Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment in Spring 2015

Draft report for the May 2015 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,* Aleutian Islands, east of 174 °W longitude (EAG) and west of 174 °W longitude (WAG).

2. *Catches*

   The Aleutian Islands golden king crab commercial fishery was developed in the early 1980s; the harvest peaked in 1986/87 at 5.900 and 8.800 million pounds, respectively, for EAG and WAG. Catches have been steady since 1996/97 following implementation of total allowable catches (TACs) of 3.000 (EAG) and 2.700 (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 3.310 million pounds for EAG and 2.980 million pounds for WAG for the 2012/13 fishery. The fishery has harvested close to TAC levels since 1996/97. Catch rates increased in both the EAG and WAG fisheries in the mid-2000s; however, in recent years the WAG catch rates have declined.

3. *Stock biomass*

   Estimated mature male biomass (MMB) has decreased following peak levels during the mid-1980s of the directed fishery and then increased and stabilized in recent years for both EAG and WAG. Estimated MMB has decreased during the last few years in the WAG area. The lowest levels of MMB for EAG were observed in early 1990s 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 numbers of recruits to the model size groups have shown fluctuating trends for both EAG and WAG. For EAG, the model recruitment was highest in 1990-91, and lowest in 1988 –1989 while for WAG, the model recruitment was highest in 1992 and 1993 and lowest in 1991 for different scenarios.

5. *Management performance*

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

6. *Basis for the OFL*

We provide the OFL estimates under Tier 4 and Tier 3 approaches for EAG and WAG, respectively.

The length-based model developed for Tier 4 analysis estimates MMB each year for the period February 15, 1986 through February 15, 2014 and projects to February 15, 2015 for OFL and ABC determination. The Tier 4 approach proposes the following OFL and ABCs based on using the 1986–2014 mean MMB as the reference biomass (B_{ref}). The total OFL and ABC estimates are provided for four scenarios denoted by 2), 3), 7), and 10) in the following four tables:

EAG (Tier 4):

Biomass, total OFL, and ABC 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)	ABC (0.9*OFL)
2) 2014/15	4a	11.570	19.084	1.65	0.18	1986–2014	0.18	2.593	2.580	2.334
3) 2014/15	4a	12.911	24.537	1.90	0.18	1986–2014	0.18	3.414	3.392	3.073
7) 2014/15	4a	12.668	21.453	1.69	0.18	1986–2014	0.18	2.879	2.863	2.591
10) 2014/15	4a	12.739	20.668	1.62	0.18	1986–2014	0.18	2.765	2.750	2.489

Biomass in 1000 t; total OFL and ABC in t.

Season	Tier	B_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define B_{ref}	M	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
2) 2014/15	4a	5.248	8.657	1.65	0.18	1986–2014	0.18	1176.062	1170.062	1058.456
3) 2014/15	4a	5.856	11.130	1.90	0.18	1986–2014	0.18	1548.717	1538.629	1393.845
7) 2014/15	4a	5.746	9.731	1.69	0.18	1986–2014	0.18	1305.918	1298.741	1175.326
10) 2014/15	4a	5.778	9.375	1.62	0.18	1986–2014	0.18	1254.294	1247.373	1128.865

WAG (Tier 4):

Biomass, total OFL, and ABC 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)	ABC (0.9*OFL)
2) 2014/15	4b	9.386	7.866	0.84	0.175	1986–2014	0.18	1.141	1.126	1.027
3) 2014/15	4b	10.378	9.007	0.87	0.175	1986–2014	0.18	1.329	1.311	1.196
7) 2014/15	4b	10.591	8.481	0.80	0.165	1986–2014	0.18	1.134	1.119	1.021
10) 2014/15	4b	10.826	9,731	0.90	0.179	1986–2014	0.18	1.392	1.375	1.253

Biomass in 1000 t; total OFL and ABC in t.

Season	Tier	B_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define B_{ref}	M	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
2) 2014/15	4b	4.257	3.568	0.84	0.175	1986–2014	0.18	517.429	510.888	465.686
3) 2014/15	4b	4.707	4.085	0.87	0.175	1986–2014	0.18	602.897	594.636	542.607
7) 2014/15	4b	4.804	3.847	0.80	0.165	1986–2014	0.18	514.482	507.771	463.034
10) 2014/15	4b	4.911	4.414	0.90	0.179	1986–2014	0.18	631.286	623.911	568.157

The Tier 3 approach as an alternative to Tier 4 provides additional sets of OFL estimates based on the mean number of recruits for the period 1986 to 2014 in the following four tables for EAG and WAG, respectively. Either F_{35} can be used as a multiplier of M if a Tier 4 approach is to be strictly followed or it can be used as it is by promoting the assessment to Tier 3. Assuming M as the F_{ofl} value under Tier 4 approach seems to be more conservative, especially for the WAG stock.

EAG (Tier 3):

Biomass, total OFL, and ABC in million pounds.

Season	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Years to define Bref	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
2) 2014/15	3a	14.667	17.824	1.22	0.39	1986–2014	0.39	5.120	5.094	4.608
3) 2014/15	3a	15.772	22.083	1.40	0.38	1986–2014	0.38	6.590	6.547	5.931
7) 2014/15	3a	15.345	19.761	1.29	0.39	1986–2014	0.39	5.686	5.656	5.117
10) 2014/15	3a	15.279	19.118	1.25	0.39	1986–2014	0.39	5.463	5.434	4.917

Biomass in 1000 t; total OFL and ABC in t.

Season	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
2) 2014/15	3a	6.653	8.085	1.22	0.39	1986–2014	0.39	2322.435	2310.670	2090.192
3) 2014/15	3a	7.154	10.017	1.40	0.38	1986–2014	0.38	2989.069	2969.506	2690.162
7) 2014/15	3a	6.960	8.963	1.29	0.39	1986–2014	0.39	2579.215	2565.403	2321.294
10) 2014/15	3a.	6.930	8.672	1.25	0.39	1986–2014	0.39	2478.222	2464.950	2230.400

WAG (Tier 3):

Biomass, total OFL, and ABC in million pounds.

Season	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
2) 2014/15	3b	12.188	9.380	0.77	0.25	1986–2014	0.33	1.541	1.530	1.387
3) 2014/15	3b	12.768	9.532	0.81	0.26	1986–2014	0.33	1.846	1.831	1.661
7) 2014/15	3b	11.726	9.724	0.83	0.28	1986–2014	0.34	1.789	1.775	1.610
10) 2014/15	3b	12.349	10.649	0.86	0.29	1986–2014	0.34	2.121	2.108	1.909

Biomass in 1000 t; total OFL and ABC in t.

Season	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
2) 2014/15	3b	5.529	4.255	0.77	0.25	1986–2014	0.33	698.841	693.82	628.957
3) 2014/15	3b	5.791	4.323	0.81	0.26	1986–2014	0.33	837.30	830.42	753.570
7) 2014/15	3b	5.319	4.411	0.83	0.28	1986–2014	0.34	811.589	805.255	730.430
10) 2014/15	3b	5.601	4.830	0.86	0.29	1986–2014	0.34	962.107	955.996	865.896

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 2013/14 commercial fishery retained and total catch, observer nominal total CPUE and fishing effort (pot lifts) to calculate total catches for 1990/91–2013/14, and groundfish discarded catch by size are added. With the availability of additional data, the groundfish bycatch time series is extended back to 1989/90. 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. A limited number of tag recaptures from the WAG area was used in a model scenario for the WAG assessment.
   (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 2005/06–2013/14 periods (Details in the September 2013 CPT presentation on CPUE standardization).
   (d) Fish ticket retained catch CPUE are standardized by the GLM with the additional data (2013/14 fishery) using a lognormal link function considering only the year effect. The 1985-1998 indices are used in the model for scenario 3.

3. *Changes to assessment methodology*
   None. The same model has been improved.

4. *Changes to assessment results*
   Not applicable because the model has not been used previously.

B. Response to 2014 CPT comments

The CPT reviewed the model in detail during the September 2014 CPT meeting. So, we present the responses to their comments:

Comment 1: The predicted sample size is generally greater than the input sample size (effective sample size) this may indicate over fitting to the length frequency data. The CPT discussed the weighting of length frequency data, relative abundance index data, and the possibility of using the method of Francis (2011). The CPT recommends the Francis method should be investigated in a model workshop context as this would apply to all crab stock assessments not just Aleutian Golden king crab.

Response: We considered a scenario (11) by iteratively reweighting the input effective sample size. A figure is shown in this document (Figure56).

Comment 2: The better fit to growth data for scenario 5 when the growth matrix is fixed vs. estimated in the model, seems to indicate the model is fitting some other data component at the expense of the growth (tagging) data. A higher weight was put on the total catch likelihood in this assessment to improve fit. There was concern that the fishing mortality values in the early 1990's were too high for the east and west areas. The model estimates more decline in the stock in the early period than indicated by the CPUE time series. There are also very high estimates of discard in 1994 for the WAG and in 1991 and 1992 for EAG. Fits to the length frequency data in the years where total catch was very high shows a distinct lack of fit. This could be due to model initialization or model trying to fit anomalously large total catches.

Response: We considered a scenario (7) where pre 1995 total catches and total catch composition likelihood components are disregarded in the optimization. Indeed this scenario produced better results.

Comment 3: Including a separate molting probability (scenario 2) improved the fit of the model compared to scenario 1. This results in a higher fraction of crab in the diagonal of the growth matrix than can be estimated by a normal distribution.
Scenario 4 estimated lower q for CPUE index and higher biomass than other scenarios. It was not clear why this occurs. The CPT recommends the author do a manual likelihood profile on q to investigate the differences in q estimates.

Response: We provide the manual likelihood profile on q for EAG and WAG in this document (Figures 29 and 55). The CPUE and total negative likelihoods behaved similarly even though the length compositions provided were more influential on the total likelihoods.

Comment 4: Scenarios 6 and 7 (no fishing mortality penalties in any phase) gave same results as scenarios with fishing mortality penalties removed in the last phase. The author doesn't need to include these scenarios in future.

Response: We did not include these scenarios in this report.

Comment 5: Figure 57 retrospective plot appears to be incorrect.

Response: corrected.

The CPT recommendations:

1) Total catch in the early 1990's for both east and west areas have very large discard estimated relative to other years. Need to check these values to see if they are correct and also are they reliable estimates.

Response: We checked the data and apparently large number of vessels moved to the Aleutian Islands golden king crab area as a result of Bristol Bay red king crab closure.

2) If total catch in early1990's is correct however unreliable then run a scenario of the model with total catch time series starting from 1995 to present only.

   Response: we ran a scenario (7) excluding the pre-1996/97 period for EAG and pre-1995/96 for WAG.

3) Do sensitivity of initialization of the stock and the fits to the 1990's length frequency data and CPUE data.

   Response: We did a sensitivity analysis with an alternative formulation of initial size composition calculator (Quinn and Deriso, 1999). It did not make much difference (scenario 6, table 31).

4) Model run estimating the growth matrix in the model with 1 year tag return data only (instead of scenario 5 which had growth matrix fixed however had a much better fit to growth data then scenario 2).
5)

   Response: We considered a scenario with one year tag-recapture data only inside the model (scenario 5, Table 31).

6) There is uncertainty in the scale of biomass (q for the CPUE index). Run the model with fixed values of q and plot all likelihood components vs q.

   Response: We did in this report (Figures 29 and 55).

7) Lower weights on likelihoods for length composition data as a sensitivity on the fit to the CPUE data following the method of Francis (2011).

Response: we ran a scenario with iterative re-weighting following Francis (Figure 56).

C. Introduction

1. Scientific name: Golden king crab, *Lithodes aequispinus.*
2. Distribution: In Alaska, golden king crab is distributed in the Aleutian Islands, on the continental slope of the eastern Bering Sea, and 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 for large males (adults) in Southeast Alaska is 16.3 mm CL per molt (Koeneman and Buchanan 1985), and for legal males in the EAG was estimated at 14.4 mm CL (Watson et al. 2002). Annual molting probability of males decreases with increasing size, which results in a protracted inter-molt period and 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 Saint Matthew Island section (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 management of the Aleutian Islands golden king crab fishery at 174° W longitude (ADF&G 2002). Hereafter, the east of 174 °W longitude stock segment is referred to as EAG and the west of 174° W longitude stock segment is referred to as WAG. The stocks in the two areas are managed with a constant annual guideline harvest level or total allowable (retained) catch (3.000 million pounds for EAG and 2.700 million pounds for WAG). In 2008, however, the total allowable catch was increased by the BOF decision to 3.150 and 2.830 million pounds for EAG and WAG, respectively (an approximately 5% increase in TAC). 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 2000 and 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 2013/14 commercial fishery retained and estimated total catch by size, observer CPUE, and male groundfish discard catch by size to the time series. Following the new groundfish bycatch data dump we recalculated the whole time series of groundfish bycatch data which extends back to 1989/90. As a result a number of data points have changed.
    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. We also considered a limited tag-recapture data from WAG that were released in the 1980s. We did not mix the two sets of data.

2. Available catch and tagging data.

Data set	Years	Data type(s)
Retained pot catch	1985/86–2013/14	Catch by length
Total pot catch	199091–2013/14	Catch by length (Observer nominal total CPUE with effort were used to estimate total pot catch)
Groundfish discarded catch	1989/90–2013/14	Catch by length
Observer legal size crab CPUE	1995/96–2013/14	Independent estimated annual CPUE index with standard error (by negative binomial GLM) (Fox and Weisberg 2011)
Pot Fishery retained catch CPUE	1985/86–1998/99	Independently estimated annual CPUE index with standard error considering only the year effect (by lognormal GLM). This series is used in the model only for scenario 3
Tag-recapture data	EAG: 1991, 1997, 2000, 2003, 2006	Release-recapture length and time-at-large - 1717 records
	WAG: 1980s	- 65 records

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, observer sample size, and estimated observer CPUE index (Table 2 for EAG and Table 17 for WAG).

c. Information on length compositions (Figures 8 a, b; 9 a, b; and 10 a, b for EAG and Figures 31 to 36 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: $W = al^?$ 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, and 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:

$$\sum_{??\,?}^{?} ?_{?} \frac{???_{??}}{\sum_{??\,?}^{?} ???_{??}} \qquad (1)$$

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 fishing effort (number of pot lifts). The weighted length frequency of the observer sample was estimated using Equation 1 and then the relative frequency for the year was calculated. Observer measurement of crab ranged from 20 to 220 mm CL. To restrict the total number of crabs to the model assumed size range (101-185 mm CL), the proportion of observer total relative length frequency corresponding to this size range was multiplied by the total catch (number of crabs). This total number of crabs was distributed into length-classes using the weighted relative length frequency. 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 directed fishery discarded [dead] catch).

Observer data have been collected since 1988 (Moore et al., 2000; Barnard et al., 2001; Barnard and Burt, 2004; Gaeuman, 2011), but data are not comprehensive in the initial years, so a shorter time series of data for the period 1990–2013 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 1995–2013 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 2005–2013.

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 scenario 3. 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 this scenario, we considered three sets of catchability, 1985–1998, 1999–2004, and 2005–2013, but the same two sets of selectivity parameters. For another scenario (scenario 10), we considered three sets of catchability and selectivity.

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 2013/14 for retained catch biomass and size composition; 1995/96 to 2013/14 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 2013/14 for total catch biomass and total catch length composition; 1989/90 to 2013/14 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 < 1999, 1999 to < 2005 and >= 2005 under scenario 10. For scenario 3, we assumed three different q's and two selectivity (pre- and post-rationalization periods) patterns. 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 GLM fitting procedure (Starr 2012) shown below 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. The negative binomial model uses the log link function for the GLM fit. Therefore, we assumed the null model to be

. Ú (? ? ? ??) ? ? ? ??? ?? (2)

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

Ú Æ ? ? ?? ? ? ? ??? ? ?(? ? ? ??? ? ?) ? ? ? ?h?? ? ? ? ??? ? ? ? ? ? ??? ? ? ? ? ? ? ???
? ? ? ??? ? ?(? ? ? ?h?? ? ?) ? ? Æ ? ? ? ? ? ???? ? ? ?? , (3)

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

The final models for EAG were:

Ú Æ ? ? ?   ? ? ? ?   ? ? ? ?   ? ? ? ? ? ?   ? ? Æ ? ? ? Ê (forced in) θ=1.33, ?[?] ÇÉÊ (4) for the 1995-2004 period,

and

Ú (? ? ? ?)   ? ? ? ?   ? ? ? ? ? ?   ? ? (? ? ? ? È)   ? ? ? ? θ ÉÇÉ ?[?] Ç (5) for the 2005-2013 period.

The final models for WAG were:

Ú Æ ? ? ?   ? ? ? ?   ? ? ? ? ? ?   ? ? ? ?   ? ? Æ ? ? ? , θ=0.98, ?[?] ÇÈ (6) for the 1995-2004 period,

and

Ú Æ ? ? ?   ? ? ? ?   ? ? ? ? ? ?   ? ? Æ ? ? ? ?h È   ? ? Æ ? ? ? È (forced in) θ=1.2, ?[É] Ç (7) for the 2005-2013 period.

Figures 7 and 30 depict the trends in nominal and standardized CPUE indices for EAG and WAG, respectively.

Standardized nominal CPUE 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 2013 CPUE series and used the 1985 to 1998 indices with standard errors in the model under scenario 3 (Tables 3 and 18). The lognormal model is:

Ú Æ Ò ? Ö ?? ε? (8)

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 and validated. The code is available from the authors.

3. *Model Selection and Evaluation*

a. Description of alternative model configurations:

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

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

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

Scenario 7: Determination of size transition matrix considering pseudo molt probability and disregarding pre-1996/97 for EAG and pre-1995/96 for WAG total size composition and total catch; and

Scenario 10: Determination of size transition matrix considering logistic pseudo molt probability and including different catchability indices and selectivity for three periods 1985/86–1998/99, 1999/00–2004/05, and 2005/06 – 2013/14.

b. The entire time period 1985/86–2013/14 was used to define $B_{current}/B_{ref}$ (Tier 4) and the 1986–2014 period was used to define mean number of recruits (Tier 3).

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 (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 eleven scenarios also considered different configuration of parameters to select the parsimonious models. The detailed results of the preferred four scenarios are provided in tables and figures. The total and retained catch OFL for all the 11 scenarios are provided in Table 31 for their relative merits.

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, 150 for total catch, and 25 for groundfish by catch (see Tables 4 and 19 for details)). We estimated the predicted effective sample size from estimated input effective sample size as follows:

$$n_y = \sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l}) / \sum_l (P_{y,l} - \hat{P}_{y,l})^2 \qquad (9)$$

where $\hat{?}_{? ?}$ and $?_{? ?}$ 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. We used the above formula for iteratively reweighting the effective sample sizes in scenario 11.

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 with four scenarios 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 37 for retained catch, 12 and 38 for total catch, and 13 and 39 for groundfish discard catch for EAG and WAG, respectively. The line passing through the plot is the 1:1 line and in most cases the points are equally spread on both sides of the line indicating that the input effective sample sizes are reasonable for the four scenarios. We also provide an example plot showing the result of iteratively weighting of the effective sample sizes for retained catch in the EAG and WAG (Figure 56).

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 address 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 (parameter estimates: Tables 5 and 6 for EAG and 20 and 21 for WAG for scenarios 2, 3, 7 and 10, respectively). The numbers of estimable parameters are listed in Table A1 of Appendix A. The weights with the corresponding standard error specifications are detailed in Tables A2a and A2b of Appendix A for EAG and WAG, respectively.

2. Tables of estimates:

a. The parameter estimates with one standard deviation for the scenarios 2, 3, 7, and 10 are summarized respectively in Tables 5 and 6 for EAG and 20 and 21 for WAG. We have also provided the boundaries for parameter searches in those tables, and the estimates were within the bounds. Scenario 1 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, all other scenarios considered pseudo molting probability parameters in addition to the linear growth increment and normal growth variability 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 for the four scenarios are summarized in Tables 11 to 14 for EAG and Tables 26 to 29 for WAG.
d. The recruitment estimates for the four scenarios are summarized in Tables 11 to 14 for EAG and Tables 26 to 29 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 scenarios 7 and 10 in the two areas are lower but reflect the change in number of parameters.

3. Graphs of estimates:
   a. The pre- and post-rationalization periods total and retained selectivity curves for the four scenarios are illustrated in Figure 14 for EAG and Figure 40 for WAG. Total selectivity for the pre-rationalization period was used in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis indicating that all size groups were vulnerable to the gear. This is also shown in the size compositions of

groundfish bycatch (Figures 10a and 10b, and 35 and 36, for scenarios 7 and 10, respectively). Thus, we set the groundfish bycatch selectivity to 1.0 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 48 and 49 for WAG. Both legal and mature male biomass trends tracked the CPUE trends well. The GLM-predicted standardized CPUE trends are shown with the mature male biomass figures. We determined the mature male biomass values on 15 February and considered the entire time series for B_{ref} (for Tier 4 approach) and mean number of recruits (for Tier 3 approach) calculations.

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 50. The F peaked in 1990s and systematically declined since then in the EAG and generally declined since then in the WAG, but with an increasing trend in the WAG 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 46 for WAG. The recruitment distribution to the model size group (101–170+ mm CL) is shown in Figures 21 and 47 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 51 to 53 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 45 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 44 for WAG. All four scenarios appear to fit tag-recaptures well. Note that we used the EAG tagging information for WAG for all scenarios except one (scenario 4).

k. Molt probability: The predicted molt probabilities vs. CLs for scenario 7 are depicted in Figure 57 for EAG and WAG. The fits appear to be satisfactory.

l. Fit to catch size compositions: Retained, total, and groundfish discard length compositions are shown in Figures 8a, 8b, 9a, 9b, and 10 a, 10b for EAG for the scenarios 7 and 10, respectively, and in Figures 31 to 36 for WAG for scenarios 7 and 10, 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 catch (Figures 15 and 41 for EAG and WAG, respectively), for total catch (Figures 16 and 42 for EAG and WAG, respectively), and for groundfish discard catch (Figures 17 and 43 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 37 for retained catch, 12 and 38 for total catch, and 13 and 39 for groundfish discard catch for EAG and WAG, respectively. The line passing through the plot is the 1:1 line and in most cases the points are equally spread on both sides of the line indicating that the input effective sample sizes seem reasonable 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 the four scenarios are shown in Figure 28 for EAG and in Figure 54 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 using or not using a pseudo molt probability (additional two parameters) function. The model fit is better when the pseudo molt probability sub model is included.
      We also determined likelihood values at different q values and plotted component negative likelihood against the q values. It appears that the trend in negative log likelihood of CPUE was similar to that of the total (Figures 29 and 55 for EAG and WAG, respectively).

F. Calculation of the OFL

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 attempts to upgrade this stock to the Tier 4 level or possibly to the Tier 3 level. The two Tier level OFL calculation procedures are described below:

Tier 4 Approach:

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

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

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

$$F_{OFL} = \gamma M \frac{(\frac{MMB_t}{MMB_{ref}} - \alpha)}{(1-\alpha)} \tag{10}$$

(c) If $MMB_t \leq 0.25 MMB_{ref}$, $F_{OFL} = 0$,

where MMB is mature male biomass, MMB_{ref} is average mature male biomass, and γ 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 from February 15, 1986 to February 15, 2014. This resulted in a MMB_{ref} range of 5.248 to 5.856 thousand metric tons for EAG and 4.257 to 4.911 thousand metric tons for WAG for the four scenarios. The current MMB_{2013} range was 8.657 to 11.130 thousand metric tons for EAG and 3.568 to 4.414 thousand metric tons for WAG for the four scenarios, resulting in an F_{OFL} of 0.18 for EAG and slightly less for WAG. The total OFL for EAG ranged 1.176 to 1.548 thousand metric tons and 0.517 to 0.631 thousand metric tons for WAG for the four scenarios. The γ value was set to 1.0 and an M value of 0.18 was used for OFL calculation (see tables in the Executive Summary).

3. 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 1,127 to 1,487 t and that for WAG ranged 475 to 586 t for the four scenarios.

4. 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 = 1,306 t, retained catch portion of the OFL = 1251 t (under scenario 7).

WAG: F_{OFL} = 0.18; OFL total catch = 514 t; retained catch portion of the OFL = 475 t (under scenario 7).

Tier 3 Approach:

We used the model estimated parameter values for the scenarios 2, 3, 7, and 10 to calculate F_{35} reference points. The critical assumptions for reference point estimation are:

a. Natural mortality is constant (0.18) over all 14 size groups.
b. Growth transition matrix is estimated using tagging data with the pseudo molt probability sub-model.
c. The catchability parameter estimate for the 2005/06-2013/14 period is used.
d. Total and retained fishery selectivities are length depended and the 2005/06-2013/14 period selectivity estimates are used. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated molt probability is not time dependent, but is length dependent.
f. Model estimated recruits (in millions of crabs) are averaged for the time period 1986 to 2014.
g. Model estimated groundfish bycatch mortality values are averaged for the period 2004 to 2013 (10 years).

Method: We simulated the population abundance starting from the model estimated terminal year stock size by length, model estimated parameter values, a fishing mortality value (F), and adding a constant number of annual recruits. Once the stock dynamics was stabilized (we used the 99th year estimates) for an F, we calculated the MMB/R for that F.

We computed the relative MMB/R in percentage, ?$\frac{???}{?}$?$_{?Å}$ (where x% = $\frac{\frac{???_?}{?}}{\frac{???_?}{?}}$ ó È

and ? ? ?$_?$? is the virgin MMB/R) for different F values.

F_{35} is the F value that produces the MMB/R value equal to 35% of ? ? ?$_?$? .

MMB_{35} (or B_{35}) is estimated using the following formula:

? ? ?$_{??}$?$\frac{???}{?}$?$_{??}$ ó ?̄ , where ?̄ is the mean number of model estimated recruits for a selected period.

?$_{???}$ is determined using Equation 10 replacing ?? by ?$_{??}$ and ?$_{???}$ by ?$_{??}$.

Recommendation for F_{OFL}, OFL total catch, and the retained catch portion of the OFL for coming year:

EAG: F_{OFL} = 0.39; OFL total catch = 2,579 t, retained catch portion of the OFL = 2,466 t (under scenario 7).

WAG: F_{OFL} = 0.28; OFL total catch = 812 t; retained catch portion of the OFL = 751 t (under scenario 7).

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,

   Under Tier 4 approach, the ABC estimates ranged 1,170 to 1,539 t for EAG and 508 to 624 t for WAG for the four scenarios.

   Under Tier 3 approach, the ABC estimates ranged 2,311 to 2,970 t for EAG and 694 to 956 t for WAG for the four scenarios (see the 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 the possibility that additional recruitment may occur 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 (Kruse et al. 2000, Siddeek 2002). An experimentally-based independent estimate of handling mortality is needed for golden king crab.

J. Acknowledgments

We thank Heather Fitch, Robert Foy, and William Gaeuman, for providing various fisheries data for this assessment; Vicki Vanek and Daniel Urban for providing tagging data ; Leland Hulbert for preparing the catch distribution by ADFG statistical areas; CPT members and industry personnel for various critical questions and modeling guidance; and Joel Webb, William Bechtol, and Chris Siddon for additional editorial review of this document.

K. Literature Cited

ADF&G (Alaska Department of Fish and Game). 2002. Annual management report for the shellfish fisheries of the Westward Region, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02–54, Kodiak, Alaska.

ADF&G (Alaska Department of Fish and Game). 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 08-02, Anchorage, Alaska.

ADF&G (Alaska Department of Fish and Game). 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Region's shellfish observer program, 2009/10. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 11-05, Anchorage, Alaska.

Adams, C. F., and A. J. Paul. 1999. Phototaxis and geotaxis of light-adapted zoeae of the golden king crab *Lithodes aequispinus* (Anomura:Lithodidae) in the laboratory. Journal of Crustacean Biology. 19(1): 106-110.

Barnard, D.R., and R. Burt. 2004. Summary of the 2002 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04–27, Kodiak, Alaska.

Barnard, D.R., R. Burt, and H. Moore. 2001. Summary of the 2000 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K01–39, Kodiak, Alaska.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124–1138.

Fox, J., and S. Weisberg. 2011. An R companion to applied regression. Second edition. Sage Publications, Inc. 449 p.

Gaeuman, W.B. 2011. Summary of the 2009/10 mandatory crab observer program database for the BSAI commercial crab fisheries. Fishery Data Series No. 11-04. Alaska Department of Fish and Game, Kodiak.

Hiramoto, K. 1985. Overview of the golden king crab, *Lithodes aequispina*, fishery and its fishery biology in the Pacific waters of Central Japan. Pages 297-315, In:

Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Koeneman, T. M., and D. V. Buchanan. 1985. Growth of the golden king crab, *Lithodes aequispina*, in Southeast Alaskan waters. Pages 281-297, In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Kruse, G.H., L.C. Byrne, F.C. Funk, S.C. Matulich, and J. Zheng. 2000. Analysis of minimum size limit for the red king crab fishery in Bristol Bay, Alaska. N. Am. J. Fish. Manage. 20:307-319.

Moore, H., L.C. Byrne, and M.C. Schwenzfeier. 2000. Summary of the 1999 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K00–50, Kodiak, Alaska.

NPFMC (North Pacific Fishery Management Council) 2007. Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands king and Tanner crabs to revise overfishing definitions. North Pacific Fishery Management Council, Anchorage, Alaska.

Otto, R.S., and P.A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. Pages 123-135 In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Punt, A.E., R.B. Kennedy, and S.D. Frusher. 1997. Estimating the size-transition matrix for Tasmanian rock lobster, *Jasus edwardsii*,. Mar.Freshwater Res., 48:981-982.

Quinn,T.J., and R.B. Deriso, 1999. Quantitative fish dynamics. Oxford University Press. New York.

Shirley, T.C., and S. Zhou. 1997. Lecithotrophic development of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). J. Crust. Biol., 17(2):207-216.

Siddeek, M.S.M. 2002. Review of biological reference points used in Bering Sea and Aleutian Islands (king and Tanner) crab management. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J02-06, Juneau, Alaska.

Siddeek, M.S.M., D.R. Barnard, L.J. Watson, and R.K. Gish. 2005. A modified catch-length analysis model for golden king crab (*Lithodes aequispinus*) stock assessment in the eastern Aleutian Islands. Pages 783-805 *In*: Fisheries assessment and management in data limited situations, Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, Alaska.

Somerton, D. A., and R. S. Otto. 1986. Distribution and reproductive biology of the golden king crab, Lithodes aequispina, in the Eastern Bering Sea. Fishery Bulletin. 81(3): 571-584.

Starr, P.J. 2012. Standardized CPUE analysis exploration: using the rock lobster voluntary logbook and observer catch sampling programmes. New Zealand Fisheries Assessment Report 2012/34, 75 p.

Watson, L.J., D. Pengilly, and S.F. Blau. 2002. Growth and molting of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169-187 In: Crabs in cold water regions: biology, management, and economics, Alaska Sea Grant College Program, AK-SG-02-01, Fairbanks, Alaska.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 In: B.G. Stevens (ed.), King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Table 1. Time series of annual retained catch (number of crabs), total catch (number of crabs on the deck), pot fishery effort (number of pot lifts), and groundfish fishery discard mortality (number of crabs) (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. The directed fishery data include cost-recovery beginning in 2013/14.

Year	Retained Catch (no.)	Total Catch (no.)	Pot Fishery Effort (no. pot lifts)	Groundfish Discard Mortality(no.)
1985	1251267		117718	
1986	1374943		155240	
1987	968614		146501	
1988	1156046		155518	
1989	1419777		155262	388
1990	892699	1148518	106281	1190
1991	1083243	4492091	133428	0
1992	1127291	4324217	133778	779
1993	767918	NA	106890	719
1994	1086560	1712658	191455	311
1995	1150168	2735495	177773	569
1996	848045	1435654	113460	46
1997	780481	1778564	106403	76
1998	740011	2011514	83378	587
1999	709332	1551704	79129	284
2000	704363	1704440	71551	387
2001	730030	1359794	62639	934
2002	643668	1117015	52042	707
2003	643074	1112533	58883	392
2004	637536	965144	34848	59
2005	623971	929284	24569	252
2006	650587	857345	26195	679
2007	633253	911318	22653	697
2008	666947	931031	24466	808
2009	679886	936684	26298	718
2010	670698	944157	25851	2415
2011	668828	927001	17915	1208
2012	687666	986843	20827	2058
2013	720220	978645	21388	274

Table 2. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the EAG golden king crab stock. Observer retained CPUE includes retained and non retained legal size crabs. 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	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	8.898	2.167	13.000	90	
1991	8.199	17.453	37.811	206	
1992	8.364	10.418	38.458	137	
1993	7.786	5.074	20.815	NA	
1994	5.892	2.540	12.911	NA	
1995	5.888	5.031	16.936	7547	0.734
1996	6.451	5.110	13.647	6561	0.758
1997	7.336	7.106	18.149	4676	0.791
1998	8.875	9.104	25.763	3616	0.954
1999	8.964	9.216	20.710	3857	0.884
2000	9.849	9.900	25.352	5047	0.907
2001	11.655	11.194	22.593	4629	1.184
2002	12.372	11.939	22.541	3990	1.261
2003	10.921	11.028	19.454	3970	1.105
2004	18.295	17.716	28.474	2208	1.802
2005	25.397	29.574	38.551	1198	1.208
2006	24.836	25.114	33.390	1103	0.843
2007	27.954	31.105	40.379	1006	0.969
2008	27.260	29.840	38.233	613	0.961
2009	25.853	26.630	35.882	411	0.834
2010	25.956	26.478	37.100	436	0.839
2011	37.333	39.263	52.035	361	1.202
2012	33.018	37.807	47.567	438	1.139
2013	32.271	35.827	46.162	499	1.102

Table 3. Time series of GLM estimated CPUE Indices and standard errors considering only the year effect for the fish ticket based retained catch-per-pot lift for the EAG golden king crab stock. The GLM was fitted to the 1985/86 to 2013/14 time series of data and up to 1998/99 indices were used in the model. 1985 refers to the 1985/86 fishery.

Year	CPUE Index	Standard Error
1985	1.015	0.046
1986	0.749	0.044
1987	0.628	0.047
1988	0.606	0.044
1989	0.687	0.036
1990	0.619	0.051
1991	0.623	0.044
1992	0.657	0.049
1993	0.673	0.059
1994	0.475	0.044
1995	0.386	0.042
1996	0.422	0.042
1997	0.585	0.043
1998	0.724	0.054

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 1985–2013, total fishery catch for 1990–2013, observer legal size crab CPUE index for 1995–2013, and groundfish bycatch for 1989–2013; 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 without the molt probability sub-model. Two logistic selectivity models and two catchability coefficients were considered for the pre- and post-rationalization periods. Groundfish fishery selectivity was set to 1.	Retained catch = 500 (0.032), total catch = 300(0.041), groundfish discard catch = 5(0.324), recruitment deviation = 1.5 (0.629), pot fishery F deviation (initial) = 1000 (0.022) (later relaxed to 0.001(very high)), penalty for regularizing the mean F to 0.35 (initial) = 1000 (later relaxed to 0.001), groundfish bycatch fishery F deviation (initial) = 1000 (later relaxed to 0.001), tagging data = 1.0(0.805), and posfunction = 1000.	Retained = 200, total = 150, groundfish discard = 25
2	Same as scenario 1, but considered a composite normal and the logistic (molt probability) functions for the size transition matrix calculation.	Same as scenario 1.	Same as scenario 1.
3	Scenario 2, considered 1985–1998 commercial fishery retained CPUE indices as an additional likelihood component and assumed three catchability coefficients for 1985/86-1998/99, 1999/00 -2004/05, and 2005/06-2013/14 .	Same as scenario 1.	Same as scenario 1.
4	This scenario pertains to replacing EAG tagging data by the WAG tagging data and not considered for EAG optimization.		
5	Scenario 2, considered only the first year tagging data to compute the size transition matrix.	Same as scenario 1.	Same as scenario 1.
6	Scenario 2 with initial size composition estimated using a different formulation to that given in Appendix A (see page 332, Quinn and Deriso, 1999).	Same as scenario 1.	Same as scenario 1.
7	Scenario 2, considered total catch and length frequency time series from 1996/97 onward in the likelihood functions to avoid unusually high total catches in 1994/95 and 1995/96 seasons.	Same as scenario 1.	Same as scenario 1.
8	Scenario 2, considered only one catchability coefficient.	Same as scenario 1.	Same as scenario 1.

Table 4 continued.			
9	Scenario 2, shut off groundfish bycatch, length frequency, and fishing mortality deviation likelihood functions in the minimization and set groundfish F to a minimum of 0.01.	Same as scenario 1.	Same as scenario 1.
10	Scenario 2, considered three logistic selectivity models and catchability parameters for the periods 1985/86-1998/99, 1999/00-2004/05, and 2005/06-2013/14.	Same as scenario 1.	Same as scenario 1.
11	Same as scenario 2.	Same as scenario 1.	Iteratively estimated effective sample sizes

∗ ????????????? ????????? ?? ? ??6? ???? ? – È

Table 5. Parameter estimates and standard deviations with the 2014 (February 15) MMB for the scenarios 2 and 3 model for the golden king crab data from the EAG, 1985/86–2013/14. A total of 118 and 120 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 2			**Scenario 3**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.589	0.011	1.,4.50	2.588	0.011	1.,4.50
G_b	-7.801	1.677	-10.0,-5.0	-8.201	1.665	-10.0,-5.0
log_aa	-2.502	0.074	-4.61,-1.39	-2.463	0.070	-4.61,-1.39
log_b	4.955	0.005	3.869,5.0	4.955	0.005	3.869,5.0
Growth StdDev	3.702	0.102	0.1,12.0	3.690	0.102	0.1,12.0
log_T04delta	3.155	0.116	0.,4.4	3.142	0.136	0.,4.4
log_T12delta	2.694	0.295	0.,4.4	2.637	0.309	0.,4.4
log_R04delta	1.521	0.120	0.,4.4	1.537	0.120	0.,4.4
log_R12delta	2.161	0.282	0.,4.4	2.148	0.284	0.,4.4
log_T04L50	4.823	0.017	4.0,5.0	4.800	0.016	4.0,5.0
log_T12L50	4.897	0.016	4.0,5.0	4.891	0.015	4.0,5.0
log_R04L50	4.904	0.002	4.0,5.0	4.904	0.002	4.0,5.0
log_R12L50	4.931	0.005	4.3,5.2	4.931	0.005	4.3,5.2
log_betar	19.681	847.400	-4.6, 25.0	20.407	114.000	-4.6, 25.0
Logq1				-0.916	0.102	-9.0, 2.01
logq2	-0.453	0.103	-9.0, 2.01	-0.616	0.137	-9.0, 2.01
logq3	-0.789	0.172	-9.0, 5.01	-0.976	0.215	-9.0, 5.01
log_newsh1	2.136	0.057	0.01, 10.0	2.142	0.066	0.01, 10.0
log_mean_rec	0.652	0.058	0.01, 5.0	0.727	0.075	0.01, 5.0
log_mean_Fpot	-0.708	0.092	-15.0, -0.013	-0.858	0.098	-15.0, -0.145
log_mean_Fground	-9.044	0.866	-15.0, -1.6	-9.138	0.918	-15.0, -1.6
prelegal_var	0.019	0.008	0.0, 0.15	0.048	0.022	0.0, 0.15
Fishtick_var				0.094	0.033	0.0, 1.0
Ftemp	0.180	0.707	0.0, 0.75	0.180	0.707	0.0, 0.75
2014 MMB	8657	1659		11130	2862	

Table 6. Parameter estimates and standard deviations with the 2014 (February 15) MMB for the scenarios 7 and 10 model for the golden king crab data from the EAG, 1985/86–2013/14. A total of 118 and 123 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 7			**Scenario 10**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.581	0.012	1.0, 4.50	2.580	0.012	1.0,4.50
G_b	-6.677	1.711	-12.0,12.0	-8.068	1.679	-10.0,-5.0
log_aa	-2.556	0.079	-4.61,-1.39	-2.476	0.067	-4.61,-1.39
log_b	4.953	0.005	3.869,5.0	4.948	0.005	3.869,5.0
Growth StdDev	3.684	0.103	0.1,12.0	3.702	0.102	0.1,12.0
log_T98delta				1.246	0.522	0.,4.4
log_T04delta	3.235	0.106	0.,4.4	3.178	0.131	0.,4.4
log_T12delta	2.690	0.285	0.,4.4	2.720	0.300	0.,4.4
log_R98delta				1.313	0.202	0.,4.4
log_R04delta	1.834	0.089	0.,4.4	1.898	0.195	0.,4.4
log_R12delta	2.151	0.284	0.,4.4	2.167	0.284	0.,4.4
log_T98L50				4.749	0.011	4.0,5.0
log_T04L50	4.835	0.017	4.0,5.0	4.847	0.018	4.0,5.0
log_T12L50	4.898	0.015	4.0,5.0	4.898	0.017	4.0,5.0
log_R98L50				4.901	0.002	4.0,5.0
log_R04L50	4.909	0.002	4.0,5.0	4.919	0.004	4.0,5.0
log_R12L50	4.931	0.005	4.3,5.2	4.931	0.005	4.3,5.2
log_betar	19.993	768.500	-4.6, 25.0	21.224	162.000	-4.6, 25.
logq 1				-0.708	0.093	-9.0, 2.01
logq2	-0.447	0.099	-9.0, 2.01	-0.407	0.125	-9.0, 2.01
logq3	-0.858	0.180	-9.0, 5.01	-0.855	0.188	-9.0, 5.01
log_newsh1	2.156	0.071	0.01, 10.0	2.192	0.053	0.01, 10.0
log_mean_rec	0.785	0.061	0.01, 5.0	0.669	0.061	0.01, 5.0
log_mean_Fpot	-0.788	0.086	-15.0, -0.335	-0.869	0.081	-15.0, -0.055
log_mean_Fground	-9.135	0.876	-15.0, -1.6	-9.131	0.855	-15.0, -1.6
prelegal_var	0.023	0.009	0.0, 0.15	0.021	0.008	0.0, 0.11
Ftemp	0.180	0.707	0.0, 0.75	0.180	0.707	0.0, 0.75
2014 MMB	9731	1991		9375	1891	

Table 7. Estimate of the size transition matrix for the scenario 2 model for the golden king crab data from the EAG.

0.040	0.018	0.207	0.480	0.232	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.059	0.021	0.222	0.471	0.208	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.086	0.025	0.235	0.455	0.184	0.015	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.125	0.028	0.244	0.432	0.159	0.012	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.177	0.031	0.248	0.401	0.135	0.009	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.244	0.034	0.244	0.361	0.111	0.007	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.327	0.035	0.232	0.313	0.088	0.005	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.423	0.035	0.211	0.261	0.067	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.524	0.034	0.184	0.207	0.048	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.624	0.031	0.153	0.157	0.035
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.715	0.027	0.121	0.137
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.790	0.022	0.187
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.150
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 8. Estimate of the size transition matrix for the scenario 3 model for the golden king crab data from the EAG.

0.035	0.017	0.202	0.483	0.239	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.053	0.020	0.218	0.475	0.213	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.079	0.024	0.233	0.461	0.188	0.015	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.116	0.027	0.244	0.438	0.162	0.012	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.167	0.031	0.249	0.407	0.137	0.009	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.235	0.034	0.247	0.366	0.112	0.007	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.320	0.035	0.235	0.317	0.088	0.005	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.419	0.036	0.214	0.262	0.066	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.524	0.034	0.185	0.207	0.047	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.628	0.031	0.153	0.155	0.033
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.721	0.027	0.120	0.132
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.799	0.022	0.179
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.859	0.141
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 9. Estimate of the size transition matrix for the scenario 7 model for the golden king crab data from the EAG.

0.048	0.022	0.231	0.478	0.204	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.069	0.025	0.243	0.465	0.183	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.098	0.028	0.252	0.447	0.163	0.012	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.138	0.031	0.257	0.422	0.142	0.009	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.191	0.034	0.257	0.389	0.121	0.007	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.258	0.036	0.249	0.350	0.101	0.006	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.339	0.037	0.235	0.305	0.081	0.004	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.431	0.036	0.212	0.255	0.063	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.527	0.034	0.185	0.205	0.047	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.622	0.031	0.154	0.159	0.035
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.708	0.027	0.124	0.141
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.782	0.022	0.196
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.841	0.159
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

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

0.040	0.019	0.210	0.480	0.228	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.059	0.022	0.226	0.471	0.204	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.088	0.026	0.240	0.454	0.179	0.014	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.128	0.029	0.249	0.429	0.154	0.011	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.182	0.033	0.252	0.396	0.129	0.008	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.253	0.035	0.247	0.353	0.105	0.006	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.340	0.037	0.233	0.304	0.082	0.004	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.440	0.036	0.210	0.249	0.061	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.545	0.034	0.180	0.195	0.044	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.645	0.031	0.148	0.145	0.031
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.735	0.027	0.115	0.123
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.809	0.022	0.169
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.866	0.134
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

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 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	7712	1484	8007	1106
1986	1.27	6218	370	7623	701
1987	3.83	5019	249	6125	318
1988	0.94	4682	208	5020	241
1989	0.40	3408	231	4552	203
1990	4.92	2665	265	3298	233
1991	5.03	2881	211	2675	266
1992	0.78	4276	237	2762	204
1993	1.00	4794	257	4036	246
1994	2.79	3984	228	4710	264
1995	1.14	3364	205	3999	233
1996	2.07	3199	220	3285	211
1997	2.55	3118	235	3135	223
1998	1.91	3490	266	3059	238
1999	2.55	3879	308	3396	269
2000	2.09	4370	344	3808	309
2001	1.67	4832	387	4295	346
2002	2.79	5116	429	4766	387
2003	1.67	5748	500	5088	427
2004	1.28	6140	574	5684	492
2005	2.51	5889	618	6089	564
2006	2.19	6073	685	5881	611
2007	2.00	6426	768	6022	673
2008	2.47	6613	842	6357	754
2009	1.49	6950	912	6566	829
2010	3.20	6931	964	6890	899
2011	2.98	7478	1128	6908	954
2012	2.10	8290	1393	7412	1108
2013	1.73	8657	1659	8193	1367
2014	1.92	8894	4313	8605	1640

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 scenario3 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	6843	1600	7905	921
1986	1.27	6040	558	7079	680
1987	4.22	4944	259	5930	397
1988	1.17	4834	225	4954	253
1989	0.45	3779	254	4725	218
1990	4.39	3132	294	3685	255
1991	5.29	3100	224	3154	293
1992	0.79	4497	239	3026	218
1993	1.04	5043	264	4309	245
1994	2.85	4244	238	4995	265
1995	1.26	3665	221	4282	240
1996	2.09	3561	244	3611	224
1997	2.63	3511	264	3519	244
1998	2.00	3919	310	3476	265
1999	2.58	4359	371	3856	310
2000	2.20	4870	435	4316	369
2001	1.71	5371	512	4828	432
2002	2.70	5674	586	5334	508
2003	1.77	6242	701	5669	581
2004	1.44	6615	808	6209	692
2005	2.74	6418	870	6588	798
2006	2.52	6744	983	6423	863
2007	2.27	7319	1139	6707	970
2008	2.74	7718	1297	7265	1122
2009	1.66	8241	1486	7691	1283
2010	3.88	8329	1632	8205	1471
2011	3.59	9218	1985	8332	1623
2012	2.46	10474	2475	9166	1962
2013	2.00	11130	2862	10391	2445
2014	2.07	11144	5902	11102	2847

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 7 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	7623	990	8206	1104
1986	1.42	6271	452	7736	757
1987	4.21	5185	287	6182	367
1988	2.66	4994	282	5142	277
1989	2.13	4594	309	4776	259
1990	1.84	4884	334	4349	286
1991	3.50	4456	401	4720	319
1992	1.62	4546	334	4338	384
1993	1.84	4906	285	4348	324
1994	1.89	4360	226	4756	275
1995	1.29	3627	200	4246	219
1996	2.27	3304	213	3498	198
1997	2.60	3284	229	3206	211
1998	2.01	3695	263	3159	226
1999	2.57	4138	308	3525	258
2000	2.19	4629	349	3991	301
2001	1.73	5118	399	4478	342
2002	2.85	5437	453	4975	390
2003	1.71	6061	542	5338	441
2004	1.37	6468	632	5918	523
2005	2.68	6255	688	6343	613
2006	2.30	6490	771	6183	673
2007	2.16	6899	874	6358	749
2008	2.61	7155	973	6740	848
2009	1.58	7545	1073	7017	947
2010	3.51	7575	1151	7391	1047
2011	3.31	8215	1358	7470	1129
2012	2.32	9203	1684	8042	1319
2013	1.93	9731	1991	8975	1632
2014	2.19	9966	4841	9564	1947

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 10 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	7678	972	8279	1093
1986	1.28	6583	339	7936	666
1987	4.50	5349	288	6474	338
1988	0.98	5203	269	5311	270
1989	0.32	4021	265	4990	231
1990	6.35	3186	269	3849	239
1991	4.13	4027	320	3176	256
1992	0.91	5352	313	3804	273
1993	0.83	5725	282	5038	270
1994	2.98	4730	249	5602	254
1995	0.91	4085	222	4717	232
1996	2.12	3745	225	3962	205
1997	2.45	3554	241	3647	212
1998	2.09	3820	303	3457	232
1999	2.60	4211	359	3683	297
2000	2.11	4745	407	4083	353
2001	1.74	5219	464	4609	401
2002	2.84	5522	522	5097	456
2003	1.66	6167	619	5441	511
2004	1.34	6542	705	6043	601
2005	2.63	6284	747	6435	686
2006	2.29	6498	819	6225	732
2007	2.11	6892	911	6384	798
2008	2.57	7116	994	6751	885
2009	1.54	7480	1077	6997	968
2010	3.38	7459	1138	7345	1050
2011	3.18	8050	1322	7368	1114
2012	2.21	8952	1614	7903	1285
2013	1.83	9375	1891	8759	1567
2014	1.95	9557	4638	9231	1850

Table 15. Negative log-likelihood values of the fits for scenarios 2,3,7, and 10 for golden king crab in the EAG.

Likelihood Component	Scenario 2	Scenario 3	Scenario 7	Scenario 10
Number of free parameters	118	120	118	123
like_retlencomp	-548.86	-557.61	-587.96	-558.32
like_totallencomp	-620.84	-621.95	-532.06	-601.79
like_gdiscdlencomp	-469.19	-471.37	-478.16	-465.68
like_retcpue	-10.19	-1.72	-8.70	-9.32
like_retdcatchB	35.46	40.28	7.04	27.56
like_totalcatchB	64.58	73.21	11.64	50.48
like_gdiscdcatchB	0.00	0.00	0.00	0.00
like_rec_dev	12.47	11.89	3.57	14.95
like_F	0.01	0.01	0.01	0.00
like_gF	0.02	0.02	0.02	0.02
like_Tag	337.60	338.27	337.48	334.31
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		6.88		
Total	-1198.95	-1182.08	-1247.13	-1207.77

Table 16. Time series of annual retained catch (number of crabs), total catch (number of crabs on the deck), pot fishery effort (number of pot lifts), and groundfish fishery discard mortality (number of crabs) (handling mortality rates of 50% for pot and 80% for trawl gear were applied, only to the male portion) for the WAG golden king crab stock. The crab numbers are for the size range 101–170+ mm CL. 1985 refers to the 1985/86 fishery.

Year	Retained Catch (no.)	Total Catch (no.)	Pot Fishery Effort (no. pot lifts)	Groundfish Discard Mortality (no.)
1985	981949		118563	
1986	2052652		277780	
1987	1248732		160229	
1988	1285914		166409	
1989	1610281		202541	51
1990	889017	2753326	108533	374
1991	747852	1873645	101429	16
1992	543541	1118704	69443	318
1993	352339	2001547	127764	0
1994	845058	3634246	195138	82
1995	619636	1571544	115248	628
1996	652801	1270434	99267	559
1997	558446	1237039	86811	211
1998	505407	783606	35975	1182
1999	658377	1471915	107040	1091
2000	723794	1614016	101239	692
2001	686738	1503857	105512	303
2002	664823	1335747	78979	700
2003	676633	1194074	66236	200
2004	685465	1249016	56846	699
2005	639368	1079095	30116	1798
2006	523701	894219	26870	1311
2007	600595	965889	29950	943
2008	587661	997911	26200	3979
2009	628332	900862	26489	2173
2010	626246	868127	29994	1056
2011	616118	818645	26326	1576
2012	672916	1001143	32716	2216
2013	686883	1037742	41835	2090

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), and GLM estimated observer CPUE Index for the WAG golden king crab stock. 1990 refers to the 1990/91 fishery. Observer retained CPUE includes retained and non-retained legal size crabs.

Year	Pot Fishery Nominal Retained CPUE	Obs. Nominal Retained CPUE	Obs. Nominal Total CPUE	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	6.980	11.833	26.667		
1991	7.428	7.975	19.660		
1992	5.895	6.425	16.911		
1993	4.425	6.542	17.232		
1994	4.080	6.714	19.234		
1995	4.647	4.964	14.320	8274	1.174
1996	6.074	5.421	13.549	5669	0.952
1997	6.561	6.520	15.032	3910	0.962
1998	11.397	9.423	23.117	1351	1.070
1999	6.321	5.942	14.532	4573	0.909
2000	6.970	6.405	16.655	4687	0.853
2001	6.509	5.993	14.657	4453	0.827
2002	8.418	7.463	17.381	2505	0.924
2003	10.215	9.296	18.193	3324	1.157
2004	12.058	11.141	22.449	2617	1.267
2005	21.230	23.741	35.939	1365	1.109
2006	19.490	23.963	33.408	1183	1.018
2007	20.053	21.041	32.461	1082	0.950
2008	22.430	24.596	38.191	979	1.095
2009	23.720	26.529	34.050	893	1.120
2010	20.879	22.339	29.029	867	0.986
2011	23.403	23.843	31.163	837	1.044
2012	20.568	22.824	30.786	1109	1.062
2013	16.419	16.936	24.960	1223	0.695

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-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 2013/14 time series of data and up to 1998/99 indices were used in the model. 1985 refers to the 1985/86 fishery.

Year	CPUE Index	Standard Error
1985	1.153	0.049
1986	0.906	0.040
1987	0.698	0.044
1988	0.851	0.035
1989	0.816	0.028
1990	0.776	0.037
1991	0.717	0.038
1992	0.594	0.043
1993	0.582	0.064
1994	0.516	0.038
1995	0.438	0.038
1996	0.601	0.035
1997	0.640	0.033
1998	1.012	0.041

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 1985–2013, total fishery catch for 1990–2013, observer legal size crab CPUE index for 1995–2013, and groundfish bycatch for 1989–2013; M = 0.18, pot fishery handling mortality = 0.2, and ground fish bycatch handling mortality for trawl = 0.8 and for pot = 0.5. EAG 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 without the molt probability sub-model. Two logistic selectivity models and two catchability coefficients were considered for the pre- and post-rationalization periods. Groundfish fishery selectivity was set to 1.	Retained catch = 500 (0.032), total catch = 300(0.041), groundfish discard catch = 5(0.324), recruitment deviation = 1.5 (0.629), pot fishery F deviation (initial) = 1000 (0.022) (later relaxed to 0.001(very high)), penalty for regularizing the mean F to 0.18 (initial) = 1000 (later relaxed to 0.001), groundfish bycatch fishery F deviation = (initial) = 1000 (later relaxed to 0.001), tagging data = 1.0(0.805), and posfunction = 1000 (0.022)	Retained = 200, total = 150, groundfish discard = 25
2	Same as scenario 1, but considered a composite normal and the logistic (molt probability) functions for the size transition matrix calculation.	Same as scenario 1.	Same as scenario 1.
3	Scenario 2, considered 1985–1998 commercial fishery retained CPUE indices as an additional likelihood component and assumed three catchability coefficients for 1985/86-1998/99, 1999/00 -2004/05, and 2005/06-2013/14 .	Same as scenario 1.	Same as scenario 1.
4	Scenario 2, replaced EAG tagging data with the WAG tagging data.	Same as scenario 1.	Same as scenario 1.
5	Scenario 2, considered only the first year tagging data to compute the size transition matrix.	Same as scenario 1.	Same as scenario 1.
6	Scenario 2 with initial size composition estimated using a different formulation to that in Appendix A (page 332, Quinn and Deriso, 1999).	Same as scenario 1.	Same as scenario 1.
7	Scenario 2, considered total catch and length frequency time series from 1995/96 onward in the likelihood functions to avoid unusually high total catches in the 1995/96 season.	Same as scenario 1.	Same as scenario 1.

Table 19 continued

8	Scenario 2, considered only one catchability coefficient.	Same as scenario 1.	Same as scenario 1.
9	Scenario 2, shut off groundfish bycatch, length frequency, and fishing mortality deviation likelihood functions in the minimization and set the groundfish F to a small value of 0.01.	Same as scenario 1.	Same as scenario 1.
10	Scenario 2 with three logistic selectivity models and catchability parameters for the periods 1985/86-1998/99, 1999/00-2004/05, and 2005/06-2013/14.	Same as scenario 1.	Same as scenario 1.
11	Same as scenario 2.	Same as scenario 1.	Iteratively estimated effective sample sizes

* ?????????? ?? ???????? ?? ? ??6? ????? – È

Table 20. Parameter estimates and standard deviations with the 2014 (February 15) MMB for the scenarios 2 and 3 model for the golden king crab data from the WAG, 1985/86–2013/14. A total of 118 and 120 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 2			**Scenario 3**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.590	0.011	2.0, 3.85	2.587	0.011	2.0,3.85
G_b	-7.529	1.705	-45.0,-1.0	-7.819	1.671	-40.0,-0.01
log_aa	-2.443	0.062	-4.61,-1.39	-2.382	0.058	-4.61,-1.39
log_b	4.952	0.004	3.869,6.0	4.948	0.004	3.869,6.0
Growth StdDev	3.727	0.102	0.1,9.0	3.691	0.101	0.1,9.0
log_T04delta	3.059	0.112	0.,4.4	3.033	0.131	0.,4.4
log_T12delta	2.636	0.224	0.,4.4	2.602	0.212	0.,4.4
log_R04delta	1.624	0.072	0.,4.4	1.609	0.076	0.,4.4
log_R12delta	1.869	0.155	0.,4.4	1.816	0.157	0.,4.4
log_T04L50	4.804	0.014	3.98,5.1	4.780	0.014	3.98,5.1
log_T12L50	4.844	0.011	3.98,5.5	4.831	0.012	3.98,5.5
log_R04L50	4.909	0.002	4.85,4.98	4.910	0.002	4.85,4.98
log_R12L50	4.921	0.003	4.75,5.1	4.920	0.003	4.75,5.1
log_betar	-0.239	0.629	-4.6, 25.0	0.081	0.878	-4.6, 25.0
Logq1				-0.500	0.078	-9.0, 2.01
logq2	-0.278	0.085	-9.0, 5.01	-0.581	0.107	-9.0, 5.01
logq3	-0.720	0.113	-9.0, 5.01	-0.863	0.132	-9.0, 5.01
log_newsh1	2.370	0.060	0.01, 10.0	2.461	0.108	0.01, 10.0
log_mean_rec	0.467	0.046	0.01, 5.0	0.518	0.055	0.01, 5.0
log_mean_Fpot	-0.591	0.065	-9.0, -0.139	-0.730	0.074	-9.0, -0.196
log_mean_Fground	-8.710	0.219	-9.0, -2.0	-8.812	0.222	-9.0, -2.0
prelegal_var	0.021	0.009	0.0, 0.15	0.026	0.012	0.0, 0.15
Fishtick_var				0.107	0.031	0.0,1.0
Ftemp	0.175	0.630	0.0, 0.75	0.176	0.627	0.0, 0.75
2014 MMB	3568	715		4085	939	

Table 21. Parameter estimates and standard deviations with the 2014 (February 15) MMB for the scenarios 7 and 10 model for the golden king crab data from the WAG, 1985/86–2013/14. A total of 118 and 123 parameters were estimated for the two respective scenarios, but recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 7			**Scenario 10**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.574	0.012	2.0, 3.85	2.575	0.012	2.0, 3.85
G_b	-7.941	1.691	-45.0, -1.0	-6.571	1.681	-12.0, 2.0
log_aa	-2.521	0.067	-4.61, -1.39	-2.522	0.065	-4.61,-1.39
log_b	4.945	0.005	3.869, 6.0	4.941	0.005	3.869, 6.0
Growth StdDev	3.675	0.099	0.1, 9.0	3.714	0.103	0.1, 9.0
log_T98delta				0.002	3.403	0, 4.4
log_T04delta	3.267	0.095	0., 4.4	3.154	0.102	0., 4.4
log_T12delta	2.651	0.231	0., 4.4	2.665	0.227	0., 4.4
log_R98delta				1.647	0.085	0., 4.4
log_R04delta	1.659	0.079	0., 4.4	1.707	0.106	0., 4.4
log_R12delta	1.896	0.155	0., 4.4	1.888	0.155	0., 4.4
log_T98L50				4.732	0.017	4.0, 5.0
log_T04L50	4.849	0.015	3.98, 5.1	4.860	0.014	3.98, 5.1
log_T12L50	4.847	0.012	3.98, 5.5	4.845	0.012	3.98, 5.5
log_R98L50				4.912	0.002	4.0, 5.0
log_R04L50	4.906	0.002	4.85, 4.98	4.911	0.003	4.85, 4.98
log_R12L50	4.922	0.003	4.75, 5.1	4.922	0.003	4.75, 5.1
log_betar	-0.217	0.580	-4.6, 25.0	0.491	1.549	-4.6, 25.0
Logq1				-0.234	0.071	-9.0, 5.01
logq2	-0.169	0.091	-9.0, 5.01	-0.274	0.096	-9.0, 5.01
logq3	-0.776	0.122	-9.0, 5.01	-0.850	0.113	-9.0, 5.01
log_newsh1	2.496	0.103	0.01, 10.0	2.560	0.109	0.01, 10.0
log_mean_rec	0.517	0.051	0.01, 5.0	0.506	0.051	0.01, 5.0
log_mean_Fpot	-0.725	0.065	-9.0, -0.12	-0.736	0.055	-9.0, -0.23
log_mean_Fground	-8.830	0.220	-9.0, -2.0	-8.843	0.220	-9.0, -2.0
prelegal_var	0.026	0.011	0.0, 0.15	0.011	0.005	0.0, 0.15
Ftemp	0.165	0.635	0.0, 0.75	0.179	0.628	0.0, 0.75
2014 MMB	3847	813		4414	748	

Table 22. Estimate of the size transition matrix for the scenario 2 model for the golden king crab data from the WAG.

0.035	0.019	0.212	0.480	0.231	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.052	0.022	0.227	0.471	0.208	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.079	0.026	0.239	0.456	0.185	0.015	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.116	0.029	0.248	0.434	0.161	0.012	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.169	0.032	0.250	0.402	0.137	0.009	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.239	0.035	0.245	0.361	0.113	0.007	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.326	0.036	0.231	0.312	0.089	0.005	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.428	0.035	0.208	0.258	0.068	0.004	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.536	0.033	0.178	0.202	0.049	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.641	0.029	0.145	0.151	0.035
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.734	0.025	0.112	0.130
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.810	0.020	0.170
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.868	0.132
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 23. Estimate of the size transition matrix for the scenario 3 model for the golden king crab data from the WAG.

0.030	0.018	0.210	0.487	0.233	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.046	0.021	0.226	0.479	0.209	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.071	0.025	0.240	0.464	0.185	0.015	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.108	0.029	0.250	0.441	0.160	0.012	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.162	0.032	0.254	0.408	0.135	0.009	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.234	0.034	0.249	0.365	0.111	0.007	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.327	0.035	0.234	0.313	0.086	0.005	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.435	0.035	0.208	0.255	0.064	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.550	0.032	0.175	0.196	0.045	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.660	0.028	0.139	0.142	0.031
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.755	0.023	0.105	0.117
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.830	0.018	0.151
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.886	0.114
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 24. Estimate of the size transition matrix for the scenario 7 model for the golden king crab data from the WAG.

0.047	0.019	0.216	0.480	0.218	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.069	0.023	0.231	0.468	0.194	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.100	0.026	0.243	0.449	0.169	0.012	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.142	0.030	0.251	0.422	0.145	0.010	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.198	0.033	0.253	0.387	0.121	0.007	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.270	0.035	0.247	0.345	0.098	0.005	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.356	0.037	0.232	0.295	0.076	0.004	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.452	0.036	0.209	0.242	0.057	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.553	0.034	0.180	0.190	0.041	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.649	0.031	0.148	0.143	0.029
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.734	0.027	0.117	0.122
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.805	0.023	0.172
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.861	0.139
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 25. Estimate of the size transition matrix for the scenario 10 model for the golden king crab data from the WAG.

0.050	0.024	0.237	0.473	0.198	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.072	0.028	0.249	0.459	0.178	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.104	0.031	0.256	0.439	0.158	0.011	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.148	0.034	0.260	0.412	0.137	0.009	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.206	0.036	0.257	0.378	0.117	0.007	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.279	0.037	0.246	0.336	0.096	0.005	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.366	0.037	0.228	0.288	0.076	0.004	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.463	0.036	0.202	0.238	0.058	0.003	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.563	0.033	0.172	0.187	0.043	0.002
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.658	0.029	0.140	0.142	0.031
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.742	0.024	0.110	0.124
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.811	0.020	0.169
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.865	0.135
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

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 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	6439	840	4158	1816
1986	3.36	6126	332	9507	944
1987	1.81	5542	272	7989	686
1988	1.77	4644	197	6019	316
1989	2.27	2753	165	5436	259
1990	0.58	2448	110	4550	190
1991	0.30	1776	90	2663	151
1992	3.85	1114	95	2339	104
1993	3.36	2316	177	1712	90
1994	0.98	2964	163	1118	94
1995	1.56	3124	169	2209	160
1996	1.88	3057	179	2783	155
1997	0.99	3304	181	3054	168
1998	1.75	3432	185	3021	176
1999	1.98	3255	188	3241	179
2000	2.20	3298	215	3405	181
2001	2.13	3678	261	3207	184
2002	2.36	4206	312	3226	210
2003	2.11	4830	383	3597	254
2004	1.99	5339	444	4135	303
2005	2.33	5680	487	4758	371
2006	1.60	6314	515	5278	431
2007	2.51	6443	530	5633	476
2008	0.64	6822	538	6251	502
2009	1.11	6285	542	6406	518
2010	1.19	5534	534	6743	527
2011	1.34	4899	541	6260	533
2012	1.06	4276	604	5511	526
2013	1.63	3568	715	4850	532
2014	1.59	4158	1816	4210	593

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 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	6542	1087	7366	1099
1986	2.39	5550	679	6984	867
1987	2.37	5340	302	5424	469
1988	2.02	4639	204	5195	283
1989	2.23	2994	173	4539	195
1990	0.72	2728	136	2892	159
1991	0.37	2116	126	2626	130
1992	3.79	1501	134	2055	126
1993	3.21	2651	185	1505	133
1994	1.11	3200	176	2555	172
1995	1.65	3398	192	3037	167
1996	1.99	3387	207	3332	187
1997	1.07	3699	215	3351	203
1998	1.87	3882	231	3636	211
1999	2.18	3763	244	3851	224
2000	2.40	3912	284	3714	239
2001	2.27	4419	345	3837	277
2002	2.50	5045	414	4334	336
2003	2.03	5738	498	4972	403
2004	2.10	6183	571	5663	484
2005	2.43	6481	614	6123	557
2006	1.63	7105	646	6428	602
2007	2.58	7202	672	7029	633
2008	0.68	7545	712	7148	658
2009	1.14	6974	730	7452	697
2010	1.22	6160	734	6927	718
2011	1.40	5467	754	6119	723
2012	1.12	4809	826	5402	741
2013	1.73	4085	939	4730	811
2014	1.68	4608	2119	4022	923

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 7 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	8936	1287	10232	1473
1986	2.14	6108	482	9146	802
1987	2.06	6196	327	6106	376
1988	2.45	5368	252	5847	293
1989	1.62	3865	221	5123	232
1990	1.20	3592	210	3622	200
1991	1.73	3234	220	3399	195
1992	1.10	3358	206	3101	207
1993	1.61	3664	179	3213	194
1994	1.80	3035	157	3551	170
1995	1.55	3012	154	2898	147
1996	1.90	3026	169	2847	145
1997	1.03	3273	170	2870	157
1998	1.77	3419	178	3101	160
1999	2.06	3240	181	3300	166
2000	2.32	3305	214	3101	171
2001	2.28	3740	273	3125	200
2002	2.67	4354	343	3531	254
2003	2.34	5155	446	4144	320
2004	1.98	5844	519	4924	414
2005	2.44	6226	562	5622	488
2006	1.64	6863	585	6042	537
2007	2.53	6979	601	6657	560
2008	0.64	7302	611	6809	577
2009	1.09	6715	617	7082	589
2010	1.20	5898	609	6584	598
2011	1.41	5202	619	5794	594
2012	1.11	4558	695	5075	602
2013	1.72	3847	813	4406	670
2014	1.68	4454	1953	3713	785

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 10 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	8789	1397	10266	1591
1986	2.12	6369	950	9068	1050
1987	2.01	6235	332	6239	526
1988	2.20	5203	233	5835	298
1989	2.09	3377	209	4922	204
1990	0.68	3025	161	3126	167
1991	0.41	2377	140	2785	132
1992	5.15	1736	143	2224	122
1993	2.10	3417	237	1684	130
1994	1.04	3681	189	3090	187
1995	1.39	3611	177	3337	151
1996	1.81	3353	177	3425	152
1997	0.67	3427	168	3215	159
1998	2.46	3316	179	3252	156
1999	1.87	3300	187	3201	171
2000	2.44	3408	221	3104	176
2001	2.39	3854	280	3179	206
2002	2.88	4531	353	3601	259
2003	2.52	5439	467	4267	327
2004	1.79	6267	550	5144	427
2005	2.55	6608	603	5973	509
2006	1.71	7200	643	6381	570
2007	2.70	7344	657	6952	610
2008	0.67	7704	656	7120	627
2009	1.20	7187	652	7426	628
2010	1.32	6398	625	7002	627
2011	1.48	5740	610	6256	605
2012	1.21	5103	650	5575	590
2013	1.78	4414	748	4914	623
2014	1.66	4893	2110	4240	714

Table 30. Negative log-likelihood values of the fits for scenarios 2, 3, 7, and 10 for golden king crab in the WAG.

Likelihood Component	Scenario 2	Scenario 3	Scenario 7	Scenario 10
Number of free parameters	118	120	118	123
like_retlencomp	-588.44	-608.71	-676.96	-630.72
like_totallencomp	-696.85	-698.48	-602.93	-696.03
like_gdiscdlencomp	-382.10	-387.29	-391.71	-379.20
like_retcpue	-9.52	-7.28	-7.51	-15.53
like_retdcatchB	16.53	24.14	8.28	17.46
like_totalcatchB	33.93	45.30	14.70	35.87
like_gdiscdcatchB	0.01	0.01	0.01	0.01
like_rec_dev	12.65	10.50	4.69	11.76
like_F	0.01	0.01	0.01	0.01
like_gF	0.12	0.12	0.12	0.12
like_Tag	338.15	340.23	334.74	333.62
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		17.50		
Total	-1275.51	-1263.95	-1316.54	-1322.64

Table 31. Predicted total and retained catch OFL (t) for 2014/15 under Tier 4 assumption for various scenarios.

Scenario	EAG		WAG	
	Total Catch OFL (t)	Retained Catch OFL (t)	Total Catch OFL (t)	Retained Catch OFL (t)
1	1139	1092	484	447
2	1176	1127	517	478
3	1549	1487	603	557
4	-	-	604	560
5	1030	989	480	444
6	1176	1127	504	466
7	1306	1251	514	475
8	888	851	249	225
9	1099	979	515	441
10	1254	1201	631	586
11	1041	958	423	391

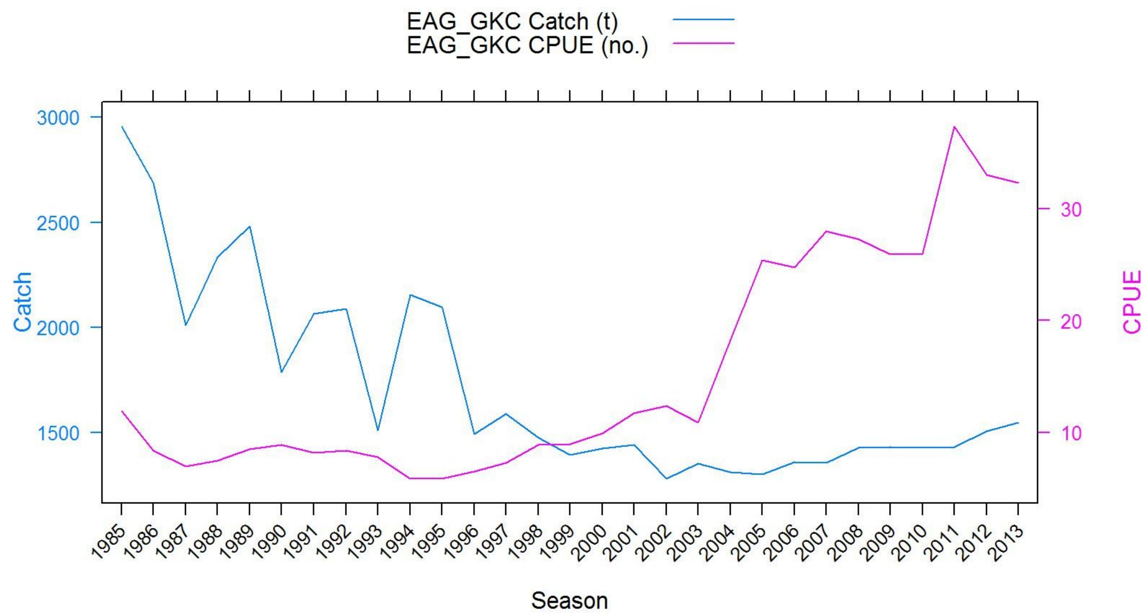


Figure 1. Historical commercial harvest (from fish ticket and in metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2013/14 fisheries (note: 1985 refers to the 1985/86 fishery).

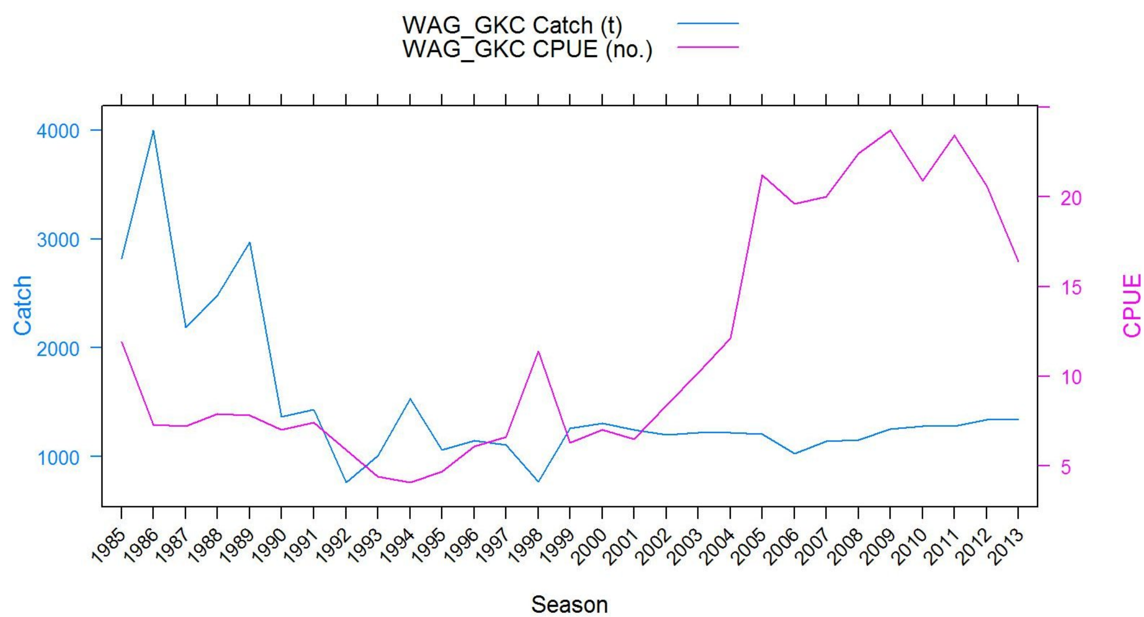


Figure 2. Historical commercial harvest (from fish ticket and in metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2013/14 fisheries (note: 1985 refers to the 1985/86 fishery).

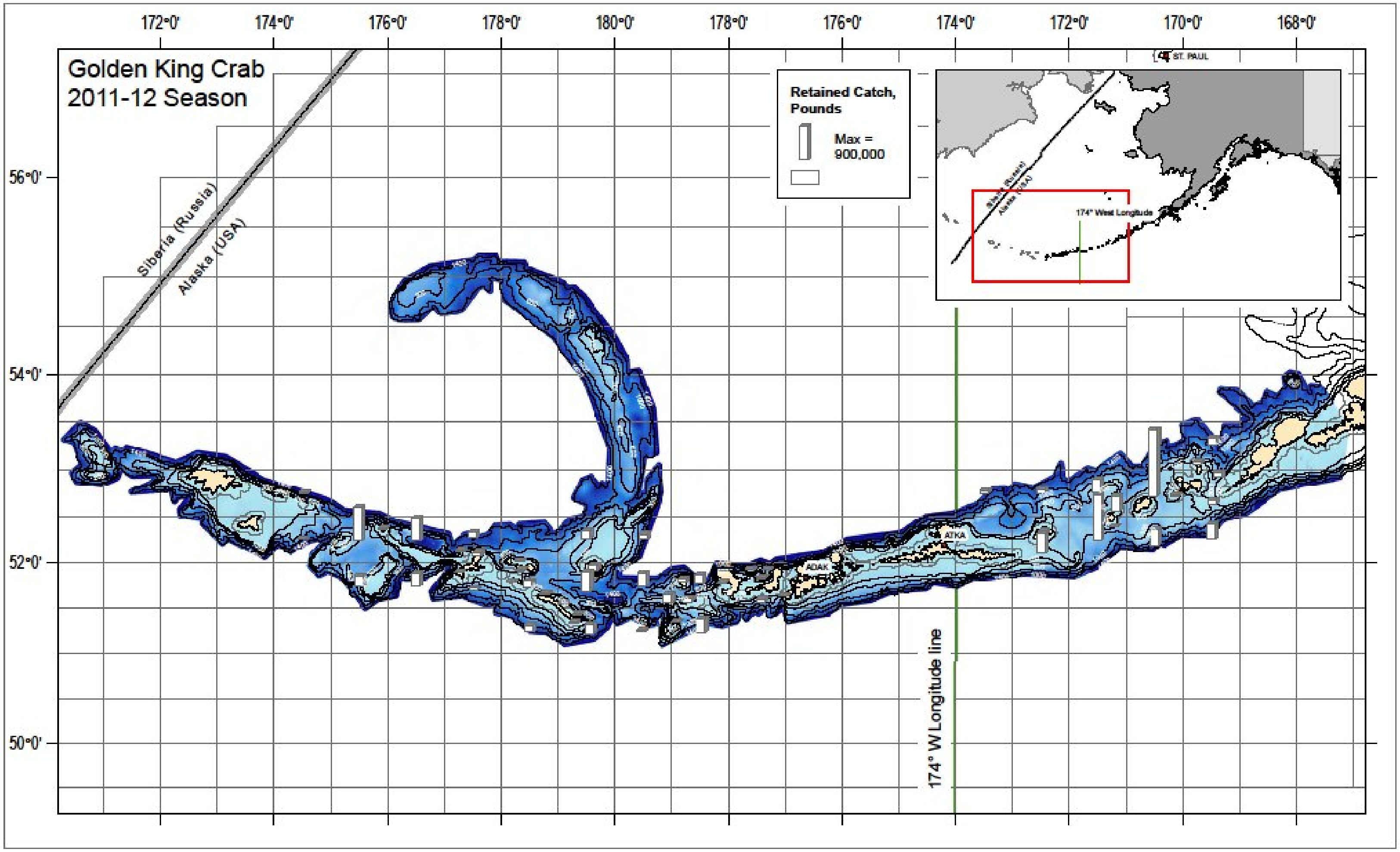


Figure 3. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2011/12.

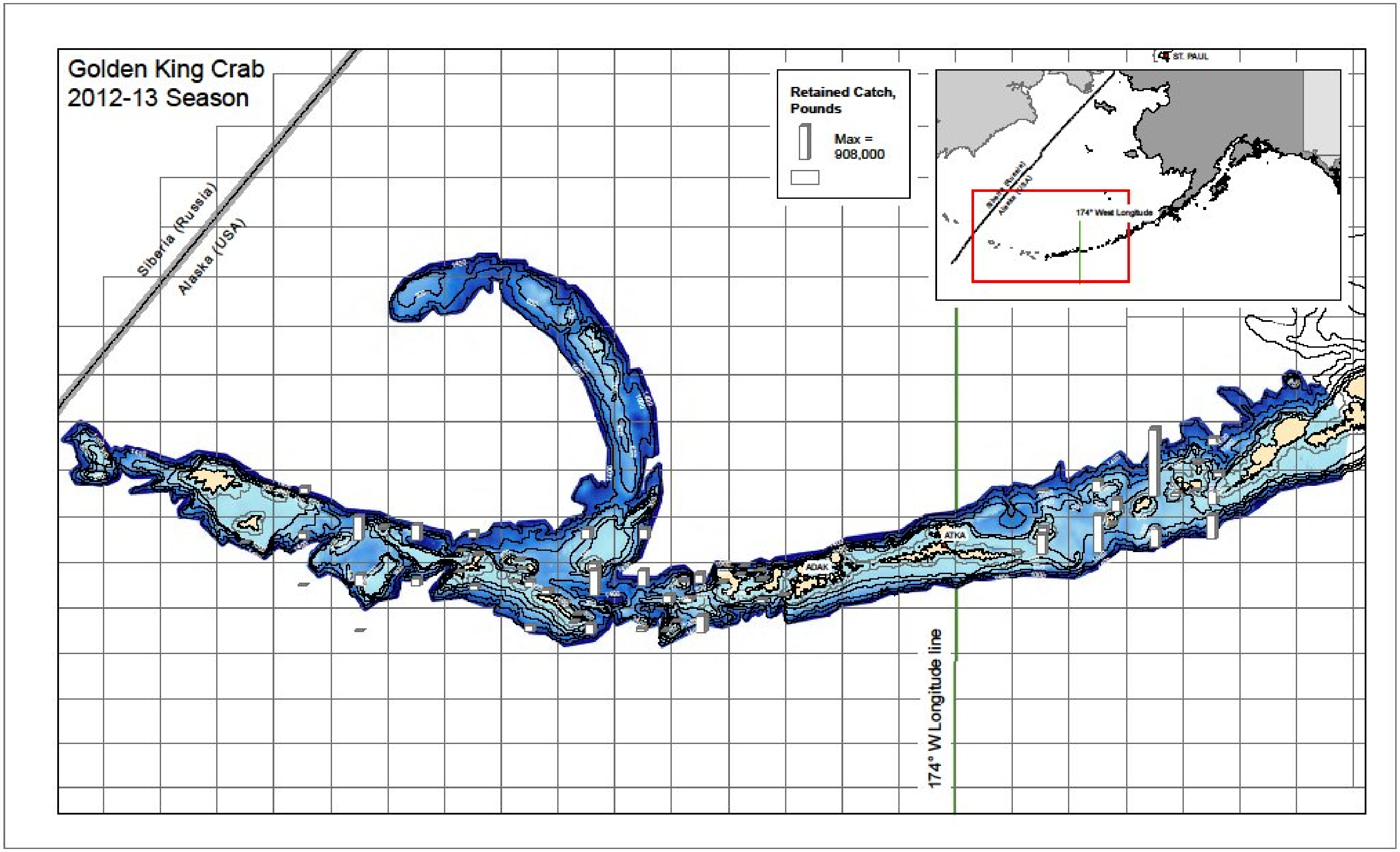


Figure 4. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2012/13.

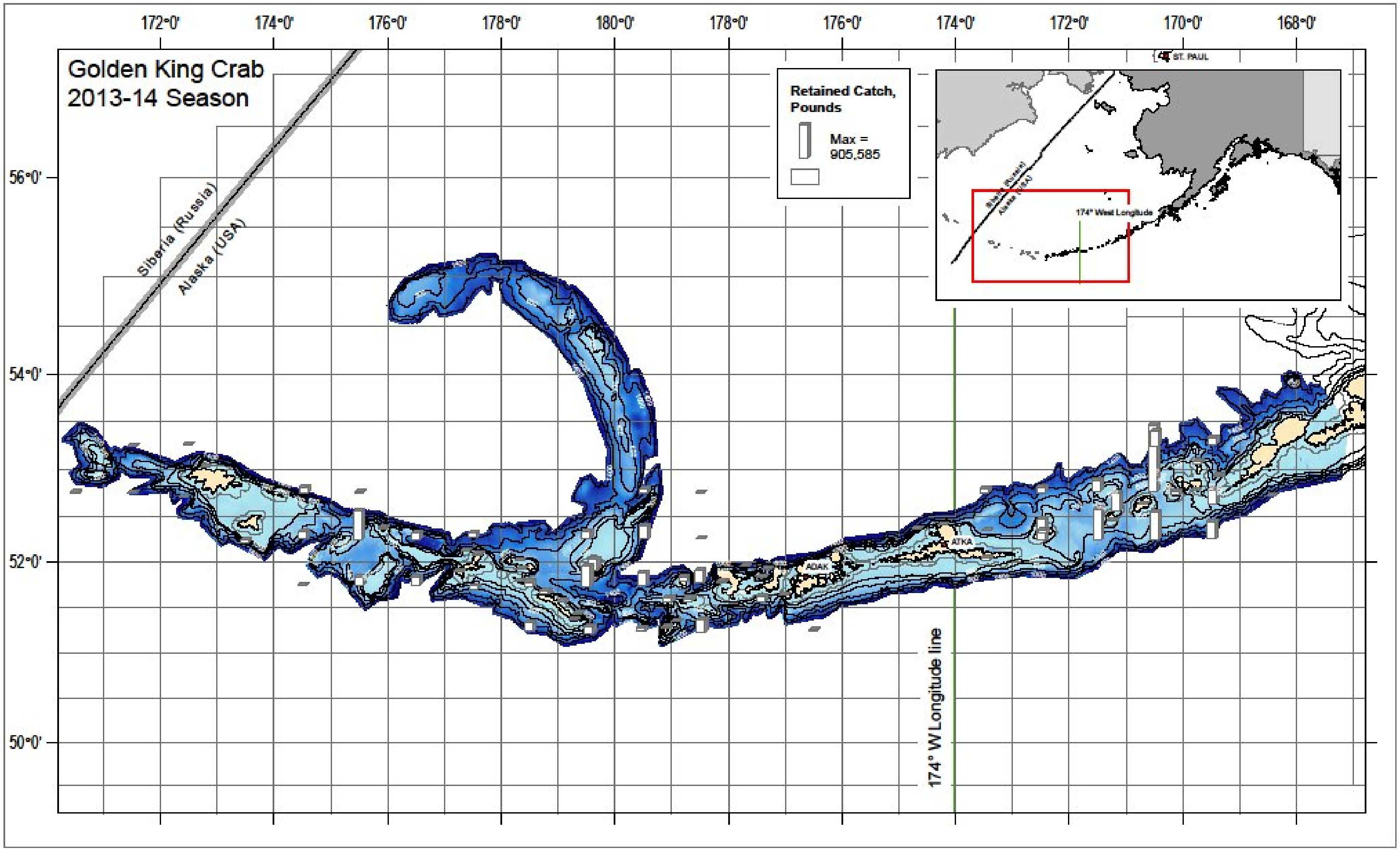


Figure 5. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2013/14.

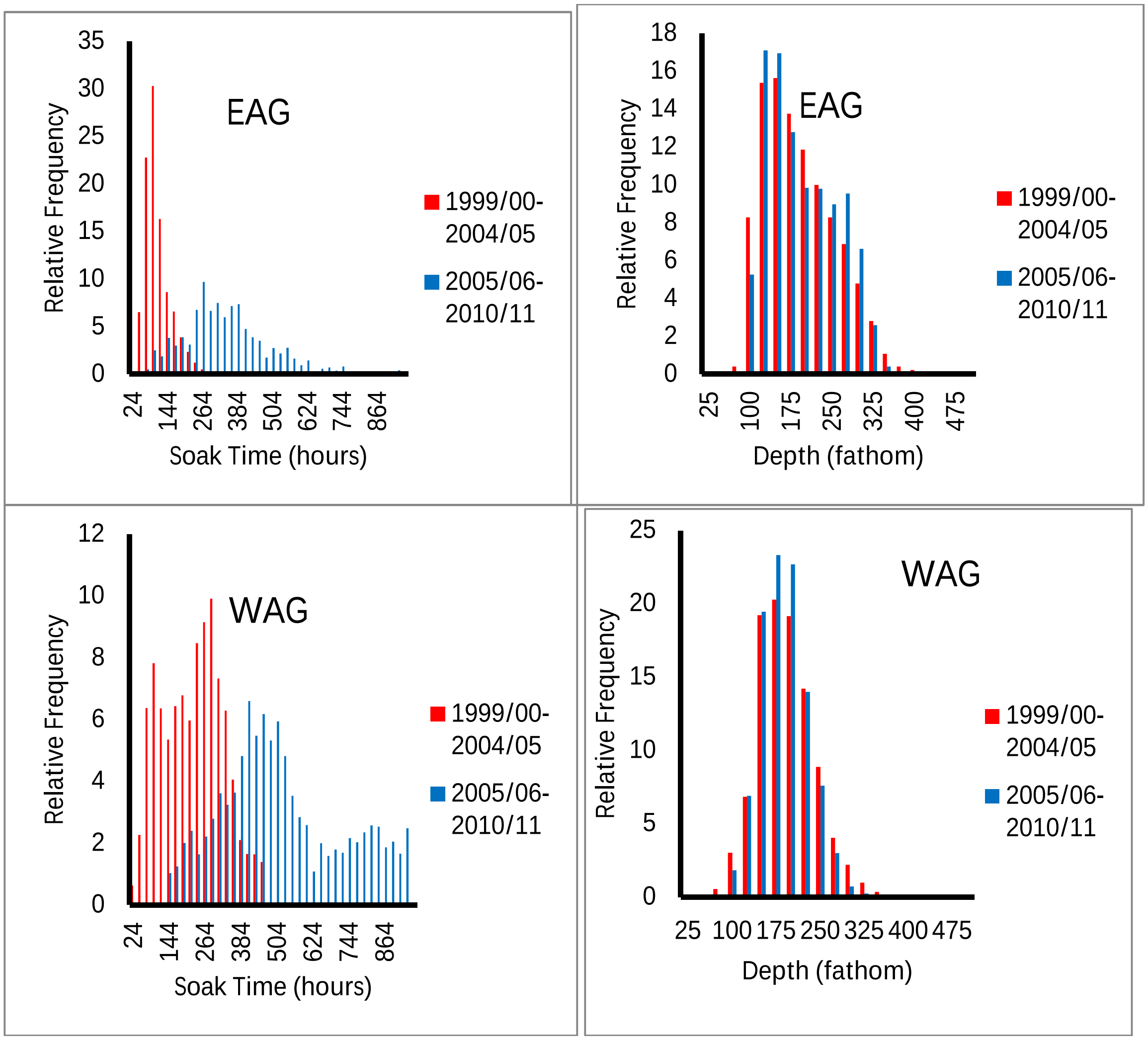


Figure 6. Soak time and depth relative frequency distributions of golden king crab pots during pre (1999/00–2004/05) - and post (2005/06–2010/11) - rationalization periods.

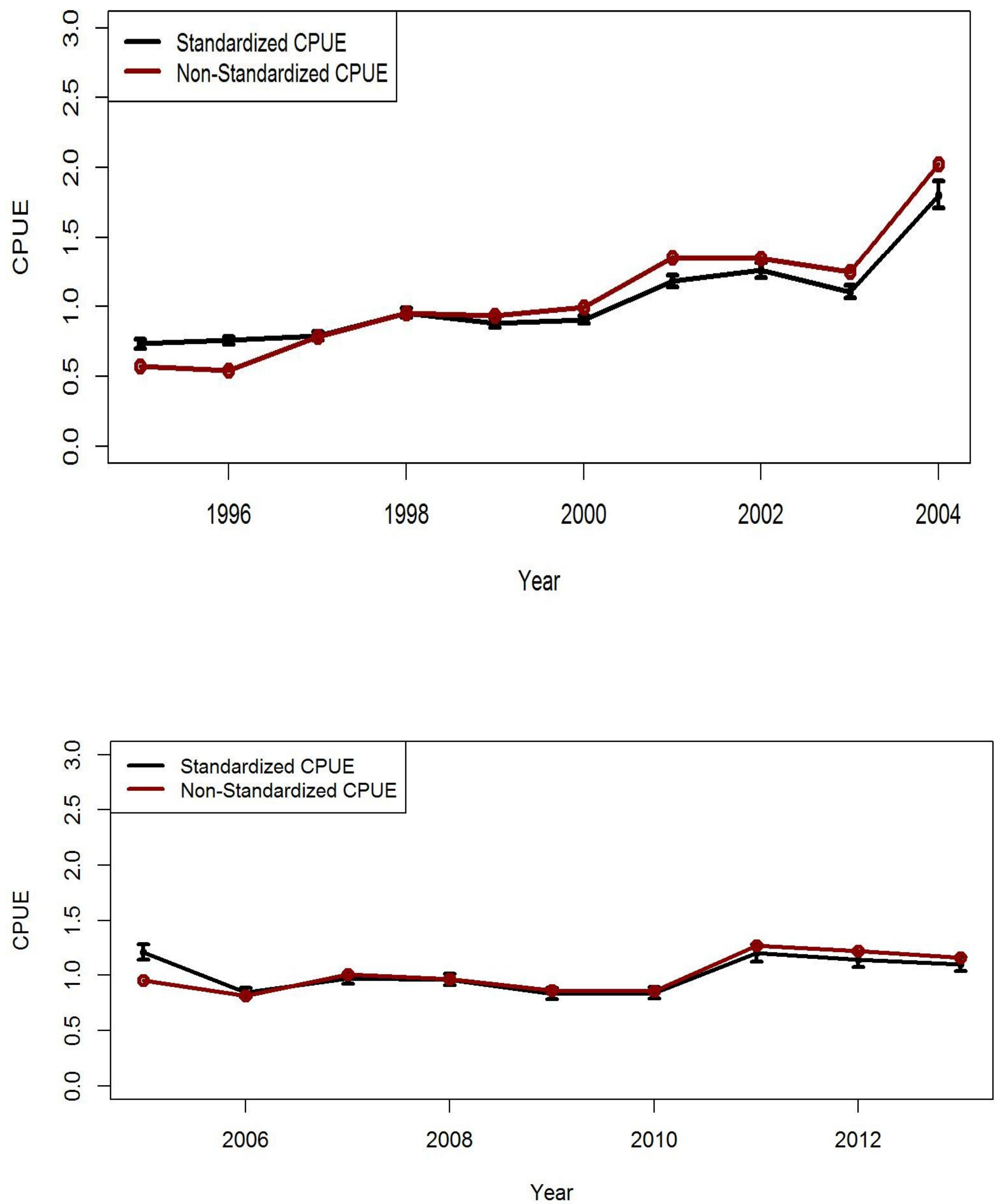


Figure 7. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174°W longitude). Top panel: 1995/96-2004/05 observer data and bottom panel: 2005/06-2013/14 observer data. Standardized indices: black line and non-standardized indices: red line.

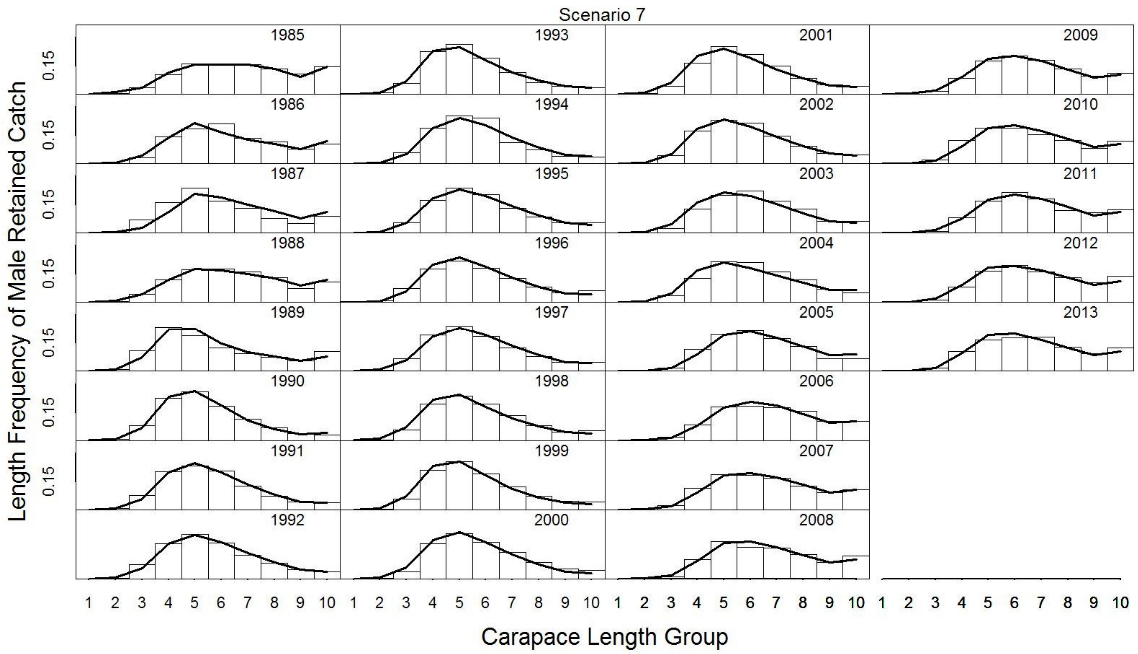


Figure 8a. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 7 data of golden king crab in the EAG, 1985/86 to 2013/14. Length group 1 is 123 mm CL.

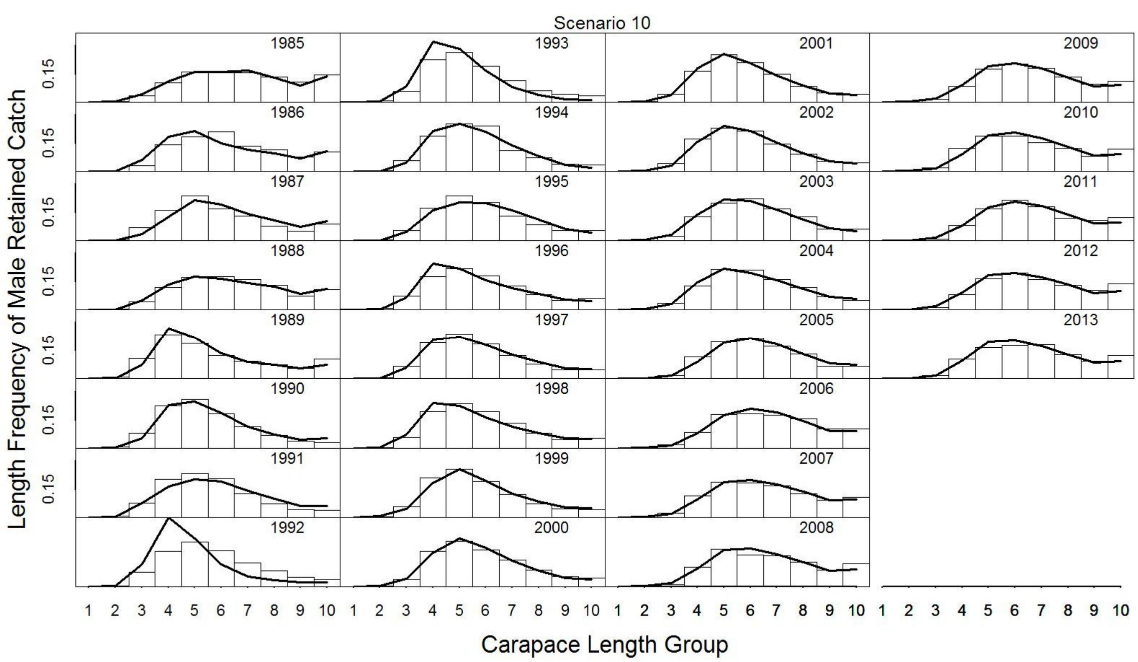


Figure 8b. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 10 data of golden king crab in the EAG, 1985/86 to 2013/14. Length group 1 is 123 mm CL.

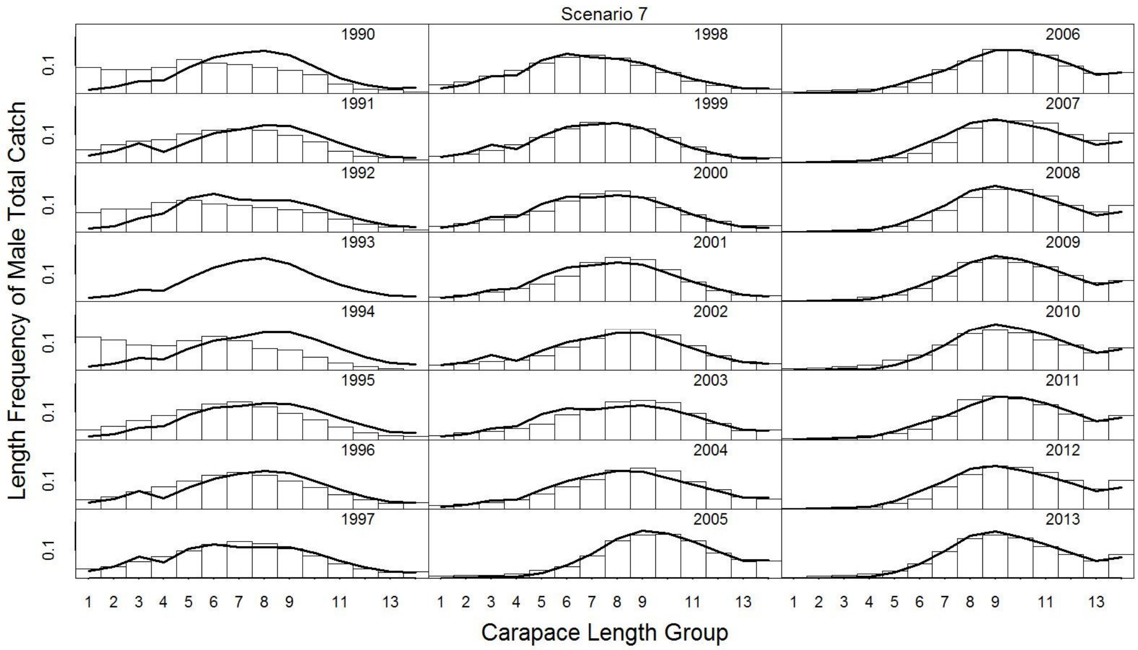


Figure 9a. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 7 data of golden king crab in the EAG, 1990/91 to 2013/14. Length group 1 is 103 mm CL.

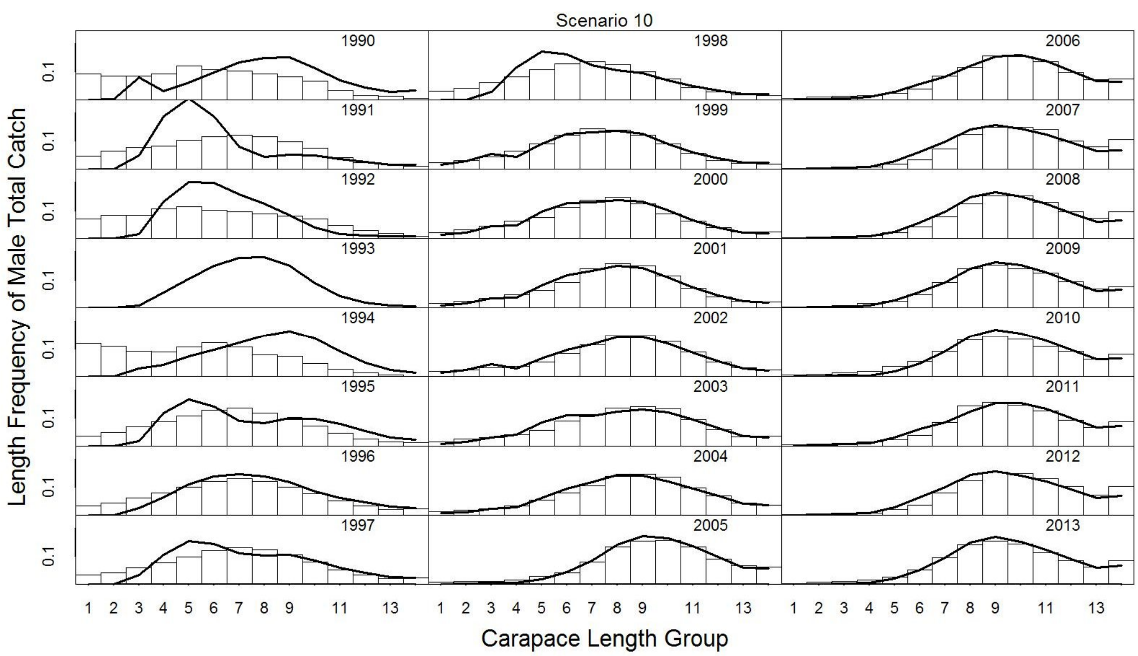


Figure 9b. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 10 data of golden king crab in the EAG, 1990/91 to 2013/14. Length group 1 is 103 mm CL.

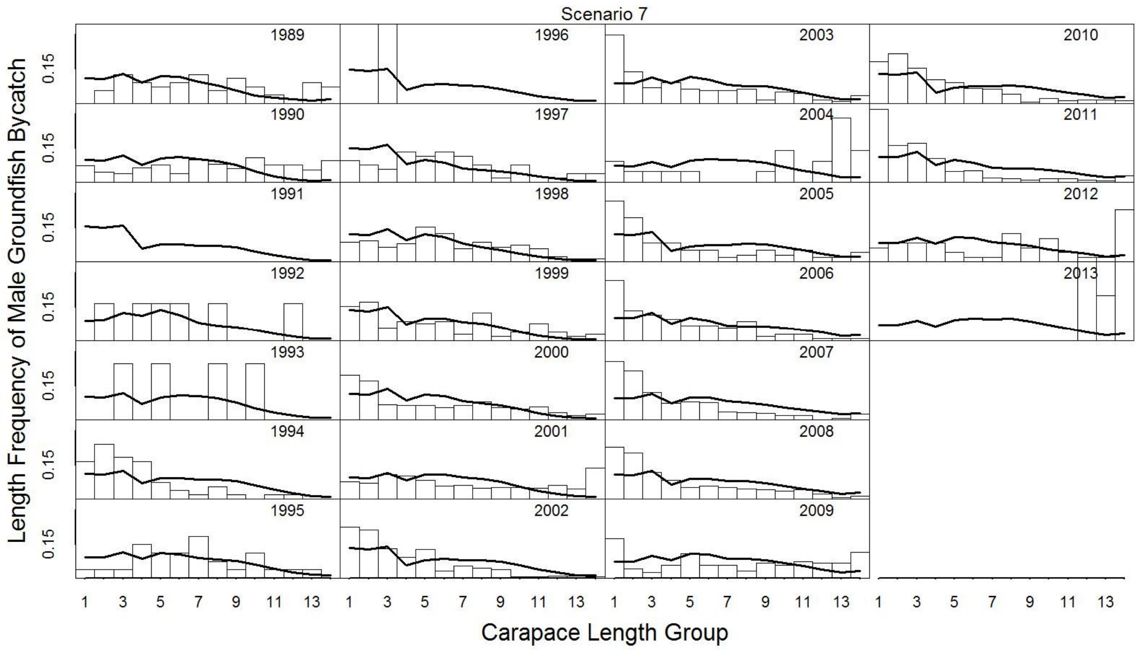


Figure 10a. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 7 data of golden king crab in the EAG, 1989/90 to 2013/14. Length group 1 is 103 mm CL.

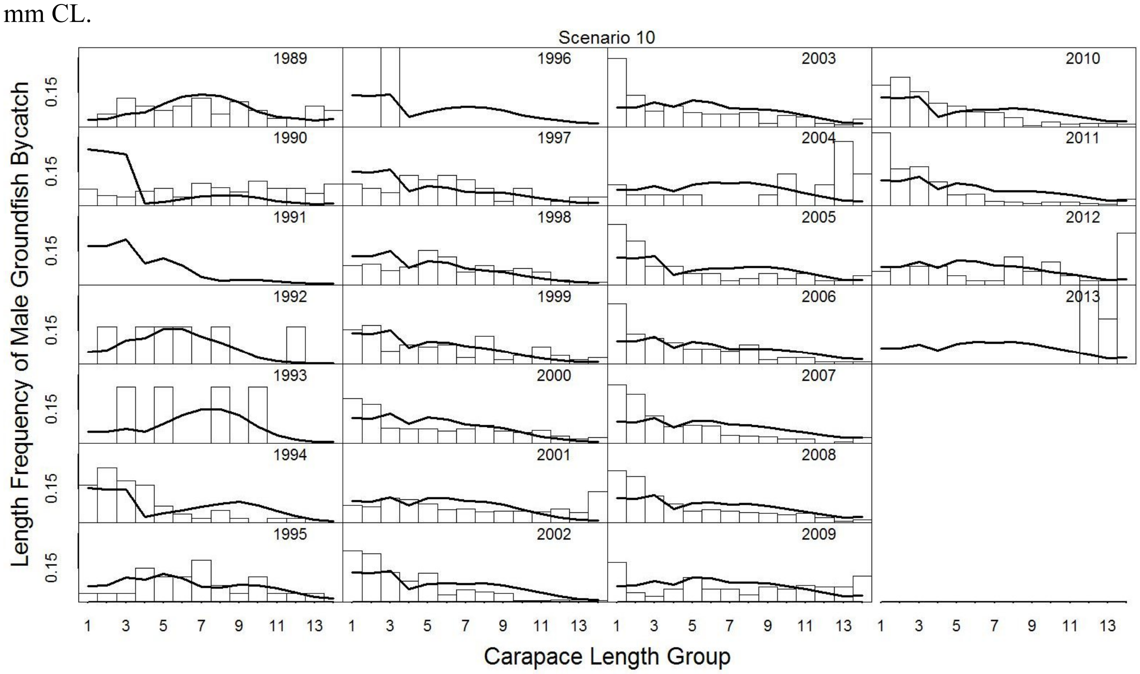


Figure 10b. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 10 data of golden king crab in the EAG, 1989/90 to 2013/14. Length group 1 is 103 mm CL.

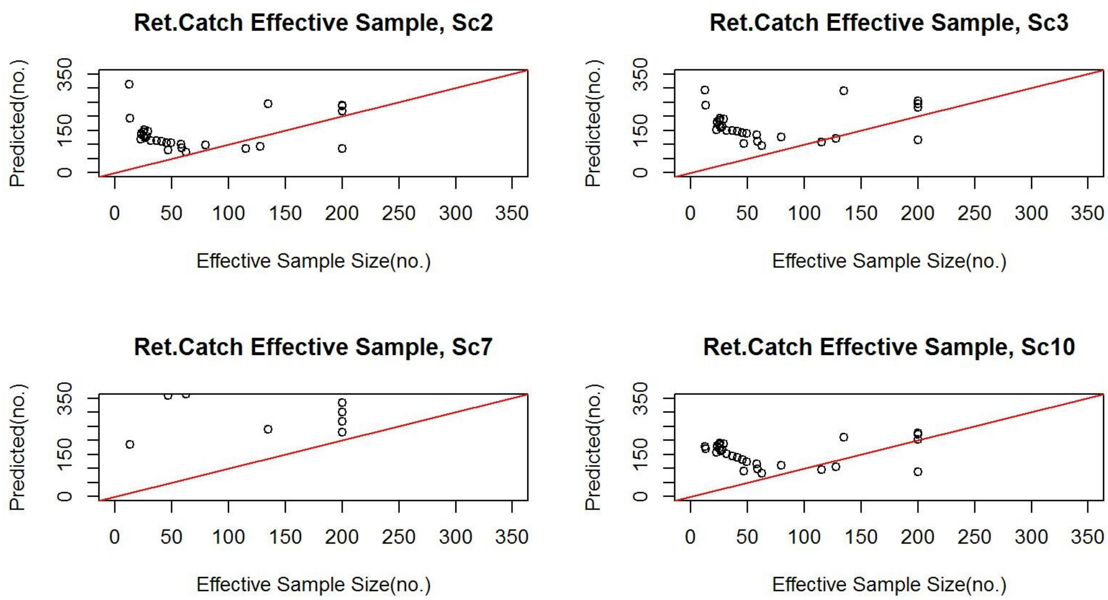


Figure 11. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios (Sc) 2, 3, 7, and 10 fits to golden king crab data in the EAG, 1985/86 to 2013/14. The red line is the 45^0 line passing through the origin.

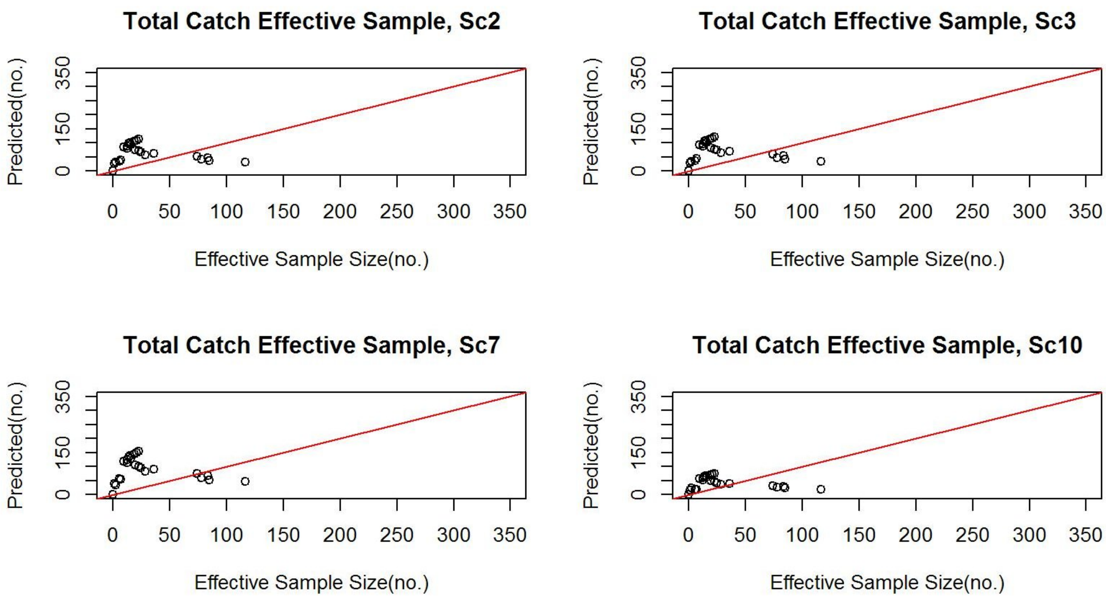


Figure 12. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios (Sc) 2, 3, 7, and 10 fits to golden king crab data in the EAG, 1990/91 to 2013/14. The red line is the 45^0 line passing through the origin.

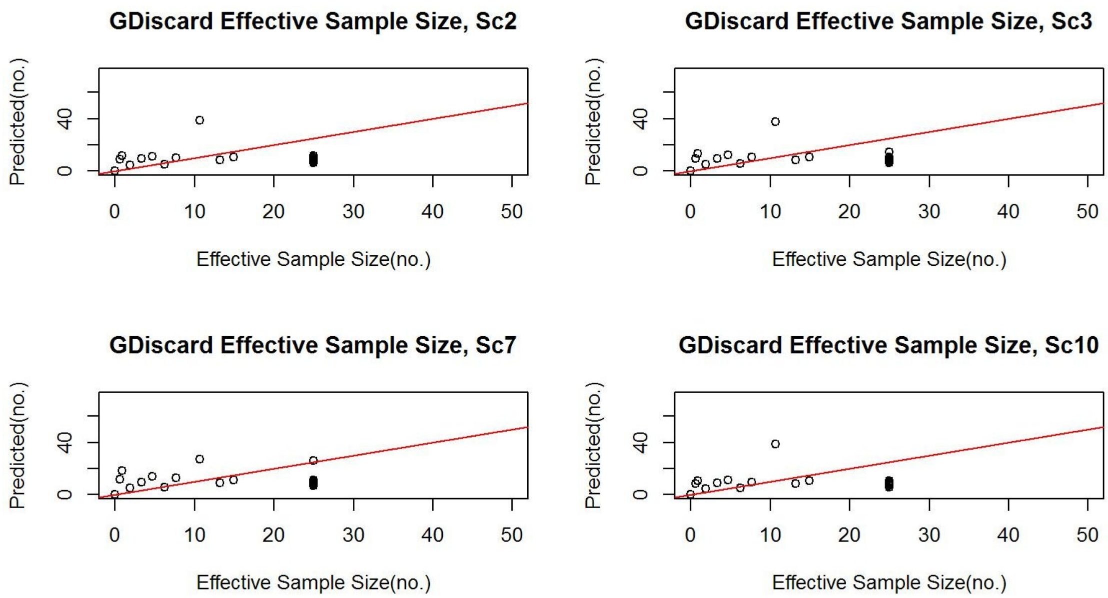


Figure 13. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for scenarios (Sc) 2, 3, 7, and 10 fits to golden king crab data in the EAG, 1989/90 to 2013/14. The red line is the 45^0 line passing through the origin.

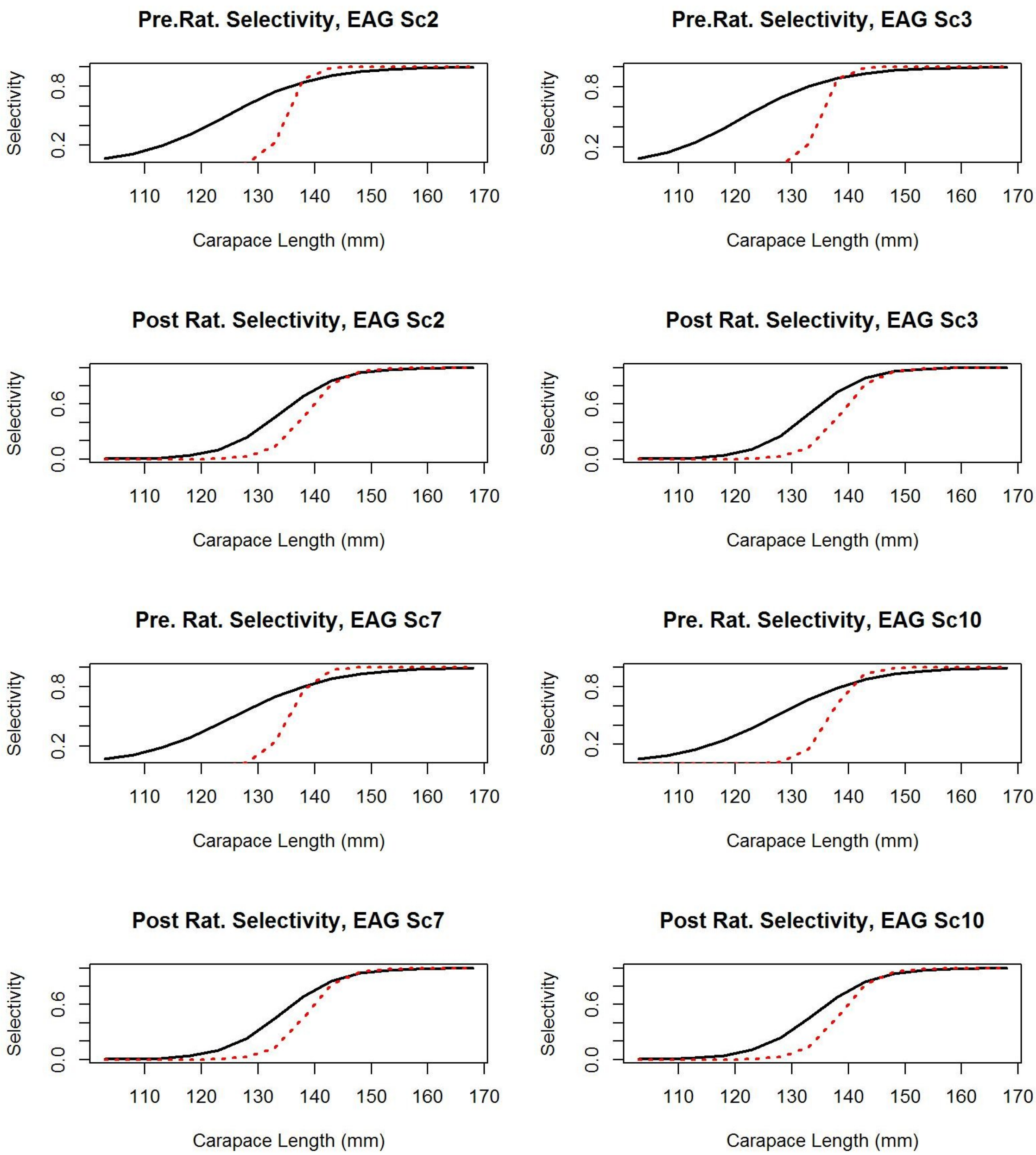
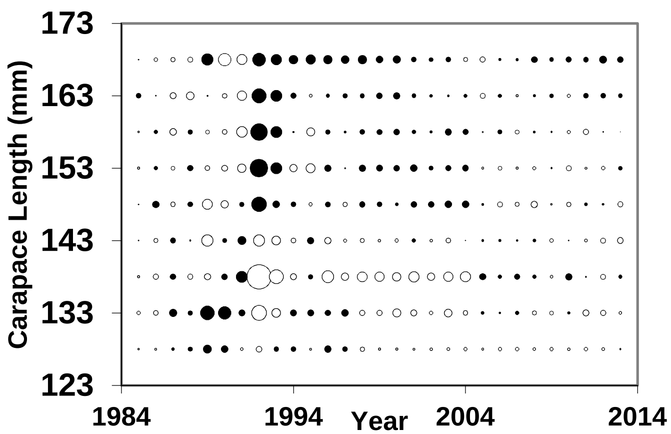
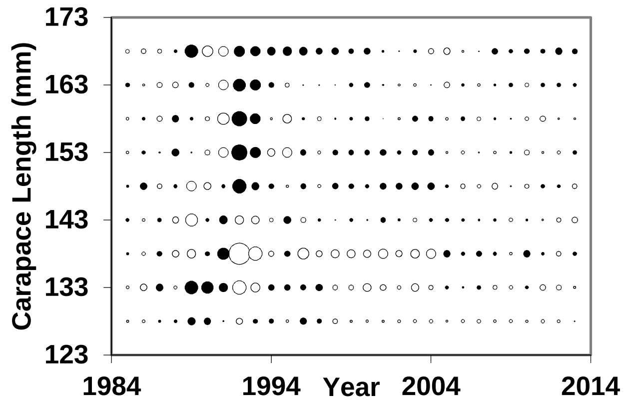


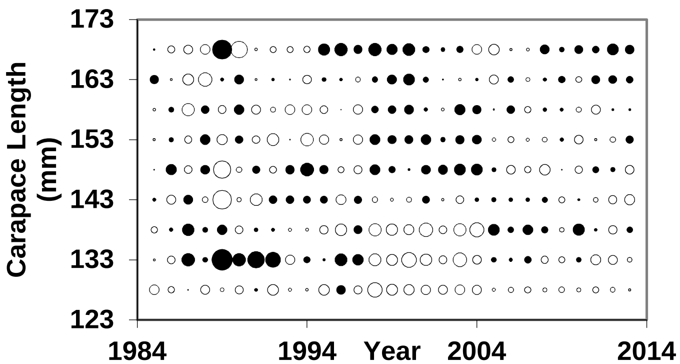
Figure 14. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 2, 3, 7, and 10 fits of EAG golden king crab data..

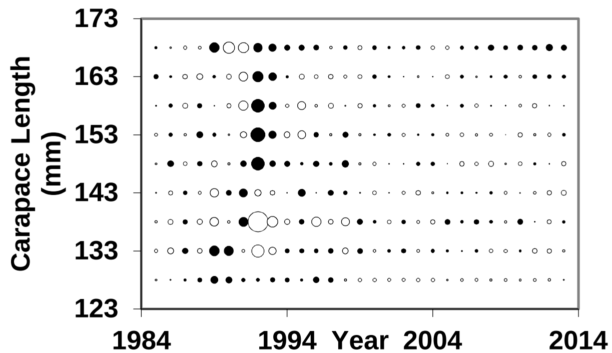




Scenario 2

Scenario 3

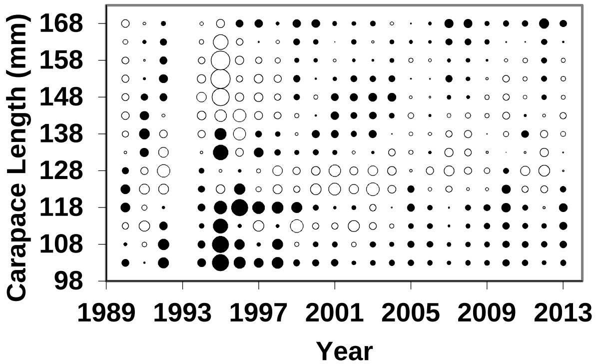




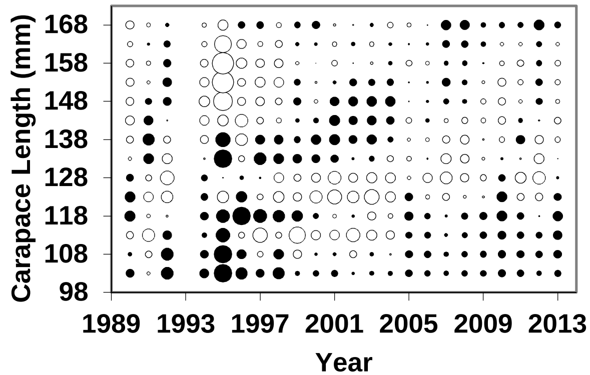
Scenario 7

Scenario 10

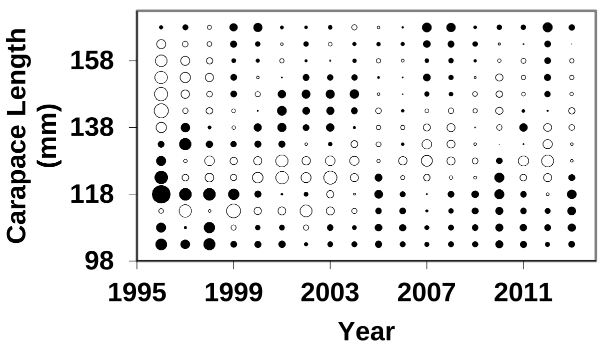
Figure 15. Bubble plots of standardized residuals of retained catch length composition for scenarios 2, 3, 7, and 10 fits for EAG golden king crab, 1985/86–2013/14. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



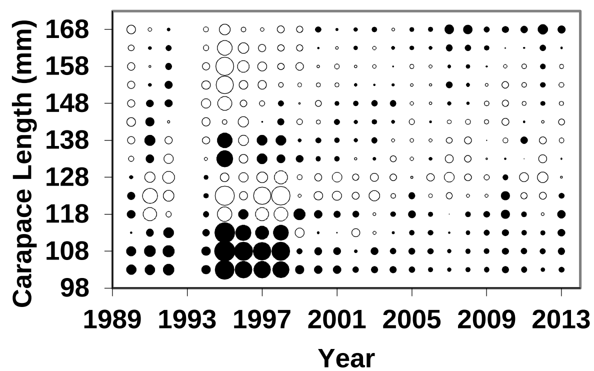
Scenario 2



Scenario 3

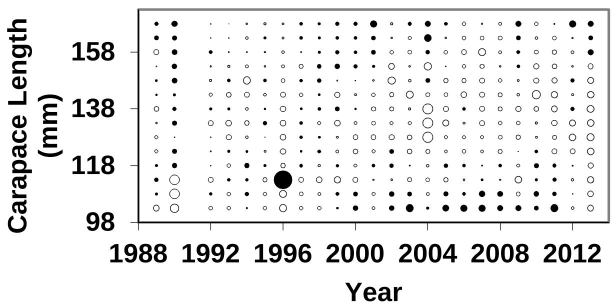


Scenario 7

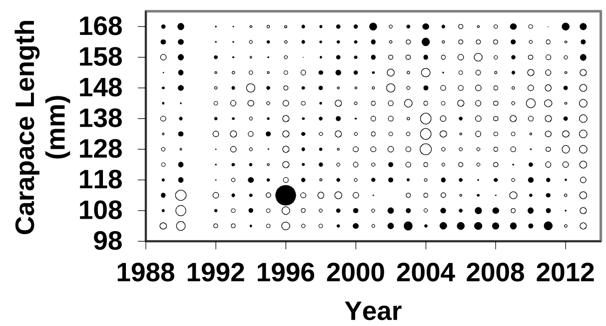


Scenario 10

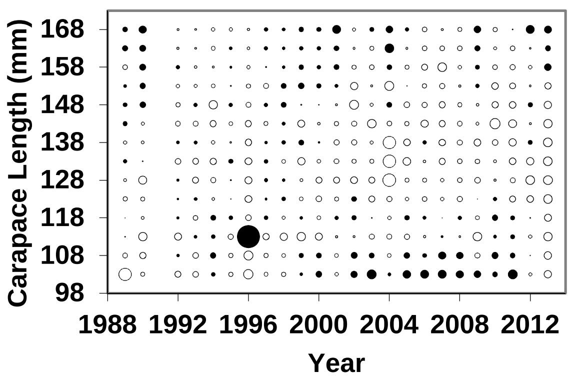
Figure 16. Bubble plots of standardized residuals of total catch length composition for scenarios 2, 3, 7, and 10 fits for EAG golden king crab, 1990/91–2013/14. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



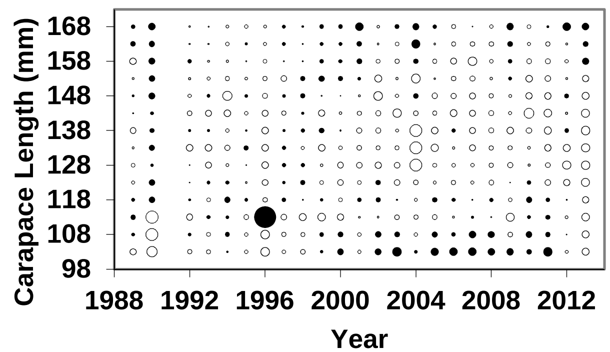
Scenario 2



Scenario 3



Scenario 7



Scenario 10

Figure 17. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 2, 3, 7, and 10 fits for EAG golden king crab, 1989/90–2013/14. 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.

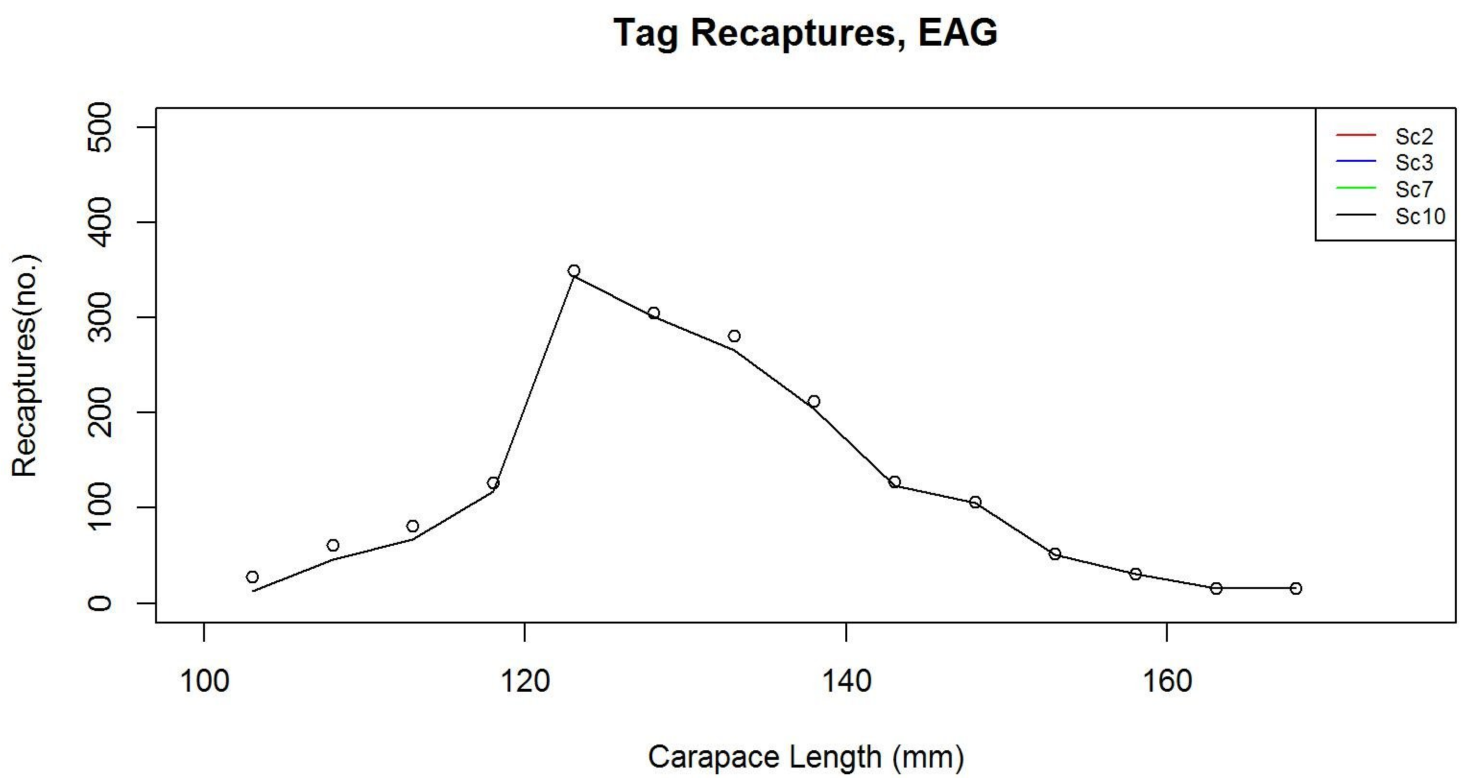


Figure 18. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for scenarios (Sc) 2, 3, 7, and 10 fits of EAG golden king crab data.

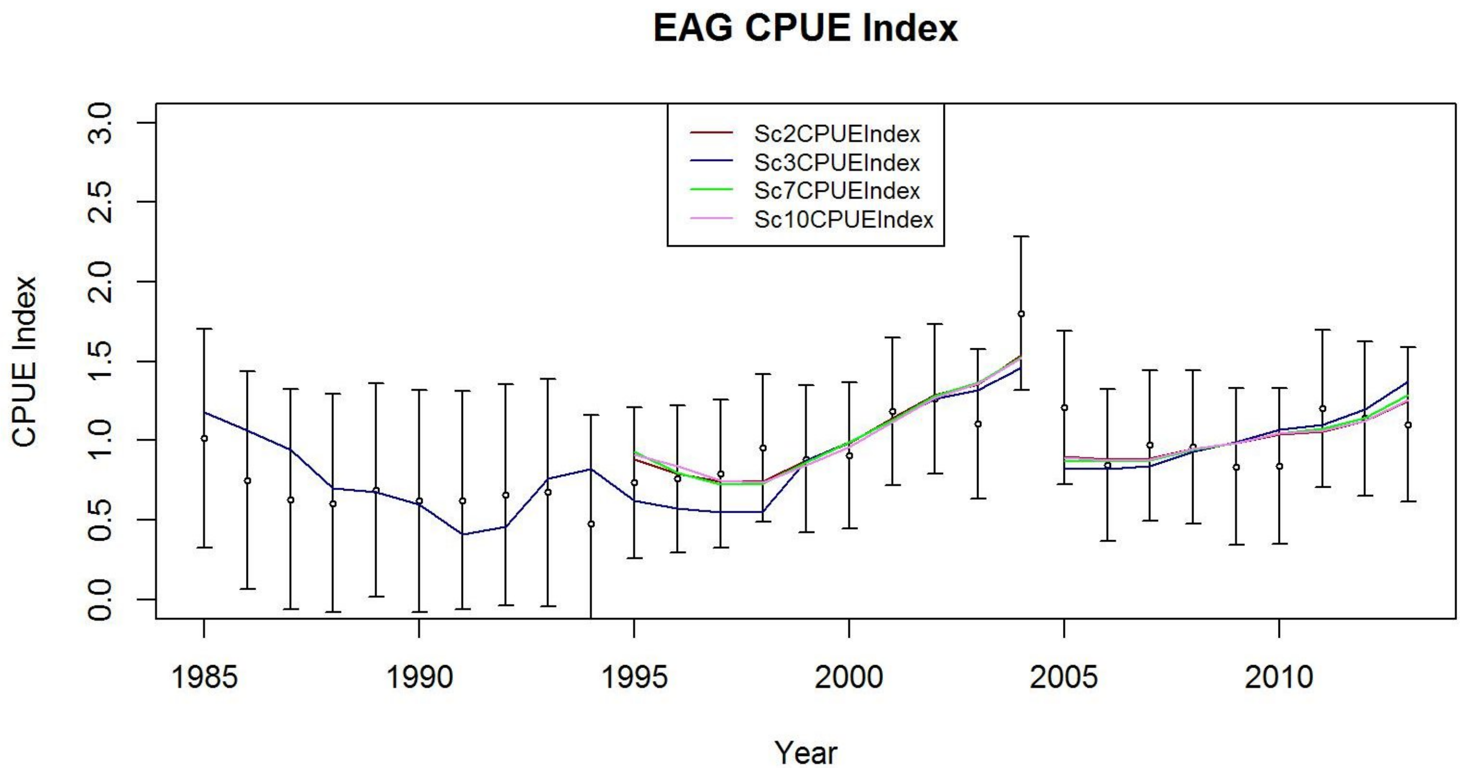


Figure 19. Comparison of input CPUE indices (open circles with 1.96 standard error) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 2, 3, 7, and 10 fits for EAG golden king crab data, 1995/96–2013/14. Model estimated additional standard error was added to each input standard error.

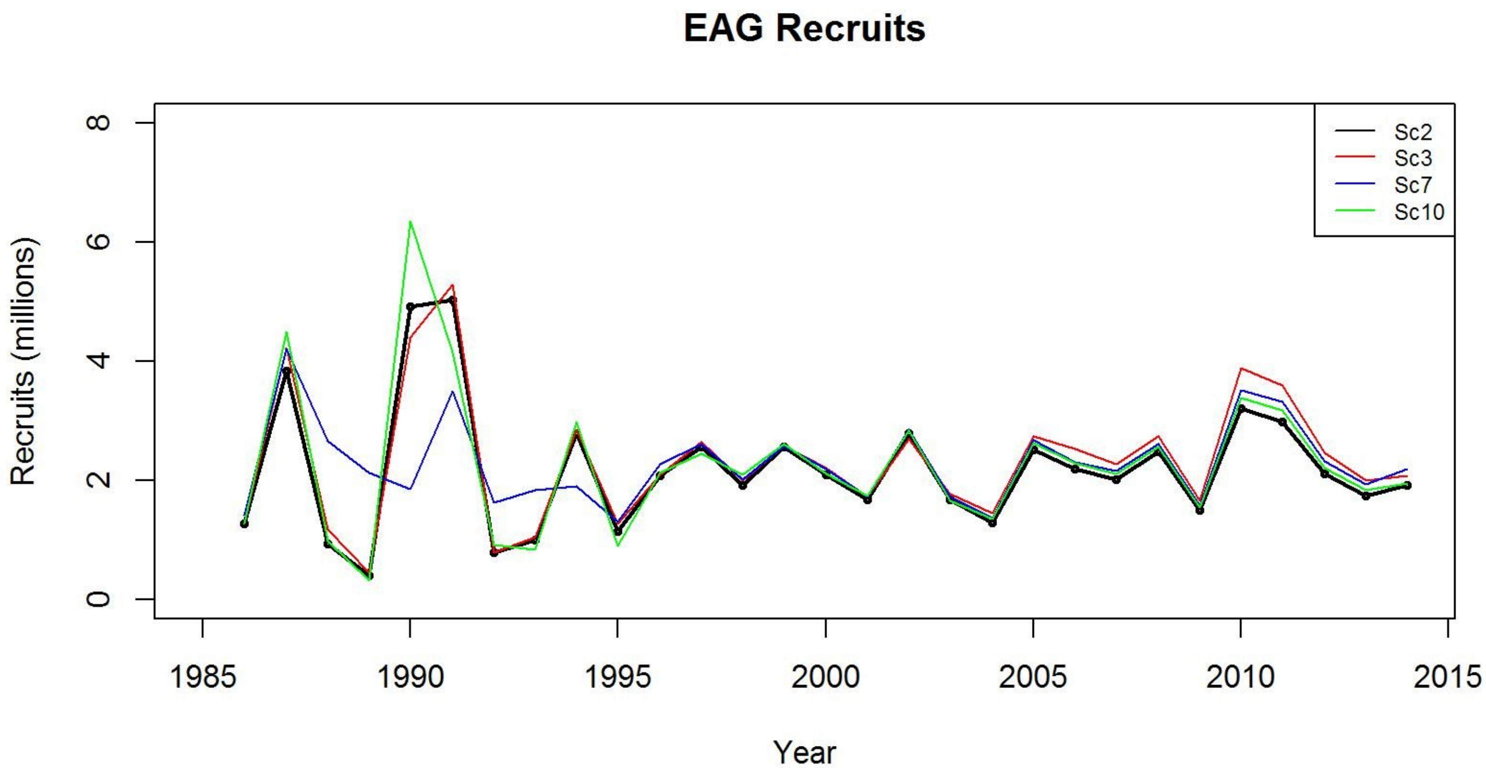


Figure 20. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 2, 3, 7, and 10 fits in EAG, 1986–2014.

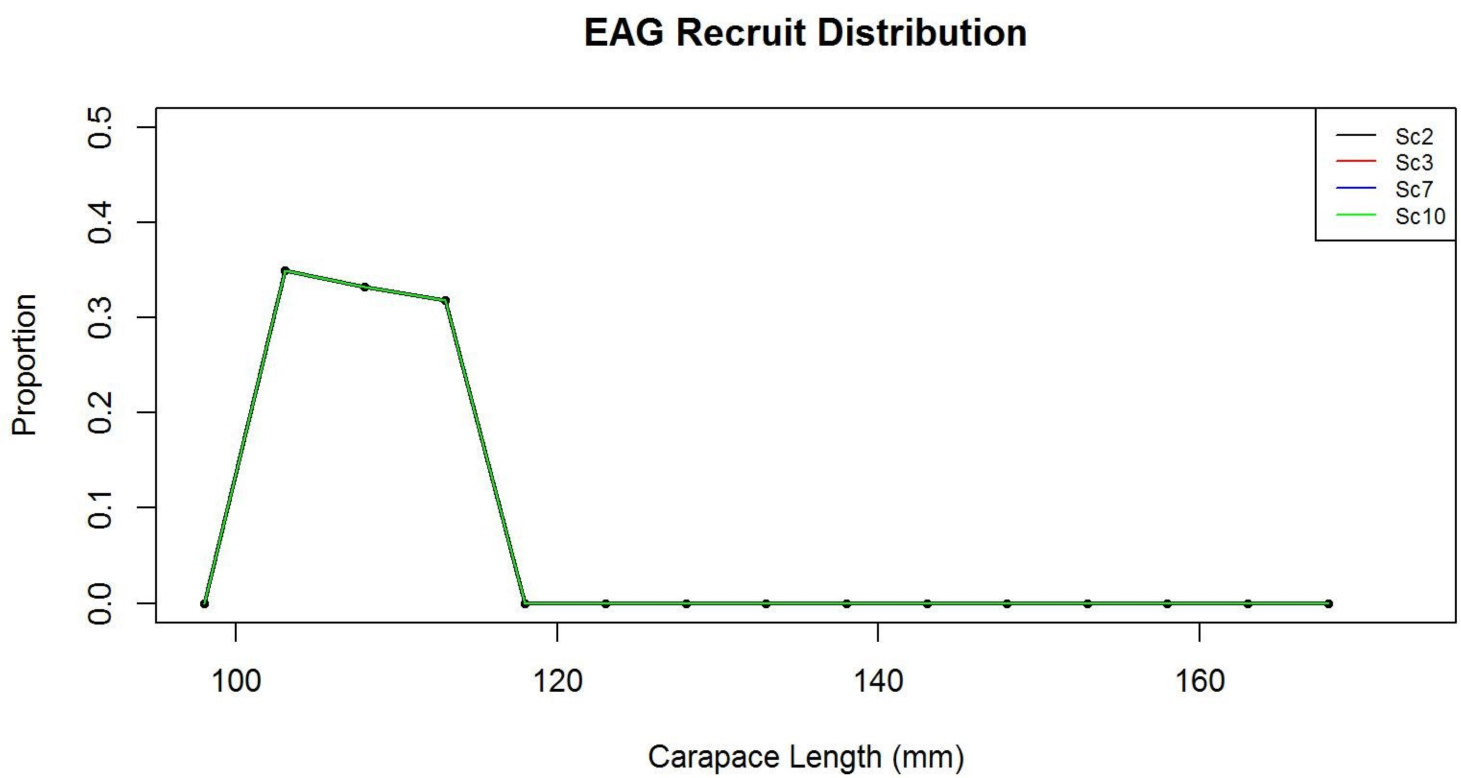
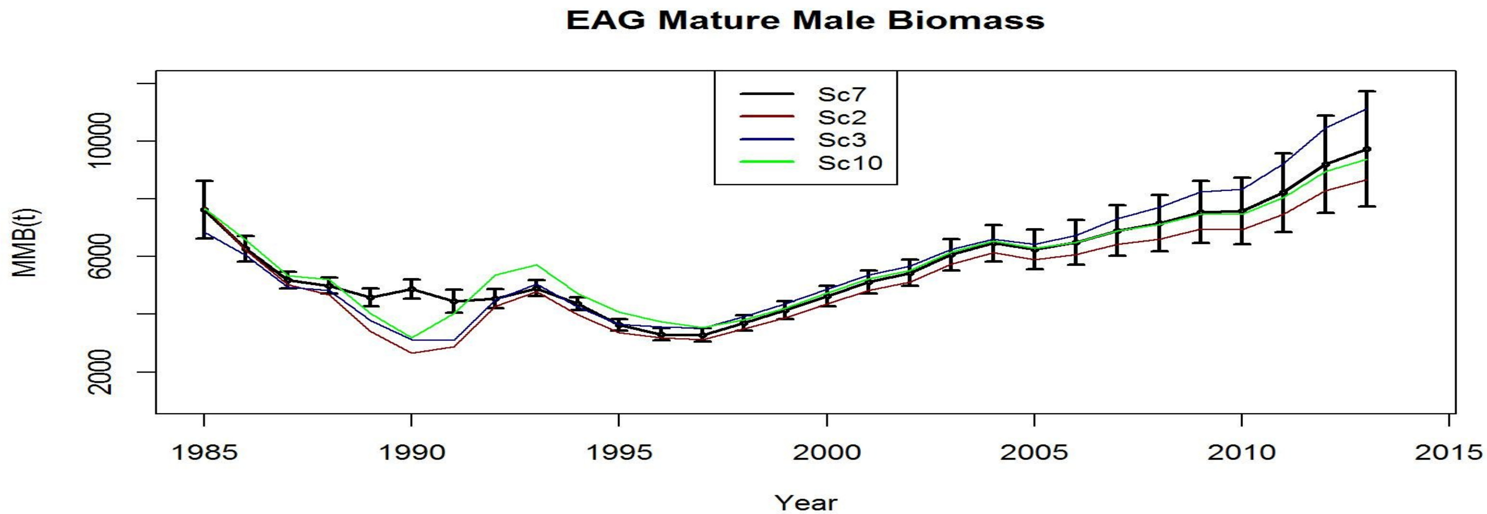


Figure 21. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 2, 3, 7, and 10 fits in EAG.



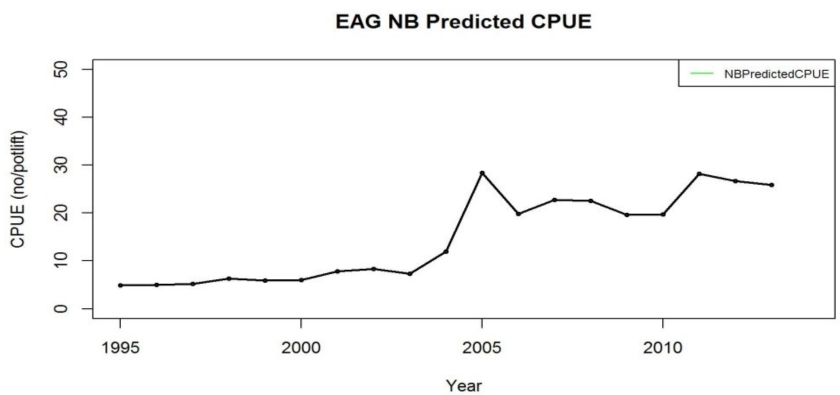


Figure 22. Upper panel: Trends in golden king crab mature male biomass for scenarios (Sc) 2, 3, 7, and 10 fits in the EAG, 1985/86–2013/14. Mature male crabs are ≥ 121 mm CL. Scenario 7 estimates have one standard error confidence limits. Lower panel: GLM predicted standardized CPUE index converted to CPUE in number of crabs per pot lift given as a comparison.

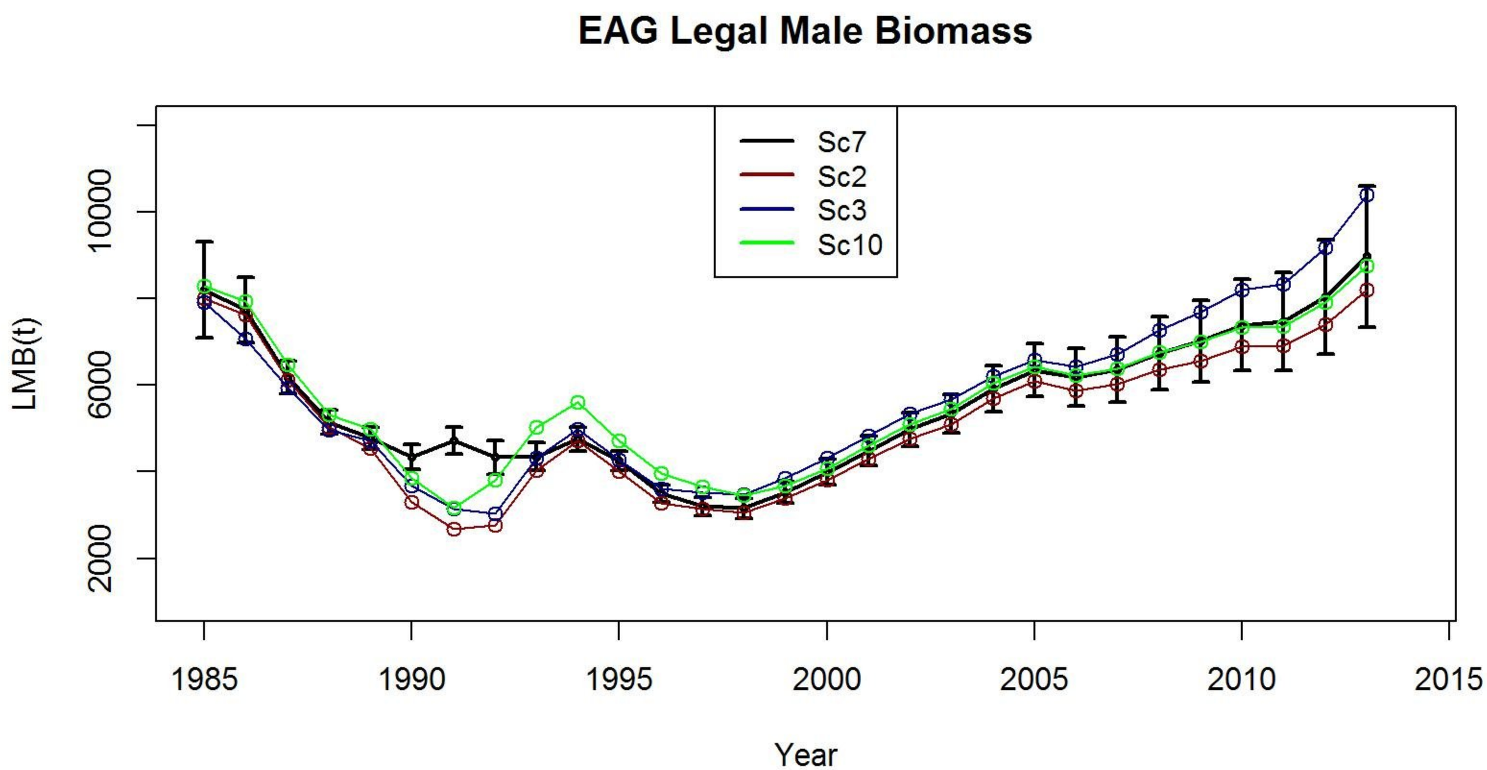


Figure 23. Trends in golden king crab legal male biomass for scenarios (Sc) 2, 3, 7, and 10 fits in the EAG, 1985/86–2013/14. Legal male crabs are ≥ 136 mm CL. Scenario 7 estimates have one standard error confidence limits.

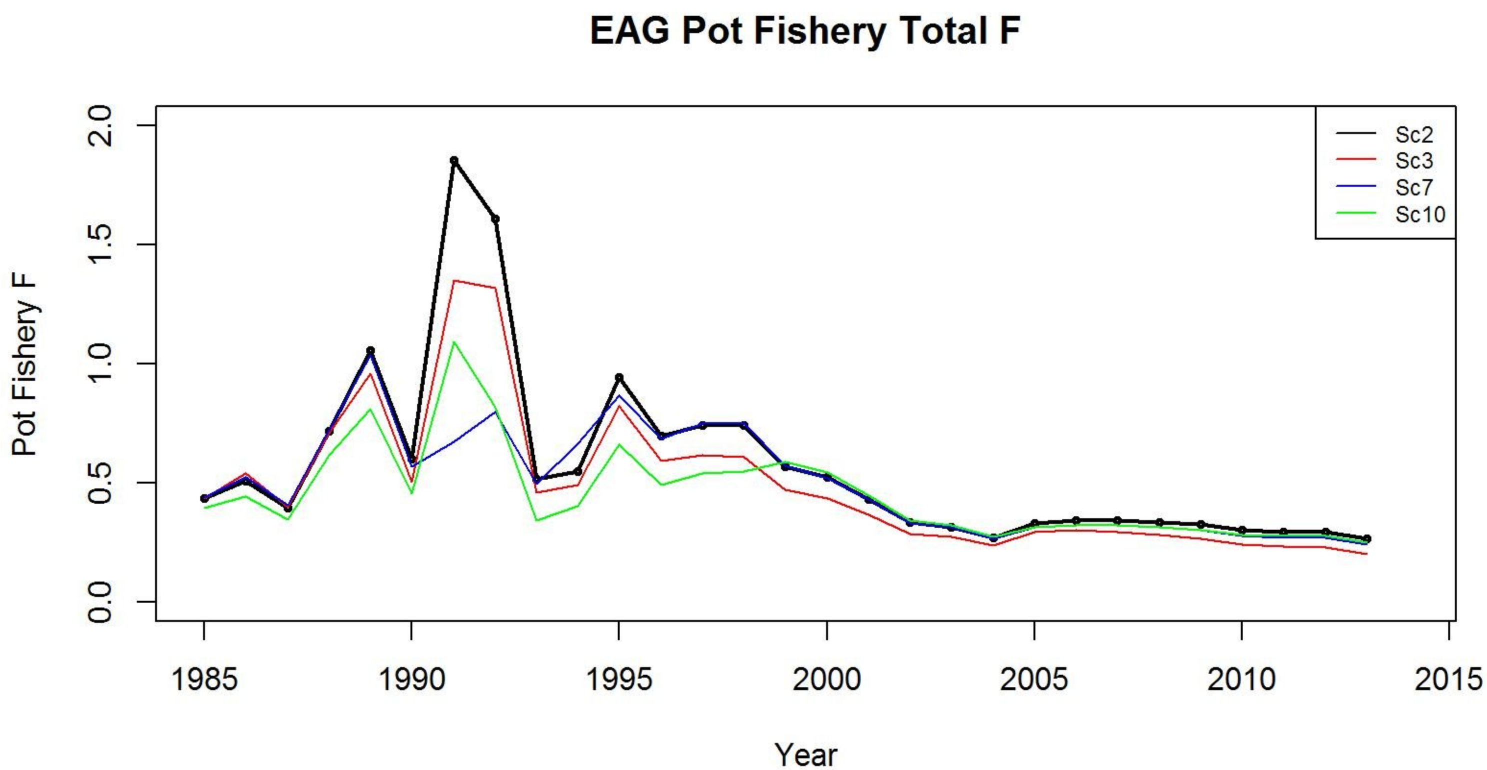


Figure 24. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the EAG, 1985–2013 (note: 1985 refers to the1985/86 fishery).

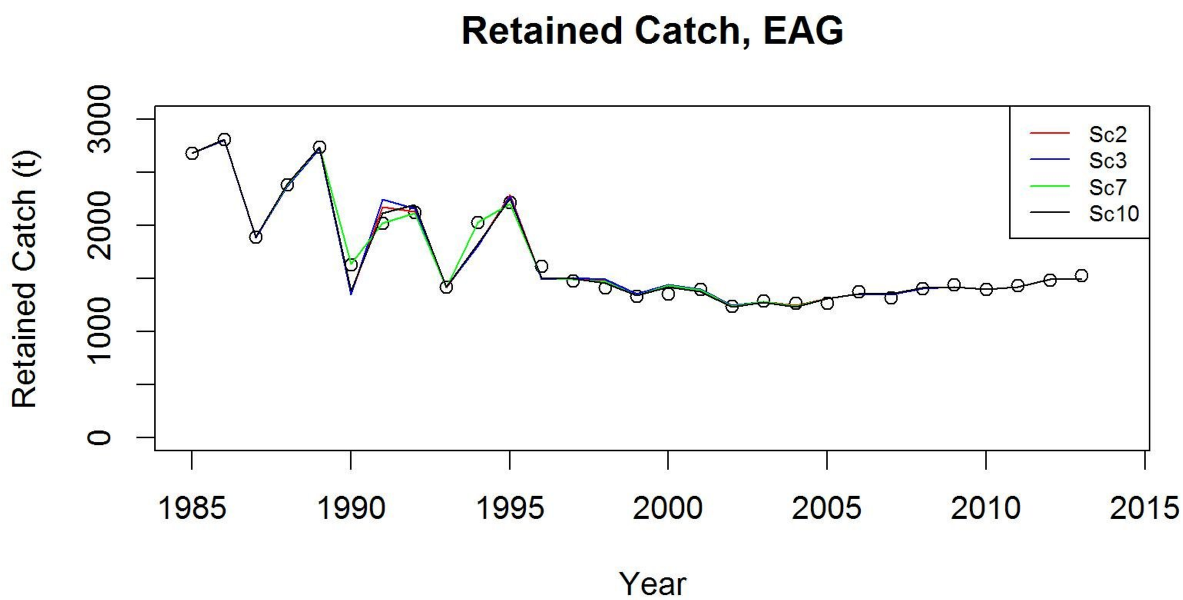


Figure 25. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the EAG, 1985–2013. (note: 1985 refers to the1985/86 fishery).

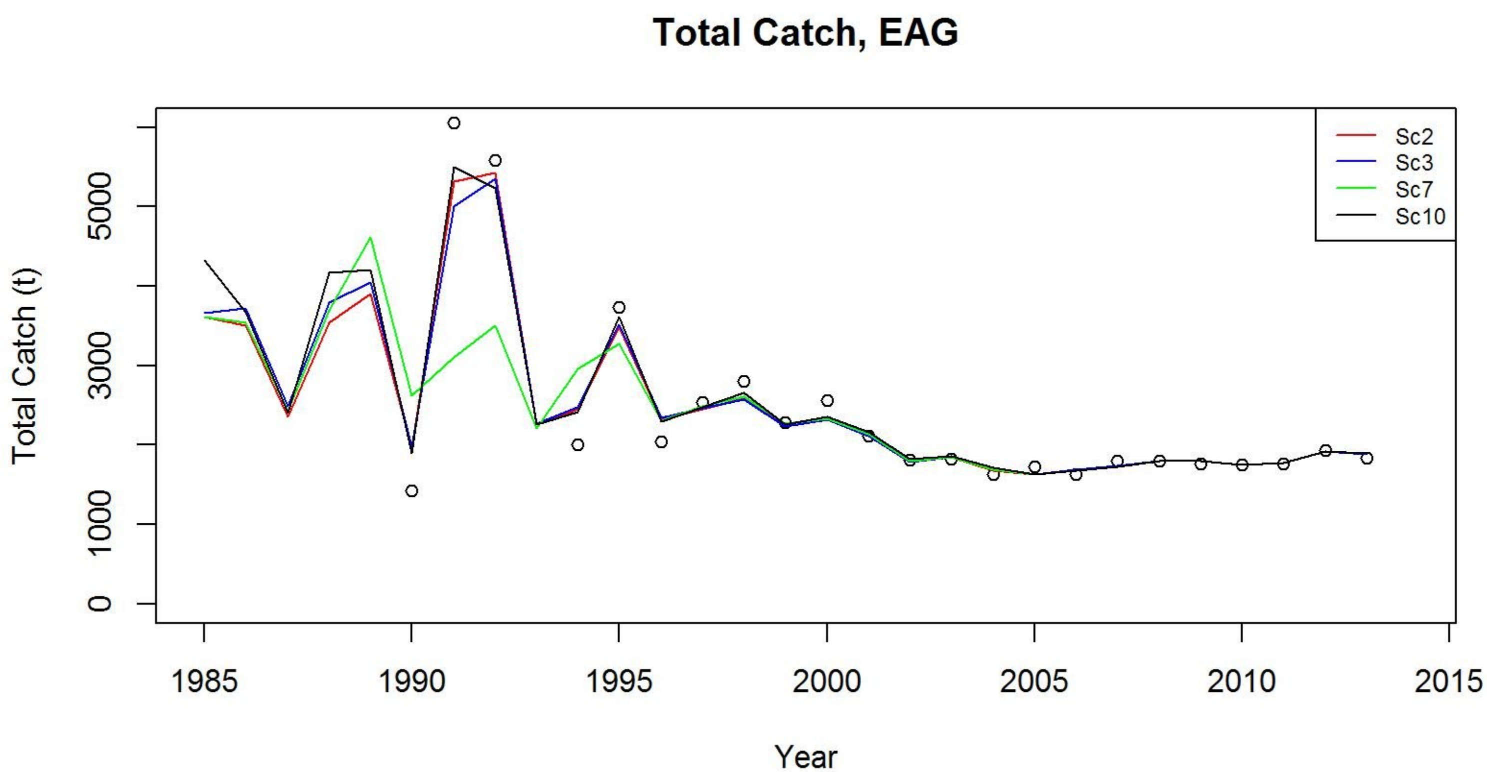


Figure 26. Observed (open circle starts from 1990) vs. predicted (solid line) total catch of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the EAG, 1985–2013. A handling mortality rate of 20% was applied to pot discarded catch and it was added to retained catch to get the total catch. (note: 1985 refers to the1985/86 fishery). Predicted total catch time series is extended from 1990/91 to 1985/86.

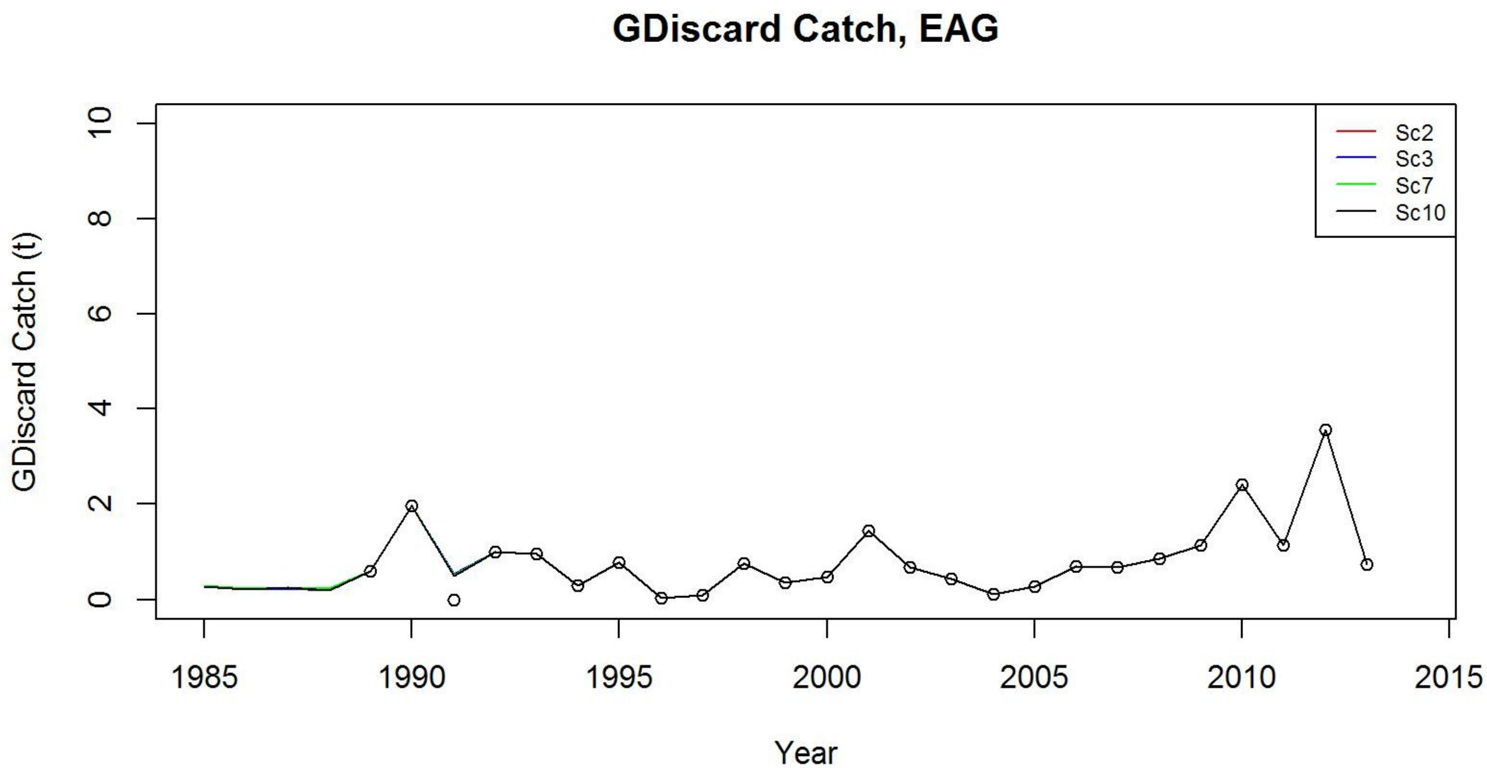
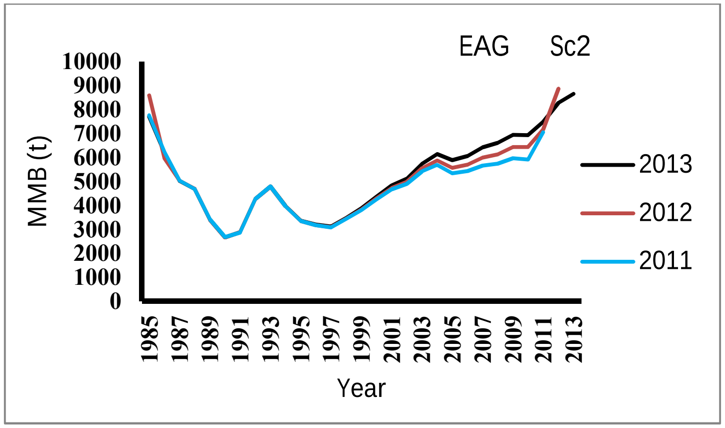
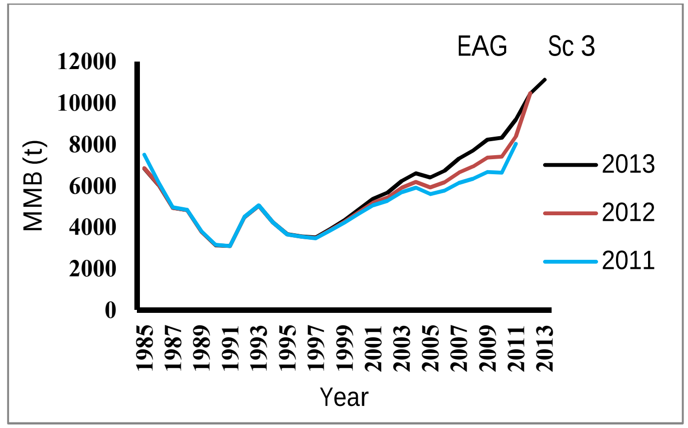


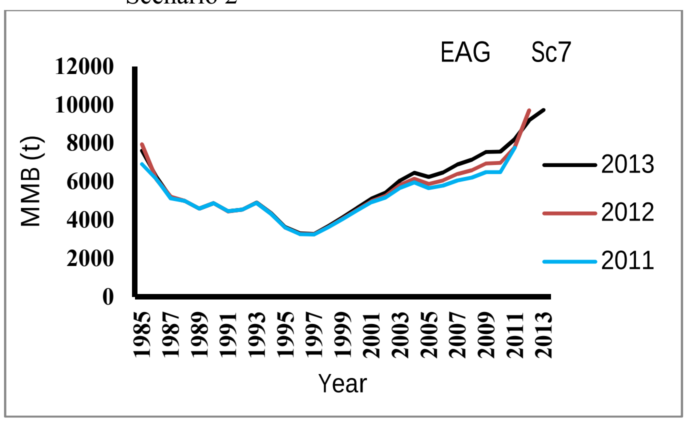
Figure 27. Observed (open circle starts from 1989) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the EAG, 1985–2013. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1989 refers to the1989/90 fishery). Predicted groundfish discarded catch time series is extended from 1989/90 to 1985/86.



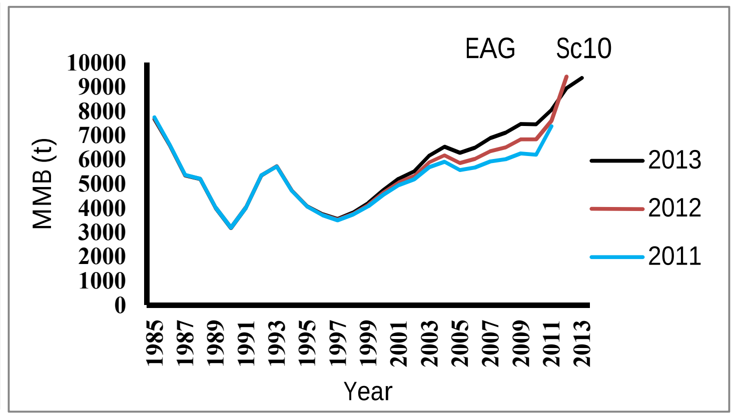
Scenario 2



Scenario 3



Scenario 7



Scenario 10

Figure 28. Retrospective fits of the model for removal of terminal year's data for scenarios (Sc) 2, 3, 7, and 10 fits for golden king crab in the EAG, 1985–2013 (note: 1985 refers to the1985/86 fishery) .

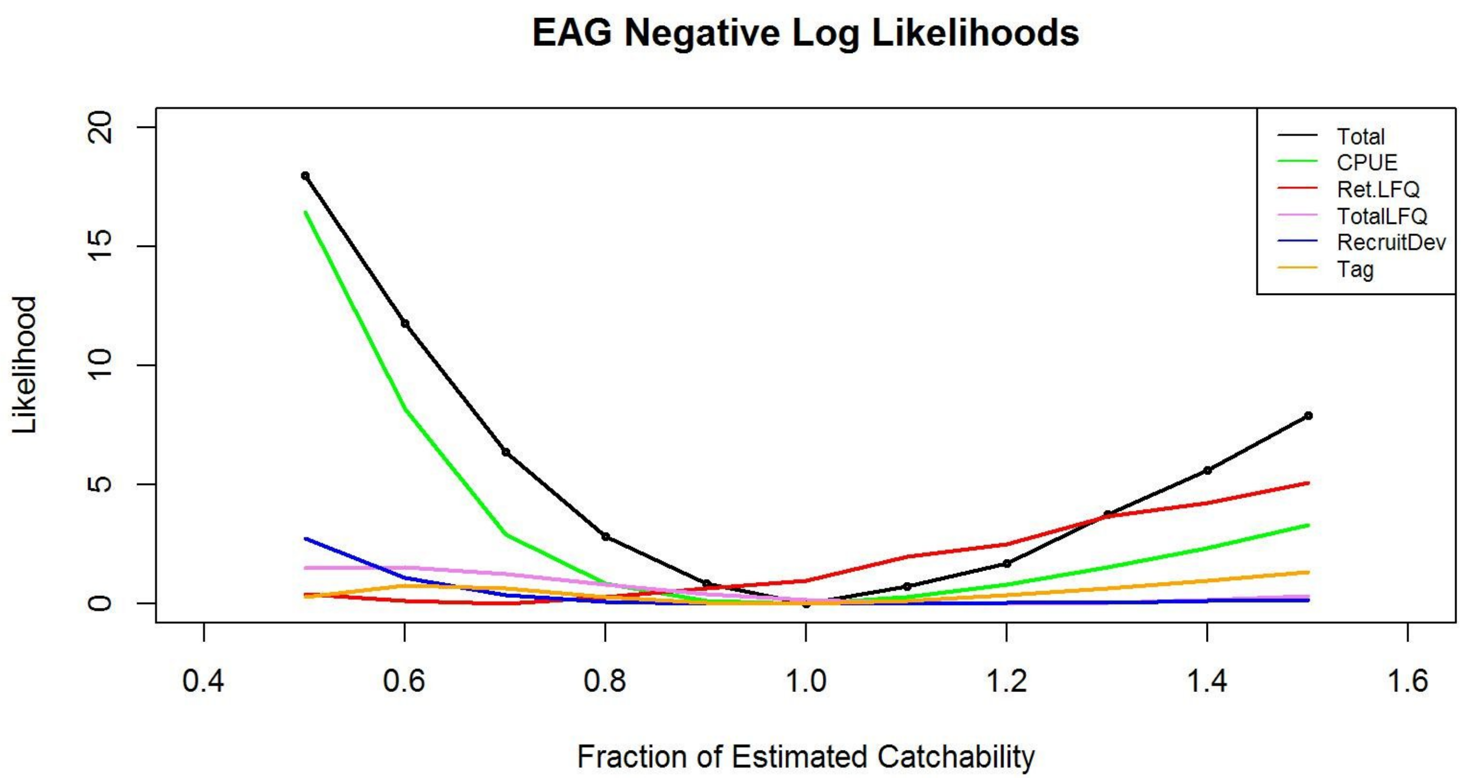
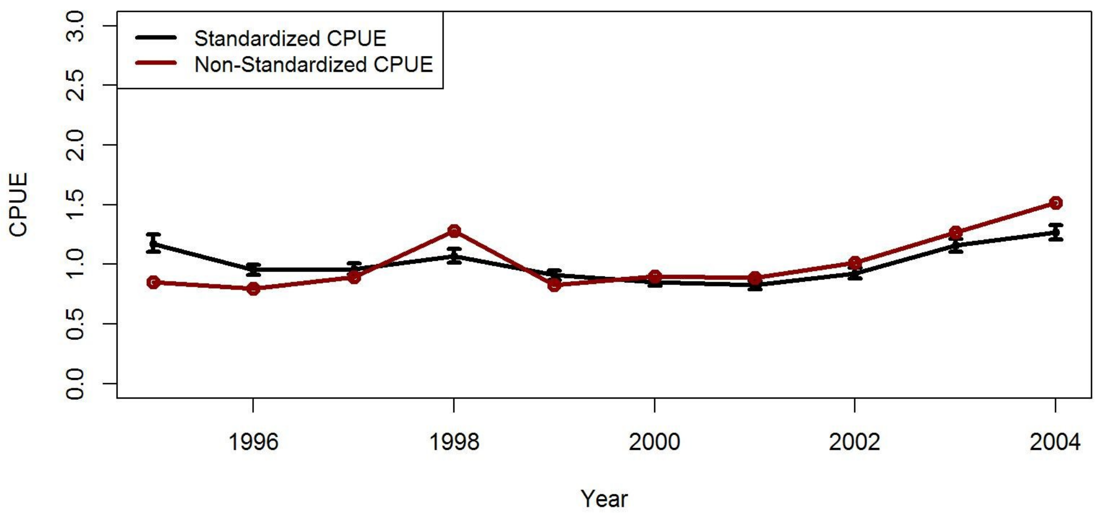


Figure 29. Total and components negative log-likelihoods vs. fractions of the estimated catchability for scenario 7 fit for golden king crab in the EAG, 1985–2013 (note: 1985 refers to the1985/86 fishery).



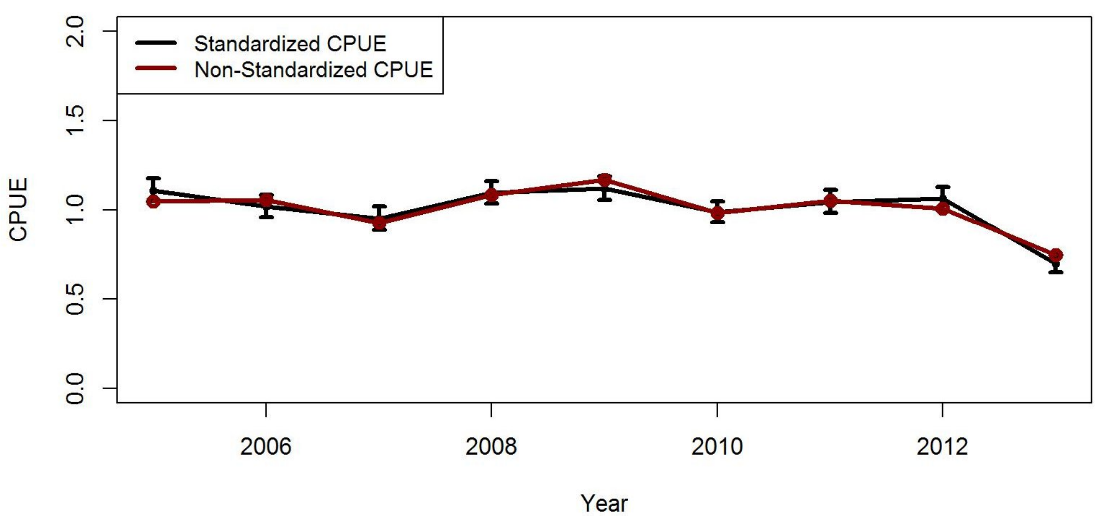


Figure 30. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with two standard errors of Aleutian Islands golden king crab from WAG (west of 174°W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2013/14 observer data. Standardized indices: black line and non-standardized indices: red line.

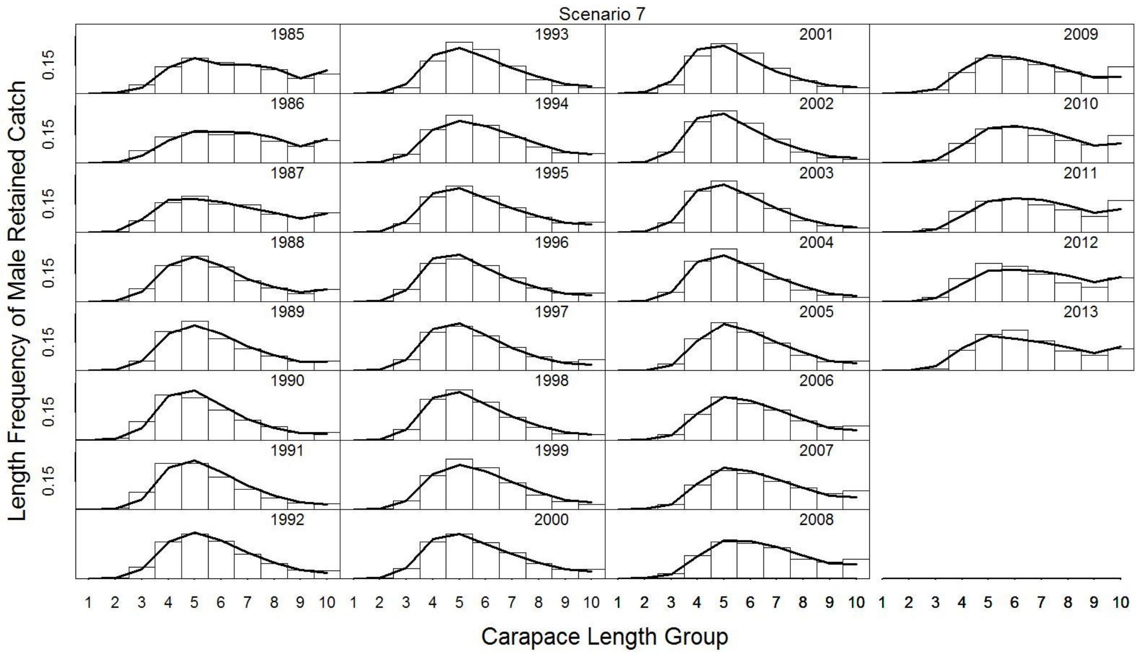


Figure 31. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 7 data of golden king crab in the WAG, 1985/86 – 2013/14. Length group 1 is 123 mm CL.

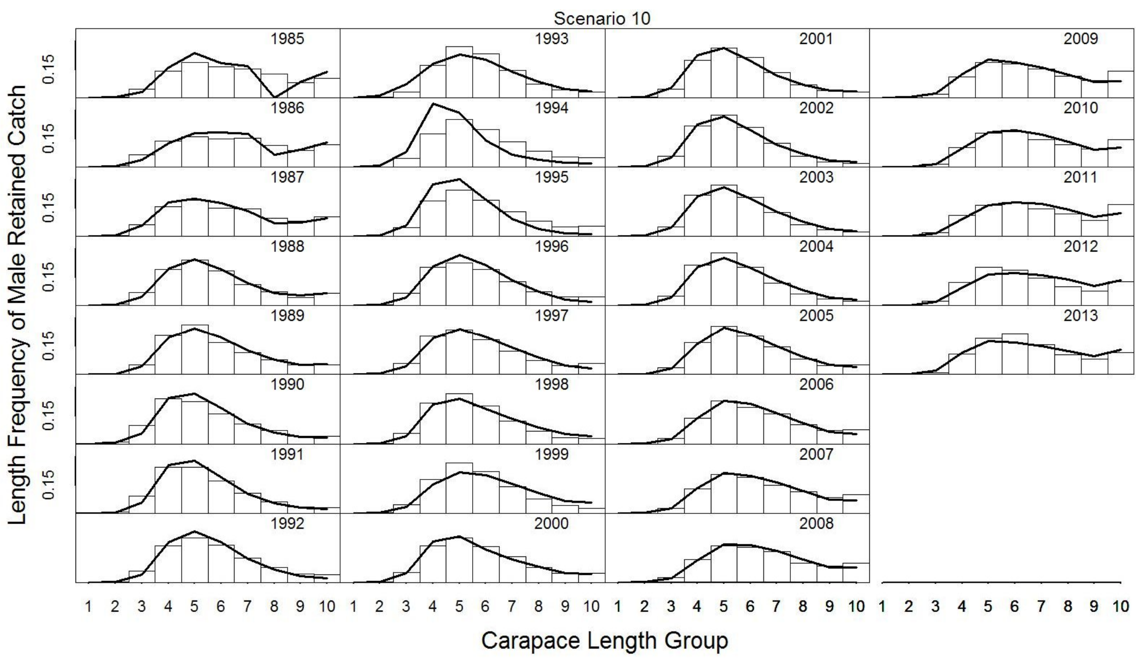


Figure 32. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 10 data of golden king crab in the WAG, 1985/86 – 2013/14. Length group 1 is 123 mm CL.

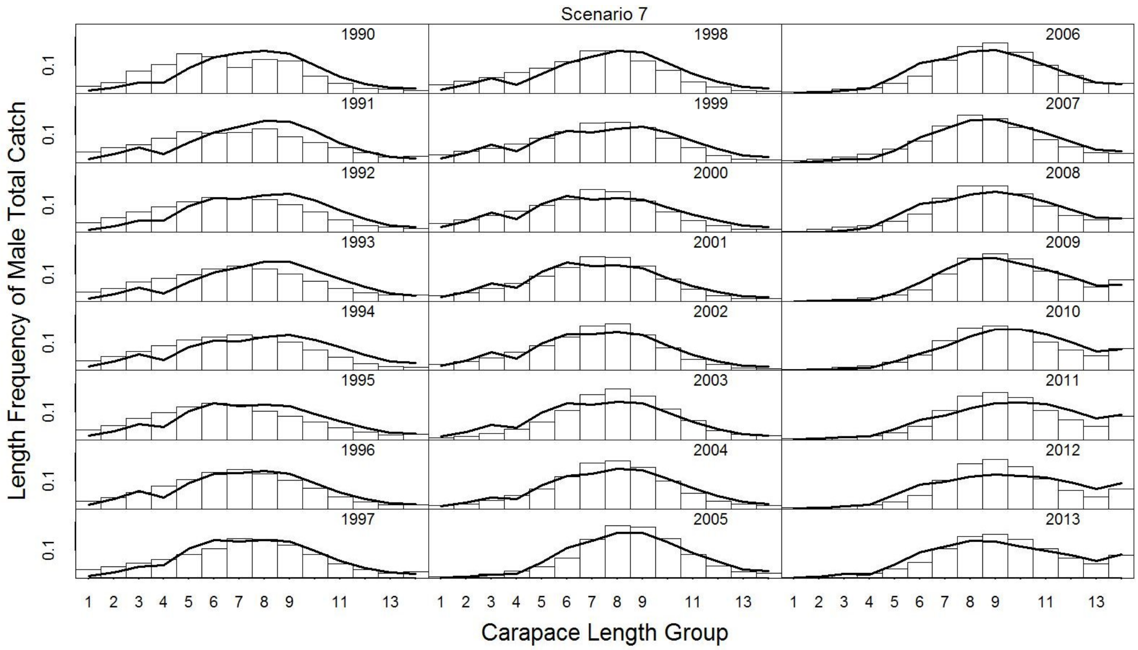


Figure 33. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 7 data of golden king crab in the WAG, 1990/91 – 2013/14. Length group 1 is 103 mm CL.

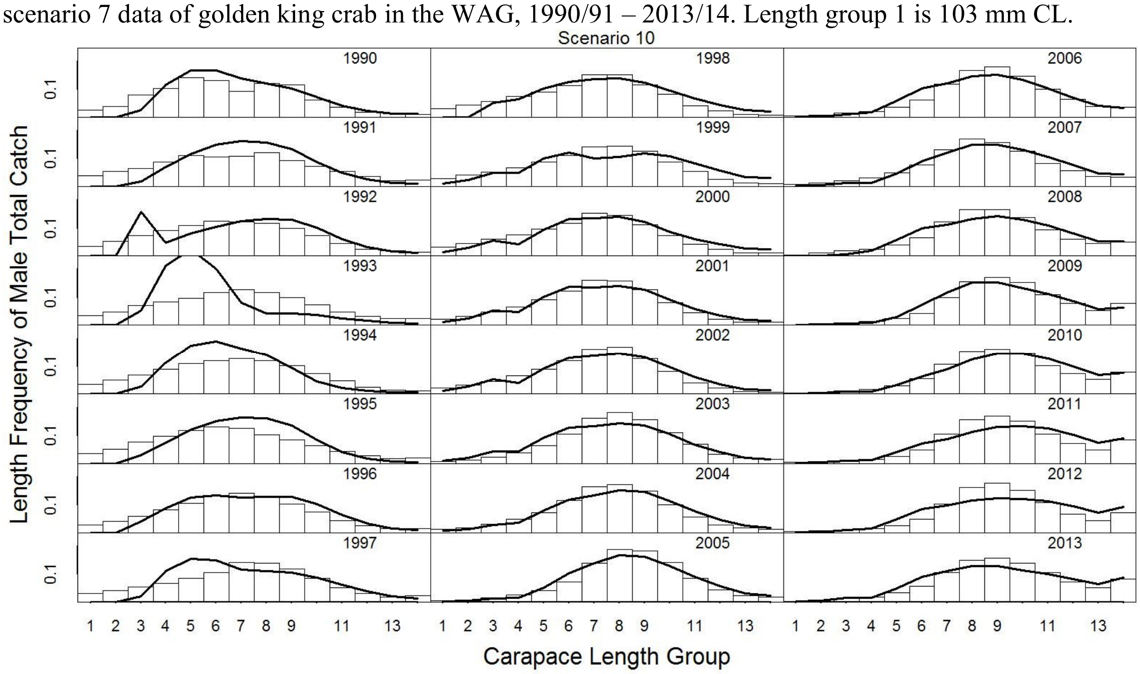


Figure 34. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 10 data of golden king crab in the WAG, 1990/91 – 2013/14. Length group 1 is 103 mm CL.

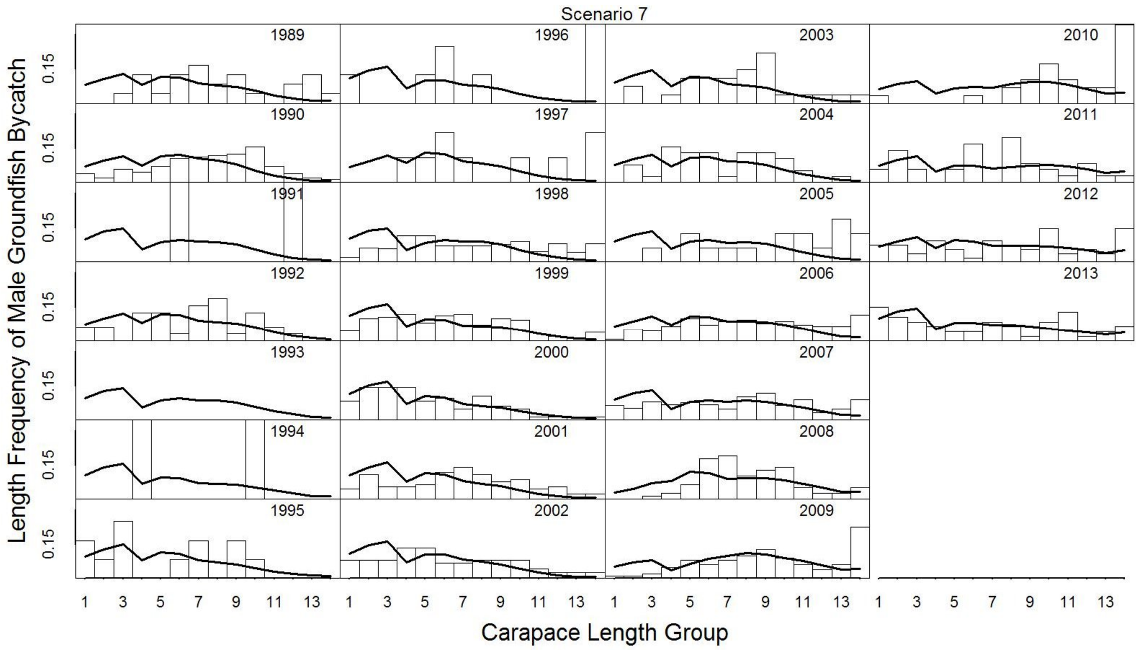


Figure 35. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 7 data of golden king crab in the WAG, 1989/90 – 2013/14. Length group 1 is 103 mm CL.

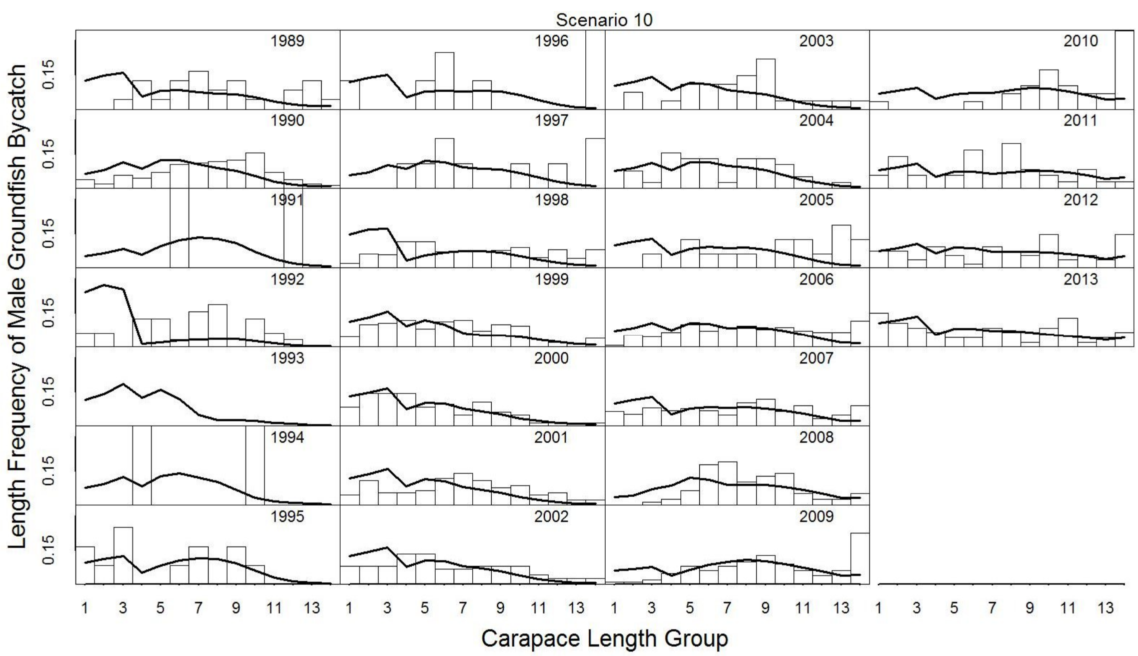


Figure 36. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 10 data of golden king crab in the WAG, 1989/90 – 2013/14. . Length group 1 is 103 mm CL.

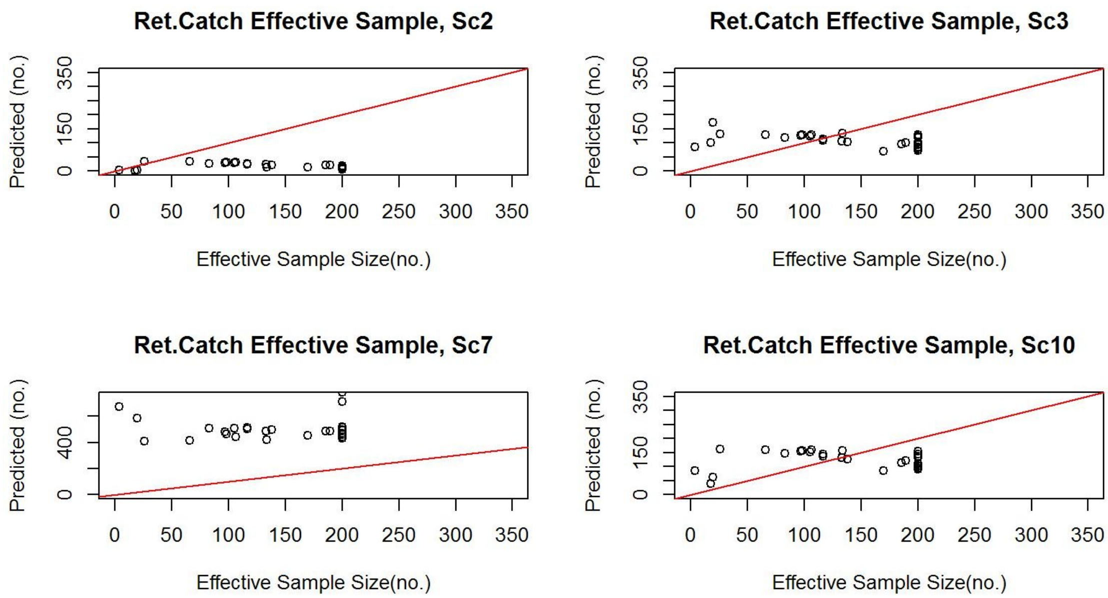


Figure 37. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios (Sc) 2, 3, 7, and 10 fits to golden king crab data in the WAG, 1985/96 – 2013/14. The red line is the 45^0 line passing through the origin.

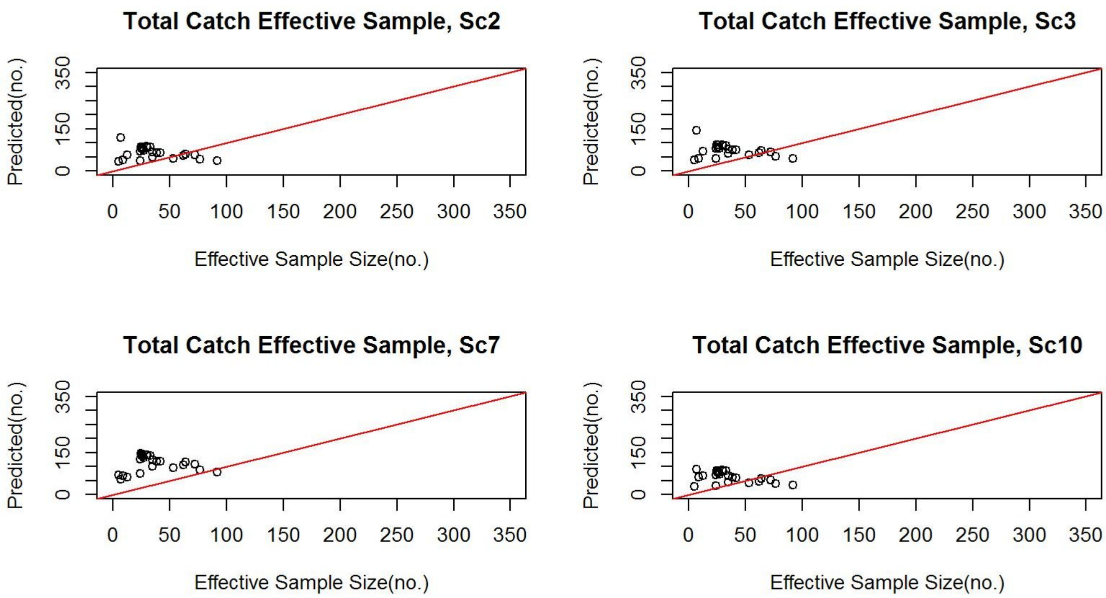


Figure 38. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios (Sc) 2, 3, 7, and 10 fits to golden king crab data in the WAG, 1990/91 – 2013/14. The red line is the 45^0 line passing through the origin.

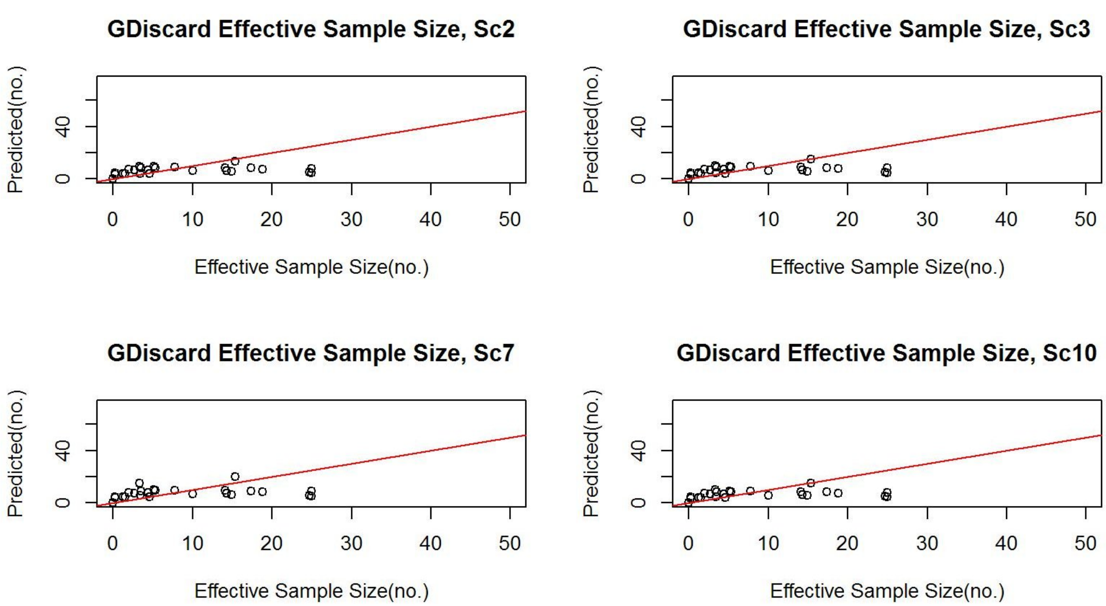


Figure 39. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for scenarios (Sc) 2, 3, 7, and 10 fits to golden king crab data in the WAG, 1995/96 – 2013/14. The red line is the 45^0 line passing through the origin.

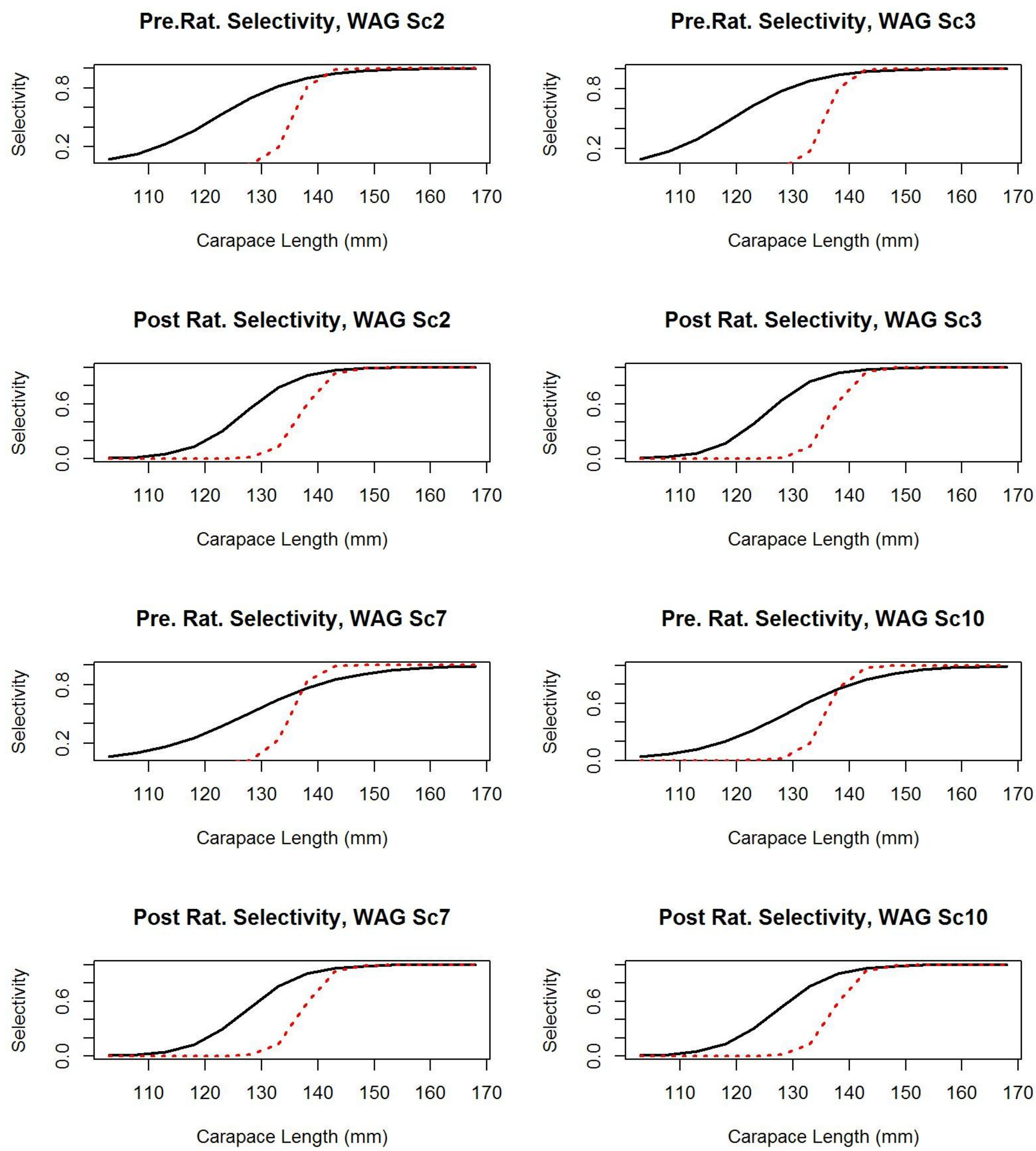
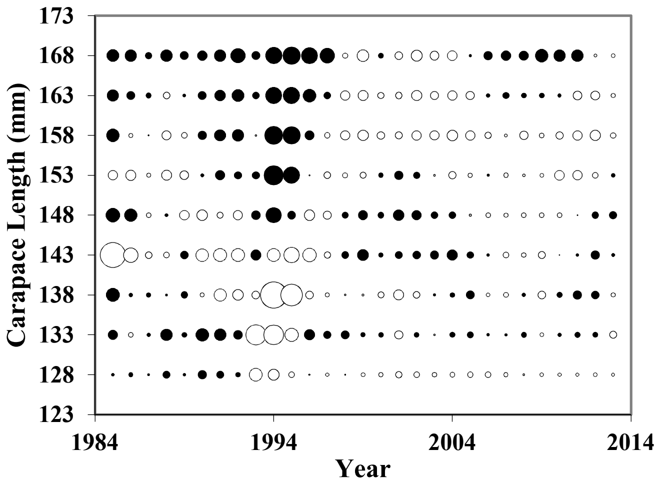
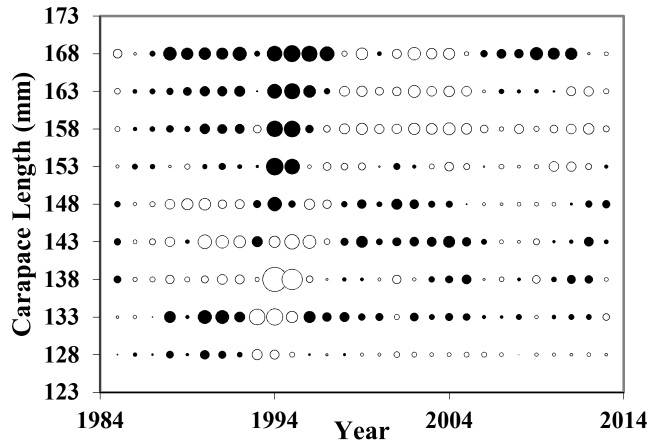


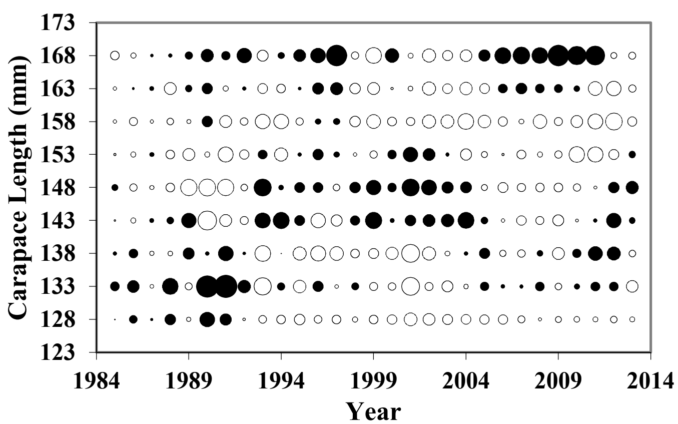
Figure 40. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 2, 3, 7, and 10 fits of WAG golden king crab data..



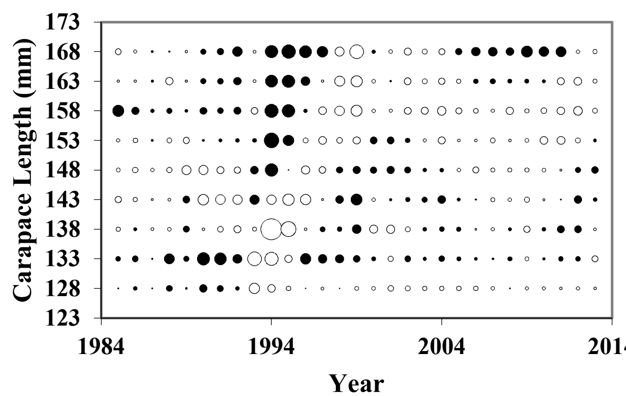
Scenario 2



Scenario 3

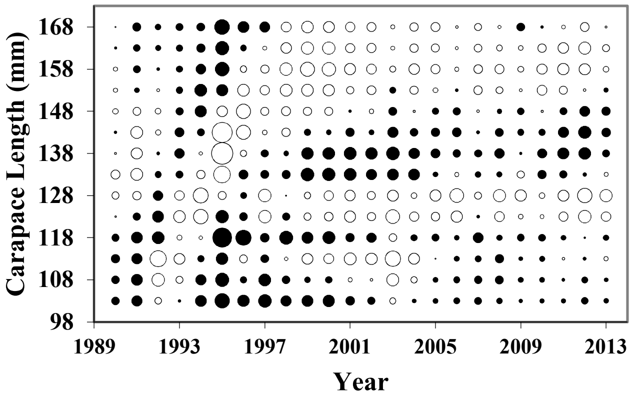


Scenario 7

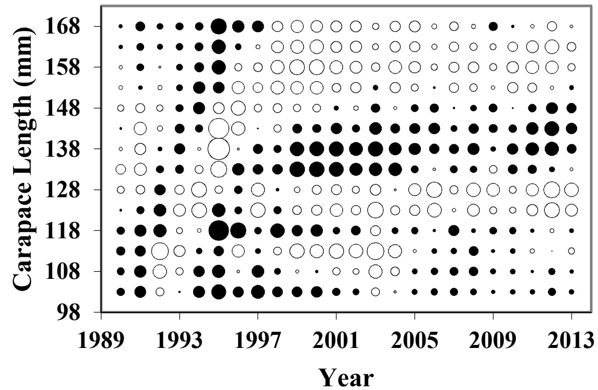


Scenario 10

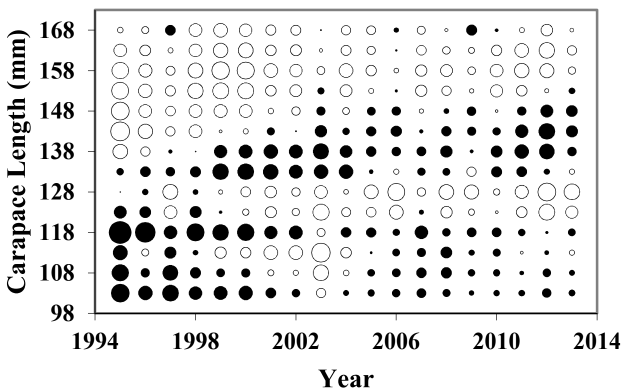
Figure 41. Bubble plots of standardized residuals of retained catch length composition for scenarios 2, 3, 7, and 10 fits for WAG golden king crab, 1985/86–2013/14. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



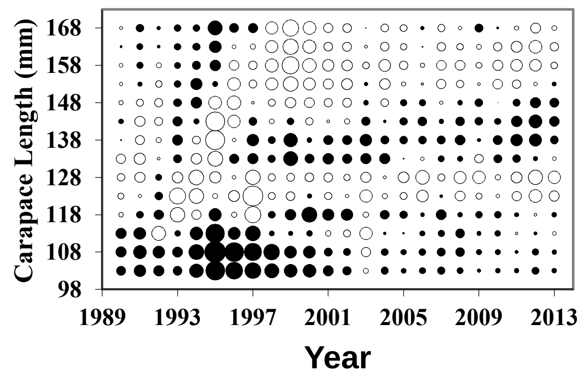
Scenario 2



Scenario 3

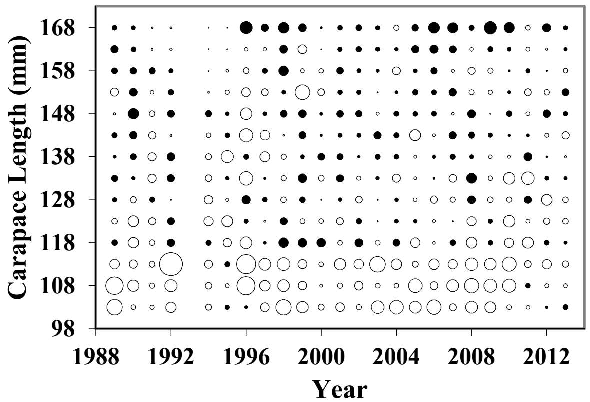


Scenario 7

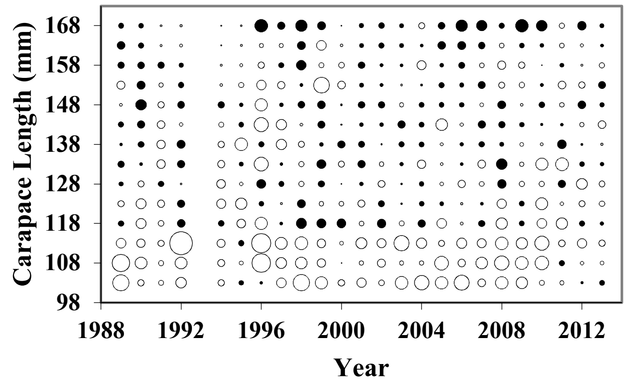


Scenario 10

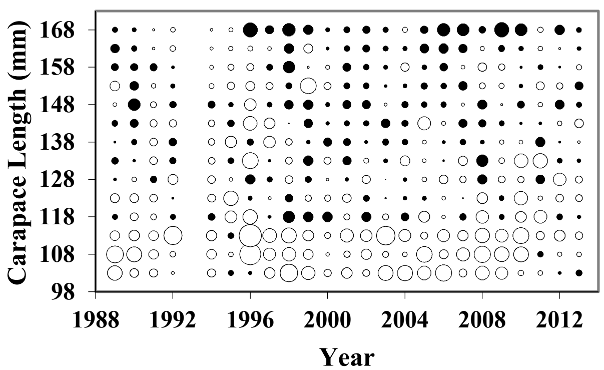
Figure 42. Bubble plots of standardized residuals of total catch length composition for scenarios 2, 3, 7, and 10 fits for WAG golden king crab, 1990/91–2013/14. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



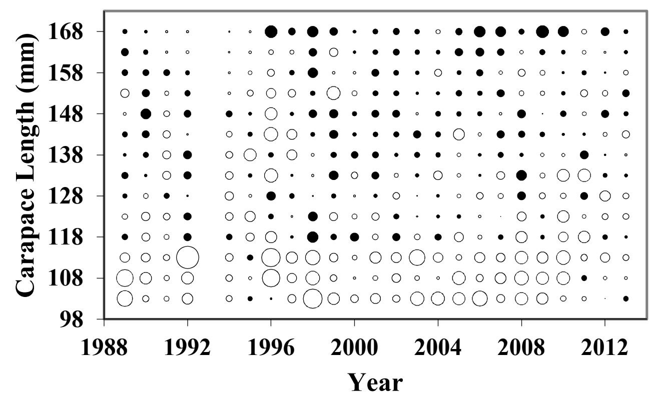
Scenario 2



Scenario 3



Scenario 7



Scenario 10

Figure 43. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 2, 3, 7, and 10 fits for WAG golden king crab, 1989/90–2013/14. 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.

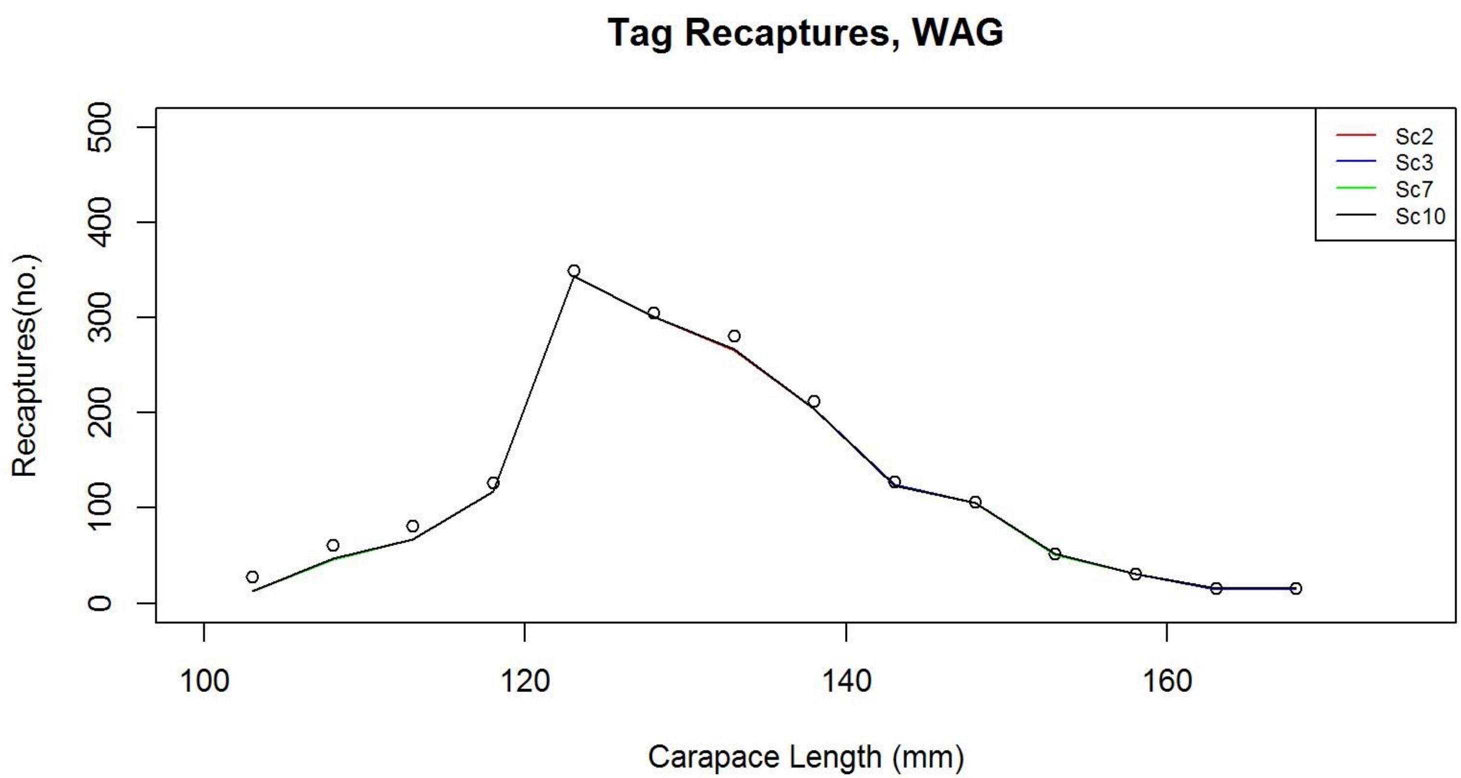
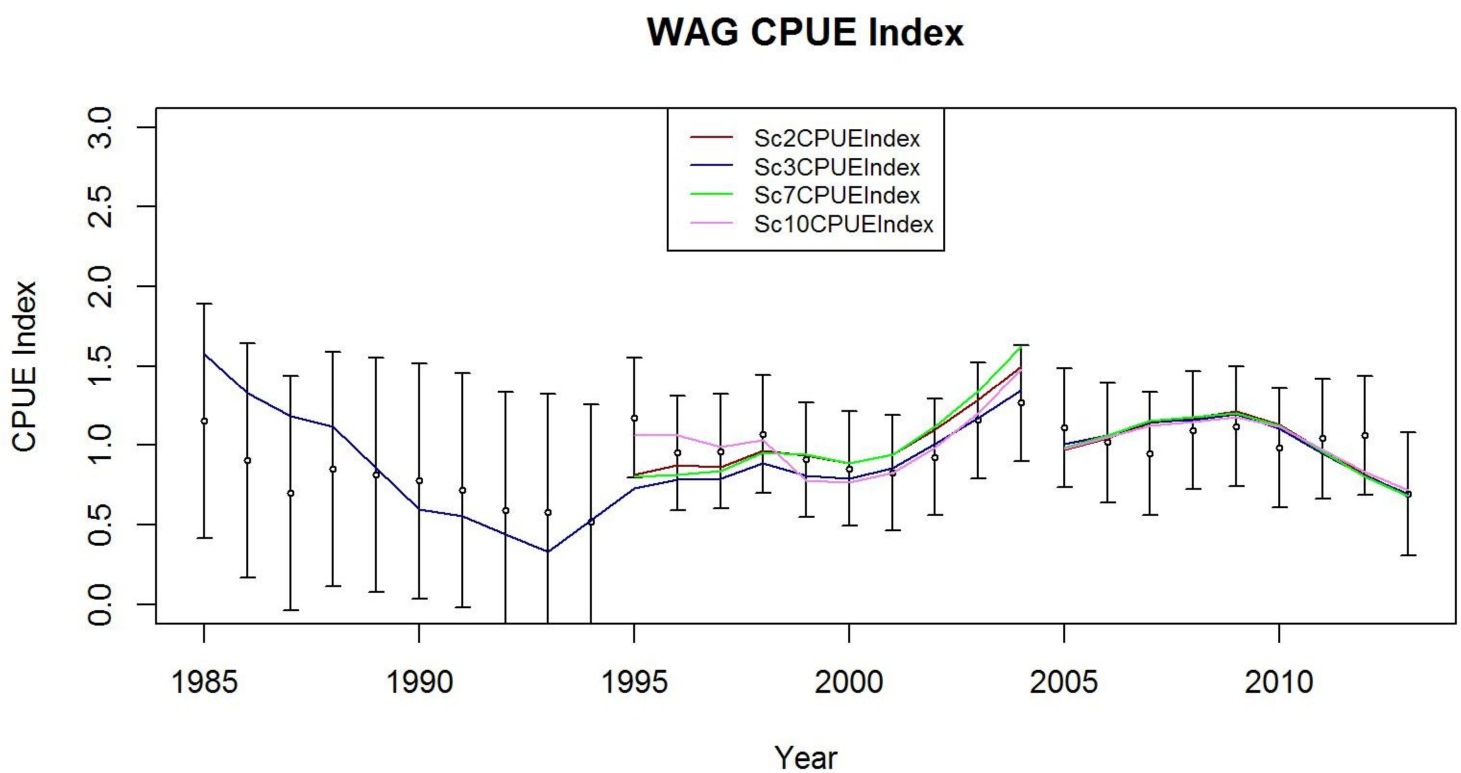


Figure 44. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for scenarios (Sc) 2, 3, 7, and 10 fits of WAG golden king crab data. The tagging experiments were conducted in EAG.



.

Figure 45. Comparison of input CPUE indices (open circles with 1.96 standard errors) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 2, 3, 7, and 10 fits for WAG golden king crab data. 1995/96–2013/14. Model estimated additional standard error was added to each input standard error.

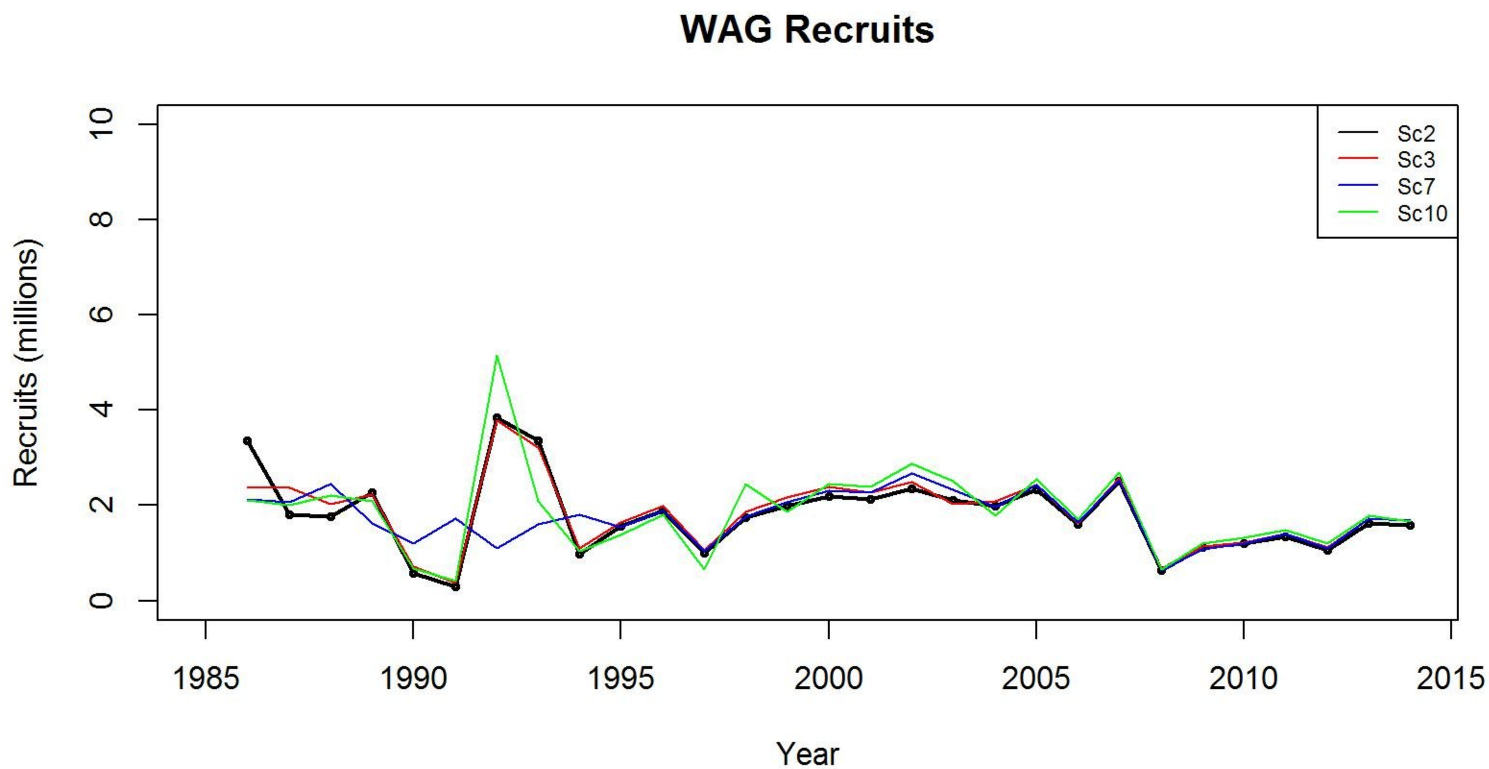


Figure 46. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 2, 3, 7, and 10 fits in WAG, 1986–2014.

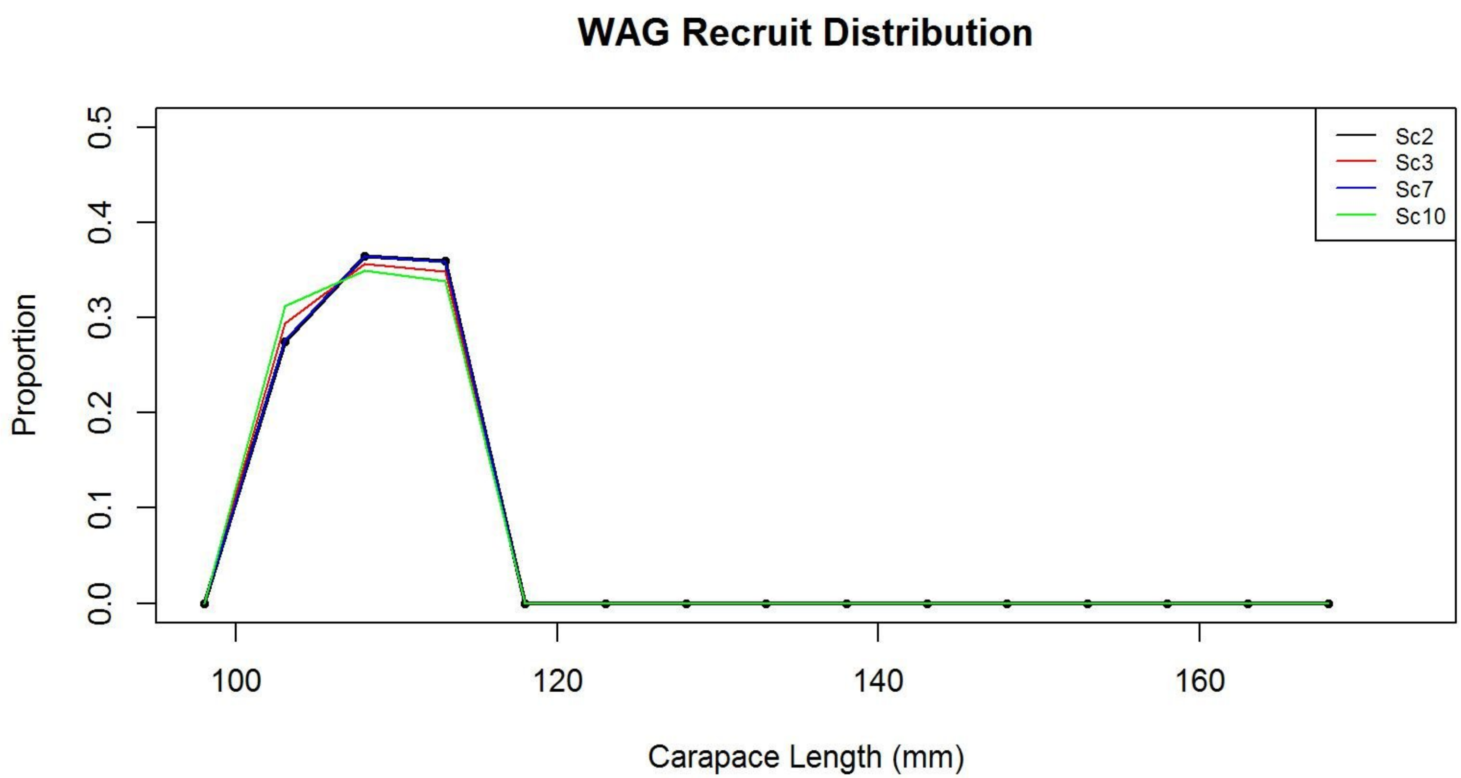
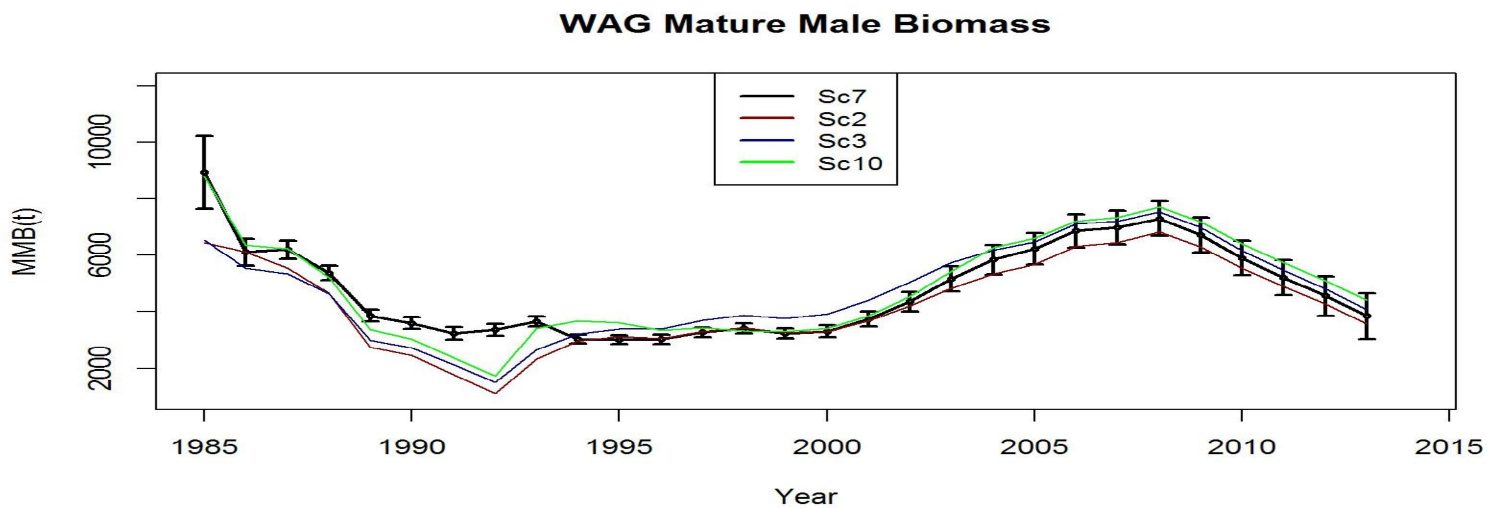


Figure 47. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 2, 3, 7, and 10 fits in WAG.



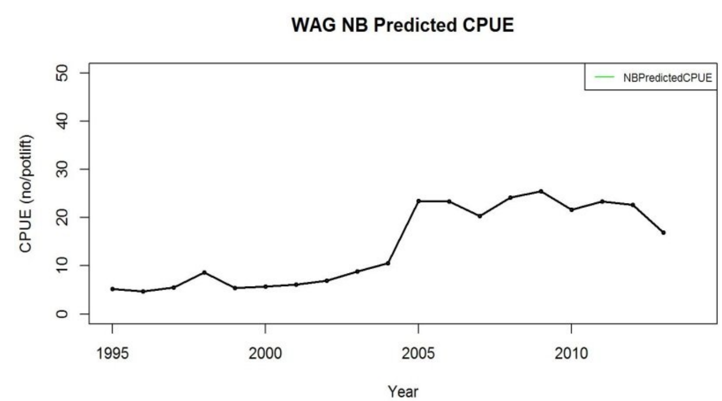


Figure 48. Upper panel: Trends in golden king crab mature male biomass for scenarios (Sc) 2, 3, 7, and 10 fits in the WAG, 1985/86–2013/14. Mature male crabs are ≥ 121 mm CL. Scenario 7 estimates have one standard error confidence limits. Lower panel: GLM predicted standardized CPUE index converted to CPUE in number of crabs per pot lift given for comparison.

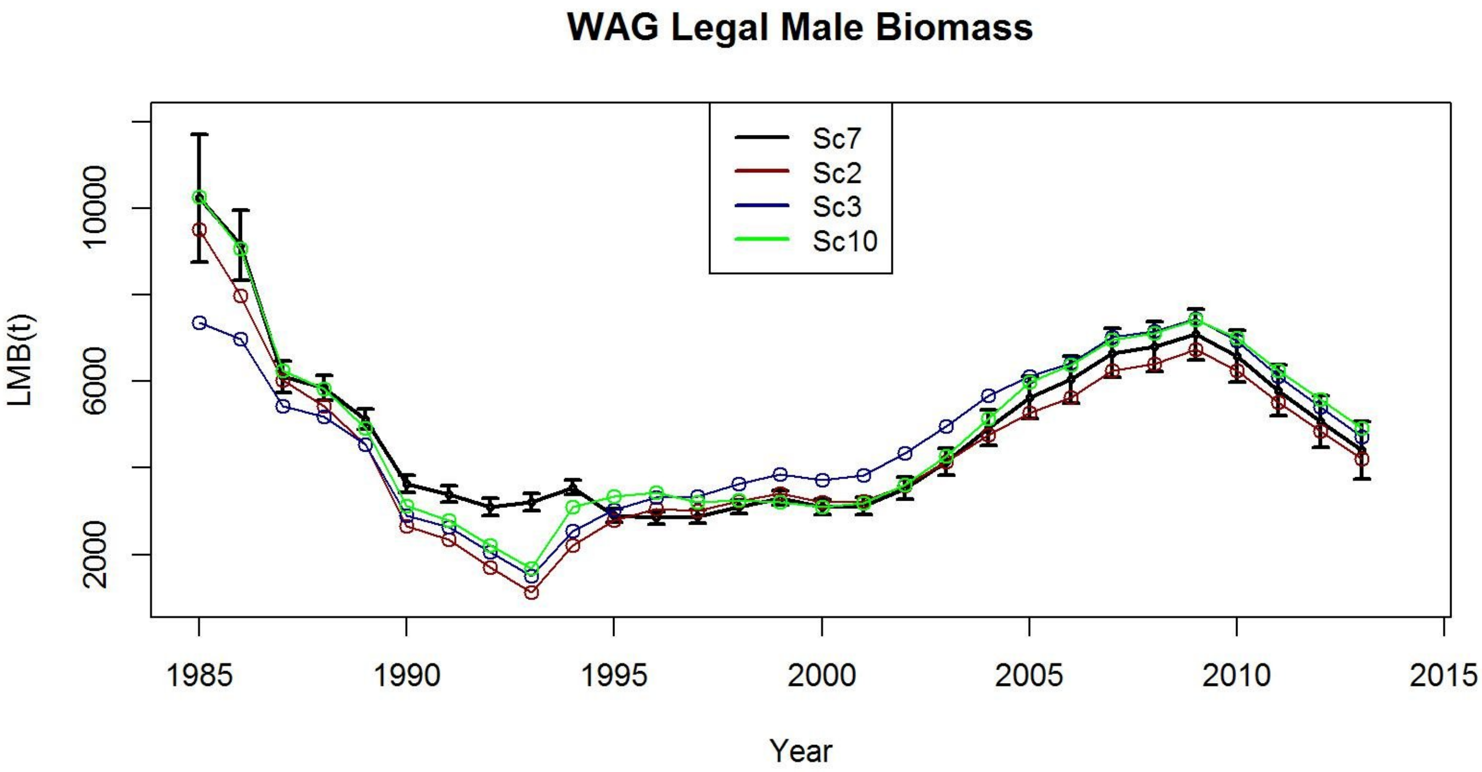


Figure 49. Trends in golden king crab legal male biomass for scenarios (Sc) 2, 3, 7, and 10 fits in the WAG, 1985/86–2013/14. Legal male crabs are ≥ 136 mm CL. Scenario 7 estimates have one standard error confidence limits.

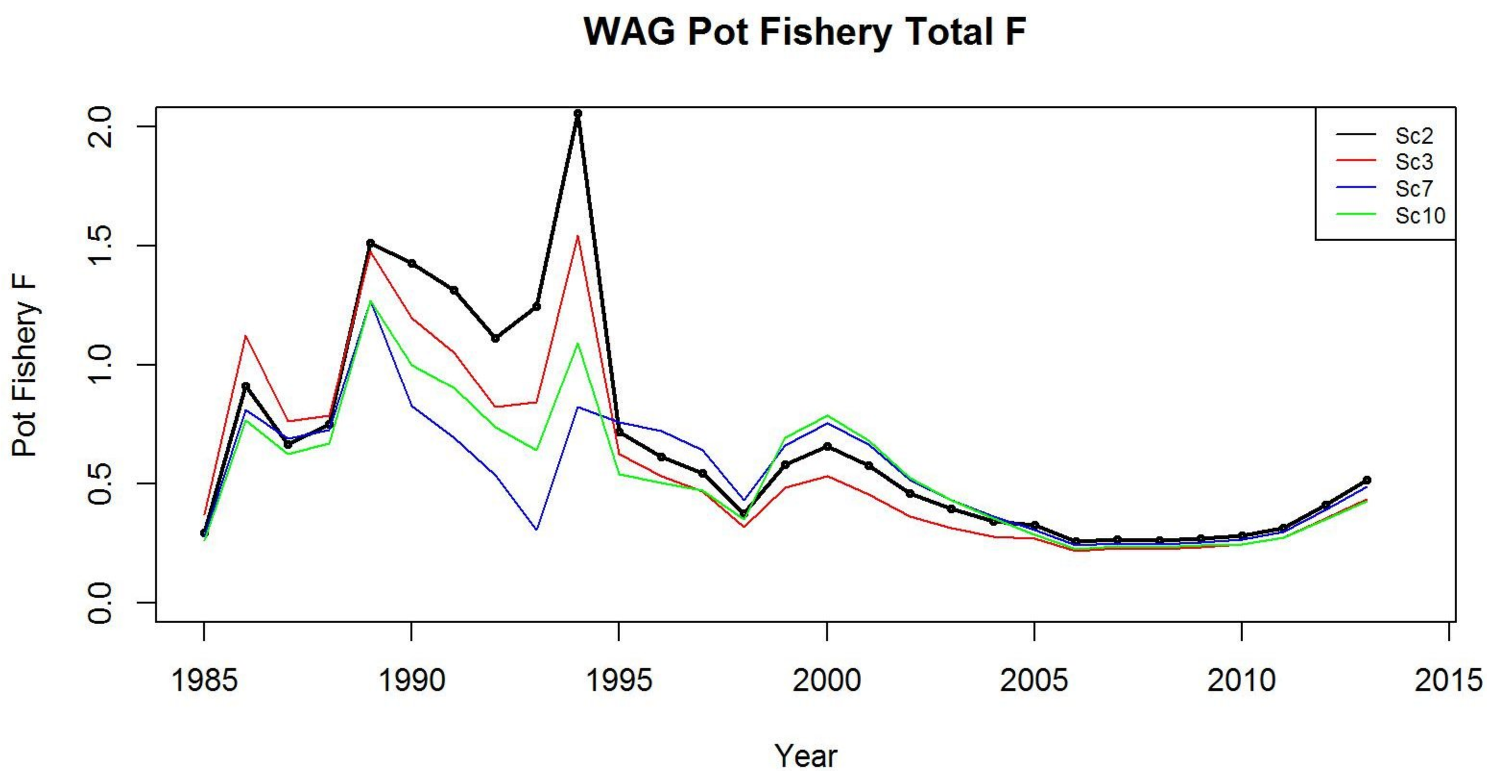


Figure 50. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the WAG, 1985–2013 (note: 1985 refers to the1985/86 fishery).

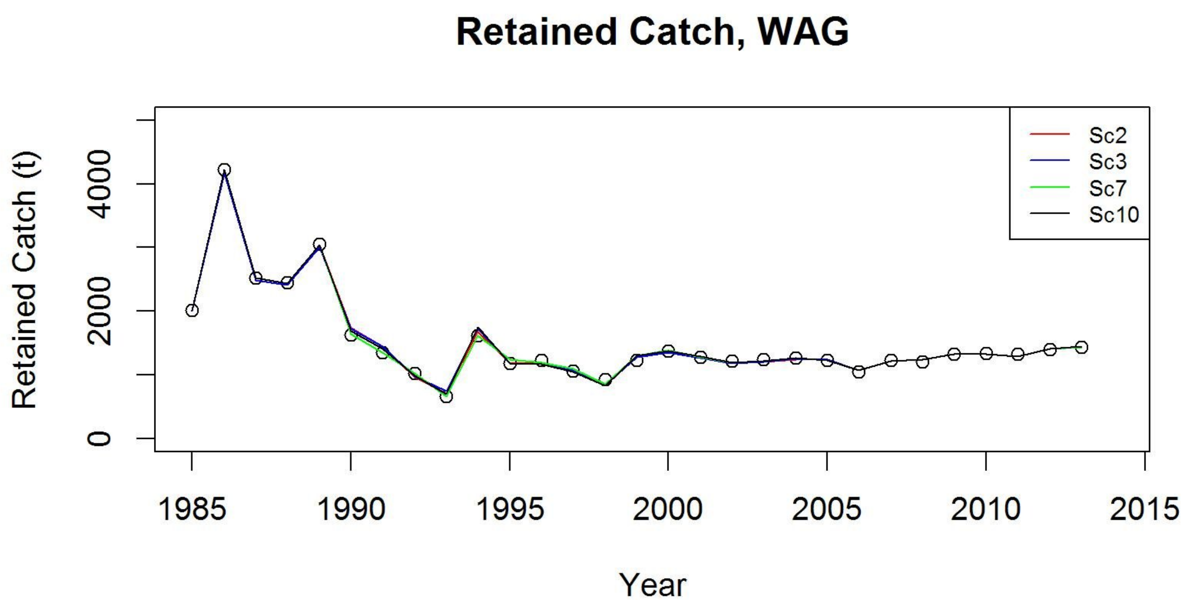


Figure 51. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the WAG, 1985–2013. (note: 1985 refers to the1985/86 fishery).

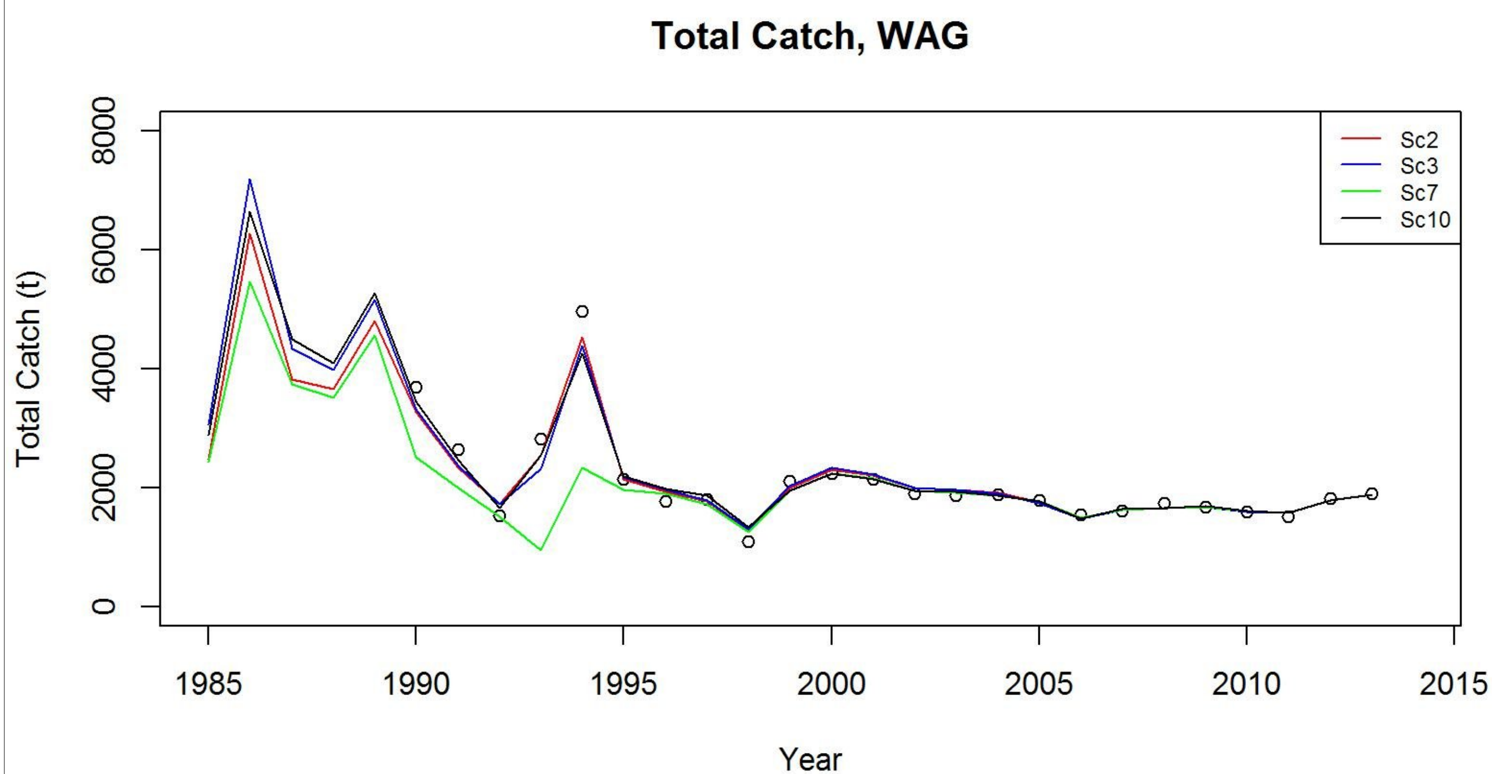


Figure 52. Observed (open circle starting from 1990) vs. predicted (solid line) total catch of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the WAG, 1985–2013. A handling mortality rate of 20% was applied to pot discarded catch and it was added to retained catch to get the total catch. (note: 1990 refers to the1990/91 fishery). Predicted total catch time series is extended from 1990/91 to 1985/86.

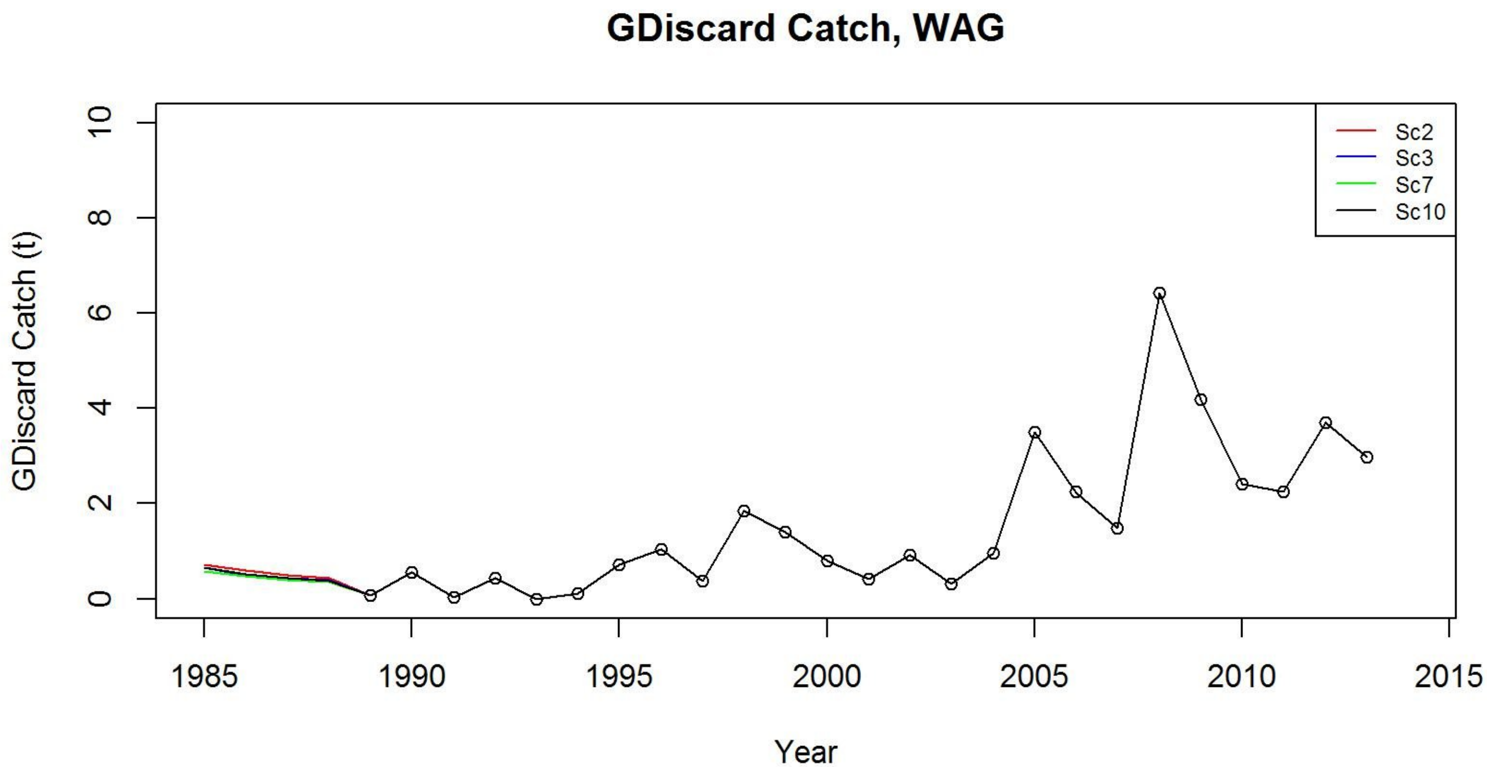


Figure 53. Observed (open circle starts from 1989) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios (Sc) 2, 3, 7, and 10 fits in the WAG, 1985–2013. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1989 refers to the1989/90 fishery). Predicted groundfish discarded catch time series is extended from 1989/90 to 1985/86.

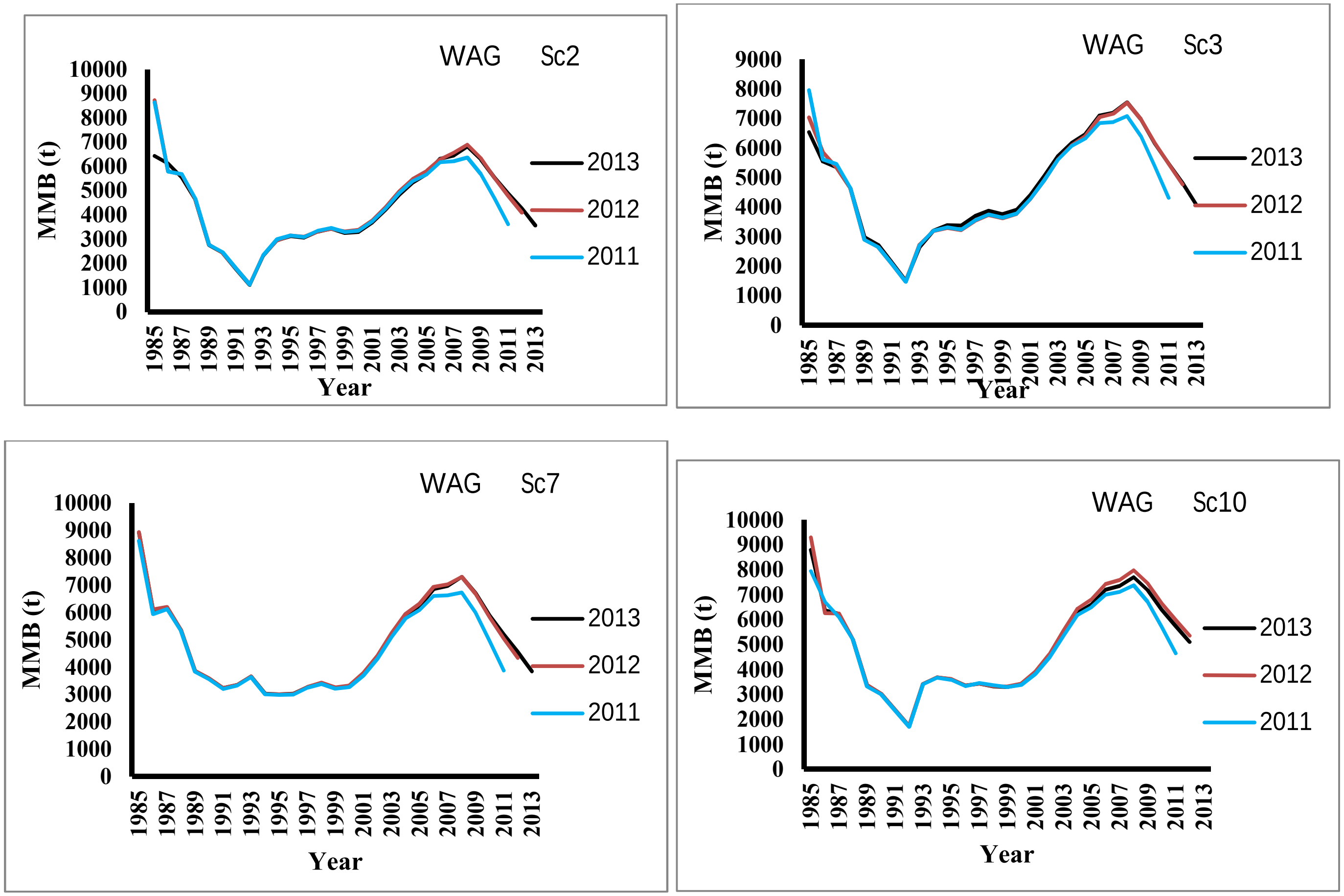


Figure 54. Retrospective fits of mature male biomass by the model when terminal year's data were systematically removed until 2008/09 for scenarios (Sc) 2, 3, 7, and 10 fits for golden king crab in the WAG, 1985–2013 (note: 1985 refers to the1985/86 fishery).

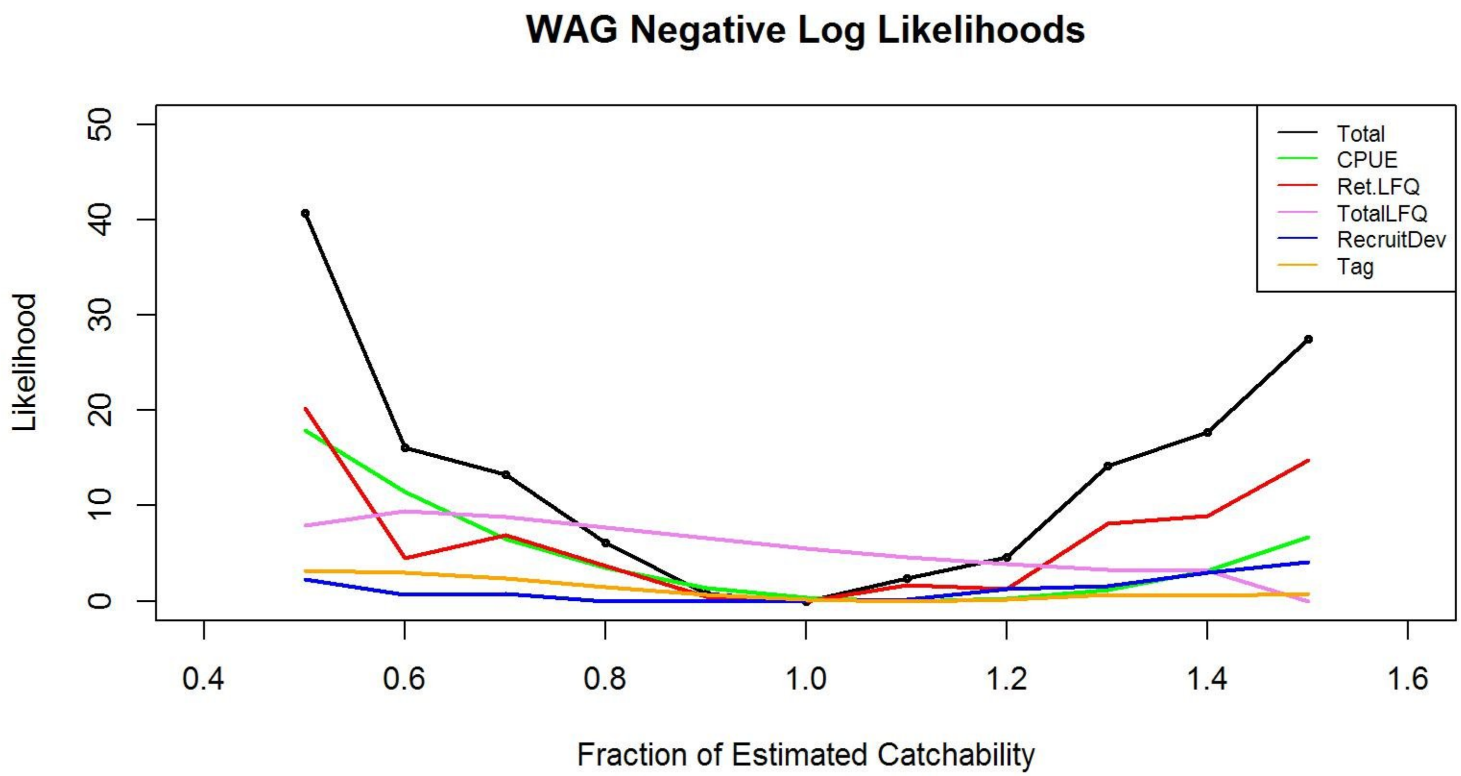


Figure 55. Total and components negative log-likelihoods vs. fractions of the estimated catchability for scenario 7 fit for golden king crab in the WAG, 1985–2013 (note: 1985 refers to the1985/86 fishery).

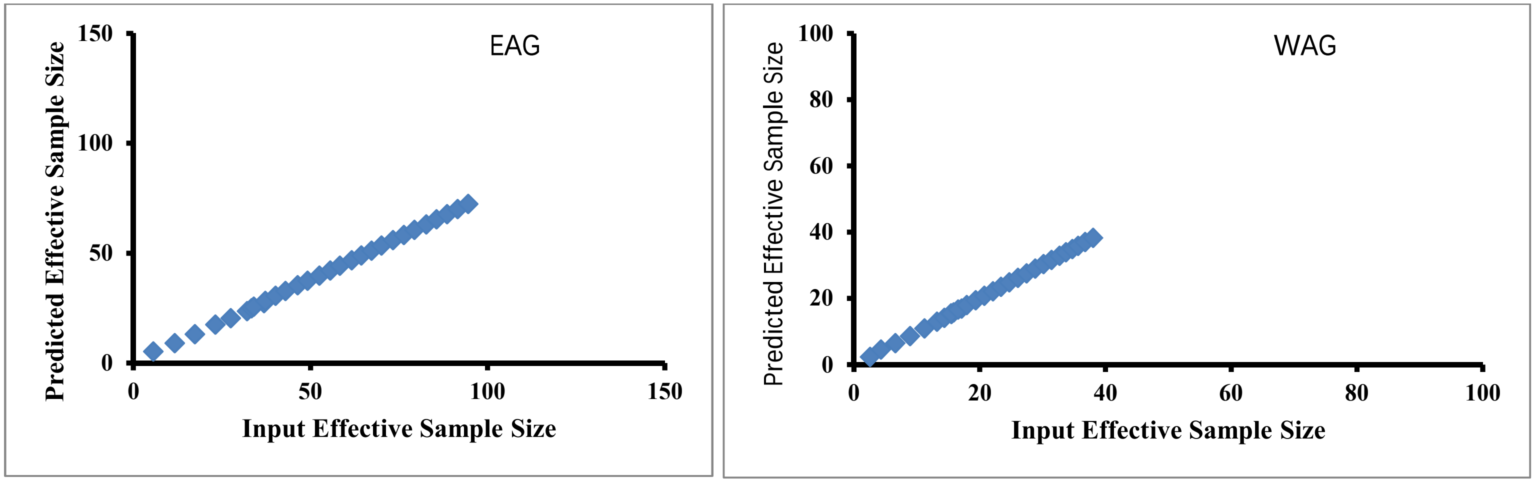


Figure 56. Predicted effective sample size vs. input calculated effective sample size for retained catch length composition for scenarios 11 fit (iterative estimation of effective sample size following Francis (2011)) to golden king crab data in the EAG and WAG, 1985/96 – 2013/14.

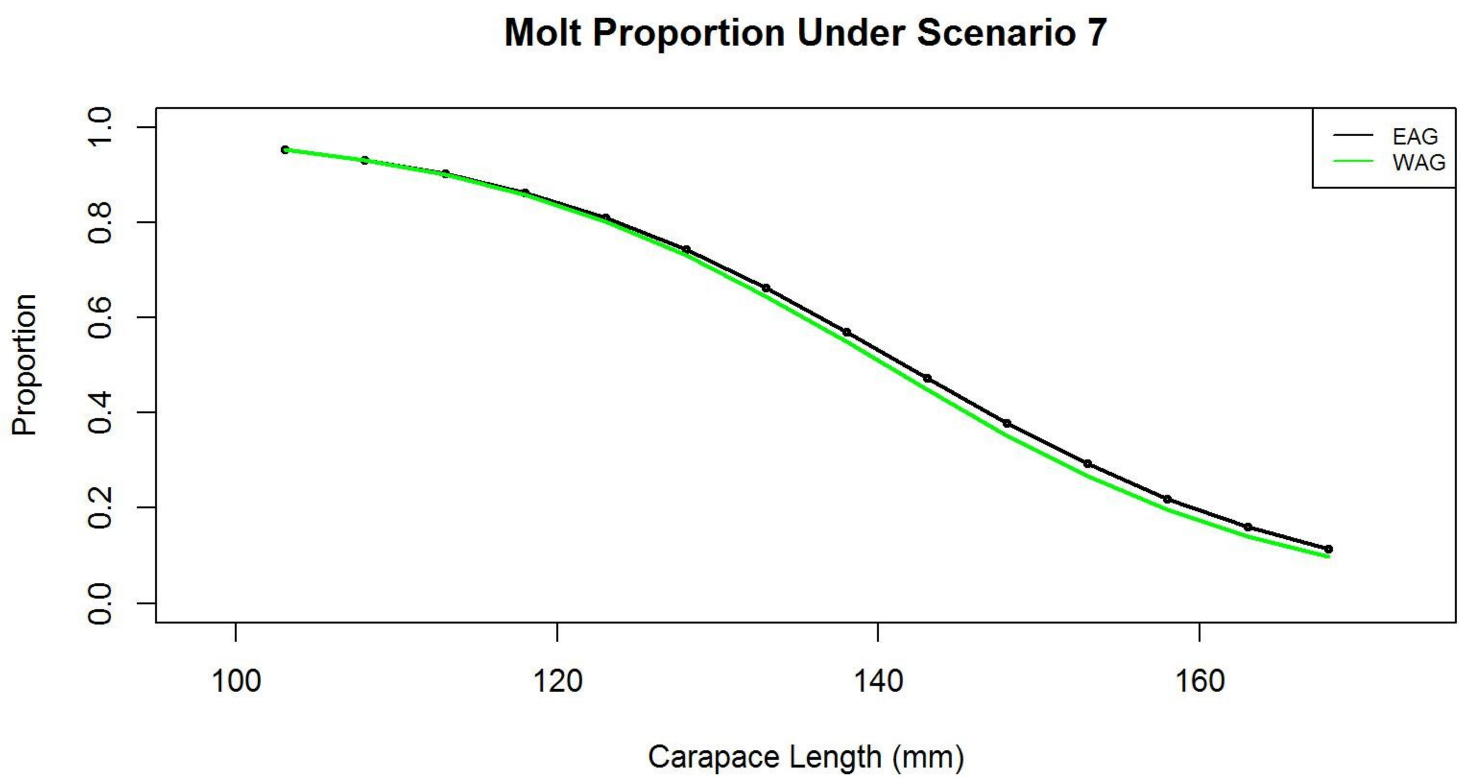


Figure 57. Estimated molt probability vs. carapace length of golden king crab under scenario 7 for EAG (black line) and WAG (green line).

Appendix A: Integrated model

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

Basic population dynamics

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

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

where $N_{t,i}$ is the number of [male] crab in length class i on 1 July (start of biological year coinciding with mid survey time) of year t; $\hat{C}_{t,i}$, $\hat{D}_{t,i}$, and ? ?? ? are respectively the predicted fishery retained, pot fishery discard dead, and groundfish fishery discard dead catches in length class i during year t; ? ? ? is estimated from the intermediate total (? ? ???? ?) catch and the retained (? ? ?) catch by 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

? ? ? ??? ? ? ?? ? ? / ? ? ? ? ? ? ? ? ? ? ? Æ − ? ? ? ? ? (2a)

? ? ? ? ?? ? ?? ? ? ? / ? ? ? ? ? ? ? ? ? ? ? Æ − ? ? ? ? ? (2b)

? ? ? ÉÆ? ? ? ??? ? − ? ? ? (2c)

? ? ? ? Ç ? ? ? ? ? ? / ? ? ? ? ? ? ? ? ? ? ? Æ − ? ? ? ? ? (2d)

? ? ? ? ? ? ? ? ? (2e)

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

? ? ? ? ? ? ? ? ? ? ? ? ? ? (3)

F_t is the full selection fishing mortality in the pot fishery, ? ? ? is the full selection fishing mortality in the trawl fishery, ? ? ? ? is the total selectivity for animals in length-class j by the pot fishery during year t, ? ? ? is the selectivity for animals in length-class j by the trawl fishery, ? ? ? ? is the probability of retention for animals in length-class j by the pot fishery during year t.

The initial conditions (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 ε_i are parameters which determine the initial (1985) length-structure (one of ε_i =0 to ensure identifiability).
In scenario 6 we used an alternative formulation described on page 332 of Quinn and Deriso (1999).

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,

? ? ? / ? ? ? ? Æ?? ? (4)

where a and b are parameters and τ_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:

??? ? ? ∫??? ?? ? ?? ?? ? ? ??? / Σ?? ? ∫??? ?? ? (? |? ? ? ?)? ? where ? (? |? ? ? ?) ? / √? ? ? ? ? ? Æ ? ? ? ? / ? (5)

??? ? ??? ? h?? ? ≠ ? / ??? (È − ? ?) ? h?? ? ? (6)

where $?_i$ is the expected growth increment (?? ? ? ? ???), ω_1, ω_2, and ? are parameters, and j_1 and j_2 are the lower and upper limits of the receiving length interval j (in mm CL), τ_i is the mid-point of the contributing length interval i, which is ≪ j, and n is the total number of receiving length intervals.

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

?? ? / ?? ? ?? ?? Æ ? ??? ??? / ??? ??? ? (7)

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

Recruitment

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

??? ? ??? ?? ? ? ? ? ?? ?−È ? ? ? / ? ? ?? Γ Æ ? (8)

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

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

Tables A2a and A2b 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:

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

?? ?? ??? ? ? ∑? Ú Æ∑? ? ? ? ? ? ? − Ú Æ∑? ? ? ? ? ? ? ? (9b)

?? ?? ??? ? ? ? ∑? Ú Æ∑? ? ? ? ? ? ? ? − Ú Æ∑? ? ? ? ? ? ? ? ? (9c)

where λ_r, λ_T and λ_{GD} are weights assigned to likelihood components for the retained, pot total and groundfish discard catches; w_j is the average mass of a crab is size-class *j*; $C_{t,j}$, ? ? ?, and ? ? ? ? are, respectively, the observed numbers of crab in size class *j* for retained, pot total, and groundfish fishery discarded crab during year *t*.

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:

?? ?? ? ? ? ????? ? Ë ∑? Ú ?É? ?? ? ? ? ? ?? ∑? ??? Æ? ? ? ? ? ? ? ?? Æ? ? ? ? ? ? ? ? / ??? ? ? ? ? ? ? ? (10)

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

?? ? ? ?? ? ? ∑? ?? ?? ?? ? ? − ?É?? ? ? ?? ? ? ? ? ? ? ??? ? ? ? (11)

where q_t is the catchability coefficient for year *t*, σ_e is the extent of over-dispersion, *c* is a small constant to prevent zero values (0.001), and ? ? ? ? ? ? is the weight assigned to the catch-rate data.

Length-composition data

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

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

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.:

?? ? ? = ?? ? ? / ∑? ?? ? ?

?? ? ? = ?? ? ? / ∑? ?? ? ?

??? ? ? = ? ? ? ? / ∑? ? ? ? ?

(13)

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

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

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

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

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

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

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

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

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

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

Penalties

Penalties are imposed on the deviations of annual pot fishing mortality about mean pot fishing mortality, annual trawl fishing mortality about mean trawl fishing mortality, recruitment about mean recruitment, average pot fishing mortality about a fixed F value k, and the posfunction :

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

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

$$P_3 = \lambda_R \sum_t (\ell n \varepsilon_t)^2 \tag{20}$$

?? ?? ??? Æ? – ? ? (21)

?? ?????? * ???? (22)

Standardized Residual of Length Composition

??? Ç? ??? ? ??? ??? / ? ??? ?? (23)

Output Quantities

Harvest rate

Total pot fishery harvest rate:

? ? Σ?? ? ??? ? ? ? ? ? ? ? / Σ?? ? ? ? ? (24)

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

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

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:

? ? ? ? Σ?? ? ??? ?? ??? ? ? ??^{? ?} − Æ? ? ? ? ? ? ? ? ? ? ?^{(? ? ? ? ?)?} ? ? (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 $MMB_t > 0.25 M\overline{M}B$,

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

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

where γ is a constant multiplier of M, α is a parameter, and $M\overline{M}B$ is the mean mature male biomass estimated for a selected time period and used as a the ? ? ?? ????? 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 applied 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, ε_i	*n*-1
Fishing mortalities	
Pot fishery, F_t	1985–2013
Mean pot fishery fishing mortality, $\overline{F}$	1
Trawl fishery, F_t^{Tr}	1989–2013 (the mean F for 1989 to 1994 was used to project back the trawl discards up to 1985.
Mean trawl fishery fishing mortality, $\overline{F}^{Tr}$	1
Selectivity and retention	
Pot fishery total selectivity ???	2 (1985–2004; 2005+)
Pot fishery total selectivity difference, ??????	2 (1985–2004; 2005+)
Trawl fishery selectivity ????	1
Trawl fishery selectivity difference ???????	1
Pot fishery retention ???	2 (1985–2004; 2005+)
Pot fishery retention difference ??????	2 (1985–2004; 2005+)
Growth	
Expected growth increment, ω_1, ω_2	2
Variability in growth increment, ?	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}

Table A1 continued

Recruitment	
Distribution to length-class, α_r, β_r	2
Recruitment deviations, ε_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**	**Scenario5**	**Scenario6**	**Scenario7**	**Scenario8**
Catch:							
Retained catch. λ_r	500 (0.032)	500	500	500	500	500	500
Total catch, λ_D	300(0.041)	300	300	300	300	300	300
Groundfish catch, λ_{GD}	5(0.324)	5	5	5	5	5	5
Catch-rate:							
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$ 1995–2012	1(0.805)	1	1	1	1	1	1
Fish ticket legal size crab catch-rate, $\lambda_{r,CPUE}$ 1985–1998			2(0.533)				
Penalty weights:							
Mean pot fishing mortality, ??? ???	Initially 1000(0.022), relaxed to 0.001 (very large) at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Recruitment, λ_R	1.5(0.629)	1.5	1.5	1.5	1.5	1.5	1.5
Tagging likelihood	1(0.805)	1	1	1	1	1	1

Table A2a continued.

Weight	Value		
	Scenario 9	**Scenario 10**	**Scenario 11**
Catch:			
Retained catch. λ_r	500 (0.032)	500	500
Total catch, λ_D	300(0.041)	300	300
Groundfish catch, λ_{GD}	0	5	5
Catch-rate:			
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$			
1995–2012	1(0.805)	1	1
Penalty weights:			
Mean pot fishing mortality, ??? ???	Initially 1000(0.022), relaxed to 0.001 (very large) at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	0	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Recruitment, λ_R	1.5(0.629)	1.5	1.5
Tagging likelihood	1(0.805)	1	1

* ?????????? ?? ???????? ?? ? ??6? ????? – È

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. λ_r	500 (0.032)	500	500	500	500	500	500
Total catch, λ_D	300(0.041)	300	300	300	300	300	300
Groundfish catch, λ_{GD}	5(0.324)	5	5	5	5	5	5
Catch-rate:							
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$ 1995–2012	1(0.805)	1	1	1	1	1	1
Fish ticket legal size crab catch-rate, $\lambda_{r,CPUE}$ 1985–1998			4(0.365)				
Penalty weights:							
Mean pot fishing mortality, ??? ???	Initially 1000(0.022), relaxed to 0.001 (very large) at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Recruitment, λ_R	1.5(0.629)	1.5	1.5	1.5	1.5	1.5	1.5
Tagging likelihood	1(0.805)	1	1	1 (Adak tagged)	1	1	1

Table A2b continued.

Weight	Value			
	Scenario 8	**Scenario 9**	**Scenario 10**	**Scenario 11**
Catch:				
Retained catch. λ_r	500 (0.032)	500	500	500
Total catch, λ_D	300(0.041)	300	300	300
Groundfish catch, λ_{GD}	5	0	5	5
Catch-rate:				
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$				
1995–2012	1(0.805)	1	1	1
Penalty weights:				
Mean pot fishing mortality, ??? ???	Initially 1000(0.022), relaxed to 0.001 (very large) at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at the final phase	0	Initially 1000, relaxed to 0.001 at the final phase	Initially 1000, relaxed to 0.001 at the final phase
Recruitment, λ_R	1.5(0.629)	1.5	1.5	1.5
Tagging likelihood	1(0.805)	1	1	1