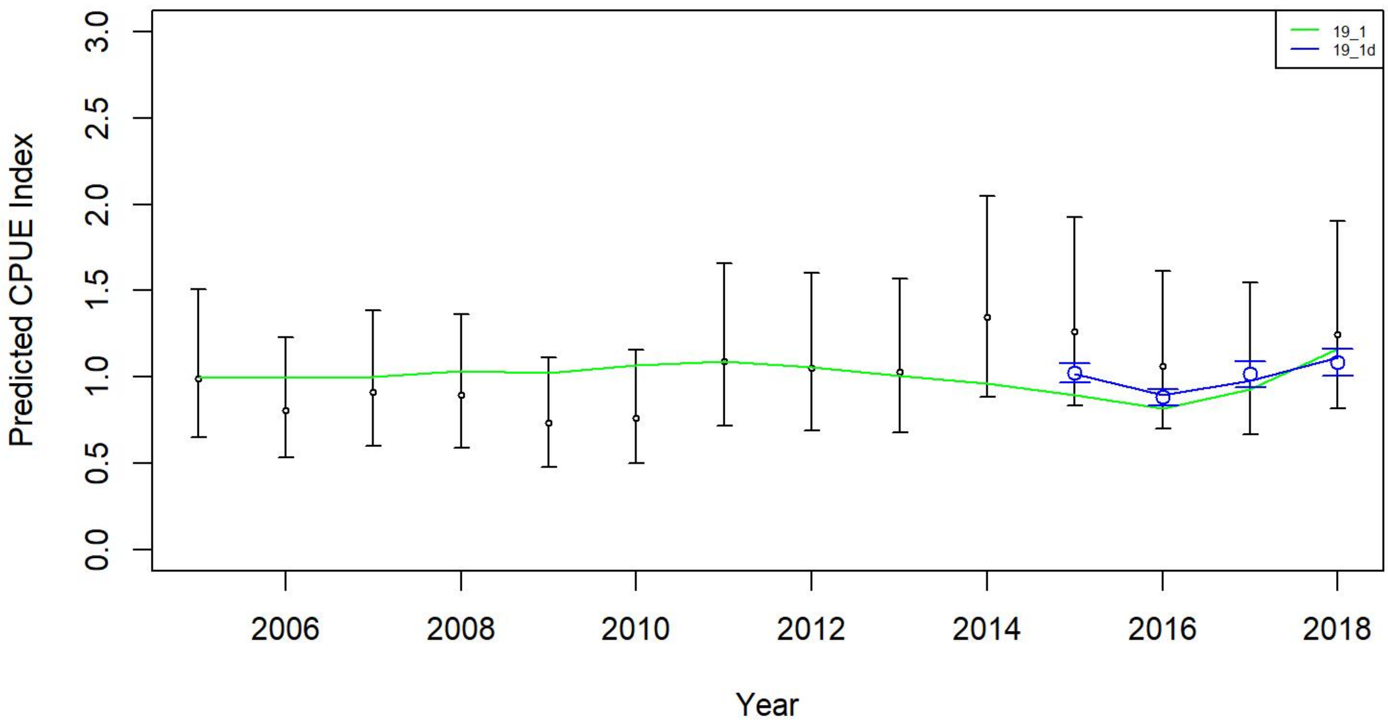


Figure A.13. Comparison of input CPUE indices [with +/- 2 SE for model 19.1 (black small circles) and model 19.1d (cooperative survey, blue large circles)] with predicted CPUE indices (green (19.1) and blue (19.1d) solid lines) by 19.1 and 19.1d model fits for EAG golden king crab (fishery data:2005/06–2018/19 and survey data: 2015–2018). Model estimated additional standard error was added to each input standard error.

Appendix B: Aleutian Islands golden king crab male maturity determination

We used two independent (Bent-Point and Cut-Line) approaches to classify golden king crab males into immature and mature based on chela height (CH) and carapace length (CL) data. Then used the proportion of mature vs CL to determine the maturity curve by the logistic regression method. We performed all analyses using R packages (version 3.5.1, R Core Team, 2018).

Data

The observer, retained catch, and cooperative survey samples during the 2018/19 fishing season provided CH vs CL data pairs for this analysis. These data are in addition to 1984 and 1991 CH vs CL data pairs used previously for maturity analysis. Observers, biologist, and dockside samplers measured CL to 1 mm and CH to 0.1 mm precision. Table B.1 provides the number of records from each source and the total (combined) for the 2018/19 fishing season. The data collections are continuing for the 2019/20 season. To increase the sample size, we combined all sources of data for the 2018/19 seasons and divided into EAG, WAG, and combined for maturity analysis.

Table B.1. Samples sizes from various times and areas for maturity analysis.

Source	n	EAG	WAG
NMFS 1984 biologist	1,343		
ADF&G 1991 biologist	2,457		
2018/19 observer	3220		
2018/19 retained catch	2453		
2018/19 cooperative pot survey	362		
2018/19 combined	6035	3128	2907

Bent-Point method

We used the growth changes in chela height with the onset of maturity to determine two segments of straight lines that join at the bending point assuring continuity of lines using the segmented regression package. Golden king crab chela height growth is different from those of *Chionoecetes* (Tanner and snow) crab growth pattern. However, among the king crab, golden king crab show clear bending pattern at maturity ((Somerton and Otto, 1986). **We fitted the segmented lines to a restricted size range (80–130 mm CL) where mature and immature sizes overlap.**

Segmented regression:

First we fitted a linear regression model “lm()” to the ln(CH/CL) vs CL pair using the R package as follows:

$$\ln(CH/CL) = \beta_0 + \beta_1 CL \tag{B.1}$$

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

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

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,

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

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

We used the rising part of the bent line above 80 mm CL to classify morphometrically immature (below the rising line) and mature (on or above the rising line) crab in the whole data. We also considered hard-cutoff size ranges to classifying fully immature (mature probability=0) and fully mature (mature probability = 1) crab (see Table B.2). Then we used the proportion mature vs CL pair to fit a logistic model in R. The linearized form of the logistic model is:

$$\ln\left(\frac{p}{1-p}\right) = a_0 + a_1\, CL \quad \text{(B.4)}$$

where p is the maturity proportion, and a_0 and a_1 are regression parameters.

Cut-Line method

Following Conan *et al*.'s (1996) maturity study of Canadian male snow crab, the Kodiak AFSC personnel developed a method to determine maturity proportion on *Chionoecetes* crab (Richar, personal communication). The Kodiak ADF&G personnel (Tyler Jackson, personal communication) modified the AFSC developed R codes for snow crab maturity analysis. We considered both sources of R codes with some modifications to determine golden king crab maturity.

To apply this method, CH and CL measurements were first linearized by natural log transformation. Within the size range of overlap between mature and immature crab, log-transformed paired CL-CH data were binned by small increments (0.025). For each bin range, the underlying bimodal distribution of data was computed via application of a kernel density estimation function available in R and the minima between distribution density peak were calculated (Figures B.1 and B.2).

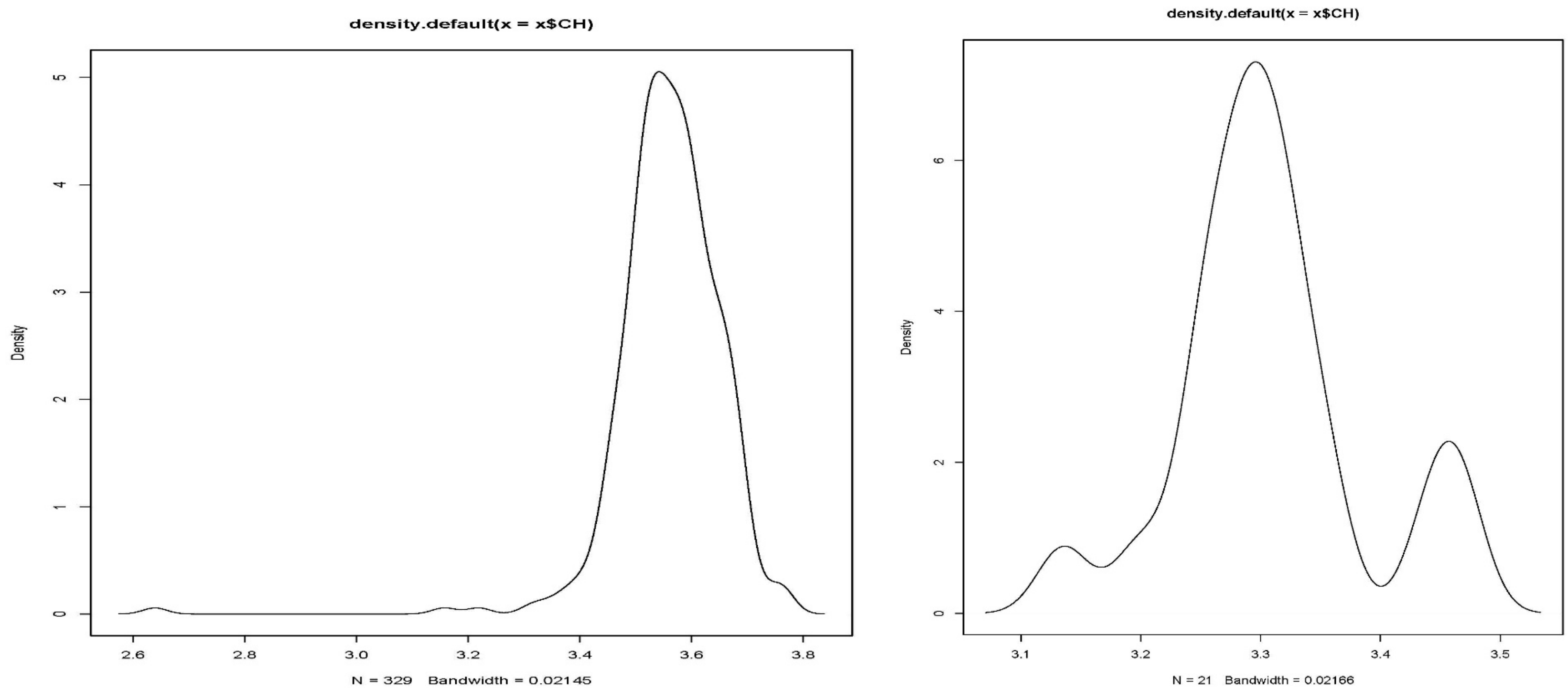


Figure B.1. Kernel density plots for 2018 EAG (left) and 2018 WAG (right) chela height data. The Cut-Line method identifies the minimum points of the density distributions in each size bin and fit a straight line through the points to delineate mature and immature crab.

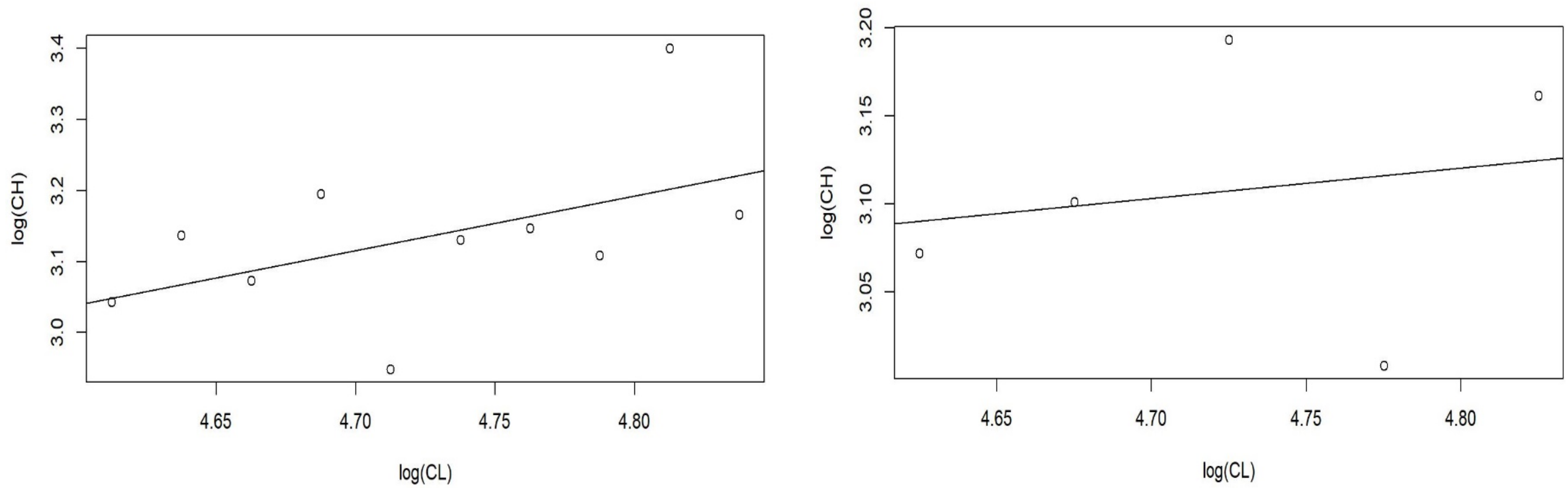


Figure B.2. The cutline (regression line fitted to all minimum points) for 2018 EAG (left) and 2018 WAG (right).

Minima x- and y- coordinates for each increment were extracted and the underlying linear relationship was determined via the R function lm() (version 3.5.1. R Core Team, 2018). The fitted linear line was then applied as a cutline to classify morphometrically immature (points below the cutline) and mature (points on or above the cutline) crab in the whole CH vs CL sample data. Hard-cutoff size ranges for classifying fully immature and fully mature crab were pre-determined for the logistic model fitting. All crab < 80 mm CL were assigned a maturity probability of zero and all crab >= 160 mm CL were assigned a maturity probability of one.

The logistic model parameter estimates for various sets of data are listed in Table B.2. Except very high (129.77 mm CL) and low (82.2 mm CL) estimates of 50% length at maturity for 2018 EAG and WAG respectively, the estimates ranged from 100 to 109 mm CL for different data sets, areas, and the two methods. Additional data gathered during the 2019/20 fishing season would likely improve the estimates. Nevertheless, since the latitude differences of samples were not very large (~51^{o} -53^{o} latitude range), we did not expect widely differing 50% maturity sizes between EAG and WAG. Somerton and Otto (1986) and Otto and Cummiskey (1985) observed decrease in the size at maturity with decrease in latitude.

Figure B.3 illustrates the bent line fitted to ln(CH/CL) vs CL data whereas Figures B.4 to B. 6 depict the estimated Cut-Line passing through the ln(CH) vs ln(CL) data for various years and regions of samples. Figure B.7 shows the logistic curves (parameter estimates are in Table B.2). Considering similar L50 estimates and spread of maturity probability, we chose two logistic curves estimated by the Bent-Point and Cut-Line analyses on combined 2018 CH vs CL data for mature male biomass (MMB) estimation. This is in addition to the status quo knife-edge maturity size of 111 mm CL used for MMB calculation.

Issues on determining maturity based on Bent-Point and Cut-Line methods:

The logistic curves fitted to maturity determined by the bent point lines underestimated the maturity at larger sizes (see Figure B.7). We used the fitted straight line to declare any chela heights equal and above this line to be mature. Because of large variability of observed ln(CH/CL) values about the fitted line, this assumption is likely to have underestimated maturity. This is also true for maturity assumption made under the Cut-Line method (see Figure B2). So,

we considered the following procedures to modify the maturity curves:

1. Robust regression method ["*rlm()*" in R] to fit a straight line under the Cut-Line method. This is to reduce the influence of outlier values on the fitted line (Fox and Weisberg , 2011).

   library(MASS)
   Fit<- rlm(ln(CH)~ln(CL), data, method="MM")

2. The 25% below fitted ln(CH/CL) and 10% below fitted ln(CH) lines under segmented regression and cut line methods, respectively to declare maturity. Two different percentage drops were considered for the two methods to make the absolute Y (each method has a different Y formula) drops similar.

Figure B.8 compares the logistic curves under status quo and modified maturity assumption. Models 19.1ba, 19.1ca, 19.2ba, and 19.2ca considered modified maturity curves.

Table B.2. Logistic model fit to maturity proportion by carapace size for various sample data by the Bent-Point and Cut-Line analyses. All fitted parameters were significant at p<0.05.

Data	Method	Size range (mm CL) for the fit	Logistic fit	L50 (mm CL)	Size range (mm CL) for hard cutoff for determining zero and one maturity probability
1984 NMFS chela data from WAG	Bent-Point analysis	80–130	$\ln\left(\frac{p}{1-p}\right) = -2.11028 + 0.021029CL$	100.35	Maturity probability 0 for crab < 80 and 1 for crab > = 160
1991 ADF&G chela data from EAG	ditto	80–130	$\ln\left(\frac{p}{1-p}\right) = -2.52221 + 0.023147CL$	109.00	ditto
2018 EAG chela data	ditto	80–125	$\ln\left(\frac{p}{1-p}\right) = -3.2426 + 0.02499CL$	129.77	ditto
2018 WAG chela data	ditto	80–130	$\ln\left(\frac{p}{1-p}\right) = -0.93899 + 0.011426CL$	82.20	ditto
2018 combined chela data	ditto	80–130	$\ln\left(\frac{p}{1-p}\right) = -2.1826 + 0.02161CL$	101.00	ditto
1984 NMFS chela data from WAG	Cut-Line analysis	70–105	$\ln\left(\frac{p}{1-p}\right) = -3.85751 + 0.036337CL$	106.20	Maturity probability 0 for crab < 80 and 1 for crab > = 160.
	ditto	88–122	$\ln\left(\frac{p}{1-p}\right) = -9.07713 + 0.089999CL$	100.86	ditto

1991 ADF&G chela data from EAG					
2018 EAG chela data	ditto	99–130	$\ln\left(\frac{p}{1-p}\right) = -11.3368 + 0.107873CL$	105.10	ditto
2018 WAG chela data	ditto	108–147	$\ln\left(\frac{p}{1-p}\right) = -9.89243 + 0.099041CL$	99.90	ditto
2018 combined chela data	ditto	119–133	$\ln\left(\frac{p}{1-p}\right) = -11.8139 + 0.117669CL$	100.40	ditto

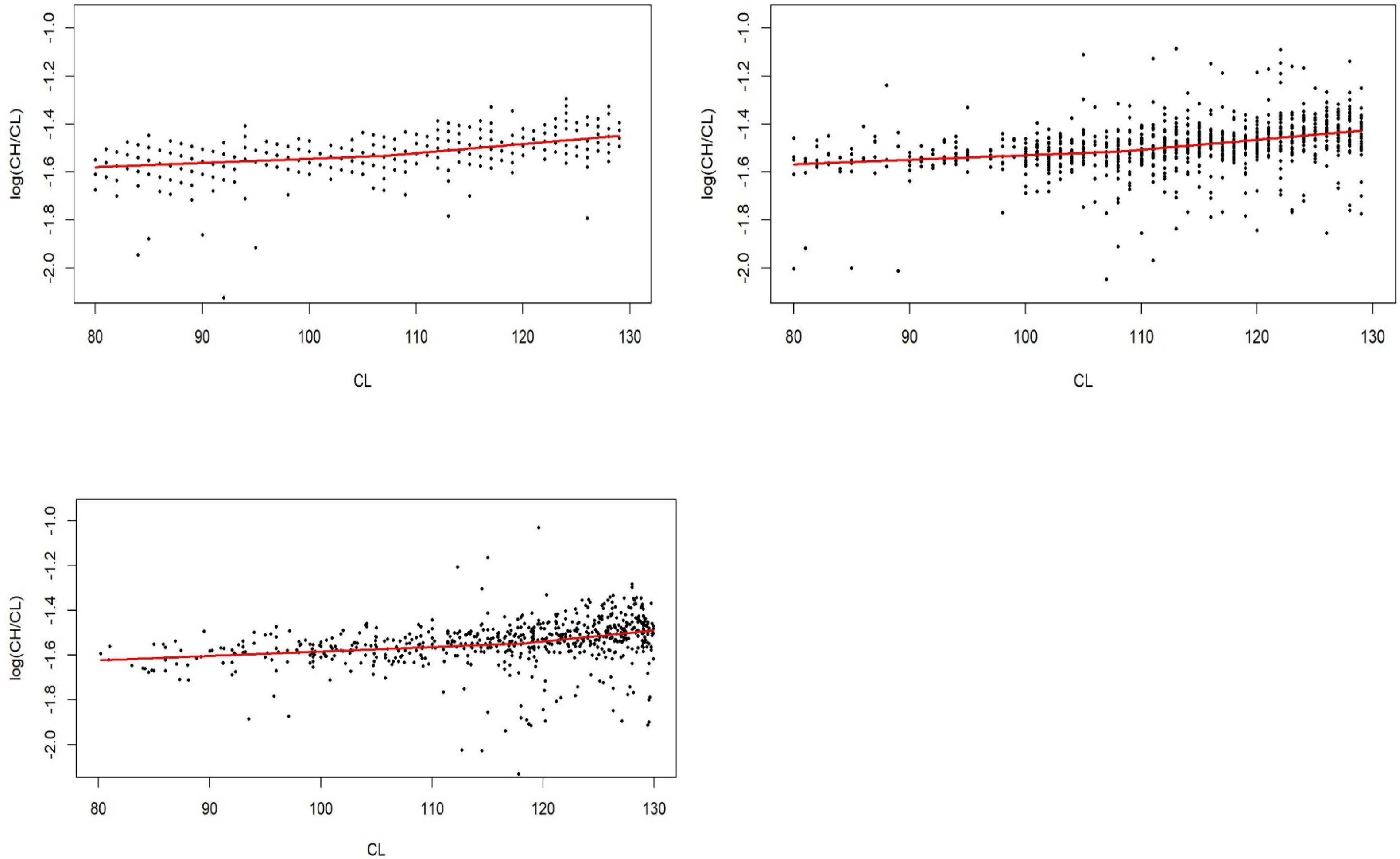


Figure B.3. Log (CH/CL) vs CL fits by the Bent-Point analysis on NMFS 1984 (left), ADF&G 1991 (right), and combined 2018/19 data (bottom left). The 80–130 mm CL range was considered for the Bent-point analysis. Logistic model was fitted to the mature proportion determined by the Bent-point analysis.

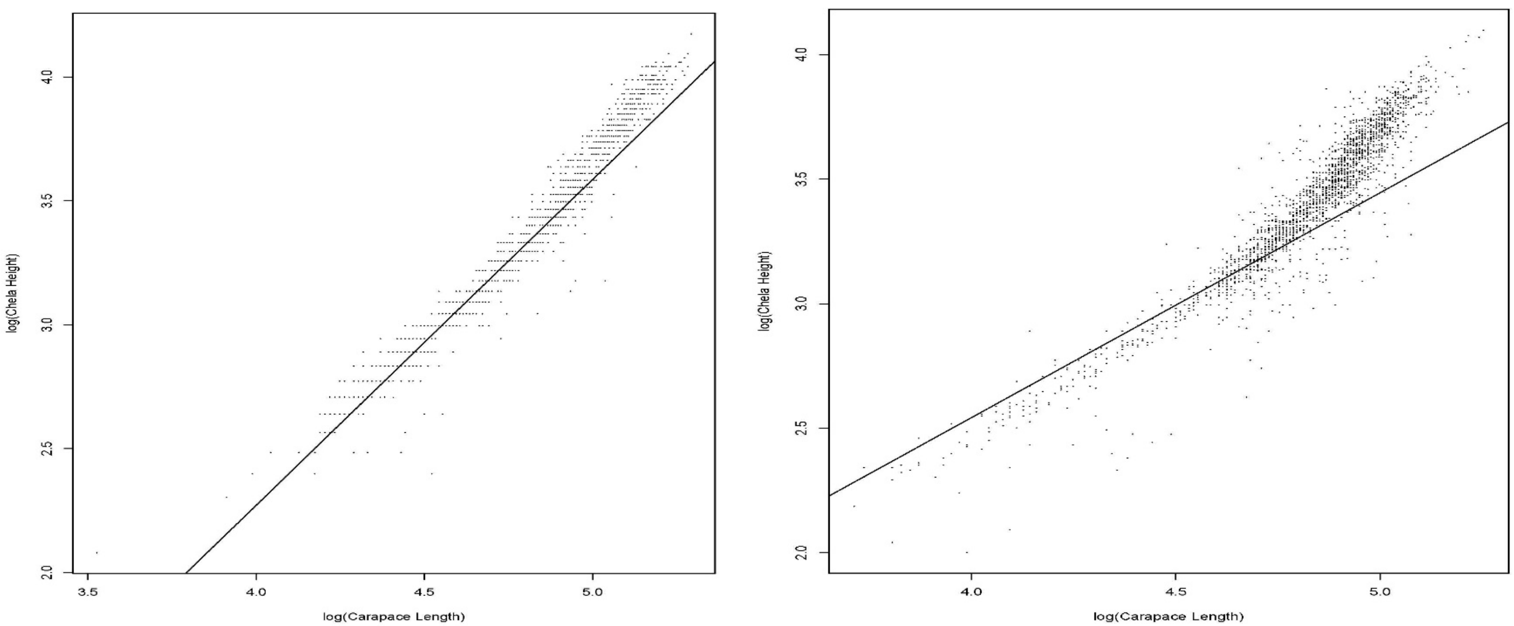


Figure B.4. NMFS 1984 data (left) and ADF&G 1991 data (right) for Cut-Line analysis followed by the logistic model fit. The 70–105 mm CL range for NMFS and 88–122 mm CL range for ADF&G data were considered in the analyses.

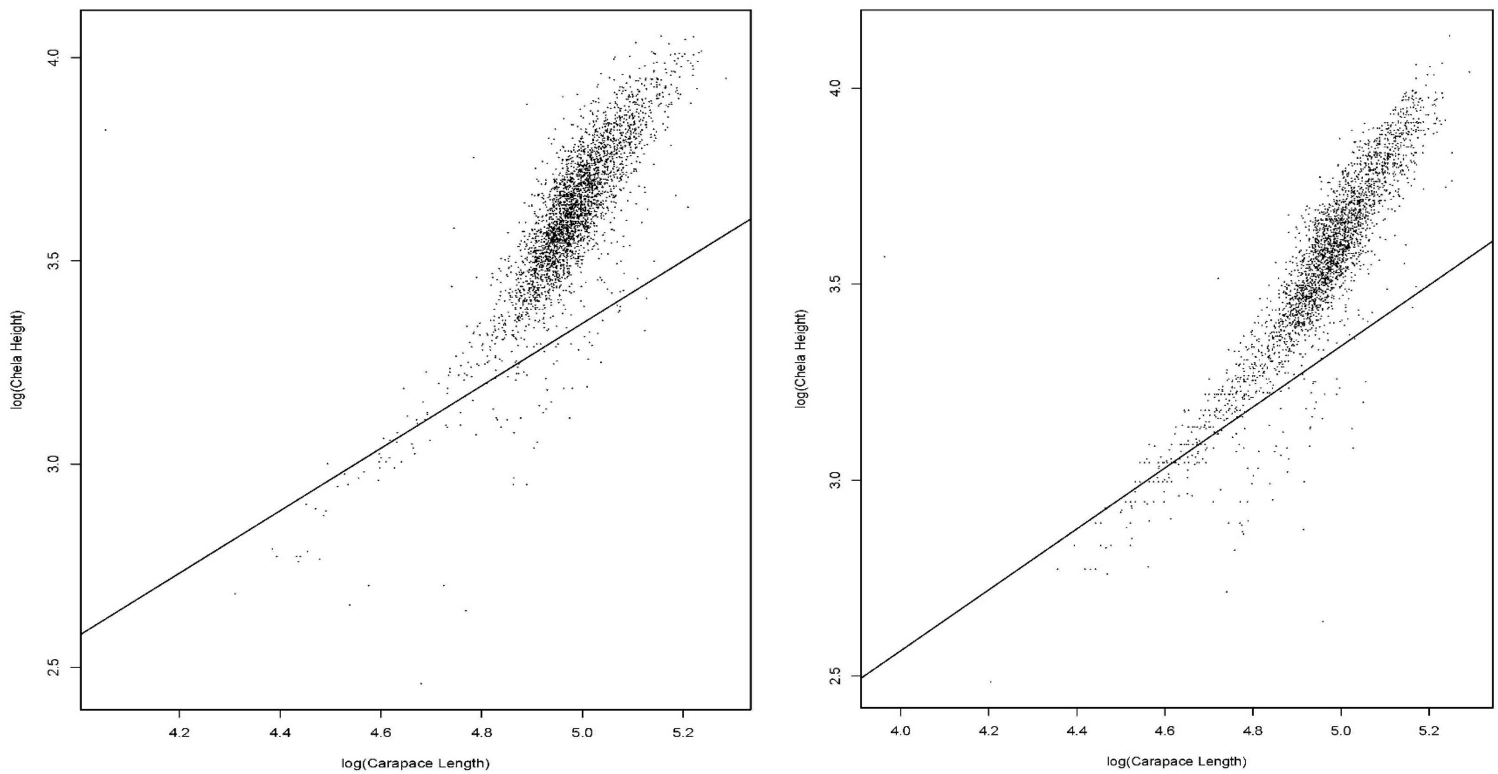


Figure B.5. EAG 2018 data (left) and WAG 2018 data (right) for Cut-Line analysis followed by the logistic model fit. The 99–130 mm CL range for EAG and 108–147 mm CL range for WAG were considered for analyses.

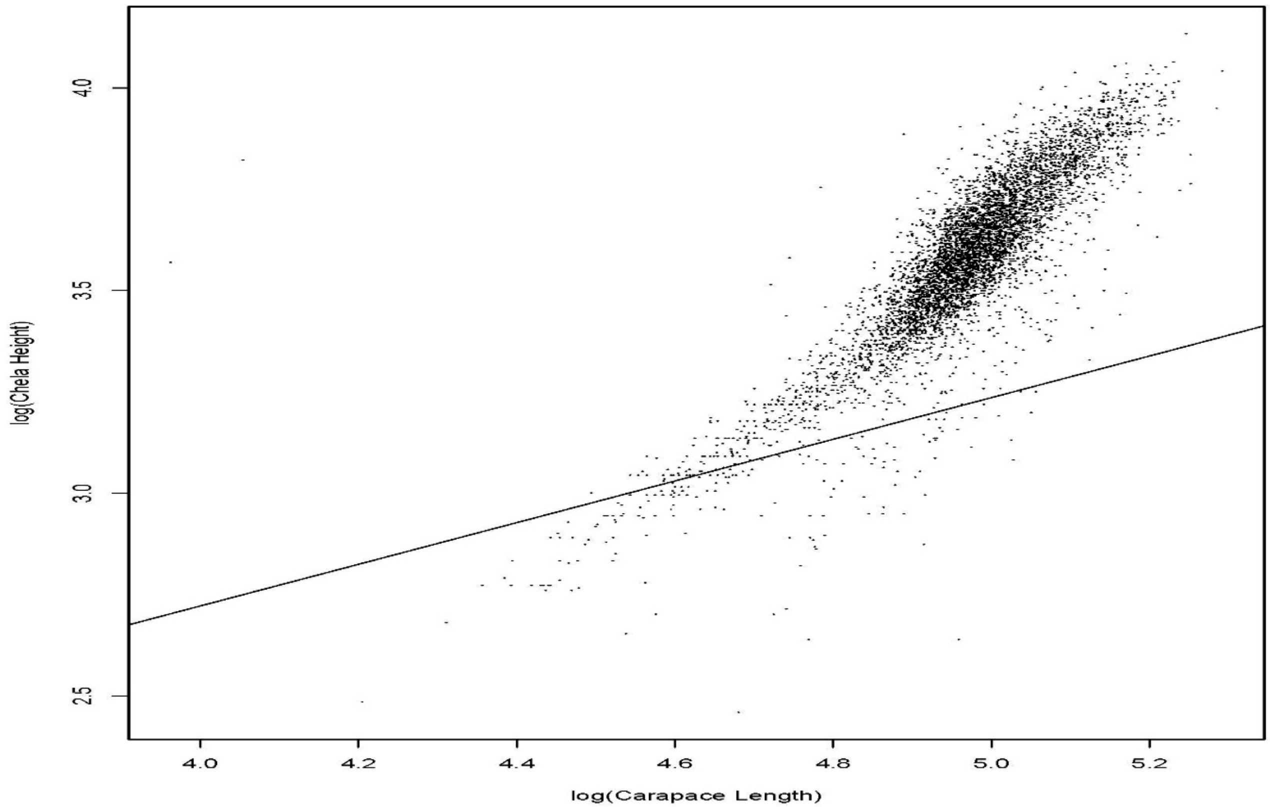


Figure B.6. Combined 2018 data for Cut-Line analysis followed by the logistic model fit. The 119–133 mm CL range for data analyses.

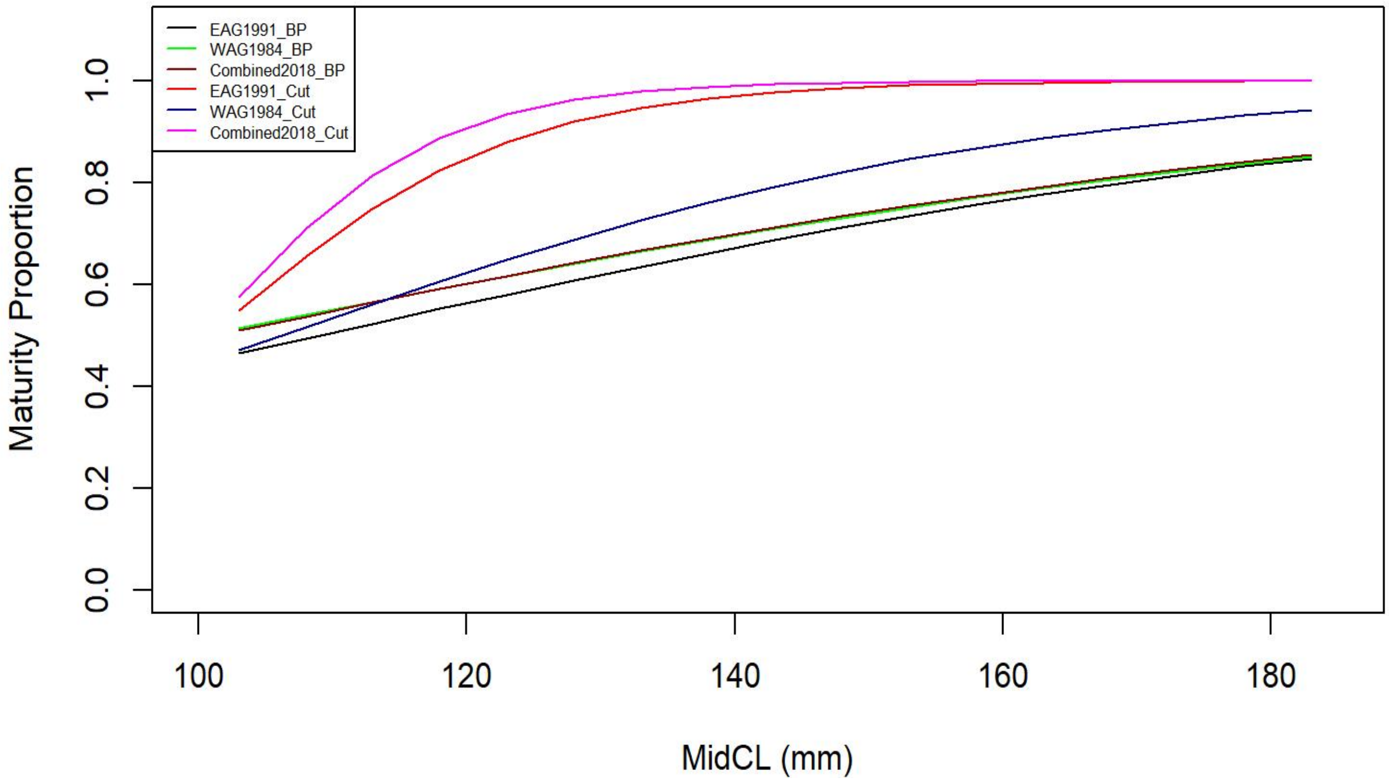


Figure B.7. Fitted logistic maturity curves for EAG 1991, WAG 1984, and combined 2018 data for the two methods of analyses: BP=Bent-Point and Cut: Cut-Line.

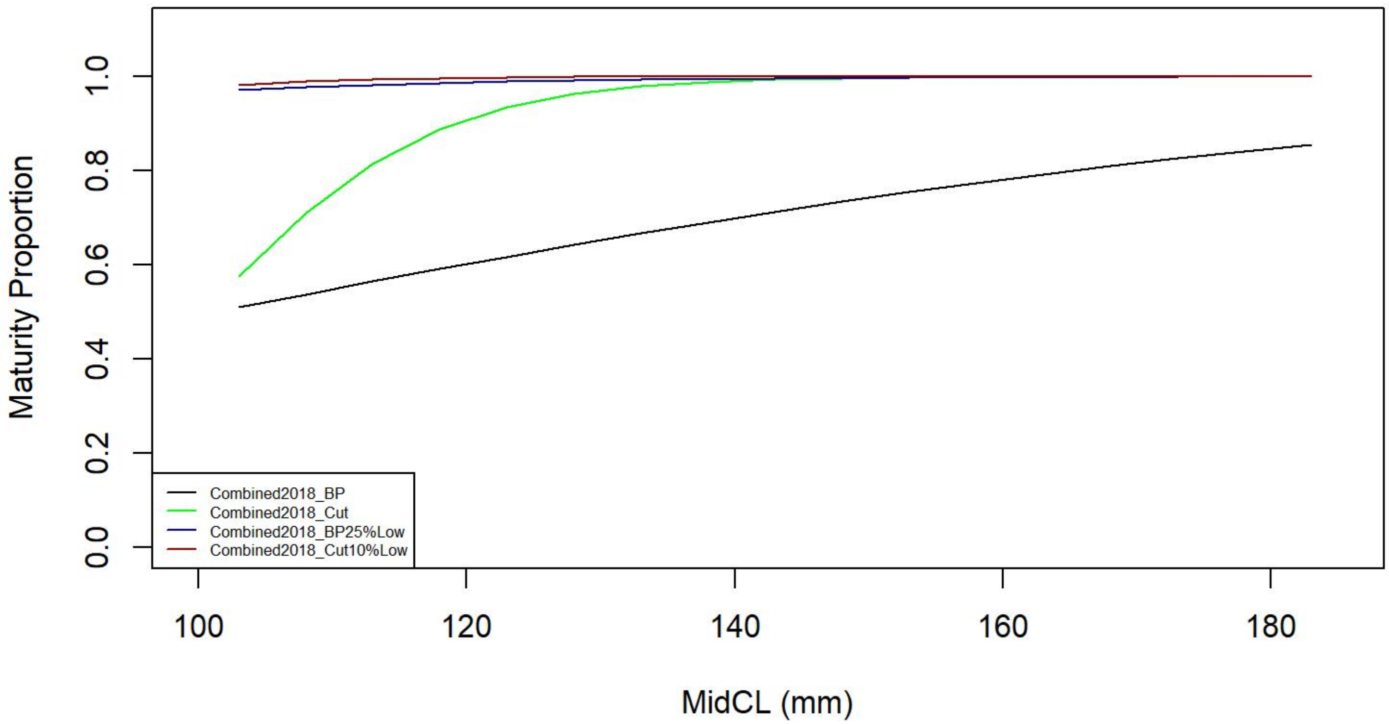


Figure B.8. Comparison of fitted logistic maturity curves for combined 2018 maturity data between two options of maturity assignment: (1) assigned mature when observed Y $\geq$ Bent-Point or Cut-Line (status quo) fitted lines and (2) declared mature when observed Y $\geq$ 25% below the fitted Bent-Point line or 10% below the fitted Cut-Line. BP=Bent-Point and Cut: Cut-Line.