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

Draft report for the Sep 2015 Crab Plan Team Meeting

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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 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 3.150 and 2.835 million pounds for the two respective regions beginning with 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 most recent crab management plan. The TACs were further increased by another BOF decision to 3.310 million pounds for EAG and 2.980 million pounds for WAG beginning with the 2012/13 fishery. The fishery has harvested close to TAC levels since 1996/97. Catch rates increased in both EAG and WAG fisheries in the mid-2000s; however, in recent years WAG catch rates have declined.

3. *Stock biomass*

Estimated mature male biomass (MMB) for EAG has decreased following peak levels during the mid-1980s of the directed fishery and then increased and stabilized in recent years. Estimated MMB decreased during the last few years since 2009 in WAG. The lowest levels of MMB for EAG were observed in the 1990s and MMB consistently increased since 1998. The pattern was similar for WAG with the lowest levels of MMB in 1992–1993. Stock trends reflected the fishery standardized CPUE trends in both regions.

4. *Recruitment*

The numbers of recruits to the model size groups have fluctuated in both EAG and WAG. For EAG, the model recruitment was highest in 1990–91, and lowest in 1989, while model recruitment for WAG was highest in 1986 and lowest in 2008.

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 on February 15 each year for the period 1986 through 2015 and projects to February 15, 2016 for OFL and ABC determination. The Tier 4 approach proposes the following OFL and ABCs based on using the 1986–2015 mean MMB as the reference biomass (B_{ref}). The total OFL and ABC estimates are provided for six and five scenarios for EAG and WAG, respectively in the following four tables. For this presentation, we treat scenario 1 as the base scenario.

EAG (Tier 4):

Biomass, total OFL, and ABC for 2015/16 in million pounds.

Seenario	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)
1	4a	13.012	21.464	1.65	0.18	1986–2015	0.18	2.937	2.922	2.643
2	4a	13.174	22.045	1.67	0.18	1986–2015	0.18	2.907	2.890	2.616
3	4a	13.164	21.792	1.66	0.18	1986–2015	0.18	3.008	2.993	2.707
5	4a	12.976	21.595	1.66	0.18	1986–2015	0.18	2.915	2.900	2.624
11	4a	14.032	25.318	1.80	0.18	1986–2015	0.18	3.545	3.533	3.191
12	4a	13.875	21.433	1.54	0.18	1986–2015	0.18	3.000	2.984	2.700

Biomass in 1000 t; total OFL and ABC ABC for 2015/16 in t.

Scenario	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)
1	4a	5.902	9.736	1.65	0.18	1986–2015	0.18	1332.297	1325.536	1199.067
2	4a	5.976	10.000	1.67	0.18	1986–2015	0.18	1318.433	1310.868	1186.590
3	4a	5.971	9.885	1.66	0.18	1986–2015	0.18	1364.512	1357.841	1228.061
5	4a	5.886	9.796	1.66	0.18	1986–2015	0.18	1322.240	1315.253	1190.016
11	4a	6.365	11.484	1.80	0.18	1986–2015	0.18	1608.141	1602.439	1447.327
12	4a	6.293	9.722	1.54	0.18	1986–2015	0.18	1360.979	1353.684	1224.881

WAG (Tier 4):

Biomass, total OFL, and ABC in million for 2015/16 in million pounds.

Scenario	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)
1	4a	10.740	10.880	1.01	0.18	1986–2015	0.18	1.612	1.607	1.451
2	4a	11.255	11.574	1.03	0.18	1986–2015	0.18	1.683	1.678	1.515
5	4a	10.894	11.004	1.01	0.18	1986–2015	0.18	1.593	1.589	1.434
11	4b	10.742	10.355	0.96	0.179	1986–2015	0.18	1.549	1.545	1.394
12	4a	10.376	11.102	1.07	0.18	1986–2015	0.18	1.635	1.631	1.471

Biomass in 1000 t; total OFL and ABC for 2015/16 in t.

Scenario	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)
1	4a	4.872	4.935	1.01	0.18	1986–2015	0.18	731.094	729.057	657.985
2	4a	5.105	5.250	1.03	0.18	1986–2015	0.18	763.354	761.349	687.019
5	4a	4.941	4.991	1.01	0.18	1986–2015	0.18	722.709	720.631	650.438
11	4b	4.873	4.697	0.96	0.179	1986–2015	0.18	702.795	700.701	632.516
12	4a	4.707	5.036	1.07	0.18	1986–2015	0.18	741.492	739.817	667.343

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 2015 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 for 2015/16 in million pounds.

Scenario	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to define B_{ref}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
1	3a	15.807	19.677	1.24	0.37	1986–2015	0.37	5.593	5.565	5.034
2	3a	15.987	20.092	1.26	0.39	1986–2015	0.39	5.795	5.762	5.216
3	3a	15.831	19.885	1.26	0.37	1986–2015	0.37	5.726	5.698	5.153
5	3a	15.599	19.731	1.26	0.38	1986–2015	0.38	5.681	5.651	5.113
11	3a	16.408	22.630	1.38	0.36	1986–2015	0.36	6.581	6.558	5.923
12	3a	16.021	19.676	1.23	0.36	1986–2015	0.36	5.574	5.545	5.017

Biomass in 1000 t; total OFL and ABCfor 2015/16 in t.

Scenario	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)
1	3a	7.170	8.926	1.24	0.37	1986–2015	0.37	2536.988	2524.280	2283.289
2	3a	7.252	9.114	1.26	0.39	1986–2015	0.39	2628.684	2613.711	2365.816
3	3a	7.181	9.020	1.26	0.37	1986–2015	0.37	2597.073	2584.590	2337.365
5	3a	7.076	8.950	1.26	0.38	1986–2015	0.38	2576.730	2563.164	2319.057
11	3a	7.443	10.265	1.38	0.36	1986–2015	0.36	2985.267	2974.867	2686.740
12	3a.	7.267	8.925	1.23	0.36	1986–2015	0.36	2528.319	2515.104	2275.487

WAG (Tier 3):

Biomass, total OFL, and ABC for 2015/16 in million pounds.

Scenario	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)
1	3b	12.987	11.407	0.88	0.28	1986–2015	0.32	2.384	2.378	2.146
2	3b	13.151	11.848	0.90	0.29	1986–2015	0.33	2.620	2.614	2.358
5	3b	12.742	11.436	0.90	0.29	1986–2015	0.33	2.474	2.467	2.227
11	3b	12.914	11.026	0.85	0.27	1986–2015	0.32	2.228	2.222	2.005
12	3b	13.047	11.586	0.89	0.28	1986–2015	0.32	2.438	2.428	2.194

Biomass in 1000 t; total OFL and ABC for 2015/16 in t.

Scenario	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)
1	3b	5.891	5.174	0.88	0.28	1986–2015	0.32	1081.579	1078.588	973.421
2	3b	5.965	5.374	0.90	0.29	1986–2015	0.33	1188.485	1185.487	1069.636
5	3b	5.780	5.187	0.90	0.29	1986–2015	0.33	1122.220	1119.024	1009.998
11	3b	5.858	5.002	0.85	0.27	1986–2015	0.32	1010.732	1007.884	909.659
12	3b	5.918	5.256	0.89	0.28	1986–2015	0.32	1105.858	1101.470	995.273

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 2014/15 commercial fishery retained and total catch, observer nominal total CPUE and fishing effort (pot lifts) to calculate total catches for 1990/91–2014/15, and groundfish male discard mortality by size for 1989/89–2013/14 were recalculated. The commercial retained size frequency and observer sample size frequency data were calculated 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 were considered for the WAG model analysis. 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 were standardized by the generalized linear model (GLM) with the negative binomial link function, separately for 1995/96–2004/05 and 2005/06–2014/15 periods, and for the whole time period (details in the September 2013 CPT presentation on CPUE standardization method). The 1995/96 to 2014/15 time series as a whole was used in model scenario 11.

(d) Fish ticket retained catch CPUE were standardized by the GLM using a lognormal link function considering a suite of explanatory variables. The 1985–1998 data were used in the fit and the indices were used in model 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 2015 CPT comments

The CPT reviewed the model in detail during the May 2015 CPT meeting. So, we present the responses to their comments:

CPT Notes: The assessment author addressed most of the issues raised by the CPT, though several follow-up recommendations are identified below. On the whole, considerable progress has been made in model development for AIGKC. The tasks that now occupy the CPT consist of recommending relatively minor tweaks and sensitivity analyses to better understand model performance. The draft assessment achieves a good fit to the composition data and an adequate fit to the CPUE indices. The assessment model does not show strong retrospective patterns. A likelihood profile indicated that the CPUE index is most important data for determining catchability for both eastern and western models, and thus determines the scale of the population. However stock assessments using an index of abundance often depend on relatively subtle features of the data, and it is unclear what those features are at present. The standardized abundance indices are relatively flat throughout the entire period. The draft assessment does estimate relatively high fishing mortalities in the period prior to establishing the GHL, however high fishing mortalities have been estimated for other pot fisheries in Alaska. Whether or not estimated fishing mortalities are unrealistically high is a factor that will need to be considered when evaluating whether or not to accept the model?

The CPT has the following **recommendations** for the September 2015 CPT meeting:

- Include results from the CPUE standardization in the assessment document.

  Response: we have included diagnostic plots for EAG and WAG CPUE standardization (Figures 8–10 for EAG and 36–38 for WAG).

- Use the improved set of equations for fishing mortality for all models.

  Response: We have modified the Z formula as per CPT suggestion in the current analyses (see Appendix A). We compared the F and MMB distributions between the old formula and the modified formula. The differences are minor (see Figure 67).

- Explore methods for standardizing the commercial fishery retained CPUE indices using available information.

Response: We have scoped a number of predictor variables (e.g., Year, Vessel, Captain, Area, and Month) in the model selection by lognormal GLM.

- Total catch estimates should be given weights based on the observer sample sizes when model fitting.

  Response: We have used the number of pots sampled scaled to a maximum of 300 as weights to the total catch biomass likelihood.

- Provide likelihood profiles with results re-expressed with other variables (e.g. current biomass) on the x-axis.

  Response: We investigated the component likelihoods against terminal MMB (Figure 34 for EAG and Figure 63 for WAG).

- If possible do profile on current MMB and not catchability. Since MMB is model output and not a parameter, this is usually done by forcing the model to fit a pseudo survey in the final year and varying the survey values.

  Response: Please refer to the above response. We did.

- Provide a sensitivity analysis to potential changes in catchability and selectivity in the CPUE time series. Results should be compared for the following alternatives: Alternative 1—no changes in selectivity or catchability, Alternative 2—One break in catchability/selectivity for post rationalization period, Alternative 3—Two catchability/selectivity breaks, one break in 1999 and another post-rationalization. Provide likelihood profiles as described above for each alternative.

  Response: We followed the suggestions as different scenarios in this analysis. We provide component likelihoods for selected scenarios.

- Provide additional plots to evaluate the fit to the tagging data:
  - Plot observed tag recaptures vs. predicted tag recapture by year at liberty.
  - Plot the growth increment rather than size at recapture (and by year at liberty)
  - Plot the growth increment but break the lengths-at-release into groups.

    Response: We provide observed vs. predicted number of recaptures for different time-at-large and observed mean length and predicted mean length of recaptures for each release size for different time-at-large. Andre Punt provided necessary codes to do this. Thanks.

- Provide confidence intervals assuming log-normality for the quantity of interest (see Burnham et al. 1987:212)

Response: We used the ln(1+CV^2) for variance of ln(CPUE) and ln(MMB) as suggested by Burnham et al. (1987).

- Provide an analysis of sensitivity to the F penalty in model fitting. During estimation phases, relax the F penalty earlier than the final phase. Evaluate the effect of different mean F values in the F penalty term (from low to high).

  Response: We relaxed the F penalty to an earlier phase (selectivity phase) and investigated different mean F in the F penalty (scenario 7). We did not see any appreciable differences in the OFL estimates (Table 31).

- The model currently initializes by estimating the abundance by length category in the first year. To evaluate sensitivity to this method, compare this method to an approach that assumes some average level of recruitment to populate the initial size composition.

  Response: We considered the equilibrium condition as one scenario (scenario 8) for EAG and all scenarios for WAG. Appendix A provides the equilibrium condition estimation procedure.

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 last approximately 24 months 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 (Webb 2014), but 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 were 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 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). In the model scenarios, a knife-edge 50% maturity length of 121 mm CL was used for mature male biomass (MMB) estimation. Daily catch and catch-per-unit effort (CPUE) are determined in-season to monitor fishery performance and progress towards the respective TACs. 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 during the late 1990s through the early 2000s, and with the implementation of crab rationalization in 2005. This is likely due to changes in gear in the late 1990s (crab fishermen, personal communication, July 1, 2008) and, after rationalization, to increased soak time (Figure 6), and decreased competition owing to the reduced number of vessels fishing. Decreased competition could allow crab vessels to target only the most productive fishing areas. In 2012, the BOF increased the TAC levels to 3.31 million pounds for EAG and 2.98 million pounds for WAG beginning with the 2012/13 fishery.

D. Data

1. Summary of new information:

Data are updated by adding the 2014/15 commercial fishery retained and estimated total catch by size, and observer CPUE by size to the time series. Because of time constraints, we used the 1989/90 to 2013/14 estimated male groundfish discard mortality by size and did not add the 2014/15 data.

2. Available catch and tagging data.

Data set	**Years**	**Data type(s)**
Retained pot catch	1985/86–2014/15	Catch by length
Total pot catch	1990/91–2014/15	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	1995/96–2014/15	Independently 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 (by lognormal GLM). This series is used in scenario 3
Tag-recapture data	EAG: 1991, 1997, 2000, 2003, 2006	Release-recapture length and time-at-large - 1717 records
	WAG: 1980s	Release-recapture length and time-at-large - 64 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 11 a, b; 12 a, b; 13 a, b; 69 a, b; 70 a, b; 39–44; and 71 a, b).

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

f. Other time series data: None.

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

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

Catch and CPUE data

The commercial catch and length frequency distribution were estimated from ADF&G landing records and dockside sampling (Bowers et al. 2008, 2011). The annual retained catch, total catch, and groundfish discard 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 each sampled vessel's catch as follows. The *i*-th length-class frequency was estimated as:

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

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

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

Observer data have been collected since 1988 (Moore et al. 2000; Barnard et al. 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91–2014/15 was selected for this analysis. During 1990/91–1994/95, observers were only deployed on catcher-processor vessels. During 1995/96–2004/05, observers were deployed on all fishing vessels during their fishing activity. Observers have been deployed on all fishing vessels since 2005/06, but catcher-only vessels are required to carry observers for a minimum of 50% of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity. Onboard observers count and measure all crab caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crab were estimated considering all sampled pots within each season (Tables 2 and 17). For model-fitting the CPUE time series was further restricted to 1995/96–2014/15 because the reliability of categorization of crab by observers improved after

1995. Length-specific CPUE data collected by observers provides information on a wider size range of the stock than did the commercial catch length frequency data obtained from mostly legal-sized landed males.

There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9” since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two catchabilities and total selectivities with only one retention curve for the periods 1985/86–2004/05 and 2005/06–2014/15.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE as a separate likelihood component in scenario 3. Because of the lack of soak time data previous to 1990, we estimated the CPUE index considering a limited set of explanatory variables (e.g., vessel, captain, area, month) and fitting the lognormal GLM to fish ticket data (Tables 3 and 18). For this scenario, we considered two catchabilities and total selectivities and one retention curve. For scenario 2, we considered three catchabilities and total selectivities, and one retention curve.

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 discard mortality, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, groundfish discard mortality 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 2014/15 for retained catch biomass and size composition; 1995/96 to 2014/15 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 2014/15 for total catch biomass and length composition; 1989/90 to 2013/14 for groundfish fishery male bycatch mortality 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, assumed directed pot fishery discard mortality proportion at 0.20, assumed groundfish fishing mortality proportion at 0.65, groundfish fishery selectivity at full selection for all length classes (selectivity = 1), and discard of legal size males in the directed pot fishery was 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 2. For most scenarios, we assumed two different q's and two total selectivity (pre- and post-rationalization periods) and only one retention curve 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:

Observer CPUE index:

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

$$\ln(CPUE_i) = Year_{y_i} + \varepsilon_i \quad (2)$$

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

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

where *ns*=cubic spline , *df* = degree of freedom, and all variables are self-explanatory.

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:

$$\ln(CPUE) = Year + Gear + Captain + ns(Soak, 3) \quad (4)$$

for the 1995–2004 period (θ=1.33, $R^2 = 0.23$ with ns(Soak, 3) forced in)

$$\ln(CPUE) = Year + Captain + ns(Soak, 16) + Gear \quad (5)$$

for the 2005–2014 period ($\theta = 2.25$, $R^2 = 0.11$).

The final models for WAG were:

$$\ln(CPUE) = Year + Captain + Gear + ns(Soak, 8) \quad (6)$$

for the 1995–2004 period (θ=0.98, $R^2 = 0.18$), and

$$\ln(CPUE) = Year + Captain + Gear + ns(Soak, 16) \quad (7)$$

for the 2005–2014 period (θ=1.16, $R^2 = 0.05$ with ns(Soak, 16) forced in)

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

We also fitted the entire time series (1995/96 – 2014/15) of observer CPUE data by the negative binomial GLM. Table 32 provides support to use the entire time series. Because of high variability of individual observer CPUE, the interactions were not significant.

The final model for EAG was:

$$\ln(CPUE) = Year + Gear + Captain + ns(Soak, 7) \quad (8)$$

with $\theta = 1.42,\ R^2 = 0.36$

The final model for WAG was:

$$\ln(CPUE) = Year + Captain + ns(Soak, 16), + Gear, \quad (9)$$

with $\theta = 1.16,\ R^2 = 0.27$

Figures 7 and 35 depict the trends in nominal and standardized CPUE indices for EAG and WAG, respectively. Figures 8–10 and 36–38 show the diagnostic plots for all the fits for EAG and WAG, respectively.

Fish Ticket CPUE index:

We also fitted the lognormal GLM for fish ticket retained CPUE time series 1985/86–1998/99 offering year, month, vessel, captain, and area as explanatory variables. The final model for EAG was:

$$\ln(CPUE) = Year + Captain + Vessel,\ R^2 = 0.45 \quad (10)$$

and for WAG was:

$$\ln(CPUE) = Year + Captain + Vessel, \; R^2 = 0.46 \quad (11)$$

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

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 12 scenarios for EAG (details are in Table 4) and 11 scenarios for WAG (details are in Table 19). We presented OFL and ABC results for preferred six and five scenarios for EAG and WAG, respectively.

The preferred scenarios are:

Scenario 1: Two catchabilities, two total selectivities, and a single retention curve. The molt probability model is included in the size transition matrix calculation;

Scenario 2: Three catchabilities, three total selectivities, and a single retention curve. The molt probability model is included in the size transition matrix calculation;

Scenario 3: Same as scenario 1, with an additional commercial fishery standardized CPUE likelihood component;

Scenario 5: Same as scenario 1, but disregarding pre-1996/97 for EAG and pre-1995/96 for WAG total size composition and total catch;

Scenario 11: One catchability, two total selectivities, and a single retention curve. The molt probability model is included in the size transition matrix calculation. The observer CPUE indices are estimated using the whole time series of data without any break point.

Scenario 12: Same as scenario 1, but groundfish bycatch mortality data are excluded in the model fit.

b. The entire time period 1985/86–2014/15 was used to define $B_{current}/B_{ref}$ (Tier 4) and the 1986–2015 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 a few 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/specific information. We fixed a number of model parameters after initially running the model with free parameters to reduce the number of parameters to be estimated (e.g., groundfish bycatch selectivity parameters were fixed). The twelve/eleven scenarios also considered different configuration of parameters to select the parsimonious models. The detailed results of some of the preferred scenarios are provided in tables and figures. The total and retained catch OFLs for all scenarios are provided in Table 31.
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, 200) for retained catch, min (0.001*observed sample size, 150) for total catch, and min (0.1*observed sample size, 25) for groundfish bycatch mortality (see Tables 4 and 19 for details). We estimated the predicted effective sample size from estimated input effective sample size as follows:

$$n_y = \sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l}) / \sum_l (P_{y,l} - \hat{P}_{y,l})^2 \qquad (12)$$

where $\hat{P}_{y,1}$ and $P_{y,l}$ are estimated and observed size compositions in year y and length class l, respectively. We plotted the predicted effective sample sizes against the input effective sample sizes. We used the above formula to iteratively reweight the effective sample sizes in scenario 6.

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 compare various models: CPUE fits, observed vs. predicted tag recapture numbers by time-at-large and release size, observed and predicted mean lengths by time-at-large and release length class, and catch and bycatch fits. Figures are provided for some preferred 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 a number of preferred 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 14 and 45 for retained catch, 15 and 46 for total catch, and 16 and 47 for groundfish discard mortality for EAG and WAG, respectively. The line passing through the plot is the 1:1 line and in some cases the points are equally spread on both sides of the line indicating that the input effective sample sizes are reasonable for the preferred 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 for scenario 1 (Figure 64).

We used weighting factors (corresponding standard errors are included in parentheses) for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. We set the CPUE weights to 1 for all scenarios because additional variance components in the likelihoods should address under-estimation of sampling variance. We used the Burnham et al. (1987) suggested formula for ln(CPUE) [and ln(MMB)] variance estimation (Equation 15, Appendix A), 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 are in Tables 5 and 6 for EAG and 20 and 21 for WAG for four arbitrarily selected scenarios from preferred scenarios, 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 four arbitrarily selected scenarios from preferred scenarios 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 4 did not consider the 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 molt 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 matrices for the four arbitrarily selected scenarios are summarized in Tables 7–10 for EAG and in Tables 22–25 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 arbitrarily selected scenarios are summarized in Tables 11–14 for EAG and Tables 26–29 for WAG.

d. The recruitment estimates for the four arbitrarily selected scenarios are summarized in Tables 11–14 for EAG and Tables 26–29 for WAG.

e. The likelihood component values and the total likelihood values for the four arbitrarily selected scenarios are summarized in Table 15 for EAG and Table 30 for WAG.

3. Graphs of estimates:

a. Total selectivity and retention curves of the pre- and post-rationalization periods for the four arbitrarily selected scenarios are illustrated in Figure 17 for EAG and Figure 48 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 mortality (Figures 13a and 13b, and 43 and 44, for scenarios 2 and 11 for EAG and scenarios 1 and 2 for WAG, respectively). Thus, we set the groundfish bycatch selectivity to 1.0 for all size-classes in the subsequent analysis.

b. The mature male biomass time series for all (9) scenarios are depicted in Figures 26 and 56 and the legal male biomass time series for four arbitrarily selected scenarios are illustrated in Figures 27 and 57 for EAG and WAG, respectively. Mature male biomass tracked the CPUE trends well for all scenarios for EAG, but for WAG, scenarios 3, 4, and 6 did not track the CPUE after 2009. The legal male biomass trends tracked the CPUE trends well for the four arbitrarily selected scenarios for both EAG and WAG. The biomass variance was estimated using Burnham et al. (1987) suggested formula (Equation 15 in Appendix A). We determined the mature male biomass values on 15 February and considered the entire time series for B_{ref} (for Tier 4 approach) and for mean number of recruits (for Tier 3 approach) calculations.

c. The full selection pot fishery F over time for six scenarios for EAG is shown in Figure 28 and for five scenarios for WAG is depicted in Figure 58. The F peaked in late 1980s and 1990s and systematically declined in the EAG and generally declined in the WAG in subsequent years, but with a slightly 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 arbitrarily selected scenarios are illustrated in Figure 24 for EAG and in Figure 54 for WAG. The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 25 and 55 for EAG and WAG, respectively for the four arbitrarily selected scenarios.

4. Evaluation of the fit to the data:

g. Fits to catches: The fishery retained, total, and groundfish bycatch mortality (observed vs. estimated) plots for the four arbitrarily selected scenarios are illustrated in Figures 29–31 for EAG and 59 – 61 for WAG. All predicted fits were very closer to observed values, especially for retained catch and groundfish bycatch mortality.

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 all (9) scenarios are shown in Figure 23 for EAG and Figure 53 for WAG. Scenario 3 tracks indices back to 1985/86. All scenarios appear to fit the CPUE indices satisfactorily except scenario 11 for EAG and scenarios 9 and 11 for WAG. The CPUE variance was estimated using Burnham et al. (1987) suggested formula (Equation 15 in Appendix A).

j. Tagging data: The predicted vs observed tag recaptures by length-class for years 1 to 6 recaptures are depicted in Figure 21 for EAG and Figure 52 for WAG. The predictions appear reasonable. Observed and predicted mean lengths of recaptures vs. release length for different periods of recaptures for EAG tagging data are tracking reasonably well (Figure 22). Note that we used the tagging information on molt probability and growth per molt from EAG in all scenarios for WAG except scenario 9.

k. Molt probability: The predicted molt probabilities vs. CLs for scenario 1 are depicted in Figure 65 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 11 a, b; 12 a, b; 13 a, b; 69 a, b; and 70 a, b for EAG for the scenarios 2, 11, 1, and 12, respectively, and in Figures 39–44, and 71 a, b for WAG for the scenarios 1, 2, and 12, 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 18 and 49 for EAG and WAG, respectively), for total catch (Figures 19 and 50 for EAG and WAG, respectively), and for groundfish discard catch (Figures 20 and 51 for EAG and WAG, respectively).
m. Marginal distributions for the fits to the composition data: We did not provide this plot in this report.
n. 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 14 and 45 for retained catch, 15 and 46 for total catch, and 16 and 47 for groundfish discard catch for EAG and WAG, respectively. The line passing through the plot is the 1:1 line and in some cases the points are equally spread on both sides of the line indicating that the input effective sample sizes seem reasonable.
o. Tables of RMSEs for the indices: We did not provide this table in this report.
p. Quantile-quantile plot: We did not provide this plot in this report.
q. Retrospective and historical analysis: The retrospective fits for the four arbitrarily selected scenarios are shown in Figure 32 for EAG and in Figure 62 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.

r. Others: Trend in estimated OFL catch against terminal MMB showed systematic increases with increases in MMB, but not proportionate under Tier 4 calculation (Figure 66). Figure 67 depicts the trends in F and MMB under the previous (i.e., May 2014 CPT presentation) Z formula and the revised Z formula. The differences are minor. Figure 68 depicts the reduction in the equilibrium size composition at the initial year (1985) of modeling for EAG and WAG. Figures 69a, 69b, 70a, and 70b show the retained and total length composition plots for scenarios 1 and 12 models respectively for EAG. Figures 71a and 71b depict the retained and total length composition plots for the scenario 12 model for WAG.

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 molt probability (additional two parameters) function (Siddeek et al. *in press*). The model fit is better when the molt probability model is included. Therefore, most of our scenarios included the molt probability model.

   We also determined likelihood values at different *q* values and terminal MMB and plotted component negative likelihood against the *q* values and MMB values, respectively. It appears that the trend in negative log likelihood of CPUE was similar to that of the total for changes in *q* (Figure 33 for EAG). The negative log total likelihood tracked well against estimated terminal MMB (Figures 34 and 63) 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 $MMB_t > 0.25 MMB_{ref}$,

$$F_{OFL} = \gamma M \frac{\left(\frac{MMB_t}{MMB_{ref}} - \alpha\right)}{(1-\alpha)} \qquad (13)$$

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

where MMB_t is mature male biomass in year t, 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 1986 to 2015. This resulted in a MMB_{ref} range of 5.886 to 6.365 thousand metric tons for EAG and 4.707 to 5.105 thousand metric tons for WAG for the preferred scenarios. The current MMB_{2014} range was 9.722 to 11.484 thousand metric tons for EAG and 4.697 to 5.250 thousand metric tons for WAG for the preferred scenarios, resulting in an F_{OFL} of 0.18 for EAG and slightly less for scenario 11 for WAG. The total OFL for EAG ranged from 1.318 to 1.608 thousand metric tons and 0.703 to 0.763 thousand metric tons for WAG for the preferred 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 the retention curve to calculate the retained catch portion of the total catch OFL. The retained catch OFLs for EAG ranged from 1,280 to 1,563 t and that for WAG ranged 657 to 717 t for the preferred 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 = 1,361t, retained catch portion of the OFL = 1,315 t (under scenario 12).

   WAG: F_{OFL} = 0.18; OFL total catch = 741 t; retained catch portion of the OFL = 696 t (under scenario 12).

Tier 3 Approach:

The critical assumptions for reference point estimation are:

a. Natural mortality is constant (0.18) over all 17 size groups.
b. Growth transition matrix is estimated using tagging data with the molt probability sub-model.
c. The catchability parameter estimate for the 2005/06-2014/15 period is used.
d. Total fishery selectivity and retention curves are length dependent and the 2005/06-2014/15 period selectivity estimates are used. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated molt probability is not time dependent, but is length dependent.
f. Model estimated recruits (in millions of crab) are averaged for the time period 1986 to 2015 (30 years).
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 were stabilized (we used the 99^{th} year estimates) for an F, we calculated the MMB/R for that F. We computed the relative *MMB/R* in percentage, $\left(\frac{MMB}{R}\right)_{x\%}$ (where x% = $\frac{\frac{MMB_F}{R}}{\frac{MMB_0}{R}} \times 100$ and MMB_0/R is the virgin *MMB/R*) for different F values.

F_{35} is the F value that produces the MMB/R value equal to 35% of MMB_0/R.

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

$MMB_{35} = \left(\frac{MMB}{R}\right)_{35} \times \bar{R}$, where $\bar{R}$ is the mean number of model estimated recruits for a selected period.

F_{OFL} is determined using Equation 13 replacing γM by F_{35} and B_{ref} by B_{35}.

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

EAG: F_{OFL} = 0.36; OFL total catch = 2,528 t, retained catch portion of the OFL = 2,440 t (under scenario 12).

WAG: F_{OFL} = 0.28; OFL total catch = 1,106 t; retained catch portion of the OFL = 1,037 t (under scenario 12).

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 1,311 to 1,602 t for EAG and 701 to 761 t for WAG for the preferred scenarios.

   Under Tier 3 approach, the ABC estimates ranged 2,515 to 2,975 t for EAG and 1,008 to 1,185 t for WAG for the preferred 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.

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Table 1. Time series of annual retained catch (number and weight of crab), estimated total male catch (number and weight of crab on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crab) (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 included cost-recovery beginning in 2013/14.

Year	Retained Catch (no.)	Retained Catch Biomass (t)	Total Catch (no.)	Total Catch Biomass (t)	Pot Fishery Effort (no. pot lifts)	Groundfish Discard Mortality(no.)	Groundfish Discard Mortality (t)
1985	1251267	2695			117718		
1986	1374943	2818			155240		
1987	968614	1893			146501		
1988	1156046	2397			155518		
1989	1419777	2753			155262	388	0.61
1990	892699	1632	1148518	1422	106281	1190	1.98
1991	1083243	2018	4385096	5910	133428	0	0.00
1992	1127291	2115	4331508	5589	133778	779	1.01
1993	767918	1415	NA	NA	106890	719	0.95
1994	1086560	2029	1712658	2001	191455	311	0.29
1995	1150168	2211	2742782	3742	177773	569	0.78
1996	848045	1615	1452362	2064	113460	46	0.04
1997	780481	1474	1788351	2555	106403	76	0.10
1998	740011	1407	2011777	2804	83378	587	0.76
1999	709332	1329	1556398	2287	79129	284	0.35
2000	704363	1352	1706999	2564	71551	387	0.47
2001	730030	1394	1352904	2105	62639	934	1.47
2002	643668	1236	1119586	1808	52042	707	0.68
2003	643074	1287	1111206	1825	58883	392	0.43
2004	637536	1261	965443	1627	34848	59	0.12
2005	623971	1262	927444	1724	24569	252	0.28
2006	650587	1375	860688	1632	26195	679	0.70
2007	633253	1316	911185	1802	22653	697	0.69
2008	666947	1406	929694	1799	24466	808	0.85
2009	679886	1433	936938	1761	26298	718	1.14
2010	670698	1398	935574	1729	25851	2415	2.41
2011	668828	1428	920866	1747	17915	1208	1.15
2012	687666	1482	990519	1939	20827	2058	3.61
2013	720220	1529	978645	1829	21388	274	0.71
2014	719064	1536	1012683	1951	17002	-	-

Table 2. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crab 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 crab and 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	138	
1991	8.199	17.357	36.911	377	
1992	8.364	10.427	38.522	199	
1993	7.786	5.074	20.815	31	
1994	5.892	2.540	12.911	127	
1995	5.888	5.063	16.981	6388	0.734
1996	6.451	5.168	13.806	8360	0.758
1997	7.336	7.126	18.248	4670	0.791
1998	8.875	9.170	25.766	3616	0.954
1999	8.964	9.251	20.773	3851	0.884
2000	9.849	9.922	25.390	5043	0.907
2001	11.655	11.140	22.479	4626	1.184
2002	12.372	11.992	22.593	3980	1.261
2003	10.921	11.022	19.431	3960	1.105
2004	18.295	17.732	28.483	2206	1.802
2005	25.397	29.439	38.475	1193	1.053
2006	24.836	25.203	33.520	1098	0.844
2007	27.954	31.088	40.373	998	0.977
2008	27.260	29.733	38.178	613	0.949
2009	25.853	26.643	35.891	408	0.789
2010	25.956	26.052	36.763	436	0.802
2011	37.333	38.793	51.691	361	1.161
2012	33.018	38.000	47.744	438	1.116
2013	33.674	35.827	46.162	499	1.077
2014	42.293	46.959	59.997	376	1.374

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

Year	**CPUE Index**	**Standard Error**
1985	1.671	0.078
1986	1.222	0.065
1987	0.958	0.061
1988	1.026	0.050
1989	1.041	0.043
1990	0.826	0.052
1991	0.841	0.052
1992	0.928	0.053
1993	0.897	0.056
1994	0.801	0.053
1995	0.769	0.053
1996	0.827	0.055
1997	1.196	0.059
1998	1.357	0.064

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	**Two catchability, two sets of total selectivity, and a single set of retention curve parameters:** Commercial fishery retained catch for 1985–2014, total fishery catch for 1990–2014, observer legal size crab CPUE index for 1995–2014, 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 with 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 = weighted by number of pots sampled scaled to a maximum of 300, groundfish discard catch = 1 (0.805), recruitment deviation = 2.0 (0.533), 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), and posfunction = 1000.	Retained = 200, total = 150, groundfish discard = 25
2	Scenario 1, but three catchability, three sets of total selectivity for 1985/86 – 1998/99, 1999/90 – 2004/05, and 2005/06-2014/15 , and a single set of retention curve parameters.	Same as scenario 1.	Same as scenario 1.
3	Scenario 1, but 1985–1998 commercial fishery retained CPUE indices are considered as an additional likelihood component.	Same as scenario 1.	Same as scenario 1.
4	Scenario 1, but without molt probability model.	Same as scenario 1.	Same as scenario 1.
5	Scenario 1, but total catch and length frequency time series from 1996/97 onward are considered 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.
6	Scenario 1, but effective sample sizes for retained catch, total catch, and groundfish bycatch are iteratively estimated.	Same as scenario 1.	Iteratively estimated effective sample sizes
7	Scenario 1, but evaluated the effect of different mean F (0.09, 0.18, 0.45) in the F-penalty function.	Same as scenario 1.	Same as scenario 1.

Table 4 continued.

8	Scenario 1, but initial size composition from equilibrium estimate is considered. 1981/82 - 1983/84 retained catches are used in the equilibrium likelihood penalty.	Same as scenario 1.	Same as scenario 1.
9	Scenario 1 and explored the component likelihoods for varying fixed values of terminal MMB.	Same as scenario 1.	Same as scenario 1.
10	Scenario 1 and explored the component likelihoods for varying fixed values of the pair of catchability coefficients.	Same as scenario 1.	Same as scenario 1.
11	Scenario 1, but observer CPUE indices are estimated considering the whole 1995/96-2014/15 time series as one and a single catchability parameter is estimated	Same as scenario 1.	Same as scenario 1.
12	Scenario 1, but groundfish bycatch biomass and length composition data are not considered for the model fit. A mean bycatch F of 0.000148 is considered..	Same as scenario 1.	Same as scenario 1.

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

Table 5. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 2 and 3 for the golden king crab data from the EAG, 1985/86–2014/15. A total of 124 and 122 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. Initial size structure was created using an exponential formula (Appendix A).

	Scenario 2			**Scenario 3**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.537	0.017	1.,4.50	2.540	0.016	1.,4.50
G_b	-8.547	1.821	-10.0,-5.0	-9.141	1.778	-40.0,-2.0
log_aa	-2.602	0.090	-4.61,-1.39	-2.494	0.073	-4.61,-1.39
log_b	4.949	0.006	3.869,5.0	4.954	0.005	3.869,5.0
Growth StdDev	3.690	0.101	0.1,12.0	3.677	0.100	0.1,12.0
log_T98delta	3.561	0.235	0.,4.4			
log_T04delta	3.186	0.130	0.,4.4	3.378	0.133	0.,4.4
log_T12delta	3.072	0.196	0.,4.4	3.046	0.196	0.,4.4
log_Retdelta	1.859	0.078	0.,4.4	1.842	0.081	0.,4.4
log_ T98L50	4.809	0.032	0.,4.4			
log_T04L50	4.863	0.018	4.0,5.0	4.817	0.018	4.0,5.0
log_T12L50	4.916	0.023	4.0,5.0	4.906	0.020	4.0,5.0
log_RetL50	4.914	0.002	4.0,5.0	4.913	0.002	4.0,5.0
log_betar	-0.772	0.242	-10.0, 12.0	-0.823	0.235	-10.0, 12.0
Logq1	-0.476	0.142	-9.0, 2.25			
logq2	-0.351	0.129	-9.0, 2.25	-0.534	0.083	-9.0, 2.25
logq3	-0.886	0.223	-9.0, 2.25	-0.940	0.182	-9.0, 2.25
log_newsh1	2.109	0.066	0.01, 10.0	2.086	0.059	0.01, 10.0
log_mean_rec	0.767	0.058	0.01, 5.0	0.758	0.052	0.01, 5.0
log_mean_Fpot	-0.791	0.111	-15.0, -0.013	-0.861	0.089	-15.0, -0.01
log_mean_Fground	-9.151	0.871	-15.0, -1.6	-9.156	0.868	-15.0, -1.6
prelegal_var	0.020	0.008	0.0, 0.15	0.016	0.006	0.0, 0.15
Fishtick_var				0.049	0.021	0.0, 1.0
Ftemp	0.180	0.707	0.0, 0.75	0.180	0.707	0.0, 0.75
2015 MMB	10289	4852		10140	4928	

Table 6. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 5 and 11 for the golden king crab data from the EAG, 1985/86–2014/15. A total of 121 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. Initial size structure was created using an exponential formula (Appendix A).

	Scenario 5			**Scenario 11**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.539	0.017	1.0, 4.5	2.539	0.017	1.0-4.5
G_b	-8.729	1.808	-12.0,-5.0	-8.641	1.804	-10.0, -5.0
log_aa	-2.544	0.079	-4.61,-1.39	-2.556	0.079	-4.61,-1.39
log_b	4.953	0.005	3.869,5.0	4.952	0.005	3.869,5.0
Growth StdDev	3.692	0.101	0.1,12.0	3.688	0.101	0.1,12.0
log_T04delta	3.263	0.118	0.,4.4	3.278	0.116	0.,4.4
log_T12delta	3.062	0.195	0.,4.4	2.983	0.172	0.,4.4
log_Retdelta	1.871	0.084	0.,4.4	1.884	0.083	0.,4.4
log_T04L50	4.840	0.016	4.0,5.0	4.845	0.016	4.0,5.0
log_T12L50	4.912	0.021	4.0,5.0	4.901	0.015	4.0,5.0
log_RetL50	4.913	0.002	4.0,5.0	4.914	0.002	4.0,5.0
log_betar	-0.830	0.246	-10.0, 12.0	-0.840	0.244	-10.0, 12.0
logq2	-0.445	0.099	-9.0, 2.25	-0.759	0.101	-9.0, 2.25
logq3	-0.899	0.201	-9.0, 2.25			
log_newsh1	2.099	0.070	0.01, 10.0	2.091	0.071	0.01, 10.0
log_mean_rec	0.747	0.055	0.01, 5.0	0.791	0.048	0.01, 5.0
log_mean_Fpot	-0.822	0.094	-15.0, -0.01	-0.873	0.082	-15.0, -0.09
log_mean_Fground	-9.139	0.887	-15.0, -1.6	-9.192	0.895	-15.0, -1.6
prelegal_var	0.019	0.007	0.0, 0.15	0.018	0.007	0.0, 0.15
Ftemp	0.180	0.707	0.0, 0.75	0.180	0.707	0.0, 0.75
2015 MMB	10069	4820		11465	5710	

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

0.06	0.02	0.21	0.47	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.08	0.02	0.23	0.46	0.19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.11	0.03	0.24	0.44	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.15	0.03	0.25	0.42	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.21	0.03	0.25	0.38	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.28	0.04	0.25	0.34	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.04	0.23	0.29	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.04	0.21	0.24	0.06	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.04	0.19	0.20	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.03	0.16	0.15	0.03	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.03	0.13	0.11	0.02	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.03	0.10	0.08	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.02	0.08	0.06	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.02	0.06	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01	0.07
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.06
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

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

0.04	0.02	0.20	0.48	0.24	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.06	0.02	0.22	0.47	0.21	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.09	0.02	0.24	0.46	0.18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.12	0.03	0.25	0.43	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.18	0.03	0.25	0.40	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.24	0.04	0.25	0.36	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.04	0.24	0.31	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.04	0.22	0.26	0.06	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.04	0.19	0.20	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.03	0.16	0.15	0.03	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.03	0.12	0.11	0.02	0.00	0.00

Table 8 continued

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.02	0.09	0.07	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.02	0.07	0.05	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.02	0.05	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.01	0.06
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.05
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 9. Estimate of the size transition matrix for scenario 5 for the golden king crab data from the EAG.

0.05	0.02	0.21	0.48	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.07	0.02	0.23	0.47	0.20	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.10	0.03	0.24	0.45	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.14	0.03	0.25	0.42	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.19	0.03	0.25	0.39	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.26	0.04	0.25	0.35	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.04	0.24	0.30	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.04	0.22	0.25	0.06	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.04	0.19	0.20	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.03	0.16	0.15	0.03	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.03	0.13	0.11	0.02	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.03	0.10	0.08	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.02	0.07	0.05	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.02	0.05	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01	0.06
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.05
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 10. Estimate of the size transition matrix for scenario 11 for the golden king crab data from the EAG.

0.05	0.02	0.21	0.48	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.07	0.02	0.23	0.47	0.20	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.10	0.03	0.24	0.45	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.14	0.03	0.25	0.42	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.19	0.03	0.25	0.39	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.26	0.04	0.25	0.35	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.04	0.24	0.30	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.04	0.22	0.25	0.06	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.04	0.19	0.20	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.03	0.16	0.15	0.03	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.03	0.13	0.11	0.02	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.03	0.10	0.08	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.02	0.07	0.05	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.02	0.05	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01	0.06
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.05
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 11. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 2 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of biological year) 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	8328	1528	8373	1111
1986	1.54	6284	382	8057	734
1987	3.10	5358	317	6203	366
1988	3.89	4911	331	5306	290
1989	1.32	4622	308	4736	279
1990	2.13	4600	324	4312	271
1991	4.23	4219	362	4445	295
1992	1.82	4707	363	4115	325
1993	1.78	5125	314	4418	320
1994	2.32	4646	277	4933	281
1995	1.20	4067	237	4519	249
1996	1.65	3755	225	3891	224
1997	2.16	3524	226	3647	216
1998	1.98	3624	272	3422	222
1999	2.73	3928	332	3477	269
2000	1.90	4562	383	3789	329
2001	1.73	4945	444	4356	379
2002	2.88	5310	511	4774	436
2003	1.73	6096	629	5201	499
2004	1.27	6457	723	5894	602
2005	2.57	6311	787	6294	696
2006	2.18	6649	884	6233	764
2007	2.14	7036	986	6483	852
2008	2.38	7321	1076	6856	950
2009	1.58	7621	1150	7156	1040
2010	3.25	7662	1207	7427	1114
2011	3.16	8431	1380	7552	1178
2012	2.42	9348	1573	8219	1329
2013	2.28	9823	1739	9082	1516
2014	2.22	10000	1916	9610	1688

Table 11 continued

2015	2.15	10289	4852	9821	1865

Table 12. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 3 for golden king crab in the EAG. Legal male biomass was estimated on July 1(start of biological year) 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	7452	1370	8408	975
1986	1.49	6021	336	7639	688
1987	2.94	5177	280	5996	329
1988	3.57	4726	278	5190	262
1989	1.35	4385	249	4667	247
1990	2.20	4369	261	4222	233
1991	3.82	4042	303	4333	250
1992	1.76	4452	308	4038	281
1993	1.78	4828	257	4311	284
1994	2.50	4384	226	4769	244
1995	1.27	3970	214	4367	216
1996	1.92	3786	227	3882	210
1997	2.49	3787	243	3762	221
1998	1.97	4173	274	3764	237
1999	2.45	4593	313	4102	267
2000	2.11	5107	349	4556	304
2001	1.63	5517	395	5051	341
2002	2.68	5803	442	5462	385
2003	1.58	6432	531	5807	433
2004	1.22	6612	612	6361	515
2005	2.53	6336	673	6568	598
2006	2.16	6638	763	6354	661
2007	2.04	7008	850	6577	744
2008	2.37	7242	923	6941	831
2009	1.59	7543	987	7202	905
2010	3.17	7584	1034	7471	968
2011	3.04	8350	1182	7589	1021
2012	2.41	9233	1345	8281	1154
2013	2.26	9702	1499	9134	1317
2014	2.20	9885	1686	9643	1477

	Table 12 continued				
2015	2.14	10140	4928	9843	1661

Table 13. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 5 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of biological year) 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	7244	859	9306	1012
1986	1.44	6144	384	7552	596
1987	2.78	5294	304	6018	328
1988	3.99	4773	307	5249	285
1989	1.49	4649	299	4679	270
1990	2.04	4778	327	4411	274
1991	3.11	4454	383	4675	311
1992	1.90	4533	364	4395	356
1993	1.84	4870	295	4379	337
1994	2.06	4416	241	4765	278
1995	1.02	3775	206	4337	226
1996	2.12	3372	217	3657	203
1997	2.43	3420	236	3334	214
1998	1.94	3811	273	3347	231
1999	2.51	4230	316	3690	266
2000	2.00	4781	360	4146	308
2001	1.67	5167	410	4668	352
2002	2.74	5483	463	5069	401
2003	1.64	6173	561	5444	454
2004	1.25	6434	644	6052	542
2005	2.53	6226	704	6347	626
2006	2.17	6545	797	6208	690
2007	2.08	6927	892	6444	775
2008	2.37	7190	973	6817	868
2009	1.56	7494	1043	7102	950
2010	3.18	7524	1094	7375	1019
2011	3.07	8281	1254	7487	1078
2012	2.39	9169	1432	8157	1219
2013	2.24	9630	1595	9006	1395
2014	2.18	9796	1778	9513	1563

Table 13 continued.

2015	2.11	10069	4820	9703	1745

Table 14. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 11 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of biological year) 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	8648	937	8360	1131
1986	1.50	6253	355	8107	710
1987	2.85	5282	301	6176	338
1988	3.94	4781	306	5259	280
1989	1.50	4643	297	4672	268
1990	2.04	4776	326	4388	271
1991	3.11	4455	382	4656	309
1992	1.90	4534	363	4380	354
1993	1.84	4871	294	4362	334
1994	2.04	4413	240	4748	276
1995	1.03	3762	206	4319	224
1996	2.14	3365	217	3632	202
1997	2.45	3425	238	3315	214
1998	1.97	3832	278	3338	232
1999	2.56	4276	325	3695	271
2000	2.06	4865	372	4176	317
2001	1.74	5300	421	4733	364
2002	2.93	5682	468	5183	414
2003	1.79	6505	540	5627	461
2004	1.37	6895	578	6359	527
2005	2.76	6790	598	6784	568
2006	2.35	7254	650	6757	590
2007	2.28	7769	707	7126	636
2008	2.57	8157	762	7631	695
2009	1.71	8575	824	8039	752
2010	3.59	8690	875	8424	812
2011	3.39	9651	1028	8630	870
2012	2.57	10729	1214	9482	1008
2013	2.41	11282	1419	10514	1194
2014	2.28	11484	1653	11125	1399

Table 14 continued

2015	2.21	11465	5710	11354	1629

Table 15. Negative log-likelihood values of the fits for scenarios 2,3,5, and 11 for golden king crab in the EAG.

Likelihood Component	Scenario 2	Scenario 3	Scenario 5	Scenario 11
Number of free parameters	124	122	121	120
like_retlencomp	-891.04	-890.40	-889.84	-891.27
like_totallencomp	-870.66	-868.06	-732.45	-732.46
like_gdiscdlencomp	-649.40	-647.80	-648.59	-649.23
like_retcpue	-10.50	-12.50	-10.98	-11.11
like_retdcatchB	8.28	8.74	5.94	5.92
like_totalcatchB	30.86	32.25	11.75	11.60
like_gdiscdcatchB	0.00	0.00	0.00	0.00
like_rec_dev	5.56	4.84	4.89	5.03
like_meanFpot	0.00	0.00	0.00	0.00
like_F	0.01	0.01	0.01	0.01
like_gF	0.02	0.02	0.02	0.02
like_Tag	2688.62	2691.78	2690.57	2690.46
like_finalF	0.00	0.00	0.00	0.00
like_fpen	0.00	0.00	0.00	0.00
LikefishtickCPUE		-0.83		
Total	311.75	318.06	431.32	428.98

Table 16. Time series of annual retained catch (number and weight of crab), estimated total male catch (number and weight of crab on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crab) (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.)	Retained Catch Biomass (t)	Total Catch (no.)	Total Catch Biomass (t)	Pot Fishery Effort (no. pot lifts)	Groundfish Discard Mortality(no.)	Groundfish Discard Mortality (t)
1985	981949	2010			118563		
1986	2052652	4230			277780		
1987	1248732	2514			160229		
1988	1285914	2454			166409		
1989	1610281	3047			202541	51	0.08
1990	889017	1630	2753326	3691	108533	374	0.57
1991	747852	1355	1827434	2572	101429	16	0.03
1992	543541	1025	1113229	1520	69443	318	0.43
1993	352339	665	2001547	2822	127764	0	0.00
1994	845058	1617	3634246	4953	195138	82	0.12
1995	619636	1185	1567028	2132	115248	628	0.71
1996	652801	1231	1269315	1767	99267	559	1.04
1997	558446	1062	1236592	1799	86811	211	0.37
1998	505407	931	782551	1087	35975	1182	1.85
1999	658377	1235	1467177	2093	107040	1091	1.42
2000	723794	1378	1612997	2233	101239	692	0.80
2001	686738	1282	1503857	2138	105512	303	0.43
2002	664823	1214	1335068	1893	78979	700	0.92
2003	676633	1245	1192551	1862	66236	200	0.31
2004	685465	1262	1249016	1880	56846	699	0.95
2005	639368	1230	1079095	1780	30116	1798	3.46
2006	523701	1048	894219	1547	26870	1311	2.28
2007	600595	1230	965889	1609	29950	943	1.50
2008	587661	1208	997465	1730	26200	3979	6.45
2009	628332	1333	900797	1676	26489	2173	4.31
2010	626246	1338	868127	1588	29994	1056	2.48
2011	616118	1332	817532	1514	26326	1576	2.25
2012	672916	1404	1000311	1822	32716	2216	3.74
2013	686883	1440	1037749	1901	41835	2090	2.99
2014	635312	1257	935794	1591	41548	-	-

Table 17. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crab 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 crab.

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	340	
1991	7.428	7.778	19.175	857	
1992	5.895	6.393	16.829	690	
1993	4.425	6.542	17.232	174	
1994	4.080	6.714	19.234	1270	
1995	4.647	4.964	14.279	5598	1.174
1996	6.074	5.424	13.537	7194	0.952
1997	6.561	6.520	15.027	3985	0.962
1998	11.397	9.415	23.085	1876	1.070
1999	6.321	5.926	14.485	4523	0.909
2000	6.970	6.402	16.644	4740	0.853
2001	6.509	5.993	14.657	4454	0.827
2002	8.418	7.465	17.373	2509	0.924
2003	10.215	9.289	18.170	3334	1.157
2004	12.058	11.141	22.449	2619	1.267
2005	21.230	23.741	35.939	1365	1.116
2006	19.640	23.963	33.408	1183	1.029
2007	20.053	21.041	32.461	1082	0.968
2008	22.430	24.592	38.174	979	1.106
2009	23.720	26.533	34.047	892	1.163
2010	20.879	22.339	29.029	867	1.023
2011	23.403	23.811	31.121	837	1.068
2012	20.568	22.821	30.760	1109	1.079
2013	16.419	16.949	24.960	1223	0.769
2014	15.291	15.277	22.669	1137	0.772

Table 18. Time series of GLM estimated CPUE Indices and standard errors for the fish ticket based retained catch-per-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data and used in scenario 3. 1985 refers to the 1985/86 fishery.

Year	**CPUE Index**	**Standard Error**
1985	2.023	0.065
1986	1.724	0.052
1987	1.213	0.050
1988	1.353	0.035
1989	1.142	0.031
1990	0.875	0.036
1991	0.721	0.042
1992	0.718	0.046
1993	0.683	0.055
1994	0.823	0.041
1995	0.876	0.043
1996	0.844	0.035
1997	0.771	0.034
1998	1.053	0.037

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	**Two catchability, two sets of total selectivity, and a single set of retention curve parameters::** Commercial fishery retained catch for 1985–2014, total fishery catch for 1990–2014, observer legal size crab CPUE index for 1995–2014, 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 with 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. considered initial size composition from equilibrium estimate. 1981/82 -1983/84 catches were used in the	Retained catch = 500 (0.032), total catch = weighted by number of pots sampled scaled to a maximum of 300, groundfish discard catch = 1(0.805), recruitment deviation = 2.0 (0.533), 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), and posfunction = 1000.	Retained = 200, total = 150, groundfish discard = 25
2	Scenario 1, but three catchability, three sets of total selectivity for 1985/86 – 1998/99, 1999/90 – 2004/05, and 2005/06-2014/15 , and a single set of retention curve parameters.	Same as scenario 1.	Same as scenario 1.
3	Scenario 1, but 1985–1998 commercial fishery retained CPUE indices are considered as an additional likelihood component.	Same as scenario 1.	Same as scenario 1.
4	Scenario 1, but without molt probability model.	Same as scenario 1.	Same as scenario 1.
5	Scenario 1, but total catch and length frequency time series from 1995/96 onward are considered in the likelihood functions to avoid unusually high total catches in 1993/94 and 1994/95 seasons.	Same as scenario 1.	Same as scenario 1.

Table 19 continued.

6	Scenario 1, but iteratively estimated effective sample sizes for retained catch, total catch, and groundfish bycatch.	Same as scenario 1.	Iteratively estimated effective sample sizes
7	Scenario 1, but evaluated the effect of different mean F (0.09, 0.27, 0.36) in the F-penalty function.	Same as scenario 1.	Same as scenario 1.
8	Scenario 1 and explored the component likelihoods for varying fixed values of terminal MMB.	Same as scenario 1.	Same as scenario 1.
9	Scenario 1, but considered WAG tagging data.	Same as scenario 1.	Same as scenario 1.
11 (note: change in indexing to mimic the same EAG scenario 11)	Scenario 1, but observer CPUE indices are estimated considering the whole 1995/96-2014/15 time series as one and a single catchability parameter is estimated	Same as scenario 1.	Same as scenario 1.
12	Scenario 1, but groundfish bycatch biomass and length composition data are not considered for the model fit. A mean bycatch F of 0.000332 is considered..	Same as scenario 1.	Same as scenario 1.

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

Table 20. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 2 and 3 for the golden king crab data from the WAG, 1985/86–2014/15. A total of 108 and 111 parameters for the two respective scenarios were estimated, but recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list. Initial size structure was created using an equilibrium condition (Appendix A).

	Scenario 1			**Scenario 2**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.531	0.016	1.0, 3.85	2.528	0.017	1.0, 3.85
G_b	-10.534	1.735	-60.0,-2.0	-10.015	1.767	-60.0,-2.0
log_aa	-2.418	0.060	-4.61,-1.39	-2.470	0.064	-4.61,-1.39
log_b	4.946	0.004	3.869,6.0	4.941	0.005	3.869,6.0
Growth StdDev	3.666	0.098	0.1,9.0	3.678	0.099	0.1,9.0
log_T98delta				3.655	0.264	0.0,4.4
log_T04delta	3.329	0.120	0.,4.4	3.203	0.116	0.,4.4
log_T12delta	2.830	0.184	0.,4.4	2.852	0.187	0.,4.4
log_Retdelta	1.724	0.064	0.,4.4	1.732	0.062	0.,4.4
log_T98L50				4.799	0.034	4.0,5.1
log_T04L50	4.824	0.015	3.98,5.1	4.859	0.015	3.98,5.1
log_T12L50	4.854	0.013	3.98,5.5	4.854	0.013	3.98,5.5
log_RetL50	4.913	0.002	4.85,4.98	4.913	0.002	4.85,4.98
log_betar	-0.700	0.303	-10.0, 12.0	-0.575	0.317	-10.0, 12.0
Logq1				-0.051	0.131	-2.0,2.25
logq2	-0.252	0.088	-9.0, 2.25	-0.307	0.096	-2.0,2.25
logq3	-0.838	0.103	-9.0, -0.8	-0.890	0.097	-2.0,2.25
log_mean_rec	0.559	0.028	0.01, 5.0	0.583	0.029	0.01, 5.0
log_mean_Fpot	-0.996	0.064	-9.0, -0.09	-1.002	0.082	-9.0, -0.09
log_mean_Fground	-8.461	0.925	-9.0, -2.0	-8.504	0.887	-15.0, -2.0
prelegal_var	0.019	0.008	0.0, 0.15	0.008	0.003	0.0, 0.15
Ftemp	0.180	0.707	0.0, 0.75	0.180	0.707	0.0, 0.75
2015 MMB	5673	2636		5866	2744	

Table 21. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 5 and 11 for the golden king crab data from the WAG, 1985/86–2014/15. A total of 108 and 107 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. Initial size structure was created using an equilibrium condition (Appendix A).

	Scenario 5			**Scenario 11**		
Parameter	Estimate	Std Dev	Limits	Estimate	Std Dev	Limits
log_a	2.528	0.017	1.0, 3.85	2.531	0.016	1.0, 3.85
G_b	-10.015	1.760	-60.0, -2.0	-10.480	1.730	-60.0, -2.0
log_aa	-2.469	0.063	-4.61, -1.39	-2.420	0.059	-4.61,-1.39
log_b	4.944	0.005	3.869, 6.0	4.946	0.004	3.869, 6.0
Growth StdDev	3.666	0.099	0.1, 9.0	3.667	0.098	0.1, 9.0
log_T04delta	3.278	0.106	0., 4.4	3.339	0.115	0., 4.4
log_T12delta	2.915	0.179	0., 4.4	2.798	0.181	0., 4.4
log_Retdelta	1.722	0.068	0., 4.4	1.724	0.063	0., 4.4
log_T04L50	4.852	0.014	3.98, 5.1	4.826	0.014	3.98, 5.1
log_T12L50	4.860	0.014	3.98, 5.5	4.852	0.012	3.98, 5.5
log_RetL50	4.911	0.002	4.85, 4.98	4.913	0.002	4.85, 4.98
log_betar	-0.727	0.330	-10.0, 12.0	-0.704	0.304	-10.0, 12.0
logq2	-0.156	0.089	-9.0, 2.25	-0.547	0.079	-9.0, 2.25
logq3	-0.835	0.110	-9.0, -0.80			
log_mean_rec	0.558	0.027	0.01, 5.0	0.556	0.028	0.01, 5.0
log_mean_Fpot	-0.982	0.066	-9.0, -0.09	-0.995	0.065	-9.0, -0.09
log_mean_Fground	-8.474	0.932	-15.0, -2.0	-8.820	0.261	-15.0, -2.0
prelegal_var	0.020	0.009	0.0, 0.15	0.023	0.009	0.0, 0.15
Ftemp	0.180	0.707	0.0, 0.75	0.180	0.707	0.0, 0.75
2015 MMB	5700	2608		5524	2538	

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

0.03	0.01	0.18	0.48	0.26	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.05	0.02	0.21	0.48	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.08	0.02	0.22	0.46	0.19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.12	0.03	0.24	0.44	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.17	0.03	0.25	0.41	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.25	0.03	0.25	0.36	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.04	0.24	0.31	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.04	0.21	0.25	0.06	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.04	0.18	0.19	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.03	0.15	0.13	0.02	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.03	0.11	0.09	0.01	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.02	0.08	0.06	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.02	0.06	0.04	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01	0.04	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.01	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

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

0.04	0.02	0.20	0.48	0.24	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.06	0.02	0.21	0.47	0.21	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.09	0.02	0.23	0.45	0.18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.14	0.03	0.24	0.43	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.19	0.03	0.25	0.39	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.27	0.04	0.25	0.35	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.04	0.23	0.29	0.07	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.04	0.21	0.24	0.05	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.04	0.18	0.18	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.03	0.15	0.13	0.02	0.00	0.00	0.00

Table 23 continued

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.03	0.11	0.09	0.01	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.02	0.08	0.06	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.02	0.06	0.04	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01	0.04	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.01	0.05
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 24. Estimate of the size transition matrix for scenario 5 for the golden king crab data from the WAG.

0.04	0.02	0.20	0.48	0.24	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.06	0.02	0.21	0.47	0.21	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.09	0.02	0.23	0.46	0.18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.13	0.03	0.24	0.43	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.19	0.03	0.25	0.40	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.26	0.03	0.25	0.35	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.04	0.23	0.30	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.04	0.21	0.24	0.05	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.04	0.18	0.18	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.03	0.15	0.13	0.02	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.03	0.12	0.09	0.02	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.02	0.09	0.06	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.87	0.02	0.06	0.04	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.02	0.04	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.01	0.05
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 25. Estimate of the size transition matrix for scenario 11for the golden king crab data from the WAG.

0.03	0.01	0.19	0.48	0.26	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.05	0.02	0.21	0.48	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.08	0.02	0.23	0.46	0.19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.12	0.03	0.24	0.44	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.17	0.03	0.25	0.40	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.25	0.03	0.25	0.36	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.04	0.24	0.30	0.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.04	0.21	0.25	0.06	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.04	0.18	0.19	0.04	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.03	0.15	0.13	0.02	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.03	0.11	0.09	0.01	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.02	0.08	0.06	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.02	0.06	0.04	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.01	0.04	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.01	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 26. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of biological year) 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	9624	373	10841	362
1986	4.06	6146	329	9437	358
1987	1.93	5885	312	6084	306
1988	2.03	5083	239	5701	275
1989	2.01	3340	199	4977	216
1990	1.38	3071	177	3264	177
1991	1.33	2810	184	2989	163
1992	1.11	2806	187	2755	173
1993	3.10	3170	189	2762	176
1994	1.20	3211	167	3198	172
1995	1.54	3254	172	3092	154
1996	1.67	3251	198	3200	163
1997	1.19	3390	185	3216	182
1998	1.52	3549	187	3332	176
1999	2.03	3396	194	3522	178
2000	2.08	3525	229	3370	185
2001	2.05	3913	280	3471	217
2002	2.57	4459	337	3850	265
2003	1.85	5228	418	4416	321
2004	2.31	5669	472	5145	396
2005	2.02	6177	515	5626	451
2006	1.75	6716	533	6114	492
2007	2.75	6907	548	6648	512
2008	0.77	7441	541	6878	526
2009	1.32	6899	533	7305	522
2010	1.28	6296	510	6854	518
2011	1.58	5749	489	6245	495
2012	1.58	5309	486	5692	474
2013	1.69	4947	520	5235	469
2014	1.91	4935	583	4876	503

Table 26 continued.

2015	1.75	5673	2636	4873	553

Table 27. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 2 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of biological year) 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	9842	396	10988	379
1986	4.38	6369	350	9571	372
1987	1.93	6128	336	6221	319
1988	2.25	5307	271	5825	287
1989	2.11	3597	235	5105	236
1990	1.44	3331	218	3437	202
1991	1.34	3070	222	3177	194
1992	1.11	3040	215	2954	201
1993	3.22	3395	212	2941	198
1994	1.16	3417	186	3359	188
1995	1.52	3426	189	3220	165
1996	1.45	3352	188	3304	170
1997	1.32	3334	173	3252	170
1998	1.44	3488	176	3234	162
1999	2.24	3274	186	3398	167
2000	2.05	3478	221	3191	179
2001	2.18	3890	271	3338	208
2002	2.79	4525	331	3742	254
2003	2.29	5461	424	4386	310
2004	2.12	6178	484	5273	388
2005	1.94	6659	531	6003	447
2006	1.83	7090	560	6500	497
2007	2.87	7272	579	6942	529
2008	0.79	7808	575	7150	548
2009	1.41	7287	563	7570	547
2010	1.35	6713	529	7161	539
2011	1.54	6187	499	6594	508
2012	1.61	5694	485	6060	478
2013	1.72	5294	499	5554	462
2014	1.83	5250	544	5151	473

Table 27 continued.

2015	1.79	5866	2744	5106	506

Table 28. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 5 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of biological year) 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	9713	379	10864	366
1986	4.11	6262	336	9470	362
1987	1.90	6047	321	6137	311
1988	2.16	5283	259	5773	279
1989	1.87	3642	229	5104	230
1990	1.36	3394	213	3492	202
1991	1.69	3176	224	3258	195
1992	1.07	3364	201	3086	204
1993	1.56	3685	186	3257	187
1994	1.62	3093	163	3624	171
1995	1.62	3032	159	3009	149
1996	1.63	3097	197	2935	149
1997	1.16	3233	174	2997	173
1998	1.54	3381	173	3124	160
1999	2.01	3227	180	3311	162
2000	2.09	3343	216	3154	169
2001	2.09	3731	271	3235	201
2002	2.69	4309	338	3608	253
2003	2.06	5168	439	4199	317
2004	2.31	5762	502	5011	408
2005	1.99	6324	541	5636	472
2006	1.79	6847	556	6187	513
2007	2.75	7039	569	6718	531
2008	0.77	7549	558	6945	542
2009	1.30	6998	548	7346	536
2010	1.28	6370	522	6902	529
2011	1.62	5806	499	6279	505
2012	1.60	5367	495	5709	482
2013	1.71	5007	528	5246	475
2014	1.87	4991	589	4886	506

Table 28 continued

2015	1.75	5700	2608	4873	555

Table 29. Annual abundance estimates of model recruits (millions of crab), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 11 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of biological year) 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	9581	369	10795	360
1986	4.11	6114	325	9391	356
1987	1.92	5878	311	6050	303
1988	2.03	5081	239	5687	274
1989	2.01	3340	199	4970	215
1990	1.38	3069	176	3259	176
1991	1.33	2806	183	2984	161
1992	1.10	2801	186	2748	170
1993	3.09	3162	188	2753	174
1994	1.22	3197	163	3186	170
1995	1.54	3251	169	3075	147
1996	1.68	3250	198	3191	157
1997	1.19	3394	182	3211	179
1998	1.53	3555	186	3333	170
1999	2.05	3408	194	3525	174
2000	2.10	3550	232	3379	184
2001	2.07	3952	286	3492	219
2002	2.63	4516	345	3884	271
2003	1.88	5326	420	4469	330
2004	2.34	5795	459	5235	400
2005	2.00	6321	481	5746	440
2006	1.76	6846	481	6250	462
2007	2.69	7019	485	6773	464
2008	0.76	7505	469	6983	467
2009	1.26	6927	461	7365	456
2010	1.22	6268	442	6875	451
2011	1.53	5661	428	6213	432
2012	1.50	5168	430	5602	417
2013	1.63	4746	479	5090	419
2014	2.02	4697	567	4673	468

Table 29 continued

2015	1.74	5524	2538	4637	540

Table 30. Negative log-likelihood values of the fits for scenarios 1, 2, 5, and 11 for golden king crab in the WAG.

Likelihood Component	**Scenario 1**	**Scenario 2**	**Scenario 5**	**Scenario 11**
Number of free parameters	108	111	108	107
like_retlencomp	-1001.90	-1007.05	-1016.08	-1002.04
like_totallencomp	-985.01	-991.24	-834.84	-984.84
like_gdiscdlencomp	-566.41	-566.61	-567.54	-567.39
like_retcpue	-10.92	-19.16	-10.19	-8.86
like_retdcatchB	10.77	11.98	6.64	10.78
like_totalcatchB	49.73	48.43	16.48	49.80
like_gdiscdcatchB	0.00	0.00	0.00	0.01
like_rec_dev	6.33	6.88	5.58	6.61
like_meanFpot	0.00	0.00	0.00	0.00
like_F	0.03	0.03	0.03	0.03
like_gF	0.03	0.03	0.03	0.11
like_Tag	2689.34	2687.11	2687.71	2689.31
like_finalF	0.00	0.00	0.00	0.00
like_fpen	0.00	0.00	0.00	0.00
Total	191.99	170.41	287.81	193.52

Table 31. Predicted total and retained catch OFL (t) for 2015/16 under Tier 4 assumption for various scenarios. For scenario 7, mean Fs in the penalty function were (a) 0.09, (b) 0.27, and (c) 0.36; and (a) 0.09, (b) 0.18, and (c) 0.45 for WAG and EAG, respectively.

	EAG		**WAG**	
Scenario	**Total Catch OFL (t)**	**Retained Catch OFL (t)**	**Total Catch OFL (t)**	**Retained Catch OFL (t)**
1	1331	1292	731	686
2	1318	1280	763	717
3	1364	1325	666	628
4	743	720	674	634
5	1322	1284	722	680
6	1357	1317	619	579
7a	1329	1291	729	685
7b	1331	1292	729	685
7c	1331	1292	729	685
8	1954	1146	Explore MMB	
9	Explore MMB		691	648
10	Explore *q*			
11	1608	1563	703	657
12	1361	1315	741	696

Table 32. Step-wise model selection for various model scenarios including interactions for the Aleutian Islands golden king crab observer data. Observer legal size male crab CPUE data for EAG for 1995/96–2004/05, 2005/06–2013/14, and 1995/96–2013/14 time periods were used. R^2 determines the relative merit of each fit. ns = cubic splines, df = degree of freedom, and θ = dispersion parameter of the negative binomial model. (Source: 2015 Sea Grant Symposium).

Fishing period	Final model	R^2
1995/96–2004/05	CPUE = Year+Gear+Captain , θ =1.33	0.23
2005/06–2013/14	CPUE = Year+Vessel+ns(Soak, df=16)+ Gear , θ =2.20	0.09
1995/96–2013/14	When 'soak' is a continuous variable:	
	a. CPUE = Year+Gear+Captain+ns(Soak, df=18) , θ =1.42	0.32
	b. CPUE = Year+Gear+Captain+Year:Captain , θ =1.42	0.33
	c. CPUE = Year+Gear+Captain+ns(Soak, df=18)+Year:Gear , θ =1.42	0.33
	When 'soak' is a factor variable:	
	a. CPUE = Year+Gear+Captain+Soak , θ =1.42	0.32
	b. CPUE = Year+Gear+Captain+Soak , θ =1.42 Offered Year:Soak, but did not pick up	0.32
	c. CPUE = Year+Gear+Captain+Year:Captain , θ =1.42	0.33
	d. CPUE = Year+Gear+Captain+Soak +Year:Gear, θ =1.42	0.33
	e. CPUE = Year+Gear+Captain+Soak , θ =1.42 Offered Soak:Gear, but did not pick up	0.32
	f. CPUE = Year+Gear+Captain+Year:Captain , θ =1.42 Offered Year:Captain, Year:Soak and Year:Gear, but picked up only the first.	0.33

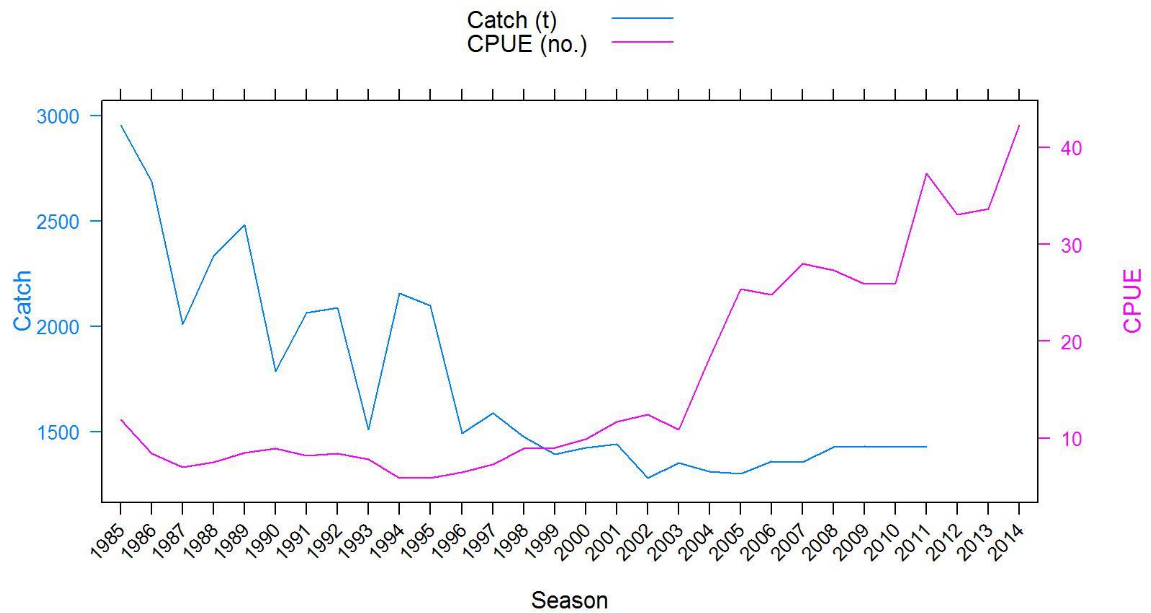


Figure 1. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the EAG, 1985/86–2014/15 fisheries (note: 1985 refers to the 1985/86 fishery).

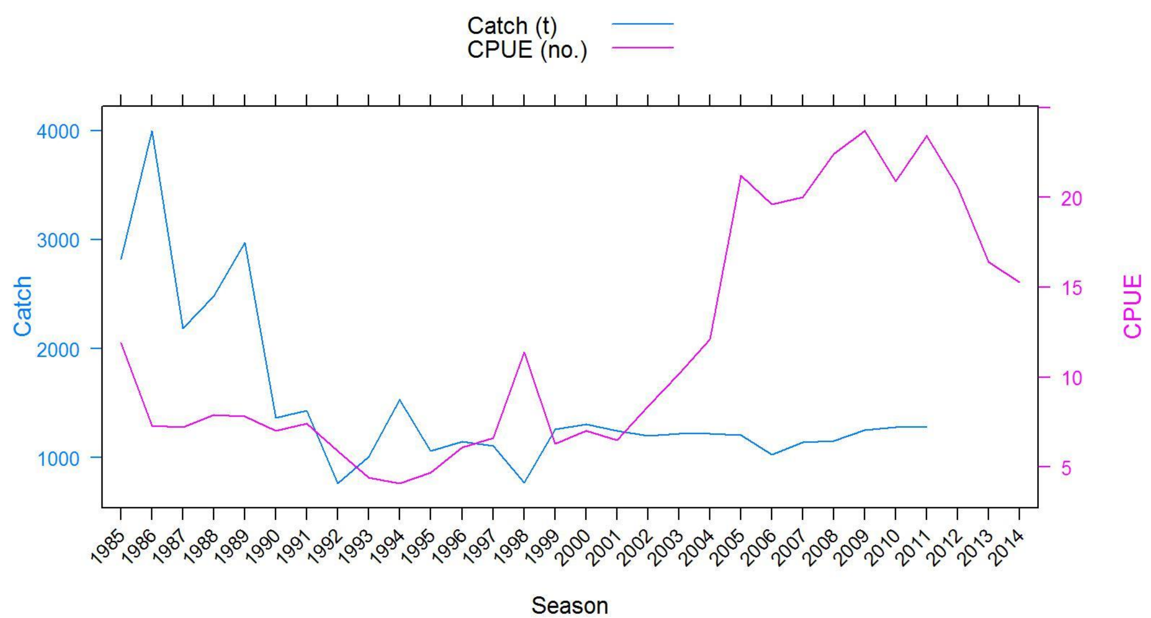


Figure 2. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crab per pot lift) of golden king crab in the WAG, 1985/86–2014/15 fisheries (note: 1985 refers to the 1985/86 fishery).

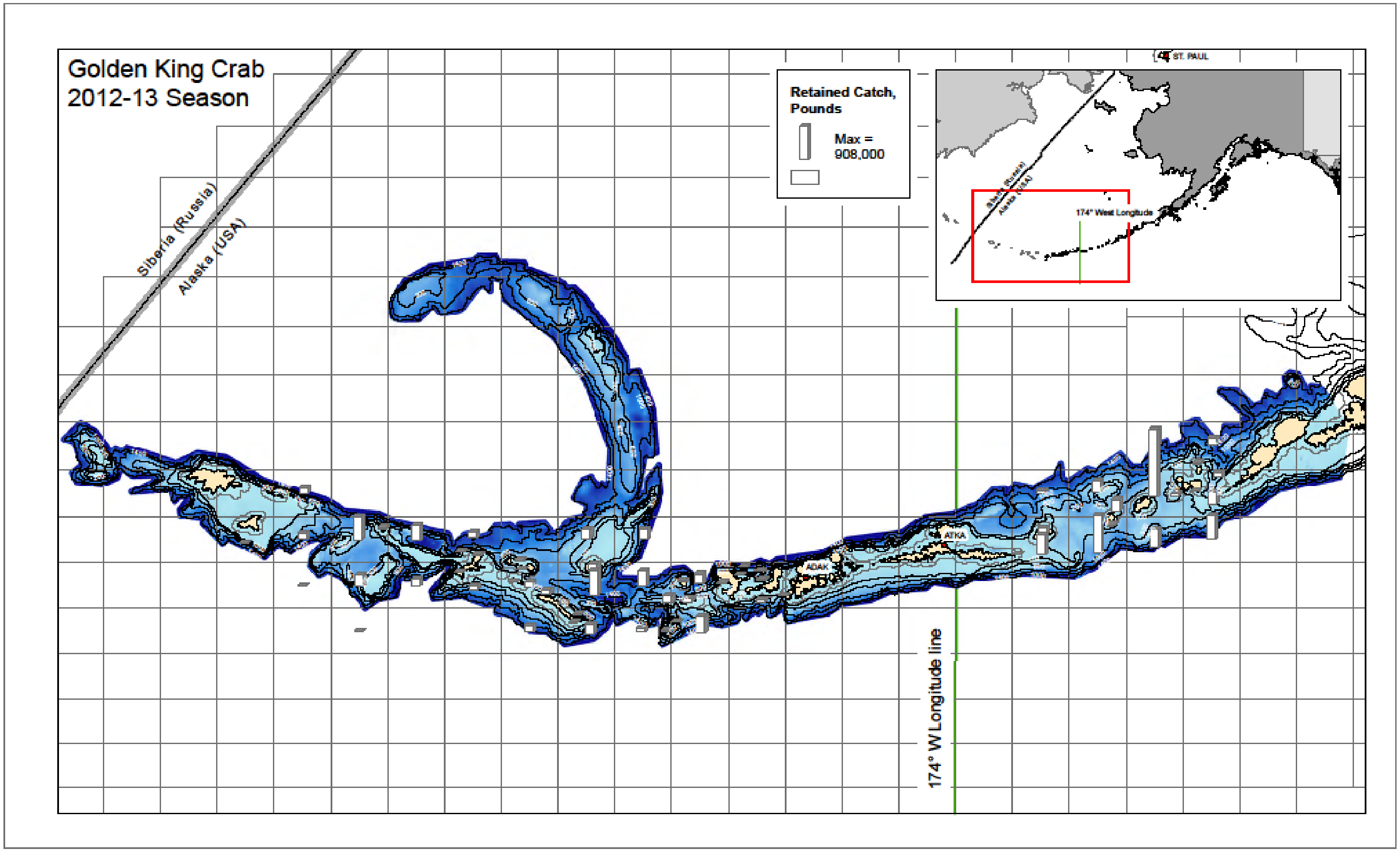


Figure 3. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2012/13.

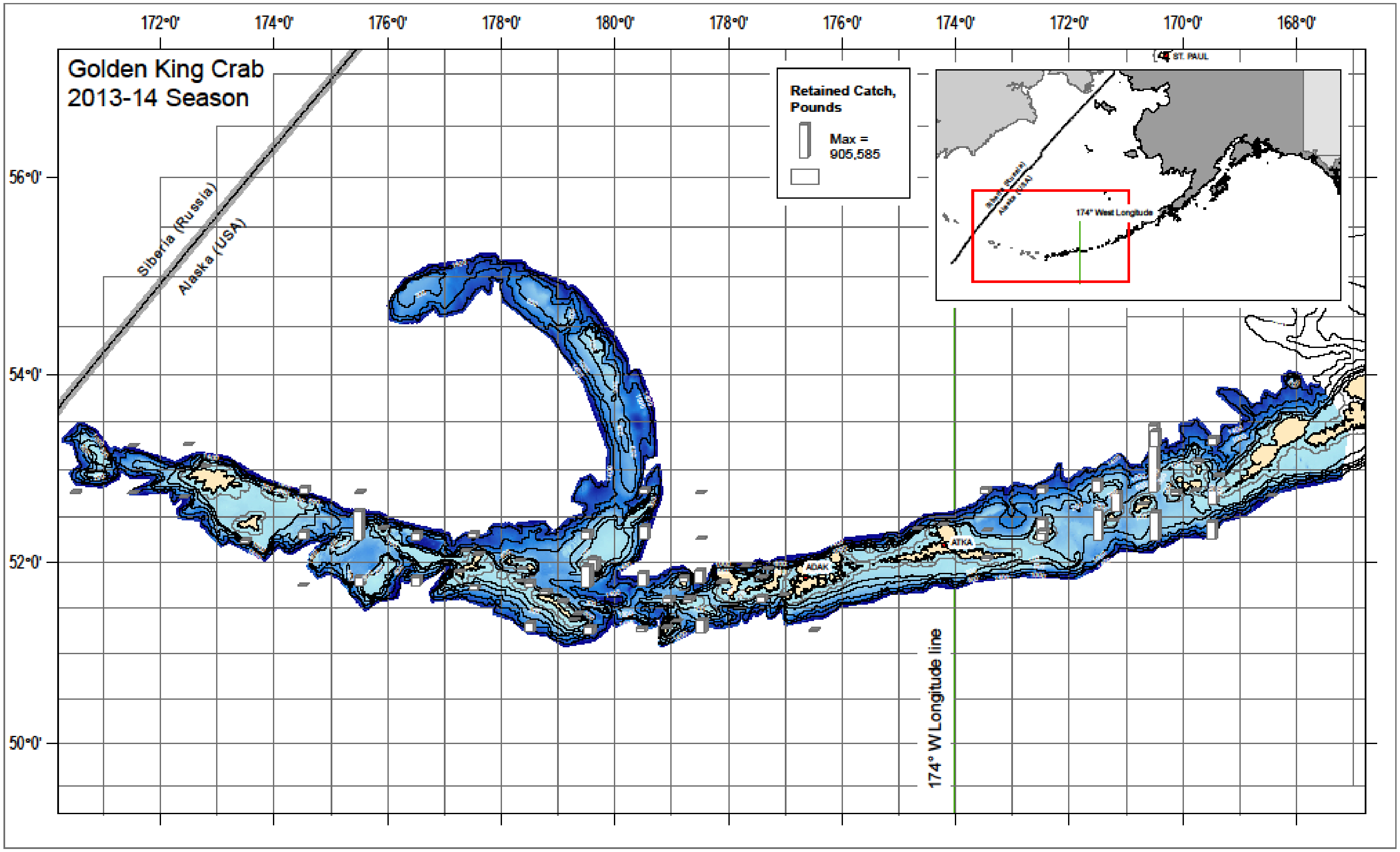


Figure 4. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2013/14.

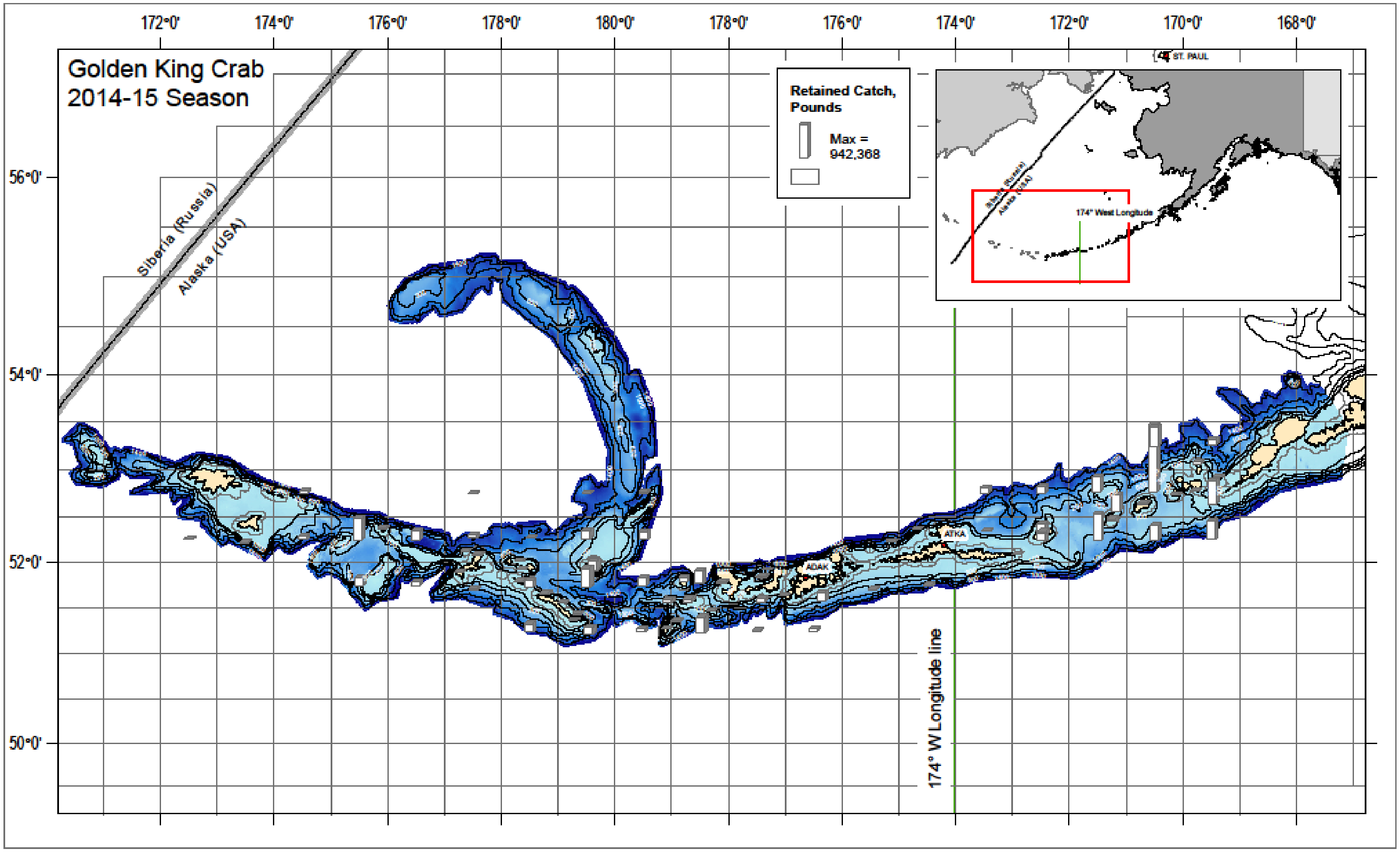


Figure 5. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2014/15.

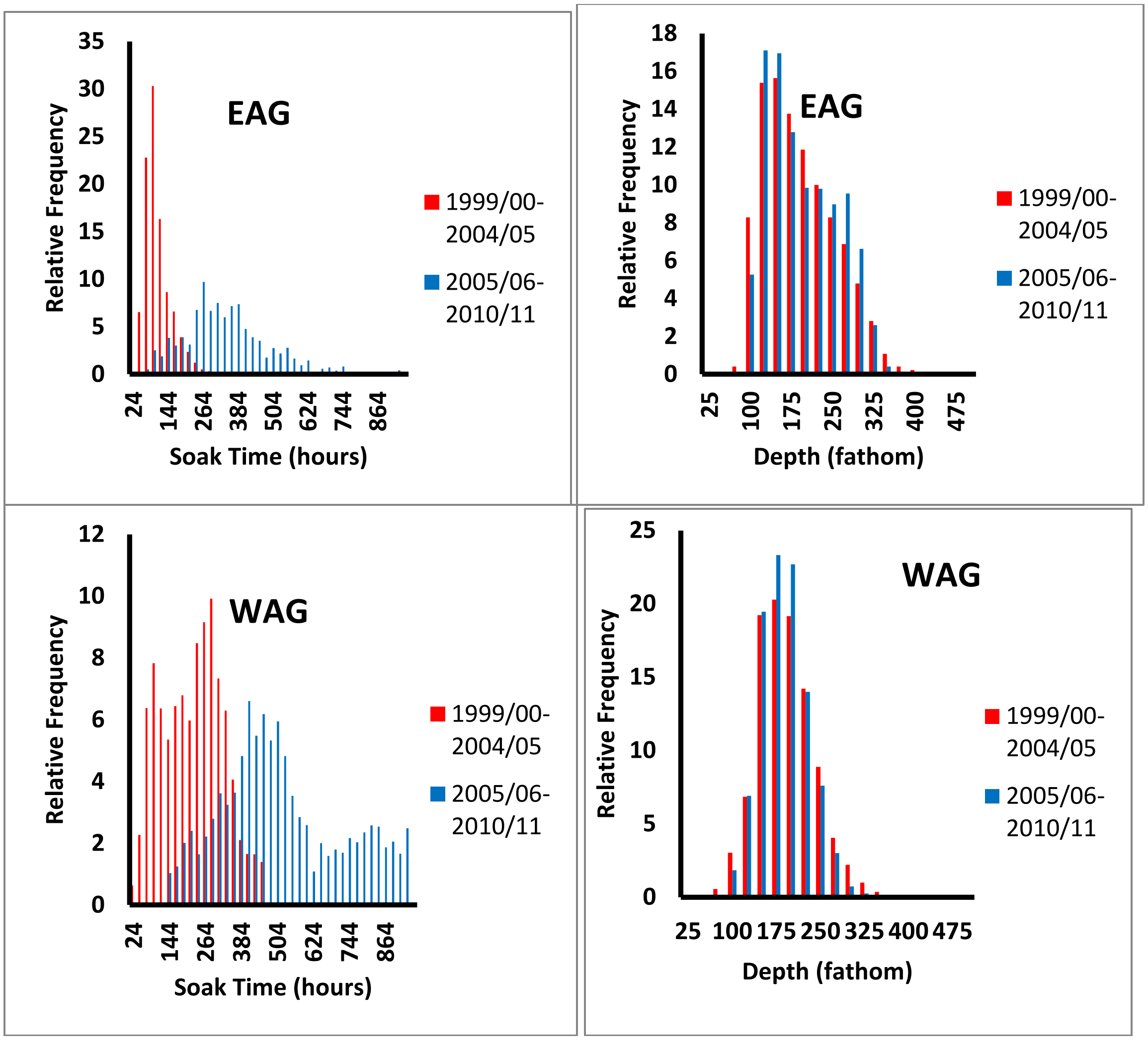


Figure 6. Relative frequency distributions of soak time and depth of golden king crab pots fished during pre (1999/00–2004/05) – and post (2005/06–2010/11) – rationalization years.

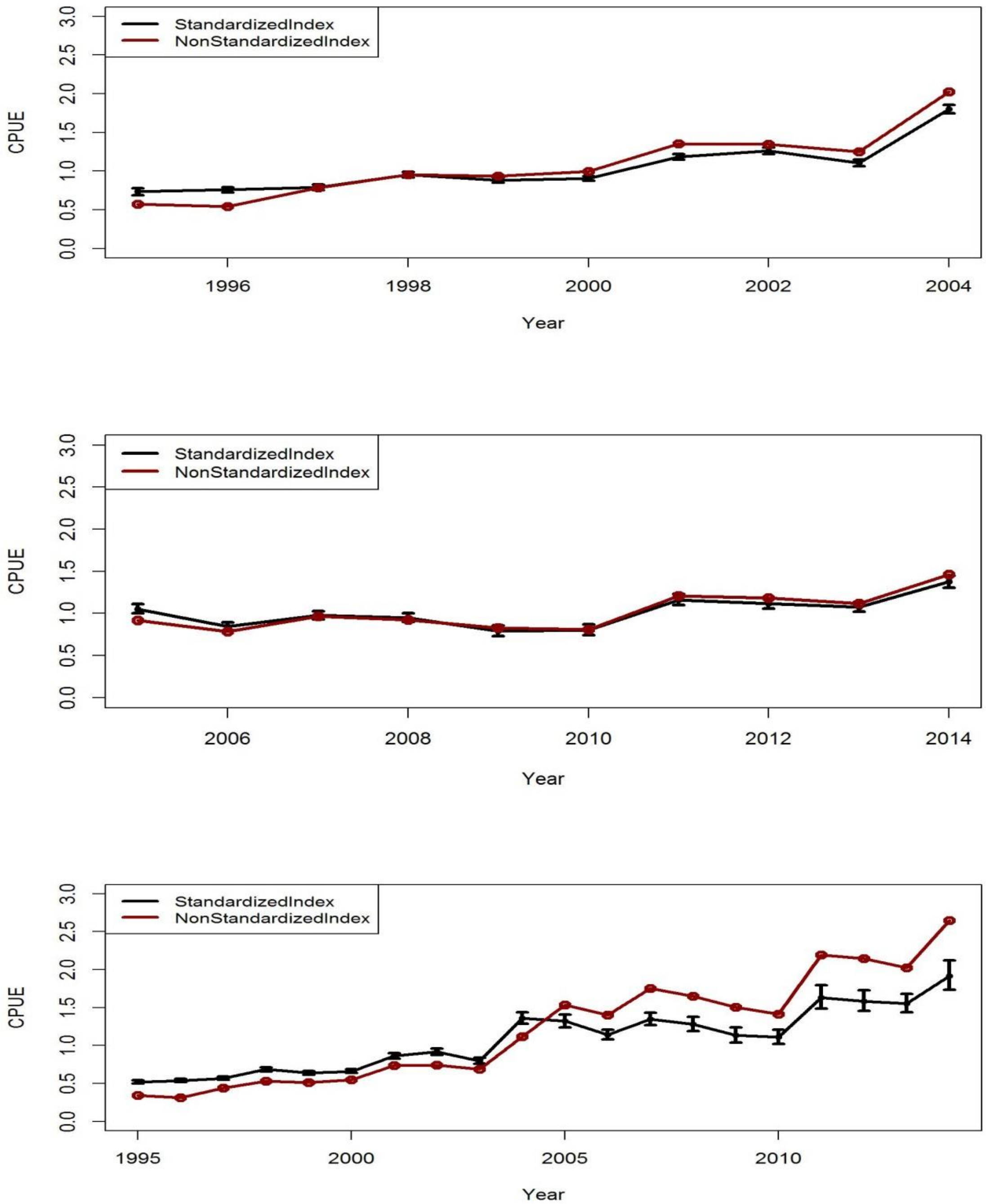


Figure 7. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). Top panel: 1995/96-2004/05 observer data, center panel: 2005/06-2014/15 observer data, and bottom panel: 1995/96-2014/15 observer data. Standardized indices: black line and non-standardized indices: red line.

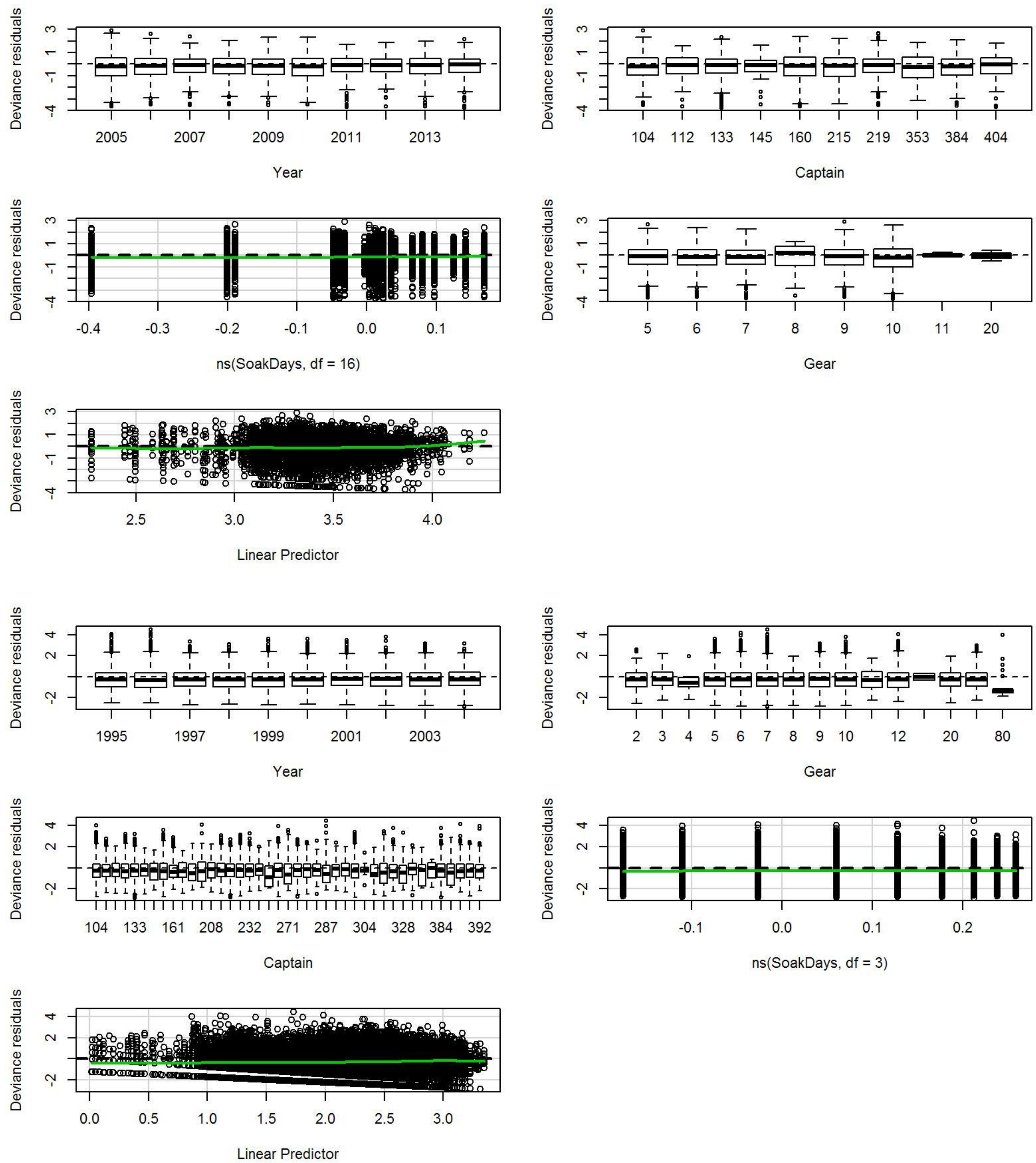


Figure 8. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 1995/96–2004/05 (top) and 2005/06–2014/15 (bottom) periods were used. The solid green lines are the loess smoother through the plotted values.

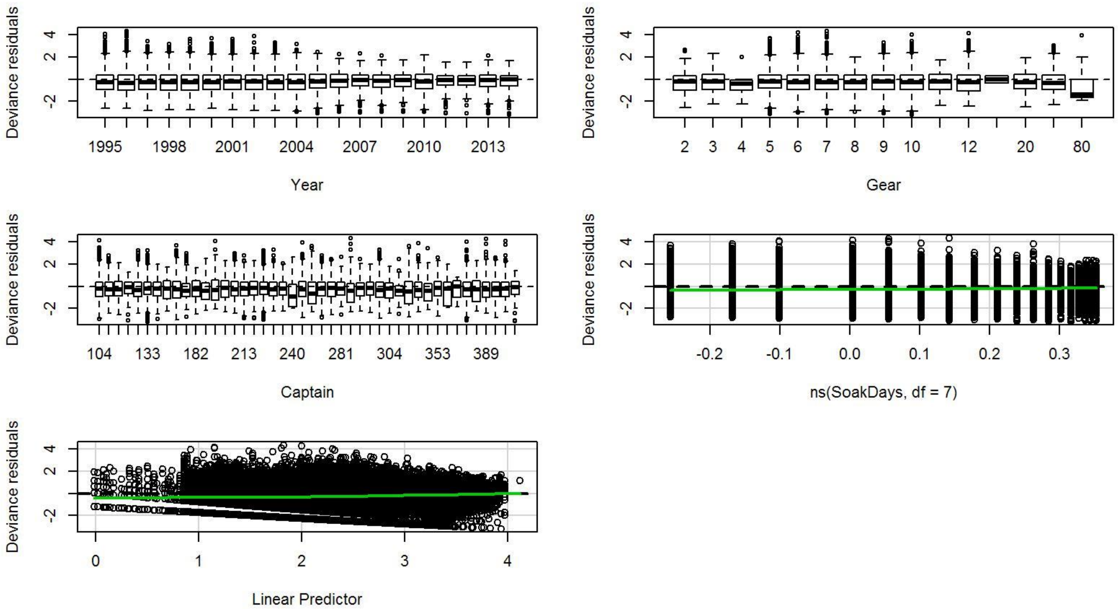


Figure 9. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 1995/96–2014/15 period were used. The solid green lines are the loess smoother through the plotted values.

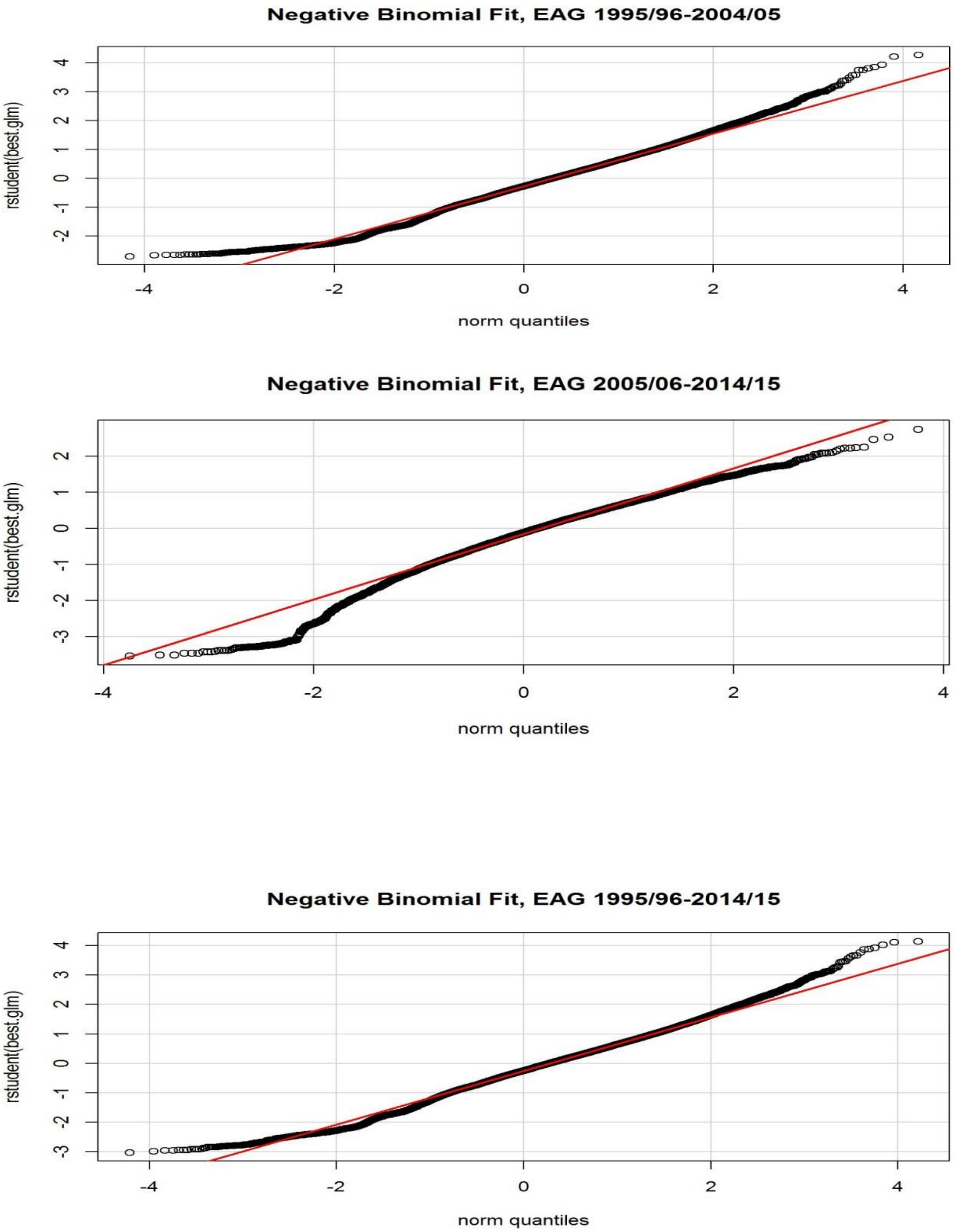


Figure 10. Studentized residual plots for negative binomial GLM fit for EAG golden king crab observer legal size male crab CPUE data. Top panel is for 1995/96–2004/05, center panel is for 2005/06–2014/15, and the bottom panel is for 1995/96–2014/15 data.

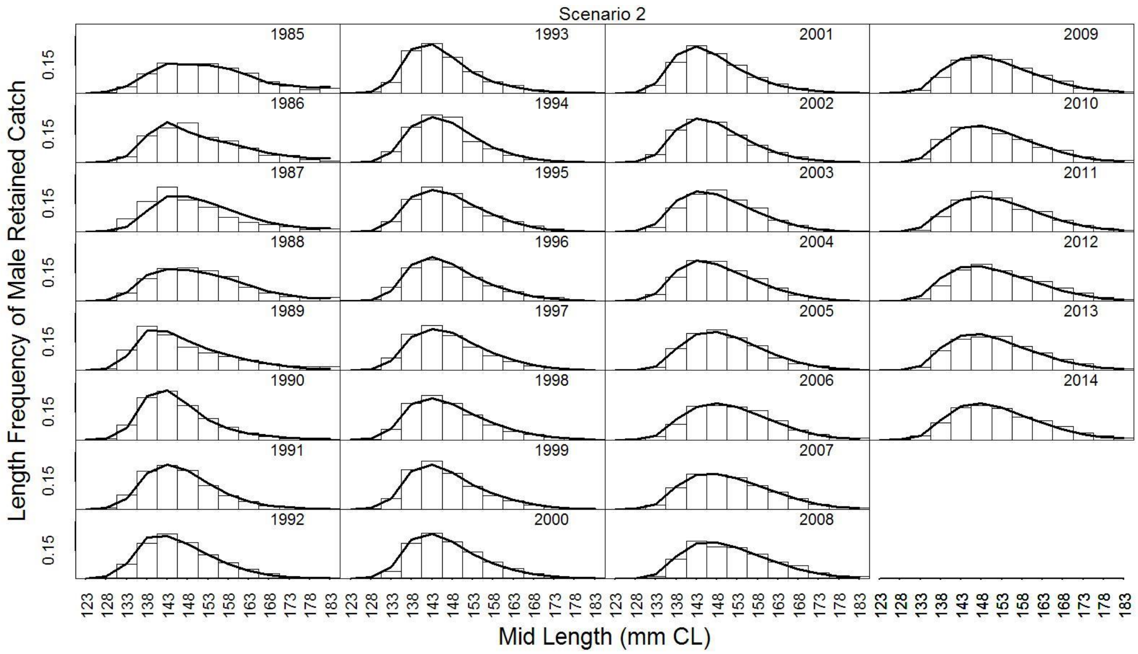


Figure 11a. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 2 data of golden king crab in the EAG, 1985/86 to 2014/15.

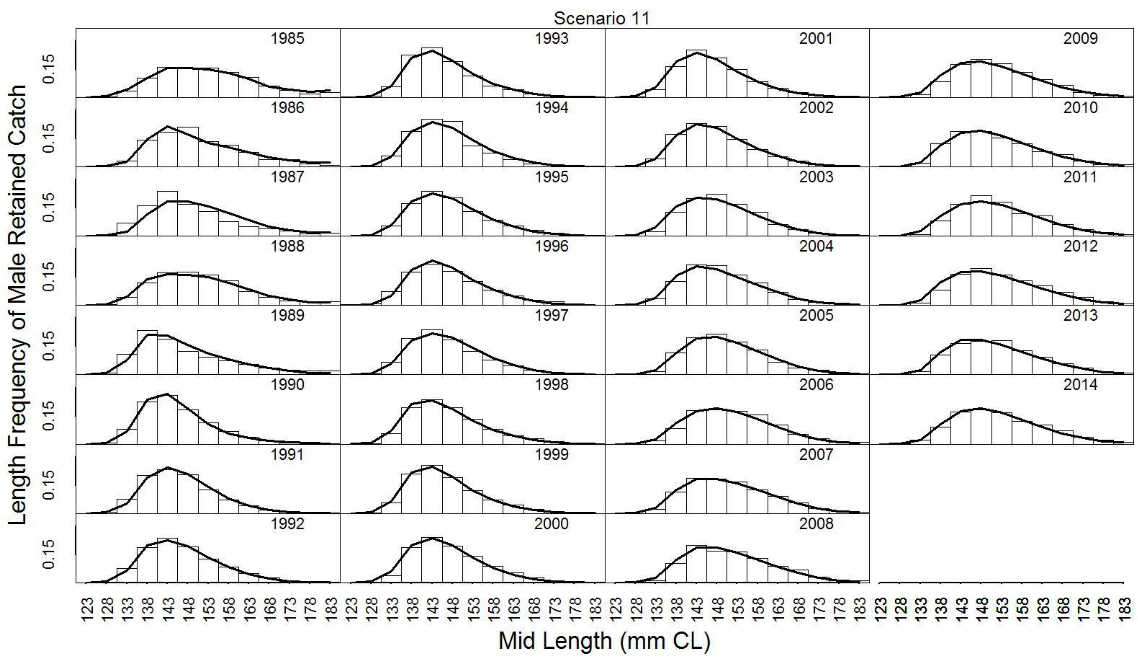


Figure 11b. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 11 data of golden king crab in the EAG, 1985/86 to 2014/15.

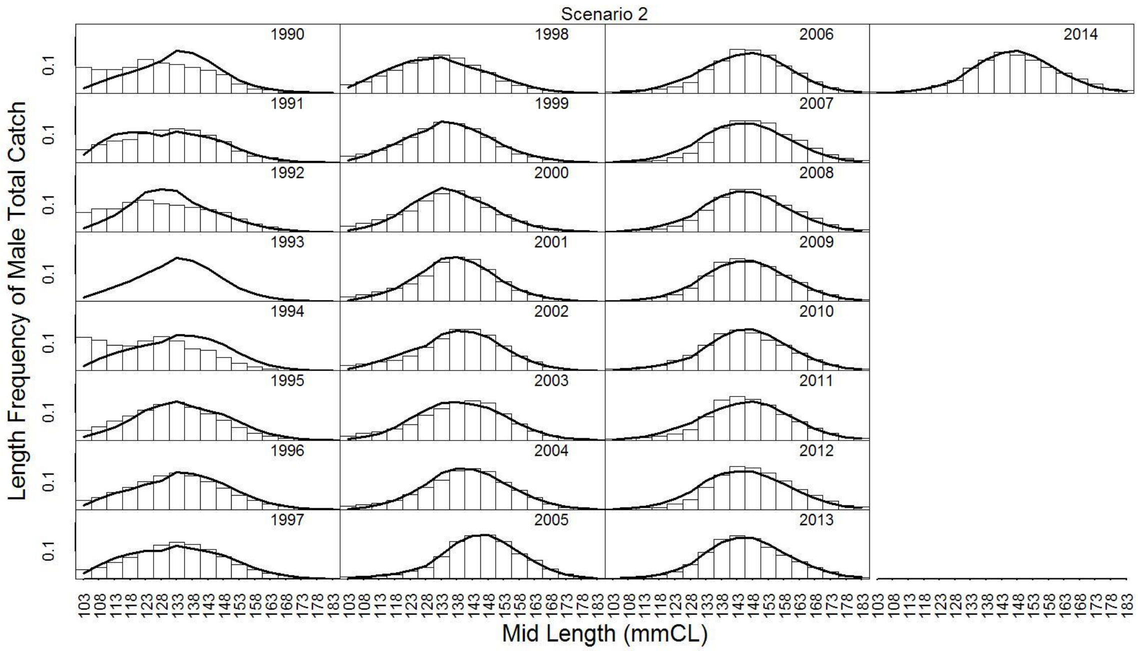


Figure 12a. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 2 data of golden king crab in the EAG, 1990/91 to 2014/15.

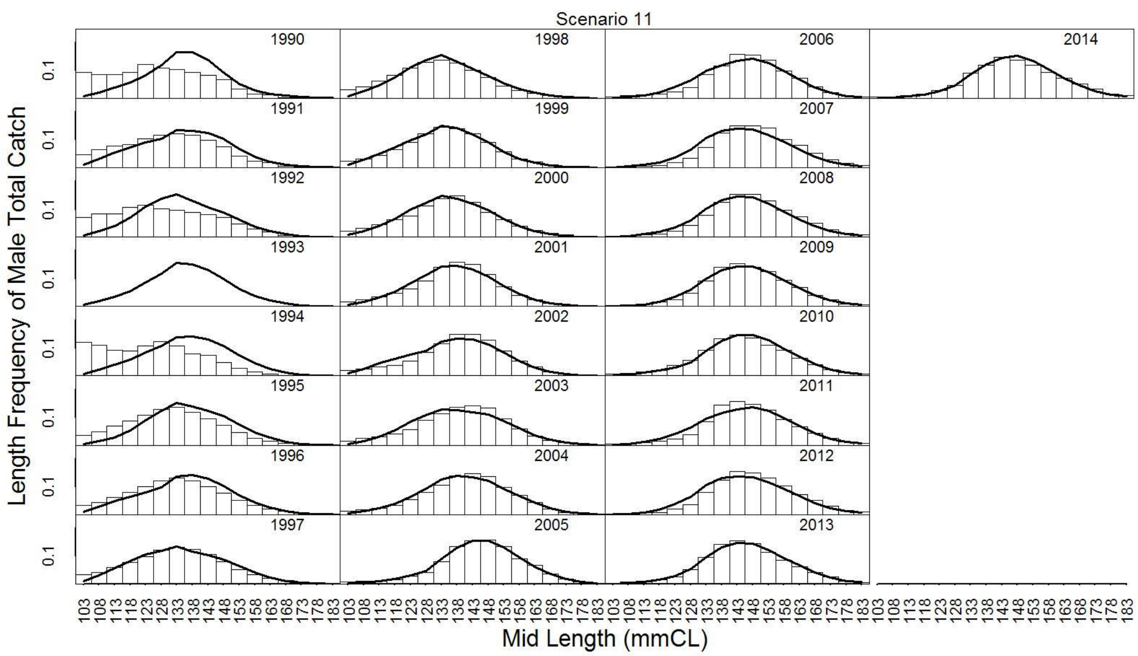


Figure 12b. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 11 data of golden king crab in the EAG, 1990/91 to 2014/15. L.

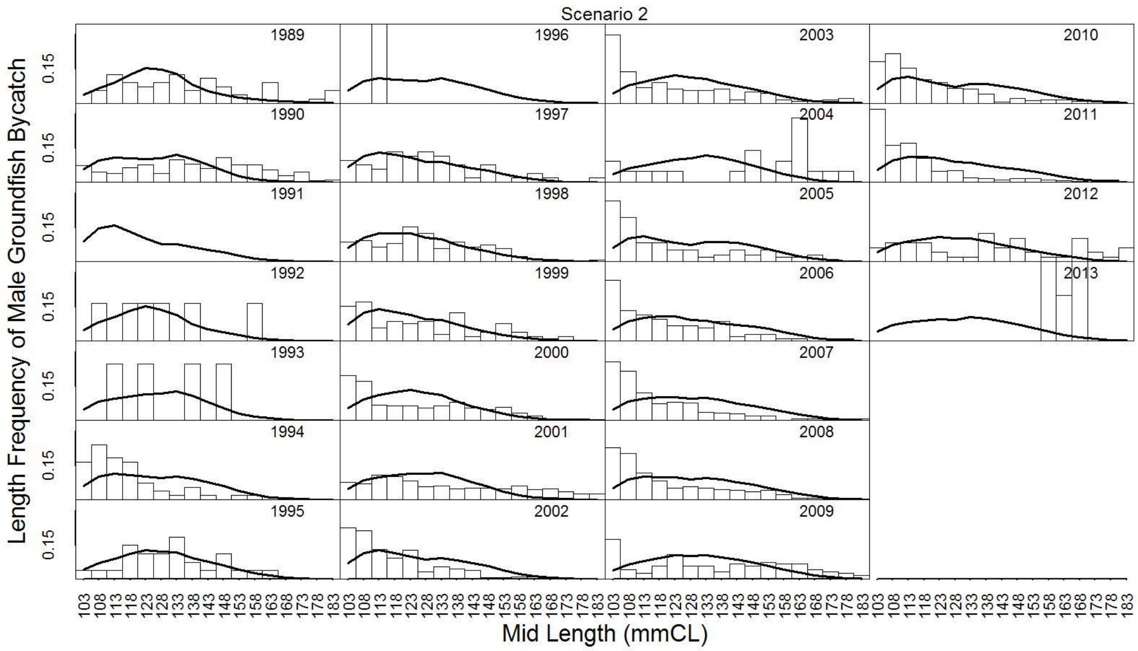


Figure 13a. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 2 data of golden king crab in the EAG, 1989/90 to 2014/15.

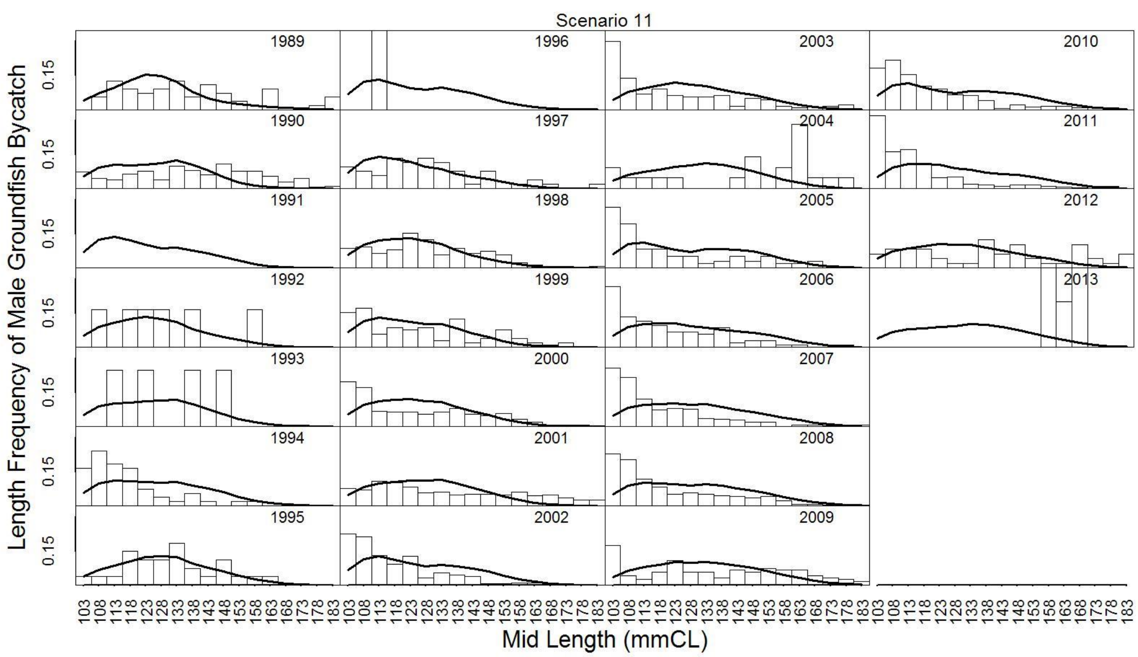


Figure 13b. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 11 data of golden king crab in the EAG, 1989/90 to 2013/14.

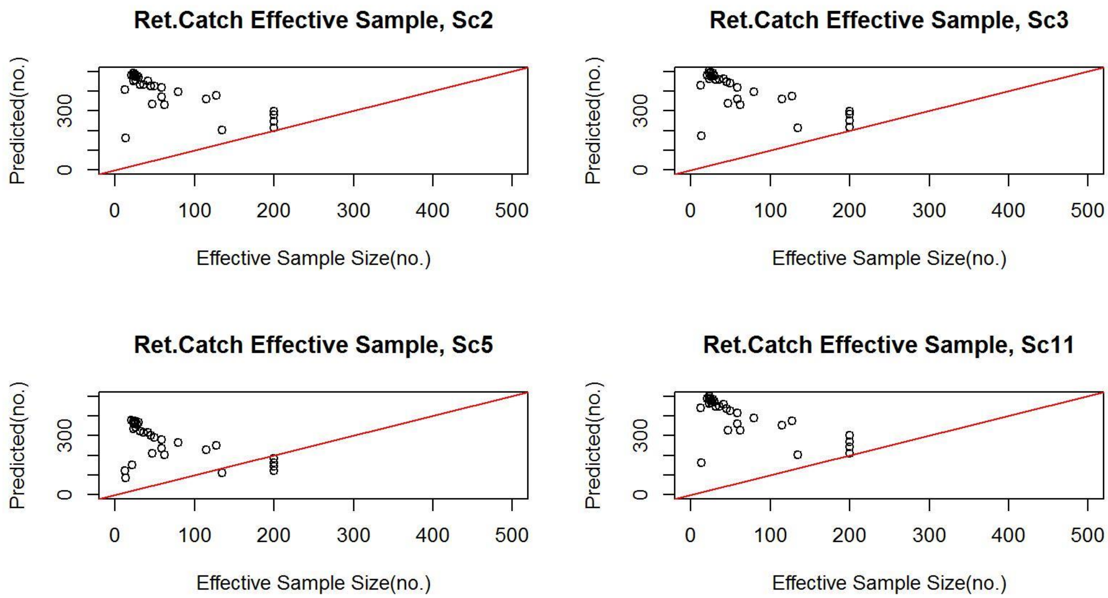


Figure 14. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios (Sc) 2, 3, 5 and 11 fits to golden king crab data in the EAG, 1985/86 to 2014/15. The red line is the 1:1 line passing through the origin.

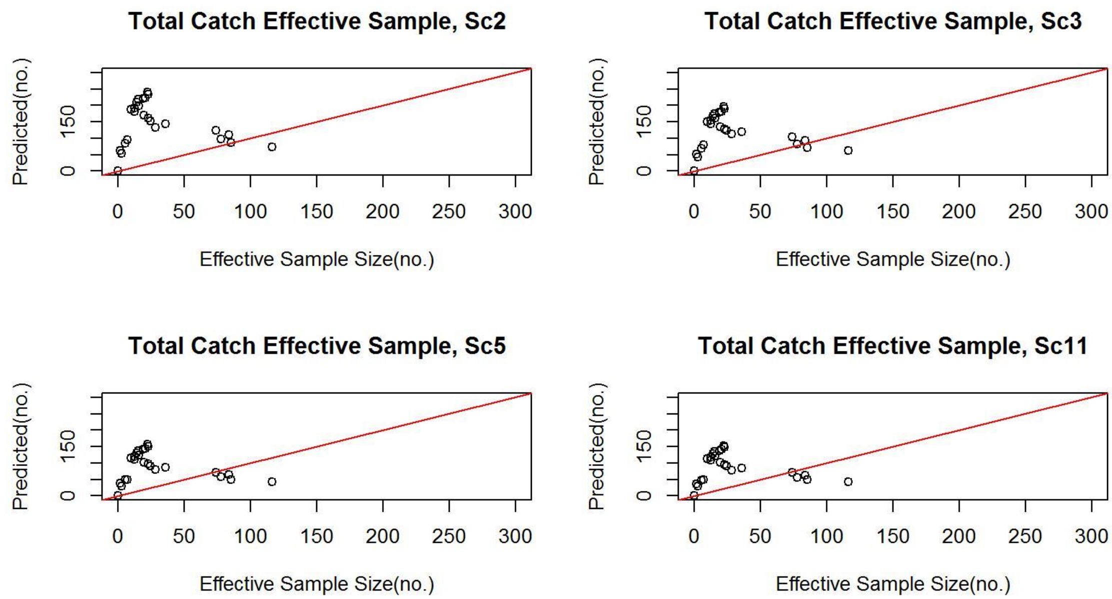


Figure 15. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios (Sc) 2, 3, 5, and 11 fits to golden king crab data in the EAG, 1990/91 to 2014/15. The red line is the 1:1 line passing through the origin.

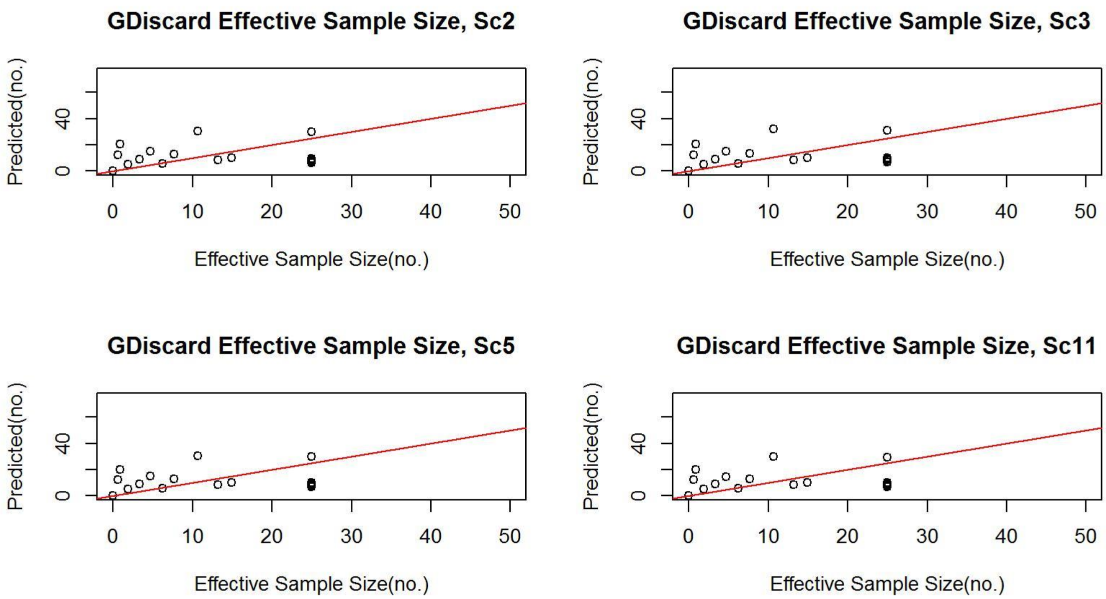


Figure 16. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for scenarios (Sc) 2, 3, 5, and 11 fits to golden king crab data in the EAG, 1989/90 to 2014/15. The red line is the 1:1 line passing through the origin.

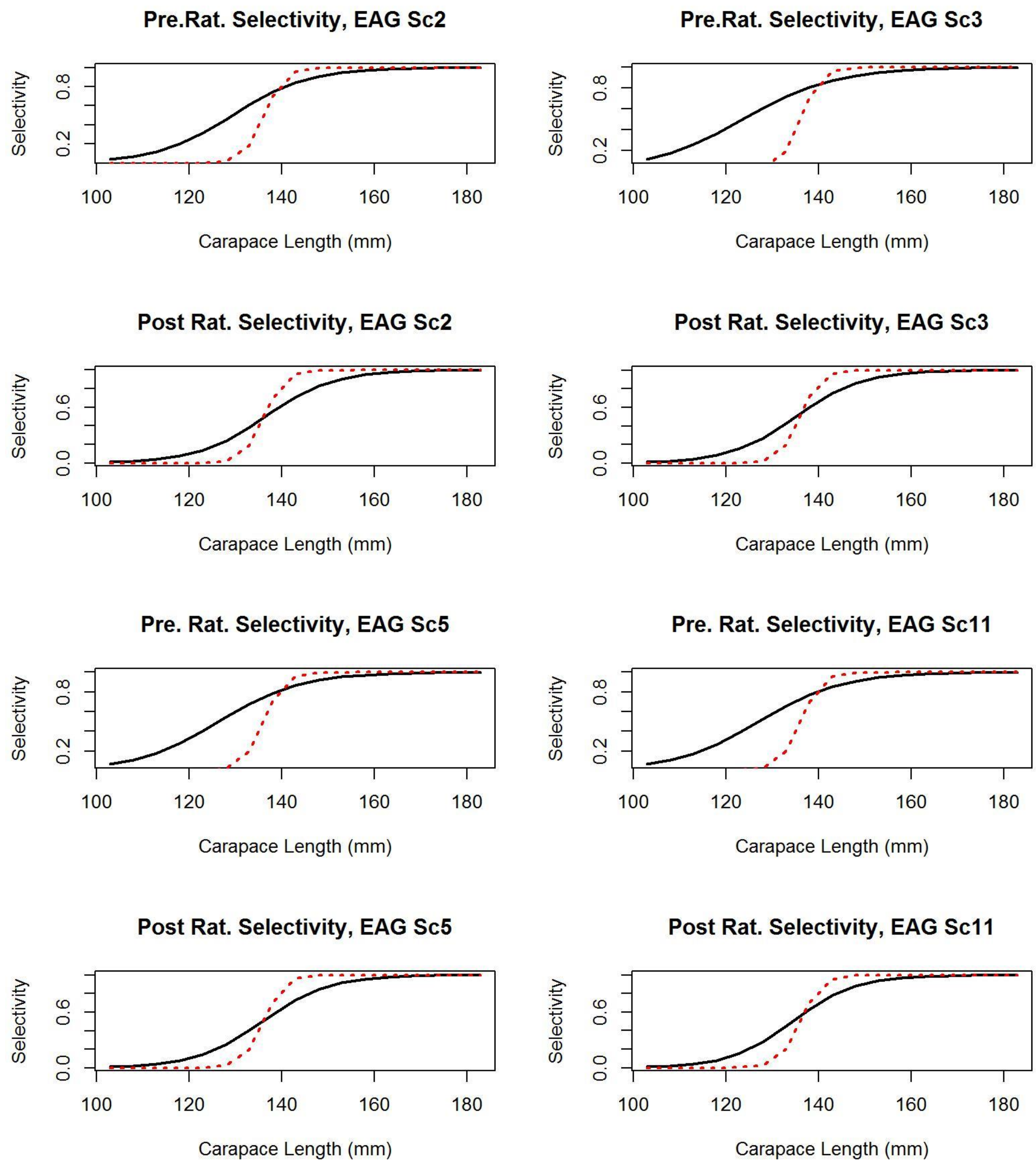
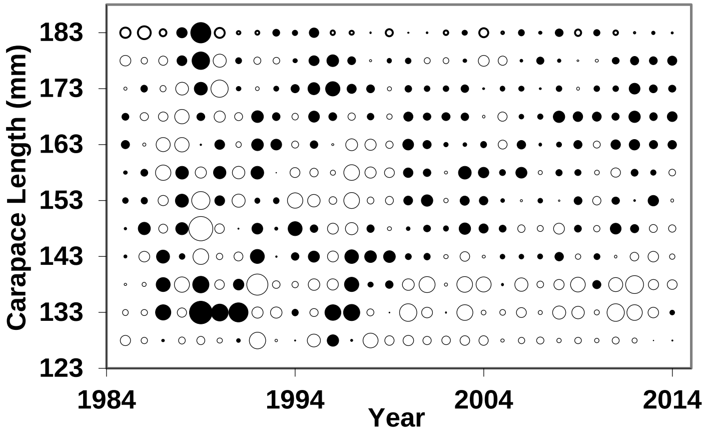
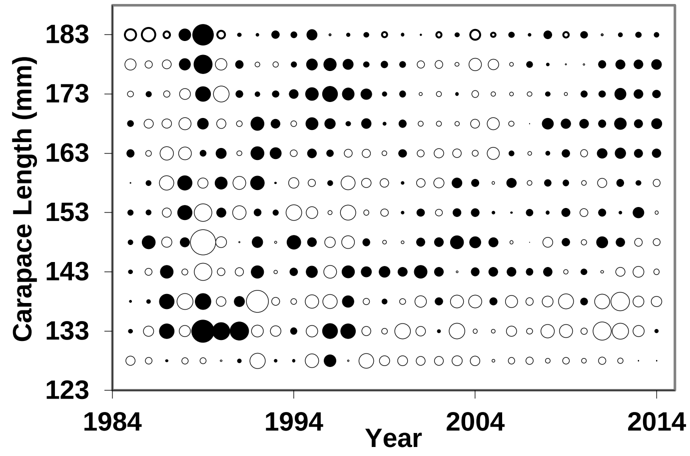


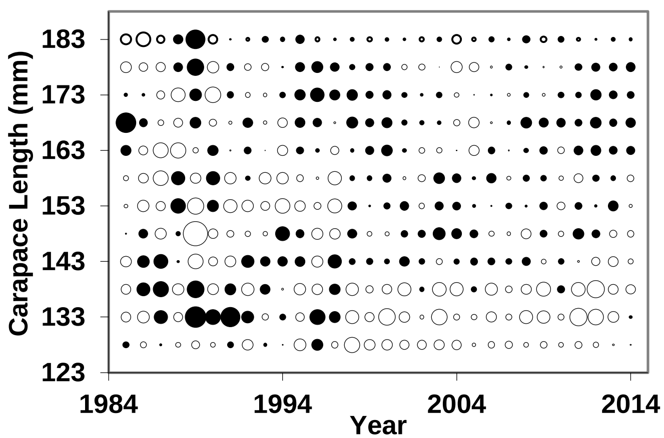
Figure 17. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 2, 3, 5, and 11 fits of EAG golden king crab data.



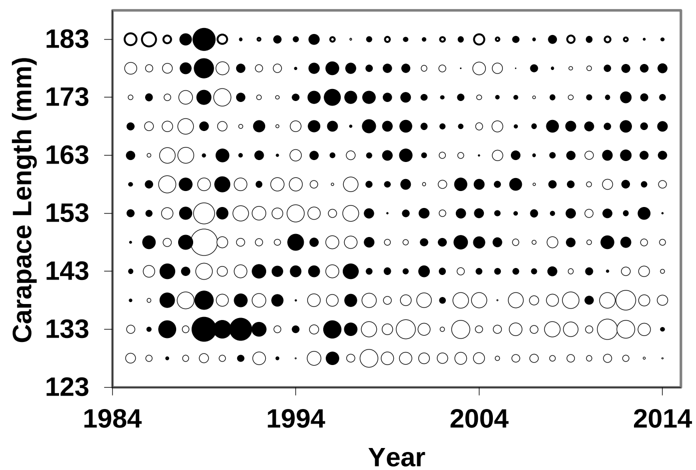
Scenario 2



Scenario 3



Scenario 5



Scenario 11

Figure 18. Bubble plots of standardized residuals of retained catch length composition for scenarios 2, 3, 5, and 11fits for EAG golden king crab, 1985/86–2014/15. 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.

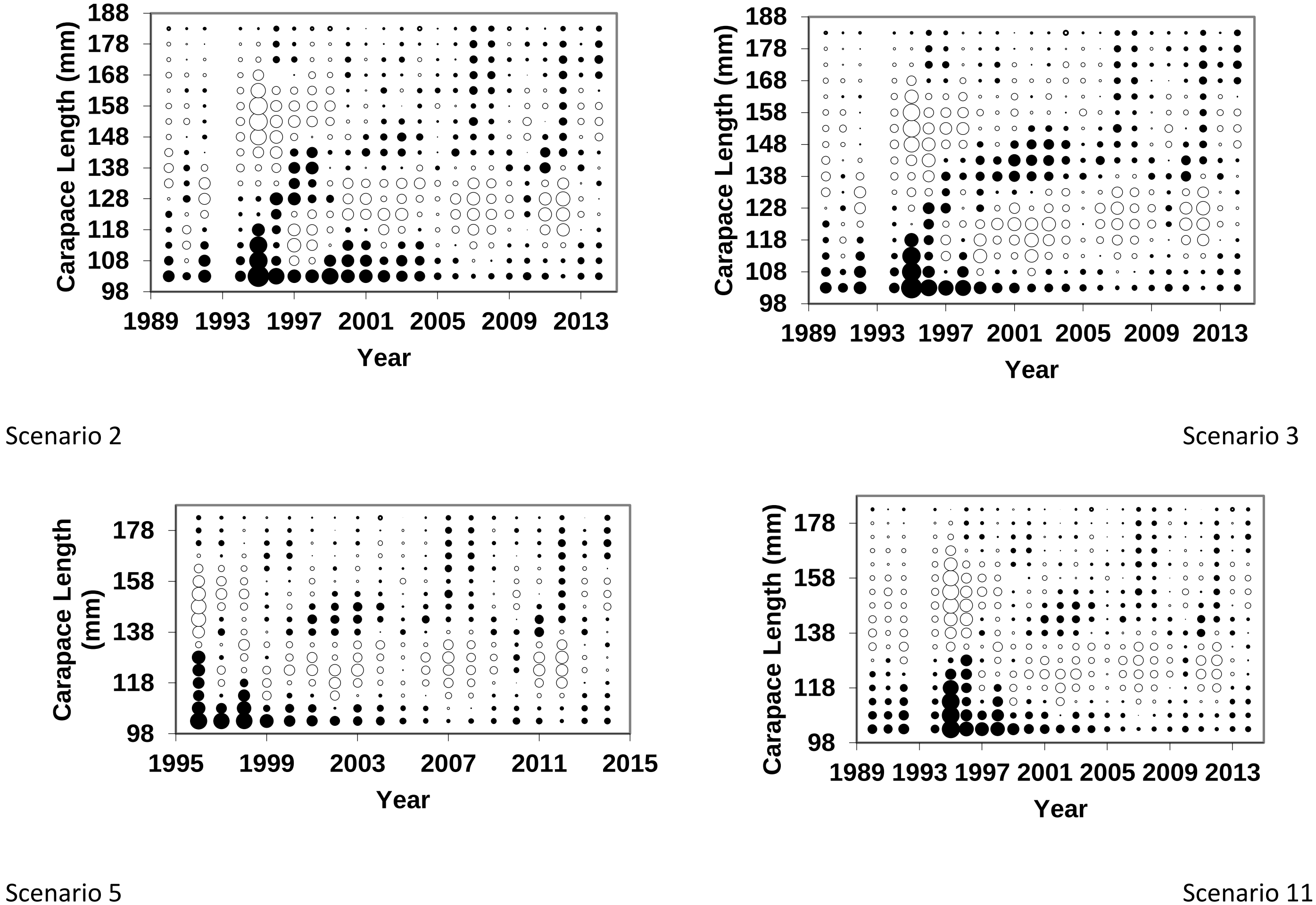
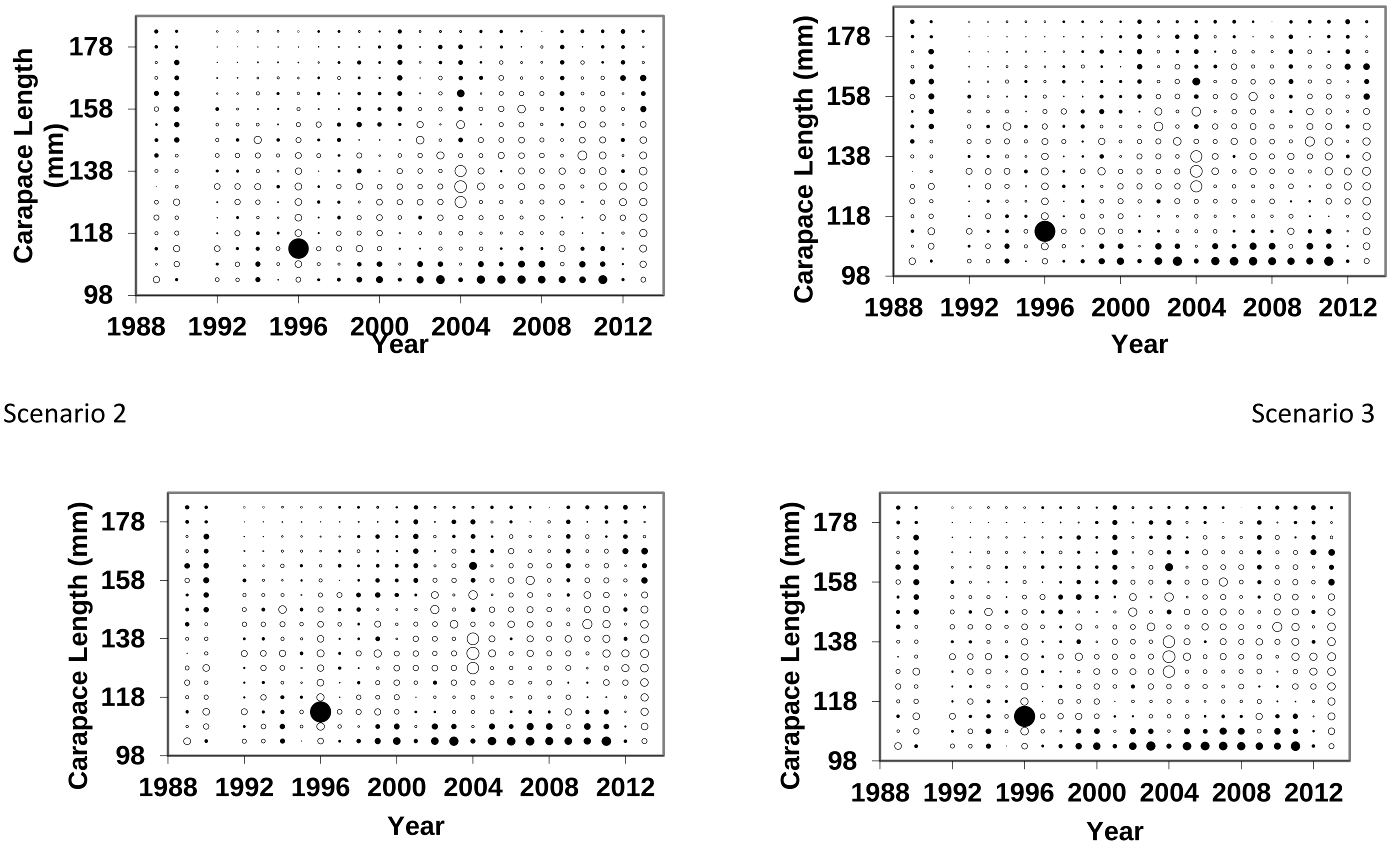


Figure 19. Bubble plots of standardized residuals of total catch length composition for scenarios 2, 3, 5, and 11 fits for EAG golden king crab, 1990/91–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



Scenario 2

Scenario 3

Scenario 5

Scenario 11

Figure 20. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 2, 3, 5, and 11 fits for EAG golden king crab, 1989/90–2014/15. 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.

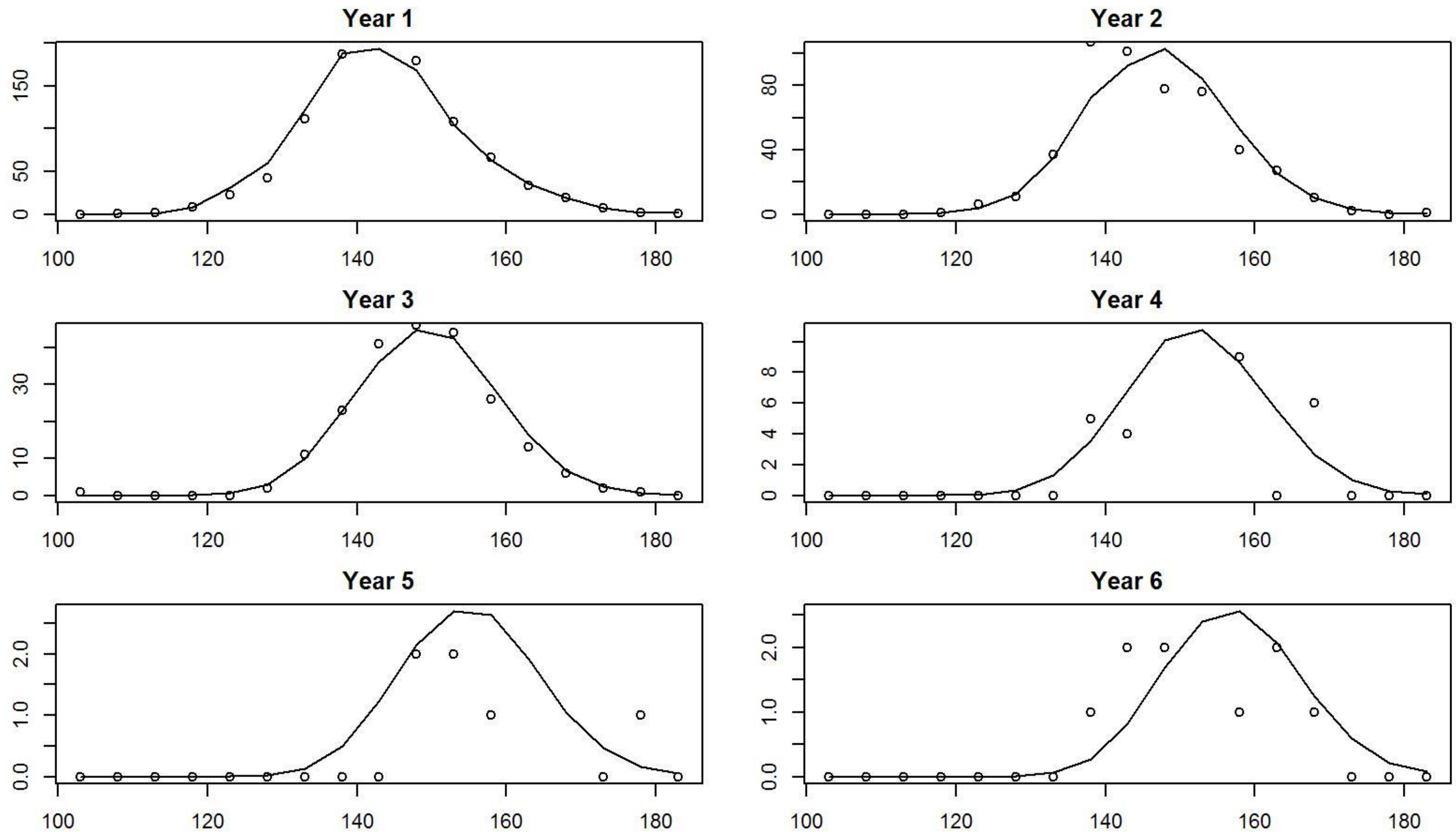


Figure 21. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures of EAG golden king crab.

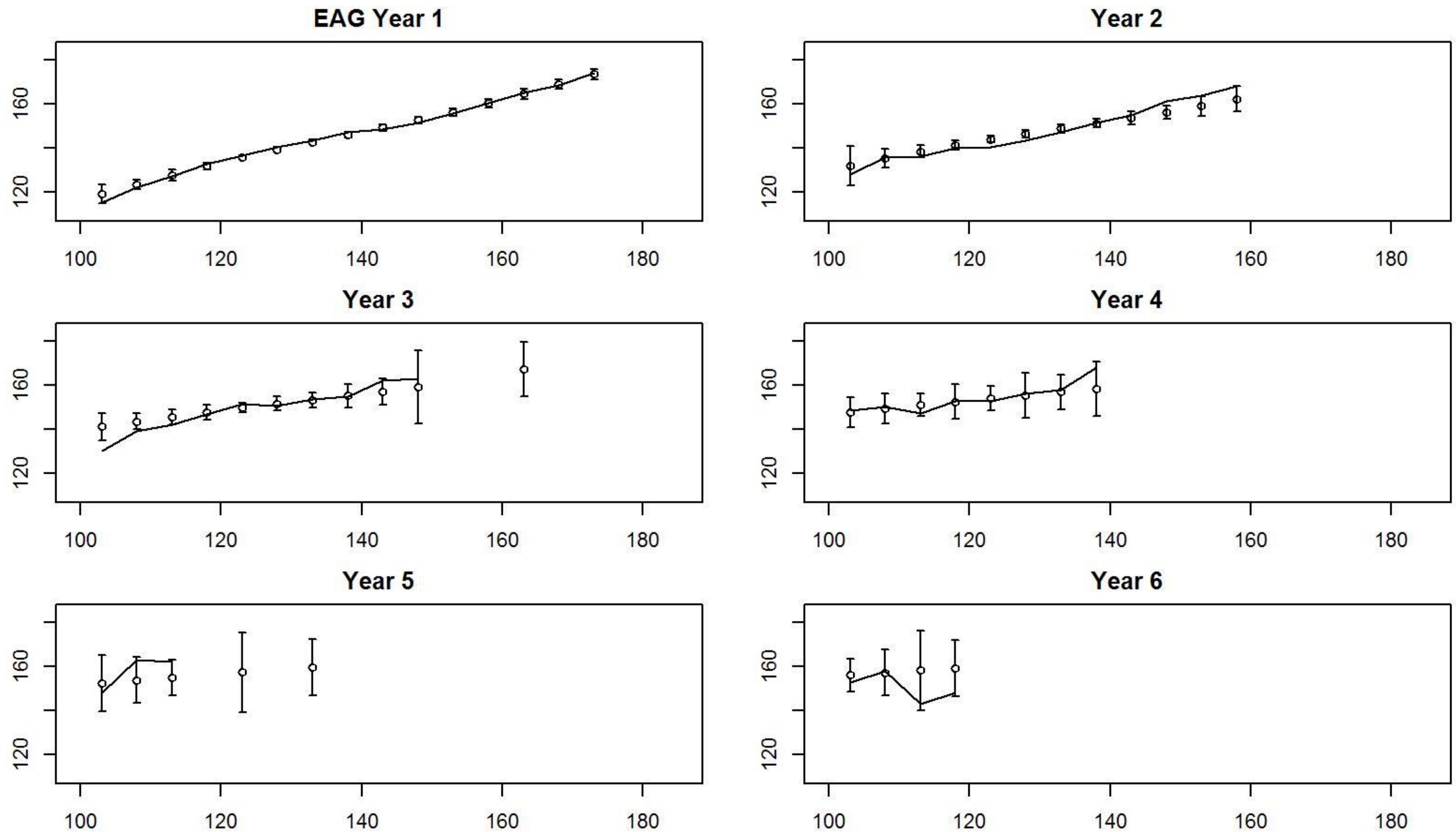


Figure 22. Observed and predicted mean length (with two SE) of recaptures vs. release length for years 1 to 6 recaptures of EAG golden king crab.

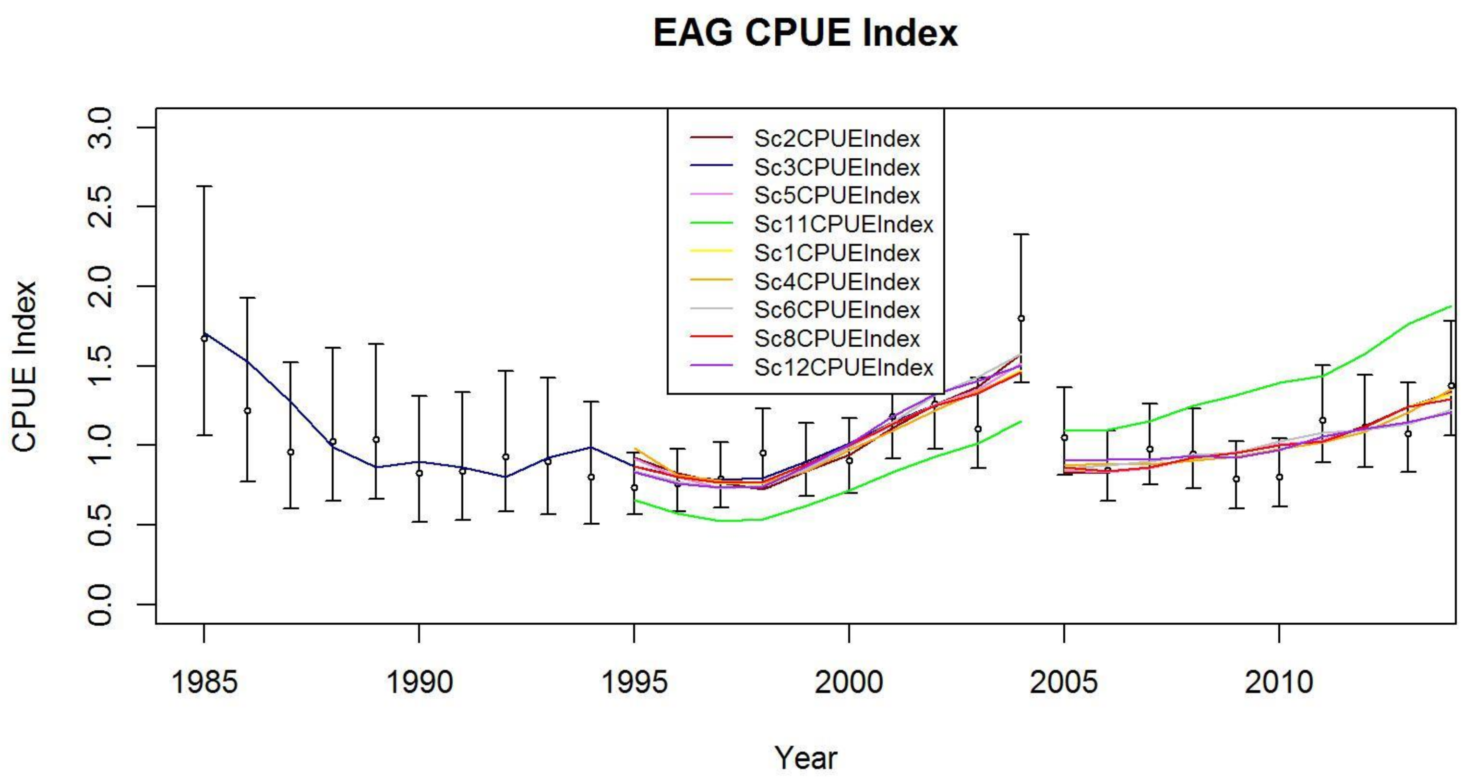


Figure 23. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1, 2, 3, 4, 5, 6, 8, 11, and 12 fits for EAG golden king crab data, 1995/96–2014/15. Model estimated additional standard error was added to each input standard error.

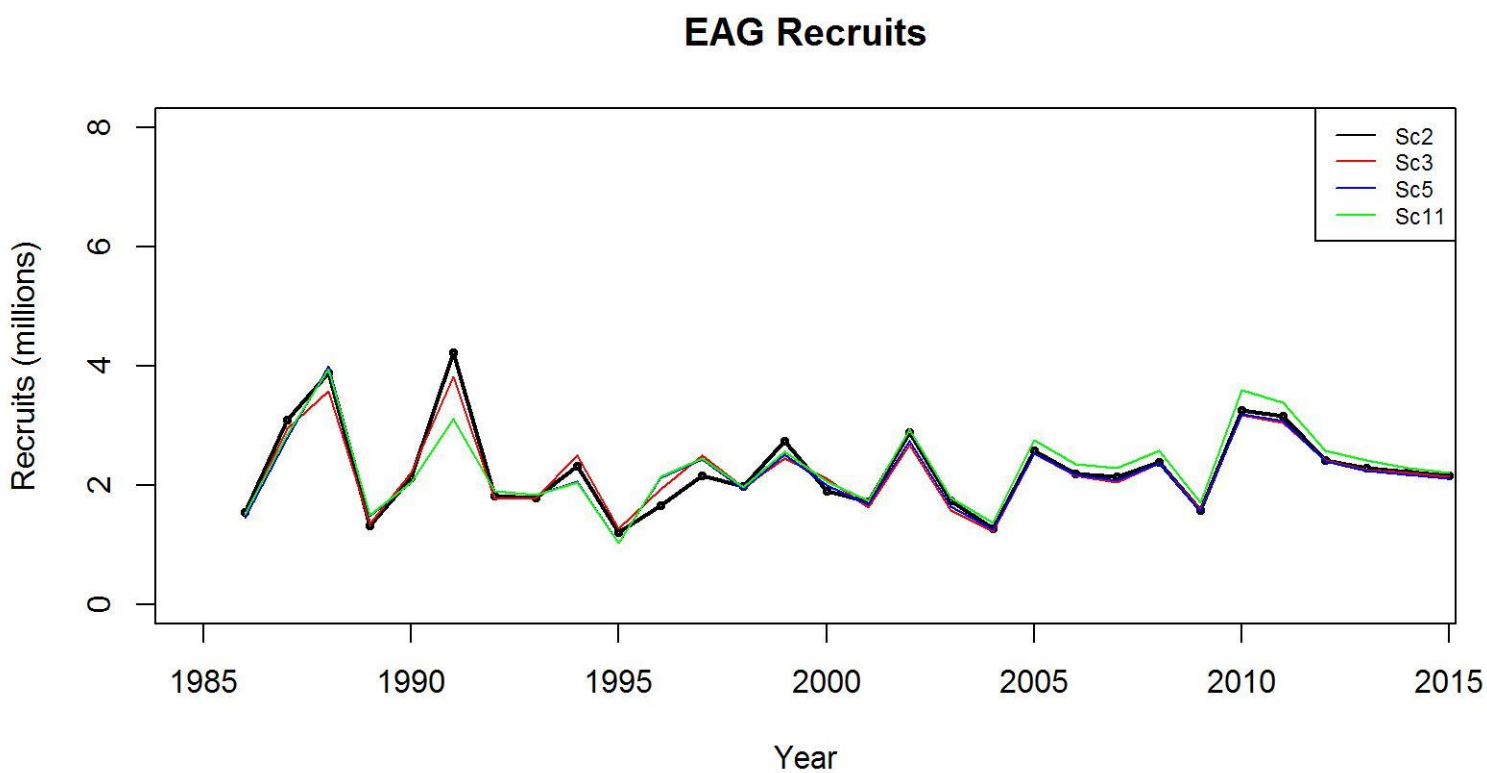


Figure 24. Estimated number of male recruits (millions of crab ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 2, 3, 5, and 11 fits in EAG, 1986–2015.

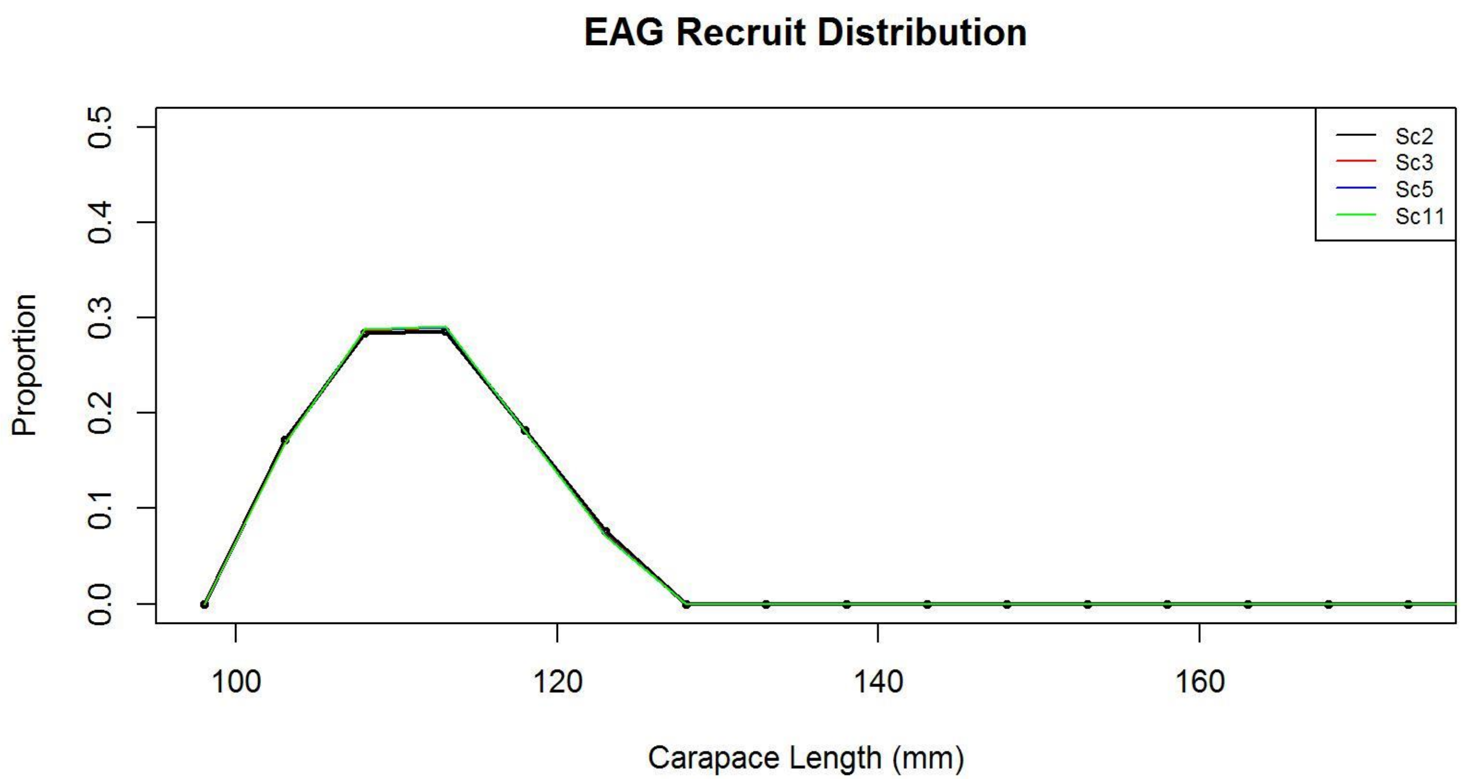


Figure 25. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 2, 3, 5, and 11 fits in EAG.

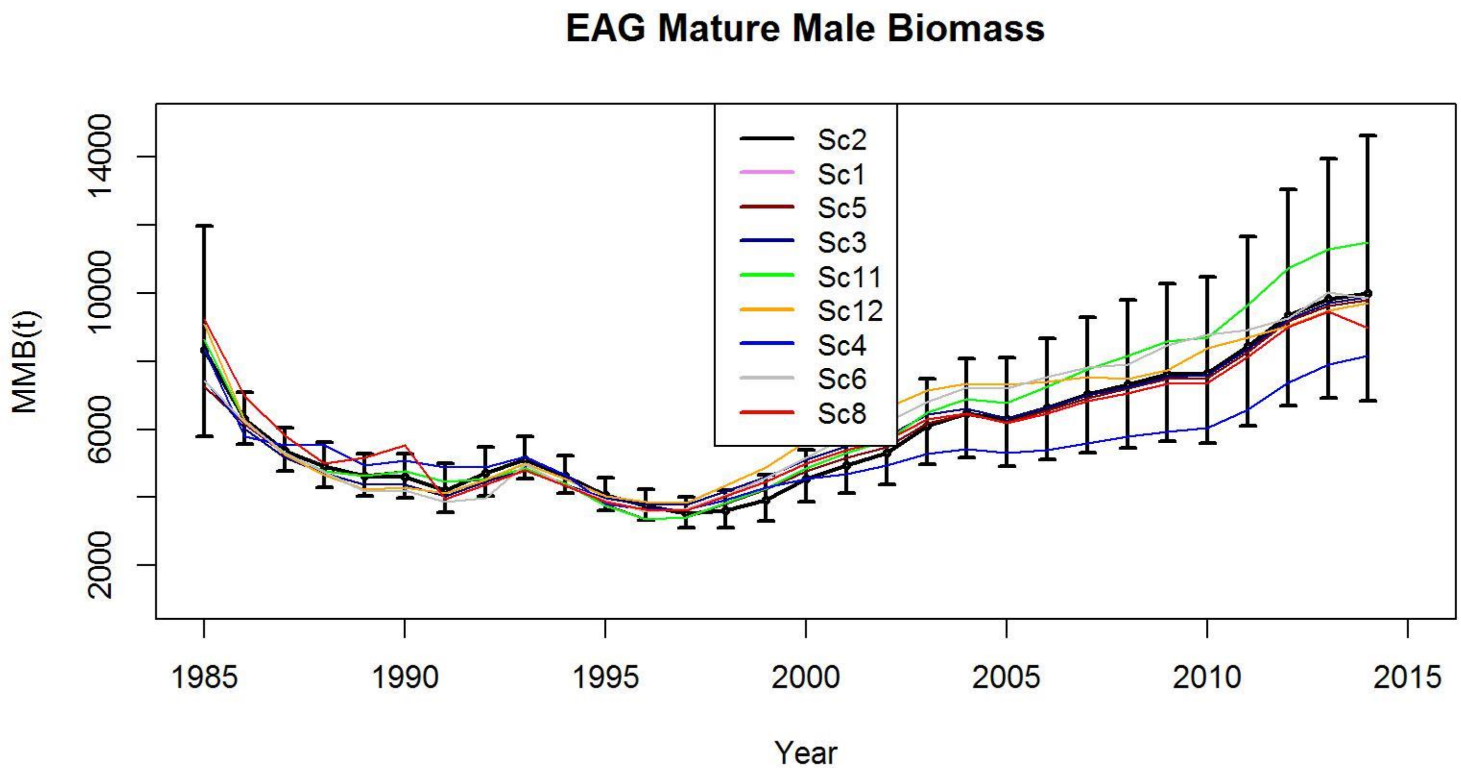


Figure 26. Trends in golden king crab mature male biomass for scenarios (Sc) 1, 2, 3, 4, 5, 6, 8, 11, and 12 model fits in the EAG, 1985/86–2014/15. Mature male crab are ≥ 121 mm CL. Scenario 2 estimates have two standard errors confidence limits.

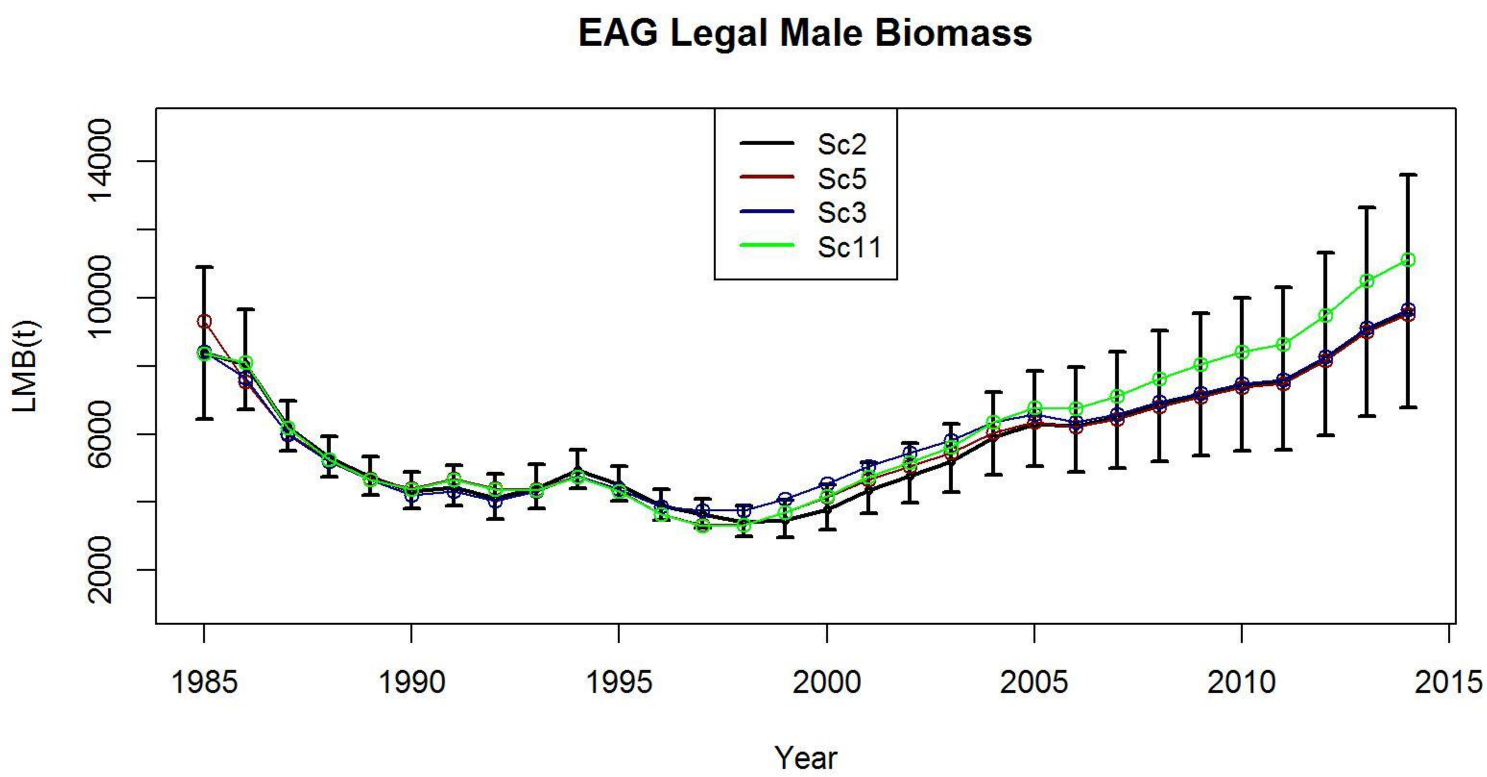


Figure 27. Trends in golden king crab legal male biomass for scenarios (Sc) 2, 3, 5, and 11 fits in the EAG, 1985/86–2014/15. Legal male crab are ≥ 136 mm CL. Scenario 2 estimates have two standard errors confidence limits.

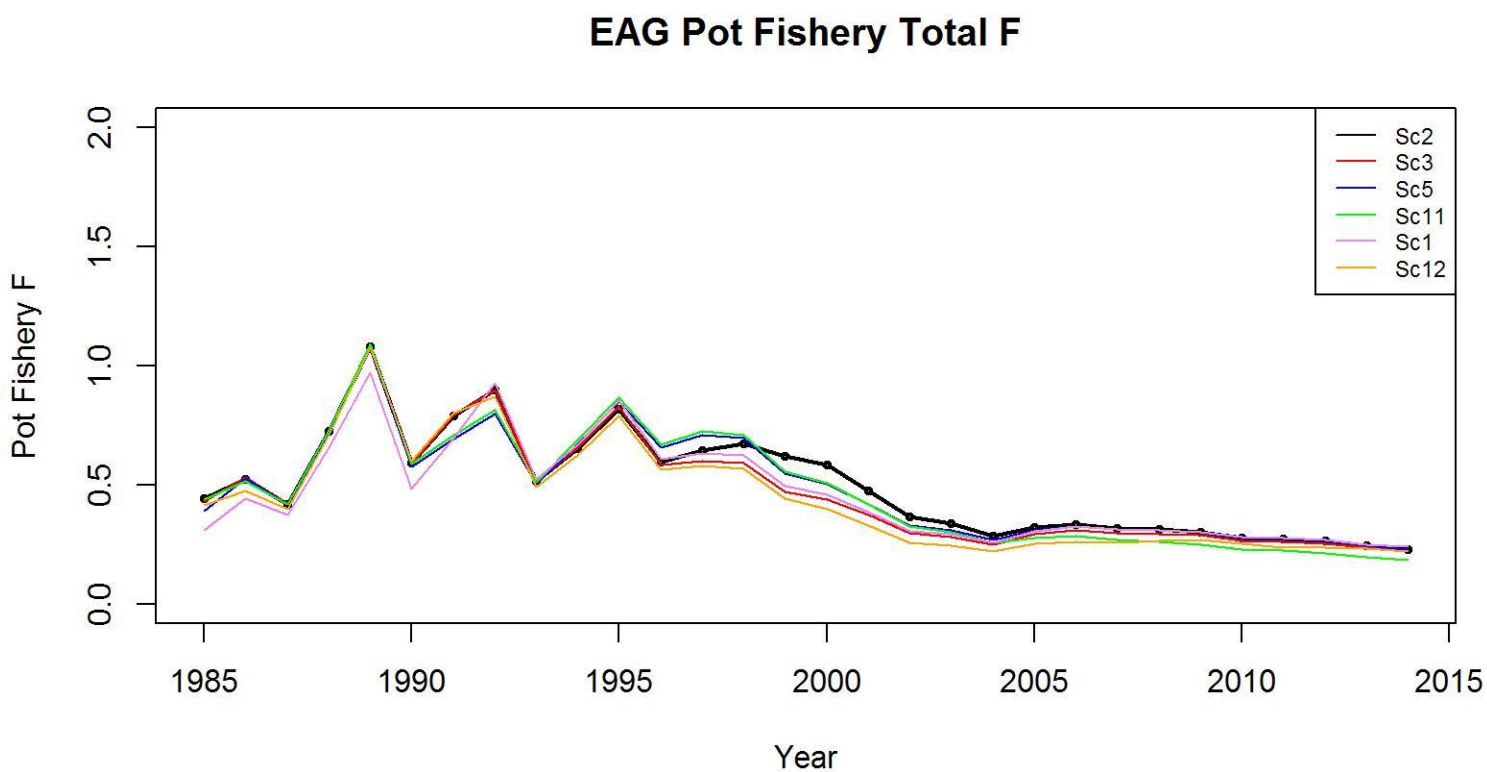


Figure 28. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1,2, 3, 5, 11, and 12 model fits in the EAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

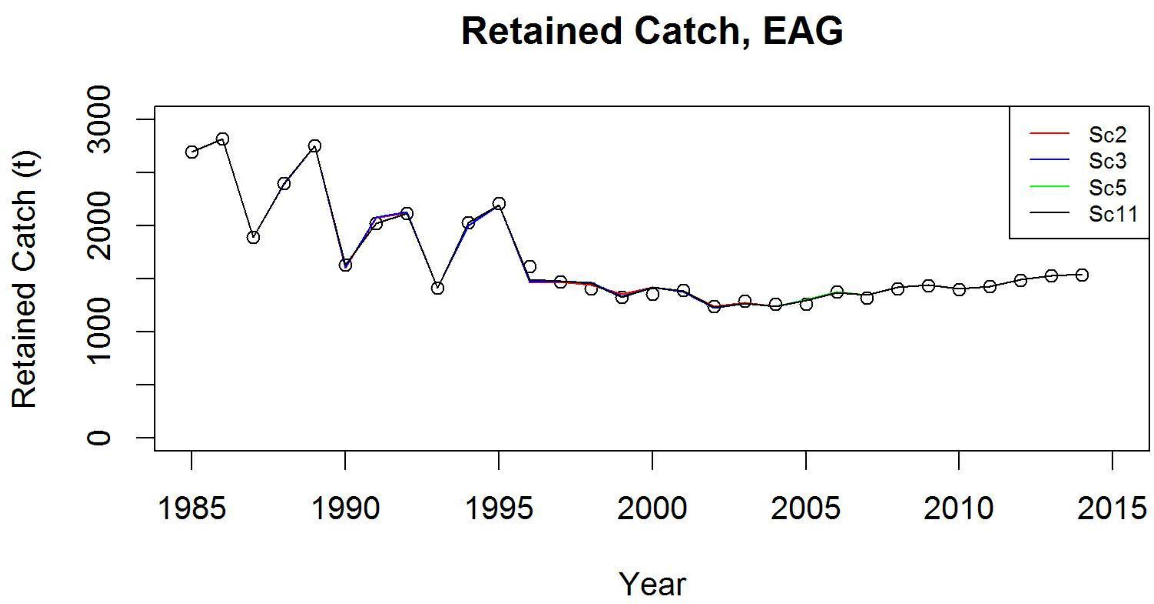


Figure 29. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 2, 3, 5, and 11 fits in the EAG, 1985–2014. (note: 1985 refers to the1985/86 fishery).

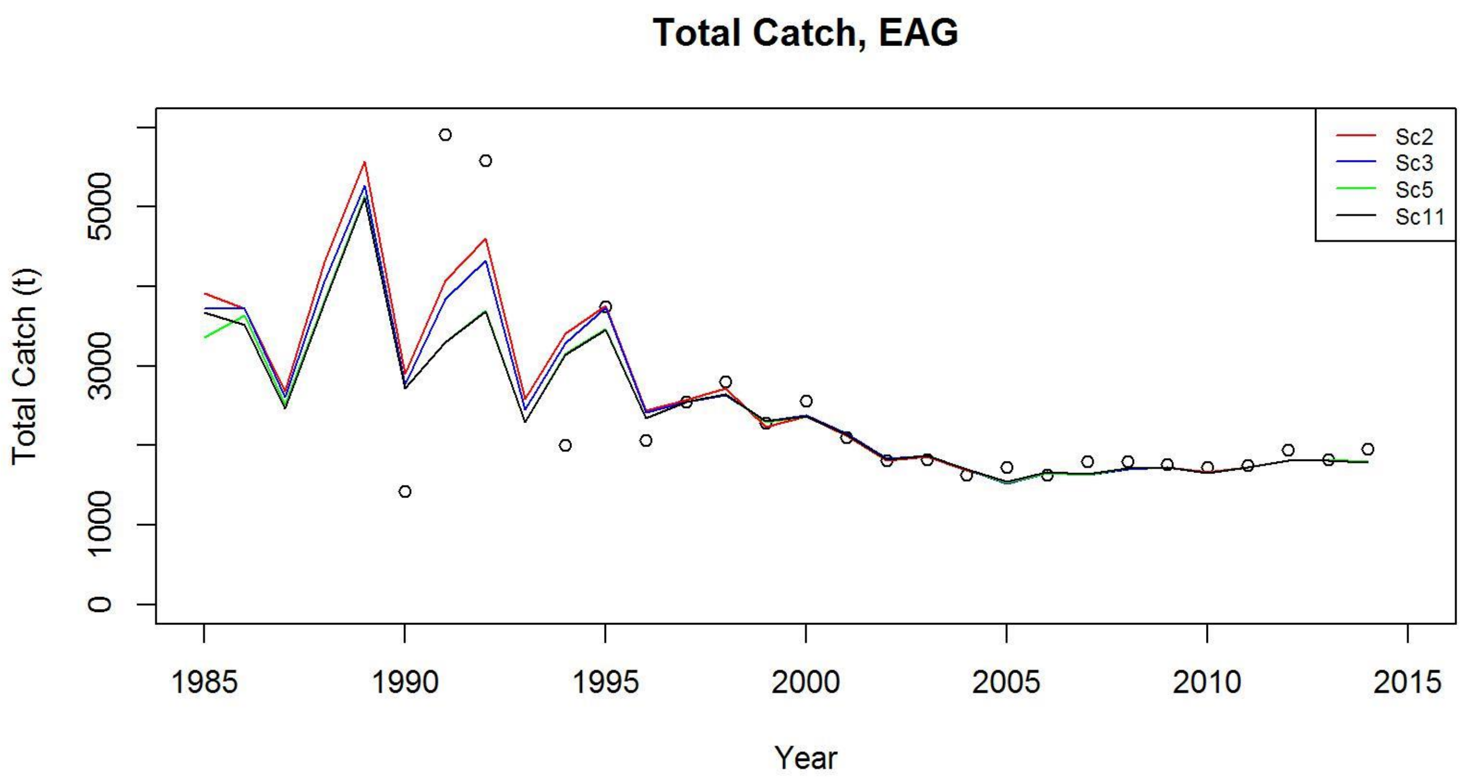


Figure 30. Observed (open circle starts from 1990) vs. predicted (solid line) total catch of golden king crab for scenarios (Sc) 2, 3, 5, and 11 fits in the EAG, 1985–2014. A handling mortality rate of 20% was applied to pot discarded catch and discard mortality added to retained catch to get the total catch. (note: 1985 refers to the1985/86 fishery). Predicted total catch time series is extended from 1990/91 to 1985/86.

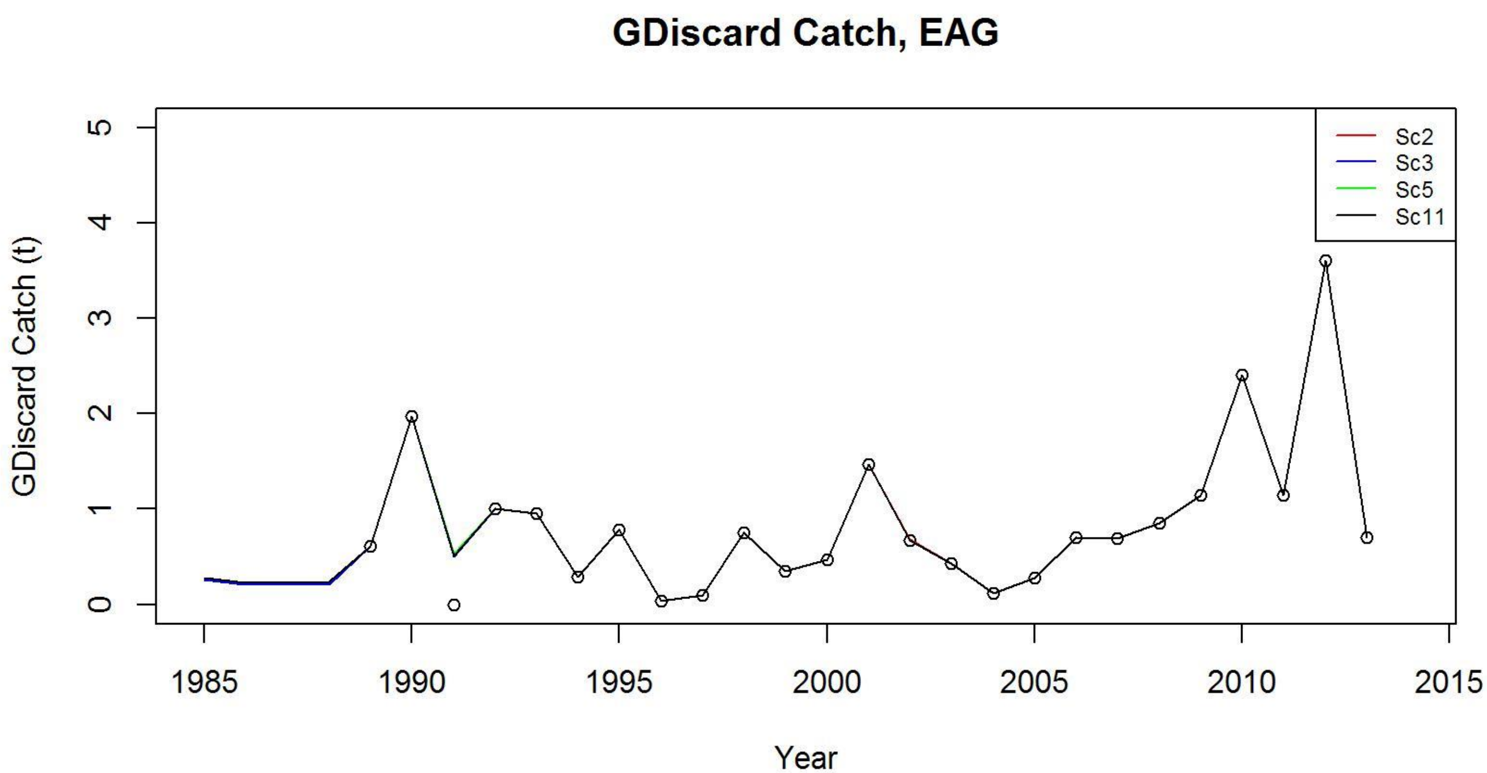


Figure 31. Observed (open circle starts from 1989) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios (Sc) 2, 3, 5, and 11 fits in the EAG, 1985–2013. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1989 refers to the1989/90 fishery). Predicted groundfish discarded catch time series is extended from 1989/90 to 1985/86.

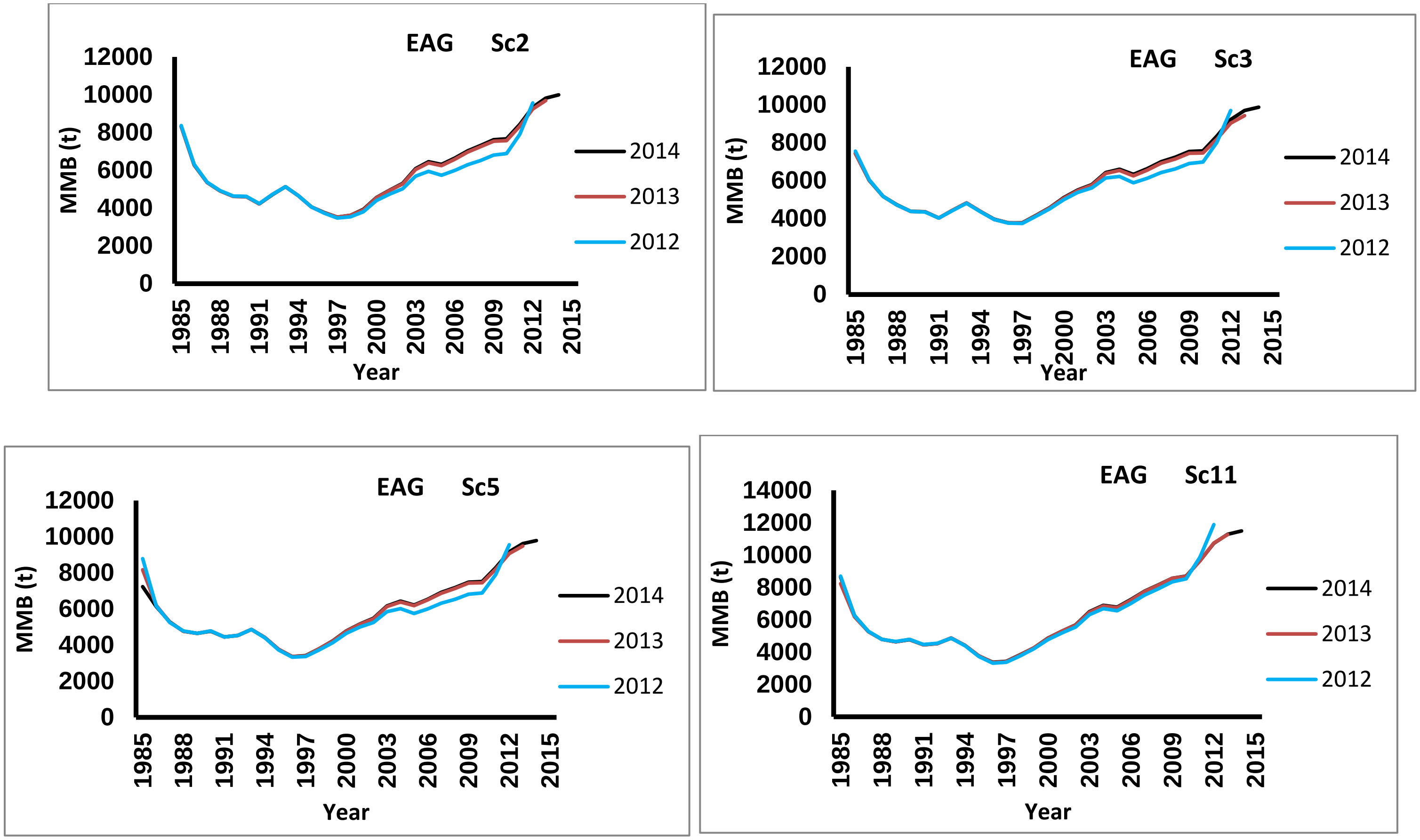


Figure 32. Retrospective fits of the model for removal of terminal year's data for scenarios (Sc) 2, 3, 5, and 11 fits for golden king crab in the EAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

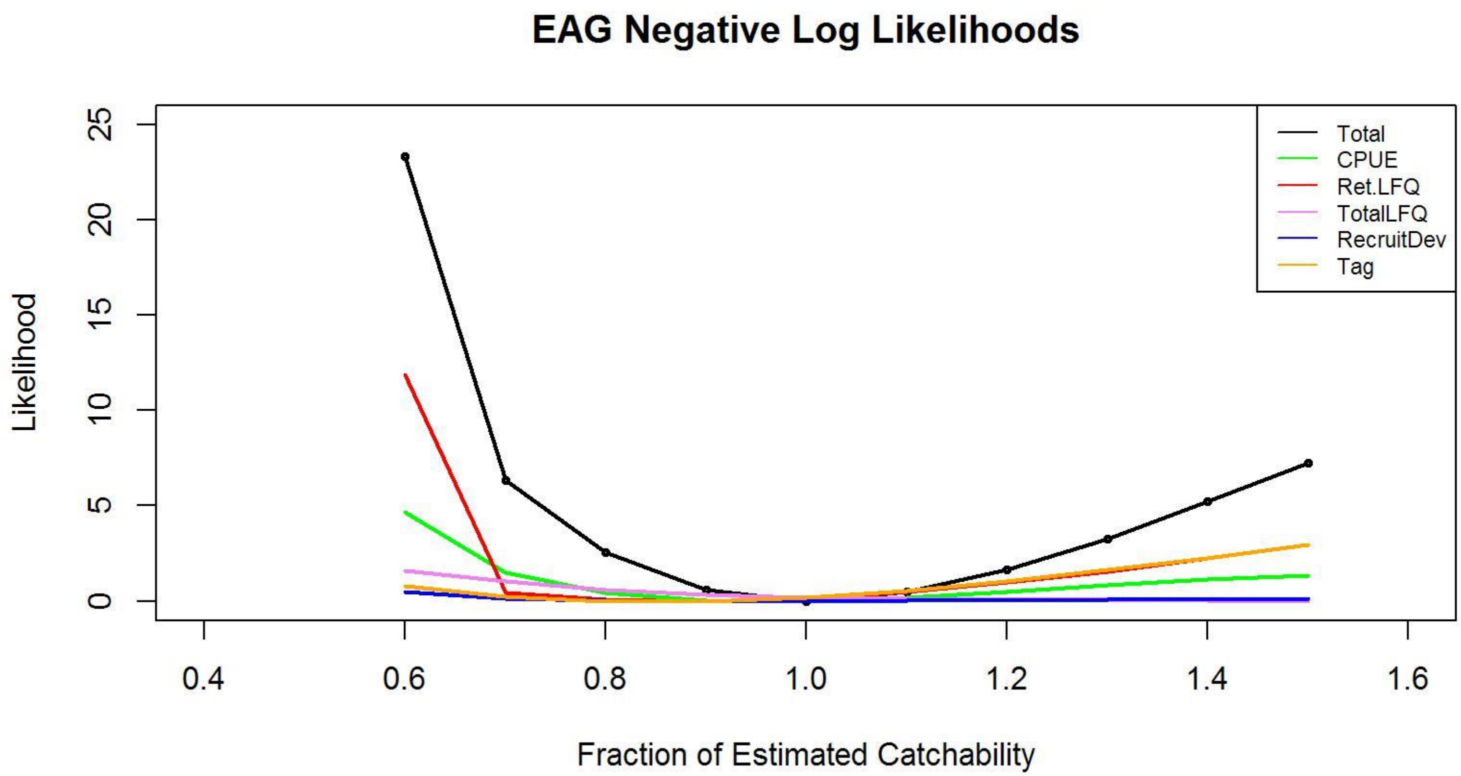


Figure 33. Total and components negative log-likelihoods vs. fractions of the estimated pair of catchability coefficients for scenario 1 fit for golden king crab in the EAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

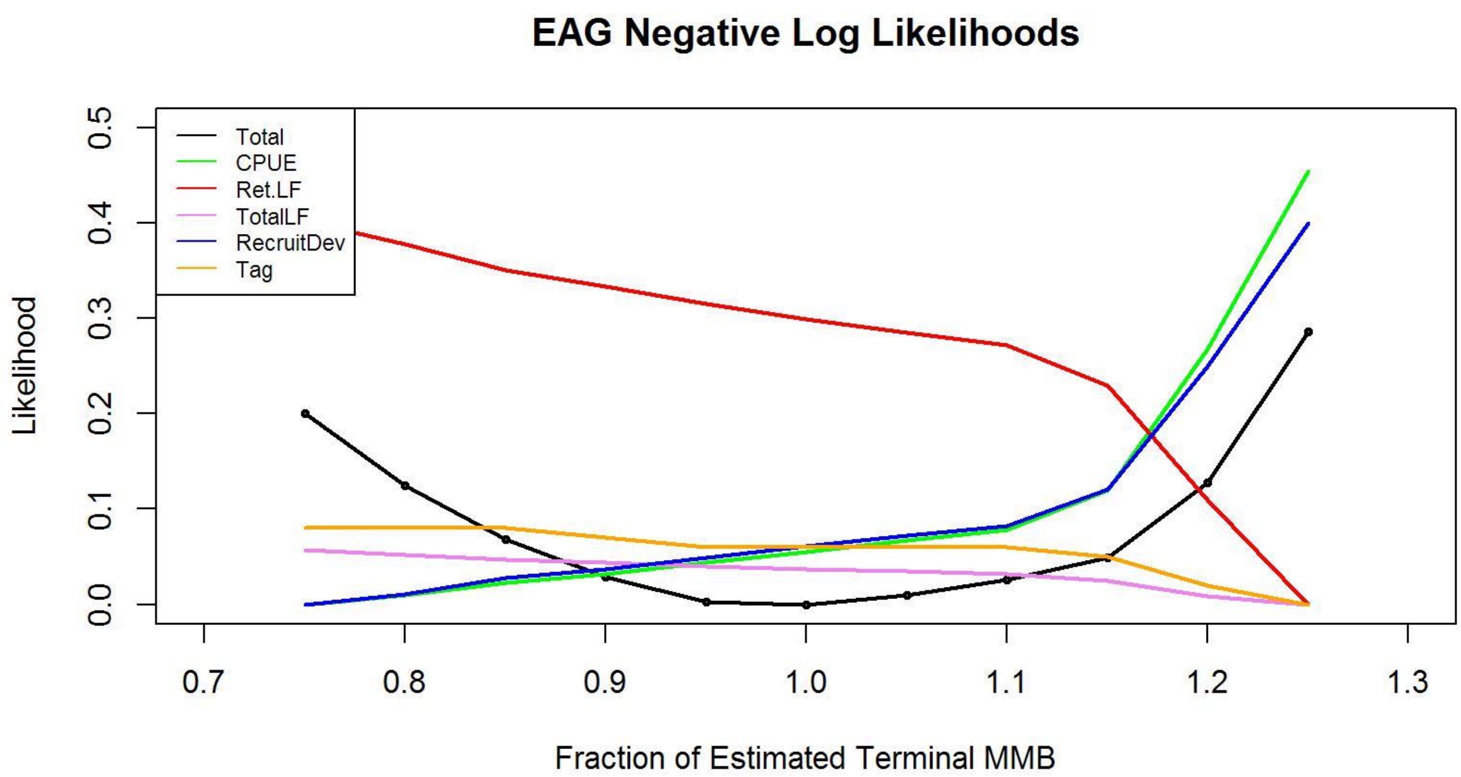


Figure 34. Total and components negative log-likelihoods vs. fractions of the estimated terminal MMB for scenario 1 fit for golden king crab in the EAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

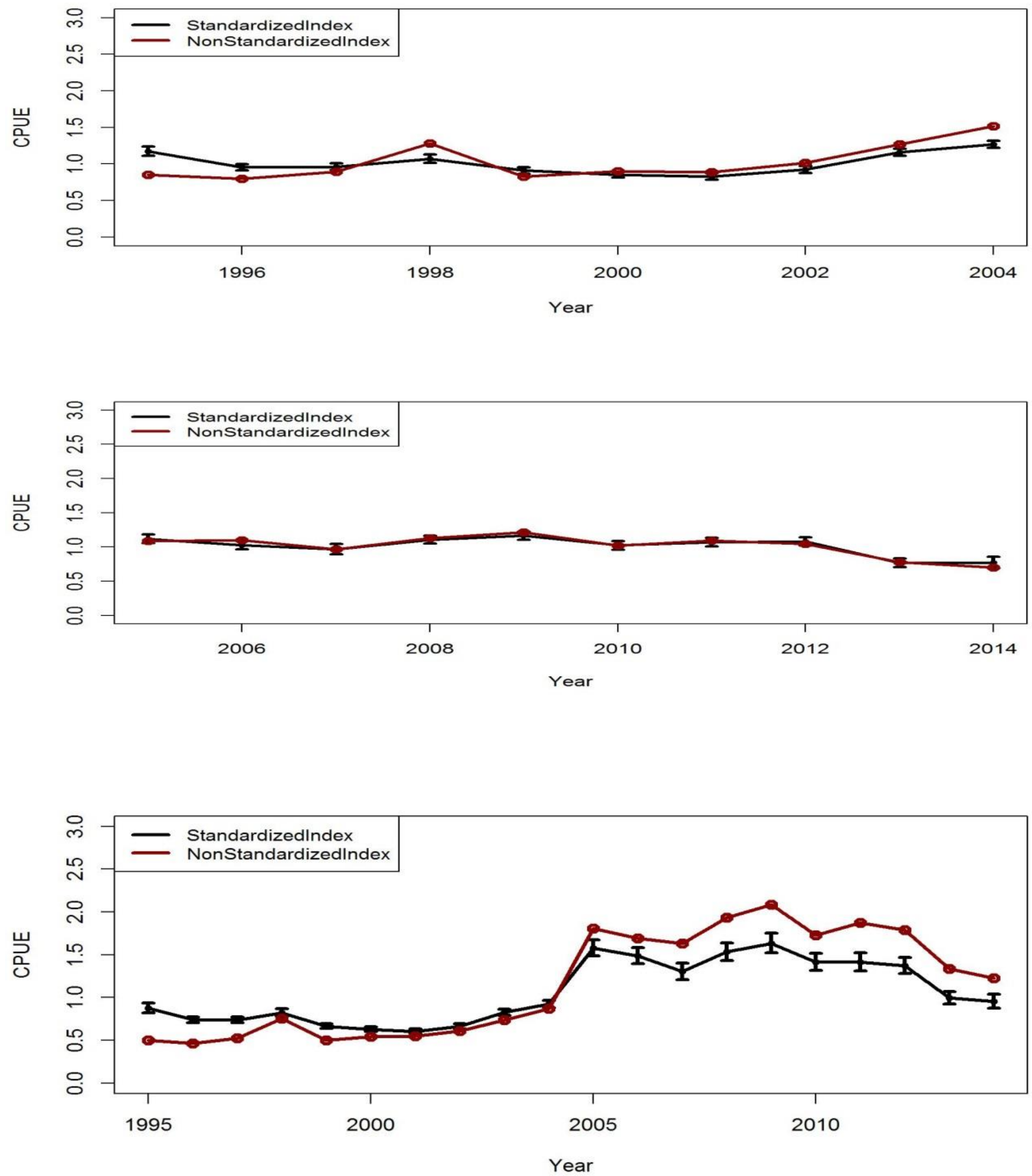


Figure 35. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (west of 174° W longitude). Top panel: 1995/96-2004/05 observer data, center panel: 2005/06-2014/15 observer data, and bottom panel: 1995/96-2014/15 observer data. Standardized indices: black line and non-standardized indices: red line.

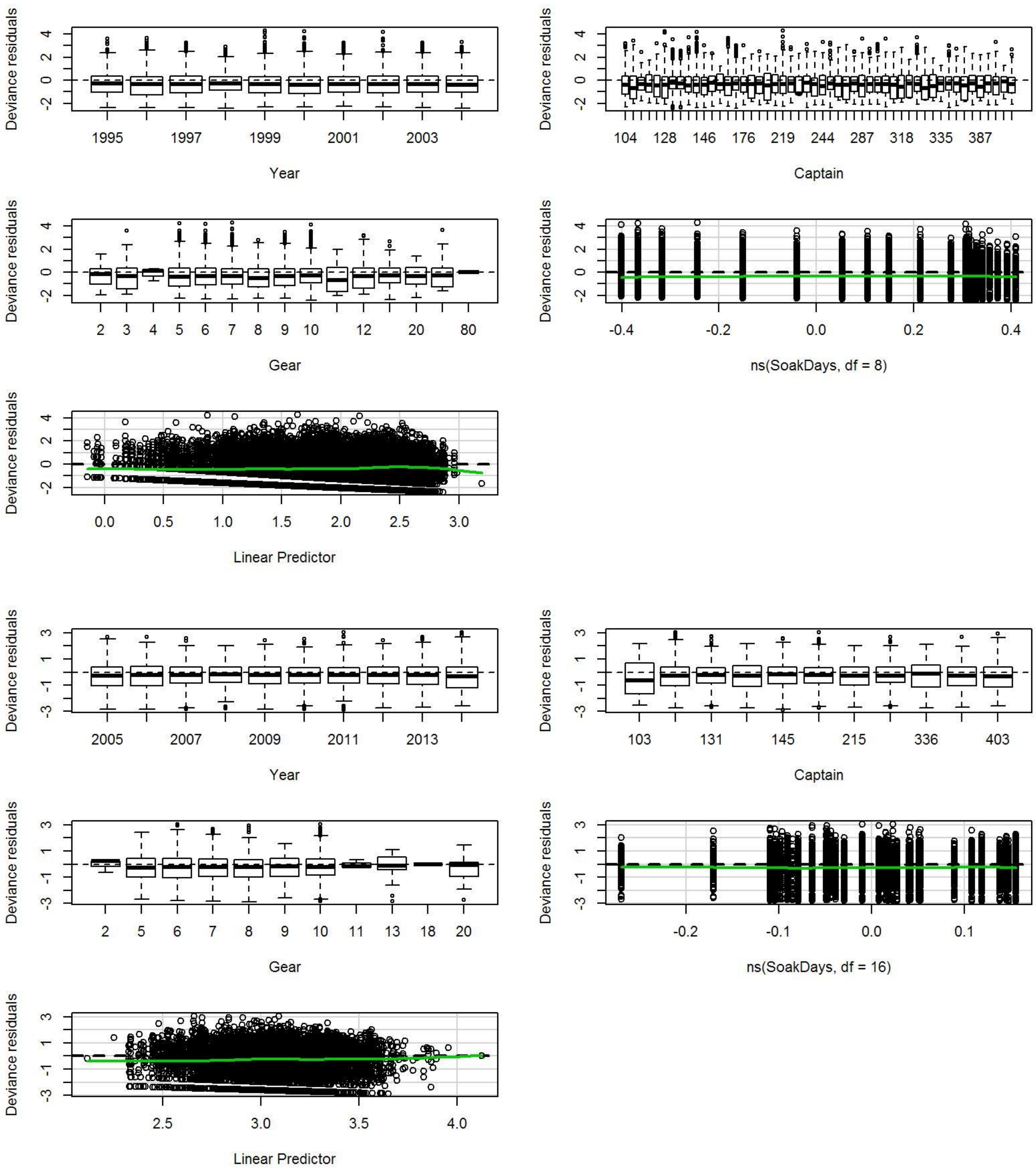


Figure 36. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from WAG for 1995/96–2004/05 (top) and 2005/06–2014/15 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.

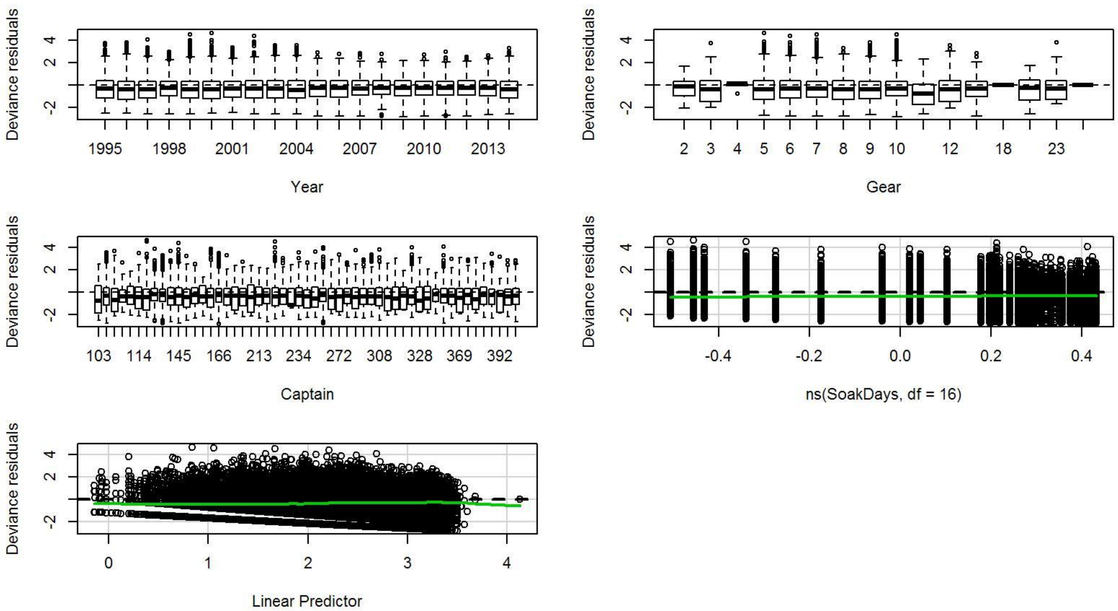


Figure 37. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from WAG for 1995/96–2014/15 period were used. The solid lines are the loess smoother through the plotted values.

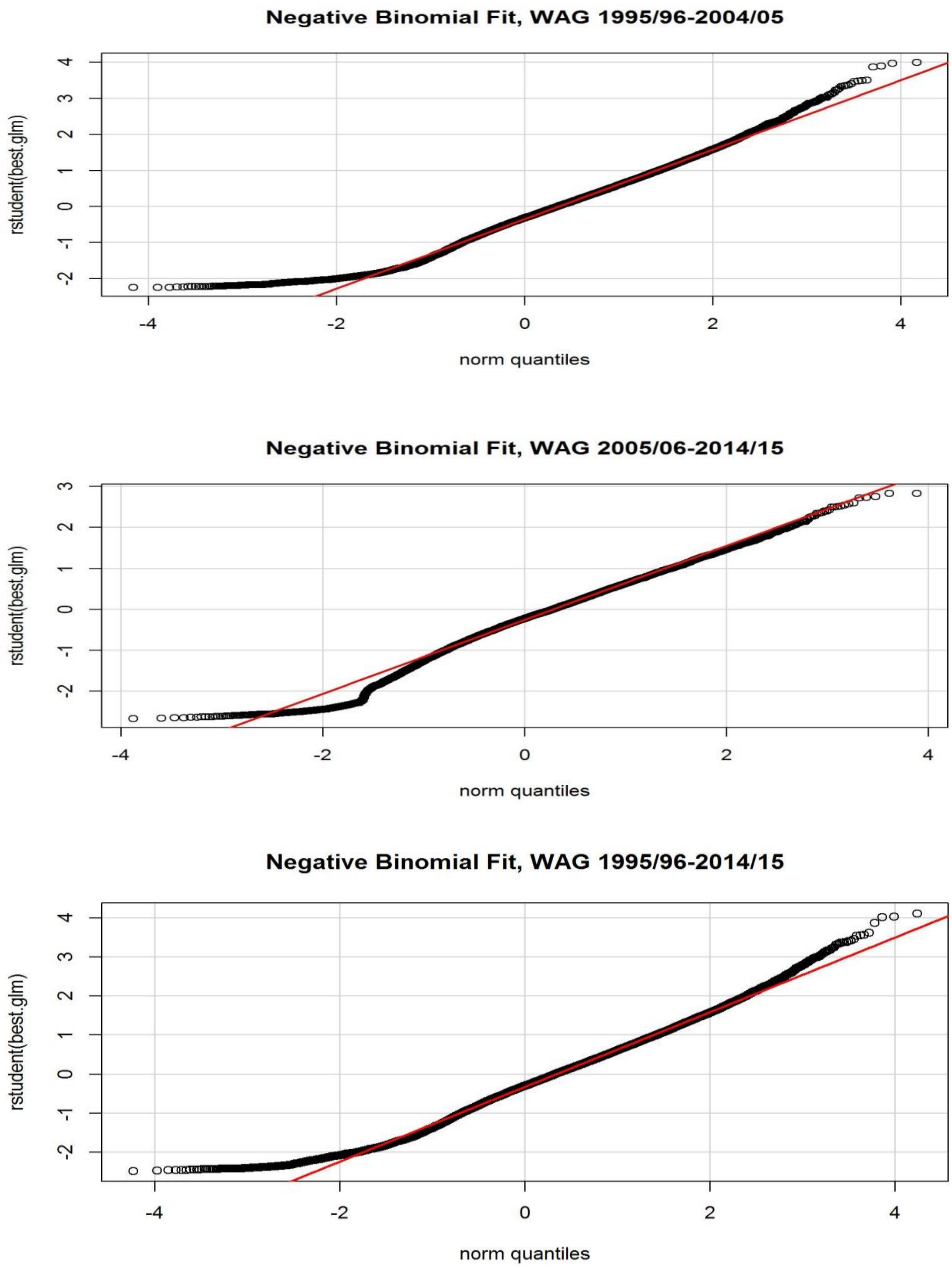


Figure 38. Studentized residual plots for negative binomial GLM fit for WAG golden king crab observer legal size male crab CPUE data. Top panel is for 1995/96–2004/05, center panel is for 2005/06–2014/15, and the bottom panel is for 1995/96–2014/15 data sets, respectively.

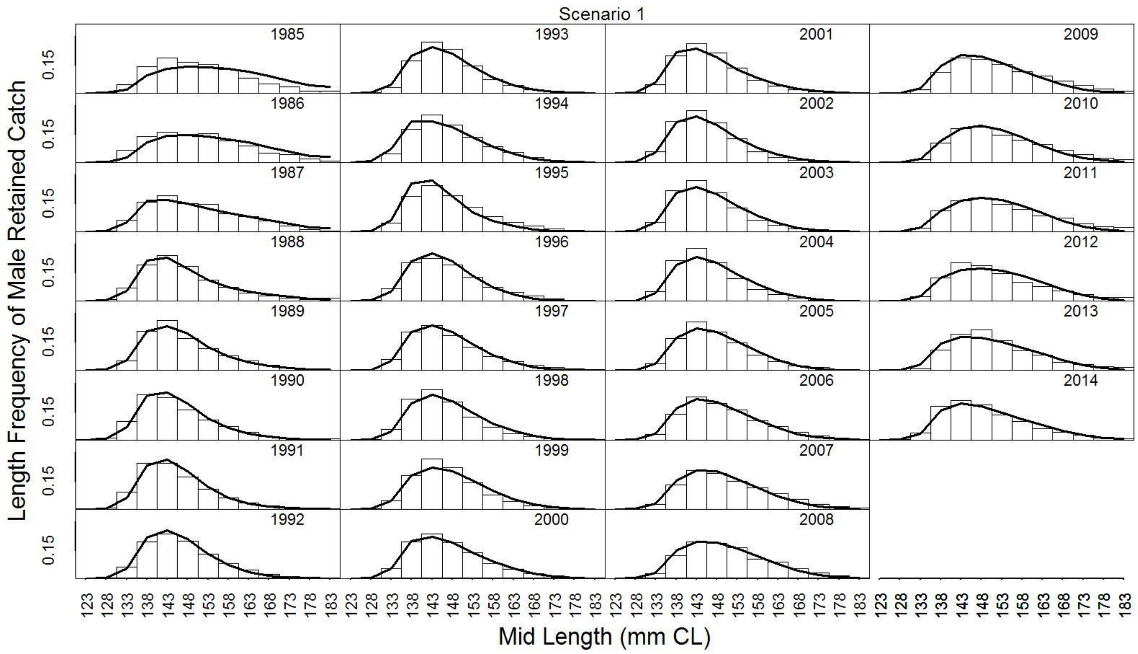


Figure 39. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 1 data of golden king crab in the WAG, 1985/86 – 2014/15.

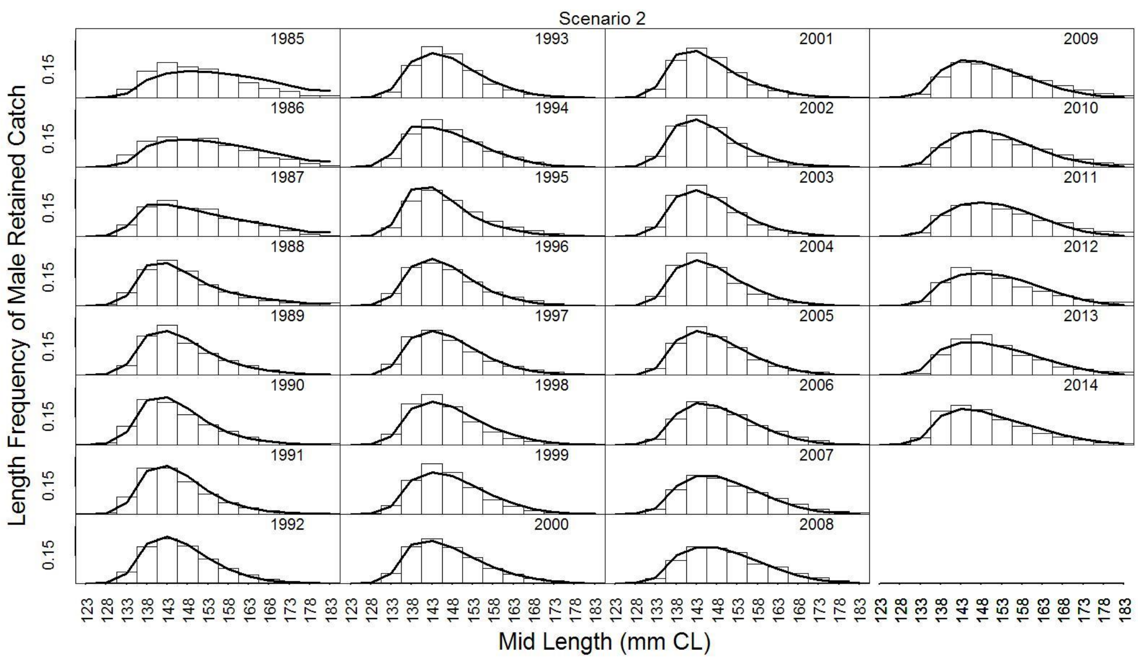


Figure 40. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 2 data of golden king crab in the WAG, 1985/86 – 2014/15.

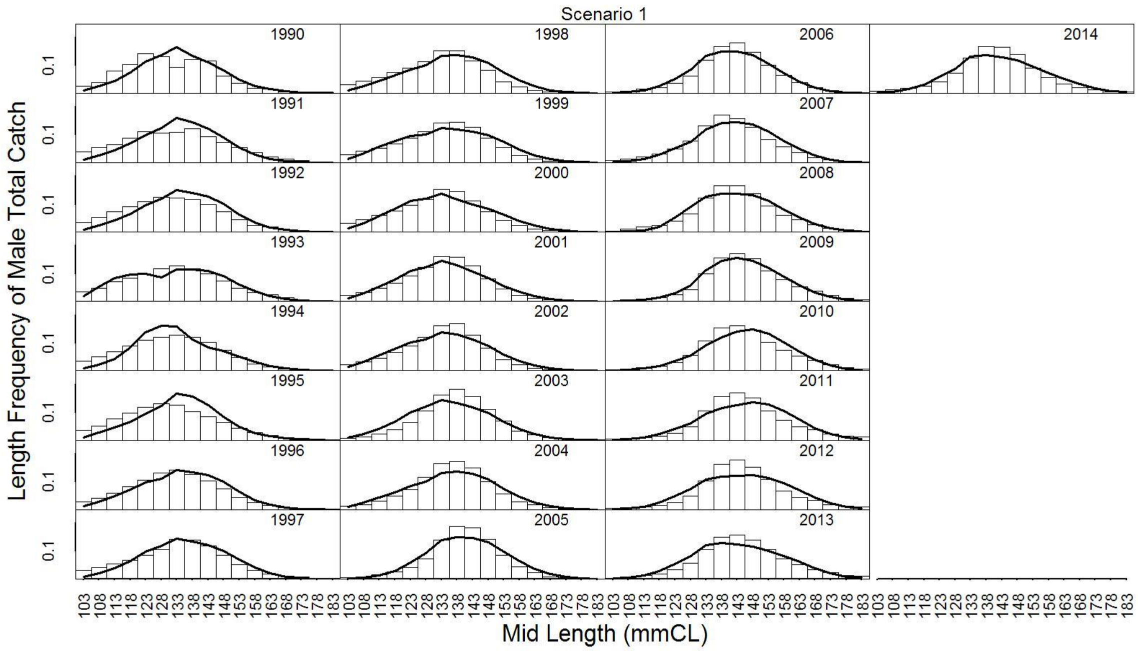


Figure 41 Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 1 data of golden king crab in the WAG, 1990/91 – 2014/15.

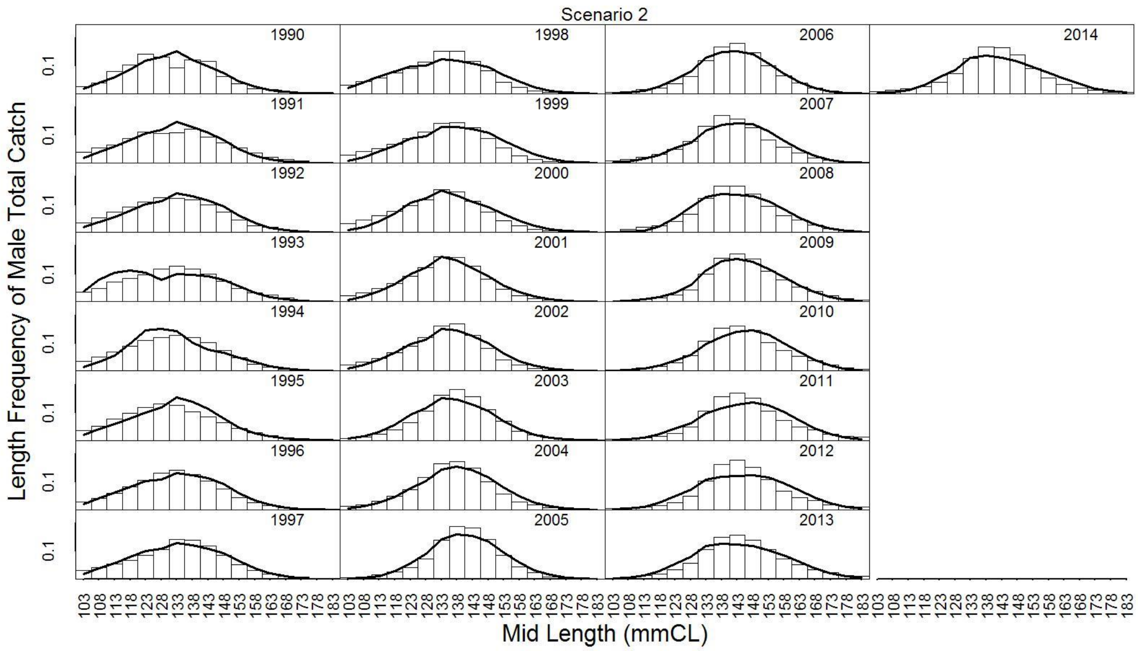


Figure 42. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenario 2 data of golden king crab in the WAG, 1990/91 – 2014/15.

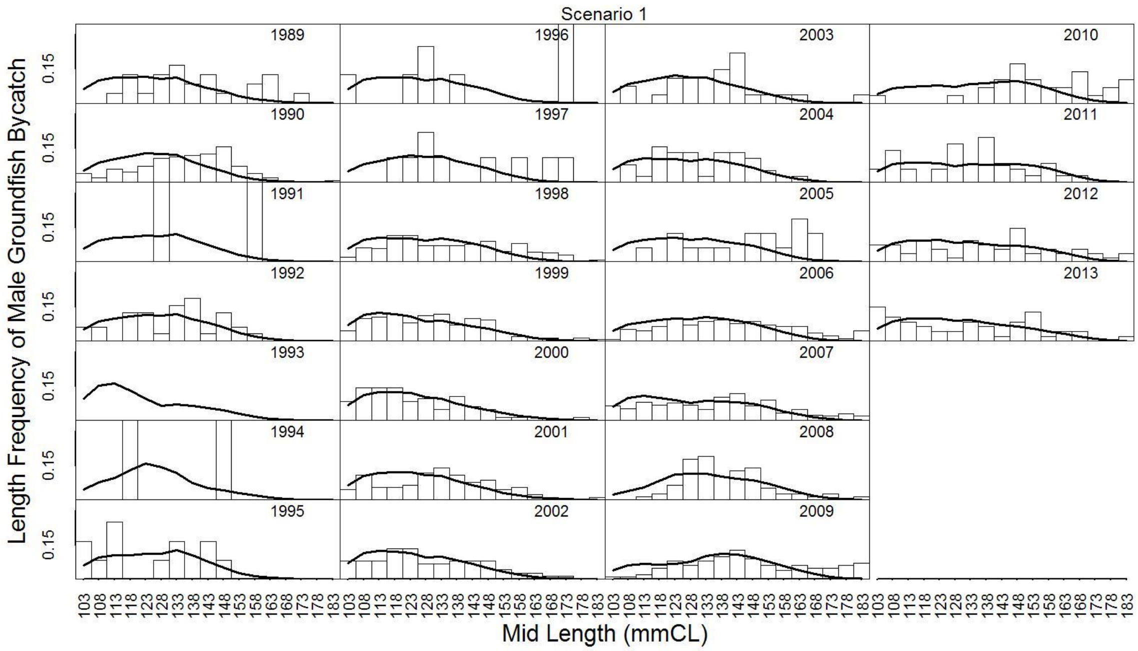


Figure 43. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 1 data of golden king crab in the WAG, 1989/90 – 2013/14.

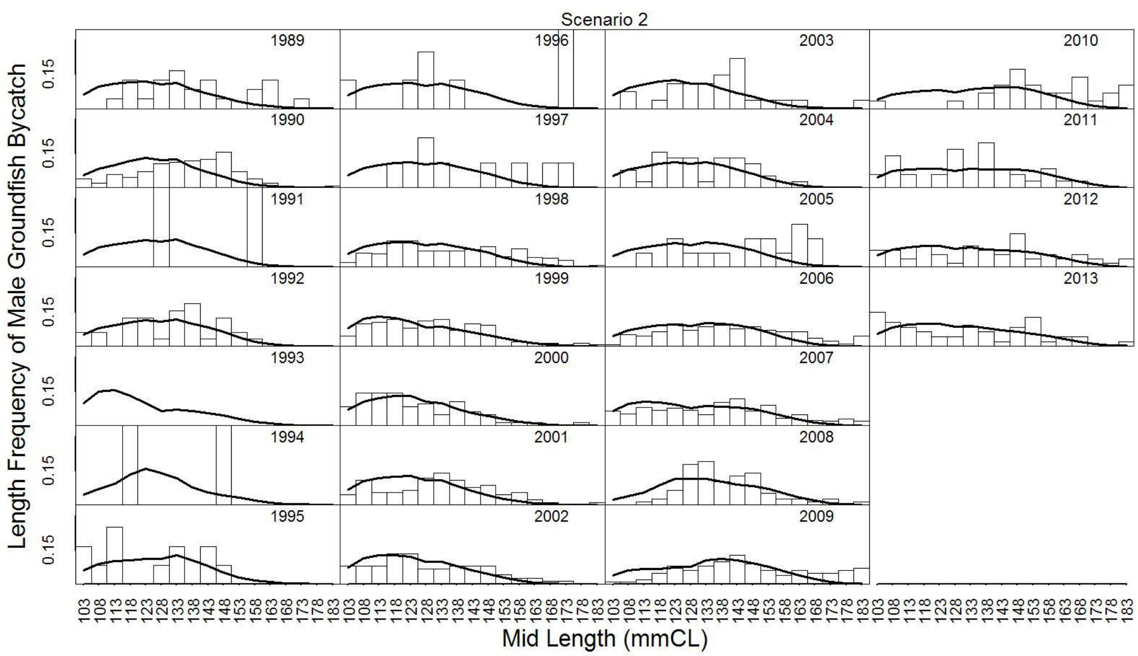


Figure 44. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenario 2 data of golden king crab in the WAG, 1989/90 – 2013/14.

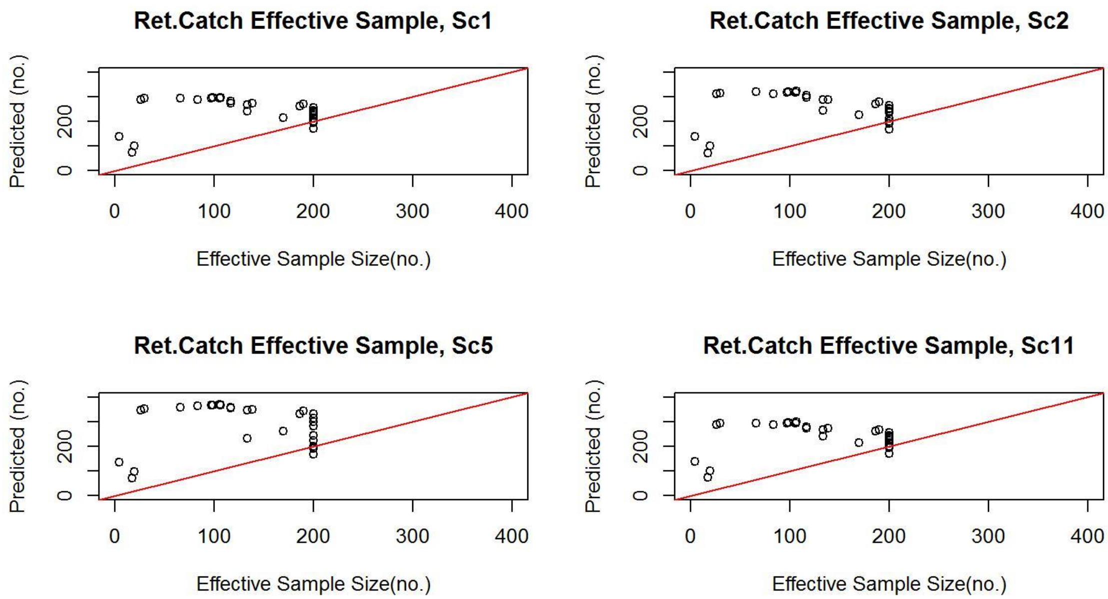


Figure 45. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios (Sc) 1, 2, 5, and 11 fits to golden king crab data in the WAG, 1985/96 – 2014/15. The red line is the 1:1 line passing through the origin.

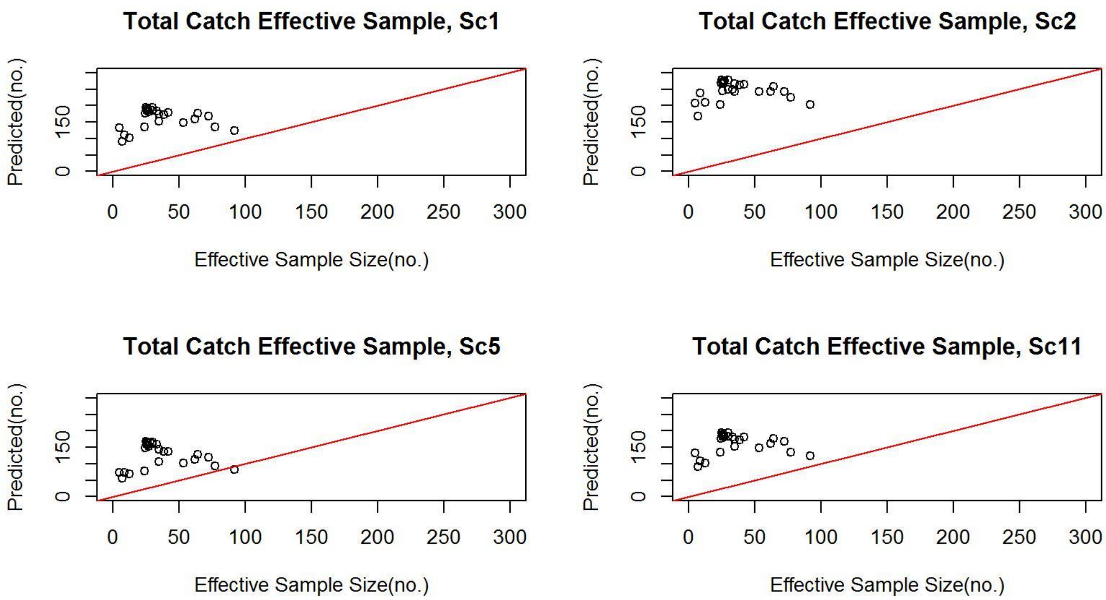


Figure 46. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios (Sc) 1, 2, 5, and 11 fits to golden king crab data in the WAG, 1990/91 – 2014/15. The red line is the 1:1 line passing through the origin.

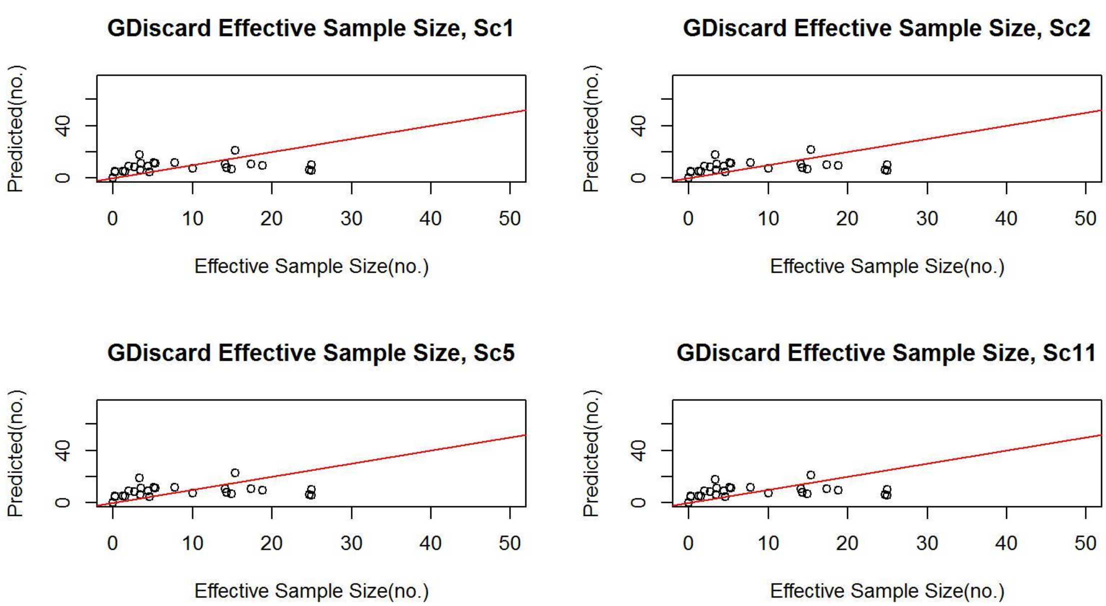


Figure 47. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for scenarios (Sc) 1, 2, 5, and 11 fits to golden king crab data in the WAG, 1989/90 – 2013/14. The red line is the 1:1 line passing through the origin.

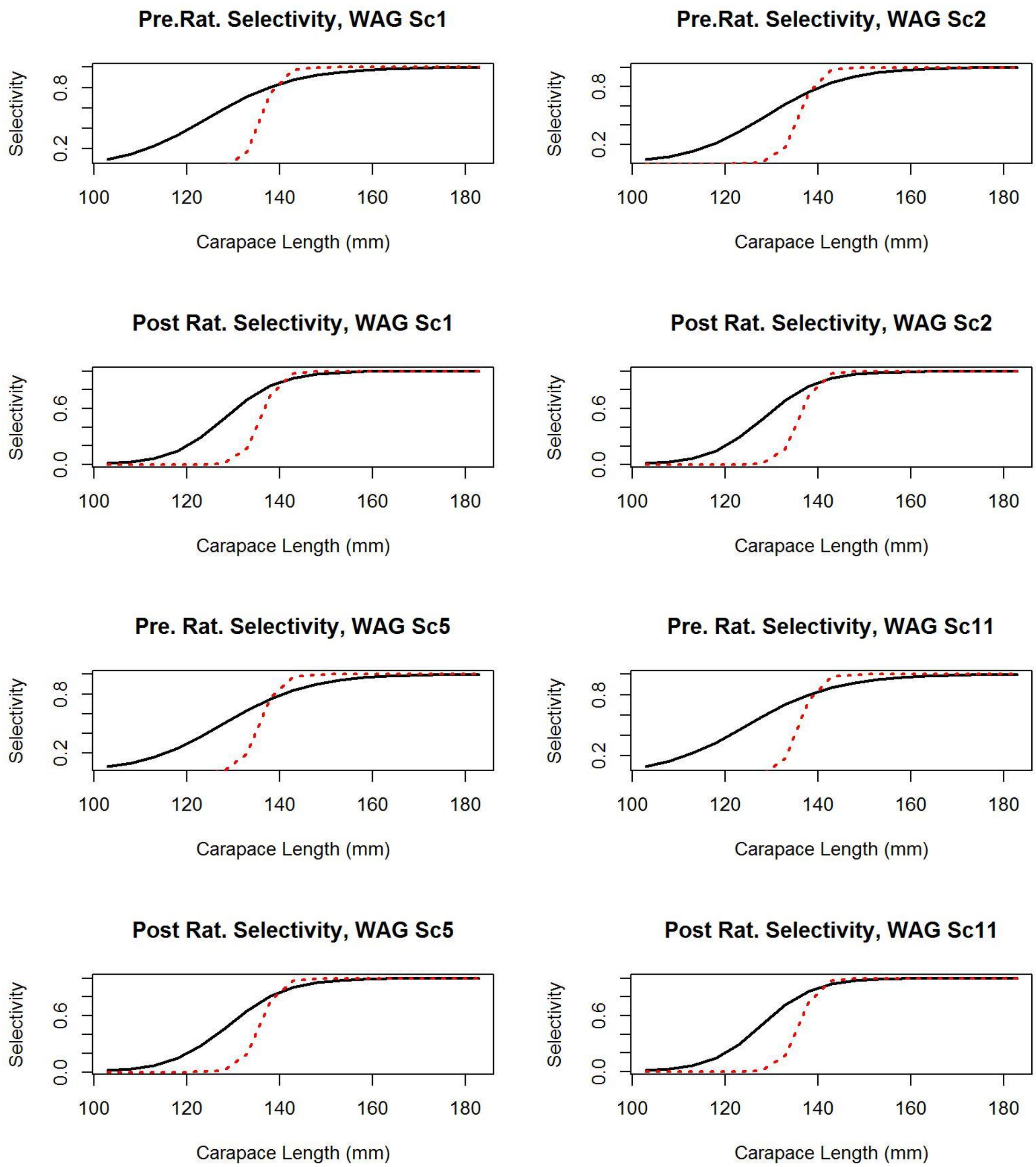
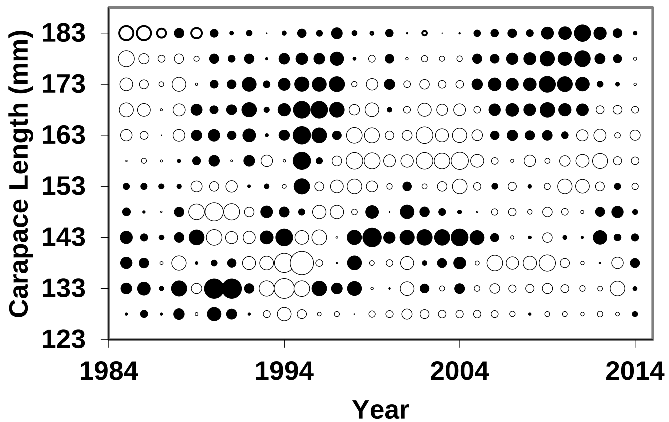
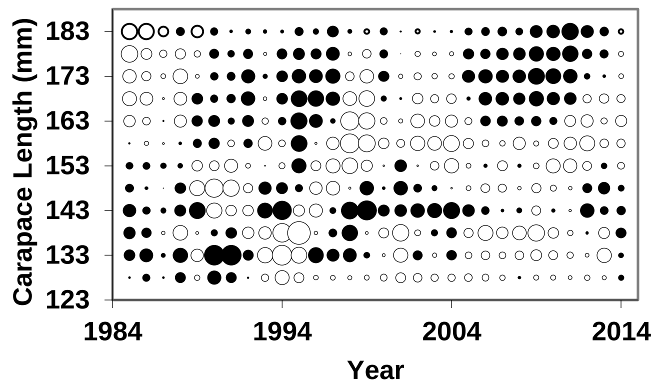


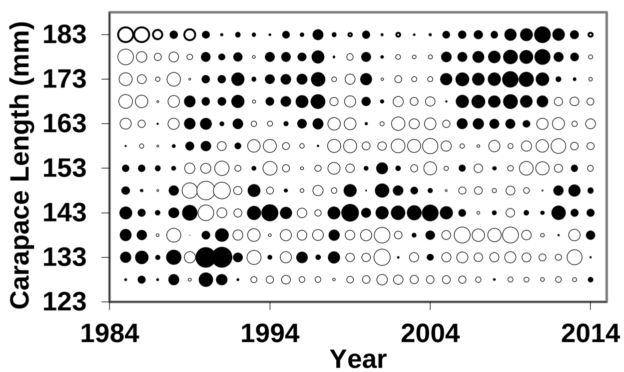
Figure 48. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 1, 2, 5, and 11 fits of WAG golden king crab data.



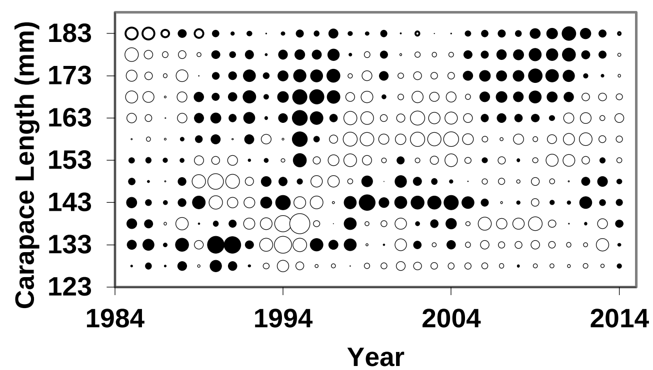
Scenario 1



Scenario 2

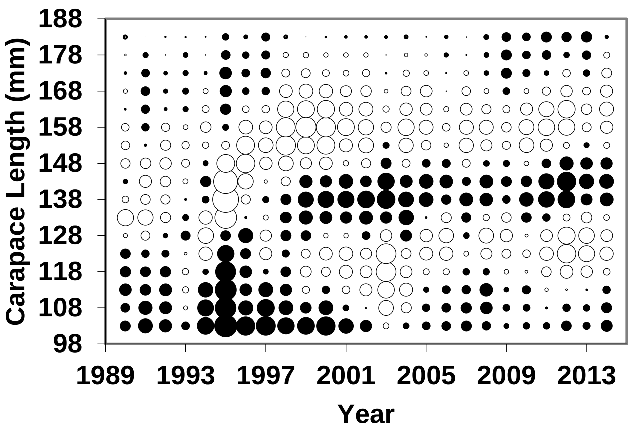


Scenario 5

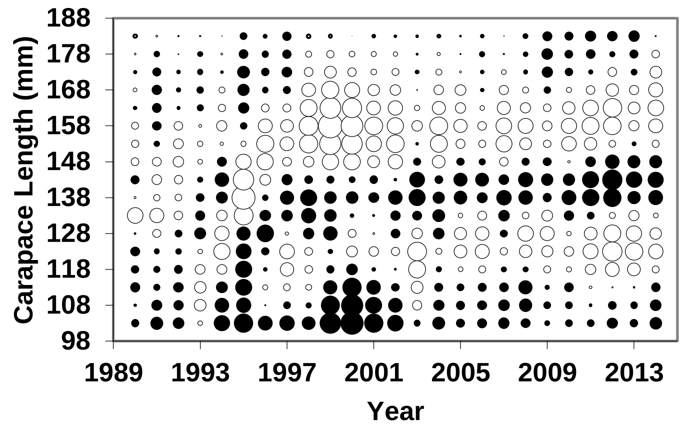


Scenario 11

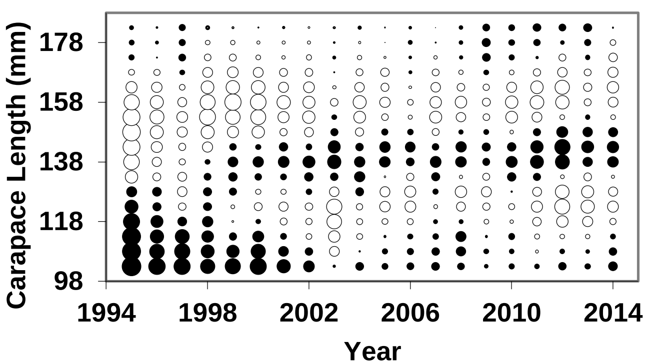
Figure 49. Bubble plots of standardized residuals of retained catch length composition for scenarios 1, 2, 5, and 11 fits for WAG golden king crab, 1985/86–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



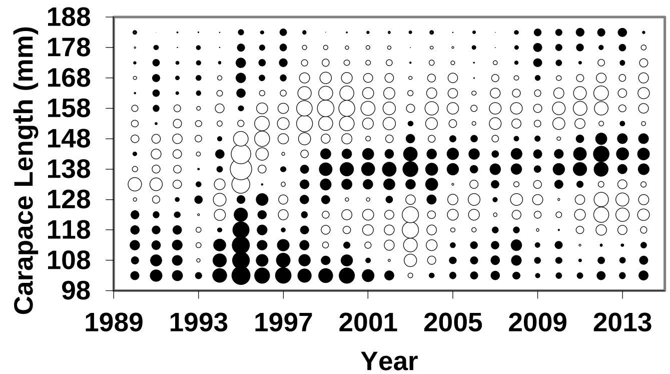
Scenario 1



Scenario 2

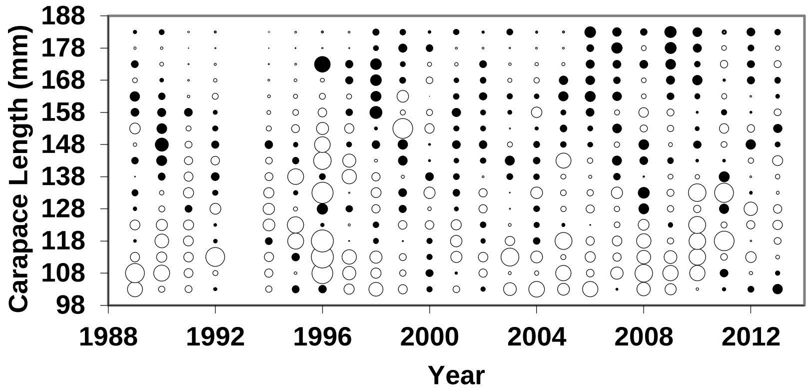


Scenario 5

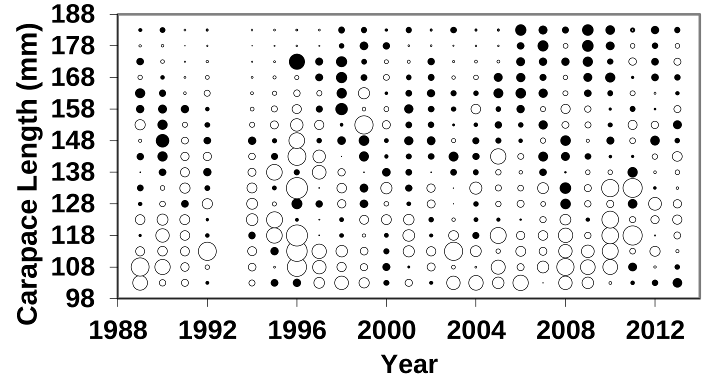


Scenario 11

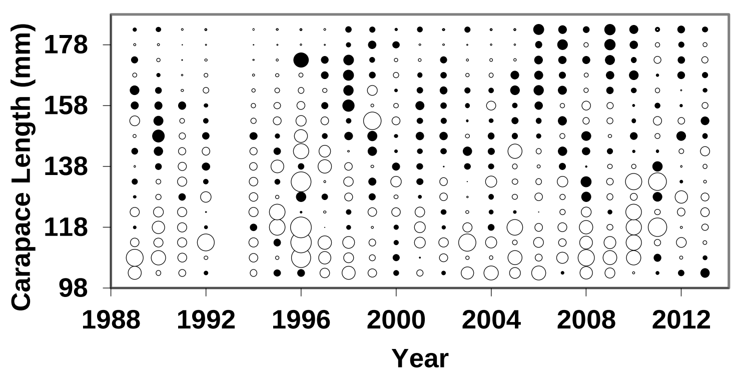
Figure 50. Bubble plots of standardized residuals of total catch length composition for scenarios 1, 2, 5, and 11 fits for WAG golden king crab, 1990/91–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



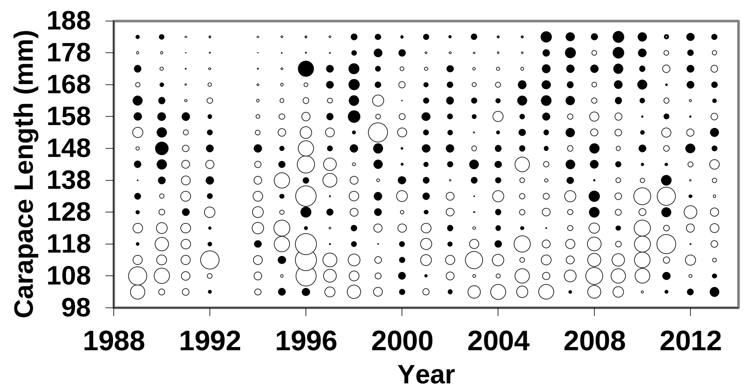
Scenario 1



Scenario 2



Scenario 5



Scenario 11

Figure 51. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 1, 2, 5, and 11 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.

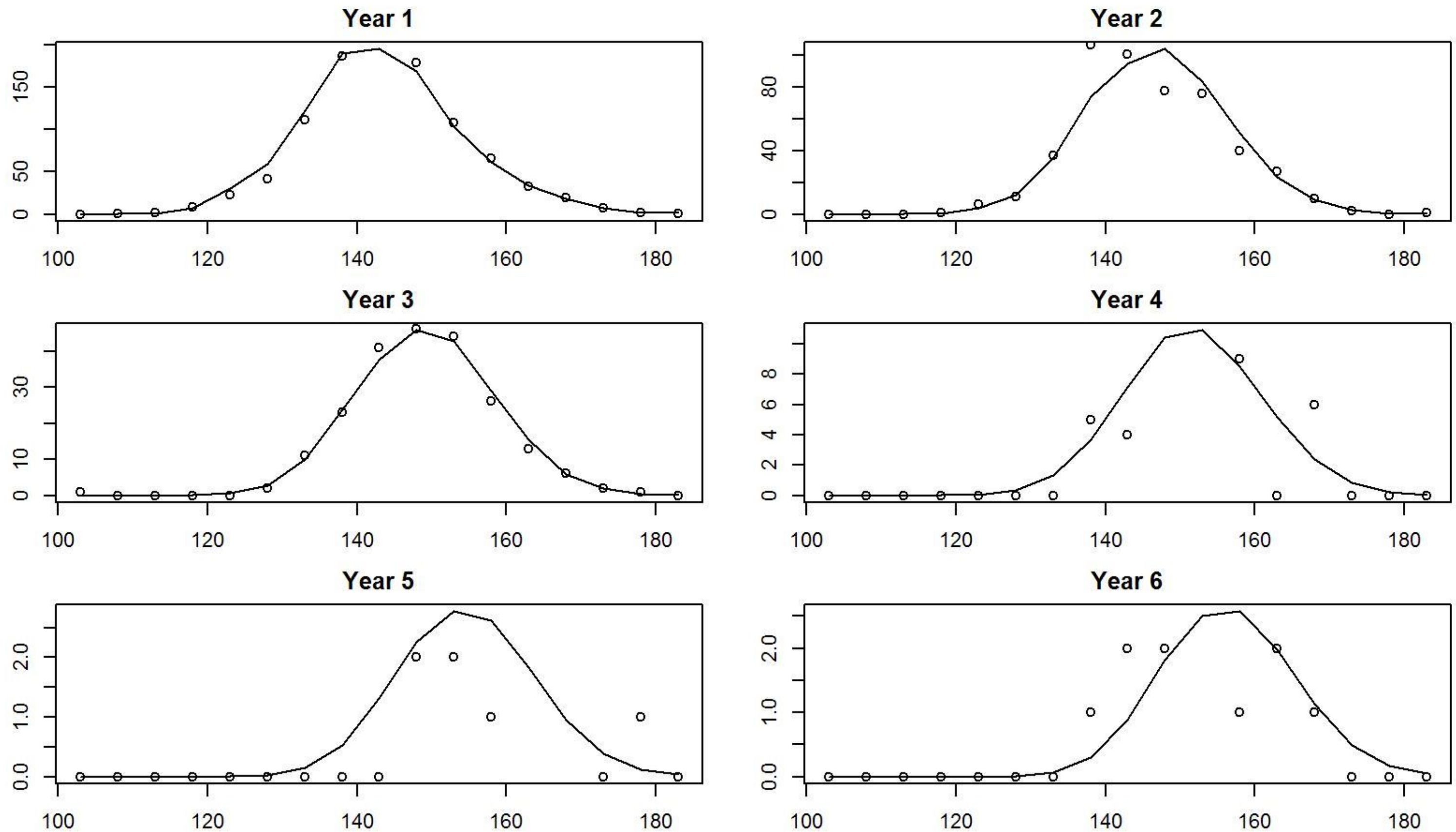


Figure 52. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures of WAG golden king crab. The tagging experiments were conducted in EAG.

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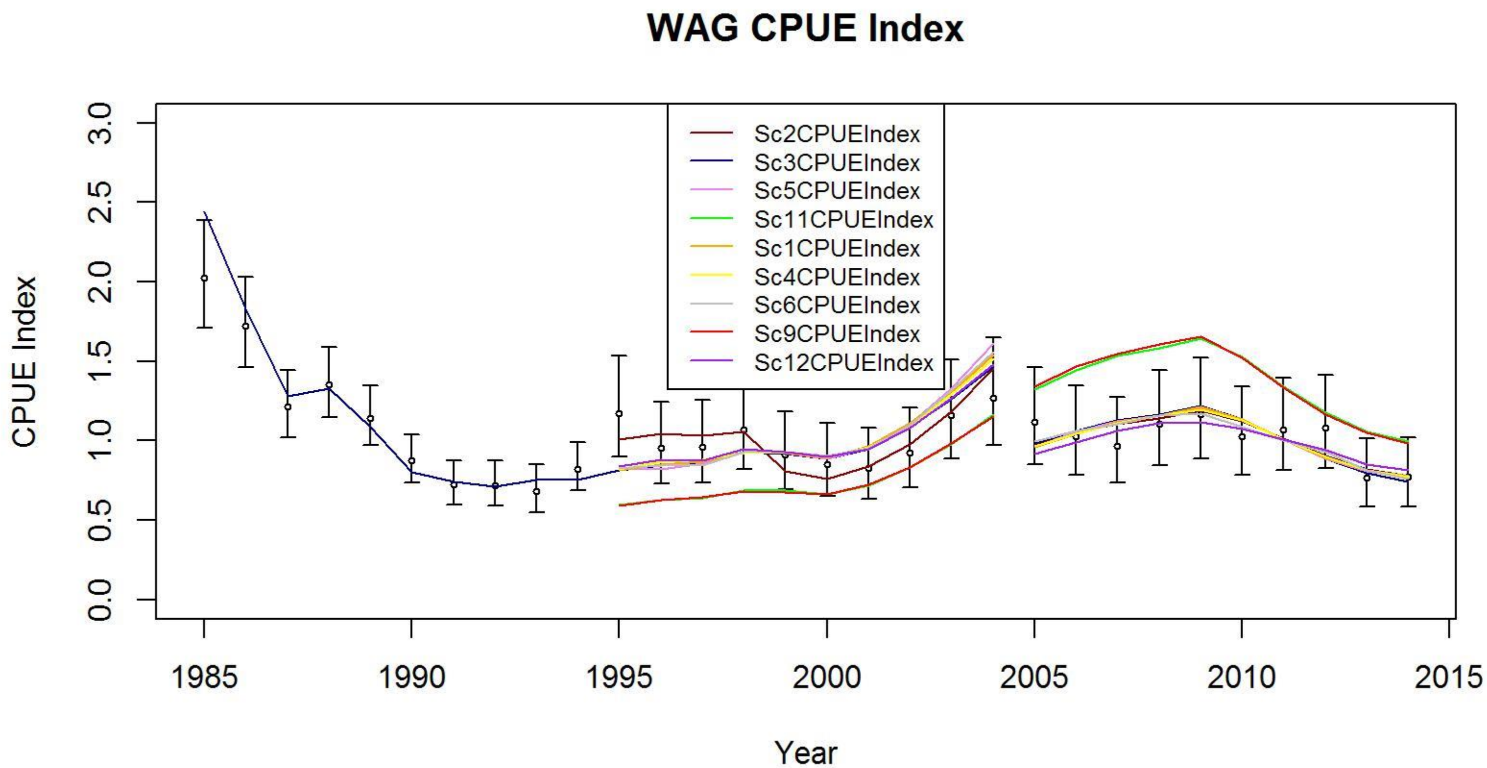

Figure 53. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1, 2, 3, 4, 5, 6, 9, 11, and 12 fits for WAG golden king crab data. 1995/96–2014/15. Model estimated additional standard error was added to each input standard error.

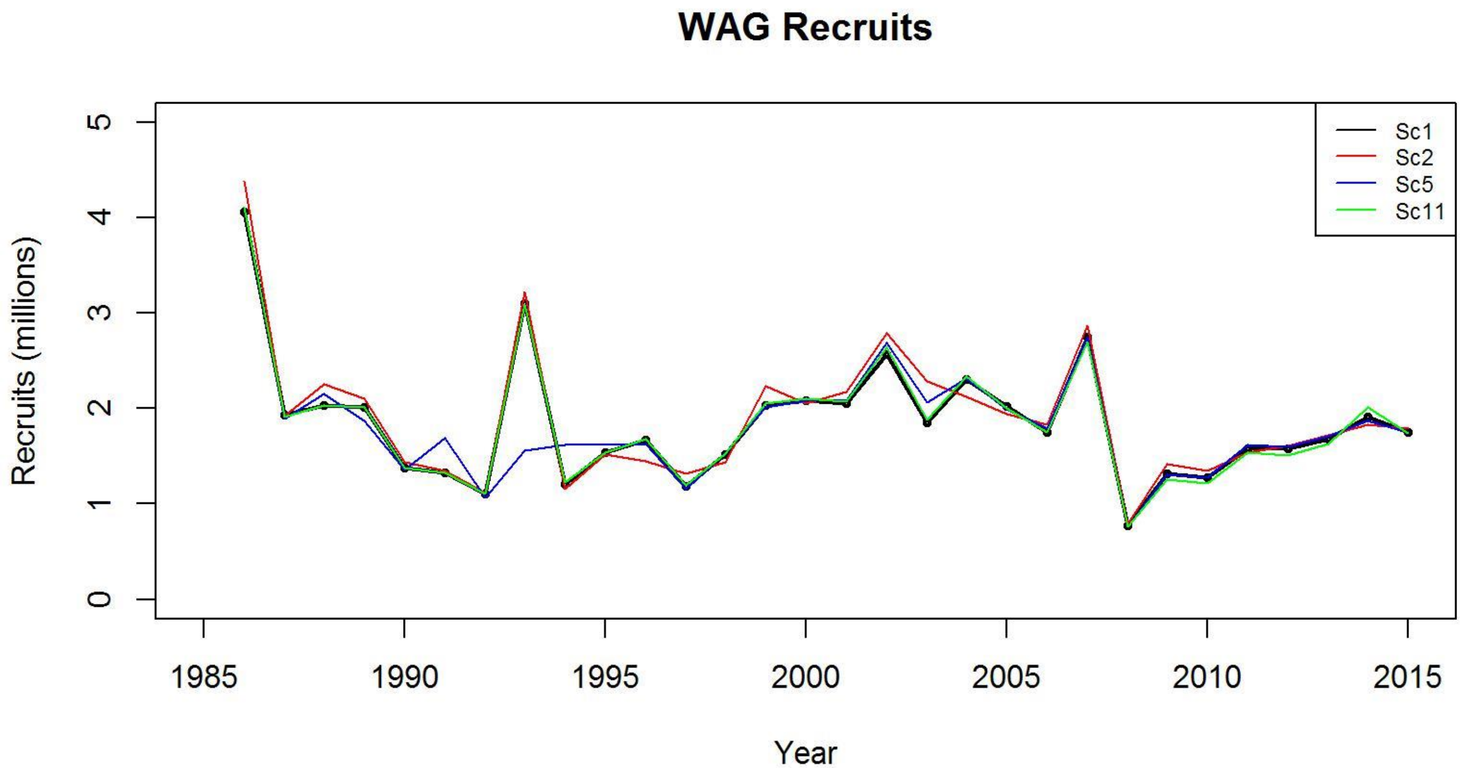

Figure 54. Estimated number of male recruits (millions of crab ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 1, 2, 5, and 11 fits in WAG, 1986–2015.

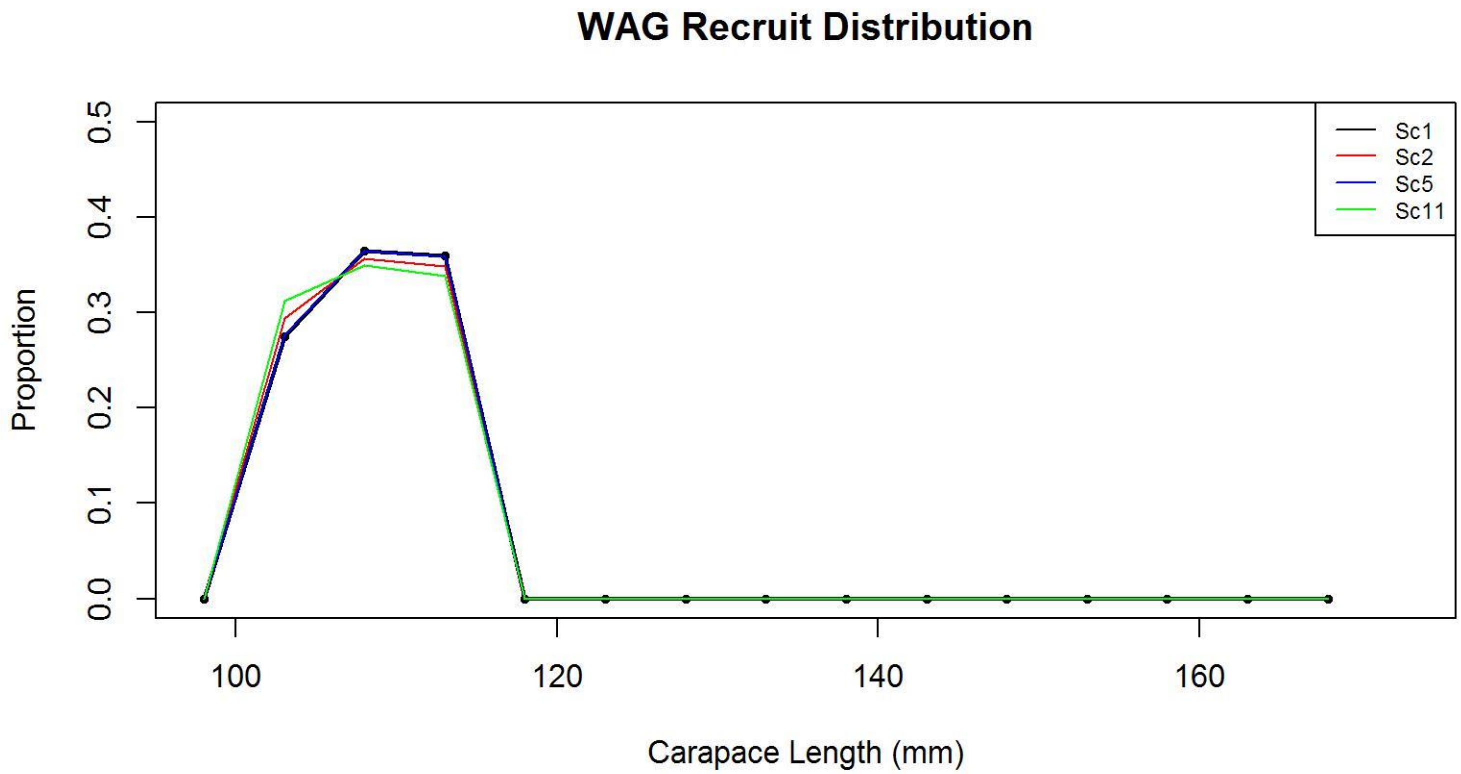

Figure 55. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 1, 2, 5, and 11 fits in WAG.

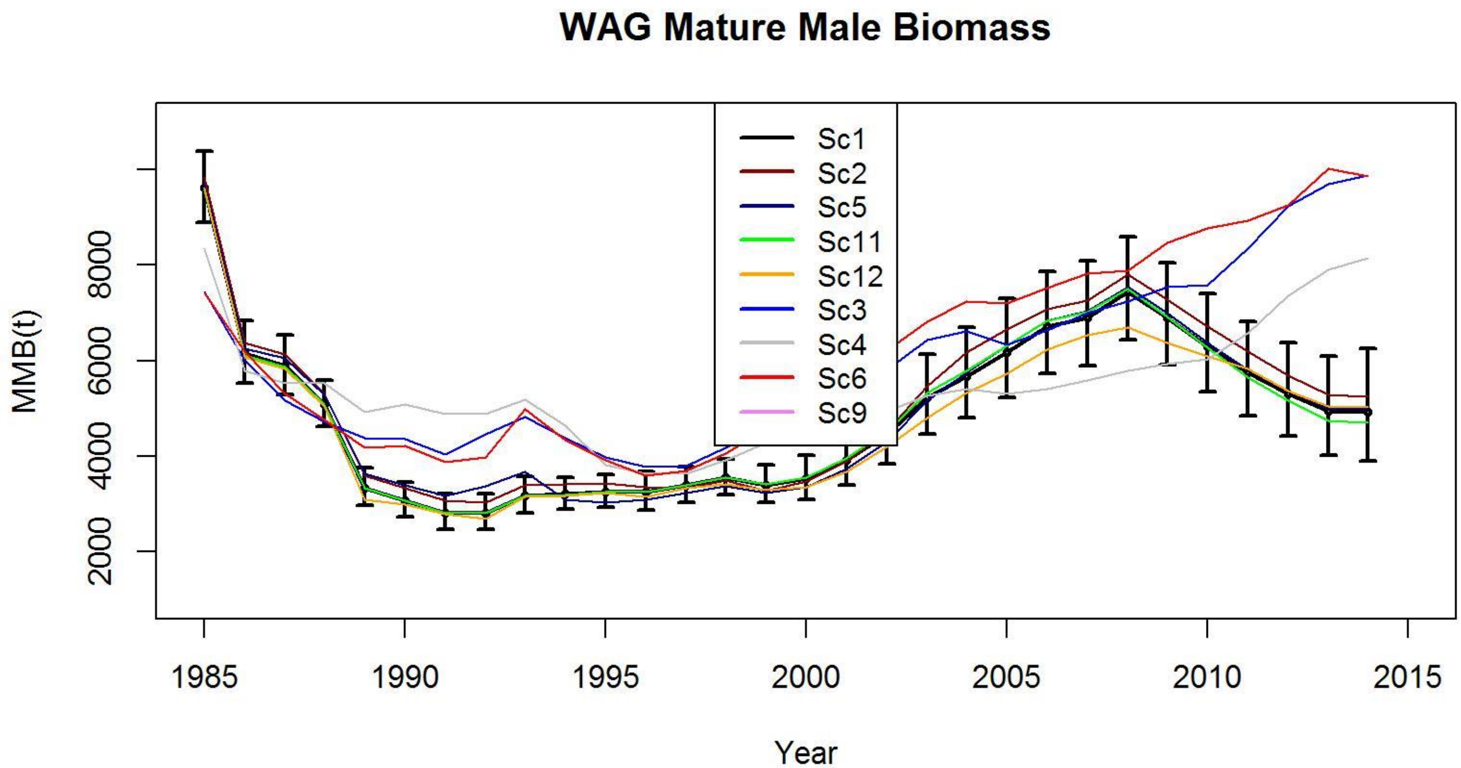

Figure 56. Trends in golden king crab mature male biomass for scenarios (Sc) 1, 2, 3, 4, 5, 6, 9, 11, and 12 model fits in the WAG, 1985/86–2014/15. Mature male crab are ≥ 121 mm CL. Scenario 1 estimates have two standard errors confidence limits.

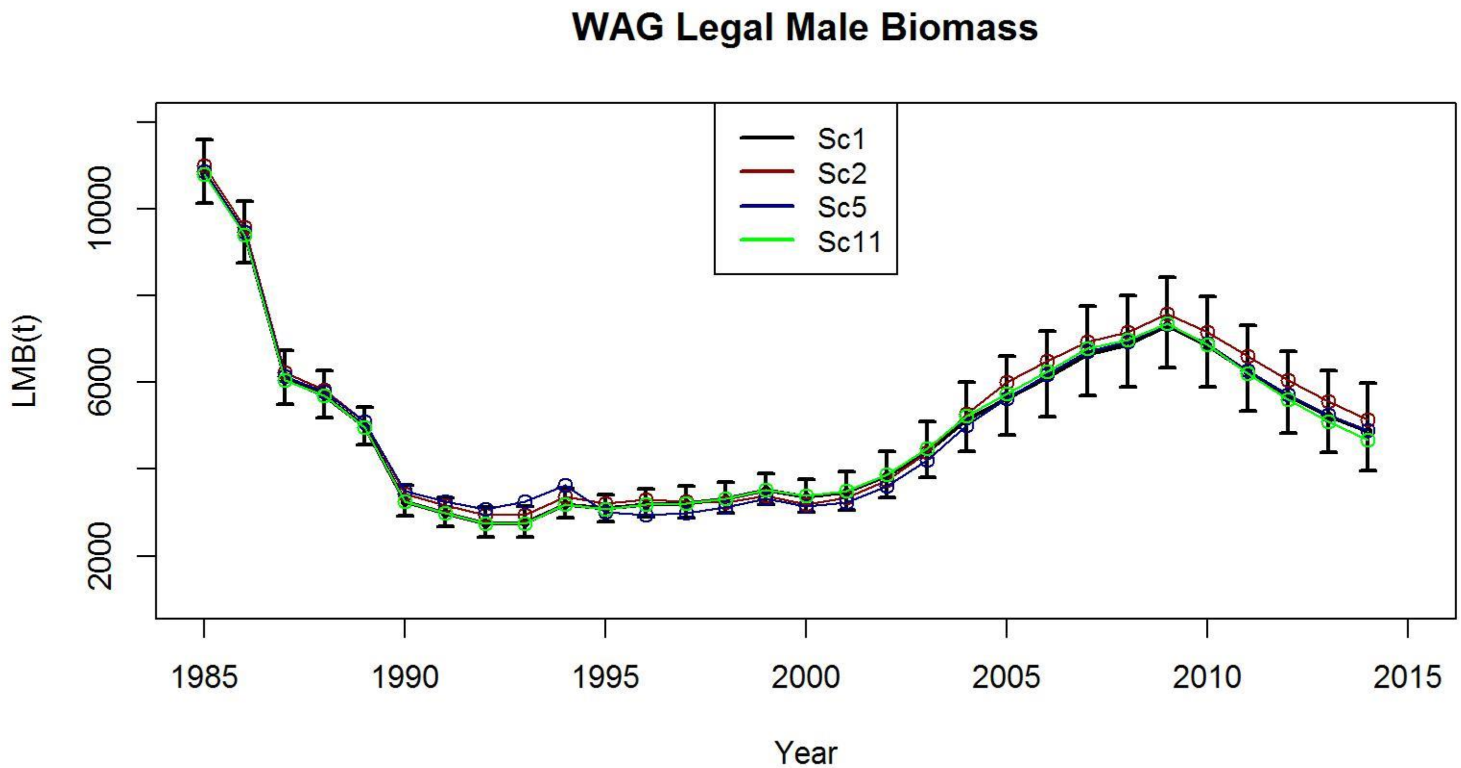

Figure 57. Trends in golden king crab legal male biomass for scenarios (Sc) 1, 2, 5, and 11 fits in the WAG, 1985/86–2014/15. Legal male crab are ≥ 136 mm CL. Scenario 1 estimates have two standard errors confidence limits.

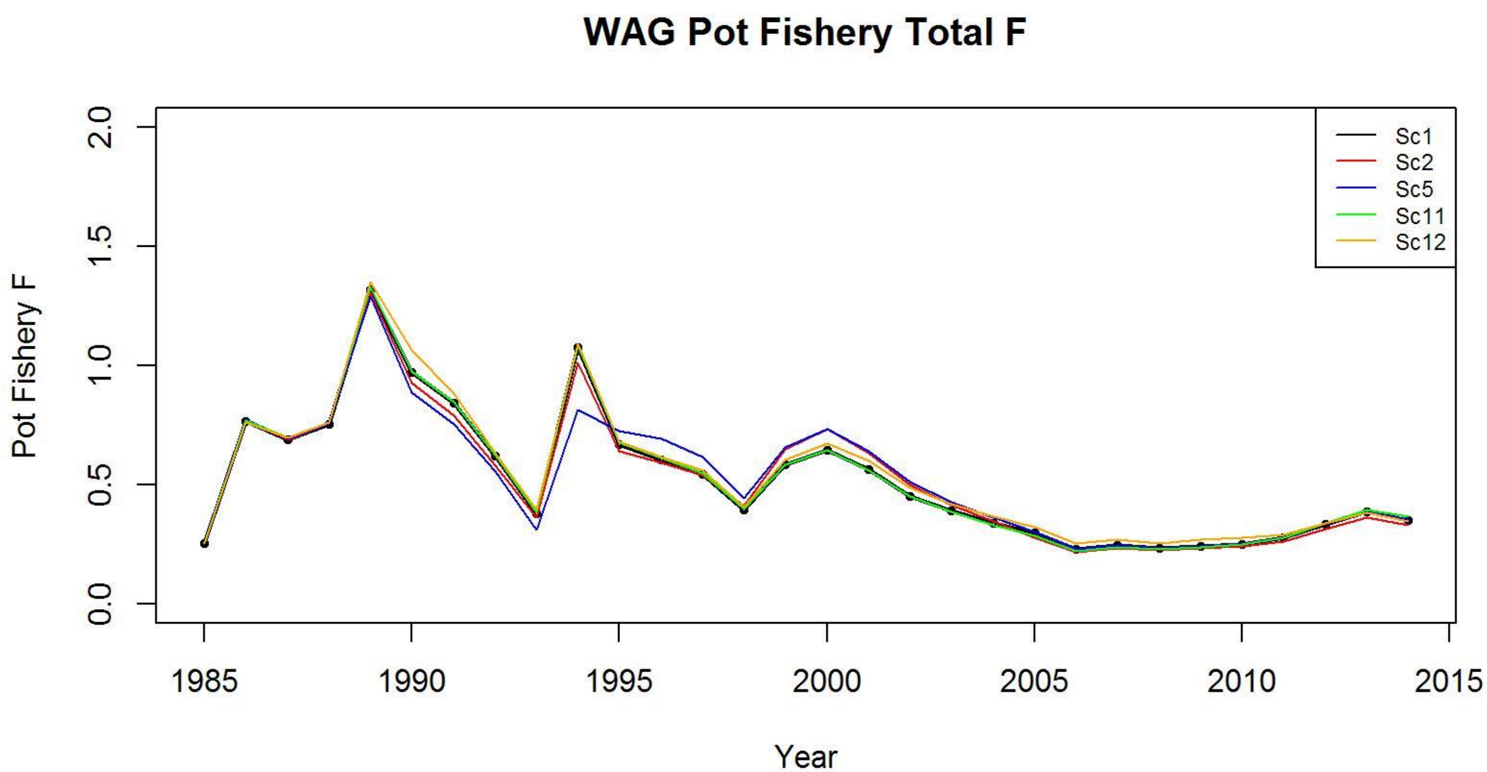

Figure 58. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1, 2, 5, 11, and 12 model fits in the WAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

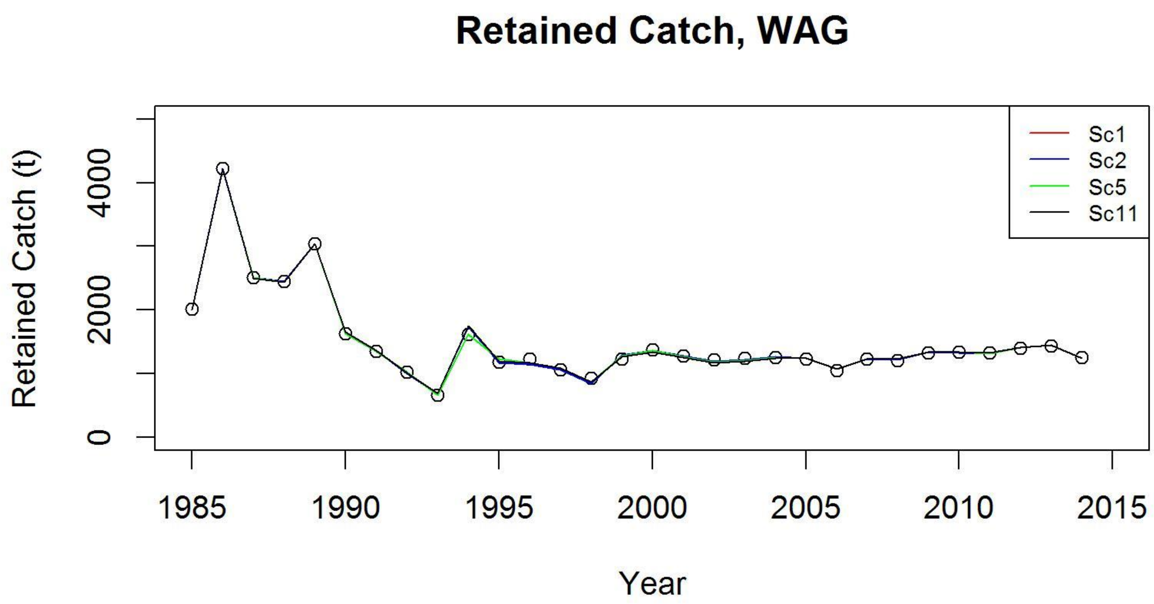

Figure 59. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 1, 2, 5, and 11 fits in the WAG, 1985–2014. (note: 1985 refers to the1985/86 fishery).

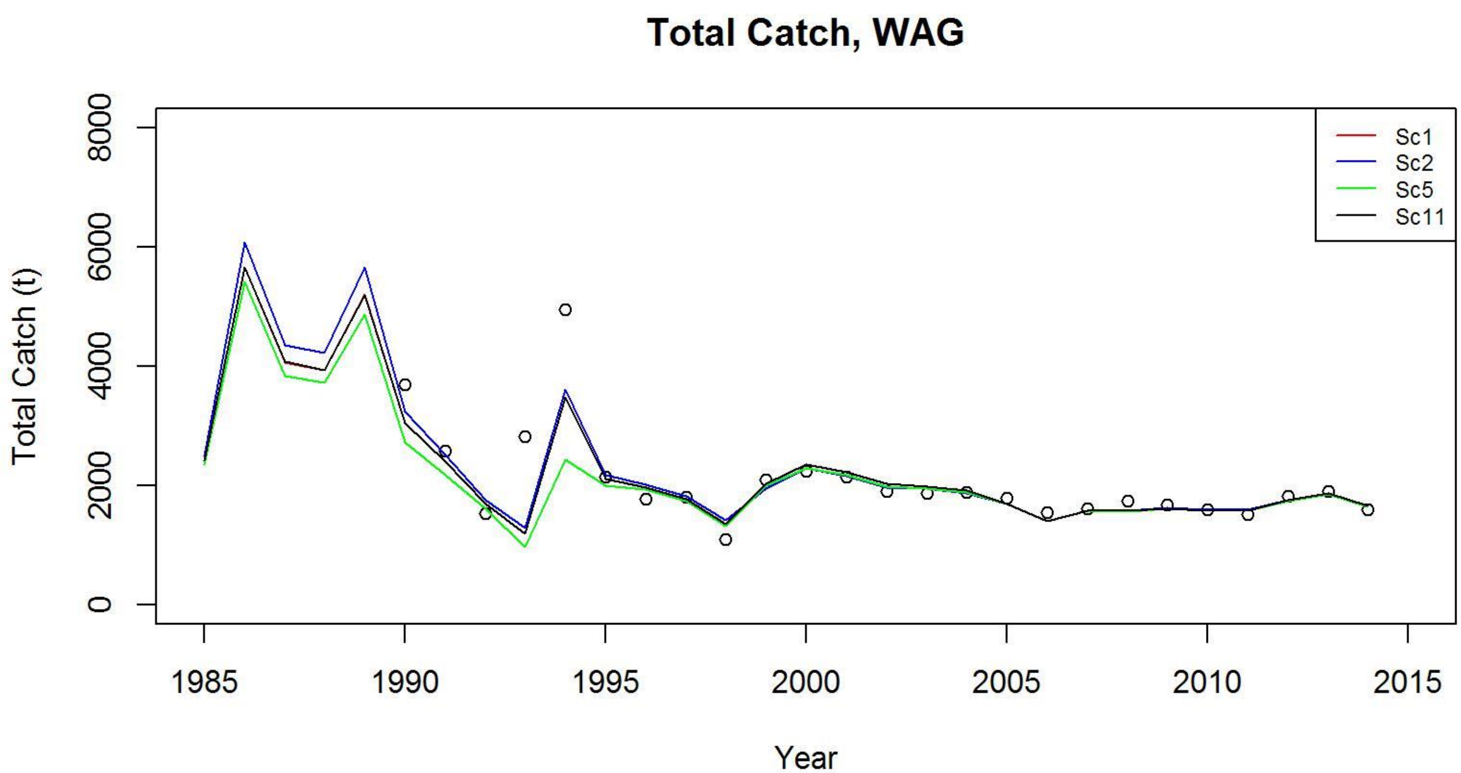

Figure 60. Observed (open circle starting from 1990) vs. predicted (solid line) total catch of golden king crab for scenarios (Sc) 1, 2, 5, and 11 fits in the WAG, 1985–2014. A handling mortality rate of 20% was applied to pot discarded catch and discard mortality added to retained catch to get the total catch. (note: 1990 refers to the1990/91 fishery). Predicted total catch time series is extended from 1990/91 to 1985/86.

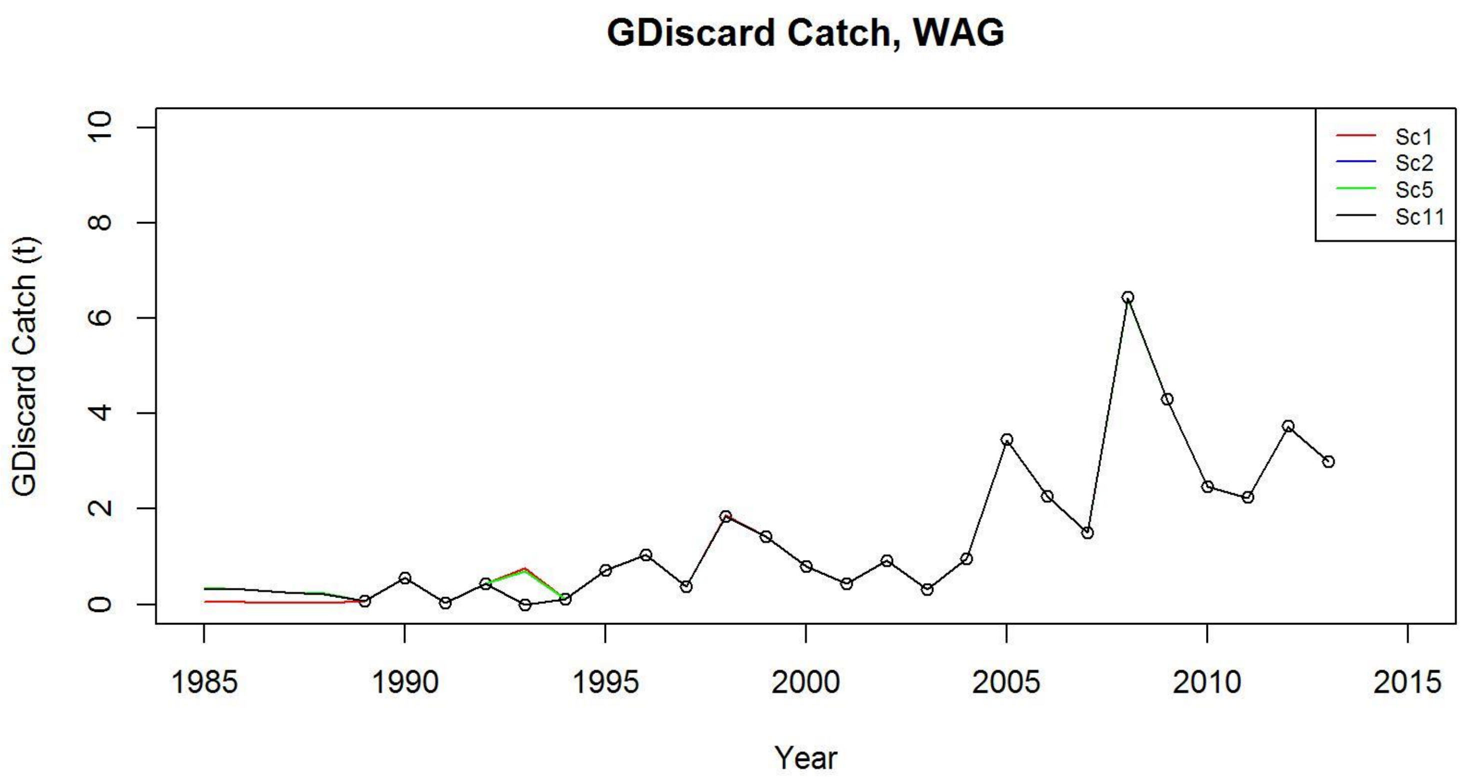

Figure 61. Observed (open circle, starts in 1989) vs. predicted (solid line) groundfish discard of golden king crab for scenarios (Sc) 1, 2, 5, and 11 fits in the WAG, 1985–2013. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1989 refers to the1989/90 fishery).

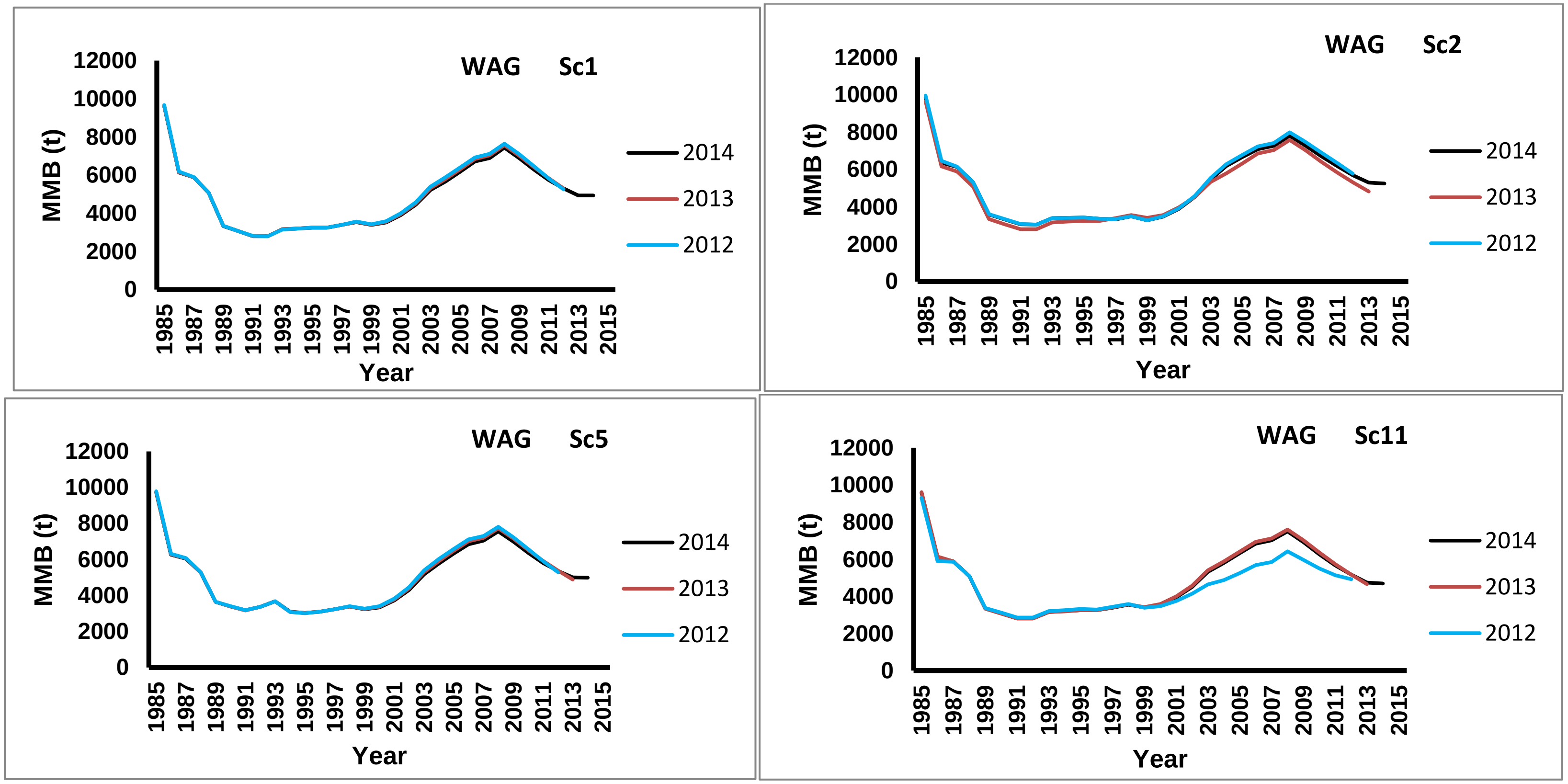

Figure 62. Retrospective fits of mature male biomass by the model when terminal year's data were systematically removed until 2012/13 for scenarios (Sc) 1, 2, 5, and 11 for golden king crab in the WAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

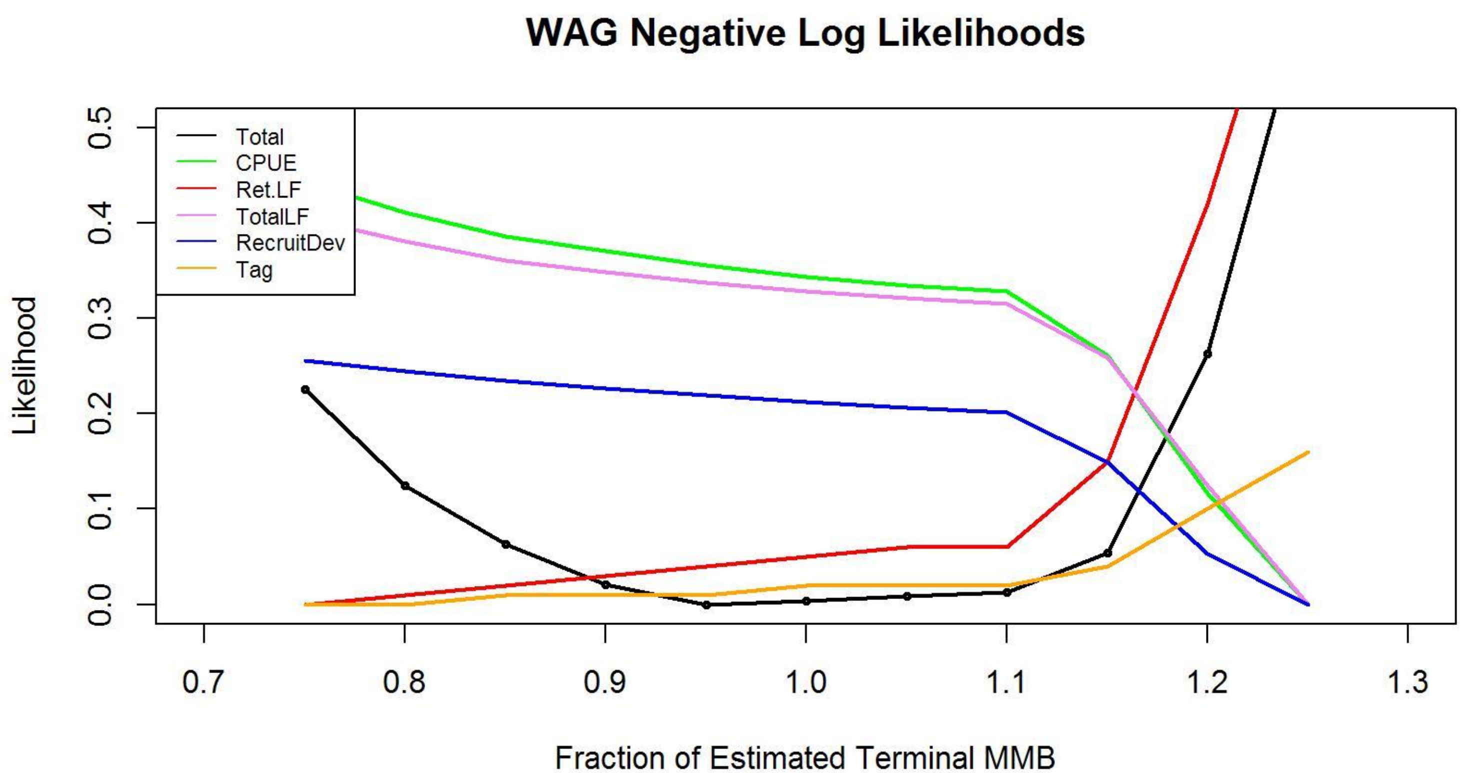

Figure 63. Total and components negative log-likelihoods vs. fractions of the estimated terminal MMB for scenario 1 fit for golden king crab in the WAG, 1985–2014 (note: 1985 refers to the1985/86 fishery).

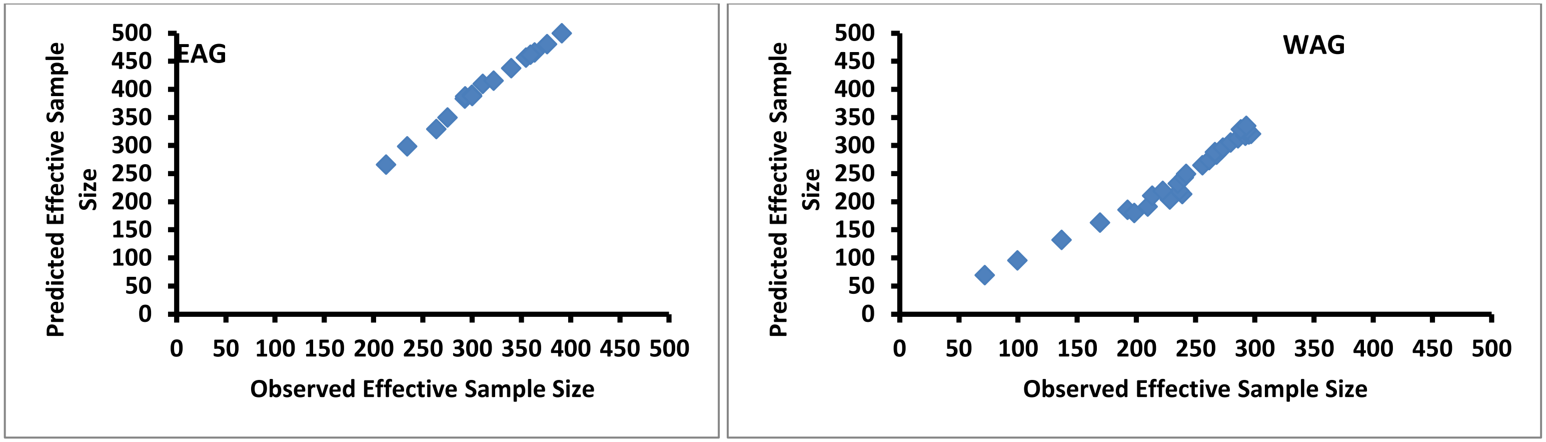

Figure 64. Predicted effective sample size vs. observed effective sample size for retained catch length composition for scenario 6 fit to golden king crab data in the EAG and WAG, 1985/96 – 2014/15.

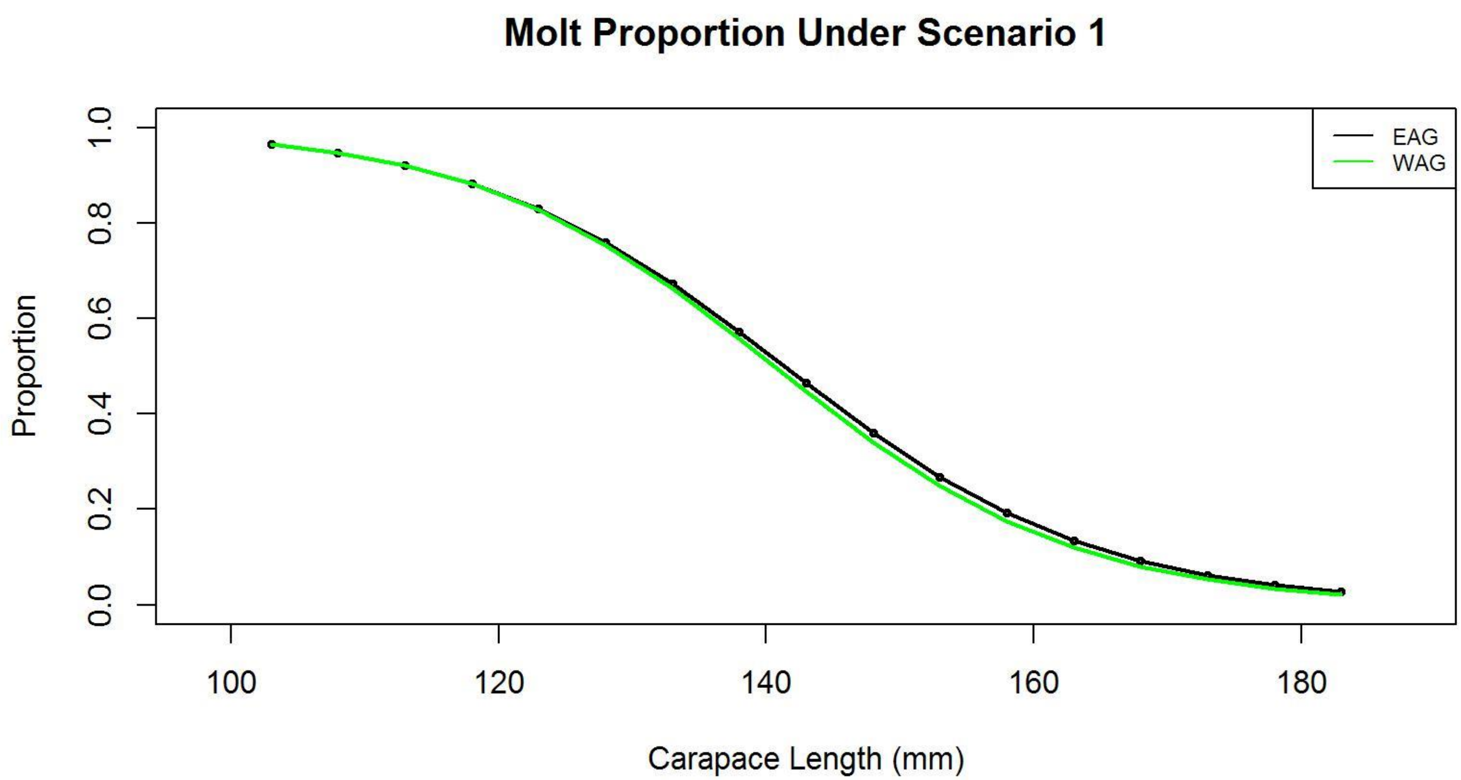

Figure 65. Estimated molt probability vs. carapace length of golden king crab under scenario 1 for EAG (black line) and WAG (green line).

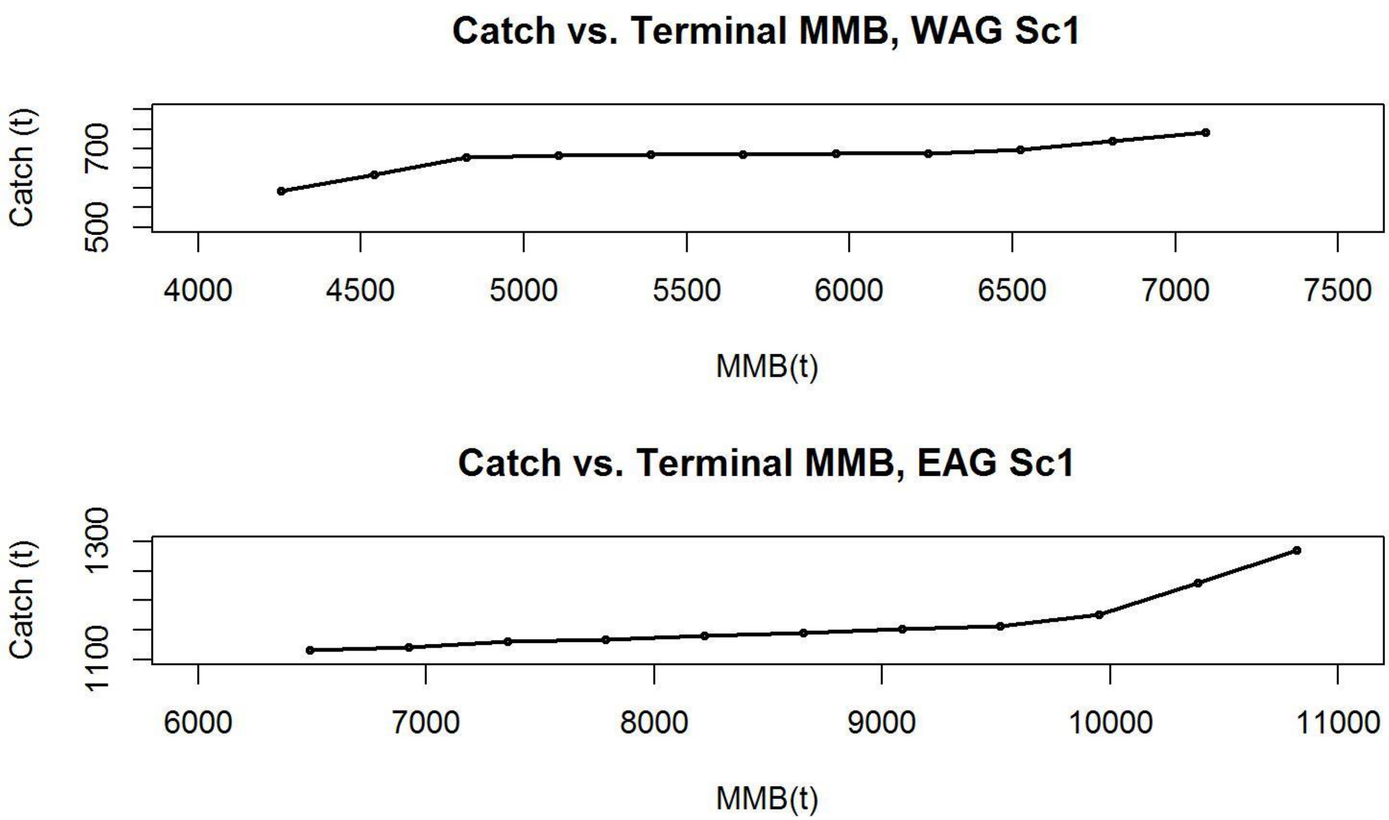

Figure 66. Estimated catch by Tier 4 formula vs. terminal MMB (i.e., final year MMB) for WAG (top) and EAG (bottom) under scenario 1 model fit.

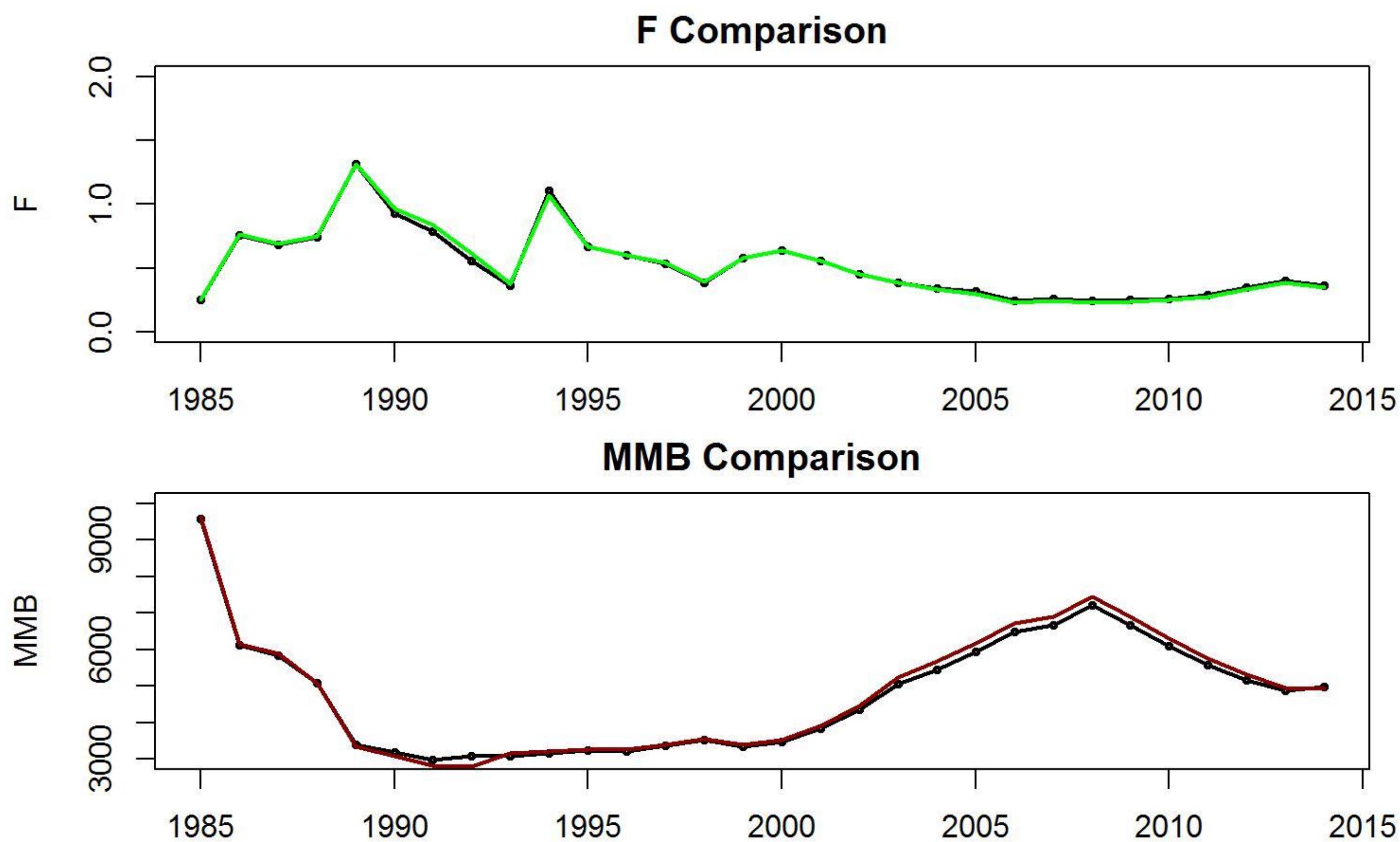

Figure 67. Comparison of F (top) and MMB (bottom) estimates between using the old Z formula (i.e., in May 2015 CPT draft document) and the revised Z formula for scenario 1 for WAG.

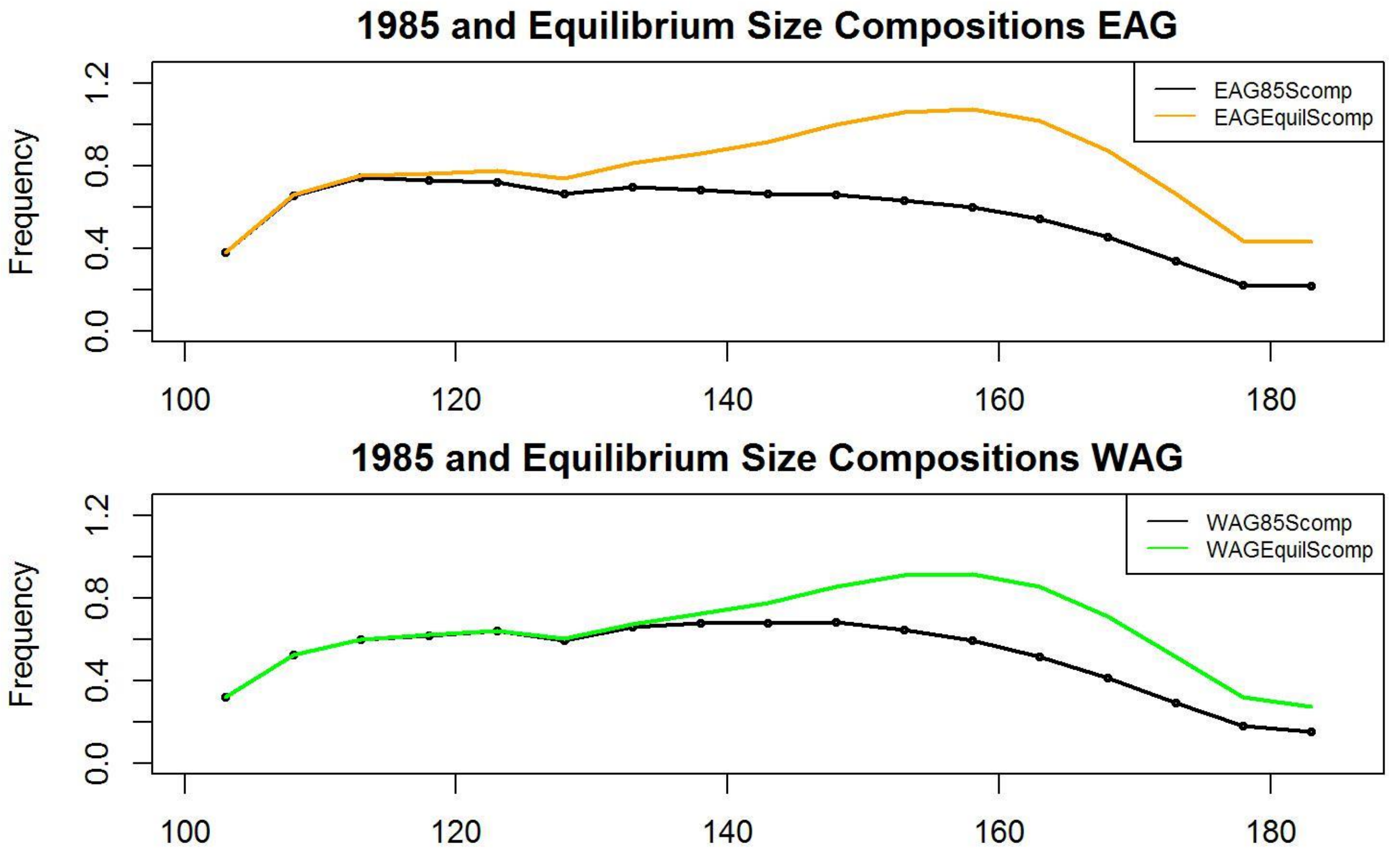

Figure 68. Equilibrium and 1985 size compositions for scenario 1 for EAG (top) and WAG (bottom).

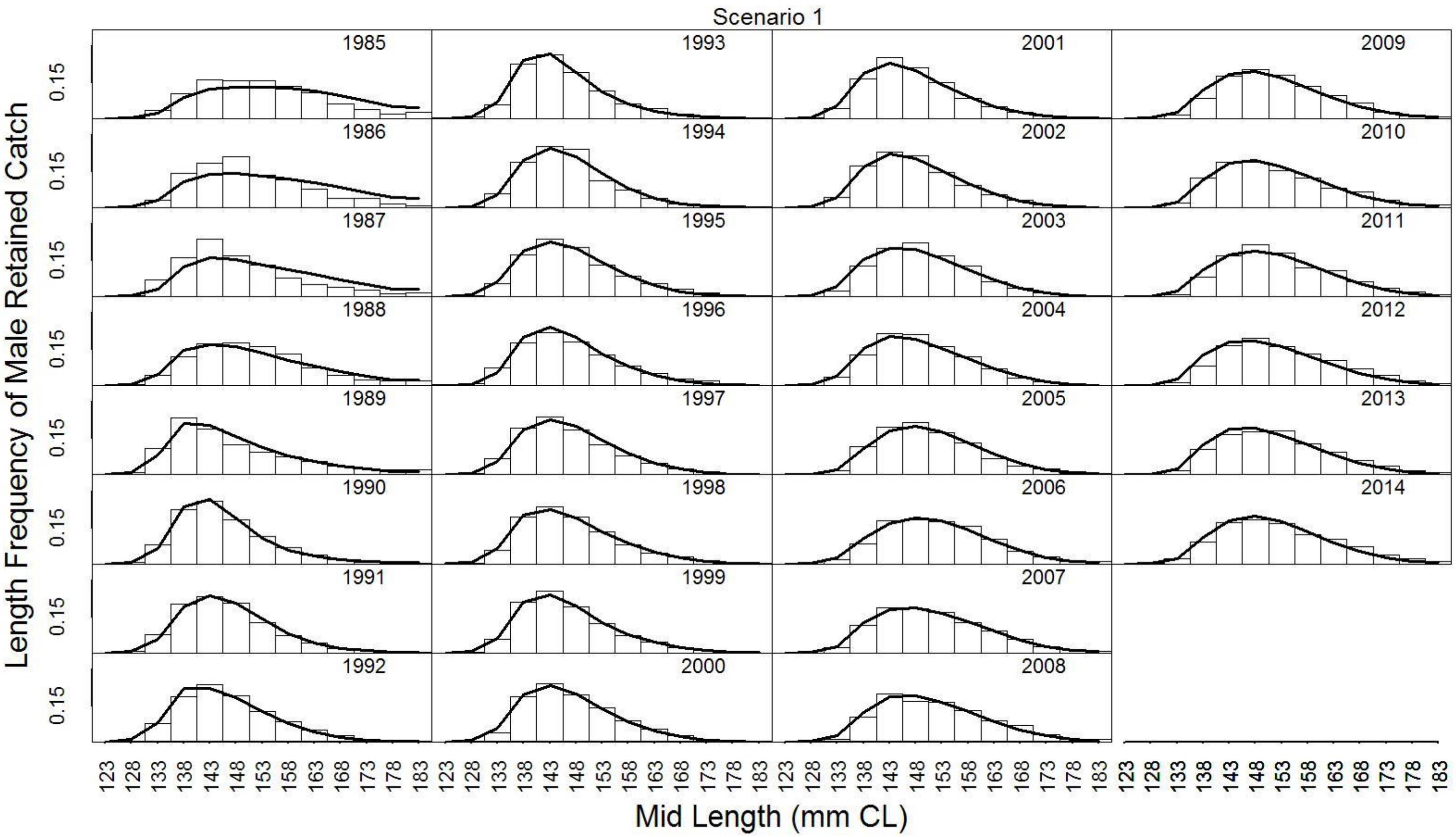

Figure 69a. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 1 of golden king crab in the EAG, 1985/86 to 2014/15.

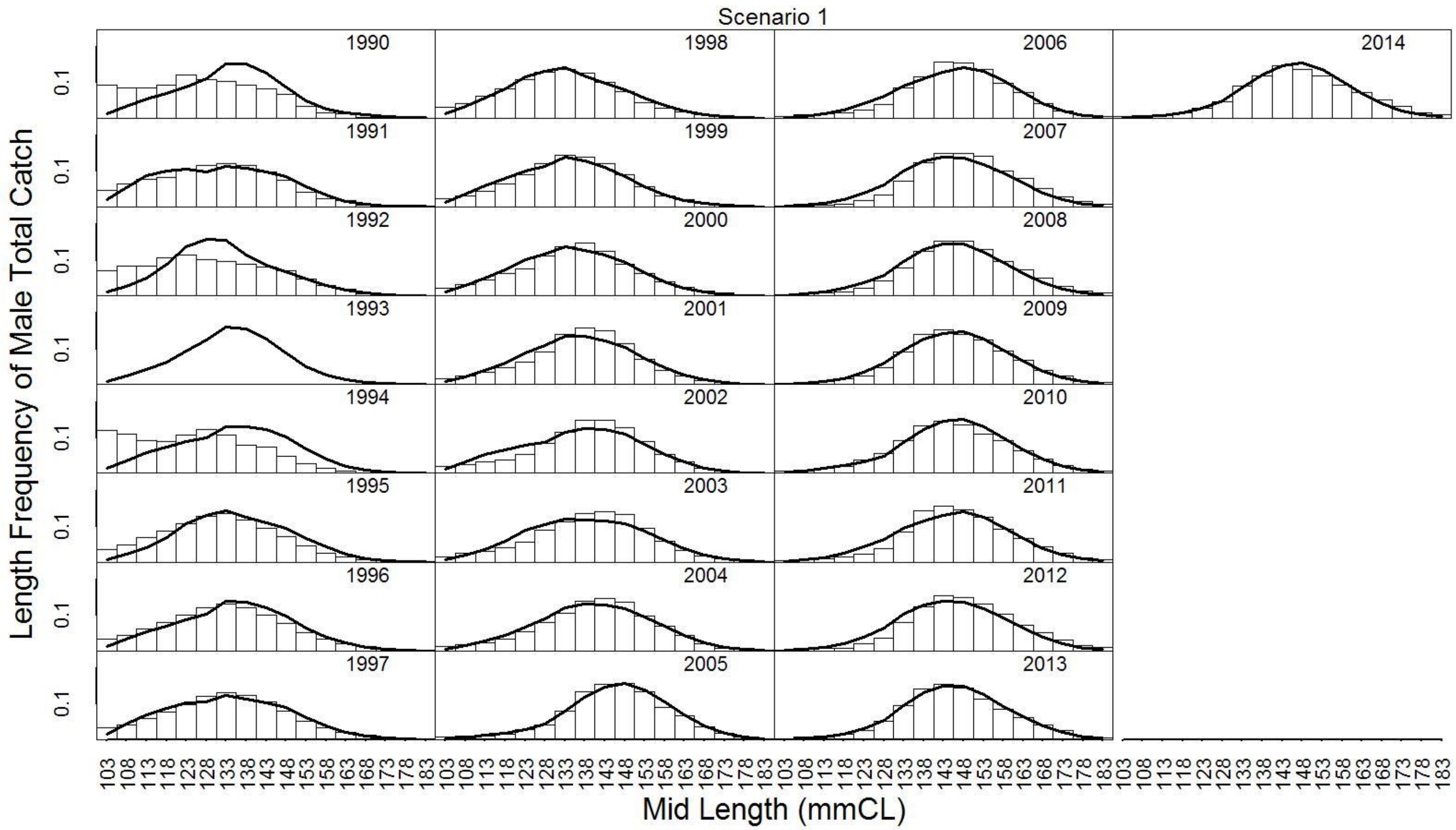

Figure 69b. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenario 1 of golden king crab in the EAG, 1985/86 to 2014/15.

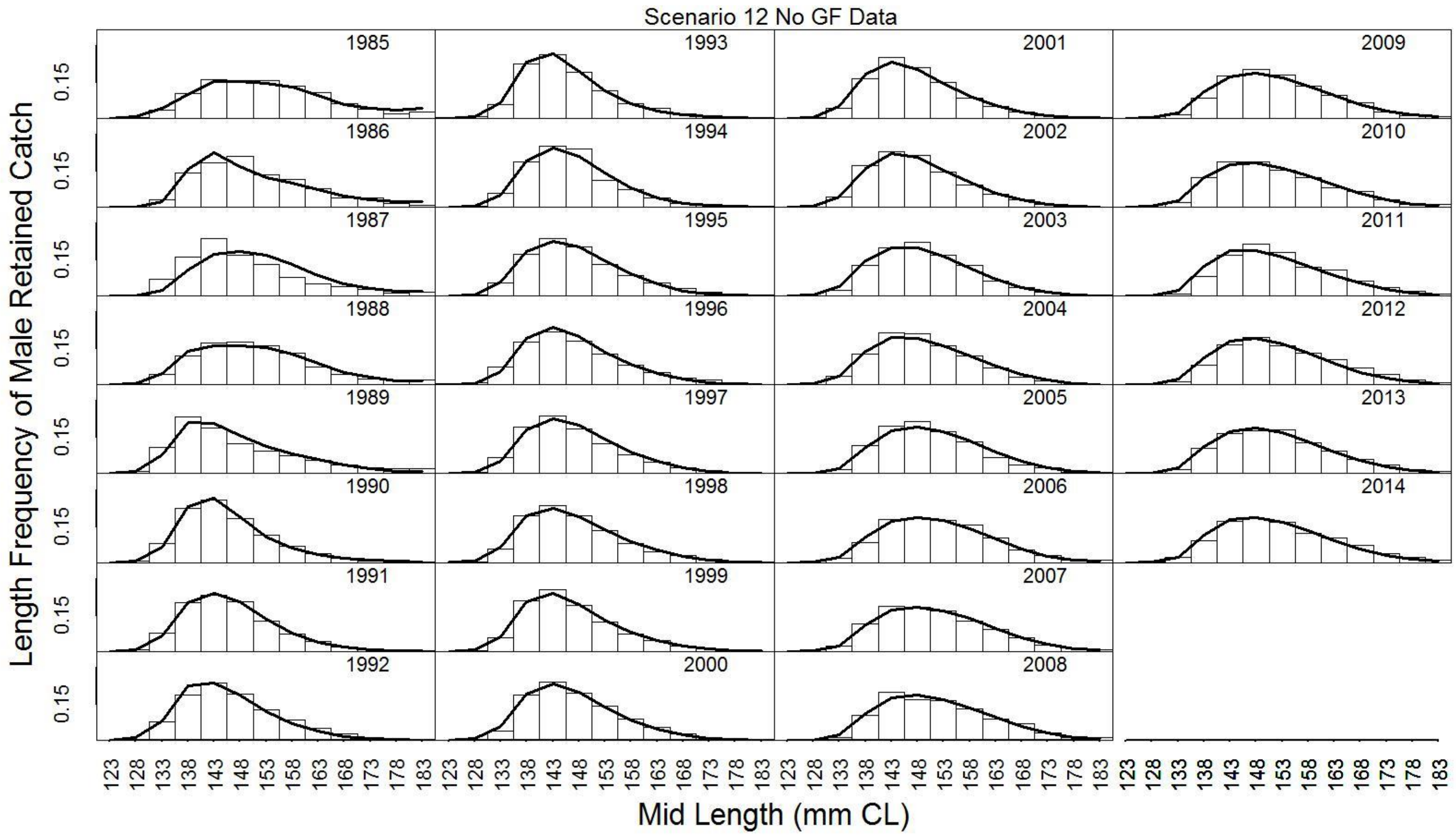

Figure 70a. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 12 of golden king crab in the EAG, 1985/86 to 2014/15.

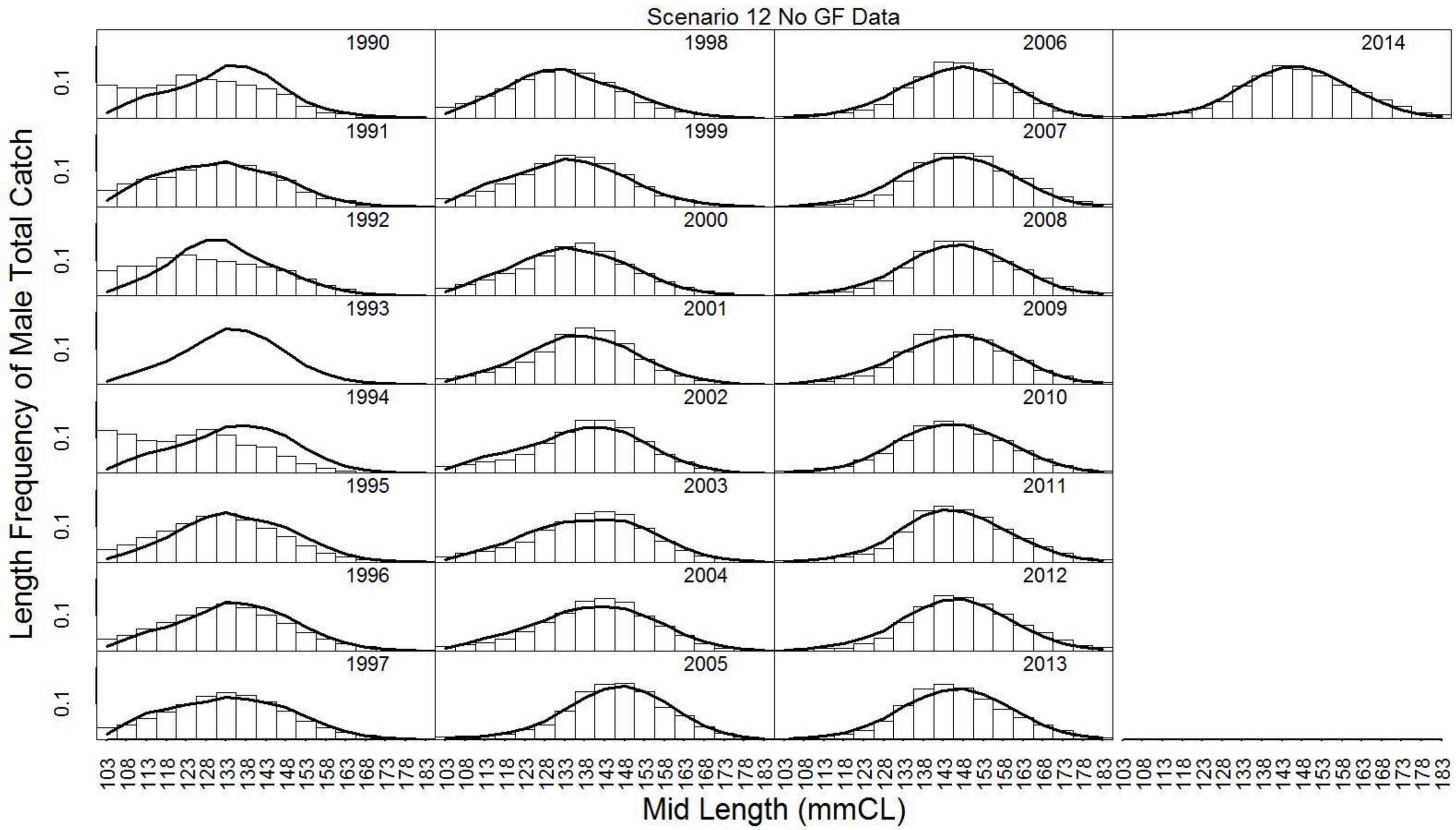

Figure 70b. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenario 12 of golden king crab in the EAG, 1985/86 to 2014/15.

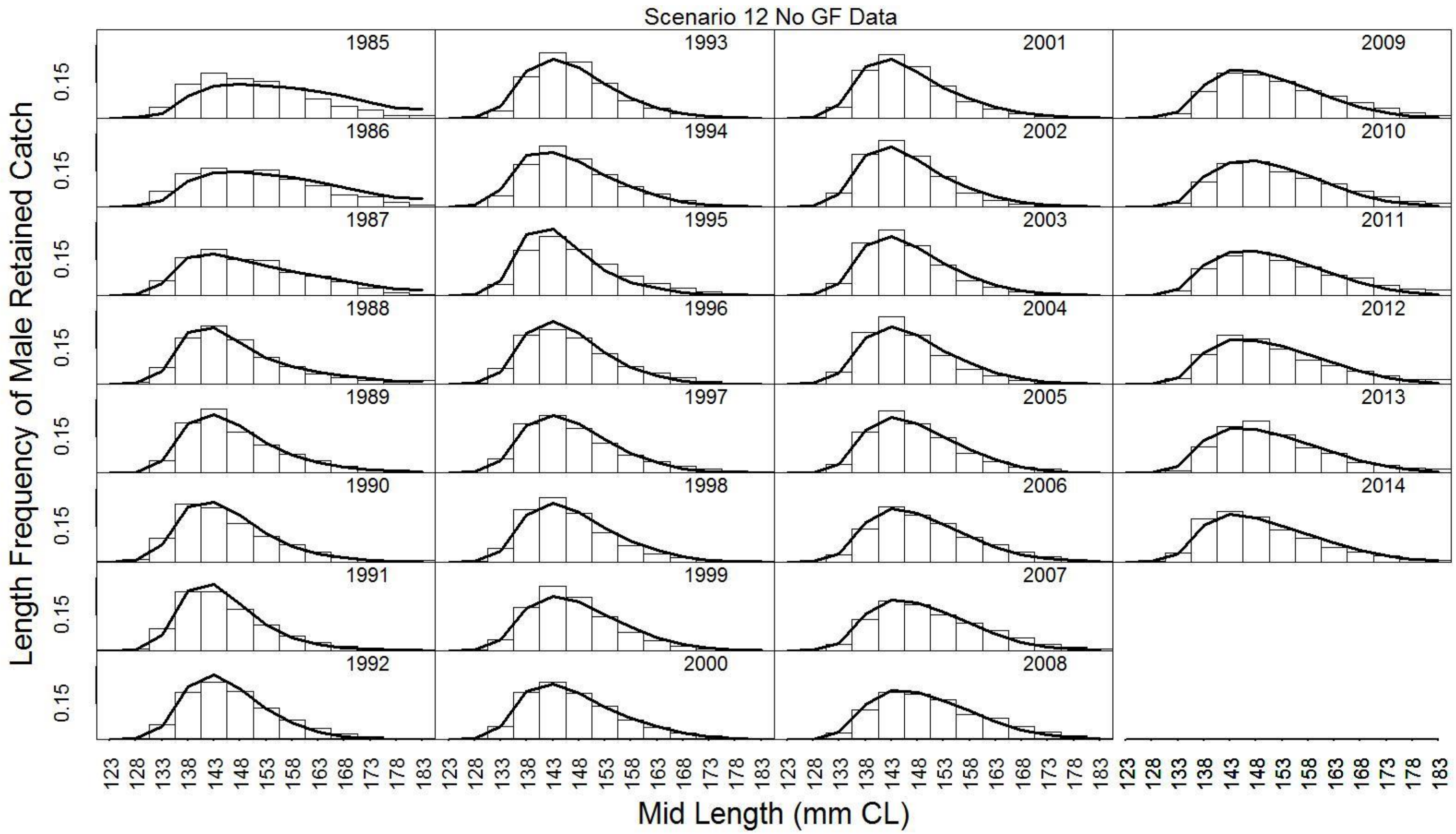

Figure 71a. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenario 12 of golden king crab in the WAG, 1985/86 to 2014/15.

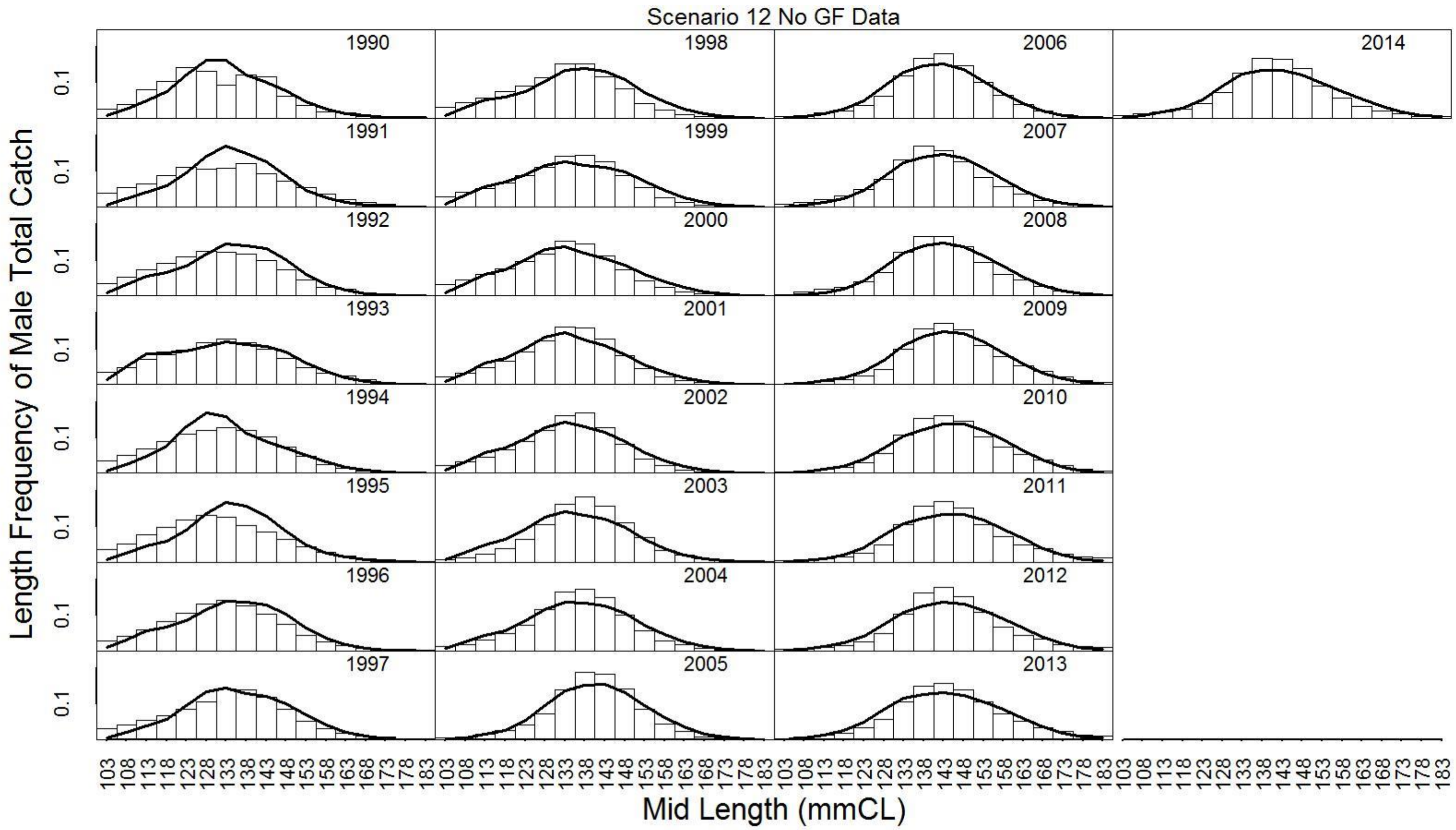

Figure 71b. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenario 12 of golden king crab in the WAG, 1985/86 to 2014/15.

Appendix A: Integrated model

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

Basic population dynamics

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

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

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

The catches are predicted using the equations

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

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

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

$$\widehat{Tr}_{t,j} = 0.65\frac{F_t^{Tr} s_j^{Tr}}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \quad (2d)$$

$$\hat{T}_{t,j} = \hat{C}_{t,j} + \widehat{D}_{t,j}$$
(2e)

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

$$Z_{t,j} = F_t s_{t,j}^T s_{t,j}^r + 0.2F_t s_{t,j}^T(1 - s_{t,j}^r) + 0.65\, F_t^{Tr} s_j^{Tr} \quad (3)$$

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

The initial conditions (t=1985) are computed using the equation

$$N_{1985,i} = \tilde{N}_{1985}\, e^{\varepsilon_i} / \sum_j e^{\varepsilon_j} \tag{4}$$

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).

We also used the equilibrium initial condition using the following relations:
The equilibrium stock abundance is

$$N = X.S.N + R \tag{5}$$

where X is size transition matrix, S is survival, N is numbers-at-length and R is the recruitment vectors. The equilibrium N is

$$N = (I - XS)^{-1}R \tag{6}$$

where I is the identity matrix.

We used the mean number of recruits from 1996 to 2014 in equation (6) to obtain the equilibrium solution under only natural mortality (0.18) in year 1981, and then projected the equilibrium abundance up to 1985 with removal of retained catches during 1981/82 to 1984/85.

We used the exponential formulation for EAG and equilibrium condition for WAG for most scenarios. As a sensitivity analysis we used the equilibrium condition for scenario 8 for EAG.

Molt and Growth

Molt probability

Growth increment probability with molt probability is used to estimate the size transition matrix using tagging data in all scenarios, but scenario 4. In scenario 4, only growth increment probability without molt probability is used to estimate the size transition matrix. Molt probability is assumed to be a logistic function of length,

$$m_i = \frac{1}{1 + e^{a(\tau_i - b)}} \tag{7}$$

where a and b are parameters and τ_i is the mid-point of the contributing length interval i.

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

$$P_{i,j} = m_i \frac{\int_{j_1-\tau_i}^{j_2-\tau_i} N(x|\mu_i,\sigma^2)dx}{\sum_{j=1}^{n}\int_{j_1-\tau_i}^{j_2-\tau_i} N(x|\mu_i,\sigma^2)dx} \quad \text{where } N(x|\mu_i,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(\frac{x-\mu_i}{\sigma})^2} \tag{8}$$

$$X_{i,j} = \begin{cases} P_{i,j} & when\ i \neq j, \\ P_{i,j} + (1-m_i) & when\ i = j \end{cases} \tag{9}$$

where μ_i is the expected growth increment ($\mu_i = \omega_1 + \omega_2\tau_i$), ω_1, ω_2, and σ 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 $\ll j$, 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:

$$S_i = \frac{1}{1+ e^{\left[-\ln(19)\frac{\tau_i-\theta_{50}}{\theta_{95}-\theta_{50}}\right]}} \tag{10}$$

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 $\log(delta\theta)$ so that the difference is always positive.

Recruitment

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

$$gamma(x|\alpha_r,\beta_r) = \frac{x^{\alpha_r-1}e^{\frac{x}{\beta_r}}}{{\beta_r}^{\alpha_r}\,\Gamma_{(\alpha_r)}} \tag{11}$$

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

Parameter estimation

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

Tables 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:

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

$$LL_T^{catch} = \lambda_T \sum_t \{\ln(\sum_j \hat{T}_{t,j} w_j + c) - \ln(\sum_j T_{t,j} w_j + c)\}^2 \quad (12b)$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{\ln(\sum_j \widehat{Tr}_{t,j} w_j + c) - \ln(\sum_j Tr_{t,j} w_j + c)\}^2 \quad (12c)$$

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

Catch-rate indexes

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

$$LL_r^{CPUE} = \lambda_{rCPUE} \left\{ 0.5 \sum_t \ln\left[2\pi\left(\sigma_{r,t}^2 + \sigma_e^2\right)\right] + \sum_t \frac{\left(ln(CPUE_t^r + c) - \ln(\widehat{CPUE}_t^r + c)\right)^2}{2\left(\sigma_{r,t}^2 + \sigma_e^2\right)} \right\} \quad (13)$$

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

$$\widehat{CPUE}_t^r = q_k \sum_j S_j^T S_j^r \left(N_{t,j} - 0.5\left[\widehat{C_{t,J}} + \widehat{D_{t,J}} + \widehat{Tr_{t,J}}\right]\right) e^{-y_t M} \quad (14)$$

where q_k is the catchability coefficient during the k-th time period (e.g., pre- and post-rationalization time periods), σ_e is the extent of over-dispersion, *c* is a small constant to prevent zero values (0.001), and λ_{rCPUE} is the weight assigned to the catch-rate data.
Following Burnham et al. (1987), we computed the *ln(CPUE)* variance by:

$$\sigma_{r,t}^2 = \ln(1 + CV_{r,t}^2) \tag{15}$$

Length-composition data

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

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

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

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

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

$$\hat{L}_{t,j}^{GF} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \tag{17}$$

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

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

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

The input effective sample sizes were rescaled from actual numbers of length measurements as follows:

$$S_t^r = \min(0.01 * number\ of\ length\ measurements\ in\ year\ t, 200)$$

$$S_t^T = \min(0.001 * number\ of\ length\ measurements\ in\ year\ t, 150)$$

$$S_t^{GF} = \min(0.1 * number\ of\ length\ measurements\ in\ year\ t, 25)$$

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:

$$\ell n L = \sum_t \sum_j \sum_y \sum_i \tilde{V}_{j,t,y,i} \ell n \hat{\rho}_{j,t,y,i} \tag{19}$$

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:

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

where $\underline{\Omega}^{(j)}$ is a vector with $V_{j,t,y}$ at element *j* and 0 otherwise, and s^T 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:

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

The last term, $\sum_k V_{j,k,t}$, is the number of recaptured male crab 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 :

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

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

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

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

$$P_5 = \lambda_{posfn} * fpen \tag{25}$$

Standardized Residual of Length Composition

$$Std.Res_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma^2_{t,j}}} \tag{26}$$

Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n}(\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \tag{27}$$

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

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

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

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

$$MMB_t = \sum_{j=mature\ size}^{n}\{N_{j,t}e^{y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t})e^{(y_t - y')M}\}w_j \tag{29}$$

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

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

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

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

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

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

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 $B_{MSY}\ proxy$ for the Tier 4 stock.

Because projected MMB_t is depended on the intervening retained and discard catch (i.e., MMB_t is estimated after the fishery), an iterative procedure is applied using Equations 29 and 30 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
Length specific equilibrium abundance N_{eq}	n
Fishing mortalities	
Pot fishery, F_t	1985–2014
Mean pot fishery fishing mortality, $\bar{F}$	1
Grounsfish fishery, F_t^{Tr}	1989–2013 (the mean F for 1989 to 1994 was used to estimate trawl discards back to 1985.
Mean groudfish fishery fishing mortality, $\bar{F}^{Tr}$	1
Selectivity and retention	
Pot fishery total selectivity θ_{50}^{T}	2 (1985–2004; 2005+)
Pot fishery total selectivity difference, $delta\theta^{T}$	2 (1985–2004; 2005+)
Groundfish fishery selectivity θ_{50}^{Tr}	1
Groundfish fishery selectivity difference $delta\theta^{Tr}$	1
Pot fishery retention θ_{50}^{r}	2 (1985–2004; 2005+)
Pot fishery retention difference $delta\theta^{r}$	2 (1985–2004; 2005+)
Growth	
Expected growth increment, ω_1, ω_2	2
Variability in growth increment, σ	1
Molt probability (size transition matrix with tag data) a	1
Molt probability (size transition matrix with tag data) b	1
Natural mortality, M	Pre-specified, 0.18yr^{-1}
Recruitment	
Distribution to length-class, 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**	**Scenario4**	**Scenario5**	**Scenario6**	**Scenario7**
Catch:							
Retained catch for 1981-1984 and 1985-2014, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch, λ_D	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300
Groundfish bycatch, λ_{GD}	1 (0.805)	1	1	1	1	1	1
Catch-rate:							
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$ 1995–2014	1(0.805)	1	1	1	1	1	1
Fish ticket legal size crab catch-rate, $\lambda_{r,CPUE}$ 1985–1998			1(0.805)				

Table A2a continued.

Penalty weights:							
Mean pot fishing mortality, λ_{Fmean}	Initially 1000(0.022), relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Recruitment, λ_R	2.0(0.533)	2	2	2	2	2	2
Tagging likelihood	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data

Table A2a continued.

Weight	Value				
	Scenario 8	**Scenario 9**	**Scenario 10**	**Scenario 11**	**Scenario 12**
Catch:					
Retained catch. λ_r	500 (0.032)	500	500	500	500
Total catch, λ_D	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300
Groundfish bycatch, λ_{GD}	1	1	1	1	Disregarded
Catch-rate:					
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$					
1995–2014	1(0.805)	1	1	1 (one catchability)	1
Penalty weights:					
Mean pot fishing mortality, λ_{Fmean}	Initially 1000(0.022), relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase

Table A2a continued.

Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Disregarded
Recruitment, λ_R	2	2	2	2	2
Tagging likelihood	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data

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

	Value						
Weight	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario4**	**Scenario5**	**Scenario6**	**Scenario7**
Catch:							
Retained catch for 1981-1984 and 1985-2014, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch, λ_D	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300
Groundfish catch, λ_{GD}	1(0.805)	1	1	1	1	1	1
Catch-rate:							
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$ 1995–2014	1(0.805)	1	1	1	1	1	1
Fish ticket legal size crab catch-rate, $\lambda_{r,CPUE}$ 1985–1998			1(0.805)				

Table A2b continued.

Penalty weights:							
Mean pot fishing mortality, λ_{Fmean}	Initially 1000(0.022), relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Pot fishing mortality dev, λ_{F}	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Recruitment, λ_{R}	2(0.533)	2	2	2	2	2	2
Tagging likelihood	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data

Table A2b continued.

Weight	Value			
	Scenario 8	**Scenario 9**	**Scenario 11 (note: no scenario 10)**	**Scenario 12**
Catch:				
Retained catch for 1981-1984 and 1985-2014, λ_r	500 (0.032)	500	500	500
Total catch, λ_D	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300	Number of sampled pots scaled to a max 300
Groundfish catch, λ_{GD}	1	1	1	Disregarded
Catch-rate:				
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$				
1995–2014	1(0.805)	1	1 (one catchability)	1
Penalty weights:				
Mean pot fishing mortality, λ_{Fmean}	Initially 1000(0.022), relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase

Table A2b continued.

Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase
Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Initially 1000, relaxed to 0.001 at phases ≥ selectivity phase	Disregarded
Recruitment, λ_R	2	2	2	2
Tagging likelihood	EAG tag data	WAG tag data	EAG tag data	EAG tag data

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