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

Draft report for the September 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 were 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 (crab / pot-pull) increased in both EAG and WAG fisheries in the mid-2000s; however, in recent years WAG catch rates have declined and the fishery did not harvest the allotted TAC.

3. *Stock biomass*

Estimated mature male biomass (MMB) for EAG under scenario 1c decreased from peak levels during the mid-1990s of the directed fishery, then systematically increased and stabilized in recent years. Estimated MMB under scenario 1a for WAG decreased during the late 1980s and 1990s, 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 in 1991–1992 for WAG. Stock trends reflected the fishery standardized CPUE trends in both regions.

4. *Recruitment*

The numbers of recruits to the model size groups under scenarios 1a and 1c have fluctuated in both EAG and WAG. For EAG, the model recruitment was high in 1988, 1991, 2010, 2012, and 2015, and lowest in 1986, while model recruitment for WAG was highest in 1985 and 1986, and lowest in 2008.

5. *Management performance*

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

6. *Basis for the OFL*

We provide the OFL estimates under the Tier 4 and Tier 3 approaches for EAG, WAG, and the two regions pooled together (i.e., for the entire Aleutian Islands, AI), respectively. The length-based model developed for the Tier 4 and Tier 3 analysis estimated MMB on February 15 each year for the period 1986 through 2016 and projected to February 15, 2017 for OFL and ABC determination.

The Tier 4 approach proposes a maximum F_{OFL} of γM. The OFLs and ABCs were determined based on using the 1986–2016 mean MMB as the reference biomass (MMB_{ref}). On the other hand, Tier 3 approach estimates OFLs and ABCs based on the mean number of recruits for the period 1986 to 2016.

The total OFL and ABC estimates are provided for thirteen scenarios for EAG, WAG, and AI, respectively in the following tables. We treat scenario 1c (effective sample size is the number of fishing trips) as the base scenario for EAG and scenario 1a (effective sample size is the number of length measurements scaled to a maximum) as the base scenario for WAG. **If the model is accepted, we recommend the OFL and ABC estimates for any one of scenarios 1a (base, effective sample size is the number of length measurements), 1c (base, effective sample size is the number of fishing trips), 2a (1a with fish ticket CPUE), 2c (1c with fish ticket CPUE), 6a (1a with iteratively estimated effective sample sizes), 6c (1c with iteratively estimated effective sample sizes), 8a (1a with dome shaped selectivity), and 8c (1c with dome shaped selectivity) under Tier 3 or Tier 4 estimation procedure.**

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)	ABC (0.8*OFL)
1a	4a	14.672	27.037	1.84	0.23	1986–2016	1	0.2339	3.679	3.660	2.943
1b	4a	13.032	21.820	1.67	0.23	1986–2016	1	0.2339	2.590	2.575	2.072
1c	4a	15.043	21.876	1.45	0.23	1986–2016	1	0.2339	3.319	3.302	2.655
2a	4a	15.315	25.808	1.69	0.24	1986–2016	1	0.2426	3.739	3.721	2.991
2c	4a	15.387	23.411	1.52	0.24	1986–2016	1	0.2426	3.581	3.563	2.865
4c	4a	15.447	22.534	1.46	0.23	1986–2016	1	0.2339	3.664	3.644	2.931
6a	4a	15.431	23.952	1.55	0.23	1986–2016	1	0.2339	3.610	3.593	2.888
6c	4a	16.362	22.356	1.37	0.23	1986–2016	1	0.2339	3.814	3.797	3.051
7c	4a	16.402	22.080	1.35	0.24	1986–2016	1	0.2426	3.796	3.780	3.037
8a	4a	16.189	27.286	1.69	0.23	1986–2016	1	0.2339	3.958	3.935	3.167
8c	4a	17.509	25.781	1.47	0.23	1986–2016	1	0.2339	3.890	3.870	3.112
16c	4a	14.203	21.649	1.52	0.18	1986–2016	1	0.18	2.537	2.525	2.030
19c	4a	13.850	18.954	1.37	0.23	1986–2016	1	0.2339	2.654	2.636	2.123

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

Scenario	Tier	MMB_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define MMBref	γ	M	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1a	4a	6.665	12.264	1.84	0.23	1986–2016	1	0.2339	1,668.785	1,660.004	1,335.028
1b	4a	5.911	9.898	1.67	0.23	1986–2016	1	0.2339	1,174.966	1,168.044	939.973
1c	4a	6.824	9.923	1.45	0.23	1986–2016	1	0.2339	1,505.597	1,497.713	1,204.478
2a	4a	6.947	11.707	1.69	0.24	1986–2016	1	0.2426	1,696.043	1,687.795	1356.834
2c	4a	6.980	10.619	1.52	0.24	1986–2016	1	0.2426	1,624.393	1,616.270	1,299.515
4c	4a	7.007	10.221	1.46	0.23	1986–2016	1	0.2339	1,661.950	1,652.751	1,329.560
6a	4a	7.000	10.864	1.55	0.23	1986–2016	1	0.2339	1,637.623	1,629.849	1,310.098
6c	4a	7.422	10.141	1.37	0.23	1986–2016	1	0.2339	1,729.963	1,722.534	1,383.970
7c	4a	7.440	10.016	1.35	0.24	1986–2016	1	0.2426	1,721.886	1,714.740	1,377.509
8a	4a	7.343	12.377	1.69	0.23	1986–2016	1	0.2339	1,795.450	1,784.976	1,436.360
8c	4a	7.942	11.694	1.47	0.23	1986–2016	1	0.2339	1,764.359	1,755.579	1,411.487
16c	4a	6.442	9.820	1.52	0.18	1986–2016	1	0.18	1,150.926	1,145.202	920.741
19c	4a	6.282	8.598	1.37	0.23	1986–2016	1	0.2339	1,203.986	1,195.558	963.189

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)	ABC (0.8*OFL)
1a	4b	11.766	11.428	0.97	0.23	1986–2016	1	0.2339	1.813	1.792	1.450
1b	4a	12.219	12.536	1.03	0.23	1986–2016	1	0.2339	2.133	2.120	1.706
1c	4b	11.789	11.148	0.95	0.22	1986–2016	1	0.2339	1.730	1.709	1.384
2a	4b	12.219	11.794	0.97	0.23	1986–2016	1	0.2426	1.970	1.948	1.576
2c	4b	11.486	10.492	0.91	0.22	1986–2016	1	0.2426	1.605	1.586	1.284
4a	4a	10.153	10.320	1.02	0.23	1986–2016	1	0.2339	1.309	1.303	1.047
6a	4a	10.760	11.851	1.10	0.23	1986–2016	1	0.2339	1.728	1.720	1.382
6c	4b	11.255	10.359	0.92	0.21	1986–2016	1	0.2339	1.524	1.507	1.219
7a	4a	11.254	12.425	1.10	0.24	1986–2016	1	0.2426	1.898	1.888	1.518
8a	4b	17.615	16.669	0.95	0.22	1986–2016	1	0.2339	2.179	2.155	1.743
8c	4b	14.200	11.991	0.84	0.19	1986–2016	1	0.2339	1.429	1.413	1.072
16a	4b	10.378	10.080	0.97	0.17	1986–2016	1	0.18	1.270	1.255	1.016
19a	4a	12.812	13.507	1.05	0.23	1986–2016	1	0.2339	2.385	2.369	1.908

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)	ABC (0.8*OFL)
1a	4b	5.337	5.184	0.97	0.23	1986–2016	1	0.2339	822.188	812.759	657.750
1b	4a	5.543	5.686	1.03	0.23	1986–2016	1	0.2339	967.330	961.841	773.864
1c	4b	5.348	5.057	0.95	0.22	1986–2016	1	0.2339	784.504	775.254	627.603
2a	4b	5.543	5.350	0.97	0.23	1986–2016	1	0.2426	893.678	883.720	714.942
2c	4b	5.210	4.759	0.91	0.22	1986–2016	1	0.2426	727.801	719.556	582.241
4a	4a	4.605	4.681	1.02	0.23	1986–2016	1	0.2339	593.781	591.086	475.025
6a	4a	4.881	5.375	1.10	0.23	1986–2016	1	0.2339	783.675	780.315	626.940
6c	4b	5.105	4.699	0.92	0.21	1986–2016	1	0.2339	691.366	683.500	553.093
7a	4a	5.105	5.636	1.10	0.24	1986–2016	1	0.2426	860.701	856.526	688.561
8a	4b	7.990	7.561	0.95	0.22	1986–2016	1	0.2339	988.448	977.538	790.759
8c	4b	6.441	5.439	0.84	0.19	1986–2016	1	0.2339	648.085	641.056	486.064
16a	4b	4.708	4.572	0.97	0.17	1986–2016	1	0.18	576.279	569.415	461.023
19a	4a	5.811	6.127	1.05	0.23	1986–2016	1	0.2339	1,081.654	1,074.630	865.323

The Tier 3 approach as an alternative to Tier 4 provides additional sets of OFL estimates based on the mean number of recruits for the period 1986 to 2016 in the following four tables for EAG and WAG, respectively. Either F_{35} can be used as a multiplier of M if a Tier 4 approach is to be strictly followed or it can be used as it is by promoting the assessment to Tier 3. Assuming M as the F_{ofl} value under Tier 4 approach seems to be more conservative, especially for the WAG stock.

EAG (Tier 3):

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

Scenario	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to define B_{ref}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1a	3a	13.720	20.400	1.49	0.61	1986–2016	0.61	8.374	8.332	6.699
1b	3a	12.699	16.434	1.29	0.67	1986–2016	0.67	6.409	6.372	5.127
1c	3a	13.342	16.183	1.21	0.61	1986–2016	0.61	7.503	7.465	6.002
2a	3a	13.540	18.631	1.38	0.64	1986–2016	0.64	8.523	8.482	6.818
2c	3a	13.283	17.785	1.34	0.65	1986–2016	0.65	8.254	8.214	6.603
4c	3a	13.430	19.011	1.42	0.61	1986–2016	0.61	8.297	8.253	6.637
6a	3a	13.640	18.921	1.39	0.61	1986–2016	0.61	8.186	8.148	6.549
6c	3a	13.842	18.674	1.35	0.58	1986–2016	0.58	8.256	8.221	6.605
7c	3a	13.421	18.034	1.34	0.64	1986–2016	0.64	8.594	8.559	6.875
8a	3a	14.284	21.147	1.48	0.53	1986–2016	0.53	8.029	7.982	6.423
8c	3a	14.544	20.690	1.42	0.53	1986–2016	0.53	7.891	7.852	6.313
16c	3a	15.945	18.268	1.15	0.37	1986–2016	0.37	4.849	4.826	3.879
19c	3a	12.702	14.542	1.14	0.62	1986–2016	0.62	6.109	6.068	4.887

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

Scenario	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1a	3a	6.223	9.253	1.49	0.61	1986–2016	0.61	3,798.509	3,779.152	3,038.807
1b	3a	5.760	7.454	1.29	0.67	1986–2016	0.67	2,907.056	2,890.469	2,325.645
1c	3a	6.052	7.340	1.21	0.61	1986–2016	0.61	3,403.124	3,385.947	2,722.499
2a	3a	6.142	8.451	1.38	0.64	1986–2016	0.64	3,865.873	3,847.203	3,092.698
2c	3a	6.025	8.067	1.34	0.65	1986–2016	0.65	3,744.132	3,726.068	2,995.305
4c	3a.	6.092	8.623	1.42	0.61	1986–2016	0.61	3,763.368	3,743.324	3,010.694

6a	3a	6.187	8.583	1.39	0.61	1986–2016	0.61	3,713.169	3,695.785	2,970.535
6c	3a	6.279	8.471	1.35	0.58	1986–2016	0.58	3,744.927	3,729.123	2,995.941
7c	3a	6.088	8.180	1.34	0.64	1986–2016	0.64	3,898.309	3,882.520	3,118.647
8a	3a	6.479	9.592	1.48	0.53	1986–2016	0.53	3,641.944	3,620.606	2,913.555
8c	3a	6.597	9.385	1.42	0.53	1986–2016	0.53	3,579.183	3,561.612	2,863.347
16c	3a	7.233	8.286	1.15	0.37	1986–2016	0.37	2,199.504	2,189.020	1,759.604
19c	3a	5.761	6.596	1.14	0.62	1986–2016	0.62	2,770.911	2,752.309	2,216.729

WAG (Tier 3):

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

Scenario	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1a	3b	10.784	10.305	0.96	0.46	1986–2016	0.48	3.328	3.305	2.662
1b	3a	11.050	11.196	1.01	0.47	1986–2016	0.47	3.890	3.868	3.112
1c	3b	10.726	10.138	0.95	0.45	1986–2016	0.48	3.230	3.205	2.584
2a	3b	10.739	10.476	0.98	0.49	1986–2016	0.50	3.707	3.683	2.965
2c	3b	10.403	9.520	0.92	0.46	1986–2016	0.51	3.063	3.043	2.451
4a	3b	10.111	8.923	0.88	0.48	1986–2016	0.55	2.450	2.433	1.960
6a	3b	10.633	10.440	0.98	0.48	1986–2016	0.49	3.220	3.199	2.576
6c	3b	10.324	9.459	0.92	0.44	1986–2016	0.49	2.893	2.873	2.315
7a	3a	10.446	10.737	1.03	0.52	1986–2016	0.52	3.646	3.629	2.917
8a	3a	12.993	14.727	1.13	0.51	1986–2016	0.51	4.569	4.545	3.655
8c	3b	11.618	10.826	0.93	0.45	1986–2016	0.49	3.041	3.020	2.280
16a	3b	12.186	9.880	0.81	0.26	1986–2016	0.33	1.833	1.822	1.467
19a	3a	11.224	12.066	1.07	0.46	1986–2016	0.46	4.268	4.241	3.415

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

Scenario	Tier	B_{35}	Current MMB	MMB $/B_{35}$	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1a	3b	4.891	4.674	0.96	0.46	1986–2016	0.48	1,509.437	1,499.075	1,207.549
1b	3a	5.012	5.078	1.01	0.47	1986–2016	0.47	1,764.355	1,754.428	1,411.484
1c	3b	4.865	4.599	0.95	0.45	1986–2016	0.48	1,464.986	1,453.667	1,171.989
2a	3b	4.871	4.752	0.98	0.49	1986–2016	0.50	1,681.368	1,670.540	1,345.094
2c	3b	4.719	4.318	0.92	0.46	1986–2016	0.51	1,389.436	1,380.478	1,111.549
4a	3b	4.586	4.048	0.88	0.48	1986–2016	0.55	1,111.115	1,103.797	888.892
6a	3b	4.823	4.736	0.98	0.48	1986–2016	0.49	1,460.555	1,451.069	1,168.444
6c	3b	4.683	4.291	0.92	0.44	1986–2016	0.49	1,312.390	1,303.175	1,049.912
7a	3a	4.738	4.870	1.03	0.52	1986–2016	0.52	1,653.865	1,645.934	1,323.092
8a	3a	5.894	6.680	1.13	0.51	1986–2016	0.51	2,072.552	2,061.602	1,658.041
8c	3b	5.270	4.911	0.93	0.45	1986–2016	0.49	1,379.215	1,369.791	1034.411
16a	3b	5.527	4.481	0.81	0.26	1986–2016	0.33	831.564	826.319	665.251
19a	3a	5.091	5.473	1.07	0.46	1986–2016	0.46	1,936.123	1,923.597	1,548.898

Aleutian Islands (sum of OFL and ABC for EAG and WAG under Tier 4):

Total OFL and ABC for the next fishing season.

Scenario	OFL (million pounds)	ABC (P*=0.49) (million pounds)	ABC (0.8*OFL) (million pounds)	OFL (1,000 t)	ABC (P*=0.49) (1,000 t)	ABC (0.8*OFL) (1,000 t)
1a	5.492	5.452	4.393	2.491	2.473	1.993
1b	4.723	4.695	3.778	2.142	2.130	1.714
1c	5.049	5.011	4.039	2.290	2.273	1.832
2a	5.709	5.669	4.567	2.590	2.572	2.072
2c	5.186	5.149	4.149	2.352	2.336	1.882
4a,c	4.973	4.947	3.978	2.256	2.244	1.805
6a	5.338	5.313	4.270	2.422	2.410	1.937
6c	5.338	5.304	4.270	2.421	2.407	1.937
7a,c	5.694	5.668	4.555	2.583	2.571	2.066
8a	6.137	6.090	4.910	2.783	2.763	2.227
8c	5.319	5.283	4.184	2.412	2.397	1.897
16a,c	3.807	3.78	3.046	1.727	1.715	1.382
19a,c	5.039	5.005	4.031	2.286	2.270	1.829

Aleutian Islands (sum of OFL and ABC for EAG and WAG under Tier 3):

Scenario	OFL (million pounds)	ABC (P*=0.49) (million pounds)	ABC (0.8*OFL) (million pounds)	OFL (1,000 t)	ABC (P*=0.49) (1,000 t)	ABC (0.8*OFL) (1,000 t)
1a	11.702	11.637	9.361	5.308	5.278	4.246
1b	10.299	10.24	8.239	4.671	4.645	3.737
1c	10.733	10.67	8.586	4.868	4.840	3.894
2a	12.23	12.165	9.783	5.547	5.518	4.438
2c	11.317	11.257	9.054	5.134	5.107	4.107
4a,c	10.747	10.686	8.597	4.874	4.847	3.900
6a	11.406	11.347	9.125	5.133	5.147	4.139
6c	11.149	11.094	8.920	5.057	5.032	4.046
7a,c	12.24	12.188	9.792	5.552	5.528	4.442
8a	12.598	12.527	10.078	5.715	5.683	4.572
8c	10.932	10.872	8.593	4.958	4.932	3.897
16a,c	6.682	6.648	5.346	3.031	3.015	2.425
19a,c	10.377	10.309	8.302	4.707	4.676	3.766

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 2015/16 commercial fishery retained and total catch, observer nominal total CPUE and fishing effort (pot lifts) to calculate total catches for 1990/91–2015/16, and groundfish discarded catch by size for 1989/89–2015/16 were added. The commercial retained size frequency and observer sample size frequency data were recalculated weighting by sampled vessel's catch.
   (b) 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 2005/06–2015/16 periods. Although the 1995/96–2004/05 CPUE indices need not be recalculated, however we recalculated them because the 5% soak time and 1% depth cutoff points for excluding observer CPUE records changed a little when 2015/16 data were added.

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 May 2016 CPT comments

Comment 1: The CPT recommended bringing forward a Tier 3 assessment in addition to Tier 4 as M may not be stable.

Response:
In this report, we are providing the Tier 3 assessment as well.

Comment 2: The CPT recommended using the equilibrium model (and no longer bringing forward the exponential model) as it better tracked the variability in the initial size classes. The author should provide a plot of the full time series to show the pattern in depletion relative to removals prior to the start of the model.

Response:

We considered only the equilibrium model scenarios in this report. We provide the full time series (1960 onward) of MMB and their retrospective patterns (see the text).

Comment 3: The author should double check the profile on CPUE and provide an estimate for how long tagged animals are out in the tagging data to calculate an independent estimate of Z (i.e. inverse time to recapture). **The CPT recommended continuing to bring forward models with both M=0.23 and M=0.18**.

Response:

(a) We double checked the profile on CPUE for WAG data and did not find any errors.

(b) We estimated an average Z yr^{-1} using the available tagging data in Table D. The Z estimate from tagging data is 0.99, which accounts for additional tagging related loss rate as well (Siddeek et al., 2002). It appears that an M value higher than 0.18 is feasible.

Table D. Estimate of an average Zyr^{-1} by fitting a linear regression to the tag population depletion model, $\ln(n_r) = ln\left[\frac{F}{Z} N_0(1 - e^{-Z})\right] - (r-1)Z$, where n_r is the number of male tag recaptures within the model size range in year r, r=1,2,3,4,5, and 6; N_0 = total number of crabs released within the model size range (=27,131); F = annual fishing mortality; and Z = annual total mortality.

Time-at-Large (years)	Number of Recoveries by Time-at-Large	Z yr^{-1}
1	1005	0.9861(CV=0.0923)
2	497	Adjusted R^2 = 0.9588, p =0.0004
3	216	
4	51	
5	13	
6	12	

Comment 4. The CPT recommended dropping the groundfish bycatch weight due to poor fits to the groundfish bycatch length frequency data (e.g. scenario 7). A scenario should be provided with the groundfish data removed.

Response:
We considered scenarios 4c and 4a by dropping the entire groundfish bycatch data (size composition and bycatch) for EAG and WAG, respectively. The OFL for EAG did not change appreciably from other scenarios with those data included. However, the OFL for WAG significantly reduced (Table 29).

Comment 5. The CPT recommended continuing with the dome shaped selectivity and doing an *M* profile with a dome shaped selectivity.

Response:
We provide a number of *M* profile plots in Figures 1 (EAG) and 2 (WAG) below in response to various CPT comments, which included the dome shaped selectivity (bottom right plots). The *M* profiles were determined without an *M* penalty function because *M* was fixed at different values.

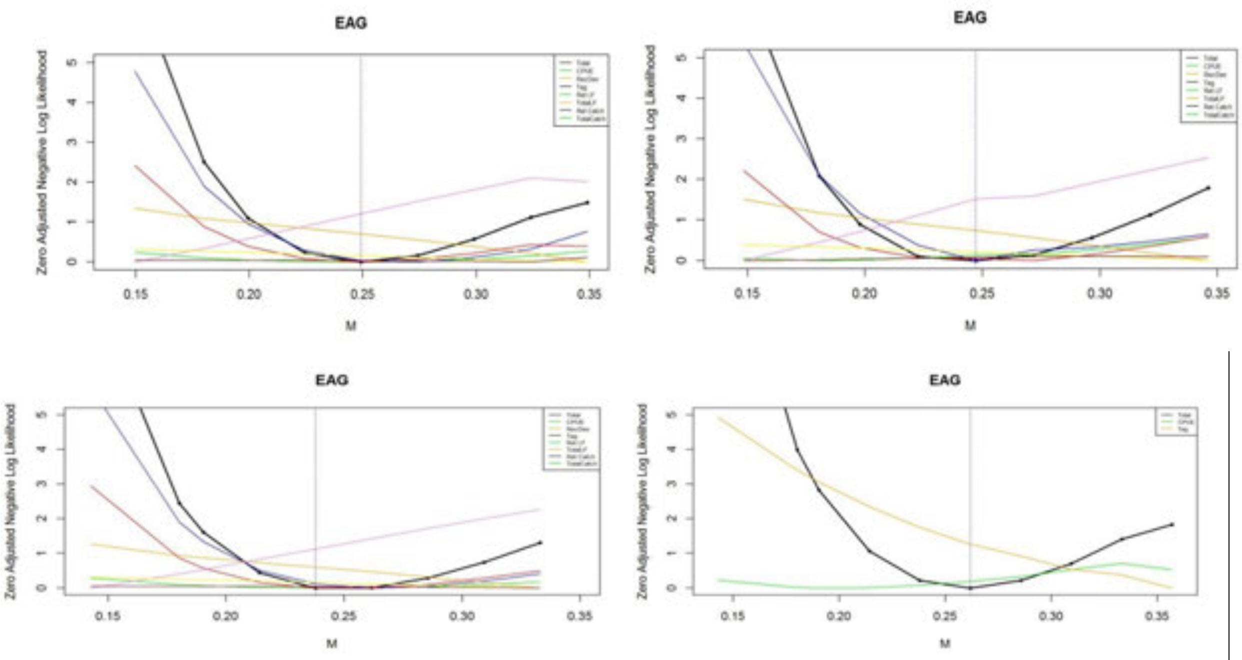


Figure 1. Total and components negative log-likelihoods vs. *M* for scenario 1c model fit **without *M* penalty** for EAG. Top left: EAG data with a minimum (vertical bar) at M = 0.2493 yr^{-1}; top right: *M* profiles for the EAG portion of the EAG and WAG combined likelihood including the fish ticket CPUE likelihood with a minimum at M = 0.2472 yr^{-1}; bottom left: *M* profiles for the EAG portion of the EAG and WAG combined likelihood without fish ticket CPUE likelihood with a minimum at M = 0.2379 yr^{-1}; bottom right: EAG data with the dome shaped selectivity with a minimum of M = 0.2617 yr^{-1}. The negative log likelihood values were zero adjusted.

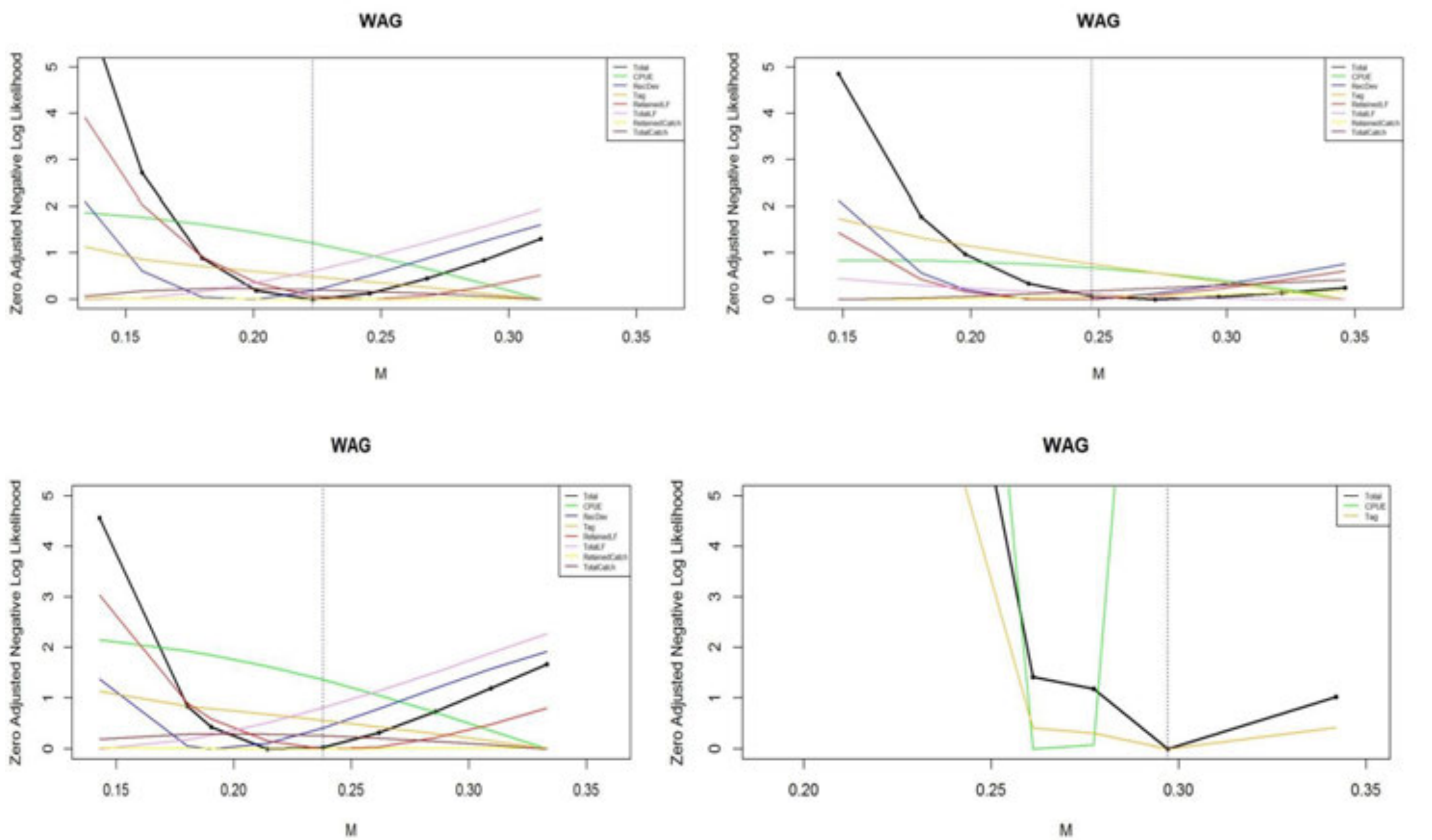


Figure 2. Total and components negative log-likelihoods vs. *M* for scenario 1c model fit without *M* penalty for WAG. Top left: WAG data with a minimum (vertical bar) at *M* = 0.2232 yr^{-1}; top right: *M* profiles for the WAG portion of the EAG and WAG combined likelihood including the fish ticket CPUE likelihood with a minimum at *M* = 0.2472 yr^{-1}; bottom left: *M* profiles for the WAG portion of the EAG and WAG combined likelihood without fish ticket CPUE likelihood with a minimum at *M* = 0.2379 yr^{-1}; bottom right: WAG data with the dome shaped selectivity with a minimum at *M* =0.2970yr^{-1}. The negative log likelihood values were zero adjusted.

The *M* profiles indicate that the current data sets support a higher *M* value for good fits. As per June 2016 SSC recommendation, we used the EAG and WAG combined likelihood with the following *M* penalty function to estimate a common *M* of 0.2339yr^{-1} (CV=0.12) for scenarios without the fish ticket CPUE likelihood and a common *M* of 0.2426yr^{-1} (CV=0.11) for scenarios with the fish ticket CPUE likelihood.

$$-LL = \frac{0.5}{\ln(1+CV^2)}[(\ln(M) - \ln(0.18))^2] \qquad \text{C.1}$$

where *LL*= negative log likelihood, CV=coefficient of variation. We used a CV value of 0.5.
In our May 2016 CPT presentation we argued that there was no justification to consider separate values of *M* for the two regions.

Comment 6. Size-composition effective sample sizes based only on initial weighting (stage-1) or on reweighted (stage-2) according to Francis (2011, scenario 9). Stage 2 should be a multiplier of Stage 1. The author multiplied the actual sample mean by the harmonic mean which is why the length comps are being fitted and the recruits for scenario 9 stand out. **The CPT recommended putting a bound (e.g. 200) and reconsider using the weighting without increasing above the observed. The author should bring forward scenario 3 with appropriate reweighting using the Francis (2011) method.**

Response:

Francis (*in press*, 2016) recommends setting no bounds to sample sizes in the iteration process.

In the May CPT document (Siddeek *et al.*, 2016c), we misidentified the McAllister and Ianelli (1997) method as Francis (2011) method although Francis has summarized this method in one of his appendixes. In the current analysis we adopted Francis method proper (see the text Equations 1-4) to get the Stage-2 weighting multiplier. We used this multiplier to multiply the Stage-1 effective sample sizes. We performed Francis reweighting on scenarios 1 a,c (as new scenarios 6 a,c) and scenarios 2a, c that included fish ticket CPUE likelihood (as new scenarios 7a, c). Francis (*in press*, 2016) suggested that a good stopping criterion to stop iterations is no appreciable change in the key outputs. Hence, we considered the criterion that no appreciable change in terminal MMB and retained catch OFL to stop the iteration. (see Tables 4 and 5 for scenarios 6c and 7c for EAG; and Tables 18 and 19 for scenarios 6a and 7a for WAG). Tables 6 and 20 provide the Stage-1 and Stage-2 sample sizes for EAG and WAG, respectively.

Comment 7. The way that the author calculated the variability in total area fished would not appropriately weight the CPUE. **The CPT recommended a low priority item to see if there are enough data to consider a spatial model where you consider differently fished areas.**

Response:

In this analysis, we did not pursue this task.

Comment 8. Down-weighting data components by 75% in the model based on minima in negative log likelihoods at low OFL levels. The CPT did not see the value in this approach.

Response:
In this analysis, we did not pursue this task.

General recommendations:

Comment 9. Provide CVs instead of SDs throughout analysis.

Response:
In this report, we provide CVs of parameter and dependent variable estimates.

Comment 10. Profiling negative log likelihoods on OFL not informative. It would be better to profile on mean biomass (middle of the time series) or on depletions (mean divided by total biomass).

Response:
Please see our response to Comment 8.

Comment 11. Start all retrospective and biomass plots in 1960s and fishing mortality plots at least back to 1981. It is important to understand what is forcing the drop in abundance between the model startup and 1985 when data are available. Is it recruitment or catch (which looks low)?

Response:
In this report, we started the retrospective and biomass plots in 1960 and fishing mortality plots in 1981.

Comment 12. The weightings used in the model need more detail to properly assess.

Response:
The retained catch base weight (500) was selected based on the best fit to retained catch data. Higher weight is given to the retained weight component because it is the most reliable information among all available data sets. The total catch base weight was scaled to a maximum 250 based on number of observer sampled pots as per previous CPT suggestion. This was because total catches were estimated from observer total CPUE and fishing effort data. The ground fish bycatch base weight (0.2) was chosen based on another CPT suggestion of lowering 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 considered initial effective sample sizes in two ways:

(a) As number of length measurements scaled to a maximum following Fournier et al. (1998). The base input effective sample sizes for retained catch, total catch, and groundfish bycatch size compositions were computed using the set of equations A.19 provided in Appendix A. The effective sample sizes were scaled to maximum values of 200, 150, and 25 for retained catch, total catch, and groundfish discarded catch size compositions, respectively. The maximum values were chosen based on visual determination of best fit to size composition data. However, for the Francis iterative reweighting scenarios, we did not rescale the intermediate sample sizes after Stage-1 sample sizes have been scaled.

(b) Following June 2016 SSC suggestion and the work by Thorson (2014), we considered number of trips made by the dock side sampled vessels as Stage-1 effective sample sizes without enforcing any scaling measure (see the response to comment 6). Scenarios ending with "c" and "d" consider number of trips as Stage-1 effective sample sizes.

Response to June 2016 SSC comments

Comment 1: Reconsider the approach for estimating natural mortality. Rather than averaging estimates from the two areas, consider joint estimation of *M* between the two areas and use a likelihood test or information criteria to see if there is a difference between the areas. Also, investigate whether there really is information in the data to estimate *M* (looking at likelihood surfaces or variances), noting that this conclusion may be very sensitive to data weighting. If not, determining *M* (or deriving a prior distribution) externally from life history information may be warranted.

Response:
We obtained a joint estimate of *M* using a prior (Equation C.1) to use in all scenarios by minimizing the sum of the likelihood components from EAG and WAG; thus, keeping the fishery and abundance differences between the two regions intact. For this joint estimate, we considered a common *M* and the common tagging data set for the two regions.

Comment 2: Look at the tradeoff between natural mortality versus dome-shaped selectivity, because both can explain a lack of older fish.

Response:
We did an *M* profile considering a dome shaped selectivity. But, the analysis indicated that higher *M* than 0.18yr^{-1} was most suitable for the data in hand (bottom left plots in Figures 1 and 2).

Comment 3: Conduct further analysis on area-shrinkage and standardization of CPUE. Further support is necessary to determine whether the assumption that CPUE is proportional to abundance is warranted. The

effect of area-shrinkage may be informed by in-depth examination of spatial data.

Response:
Please refer to CPT comment 7 on this task and our response to the comment. At this time we are not pursuing this task.

Comment 4: For standardization, further investigation of whether vessel and/or captain is confounded with abundance (the year effect) is desirable, because not all combinations of factor levels may exist (vessels or captains not fishing in some years or months) and there may be very few levels of these factors in some years.

Response:
We included Year:Captain and Year:Gear interaction terms in the scope for CPUE standardization because Year and Gear were the selected predictor variables in most cases. Although Year:Captain interaction term was selected by the GLM forward selection procedure, a number of interaction level estimates produced NAs. When we removed the NA producing levels and refitted the GLM model, it reverted back to the selection of only the main factor parameters. Nevertheless, for demonstration purpose, we present the CPUE indices estimated by the interaction model in Figure B.9 for EAG and Figure B.17 for WAG. We also used the CPUE indices in scenarios 19a, c. There were no dramatic changes in OFL or rate of reduction of terminal MMB from the pristine MMB (Table 29).

Comment 5: Nominal sample sizes (the number of crab measured) are extremely large and heterogeneous among years. It is common practice to use the number of sets/pot lifts or other measure of sampling units as a starting point for sample sizes instead of the number of length measurements. This change, and reporting of the actual input sample sizes used for all model runs should be added to the analysis.

Response:
We considered number of fishing trips as Stage-1 effective sample size in scenarios ending with c and d. Although the management parameters (MMB and OFL) were not affected between considering number of length measurements and number of trips for EAG, they were affected for WAG. Scenarios that considered number of length measurements produced higher OFLs than that considered number of trips for WAG (Table 29).

Comment 6: adding the scale of the standardized residuals to the figures will allow better evaluation of the how the scaling of sample sizes may be influencing the assessment.

Response:
We assumed that the area of the circles sufficiently depicted the relative size of the standardized residuals. We will improve on this in the next cycle of model runs.

Comment 7: The fit to the groundfish bycatch length frequencies was relatively poor. It appeared that the selectivity curve for this fleet was fixed in the model runs, which could cause lack of fit in other aspects of the model.

Estimation of the selectivity and/or addressing data weighting for this component should be evaluated further.

Response:
We estimated groundfish selectivity in scenarios 3 a and c for EAG and WAG, respectively. Estimated selectivity parameters had unreasonably high CVs and the selection curves were flat near 1. Hence, we fixed the selectivity to 1 for all other scenarios.

Comment 8: Depending on the outcome of this additional work, additional scenarios may need to be brought forward, along with models 1, 10, and 16 recommended by the author and CPT.

Response:
We considered additional model runs as a result of CPT and SSC informative recommendations and brought forward 13 scenarios for discussion at this meeting.

Comment 9: The SSC noted very small buffers between OFLs and ABCs. Such small differences are rare even for data rich groundfish stocks. The SSC looks forward to author and CPT recommendations on appropriate methods (and alternatives) to estimation of ABCs in the full 2016 assessment.

Response:
We considered both P*=0.49 and an additional buffer of 20% in the ABC estimation.

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 (Otto and Cummiskey 1985; Shirley and Zhou 1997) 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 longitudes (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 the recent fishing season. 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 3.310 million pounds for EAG and 2.980 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 assessment model has not yet been accepted.

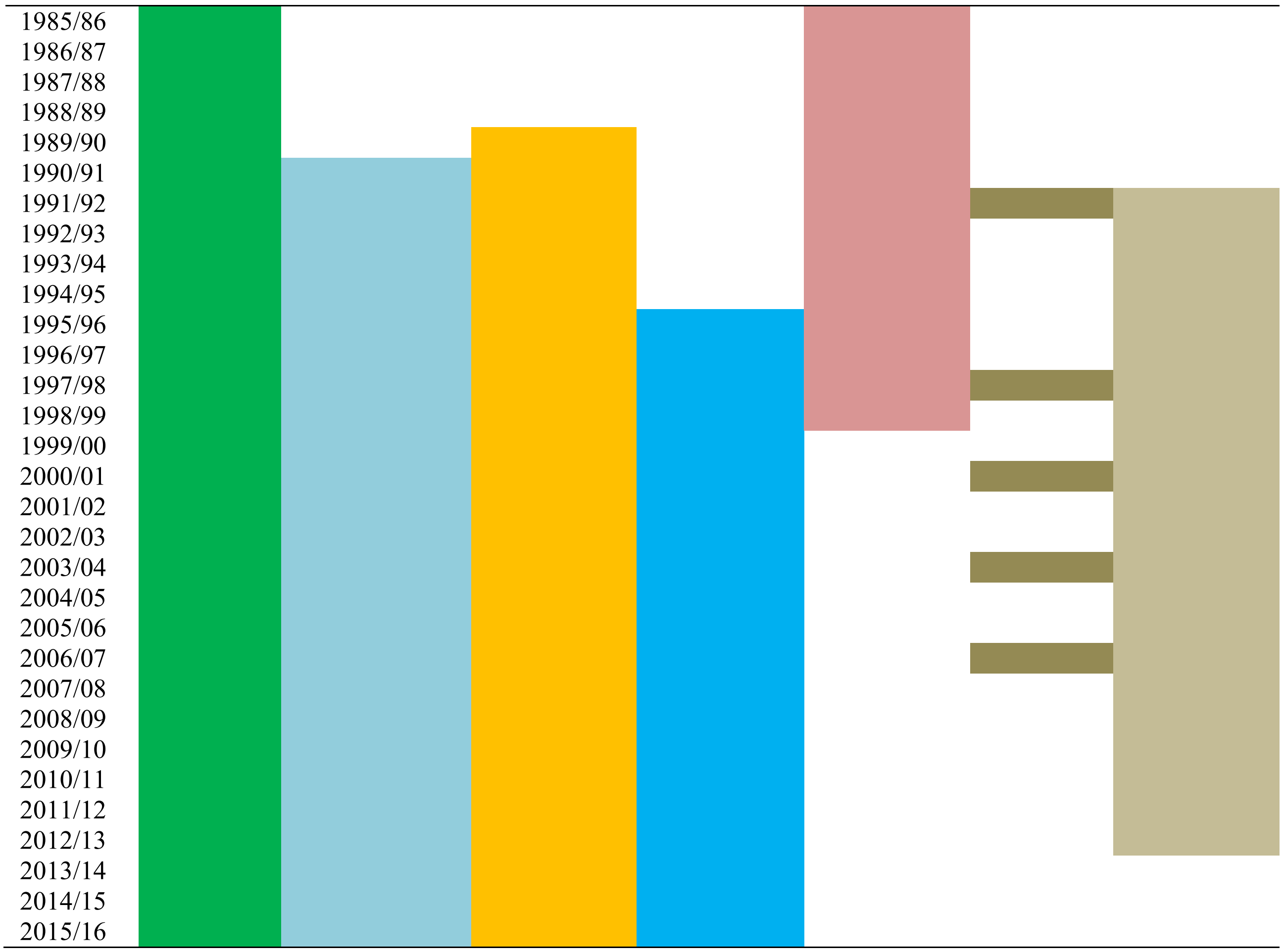
D. Data

1. Summary of new information:

   Data are updated by adding the 2015/16 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 1794 records.



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 described in Appendix B.

c. Information on length compositions (Figures 6 to 8 for length compositions for EAG; and 24 to 26 for length compositions 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, the CPT proposed a number of ways to improve 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 the May 2016 assessment and further improved on those in the current assessment following May 2016 CPT and June 2016 SSC recommendations.

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 a number of scenarios (see Table E).

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 2005/06–2015/16. However, in order to respond to a previous CPT comment, we considered three catchabilities, three sets of total selectivity, and one set of retention curves in one scenario (scenario 5a for WAG and scenario 5c for EAG).

The data series used in the current assessment for EAG ranges from 1985/86 to 2015/16 for retained catch biomass and size composition; 1995/96 to 2015/16 for standardized legal size crab observer CPUE index; 1989/90 to 2015/16 for groundfish fishery male bycatch biomass and size composition; 1985/86 to 1998/99 for standardized crab fish ticket CPUE index; 1990/91 to 2015/16 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 0.2339 yr^{-1} (for analyzing data without fish ticket CPUE indices, Equation C.1) or 0.2426 yr-1 (for analyzing data with fish ticket CPUE indices, Equation C.1). The *M* values were the combined estimates for EAG and WAG. We assumed directed pot fishery discard mortality proportion at 0.20 yr^{-1}, overall groundfish fishery mortality proportion at 0.65 yr^{-1} [mean of groundfish pot fishery mortality (0.5 yr^{-1}) and groundfish trawl fishery mortality (0.8 yr^{-1})], groundfish fishery selectivity at full selection for all length classes (selectivity = 1.0). Any discard of legal size males in the directed pot fishery was not considered in this analysis. 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.9) for different periods for the pot fishery. We also assumed a dome shaped selectivity (Equation A.10) (see the scenarios Table E 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 34 scenarios overall for EAG and WAG. We presented OFL and ABC results for the preferred thirteen scenarios separately for EAG and WAG in the executive summary tables. We considered scenarios 1a or 1c as the base scenarios. They consider:

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 2005/06–2015/16, and a single set of logistic retention curve parameters;

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

iv) Stock dynamics $M = 0.2339\ yr^{-1}$, 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.19 with a set of maximum effective sample sizes (retained catch = 200, total catch= 150, and groundfish (trawl) discarded catch = 25) for Stage-1 effective sample size for scenario 1a. Using number of fishing trips without any rescaling for Stage-1 effective sample size for scenario 1c.

vii) The salient features and variations from the base scenario of all other scenarios are listed in Table E. 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 E. Features of model scenarios. Initial condition was estimated by the equilibrium condition for all scenarios. Changes from scenario 1a specifications are highlighted by the light blue shade.

Scenario	Size-composition weighting	Catchability and total selectivity sets	Total selectivity type	CPUE data type	GLM predictor variable selection criterion	Treatment of trawl/total size composition and catch data	Natural mortality ($M\ yr^{-1}$)
1a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
1b	Stage-1:Number of lengths	2	logistic	Observer	AIC	Trawl bycatch size-composition data included	0.2339
1c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
1d	Stage-1:Number of trips	2	logistic	Observer	AIC	Trawl bycatch size-composition data included	0.2339
2a	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
2b	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	AIC	Trawl bycatch size-composition data included	0.2426
2c	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
2d	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	AIC	Trawl bycatch size-composition data included	0.2426
3a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included, groundfish selectivity estimated	0.2339
3c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included, groundfish selectivity estimated	0.2339
4a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Dropped trawl bycatch & size-composition data	0.2339
4c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Dropped trawl bycatch & size-composition data	0.2339
5a	Stage-1:Number of lengths	3	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
5c	Stage-1:Number of trips	3	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339

Scenario	Size-composition weighting	Catchability and total selectivity sets	Total selectivity type	CPUE data type	GLM predictor variable selection criterion	Treatment of trawl/total size composition and catch data	Natural mortality ($M\ yr^{-1}$)
6a	Stage-2:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
6c	Stage-2:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
7a	Stage-2:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
7c	Stage-2:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
8a	Stage-1:Number of lengths	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
8c	Stage-1:Number of trips	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
9a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2339
9c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2339
10a	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2426
10c	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2426
11a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.18
11c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.18
12a	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.18
12c	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.18
14a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Dropped trawl bycatch size-composition data	0.18

Scenario	Size-composition weighting	Catchability and total selectivity sets	Total selectivity type	CPUE data type	GLM predictor variable selection criterion	Treatment of trawl/total size composition and catch data	Natural mortality ($M\ yr^{-1}$)
14c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Dropped trawl bycatch size-composition data	0.18
16a	Stage-1:Number of lengths	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.18
16c	Stage-1:Number of trips	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.18
19a	Stage-1:Number of lengths	2	logistic	Observer	R-squared, Interaction	Trawl bycatch size-composition data included	0.2339
19c	Stage-1:Number of trips	2	logistic	Observer	R-squared, Interaction	Trawl bycatch size-composition data included	0.2339

viii) The entire time period, 1985/86–2015/16, was used to determine the mean MMB as MMB_{ref} (a proxy for MMB_{MSY}) for $MMB_{current}/MMB_{ref}$ estimation under Tier 4 and mean number of recruits for 1986 to 2016 for MMB_{35} (a proxy for MMB_{MSY}) estimation under Tier 3 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 34 scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the preferred thirteen scenarios are provided in tables and figures. The total catch OFLs and the reduction in terminal (2016) MMB from the initial condition (i.e., virgin MMB in 1961) for the entire 34 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 0.2339 yr^{-1} or 0.2426 yr^{-1}.

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) either from the original number of length measurements using Equation A.19 or number of fishing trips for all scenarios except scenarios 6 a,c and 7a,c. For scenarios 6 and 7 (iterative reweighting), we estimated the Stage-1 sample sizes using either Equation A.19 on number of length measurements or without setting any limit on number fishing trips. We estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes using the Francis' (2011) mean length based method (i.e., Francis TA1.8 method, Punt *in press*) as follows:

Observed mean length for year *t*,

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

Predicted mean length for year *t*,

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

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

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

Francis' reweighting parameter *W*,

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

where $\hat{P}_{t,i}$ and $P_{t,i}$ are the estimated and observed proportions of the catch during year *t* in length-class *i*, $l_{t,i}$ is the mid length of the length-class *i* during year *t*, S_t is the effective sample size in year *t*, $\hat{\bar{l}}_t$ 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 (Stage-1) and Stage-2 effective sample sizes in Tables 6 and 20 for EAG and WAG, respectively. We multiplied the initial input (Stage-1) annual sample sizes by the estimated *W* for a number of iterative fittings until we found no appreciable changes in the terminal MMB and retained catch OFL estimates.

g. Provide the basis for data weighting, including whether the input effective sample sizes are tuned and the survey CV adjusted: Described previously (f) and the response to CPT comment #12.
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* value 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 6 and 20 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 to a large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass in accordance with the observer annual sample sizes with a maximum of 250.0. 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 groundfish bycatch weight (0.2) based on the September 2015 CPT suggestion to lower its weight. We used the best fit criteria to choose the lower weight for the groundfish bycatch. Groundfish bycatch of Aleutian Islands golden king crab is very low. We set the CPUE weights to 1.0 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.15). However, the estimated additional variance values were small for both observer and fish ticket CPUE indices for the two regions. Nevertheless, the CPUE index variances estimated from the negative binomial and lognormal GLMs were adequate to fit the model, as confirmed by the fit diagnostics (Fox and Weisberg 2011). Parameter estimates are provided in Tables 7 and 8 for EAG and 21 and 22 for WAG for a subset of thirteen 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 coefficient of variation for eight scenarios which are a subset of preferred thirteen scenarios are summarized respectively in Tables 7 and 8 for EAG and 21 and 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 representative five scenarios among the thirteen scenarios are summarized in Tables 9 to 13 (scenarios 1a, 1c, 6c, 8c, and 16c) for EAG and Tables 23 to 27 (scenarios 1a, 1c, 6a, 8a, and 16a) 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 nine scenarios are summarized in Table 14 for EAG and Table 28 for WAG. Scenarios 6c (iterative reweighting of effective sample sizes) and 8a (dome shaped total selectivity) 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 thirteen scenarios are illustrated in Figure 9 for EAG and Figure 27 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 26 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 nine (a subset of thirteen) scenarios are depicted in Figures 19 and 35 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.15 in Appendix A). We determined the mature male biomass values on 15 February and considered the entire time series (1985/86–2015/16) for MMB_{ref} calculation for Tier 4 approach and mean number of recruits for MMB_{35} calculation for Tier 3 approach.

c. The full selection pot fishery F over time for nine scenarios is shown in Figures 20 and 36 for EAG and WAG, respectively. The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. On the other hand, the F peaked in late 1980s, 1990s and early 2000s, then declined in late 2000s and slightly increased since 2010 in the WAG. The increase in F in recent years may be due to a decline in abundance under constant high harvest allocation to WAG.

d. F vs. MMB: We provide these plots for EAG and WAG in Figure 40.

e. Stock-Recruitment relationship: None.

f. The temporal changes in total number of recruits to the modeled population for nine scenarios are illustrated in Figure 17 for EAG and in Figure 33 for WAG. The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 18 and 34 for EAG and WAG, respectively for the nine 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 nine scenarios are illustrated in Figures 21 and 37 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 nine scenarios are shown in Figure 16 for EAG and Figure 32 for WAG. Scenarios with fish ticket CPUE indices track indices back to 1985/86. All scenarios appear to fit the CPUE indices satisfactorily for EAG. However, iterative fitting of effective sample sizes with fish ticket CPUE indices overestimated the CPUE trend in early years for WAG. The CPUE variance was estimated using Burnham et al. (1987) suggested formula (Equation A.15 in Appendix A).

j. Tagging data: The predicted vs. observed tag recaptures by length-class for years 1 to 6 recaptures are depicted in Figure 13 for EAG and Figure 31 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 14). 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 scenario 1a are compared between EAG and WAG. The matrix elements appear very similar (Figure 15).

k. Molt probability: The predicted molt probabilities vs. CL for the nine scenarios are depicted in Figures 23 and 39 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 24 to 26 for WAG. The retained and total catch size composition fits appear satisfactory. But, the fits to groundfish bycatch size compositions are bad.

   We illustrate the standardized residual plots as bubble plots of size composition over time for retained catch (Figures 10 and 28 for EAG and WAG, respectively), for total catch (Figures 11 and 29 for EAG and WAG, respectively), and for groundfish discard catch (Figures 12 and 30 for EAG and WAG, respectively) for four selected scenarios (1a, 1c, 6a or 6c, 8a or 8c). 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 6 and 20 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 eight scenarios (a subset of thirteen scenarios) are shown in Figure 22 for EAG and in Figure 38 for WAG. The retrospective fits were prepared for the whole time series 1961 to 2016. The retrospective patterns did not show severe departure when five terminal year's data were removed systematically and hence the current formulation of the model appears stable. A severe drop in modeled biomass from the initial MMB occurred when the fishery time series started in 1981.
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*. 2016a). 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 (Figures 1 and 2). We discussed the merit of M estimation within the model in the CPT comment section.
   c. Conduct 'jitter analysis': We did not conduct the (random) jitter analysis on model parameters.

F. Calculation of the OFL

Specification of the Tier level:

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

Tier 4 level or to the Tier 3 level. The two Tier level OFL calculation procedures are described below:

Tier 4 approach:

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

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

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

where $\mathrm{MMB}_{current}$ 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 2016. This resulted in an *MMBref* range of 5.911 to 7.942 thousand metric tons for EAG and 4.605 to 7.990 thousand metric tons for WAG for the thirteen scenarios. The current MMB (in 2016) range was 8.598 to 12.264 thousand metric tons for EAG and 4.572 to 7.561 thousand metric tons for WAG for the thirteen scenarios, resulting in an F_{OFL} range of 0.18 to 0.24 for EAG and 0.17 to 0.24 for WAG. The total OFL for EAG ranged from 1.151 to 1.764 thousand metric tons and for WAG from 0.576 to 1.082 thousand metric tons for the thirteen scenarios. The γ-value was set to 1.0 and an *M* value of 0.2339 or 0.2426 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 1.113 to 1.704 thousand metric tons and that for WAG ranged from 0.545 to 1.026 thousand metric tons for the thirteen scenarios.

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

We recommend them for scenarios 1a, 1c, 2a, 2c, 6a, 6c, 8a, and 8c, respectively.

Scenario 1a:

EAG: F_{OFL} = 0.23; OFL total catch = 1.669 thousand metric tons; retained catch portion of the OFL = 1.607 thousand metric tons.

WAG: F_{OFL} = 0.226; OFL total catch = 0.822 thousand metric tons; retained catch portion of the OFL = 0.778 thousand metric tons.

Scenario 1c:

EAG: F_{OFL} = 0.23; OFL total catch = 1.506 thousand metric tons; retained catch portion of the OFL = 1.459 thousand metric tons.

WAG: F_{OFL} = 0.22; OFL total catch = 0.785 thousand metric tons; retained catch portion of the OFL = 0.743 thousand metric tons.

Scenario 2a:

EAG: F_{OFL} = 0.24; OFL total catch = 1.696 thousand metric tons; retained catch portion of the OFL = 1.634 thousand metric tons.

WAG: F_{OFL} = 0.23; OFL total catch = 0.894 thousand metric tons; retained catch portion of the OFL = 0.846 thousand metric tons.

Scenario 2c:

EAG: F_{OFL} = 0.24; OFL total catch = 1.624 thousand metric tons; retained catch portion of the OFL = 1.572 thousand metric tons.

WAG: F_{OFL} = 0.219; OFL total catch = 0.728 thousand metric tons; retained catch portion of the OFL = 0.689 thousand metric tons.

Scenario 6a:

EAG: F_{OFL} = 0.23; OFL total catch = 1.638 thousand metric tons; retained catch portion of the OFL = 1.588 thousand metric tons.

WAG: F_{OFL} = 0.23; OFL total catch = 0.784 thousand metric tons; retained catch portion of the OFL = 0.734 thousand metric tons.

Scenario 6c:

EAG: F_{OFL} = 0.23; OFL total catch = 1.730 thousand metric tons; retained catch portion of the OFL = 1.687 thousand metric tons.

WAG: F_{OFL} = 0.21; OFL total catch = 0.691 thousand metric tons; retained catch portion of the OFL = 0.655 thousand metric tons.

Scenario 8a:

EAG: F_{OFL} = 0.23; OFL total catch = 1.795 thousand metric tons; retained catch portion of the OFL = 1.726 thousand metric tons.

WAG: F_{OFL} = 0.22; OFL total catch = 0.988 thousand metric tons; retained catch portion of the OFL = 0.936 thousand metric tons.

Scenario 8c:

EAG: F_{OFL} = 0.23; OFL total catch = 1.764 thousand metric tons; retained catch portion of the OFL = 1.704 thousand metric tons.

WAG: F_{OFL} = 0.19; OFL total catch = 0.648 thousand metric tons; retained catch portion of the OFL = 0.613 thousand metric tons.

Tier 3 Approach:

The critical assumptions for reference point estimation are:

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

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

Method: We simulated the population abundance starting from the model estimated terminal year stock size by length, model estimated parameter values, a fishing mortality value (F), and adding a constant number of annual recruits. Once the stock dynamics were stabilized (we used the 99th year estimates) for an F, we calculated the MMB/R for that F. We computed the relative *MMB/R* in percentage, $\left(\frac{MMB}{R}\right)_{x\%}$ (where x% = $\frac{\frac{MMB_F}{R}}{\frac{MMB_0}{R}} \times 100$ and MMB_0/R is the virgin *MMB/R*) for different F values.

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

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

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

F_{OFL} is determined using Equation 5 replacing γM by F_{35} and B_{ref} by MMB_{35}.

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

Scenario 1a:

EAG: F_{OFL} = 0.61; OFL total catch = 3.799 thousand metric tons, retained catch portion of the OFL = 3.641 thousand metric tons.

WAG: F_{OFL} = 0.46; OFL total catch = 1.509 thousand metric tons; retained catch portion of the OFL = 1.424 thousand metric tons.

Scenario 1c:

EAG: F_{OFL} = 0.61; OFL total catch = 3.403 thousand metric tons, retained catch portion of the OFL = 3.284 thousand metric tons.

WAG: F_{OFL} = 0.45; OFL total catch = 1.465 thousand metric tons; retained catch portion of the OFL = 1.382 thousand metric tons.

Scenario 2a:

EAG: F_{OFL} = 0.64; OFL total catch = 3.866 thousand metric tons, retained catch portion of the OFL = 3.706 thousand metric tons.

WAG: F_{OFL} = 0.49; OFL total catch = 1.681 thousand metric tons; retained catch portion of the OFL = 1.585 thousand metric tons.

Scenario 2c:

EAG: F_{OFL} = 0.65; OFL total catch = 3.744 thousand metric tons, retained catch portion of the OFL = 3.608 thousand metric tons.

WAG: F_{OFL} = 0.46; OFL total catch = 1.389 thousand metric tons; retained catch portion of the OFL = 1.311 thousand metric tons.

Scenario 6a:

EAG: F_{OFL} = 0.61; OFL total catch = 3.713 thousand metric tons, retained catch portion of the OFL = 3.585 thousand metric tons.

WAG: F_{OFL} = 0.48; OFL total catch = 1.460 thousand metric tons; retained catch portion of the OFL = 1.362 thousand metric tons.

Scenario 6c:

EAG: F_{OFL} = 0.58; OFL total catch = 3.745 thousand metric tons, retained catch portion of the OFL = 3.641 thousand metric tons.

WAG: F_{OFL} = 0.44; OFL total catch = 1.312 thousand metric tons; retained catch portion of the OFL = 1.240 thousand metric tons.

Scenario 8a:

EAG: F_{OFL} = 0.53; OFL total catch = 3.642 thousand metric tons, retained catch portion of the OFL = 3.487 thousand metric tons.

WAG: F_{OFL} = 0.51; OFL total catch = 2.072 thousand metric tons; retained catch portion of the OFL = 1.956 thousand metric tons.

Scenario 8c:

EAG: F_{OFL} = 0.53; OFL total catch = 3.579 thousand metric tons, retained catch portion of the OFL = 3.445 thousand metric tons.

WAG: F_{OFL} = 0.45; OFL total catch = 1.379 thousand metric tons; retained catch portion of the OFL = 1.300 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 and considered an additional buffer by setting ABC =0.8*OFL. The ABC estimates varied for different scenarios.

Under Tier 4 approach, the ABC estimates calculated with an additional buffer (i.e. = 0.8*OFL) ranged from 0.963 to 1.411 thousand metric tons for EAG and 0.461 to 0.865 thousand metric tons for WAG for the thirteen scenarios.

Under Tier 3 approach, the ABC estimates calculated with an additional buffer (i.e. 0.8*OFL) ranged from 1.760 to 3.119 thousand metric tons for EAG and 0.665 to 1.658 thousand metric tons for WAG for the thirteen 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 gaps and expand data sources.
6. We have been using the length-weight relationship established based on 1990s data for golden king crab. The Aleutian king crab research foundation program can help us to update this relationship by collecting new length weight information.

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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
2015	763,604	1,670	1,129,964	2,114	19,376	166	0.19

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

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	1.02
2006	24.84	25.20	33.52	1,098	0.82
2007	27.95	31.09	40.37	998	0.96
2008	27.26	29.73	38.18	613	0.92
2009	25.85	26.64	35.89	408	0.77
2010	25.96	26.05	36.76	436	0.77
2011	37.33	38.79	51.69	361	1.13
2012	33.02	38.00	47.74	438	1.09
2013	33.67	35.83	46.16	499	1.05
2014	42.29	46.96	60.00	376	1.36
2015	39.41	43.08	58.75	478	1.30

Table 3. Time series of GLM estimated CPUE Indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the EAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data and used in scenarios 2c and 7c. R^2 criteria was used for predictor variable selection for the GLM.

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

Table 4. Iteration process for Stage-2 effective sample size determination by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 6c model fit to 1985 to 2015 EAG data. The effective sample sizes are numbers of trips.

Iteration No.	Retained Size Comp Effective Sample Multiplier (W)	Total Size Comp Effective Sample Multiplier (W)	Groundfish Discard Size Comp Effective Sample Multiplier (W)	Terminal MMB (t)	Retained Catch OFL (t)
1 (start)	1	1	1	9,923	1,459
2	3.5834	1.0578	0.1712	10,141	1,659
3	5.1500	1.2737	0.1614	10,152	1,679
4	5.7219	1.3202	0.1619	10,146	1,685
5	5.9123	1.3229	0.1622	10,141	1,687
6	5.9787	1.3196	0.1623	10,141	1,687

Table 5. Iteration process for Stage-2 effective sample size determination by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 7c model fit to 1985 to 2015 EAG data. The effective sizes are numbers of trips.

Iteration No.	Retained Size Comp Effective Sample Multiplier (W)	Total Size Comp Effective Sample Multiplier (W)	Groundfish Discard Size Comp Effective Sample Multiplier (W)	Terminal MMB (t)	Retained Catch OFL (t)
1 (start)	1	1	1	10,619	1,572
2	3.5692	1.0828	0.1710	10,226	1,684
3	5.2586	1.3135	0.1600	10,019	1,663
4	5.9227	1.3059	0.1615	10,316	1,736
5	6.0478	1.3630	0.1606	10,019	1,674
6	6.1863	1.3065	0.1619	10,017	1,678
7	6.2542	1.2867	0.1622	10,016	1,679

Table 6. The initial input number of trips of sampled vessel and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 6c model fit to 1985 to 2015 EAG data. NA: not available.

Year	Initial Input Retained Trip Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Trip Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985	18	108				
1986	11	66				
1987	15	90				
1988	65	390				
1989	147	882			9	2
1990	66	396	22	29	13	2
1991	51	306	47	62	NA	NA
1992	50	300	41	54	2	0.3
1993	30	180	NA	NA	2	0.3
1994	43	258	3	4	4	0.7
1995	87	522	100	132	5	0.8
1996	60	360	70	92	4	0.7
1997	56	336	73	96	8	1
1998	49	294	52	68	15	2
1999	45	270	59	78	14	2
2000	44	264	50	66	16	3
2001	43	258	45	59	13	2
2002	39	234	42	55	15	2
2003	36	216	37	49	17	3
2004	30	180	32	42	10	2
2005	20	120	18	24	12	2
2006	23	138	17	22	14	2
2007	21	126	19	25	17	3
2008	18	108	12	16	15	2
2009	20	120	12	16	16	3
2010	19	114	11	14	26	4
2011	18	108	12	16	13	2
2012	23	138	14	18	18	3
2013	22	132	14	18	17	3
2014	20	120	12	16	16	3
2015	21	126	13	17	10	2

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

	Scenario 1a		**Scenario 1c**		**Scenario 2c**		**Scenario 4c**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.01	2.53	0.01	2.53	0.01	2.53	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-9.17	0.19	-9.57	0.18	-9.70	0.18	-10.16	0.18	-12.0,-5.0
log_a (molt prob. slope)	-2.52	0.03	-2.48	0.03	-2.47	0.03	-2.43	0.03	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.68	0.03	3.67	0.03	3.66	0.03	3.66	0.03	0.1,12.0
log_total sel deltaθ, 1985-04	3.39	0.04	3.45	0.04	3.43	0.04	3.46	0.04	0.,4.4
log_ total sel deltaθ, 2005-15	3.05	0.06	3.07	0.06	3.08	0.06	3.09	0.07	0.,4.4
log_ ret. sel deltaθ, 1985-15	1.84	0.04	1.83	0.06	1.83	0.06	1.82	0.06	0.,4.4
log_tot sel θ_{50}, 1985-04	4.84	0.004	4.83	0.001	4.83	0.004	4.83	0.005	4.0,5.0
log_tot sel θ_{50}, 2005-15	4.93	0.004	4.93	0.001	4.93	0.004	4.93	0.01	4.0,5.0
log_ret. sel θ_{50}, 1985-15	4.91	0.001	4.91	0.001	4.91	0.001	4.91	0.001	4.0,5.0
log_β_r (rec.distribution par.)	-0.74	0.33	-0.69	0.42	-0.74	0.37	-0.91	0.38	-10.0, 12.0
logq2 (catchability 1985-04)	-0.61	0.17	-0.66	0.18	-0.69	0.14	-0.75	0.18	-9.0, 2.25
logq3 (catchability 2005-15)	-0.90	0.22	-0.96	0.21	-0.95	0.20	-0.98	0.23	-9.0, 2.25
log_mean_rec (mean rec.)	0.95	0.05	0.94	0.06	0.99	0.05	0.97	0.06	0.01, 10.0
log_mean_Fpot (Pot fishery F)	-1.05	0.09	-1.08	0.10	-1.11	0.09	-1.12	0.11	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.26	0.09	-9.28	0.09	-9.31	0.10			-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.01	0.36	0.01	0.36	0.01	0.37	0.01	0.38	0.0, 0.15
σ_e^2 (fishery CPUE additional var)					0.04	0.45			0.0,1.0
2016 MMB	12,264	0.39	9,126	0.17	9,969	0.17	10,498	0.18	

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

	Scenario 6c		**Scenario 7c**		**Scenario 8c**		**Scenario 16c**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.01	2.54	0.01	2.57	0.01	2.57	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-9.69	0.18	-9.64	0.18	-6.98	0.27	-7.43	0.25	-12.0, -5.0
log_a (molt prob. slope)	-2.50	0.02	-2.51	0.02	-2.65	0.03	-2.56	0.03	-4.61, -1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.97	0.002	4.97	0.001	3.869, 5.05
σ (growth variability std)	3.67	0.03	3.66	0.03	3.72	0.03	3.72	0.03	0.1, 12.0
d1 (incr. dome sel slope 1985–04)					0.08	0.11	0.07	0.12	0.01,1.0
d2 (decr. dome sel slope 1985–04)					-0.09	0.17	-0.09	0.20	-1.0,-0.1
d3 (incr. dome sel slope 2005–15)					0.14	0.24	0.14	0.26	0.01,1.0
d4 (decr. dome sel slope 2005–15)					-0.12	0.88	-0.11	1.13	-1.0,0.01
log_total sel deltaθ, 1985–04	3.37	0.03	3.36	0.03					0., 4.4
log_ total sel deltaθ, 2005–15	2.99	0.05	3.01	0.05					0., 4.4
log_ ret. sel deltaθ, 1985–15	1.83	0.03	1.83	0.03	1.87	0.05	1.86	0.05	0., 4.4
log_tot sel θ_{50}, 1985–04	4.82	0.003	4.82	0.003	5.00	0.00005	5.00	0.00005	4.0, 5.3
log_tot sel θ_{50}, 2005–15	4.92	0.003	4.93	0.002	4.93	0.01	4.93	0.01	4.0, 5.3
log_tot sel θ_{95}, 1985–04					5.00	0.01	5.02	0.01	4.9, 5.3
log_tot sel θ_{95}, 2005–15					5.15	0.01	5.15	0.02	-6.0,5.3
log_ret. sel θ_{50}, 1985-–15	4.91	0.0003	4.91	0.0003	4.91	0.001	4.91	0.001	4.0, 5.0
log_β_r (rec.distribution par.)	-0.85	0.31	-0.87	0.30	-0.68	0.42	-0.68	0.43	-10.0, 12.0
logq2 (catchability 1985–04)	-0.76	0.13	-0.73	0.11	-0.76	0.15	-0.56	0.17	-9.0, 2.25
logq3 (catchability 2005–15)	-1.14	0.14	-1.10	0.14	-1.08	0.16	-0.86	0.18	-9.0, 2.25
log_mean_rec (mean rec.)	0.96	0.05	1.00	0.05	1.00	0.07	0.63	0.08	0.01, 10.0
log_mean_Fpot (Pot fishery F)	-1.18	0.07	-1.17	0.06	-1.15	0.08	-0.97	0.08	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.35	0.10	-9.36	0.10	-9.39	0.10	-9.44	0.04	-15.0, -1.6
σ_e^2 (CPUE additional var)	0.02	0.37	0.02	0.39	0.02	0.37	0.02	0.38	0.0, 0.15
σ_e^2 (fishery CPUE additional var)			0.05	0.43					
2016 MMB	10,467	0.16	10,323	0.15	11,129	0.20	8,746	0.19	

Table 9. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 1a 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq}=18,513 MMB_{35}=6,223			
1985	2.04			10,204	0.07
1986	1.52	8,916	0.06	8,564	0.06
1987	2.98	6,958	0.06	6,688	0.05
1988	4.95	5,931	0.06	5,766	0.05
1989	1.69	5,190	0.07	5,029	0.06
1990	2.48	5,107	0.07	4,772	0.06
1991	4.02	5,116	0.07	4,929	0.07
1992	2.36	4,723	0.09	4,590	0.08
1993	2.20	4,939	0.08	4,683	0.08
1994	3.05	5,265	0.06	5,059	0.06
1995	1.64	4,782	0.06	4,632	0.06
1996	2.42	4,380	0.06	4,166	0.06
1997	3.03	4,179	0.07	4,041	0.07
1998	2.52	4,228	0.08	4,088	0.08
1999	3.00	4,694	0.08	4,494	0.08
2000	2.71	5,165	0.08	4,984	0.08
2001	2.13	5,728	0.08	5,518	0.08
2002	3.59	6,149	0.09	5,929	0.09
2003	2.14	6,445	0.09	6,288	0.09
2004	1.51	7,196	0.09	6,926	0.09
2005	3.19	7,355	0.10	7,117	0.10
2006	2.61	6,955	0.11	6,813	0.11
2007	2.61	7,200	0.12	6,957	0.12
2008	3.04	7,464	0.12	7,217	0.12
2009	2.01	7,633	0.13	7,405	0.13
2010	3.95	7,900	0.13	7,625	0.13
2011	4.01	7,859	0.13	7,677	0.13
2012	3.22	8,649	0.13	8,369	0.13
2013	1.54	9,642	0.13	9,294	0.13
2014	5.62	10,051	0.13	9,706	0.13
2015	4.88	9,644	0.14	9,501	0.14
2016	2.58	10,875	0.19		

Table 10. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 1c 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =17,763 MMB_{35}=6,052			
1985	2.06			10,252	0.08
1986	1.63	8,856	0.07	8,518	0.07
1987	2.90	6,875	0.07	6,616	0.07
1988	4.59	5,899	0.07	5,732	0.07
1989	1.72	5,120	0.09	4,965	0.08
1990	2.85	4,849	0.08	4,555	0.08
1991	3.95	4,839	0.09	4,680	0.08
1992	2.74	4,633	0.09	4,493	0.09
1993	2.22	4,904	0.09	4,670	0.08
1994	3.01	5,423	0.06	5,211	0.06
1995	1.54	5,008	0.06	4,858	0.06
1996	2.58	4,577	0.07	4,371	0.07
1997	3.02	4,314	0.08	4,193	0.08
1998	2.66	4,419	0.08	4,279	0.08
1999	3.17	4,905	0.09	4,715	0.09
2000	2.89	5,448	0.09	5,272	0.09
2001	2.17	6,117	0.09	5,908	0.09
2002	3.43	6,638	0.09	6,412	0.09
2003	2.28	6,940	0.10	6,776	0.09
2004	1.77	7,581	0.10	7,326	0.10
2005	2.97	7,753	0.11	7,515	0.11
2006	2.54	7,445	0.12	7,277	0.12
2007	2.64	7,568	0.12	7,330	0.12
2008	2.90	7,718	0.13	7,480	0.13
2009	2.32	7,832	0.13	7,602	0.13
2010	4.67	8,013	0.13	7,755	0.13
2011	3.27	8,146	0.13	7,965	0.13
2012	4.58	9,297	0.14	8,959	0.13
2013	1.01	10,094	0.14	9,811	0.13
2014	1.61	11,018	0.14	10,600	0.14
2015	4.90	10,178	0.15	9,946	0.15
2016	2.55	9,126	0.17		

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 6c 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq}=18,473 MMB_{35}=6,279			
1985	2.00			9,822	0.05
1986	1.03	8,810	0.04	8,466	0.04
1987	2.97	6,921	0.04	6,660	0.04
1988	5.32	5,650	0.04	5,539	0.04
1989	1.74	4,840	0.06	4,734	0.05
1990	2.96	4,934	0.06	4,621	0.05
1991	3.53	5,035	0.06	4,882	0.05
1992	3.31	4,858	0.06	4,718	0.06
1993	1.96	4,968	0.06	4,779	0.05
1994	2.62	5,680	0.05	5,453	0.04
1995	2.18	5,158	0.05	5,017	0.05
1996	2.30	4,527	0.06	4,369	0.06
1997	3.29	4,493	0.06	4,352	0.06
1998	2.90	4,547	0.07	4,430	0.07
1999	3.29	5,149	0.07	4,966	0.07
2000	3.37	5,847	0.08	5,670	0.08
2001	2.36	6,636	0.08	6,440	0.08
2002	3.11	7,423	0.09	7,182	0.09
2003	2.58	7,815	0.09	7,635	0.09
2004	2.56	8,275	0.09	8,046	0.09
2005	3.11	8,526	0.10	8,299	0.10
2006	2.93	8,600	0.11	8,387	0.10
2007	2.54	8,877	0.11	8,622	0.11
2008	3.79	9,150	0.11	8,881	0.11
2009	3.21	9,186	0.12	8,972	0.12
2010	3.10	9,749	0.12	9,453	0.12
2011	3.43	10,223	0.12	9,929	0.12
2012	3.78	10,521	0.12	10,247	0.12
2013	2.39	10,877	0.12	10,590	0.12
2014	2.55	11,308	0.13	10,953	0.13
2015	3.00	11,020	0.14	10,735	0.14
2016	2.60	10,467	0.16		

Table 12. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with coefficient of variation (CV) for scenario 8c 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=19,550 MMB_{35}=6,597			
1985	2.35			12,705	0.12
1986	1.69	11,187	0.11	10,837	0.11
1987	2.76	9,057	0.12	8,754	0.12
1988	4.94	7,799	0.12	7,598	0.12
1989	1.77	6,644	0.13	6,487	0.13
1990	2.91	6,192	0.13	5,903	0.13
1991	4.06	6,052	0.12	5,923	0.12
1992	2.77	5,726	0.13	5,631	0.13
1993	2.25	5,908	0.12	5,735	0.12
1994	3.15	6,351	0.10	6,222	0.10
1995	1.63	5,879	0.10	5,806	0.10
1996	2.66	5,425	0.11	5,283	0.11
1997	3.24	5,158	0.12	5,095	0.12
1998	2.82	5,248	0.12	5,175	0.12
1999	3.38	5,780	0.12	5,662	0.12
2000	3.06	6,379	0.12	6,292	0.12
2001	2.27	7,120	0.12	7,012	0.12
2002	3.44	7,697	0.12	7,580	0.12
2003	2.24	8,012	0.12	7,956	0.12
2004	1.93	8,574	0.12	8,437	0.13
2005	3.09	8,650	0.13	8,530	0.13
2006	2.67	8,345	0.14	8,275	0.14
2007	2.68	8,474	0.15	8,338	0.15
2008	2.99	8,638	0.15	8,507	0.15
2009	2.41	8,731	0.16	8,617	0.16
2010	4.85	8,897	0.16	8,759	0.16
2011	3.34	9,041	0.16	8,983	0.16
2012	4.41	10,216	0.16	10,024	0.16
2013	1.00	11,014	0.16	10,894	0.16
2014	3.85	11,799	0.16	11,579	0.16
2015	4.34	11,088	0.18	11,066	0.17
2016	2.73	11,129	0.20		

Table 13. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 16c 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq} =20,605 MMB_{35}=7,233			
1985	1.91			11,520	0.11
1986	1.34	10,030	0.11	9,849	0.11
1987	2.31	8,148	0.11	7,991	0.11
1988	3.96	7,092	0.12	7,019	0.11
1989	1.39	6,062	0.13	6,019	0.12
1990	2.34	5,541	0.12	5,392	0.12
1991	3.13	5,429	0.12	5,417	0.12
1992	2.14	5,087	0.12	5,098	0.12
1993	1.75	5,111	0.11	5,066	0.11
1994	2.43	5,493	0.09	5,490	0.09
1995	1.24	5,009	0.09	5,042	0.09
1996	1.99	4,481	0.09	4,449	0.10
1997	2.42	4,213	0.10	4,240	0.10
1998	2.08	4,203	0.10	4,227	0.10
1999	2.43	4,563	0.10	4,561	0.10
2000	2.18	5,010	0.10	5,040	0.10
2001	1.61	5,544	0.10	5,571	0.10
2002	2.43	5,964	0.10	5,990	0.10
2003	1.54	6,220	0.10	6,296	0.10
2004	1.31	6,657	0.10	6,679	0.10
2005	2.15	6,722	0.11	6,757	0.11
2006	1.88	6,471	0.12	6,541	0.12
2007	1.87	6,539	0.13	6,562	0.13
2008	2.07	6,678	0.13	6,706	0.13
2009	1.71	6,743	0.14	6,787	0.14
2010	3.36	6,858	0.14	6,889	0.14
2011	2.27	6,983	0.14	7,075	0.14
2012	3.00	7,880	0.14	7,893	0.14
2013	0.71	8,493	0.15	8,572	0.14
2014	2.81	9,108	0.15	9,123	0.15
2015	3.07	8,641	0.16	8,788	0.16
2016	1.88	8,746	0.19		

Table 14. Negative log-likelihood values of the fits for scenarios (Sc) 1a (equilibrium initial cond.), 1c (trips as effective sample), 2c (added fish ticket CPUE likelihood), 4c (drop groundfish size composition and bycatch), 6c (Francis reweighting on Sc1c), 7c (Francis reweighting on Sc2c), 8c (dome shaped total selectivity), 11c (similar to Sc1a, but M=0. 18yr^{-1}), and 16c (dome shaped total sel. and M=0.18yr^{-1}) 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 1a**	**Sc 1c**	**Sc 2c**	**Sc 4c**	**Sc 6c**	**Sc 7c**	**Sc 8c**	**Sc 11c**	**Sc16c**	**Sc1a– Sc 1c**	**Sc 6c – Sc 1c**	**Sc 8c – Sc 1c**	**Sc 11c – Sc 1c**	**Sc 16c – Sc 1c**
Number of free parameters	137	137	138	109	137	138	141	137	141					
Data	base	base	base+ fishery CPUE	base- groundfish data	base	base+ fishery CPUE	base	base	base					
Retlencomp	-914.88	-858.71	-858.24	-858.26	-1149.00	- 1154.50	-859.12	-857.38	-856.93	-56.17	- 290.29	-0.41	1.33	1.78
Totallencomp	-920.10	-953.32	-953.60	-956.55	-1007.99	- 1003.25	-954.65	-954.16	-955.32	33.22	-54.67	-1.33	-0.84	-2
GroundFish discdlencomp	-714.68	-687.72	-688.76		-424.89	-424.97	-693.55	-682.50	-689.02	-26.96	262.83	-5.83	5.22	-1.3
Observer cpue	-14.45	-14.76	-14.81	-15.60	-12.37	-12.20	-13.73	-14.41	-13.25	0.31	2.39	1.03	0.35	1.51
RetdcatchB	4.77	4.35	4.75	4.22	4.88	5.17	4.37	4.43	4.43	0.42	0.53	0.02	0.08	0.08
TotalcatchB	18.81	17.43	18.19	16.94	19.30	19.68	17.71	17.31	17.61	1.38	1.87	0.28	-0.12	0.18
GdiscdcatchB	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.01	0	0	0	0	0.01
Rec_dev	7.86	8.03	7.12	3.63	6.08	5.56	7.29	9.47	8.55	-0.17	-1.95	-0.74	1.44	0.52
Pot F_dev	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0
Gbyc_F_dev	0.02	0.02	0.02		0.02	0.02	0.02	0.02	0.08	0	0	0	0	0.06
Tag	2691.05	2690.41	2690.41	2689.81	2690.87	2690.99	2685.17	2690.54	2686.83	0.64	0.46	-5.24	0.13	-3.58
Fishery cpue	-	-	-2.03	-	-	-0.65	-	-						
Total	158.42	205.74	203.08	884.21	126.93	125.85	193.52	213.36	203.00	-47.32	-78.81	-12.22	7.62	-2.74

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.)	Ground-fish 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
2015	confidential	confidential	confidential	confidential	confidential	978	1.42

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	19.17	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	9.41	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	23.89	36.23	1,365	1.17
2006	19.64	24.01	33.47	1,183	1.09
2007	20.05	21.04	32.46	1,082	1.01
2008	22.43	24.57	38.16	979	1.15
2009	23.72	26.55	34.08	892	1.22
2010	20.88	22.35	29.05	867	1.08
2011	23.40	23.79	31.13	837	1.11
2012	20.57	22.82	30.76	1,109	1.07
2013	16.42	16.96	25.01	1,223	0.81
2014	15.29	15.28	22.67	1,137	0.71
2015	confidential	confidential	confidential	confidential	confidential

Table 17. Time series of GLM estimated CPUE Indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data and used in scenarios 2c and 7c. R^2 criteria was used for predictor variable selection for the GLM.

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

Table 18. Iteration process for Stage-2 effective sample size determination by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 6a model fit to 1985 to 2015 WAG data. The effective sizes are numbers of length measurements.

Iteration No.	Retained Size Comp Effective Sample Multiplier (W)	Total Size Comp Effective Sample Multiplier (W)	Groundfish Discard Size Comp Effective Sample Multiplier (W)	Terminal MMB (t)	Retained Catch OFL (t)
1 (start)	1	1	1	5,184	778
2	3.2965	1.3499	0.1192	5,185	694
3	6.7135	0.9958	0.1043	5,348	726
4	9.0255	0.7202	0.1026	5,380	733
5	10.6366	0.5720	0.1017	5,380	734
6	11.9215	0.4956	0.1012	5,375	734

Table 19. Iteration process for Stage-2 effective sample size determination by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 7a model fit to 1985 to 2015 WAG data. The effective sizes are numbers of length measurements.

Iteration No.	Retained Size Comp Effective Sample Multiplier (W)	Total Size Comp Effective Sample Multiplier (W)	Groundfish Discard Size Comp Effective Sample Multiplier (W)	Terminal MMB (t)	Retained Catch OFL (t)
1 (start)	1	1	1	5,350	846
2	2.3779	1.3329	0.0794	5,507	791
3	4.9265	1.1920	0.0709	5,678	819
4	7.8128	0.8898	0.0702	5,698	818
5	9.7682	0.6834	0.0694	5,678	814
6	11.4777	0.5600	0.0688	5,650	809
7	12.4903	0.4947	0.0686	5,636	806
8	12.8109	0.4635	0.0685	5,636	806

Table 20. The initial input number of length measurements (scaled to a maximum) and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 6a model fit to 1985 to 2015 WAG data. NA: not available.

Year	Initial Input Retained Length Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Length Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Length Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985	17	205				
1986	20	233				
1987	4	45				
1988	200	2384				
1989	200	2384			3	0.33
1990	200	2384	7	4	15	2
1991	200	2384	13	6	0.20	0.02
1992	200	2384	9	4	3	0.34
1993	133	1591	5	3	NA	NA
1994	200	2384	25	12	0.20	0.02
1995	170	2021	96	48	2	0.15
1996	200	2384	82	40	5	0.47
1997	200	2384	56	28	1	0.12
1998	200	2384	36	18	25	3
1999	200	2384	65	32	25	3
2000	200	2384	75	37	15	2
2001	186	2215	66	33	10	1
2002	189	2258	43	21	14	1
2003	138	1646	39	19	3	0.27
2004	133	1585	36	18	4	0.45
2005	117	1392	24	12	2	0.20
2006	116	1387	27	13	19	2
2007	83	986	27	13	25	3
2008	105	1255	25	13	17	2
2009	97	1155	30	15	14	1
2010	98	1170	25	12	4	0.35
2011	106	1268	26	13	5	0.54
2012	65	780	33	16	8	0.79
2013	26	311	30	15	6	0.65
2014	29	349	26	13	5	0.46
2015	30	353	28	14	2	0.23

Table 21. Parameter estimates and standard deviations with the 2015 (February 15) MMB for scenarios 1a, 1c, 2a, and 4a for the golden king crab data from the WAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 1a		**Scenario 1c**		**Scenario 2a**		**Scenario 4a**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.53	0.01	2.52	0.01	2.53	0.01	2.54	0.01	1.0, 3.85
ω_2 (growth incr. slope)	-10.43	0.17	-10.77	0.16	-10.53	0.16	-8.83	0.20	-60.0,-2.0
log_a (molt prob. slope)	-2.48	0.03	-2.42	0.03	-2.47	0.03	-2.55	0.03	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.66	0.03	3.66	0.03	3.65	0.03	3.68	0.03	0.1,9.0
log_total sel deltaθ, 1985-04	3.28	0.03	3.46	0.03	3.23	0.03	3.25	0.03	0.,4.4
log_ total sel deltaθ, 2005-15	2.87	0.06	2.86	0.07	2.84	0.06	3.04	0.05	0.,4.4
log_ ret. sel deltaθ, 1985-15	1.74	0.04	1.71	0.05	1.73	0.04	1.74	0.04	0.,4.4
log_tot sel θ_{50}, 1985-04	4.84	0.003	4.84	0.004	4.83	0.003	4.85	0.003	3.98,5.1
log_tot sel θ_{50}, 2005-15	4.88	0.003	4.87	0.003	4.87	0.002	4.91	0.003	3.98,5.5
log_ret. sel θ_{50}, 1985-15	4.91	0.0003	4.91	0.0004	4.91	0.0003	4.91	0.0004	4.85,4.98
log_β_r (rec.distribution par.)	-0.68	0.46	-0.30	1.25	-0.81	0.34	-1.22	0.23	-12.0, 12.0
logq2 (catchability 1985-04)	-0.30	0.32	-0.33	0.35	-0.40	0.16	-0.15	0.56	-9.0, 2.25
logq3 (catchability 2005-15)	-0.79	0.17	-0.79	0.22	-0.86	0.15	-0.40	0.38	-9.0, 2.25
log_mean_rec (mean rec.)	0.83	0.06	0.82	0.06	0.87	0.06	0.80	0.06	0.01, 10.0
log_mean_Fpot (Pot fishery F)	-1.02	0.08	-1.01	0.10	-1.06	0.07	-0.82	0.10	-9.0, -0.01
log_mean_Fground (GF byc. F)	-8.82	0.04	-8.81	0.04	-8.86	0.04			-15.0, -2.0
σ_e^2 (observer CPUE additional var)	0.02	0.47	0.02	0.53	0.02	0.43	0.01	0.55	0.0, 0.15
σ_e^2 (fishery CPUE additional var)					0.002	1.53			0.0,1.0
2016 MMB	4,933	0.18	4,811	0.20	5,180	0.18	3,896	0.16	

Table 22. Parameter estimates and coefficient of variations (CV) with the 2016 (February 15) MMB for scenarios 6a, 7a, 8a (dome shaped selectivity), and 16a (dome shaped selectivity) for the golden king crab data from the WAG, 1985/86–2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 6a		**Scenario 7a**		**Scenario 8a**		**Scenario 16a**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.55	0.01	2.55	0.01	2.58	0.01	2.55	0.01	1.0, 3.85
ω_2 (growth incr. slope)	-7.78	0.22	-7.98	0.22	-8.36	0.22	-9.75	0.18	-60.0,-2.0
log_a (molt prob. slope)	-2.80	0.02	-2.80	0.02	-2.57	0.03	-2.46	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.96	0.001	4.95	0.001	4.98	0.002	4.96	0.001	3.869,5.05
σ (growth variability std)	3.69	0.03	3.69	0.03	3.71	0.03	3.68	0.03	0.1,9.0
d1 (incr. dome sel slope 1985–04)					0.07	0.12	0.10	0.10	0.01,1.0
d2 (decr. dome sel slope 1985–04)					-0.14	0.07	-0.05	0.25	-1.0,-0.1
d3 (incr. dome sel slope 2005–15)					0.18	0.09	0.17	0.15	0.01,1.0
d4 (decr. dome sel slope 2005–15)					-0.05	0.27	-0.01	0.71	-1.0,0.01
log_total sel deltaθ, 1985–04	2.95	0.03	2.92	0.03					0., 4.4
log_ total sel deltaθ, 2005–15	2.81	0.05	2.76	0.05					0., 4.4
log_ ret. sel deltaθ, 1985–15	1.79	0.02	1.79	0.02	1.82	0.03	1.77	0.04	0., 4.4
log_tot sel θ_{50}, 1985–04	4.87	0.001	4.87	0.001	5.22	0.02	4.92	0.01	3.98,5.1
log_tot sel θ_{50}, 2005–15	4.89	0.002	4.88	0.001	4.93	0.004	4.89	0.005	3.98,5.5
log_tot sel θ_{95}, 1985–04					4.96	0.003	4.90	0.0001	4.9, 5.3
log_tot sel θ_{95}, 2005–15					-5.74	134.71	-5.92	44.53	-6.0,5.3
log_ret. sel θ_{50}, 1985-–15	4.92	0.0002	4.92	0.0002	4.91	0.0004	4.91	0.0004	4.85, 4.98
log_β_r (rec.distribution par.)	-1.40	0.14	-1.43	0.13	-0.52	0.61	-0.59	0.52	-12.0, 12.0
logq2 (catchability 1985–04)	-0.05	1.21	-0.20	0.30	-0.59	0.26	-0.26	0.31	-9.0, 2.25
logq3 (catchability 2005–15)	-0.61	0.14	-0.67	0.14	-0.92	0.16	-0.66	0.16	-9.0, 2.25
log_mean_rec (mean rec.)	0.74	0.06	0.80	0.06	0.95	0.10	0.49	0.09	0.01, 10.0
log_mean_Fpot (Pot fishery F)	-0.82	0.06	-0.87	0.06	-1.14	0.09	-0.92	0.07	-9.0, -0.01
log_mean_Fground (GF byc. F)	-8.77	0.04	-8.82	0.04	-9.15	0.04	-8.67	0.04	-15.0, -2.0
σ_e^2 (CPUE additional var)	0.02	0.37	0.03	0.38	0.02	0.57	0.01	0.51	0.0, 0.15
σ_e^2 (fishery CPUE additional var)			0.03	0.50					
2016 MMB	4,834	0.17	5,132	0.19	7,440	0.28	4,088	0.18	

Table 23. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 1a 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=13,707 MMB_{35}=4,891			
1985	3.21			10,818	0.08
1986	3.89	10,234	0.07	9,866	0.06
1987	2.73	7,135	0.06	6,853	0.06
1988	2.57	6,553	0.06	6,240	0.05
1989	2.43	5,680	0.05	5,431	0.05
1990	1.75	3,910	0.06	3,716	0.06
1991	2.03	3,655	0.06	3,469	0.06
1992	1.41	3,417	0.07	3,279	0.07
1993	2.76	3,573	0.07	3,419	0.06
1994	1.75	3,927	0.06	3,829	0.05
1995	1.97	3,608	0.06	3,428	0.05
1996	2.04	3,571	0.06	3,424	0.06
1997	1.71	3,581	0.07	3,442	0.06
1998	1.81	3,727	0.06	3,574	0.06
1999	2.43	3,910	0.06	3,771	0.06
2000	2.60	3,731	0.06	3,607	0.06
2001	2.67	3,826	0.08	3,672	0.07
2002	3.45	4,253	0.09	4,076	0.09
2003	2.47	4,896	0.10	4,722	0.09
2004	2.99	5,847	0.10	5,598	0.10
2005	2.61	6,388	0.11	6,180	0.10
2006	2.27	6,963	0.11	6,723	0.11
2007	3.53	7,491	0.10	7,242	0.10
2008	0.95	7,614	0.10	7,409	0.10
2009	1.64	8,124	0.09	7,784	0.09
2010	1.60	7,345	0.10	7,141	0.09
2011	1.92	6,544	0.10	6,354	0.10
2012	1.83	5,849	0.10	5,664	0.10
2013	2.54	5,301	0.11	5,105	0.11
2014	1.69	4,863	0.13	4,695	0.12
2015	1.69	5,005	0.15	4,786	0.15
2016	2.30	4,933	0.18		

Table 24. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 1c 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq}=13,587 MMB_{35}=4,865			
1985	3.11			10,992	0.09
1986	3.76	10,379	0.07	10,003	0.06
1987	2.81	7,220	0.06	6,939	0.06
1988	2.75	6,533	0.06	6,240	0.05
1989	1.59	5,675	0.05	5,436	0.05
1990	2.25	3,906	0.06	3,696	0.06
1991	1.94	3,311	0.07	3,182	0.07
1992	1.64	3,189	0.08	3,049	0.08
1993	2.79	3,380	0.08	3,237	0.08
1994	2.04	3,891	0.07	3,783	0.06
1995	1.77	3,653	0.07	3,482	0.06
1996	2.43	3,762	0.06	3,601	0.06
1997	1.28	3,760	0.07	3,634	0.07
1998	2.14	4,017	0.07	3,842	0.07
1999	2.43	4,056	0.07	3,938	0.07
2000	2.67	3,981	0.08	3,845	0.08
2001	2.63	4,120	0.09	3,961	0.09
2002	3.31	4,568	0.10	4,387	0.10
2003	1.55	5,190	0.11	5,012	0.11
2004	3.61	5,935	0.12	5,681	0.12
2005	2.09	6,030	0.13	5,882	0.13
2006	2.62	6,705	0.13	6,445	0.13
2007	4.05	7,101	0.14	6,877	0.13
2008	0.97	7,446	0.14	7,238	0.14
2009	1.63	8,276	0.14	7,916	0.14
2010	0.97	7,636	0.14	7,414	0.14
2011	2.11	6,775	0.12	6,568	0.12
2012	1.69	5,753	0.11	5,600	0.11
2013	2.60	5,168	0.13	4,971	0.12
2014	1.72	4,699	0.15	4,535	0.14
2015	1.55	4,855	0.17	4,644	0.17
2016	2.27	4,811	0.20		

Table 25. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 6a 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	**Recruits to the Model (≥ 101 mm CL)**	**Mature Male Biomass (≥ 121 mm CL)**	**CV**	**Legal Male Biomass (≥ 136 mm CL)**	**CV**
		MMB_{eq}=13,851 MMB_{35}=4,823			
1985	3.64			10,083	0.04
1986	3.90	9,680	0.04	9,288	0.03
1987	2.95	6,843	0.04	6,423	0.03
1988	1.93	6,406	0.04	5,925	0.03
1989	3.02	5,687	0.03	5,253	0.03
1990	1.20	3,699	0.04	3,423	0.03
1991	2.48	3,671	0.04	3,318	0.03
1992	1.69	3,253	0.05	3,052	0.04
1993	1.90	3,596	0.04	3,330	0.03
1994	1.66	4,087	0.03	3,858	0.03
1995	1.50	3,367	0.04	3,134	0.03
1996	2.71	3,096	0.04	2,880	0.03
1997	1.56	2,828	0.04	2,663	0.03
1998	1.61	3,258	0.04	2,972	0.03
1999	2.35	3,483	0.04	3,250	0.03
2000	2.32	3,194	0.04	3,007	0.03
2001	2.89	3,177	0.05	2,936	0.04
2002	3.85	3,421	0.05	3,168	0.05
2003	3.27	4,113	0.06	3,826	0.05
2004	2.09	5,365	0.07	4,953	0.06
2005	2.49	6,395	0.06	5,959	0.06
2006	2.35	6,675	0.06	6,360	0.05
2007	1.95	7,030	0.05	6,722	0.05
2008	1.47	7,068	0.05	6,747	0.05
2009	1.61	6,848	0.05	6,546	0.04
2010	2.25	6,170	0.05	5,927	0.05
2011	1.22	5,545	0.05	5,327	0.05
2012	1.90	5,280	0.06	4,982	0.05
2013	3.08	4,561	0.07	4,349	0.07
2014	2.03	4,099	0.09	3,900	0.09
2015	2.00	4,576	0.13	4,233	0.13
2016	2.10	4,834	0.17		

Table 26. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 8a 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =16,786 MMB_{35}=5,894			
1985	5.00			13,554	0.14
1986	3.27	12,891	0.13	12,798	0.13
1987	3.44	10,290	0.13	10,102	0.13
1988	2.83	9,249	0.13	9,148	0.13
1989	2.99	8,244	0.13	8,158	0.14
1990	2.17	6,348	0.17	6,279	0.17
1991	2.20	6,104	0.18	6,048	0.18
1992	1.62	5,895	0.19	5,880	0.19
1993	3.17	5,962	0.18	5,948	0.18
1994	2.18	6,242	0.17	6,301	0.17
1995	2.43	5,965	0.18	5,939	0.18
1996	2.28	6,015	0.18	6,024	0.19
1997	2.19	6,130	0.19	6,142	0.19
1998	2.09	6,289	0.19	6,305	0.19
1999	2.95	6,550	0.19	6,568	0.19
2000	3.05	6,405	0.20	6,439	0.21
2001	3.05	6,609	0.21	6,625	0.22
2002	3.70	7,130	0.22	7,155	0.22
2003	2.69	7,830	0.22	7,892	0.22
2004	3.33	8,746	0.22	8,775	0.22
2005	2.98	9,216	0.22	9,287	0.22
2006	2.54	9,775	0.22	9,823	0.22
2007	3.96	10,332	0.21	10,367	0.21
2008	1.15	10,468	0.21	10,543	0.21
2009	1.95	11,012	0.20	10,956	0.20
2010	1.87	10,175	0.21	10,183	0.21
2011	2.12	9,310	0.21	9,275	0.21
2012	2.00	8,527	0.22	8,473	0.22
2013	2.93	7,847	0.23	7,782	0.23
2014	2.16	7,281	0.25	7,259	0.25
2015	1.99	7,421	0.26	7,380	0.26
2016	2.58	7,440	0.28		

Table 27. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 16a 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 2016 are restricted to 1985–2016. Equilibrium MMB_{eq} and MMB_{35} are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	CV	Legal Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =15,482 MMB_{35}=5,527			
1985	3.45			9,843	0.08
1986	2.74	9,292	0.08	9,231	0.07
1987	2.45	6,806	0.07	6,706	0.06
1988	2.05	6,166	0.06	6,107	0.06
1989	1.98	5,408	0.06	5,371	0.06
1990	1.41	3,697	0.07	3,665	0.07
1991	1.56	3,417	0.08	3,390	0.08
1992	1.13	3,188	0.08	3,191	0.08
1993	2.23	3,303	0.08	3,301	0.08
1994	1.36	3,676	0.06	3,730	0.06
1995	1.63	3,349	0.07	3,327	0.07
1996	1.49	3,306	0.07	3,313	0.07
1997	1.41	3,325	0.07	3,330	0.07
1998	1.42	3,401	0.07	3,408	0.07
1999	1.91	3,602	0.07	3,618	0.07
2000	1.98	3,439	0.07	3,463	0.08
2001	2.00	3,467	0.08	3,473	0.09
2002	2.49	3,760	0.09	3,765	0.09
2003	1.81	4,234	0.10	4,263	0.10
2004	2.07	4,927	0.10	4,929	0.10
2005	1.82	5,325	0.10	5,361	0.10
2006	1.65	5,716	0.11	5,745	0.11
2007	2.55	6,143	0.11	6,175	0.11
2008	0.73	6,279	0.11	6,340	0.10
2009	1.28	6,742	0.10	6,712	0.10
2010	1.23	6,213	0.10	6,250	0.10
2011	1.36	5,646	0.10	5,664	0.10
2012	1.34	5,116	0.11	5,119	0.11
2013	1.85	4,594	0.11	4,587	0.11
2014	1.25	4,134	0.13	4,143	0.13
2015	1.23	4,174	0.14	4,155	0.14
2016	1.63	4,088	0.18		

Table 28. Negative log-likelihood values of the fits for scenarios (Sc) 1a (equilibrium initial cond.), 1c (trips as effective sample), 2a (added fish ticket CPUE likelihood), 4a (drop groundfish size composition and bycatch), 6a (Francis reweighting on Sc1a), 7a (Francis reweighting on Sc2a), 8a (dome shaped total selectivity), 11a (similar to Sc1a, but M=0. 18yr^{-1}), and 16a (dome shaped total sel. and M=0.18yr^{-1}) 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 1a**	**Sc 1c**	**Sc 2a**	**Sc 4a**	**Sc 6a**	**Sc 7a**	**Sc 8a**	**Sc 11a**	**Sc16a**	**Sc1c–Sc 1a**	**Sc 6a–Sc 1a**	**Sc 8a–Sc 1a**	**Sc 11a – Sc 1a**	**Sc 16a–Sc 1a**
Number of free parameters	137	137	138	109	137	138	141	137	141					
Data	base	base	base+ fishery CPUE	base- groundfish data	base	base+ fishery CPUE	base	base	base					
Retlencomp	-1045.10	-917.99	-1038.84	-1046.98	-1342.85	-1345.38	-1048.96	-1044.20	-1047.76	127.11	-297.75	-3.86	0.9	-2.66
Totallencomp	-1034.76	-1097.24	-1031.89	-1034.47	-883.03	-868.82	-1040.34	-1035.25	-1037.38	-62.48	151.73	-5.58	-0.49	-2.62
GroundFish discdlencomp	-604.52	-649.91	-605.16		-192.30	-106.73	-611.16	-610.12	-611.83	-45.39	412.22	-6.64	-5.6	-7.31
Observer cpue	-11.62	-11.03	-11.27	-21.97	-11.00	-7.40	-11.33	-14.26	-15.09	0.59	0.62	0.29	-2.64	-3.47
RetdcatchB	3.83	3.42	3.36	4.10	4.76	4.17	4.05	3.87	4.01	-0.41	0.93	0.22	0.04	0.18
TotalcatchB	33.35	28.73	30.83	33.71	44.30	44.63	32.00	33.76	33.31	-4.62	10.95	-1.35	0.41	-0.04
GdiscdcatchB	0.01	0.01	0.01		0.01	0.01	0.01	0.01	0.01	0	0	0	0	0
Rec_dev	6.22	8.55	6.91	4.09	10.00	9.69	5.83	6.22	7.19	2.33	3.78	-0.39	0	0.97
Pot F_dev	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0	-0.01	-0.01	0	-0.01
Gbyc_F_dev	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0	0	0	0	0
Tag	2688.69	2689.43	2688.96	2689.45	2693.76	2692.69	2686.62	2689.04	2686.74	0.74	5.07	-2.07	0.35	-1.95
Fishery cpue			-19.02			-4.09								
Total	36.23	54.10	24.02	627.96	323.80	418.90	16.84	29.20	19.33	17.87	287.57	-19.39	-7.03	-16.9

Table 29. Predicted total catch OFL (t) under Tier 4 and Tier 3 assumptions for various scenarios for EAG and WAG, respectively. Sc = scenario; MMB_{2016} / $MMB_{initial}$ = ratio of terminal MMB relative to initial MMB (= MMB_{1961}); ESS= effective sample size; LF=length composition.

Notes on letters attached to scenario numbers: a= scaled number of length measurements were used for ESS; b= AIC criterion was used for CPUE predictor variable selection; c = number of fishing trips made by sampled vessels were used for ESS; d = number of fishing trips were used for ESS and AIC criterion was used for CPUE predictor variable selection.

EAG				WAG					
Sc	Tier 4 Total Catch OFL (t)	Tier 3 Total Catch OFL (t)	MMB_{2016} / $MMB_{initial}$	Sc	Tier 4 Total Catch OFL (t)	Tier 3 Total Catch OFL (t)	MMB_{2016} / $MMB_{initial}$	M yr^{-1}	Remarks
1a	1,669	3,799	0.66		822	1,509	0.38	0.2339	Equilibrium initial condition, asymptotic selectivity, ESS= no. of length measurements
1b	1,175	2,907	0.60		967	1,764	0.40	0.2339	Same as Sc1a, but CPUE predictor variables were selected by AIC
1c	1,506	3,822	0.56		784	1,465	0.37	0.2339	Same as Sc1a, but ESS = number of trips made by sampled vessels
1d	1,062	2,647	0.53		883	1,614	0.39	0.2339	Same as Sc1c, but CPUE predictor variables were selected by AIC
2a	1,696	3,866	0.64		894	1,681	0.39	0.2426	Sc1a with fish ticket CPUE
2b	1,323	3,268	0.63		1,043	1,904	0.41	0.2426	Same as Sc2a, but CPUE predictor variables were selected by AIC
2c	1,624	4,036	0.60		727	1,389	0.36	0.2426	Same as Sc2a, but ESS = number of trips made by sampled vessels
2d	1,158	2,884	0.55		939	1,762	0.40	0.2426	Same as Sc2c, but CPUE predictor variables were selected by AIC
3c	1,506	3,403	0.56	3a	646	1,254	0.38	0.2339	Estimate groundfish selectivity
4c	1,662	3,763	0.57	4a	594	1,111	0.37	0.2339	Drop groundfish bycatch and bycatch LF
5c	1,435	3,216	0.58	5a	814	1,298	0.37	0.2339	Three catchability and asymptotic total selectivity
6c	1,730	3,745	0.55	6a	783	1,460	0.39	0.2339	Francis iterative estimation of ESS
7c	1,722	3,898	0.56	7a	860	1,654	0.41	0.2426	Francis iterative estimation of ESS with fish ticket CPUE
8c	1,764	3,579	0.60	8a	988	2,072	0.45	0.2339	Dome shaped selectivity
9c	1,452	3,368	0.55	9a	820	1,547	0.38	0.2339	Total catch & LF started from 1996/97 for EAG or 1995/96 for WAG.
10c	1,610	3,693	0.57	10a	933	1,782	0.40	0.2426	Sc 9.. with fish ticket CPUE
11c	1,049	2,138	0.45	11a	579	812	0.30	0.18	Same as Sc1a or Sc1c with lower *M*
12c	1,086	2,165	0.46	12a	621	880	0.30	0.18	Same as Sc2a or Sc2c with lower *M*
14c	1,238	2,468	0.47	14a	444	615	0.29	0.18	Drop groundfish bycatch and bycatch LF with lower *M*
16c	1,151	2,199	0.48	16a	576	831	0.30	0.18	Dome shaped selectivity with lower *M*
19c	1,203	2,771	0.52	19a	1,081	1,936	0.41	0.2339	Same as Sc1a or Sc1c, but CPUE predictor variables set contains the Year:Captain interaction term

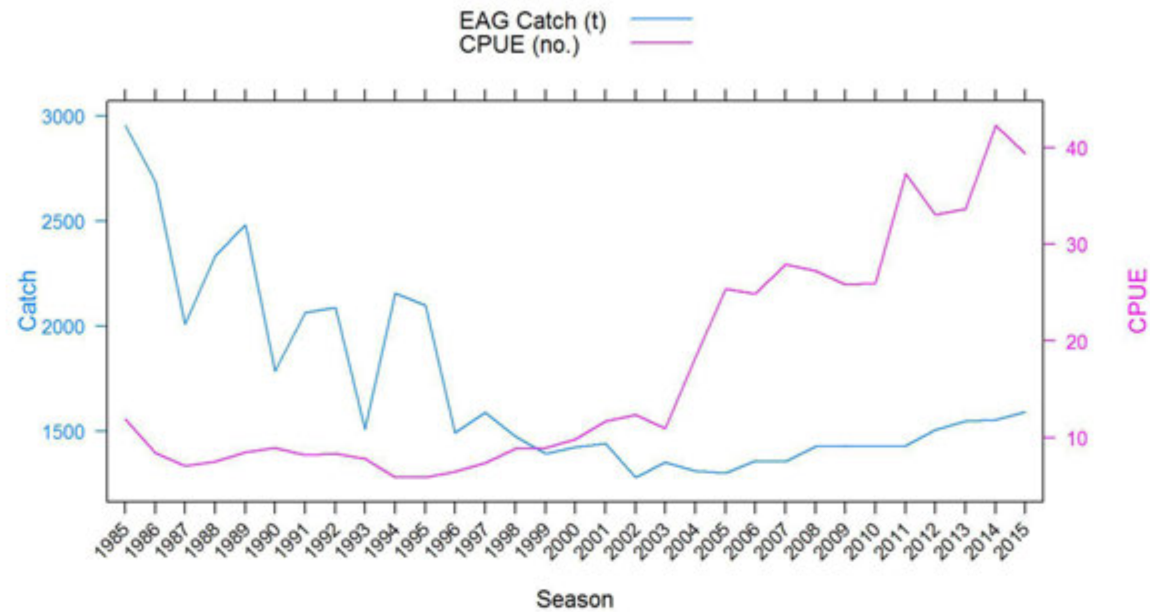


Figure 3. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2015/16 fisheries (note: 1985 refers to the 1985/86 fishing year).

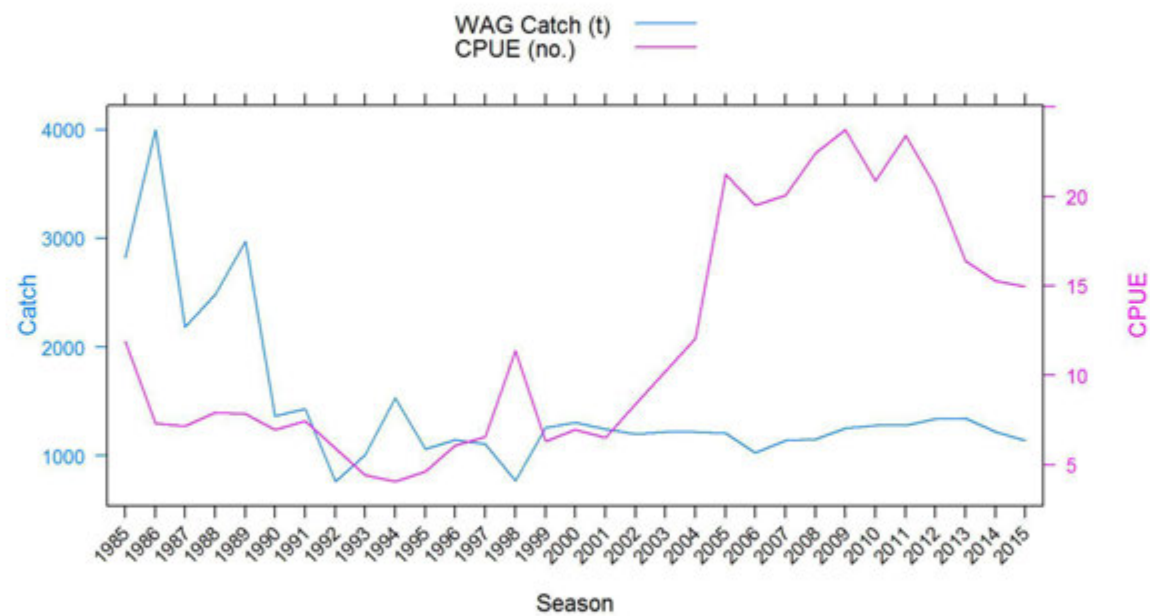


Figure 4. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2015/16 fisheries (note: 1985 refers to the 1985/86 fishing year).

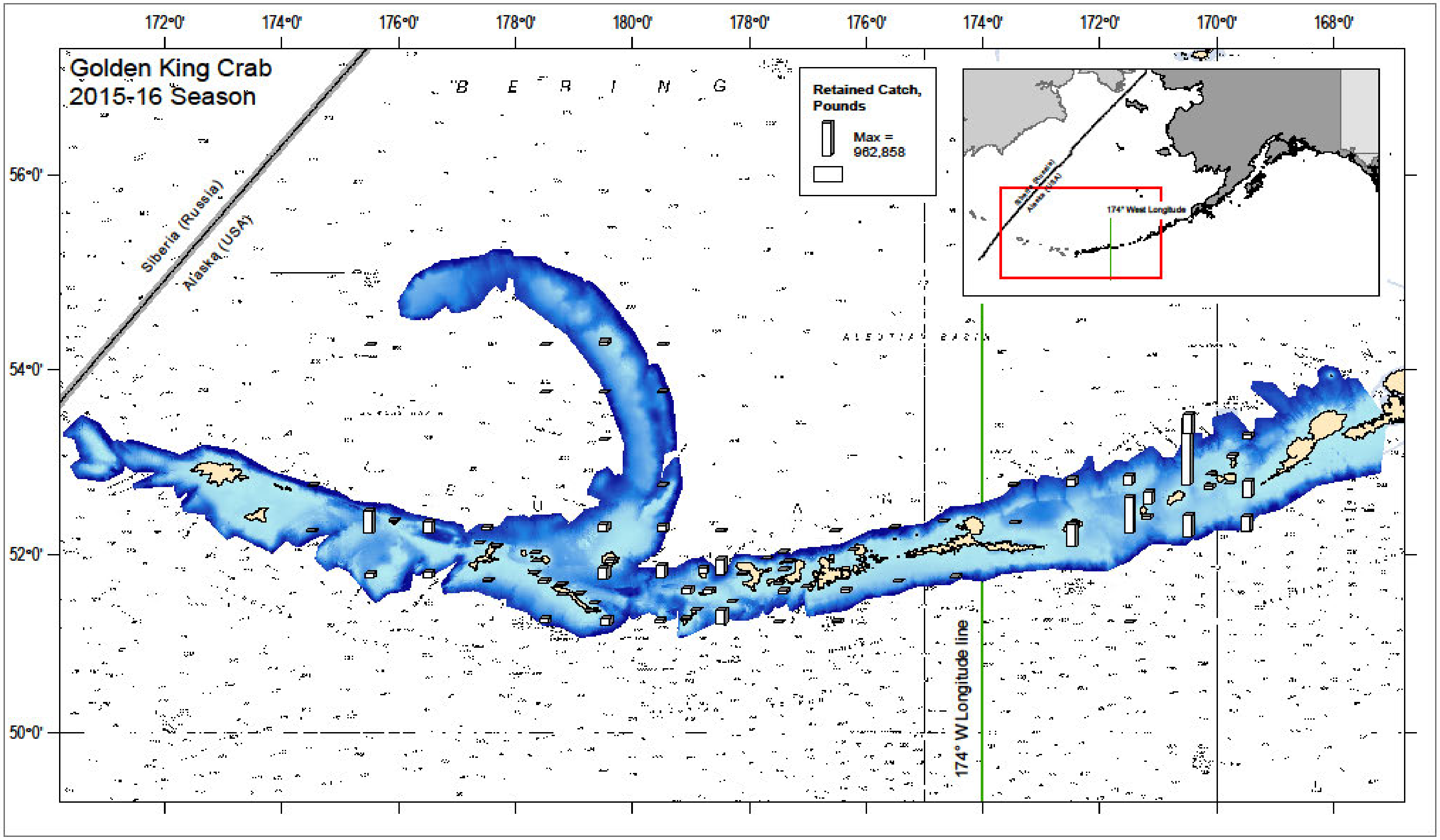


Figure 5. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2015/16.

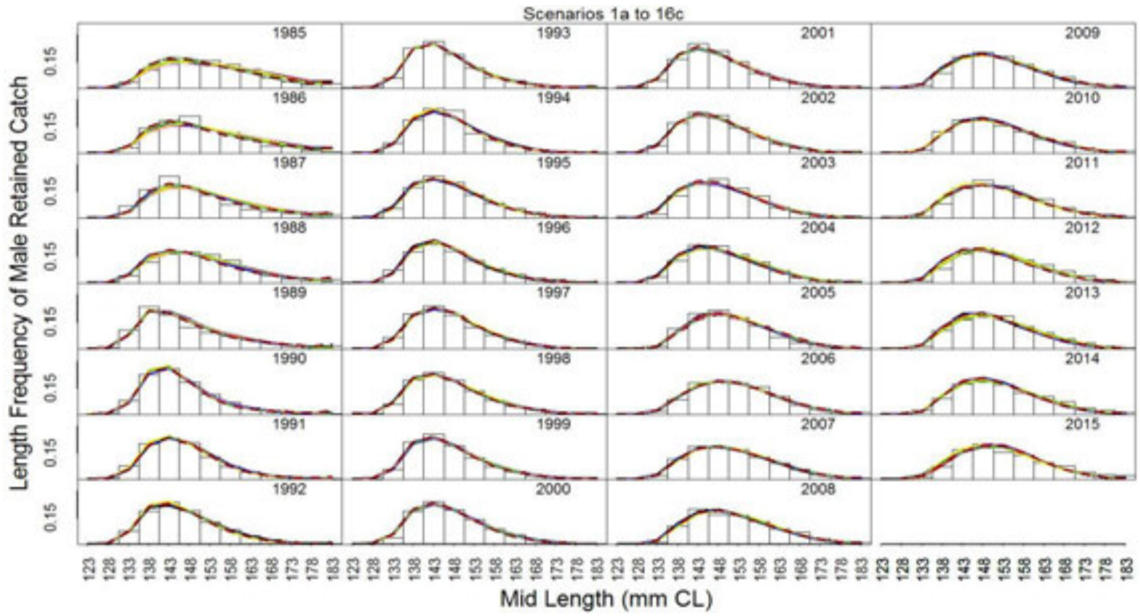


Figure 6. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenarios 1a (black line), 1c (red line), 2c (blue line), 4c (yellow line), 6c (orange line), 7c (green line), 8c (dark green line), 11c (violet line), and 16c (dark red line) data of golden king crab in the EAG, 1985/86 to 2015/16.

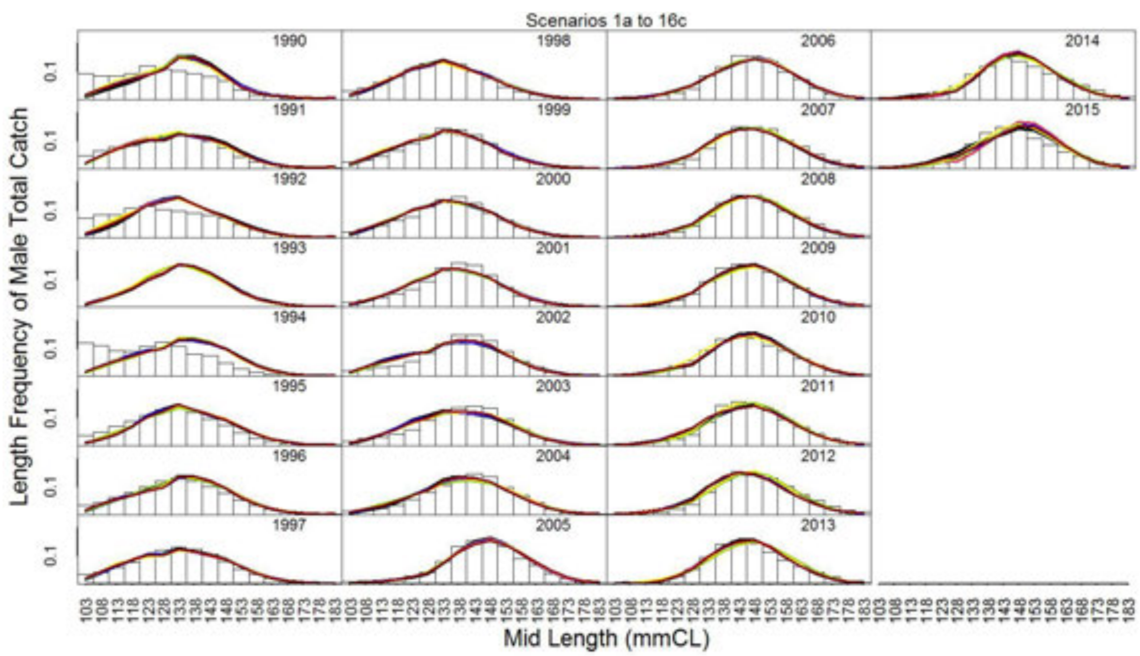


Figure 7. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenarios 1a (black line), 1c (red line), 2c (blue line), 4c (yellow line), 6c (orange line), 7c (green line), 8c (dark green line), 11c (violet line), and 16c (dark red line) data of golden king crab in the EAG, 1990/91 to 2015/16.

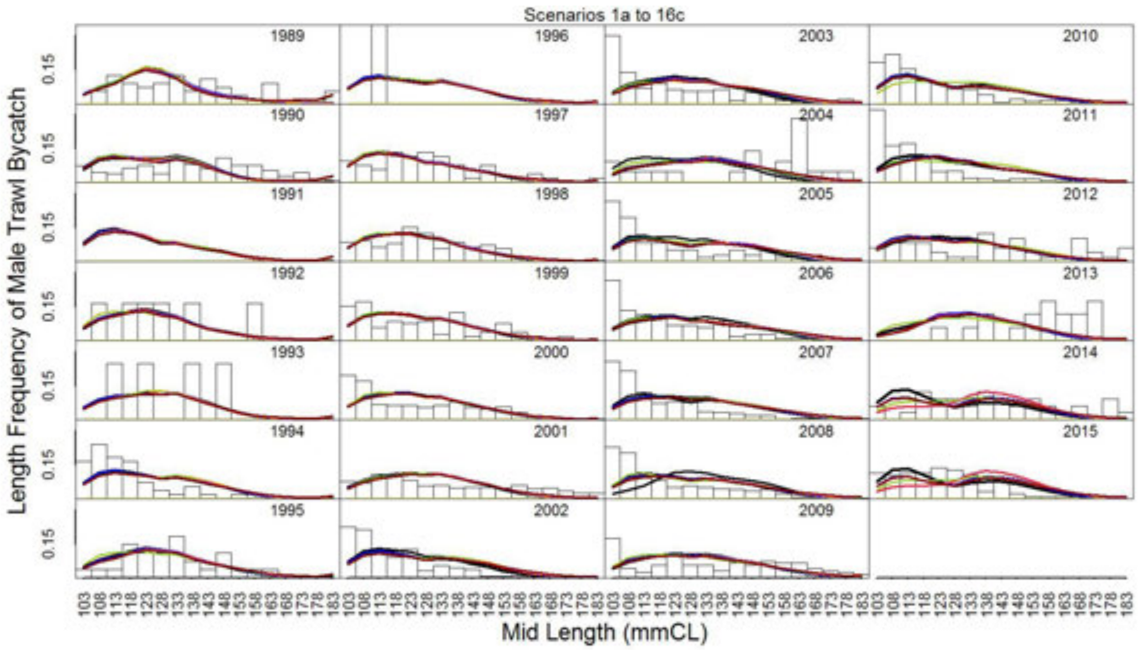


Figure 8. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions for scenarios 1a (black line), 1c (red line), 2c (blue line), 4c (yellow line), 6c (orange line), 7c (green line), 8c (dark green line), 11c (violet line), and 16c (dark red line) data of golden king crab in the EAG, 1989/86 to 2015/16.

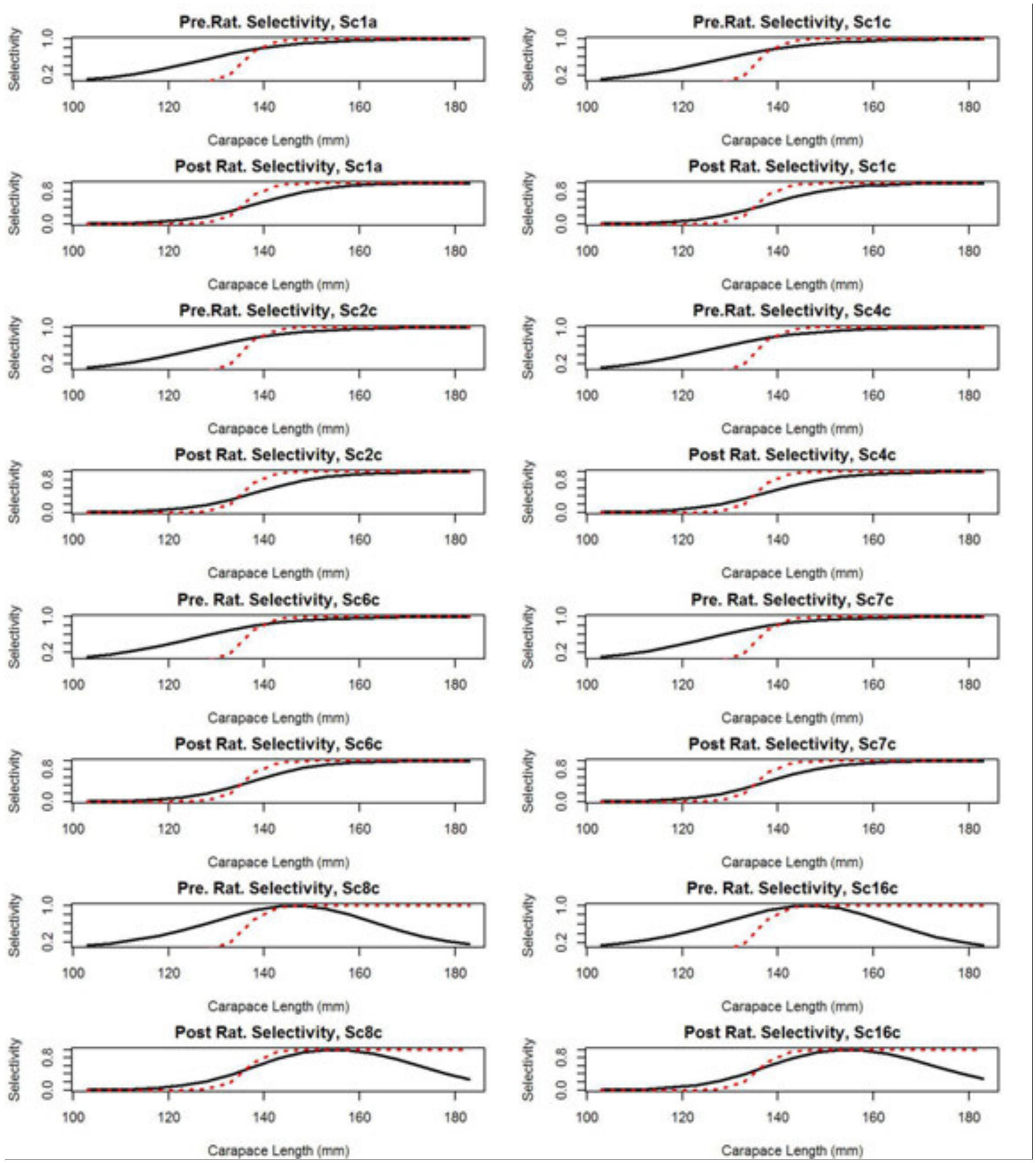
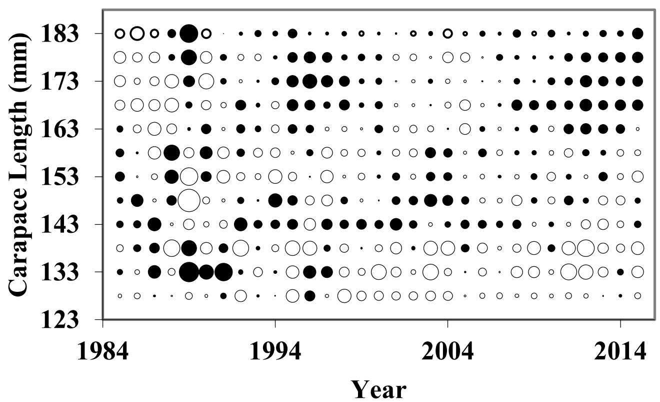
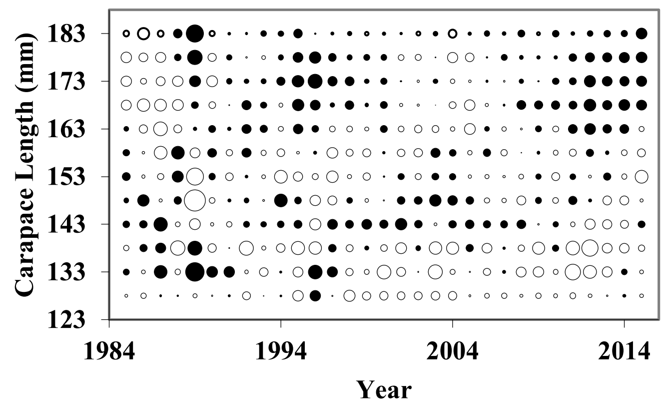


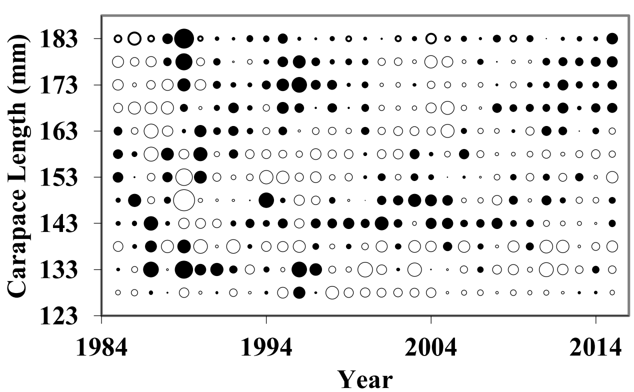
Figure 9. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, and 16c fits of EAG golden king crab data



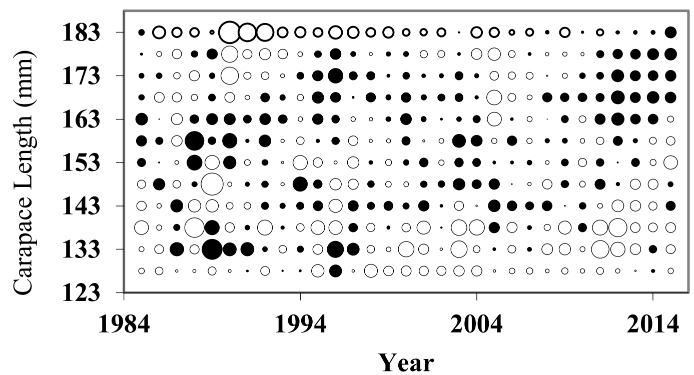
Scenario 1a



Scenario 1c

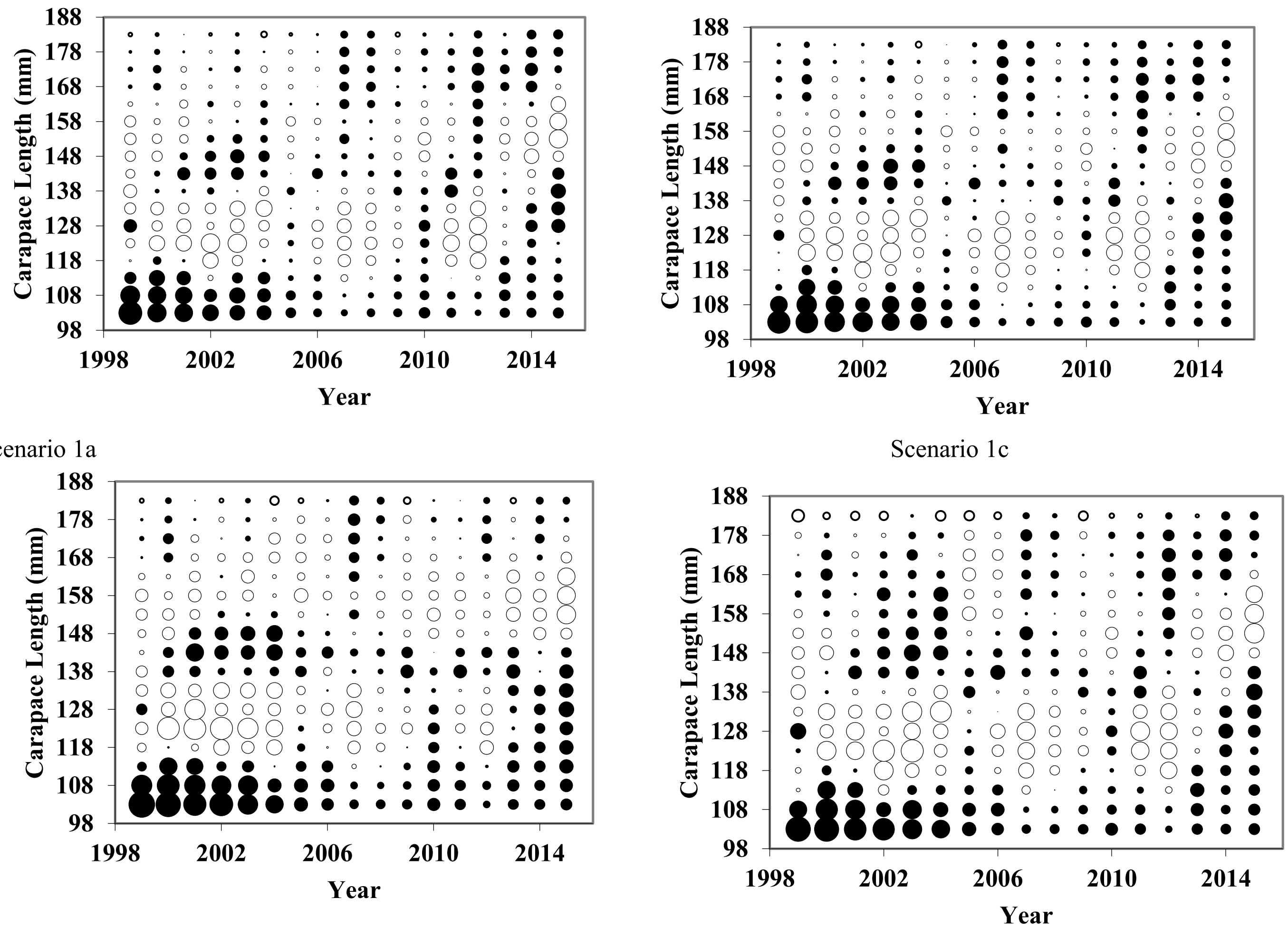


Scenario 6c



Scenario 8c

Figure 10. Bubble plots of standardized residuals of retained catch length composition for scenarios 1a, 1c, 6c, and 8c fits for EAG golden king crab, 1985/86–2015/16. 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.



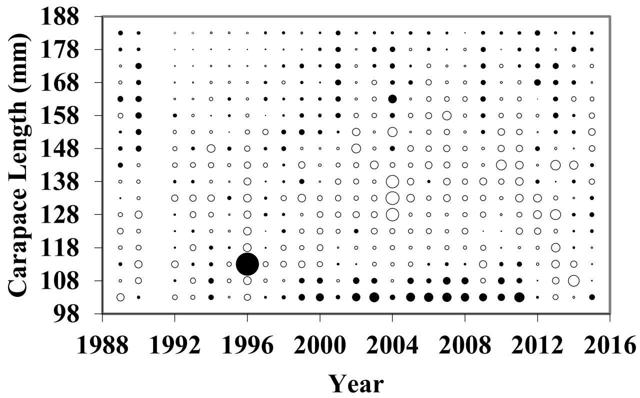
Scenario 1a

Scenario 1c

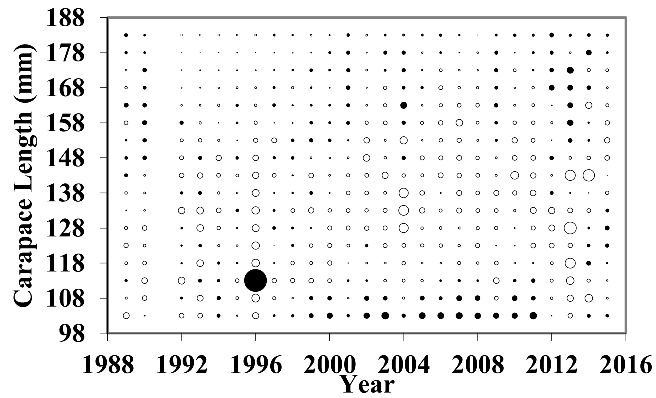
Scenario 6c

Scenario 8c

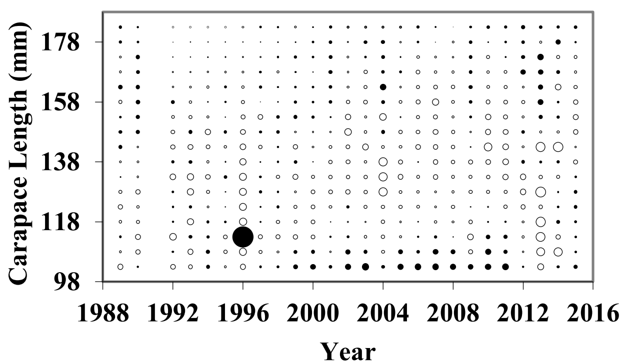
Figure 11. Bubble plots of standardized residuals of total catch length composition for scenarios 1a, 1c, 6c, and 8c fits for EAG golden king crab, 1999/00–2015/16. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



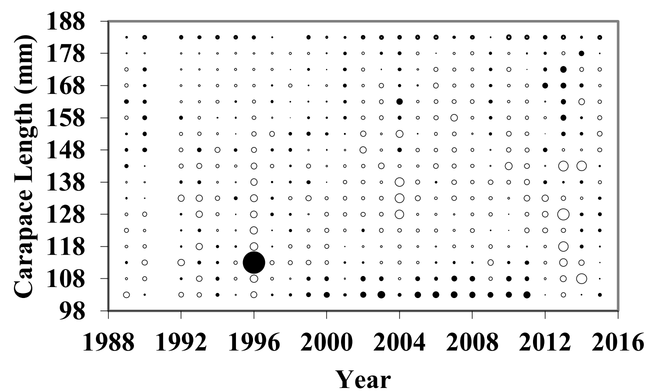
Scenario 1a



Scenario 1c



Scenario 6c



Scenario 8c

Figure 12. Bubble plots of standardized residuals of groundfish (trawl) bycatch length composition for scenarios 1a, 1c, 6c, and 8c fits for EAG golden king crab, 1989/90–2015/16. 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.

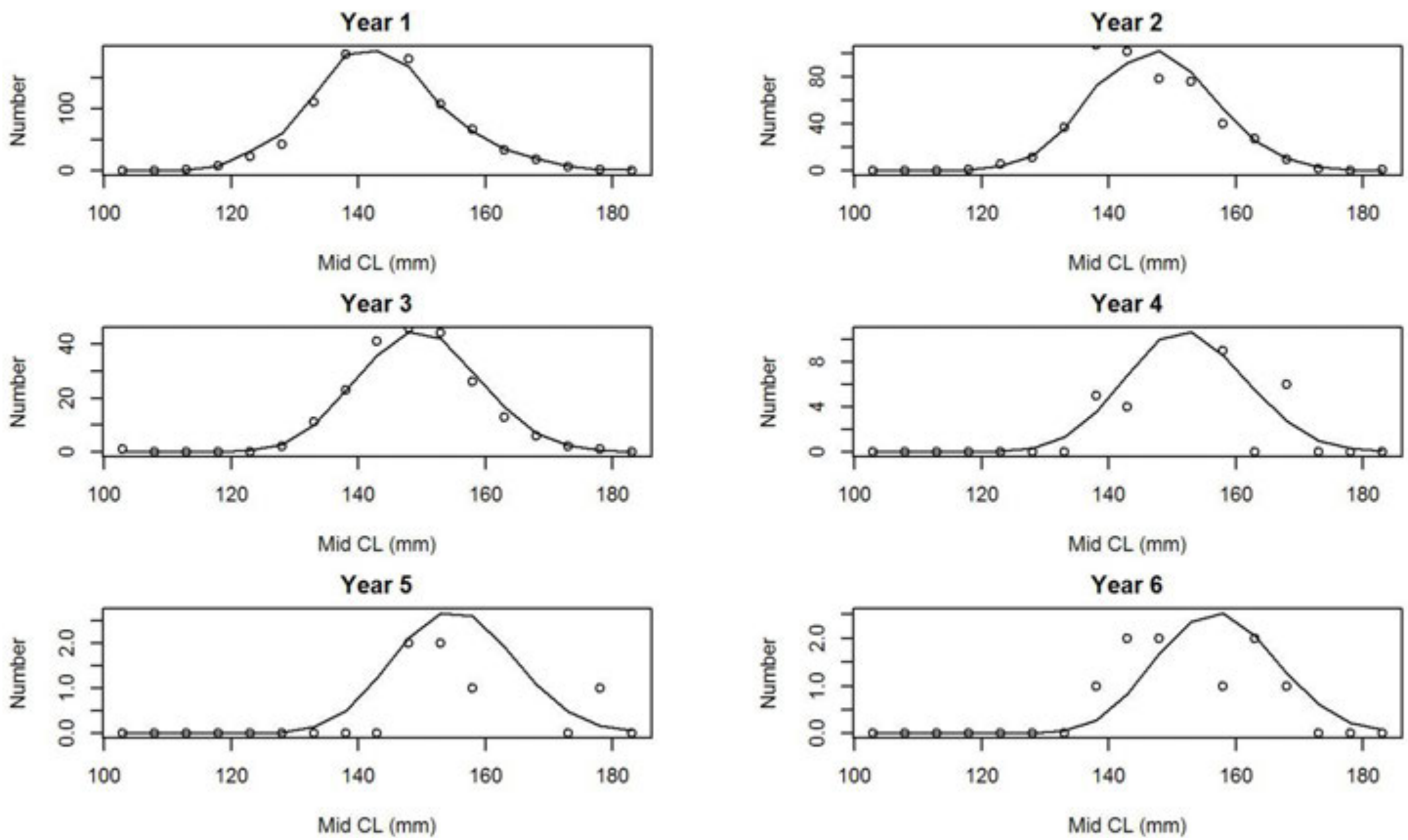


Figure 13. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures for scenario 1c fit of EAG golden king crab.

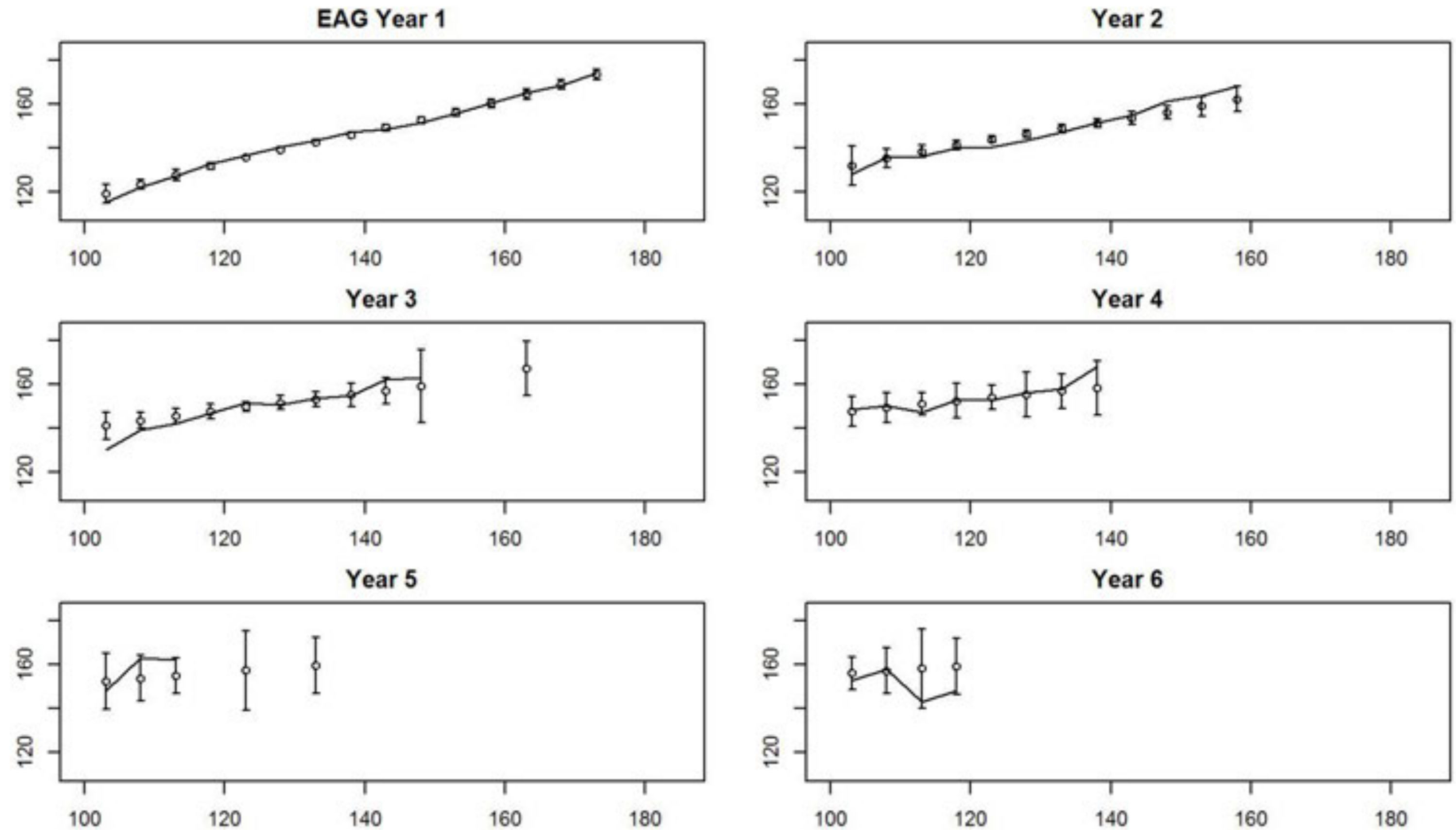


Figure 14. Observed (open circles with two SE) and predicted (line) mean length of recaptures vs. release length for years 1 to 6 recaptures for scenario 1c fit of EAG golden king crab.

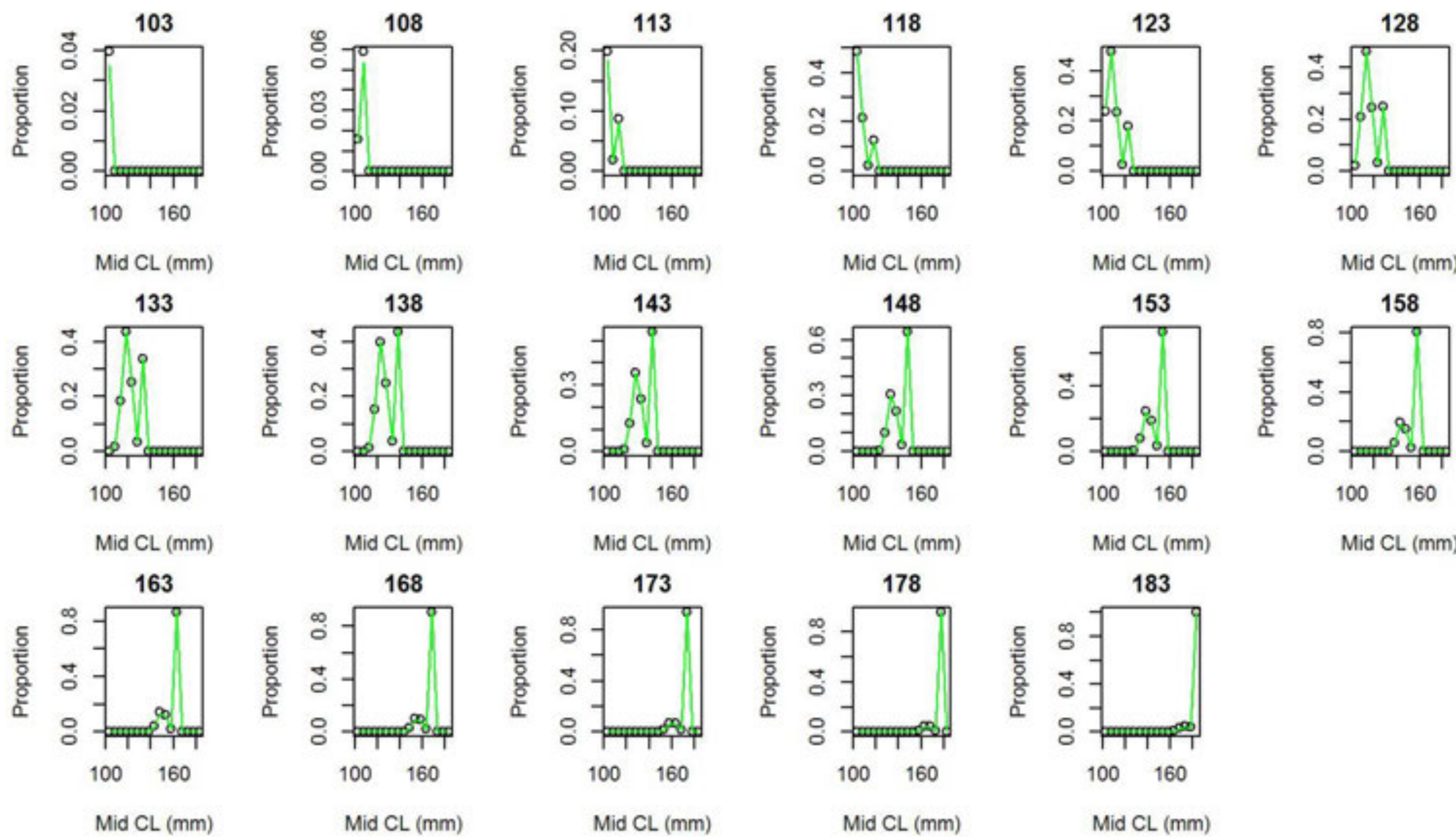


Figure 15. Comparison of estimated growth matrix elements (proportions) between EAG (open circles) and WAG (green line) for scenario 1a fits to golden king crab data. The number at the top of each plot is the mid length (mm CL) of the contributing length-class. The proportions in each plot are the proportions falling into different length-classes from the contributing length-class after one molt growth.

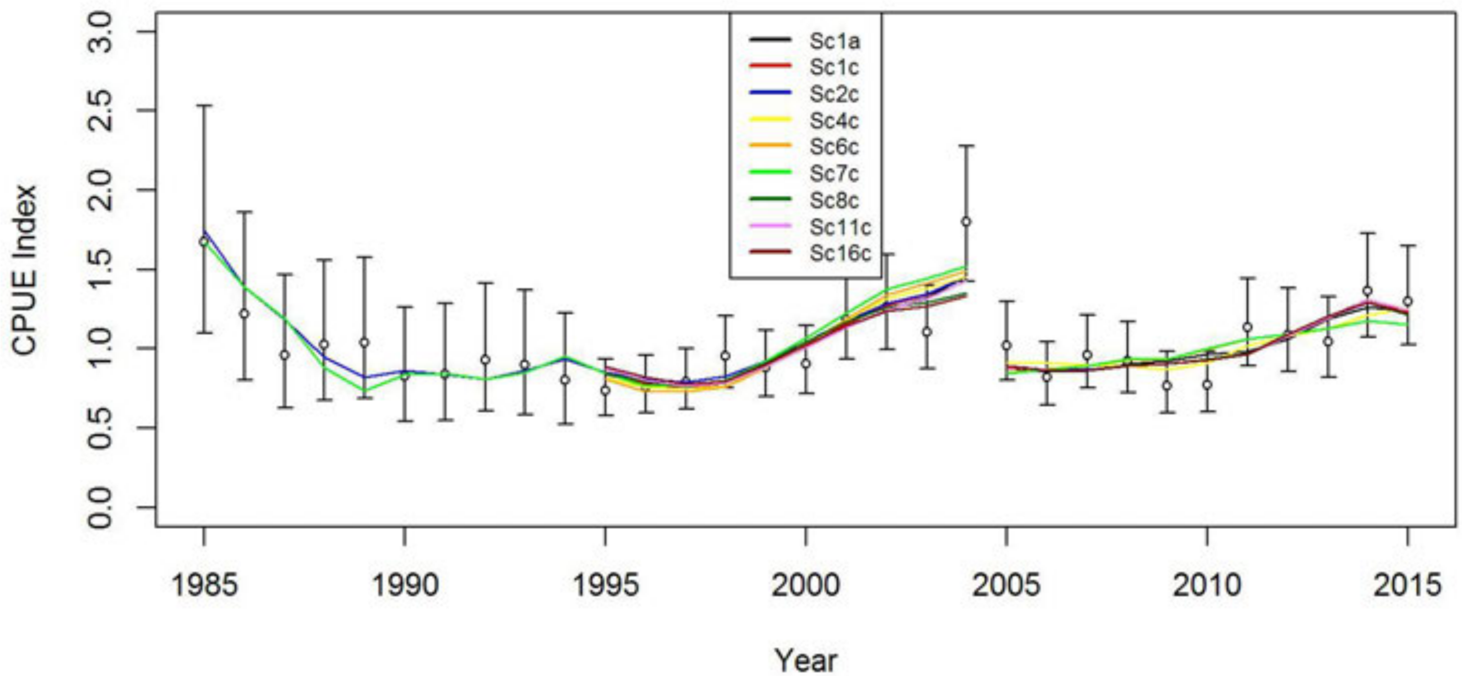


Figure 16. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c fits for EAG golden king crab data, 1985/86–2015/16. Model estimated additional standard error was added to each input standard error.

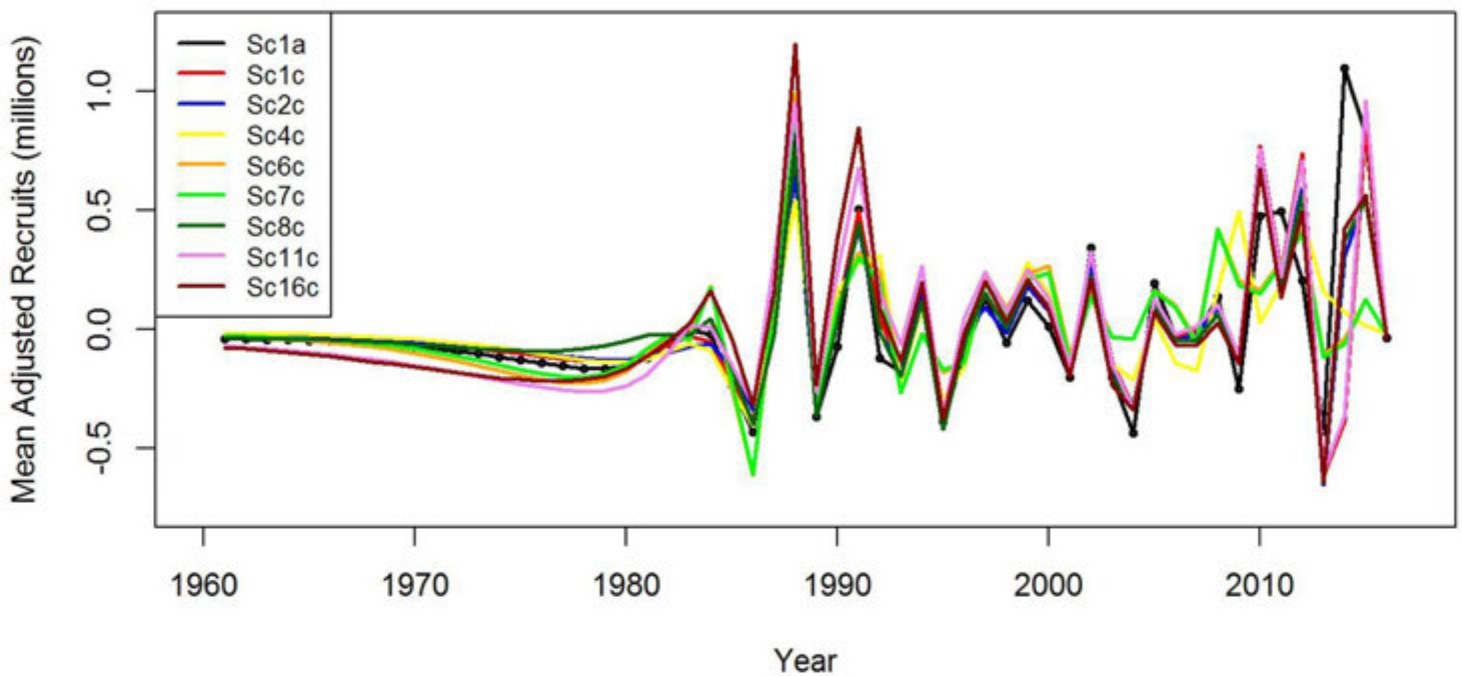


Figure 17. Estimated number of male recruits (millions of crab ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c fits for EAG golden king crab data, 1961–2016. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

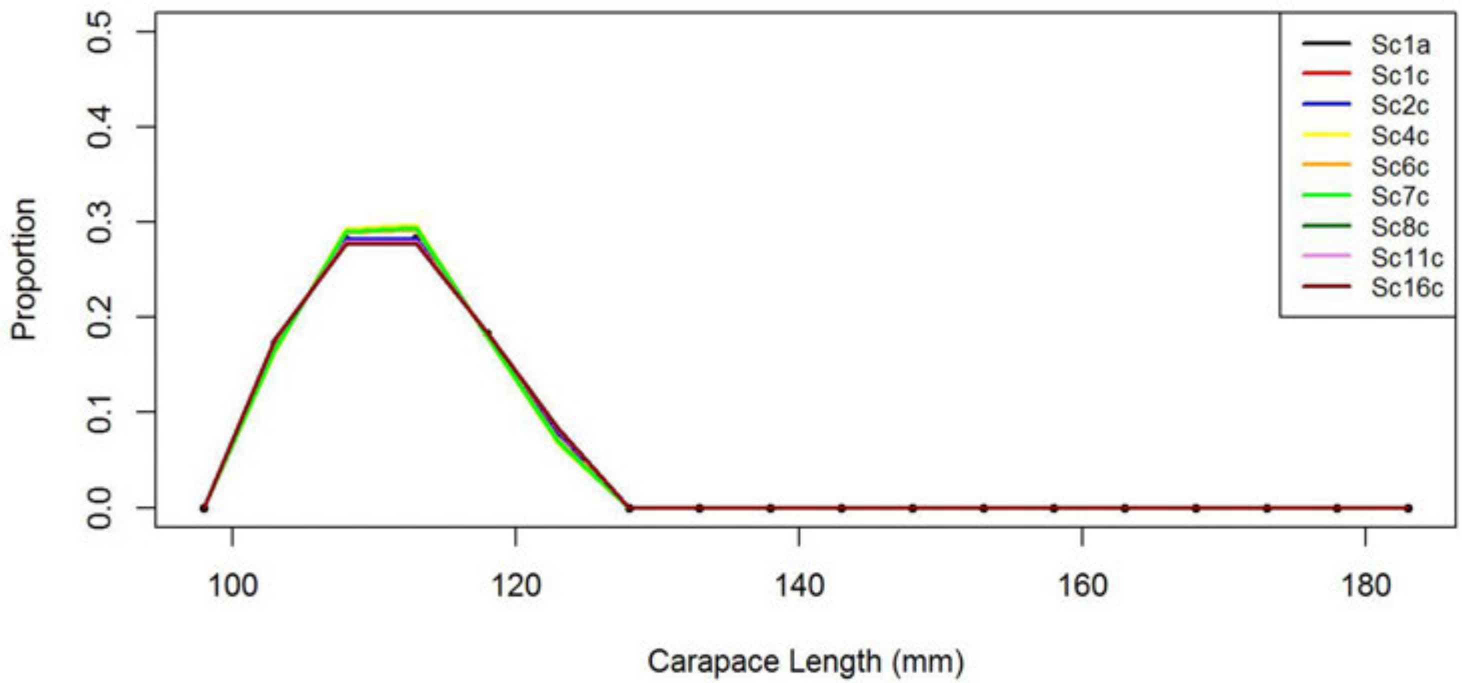


Figure 18. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c fits in EAG.

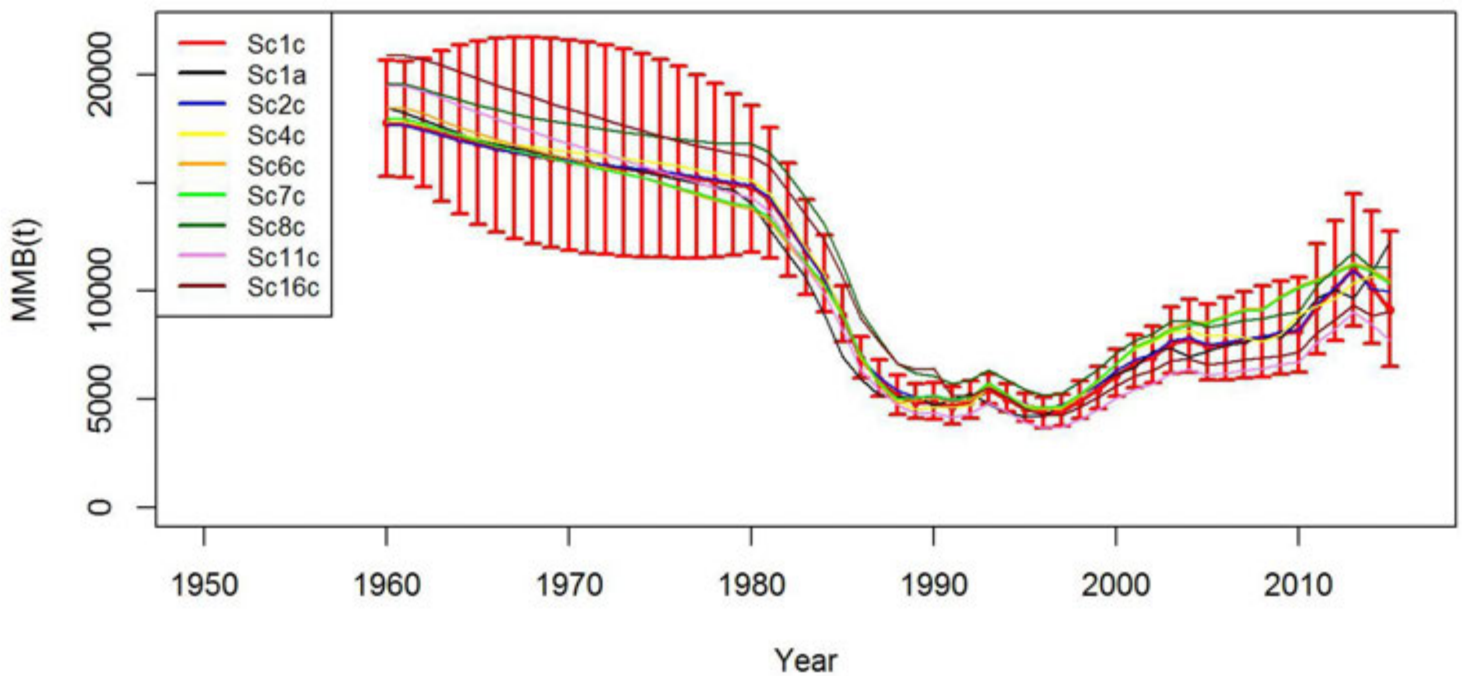


Figure 19. Trends in golden king crab mature male biomass for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c fits in the EAG, 1960/61–2015/16. Mature male crab is ≥ 121 mm CL. Scenario 1c estimates have two standard errors confidence limits.

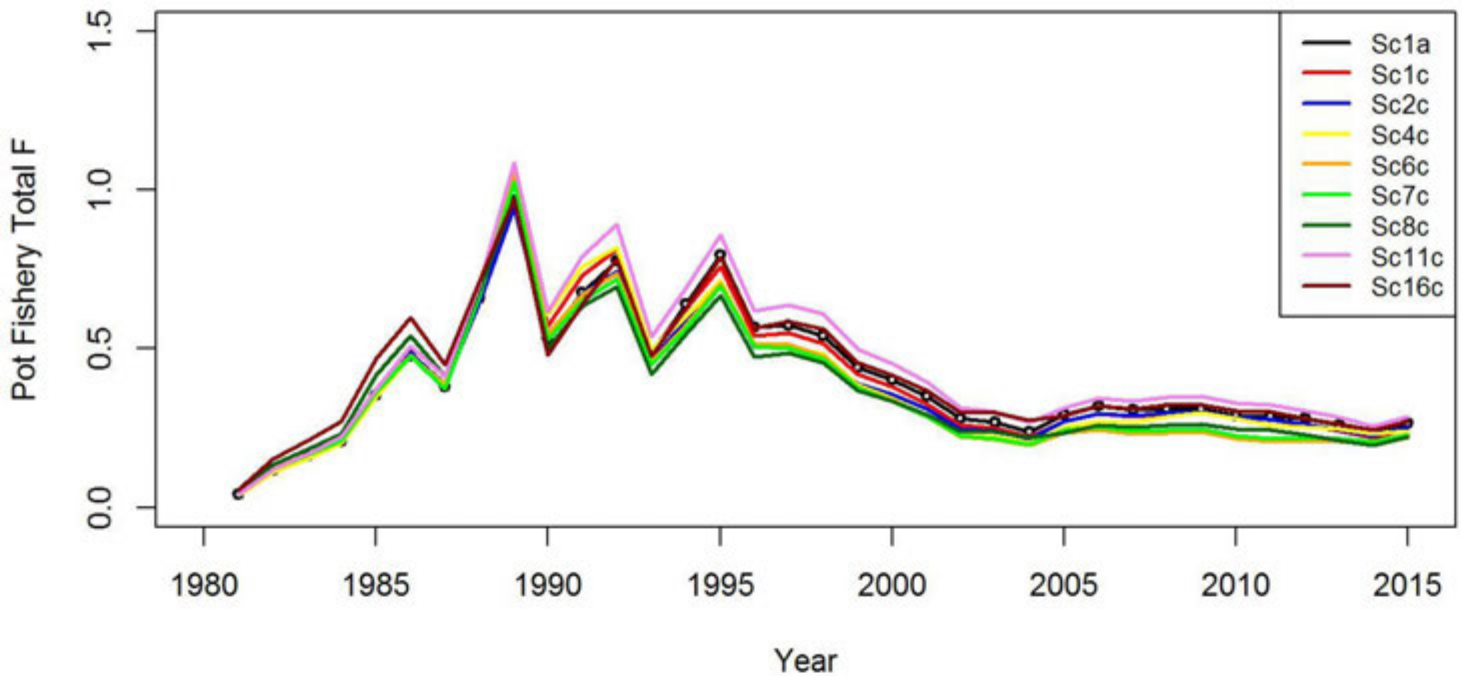


Figure 20. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c fits in the EAG, 1981–2015 (note: 1981 refers to the1981/82 fishing year).

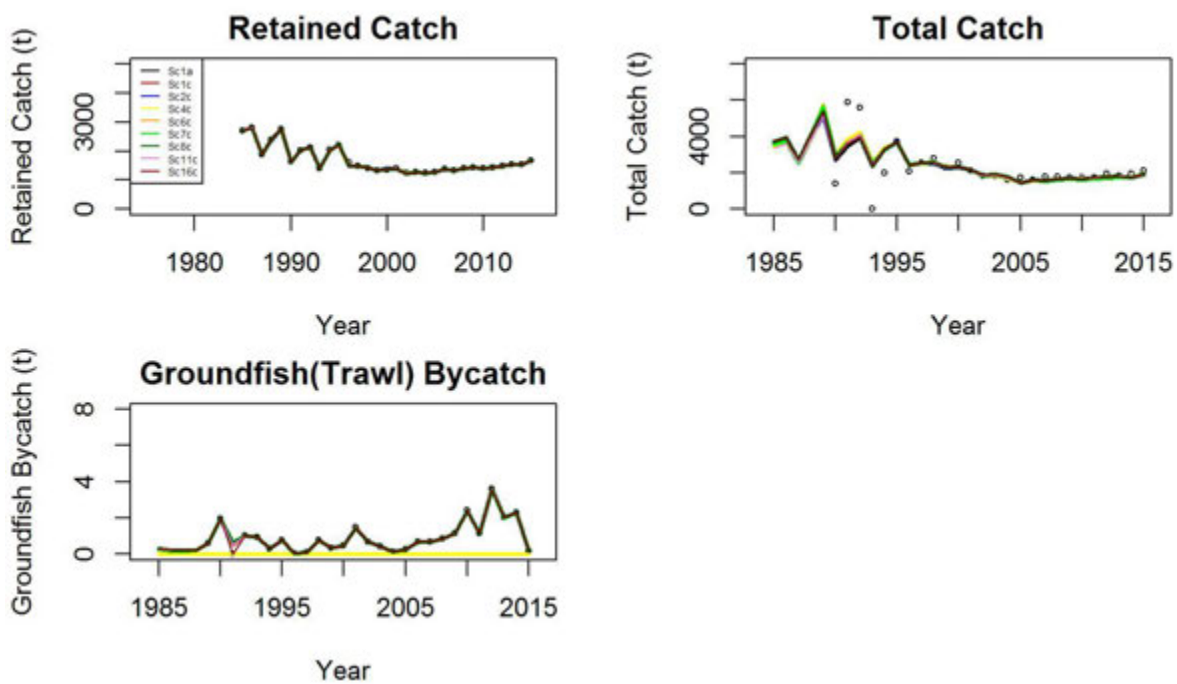


Figure 21. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and trawl (or groundfish) bycatch (bottom left) of golden king crab for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c fits in the EAG, 1985–2015. (note: 1985 refers to the1985/86 fishing year). Scenario 4c disregarded groundfish bycatch data.

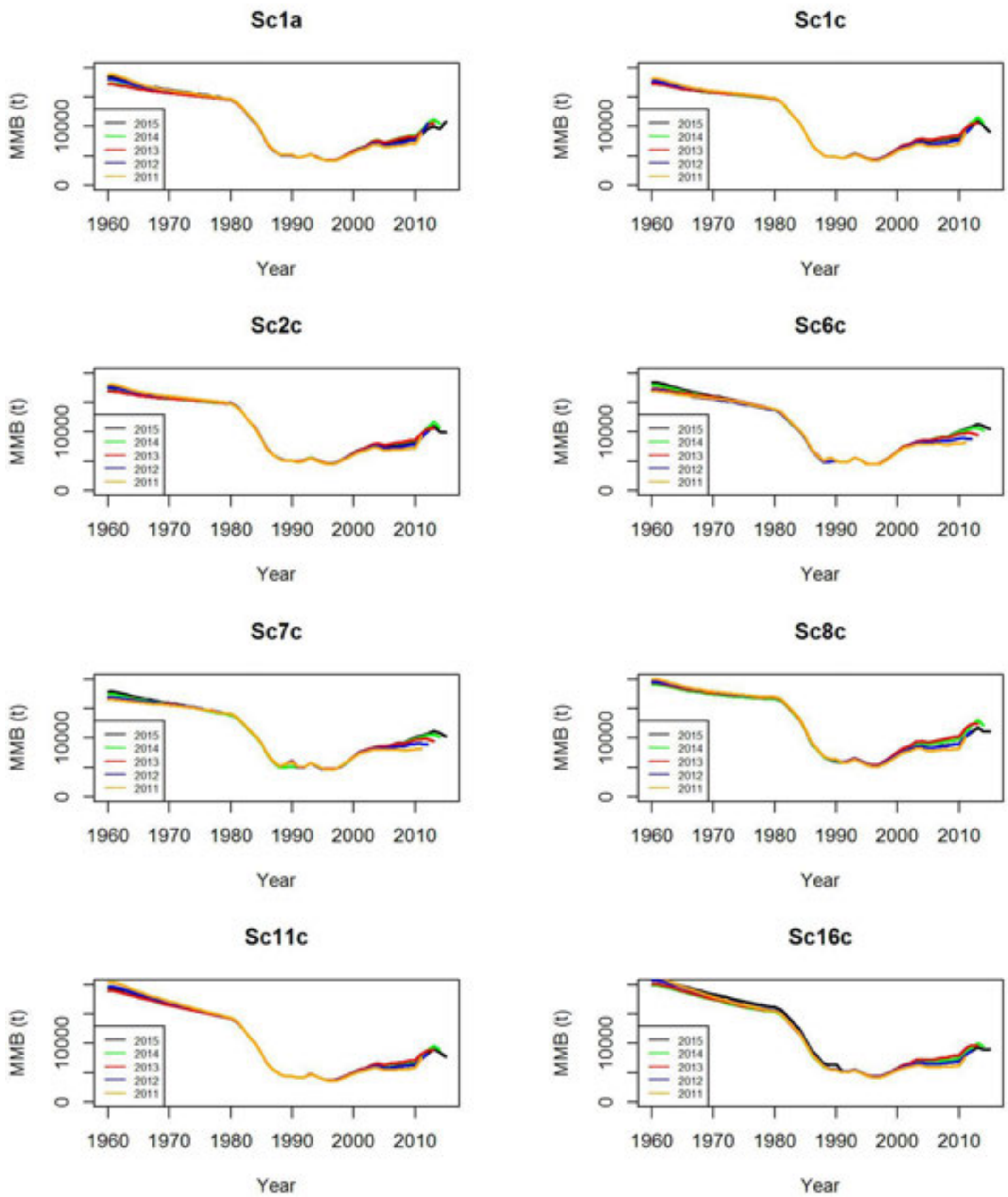


Figure 22. Retrospective fits of the model for removal of terminal year's data for scenarios (Sc) 1a, 1c, 2c, 6c, 7c, 8c, 11c, and 16c fits for golden king crab in the EAG, 1960–2015.

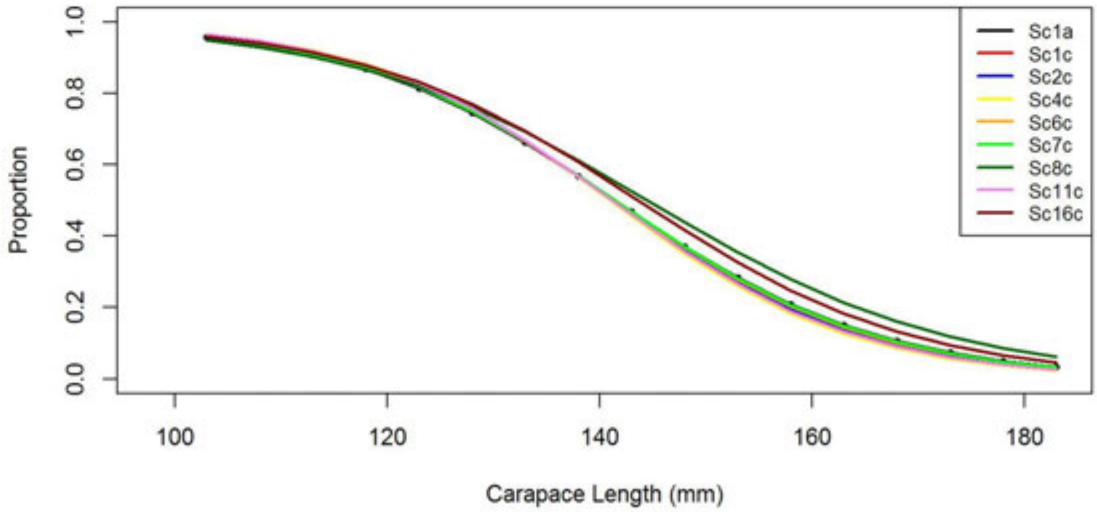


Figure 23. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and 16c model fits in the EAG, 1985/86–2015/16.

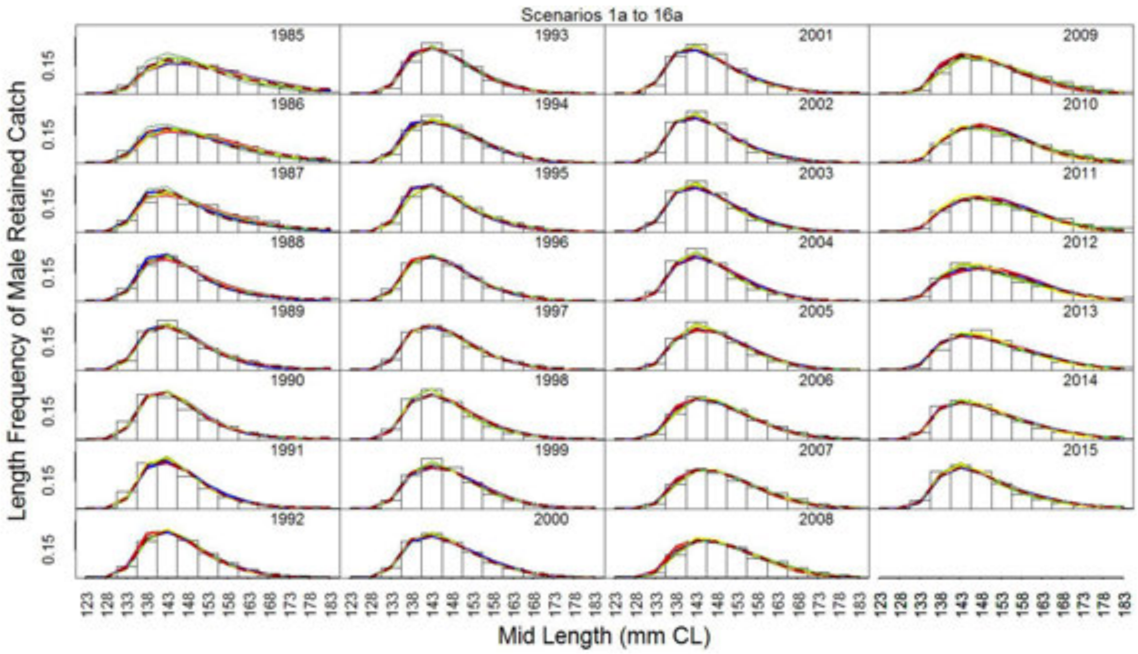


Figure 24. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenarios 1a (black line), 1c (red line), 2a (blue line), 4a (yellow line), 6a (orange line), 7a (green line), 8a (dark green line), 11a (violet line), and 16a (dark red line) data of golden king crab in the WAG, 1985/86 to 2015/16.

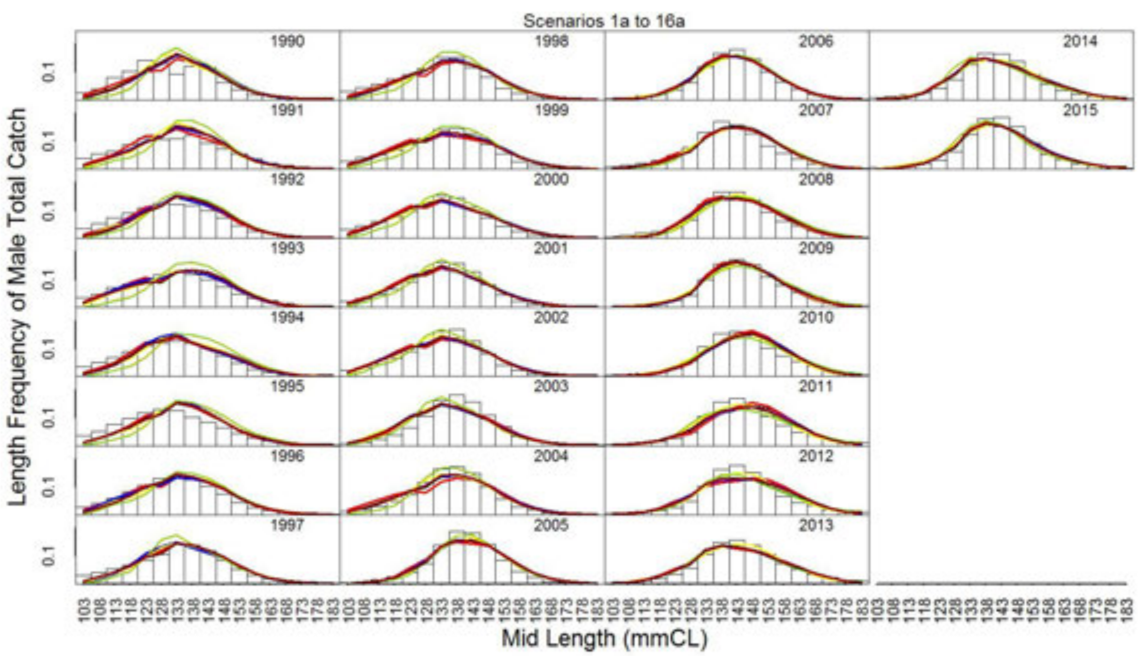


Figure 25. Predicted (line) vs. observed (bar) total catch relative length frequency distributions for scenarios 1a (black line), 1c (red line), 2a (blue line), 4a (yellow line), 6a (orange line), 7a (green line), 8a (dark green line), 11a (violet line), and 16a (dark red line) data of golden king crab in the WAG, 1990/91 to 2015/16.

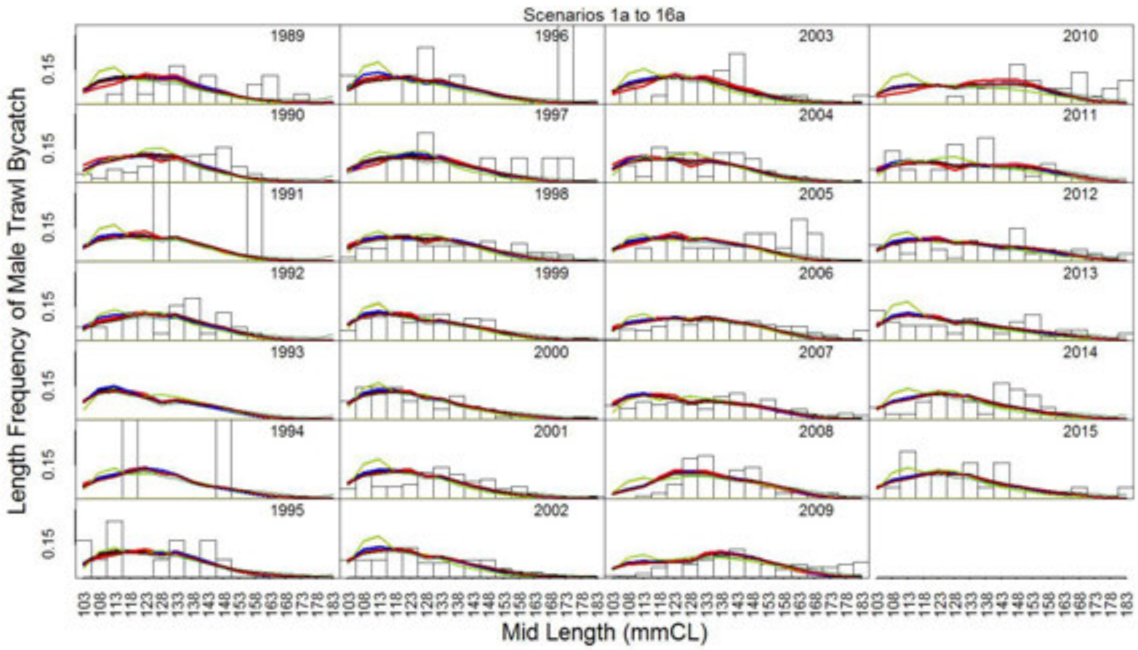


Figure 26. Predicted (line) vs. observed (bar) groundfish (trawl) discarded catch relative length frequency distributions for scenarios 1a (black line), 1c (red line), 2a (blue line), 4a (yellow line), 6a (orange line), 7a (green line), 8a (dark green line), 11a (violet line), and 16a (dark red line) data of golden king crab in the WAG, 1989/90 to 2015/16.

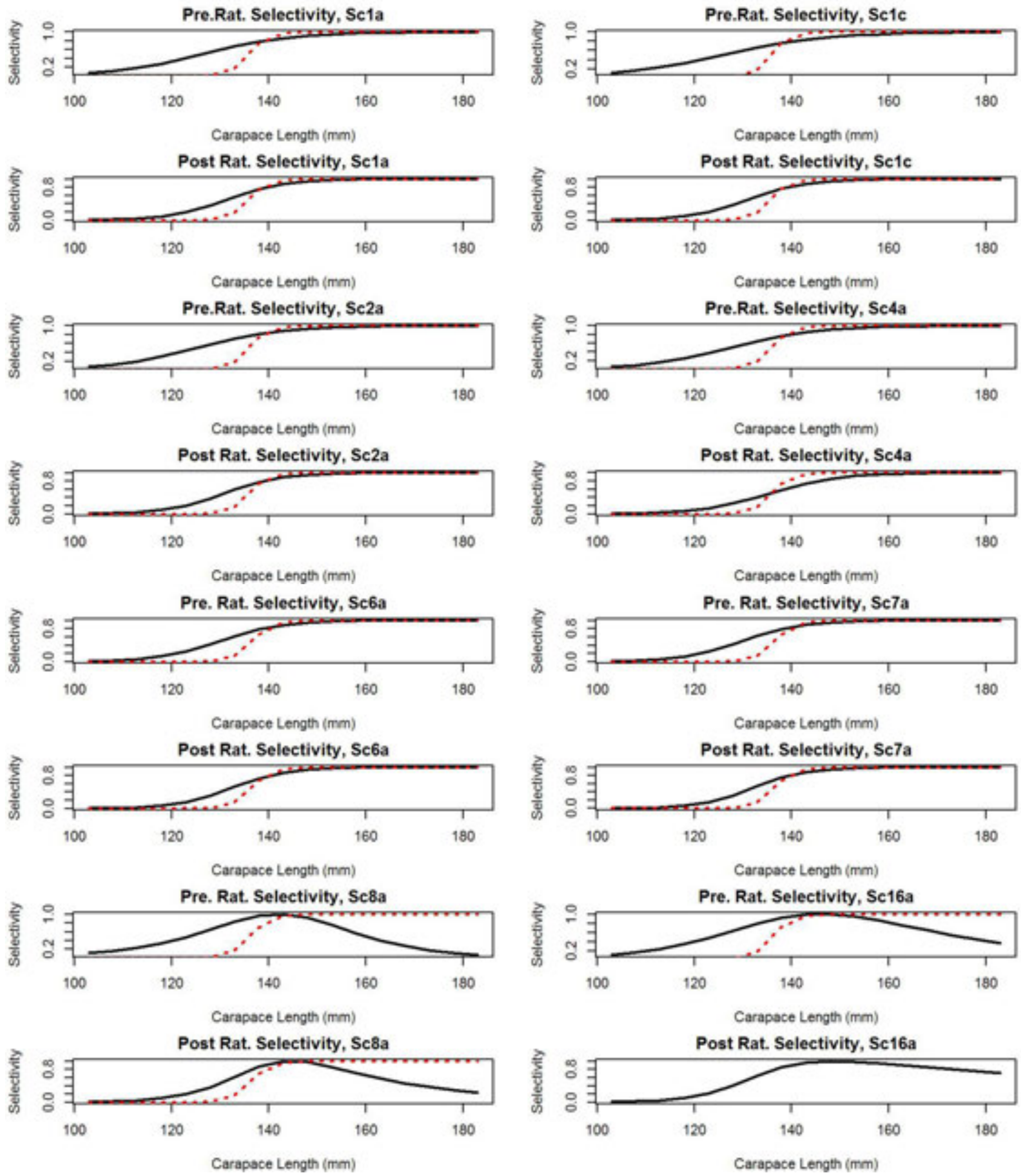
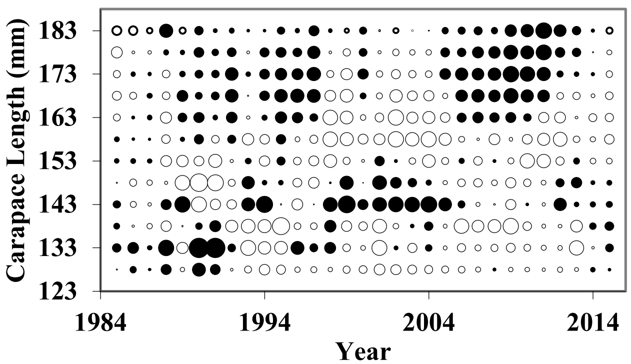
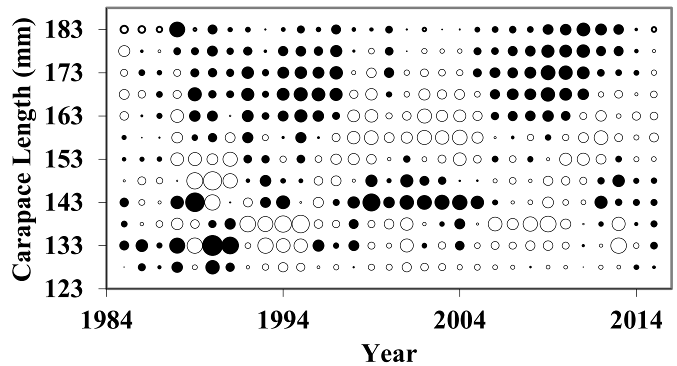


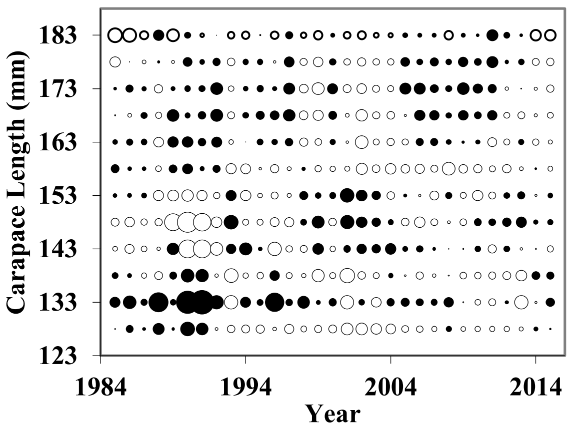
Figure 27 Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, and 16a fits of WAG golden king crab data.



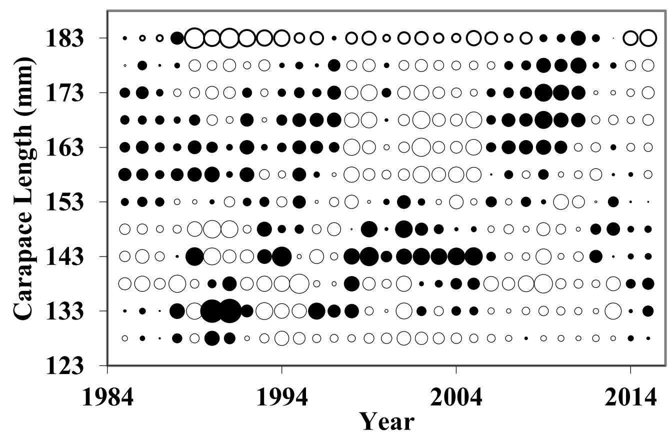
Scenario 1a



Scenario 1c

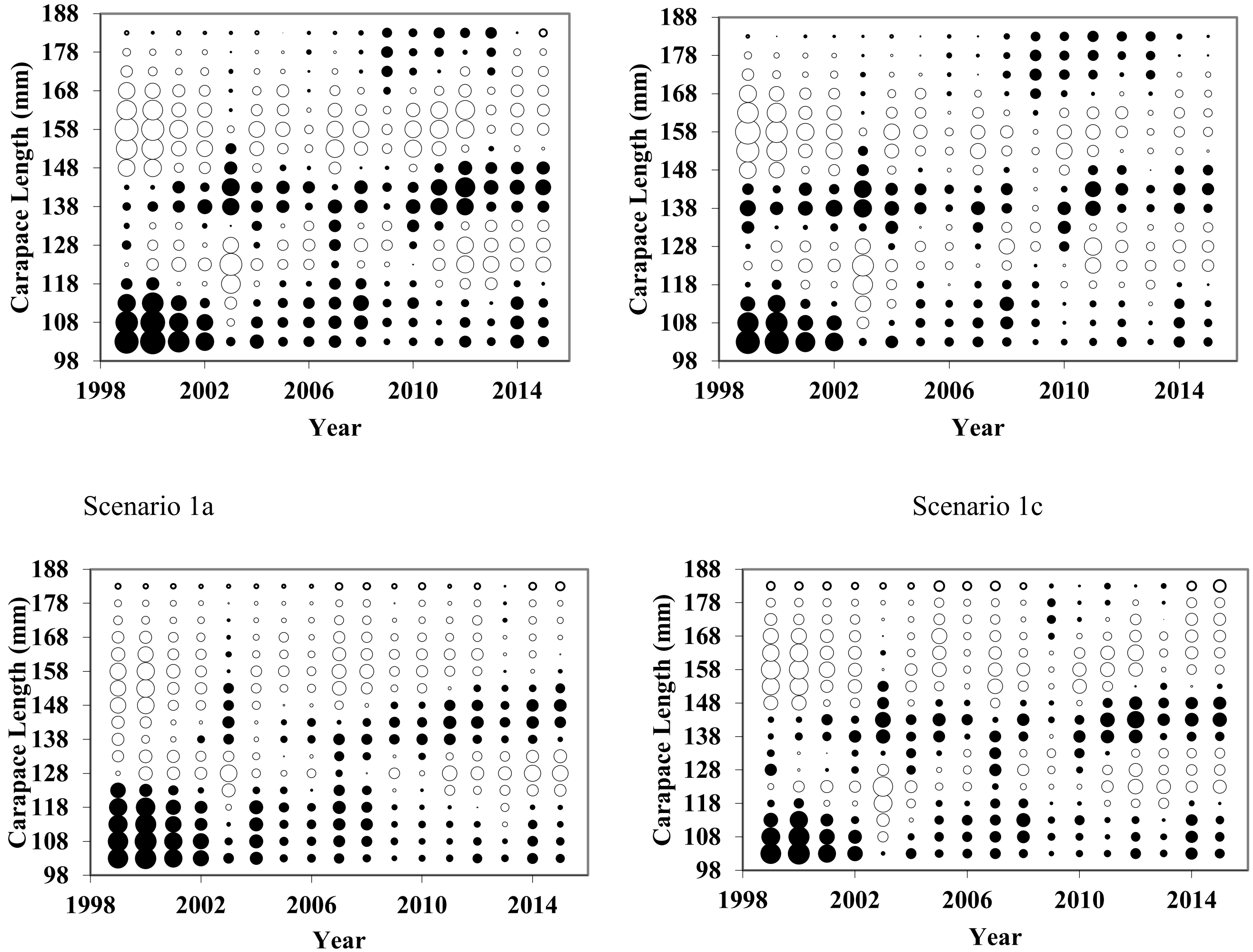


Scenario 6a



Scenario 8a

Figure 28 Bubble plots of standardized residuals of retained catch length composition for scenarios 1a, 1c, 6a and 8a fits for WAG golden king crab, 1985/86–2015/16. 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.



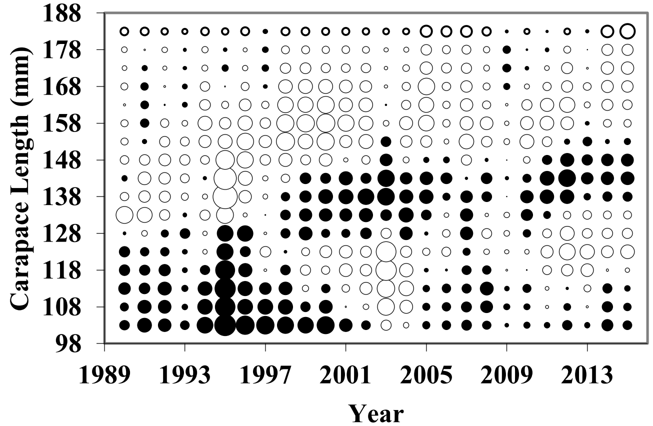
Scenario 1a

Scenario 1c

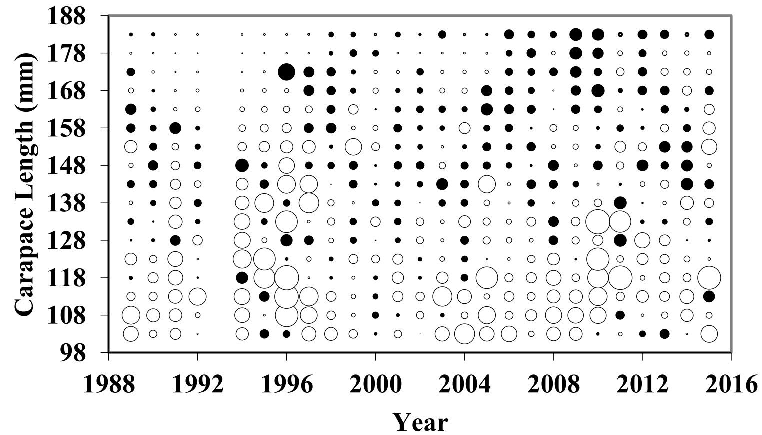
Scenario 6a

Scenario 8a

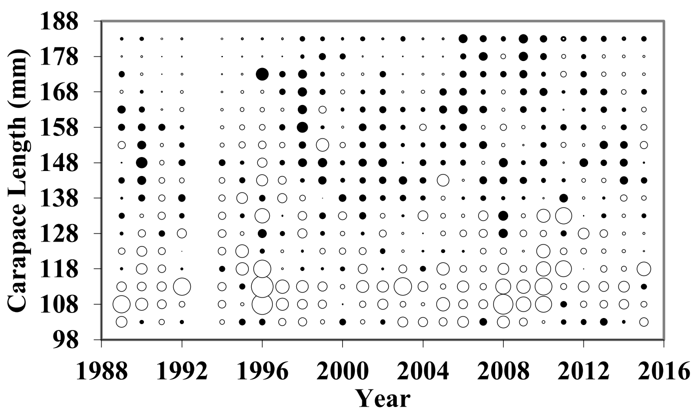
Figure 29. Bubble plots of standardized residuals of total catch length composition for scenarios 1a, 1c, 6a, and 8a fits for WAG golden king crab, 1999/00–2015/16. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



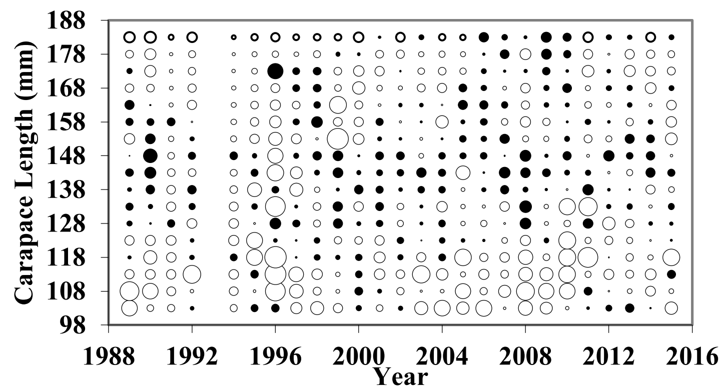
Scenario 1a



Scenario 1c



Scenario 6a



Scenario 8a

Figure 30. Bubble plots of standardized residuals of groundfish (trawl) bycatch length composition for scenarios 1a, 1c, 6a, and 8a fits for WAG golden king crab, 1989/90–2015/16. 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.

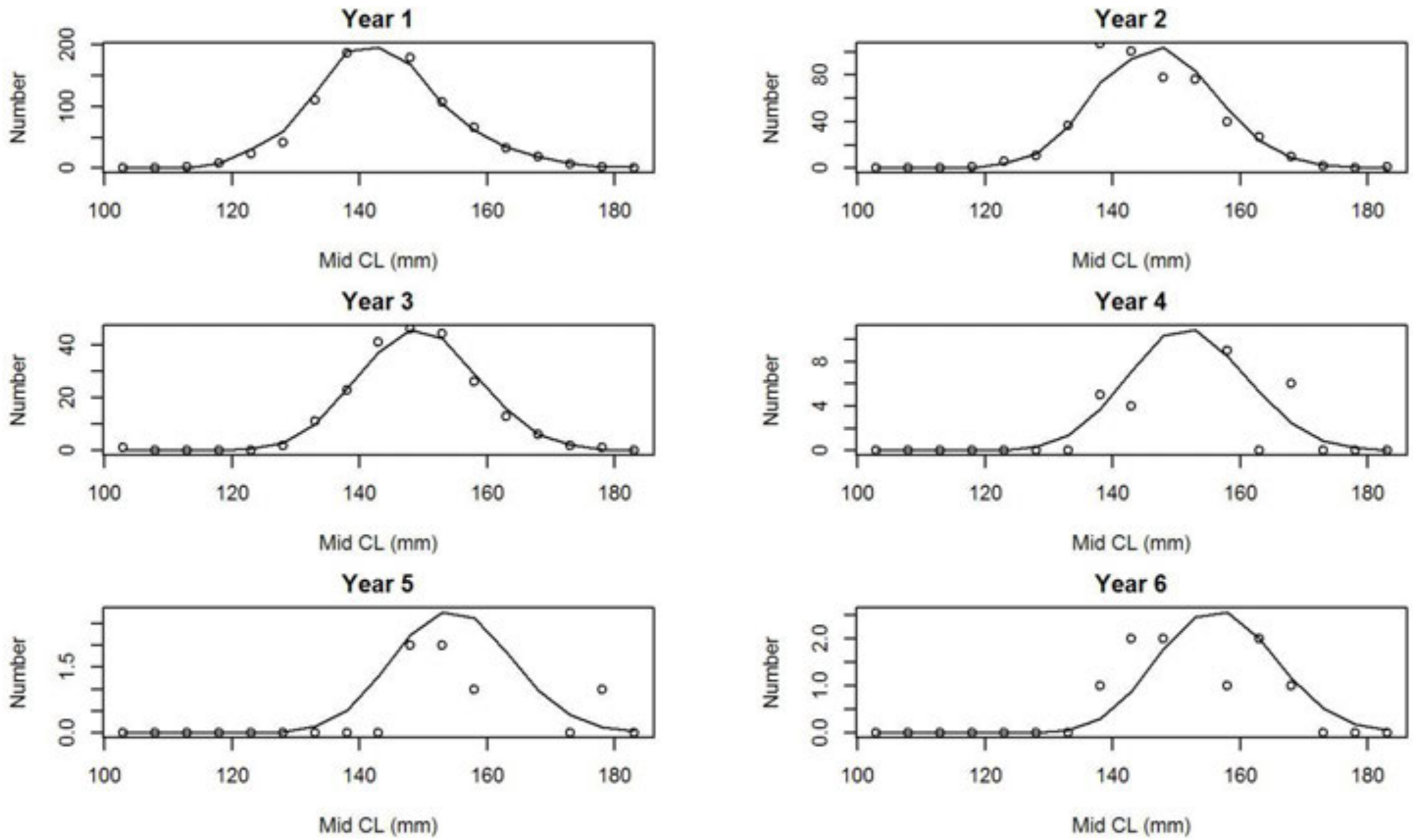


Figure 31. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures for scenario 1a fit of WAG golden king crab data. The tagging experiments were conducted in EAG.

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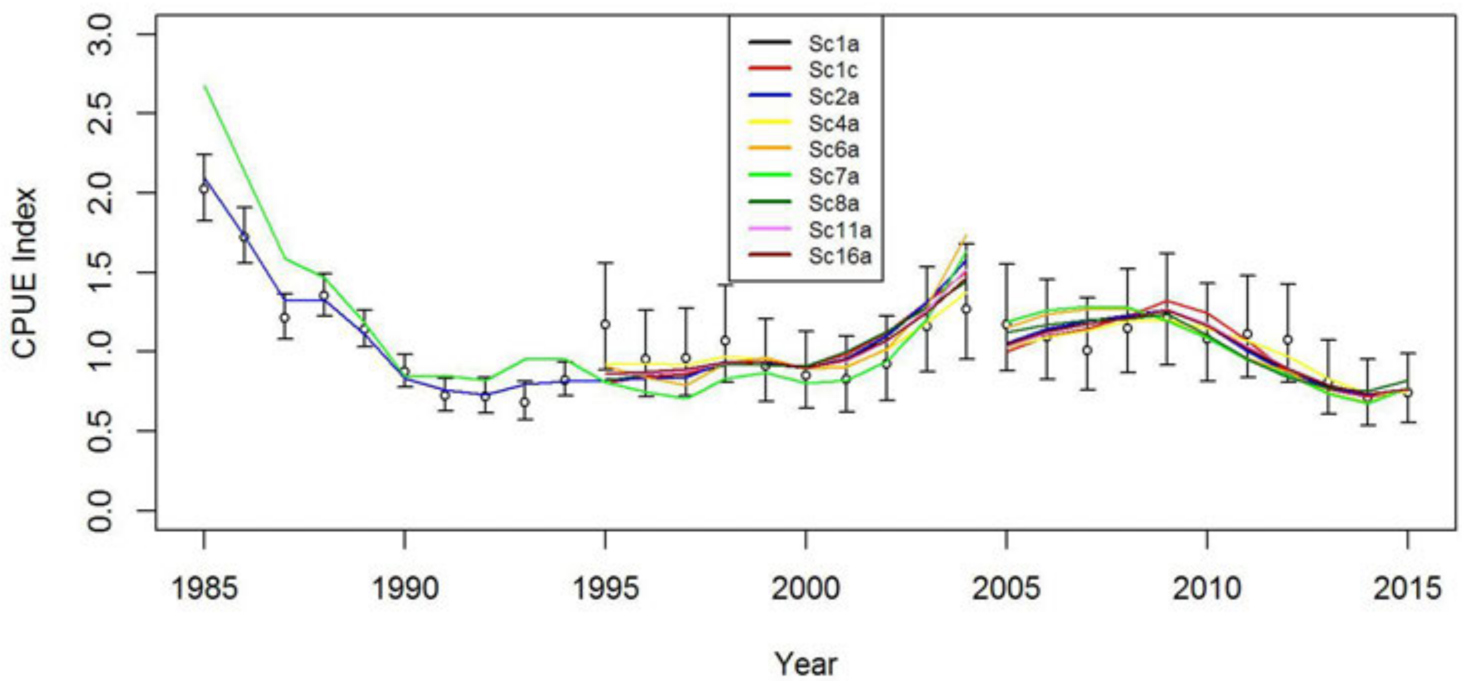


Figure 32. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a fits for WAG golden king crab data, 1985/86–2015/16. Model estimated additional standard error was added to each input standard error.

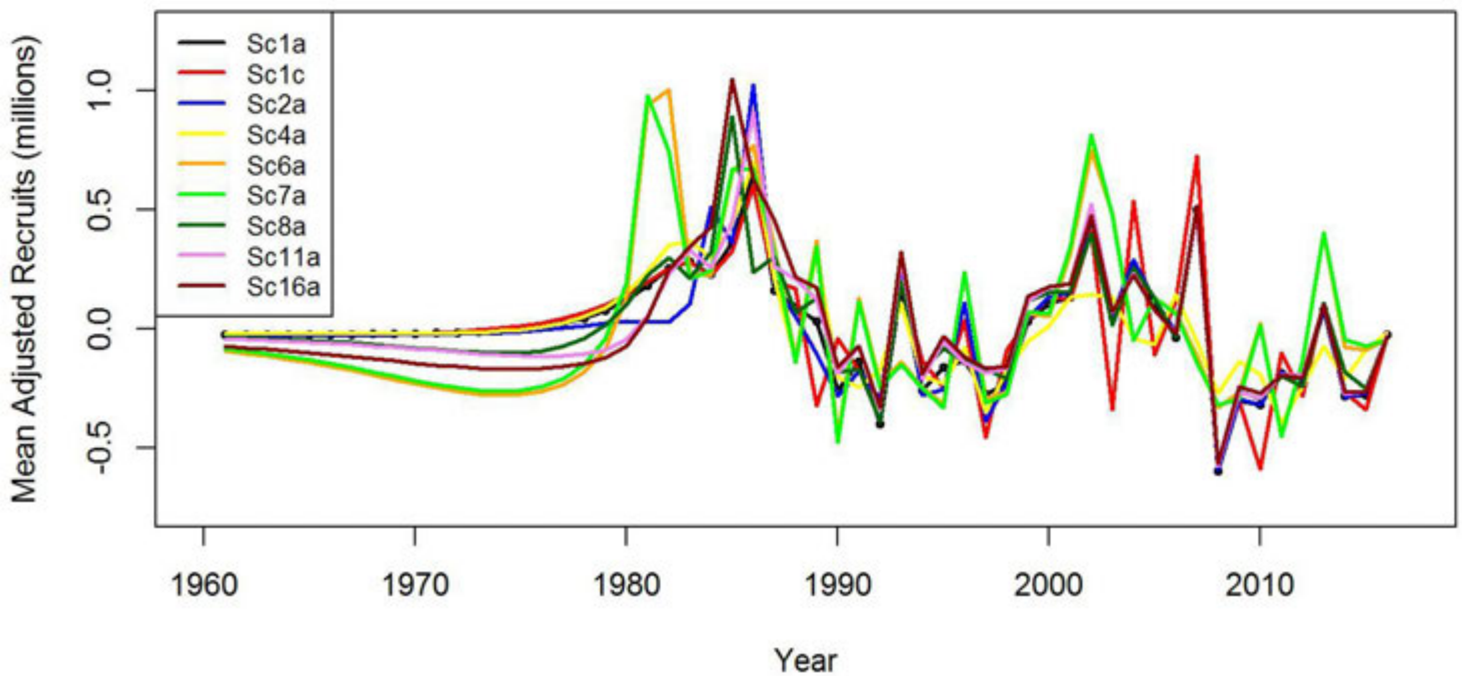


Figure 33. Estimated number of male recruits (millions of crab ≥ 101 mm CL) to the golden king crab assessment model for scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a fits in WAG, 1961–2016. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

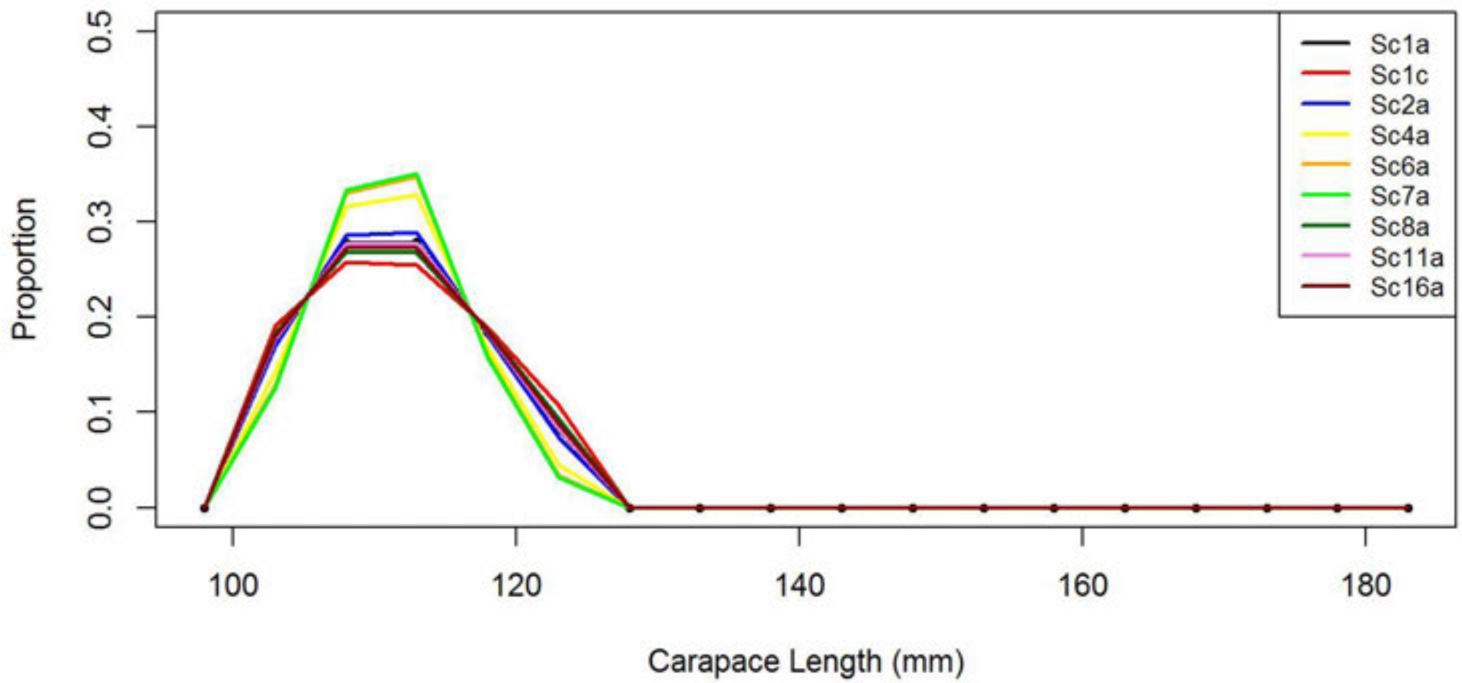


Figure 34. Recruit distribution to the golden king crab assessment model size group for scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a fits in WAG.

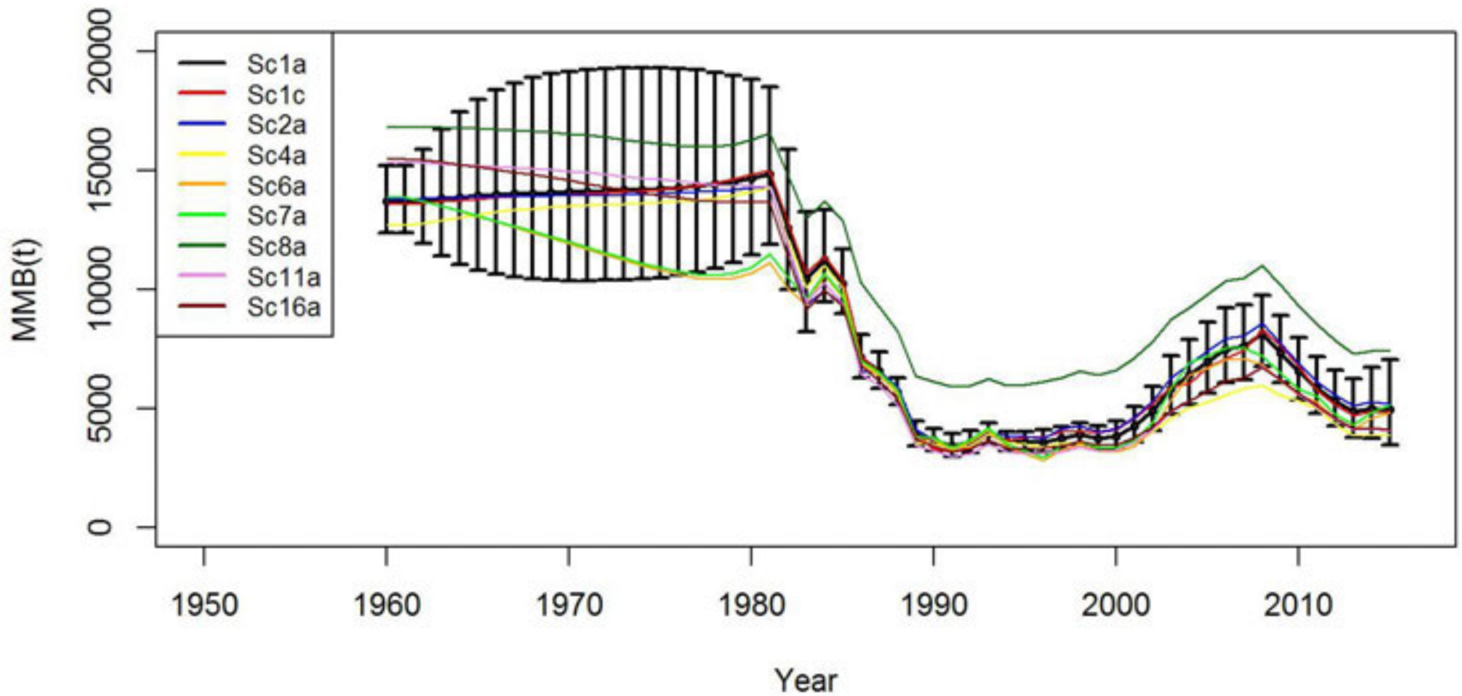


Figure 35. Trends in golden king crab mature male biomass for scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a model fits in the WAG, 1960/61–2015/16. Mature male crab is ≥ 121 mm CL. Scenario 1a estimates have two standard errors confidence limits.

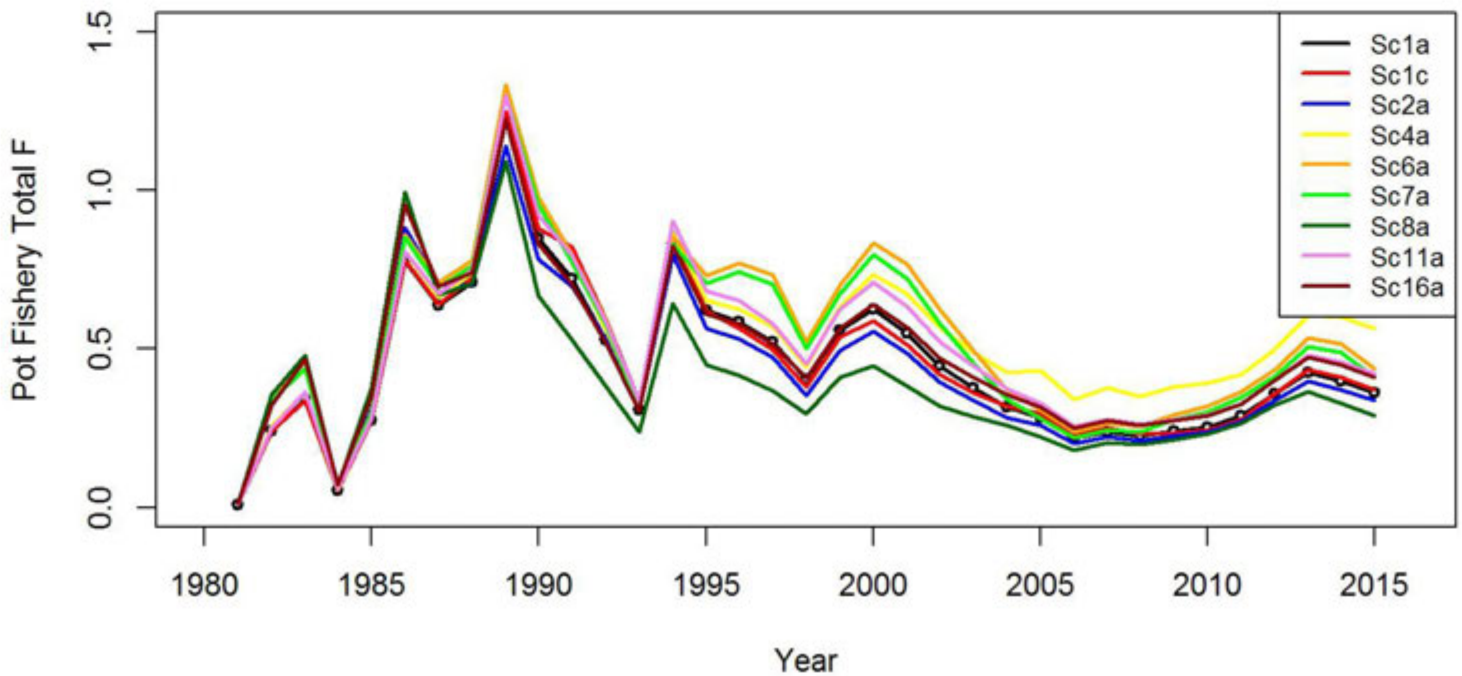


Figure 36. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a model fits in the WAG, 1981–2015 (note: 1981 refers to the1981/82 fishing year).

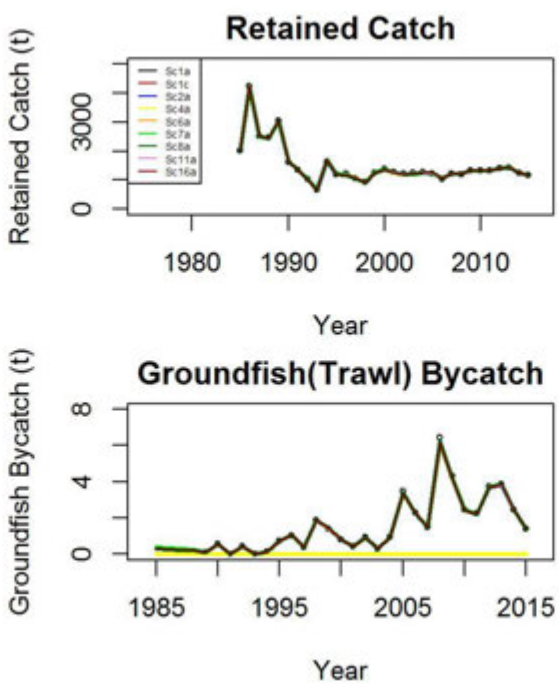


Figure 37. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish (or trawl) bycatch (bottom left) of golden king crab for scenarios (Sc) 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a fits in the WAG, 1985–2015. (note: 1985 refers to the1985/86 fishing year). Scenario 4c disregarded groundfish bycatch data.

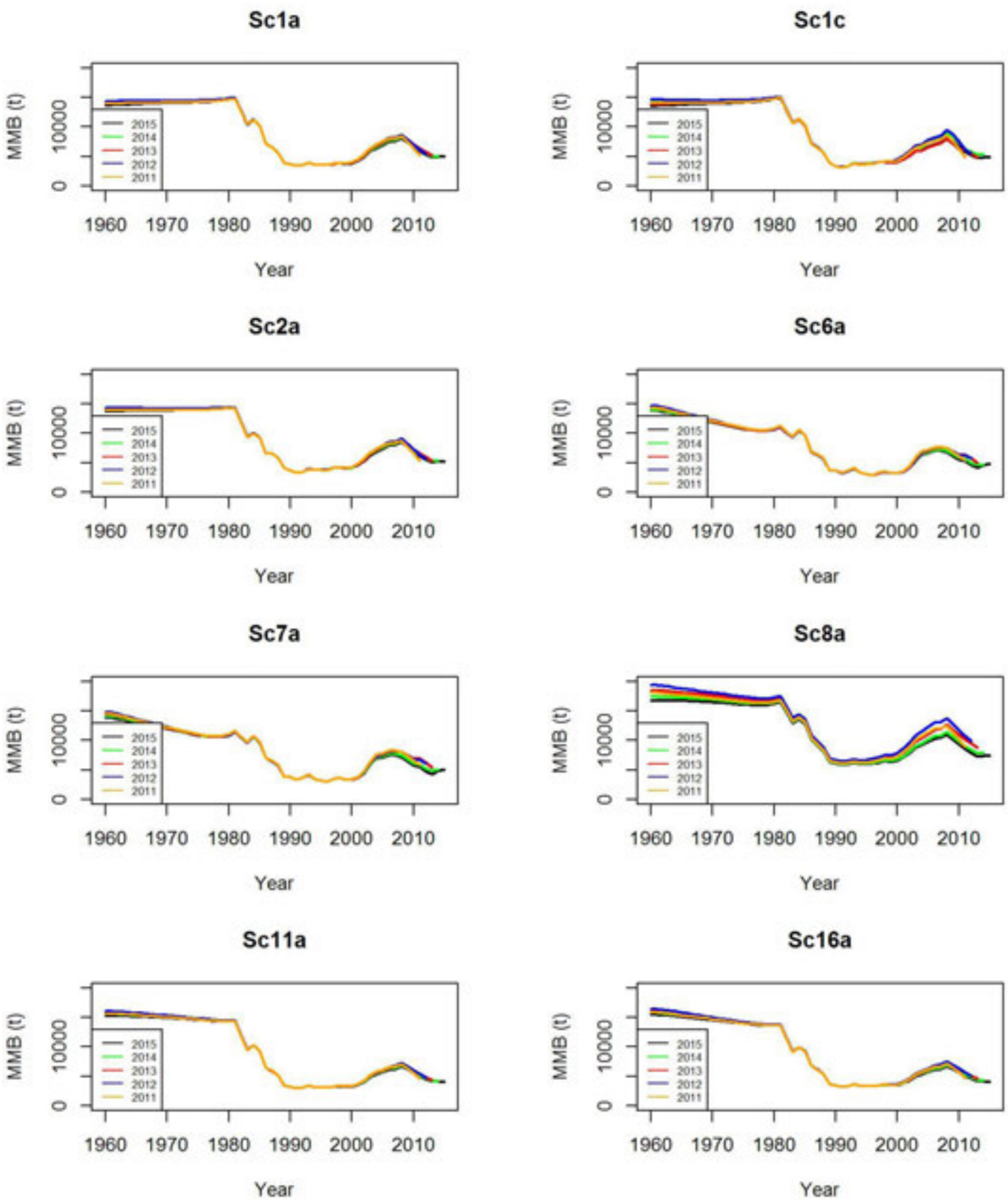


Figure 38. Retrospective fits of mature male biomass by the model when terminal year's data were systematically removed until 2011/12 for scenarios (Sc) 1a, 1c, 2a, 6a, 7a, 8a, 11a, and 16a fits for golden king crab in the WAG, 1960–2015.

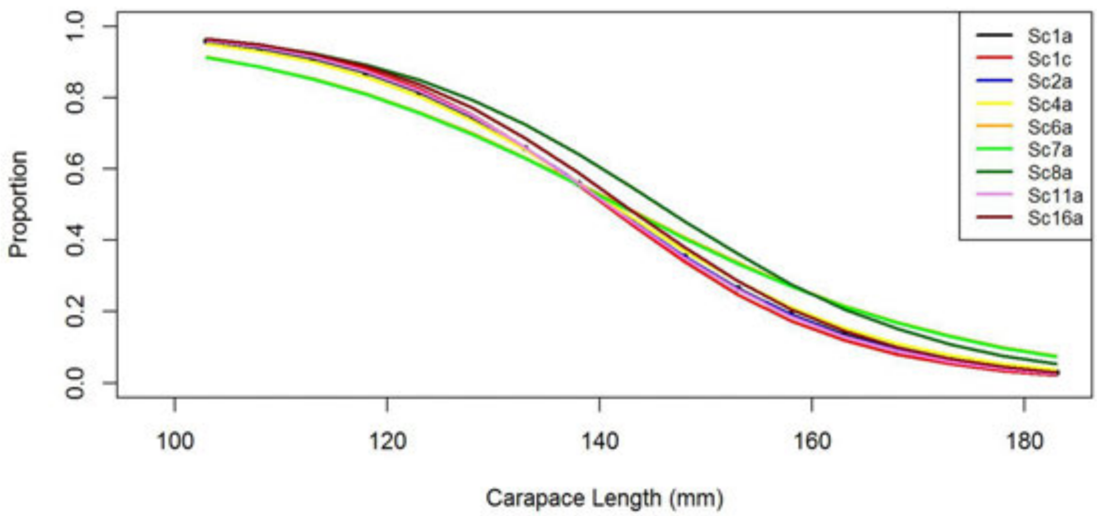


Figure 39. Estimated molt probability vs. carapace length of golden king crab under scenarios 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a for WAG.

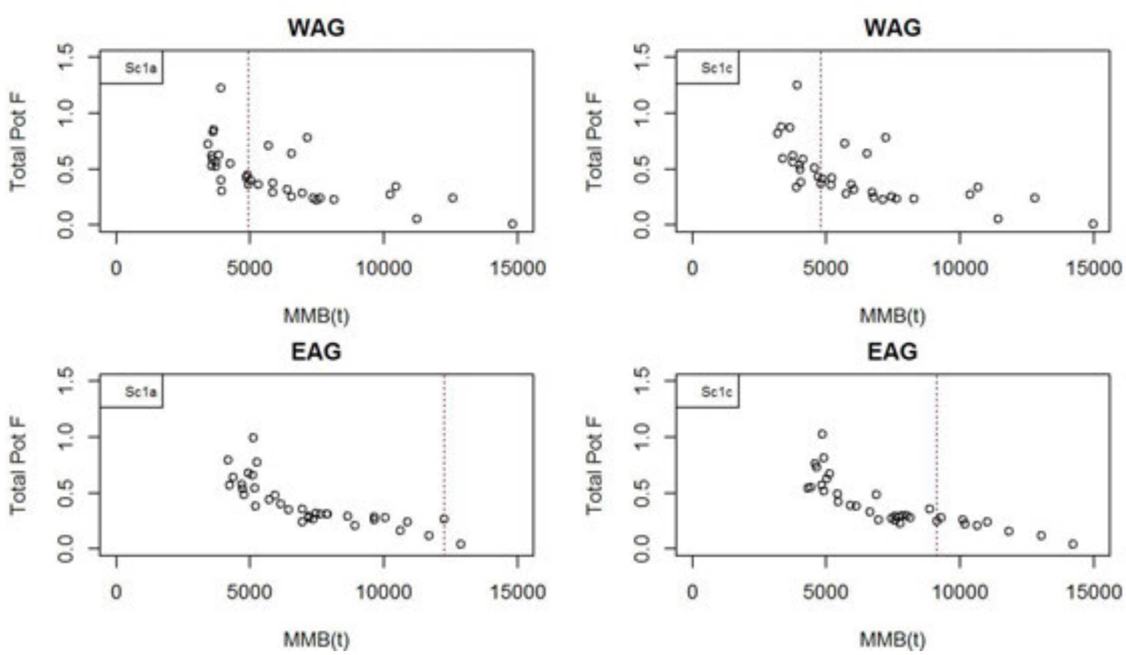


Figure 40. F vs. MMB plots for EAG (top) and WAG (bottom), respectively. The red vertical lines cut through the 2015 MMB and F values.

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 A.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 are computed using the equilibrium initial condition using the following relations:

The equilibrium stock abundance is

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

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

$$\underline{N}_{1960} = (\mathbf{I} - \mathbf{XS})^{-1}\underline{R} \tag{A.5}$$

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

We used the mean number of recruits from 1996 to 2015 in equation (A.5) to obtain the equilibrium solution under only natural mortality (0.2339 or 0.2426) 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:

$$X_{i,j} = \begin{cases} 0 & if\ j < i \\ P_{i,j} + (1 - m_i) & if\ j = i \\ P_{i,j} & if\ j > i \end{cases} \tag{A.6}$$

where:

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

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

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

$$\mu_i = \omega_1 + \omega_2 * \bar{L}_i. \tag{A.7}$$

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*:

$$m_i = \frac{1}{1 + e^{c(\tau_i - d)}} \tag{A.8}$$

where *c* and *d* are parameters.

Selectivity and retention

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

$$S_i = \frac{1}{1 + e^{\left[-\ln(19)\frac{\tau_i - \theta_{50}}{\theta_{95} - \theta_{50}}\right]}} \tag{A.9}$$

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

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

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

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

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

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

Parameter estimation

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

Tables A2 lists 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:

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

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

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

where λ_r, λ_T and λ_{GD} are weights assigned to likelihood components for the retained, pot total and groundfish discard catches; w_j is the average mass of a crab is length-class *j*; $C_{t,j}$, $T_{t,j}$, 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:

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

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

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

where q_k is the catchability coefficient during the k-th time period (e.g., pre- and post-rationalization time periods), σ_e is the extent of over-dispersion, c is a small constant to prevent zero values (0.001), and $\lambda_{r,CPUE}$ 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:

$$\sigma_{r,t}^2 = \ln(1 + CV_{r,t}^2) \quad \text{(A.15)}$$

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

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

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

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

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

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

(A.17)

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

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

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:

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

$$S_t^T = \min(0.001 * number\ of\ length\ measurements\ in\ year\ t, 150) \qquad \text{(A.19)}$$

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

Iterative reweighting of effective sample sizes at stage-2 for scenarios 6a,c and 7a,c was done using Francis' (2011) method. Initial Stage-1 weighting for this procedure was done using equation A.19, but subsequent iterations to determine the multiplier weight did not implement 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:

$$\ell \mathrm{n} L = \sum_t \sum_j \sum_y \sum_i \tilde{V}_{j,t,y,i} \ell \mathrm{n} \hat{\rho}_{j,t,y,i} \qquad \text{(A.20)}$$

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:

$$\underline{\hat{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{\Omega}^{(j)} \qquad \text{(A.21)}$$

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:

$$r_l = \sum_t \sum_j \frac{s_l [\mathbf{X}^t]_{j,l}}{\sum_{l'} s_{l'} [\mathbf{X}^t]_{j,l'}} \sum_k V_{j,k,t} \tag{A.22}$$

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) :

$$P_1 = \lambda_F \sum_t (\ell n F_t - \ell n \bar{F})^2 \tag{A.23}$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ell n F_t^{Tr} - \ell n \bar{F}^{Tr})^2 \tag{A.24}$$

$$P_3 = \lambda_R \sum_t (\ell n \varepsilon_t)^2 \tag{A.25}$$

$$P_5 = \lambda_{posfn} * fpen \tag{A.26}$$

Standardized Residual of Length Composition

$$Std.Res_{t,j} = \frac{P_{t,j} - \widehat{P_{t,J}}}{\sqrt{2\sigma_{t,j}^2}} \tag{A.27}$$

Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n} (\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \tag{A.28}$$

Exploited legal male biomass at the start of year t:

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \tag{A.29}$$

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:

$$MMB_t = \sum_{j=mature\ size}^{n} \{N_{j,t} e^{y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t}) e^{(y_t - y')M}\} w_j \tag{A.30}$$

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

$$F' = \gamma M \frac{\left(\frac{MMB_t}{M\overline{M}B} - \alpha\right)}{(1-\alpha)} \tag{A.31}$$

(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.30 and A.31 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:	
Length specific equilibrium abundance $N_{1960,l}$	n
Fishing mortalities:	
Pot fishery, F_t	1985–2015
Mean pot fishery fishing mortality, $\bar{F}$	1
Trawl fishery, F_t^{Tr}	1989–2015 (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 or 3 (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+)
Trawl fishery selectivity θ_{50}^{Tr}	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, 0.2339 yr^{-1} or 0.2426 yr^{-1}
Recruitment:	
Distribution to length-class, α_r, β_r	2
Median recruitment, $\bar{R}$	1
Recruitment deviations, ε_t	56 (1961–2016)
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 1a,b,c,d	**Scenario 2a,b,c,d**	**Scenario 3a,c**	**Scenario 4a,c**	**Scenario 5a,c**	**Scenario 6a,c**	**Scenario 7a,c**
Catch:							
Retained catch for 1981–1984 and/or 1985–2015, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch for 1990–2015, λ_T	Number of sampled pots scaled to a max 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 1989–2015, λ_{GD}	0.2 (3.344)	0.2	0.2	-	0.2	0.2	0.2
Catch-rate:							
Observer legal size crab catch-rate for 1995–2015, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	1	1
Fish ticket retained crab catch-rate for 1985–1998 , $\lambda_{r,CPUE}$		1(0.805)					1(0.805)
Penalty weights:							
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥	Initially 1000, relaxed to 0.001 at phases ≥	Initially 1000, relaxed to 0.001 at phases ≥	Initially 1000, relaxed to 0.001 at phases ≥	Initially 1000, relaxed to 0.001 at phases ≥	Initially 1000, relaxed to 0.001 at phases ≥	Initially 1000, relaxed to 0.001 at phases ≥

	select. phase	select. phase	select. phase	select. phase	select. phase	select. phase	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
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 8a,c	**Scenario 9a,c**	**Scenario 10a,c**	**Scenario 11a,c**	**Scenario 12a,c**
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
Fish ticket retained crab catch-rate for 1985–1998 , $\lambda_{r,CPUE}$			1(0.805)		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
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 14a,c	**Scenario 16a,c**	**Scenario 19a,c**
Catch:			
Retained catch, λ_r	500 (0.032)	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
Groundfish bycatch, λ_{GD}	-	0.2	0.2
Catch-rate:			
Observer legal size crab catch-rate, $\lambda_{r,CPUE}$	1(0.805)	1	1 (Year:Captain interaction in the final GLM model)
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
Trawl fishing mortality	-	Initially 1000, relaxed to	Initially 1000, relaxed

dev, $\lambda_{F^{Tr}}$		0.001 at phases ≥ select. phase	to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2(0.533)	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000
Tagging likelihood	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 15 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:

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

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 1995/96–2015/16 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 2005/06–2015/16, to estimate CPUE indices for model input.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE as a separate likelihood component in a number of scenarios (Table D). 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 17).

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

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

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

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

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. We used the R^2 and AIC criteria for predictor variable selection (Siddeek *et al*. 2016b).

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

$$R^2 = \frac{(null\ model\ deviance - added\ parameter\ model\ deviance)}{null\ model\ deviance} \qquad \text{(B.4)}$$

An arbitrary R^2 minimum increment of 0.01 was set to select the model terms. The following consistent AIC formula (CAIC) was used in the "stepAIC" routine in R (version 3.3.1, R Core Team, 2016) for fitting large sample sizes (Shono, 2005):

$$CAIC = -2\ln(MLH) + p(\ln(n) + 1) \quad \text{(B.5)}$$

where n= sample size and p = number of unknown parameters.

This routine starts from the null model and select the explanatory variable with the lowest CAIC for forward stepwise selection. It stops addition of explanatory variable when there is no significant reduction in the CAIC value.

The final models with no interaction option for EAG were:

(a) Under R^2 criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 3) \quad \text{(B.6)}$$

for the 1995/96–2004/05 period [θ=1.33, $R^2 = 0.2417$ with ns(Soak, 3) forced in]

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 11) \quad \text{(B.7)}$$

for the 2005/06–2015/16 period ($\theta = 2.27$, $R^2 = 0.1195$).

(b) Under CAIC criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 3) + Month + Area + Vessel \quad \text{(B.8)}$$

for the 1995/96–2004/05 period [θ=1.33, $R^2 = 0.2580$]

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Gear} + \text{ns}(\text{Soak}, 11) \quad \text{(B.9)}$$

for the 2005/06–2015/16 period ($\theta = 2.27$, $R^2 = 0.1187$).

The final models with no interaction option for WAG were:

(a) Under R^2 criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 8) \quad \text{(B.10)}$$

for the 1995/96–2004/05 period (θ=0.98, $R^2 = 0.1783$)

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{ns}(\text{Soak}, 17) \quad \text{(B.11)}$$

for the 2005/06–2015/16 period [θ=1.13, $R^2 = 0.0564$ with $ns(Soak, 17)$ forced in]

(b) Under CAIC criteria:

$$\ln(CPUE) = Year + Captain + ns(Soak, 8) + Gear + Area + Month + Vessel \quad (B.12)$$

for the 1995/96–2004/05 period [θ=0.98, $R^2 = 0.1915$]

$$\ln(CPUE) = Year + Gear + Vessel + Month + ns(Soak, 17) \quad (B.13)$$

for the 2005/06–2015/16 period [θ=1.13, $R^2 = 0.0682$ with $ns(Soak, 17)$ *forced in*]

Following the industry and the SSC (June 2016) suggestions, we also investigated the interaction terms under R^2 criteria for the GLM fit. We added additional Year:Captain and Year:Gear interaction terms to the scope function for variable selection by the GLM.

The final models with the interaction option for EAG were:

$$\ln(CPUE) = Year + Gear + Captain + Year{:}Captain + ns(Soak, 3) \quad (B.14)$$

for the 1995/96–2004/05 period [θ=1.33, $R^2 = 0.2683$ with ns(Soak, 3) forced in]

$$\ln(CPUE) = Year + Captain + Gear + ns(Soak, 11) + Year{:}Captain \quad (B.15)$$

for the 2005/06–2015/16 period [θ=2.27, $R^2 = 0.1313$]

The final models with the interaction option for WAG were:

$$\ln(CPUE) = Year + Captain + ns(Soak, 8) + Gear + Year{:}Captain \quad (B.16)$$

for the 1995/96–2004/05 period [θ=0.98, $R^2 = 0.2016$]

$$\ln(CPUE) = Year + Gear + Captain + ns(Soak, 17) + Year{:}Captain \quad (B.17)$$

for the 2005/06–2015/16 period [θ=1.13, $R^2 = 0.0923$ with $ns(Soak, 17)$ *forced in*]

Note:

1. The CAIC criteria selected more predictor variables than the R^2 criteria, but with little improvement on the overall fit of final models (see the R^2 values). It appears that the AIC and its variants over parameterize the model despite the enforced penalty on number of estimated parameters.
2. The addition of Year:Captain interaction term did not dramatically improve the fit (see the R^2 values). Furthermore, the GLM summary output listed a number of NAs for the estimated interaction terms. If we had removed the NA producing parameter levels, the final models would have reverted back to main factor models. Nevertheless, we used the observer CPUE indices estimated under the interaction models in scenarios 19a,c for demonstration purpose.

Standardized nominal CPUE data under no interaction option and R^2 criteria are presented in Tables 2 and 16 respectively, for EAG and WAG. The analysis of deviance table for the final model is provided in Table B.1.

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. The predictor variables were selected by the R^2 criteria. Figures B.2 and B.11 show the trend in CPUE indices that were determined by the predictor variables selected by the CAIC criteria. Figures B.9 and B.17 depict the nominal and standardized CPUE indices trends for the two CPUE time series for EAG and WAG respectively when Year:Captain interaction term was included (Note that the final interaction models have shortcomings with respect to parameter estimates).
Figures B.3-B.4 and B.12-B.13 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.5-B.8 and B.13-B.16 depict CDI plots of the predictor variables for EAG and WAG, respectively.

Table B.1. Analysis of deviance for stepwise negative binomial models selection for observer CPUE standardization. Explanatory variables (without interactions) are listed in the order of acceptance to the model. Significant reductions in AIC and residual deviance associated with an acceptance tolerance of R^2 difference were used for the variable selection. The EAG and WAG golden king crab observer legal size male data for 1995/96–2004/05 and 2005/06–2015/16 time periods were used. + = indicates stepwise addition of variables.

Region/ Fishing period	**Predictor variable**	**Residual DF**	**Estimated Parameters**	**Residual Deviance**	**Decrease in AIC**	**R^2**
EAG						:
1995/96–2004/05	*Year*	31,653	9	42,187	204,269	0.1008
	+Gear	31,639	14	37,526	199,637	0.2002
	+Captain	31,599	40	36,043	198,234	0.2318
2005/06–2015/16	*Year*	6,254	10	7,486	54,671	0.0616
	+Captain	6,245	9	7,237	54,440	0.0929
	+Gear	6,238	7	7,127	54,344	0.1066
	+Soak	6,227	11	7,024	54,263	0.1195
WAG						
1995/96–2004/05	*Year*	32,458	9	44,187	195,977	0.0268
	+Captain	32,409	49	39,516	191,404	0.1297
	+Gear	32,395	14	38,442	190,358	0.1533
	+Soak	32,387	8	37,310	189,242	0.1783
						:
2005/06–2015/16	*Year*	10,768	10	12,765	87,511	0.0299
	Gear	10,758	10	12,532	87,297	0.0477

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 were:

(a) Under R^2 criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel} + \text{Month},\ R^2 = 0.4541 \tag{B.18}$$

(b) Under CAIC criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area} + \text{Month},\ R^2 = 0.3758 \tag{B.19}$$

and those for WAG were:

(a) Under R^2 criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel},\ R^2 = 0.4561 \tag{B.20}$$

(c) Under CAIC criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area},\ R^2 = 0.3804 \tag{B.21}$$

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

Figures B.18 and B.20 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively. Figures B.19 and B.21 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.

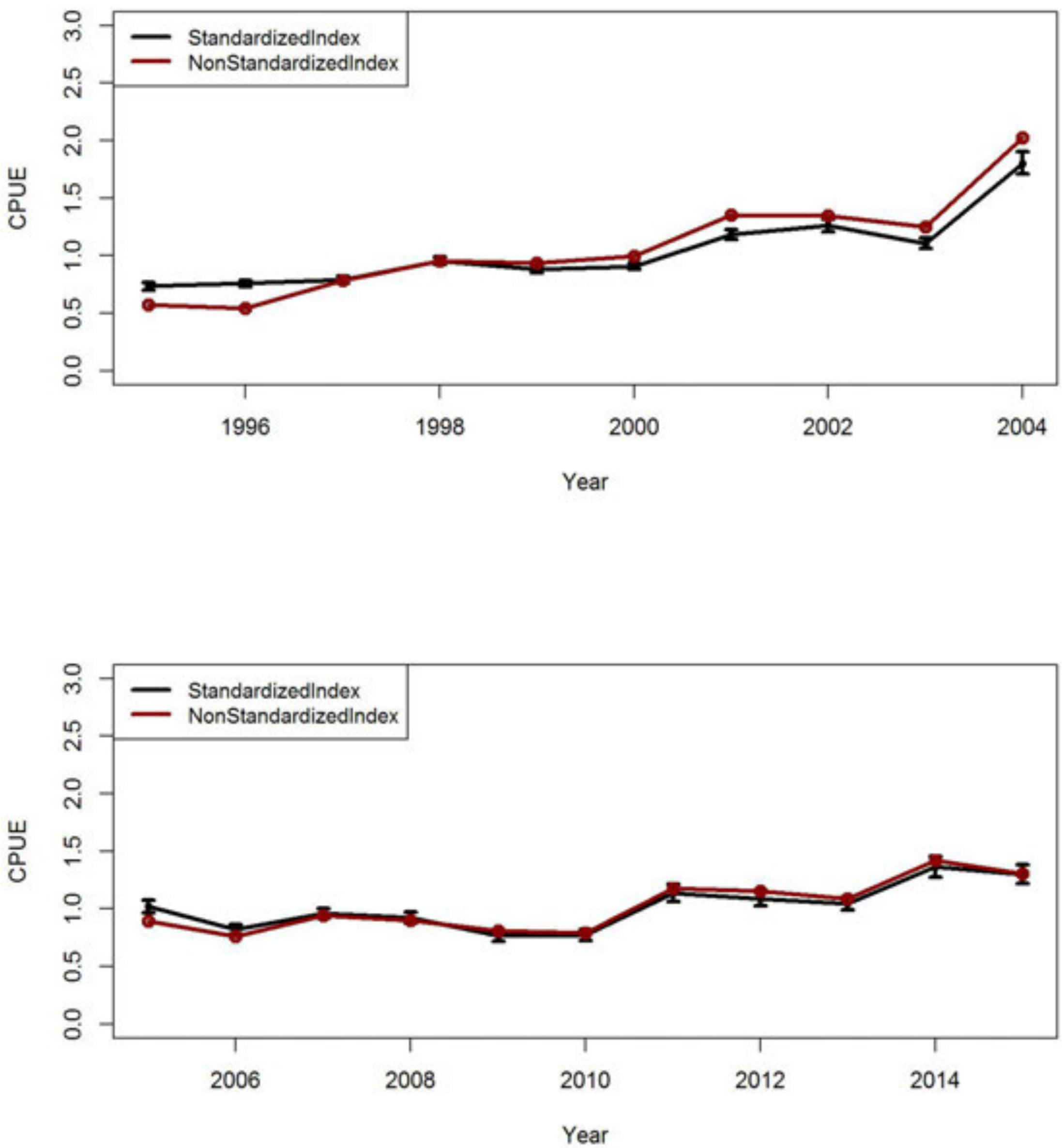
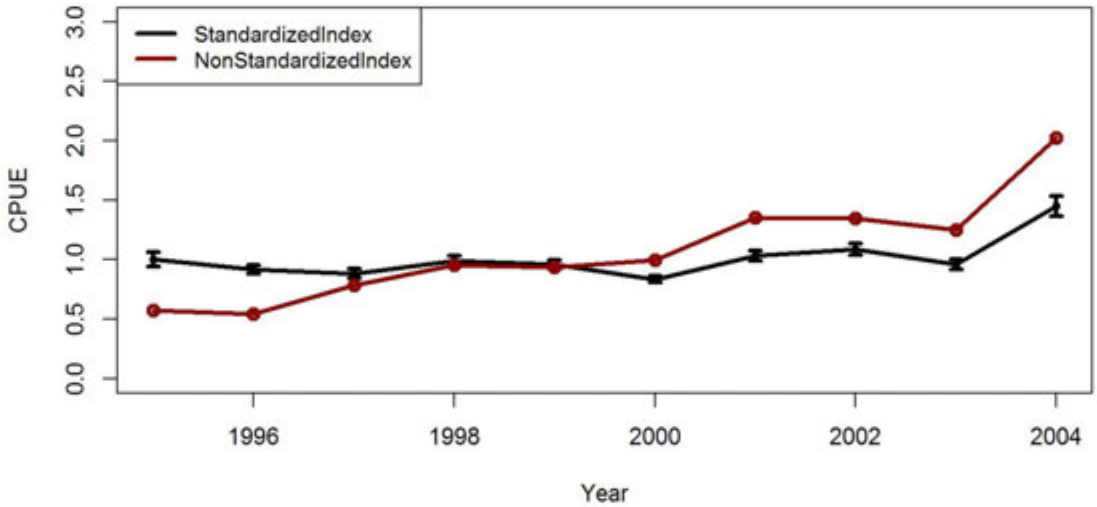


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Predictor variables were selected by R^2 criteria. Standardized indices: black line and non-standardized indices: red line.



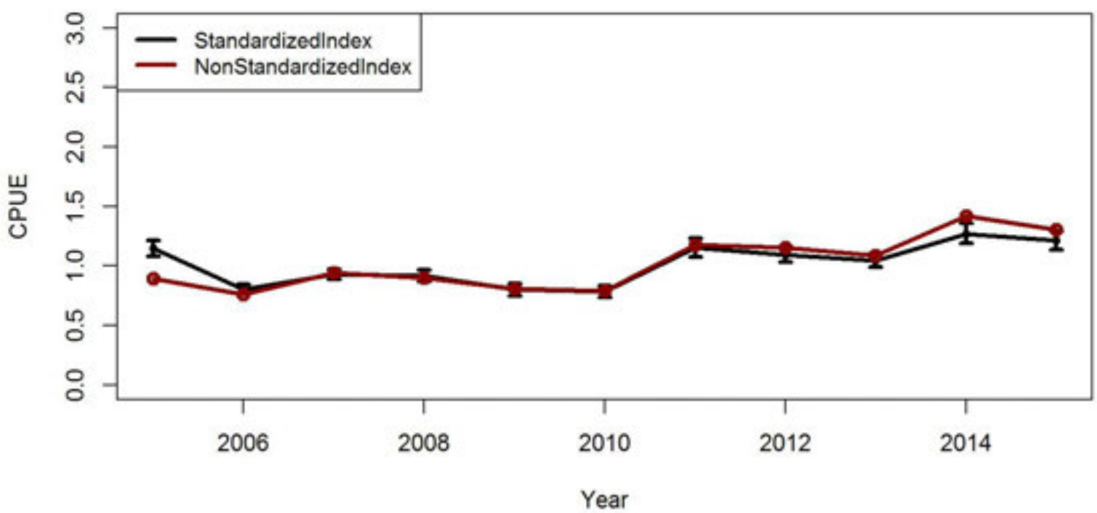


Figure B.2. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Predictor variables were selected by CAIC criteria. Standardized indices: black line and non-standardized indices: red line.

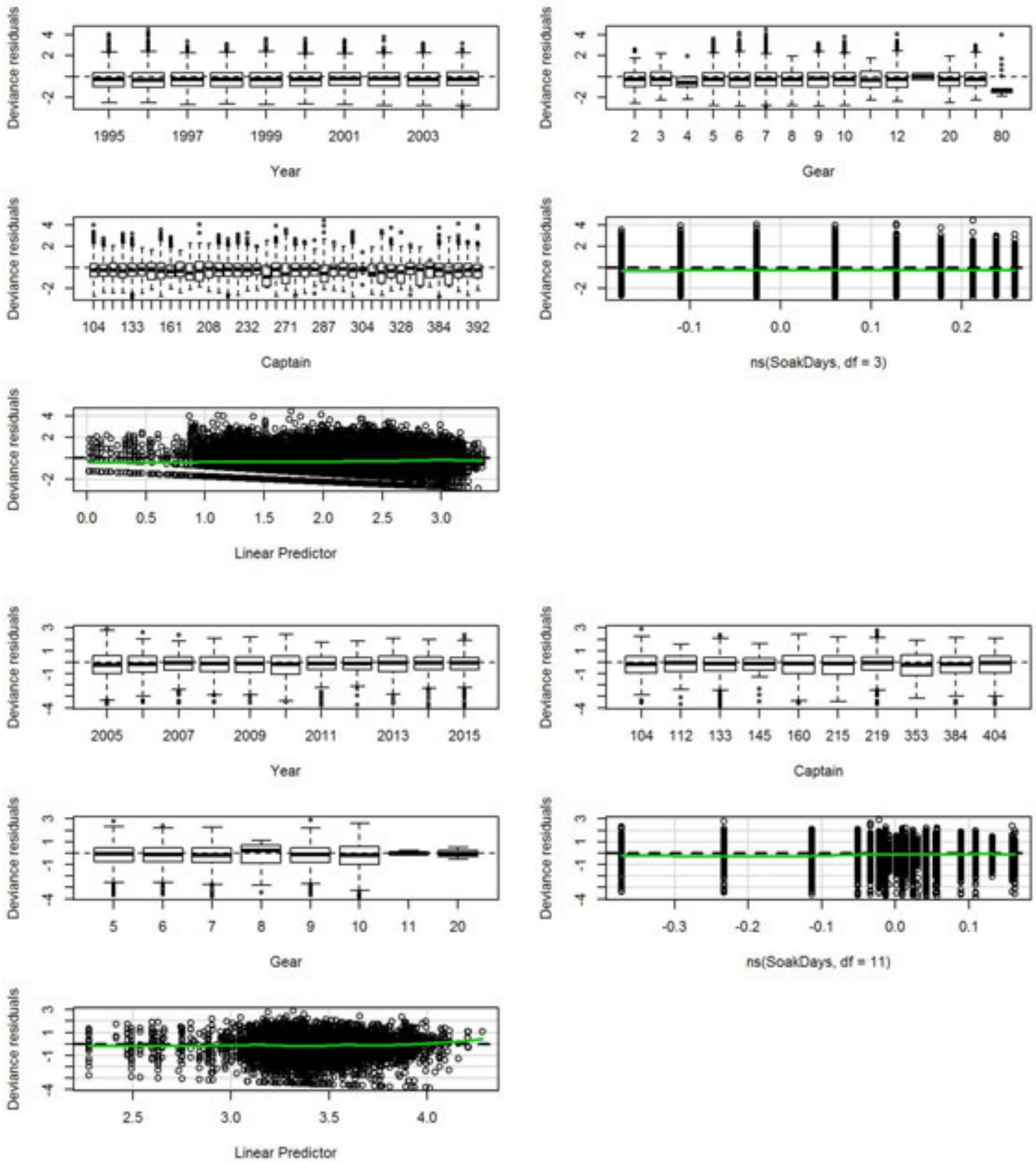
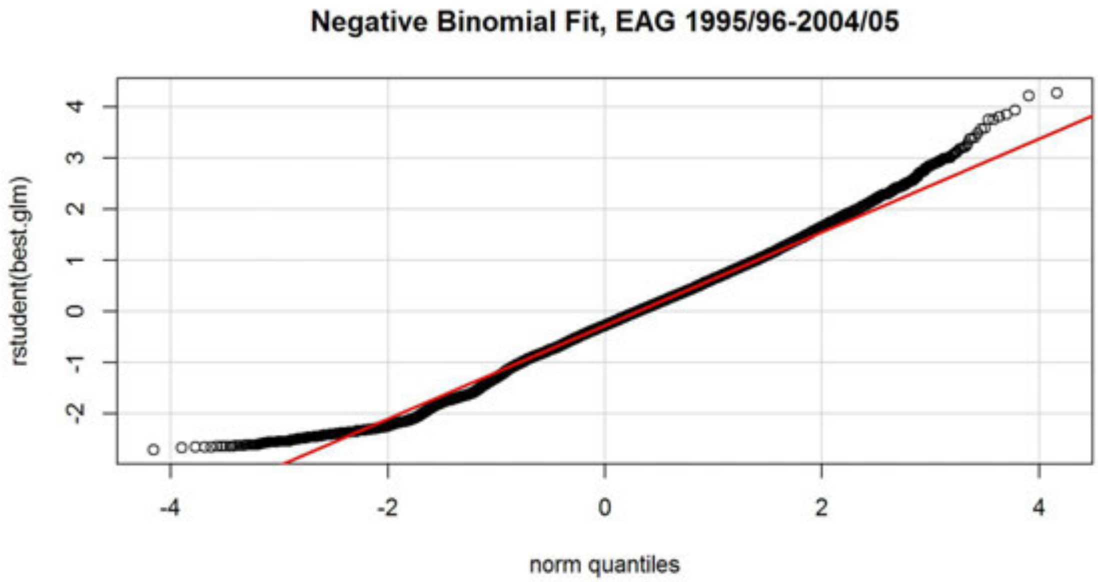


Figure B.3. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from EAG for 1995/96–2004/05 (top) and 2005/06–2015/16 (bottom) periods were used. Predictor variables were selected by R^2 criteria. The solid green lines are the loess smoother through the plotted values.



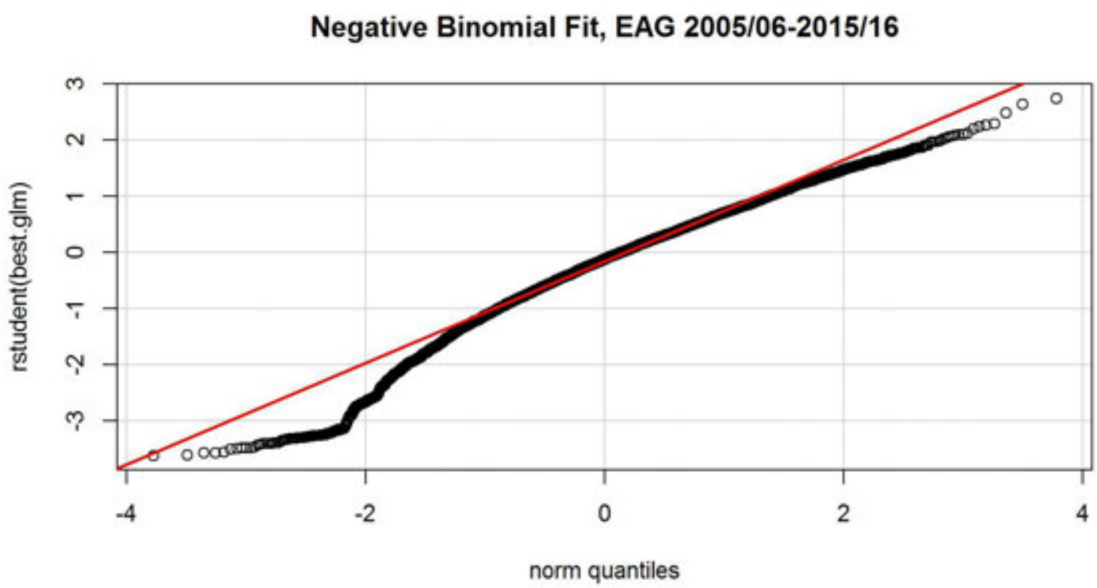


Figure B.4. Studentized residual plots for negative binomial GLM fit for EAG golden king crab observer legal size male crab CPUE data. Predictor variables were selected by R^2 criteria. Top panel is for 1995/96–2004/05 data and the bottom panel is for 2005/06–2015/16 data.

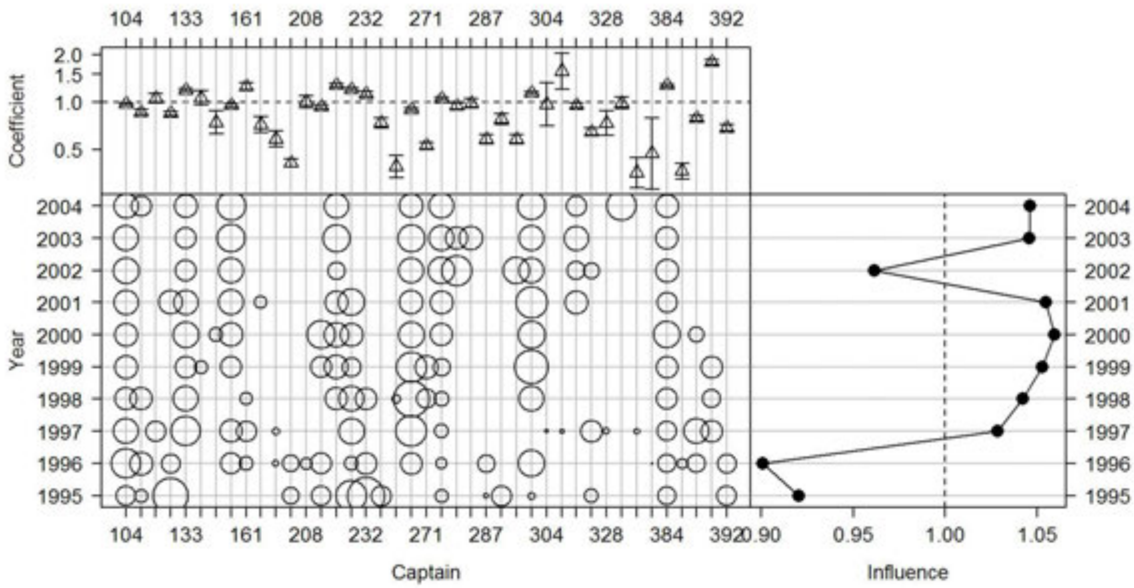


Figure B.5. CDI plot for Captain for the negative binomial fit of 1995/96–2004/05 data for EAG.

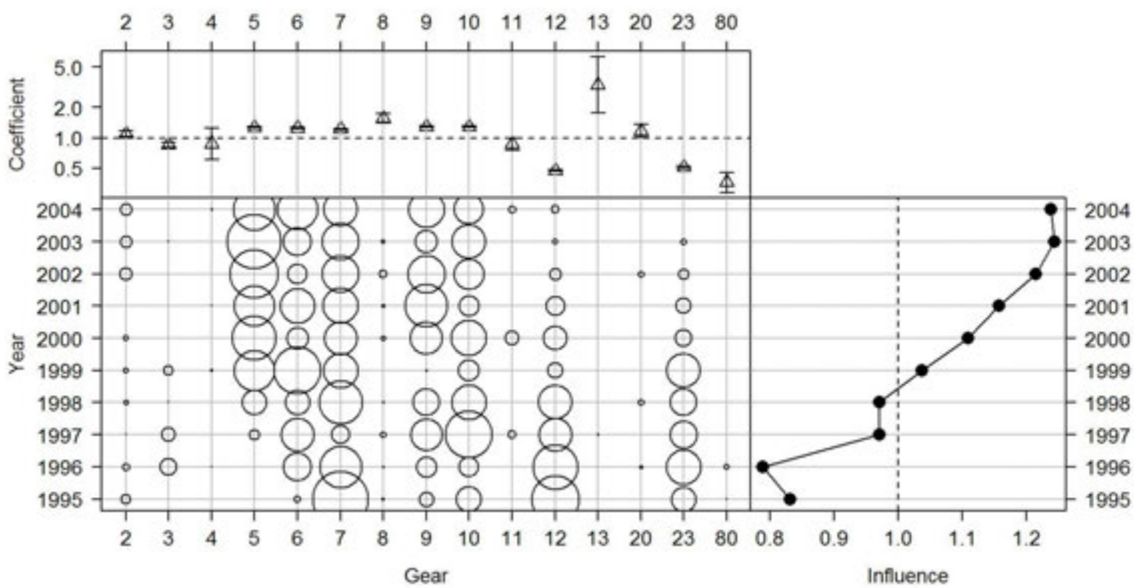


Figure B.6. CDI plot for Gear for the negative binomial fit of 1995/96–2004/05 data for EAG.

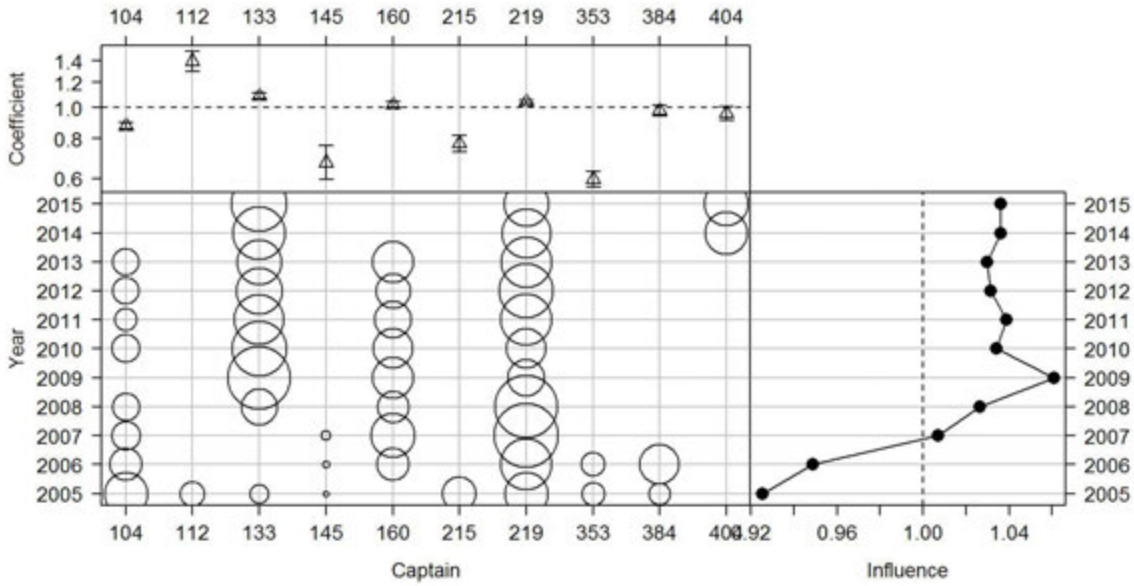


Figure B.7. CDI plot for Captain for the negative binomial fit of 2005/06–2015/16 data for EAG.

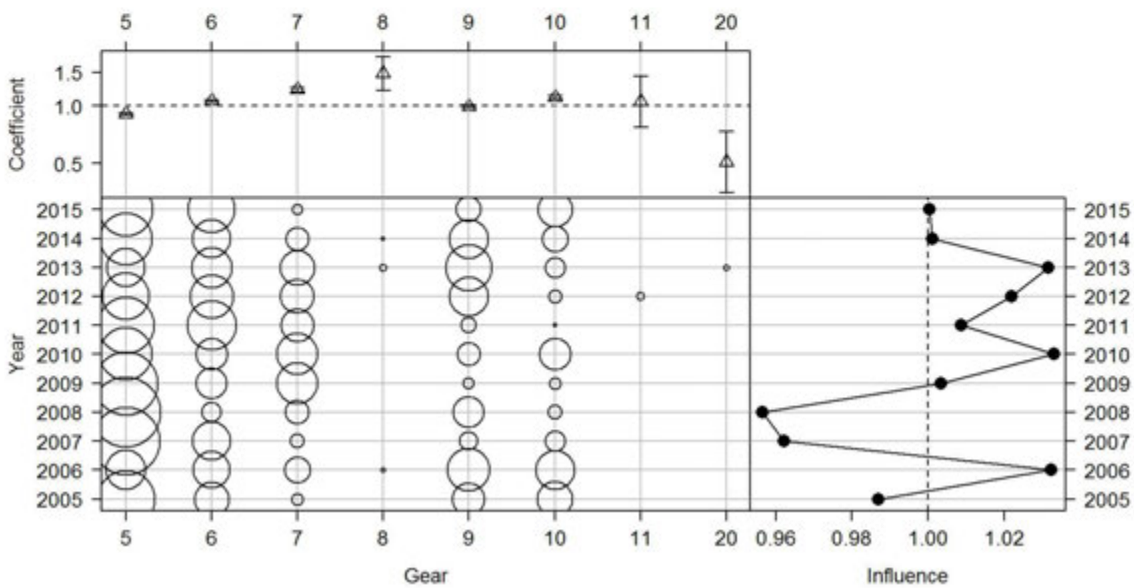


Figure B.8. CDI plot for Gear for the negative binomial fit of 2005/06–2015/16 data for EAG.

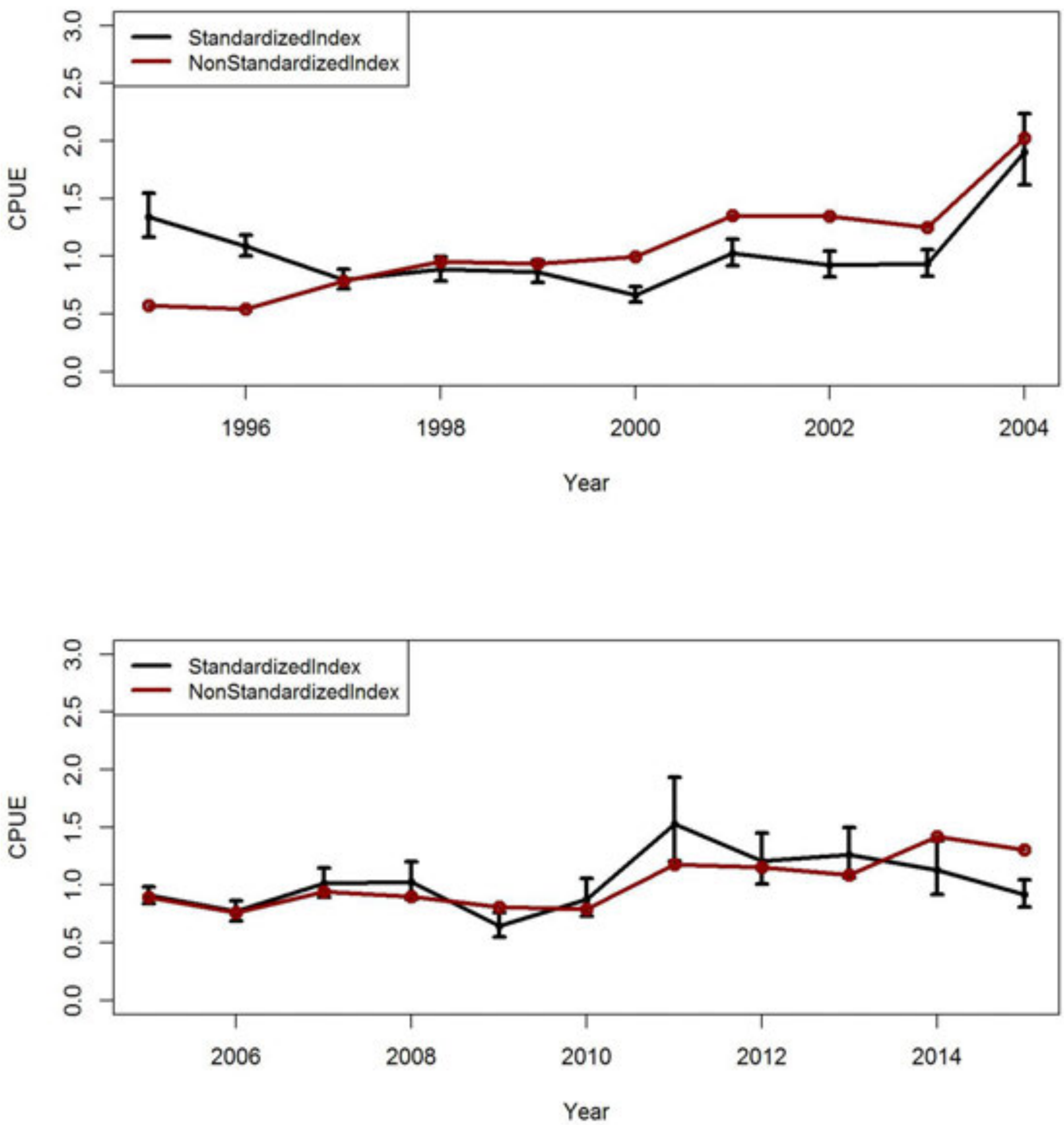


Figure B.9. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). The final model included the interaction term Year:Captain. Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Standardized indices: black line and non-standardized indices: red line.

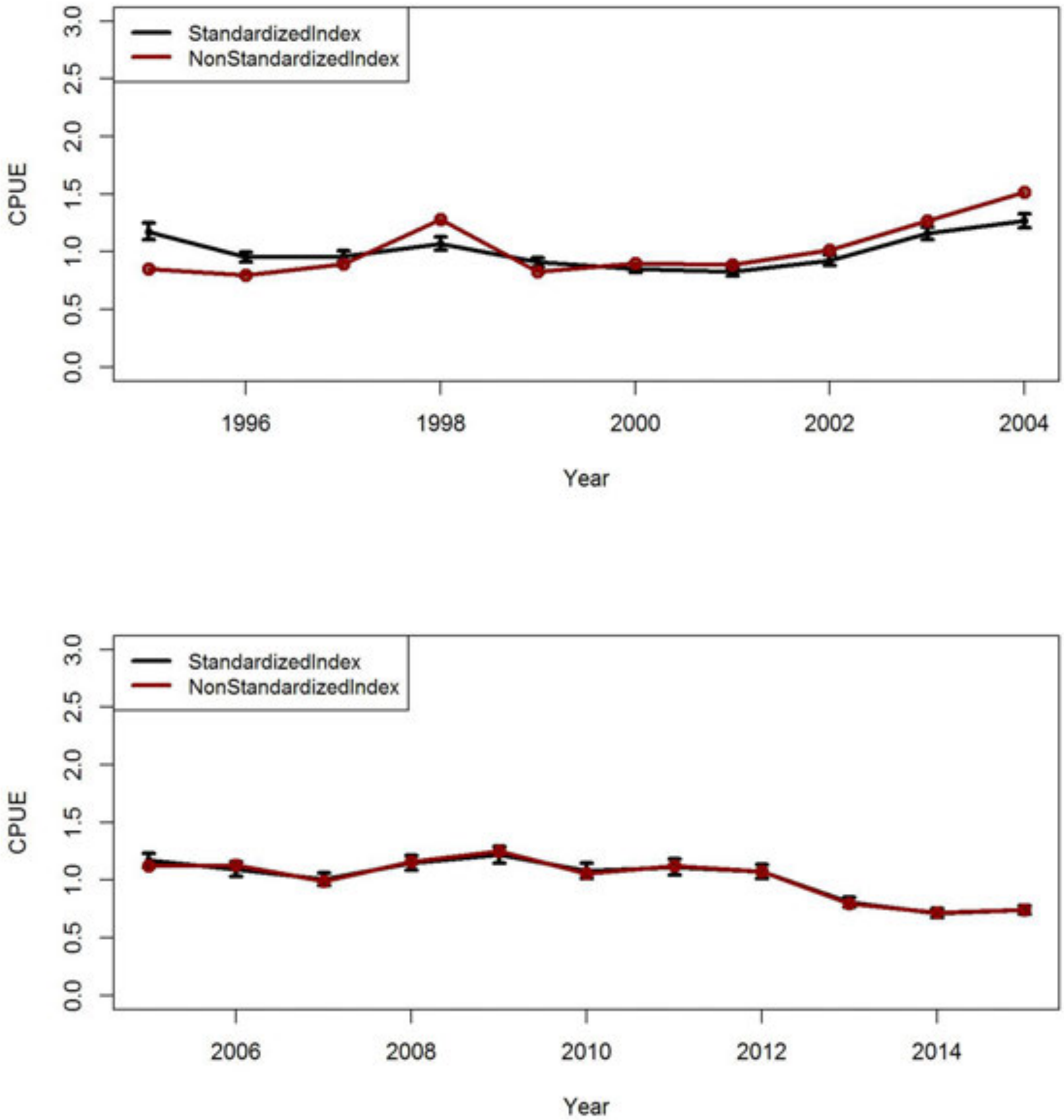
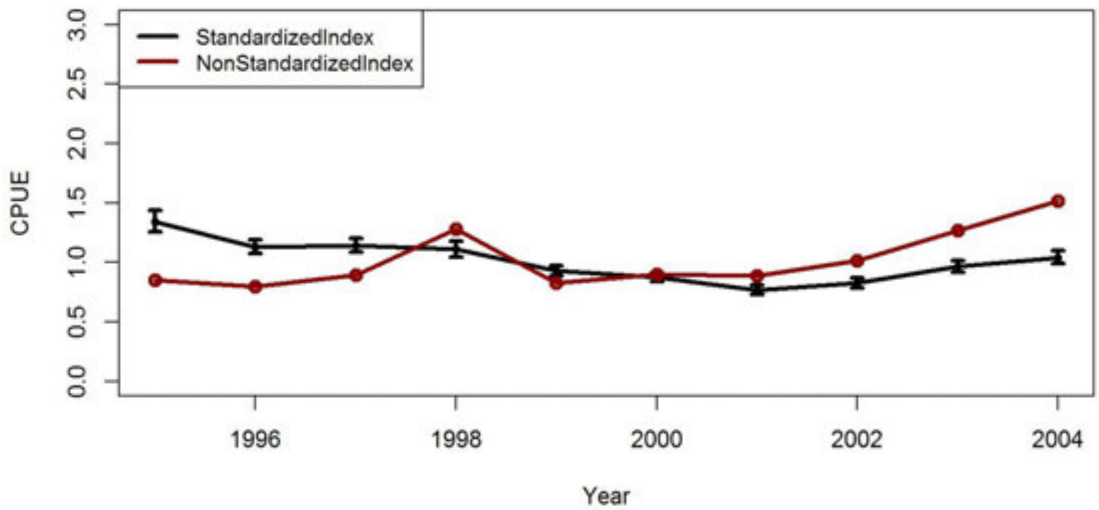


Figure B.10. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Predictor variables were selected by R^2 criteria. Standardized indices: black line and non-standardized indices: red line.



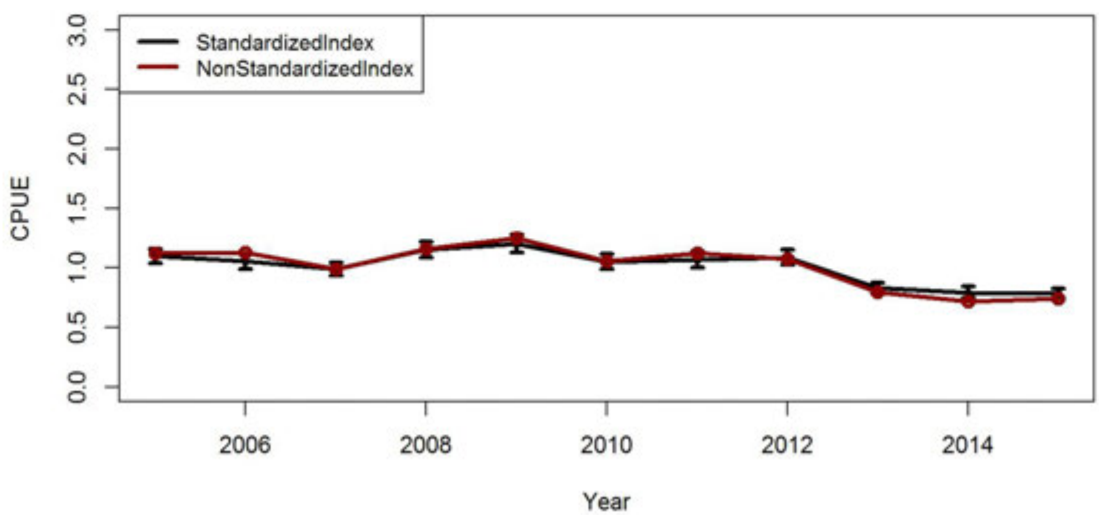


Figure B.11. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Predictor variables were selected by CAIC criteria. Standardized indices: black line and non-standardized indices: red line.

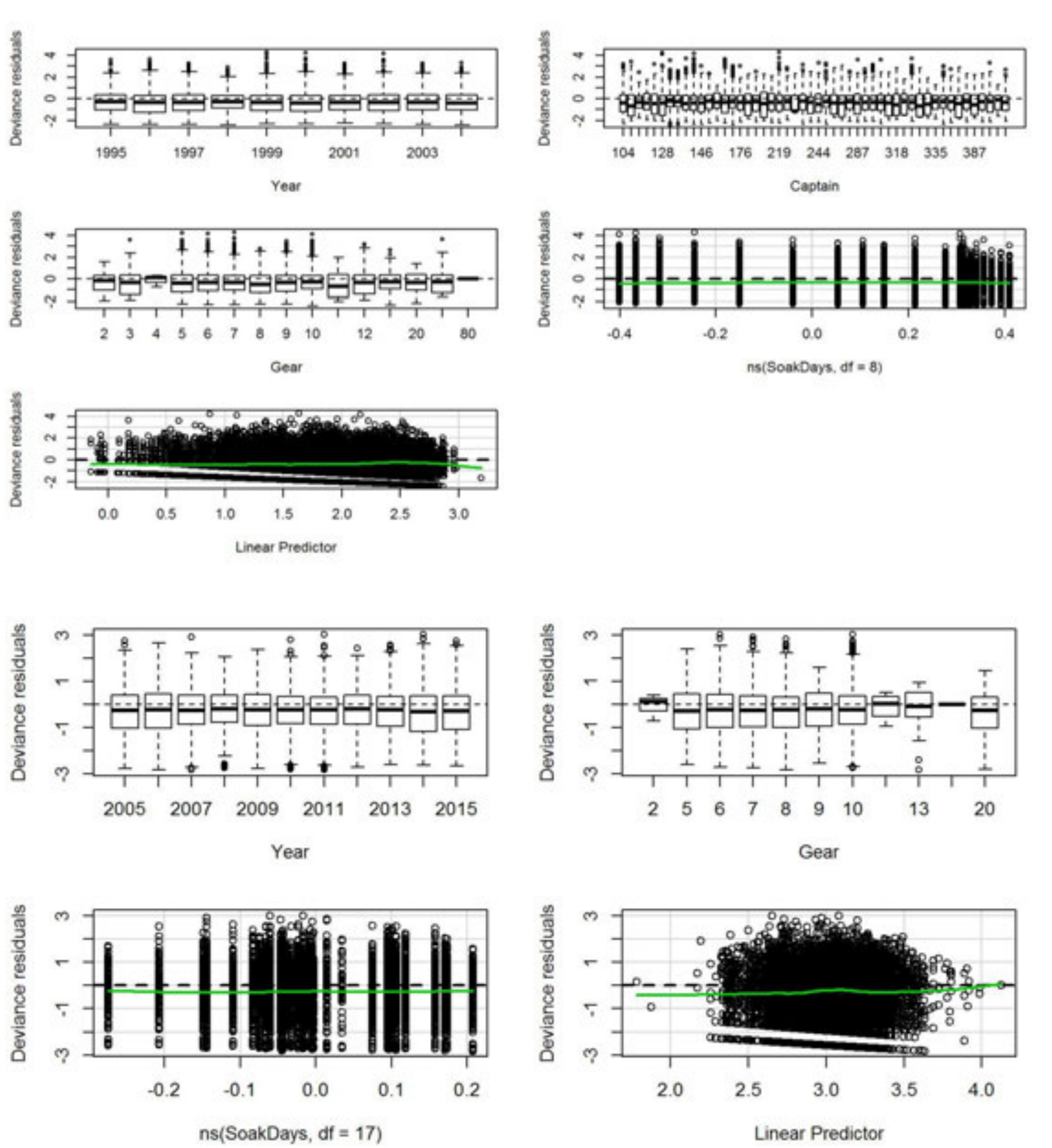
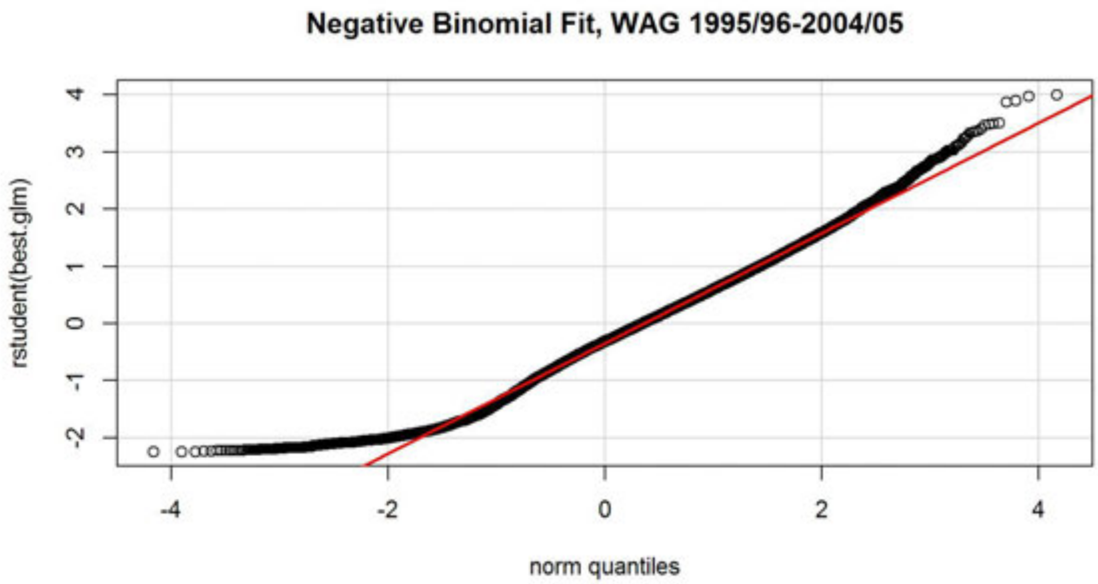


Figure B.12. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. Observer data from WAG for 1995/96–2004/05 (top) and 2005/06–2015/16 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.



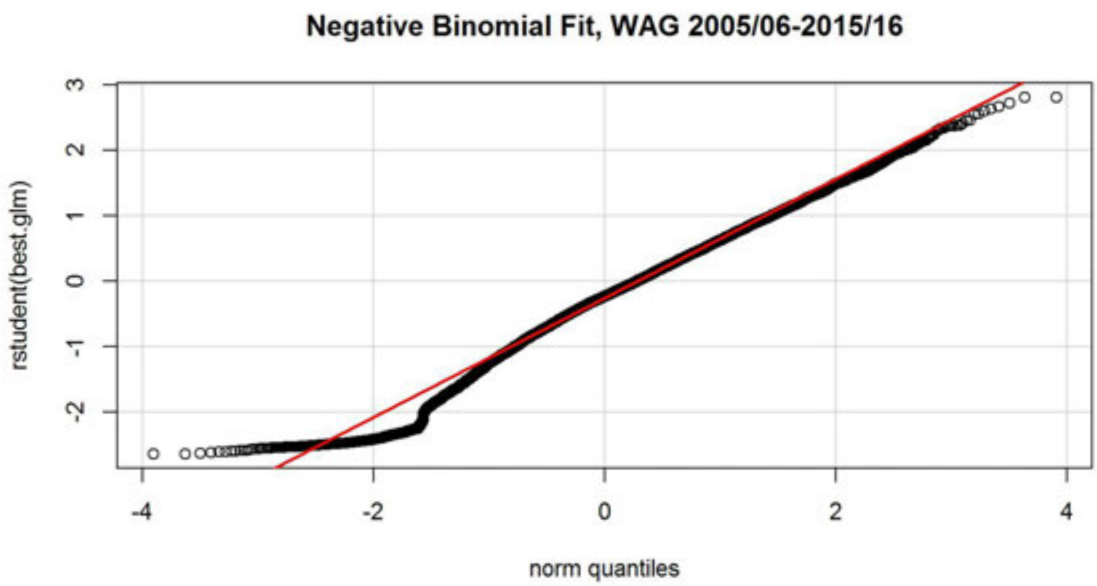


Figure B.13. Studentized residual plots for negative binomial GLM fit for WAG golden king crab observer legal size male crab CPUE data. Top panel is for 1995/96–2004/05 and bottom panel is for 2005/06–2015/16 data sets, respectively.

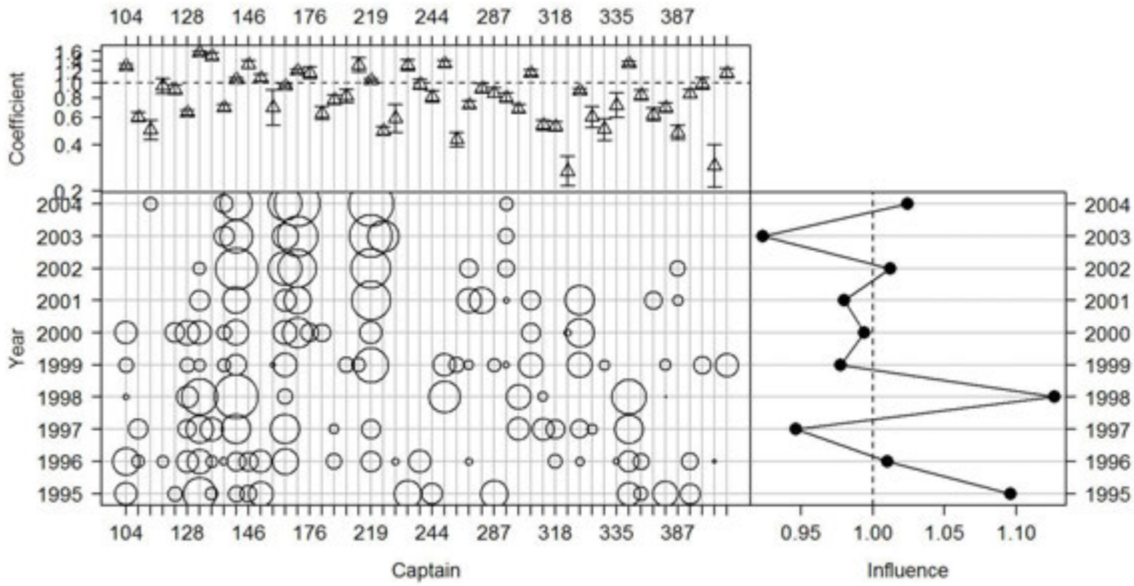


Figure B.14. CDI plot for Captain for the negative binomial fit of 1995/96–2004/05 data for WAG.

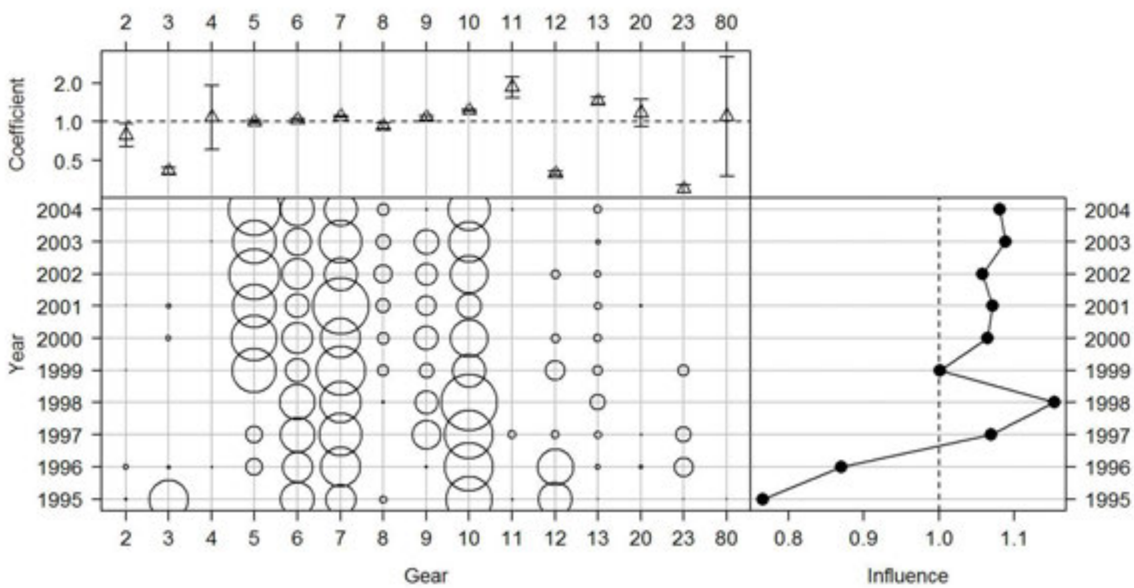


Figure B.15. CDI plot for Gear for the negative binomial fit of 1995/96–2004/05 data for WAG.

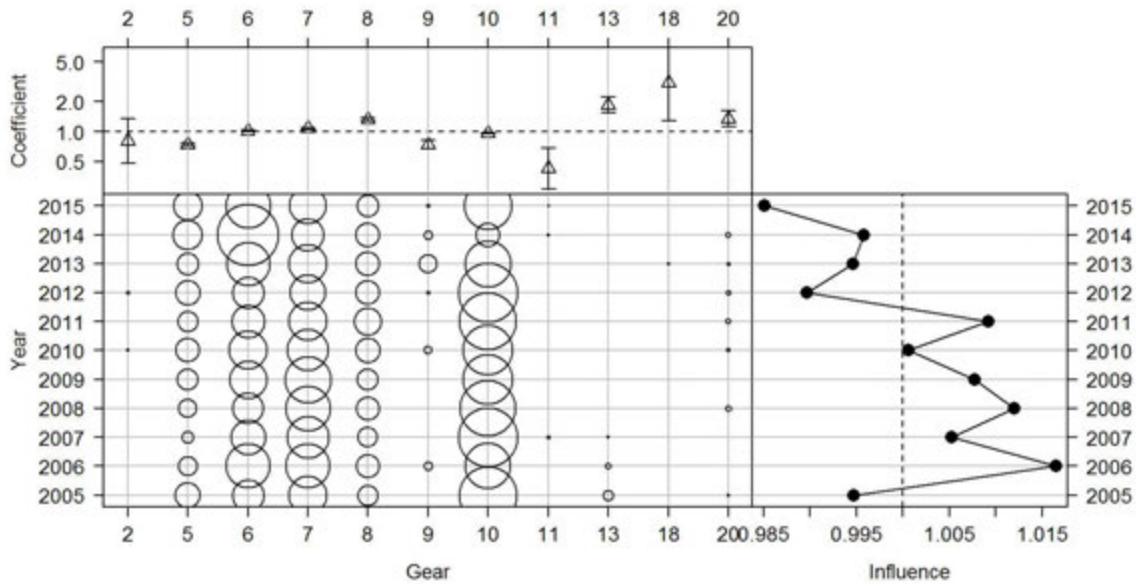
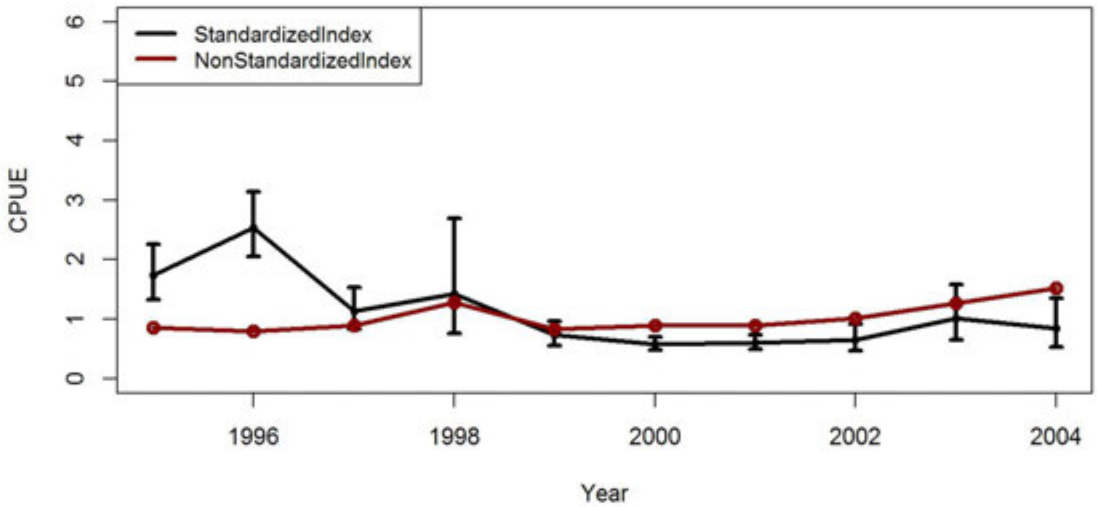


Figure B.16. CDI plot for Gear for the negative binomial fit of 2005/06–2015/16 data for WAG.



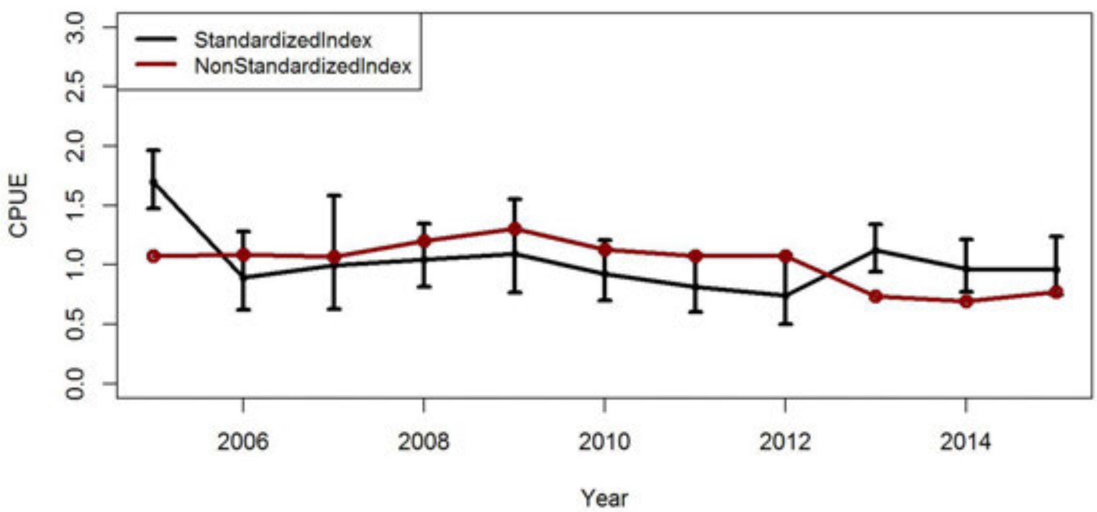


Figure B.17. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). The final model included the interaction term Year:Captain. Top panel: 1995/96–2004/05 observer data and bottom panel: 2005/06–2015/16 observer data. Standardized indices: black line and non-standardized indices: red line.

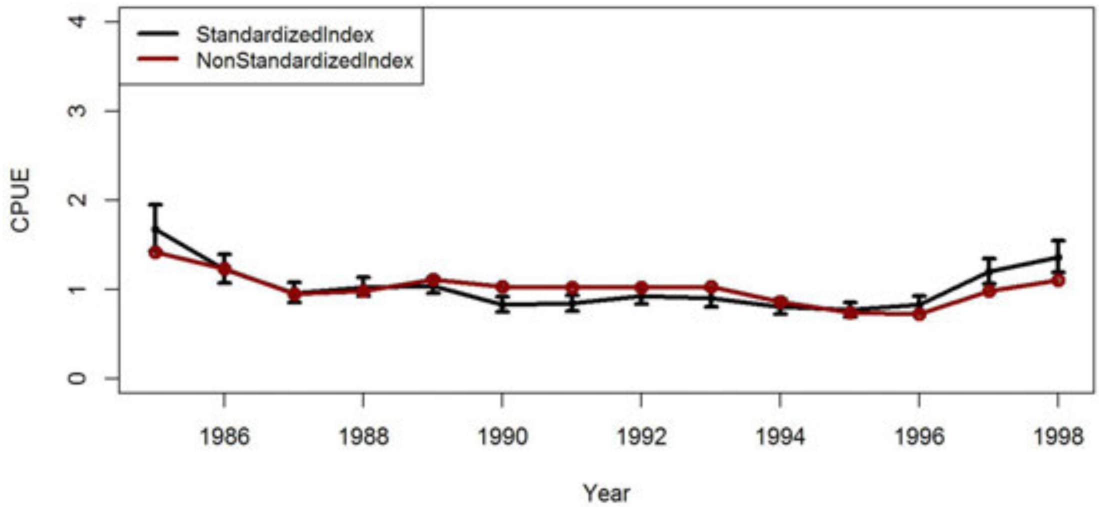


Figure B.18. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG (east of 174 ° W longitude). The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

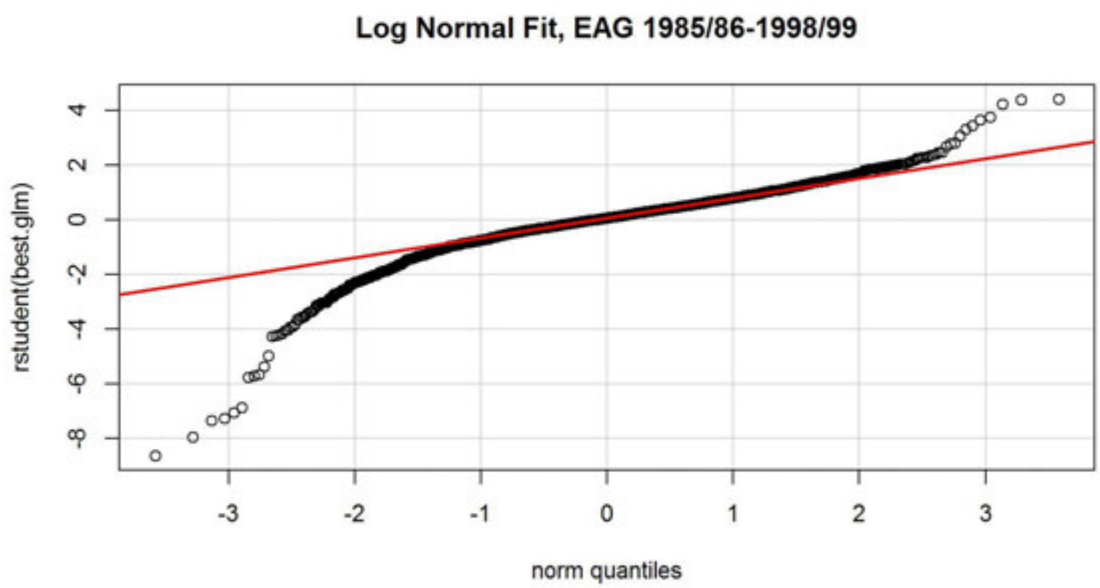


Figure B.19. Studentized residual plots for lognormal GLM fit for EAG golden king crab fish ticket CPUE data. The 1985/86–1998/99 fish ticket data set was used.

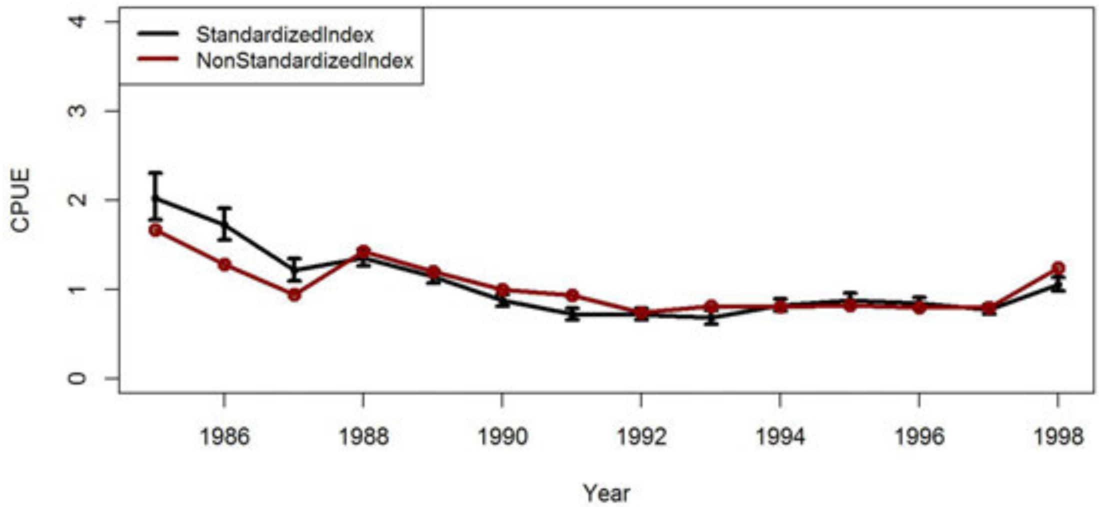


Figure B.20. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG (east of 174 ° W longitude). The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

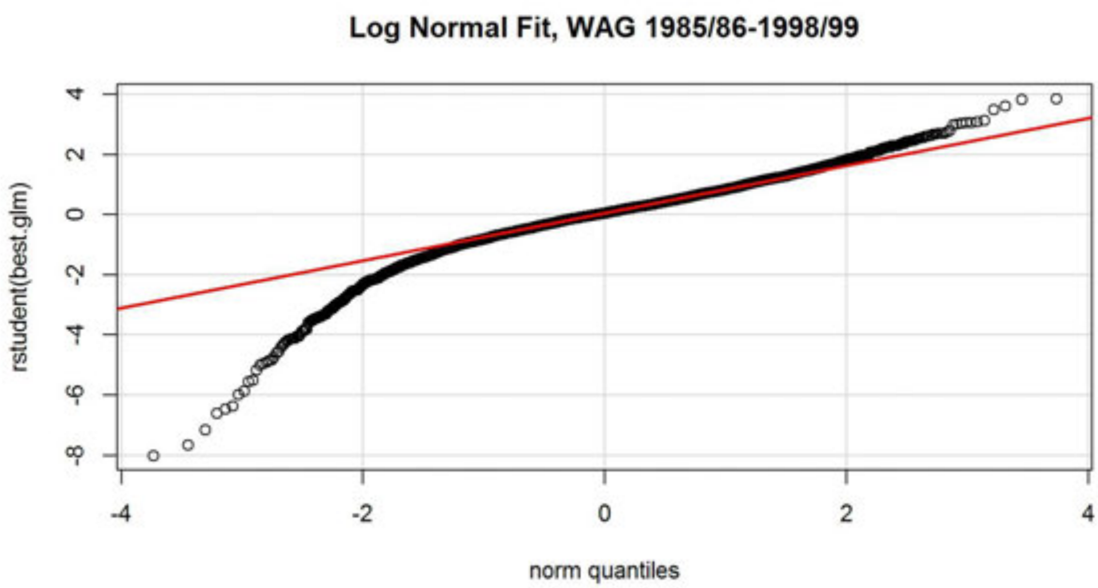


Figure B.21. Studentized residual plots for lognormal GLM fit for WAG golden king crab fish ticket CPUE data. The 1985/86–1998/99 fish ticket data set was used.