Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment

Draft summary report for the January 2017 Crab Plan Team Discussion

Prepared by:

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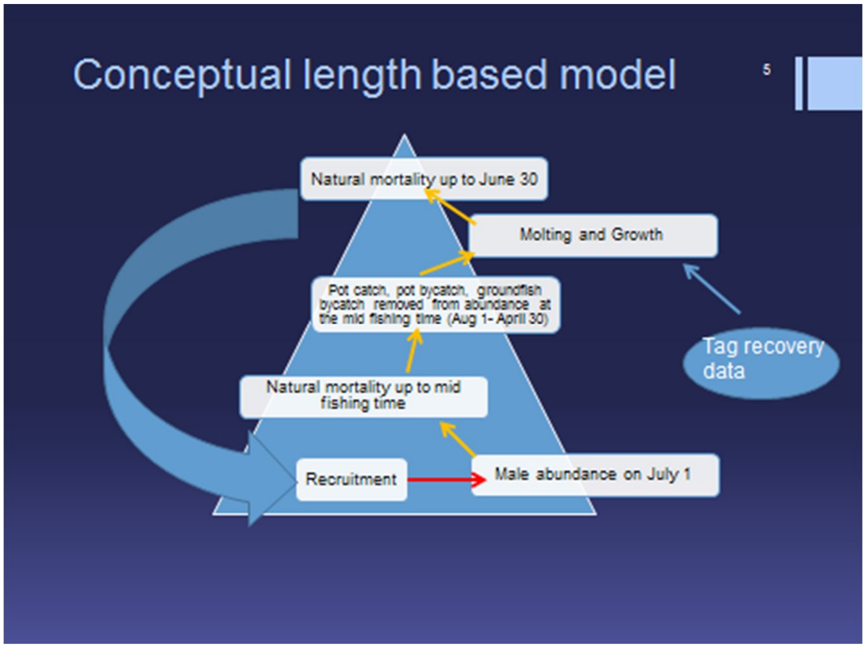
Preamble

The length-based stock assessment model for the Aleutian Islands golden king crab was accepted at the September 2016 CPT and October 2016 SSC meetings for OFL determination for the next fishery cycle . In this report, we present methods and results in response to September 2016 CPT and October 2016 SSC comments and suggestions. Note that this document does not follow the standard CPT stock assessment format. The primary purpose of this report is to present the methods and results for discussion and feedback under the workshop setting. A conceptual framework for our approach is presented below.

For detailed accounts of the Aleutian Islands golden king crab fisheries, stock status (trends in recruitment and mature male biomass), and biology, we direct you to the 2016 stock assessment report (Siddeek et al. 2016c).

Conceptual framework of the length based model



Conceptual length based model
5
Natural mortality up to June 30
Molting and Growth
Pot catch, pot bycatch, groundfish bycatch removed from abundance at the mid fishing time (Aug 1- April 30)
Tag recovery data
Natural mortality up to mid fishing time
Recruitment
Male abundance on July 1

Input Data

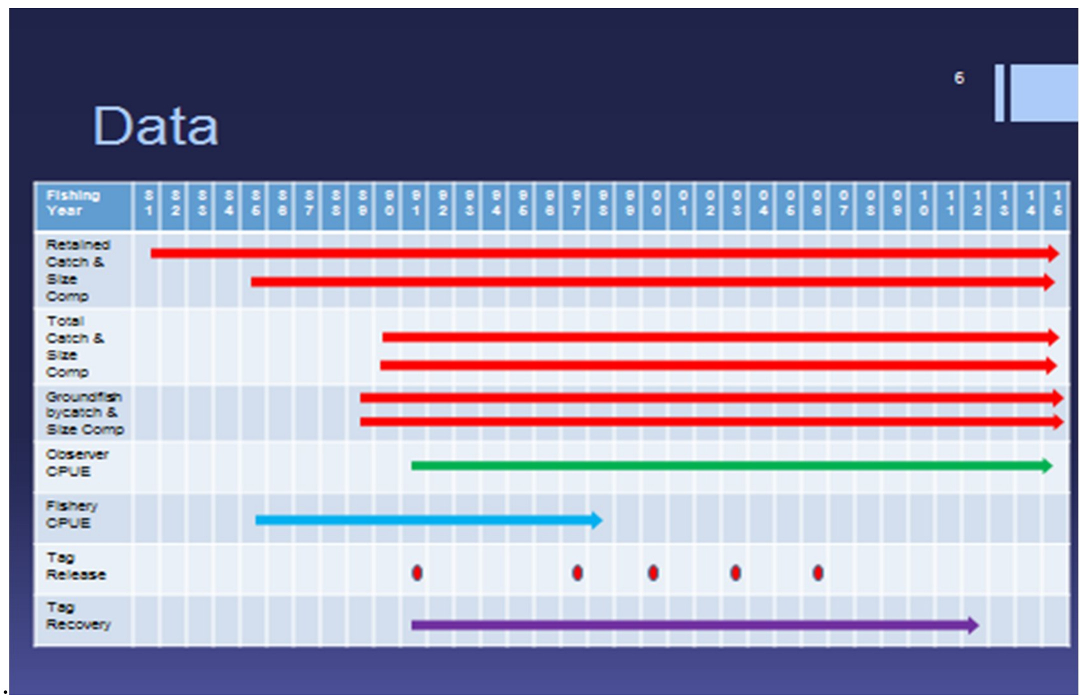
Summary of Major Changes

Changes to input data

(a) Retained catch (1981/82–2015/16), total catch (1990/91–2015/16), and groundfish bycatch (1989/90–2015/16) biomass and size compositions were the same as in the September 2016 assessment.

(b) Observer pot sample legal size crab CPUE data were extended back to 1991/92 and standardized by the generalized linear model (GLM) with the negative binomial link function, separately for 1991/92–2004/05 and 2005/06–2015/16 periods.

(c) Fish ticket retained CPUE were standardized by the GLM with the lognormal link function for the 1985/86–1998/98 period.



Model Scenarios

The listed scenarios were common to both EAG and WAG, except scenario Sc1d, which specifically explores the initial MMB trend as a result of systematically removing the retained catch size composition data in early years for EAG.

Sc.	Size-composition weighting	Catchability and total selectivity sets	Total selectivity type	CPUE data type	CPUE to Biomass relation	Treatment of groundfish/total size composition and catch data	Natural mortality (M yr^{-1})
1	stage-1:number of days	2	logistic	Observer indices from 1991/92–2015/16	linear	groundfish bycatch size-composition data excluded	0.225
2	stage-1:number of days	2	logistic	observer	linear	groundfish bycatch size-composition data excluded	0.18
3	stage-1:number of days	2	logistic	observer	linear	total size composition and catch data started from 1996/97 for EAG and 1995/96 for WAG; groundfish bycatch size-composition data excluded;	0.225

4	stage-1:number of days	2	logistic	observer & fish ticket	linear	groundfish bycatch size-composition data excluded	0.225
5	stage-1:number of days	2	logistic	observer	square root of biomass	groundfish bycatch size-composition data excluded	0.225
6	stage-1:number of days	2	logistic	observer	Square of biomass	groundfish bycatch size-composition data excluded	0.225
7	stage-1:number of days; stage-2 Francis method	2	logistic	observer	linear	groundfish bycatch size-composition data excluded	0.225
8	stage-1:number of days; stage-2 McAllister & Ianelli method	2	logistic	observer	linear	groundfish bycatch size-composition data excluded	0.225
9	stage-1:number of days	3	logistic	observer	linear	separate catchability and total selectivity for 1985/86–1994/95, 1995/96–2004/05., and 2005/06–2015/16; groundfish bycatch size-	0.225

						composition data excluded	
10	stage-1:number of days	2	dome shaped	observer	linear	groundfish bycatch size-composition data excluded	0.225
11	stage-1:number of days	2	logistic	observer indices from 1995/96–2015/16	linear	groundfish bycatch size-composition data excluded	0.225
12	stage-1:number of days	2	logistic	observer	linear	groundfish bycatch size-composition data included with input effective sample size as number of trips	0.225
1d	stage-1:number of days	2	logistic	observer	linear	Removed retained length composition systematically for EAG: 1985, 1985–86, 1985–87, and 1985–88; groundfish bycatch size-composition data excluded	0.225
14a	stage-1:number of days	2	logistic	observer	linear	groundfish bycatch size-composition data excluded; Mean MMB (for B_{ref}) and mean R (for	0.225

						equil. & F_{35}) from 1981–2015	
14b	stage-1:number of days	2	logistic	observer	linear	groundfish bycatch size-composition data excluded; Mean MMB (for B_{ref}) and mean R (for equil. & F_{35}) from 1985–2015	0.225
14c	stage-1:number of days	2	logistic	observer	linear	groundfish bycatch size-composition data excluded; Mean MMB (for B_{ref}) and mean R (for equil. & F_{35}) from 1996–2015	0.225

Response to September 2016 CPT comments

Comment 1: The analysts provided an estimate of total mortality based on tagging data. However, given uncertainties related to, for example, the tag loss rate and estimation of fishing mortality, there is little power to discriminate among alternative values for M (CPT comment 3).

Response:

We did not consider alternative values for *M* in this run. We estimated one *M* value using the EAG and WAG combined data (Figure 1).

Comment 2: The likelihood profile for M did not include results for the EAG and WAG combined. Siddeek provided the plot to the CPT, which indicated that the data are informative for M when all data are considered (CPT comment 4). The plot of the total likelihood (EAG and WAG combined) should be included in future assessment reports.

Response:

We estimated *M* based on the combined EAG and WAG data. Figure 1 depicts the likelihood profile of *M*. The overall total (black line), the total for EAG (dark green line), and the total for WAG (light green line) indicate that the data were informative for *M* when all data were considered.

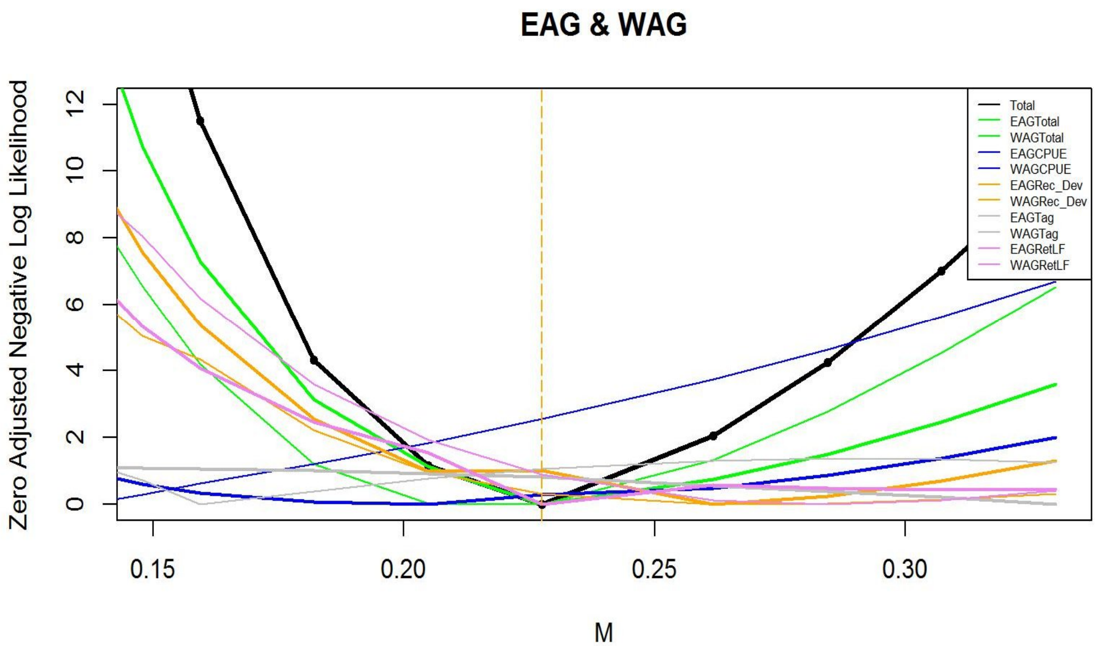


Figure 1. Total and components negative log-likelihoods vs. *M* for scenario 1 model fit **without *M* penalty** for EAG and WAG combined data. The *M* estimate was 0.225 yr^{-1} ($\pm$ 0.019 yr^{-1}). The negative log likelihood values were zero adjusted.

Comment 3: The "base model" should:

- **ignore the groundfish length-frequency data (but retain the catches);**
- **base the annual stage-1 sample sizes on the number of days on which sampling took place (rather than the number of length measurements) - the stage-1 sample sizes should be based on the number of trips if it is not possible to compute the annual number of days on which sampling occurred;**
- **set M to the estimate based on fitting to all of the data combined; and**
- **fit to the early observer CPUE data.**

Response:

We formulated the base model (scenario 1) following the above suggestion.

1. We ignored the groundfish length composition data for all scenarios except scenario 12.

2. We used number of days as the stage-1 effective sample sizes for retained and total size compositions without enforcing any maximum constraints. We used number of trips as the stage-1 effective sample size for groundfish data because it was impossible to combine the groundfish trawl and pot efforts.
3. We used the M estimate of 0.225 yr^{-1} from all of the data combined in all model scenarios except scenario 2.
4. We extended back the observer CPUE data to 1991/92 for standardization and used the extended indices for both EAG and WAG analysis.

Comment 4: The additional model runs should involve changing one aspect of the specifications of the base model in turn to allow the impact of changes to be examined.

Response:
We modified the base model (Sc1) scenario one-at-a time to explore the effects of changes (see the scenario table, changes are marked with highlighted blue).

Comment 5: The Additional sensitivity tests should be conducted in which catch rate is assumed to be proportional to the square root and the square of exploitable biomass to evaluate sensitivity to non-linear relationships between catch rate and abundance.

Response:
We used the CPUE = square root of exploitable biomass in scenario 5 and CPUE = square of exploitable biomass in scenario 6. Square root transformation reduced the recent MMB values compared to that of the square transformation for WAG and the opposite occurred for EAG.

Comment 6: When applying Francis weighting, there is no need to impose an upper bound on the effective sample sizes, except that the effective sample sizes should not exceed the actual number of sampled animals (CPT comment 5).

Response:
We did not impose any upper bound on either stage-1 or stage-2 (Francis method or McAlister and Ianelli method) effective sample sizes.

Specific recommendations for presentation to the CPT in January:

Comment 7: The catches in tables 1 and 15 do not match those in Figs 21 and 37. These figures should not include zero catches when these are actually "missing" catches.

Response:

We corrected that.

Comment 8: Consider analyses to more fully understand the behavior of the model. In particular, (a) analyses should be undertaken where the early length-frequency data are omitted from the assessment one year at a time, (b) the author should assess which data are causing scenarios 6c and 7c to estimate high recruitment in the early 1980s, and (c) the predicted catches and fishing mortality time-series should be extended back to 1981.

Response:

(a) We did the prospective analysis, where the early retained length compositions were omitted from the assessment one year at a time for EAG. Once the removal of data reached 1988 (scenario 1a: omit 1985, scenario 1b: omit 1985-86; scenario 1c: omit 1985-1987; and scenario 1d: omit 1985-1988), the pre-fishery MMB trend appeared flat (only scenario 1d curve is included with other scenario curves in Figure 2). We did not consider WAG for this analysis because the pre-fishery MMB trends were almost horizontal for most scenarios (Figure 3).

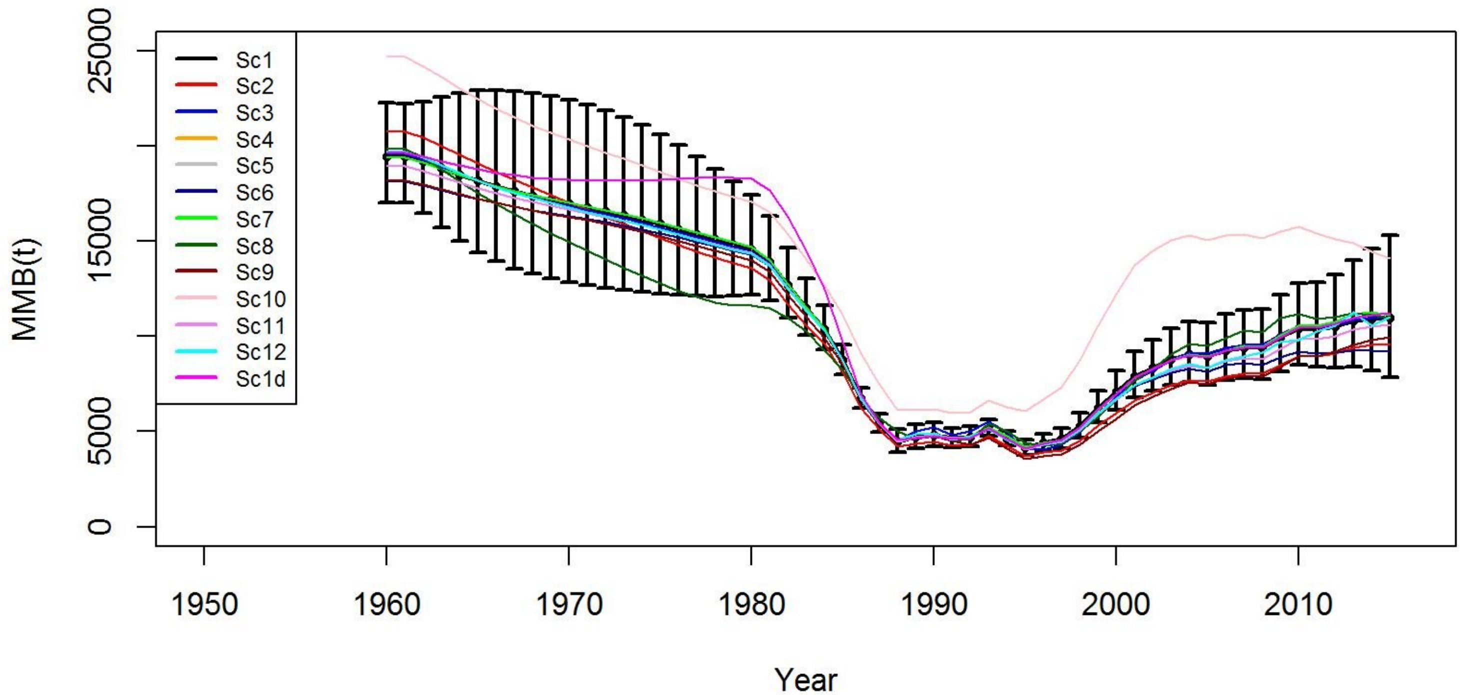


Figure 2. Trends in golden king crab mature male biomass for scenarios (Sc) 1 to 12 and 1d fits in the EAG, 1960/61–2015/16. Mature male crab size is ≥ 121 mm CL. Scenario 1 estimates have two standard errors confidence limits.

Note that the Sc1d (magenta colored line) is almost flat in the pre-fishery period. The Sc10 (light pink line) with dome shaped selectivity provides higher estimates of MMB beginning in the mid 1980s.

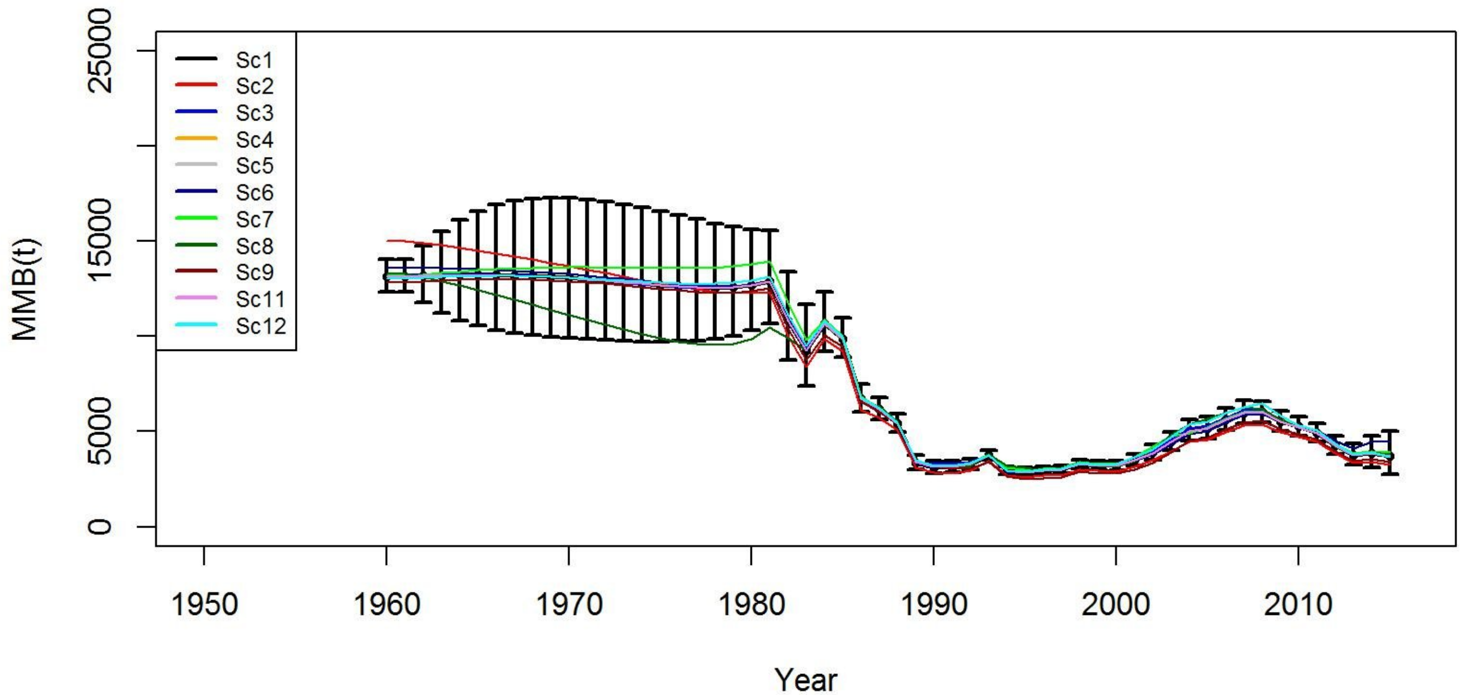


Figure 3. Trends in golden king crab mature male biomass for scenarios (Sc) 1 to 12 and 1d fits in the WAG, 1960/61–2015/16. Mature male crab size is ≥ 121 mm CL. Scenario 1 estimates have two standard errors confidence limits.

Note that the pre-fishery MMB trend of Sc 7 (green line, Francis reweighting of effective sample sizes) is flat whereas Sc 8 (dark green line, McAllister and Ianelli reweighting of effective sample sizes) is slant. We omitted the MMB trend for Sc 10 with dome shaped selectivity because it provided unusually high values of MMB estimates and high variability of selectivity parameters.

(b) Scenarios 6 and 7 model fits presented at the September CPT meeting were for Francis method of iterative estimation of stage-2 effective sample sizes. The inconsistency does not occur with the improvement of model fitting.

(c) We extended the time series of predicted catches (Figures 4 and 5) and total pot fishery mortality (Figures 6 and 7) back to 1981.

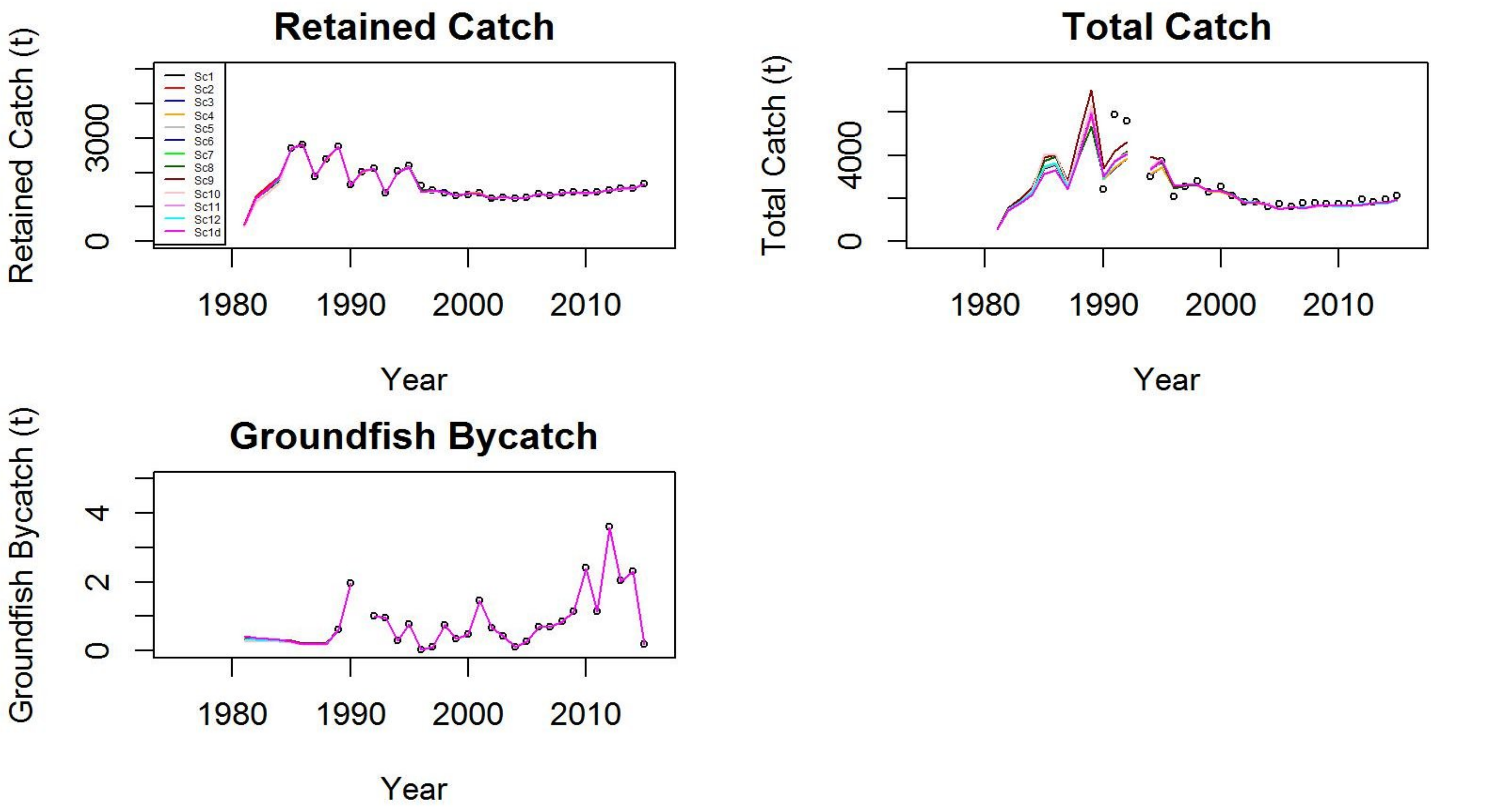


Figure 4. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish (or trawl) bycatch (bottom left) of golden king crab for scenarios (Sc) 1 to 12, and 1d fits in the EAG, 1985–2015. Note that missing total catch (in 1993) and groundfish bycatch (in 1991) data were omitted from the fit.

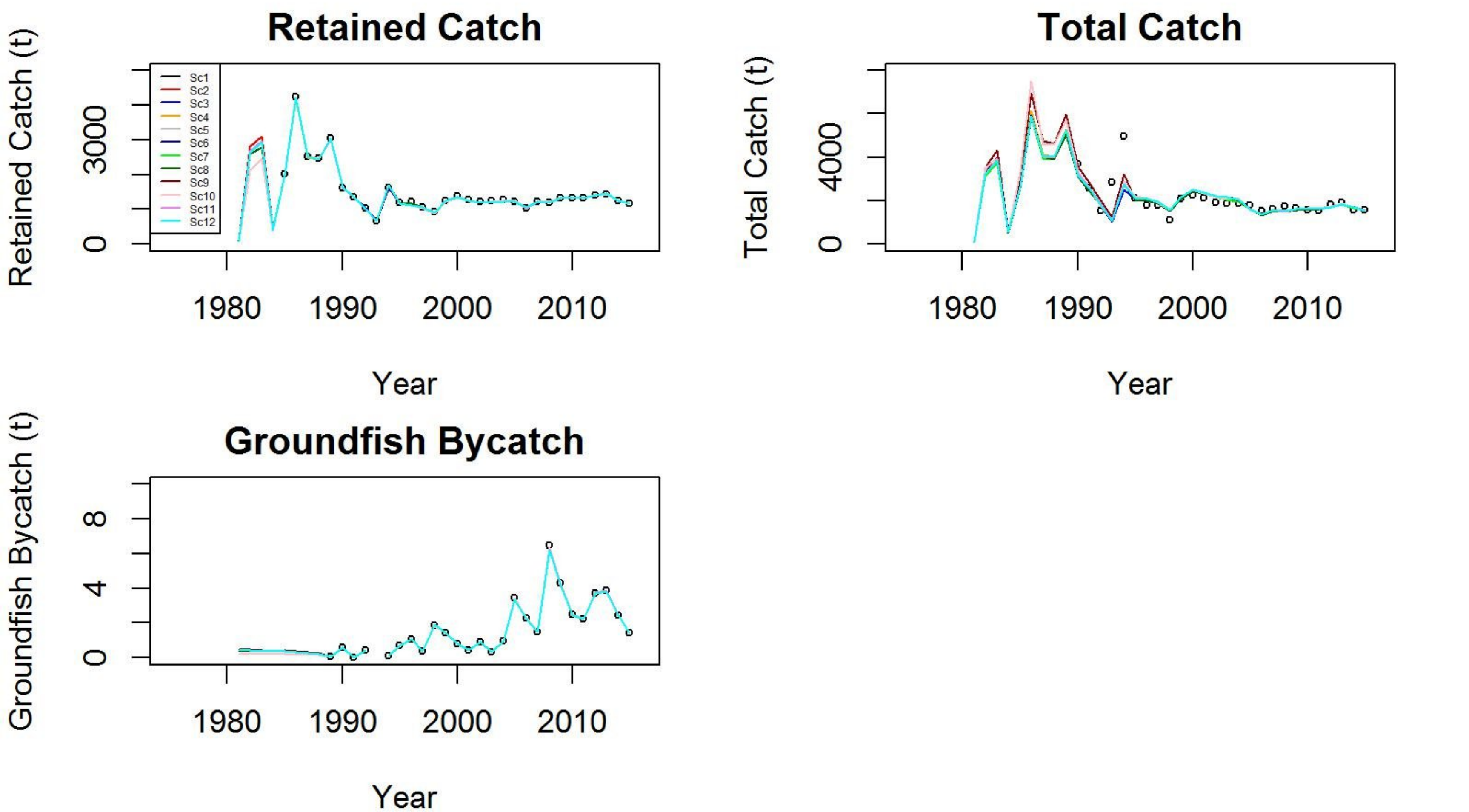


Figure 5. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish (or trawl) bycatch (bottom left) of golden king crab for scenarios (Sc) 1 to 12 fits in the WAG, 1985–2015. Note that missing groundfish bycatch datum in 1993 was omitted from the fit.

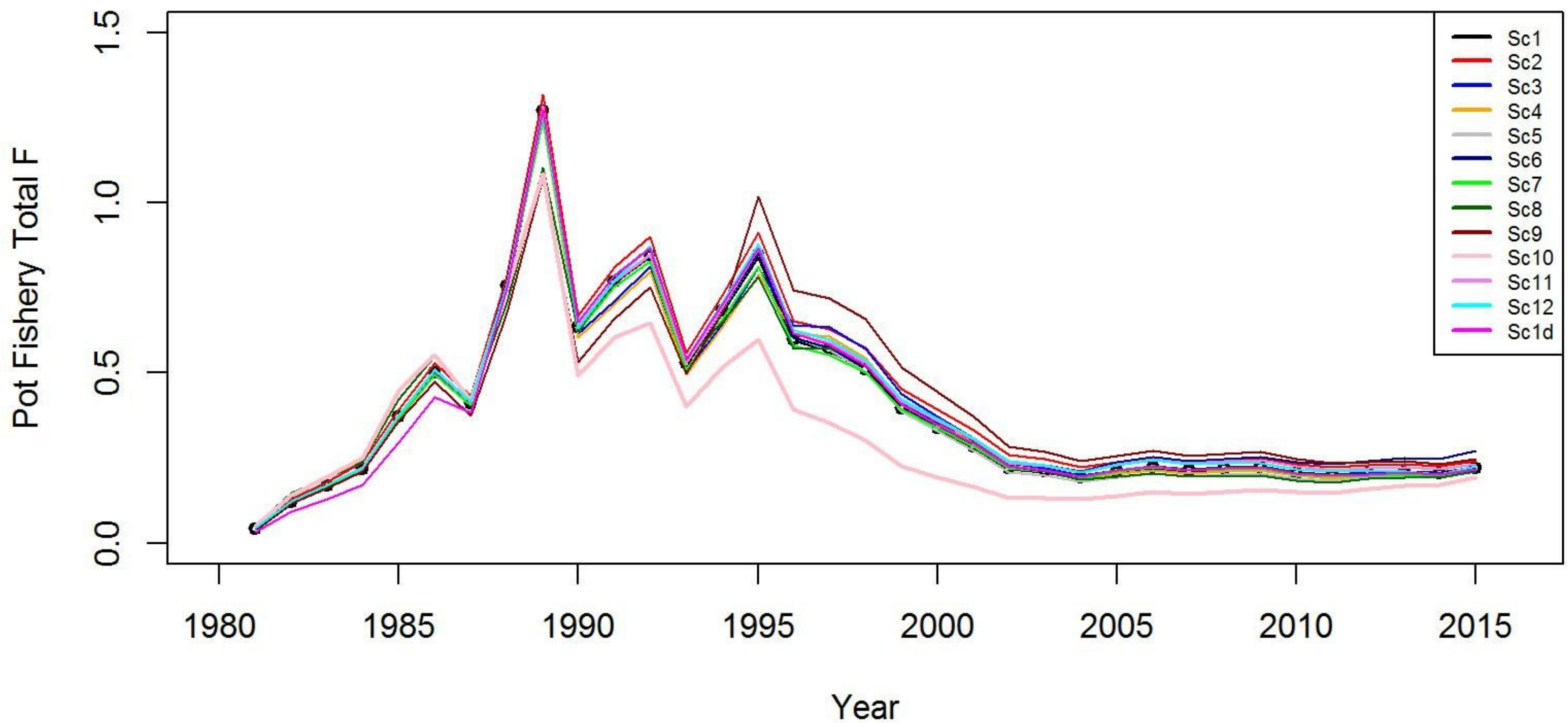


Figure 6. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 12, and 1d model fits in the EAG, 1981–2015.

Note that the fishing mortality estimates for scenario 10 (light pink line) with the dome shaped total selectivity were lower than the rest.

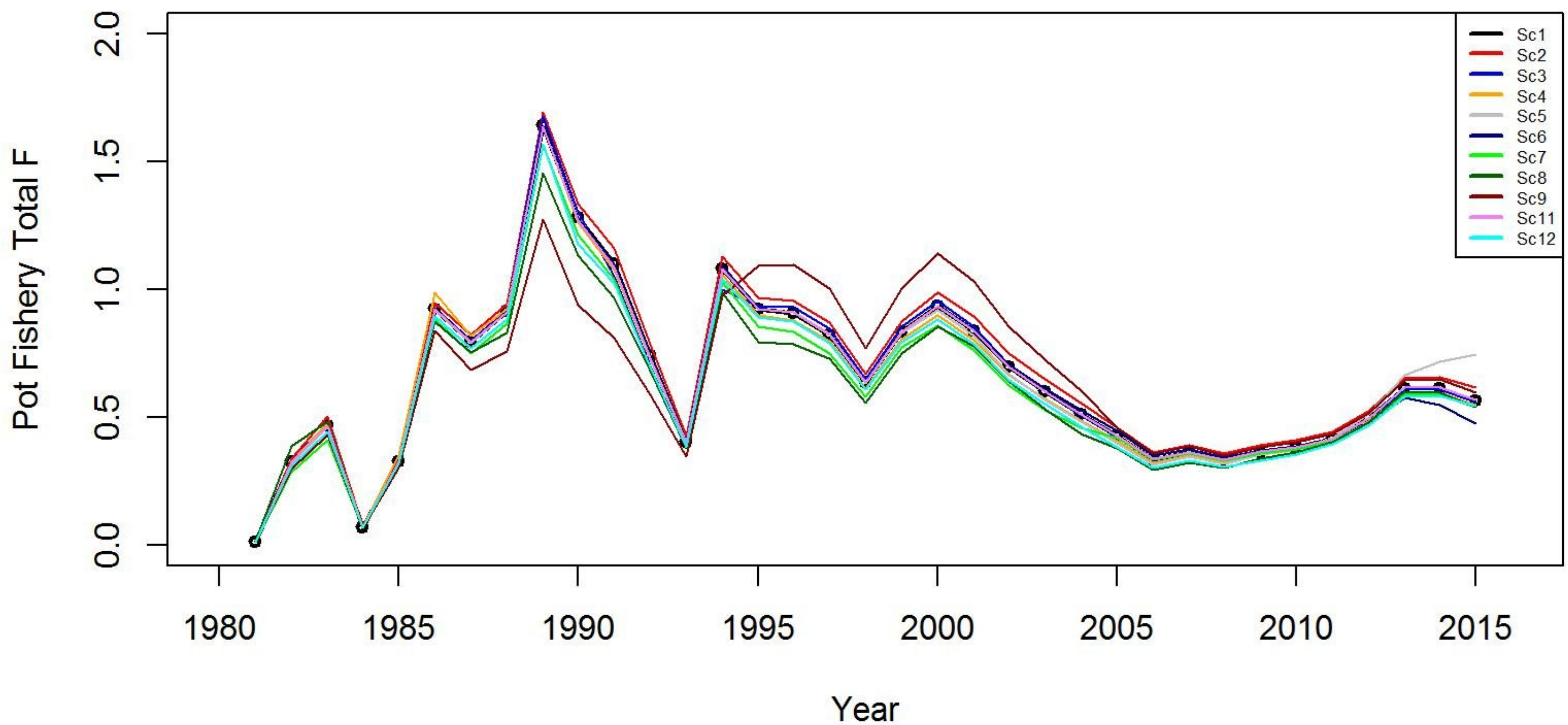


Figure 7. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 12, and 1d model fits in the WAG, 1981–2015.

Note that the fishing mortality trend for scenario 9 (burgundy line) with three catchability and total selectivity parameter sets appears different from the rest.

Response to October 2016 SSC comments

Comment 1: The SSC recommends that this assessment continue to be developed for use in determining OFLs and ABCs in June 2017.

Response:

Yes, that is the intention.

Comment 2: The SSC supports the CPT recommendation for additional analyses regarding the spatial and depth distribution of trawl fishing and overlap with the AIGKC survey and fishery.

Response:

We have not looked at this yet because NMFS has access to detailed information on groundfish trawl activities in these areas.

Comment 3: The SSC generally supports the CPTs recommendations for improvement of the model for the January meeting. Specifically,

- **For analyses removing the groundfish length-frequencies, the groundfish catches should not be removed.**
- **Differences in catch amounts between tables and graphs be reconciled.**
- **The presentation noted the discrepancy in treatment of input samples sizes between the two areas (number of trips vs. number of individual lengths), and that the CPT had recommended using the number of days on which sampling was conducted as a more consistent starting point for both models.**

Response:

-We have removed the groundfish length composition data while keeping the groundfish catches in all scenarios except scenario 12. Scenario 12 was run to investigate the effect of including the groundfish length composition.

-We have reconciled the difference in catch amounts between tables and graphs.

-We used number of days for retained and total size compositions and number of trips for groundfish size composition as effective sample sizes without enforcing any upper bounds in both regions.

Comment 4: The SSC suggests that the CPT consider developing a prior probability distribution for this stock to aid in stabilizing the estimation of natural mortality while still propagating a reasonable amount of uncertainty in this key population parameter (see general request to CPT above).

Response:

We used the following penalty function (P) to estimate *M*:

? ?? [?? (?) − ?? Æ(È]?

where ?? was the weight based on a CV of 50% assigned to the penalty and $0.18 yr^{-1}$ is the *M* value used for king crab stock assessments.

Note: For *M* profile estimation we disabled this penalty.

We will welcome any new suggestions by the CPT/SSC on any appropriate *M* prior.

Comment 5: In order to better understand the outcome of any data-weighting method, the scale of the standardized residual plots must be reported. The SSC requests again that this is added for the next assessment.

Response:

We provide the scaled standardized residual plots for retained and total catch size compositions for scenario 1 for EAG and WAG, respectively in the following figures:

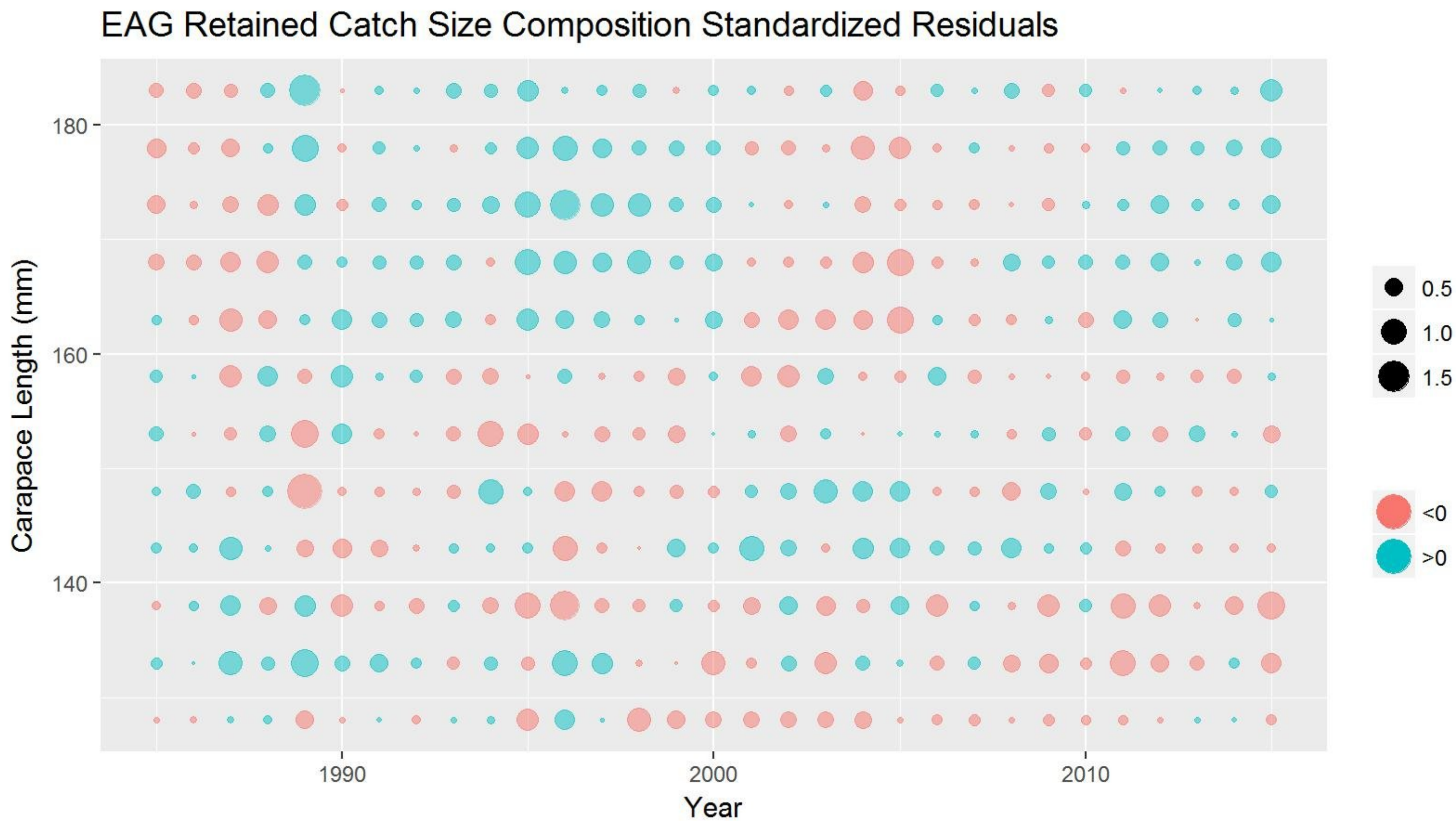


Figure 8. Bubble plot of standardized residuals of retained catch length composition for scenario 1 fit for EAG golden king crab, 1985/86–2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

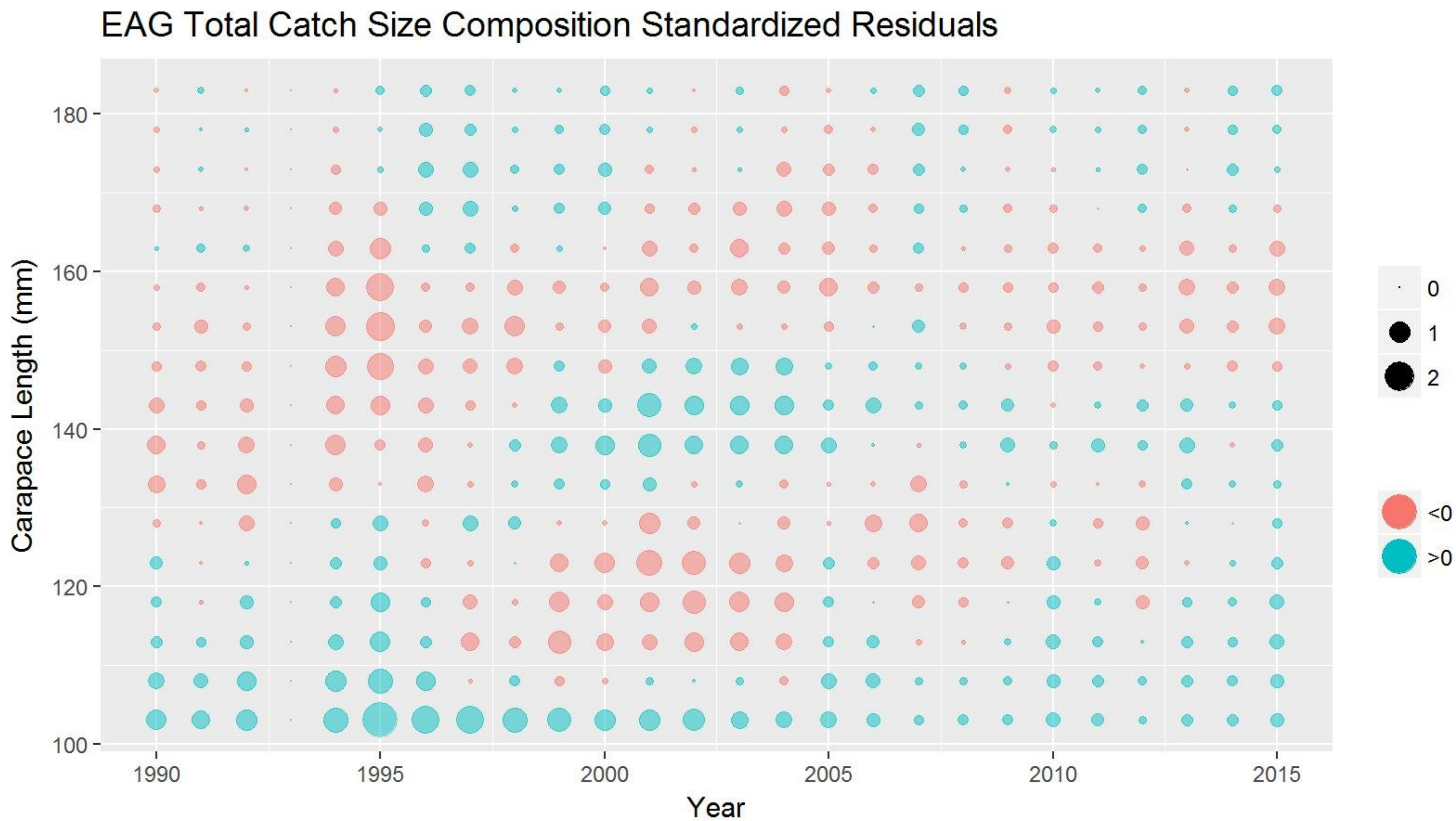


Figure 9. Bubble plot of standardized residuals of total catch length composition for scenario 1 fit for EAG golden king crab, 1990/91–2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

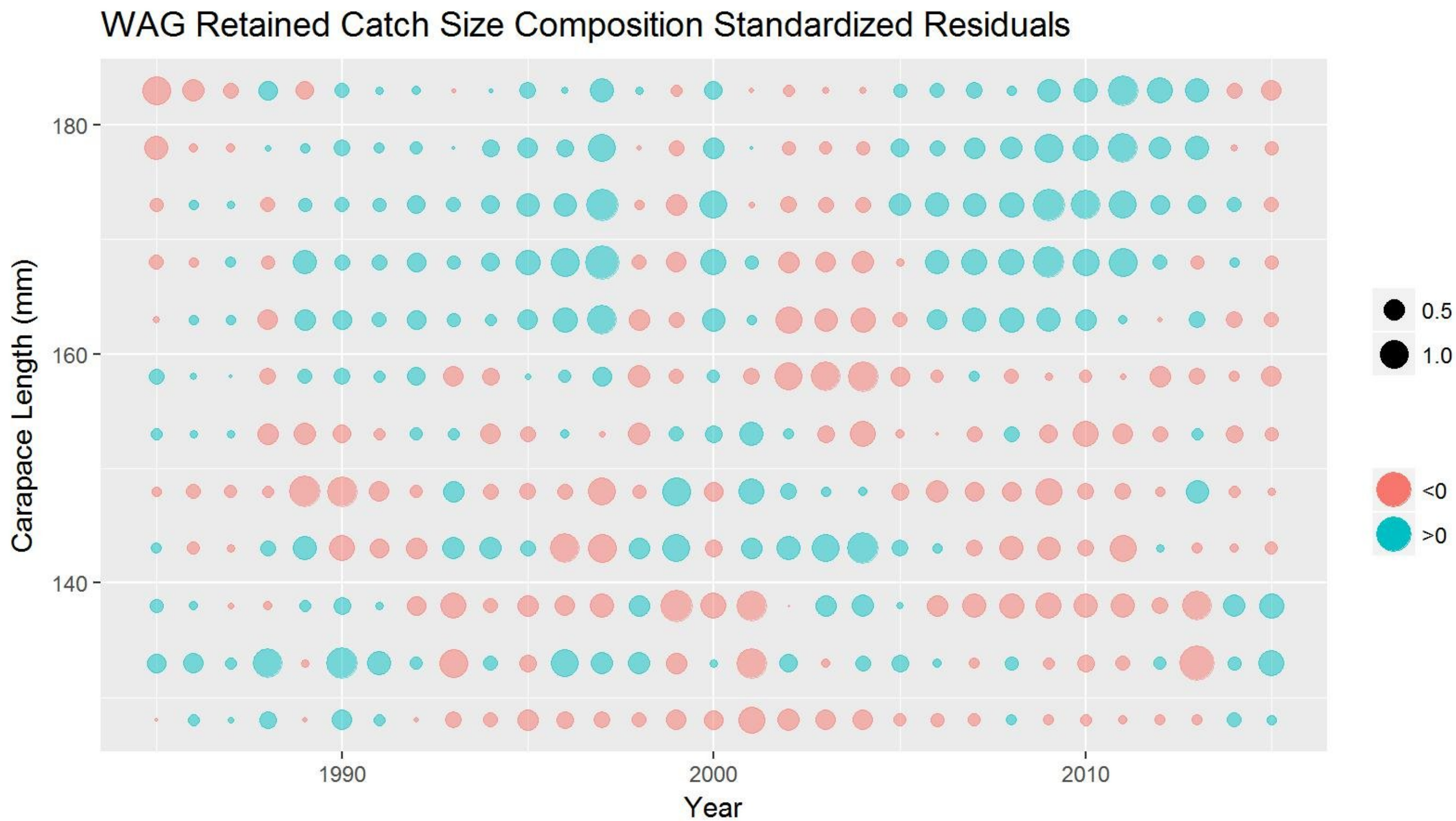


Figure 10. Bubble plot of standardized residuals of retained catch length composition for scenario 1 fit for WAG golden king crab, 1985/86–2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

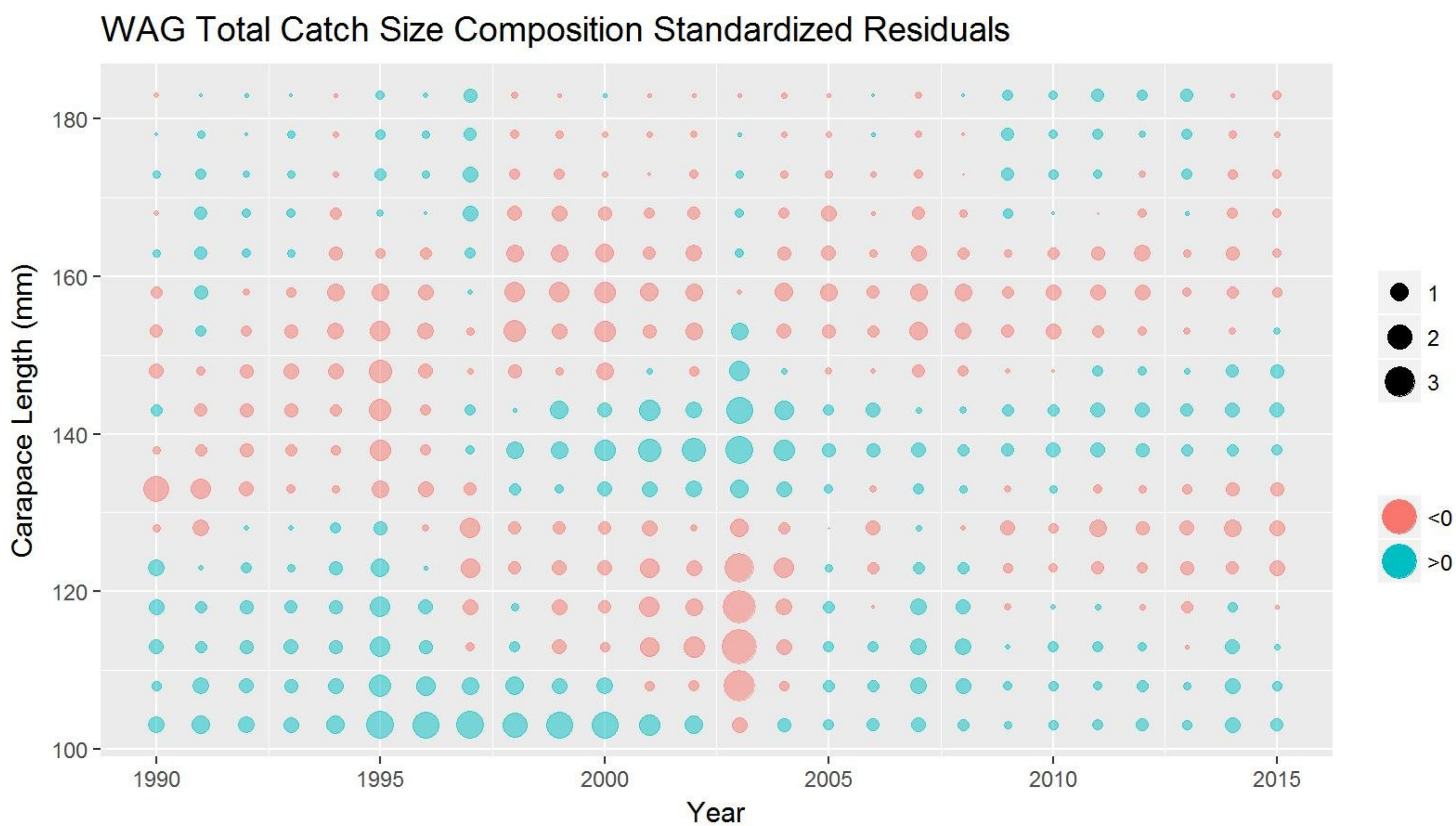


Figure 11. Bubble plot of standardized residuals of total catch length composition for scenario 1 fit for WAG golden king crab, 1990/91–2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

Comment 6: The SSC noted that this is the only crab assessment that relies solely on fishery CPUE as an index of abundance. The standardization of these data has been well explored, the series is truncated to eliminate early years (pre 1995/1996) where

the fishery was likely changing without respect to population trend, and broken in 2005 due to the changes associated with rationalization. Nevertheless, other factors (such as trawl activity mentioned above) could result in CPUE that is not proportional to abundance. The SSC recommends the CPT consider use of a larger buffer (greater than the current 20%) from the OFL, given the lack of a standardized survey for this stock.

Response:

We have extended the observer CPUE time series back to 1991/92 in the current analysis.

We provide a 25% buffer to OFL as an example for further discussion on this topic.

Introduction

There is no direct evidence of separate golden king crab (*Lithodes aequispinus*) stock structure in the Aleutian Islands between areas west and east of 174° W longitude. But CPUE trends suggest stock productivity may differ between these areas. There is a paucity of information on golden king crab life history characteristics due in part to the deep depth distribution (~200–1000 m) and the asynchronous nature of life history events (Otto and Cummiskey 1985; Somerton and Otto 1986). Molt increment for legal males in the eastern area was estimated at 14.4 mm carapace length (CL) (Watson et al. 2002). The 50% male size-at-maturity was determined to be 120.8 mm CL (Otto and Cummiskey 1985).

Since 1996, the Alaska Department of Fish and Game (ADF&G) has divided management of the Aleutian Islands golden king crab fishery at 174° W longitude (ADF&G 2002). Hereafter, the east of 174° W longitude stock segment is referred to as EAG and the west of 174° W longitude stock segment is referred to as WAG. The stocks in the two areas have been managed with a constant annual guideline harvest level or total allowable (retained) catch. Additional management measures include a male-only fishery and a minimum legal size limit (152.4 mm carapace width [CW], or approximately 136 mm carapace length [CL]), which is at least one annual molt increment larger than the 50% maturity length. In the model scenarios, a knife-edge maturity length of 121 mm CL was used for mature male biomass (MMB) estimation and the length-weight relationship of Ô Û, where a= 2.988*10^{-4} and b = 3.135, was used for biomass calculation from number of crabs by length.

Figures 12 and 13 provide the historical time series of catches and CPUE for EAG and WAG, respectively. Increases in CPUE were observed during the late 1990s through the early 2000s, and with the implementation of crab rationalization in 2005. In 2012, the BOF increased the TAC levels to 3.310 million pounds for EAG and 2.980 million pounds for WAG beginning with the 2012/13 fishing year. As a result of declining catch rate and harvest in the WAG, ADF&G reduced the WAG TAC to 2.235 million pounds for the 2016/17 fishery (citation?).

Analytic Approach

The assessment model was accepted at the September 2016 CPT and October 2016 SSC meetings. The underlying population dynamics model is male-only and length-based (Appendix A). This model combines commercial retained catch, total catch, groundfish (trawl and pot) fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, groundfish discard catch size composition, and tag recaptures by release-recapture lengths to estimate stock assessment parameters. The tagging data were used to calculate the size transition matrix. To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 commercial fishery standardized CPUE indices as a separate likelihood component in scenario 4.

We fitted the observer and commercial fishery CPUE indices with GLM estimated standard errors and an additional constant variance. The additional constant variance was estimated by the model fit. There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9-inch since 1999), and improved observer coverage in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86–2004/05 and 2005/06–2015/16. Following a CPT suggestion, we also considered three catchabilities, three sets of total selectivity, and one set of retention curves in one scenario (scenario 9).

We used standardized CPUE indices (Appendix B) and catch and size composition information to determine the stock abundance trends in both regions. We assumed that the observer and fish ticket CPUE indices are linearly related to exploitable abundance. We kept M constant at 0.225 yr^{-1} (the optimized M estimate from the combined EAG and WAG data). We assumed directed pot fishery discard mortality proportion at 0.20 yr^{-1}, overall groundfish fishery mortality proportion at 0.65 yr^{-1} [mean of groundfish pot fishery mortality (0.5 yr^{-1}) and groundfish trawl fishery mortality (0.8 yr^{-1})], and groundfish fishery selectivity at full selection for all length classes (selectivity = 1.0). Any discard of legal size males in the directed pot fishery was not considered in this analysis.

We considered number of fishing days as the initial input effective sample sizes (i.e., stage-1) for retained and total *size* compositions and number of trips for groundfish discard catch size composition without enforcing any upper limit. For scenarios 7 and 8 (iterative reweighting by Francis [2011] and McAllister and Ianelli [1997] methods), we estimated the stage-2 effective sample sizes iteratively from stage-1 input effective sample sizes. We refer to the stage-1 effective samples sizes for the size-composition of the retained catch, total catch, and the groundfish crab bycatch for year *t* as $\tau^{r}_{1,t}, \tau^{T}_{1,t}$, and $\tau^{Tr}_{1,t}$ respectively. The reiterated effective sample sizes' subscripts replace 1 by 2.

Francis method:

The Francis' (2011) mean length based method (i.e., Francis TA1.8 method, Punt (*in press*) uses the following formulas:

Observed mean length for year *t*,

$$\bar{?}_{?} \quad \sum^{?}_{?? ?} ?_{? ?} ó \; ?_{? ?} \tag{1}$$

Predicted mean length for year *t*,

$$\bar{?}_{?} \quad \sum^{?}_{?? ?} ?_{? ?} ó \; \bar{?}_{? ?} \tag{2}$$

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

$$? ? ? \; ?\bar{?}_{?} ? \quad \frac{\sum^{?}_{?? ?} \bar{?}_{? ?} ? ?_{? ?} ? \; \bar{?}_{?} ?^{?}}{?_{?}} \tag{3}$$

Francis' reweighting parameter *W*,

$$? \qquad \frac{?}{????\frac{\bar{?}_{?}\;?\;\hat{?}_{?}}{?\,?????\hat{?}_{??}}?} \tag{4}$$

where $\hat{?}_{??}$ and $?_{??}$ are the estimated and observed proportions of the catch during year *t* in length-class *i*, $?_{??}$ is the mid length of the length-class *i* during year *t*, $?_{?}$ is the effective sample size in year *t*, $\hat{\bar{?}}_{?}$ and $\bar{?}_{?}$ are predicted and observed mean lengths of the catch during year *t*, and *W* is the reweighting multiplier of stage-1 sample sizes.

Francis (*in press*) suggested that a good stopping criterion for the iteration process is when there are no appreciable changes in the key outputs. Hence, we considered a stopping criterion of no appreciable change (<0.01%) in *W*, terminal year MMB, and retained catch overfishing level (OFL).

$?_{?}$ is related to the initial (stage-1) effective sample size according to:

$$?_{??} \quad ?\;{}_{?}?_{??} \tag{5}$$

where $?_{??}$ is the effective sample size for year *t* in iteration *i* and $?_{\,?}$ is the Francis weight calculated using Equation 4 during iteration *i*.

<u>McAllister and Ianelli method</u>:

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

$$?_{??} \quad \frac{\sum_{?} \hat{?}_{??}Æ?\,\hat{?}_{??}}{\sum_{?}Æ_{??}?\,\hat{?}_{??}{}^{?}} \tag{6}$$

where $\hat{?}_{??}$ and $?_{??}$ are the estimated and observed proportions of the catch during year *t* in size-class *l*, and $?_{??}$ is the stage-2 effective sample size for year *t*.

McAllister and Ianelli (1997) defined the effective sample size for each size-composition data set for eastern Bering Sea yellowfin sole (*Limanda aspera*) as the arithmetic mean of $?_{??}$ over years t (i.e., a year-invariant effective sample size) and iterated the model fitting, updating the effective sample sizes, until convergence occurred. Equation 6 ignores correlation among the residuals for the catch proportions and likely overestimates effective sample sizes (Francis 2011). Punt (*in press*) suggests using the harmonic mean of $?_{??}$ if the McAllister and Ianelli formula is used. A harmonic mean (constant) multiplier was consequently used to update the effective sample sizes at each iteration of model fitting until convergence occurred; i.e.

$$?_{???} \quad ?\frac{?}{??}\sum_{?} ?\frac{?????}{?????}?^{??} \quad ?^{??} \quad ?_{?????} \qquad (7)$$

where $\tau_{2,t,i}$ is the stage-2 effective sample size for year t in iteration i ($\tau_{2,t,0} = \tau_{1,t}$) and $?_{???}$is from Equation 6. Convergence of the process of setting the stage-2 effective sample sizes using Equation 7 was visually assessed by plotting $?_{?????}$ vs. $?_{???}$ at the final iteration.

We used the entire time period, 1985/86–2015/16, to determine the mean mature male biomass (MMB) as MMB_{ref} (a proxy for MMB_{MSY}) under Tier 4 and mean number of recruits for 1986–2016 and mean groundfish fishery F for 2006/07–2015/16 for MMB_{35} (a proxy for MMB_{MSY}) estimation under Tier 3. We varied the time ranges in scenario 14 for exploratory analysis on OFL and ABC.

Results

Weights for different data sets are provided in the Appendix A Table A2 for various scenarios, respectively, for EAG and WAG. These weights (with the corresponding coefficient of variations) adequately fitted various data under the integrated model setting. All scenarios considered molt probability parameters in addition to the linear growth increment and normal growth variability parameters to determine the size transition matrix.

Tables of input values and parameter estimates:

a. Time series of retained and total catch, groundfish fishery discard mortality, and pot fishery effort are summarized in Table 1 for EAG and Table 17 for WAG. The estimation methods are described in Appendix B.
b. Time series of pot fishery and observer nominal retained and total CPUE, observer sample size, estimated observer CPUE index are listed in Table 2 for EAG and Table 18 for WAG. The estimated commercial fishery CPUE indices are provided in Table 3 for EAG and Table 19 for WAG. The estimation methods, CPUE fits and diagnostic plots are described in Appendix B.
c. The process of iterations to determine the Francis weight multiplier for the initial input effective sample sizes are given in Tables 4 for EAG and Table 20 for WAG.
d. Time series of stage-1 (initial) and stage-2 effective sample sizes under the Francis method are listed in Table 5 for EAG and Table 21 for WAG. We multiplied the initial input (stage-1) annual sample sizes by the estimated *W* for a number of iterative fittings until we found no appreciable changes in *W*, terminal MMB, and retained catch OFL estimates. Time series of stage-1 (initial) and stage-2 effective sample sizes under the McAllister and Ianelli method are listed in Table 6 for EAG and Table 22 for WAG.
e. The parameter estimates with coefficient of variation for twelve scenarios are summarized respectively in Tables 7 to 9 for EAG and 23 to 25 for WAG. We have also provided the boundaries for parameter searches in those tables, and the estimates were within the bounds.
f. The mature male and legal male abundance time series for representative scenarios 1, 2, 5, 6, 7, and 8 are summarized in Tables 10 to 15 for EAG and Tables 26 to 31 for WAG.
g. The recruitment estimates for those six scenarios are also summarized in Tables 10 to 15 for EAG and Tables 26 to 31 for WAG.
h. The likelihood component values and the total likelihood values for nine scenarios are summarized in Table 16 for EAG and Table 32 for WAG. Scenario

8 with the McAllister and Ianelli method of reweighting effective sample sizes produced the overall minimum of the total negative log-likelihood.

i. The total OFL catch under Tier 4 and Tier 3, and the terminal biomass depletion ratio values for all scenarios are listed in Table 33.

Graphs of estimates:

a. We provide the retained length composition fits in Figure 14 for EAG and Figure 24 for WAG, total length composition fits in Figure 15 for EAG and Figure 25 for WAG, and groundfish discarded catch length composition fits in Figure 16 for EAG and Figure 26 for WAG for all scenarios. The retained and total catch size composition fits appear satisfactory. But, fits to groundfish bycatch size compositions are poor.
b. We provide the pre- and post-rationalization periods' total and retained selectivity curves in Figure 17 for EAG and Figure 27 for WAG for all scenarios.
c. We show the fits to tag recapture numbers by length-class for year-at-large 1 to 6 in Figure 18 for EAG and Figure 28 for WAG. The predictions appear reasonable.
d. We provide the CPUE fits by all scenarios in Figure 19 for EAG and Figure 29 for WAG. Scenario 4 with fish ticket CPUE indices tracks indices back to 1985/86. All scenarios appear to fit the CPUE indices satisfactorily for both management areas. However, scenario 9 with three catchability and total selectivity parameters fit the initial years' observer indices better.
e. We show the recruitment trends for all scenarios in Figure 20 for EAG and Figure 30 for WAG. Although McAllister and Ianelli reweighting of effective sample sizes produced the lowest total negative log-likelihood, the pre-fishery recruitment trend dipped.
f. We provide the recruitment distribution to the first five length-classes for all scenarios in Figure 21 for EAG and Figure 31 for WAG. There was no abnormality among the scenario results.
g. We show the retrospective plots for all scenarios in Figure 22 for EAG and Figure 32 for WAG. The pre-fishery MMB trends were mostly horizontal for WAG, but

not for EAG. Scenario 1d straightened the pre-fishery MMB trend for EAG. This scenario was not considered for WAG because MMB trends during non-fishing period were flat.

h. We provide the predicted molt probability curves for all scenarios in Figure 23 for EAG and Figure 33 for WAG. There was no abnormality among the scenario results.

i. We provide the initial and i-th step input effective sample sizes versus the predicted effective sample sizes under the McAllister and Ianelli iterative reweighting method for retained and total catch size compositions in Figure 34 for EAG and Figure 35 for WAG. Nearly 1:1 fits were achieved by the i-th iteration.

j. We provide the R0 profile (R0 is the base scenario estimate of mean recruitment) for the scenario 1 fit to EAG data in Figure 36 and that for WAG data in Figure 37. The overall total (black line) likelihoods indicate that they were informative for absolute abundance estimation when all data were considered for EAG and WAG, respectively. The CPUE, recruitment deviation, tag, and total length composition component likelihoods also indicate that those data sets (or penalty) were individually informative for abundance estimation for EAG. However, the information contents of the above data components for WAG abundance estimation were not as clear as that of EAG although they were informative.

k. We provide the fits to pre–1985 retained catches (in number of crabs) by all scenarios in Figure 38 for EAG and Figure 39 for WAG. All scenarios adequately fitted the 1881/82–1984/85 retained catches in both areas.

Calculation of the OFL

Specification of the Tier level:

The Aleutian Islands golden king crab stocks are currently managed under a Tier 5 (average catch OFL) control rule. Our analysis attempts to upgrade this stock to either the Tier 4 level or to the Tier 3 level. The two tier level OFL calculation procedures are described below:

Tier 4 approach:

1. List of parameters and stock size required by the control rule are:
   An average mature male biomass (*MMB*) for a specified time period, MMB_{ref} (a proxy for MMB_{MSY}), current *MMB*; an *M* value; and a γ value.
2. Specification of the total catch OFL:
   (a) if ? ? ?$_{???????}$ ≥ ? ? ?$_{???}$?$_{???}$?? ;
   (b) if ? ? ?$_{???????}$? ? ?$_{???}$??? ? ? ?$_{???????}$ ĆÉË? ? ?$_{???}$

   ?$_{???}$?? $\frac{?\frac{? ? ? ???????}{? ? ? ???} ? ??}{(???)}$ (8)

   (c) if ? ? ?$_{???????}$ ≤ ĆÉË? ? ?$_{???}$?$_{???}$,

   where Î$_{???????}$ is the mature male biomass in the current year, MMB_{ref} is average mature male biomass, γ is a multiplying factor of *M*, and α is a fixed parameter (= 0.1) that determines the rate at which F_{OFL} declines as B declines. The OFL is estimated by an iterative procedure accounting for intervening total removals (see Appendix A for the formulas).

Tier 3 Approach:

The critical assumptions for reference point estimation are:

a. Natural mortality is constant over all 17 size groups.
b. Growth transition matrix is estimated using tagging data with the molt probability sub-model.
c. The catchability parameter estimate for the 2005/06-2015/16 period is used.
d. Total fishery selectivity and retention curves are length dependent and the 2005/06-2015/16 period selectivity estimates are used. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated molt probability is not time dependent, but is length dependent.
f. Model estimated recruits (in millions of crab) are averaged for the time period 1986 to 2016 (31 years).

g. Model estimated groundfish bycatch mortality values are averaged for the period 2005 to 2014 (10 years).

Method: We simulated the population abundance starting from the model estimated final year stock abundance by length-class and parameter values; projecting the abundance with a fishing mortality (F) and a constant natural mortality values; and adding a constant number of annual recruits. Once the stock dynamics were stabilized (we used the 99th year estimates) for an F, we calculated the MMB/R for that F. We computed the relative *MMB/R* in percentage, $?\frac{???}{?}?_{?Å}$ (where x% = $\frac{\frac{????}{?}}{\frac{????}{?}}$ ó È and $???_{?}$? is the virgin *MMB/R*) for different F values. Estimated F_{35} is the F value that produces the MMB/R value equal to 35% of $???_{?}$?. The parameter MMB_{35} (or B_{35}) is estimated using the following formula:

$???_{??}$ $?\frac{???}{?}?_{??}$ ó ?, where ? is the mean number of model estimated recruits for a selected period. The $?_{???}$ is determined from Equation 8 by replacing ?? with $?_{??}$ and $?_{???}$ with $???_{??}$.

Calculation of the ABC

Specification of the probability distribution of the total catch OFL:

We estimated the cumulative probability distribution of OFL assuming a log normal distribution of OFL. We calculated the OFL at the 0.5 probability and the ABC at the 0.49 probability and considered an additional buffer by setting ABC =0.75*OFL.

The OFL and ABC estimates under Tier 4 and Tier 3 are summarized below. We also provide the Tier 4 OFL estimates for the scenario 1 with ? set to 2 as a heuristic approach.

EAG (Tier 4):

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

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define MMB_{ref}	?	M	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	4a	16.442	24.249	1.47	0.225	1986–2016	1	0.225	3.907	3.890	2.930
1	4a	16.442	21.299	1.30	0.450	1986–2016	**2**	0.225	7.142	7.112	5.357
2	4a	14.375	21.963	1.53	0.18	1986–2016	1	0.18	2.925	2.913	2.194
3	4a	16.525	24.290	1.47	0.225	1986–2016	1	0.225	3.879	3.861	2.909
4	4a	16.902	24.850	1.47	0.225	1986–2016	1	0.225	4.018	4.001	3.014
5	4a	16.933	23.725	1.40	0.225	1986–2016	1	0.225	3.902	3.879	2.927
6	4a	15.251	21.155	1.39	0.225	1986–2016	1	0.225	3.210	3.198	2.408
7	4a	16.528	24.013	1.45	0.225	1986–2016	1	0.225	3.991	3.974	2.993
8	4a	16.874	24.466	1.45	0.225	1986–2016	1	0.225	4.003	3.985	3.002
9	4a	14.402	22.558	1.57	0.225	1986–2016	1	0.225	3.570	3.556	2.678
10	4a	24.720	30.402	1.23	0.225	1986–2016	1	0.225	4.268	4.247	3.201
11	4a	15.783	23.710	1.50	0.225	1986–2016	1	0.225	3.715	3.700	2.786
12	4a	16.040	26.199	1.63	0.225	1986–2016	1	0.225	3.869	3.853	2.902
1d	4a	16.546	24.977	1.51	0.225	1986–2016	1	0.225	3.996	3.979	2.997

Biomass in 1,000 t; total OFL and ABC for the next fishing season in t.

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define MMBref	?	M	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	4a	7.458	10.999	1.47	0.225	1986–2016	1	0.225	1,772.180	1764.686	1329.135
1	4a	7.458	9.661	1.30	0.450	1986–2016	**2**	0.225	3,239.657	3,226.098	2,429.743
2	4a	6.521	9.962	1.53	0.18	1986–2016	1	0.18	1,326.727	1,321.236	995.045
3	4a	7.496	11.018	1.47	0.225	1986–2016	1	0.225	1,759.427	1,751.445	1,319.570
4	4a	7.667	11.272	1.47	0.225	1986–2016	1	0.225	1,822.674	1,814.638	1,367.006
5	4a	7.681	10.762	1.40	0.225	1986–2016	1	0.225	1,770.075	1,759.526	1,327.556
6	4a	6.918	9.596	1.39	0.225	1986–2016	1	0.225	1,456.127	1,450.717	1,092.095
7	4a	7.497	10.892	1.45	0.225	1986–2016	1	0.225	1,810.332	1,802.510	1,357.749
8	4a	7.654	11.098	1.45	0.225	1986–2016	1	0.225	1,815.564	1,807.717	1,361.673

9	4a	6.533	10.232	1.57	0.225	1986–2016	1	0.225	1,619.500	1,613.175	1,214.625
10	4a	11.213	13.790	1.23	0.225	1986–2016	1	0.225	1,935.919	1,926.293	1,451.939
11	4a	7.159	10.755	1.50	0.225	1986–2016	1	0.225	1,684.932	1,678.355	1,263.699
12	4a	7.276	11.884	1.63	0.225	1986–2016	1	0.225	1,755.183	1,747.753	1,316.387
1d	4a	7.505	11.329	1.51	0.225	1986–2016	1	0.225	1,812.449	1,804.775	1,359.336

WAG (Tier 4):

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

Scenario	Tier	*MMB_{ref}*	Current MMB	MMB/ *MMB_{ref}*	F_{OFL}	Years to define *MMB_{ref}*	*?*	*M*	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	4b	9.782	9.781	0.999	0.225	1986–2016	1	0.225	1.241	1.228	0.931
1	4b	9.782	8.961	0.92	0.408	1986–2016	**2**	0.225	2.095	2.076	1.571
2	4a	8.840	8.848	1.00	0.225	1986–2016	1	0.18	0.930	0.926	0.697
3	4b	9.907	9.901	0.999	0.225	1986–2016	1	0.225	1.250	1.237	0.937
4	4a	9.876	9.915	1.00	0.225	1986–2016	1	0.225	1.275	1.270	0.956
5	4b	9.714	7.545	0.78	0.169	1986–2016	1	0.225	0.696	0.687	0.522
6	4a	9.865	11.601	1.18	0.225	1986–2016	1	0.225	1.497	1.492	1.123
7	4a	9.978	10.276	1.03	0.225	1986–2016	1	0.225	1.312	1.307	0.984
8	4b	9.989	9.885	0.99	0.222	1986–2016	1	0.225	1.291	1.278	0.968
9	4a	9.056	9.134	1.01	0.225	1986–2016	1	0.225	1.191	1.186	0.893
10	4b	64.596	61.245	0.95	0.212	1986–2016	1	0.225	4.505	4.452	3.379
11	4b	9.779	9.753	0.997	0..224	1986–2016	1	0.225	1.232	1.219	0.924
12	4b	10.066	9.045	0.90	0.200	1986–2016	1	0.225	1.111	1.098	0.833

Biomass in 1,000 t; total OFL and ABC for the next fishing season in t.

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMBref	F_{OFL}	Years to define MMB_{ref}	□	M	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	4b	4.437	4.436	0.999	0.225	1986–2016	1	0.225	562.838	557.054	422.128
1	4b	4.437	4.065	0.92	0.408	1986–2016	**2**	0.225	950.278	941.610	712.708
2	4a	4.010	4.013	1.00	0.225	1986–2016	1	0.18	421.636	420.007	316.227
3	4b	4.494	4.491	0.999	0.225	1986–2016	1	0.225	566.963	561.126	425.222
4	4a	4.480	4.497	1.00	0.225	1986–2016	1	0.225	578.245	575.911	433.684

5	4b	4.406	3.423	0.78	0.169	1986–2016	1	0.225	315.485	311.604	236.614
6	4a	4.475	5.262	1.18	0.225	1986–2016	1	0.225	679.188	676.741	509.391
7	4a	4.526	4.661	1.03	0.225	1986–2016	1	0.225	595.213	592.708	446.409
8	4b	4.531	4.484	0.99	0.222	1986–2016	1	0.225	585.556	579.701	439.167
9	4a	4.108	4.143	1.01	0.225	1986–2016	1	0.225	540.224	538.106	405.168
10	4b	29.300	27.781	0.95	0.212	1986–2016	1	0.225	2,043.468	2,019.245	1,532.601
11	4b	4.436	4.424	0.997	0..224	1986–2016	1	0.225	558.942	553.143	419.207
12	4b	4.566	4.103	0.90	0.200	1986–2016	1	0.225	503.809	498.121	377.857

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in million pounds. Terminal MMB= MMB on 15 Feb. 2016.

Scenario	Tier	B_{35}	Terminal MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	3a	14.458	20.252	1.40	0.53	1986–2016	0.53	7.503	7.465	6.002
2	3a	15.961	19.559	1.23	0.37	1986–2016	0.37	5.561	5.538	4.171
3	3a	14.397	20.270	1.41	0.54	1986–2016	0.54	8.224	8.187	6.168
4	3a	14.506	20.707	1.43	0.54	1986–2016	0.54	8.514	8.477	6.386
5	3a	14.535	19.813	1.36	0.52	1986–2016	0.52	8.013	7.966	6.010
6	3a	13.711	17.476	1.27	0.55	1986–2016	0.55	6.921	6.897	5.191
7	3a	14.325	20.050	1.40	0.55	1986–2016	0.55	8.327	8.291	6.245
8	3a	14.526	20.157	1.39	0.52	1986–2016	0.52	8.216	8.180	6.162
9	3a	13.828	18.875	1.36	0.52	1986–2016	0.52	7.350	7.322	5.513
10	3a	17.684	26.466	1.50	0.50	1986–2016	0.50	8.626	8.583	6.470
11	3a	14.088	19.667	1.40	0.55	1986–2016	0.55	8.000	7.969	6.000
12	3a	14.568	20.359	1.40	0.54	1986–2016	0.54	8.216	8.182	6.162
1d	3a	14.608	20.725	1.42	0.53	1986–2016	0.53	8.344	8.309	6.258

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

Scenario	Tier	B_{35}	Terminal MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	3a	6.588	9.186	1.40	0.53	1986–2016	0.53	3,403.124	3,385.947	2,722.499
2	3a	7.239	8.872	1.23	0.37	1986–2016	0.37	2,522.525	2,512.124	1,891.894
3	3a	6,530	9.194	1.41	0.54	1986–2016	0.54	3,730.378	3,713.758	2,797.783
4	3a	6.579	9.392	1.43	0.54	1986–2016	0.54	3,862.063	3,845.099	2,896.547
5	3a	6.593	8.987	1.36	0.52	1986–2016	0.52	3,634.771	3,613.335	2,726.078
6	3a	6.219	7.926	1.27	0.55	1986–2016	0.55	3,139.556	3,128.247	2,354.667
7	3a	6.497	9.094	1.40	0.55	1986–2016	0.55	3,776.881	3,760.841	2,832.661
8	3a	6.589	9.143	1.39	0.52	1986–2016	0.52	3,726.583	3,710.646	2,794.937
9	3a	6.272	8.562	1.36	0.52	1986–2016	0.52	3,334.075	3,321.235	2,500.557
10	3a	8.021	12.005	1.50	0.50	1986–2016	0.50	3,912.864	3,893.319	2,934.648

11	3a	6.390	8.921	1.40	0.55	1986–2016	0.55	3,628.682	3,614.569	2,721.511
12	3a	6.608	9.234	1.40	0.54	1986–2016	0.54	3,726.583	3,711.122	2,794.937
1d	3a	6.626	9.400	1.42	0.53	1986–2016	0.53	3,784.866	3,769.105	2,838.649

WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in million pounds. Terminal MMB= MMB on 15 Feb. 2016.

Scenario	Tier	B_{35}	Terminal MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	3b	10.490	8.841	0.84	0.41	1986–2016	0.50	2.118	2.106	1.589
2	3b	11.982	8.593	0.72	0.25	1986–2016	0.36	1.242	1.234	0.931
3	3b	10.429	8.893	0.85	0.43	1986–2016	0.51	2.194	2.182	1.646
4	3b	10.490	8.922	0.85	0.42	1986–2016	0.50	2.193	2.180	1.645
5	3b	10.151	7.194	0.71	0.34	1986–2016	0.50	1.299	1.289	0.974
6	3b	10.641	10.011	0.94	0.48	1986–2016	0.51	2.881	2.865	2.160
7	3b	10.382	9.078	0.87	0.44	1986–2016	0.51	2.360	2.346	1.770
8	3b	10.473	8.958	0.86	0.41	1986–2016	0.49	2.218	2.205	1.663
9	3b	10.426	8.390	0.81	0.37	1986–2016	0.47	1.844	1.833	1.383
10	3a??	30.587	54.361	1.78	0.65	1986–2016	0.65	12.230	12.089	9.173
11	3b	10.487	8.822	0.84	0.41	1986–2016	0.50	2.105	2.093	1.579
12	3b	10.418	8.643	0.83	0.40	1986–2016	0.49	2.044	2.032	1.533

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

Scenario	Tier	B_{35}	Terminal MMB	MMB $/B_{35}$	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
1	3b	4.758	4.010	0.84	0.41	1986–2016	0.50	960.776	955.190	720.582
2	3b	5.435	3.898	0.72	0.25	1986–2016	0.36	563.145	559.777	422.358
3	3b	4.731	4.034	0.85	0.43	1986–2016	0.51	995.371	989.604	746.528
4	3b	4.758	4.047	0.85	0.42	1986–2016	0.50	994.890	989.059	746.167
5	3b	4.605	3.263	0.71	0.34	1986–2016	0.50	589.105	584.738	441.829
6	3b	4.827	4.541	0.94	0.48	1986–2016	0.51	1,306.631	1,299.658	979.973
7	3b	4.709	4.118	0.87	0.44	1986–2016	0.51	1,070.694	1,064.026	803.021
8	3b	4.750	4.063	0.86	0.41	1986–2016	0.49	1,006.061	1,000.330	754.546
9	3b	4.729	3.806	0.81	0.37	1986–2016	0.47	836.449	831.588	627.337
10	3a??	13.874	24.658	1.78	0.65	1986–2016	0.65	5,547.710	5,483.726	4,160.782
11	3b	4.757	4.002	0.84	0.41	1986–2016	0.50	954.881	949.258	716.161
12	3b	4.726	3.920	0.83	0.40	1986–2016	0.49	927.315	921.865	695.486

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Table 1. Time series of annual retained catch (number and weight of crabs), estimated total male catch (number and weight of crabs on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crabs) (handling mortality rates of 50% for pot and 80% for trawl gear were applied, only to the male portions) for the EAG golden king crab stock. Crab numbers are for crab ≥101 mm CL. NA: no observer sampling to compute catch. The directed fishery data included cost-recovery beginning in 2013/14.

Year	Retained Catch (no.)	Retained Catch Biomass (t)	Total Catch (no.)	Total Catch Biomass (t)	Pot Fishery Effort (no. pot lifts)	Groundfish Discard Mortality (no.)	Groundfish Discard Mortality (t)
1981	203,968						
1982	529,787						
1983	662,280						
1984	801,100						
1985	1,251,267	2,695			117,718		
1986	1,374,943	2,818			155,240		
1987	968,614	1,893			146,501		
1988	1,156,046	2,397			155,518		
1989	1,419,777	2,753			155,262	388	0.61
1990	892,699	1,632	1,148,518	2,422	106,281	1,190	1.98
1991	1,083,243	2,018	4,385,096	5,910	133,428	NA	NA
1992	1,127,291	2,115	4,331,508	5,589	133,778	779	1.01
1993	767,918	1,415	NA	NA	106,890	719	0.95
1994	1,086,560	2,029	1,712,658	3,001	191,455	311	0.29
1995	1,150,168	2,211	2,742,782	3,742	177,773	569	0.78
1996	848,045	1,615	1,452,362	2,064	113,460	46	0.04
1997	780,481	1,474	1,788,351	2,555	106,403	76	0.10
1998	740,011	1,407	2,011,777	2,804	83,378	587	0.76
1999	709,332	1,329	1,556,398	2,287	79,129	284	0.35
2000	704,363	1,352	1,706,999	2,564	71,551	387	0.47
2001	730,030	1,394	1,352,904	2,105	62,639	934	1.47
2002	643,668	1,236	1,119,586	1,808	52,042	707	0.68
2003	643,074	1,287	1,111,206	1,825	58,883	392	0.43
2004	637,536	1,261	965,443	1,627	34,848	59	0.12
2005	623,971	1,262	927,444	1,724	24,569	252	0.28
2006	650,587	1,375	860,688	1,632	26,195	679	0.70
2007	633,253	1,316	911,185	1,802	22,653	697	0.69
2008	666,947	1,406	929,694	1,799	24,466	808	0.85
2009	679,886	1,433	936,938	1,761	26,298	718	1.14
2010	670,698	1,398	935,574	1,729	25,851	2,415	2.41
2011	668,828	1,428	920,866	1,747	17,915	1,208	1.15
2012	687,666	1,482	990,519	1,939	20,827	2,058	3.61
2013	720,220	1,529	978,645	1,829	21,388	894	2.04
2014	719,064	1,536	1,012,683	1,951	17,002	1,327	2.31
2015	763,604	1,670	1,129,964	2,114	19,376	166	0.19

Table 2. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the EAG golden king crab stock. Observer retained CPUE includes retained and non-retained legal size crabs.

Year	Pot Fishery Nominal Retained CPUE	Obs. Nominal Retained CPUE	Obs. Nominal Total CPUE	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	8.90	2.17	13.00	138	
1991	8.20	17.36	36.91	377	0.74
1992	8.36	10.43	38.52	199	0.57
1993	7.79	5.07	20.82	31	0.48
1994	5.89	2.54	12.91	127	0.55
1995	5.89	5.06	16.98	6,388	0.91
1996	6.45	5.17	13.81	8,360	0.95
1997	7.34	7.13	18.25	4,670	0.99
1998	8.88	9.17	25.77	3,616	1.19
1999	8.96	9.25	20.77	3,851	1.10
2000	9.85	9.92	25.39	5,043	1.13
2001	11.66	11.14	22.48	4,626	1.47
2002	12.37	11.99	22.59	3,980	1.58
2003	10.92	11.02	19.43	3,960	1.37
2004	18.30	17.73	28.48	2,206	2.25
2005	25.40	29.44	38.48	1,193	1.02
2006	24.84	25.20	33.52	1,098	0.82
2007	27.95	31.09	40.37	998	0.96
2008	27.26	29.73	38.18	613	0.93
2009	25.85	26.64	35.89	408	0.76
2010	25.96	26.05	36.76	436	0.77
2011	37.33	38.79	51.69	361	1.13
2012	33.02	38.00	47.74	438	1.09
2013	33.67	35.83	46.16	499	1.05
2014	42.29	46.96	60.00	376	1.37
2015	39.41	43.08	58.75	478	1.31

Table 3. Time series of GLM estimated CPUE indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the EAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data and used in scenario 4.

Year	**CPUE Index**	**CV**
1985/86	1.67	0.05
1986/87	1.22	0.05
1987/88	0.96	0.06
1988/89	1.03	0.05
1989/90	1.04	0.04
1990/91	0.83	0.06
1991/92	0.84	0.06
1992/93	0.93	0.06
1993/94	0.90	0.06
1994/95	0.80	0.07
1995/96	0.77	0.07
1996/97	0.83	0.07
1997/98	1.20	0.05
1998/99	1.36	0.05

Table 4. Iteration process for stage-2 effective sample size determination by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 7 model fit to EAG data. The effective sample sizes are numbers of days for retained and total catch, but number of trips for groundfish discarded catch size compositions. Note: Groundfish bycatch size compositions were not fitted to the model, but different predicted weights resulted from different iterations.

Iteration No.	Retained Size Comp Effective Sample Multiplier (W)	Total Size Comp Effective Sample Multiplier (W)	Groundfish Discard Size Comp Effective Sample Multiplier (W)	Terminal MMB (t)	Retained Catch OFL (t)
1 (start)	0.823	0.549	0.417	11,148	1,759
2	0.821	0.551	0.429	11,148	1,759
3	0.820	0.552	0.429	11,148	1,759

Table 5. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 7 model fit to EAG data. NA: not available.

Year	Initial Input Retained Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985	57	47				
1986	11	9				
1987	61	50				
1988	352	289				
1989	792	650			9	4
1990	163	134	22	12	13	6
1991	140	115	48	26	NA	NA
1992	49	40	41	23	2	1
1993	340	279	NA	NA	2	1
1994	319	262	34	19	4	2
1995	879	721	1,117	616	5	2
1996	547	449	509	281	4	2
1997	538	441	711	392	8	3
1998	541	444	574	317	15	6
1999	463	380	607	335	14	6
2000	436	358	495	273	16	7
2001	488	400	510	281	13	6
2002	406	333	438	242	15	6
2003	405	332	416	229	17	7
2004	280	230	299	165	10	4
2005	266	218	232	128	12	5
2006	234	192	143	79	14	6
2007	199	163	134	74	17	7
2008	197	162	113	62	15	6
2009	170	139	95	52	16	7
2010	183	150	108	60	26	11
2011	160	131	107	59	13	6
2012	187	153	99	55	18	8
2013	193	158	122	67	17	7
2014	168	138	99	55	16	7
2015	190	156	125	69	9	4

Table 6. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by McAllister and Ianelli method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 8 model fit to EAG data. NA: not available.

Year	Initial Input Retained Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985	57	528				
1986	11	337				
1987	61	197				
1988	352	249				
1989	792	275			9	24
1990	163	275	22	37	13	24
1991	140	305	48	68	NA	NA
1992	49	334	41	67	2	18
1993	340	371	NA	NA	2	12
1994	319	378	34	48	4	12
1995	879	408	1,117	58	5	14
1996	547	418	509	68	4	5
1997	538	445	711	78	8	6
1998	541	476	574	89	15	6
1999	463	504	607	99	14	7
2000	436	531	495	108	16	8
2001	488	544	510	115	13	8
2002	406	566	438	122	15	8
2003	405	574	416	129	17	9
2004	280	579	299	136	10	9
2005	266	578	232	144	12	9
2006	234	593	143	153	14	9
2007	199	616	134	160	17	9
2008	197	625	113	169	15	9
2009	170	635	95	176	16	10
2010	183	653	108	183	26	10
2011	160	649	107	190	13	10
2012	187	659	99	197	18	10
2013	193	677	122	202	17	10
2014	168	693	99	209	16	10
2015	190	692	125	210	9	11

Table 7. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 1, 2, 3, and 4 for the golden king crab data from the EAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.53	0.01	2.53	0.01	2.53	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-10.46	0.16	-10.43	0.16	-10.00	0.17	-10.09	0.17	-12.0,-5.0
log_a (molt prob. slope)	-2.54	0.02	-2.51	0.02	-2.57	0.02	-2.56	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.00	4.95	0.00	4.95	0.00	4.95	0.001	3.869,5.05
σ (growth variability std)	3.66	0.03	3.66	0.03	3.67	0.03	3.66	0.03	0.1,12.0
log_total sel deltaθ, 1985-04	3.44	0.02	3.48	0.02	3.39	0.02	3.38	0.02	0.,4.4
log_ total sel deltaθ, 2005-15	2.94	0.03	2.94	0.03	2.95	0.03	2.95	0.03	0.,4.4
log_ ret. sel deltaθ, 1985-15	1.84	0.02	1.83	0.02	1.84	0.02	1.84	0.02	0.,4.4
log_tot sel θ_{50}, 1985-04	4.84	0.00	4.83	0.00	4.86	0.00	4.85	0.002	4.0,5.0
log_tot sel θ_{50}, 2005-15	4.91	0.00	4.91	0.00	4.92	0.00	4.91	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985-15	4.91	0.00	4.91	0.00	4.91	0.00	4.91	0.0005	4.0,5.0
log_β_r (rec.distribution par.)	-0.93	0.13	-0.90	0.14	-0.98	0.14	-0.98	0.14	-12.0, 12.0
logq2 (catchability 1985-04)	-0.54	0.17	-0.42	0.20	-0.50	0.19	-0.53	0.14	-9.0, 2.25
logq3 (catchability 2005-15)	-1.18	0.11	-1.07	0.11	-1.18	0.12	-1.22	0.11	-9.0, 2.25
log_mean_rec (mean rec.)	0.94	0.05	0.63	0.06	0.94	0.05	0.95	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.15	0.06	-1.05	0.06	-1.13	0.06	-1.16	0.06	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.36	0.09	-9.20	0.10	-9.36	0.09	-9.38	0.09	-15.0, -1.6
$?^?_?$ (observer CPUE additional var)	0.02	0.39	0.02	0.40	0.03	0.40	0.03	0.39	0.0, 0.15
$?^?_?$ (fishery CPUE additional var)							0.05	0.42	0.0,1.0
2015 MMB	10,974	0.17	9,604	0.16	11,016	0.18	11,334	0.17	

Table 8. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 5, 6, 7, and 8 for the golden king crab data from the EAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 5		Scenario 6		Scenario 7		Scenario 8		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.53	0.01	2.53	0.01	2.54	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-10.40	0.16	-10.48	0.16	-10.15	0.17	-8.81	0.19	-12.0,-5.0
log_a (molt prob. slope)	-2.54	0.02	-2.56	0.02	-2.52	0.02	-2.51	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.0009	4.95	0.0009	3.869,5.05
σ (growth variability std)	3.67	0.03	3.66	0.03	3.66	0.03	3.67	0.03	0.1,12.0
log_total sel deltaθ, 1985-04	3.45	0.02	3.45	0.02	3.42	0.02	3.36	0.03	0.,4.4
log_ total sel deltaθ, 2005-15	2.92	0.03	2.97	0.03	2.95	0.03	3.01	0.02	0.,4.4
log_ ret. sel deltaθ, 1985-15	1.84	0.02	1.84	0.02	1.83	0.02	1.83	0.02	0.,4.4
log_tot sel θ_{50}, 1985-04	4.84	0.002	4.84	0.002	4.84	0.003	4.82	0.003	4.0,5.0
log_tot sel θ_{50}, 2005-15	4.91	0.002	4.92	0.002	4.91	0.002	4.93	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985-15	4.91	0.0003	4.91	0.0003	4.91	0.0003	4.91	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-0.93	0.13	-0.93	0.13	-0.93	0.17	-0.87	0.17	-12.0, 12.0
logq2 (catchability 1985-04)	-1.11	0.07	0.27	0.51	-0.56	0.17	-0.73	0.17	-9.0, 2.25
logq3 (catchability 2005-15)	-1.62	0.06	-0.40	0.51	-1.20	0.12	-1.10	0.09	-9.0, 2.25
log_mean_rec (mean rec.)	0.95	0.06	0.91	0.05	0.94	0.05	1.00	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.17	0.07	-1.08	0.06	-1.16	0.07	-1.17	0.06	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.39	0.09	-9.30	0.09	-9.36	0.09	-9.36	0.09	-15.0, -1.6
$?^{?}_{?}$ (observer CPUE additional var)	0.03	0.40	0.06	0.38	0.02	0.40	0.02	0.39	0.0, 0.15
2015 MMB	10,756	0.24	9,228	0.14	11,148	0.17	10,997	0.17	

Table 9. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 9, 10 (dome shaped selectivity), 11, and 12 for the golden king crab data from the EAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.01	2.56	0.01	2.53	0.01	2.53	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-10.84	0.15	-9.73	0.18	-10.45	0.16	-10.00	0.17	-12.0, -5.0
log_a (molt prob. slope)	-2.51	0.02	-2.53	0.02	-2.56	0.02	-2.58	0.02	-4.61, -1.39
log_b (molt prob. L50)	4.96	0.001	4.97	0.001	4.95	0.001	4.95	0.001	3.869, 5.05
σ (growth variability std)	3.65	0.03	3.70	0.03	3.66	0.03	3.67	0.03	0.1, 12.0
d1 (incr. dome sel slope 1985–04)			0.08	0.10					0.01,1.0
d2 (decr. dome sel slope 1985–04)			-0.08	0.18					-1.0,-0.1
d3 (incr. dome sel slope 2005–15)			0.18	0.05					0.01,1.0
d4 (decr. dome sel slope 2005–15)			-0.05	0.20					-1.0,0.01
log_total sel deltaθ, 1985–94	3.46	0.06							0., 4.4
log_total sel deltaθ, 1985–04 or 1995–04	3.51	0.02			3.45	0.02	3.46	0.02	0., 4.4
log_ total sel deltaθ, 2005–15	2.96	0.03			2.96	0.03	2.94	0.02	0., 4.4
log_ ret. sel deltaθ, 1985–15	1.83	0.02	1.87	0.04	1.84	0.02	1.84	0.02	0., 4.4
log_tot sel θ_{50}, 1985–94	4.73	0.01							4.0, 5.0
log_tot sel θ_{50}, 1985–04 or 1995–04	4.86	0.003	4.96	0.01	4.84	0.002	4.85	0.002	4.0, 5.0
log_tot sel θ_{50}, 2005–15	4.92	0.002	4.96	0.002	4.92	0.002	4.92	0.002	4.0, 5.0
log_tot sel θ_{95}, 1985–04			4.96	0.01					4.9, 5.3
log_tot sel θ_{95}, 2005–15			-5.90	65.35					-6.0,5.3
log_ret. sel θ_{50}, 1985-–15	4.91	0.0002	4.92	0.0003	4.91	0.0003	4.91	0.0003	4.0, 5.0
log_β_r (rec.distribution par.)	-0.90	0.14	-0.87	0.14	-0.94	0.13	-0.87	0.14	-12.0, 12.0
Logq1 (catchability 1985–94)	-1.06	0.15							-9.0, 2.25
logq2 (catchability 1985–04 or 1995–04)	-0.26	0.41	-1.00	0.14	-0.66	0.13	-0.48	0.18	-9.0, 2.25
logq3 (catchability 2005–15)	-1.02	0.12	-1.48	0.10	-1.10	0.11	-1.13	0.11	-9.0, 2.25
log_mean_rec (mean rec.)	0.89	0.05	1.07	0.08	0.92	0.05	0.93	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.05	0.07	-1.39	0.07	-1.10	0.06	-1.10	0.06	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.23	0.10	-9.70	0.09	-9.33	0.09	-9.34	0.09	-15.0, -1.6
?? (CPUE additional var)	0.02	0.36	0.04	0.42	0.02	0.37	0.02	0.38	0.0, 0.15
2015 MMB	9,976	0.15	14,082	0.21	10,627	0.15	10,999	0.16	

Table 10. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 1 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq}=19,462 MMB_{35}=6,558			
1985	1.81			9,973	0.05
1986	1.06	8,756	0.04	8,375	0.04
1987	2.58	6,726	0.04	6,436	0.04
1988	5.63	5,440	0.04	5,291	0.04
1989	1.59	4,491	0.07	4,378	0.06
1990	2.91	4,720	0.07	4,325	0.06
1991	3.40	4,828	0.07	4,618	0.06
1992	2.73	4,658	0.05	4,464	0.05
1993	1.96	4,718	0.05	4,462	0.05
1994	2.65	5,184	0.04	4,928	0.04
1995	2.51	4,645	0.04	4,467	0.04
1996	2.36	4,163	0.05	3,966	0.04
1997	3.24	4,410	0.05	4,205	0.05
1998	3.32	4,610	0.06	4,433	0.05
1999	3.20	5,286	0.06	5,055	0.06
2000	3.38	6,244	0.07	5,974	0.06
2001	2.48	7,089	0.07	6,817	0.07
2002	2.96	7,915	0.08	7,601	0.07
2003	2.67	8,376	0.08	8,118	0.08
2004	2.14	8,795	0.08	8,507	0.08
2005	3.36	9,058	0.09	8,751	0.09
2006	2.63	8,934	0.09	8,688	0.09
2007	2.50	9,270	0.09	8,928	0.09
2008	3.72	9,427	0.09	9,095	0.09
2009	3.25	9,408	0.10	9,131	0.10
2010	2.41	9,955	0.10	9,586	0.10
2011	3.22	10,436	0.10	10,040	0.10
2012	3.40	10,388	0.11	10,076	0.10
2013	2.97	10,538	0.12	10,197	0.11
2014	3.24	10,826	0.13	10,436	0.13
2015	3.23	10,930	0.15	10,566	0.14
2016	2.56	10,974	0.17		

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 2 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =20,791 MMB_{35}=7,240			
1985	1.51			9,350	0.05
1986	0.87	8,856	0.07	7,897	0.04
1987	2.26	6,875	0.07	6,093	0.04
1988	4.83	5,899	0.07	5,059	0.04
1989	1.30	5,120	0.09	4,198	0.06
1990	2.48	4,849	0.08	4,073	0.06
1991	2.87	4,839	0.09	4,356	0.06
1992	2.29	4,633	0.09	4,190	0.05
1993	1.65	4,904	0.09	4,143	0.04
1994	2.20	5,423	0.06	4,611	0.03
1995	2.05	5,008	0.06	4,166	0.03
1996	1.90	4,577	0.07	3,625	0.04
1997	2.57	4,314	0.08	3,806	0.04
1998	2.59	4,419	0.08	3,954	0.05
1999	2.46	4,905	0.09	4,433	0.05
2000	2.57	5,448	0.09	5,183	0.05
2001	1.87	6,117	0.09	5,861	0.06
2002	2.25	6,638	0.09	6,504	0.06
2003	2.01	6,940	0.10	6,970	0.07
2004	1.59	7,581	0.10	7,330	0.07
2005	2.52	7,753	0.11	7,574	0.07
2006	1.95	7,445	0.12	7,550	0.08
2007	1.87	7,568	0.12	7,752	0.08
2008	2.81	7,718	0.13	7,910	0.08
2009	2.43	7,832	0.13	7,948	0.08
2010	1.81	8,013	0.13	8,341	0.09
2011	2.45	8,146	0.13	8,759	0.09
2012	2.61	9,297	0.14	8,839	0.10
2013	2.26	10,094	0.14	8,988	0.11
2014	2.43	11,018	0.14	9,250	0.12
2015	2.32	10,178	0.15	9,418	0.14
2016	1.88	9,126	0.17		

Table 12. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 5 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMBeq =19,697 MMB35=6,593			
1985	1.80			10,012	0.05
1986	1.06	8,779	0.04	8,391	0.04
1987	2.57	6,731	0.04	6,436	0.04
1988	5.62	5,439	0.04	5,284	0.04
1989	1.61	4,483	0.07	4,365	0.06
1990	2.95	4,705	0.07	4,306	0.06
1991	3.43	4,821	0.07	4,605	0.06
1992	2.72	4,674	0.06	4,473	0.05
1993	1.92	4,750	0.05	4,486	0.05
1994	2.66	5,210	0.04	4,947	0.04
1995	2.52	4,640	0.04	4,461	0.04
1996	2.40	4,154	0.05	3,953	0.05
1997	3.33	4,414	0.05	4,203	0.05
1998	3.47	4,644	0.06	4,462	0.06
1999	3.34	5,389	0.07	5,148	0.06
2000	3.56	6,448	0.07	6,162	0.07
2001	2.61	7,399	0.08	7,108	0.08
2002	3.09	8,340	0.08	8,001	0.08
2003	2.78	8,887	0.09	8,605	0.09
2004	2.22	9,371	0.10	9,057	0.09
2005	3.43	9,671	0.10	9,338	0.10
2006	2.76	9,553	0.10	9,281	0.10
2007	2.63	9,877	0.11	9,510	0.10
2008	3.80	10,048	0.11	9,687	0.11
2009	3.14	10,052	0.11	9,741	0.11
2010	2.40	10,583	0.12	10,178	0.12
2011	3.15	10,937	0.13	10,522	0.13
2012	3.21	10,782	0.14	10,449	0.14
2013	2.82	10,809	0.16	10,445	0.16
2014	3.10	10,910	0.18	10,511	0.18
2015	3.26	10,844	0.21	10,473	0.21
2016	2.59	10,756	0.24		

Table 13. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with coefficient of variation (CV) for scenario 6 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=18,135 MMB_{35}=6,219			
1985	1.82			9,901	0.05
1986	1.05	8,716	0.04	8,340	0.04
1987	2.58	6,709	0.04	6,423	0.04
1988	5.68	5,431	0.04	5,285	0.04
1989	1.58	4,491	0.07	4,379	0.06
1990	2.86	4,741	0.07	4,343	0.06
1991	3.36	4,850	0.06	4,639	0.06
1992	2.72	4,657	0.05	4,466	0.05
1993	2.03	4,688	0.05	4,436	0.05
1994	2.63	5,143	0.04	4,893	0.04
1995	2.49	4,636	0.04	4,457	0.04
1996	2.32	4,155	0.05	3,959	0.04
1997	3.14	4,386	0.05	4,183	0.05
1998	3.16	4,550	0.05	4,376	0.05
1999	3.02	5,153	0.06	4,927	0.06
2000	3.16	5,994	0.06	5,737	0.06
2001	2.31	6,709	0.07	6,453	0.06
2002	2.77	7,394	0.07	7,102	0.07
2003	2.55	7,750	0.07	7,513	0.07
2004	2.04	8,080	0.08	7,817	0.07
2005	3.23	8,301	0.08	8,018	0.08
2006	2.45	8,171	0.08	7,947	0.08
2007	2.31	8,493	0.08	8,175	0.08
2008	3.32	8,605	0.08	8,304	0.08
2009	2.97	8,514	0.09	8,266	0.09
2010	2.21	8,884	0.09	8,562	0.09
2011	2.86	9,228	0.09	8,881	0.09
2012	3.02	9,111	0.09	8,838	0.09
2013	2.63	9,138	0.10	8,845	0.10
2014	2.91	9,281	0.11	8,948	0.10
2015	3.12	9,265	0.12	8,960	0.12
2016	2.48	9,228	0.14		

Table 14. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 7 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=19,430 MMB_{35}=6,541			
1985	1.83			10,008	0.06
1986	1.10	8,730	0.05	8,376	0.04
1987	2.54	6,702	0.04	6,433	0.04
1988	5.58	5,439	0.05	5,301	0.04
1989	1.64	4,481	0.07	4,385	0.06
1990	2.87	4,690	0.07	4,329	0.07
1991	3.51	4,818	0.07	4,632	0.07
1992	2.68	4,646	0.06	4,481	0.05
1993	2.08	4,764	0.06	4,527	0.05
1994	2.56	5,235	0.04	5,010	0.04
1995	2.46	4,750	0.04	4,586	0.04
1996	2.27	4,225	0.05	4,051	0.05
1997	3.25	4,424	0.05	4,242	0.05
1998	3.21	4,565	0.06	4,417	0.06
1999	3.22	5,227	0.07	5,021	0.06
2000	3.37	6,134	0.07	5,902	0.07
2001	2.45	6,984	0.08	6,746	0.07
2002	2.99	7,820	0.08	7,539	0.08
2003	2.72	8,284	0.09	8,060	0.08
2004	2.16	8,736	0.09	8,478	0.09
2005	3.31	9,045	0.09	8,764	0.09
2006	2.74	8,947	0.10	8,724	0.10
2007	2.46	9,272	0.10	8,966	0.10
2008	3.79	9,487	0.10	9,178	0.10
2009	3.25	9,472	0.11	9,225	0.11
2010	2.51	10,061	0.11	9,718	0.11
2011	3.31	10,558	0.11	10,197	0.11
2012	3.53	10,566	0.11	10,280	0.11
2013	2.98	10,788	0.12	10,470	0.12
2014	3.03	11,157	0.13	10,787	0.13
2015	2.92	11,259	0.15	10,915	0.15
2016	2.56	11,148	0.17		

Table 15. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 8 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=19,889 MMB_{35}=6,589			
1985	2.35			8,975	0.05
1986	1.17	8,239	0.05	7,872	0.05
1987	3.15	6,759	0.05	6,447	0.05
1988	4.09	5,723	0.05	5,584	0.05
1989	2.11	5,014	0.06	4,825	0.05
1990	2.72	4,643	0.06	4,327	0.05
1991	3.46	4,773	0.05	4,565	0.05
1992	3.27	4,542	0.05	4,359	0.05
1993	2.10	4,636	0.06	4,396	0.05
1994	2.52	5,411	0.05	5,130	0.04
1995	1.91	5,023	0.05	4,825	0.04
1996	2.34	4,424	0.05	4,217	0.05
1997	3.29	4,284	0.06	4,121	0.05
1998	2.91	4,346	0.06	4,192	0.06
1999	3.37	5,009	0.07	4,773	0.06
2000	3.62	5,772	0.07	5,542	0.06
2001	2.48	6,682	0.07	6,427	0.07
2002	3.47	7,710	0.07	7,390	0.07
2003	3.05	8,280	0.08	8,043	0.07
2004	2.06	9,040	0.08	8,739	0.07
2005	3.54	9,618	0.08	9,281	0.07
2006	3.12	9,507	0.08	9,269	0.08
2007	2.31	9,914	0.08	9,576	0.08
2008	4.35	10,302	0.08	9,928	0.08
2009	2.77	10,196	0.08	9,934	0.08
2010	2.38	10,954	0.09	10,526	0.09
2011	3.39	11,179	0.09	10,795	0.09
2012	3.29	10,934	0.10	10,635	0.10
2013	2.77	11,048	0.11	10,686	0.11
2014	3.12	11,209	0.13	10,810	0.13
2015	3.55	11,104	0.15	10,750	0.15
2016	2.44	10,997	0.17		

Table 16. Negative log-likelihood values of the fits for scenarios (Sc) 1 (base), 2 (M=0.18yr^{-1}), 3 (truncated total size comp and catch), 4 (added fish ticket CPUE likelihood), 5 (CPUE is related to square root of exploitable abundance), 6 (CPUE is related to square of exploitable abundance), 7 (Francis reweighting), 8 (McAllister and Ianelli reweighting), and 9 (three catchability and total selectivity parameter sets) for golden king crab in the EAG. Differences in likelihood values are given for scenarios with the same number of data points and free parameters (base). Likelihood components with zero entry in the entire rows are omitted. Grey highlighted values are minima for scenarios with comparable base number of data points. RetdcatchB= retained catch biomass. q = catchability.

Likelihood Component	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 5**	**Sc 6**	**Sc 7**	**Sc 8**	**Sc9**	**Sc2– Sc 1**	**Sc 3 – Sc 1**	**Sc 5 – Sc 1**	**Sc 6 – Sc 1**	**Sc 7 – Sc 1**	**Sc 8 – Sc 1**
Number of free parameters	137	137	137	138	137	137	137	137	140						
Data	base	base	base	base+ fishery CPUE	base	base	base	base	Three q and total select.						
Retlencomp	-1161.92	-1160.37	-1167.75	-1167.74	-1162.19	-1161.48	-1139.56	-1270.56	-1167.73	1.55	-5.83	-0.27	0.44	22.36	-108.64
Totallencomp	-1304.48	-1305.93	-1101.07	-1100.50	-1304.84	-1304.28	-1212.52	-1244.93	-1310.93	-1.45	203.41	-0.36	0.2	91.96	59.55
Observer cpue	-5.72	-5.71	-2.87	-3.43	-4.34	1.54	-6.09	-4.21	-11.99	0.01	2.85	1.38	7.26	-0.37	1.51
RetdcatchB	8.16	8.35	5.13	5.46	8.17	8.10	7.04	4.52	8.17	0.19	-3.03	0.01	-0.06	-1.12	-3.64
TotalcatchB	23.15	23.10	12.59	12.79	23.06	23.52	21.89	18.22	22.46	-0.05	-10.56	-0.09	0.37	-1.26	-4.93
GdiscdcatchB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rec_dev	6.20	8.66	6.67	6.51	6.25	5.54	5.87	8.81	5.54	2.46	0.47	0.05	-0.66	-0.33	2.61
Pot F_dev	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.00	0.00	0.00	-0.01	0.00	-0.01
Gbyc_F_dev	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00
Tag	2691.27	2691.48	2690.10	2690.06	2691.05	2691.66	2690.62	2689.86	2697.01	0.21	-1.17	-0.22	0.39	-0.65	-1.41
Fishery cpue	-	-	-	-0.21	-	-	-	-							
Total	256.71	259.64	442.84	443.00	257.21	264.63	367.30	201.79	242.58	2.93	186.13	0.5	7.92	110.59	-54.92

Table 17. Time series of annual retained catch (number and weight of crabs), estimated total male catch (number and weight of crabs on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crabs) (handling mortality rates of 50% for pot and 80% for trawl gear were applied, only to the male portion) for the WAG golden king crab stock. The crab numbers are for the size range ≥ 101mm CL. NA: no observer sampling to compute catch.

Year	Retained Catch (no.)	Retained Catch Biomass (t)	Total Catch (no.)	Total Catch Biomass (t)	Pot Fishery Effort (no. pot lifts)	Groundfish Discard Mortality (no.)	Ground-fish Discard Mortality (t)
1981	38,436						
1982	1,114,351						
1983	1,288,357						
1984	188,782						
1985	981,949	2,010			118,563		
1986	2,052,652	4,230			277,780		
1987	1,248,732	2,514			160,229		
1988	1,285,914	2,454			166,409		
1989	1,610,281	3,047			202,541	51	0.08
1990	889,017	1,630	2,753,326	3,691	108,533	374	0.57
1991	747,852	1,355	1,827,434	2,572	101,429	16	0.03
1992	543,541	1,025	1,113,229	1,520	69,443	318	0.43
1993	352,339	665	2,001,547	2,822	127,764	NA	NA
1994	845,058	1,617	3,634,246	4,953	195,138	82	0.12
1995	619,636	1,185	1,567,028	2,132	115,248	628	0.71
1996	652,801	1,231	1,269,315	1,767	99,267	559	1.04
1997	558,446	1,062	1,236,592	1,799	86,811	211	0.37
1998	505,407	931	782,551	1,087	35,975	1,182	1.85
1999	658,377	1,235	1,467,177	2,093	107,040	1,091	1.42
2000	723,794	1,378	1,612,997	2,233	101,239	692	0.80
2001	686,738	1,282	1,503,857	2,138	105,512	303	0.43
2002	664,823	1,214	1,335,068	1,893	78,979	700	0.92
2003	676,633	1,245	1,192,551	1,862	66,236	200	0.31
2004	685,465	1,262	1,249,016	1,880	56,846	699	0.95
2005	639,368	1,230	1,079,095	1,780	30,116	1,798	3.46
2006	523,701	1,048	894,219	1,547	26,870	1,311	2.28
2007	600,595	1,230	965,889	1,609	29,950	943	1.50
2008	587,661	1,208	997,465	1,730	26,200	3,979	6.45
2009	628,332	1,333	900,797	1,676	26,489	2,173	4.31
2010	626,246	1,338	868,127	1,588	29,994	1,056	2.48
2011	616,118	1,332	817,532	1,514	26,326	1,576	2.25
2012	672,916	1,404	1,000,311	1,822	32,716	2,216	3.74
2013	686,883	1,440	1,037,749	1,901	41,835	2,569	3.85
2014	635,312	1,257	935,794	1,591	41,548	1,635	2.46
2015	confidential	confidential	confidential	confidential	confidential	978	1.42

Table 18. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the WAG golden king crab stock. Observer retained CPUE includes retained and non-retained legal size crabs.

Year	Pot Fishery Nominal Retained CPUE	Obs. Nominal Retained CPUE	Obs. Nominal Total CPUE	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	6.98	11.83	26.67	340	
1991	7.43	7.78	19.17	857	0.77
1992	5.90	6.39	16.83	690	0.94
1993	4.43	6.54	17.23	174	0.96
1994	4.08	6.71	19.23	1,270	1.06
1995	4.65	4.96	14.28	5,598	1.24
1996	6.07	5.42	13.54	7,194	0.99
1997	6.56	6.52	15.03	3,985	1.00
1998	11.40	9.41	23.09	1,876	1.11
1999	6.32	5.93	14.49	4,523	0.93
2000	6.97	6.40	16.64	4,740	0.88
2001	6.51	5.99	14.66	4,454	0.84
2002	8.42	7.47	17.37	2,509	0.94
2003	10.22	9.29	18.17	3,334	1.18
2004	12.06	11.14	22.45	2,619	1.29
2005	21.23	23.89	36.23	1,365	1.18
2006	19.64	24.01	33.47	1,183	1.10
2007	20.05	21.04	32.46	1,082	1.00
2008	22.43	24.57	38.16	979	1.15
2009	23.72	26.55	34.08	892	1.23
2010	20.88	22.35	29.05	867	1.08
2011	23.40	23.79	31.13	837	1.11
2012	20.57	22.82	30.76	1,109	1.07
2013	16.42	16.96	25.01	1,223	0.81
2014	15.29	15.28	22.67	1,137	0.72
2015	confidential	confidential	confidential	confidential	confidential

Table 19. Time series of GLM estimated CPUE indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data and used in scenario 4.

Year	**CPUE Index**	**CV**
1985	2.02	0.03
1986	1.72	0.03
1987	1.21	0.04
1988	1.35	0.03
1989	1.14	0.03
1990	0.87	0.04
1991	0.72	0.06
1992	0.72	0.06
1993	0.68	0.08
1994	0.82	0.05
1995	0.88	0.05
1996	0.84	0.04
1997	0.77	0.04
1998	1.05	0.04

Table 20. Iteration process for stage-2 effective sample size determination by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 7 model fit to WAG data. The effective sample sizes are numbers of days for retained and total catch, but number of trips for groundfish discarded catch size compositions. Note: Groundfish bycatch size compositions were not fitted to the model, but different predicted weights resulted from different iterations.

Iteration No.	Retained Size Comp Effective Sample Multiplier (W)	Total Size Comp Effective Sample Multiplier (W)	Groundfish Discard Size Comp Effective Sample Multiplier (W)	Terminal MMB (t)	Retained Catch OFL (t)
1 (start)	0.500	0.442	0.745	3,934	560
2	0.499	0.443	0.744	3,933	560

Table 21. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 7 model fit to WAG data. NA: not available.

Year	Initial Input Retained Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985	45	22				
1986	23	11				
1987	8	4				
1988	286	143				
1989	513	256			7	5
1990	205	102	190	84	6	4
1991	102	51	104	46	1	1
1992	76	38	94	42	3	2
1993	378	189	62	27	NA	NA
1994	367	183	119	53	2	1
1995	705	352	907	402	5	4
1996	817	407	1,061	470	8	6
1997	984	491	1,116	494	6	4
1998	613	306	638	283	14	10
1999	915	456	1,155	512	18	13
2000	1,029	513	1,205	534	11	8
2001	898	448	975	432	11	8
2002	628	313	675	299	16	12
2003	688	343	700	310	8	6
2004	449	224	488	216	9	7
2005	337	168	220	97	6	4
2006	337	168	321	142	14	10
2007	276	138	257	114	17	13
2008	318	159	258	114	19	14
2009	362	181	292	129	24	18
2010	328	164	222	98	13	10
2011	295	147	252	112	14	10
2012	288	144	241	107	18	13
2013	327	163	236	105	17	13
2014	305	152	219	97	18	13
2015	287	143	243	108	10	7

Table 22. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by McAllister and Ianelli method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 8 model fit to WAG data. NA: not available.

Year	Initial Input Retained Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985	45	443				
1986	23	383				
1987	8	403				
1988	286	468				
1989	513	494			7	16
1990	205	399	190	108	6	17
1991	102	401	104	101	1	5
1992	76	389	94	112	3	6
1993	378	409	62	115	NA	NA
1994	367	440	119	122	2	5
1995	705	476	907	132	5	5
1996	817	499	1,061	151	8	5
1997	984	513	1,116	167	6	5
1998	613	539	638	179	14	6
1999	915	547	1,155	193	18	6
2000	1,029	574	1,205	205	11	7
2001	898	586	975	211	11	8
2002	628	606	675	214	16	8
2003	688	619	700	186	8	8
2004	449	603	488	188	9	9
2005	337	625	220	196	6	9
2006	337	639	321	205	14	9
2007	276	641	257	208	17	10
2008	318	637	258	215	19	10
2009	362	618	292	223	24	10
2010	328	614	222	228	13	10
2011	295	601	252	233	14	11
2012	288	616	241	237	18	11
2013	327	616	236	244	17	11
2014	305	630	219	247	18	12
2015	287	637	243	251	10	12

Table 23. Parameter estimates and standard deviations with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 1, 2, 3, and 4 for the golden king crab data from the WAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.53	0.01	2.53	0.01	2.53	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-9.30	0.18	-9.43	0.18	-8.71	0.20	-9.45	0.18	-12.0,-5.0
log_a (molt prob. slope)	-2.76	0.02	-2.72	0.02	-2.77	0.02	-2.75	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.67	0.03	3.67	0.03	3.68	0.03	3.67	0.03	0.1,12.0
log_total sel deltaθ, 1985-04	3.46	0.01	3.51	0.01	3.42	0.01	3.46	0.01	0.,4.4
log_ total sel deltaθ, 2005-15	2.90	0.02	2.90	0.02	2.90	0.02	2.89	0.02	0.,4.4
log_ ret. sel deltaθ, 1985-15	1.78	0.02	1.78	0.02	1.78	0.02	1.78	0.02	0.,4.4
log_tot sel θ_{50}, 1985-04	4.88	0.002	4.87	0.002	4.88	0.002	4.88	0.002	4.0,5.0
log_tot sel θ_{50}, 2005-15	4.90	0.001	4.90	0.001	4.90	0.001	4.90	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985-15	4.92	0.0002	4.92	0.0002	4.92	0.0002	4.92	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-0.99	0.11	-0.95	0.12	-1.06	0.10	-0.99	0.11	-12.0, 12.0
logq2 (catchability 1985-04)	0.15	0.44	0.21	0.30	0.15	0.44	0.06	1.23	-9.0, 2.25
logq3 (catchability 2005-15)	-0.41	0.19	-0.33	0.22	-0.42	0.20	-0.44	0.19	-9.0, 2.25
log_mean_rec (mean rec.)	0.73	0.06	0.46	0.08	0.74	0.06	0.74	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.65	0.08	-0.60	0.09	-0.66	0.08	-0.67	0.08	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.37	0.11	-8.25	0.11	-8.38	0.11	-8.38	0.11	-15.0, -1.6
$?_?^?$ (observer CPUE additional var)	0.02	0.34	0.01	0.33	0.02	0.34	0.02	0.36	0.0, 0.15
$?_?^?$ (fishery CPUE additional var)							0.05	0.54	0.0,1.0
2015 MMB	3,739	0.15	3,246	0.15	3,797	0.16	3,808	0.16	

Table 24. Parameter estimates and standard deviations with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 5, 6, 7, and 8 for the golden king crab data from the WAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.53	0.01	2.53	0.01	2.54	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-9.35	0.18	-9.25	0.19	-9.39	0.19	-7.82	0.22	-12.0,-5.0
log_a (molt prob. slope)	-2.75	0.02	-2.77	0.02	-2.65	0.03	-2.71	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.67	0.03	3.67	0.03	3.67	0.03	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985-04	3.46	0.01	3.46	0.01	3.44	0.02	3.33	0.02	0.,4.4
log_ total sel deltaθ, 2005-15	2.89	0.02	2.90	0.02	2.91	0.03	2.87	0.02	0.,4.4
log_ ret. sel deltaθ, 1985-15	1.78	0.02	1.78	0.02	1.76	0.03	1.79	0.02	0.,4.4
log_tot sel θ_{50}, 1985-04	4.88	0.002	4.88	0.002	4.87	0.003	4.87	0.002	4.0,5.0
log_tot sel θ_{50}, 2005-15	4.90	0.001	4.90	0.001	4.90	0.002	4.90	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985-15	4.92	0.0002	4.92	0.0002	4.91	0.0003	4.91	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-0.99	0.11	-0.99	0.11	-0.93	0.15	-1.07	0.15	-12.0, 12.0
logq2 (catchability 1985-04)	-0.77	0.06	1.51	0.06	0.06	1.22	0.03	1.88	-9.0, 2.25
logq3 (catchability 2005-15)	-1.16	0.04	0.70	0.20	-0.43	0.23	-0.47	0.16	-9.0, 2.25
log_mean_rec (mean rec.)	0.71	0.06	0.75	0.06	0.76	0.06	0.65	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.65	0.08	-0.66	0.09	-0.72	0.09	-0.72	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.35	0.11	-8.38	0.11	-8.38	0.11	-8.39	0.11	-15.0, -1.6
?$^?_?$ (observer CPUE additional var)	0.01	0.33	0.05	0.35	0.02	0.36	0.01	0.36	0.0, 0.15
2015 MMB	2,696	0.20	4,543	0.14	3,933	0.16	3,826	0.15	

Table 25. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 9, 10 (dome shaped selectivity), 11, and 12 for the golden king crab data from the WAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.01	2.61	0.01	2.53	0.01	2.53	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-9.68	0.17	-9.09	0.19	-9.31	0.18	-9.86	0.17	-12.0, -5.0
log_a (molt prob. slope)	-2.67	0.02	-2.52	0.02	-2.76	0.02	-2.71	0.02	-4.61, -1.39
log_b (molt prob. L50)	4.97	0.001	5.01	0.002	4.95	0.001	4.95	0.001	3.869, 5.05
σ (growth variability std)	3.66	0.03	3.73	0.03	3.67	0.03	3.66	0.03	0.1, 12.0
d1 (incr. dome sel slope 1985–04)			0.07	0.05					0.01,1.0
d2 (decr. dome sel slope 1985–04)			-0.17	0.04					-1.0,-0.1
d3 (incr. dome sel slope 2005–15)			0.22	0.04					0.01,1.0
d4 (decr. dome sel slope 2005–15)			-0.09	0.11					-1.0,0.01
log_total sel deltaθ, 1985–94	3.44	0.04							0., 4.4
log_total sel deltaθ, 1985–04 or 1995–04	3.51	0.01			3.46	0.01	3.46	0.01	0., 4.4
log_ total sel deltaθ, 2005–15	2.88	0.02			2.90	0.02	2.88	0.02	0., 4.4
log_ ret. sel deltaθ, 1985–15	1.78	0.02	1.88	0.02	1.78	0.02	1.78	0.02	0., 4.4
log_tot sel θ_{50}, 1985–94	4.78	0.004							4.0, 5.33
log_tot sel θ_{50}, 1985–04 or 1995–04	4.90	0.003	5.32	0.02	4.88	0.002	4.87	0.002	4.0, 5.33
log_tot sel θ_{50}, 2005–15	4.90	0.001	4.94	0.001	4.90	0.001	4.90	0.001	4.0, 5.0
log_tot sel θ_{95}, 1985–04			4.95	0.001					4.9, 5.3
log_tot sel θ_{95}, 2005–15			-5.77	214.85					-6.0,5.3
log_ret. sel θ_{50}, 1985—15	4.92	0.0002	4.92	0.0002	4.92	0.0002	4.92	0.0002	4.0, 5.0
log_β_r (rec.distribution par.)	-0.94	0.11	-0.76	0.12	-0.99	0.11	-0.95	0.11	-12.0, 12.0
Logq1 (catchability 1985–94)	-0.07	1.34							-9.0, 2.25
logq2 (catchability 1985–04 or 1995–04)	0.33	0.25	-1.36	0.46	0.13	0.52	0.09	0.71	-9.0, 2.25
logq3 (catchability 2005–15)	-0.36	0.22	-1.66	0.32	-0.40	0.20	-0.48	0.17	-9.0, 2.25
log_mean_rec (mean rec.)	0.70	0.06	1.66	0.29	0.73	0.06	0.73	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.65	0.08	-1.85	0.29	-0.65	0.08	-0.71	0.08	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.29	0.11	-10.05	0.11	-8.37	0.11	-8.39	0.11	-15.0, -1.6
$?^{?}_{?}$ (CPUE additional var)	0.02	0.34	0.05	0.37	0.02	0.36	0.02	0.34	0.0, 0.15
2015 MMB	3,415	0.15	28,625	0.65	3,725	0.15	3,650	0.15	

Table 26. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =13,162 MMB_{35}=4,758			
1985	2.76			10,132	0.07
1986	3.93	9,885	0.05	9,435	0.05
1987	2.93	6,719	0.05	6,362	0.05
1988	1.75	6,184	0.05	5,745	0.04
1989	2.58	5,439	0.04	5,028	0.04
1990	2.20	3,382	0.05	3,120	0.05
1991	1.70	3,134	0.05	2,864	0.05
1992	1.84	3,134	0.05	2,865	0.04
1993	1.53	3,272	0.05	3,050	0.04
1994	1.93	3,768	0.03	3,547	0.03
1995	2.01	2,953	0.04	2,762	0.03
1996	1.70	2,877	0.04	2,671	0.03
1997	1.93	2,960	0.04	2,729	0.03
1998	1.83	3,001	0.04	2,793	0.03
1999	2.18	3,299	0.03	3,079	0.03
2000	2.40	3,214	0.04	3,001	0.03
2001	2.29	3,215	0.04	2,982	0.04
2002	2.68	3,505	0.04	3,240	0.04
2003	2.79	3,892	0.05	3,628	0.05
2004	1.76	4,460	0.05	4,166	0.05
2005	2.41	5,059	0.05	4,719	0.05
2006	2.65	5,178	0.06	4,918	0.05
2007	1.90	5,621	0.05	5,344	0.05
2008	1.43	6,005	0.05	5,669	0.05
2009	1.97	6,018	0.05	5,722	0.04
2010	1.80	5,542	0.05	5,320	0.04
2011	1.18	5,255	0.05	5,008	0.04
2012	1.71	4,943	0.05	4,682	0.05
2013	2.34	4,255	0.06	4,062	0.05
2014	1.33	3,765	0.07	3,569	0.07
2015	1.95	3,870	0.11	3,590	0.11
2016	2.08	3,739	0.15		

Table 27. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 2 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMBeq =14,999 MMB35=5,435			
1985	2.18			9,510	0.07
1986	3.42	9,192	0.05	8,942	0.05
1987	2.46	6,157	0.05	5,959	0.04
1988	1.46	5,706	0.05	5,411	0.04
1989	2.17	5,056	0.04	4,773	0.04
1990	1.81	3,109	0.05	2,930	0.05
1991	1.39	2,851	0.05	2,663	0.04
1992	1.54	2,821	0.05	2,636	0.04
1993	1.28	2,947	0.04	2,806	0.04
1994	1.61	3,451	0.03	3,318	0.03
1995	1.67	2,697	0.03	2,575	0.03
1996	1.40	2,623	0.03	2,488	0.03
1997	1.61	2,691	0.03	2,536	0.03
1998	1.54	2,726	0.03	2,591	0.03
1999	1.81	3,015	0.03	2,875	0.03
2000	1.99	2,946	0.03	2,809	0.03
2001	1.87	2,927	0.04	2,773	0.03
2002	2.18	3,168	0.04	2,991	0.04
2003	2.19	3,497	0.05	3,330	0.04
2004	1.38	3,988	0.05	3,803	0.04
2005	1.87	4,482	0.05	4,273	0.05
2006	2.10	4,580	0.05	4,440	0.05
2007	1.49	4,971	0.05	4,826	0.05
2008	1.13	5,314	0.05	5,123	0.04
2009	1.59	5,357	0.04	5,197	0.04
2010	1.45	4,963	0.04	4,859	0.04
2011	0.94	4,726	0.04	4,594	0.04
2012	1.39	4,462	0.04	4,312	0.04
2013	1.84	3,847	0.05	3,745	0.05
2014	1.01	3,377	0.07	3,265	0.07
2015	1.51	3,415	0.10	3,235	0.10
2016	1.58	3,246	0.15		

Table 28. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 5 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMBeq =12,623 MMB35=4,605			
1985	2.75			10,172	0.07
1986	3.93	9,928	0.05	9,463	0.05
1987	2.91	6,746	0.05	6,379	0.05
1988	1.76	6,204	0.05	5,755	0.04
1989	2.63	5,450	0.04	5,029	0.04
1990	2.20	3,391	0.05	3,123	0.05
1991	1.72	3,167	0.05	2,886	0.05
1992	1.80	3,172	0.05	2,895	0.04
1993	1.49	3,313	0.05	3,081	0.04
1994	1.95	3,787	0.03	3,560	0.03
1995	2.01	2,944	0.04	2,752	0.03
1996	1.70	2,870	0.04	2,659	0.03
1997	1.95	2,957	0.04	2,721	0.03
1998	1.85	3,006	0.04	2,791	0.03
1999	2.22	3,315	0.03	3,088	0.03
2000	2.48	3,250	0.04	3,029	0.03
2001	2.39	3,283	0.04	3,040	0.04
2002	2.77	3,622	0.05	3,343	0.04
2003	2.80	4,070	0.05	3,789	0.05
2004	1.81	4,692	0.05	4,376	0.05
2005	2.39	5,299	0.05	4,944	0.05
2006	2.64	5,421	0.06	5,146	0.05
2007	1.83	5,834	0.05	5,546	0.05
2008	1.38	6,172	0.05	5,825	0.05
2009	1.87	6,111	0.04	5,808	0.04
2010	1.67	5,558	0.04	5,332	0.04
2011	1.07	5,178	0.04	4,931	0.04
2012	1.50	4,757	0.05	4,502	0.04
2013	1.78	3,970	0.05	3,783	0.05
2014	0.97	3,325	0.08	3,139	0.08
2015	1.64	3,103	0.13	2,870	0.13
2016	2.04	2,696	0.20		

Table 29. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 6 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=13,580 MMB_{35}=4,827			
1985	2.77			10,111	0.07
1986	3.92	9,862	0.05	9,420	0.05
1987	2.94	6,706	0.05	6,353	0.05
1988	1.76	6,173	0.05	5,741	0.04
1989	2.55	5,437	0.04	5,031	0.04
1990	2.18	3,387	0.05	3,127	0.05
1991	1.69	3,127	0.05	2,862	0.05
1992	1.85	3,113	0.05	2,850	0.04
1993	1.55	3,242	0.05	3,025	0.04
1994	1.92	3,742	0.03	3,526	0.03
1995	2.01	2,941	0.04	2,751	0.03
1996	1.70	2,870	0.04	2,667	0.03
1997	1.94	2,954	0.04	2,727	0.03
1998	1.83	2,998	0.04	2,793	0.03
1999	2.16	3,299	0.03	3,082	0.03
2000	2.36	3,213	0.04	3,004	0.03
2001	2.23	3,202	0.04	2,973	0.04
2002	2.58	3,464	0.05	3,205	0.04
2003	2.76	3,808	0.05	3,553	0.05
2004	1.76	4,320	0.05	4,041	0.05
2005	2.44	4,898	0.06	4,569	0.05
2006	2.62	5,025	0.06	4,773	0.05
2007	1.96	5,497	0.06	5,223	0.05
2008	1.48	5,893	0.05	5,566	0.05
2009	2.04	5,954	0.05	5,661	0.05
2010	1.93	5,536	0.05	5,315	0.05
2011	1.29	5,316	0.05	5,069	0.05
2012	1.88	5,098	0.05	4,829	0.05
2013	2.72	4,501	0.06	4,299	0.06
2014	1.63	4,134	0.08	3,927	0.08
2015	2.15	4,467	0.10	4,154	0.10
2016	2.11	4,543	0.14		

Table 30. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 7 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMBeq =13,193 MMB35=4,709			
1985	2.90			10,372	0.09
1986	3.70	10,004	0.06	9,563	0.06
1987	2.86	6,863	0.07	6,507	0.06
1988	1.85	6,237	0.06	5,836	0.05
1989	2.51	5,433	0.05	5,063	0.05
1990	2.29	3,405	0.07	3,163	0.06
1991	1.60	3,157	0.06	2,915	0.06
1992	1.85	3,198	0.06	2,945	0.05
1993	1.74	3,304	0.06	3,105	0.05
1994	1.86	3,804	0.04	3,606	0.04
1995	1.96	3,088	0.04	2,896	0.04
1996	1.71	3,005	0.04	2,812	0.04
1997	1.90	3,052	0.04	2,844	0.04
1998	1.81	3,103	0.04	2,912	0.04
1999	2.22	3,394	0.04	3,193	0.04
2000	2.44	3,300	0.04	3,108	0.04
2001	2.55	3,333	0.05	3,118	0.04
2002	2.69	3,682	0.05	3,437	0.05
2003	1.84	4,221	0.06	3,957	0.05
2004	2.43	4,781	0.06	4,481	0.06
2005	2.28	4,925	0.07	4,691	0.07
2006	2.62	5,204	0.07	4,941	0.07
2007	1.96	5,664	0.07	5,397	0.07
2008	1.52	6,029	0.07	5,717	0.06
2009	1.92	6,065	0.06	5,783	0.06
2010	1.78	5,634	0.06	5,414	0.06
2011	1.26	5,337	0.06	5,102	0.06
2012	1.69	5,006	0.06	4,762	0.06
2013	2.31	4,343	0.07	4,156	0.07
2014	1.55	3,853	0.09	3,669	0.09
2015	2.00	3,957	0.12	3,702	0.12
2016	2.14	3,933	0.16		

Table 31. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 8 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMBeq =13,295 MMB35=4,750			
1985	2.58			10,182	0.04
1986	4.55	9,791	0.04	9,427	0.03
1987	2.55	6,575	0.05	6,293	0.04
1988	1.71	6,313	0.04	5,869	0.04
1989	2.71	5,509	0.04	5,141	0.03
1990	1.82	3,421	0.05	3,199	0.04
1991	1.78	3,223	0.05	2,964	0.04
1992	1.92	3,084	0.05	2,864	0.04
1993	2.01	3,217	0.05	3,025	0.04
1994	1.73	3,792	0.04	3,597	0.03
1995	1.65	3,228	0.04	3,014	0.04
1996	2.06	3,100	0.04	2,903	0.04
1997	1.69	2,972	0.04	2,799	0.04
1998	1.77	3,125	0.04	2,919	0.04
1999	2.14	3,360	0.04	3,169	0.04
2000	2.35	3,210	0.04	3,029	0.04
2001	2.62	3,178	0.05	2,974	0.04
2002	3.02	3,467	0.05	3,238	0.05
2003	2.44	4,044	0.05	3,792	0.05
2004	2.26	4,832	0.06	4,524	0.05
2005	2.13	5,354	0.06	5,068	0.05
2006	2.55	5,661	0.05	5,396	0.05
2007	1.80	6,006	0.05	5,764	0.05
2008	1.44	6,264	0.05	5,974	0.04
2009	1.79	6,172	0.04	5,917	0.04
2010	1.92	5,640	0.04	5,442	0.04
2011	1.06	5,248	0.04	5,040	0.04
2012	1.81	4,953	0.04	4,708	0.04
2013	2.40	4,219	0.05	4,054	0.05
2014	1.37	3,760	0.07	3,582	0.07
2015	1.90	3,922	0.10	3,659	0.10
2016	1.92	3,826	0.15		

Table 32. Negative log-likelihood values of the fits for scenarios (Sc) 1 (base), 2 (M=0.18yr^{-1}), 3 (truncated total size comp and catch), 4 (added fish ticket CPUE likelihood), 5 (CPUE is related to square root of exploitable abundance), 6 (CPUE is related to square of exploitable abundance), 7 (Francis reweighting), 8 (McAllister and Ianelli reweighting), and 9 (three catchability and total selectivity parameter sets) for golden king crab in the WAG. Differences in likelihood values are given for scenarios with the same number of data points and free parameters (base). Likelihood components with zero entry in the entire rows are omitted. Grey highlighted values are minima for scenarios with comparable base number of data points. RetdcatchB= retained catch biomass. q = catchability.

Likelihood Component	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 5**	**Sc 6**	**Sc 7**	**Sc 8**	**Sc9**	**Sc2– Sc 1**	**Sc 3 – Sc 1**	**Sc 5 – Sc 1**	**Sc 6 – Sc 1**	**Sc 7 – Sc 1**	**Sc 8 – Sc 1**
Number of free parameters	137	137	137	138	137	137	137	137	140						
Data	base	base	base	base+ fishery CPUE	base	base	base	base	Three q and total select.						
Retlencomp	-1193.52	-1190.73	-1196.48	-1192.90	-1195.87	-1190.01	-1104.72	-1272.23	-1195.93	2.79	-2.96	-2.35	3.51	88.8	-78.71
Totallencomp	-1401.85	-1403.50	-1169.71	-1400.26	-1400.72	-1403.52	-1321.73	-1350.21	-1421.73	-1.65	232.14	1.13	-1.67	80.12	51.64
Observer cpue	-15.76	-16.71	-14.28	-14.03	-20.81	-1.58	-15.12	-16.99	-15.46	-0.95	1.48	-5.05	14.18	0.64	-1.23
RetdcatchB	6.89	6.89	5.86	6.46	7.18	6.95	5.28	4.65	6.80	0.00	-1.03	0.29	0.06	-1.61	-2.24
TotalcatchB	50.97	50.87	26.48	50.89	50.65	50.82	43.08	42.42	41.72	-0.1	-24.49	-0.32	-0.15	-7.89	-8.55
GdiscdcatchB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rec_dev	5.53	7.33	5.93	5.33	7.04	4.88	4.11	10.19	6.05	1.8	0.4	1.51	-0.65	-1.42	4.66
Pot F_dev	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.00	0.00	0.00	0.00	0.00	-0.01
Gbyc_F_dev	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Tag	2698.61	2697.83	2697.61	2697.69	2697.68	2699.11	2692.92	2696.22	2704.86	-0.78	-1	-0.93	0.5	-5.69	-2.39
Fishery cpue	-	-	-	-1.38	-	-	-	-							
Total	150.94	152.05	355.49	151.87	145.22	166.73	303.88	114.15	126.37	1.11	204.55	-5.72	15.79	152.94	-36.79

Table 33. Predicted total catch OFL (t) under Tier 4 and Tier 3 assumptions and terminal MMB ratio for various scenarios for EAG and WAG, respectively. Sc = scenario; MMB_{2015} / $MMB_{initial}$ = ratio of terminal MMB relative to initial MMB (= MMB_{1960}).

	EAG			WAG				
Sc	**Tier 4 Total Catch OFL (t)**	**Tier 3 Total Catch OFL (t)**	**MMB_{2015} / $MMB_{initial}$**	**Tier 4 Total Catch OFL (t)**	**Tier 3 Total Catch OFL (t)**	**MMB_{2015} / $MMB_{initial}$**	**M yr^{-1}**	**Remarks**
1	1,772	3,700	0.56	562	961	0.28	0.225	Base scenario: 1960 equilibrium initial size composition,
2	1,326	2,523	0.46	421	563	0.22	0.180	Same as Sc1 with lower M
3	1,759	3,730	0.56	566	995	0.29	0.225	Total catch and total length composition started from 1996/97 for EAG and 1995/96 for WAG.
4	1,823	3,862	0.57	578	995	0.29	0.225	Added fish ticket CPUE neg-log likelihood
5	1,770	3,635	0.55	315	589	0.21	0.225	CPUE ~ square root of exploitable abundance
6	1,456	3,139	0.51	679	1,307	0.33	0.225	CPUE ~ square of exploitable abundance
7	1,810	3,777	0.57	595	1,070	0.30	0.225	Francis iterative reweighting of effective sample sizes
8	1,815	3,727	0.55	585	1,006	0.29	0.225	McAllister and Ianelli iterative reweighting of effective sample sizes
9	1,619	3,334	0.55	540	836	0.27	0.225	Three catchability and asymptotic total selectivity 1985/86–1994/95, 1995/96–2004/05, and 2005/06–
10	1,936	3,913	0.57	2043	5,548	0.68	0.225	Dome shaped selectivity
11	1,685	3,629	0.56	559	955	0.28	0.225	Observer CPUE indices for 1995/96 to 2015/16
12	1,755	3,727	0.56	504	927	0.28	0.225	Included groundfish size composition in the fit
1d	1,812	3,785	0.57	-	-	-	0.225	Removed retained catch size compositions up to 1988/86
14a	1,773	3,702	0.60	488	920	0.26	0.225	B_{ref} for Tier 4 and mean R for Tier 3 OFL calculations were based on 1981/82 to 2015/16 averages
14b	1,773	3,701	0.59	563	961	0.27	0.225	B_{ref} for Tier 4 and mean R for Tier 3 OFL calculations were based on 1985/86 to 2015/16 averages
14c	1,772	3,700	0.56	562	981	0.28	0.225	B_{ref} for Tier 4 and mean R for Tier 3 OFL calculations were based on 1996/97 to 2015/16 averages

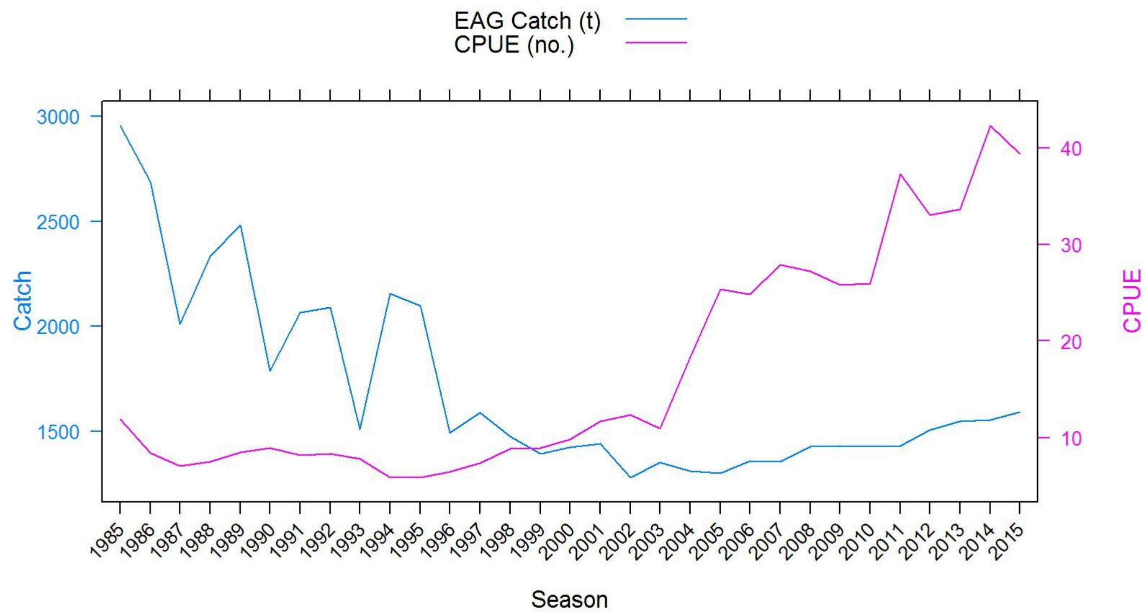


Figure 12. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2015/16 fisheries (note: 1985 refers to the 1985/86 fishing year).

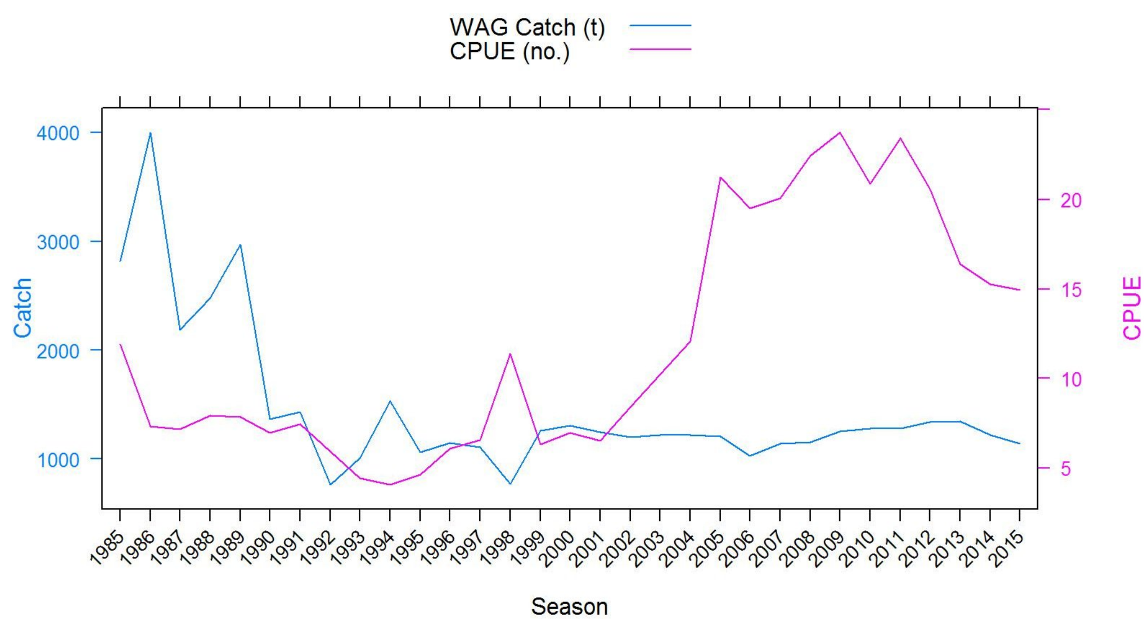


Figure 13. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2015/16 fisheries (note: 1985 refers to the 1985/86 fishing year).

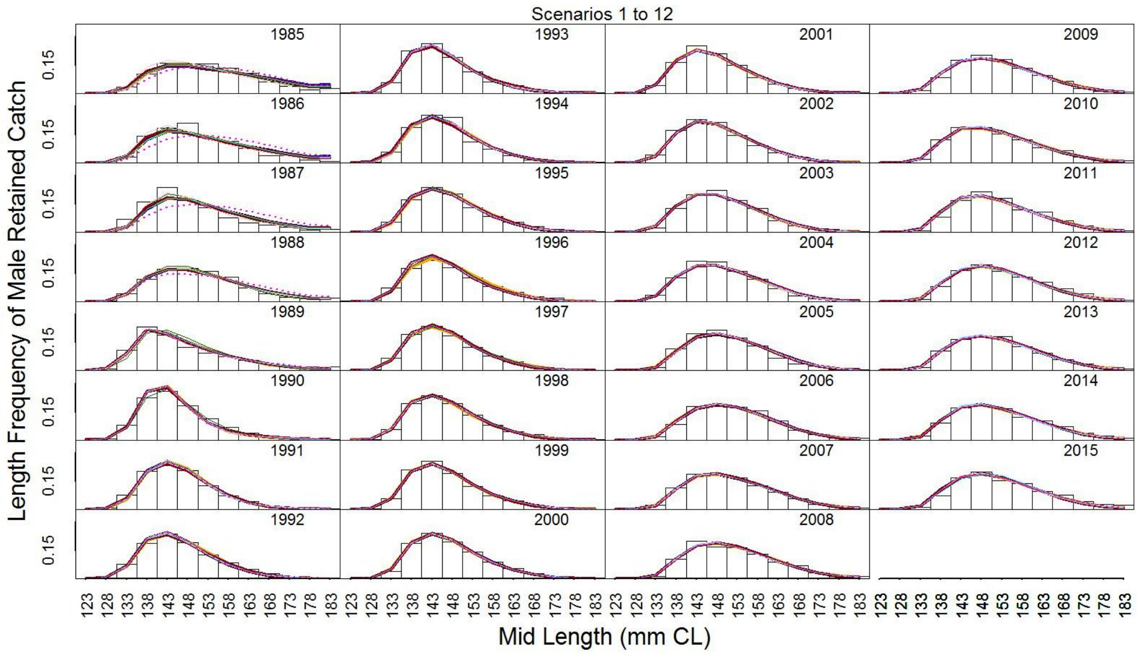


Figure 14. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (orange line), 5 (gray line), 6 (dark blue line), 7 (green line), 8 (dark green line), 9 (dark red line), 10 (pink line), 11 (violet line), 12 (cyan line), and 1d (magenta line) for golden king crab in the EAG, 1985/86 to 2015/16. This color scheme is used in all other graphs.

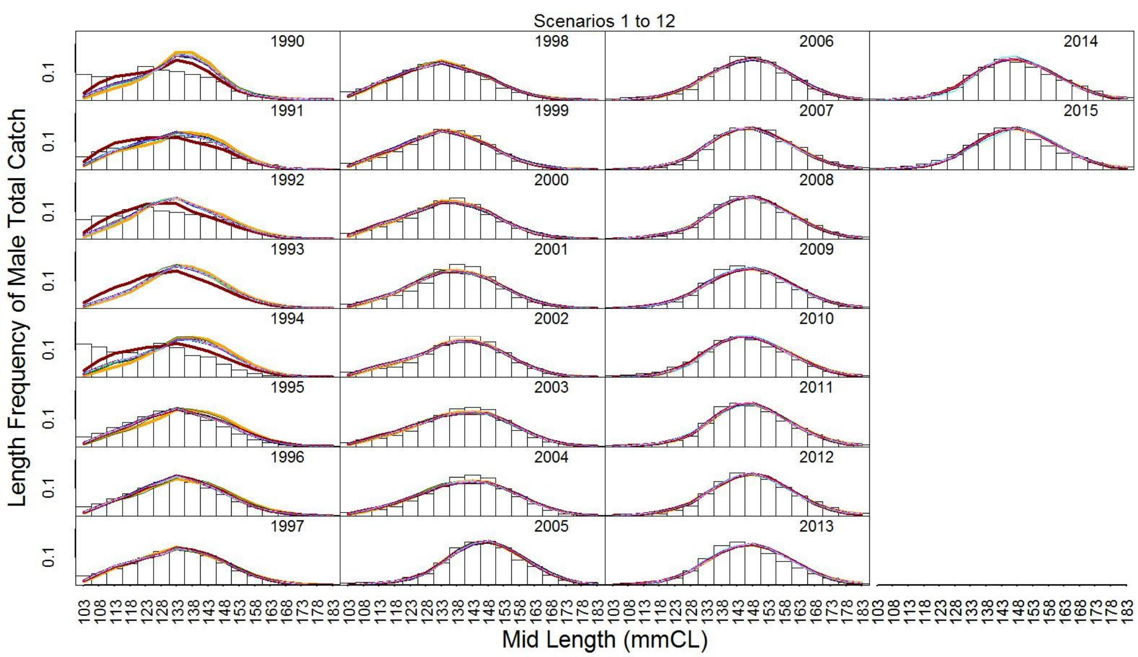


Figure 15. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 1 to 12 and 1d for golden king crab in the EAG, 1990/91 to 2015/16.

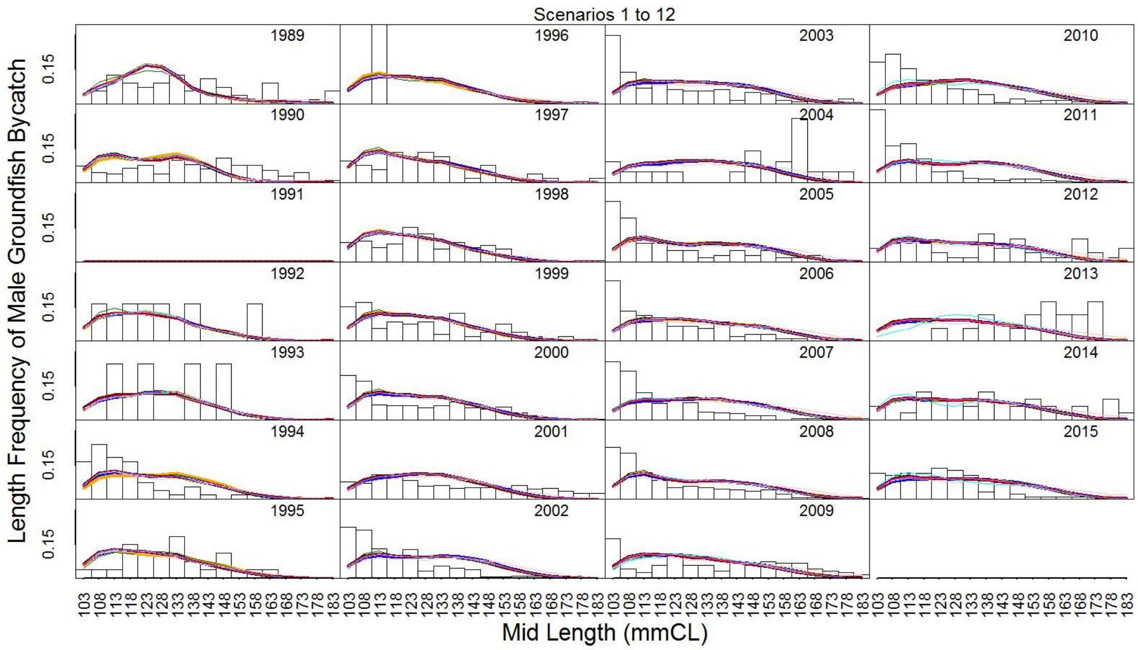
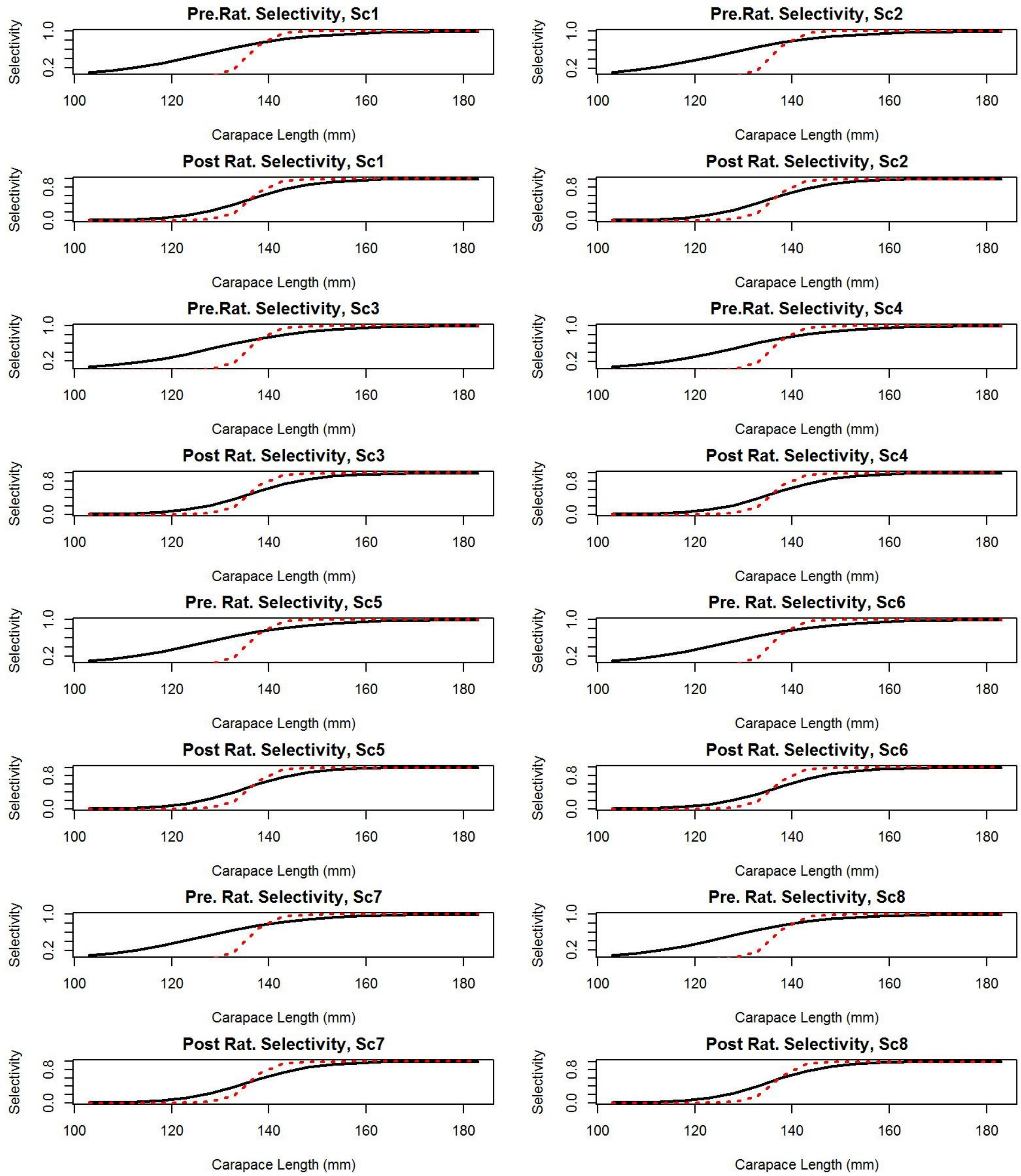


Figure 16. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 1 to 12 and 1d for golden king crab in the EAG, 1989/90 to 2015/16.


Pre.Rat. Selectivity, Sc1
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Pre.Rat. Selectivity, Sc2
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc1
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc2
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Pre.Rat. Selectivity, Sc3
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Pre.Rat. Selectivity, Sc4
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc3
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc4
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Pre. Rat. Selectivity, Sc5
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Pre. Rat. Selectivity, Sc6
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc5
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc6
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Pre. Rat. Selectivity, Sc7
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Pre. Rat. Selectivity, Sc8
Selectivity
0.2 1.0
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc7
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)
Post Rat. Selectivity, Sc8
Selectivity
0.0 0.8
100 120 140 160 180
Carapace Length (mm)

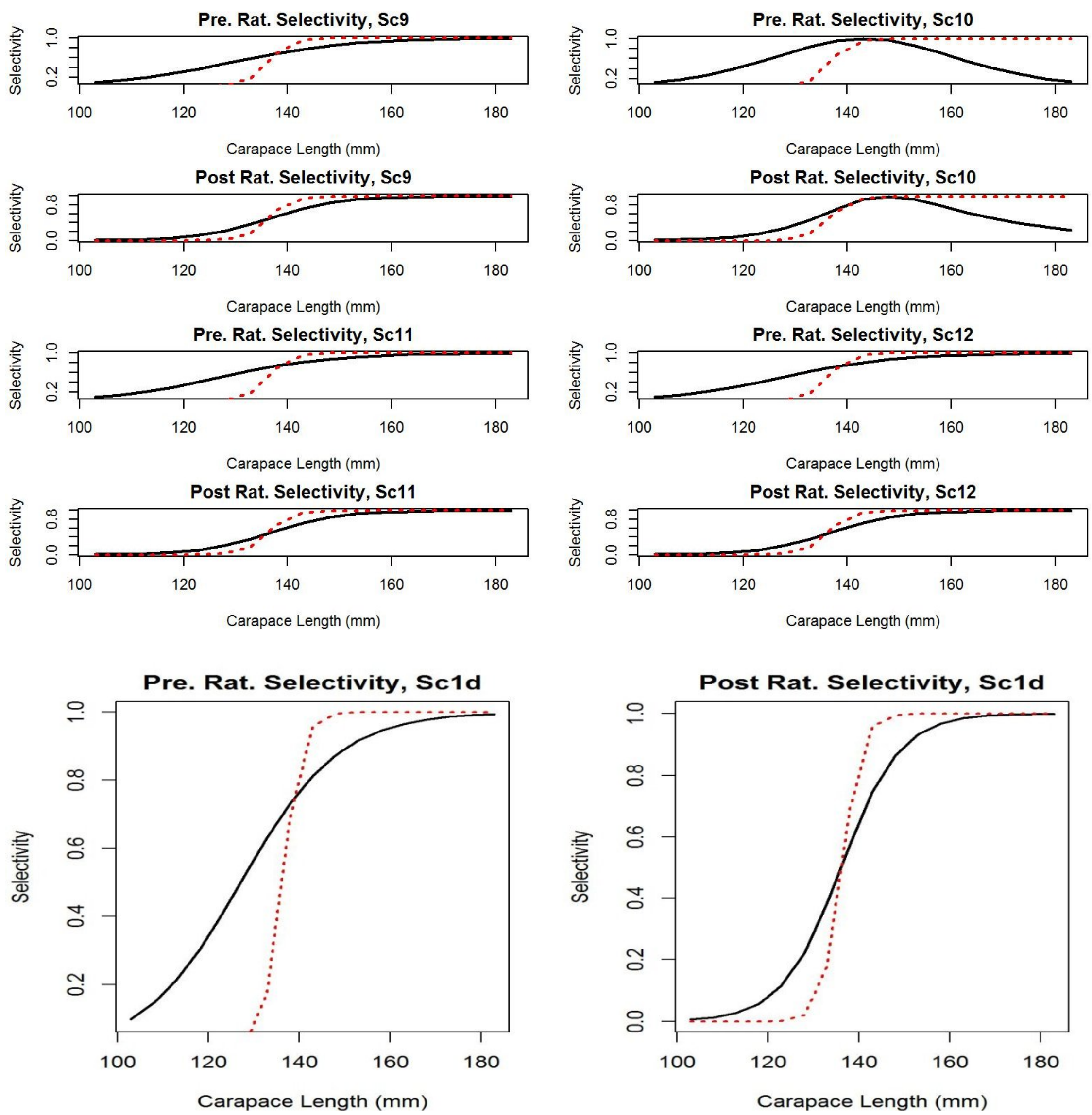


Figure 17. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 1 to 12 and 1d fits of golden king crab data in the EAG, 1985/86 to 2015/16.

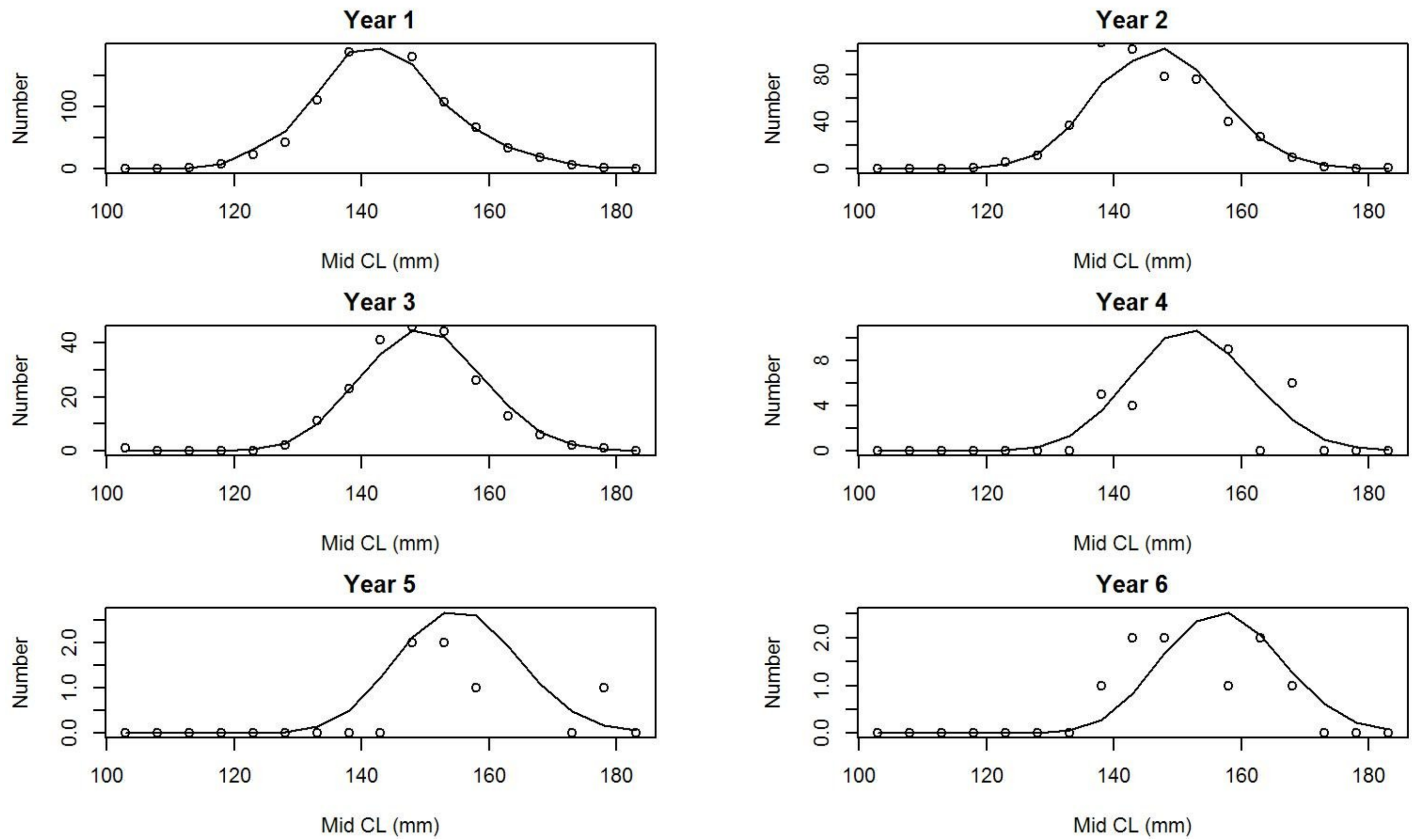


Figure 18. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 1 for EAG golden king crab.

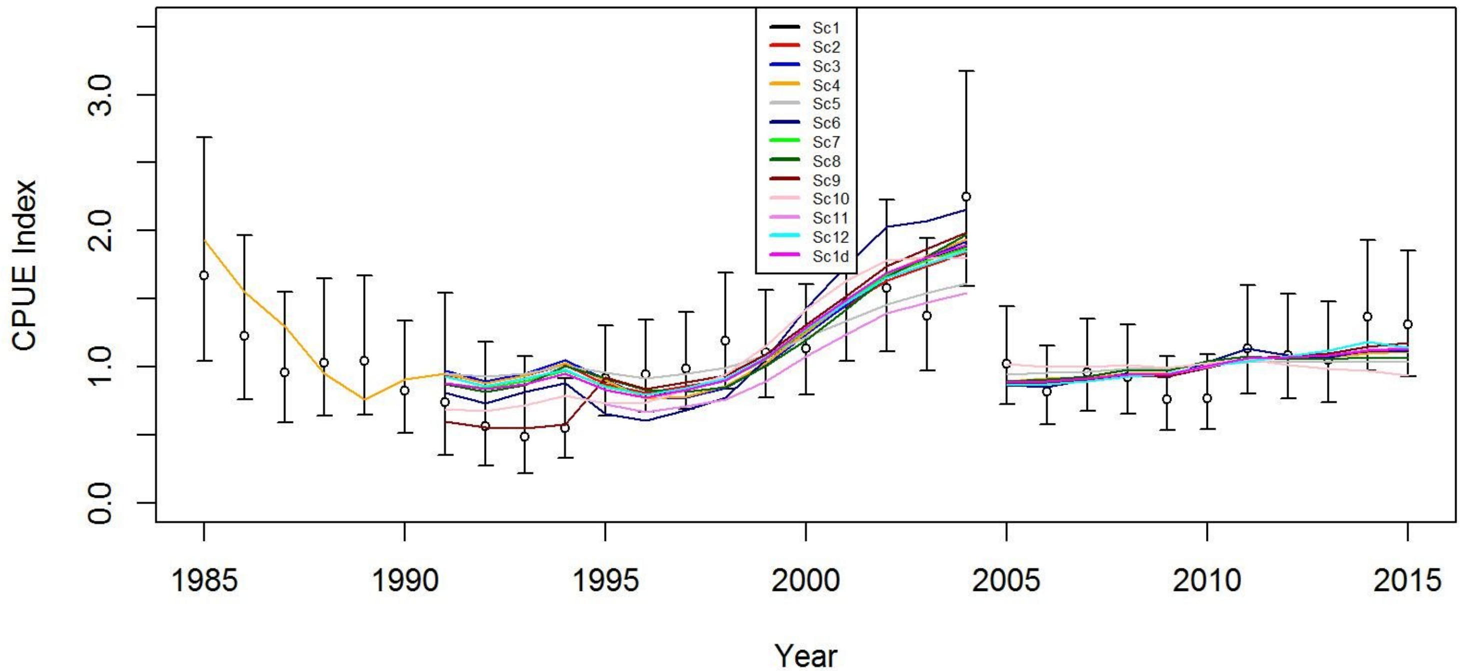


Figure 19. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) under scenarios (Sc) 1 to 12 and 1d for EAG golden king crab data, 1985/86–2015/16. Model estimated additional standard error was added to each input standard error.

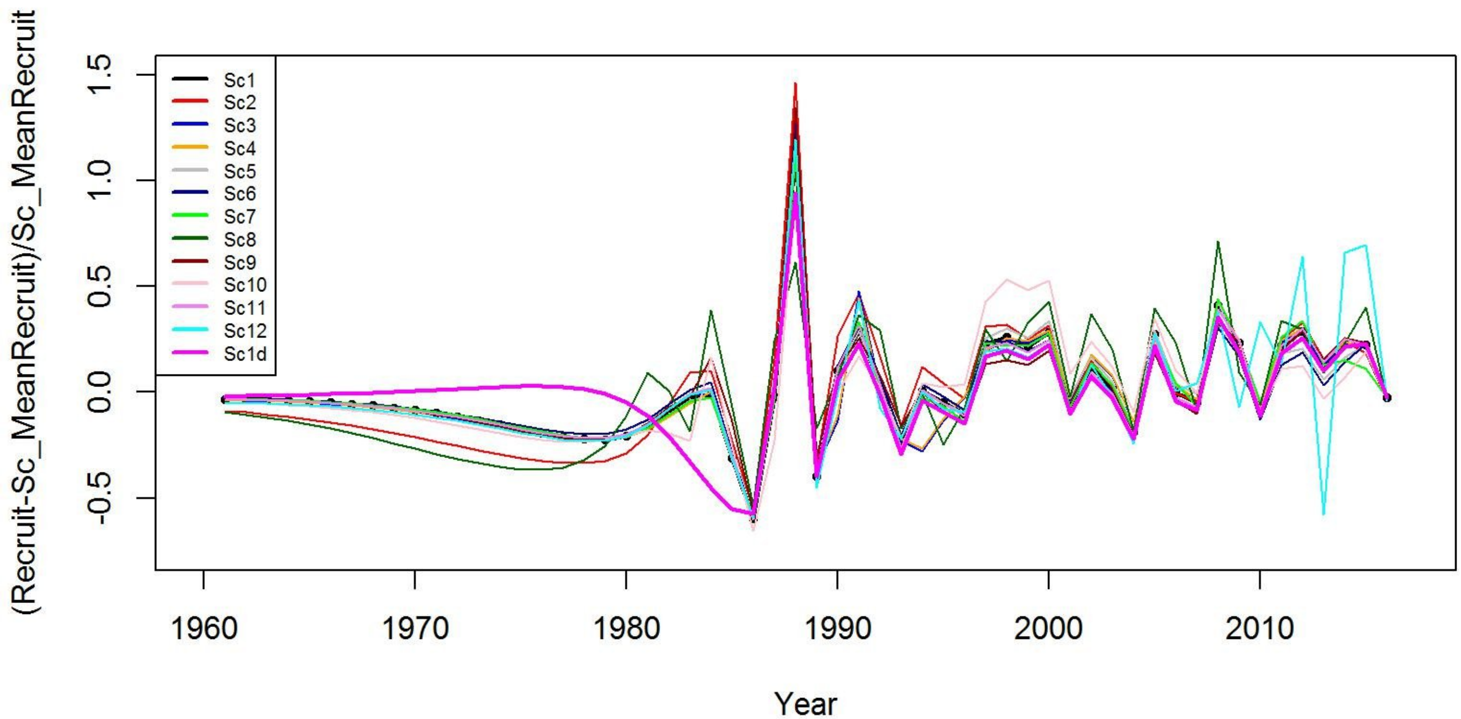


Figure 20. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 1 to 12 and 1d for EAG golden king crab data, 1961–2016. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results. Note that pre-1981 recruit trend line is almost horizontal for scenario 1d.

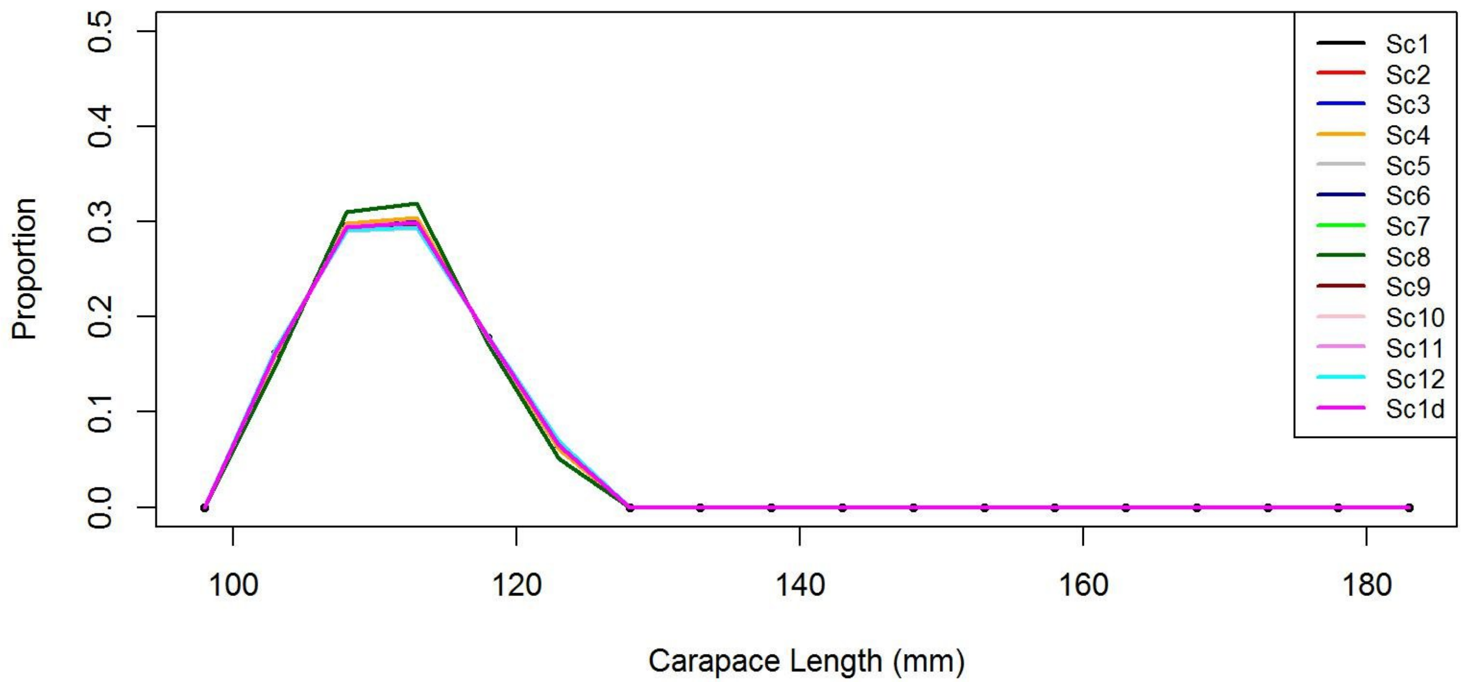


Figure 21. Recruit size distribution to the assessment model under scenarios (Sc) 1 to 12 and 1d for EAG golden king crab, 1961–2016.

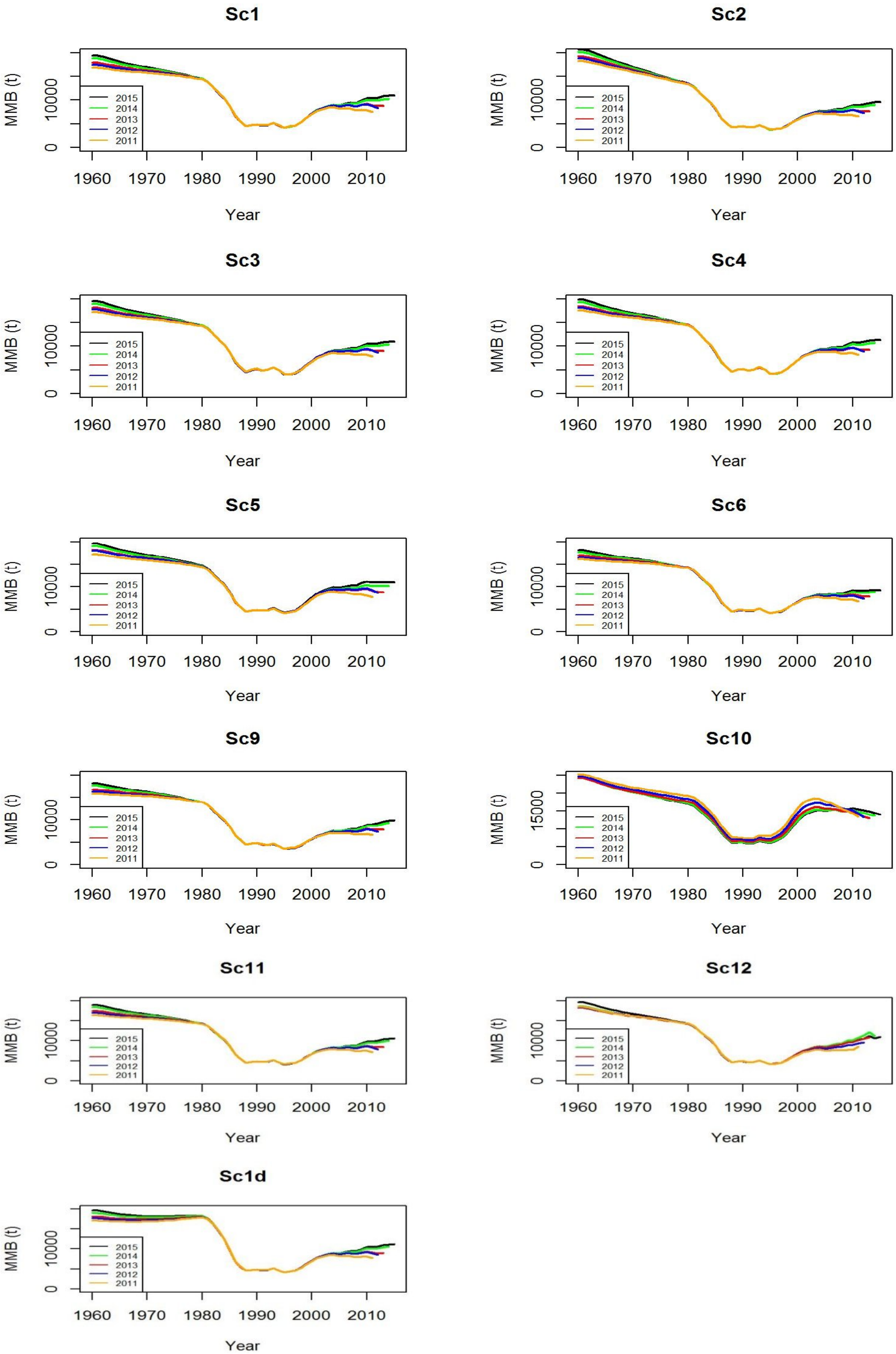


Figure 22. Retrospective fits of MMB by the model following removal of terminal year data under scenarios (Sc) 1 to 12 and 1d for golden king crab in the EAG, 1960–2015.

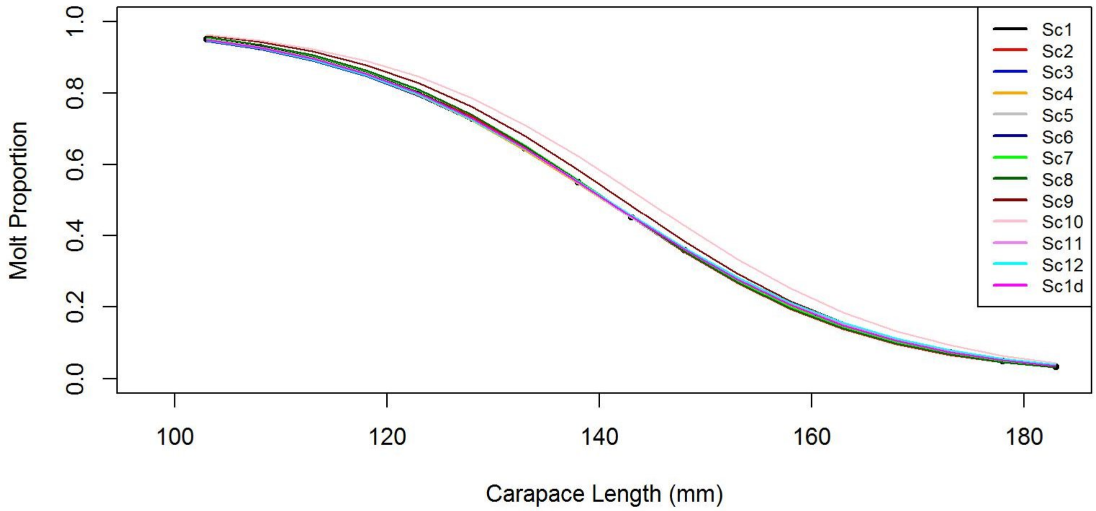


Figure 23. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 1 to 12 and 1d in the EAG, 1985/86–2015/16.

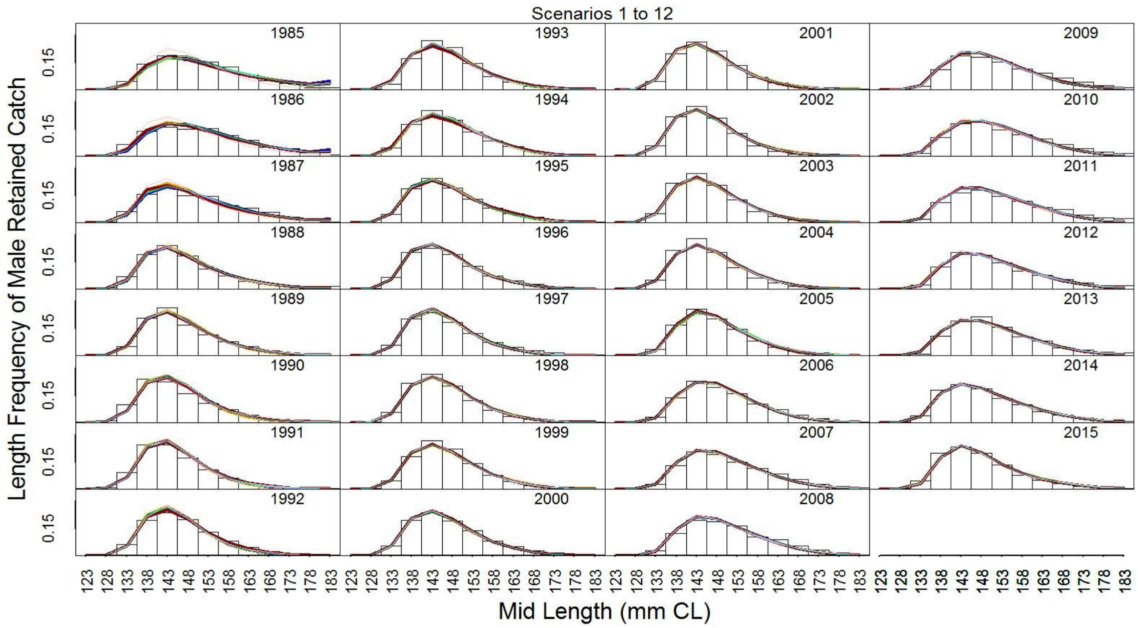


Figure 24. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (orange line), 5 (gray line), 6 (dark blue line), 7 (green line), 8 (dark green line), 9 (dark red line), 10 (pink line), 11 (violet line), and 12 (cyan line) for golden king crab in the WAG, 1985/86 to 2015/16. This color scheme is used in all other graphs.

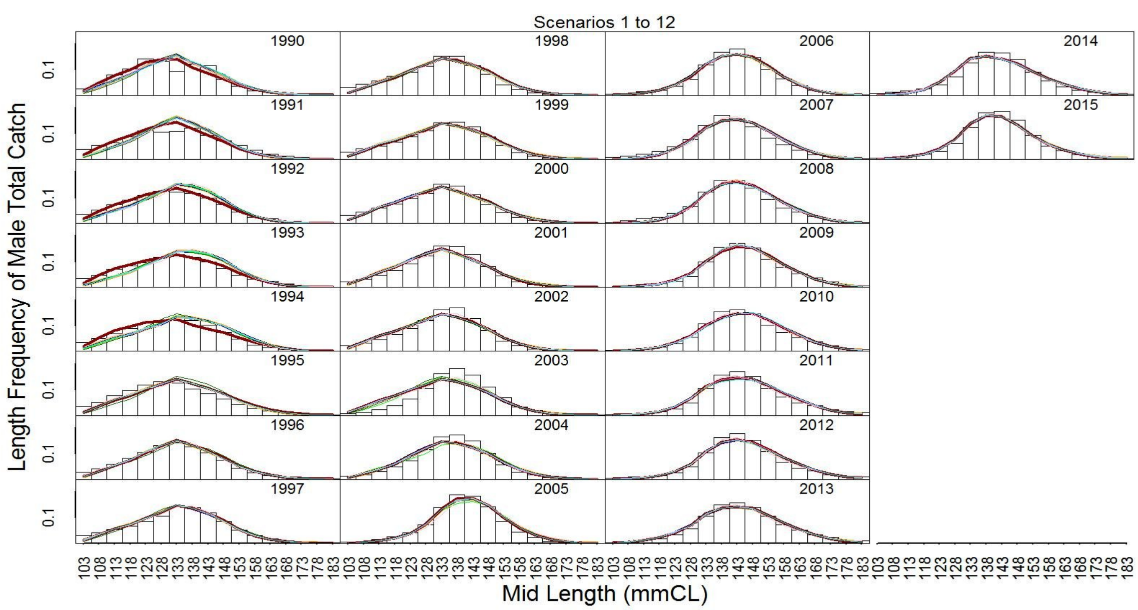


Figure 25. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 1 to 12 for golden king crab in the WAG, 1990/91 to 2015/16.

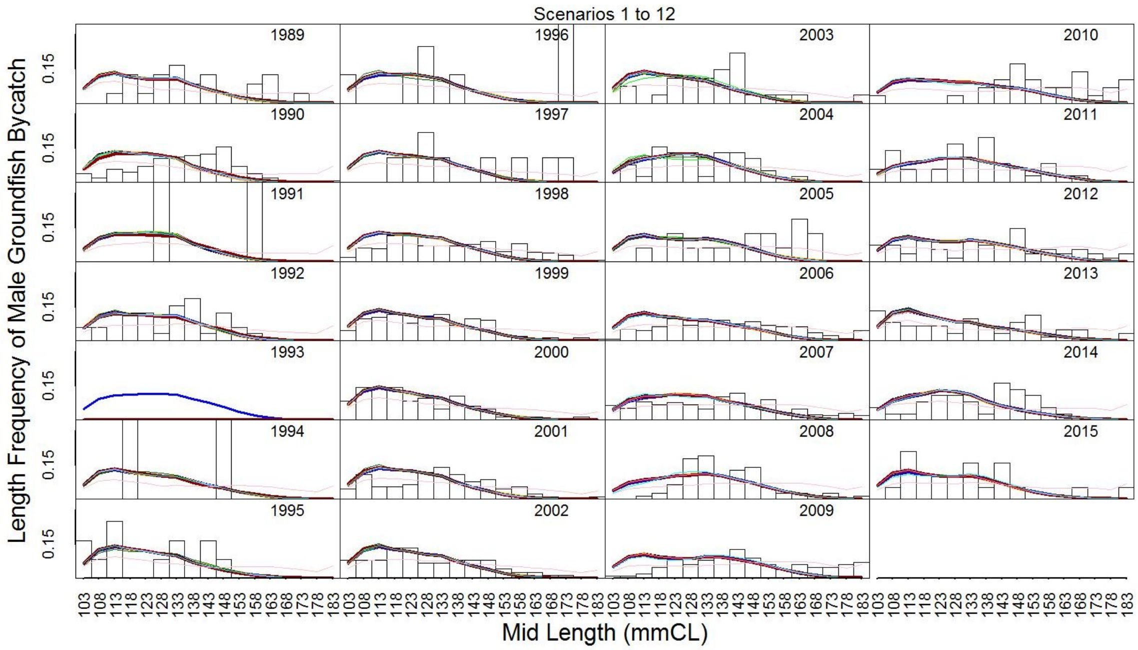
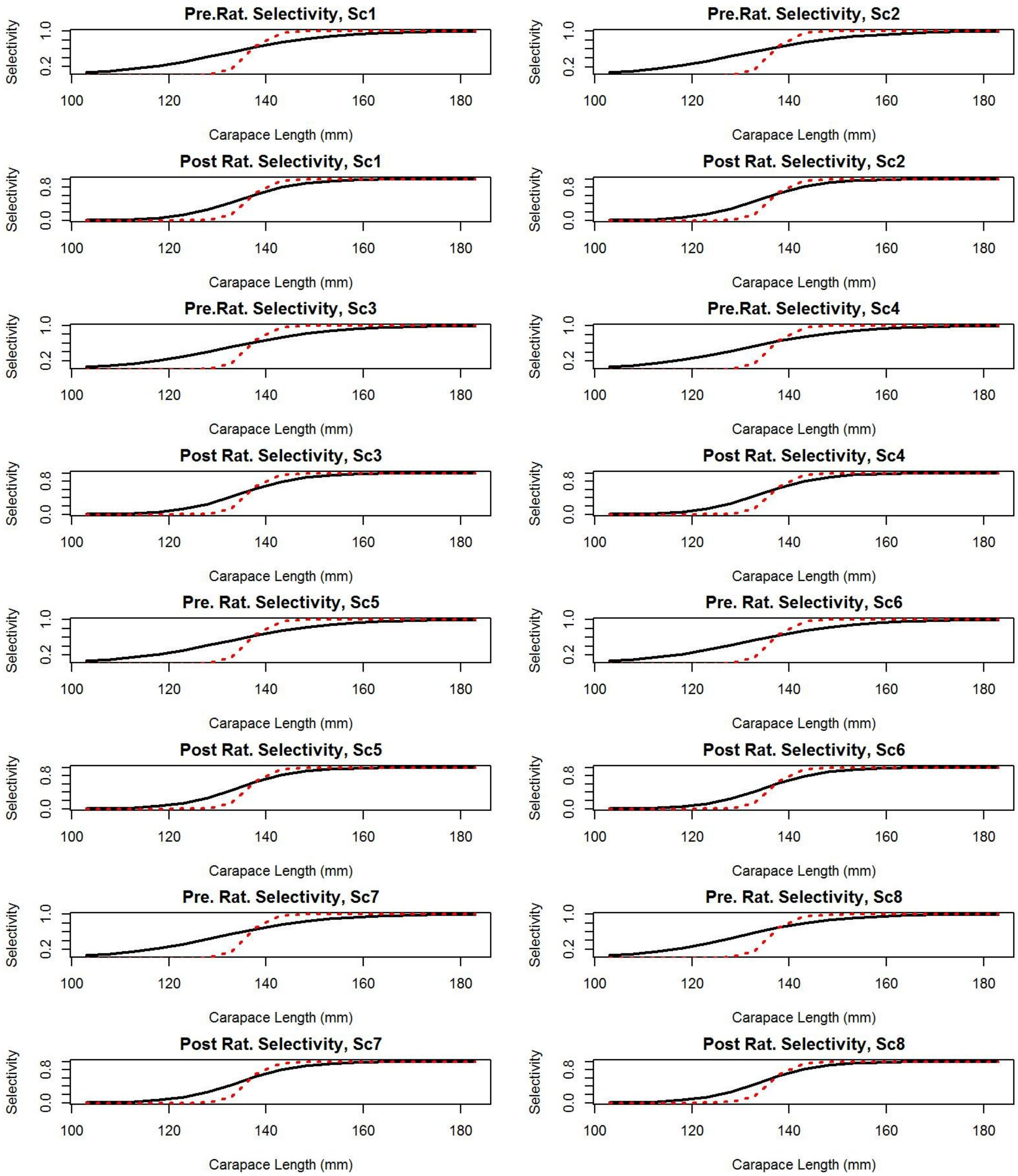


Figure 26. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 1 to 12 for golden king crab in the WAG, 1989/90 to 2015/16.



Pre.Rat. Selectivity, Sc1
Pre.Rat. Selectivity, Sc2
Post Rat. Selectivity, Sc1
Post Rat. Selectivity, Sc2
Pre.Rat. Selectivity, Sc3
Pre.Rat. Selectivity, Sc4
Post Rat. Selectivity, Sc3
Post Rat. Selectivity, Sc4
Pre. Rat. Selectivity, Sc5
Pre. Rat. Selectivity, Sc6
Post Rat. Selectivity, Sc5
Post Rat. Selectivity, Sc6
Pre. Rat. Selectivity, Sc7
Pre. Rat. Selectivity, Sc8
Post Rat. Selectivity, Sc7
Post Rat. Selectivity, Sc8
Selectivity
Carapace Length (mm)

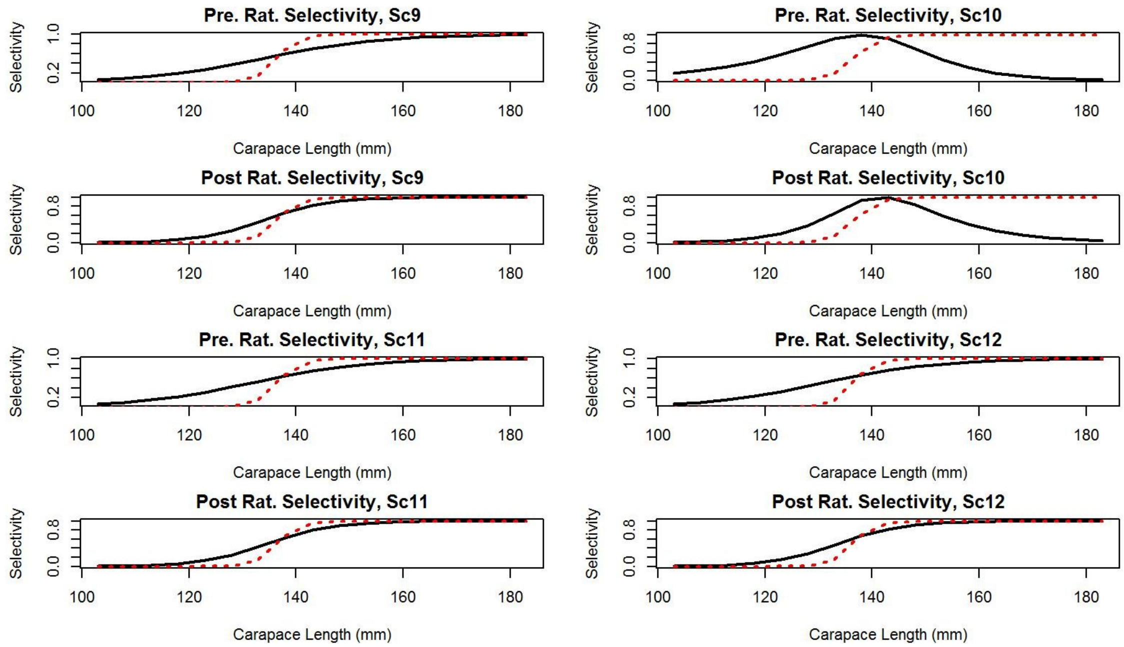


Figure 27 Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 1 to 12 fits to WAG golden king crab data.

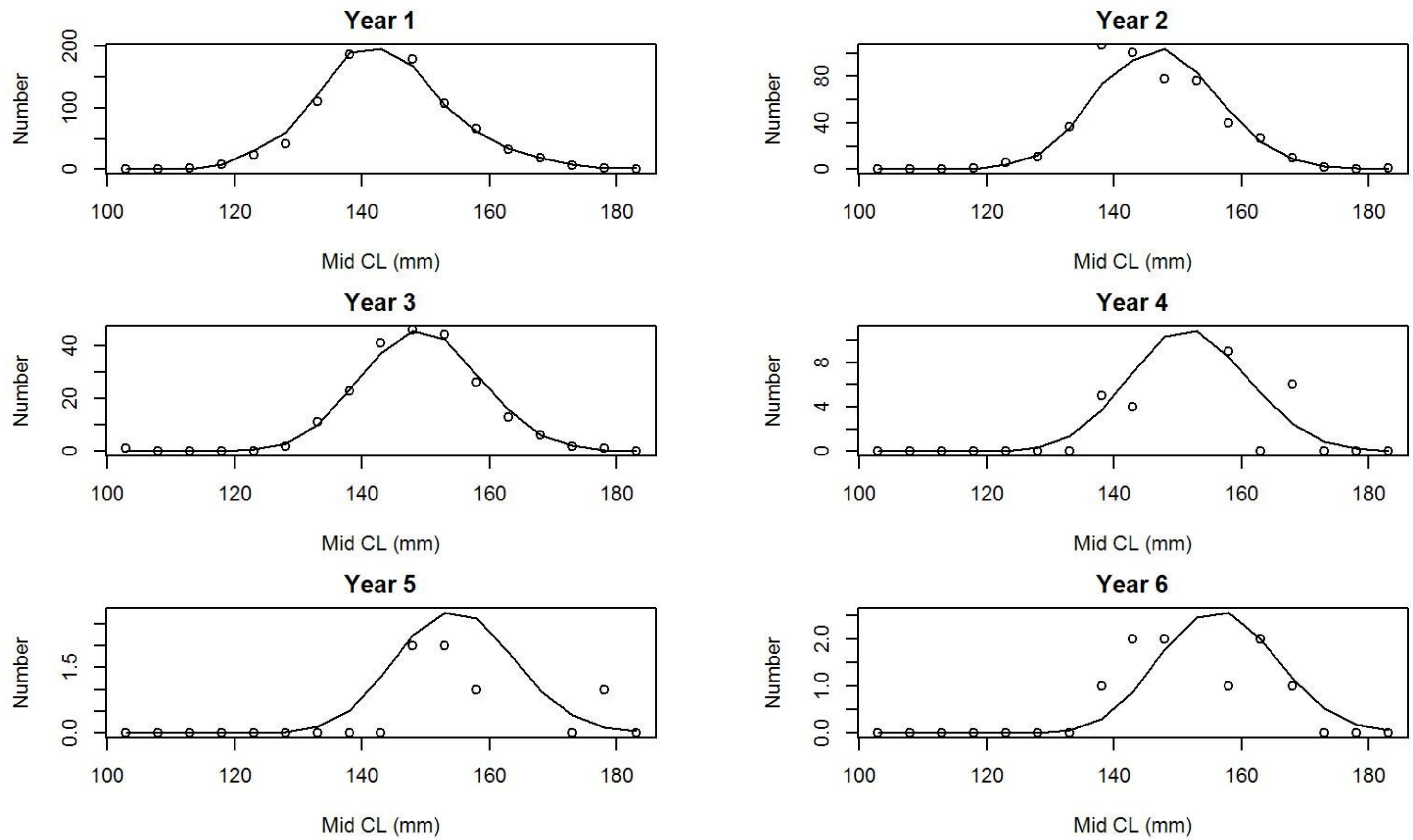


Figure 28. Observed (open circle) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures for scenario 1 fit of WAG golden king crab data. The tagging data from EAG were used.

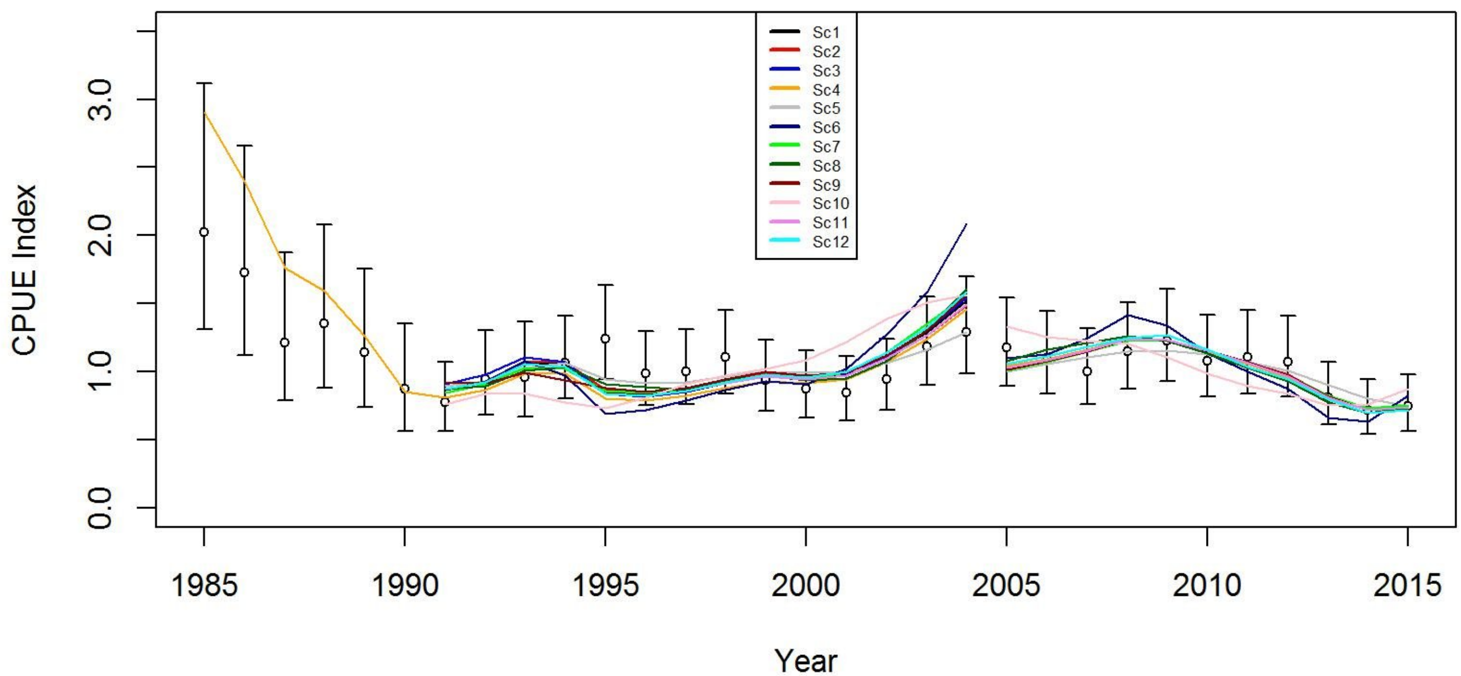


Figure 29. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1 to 12, and 1d fits to WAG golden king crab data, 1985/86–2015/16. Model estimated additional standard error was added to each input standard error.

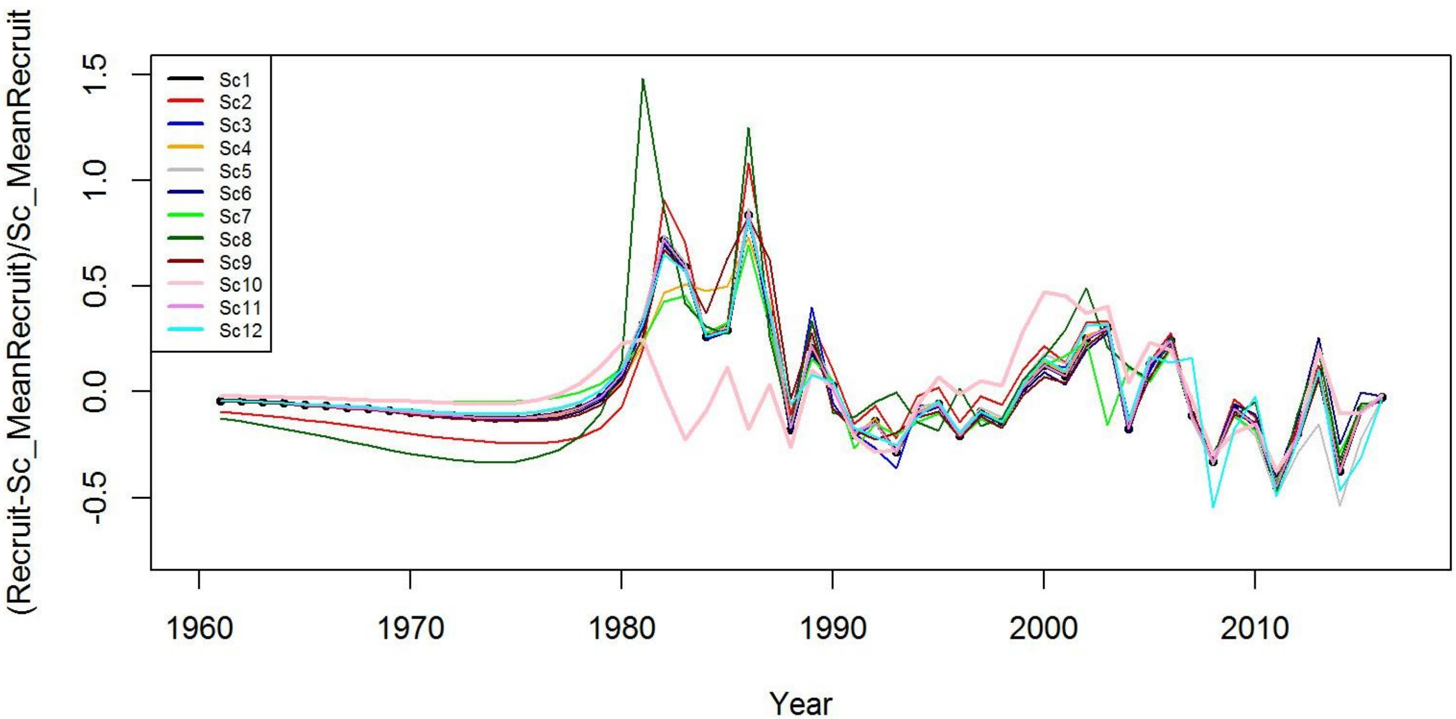


Figure 30. Estimated number of male recruits (crab size ≥ 101 mm CL) to the golden king crab assessment model under scenarios (Sc) 1 to 12 for WAG, 1961–2016. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

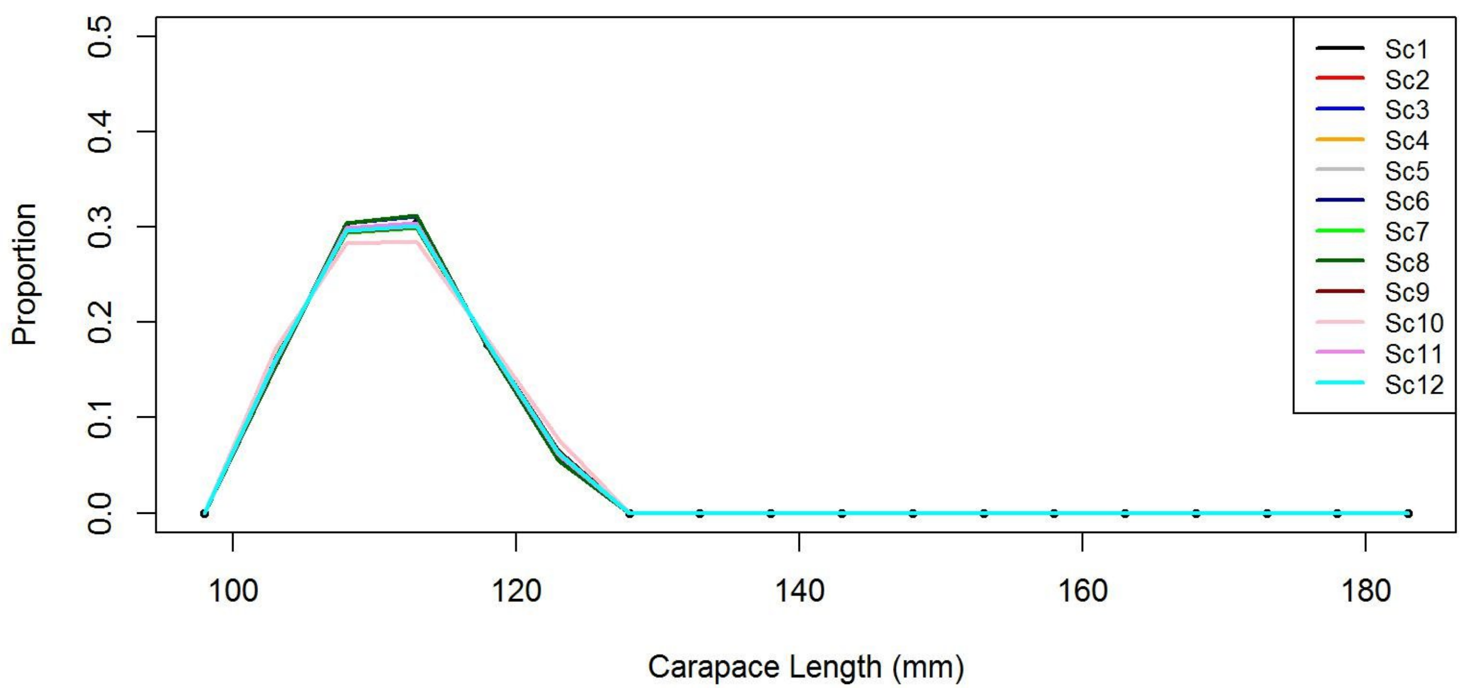


Figure 31. Recruit size distribution in the golden king crab assessment model under scenarios (Sc) 1 to 12 for WAG.

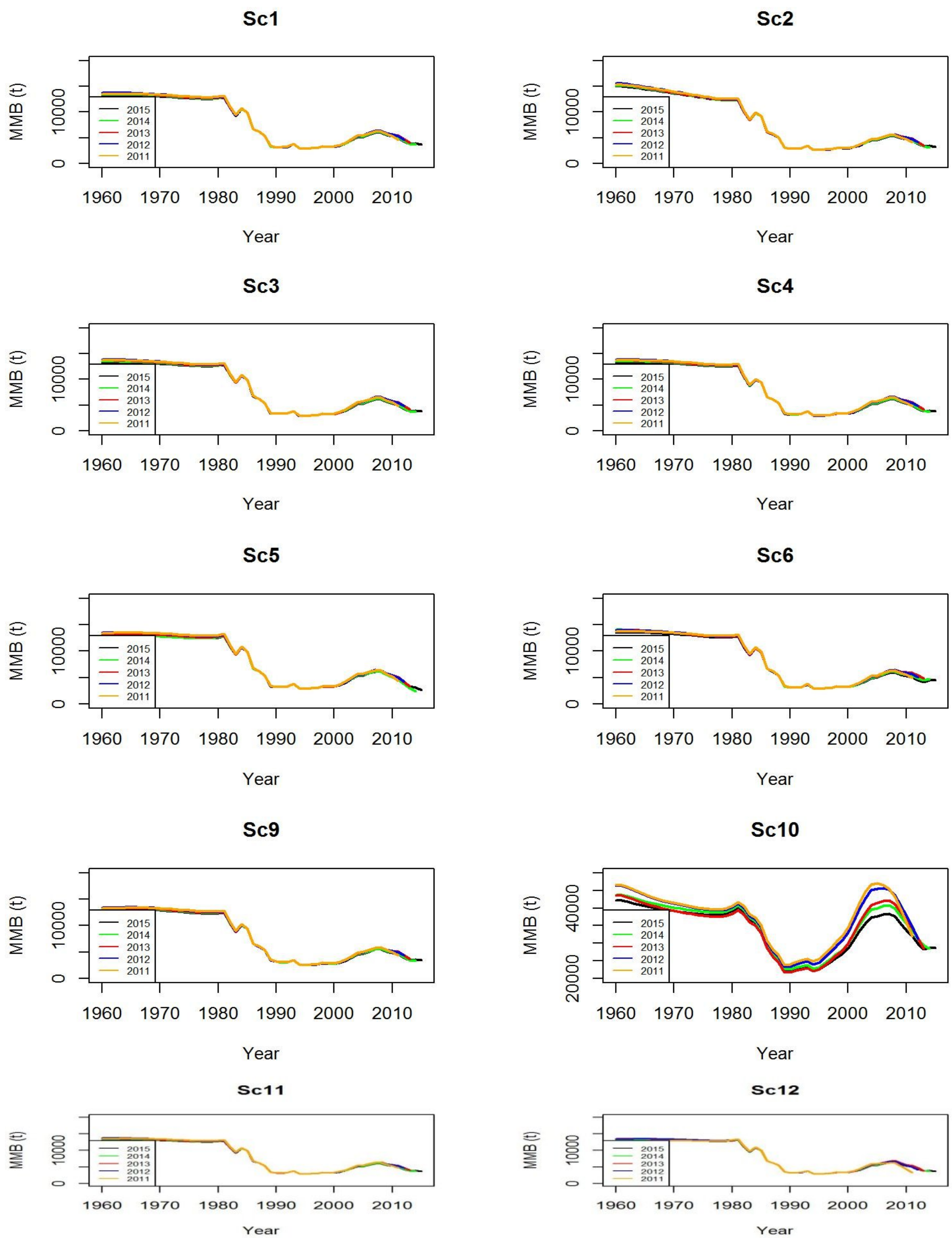


Figure 32. Retrospective fits of mature male biomass by the model when terminal year data were systematically removed until 2011/12 under scenarios (Sc) 1 to 12 for golden king crab in the WAG, 1960–2015.

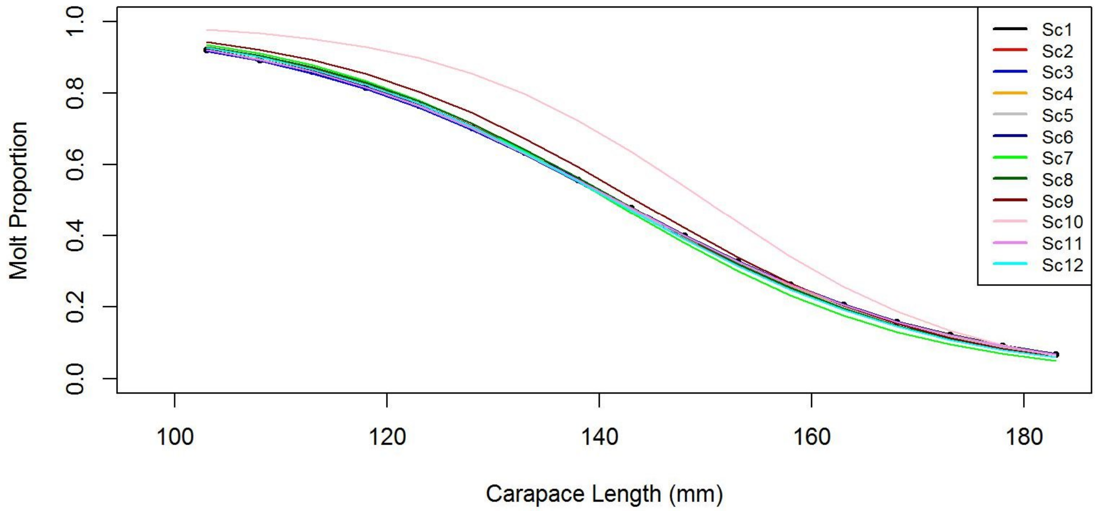


Figure 33. Estimated molt probability vs. carapace length of golden king crab under scenarios 1 to 12 for WAG.

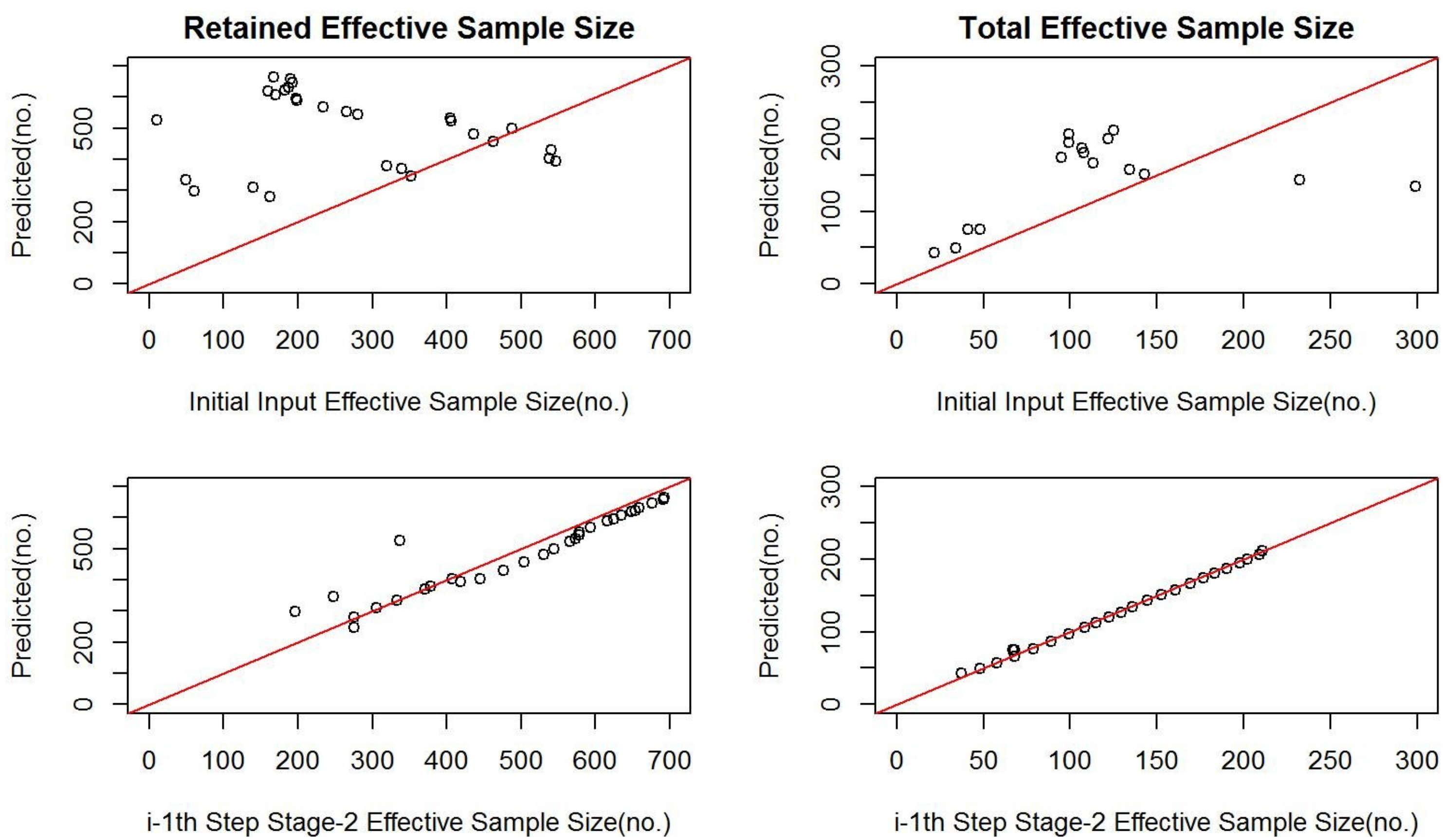


Figure 34. Predicted vs. initial input effective sample size (top panel) and predicted vs. the i-1th step input stage-2 effective sample size (bottom panel) for retained and total catch size-compositions for scenario 8 (McAllister and Ianelli reweighting) fit to golden king crab data in the EAG. The red line is the 1:1 line.

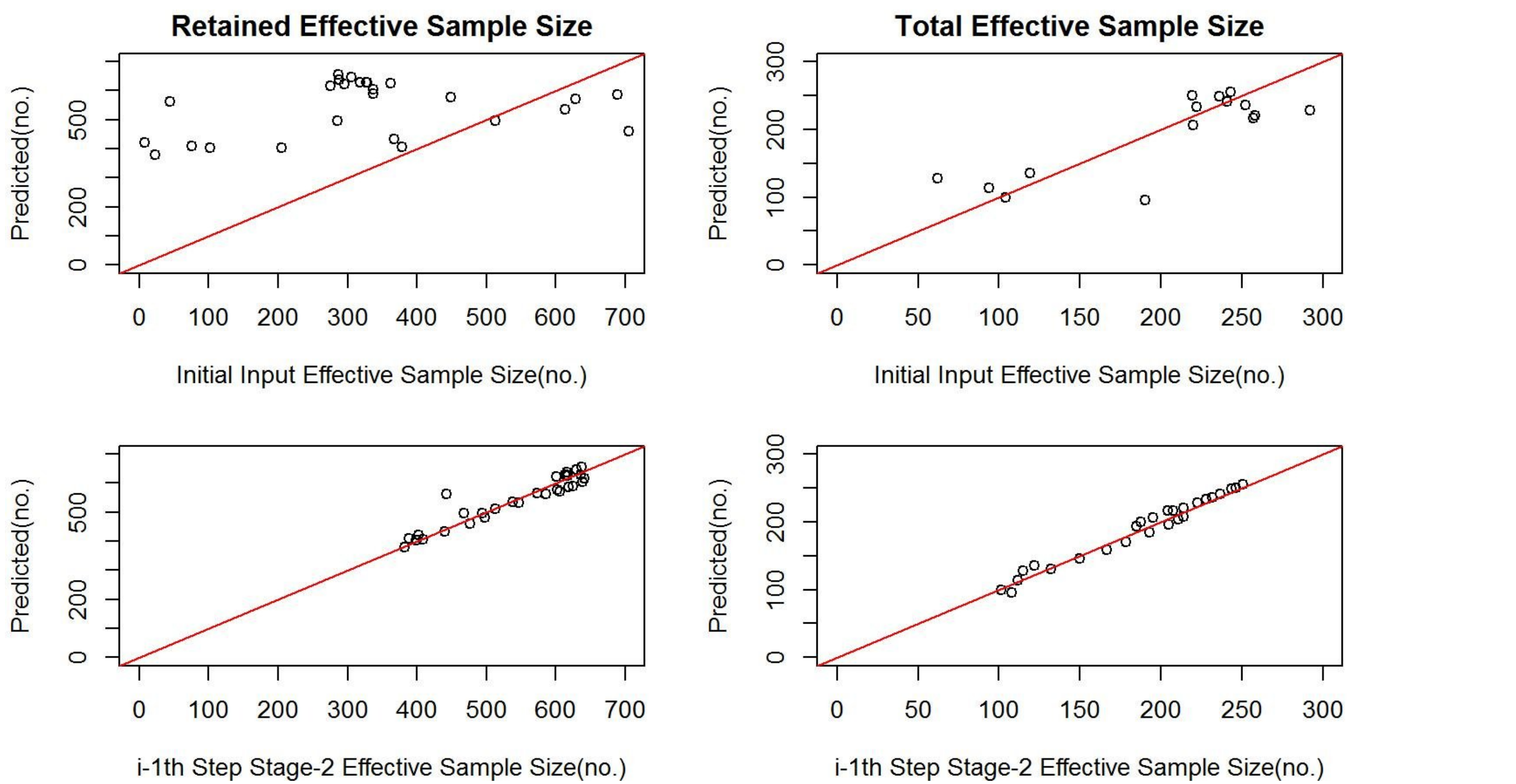


Figure 35. Predicted vs. initial input effective sample size (top panel) and predicted vs. the i-1th step input stage-2 effective sample size (bottom panel) for retained and total catch size-compositions for scenario 8 (McAllister and Ianelli reweighting) fit to golden king crab data in the WAG. The red line is the 1:1 line.

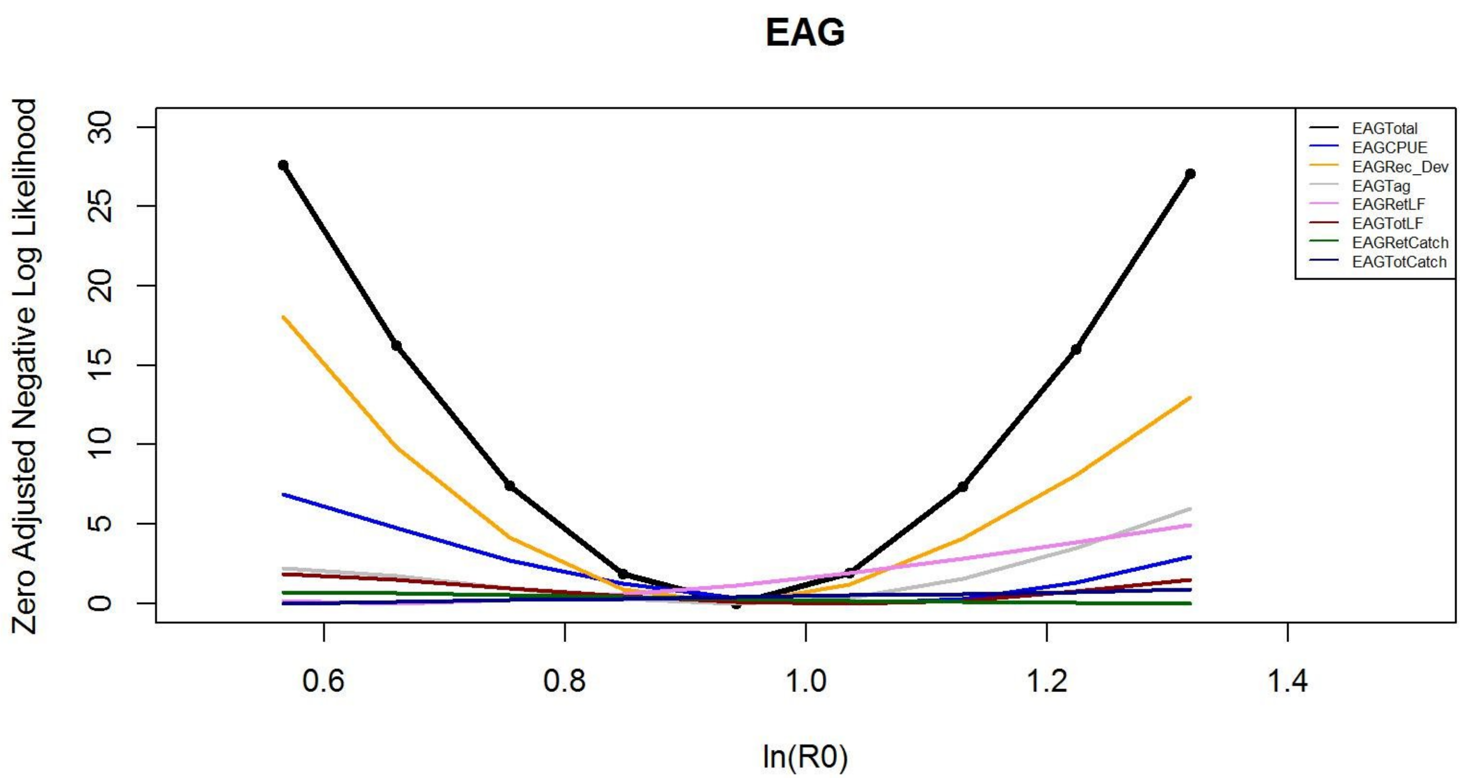


Figure 36. Total and component negative log-likelihoods vs. ln(*R0*) for scenario 1 model fit to EAG data. Negative log likelihood values were zero adjusted.

Note: ln(R0) was varied around the scenario 1 estimate of mean ln(R), 0.941827.

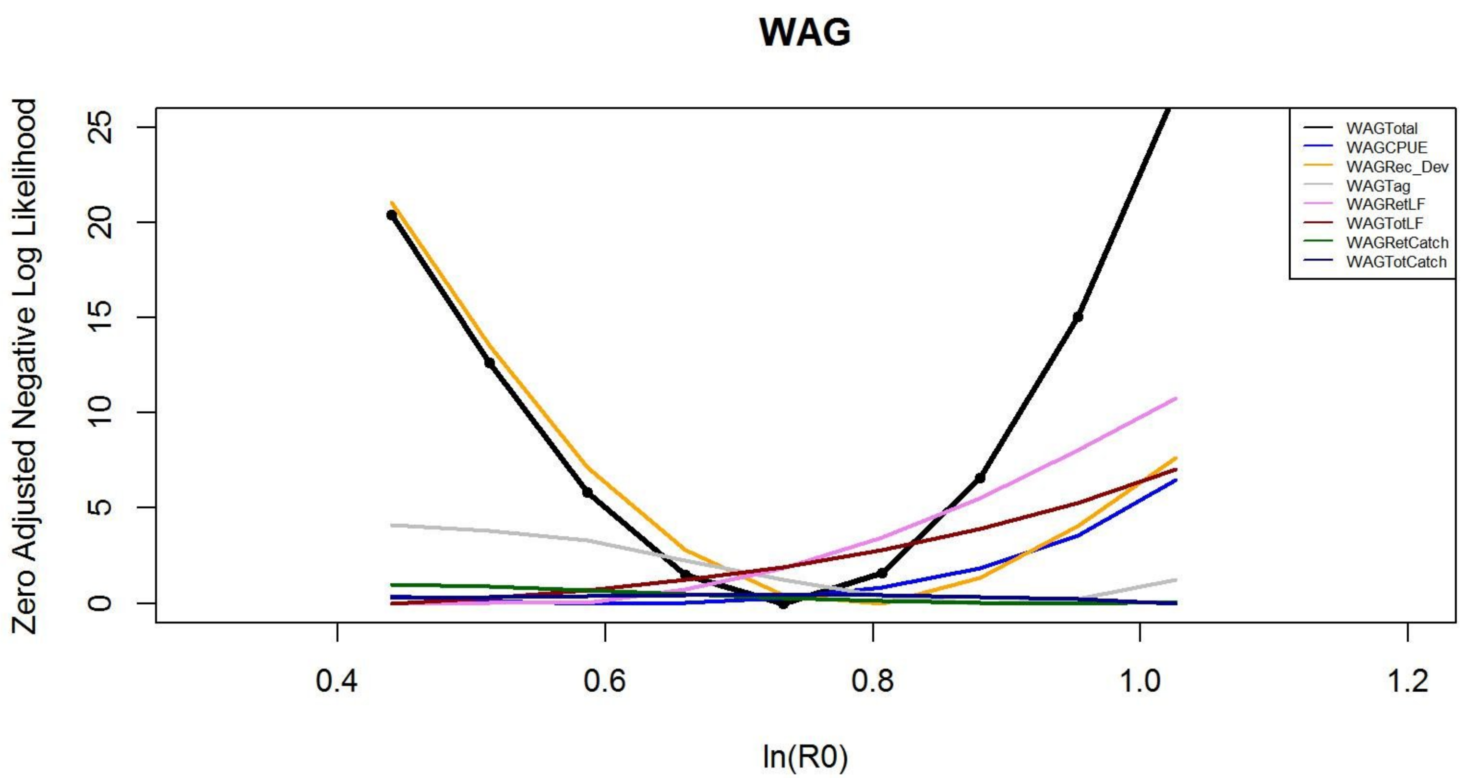


Figure 37. Total and component negative log-likelihoods vs. ln(R0) for scenario 1 model fit to WAG data. Negative log likelihood values were zero adjusted.

Note: ln(R0) was varied around the scenario 1 estimate of mean ln(R), 0.732982.

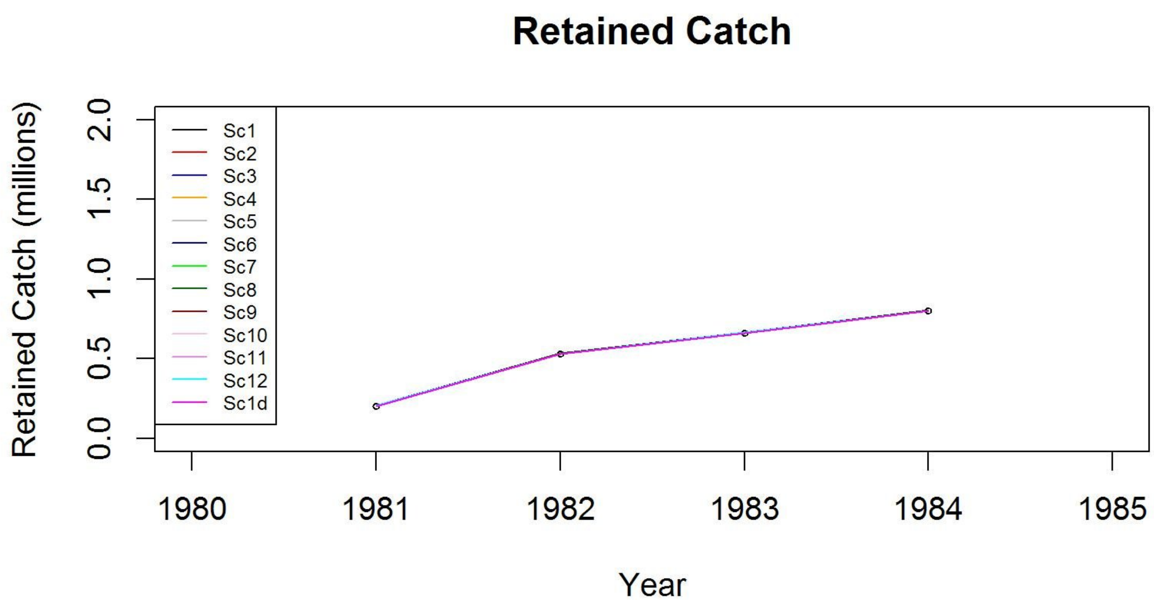


Figure 38. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 1 to 12 and Sc1d fits in the EAG, 1981–1984. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

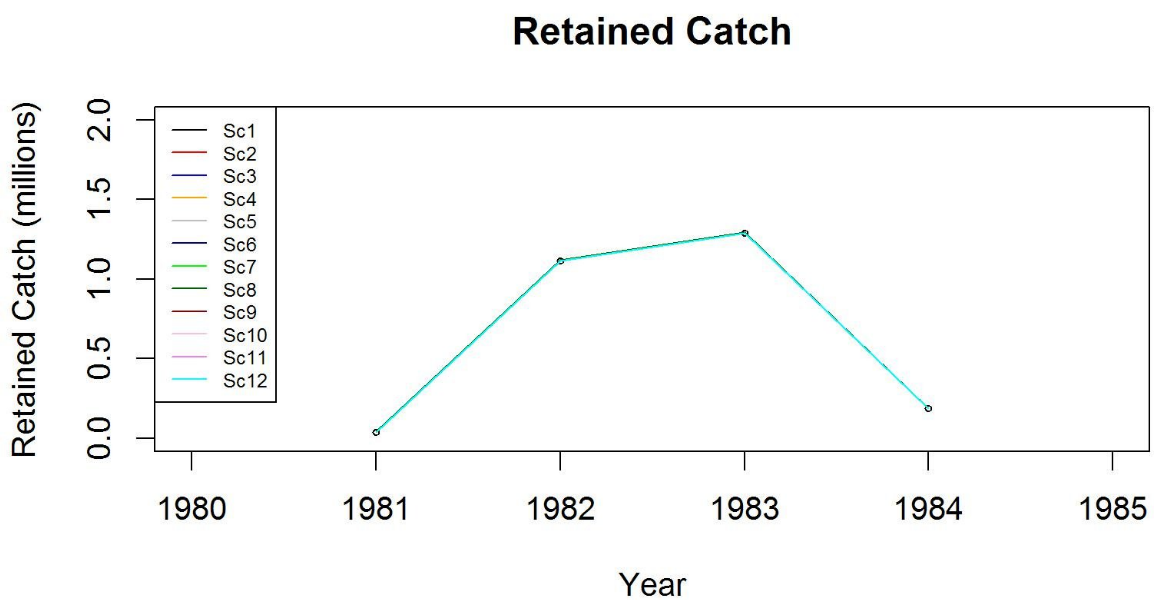


Figure 39. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab under scenarios (Sc) 1 to 12 for the WAG, 1981–1984. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

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:

? ?? ? ? ∑?? ? ? ? ?? ? ? − Æ?? ? ? ? ? ? ? ? ? ? (? ? ? ?)? Ø? ? ? ? ?? ? ? (A.1)

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

The catches are predicted using the equations

? ? ? ??? ? ? ? ? ? ? / ? ? ? ? ? ? ? ? ? ? ? Æ È − ? ? ? ? ? (A.2a)

? ? ? ? ? ? ? ? ? ? ? / ? ? ? ? ? ? ? ? ? ? ? Æ È − ? ? ? ? ? (A.2b)

? ? ? Ç É Æ ? ? ? ??? ? − ? ? ? (A.2c)

? ? ? ? Ç Ë ? ? ? ? ? ? ? / ? ? ? ? ? ? ? ? ? ? ? Æ È − ? ? ? ? ? (A.2d)

? ? ? ? ? ? ? ? ? (A.2e)

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

? ? ? ? ? ? ? ? ? ? ? ? ? Ç É ? ? ? ? ? ? Æ È − ? ? ? ? Ç Ë ? ? ? ? ? ? ? (A.3)

F_t is the full selection fishing mortality in the pot fishery, ? ? ? ? is the full selection fishing mortality in the trawl fishery, ? ? ? ? is the total selectivity for animals in length-class *j* by the pot fishery during year *t*, ? ? ? ? is the selectivity for animals in length-class *j* by the trawl fishery, $?^{?}_{??}$ is the probability of retention for animals in length-class *j* by the pot fishery during year t. Pot bycatch mortality of 0.2 and groundfish bycatch mortality of 0.65 (average of trawl (0.8) and fish pot (0.5) mortality) were assumed.

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

The equilibrium stock abundance is

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

The equilibrium abundance in 1960, $\underline{N}_{1960}$, is

$$\underline{?}_{????} \quad (? - ??)^{??}\underline{?} \tag{A.5}$$

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 1996 to 2015 in equation (A.5) to obtain the equilibrium solution under only natural mortality in year 1960, and then projected the equilibrium abundance under natural mortality with recruitment estimated for each year after 1960 up to 1985 with removal of retained catches during 1981/82 to 1984/85.

Growth Matrix
The growth matrix **X** is modeled as follows:

$$?_{??} \quad \frac{?\,?_{??}}{?_{??}} \quad (\grave{E} - ?_{?}) \quad \begin{matrix} ?? & ? & ? \\ ?? & ? & ? \\ ?? & ? & ? \end{matrix} \tag{A.6}$$

where:

$$?_{??} \quad ?_{?} \begin{cases} \int_{??}^{??\,??} ?\;(?\,|?_{?}\,?^{?}\;\;?? & ?? \;?\;\; ? \\ \int_{??\,??}^{??\,??} ?\;(?\,|?_{?}\,?^{?}\;\;?? & ?? \;?\;\; ?\;\; ? \\ \int_{??\,??}^{?} ?\;(?\,|?_{?}\,?^{?}\;\;?? & ?? \;?\;\; ? \end{cases},$$

? (?|?? ??) ?/???? ?? Æ???? ?/√?? , and

μ? is the mean growth increment for crabs in size-class *i*:

μ? ω? ω? * ??. (A.7)

ω? , ω? , and ? are estimable parameters, and j_1 and j_2 are the lower and upper limits of the receiving length-class *j* (in mm CL), and ?? is the mid-point of the contributing length interval *i*. The quantity ? ? is the molt probability for size-class *i*:

Û? ? / ? ? ???τ???? (A.8)

where *c* and *d* are parameters.

Selectivity and retention

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

?? ? / ?? ???? Æ? ???? ??/???? ??? ? (A.9)

where θ_{95} and θ_{50} are the parameters of the selectivity/ retention pattern (Mark Maunder, unpublished generic crab model). In the program, we re-parameterized the denominator (θ_{95} - θ_{50}) to ŨÜ Æ?????? so that the difference is always positive.

b) A dome shaped total selectivity is considered for certain scenarios.

Ñ? ? ? / ?? ??? ?????? ???? È − ? / ?? ??? ?????? ???? ? ?/? (A.10)

where d_j and d_k are two sets of slopes for the first (increasing) and second (decreasing) logistic curves for the pre- and post-rationalization periods; θ_{50} and θ_{95} are inflection points for the first (increasing) and second (decreasing) curves; and *X* is the maximum of the first two terms on the right hand side (Quinn and Deriso 1999).

Recruitment

Recruitment to length–class *i* during year *t* is modeled as ??? ????Ω? where Ω? is a normalized gamma function

??? ? ?(?|?$_?$?$_?$) $\dfrac{?^{?????}?^{??}}{??^{??}\,\Gamma Æ?}$ (A.11)

with α_r and β_r (restricted to the first six 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 the various parameters).

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

Likelihood components

Catches

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

$$LL_r^{catch} = \lambda_r \sum_t \{\ell n(\sum_j \hat{C}_{t,j} w_j + c) - \ell n(\sum_j C_{t,j} w_j + c)\}^2 \quad \text{(A.12a)}$$

??$^{?????}_{?}$?$_?$ ∑$_?$ Ú Æ∑$_?$?$_{???}$?$_?$? − Ú Æ∑$_?$?$_{???}$?$_?$? $^?$ (A.12b)

??$^{?????}_{??}$?$_{??}$ ∑$_?$ Ú Æ∑$_?$??$_{???}$?$_?$? − Ú Æ∑$_?$??$_{???}$?$_?$? $^?$ (A.12c)

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; $C_{t,j}$, ?$_{??}$, and ??$_{??}$ 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.

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:

??$^{????}_{?}$?$_{?????}$? Ë∑$_?$ Ú ?É? ??$^{?}_{??}$?$^{?}_{?}$?? ∑$_?$ $\dfrac{??? Æ ? ? ?? ? ? ? ?? Æ ?? ? ? ? ? ? ?}{??? ?? ?? ??}$? (A.13)

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 ?? ? ?$^{?}_{?}$ is the model-estimate of $CPUE_t^r$:

??? ?? ?? ∑? ?? ?? ?? ?? − Œ??? ??? ???? ??? ???? (A.14)

in which ?? is the catchability coefficient during the *k*-th time period (e.g., pre- and post-rationalization time periods), σ_e is the extent of over-dispersion, *c* is a small constant to prevent zero values (0.001), and ?????? is the weight assigned to the catch-rate data. We used the same likelihood formula (A.14) for fish ticket retained catch rate indices for scenario 3 model.

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

??? ÚÆ ???? (A.15)

Length-composition data

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

$$LL_r^{LF} = 0.5\sum_t\sum_j \ell\text{n}(2\pi\sigma_{t,j}^2) - \sum_t\sum_j \ell\text{n}\left[\exp\left(-\frac{(P_{t,j}-\hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right)+0.01\right] \qquad \text{(A.16)}$$

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.:

??? ??? / ∑? ???

??? ??? / ∑? ???

???? ???? / ∑? ????

(A.17)

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

$$\sigma_{t,j}^2 = \left[(1-P_{t,j})P_{t,j} + \frac{0.1}{n}\right] / S_t \qquad \text{(A.18)}$$

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 males that were released in year t that were in length-class j when they were released and were recaptured after y years, and $\underline{\tilde{V}}_{j,t,y}$ be the vector of recaptures by length-class from the males that were released in year t that were in length-class j when they were released and were recaptured after y years. The multinomial likelihood of the tagging data is then:

?? ?   ?? ??? ∑? ∑? ∑? ∑? ? ? ? ? ? ?? ?? ? ? ? ? (A.19)

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

$$\underline{\hat{\rho}}_{j,t,y} \propto \underline{s}^{T}[\mathbf{X}]^{y}\underline{\Omega}^{(j)} \tag{A.20}$$

where $\underline{\Omega}^{(j)}$ is a vector with $V_{j,t,y}$ at element j and 0 otherwise, $\mathbf{X}$ is the growth matrix, and ?? is the total selectivity vector (Punt et al. 1997).

This likelihood function is predicted on the assumption that all recaptures are in the pot fishery and the reporting rate is independent of the size of crab. The expected number of recaptures in length-class l is given by:

$$r_l = \sum_t \sum_j \frac{s_l[\mathbf{X}^t]_{j,l}}{\sum_{l'} s_{l'}[\mathbf{X}^t]_{j,l'}} \sum_k V_{j,k,t} \tag{A.21}$$

The last term, $\sum_k V_{j,k,t}$, is the number of recaptured male crab that were released in length-class j after t time-steps. The term $\sum_j \frac{s_l[\mathbf{X}^t]_{j,l}}{\sum_{l'} s_{l'}[\mathbf{X}^t]_{j,l'}} \sum_k V_{j,k,t}$ is the predicted number of animals recaptured in length-class l that were at liberty for t time-steps.

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):

$$P_1 = \lambda_F \sum_t (\ell\mathrm{n}F_t - \ell\mathrm{n}\bar{F})^2 \tag{A.22}$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ell\mathrm{n}F_t^{Tr} - \ell\mathrm{n}\bar{F}^{Tr})^2 \tag{A.23}$$

$$P_3 = \lambda_R \sum_t (\ell\mathrm{n}\varepsilon_t)^2 \tag{A.24}$$

?? ?????? * ???? (A.25)

Standardized Residual of Length Composition

??? Ç? ???? $\frac{??? ???}{? ????}$ (A.26)

Output Quantities

Harvest rate

Total pot fishery harvest rate:

?? $\frac{\Sigma ??? ???? ? ????}{\Sigma ??? ? ??}$ (A.27)

Exploited legal male biomass at the start of year *t*:

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \tag{A.28}$$

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

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

? ? ?? Σ??? ?????????? ???????? − Æ??? ??? ???? ?(?????)? ?? (A.29)

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

For estimating the next year limit harvest levels from current year stock abundances, a limit F' value is needed. Current crab management plan specifies five different Tier formulas for different stocks depending on the strength of information available for a stock, for computing F' (NPFMC 2007). For the golden king crab, the following Tier 4 formula is applied to compute F':

(a) If $MMB_t \geq M\overline{M}B$, $F' = \gamma M$,

(b) If $MMB_t < M\overline{M}B$ and $MMB_t > 0.25 M\overline{M}B$,

$$F' = \gamma M \frac{(\frac{MMB_t}{M\overline{M}B} - \alpha)}{(1-\alpha)} \tag{A.30}$$

(c) If $MMB_t \leq 0.25 M\overline{M}B$, $F' = 0$

where γ is a constant multiplier of M, α is a parameter, and $M\overline{M}B$ is the mean mature male biomass estimated for a selected time period and used as a ??? ????? for the Tier 4 stock.

Because projected MMB_t depends on the intervening retained and discard catch (i.e., MMB_t is estimated after the fishery), an iterative procedure is applied using Equations A.29 and A.30 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' value.

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

Parameter	Number of parameters
Initial conditions:	
Length specific equilibrium abundance ? ???? ?	17 (estimated)
Fishing mortalities:	
Pot fishery, F_t	1985–2015 (estimated)
Mean pot fishery fishing mortality, $\bar{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2015 (the mean F for 1989 to 1994 was used to estimate trawl discards back to 1985 (estimated)
Mean groundfish fishery fishing mortality, $\bar{F}^{Tr}$	1 (estimated)
Selectivity and retention:	
Pot fishery total selectivity ???	2 or 3 (1985–2004; 2005+) (estimated)
Pot fishery total selectivity difference, ???????	2 (1985–2004; 2005+) (estimated)
Pot fishery retention ???	2 (1985–2004; 2005+) (estimated)
Trawl fishery selectivity ????	2 (1985–2004; 2005+) (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, ?	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, 0.225yr^{-1})
Recruitment:	
Number of recruiting length-classes	5 (pre-specified)
Distribution to length-class, α_r, β_r	2 (estimated)
Median recruitment, ?	1 (estimated)
Recruitment deviations, ε_t	56 (1961–2016) (estimated)
FOFL	1 (estimated)
Fishery catchability, *q*	2 (1985–2004; 2005+) or 3 (1985–1994; 1995–2004; 2005+) (estimated)
Likelihood weights (coefficient of variation)	Pre-specified, varies by scenario

Table A2. Specifications for the weights with corresponding coefficient of variations* in parentheses for each scenario for EAG and WAG. select. phase = selectivity phase.

Weight	Value						
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
Catch:							
Retained catch for 1981–1984 and/or 1985–2015, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch for 1990–2015, λ_T	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250
Groundfish bycatch for 1989–2015, λ_{GD}	0.3 (2.072)	0.3	0.3	0.3	0.3	0.3	0.3
Catch-rate:							
Observer legal size crab catch-rate for 1995–2015, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	1	1
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	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase

Table A2 continued.

Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2 (0.533)	2	2	2	2	2	2
Posfunction (to keep abundance estimates always positive), $?_{?????}$	1000 (0.022)	1000	1000	1000	1000	1000	1000
Tagging likelihood	EAG individual tag returns	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data

$$* \ ?????????????? \ ????????? \quad ?? \quad ? \ \overline{?^{\frac{?}{?6? \ ?????}} - È}$$

Table A2 continued.

Weight	Value				
	Scenario 8	**Scenario 9**	**Scenario 10**	**Scenario 11**	**Scenario 12**
Catch:					
Retained catch. λ_r	500 (0.032)	500	500	500	500
Total catch, λ_T	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250
Groundfish bycatch, λ_{GD}	0.3 (2.072)	0.3	0.3	0.3	0.3
Catch-rate:					
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1
Penalty weights:					
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select.phase	Initially 1000, relaxed to 0.001 at phases ≥ select.phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select.phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select.phase
Recruitment, λ_R	2(0.533)	2	2	2	2
Posfunction (to keep abundance estimates always positive), ??????	1000 (0.022)	1000	1000	1000	1000
Tagging likelihood	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data

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 Table 1 for EAG and Table 15 for WAG. The weighted length frequency data were used to distribute the catch into 5-mm size intervals. The length frequency data for a year were weighted by each sampled vessel's catch as follows. The *i*-th length-class frequency was estimated as:

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

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

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

Observer data have been collected since 1988 (Moore et al. 2000; Barnard et al. 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91–2014/15 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 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 (Tables 2 and 17). For model-fitting following a September 2016 CPT meeting suggestion, the CPUE time series was restricted to 1991/92–2015/16. 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, 1991/92–2004/05 and 2005/06–2015/16, 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 a number of scenarios. Because of the lack of soak time data previous to 1990, we estimated the CPUE index considering a limited set of explanatory variables (e.g., vessel, captain, area, month) and fitting the lognormal GLM to fish ticket data (Tables 3 and 18).

Observer CPUE index:

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012). We considered the negative binomial GLM on positive and zero catches to select the explanatory variables. The response variable CPUE is the observer sample catch record for a pot haul. The negative binomial model uses the log link function for the GLM fit. Therefore, we assumed the null model to be

Ú (Ò ?) Ö ?? (B.2)

where Year is a factorial variable.

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

Ú Æ Ò ? Ö ?? (ÑÜ Ù??) Ü ? ? Í ?? Ó Ų??

?? ?? (Ï ??) ÆÓ ÑÜ Ù??? , (B.3)

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

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

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

? ? Æ???? ????????????????? ????? ???? ? ????????????? / ????? ??????????? (B.4)

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

The final models for EAG were:

Ú Æ Ò Ö ÆÑÜ Ù Ê (B.5)

for the 1991/92–2004/05 period [θ=1.33, ? Ç É É with ns(Soak, 3) forced in]

Ú (Ò) Ö (ÑÜ Ù È) ???? (B.6)

for the 2005/06–2015/16 period (θ ÉÇÉ ? ÇÈÉÊ).

The final models for WAG were:

Ú (Ò) Ö (ÑÜ Ù) (B.7)

for the 1991/92–2004/05 period (θ=0.96, ? ÇÈ ÉÈ

Ú Æ Ò Ö ÆÑÜ Ù È (B.8)

for the 2005/06–2015/16 period [θ=1.13, ? Ç Ë É ÆÑÜ Ù È Ü Ø

Figures B.1 and B.8 depict the trends in nominal and standardized CPUE indices for the two CPUE time series for EAG and WAG, respectively. Figures B.2-B.3 and B.9-B.10 show the diagnostic plots for the fits for EAG and WAG, respectively. The deviance and QQ plots support good fits to EAG and WAG data by GLM using the negative binomial error distribution. Figures B.4-B.7 and B.11-B.13 depict CDI plots of the predictor variables for EAG and WAG, respectively.

Fish Ticket CPUE index:

We also fitted the lognormal GLM for the fish ticket retained CPUE time series 1985/86 – 1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables. The final model for EAG was:

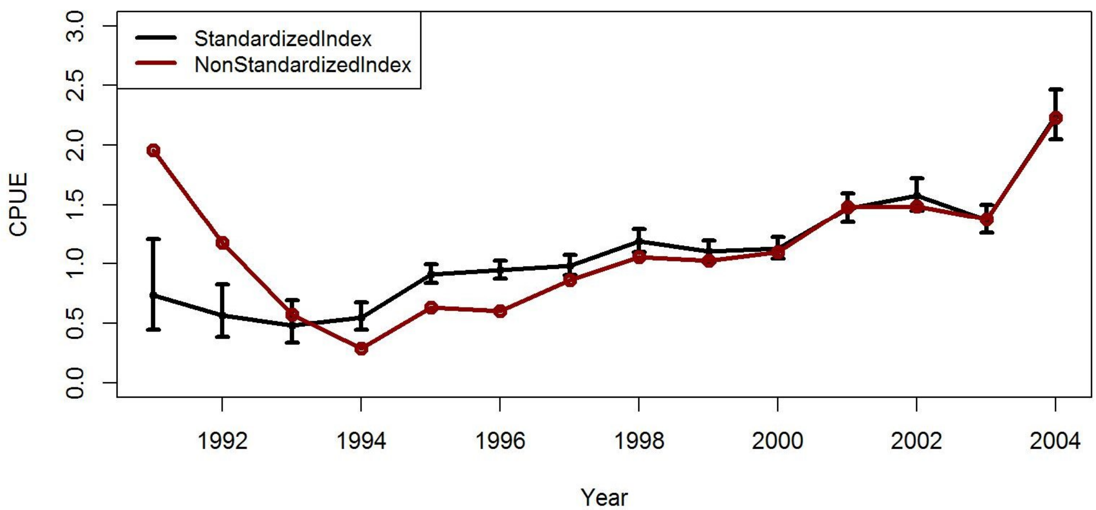
Ú (Ò) Ö Ó Ú Ü ? Ç Ë È (B.9)

and those for WAG was:

Ú (Ò) Ö Ó Ú ? Ç Ë È (B.10)

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

Figures B.14 and B.16 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively. Figures B.15 and B.17 show the QQ plots for the fits for EAG and WAG, respectively. The QQ plots support reasonable fits to EAG and WAG data by GLM using the lognormal error distribution.



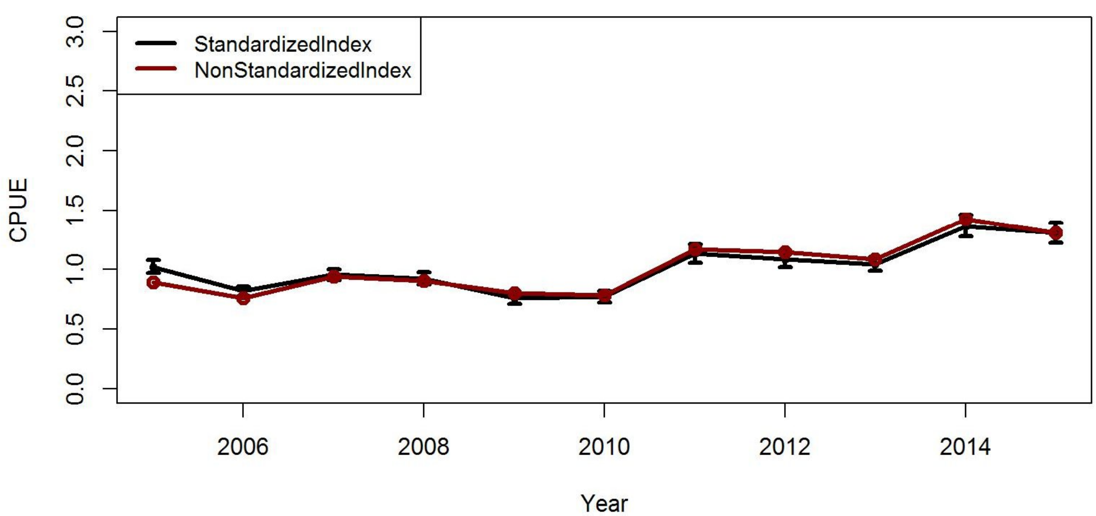


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). Top panel: 1991/92–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Standardized indices: black line and non-standardized indices: red line.

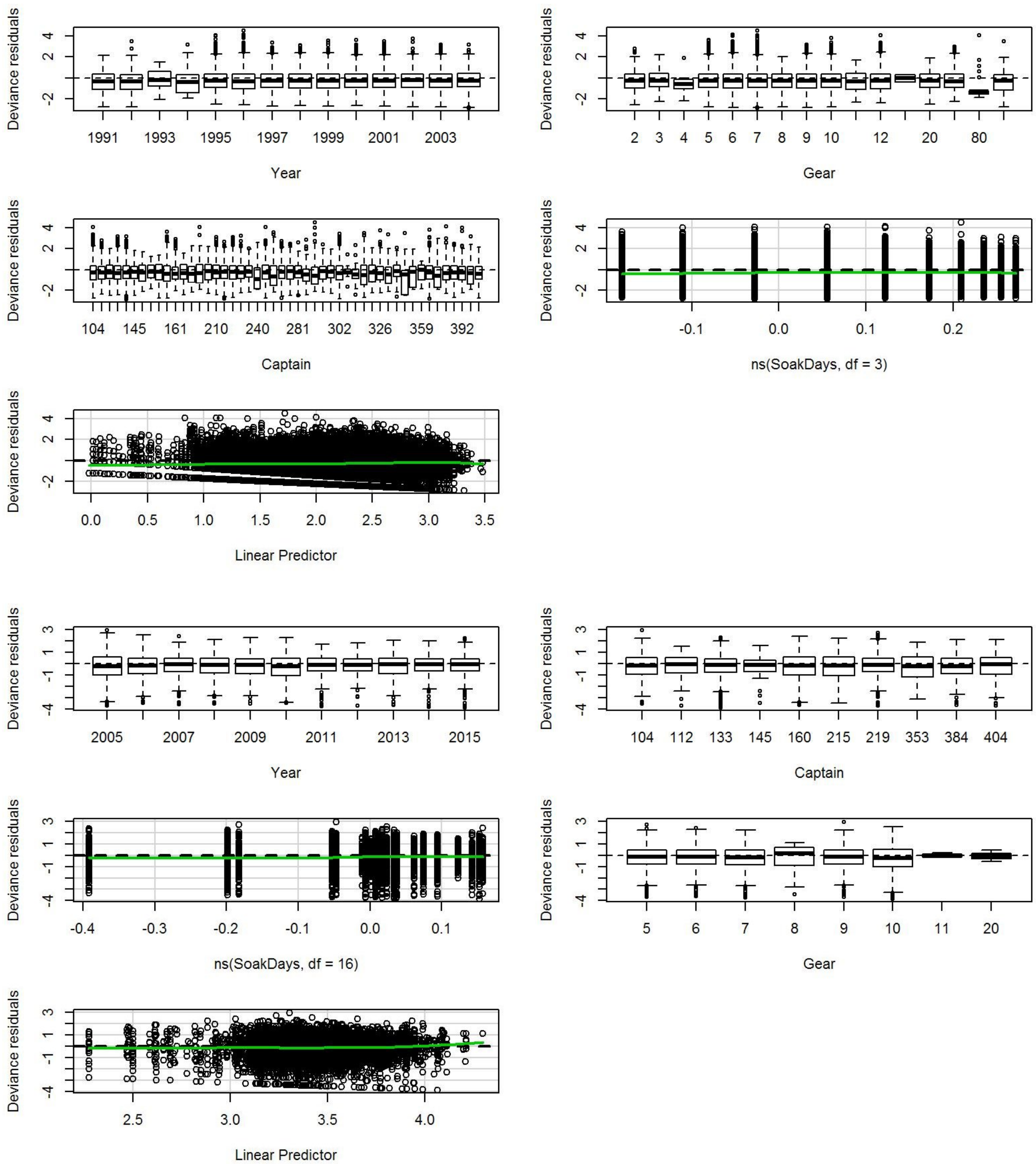


Figure B.2. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 1991/92–2004/05 (top) and 2005/06–2015/16 (bottom) periods were used. The solid green lines are the loess smoother through the plotted values.

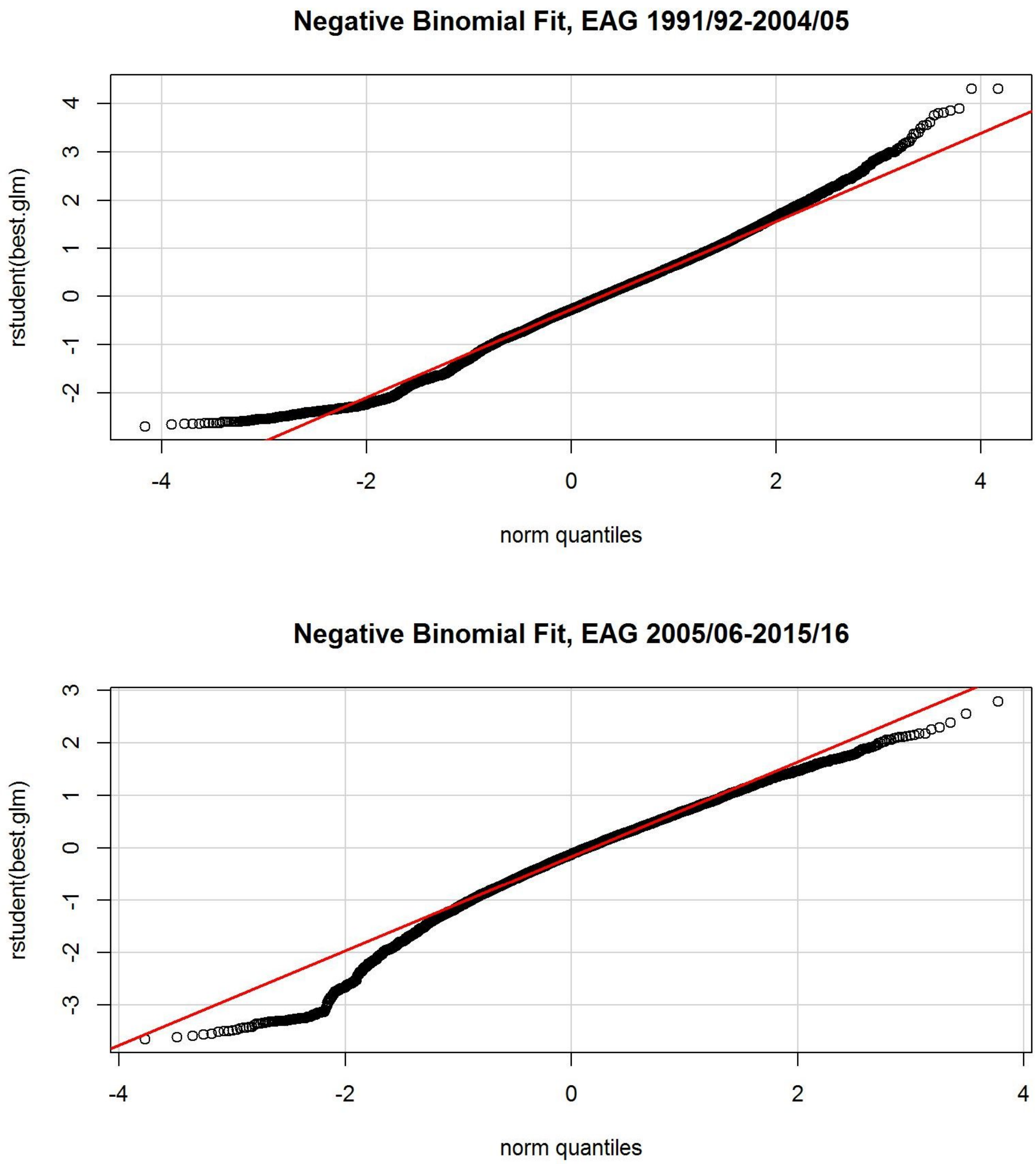


Figure B.3. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1991/92–2004/05 and bottom panel is for 2005/06–2015/16.

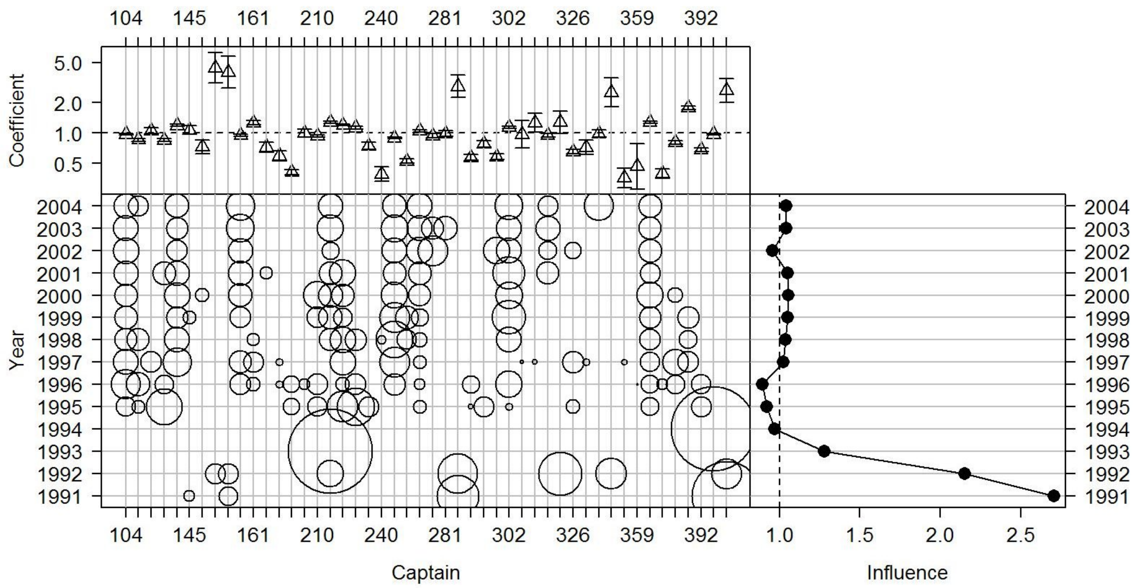


Figure B.4. CDI plot for Captain for the negative binomial fit to 1991/92–2004/05 data for EAG.

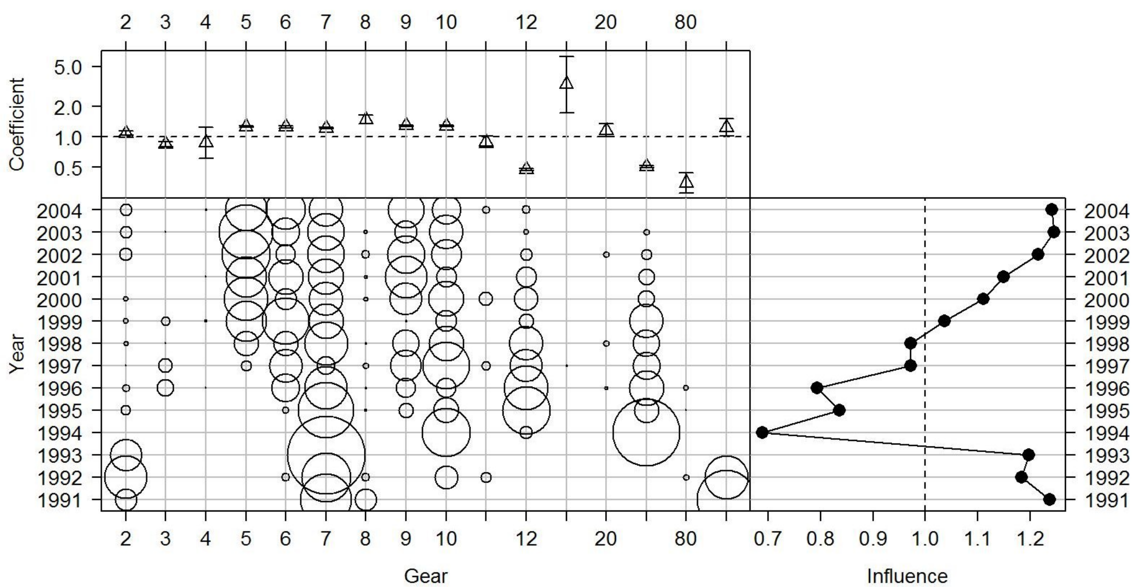


Figure B.5. CDI plot for Gear for the negative binomial fit to 1991/92–2004/05 data for EAG.

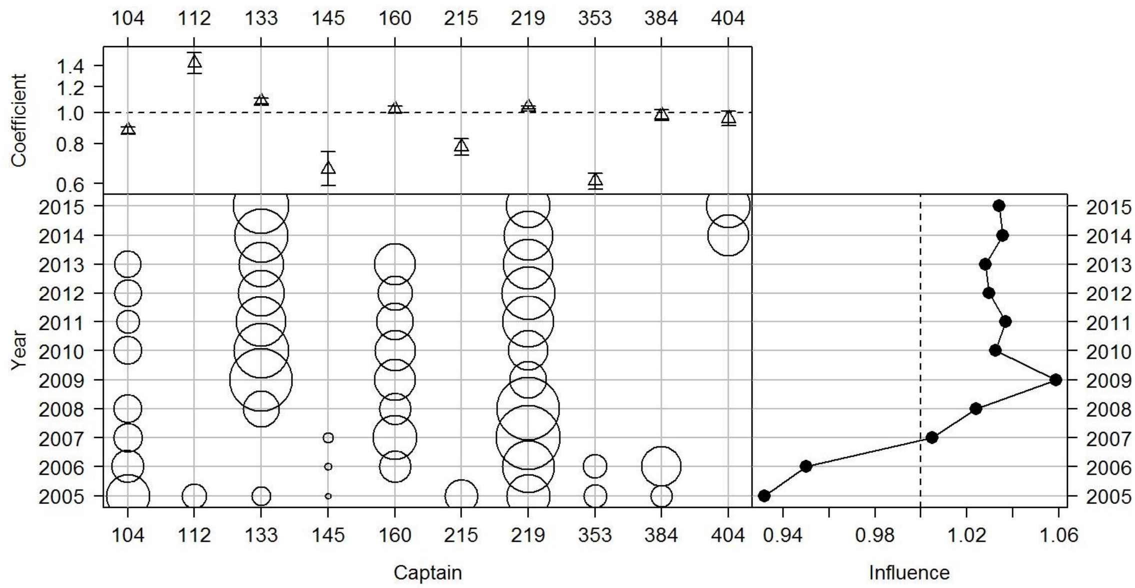


Figure B.6. CDI plot for Captain for the negative binomial fit to 2005/06–2015/16 data for EAG.

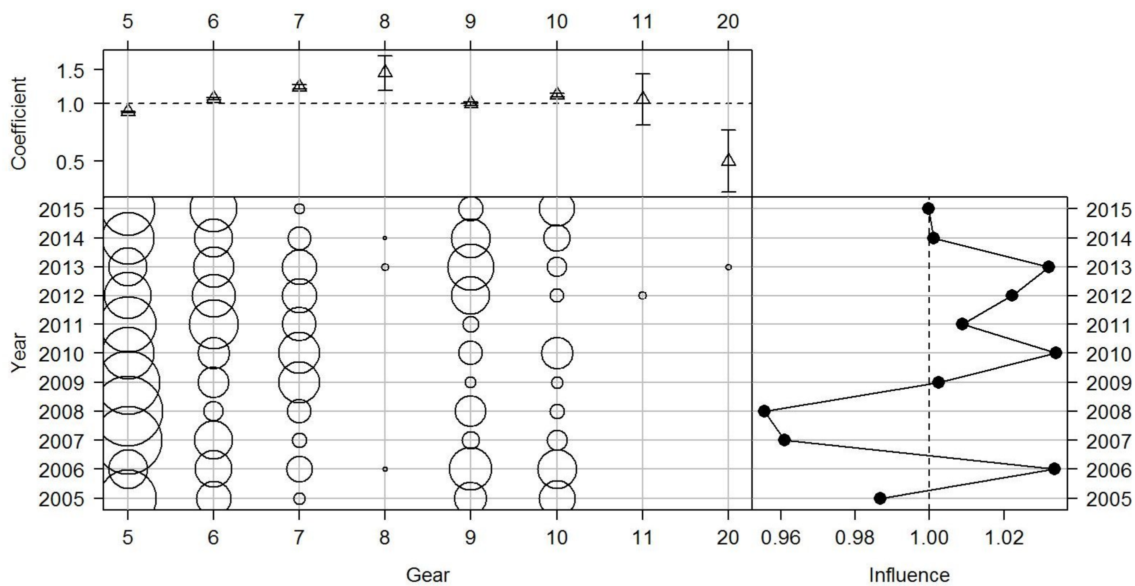


Figure B.7. CDI plot for Gear for the negative binomial fit to 2005/06–2015/16 data for EAG.

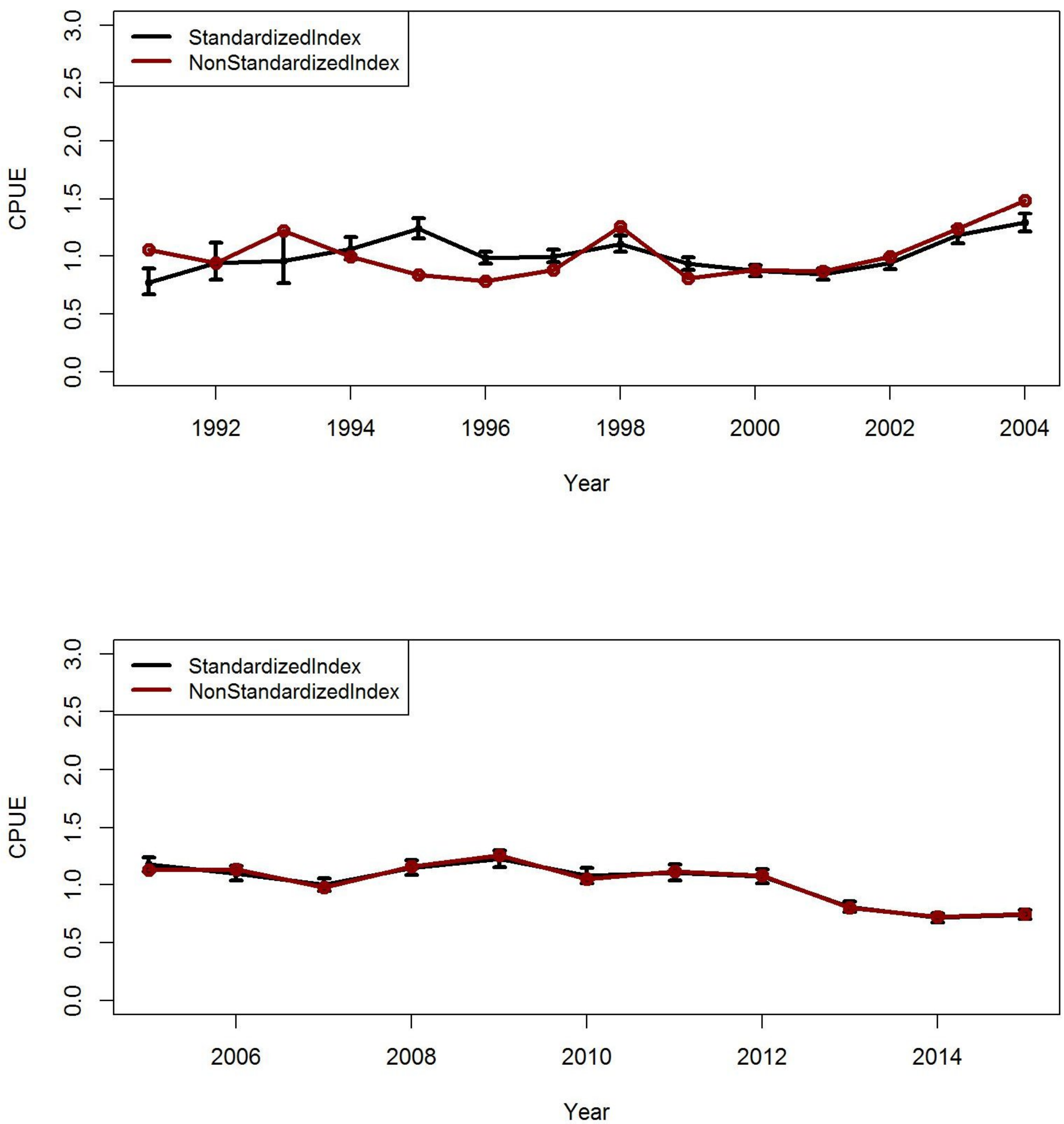


Figure B.8. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). Top panel: 1991/92–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Standardized indices: black line and non-standardized indices: red line.

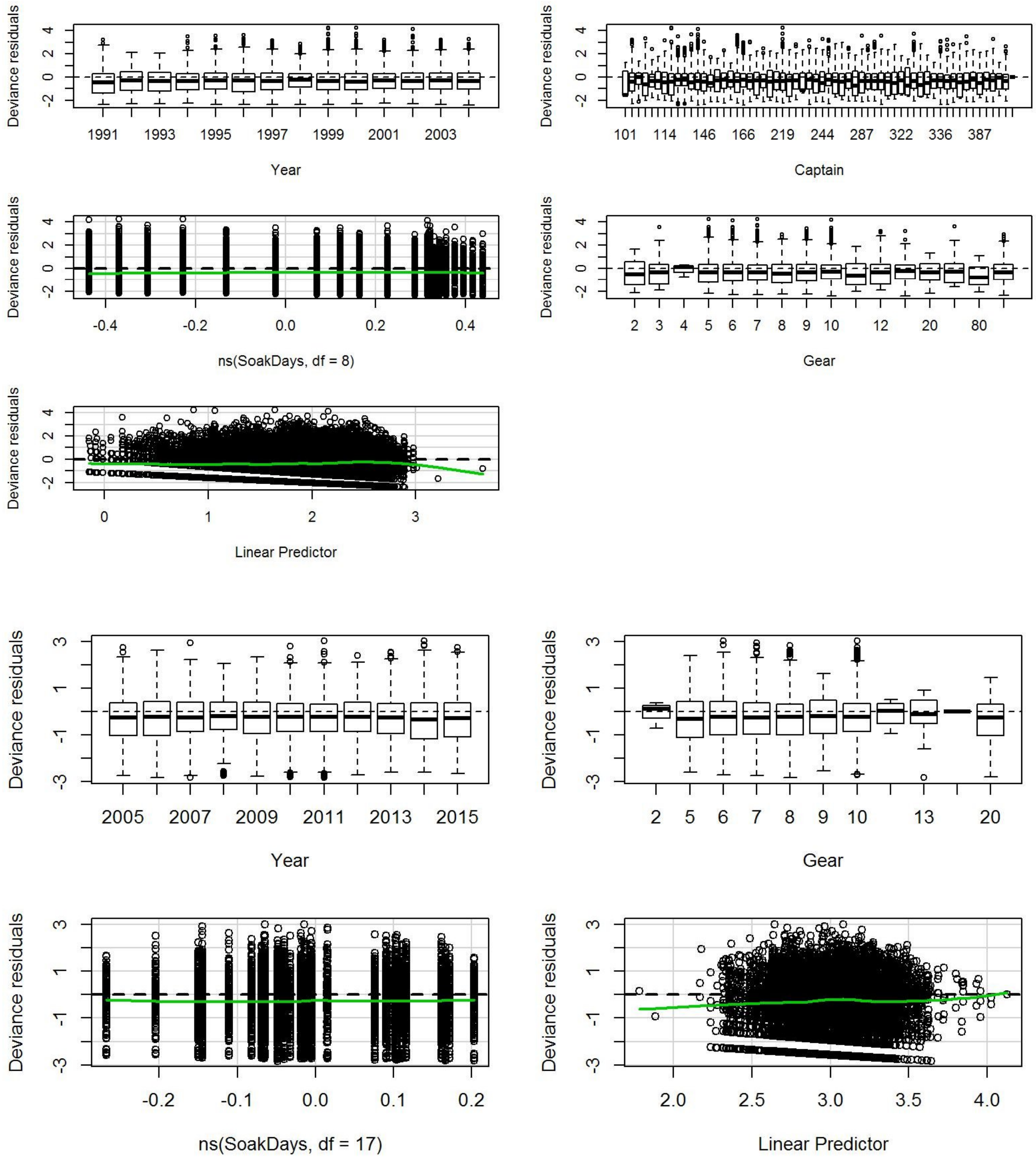


Figure B.9. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from WAG for 1991/92–2004/05 (top) and 2005/06–2015/16 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.

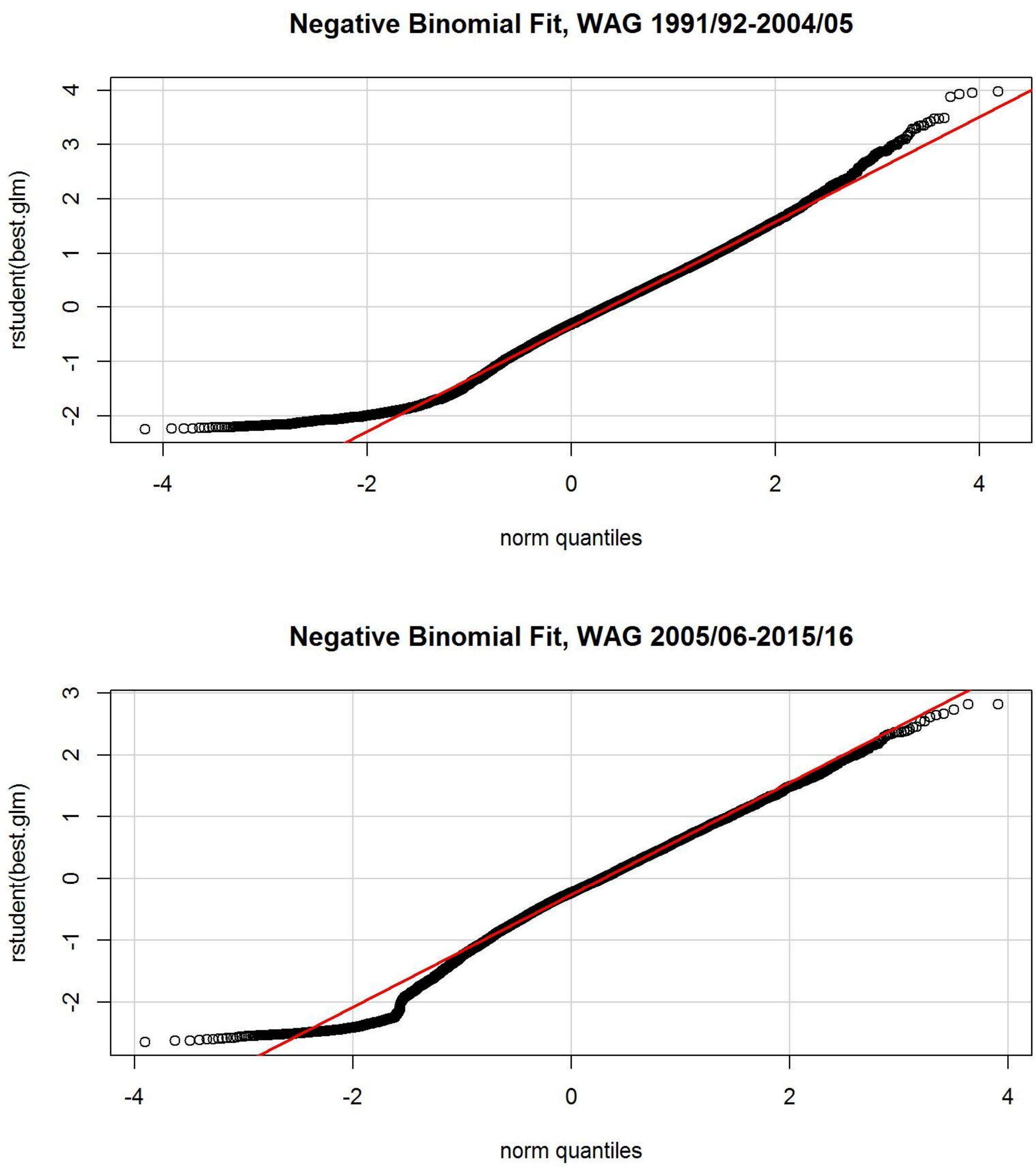


Figure B.10. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1991/92–2004/05 and bottom panel is for 2005/06–2015/16.

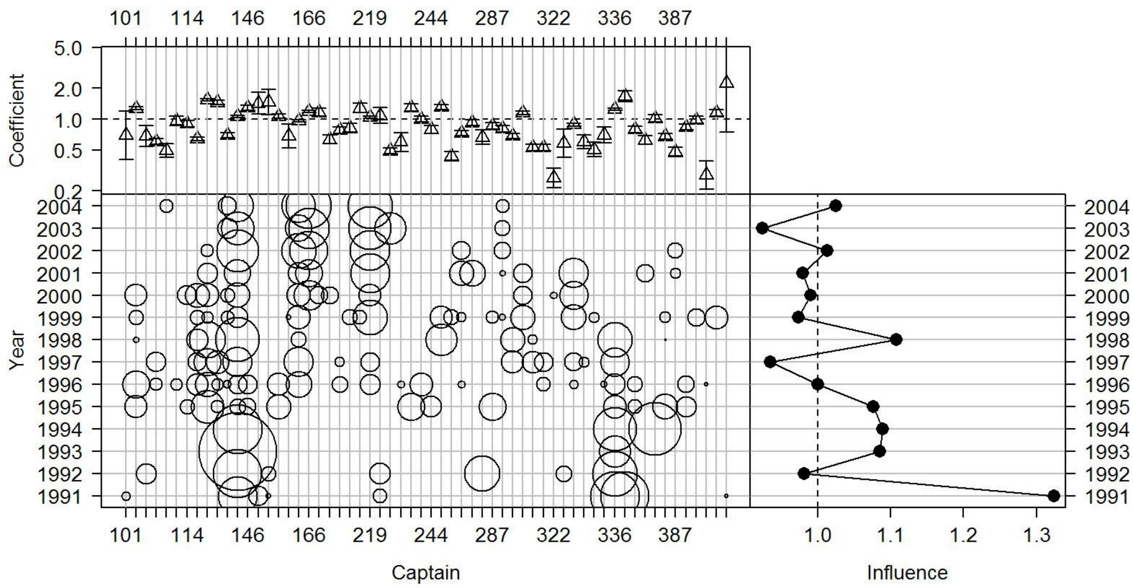


Figure B.11. CDI plot for Captain for the negative binomial fit to 1991/92–2004/05 data for WAG.

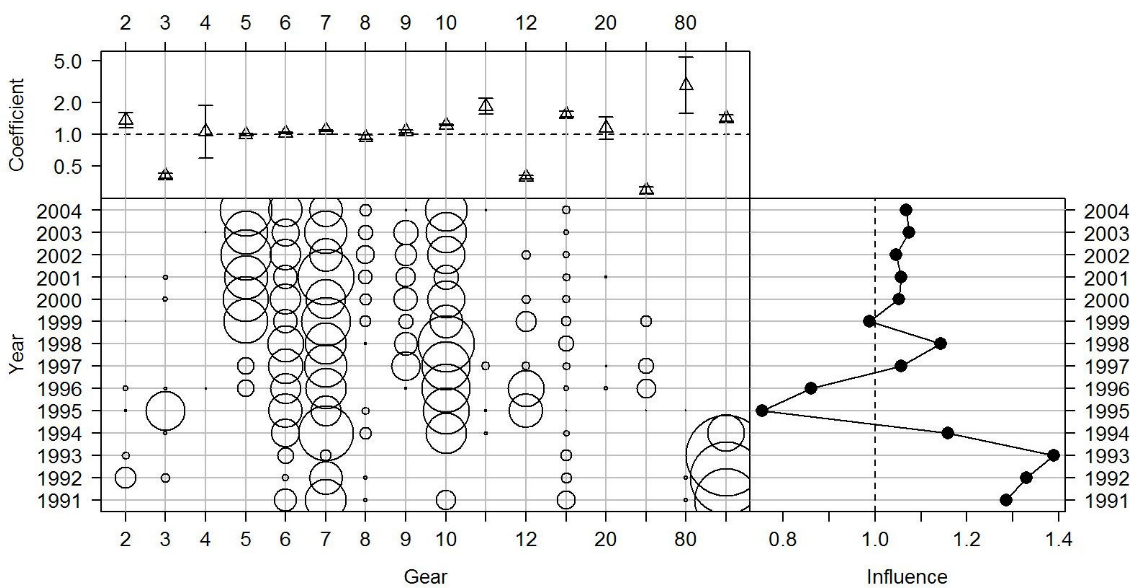


Figure B.12. CDI plot for Gear for the negative binomial fit to 1991/92–2004/05 data for WAG.

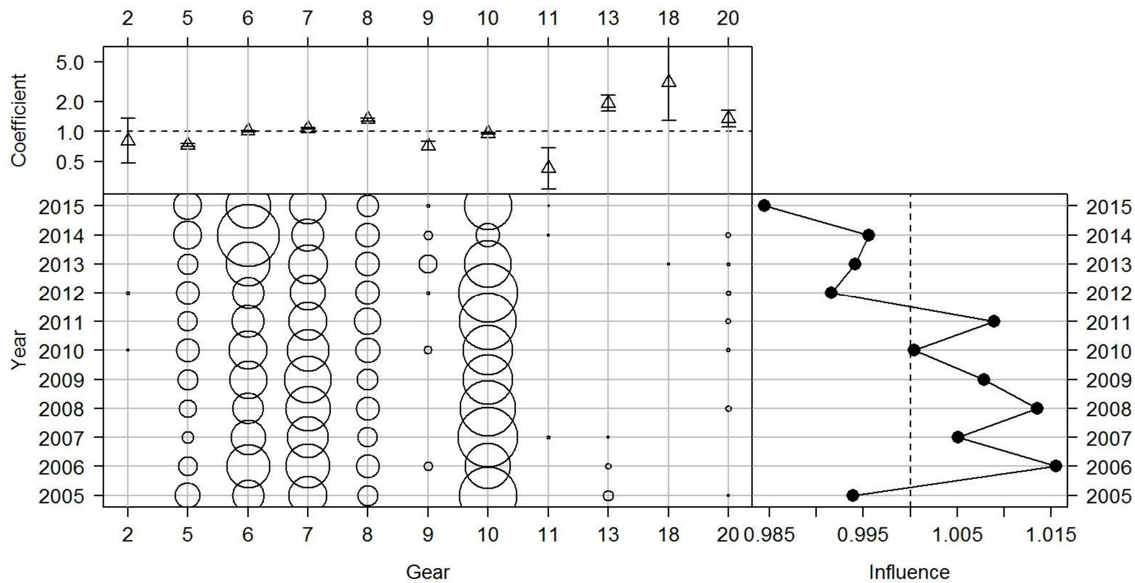


Figure B.13. CDI plot for Gear for the negative binomial fit to 2005/06–2005/15 data for WAG.

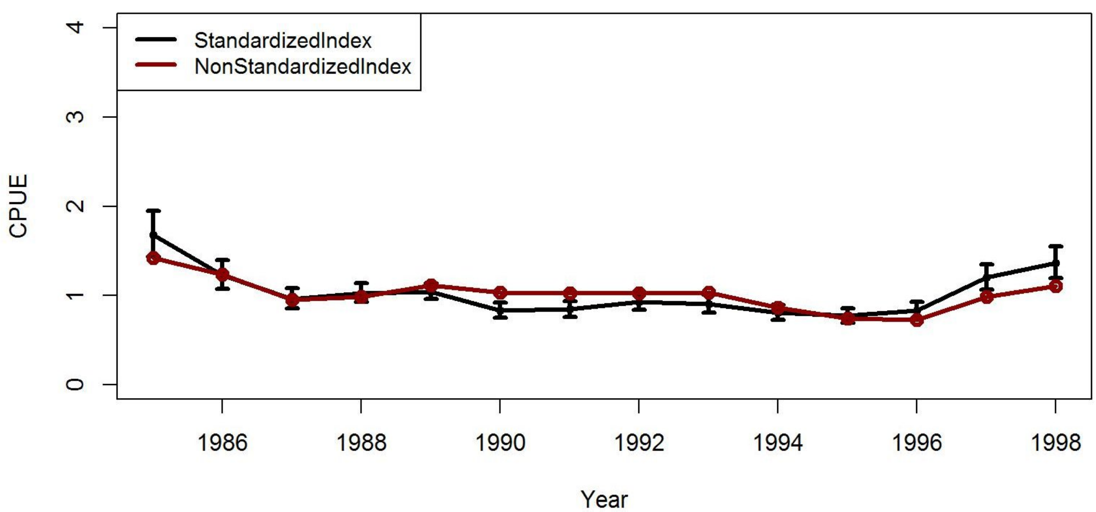


Figure B.14. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

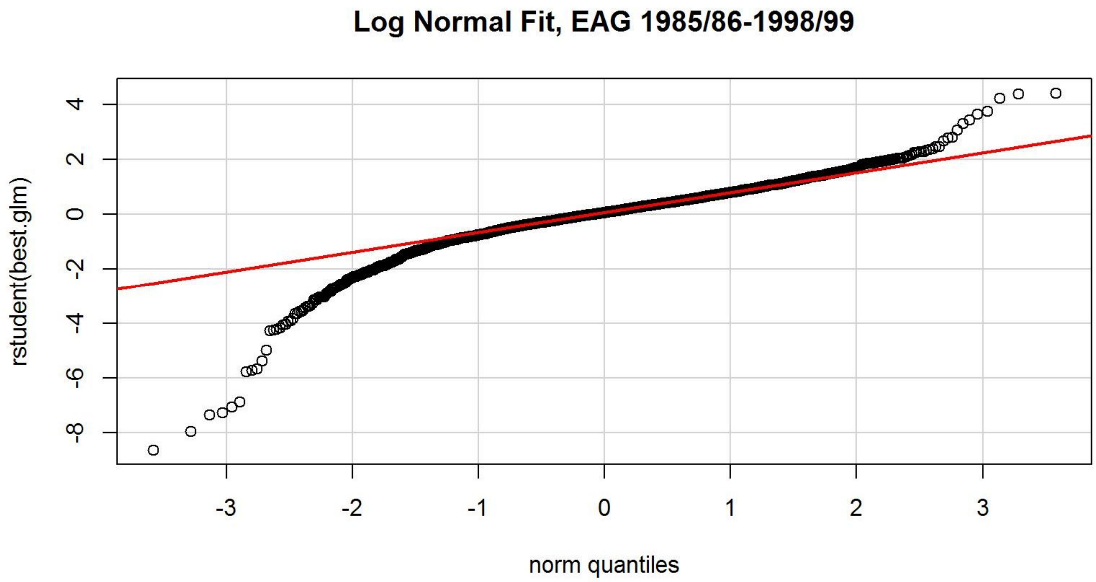


Figure B.15. Studentized residual plots for lognormal GLM fit to EAG golden king crab fish ticket CPUE data; 1985/86–1998/99.

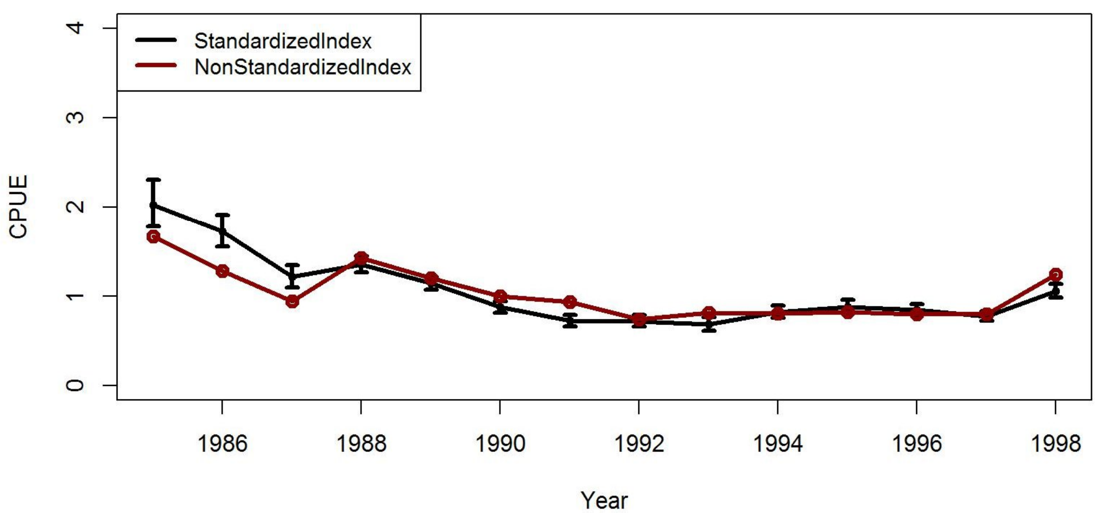


Figure B.16. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG; 1985/86–1998/99 fish ticket data. Standardized indices: black line and non-standardized indices: red line.

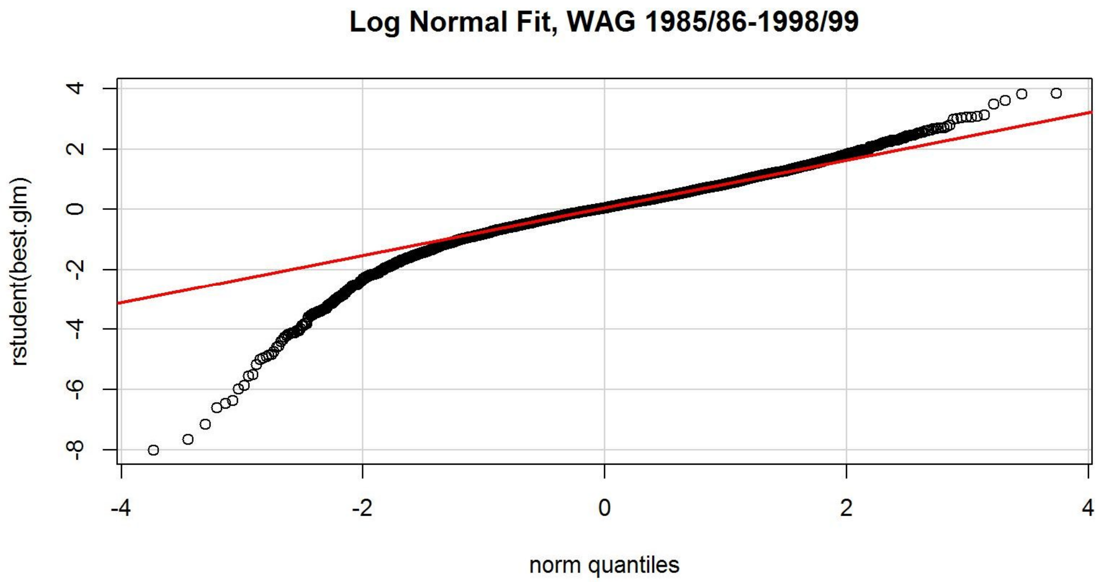


Figure B.17. Studentized residual plots for lognormal GLM fit for WAG golden king crab fish ticket CPUE data; 1985/86–1998/99.