Aleutian Islands Golden King Crab Stock Assessment Appendices

Appendix A: Integrated model

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

Basic population dynamics

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

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

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

The catches are predicted using the equations

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

$$\hat{C}_{t,j} = \frac{F_t s^T_{t,j} s^r_{t,j}}{Z_{t,j}} N_{t,j}e^{-y_t M}(1-e^{-Z_{t,j}}) \tag{A.2b}$$

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

$$\widehat{Tr}_{t,j} = 0.65\frac{F^{Tr}_t s^{Tr}_j}{Z_{t,j}} N_{t,j}e^{-y_t M}(1-e^{-Z_{t,j}}) \tag{A.2d}$$

$$\hat{T}_{t,j} = \hat{C}_{t,j} + \widehat{D}_{t,j} \tag{A.2e}$$

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

$$Z_{t,j} = F_t s^T_{t,j} s^r_{t,j} + 0.2F_t s^T_{t,j}(1-s^r_{t,j}) + 0.65\,F^{Tr}_t s^{Tr}_j \tag{A.3}$$

F_t is the full selection fishing mortality in the pot fishery, F^{Tr}_t is the full selection fishing mortality in the trawl fishery, $s^T_{t,j}$ is the total selectivity for animals in length-class *j* by the pot fishery during year *t*, s_j^{Tr} is the selectivity for animals in length-class j by the trawl fishery, $s_{t,j}^{r}$ is the probability of retention for animals in length-class j by the pot fishery during year *t*. Pot bycatch mortality of 0.2 and groundfish bycatch mortality of 0.65 (average of trawl [0.8] and groundfish pot [0.5] mortality) were assumed.

Initial abundance

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

The equilibrium stock abundance is

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

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

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

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

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

Growth Matrix

The growth matrix X is modeled as follows:

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

where:

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

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

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

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

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

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

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

Selectivity and retention

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

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

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

Recruitment

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

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

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

Parameter estimation

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

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

Likelihood components

Catches

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

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

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

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

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

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

Catch-rate indices

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

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

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

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

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

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

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

Length-composition data

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

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

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

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

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

$$\hat{\mathrm{L}}_{\mathrm{t,j}}^{\mathrm{GF}} = \frac{\widehat{\mathrm{Tr}}_{\mathrm{t,j}}}{\sum_{\mathrm{j}}^{\mathrm{n}} \widehat{\mathrm{Tr}}_{\mathrm{t,j}}} \tag{A.16}$$

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

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

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

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

Tagging data

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

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

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

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

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

Penalties

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

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

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

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

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

Standardized Residual of Length Composition

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

Output Quantities

Harvest rate

Total pot fishery harvest rate:

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

Exploited legal male biomass at the start of year t:

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

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

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

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

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

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

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

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

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

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

$F_{OFL} = 0.$

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

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

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

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

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

Additional CPUE indices standard deviation, σ_e	1 (estimated)
Likelihood weights (coefficient of variation)	Pre-specified, varies by scenario

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

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

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

Appendix B: Catch and CPUE data

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Observer CPUE index by GLM

a. Non-interaction GLM model

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

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

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

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

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

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

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

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

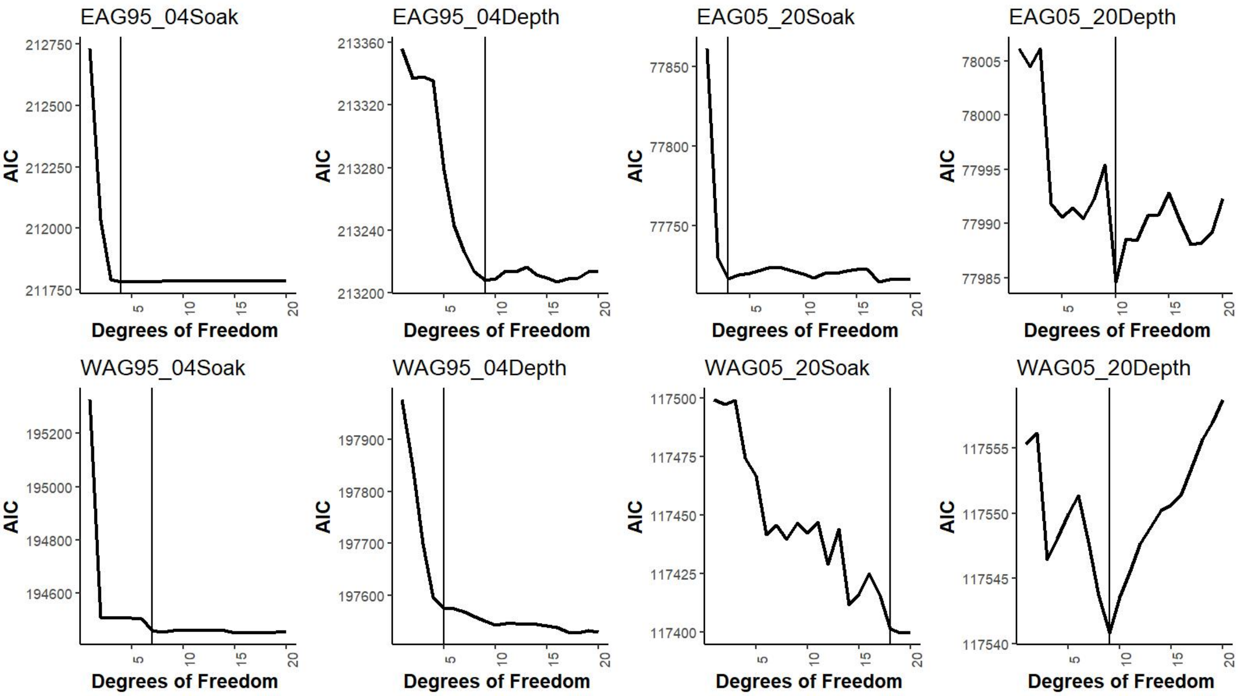


Figure B.1. AIC vs degrees of freedom for soak time and depth during pre- and post-rationalization periods for EAG (top) and WAG (bottom). Vertical lines identify the optimum degrees of freedom values chosen for CPUE standardization.

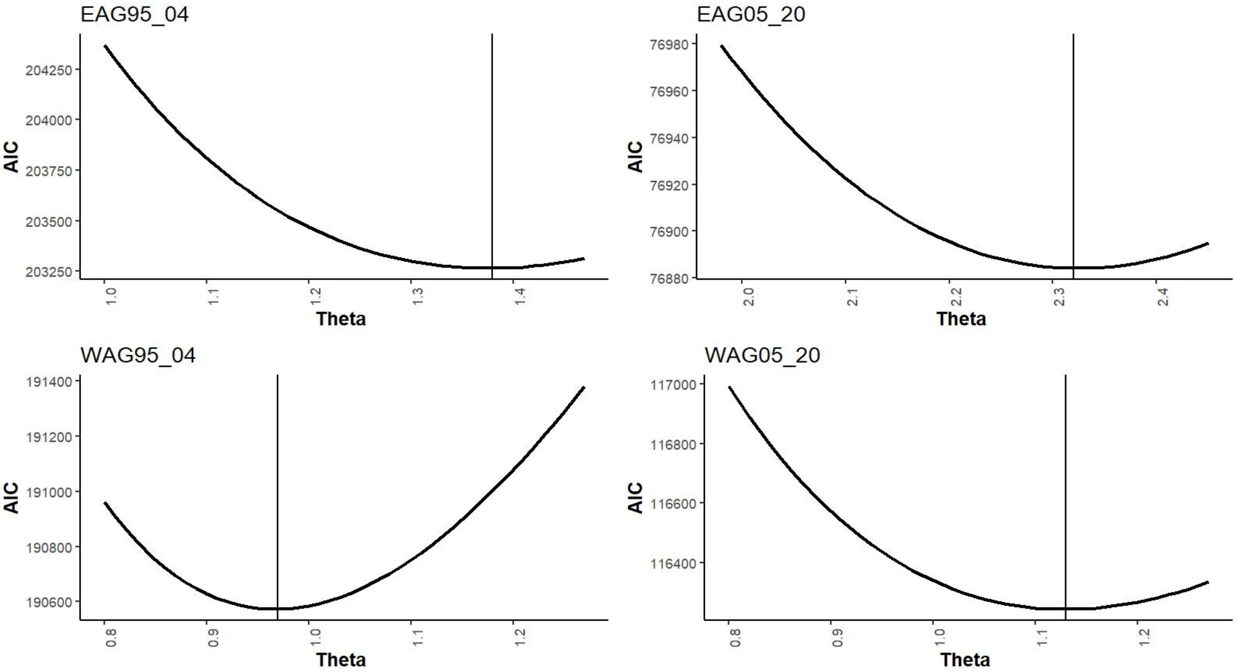


Figure B.2. AIC vs theta (dispersion parameter) during pre- and post-rationalization periods for EAG (top) and WAG (bottom). Vertical lines identify the optimum theta values chosen for CPUE standardization.

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

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

For EAG 1995_04 CPUE indices:

```
library(MASS)

 library(splines)
```

Step 1:

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

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

Step 2:

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

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

The final main effect models for EAG were:

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

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

Initial selection by stepAIC:

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

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

The final models for WAG were:

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

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

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

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

b. Year:Area interaction GLM:

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

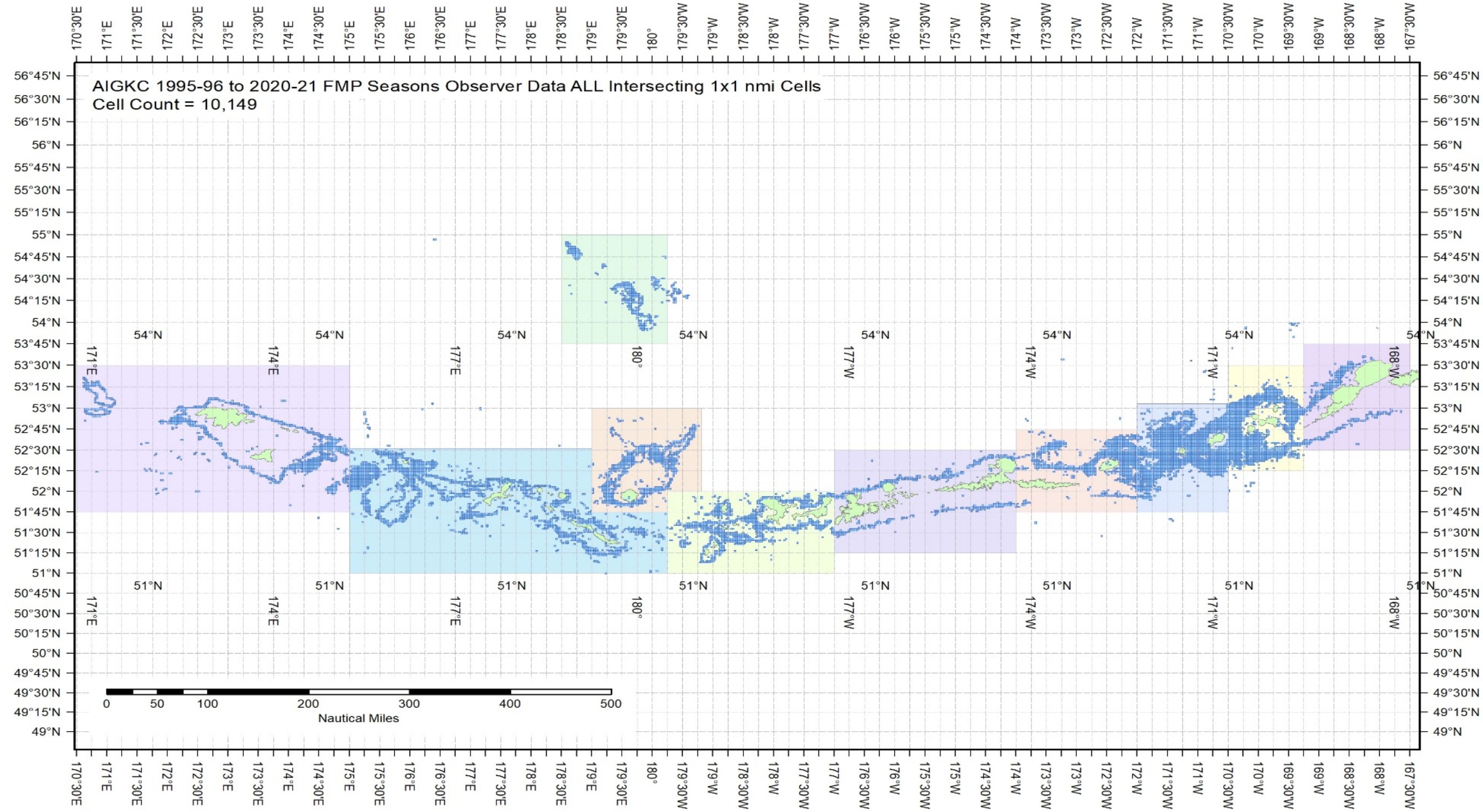


Figure B.3. The 1995/96–2020/21 observer pot samples enmeshed in 10 blocks for the Aleutian Islands golden king crab. The blocks were determined from visually exploring each year's pot distribution locations (available with the first author). The blocks contain observed patches of crab distribution during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

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

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

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

We assumed the null model to be

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

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

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

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

For WAG 1995_04 CPUE indices:

```
library(MASS)

 library(splines)
```

Step 1:

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

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

Step 2:

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

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

The final interaction effect models for EAG were:

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

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

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

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

The final interaction effect models for WAG were:

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

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

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

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

Steps:

1. *Block-scale analysis*:

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

   $CPUE_{ij} = e^{YB_{ij} + \sigma_{ij}^2/2}$ (B.14)

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

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

The abundance index for jth block in ith year is

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

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

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

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

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

```
library(MASS)
```

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

```
glm.fit<-  glm(log(Bij)~Yeari + Blockj, data=Bindex)
```

where the data frame “Bindex” contains available B_{ij},$Year_i$, and $Block_j$ column values.

To predict the missing biomass index Y:

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

where the new data frame “BindexFillpredict” contains $Year_i$ and $Block_j$ column values for which B_{ij} indices are needed and contains an empty B_{ij} column for fill in.

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

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

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

Annual biomass index, B_i , was estimated as,

$$B_i = \sum_j B_{ij} \tag{B.17}$$

The variance of the total biomass index was computed as:

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

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

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

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

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

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

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

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

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

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

c. Commercial fishery CPUE index by non-interaction model

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

The final model for EAG was:

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

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

and that for WAG was:

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

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

Appendix C. Cooperative Survey

1. *Summary of the survey method*

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

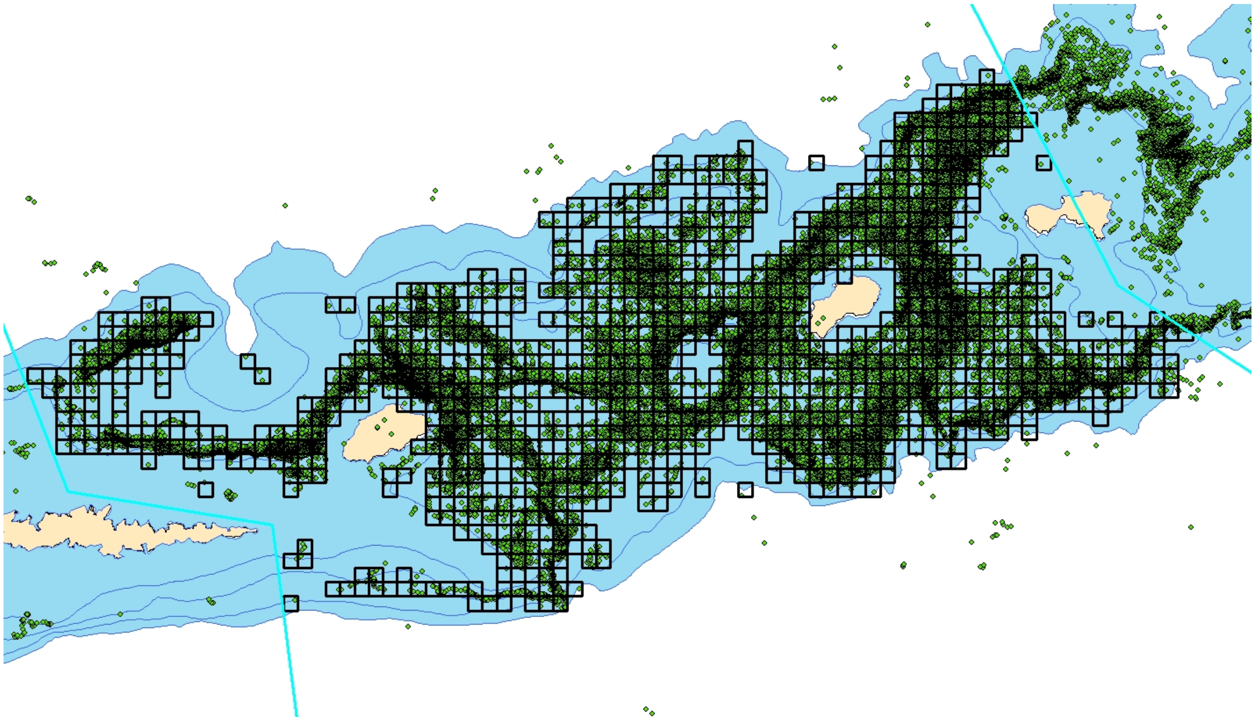


Figure C.1. Survey design: 2 nmi x 2 nmi grids overlaid on observer pot sample locations (green squares) in EAG.

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

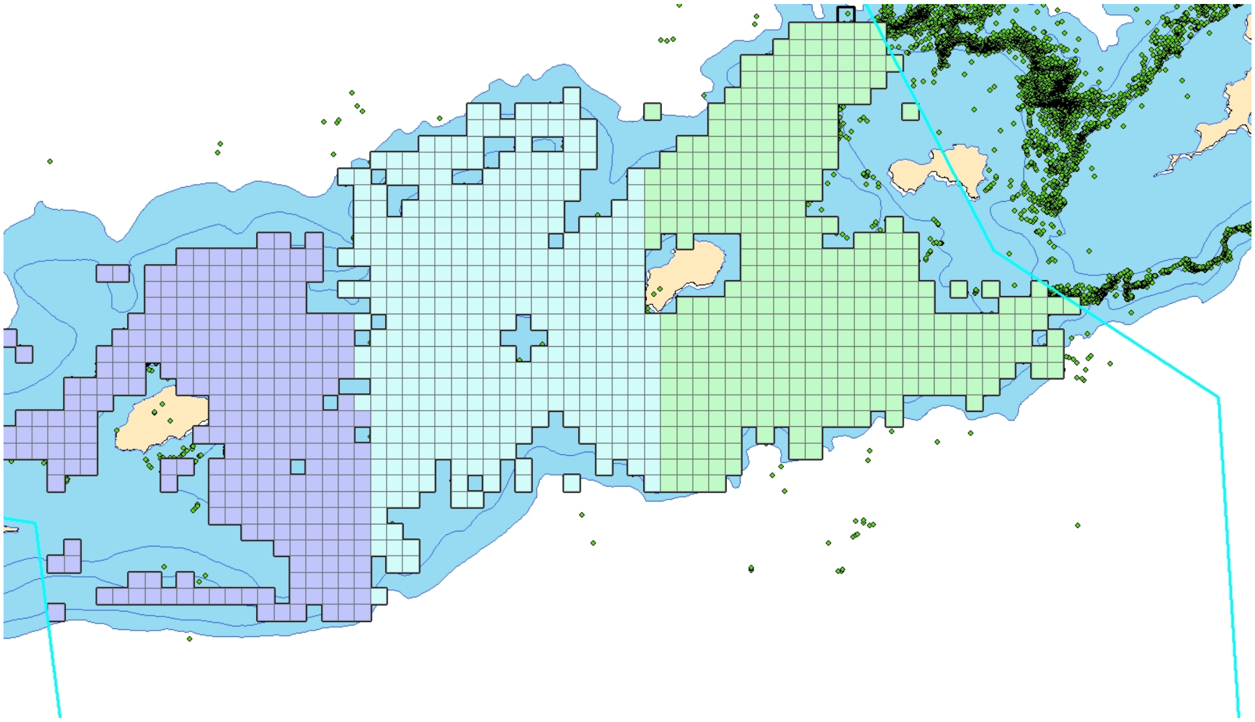


Figure C.2. Survey design: 2 nmi x 2 nmi grids stratified by three equal sizes for selecting random pot sampling locations in EAG.

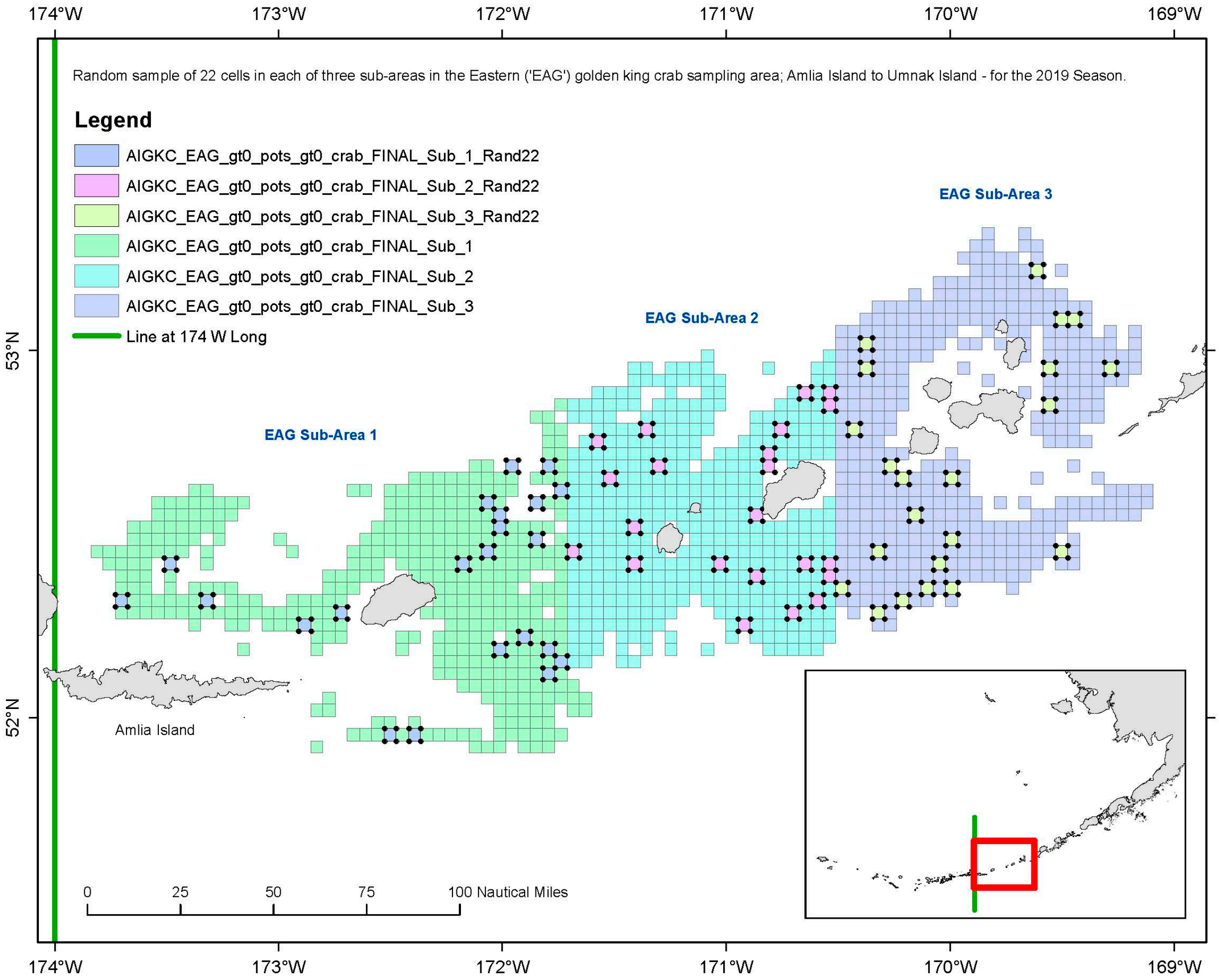


Figure C.3. Random sample of 22 cells selected in each of three sub strata in EAG during the 2019 fishery.

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

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

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

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

2. Standardization of cooperative survey CPUE

Data

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

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

Method

Data preparation for CPUE standardization:

- i.) Created two new columns by concatenating Vessel Code with String# as well as with String# and Pot# because String# and Pot# are not unique numbers to each vessel. The new column names were identified as VesString and VesStingPot. For example, a Vessel Code 20556 with a String# 3 was concatenated to be 205563 in a new column VesString, and a Vessel Code 20556 with a String#17 and a Pot# 5 was concatenated to be 20556175 in a new column VesStringPot.
- ii.) Raised the Catch in each record by the Sample Rate.
- iii.) Subset the data by large mesh king crab pot [Mesh ID not equal to 2 (i.e., small mesh pot)], legal size (> 135 mm CL), and EAG (EAGWAG=1). The female (Sex=2) and unclassified catch without any male crab (Sex=1) in a crab pot was set to 0 to account for the possibility of zero catch for expected male CPUE determination.
- iv.) Further subset the data by 5% to 95%, trimmed Soak time, and 1% to 99% trimmed Depth. This is to exclude catches from any unusual pot operations.
- v.) Summed up the catch across sizes for each Pot# and labelled it as SumCatch. Thus, each Pot# has a single catch number.

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

Results

1. Fixed effect model:

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

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

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

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

2. Random intercept model (model 1):

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

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

Table C.1. Random intercept model 1 output.

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

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

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

The random intercept model 2 converged with the following output:

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

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

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

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

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

Diagnostic test

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

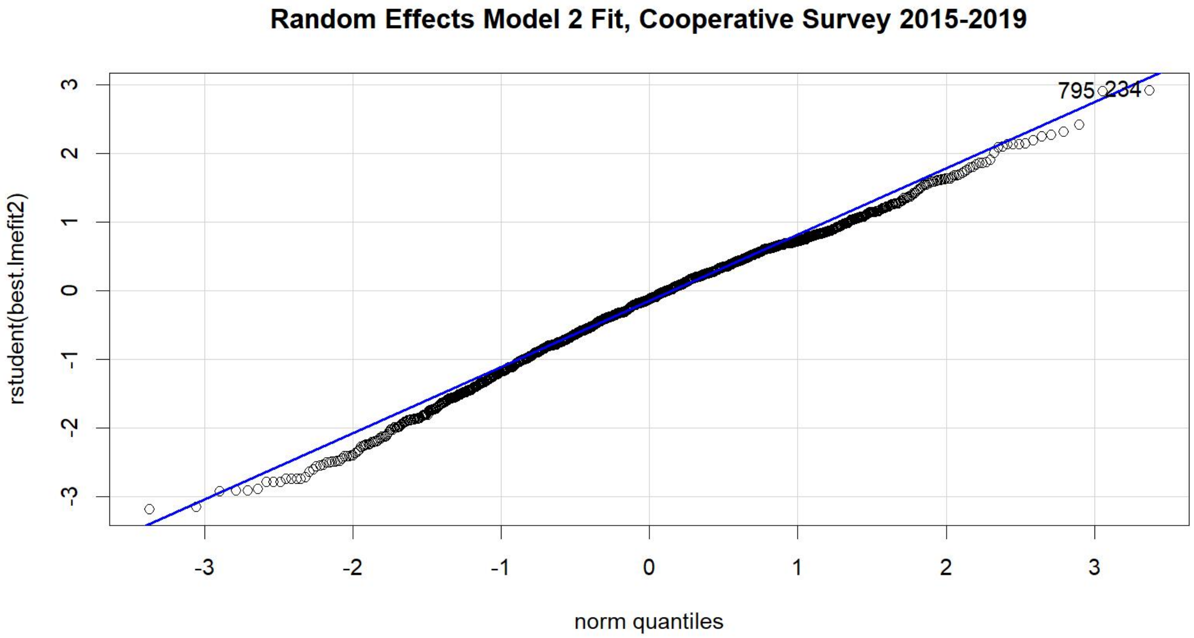


Figure C.4. Studentized residual plot for the mixed random effects model fit using the 2015–2019 EAG data.

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

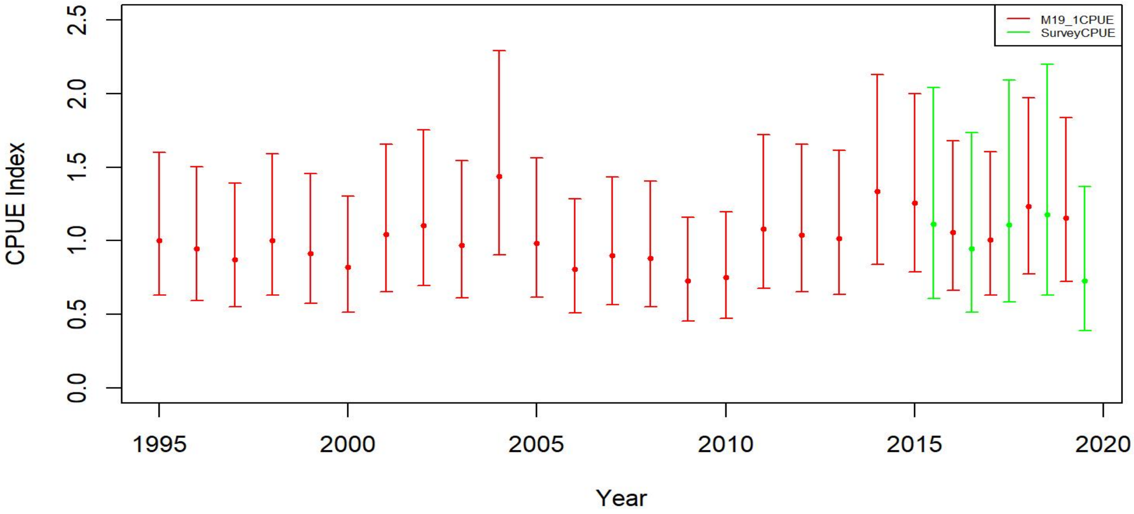


Figure C.5. Comparison of cooperative survey random effects model 2 CPUE indices (green) and observer non interaction factor model CPUE indices (red, 19.1) for EAG. The confidence limits are determined with ±2SE. Model estimated additional standard error was added to SE.

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

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

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

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

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2022

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
EAG21.1d	3a	14.686	17.823	1.21	0.62	1987–2017	0.62	5.822	5.791	4.367

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

Model	Tier	$MMB_{35\%}$	*Current MMB*	*MMB/* $MMB_{35\%}$	F_{OFL}	*Recruitment Years to Define* $MMB_{35\%}$	$F_{35\%}$	*OFL*	*ABC (P*=0.49)*	*ABC (0.75*OFL)*
EAG21.1d	3a	6661.73	8084.57	1.21	0.62	1987–2017	0.62	2,641.064	2,626.844	1,980.798

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

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

Appendix D: Male Maturity

Introduction

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

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

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

Method

We used the carapace length (mm CL) and chela height (up to one-tenth of a mm CH) data collected by the observer, retained catch, and cooperative surveys sampling during the 2018/19, 2019/20, and 2020/21 fishing seasons for male maturity investigation. We determined bend points and corresponding two segmented lines for different groups of data outside the assessment model using the 'segmented regression' package available in R version 3.6.3 (R Core Team 2020). This method has been used for golden king crab knife-edge maturity determination by Olson *et al*. (2018). They fitted chela height vs. carapace length whereas we fitted the log ratio of chela height over carapace length vs. carapace length to determine the bend point. Log ratio provided better discrimination of our data points.

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

$$ln(CH/CL) = \beta_0 + \beta_1 CL \qquad (D.1)$$

where β_0 and β_1 are regression parameters

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

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

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

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

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

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

Data

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

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

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

Results

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

Figures D.1, D.2, and D.3 show the fitted segmented regression lines overlayed on observed log (CH/CL) vs CL data for AI, EAG, and WAG, respectively.

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

	Estimate	SE	t-value	Pr(>|t|)	Breakpoint (mm CL)	SE	Remarks

AI 2018–20:							Fit to original data, 85.0–142.0 mm CL range
Intercept line 1	-1.76273	0.04974	-35.43610	0.00000	118.900	1.760	
Slope line 1	0.00183	0.00046	3.96526	0.00007			
Slope to add	0.00465	0.00053	8.70356	0.00000			
Slope line 2	0.00648						
Intercept line 1	-1.78187	0.00185			119.984	0.104	Bootstrap median estimates
Slope line 1	0.00200	0.00002					
Slope line 2	0.00663	0.00002					
EAG 2018–20:							Fit to original data, 85.0–142.0 mm CL range
Intercept line 1	-1.74671	0.15258	-11.44750	0.00000	112.574	4.125	
Slope line 1	0.00146	0.00149	0.98016	0.32713			
Slope to add	0.00515	0.00154	3.35423	0.00081			
Slope line 2	0.00661						
Intercept line 1	-1.81430	0.01115			117.800	0.317	Bootstrap median estimates
Slope line 1	0.00216	0.00012					
Slope line 2	0.00698	0.00230					
WAG 2018–20:							Fit to original data, 85.0–142.0 mm CL range
Intercept line 1	-1.73808	0.05330	-32.60763	0.00000	119.330	2.115	
Slope line 1	0.00164	0.00049	3.33148	0.00088			
Slope to add	0.00440	0.00061	7.19722	0.00000			
Slope line 2	0.00604						
Intercept line 1	-1.74555	0.00188			119.603	0.124	Bootstrap median estimates
Slope line 1	0.00171	0.00002					
Slope line 2	0.00620	0.00005					
EAG 1991:							Fit to 85.0–142.0 mm CL range
Intercept line 1	-1.60166	0.02286	-70.04911	0.00000	107.000	1.915	Estimates from 2457 measurements
Slope line 1	0.00070	0.00026	2.71486	0.00668			
Slope to add	0.00424	0.00029	14.45235	0.00000			
Slope line 2	0.00494						
WAG 1984:							Fit to 85.0–142.0 mm CL range
Intercept line 1	-1.67570	0.09222	-18.17129	0.00000	105.824	4.650	Estimates from 341 measurements

Slope line 1	0.00126	0.00097	1.29613	0.19582
Slope to add	0.00332	0.00106	3.12254	0.00195
Slope line 2	0.00458			

Figures D.1, D.2 and D.3 provide the segment regression lines fitted to the log (CH/CL) vs. CL data pairs for 2018–2020 in AI, EAG, and WAG, respectively.

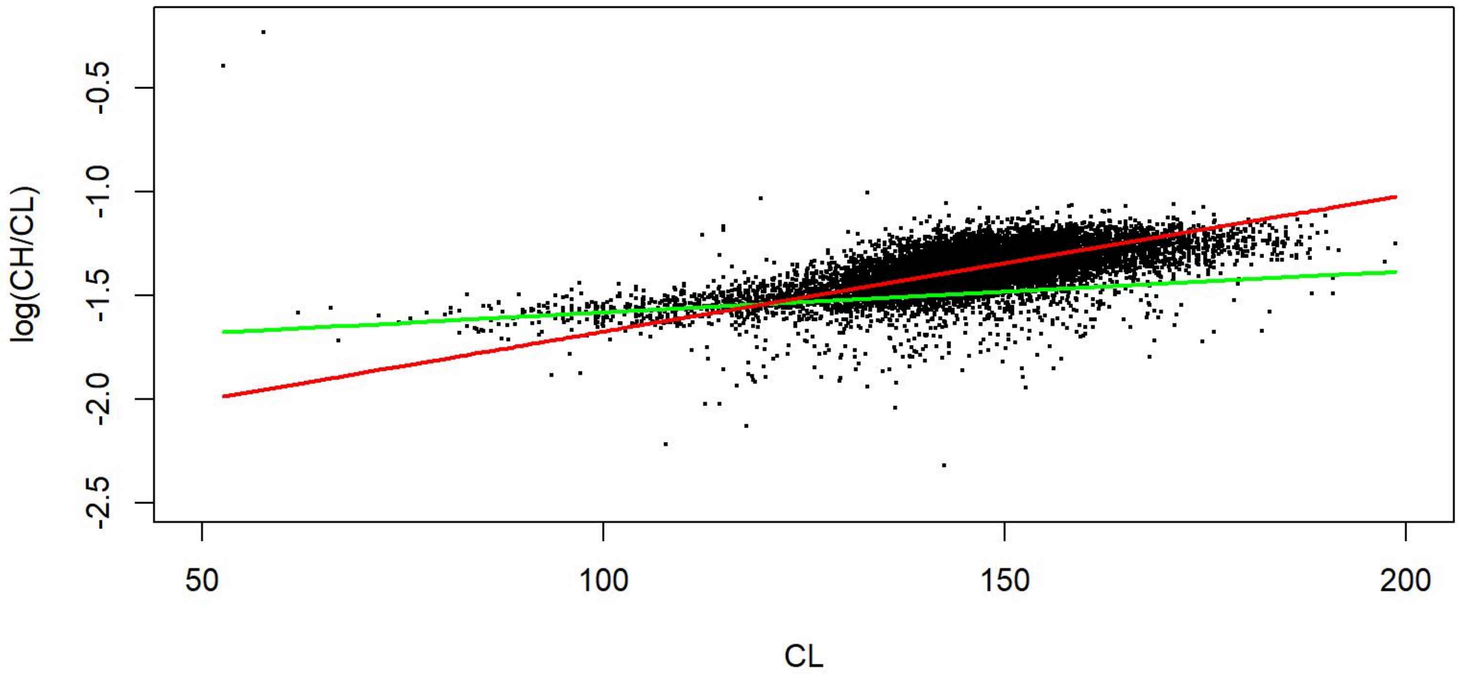


Figure D.1. Segmented linear regression fit to log(CH/CL) vs. CL data of male golden king crab for 2018–2020 in AI.

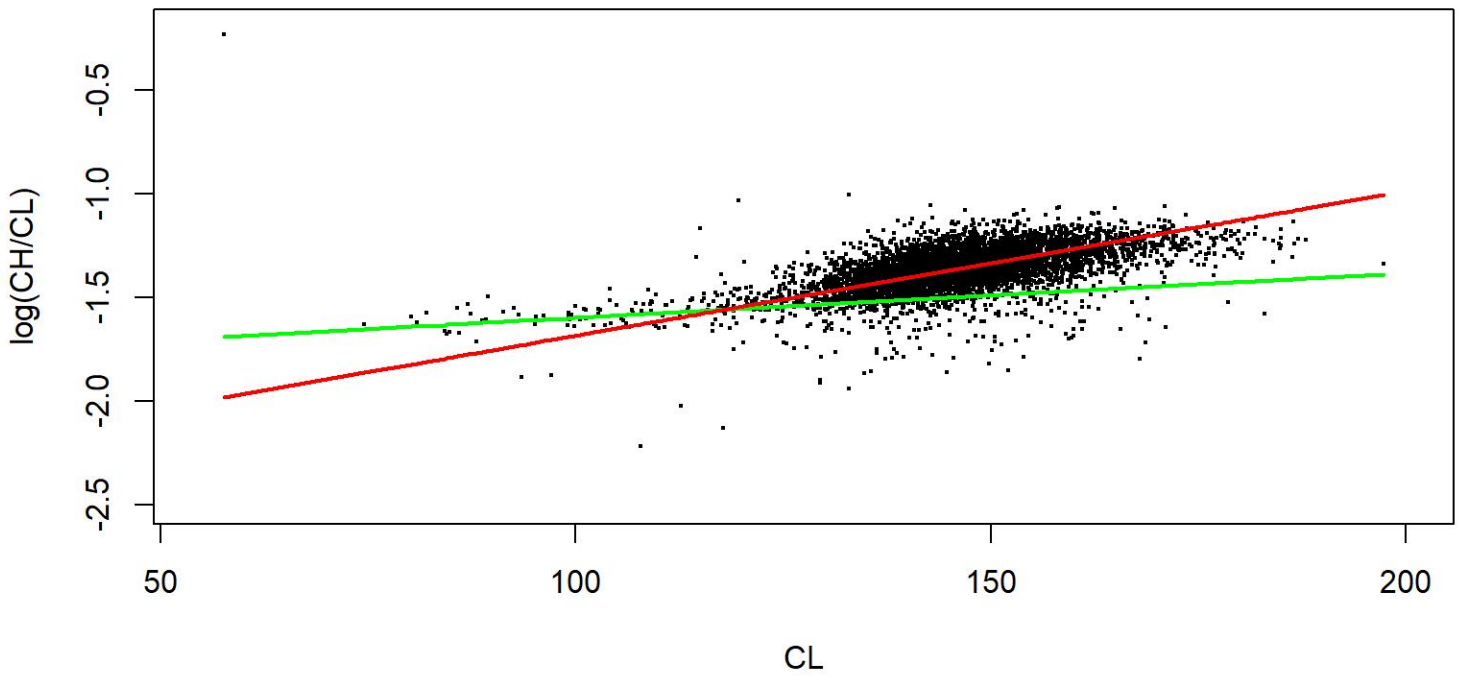


Figure D.2. Segmented linear regression fit to log(CH/CL) vs. CL data of male golden king crab for 2018–2020 in EAG.

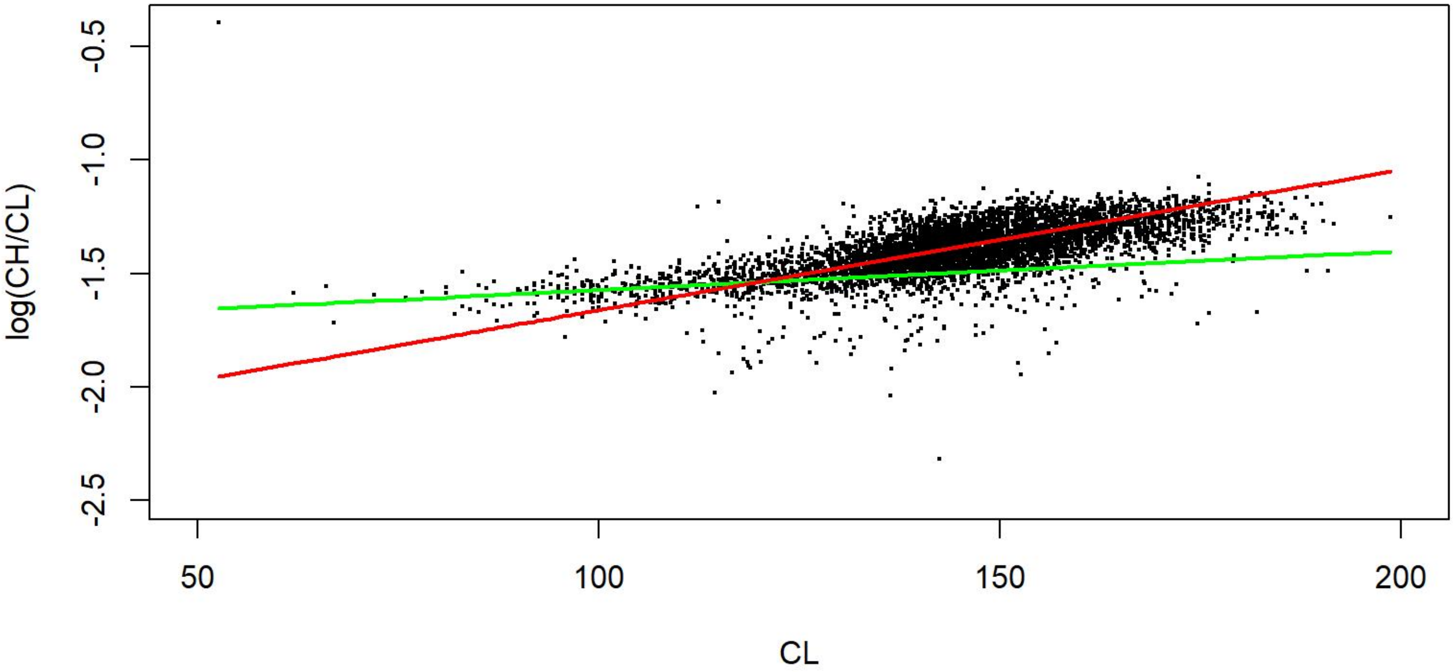


Figure D.3. Segmented linear regression fit to log(CH/CL) vs. CL data of male golden king crab for 2018–2020 in WAG.

Implication on mature male biomass estimation:

Figure D.4 provides the long-term trends in MMB by models 21.1a, 21.1b, and 21.1c with two maturity assumptions: status quo knife-edge maturity size of 111 mm CL (...1a, …1b, …1c) and higher maturity size of 116 mm CL (…1a1, …1b1, …1c1. Changes from status quo maturity assumption generally result in lower MMB values.

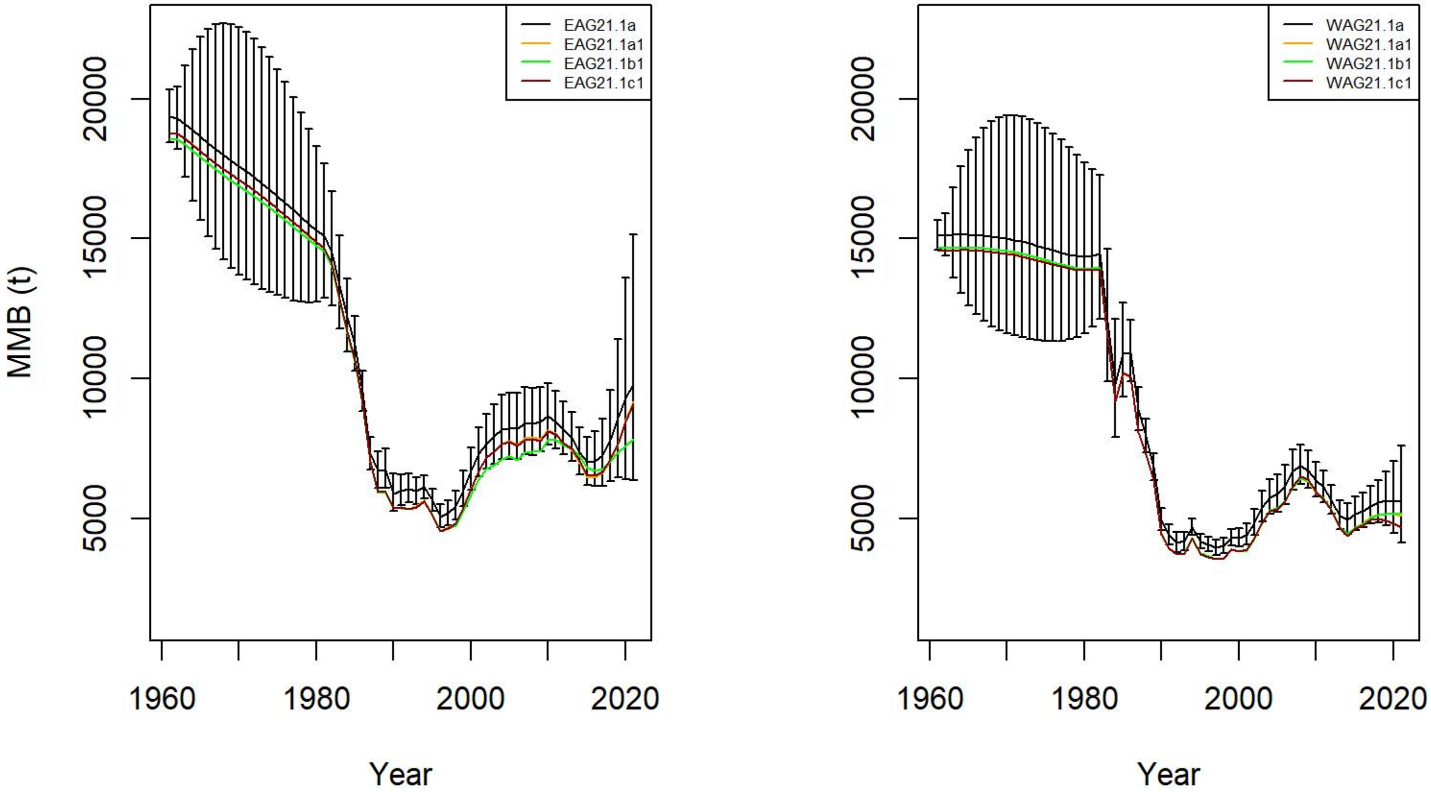


Figure D.7. Trends in golden king crab mature male biomass for models 21.1a, 21.1a1, 21.1b1, and 21.1c1 fits to EAG (left) and WAG (right) data, 1961–2021. Model 21.1a estimate has two standard error confidence limits. Year 2020 refers to 2019/20 fishing season.

Appendix E: Jittering

Jittering of model 19.1 parameter estimates

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

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

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

with the final jittered initial parameter value back transformed as:

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

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

The jitter results are based on the complete fishery data and are summarized for the selected model 21.1a in Tables E.1 and E.2 for EAG and WAG, respectively. All runs for EAG converged to the highest log likelihood values except for nonconvergent runs. We concluded from jitter results that optimization of 21.1a model achieved global minima for EAG. On the other hand, some runs for WAG converged to the highest likelihood, but few reference point estimates differed for the same minima, which was concerning at the time of assessment in May 2021. After SSC pointed out this discrepancy in June 2021, we reevaluated jitter runs for WAG with total size composition and biomass likelihoods computation restricted to a shorter period, 1995/96- 2020/21. This removed the discrepancy and jitter results for WAG are provided in this report for this restriction. Because of time limitation we did not choose the best model from this rerun for OFL and ABC determination. We will follow this procedure to choose an optimum model in the next assessment cycle.

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

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-93.905830**	**0.001469**	**6,762**	**2,945**	**8,761**
1	-93.905830	0.000097	6,762	2,945	8,761
2	-93.905830	0.000104	6,762	2,945	8,761
3	-93.905830	0.000481	6,762	2,945	8,761
4	-93.905830	0.000309	6,762	2,945	8,761

5	-93.905830	0.000103	6,762	2,945	8,761
6	-93.905830	0.000017	6,762	2,945	8,761
7	-93.905830	0.000149	6,762	2,945	8,761
8	-93.905830	0.000067	6,762	2,945	8,761
9	-93.905830	0.000041	6,762	2,945	8,761
10	-93.905830	0.000110	6,762	2,945	8,761
11	-93.905830	0.000241	6,762	2,945	8,761
12	-93.905830	0.000004	6,762	2,945	8,761
13	-93.905830	0.000191	6,762	2,945	8,761
14	-93.905830	0.000398	6,762	2,945	8,761
15	-93.905830	0.000193	6,762	2,945	8,761
16	-93.905830	0.000191	6,762	2,945	8,761
17	-93.905830	0.000433	6,762	2,945	8,761
18	-85.913090	0.000686	7,173	3,165	9,272
19	-93.905830	0.000003	6,762	2,945	8,761
20	-93.905830	0.000262	6,762	2,945	8,761
21	-93.905830	0.000117	6,762	2,945	8,761
22	-93.905830	0.000051	6,762	2,945	8,761
23	-93.905830	0.000028	6,762	2,945	8,761
24	-93.905830	0.000105	6,762	2,945	8,761
25	-93.905830	0.000319	6,762	2,945	8,761
26	-93.905830	0.000142	6,762	2,945	8,761
27	-93.905830	0.000094	6,762	2,945	8,761
28	-93.905830	0.000101	6,762	2,945	8,761
29	-93.905830	0.000739	6,762	2,945	8,761
30	-93.905830	0.000419	6,762	2,945	8,761
31	-93.905830	0.000111	6,762	2,945	8,761
32	-93.905830	0.000076	6,762	2,945	8,761
33	-93.905830	0.000334	6,762	2,945	8,761
34	-93.905830	0.000223	6,762	2,945	8,761
35	-93.905830	0.000056	6,762	2,945	8,761
36	-93.905830	0.000076	6,762	2,945	8,761
37	-93.905830	0.000003	6,762	2,945	8,761
38	-93.905830	0.000090	6,762	2,945	8,761
39	-93.905830	0.000180	6,762	2,945	8,761
40	-93.905830	0.000072	6,762	2,945	8,761
41	-93.905830	0.000038	6,762	2,945	8,761
NA	NA	NA	NA	NA	NA
43	-93.905830	0.000136	6,762	2,945	8,761
44	-93.905830	0.000106	6,762	2,945	8,761
45	-93.905830	0.000186	6,762	2,945	8,761
46	-93.905830	0.000244	6,762	2,945	8,761
47	-93.905830	0.000093	6,762	2,945	8,761
48	-93.905830	0.000196	6,762	2,945	8,761

49	-93.905830	0.000230	6,762	2,945	8,761
50	-93.905830	0.000396	6,762	2,945	8,761
51	-93.905830	0.000252	6,762	2,945	8,761
52	-93.905830	0.000060	6,762	2,945	8,761
53	-93.905830	0.000239	6,762	2,945	8,761
54	-93.905830	0.000133	6,762	2,945	8,761
55	-93.905830	0.000033	6,762	2,945	8,761
56	-93.905830	0.000057	6,762	2,945	8,761
57	-93.905830	0.000216	6,762	2,945	8,761
58	-93.905830	0.000613	6,762	2,945	8,761
59	-93.905830	0.000407	6,762	2,945	8,761
60	-93.905830	0.000644	6,762	2,945	8,761
61	-93.905830	0.000264	6,762	2,945	8,761
62	-93.905830	0.000130	6,762	2,945	8,761
63	-93.905830	0.000001	6,762	2,945	8,761
64	-93.905830	0.000016	6,762	2,945	8,761
65	-93.905830	0.000320	6,762	2,945	8,761
66	-93.905830	0.000136	6,762	2,945	8,761
67	-93.905830	0.000005	6,762	2,945	8,761
68	-93.905830	0.000122	6,762	2,945	8,761
69	-93.905830	0.000104	6,762	2,945	8,761
70	-93.905830	0.000014	6,762	2,945	8,761
71	-93.905830	0.000295	6,762	2,945	8,761
72	-93.905830	0.000131	6,762	2,945	8,761
73	-93.905830	0.000053	6,762	2,945	8,761
74	-93.905830	0.000087	6,762	2,945	8,761
75	-93.905830	0.000394	6,762	2,945	8,761
76	-93.905830	0.000061	6,762	2,945	8,761
77	-93.905830	0.000068	6,762	2,945	8,761
78	-93.905830	0.000147	6,762	2,945	8,761
79	-93.905830	0.000110	6,762	2,945	8,761
80	-93.905830	0.000028	6,762	2,945	8,761
81	-93.905830	0.000163	6,762	2,945	8,761
82	-93.905830	0.000212	6,762	2,945	8,761
83	-93.905830	0.000025	6,762	2,945	8,761
84	-93.905830	0.000085	6,762	2,945	8,761
85	-93.905830	0.000076	6,762	2,945	8,761
86	-93.905830	0.000479	6,762	2,945	8,761
87	-93.905830	0.000104	6,762	2,945	8,761
88	-93.905830	0.000135	6,762	2,945	8,761
89	-93.905830	0.000059	6,762	2,945	8,761
90	-93.905830	0.000480	6,762	2,945	8,761
91	-93.905830	0.000265	6,762	2,945	8,761
92	-93.905830	0.000136	6,762	2,945	8,761

93	-93.905830	0.000044	6,762	2,945	8,761
94	-93.905830	0.000231	6,762	2,945	8,761
95	-93.905830	0.000099	6,762	2,945	8,761
96	-93.905830	0.000115	6,762	2,945	8,761
97	-93.905830	0.000224	6,762	2,945	8,761
98	-93.905830	0.000451	6,762	2,945	8,761
99	-93.905830	0.000071	6,762	2,945	8,761
100	-93.905830	0.000055	6,762	2,945	8,761

Table E.2 Results from 100 jitter runs for scenario 21.1a for WAG. Jitter run 0 corresponds to the original optimized estimates. Objective function minimum value was achieved for run# 14, 19, 50, 69, and 79 (yellow highlighted) without inconsistent reference point estimates. NA: model did not converge.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**9.650784**	**0.001604**	**5,253**	**1,631**	**5,639**
1	9.650784	0.000249	5,253	1,631	5,639
2	9.650784	0.000079	5,253	1,631	5,639
3	9.329994	0.000040	5,709	1,656	5,813
4	9.650784	0.000058	5,253	1,631	5,639
NA	NA	NA	NA	NA	NA
6	9.650784	0.000160	5,253	1,631	5,639
7	9.650784	0.000026	5,253	1,631	5,639
8	9.650784	0.000177	5,253	1,631	5,639
9	9.650784	0.000092	5,253	1,631	5,639
NA	NA	NA	NA	NA	NA
11	9.329994	0.000073	5,709	1,656	5,813
12	9.650784	0.000440	5,253	1,631	5,639
13	9.650784	0.000079	5,253	1,631	5,639
14	5.533963	0.000067	5,784	1,705	5,904
15	9.650784	0.000006	5,253	1,631	5,639
16	9.650784	0.000042	5,253	1,631	5,639
17	9.650784	0.000338	5,253	1,631	5,639
18	9.650784	0.000168	5,253	1,631	5,639
19	5.533963	0.000053	5,784	1,705	5,904
20	9.650784	0.000160	5,253	1,631	5,639
21	9.650784	0.000246	5,253	1,631	5,639
22	9.650784	0.000124	5,253	1,631	5,639
23	9.650784	0.000231	5,253	1,631	5,639
24	9.650784	0.000097	5,253	1,631	5,639
25	9.650784	0.000047	5,253	1,631	5,639
26	9.650784	0.000212	5,253	1,631	5,639
27	9.650784	0.000097	5,253	1,631	5,639

28	10.213460	0.000027	5,759	1,722	5,911
29	9.650784	0.000339	5,253	1,631	5,639
30	9.650784	0.000034	5,253	1,631	5,639
31	9.650784	0.000549	5,253	1,631	5,639
32	9.650784	0.000265	5,253	1,631	5,639
33	9.650784	0.000129	5,253	1,631	5,639
34	9.650784	0.000178	5,253	1,631	5,639
35	9.650784	0.000196	5,253	1,631	5,639
36	9.650784	0.000077	5,253	1,631	5,639
37	9.329994	0.000026	5,709	1,656	5,813
38	9.650784	0.000151	5,253	1,631	5,639
39	9.329994	0.000342	5,709	1,656	5,813
40	9.650784	0.000148	5,253	1,631	5,639
41	9.650784	0.000026	5,253	1,631	5,639
42	9.650784	0.000113	5,253	1,631	5,639
43	9.650784	0.000311	5,253	1,631	5,639
44	9.650784	0.000050	5,253	1,631	5,639
45	9.650784	0.000250	5,253	1,631	5,639
46	9.650784	0.000188	5,253	1,631	5,639
47	9.650784	0.000036	5,253	1,631	5,639
48	9.650784	0.000068	5,253	1,631	5,639
49	9.650784	0.000089	5,253	1,631	5,639
50	5.533963	0.000219	5,784	1,705	5,904
51	9.650784	0.000054	5,253	1,631	5,639
52	10.213460	0.000159	5,759	1,722	5,911
53	9.650784	0.000101	5,253	1,631	5,639
54	9.650784	0.000005	5,253	1,631	5,639
55	9.650784	0.000050	5,253	1,631	5,639
56	9.650784	0.000056	5,253	1,631	5,639
57	9.650784	0.000010	5,253	1,631	5,639
58	9.650784	0.000320	5,253	1,631	5,639
59	9.650784	0.000060	5,253	1,631	5,639
60	9.650784	0.000236	5,253	1,631	5,639
61	9.650784	0.000099	5,253	1,631	5,639
62	9.650784	0.000084	5,253	1,631	5,639
63	10.213460	0.000041	5,759	1,722	5,911
64	10.213460	0.000045	5,759	1,722	5,911
65	9.650784	0.000040	5,253	1,631	5,639
66	9.650784	0.000230	5,253	1,631	5,639
67	9.650784	0.000159	5,253	1,631	5,639
68	9.650784	0.000267	5,253	1,631	5,639
69	5.533963	0.000108	5,784	1,705	5,904
70	9.650784	0.000522	5,253	1,631	5,639
71	9.650784	0.000268	5,253	1,631	5,639

72	9.650784	0.000121	5,253	1,631	5,639
73	9.650784	0.000014	5,253	1,631	5,639
74	9.650784	0.000636	5,253	1,631	5,639
75	9.650784	0.000038	5,253	1,631	5,639
76	9.650784	0.000059	5,253	1,631	5,639
77	9.650784	0.000201	5,253	1,631	5,639
78	9.650784	0.000219	5,253	1,631	5,639
79	5.533963	0.000293	5,784	1,705	5,904
80	9.650784	0.000132	5,253	1,631	5,639
81	9.650784	0.000123	5,253	1,631	5,639
NA	NA	NA	NA	NA	NA
83	9.650784	0.000103	5,253	1,631	5,639
84	9.650784	0.000422	5,253	1,631	5,639
85	9.650784	0.000230	5,253	1,631	5,639
86	9.650784	0.000125	5,253	1,631	5,639
87	9.650784	0.000630	5,253	1,631	5,639
88	9.650784	0.000032	5,253	1,631	5,639
NA	NA	NA	NA	NA	NA
90	9.650784	0.000162	5,253	1,631	5,639
91	9.650784	0.000144	5,253	1,631	5,639
92	9.650784	0.000136	5,253	1,631	5,639
93	9.650784	0.000139	5,253	1,631	5,639
94	9.650784	0.000023	5,253	1,631	5,639
95	9.650784	0.000066	5,253	1,631	5,639
96	9.650784	0.000112	5,253	1,631	5,639
97	9.650784	0.000122	5,253	1,631	5,639
98	9.650784	0.000043	5,253	1,631	5,639
NA	NA	NA	NA	NA	NA
100	9.329994	0.000218	5,709	1,656	5,813

Appendix F: Progress in Gmacs

Introduction

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

Method

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

Results

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

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

Table F1. gmacsEAG19.1.ctl file.

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

```
            0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1
#
##          GROWTH            PARAM           CONTROLS        ##
##          Two               lines           for             each            parameter
#
#           option                         8  is              normal          distributed
        8
#           growth increment                  model
        1
#           molt probability  function
        2
#           maximum           size-class

#           Maximum           size-class                      recruitment
        5
##          number            of              size-increment  periods
        1
##          Year(s)           size-increment  period          changes

##          number            of              molt            periods
        1
##          Year(s)           molt            period          changes

##          Beta              parameters
        1

#                             Growth          parameters
#
#           ival              lb              ub              phz             prior         p1          p2        parameter
#
                   22.456186              10              50              -3             0           0        20  alpha,
                 0.069134986            -0.4              20              -3             0           0        10  beta,
```

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

#      custom         molt         probability   matrix

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

```
                 1        1        1        0    125.5      105      180        0      100      190     -3   1960   2004
                 1        2        2        0    10.35     0.01       20        0      0.1       50     -3   1960   2004
                 1        3        1        0    137.1      105      180        0      100      190     -3   2005   2019
                 1        4        2        0    6.556     0.01       20        0      0.1       50     -3   2005   2019
#   Gear-2
                 2        5        1        0        1     0.99     1.02        0       10      200     -3   1960   2019
#
##  Retained
##  gear         par      sel      phz      start    end
#   index        index    par      sex      ival     lb       ub       prior    p1       p2       mirror period
#   Gear-1
                -1        6        1        0    136.3      105      180        0      100      190     -3   1960   2019
                -1        7        2        0    2.161    1E-04       20        0      0.1       50     -3   1960   2019

#   Gear-2
                -2        8        1        0        1     0.99     1.01        0       10      200     -3   1960   2019


#   Number       of       asyptotic parameters
        1
#   Fleet        Sex      Year     ival     lb       ub       phz
                 1        1     1960    1E-06        0        1       -3
#
##  PRIORS       FOR      CATCHABILITY
#
##  SURVEYS/INDICES ONLY
##  observer     and      fishery  CPUE
##  ival         lb       ub       phz      prior    p1       p2       Analytic? LAMBDA  Emphasis
       0.000585278   1E-07     0.01        1        0      0.1        1        0        1        1
       0.000483222   1E-07     0.01        1        0      0.1        1        0        1        1
#
##  ADDITIONAL   CV       FOR      SURVEYS/INDICES
```

```
#
##          ival               lb            ub           phz          prior        p1         p2
                  0.000235        1E-07          0.01           -1            4        0.5        100  Fish cticket  CPUE     additional  var
                  0.000189        1E-07          0.01           -1            4        0.5        100  obs          CPUE     additional  var
##
##PENALTIES                    FOR           AVERAGE      FISHING      MORTALITY    RATE       FOR        EACH         GEAR
#
##          Trap               Trawl
##          Mean_F             Fema-Offset   STD_PHZ1     STD_PHZ2     PHZ_M        PHZ_F      Lb         Ub           Lb       Ub          Lb      Ub
               0.388745475            0             3           15           -1         -1        -12            4       -10          10     -10      10
               0.000109758            0             4           15           -1         -1        -12            4       -10          10     -10      10


##          OPTIONS            FOR           SIZE         COMPOSTION   DATA         ##
#           ret                tot
#
                          2             2  Type         of           likelihood
                          0             0  Auto         tail         compression
                          1             1  effective    sample       size         multiplier
                         -4            -4  Phz          for          estimating   effective  sample     size
                          1             2  Composition               aggregator
                          1             1  LAMBDA
                          1             1  Emphasis                  Dritchlet
#

##          TIME               VARYING       NATURAL      MORTALIIY    RATES
#
                          0  #             M            type
##          M                  is            relative     (YES=1;      NO=0)

##          Phase              of            estimation
        3
```

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

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

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


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

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

##          EOF
      9999
```

Table F2. gmacs EAG19.1. dat file.

```
#           EAG19.1
#           Gmacs             Main                Data          File
#           GEAR_             INDEX               DESCRIPTION
#                         1   :                   Pot           fishery       Retained   catch
#                         2   :                   Pot           fishery       total      catch
#                         3   :                   Trawl         bycatch
#                         4   :                   Observer      CPUE
#                         5   :                   Fishery       CPUE

#           Fisheries:                        1   Pot           Fishery,              2  Pot        Total
#           Cooperative       Survey:
#
      1960  #                 start               year)
      2019  #                 terminal            year
#2020       #                 Projection          year
         6  #                 Number              of            seasons:
         2  #                 Number              of            distinct      data       groups
         1  #                 Number              of            sexes
```

```
      1  #            Number        of          shell         condition  types
      1  #            Number        of          maturity      types
     17  #            Number        of          size-classes
      6  #            Season        when        recruitment   occurs
      6  #            Season        when        molting       and        growth    occur
      5  #            Season        to          calculate     MMB
      1  #            Season        for         N             output
#        maximum      size-class
     17
#        size_breaks
  100.5        105.5          110.5       115.5        120.5     125.5     130.5       135.5      140.5    145.5  150.5  155.5  160.5
  165.5        170.5          175.5       180.5        185.5
#        Natural      mortality     per         season
      2
#        Proportion   of            the         total         natural    mortality
#                  1  Start         biological  year          (Jul       1)        instantaneous  N        estimation
#                  2  to            mid         fishing       time
#                  3  instantanous  C           removal
#                  4  to            spawning    time
#                  5  instantaneous byc         removal       and        estimate  MMB
#                  6  Rest          of          the           period     of        non            fishing
                      from          Feb                   15  to         June             30
                                                              Jul1-
#Ins     N            Jul1-MidFish  Inst        C             15Feb      Ins
      0      0.16667             0       0.463             0    0.3699   #1960
      0      0.16667             0       0.463             0    0.3699   #1961
      0      0.16667             0       0.463             0    0.3699   #1962
      0      0.16667             0       0.463             0    0.3699   #1963
      0      0.16667             0       0.463             0    0.3699   #1964
      0      0.16667             0       0.463             0    0.3699   #1965
      0      0.16667             0       0.463             0    0.3699   #1966
      0      0.16667             0       0.463             0    0.3699   #1967
      0      0.16667             0       0.463             0    0.3699   #1968
```

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

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

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

```
##      CATCH     DATA    in      t
##      Type      of      catch:        1   =    retained,        2   =    discard,  0=  total
##      Units     of      catch:        1   =    biomass,         2   =    numbers
#       Mult:     1=      use     data      as   thy     are,           2  =   multiply

##      Retained  Catch   (in           1000 crab)
#year   seas      fleet   sex     obs       cv   type    units    mult   effort  discard_mortality
  1981        3       1       1     204   0.032     1        2      1       0   0.2
  1982        3       1       1   529.8   0.032     1        2      1       0   0.2
  1983        3       1       1   662.3   0.032     1        2      1       0   0.2
  1984        3       1       1   801.1   0.032     1        2      1       0   0.2
  1985        3       1       1    1251   0.032     1        2      1       0   0.2
  1986        3       1       1    1375   0.032     1        2      1       0   0.2
  1987        3       1       1   968.6   0.032     1        2      1       0   0.2
  1988        3       1       1    1156   0.032     1        2      1       0   0.2
  1989        3       1       1    1420   0.032     1        2      1       0   0.2
  1990        3       1       1   892.7   0.032     1        2      1       0   0.2
  1991        3       1       1    1083   0.032     1        2      1       0   0.2
  1992        3       1       1    1127   0.032     1        2      1       0   0.2
  1993        3       1       1   767.9   0.032     1        2      1       0   0.2
  1994        3       1       1    1087   0.032     1        2      1       0   0.2
  1995        3       1       1    1150   0.032     1        2      1       0   0.2
  1996        3       1       1     848   0.032     1        2      1       0   0.2
  1997        3       1       1   780.6   0.032     1        2      1       0   0.2
  1998        3       1       1     740   0.032     1        2      1       0   0.2
  1999        3       1       1   709.3   0.032     1        2      1       0   0.2
  2000        3       1       1   704.7   0.032     1        2      1       0   0.2
  2001        3       1       1     730   0.032     1        2      1       0   0.2
  2002        3       1       1   643.9   0.032     1        2      1       0   0.2
  2003        3       1       1   643.1   0.032     1        2      1       0   0.2
  2004        3       1       1   637.5   0.032     1        2      1       0   0.2
  2005        3       1       1     624   0.032     1        2      1       0   0.2
```

2006	3	1	1	650.6	0.032	1	2	1	0	0.2
2007	3	1	1	633.3	0.032	1	2	1	0	0.2
2008	3	1	1	666.9	0.032	1	2	1	0	0.2
2009	3	1	1	679.9	0.032	1	2	1	0	0.2
2010	3	1	1	671	0.032	1	2	1	0	0.2
2011	3	1	1	668.8	0.032	1	2	1	0	0.2
2012	3	1	1	687.7	0.032	1	2	1	0	0.2
2013	3	1	1	720.2	0.032	1	2	1	0	0.2
2014	3	1	1	719.1	0.032	1	2	1	0	0.2
2015	3	1	1	763.6	0.032	1	2	1	0	0.2
2016	3	1	1	794	0.032	1	2	1	0	0.2
2017	3	1	1	802.6	0.032	1	2	1	0	0.2
2018	3	1	1	940.3	0.032	1	2	1	0	0.2
2019	3	1	1	1057	0.032	1	2	1	0	0.2
##	Total	Catch	(in	1000	crab,	no	mortality	applied)		
#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality
1990	3	1	1	1149	0.045	0	2	1	0	0.2
1991	3	1	1	4385	0.045	0	2	1	0	0.2
1992	3	1	1	4332	0.045	0	2	1	0	0.2
1994	3	1	1	1713	0.045	0	2	1	0	0.2
1995	3	1	1	2743	0.045	0	2	1	0	0.2
1996	3	1	1	1452	0.045	0	2	1	0	0.2
1997	3	1	1	1788	0.045	0	2	1	0	0.2
1998	3	1	1	2012	0.045	0	2	1	0	0.2
1999	3	1	1	1556	0.045	0	2	1	0	0.2
2000	3	1	1	1707	0.045	0	2	1	0	0.2
2001	3	1	1	1353	0.045	0	2	1	0	0.2
2002	3	1	1	1120	0.045	0	2	1	0	0.2
2003	3	1	1	1111	0.045	0	2	1	0	0.2
2004	3	1	1	965.4	0.045	0	2	1	0	0.2
2005	3	1	1	929.3	0.045	0	2	1	0	0.2

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

##	Trawl	fishery	discards	(in	1000	crab,	handling	mortality	rate	applied)
#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality
1989	5	2	1	0.388	1.58	2	2	1	0	1
1990	5	2	1	1.19	1.58	2	2	1	0	1
1991	5	2	1	0	1.58	2	2	1	0	1
1992	5	2	1	0.779	1.58	2	2	1	0	1
1993	5	2	1	0.719	1.58	2	2	1	0	1
1994	5	2	1	0.311	1.58	2	2	1	0	1
1995	5	2	1	0.569	1.58	2	2	1	0	1
1996	5	2	1	0.046	1.58	2	2	1	0	1
1997	5	2	1	0.076	1.58	2	2	1	0	1
1998	5	2	1	0.587	1.58	2	2	1	0	1
1999	5	2	1	0.284	1.58	2	2	1	0	1
2000	5	2	1	0.387	1.58	2	2	1	0	1
2001	5	2	1	0.934	1.58	2	2	1	0	1
2002	5	2	1	0.707	1.58	2	2	1	0	1
2003	5	2	1	0.392	1.58	2	2	1	0	1

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

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

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

		1	1985	3	1	1	0	1.6287	0.051	2	0.5
		1	1986	3	1	1	0	1.2289	0.047	2	0.5
		1	1987	3	1	1	0	0.9552	0.049	2	0.5
		1	1988	3	1	1	0	1.0358	0.041	2	0.5
		1	1989	3	1	1	0	1.0765	0.034	2	0.5
		1	1990	3	1	1	0	0.9868	0.045	2	0.5
		1	1991	3	1	1	0	0.9046	0.043	2	0.5
		1	1992	3	1	1	0	0.9172	0.043	2	0.5
		1	1993	3	1	1	0	0.9145	0.049	2	0.5
		1	1994	3	1	1	0	0.8086	0.042	2	0.5
		1	1995	3	1	1	0	0.7798	0.043	2	0.5
		1	1996	3	1	1	0	0.7791	0.044	2	0.5
		1	1997	3	1	1	0	1.0505	0.045	2	0.5
		1	1998	3	1	1	0	1.2141	0.051	2	0.5
#	Observer	CPUE	index								
		1	1995	3	1	1	0	1.0034	0.032	2	0.5
		1	1996	3	1	1	0	0.9444	0.021	2	0.5
		1	1997	3	1	1	0	0.8742	0.021	2	0.5
		1	1998	3	1	1	0	1.0004	0.019	2	0.5
		1	1999	3	1	1	0	0.9154	0.018	2	0.5
		1	2000	3	1	1	0	0.8196	0.016	2	0.5
		1	2001	3	1	1	0	1.0429	0.018	2	0.5
		1	2002	3	1	1	0	1.1029	0.021	2	0.5
		1	2003	3	1	1	0	0.9714	0.019	2	0.5
		1	2004	3	1	1	0	1.4394	0.027	2	0.5
		2	2005	3	1	1	0	0.9829	0.026	2	0.5
		2	2006	3	1	1	0	0.8087	0.023	2	0.5
		2	2007	3	1	1	0	0.9017	0.022	2	0.5
		2	2008	3	1	1	0	0.8819	0.026	2	0.5
		2	2009	3	1	1	0	0.7266	0.031	2	0.5
		2	2010	3	1	1	0	0.7518	0.031	2	0.5

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

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

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

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

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

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

```
#2019              5          2         1        2       0       0        4   0.158   0.1228   0.175   0.07   0.088   0.05263   0.105
#

##       Growth             data        (increment)
#        Type               of          growth          increment
     0
#        nobs_growth
     0
                                        Class-at-       Years-at-
#        Class-at-release;  Sex;        recapture;      liberty;    number   transition   matrix;
         RecaptureFleet     Recapture   Year
#not considered
##       eof
   9999
```

Table F3. gmacs EAG19.1. prj file.

```
          0              Do      not       compute    MSY              (1=Yes)
          1        1     if      future    F          is               to      be        fixed
       1987     2017     for     Rbar                 calc,
       1985     2019     First   and       last       year             for     average   sex     ratio
       2010     2019     First   and       last       year             for     average   F       for     discards

#       OFL      specifications
       0.35   Target     SPR     ratio     for        Bmsy             proxy.
          3   Tier
        0.1   Alpha
       0.25   Beta
          1   Gamma
       0.75   ABC-OFL    buffer
                                           curve or
          0   Produce    a       yield     not
```

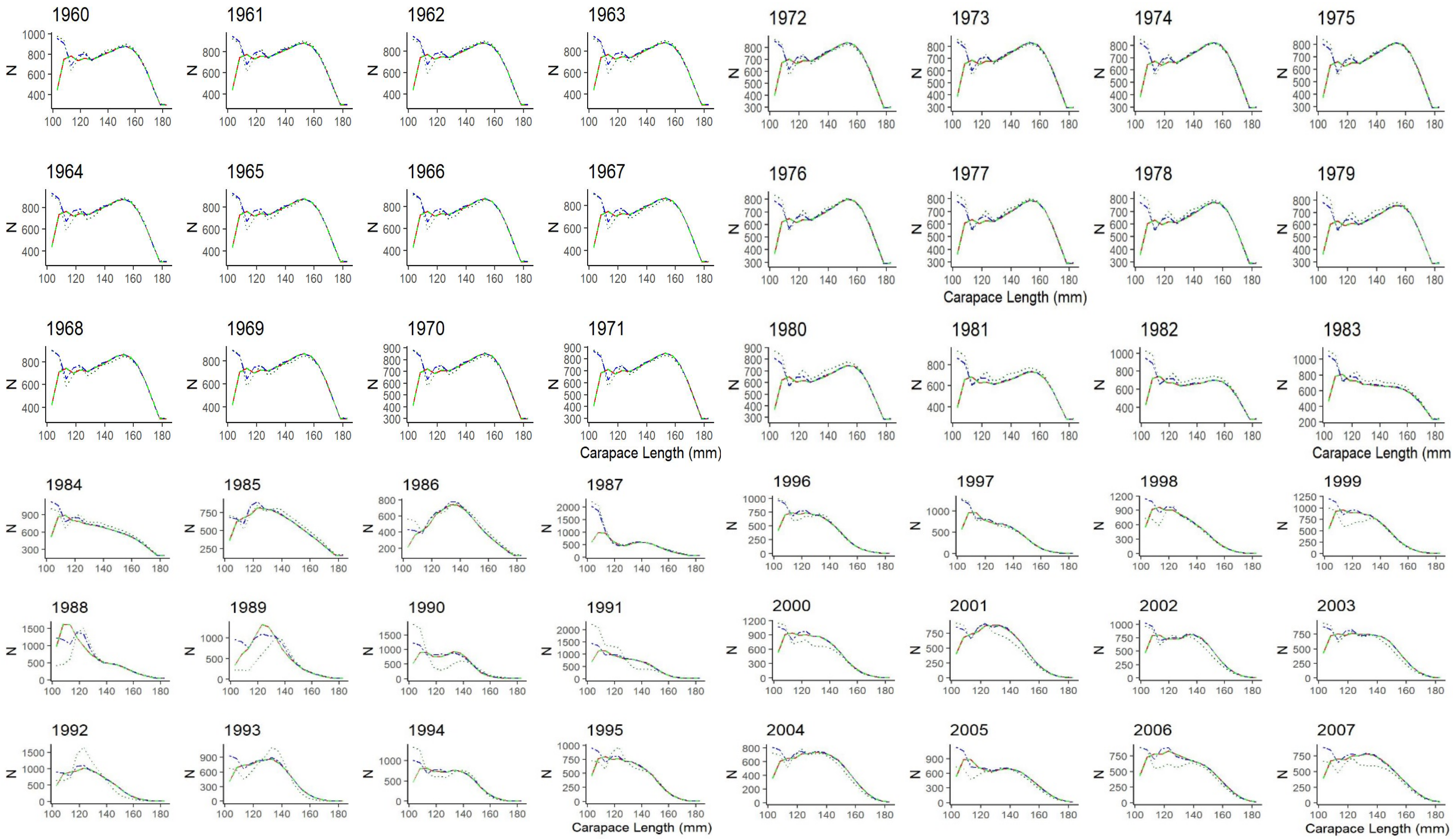
```
#         Projection  material
                2020  #           Last        year        of          projection              from        the         terminal    year
                   1  #           Number      of          strategies
                   0         0.7  Range       of          F           values
                                              non-
                   1  mortality   for         directed
                   2  Mcmc        replicates  per         draw
             -3423.8  Fixed       BMSY        (negative   number      for                     replicate-specific)

                   1  Stock-recruitment       option      (1=Mean     Rec;2=Ricker;3=BH;4=Mean  and         CV)
                   8  age-at-recruitment
#
                1960        2019  First       and         last        years                   for         generating  future      recruitment
                2294  Mean        recruitment for         projections
                 0.6  SigmaR      only        used        if          Stock_recruitment       option                2
                 0.2  ProwR
                -999  first       rec_dev,    set         to                              -999  to          generate    it

#         State       strategy
                   0  Apply       strategies  [OFL,       ABC]        (1=yes;0=no)
          0.00135303  #           Mean        weight      (mature     in                      t)
          0.00196451  #           Mean        weight      (legal      in                      t)

#         Stop        after       XX          mcdraws
               10000

##        eof
     9999
```


1960
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1992
1993
1994
1995
2004
2005
2006
2007
N
Carapace Length (mm)
100
120
140
160
180

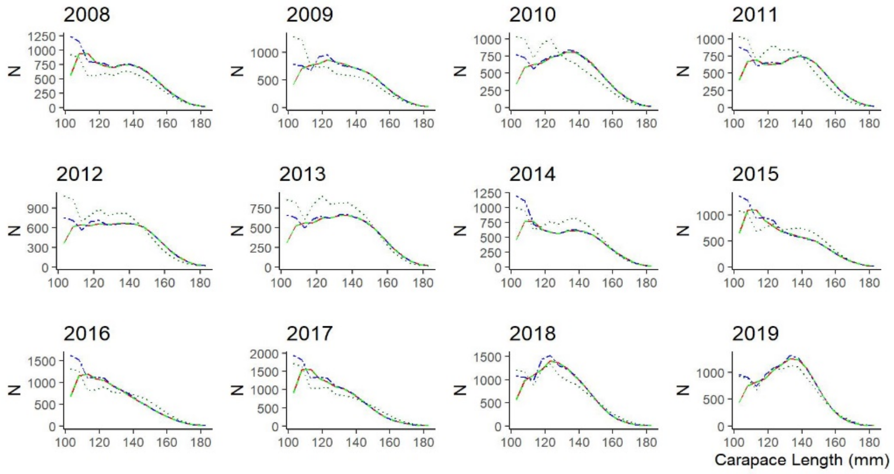

Figure F1. Comparison of time series of abundance by size (N-matrix) of EAG golden king crab, 1960–2019 [blue: OrignalEAG19.1; red: ModifiedEAG19.1; dark green: gmacs run#9 (free parameters); green: gmacs run#10(fixed parameters)]

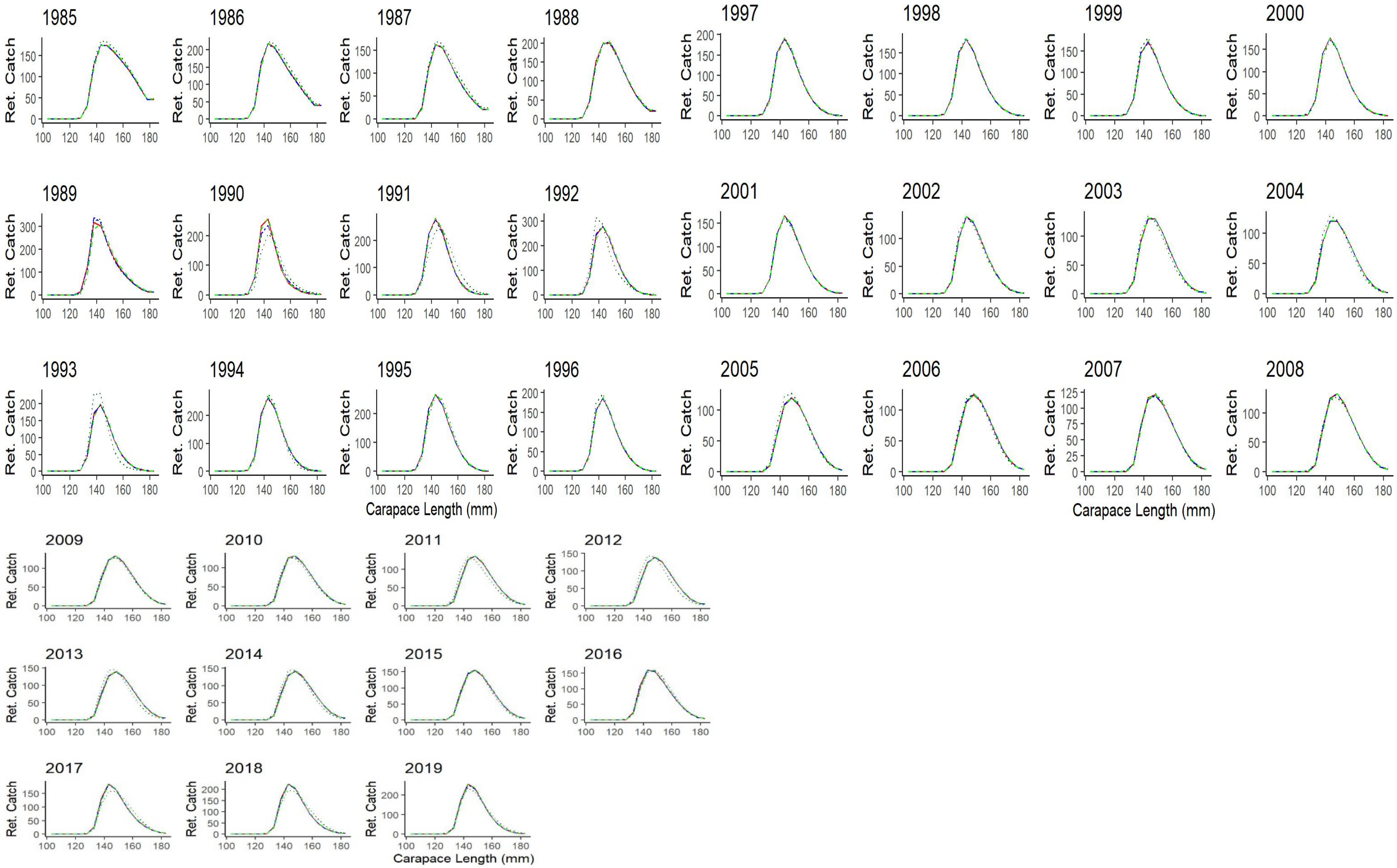

Figure F2. Comparison of time series of retained catch by size of EAG golden king crab, 1985–2019 (blue: OrignalEAG19.1; red: ModifiedEAG19.1; dark green: gmacs run#9; green: gmacs run#10)

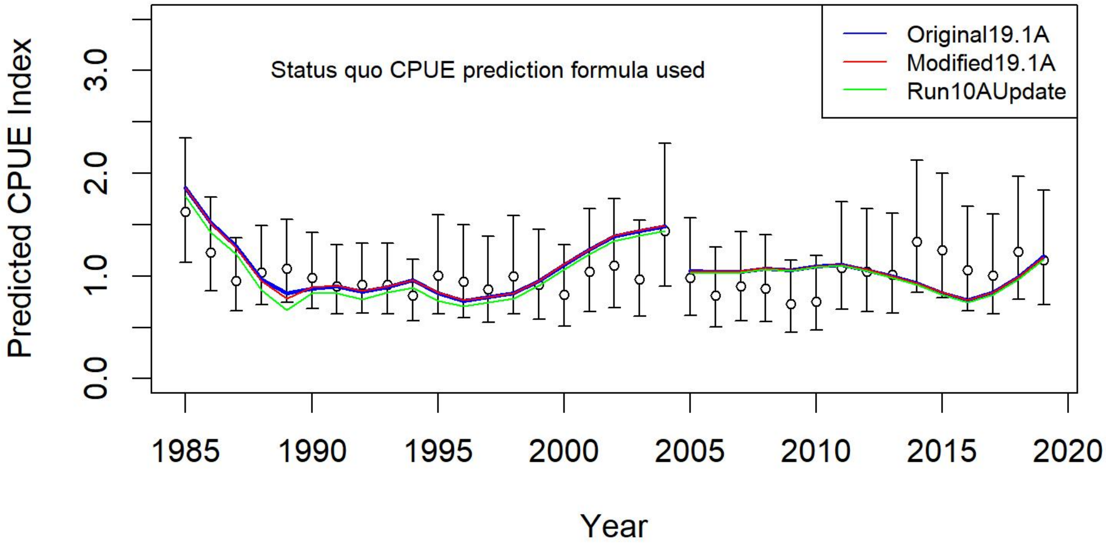

Figure F3. Comparison of time series of CPUE indices for EAG golden king crab, 1995–2019 (blue: OrignalEAG19.1A; red: ModifiedEAG19.1A; green: gmacs run#10AUpdate). For this comparison, the gmacs base model was slightly modified (update) to instantaneously remove catches at the middle of the fishing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