Aleutian Islands Golden King Crab Model Scenarios for May 2022 Assessment

January 2022 DRAFT REPORT

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Preamble

In this report, we provide a set of model scenarios that could be selected for May 2022 assessment, and OFL and ABC determinations for the Aleutian Islands golden king crab stock. The scenarios are based on May 2021 CPT and June 2021 SSC recommendations. This document does not follow the standard SAFE document format. Standard SAFE document will be presented at the May 2022 CPT meeting.

Highlights:

1. Following May 2021 CPT and June 2021 SSC concerns on currently implemented CPUE standardization procedure,

   Several methodological improvements were made, including addressing the number of degrees of freedom in the smoothers and demonstrating spline fits to raw CPUE. Only statistically significant degrees of freedom were considered.

2. Further improvement on Year:Area interaction CPUE analysis was done (Appendix A).

   Inclusion of Year:Area interaction addresses the area shrinkage issue as a result of reduction in number of vessels during the post-rationalization period.

3. Three core models were formulated considering different CPUE standardization procedures (main effects CPUE, 21.1a; Year:Area interaction CPUE, 21.1b) and a different set of catchability and additional CVs (three catchability and additional CPUE standard errors, 21.1c). The May /June 2021 accepted model 21.1a was considered as the base model with a few modifications akin to Gmacs model formulation.
4. Three additional models were considered to address the effect of higher (knife-edge) maturity size on mature male abundance estimates and to oblige with a fishing industry request to investigate the effect of omitting one (underperforming) vessel on CPUE indices and reference points in WAG:

Model 21.1a2: Model21.1a + knife-edge maturity was changed from 111 mm carapace length (CL) to 116 mm CL (lower limits of the size bins in which actual size-at-maturity fell).
Model 21.1b2: Model21.1b + knife-edge maturity was changed from 111 mm CL to 116 mm CL.
Model 21.1d for WAG: Model21.1a + CPUE indices were estimated omitting one vessel.

5. EAG model 21.1a was modified to models 21.6 and 21_7 to implement in Gmacs. Comparison of some results are provided in Appendix E.

6. Following June 2021 SSC request,

Preliminary summary statistics, comparing RACE AIGKC Slope Survey indices with Observer CPUE indices, are presented in Appendix D to solicit CPT and SSC guidance on how to proceed with incorporating slope survey indices into golden king crab assessment model.

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 2021 CPT and June 2021 SSC meetings (Siddeek et al. 2021).

Input Data

- The input data presented at the May 2021 CPT meeting were updated after completion of the fisheries. Thus, the time series of data used in the model were retained catch (1981/82–2020/21), total catch (1990/91–2020/21), and groundfish bycatch (1989/90–2020/21) biomass and size compositions.
- Observer pot sample legal size crab CPUE data were standardized by the generalized linear model (GLM) with the negative binomial link function with variable selection by first CAIC (modified AIC) and followed by R square criterion, separately for 1995/96–2004/05 (pre-rationalization) and 2005/06–2020/21 (post-rationalization) periods. Fish ticket retained CPUE were standardized by the GLM with the negative binomial link functions for the 1985/86–1998/98 period (see Appendix A).
- A Year and Area interaction was considered in one model, 21.1b, to estimate a set of observer pot sample CPUE indices for the pre- and post-rationalization periods. Area was defined based on observer sample locations within 1nmi x 1nmi grids to reflect fishing footprints.
- The 2018/19–2020/21 male golden king crab chela height and carapace length measurement data were re-analyzed to update knife-edge maturity size estimates.

  Table A lists a brief description of various models analyzed in this report.

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 for all models except 21.1c; 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 and modeling consideration**	**Knife-edge Maturity Size (Lower limit of the size bin)**	**Period for mean number of recruit calculation for (a) initial equilibrium abundance composition and (b) reference points estimations**
21.1a (accepted model in May/June 2021, implemented with up to 2020/21 data)	Observer data from 1995/96–2020/21; fish ticket data from 1985/86–1998/99; two catchability and total selectivity for the 1960–2004 and 2005–2020 periods, one retention and groundfish bycatch selectivity; and observer and Fish Ticket CPUE standardization by negative binomial models.	111 mm CL	1987–2017
21.1a1	21.1a+ consider an *M* of 0.38yr^{-1} for years >1998 (to address the retrospective issue on EAG assessment)	111 mm CL	1987–2017
21.1b	21.1a+ consider observer CPUE standardized with Year:Area interaction.	111 mm CL	1987–2017
21.1c	21.1a+ consider three catchability and additional CPUE CVs (fish ticket: 1985-1994, observer: 1995–2004, and 2005–2020).	111 mm CL	1987–2017
21.1d	21.1a+ CPUE indices estimated omitting one vessel for WAG.	111 mm CL	1987–2017
21.1a2	21.1a+ higher knife-edge maturity	116 mm CL	1987–2017
21.1b2	21.1b+ higher knife-edge maturity	116 mm CL	1987–2017
21.6 & 21.7	21.1a (EAG)+ modified for Gmacs input.	111 mm CL	1987–2017

Response to May 2021 CPT comments

Comment 1:

> The analysis of the maturity data should be repeated using, for example, the methods of Olson et al. (2018) and Somerton and Macintosh (1983). The results of the analyses should be presented to the CPT.

Response:
The analysis was repeated following Olson et al.' s approach of directly fitting chela height against carapace length by the bend point analysis package available in R. The focus was determining the knife-edge maturity rather than establishing a maturity curve (details are in Appendix B).

Comment 2:

> Consider including the NMFS Aleutian Islands trawl survey as an additional index of abundance. The first step in this process should be to compare the depths at which the survey is conducted to those at which AI golden king crab are found/fished.

Response:
A preliminary comparison figures of NMFS Aleutian Islands trawl survey index of abundance vs observer CPUE index for comparable years and areas/depths was detailed in Appendix D. The purpose was to solicit the CPT and SSC advice on how to incorporate NMFS indices into GKC assessment model.

Comment 3:

The CPUE standardization for the post rationalization years:
○ explore why the index for the WAG is lower in the last three years based on area*year interactions;
○ explore why the index for the WAG is more precise in the earlier years based on area*year interactions; and
○ better justify the degrees of freedom for smooths and plot the smooths.

Response:
The CPUE standardization procedure was revamped with special attention given to selecting non-significant predictor variable coefficients in the final GLM models and ascertaining that the final models' predictor variables were non-collinear. In this process, several (above) concerns were addressed. The degrees of freedom of selected smoother variables had drastically reduced (details are in Appendix A).

*The predicted area*year interaction curve was compared with the input area*year interaction curve in a separate plot in Figure 17 for WAG. It indicated that the index was no more precise in early years than later years.*

Figures A.3 to A.6 in Appendix A depict the fit of smoothers to observed CPUE data for a range of Soak time values at a given set of fixed values of other predictor variables chosen in the final models separately for EAG and WAG. The smoothers in the final model appeared to adequately trace through raw CPUE data. For simplicity, the fits were shown for arbitrarily selected years.

Comment 4:

> The specifications of smooths when analyzing the cooperative survey should be selected using the survey data and not taken from analyses of other indices.

Response:
The cooperative survey data analysis was not taken up in this run. Will address this issue and follow the suggestion at the May2022 CPT.

Comment 5:

> The negative log likelihood for model 21.1b (three total selectivity) is larger than that for model 21.1a model even though model 21.1a is nested within model 21.1b. This should not be, perhaps this model optimized at a local minimum. Furthermore,
>
> Model 21.1b is unable to provide a better fit to the length-frequency data for the EAG. The reasons for the change in total length-frequency in recent years need to be better understood before new models were formulated. Edward Poulsen noted that the number of vessels in the EAG was less in recent years than before and that the higher CPUE areas tend to have higher abundance of smaller animals, which may be part of the reason for the change in the total length-frequency.

Response:
Previous model 21.1b was no longer considered in the current set of models. The same model name was used for Year:Area interaction CPUE model in the current analysis

Comment 6:

> 92% of the WAG TAC is taken at the time of the meeting. Adjusting the catches to reflect the final catch is not likely to impact the TAC set by the State (which is usually well below the ABC). However, future assessments should be based on the best projection of total catch when the season is not complete.

Response:

If this situation occurs for the 2021/22 season, we will consider the above recommendation in the assessment.

Comment 7:

> Progress towards further GMACS implementation for this stock is expected for the next cycle in 2022.

Response:
That is the plan. Current progress is presented in Appendix E.

Comment 8:

> Address SSC concerns that "how many years it takes crab recruited to the model to recruit to the fishery, i.e., size at first selectivity. This could inform the last year of the period to be included for mean R calculation.

Response:
We will address this issue at the May2022 CPT meeting.

Comment 9:

> Presentational
> - Correct the x-axis labeling in Fig. CPT2.
> - Colors should be used to distinguish observed and predicted length-frequencies in Figures 11-13. However, it would be better to use plots such as Figures 11-13 to show observed length-frequencies and plots of observed vs. predicted length-frequencies (with results shown for multiple models) shown individually by year.
> - The rationale for conducting separate assessments for the EAG and WAG should be integrated into the narrative of the assessment.
> - Avoid showing fits of models such as 21.1c to observed data used to fit different models.
> - Plot selectivity for all models on the same plot to better allow comparisons.
> - Use consistent y-axis ranges in similar figures – see Figure 12a (top panels do not go to 0 vs. bottom panels that do include 0).
> - Include page numbers in the review draft.
> - Increase line width in figures for easier viewing of model runs (e.g., Figures 14 and 32).

Response:

Several suggestions were followed in the current draft report. But the entire set of suggestions will be considered when presenting the final assessment in May 2022.

Response to June 2021 SSC comments

Comment 1:

SSC agreed to all the above CPT recommendations.

Response:

Please see responses to above CPT comments.

Furthermore,

Comment 2:

> For this year (2021), the CPT recommended continuing to apply a 25% buffer. The SSC instead recommends an increase to a 30% buffer from the maximum permissible ABC, based on: 1) the continued positive retrospective pattern in the EAG Model, 2) continued model convergence concerns indicating remaining parameter confounding (specifically, the jitter analysis for the 19.1 WAG model resulted in multiple solutions for MMB and B35% at identical total likelihood values), and 3) the CPUE series which included a year:area interaction indicated a steeper decline in recent years than the series used in model 21.1a (the model accepted for harvest specifications).

Response:
The issue of WAG model producing multiple solutions for MMB and B35% at identical likelihood values was resolved in the current jitter analysis of model 21.1a. Although the contribution of groundfish bycatch to total removal is small, the likelihood emphasis factor interfered with the optimization. In this run, a higher likelihood weight of 0.5 (instead of 0.2) was used and the model produced identical solutions for MMB, B35% and OFL at identical total likelihood values.

We will address other issues as soon as possible.

Comment 3:

> The author's rationale for continued use of two separate stock assessment models for the EAG and WAG is very helpful, and the SSC recognizes that this approach is reasonable. However, the SSC notes that sharing biological parameters and basic stock dynamics within a single assessment model that

> has two largely independent areas modelled simultaneously may help address recurrent convergence and estimation challenges. The SSC suggests that such an approach be considered further, as either a replacement for the current approach, or as part of a multi-model evaluation.

Response:
Because of time constraint, we plan to do this for the May/June 2022 CPT/SSC meetings.

Comment 4:

> The SSC did not find the logistic fit to the maturity predictions based on the chela height to carapace length relationship to be compelling and supports the CPT's recommendations for additional modelling. However, the SSC also notes that direct observational data on maturity may ultimately be needed to resolve this process and recommends holding studies or any other research be considered.

Response:
Logistic fit to maturity was not considered in this run but focused on improving the method of bend point analysis following other publications (e.g., Olson et al. 2018). We agree with SSC's observation that direct observational data on mating activity are needed to identify the true minimum size at first maturity.

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). Based on the new harvest strategy, the TACs were set to 2.96 million pounds for WAG and 3.65 million pounds for EAG for the 2020/21 fishery, and to 2.32 million pounds for WAG and 3.61 million pounds for EAG for the 2021/22 fishery.

The EAG and WAG stocks were modelled separately for several reasons:
(a) Fishery catch data (e.g., CPUE magnitude and CPUE temporal trends) suggest that the productivity is different between the two areas.
(b) WAG has wider area of stock distribution compared to limited area distribution in EAG.
(c) The fishing areas are spatially separated with an area gap between EAG and WAG (Siddeek *et al.* 2021). Regions of low fishery catch suggest that availability of suitable habitat may vary longitudinally.
(d) Tagging studies have shown little mixing between the two areas (Watson and Gish 2002).
(e) Currents are known to be strong around the Aleutian Islands, thus larval mixing between the two regions may occur. Yet needed data to confirm larval drift trajectories or horizontal displacement are lacking. Unlike other king crabs, golden king crab females carry large, yolk-rich, eggs, which hatch into lecithotrophic (non-feeding) larvae that do not require a pelagic distribution for encountering food items. Depth at larval release, the lecithotrophic nature of larvae, and swimming inactivity in lab studies implies benthic distributions, which may limit larval drift between areas if horizontal current velocities are reduced at depth.
(f) Integrating contrasting data in one single model may provide parameter estimates in between the two extremes which would not be applicable to either (Richards 1991; Schnute and Hilborn 1993).
(g) Area specific assessment is superior to a holistic approach for this stock because of patchy nature of golden king crab distribution.
h) Alaska Board of Fisheries decided to manage the two areas with separate total allowable catches.
i) Genetic analysis shows no significant differentiation between areas within the Aleutian Island population (Grant and Siddon 2018), thus there is no genetic support for subdividing this population; however, above listed factors support separate stock assessments in the two regions.

Analytic Approach

The underlying population dynamics model was male-only and length-based (Siddeek et al. 2021). This model combined 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. Tagging data were used to calculate the size transition matrix.

The observer and commercial fishery CPUE indices with GLM estimated standard errors and additional constant standard errors were used in the model fit. The additional constant errors were estimated by the model. 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 2005/06–2020/21. Three catchability and additional constant CPUE standard errors were also considered in one model, 21.1c.

The equilibrium abundance in 1960 was projected with natural mortality and annual recruitment to create the initial abundance by size at the start of the fishery in 1981. The R_0 for equilibrium abundance was determined using the average model estimated number of recruits for a selected period. The standardized CPUE indices, catch, and size composition information were used to determine the stock abundance trends in both regions. The observer and fish ticket CPUE indices were assumed to be linearly related to exploitable abundance. The M was kept constant at 0.21 yr^{-1}. The directed pot fishery discard mortality proportion was assumed 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})], and groundfish fishery selectivity at full selection for all length classes (i.e., selectivity = 1.0). Any discard of legal-sized males in the directed pot fishery was not explicitly modeled and assumed to be insignificant.

The numbers of vessel-days were considered as the initial input effective sample sizes (i.e., stage-1) for retained and total size compositions and numbers of trips for groundfish discard catch size composition without enforcing any upper limit. The groundfish size composition was not fitted in any model following an earlier CPT suggestion. The stage-2 effective sample sizes were estimated iteratively from stage-1 effective sample sizes by the Francis (2011) method for all models.

Various weighting factors were used for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. The retained catch biomass weight was set to an arbitrarily large value (500.0) because retained catches are more reliable than any other data sets. The total catch biomass weight was scaled in accordance with the observer annual pot sample sizes with a maximum of 250.0. The total catches were derived from observer nominal total CPUE and effort. In some years, observer sample sizes were low (Tables 3). A small groundfish bycatch weight was chosen based on the September 2015 CPT suggestion to lower its weight (0.2 for EAG and 0.5 for WAG). The best fit to groundfish bycatch data criteria was used to choose the lower weight for the groundfish bycatch. A higher weight for WAG groundfish bycatch likelihood was chosen to get the global maximum log likelihood in the jitter runs (see Appendix C). Note that groundfish bycatch of Aleutian Islands golden king crab was very low (Table 2). The CPUE weights were set to 1.0 for all models. The Burnham et al. (1987) suggested formula was used for ln(CPUE) [and ln(MMB)] variance estimation (formula given in Siddeek et al. 2021)). The CPUE index variances estimated from the negative binomial with additional constant variances appeared to have adequately fitted the model, as confirmed by the fit diagnostics (Fox and Weisberg 2011).

The AD Model Builder (Fournier et al. 2012) was used for model fitting.

Results

Model equations and weights for different data sets are provided in Siddeek et al. (2021). These weights (with the corresponding coefficient of variations) adequately fitted various data under integrated model setting. All models 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 crab by length. The length-weight relationship parameters were updated in 2020 using cooperative survey collected data during 2018/19 with a = $1.095*10^{-4}$, b = 3.35923. Furthermore, the crab weight in a size bin was calculated using Beyer's (1987) formula, which appropriately considers integration through lower (CL_l) limit to upper (CL_u) limit of a size bin:

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

The CPT/SSC/Council plan is to bring all crab assessment models into the generalized Gmacs framework. Some results from Gmacs implementation of model 21.1a for EAG were compared with that of the original 21.1a model in Appendix E.

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 (fish ticket) CPUE indices are provided in Table 4 for EAG and WAG. The CPUE index estimation methods and fits are described in Appendix A.
e. The parameter estimates with coefficient of variation for three models 21.1a (base), 21.1b, and 21.1c are summarized respectively in Tables 5 for EAG and 10 for WAG. The boundaries for parameter searches are also provided in those tables, and the estimates are within the bounds.

f. The mature male and legal male abundance time series for models 21.1a (base), 21.1b, and 21.1c are summarized in Tables 6, 7, and 8 for EAG and for models 21.1a (base), 21.1b, 21.1c, and 21.1d are summarized in Tables 11, 12, 13, and 14 for WAG.
g. The recruitment estimates for those model scenarios are summarized in Tables 6 to 8 for EAG and Tables 11 to 14 for WAG.
h. The likelihood component values and the total likelihood values for models 21.1a, 21.1b, 21.1c, 21.1a2, and 21.1b2 are summarized in Table 9 for EAG and for models 21.1a, 21.1b, 21.1c, 21.1d, 21.1a2, and 21.1b2 are summarized in Table 15 for WAG.
i. The Tier level, $MMB_{35\%}$, current MMB, current $MMB/MMB_{35\%}$, M, F_{OFL}, $F_{35\%}$, OFL, and ABC (under 25% and 30% buffers) for EAG, WAG, and the entire Aleutian Islands (AI) are listed in Table 16 (models 21.1a, 21.1b, 21.1c, 21.1d, 21.1a2, and 21.1b2 for WAG; and 21.1a, 21.1b, 21.1c, 21.1a2, and 21.1b2 for EAG). The status of the stock in EAG is estimated to be in Tier 3a for all models except model 21.1c whereas the status of the stock in WAG is determined to be in Tier 3b for all models. The respective reference points are added disregarding the stock status to estimate the reference points for the entire AI.

Graphs of estimates

a. The retained length composition fits are provided in Figures 3a, 3b, and 3c for EAG and Figures 13a, 13b, and 13c for WAG, total length composition fits in Figures 4a, 4b, and 4c for EAG and Figures 14a, 14b, and 14c for WAG, and groundfish discarded catch length composition fits in Figures 5a, 5b, and 5c for EAG and Figures 15a, 15b, and 15c for WAG for 21.1a, 21.1b, and 21.1c models, respectively. The retained and total catch size composition fits appear satisfactory for most years but the fits to groundfish bycatch size compositions are bad.
b. The pre- and post-rationalization periods' total and retained selectivity curves are provided in Figure 6 for EAG and Figure 16 for WAG for 21.1a, 21.1b, and 21.1c models. Total selectivity for the pre-rationalization period is used in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis, indicating that all size groups are vulnerable to this gear. This is also shown in the size compositions of groundfish bycatch (Figures 5 a-c and 15 a-c).
c. The CPUE fits by 21.1a, 21.1b, and 21.1c models are provided in Figure 7 for EAG and CPUE fits by 21.1a, 21.1b, 21.1c, and 21.1d models are given in Figure 17 for WAG. The CPUE trend of model 21.1c differed from those of other models in both management areas.
d. The recruitment trends for 21.1a, 21.1b, and 21.1c model fits are shown in Figure 8 for EAG and that for 21.1a, 21.1b, 21.1c, and 21.1d model fits are given in Figure 18 for WAG. The recruitment pulse peaked in 1988 and was high during 2016–2019 for all model fits in EAG. On the other hand, large recruitment pulses occurred during 1984–1989 but stabilized in recent years for all model fits in WAG.
e. The fits to retained catch, total catch, and groundfish discarded catch by 21.1a, 21.1b, and 21.1c models are provided in Figure 9 for EAG and that by 21.1a, 21.1b, 21.1c, and 21.1d models are given in Figure 19 for WAG. The retained and ground fish bycatch fits are adequate, but the total catch fits showed some discrepancy.
f. The fits to pre–1985 retained catches by 21.1a, 21.1b, and 21.1c models are shown in Figure 10 for EAG and that by 21.1a, 21.1b, 21.1c, and 21.1d models are given in Figure

20 for WAG. All models adequately fitted the 1981/82–1984/85 retained catches in both areas.

g. Pot fishery total fishing mortality (F) plots for 21.1a, 21.1b, and 21.1c models for EAG (left) and for 21.1a, 21.1b, 21.1c, and 21.1d models for WAG (right) are shown in Figure 11. The F values increased during 1988–1992 and 1995 and systematically declined thereafter in the EAG. Slight increases in F were observed from 2015 to 2019, followed by a decline in 2020 in the EAG. On the other hand, the F in the WAG increased in 1986–1992 and 1994–2001, declined in late 2000s, and slightly increased in 2019 and 2020.
h. The MMB trends for 21.1a, 21.1b, and 21.1c models for EAG (left) and that for 21.1a, 21.1b, 21.1c, and 21.1d models for WAG (right) are shown in Figure 12. The MMB plots for the long time series (1960/61–2020/21) is shown at the top and for the short time series (2005/06–2020/21) is depicted at the bottom. The MMB systematically increased since 2017 in the EAG, but the increase was mild in the WAG.
i. The retrospective pattern of MMB has been an issue for EAG. It is investigated by comparing the status quo model (i.e., 21.1a) retrospective trends of MMB with that of higher *M* model (21.1a1) and different catchability and additional CPUE standard error model (21.1c). Model 21.1a1 assumes a high *M* of 0.38yr^{-1} (Siddeek et al. 2002) for years >1998. The six-year retrospective patterns for models 21.1a, 21.1a1, and 21.1c for EAG are compared in Figure 21. The Mohn rho values for the three models ranged from 0.4011 to 0.5092 with the lowest value determined by model 21.1a1. These values suggest that there is no significant improvement achieved in the retrospective patterns over the base model.

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, 0.21 (yr^{-1}).
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 2005/06–2020/21 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 period 1987– 2017.
f. Model estimated groundfish bycatch mortality values are averaged for the period 2011/12 – 2020/21 (10 years).
g. Knife-edge minimum maturity size of 111 mm CL is used for MMB estimation for all models except 21.1a2 and 21.1b2, which considered 116 mm CL.

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 estimated recruits for a selected period.

Specification of the OFL:
We determined F_{OFL} using the following equation with an iterative procedure accounting for intervening total crab catch removals. The formula for removal of catches and groundfish discards are given in Siddeek et al. (2021).

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

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

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

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

$F_{OFL} = 0.$

where α is a parameter, $\text{MMB}_{\text{current}}$ is the mature male biomass in the current year, and $MMB_{35\%}$ is the proxy MMB_{MSY} for Tier 3 stocks. We set α at 0.1.

Calculation of ABC:
The cumulative probability distribution of OFL, assuming a log normal distribution of OFL, was used to estimate OFL at the 0.5 probability and the ABC using 25% and 30% buffers on estimated OFL.

The OFL and ABC estimates for various models under Tier 3 are summarized separately for EAG, WAG, and the entire Aleutian Islands (AI) in Table 16.

Acknowledgments

We thank CPT and SSC members, Kodiak and Dutch Harbor ADF&G staff and industry personnel for various technical and data input. We appreciate Tyler Jackson's review of the maturity analysis Appendix B.

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

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

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

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

Note:

[a] Includes deadloss.

[b] Number of crab per pot lift.

[c] Average weight of landed crab, including dead loss.

[d] Managed with 6.5" carapace width (CW) minimum size limit.

[e] Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.

[f] Managed with 6.0" minimum size limit.

Catch and effort data include cost recovery fishery.

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

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

2013/14	1,546	1,347	113	174	5	7	1,665	1,528	3,192
2014/15	1,554	1,217	127	175	9	5	1,691	1,397	3,088
2015/16	1,590	1,139	165	157	23	2	1,778	1,298	3,076
2016/17	1,578	1,015	203	145	101	4	1,882	1,164	3,046
2017/18	1,571	1,014	219	126	47	2	1,837	1,142	2,979
2018/19	1,830	1,135	240	140	24	3	2,094	1,278	3,372
2019/20	2,031	1,288	275	112	18	6	2,327	1,406	3,733
2020/21	1,733	1,267	241	147	40	17	2,014	1,431	3,444

Table 3. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), total pot fishing effort (number of pot lifts), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index (for non-interaction model 21.1a) for the EAG and WAG golden king crab stocks, 1985/86–2020/21. Observer retained CPUE includes retained and non-retained legal-size crabs.

Year	**Pot Fishery Nominal Retained CPUE**		**Obs. Nominal Retained CPUE**		**Obs. Nominal Total CPUE**		**Pot Fishery Effort (no.pot lifts)**		**Obs. Sample Size (no.pot lifts)**		**Obs. CPUE Index**	
	EAG	**WAG**	**EAG**	**WAG**	**EAG**	**WAG**	**EAG**	**WAG**	**EAG**	**WAG**	**EAG**	**WAG**
1985/86	11.90	11.90					117,718	118,563				
1986/87	8.42	7.32					155,240	277,780				
1987/88	7.03	7.15					146,501	160,229				
1988/89	7.52	7.93					155,518	166,409				
1989/90	8.49	7.83					155,262	202,541				
1990/91	8.90	7.00	6.84	8.34	13.00	26.67	106,281	108,533	138	340		
1991/92	8.20	7.40	9.84	6.14	36.91	19.17	133,428	101,429	377	857		
1992/93	8.40	5.90	10.44	4.26	38.52	16.83	133,778	69,443	199	690		
1993/94	7.80	4.40	5.91	12.75	20.81	17.23	106,890	127,764	31	174		
1994/95	5.90	4.10	4.66	6.62	12.91	19.23	191,455	195,138	127	1,270		
1995/96	5.90	4.70	6.03	6.03	16.98	14.28	177,773	115,248	6,388	5,598	0.71	1.00
1996/97	6.50	6.10	6.02	5.90	13.81	13.54	113,460	99,267	8,360	7,194	0.72	0.93
1997/98	7.30	6.60	7.99	6.72	18.25	15.03	106,403	86,811	4,670	3,985	0.80	0.99
1998/99	8.90	11.40	9.82	9.43	25.77	23.09	83,378	35,975	3,616	1,876	0.95	1.07
1999/00	9.00	6.30	10.28	6.09	20.77	14.49	79,129	107,040	3,851	4,523	0.93	0.92
2000/01	9.90	7.00	10.40	6.46	25.39	16.64	71,551	101,239	5,043	4,740	0.88	0.80
2001/02	11.70	6.50	11.73	6.04	22.48	14.66	62,639	105,512	4,626	4,454	1.18	0.86
2002/03	12.40	8.40	12.70	7.47	22.59	17.37	52,042	78,979	3,980	2,509	1.33	0.97
2003/04	10.90	10.20	11.34	9.33	19.43	18.17	58,883	66,236	3,960	3,334	1.16	1.28
2004/05	18.30	12.10	18.34	11.14	28.48	22.45	34,848	56,846	2,206	2,619	1.74	1.30
2005/06	25.40	21.20	29.52	23.89	38.55	36.23	24,569	30,116	1,193	1,365	0.97	1.18
2006/07	24.80	19.60	25.13	23.93	33.39	33.47	26,195	26,870	1,098	1,183	0.81	1.15
2007/08	28.00	20.00	31.10	21.01	40.38	32.46	22,653	29,950	998	1,082	0.90	1.00
2008/09	27.30	22.40	29.97	24.50	38.23	38.16	24,466	26,200	613	979	0.88	1.17
2009/10	25.90	23.70	26.60	26.54	35.88	34.08	26,298	26,489	408	892	0.72	1.24
2010/11	26.00	20.90	26.40	22.43	37.10	29.05	25,851	29,994	436	867	0.75	1.08
2011/12	37.30	23.40	39.48	23.63	52.04	31.13	17,915	26,326	361	837	1.08	1.11
2012/13	33.02	20.57	37.82	22.88	47.57	30.76	20,827	32,716	438	1,109	1.04	1.09
2013/14	33.67	16.42	35.94	16.89	46.16	25.01	21,388	41,835	499	1,223	1.01	0.82
2014/15	42.29	15.29	47.01	15.25	60.00	22.67	17,002	41,548	376	1,137	1.33	0.73
2015/16	39.41	14.97	43.27	15.81	58.68	22.14	19,376	41,108	478	1,296	1.26	0.75
2016/17	32.45	14.29	36.89	16.65	52.82	24.41	24,470	38,118	617	1,060	1.06	0.86
2017/18	31.46	16.81	35.18	19.30	54.62	25.54	25,516	30,885	585	760	1.01	0.99
2018/19	36.80	19.83	41.57	22.90	62.97	30.69	25,553	29,156	475	688	1.23	1.21
2019/20	34.11	15.10	40.88	16.30	57.46	22.73	30,998	42,963	540	967	1.15	0.98
2020/21	30.00	14.61	36.15	15.71	57.21	22.82	30,072	46,701	567	1,137	1.05	0.86

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 Negative Binomial CPUE Index**	**Standard Error of ln (CPUE)**	**WAG Negative Binomial CPUE Index**	**Standard Error of ln (CPUE)**
1985/86	1.58	0.19	1.37	0.10
1986/87	0.58	0.57	1.56	0.08
1987/88	0.79	0.50	1.05	0.08
1988/89	1.60	0.16	1.49	0.04
1989/90	0.78	0.14	1.15	0.03
1990/91	1.15	0.15	0.90	0.04
1991/92	1.08	0.12	0.81	0.04
1992/93	0.79	0.15	0.65	0.04
1993/94	1.28	0.13	0.77	0.06
1994/95	0.94	0.11	0.86	0.04
1995/96	0.54	0.16	0.97	0.04
1996/97	0.89	0.11	0.90	0.03
1997/98	1.47	0.11	0.84	0.03
1998/99	1.30	0.10	1.16	0.04

Table 5. Parameter estimates and coefficient of variations (CV) with the 2020 MMB (MMB estimated on 15 Feb 2021) for models 21.1a, 21.1b, and 21.1c for the golden king crab data from the EAG, 1985/86–2020/21. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Model 21.1a		Model 21.1b		Model 21.1c		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.53	0.01	2.53	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-9.78	0.18	-9.77	0.18	-9.77	0.18	-12.0,-5.0
log_a (molt prob. slope)	-2.56	0.02	-2.56	0.02	-2.57	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.94	0.001	4.94	0.001	4.94	0.001	3.869,5.05
σ (growth variability std)	3.68	0.03	3.68	0.03	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.44	0.02	3.44	0.02	3.44	0.02	0.,4.4
log_ total sel deltaθ, 2005–19	2.97	0.02	2.98	0.02	2.99	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–19	1.86	0.02	1.86	0.02	1.86	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.88	0.002	4.88	0.002	4.88	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–19	4.92	0.002	4.92	0.002	4.92	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–19	4.92	0.0003	4.92	0.0003	4.92	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.01	0.14	-1.02	0.14	-1.02	0.14	-12.0, 12.0
Logq1 (fishery catchability 1985–04)					-0.63	16132.31	-9.0, 2.25
logq2 (fishery catchability 1985–04 / observer catchability 1995–04)	-0.49	0.19	-0.50	0.17	-0.52	0.16	-9.0, 2.25
logq3 (observer catchability 2005–20)	-0.83	0.14	-0.72	0.16	-0.56	0.17	-9.0, 2.25
log_mean_rec (mean rec.)	1.04	0.04	1.02	0.04	1.01	0.04	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.99	0.07	-0.97	0.07	-0.95	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.32	0.08	-9.30	0.08	-9.28	0.08	-15.0, -1.6
σ_e^2 (Fishery CPUE additional log standard deviation, 1985–1998)	-1.09	0.25	-1.07	0.25	-1.46	0.17	-8.0, 1.0

σ_e^2 (observer CPUE additional log standard deviation, 1995–2004)					-2.09	0.12	-8.0,0.15
σ_e^2 (observer CPUE additional log standard deviation, 2005–2020)	-1.61	0.11	-3.39	0.91	-1.10	0.23	-8.0,0.15
2020 MMB	12,561	0.20	10,820	0.20	8,280	0.26	

Table 6. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1a for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961–2021 are restricted to 1985–2020. 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}=25,859 $MMB_{35\%}$=9,250			
1985	2.60	10,380	0.03	10,335	0.05
1986	1.52	7,932	0.03	8,707	0.04
1987	4.39	7,446	0.04	6,769	0.04
1988	9.97	8,536	0.04	5,739	0.04
1989	2.41	6,976	0.05	5,038	0.05
1990	4.42	6,974	0.04	4,737	0.06
1991	5.77	7,214	0.04	5,024	0.06
1992	3.75	6,857	0.04	4,811	0.05
1993	3.16	7,086	0.03	4,760	0.05
1994	3.87	6,570	0.03	5,300	0.03
1995	3.50	5,760	0.04	4,807	0.03
1996	3.11	5,802	0.04	4,079	0.04
1997	4.24	6,112	0.04	4,189	0.04
1998	3.88	6,672	0.05	4,256	0.05
1999	3.78	7,386	0.05	4,699	0.05
2000	3.63	8,027	0.05	5,404	0.05
2001	2.62	8,351	0.06	6,071	0.06
2002	3.14	8,746	0.06	6,671	0.06
2003	2.70	9,028	0.07	7,093	0.07
2004	2.16	9,018	0.07	7,418	0.07
2005	2.89	9,092	0.07	7,617	0.07
2006	2.46	9,169	0.07	7,549	0.08
2007	2.32	9,119	0.07	7,596	0.08
2008	3.27	9,267	0.07	7,644	0.08
2009	2.50	9,437	0.06	7,562	0.08
2010	2.03	9,265	0.06	7,754	0.07
2011	2.42	9,004	0.06	7,845	0.07
2012	2.26	8,718	0.06	7,613	0.07
2013	1.93	8,237	0.06	7,319	0.06
2014	2.94	8,016	0.07	6,955	0.07
2015	3.55	8,216	0.07	6,520	0.07
2016	3.54	8,637	0.09	6,345	0.08
2017	4.30	9,433	0.10	6,590	0.09
2018	5.51	10,661	0.13	7,126	0.10
2019	4.44	11,716	0.17	7,830	0.13
2020	3.22	12,561	0.20	8,891	0.17

Table 7. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1b for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961–2021 are restricted to 1985–2020. 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}=25,511 $MMB_{35\%}$=9,177			
1985	2.60	10,384	0.03	10,315	0.05
1986	1.50	7,932	0.03	8,704	0.04
1987	4.41	7,447	0.04	6,772	0.04
1988	10.00	8,549	0.04	5,738	0.04
1989	2.38	6,986	0.05	5,039	0.05
1990	4.42	6,978	0.04	4,744	0.06
1991	5.78	7,220	0.04	5,028	0.06
1992	3.75	6,865	0.04	4,812	0.05
1993	3.15	7,091	0.03	4,764	0.05
1994	3.87	6,573	0.03	5,304	0.03
1995	3.52	5,769	0.04	4,809	0.03
1996	3.12	5,820	0.04	4,081	0.04
1997	4.23	6,129	0.04	4,199	0.04
1998	3.85	6,675	0.05	4,272	0.05
1999	3.76	7,373	0.05	4,709	0.05
2000	3.57	7,984	0.05	5,399	0.05
2001	2.60	8,276	0.06	6,047	0.06
2002	3.20	8,679	0.06	6,615	0.06
2003	2.71	8,984	0.06	7,018	0.06
2004	2.18	8,991	0.07	7,361	0.07
2005	2.90	9,084	0.06	7,580	0.07
2006	2.50	9,184	0.06	7,532	0.07
2007	2.34	9,160	0.06	7,596	0.07
2008	3.18	9,289	0.06	7,668	0.07
2009	2.36	9,380	0.06	7,604	0.07
2010	1.99	9,140	0.06	7,756	0.07
2011	2.37	8,840	0.06	7,766	0.06
2012	2.16	8,502	0.05	7,480	0.06
2013	1.86	7,967	0.06	7,147	0.06
2014	2.88	7,708	0.06	6,732	0.06
2015	3.32	7,816	0.06	6,253	0.06
2016	3.34	8,099	0.07	6,034	0.07
2017	3.95	8,701	0.09	6,170	0.08
2018	4.81	9,555	0.12	6,563	0.09
2019	3.98	10,191	0.17	7,032	0.12
2020	3.16	10,820	0.20	7,692	0.17

Table 8. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1c for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961–2021 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

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}=25,224 $MMB_{35\%}$=9,056			
1985	2.59	10,418	0.03	10,354	0.05
1986	1.49	7,957	0.03	8,745	0.04
1987	4.47	7,484	0.04	6,804	0.04
1988	9.95	8,580	0.04	5,763	0.04
1989	2.36	7,019	0.05	5,075	0.05
1990	4.38	6,999	0.04	4,785	0.06
1991	5.75	7,230	0.04	5,064	0.06
1992	3.75	6,874	0.04	4,836	0.05
1993	3.15	7,098	0.03	4,779	0.05
1994	3.87	6,580	0.03	5,315	0.03
1995	3.52	5,776	0.04	4,817	0.03
1996	3.12	5,825	0.04	4,090	0.04
1997	4.21	6,127	0.04	4,206	0.04
1998	3.81	6,655	0.05	4,277	0.05
1999	3.77	7,341	0.05	4,704	0.05
2000	3.59	7,958	0.05	5,376	0.05
2001	2.58	8,251	0.06	6,019	0.06
2002	3.14	8,631	0.06	6,595	0.06
2003	2.68	8,908	0.06	6,992	0.06
2004	2.16	8,896	0.07	7,309	0.07
2005	2.87	8,976	0.06	7,503	0.07
2006	2.45	9,058	0.06	7,442	0.07
2007	2.29	9,008	0.06	7,495	0.07
2008	3.15	9,117	0.06	7,548	0.07
2009	2.35	9,203	0.06	7,458	0.07
2010	1.95	8,958	0.06	7,598	0.07
2011	2.29	8,634	0.05	7,605	0.06
2012	2.11	8,269	0.05	7,310	0.06
2013	1.83	7,721	0.05	6,952	0.06
2014	2.78	7,429	0.06	6,516	0.06
2015	3.26	7,496	0.07	6,023	0.06
2016	3.13	7,696	0.08	5,765	0.07
2017	3.71	8,156	0.11	5,856	0.08
2018	4.37	8,776	0.16	6,145	0.11
2019	3.64	9,134	0.22	6,456	0.15
2020	3.09	8,280	0.26	6,863	0.22

Table 9. Negative log-likelihood values of the fits for models 21.1a (base), 21.1b, 21.1c, 21.1a2, and 21.1b2 for golden king crab in the EAG. Likelihood components with zero entry in the entire rows are omitted.

Likelihood Component	**21.1a**	**21.1b**	**21.1c**	**21.1a2**	**21.1b2**
Number of free parameters	152	152	154	152	152
Retlencomp	-2090.3300	-2099.7800	-2101.0800	-2090.3300	-2099.7800
Totallencomp	-1508.7500	-1506.4100	-1505.6600	-1508.7500	-1506.4100
Observer cpue	-28.7077	-30.9382	-25.7316	-28.7077	-30.9382
Fishery cpue	-15.1798	-15.0393	-13.3399	-15.1798	-15.0393
RetdcatchB	8.4172	8.4805	8.3674	8.4172	8.4805
TotalcatchB	24.4882	24.4759	24.4362	24.4882	24.4759
GdiscdcatchB	0.0003	0.0002	0.0002	0.0003	0.0002
Rec_dev	28.7325	28.2168	27.4714	28.7325	28.2168
Pot F_dev	0.0131	0.0130	0.0131	0.0131	0.0130
Gbyc_F_dev	0.0271	0.0274	0.0279	0.0271	0.0274
Tag	2690.4200	2690.4800	2690.5800	2690.4200	2690.4800
RetcatchN	0.0083	0.0079	0.0074	0.0083	0.0079
Total	-890.8550	-900.4620	-894.9110	-890.8550	-900.4620

Table 10. Parameter estimates and coefficient of variations (CV) with the 2020 MMB (MMB estimated on 15 Feb 2021) for models 21.1a, 21.1b, 21.1c, and 21.1d for the golden king crab data from the WAG, 1985/86–2020/21. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Model 21.1a		Model 21.1b		Model 21.1c		Model 21.1d		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.53	0.01	2.53	0.01	2.52	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-8.55	0.20	-8.62	0.20	-8.59	0.20	-8.79	0.20	-12.0-5.0
log_a (molt prob. slope)	-2.69	0.03	-2.69	0.03	-2.69	0.03	-2.67	0.03	-4.61,-1.39
log_b (molt prob. L50)	4.94	0.001	4.94	0.001	4.94	0.001	4.93	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	3.42	0.01	3.43	0.01	3.41	0.01	3.45	0.01	0.,4.4
log_ total sel deltaθ, 2005–19	2.88	0.02	2.88	0.02	2.91	0.02	2.86	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–19	1.81	0.02	1.81	0.02	1.80	0.02	1.81	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.91	0.002	4.92	0.002	4.91	0.002	4.92	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–19	4.91	0.001	4.91	0.001	4.91	0.001	4.90	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985–19	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.)	-1.02	0.13	-1.01	0.13	-1.04	0.13	-1.00	0.13	-12.0, 12.0
Logq1 (fishery catchability 1985–04)					-3.38	3952.89			-9.0, 2.25
logq2 (fishery catchability 1985–04 / observer catchability 1995–04)	0.11	0.68	0.11	0.80	-0.13	0.56	0.25	0.39	-9.0, 2.25
logq3 (observer catchability 2005–20)	-0.43	0.21	-0.42	0.24	-0.24	0.32	-0.50	0.18	-9.0, 2.25
log_mean_rec (mean rec.)	0.95	0.04	0.95	0.04	0.94	0.04	0.97	0.04	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.74	0.08	-0.73	0.08	-0.72	0.08	-0.77	0.08	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.56	0.09	-8.55	0.09	-8.53	0.09	-8.58	0.09	-15.0, -1.6
σ_e^2 (fishery CPUE additional log standard deviation, 1985–1998)	-1.22	0.21	-1.23	0.20	-2.05	0.18	-0.96	0.28	-8.0, 1.0

σ_e^2 (observer CPUE additional log standard deviation, 1995–2004)					-2.905	0.13			-8.0,0.15
σ_e^2 (observer CPUE additional log standard deviation, 2005–2020)	-2.23	0.08	-1.67	0.10	-2.71	0.11	-2.14	0.12	-8.0,0.15
2020 MMB	6,460	0.14	5,930	0.19	5,527	0.12	6,854	0.16	

Table 11. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1a 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– 2021 are restricted to 1985–2020. 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}=23,519 $MMB_{35\%}$=7,358			
1985	4.40	12,811	0.04	10,415	0.09
1986	6.19	10,601	0.04	9,760	0.06
1987	4.73	9,871	0.04	6,661	0.06
1988	3.54	8,714	0.04	6,233	0.05
1989	4.34	6,408	0.04	5,651	0.04
1990	3.31	5,583	0.04	3,510	0.05
1991	2.33	4,986	0.04	3,164	0.05
1992	2.64	4,903	0.04	3,027	0.05
1993	2.79	5,636	0.03	3,142	0.05
1994	2.90	5,084	0.03	3,823	0.03
1995	2.92	4,938	0.03	3,071	0.03
1996	2.49	4,666	0.03	2,997	0.03
1997	2.69	4,699	0.03	3,018	0.04
1998	2.65	5,078	0.03	3,073	0.04
1999	3.36	5,116	0.04	3,415	0.03
2000	3.61	5,205	0.04	3,330	0.04
2001	3.62	5,643	0.04	3,314	0.04
2002	3.50	6,252	0.05	3,633	0.05
2003	2.43	6,532	0.05	4,192	0.05
2004	2.89	6,694	0.06	4,744	0.05
2005	2.36	6,950	0.06	4,991	0.06
2006	3.01	7,497	0.05	5,265	0.06
2007	2.09	7,664	0.05	5,682	0.06
2008	1.73	7,432	0.05	5,983	0.06
2009	2.29	7,076	0.05	6,046	0.05
2010	2.03	6,818	0.05	5,681	0.05
2011	1.48	6,300	0.05	5,400	0.05
2012	2.20	5,751	0.05	5,081	0.05
2013	3.04	5,665	0.05	4,478	0.05
2014	2.24	5,844	0.06	4,020	0.06
2015	2.28	5,960	0.06	4,181	0.06
2016	1.99	6,138	0.06	4,404	0.06
2017	2.09	6,261	0.06	4,697	0.06
2018	2.48	6,363	0.07	4,868	0.06
2019	2.29	6,341	0.10	4,850	0.07
2020	2.80	6,460	0.14	4,788	0.09

Table 12. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1b 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 1961–2021 are restricted to 1985–2020. 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}=19,954 $MMB_{35\%}$=5,810			
1985	4.35	12,824	0.04	10,428	0.09
1986	6.21	10,612	0.04	9,773	0.06
1987	4.75	9,896	0.04	6,664	0.06
1988	3.51	8,731	0.04	6,236	0.05
1989	4.29	6,404	0.04	5,658	0.04
1990	3.32	5,574	0.04	3,512	0.05
1991	2.35	4,984	0.04	3,153	0.05
1992	2.64	4,899	0.04	3,011	0.05
1993	2.72	5,602	0.03	3,127	0.05
1994	2.94	5,037	0.03	3,801	0.03
1995	2.94	4,902	0.03	3,025	0.03
1996	2.48	4,625	0.03	2,947	0.03
1997	2.78	4,679	0.03	2,971	0.03
1998	2.69	5,093	0.03	3,026	0.04
1999	3.37	5,151	0.04	3,394	0.03
2000	3.65	5,255	0.04	3,340	0.04
2001	3.59	5,691	0.05	3,339	0.04
2002	3.49	6,288	0.05	3,669	0.05
2003	2.33	6,529	0.06	4,220	0.05
2004	2.96	6,681	0.06	4,757	0.06
2005	2.51	7,002	0.06	4,970	0.06
2006	3.05	7,617	0.05	5,250	0.07
2007	2.09	7,804	0.05	5,732	0.06
2008	1.69	7,558	0.05	6,083	0.06
2009	2.24	7,164	0.05	6,162	0.05
2010	2.02	6,870	0.05	5,778	0.05
2011	1.52	6,347	0.05	5,460	0.05
2012	2.24	5,814	0.05	5,113	0.05
2013	2.96	5,709	0.06	4,512	0.05
2014	2.17	5,834	0.06	4,064	0.06
2015	2.19	5,883	0.06	4,197	0.06
2016	1.88	5,982	0.07	4,369	0.07
2017	2.03	6,040	0.08	4,594	0.07
2018	2.34	6,067	0.10	4,691	0.08
2019	2.10	5,930	0.14	4,614	0.10
2020	2.76	5,930	0.19	4,471	0.13

Table 13. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1c for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961–2021 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

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} =23,246 $MMB_{35\%}$=7,213			
1985	4.02	12,991	0.04	10,771	0.08
1986	6.25	10,725	0.04	10,086	0.06
1987	4.59	10,007	0.04	6,873	0.06
1988	3.42	8,818	0.04	6,431	0.05
1989	4.07	6,472	0.04	5,834	0.04
1990	3.14	5,618	0.04	3,676	0.05
1991	2.27	5,027	0.04	3,300	0.05
1992	2.51	4,917	0.04	3,133	0.05
1993	2.73	5,600	0.03	3,222	0.05
1994	2.91	5,034	0.03	3,854	0.03
1995	2.88	4,876	0.03	3,056	0.03
1996	2.50	4,599	0.03	2,967	0.03
1997	2.70	4,643	0.03	2,976	0.04
1998	2.64	5,031	0.03	3,032	0.04
1999	3.34	5,072	0.04	3,385	0.03
2000	3.57	5,147	0.04	3,309	0.04
2001	3.56	5,558	0.04	3,292	0.04
2002	3.40	6,118	0.05	3,596	0.04
2003	2.39	6,357	0.05	4,125	0.05
2004	2.68	6,434	0.05	4,632	0.05
2005	2.13	6,556	0.05	4,832	0.06
2006	3.08	7,059	0.05	5,017	0.06
2007	2.09	7,262	0.05	5,322	0.06
2008	1.70	7,056	0.05	5,611	0.05
2009	2.38	6,760	0.05	5,703	0.05
2010	2.00	6,558	0.04	5,369	0.05
2011	1.40	6,045	0.04	5,153	0.05
2012	2.14	5,478	0.05	4,873	0.05
2013	2.92	5,348	0.05	4,266	0.05
2014	2.26	5,509	0.05	3,784	0.05
2015	2.36	5,671	0.05	3,905	0.06
2016	1.98	5,896	0.05	4,126	0.06
2017	1.88	5,976	0.05	4,464	0.05
2018	2.30	5,973	0.06	4,663	0.05
2019	2.20	5,875	0.08	4,588	0.06
2020	2.68	5,527	0.12	4,433	0.07

Table 14. Annual abundance estimates of model recruits (millions of crab), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 21.1d 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 1961–2021 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

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}=23,779 $MMB_{35\%}$=7,422			
1985	4.15	12,880	0.04	10,734	0.08
1986	6.17	10,601	0.04	9,941	0.06
1987	4.71	9,872	0.04	6,730	0.06
1988	3.52	8,702	0.04	6,256	0.05
1989	4.34	6,386	0.04	5,652	0.04
1990	3.35	5,565	0.04	3,501	0.05
1991	2.35	4,971	0.04	3,145	0.05
1992	2.62	4,873	0.04	3,005	0.05
1993	2.70	5,559	0.03	3,116	0.05
1994	3.03	5,008	0.03	3,777	0.03
1995	2.99	4,907	0.03	2,990	0.03
1996	2.47	4,645	0.03	2,936	0.03
1997	2.79	4,710	0.04	2,990	0.04
1998	2.80	5,171	0.03	3,058	0.04
1999	3.44	5,291	0.04	3,440	0.03
2000	3.69	5,448	0.04	3,439	0.04
2001	3.64	5,930	0.05	3,496	0.04
2002	3.57	6,583	0.05	3,872	0.05
2003	2.36	6,869	0.06	4,470	0.05
2004	2.90	7,012	0.06	5,057	0.06
2005	2.38	7,248	0.06	5,295	0.06
2006	3.05	7,790	0.06	5,542	0.07
2007	2.11	7,946	0.05	5,940	0.06
2008	1.75	7,693	0.05	6,230	0.06
2009	2.36	7,333	0.05	6,278	0.06
2010	2.05	7,072	0.05	5,896	0.06
2011	1.52	6,546	0.05	5,616	0.05
2012	2.27	6,007	0.05	5,292	0.05
2013	3.07	5,933	0.06	4,689	0.06
2014	2.26	6,112	0.06	4,247	0.06
2015	2.33	6,234	0.06	4,419	0.07
2016	2.03	6,422	0.06	4,643	0.07
2017	2.12	6,547	0.07	4,941	0.07
2018	2.55	6,657	0.08	5,115	0.07
2019	2.33	6,646	0.11	5,100	0.08
2020	2.90	6,854	0.16	5,049	0.10

Table 15. Negative log-likelihood values of the fits for models 21.1a (base), 21.1b, 21.1c, 21.1d, 21.1a2, and 21.1b2 for golden king crab in the WAG. Likelihood components with zero entry in the entire rows are omitted.

Likelihood Component	**21.1a**	**21.1b**	**21.1c**	**21.1d**	**21.1a2**	**21.1b2**
Number of free parameters	152	152	154	152	152	152
Retlencomp	-2045.3400	-2043.7300	-2030.2200	-2023.9300	-2045.3400	-2043.7300
Totallencomp	-1600.0700	-1626.2200	-1592.1800	-1624.8000	-1600.0700	-1626.2200
Observer cpue	-43.1882	-28.6586	-49.1695	-27.6625	-43.1882	-28.6586
Fishery cpue	-17.2600	-17.3922	-21.2682	-13.6626	-17.2600	-17.3922
RetdcatchB	5.7765	6.1631	7.2070	6.9146	5.7765	6.1631
TotalcatchB	43.9060	44.8060	44.9945	43.8921	43.9060	44.8060
GdiscdcatchB	0.0003	0.0002	0.0005	0.0001	0.0003	0.0002
Rec_dev	23.8881	23.9941	23.3176	23.1456	23.8881	23.9941
Pot F_dev	0.0274	0.0276	0.0262	0.0285	0.0274	0.0276
Gbyc_F_dev	0.0477	0.0476	0.0490	0.0470	0.0477	0.0476
Tag	2691.8400	2692.1700	2691.9200	2691.5700	2691.8400	2692.1700
RetcatchN	0.0087	0.0083	0.0062	0.0067	0.0087	0.0083
Total	-940.3570	-948.7790	-925.3140	-924.4570	-940.3570	-948.7790

Table 16. 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 in 2021.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	$F_{35\%}$	M(yr^{-1})	OFL	MaxABC (P*=0.49)	ABC (0.75*OFL)	ABC (0.70*OFL)
21.1a	3a	9,298	11,039	1.19	0.64	0.64	0.21	3,795	3,775	2,846	2,657
21.1b	3a	9,157	9,834	1.07	0.65	0.65	0.21	3,212	3,195	2,409	2,248
21.1c	3b	8,974	8,279	0.92	0.60	0.66	0.21	2,204	2,182	1,653	1,543
21.1a2	3a	8,999	10,668	1.19	0.56	0.56	0.21	3,416	3,398	2,562	2,391
21.1b2	3a	8,848	9,417	1.06	0.57	0.57	0.21	2,897	2,881	2,172	2,028

WAG: Biomass, OFL, and ABC are in t. Current MMB = MMB in 2021.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	$F_{35\%}$	M(yr^{-1})	OFL	MaxABC (P*=0.49)	ABC (0.75*OFL)	ABC (0.70*OFL)
21.1a	3b	7,370	6,702	0.91	0.57	0.63	0.21	1,669	1,659	1,252	1,169
21.1b	3b	7,354	6,378	0.87	0.54	0.63	0.21	1,446	1,435	1,085	1,012
21.1c	3b	7,089	6,069	0.86	0.55	0.66	0.21	1,314	1,307	986	920
21.1d	3b	7,441	6,960	0.94	0.58	0.62	0.21	1,836	1,825	1,377	1,285
21.1a2	3b	7,157	6,260	0.87	0.46	0.54	0.21	1,422	1,414	1,067	996
21.1b2	3b	7,078	5,897	0.83	0.45	0.55	0.21	1,247	1,237	935	873

AI: OFL and ABC are in t.

	OFL	ABC (0.75*OFL)	ABC (0.7*OFL)
21.1a	5,464	4,098	3,826
21.1b	4,658	3,494	3,260
21.1c	3,518	2,639	2,463
21.1a2	4,838	3,629	3,387
21.1b2	4,144	3,107	2,901

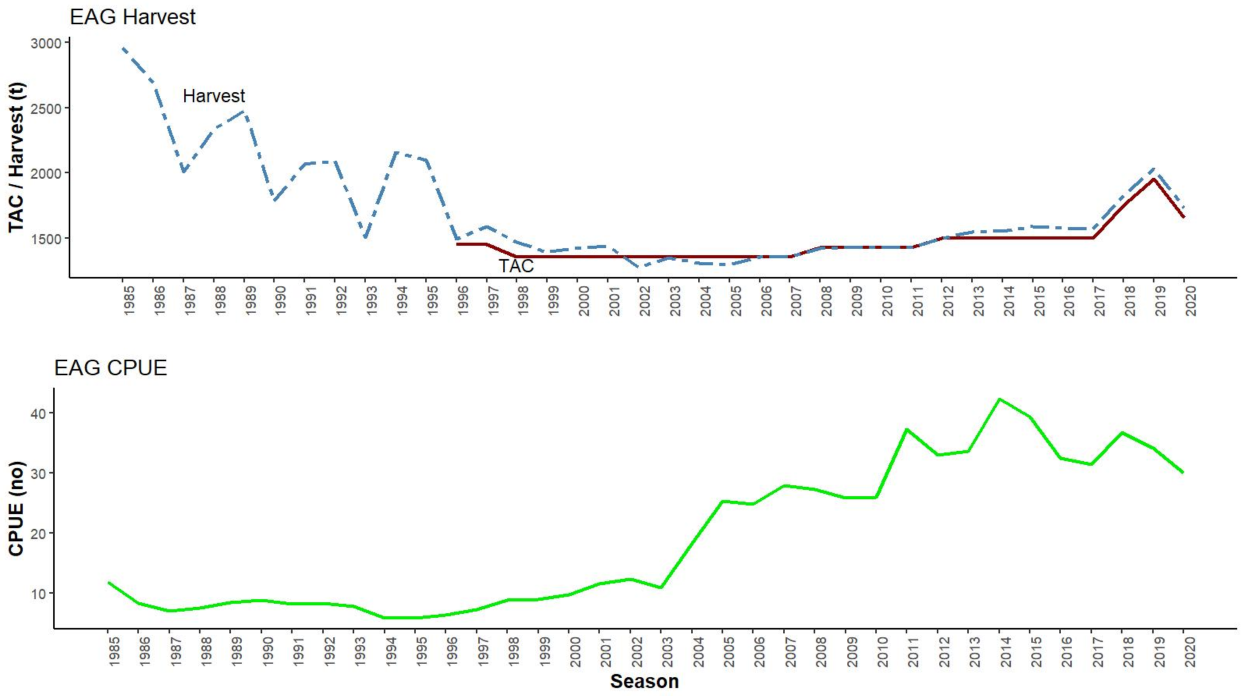


Figure 1. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the EAG, 1985/86–2020/21 fisheries (note: 1985 refers to the 1985/86 fishing year).

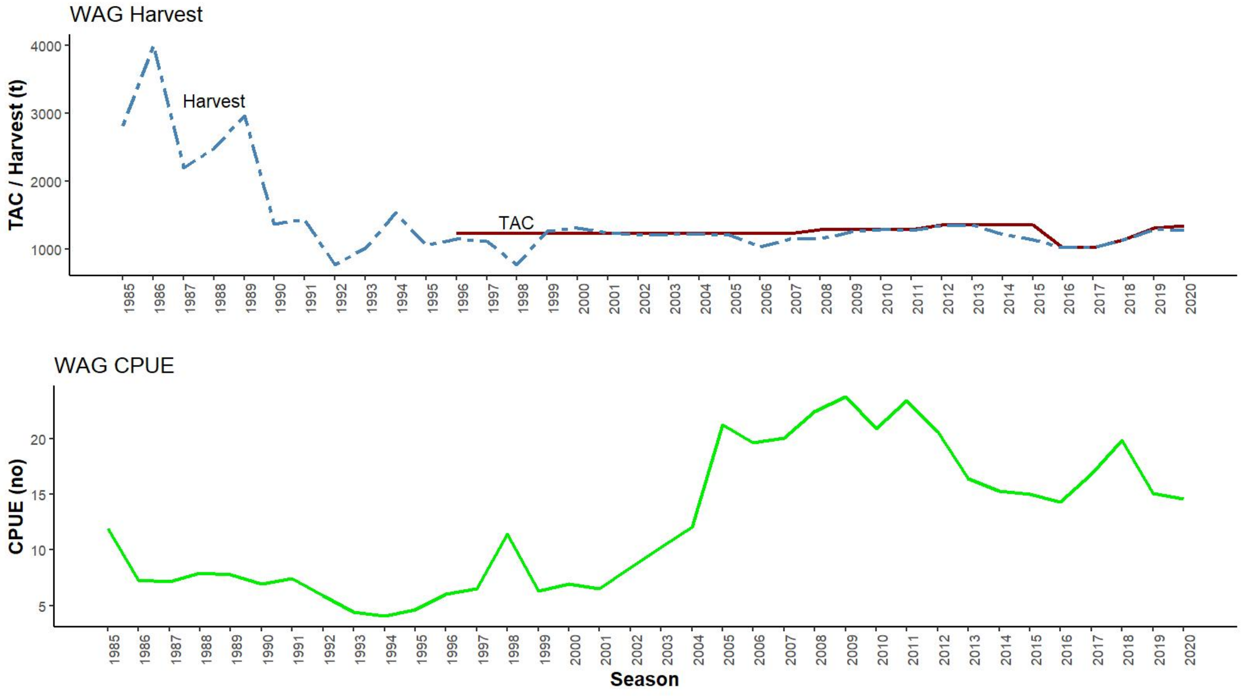


Figure 2. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the WAG, 1985/86–2020/21 fisheries (note: 1985 refers to the 1985/86 fishing year).

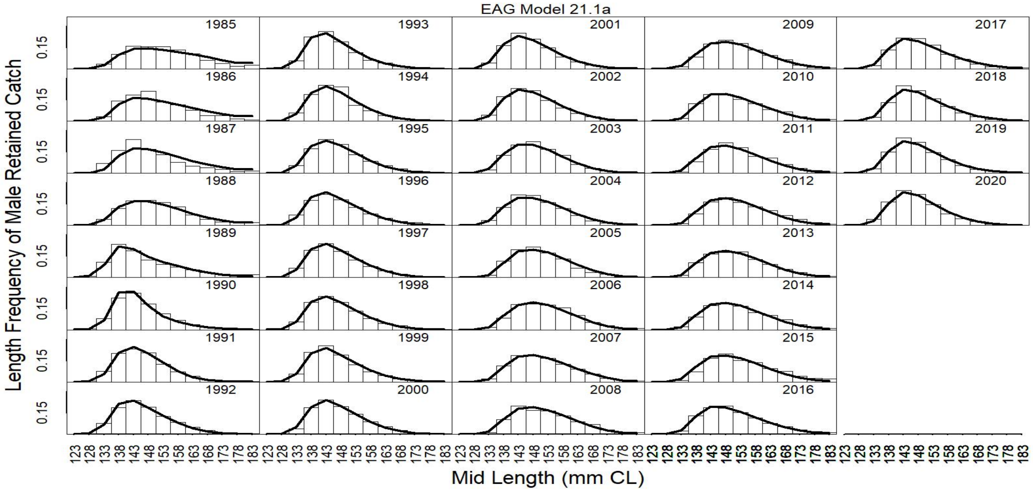


Figure 3a. Predicted (black line) vs. observed (bar) retained catch relative length frequency distributions for model 21.1a for golden king crab in the EAG, 1985/86 to 2020/21.

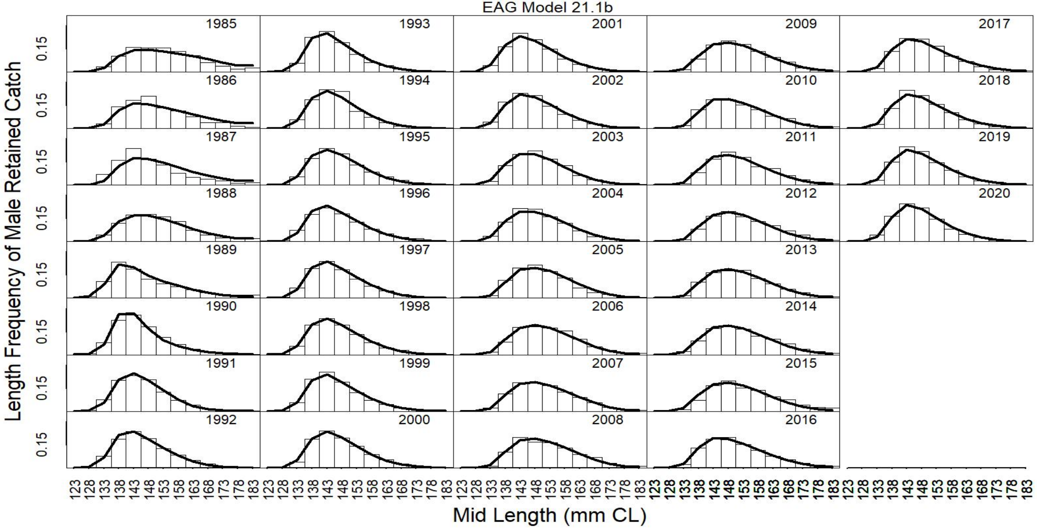


Figure 3b. Predicted (black line) vs. observed (bar) retained catch relative length frequency distributions for model 21.1b for golden king crab in the EAG, 1985/86 to 2020/21.

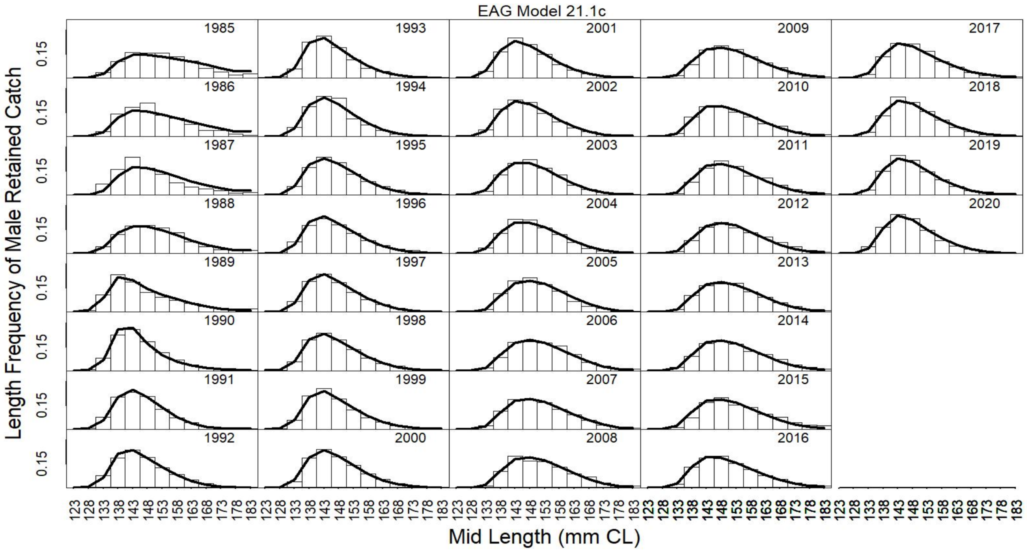


Figure 3c. Predicted (black line) vs. observed (bar) retained catch relative length frequency distributions for model 21.1c for golden king crab in the EAG, 1985/86 to 2020/21.

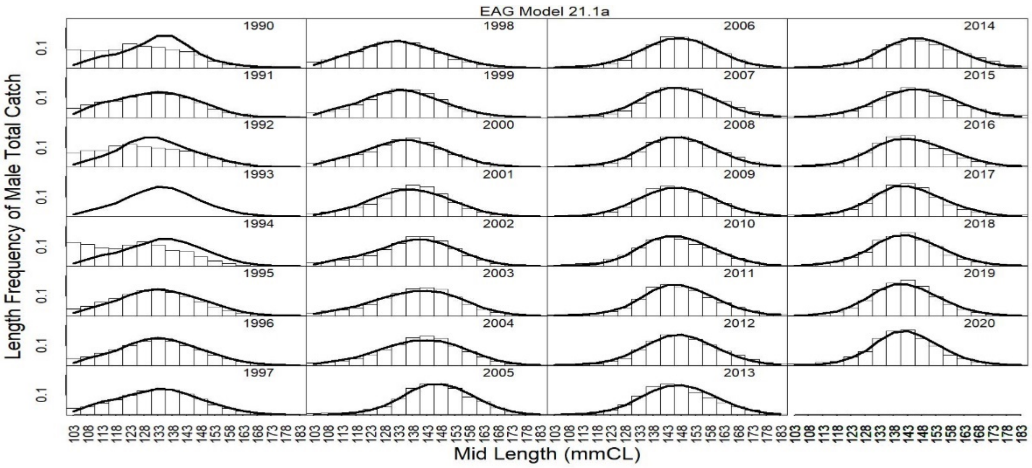


Figure 4a. Predicted (black line) vs. observed (bar) total catch relative length frequency distributions for model 21.1a for golden king crab in the EAG, 1990/91 to 2020/21.

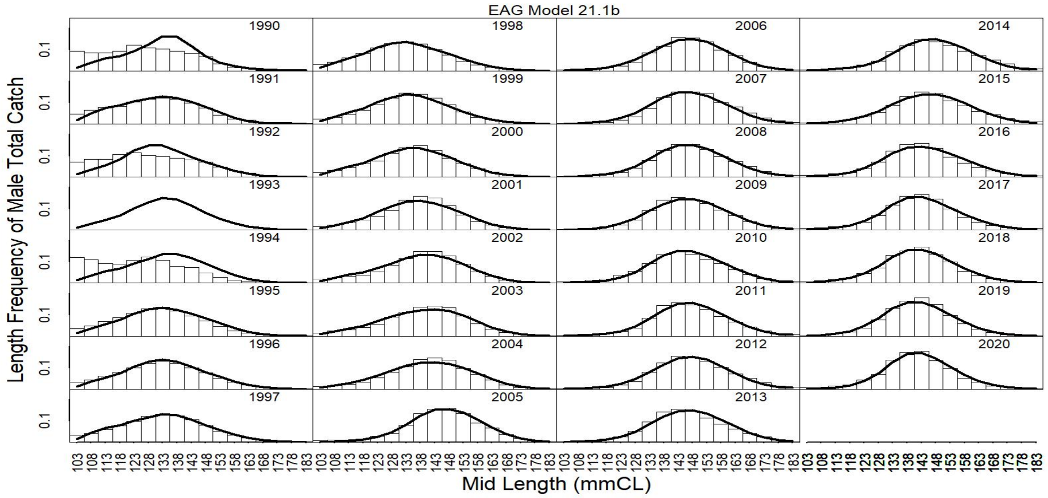


Figure 4b. Predicted (black line) vs. observed (bar) total catch relative length frequency distributions for model 21.1b for golden king crab in the EAG, 1990/91 to 2020/21.

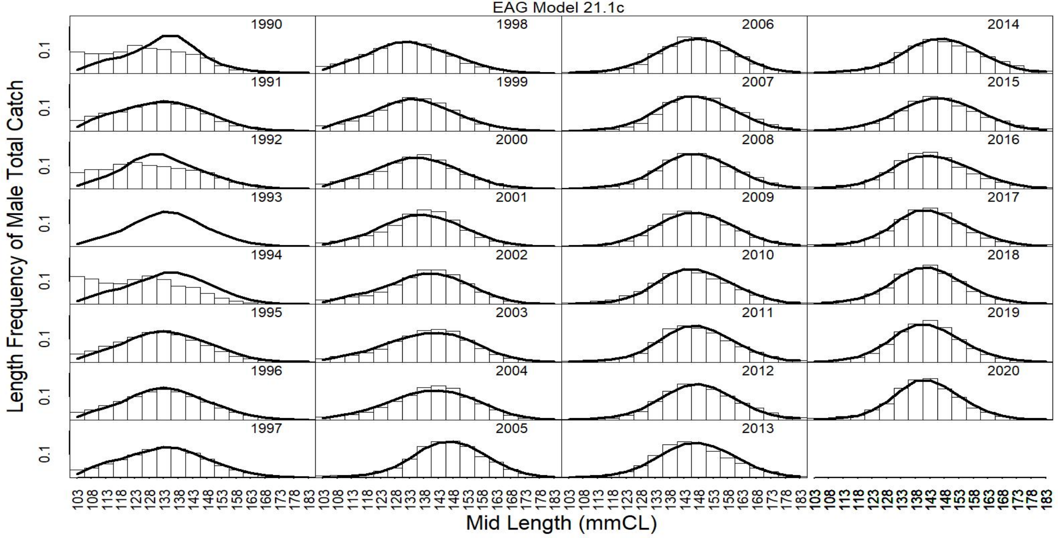


Figure 4c. Predicted (black line) vs. observed (bar) total catch relative length frequency distributions for model 21.1c for golden king crab in the EAG, 1990/91 to 2020/21.

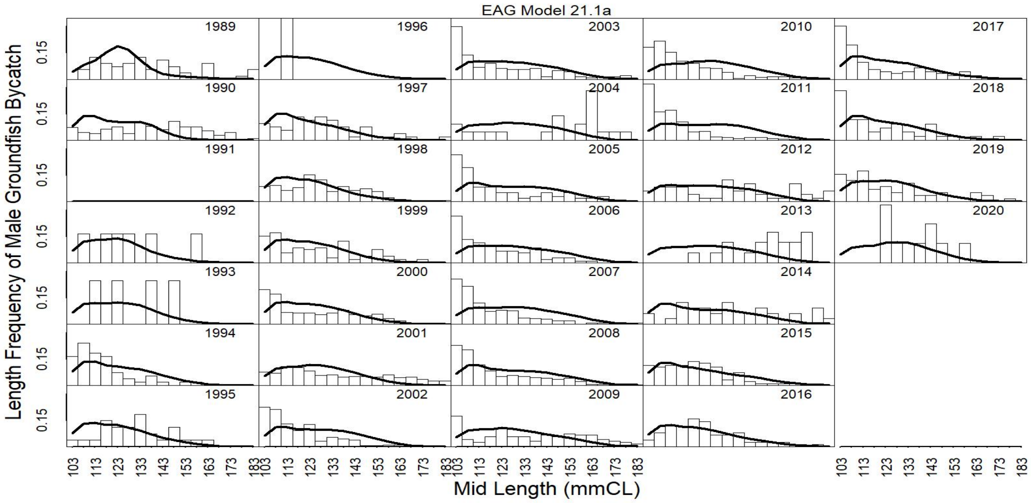


Figure 5a. Predicted (black line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for model 21.1a for golden king crab in the EAG, 1989/90 to 2020/21.

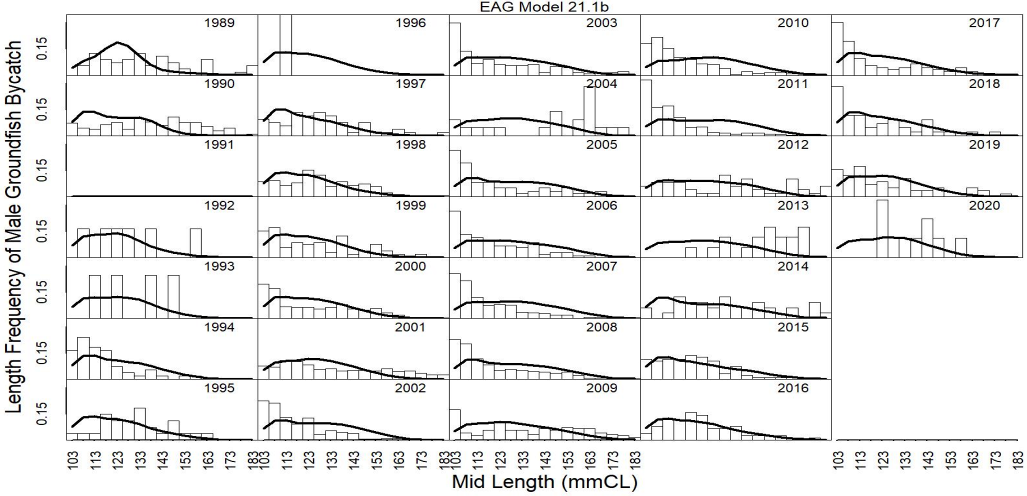


Figure 5b. Predicted (black line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for model 21.1b for golden king crab in the EAG, 1989/90 to 2020/21.

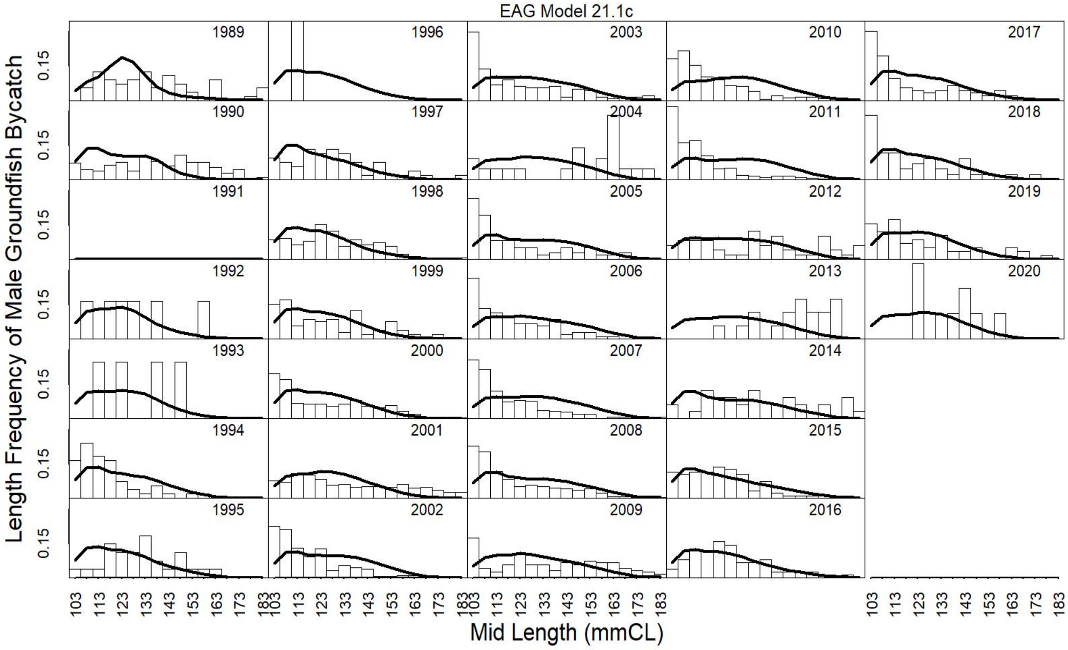


Figure 5c. Predicted (black line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for model 21.1c for golden king crab in the EAG, 1989/90 to 2020/21.

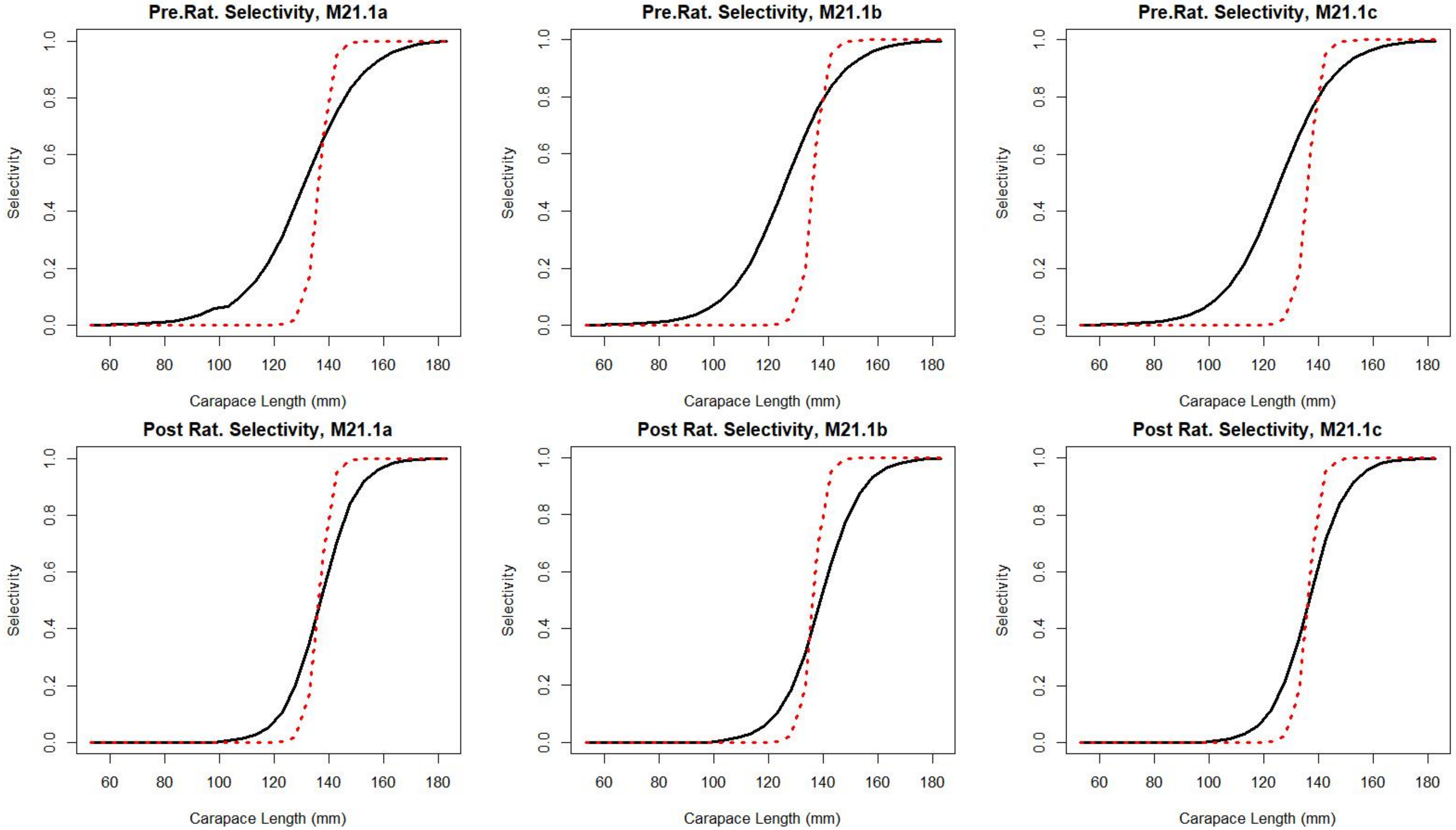


Figure 6. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods for models 21.1a, 21.1b, and 21.1c fits to golden king crab data in the EAG.

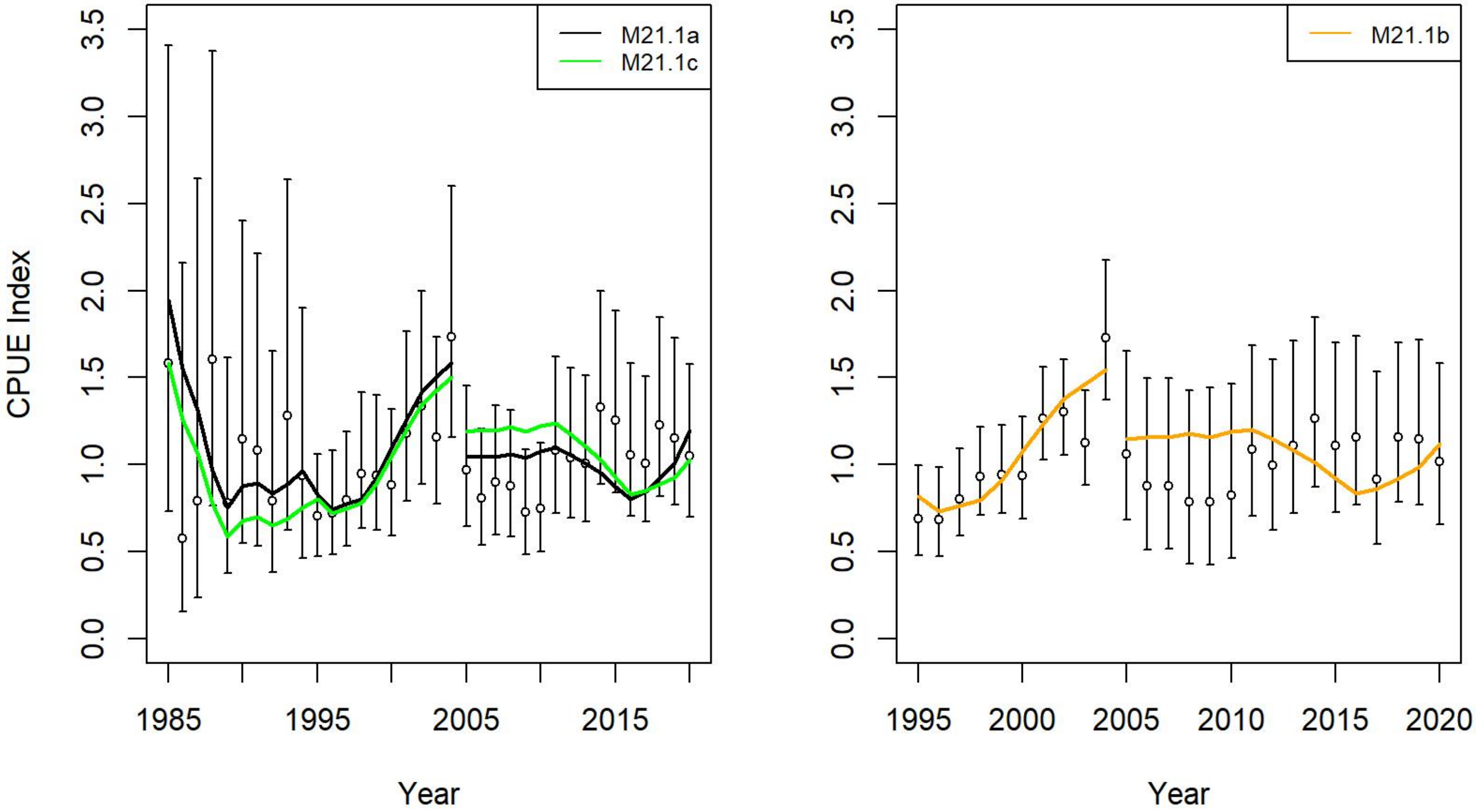


Figure 7. Comparison of input CPUE indices [black open circles with +/- 2 SE for model 21.1a (left) and model 21.1b (right)] with predicted CPUE indices (colored solid lines) by 21.1a, 21.1b, and 21.1c, model fits for EAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.

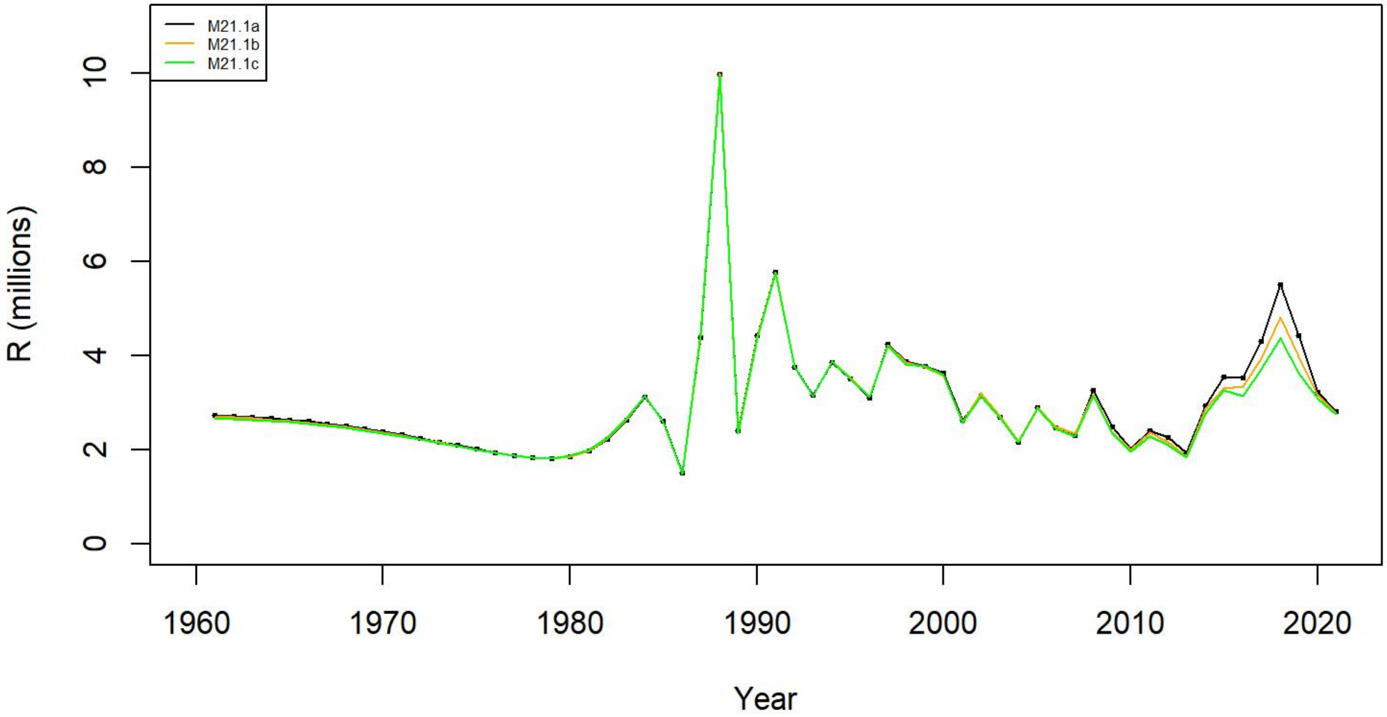


Figure 8. Estimated number of male recruits (millions of crab ≥ 101 mm CL) for 21.1a, 21.1b, and 21.1c model fits to EAG golden king crab data, 1961–2021.

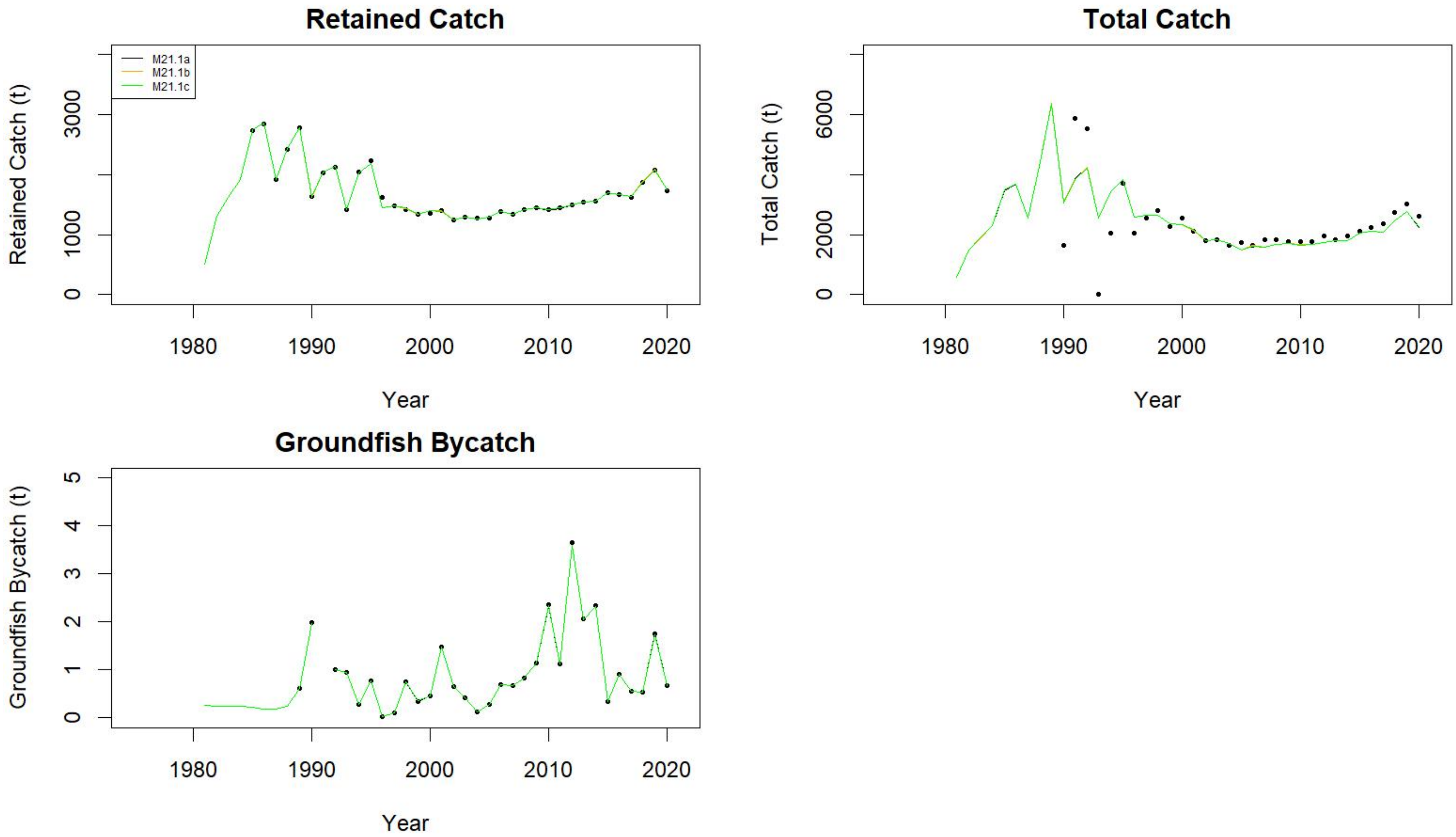


Figure 9. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for 21.1a, 21.1b, and 21.1c model fits to EAG data, 1981/82–2020/21.

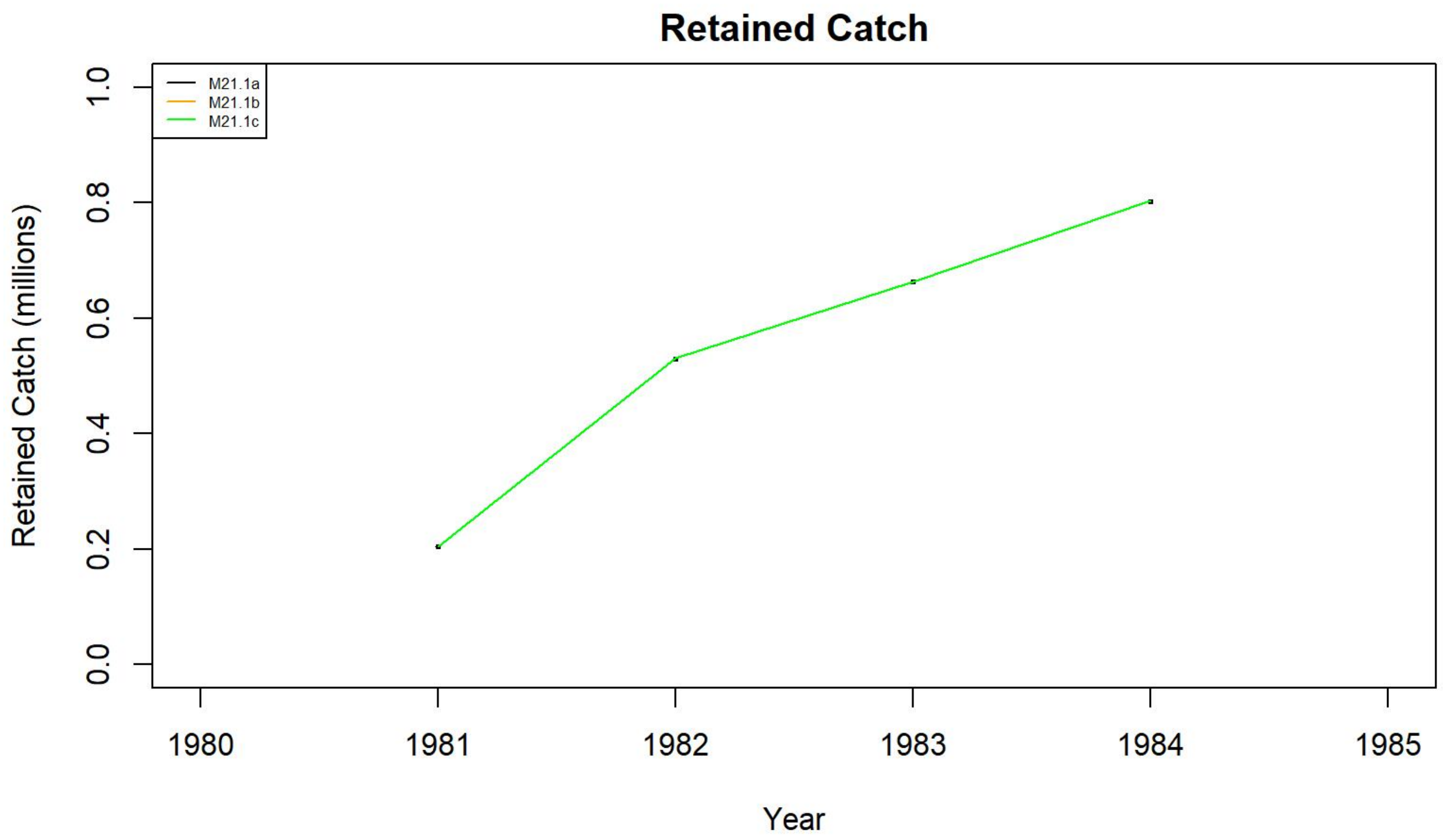


Figure 10. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for 21.1a, 21.1b, and 21.1c model fits to EAG data, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crab.

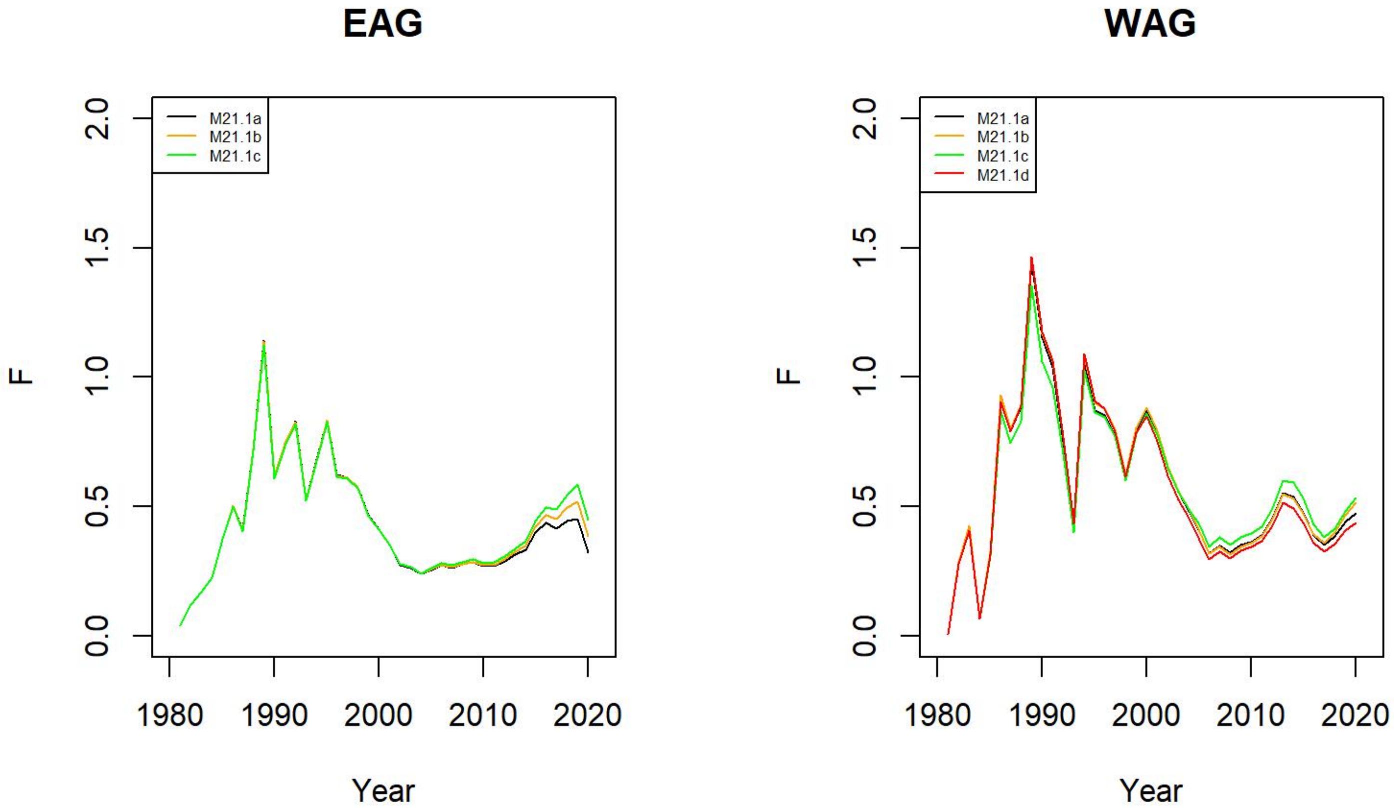


Figure 11. Trends in pot fishery full selection total fishing mortality of golden king crab for 21.1a, 21.1b, and 21.1c model fits to EAG (left) and for 21.1a, 21.1b, 21.1c, and 21.1d model fits to WAG (right) data, 1981/82–2020/21.

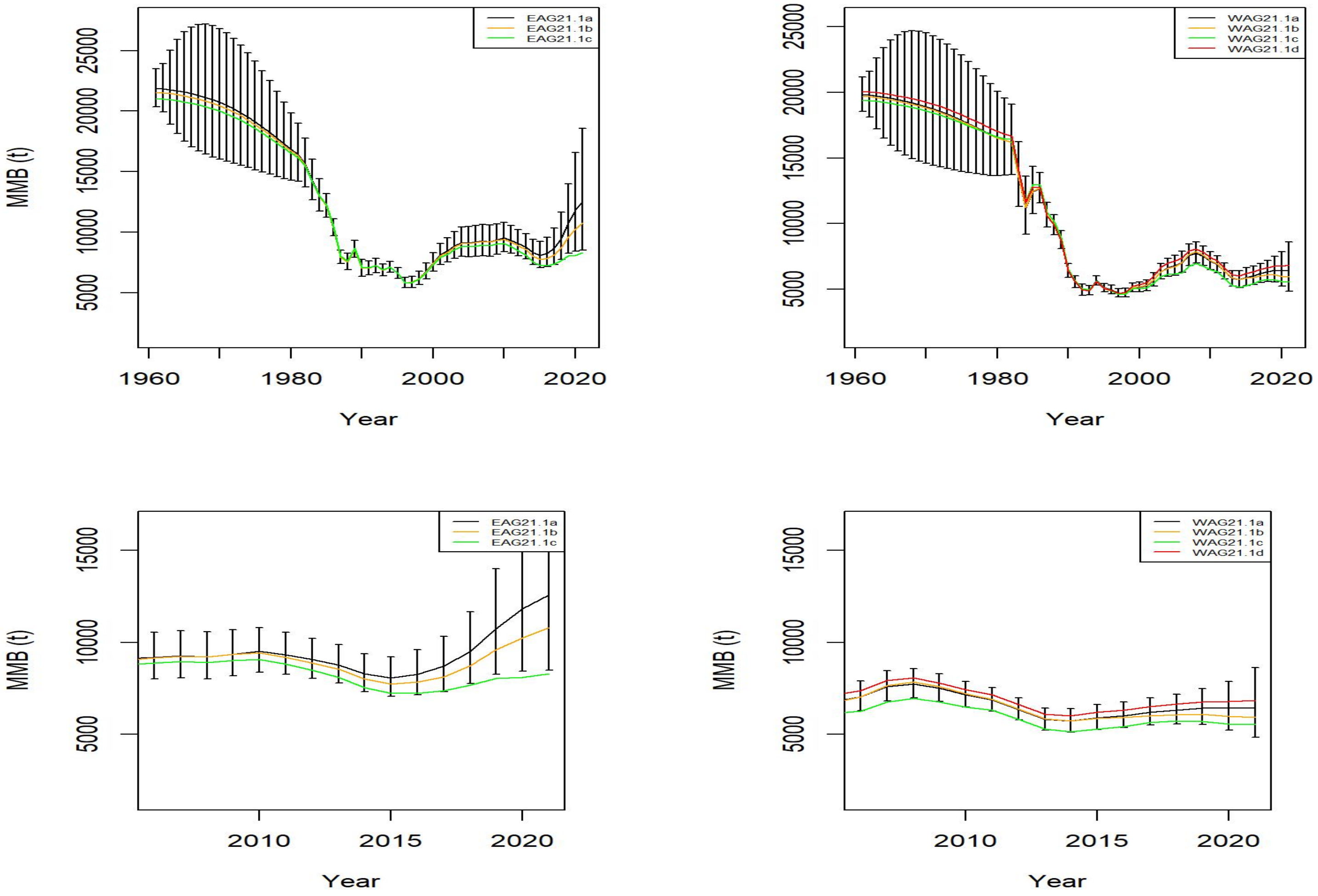


Figure 12. Trends in golden king crab mature male biomass for 21.1a, 21.1b, and 21.1c model fits to EAG (left) and for 21.1a, 21.1b, 21.1c, and 21.1d model fits to WAG (right) data. Top: 1960/61–2020/21, bottom: 2005/06–2020/21. Model21.1a estimate has two standard error confidence limits.

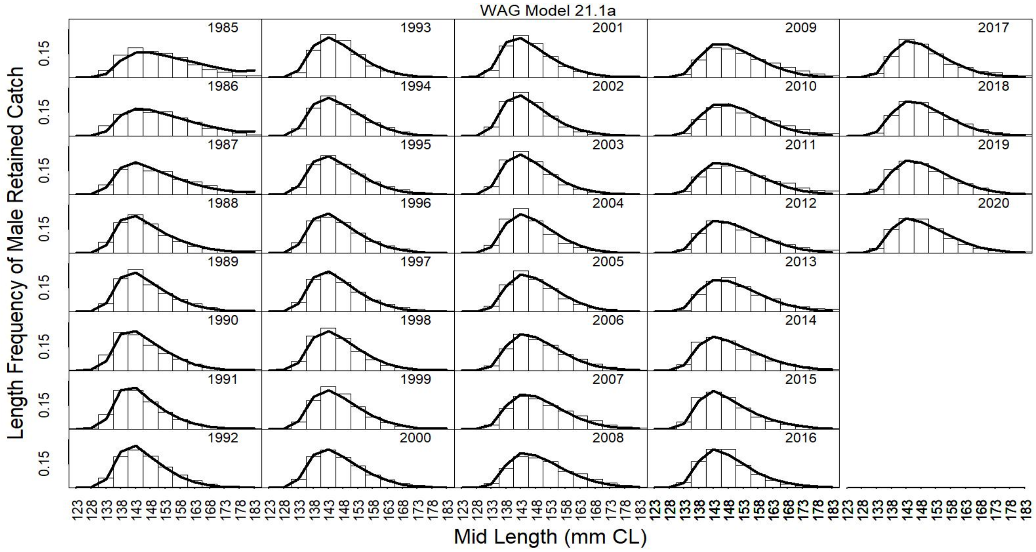


Figure 13a. Predicted (black line) vs. observed (bar) retained catch relative length frequency distributions for model 21.1a for golden king crab in the WAG, 1985/86 – 2020/21.

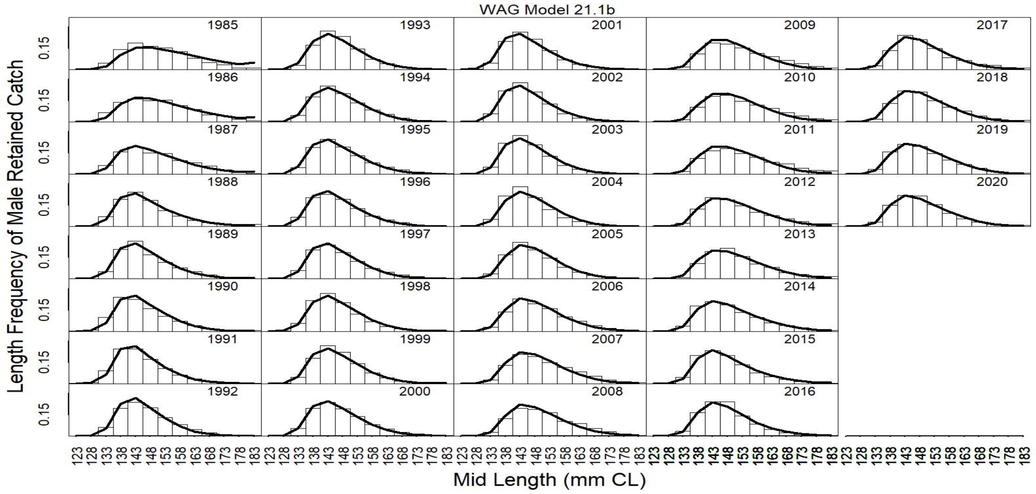


Figure 13b. Predicted (black line) vs. observed (bar) retained catch relative length frequency distributions for model 21.1b for golden king crab in the WAG, 1985/86 – 2020/21.

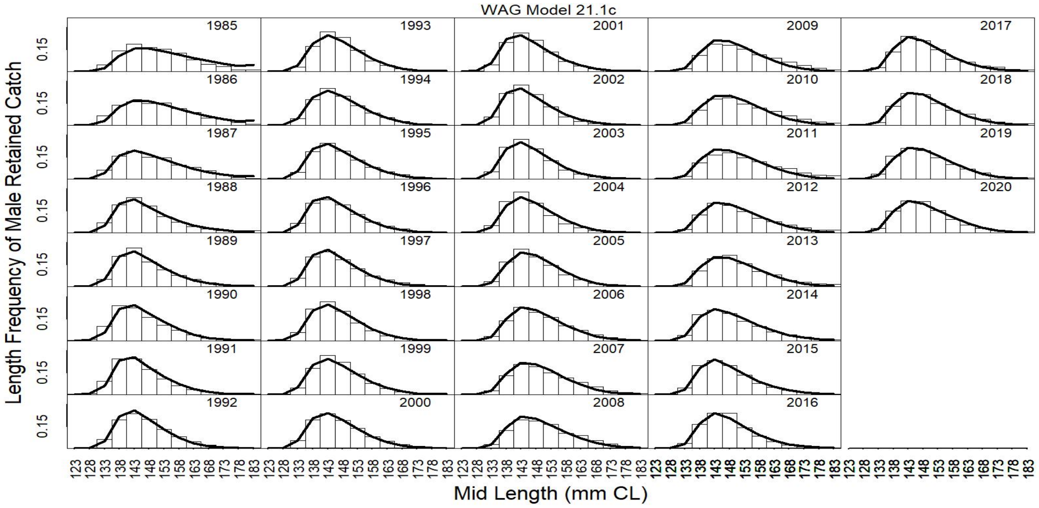


Figure 13c. Predicted (black line) vs. observed (bar) retained catch relative length frequency distributions for model 21.1c for golden king crab in the WAG, 1985/86 – 2020/21.

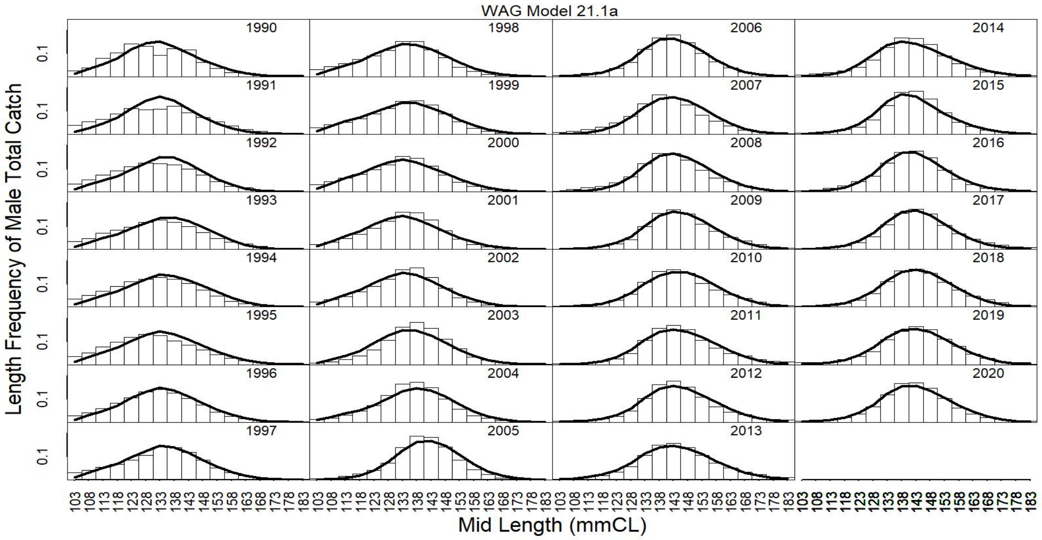


Figure 14a. Predicted (black line) vs. observed (bar) total catch relative length frequency distributions for model 21.1a for golden king crab in the WAG, 1990/91 – 2020/21.

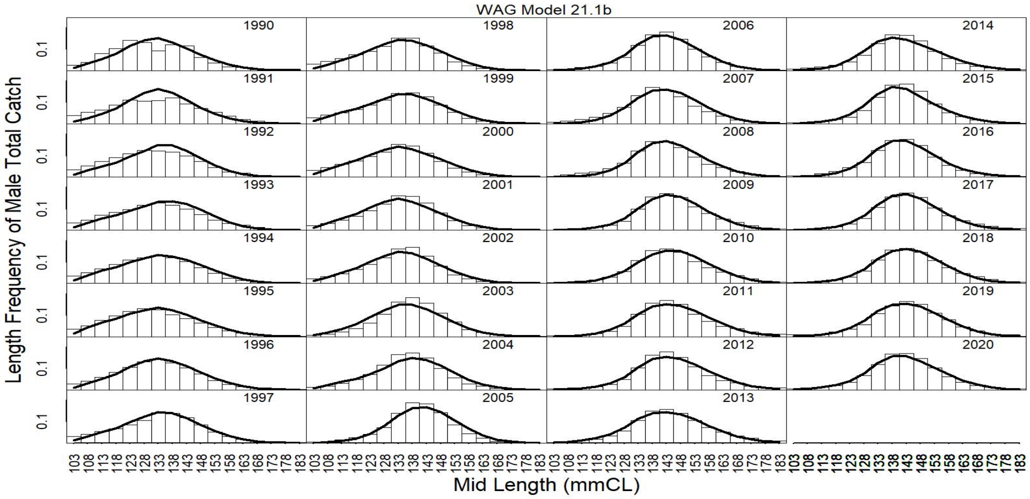


Figure 14b. Predicted (black line) vs. observed (bar) total catch relative length frequency distributions for model 21.1b for golden king crab in the WAG, 1990/91 – 2020/21.

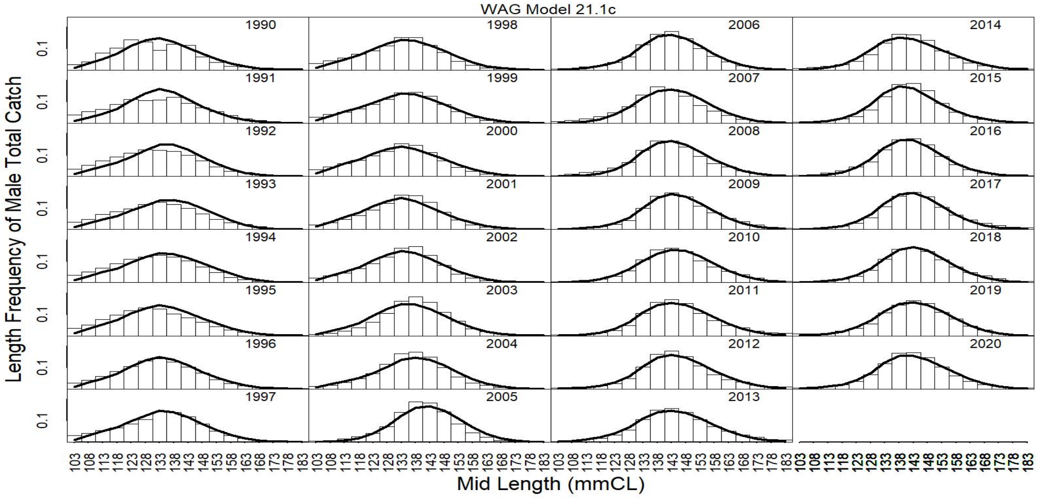


Figure 14c. Predicted (black line) vs. observed (bar) total catch relative length frequency distributions for model 21.1c for golden king crab in the WAG, 1990/91 – 2020/21.

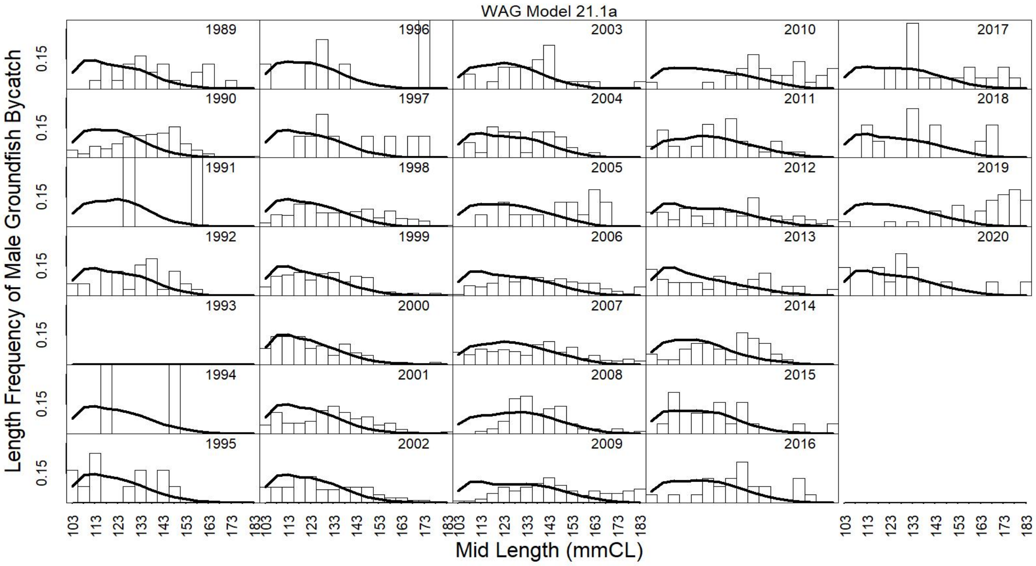


Figure 15a. Predicted (black line) vs. observed (bar) groundfish discard catch relative length frequency distributions for model 21.1a for golden king crab in the WAG, 1989/90 – 2020/21.

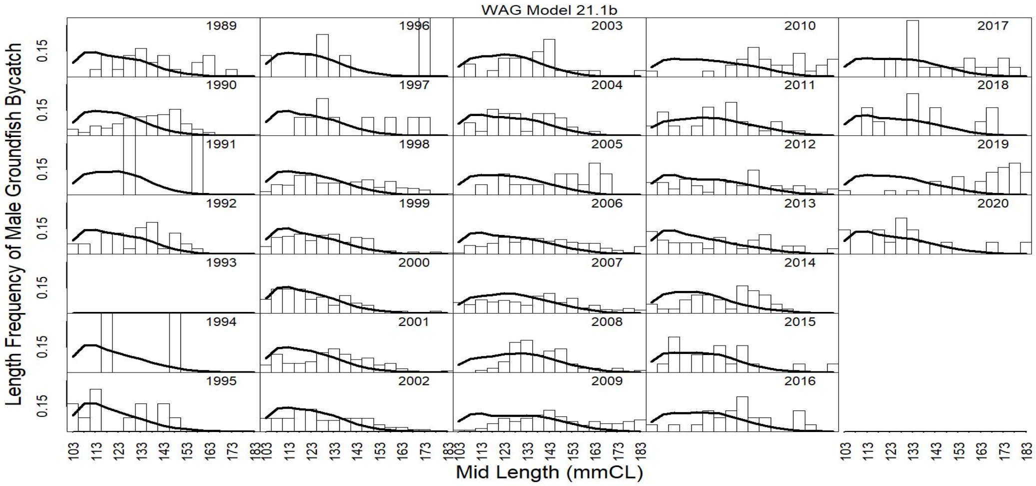


Figure 15b. Predicted (black line) vs. observed (bar) groundfish discard catch relative length frequency distributions for model 21.1b for golden king crab in the WAG, 1989/90 – 2020/21.

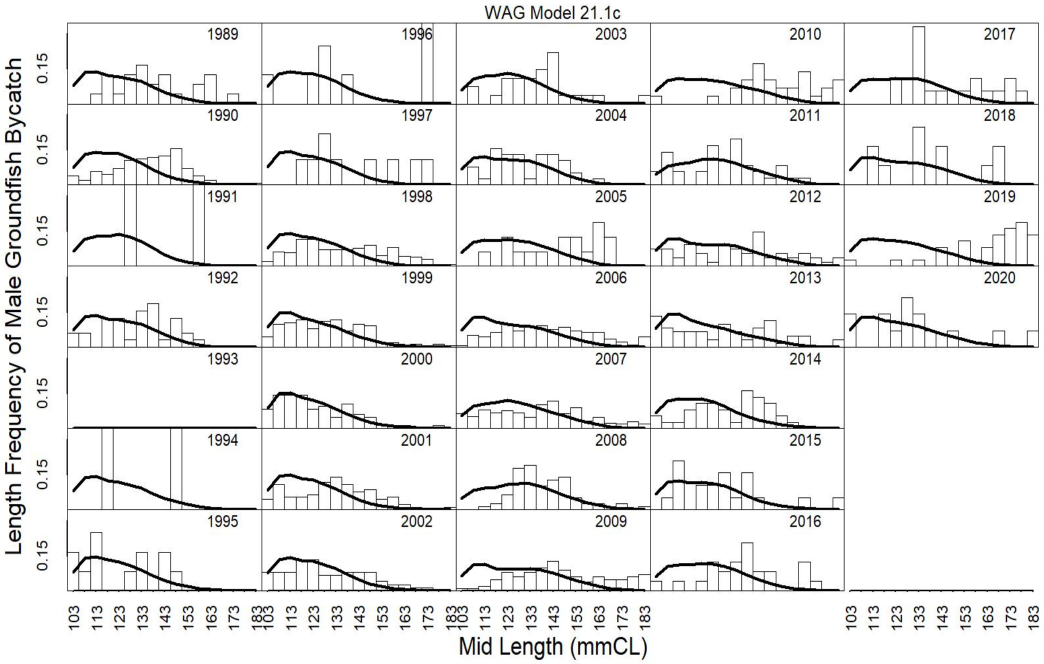


Figure 15c. Predicted (black line) vs. observed (bar) groundfish discard catch relative length frequency distributions for model 21.1c for golden king crab in the WAG, 1989/90 – 2020/21.

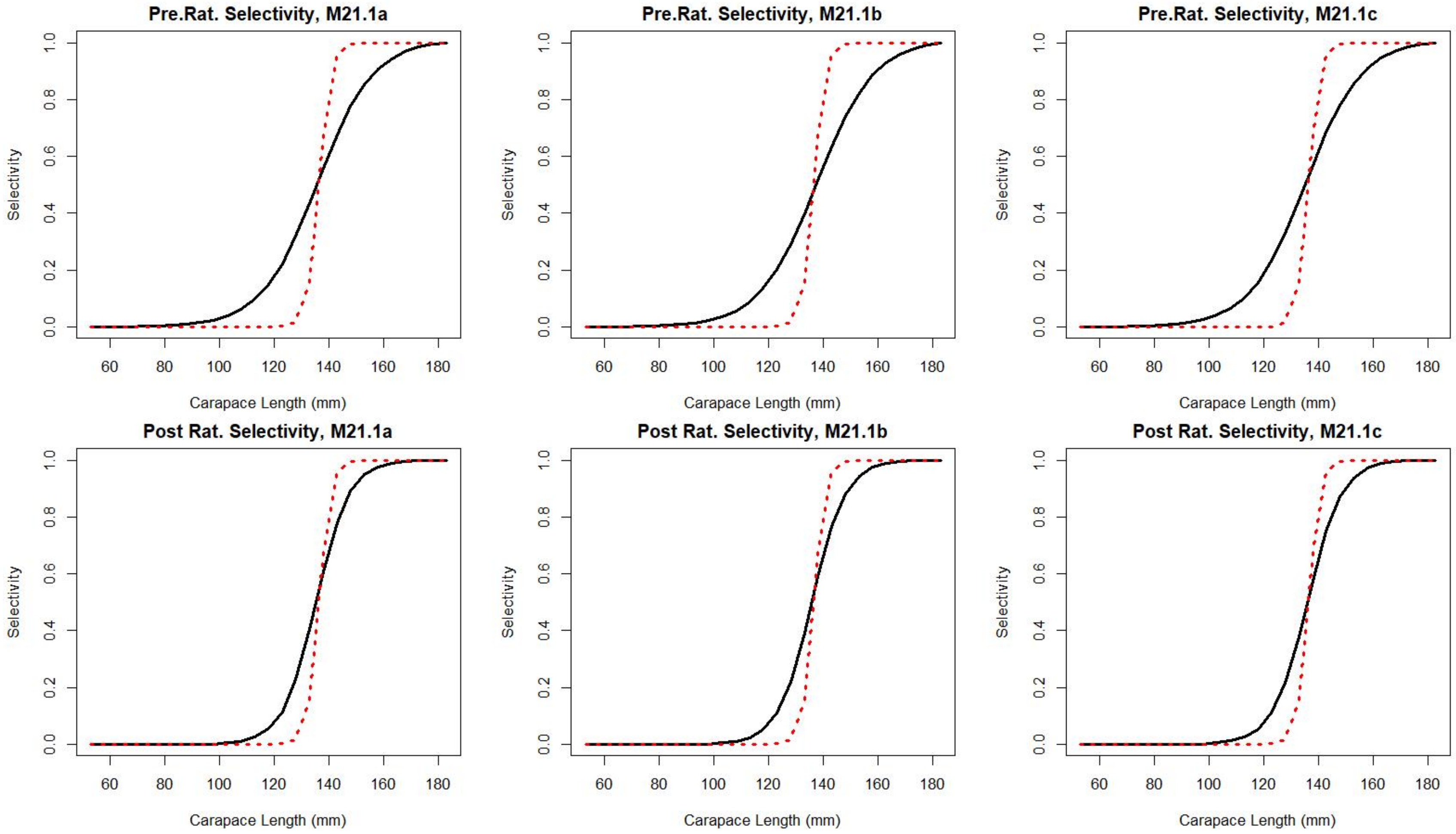


Figure 16. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods for models 21.1a, 21.1b, and 21.1c fits to golden king crab data in the WAG.

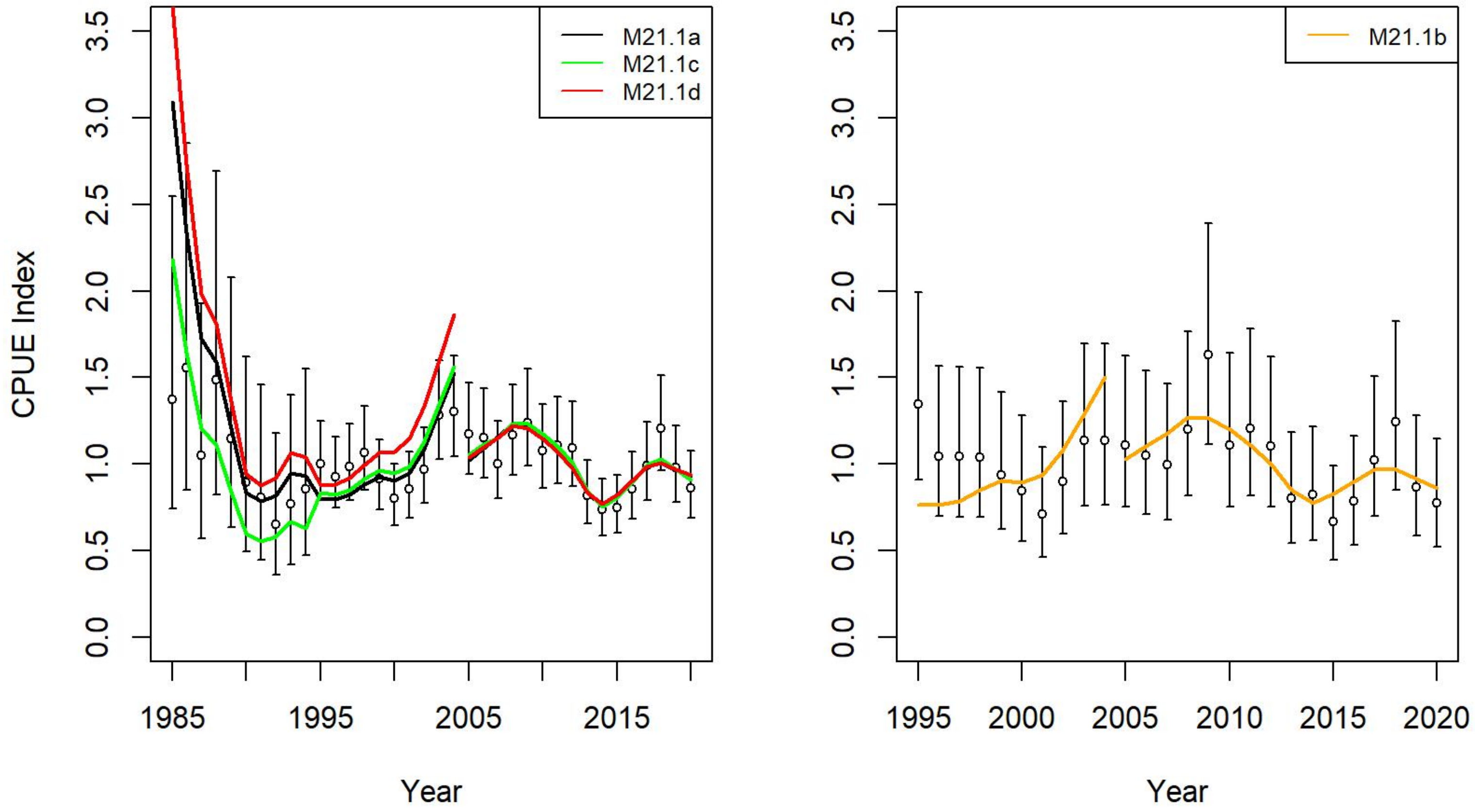


Figure 17. Comparison of input CPUE indices [black open circles with +/- 2 SE for model 21.1a (left) and model 21.1b (right)] with predicted CPUE indices (colored solid lines) by 21.1a, 21.1b, 21.1c, and 21.1d, model fits for WAG golden king crab data, 1985/86–2020/21. Model estimated additional standard error was added to each input standard error.

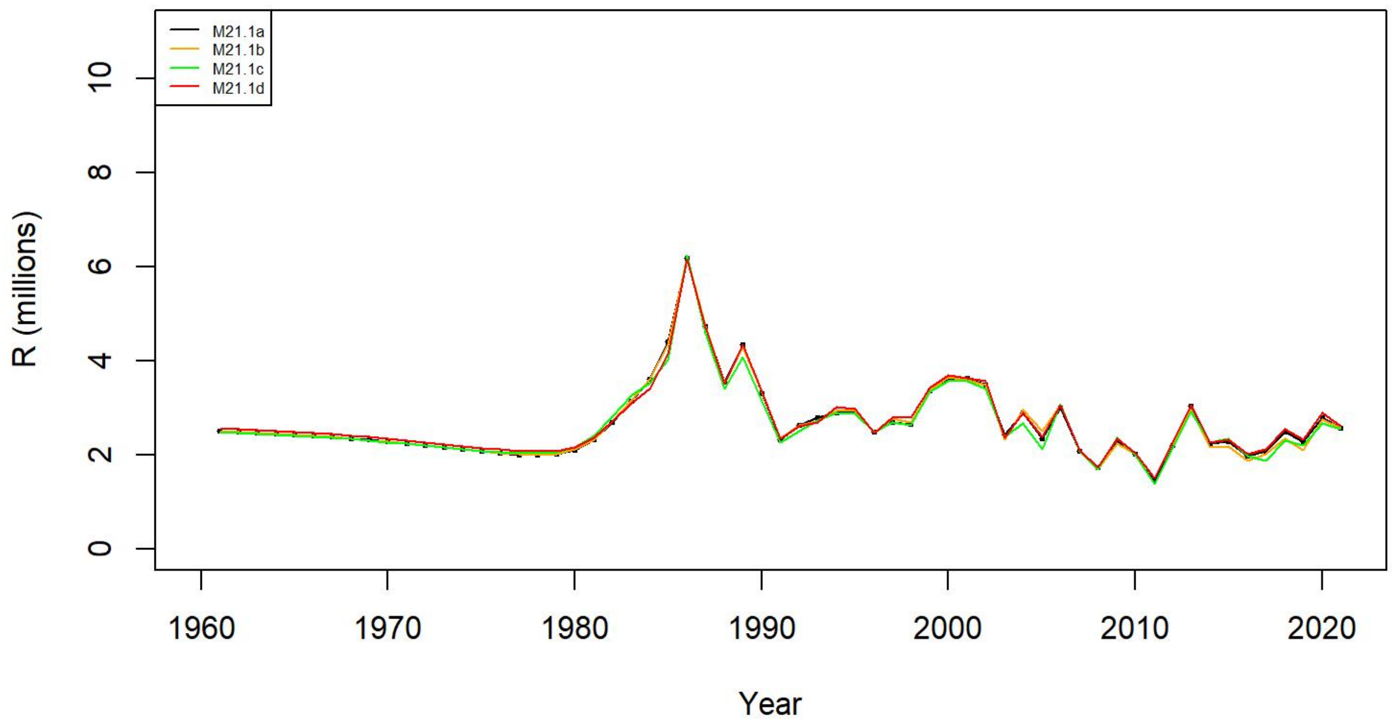


Figure 18. Estimated number of male recruits (millions of crab ≥ 101 mm CL) for 21.1a, 21.1b, 21.1c, and 21.1d model fits to WAG golden king crab data, 1961–2021.

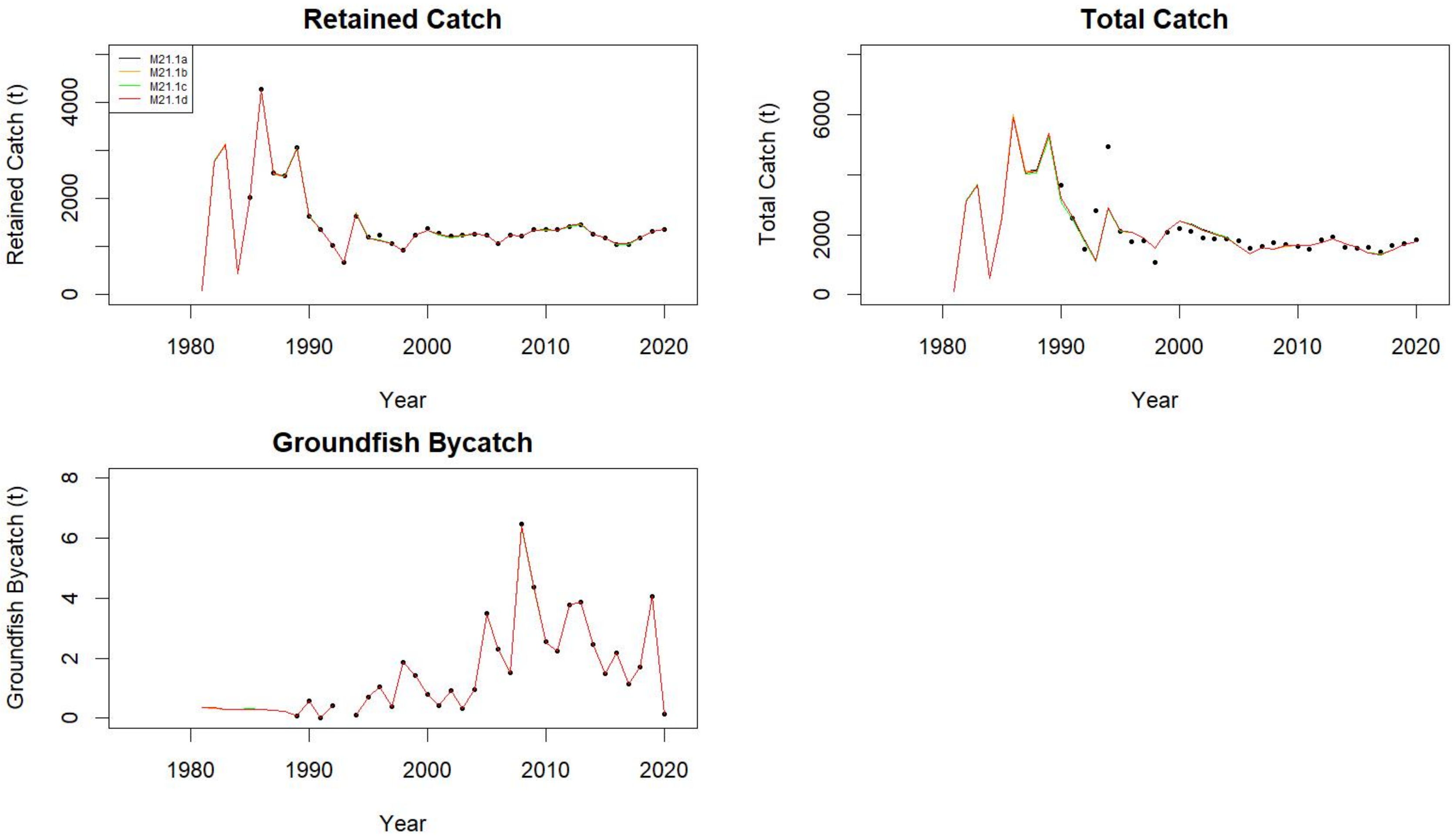


Figure 19. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for 21.1a, 21.1b, 21.1c, and 21.1d model fits to WAG data, 1981/82–2020/21.

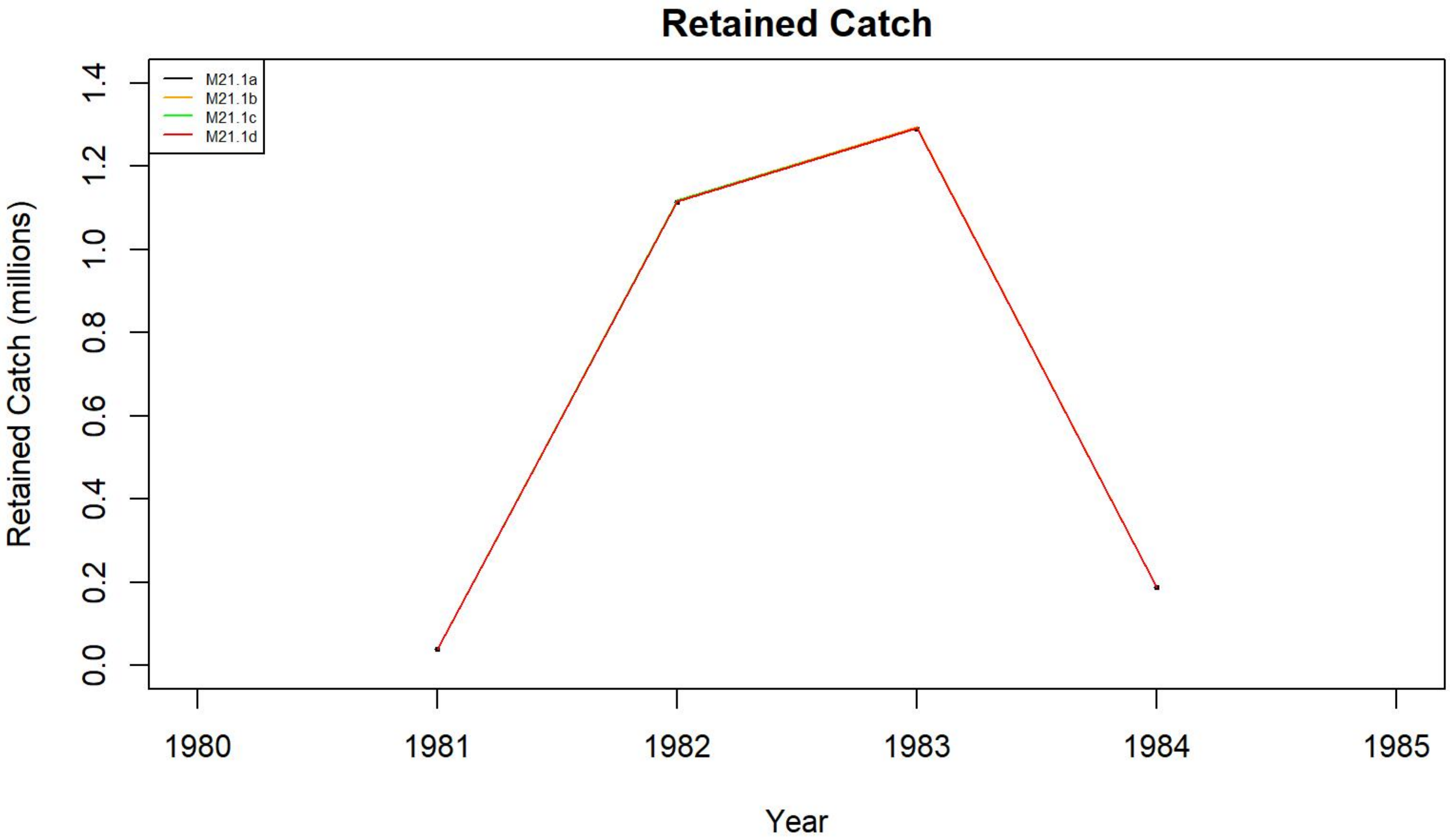
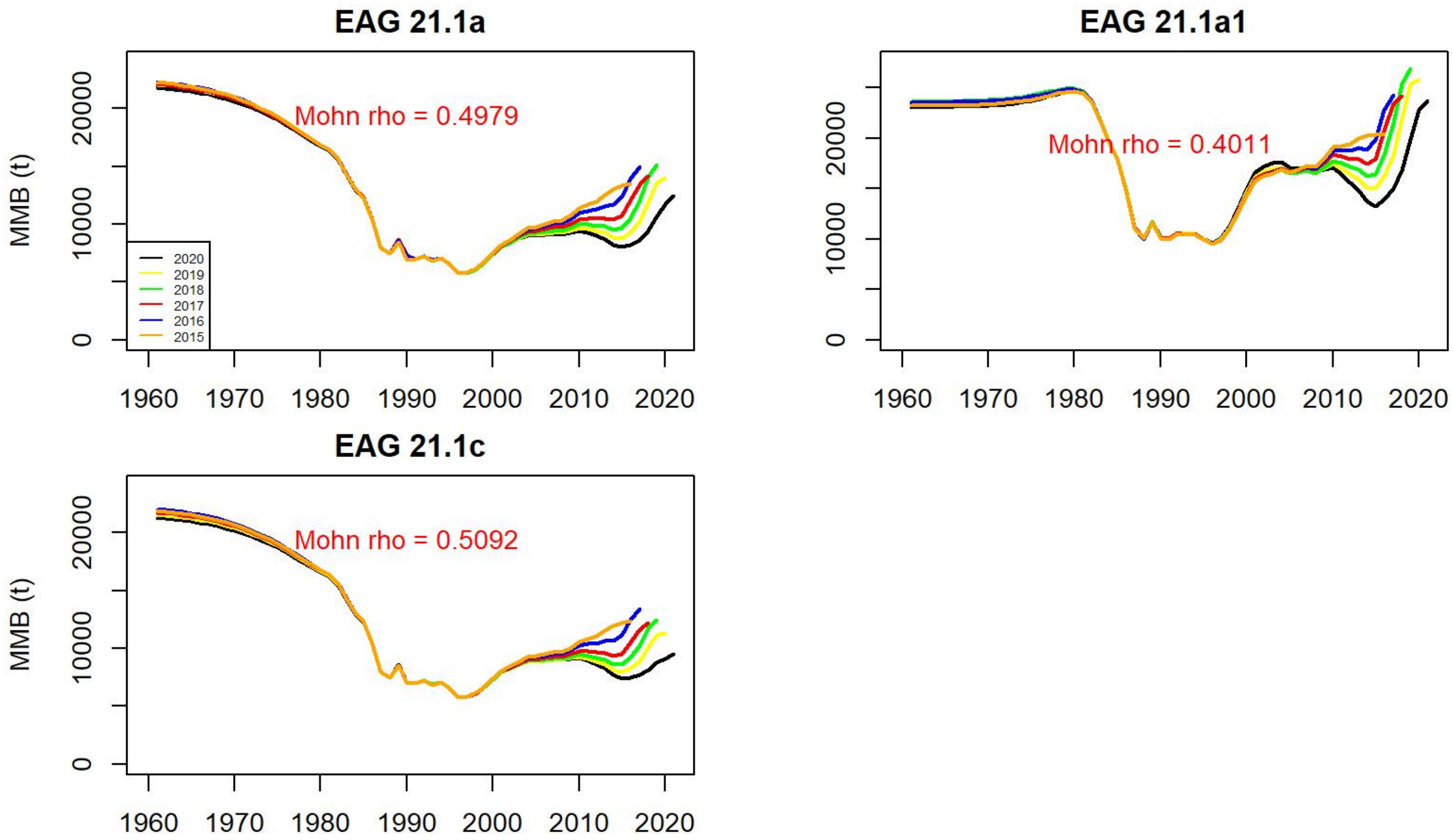


Figure 20. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for 21.1a, 21.1b, 21.1c, and 21.1d model fits to WAG data, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crab.



EAG 21.1a

EAG 21.1a1

EAG 21.1c

Figure 21. Comparison of 21.1a, 21.1a1 (a higher M of 0.38yr^{-1} was used for years > 1998 in the assessment), and 21.1c models' retrospective fits for EAG.

Appendix A: *Catch and CPUE data*

Observer data collection protocol:

Observer data have been collected since 1988 (Moore *et al.* 2000; Barnard *et al.* 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91–2020/21 was selected for this analysis. During 1990/91–1994/95, observers were only deployed on catcher-processor vessels. During 1995/96–2004/05, observers were deployed on all fishing vessels during fishing activity. Observers have been deployed on all fishing vessels since 2005/06, but catcher-only vessels are only required to carry observers for a minimum of 50% of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity. Onboard observers sample seven pots per day (may be different numbers of pots per string) and count and measure all crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season (Table 3). The observer CPUE data collection improved over the years and the data since 1995/96 are more reliable. Thus, for model fitting, the observer CPUE time series was restricted to 1995/96–2020/21. The 1990/91–2020/21 observer database consists of 118,552 records and that of 1995/96–2020/21 contains 114,273 records.

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

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

Retained catch by size-class:

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

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

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

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

Observer CPUE standardization:
For CPUE standardization, observer data were restricted to the 1995/96–2020/21 period for reliability of data and further reduced by 5% cutoff of Soak time and 1% cutoff of Depth on both ends of the variable range to remove unreliable data or data from dysfunctional pot operations and restricting to vessels which have made five trips per year for at least three years during 1985/86 –2020/21. There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9” since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two separate observer CPUE time series, 1995/96–2004/05 and 2005/06–2020/21, to estimate CPUE indices for model input.

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

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

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek *et al*. 2018). Following a suggestion from the CIE reviewers in June 2018 we reduced the number of gear codes in the database after consulting with the fishing industry

(Rip Carlton, Chad Hoefer, and Scott Goodman, personal communication December 2018; Table B1). Following an SSC suggestion in October 2018, we used a hybrid procedure: First, we selected a scope of variables set by Akike Information Criterion, AIC (Burnham and Anderson 2002). An increase of more than 2 units in the AIC was used to identify the variable to be included successively (stepAIC program, R Core Team 2020). Then, the model parsimony was improved further by successively removing the term that explained the least proportion of deviance ($R^2 < 0.01$) (stepCPUE R function was used, Siddeek *et al*. 2018). Feenstra, *et al*. (2019) used a similar hybrid approach.

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

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

80	Historical: Cod pot, any shape pot targeting cod, usually with tunnel fingers	X	711	X
81	Historical: Rectangular pot, unknown size, with escape rings	X	1123	X

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

Thus we estimated two sets of observer CPUE indices for model input, 21.1a (reduced number of gear codes and no interaction), and 21.1c (reduced number of gear codes and Year:Area interaction).

Observer CPUE index by GLM

a. Non-interaction GLM model

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

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

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

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

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

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

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

We calculated appropriate degrees of freedom and dispersion parameters by calculating AICs for a range of values and locating the best values at the minimum AIC (Figures A.1 and A.2, respectively).

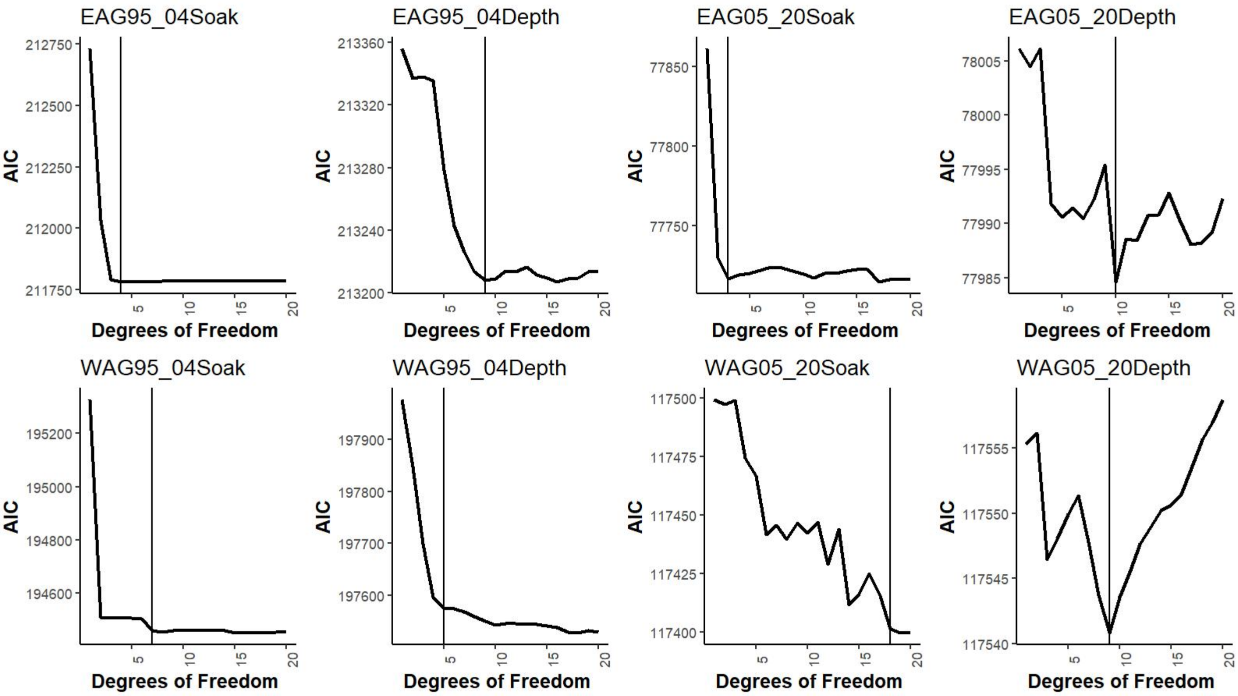


Figure A.1. AIC vs degrees of freedom for soak time and depth during pre- and post-rationalization periods for EAG (top) and WAG (bottom). Vertical lines identify the optimum degrees of freedom values chosen for CPUE standardization.

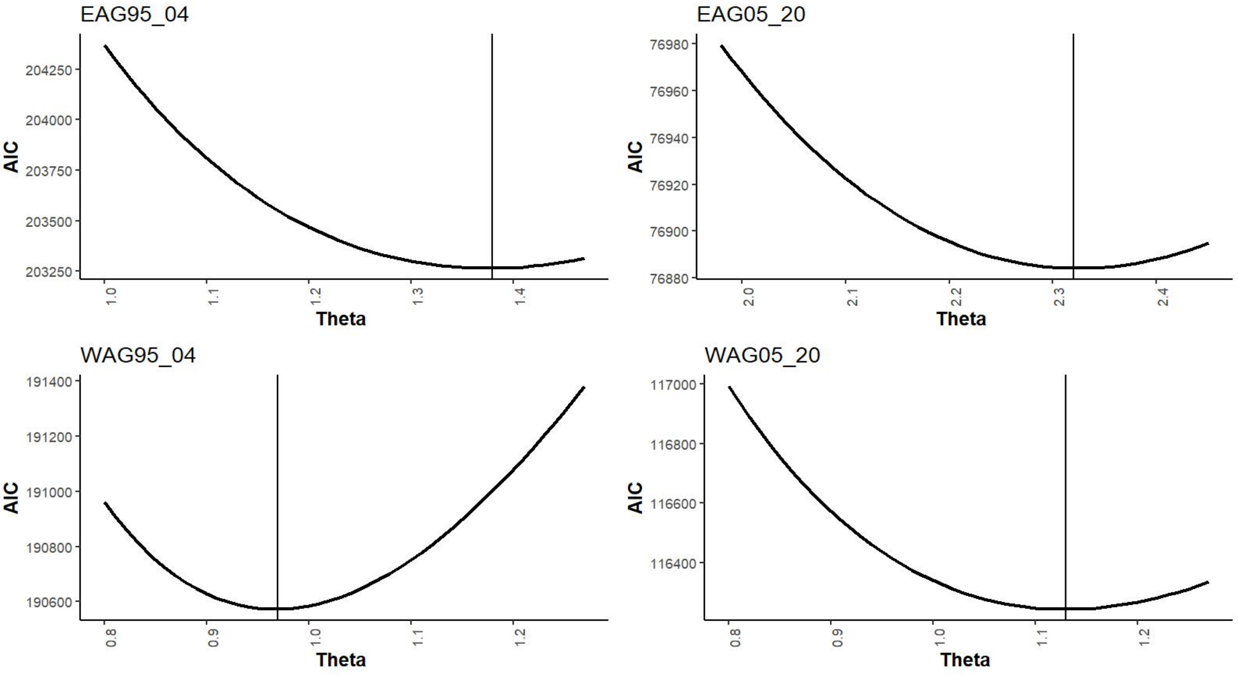


Figure A.2. AIC vs theta (dispersion parameter) during pre- and post-rationalization periods for EAG (top) and WAG (bottom). Vertical lines identify the optimum theta values chosen for CPUE standardization.

Figures A.3 to A.6 depict the fit of smoothers to observed CPUE data for a range of Soak time values at a given set of fixed values of other predictor variables chosen in the final model. For simplicity, the fits are shown for a single year.

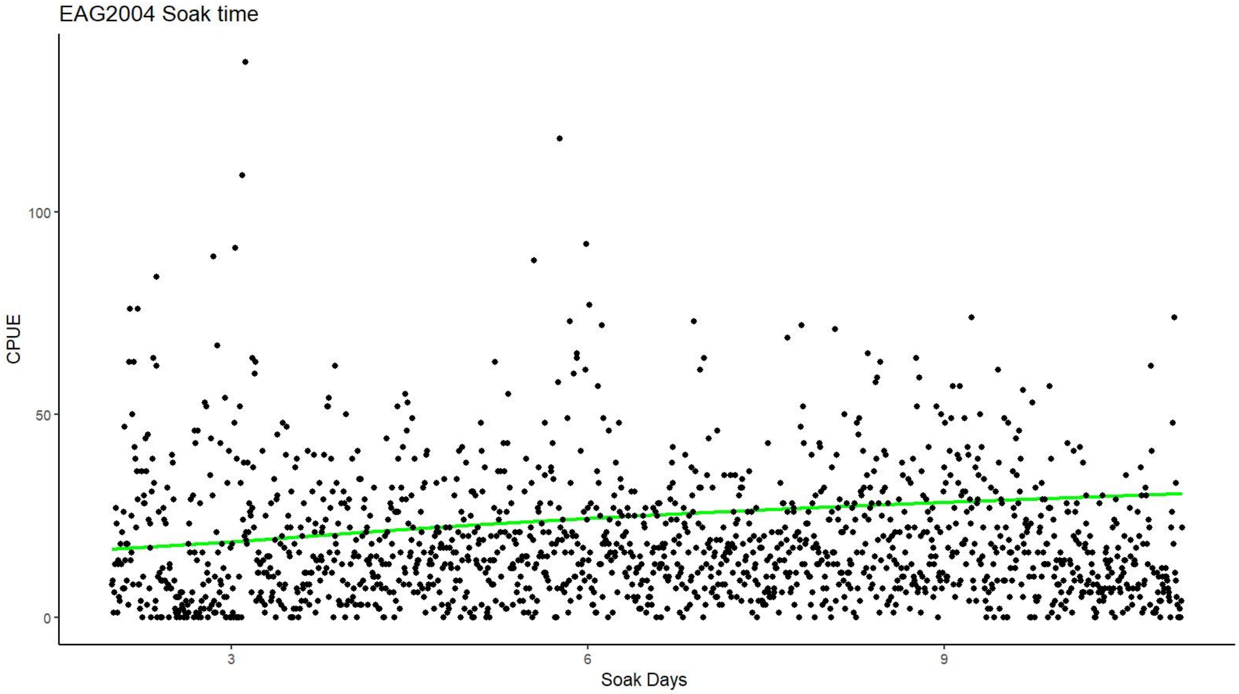


Figure A.3. Smoother fit to 2004 observed CPUE data for EAG.

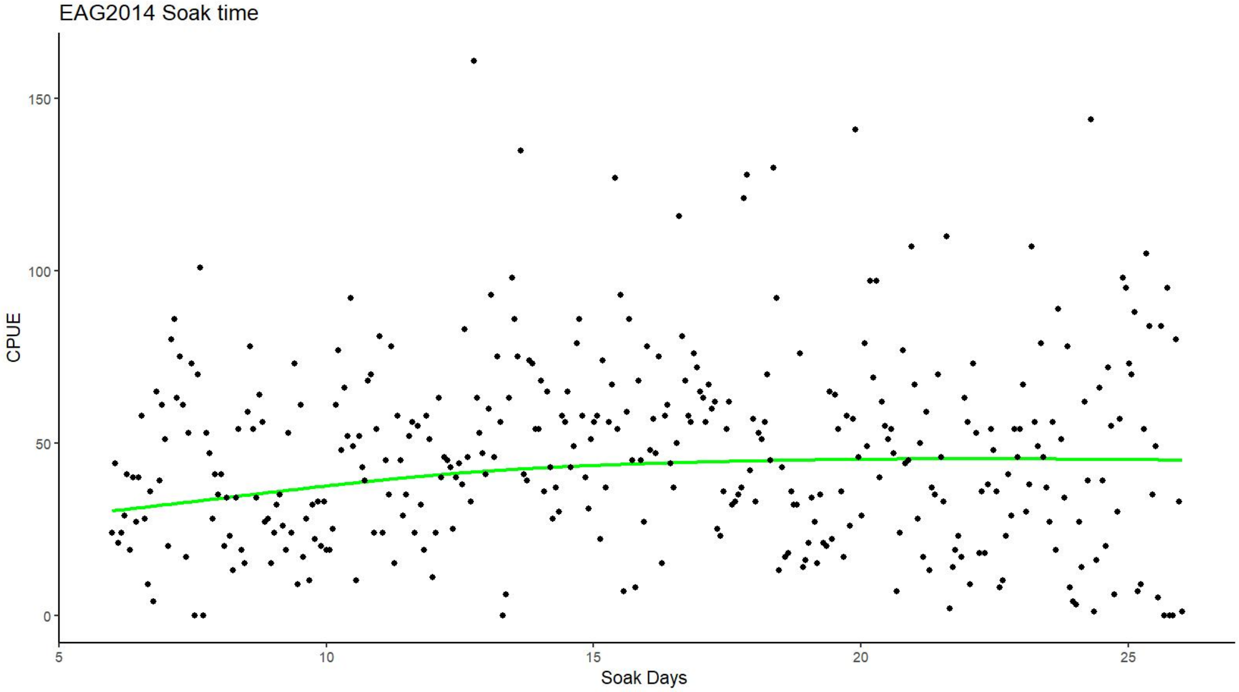


Figure A.4. Smoother fit to 2014 observed CPUE data for EAG.

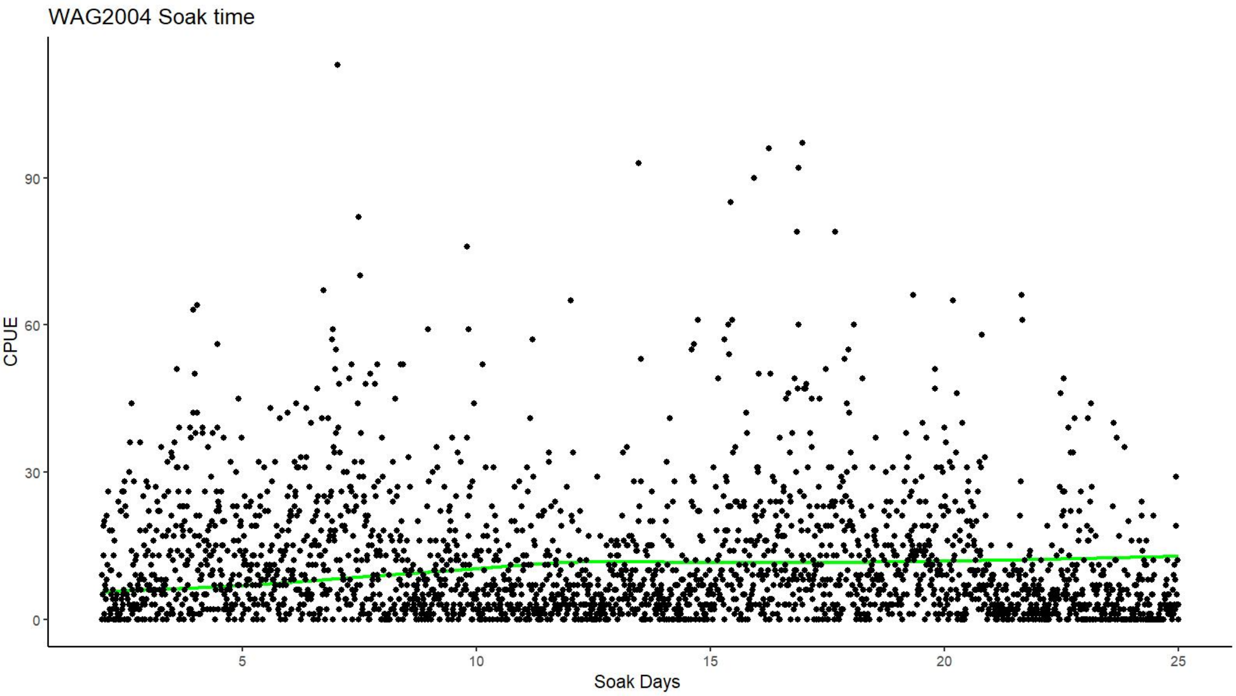


Figure A.5. Smoother fit to 2004 observed CPUE data for WAG.

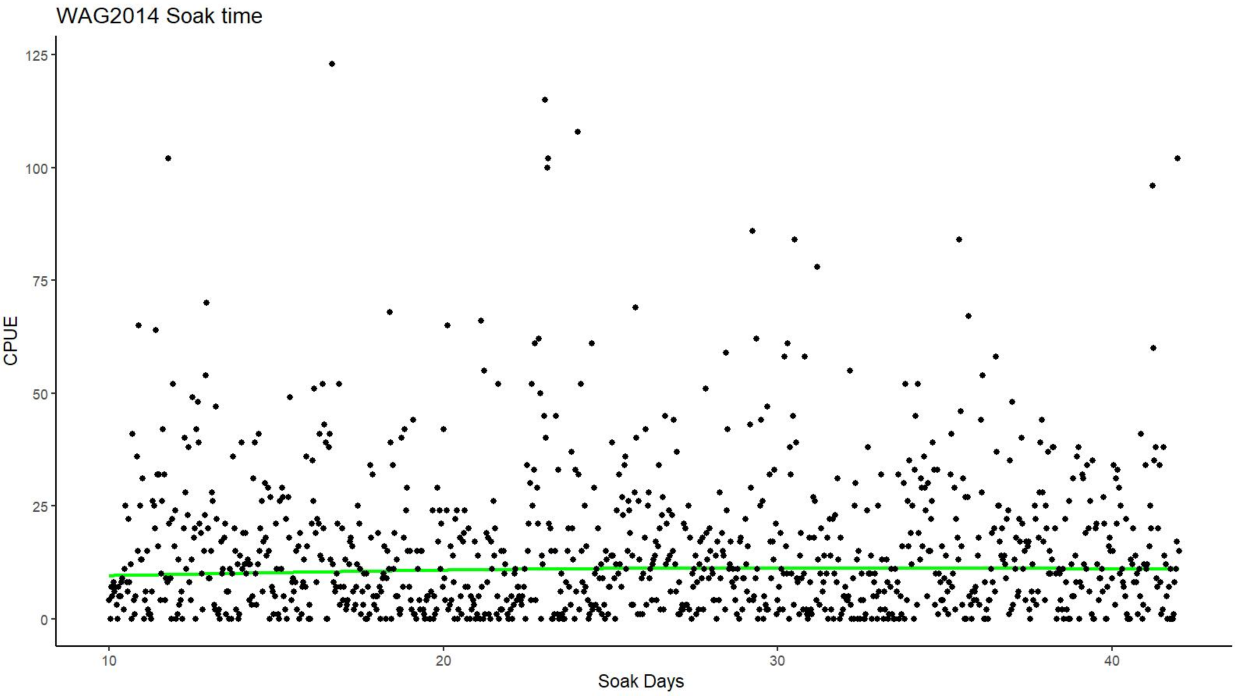


Figure A.6. Smoother fit to 2014 observed CPUE data for WAG.

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).

AIC selected high values of smoother functions' degrees of freedom for some data sets were criticized by the CPT/SSC in May/June 2021. We addressed this concern following a different approach by selecting the final CPUE model predictor variables after removing several nonsignificant variable subcomponents. In particular, the degrees of freedom of smoothers were readjusted to obtain significant degrees of freedom parameter estimates for the final CPUE model (see Tables A.2 to A.5 below).

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

For EAG 1995_04 CPUE indices:

```
library(MASS)

 library(splines)
```

Step 1:

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

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

Step 2:

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

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

The final main effect models for EAG were:

Model 21.1a:
Initial selection by stepAIC:

$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Area$
AIC=203,808

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4)$ (A.4)
for the 1995/96–2004/05 period [θ=1.38, $\mathrm{R}^2 = 0.1813, \mathrm{AIC} = 133{,}925$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 3)$
AIC=77,311

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 3)$ (A.5)
for the 2005/06–2020/21 period [$\theta = 2.32$, $\mathrm{R}^2 = 0.1027, \mathrm{AIC} = 75{,}185$].

Tables A.2 and A.3 list the summary statistics of the main effects GLM fits to 1995/96–2004/05 and 2005/06–2020/21 data series, respectively:

Table A.2. Summary statistics of the main effects GLM fit to EAG 1995/96–2004/05 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.4867	0.0417	35.6522	0.000000
Year1996	0.0195	0.0395	0.4955	0.620268
Year1997	0.1179	0.0385	3.0593	0.002222
Year1998	0.2907	0.0356	8.1664	0.000000
Year1999	0.2792	0.0374	7.4707	0.000000
Year2000	0.2199	0.0360	6.1150	0.000000
Year2001	0.5136	0.0382	13.4416	0.000000
Year2002	0.6344	0.0418	15.1926	0.000000
Year2003	0.4926	0.0405	12.1673	0.000000
Year2004	0.8981	0.0462	19.4240	0.000000
Captain133	0.3427	0.0291	11.7956	0.000000
Captain161	-0.3400	0.0569	-5.9729	0.000000
Captain204	-0.8126	0.1004	-8.0978	0.000000
Captain208	0.3052	0.1014	3.0108	0.002609
Captain210	-0.1137	0.0367	-3.0998	0.001939
Captain213	0.4689	0.0313	14.9932	0.000000
Captain219	0.3028	0.0302	10.0428	0.000000
Captain232	-0.4570	0.0505	-9.0579	0.000000
Captain240	-0.6116	0.1657	-3.6917	0.000223
Captain247	0.1122	0.0273	4.1037	0.000041
Captain271	-0.4641	0.0475	-9.7680	0.000000
Captain272	0.2183	0.0311	7.0210	0.000000
Captain287	-0.4317	0.0888	-4.8621	0.000001

Captain300	-0.4125	0.0832	-4.9559	0.000001
Captain302	0.1780	0.0330	5.3943	0.000000
Captain344	-1.3531	0.1069	-12.6579	0.000000
Captain354	0.2946	0.0500	5.8979	0.000000
Captain358	-0.8345	0.2274	-3.6699	0.000243
Captain384	0.4867	0.0283	17.2067	0.000000
Captain388	-0.7940	0.1086	-7.3140	0.000000
Captain390	0.8001	0.0437	18.3102	0.000000
ns(SoakDays, df = 4)1	0.3371	0.0323	10.4333	0.000000
ns(SoakDays, df = 4)2	0.5101	0.0364	14.0224	0.000000
ns(SoakDays, df = 4)3	0.7180	0.0621	11.5545	0.000000
ns(SoakDays, df = 4)4	0.4982	0.0535	9.3145	0.000000

Table A.3. Summary statistics of the main effects GLM fit to EAG 2005/06–2020/21 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.0056	0.0402	74.6797	0.000000
Year2006	-0.1869	0.0321	-5.8304	0.000000
Year2007	-0.0790	0.0342	-2.3074	0.021054
Year2008	-0.1017	0.0374	-2.7179	0.006583
Year2009	-0.2922	0.0428	-6.8238	0.000000
Year2010	-0.2594	0.0418	-6.2126	0.000000
Year2011	0.1061	0.0430	2.4686	0.013585
Year2012	0.0664	0.0406	1.6357	0.101936
Year2013	0.0388	0.0393	0.9876	0.323359
Year2014	0.3154	0.0432	7.3038	0.000000
Year2015	0.2576	0.0406	6.3436	0.000000
Year2016	0.0844	0.0381	2.2144	0.026828
Year2017	0.0360	0.0395	0.9120	0.361803
Year2018	0.2359	0.0446	5.2942	0.000000
Year2019	0.1723	0.0400	4.3115	0.000016
Year2020	0.0803	0.0411	1.9514	0.051039
Captain112	0.3999	0.0742	5.3911	0.000000
Captain133	0.1510	0.0271	5.5802	0.000000
Captain155	-0.5919	0.1472	-4.0194	0.000059
Captain160	0.1498	0.0320	4.6821	0.000003
Captain215	-0.1752	0.0592	-2.9591	0.003094
Captain219	0.1603	0.0244	6.5740	0.000000
Captain353	-0.4449	0.0594	-7.4953	0.000000
Captain384	0.1238	0.0448	2.7662	0.005683
Captain404	0.0977	0.0401	2.4333	0.014983
Captain405	0.9654	0.2730	3.5364	0.000408

Captain406	0.3689	0.0865	4.2641	0.000020
Captain408	-0.2410	0.0912	-2.6441	0.008206
Gear6	0.1370	0.0153	8.9336	0.000000
Gear7	0.2824	0.0268	10.5249	0.000000
Gear8	0.4400	0.1133	3.8819	0.000104
ns(SoakDays, df = 3)1	0.3039	0.0341	8.9014	0.000000
ns(SoakDays, df = 3)2	0.6289	0.0685	9.1750	0.000000
ns(SoakDays, df = 3)3	0.2108	0.0413	5.1063	0.000000

Figures A.7 and A.8 compare standardized and nominal CPUE indices for pre- and post-rationalization periods for EAG:

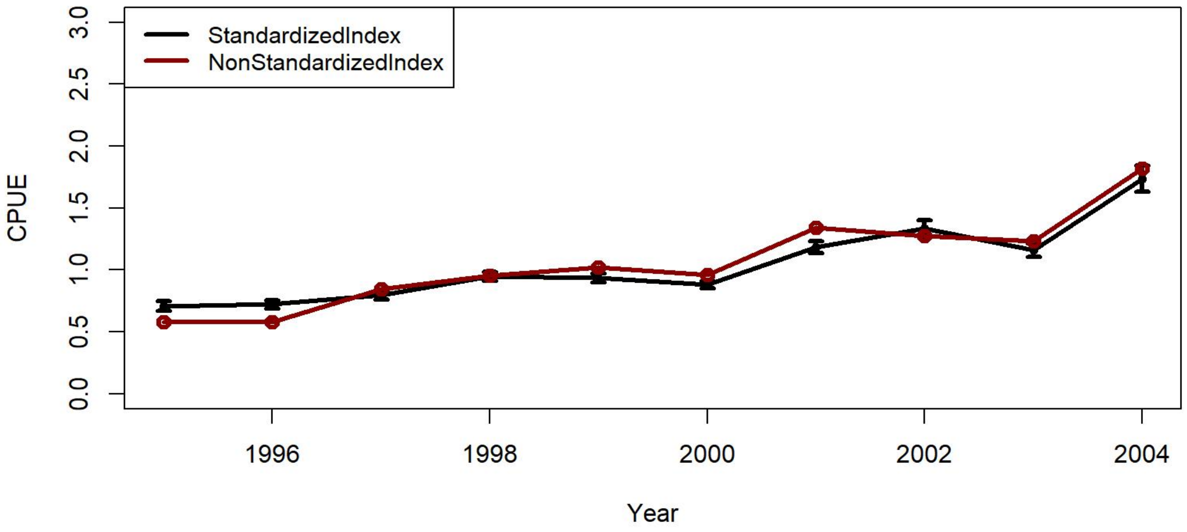


Figure A.7. Trends in non-standardized (red line) vs. standardized CPUE (black line with confidence intervals) indices during the pre-rationalization period for EAG. The confidence intervals are +/- 2 SE.

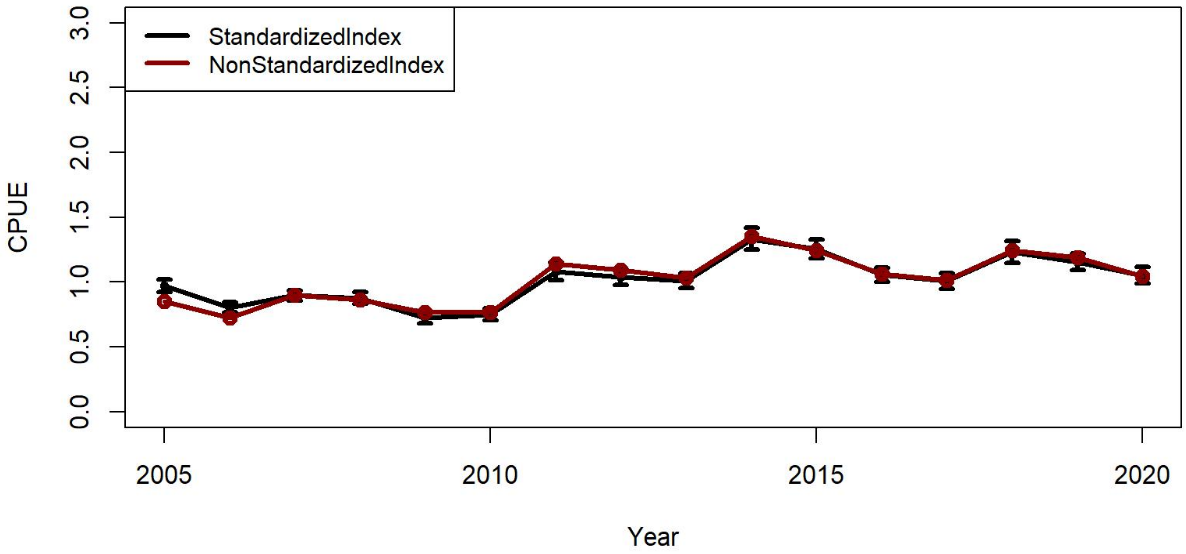


Figure A.8. Trends in non-standardized (red line) vs. standardized CPUE (black line with confidence intervals) indices during the post-rationalization period for EAG. The confidence intervals are +/- 2 SE.

The final main effect models for WAG were:

Model 21.1a:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 7) + \mathrm{Gear} + Area + Month + \mathrm{ns}(\mathrm{Depth}, 5) + Vessel$
AIC=190,897

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 7) \qquad (A.6)$$
for the 1995/96–2004/05 period [θ=0.97, $R^2 = 0.1425, \mathrm{AIC} = 146{,}246$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Vessel} + \mathrm{Month} + \mathrm{ns}(\mathrm{Soak}, 2) + \mathrm{ns}(\mathrm{Depth}, 9)$
AIC=117,799

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 2) \qquad (A.7)$$
for the 2005/06–2020/21 period [$\theta = 1.13$, $R^2 = 0.0482, \mathrm{AIC} = 117{,}673$, Soak forced in].

Tables A.4 and A.5 list the summary statistics of the main effects GLM fits to 1995/96–2004/05 and 2005/06–2020/21 data series, respectively:

Table A.4. Summary statistics of the main effects GLM fit to WAG 1995/96–2004/05 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.7843	0.0586	30.4682	0.000000
Year1996	-0.0731	0.0385	-1.9003	0.057406
Year1997	-0.0112	0.0431	-0.2610	0.794117
Year1998	0.0660	0.0501	1.3183	0.187422
Year1999	-0.0851	0.0434	-1.9612	0.049864
Year2000	-0.2193	0.0434	-5.0531	0.000000
Year2001	-0.1516	0.0468	-3.2378	0.001206
Year2002	-0.0308	0.0488	-0.6304	0.528410
Year2003	0.2503	0.0496	5.0429	0.000000
Year2004	0.2667	0.0498	5.3561	0.000000
Captain105	-0.8853	0.1828	-4.8431	0.000001
Captain108	-0.6845	0.0791	-8.6524	0.000000
Captain112	-1.0828	0.1644	-6.5853	0.000000
Captain114	-0.5768	0.0815	-7.0759	0.000000
Captain128	-0.6929	0.0510	-13.5875	0.000000
Captain130	0.2862	0.0450	6.3524	0.000000
Captain131	0.2267	0.0658	3.4462	0.000569
Captain133	-0.6598	0.0632	-10.4336	0.000000
Captain145	-0.2517	0.0440	-5.7154	0.000000
Captain156	-1.2927	0.2236	-5.7819	0.000000
Captain157	-0.4649	0.0640	-7.2670	0.000000
Captain159	-0.5926	0.2764	-2.1444	0.032010
Captain160	-0.4679	0.0458	-10.2232	0.000000
Captain182	-0.7465	0.1053	-7.0874	0.000000
Captain188	-0.4973	0.0849	-5.8597	0.000000
Captain201	-0.6832	0.0674	-10.1304	0.000000
Captain210	-0.6867	0.1217	-5.6406	0.000000
Captain219	-0.3789	0.0441	-8.6016	0.000000
Captain230	-1.0871	0.0747	-14.5505	0.000000
Captain232	-1.7885	0.2207	-8.1020	0.000000
Captain235	-1.1987	0.0754	-15.8991	0.000000
Captain244	-0.3246	0.1004	-3.2337	0.001224
Captain271	-0.8739	0.0834	-10.4819	0.000000
Captain272	-0.6511	0.0702	-9.2783	0.000000
Captain277	-0.4044	0.0792	-5.1081	0.000000
Captain287	-0.7559	0.1049	-7.2091	0.000000

Captain302	-0.6210	0.0827	-7.5112	0.000000
Captain304	-0.6541	0.0731	-8.9477	0.000000
Captain315	-0.8606	0.0863	-9.9698	0.000000
Captain318	-0.9753	0.0780	-12.5035	0.000000
Captain322	-1.4140	0.2408	-5.8730	0.000000
Captain326	-0.4077	0.0497	-8.1957	0.000000
Captain328	-0.7078	0.1657	-4.2715	0.000019
Captain332	-0.8156	0.0761	-10.7157	0.000000
Captain335	-0.4667	0.1825	-2.5572	0.010557
Captain345	-0.7582	0.1773	-4.2770	0.000019
Captain359	-0.2962	0.0809	-3.6587	0.000254
Captain363	-0.6023	0.0995	-6.0528	0.000000
Captain369	-0.8612	0.1106	-7.7869	0.000000
Captain384	-0.3961	0.0792	-5.0025	0.000001
Captain387	-1.1069	0.1218	-9.0847	0.000000
Captain389	-0.6683	0.0747	-8.9507	0.000000
Captain390	-0.3131	0.0974	-3.2147	0.001308
Captain392	-1.4343	0.2788	-5.1447	0.000000
ns(SoakDays, df = 7)1	0.1243	0.0495	2.5105	0.012063
ns(SoakDays, df = 7)2	0.3426	0.0606	5.6567	0.000000
ns(SoakDays, df = 7)3	0.4550	0.0549	8.2929	0.000000
ns(SoakDays, df = 7)4	0.7380	0.0493	14.9663	0.000000
ns(SoakDays, df = 7)5	0.6957	0.0564	12.3329	0.000000
ns(SoakDays, df = 7)6	0.7966	0.0803	9.9170	0.000000
ns(SoakDays, df = 7)7	0.7097	0.0683	10.3906	0.000000

Table A.5. Summary statistics of the main effects GLM fit to WAG 2005/06–2020/21 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.7409	0.0398	68.9145	0.000000
Year2006	-0.0208	0.0402	-0.5176	0.604752
Year2007	-0.1609	0.0394	-4.0800	0.000045
Year2008	-0.0053	0.0403	-0.1304	0.896249
Year2009	0.0520	0.0419	1.2410	0.214632
Year2010	-0.0894	0.0422	-2.1171	0.034271
Year2011	-0.0581	0.0438	-1.3250	0.185180
Year2012	-0.0756	0.0398	-1.8998	0.057474
Year2013	-0.3625	0.0392	-9.2498	0.000000
Year2014	-0.4705	0.0396	-11.8764	0.000000
Year2015	-0.4504	0.0384	-11.7403	0.000000
Year2016	-0.3174	0.0411	-7.7137	0.000000
Year2017	-0.1699	0.0439	-3.8696	0.000109

Year2018	0.0263	0.0459	0.5731	0.566572
Year2019	-0.1855	0.0425	-4.3653	0.000013
Year2020	-0.3118	0.0412	-7.5618	0.000000
Gear6	0.3004	0.0232	12.9346	0.000000
Gear7	0.3534	0.0272	13.0020	0.000000
Gear8	0.5976	0.0341	17.5139	0.000000
Gear13	1.0039	0.1840	5.4563	0.000000
Gear25	1.4570	0.3378	4.3130	0.000016
ns(SoakDays, df = 2)1	0.3401	0.0561	6.0654	0.000000
ns(SoakDays, df = 2)2	0.1445	0.0351	4.1203	0.000038

Figures A.9 and A.10 compare standardized and nominal CPUE indices for pre- and post-rationalization periods for WAG:

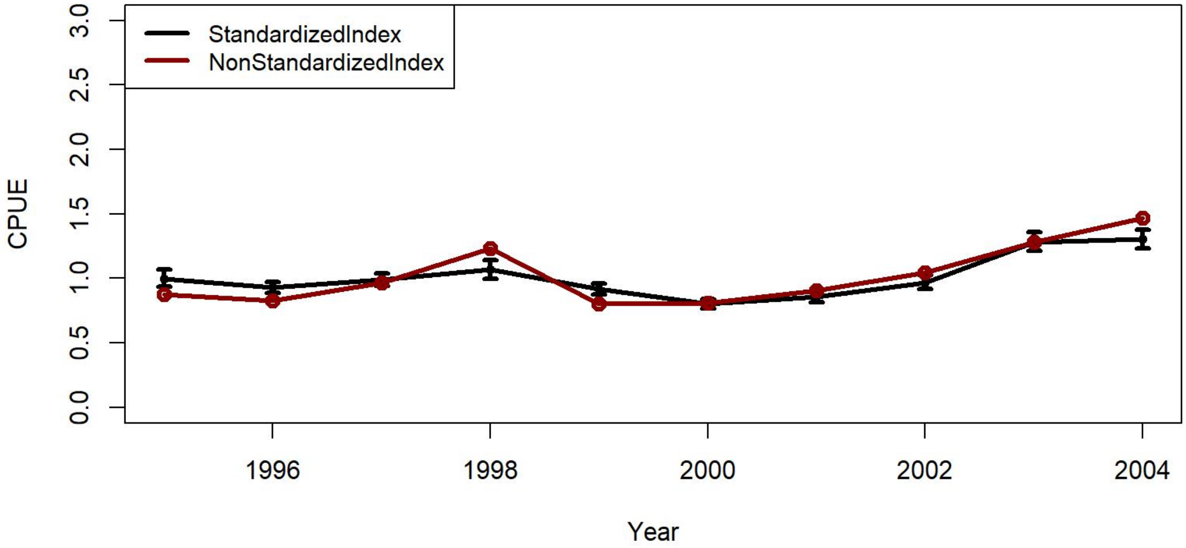


Figure A.9. Trends in non-standardized (red line) vs. standardized CPUE (black line with confidence intervals) indices during the pre-rationalization period for WAG. The confidence intervals are +/- 2 SE.

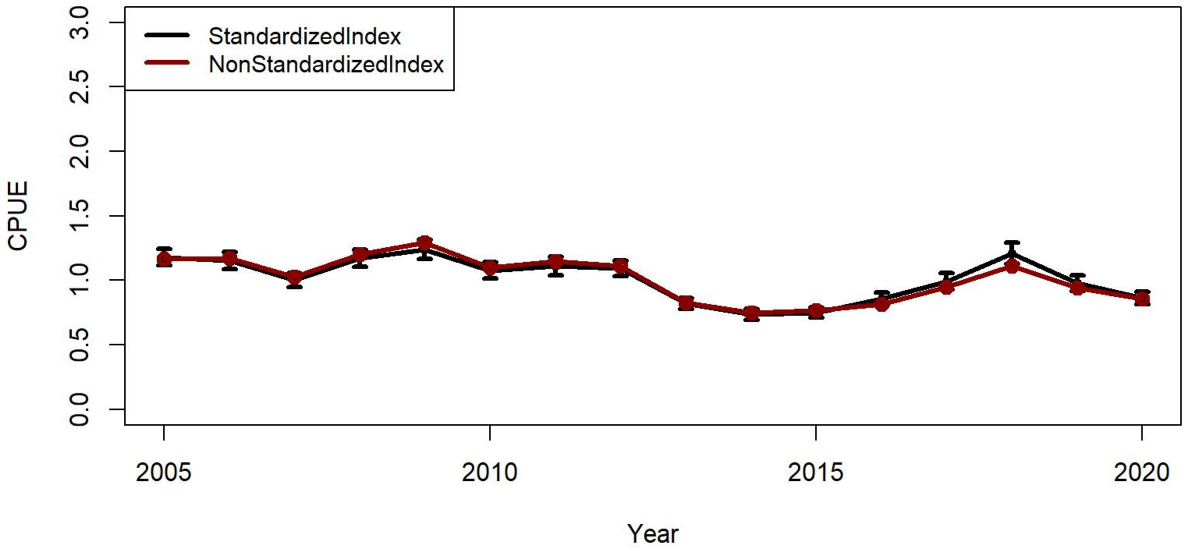


Figure A.10. Trends in non-standardized (red line) vs. standardized CPUE (black line with confidence intervals) indices during the post-rationalization period for WAG. The confidence intervals are +/- 2 SE.

b. Year:Area interaction effects GLM:

For year and area interaction analysis, we designed the areas in to 1 nmi x 1 nmi grids enmeshed in 10 larger blocks as follows. The number of blocks was restricted to a few to prevent GLM fitting problems (Figure A.11 and Table A.6).

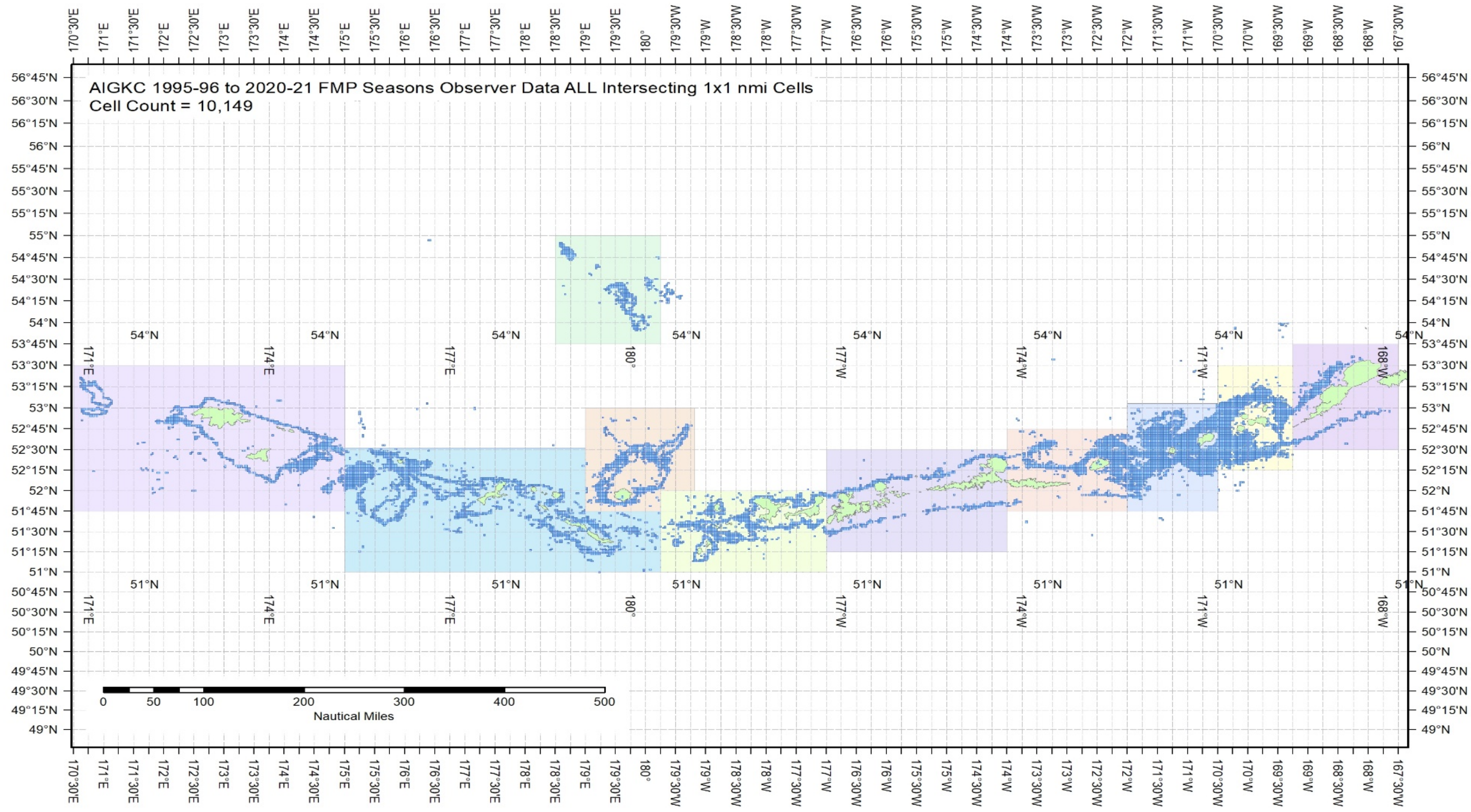


Figure A.11. The 1995/96–2020/21 observer pot samples enmeshed in 10 blocks for the Aleutian Islands golden king crab. The blocks were determined from visually exploring each year's pot distribution locations (available with the first author). The blocks contain observed patches of crab distribution during this period.

Table A.6. Number of 1 nmi x 1 nmi grids containing observer sample locations within each block by fishing year for the Aleutian Islands golden king crab, 1995/96–2020/21 data. Blocks 1–4 belong to EAG and 5–10 to WAG. Sum of ever fished number of grids for each block is listed at the bottom row.

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

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

We assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year}_{y_i}\mathrm{:Area}_{ai} \tag{A.8}$$

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

$$\ln\,(\mathrm{CPUE_I}) \ = \mathrm{Year}_{y_i}\!: Area_{ai} + \mathrm{ns}(\mathrm{Soak}_{si}, \mathrm{df}) + \mathrm{Month}_{m_i} + \mathrm{Vessel}_{vi} + \mathrm{Captain}_{ci} + \mathrm{Area}_{ai} + \mathrm{Gear}_{gi} + \mathrm{ns}(\mathrm{Depth}_{di}, \mathrm{df}). \tag{A.9}$$

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

For WAG 1995_04 CPUE indices:

```
library(MASS)

 library(splines)
```

Step 1:

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

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

Step 2:

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

 wpotsampleout<-stepCPUE(glm.object,scope=list(upper=
~(Vessel+ns(SoakDays,df=7)+Gear+Month+ns(Depth,df=5)+Year:Area),lower=
~Year:Area),family= negative.binomial(0.97),direction="forward",trace=9,r2.change=0.01)
```

The final interaction effects models for EAG were:

Model 21.1b:

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

Final selection by stepCPUE:
$$\ln(\mathrm{CPUE}) = \ \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Year\!: Area \tag{A.10}$$
for the 1995/96–2004/05 period [θ=1.38, $\mathrm{R}^2 = 0.2060$, AIC=170,920],

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Vessel} + \text{Gear} + \text{ns}(\text{Soak}, 3) + Month + Year{:}Area$
AIC=77,473

Final selection by stepCPUE:
$\ln(\text{CPUE}) = \text{Vessel} + Year{:}Area + \text{ns}(\text{Soak}, 3)$ (A.11)
for the 2005/06–2020/21 period $[\theta = 2.32,\ R^2 = 0.1047, \text{AIC} = 46{,}455, \text{Soak forced in}]$.

Tables A.6 and A.7 list the summary statistics of the interaction effects GLM fits to 1995/96–2004/05 and 2005/06–2020/21 data series, respectively:

Table A.6. Summary statistics of the interaction effects GLM fit to EAG 1995/96–2004/05 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.5926	0.0938	27.6541	0.000000
Captain105	0.1763	0.0302	5.8416	0.000000
Captain108	0.2694	0.0770	3.4977	0.000470
Captain128	0.1930	0.0383	5.0374	0.000000
Captain133	0.4112	0.0323	12.7236	0.000000
Captain145	0.2995	0.1119	2.6774	0.007425
Captain160	0.1895	0.0452	4.1907	0.000028
Captain161	0.1706	0.0677	2.5194	0.011761
Captain204	-0.4792	0.0758	-6.3175	0.000000
Captain208	0.2529	0.1007	2.5115	0.012029
Captain210	-0.0976	0.0367	-2.6588	0.007848
Captain213	0.5125	0.0312	16.4285	0.000000
Captain219	0.3765	0.0352	10.7078	0.000000
Captain232	-0.3570	0.0570	-6.2662	0.000000
Captain233	-0.1997	0.0860	-2.3231	0.020184
Captain240	-0.4844	0.1687	-2.8720	0.004083
Captain247	0.1478	0.0274	5.3913	0.000000
Captain271	-0.4623	0.0482	-9.5888	0.000000
Captain272	0.2739	0.0320	8.5506	0.000000
Captain276	0.2376	0.0572	4.1515	0.000033
Captain287	-0.2346	0.0834	-2.8116	0.004934
Captain300	-0.2967	0.0867	-3.4227	0.000621
Captain332	0.5175	0.0748	6.9136	0.000000
Captain344	-1.1827	0.2230	-5.3026	0.000000
Captain353	0.3019	0.0964	3.1310	0.001744
Captain354	0.3680	0.0558	6.5903	0.000000

Captain358	-0.8059	0.2254	-3.5750	0.000351
Captain384	0.4971	0.0284	17.4873	0.000000
Captain388	-0.6976	0.1066	-6.5436	0.000000
Captain390	1.0182	0.0623	16.3508	0.000000
Captain392	0.1242	0.0544	2.2846	0.022343
ns(SoakDays, df = 4)1	0.3006	0.0300	10.0227	0.000000
ns(SoakDays, df = 4)2	0.4499	0.0322	13.9788	0.000000
ns(SoakDays, df = 4)3	0.7053	0.0528	13.3668	0.000000
ns(SoakDays, df = 4)4	0.4991	0.0427	11.6981	0.000000
Year1995:Block1	-1.6666	0.1879	-8.8720	0.000000
Year1996:Block1	-0.7086	0.2230	-3.1772	0.001489
Year1997:Block1	-1.6974	0.1448	-11.7221	0.000000
Year1998:Block1	-1.7624	0.1669	-10.5581	0.000000
Year1999:Block1	-1.7888	0.1022	-17.4965	0.000000
Year2000:Block1	-2.5934	0.4414	-5.8753	0.000000
Year2002:Block1	-0.6584	0.2636	-2.4977	0.012506
Year1995:Block2	-0.9092	0.0993	-9.1555	0.000000
Year1996:Block2	-1.0318	0.0899	-11.4719	0.000000
Year1997:Block2	-0.7332	0.0913	-8.0322	0.000000
Year1998:Block2	-0.8568	0.0924	-9.2727	0.000000
Year1999:Block2	-0.7493	0.0913	-8.2034	0.000000
Year2000:Block2	-0.9120	0.0916	-9.9538	0.000000
Year2001:Block2	-0.5395	0.0932	-5.7908	0.000000
Year2002:Block2	-0.4806	0.0943	-5.0976	0.000000
Year2003:Block2	-0.6272	0.0927	-6.7669	0.000000
Year2004:Block2	-0.2343	0.0978	-2.3952	0.016618
Year1995:Block3	-1.3184	0.0951	-13.8670	0.000000
Year1996:Block3	-1.2736	0.0938	-13.5812	0.000000
Year1997:Block3	-1.0044	0.0973	-10.3213	0.000000
Year1998:Block3	-0.8364	0.0949	-8.8113	0.000000
Year1999:Block3	-0.8690	0.0960	-9.0495	0.000000
Year2000:Block3	-0.8673	0.0917	-9.4581	0.000000
Year2001:Block3	-0.6011	0.0929	-6.4715	0.000000
Year2002:Block3	-0.5602	0.0961	-5.8317	0.000000
Year2003:Block3	-0.6735	0.0972	-6.9293	0.000000
Year2004:Block3	-0.2005	0.1057	-1.8962	0.057932
Year1995:Block4	-1.2762	0.0978	-13.0518	0.000000
Year1996:Block4	-1.7048	0.1020	-16.7190	0.000000
Year1997:Block4	-1.5322	0.0994	-15.4188	0.000000
Year1998:Block4	-0.7937	0.1015	-7.8216	0.000000
Year1999:Block4	-0.8464	0.1089	-7.7675	0.000000
Year2000:Block4	-0.5678	0.0904	-6.2796	0.000000

Year2001:Block4	-0.4441	0.0937	-4.7409	0.000002
Year2002:Block4	-0.6174	0.1029	-6.0017	0.000000
Year2003:Block4	-0.6951	0.0978	-7.1065	0.000000

Table A.7. Summary statistics of the interaction effects GLM fit to EAG 2005/06–2020/21 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.2208	0.4366	7.3766	0.000000
Vessel3645	-0.4678	0.0654	-7.1557	0.000000
Vessel8653	-0.2262	0.0614	-3.6833	0.000233
Vessel20556	0.0410	0.0220	1.8601	0.062927
Vessel62436	-0.6778	0.0643	-10.5349	0.000000
ns(SoakDays, df = 3)1	0.2237	0.0449	4.9834	0.000001
ns(SoakDays, df = 3)2	0.6423	0.0818	7.8537	0.000000
ns(SoakDays, df = 3)3	0.2361	0.0530	4.4571	0.000008
Year2013:Block1	-0.1279	0.5334	-0.2398	0.810470
Year2019:Block1	-1.7949	0.8255	-2.1743	0.029725
Year2020:Block1	-0.5415	0.5054	-1.0714	0.284041
Year2005:Block2	-0.0134	0.4379	-0.0305	0.975666
Year2006:Block2	-0.2225	0.4388	-0.5070	0.612141
Year2007:Block2	-0.2192	0.4384	-0.5001	0.617031
Year2008:Block2	-0.3664	0.4401	-0.8327	0.405068
Year2009:Block2	-0.1183	0.4605	-0.2569	0.797284
Year2010:Block2	-0.1414	0.4446	-0.3181	0.750422
Year2011:Block2	0.1617	0.4400	0.3676	0.713194
Year2012:Block2	0.1277	0.4391	0.2907	0.771278
Year2013:Block2	0.0668	0.4392	0.1521	0.879141
Year2014:Block2	0.1903	0.4397	0.4327	0.665255
Year2015:Block2	0.0900	0.4390	0.2049	0.837660
Year2016:Block2	-0.0277	0.4403	-0.0628	0.949890
Year2017:Block2	-0.1071	0.4396	-0.2435	0.807595
Year2018:Block2	0.2189	0.4395	0.4981	0.618469
Year2019:Block2	0.1784	0.4383	0.4071	0.683970
Year2020:Block2	-0.0306	0.4380	-0.0699	0.944300
Year2005:Block3	-0.0136	0.4393	-0.0309	0.975336
Year2006:Block3	-0.0854	0.4380	-0.1949	0.845489
Year2007:Block3	-0.1782	0.4364	-0.4083	0.683052
Year2008:Block3	-0.2085	0.4378	-0.4762	0.633955
Year2009:Block3	-0.3800	0.4414	-0.8609	0.389329
Year2010:Block3	-0.1719	0.4434	-0.3876	0.698323
Year2011:Block3	0.0206	0.4428	0.0464	0.962961
Year2012:Block3	-0.1577	0.4425	-0.3564	0.721524

Year2013:Block3	0.0818	0.4402	0.1859	0.852513
Year2014:Block3	0.2426	0.4421	0.5488	0.583132
Year2015:Block3	0.0734	0.4420	0.1662	0.868026
Year2016:Block3	0.1711	0.4395	0.3893	0.697098
Year2017:Block3	-0.1834	0.4411	-0.4159	0.677517
Year2018:Block3	0.0341	0.4413	0.0773	0.938363
Year2019:Block3	0.2339	0.4390	0.5328	0.594197
Year2020:Block3	-0.0439	0.4407	-0.0995	0.920732
Year2005:Block4	0.2012	0.4379	0.4595	0.645879
Year2006:Block4	-0.1929	0.4372	-0.4413	0.659011
Year2007:Block4	-0.0009	0.4367	-0.0020	0.998387
Year2008:Block4	-0.2204	0.4389	-0.5021	0.615607
Year2009:Block4	-0.3157	0.4407	-0.7164	0.473752
Year2010:Block4	-0.4546	0.4413	-1.0301	0.302999
Year2011:Block4	-0.0189	0.4455	-0.0423	0.966238
Year2012:Block4	-0.0290	0.4415	-0.0657	0.947588
Year2013:Block4	-0.0547	0.4404	-0.1242	0.901158
Year2014:Block4	0.1934	0.4426	0.4369	0.662205
Year2015:Block4	0.0861	0.4405	0.1955	0.845004
Year2016:Block4	0.2352	0.4412	0.5332	0.593951
Year2017:Block4	-0.0031	0.4506	-0.0068	0.994545

The final interaction effects models for WAG were:

Model 21.1b:
Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + \mathrm{ns}(\mathrm{Soak}, 7) + Gear + Month + \mathrm{ns}(\mathrm{Depth}, 5) + Year\colon Area$

AIC=191,018

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + \mathrm{ns}(\mathrm{Soak}, 7) + Year\colon Area \tag{A.12}$$

for the 1995/96–2004/05 period [θ=0.97, $\mathrm{R}^2 = 0.1657, \mathrm{AIC} = 147{,}887$]

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Gear} + \mathrm{Vessel} + \mathrm{Month} + ns(Soak, 2) + ns(Depth, df = 9) + Year\colon Area$
AIC=120,656

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Gear} + Year\colon Area + ns(Soak, 2) \tag{A.13}$$

for the 2005/06–2020/21 period $[\theta = 1.13,\ R^2 = 0.0862, \mathrm{AIC} = 76{,}797, \text{Soak forced in}]$.

Tables A.8 and A.9 list the summary statistics of the interaction effects GLM fits to 1995/96–2004/05 and 2005/06–2020/21 data series, respectively:

Table A.8. Summary statistics of the interaction effects GLM fit to WAG 1995/96–2004/05 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.9199	0.1981	4.6434	0.000003
Vessel5992	-0.3046	0.0875	-3.4794	0.000503
Vessel6205	0.1216	0.0514	2.3682	0.017885
Vessel8653	0.2662	0.0470	5.6674	0.000000
Vessel9069	-0.4239	0.0568	-7.4616	0.000000
Vessel21436	-3.1442	1.1084	-2.8368	0.004561
Vessel35767	0.3836	0.0417	9.1944	0.000000
Vessel37887	0.7365	0.0412	17.8893	0.000000
Vessel39002	0.2081	0.0441	4.7224	0.000002
Vessel55124	-0.2914	0.0786	-3.7074	0.000210
Vessel59521	-0.5079	0.2203	-2.3057	0.021138
Vessel62436	-0.6407	0.0600	-10.6766	0.000000
ns(SoakDays, df = 7)1	0.2492	0.0561	4.4416	0.000009
ns(SoakDays, df = 7)2	0.5629	0.0624	9.0225	0.000000
ns(SoakDays, df = 7)3	0.7102	0.0514	13.8103	0.000000
ns(SoakDays, df = 7)4	0.7943	0.0512	15.5159	0.000000
ns(SoakDays, df = 7)5	0.8458	0.0568	14.8795	0.000000
ns(SoakDays, df = 7)6	1.0300	0.0872	11.8133	0.000000
ns(SoakDays, df = 7)7	0.9588	0.0661	14.5013	0.000000
Year1995:Block5	0.2784	0.2113	1.3177	0.187616
Year1996:Block5	0.4299	0.2173	1.9782	0.047917
Year1997:Block5	-0.0802	0.2022	-0.3966	0.691639
Year1998:Block5	-0.0851	0.3111	-0.2735	0.784457
Year1999:Block5	-0.3666	0.2117	-1.7321	0.083268
Year2000:Block5	-0.0737	0.2067	-0.3566	0.721419
Year2001:Block5	0.0936	0.2488	0.3761	0.706842
Year2002:Block5	0.0640	0.2599	0.2461	0.805606
Year2003:Block5	0.8138	0.4471	1.8200	0.068769
Year2004:Block5	-0.9071	0.3897	-2.3279	0.019925
Year1995:Block6	0.4224	0.1975	2.1391	0.032438
Year1996:Block6	0.4019	0.1960	2.0509	0.040290
Year1997:Block6	0.2397	0.1960	1.2230	0.221324
Year1998:Block6	0.2061	0.1974	1.0440	0.296496
Year1999:Block6	0.0811	0.1950	0.4157	0.677618

Year2000:Block6	0.0073	0.1952	0.0376	0.969968
Year2001:Block6	-0.1651	0.1971	-0.8378	0.402143
Year2002:Block6	-0.0752	0.1988	-0.3782	0.705263
Year2003:Block6	0.0387	0.2006	0.1928	0.847092
Year2004:Block6	0.3405	0.1981	1.7187	0.085681
Year1995:Block7	0.7610	0.2035	3.7401	0.000184
Year1996:Block7	0.4769	0.1963	2.4288	0.015156
Year1997:Block7	0.2156	0.2033	1.0607	0.288835
Year1998:Block7	0.5827	0.2007	2.9026	0.003704
Year1999:Block7	0.2610	0.2004	1.3022	0.192849
Year2000:Block7	-0.0515	0.2116	-0.2435	0.807627
Year2001:Block7	0.0720	0.1983	0.3631	0.716530
Year2002:Block7	0.0268	0.1986	0.1350	0.892639
Year2003:Block7	-0.2107	0.2019	-1.0436	0.296702
Year2004:Block7	-0.1077	0.2070	-0.5204	0.602790
Year1995:Block8	0.4407	0.1974	2.2324	0.025596
Year1996:Block8	0.1612	0.1950	0.8268	0.408348
Year1997:Block8	0.2143	0.1952	1.0979	0.272247
Year1998:Block8	0.2783	0.1994	1.3961	0.162689
Year1999:Block8	0.1986	0.1989	0.9989	0.317841
Year2000:Block8	-0.1799	0.2047	-0.8788	0.379534
Year2001:Block8	-0.1757	0.1978	-0.8884	0.374344
Year2002:Block8	0.2407	0.1984	1.2136	0.224924
Year2003:Block8	0.3854	0.1957	1.9691	0.048954
Year2004:Block8	0.5986	0.1971	3.0376	0.002387
Year1996:Block9	0.2707	0.2259	1.1984	0.230789
Year1997:Block9	0.6695	0.2109	3.1752	0.001499
Year1998:Block9	0.3100	0.2117	1.4641	0.143172
Year1999:Block9	0.4255	0.2248	1.8931	0.058351
Year2000:Block9	0.6374	0.2059	3.0957	0.001966
Year2001:Block9	-0.0225	0.2331	-0.0965	0.923099
Year2002:Block9	0.3032	0.2327	1.3029	0.192620
Year2003:Block9	0.7034	0.2036	3.4540	0.000553
Year2004:Block9	0.5940	0.2037	2.9166	0.003542

Table A.9. Summary statistics of the interaction effects GLM fit to WAG 2005/06–2020/21 data.

Parameters	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.8164	0.1584	11.4709	0.000000
Gear6	0.3374	0.0318	10.6048	0.000000

Gear7	0.3843	0.0355	10.8193	0.000000
Gear8	0.6964	0.0455	15.3021	0.000000
Gear13	1.1981	0.2382	5.0294	0.000001
Gear25	1.3304	0.3332	3.9928	0.000066
ns(SoakDays, df = 2)1	0.3087	0.0766	4.0289	0.000057
ns(SoakDays, df = 2)2	0.0715	0.0435	1.6425	0.100526
Year2006:Block5	-0.7925	0.4248	-1.8657	0.062120
Year2007:Block5	-0.8394	0.3129	-2.6827	0.007315
Year2009:Block5	1.9197	0.8850	2.1691	0.030103
Year2014:Block5	1.1934	0.2715	4.3949	0.000011
Year2015:Block5	-0.5197	0.2508	-2.0724	0.038257
Year2016:Block5	0.1773	0.3785	0.4683	0.639596
Year2017:Block5	1.0826	0.3501	3.0920	0.001994
Year2018:Block5	1.0906	0.4253	2.5643	0.010355
Year2005:Block6	1.0915	0.1674	6.5213	0.000000
Year2006:Block6	0.8692	0.1666	5.2171	0.000000
Year2007:Block6	0.6661	0.1667	3.9955	0.000065
Year2008:Block6	0.7828	0.1699	4.6073	0.000004
Year2009:Block6	0.5742	0.1761	3.2617	0.001111
Year2010:Block6	0.4267	0.1757	2.4286	0.015175
Year2011:Block6	0.9623	0.1776	5.4190	0.000000
Year2012:Block6	0.9363	0.1755	5.3345	0.000000
Year2013:Block6	0.7252	0.1751	4.1405	0.000035
Year2014:Block6	0.5758	0.1778	3.2377	0.001209
Year2015:Block6	0.5593	0.1735	3.2237	0.001270
Year2016:Block6	0.4234	0.1787	2.3690	0.017856
Year2017:Block6	0.9864	0.1807	5.4574	0.000000
Year2018:Block6	1.2769	0.1817	7.0266	0.000000
Year2005:Block7	0.8233	0.1855	4.4388	0.000009
Year2006:Block7	0.7355	0.1988	3.6996	0.000217
Year2007:Block7	0.8960	0.1817	4.9324	0.000001
Year2008:Block7	0.9549	0.1831	5.2159	0.000000
Year2009:Block7	1.1074	0.1805	6.1338	0.000000
Year2010:Block7	0.8976	0.1824	4.9223	0.000001
Year2011:Block7	0.8602	0.1862	4.6196	0.000004
Year2012:Block7	1.1296	0.1788	6.3161	0.000000
Year2013:Block7	0.7104	0.1845	3.8497	0.000119
Year2014:Block7	0.6683	0.1808	3.6963	0.000220
Year2015:Block7	0.3638	0.1774	2.0503	0.040360
Year2016:Block7	0.5057	0.1793	2.8207	0.004802
Year2017:Block7	0.5153	0.1862	2.7677	0.005656

Year2018:Block7	0.9848	0.1838	5.3582	0.000000
Year2019:Block7	0.7804	0.1796	4.3449	0.000014
Year2020:Block7	0.7788	0.1792	4.3464	0.000014
Year2005:Block8	0.8919	0.1675	5.3254	0.000000
Year2006:Block8	0.8626	0.1712	5.0388	0.000000
Year2007:Block8	0.9372	0.1744	5.3746	0.000000
Year2008:Block8	1.0895	0.1726	6.3128	0.000000
Year2009:Block8	1.1043	0.1712	6.4488	0.000000
Year2010:Block8	0.9542	0.1684	5.6674	0.000000
Year2011:Block8	0.9308	0.1702	5.4698	0.000000
Year2012:Block8	0.7119	0.1677	4.2446	0.000022
Year2013:Block8	0.4717	0.1682	2.8045	0.005049
Year2014:Block8	0.4053	0.1673	2.4223	0.015443
Year2015:Block8	0.5327	0.1688	3.1556	0.001607
Year2016:Block8	0.6549	0.1724	3.7980	0.000147
Year2017:Block8	0.5736	0.1712	3.3511	0.000808
Year2018:Block8	0.7707	0.1757	4.3852	0.000012
Year2019:Block8	0.7001	0.1662	4.2118	0.000026
Year2020:Block8	0.7245	0.1656	4.3749	0.000012
Year2005:Block9	0.7498	0.2241	3.3462	0.000822
Year2006:Block9	1.1511	0.2109	5.4587	0.000000
Year2007:Block9	0.8563	0.2683	3.1916	0.001419
Year2010:Block9	1.0404	0.5366	1.9390	0.052534
Year2011:Block9	0.9847	0.6434	1.5304	0.125962
Year2012:Block9	0.9403	0.2122	4.4305	0.000010
Year2013:Block9	0.4727	0.2232	2.1177	0.034228
Year2014:Block9	0.3945	0.2208	1.7866	0.074036
Year2015:Block9	0.1396	0.3096	0.4510	0.651994
Year2016:Block9	0.5725	0.1914	2.9911	0.002787
Year2017:Block9	0.9833	0.1759	5.5915	0.000000
Year2018:Block9	0.9785	0.1730	5.6559	0.000000
Year2019:Block9	0.4590	0.1666	2.7552	0.005877
Year2020:Block9	-0.1047	0.1769	-0.5918	0.553990
Year2015:Block10	0.4726	0.2136	2.2121	0.026986

Steps:

1. *Block-scale analysis*:

   The bias corrected estimate of CPUE index for each Year-Area (Area=Block) interaction was first obtained as:

$$CPUE_{ij} = e^{YB_{ij} + \sigma_{ij}^2/2} \tag{A.14}$$

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

The abundance index for jth block in ith year is

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

Notice in Table A.6 that none or very few observer samplings occurred in certain years for a whole block. We filled the B_{ij} index gaps resulting from Year:Area CPUE standardization model fit as follows:

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

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

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

library(MASS)

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

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

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

To predict the missing biomass index Y:

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

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

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

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

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

Annual biomass index, B_i , was estimated as,

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

The variance of the total biomass index was computed as:

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

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

To use in the assessment model 21.1b, we rescaled the B_i indices by the geometric mean of estimated B_i values (Equation A.17) separately for the pre- and post-rationalization periods. The corresponding standard error (~CV) of B_i was estimated by

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

The rescaled biomass indices with standard errors are listed in Table A.10 for EAG and Table A.11 for WAG.

Table A.10. Steps to estimate biomass-based abundance indices with standard errors for 1995/96–2020/21 in EAG. GMScaled B_index and B_Index SE were used as CPUE index and its standard error.

Year	B_Index	GMScaled B_Index	Var(B_index)	Var(B_Index)/(B_Index)^2	B_Index SE
1995	1379.633	0.691	61573.282	0.032	0.180
1996	1365.166	0.684	60106.142	0.032	0.180
1997	1605.361	0.804	58137.446	0.023	0.150
1998	1860.742	0.932	58418.764	0.017	0.130
1999	1880.171	0.941	57513.803	0.016	0.128
2000	1874.802	0.939	78660.880	0.022	0.150
2001	2528.159	1.266	62464.339	0.010	0.099
2002	2600.496	1.302	66082.978	0.010	0.099
2003	2243.100	1.123	65590.905	0.013	0.114
2004	3452.219	1.729	144799.925	0.012	0.110

2005	4917.372	1.062	1163624.359	0.048	0.219
2006	4049.173	0.875	1160862.952	0.071	0.266
2007	4073.086	0.880	1155171.590	0.070	0.264
2008	3636.378	0.786	1163779.482	0.088	0.297
2009	3626.917	0.784	1211346.496	0.092	0.303
2010	3806.297	0.822	1189199.573	0.082	0.287
2011	5040.150	1.089	1182514.876	0.047	0.216
2012	4621.799	0.998	1177368.913	0.055	0.235
2013	5136.348	1.110	1205726.963	0.046	0.214
2014	5862.202	1.266	1177918.301	0.034	0.185
2015	5136.051	1.110	1174885.547	0.045	0.211
2016	5352.054	1.156	1170521.737	0.041	0.202
2017	4226.525	0.913	1180886.859	0.066	0.257
2018	5346.671	1.155	1035892.222	0.036	0.190
2019	5317.395	1.149	1114827.923	0.039	0.199
2020	4709.373	1.017	1057118.666	0.048	0.218

Table A.11. Steps to estimate biomass-based abundance indices with standard errors for 1995/96–2020/21 in WAG. GMScaled B_index and B_Index SE were used as CPUE index and its standard error.

Year	B_Index	GMScaled B_Index	Var(B_index)	Var(B_Index)/(B_Index)^2	B_Index SE
1995	9496.922	1.346	269653.315	0.003	0.055
1996	7378.444	1.046	282106.082	0.005	0.072
1997	7352.241	1.042	275944.700	0.005	0.071
1998	7319.828	1.038	294756.661	0.006	0.074
1999	6621.496	0.939	287827.355	0.007	0.081
2000	5953.261	0.844	291509.455	0.008	0.091
2001	5027.783	0.713	294052.109	0.012	0.108
2002	6343.625	0.899	296725.139	0.007	0.086
2003	8014.390	1.136	308791.673	0.005	0.069
2004	8024.629	1.138	301091.007	0.005	0.068
2005	14217.841	1.109	261342.165	0.001	0.036
2006	13432.365	1.048	285073.428	0.002	0.040
2007	12755.536	0.995	296740.441	0.002	0.043
2008	15418.982	1.203	300907.002	0.001	0.036
2009	20944.373	1.634	429892.086	0.001	0.031
2010	14234.971	1.110	512600.828	0.003	0.050
2011	15460.033	1.206	648156.872	0.003	0.052
2012	14155.450	1.104	257682.434	0.001	0.036
2013	10298.831	0.803	264483.182	0.002	0.050
2014	10571.862	0.825	261535.472	0.002	0.048
2015	8527.265	0.665	285388.593	0.004	0.063

2016	10099.723	0.788	270564.352	0.003	0.052
2017	13139.793	1.025	260852.220	0.002	0.039
2018	15980.111	1.246	278353.271	0.001	0.033
2019	11131.903	0.868	291060.530	0.002	0.048
2020	9929.760	0.774	293822.916	0.003	0.055

Figures A.12 and A.13 compare the non-interaction and interaction effects GLM derived CPUE indices for EAG and WAG, respectively. The estimated indices by the two effects are similar but the confidence intervals for interaction effects are wider than that for main effects.

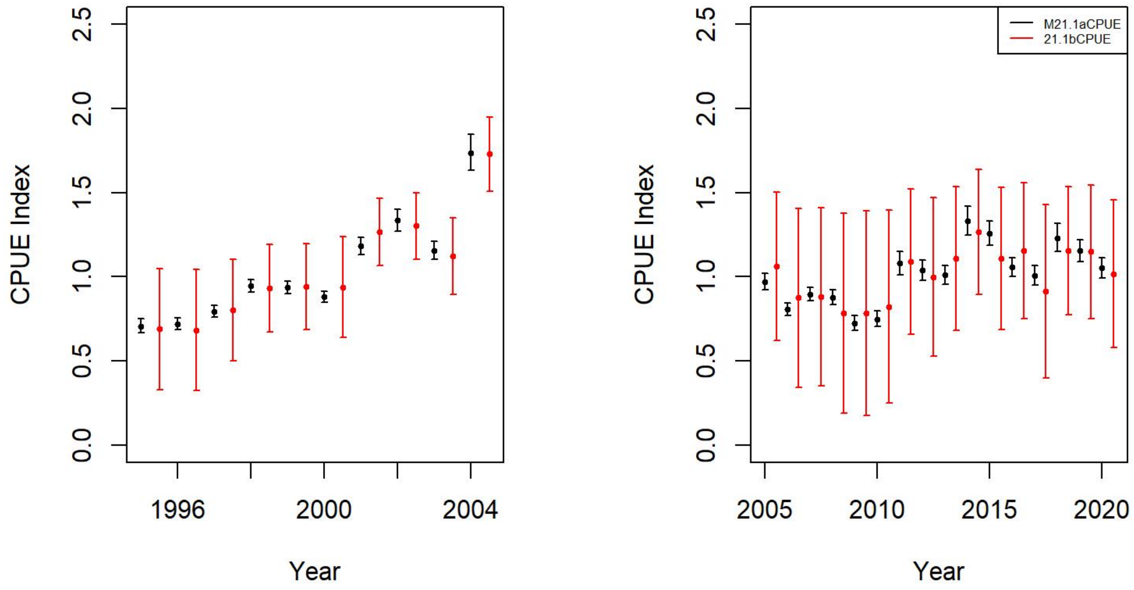


Figure A.12. Main effects (black) vs. interaction effects (red) CPUE indices during pre- (left panel) and post (right panel)-rationalization periods for EAG. The confidence intervals are +/- 2 SE.

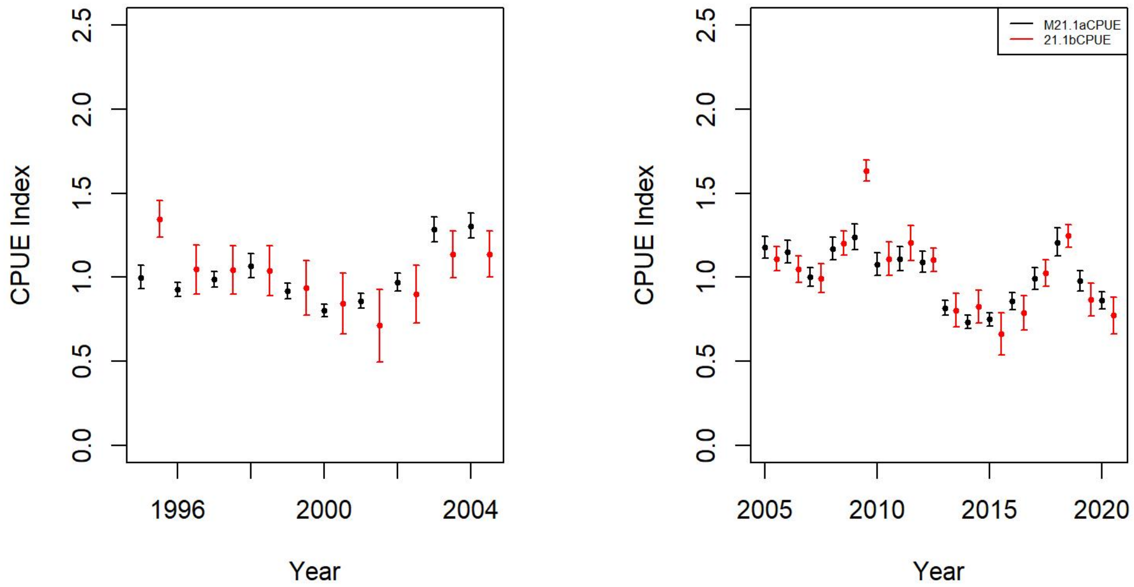


Figure A.13. Main effects (black) vs. interaction effects (red) CPUE indices during pre- (left panel) and post (right panel)-rationalization periods for WAG. The confidence intervals are +/- 2 SE.

c. Non-interaction GLM model without one vessel's data

As per industry request, we calculated non-interaction CPUE indices for pre- and post-rationalization periods after removing a vessel's data (confidential vessel identity). This analysis was done for WAG.

The final main effect models for WAG were:

Model 21.1a:
Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 5) + \text{Gear} + Area + Month + \text{ns}(\text{Depth}, 5) + Vessel$
AIC=188,469

Final selection by stepCPUE:
$$\ln(\text{CPUE}) = \text{Year} + \text{ns}(\text{Soak}, 5) + Area \tag{A.20}$$
for the 1995/96–2004/05 period [θ=0.97, $\text{R}^2 = 0.1478, \text{AIC} = 17{,}432$]

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{Month} + \text{ns}(\text{Depth}, 6) + \text{ns}(\text{Soak}, 2)$
AIC=120,331

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 2) \tag{A.21}$$

for the 2005/06–2020/21 period [$\theta = 1.13$, $R^2 = 0.0538$, $\mathrm{AIC} = 117{,}597$, Soak forced in].

Tables A.12 and A.13 list the summary statistics of the main effects GLM fits to 1995/96–2004/05 and 2005/06–2020/21 data series, respectively:

Table A.12. Summary statistics of the main effects GLM fit to WAG 1995/96–2004/05 data.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.9459	1.1432	-1.7021	0.088821
Year1996	2.1546	1.1490	1.8753	0.060839
Year1997	2.7023	1.1472	2.3555	0.018551
Year1998	2.5409	1.1549	2.2001	0.027869
Year1999	2.0416	1.1481	1.7782	0.075455
Year2000	2.7003	1.1475	2.3532	0.018670
Year2001	2.8701	1.1505	2.4946	0.012655
Year2002	2.6392	1.1497	2.2956	0.021756
Year2003	2.7290	1.1518	2.3694	0.017870
Year2004	2.7558	1.1489	2.3987	0.016507
ns(SoakDays, df = 5)1	0.5816	0.1036	5.6145	0.000000
ns(SoakDays, df = 5)2	0.2478	0.1218	2.0342	0.042006
ns(SoakDays, df = 5)3	1.1716	0.1436	8.1595	0.000000
ns(SoakDays, df = 5)4	0.7868	0.1469	5.3567	0.000000
ns(SoakDays, df = 5)5	0.6941	0.1427	4.8636	0.000001
Block8	0.2165	0.0962	2.2510	0.024448
Block9	0.4628	0.0820	5.6456	0.000000
Block10	0.9291	0.0843	11.0261	0.000000

Table A.13. Summary statistics of the main effects GLM fit to WAG 2005/06–2020/21 data.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.2212	0.1770	12.5495	0.000000
Year2006	-0.0569	0.0470	-1.2110	0.225915
Year2007	-0.1741	0.0523	-3.3287	0.000875
Year2008	-0.0388	0.0432	-0.8986	0.368856
Year2009	0.0107	0.0435	0.2460	0.805714
Year2010	-0.1360	0.0451	-3.0174	0.002554
Year2011	-0.0778	0.0468	-1.6632	0.096297
Year2012	-0.0472	0.0458	-1.0311	0.302492
Year2013	-0.3871	0.0474	-8.1736	0.000000
Year2014	-0.4423	0.0515	-8.5808	0.000000
Year2015	-0.4587	0.0504	-9.1008	0.000000

Year2016	-0.3312	0.0515	-6.4311	0.000000
Year2017	-0.1799	0.0557	-3.2313	0.001235
Year2018	0.0389	0.0569	0.6830	0.494603
Year2019	-0.1950	0.0519	-3.7556	0.000174
Year2020	-0.3312	0.0510	-6.4902	0.000000
Captain104	0.4572	0.1783	2.5649	0.010330
Captain131	0.4789	0.1795	2.6678	0.007643
Captain133	0.6408	0.1813	3.5342	0.000410
Captain145	0.6813	0.1761	3.8696	0.000109
Captain166	0.5354	0.1770	3.0245	0.002495
Captain215	0.4562	0.1961	2.3267	0.019994
Captain257	0.4944	0.1828	2.7044	0.006851
Captain336	0.4551	0.1855	2.4541	0.014134
Captain384	0.4465	0.1861	2.3996	0.016423
Captain403	0.5965	0.1793	3.3262	0.000882
Captain404	0.5224	0.1837	2.8437	0.004466
Captain405	0.5968	0.1806	3.3044	0.000954
Gear6	0.2772	0.0260	10.6599	0.000000
Gear7	0.3227	0.0289	11.1472	0.000000
Gear8	0.5816	0.0355	16.3646	0.000000
Gear13	0.8796	0.1842	4.7758	0.000002
Gear25	1.3950	0.3369	4.1409	0.000035
ns(SoakDays, df = 2)1	0.3139	0.0604	5.1988	0.000000
ns(SoakDays, df = 2)2	0.0603	0.0376	1.6035	0.108845

Figure 14 shows the comparison of CPUE indices between the full and reduced data sets for WAG. Removal of one vessel's data has significantly affected the CPUE indices during the pre-rationalization period but not the post-rationalization period.

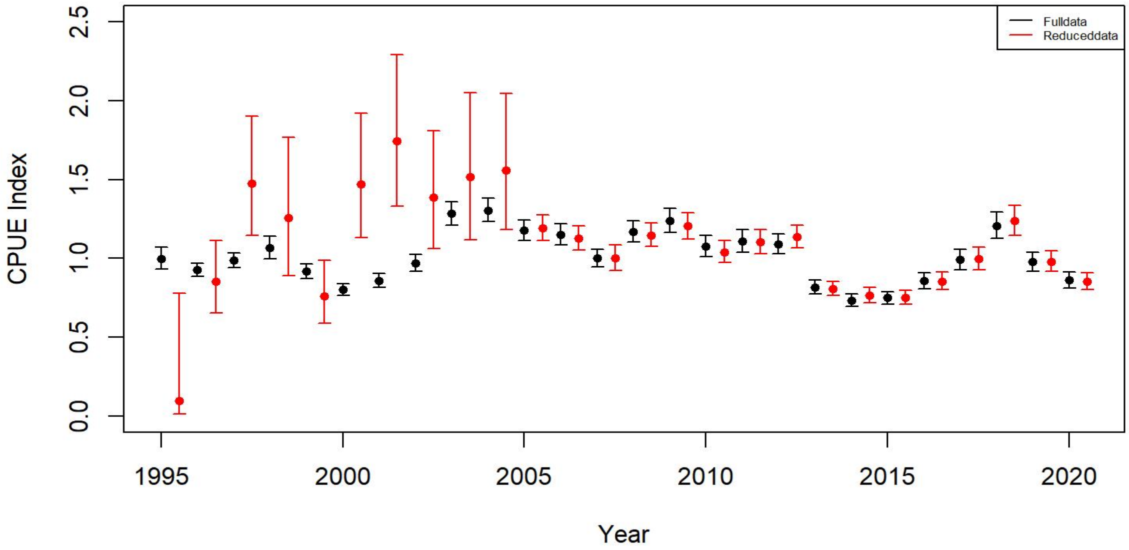


Figure A.14. Comparison of the trends in standardized CPUE indices for full data (black) and reduced data (red) for WAG. The confidence intervals are +/- 2 SE.

Commercial fishery CPUE index by non-interaction model

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

The final model for EAG was:

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

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel} + \mathrm{Month}$ (A.22)
for the 1985/86–1998/99 period [θ=10.40, $\mathrm{R}^2 = 0.3327, \mathrm{AIC} = 16{,}535$]

and that for WAG was:

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

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel} + \mathrm{Area} \qquad \text{(A.23)}$$

for the 1985/86–1998/99 period [θ=6.67, $R^2 = 0.3569$, $\mathrm{AIC} = 31{,}215$]

We did not fine tune the fishery CPUE fits for nonsignificant parameter estimates because this drastically reduced the number of data points for the fit, especially EAG data.

Figures A.15 and A.16 compare standardized and nominal CPUE indices for 1985/86–1998/99 fishery data for EAG and WAG, respectively.

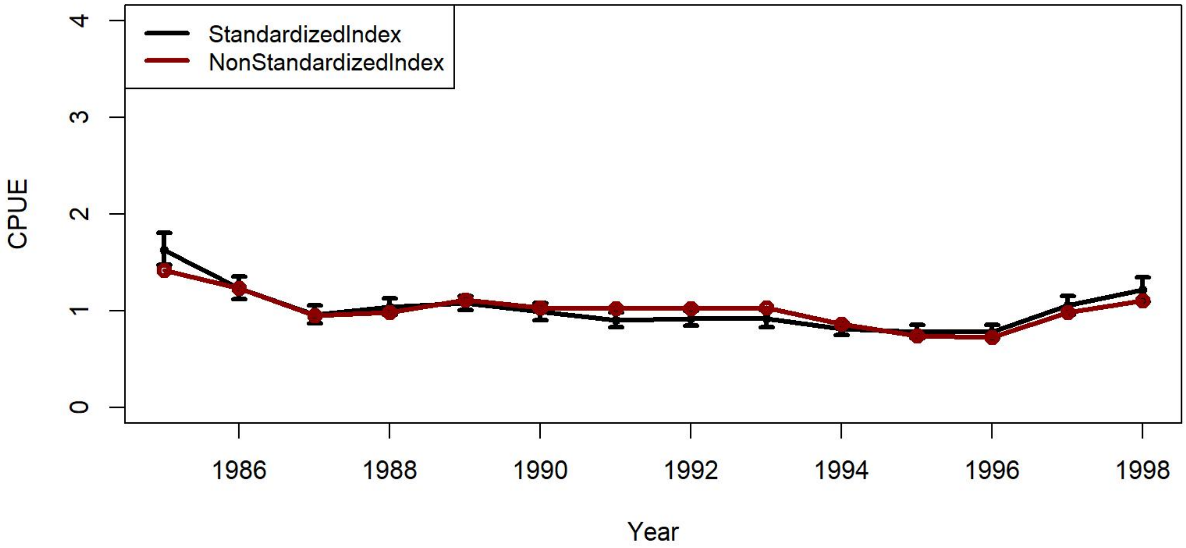


Figure A.15. Trends in non-standardized (red line) vs. standardized CPUE (black line with confidence intervals) indices during 1985/86–1998/99 period for EAG. The confidence intervals are +/- 2 SE.

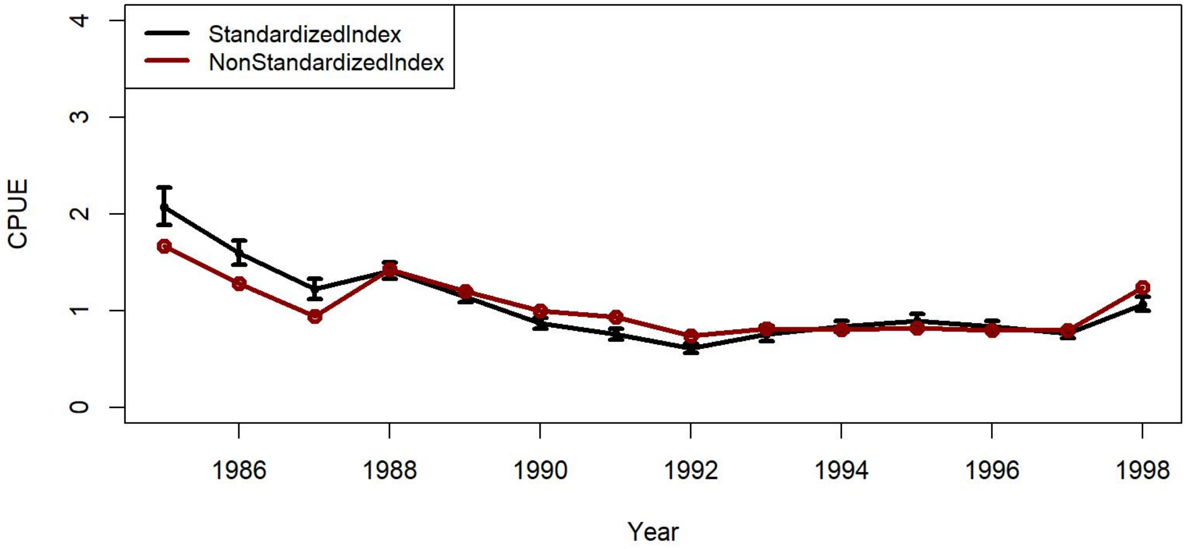


Figure A.16. Trends in non-standardized (red line) vs. standardized CPUE (black line with confidence intervals) indices during 1985/86–1998/99 period for WAG. The confidence intervals are +/- 2 SE.

Appendix B: Male Maturity

Introduction

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

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

Species	**Sex**	**Size-at-Maturity (mm CL)**	**Method**	**Area**	**Sources**
Lithodes aequispins	Male	114 (11.4)	Breakpoint analysis on ln chela height vs. ln carapace length	British Columbia, Canada	Jewett *et al.* 1985
		92 (2.4) 107 (4.6) 130 (4.0)	Breakpoint analysis on ln chela height vs. ln carapace length	St. Matthew Is. District Pribilof Is. District Eastern Aleutian Is.	Somerton and Otto 1986
		117.9 to 158.0	Breakpoint analysis on chela height vs. carapace length	Various water inlets in southeast Alaska	Olson et al. 2018
		108.6 (2.6) 120.8 (2.9)	Breakpoint analysis on chela height vs. carapace length	Bowers Ridge Seguam Pass	Otto and Cummiskey 1985
		110	Minimum size of successful mating (lab observation)	Prince William Sound	Paul and Paul 2001

Data

Male golden king crab carapace lengths (CL) were measured to the nearest mm and chela height (CH) measured to the nearest one-tenth of a mm by observers, and biologists from Alaska Fisheries Science Center (AFSC) and Alaska Department of Fish and Game (ADF&G) during the commercial fishery and special surveys in the Aleutian Islands. Crab were inspected for abnormal growth due to limb loss or diseases and disregarded from measurements. There were 14,615 measurements taken during 1984, 1991, 2018 to 2021. This analysis restricts the data to the 2018/19–2020/21 fishing period with 10,815 measurements for the whole Aleutian Islands region, comprising 5,454 measurements for EAG and 5,361 measurements for WAG (Table B.2).

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

Measurement type	Source and season of data collection	Aleutian Islands (AI) 2018/19–2020/21	EAG 2018/19–2019/20	WAG 2018/19–2020/21
Carapace length and chela height records (all sizes)	Co-operative survey (2018/19, 2019/20) Observer sampling (2018/19, 2019/20) Retained catch sampling (2018/19, 2019/20, 2020/21) Special sampling WAG (2020/21)	10815	5454	5361

Method

The male size-at-maturity is determined as the breakpoint in the following model:

$$CH = \beta_0 + \beta_1 CL + \beta_2 [CL - c]^+ + \varepsilon \qquad \text{(B.1)}$$

where β_0 is the intercept, β_1 is the left slope, β_2 is the difference in slopes when $CL \geq c$, and c is the breakpoint and ε is the random error.

The term $[CL - c]^+$ reduces to zero if $CL < c$, otherwise takes the value of the argument in the following form of the model:

$$CH = \beta_0 + \beta_1 CL + \beta_2 [CL - c] \qquad \text{(B.2)}$$

The "segmented regression" package by Muggeo (2003, 2008), available in R (ver 4.1, R Core Team 2021), is used to determine breakpoints and corresponding two segmented lines for different groups of data outside the assessment model. Muggeo's method first fits a single line to CH vs CL data and then proceeds to estimate an optimum break point iteratively from an initial guess value over the CL range. In the process, it estimates the parameters of equation B.2 including the breakpoint. Olson et al. (2018) followed a similar approach to analyze CH vs CL data in the southeast Alaska but used a different R package to that of Muggeo.

The estimates are further refined by bootstrapping each data set (CH, CL pairs) 1000 times and applying 'segmented regression' to each boot strapped sample. The bootstrap median breakpoint (i.e., size-at-maturity), standard error, and confidence intervals are also estimated.

Results

The original sample data produced the breakpoints (size-at-maturity) of 117.865 mm CL, 104.295 mm CL, and 120.199 mm CL for AI, EAG, and WAG, respectively. The EAG data produced the lowest estimate but unreliable. This is likely due to existence of outliers in the EAG data. Hence, the EAG data are restricted to a plausible size range 85–142 mm CL within which the breakpoint is likely to fall, and re-estimated the breakpoint to be 128.72 mm CL. On the other hand, breakpoint estimates from whole data of WAG and AI are reliable (see Figures B.1, B.2, and B.3).

Because of uncertainty in EAG breakpoint estimate, the AI estimate is considered as reliable for applying to both EAG and WAG regions. The bootstrap analysis is also done only on AI data. The bootstrap statistics are listed in Table B.3:

Table B.3. Bootstrap estimate of breakpoint with standard error and confidence bounds for AI 2018/19–2020/21 data.

Parameter	Mean	Median	SE	Upper Bound	Lower Bound
breakpoint	116.575	117.996	0.159	122.562	105.212

The breakpoint (mean/median) values are approximately one 5 mm CL bin higher than the currently used 111 mm CL. **Two options for MMB estimation are suggested: ≥111 mm CL (lower limit of the 111–115 mm CL bin, status quo knife edge maturity) and ≥116 mm CL (lower limit of the 116–120 mm CL bin, based on present analysis).**

Note that the mean and median estimates are 117 and 118 mm CL, respectively, falling within the 116–120 mm CL bin.

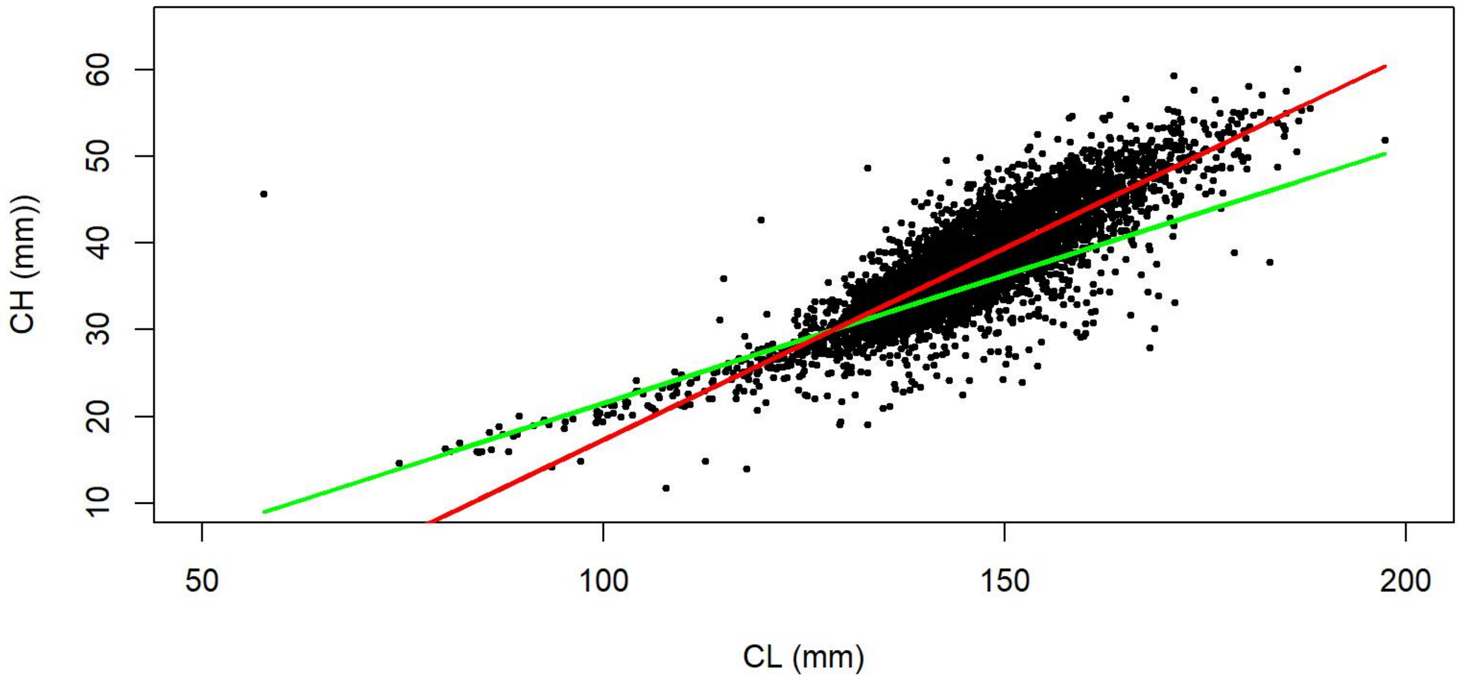


Figure B.1. Segmented linear regression fit to CH vs. CL data (restricted to 85–142 mm CL size range) of male golden king crab for 2018/19–2020/21 in EAG.

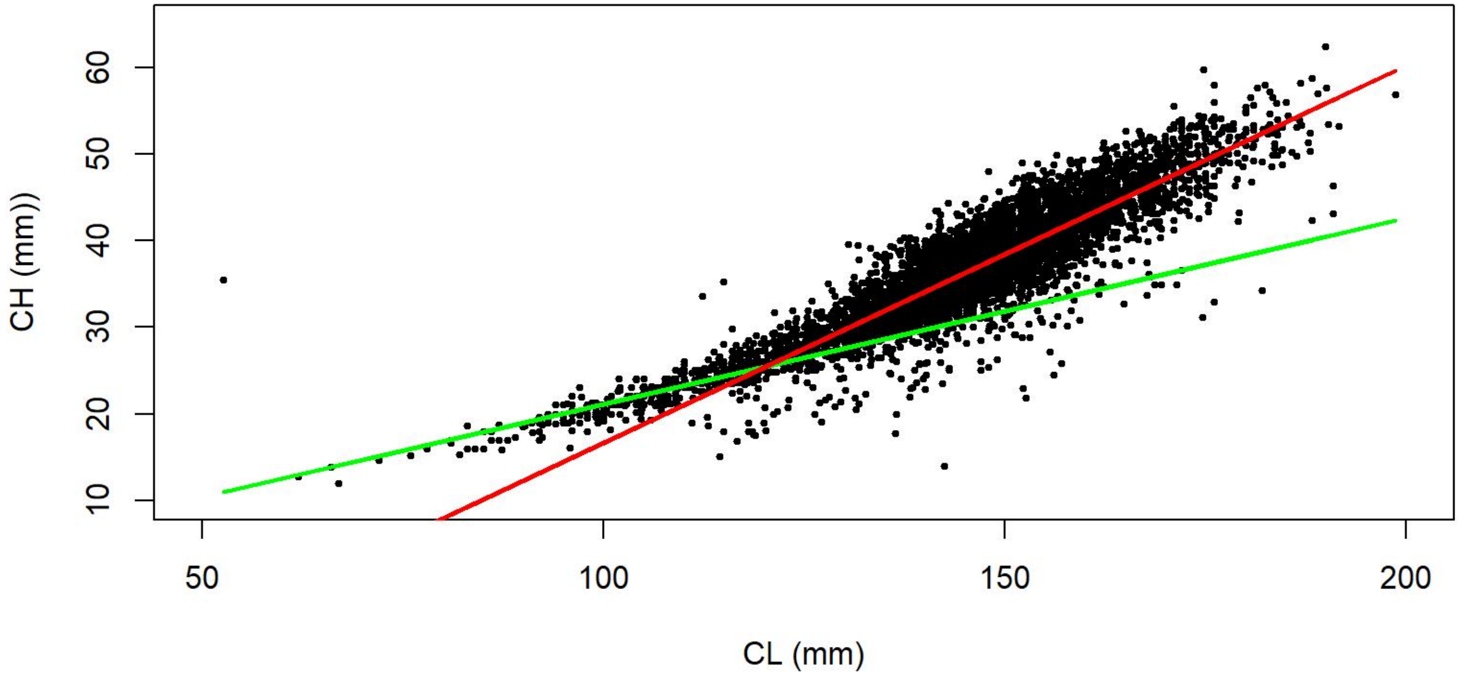


Figure B.2. Segmented linear regression fit to CH vs. CL data of male golden king crab for 2018/19–2020/21 in WAG.

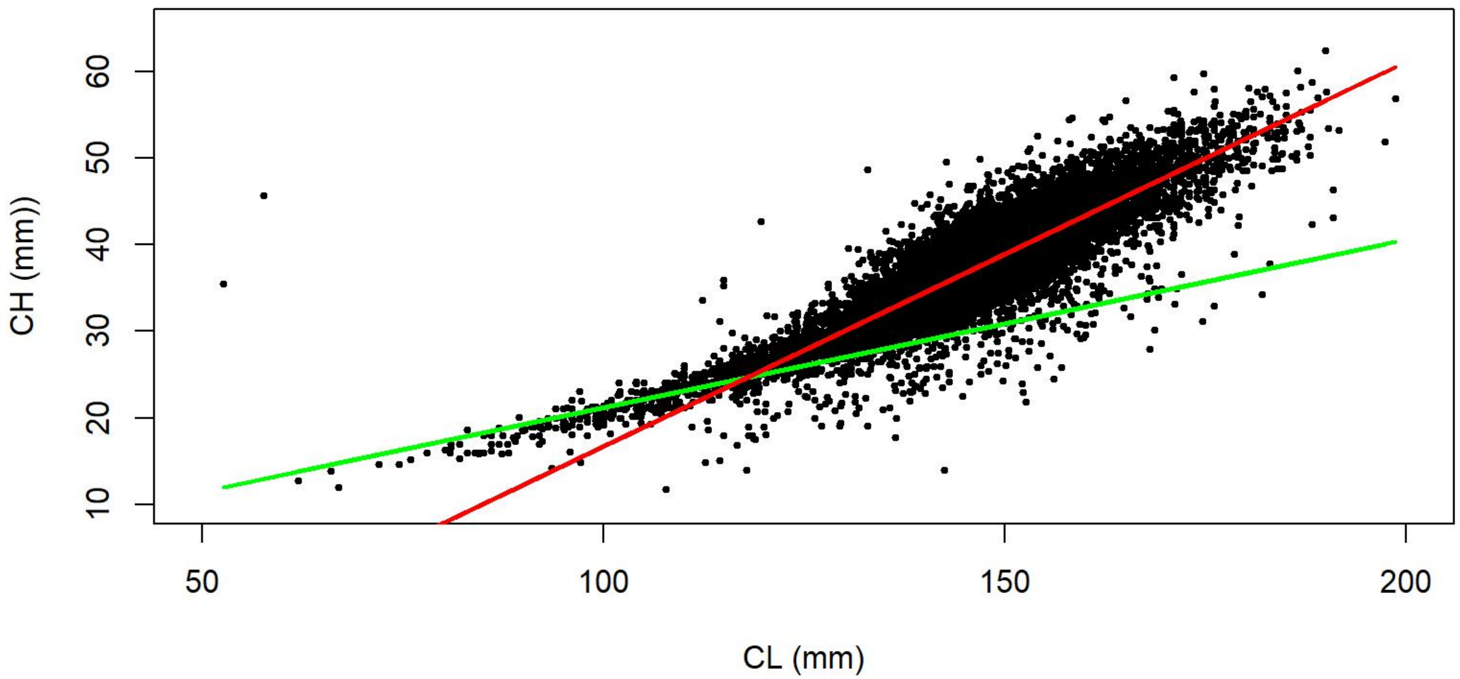


Figure B.3. Segmented linear regression fit to CH vs. CL data of male golden king crab for 2018–2020 in AI.

Appendix C: Jittering

Jittering of model 21.1a parameter estimates:

We followed the Stock Synthesis approach to do 100 jitter runs of model 21.1a parameter estimates to use as initial parameter values (as .PIN file in ADMB) to assess model stability and to determine whether a global as opposed to local minima has been reached by the search algorithm:

> The *Jitter* factor of 0.3 was multiplied by a random normal deviation *rdev*=*N*(0,1), to a transformed parameter value based upon the predefined parameter:
>
> $$temp = 0.5 * rdev * Jitterfactor * \ln\left(\frac{P_{\max} - P_{\min} + 0.0000002}{P_{val} - P_{\min} + 0.0000001} - 1\right), \qquad \text{(C.1)}$$
>
> with the final jittered initial parameter value back transformed as:
>
> $$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0\, temp)}, \qquad \text{(C.2)}$$
>
> where P_{max} and P_{min} are upper and lower bounds of parameter search space and P_{val} is the estimated parameter value before the jittering.

The jitter results are summarized for model 21.1a in Table C.1 for EAG and in Table C.2 for WAG. Original fits produced the highest log likelihood values (global minimum) for EAG and WAG.

Table C.1. Results from 100 jitter runs for model 21.1a for EAG. Jitter run 0 corresponds to the original optimized estimates. NA: not converged.

Jitter Run	Negative Log Likelihood	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-890.8549**	**0.00002343**	**9,298**	**3,795**	**11,039**
1	-890.8549	0.00005882	9,298	3,795	11,039
2	-890.8549	0.00006008	9,298	3,795	11,039
3	-890.8549	0.00001137	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
5	-890.8549	0.00002713	9,298	3,795	11,039
6	-890.8549	0.00039601	9,298	3,795	11,039
7	-890.8549	0.00006976	9,298	3,795	11,039
8	-890.8549	0.00005404	9,298	3,795	11,039
9	-890.8549	0.00006291	9,298	3,795	11,039
10	-890.8549	0.00000986	9,298	3,795	11,039
11	-890.8549	0.00053273	9,298	3,795	11,039
12	-890.8549	0.00005723	9,298	3,795	11,039

13	-890.8549	0.00012718	9,298	3,795	11,039
14	-890.8549	0.00004932	9,298	3,795	11,039
15	-890.8549	0.00004341	9,298	3,795	11,039
16	-890.8549	0.00005957	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
18	-890.8549	0.00001289	9,298	3,795	11,039
19	-890.8549	0.00002160	9,298	3,795	11,039
20	-890.8549	0.00010556	9,298	3,795	11,039
21	-890.8549	0.00021061	9,298	3,795	11,039
22	-890.8549	0.00011557	9,298	3,795	11,039
23	-890.8549	0.00009713	9,298	3,795	11,039
24	-890.8549	0.00018017	9,298	3,795	11,039
25	-890.8549	0.00007353	9,298	3,795	11,039
26	-890.8549	0.00003597	9,298	3,795	11,039
27	-890.8549	0.00013828	9,298	3,795	11,039
28	-890.8549	0.00004217	9,298	3,795	11,039
29	-890.8549	0.00083071	9,298	3,795	11,039
30	-890.8549	0.00011215	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
32	-890.8549	0.00006960	9,298	3,795	11,039
33	-890.8549	0.00005285	9,298	3,795	11,039
34	-890.8549	0.00012247	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
36	-890.8549	0.00008052	9,298	3,795	11,039
37	-890.8549	0.00010387	9,298	3,795	11,039
38	-890.8549	0.00005176	9,298	3,795	11,039
39	-890.8549	0.00000578	9,298	3,795	11,039
40	-890.8549	0.00031361	9,298	3,795	11,039
41	-890.8549	0.00011616	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
43	-890.8549	0.00009063	9,298	3,795	11,039
44	-890.8549	0.00010026	9,298	3,795	11,039
45	-890.8549	0.00006277	9,298	3,795	11,039
46	-890.8549	0.00018020	9,298	3,795	11,039
47	-890.8549	0.00010279	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
49	-890.8549	0.00017332	9,298	3,795	11,039
50	-890.8549	0.00003975	9,298	3,795	11,039
51	-890.8549	0.00000943	9,298	3,795	11,039
52	-890.8549	0.00059529	9,298	3,795	11,039
53	-890.8549	0.00005547	9,298	3,795	11,039
54	-890.8549	0.00007443	9,298	3,795	11,039
55	-890.8549	0.00006177	9,298	3,795	11,039
56	-890.8549	0.00013119	9,298	3,795	11,039

57	-890.8549	0.00011010	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
59	-890.8549	0.00041269	9,298	3,795	11,039
60	-890.8549	0.00006274	9,298	3,795	11,039
61	-890.8549	0.00017939	9,298	3,795	11,039
62	-890.8549	0.00032294	9,298	3,795	11,039
63	-890.8549	0.00001816	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
65	-890.8549	0.00013484	9,298	3,795	11,039
66	-890.8549	0.00002163	9,298	3,795	11,039
67	-890.8549	0.00016984	9,298	3,795	11,039
68	-890.8549	0.00000458	9,298	3,795	11,039
69	-890.8549	0.00005449	9,298	3,795	11,039
70	-890.8549	0.00001224	9,298	3,795	11,039
71	-890.8549	0.00036414	9,298	3,795	11,039
72	-890.8549	0.00004862	9,298	3,795	11,039
73	-890.8549	0.00013950	9,298	3,795	11,039
74	-890.8549	0.00002795	9,298	3,795	11,039
75	-890.8549	0.00002993	9,298	3,795	11,039
76	-890.8549	0.00004651	9,298	3,795	11,039
77	-890.8549	0.00002200	9,298	3,795	11,039
78	-890.8549	0.00000375	9,298	3,795	11,039
79	-890.8549	0.00016000	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA
83	-890.8549	0.00003306	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
85	-890.8549	0.00004509	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
87	-890.8549	0.00003641	9,298	3,795	11,039
88	-890.8549	0.00003627	9,298	3,795	11,039
89	-890.8549	0.00014956	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
91	-890.8549	0.00022100	9,298	3,795	11,039
92	-890.8549	0.00002847	9,298	3,795	11,039
93	-890.8549	0.00004365	9,298	3,795	11,039
94	-890.8549	0.00012989	9,298	3,795	11,039
95	-890.8549	0.00010442	9,298	3,795	11,039
NA	NA	NA	NA	NA	NA
97	-890.8549	0.00013491	9,298	3,795	11,039
98	-890.8549	0.00012592	9,298	3,795	11,039
99	-890.8549	0.00012853	9,298	3,795	11,039
100	-890.8549	0.00003000	9,298	3,795	11,039

Table C.2. Results from 100 jitter runs for model 21.1a for WAG. Jitter run 0 corresponds to the original optimized estimates. NA: not converged.

Jitter Run	Negative Log Likelihood	Maximum Gradient	B$_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-940.3565**	**0.00012460**	**7,370**	**1,669**	**6,702**
1	-940.3565	0.00018420	7,370	1,669	6,702
2	-940.3565	0.00009135	7,370	1,669	6,702
NA	NA	NA	NA	NA	NA
4	-940.3565	0.00013242	7,370	1,669	6,702
5	-940.3565	0.00024676	7,370	1,669	6,702
6	-940.3565	0.00000718	7,370	1,669	6,702
7	-940.3565	0.00031064	7,370	1,669	6,702
8	-940.3565	0.00004772	7,370	1,669	6,702
9	1016.2650	12490.57000000	0	4	24,262
10	-940.3565	0.00008327	7,370	1,669	6,702
11	-940.3565	0.00005325	7,370	1,669	6,702
12	-940.3565	0.00016437	7,370	1,669	6,702
13	6409.1580	3123883.00000000	82,616	2,491	33,440
14	-940.3565	0.00005322	7,370	1,669	6,702
15	-940.3565	0.00001754	7,370	1,669	6,702
16	-940.3565	0.00005742	7,370	1,669	6,702
17	-531.8893	1452.33500000	9,208	2,710	8,619
18	-940.3565	0.00015244	7,370	1,669	6,702
NA	NA	NA	NA	NA	NA
20	-940.3565	0.00006466	7,370	1,669	6,702
21	-940.3565	0.00000543	7,370	1,669	6,702
22	-940.3565	0.00033342	7,370	1,669	6,702
23	-940.3565	0.00003234	7,370	1,669	6,702
24	-940.3565	0.00031754	7,370	1,669	6,702
25	-940.3565	0.00000897	7,370	1,669	6,702
26	-940.3565	0.00007067	7,370	1,669	6,702
27	-940.3565	0.00006223	7,370	1,669	6,702
28	16324.7100	738.99210000	1,974,190	1,145,060	2,986,830
29	-940.3565	0.00218114	7,370	1,669	6,702
30	-940.3565	0.00016393	7,370	1,669	6,702
31	-940.3565	0.00004037	7,370	1,669	6,702
32	-494.3506	1517.71400000	8,991	2,597	8,674
33	-940.3565	0.00008052	7,370	1,669	6,702
34	-940.3565	0.00020356	7,370	1,669	6,702
35	-940.3565	0.00008063	7,370	1,669	6,702
36	1014.9310	1597.97000000	195,483	165,717	442,185

37	-940.3565	0.00012173	7,370	1,669	6,702
38	-940.3565	0.00007363	7,370	1,669	6,702
39	-940.3565	0.00013596	7,370	1,669	6,702
40	-940.3565	0.00011785	7,370	1,669	6,702
41	1955.0850	2440.73800000	11,428	2,785	976
42	-940.3565	0.00001743	7,370	1,669	6,702
43	-940.3565	0.00014257	7,370	1,669	6,702
44	-940.3565	0.00006468	7,370	1,669	6,702
45	-940.3565	0.00027955	7,370	1,669	6,702
46	-940.3565	0.00004034	7,370	1,669	6,702
47	-940.3565	0.00007934	7,370	1,669	6,702
48	16057.2500	759.14390000	53,287	45,551	118,591
49	-940.3565	0.00008810	7,370	1,669	6,702
50	-940.3565	0.00002177	7,370	1,669	6,702
51	-940.3565	0.00005384	7,370	1,669	6,702
52	-940.3565	0.00009783	7,370	1,669	6,702
53	-940.3565	0.00032531	7,370	1,669	6,702
54	-940.3565	0.00005679	7,370	1,669	6,702
55	-940.3565	0.00004213	7,370	1,669	6,702
56	-940.3565	0.00010423	7,370	1,669	6,702
57	922.1206	3510.20200000	6,339	1,777	5,545
58	-940.3565	0.00003724	7,370	1,669	6,702
59	-940.3565	0.00002954	7,370	1,669	6,702
60	-940.3565	0.00006124	7,370	1,669	6,702
61	-940.3565	0.00004589	7,370	1,669	6,702
62	-940.3565	0.00001069	7,370	1,669	6,702
63	-940.3565	0.00000625	7,370	1,669	6,702
64	-940.3565	0.00039464	7,370	1,669	6,702
65	-940.3565	0.00005705	7,370	1,669	6,702
66	1396.0840	142015.20000000	374,199	261,351	972,679
67	-940.3565	0.00001739	7,370	1,669	6,702
68	3966.7420	40652.93000000	0	3	27,940
69	-940.3565	0.00015450	7,370	1,669	6,702
70	-940.3565	0.00006020	7,370	1,669	6,702
71	-940.3565	0.00012604	7,370	1,669	6,702
72	-940.3565	0.00004411	7,370	1,669	6,702
73	-940.3565	0.00012948	7,370	1,669	6,702
74	723.5230	32543.63000000	43,405	39,397	72,414
75	-589.7174	0.00080621	7,780	2,211	7,481
76	-940.3565	0.00005599	7,370	1,669	6,702
77	-940.3565	0.00033817	7,370	1,669	6,702
78	703.5092	4897.44500000	242,756	210,920	415,783
79	-940.3565	0.00025400	7,370	1,669	6,702
80	1211.0410	79437.21000000	213,118	184,110	761,577

81	-842.6195	0.00002915	7,088	1,468	6,272
82	-940.3565	0.00004797	7,370	1,669	6,702
83	-940.3565	0.00002080	7,370	1,669	6,702
84	-940.3565	0.00004050	7,370	1,669	6,702
85	-940.3565	0.00009084	7,370	1,669	6,702
86	819.5523	8582.10500000	89,624	84,054	186,557
87	-940.3565	0.00010075	7,370	1,669	6,702
88	-940.3565	0.00005397	7,370	1,669	6,702
89	408.8454	100758.20000000	24,013	19,444	41,721
90	-940.3565	0.00000698	7,370	1,669	6,702
91	-940.3565	0.00013725	7,370	1,669	6,702
92	1170.6040	257733.60000000	28,695	4,546	15,019
93	-489.5243	0.00025367	8,991	2,597	8,674
94	-940.3565	0.00031713	7,370	1,669	6,702
95	-940.3565	0.00005909	7,370	1,669	6,702
96	382.8459	0.00316184	5,071	1,418	4,999
97	-940.3565	0.00008396	7,370	1,669	6,702
98	-940.3565	0.00004028	7,370	1,669	6,702
99	-842.6195	0.00040310	7,088	1,468	6,272
100	-940.3565	0.00006259	7,370	1,669	6,702

Appendix D: RACE AIGKC Slope Survey

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Introduction

The SSC in their June 2021 meeting requested Aleutian Islands golden king crab (AIGKC) assessment authors to consider including Resource Assessment and Conservation Engineering (RACE) Division biennial slope survey data in the assessment. This appendix provides some introductory tables and figures on AIGKC slope (trawl) surveys' data with the anticipation of some guidance from CPT/SSC on appropriate ways to incorporate these data into AIGKC assessment model.

Method

Comparison of RACE AIGKC slope survey data with observer sample data

The RACE conducted biennial (trawl) slope surveys in the Aleutian Islands starting in 1980. The Poly'Noreatern (PNE) net was used in the trawl since 1991. Due to logistic problems, there were some gaps in survey periodicity during the 1980−2018 period (Table D.1). For data exploration and comparison with observer pot sample CPUE, the 1997−2018 slope survey CPUE (standardized for 15 minutes tow for the trawl configuration in 1991) were used. The trawl survey data comprised of all sizes and sexes of golden king crab. Unfortunately, no size measurements were recorded in trawl samples. To obtain a comparable observer CPUE to that of trawl survey, a new "Total Crab" column was created in the observer database with females, sublegal, legal retained, and legal non retained crab numbers pooled. Observer CPUE data by lat//long. locations were summed up within a given 1x1nmi cell. Since trawl CPUE data were reported by trawl start locations, they were not summed up within the 1x1 nmi cells but used as they were.

Furthermore, because the magnitude of survey CPUE and observer CPUE were different, they were scaled by the respective maxima for the Fisheries Management (FMP) seasons. The scaled (i.e., proportion) CPUE values for 1997, 2000, 2002, 2004, 2006, 2008, 2010, 2012, 2014, 2016, and 2018 of observer and trawl survey samples were plotted in several figures (Figures D.1 to D.7). The total crab counts for observer samples summed up within the 1x1 nmi cells ranged from 467 to 1433 whereas the crab counts per trawl tow ranged from 10 to 289.

Results

Table D.1 lists the trawl survey nonzero CPUE, and abundance estimates made for EAG, WAG, and the other nonspecific Aleutian Islands areas by RACE for 1980−2018. Unusually high catches in certain year's trawl tow (for example, 2018) yielded high abundance variance. A detailed trawl survey database with zero golden king crab catch tows is available but not summarized in this note.

Figure D.1 shows the Observer-Trawl CPUE proportion summary comparison bars in 10 blocks, which covers the entire Aleutian Islands and for the selected 1997 to 2018 range. These blocks are currently used in AIGKC CPUE standardization with 1 to 4 numbered blocks for EAG and 5 to 10 blocks for WAG. Figures D.2 to D.7 show the detail observer CPUE proportion bars by 1x1 nmi cell and trawl CPUE proportion bars by location for the entire Aleutian Islands, EAG, and WAG, respectively for arbitrarily selected years, 1997 and 2018. These figures indicate that trawl survey encountered golden king crab density outside the observer sampled areas. Whether any fishing vessel frequented these locations or not during the fishing season was not investigated.

Acknowledgement

Wayne Palsson from the RACE division of AFSC provided the AIGKC slope survey data and it is greatly appreciated.

Table D.1. Summary CPUE and biomass estimates of Aleutian Islands golden king crab from RACE slope survey during 1980−2018.

FMP Area	Year	Area Code	Haul Count	Catch Count	Mean CPUE (Kg)	Var CPUE	Mean CPUE (no.)	Var CPUE	Area Biomass(t)	Var Biomass	Area Abundance (no.)	Var Abundance
WAG	1980	543	11	4	19.265	167.693	12.350	25.059	236.700	25353.636	152394	3788715876
AI	1980	518+519	18	1	11.998	143.932	10.290	105.802	77.200	5966.406	66225	4385809142
WAG	1980	542	52	17	85.275	734.599	89.150	587.655	1272.500	163634.690	1330855	130902000000
EAG	1980	541	46	9	48.845	99.868	49.754	131.784	1053.500	46391.993	1072126	61217973504
WAG	1983	543	63	40	45.151	112.667	32.593	60.710	685.900	25997.674	495178	14008607911
AI	1983	518+519	34	7	3.821	4.803	3.126	2.029	28.700	268.851	23398	113598097.1
WAG	1983	542	96	47	103.988	2685.281	64.591	600.455	1430.900	508491.312	888990	113704000000
EAG	1983	541	97	15	10.110	17.876	8.542	14.987	222.900	8672.056	188387	7270693560
WAG	1986	543	81	41	58.454	405.428	51.184	198.123	818.700	79544.021	716840	38871177904
AI	1986	518+519	63	9	3.996	2.121	3.932	1.693	29.900	118.743	29451	94786651.87
WAG	1986	542	121	47	19.337	14.561	18.945	15.946	320.100	3984.618	313382	4363767214
EAG	1986	541	118	27	12.740	9.250	13.918	16.443	321.000	5874.043	350737	10442574472
WAG	1991	543	56	7	8.543	11.016	10.811	23.126	129.800	2542.017	164278	5336232548
AI	1991	518+519	55	3	2.651	2.858	2.615	3.011	19.800	159.989	19561	168551567.2
WAG	1991	542	91	19	15.797	9.875	17.159	11.551	261.000	2702.328	284065	3160909866
EAG	1991	541	129	17	5.367	3.753	4.452	2.012	135.300	2383.157	111957	1278027114
WAG	1994	543	69	16	12.234	8.721	17.771	14.258	185.800	2012.387	270092	3290012068
AI	1994	518+519	64	3	4.198	3.640	8.625	19.559	31.400	203.725	64509	1094811866
WAG	1994	542	114	30	31.464	76.864	27.701	54.770	520.700	21034.499	458009	14988180030
EAG	1994	541	133	37	15.318	15.525	19.341	16.161	386.000	9859.527	487340	10262963120
WAG	1997	543	92	16	15.572	19.626	17.675	23.512	236.400	4528.685	268548	5425278407
AI	1997	518+519	52	3	1.617	0.856	2.620	2.814	12.100	47.930	19638	157529796.8
WAG	1997	542	116	19	9.048	5.516	12.285	7.802	149.600	1509.376	203159	2135098797
EAG	1997	541	136	38	34.274	25.520	30.520	17.876	863.700	16207.115	769185	11352306878
WAG	2000	543	113	26	16.454	30.248	17.236	32.760	249.800	6979.702	261830	7559351301
AI	2000	518+519	58	5	13.124	57.032	32.078	378.820	98.200	3192.318	239992	21203988926
WAG	2000	542	110	27	28.265	66.037	28.046	83.672	467.600	18071.623	463851	22897430722
EAG	2000	541	138	53	33.856	56.748	42.181	48.507	853.300	36038.604	1063064	30804930379
WAG	2002	543	107	39	33.398	39.411	33.203	17.977	507.300	9093.912	504335	4148202305

AI	2002	518+519	61	6	8.439	23.213	12.957	42.515	63.200	1299.294	96917	2379716807
WAG	2002	542	114	25	34.388	116.472	43.792	175.112	568.800	31873.483	724447	47920683833
EAG	2002	541	132	39	29.196	32.510	36.388	47.325	735.700	20645.914	917304	30054356912
WAG	2004	543	124	25	22.603	29.164	16.455	11.404	343.200	6729.447	249763	2631445737
AI	2004	518+519	53	6	11.464	56.042	19.011	132.096	85.800	3136.876	142259	7393916636
WAG	2004	542	130	29	34.812	64.564	32.933	53.801	575.900	17668.550	544857	14723044390
EAG	2004	541	112	35	47.289	132.887	43.661	80.601	1191.700	84391.707	1100458	51186919912
WAG	2006	543	112	38	29.132	29.122	31.202	59.603	442.400	6719.867	474126	13753283045
AI	2006	518+519	44	6	42.705	310.252	70.652	1271.771	319.500	17365.938	528625	71185748167
WAG	2006	542	110	20	36.027	418.409	33.510	436.353	596.000	114500.967	554347	119411000000
EAG	2006	541	91	34	47.617	110.667	43.110	67.536	1199.800	70280.696	1086721	42889790268
WAG	2010	543	118	42	57.886	130.248	46.341	106.550	879.500	30054.498	704058	24586118732
AI	2010	518+519	51	3	10.806	29.846	14.152	43.404	80.800	1670.570	105884	2429491153
WAG	2010	542	128	21	30.437	54.021	23.633	27.481	503.400	14783.401	390787	7520442999
EAG	2010	541	121	34	34.371	39.101	28.945	35.782	866.500	24831.388	729297	22723745641
WAG	2012	543	120	43	43.611	60.776	41.818	58.628	662.400	14024.029	635292	13528187569
AI	2012	518+519	55	7	13.615	38.741	15.753	65.204	101.800	2168.505	117853	3649691138
WAG	2012	542	113	29	42.050	143.618	35.735	74.063	695.500	39302.255	591184	20267923534
EAG	2012	541	132	46	50.091	197.620	65.206	667.864	1262.400	125501.093	1643226	424136000000
WAG	2014	543	134	48	45.987	44.653	37.885	49.998	698.700	10303.650	575577	11536988323
AI	2014	518+519	44	4	36.935	473.737	56.115	1358.509	276.300	26516.828	419856	76040808114
WAG	2014	542	110	14	20.185	44.188	53.795	1384.010	333.900	12092.417	889822	378745000000
EAG	2014	541	122	40	92.271	504.653	103.911	1821.531	2325.400	320486.541	2618618	1156790000000
WAG	2016	543	135	36	36.030	52.539	21.555	16.354	547.500	12123.182	327299	3773719235
AI	2016	518+519	43	5	9.520	20.923	7.931	14.731	71.300	1171.165	59278	824527966.8
WAG	2016	542	114	17	11.674	16.990	11.568	13.615	193.200	4649.368	191277	3725777828
EAG	2016	541	127	37	34.533	69.894	36.160	78.286	869.900	44387.175	911427	49716540459
WAG	2018	543	129	33	27.739	50.241	18.340	15.318	421.500	11592.979	278860	3534573172
AI	2018	518+519	45	7	16.027	13.350	17.651	19.676	120.000	747.269	132046	1101315220
WAG	2018	542	120	19	21.075	55.306	16.387	23.418	348.400	15134.868	271070	6408654749
EAG	2018	541	126	39	156.633	13816.580	119.392	3756.474	3947.300	8774393.941	3008811	2385600000000

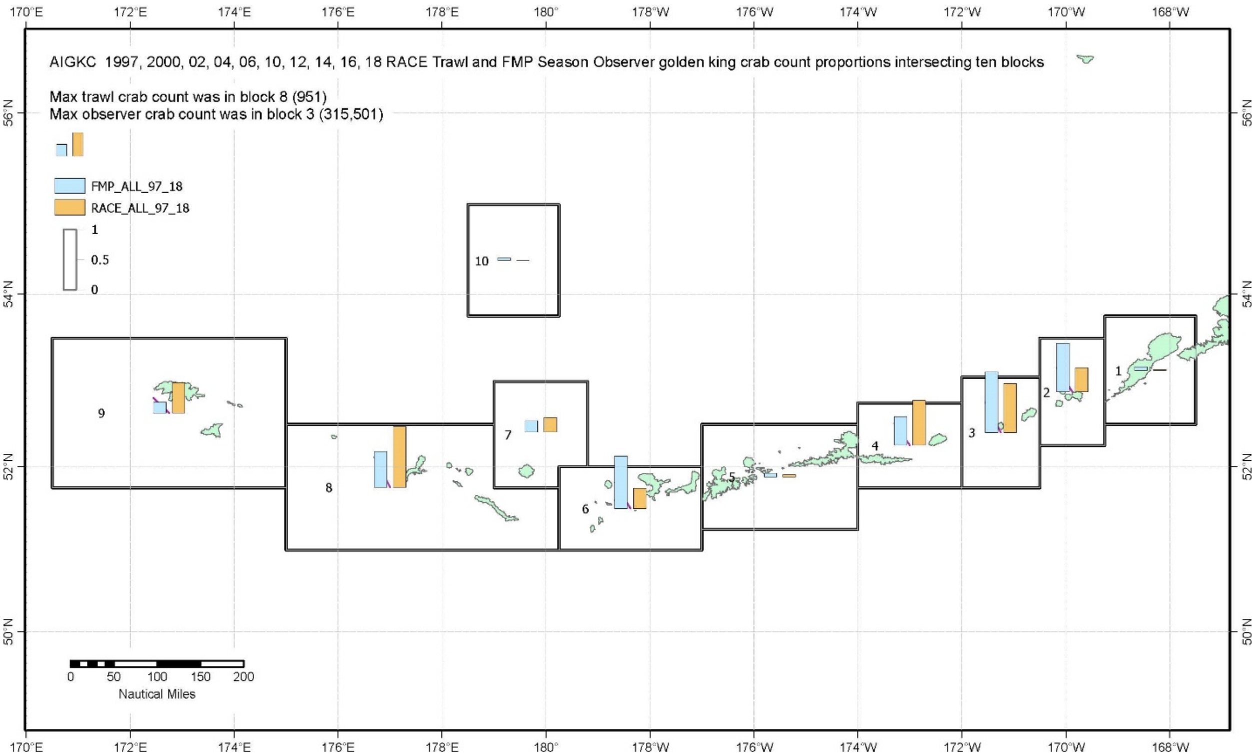

Figure D.1. Comparison of Aleutian Islands golden king crab index of abundance in Blocks#1 to 10 between RACE slope survey (light brown bars) and corresponding years' observer samples (light blue bars).

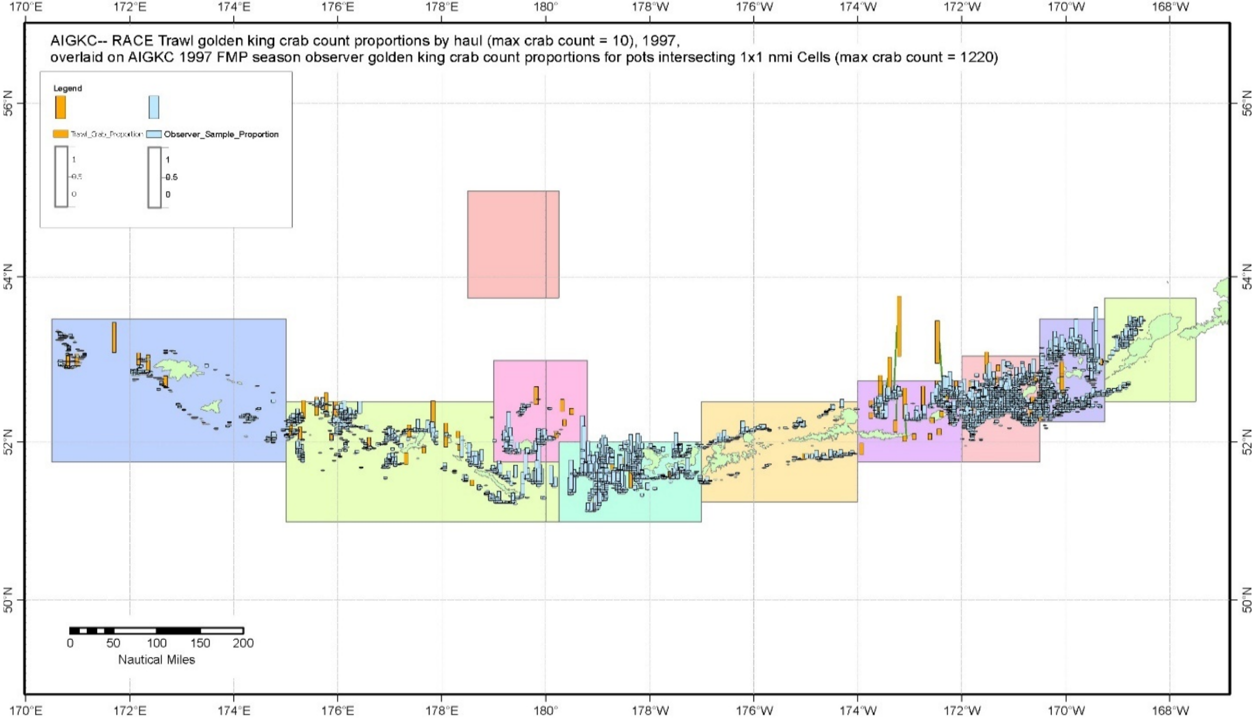

Figure D.2. Comparison of Aleutian Islands golden king crab index of abundance in Blocks#1 to 10 between RACE slope survey (light brown bars) and observer samples (light blue bars) during 1997.

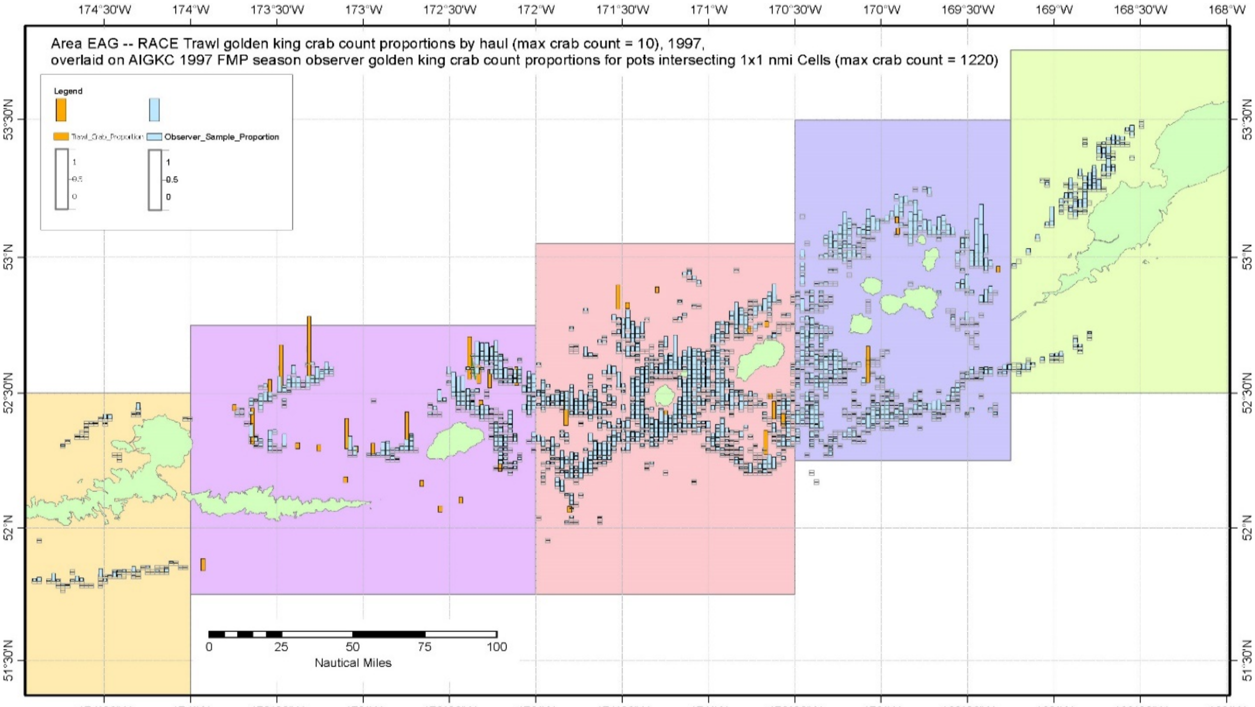

Figure D.3. Comparison of EAG golden king crab index of abundance in Blocks#1 to 4 between RACE slope survey (light brown bars) and observer samples (light blue bars) during 1997.

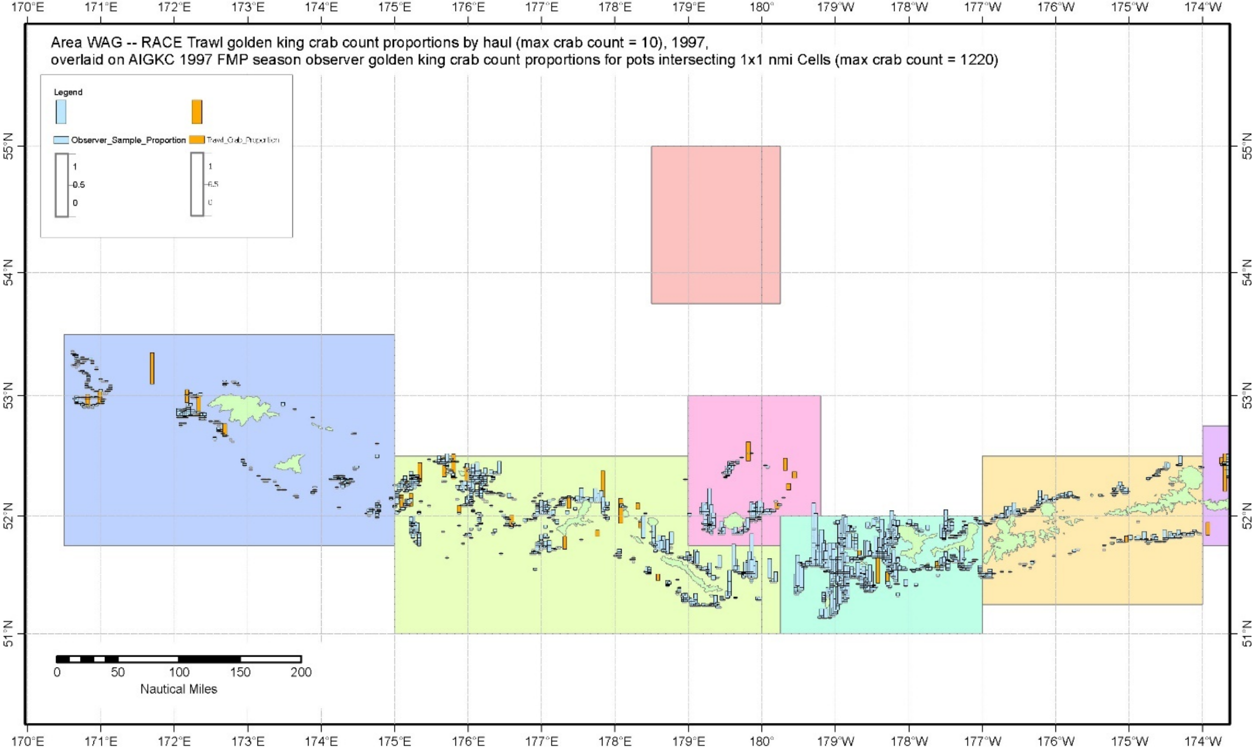

Figure D.4. Comparison of WAG golden king crab index of abundance in Blocks#5 to 10 between RACE slope survey (light brown bars) and observer samples (light blue bars) during 1997.

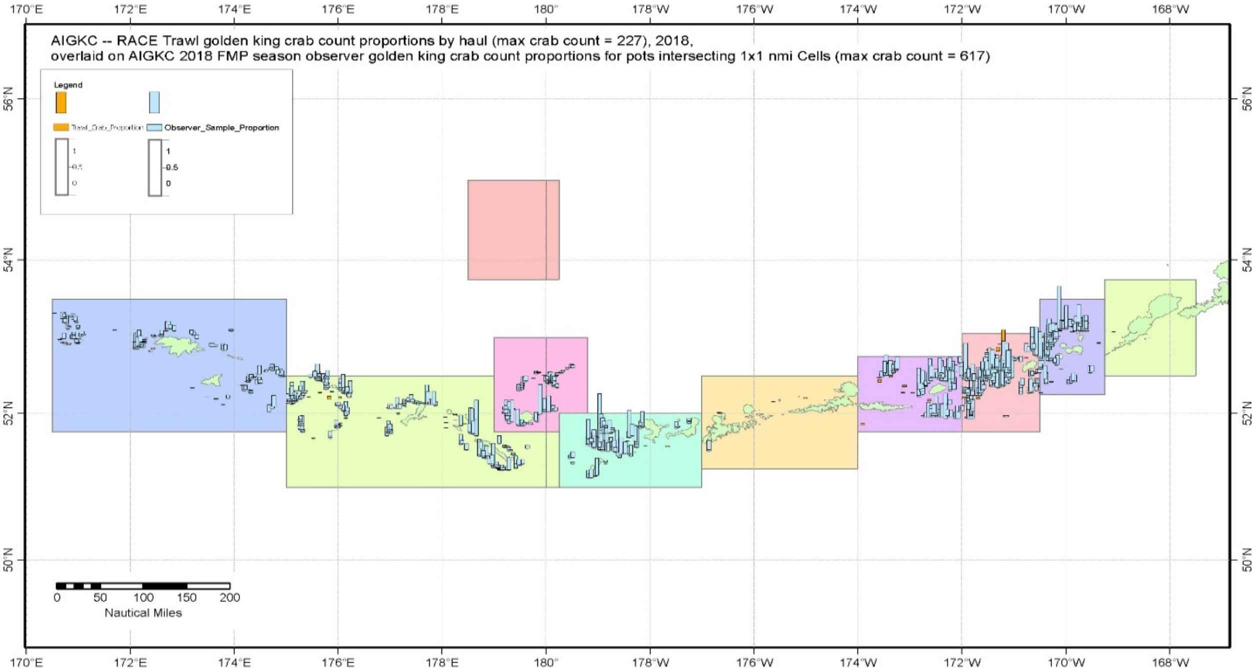

Figure D.5. Comparison of Aleutian Islands golden king crab index of abundance in Blocks#1 to 10 between RACE slope survey (light brown bars) and observer samples (light blue bars) during 2018.

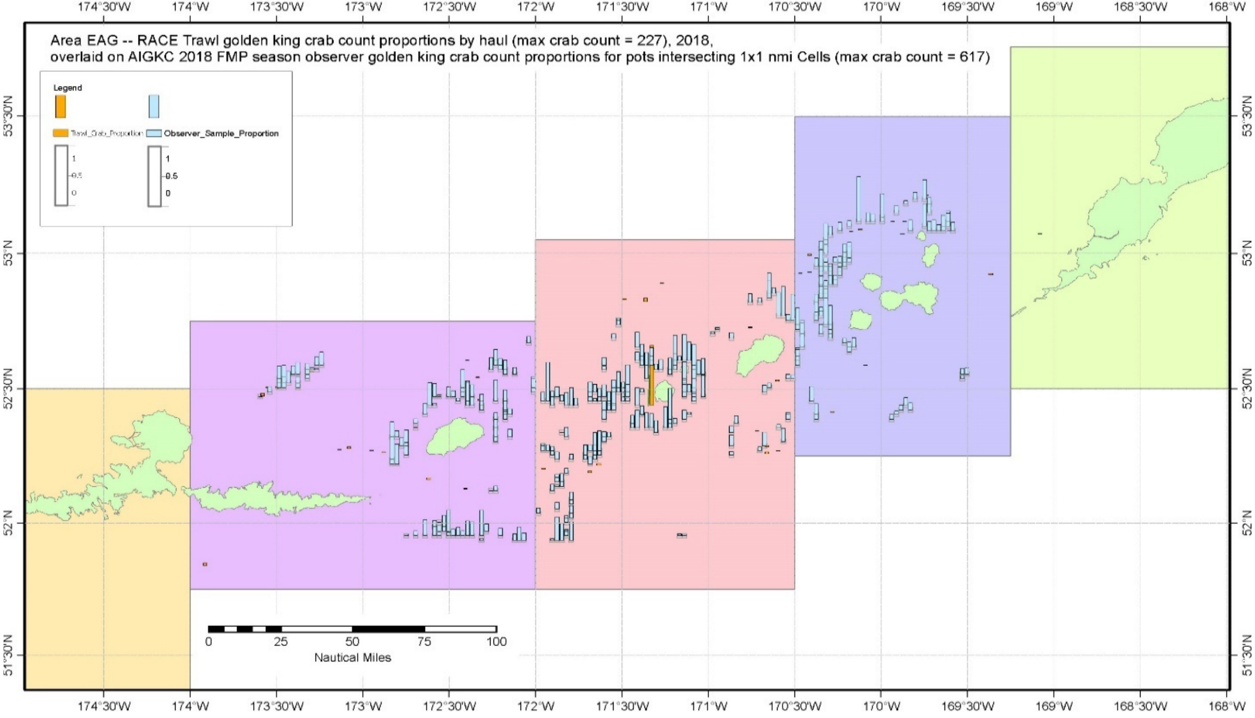

Figure D.6. Comparison of EAG golden king crab index of abundance in Blocks#1 to 4 between RACE slope survey (light brown bars) and observer samples (light blue bars) during 2018.

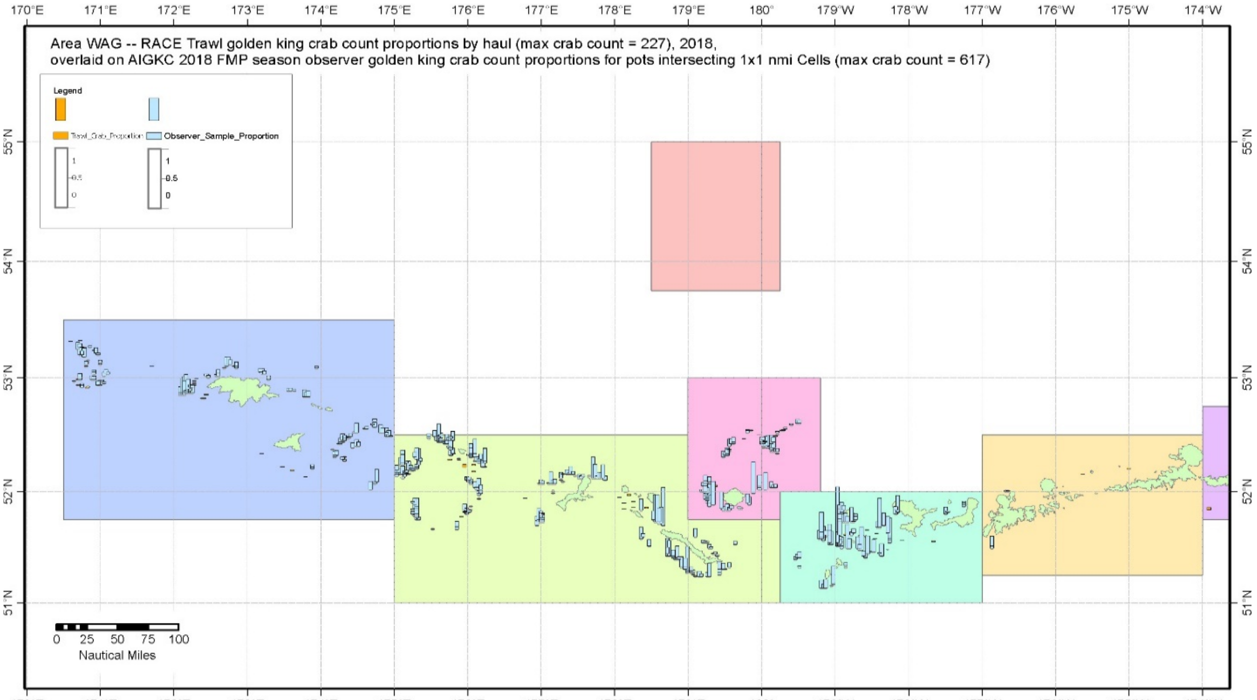

Figure D.7. Comparison of WAG golden king crab index of abundance in Blocks#5 to 10 between RACE slope survey (light brown bars) and observer samples (light blue bars) during 2018.

Appendix E: EAG 21.1a model implementation in Gmacs

Gmacs working session:

A working session on AIGKC model implementation in Gmacs was conducted by Andre Punt during 1−3 December 2021 in Juneau. Andre Punt, Shareef Siddeek, Katie Palof, and Cody Szuwalski participated actively in person or via google virtual. William Stockhausen, Martin Dorn, and Michael Martinez also participated occasionally via google virtual.

Focus:

The focus was to modify eastern Aleutian Islands golden king status quo assessment model EAG21.1a to model EAG21.6 and implement it in Gmacs.

Results:

The results are compared in tables and figures.
Differences between the base model EAG21.1a and modification of the base model EAG21.6 are highlighted yellow in the following Table 1.

Table 1. Status quo and modified EAG models' differences.

EAG21.6 (Modification of EAG21.1a)	EAG21.1a (Original model)
Data: 1981−2020 retained, 1990−2020 total, 1989−2020 groundfish discard, 1985−1998 Fish Ticket CPUE, 1995−2020 Observer CPUE, Tag release-recaptures (6 years' returns)	Data: coequal
1) Equilibrium starts of simulation in 1960 with R_0= 1987−2017 mean of mfexp(log_mean_rec)*rec_len(l)	1) Equilibrium starts of simulation in 1960 with R_0=1987−2017 mean of mfexp(log_mean_rec+rec_dev(t))*rec_len(l)
2) Recruit distribution to first five bins by gamma, using size at lower limit of the bin	2) Recruit distribution to first five bins by gamma, using size at mid point of the bin
3) For reference points, mean R is estimated as in 1) of EAG21.1a Original model	3) For reference points, mean R is estimated as in 1).
4) Retained size composition likelihood is multinomial without offset for size bins 1 to 17 for 1985−2020. Francis final ESS values are used	4) Retained size composition likelihood is robust normal for size bins 6 to 17 for 1985 −2020. Francis final ESS values are used
5) Total size composition likelihood is multinomial without offset for size bins 1 to 17 for 1990 to 2020. Francis final ESS values are used	5) Total size composition is robust normal for size bins 1 to 17 for 1990−2020. Francis final ESS values are used
6) No groundfish size composition likelihood is used	6) No groundfish size composition likelihood is used
7) Observer CPUE likelihood uses log CPUE difference residuals for 1995−2020 and reformatted as like1 = log(stddev) + 0.5*square(residual/stddev), where stddev = CV of CPUE+model estimated additional CV	7) Observer CPUE likelihood uses log CPUE difference residuals for 1995−2020 with CPUE variance + model estimated constant variance
8) Fish Ticket CPUE likelihood uses log CPUE difference residuals for 1985-1998 and reformatted as like1 = log(stddev) + 0.5*square(residual/stddev), where stddev = CV of CPUE+model estimated additional CV	8) Fish Ticket CPUE likelihood uses log CPUE difference residuals for 1985−1998 with CPUE variance + model estimated constant variance
9) Retained catch likelihood uses 1981−1984 catches in number of crabs and 1985−2020 catches in biomass, all transformed into log form, and dnorm(observed catch, expected catch, gmacs CV (0.032) converted to	9) Retained catch likelihood uses 1981−1984 catches in number of crabs as normal likelihood with the weight of 500 and the 1985−2020 catch biomass as lognormal likelihood with the weight of 500

STD) function applied with the emphasis factor 4 (as weight) considered in gmacs	
10) Total catch likelihood uses catch biomasses for 1990−2020 as in 9) with gmacs CV (0.045) converted to STD, and the gmacs emphasis factor 2 (as weight)	10) Total catch likelihood uses catch biomasses for 1990-2020 as lognormal with the graded weight going up to a maximum of 250. Grading of weights is by observer sampled number of pots
11) Groundfish bycatch likelihood uses groundfish bycatch biomasses for 1989−2020 as in 9) with gmacs CV (1.58) converted to STD, and the gmacs emphasis factor 1 (as weight)	11) Groundfish bycatch likelihood uses groundfish bycatch biomasses for 1989−2020 as lognormal with the weight of 0.2
12) likelihood for pot F	coequal
13) likelihood for groundfish bycatch F	coequal
14) likelihood for tagging data	coequal
15) Additional: a. like_rec_dev = dnorm(rec_dev+0.5*sigR*sigR, sigR) where sigR=0.3535 (for bias correction) b. At the end added a tst*tst to the total likelihood function?	15) like_rec_dev= 2*square(rec_dev(t))
16) Reference points: B_{35} = 6,606.73t; F_{35} = 0.57; OFL = 2,165.33t; B/B_{35}= 1.095; R_0= 2.17722 mill; B_0=17031t	16) Reference points: B_{35} = 6,767.93t; F_{35} = 0.61; OFL = 2,928.87t; B/B_{35}= 1.299; R_0= 2.28883 mill; B_0=19,376t

During the working session, a bridging analysis was done between models EAG21.6 and EAG21.1a. Comparison of reference points between models EAG21.6 and EAG21.1a are listed in Table 2. The comparison of MMB trends are shown in Figure1.

Table 2. Estimates of reference points for various changes of the May 2021 accepted model EAG21.1a.

Model Changes	EAG21.1a Base model (May 2021 accepted model)	EAG21.6 Modification of base model for gmacs	EAG21.1aSid1 EAG21.1a+ Retained, Total, and GF (by) catch likelihoods changed to EAG21.6 form	EAG21.1aSid2 EAG21.1aSid1+ Retained and Total size comps likelihoods changed to EAG21.6 form	EAG21.1aSid3 EAG21.1aSid2+ Rec_dev bias correction factor introduced as in EAG21.6	EAG21.1aSid4 EAG21.1aSid3+ CPUE likelihoods changed to EAG21.6 form
M	0.21	0.21	0.21	0.21	0.21	0.21
R_0 (millions)	2.55756	2.17147	2.44195	2.46983	2.43102	2.43102
B_0 (t)	19,376	17,031	18,581	18,845	18,577	18,577
B_{35} (t)	6,767.93	6,606.73	6,490.46	6,553.45	6,448.36	6,448.36
Bcurrent/B_{35}	1.299	1.095	1.222	1.233	1.067	1.067
F_{35}	0.61	0.57	0.55	0.55	0.55	0.55
F_{ofl}	0.61	0.57	0.55	0.55	0.55	0.55
Mean Trawl Byc F	0.00021	0.00023	0.00022	0.00022	0.00023	0.00023
Total catch OFL (t)	2,928.87	2,165.33	2,390.62	2,431.11	2,007.42	2,007.42

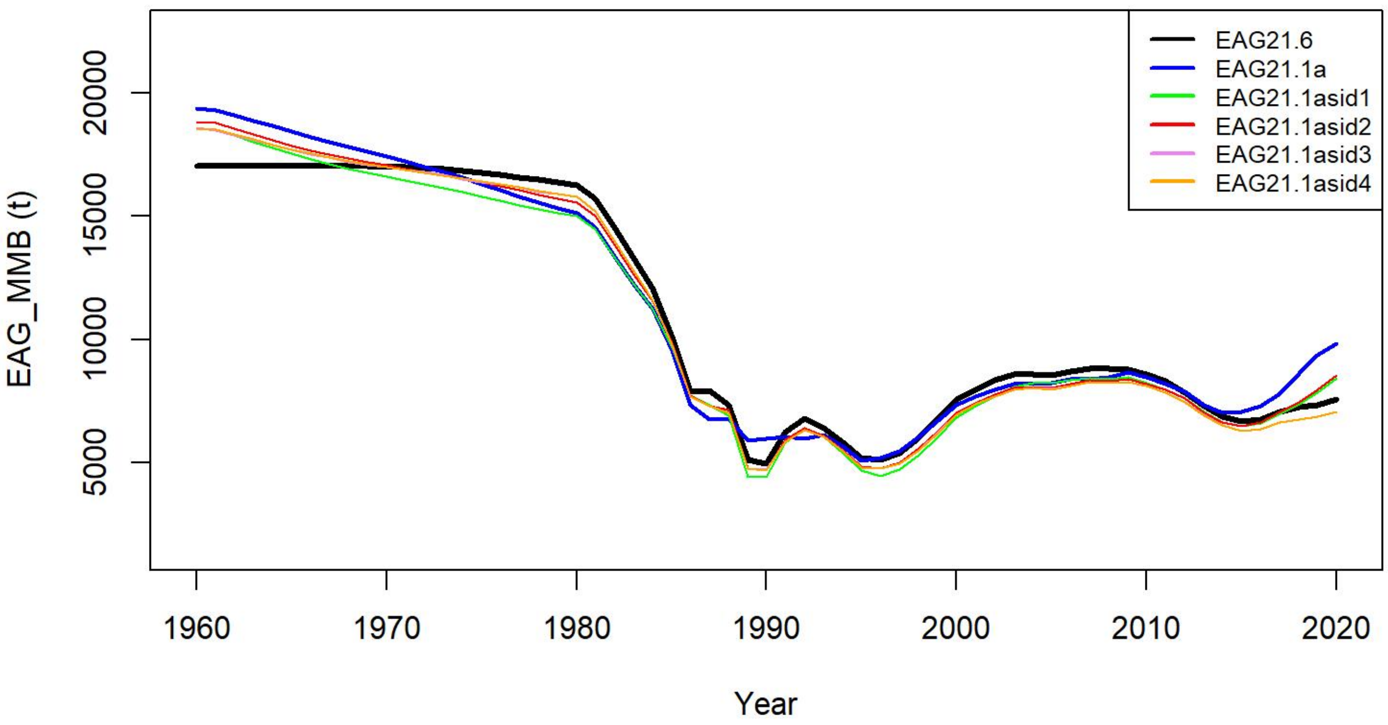

Figure 1. Comparison of MMB trends for various modifications of model EAG21.1a.

After the working session, a bridging analysis was done to assess the progress of model EAG21.6 toward model EAG 21.7. The model EAG21.7 made a few improvements to EAG21.6, one-step-at a time: SigmaR was changed from 0.3535 to 0.5, growth parameters were estimated in the model, catch and bycatch were expressed in number of crab, and observer CPUE indices were updated following May/June 2021 CPT and SSC suggestions. Furthermore, these progressions were implemented in Gmacs models. The reference points among models EAG21.1aUpdate, EAG21.6, EAG21.7, Gmacs6b (implementation of EAG21_6 in Gmacs), Gmacs7b, Gamcs7c, and Gmacs7d are compared in Table 3. The comparison of MMB trends are shown in Figure2 and the abundance by size trends among models EAG21.6, EAG21.7, and Gmacs6b are provided in Figures 3−8.

Table 3. Progression of model EAG21.6 (developed during the December 2021 working session in Juneau) toward EAG21.7 and comparison of reference points among base, modified, and Gmacs models.

	EAG21.1a Update	EAG21.6	EAG21.7	Gmacs6b	Gmacs7b	Gmacs7c	Gmacs7d
Model Changes	Base model EAG21.1a data with updated observer CPUE indices [Gmacs version of R0 and CPUE, and CPUE likelihood]	Modification of EAG21.1a for Gmacs, EAG21.1a data with status quo observer CPUE indices [Gmacs version of R0, size comp, catch, CPUE, and bycatch likelihoods]	EAG21.6+ Use EAG21.1a data with status quo CPUE indices	Convert EAG21.6 estimated par. values for input to Gmacs6b.ctl, use Gmacs6b.dat	Convert EAG21.7 estimated par. values for input to Gmacs7b.ctl, use Gmacs6b.dat	Gmacs7b+ change retained, total, and bycatch from tons to number of crab (in 1000s) in Gmacs6b.dat	Gmacs7c+ Run EAG21.7 with updated observer CPUE, convert EAG21.7 par. values for input to Gmacs7d.ctl
Additional Changes	SigmaR= 0.5 bias correction	sigmaR=0.3535, Growth parameters fixed to previously estimated values	sigmaR=0.5, Growth parameters estimated				
M	0.21	0.21	0.21	0.21	0.21	0.21	0.21
R_0 (millions)	2.83536	2.15772	2.12642	2.60732	3.58235	2.65106	2.69891
B_0 (t)	25,937	20,058	19,871	20,280	24,838	16,322	16,895
B_{35} (t)	9,297.68	6,553.5	6,600.21	7,097.9	8,693.13	5,712.58	5,913.28
Bcurrent/ B_{35}	1.187	1.132	1.317	1.265	1.407	1.345	1.427
F_{35}	0.64	0.56	0.53	0.59	0.97	1.67	1.59
F_{ofl}	0.64	0.56	0.53	0.59	0.97	1.67	1.59
Mean Trawl Byc F	0.00018	0.00022	0.00022	0.00022	0.00014	0.00014	0.00013
Total catch OFL (t)	3,795.0	2,240.17	2,714.16	2,876.88	5,309.06	4,349.77	4,912.36

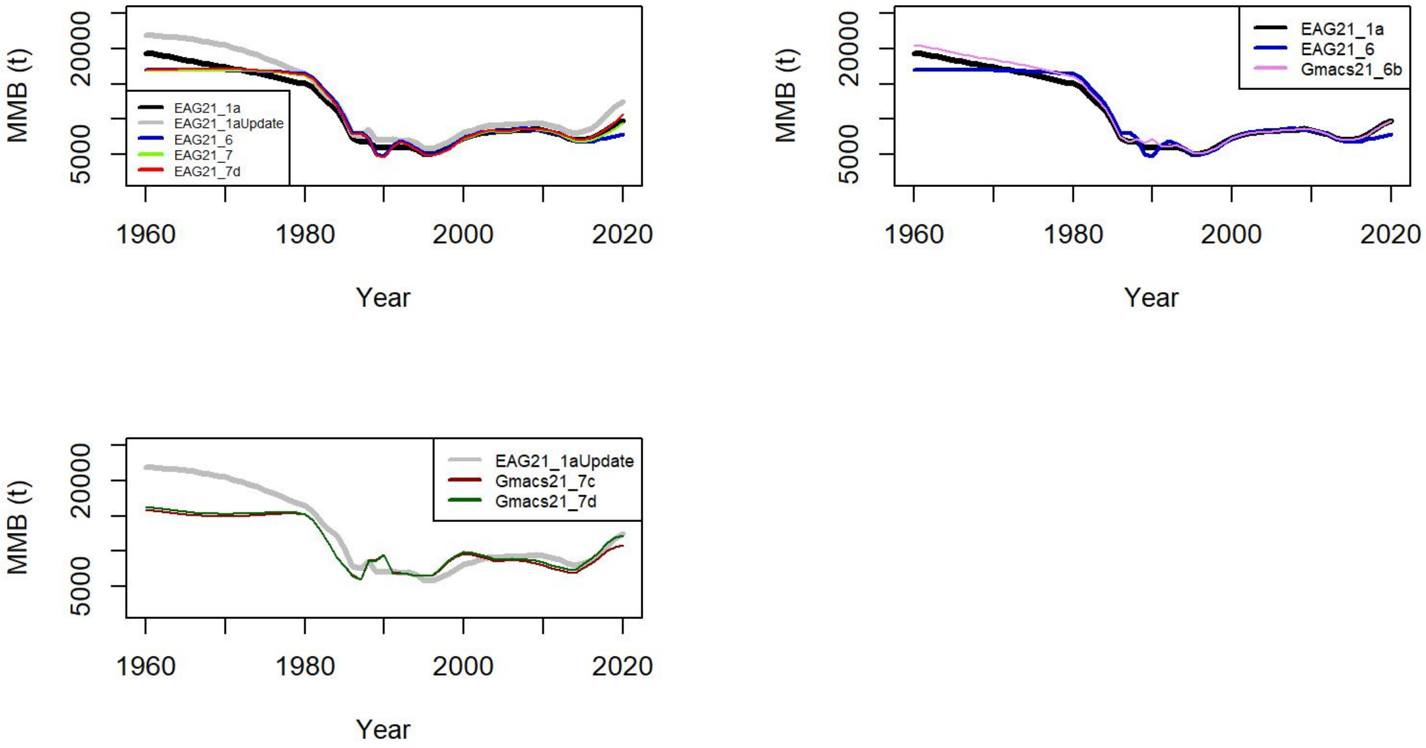

Figure 2. Comparison of MMB trends for various modifications of EAG golden king crab model and Gmacs runs. EAG21.1a refers to the model accepted at the May/June 2021 CPT/SSC meeting whereas EAG21.1aUpdate refers to the updated model following CPT/SSC suggestions (mostly improving observer CPUE standardization).

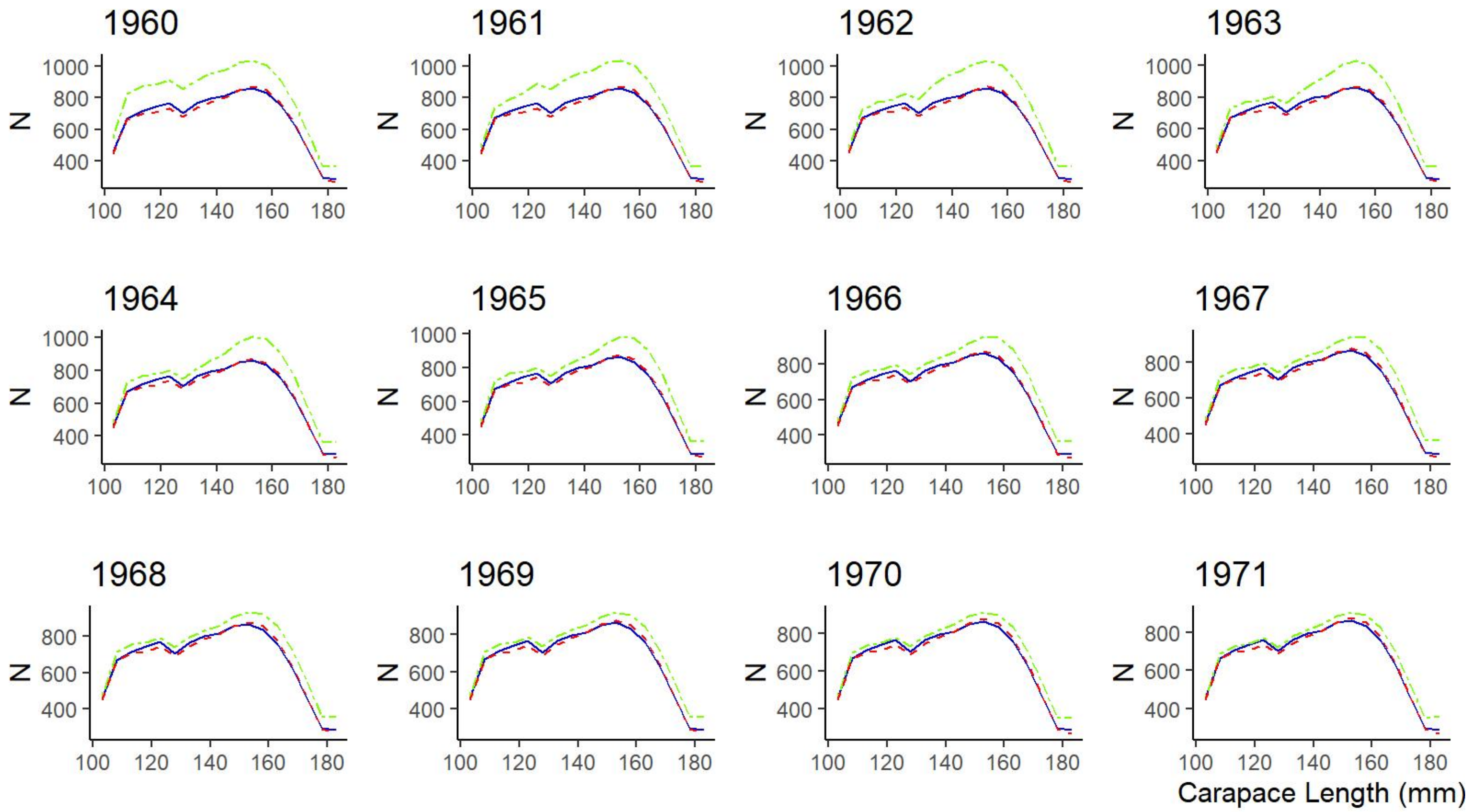

Figure 3. Model predicted abundance by size. N matrix plot 1: 1960−1971.

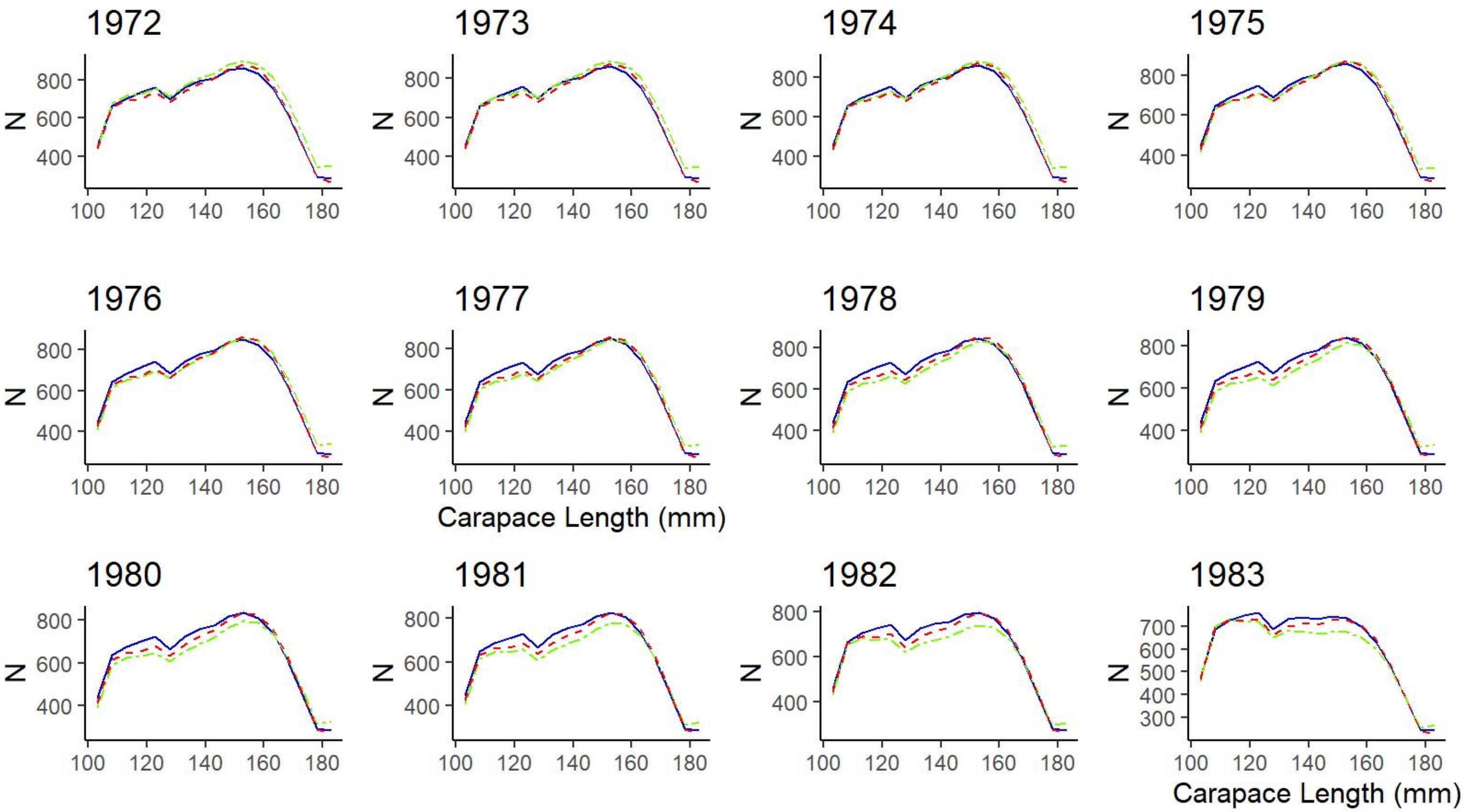

Figure 4. Model predicted abundance by size. N matrix plot 2: 1972−1983.

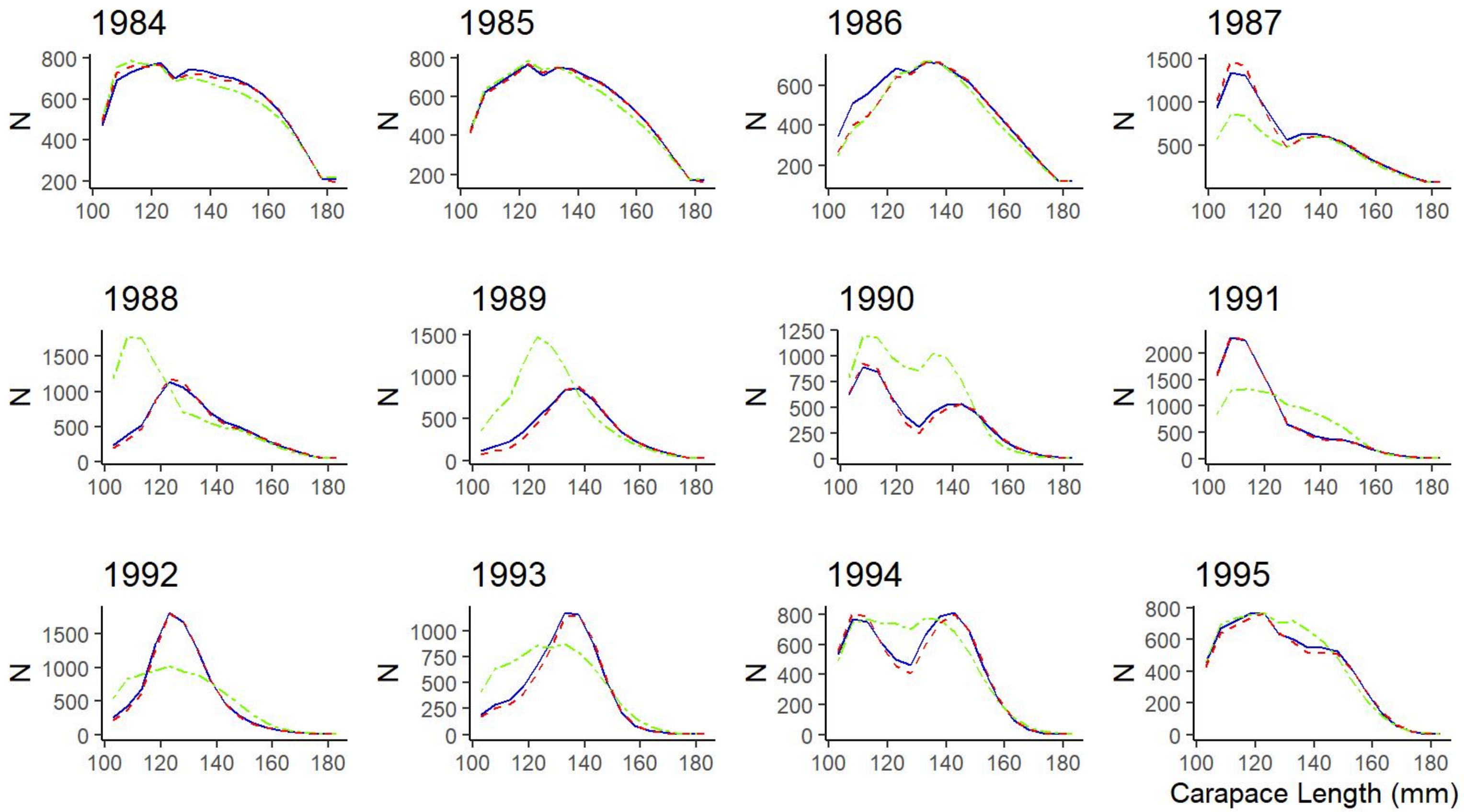

Figure 5. Model predicted abundance by size. N matrix plot 3: 1984−1995.

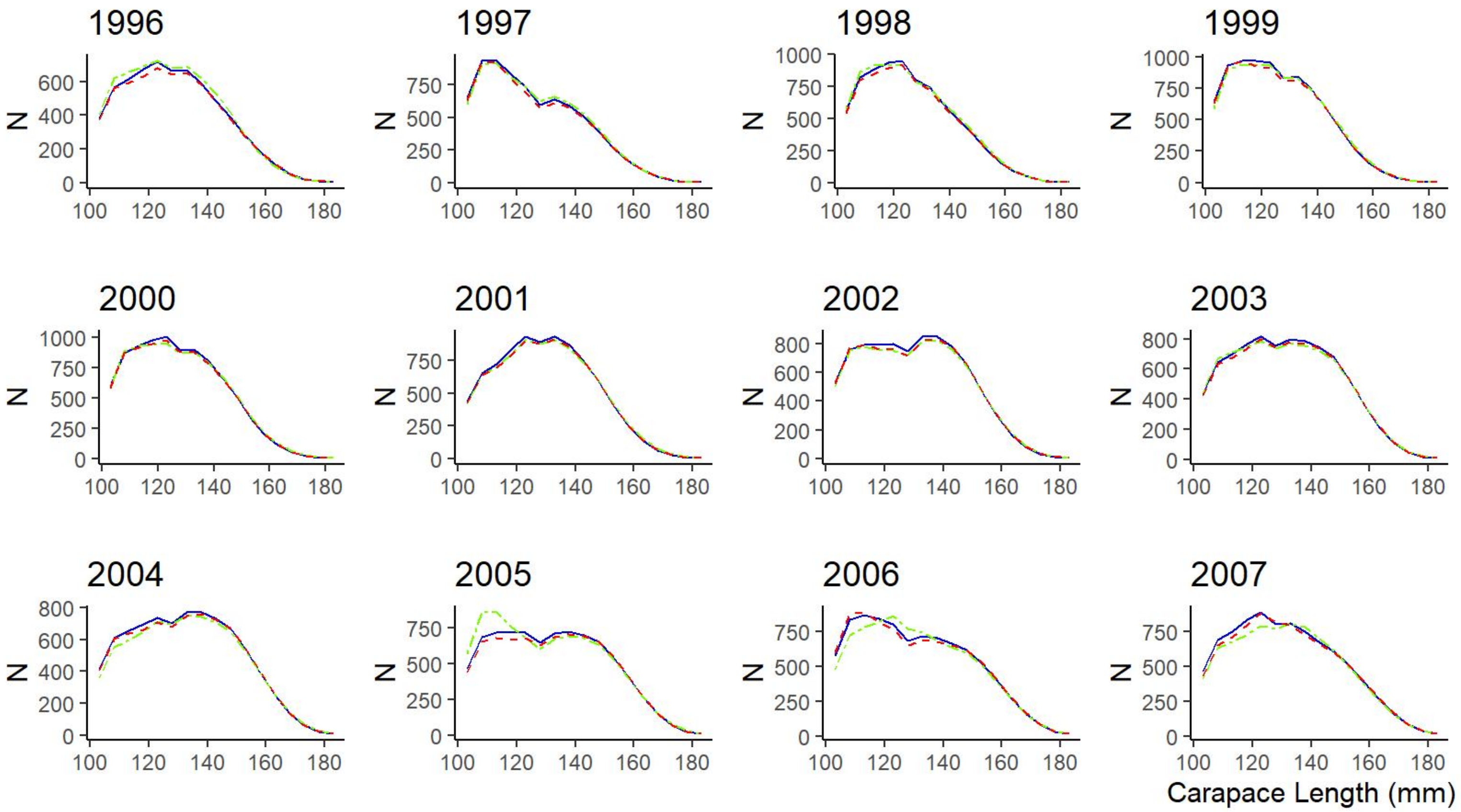

Figure 6. Model predicted abundance by size. N matrix plot 4: 1996−2007.

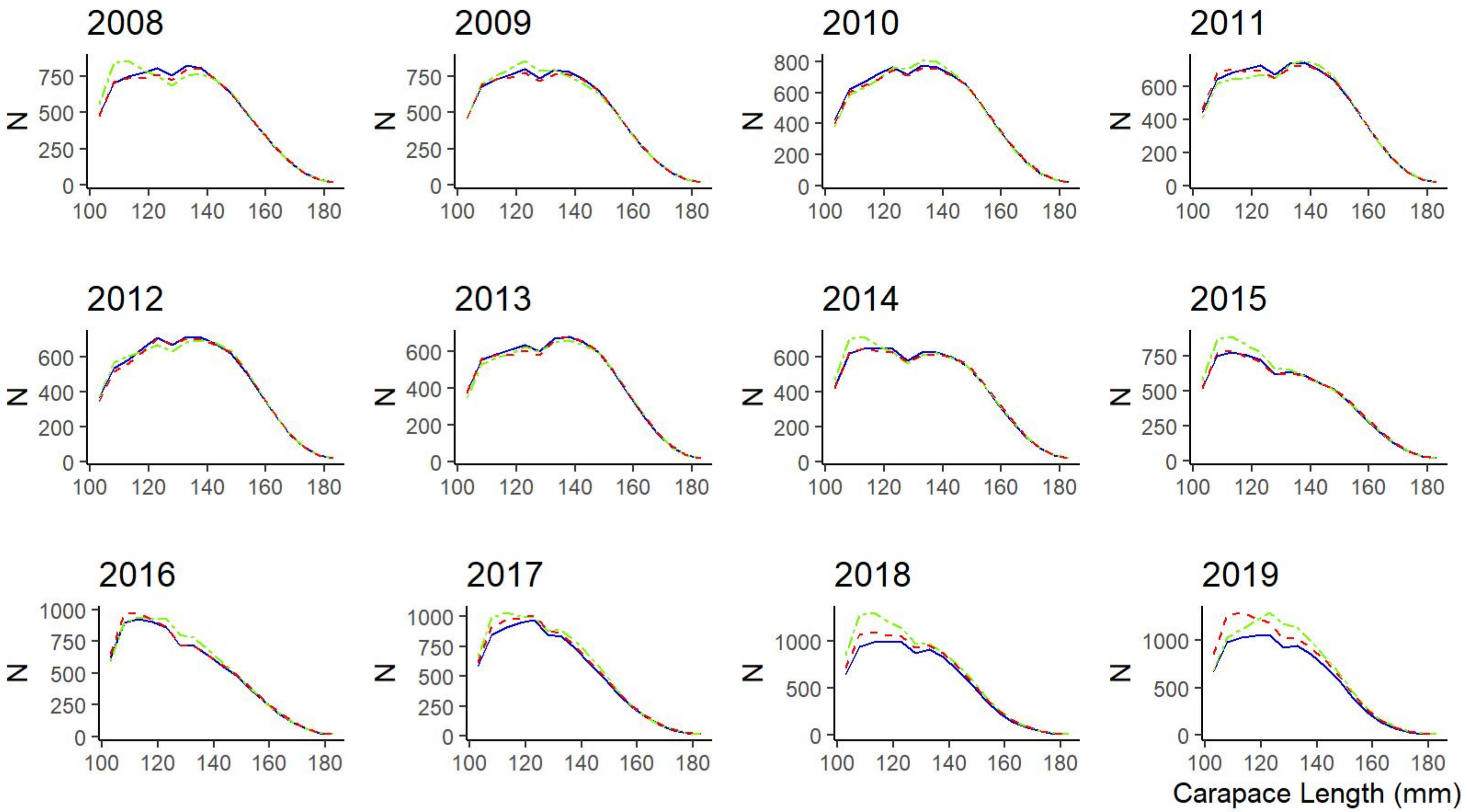

Figure 7. Model predicted abundance by size. N matrix plot 5: 2008-2019.

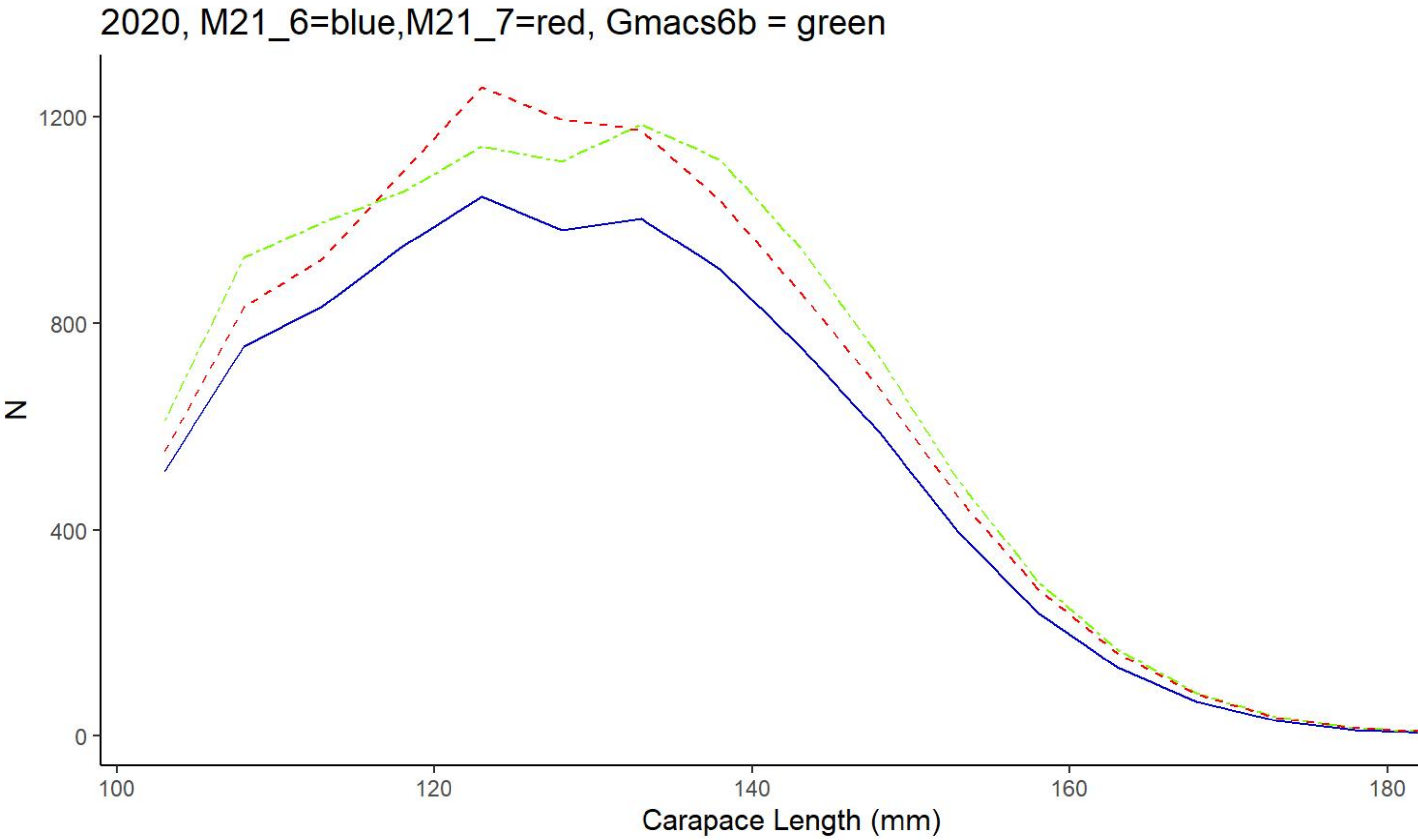

Figure 8. Model predicted abundance by size. N matrix plot 6: 2020. Color key for all plots is provided here.