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

Draft report for the September 2014 (Fall) Crab Plan Team Meeting

Prepared by:

M.S.M. Siddeek[1], J. Zheng[1], and D. Pengilly[2]

[1] Alaska Department of Fish and Game , Division of Commercial Fisheries, P.O. Box 115526, Juneau, Alaska 99811
[2] Alaska Department of Fish and Game, Division of Commercial Fisheries, 351 Research Court, Kodiak, AK 99615

## *Executive Summary*

### 1. *Stock*

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

### 2. *Catches*

The Aleutian Islands golden king crab commercial fishery developed in the early 1980s; the harvest peaked in 1986/87 at 5.9 and 8.8 million pounds, respectively, for EAG and WAG. Catches have been steady since 1996/97 following implementation of total allowable catches (TACs) of 3.0 (EAG) and 2.7 (WAG) million pounds. The TACs were increased to 3.15 and 2.835 million pounds for the two respective regions for the 2008/09 fishery following an Alaska Board of Fisheries (BOF) decision. These levels are below the limit TACs determined under Tier 5 criteria (considering 1991–1995 mean catch as the limit catch) under the new crab management plan. TACs were further increased by another BOF decision to 3.31 million pounds for EAG and 2.98 million pounds for WAG for the 2012/13 fishery. The fishery has harvested close to TAC levels since 1996/97.

### 3. *Stock biomass*

Estimated mature male biomass (MMB) has decreased following peak levels during the early years of the directed fishery and then increased and stabilized in recent years for both EAG and WAG. There was a tendency to decrease during the last few years in both areas. The lowest levels of MMB for EAG were observed in 1991 and MMB systematically increased since 1997. The pattern was similar for WAG with the lowest levels of MMB in 1991 –1992. Stock trends reflected the fishery standardized CPUE trends in both regions.

### 4. *Recruitment*

The number of recruits to the model size group has shown fluctuating trends for both EAG and WAG. For EAG, model recruitment was highest in 1991, and lowest in

1989 –1990 while for WAG, model recruitment was highest in 1986 and 1993 and lowest in 1992 for different scenarios.

### *5. Management performance*

The model has not yet been used for making any management decisions.

### *6. Basis for the OFL*

The length-based model developed for Tier 4 analysis estimates MMB each year for the period February 15, 1986 through February 15, 2013 and projects to February 15, 2014 for OFL and ABC determination. This model proposes the following OFL and ABCs based on using the 1986–2013 mean MMB as the reference biomass ($B_{ref}$) and a projected MMB on Feb 15, 2014. The total OFL and ABC estimates are provided for four scenarios denoted by 1), 2), 3), and 4).

EAG:

Biomass in million pounds

| Season | Tier | $B_{ref}$ | Current MMB | $MMB/MMB_{ref}$ | $F_{OFL}$ | Years to define $B_{ref}$ | M | OFL | ABC (P*=0.49) |
|---|---|---|---|---|---|---|---|---|---|
| 1) 2014/15 | 4a | 12.165 | 15.883 | 1.31 | 0.18 | 1986–2013 | 0.18 | 2.326 | 2.314 |
| 2) 2014/15 | 4a | 12.438 | 16.318 | 1.31 | 0.18 | 1986–2013 | 0.18 | 2.401 | 2.389 |
| 3) 2014/15 | 4a | 13.207 | 18.192 | 1.38 | 0.18 | 1986–2013 | 0.18 | 2.707 | 2.691 |
| 4) 2014/15 | 4a | 14.045 | 19.746 | 1.41 | 0.18 | 1986–2013 | 0.18 | 2.947 | 2.930 |

Biomass in 1000 t , and total OFL and ABC are in t.

| Season | Tier | $B_{ref}$ | Current MMB | $MMB/MMB_{ref}$ | $F_{OFL}$ | Years to define $B_{ref}$ | M | OFL | ABC (P*=0.49) |
|---|---|---|---|---|---|---|---|---|---|
| 1) 2014/15 | 4a | 5.518 | 7.204 | 1.31 | 0.18 | 1986–2013 | 0.18 | 1055.137 | 1049.510 |
| 2) 2014/15 | 4a | 5.642 | 7.402 | 1.31 | 0.18 | 1986–2013 | 0.18 | 1089.059 | 1083.442 |
| 3) 2014/15 | 4a | 5.991 | 8.252 | 1.38 | 0.18 | 1986–2013 | 0.18 | 1227.845 | 1220.636 |
| 4) 2014/15 | 4a | 6.371 | 8.957 | 1.41 | 0.18 | 1986–2013 | 0.18 | 1336.857 | 1328.983 |

WAG:

Biomass in million pounds

| Season | Tier | $B_{ref}$ | Current MMB | $MMB/MMB_{ref}$ | $F_{OFL}$ | Years to define $B_{ref}$ | M | OFL | ABC (P*=0.49) |
|---|---|---|---|---|---|---|---|---|---|
| 1) 2014/15 | 4a | 9.166 | 10.502 | 1.15 | 0.18 | 1986–2013 | 0.18 | 1.515 | 1.508 |
| 2) 2014/15 | 4a | 9.422 | 10.722 | 1.14 | 0.18 | 1986–2013 | 0.18 | 1.547 | 1.539 |
| 3) 2014/15 | 4a | 10.115 | 12.170 | 1.20 | 0.18 | 1986–2013 | 0.18 | 1.771 | 1.761 |
| 4) 2014/15 | 4a | 10.641 | 12.831 | 1.21 | 0.18 | 1986–2013 | 0.18 | 1.888 | 1.878 |

Biomass in 1000 t, and total OFL and ABC are in t.

| Season | Tier | $B_{ref}$ | Current MMB | $MMB/MMB_{ref}$ | $F_{OFL}$ | Years to define $B_{ref}$ | M | OFL | ABC (P*=0.49) |
|---|---|---|---|---|---|---|---|---|---|
| 1) 2014/15 | 4a | 4.158 | 4.764 | 1.15 | 0.18 | 1986–2013 | 0.18 | 687.367 | 684.173 |
| 2) 2014/15 | 4a | 4.274 | 4.864 | 1.14 | 0.18 | 1986–2013 | 0.18 | 701.656 | 698.161 |
| 3) 2014/15 | 4a | 4.588 | 5.520 | 1.20 | 0.18 | 1986–2013 | 0.18 | 803.421 | 798.936 |
| 4) 2014/15 | 4a | 4.827 | 5.820 | 1.21 | 0.18 | 1986–2013 | 0.18 | 856.522 | 851.903 |

7. ***Probability density functions of OFL***

   Assuming a lognormal distribution of total OFL, we determined the cumulative distributions of OFL and selected the median as the OFL.

8. ***The basis for the ABC recommendation***

   See the ABC section

9. ***A summary of results of any rebuilding analysis:***

   Not applicable.

## A. Summary of Major Changes

1. ***Changes (if any) to management of the fishery***

   None.

2. ***Changes to input data***

   (a) Data update: The 2011/12 and 2012/13 commercial fishery retained and total catch, observer nominal total CPUE and fishing effort (pot lifts) to calculate total catches for 1990/91–2012/13, and groundfish discarded catch by size are added. The commercial retained size frequency and observer sample size frequency data are recalculated weighting by sampled vessel's catch.

   (b) New data: EAG male tag-recapture data by size and time at large for 1991, 1997, 2000, 2003, and 2006 releases are considered for the WAG model analysis as well.

   (c) Observer pot sample legal size crab CPUE are standardized by the generalized linear model (GLM) with the negative binomial link function, separately for 1995/96–2004/205 and 2005/06–2012/13 periods (Details in the September 2013 CPT presentation on CPUE standardization).

   (d) Fish ticket retained catch CPUE are standardized by the GLM with the lognormal link function considering only the year effect. The 1985-1998 indices are used in the model for scenarios 3 and 4.

3. ***Changes to assessment methodology***

   None. The same model has been improved. The WAG size transition matrix was also estimated using tag-recapture data for EAG.

4. ***Changes to assessment results***

   Not applicable because the model has not been used previously.

## B. Response to 2012 and 2013 SSC and CPT comments

We present the responses to the model workshop and subsequent CPT and SSC comments:

### February 2013 NPFMC modelling workshop

The workshop focused on two aspects of the stock assessment: (a) the standardization of CPUE, and (b) the model on which the stock assessment is based.

(a) The standardization of CPUE

1. The workshop concluded that soak time affected the catch rate per pot lift and hence should be included in the CPUE standardizations (see Figure 6). The commercial CPUE data has no soak time information. Hence only observer data can be used for standardization.

   *Response: We included soak time as a factor whether selected or not selected by the GLM on observer data. We restricted the observer data to 1995/96–2012/13 because prior to 1995 the data by different crab categories (sublegal, legal non- retained and legal retained) were unreliable. Furthermore, we estimated CPUE indices separately for the 1995/96–2004/05 and 2005/06–2012/13 periods because of the large difference in soak time during the pre- and post-rationalization periods.*

2. It is known that the industry is modifying its fishing practices to minimize the catch of sublegal crab, which means that an index based on the catch of sublegal crabs is not likely to reflect sub legal abundance because of a trend towards reduced vulnerability in this component of the catch Consequently, a CPUE index for sublegal crab should not be included in the base assessment.

   *Response: We did not consider the sub legal crab in the subsequent CPUE index analyses.*

3. (a) The catch rate indices for the pre- and post-rationalization period should be treated as separate series, and (b) soak time should be forced into the CPUE standardization in the same way that year is forced. The analysis should be presented at the May 2013 CPT meeting.

   *Response: We followed the suggestions and estimated the CPUE indices accordingly.*

(b) The GKC model

1. The workshop identified discrepancies between the model description and the code, which implemented in the model (e.g., how growth was modelled and whether old and new shell crabs were represented separately in the model) as well as problems with how the model was coded.

   *Responses:*

   *(i) In the current assessment model, we considered two approaches to estimate the size transition matrix from the tag release-recapture lengths:*

   *Approach 1: We used a composite linear growth increment model with a gamma stochastic variability function (three parameters) and a pseudo-molt probability model (two parameters)) to calculate the size transition matrix.*

*We used this size transition matrix on crab population dynamics without separating the crabs into new and old shell*

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*Approach 2: We followed Approach 1 without the pseudo molt probability component. That is modeling the size transition matrix only with a linear growth increment and a gamma stochastic distribution.*

*We used this size transition matrix on crab population dynamics without separating the crabs into new or old shell.*

*(ii) We unified the model coding for EAG and WAG (see appendix A) to reflect that the equations in Appendix A are followed in the coding.*
*(iii) We avoided using the "if" statements especially for parameters, instead used "posfunction" in the ADMB code.*
*(iv) We relaxed the pot fishery F estimation likelihood weights in the last phase of optimization.*

May 2013 CPT

1. Estimate the overdispersion parameter when applying the negative binomial GLM, either using maximum likelihood or by profile likelihood. An initial estimate of the overdispersion parameter can be obtained by applying a GLM with a Poisson error model.

   *Response: Following Fox and Weisberg (2011), we employed a grid search method to identify the optimum overdispersion parameter value corresponding to the lowest AIC.*

2. The Q-Q plots for all models appear poor. The authors improved the Q-Q plots for the log-normal component of the model by deleting data points with large residuals. This may be acceptable, but further justification is required, and the features of the rejected data points need to be summarized.

   *Response: We did not trim the post-rationalization period data for the final CPUE indices estimation (see the response to the September 2013 CPT comments below)*

3. Pearson residuals are hard to interpret for binomial and negative binomial GLMs. Use of deviance residuals should be examined.

   *Response: In the final analysis, we used deviance residuals for the negative binomial fits.*

4. The performance of the binomial model can be explored by allocating the predicted positive catch proportions to bins (e.g., in steps of 0.025), and computing the observed proportion of positive catches for each bin. A plot of the average predicted proportion versus observed proportion of positive catches should be linear.

   *Response: We included observed versus predicted catch proportion plot to investigate the performance of the binomial model for the September CPT presentation.*

5. The influence plots should be provided.

   *Response: We presented influence plots at the September CPT presentation.*

September 2013 CPT

The CPT discussed the CPUE analysis and recommended that :

1. The negative binomial approach without trimming should be used to construct a CPUE index for the May 2014 meeting.

   *Response: We standardized the CPUE separately for the two periods, 1995/96–2004/05 and 2005/06–2012/13, using the negative binomial model in the GLM. We did not trim the post rationalization period data for the CPUE index estimation. This is used in the current assessment model.*

2. A survey is needed to provide a better index of abundance and information on recruitment for stock assessment.

   *Response: This is a good idea and needs to be considered by the industry and the agencies.*

May 2014 CPT

1. Comment: Authors have substantially down-weighted the tagging data likelihood.. The CPT requests that the basis for any weight be provided.
   *Response: Increased the weights to 0.5 in the current runs. In the absence of CV estimate, this weight was selected arbitrarily to be at the center of 1 and 0.*
2. Comment: The fishery F "devs" for the groundfish fishery F are weighted differently between the assessments for the WAG and EAG. The rationale for this is unclear.
   *Response: We kept the weights same in these runs in this report.*
3. Comment: The "beta" parameter of the growth model is set to 0.74. However, the basis for this selection is unclear. If this parameter cannot be estimated within the assessment, it should be set to the estimate obtained by fitting the growth model to tagging data based on an analysis conducted independently of fitting the assessment model.
   *Response: We used the normal distribution to estimate the size transition matrix in these runs. So, this issue does not arise now.*
4. Comment: The variance of the residuals of the fit to the total catch in numbers changes over time. Consideration should be given to weighting these data by the number of pots or the proportion of the catch measured each year.
   *Response: We used lower weights in the previous runs. Now we have increased the weights for the total catch likelihood. This issue does not arise now.*
5. Comment: It is unclear why the model based on scenario 2 fits the data for the WAG worse than model based on scenario 1 given the former model has more parameters.
   *Response: Resolved in the current runs.*
6. Comment: Show the predicted catches for all years and not just the years with data.
   *Response: We have done this in the current runs.*
7. Comment: The fit to the CPUE data appears overdispersed. However, this plot does not show the impact of the estimated extent of overdispersion but needs to.
   Response: *We have done this in the current runs.*
8. Comment: Equation 15 should be corrected to account for the fact that some animals were recaptured more than one year after they were released.

*Response: We have corrected this equation following Andre Punt provided equation and implemented it in the program codes. The equation number has changed to (17) in Appendix A.*

9. Comment: The residual patterns for the fits to the total catch length-frequencies are very similar for the EAG and WAG. This is unexpected if these are independent populations, and efforts should be made to understand why this occurs.
   *Response: This pattern has changed in the current runs.*
10. Comment: The fishing mortality rates are relatively high (~0.4) and remarkably similarly between the WAG and EAG. The analysts should explore (e.g. using a likelihood profile on the mean fishing mortality in the directed fishery) what in the data suggests this and moreover how the model is able to estimate absolute biomass given what amount to relatively flat CPUE indices (using perhaps a likelihood profile on current abundance).
    *Response: The F rates are not high and not similar between the two regions in the current runs. We have provided the likelihood profiles of current MMB and mean F in this document (Figures 30-31 for EAG and 59-60 for WAG).*
11. Comments: The weighting factors should be specified as CVs and not as lambda values to assist with interpretation of how much weight is assigned to each likelihood component.
    *Response: We have provided the weighting factors with the corresponding CVs in this document.*
12. Comment: Ensure that the document is clear between 'input effective sample sizes' and 'estimated effective sample sizes'.
    *Response: We revised the corresponding figure titles accordingly.*

## C. Introduction

1. Scientific name: Golden king crab, *Lithodes aequispinus.*
2. Distribution: In Alaska golden king crab are distributed in the Aleutian Islands, on the continental slope of the eastern Bering Sea, and in around the Gulf of Alaska to southeastern Alaska.
3. Evidence of stock structure: There is no direct evidence of separate stock structure in the Aleutian Islands.
4. Life history characteristics relevant to management: There is a paucity of information on golden king crab life history characteristics due in part to the deep depth distribution (~200- 1000 m) and the asynchronous nature of life history events(Otto and Cummiskey 1985, Somerton and Otto 1986). The reproductive cycle is thought to be approximately 24 months in length and at any one time, ovigerous females can be found carrying egg clutches in highly disparate developmental states (Otto and Cummiskey 1985). Females carry large, yolk-rich eggs which hatch into lecithotrophic (non-feeding) larvae that are negatively phototactic (Adams and Paul 1999). Molting and mating are also asynchronous and protracted (Shirley and Zhou 1997; Otto and Cummiskey 1985) with some

indications of seasonality (Hiramoto 1985). Molt increment has been described for Southeast Alaska, where it is 16.5 mm CW per molt (Koeneman and Buchanan 1985), and males begin to skip molt when sexual maturity is reached. Thus, the inter-molt period is protracted, which creates difficulty in determining annual molt probability (Watson et al., 2002). Male size-at-maturity varies among stocks (reviewed by Webb 2014) and declines with increasing latitude from about 130 mm CL in the Aleutian Islands to 90 mm CL in St. Matthew Is. district (Somerton and Otto 1986). Along with a lack of annual survey data, limited stock-specific life history stock information prevents development of the standard length-based assessment model.

5. Brief summary of management history: Since 1996, the Alaska Department of Fish and Game (ADF&G) has divided the Aleutian Islands golden king crab fishery into eastern and western districts 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 are managed with a constant annual guideline harvest level or total allowable catch (3.0 million pounds for EAG and 2.7 million pounds for WAG). In 2008, however, the total allowable catch was increased by the BOF decision to 3.15 and 2.83 million pounds for EAG and WAG, respectively (an approximately 5% increase in TAC). Because of a lack of information on total removal of crabs, the TAC was determined to be the retained catch. Additional management measures include a male-only fishery and a minimum legal size limit (152.4 mm CW or approximately 136 mm CL) which is at least one annual molt increment larger than the 50% maturity length of 120.8 mm CL for males (Otto and Cummiskey 1985). Daily catch and catch-per-unit effort (CPUE) are determined in-season to monitor fishery performance and progress towards the TAC. Figures 1 to 5 provide the time series of catches, CPUE, and the geographic distribution of catch during recent fishing seasons.. Increases in CPUE were observed beginning in 2000and again with the implementation of crab rationalization in 2005. This is likely due to changes in gear (crab fishermen, personal communication, July 1, 2008), increased soak time (Figure 6), and decreased competition from the

reduced number of vessels fishing. Decreased competition could allow crab vessels to target only the most productive fishing areas. In 2012, a BOF decision increased the TAC levels to 3.31 million pounds for EAG and 2.98 million pounds for WAG for the 2012/13 fishery.

## *D. Data*

1. Summary of new information:
   a. Data are updated by adding the 2011/12 and 2012/13 commercial fishery retained and estimated total catch by size, observer CPUE, and male groundfish discard catch by size to the time series.
   b. New data are added by including male tag-recapture data by size and time at large for 1991, 1997, 2000, 2003, and 2006 releases. The tagging experiments were conducted in the EAG area. However, following one of the CPT suggestions, we used the same tagging data for the EAG and WAG modeling.

2. Available catch and tagging data.

| **Data set** | **Years** | **Data type(s)** |
|---|---|---|
| Retained pot catch | 1985–2012 | Catch by length |
| Total pot catch | 1990–2012 | Catch by length |
| Groundfish discarded catch | 1995–2012 | Catch by length |
| Observer legal size crab CPUE | 1995–2012 | Independently estimated annual CPUE index (by negative binomial GLM) with standard error |
| Pot Fishery legal size CPUE | 1985–2012 | Independently estimated annual CPUE index with standard error considering only the year effect (by lognormal GLM). The 1985-1998 indices were used in the model for scenarios 3 and 4. |
| Observer total (entire pot catch sample) CPUE | 1990–2012 | Nominal total CPUE data for estimating total pot catch |
| Tag-recapture data | 1991, 1997, 2000, 2003, 2006 | Release-recapture length and time-at-large |

a. A time series of retained and total catch, groundfish fishery discard mortality, and pot fishery effort (Table 1 for EAG and Table 16 for WAG).

b. Time series of pot fishery and observer nominal retained and total CPUE, estimated CPUE index, and nominal CPUE standardized by the CPUE index (Table 2 for EAG and Table 17 for WAG).

c. Information on length compositions (Figures 8 a, b –10 a, b for EAG and Figures 34–39 for WAG).

d. Survey biomass estimates are not available for the area because no systematic surveys, covering the entire fishing area, have occurred.

f. Other time series data: None.

3. Length-weight relationship: $W = al^b$ where a= $2.988*10^{-4}$, b = 3.135.

4. Information on any data sources available, but were excluded from the assessment: None.

*Catch and CPUE data*

The commercial catch and length frequency distribution were estimated from Alaska Department of Fish and Game (ADF&G) landing records and dockside sampling (ADF&G, 2008, 2011). The annual retained catch, total catch, groundfish discarded mortality are provided in Table 1 for EAG and Table 16 for WAG. The weighted length frequency data were used to distribute the catch into different (5-mm) size intervals. The length frequency data for a year were weighted by the sampled vessel's catch as follows. The *i*-th length-class frequency was estimated as:

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

where $k$ = number of sampled vessels in an year; $LFQ_{j,i}$ = number of crabs in the *i*-th length-class in the sample from *j*-th vessel. $C_j$ = 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 the catch by length-class.

The annual total catch (in number of crabs) was estimated by the observer nominal total CPUE multiplied by the total effort (number of pot lifts). The weighted relative length frequency distribution of the observer samples was estimated using equation

(1). Observer measurement of crab ranges 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 corresponds to this size range was used to multiply the total catch (number of crabs). This total number of crabs was distributed into length-class using the weighted relative length frequency. The size range was further restricted to 101-170+ mm CL for modeling purpose because groundfish bycatch data have a number of zero entries at the 171-185 mm CL range. 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 can be deducted from this total and multiplied by an appropriate handling mortality (we used a 20% handling mortality (Siddeek et al., 2005)) to obtain the 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 are not comprehensive in the initial years, so a shorter time series of data for the period 1990–2012 was selected for this analysis. 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. Annual mean nominal CPUE of retained and total crabs were estimated considering all sampled pots within each season(Tables 2 and 17). For model fitting the CPUE time series was further restricted to 1995–2012 because the reliability of categorization of crabs by observers improved after 1995. Length-specific CPUE data collected by observers provide information on a wider size range of the stock than does 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 regulation (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (increase in escape web on the pot door to 9" since 1999), and improvement in observer recording in Aleutian Islands golden king crab fisheries (since 1998). These changes prompted us to consider two sets of catchability and selectivity (total and retained) parameters for the periods 1985–2004 and 2005–2012.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985–1998 legal size standardized CPUE as a separate likelihood component in scenarios 3 and 4. Because of the lack of soak time data previous to 1990, we estimated the CPUE index considering only the year effect by fitting the lognormal GLM to fish ticket data (Tables 3 and 18). For these two scenarios, we considered three sets of catchability, 1985–1998, 1999–2004, and 2005–2012, but the same two sets of selectivity parameters.

## E. Analytic Approach

1. *History of modeling approaches for this stock*

   The model is under development, and yet to be accepted for OFL and ABC setting.

2. *Model Description*

   a. The underlying population dynamics model is male-only and length-based (Appendix A). This model combines commercial retained catch, total catch, groundfish fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, groundfish discard catch size composition, and tag recaptures by release-recapture length to estimate stock assessment parameters.

      The data series used in the current assessment for EAG ranges from 1985/86 to 2012/13 for retained catch biomass and size composition; 1995/96 to 2012/13 for standardized legal size crab observer CPUE index; 1985/86 to 1998/99 for standardized legal size crab fish ticket CPUE index; 1990/91 to 2012/13 pot total catch biomass and total catch length composition; 1995/96 to 2012/13 for groundfish fishery male bycatch biomass and size composition; and 1991, 1997, 2000, 2003, and 2006 releases and up to 2012 recapture time period for tagging information.

The data series used for the WAG ranges are the same as those for EAG.

b. Software: AD model builder (Fournier et al., 2012).

c.–f. Details are given in Appendix A.

g. Critical assumptions and consequences of assumption failures: We kept $M$ constant at 0.18, the groundfish selectivity to full selection (selectivity = 1), and discard of legal size males is not considered. These fixed values invariably reduced the number of model parameters to be estimated and helped in convergence. We assumed different $q$'s (scaling parameter for standardized CPUE in the model) and logistic selectivity patterns for different periods for the pot fishery,1985 to < 1998 (for Scenarios 3 and 4), 1999 to < 2004 and >= 2005. Because of the lack of an annual stock survey we relied heavily on standardized CPUE indices and catch information to determine the stock abundance trends in both regions. The CPUE standardization followed the following GLM fitting procedure for EAG and WAG, respectively:

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. We assumed the null model to be

$$CPUE_i = Year_{y_i} + \varepsilon_i \tag{2}$$

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

$$CPUE_I = Year_{y_i} + ns(Soak_{si}, df) + Month_{m_i} + Area_{ai} + Vessel_{vi} + Captain_{ci} + Gear_{gi} + ns(Depth_{di}, df) + ns(VesSoak_{vsi}, df) + \varepsilon_i\ , \tag{3}$$

We used a log link function and a dispersion parameter ($\theta$) value in the GLM fitting process (September 2013 CPT presentation).

The final models for EAG were:

*CPUE = Year+Gear+Captain+Soak* (forced in) (4) for the 1995-2004 period, and

*CPUE = Year + Captain + Soak + Gear* (5) for the 2005-2012 period

The final models for WAG were:

*CPUE = Year + Captain + Gear + Soak* (6) for the 1995-2004 period, and

*CPUE = Year + Captain + Depth+ Soak* (forced in) (7) for the 2005-2012 period.

Figures 7 and 33 depict the trends in nominal and standardized CPUE indices for EAG and WAG, respectively.

We also used the standardized CPUE indices to transform the nominal CPUE values into standardized CPUE values by first calculating the geometric mean of nominal CPUE for each period (1995-2004 and 2005-2012) and then multiplying each period's annual CPUE indices by the respective period's geometric mean (Starr, 2012). The geometric mean formula is

$$\widehat{GM}_{period\ i} = e^{\frac{\sum_j \ln(CPUE_j)}{n_i}} \qquad (8)$$

Where GM is the geometric mean of CPUE for the period i and $n_i$ is the number of years in period i.

Standardized nominal CPUE standardized data are presented in Tables 2 and 17 respectively, for EAG and WAG.

We also fitted the lognormal GLM for fish ticket retained CPUE data considering only the year effect for the 1985 to 2010 CPUE series and used the 1985 to 1998 indices with standard errors in the model under Scenarios 3 and 4 (Tables 3 and 18). Lognormal model is as follows:

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year}_{y_i} + \varepsilon_i \tag{9}$$

h. Changes to any of the above since the previous assessment: Does not apply for this assessment since the model has not yet been used.

i. Model code has been checked by one of the co-authors and validated. The code is available from the author.

3. *Model Selection and Evaluation*

a. Description of alternative model configurations:

We considered seven similar scenarios for EAG (details are in Table 4) and WAG (details are in Table 19) and presented OFL and ABC results for four scenarios. The four scenarios revolved around:

Scenario 1: Determination of size transition matrix ignoring pseudo molt probability;

Scenario 2: Determination of size transition matrix considering logistic pseudo molt probability.

Scenario 3: Determination of size transition matrix ignoring pseudo molt probability and including the commercial fishery standardized CPUE likelihood component; and

Scenario 4: Determination of size transition matrix considering logistic pseudo molt probability and including the commercial fishery standardized CPUE likelihood component.

b. The entire time period 1985/86–2012/13 was used to define $B_{current}/B_{ref}$.

c. Progression of results: Model was not previously used, so, not applicable.

d. Evidence of search for balance between realistic and simpler models: Unlike annually surveyed stocks, Aleutian Islands golden king crab stock biomass is difficult to track and essential biological parameters are assumed based on knowledge from red king crab stock (e.g., *M* of 0.18 and pot fishery handling mortality rate of 0.2) due to a lack of species/stock specific information. We fixed a number of model parameters after initially running the model with all parameters floated to reduce the number of parameters to be estimated (e.g., groundfish bycatch selectivity parameters were fixed). The seven scenarios also considered different configuration of parameters to select the parsimonious models. The detail results of the first four scenarios are provided in a number of tables and figures.

e. Convergence status and criteria: ADMB default convergence criteria.

f. Table of the sample sizes assumed for the size compositional data:

We estimated the input effective sample sizes as min(0.01*observed sample size, N) for retained catch, min(0.001*observed sample size, N) for total catch, and min(0.1*observed sample size, N)  for groundfish bycatch, where N is the maximum sample size (200 for retained catch, 125 for total catch, and 20 or 30 for groundfish by catch (see Tables 4 and 19 for details)). We estimated the predicted effective sample size from observed effective sample size as follows:

$$n_y = \sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l}) / \sum_l (P_{y,l} - \hat{P}_{y,l})^2 \qquad (10)$$

where $\hat{P}_{y,1}$ and $P_{y,l}$ are estimated and observed size compositions in year *y* and length class *l*, respectively. We plotted the predicted effective sample sizes against the input effective sample sizes.

g. Do parameter estimates make sense? The estimated parameter values are within the bounds and various plots support that the parameter values are reasonable for a fixed *M* of 0.18 for this stock.

h. Model selection criteria: We used a number of diagnostic criteria to select the base model over the other model: CPUE fits, observed vs. predicted tag recapture numbers by length class, and catch and bycatch fits. A few figures are provided for the four scenarios in the Results section.

i. Residual analysis: We illustrated residual fits by bubble plots in various figures in the Results section.

j. Model evaluation: Only one model is presented and the evaluations are presented in the Results section below.

*4. Results*

1. List of effective sample sizes and weighting factors:

The maximum effective sample sizes for various scenarios are listed in Tables 4 and 19 respectively, for EAG and WAG. These weights (with the corresponding standard errors) adequately fitted the length compositions and no further changes were examined. The input effective sample sizes vs. predicted effective sample sizes are plotted in Figures 11 and 40 for retained catch, 12 and 41 for total catch, and 13 and 42 for groundfish discard catch for EAG and WAG, respectively. The red line passing through the plot is the $45^{\circ}$ degree line and in a number of cases the points are spread on both sides of the line indicating that the input effective sample sizes are reasonable for the four scenarios.

We used weighting factors (corresponding standard errors are included in parentheses) for catch biomass; recruitment deviation; pot fishery F; groundfish fishery F; and tagging (multinomial likelihood). We set the CPUE weights to 1 for all scenarios because additional variance components in the likelihoods should take care of under estimation of sampling variance. However, the estimated additional variance values were small for observer CPUE indices, but relatively large for the fish ticket CPUE indices. Nevertheless the CPUE index variances estimated from the negative binomial and lognormal GLMs were adequate to fit the model (Tables 5 and 6 for EAG and 20 and 21 for WAG for scenarios 1 to 4, respectively). The weight with the corresponding standard error specification is detailed in Tables A1 and A2 of Appendix A for EAG and WAG, respectively.

2. Tables of estimates:

   a. The parameter estimates with one standard deviation for the scenarios 1 to 4 are summarized respectively in Tables 5 and 6 for EAG and 20 and 21 for WAG. We have also provided the boundaries for parameter search in those tables and the estimates were within the bounds. Scenarios 1 and 3 did not consider the pseudo molt probability function and determined the size transition matrix based on the linear growth increment model with a normal growth variability model. On the other hand, scenarios 2 and 4 considered pseudo molting probability parameters in addition to the scenario 1 parameters to determine the size transition matrix.

b. The estimated size transition matrixes for the four scenarios are summarized in Tables 7 to 10 for EAG and in Tables 22 to 25 for WAG. Overall the matrix elements for the four scenarios appear reasonable to describe golden king crab growth.

c. The mature male and legal male abundance time series are summarized in Tables 11 to 14 for scenarios 1 to 4 for EAG and Tables 26 to 29 for scenarios 1 to 4 for WAG.

d. The recruitment estimates are summarized in Tables 11 to 14 for scenarios 1 to 4 for EAG and Tables 26 to 29 for scenarios 1 to 4 for WAG.

e. The likelihood component values and the total likelihood values for the four scenarios are summarized in Table 15 for EAG and Table 30 for WAG. Total likelihood values for the four scenarios in the two areas are similar and reflect the change in number of parameters. The likelihood components and the total likelihood values for scenarios 6 and 7 (switching off the mean F, and mean F with F deviation penalties) did not drastically change from those of scenario 1 results for EAG and WAG (Table 31), where the other parameter specifications were the same.

3. Graphs of estimates:

   a. The year 2000 and 2012 total and retained selectivity curves for the four scenarios are illustrated in Figure 14 for EAG and Figure 43 for WAG. Total selectivity for year 2000 was used in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis indicating that all size groups were vulnerable to the gear. This is also shown in the size compositions of groundfish bycatch (Figures 10a and b, and 36 and 39 for scenarios 1 and 2, respectively). Thus, we set the groundfish bycatch selectivity to 1 for all size-classes in the subsequent analysis.

b. The mature male and legal male biomass time series for the four scenarios are illustrated in Figures 22 and 23 for EAG and in Figures 51 and 52 for WAG. Both legal and mature male biomass trends tracked the CPUE trends well. We determined the mature male biomass values on 15 February and considered the entire time series for $B_{ref}$ calculation.

c. The full selection pot fishery F over time for the four scenarios for EAG is shown in Figure 24 and for WAG in Figure 53. The F peaked in 1990s and systematically declined in the recent years.

d. F vs. MMB: We did not provide this figure because the model has not yet been approved.

e. Stock-Recruitment relationship: None.

f. The temporal changes in total number of recruits to the modeled population for the four scenarios are illustrated in Figure 20 for EAG and in Figure 49 for WAG. The recruitment distribution to the model size group (101–170+ mm CL) is shown in Figures 21 and 50 for EAG and WAG, respectively for the four scenarios.

4. Evaluation of the fit to the data:

g. Fits to catches: The fishery retained, total, and groundfish bycatch (observed vs. estimated) plots for the four scenarios are illustrated in Figures 25 to 27 for EAG and 54 to 56 for WAG. All predicted fits were closer to observed values.

h. Survey data plot: We did not consider the pot survey data for the analysis.

i. CPUE index data: The predicted vs. input CPUE indices for the four scenarios are shown in Figure 19 for EAG and Figure 48 for WAG. The four scenarios appear to fit the CPUE indices equally well.

j. Tagging data: The predicted vs observed tag recaptures in length-class for the four scenarios are depicted in Figure 18 for EAG and Figure 47 for

WAG. All four scenarios appear to fit tag-recaptures well. Note that we used the EAG tagging information for WAG.

k. Molt probability: The fitted molt probability curves for scenarios 3 and 4 are depicted in Figure 32 for EAG and Figure 61 for WAG. They appear adequate to describe the molting patterns in the two areas.

l. Fit to catch size compositions: Retained, total, and groundfish discard length compositions are shown in Figures 8a,b –10 a, b for EAG for scenarios 1 and 4, respectively and in Figures 34–39 for WAG for scenarios 1 and 4, respectively. The retained and total catch size composition fits appear satisfactory. We illustrate the standardized residual plots as bubble plots of size composition over time for retained (Figures 15 and 44 for EAG and WAG, respectively), for total (Figures 16 and 45 for EAG and WAG, respectively), and for groundfish discard catch (Figures 17 and 46 for EAG and WAG, respectively).

m. Marginal distributions for the fits to the composition data: We did not provide this plot in this report.

   Plots of implied versus input effective sample sizes and time series of implied effective sample sizes: The input effective sample sizes vs. predicted effective sample sizes are plotted in Figures 11 and 40 for retained catch, 12 and 41 for total catch, and 13 and 42 for groundfish discard catch for EAG and WAG, respectively. The red line passing through the plot is the $45^{\circ}$ degree line and in a number of cases the points are spread on both sides of the line indicating that the input effective sample sizes are not too bad for the four scenarios.

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

o. Quantile-quantile plot: We did not provide this plot in this report.

p. Retrospective and historical analysis: The retrospective fits for scenarios 1 and 2 are shown in Figure 28 for EAG and in Figure 57 for WAG. The retrospective patterns did not show severe departure when terminal year's data were removed systematically and hence the current formulation of the model appears stable.

5. Uncertainty and sensitivity analysis:
   a. The main task was to determine a plausible size transition matrix to project the population over time. We investigated the sensitivity of the model to determine the size transition matrix by pseudo molt probability (additional two parameters) function and not considering it. The transition matrix estimates appear not affected by either consideration.
   b. To describe the uncertainty of total OFL, current MMB, and mean F in the current assessment the likelihood profiles for each statistic are provided Figures 29-31 for EAG and 58-60 for WAG. We rescaled the profile to probability. The distribution is satisfactorily symmetric around the mean estimate..

## F. Calculation of the OFL

1. Specification of the Tier level:

   The Aleutian Islands golden king crab stocks are currently managed under Tier 5 (average catch OFL) control rule. Our analysis tries to upgrade this stock to the Tier 4 level.

2. List of parameters and stock size required by the control rule:

   An average mature male biomass (*MMB*) for a specified period, $MMB_{ref}$, current *MMB*, an *M* value, and a $\gamma$ value.

3. Specification of the total catch OFL:

   (a) If $MMB_t \geq MMB_{ref}$ , $F_{OFL} = \gamma M$ ,

   (b) If $MMB_t < MMB_{ref}$ and $MMB_t > 0.25MMB_{ref}$ ,

$$F_{OFL} = \gamma M \frac{\left(\frac{MMB_t}{MMB_{ref}} - \alpha\right)}{(1-\alpha)}$$

   (c ) If $MMB_t \leq 0.25MMB_{ref}$ , $F_{OFL} = 0$ , where *MMB* is mature male biomass, $MMB_{ref}$ is average mature male biomass, and $\gamma$ is a multiplying factor of *M*.

The *OFL* is estimated by an iterative procedure accounting for intervening total removals (see Appendix A for the formulas).

For the selection of $MMB_{ref}$, we chose the period between 1986 Feb 15 to 2013 Feb 15. This resulted in a $MMB_{ref}$ range of 5.518 –6.371 thousand metric tons for EAG and 4.158 – 4.827 thousand metric tons for WAG for the four scenarios. The current $MMB_{2013}$ range was 7.204– 8.957 thousand metric tons for EAG and 4.764–5.820 thousand metric tons for WAG for the four scenarios, resulting in an $F_{OFL}$ of 0.18 for both regions. The total OFL for EAG ranged 1.055–1.337 thousand metric tons and 0.687 –0.857 thousand metric tons for WAG for the four scenarios. The $\gamma$ value was set to 1 and an *M* value of 0.18 was used for *OFL* calculation.

We estimated the total catch OFL under four scenarios for EAG and WAG (Tables in the Executive Summary).

4. Specification of the retained catch portion of the total catch OFL:
   We applied the $F_{OFL}$ with retained selectivity to calculate the retained catch portion of the total catch OFL. The retained catch OFLs for EAG ranged from 1000t –1272t for the four scenarios and that for WAG ranged 646t–806t.
5. Recommendation for $F_{OFL}$, OFL total catch, and the retained catch portion of the OFL for coming year:
   EAG: $F_{OFL}$ = 0.18; OFL total catch = 1337t , retained catch portion of the OFL = 1272t (under scenario 4).
   WAG: $F_{OFL}$ = 0.18; OFL total catch = 857t; retained catch portion of the OFL = 806t (under scenario 4).

## G. Calculation of the ABC

1. 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. The ABC estimate varied for different scenarios, 1.049–1.329 thousand metric tons for EAG and 0.682–0.852 thousand metric tons for WAG for the four scenarios (see Tables in the executive summary).

## *H. Rebuilding Analysis*

Not applicable.

## *I. Data Gaps and Research Priorities*

1. The recruit abundances were estimated from commercial catch sampling data. The implicit assumption in the analysis was that the estimated recruits come solely from the same exploited stock through growth and mortality. The current analysis did not consider this possibility that additional recruitment occurs through immigration from neighboring areas and possibly separate sub-stocks. Extensive tagging experiments or resource surveys are needed to investigate stock distributions.

2. An independent estimate of *M* is needed for this stock. Tagging is one possibility.

3. An extensive tagging study will also provide independent estimates of molting probability and growth. We used the historical tagging data to determine the size transition matrix.

4. An arbitrary 20% handling mortality rate on discarded males was used, which was obtained from the red king crab literature (Siddeek 2002, Kruse et al. 2000). An experiment based independent estimate of handling mortality is needed for golden king crab.

5.

## J. Acknowledgments

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Table 1. Time series of annual retained catch, total catch (number of crabs on the deck), pot fishery effort (number of pot lifts), and groundfish fishery discard mortality (handling mortality rates of 50% for pot and 80% for trawl gear were applied, only to the male portion) for the EAG golden king crab stock. The crab numbers are for the size range 101–170+ mm CL. 1985 refers to the 1985/86 fishery. NA: no observer sampling to compute total catch.

| Year | Retained Catch | Total Catch | Pot Fishery Effort | Groundfish Discard Mortality |
|---|---|---|---|---|
| 1985 | 1251267 | | 117718 | |
| 1986 | 1374943 | | 155240 | |
| 1987 | 968614 | | 146501 | |
| 1988 | 1156046 | | 155518 | |
| 1989 | 1419777 | | 155262 | |
| 1990 | 892699 | 1148518 | 106281 | |
| 1991 | 1083243 | 3758078 | 133428 | |
| 1992 | 1127291 | 4350561 | 133778 | |
| 1993 | 767918 | NA | 106890 | |
| 1994 | 1086560 | 1884229 | 191455 | |
| 1995 | 1150168 | 2754746 | 177773 | 339 |
| 1996 | 848045 | 1443634 | 113460 | 133 |
| 1997 | 780481 | 1774902 | 106403 | 25 |
| 1998 | 740011 | 1969432 | 83378 | 364 |
| 1999 | 709332 | 1544013 | 79129 | 648 |
| 2000 | 704363 | 1708649 | 71551 | 349 |
| 2001 | 730030 | 1353490 | 62639 | 132 |
| 2002 | 643668 | 1125801 | 52042 | 7620 |
| 2003 | 643074 | 1112774 | 58883 | 4277 |
| 2004 | 637536 | 961070 | 34848 | 100 |
| 2005 | 623971 | 860919 | 24569 | 114 |
| 2006 | 650587 | 847280 | 26195 | 3063 |
| 2007 | 633253 | 892203 | 22653 | 19942 |
| 2008 | 666947 | 916778 | 24466 | 4858 |
| 2009 | 679886 | 948856 | 26298 | 1079 |
| 2010 | 670698 | 906409 | 25851 | 12735 |
| 2011 | 668828 | 942859 | 17915 | 2925 |
| 2012 | 687666 | 982606 | 20827 | 4439 |

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), GLM estimated CPUE Index, and nominal legal size crabs CPUE standardized by the CPUE index for the EAG golden king crab stock. NA = no sampling information. 1990 refers to the 1990/91 fishery.

| Year | Pot Fishery Nominal Retained CPUE | Obs. Nominal Retained CPUE | Obs. Nominal Total CPUE | Sample Size (no.pot lifts) | CPUE Index | Nominal CPUE Standardized |
|---|---|---|---|---|---|---|
| 1990 | 8.898 | 2.167 | 13.000 | 90 | | |
| 1991 | 8.199 | 14.633 | 31.633 | 206 | | |
| 1992 | 8.364 | 10.111 | 38.692 | 137 | | |
| 1993 | 7.786 | 5.300 | 20.400 | NA | | |
| 1994 | 5.892 | 2.488 | 14.205 | NA | | |
| 1995 | 5.888 | 5.283 | 17.055 | 7547 | 0.734 | 6.693 |
| 1996 | 6.451 | 5.167 | 13.723 | 6561 | 0.758 | 6.910 |
| 1997 | 7.336 | 7.127 | 18.111 | 4676 | 0.791 | 7.210 |
| 1998 | 8.875 | 8.900 | 25.224 | 3616 | 0.954 | 8.701 |
| 1999 | 8.964 | 9.141 | 20.607 | 3857 | 0.884 | 8.058 |
| 2000 | 9.849 | 9.885 | 25.414 | 5047 | 0.907 | 8.266 |
| 2001 | 11.655 | 11.015 | 22.488 | 4629 | 1.184 | 10.797 |
| 2002 | 12.372 | 11.945 | 22.718 | 3990 | 1.261 | 11.494 |
| 2003 | 10.921 | 11.003 | 19.458 | 3970 | 1.105 | 10.079 |
| 2004 | 18.295 | 17.541 | 28.354 | 2208 | 1.802 | 16.432 |
| 2005 | 25.397 | 27.536 | 35.715 | 1198 | 1.109 | 33.144 |
| 2006 | 24.836 | 24.802 | 32.998 | 1103 | 0.884 | 26.421 |
| 2007 | 27.954 | 30.723 | 39.532 | 1006 | 1.019 | 30.452 |
| 2008 | 27.260 | 29.520 | 37.648 | 613 | 0.991 | 29.620 |
| 2009 | 25.853 | 26.669 | 36.348 | 411 | 0.829 | 24.773 |
| 2010 | 25.956 | 25.374 | 35.617 | 436 | 0.849 | 25.363 |
| 2011 | 37.333 | 40.127 | 52.925 | 361 | 1.223 | 36.525 |
| 2012 | 33.018 | 37.735 | 47.363 | 438 | 1.172 | 35.015 |

Table 3. Time series of GLM estimated CPUE Index and standard errors considering only the year effect for the fish ticket based retained catch-per-unit-effort for the EAG golden king crab stock. 1985 refers to the 1985/86 fishery.

| Year | CPUE Index | Standard Error |
|---|---|---|
| 1985 | 1.147 | 0.047 |
| 1986 | 0.847 | 0.045 |
| 1987 | 0.710 | 0.048 |
| 1988 | 0.685 | 0.046 |
| 1989 | 0.777 | 0.037 |
| 1990 | 0.700 | 0.053 |
| 1991 | 0.704 | 0.045 |
| 1992 | 0.742 | 0.050 |
| 1993 | 0.761 | 0.060 |
| 1994 | 0.536 | 0.046 |
| 1995 | 0.436 | 0.043 |
| 1996 | 0.477 | 0.043 |
| 1997 | 0.661 | 0.044 |
| 1998 | 0.818 | 0.056 |

Table 4. Optimization scenarios considered for the stock assessment model for the eastern Aleutian Islands golden king crab (EAG) stock.

| **Scenario** | | **Likelihood/Penalty Weights (CV)*** | **Maximum Effective Sample Size** |
|---|---|---|---|
| 1 | Commercial fishery retained catch for 1985–2012, total fishery catch for 1990–2012, observer legal size crab CPUE index for 1995–2012, and groundfish bycatch for 1995–2012; M = 0.18, pot fishery handling mortality = 0.2, and ground fish bycatch handling mortality for trawl = 0.8 and for pot = 0.5. Tag-release-recapture size data for 1991, 1997, 2000, 2003, and 2006. Size transition matrix was calculated from tagging data by the normal probability function. Groundfish fishery selectivity was set to 1. | Retained catch = 500 (0.032), total catch = 400(0.035), groundfish discard catch = 0.041(444.77), recruitment deviation = 1.5 (0.629), pot fishery F deviation (initial) = 1000 (0.022) (later relaxed to 0.00001(very high)), penalty for regularizing the mean F to 0.3 (initial) = 1000 (later relaxed to 0.00001), groundfish bycatch fishery F deviation = (initial) = 1000 (later relaxed to 0.00001), tagging data = 0.5 (1.311), and posfunction = 1000 | Retained = 200, total = 125, groundfish discard = 30 |
| 2 | Same as scenario 1, but considered a composite normal and the logistic (molt probability) functions for the size transition matrix calculation. | Same as those in scenario 1. | Same as those in scenario 1. |
| 3 | Scenario 1 with 1985–1998 fishery retained CPUE indices as an additional likelihood component. | Same as those in scenario 1. | Same as those in scenario 1. |
| 4 | Scenario 2 with 1985–1998 fishery retained CPUE indices as an additional likelihood component. | Same as those in scenario 1. | Same as those in scenario 1. |
| 5 | Scenario 2 with independently estimated transition matrix from first year tag returns . | Same as those in scenario 1. | Same as those in scenario 1. |
| 6 | Scenario 1 with mean F penalty switched off. | Same as those in scenario 1. | Same as those in scenario 1. |
| 7 | Scenario 1 with mean F and F deviation penalties switched off. | Same as those in scenario 1. | Same as those in scenario 1. |

$$* \ Coefficient\ of\ Variation, \qquad CV = \sqrt{e^{\frac{1}{2\times Weight}} - 1}$$

Table 5. Parameter estimates and standard deviations with the 2013 (February 15) MMB for the scenarios 1and 2 model for the golden king crab data from the EAG, 1985/86–2012/13. A total of 107and 109 parameters for the two respective scenarios were estimated, but recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

| | **Scenario 1** | | | **Scenario 2** | | |
|---|---|---|---|---|---|---|
| Parameter | Estimate | Std Dev | Limits | Estimate | Std Dev | Limits |
| log_a | 3.8150 | 0.0576 | 2.5,4.50 | 3.0987 | 0.1089 | 2.5,4.50 |
| G_b | -0.2791 | 0.0191 | -0.39,-0.01 | -0.0651 | 0.0185 | -0.39,-0.01 |
| log_aa | | | | -2.3834 | 0.0819 | -4.61,-1.39 |
| log_b | | | | 4.9516 | 0.0057 | 3.869,5.0 |
| Growth StdDev | 6.7578 | 0.2211 | 0.1,9.0 | 3.6369 | 0.1361 | 0.1,9.0 |
| log_T04delta | 3.8082 | 0.2062 | 0.,4.4 | 3.6789 | 0.2069 | 0.,4.4 |
| log_T12delta | 2.6705 | 0.3428 | 0.,4.4 | 2.6602 | 0.3477 | 0.,4.4 |
| log_R04delta | 1.5459 | 0.1188 | 0.,4.4 | 1.4708 | 0.1366 | 0.,4.4 |
| log_R12delta | 2.0232 | 0.3248 | 0.,4.4 | 2.0327 | 0.3325 | 0.,4.4 |
| log_T04L50 | 4.8203 | 0.0417 | 4.0,5.0 | 4.7850 | 0.0331 | 4.0,5.0 |
| log_T12L50 | 4.8826 | 0.0158 | 4.0,5.0 | 4.8789 | 0.0164 | 4.0,5.0 |
| log_R04L50 | 4.9036 | 0.0031 | 4.0,5.0 | 4.9004 | 0.0022 | 4.0,5.0 |
| log_R12L50 | 4.9292 | 0.0056 | 4.3,5.2 | 4.9290 | 0.0056 | 4.3,5.2 |
| log_betar | 0.0278 | 0.4484 | -4.6, 6. | -0.2199 | 0.3164 | -4.6, 6. |
| logq2 | -0.4504 | 0.1457 | -9.0, 2.01 | -0.5931 | 0.1313 | -9.0, 2.01 |
| logq3 | -0.9177 | 0.1753 | -9.0, 5.01 | -0.9690 | 0.1789 | -9.0, 5.01 |
| log_newsh1 | 2.0161 | 0.0692 | 0.01, 10.0 | 2.0781 | 0.0575 | 0.01, 10.0 |
| log_mean_rec | 0.5492 | 0.0641 | 0.01, 5.0 | 0.5608 | 0.0650 | 0.01, 5.0 |
| log_mean_Fpot | -0.7392 | 0.1150 | -15.0, -0.05 | -0.8477 | 0.1076 | -15.0, -0.15 |
| log_mean_Fground | -8.3577 | 0.8322 | -15.0, -1.6 | -8.3977 | 0.8307 | -15.0, -1.6 |
| prelegal_var | 0.0192 | 0.0073 | 0.0, 0.15 | 0.0186 | 0.0072 | 0.0, 0.15 |
| Ftemp | 0.1800 | 0.7071 | 0.0, 0.75 | 0.1800 | 0.7071 | 0.0, 0.75 |
| 2013 MMB | 7728 | 3888 | | 7906 | 4006 | |

Table 6. Parameter estimates and standard deviations with the 2013 (February 15) MMB for the scenarios 3 and 4 model for the golden king crab data from the EAG, 1985/86–2012/13. A total of 109 and 111 parameters for the two respective scenarios were estimated, but recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

| | **Scenario 3** | | | **Scenario 4** | | |
|---|---|---|---|---|---|---|
| Parameter | Estimate | Std Dev | Limits | Estimate | Std Dev | Limits |
| log_a | 3.8253 | 0.0564 | 2.5, 4.50 | 3.0821 | 0.1109 | 2.5,4.50 |
| G_b | -0.2828 | 0.0189 | -0.39,-0.01 | -0.0625 | 0.0186 | -0.39,-0.01 |
| log_aa | | | | -2.3634 | 0.0798 | -4.61,-1.39 |
| log_b | | | | 4.9501 | 0.0056 | 3.869,5.0 |
| Growth StdDev | 6.7334 | 0.2174 | 0.1,9.0 | 3.6353 | 0.1362 | 0.1,9.0 |
| log_T04delta | 3.8077 | 0.2137 | 0.,4.4 | 3.6908 | 0.2205 | 0.,4.4 |
| log_T12delta | 2.5824 | 0.3614 | 0.,4.4 | 2.5398 | 0.3718 | 0.,4.4 |
| log_R04delta | 1.5442 | 0.1109 | 0.,4.4 | 1.4716 | 0.1400 | 0.,4.4 |
| log_R12delta | 1.9945 | 0.3308 | 0.,4.4 | 2.0044 | 0.3393 | 0.,4.4 |
| log_T04L50 | 4.8038 | 0.0414 | 4.0,5.0 | 4.7673 | 0.0343 | 4.0,5.0 |
| log_T12L50 | 4.8742 | 0.0153 | 4.0,5.0 | 4.8684 | 0.0156 | 4.0,5.0 |
| log_R04L50 | 4.9038 | 0.0023 | 4.0,5.0 | 4.9019 | 0.0024 | 4.0,5.0 |
| log_R12L50 | 4.9295 | 0.0057 | 4.3,5.2 | 4.9294 | 0.0056 | 4.3,5.2 |
| log_betar | 0.1019 | 0.4399 | -4.6, 6. | 0.0300 | 0.4043 | -4.6, 6. |
| Logq1 | -0.6169 | 0.1512 | -9.0, 2.01 | -0.7560 | 0.1371 | -9.0, 2.01 |
| logq2 | -0.6117 | 0.1639 | -9.0, 2.01 | -0.7872 | 0.1597 | -9.0, 2.01 |
| logq3 | -1.0698 | 0.2009 | -9.0, 5.01 | -1.1763 | 0.2104 | -9.0, 5.01 |
| log_newsh1 | 2.0098 | 0.0542 | 0.01, 10.0 | 2.0749 | 0.0589 | 0.01, 10.0 |
| log_mean_rec | 0.5897 | 0.0721 | 0.01, 5.0 | 0.6175 | 0.0784 | 0.01, 5.0 |
| log_mean_Fpot | -0.8427 | 0.1215 | -15.0, -0.149 | -0.9781 | 0.1197 | -15.0, -0.28 |
| log_mean_Fground | -8.4345 | 0.8305 | -15.0, -1.6 | -8.5110 | 0.8304 | -15.0, -1.6 |
| prelegal_var | 0.0209 | 0.0091 | 0.0, 0.15 | 0.0198 | 0.0087 | 0.0, 0.15 |
| fishtick_var | 0.1169 | 0.0568 | 0.0, 0.15 | 0.1095 | 0.0530 | 0.0, 0.15 |
| Ftemp | 0.1800 | 0.7071 | 0.0, 0.75 | 0.1800 | 0.7071 | 0.0, 0.75 |
| 2013 MMB | 8553 | 4543 | | 9082 | 4940 | |

Table 7. Estimate of the size transition matrix for the scenario 1 model for the golden king crab data from the EAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0183 | 0.0702 | 0.1824 | 0.2807 | 0.2561 | 0.1385 | 0.0444 | 0.0084 | 0.0009 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0298 | 0.0966 | 0.2168 | 0.2884 | 0.2274 | 0.1062 | 0.0294 | 0.0048 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0468 | 0.1276 | 0.2475 | 0.2845 | 0.1938 | 0.0782 | 0.0187 | 0.0026 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.0707 | 0.1618 | 0.2712 | 0.2694 | 0.1586 | 0.0553 | 0.0114 | 0.0014 | 0.0001 | 0.0000 | 0.0000 |
| | | | | 0.1032 | 0.1970 | 0.2853 | 0.2449 | 0.1246 | 0.0375 | 0.0067 | 0.0007 | 0.0000 | 0.0000 |
| | | | | | 0.1452 | 0.2303 | 0.2882 | 0.2138 | 0.0940 | 0.0244 | 0.0038 | 0.0003 | 0.0000 |
| | | | | | | 0.1975 | 0.2584 | 0.2795 | 0.1791 | 0.0680 | 0.0153 | 0.0020 | 0.0002 |
| | | | | | | | 0.2598 | 0.2784 | 0.2602 | 0.1441 | 0.0473 | 0.0092 | 0.0011 |
| | | | | | | | | 0.3310 | 0.2881 | 0.2327 | 0.1114 | 0.0316 | 0.0053 |
| | | | | | | | | | 0.4099 | 0.2868 | 0.2002 | 0.0828 | 0.0203 |
| | | | | | | | | | | 0.4972 | 0.2765 | 0.1667 | 0.0596 |
| | | | | | | | | | | | 0.6012 | 0.2622 | 0.1366 |
| | | | | | | | | | | | | 0.7481 | 0.2519 |
| | | | | | | | | | | | | | 1.0000 |

Table 8. Estimate of the size transition matrix for the scenario 2 model for the golden king crab data from the EAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0283 | 0.0137 | 0.1880 | 0.4905 | 0.2538 | 0.0253 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0441 | 0.0168 | 0.2069 | 0.4856 | 0.2261 | 0.0202 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0682 | 0.0204 | 0.2241 | 0.4731 | 0.1982 | 0.0159 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.1040 | 0.0241 | 0.2377 | 0.4517 | 0.1702 | 0.0122 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | 0.1553 | 0.0278 | 0.2456 | 0.4199 | 0.1422 | 0.0091 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | 0.2258 | 0.0309 | 0.2449 | 0.3769 | 0.1148 | 0.0066 | 0.0001 | 0.0000 | 0.0000 |
| | | | | | | 0.3162 | 0.0329 | 0.2338 | 0.3239 | 0.0887 | 0.0046 | 0.0000 | 0.0000 |
| | | | | | | | 0.4231 | 0.0332 | 0.2118 | 0.2640 | 0.0650 | 0.0030 | 0.0000 |
| | | | | | | | | 0.5377 | 0.0316 | 0.1809 | 0.2031 | 0.0449 | 0.0018 |
| | | | | | | | | | 0.6486 | 0.0284 | 0.1461 | 0.1476 | 0.0293 |
| | | | | | | | | | | 0.7455 | 0.0259 | 0.1197 | 0.1089 |
| | | | | | | | | | | | 0.8236 | 0.0342 | 0.1421 |
| | | | | | | | | | | | | 0.8857 | 0.1143 |
| | | | | | | | | | | | | | 1.0000 |

Table 9. Estimate of the size transition matrix for the scenario 3 model for the golden king crab data from the EAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0174 | 0.0682 | 0.1800 | 0.2807 | 0.2585 | 0.1406 | 0.0451 | 0.0085 | 0.0009 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0286 | 0.0946 | 0.2154 | 0.2893 | 0.2295 | 0.1075 | 0.0297 | 0.0048 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0454 | 0.1260 | 0.2469 | 0.2858 | 0.1954 | 0.0788 | 0.0188 | 0.0026 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.0693 | 0.1608 | 0.2715 | 0.2708 | 0.1595 | 0.0554 | 0.0114 | 0.0014 | 0.0001 | 0.0000 | 0.0000 |
| | | | | 0.1018 | 0.1967 | 0.2862 | 0.2459 | 0.1248 | 0.0373 | 0.0066 | 0.0007 | 0.0000 | 0.0000 |
| | | | | | 0.1443 | 0.2307 | 0.2892 | 0.2141 | 0.0936 | 0.0241 | 0.0037 | 0.0003 | 0.0000 |
| | | | | | | 0.1973 | 0.2594 | 0.2802 | 0.1787 | 0.0673 | 0.0149 | 0.0020 | 0.0001 |
| | | | | | | | 0.2607 | 0.2797 | 0.2603 | 0.1431 | 0.0464 | 0.0089 | 0.0010 |
| | | | | | | | | 0.3333 | 0.2892 | 0.2319 | 0.1098 | 0.0307 | 0.0050 |
| | | | | | | | | | 0.4137 | 0.2873 | 0.1985 | 0.0810 | 0.0195 |
| | | | | | | | | | | 0.5022 | 0.2759 | 0.1642 | 0.0577 |
| | | | | | | | | | | | 0.6068 | 0.2599 | 0.1333 |
| | | | | | | | | | | | | 0.7526 | 0.2474 |
| | | | | | | | | | | | | | 1.0000 |

Table 10. Estimate of the size transition matrix for the scenario 4 model for the golden king crab data from the EAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0269 | 0.0147 | 0.1949 | 0.4927 | 0.2466 | 0.0237 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0424 | 0.0179 | 0.2133 | 0.4869 | 0.2202 | 0.0191 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0662 | 0.0214 | 0.2298 | 0.4739 | 0.1936 | 0.0151 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.1018 | 0.0251 | 0.2426 | 0.4520 | 0.1668 | 0.0117 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | 0.1535 | 0.0286 | 0.2493 | 0.4198 | 0.1399 | 0.0088 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | 0.2249 | 0.0315 | 0.2474 | 0.3765 | 0.1132 | 0.0064 | 0.0001 | 0.0000 | 0.0000 |
| | | | | | | 0.3171 | 0.0332 | 0.2347 | 0.3228 | 0.0876 | 0.0045 | 0.0000 | 0.0000 |
| | | | | | | | 0.4264 | 0.0331 | 0.2110 | 0.2623 | 0.0643 | 0.0029 | 0.0000 |
| | | | | | | | | 0.5434 | 0.0311 | 0.1786 | 0.2007 | 0.0444 | 0.0018 |
| | | | | | | | | | 0.6558 | 0.0276 | 0.1427 | 0.1450 | 0.0289 |
| | | | | | | | | | | 0.7533 | 0.0248 | 0.1157 | 0.1062 |
| | | | | | | | | | | | 0.8309 | 0.0325 | 0.1367 |
| | | | | | | | | | | | | 0.8915 | 0.1085 |
| | | | | | | | | | | | | | 1.0000 |

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 1 model for golden king crab in the EAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model ( ≥ 101 mm CL) | Mature Male Biomass ( ≥ 121 mm CL) | Standard Deviation | Legal Male Biomass ( ≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 8666 | 416 | 8024 | 1097 |
| 1986 | 1.23 | 5956 | 354 | 8079 | 604 |
| 1987 | 3.28 | 5113 | 289 | 6048 | 304 |
| 1988 | 2.48 | 4836 | 331 | 5235 | 247 |
| 1989 | 0.47 | 3883 | 260 | 4757 | 245 |
| 1990 | 0.45 | 3287 | 268 | 3727 | 238 |
| 1991 | 7.91 | 2830 | 389 | 3278 | 260 |
| 1992 | 1.04 | 4648 | 285 | 3098 | 277 |
| 1993 | 0.71 | 5104 | 286 | 4296 | 260 |
| 1994 | 1.90 | 4325 | 280 | 5003 | 263 |
| 1995 | 2.20 | 3476 | 238 | 4417 | 246 |
| 1996 | 0.93 | 3540 | 258 | 3490 | 223 |
| 1997 | 2.75 | 3351 | 288 | 3462 | 238 |
| 1998 | 2.08 | 3803 | 327 | 3397 | 261 |
| 1999 | 1.94 | 4319 | 380 | 3755 | 303 |
| 2000 | 2.79 | 4763 | 432 | 4281 | 353 |
| 2001 | 1.49 | 5439 | 500 | 4786 | 407 |
| 2002 | 2.67 | 5914 | 571 | 5384 | 476 |
| 2003 | 1.64 | 6538 | 660 | 5971 | 548 |
| 2004 | 1.39 | 6761 | 737 | 6520 | 636 |
| 2005 | 2.01 | 6654 | 796 | 6770 | 717 |
| 2006 | 2.23 | 6808 | 870 | 6710 | 778 |
| 2007 | 2.04 | 7118 | 963 | 6828 | 848 |
| 2008 | 2.05 | 7359 | 1049 | 7101 | 936 |
| 2009 | 2.03 | 7541 | 1120 | 7355 | 1022 |
| 2010 | 1.80 | 7702 | 1202 | 7546 | 1096 |
| 2011 | 1.30 | 7572 | 1309 | 7703 | 1181 |
| 2012 | 2.33 | 7204 | 1434 | 7565 | 1290 |
| 2013 | 1.73 | 7728 | 3888 | 7259 | 1427 |

Table 12. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 2 model for golden king crab in the EAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model (≥ 101 mm CL) | Mature Male Biomass (≥ 121 mm CL) | Standard Deviation | Legal Male Biomass (≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 7826 | 957 | 8684 | 1122 |
| 1986 | 1.08 | 6274 | 336 | 8066 | 684 |
| 1987 | 2.77 | 5302 | 277 | 6284 | 338 |
| 1988 | 2.80 | 4734 | 273 | 5355 | 260 |
| 1989 | 0.47 | 3877 | 226 | 4733 | 238 |
| 1990 | 0.48 | 3357 | 229 | 3812 | 217 |
| 1991 | 8.03 | 2761 | 265 | 3368 | 226 |
| 1992 | 0.90 | 4661 | 284 | 2938 | 237 |
| 1993 | 0.71 | 5185 | 291 | 4524 | 279 |
| 1994 | 2.18 | 4412 | 277 | 5190 | 282 |
| 1995 | 1.94 | 3617 | 249 | 4505 | 264 |
| 1996 | 1.10 | 3624 | 270 | 3636 | 244 |
| 1997 | 2.79 | 3451 | 289 | 3616 | 262 |
| 1998 | 2.05 | 3918 | 340 | 3503 | 283 |
| 1999 | 2.10 | 4454 | 400 | 3923 | 332 |
| 2000 | 2.79 | 4951 | 457 | 4477 | 390 |
| 2001 | 1.55 | 5666 | 543 | 5002 | 450 |
| 2002 | 2.75 | 6160 | 617 | 5680 | 532 |
| 2003 | 1.65 | 6819 | 720 | 6233 | 608 |
| 2004 | 1.42 | 7053 | 807 | 6843 | 708 |
| 2005 | 2.07 | 6921 | 866 | 7086 | 795 |
| 2006 | 2.27 | 7058 | 938 | 6973 | 855 |
| 2007 | 2.07 | 7362 | 1034 | 7087 | 924 |
| 2008 | 2.12 | 7598 | 1119 | 7375 | 1016 |
| 2009 | 2.05 | 7785 | 1184 | 7623 | 1102 |
| 2010 | 1.83 | 7943 | 1257 | 7812 | 1168 |
| 2011 | 1.30 | 7809 | 1360 | 7966 | 1242 |
| 2012 | 2.43 | 7402 | 1476 | 7821 | 1346 |
| 2013 | 1.75 | 7906 | 4006 | 7446 | 1470 |

Table 13. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 3 model for golden king crab in the EAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model ( ≥ 101 mm CL) | Mature Male Biomass ( ≥ 121 mm CL) | Standard Deviation | Legal Male Biomass ( ≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 8580 | 397 | 7871 | 892 |
| 1986 | 1.28 | 5890 | 319 | 7990 | 401 |
| 1987 | 3.30 | 5099 | 282 | 5980 | 308 |
| 1988 | 2.61 | 4872 | 308 | 5209 | 243 |
| 1989 | 0.47 | 3978 | 231 | 4791 | 233 |
| 1990 | 0.44 | 3394 | 231 | 3816 | 215 |
| 1991 | 7.84 | 2964 | 315 | 3383 | 226 |
| 1992 | 1.14 | 4742 | 288 | 3216 | 233 |
| 1993 | 0.74 | 5216 | 285 | 4396 | 261 |
| 1994 | 1.88 | 4461 | 273 | 5115 | 266 |
| 1995 | 2.33 | 3641 | 245 | 4547 | 248 |
| 1996 | 0.95 | 3758 | 272 | 3657 | 234 |
| 1997 | 2.85 | 3619 | 306 | 3676 | 256 |
| 1998 | 2.20 | 4147 | 374 | 3664 | 288 |
| 1999 | 2.01 | 4744 | 459 | 4097 | 355 |
| 2000 | 2.98 | 5273 | 549 | 4703 | 438 |
| 2001 | 1.57 | 6055 | 669 | 5299 | 533 |
| 2002 | 2.83 | 6614 | 781 | 5996 | 649 |
| 2003 | 1.73 | 7319 | 926 | 6672 | 766 |
| 2004 | 1.44 | 7577 | 1035 | 7297 | 905 |
| 2005 | 2.10 | 7481 | 1105 | 7583 | 1018 |
| 2006 | 2.42 | 7671 | 1194 | 7535 | 1092 |
| 2007 | 2.18 | 8059 | 1321 | 7687 | 1177 |
| 2008 | 2.16 | 8361 | 1436 | 8028 | 1294 |
| 2009 | 2.14 | 8576 | 1539 | 8344 | 1410 |
| 2010 | 1.92 | 8759 | 1656 | 8571 | 1516 |
| 2011 | 1.37 | 8640 | 1778 | 8751 | 1633 |
| 2012 | 2.34 | 8252 | 1885 | 8621 | 1756 |
| 2013 | 1.80 | 8553 | 4543 | 8291 | 1873 |

Table 14. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 4 model for golden king crab in the EAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model (≥ 101 mm CL) | Mature Male Biomass (≥ 121 mm CL) | Standard Deviation | Legal Male Biomass (≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 7628 | 954 | 8609 | 1061 |
| 1986 | 1.11 | 6225 | 344 | 7875 | 687 |
| 1987 | 2.83 | 5339 | 287 | 6204 | 343 |
| 1988 | 2.99 | 4851 | 288 | 5371 | 268 |
| 1989 | 0.49 | 4050 | 246 | 4837 | 252 |
| 1990 | 0.45 | 3562 | 249 | 3977 | 236 |
| 1991 | 7.87 | 3094 | 310 | 3565 | 245 |
| 1992 | 1.10 | 4795 | 308 | 3232 | 279 |
| 1993 | 0.76 | 5374 | 315 | 4662 | 298 |
| 1994 | 2.05 | 4663 | 306 | 5367 | 305 |
| 1995 | 2.21 | 3862 | 280 | 4736 | 291 |
| 1996 | 1.05 | 3946 | 313 | 3878 | 275 |
| 1997 | 2.99 | 3861 | 355 | 3926 | 304 |
| 1998 | 2.25 | 4441 | 443 | 3902 | 346 |
| 1999 | 2.18 | 5113 | 552 | 4438 | 433 |
| 2000 | 3.12 | 5747 | 670 | 5123 | 540 |
| 2001 | 1.65 | 6614 | 822 | 5791 | 661 |
| 2002 | 3.01 | 7253 | 958 | 6617 | 808 |
| 2003 | 1.80 | 8016 | 1130 | 7314 | 948 |
| 2004 | 1.49 | 8307 | 1260 | 8028 | 1115 |
| 2005 | 2.22 | 8195 | 1335 | 8324 | 1244 |
| 2006 | 2.54 | 8379 | 1427 | 8229 | 1321 |
| 2007 | 2.28 | 8780 | 1562 | 8386 | 1409 |
| 2008 | 2.27 | 9101 | 1684 | 8765 | 1536 |
| 2009 | 2.23 | 9329 | 1786 | 9097 | 1658 |
| 2010 | 2.01 | 9517 | 1899 | 9330 | 1762 |
| 2011 | 1.41 | 9391 | 2018 | 9512 | 1874 |
| 2012 | 2.37 | 8957 | 2111 | 9374 | 1993 |
| 2013 | 1.85 | 9082 | 4940 | 8963 | 2091 |

Table 15. Likelihood values of the fits for scenarios 1 to 4 for golden king crab in the EAG.

| Likelihood Component | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| like_retlencomp | -537.24 | -537.49 | -539.25 | -541.72 |
| like_totallencomp | -592.93 | -591.46 | -592.95 | -591.55 |
| like_gdiscdlencomp | -301.74 | -303.31 | -301.21 | -301.63 |
| like_retcpue | -9.74 | -10.00 | -9.00 | -9.47 |
| like_retdcatchB | 33.88 | 32.71 | 35.03 | 34.47 |
| like_totalcatchB | 45.77 | 44.14 | 46.80 | 46.10 |
| like_gdiscdcatchB | 0.00 | 0.00 | 0.00 | 0.00 |
| like_rec_dev | 13.66 | 13.56 | 13.83 | 13.80 |
| like_F | 0.00 | 0.00 | 0.00 | 0.00 |
| like_gF | 0.00 | 0.00 | 0.00 | 0.00 |
| like_Tag | 279.35 | 168.97 | 279.37 | 168.77 |
| like_meanFpot | 0.00 | 0.00 | 0.00 | 0.00 |
| like_fpen | 0.00 | 0.00 | 0.00 | 0.00 |
| like_finalF | 0.00 | 0.00 | 0.00 | 0.00 |
| LikefishtickCPUE | | | 4.97 | 4.52 |
| Total | -1068.99 | -1182.88 | -1062.40 | -1176.71 |

Table 16. Time series of annual retained catch, total catch (number of crabs on the deck), pot fishery effort (number of pot lifts), and groundfish fishery discard mortality (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 101–185 mm CL. 1985 refers to the 1985/86 fishery.

| Year | Retained Catch | Total Catch | Pot Fishery Effort | Groundfish Discard Mortality |
|---|---|---|---|---|
| 1985 | 981949 | | 118563 | |
| 1986 | 2052652 | | 277780 | |
| 1987 | 1248732 | | 160229 | |
| 1988 | 1285914 | | 166409 | |
| 1989 | 1610281 | | 202541 | |
| 1990 | 889017 | 957928 | 108533 | |
| 1991 | 747852 | 1571772 | 101429 | |
| 1992 | 543541 | 1085028 | 69443 | |
| 1993 | 352339 | 1872683 | 127764 | |
| 1994 | 845058 | 3671046 | 195138 | |
| 1995 | 619636 | 1511578 | 115248 | 331 |
| 1996 | 652801 | 1245378 | 99267 | 398 |
| 1997 | 558446 | 1221796 | 86811 | 136 |
| 1998 | 505407 | 779312 | 35975 | 479 |
| 1999 | 658377 | 1448795 | 107040 | 330 |
| 2000 | 723794 | 1590954 | 101239 | 230 |
| 2001 | 686738 | 1515487 | 105512 | 184 |
| 2002 | 664823 | 1325375 | 78979 | 593 |
| 2003 | 676633 | 1171076 | 66236 | 3087 |
| 2004 | 685465 | 1237945 | 56846 | 559 |
| 2005 | 639368 | 999309 | 30116 | 2145 |
| 2006 | 523701 | 829068 | 26870 | 1488 |
| 2007 | 600595 | 943143 | 29950 | 3794 |
| 2008 | 587661 | 985735 | 26200 | 8953 |
| 2009 | 628332 | 885764 | 26489 | 2738 |
| 2010 | 626246 | 856981 | 29994 | 1112 |
| 2011 | 616118 | 821257 | 26326 | 2605 |
| 2012 | 672916 | 971860 | 32716 | 2508 |

Table 17. 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), GLM estimated CPUE Index, and nominal legal size crabs CPUE standardized by the CPUE index for the WAG golden king crab stock. 1990 refers to the 1990/91 fishery.

| Year | Pot Fishery Nominal Retained CPUE | Obs. Nominal Retained CPUE | Obs. Nominal Total CPUE | Sample Size (no.pot lifts) | CPUE Index | Nominal CPUE Standardized |
|---|---|---|---|---|---|---|
| 1990 | 6.980 | | 9.277778 | | | |
| 1991 | 7.428 | | 16.49228 | | | |
| 1992 | 5.895 | | 16.40238 | | | |
| 1993 | 4.425 | | 16.12281 | | | |
| 1994 | 4.080 | | 19.42891 | | | |
| 1995 | 4.647 | 4.813 | 13.77329 | 8274 | 1.174 | 8.350 |
| 1996 | 6.074 | 5.320 | 13.28176 | 5669 | 0.952 | 6.769 |
| 1997 | 6.561 | 6.499 | 14.84698 | 3910 | 0.962 | 6.839 |
| 1998 | 11.397 | 9.494 | 22.98983 | 1351 | 1.070 | 7.610 |
| 1999 | 6.321 | 6.116 | 14.30363 | 4573 | 0.909 | 6.463 |
| 2000 | 6.970 | 6.646 | 16.41675 | 4687 | 0.853 | 6.067 |
| 2001 | 6.509 | 6.389 | 14.77008 | 4453 | 0.827 | 5.877 |
| 2002 | 8.418 | 7.766 | 17.2464 | 2505 | 0.924 | 6.571 |
| 2003 | 10.215 | 9.361 | 17.84277 | 3324 | 1.157 | 8.229 |
| 2004 | 12.058 | 11.067 | 22.25029 | 2617 | 1.267 | 9.005 |
| 2005 | 21.230 | 21.511 | 33.28132 | 1365 | 1.035 | 23.506 |
| 2006 | 19.640 | 21.362 | 30.97375 | 1183 | 0.970 | 22.011 |
| 2007 | 20.049 | 20.389 | 31.69694 | 1082 | 0.884 | 20.078 |
| 2008 | 22.430 | 24.322 | 37.72495 | 979 | 1.045 | 23.726 |
| 2009 | 23.720 | 26.229 | 33.47924 | 893 | 1.059 | 24.036 |
| 2010 | 20.879 | 21.920 | 28.65665 | 867 | 0.943 | 21.419 |
| 2011 | 23.403 | 24.126 | 31.26291 | 837 | 1.014 | 23.013 |
| 2012 | 20.570 | 22.315 | 29.88538 | 1109 | 1.064 | 24.157 |

Table 18. Time series of GLM estimated CPUE Index and standard errors considering only the year effect for the fish ticket based retained catch-per-unit-effort for the WAG golden king crab stock. 1985 refers to the 1985/86 fishery.

| Year | CPUE Index | Standard Error |
|---|---|---|
| 1985 | 1.245 | 0.050 |
| 1986 | 0.979 | 0.040 |
| 1987 | 0.754 | 0.045 |
| 1988 | 0.919 | 0.036 |
| 1989 | 0.881 | 0.029 |
| 1990 | 0.838 | 0.038 |
| 1991 | 0.774 | 0.039 |
| 1992 | 0.641 | 0.044 |
| 1993 | 0.628 | 0.065 |
| 1994 | 0.558 | 0.039 |
| 1995 | 0.473 | 0.039 |
| 1996 | 0.649 | 0.035 |
| 1997 | 0.691 | 0.034 |
| 1998 | 1.093 | 0.042 |

Table 19. Optimization scenarios considered for the stock assessment model for the western Aleutian Islands golden king crab (WAG) stock.

| **Scenario** | | **Likelihood/Penalty Weights (CV)*** | **Maximum Effective Sample Size** |
|---|---|---|---|
| 1 | Commercial fishery retained catch for 1985–2012, total fishery catch for 1990–2012, observer legal size crab CPUE index for 1995–2012, and groundfish bycatch for 1995–2012; M = 0.18, pot fishery handling mortality = 0.2, and ground fish bycatch handling mortality for trawl = 0.8 and for pot = 0.5. Tag-release-recapture size data for 1991, 1997, 2000, 2003, and 2006 (EAG data). Size transition matrix was calculated from tagging data by the normal probability function. Groundfish fishery selectivity was set to 1. | Retained catch = 500 (0.032), total catch = 400(0.035), groundfish discard catch = 0.09 (16.052), recruitment deviation = 1.5 (0.629), pot fishery F deviation (initial) = 1000 (0.022) (later relaxed to 0.00001(very high)), penalty for regularizing the mean F to 0.18 (initial) = 1000 (later relaxed to 0.00001), groundfish bycatch fishery F deviation = (initial) = 1000 (later relaxed to 0.00001), tagging data = 0.5 (1.311), and posfunction = 1000 | Retained = 200, total = 125, groundfish discard = 20 |
| 2 | Same as scenario 1, but considered a composite normal and the logistic (molt probability) functions for the size transition matrix calculation. | Same as those in scenario 1. | Same as those in scenario 1. |
| 3 | Scenario 1 with 1985–1998 fishery retained CPUE indices as an additional likelihood component. | Same as those in scenario 1. | Same as those in scenario 1. |
| 4 | Scenario 2 with 1985–1998 fishery retained CPUE indices as an additional likelihood component. | Same as those in scenario 1. | Same as those in scenario 1. |
| 5 | Scenario 2 with independently estimated transition matrix from first year tag returns. | Same as those in scenario 1. | Same as those in scenario 1. |
| 6 | Scenario 1 with mean F penalty switched off. | Same as those in scenario 1. | Same as those in scenario 1. |
| 7 | Scenario 1 with mean F and F deviation penalties switched off. | Same as those in scenario 1. | Same as those in scenario 1. |

$* \, Coefficient\ of\ Variation,\ CV = \sqrt{e^{\frac{1}{2 \times Weight}} - 1}$

Table 20. Parameter estimates and standard deviations with the 2013 (February 15) MMB for the scenarios 1 and 2 model for the golden king crab data from the WAG, 1985/86–2012/13. A total of 107and 109 parameters for the two respective scenarios were estimated, but recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

| | Scenario 1 | | | Scenario 2 | | |
|---|---|---|---|---|---|---|
| Parameter | Estimate | Std Dev | Limits | Estimate | Std Dev | Limits |
| log_a | 3.8103 | 0.0597 | 2.0, 3.85 | 3.0521 | 0.1124 | 2.0,3.8 |
| G_b | -0.2788 | 0.0199 | -0.39,-0.01 | -0.0572 | 0.0183 | -0.39,-0.01 |
| log_aa | | | | -2.4748 | 0.0876 | -4.61,-1.39 |
| log_b | | | | 4.9463 | 0.0063 | 3.869,5.0 |
| Growth StdDev | 7.0919 | 0.2419 | 0.1,9.0 | 3.6856 | 0.1395 | 0.1,9.0 |
| log_T04delta | 3.6420 | 0.1477 | 0.,4.4 | 3.6330 | 0.1496 | 0.,4.4 |
| log_T12delta | 2.6629 | 0.2869 | 0.,4.4 | 2.6628 | 0.2935 | 0.,4.4 |
| log_R04delta | 1.4948 | 0.0831 | 0.,4.4 | 1.3971 | 0.1122 | 0.,4.4 |
| log_R12delta | 1.8889 | 0.1537 | 0.,4.4 | 1.9114 | 0.1566 | 0.,4.4 |
| log_T04L50 | 4.8585 | 0.0264 | 3.98,5.1 | 4.8424 | 0.0276 | 3.98,5.1 |
| log_T12L50 | 4.8675 | 0.0111 | 3.98,5.5 | 4.8643 | 0.0117 | 3.98,5.5 |
| log_R04L50 | 4.9044 | 0.0017 | 4.85,4.98 | 4.9019 | 0.0018 | 4.85,4.98 |
| log_R12L50 | 4.9193 | 0.0036 | 4.75,5.1 | 4.9195 | 0.0036 | 4.75,5.1 |
| log_betar | 0.8215 | 0.6801 | -4.6, 6.0 | 0.5970 | 0.4018 | -4.6, 6.0 |
| logq2 | 0.0177 | 0.1156 | -9.0, 5.01 | -0.0945 | 0.1206 | -9.0, 5.01 |
| logq3 | -0.6442 | 0.1274 | -9.0, 5.01 | -0.7029 | 0.1333 | -9.0, 5.01 |
| log_newsh1 | 2.0476 | 0.0929 | 0.01, 10.0 | 2.4135 | 0.1097 | 0.01, 10.0 |
| log_mean_rec | 0.3692 | 0.0458 | 0.01, 5.0 | 0.3505 | 0.0529 | 0.01, 5.0 |
| log_mean_Fpot | -0.4109 | 0.0864 | -9.0, -0.20 | -0.4961 | 0.0907 | -9.0, -0.03 |
| log_mean_Fground | -7.8768 | 0.5538 | -9.0, -2.0 | -7.9292 | 0.5538 | -9.0, -2.0 |
| prelegal_var | 0.0170 | 0.0076 | 0.0, 0.15 | 0.0179 | 0.0082 | 0.0, 0.15 |
| Ftemp | 0.1800 | 0.7071 | 0.0, 0.75 | 0.1800 | 0.7071 | 0.0, 0.75 |
| 2013 MMB | 5378 | 2608 | | 5420 | 2660 | |

Table 21. Parameter estimates and standard deviations with the 2013 (February 15) MMB for the scenarios 3 and 4 model for the golden king crab data from the WAG, 1985/86–2012/13. A total of 109 and 111 parameters for the two respective scenarios were estimated, but recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

| | **Scenario 3** | | | **Scenario 4** | | |
|---|---|---|---|---|---|---|
| Parameter | Estimate | Std Dev | Limits | Estimate | Std Dev | Limits |
| log_a | 3.8309 | 0.0615 | 2.0,3.9 | 3.0183 | 0.1155 | 2.0,3.8 |
| G_b | -0.2873 | 0.0207 | -0.39,-0.01 | -0.0522 | 0.0182 | -0.39,-0.01 |
| log_aa | | | | -2.3717 | 0.0823 | -4.61,-1.39 |
| log_b | | | | 4.9399 | 0.0056 | 3.87,6.0 |
| Growth StdDev | 6.9596 | 0.2540 | 0.1,9.0 | 3.6680 | 0.1378 | 0.1,9.0 |
| log_T04delta | 3.9016 | 0.2378 | 0.,4.4 | 3.8628 | 0.2237 | 0.,4.4 |
| log_T12delta | 2.5573 | 0.3030 | 0.,4.4 | 2.5595 | 0.2917 | 0.,4.4 |
| log_R04delta | 1.4437 | 0.0956 | 0.,4.4 | 1.3995 | 0.1166 | 0.,4.4 |
| log_R12delta | 1.8562 | 0.1547 | 0.,4.4 | 1.8664 | 0.1568 | 0.,4.4 |
| log_T04L50 | 4.8216 | 0.0617 | 3.98,5.1 | 4.7855 | 0.0516 | 3.98,5.1 |
| log_T12L50 | 4.8573 | 0.0110 | 3.98,5.5 | 4.8500 | 0.0114 | 3.98,5.5 |
| log_R04L50 | 4.9040 | 0.0017 | 4.85,4.98 | 4.9019 | 0.0018 | 4.85,4.98 |
| log_R12L50 | 4.9190 | 0.0036 | 4.75,5.1 | 4.9186 | 0.0036 | 4.75,5.1 |
| log_betar | 2.3273 | 2.7093 | -4.6,6.0 | 0.9373 | 0.6385 | -4.6,6.0 |
| Logq1 | -0.2573 | 0.2052 | -9.0, 5.01 | -0.3761 | 0.1561 | -9.0, 2.01 |
| logq2 | -0.3051 | 0.2096 | -9.0, 5.01 | -0.4802 | 0.1750 | -9.0, 2.01 |
| logq3 | -0.8207 | 0.1448 | -9.0, 5.01 | -0.9176 | 0.1484 | -9.0, 5.01 |
| log_newsh1 | 1.7577 | 0.1532 | 0.01, 10.0 | 2.4780 | 0.1203 | 0.01, 10.0 |
| log_mean_rec | 0.4253 | 0.0550 | 0.01, 5.0 | 0.4151 | 0.0619 | 0.01, 5.0 |
| log_mean_Fpot | -0.5621 | 0.1815 | -9.0, -0.115 | -0.6902 | 0.1392 | -9.0, -0.15 |
| log_mean_Fground | -7.9895 | 0.5578 | -9.0, -2.0 | -8.0705 | 0.5582 | -9.0, -2.0 |
| prelegal_var | 0.0246 | 0.0107 | 0.0, 0.15 | 0.0207 | 0.0094 | 0.0, 0.15 |
| fishtick_var | 0.1011 | 0.0456 | 0.0, 1.5 | 0.0979 | 0.0254 | 0.0, 1.5 |
| Ftemp | 0.1800 | 0.7071 | 0.0, 0.75 | 0.1800 | 0.7071 | 0.0, 0.75 |
| 2013 MMB | 5969 | 3074 | | 6195 | 3248 | |

Table 22. Estimate of the size transition matrix for the scenario 1 model for the golden king crab data from the WAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0255 | 0.0808 | 0.1879 | 0.2710 | 0.2425 | 0.1347 | 0.0464 | 0.0099 | 0.0013 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0394 | 0.1069 | 0.2179 | 0.2757 | 0.2163 | 0.1053 | 0.0318 | 0.0059 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0589 | 0.1364 | 0.2438 | 0.2704 | 0.1861 | 0.0794 | 0.0210 | 0.0034 | 0.0003 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.0854 | 0.1679 | 0.2631 | 0.2559 | 0.1544 | 0.0578 | 0.0134 | 0.0019 | 0.0002 | 0.0000 | 0.0000 |
| | | | | 0.1200 | 0.1993 | 0.2738 | 0.2335 | 0.1235 | 0.0405 | 0.0082 | 0.0010 | 0.0001 | 0.0000 |
| | | | | | 0.1633 | 0.2281 | 0.2749 | 0.2055 | 0.0953 | 0.0274 | 0.0049 | 0.0005 | 0.0000 |
| | | | | | | 0.2157 | 0.2518 | 0.2661 | 0.1745 | 0.0709 | 0.0179 | 0.0028 | 0.0003 |
| | | | | | | | 0.2768 | 0.2682 | 0.2485 | 0.1428 | 0.0509 | 0.0112 | 0.0015 |
| | | | | | | | | 0.3455 | 0.2756 | 0.2239 | 0.1129 | 0.0353 | 0.0068 |
| | | | | | | | | | 0.4210 | 0.2740 | 0.1952 | 0.0862 | 0.0236 |
| | | | | | | | | | | 0.5049 | 0.2652 | 0.1657 | 0.0642 |
| | | | | | | | | | | | 0.6067 | 0.2541 | 0.1392 |
| | | | | | | | | | | | | 0.7522 | 0.2478 |
| | | | | | | | | | | | | | 1.0000 |

Table 23. Estimate of the size transition matrix for the scenario 2 model for the golden king crab data from the WAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0406 | 0.0165 | 0.2001 | 0.4811 | 0.2379 | 0.0235 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0605 | 0.0195 | 0.2151 | 0.4722 | 0.2133 | 0.0192 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0892 | 0.0227 | 0.2277 | 0.4565 | 0.1883 | 0.0154 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.1298 | 0.0259 | 0.2363 | 0.4328 | 0.1630 | 0.0121 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | 0.1851 | 0.0287 | 0.2391 | 0.4001 | 0.1375 | 0.0093 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | 0.2570 | 0.0309 | 0.2344 | 0.3583 | 0.1124 | 0.0069 | 0.0001 | 0.0000 | 0.0000 |
| | | | | | | 0.3450 | 0.0320 | 0.2210 | 0.3086 | 0.0884 | 0.0050 | 0.0001 | 0.0000 |
| | | | | | | | 0.4452 | 0.0316 | 0.1992 | 0.2541 | 0.0664 | 0.0034 | 0.0000 |
| | | | | | | | | 0.5501 | 0.0298 | 0.1710 | 0.1994 | 0.0475 | 0.0022 |
| | | | | | | | | | 0.6507 | 0.0268 | 0.1404 | 0.1495 | 0.0325 |
| | | | | | | | | | | 0.7396 | 0.0250 | 0.1193 | 0.1161 |
| | | | | | | | | | | | 0.8130 | 0.0349 | 0.1520 |
| | | | | | | | | | | | | 0.8739 | 0.1261 |
| | | | | | | | | | | | | | 1.0000 |

Table 24. Estimate of the size transition matrix for the scenario 3 model for the golden king crab data from the WAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0250 | 0.0820 | 0.1928 | 0.2766 | 0.2423 | 0.1295 | 0.0422 | 0.0084 | 0.0010 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0391 | 0.1092 | 0.2239 | 0.2802 | 0.2140 | 0.0998 | 0.0284 | 0.0049 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0591 | 0.1400 | 0.2503 | 0.2732 | 0.1820 | 0.0740 | 0.0183 | 0.0028 | 0.0003 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.0863 | 0.1728 | 0.2695 | 0.2565 | 0.1490 | 0.0528 | 0.0114 | 0.0015 | 0.0001 | 0.0000 | 0.0000 |
| | | | | 0.1221 | 0.2054 | 0.2793 | 0.2318 | 0.1175 | 0.0363 | 0.0068 | 0.0008 | 0.0001 | 0.0000 |
| | | | | | 0.1671 | 0.2350 | 0.2787 | 0.2018 | 0.0891 | 0.0240 | 0.0039 | 0.0004 | 0.0000 |
| | | | | | | 0.2216 | 0.2588 | 0.2677 | 0.1690 | 0.0651 | 0.0153 | 0.0022 | 0.0002 |
| | | | | | | | 0.2851 | 0.2745 | 0.2477 | 0.1364 | 0.0458 | 0.0094 | 0.0012 |
| | | | | | | | | 0.3563 | 0.2805 | 0.2207 | 0.1060 | 0.0310 | 0.0055 |
| | | | | | | | | | 0.4340 | 0.2765 | 0.1898 | 0.0795 | 0.0203 |
| | | | | | | | | | | 0.5191 | 0.2647 | 0.1584 | 0.0578 |
| | | | | | | | | | | | 0.6199 | 0.2497 | 0.1303 |
| | | | | | | | | | | | | 0.7613 | 0.2387 |
| | | | | | | | | | | | | | 1.0000 |

Table 25. Estimate of the size transition matrix for the scenario 4 model for the golden king crab data from the WAG.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0317 | 0.0185 | 0.2145 | 0.4886 | 0.2259 | 0.0205 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0495 | 0.0215 | 0.2288 | 0.4792 | 0.2038 | 0.0170 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | 0.0766 | 0.0246 | 0.2404 | 0.4632 | 0.1812 | 0.0138 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | 0.1166 | 0.0276 | 0.2476 | 0.4390 | 0.1579 | 0.0111 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | 0.1738 | 0.0302 | 0.2483 | 0.4050 | 0.1340 | 0.0086 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | 0.2511 | 0.0319 | 0.2402 | 0.3606 | 0.1097 | 0.0064 | 0.0001 | 0.0000 | 0.0000 |
| | | | | | | 0.3483 | 0.0321 | 0.2222 | 0.3069 | 0.0858 | 0.0046 | 0.0000 | 0.0000 |
| | | | | | | | 0.4601 | 0.0307 | 0.1948 | 0.2477 | 0.0636 | 0.0031 | 0.0000 |
| | | | | | | | | 0.5760 | 0.0276 | 0.1612 | 0.1886 | 0.0445 | 0.0020 |
| | | | | | | | | | 0.6842 | 0.0236 | 0.1265 | 0.1362 | 0.0295 |
| | | | | | | | | | | 0.7757 | 0.0208 | 0.1023 | 0.1013 |
| | | | | | | | | | | | 0.8470 | 0.0277 | 0.1253 |
| | | | | | | | | | | | | 0.9020 | 0.0980 |
| | | | | | | | | | | | | | 1.0000 |

Table 26. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 1 model for golden king crab in the WAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model ( ≥ 101 mm CL) | Mature Male Biomass ( ≥ 121 mm CL) | Standard Deviation | Legal Male Biomass ( ≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 9654 | 556 | 9381 | 1404 |
| 1986 | 4.54 | 5966 | 385 | 9351 | 480 |
| 1987 | 2.69 | 5799 | 345 | 6083 | 333 |
| 1988 | 1.25 | 5331 | 220 | 5648 | 264 |
| 1989 | 0.62 | 3253 | 149 | 5144 | 184 |
| 1990 | 0.65 | 2542 | 118 | 3139 | 129 |
| 1991 | 0.91 | 1589 | 85 | 2515 | 105 |
| 1992 | 0.36 | 1099 | 83 | 1564 | 76 |
| 1993 | 5.90 | 1970 | 211 | 1046 | 74 |
| 1994 | 0.76 | 2827 | 168 | 2020 | 127 |
| 1995 | 1.04 | 3012 | 180 | 2532 | 134 |
| 1996 | 1.59 | 2858 | 177 | 2882 | 153 |
| 1997 | 1.33 | 2912 | 176 | 2829 | 154 |
| 1998 | 0.80 | 3079 | 176 | 2858 | 154 |
| 1999 | 2.36 | 2857 | 188 | 3023 | 157 |
| 2000 | 1.50 | 3016 | 211 | 2844 | 160 |
| 2001 | 1.96 | 3229 | 248 | 2915 | 181 |
| 2002 | 2.19 | 3746 | 300 | 3151 | 217 |
| 2003 | 1.65 | 4277 | 354 | 3673 | 265 |
| 2004 | 2.05 | 4657 | 412 | 4187 | 322 |
| 2005 | 1.77 | 5072 | 465 | 4606 | 382 |
| 2006 | 1.25 | 5422 | 497 | 5011 | 436 |
| 2007 | 2.45 | 5567 | 529 | 5366 | 475 |
| 2008 | 1.30 | 5869 | 562 | 5559 | 505 |
| 2009 | 1.15 | 5688 | 584 | 5784 | 537 |
| 2010 | 1.19 | 5292 | 610 | 5637 | 565 |
| 2011 | 1.65 | 4979 | 691 | 5268 | 597 |
| 2012 | 1.60 | 4760 | 877 | 4954 | 679 |
| 2013 | 1.45 | 5374 | 2602 | 4698 | 855 |

Table 27. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 2 model for golden king crab in the WAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model ( ≥ 101 mm CL) | Mature Male Biomass ( ≥ 121 mm CL) | Standard Deviation | Legal Male Biomass ( ≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 8570 | 1241 | 10036 | 1479 |
| 1986 | 1.52 | 6056 | 472 | 8874 | 782 |
| 1987 | 2.63 | 6004 | 336 | 6105 | 374 |
| 1988 | 1.46 | 5302 | 223 | 5835 | 278 |
| 1989 | 0.63 | 3276 | 149 | 5182 | 194 |
| 1990 | 0.67 | 2600 | 120 | 3178 | 135 |
| 1991 | 0.86 | 1629 | 85 | 2563 | 110 |
| 1992 | 0.38 | 1113 | 82 | 1598 | 79 |
| 1993 | 6.06 | 1947 | 173 | 1073 | 77 |
| 1994 | 0.71 | 2830 | 172 | 1951 | 136 |
| 1995 | 1.21 | 3112 | 193 | 2630 | 156 |
| 1996 | 1.59 | 3020 | 192 | 3014 | 177 |
| 1997 | 1.33 | 3078 | 193 | 2985 | 182 |
| 1998 | 0.85 | 3250 | 194 | 3030 | 184 |
| 1999 | 2.39 | 3021 | 198 | 3205 | 184 |
| 2000 | 1.55 | 3172 | 230 | 2994 | 186 |
| 2001 | 2.06 | 3422 | 274 | 3093 | 215 |
| 2002 | 2.23 | 3972 | 333 | 3355 | 257 |
| 2003 | 1.72 | 4534 | 402 | 3907 | 313 |
| 2004 | 2.09 | 4942 | 468 | 4461 | 379 |
| 2005 | 1.86 | 5372 | 529 | 4889 | 445 |
| 2006 | 1.32 | 5765 | 565 | 5315 | 505 |
| 2007 | 2.48 | 5919 | 595 | 5708 | 544 |
| 2008 | 1.29 | 6192 | 625 | 5885 | 574 |
| 2009 | 1.15 | 5987 | 642 | 6115 | 604 |
| 2010 | 1.20 | 5549 | 661 | 5929 | 625 |
| 2011 | 1.57 | 5167 | 732 | 5507 | 648 |
| 2012 | 1.63 | 4864 | 905 | 5121 | 720 |
| 2013 | 1.42 | 5420 | 2660 | 4799 | 888 |

Table 28. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 3 model for golden king crab in the WAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model ( ≥ 101 mm CL) | Mature Male Biomass ( ≥ 121 mm CL) | Standard Deviation | Legal Male Biomass ( ≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 6858 | 1866 | 6331 | 1934 |
| 1986 | 8.40 | 4489 | 1060 | 6674 | 1862 |
| 1987 | 1.93 | 5608 | 374 | 4390 | 1107 |
| 1988 | 1.76 | 5441 | 246 | 5113 | 441 |
| 1989 | 0.66 | 3555 | 169 | 5119 | 227 |
| 1990 | 0.45 | 2861 | 141 | 3374 | 151 |
| 1991 | 1.27 | 1954 | 126 | 2796 | 132 |
| 1992 | 0.36 | 1536 | 133 | 1901 | 115 |
| 1993 | 5.62 | 2604 | 217 | 1450 | 123 |
| 1994 | 0.93 | 3167 | 222 | 2469 | 149 |
| 1995 | 1.08 | 3365 | 243 | 2811 | 193 |
| 1996 | 1.58 | 3258 | 241 | 3175 | 232 |
| 1997 | 1.58 | 3377 | 241 | 3160 | 234 |
| 1998 | 0.70 | 3571 | 247 | 3259 | 228 |
| 1999 | 2.57 | 3455 | 264 | 3458 | 235 |
| 2000 | 1.64 | 3679 | 303 | 3354 | 243 |
| 2001 | 2.14 | 4020 | 352 | 3496 | 278 |
| 2002 | 2.29 | 4650 | 413 | 3846 | 324 |
| 2003 | 1.61 | 5169 | 476 | 4470 | 380 |
| 2004 | 2.10 | 5521 | 540 | 4992 | 445 |
| 2005 | 1.93 | 5917 | 591 | 5379 | 510 |
| 2006 | 1.30 | 6260 | 629 | 5762 | 562 |
| 2007 | 2.54 | 6462 | 677 | 6115 | 604 |
| 2008 | 1.39 | 6724 | 744 | 6334 | 649 |
| 2009 | 1.14 | 6502 | 800 | 6547 | 713 |
| 2010 | 1.24 | 6054 | 859 | 6369 | 776 |
| 2011 | 1.69 | 5726 | 975 | 5957 | 839 |
| 2012 | 1.60 | 5466 | 1168 | 5614 | 949 |
| 2013 | 1.53 | 5923 | 3026 | 5315 | 1130 |

Table 29. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 4 model for golden king crab in the WAG. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

| Year | Recruits to the Model ( ≥ 101 mm CL) | Mature Male Biomass ( ≥ 121 mm CL) | Standard Deviation | Legal Male Biomass ( ≥ 136 mm CL) | Standard Deviation |
|---|---|---|---|---|---|
| 1985 | NA | 5998 | 1106 | 6836 | 1125 |
| 1986 | 1.50 | 5348 | 782 | 6452 | 910 |
| 1987 | 3.19 | 5627 | 361 | 5203 | 579 |
| 1988 | 2.01 | 5303 | 259 | 5427 | 314 |
| 1989 | 0.62 | 3618 | 194 | 5160 | 226 |
| 1990 | 0.48 | 2986 | 170 | 3490 | 181 |
| 1991 | 1.23 | 2026 | 149 | 2933 | 162 |
| 1992 | 0.38 | 1597 | 156 | 1996 | 145 |
| 1993 | 5.86 | 2506 | 229 | 1547 | 152 |
| 1994 | 0.86 | 3228 | 225 | 2480 | 201 |
| 1995 | 1.27 | 3571 | 259 | 3034 | 216 |
| 1996 | 1.64 | 3526 | 269 | 3463 | 249 |
| 1997 | 1.59 | 3663 | 282 | 3477 | 262 |
| 1998 | 0.79 | 3902 | 299 | 3602 | 275 |
| 1999 | 2.67 | 3757 | 322 | 3835 | 289 |
| 2000 | 1.74 | 4021 | 372 | 3710 | 311 |
| 2001 | 2.28 | 4422 | 436 | 3923 | 359 |
| 2002 | 2.41 | 5104 | 513 | 4330 | 419 |
| 2003 | 1.67 | 5698 | 591 | 5013 | 492 |
| 2004 | 2.16 | 6054 | 662 | 5598 | 567 |
| 2005 | 2.06 | 6445 | 723 | 5975 | 638 |
| 2006 | 1.39 | 6843 | 764 | 6357 | 698 |
| 2007 | 2.64 | 7023 | 810 | 6745 | 739 |
| 2008 | 1.39 | 7289 | 875 | 6943 | 786 |
| 2009 | 1.20 | 7058 | 920 | 7169 | 848 |
| 2010 | 1.28 | 6567 | 961 | 6958 | 896 |
| 2011 | 1.67 | 6152 | 1050 | 6486 | 941 |
| 2012 | 1.69 | 5820 | 1217 | 6066 | 1030 |
| 2013 | 1.51 | 6195 | 3248 | 5718 | 1191 |

Table 30. Likelihood values of the fits for scenarios 1 to 4 for golden king crab in the WAG.

| Likelihood Component | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| like_retlencomp | -569.51 | -573.73 | -562.64 | -572.10 |
| like_totallencomp | -670.96 | -670.50 | -671.25 | -670.83 |
| like_gdiscdlencomp | -282.85 | -283.18 | -284.59 | -285.07 |
| like_retcpue | -10.67 | -10.26 | -7.51 | -8.98 |
| like_retdcatchB | 38.76 | 38.11 | 48.82 | 48.59 |
| like_totalcatchB | 54.07 | 52.80 | 63.23 | 62.70 |
| like_gdiscdcatchB | 0.00 | 0.00 | 0.00 | 0.00 |
| like_rec_dev | 13.67 | 11.67 | 16.32 | 13.07 |
| like_F | 0.00 | 0.00 | 0.00 | 0.00 |
| like_gF | 0.00 | 0.00 | 0.00 | 0.00 |
| like_Tag | 279.44 | 169.23 | 280.13 | 170.50 |
| like_meanFpot | 0.00 | 0.00 | 0.00 | 0.00 |
| like_fpen | 0.00 | 0.00 | 0.00 | 0.00 |
| like_finalF | 0.00 | 0.00 | 0.00 | 0.00 |
| Like_fishtickCPUE | | | 23.96 | 22.61 |
| Total | -1148.06 | -1265.86 | -1093.52 | -1219.53 |

Table 31. Likelihood values of the fits for scenarios 6 and 7 for golden king crab in the EAG and WAG.

| | EAG | | WAG | |
|---|---|---|---|---|
| Likelihood Component | Scenario **6** | Scenario **7** | Scenario 6 | Scenario 7 |
| like_retlencomp | -537.24 | -536.93 | -571.03 | -570.99 |
| like_totallencomp | -592.94 | -592.92 | -670.94 | -670.88 |
| like_gdiscdlencomp | -301.73 | -301.75 | -282.79 | -282.82 |
| like_retcpue | -9.73 | -9.74 | -10.61 | -10.67 |
| like_retdcatchB | 33.88 | 33.89 | 38.82 | 38.73 |
| like_totalcatchB | 45.77 | 45.78 | 54.14 | 54.08 |
| like_gdiscdcatchB | 0.00 | 0.00 | 0.00 | 0.00 |
| like_rec_dev | 13.65 | 13.68 | 11.83 | 12.72 |
| like_F | 0.00 | 0.00 | 0.00 | 0.00 |
| like_gF | 0.00 | 0.00 | 0.00 | 0.00 |
| like_Tag | 279.34 | 279.36 | 279.28 | 279.20 |
| like_meanFpot | 0.00 | 0.00 | 0.00 | 0.00 |
| like_fpen | 0.00 | 0.00 | 0.00 | 0.00 |
| like_finalF | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | -1068.99 | -1068.64 | -1151.30 | -1150.63 |

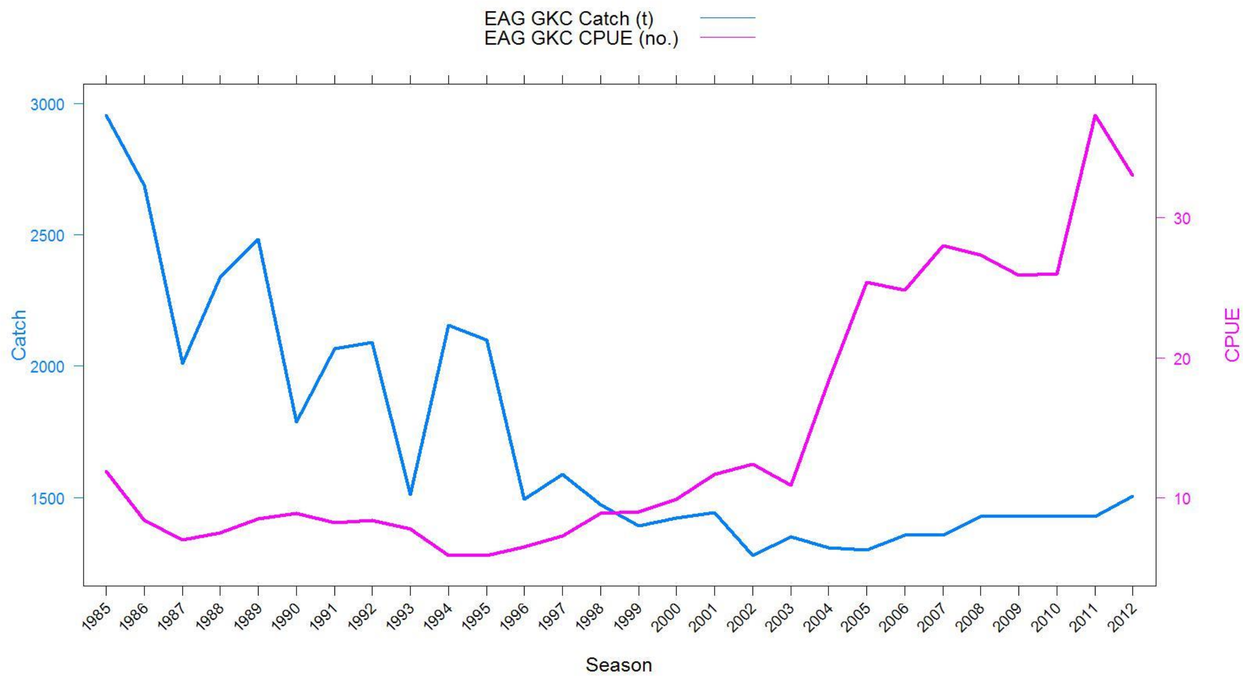



Figure 1. Historical commercial harvest (from fish ticket and in metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2012/13 fisheries (note: 1985 refers to the 1985/86 fishery).

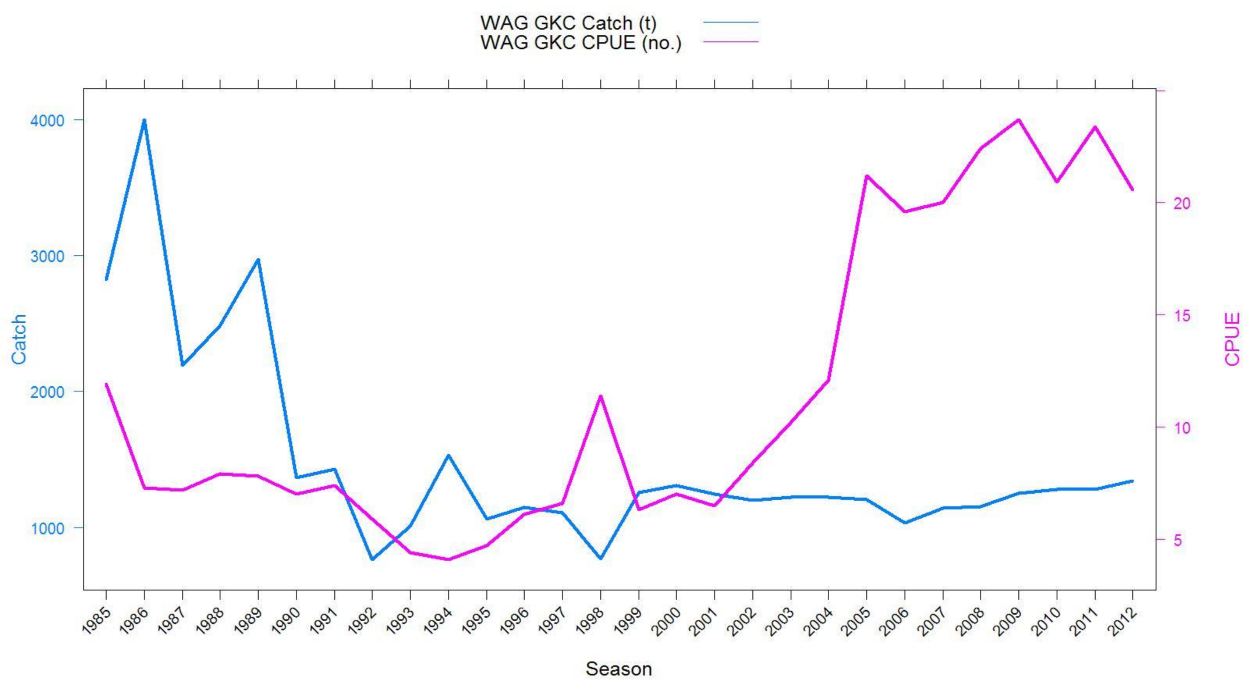



Figure 2. Historical commercial harvest (from fish ticket and in metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2012/13 fisheries (note: 1985 refers to the 1985/86 fishery).

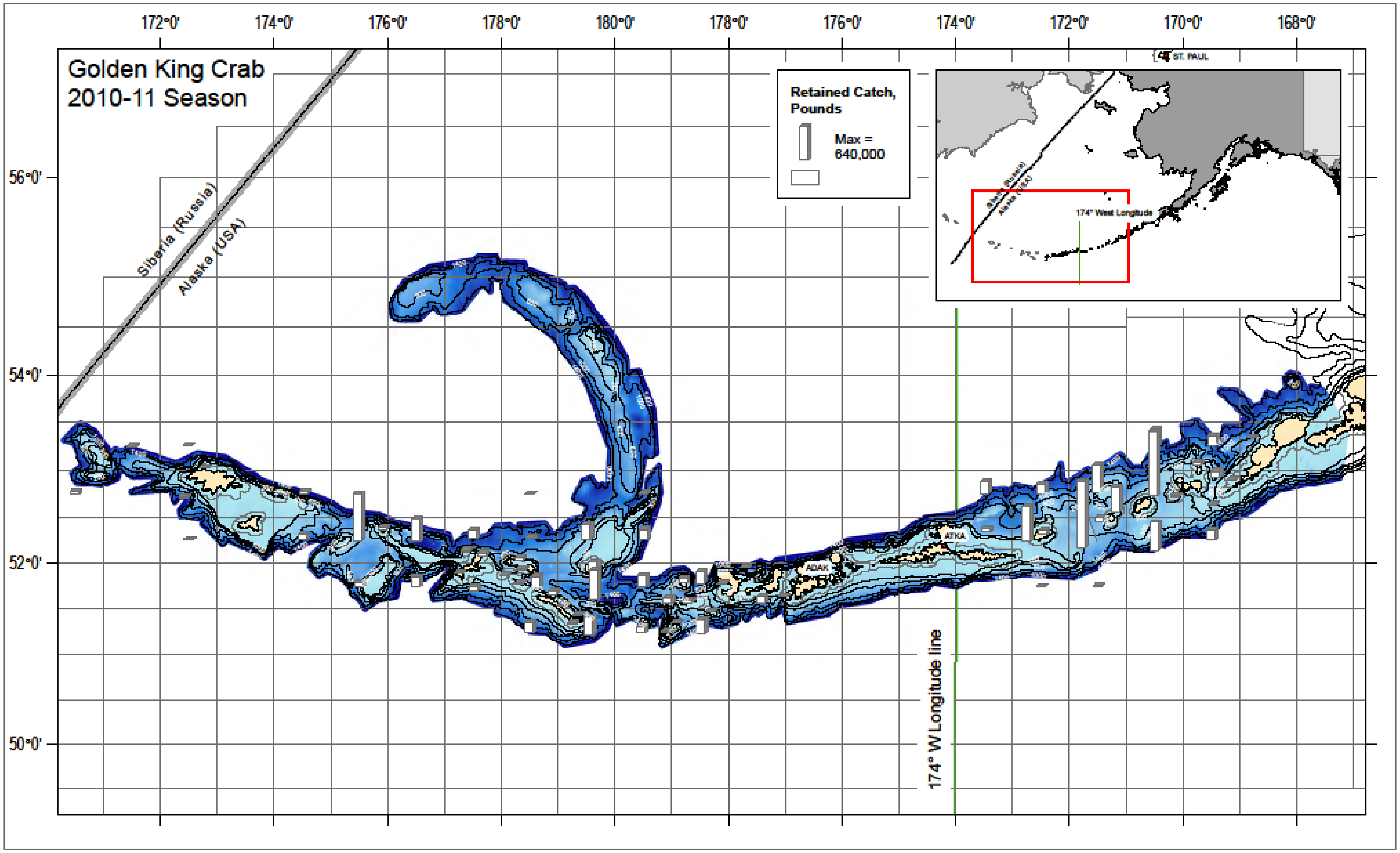



Figure 3. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2010/11.

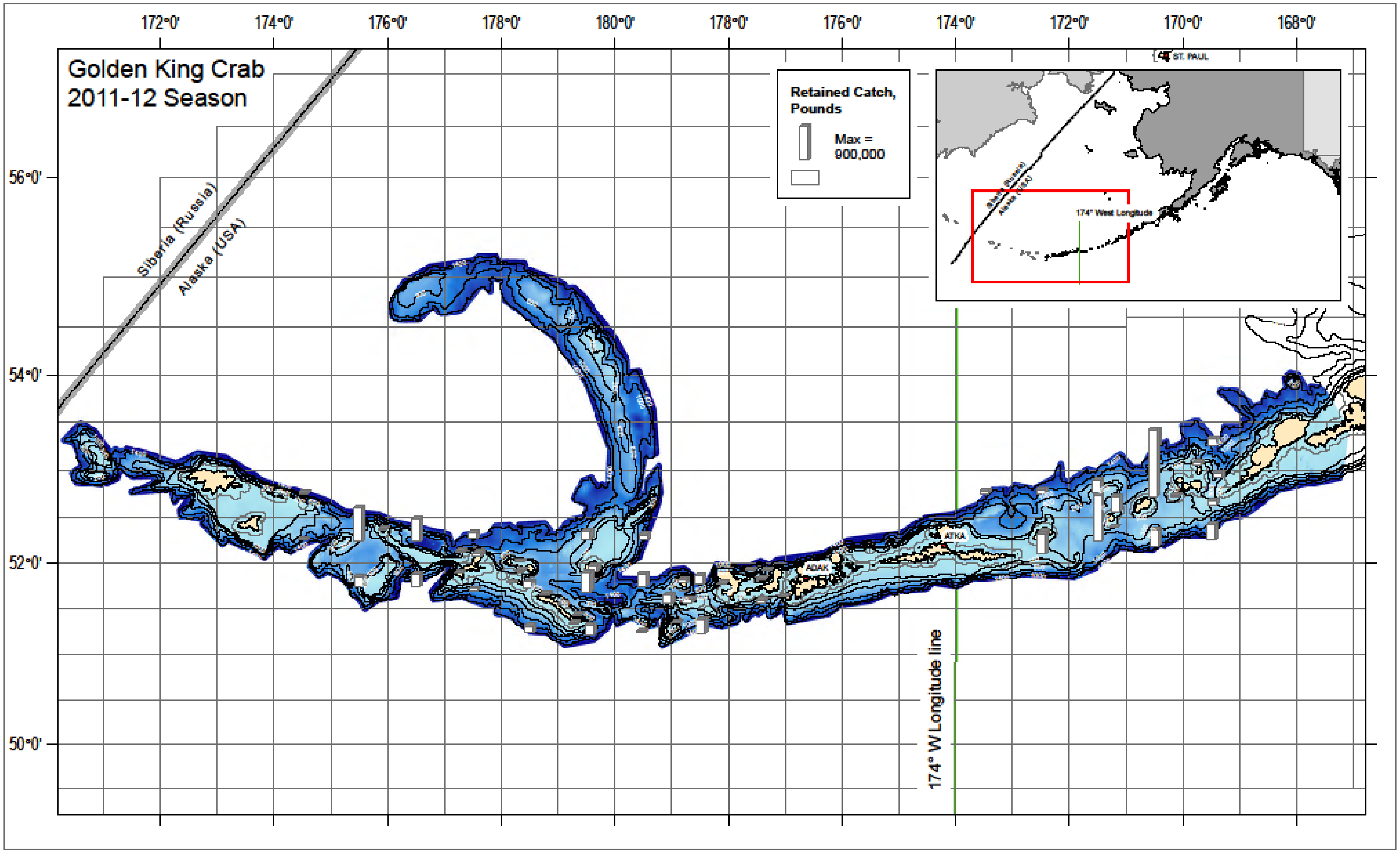



Figure 4. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2011/12.

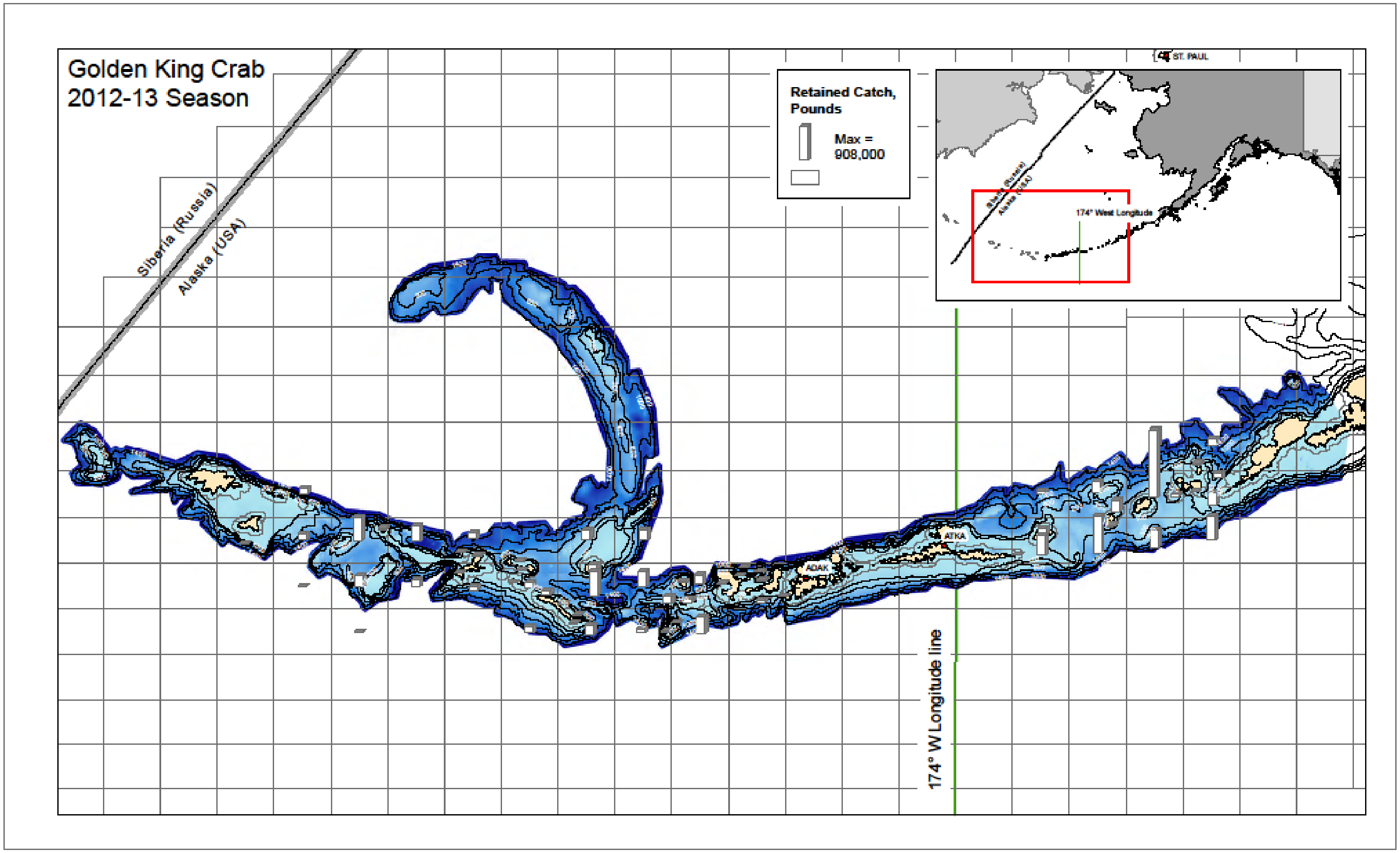



Figure 5. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2012/13.

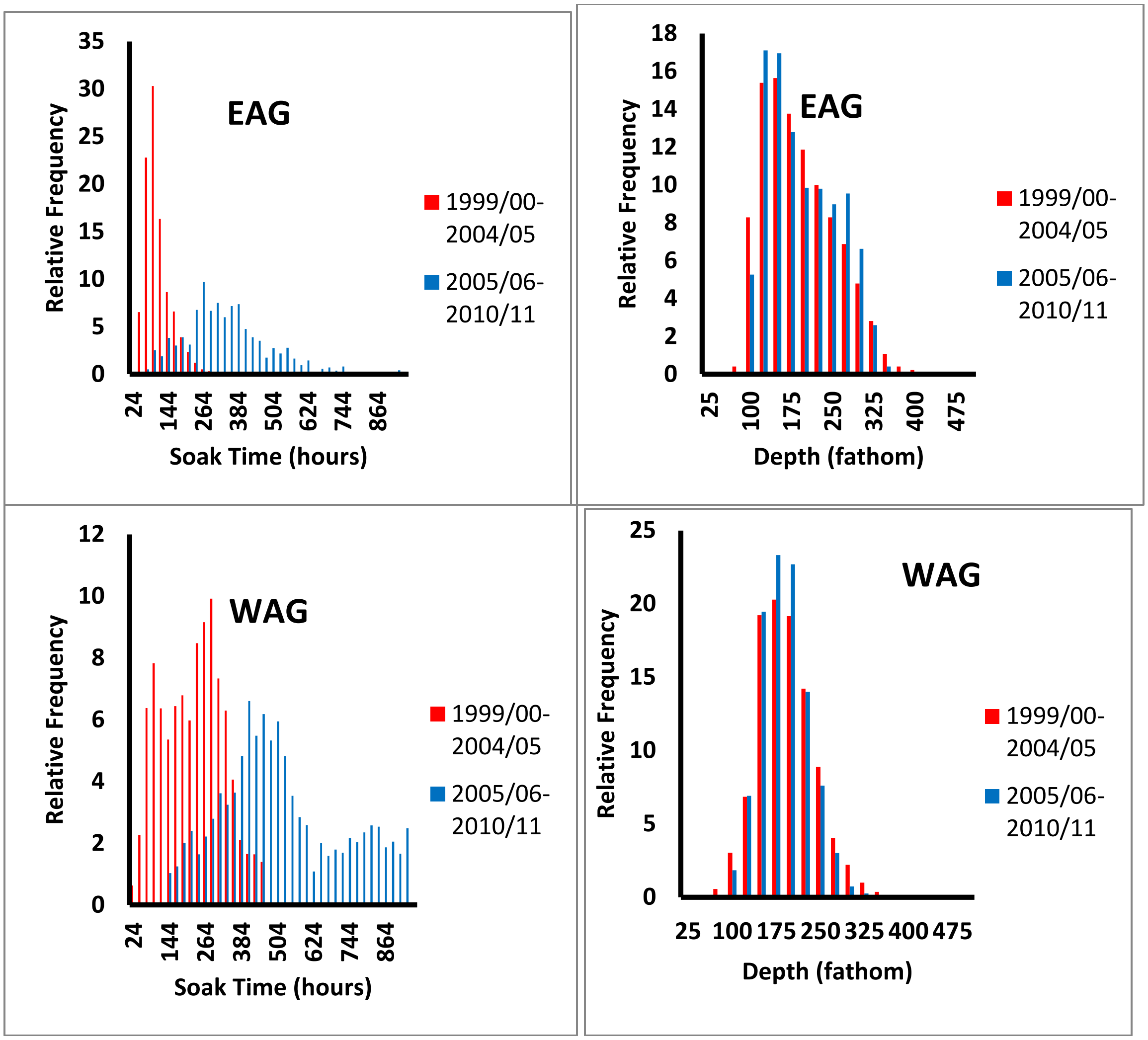



Figure 6. Soak time and depth relative frequency distributions of golden king crab pots during pre (1999/00–2004/05) - and post (2005/06–2010/11) - rationalization periods.

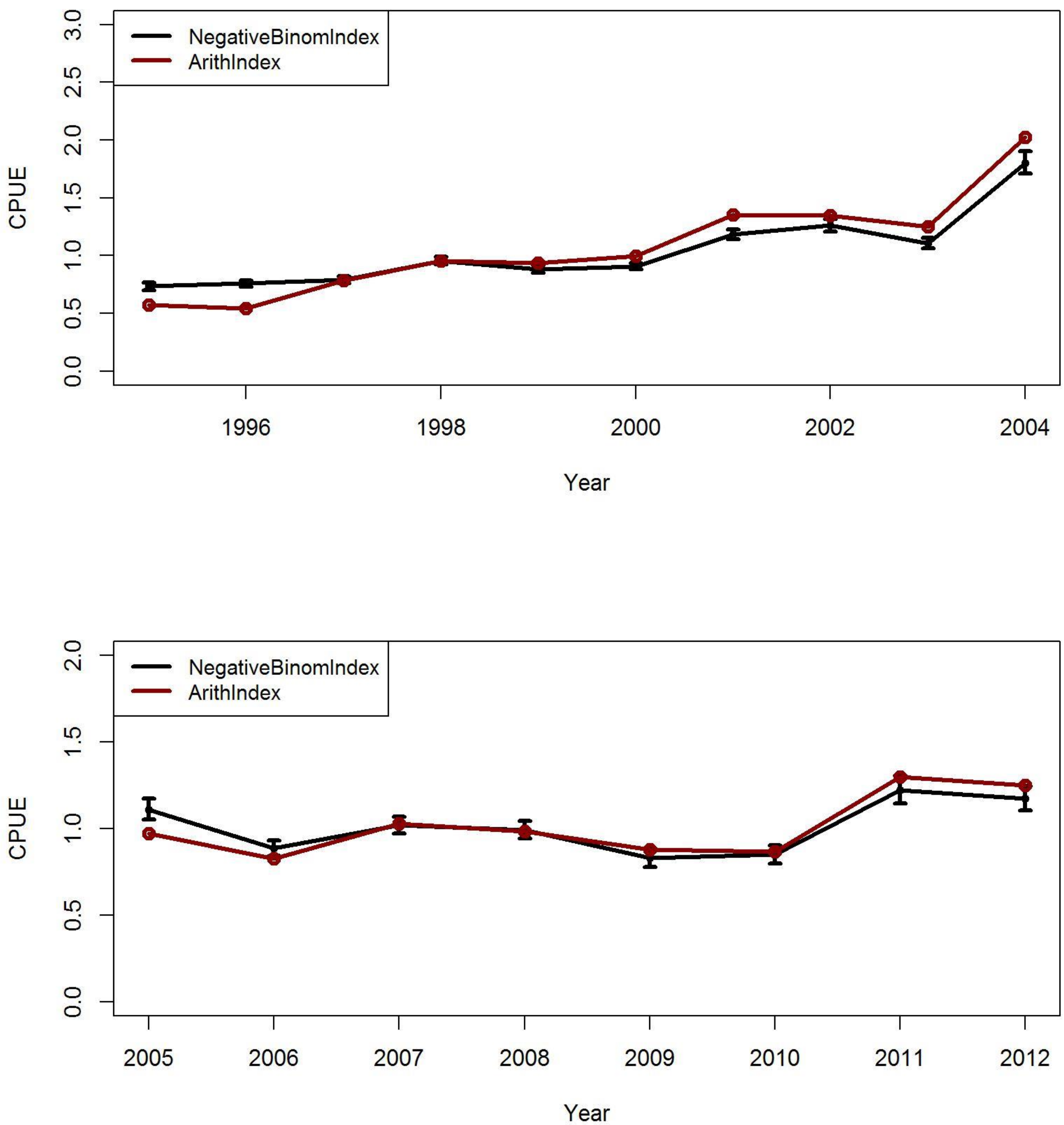



Figure 7. Trends in arithmetic (nominal) and negative binomial CPUE indices with +/- 1 SE for Aleutian Islands golden king crab from EAG (east of 174°W longitude). Top panel: 1995/96-2004/05 observer data and bottom panel: 2005/06-2012/13 observer data. Negative binomial indices: black line and Arithmetic indices: red line.

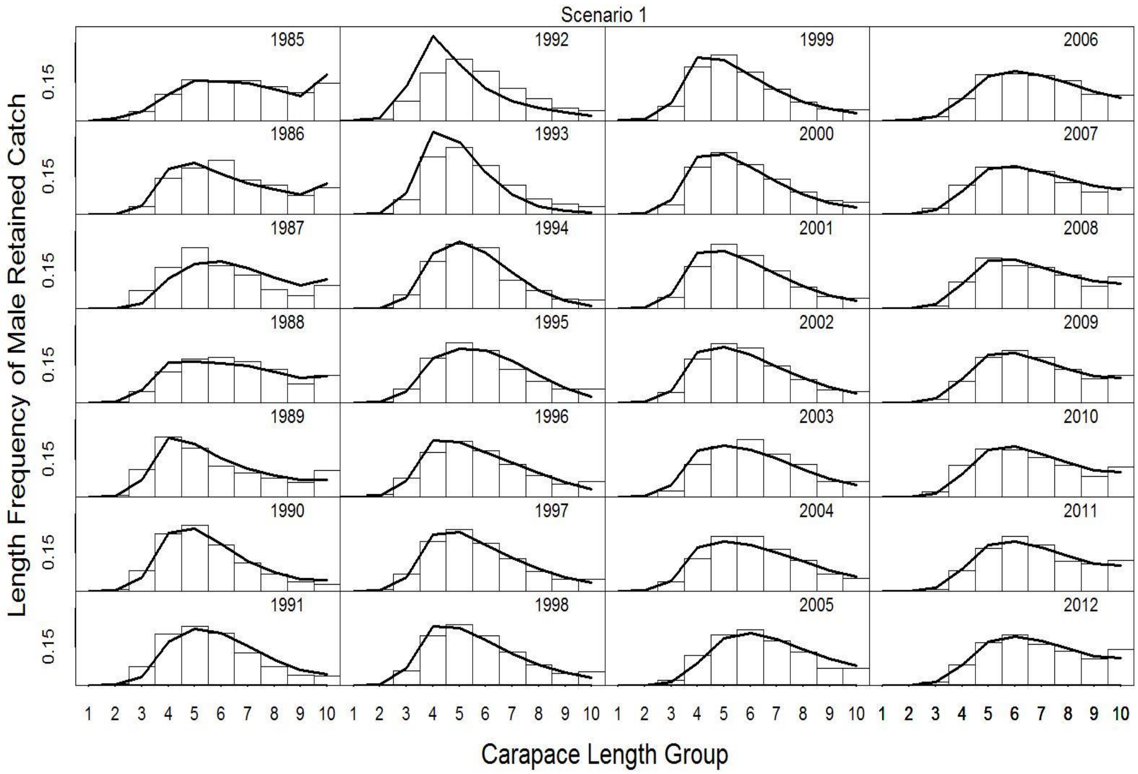



Figure 8a. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 1 data of golden king crab in the EAG, 1985/86 to 2012/13. Length group 1 is 103 mm CL.

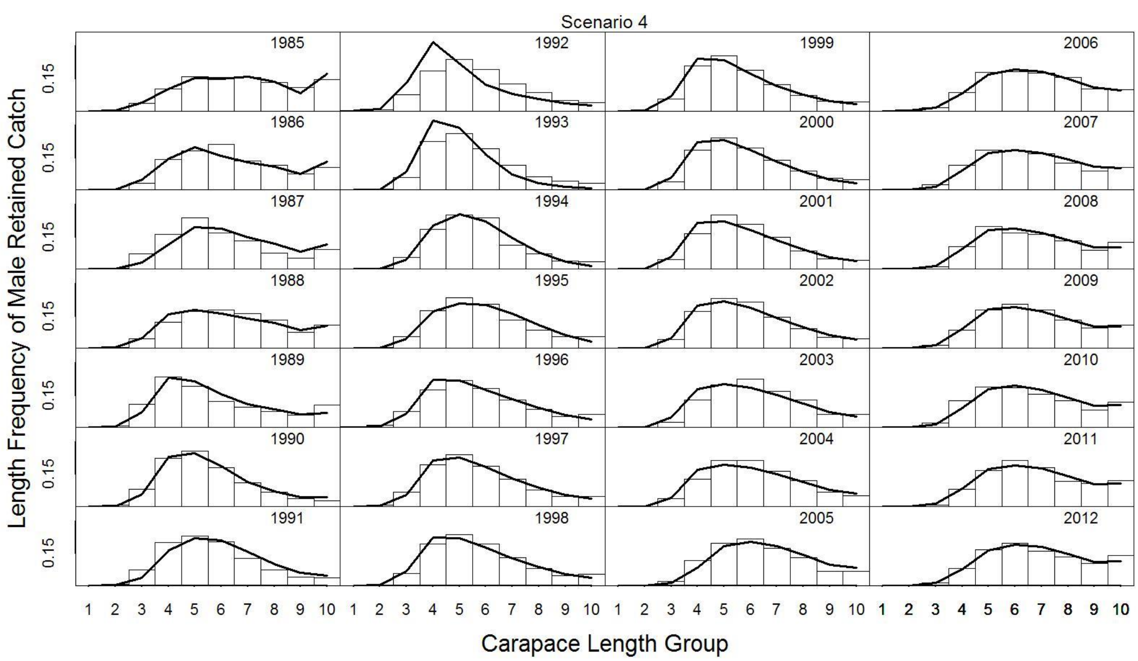



Figure 8b. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 4 data of golden king crab in the EAG, 1985/86 to 2012/13. Length group 1 is 103 mm CL.

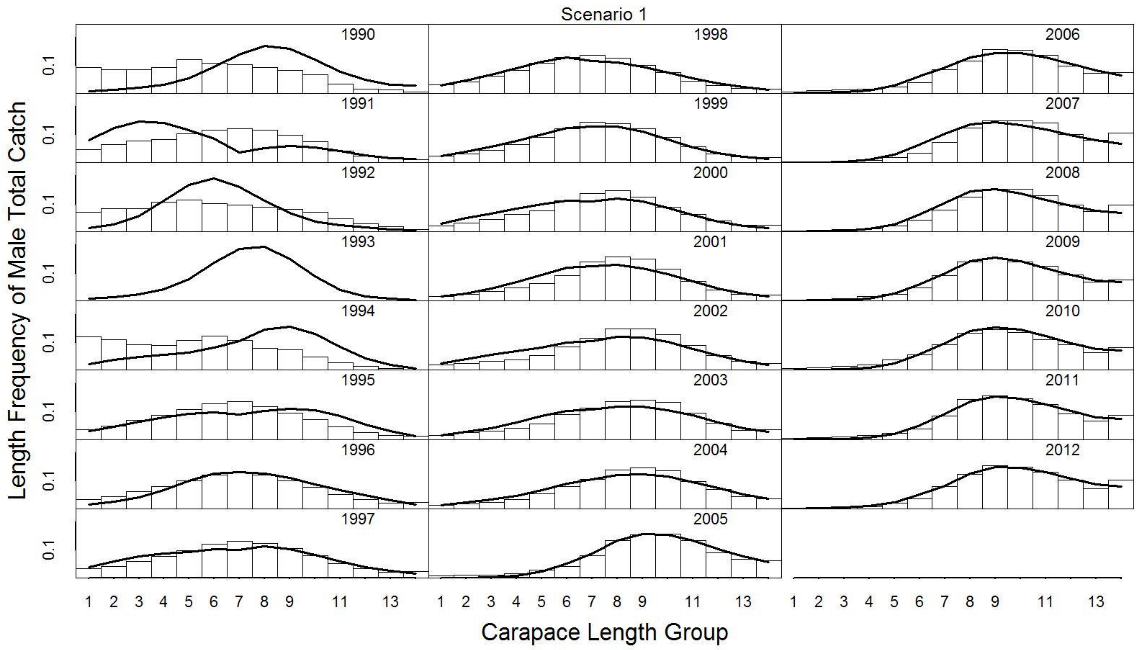



Figure 9a. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 1 data of golden king crab in the EAG, 1990/91 to 2012/13. Length group 1 is 103 mm CL.

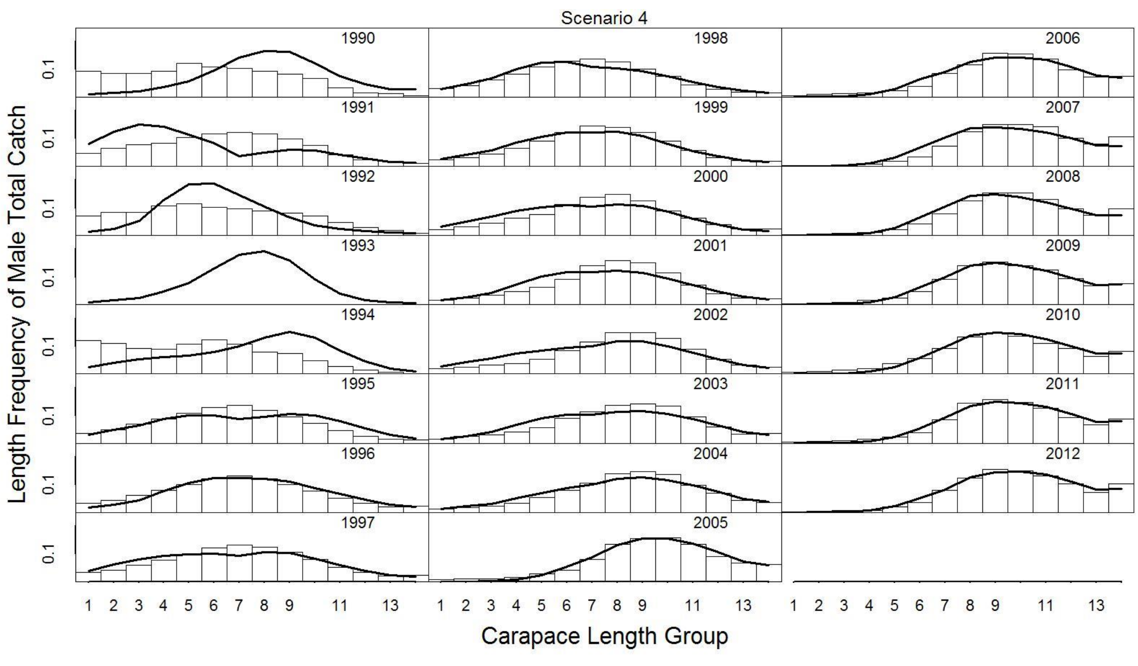



Figure 9b. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 4 data of golden king crab in the EAG, 1990/91 to 2012/13. Length group 1 is 103 mm CL.

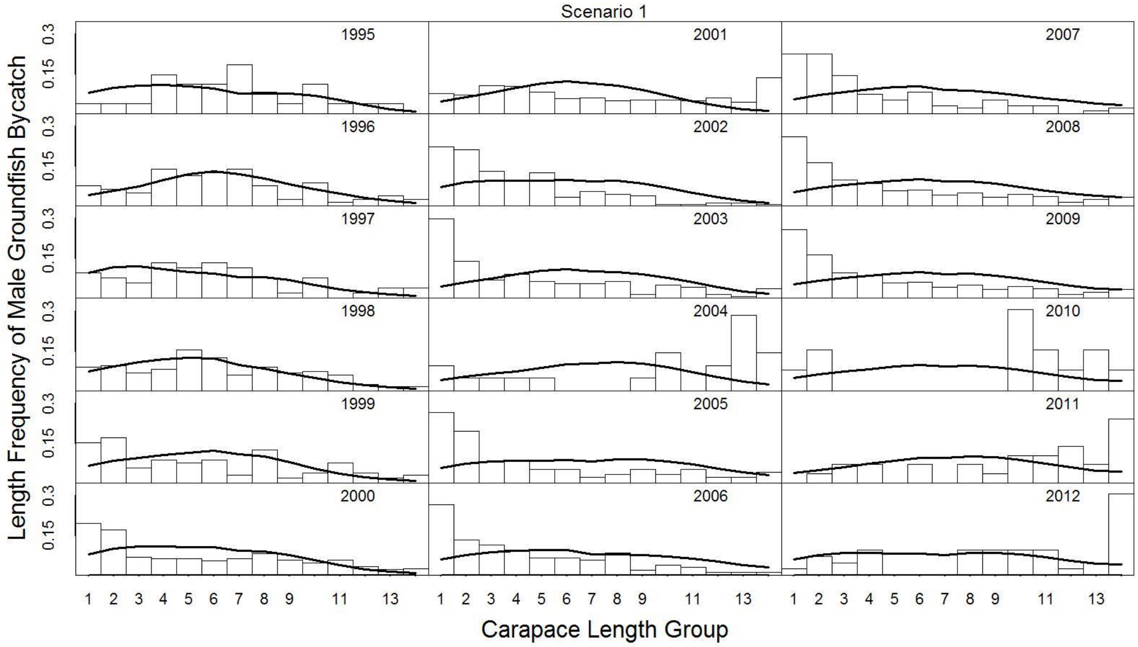



Figure 10a. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 1 data of golden king crab in the EAG, 1995/96 to 2012/13. Length group 1 is 103 mm CL.

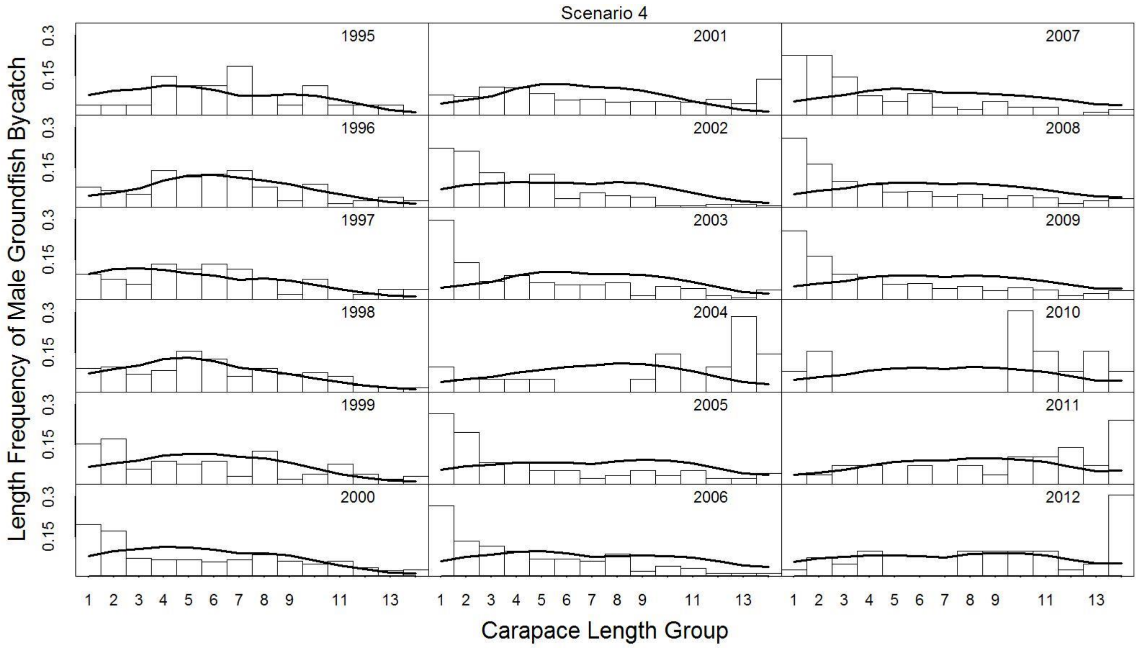



Figure 10b. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 4 data of golden king crab in the EAG, 1995/96 to 2012/13. Length group 1 is 103 mm CL.

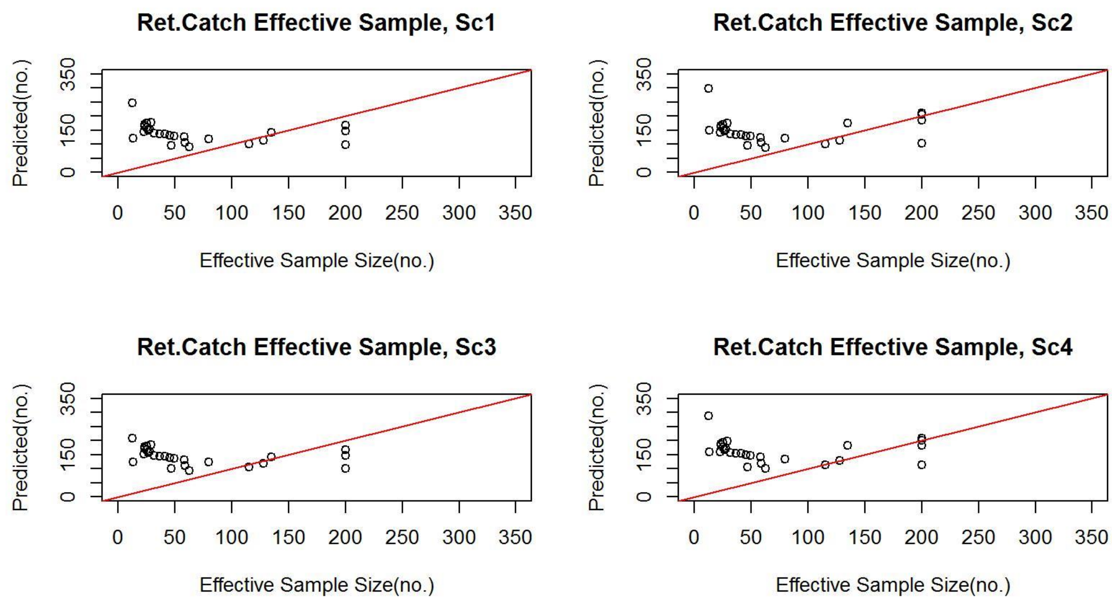



Figure 11. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios (Sc) 1 to 4 fits to golden king crab data in the EAG, 1985/96 to 2012/13. The red line is the $45^0$ line passing through the origin.

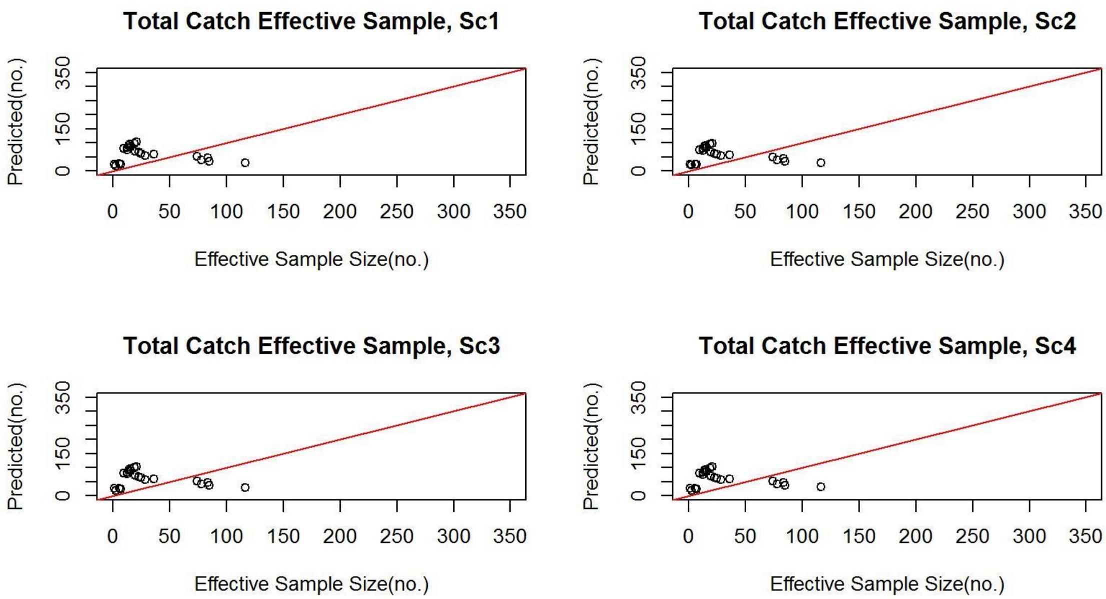



Figure 12. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios (Sc) 1 to 4 fits to golden king crab data in the EAG, 1990/91 to 2012/13. The red line is the $45^0$ line passing through the origin.

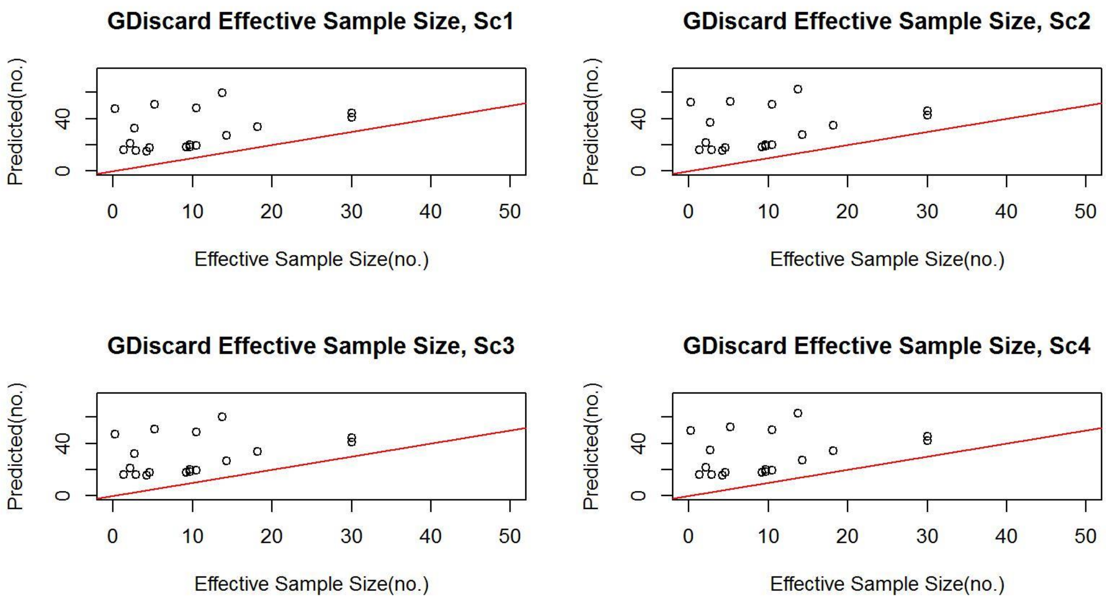



Figure 13. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for scenarios (Sc) 1 to 4 fits to golden king crab data in the EAG, 1995/96 to 2012/13. The red line is the $45^0$ line passing through the origin.

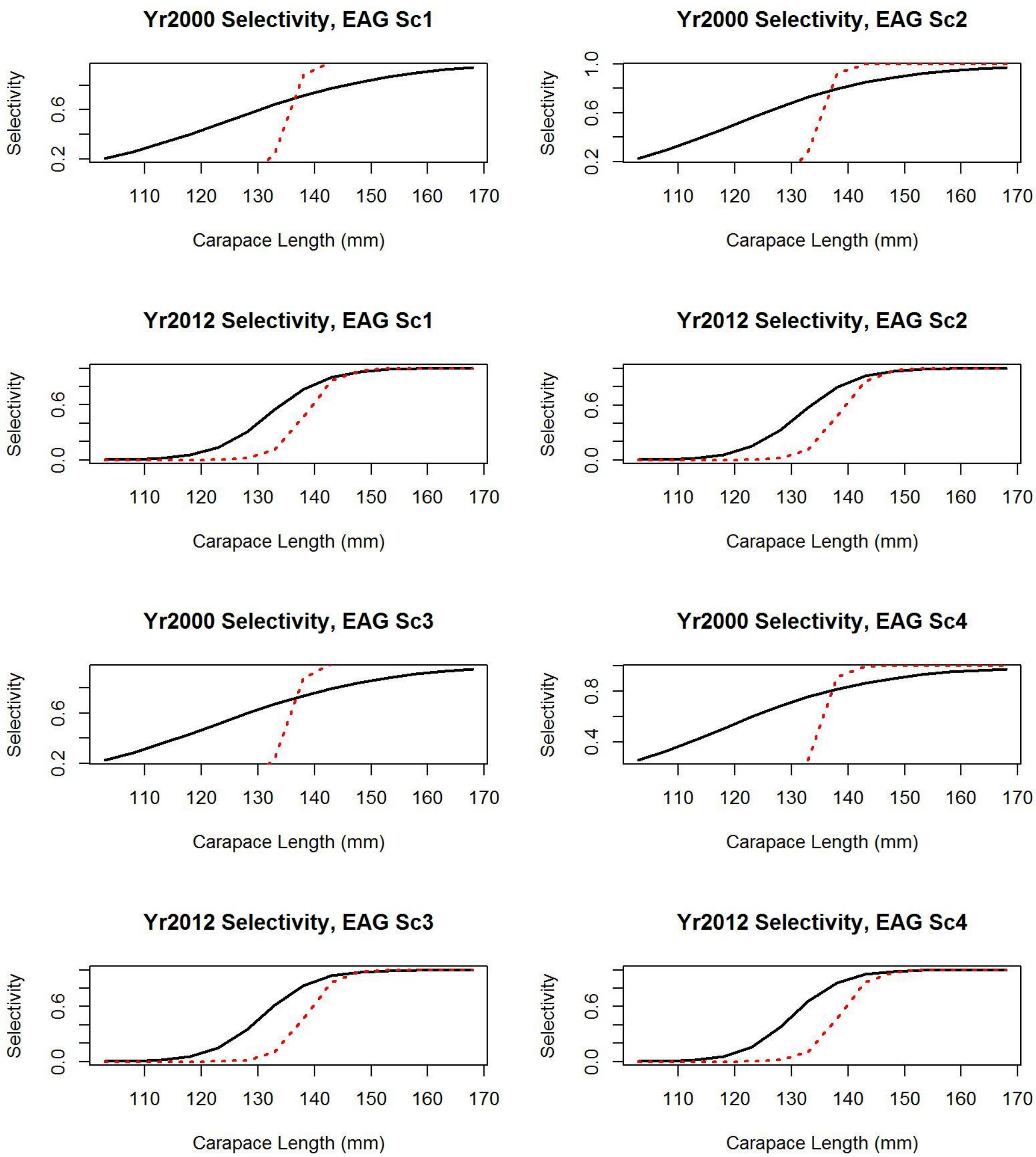
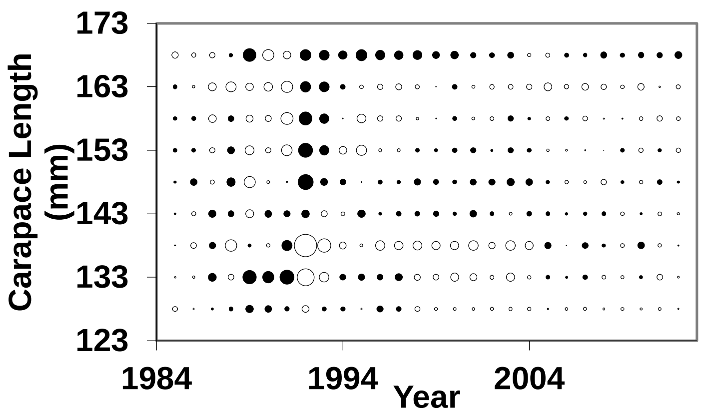
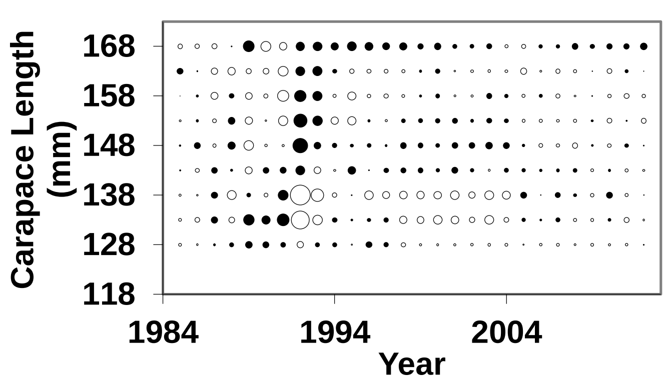


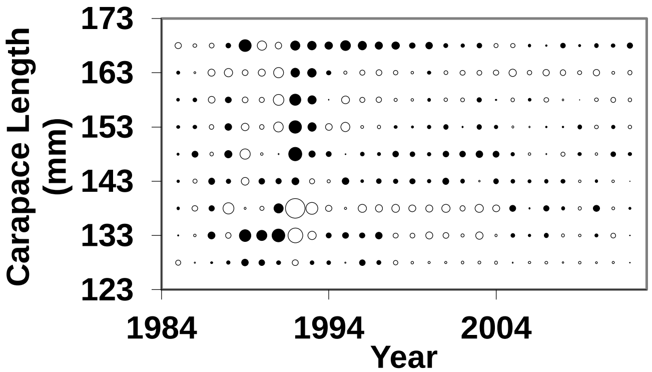

Figure 14. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- (Yr2000) and post- (Yr2012) rationalization periods under scenarios (Sc) 1 to 4 fits of EAG golden king crab data. Yr2000 refers to the 1985–2004 period's selectivity and Yr2012 refers to the 2005–2012 period's selectivity.

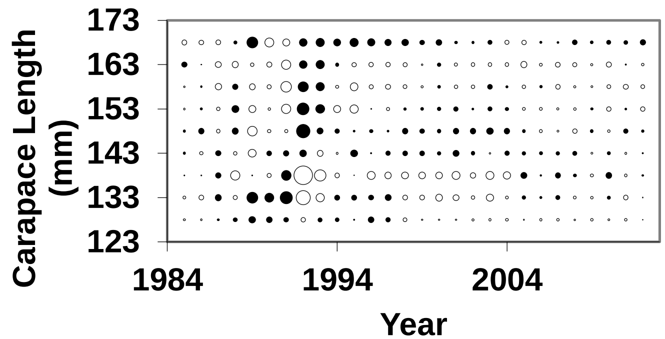



Scenario 1

Scenario 2




Scenario 3

Scenario 4

Figure 15. Bubble plots of standardized residuals of retained catch length composition for scenarios 1 to 4 for EAG golden king crab, 1985/86–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

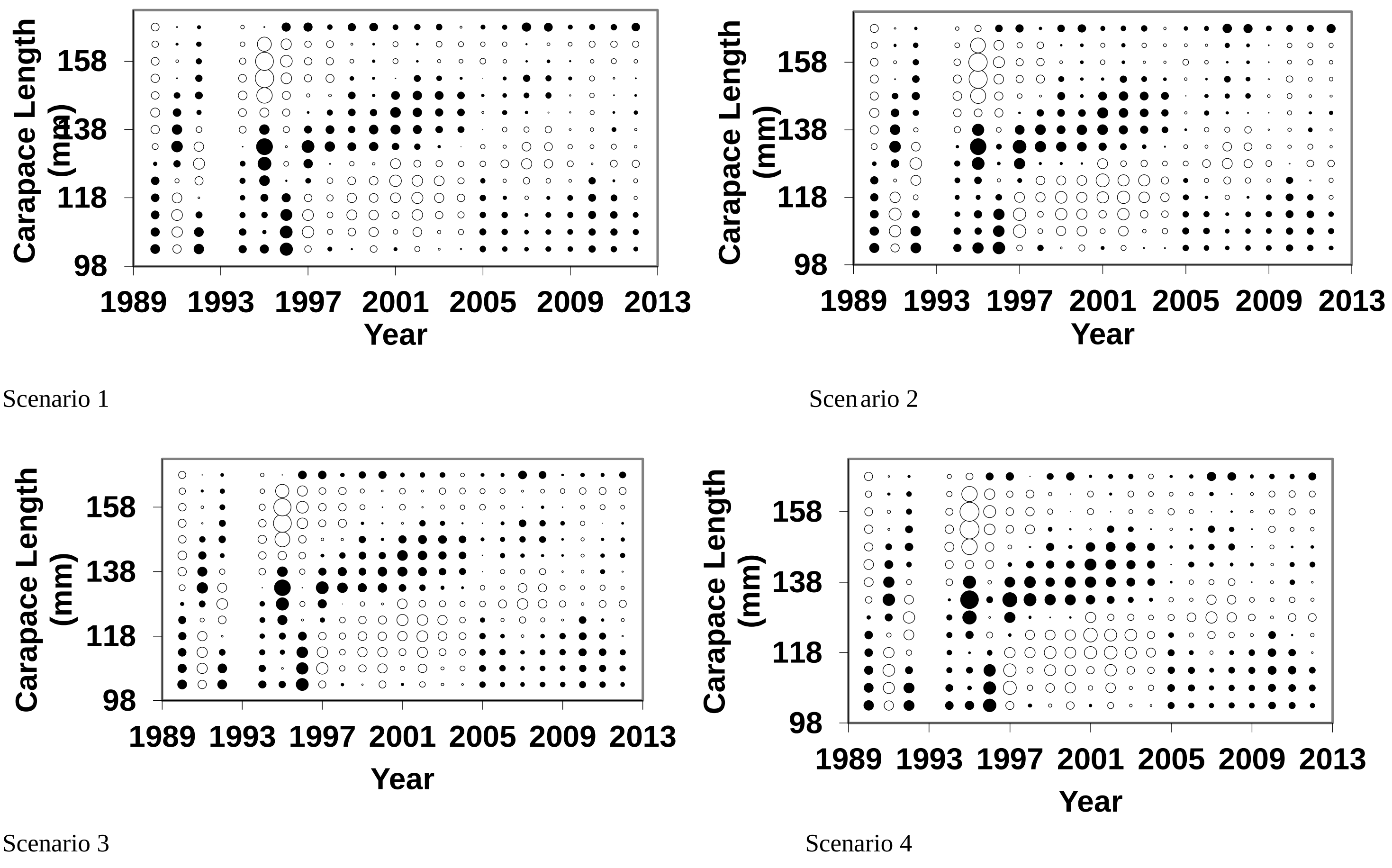
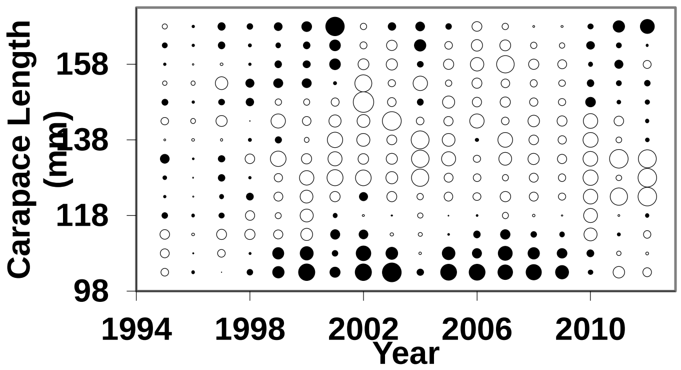
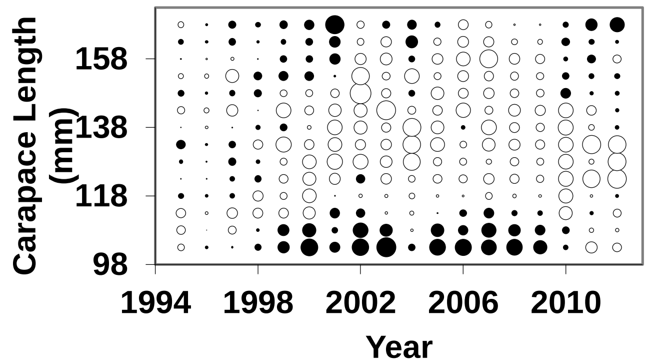


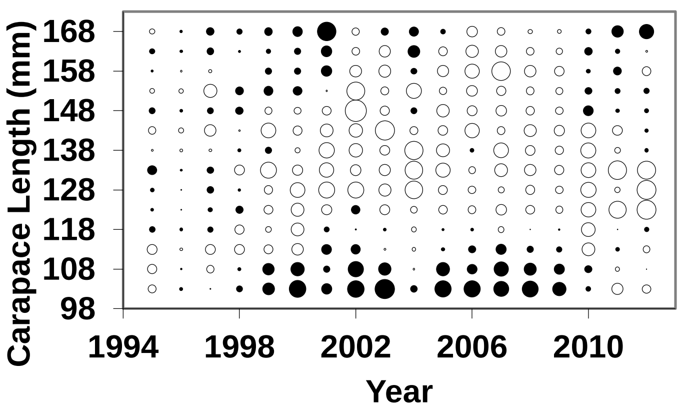

Figure 16. Bubble plots of standardized residuals of total catch length composition for scenarios 1 to 4 for EAG golden king crab, 1990/91–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



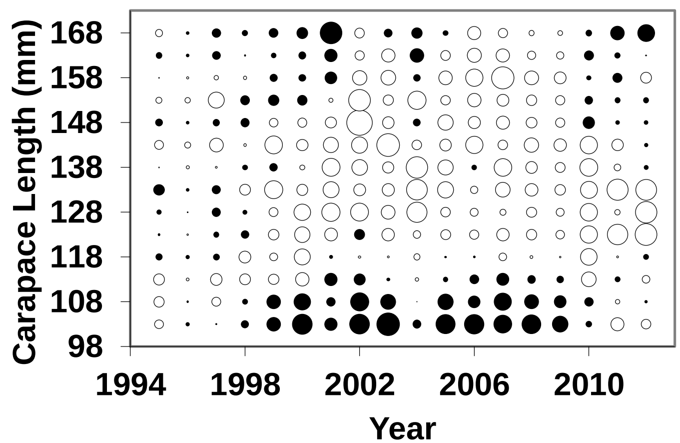

Scenario 1




Scenario 2




Scenario 3




Scenario 4

Figure 17. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 1 to 4 for EAG golden king crab, 1995/96–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

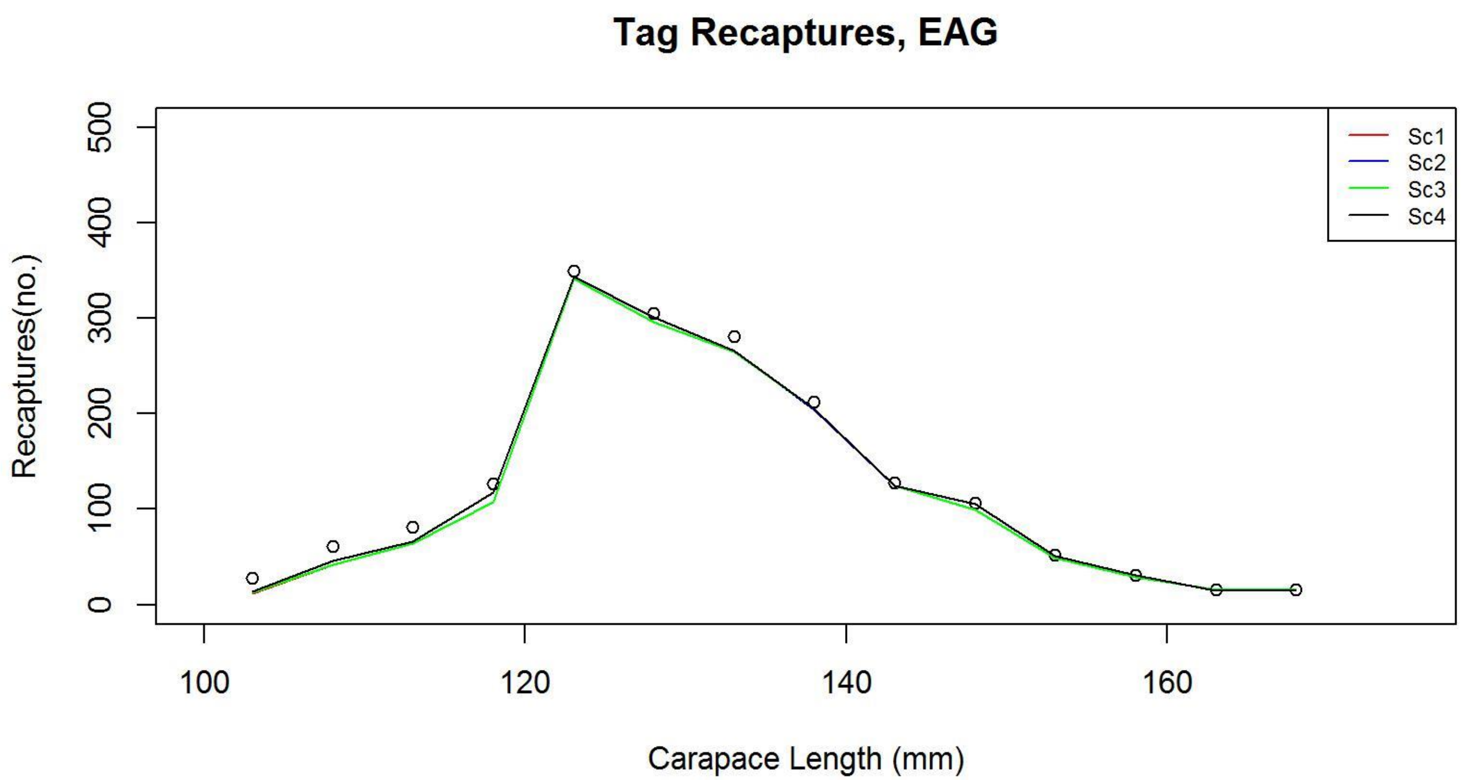



Figure 18. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for scenarios 1 to 4 fits of EAG golden king crab data.

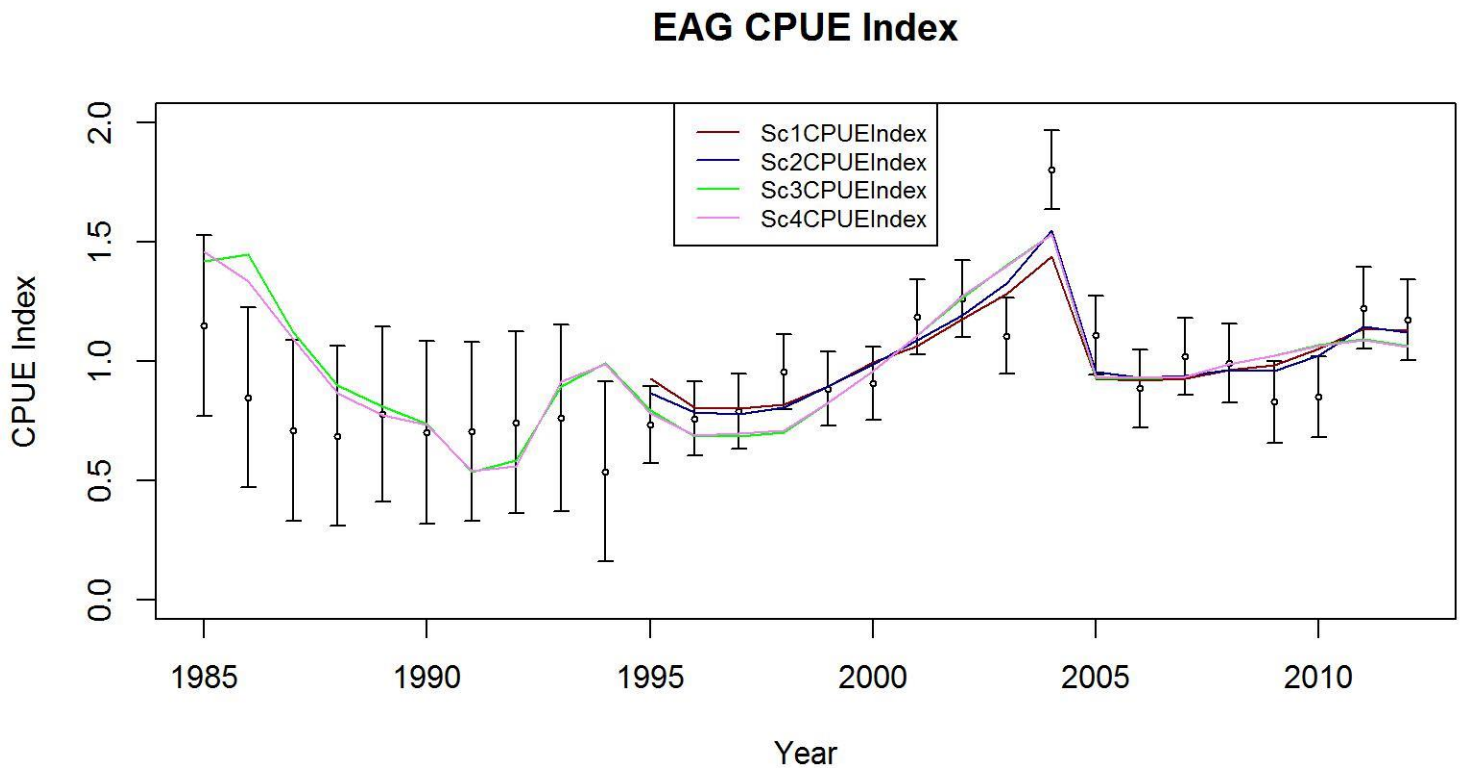



Figure 19. Comparison of input CPUE indices (open circles with one standard error) with predicted CPUE indices (colored solid lines) for scenarios 1 to 4 fits for EAG golden king crab data. Model estimated additional standard error was added to each input standard error.

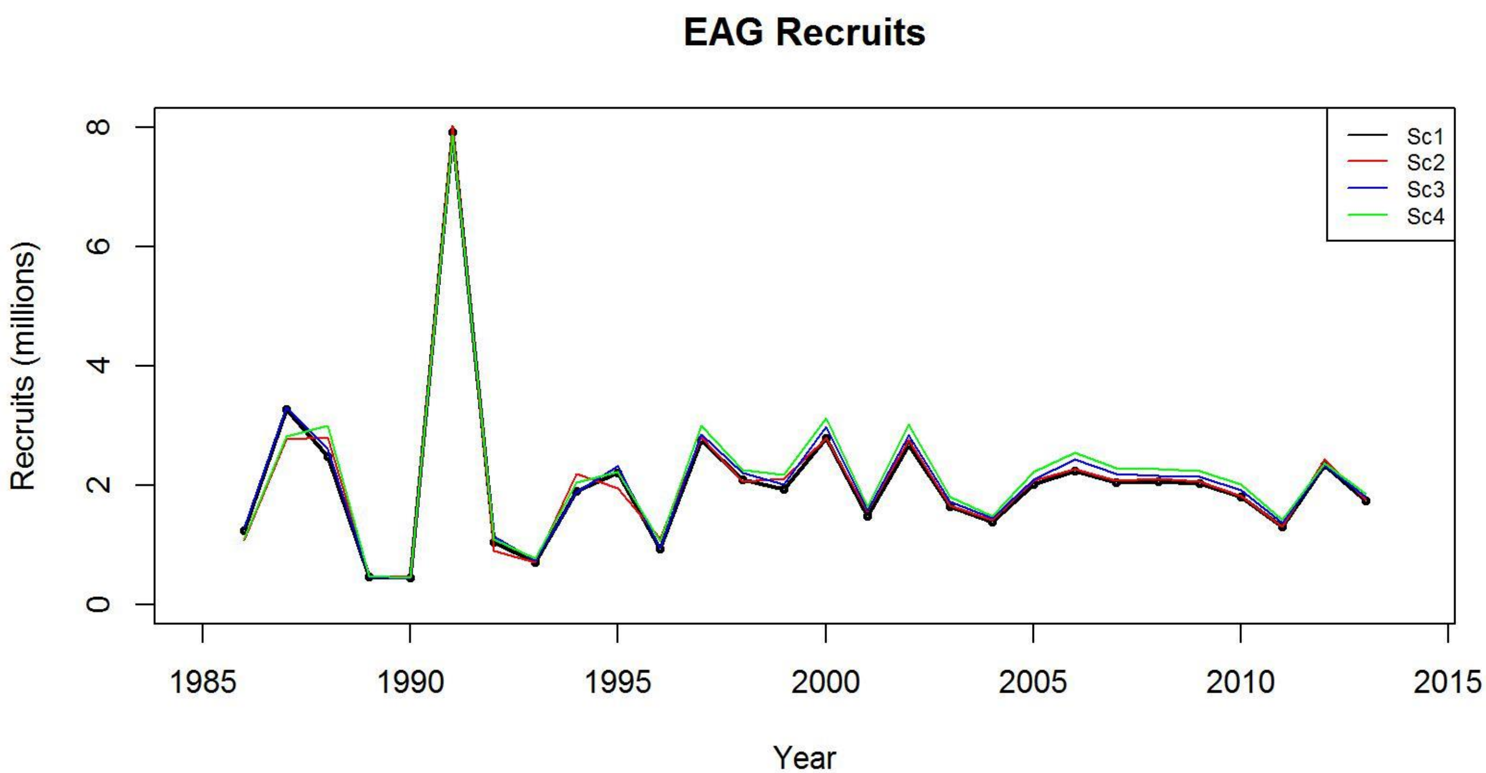



Figure 20. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab assessment model for scenarios 1 to 4 fits in EAG, 1986–2013.

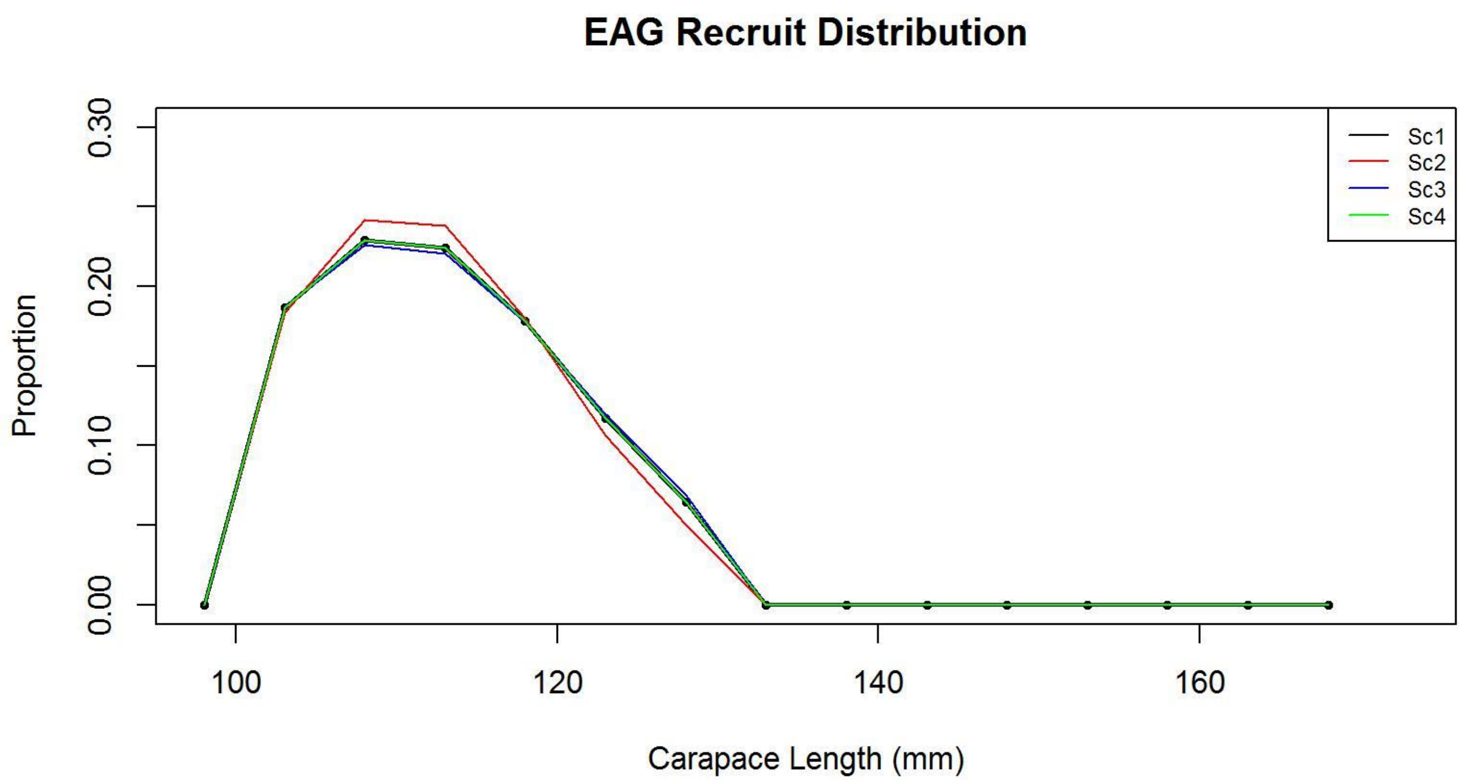



Figure 21. Recruit distribution to the golden king crab assessment model size group for scenarios 1 to 4 fits in EAG.

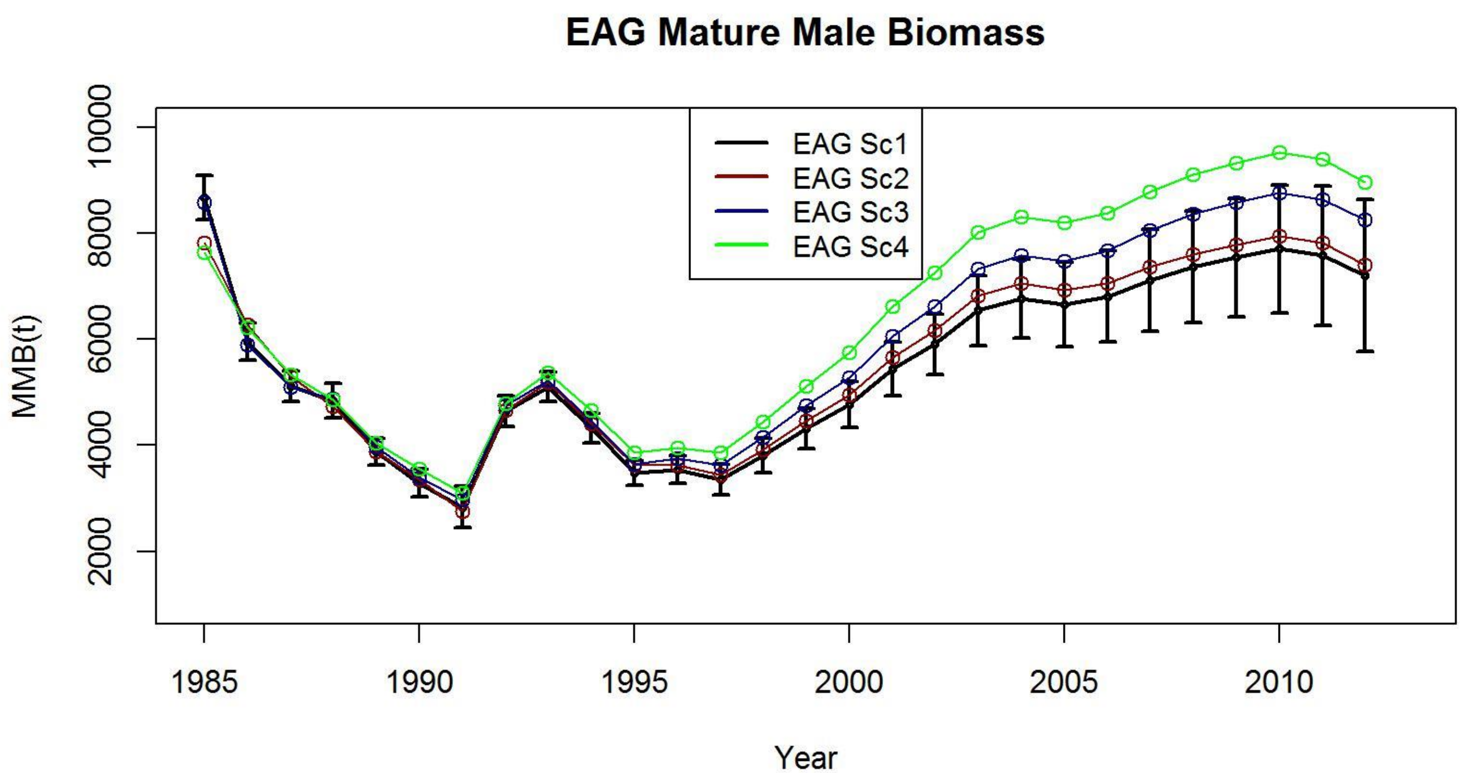



Figure 22. Trends in golden king crab mature male biomass for scenarios 1 to 4 fits in the EAG, 1985/86–2012/13. Mature male crabs are ≥ 121 mm CL. Estimates have one standard error confidence limits.

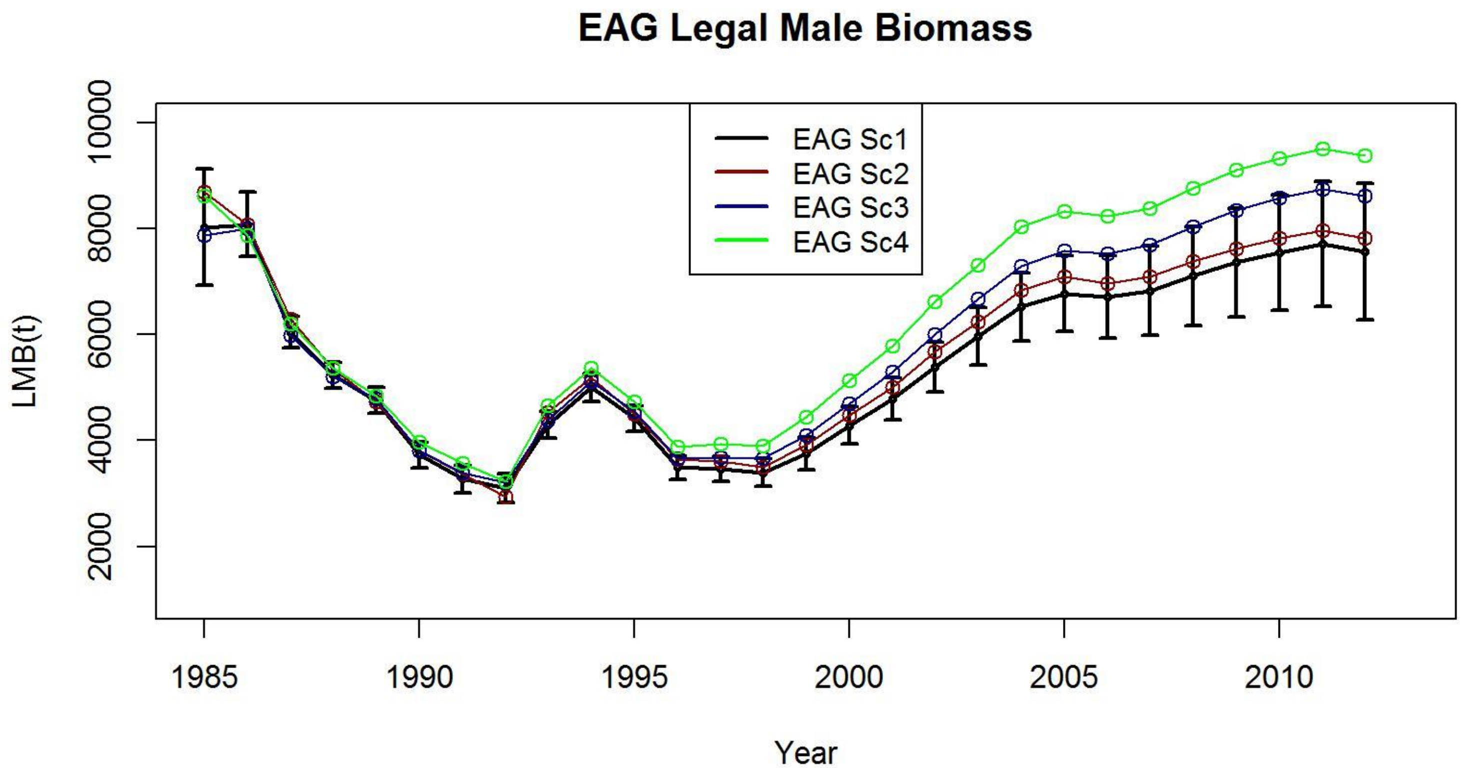



Figure 23. Trends in golden king crab legal male biomass for scenarios 1 to 4 fits in the EAG, 1985/86–2012/13. Legal male crabs are ≥ 136 mm CL. Estimates have one standard error confidence limits.

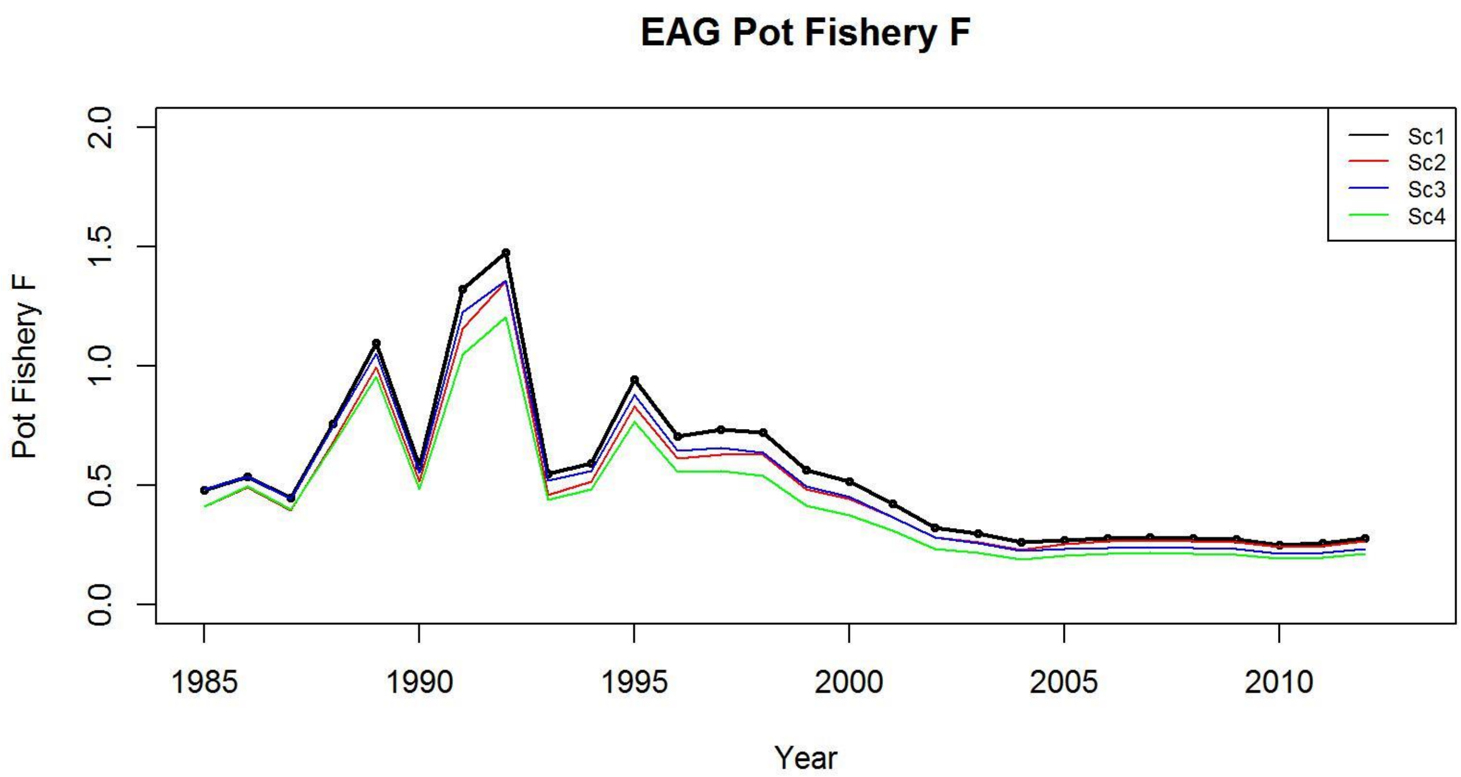



Figure 24. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 1 to 4 fits in the EAG, 1985–2012 (note: 1985 refers to the1985/86 fishery).

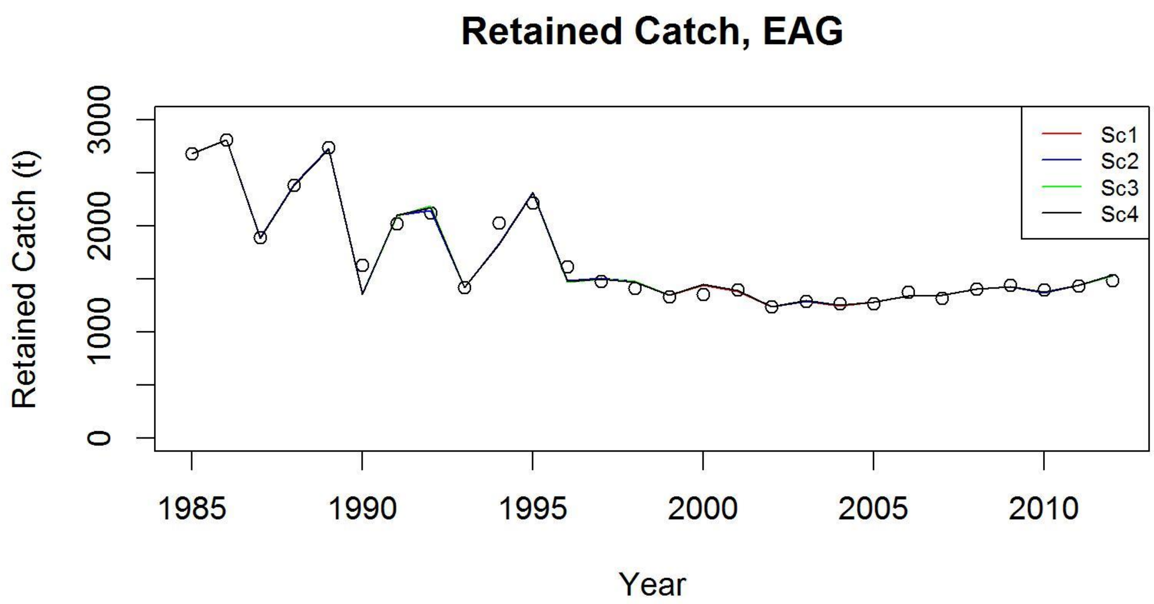



Figure 25. Observed (filled circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 1 to 4 fits in the EAG, 1985–2012. (note: 1985 refers to the1985/86 fishery).

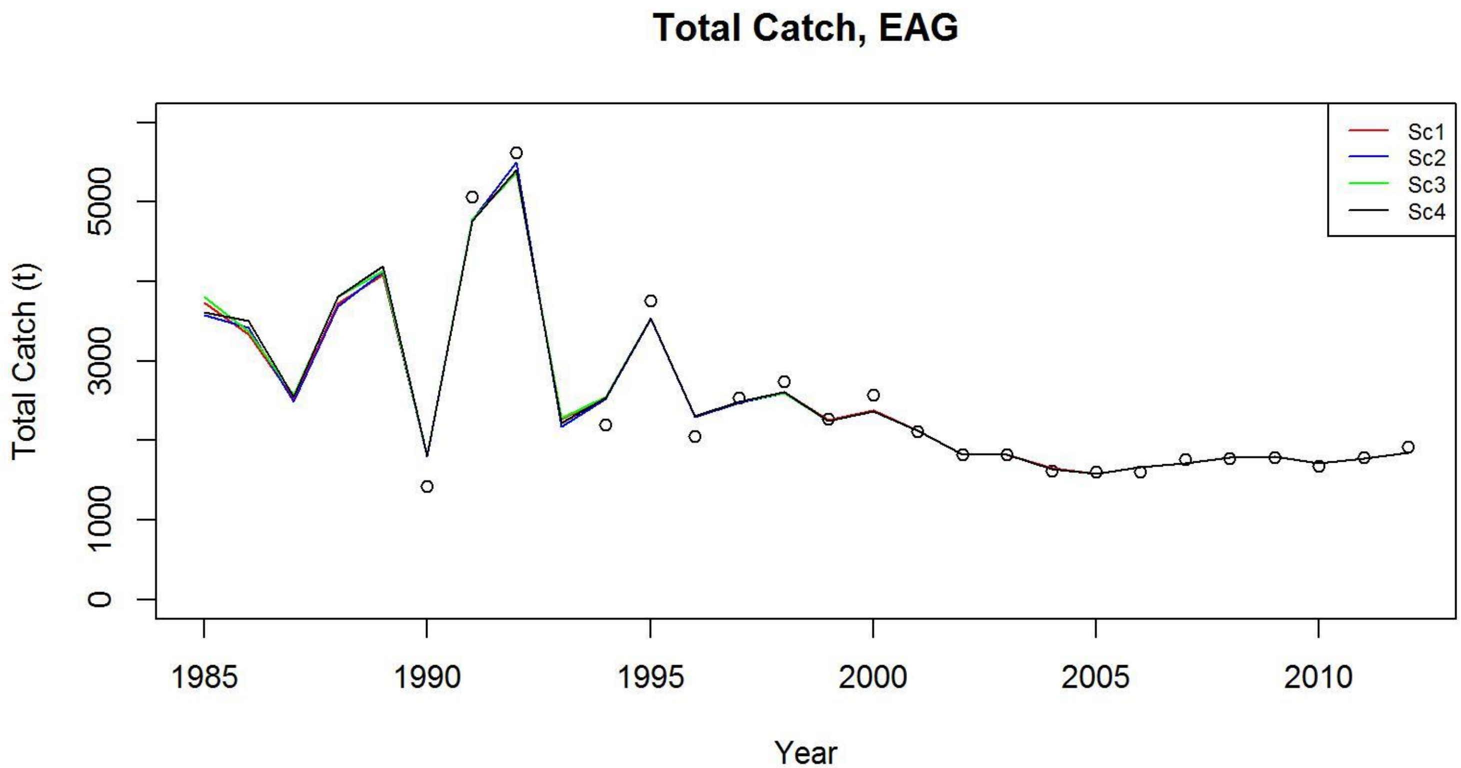



Figure 26. Observed (filled circle) vs. predicted (solid line) total catch of golden king crab for scenarios 1 to 4 fits in the EAG, 1990–2012. A handling mortality rate of 20% was applied to pot discarded catch and it was added to retained catch to get the total catch. (note: 1990 refers to the1990/91 fishery). Predicted total catch time series is extended to 1985/86.

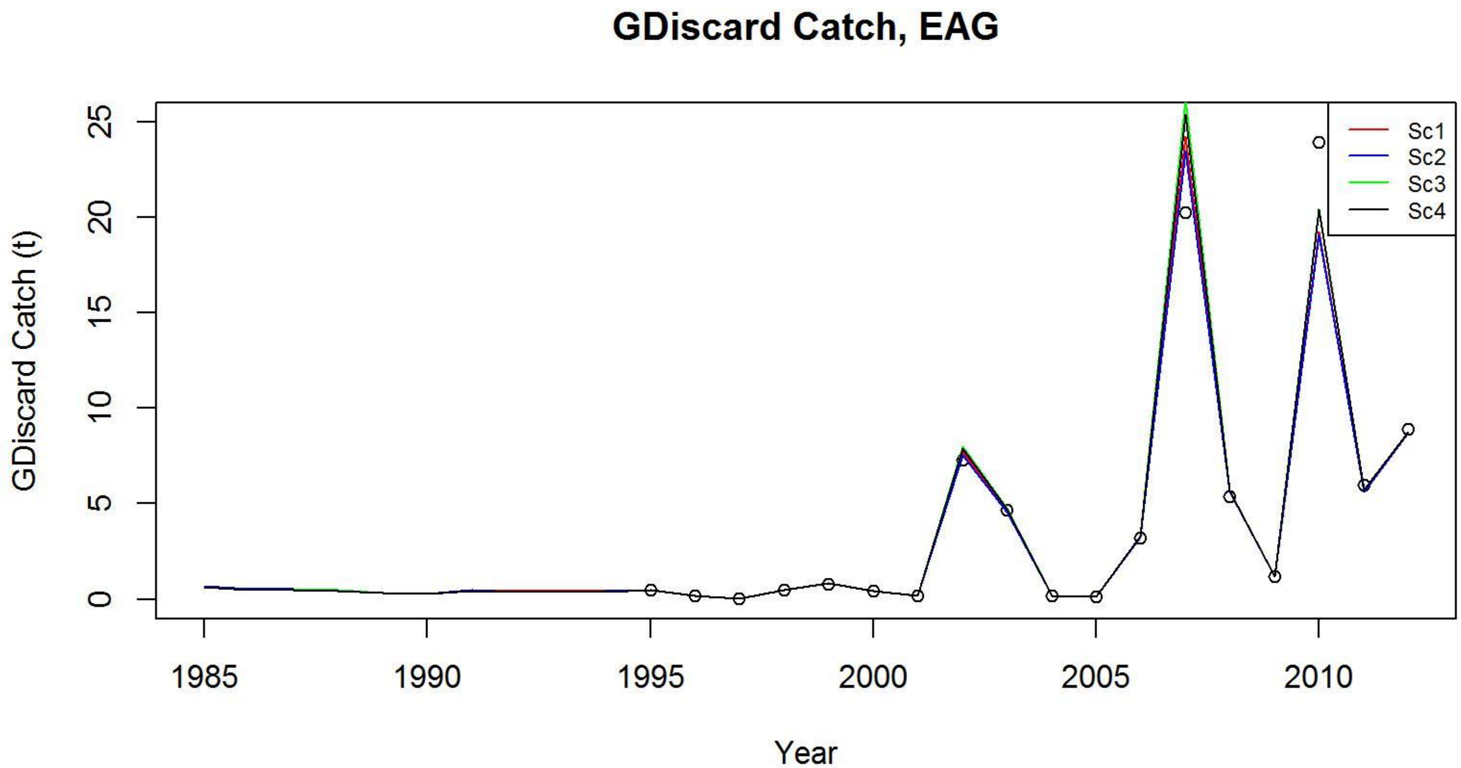
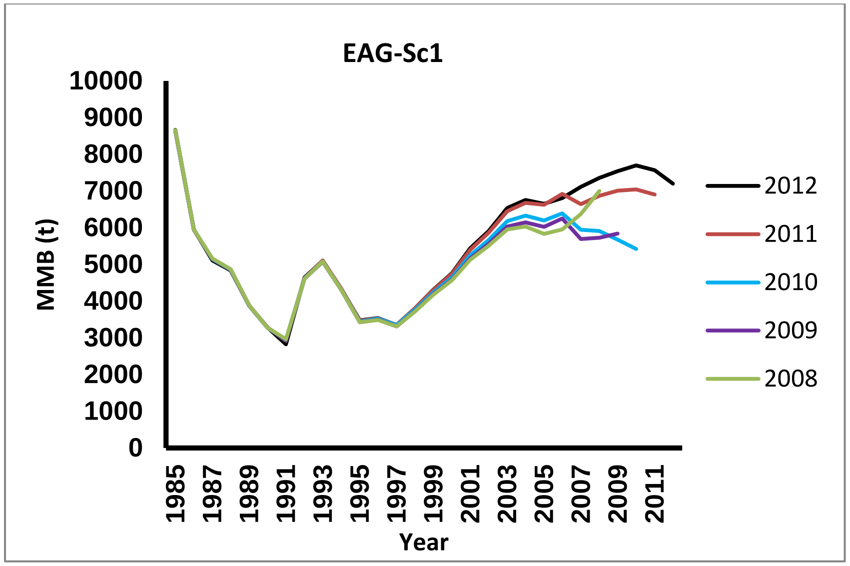
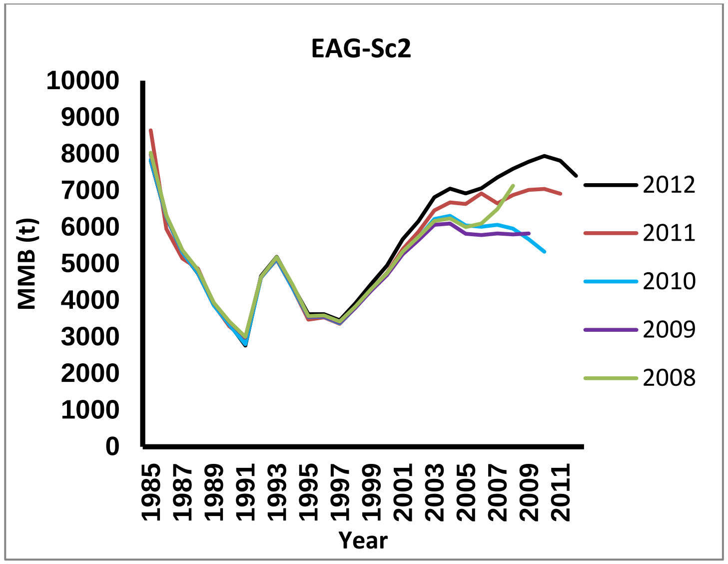



Figure 27. Observed (filled circle) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios 1 to 4 fits in the EAG, 1990–2012. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1995 refers to the1995/96 fishery). Predicted groundfish discarded catch time series is extended to 1985/86.




Scenario 1




Scenario 2

Figure 28. Retrospective fits of the model for removal of terminal year's data for scenarios 1 (Sc1) and 2 (Sc2) fits for golden king crab in the EAG, 1985–2012.

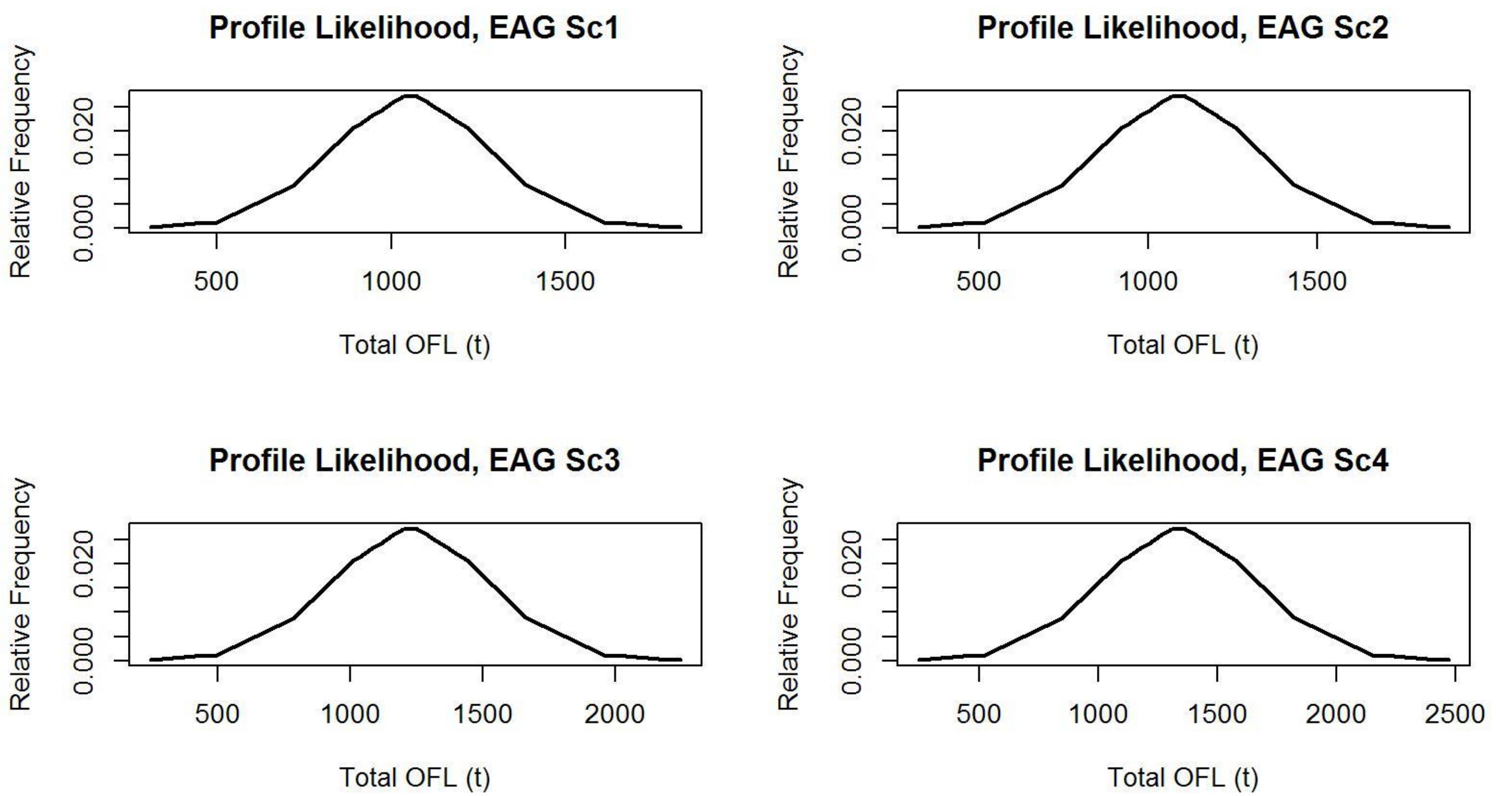



Figure 29. Probability distribution of total OFL based on 1985–2012 data for scenarios 1 to 4 (Sc1- Sc4) fits for EAG golden king crab. Profile likelihood was used to create the probability distribution.

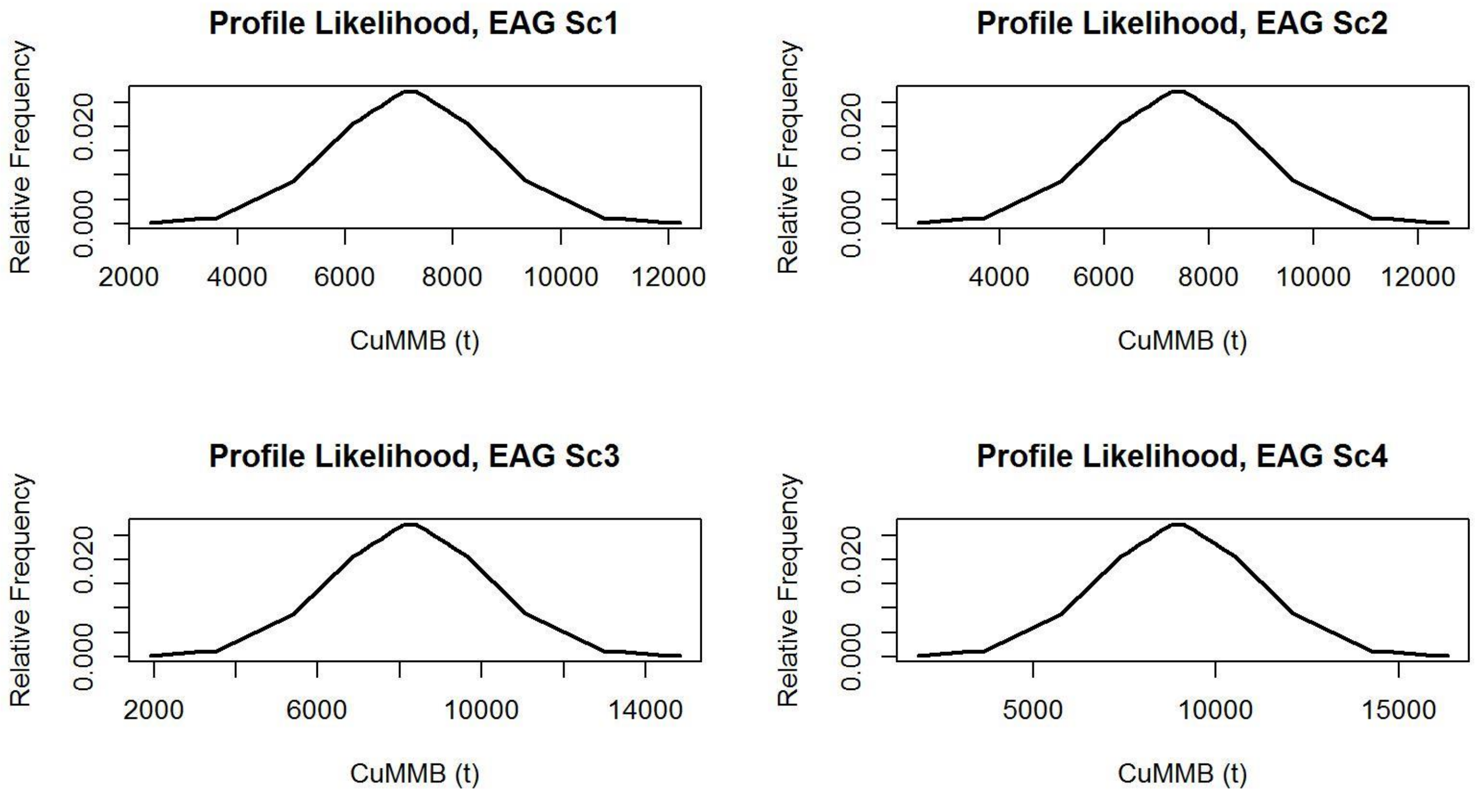



Figure 30. Probability distribution of current MMB based on 1985–2012 data for scenarios 1 to 4 (Sc1-Sc4) fits for EAG golden king crab. Profile likelihood was used to create the probability distribution.

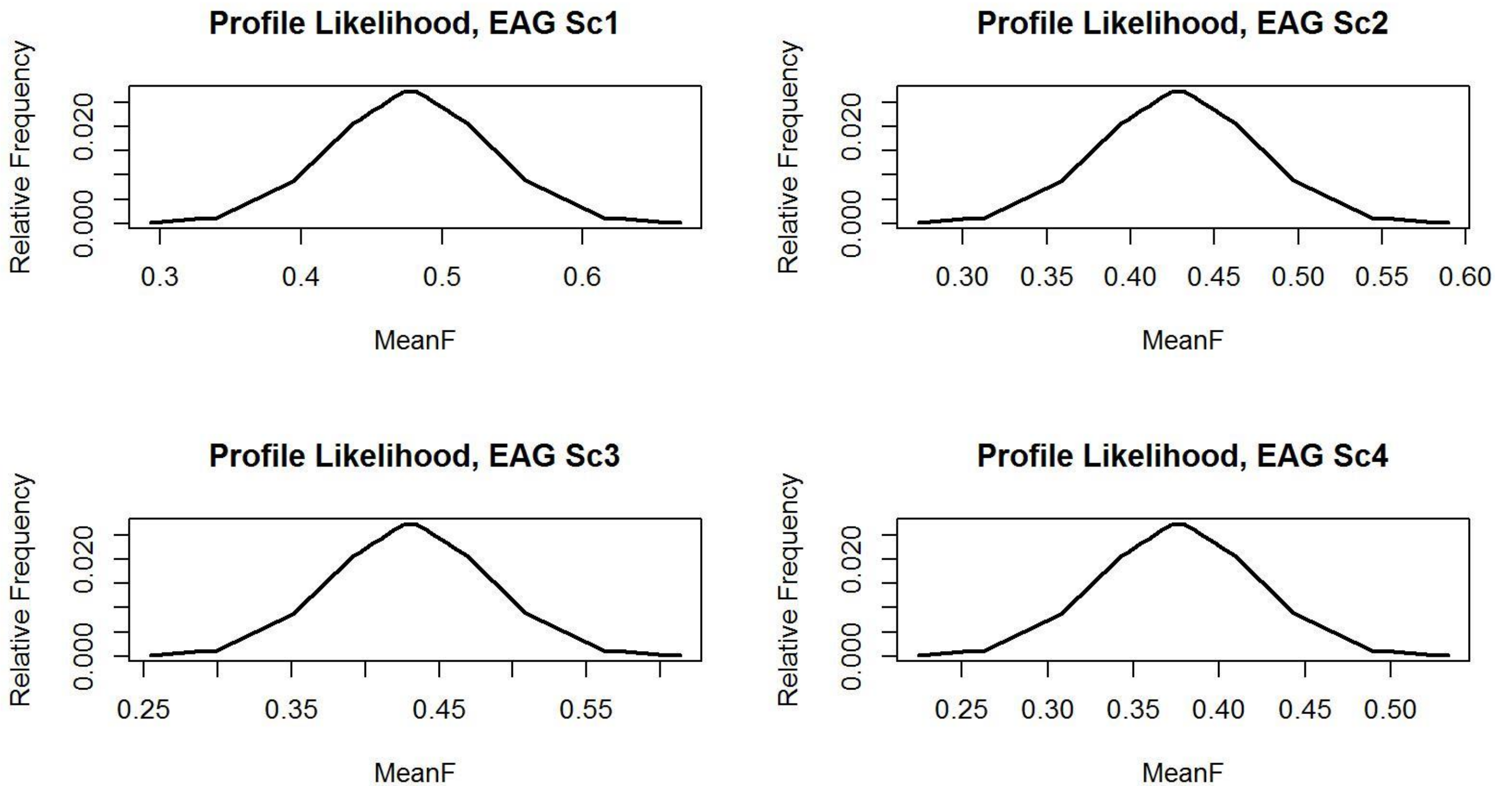



Figure 31. Probability distribution of mean F based on 1985–2012 data for scenarios 1 to 4 (Sc1- Sc4) fits for EAG golden king crab. Profile likelihood was used to create the probability distribution.

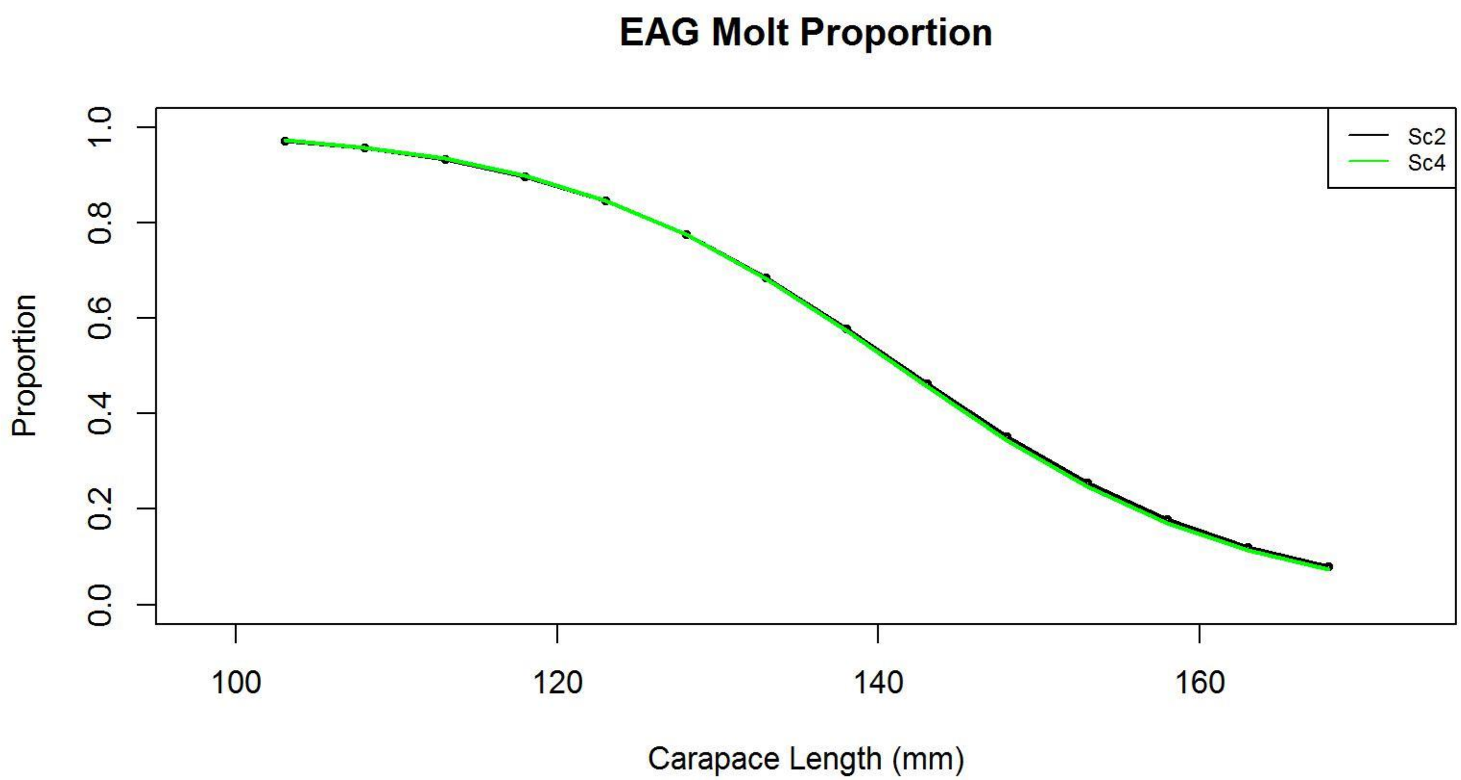



Figure 32. Molt probability for scenarios 2 (Sc2)and 4 (Sc4) fits for EAG golden king crab.

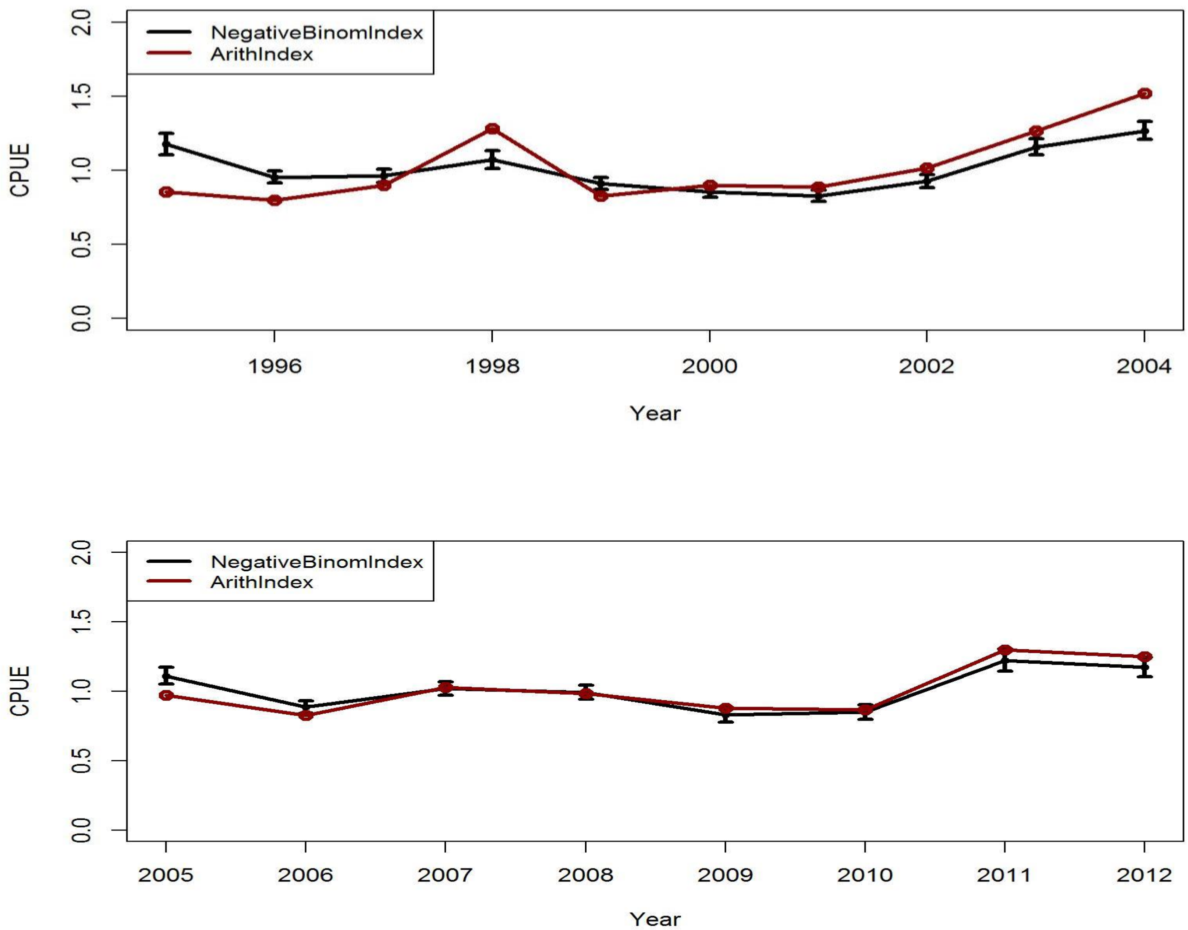



Figure 33. Trends in arithmetic (nominal) and negative binomial CPUE indices with two standard errors of Aleutian Islands golden king crab from WAG (west of 174°W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2012/13 observer data. Negative binomial indices: black line and Arithmetic indices: red line.

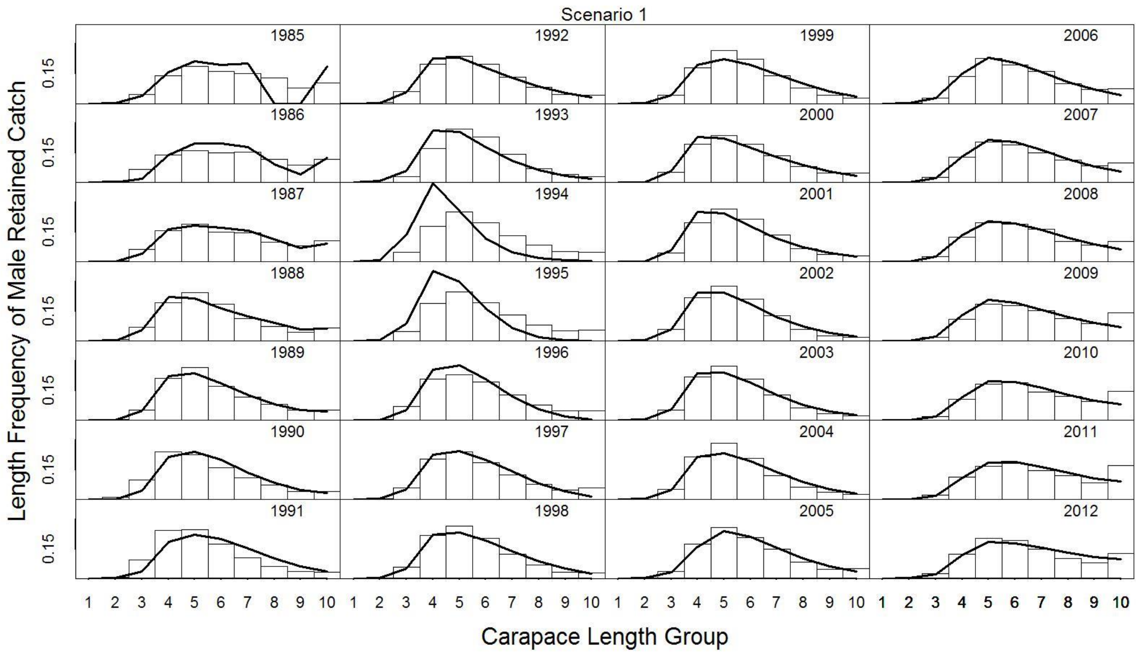



Figure 34. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 1 data of golden king crab in the WAG, 1985/86 – 2012/13. Length group 1 is 103 mm CL.

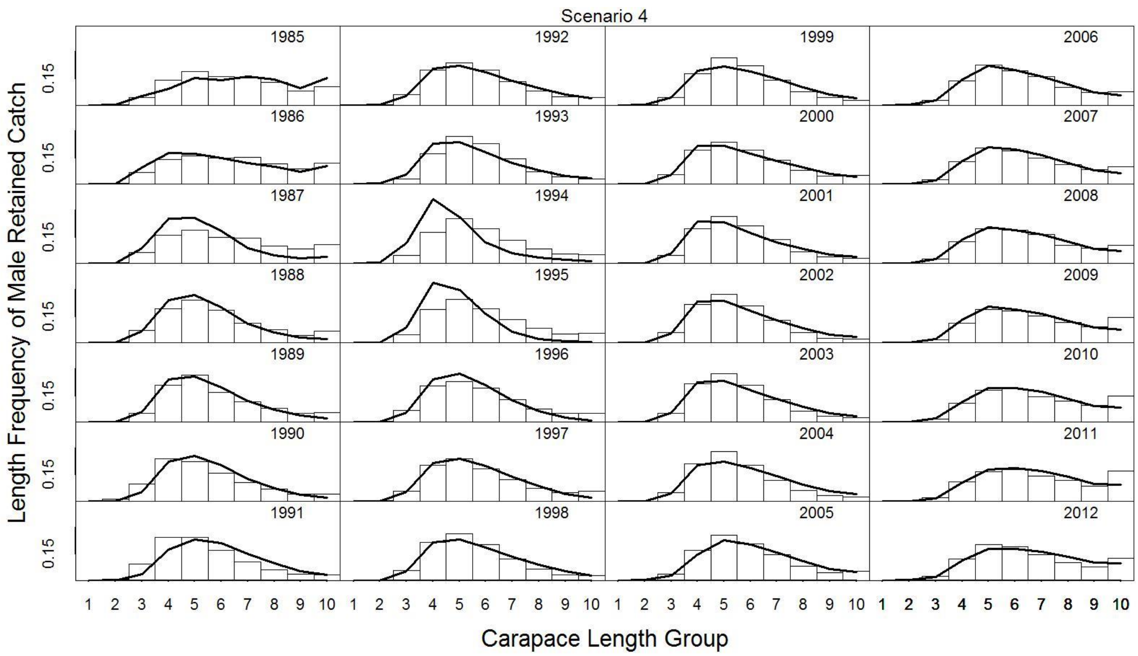



Figure 35. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 4 data of golden king crab in the WAG, 1985/86 – 2012/13. Length group 1 is 103 mm CL.

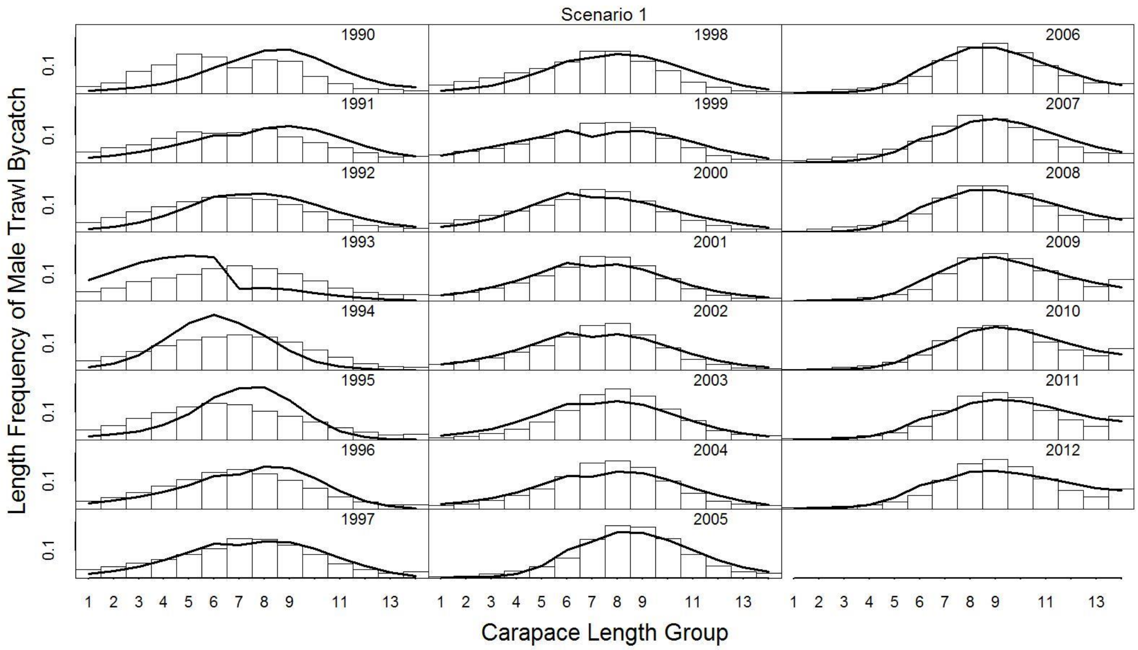



Figure 36. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 1 data of golden king crab in the WAG, 1990/91 – 2012/13. Length group 1 is 103 mm CL.

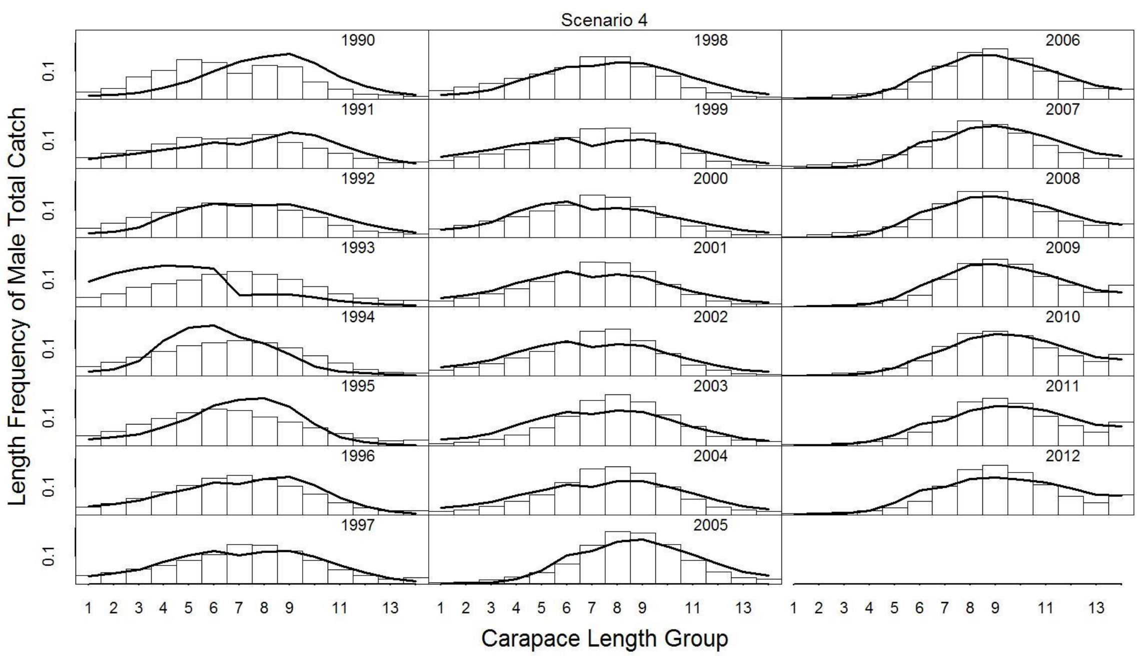



Figure 37. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 4 data of golden king crab in the WAG, 1990/91 – 2012/13. Length group 1 is 103 mm CL.

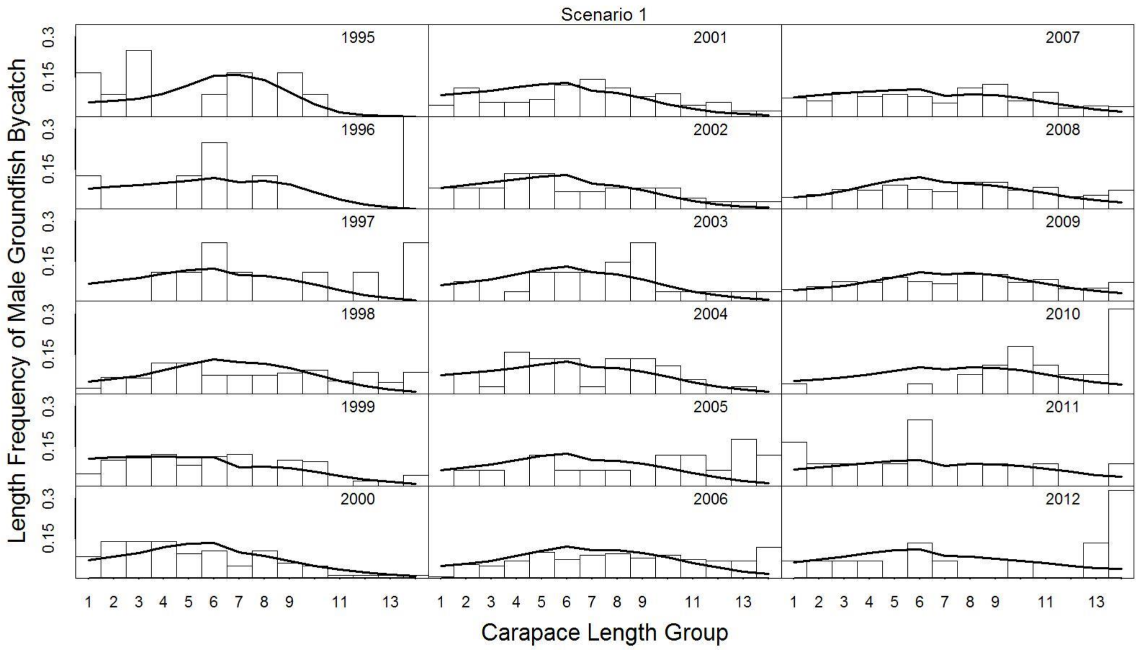



Figure 38. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 1 data of golden king crab in the WAG, 1995/96 – 2012/13. Length group 1 is 103 mm CL.

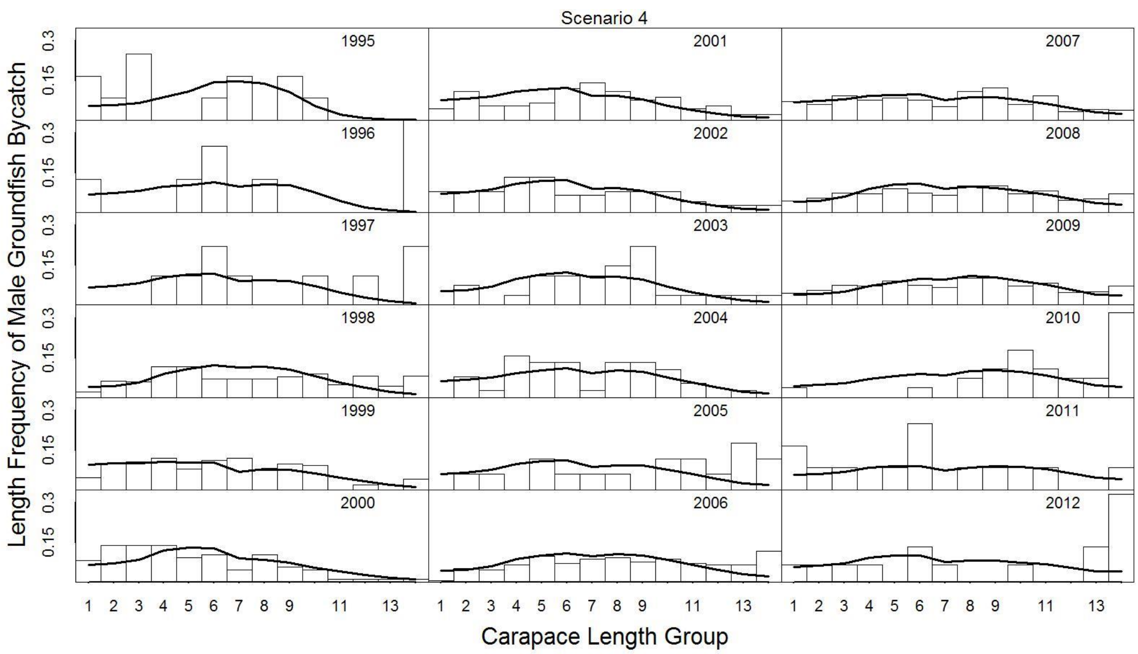



Figure 39. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 4 data of golden king crab in the WAG, 1995/96 – 2012/13. . Length group 1 is 103 mm CL.

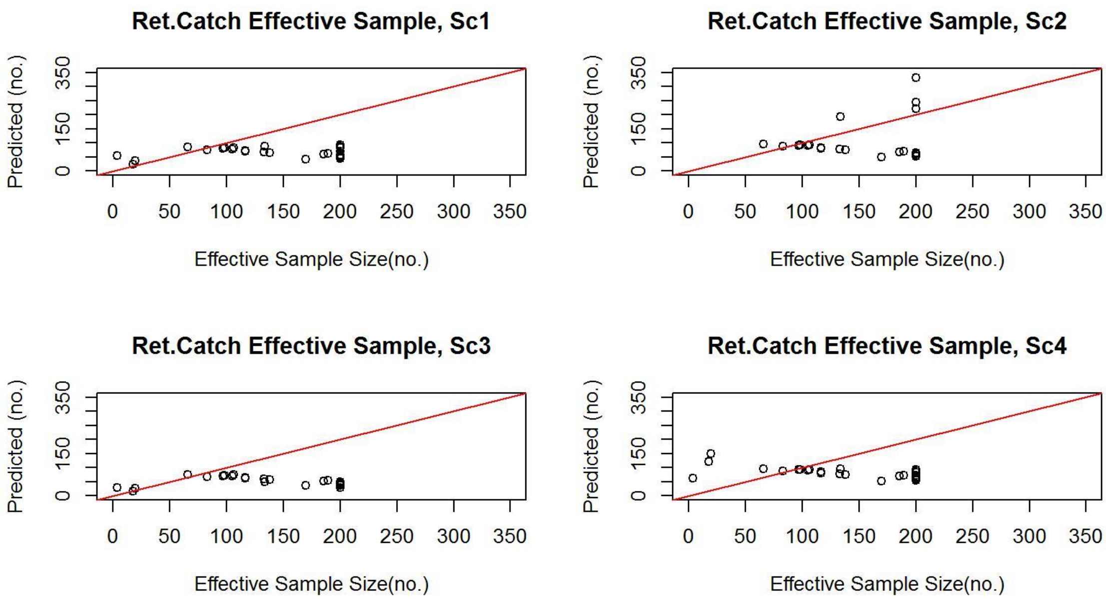



Figure 40. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios (Sc) 1 to 4 fits to golden king crab data in the WAG, 1985/96 – 2012/13. The red line is the $45^0$ line passing through the origin.

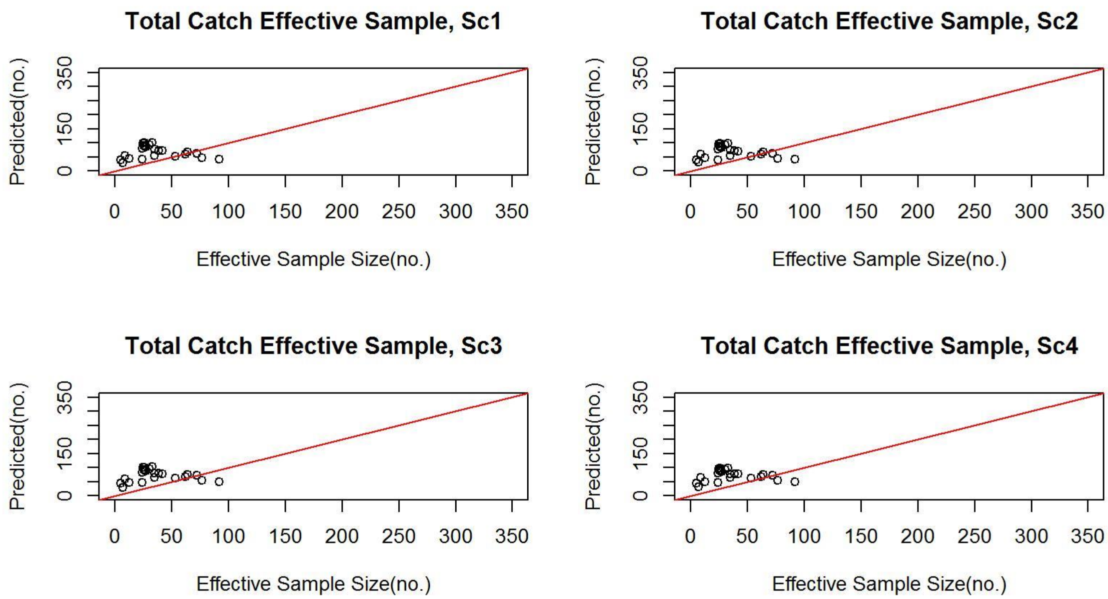



Figure 41. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios (Sc) 1 to 4 fits to golden king crab data in the WAG, 1990/91 – 2012/13. The red line is the $45^0$ line passing through the origin.

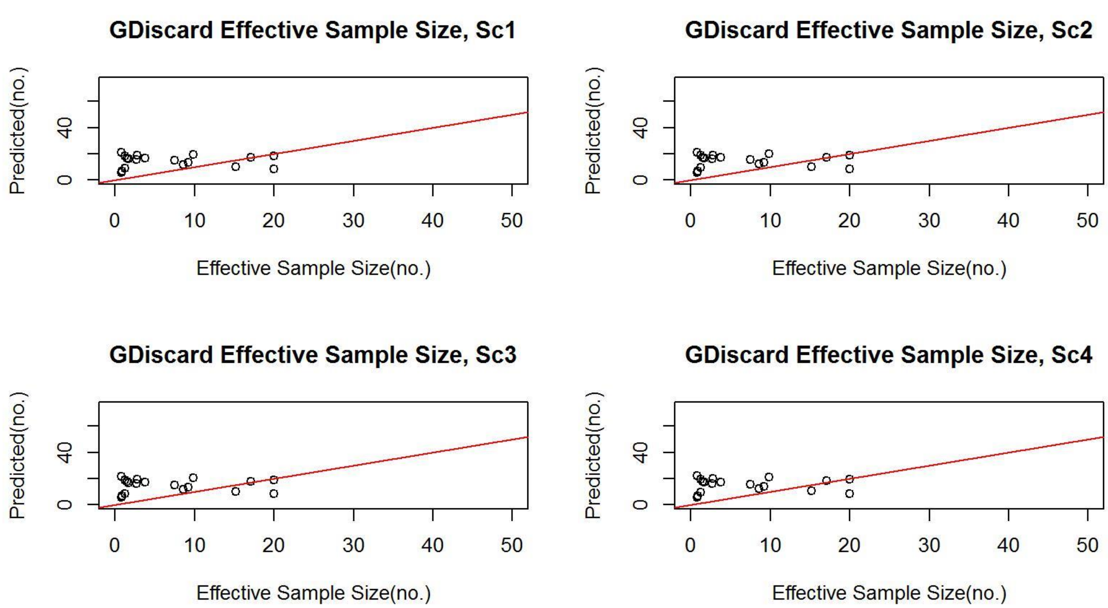



Figure 42. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for scenarios (Sc) 1 to 4 fits to golden king crab data in the WAG, 1995/96 – 2012/13. The red line is the $45^0$ line passing through the origin.

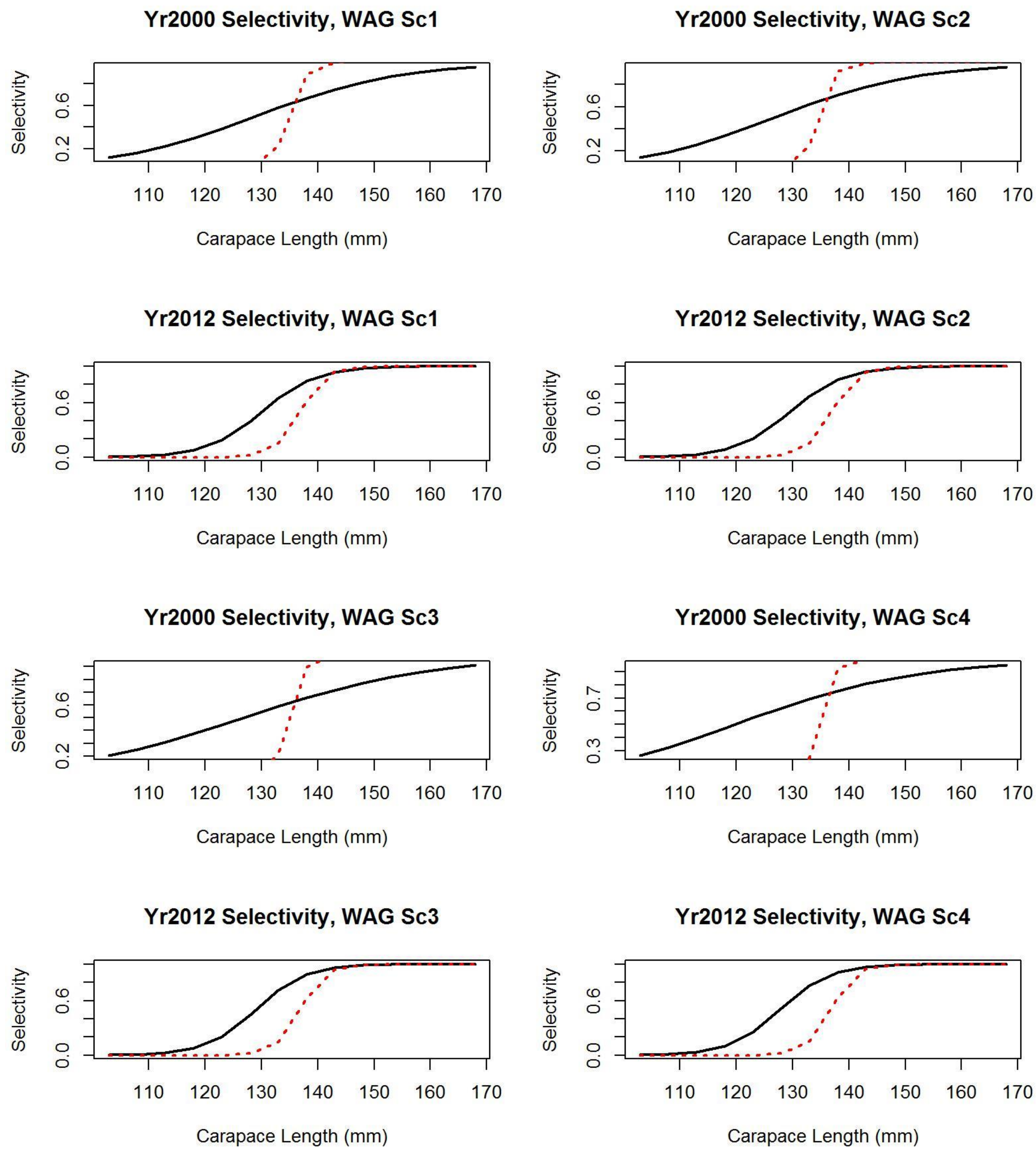



Figure 43. Estimated total selectivity (black solid line) and retained selectivity (red dotted line) for pre- (Yr2000) and post- (Yr2012) rationalization periods under scenarios (Sc) 1 to 4 fits to WAG golden king crab data. Yr2000 refers to the 1985–2004 period's selectivity and Yr2012 refers to the 2005–2012 period's selectivity.

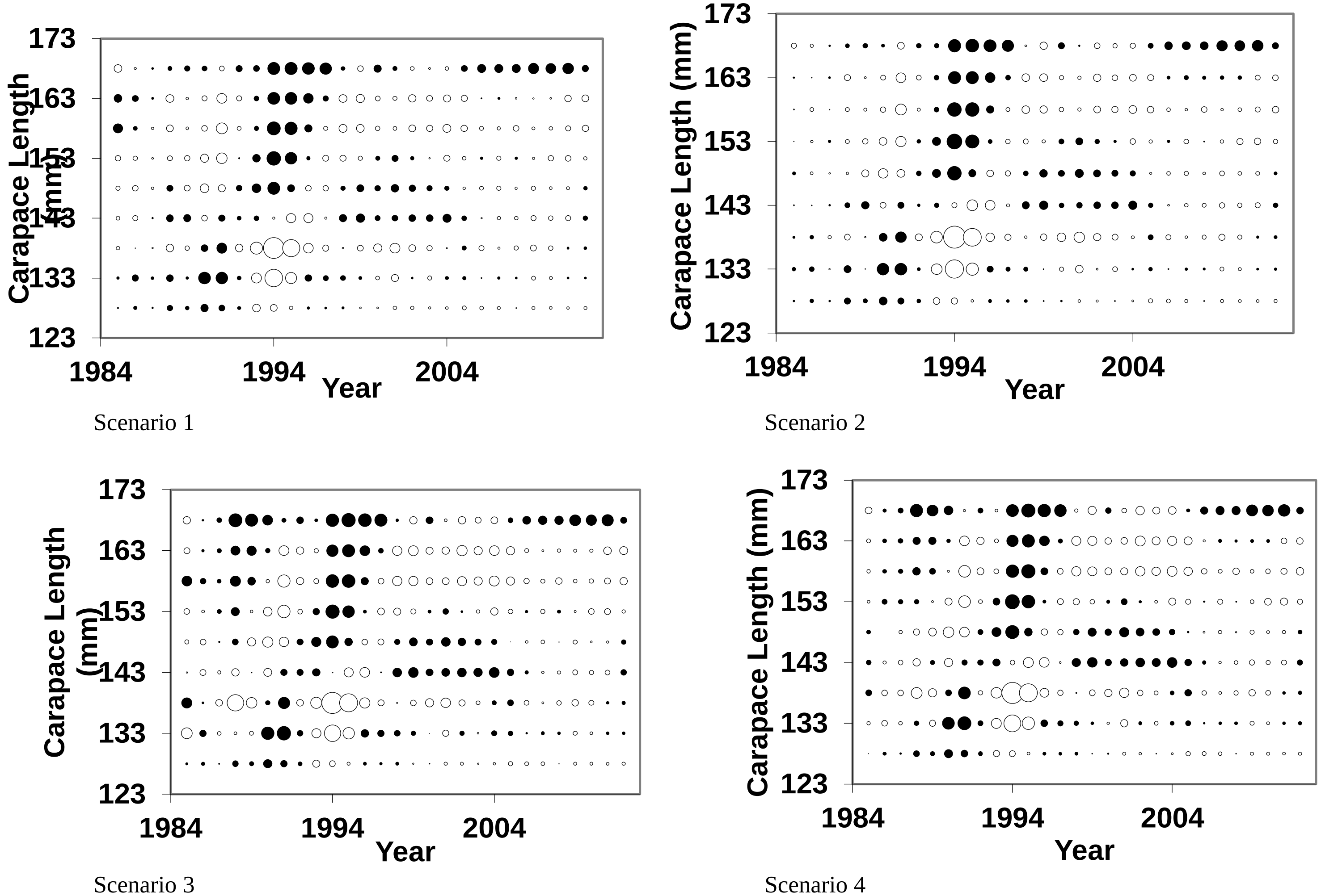
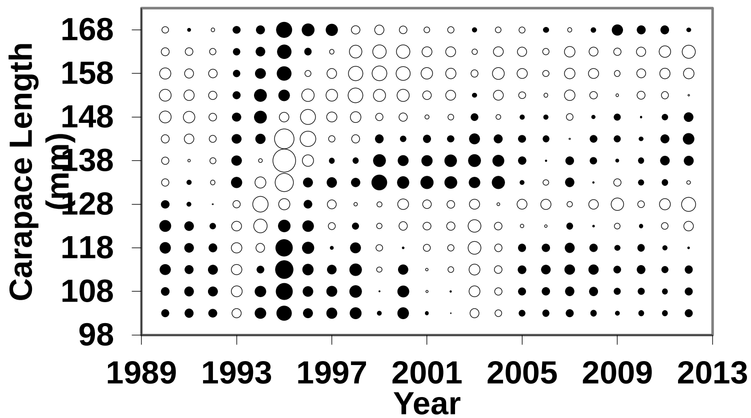
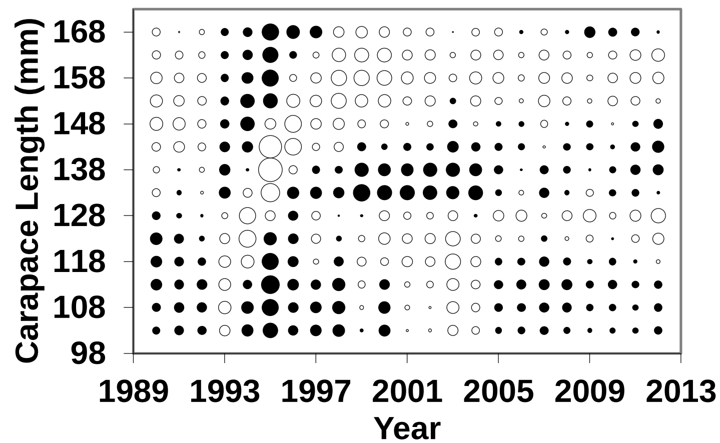


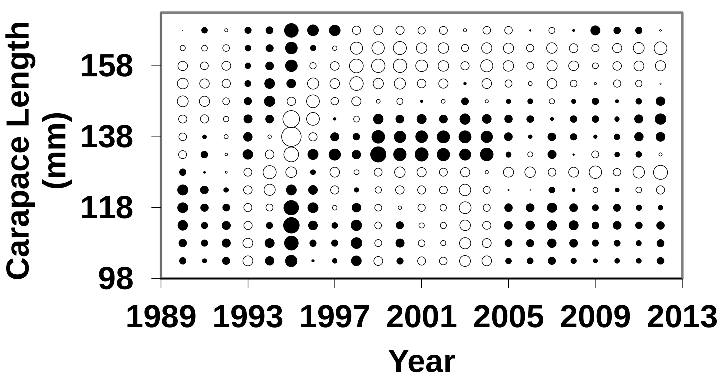

Figure 44. Bubble plots of standardized residuals of retained catch length composition for scenarios 1 to 4 fits for WAG golden king crab, 1985/86–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



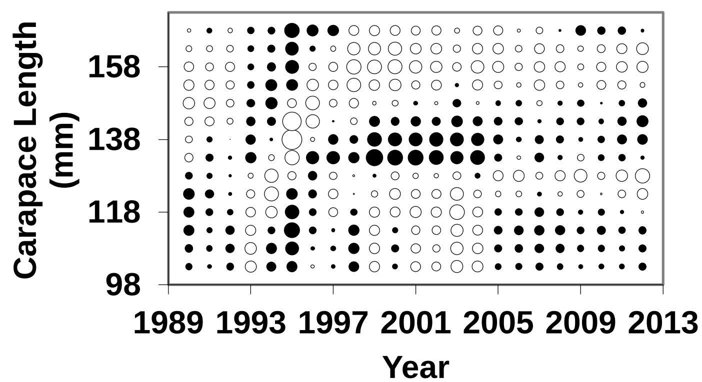

Scenario 1




Scenario 2

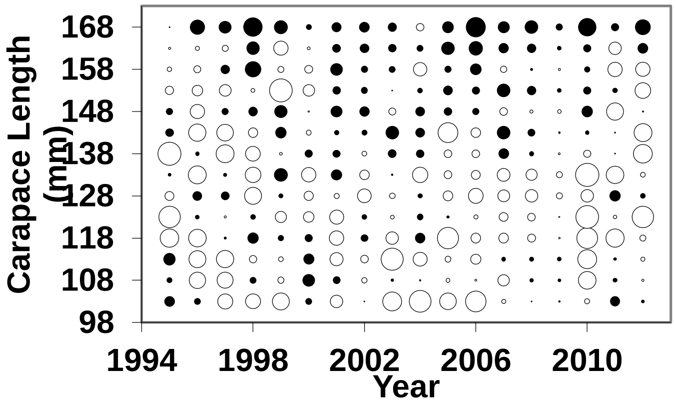



Scenario 3

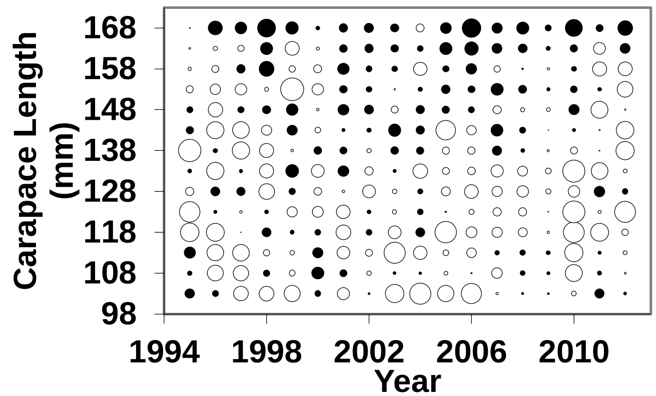



Scenario 4

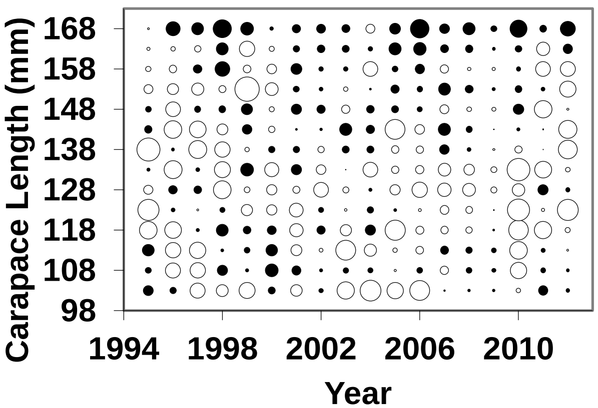
Figure 45. Bubble plots of standardized residuals of total catch length composition for scenarios 1 to 4 fits for WAG golden king crab, 1990/91–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



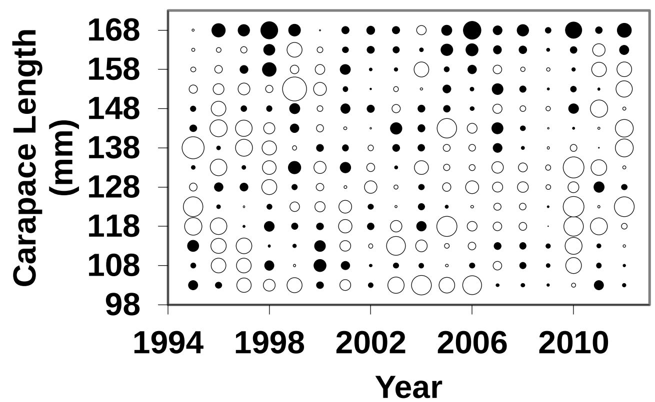

Scenario 1




Scenario 2




Scenario 3




Scenario 4

Figure 46. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 1 to 4 fits for WAG golden king crab, 1995/96–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

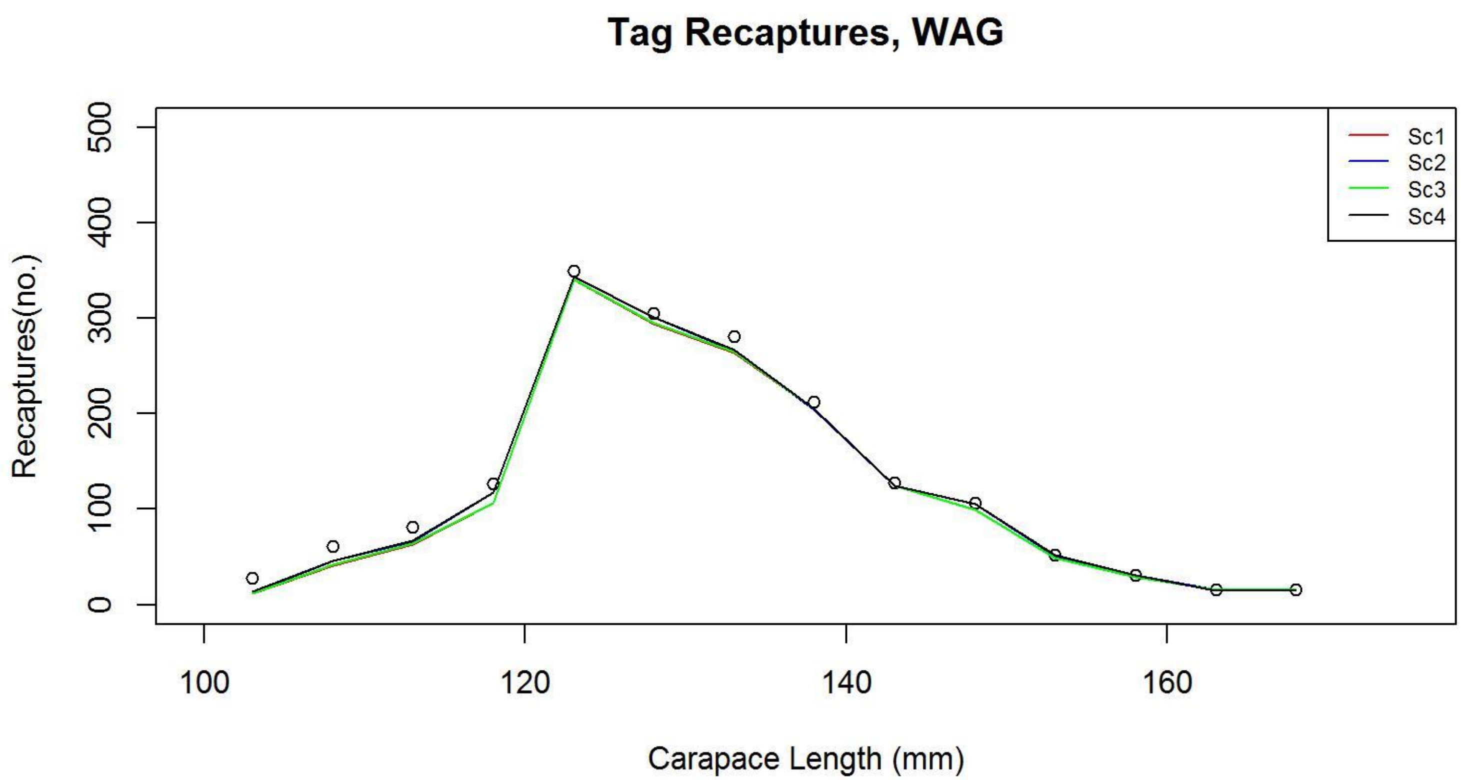



Figure 47. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for scenarios 1 to 4 fits of WAG golden king crab data.

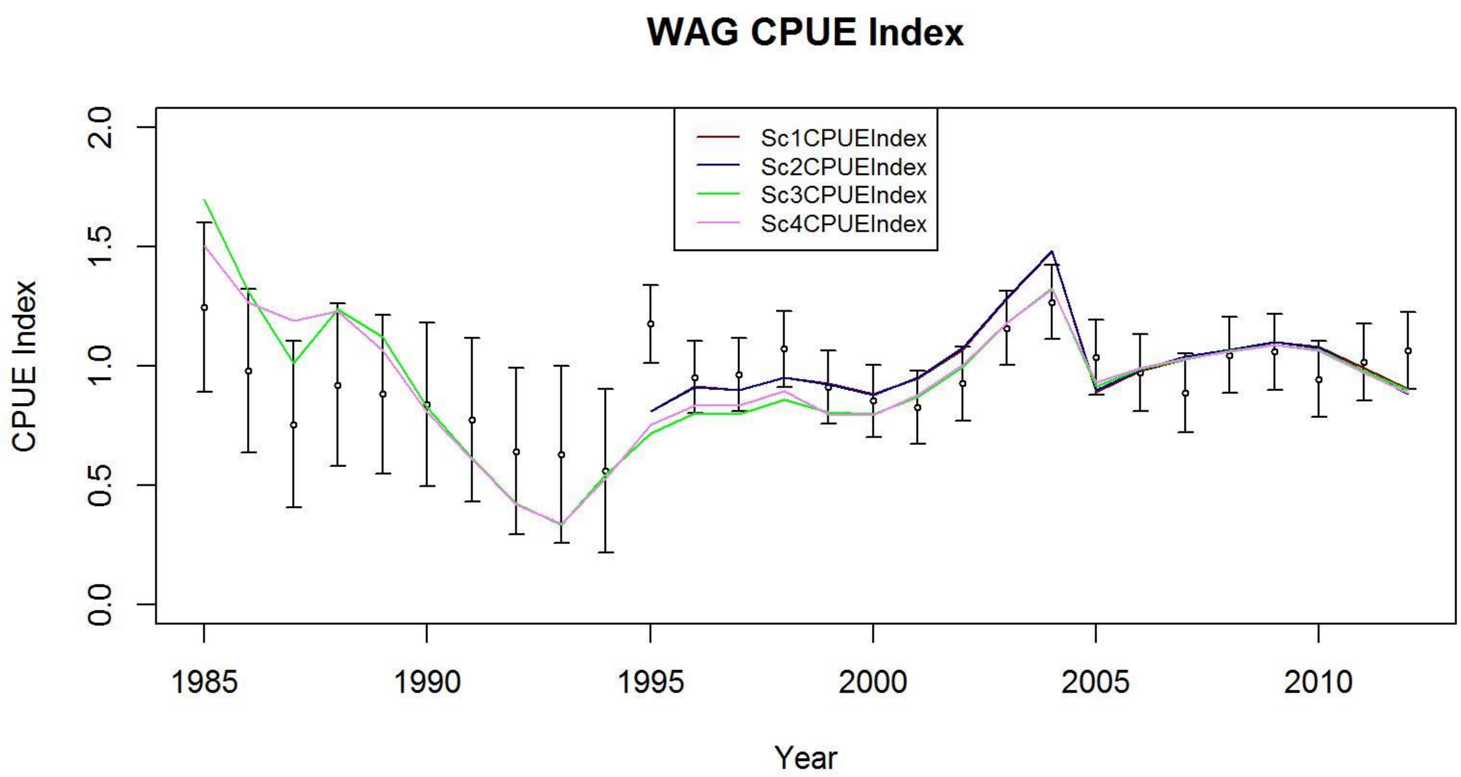



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Figure 48. Comparison of input CPUE indices (open circles with one standard error) with predicted CPUE indices (colored solid lines) for scenarios 1 to 4 fits for WAG golden king crab data. 1995/96–2012/13. Model estimated additional standard error was added to each input standard error.

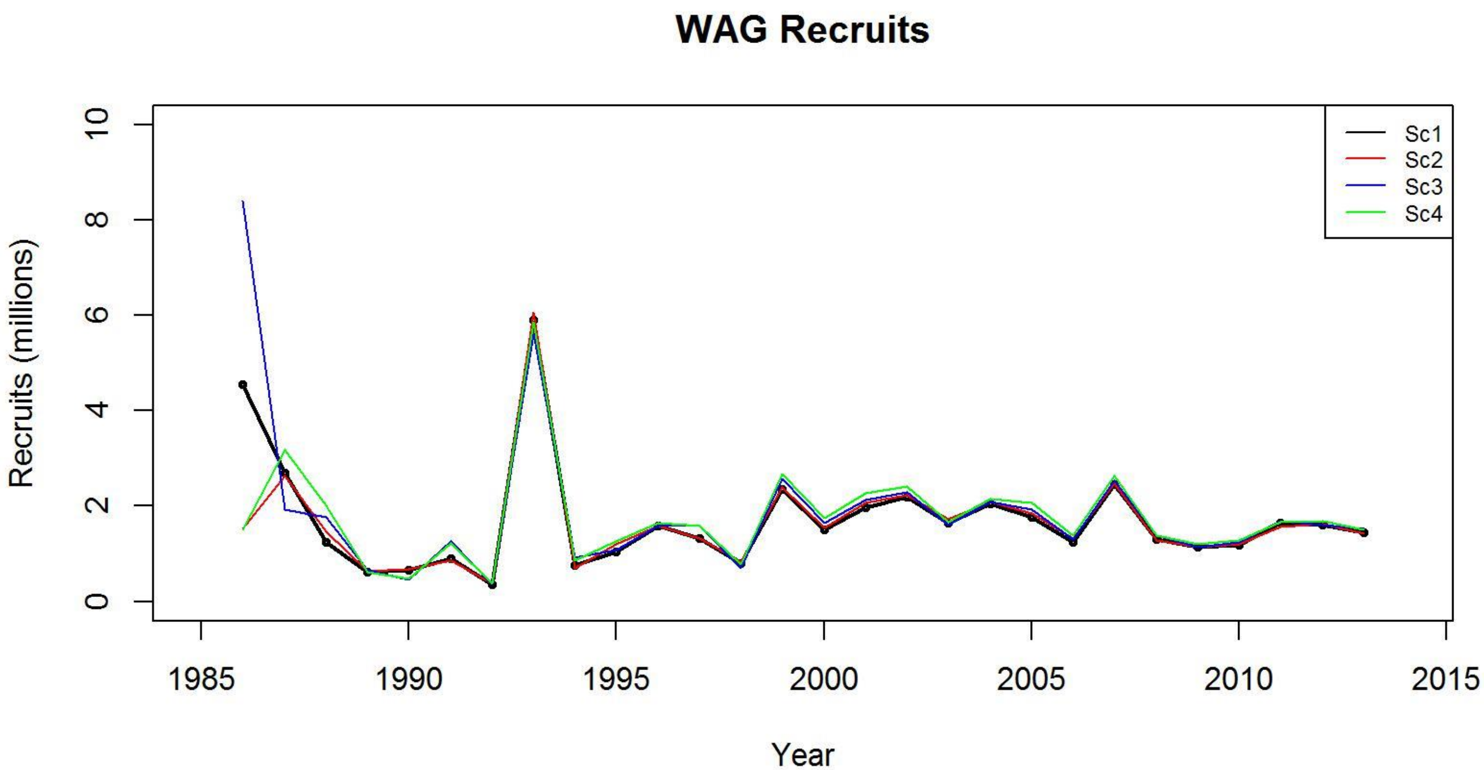


Figure 49. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab assessment model for scenarios 1 to 4 fits in WAG, 1986–2013.

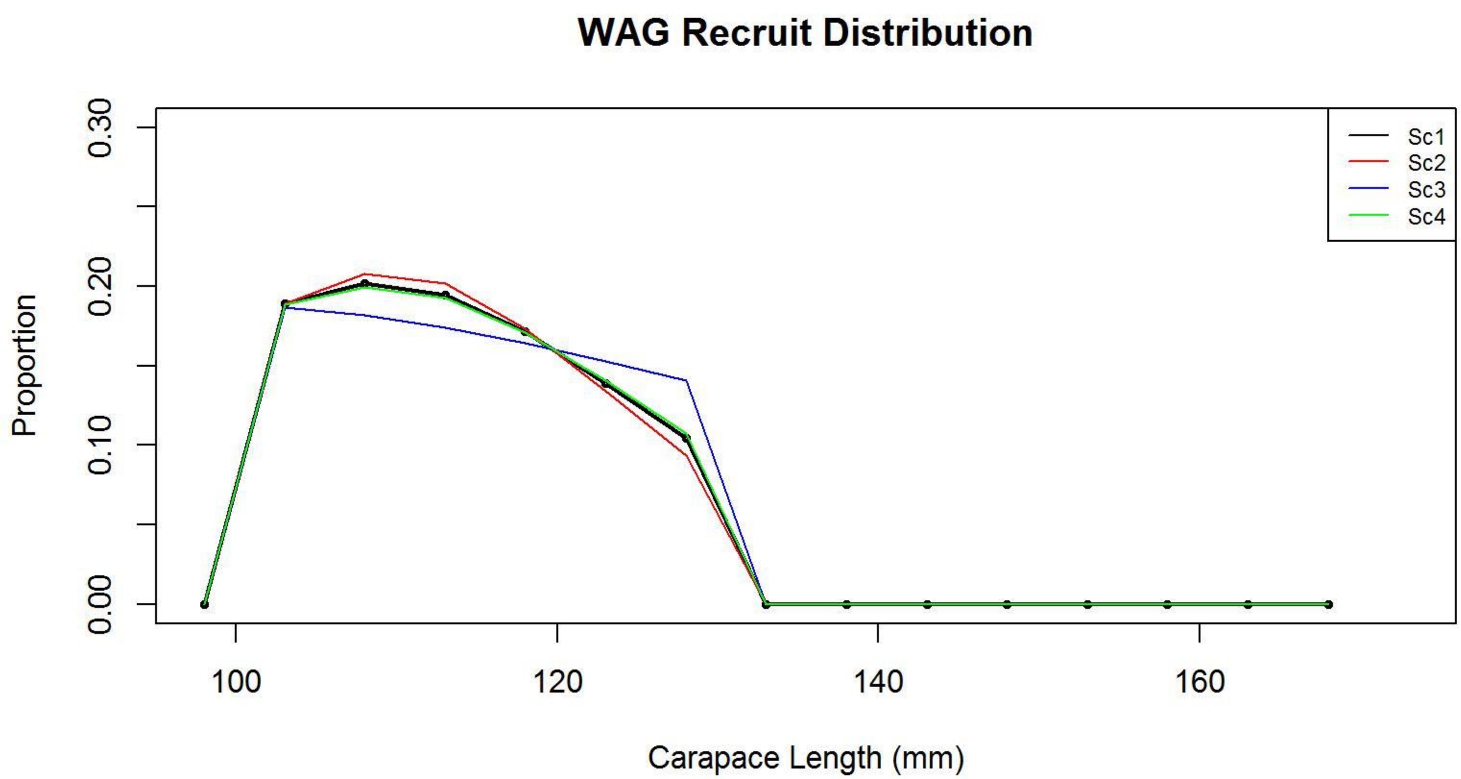


Figure 50. Recruit distribution to the golden king crab assessment model size group for scenarios 1 to 4 fits in WAG.

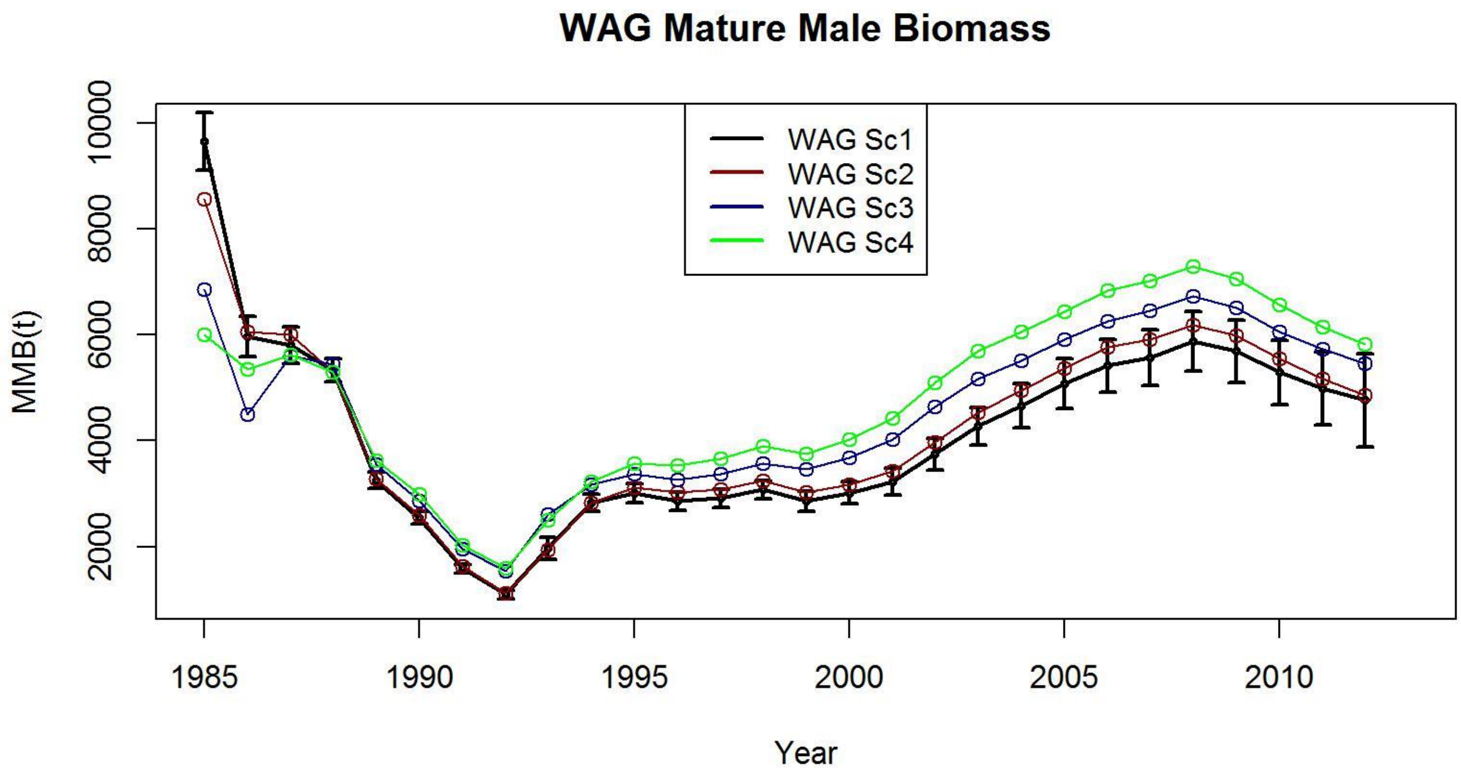


Figure 51. Trends in golden king crab mature male biomass for scenarios 1 to 4 fits in the WAG, 1985/86–2012/13. Mature male crabs are ≥ 121 mm CL. Estimates have one standard error confidence limits.

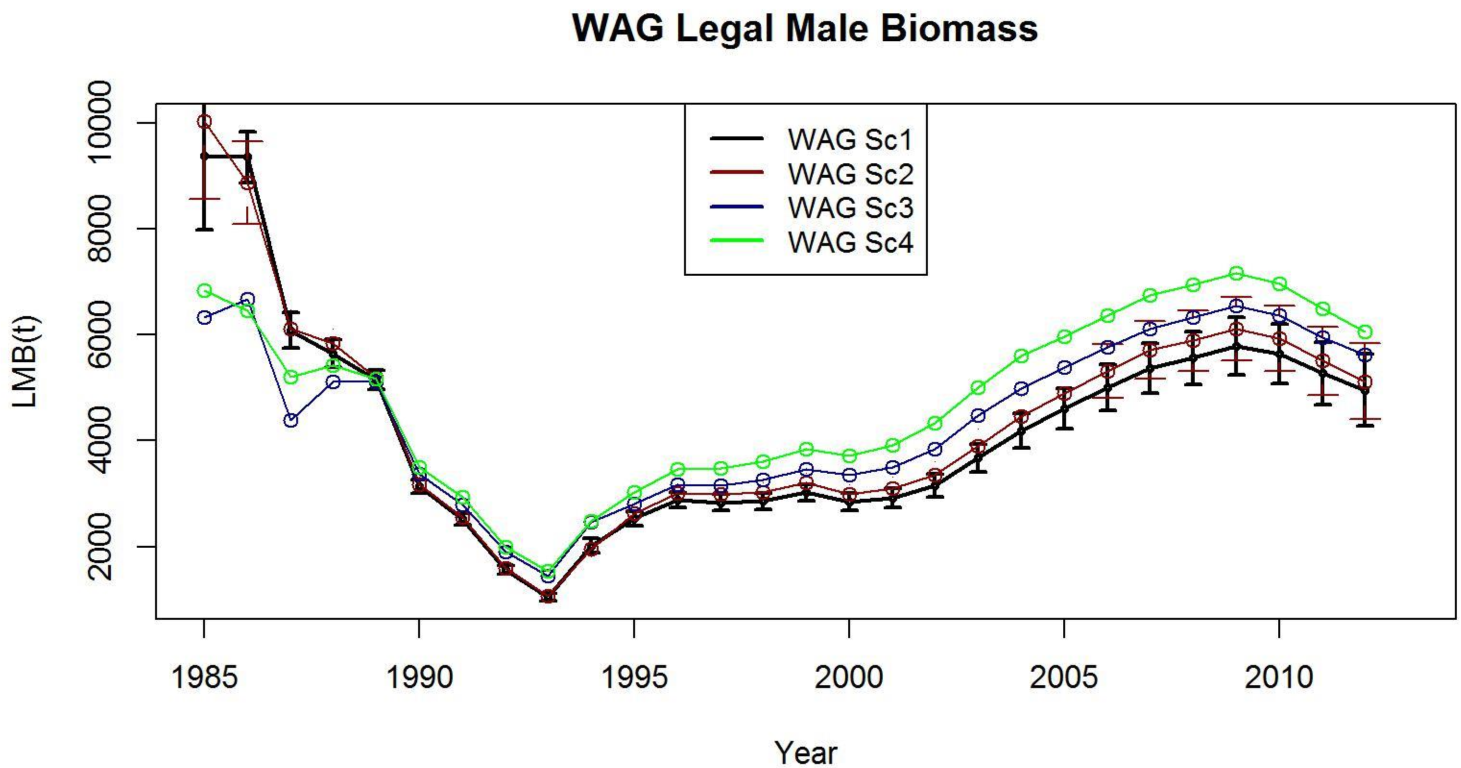


Figure 52. Trends in golden king crab legal male biomass for scenarios 1 to 4 fits in the WAG, 1985/86–2012/13. Legal male crabs are ≥ 136 mm CL. Estimates have one standard error confidence limits.

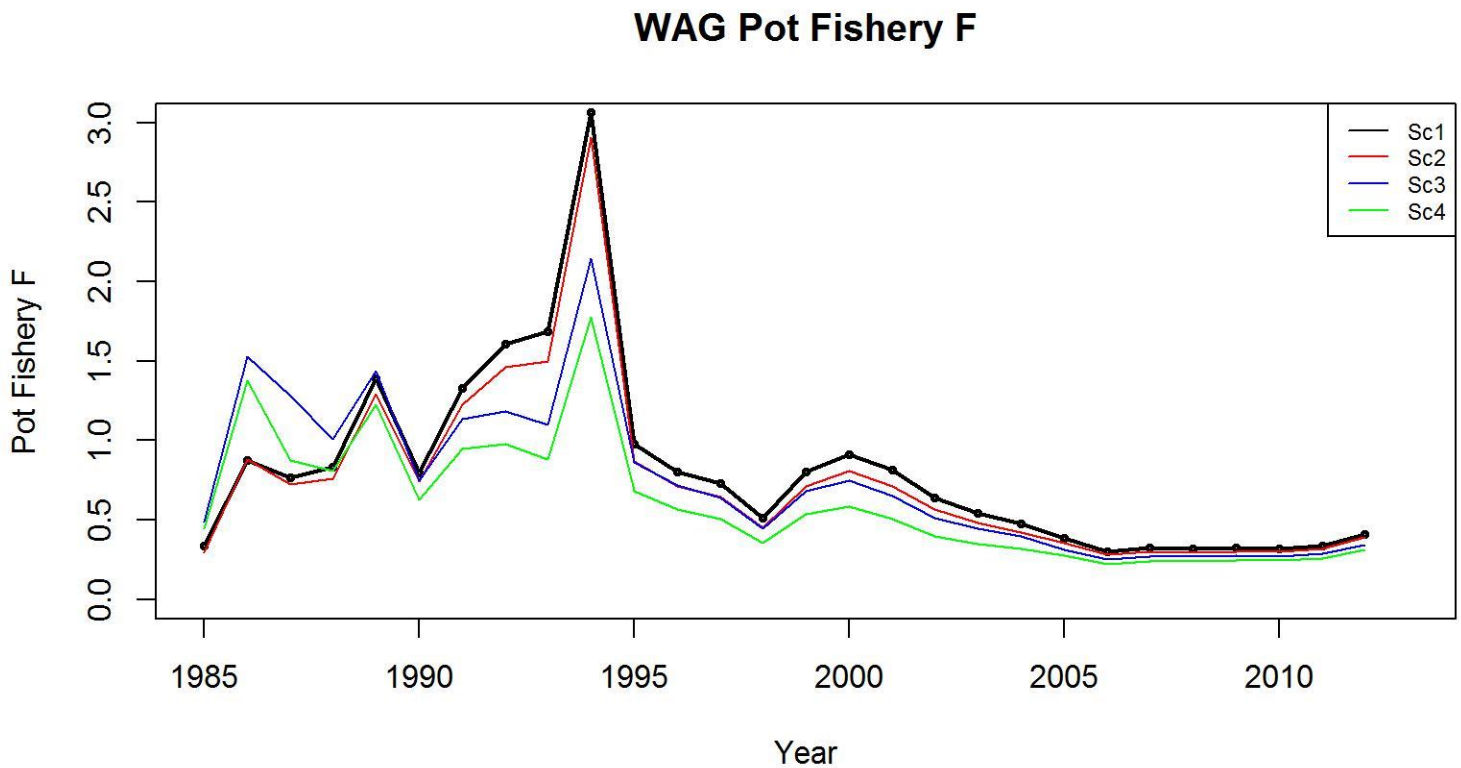


Figure 53. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 1 to 4 fits in the WAG, 1985–2012 (note: 1985 refers to the1985/86 fishery).

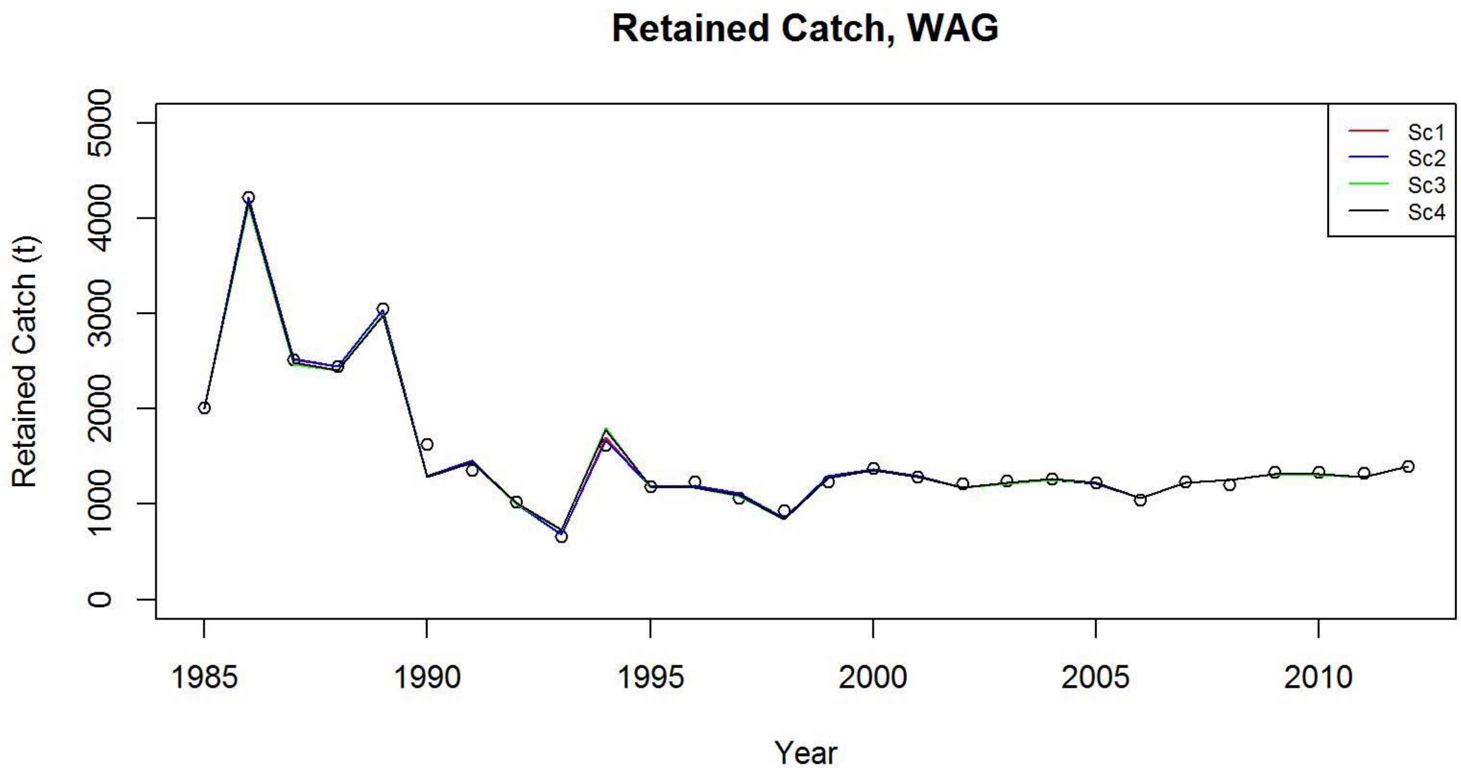


Figure 54. Observed (filled circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 1 to 4 fits in the WAG, 1985–2012. (note: 1985 refers to the1985/86 fishery).

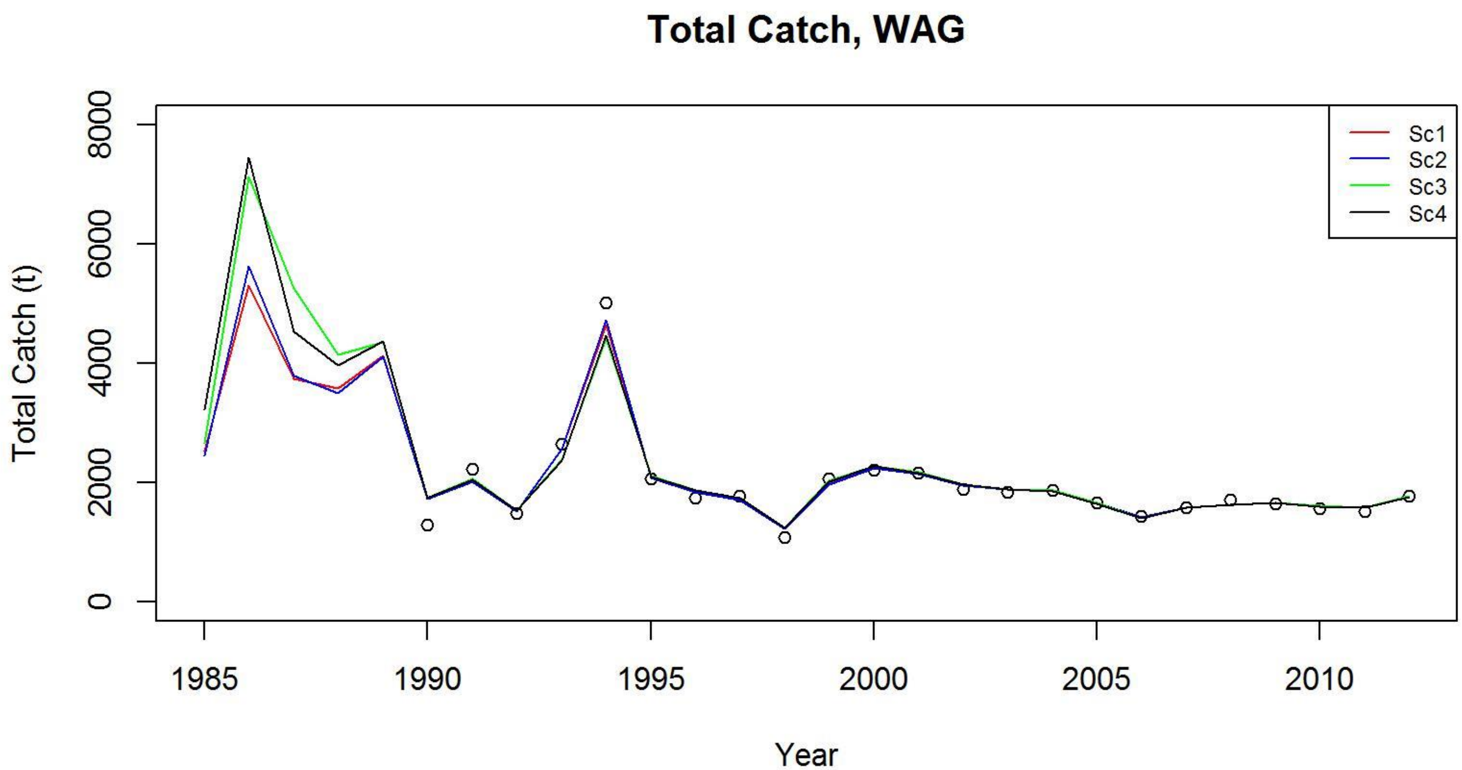


Figure 55. Observed (filled circle) vs. predicted (solid line) total catch of golden king crab for scenarios 1 to 4 fits in the WAG, 1990–2012. A handling mortality rate of 20% was applied to pot discarded catch and it was added to retained catch to get the total catch. (note: 1990 refers to the1990/91 fishery). Predicted total catch time series is extended to 1985/86.

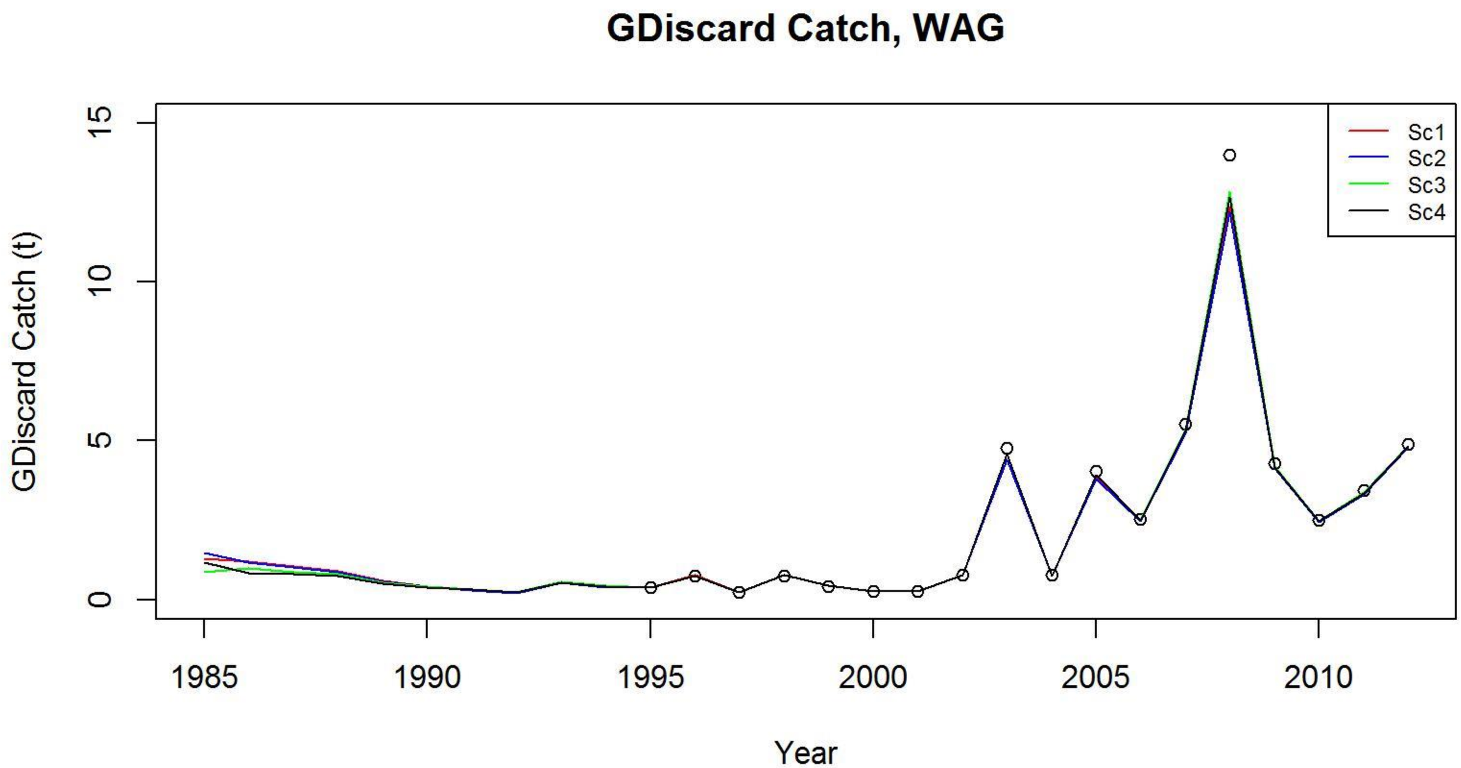


Figure 56. Observed (filled circle) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios 1 to 4 fits in the WAG, 1990–2012. An average handling mortality rate of 65% (average of 80%  and 50%) was applied to groundfish discard. (note: 1995 refers to the1995/96 fishery). Predicted groundfish discarded catch time series is extended to 1985/86.

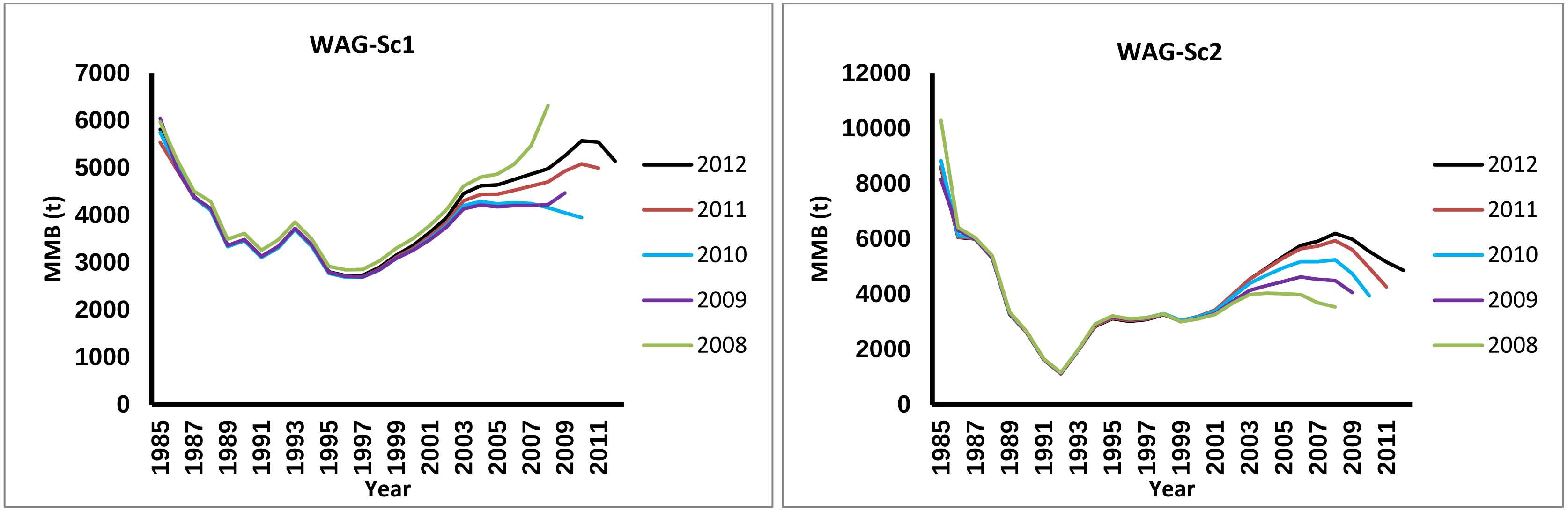


Figure 57. Retrospective fits of mature male biomass by the model when terminal year's data were systematically removed until 2008/09 for scenarios 1 and 2 for golden king crab in the WAG, 1985–2012.

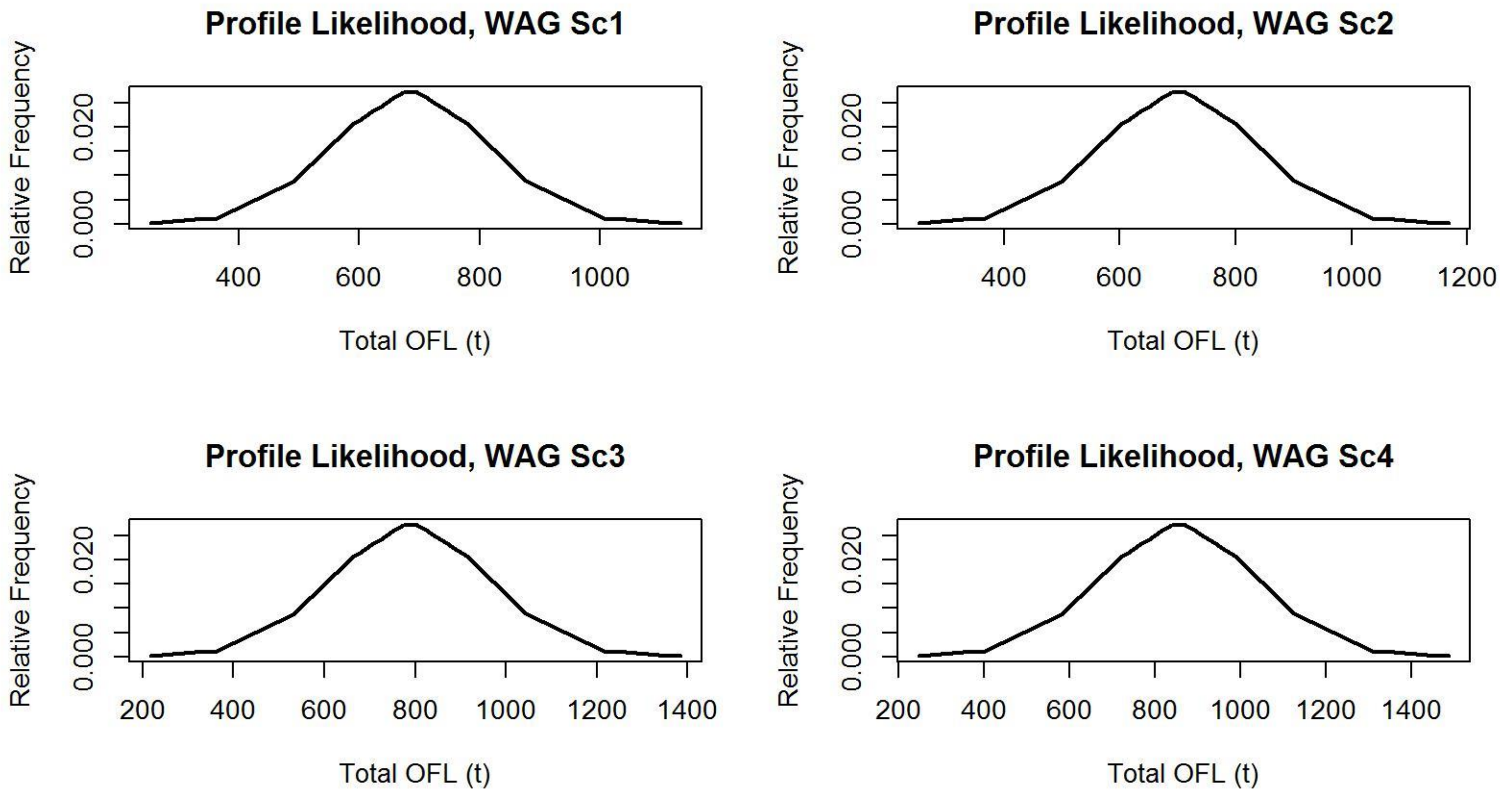


Figure 58. Probability distribution of total OFL based on 1985–2012 data for scenarios 1 to 4 fits for WAG golden king crab. Profile likelihood was used to create the probability distribution.

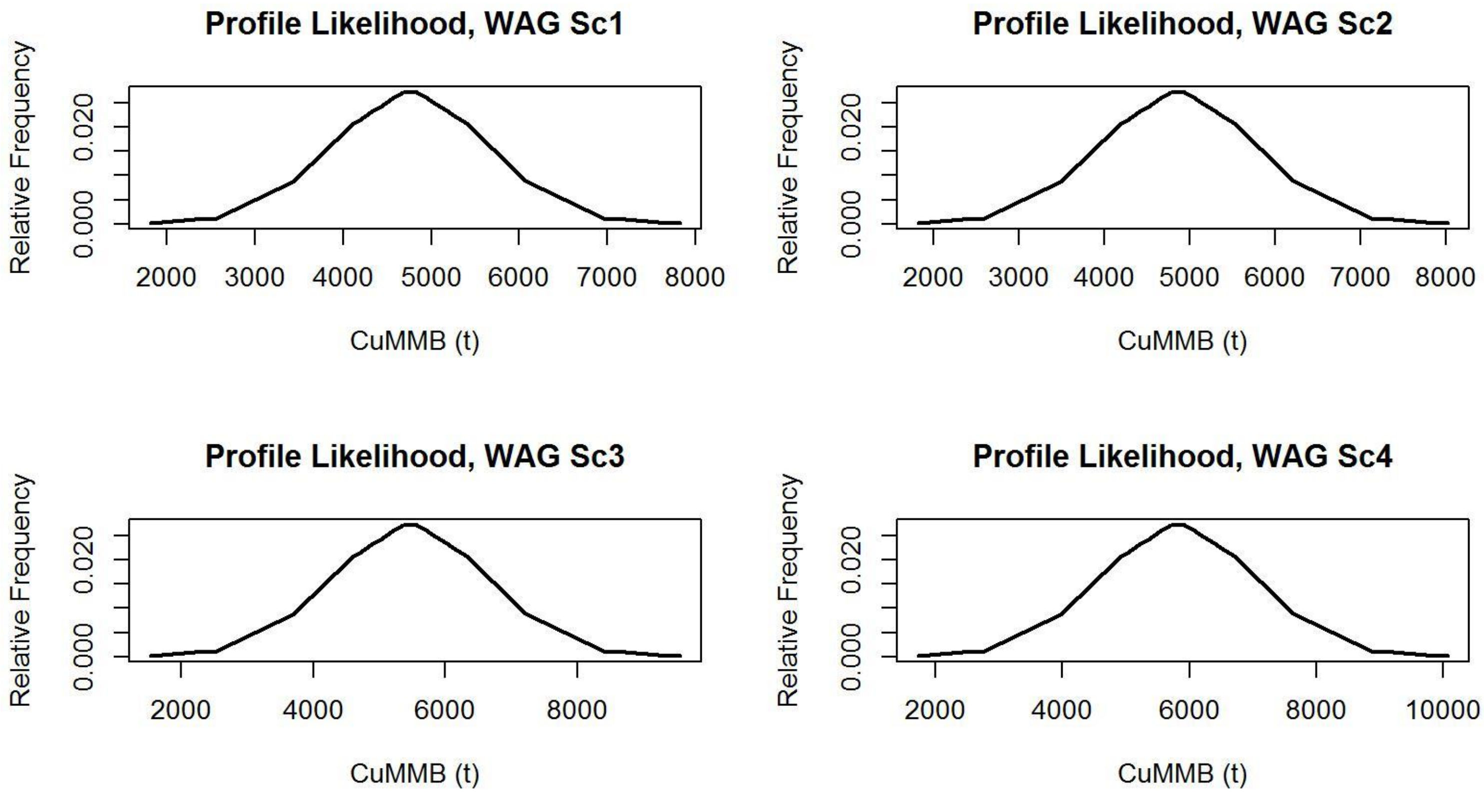


Figure 59. Probability distribution of current MMB based on 1985–2012 data for scenarios 1 to 4 fits for WAG golden king crab. Profile likelihood was used to create the probability distribution.

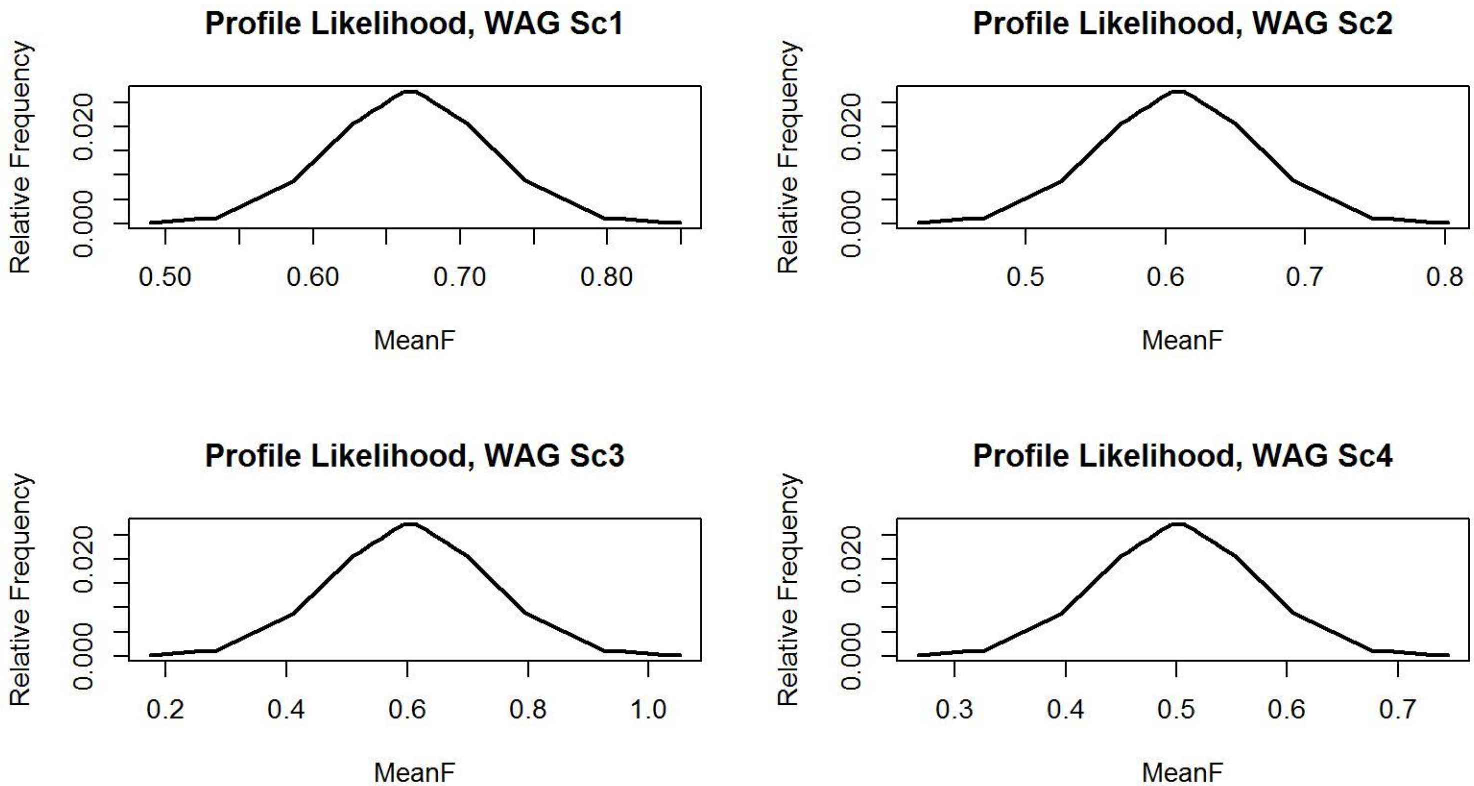


Figure 60. Probability distribution of mean F based on 1985–2012 data for scenarios 1 to 4 fits for WAG golden king crab. Profile likelihood was used to create the probability distribution.

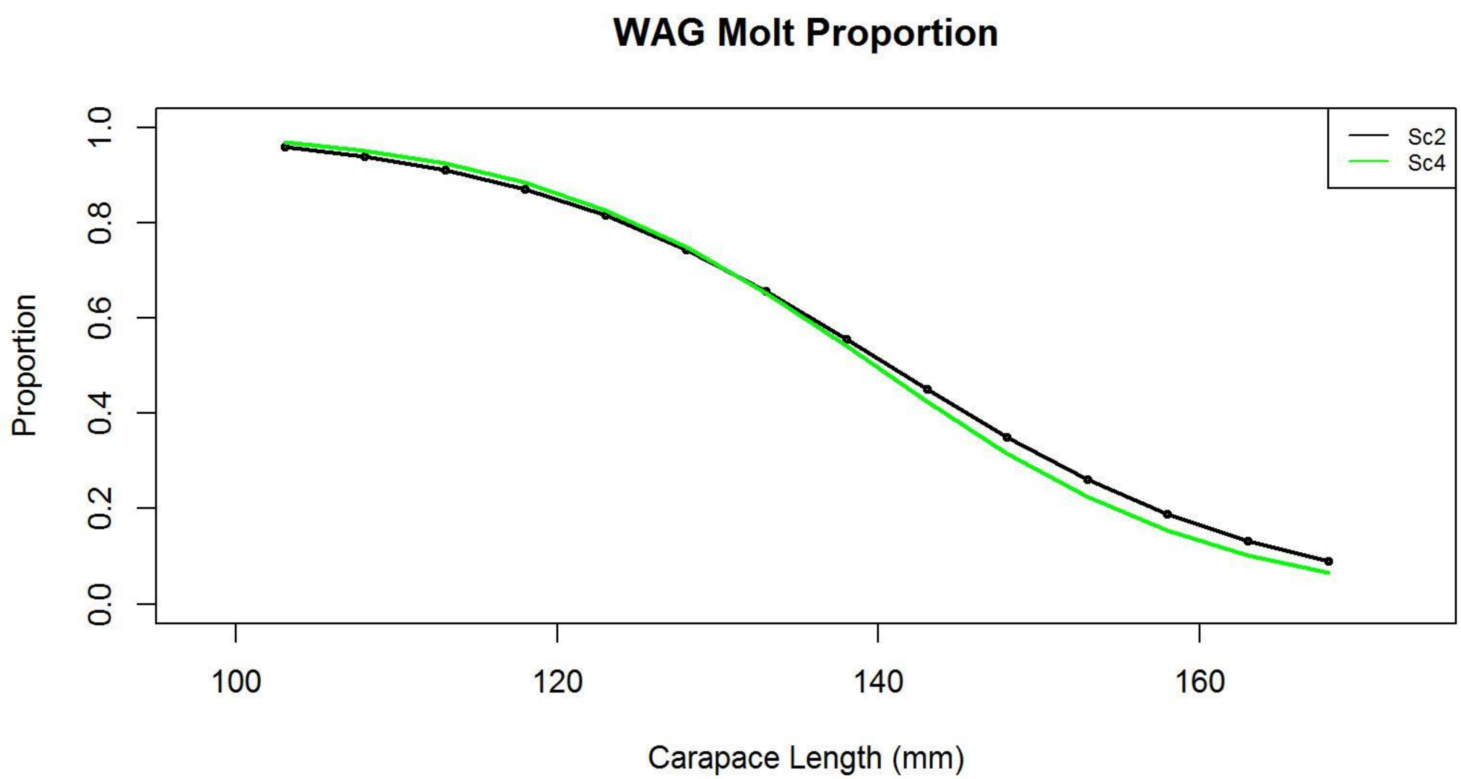


Figure 61. Molt probability for scenarios 2 (Sc2) and 4 (Sc4) fits for WAG golden king crab.

Appendix A: Integrated model

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

**Basic population dynamics**
The annual [male] abundances by size are modeled using the equation:

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

where $N_{t,i}$ is the number of [male] crab in length class *i* on 1 July (start of biological year coincided with mid survey time) of year *t*; $\hat{C}_{t,i}$, $\hat{D}_{t,i}$, and $\hat{T}r_{t,i}$ are respectively the predicted fishery retained, pot fishery discard dead, and groundfish fishery discard dead catches in length class *i* during year *t*; $\widehat{D}_{t,i}$ is estimated from the total ($\hat{T}_{t,i}$) and the retained (($\hat{T}_{t,i}$) catch by the equation (2c). $X_{i,j}$ is the probability in 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*; and *M* is instantaneous rate of natural mortality.

The catches are predicted using the equations

$$\hat{T}_{t,j} = \frac{F_t s_{t,j}^T}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \quad (2a)$$

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

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

$$\widehat{Tr}_{t,j} = 0.8\frac{F_t^{Tr} s_j^{Tr}}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \quad (2d)$$

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

$$Z_{t,j} = F_t s^T_{t,j} + F^{Tr}_t s^{Tr}_j \qquad (3)$$

$F_t$ is the full selection fishing mortality in the pot fishery, $F^{Tr}_t$ is the full selection fishing mortality in the trawl fishery, $s^T_{t,j}$ is the total selectivity for animals in length-class *j* by the pot fishery during year *t*, $s^{Tr}_j$ is the selectivity for animals in length-class j by the trawl fishery, $s^r_{t,j}$ is the probability of retention for animals in length-class *j* by the pot fishery during year t.

The initial condition (t=1985) are computed using the equation $N_{1985,i} = \tilde{N}_{1985} e^{\varepsilon_i} / \sum_j e^{\varepsilon_j}$ where $\tilde{N}_{1985}$ is the total abundance in 1985, and $\varepsilon_i$ are parameters which determine the initial (1985) length-structure (one of $\varepsilon_i$ =0 to ensure identifiability).

**Growth**

**Molt probability**

Growth increment probability with (scenarios 2 and 4) and without molt probability (scenarios 1 and 3) are used to estimate the size transition matrix using tagging data. Molt probability is assumed to be a logistic function of length,

$$m_i = \frac{1}{1 + e^{a(\tau_i - b)}} \qquad (4)$$

Where *a* and *b* are parameters and $\tau_i$ is the mid-point of the contributing length interval *i*.

The expected proportion of molting crabs growing from length class *i* to length class *j* during a year, $X_{i,j}$, is:

$$P_{i,j} = m_i \frac{\int_{j_1-\tau_i}^{j_2-\tau_i} N(x|\mu_i,\sigma^2)dx}{\sum_{j=1}^{n} \int_{j_1-\tau_i}^{j_2-\tau_i} N(x|\mu_i,\sigma^2)dx} \quad \text{where } N(x|\mu_i,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(\frac{x-\mu_i}{\sigma})^2} \qquad (5)$$

$$X_{i,j} = \begin{cases} P_{i,j} & when\ i \neq j, \\ P_{i,j} + (1 - m_i) & when\ i = j \end{cases} \qquad (6)$$

where $\mu_i$ is the expected growth increment ($\mu_i = \omega_1 + \omega_2 \tau_i$), $\omega_1$, $\omega_2$, and $\sigma$ are parameters, and $j_1$ and $j_2$ are the lower and upper limits of the receiving length interval $j$ (in mm CL), $\tau_i$ is the mid-point of the contributing length interval $i$, which is $\ll j$, and $n$ is the total number of receiving length intervals.

**Selectivity and retention**

Selectivity and retention are both assumed to be logistic function of length. Selectivity depends on year for the pot fishery:

$$S_i = \frac{1}{1 + e^{\left[-\ln(19)\frac{\tau_i - \theta_{50}}{\theta_{95} - \theta_{50}}\right]}} \qquad (7)$$

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

**Recruitment**

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

$$gamma(x|\alpha_r, \beta_r) = \frac{x^{\alpha_r - 1} e^{\frac{x}{\beta_r}}}{\beta_r{}^{\alpha_r}\,\Gamma_{(\alpha_r)}} \qquad (8)$$

with $\alpha_r$ and $\beta_r$ (restricted to the first six length- classes).

**Parameter estimation**

Table 1 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 2a and 2b list the values for the parameters which weight (with the corresponding standard errors in parentheses) the components of the objective function for EAG and WAG, respectively.

**Likelihood components**

*Catches*

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

$$LL_r^{catch} = \lambda_r \sum_t \{\ell n(\sum_j \hat{C}_{t,j} w_j + c) - \ell n(\sum_j C_{t,j} w_j + c)\}^2 \tag{9a}$$

$$LL_T^{catch} = \lambda_T \sum_t \{\ln(\sum_j \hat{T}_{t,j} w_j + c) - \ln(\sum_j T_{t,j} w_j + c)\}^2 \tag{9b}$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{\ln(\sum_j \widehat{Tr}_{t,j} w_j + c) - \ln(\sum_j Tr_{t,j} w_j + c)\}^2 \tag{9c}$$

where $\lambda_r$, $\lambda_T$ and $\lambda_{GD}$ 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 size-class $j$, $C_{t,j}$, $T_{t,j}$, and $Tr_{t,j}$are respectively the observed number of crab in size class $j$ retained, pot total, and groundfish fishery discarded crab during year $t$.

*Catch-rate indexes*

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

$$LL_r^{CPUE} = \lambda_{rCPUE} \left\{0.5 \sum_t \ln\left[2\pi\left(\sigma_{r,t}^2 + \sigma_e^2\right)\right] + \sum_t \frac{\left(ln(CPUE_t^r + c) - \ln(\widehat{CPUE}_t^r + c)\right)^2}{2\left(\sigma_{r,t}^2 + \sigma_e^2\right)}\right\} \tag{10}$$

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

$$\widehat{CPUE}_t^r = q_t \sum_j S_j^T S_j^r \left(N_{t,j} - 0.5\left[\widehat{C_{t,J}} + \widehat{D_{t,J}} + \widehat{Tr_{t,J}}\right]\right) e^{-y_t M} \tag{11}$$

where $q_t$ is the catchability coefficient for year *t*, $\sigma_e$ is the extent of over-dispersion, *c* is a small constant (0.001), and $\lambda_{rCPUE}$ is the weight assigned to the catch-rate data.

*Length-composition data*

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

$$LL_r^{LF} = 0.5\sum_t\sum_j \ell n(2\pi\sigma_{t,j}^2) - \sum_t\sum_j \ell n\left[\exp\left(-\frac{(P_{t,j}-\hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right)+0.01\right] \quad (12)$$

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

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

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

$$\hat{L}_{t,j}^{GF} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \quad (13)$$

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

$$\sigma_{t,j}^2 = \left[(1-P_{t,j})P_{t,j} + \frac{0.1}{n}\right]/S_t \quad (14)$$

$S_t$ is the effective sample size for year ***t*.**

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 $\underline{\rho}_{j,t,y}$ 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 likelihood of the tagging data is then:

$$\ell \text{n} L = \sum_t \sum_j \sum_y \sum_i \rho_{j,t,y,i} \ell \text{n} \hat{\rho}_{j,t,y,i} \tag{15}$$

where $\hat{\rho}_{j,t,y,i}$ is the proportion in length-class *i* of the recaptures of males which were released in year *t* that were in length-class *j* when they were released and were recaptured after *y* years:

$$\hat{\underline{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{Z}^{(j)} \tag{16}$$

where $S^T$ is the target total fishery selectivity vector with $S_i^T$ at element i and 0 otherwise, and $Z^{(j)}$ is a vector with $V_{j,t,y}$ at element *j* and 0 otherwise (Punt et al., 1997).

We assume that all recaptures are in the pot fishery and not the survey, and the reporting rate is independent of the size of crab.

We predict the expected number of recaptures in length-class *l* by

$$r_l = \sum_t \sum_j \frac{s_l [\mathbf{X}^t]_{j,l}}{\sum_{l'} s_{l'} [\mathbf{X}^t]_{j,l'}} \sum_k V_{j,k,t} \tag{17}$$

The last term, $\sum_k V_{j,k,t}$, is the numbers recaptured after t time-steps of male crabs that were released in size-class *j*. The $\sum_j \frac{s_l [\mathbf{X}^t]_{j,l}}{\sum_{l'} s_{l'} [\mathbf{X}^t]_{j,l'}} \sum_k V_{j,k,t}$ is the predicted number of animals recaptured in length-class *l* that were out 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, average pot fishing mortality about a fixed F value k, and the posfunction :

$$P_1 = \lambda_F \sum_t (\ell n F_t - \ell n \bar{F})^2 \qquad (18)$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ell n F_t^{Tr} - \ell n \bar{F}^{Tr})^2 \qquad (19)$$

$$P_3 = \lambda_R \sum_t (\ell n \varepsilon_t)^2 \qquad (20)$$

$$P_4 = \lambda_{Fmean} (\bar{F} - k)^2 \qquad (21)$$

$$P_5 = \lambda_{posfn} * fpen \qquad (22)$$

**Standardized Residual of Length Composition**

$$Std.Res_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma_{t,j}^2}} \qquad (23)$$

**Output Quantities**

*Harvest rate*

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n} (\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \qquad (24)$$

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

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \qquad (25)$$

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

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

$$MMB_t = \sum_{j=mature\ size}^{n} \{N_{j,t} e^{y'M} - (\hat{C}_{j,t} + \widehat{D}_{j,t} + \widehat{Tr}_{j,t}) e^{(y_t - y')M}\} w_j \quad (26)$$

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

For estimating next year limit harvest level from current year stock abundance, 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 $MMB_t > 0.25M\overline{M}B$,

$$F' = \gamma M \frac{\left(\frac{MMB_t}{M\overline{M}B} - \alpha\right)}{(1-\alpha)} \quad (27)$$

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

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

Because projected $MMB_t$ is depended on the intervening retained and discard catch (i.e., $MMB_t$ is estimated after the fishery), an iterative procedure is used using equations (26) and (27) with retained and discard catch predicted from equations (2b-d). The next year limit harvest catch is estimated using equations (2b-d) with the estimated $F'$ value.

Table A1. Estimated parameters of the population dynamics model

| Parameter | Number of parameters |
|---|---|
| Initial conditions | |
| Initial total numbers, $\tilde{N}_{1985}$ | 1 |
| Length-specific proportions, $\varepsilon_i$ | *n*-1 |
| Fishing mortalities | |
| Pot fishery, $F_t$ | 1985–2012 |
| Mean pot fishery fishing mortality, $\bar{F}$ | 1 |
| Trawl fishery, $F_t^{Tr}$ | 1995–2012 (the mean F for 1995 to 1999 was used to project back the trawl discards up to 1985. |
| Mean trawl fishery fishing mortality, $\bar{F}^{Tr}$ | 1 |
| Selectivity and retention | |
| Pot fishery total selectivity $\theta_{50}^{T}$ | 2 (1985–2004; 2005+) |
| Pot fishery total selectivity difference, $delta\theta^{T}$ | 2 (1985–2004; 2005+) |
| Trawl fishery selectivity $\theta_{50}^{Tr}$ | 1 |
| Trawl fishery selectivity difference $delta\theta^{Tr}$ | 1 |
| Pot fishery retention $\theta_{50}^{r}$ | 2 (1985–2004; 2005+) |
| Pot fishery retention difference $delta\theta^{r}$ | 2 (1985–2004; 2005+) |
| Growth | |
| Expected growth increment, $\omega_1, \omega_2$ | 2 |
| Variability in growth increment, $\sigma$ | 1 |
| Molt probability (size transition matrix with tag data) *a* | 1 |
| Molt probability (size transition matrix with tag data) *b* | 1 |
| Natural mortality, *M* | Pre-specified, 0.18yr$^{-1}$ |

| | |
|---|---|
| Recruitment | |
| Distribution to length-class, $\alpha_r, \beta_r$ | 2 |
| Recruitment deviations, $\varepsilon_t$ | $n$ |
| $F_{OFL}$ | 1 |
| Fishery catchability, $q$ | 3 (1985–1998; 1999–2004; 2005+) |
| Likelihood weights (standard error) | Pre-specified, varies for different scenarios |

Table A2a. Specifications for the weights with corresponding coefficient of variations* in parentheses for each scenario for EAG.

| Weight | Value | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario4** | **Scenario5** | **Scenario6** | **Scenario7** |
| Catch: | | | | | | | |
| Retained catch. $\lambda_r$ | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) |
| Total catch, $\lambda_D$ | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) |
| Groundfish catch, $\lambda_{GD}$ | 0.041(444.7705) | 0.041(444.7705) | 0.041(444.7705) | 0.041(444.7705) | 0.041(444.7705) | 0.041(444.7705) | 0.041(444.7705) |
| Catch-rate: | | | | | | | |
| Observer legal size crab catch-rate, $\lambda_{r,CPUE}$ 1995–2012 | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) |
| Fish ticket legal size crab catch-rate, $\lambda_{r,CPUE}$ 1985–1998 | | | 1(0.8054) | 1(0.8054) | | | |
| Penalty weights: | | | | | | | |
| Mean pot fishing mortality, $\lambda_{Fmean}$ | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | 0.0 | 0.0 |
| Pot fishing mortality dev, $\lambda_F$ | Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase | 0.0 |
| Trawl fishing mortality | Initially 1000(0.0224), | Initially 1000(0.0224), | Initially 1000(0.0224), | Initially 1000(0.0224), | Initially 1000(0.0224), | Initially 1000(0.0224), | Initially 1000(0.0224), |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| dev, $\lambda_{F^{Tr}}$ | relaxed to 0.00001 (very large)at the final phase | relaxed to 0.00001 (very large)at the final phase | relaxed to 0.00001 (very large)at the final phase | relaxed to 0.00001 (very large)at the final phase | relaxed to 0.00001 (very large)at the final phase | relaxed to 0.00001 (very large)at the final phase | relaxed to 0.00001 (very large)at the final phase |
| Recruitment, $\lambda_R$ | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) |
| Tagging likelihood weight | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) |

$$* \ Coefficient\ of\ Variation, \qquad CV = \sqrt{e^{\frac{1}{2\times Weight}} - 1}$$

Table A2b. Specifications for the weights with corresponding coefficient of variations in parentheses for each scenario for WAG.

| Weight | Value | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario4** | **Scenario5** | **Scenario6** | **Scenario7** |
| Catch: | | | | | | | |
| Retained catch. $\lambda_r$ | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) | 500 (0.0316) |
| Total catch, $\lambda_D$ | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) | 400(0.0354) |
| Groundfish catch, $\lambda_{GD}$ | 0.09(2.3570) | 0.09(2.3570) | 0.09(2.3570) | 0.09(2.3570) | 0.09(2.3570) | 0.09(2.3570) | 0.09(2.3570) |
| Catch-rate: | | | | | | | |
| Observer legal size crab catch-rate, $\lambda_{r,CPUE}$ 1995–2012 | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) | 1(0.8054) |
| Fish ticket legal size crab catch-rate, $\lambda_{r,CPUE}$ 1985–1998 | | | 1(0.8054) | 1(0.8054) | | | |
| Penalty weights: | | | | | | | |
| Mean pot fishing mortality, $\lambda_{Fmean}$ | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | 0.0 | 0.0 |
| Pot fishing mortality dev, $\lambda_F$ | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | 0.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Trawl fishing mortality dev, $\lambda_{F^{Tr}}$ | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase | Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase |
| Recruitment, $\lambda_R$ | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) | 1.5(0.6290) |
| Tagging likelihood weight | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) | 0.5(1.3108) |