Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment in spring 2016

Draft report for the May 2016 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 for the 2008/09 fishing year 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 fishing year. 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 under scenario 1 decreased from peak levels during the mid-1990s of the directed fishery and then systematically increased and stabilized in recent years. Estimated MMB under scenario 1 for WAG decreased during the late 1980s and 1990s and systematically increased during 2000s and decreased during last few years since 2009. The lowest levels of MMB for EAG were observed in 1996–1997 and that for WAG were in 1991–1992. Stock trends reflected the fishery standardized CPUE trends in both regions.

4. *Recruitment*

   The numbers of recruits to the model size groups under scenario 1 have fluctuated in both EAG and WAG. For EAG, the model recruitment was high in 1988, 1991 and

2010–2011, and lowest in 1986, while model recruitment for WAG was highest in 1986 and 1993 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 the Tier 4 approach for EAG, WAG, and the two regions sum together (i.e. for the entire Aleutian Islands, AI), 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 a maximum F_{OFL} of γM. The following OFLs and ABCs were determined under Tier 4 based on using the 1986–2015 mean MMB as the reference biomass (MMB_{ref}). The total OFL and ABC estimates are provided for ten scenarios for EAG, WAG, and AI, respectively in the following five tables. We treat scenario 1 as the base scenario. **If the model is accepted, we recommend the OFL and ABC estimates for scenario 1 (base), scenario 10 (dome shaped selectivity), or scenario 16 (restricted time series of total catch and total catch size composition).**

EAG (Tier 4):

Biomass, total OFL, and ABC for the next fishing season in million pounds.

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define MMB_{ref}	γ	M	OFL	ABC (P*=0.49)
1	4a	14.716	20.250	1.38	0.23	1986–2015	1	0.23	3.577	3.559
2	4a	15.034	21.239	1.41	0.23	1986–2015	1	0.23	3.792	3.772
3	4a	14.810	20.217	1.37	0.23	1986–2015	1	0.23	3.587	3.570
4	4a	14.773	20.263	1.37	0.23	1986–2015	1	0.23	3.445	3.427
5	4a	14.941	21.412	1.43	0.23	1986–2015	1	0.23	3.456	3.437
7	4a	13.871	19.183	1.38	0.23	1986–2015	1	0.23	3.330	3.313
10	4a	15.779	20.825	1.32	0.23	1986–2015	1	0.23	3.794	3.776
12	4a	13.736	18.144	1.32	0.23	1986–2015	1	0.23	2.998	2.981
14	4a	14.770	17.836	1.21	0.23	1986–2015	1	0.23	3.100	3.085
16	4a	14.712	20.340	1.38	0.23	1986–2015	1	0.23	3.535	3.516

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

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ $MMBref$	F_{OFL}	Years to define MMB_{ref}	γ	M	OFL	ABC (P*=0.49)
1	4a	6.675	9.185	1.38	0.23	1986–2015	1	0.23	1,622.295	1,614.138
2	4a	6.819	9.634	1.41	0.23	1986–2015	1	0.23	1,719.981	1,710.918
3	4a	6.718	9.171	1.37	0.23	1986–2015	1	0.23	1,627.186	1,619.455
4	4a	6.701	9.191	1.37	0.23	1986–2015	1	0.23	1,562.467	1,554.335
5	4a	6.777	9.712	1.43	0.23	1986–2015	1	0.23	1,567.593	1,559.103
7	4a	6.292	8.701	1.38	0.23	1986–2015	1	0.23	1,510.556	1,502.590
10	4a	7.157	9.446	1.32	0.23	1986–2015	1	0.23	1,720.784	1,712.579
12	4a	6.231	8.230	1.32	0.23	1986–2015	1	0.23	1,360.065	1,352.061
14	4a	6.700	8.090	1.21	0.23	1986–2015	1	0.23	1,406.115	1,399.142
16	4a	6.673	9.226	1.38	0.23	1986–2015	1	0.23	1,603.256	1,594.831

WAG (Tier 4):

Biomass, total OFL, and ABC for the next fishing season in million pounds.

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define MMB_{ref}	γ	M	OFL	ABC (P*=0.49)
1	4a	12.141	12.226	1.01	0.23	1986–2015	1	0.23	2.041	2.031
2	4b	11.892	11.731	0.99	0.226	1986–2015	1	0.23	1.918	1.895
3	4a	11.957	11.969	1.00	0.23	1986–2015	1	0.23	2.010	2.000
4	4a	11.299	11.588	1.03	0.23	1986–2015	1	0.23	1.798	1.789
5	4a	10.485	10.950	1.04	0.23	1986–2015	1	0.23	1.502	1.494
7	4a	11.156	11.630	1.04	0.23	1986–2015	1	0.23	1.983	1.974
10	4a	19.265	19.809	1.03	0.23	1986–2015	1	0.23	2.554	2.488
12	4a	12.242	13.412	1.10	0.23	1986–2015	1	0.23	2.253	2.242
14	4a	19.359	21.256	1.10	0.23	1986–2015	1	0.23	2.809	2.795
16	4a	12.287	12.384	1.01	0.23	1986–2015	1	0.23	2.013	2.002

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

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define MMB_{ref}	γ	M	OFL	ABC (P*=0.49)
1	4a	5.507	5.546	1.01	0.23	1986–2015	1	0.23	925.882	921.389
2	4b	5.394	5.321	0.99	0.226	1986–2015	1	0.23	869.988	859.640
3	4a	5.424	5.429	1.00	0.23	1986–2015	1	0.23	911.578	907.304
4	4a	5.125	5.256	1.03	0.23	1986–2015	1	0.23	815.478	811.430
5	4a	4.756	4.967	1.04	0.23	1986–2015	1	0.23	681.168	677.799
7	4a	5.060	5.275	1.04	0.23	1986–2015	1	0.23	899.695	895.246
10	4a	8.738	8.986	1.03	0.23	1986–2015	1	0.23	1,158.281	1,128.612
12	4a	5.553	6.084	1.10	0.23	1986–2015	1	0.23	1,021.916	1,016.889
14	4a	8.781	9.642	1.10	0.23	1986–2015	1	0.23	1,274.247	1,268.009
16	4a	5.573	5.617	1.01	0.23	1986–2015	1	0.23	912.973	908.270

Aleutian Islands (sum of OFL and ABC for EAG and WAG):

Total OFL and ABC for the next fishing season.

Scenario	OFL (million pounds)	ABC (P*=0.49) (million pounds)	OFL (1,000 t)	ABC (P*=0.49) (1,000 t)
1	5.618	5.590	2.548	2.536
2	5.71	5.667	2.590	2.571
3	5.597	5.570	2.539	2.527
4	5.243	5.216	2.378	2.366
5	4.958	4.931	2.249	2.237
7	5.560	5.532	2.410	2.398
10	6.348	6.264	2.880	2.841
12	5.251	5.223	2.382	2.369
14	5.909	5.880	2.680	2.667
16	5.547	5.518	2.516	2.503

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 discarded catch by size for 1989/89–2014/15 were added. The commercial retained size frequency and observer sample size frequency data were recalculated weighting by sampled vessel's catch.

(b) New data: EAG male tag-recapture data by size and time-at-large for 1991, 1997, 2000, 2003, and 2006 releases were considered for the WAG model analysis.
(c) Observer pot sample legal size crab CPUE data 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.
(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 September 2015 CPT comments

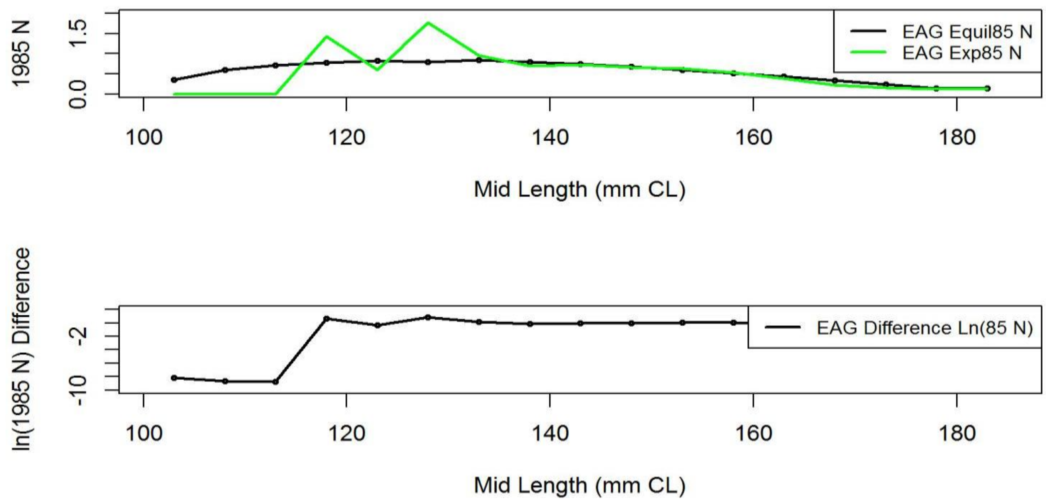
Comment 1: the impact of the way the initial conditions are specified:

- **estimated as log-deviations about an initial abundance (as in Scenario 1 for the EAG)**
- **based on projecting the model from unfished equilibrium at some earlier time (e.g.1960), with recruitments estimated for each year after that time and catches from 1981.**

Response:

1. The initial abundance in 1985 was determined by two methods: a) projecting the model from unfished equilibrium in 1960 with recruitment estimated for each year after 1960 up to 1985 (Equation A.6) and considering retained catches during 1981/82–1984/85; and b) using the exponential formula (Equation A.4) to generate the initial abundance. Initial abundance and the difference in log initial abundance are compared for the two methods for EAG and WAG, respectively:

(a)



(b)

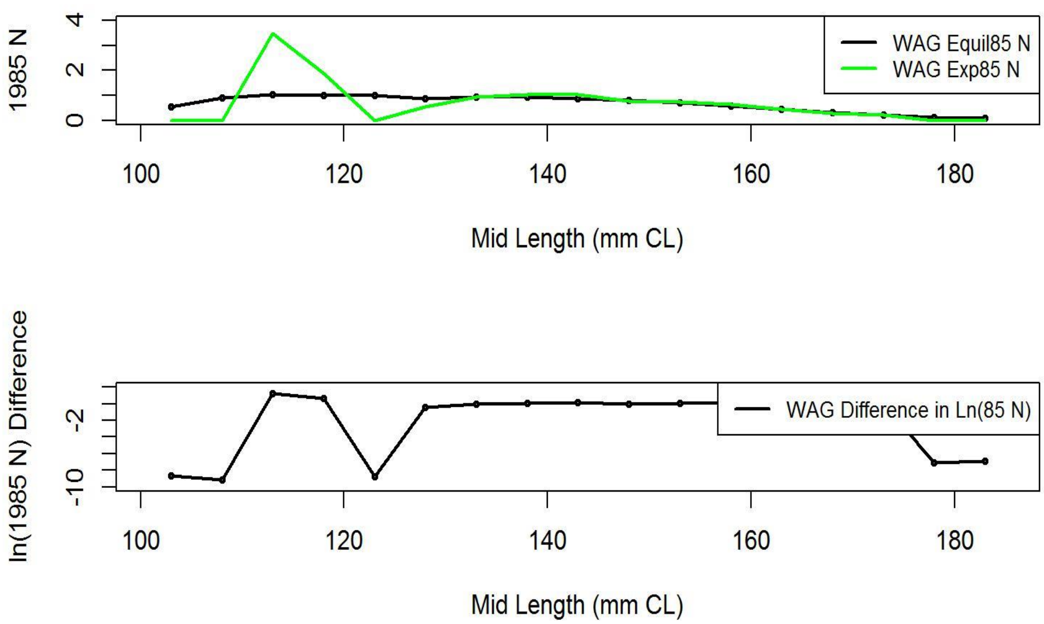


Figure 1. Plots of the initial (1985/86) abundances [top plots in (a) and (b)] and differences of the log initial abundances [bottom plots in (a) and (b)] derived by equilibrium and exponential formulations vs. the length-class mid length for EAG [(a)] and WAG [(b)]. An *M* value of 0.23 yr^{-1} was used.

The initial abundances for length-classes above 128 mm CL are similar for both regions (Figure 1). There are few zero entries for certain size bins when exponential formulation was used, but not when equilibrium condition was used. So, equilibrium initial condition appears to be a better formulation.

Comment 2. The impact of the choice of the value for natural mortality. The scenarios can be based on factors included in current Scenario 1 (two total selectivity curves, two catchabilities, and one retention curve). Each of the following scenarios should be conducted for all options to specify the initial conditions and for natural mortality.

2(a) Drop the groundfish bycatch size-composition data, pre-specify selectivity for the groundfish fishery (e.g., uniform across sizes), and assign a low weight to the groundfish bycatch mass data.

Response

Natural mortality, *M*:
The natural mortality was estimated within the integrated model, separately for EAG and WAG stocks without using any penalty function for *M*. The groundfish (or trawl) bycatch length composition data were not considered for *M* estimation because the fits were bad (see Figures 8 and 28 for EAG and WAG, respectively). The *M* was optimized within the range 0.1 to 0.4 yr^{-1}. We tried several different initial *M* values and found that the *M* estimates were stable (Table C). The best *M* estimate for EAG was 0.2462 yr^{-1} (*SE*= 0.0378yr^{-1}) and that for WAG was 0.2160 yr^{-1} (*SE*=0.0343 yr^{-1}). The best *M* estimates were obtained for a starting value of 0.26yr^{-1} in the optimization (Table C). Then we explored the total and component negative log likelihood values for different levels of *M*. The plots in Figure 2 show well defined minima in the total negative log likelihood values at the best *M* estimates for EAG and WAG, respectively, which are greater than the currently used *M* of 0.18 yr^{-1}. For the base and most other model scenarios, an average of the two *M* estimates for EAG and WAG, which is 0.23 yr^{-1} (rounded to two decimal places), was used. There are no evidences for the stocks in the two regions to have different *M* values. Hence, an average *M* value would be an appropriate choice for a common *M* to use in the stock assessment for the two fisheries.

Table C. Estimates of *M* by the integrated model for different initial *M* values in EAG and WAG. *SE*= asymptotic standard error of *M*.

	EAG		WAG	
Initial *M* yr^{-1}	Estimated *M* yr^{-1}	*SE* yr^{-1}	Estimated *M* yr^{-1}	*SE* yr^{-1}
0.1	0.24624	0.03777	0.21595	0.03433
0.15	0.24624	0.03777	0.21593	0.03432
0.20	0.24624	0.03777	0.21595	0.03433
0.26	0.24624	0.03777	0.21595	0.03433
0.30	0.24624	0.03777	0.21590	0.03431
0.35	0.24624	0.03777	0.21595	0.03433
0.40	0.24624	0.03777	0.21595	0.03433

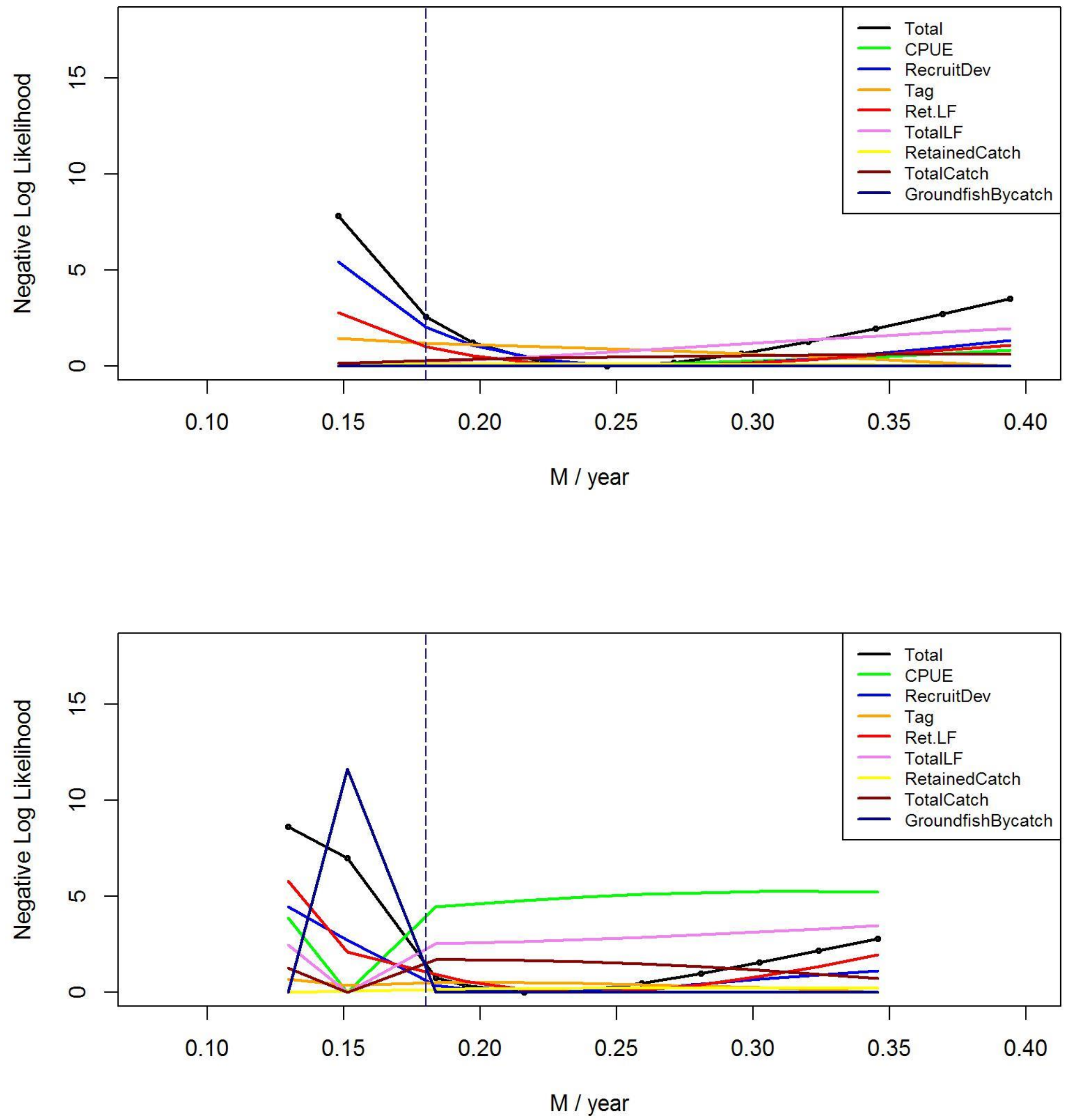


Figure 2. Total and components negative log-likelihoods vs. M for scenario 1 model fit to 1985/86–2014/15 golden king crab data in the EAG (top panel) and WAG (bottom panel). The negative log likelihood values were zero adjusted. The dotted vertical line is for $M = 0.18\ yr^{-1}$.

2(a): All EAG and WAG scenarios used a low groundfish bycatch likelihood weight, 0.2 (CV= 3.344). Scenarios 5 and 6 provide the OFL and ABC estimates when groundfish size composition was dropped. Dropping groundfish size composition and pre-specifying its selectivity to 1 for all length-classes resulted in lower OFL and ABC estimates than that for other scenarios for WAG, but not for EAG. Contribution of groundfish bycatch removal to the total removal during 1989/90–2014/15 was very small, 0.03% for EAG and 0.05% for WAG.

2 (b) Estimate a new selectivity pattern in 1994/95 rather than 1998/99 as in Scenario 2 because the total catch size-composition data for the EAG for the years before 1995 were only collected from Catcher Processor (CP) vessels and appear to contain far more small crab than for the years after 1995.

Response

Scenarios 7 (equilibrium initial cond.) provides the OFL estimates for EAG and WAG, respectively, when the total selectivity and catchability patterns were split into 1985/86–1994/95, 1995/96–2004/05, and 2005/06–2014/15. This recommendation produced similar fit to that of scenario 1. However, this scenario reduced the pot fishery fishing mortality, total and retained catch OFLs from that of scenario 1 (Table 29).

2 (c) Consider dome-shaped rather than asymptotic selectivity.

Response

1. Scenarios 10, 11, 14, and 15 provide the OFL estimates for EAG and WAG, respectively; when the dome shaped selectivity (Equation A.11) was used (Table 29).

2. Area shrinkage: Scenarios 12 and 13 provide the OFL estimates considering the asymptotic total selectivity and the shrinkage of area over the years in the CPUE calculation (Equation A.17) whereas scenarios 14 and 15 provide those estimates made under the same condition considering the dome shaped total selectivity (Table 29).

   The OFL estimates are higher and the F estimates are lower (Table 29, Figures 22 and 40 for EAG and WAG, respectively) for the dome shaped total selectivity compared to asymptotic total selectivity. However, the trends in F values are similar. The shrinkage of area with dome shaped selectivity dramatically increased the OFL estimates for WAG, but not for EAG.

The SSC concurred with the CPT comments.

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. But different CPUE trends suggest different factors may influence stock productivity in EAG and WAG.
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. and

6. Brief summary of management history and annual ADFG harvest strategy: 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 3 to 5 provide the historical 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 (Siddeek et al. 2015), 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 fishing year.
7. Summary of the history of the basis and estimates MMB_{MSY} or proxy MMB_{MSY}: The Tier 4 assessment model has not yet been accepted.

D. Data

1. Summary of new information:

   Data are updated by adding the 2014/15 commercial fishery retained catch by size, estimated total catch by size, groundfish male discard catch by size, and observer CPUE index with standard error to the time series. The details are given in the following table:

   2. Available catch and tagging data.

Years	Retained Catch	Total Catch	Groundfish Discarded Catch	Observer CPUE Index	Fishery Retained Catch CPUE	Tag Releases	Tag Recaptures
Data Types	By length	By length (Observer nominal total CPUE and effort were used to estimate total catch)	By length	Annual CPUE indices with standard errors were estimated by negative binomial GLM	Annual CPUE indices with standard errors were estimated by lognormal GLM for scenario 3		Release-recapture length and time-at-liberty. There are 1717 records.
1985/86							
1986/87							
1987/88							
1988/89							
1989/90							
1990/91							
1991/92							
1992/93							
1993/94							
1994/95							
1995/96							
1996/97							
1997/98							
1998/99							
1999/00							
2000/01							
2001/02							
2002/03							
2003/04							
2004/05							
2005/06							
2006/07							
2007/08							
2008/09							
2009/10							
2010/11							
2011/12							
2012/13							
2013/14							
2014/15							

a. A time series of retained and total catch, groundfish fishery discard mortality, and pot fishery effort (Table 1 for EAG and Table 15 for WAG). The estimation methods are described in Appendix B.

b. Time series of pot fishery and observer nominal retained and total CPUE, observer sample size, estimated observer CPUE index (Table 2 for EAG and Table 16 for WAG), and estimated commercial fishery CPUE index (Table 3 for EAG and Table 17 for WAG). The estimation methods, CPUE fits and diagnostic plots are given in Appendix B.

c. Information on length compositions (Figures 6 to 8 for length compositions and 9 for mean lengths for EAG; and 25 to 27 for length compositions and 28 for mean lengths for WAG).

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

f. Other time series data: None.

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

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

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. The main stumbling block for model acceptance is the scaling of biomass which appears to be low, especially for WAG. In the September 2015 meeting, CPT proposed a number of ways to improving the model fit and scaling biomass: (a) estimate the initial abundance in 1985/86 by equilibrium condition; (b) determine *M* in the model; and (c) consider dome shaped total selectivity. We considered all these suggestions in this modeling.

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 (trawl) fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, groundfish discard catch size composition, and tag recaptures by release-recapture length to estimate stock assessment parameters. 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 indices as a separate likelihood component in scenario 3.

      We fitted the observer and commercial fishery CPUE indices with GLM estimated standard errors and an additional constant variance, the latter was estimated by the model fit.

      There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9-inch since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86–2004/05 and 2005/06–2014/15. However, in order to respond to one of the September 2015 CPT comments, we considered three catchabilities, three sets of total selectivity, and one set of retention curve in one scenario (scenario 7).

      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; 1989/90 to 2014/15 for groundfish fishery male bycatch biomass and size composition; 1985/86 to 1998/99 for standardized crab fish ticket CPUE index; 1990/91 to

2014/15 for total catch biomass and total catch length 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: Because of the lack of an annual stock survey we relied heavily on standardized CPUE indices (Appendix B) and catch and size composition information to determine the stock abundance trends in both regions. We assumed that the observer and fish ticket CPUE indices are proportional to crab abundances. We kept M constant at 0.23 yr^{-1} (the mean value from EAG and WAG M estimates), assumed directed pot fishery discard mortality proportion at 0.20 yr^{-1}, assumed overall groundfish fishery mortality proportion at 0.65 yr^{-1} [mean of groundfish pot fishery mortality (0.5 yr^{-1}) and groundfish trawl fishery mortality (0.8 yr^{-1})], groundfish fishery selectivity at full selection for all length classes (selectivity = 1.0), 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 (Equation A.10) for different periods for the pot fishery. We also assumed a dome shaped selectivity (Equation A.11) (see the scenarios Table D in the subsequent section).

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 16 scenarios for EAG and WAG. We presented OFL and ABC results for preferred ten scenarios in the executive summary tables. We considered scenario 1 as the base scenario. It considers:

i) Estimating initial abundance by the equilibrium condition;

ii) Two catchability and two sets of logistic total selectivity for the periods 1985/86–2004/05 and 2005/06–2014/15, and a single set of logistic retention curve parameters;

iii) Full selectivity (selectivity =1.0) for groundfish (trawl) bycatch;

iv) Stock dynamics M = 0.23 yr^{-1}, pot fishery handling mortality = 0.2 yr^{-1}; and ground fish bycatch handling mortality for trawl = 0.8 yr^{-1} and for fish pot = 0.5 yr^{-1};

v) Calculating size transition matrix using tagging data by the normal probability function with the logistic molt probability sub-model. The tag-recaptures were treated as Bernoulli trials (i.e., stage-1 weighting); and

vi) Rescaling initial length composition sample sizes using Equation A.21 with a set of maximum effective sample sizes (retained catch = 200, total catch= 150, and groundfish (trawl) discarded catch = 25).

vii) The salient features and variations from the base scenario of all other scenarios are listed in Table D. The stage-1 weighting refers to initial weighting of effective sample sizes and stage-2 weighting refers to iterative reweighting of effective sample sizes. The detail weights with coefficient of variations (CVs) assigned to each type of data are listed in Table A2.

Table D. Features of model scenarios.

Scenario	Initial Condition estimation	Size-composition weighting	Catchability and total selectivity sets	Total selectivity type	CPUE data type	Treatment of trawl/total size composition and catch data	Natural mortality ($M\ yr^{-1}$)
1	Equilibrium	Stage-1	2	logistic	Observer	Trawl bycatch size-composition data included	0.23
2	Exponential	Stage-1	2	logistic	Observer	Trawl bycatch size-composition data included	0.23
3	Equilibrium	Stage-1	2	logistic	Observer and fish ticket	Trawl bycatch size-composition data included	0.23
4	Equilibrium	Stage-1	2	logistic	Observer	Trawl bycatch size-composition data down weighted (0.5)	0.23
5	Equilibrium	Stage-1	2	logistic	Observer	Trawl bycatch size-composition data not included	0.23
6	Exponential	Stage-1	2	logistic	Observer	Trawl bycatch size-composition data not included	0.23
7	Equilibrium	Stage-1	3	logistic	Observer	Trawl bycatch size-composition data included	0.23
8	Equilibrium	Stage-1	2	logistic	Observer	Trawl bycatch size-composition data included	0.18
9	Equilibrium	Stage-2	2	logistic	Observer	Trawl bycatch size-composition data included	0.23
10	Equilibrium	Stage-1	2	dome shaped	Observer	Trawl bycatch size-composition data included	0.23
11	Equilibrium	Stage-1	2	dome shaped	Observer	Trawl bycatch size-composition data included	0.18
12	Equilibrium	Stage-1	2	logistic	Observer and fishing area	Trawl bycatch size-composition data included	0.23
13	Equilibrium	Stage-1	2	logistic	Observer and fishing area	Trawl bycatch size-composition data included	0.18
14	Equilibrium	Stage-1	2	dome shaped	Observer and fishing area	Trawl bycatch size-composition data included	0.23
15	Equilibrium	Stage-1	2	dome shaped	Observer and fishing area	Trawl bycatch size-composition data included	0.18
16	Equilibrium	Stage-1	2	logistic	Observer	Total size composition and catch data for 1990/91-1995/96 (EAG) or -1994/95 (WAG) not included	0.23

Note: proportion of fishing area by year used in scenarios 12 to 15 are provided in Tables 5 and 19 for EAG and WAG, respectively.

viii) The entire time period, 1985/86–2014/15, was used to determine the mean MMB as MMB_{ref} (a proxy for MMB_{MSY}) for $\mathrm{MMB}_{\mathrm{current}}/MMB_{ref}$ estimation under Tier 4 for all scenarios.

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

c. Model has not yet been approved. So labeling the previous year approved model as model 0 is 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 few biological parameters are assumed based on knowledge from red king crab (e.g., handling mortality rate of 0.2 yr^{-1}) due to a lack of species/stock 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 16 scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the preferred ten scenarios are provided in tables and figures. The total and retained catch OFLs, maximum total pot fishing mortality during 1985/86–2014/15, and the reduction in terminal (2015) and 1985 MMB from the initial condition (i.e., virgin MMB in 1960 for equilibrium initial abundance or 1985 initial abundance for exponential initial condition) for the entire 16 scenarios for EAG and WAG are provided in Table 29. The reduction in terminal MMB from the initial condition is higher for M = 0.18 yr^{-1} than 0.23 yr^{-1}. The exponential formulation of initial condition (i.e., 1985 abundance estimate) produced lower reduction in terminal MMB for WAG, but exceeded the initial MMB for EAG. This is not surprising because 1985 initial abundance is not the virgin stock abundance. The reduction in 1986 MMB from equilibrium initial MMB is higher for EAG (reduced to 0.43 to 0.61 of initial MMB) than that for WAG (reduced to 0.56 to 0.78 of initial MMB).

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

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

We estimated the initial input effective sample sizes (i.e., stage-1) from the original number of length measurements using Equation A.21 for all scenarios except scenario 9. For scenario 9 (iterative reweighting), we estimated the stage-1 sample sizes using

Equation A.21 without setting limits to maximum sample sizes. We estimated the stage-2 effective sample sizes from estimated input effective sample sizes (i.e., stage-1 sample sizes) using Francis' (2011) mean length based method (i.e., Francis TA1.8 method, Punt in press) as follows:

Observed mean length for year t,

$$\overline{l_t} = \sum_{i=1}^{n} l_{t,i} \times P_{t,i} \tag{1}$$

Predicted mean length for year t,

$$\hat{\bar{l}}_t = \sum_{i=1}^{n} l_{t,i} \times \hat{P}_{t,i} \tag{2}$$

Variance of the predicted mean length in year t,

$$var\left(\hat{\bar{l}}_t\right) = \frac{\sum_{i=1}^{n} \hat{P}_{t,i}\left(l_{t,i} - \hat{\bar{l}}_t\right)^2}{S_t} \tag{3}$$

Francis' reweighting parameter W,

$$W = \frac{1}{var\left\{\frac{\bar{l}_t - \hat{\bar{l}}_t}{\sqrt{var\left(\hat{\bar{l}}_t\right)}}\right\}} \tag{4}$$

where $\widehat{P}_{t,i}$ and $P_{t,i}$ are the estimated and observed proportions of the catch during year t in size-class i, $\hat{\bar{l}}_t$ and $\overline{l_t}$ are predicted and observed mean length of the catch during year t, and W is the reweighting multiplier of stage-1 sample sizes.

We provide the initial input sample sizes and stage-2 effective sample sizes in Tables 4 and 18 for EAG and WAG, respectively. We multiplied the input sample sizes by the estimated W for a number of iterative fittings until the estimated W approached 1.0.

g. Provide the basis for data weighting, including whether the input effective sample sizes are tuned and the survey CV adjusted: Described previously (f).

h. Do parameter estimates make sense? The estimated parameter values are within the bounds and various plots suggest that the parameter values are reasonable for a fixed *M* of 0.23 yr^{-1} for these stocks.

i. Model selection criteria: We used a number of diagnostic criteria to select the base model over alternative 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 (for EAG), and catch and bycatch fits. Figures are provided for the preferred scenarios in the Results section.

j. Residual analysis: We illustrated residual fits by bubble plots for size composition predictions in various figures in the Results section.

k. Model evaluation: Only one model with a number of 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 input effective sample sizes are listed in Tables 4 and 18 and weights for different data sets are provided in Table A2 for various scenarios respectively for EAG and WAG. These weights (with the corresponding coefficient of variations) adequately fitted the length compositions and no further changes were examined.

We used weighting factors for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. We set the retained catch biomass weight to a large value (500) because retained catches are more reliable than any other data sets. We scaled the total catch biomass weight in accordance with the observer annual sample sizes with a maximum of 300. The total catches were derived from observer total CPUE and effort. In some years, observer sample sizes were low (Tables 2 and 16). We chose a small ground fish bycatch weight (0.2) based on the September CPT suggestion to lower its weight. We used the best fit criteria to choose the lower weight for the groundfish bycatch. Groundfish bycatch in the golden king crab fisheries is very minor. We set the CPUE weights to 1 for all scenarios. We included a constant (model estimated) variance in addition to input CPUE variance for the CPUE fit. We used the Burnham et al. (1987) suggested formula for ln(CPUE) [and ln(MMB)] variance estimation (Equation A.16). However, the estimated additional variance values were small for observer CPUE indices, but relatively large for the fish ticket CPUE indices for EAG. But both values are small for WAG (scenario 3). Nevertheless, the CPUE index variances estimated from the negative binomial and lognormal GLMs were adequate to fit the model confirmed by the fit diagnostics (Fox and Weisberg 2011). Parameter estimates are provided in Tables 6 to 8 for EAG and 20 to 22 for WAG for eleven scenarios. The numbers of estimable parameters are listed in Table A1 of Appendix A. The weights with the corresponding coefficient of variations specifications are detailed in Tables A2 of Appendix A for EAG and WAG.

2. Include tables showing differences in likelihood: Tables 14 and 28 list the total and component negative log likelihood values and their differences between scenarios of similar sample sizes for EAG and WAG, respectively.
3. Tables of estimates:
    a. The parameter estimates with one standard deviation for eleven scenarios which included ten preferred scenarios are summarized respectively in Tables 6 to 8 for EAG and 20 to 22 for WAG. We have also provided the boundaries for parameter searches in those tables, and the estimates were within the bounds.
    b. All scenarios considered molt probability parameters in addition to the linear growth increment and normal growth variability parameters to determine the size transition matrix.
    c. The mature male and legal male abundance time series for arbitrarily selected five scenarios (1, 5, 10, 14, and 16) among the ten scenarios are summarized in Tables 9 to 13 for EAG and Tables 23 to 27 for WAG.
    d. The recruitment estimates for those five scenarios are summarized in Tables 9 to 13 for EAG and Tables 23 to 27 for WAG.
    e. The likelihood component values and the total likelihood values for preferred ten scenarios with scenario 9 (iteratively reweighting the effective sample sizes) are summarized in Table 14 for EAG and Table 28 for WAG. Scenarios 10 and 9 have the minima among the total negative log likelihoods for models with base data for EAG and WAG, respectively.
4. Graphs of estimates:
    a. Total selectivity and retention curves of the pre- and post-rationalization periods for eight of the preferred ten scenarios are illustrated in Figure 10 for EAG and Figure 29 for WAG. Total selectivity for the pre-rationalization period was used

in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis, indicating that all size groups were vulnerable to the gear. This is also shown in the size compositions of groundfish bycatch (Figures 8 and 27 for EAG and WAG, respectively). Thus, we set the groundfish bycatch selectivity to 1.0 for all length-classes in the subsequent analysis.

b. The mature male biomass time series for eleven scenarios (preferred 10 plus scenario 9) are depicted in Figures 20 and 37 for EAG and WAG, respectively. Mature male biomass tracked the CPUE trends well for all scenarios for EAG and WAG. The biomass variance was estimated using Burnham et al. (1987) suggested formula (Equation A.16 in Appendix A). We determined the mature male biomass values on 15 February and considered the entire time series (1985/86–2014/15) for MMB_{ref} calculation for Tier 4 approach.

c. The full selection pot fishery F over time for eleven scenarios (preferred 10 plus scenario 9) are shown in Figures 21 and 38 for EAG and WAG, respectively. 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 eleven scenarios (preferred 10 plus scenario 9) are illustrated in Figure 18 for EAG and in Figure 35 for WAG. The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 19 and 36 for EAG and WAG, respectively for the eleven scenarios.

5. Evaluation of the fit to the data:

g. Fits to catches: The fishery retained, total, and groundfish bycatch (observed vs. estimated) plots for eleven scenarios are illustrated in Figures 22 and 39 for EAG and WAG, respectively. All predicted fits were very closer to observed values, especially for retained catch and groundfish bycatch mortality. However, pre 1995 total catch data did not fit well.

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 eleven scenarios are shown in Figure 17 for EAG and Figure 34 for WAG. Scenario 3 tracks indices back to 1985/86. All scenarios appear to fit the CPUE indices satisfactorily. The CPUE variance was estimated using Burnham et al. (1987) suggested formula (Equation A.16 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 14 for EAG and Figure 33 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 15). Note that we used the EAG tagging information for size transition matrix estimation for both stocks (EAG and WAG). The size transition matrices estimated using EAG tagging data in the EAG and WAG models were similar. For illustrative purpose, the estimated size transition matrix elements for the base scenario (scenario 1) are compared between EAG and WAG. The matrix elements appear very similar (Figure 16).

k. Molt probability: The predicted molt probabilities vs. CL for the eleven scenarios are depicted in Figures 24 and 41 for EAG and WAG, respectively. The fits appear to be satisfactory.

l. Fit to catch size compositions: Retained, total, and groundfish discard length compositions are shown in Figures 6 to 8 for EAG and 25 to 27 for WAG. The corresponding observed vs. predicted mean lengths with 95% confidence intervals are depicted in Figures 9 and 28 for EAG and WAG, respectively. The retained and total catch size composition fits appear satisfactory. The predicted mean lengths track the observed mean lengths well; however, the 95% confidence intervals for retained catch and total catch mean lengths appear narrower than that for the groundfish (trawl) mean length; furthermore, pre-1995 confidence intervals for all categories are wider than that of post-1995.

   We illustrate the standardized residual plots as bubble plots of size composition over time for retained catch (Figures 11 and 30 for EAG and WAG, respectively), for total catch (Figures 12 and 31 for EAG and WAG, respectively), and for groundfish discard catch (Figures 13 and 32 for EAG and WAG, respectively) for four selected scenarios (1, 5, 10, 14). The retained catch bubble plots appear random for the selected four scenarios.

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: We did not provide the plots, but provided the estimated values in Tables 4 and 18 for EAG and WAG, respectively.
o. Tables of RMSEs for the indices: We did not provide this table in this report.
p. Quantile-quantile (q-q) plots: We did not provide this plot in this report.

6. Retrospective and historical analysis: The retrospective fits for the ten scenarios are shown in Figure 23 for EAG and in Figure 40 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.
7. Uncertainty and sensitivity analysis:
   a. The main task was to determine a plausible size transition matrix to project the population over time. In a previous study, we investigated the sensitivity of the model to determine the size transition matrix by using or not using a molt probability function (Siddeek et al. 2016). The model fit is better when the molt probability model is included. Therefore, we included a molt probability sub-model for the size transition matrix calculation in all scenarios.
   b. We also determined likelihood values at different *M* values and plotted component negative likelihood against *M*. It appears that the trends in negative log likelihood of retained length frequency, recruitment deviation, and CPUE were similar to that of the total for changes in *M* for EAG (Figure 2). For WAG, the trends in negative likelihood for retained length composition and recruitment deviation were similar to that of the total for changes in *M*, but the minimum negative likelihood of CPUE was attained at a lower *M* value (Figure 2).
8. Conduct 'jitter analysis': We did not conduct the (random) jitter analysis on model parameters. However, we performed a system search on input values within the

bound only for the *M* parameter in the "Response to September 2015 CPT comments" section on page 8. The *M* estimates were robust to different starting *M* values.

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. The Tier 4 calculation procedure is described below:

1. List of parameters and stock size required by the control rule are:
   An average mature male biomass (*MMB*) for a specified time period, MMB_{ref} (a proxy for MMB_{MSY}) current *MMB*; an *M* value; and a γ value.
2. Specification of the total catch OFL:
   (a) if $MMB_{current} \geq MMB_{ref}, F_{OFL} = \gamma M$;
   (b) if $MMB_{current} < MMB_{ref}\ and\ MMB_{current} > 0.25MMB_{ref}$,

$$F_{OFL} = \gamma M \frac{\left(\frac{MMB_{current}}{MMB_{ref}} = \alpha\right)}{(1-\alpha)} \qquad (5)$$

   (c) if $MMB_{current} \leq 0.25MMB_{ref},\ F_{OIFL} = 0$,

where $\text{MMB}_{current}$ is the mature male biomass in the current year, 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 *MMBref* range of 6.231 to 7.157 thousand metric tons for EAG and 4.756 to 8.781 thousand metric tons for WAG for the preferred ten scenarios. The current MMB (in 2015) range was 8.090 to 9.712 thousand metric tons for EAG and 4.967 to 9.642

thousand metric tons for WAG for the ten scenarios, resulting in an F_{OFL} of 0.23 for EAG and slightly less for scenario 2 for WAG. The total OFL for EAG ranged from 1.360 to 1.721 thousand metric tons and for WAG from 0.681 to 1.274 thousand metric tons for the ten scenarios. The γ value was set to 1.0 and an M value of 0.23 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 1.327 to 1.679 thousand metric tons and that for WAG ranged from 0.638 to 1.202 thousand metric tons for the ten scenarios.

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

   We recommend them for scenarios 1, 10, and 16, respectively.

   Scenario 1:

   EAG: F_{OFL} = 0.23; OFL total catch = 1.622 thousand metric tons; retained catch portion of the OFL = 1.583 thousand metric tons.

   WAG: F_{OFL} = 0.23; OFL total catch = 0.926 thousand metric tons; retained catch portion of the OFL = 0.871 thousand metric tons.

   Scenario 10:

   EAG: F_{OFL} = 0.23; OFL total catch = 1.721 thousand metric tons; retained catch portion of the OFL = 1.677 thousand metric tons.

   WAG: F_{OFL} = 0.23; OFL total catch = 1.158 thousand metric tons; retained catch portion of the OFL = 1.089 thousand metric tons.

   Scenario 16:

   EAG: F_{OFL} = 0.23; OFL total catch = 1.603 thousand metric tons; retained catch portion of the OFL = 1.565thousand metric tons.

   WAG: F_{OFL} = 0.23; OFL total catch = 0.913 thousand metric tons; retained catch portion of the OFL = 0.861 thousand metric tons.

G. Calculation of the ABC

Specification of the probability distribution of the total catch OFL:

We estimated the cumulative probability distribution of OFL assuming a log normal distribution of OFL. We calculated the OFL at the 0.5 probability and the ABC at the 0.49 probability. The ABC estimates varied for different scenarios.

Under Tier 4 approach, the ABC estimates calculated at 0.49 probability ranged 1.352 to 1.713 thousand metric tons for EAG and 0.678 to 1.268 thousand metric tons for WAG for the ten scenarios.

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. We estimated M in the model. However, an independent estimate of M is needed for comparison. 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.
5. The Aleutian king crab research foundation has recently initiated crab survey programs in the Aleutian Islands. This program needs to be strengthened and

continued for golden king crab research to address some of the data gap and expand the data sources.

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Table 1. Time series of annual retained catch (number and weight of crabs), estimated total male catch (number and weight of crabs on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crabs) (handling mortality rates of 50% for pot and 80% for trawl gear were applied, only to the male portion) for the EAG golden king crab stock. The crab numbers are for the size range 101–185+ mm CL. 1985 refers to the 1985/86 fishing year. 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	1,251,267	2,695			117,718		
1986	1,374,943	2,818			155,240		
1987	968,614	1,893			146,501		
1988	1,156,046	2,397			155,518		
1989	1,419,777	2,753			155,262	388	0.61
1990	892,699	1,632	1,148,518	2,738	106,281	1,190	1.98
1991	1,083,243	2,018	4,385,096	5,910	133,428	0	0.00
1992	1,127,291	2,115	4,331,508	5,589	133,778	779	1.01
1993	767,918	1,415	NA	NA	106,890	719	0.95
1994	1,086,560	2,029	1,712,658	3,257	191,455	311	0.29
1995	1,150,168	2,211	2,742,782	3,742	177,773	569	0.78
1996	848,045	1,615	1,452,362	2,064	113,460	46	0.04
1997	780,481	1,474	1,788,351	2,555	106,403	76	0.10
1998	740,011	1,407	2,011,777	2,804	83,378	587	0.76
1999	709,332	1,329	1,556,398	2,287	79,129	284	0.35
2000	704,363	1,352	1,706,999	2,564	71,551	387	0.47
2001	730,030	1,394	1,352,904	2,105	62,639	934	1.47
2002	643,668	1,236	1,119,586	1,808	52,042	707	0.68
2003	643,074	1,287	1,111,206	1,825	58,883	392	0.43
2004	637,536	1,261	965,443	1,627	34,848	59	0.12
2005	623,971	1,262	927,444	1,724	24,569	252	0.28
2006	650,587	1,375	860,688	1,632	26,195	679	0.70
2007	633,253	1,316	911,185	1,802	22,653	697	0.69
2008	666,947	1,406	929,694	1,799	24,466	808	0.85
2009	679,886	1,433	936,938	1,761	26,298	718	1.14
2010	670,698	1,398	935,574	1,729	25,851	2,415	2.41
2011	668,828	1,428	920,866	1,747	17,915	1,208	1.15
2012	687,666	1,482	990,519	1,939	20,827	2,058	3.61
2013	720,220	1,529	978,645	1,829	21,388	894	2.04
2014	719,064	1,536	1,012,683	1,951	17,002	1,327	2.31

Table 2. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the EAG golden king crab stock. Observer retained CPUE includes retained and non-retained legal size crabs and 1990 refers to the 1990/91 fishing year.

Year	**Pot Fishery Nominal Retained CPUE**	**Obs. Nominal Retained CPUE**	**Obs. Nominal Total CPUE**	**Obs. Sample Size (no.pot lifts)**	**Obs. CPUE Index**
1990	8.90	2.17	13.00	138	
1991	8.20	17.36	36.91	377	
1992	8.36	10.43	38.52	199	
1993	7.79	5.07	20.82	31	
1994	5.89	2.54	12.91	127	
1995	5.89	5.06	16.98	6,388	0.73
1996	6.45	5.17	13.81	8,360	0.76
1997	7.34	7.13	18.25	4,670	0.79
1998	8.88	9.17	25.77	3,616	0.95
1999	8.96	9.25	20.77	3,851	0.88
2000	9.85	9.92	25.39	5,043	0.91
2001	11.66	11.14	22.48	4,626	1.18
2002	12.37	11.99	22.59	3,980	1.26
2003	10.92	11.02	19.43	3,960	1.11
2004	18.30	17.73	28.48	2,206	1.80
2005	25.40	29.44	38.48	1,193	1.05
2006	24.84	25.20	33.52	1,098	0.84
2007	27.95	31.09	40.37	998	0.98
2008	27.26	29.73	38.18	613	0.95
2009	25.85	26.64	35.89	408	0.79
2010	25.96	26.05	36.76	436	0.80
2011	37.33	38.79	51.69	361	1.16
2012	33.02	38.00	47.74	438	1.12
2013	33.67	35.83	46.16	499	1.08
2014	42.29	46.96	60.00	376	1.37

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 fishing year.

Year	**CPUE Index**	**Standard Error**
1985	1.67	0.08
1986	1.22	0.06
1987	0.96	0.06
1988	1.03	0.05
1989	1.04	0.04
1990	0.83	0.05
1991	0.84	0.05
1992	0.93	0.05
1993	0.90	0.06
1994	0.80	0.05
1995	0.77	0.05
1996	0.83	0.05
1997	1.20	0.06
1998	1.36	0.06

Table 4. The number of length measurements and stage-2 effective sample size iteratively estimated by Francis method for retained, total, and groundfish discard catches of golden king crab during 1985 to 2014 in EAG. NA: not available.

Year	Retained Length Sample Size (no)	Retained Stage-2 Effective Sample Size (no)	Total Length Sample Size (no)	Total Stage-2 Effective Sample Size (no)	Groundfish Length Sample Size (no)	Groundfish Stage-2 Effective Sample Size (no)
1985	2,108	100				
1986	1,226	58				
1987	1,304	62				
1988	13,456	636				
1989	59,054	2,789			107	0.56
1990	22,720	1,073	2,600	5	486	2.54
1991	23,343	1,103	6,654	12	NA	NA
1992	20,629	974	5,469	9	9	0.05
1993	6,254	295	NA	NA	6	0.03
1994	4,666	220	1,235	2	77	0.40
1995	11,514	544	116,305	201	47	0.25
1996	5,889	278	85,021	147	19	0.10
1997	12,775	603	77,565	134	62	0.32
1998	7,960	376	83,374	144	263	1.38
1999	5,820	275	73,728	128	291	1.52
2000	4,907	232	28,334	49	1,682	8.80
2001	4,539	214	35,606	62	606	3.17
2002	4,119	195	24,536	42	945	4.94
2003	3,629	171	22,859	40	699	3.66
2004	3,123	148	19,481	34	132	0.69
2005	2,290	108	12,451	22	1,129	5.91
2006	2,629	124	9,464	16	795	4.16
2007	2,776	131	12,530	22	1,002	5.24
2008	2,542	120	15,715	27	3,515	18.39
2009	2,355	111	13,972	24	385	2.02
2010	2,353	111	15,291	26	1,253	6.55
2011	2,507	118	18,994	33	1,686	8.82
2012	2,926	138	20,648	36	149	0.78
2013	2,605	123	22,819	39	52	0.26
2014	2,075	98	22,365	39	54	0.28

Table 5. Total fished area (square miles) and relative proportion of area fished (relative to the maximum area fished) during 1985/86–2014/15 in EAG.

Year	Fished Area (sq.miles)	Relative Proportion	Year	Fished Area (sq.miles)	Relative Proportion
1985	257,180	0.57	2005	134,060	0.30
1986	281,826	0.63	2006	140,498	0.31
1987	244,721	0.54	2007	164,523	0.37
1988	278,705	0.62	2008	157,924	0.35
1989	450,286	1.00	2009	139,148	0.31
1990	188,461	0.42	2010	155,592	0.35
1991	257,978	0.57	2011	125,924	0.28
1992	234,338	0.52	2012	141,013	0.31
1993	158,490	0.35	2013	147,034	0.33
1994	257,087	0.57	2014	136,227	0.30
1995	280,213	0.62			
1996	269,754	0.60			
1997	263,378	0.58			
1998	166,178	0.37			
1999	176,031	0.39			
2000	171,383	0.38			
2001	144,729	0.32			
2002	138,283	0.31			
2003	120,167	0.27			
2004	87,066	0.19			

Table 6. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 1, 2, 3, and 4 for the golden king crab data from the EAG, 1985/86–2014/15. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**		
Parameter	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Limits
log_ω_1 (growth incr. intercept)	2.54	0.02	2.54	0.02	2.54	0.02	2.54	0.02	1.0, 4.5
ω_2 (growth incr. slope)	-9.30	1.77	-9.20	1.78	-9.37	1.77	-9.59	1.77	-12.0,-5.0
log_a (molt prob. slope)	-2.50	0.07	-2.51	0.07	-2.50	0.07	-2.48	0.07	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.01	4.95	0.01	4.95	0.01	4.95	0.01	3.87,5.05
σ (growth variability std)	3.68	0.10	3.68	0.10	3.67	0.10	3.67	0.10	0.1,12.0
log_total sel deltaθ, 1985-04	3.38	0.13	3.37	0.13	3.37	0.13	3.38	0.13	0.,4.4
log_ total sel deltaθ, 2005-14	3.10	0.19	3.08	0.19	3.10	0.19	3.12	0.19	0.,4.4
log_ ret. sel deltaθ, 1985-14	1.86	0.08	1.85	0.08	1.86	0.08	1.86	0.08	0.,4.4
log_tot sel θ_{50}, 1985-04	4.83	0.02	4.83	0.02	4.83	0.02	4.83	0.02	4.0,5.0
log_tot sel θ_{50}, 2005-14	4.92	0.02	4.92	0.02	4.92	0.02	4.92	0.02	4.0,5.0
log_ret. sel θ_{50}, 1985-14	4.91	0.002	4.91	0.002	4.91	0.002	4.91	0.002	4.0,5.0
log_β_r (rec.distribution par.)	-0.73	0.25	-0.72	0.25	-0.72	0.25	-0.78	0.28	-12.0, 12.0
logq2 (catchability 1985-04)	-0.63	0.11	-0.64	0.11	-0.65	0.09	-0.67	0.12	-9.0, 2.25
logq3 (catchability 2005-14)	-0.96	0.21	-1.01	0.21	-0.97	0.19	-0.96	0.21	-9.0, 2.25
log_newsh1 (N1985)			2.21	0.07					0.01, 10.0
log_mean_rec (mean rec.)	0.90	0.05	0.97	0.06	0.90	0.05	0.91	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.07	0.10	-0.94	0.11	-1.09	0.09	-1.09	0.10	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.51	0.39	-9.53	0.39	-9.51	0.39	-9.51	0.39	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.0, 0.15
σ_e^2 (fishery CPUE additional var)					0.05	0.02			0.0,1.0
2015 MMB	10,124	1,714	10,635	1,909	10,125	1,652	9,802	1,658	

Table 7. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 5, 10, 12, and 14 for the golden king crab data from the EAG, 1985/86–2014/15. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 5		Scenario 10		Scenario 12		Scenario 14		
Parameter	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Limits
log_ω_1 (growth incr. intercept)	2.53	0.02	2.57	0.02	2.54	0.02	2.57	0.02	1.0, 4.5
ω_2 (growth incr. slope)	-9.96	1.78	-7.45	1.88	-9.36	1.77	-7.21	1.98	-12.0, -5.0
log_a (molt prob. slope)	-2.44	0.07	-2.59	0.08	-2.50	0.07	-2.59	0.09	-4.61, -1.39
log_b (molt prob. L50)	4.95	0.01	4.97	0.01	4.95	0.01	4.97	0.01	3.869, 5.05
σ (growth variability std)	3.66	0.10	3.72	0.10	3.67	0.10	3.73	0.11	0.1, 12.0
d1 (incr. dome sel slope 1985–04.)			0.07	0.01			0.07	0.01	0.01,1.0
d2 (decr. dome sel slope 1985–04.)			-0.12	0.01			-0.12	0.01	-1.0,-0.1
d3 (incr. dome sel slope 2005–14.)			0.14	0.03			0.14	0.03	0.01,1.0
d4 (decr. dome sel slope 2005–14.)			-0.11	0.15			-0.15	0.16	-1.0,0.01
log_total sel deltaθ, 1985–04	3.36	0.14			3.37	0.13			0., 4.4
log_ total sel deltaθ, 2005–14	3.11	0.20			3.15	0.19			0., 4.4
log_ ret. sel deltaθ, 1985–14	1.85	0.08	1.91	0.08	1.85	0.08	1.90	0.08	0., 4.4
log_tot sel θ_{50}, 1985–04	4.82	0.02	5.92	72.61	4.83	0.02	5.29	0.31	4.0, 6.0
log_tot sel θ_{50}, 2005–14	4.92	0.03	4.93	0.05	4.93	0.03	4.93	0.03	4.0, 5.3
log_tot sel θ_{95}, 1985–04			4.97	0.03			4.97	0.03	4.9, 5.3
log_tot sel θ_{95}, 2005–14			5.17	0.06			5.17	0.04	-6.0,5.3
log_ret. sel θ_{50}, 1985–-14	4.91	0.002	4.92	0.002	4.91	0.002	4.92	0.002	4.0, 5.0
log_β_r (rec.distribution par.)	-1.00	0.34	-0.63	0.26	-0.73	0.25	-0.62	0.27	-12.0, 12.0
logq2 (catchability 1985–04)	-0.73	0.13	-0.70	0.10	-0.84	0.16	-1.00	0.16	-9.0, 2.25
logq3 (catchability 2005–14)	-0.98	0.22	-1.06	0.18	-1.04	0.22	-1.24	0.19	-9.0, 2.25
log_η (stock mixing parameter)					-0.24	0.14	-0.35	0.15	-9.0, 0.01
log_mean_rec (mean rec.)	0.94	0.05	0.90	0.06	0.87	0.05	0.87	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.12	0.11	-1.10	0.09	-1.01	0.10	-1.02	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.53	0.39	-9.56	0.39	-9.45	0.39	-9.49	0.39	-15.0, -1.6
σ_e^2 (CPUE additional var)	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.0, 0.15
2015 MMB	9,837	1,734	10,410	1,851	8,883	1,587	8,664	1,609	

Table 8 Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 7, 9, and 16 for the golden king crab data from the EAG, 1985/86–2014/15. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 7		**Scenario 9**		**Scenario 16**		
Parameter	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Limits
log_ω_1 (growth incr. intercept)	2.54	0.02	2.54	0.02	2.54	0.02	1.0, 4.5
ω_2 (growth incr. slope)	-9.21	1.82	-8.78	1.75	-8.94	1.79	-12.0, -5.0
log_a (molt prob. slope)	-2.50	0.09	-2.52	0.06	-2.54	0.08	-4.61, -1.39
log_b (molt prob. L50)	4.95	0.01	4.95	0.005	4.95	0.01	3.869, 5.05
σ (growth variability std)	3.68	0.10	3.67	0.10	3.68	0.10	0.1, 12.0
log_total sel deltaθ, 1985–94	3.18	0.21					0., 4.4
log_total sel deltaθ, 1995–04	3.59	0.19					0., 4.4
log_total sel deltaθ, 1985–04			3.37	0.10	3.26	0.12	0., 4.4
log_ total sel deltaθ, 2005–14	3.11	0.19	3.13	0.13	3.10	0.19	0., 4.4
log_ ret. sel deltaθ, 1985–14	1.87	0.08	1.87	0.04	1.89	0.08	0., 4.4
log_tot sel θ_{50}, 1985–94	4.82	0.03					4.0, 5.0
log_tot sel θ_{50}, 1995–04	4.87	0.04					4.0, 5.0
log_tot sel θ_{50}, 1985–04			4.83	0.01	4.85	0.02	4.0, 5.0
log_tot sel θ_{50}, 2005–14	4.93	0.02	4.93	0.01	4.93	0.02	4.0, 5.0
log_ret. sel θ_{50}, 1985–-14	4.91	0.002	4.91	0.001	4.91	0.002	4.0, 5.0
log_β_r (rec.distribution par.)	-0.66	0.26	-1.00	0.21	-0.72	0.26	-12.0, 12.0
Logq1 (catchability 1985–94)	-0.63	10164.00					-9.0, 2.25
logq2 (catchability 1995–04)	-0.40	0.21					-9.0, 2.25
logq2 (catchability 1985–04)			-0.66	0.09	-0.57	0.11	-9.0, 2.25
logq3 (catchability 2005–14)	-0.88	0.21	-0.98	0.16	-0.94	0.21	-9.0, 2.25
log_mean_rec (mean rec.)	0.87	0.05	0.92	0.05	0.90	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.98	0.12	-1.08	0.08	-1.06	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.45	0.39	-9.54	0.39	-9.50	0.39	-15.0, -1.6
σ_e^2 (CPUE additional var)	0.02	0.01	0.02	0.01	0.02	0.01	0.0, 0.15
2015 MMB	9,504	1,651	10,230	1,621	10,165	1,762	

Table 9. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 1 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	1.98			10,126	723
1986	1.47	8,817	526	8,493	496
1987	2.99	6,855	374	6,610	355
1988	4.61	5,828	328	5,686	303
1989	1.52	5,095	328	4,949	289
1990	2.52	4,864	307	4,568	283
1991	4.78	4,784	324	4,637	307
1992	2.13	4,415	373	4,323	343
1993	2.05	5,005	383	4,732	348
1994	3.04	5,370	311	5,180	293
1995	1.51	4,836	282	4,717	268
1996	2.32	4,413	279	4,218	271
1997	3.20	4,165	296	4,049	286
1998	2.48	4,177	321	4,064	311
1999	3.15	4,713	377	4,524	363
2000	2.73	5,235	436	5,078	420
2001	2.08	5,884	495	5,689	477
2002	3.50	6,375	558	6,171	537
2003	2.09	6,669	610	6,532	591
2004	1.57	7,386	713	7,143	682
2005	3.31	7,533	787	7,319	756
2006	2.77	7,145	829	7,019	802
2007	2.67	7,490	929	7,260	889
2008	3.07	7,862	1,022	7,622	981
2009	2.03	8,094	1,093	7,878	1,052
2010	4.10	8,383	1,147	8,124	1,104
2011	4.21	8,349	1,178	8,184	1,143
2012	3.34	9,221	1,350	8,955	1,293
2013	1.55	10,337	1,528	9,999	1,462
2014	1.82	10,826	1,654	10,489	1,590
2015	2.99	10,124	1,714	9,909	1,666

Table 10. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 5 for golden king crab in the EAG. Legal male biomass was estimated on July 1(start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	1.95			10,333	738
1986	1.44	8,934	538	8,626	507
1987	3.05	6,914	383	6,682	364
1988	4.24	5,810	337	5,693	312
1989	1.77	5,048	339	4,925	299
1990	3.04	4,702	329	4,460	303
1991	4.30	4,689	350	4,584	329
1992	2.51	4,565	417	4,472	383
1993	2.10	5,071	449	4,853	408
1994	2.80	5,555	352	5,387	336
1995	1.82	5,049	328	4,945	318
1996	2.20	4,535	330	4,380	328
1997	3.36	4,369	356	4,262	351
1998	2.67	4,337	386	4,258	383
1999	3.49	4,968	466	4,804	459
2000	2.95	5,611	556	5,481	545
2001	2.25	6,480	648	6,299	637
2002	3.06	7,133	744	6,939	728
2003	2.10	7,437	802	7,301	786
2004	2.21	7,886	889	7,679	865
2005	2.79	7,921	970	7,741	942
2006	2.54	7,741	1,033	7,580	1,001
2007	2.25	7,842	1,091	7,637	1,054
2008	3.05	7,921	1,133	7,711	1,097
2009	3.61	7,802	1,165	7,637	1,127
2010	2.65	8,087	1,213	7,901	1,167
2011	3.10	8,819	1,270	8,559	1,222
2012	3.38	9,100	1,321	8,894	1,278
2013	2.80	9,380	1,394	9,170	1,346
2014	2.60	9,768	1,529	9,513	1,475
2015	2.55	9,837	1,734	9,597	1,675

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 10 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	2.20			10,746	976
1986	1.43	9,584	798	9,285	778
1987	2.78	7,702	659	7,462	647
1988	5.03	6,571	578	6,441	563
1989	1.48	5,636	530	5,535	511
1990	2.55	5,415	517	5,159	507
1991	4.78	5,317	515	5,220	514
1992	2.12	4,922	535	4,883	525
1993	2.03	5,446	520	5,252	512
1994	3.12	5,780	449	5,673	457
1995	1.57	5,225	417	5,176	424
1996	2.33	4,795	419	4,663	426
1997	3.29	4,571	434	4,507	439
1998	2.57	4,584	459	4,530	464
1999	3.21	5,140	523	5,021	525
2000	2.84	5,712	592	5,629	594
2001	2.09	6,390	661	6,284	664
2002	3.49	6,921	733	6,806	732
2003	2.05	7,222	786	7,172	786
2004	1.58	7,890	884	7,744	873
2005	3.38	7,984	949	7,861	937
2006	2.83	7,580	987	7,532	977
2007	2.66	7,926	1,097	7,784	1,074
2008	3.07	8,315	1,201	8,171	1,178
2009	2.09	8,535	1,275	8,422	1,254
2010	4.23	8,800	1,336	8,650	1,312
2011	4.05	8,808	1,377	8,743	1,360
2012	3.13	9,719	1,556	9,564	1,521
2013	1.64	10,737	1,713	10,543	1,675
2014	1.94	11,083	1,804	10,903	1,772
2015	2.46	10,410	1,851	10,308	1,827

Table 12. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 14 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	2.26			11,208	1,487
1986	1.42	10,059	1,325	9,777	1,291
1987	2.78	8,171	1,151	7,938	1,117
1988	5.17	6,983	1,005	6,859	972
1989	1.49	5,992	895	5,904	857
1990	2.57	5,772	827	5,530	796
1991	4.84	5,647	780	5,569	764
1992	2.19	5,231	761	5,213	742
1993	2.11	5,758	716	5,591	702
1994	3.15	6,107	635	6,029	638
1995	1.58	5,578	592	5,550	596
1996	2.25	5,149	578	5,038	581
1997	3.13	4,892	571	4,846	573
1998	2.42	4,813	565	4,778	567
1999	2.97	5,223	594	5,133	594
2000	2.56	5,640	635	5,586	636
2001	1.84	6,124	687	6,051	687
2002	3.07	6,444	743	6,364	742
2003	1.87	6,547	790	6,525	788
2004	1.49	6,974	870	6,873	859
2005	3.16	6,950	917	6,866	906
2006	2.44	6,527	940	6,512	929
2007	2.30	6,822	1,015	6,725	994
2008	2.78	7,063	1,101	6,980	1,079
2009	1.92	7,134	1,168	7,085	1,146
2010	3.68	7,312	1,208	7,226	1,185
2011	3.59	7,291	1,231	7,277	1,215
2012	3.02	8,016	1,379	7,939	1,347
2013	1.48	8,865	1,508	8,764	1,471
2014	1.78	9,244	1,563	9,138	1,535
2015	2.38	8,664	1,609	8,628	1,589

Table 13. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 16 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	1.98			10,129	724
1986	1.50	8,877	531	8,511	501
1987	2.94	6,926	386	6,645	365
1988	5.13	5,917	343	5,739	316
1989	1.71	5,199	355	5,021	312
1990	2.44	5,235	363	4,860	329
1991	3.83	5,320	395	5,099	371
1992	2.31	4,956	452	4,795	414
1993	2.21	5,106	435	4,831	395
1994	2.57	5,412	350	5,185	324
1995	1.24	4,909	291	4,725	269
1996	2.60	4,274	263	4,055	254
1997	3.07	3,833	275	3,712	268
1998	2.44	3,932	303	3,773	293
1999	3.22	4,447	356	4,219	342
2000	2.62	4,957	413	4,762	396
2001	2.13	5,641	472	5,396	453
2002	3.57	6,106	531	5,866	511
2003	2.17	6,436	588	6,260	566
2004	1.61	7,217	699	6,928	663
2005	3.32	7,449	781	7,192	746
2006	2.79	7,126	831	6,963	799
2007	2.72	7,486	935	7,216	891
2008	3.08	7,870	1,034	7,586	987
2009	2.01	8,126	1,112	7,861	1,065
2010	4.14	8,415	1,170	8,108	1,121
2011	4.28	8,374	1,203	8,165	1,163
2012	3.35	9,245	1,381	8,923	1,315
2013	1.54	10,378	1,569	9,971	1,493
2014	1.82	10,867	1,704	10,470	1,630
2015	2.45	10,165	1,762	9,909	1,707

Table 14. Negative log-likelihood values of the fits for scenarios (Sc) 1 (equilibrium initial cond.), 2 (exponential formula initial cond.), 3 (added fish ticket CPUE likelihood), 4 (down weight groundfish size composition), 5 (drop groundfish size composition), 7 (three q and total sel.), 9 (stage-2 effective sample size), 10 (dome shaped total selectivity), 12 (area shrinkage), 14 (dome shaped total sel. and area shrinkage), and 16 (restricted time series of total catch and size comp.) for golden king crab in the EAG. Differences in likelihood values are given for scenarios with the same number of data points (base). Likelihood components with zero entry in the entire rows are omitted. Grey highlighted values are minima for scenarios with comparable base number of data points. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 5**	**Sc 7**	**Sc 9**	**Sc 10**	**Sc 12**	**Sc 14**	**Sc16**	**Sc 2 – Sc 1**	**Sc 4 – Sc 1**	**Sc 7 – Sc 1**	**Sc 9 – Sc 1**	**Sc 10 – Sc 1**
Number of free parameters	134	122	135	134	134	137	134	138	135	139	134					
Data	base	base	base+ fishery CPUE	base	base- groundfish length comp	base	base	base	Base+ area	Base + area	Base- pre1996 Total catch & length comp					
Retlencomp	-889.22	-890.22	-889.13	-889.47	-889.26	-889.80	-892.08	-887.75	-888.79	-886.46	-890.25	-1.00	-0.25	-0.59	-2.86	1.47
Totallencomp	-866.78	-866.83	-867.17	-867.69	-868.29	-867.35	-865.16	-868.53	-866.25	-867.93	-731.75	-0.05	-0.91	-0.57	1.62	-1.74
GroundFish discdlencomp	-678.72	-678.71	-678.95	-336.01	0.00	-679.51	-665.38	-684.40	-679.16	-686.15	-679.27	0.01	342.71	-0.78	13.34	-5.68
Observer cpue	-12.59	-12.43	-12.81	-12.94	-13.25	-12.54	-9.19	-12.28	-14.75	-15.65	-11.47	0.16	-0.35	0.05	3.40	0.31
RetdcatchB	8.10	8.11	8.76	7.82	7.59	8.16	8.95	8.45	8.28	8.90	6.02	0.01	-0.28	0.05	0.85	0.34
TotalcatchB	31.77	31.79	32.67	31.18	30.71	32.29	34.55	32.70	31.99	33.46	12.15	0.02	-0.60	0.51	2.77	0.93
GdiscdcatchB	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Rec_dev	7.08	6.11	6.76	5.24	4.07	6.75	10.40	7.39	6.85	7.10	6.91	-0.97	-1.84	-0.33	3.31	0.31
Pot F_dev	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-0.01	0.00	0.00	0.00	0.00
Gbyc_F_dev	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.00	0.00	0.00	0.00	0.00
Tag	2,690.79	2,690.99	2,690.89	2,690.15	2,689.64	2690.86	2,693.07	2,684.31	2,691.06	2,684.19	2689.57	0.20	-0.64	0.07	2.28	-6.48
Fishery cpue	-	-	-1.19	-	-		-	-	-	-						
Total	290.54	288.90	289.94	628.37	961.31	288.97	315.24	279.99	289.34	277.58	402.03	-1.63	337.83	-1.57	24.71	-10.54

Table 15. Time series of annual retained catch (number and weight of crabs), estimated total male catch (number and weight of crabs on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crabs) (handling mortality rates of 50% for pot and 80% for trawl gear were applied, only to the male portion) for the WAG golden king crab stock. The crab numbers are for the size range 101–185+ mm CL. 1985 refers to the 1985/86 fishing year.

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	981,949	2,010			118,563		
1986	2,052,652	4,230			277,780		
1987	1,248,732	2,514			160,229		
1988	1,285,914	2,454			166,409		
1989	1,610,281	3,047			202,541	51	0.08
1990	889,017	1,630	2,753,326	3,691	108,533	374	0.57
1991	747,852	1,355	1,827,434	2,572	101,429	16	0.03
1992	543,541	1,025	1,113,229	1,520	69,443	318	0.43
1993	352,339	665	2,001,547	2,822	127,764	0	0.00
1994	845,058	1,617	3,634,246	4,953	195,138	82	0.12
1995	619,636	1,185	1,567,028	2,132	115,248	628	0.71
1996	652,801	1,231	1,269,315	1,767	99,267	559	1.04
1997	558,446	1,062	1,236,592	1,799	86,811	211	0.37
1998	505,407	931	782,551	1,087	35,975	1,182	1.85
1999	658,377	1,235	1,467,177	2,093	107,040	1,091	1.42
2000	723,794	1,378	1,612,997	2,233	101,239	692	0.80
2001	686,738	1,282	1,503,857	2,138	105,512	303	0.43
2002	664,823	1,214	1,335,068	1,893	78,979	700	0.92
2003	676,633	1,245	1,192,551	1,862	66,236	200	0.31
2004	685,465	1,262	1,249,016	1,880	56,846	699	0.95
2005	639,368	1,230	1,079,095	1,780	30,116	1,798	3.46
2006	523,701	1,048	894,219	1,547	26,870	1,311	2.28
2007	600,595	1,230	965,889	1,609	29,950	943	1.50
2008	587,661	1,208	997,465	1,730	26,200	3,979	6.45
2009	628,332	1,333	900,797	1,676	26,489	2,173	4.31
2010	626,246	1,338	868,127	1,588	29,994	1,056	2.48
2011	616,118	1,332	817,532	1,514	26,326	1,576	2.25
2012	672,916	1,404	1,000,311	1,822	32,716	2,216	3.74
2013	686,883	1,440	1,037,749	1,901	41,835	2,569	3.85
2014	635,312	1,257	935,794	1,591	41,548	1,635	2.46

Table 16. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the WAG golden king crab stock. 1990 refers to the 1990/91 fishing year. Observer retained CPUE includes retained and non-retained legal size crabs.

Year	Pot Fishery Nominal Retained CPUE	Obs. Nominal Retained CPUE	Obs. Nominal Total CPUE	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	6.98	11.83	26.67	340	
1991	7.43	7.78	19.18	857	
1992	5.90	6.39	16.83	690	
1993	4.43	6.54	17.23	174	
1994	4.08	6.71	19.23	1,270	
1995	4.65	4.96	14.28	5,598	1.17
1996	6.07	5.42	13.54	7,194	0.95
1997	6.56	6.52	15.03	3,985	0.96
1998	11.40	9.42	23.09	1,876	1.07
1999	6.32	5.93	14.49	4,523	0.91
2000	6.97	6.40	16.64	4,740	0.85
2001	6.51	5.99	14.66	4,454	0.83
2002	8.42	7.47	17.37	2,509	0.92
2003	10.22	9.29	18.17	3,334	1.16
2004	12.06	11.14	22.45	2,619	1.27
2005	21.23	23.74	35.94	1,365	1.12
2006	19.64	23.96	33.41	1,183	1.03
2007	20.05	21.04	32.46	1,082	0.97
2008	22.43	24.59	38.17	979	1.11
2009	23.72	26.53	34.05	892	1.16
2010	20.88	22.34	29.03	867	1.02
2011	23.40	23.81	31.12	837	1.07
2012	20.57	22.82	30.76	1,109	1.08
2013	16.42	16.95	24.96	1,223	0.77
2014	15.29	15.28	22.67	1,137	0.77

Table 17. 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 – 1998/99 time series of data and used in scenario 3. 1985 refers to the 1985/86 fishing year.

Year	CPUE Index	Standard Error
1985	2.02	0.07
1986	1.72	0.05
1987	1.21	0.05
1988	1.35	0.04
1989	1.14	0.03
1990	0.88	0.04
1991	0.72	0.04
1992	0.72	0.05
1993	0.68	0.06
1994	0.82	0.04
1995	0.88	0.04
1996	0.84	0.04
1997	0.77	0.03
1998	1.05	0.04

Table 18. The number of length measurements and stage-2 effective sample size iteratively estimated by Francis method for retained, total, and groundfish discard catches of golden king crab during 1985 to 2014 in WAG. NA: not available.

Year	Retained Length Sample Size (no)	Retained Stage-2 Effective Sample Size (no)	Total Length Sample Size (no)	Total Stage-2 Effective Sample Size (no)	Groundfish Length Sample Size (no)	Groundfish Stage-2 Effective Sample Size (no)
1985	1,730	5				
1986	1,952	6				
1987	377	1				
1988	61,604	179				
1989	99,433	289			33	2.83
1990	48,582	141	6,907	29	154	13.2
1991	50,886	148	12,165	51	2	0.17
1992	43,491	126	8,401	35	34	2.91
1993	13,343	39	4,630	19	NA	NA
1994	27,068	79	23,668	99	2	0.17
1995	16,956	49	91,652	384	15	1.29
1996	23,385	68	76,743	321	46	3.94
1997	29,437	86	53,100	222	12	1.03
1998	25,304	74	34,535	145	269	23.05
1999	21,387	62	61,770	259	247	21.17
2000	23,956	70	71,869	301	149	12.77
2001	18,583	54	63,707	267	100	8.57
2002	18,937	55	41,863	175	143	12.25
2003	13,810	40	38,578	162	27	2.31
2004	13,295	39	34,832	146	44	3.77
2005	11,675	34	24,111	101	20	1.71
2006	11,631	34	26,988	113	188	16.11
2007	8,272	24	26,643	112	291	24.94
2008	10,530	31	25,190	106	174	14.91
2009	9,690	28	29,909	125	141	12.08
2010	9,818	29	24,817	104	35	3
2011	10,639	31	26,054	109	53	4.54
2012	6,542	19	32,921	138	78	6.68
2013	2,609	8	29,736	125	64	5.48
2014	2,929	9	25,491	107	45	3.86

Table 19. Total fished area (square miles) and relative proportion of area fished (relative to the maximum area fished) during 1985/86–2014/15 in WAG.

Year	Fished Area (sq.miles)	Relative Proportion	Year	Fished Area (sq.miles)	Relative Proportion
1985	35,082	0.60	2008	26,226	0.45
1986	54,680	0.93	2009	29,622	0.51
1987	45,732	0.78	2010	37,396	0.64
1988	55,326	0.94	2011	26,242	0.45
1989	57,678	0.98	2012	30,759	0.52
1990	57,164	0.97	2013	43,957	0.75
1991	51,506	0.88	2014	41,569	0.71
1992	53,059	0.90			
1993	32,066	0.55			
1994	50,503	0.86			
1995	51,717	0.88			
1996	46,477	0.79			
1997	53,534	0.91			
1998	42,970	0.73			
1999	51,592	0.88			
2000	58,644	1.00			
2001	50,478	0.86			
2002	51,968	0.89			
2003	53,717	0.92			
2004	52,812	0.90			
2005	29,039	0.50			
2006	34,008	0.58			
2007	35,811	0.61			

Table 20. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 1, 2, 3, and 4 for the golden king crab data from the WAG, 1985/86–2014/15. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**		
Parameter	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Limits
log_ω_1 (growth incr. intercept)	2.53	0.02	2.53	0.02	2.53	0.02	2.53	0.02	1.0, 3.85
ω_2 (growth incr. slope)	-10.54	1.74	-10.51	1.74	-10.64	1.72	-10.02	1.75	-60.0,-2.0
log_a (molt prob. slope)	-2.46	0.06	-2.47	0.07	-2.45	0.06	-2.48	0.07	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.004	4.95	0.01	4.95	0.004	4.95	0.01	3.869,6.0
σ (growth variability std)	3.66	0.10	3.66	0.10	3.66	0.10	3.67	0.10	0.1,9.0
log_total sel deltaθ, 1985-04	3.27	0.11	3.27	0.11	3.21	0.11	3.26	0.11	0.,4.4
log_ total sel deltaθ, 2005-14	2.87	0.18	2.89	0.18	2.87	0.17	2.97	0.17	0.,4.4
log_ ret. sel deltaθ, 1985-14	1.73	0.06	1.73	0.06	1.72	0.06	1.73	0.06	0.,4.4
log_tot sel θ_{50}, 1985-04	4.83	0.01	4.83	0.01	4.82	0.01	4.83	0.01	3.98,5.1
log_tot sel θ_{50}, 2005-14	4.86	0.01	4.87	0.01	4.86	0.01	4.88	0.02	3.98,5.5
log_ret. sel θ_{50}, 1985-14	4.91	0.002	4.91	0.002	4.91	0.002	4.91	0.002	4.85,4.98
log_β_r (rec.distribution par.)	-0.71	0.30	-0.70	0.30	-0.82	0.28	-0.97	0.29	-12.0, 12.0
logq2 (catchability 1985-04)	-0.37	0.10	-0.36	0.10	-0.38	0.06	-0.30	0.09	-9.0, 2.25
logq3 (catchability 2005-14)	-0.92	0.14	-0.89	0.14	-0.91	0.13	-0.76	0.15	-9.0, 2.25
log_newsh1 (N1985)			2.49	0.12					0.01, 10.0
log_mean_rec (mean rec.)	0.83	0.05	0.76	0.05	0.81	0.05	0.82	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.06	0.08	-0.84	0.08	-1.06	0.07	-0.98	0.08	-9.0, -0.01
log_mean_Fground (GF byc. F)	-8.87	0.38	-8.86	0.38	-8.86	0.38	-8.81	0.38	-15.0, -2.0
σ_e^2 (observer CPUE additional var)	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.0, 0.15
σ_e^2 (fishery CPUE additional var)					0.001	0.003			0.0,1.0
2015 MMB	5,343	999	5,117	962	5,237	941	4,864	877	

Table 21. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 5, 10, 12, and 14 for the golden king crab data from the WAG, 1985/86–2014/15. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 5		**Scenario 10**		**Scenario 12**		**Scenario 14**		
Parameter	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Limits
log_ω_1 (growth incr. intercept)	2.54	0.02	2.58	0.02	2.53	0.02	2.58	0.02	1.0, 3.85
ω_2 (growth incr. slope)	-9.16	1.78	-8.23	1.85	-10.57	1.74	-8.26	1.84	-60.0,-2.0
log_a (molt prob. slope)	-2.51	0.07	-2.55	0.07	-2.46	0.06	-2.55	0.07	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.01	4.98	0.01	4.95	0.004	4.98	0.01	3.869,6.0
σ (growth variability std)	3.68	0.10	3.72	0.10	3.66	0.10	3.72	0.10	0.1,9.0
d1 (incr. dome sel slope 1985-04.)			0.07	0.01			0.07	0.01	0.01,1.0
d2 (decr. dome sel slope 1985-04.)			-0.14	0.01			-0.14	0.01	-1.0,-0.1
d3 (incr. dome sel slope 2005-14.)			0.18	0.02			0.18	0.02	0.01,1.0
d4 (decr. dome sel slope 2005-14.)			-0.05	0.01			-0.05	0.01	-1.0,0.01
log_total sel deltaθ, 1985-04	3.24	0.10			3.27	0.11			0., 4.4
log_ total sel deltaθ, 2005-14	3.06	0.15			2.88	0.18			0., 4.4
log_ ret. sel deltaθ, 1985-14	1.73	0.06	1.81	0.06	1.73	0.06	1.81	0.06	0., 4.4
log_tot sel θ_{50}, 1985-04	4.84	0.01	5.22	0.11	4.83	0.01	5.21	0.11	3.98, 5.3
log_tot sel θ_{50}, 2005-14	4.90	0.02	4.93	0.02	4.87	0.01	4.93	0.02	3.98, 5.5
log_tot sel θ_{95}, 1985-04			4.96	0.02			4.96	0.02	4.9, 5.2
log_tot sel θ_{95}, 2005-14			-5.71	870.52			-5.71	849.52	-6.0,5.2
log_ret. sel θ_{50}, 1985-14	4.91	0.002	4.92	0.002	4.91	0.002	4.92	0.002	4.85, 4.98
log_β_r (rec.distribution par.)	-1.28	0.27	-0.56	0.31	-0.68	0.31	-0.54	0.31	-12.0, 12.0
logq2 (catchability 1985-04)	-0.22	0.09	-0.70	0.15	-0.42	0.10	-0.74	0.15	-9.0, 2.25
logq3 (catchability 2005-14)	-0.55	0.16	-1.07	0.16	-1.17	0.23	-1.34	0.22	-9.0, 2.25
log_η (stock mixing parameter)					-0.41	0.27	-0.43	0.24	-9.0, 0.01
log_mean_rec (mean rec.)	0.80	0.05	0.97	0.09	0.84	0.05	0.98	0.09	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.88	0.08	-1.19	0.11	-1.07	0.08	-1.19	0.11	-9.0, -0.01
log_mean_Fground (GF byc. F)	-8.76	0.38	-9.26	0.41	-8.88	0.38	-9.27	0.41	-15.0, -2.0
σ_e^2 (CPUE additional var)	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.0, 0.15
2015 MMB	4,287	742	8,920	2,263	5,932	1,125	9,638	2,353	

Table 22. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 7, 9, and 16 for the golden king crab data from the WAG, 1985/86–2014/15. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 7		**Scenario 9**		**Scenario 16**		
Parameter	Estimate	Std Dev	Estimate	Std Dev	Estimate	Std Dev	Limits
log_ω_1 (growth incr. intercept)	2.54	0.02	2.52	0.02	2.53	0.02	1.0, 3.85
ω_2 (growth incr. slope)	-11.39	1.69	-11.46	1.72	-10.01	1.76	-60.0,-2.0
log_a (molt prob. slope)	-2.35	0.06	-2.45	0.06	-2.51	0.07	-4.61, -1.39
log_b (molt prob. L50)	4.96	0.004	4.94	0.005	4.95	0.005	3.869, 6.0
σ (growth variability std)	3.64	0.10	3.66	0.10	3.66	0.10	0.1, 9.0
log_total sel deltaθ, 1985–94	3.47	0.55					0., 4.4
log_total sel deltaθ, 1995–04	3.36	0.13					0., 4.4
log_total sel deltaθ, 1985–04			3.52	0.09	3.22	0.10	0., 4.4
log_ total sel deltaθ, 2005–14	2.87	0.18	2.85	0.10	2.95	0.17	0., 4.4
log_ ret. sel deltaθ, 1985–14	1.70	0.06	1.72	0.08	1.73	0.07	0., 4.4
log_tot sel θ_{50}, 1985–94	4.57	0.14					3.98, 5.1
log_tot sel θ_{50}, 1995–04	4.87	0.02					3.98,5.1
log_tot sel θ_{50}, 1985–04			4.85	0.02	4.86	0.01	3.98,5.1
log_tot sel θ_{50}, 2005–14	4.86	0.01	4.88	0.01	4.87	0.02	3.98,5.5
log_ret. sel θ_{50}, 1985-–14	4.91	0.002	4.91	0.002	4.91	0.002	4.85,4.98
log_β_r (rec.distribution par.)	-0.70	0.28	-0.60	0.18	-0.72	0.32	-12.0, 12.0
Logq1 (catchability 1985–94)	-1.09	11141.00					-9.0, 2.25
logq2 (catchability 1995–04)	-0.09	0.14					-9.0, 2.25
logq2 (catchability 1985–04)			-0.21	0.10	-0.26	0.10	-9.0, 2.25
logq3 (catchability 2005–14)	-0.87	0.14	-0.67	0.13	-0.91	0.15	-9.0, 2.25
log_mean_rec (mean rec.)	0.81	0.05	0.81	0.05	0.83	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.01	0.08	-0.89	0.08	-1.04	0.08	-9.0, -0.01
log_mean_Fground (GF byc. F)	-8.77	0.38	-8.76	0.38	-8.88	0.39	-15.0, -2.0
σ_e^2 (CPUE additional var)	0.02	0.01	0.02	0.01	0.02	0.01	0.0, 0.15
2015 MMB	5,020	978	4,248	793	5,409	1,036	

Table 23. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	3.12			10,812	899
1986	3.80	10,166	667	9,835	612
1987	2.67	7,041	443	6,797	389
1988	2.42	6,433	367	6,160	319
1989	2.47	5,538	272	5,323	242
1990	1.69	3,712	235	3,555	206
1991	1.66	3,454	212	3,294	194
1992	1.34	3,178	222	3,056	206
1993	3.80	3,174	224	3,060	208
1994	1.54	3,530	221	3,494	199
1995	1.86	3,658	206	3,452	189
1996	2.23	3,715	216	3,580	203
1997	1.44	3,708	250	3,602	229
1998	1.90	3,929	239	3,780	224
1999	2.54	4,056	243	3,949	229
2000	2.65	3,885	259	3,783	246
2001	2.62	4,077	316	3,937	298
2002	3.28	4,566	399	4,405	376
2003	2.39	5,213	493	5,062	468
2004	3.11	6,096	629	5,882	592
2005	2.75	6,584	720	6,413	684
2006	2.27	7,211	796	6,997	757
2007	3.67	7,825	831	7,592	793
2008	0.97	7,991	848	7,813	810
2009	1.68	8,584	852	8,260	813
2010	1.64	7,828	819	7,637	788
2011	2.08	7,036	774	6,854	743
2012	1.95	6,356	738	6,181	708
2013	2.07	5,876	754	5,683	722
2014	1.82	5,453	833	5,274	800
2015	2.29	5,343	999	5,163	957

Table 24. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 5 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	3.18			10,562	903
1986	3.77	10,009	687	9,663	624
1987	2.69	6,928	444	6,656	381
1988	1.87	6,355	368	6,044	315
1989	2.98	5,460	259	5,197	230
1990	1.69	3,383	224	3,244	195
1991	1.38	3,330	211	3,125	186
1992	1.85	3,115	215	2,956	197
1993	3.52	3,001	224	2,900	204
1994	1.59	3,494	221	3,419	195
1995	1.70	3,591	199	3,352	179
1996	2.20	3,616	197	3,456	184
1997	1.26	3,497	204	3,382	190
1998	2.00	3,688	207	3,517	195
1999	2.21	3,703	207	3,599	194
2000	2.35	3,532	209	3,406	196
2001	2.47	3,537	236	3,389	220
2002	2.50	3,818	278	3,657	259
2003	2.40	4,298	322	4,124	302
2004	2.40	4,781	391	4,597	365
2005	2.36	5,166	468	4,982	439
2006	2.47	5,476	550	5,285	517
2007	2.29	5,913	614	5,723	578
2008	1.67	6,188	632	5,980	599
2009	1.91	6,324	618	6,103	589
2010	1.90	5,955	595	5,784	568
2011	1.55	5,644	565	5,470	538
2012	1.94	5,362	537	5,175	512
2013	1.82	4,809	536	4,661	510
2014	2.12	4,415	581	4,253	554
2015	2.23	4,287	742	4,137	702

Table 25. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 10 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	4.98			13,550	1,786
1986	3.17	12,847	1,586	12,780	1,559
1987	3.37	10,246	1,285	10,080	1,272
1988	2.67	9,167	1,150	9,089	1,138
1989	2.99	8,122	1,044	8,054	1,038
1990	2.11	6,150	986	6,100	981
1991	1.85	5,877	994	5,836	995
1992	1.51	5,623	1,013	5,613	1,018
1993	4.44	5,536	996	5,540	1,005
1994	2.13	5,836	982	5,954	999
1995	2.48	6,147	1,075	6,124	1,093
1996	2.63	6,449	1,166	6,502	1,193
1997	1.96	6,694	1,252	6,764	1,280
1998	2.28	7,039	1,330	7,080	1,357
1999	3.21	7,285	1,375	7,347	1,400
2000	3.26	7,190	1,430	7,254	1,455
2001	3.17	7,553	1,556	7,595	1,581
2002	3.71	8,210	1,718	8,263	1,746
2003	2.68	8,982	1,871	9,073	1,906
2004	3.62	9,883	2,037	9,940	2,066
2005	3.31	10,309	2,124	10,411	2,156
2006	2.68	10,952	2,247	11,025	2,270
2007	4.34	11,648	2,337	11,702	2,356
2008	1.25	11,862	2,378	11,972	2,398
2009	2.11	12,549	2,437	12,514	2,444
2010	2.02	11,728	2,357	11,755	2,361
2011	2.42	10,855	2,253	10,829	2,244
2012	2.36	10,071	2,158	10,024	2,144
2013	2.70	9,461	2,121	9,401	2,105
2014	2.39	8,963	2,137	8,929	2,129
2015	2.64	8,920	2,263	8,892	2,257

Table 26. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 14 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	4.98			13,673	1,801
1986	3.18	12,847	1,586	12,894	1,572
1987	3.38	10,246	1,285	10,181	1,286
1988	2.67	9,167	1,150	9,181	1,150
1989	3.00	8,122	1,044	8,139	1,051
1990	2.12	6,150	986	6,180	994
1991	1.85	5,877	994	5,915	1,009
1992	1.52	5,623	1,013	5,695	1,033
1993	4.50	5,536	996	5,621	1,020
1994	2.07	5,836	982	6,043	1,014
1995	2.50	6,147	1,075	6,230	1,110
1996	2.57	6,449	1,166	6,583	1,205
1997	1.96	6,694	1,252	6,826	1,287
1998	2.27	7,039	1,330	7,103	1,358
1999	3.11	7,285	1,375	7,350	1,396
2000	3.18	7,190	1,430	7,235	1,444
2001	3.14	7,553	1,556	7,514	1,557
2002	3.62	8,210	1,718	8,122	1,709
2003	2.65	8,982	1,871	8,896	1,852
2004	3.64	9,883	2,037	9,724	1,993
2005	3.27	10,309	2,124	10,185	2,070
2006	2.58	10,952	2,247	10,823	2,187
2007	4.50	11,648	2,337	11,503	2,289
2008	1.28	11,862	2,378	11,769	2,346
2009	2.16	12,549	2,437	12,407	2,408
2010	2.19	11,728	2,357	11,731	2,336
2011	2.73	10,855	2,253	10,888	2,229
2012	2.55	10,071	2,158	10,233	2,144
2013	2.92	9,461	2,121	9,828	2,138
2014	2.46	8,963	2,137	9,533	2,197
2015	2.67	8,920	2,263	9,629	2,354

Table 27. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for scenario 16 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) and mature male biomass for fishing year y was estimated on February 15, fishing year y+1 after the fishing year y fishery total catch removal. 1985 refers to the 1985/86 fishing year. Recruits estimates for 1961 to 2015 are restricted to 1985–2015.

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	3.18			10,799	896
1986	3.82	10,270	671	9,853	614
1987	2.67	7,200	459	6,863	396
1988	2.64	6,631	381	6,259	328
1989	2.33	5,776	298	5,477	261
1990	1.68	4,080	274	3,831	238
1991	2.16	3,842	258	3,613	233
1992	1.32	3,610	269	3,440	242
1993	1.92	3,826	241	3,627	221
1994	2.03	4,106	219	3,958	200
1995	1.93	3,471	196	3,310	178
1996	2.20	3,422	193	3,243	180
1997	1.38	3,481	237	3,308	207
1998	1.91	3,707	217	3,501	199
1999	2.50	3,822	218	3,670	203
2000	2.64	3,650	233	3,497	218
2001	2.67	3,823	291	3,626	271
2002	3.42	4,314	382	4,088	355
2003	2.69	5,004	492	4,779	462
2004	3.14	5,997	660	5,698	612
2005	2.71	6,682	771	6,409	723
2006	2.33	7,381	845	7,073	798
2007	3.68	7,974	877	7,663	832
2008	0.97	8,138	891	7,878	847
2009	1.66	8,696	891	8,290	846
2010	1.64	7,927	855	7,675	819
2011	2.14	7,104	805	6,875	771
2012	1.98	6,406	767	6,183	733
2013	2.11	5,934	786	5,683	747
2014	1.83	5,516	868	5,277	827
2015	2.30	5,409	1,036	5,168	982

Table 28. Negative log-likelihood values of the fits for scenarios (Sc) 1 (equilibrium initial cond.), 2 (exponential formula initial cond.), 3 (added fish ticket CPUE likelihood), 4 (down weight groundfish size composition), 5 (drop groundfish size composition), 7 (three q and total sel.), 9 (stage-2 effective sample size), 10 (dome shaped total selectivity), 12 (area shrinkage), 14 (dome shaped total sel. and area shrinkage), and 16 (restricted time series of total catch and size comp.) for golden king crab in the WAG. Differences in likelihood values are given for scenarios with the same number of data points (base). Likelihood components with zero entry in the entire rows are omitted. Grey highlighted values are minima for scenarios with comparable base number of data points. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 5**	**Sc 7**	**Sc 9**	**Sc 10**	**Sc 12**	**Sc 14**	**Sc16**	**Sc 2 – Sc 1**	**Sc 4 – Sc 1**	**Sc 7 – Sc 1**	**Sc 9 – Sc 1**	**Sc 10 – Sc 1**
Number of free parameters	134	122	135	134	134	137	134	138	135	139	134					
Data	base	base	base+ fishery CPUE	base	base- groundfish length comp	base	base	base	Base + area	Base + area	Base- pre1995 Total catch & length comp					
Retlencomp	-1,004.70	-1,004.56	-1,002.28	-1,006.78	-1,007.14	-1013.77	-847.09	-1,010.79	-1,004.59	-1,010.61	-1019.70	0.14	-2.08	-9.07	157.62	-6.09
Totallencomp	-984.67	-984.68	-982.21	-985.23	-984.78	-984.72	-1237.43	-990.65	-984.62	-990.22	-834.34	-0.01	-0.57	-0.05	-252.76	-5.99
GroundFish discdlencomp	-586.66	-586.37	-587.32	-287.78	0.00	-586.85	-562.34	-591.73	-585.80	-590.69	-587.28	0.28	298.88	-0.19	24.32	-5.07
Observer cpue	-9.43	-9.75	-10.23	-13.07	-17.01	-8.66	-9.26	-10.30	-11.47	-13.57	-8.49	-0.31	-3.63	0.78	0.17	-0.87
RetdcatchB	10.74	10.73	11.35	10.80	11.11	7.04	12.04	11.68	10.81	11.79	6.51	-0.01	0.06	-3.70	1.30	0.94
TotalcatchB	49.13	49.19	50.01	48.83	49.21	28.73	52.48	47.61	49.33	47.83	16.22	0.06	-0.30	-20.40	3.35	-1.53
GdiscdcatchB	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Rec_dev	6.66	5.91	7.62	5.18	4.62	7.43	5.27	6.11	6.38	5.90	6.10	-0.75	-1.48	0.77	-1.39	-0.55
Pot F_dev	0.03	0.01	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.03	-0.02	0.00	0.00	0.00	-0.01
Gbyc_F_dev	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Tag	2,688.94	2,689.02	2,689.23	2,688.89	2,689.18	2695.16	2,689.91	2,687.12	2,688.95	2,687.21	2687.35	0.08	-0.05	6.22	0.97	-1.82
Fishery cpue	-	-	-21.20	-	-		-	-	-	-						
Total	170.15	169.60	155.11	460.98	745.34	144.51	103.72	149.17	169.12	147.78	266.49	-0.55	290.83	-25.65	-66.44	-20.98

Table 29. Predicted total and retained catch OFL (t) under Tier 4 assumption for various scenarios for EAG and WAG, respectively. Sc = scenario; F_{max} = estimated maximum instantaneous total pot fishery mortality during 1985/86–2014/15; MMB_{2015} or MMB_{1986} / $MMB_{initial}$ = ratio of terminal MMB or 1986 MMB relative to initial MMB (= MMB_{1961} for equilibrium condition or MMB_{1986} for exponential initial condition); and LF=length composition.

	EAG					WAG						
Sc	**Total Catch OFL (t)**	**Retained Catch OFL (t)**	**F_{max} yr^{-1}**	**MMB_{2015} / $MMB_{initial}$**	**MMB_{1986} / $MMB_{initial}$**	**Total Catch OFL (t)**	**Retained Catch OFL (t)**	**F_{max} yr^{-1}**	**MMB_{2015} / $MMB_{initial}$**	**MMB_{1986} / $MMB_{initial}$**	**M yr^{-1}**	**Remarks**
1	1,622	1,583	1.02	0.53	0.51	926	871	1.25	0.39	0.71	0.23	Equilibrium initial condition, asymptotic selectivity
2	1,720	1,679	1.02	1.07	1.00	870	819	1.25	0.61	1.00	0.23	Exponential initial condition, asymptotic selectivity
3	1,627	1,588	0.99	0.53	0.50	911	858	1.16	0.38	0.63	0.23	Equilibrium initial condition, asymptotic selectivity, fish ticket CPUE
4	1,562	1,519	1.02	0.53	0.51	815	767	1.28	0.38	0.73	0.23	Equilibrium initial condition, asymptotic selectivity, down weighted groundfish bycatch LF.
5	1,567	1,515	1.01	0.55	0.51	681	638	1.31	0.38	0.76	0.23	Equilibrium initial condition, asymptotic selectivity, removed groundfish bycatch LF.
6	1,692	1,634	1.01	1.11	1.00	693	650	1.35	0.44	1.00	0.23	Exponential initial condition, asymptotic selectivity, removed groundfish bycatch LF.
7	1,510	1,474	0.97	0.52	0.52	900	848	1.02	0.38	0.72	0.23	Equilibrium initial condition, three catchability and asymptotic total selectivity.
8	1,159	1,132	1.07	0.44	0.43	660	622	1.32	0.32	0.59	0.18	Equilibrium initial condition, asymptotic selectivity
9	1,596	1,567	1.01	0.57	0.49	702	661	1.35	0.32	0.78	0.23	Equilibrium initial condition, asymptotic selectivity, iterative effective sample sizes.
10	1,721	1,677	1.00	0.52	0.53	1,158	1,089	1.15	0.48	0.69	0.23	Equilibrium initial condition, dome shaped selectivity.
11	1,202	1,172	1.06	0.43	0.44	684	644	1.28	0.33	0.56	0.18	Equilibrium initial condition, dome shaped selectivity.
12	1,360	1,327	1.00	0.50	0.54	1,022	965	1.25	0.42	0.69	0.23	Equilibrium initial condition, asymptotic selectivity, fishing area shrinkage proportion used for CPUE prediction.
13	936	913	1.05	0.41	0.45	740	699	1.31	0.34	0.58	0.18	Equilibrium initial condition, asymptotic selectivity, fishing area shrinkage proportion used for CPUE prediction.
14	1,406	1,369	0.99	0.49	0.61	1,274	1,202	1.14	0.51	0.69	0.23	Equilibrium initial condition, dome shaped selectivity, fishing area shrinkage proportion used for CPUE prediction.
15	964	939	1.05	0.39	0.48	766	723	1.28	0.51	0.69	0.18	Equilibrium initial condition, dome shaped selectivity, fishing area shrinkage proportion used for CPUE prediction.
16	1,603	1,565	0.99	0.53	0.51	913	861	1.21	0.39	0.71	0.23	Equilibrium initial condition, asymptotic selectivity, total LF and total catch time series restricted to 1996/97–2014/15 for EAG or 1995/96–2014/15 for WAG.

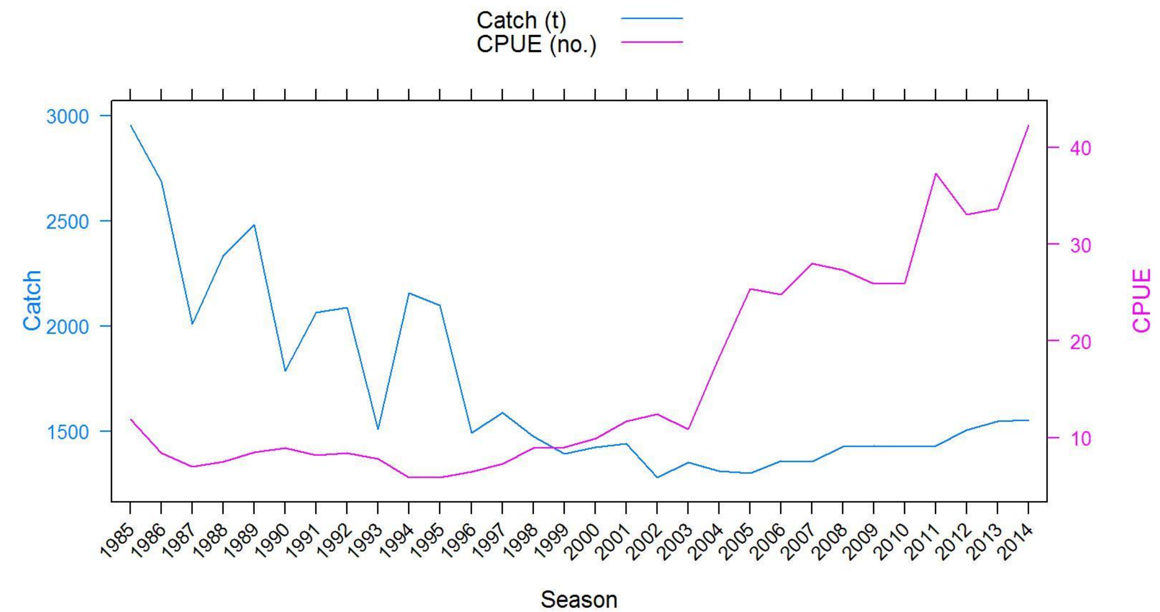


Figure 3. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2014/15 fisheries (note: 1985 refers to the 1985/86 fishing year).

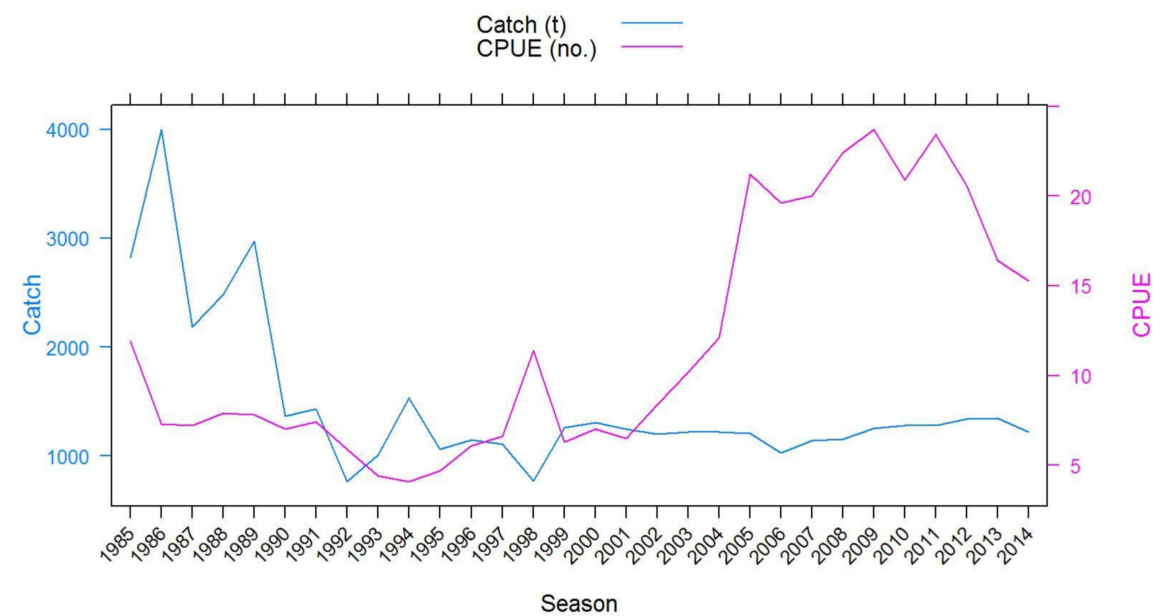


Figure 4. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2014/15 fisheries (note: 1985 refers to the 1985/86 fishing year).

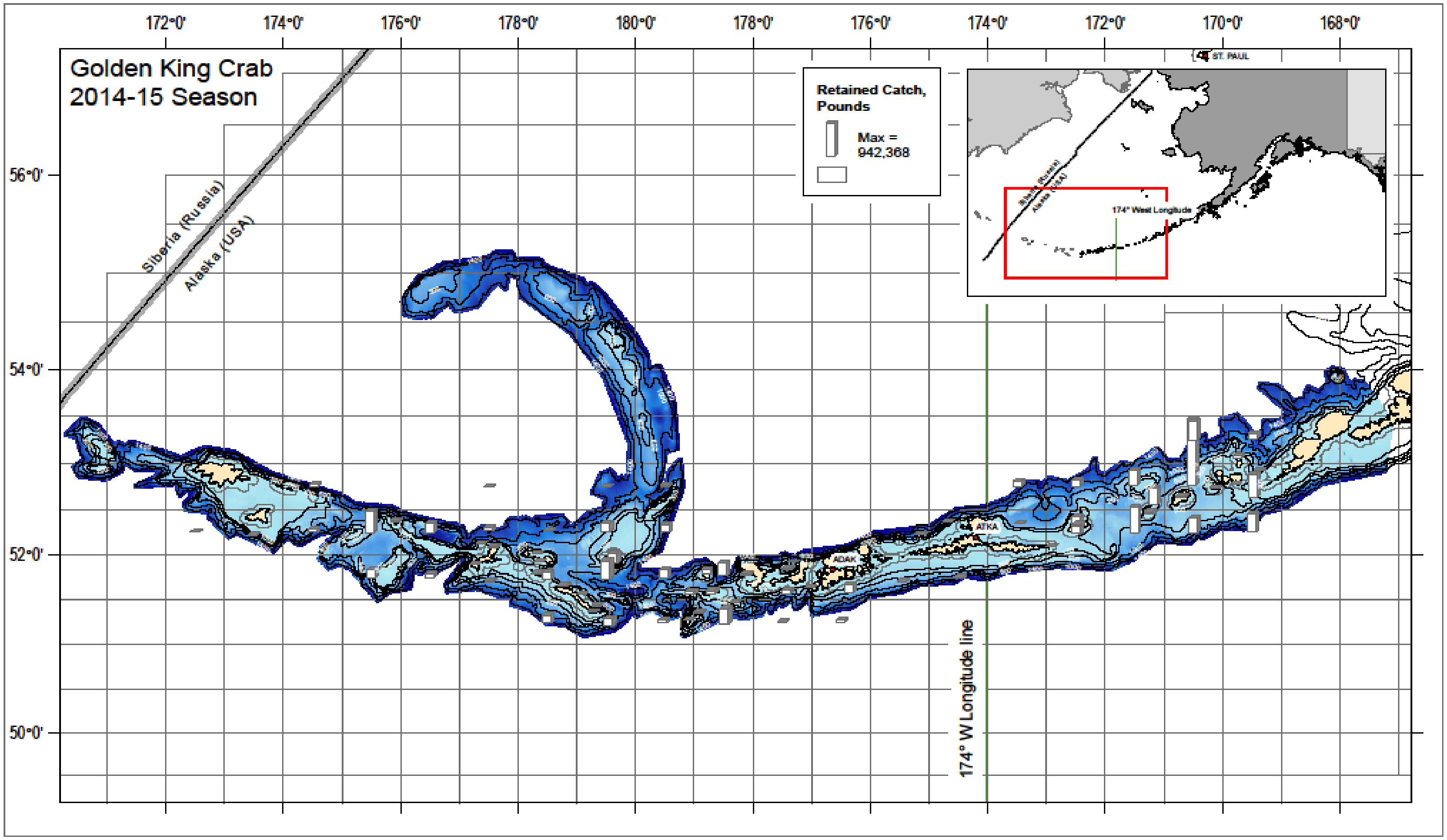


Figure 5. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2014/15.

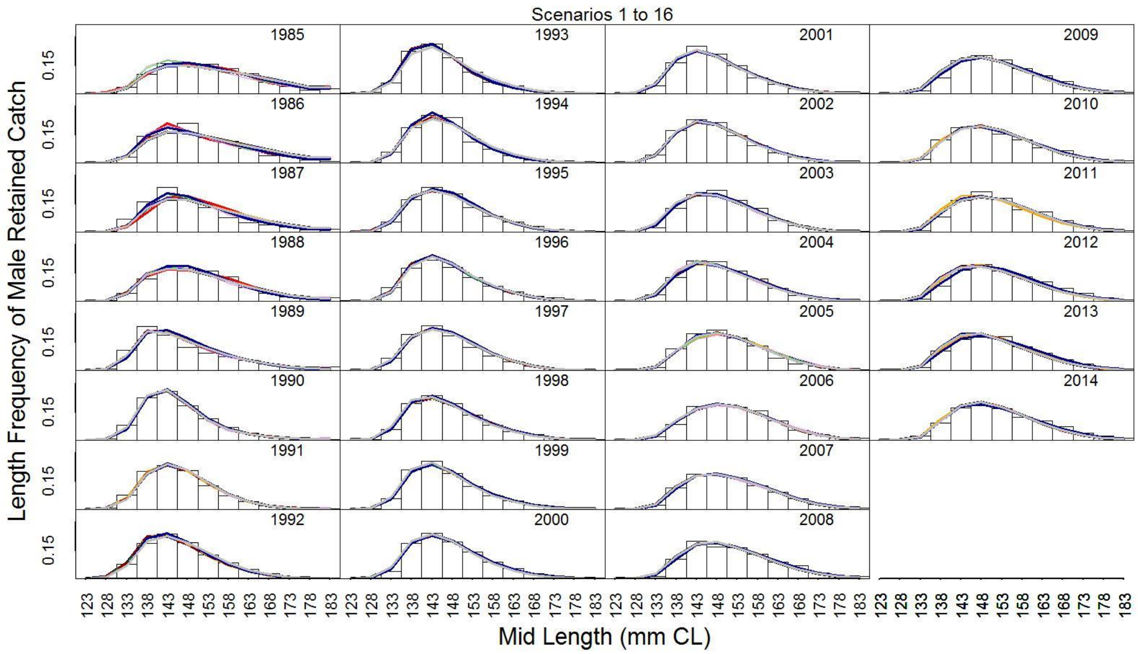


Figure 6. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (yellow line), 5 (orange line), 7 (dark red dashed line), 9 (dark blue line), 10 (green line), 12 (dark green line), 14 (violet line), and 16 (gray line) data of golden king crab in the EAG, 1985/86 to 2014/15.

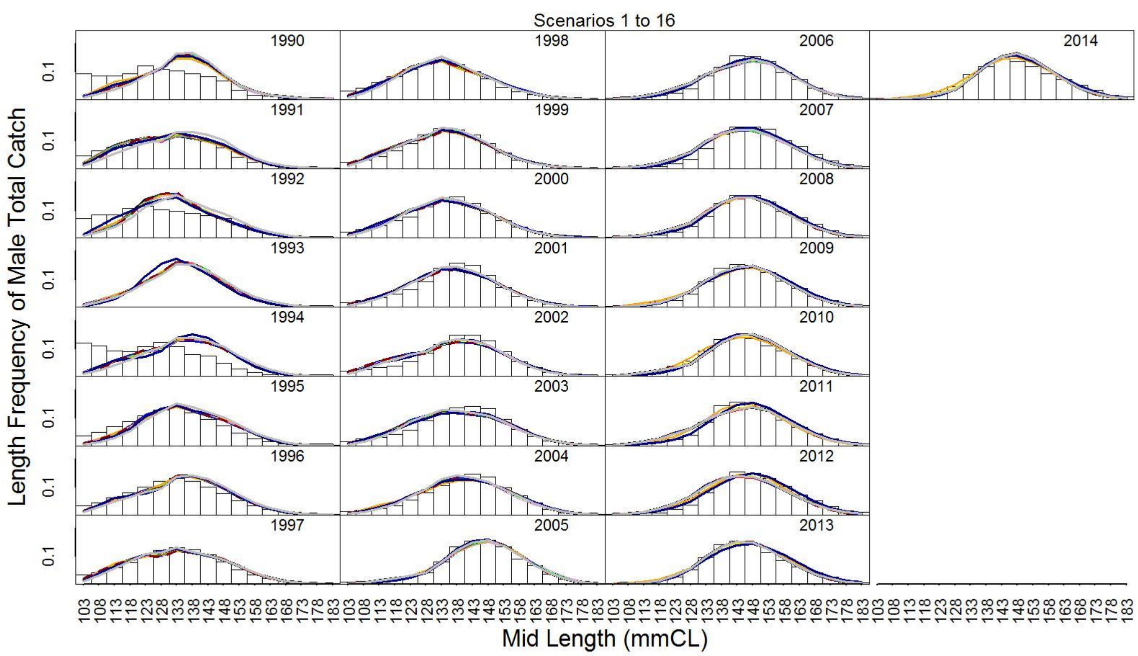


Figure 7. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (yellow line), 5 (orange line), 7 (dark red dashed line), 9 (dark blue line), 10 (green line), 12 (dark green line), 14 (violet line), and 16 (gray line) data of golden king crab in the EAG, 1990/91 to 2014/15.

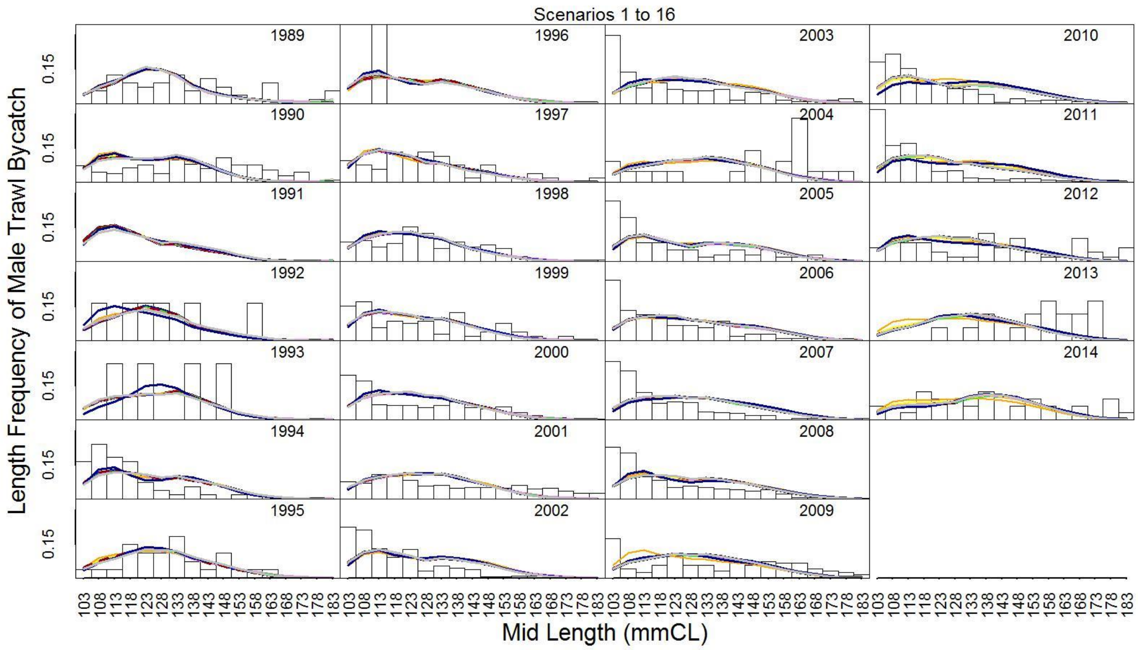


Figure 8. Predicted (line) vs. observed (bar) groundfish (trawl) discarded catch relative length frequency distributions for scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (yellow line), 5 (orange line), 7 (dark red dashed line), 9 (dark blue line), 10 (green line), 12 (dark green line), 14 (violet line), and 16 (gray line) data of golden king crab in the EAG, 1989/90 to 2014/15.

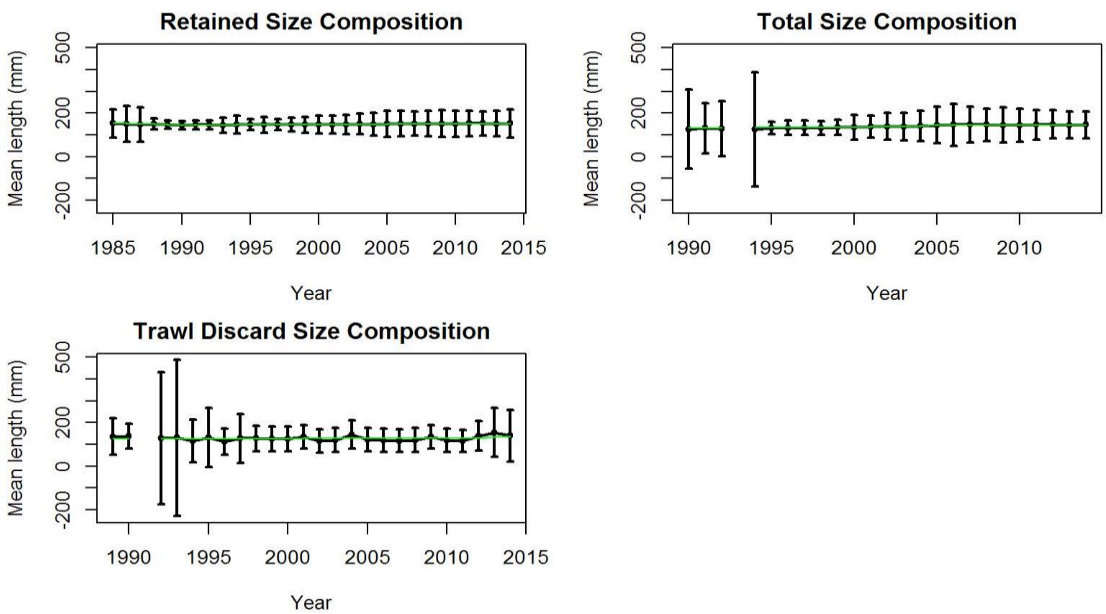


Figure 9. Predicted (green line) vs. observed (black line) mean lengths (with +/- 1.96 SE) of retained (top right), total (top left), and groundfish (trawl) discarded (bottom right) catch compositions for scenario 1 data of golden king crab in the EAG, 1985/86 to 2014/15.

Note: $\overline{l_t} = \sum_{i=1}^{n} l_{t,i} \times P_{t,i}$ and $SE^2 = \sum_{i=1}^{n} l_{t,i}^2 \times Var(P_{t,i})$, where $\overline{l_t}$ is the mean mid length for year *t*; $P_{t,i}$ is the proportion of ith size-class in year *t*; *SE* is the standard error; *n* is the number of length classes; and $Var\,(P_{t,i})$ is computed using Equation A.20.

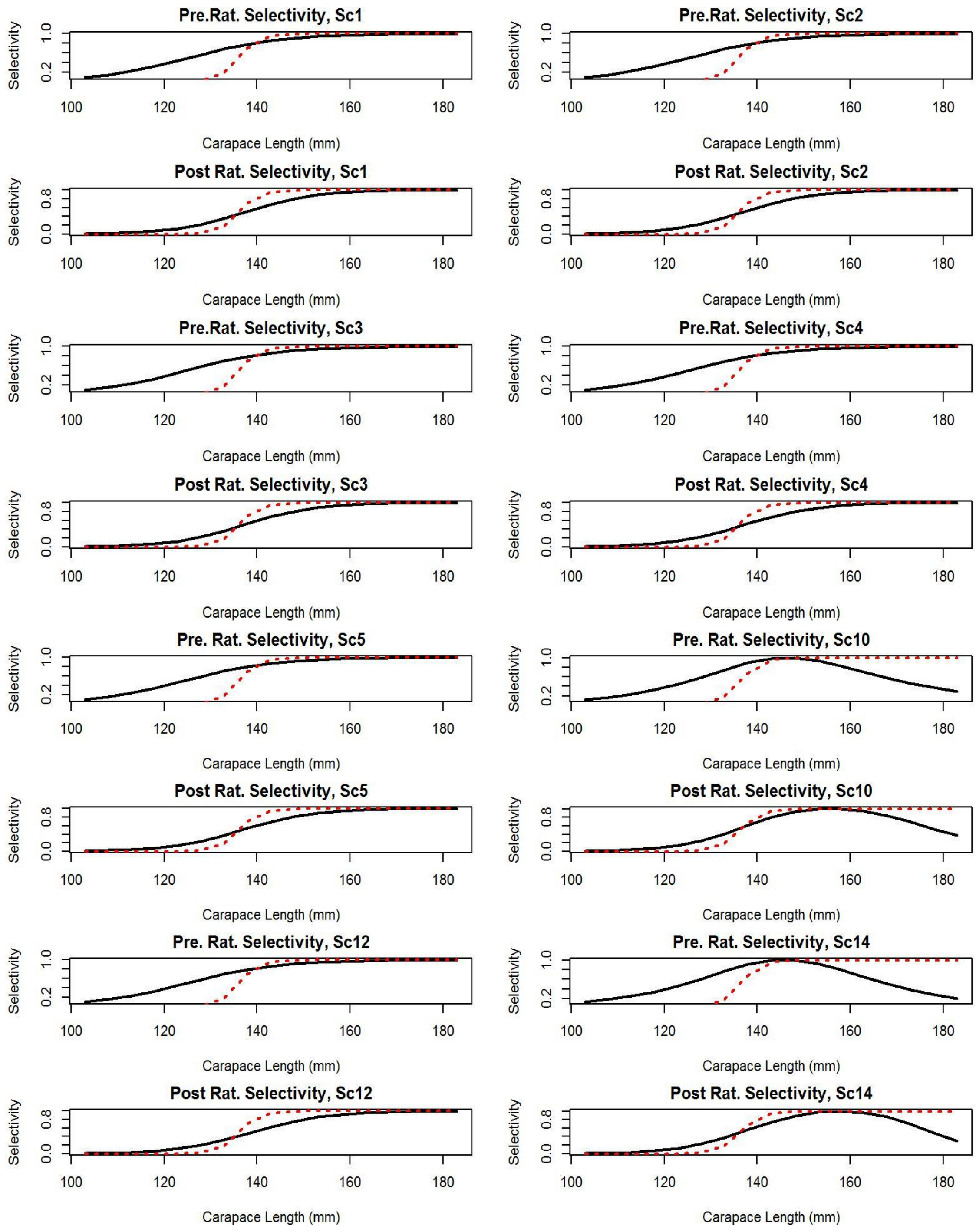
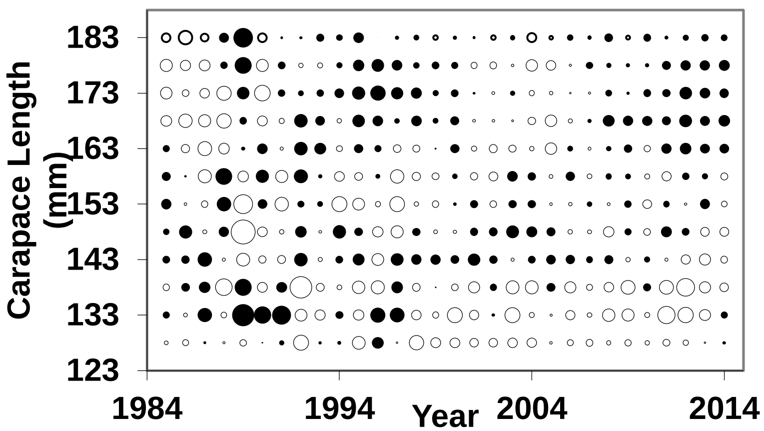
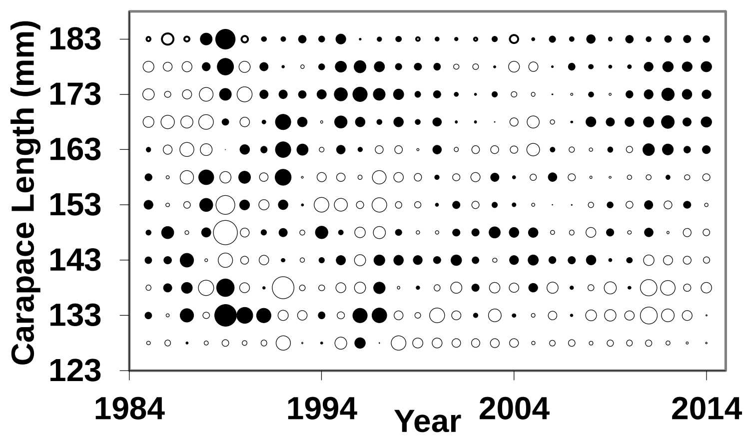


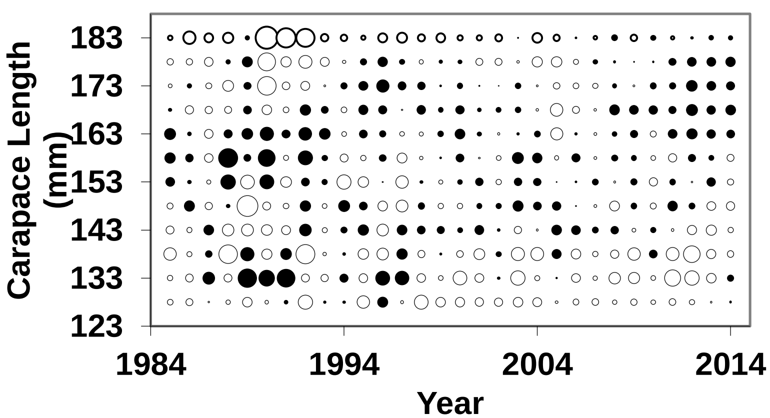
Figure 10. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 1, 2, 3, 4, 5, 10, 12, and 14 fits of EAG golden king crab data.



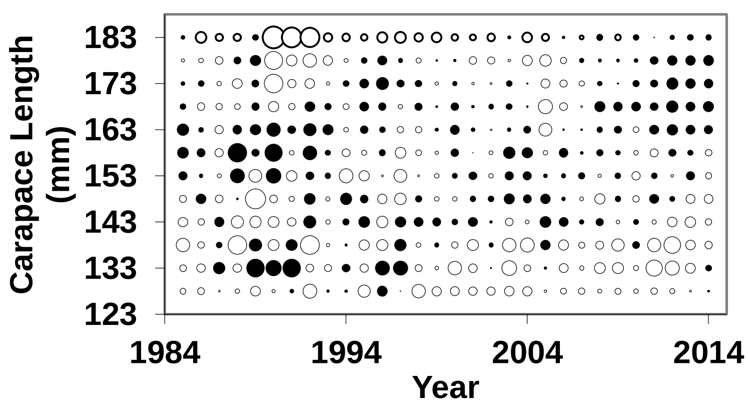
Scenario 1



Scenario 5

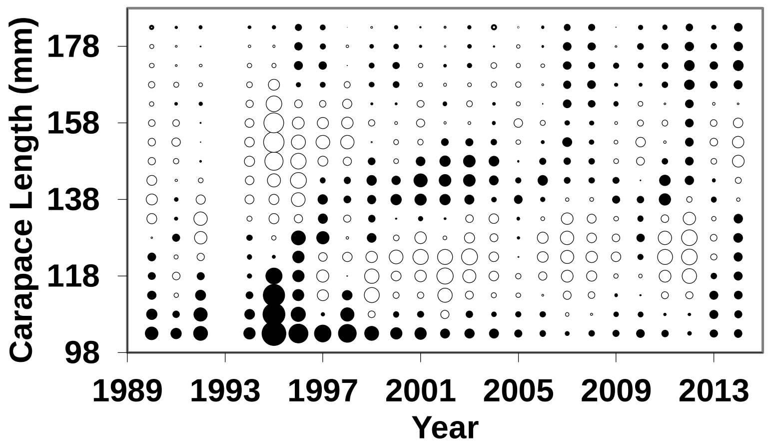


Scenario 10

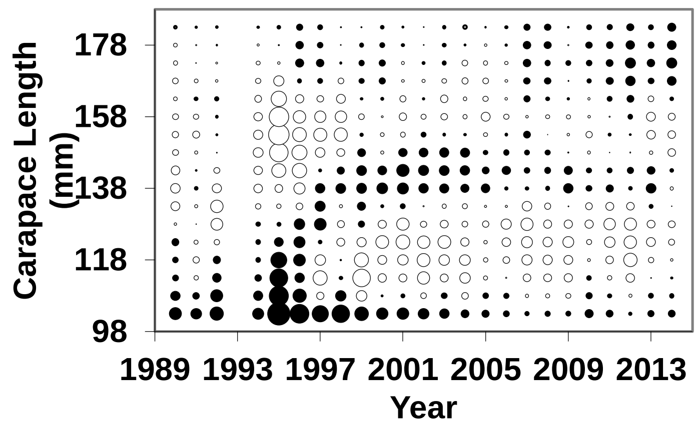


Scenario 14

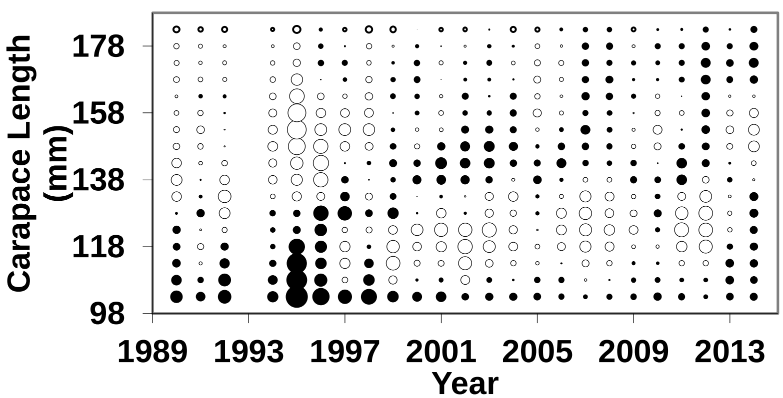
Figure 11. Bubble plots of standardized residuals of retained catch length composition for scenarios 1, 5, 10, and 14 fits for EAG golden king crab, 1985/86–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



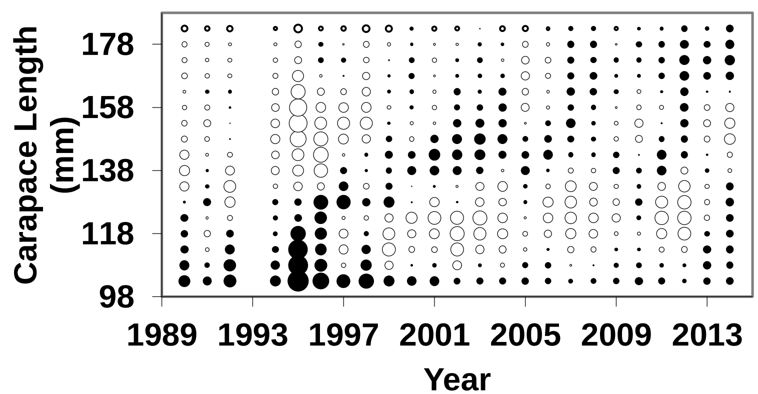
Scenario 1



Scenario 5

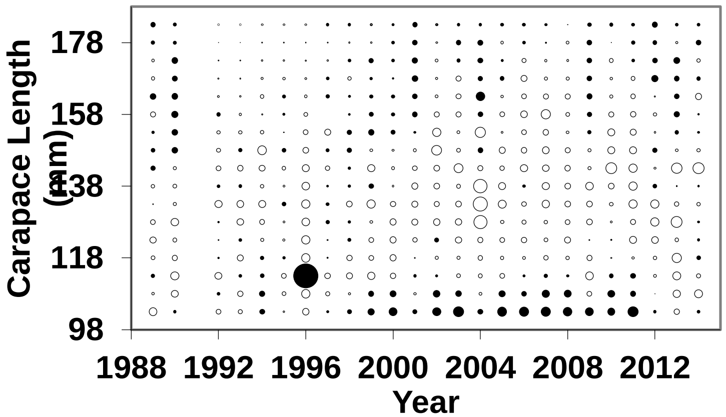


Scenario 10

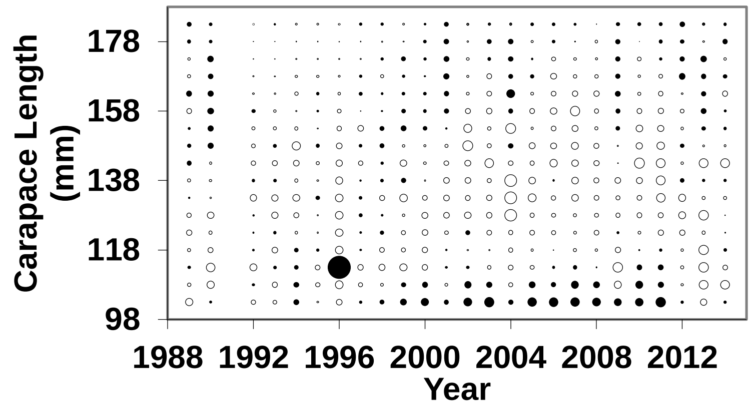


Scenario 14

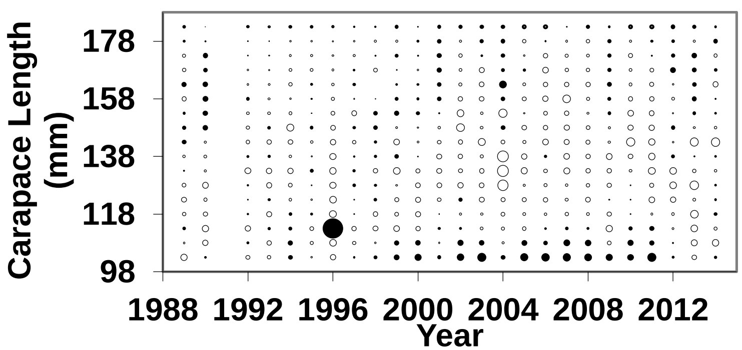
Figure 12. Bubble plots of standardized residuals of total catch length composition for scenarios 1, 5, 10, and 14 fits for EAG golden king crab, 1990/91–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



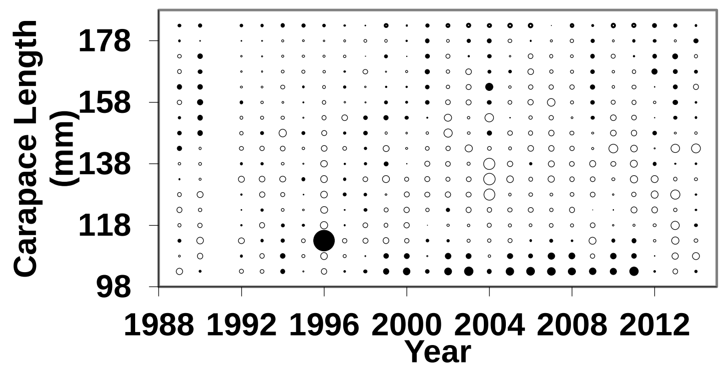
Scenario 1



Scenario 5



Scenario 10



Scenario 14

Figure 13. Bubble plots of standardized residuals of groundfish (trawl) bycatch length composition for scenarios 1, 5, 10, and 14 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.

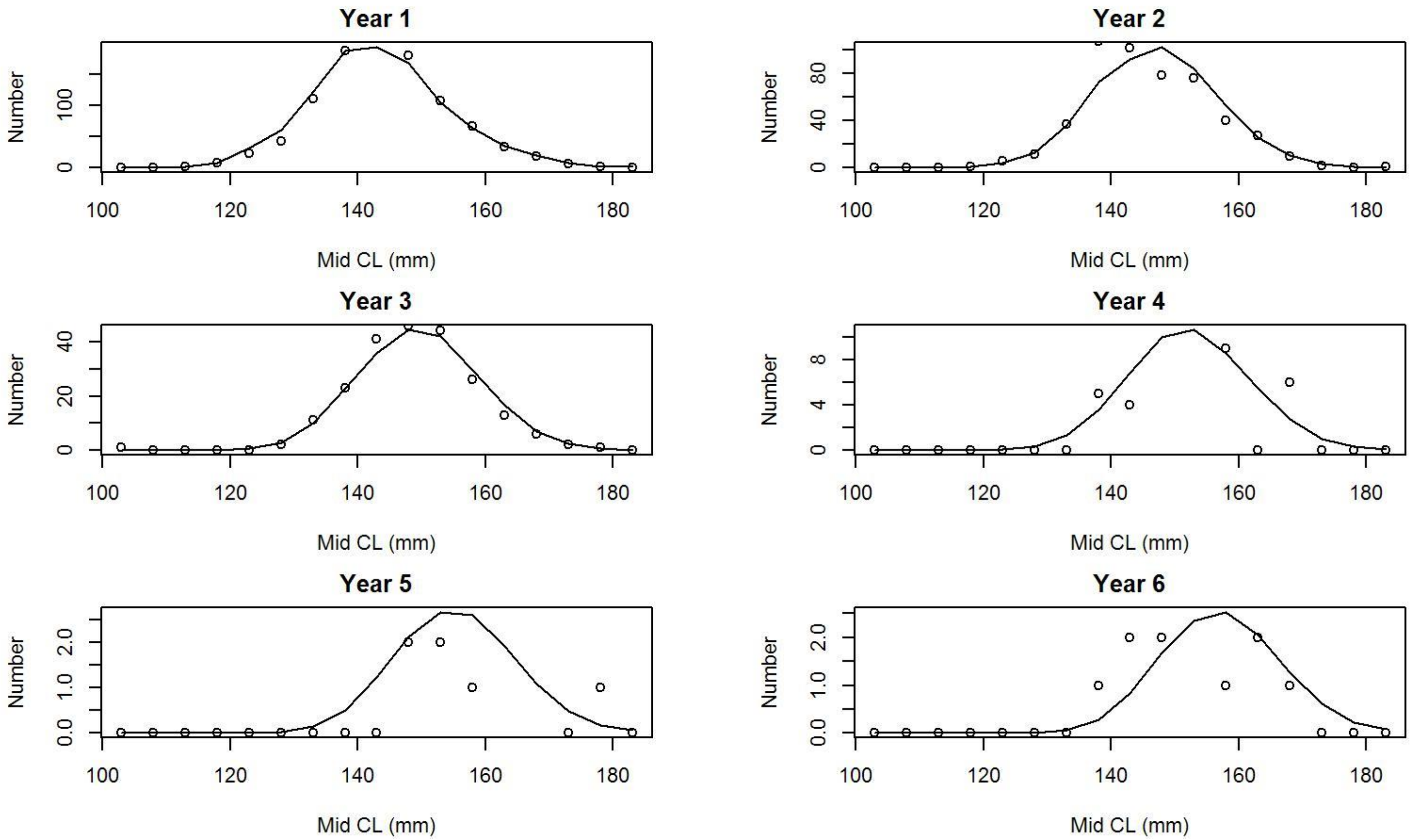


Figure 14. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures for scenario 1 fit of EAG golden king crab.

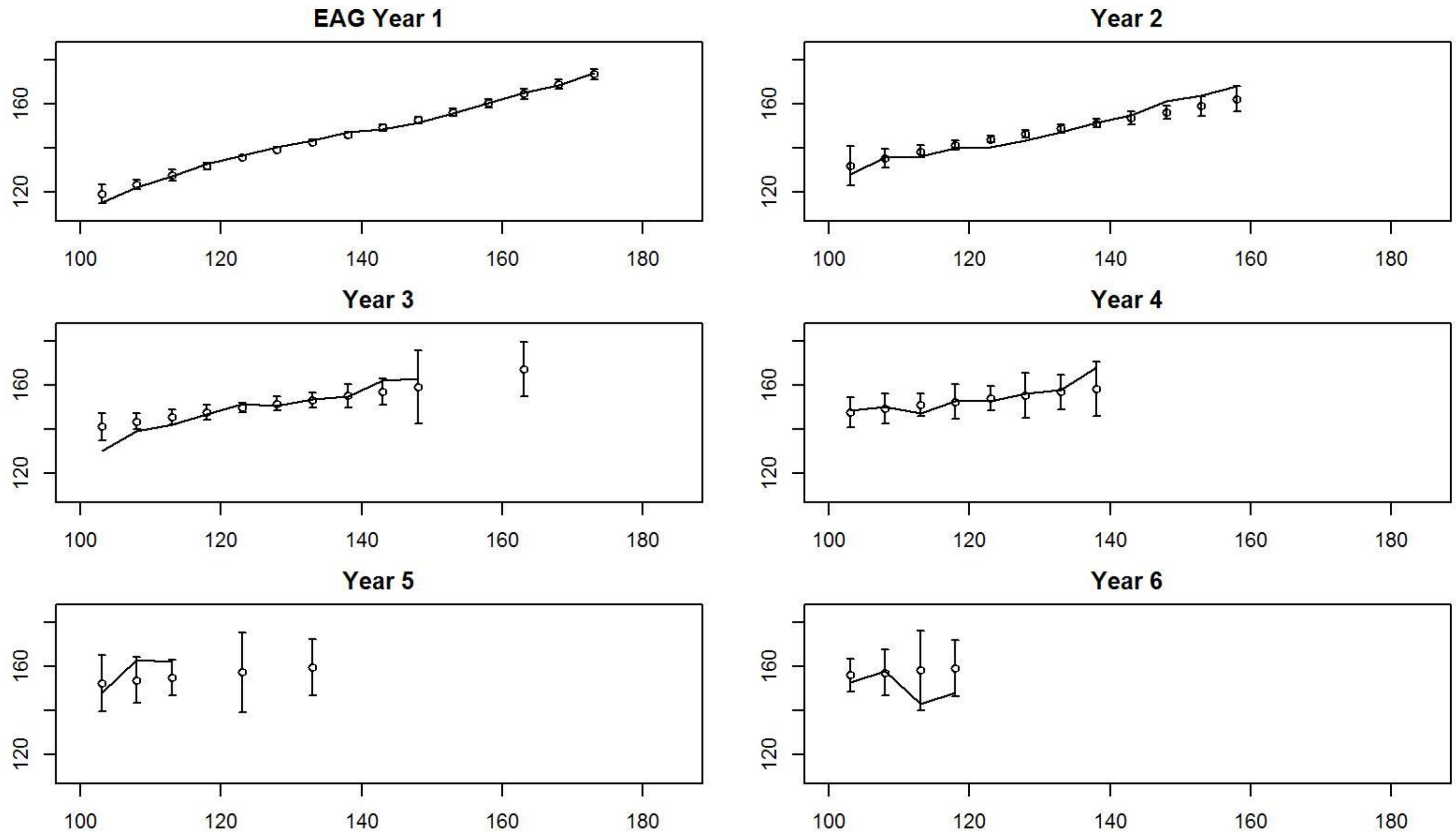


Figure 15. Observed and predicted mean length (with two SE) of recaptures vs. release length for years 1 to 6 recaptures for scenario 1 fit of EAG golden king crab.

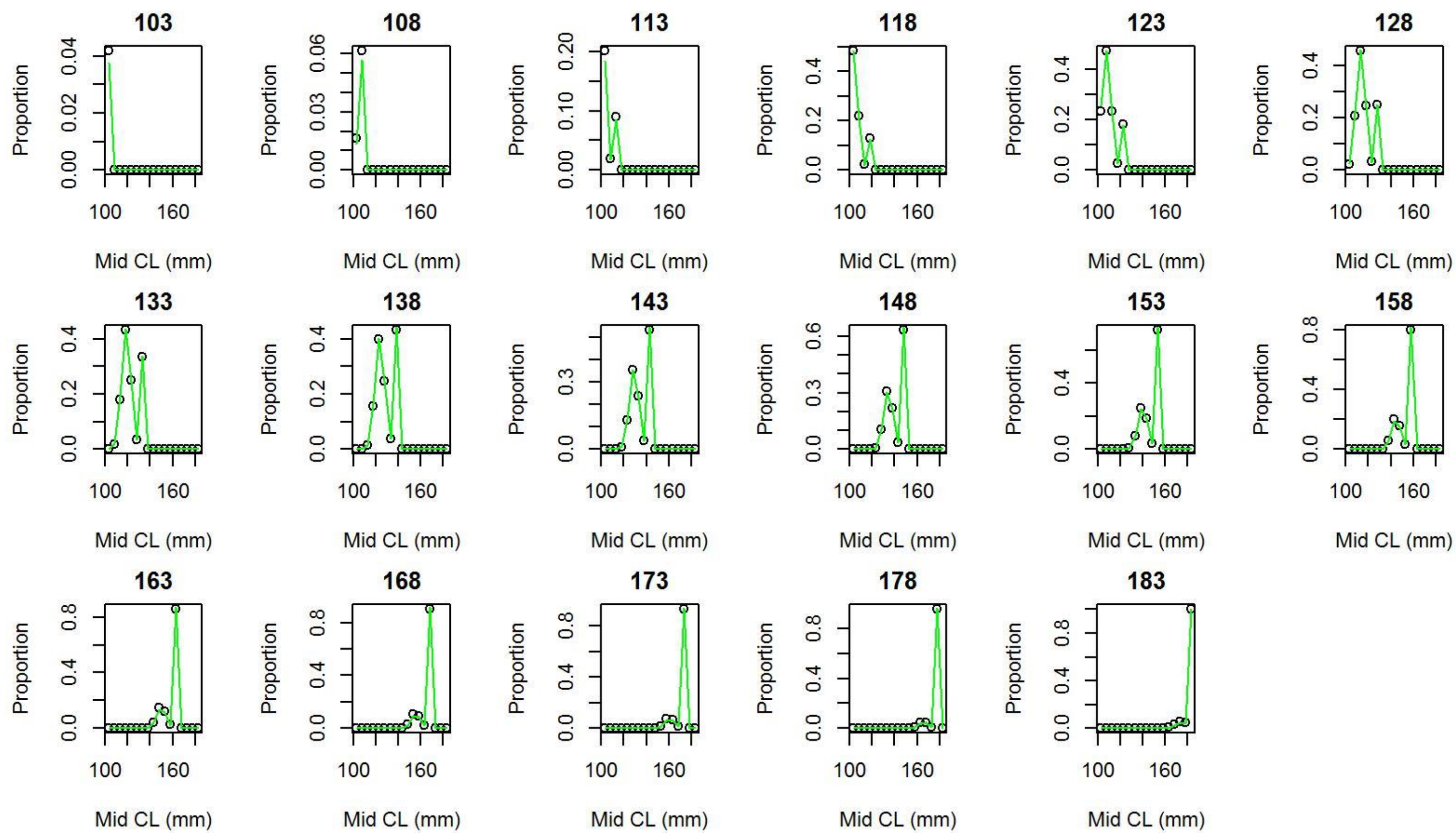


Figure 16. Comparison of estimated growth matrix components (proportions) between EAG (black circles) and WAG (green line) for scenario 1 fits to golden king crab data. The number at the top of each plot is the mid length (mm CL) of the contributing length-class. The proportions in each plot are the proportions falling into different length-classes as a result of growth of the contributing length-class.

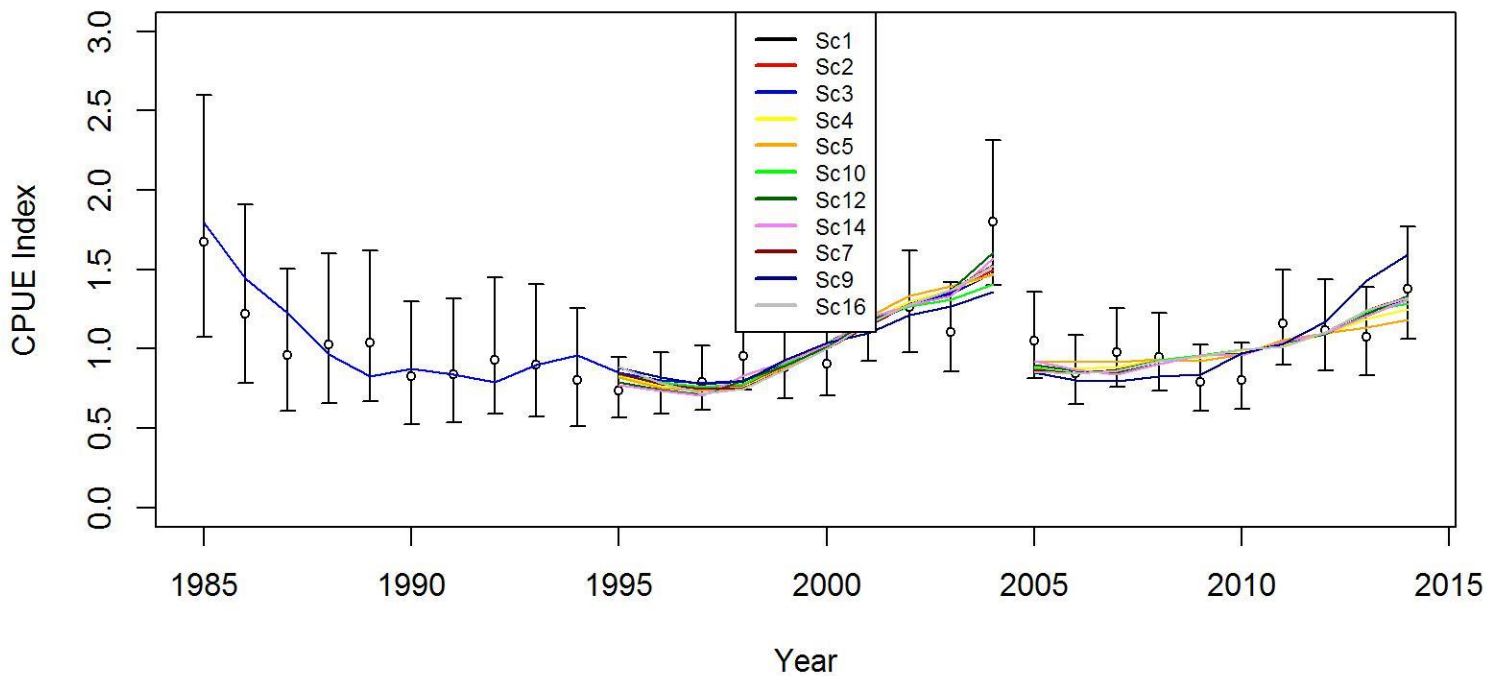


Figure 17. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits for EAG golden king crab data, 1985/86–2014/15. Model estimated additional standard error was added to each input standard error.

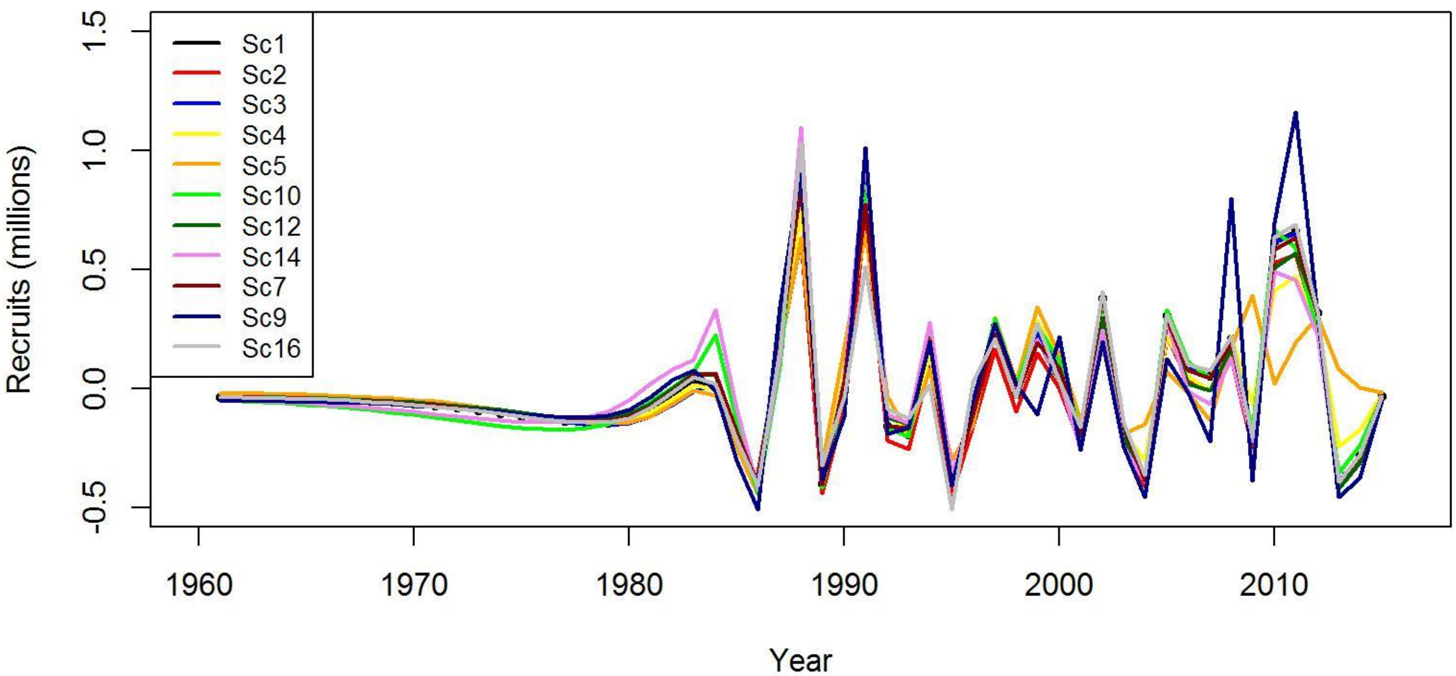


Figure 18. Estimated number of male recruits (millions of crab ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits in EAG, 1961–2015. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

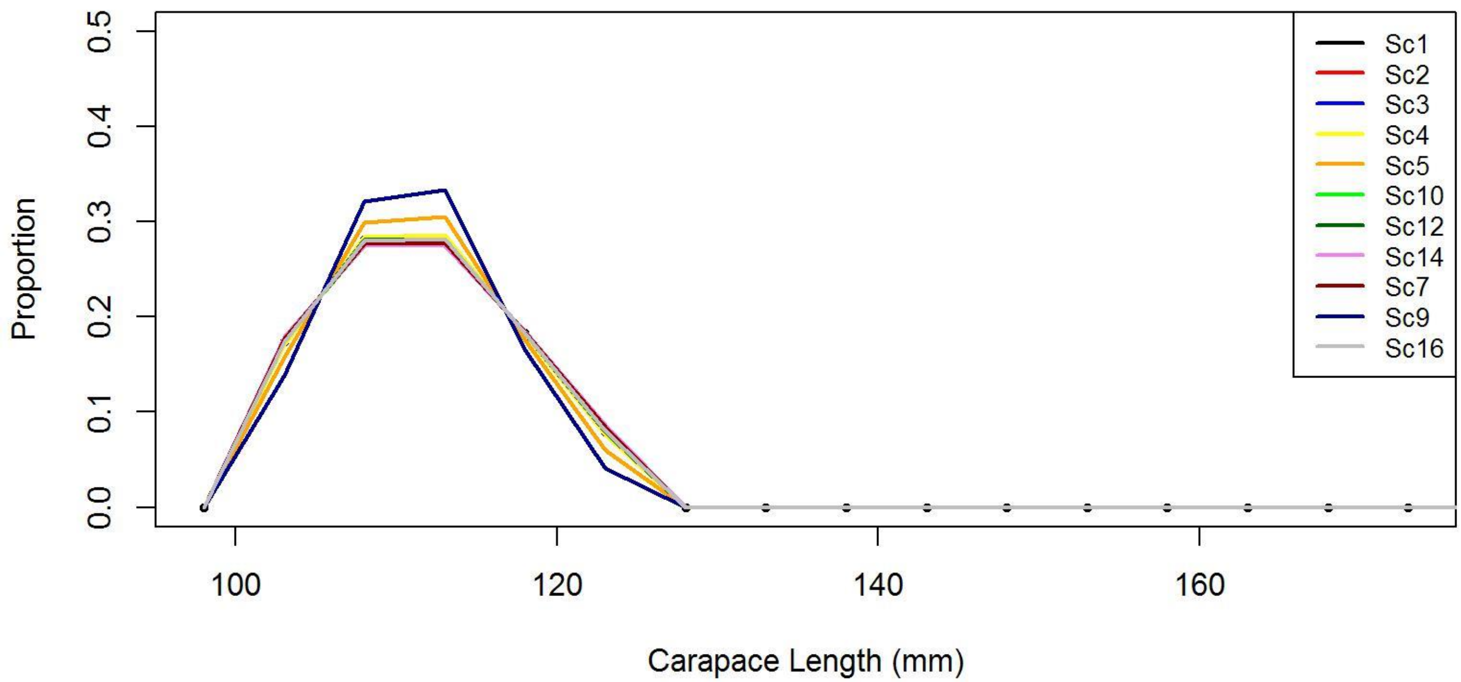


Figure 19. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits in EAG.

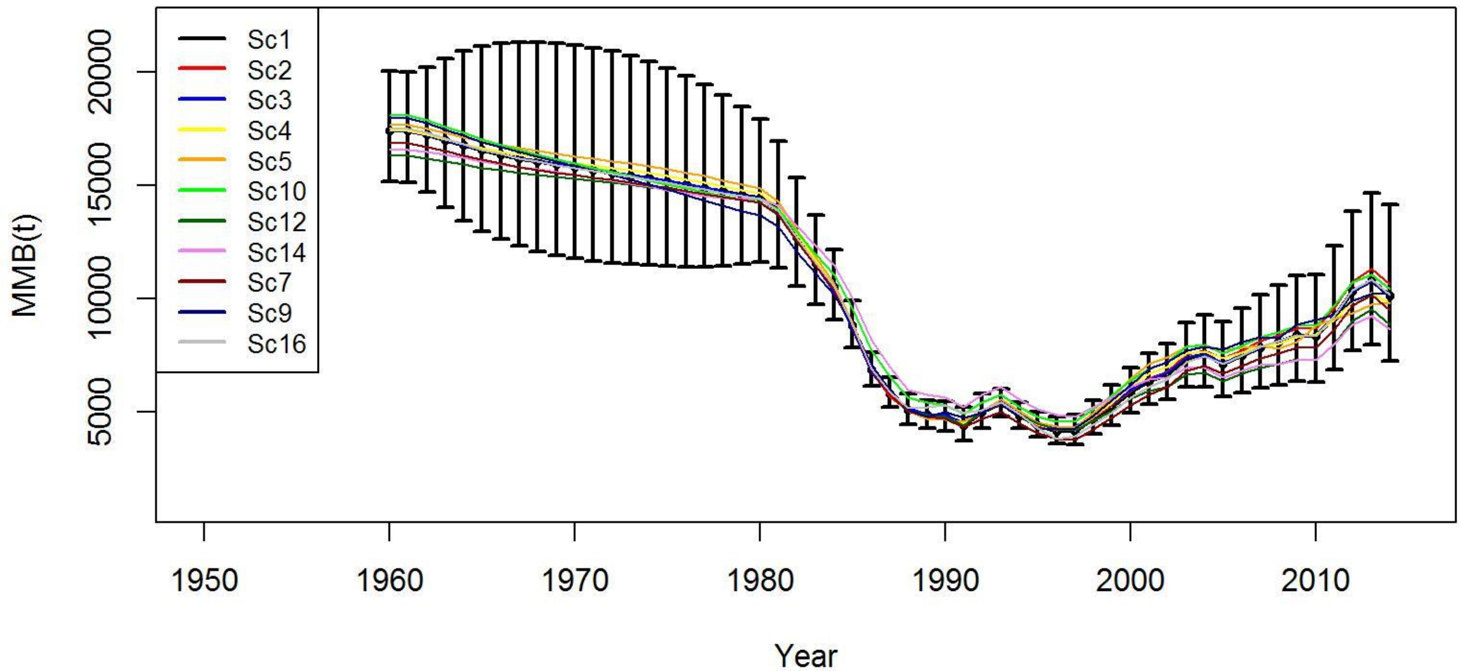


Figure 20. Trends in golden king crab mature male biomass for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 model fits in the EAG, 1960/61–2014/15. Mature male crab is ≥ 121 mm CL. Scenario 1 estimates have two standard errors confidence limits.

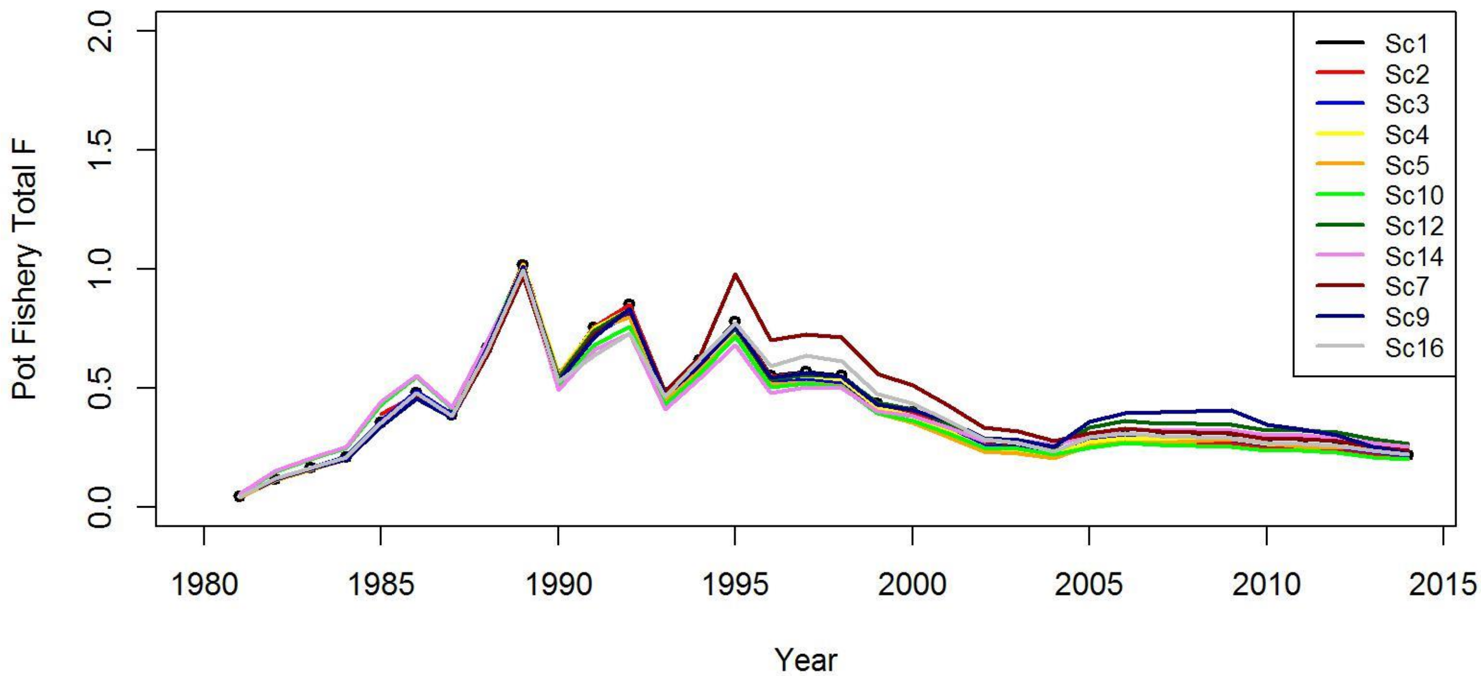


Figure 21. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1,2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 model fits in the EAG, 1981–2014 (note: 1981 refers to the1981/82 fishing year).

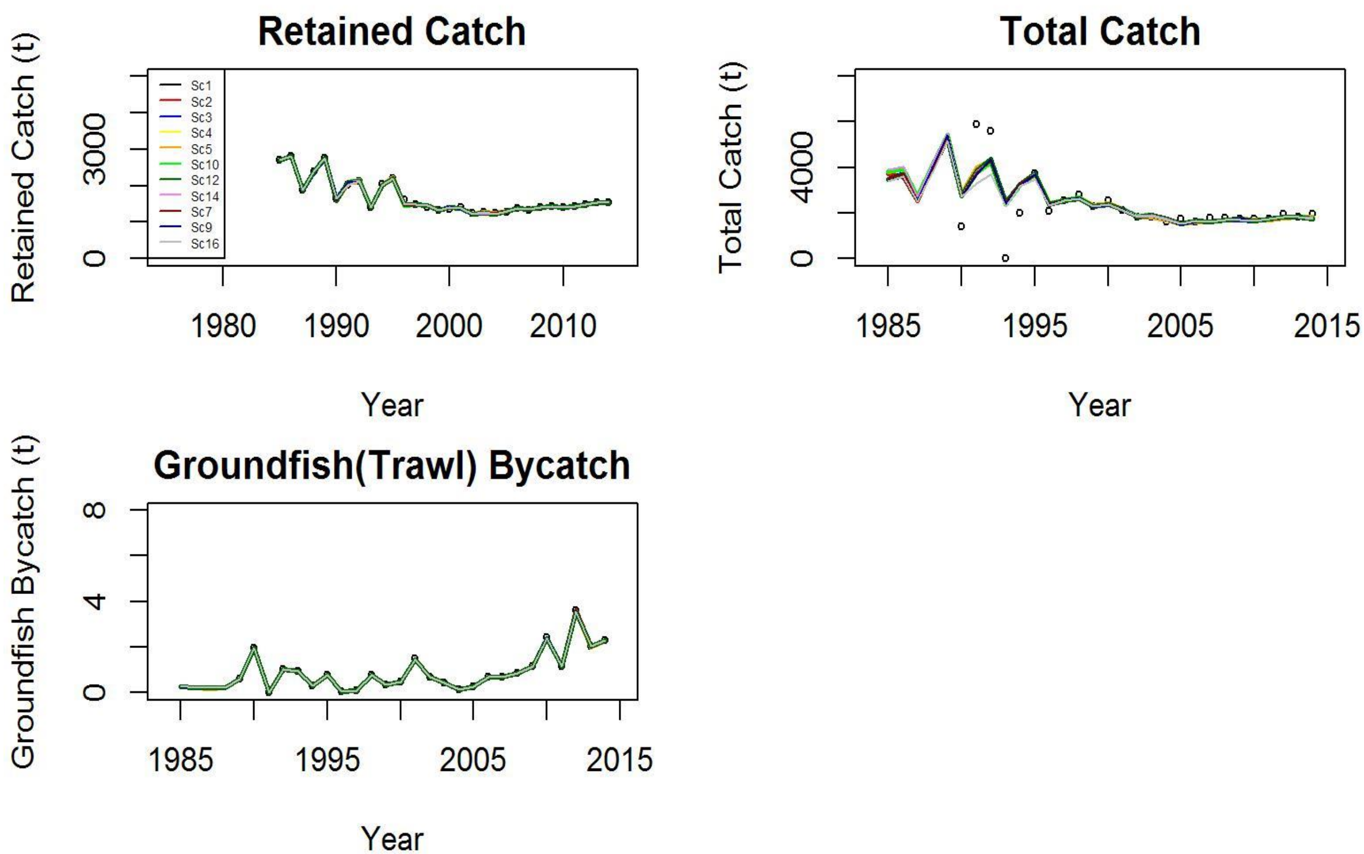


Figure 22. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and trawl (or groundfish) bycatch (bottom left) of golden king crab for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits in the EAG, 1985–2014. (note: 1985 refers to the1985/86 fishing year).

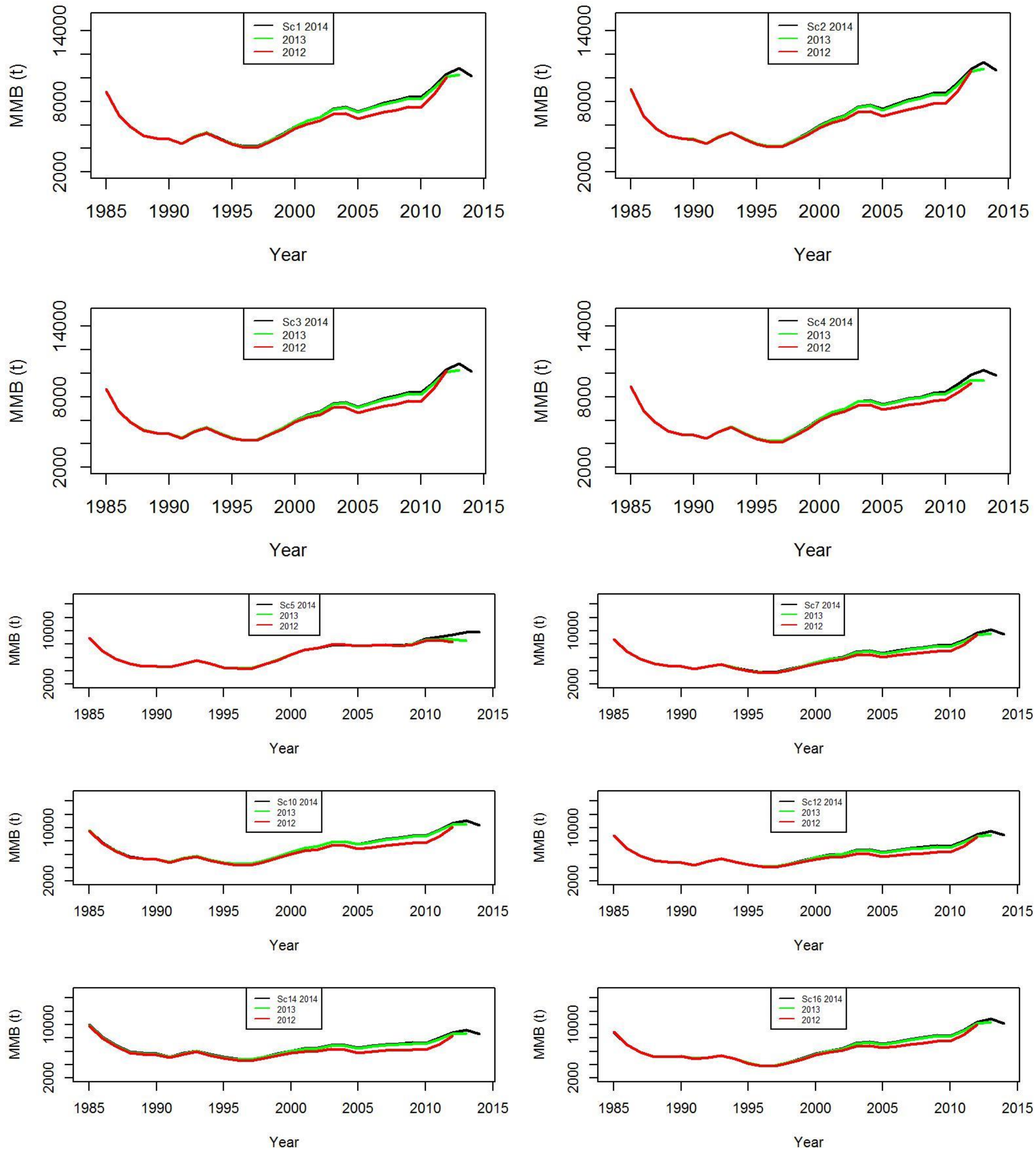


Figure 23. Retrospective fits of the model for removal of terminal year's data for scenarios (Sc) 1, 2, 3, 4, 5, 7, 10, 12, 14, and 16 fits for golden king crab in the EAG, 1985–2014 (note: 1985 refers to the1985/86 fishing year).

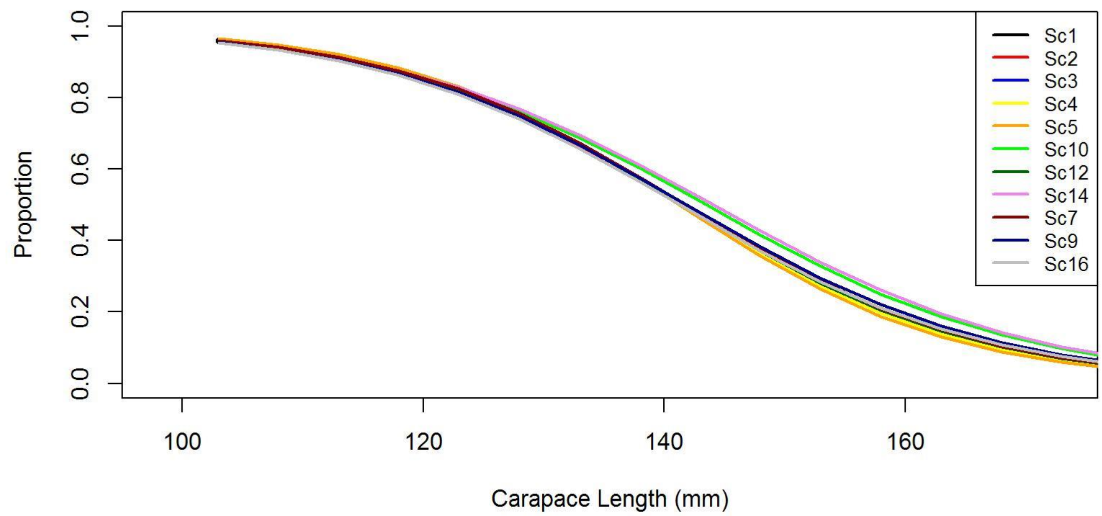


Figure 24. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 model fits in the EAG, 1985/86–2014/15.

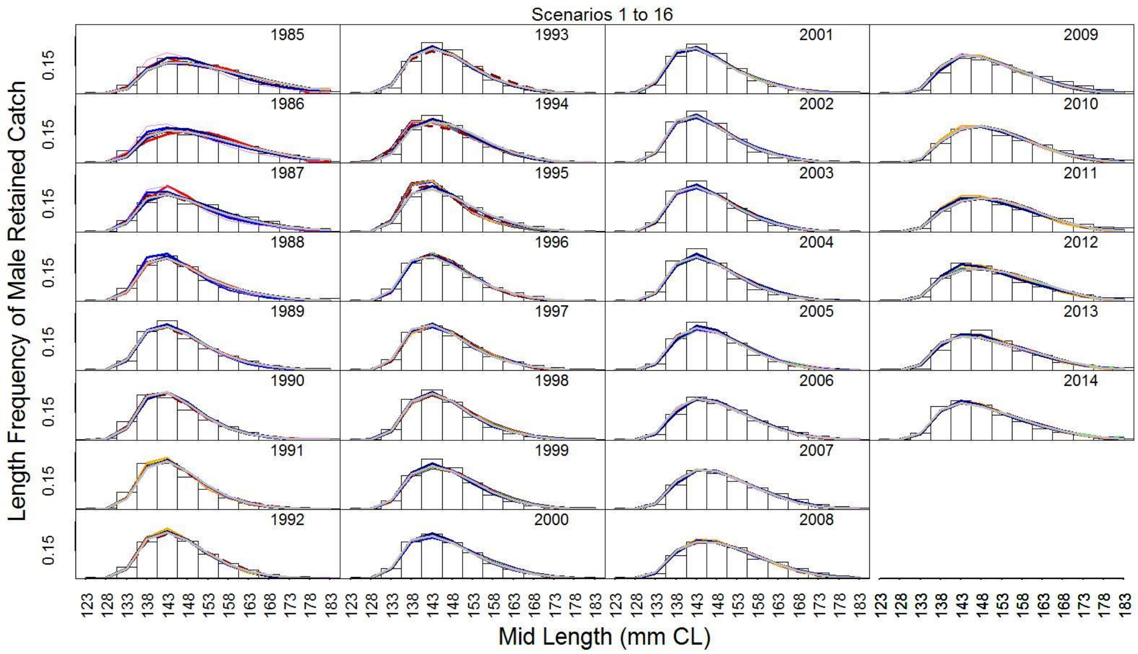


Figure 25. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (yellow line), 5 (orange line), 7 (dark red dashed line), 9 (dark blue line), 10 (green line), 12 (dark green line), 14 (violet line), and 16 (gray line) data of golden king crab in the WAG, 1985/86 to 2014/15.

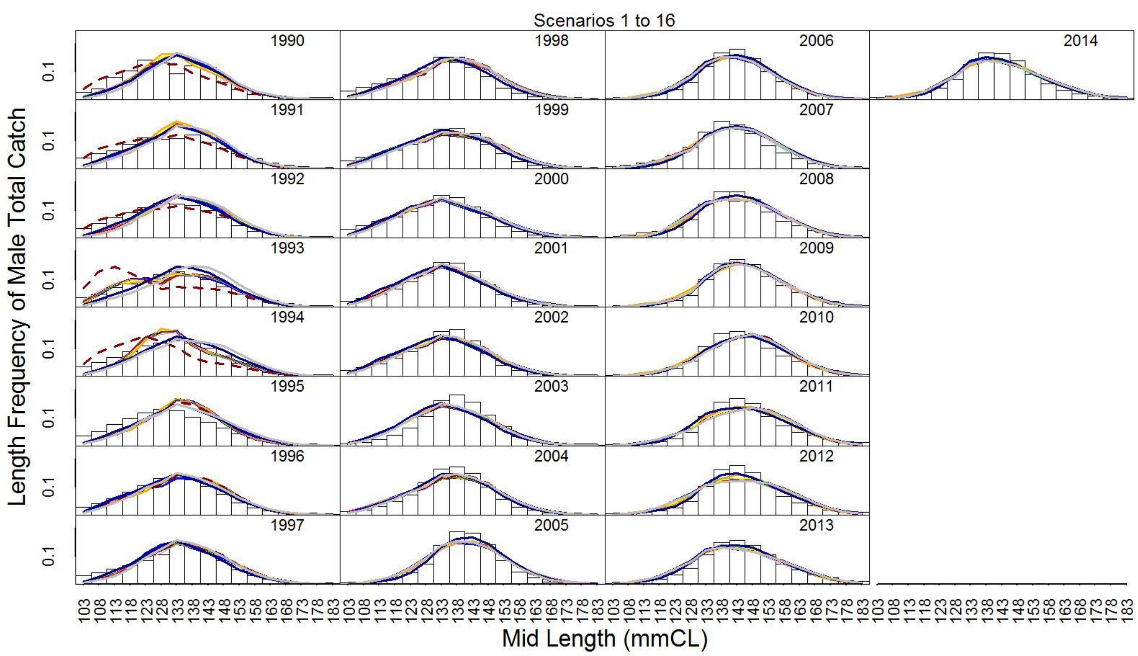


Figure 26. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (yellow line), 5 (orange line), 7 (dark red dashed line), 9 (dark blue line), 10 (green line), 12 (dark green line), 14 (violet line), and 16 (gray line) data of golden king crab in the WAG, 1990/91 to 2014/15.

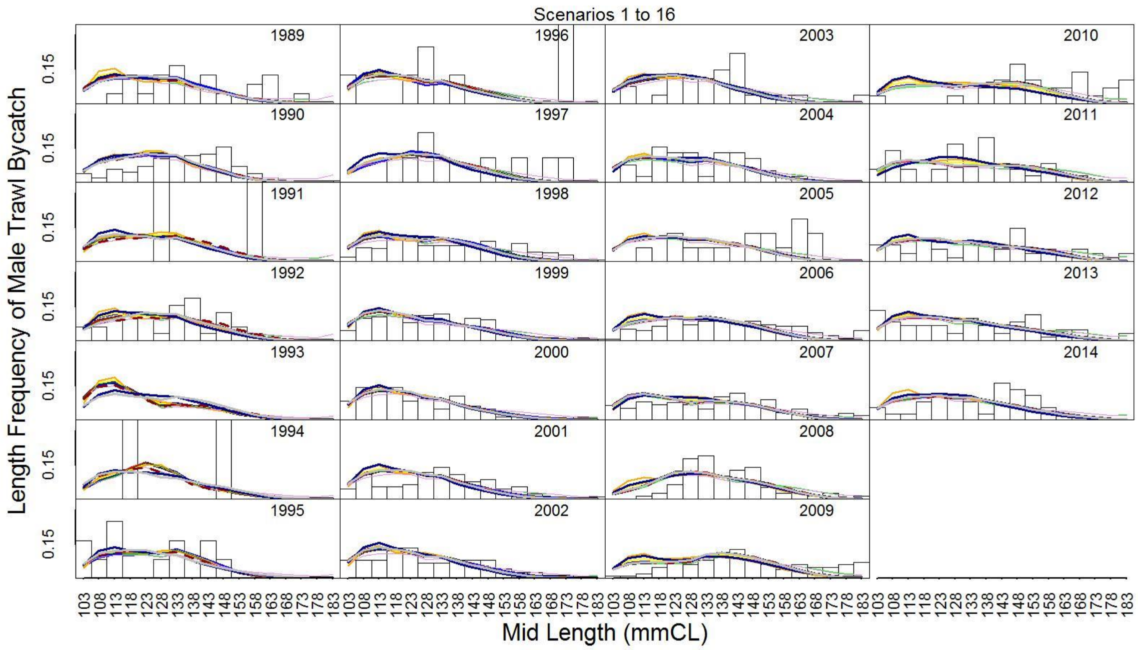


Figure 27. Predicted (line) vs. observed (bar) groundfish (trawl) discarded catch relative length frequency distributions for scenarios 1 (black line), 2 (red line), 3 (blue line), 4 (yellow line), 5 (orange line), 7 (dark red dashed line), 9 (dark blue line), 10 (green line), 12 (dark green line), 14 (violet line), and 16 (gray line) data of golden king crab in the WAG, 1989/90 to 2014/15.

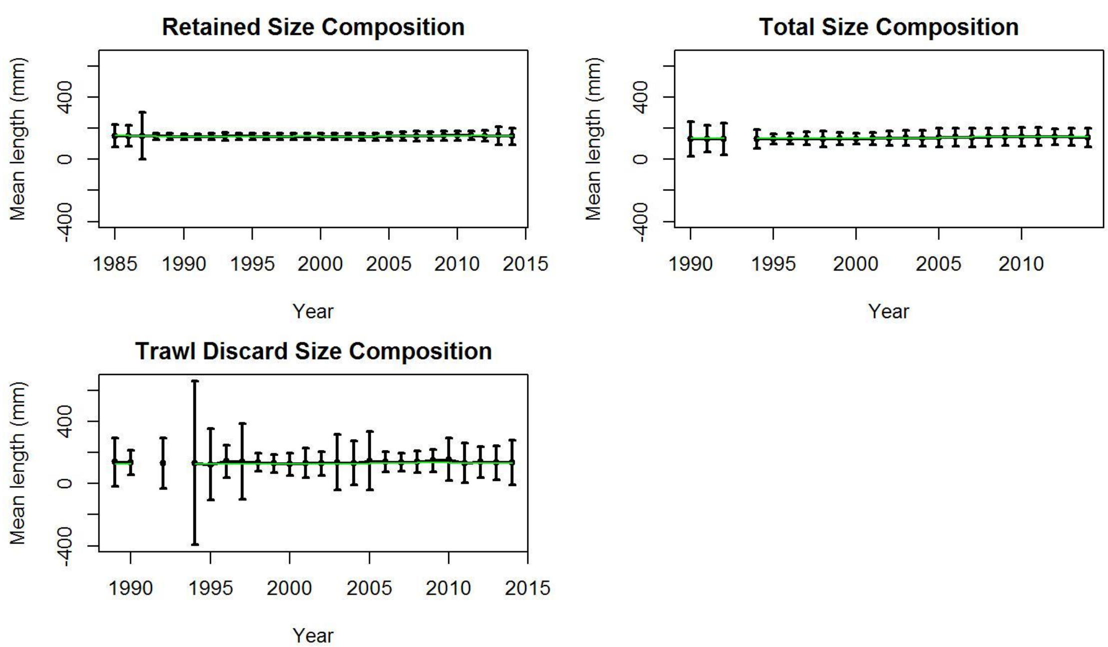


Figure 28. Predicted (green line) vs. observed (black line) mean lengths (with +/- 1.96 SE) of retained (top right), total (top left), and groundfish (trawl) discarded (bottom right) catch compositions for scenario 1 data of golden king crab in the WAG, 1985/86 to 2014/15.

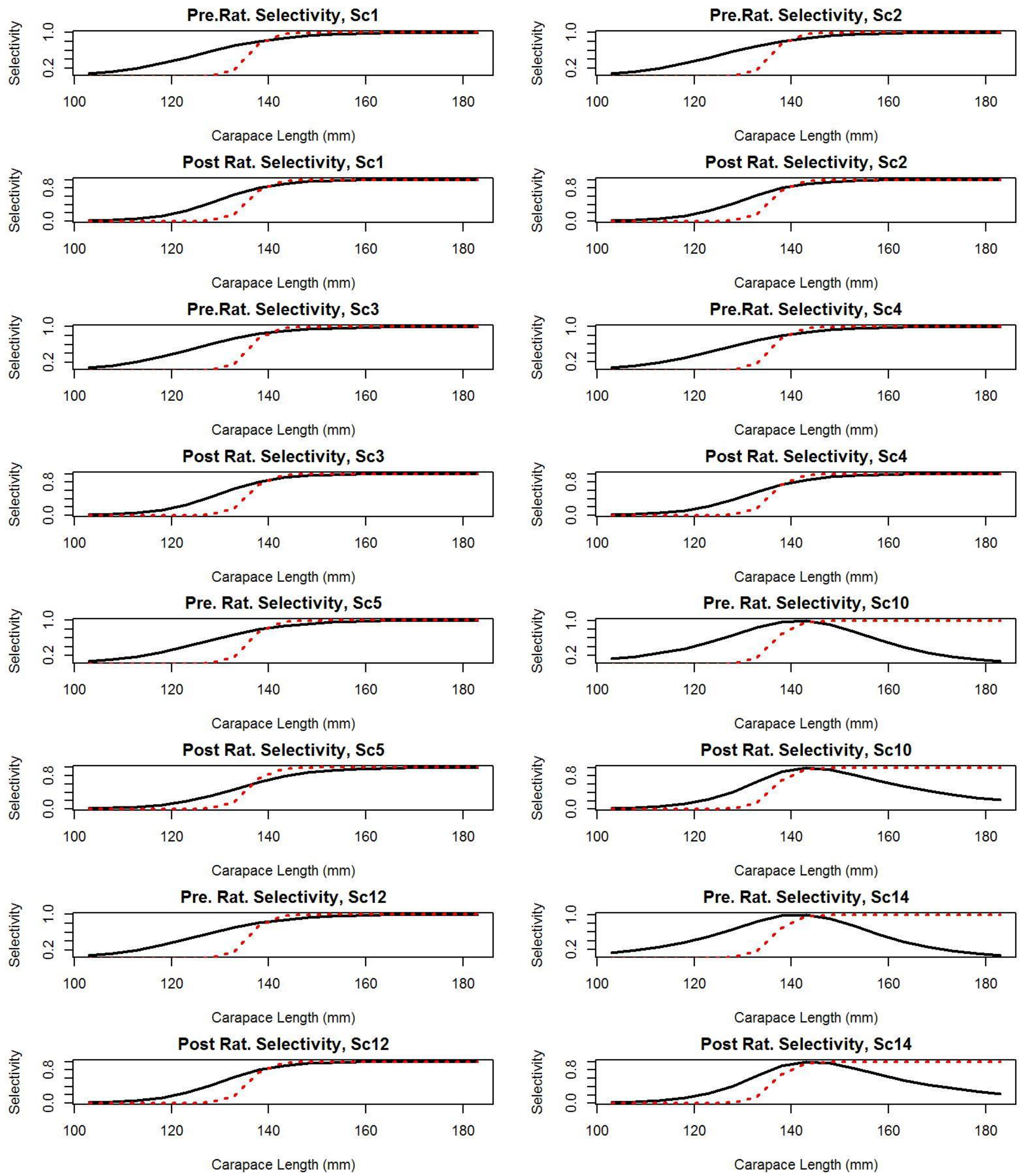
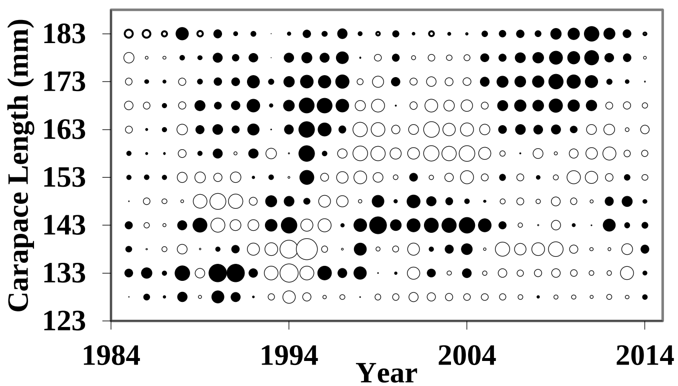
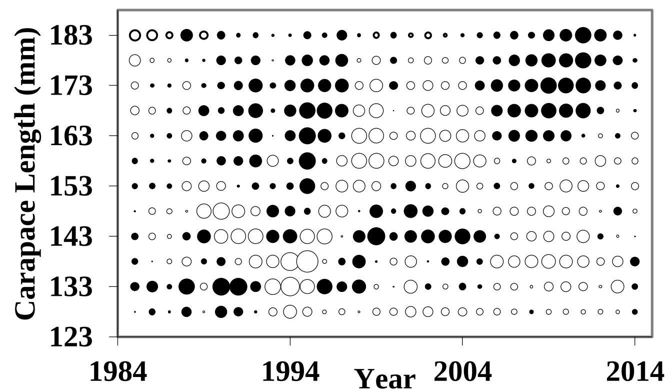


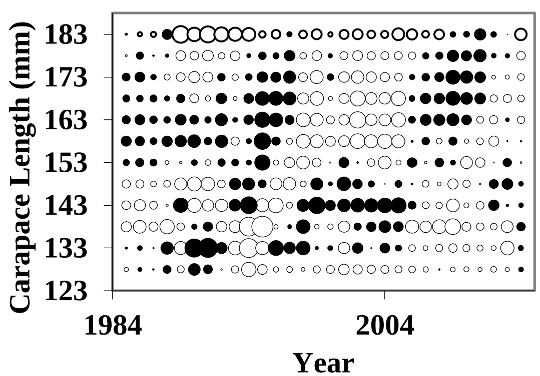
Figure 29. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 1, 2, 3, 4, 5, 10, 12, and 14 fits of WAG golden king crab data.



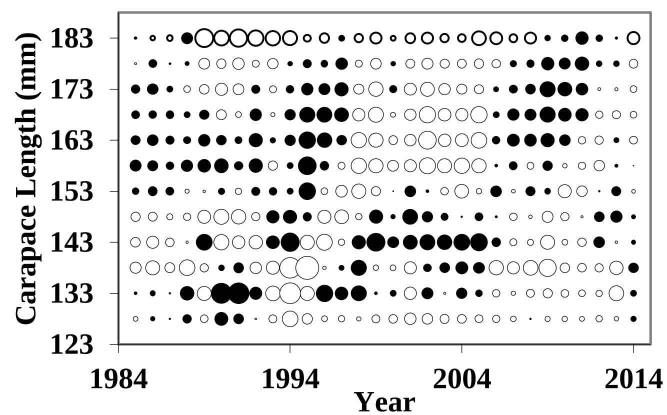
Scenario 1



Scenario 5



Scenario 10



Scenario 14

Figure 30. Bubble plots of standardized residuals of retained catch length composition for scenarios 1, 5, 10 and 14 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.

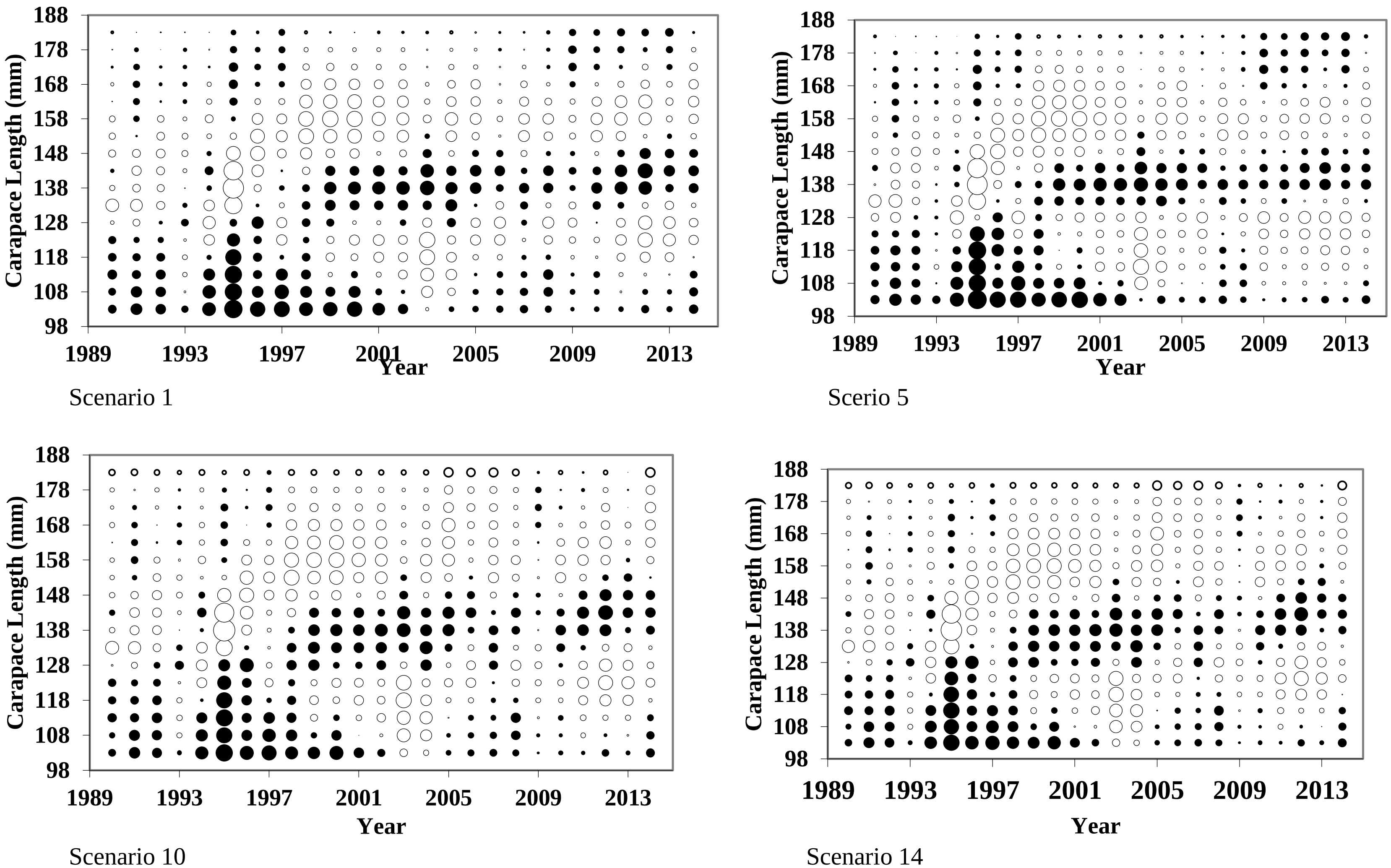


Figure 31. Bubble plots of standardized residuals of total catch length composition for scenarios 1, 5, 10, and 14 fits for WAG golden king crab, 1990/91–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

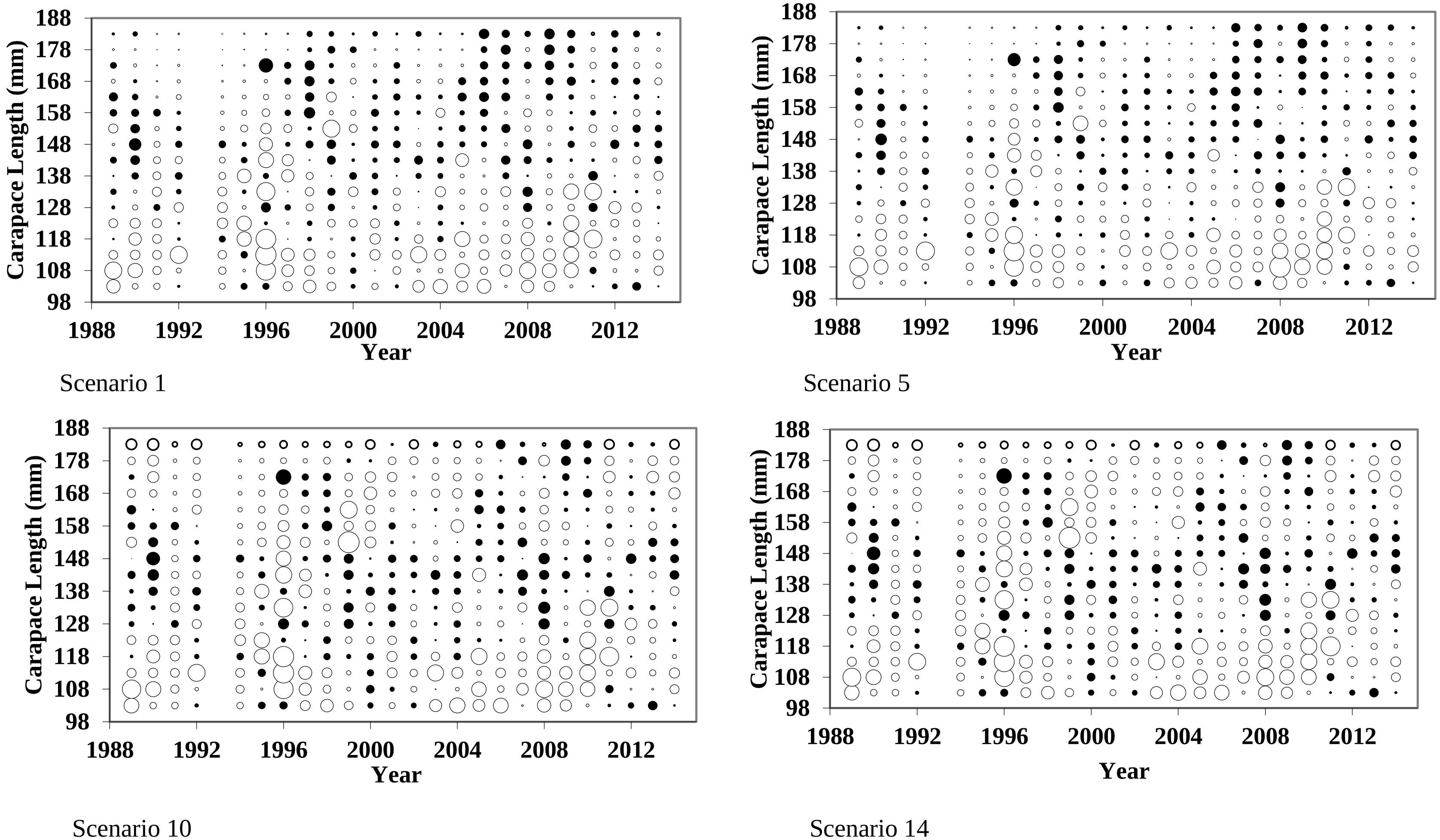


Figure 32. Bubble plots of standardized residuals of groundfish (trawl) bycatch length composition for scenarios 1, 5, 10, and 14 fits for WAG golden king crab, 1989/90–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

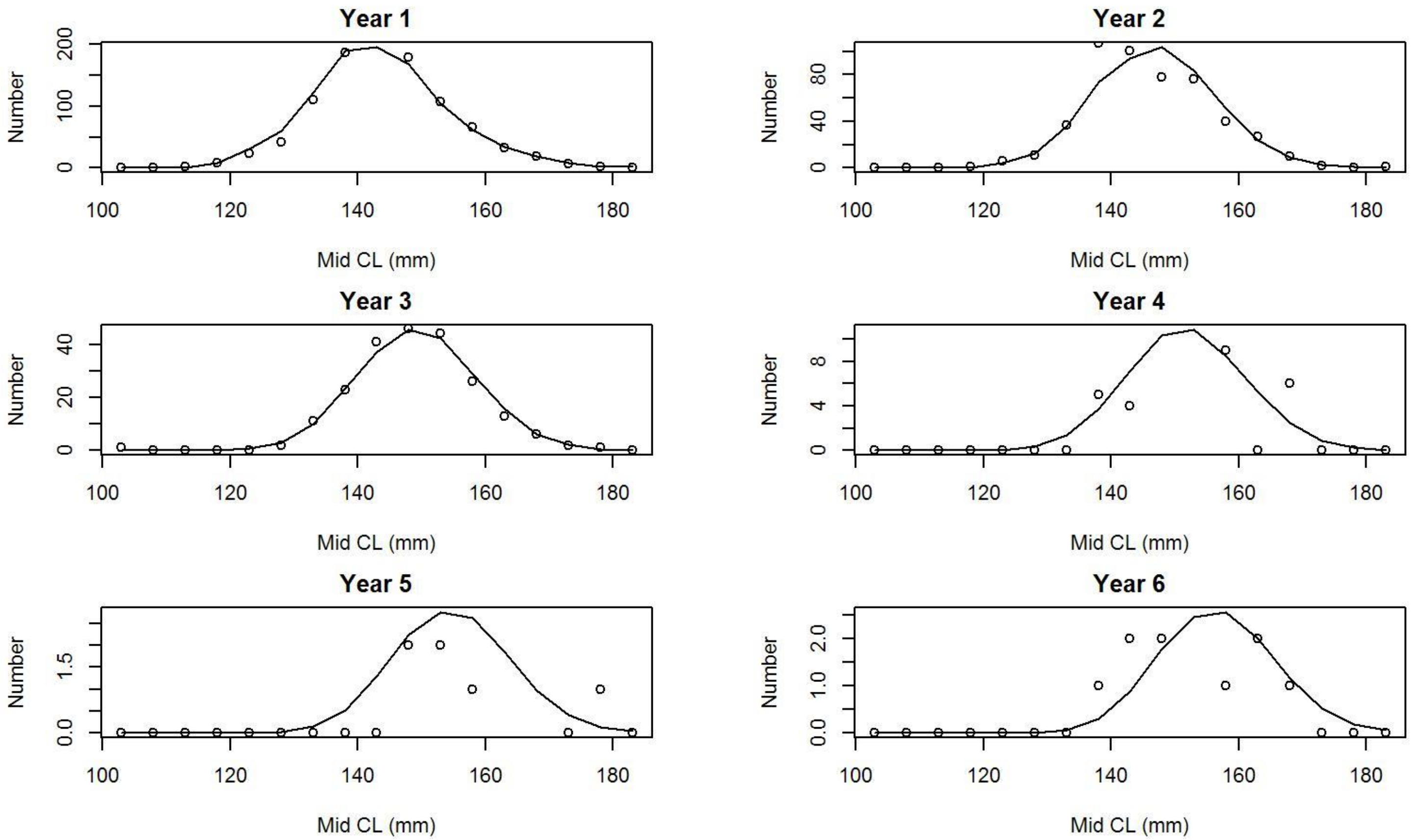


Figure 33. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures for scenario 1 fit of WAG golden king crab data. The tagging experiments were conducted in EAG.

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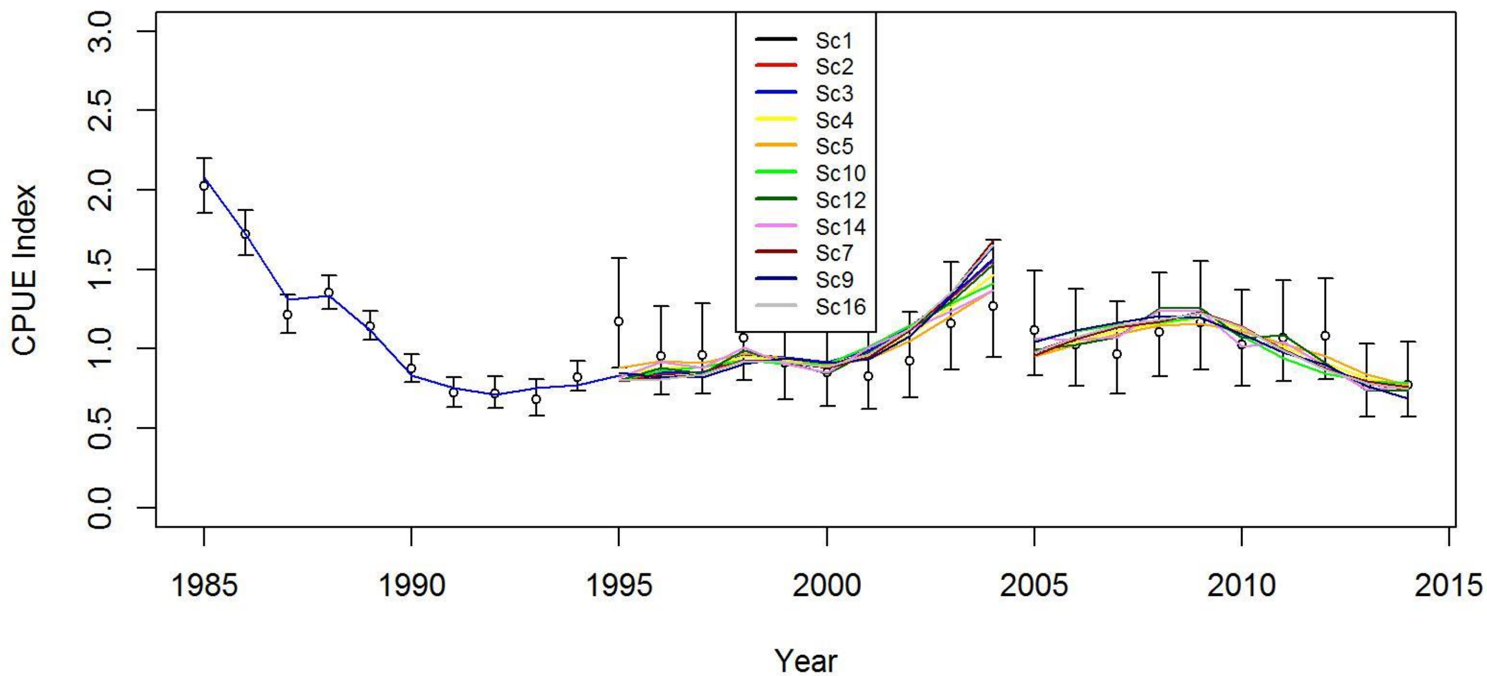


Figure 34. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits for WAG golden king crab data, 1985/86–2014/15. Model estimated additional standard error was added to each input standard error.

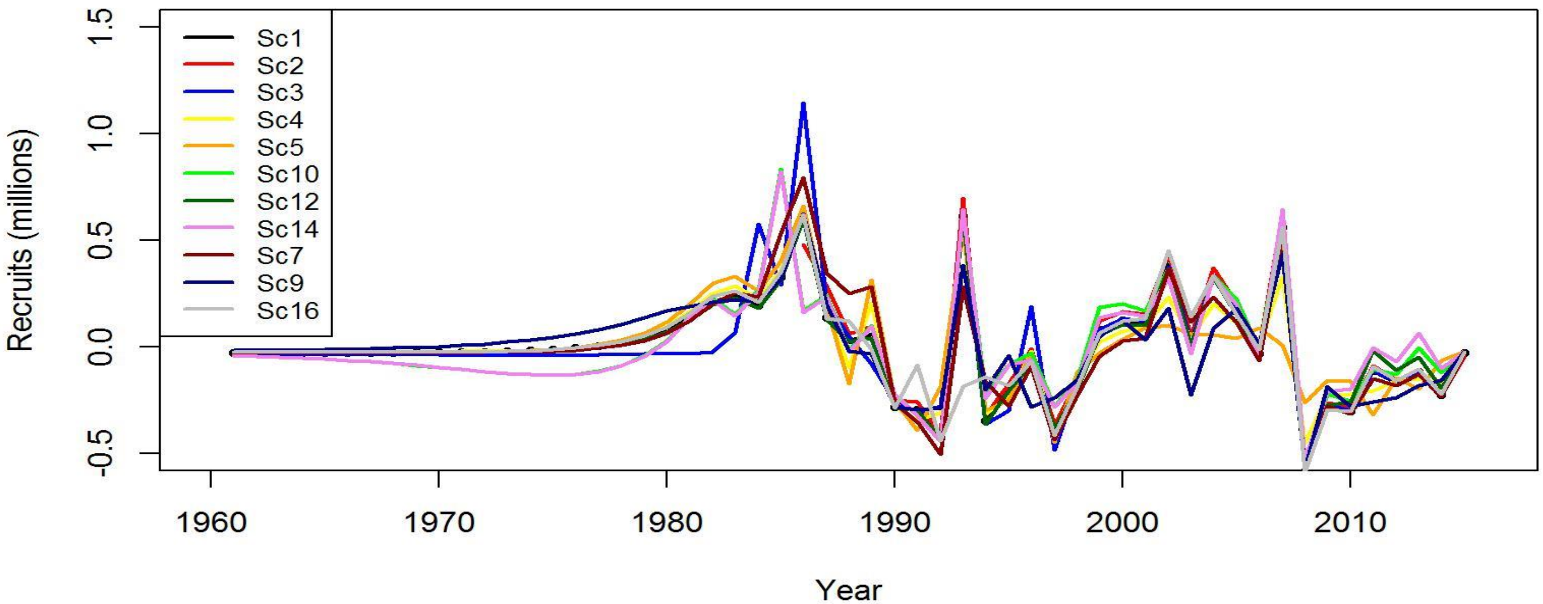


Figure 35. Estimated number of male recruits (millions of crab ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits in WAG, 1961–2015. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

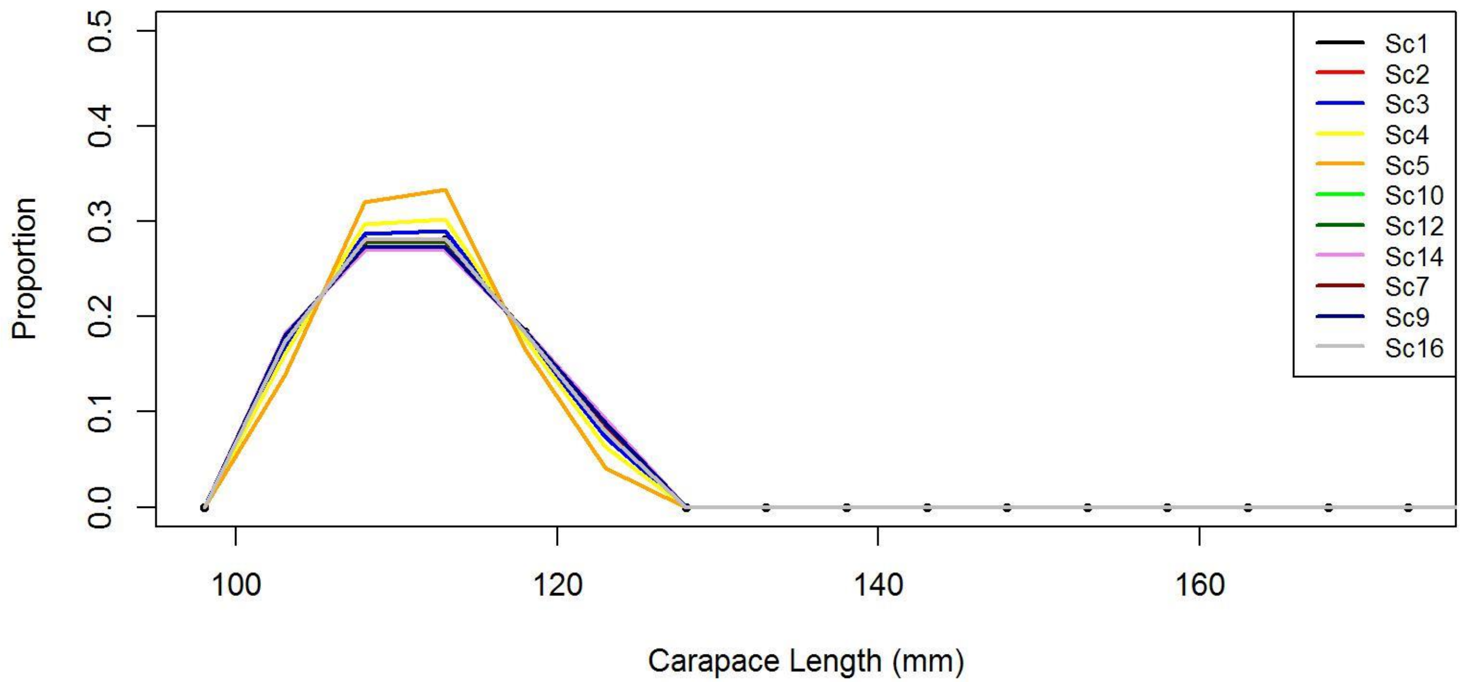


Figure 36. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits in WAG.

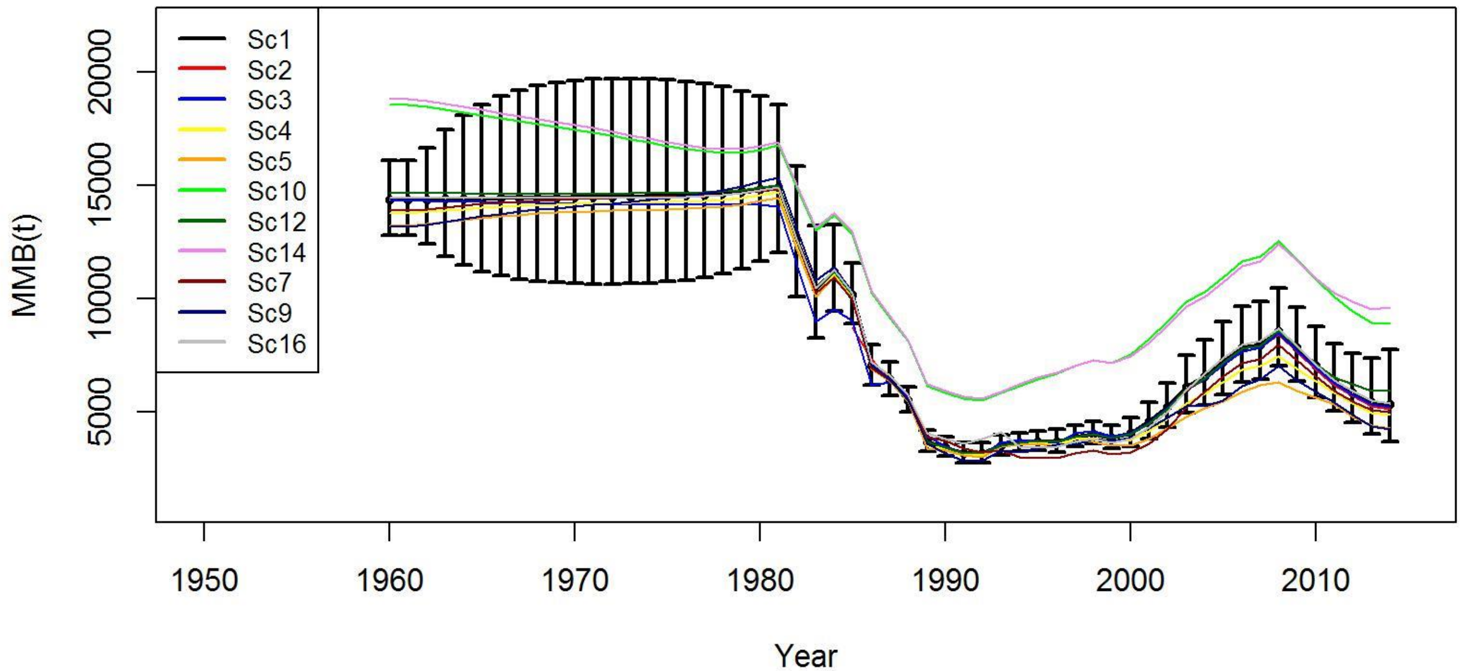


Figure 37. Trends in golden king crab mature male biomass for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 model fits in the WAG, 1960/61–2014/15. Mature male crab is ≥ 121 mm CL. Scenario 1 estimates have two standard errors confidence limits. The MMB trend lines for scenarios 10 (green line, dome shaped selectivity) and 14 (violet line, area shrinkage factor on CPUE prediction and dome shaped selectivity) are higher than the rest.

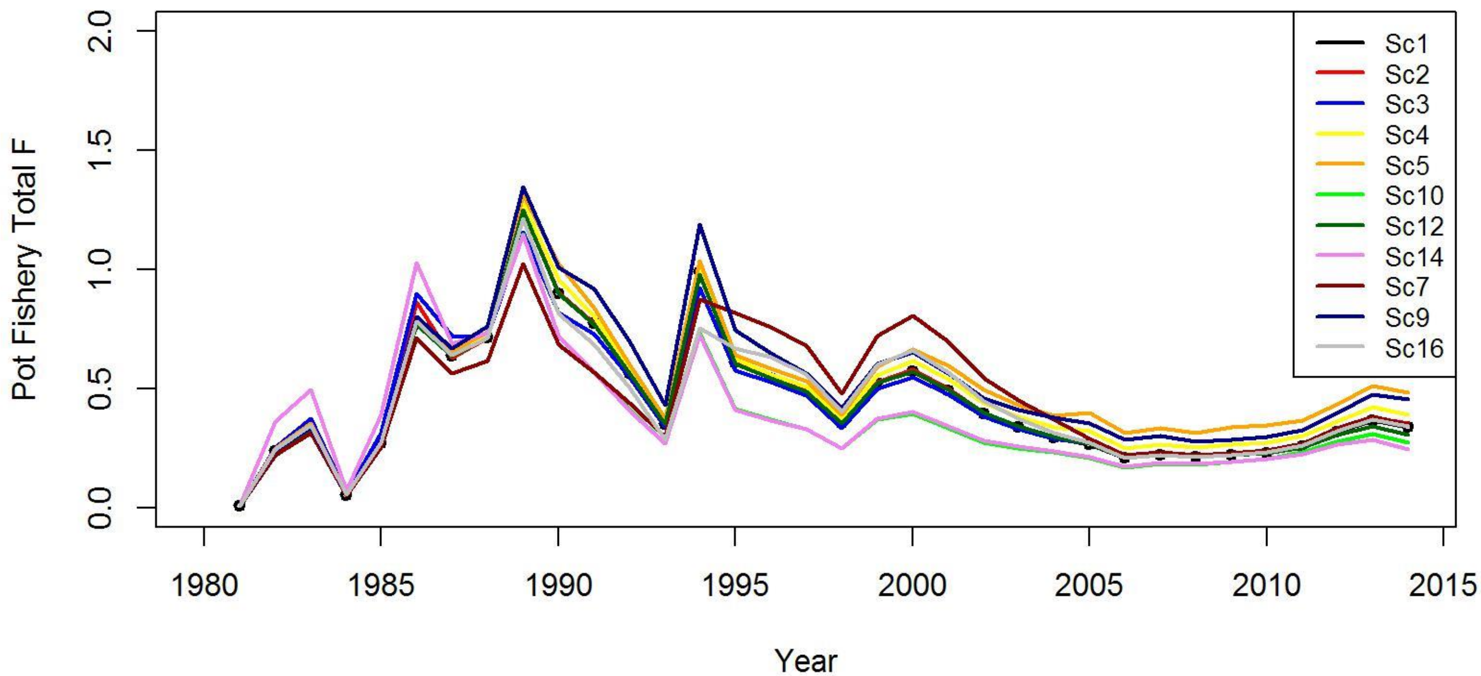


Figure 38. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 model fits in the WAG, 1981–2014 (note: 1981 refers to the1981/82 fishing year).

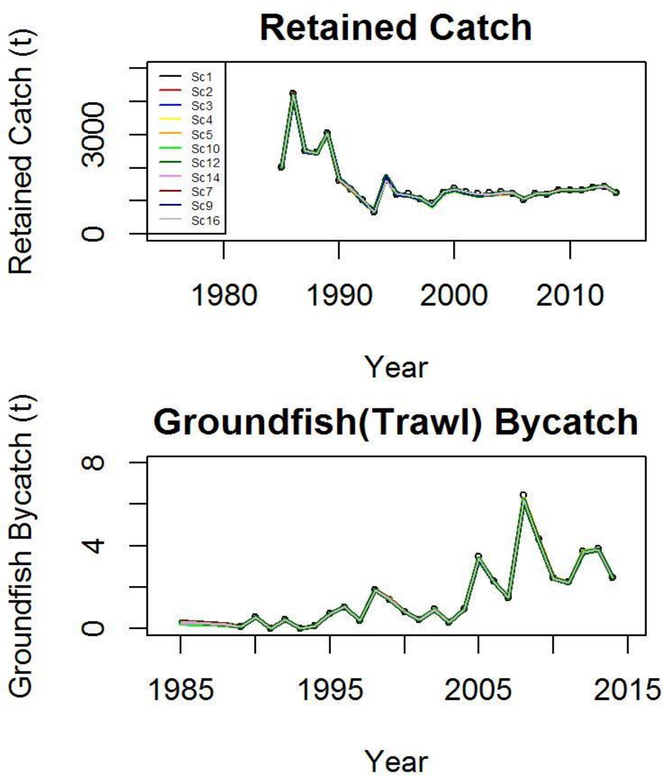


Figure 39. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and trawl (or groundfish) bycatch (bottom left) of golden king crab for scenarios (Sc) 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 fits in the WAG, 1985–2014. (note: 1985 refers to the1985/86 fishing year).

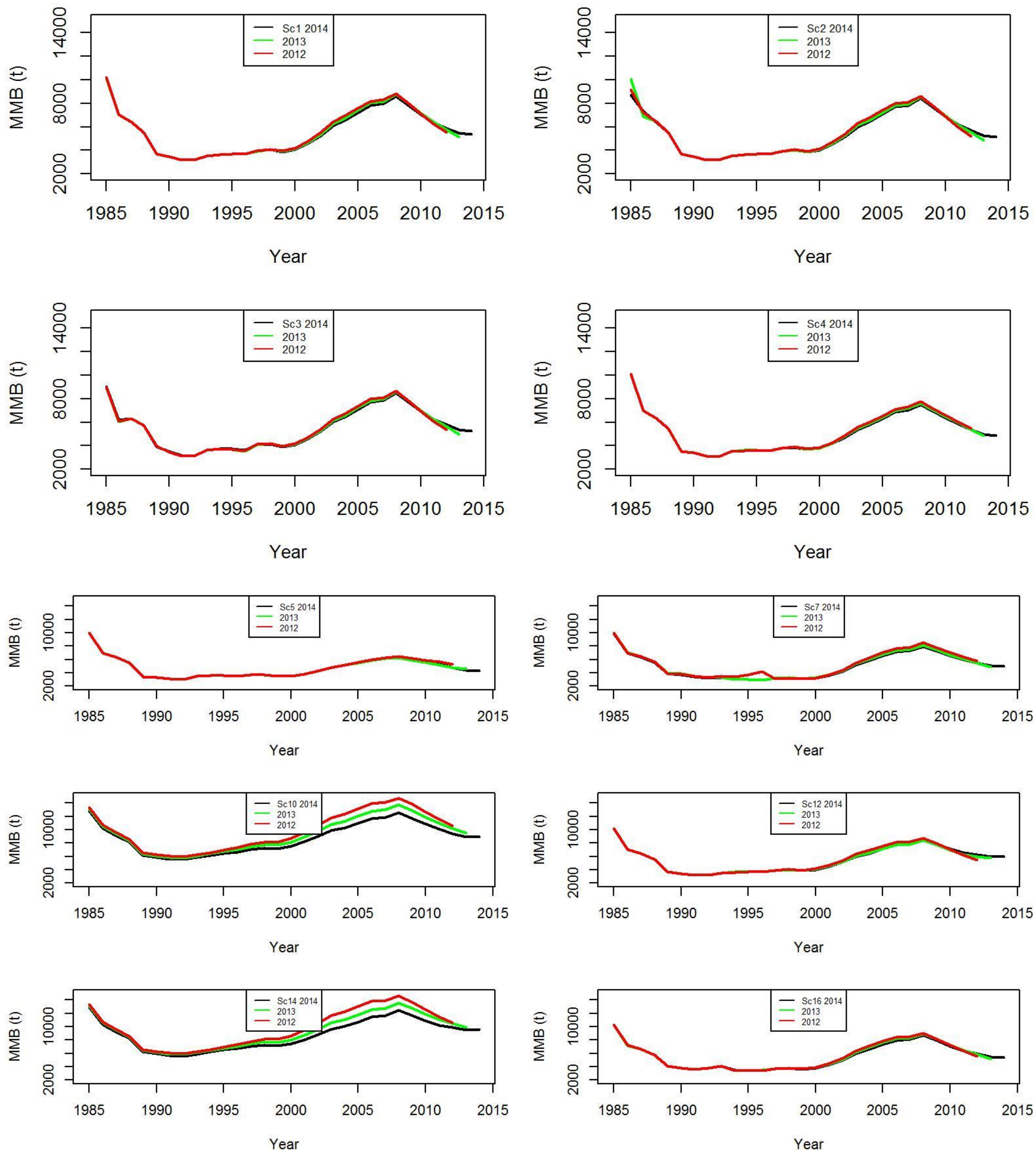


Figure 40. Retrospective fits of mature male biomass by the model when terminal year's data were systematically removed until 2012/13 for scenarios (Sc) 1, 2, 3, 4, 5, 7, 10, 12, 14, and 16 fits for golden king crab in the WAG, 1985–2014 (note: 1985 refers to the1985/86 fishing year).

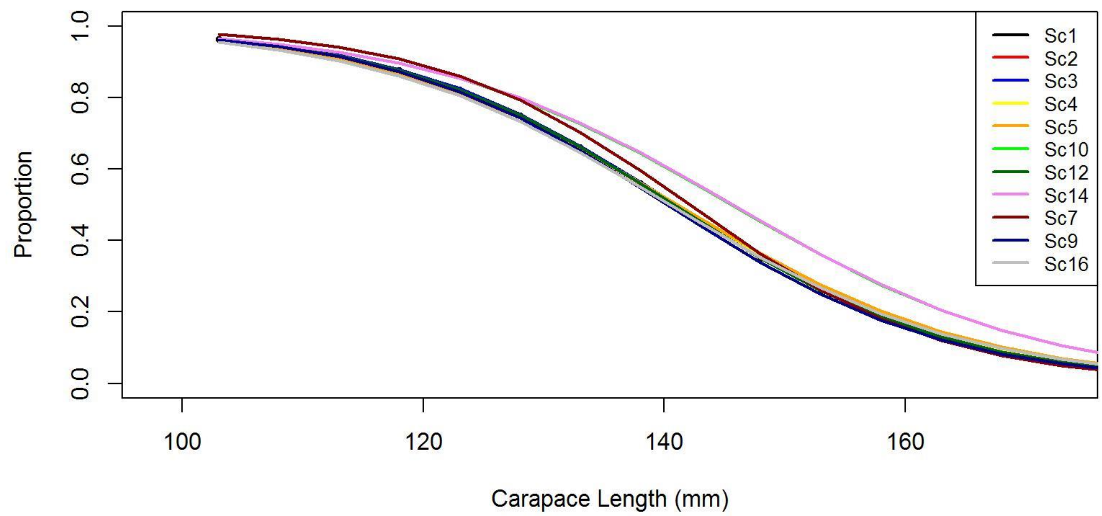


Figure 41. Estimated molt probability vs. carapace length of golden king crab under scenarios 1, 2, 3, 4, 5, 7, 9, 10, 12, 14, and 16 for WAG.

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:

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

where $N_{t,i}$ is the number of [male] crab in length class *i* on 1 July (start of fishing year) of year *t*; $\hat{C}_{t,i}$, $\hat{D}_{t,i}$, and $\hat{T}r_{t,i}$ 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

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

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

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

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

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

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

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

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

$$N_{1985,i} = \tilde{N}_{1985}\, e^{\varepsilon_i} / \sum_j e^{\varepsilon_j} \qquad \text{(A.4)}$$

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

$$\underline{N} = \mathbf{X}.\mathbf{S}.\underline{N} + \underline{R} \qquad \text{(A.5)}$$

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

$$\underline{N}_{1960} = (\mathbf{I} - \mathbf{XS})^{-1}\underline{R} \qquad \text{(A.6)}$$

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

We used the mean number of recruits from 1996 to 2014 in equation (A.6) to obtain the equilibrium solution under only natural mortality (0.23) in year 1960, and then projected the equilibrium abundance under natural mortality with recruitment estimated for each year after 1960 up to 1985 with removal of retained catches during 1981/82 to 1984/85.

Growth Matrix

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

$$X_{i,j} = \begin{cases} 0 & if\ j < i \\ P_{i,j} + (1 - m_i) & if\ j = i \\ P_{i,j} & if\ j > i \end{cases} \qquad \text{(A.7)}$$

where:

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

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

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

$$\mu_i = \omega_1 + \omega_2 * \bar{L}_i. \tag{A.8}$$

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

$$m_i = \frac{1}{1 + e^{c(\tau_i - d)}} \tag{A.9}$$

where *c* and *d* are parameters.

Selectivity and retention

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

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

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.

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

$$S_i = \left[\frac{1}{1 + e^{[-dj(\tau_i - \theta_{50})]}} \times \{1 - \frac{1}{1 + e^{[dk(\tau_i - \theta_{95})]}}\right] \frac{1}{X} \tag{A.11}$$

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

Recruitment

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

$$gamma(x|\alpha_r, \beta_r) = \frac{x^{\alpha_r - 1} e^{\frac{x}{\beta_r}}}{{\beta_r}^{\alpha_r} \Gamma_{(\alpha_r)}} \tag{A.12}$$

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

Parameter estimation

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

Tables A2 lists the values for the weight parameters, which weight (with the corresponding coefficient of variations in parentheses) the components of the objective function for EAG and WAG, respectively.

Likelihood components

Catches

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

$$LL_r^{catch} = \lambda_r \sum_t \{\ell n(\sum_j \hat{C}_{t,j} w_j + c) - \ell n(\sum_j C_{t,j} w_j + c)\}^2 \tag{A.13a}$$

$$LL_T^{catch} = \lambda_T \sum_t \{\ln(\sum_j \hat{T}_{t,j} w_j + c) - \ln(\sum_j T_{t,j} w_j + c)\}^2 \tag{A.13b}$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{\ln(\sum_j \widehat{Tr}_{t,j} w_j + c) - \ln(\sum_j Tr_{t,j} w_j + c)\}^2 \tag{A.13c}$$

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

Catch-rate indices

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

$$LL_r^{CPUE} = \lambda_{r,CPUE}\left\{0.5\sum_t \ln\left[2\pi\left(\sigma_{r,t}^2 + \sigma_e^2\right)\right] + \sum_t \frac{\left(ln(CPUE_t^r+c) - \ln(\widehat{CPUE}_t^r+c)\right)^2}{2\left(\sigma_{r,t}^2+\sigma_e^2\right)}\right\} \quad \text{(A.14)}$$

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 $CPUE_t^r$:

$$\widehat{CPUE}_t^r = q_k \sum_j S_j^T S_j^r \left(N_{t,j} - 0.5\left[\widehat{C_{t,J}} + \widehat{D_{t,J}} + \widehat{Tr_{t,J}}\right]\right)e^{-y_t M} \quad \text{(A.15)}$$

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 $\lambda_{r,CPUE}$ is the weight assigned to the catch-rate data. We used the same likelihood formula (A.14) for fish ticket retained catch rate indices for scenario 3 model.

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

$$\sigma_{r,t}^2 = \ln(1 + CV_{r,t}^2) \quad \text{(A.16)}$$

We also considered area shrinkage component in the catch rate estimation for some scenarios following (Zhou et al. (2011):

$$\widehat{\mathrm{CPUE}}_t^r = q_k\left(\frac{a_t}{A}\right)^{\eta} \sum_j S_j^T S_j^r \left(N_{t,j} - 0.5\left[\widehat{C_{t,J}} + \widehat{D_{t,J}} + \widehat{Tr_{t,J}}\right]\right)e^{-y_t M} \quad \text{(A.17)}$$

where a_t is the area fished during year t and A is the maximum area where stock has been caught during 1985-2014. However we used only the 1995-2014 proportions in the model scenarios (because observer standardized CPUE indices are available only for 1995-2014). We treated the WAG and EAG stocks separate for this analysis and assumed that the shrinkage of fishing area occurred separately at each stock inhabiting area. The parameter η determines the mixing process in each area: no mixing when $\eta = 1$, full mixing when $\eta = 0$, and partial mixing when $0 < \eta < 1$.

Length-composition data

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

$$LL_r^{LF} = 0.5\sum_t\sum_j \ell\mathrm{n}(2\pi\sigma_{t,j}^2) - \sum_t\sum_j \ell\mathrm{n}\left[\exp\left(-\frac{(P_{t,j}-\hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right) + 0.01\right] \quad \text{(A.18)}$$

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

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

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

$$\hat{L}^{GF}_{t,j} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \tag{A.19}$$

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

$$\sigma^2_{t,j} = \left[(1-P_{t,j})P_{t,j} + \frac{0.1}{n}\right] / S_t \tag{A.20}$$

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

The input effective sample sizes were rescaled from actual numbers of length measurements for all scenarios except scenario 9 (iterative reweighting) as follows:

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

$$S^T_t = \min(0.001 * number\ of\ length\ measurements\ in\ year\ t, 150) \tag{A.21}$$

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

Iterative reweighting of effective sample sizes at stage-2 for scenario 9 was done using Francis' (2011) method. Stage-1 weighting for this procedure was done using equation A.21, but without implementing the maximum limits of 200, 150, and 25 for retained catch, total catch, and groundfish bycatch, respectively.

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:

$$\ell \mathrm{n} L=\sum_t \sum_j \sum_y \sum_i \tilde{V}_{j,t,y,i} \ell \mathrm{n} \hat{\rho}_{j,t,y,i} \tag{A.22}$$

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

$$\underline{\hat{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{\Omega}^{(j)} \tag{A.23}$$

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 length-class l is given by:

$$r_l=\sum_t \sum_j \frac{s_l [\mathbf{X}^t]_{j,l}}{\sum_{l'} s_{l'} [\mathbf{X}^t]_{j,l'}} \sum_k V_{j,k,t} \tag{A.24}$$

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

Penalties

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

$$P_1=\lambda_F \sum_t (\ell \mathrm{n} F_t - \ell \mathrm{n} \bar{F})^2 \tag{A.25}$$

$$P_2=\lambda_{F^{Tr}} \sum_t (\ell \mathrm{n} F_t^{Tr} - \ell \mathrm{n} \bar{F}^{Tr})^2 \tag{A.26}$$

$$P_3=\lambda_R \sum_t (\ell \mathrm{n} \varepsilon_t)^2 \tag{A.27}$$

$$P_5 = \lambda_{posfn} * fpen \tag{A.28}$$

Standardized Residual of Length Composition

$$Std.Res_{t,j} = \frac{P_{t,j} - \widehat{P_{t,J}}}{\sqrt{2\sigma_{t,j}^2}} \tag{A.29}$$

Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n}(\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \tag{A.30}$$

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

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \tag{A.31}$$

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:

$$MMB_t = \sum_{j=mature\ size}^{n} \{N_{j,t} e^{y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t}) e^{(y_t - y')M}\} w_j \tag{A.32}$$

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 $MMB_t > 0.25M\overline{M}B$,

$$F' = \gamma M \frac{\left(\frac{MMB_t}{M\overline{M}B} - \alpha\right)}{(1-\alpha)} \tag{A.33}$$

(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 A.32 and A.33 with retained and discard catch predicted from Equations A.2b-d. The next year limit harvest catch is estimated using Equations A.2b-d with the estimated F' value.

Table A1. 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
Trawl fishery, F_t^{Tr}	1989–2014 (the mean F for 1989 to 1994 was used to estimate trawl discards back to 1985.
Mean trawl 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+)
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, 0.23 yr^{-1}
Recruitment:	
Distribution to length-class, α_r, β_r	2
Median recruitment, $\bar{R}$	1
Recruitment deviations, ε_t	55 (1961–2015) or 30 (1986–2015)
F_{OFL}	1
Fishery catchability, q	2 (1985–2004; 2005+) or 3 (1985–1994; 1995–2004; 2005+)
Likelihood weights (coefficient of variation)	Pre-specified, varies for different scenarios

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

Weight	Value						
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
Catch:							
Retained catch for 1981–1984 and/or 1985–2014, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch for 1990–2014, λ_T	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 for 1989–2014, λ_{GD}	0.2 (3.344)	0.2	0.2	0.2	0.2	0.2	0.2
Catch-rate:							
Observer legal size crab catch-rate for 1995–2014, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	1	1
Fish ticket retained crab catch-rate for 1985–1998 , $\lambda_{r,CPUE}$			1(0.805)				
Penalty weights:							
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase

Table A2 continued.

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

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

Table A2 continued.

Weight	Value				
	Scenario 8	**Scenario 9**	**Scenario 10**	**Scenario 11**	**Scenario 12**
Catch:					
Retained catch. λ_r	500 (0.032)	500	500	500	500
Total catch, λ_T	Number of sampled pots scaled to a max 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}	0.2 (3.344)	0.2	0.2	0.2	0.2
Catch-rate:					
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1
Penalty weights:					
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select.phase	Initially 1000, relaxed to 0.001 at phases ≥ select.phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select.phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select.phase
Recruitment, λ_R	2(0.533)	2	2	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000	1000	1000
Tagging likelihood	EAG individual tag returns	EAG individual tag returns	EAG individual tag returns	EAG individual tag returns	EAG individual tag returns

Table A2 continued.

Weight	Value			
	Scenario 13	**Scenario 14**	**Scenario 15**	**Scenario 16**
Catch:				
Retained catch, λ_r	500 (0.032)	500	500	500
Total catch, λ_T	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}	0.2 (3.344)	0.2	0.2	0.2
Catch-rate:				
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$	1(0.805)	1	1	1
Penalty weights:				
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2(0.533)	2	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000	1000
Tagging likelihood	EAG individual tag returns	EAG individual tag returns	EAG individual tag returns	EAG individual tag returns

Appendix B: ***Catch and CPUE data***

The commercial catch and length frequency distribution were estimated from ADF&G landing records and dockside sampling (Bowers et al., 2008, 2011). The annual retained catch, total catch, and groundfish (or trawl) discarded mortality are provided in Table 1 for EAG and Table 14 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:

$$\sum_{j=1}^{k} C_j \frac{LF_{j,i}}{\sum_{i=1}^{n} LF_{j,i}} \qquad \text{(B.1)}$$

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

The annual total catch (in number of crabs) was estimated by the observer nominal (unstandardized) total CPUE considering all vessels multiplied by the total fishing effort (number of pot lifts). The weighted length frequency of the observer samples across the fleet was estimated using Equation B.1. Observer measurement of crab ranged from 20 to 220 mm CL. To restrict the total number of crabs to the model assumed size range (101-185+ mm CL), the proportion of observer total relative length frequency corresponding to this size range was multiplied by the total catch (number of crabs). This total number of crabs was distributed into length-classes using the weighted relative length frequency. Thus crab sizes < 101 mm CL were excluded from the model. 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 crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season (Tables 2 and 15). For model-fitting the CPUE time series was further restricted to 1995/96–2014/15 because the reliability of categorization of crabs 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 separate observer CPUE time series, 1995/96–2004/05 and 2005/06–2014/15, to estimate CPUE indices for model input.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE as a separate likelihood component in 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 16).

Observer CPUE index:

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

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \quad \text{(B.2)}$$

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

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

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 (Siddeek et al., *in press*).

The final models for EAG were:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns(Soak, 3)} \quad \text{(B.4)}$$

for the 1995/96–2004/05 period [θ=1.33, $R^2 = 0.23$ with ns(Soak, 3) forced in]

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 16) + \mathrm{Gear} \tag{B.5}$$

for the 2005/06–2014/15 period ($\theta = 2.25$, $R^2 = 0.11$).

The final models for WAG were:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 8) \tag{B.6}$$

for the 1995/96–2004/05 period (θ=0.98, $R^2 = 0.18$), and

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 16) \tag{B.7}$$

for the 2005/06–2014/15 period [θ=1.16, $R^2 = 0.05$ with ns(Soak, 16) forced in]

Standardized nominal CPUE data are presented in Tables 2 and 15 respectively, for EAG and WAG.

Figures B.1 and B.10 depict the trends in nominal and standardized CPUE indices for the two CPUE time series for EAG and WAG, respectively. Figures B.2-B.3 and B.11-B.12 show the diagnostic plots for the fits for EAG and WAG, respectively. The deviance and QQ plots support good fits to EAG and WAG data by GLM using the negative binomial error distribution. Figures B.4-B.9 and B.13-B.18 depict CDI and influence plots of the predictor variables 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:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Vessel} + \mathrm{Month}, \quad R^2 = 0.45 \tag{B.8}$$

and for WAG was:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Vessel}, \quad R^2 = 0.46 \tag{B.9}$$

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

Figures B.19 and B.21 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively. Figures B.20 and B.22 show the QQ plots for the fits for EAG and WAG, respectively. The QQ plots support reasonable fits to EAG and WAG data by GLM using the lognormal error distribution.

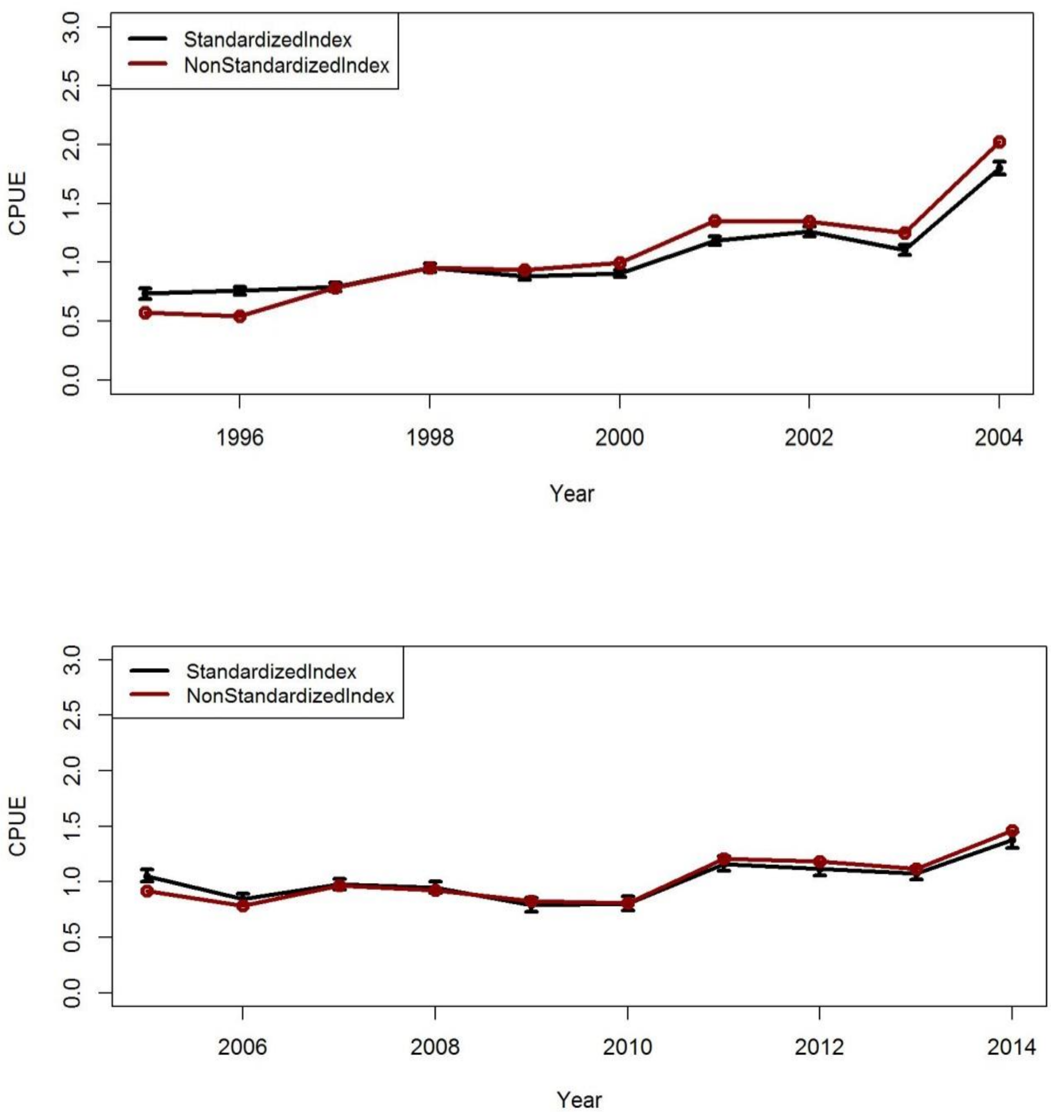


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2014/15 observer data. Standardized indices: black line and non-standardized indices: red line.

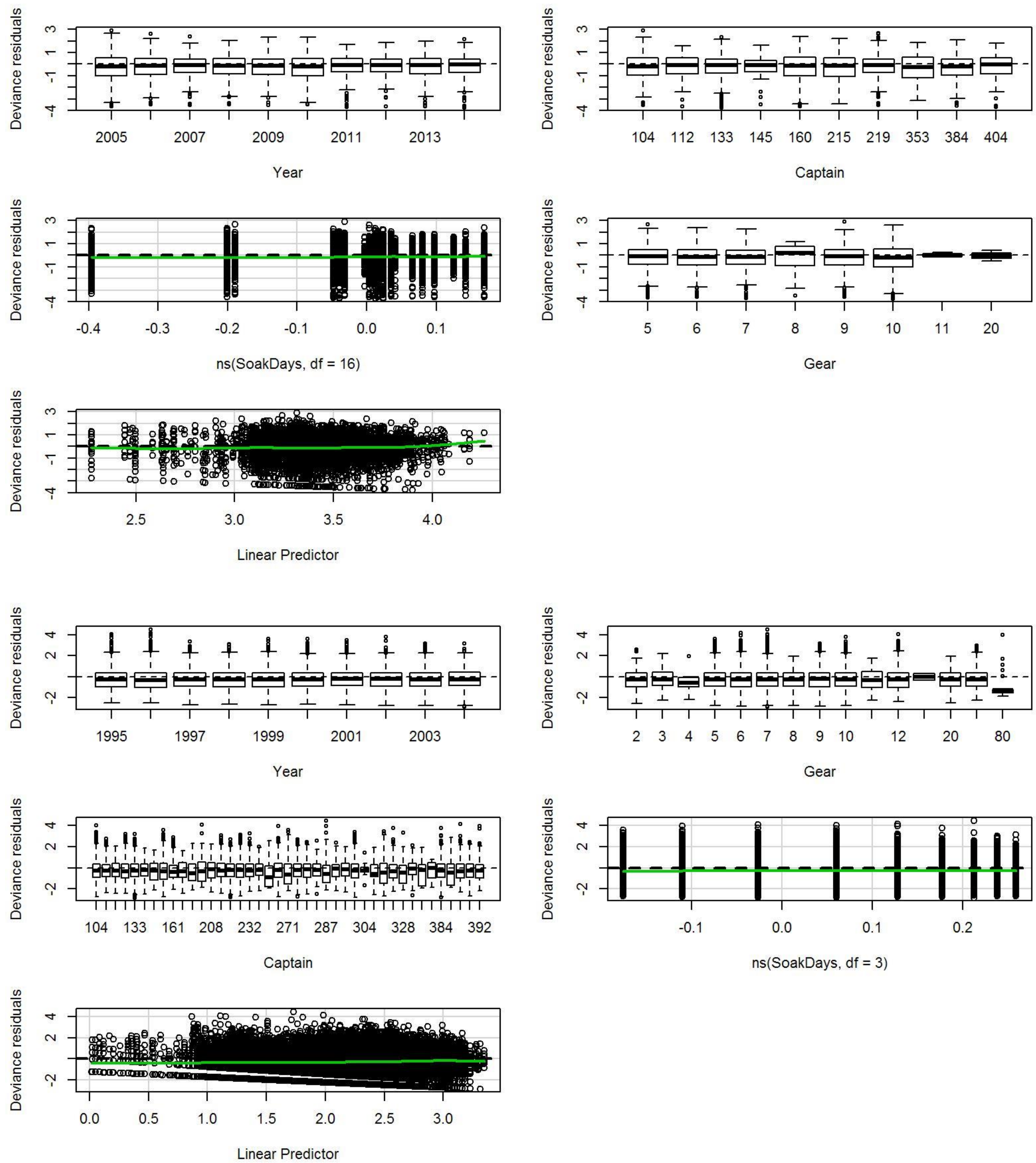


Figure B.2. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 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.

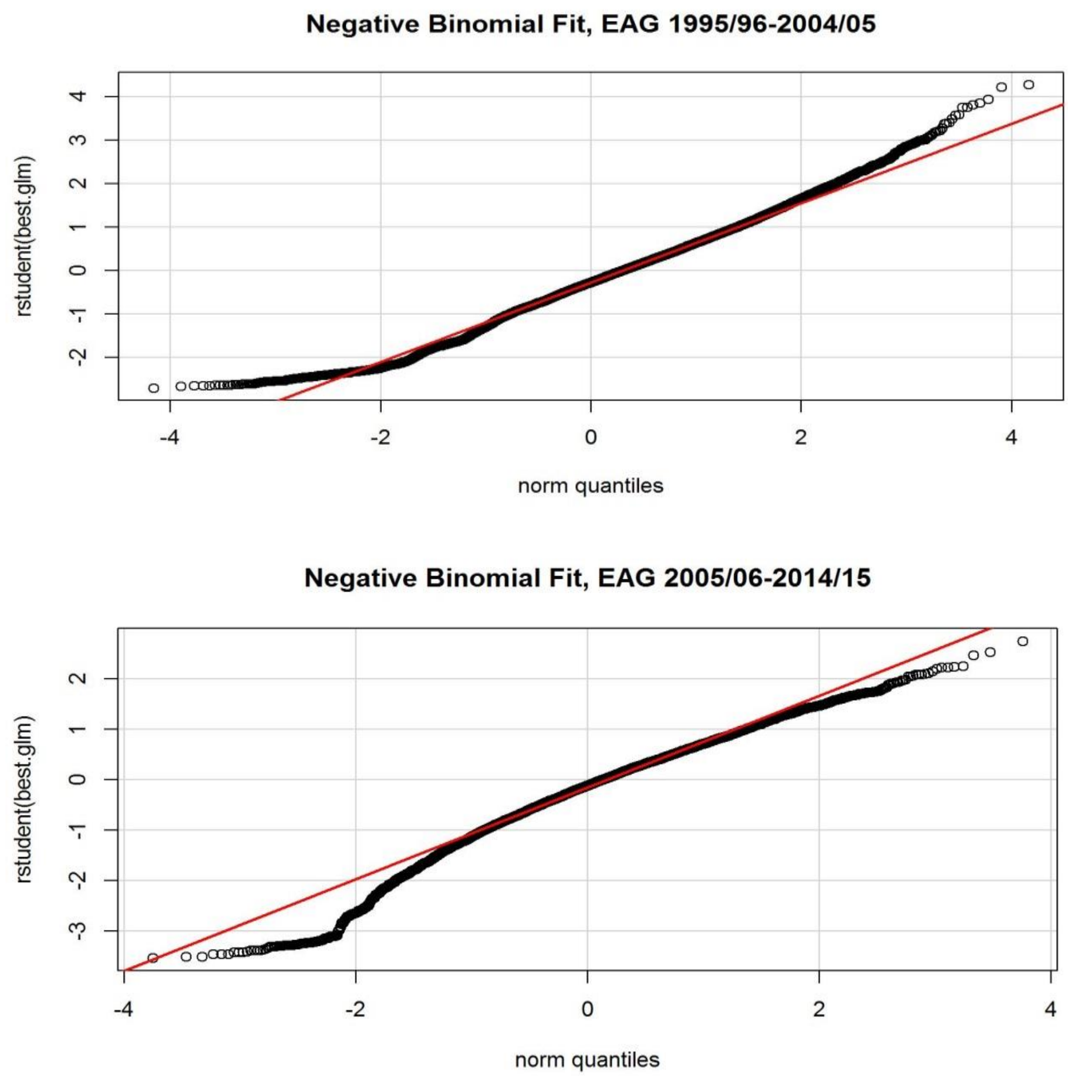


Figure B.3. Studentized residual plots for negative binomial GLM fit for EAG golden king crab observer legal size male crab CPUE data. Top panel is for 1995/96–2004/05 data and the bottom panel is for 2005/06–2014/15 data.

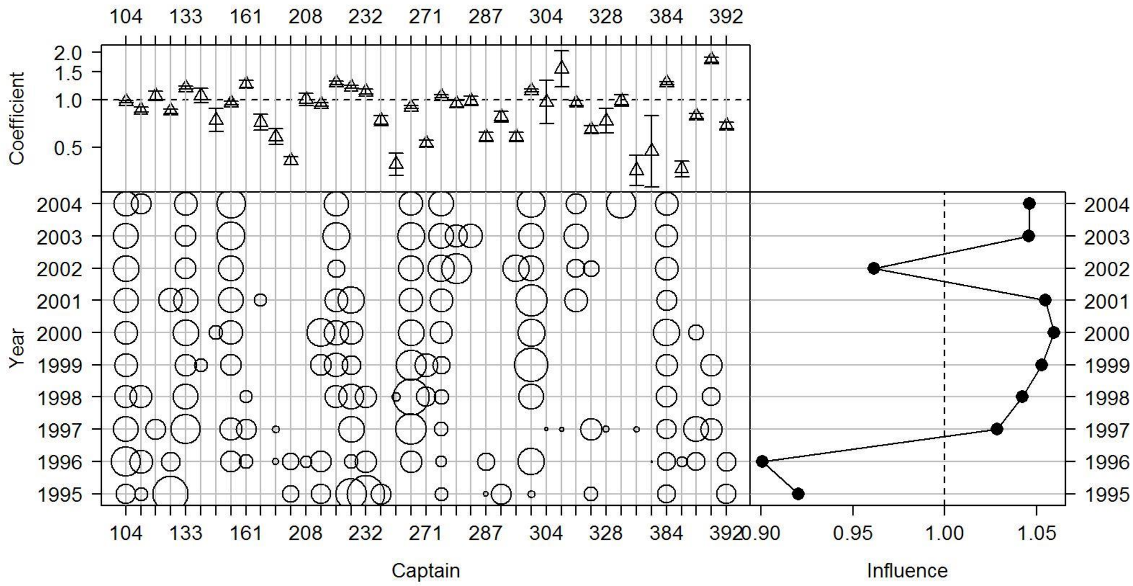


Figure B.4. CDI plot for Captain for the negative binomial fit of 1995/96–2004/05 data for EAG.

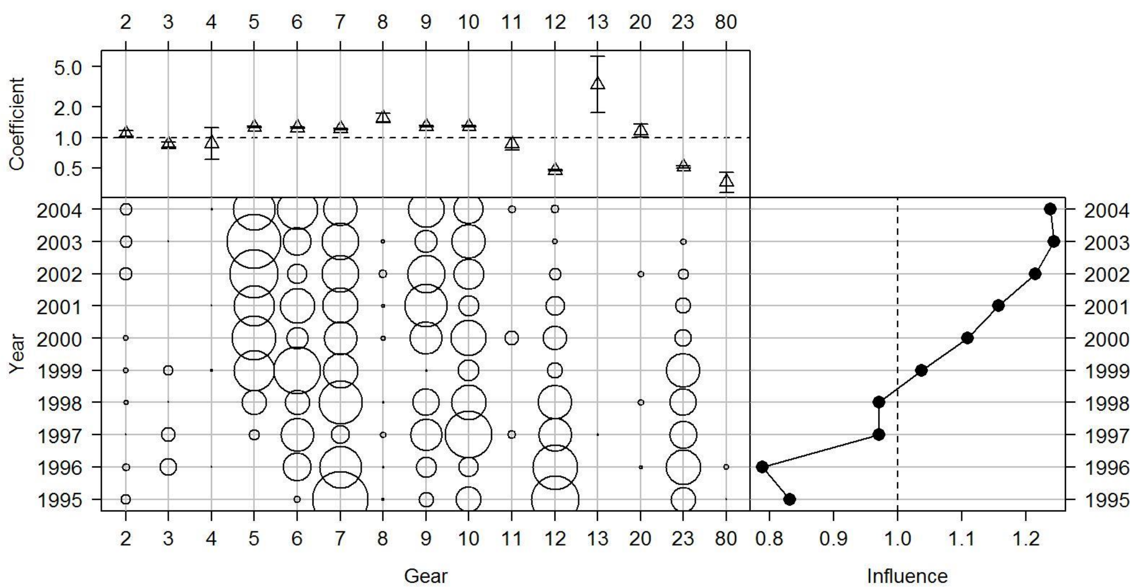


Figure B.5. CDI plot for Gear for the negative binomial fit of 1995/96–2004/05 data for EAG.

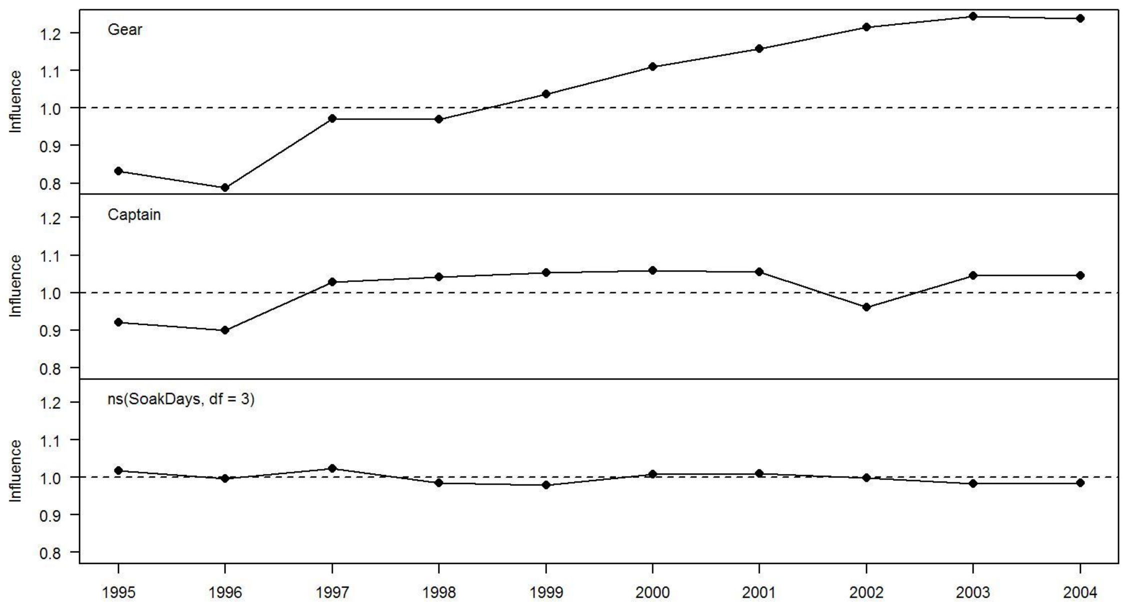


Figure B.6. Influence plot of predictor variables in the final model for the negative binomial fit of 1995/96–2004/05 data for EAG.

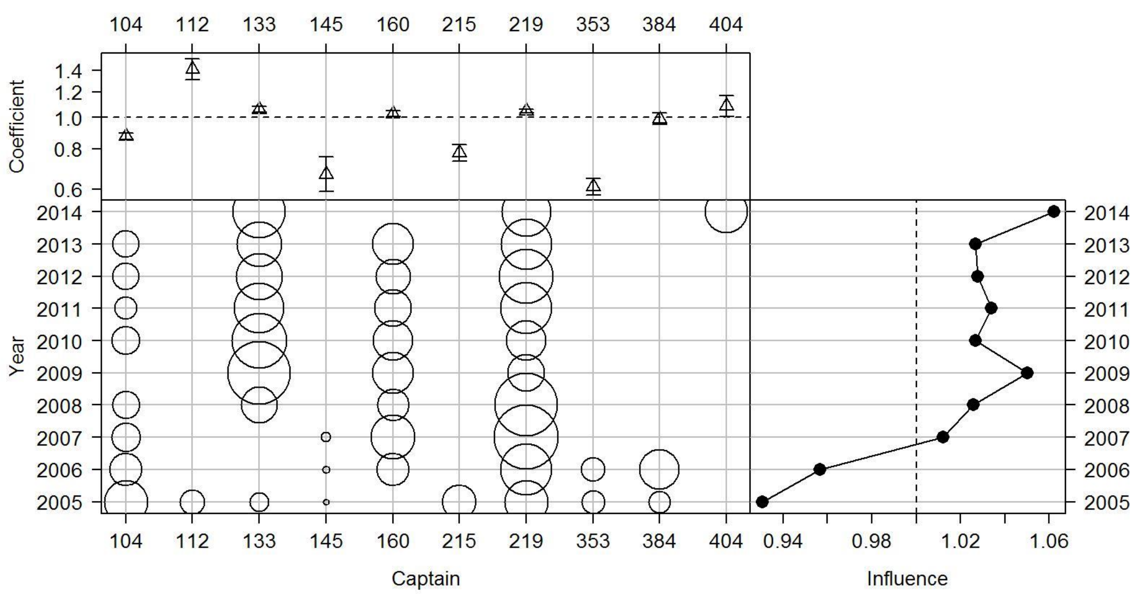


Figure B.7. CDI plot for Captain for the negative binomial fit of 2005/06–2014/15 data for EAG.

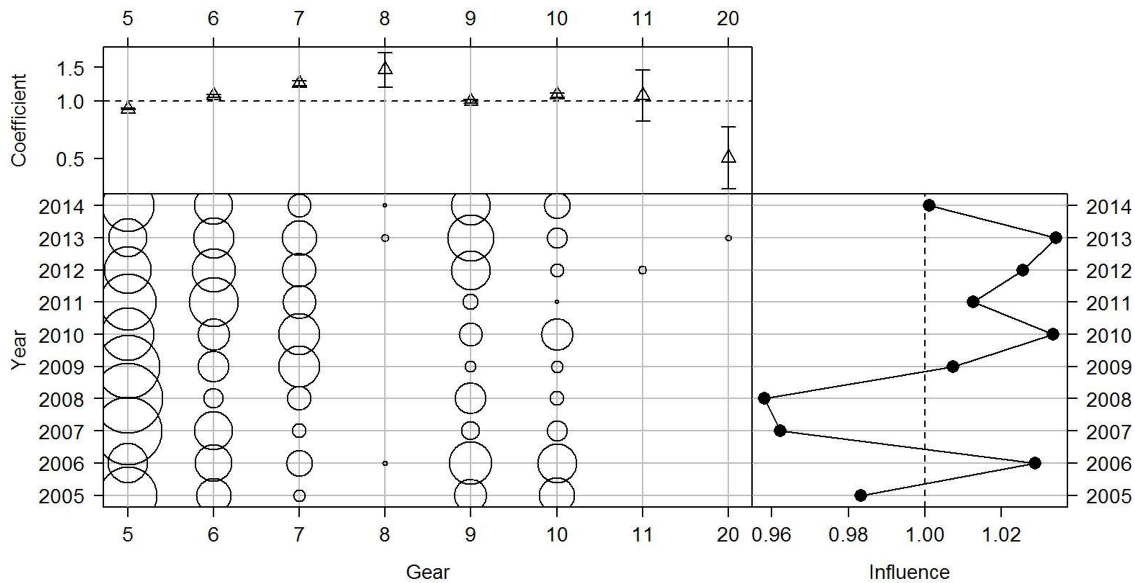


Figure B.8. CDI plot for Gear for the negative binomial fit of 2005/06–2014/15 data for EAG.

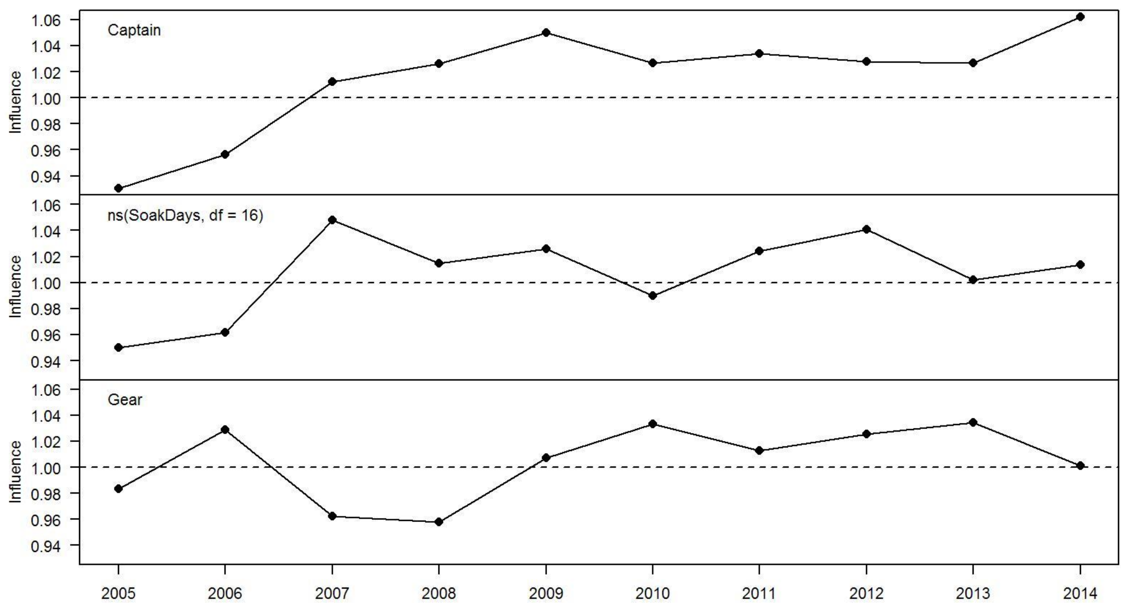
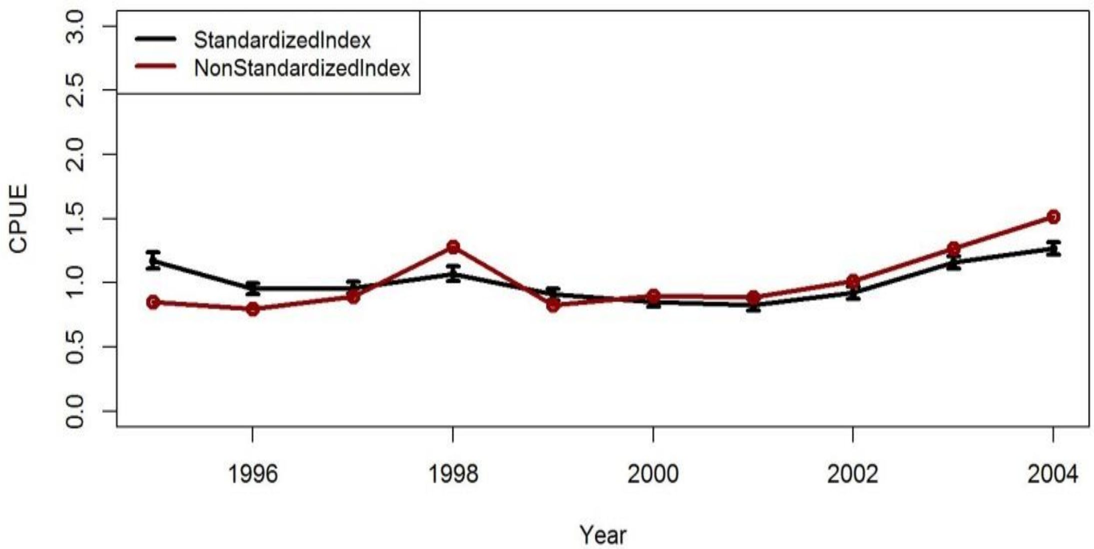


Figure B.9. Influence plot of predictor variables in the final model for the negative binomial fit of 2005/06–2014/15 data for EAG.



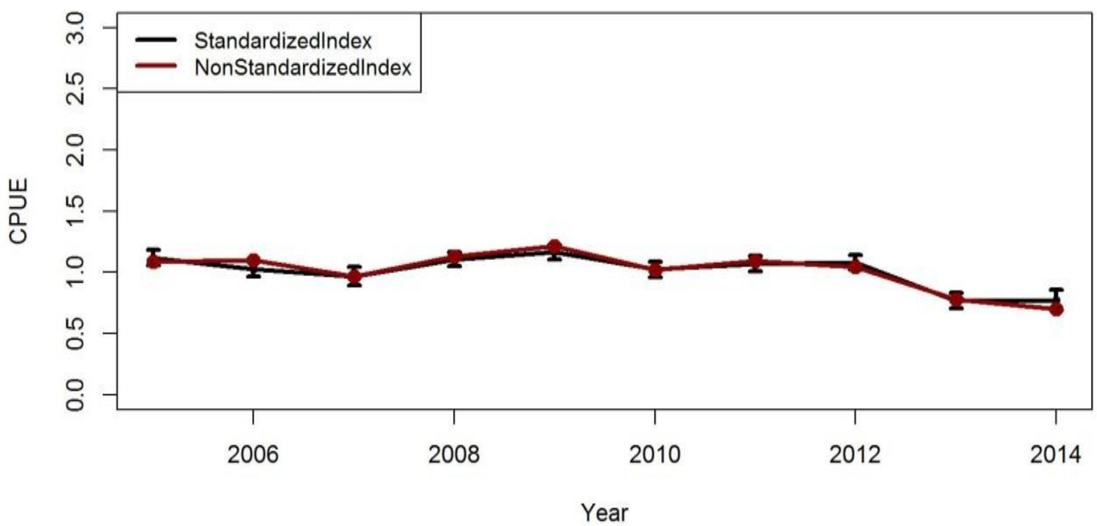


Figure B.10. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2014/15 observer data. Standardized indices: black line and non-standardized indices: red line.

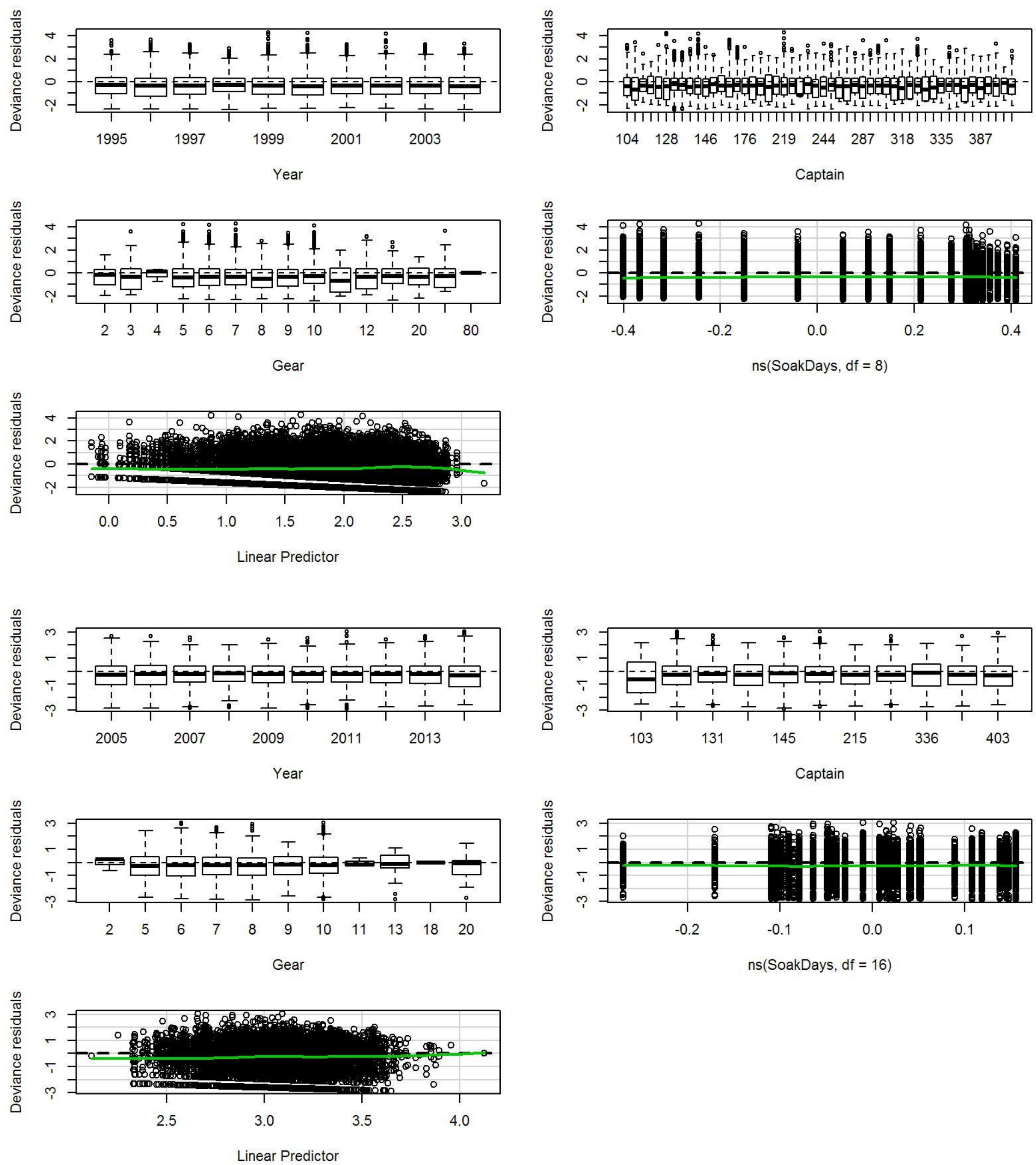
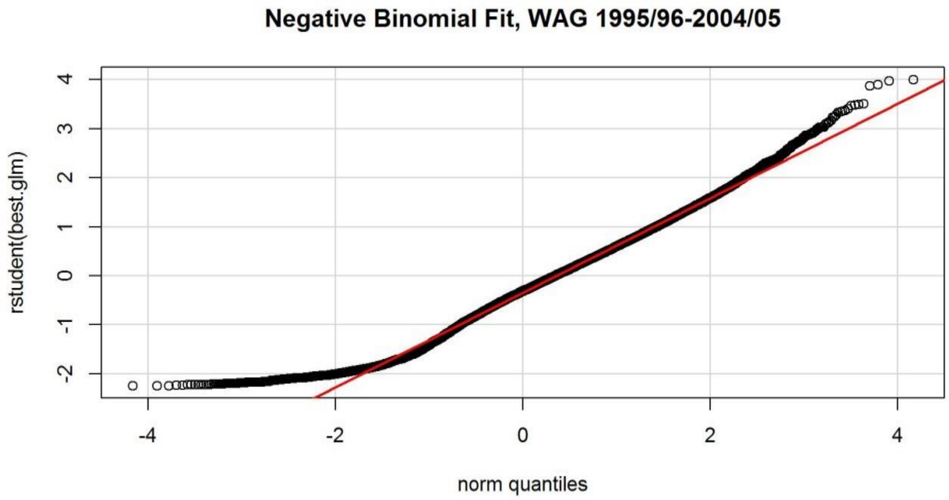


Figure B.11. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer 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.



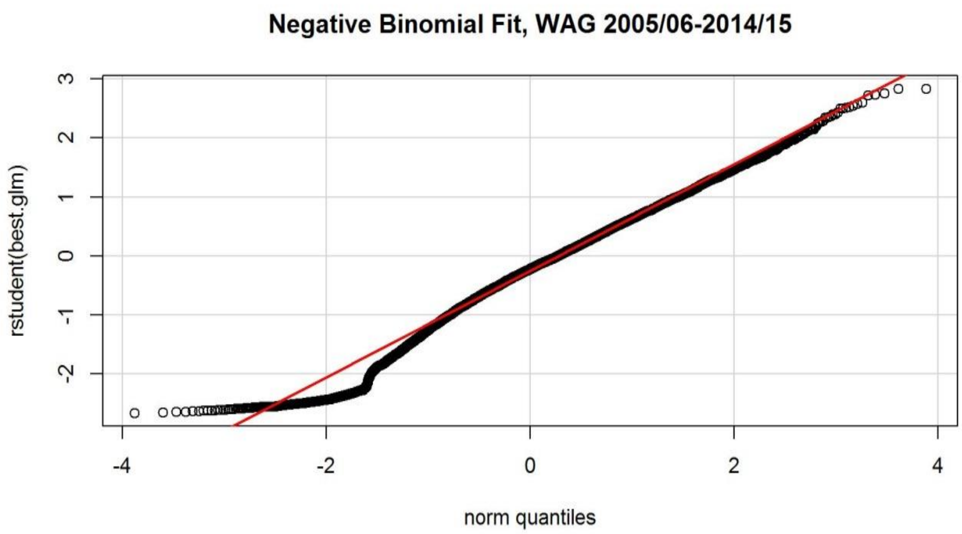


Figure B.12. Studentized residual plots for negative binomial GLM fit for WAG golden king crab observer legal size male crab CPUE data. Top panel is for 1995/96–2004/05 and bottom panel is for 2005/06–2014/15 data sets, respectively.

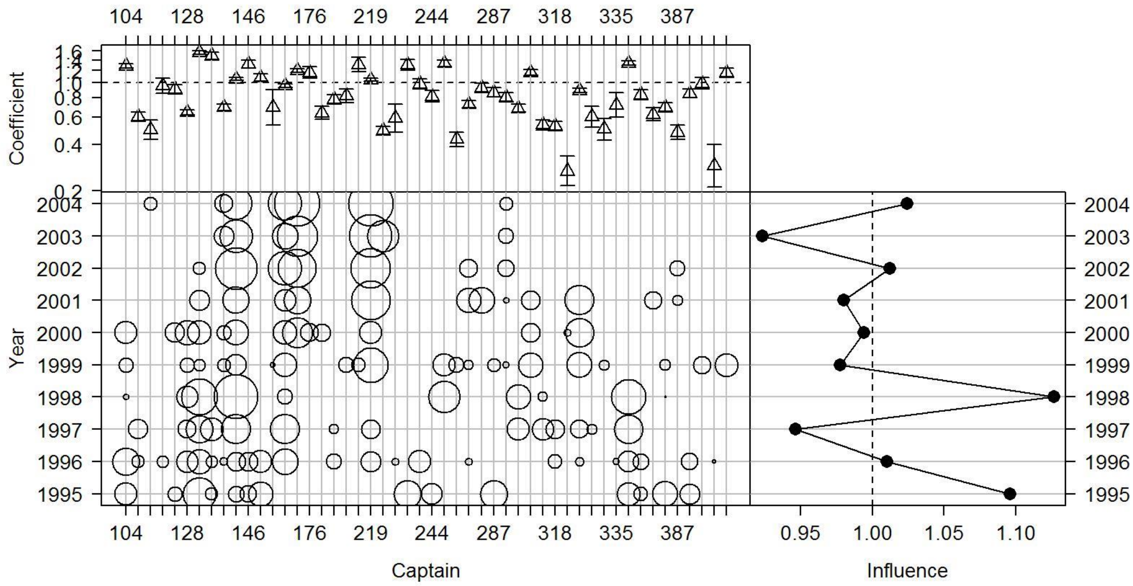


Figure B.13. CDI plot for Captain for the negative binomial fit of 1995/96–2004/05 data for WAG.

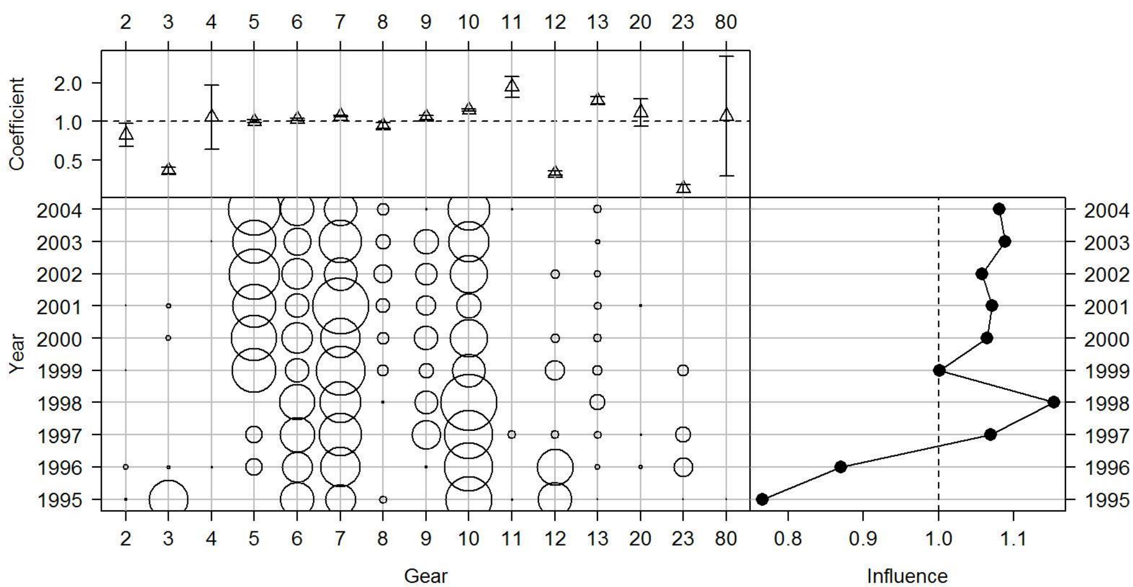


Figure B.14. CDI plot for Gear for the negative binomial fit of 1995/96–2004/05 data for WAG.

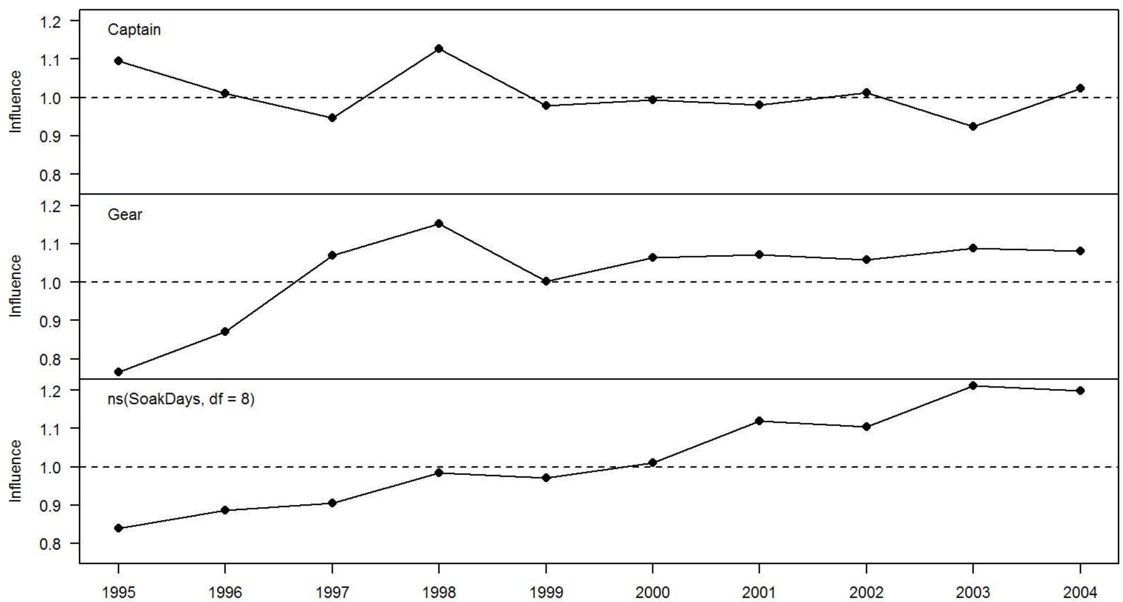


Figure B.15. Influence plot of predictor variables in the final model for the negative binomial fit of 1995/96–2004/05 data for WAG.

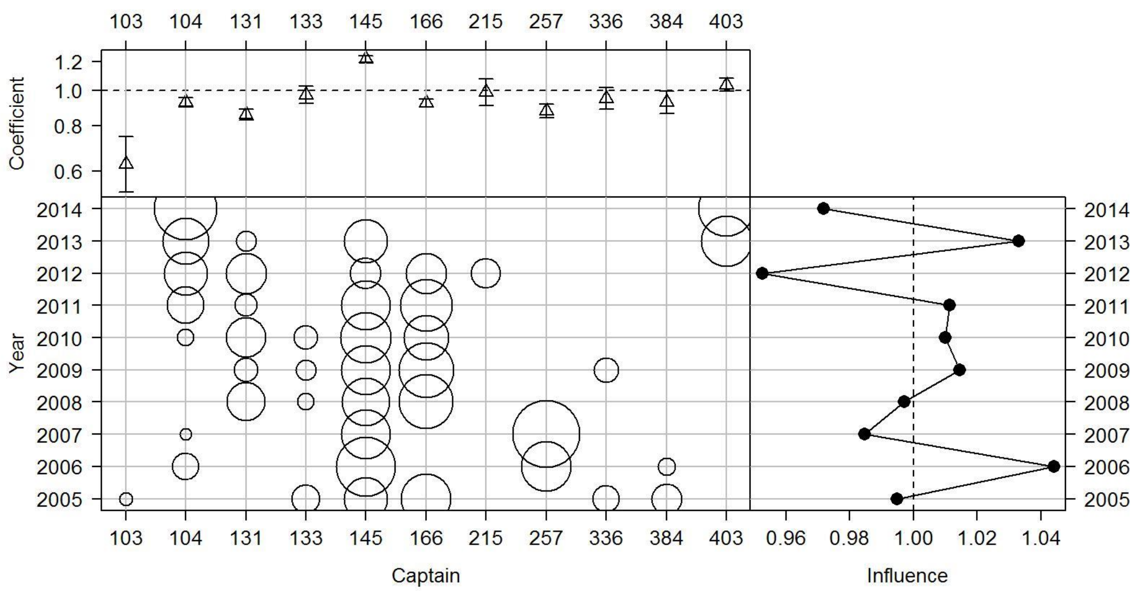


Figure B.16. CDI plot for Captain for the negative binomial fit of 2005/06–2014/15 data for WAG.

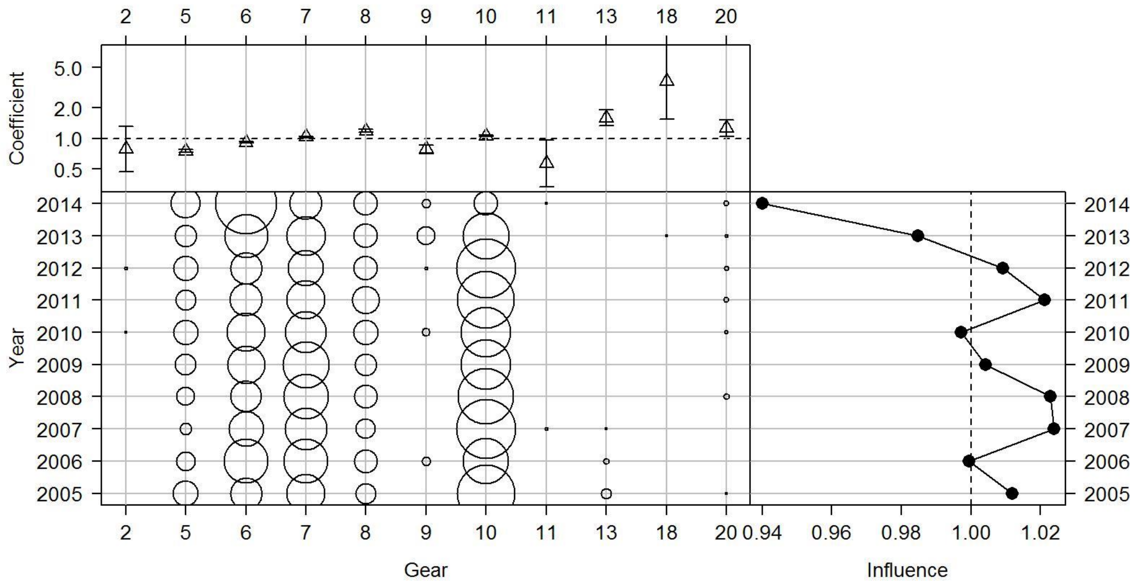


Figure B.17. CDI plot for Gear for the negative binomial fit of 2005/06–2014/15 data for WAG.

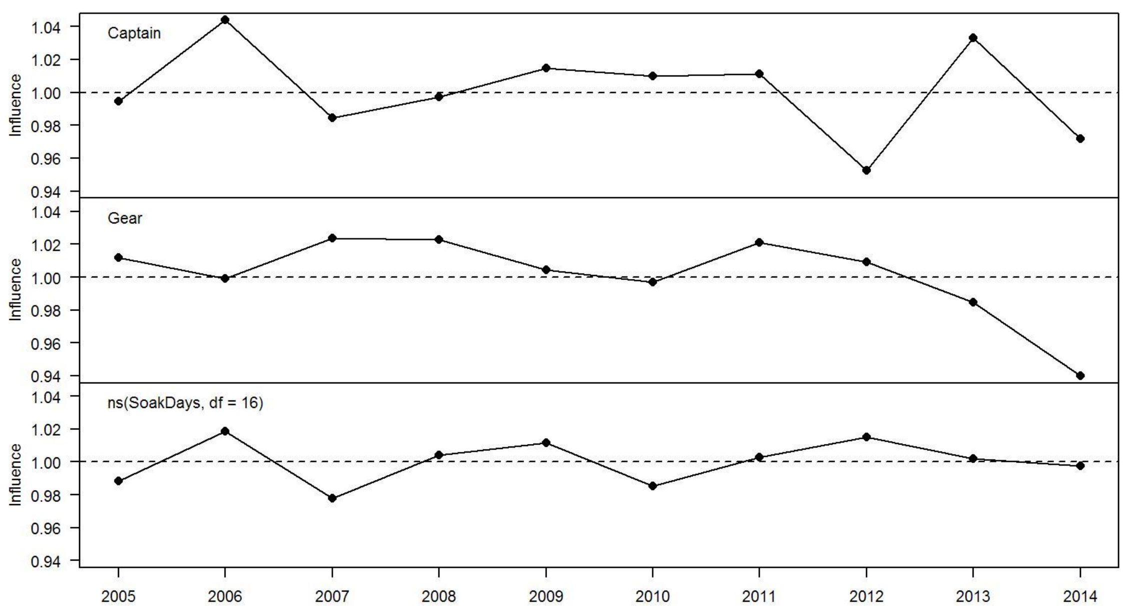


Figure B.18. Influence plot of predictor variables in the final model for the negative binomial fit of 2005/06–2014/15 data for WAG.

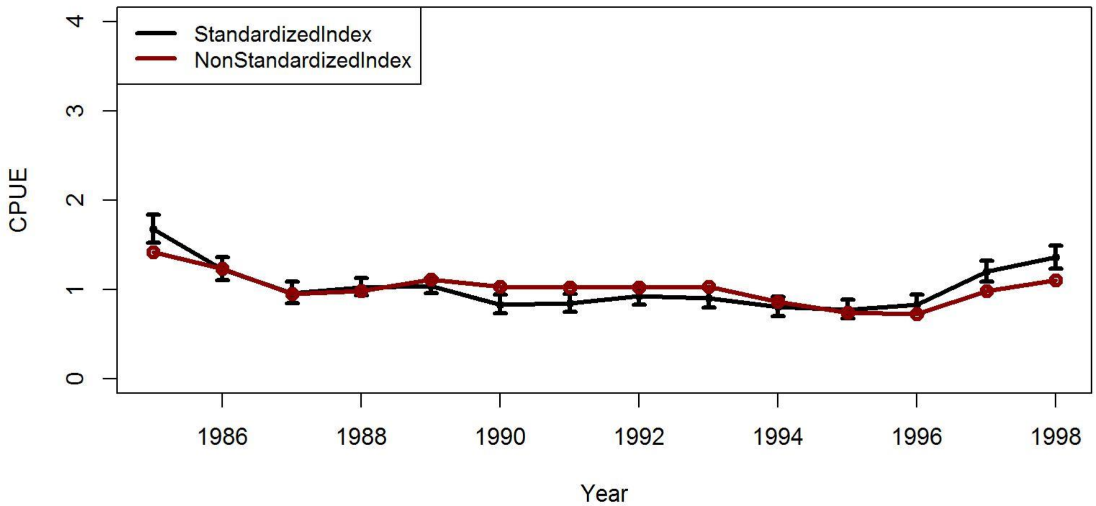


Figure B.19. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

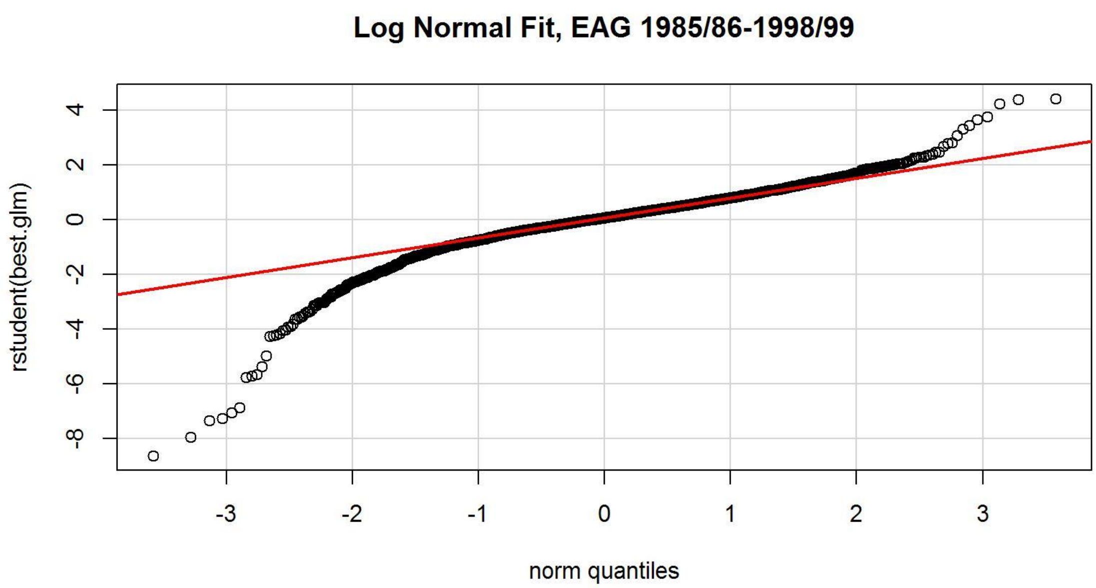


Figure B.20. Studentized residual plots for lognormal GLM fit for EAG golden king crab fish ticket CPUE data. The 1985/86–1998/99 fish ticket data set was used.

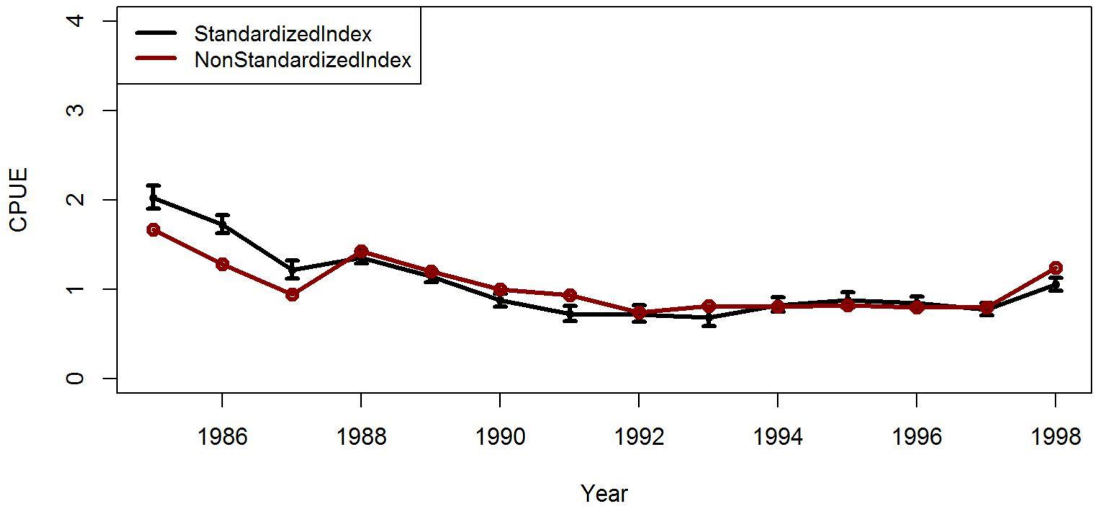


Figure B.21. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

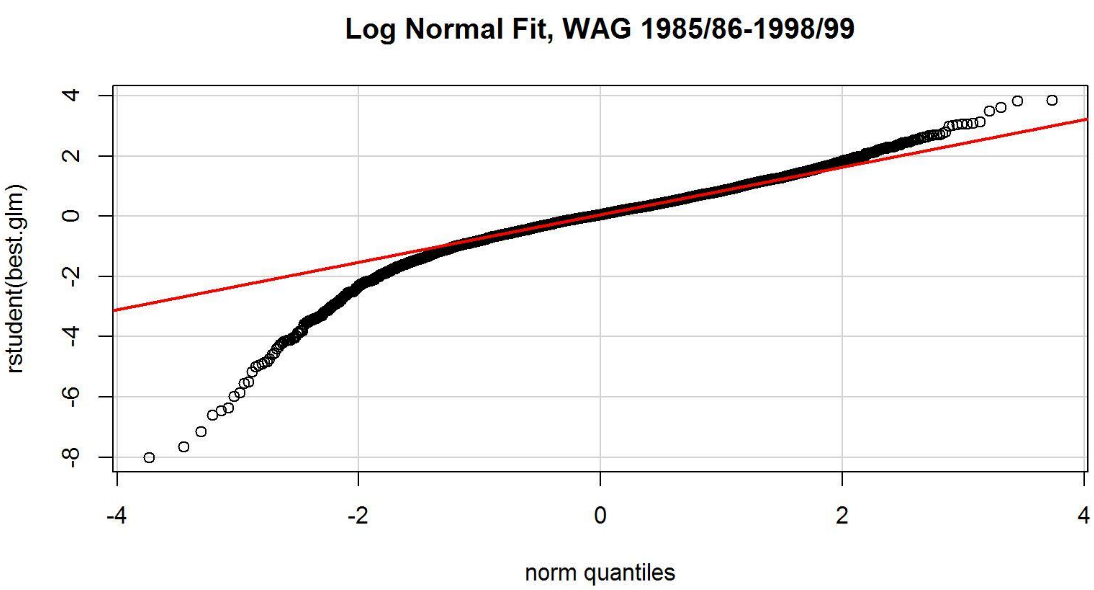


Figure B.22. Studentized residual plots for lognormal GLM fit for WAG golden king crab fish ticket CPUE data. The 1985/86–1998/99 fish ticket data set was used.