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

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Goals

- Address CPT and SSC comments on the assessment method.
- Get consent from the CPT for the methodology used in OFL and ABC determination and go forward to the next step.
- Provide the Tier 4 assessment method to determine OFL and ABC for EAG and WAG.
- Provide the F_{35} estimates of OFL (Discussion paper)

Approach

- We developed an integrated model to analyze data from pot fishery retained (1985/86–2012/13) and total catch (1990/91–2012/13), standardized legal size CPUE from observer data (1995/96-2004/05; and 2005/06–2012/13), groundfish fishery bycatch (1995/96–2012/13), and tag release-recapture lengths (from 1991,1997,2000,2003, and 2006 tagging experiments). We also used the standardized fish ticket retained CPUE index in one scenario.
- We used the Tier 4 approach to determine overfishing levels (OFL) and allowable biological catches (ABC) separately for EAG and WAG. We also provide ABC and OFL estimates by the F_{35} approach (Tier 3).
- We considered seven scenarios for exploratory analysis, but considered four scenarios (scenarios 1-4) under Tier 4 and two scenarios (scenarios 1 and 4 (latter numbered as 2)) under F_{35} (or Tier 3) approaches to determine OFL and ABC.
- We present a number of tables and figures: description of scenarios; parameter estimates; growth matrices; recruitment, mature male and legal male biomass trends; likelihood values; fishing mortality trends; size compositions; size composition bubble plots; fits to catch, bycatch, tag-recaptures, and CPUE; retrospective fits to mature male biomass; profile likelihoods of total catch OFL.

Responses to May 2014 CPT comments

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

Responses to May 2014 CPT comments– continued

- Comment: Equation 15 should be corrected to account for the fact that some animals were recaptured more than one year after they were released.
- *Response: We have corrected this equation following Andre Punt provided equation and implemented it in the program codes. The equation number has been changed to (17) in Appendix A*.
- Comment: The residual patterns for the fits to the total catch length-frequencies are very similar for the EAG and WAG. This is unexpected if these are independent populations, and efforts should be made to understand why this occurs.
- *Response: This pattern has changed in the current runs.*
- Comment: The fishing mortality rates are relatively high (~0.4) and remarkably similarly between the WAG and EAG. The analysts should explore (e.g. using a likelihood profile on the mean fishing mortality in the directed fishery) what in the data suggests this and moreover how the model is able to estimate absolute biomass given what amount to relatively flat CPUE indices (using perhaps a likelihood profile on current abundance).
- *Response: The F rates are not high and not similar between the two regions in the current runs. We have provided the likelihood profiles of current MMB and mean F in this document (Figures 30-31 for EAG and 59-60 for WAG).*
- Comments: The weighting factors should be specified as CVs and not as lambda values to assist with interpretation of how much weight is assigned to each likelihood component.
- *Response: We have provided the weighting factors with the corresponding CVs in this document.*
- Comment: Ensure that the document is clear between ‘input effective sample sizes’ and ‘estimated effective sample sizes’.
- *Response: We revised the corresponding figure titles accordingly.*

Table 4. Scenarios 1 to 7 for the EAG assessment

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

Table 19. Scenarios 1 to 7 for the WAG assessment

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

Catch and Tagging Data (page 9)

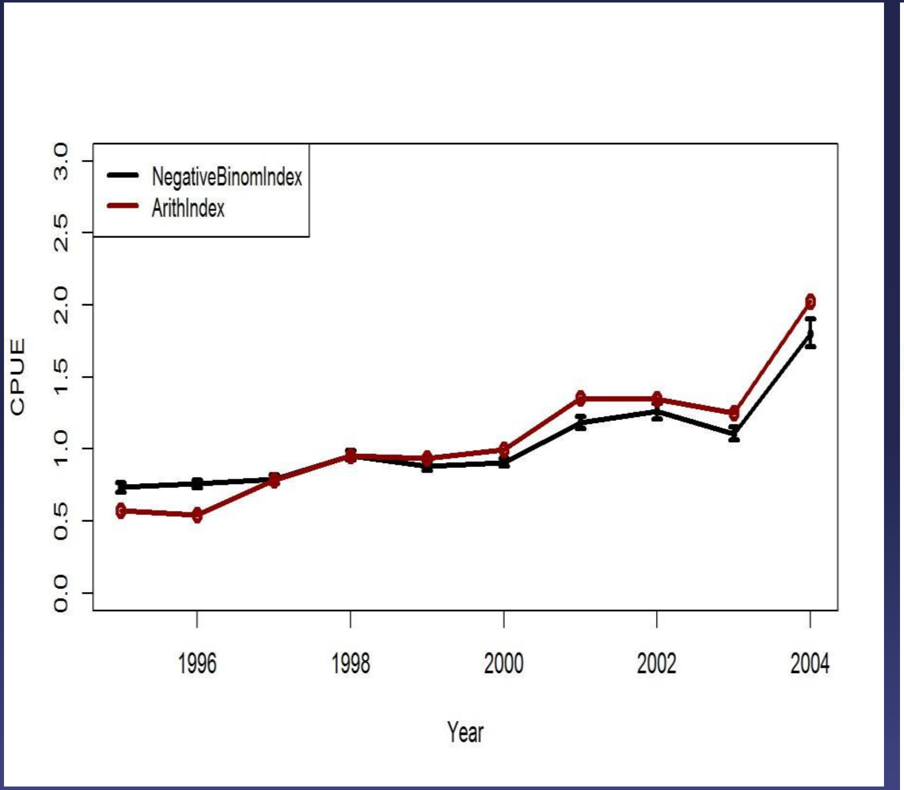
Data set	Years	Data type(s)
Retained pot catch	1985–2012	Catch by length
Total pot catch	1990–2012	Catch by length
Groundfish discarded catch	1995–2012	Catch by length
Observer legal size crab CPUE	1995–2012	Independently estimated annual CPUE index (by negative binomial GLM) with standard error
Pot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

Fixed parameter values

Parameter	Value
M	0.18/yr
a in $W = al^b$	0.0002988
b in $W = al^b$	3.135

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

1995/96–2004/05



2005/06–2012/13

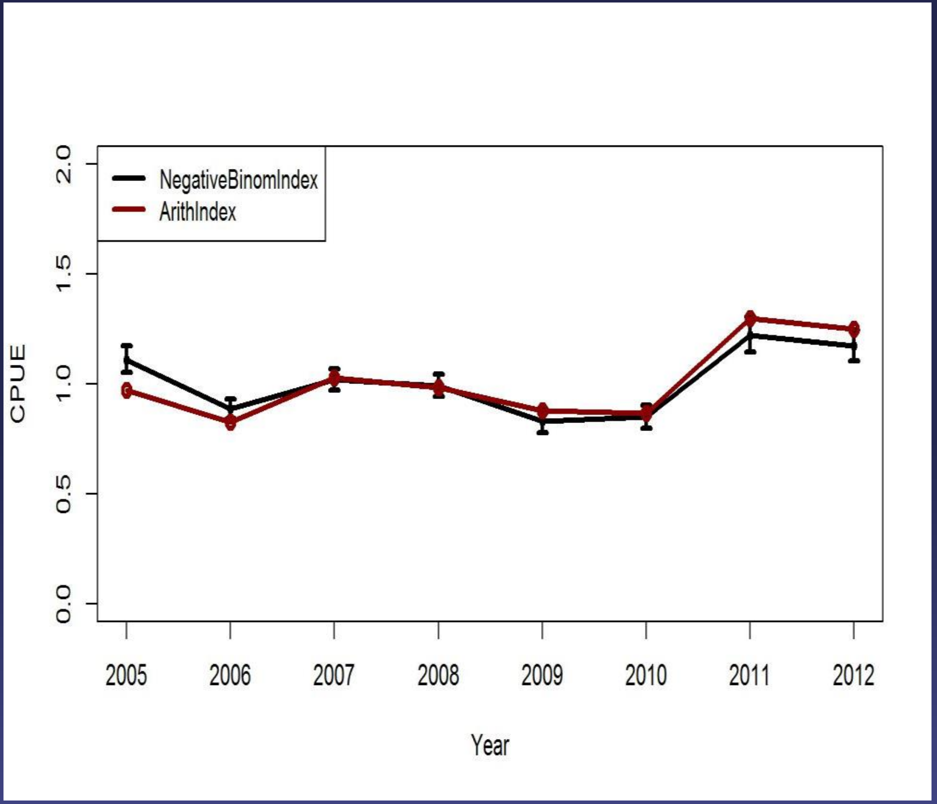
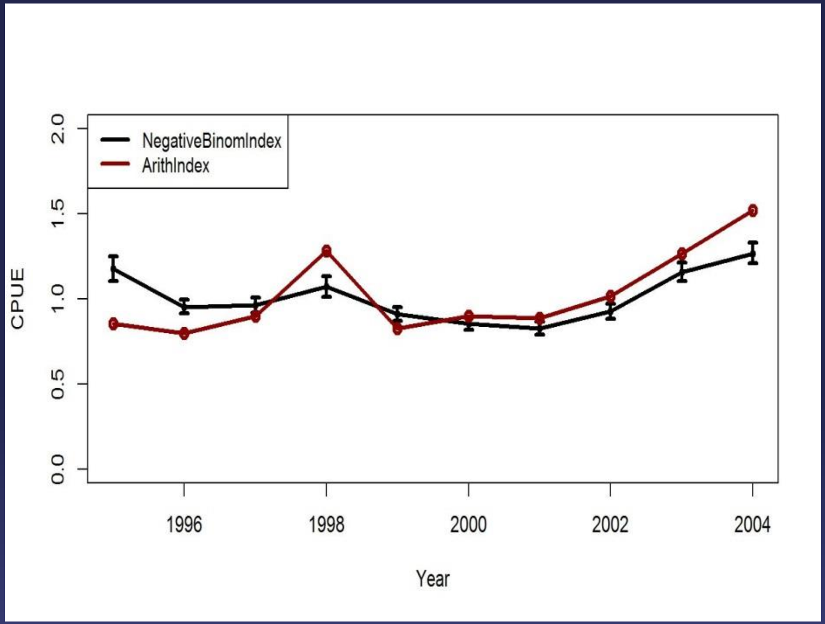


Figure 29. Trends in arithmetic (nominal) and negative binomial CPUE indices with two standard errors of Aleutian Islands golden king crab from WAG (west of 174°W longitude). Left panel: 1995/96–2004/05 observer data and right panel: 2005/06–2012/13 observer data. Negative binomial indices: black line and Arithmetic indices: red line.

1995/96–2004/05



2005/06–2012/13

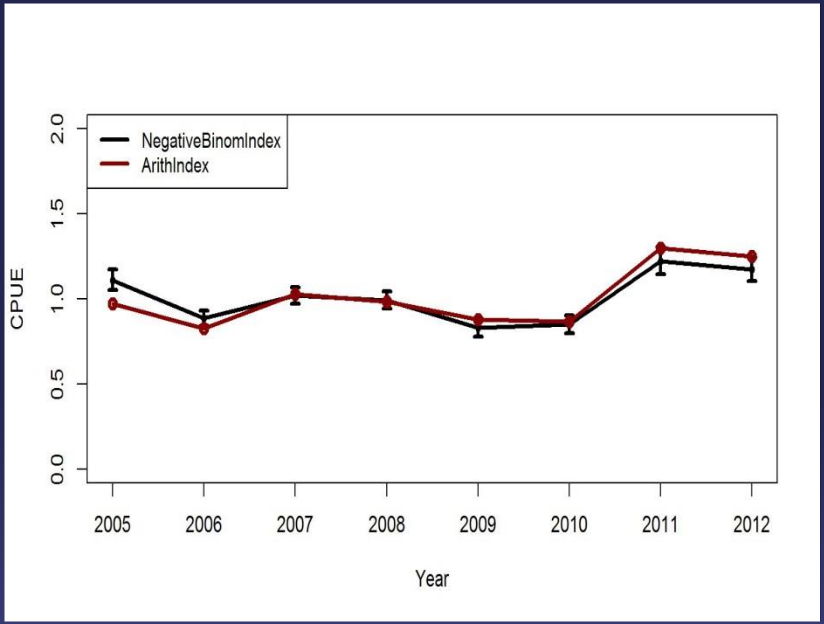


Table A1. Estimated parameters of the population dynamics model (Appendix A)

Parameter	Number of parameters
Initial conditions	
Initial total numbers, $\tilde{N}_{1985}$	1
Length-specific proportions, ε_i	n-1
Fishing mortalities	
Pot fishery, F_t	1985–2012
Mean pot fishery fishing mortality, $\bar{F}$	1
Trawl fishery, F_t^{Tr}	1995–2012 (the mean F for 1995 to 1999 was used to project back the trawl discards up to 1985.
Mean trawl fishery fishing mortality, $\bar{F}^{Tr}$	1
Selectivity and retention	
Pot fishery total selectivity θ_{50}^{T}	2 (1985–2004; 2005+)
Pot fishery total selectivity difference, $delta\theta^{T}$	2 (1985–2004; 2005+)
Trawl fishery selectivity θ_{50}^{Tr}	1
Trawl fishery selectivity difference $delta\theta^{Tr}$	1
Pot fishery retention θ_{50}^{r}	2 (1985–2004; 2005+)
Pot fishery retention difference $delta\theta^{r}$	2 (1985–2004; 2005+)
Growth	
Expected growth increment, ω_1, ω_2	2
Variability in growth increment, σ	1
Molt probability (size transition matrix with tag data) a	1
Molt probability (size transition matrix with tag data) b	

Table A2 a and b (Appendix A). Specifications for the weights for each scenario for EAG and WAG.

	Weight with CV in parenthesis
Retained catch. λ_r	500 (0.0316)
Total catch, λ_D	400(0.0354)
Groundfish bycatch, λ_{GD}	0.041(444.7705) for EAG, 0.09(2.3570) for WAG
Observer legal size crab catch-rate, 1995–2012 $\lambda_{r,CPUE}$	1(0.8054)
Fish ticket legal size crab catch-rate, 1985–1998 $\lambda_{r,CPUE}$	
Mean pot fishing mortality, λ_{Fmean}	Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase
Pot fishing mortality dev, λ_F	Initially 1000(0.0224), relaxed to 0.00001 (very large) at the final phase
Trawl fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000(0.0224), relaxed to 0.00001 (very large)at the final phase

Table 2. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), GLM estimated CPUE Index, and nominal legal size crabs CPUE standardized by the CPUE index for the EAG golden king crab stock. NA = no sampling information. 1990 refers to the 1990/91 fishery.

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

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

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

Tag release and recapture summary (103 to 183 mm Mid CL), EAG

Total Release	27131	Number of Recoveries by Year
	Year1	936
	Year2	491
	Year3	214
	Year4	51
	Year5	13
	Year6	12
	Overall % recovery	6.33

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

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

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

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

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

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

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

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

Table 15 (modified). Differences in Likelihood values relative to Scenario 1 of the fits for scenarios 1 to 5 for golden king crab in the EAG.

Likelihood Component	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
like_retlencomp	-537.24	-0.25	-2.01	-4.48	-2.66
like_totallencomp	-592.93	1.47	-0.02	1.38	7.47
like_gdiscdlencomp	-301.74	-1.57	0.53	0.11	-1.35
like_retcpue	-9.74	-0.26	0.74	0.27	-0.53
like_retdcatchB	33.88	-1.17	1.15	0.59	-2.02
like_totalcatchB	45.77	-1.63	1.03	0.33	-2.45
like_gdiscdcatchB	0	0	0	0	0
like_rec_dev	13.66	-0.10	0.17	0.14	-0.92
like_F	0	0	0	0	0
like_gF	0	0	0	0	0
like_Tag	279.35	-110.38	0.02	-110.58	-54.55
like_meanFpot	0	0	0	0	0
Like_fishtickCPUE			4.97	4.52	
Total	-1068.99	-113.89	6.59	-107.72	-57.00
Free parameters (no.)	108	2	2	4	-3

Table 17. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), GLM estimated CPUE Index, and nominal legal size crabs CPUE standardized by the CPUE index for the WAG golden king crab stock. 1990 refers to the 1990/91 fishery.

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

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

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

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

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

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

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

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

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

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

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

Table 30 (modified). Differences in likelihood values of the fits for scenarios 1 to 5 for golden king crab in the WAG.

Likelihood Component	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
like_retlencomp	-569.51	-4.22	6.87	-2.59	29.61
like_totallencomp	-670.96	0.46	-0.29	0.13	85.50
like_gdiscdlencomp	-282.85	-0.33	-1.74	-2.22	-20.24
like_retcpue	-10.67	0.41	3.16	1.69	0.40
like_retdcatchB	38.76	-0.65	10.06	9.83	-6.90
like_totalcatchB	54.07	-1.27	9.16	8.63	-10.75
like_gdiscdcatchB	0	0	0	0	0
like_rec_dev	13.67	-2.00	2.65	-0.60	-0.93
like_F	0	0	0	0	0
like_gF	0	0	0	0	0
like_Tag	279.44	-110.21	0.69	-108.94	-54.64
like_meanFpot	0	0	0	0	0
Like_fishtickCPUE			23.96	22.61	
Total	-1148.06	-117.80	54.54	-71.47	22.07
Free parameters (no.)	108	2	2	4	-3

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

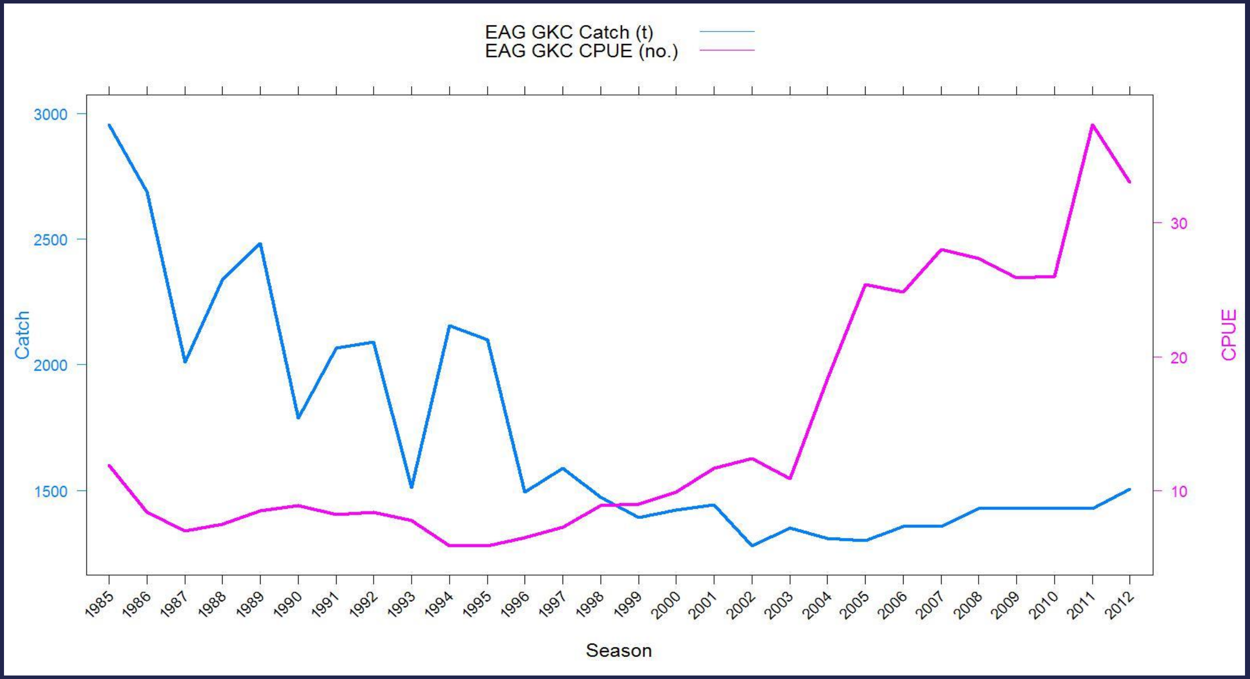


Figure 2. Historical commercial harvest (from fish ticket and in metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2012/13 fisheries (note: 1985 refers to the 1985/86 fishery).

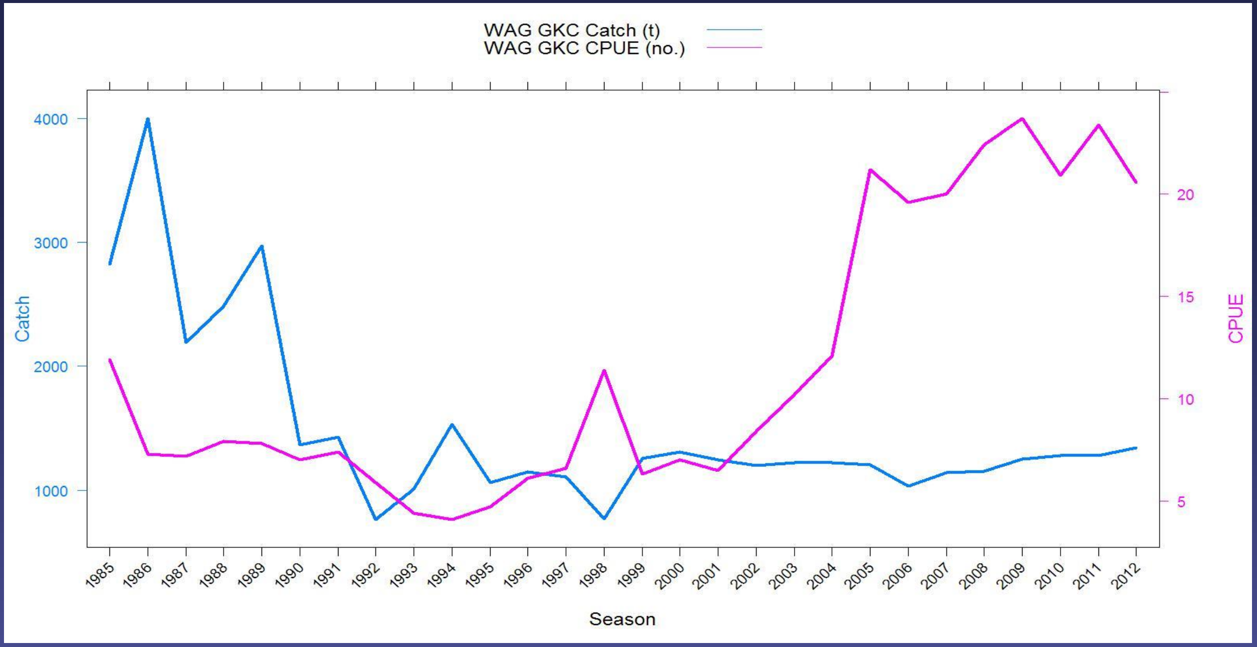
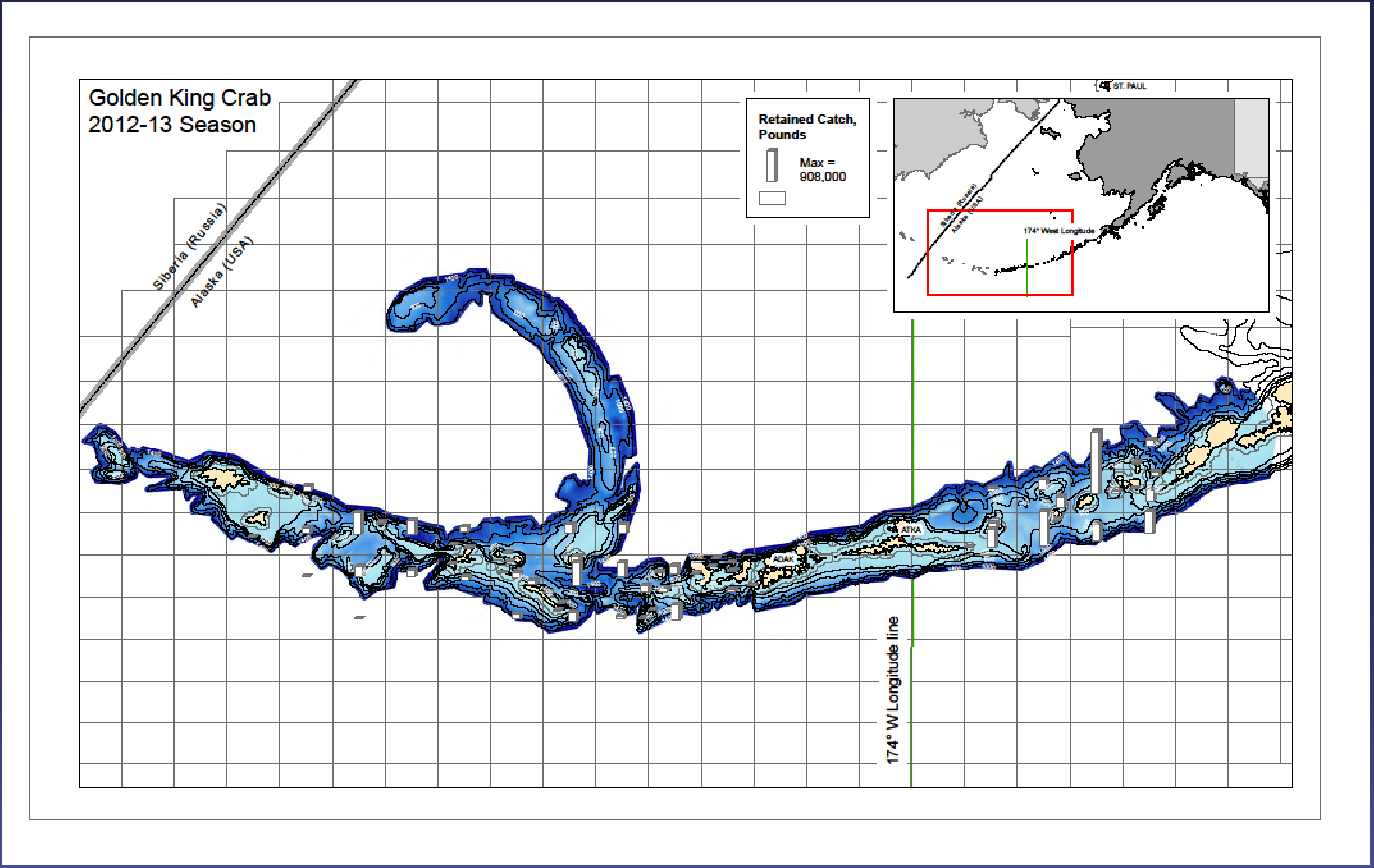
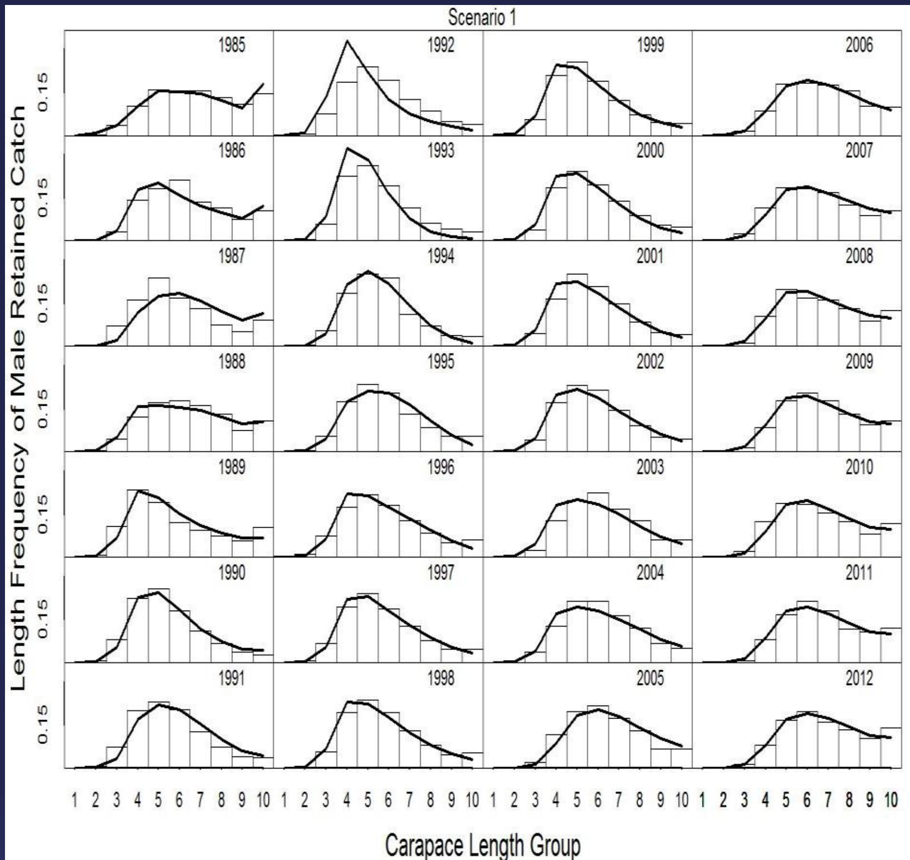
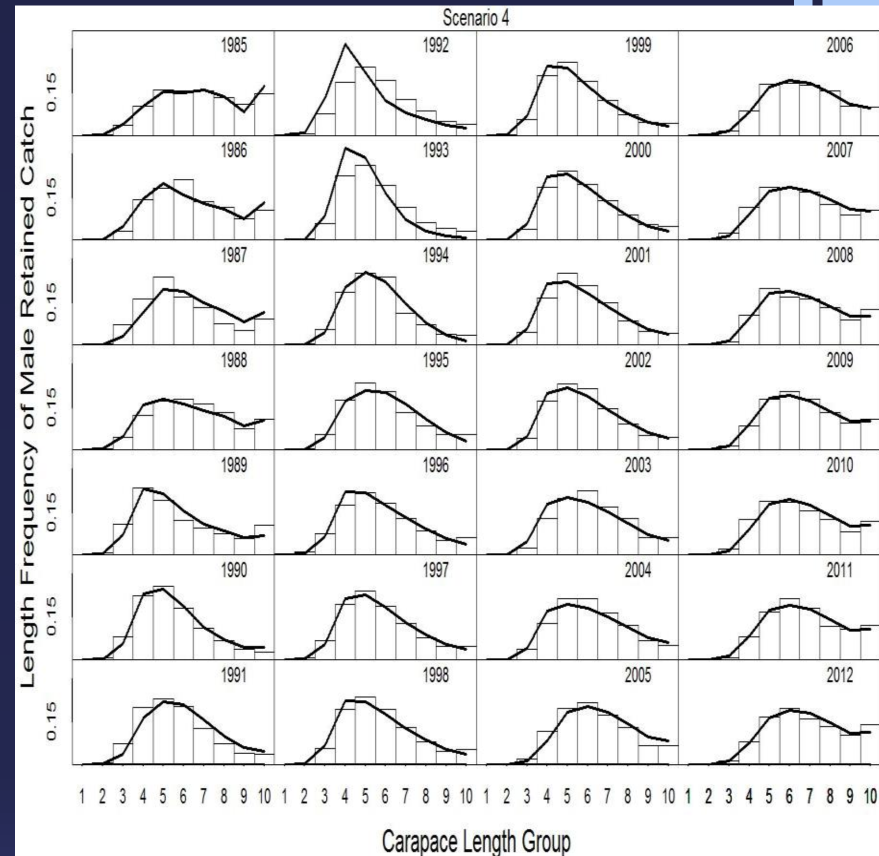


Figure 5. Aleutian Islands golden king crab harvest by ADF&G statistical areas for 2012/13.

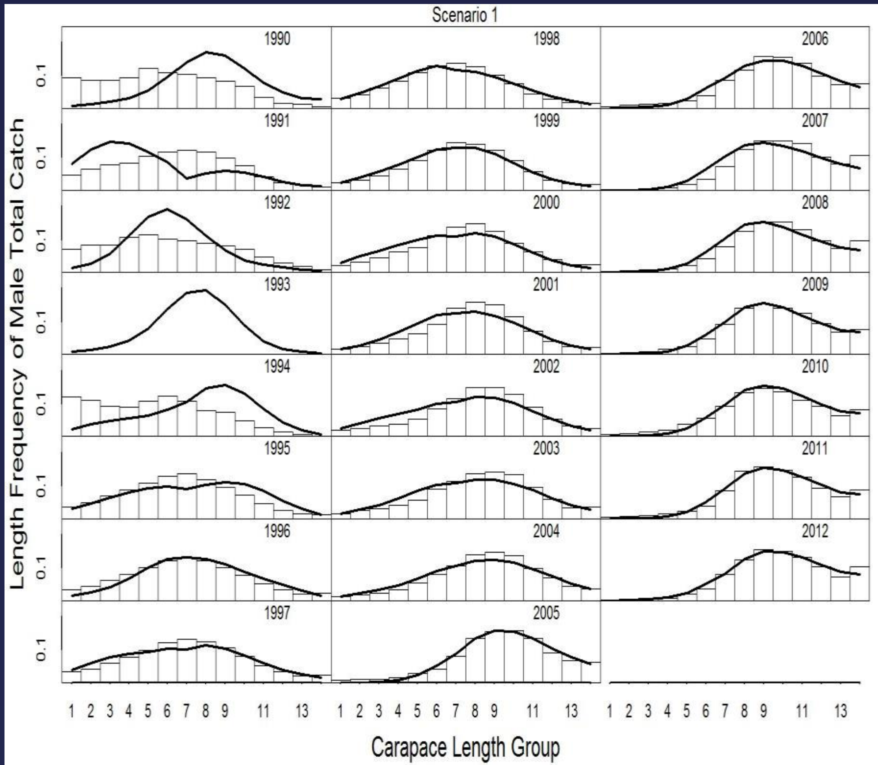


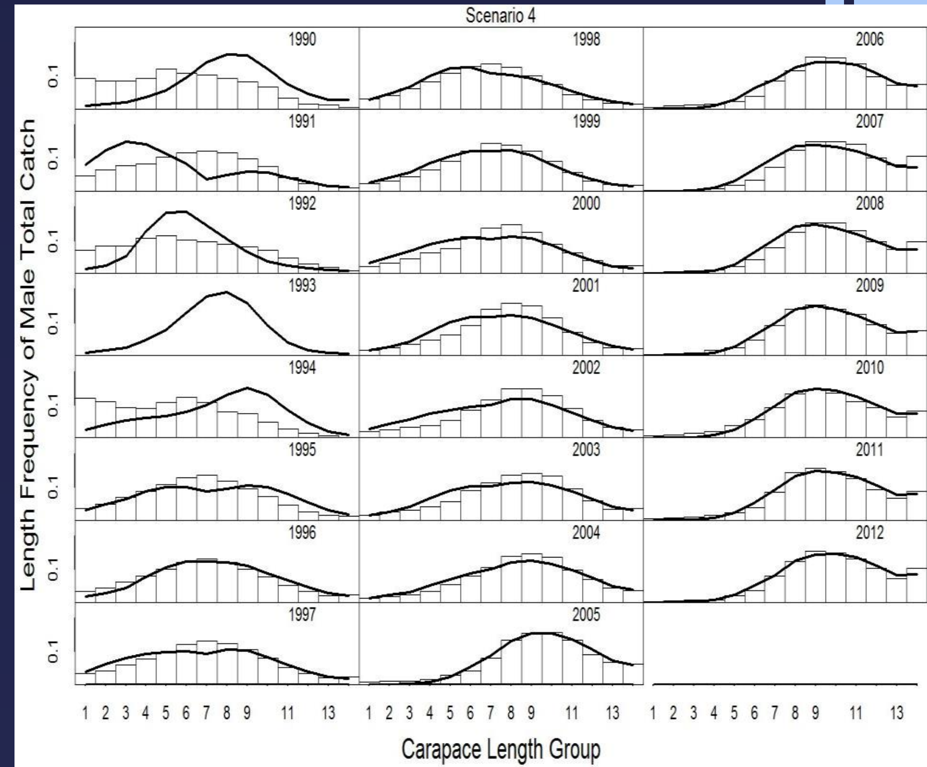
Figures 8a-b. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenarios1 and 4 data of golden king crab in the EAG, 1985/86 to 2012/13. Length group 1 is 103 mm CL.





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





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

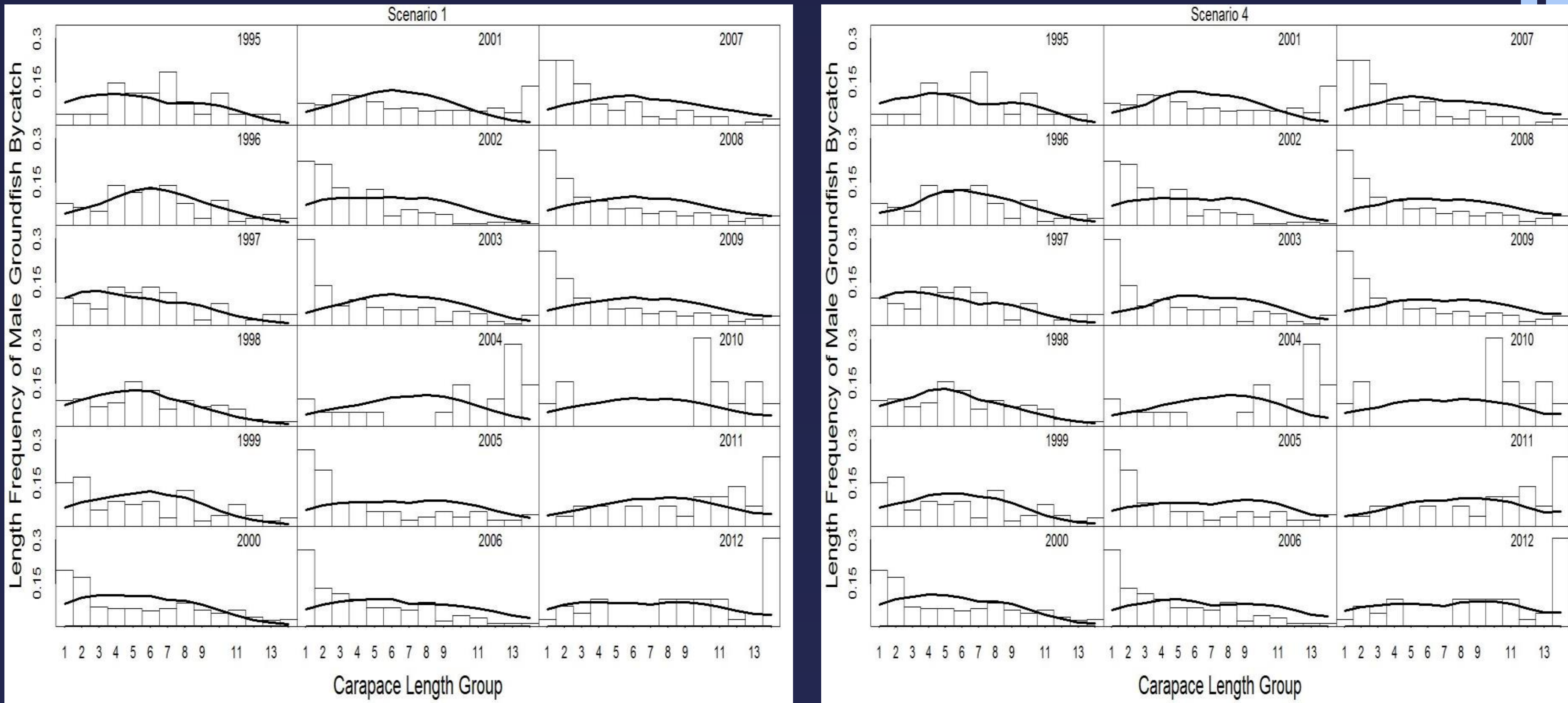


Figure 11. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios 1 to 4 fits to golden king crab data in the EAG, 1985/96 to 2012/13. The red line is the 45^0 line passing through the origin.

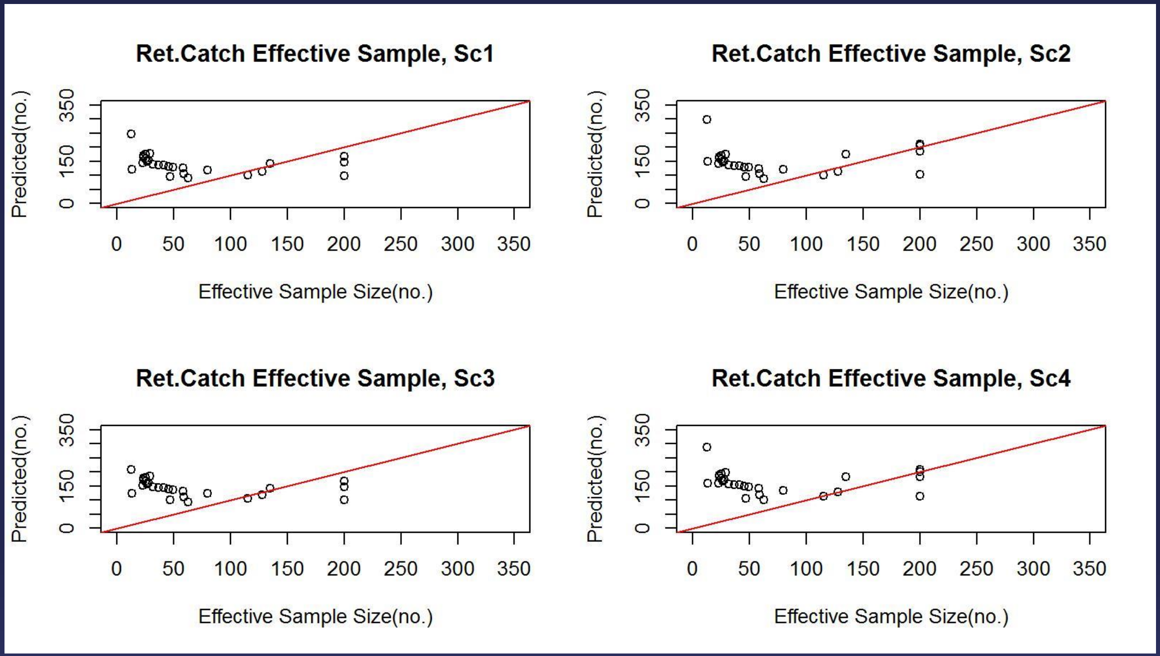


Figure 12. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios 1 to 4 fits to golden king crab data in the EAG, 1990/91 to 2012/13. The red line is the 45^0 line passing through the origin.

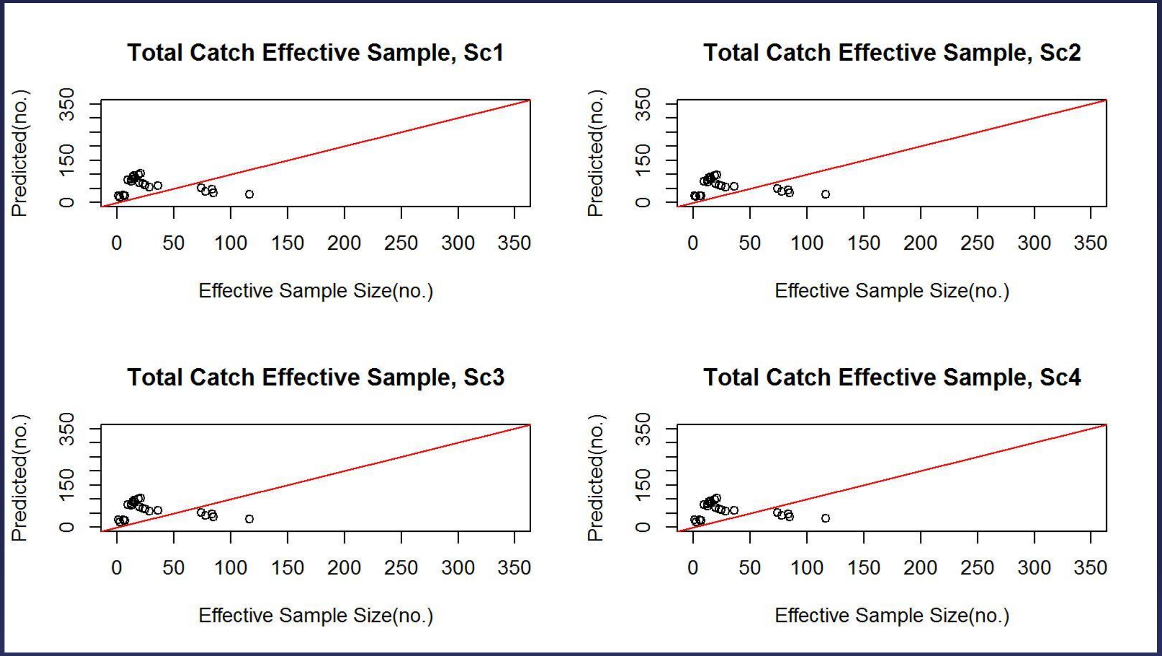


Figure 13. Predicted effective sample size vs. input sample size for groundfish discarded catch length composition for scenarios 1 to 4 fits to golden king crab data in the EAG, 1995/96 to 2012/13. The red line is the 45^0 line passing through the origin.

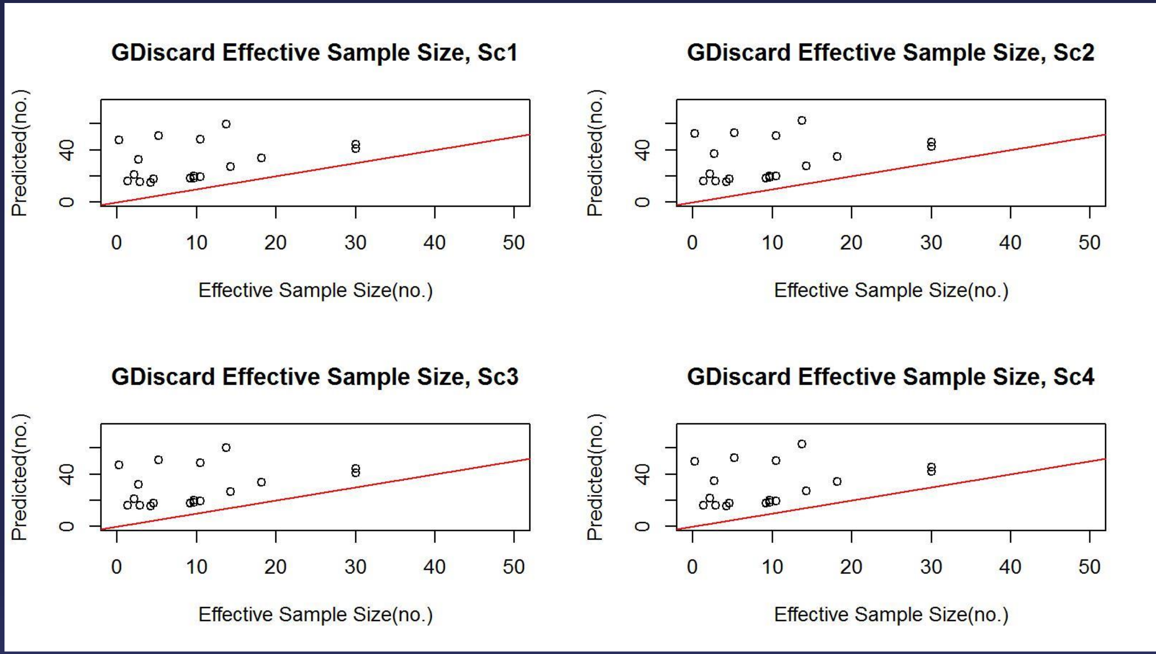


Figure 14. Estimated total selectivity (black solid line) and retained selectivity (red dotted line) for pre- (Yr2000) and post- (Yr2012) rationalization periods under scenarios 1 to 4 fits of EAG golden king crab data.

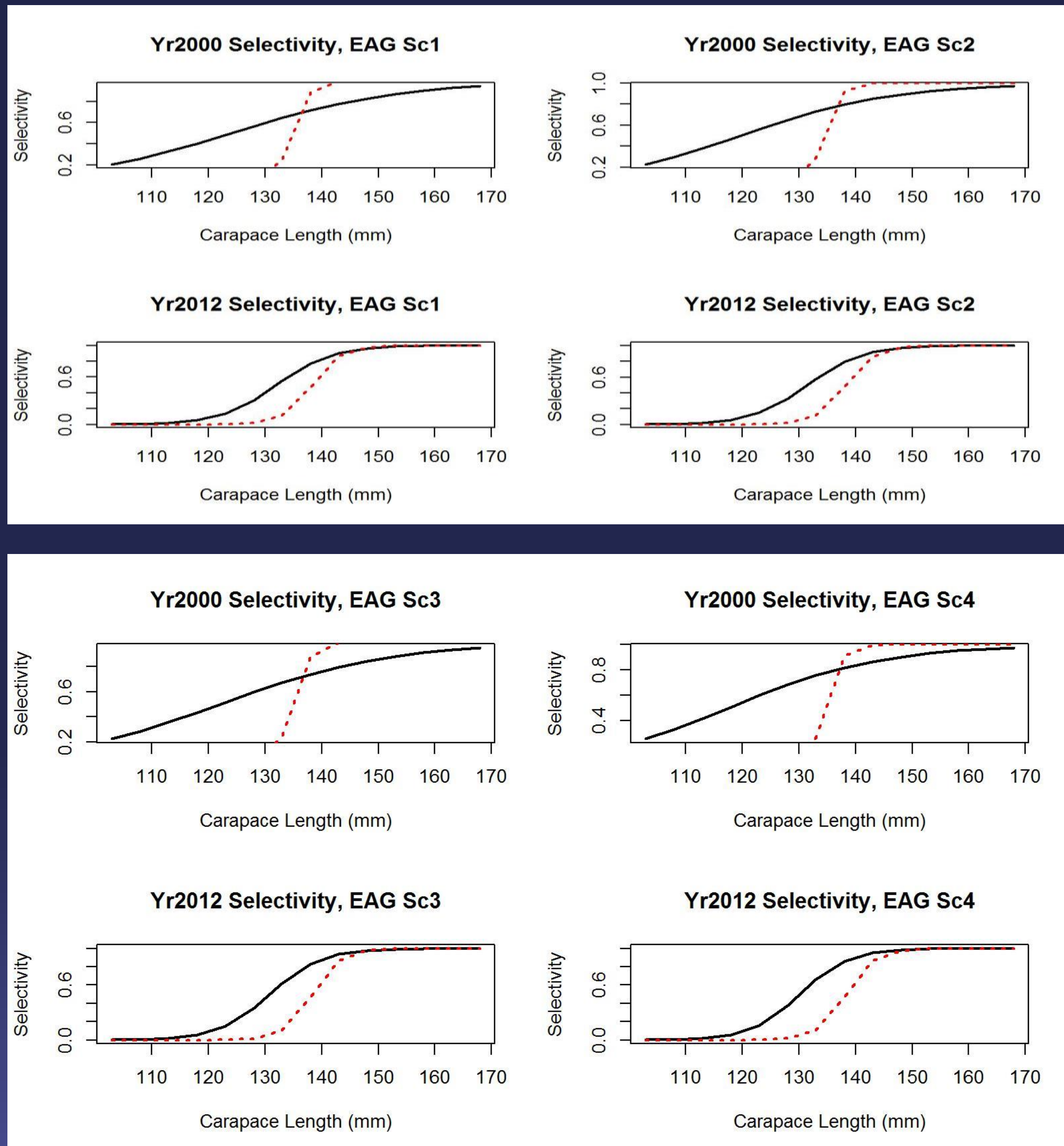


Figure 18. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for scenarios 1 to 4 fits of EAG golden king crab data.

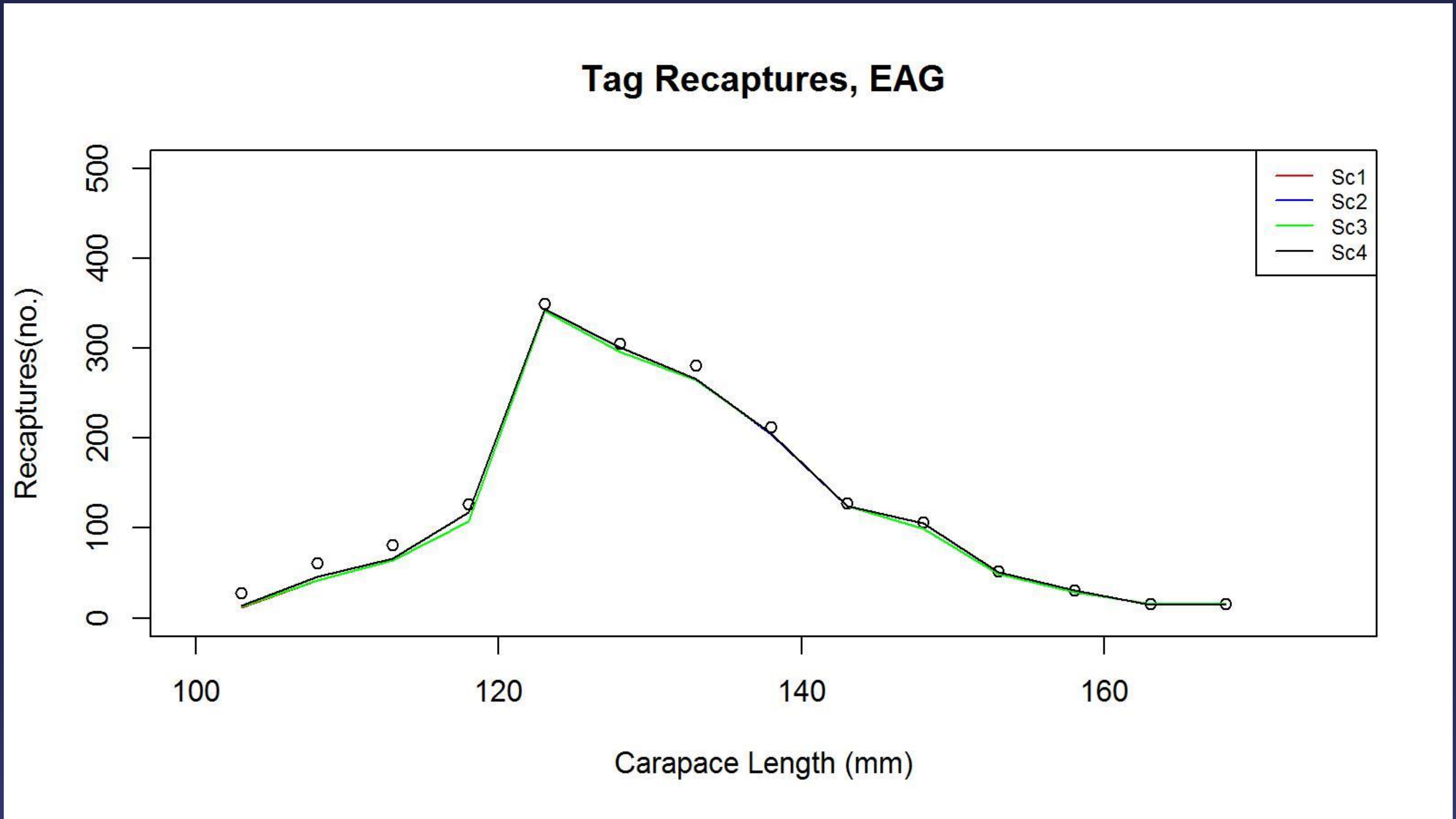


Figure 19. Comparison of input CPUE indices (open circles with one standard error) with predicted CPUE indices (colored solid lines) for scenarios 1 to 4 for EAG golden king crab data, 1985-2012.

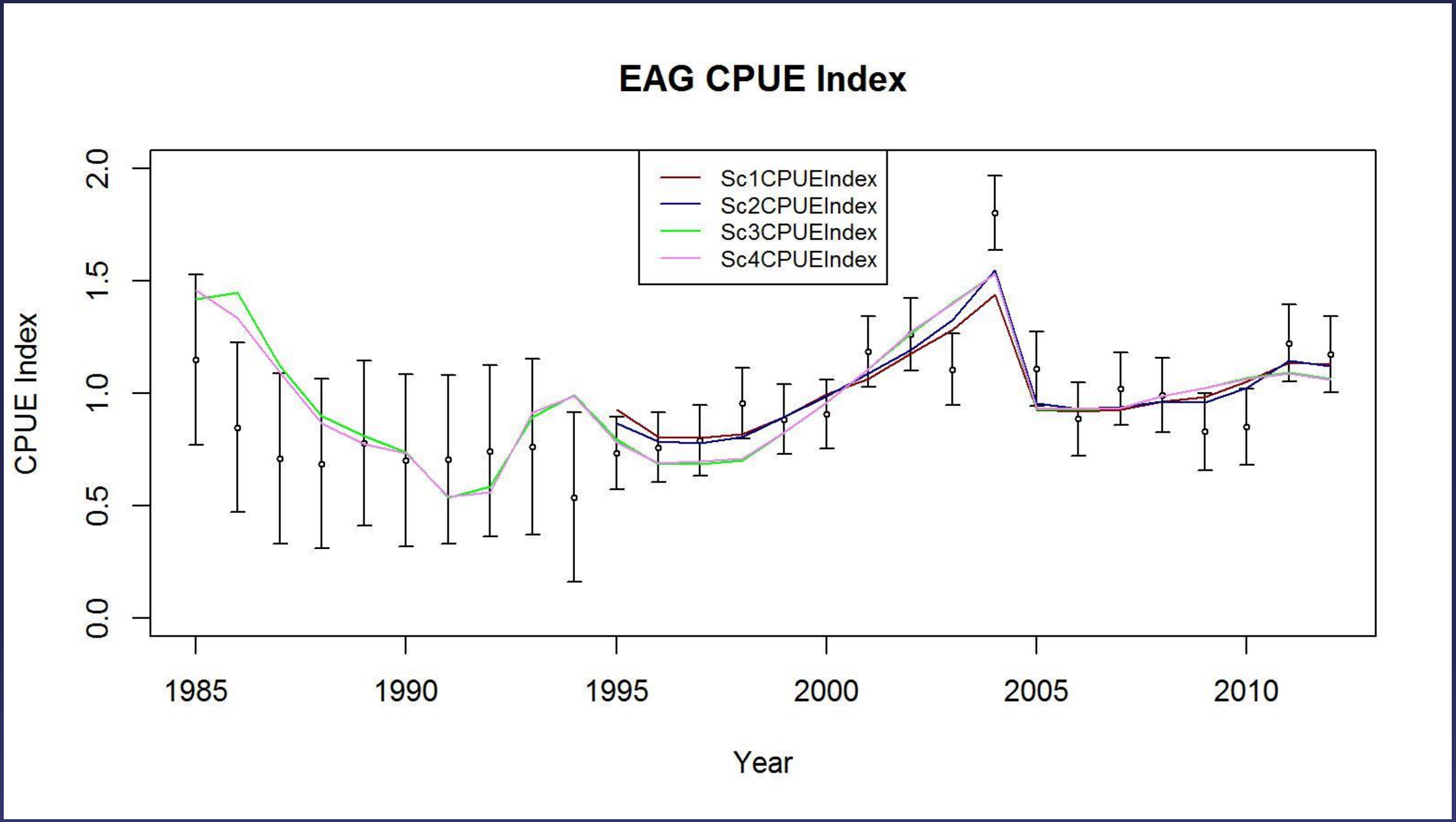
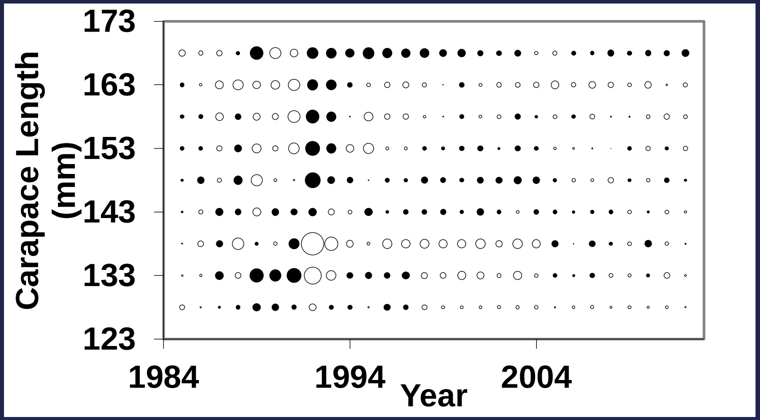
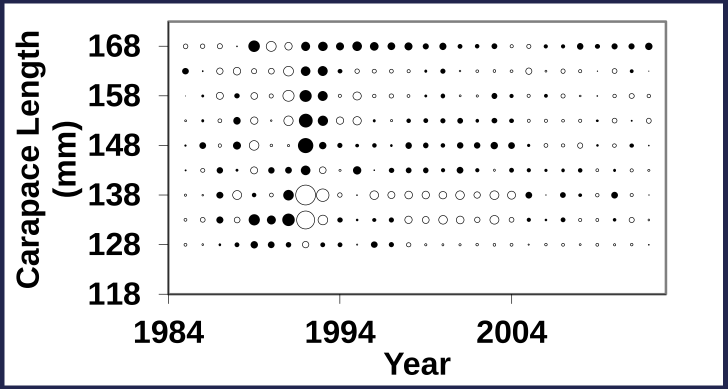


Figure 15. Bubble plots of standardized residuals of retained catch length composition for scenarios 1 to 4 for EAG golden king crab, 1985/86–2012/13.

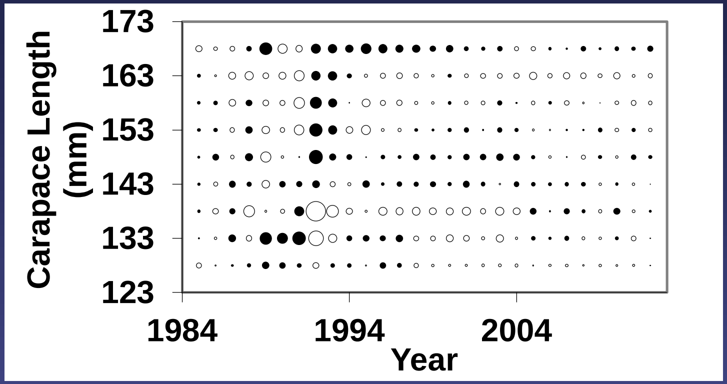
Scenario 1



Scenario 2



Scenario 3



Scenario 4

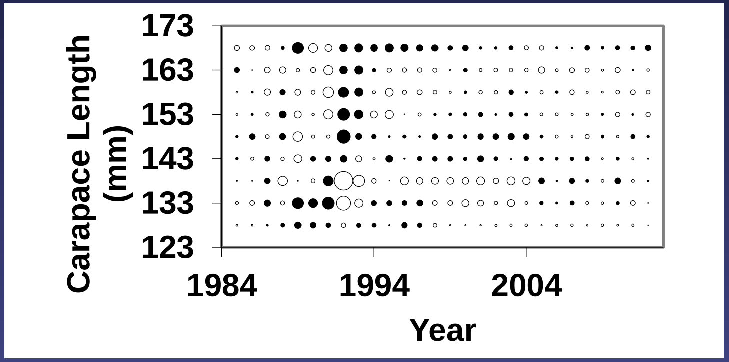


Figure 16. Bubble plots of standardized residuals of total catch length composition for scenarios 1 to 4 for EAG golden king crab, 1990/91–2012/13.

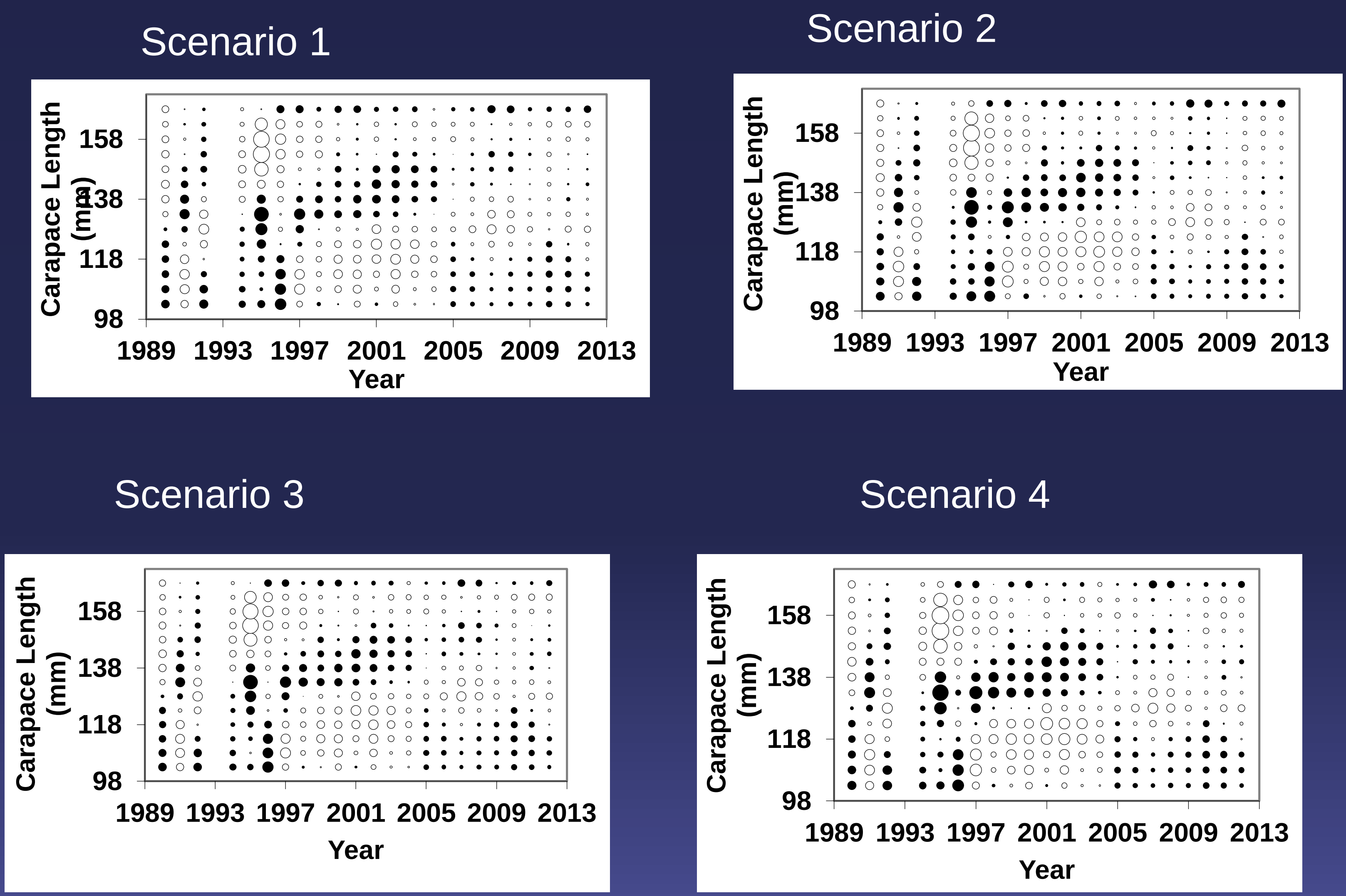
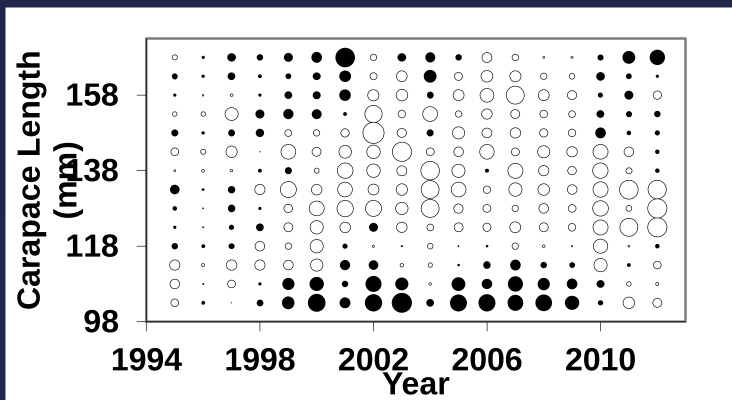
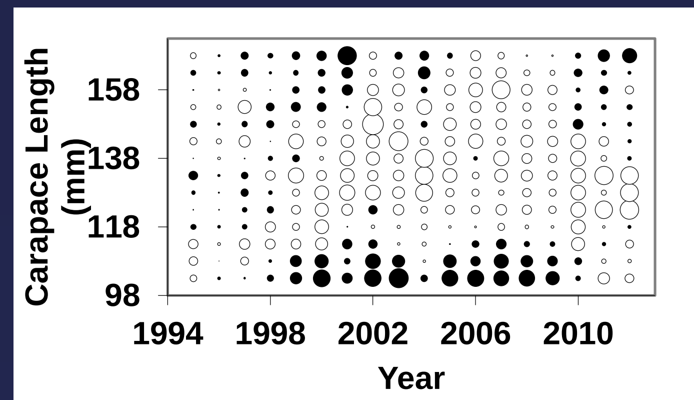


Figure 17. Bubble plots of standardized residuals of groundfish discarded catch length composition for scenarios 1 to 4 for EAG golden king crab, 1990/91–2012/13.

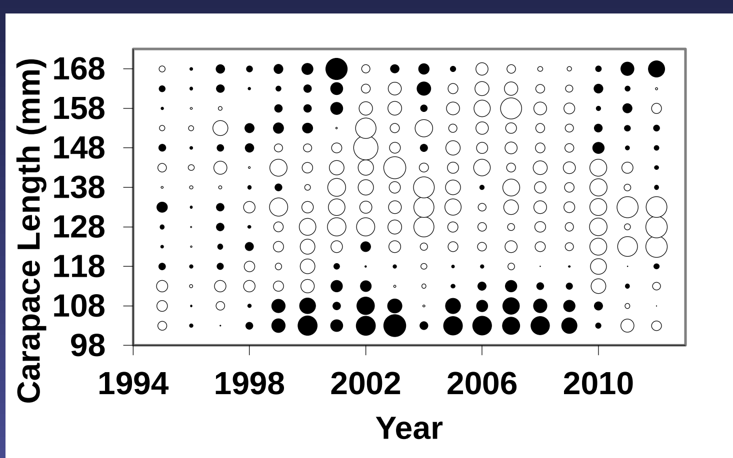
Scenario 1



Scenario 2



Scenario 3



Scenario 4

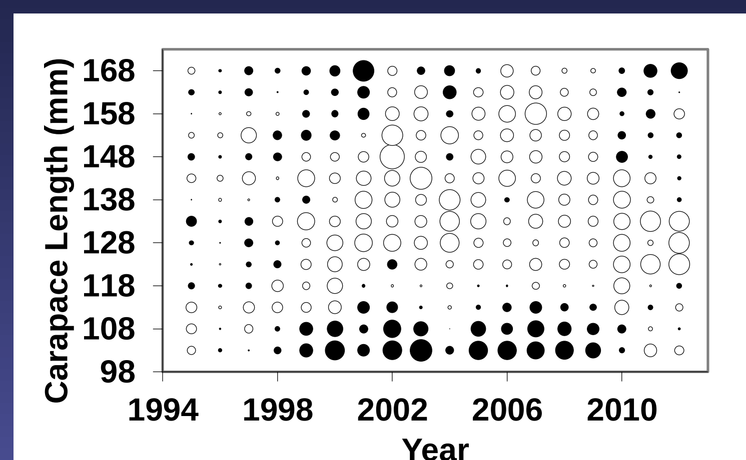


Figure 20. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab assessment model for scenarios 1 to 4 in EAG, 1986–2013.

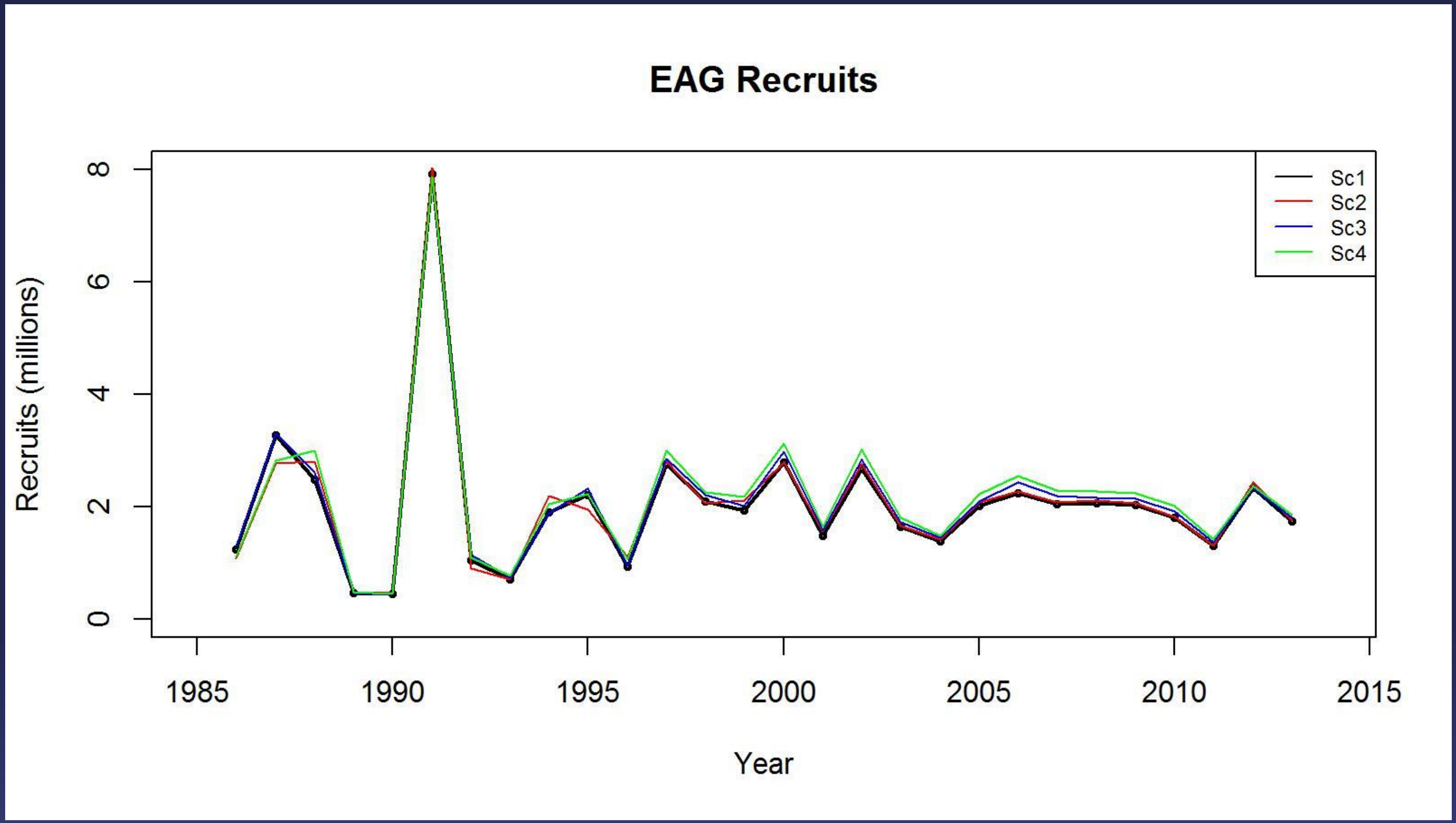


Figure 22. Trends in golden king crab mature male biomass for scenarios 1 to 4 in the EAG, 1985/86–2012/13. Mature male crabs are ≥ 121 mm CL. Estimates have one standard error confidence limits.

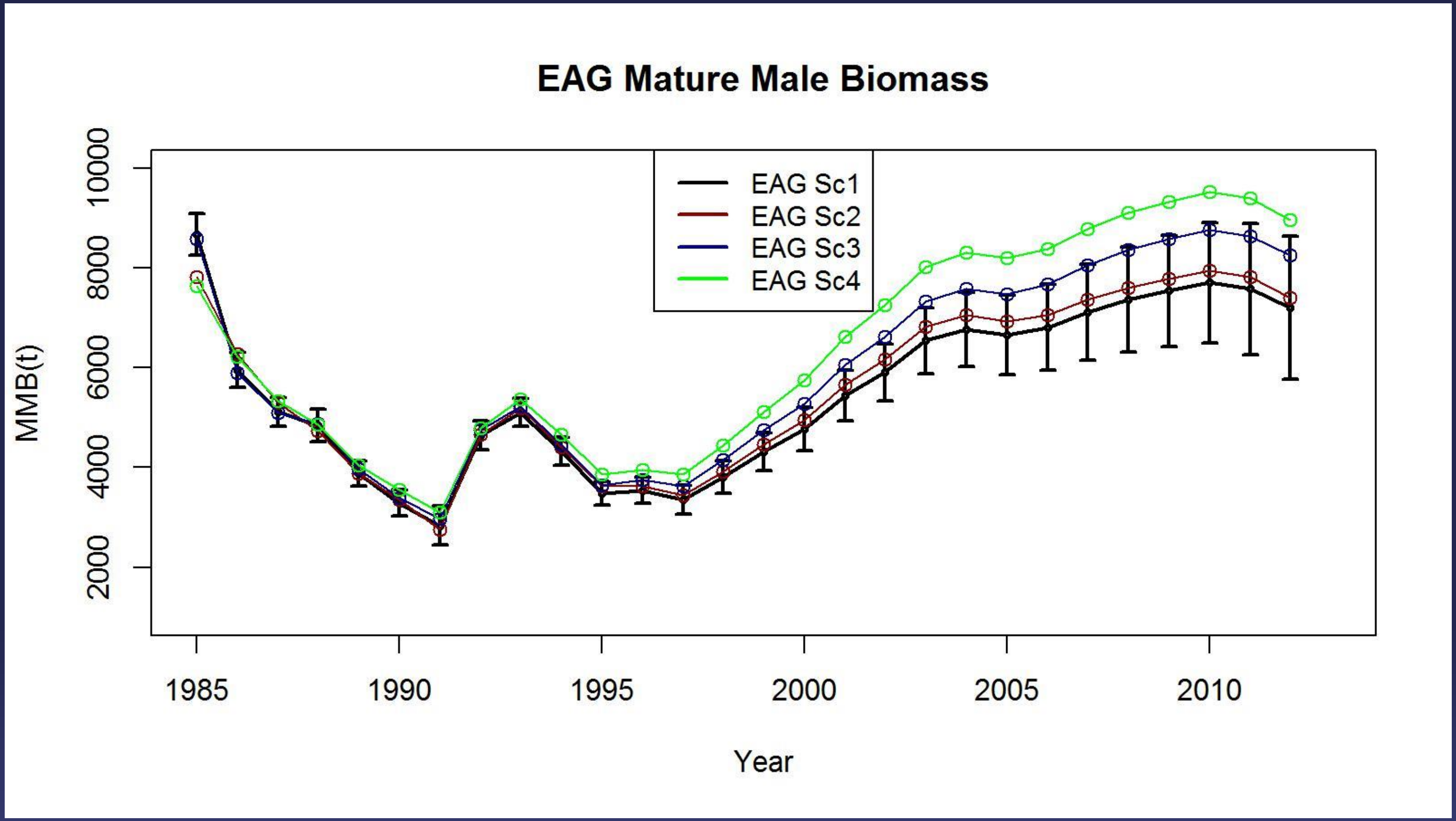


Figure 24. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 1 to 4 in the EAG, 1985–2012 (note: 1985 refers to the1985/86 fishery).

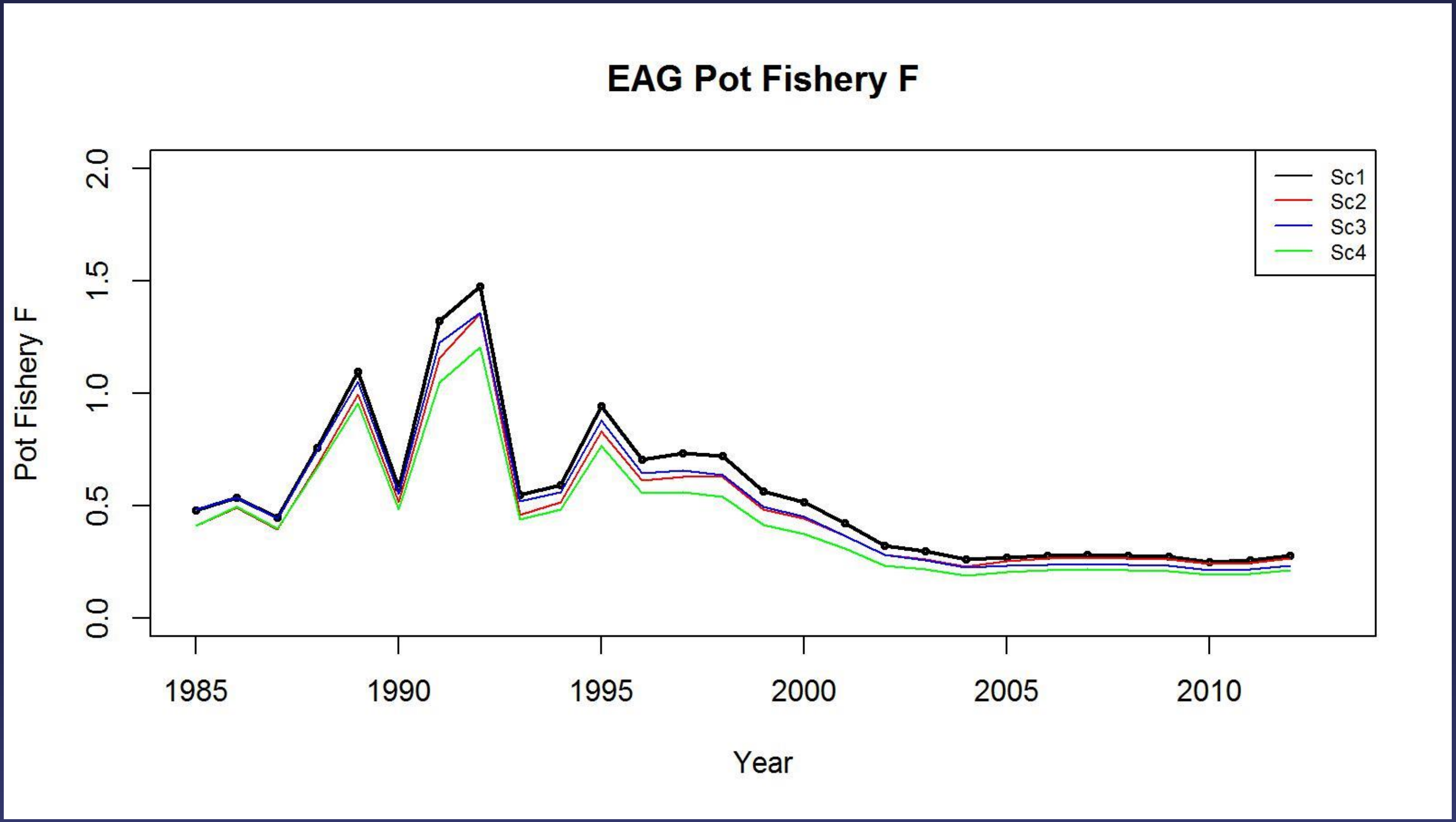


Figure 25. Observed (filled circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 1 to 4 in the EAG, 1985–2012. (note: 1985 refers to the1985/86 fishery).

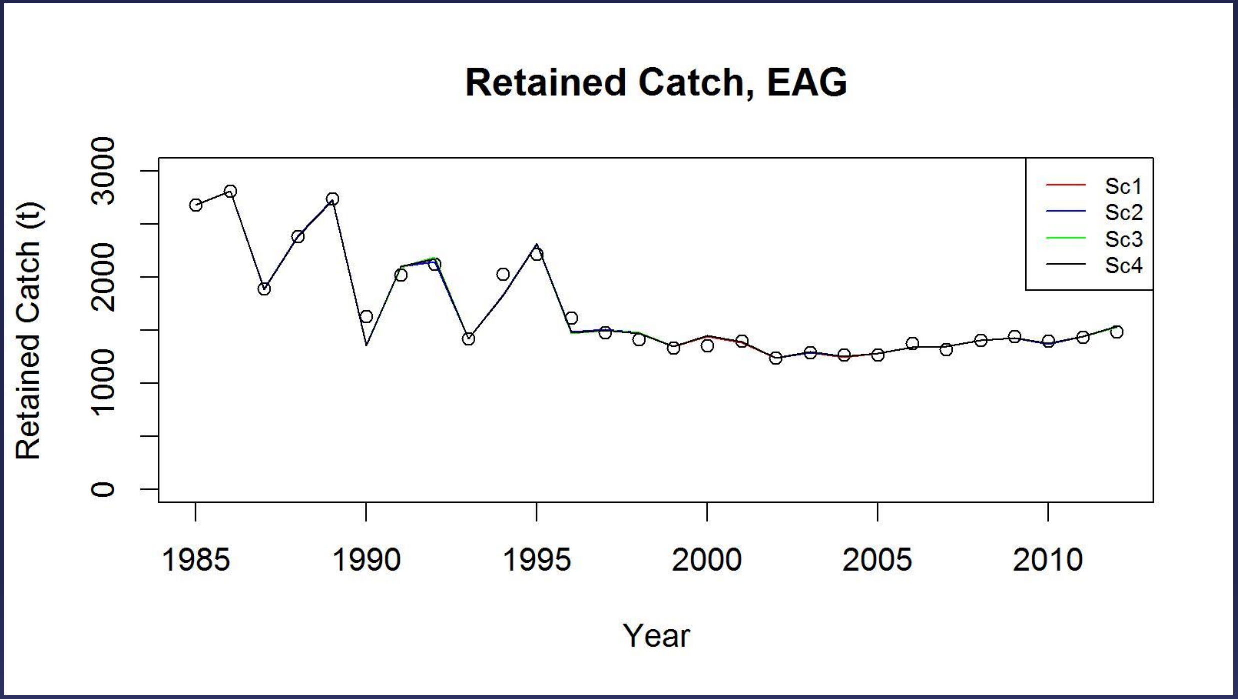


Figure 26. Observed (filled circle) vs. predicted (solid line) total catch of golden king crab for scenarios 1 to 4 in the EAG, 1985–2012. A handling mortality rate of 20% was applied to pot discarded catch and it was added to retained catch to get the total catch. (note: 1990 refers to the1990/91 fishery).

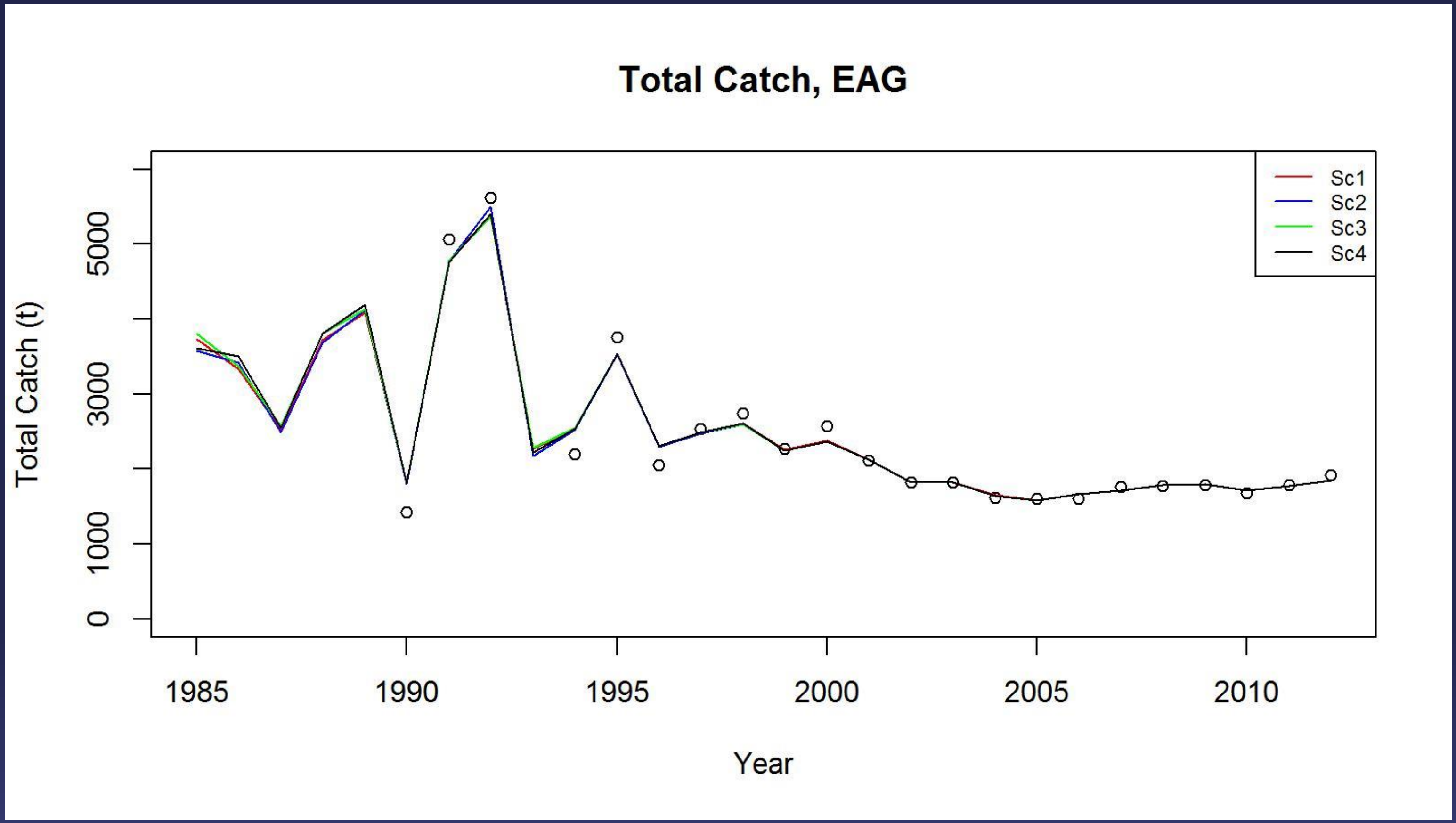


Figure 27. Observed (filled circle) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios 1 to 4 in the EAG, 1990–2012. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1995 refers to the1995/96 fishery).

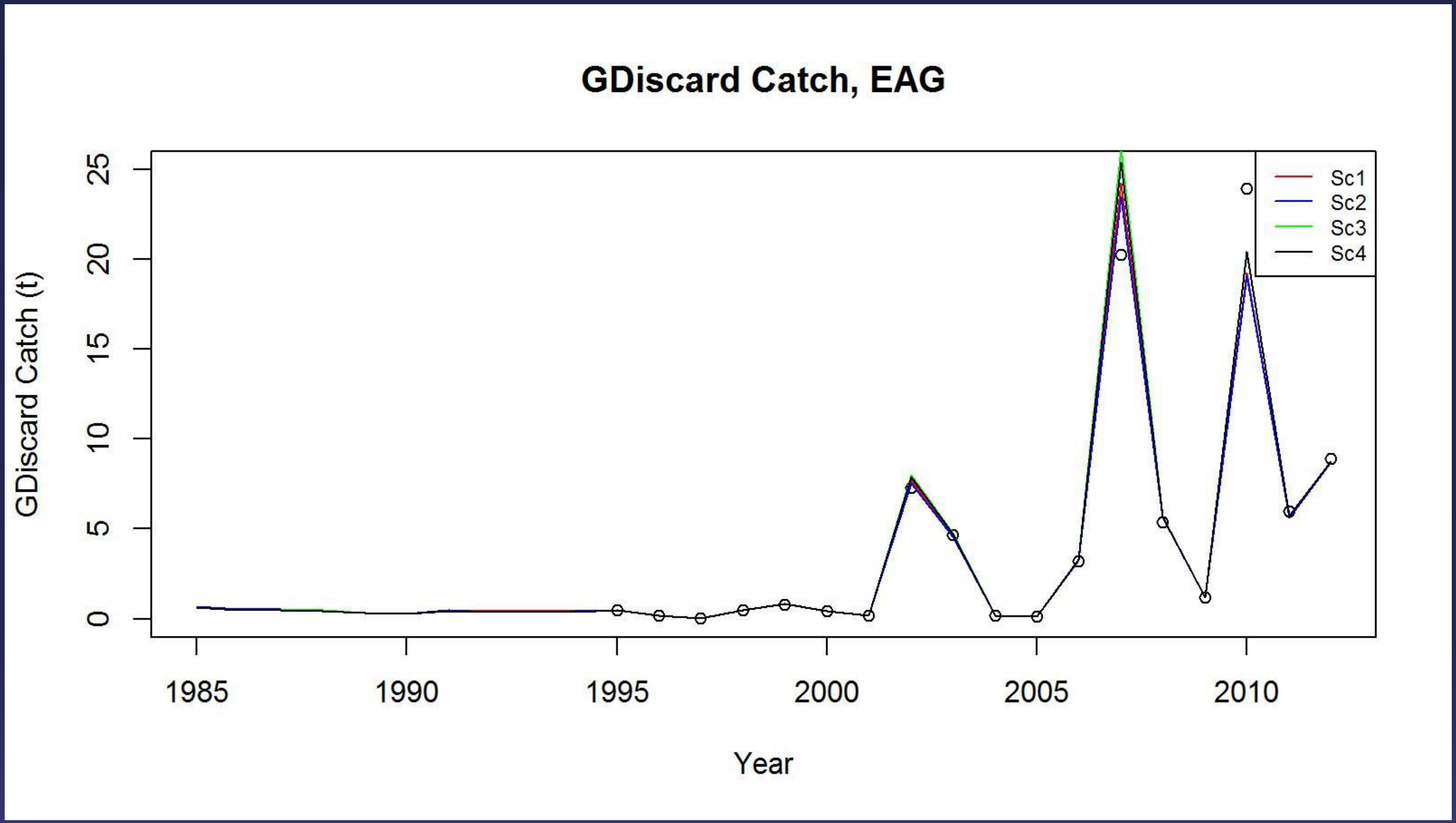


Figure 32. Molt probability for scenarios 2 (Sc2)and 4 (Sc4) fits for EAG golden king crab.

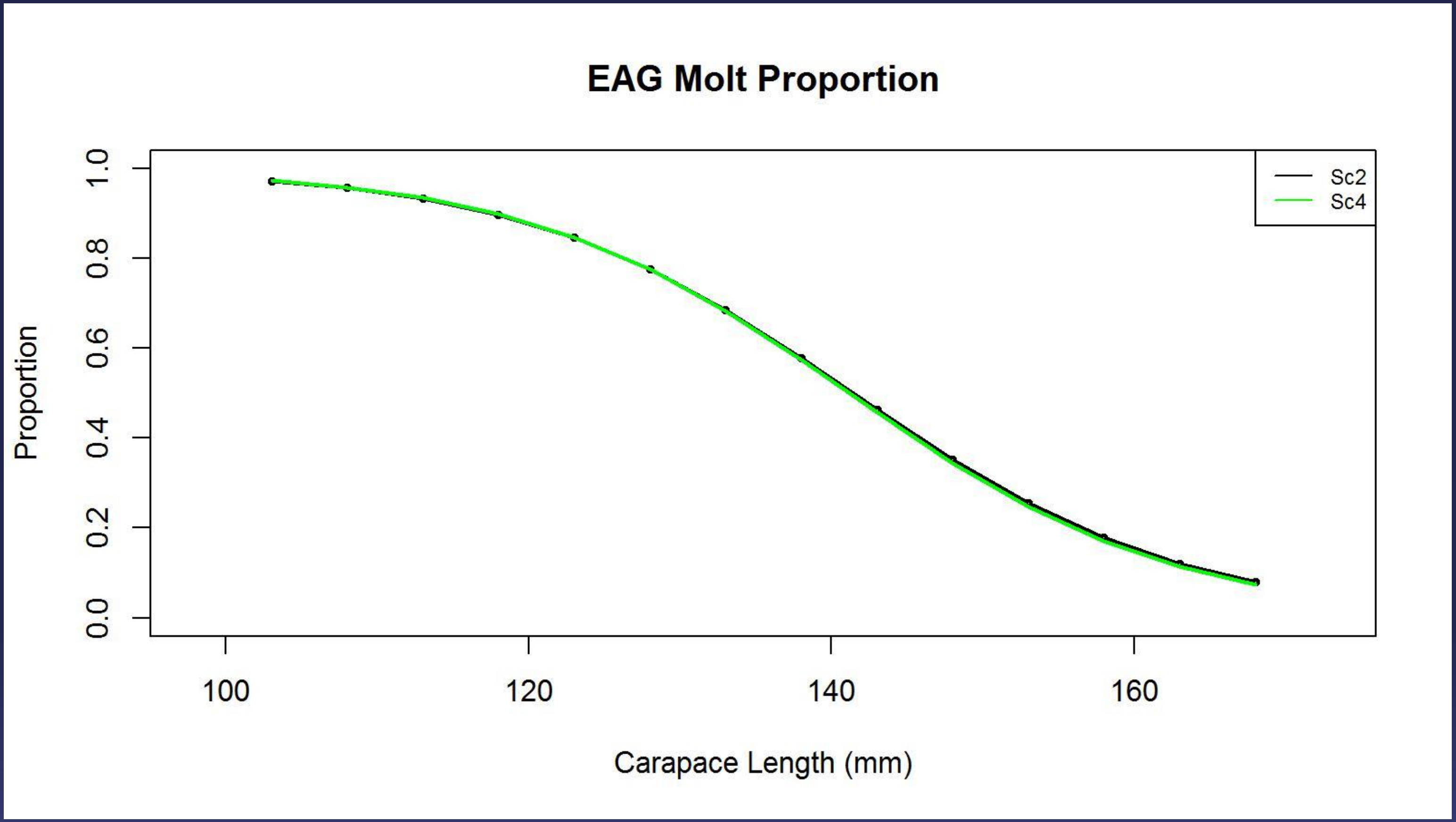
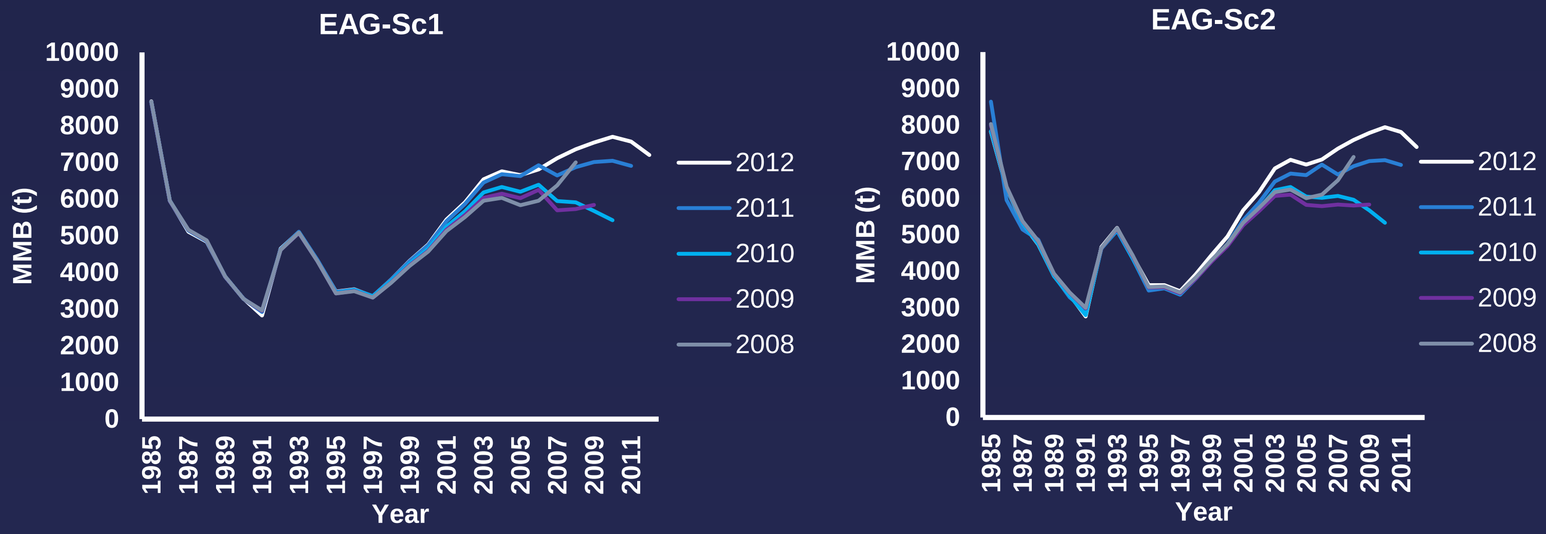
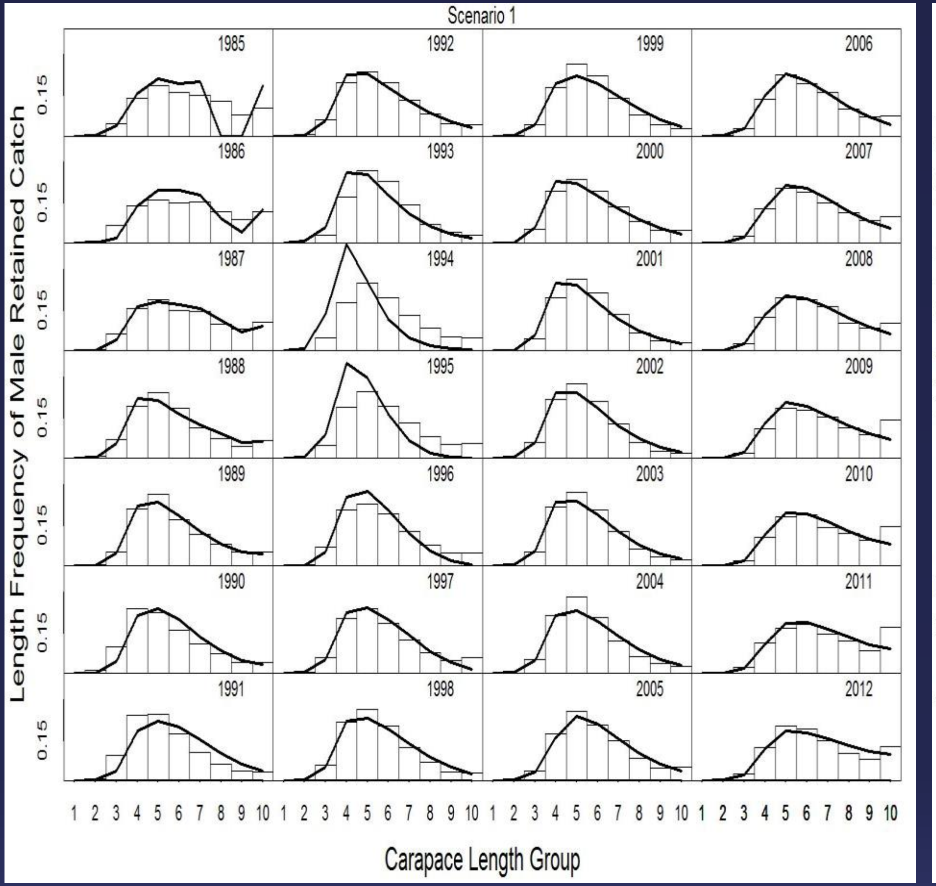
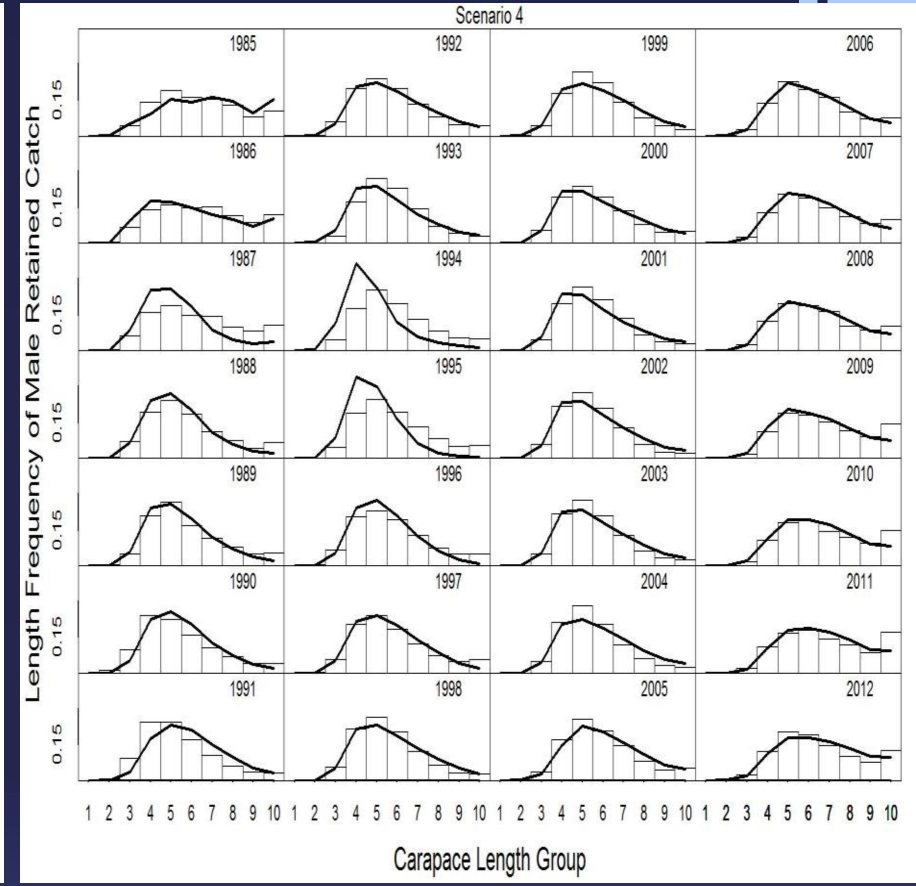


Figure 28. Retrospective fits of the model for removal of terminal year's data for scenarios 1 (Sc1) and 2 (Sc2) fits for golden king crab in the EAG, 1985–2012.

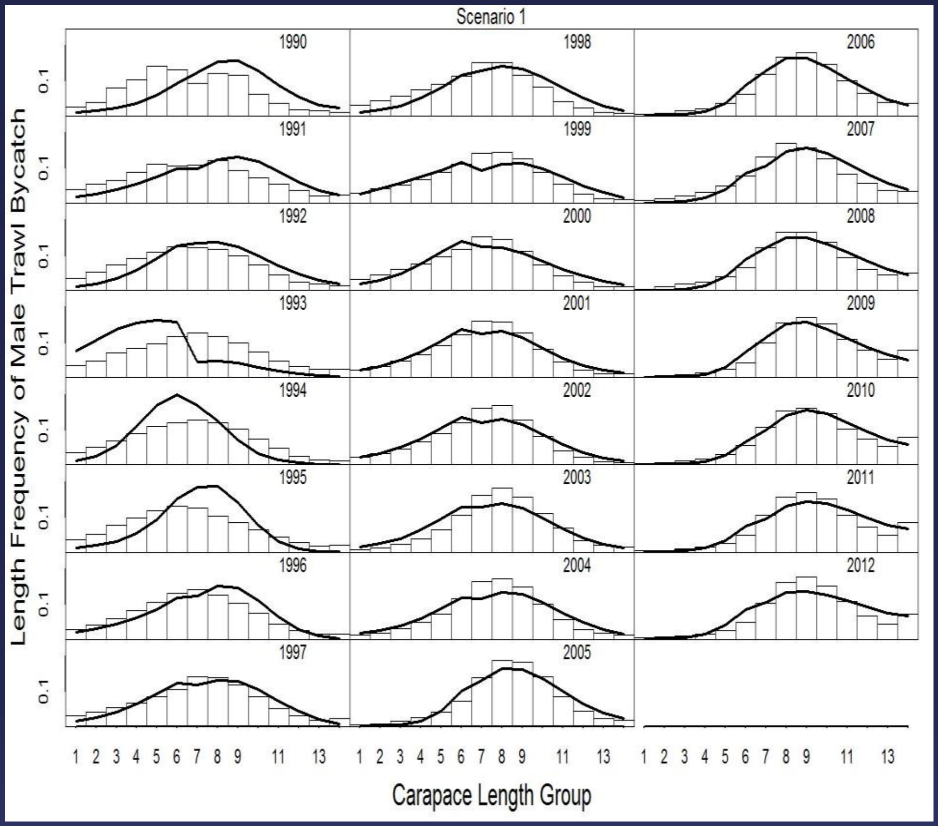


Figures 34 and 35. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions for scenarios 1 and 4 data of golden king crab in the WAG, 1985/86 – 2012/13. Length group 1 is 103 mm CL.





Figures 36 and 37. Predicted (line) vs. observed (bar) pot total catch relative length frequency distributions for scenarios 1 and 4 data of golden king crab in the WAG, 1990/91 – 2012/13. Length group 1 is 103 mm CL.



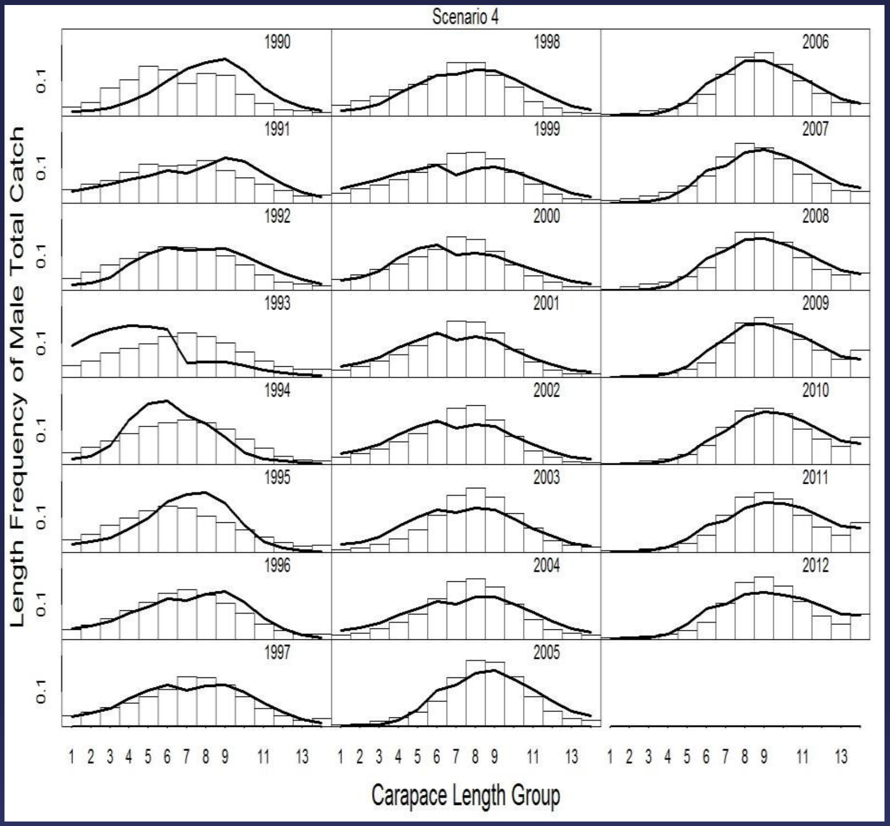
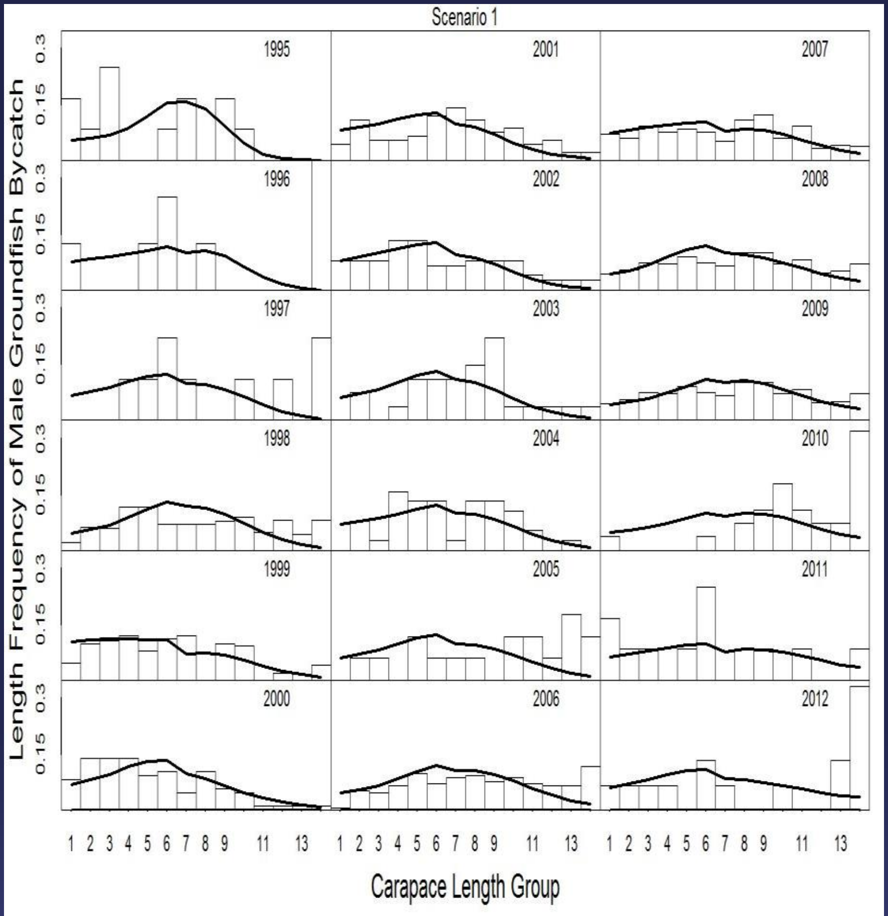


Figure 38 and 39. Predicted (line) vs. observed (bar) groundfish discarded catch relative length frequency distributions for scenarios 1 and 4 data of golden king crab in the WAG, 1995/96 – 2012/13. Length group 1 is 103 mm CL.



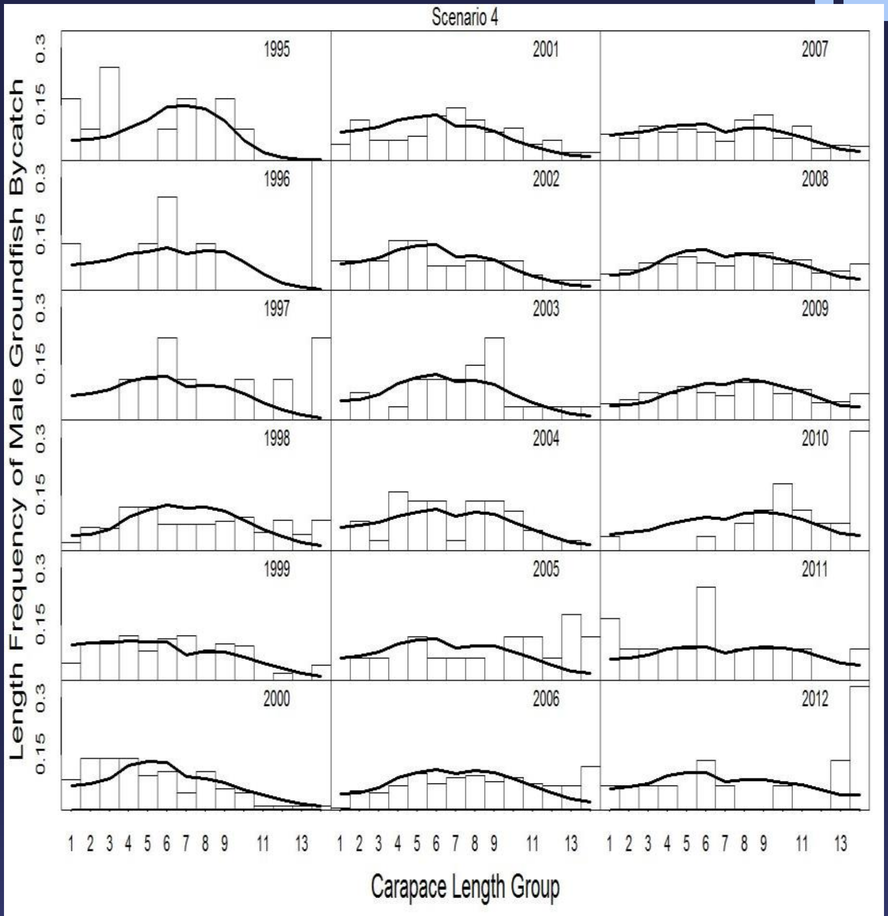


Figure 40. Predicted effective sample size vs. input effective sample size for retained catch length composition for scenarios 1 to 4 fits to golden king crab data in the WAG, 1985/96 – 2012/13. The red line is the 45^0 line passing through the origin.

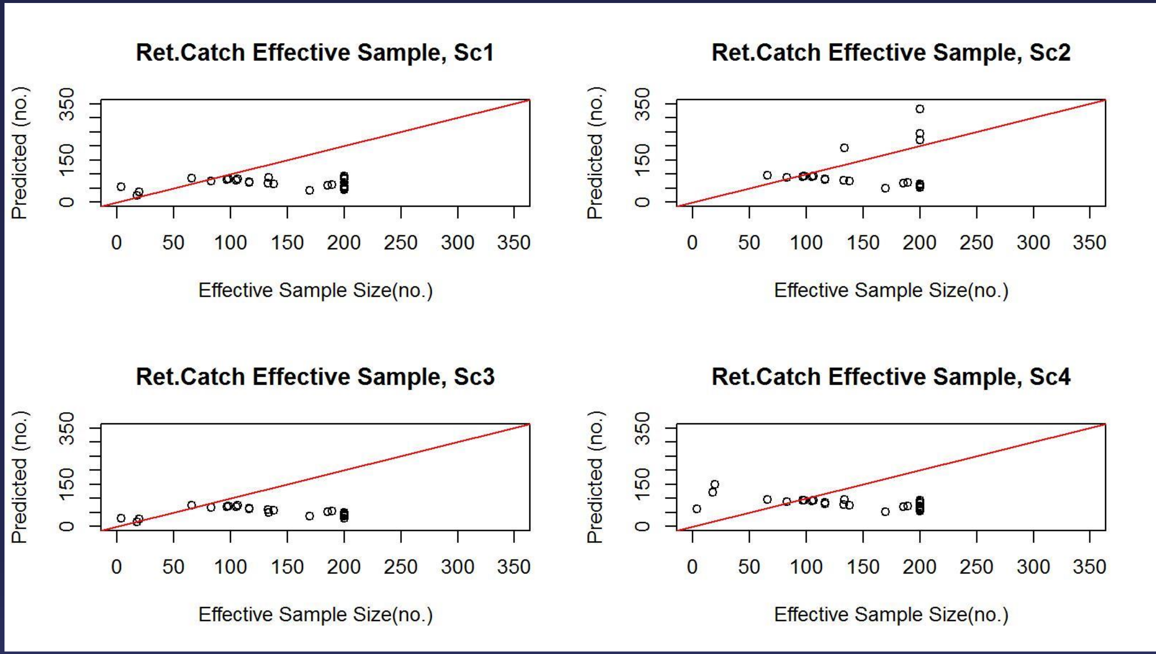


Figure 41. Predicted effective sample size vs. input effective sample size for total catch length composition for scenarios 1 to 4 fits to golden king crab data in the WAG, 1990/91 – 2012/13. The red line is the 45^0 line passing through the origin.

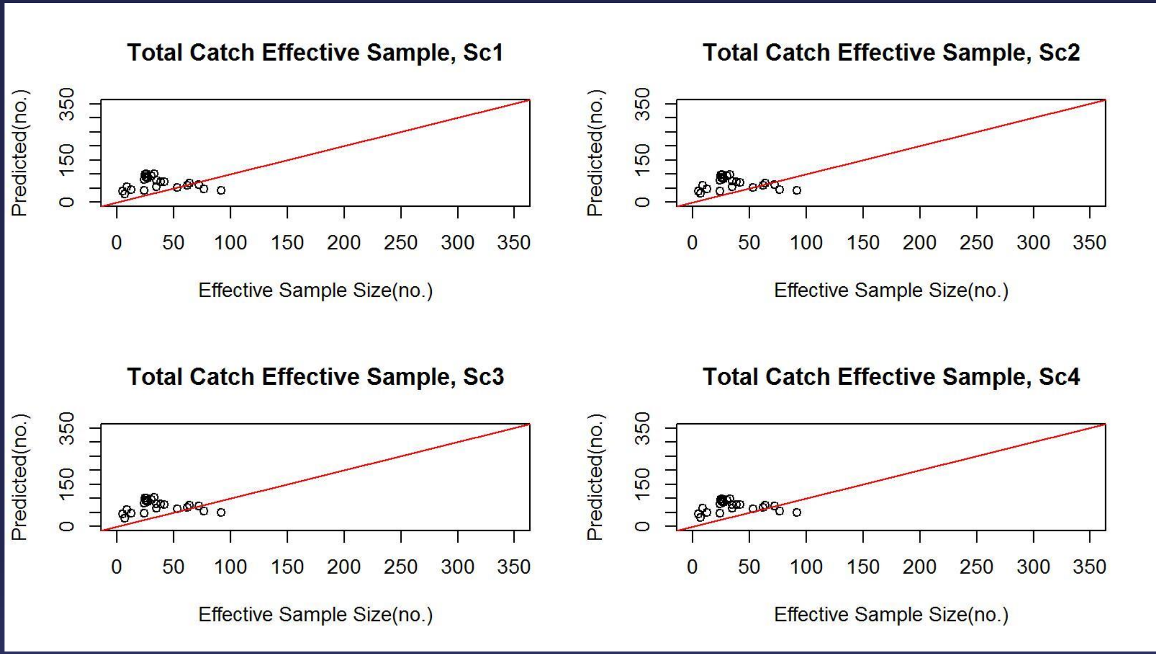


Figure 42. Predicted effective sample size vs. input sample size for groundfish discarded catch length composition for scenarios 1 to 4 fits to golden king crab data in the WAG, 1995/96 – 2012/13. The red line is the 45^0 line passing through the origin.

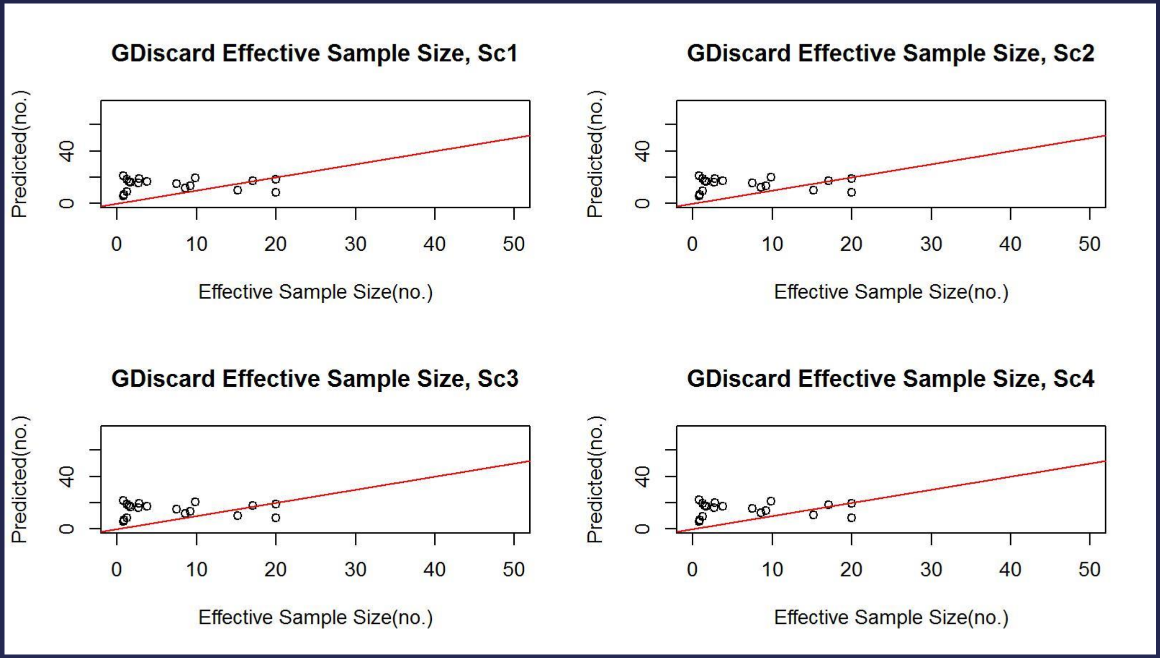


Figure 43. Estimated total selectivity (black solid line) and retained selectivity (red dotted line) for pre- (Yr2000) and post- (Yr2012) rationalization periods under scenarios 1 to 4 fits to WAG golden king crab data.

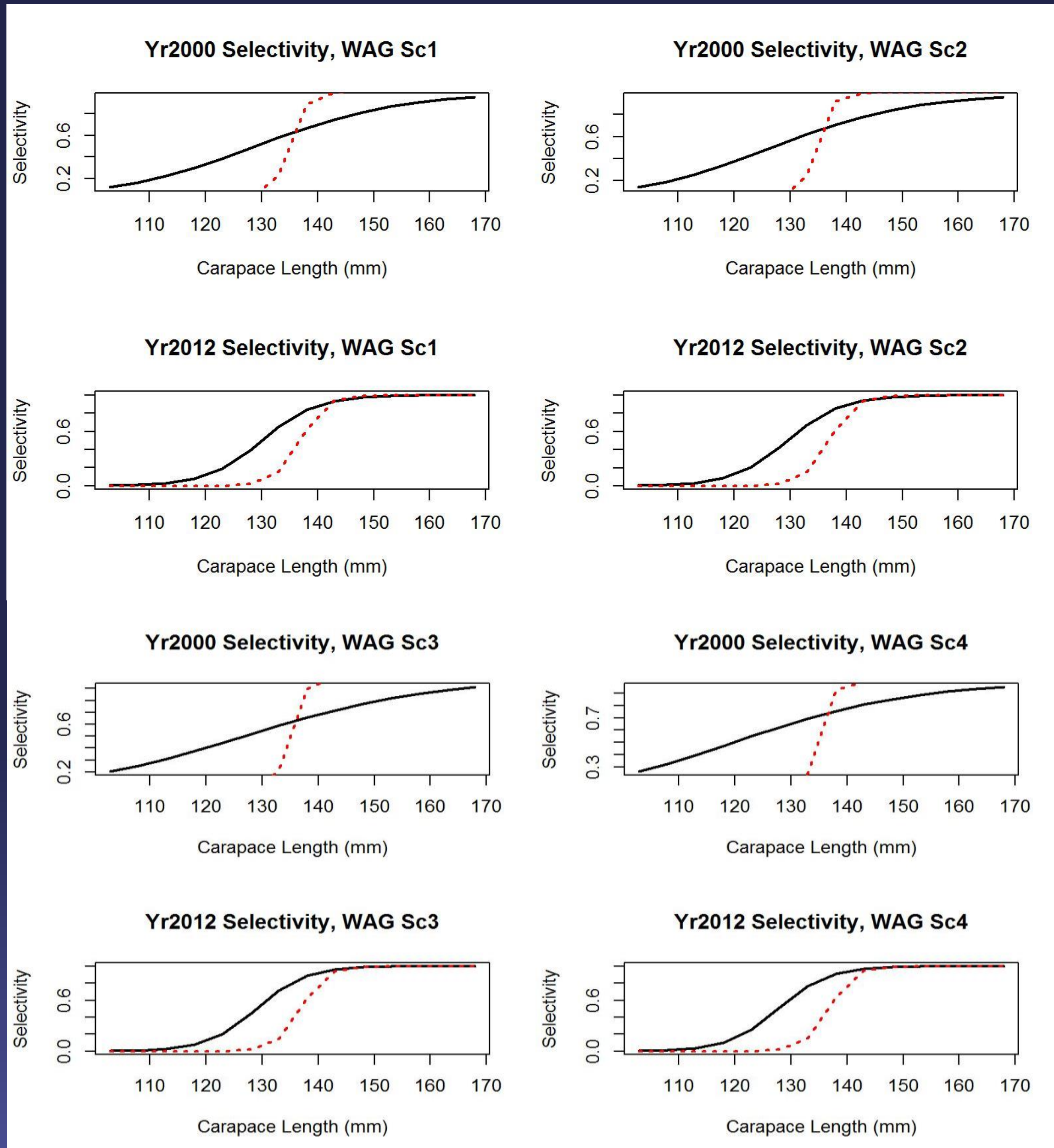


Figure 47. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for scenarios 1 to 4 fits of WAG golden king crab data.

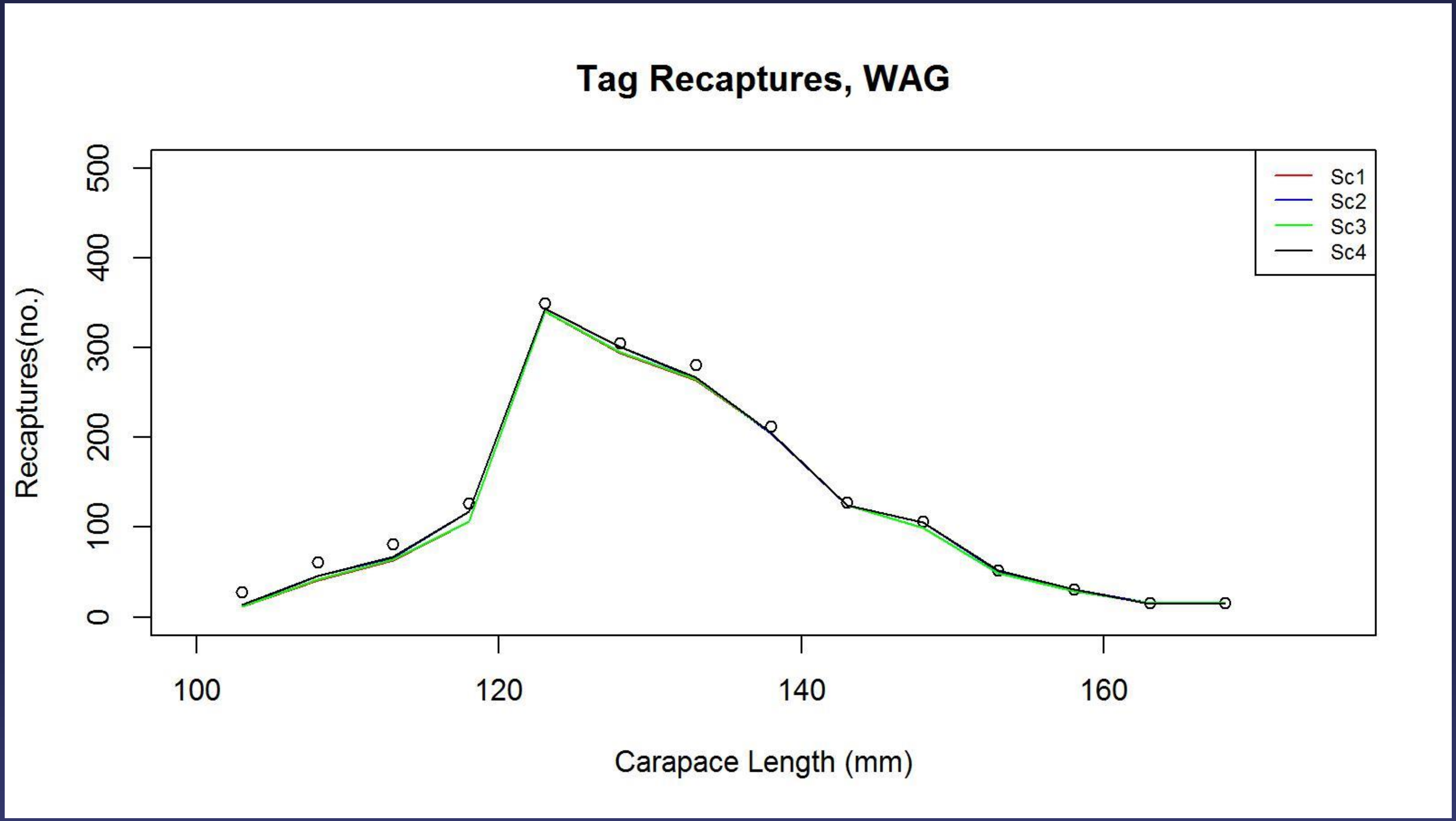


Figure 48. Comparison of input CPUE indices (open circles with one standard error) with predicted CPUE indices (colored solid lines) for scenarios 1 to 4 fits for WAG golden king crab data. 1985/96–2012/13. Model estimated additional standard error was added to each input standard error.

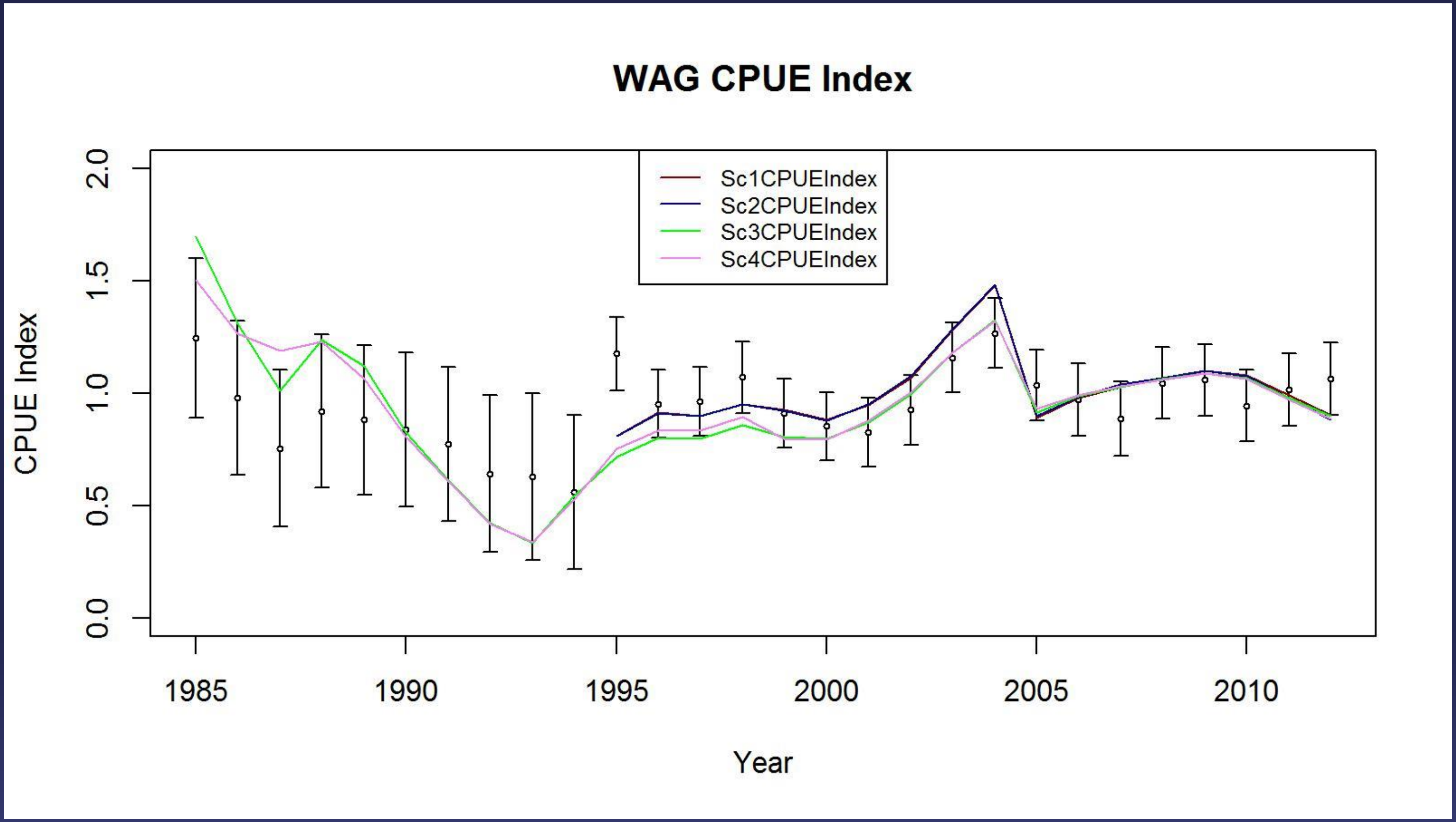


Figure 44. Bubble plots of standardized residuals of retained catch length composition for scenarios 1 to 4 fits for WAG golden king crab, 1985/86–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of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

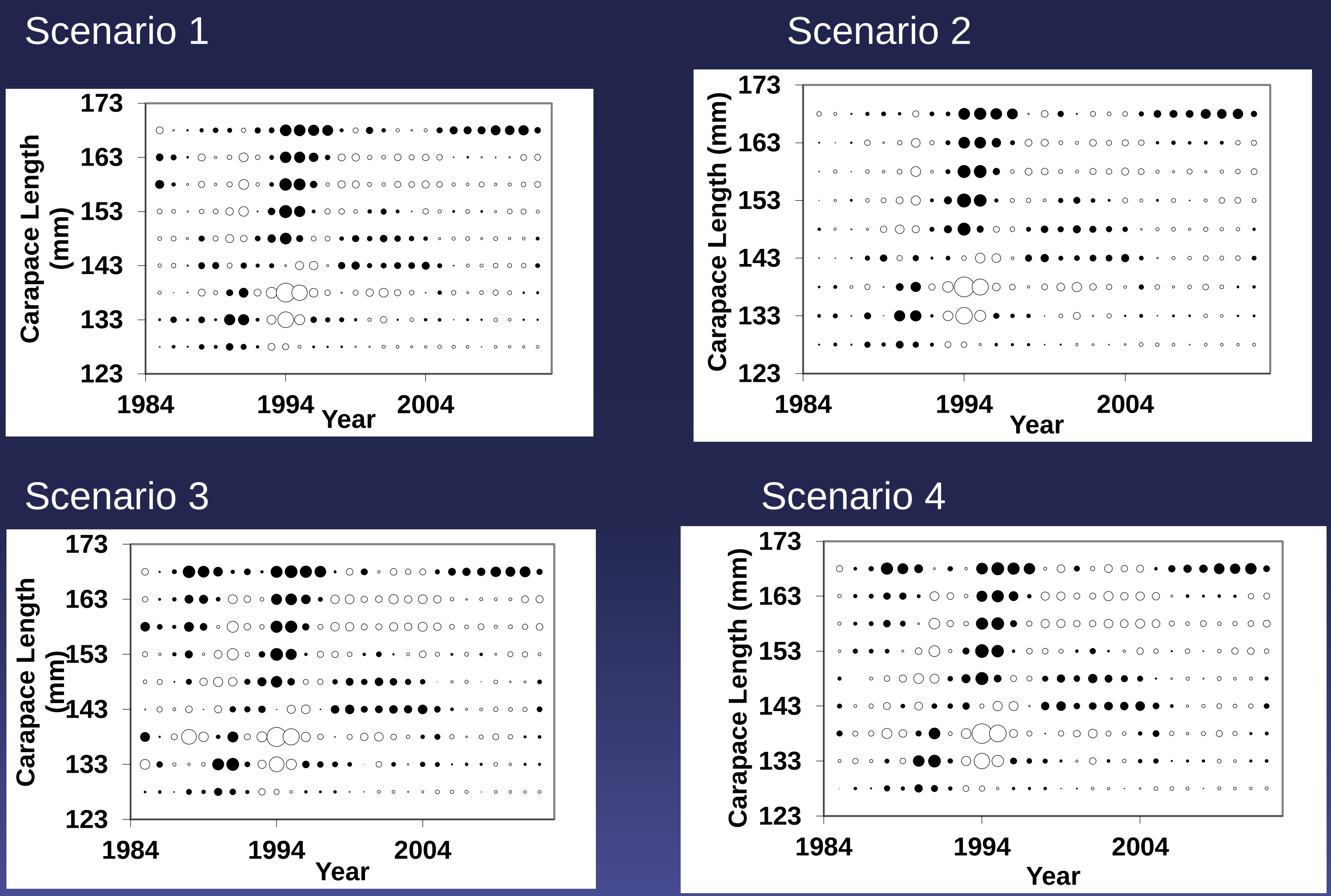
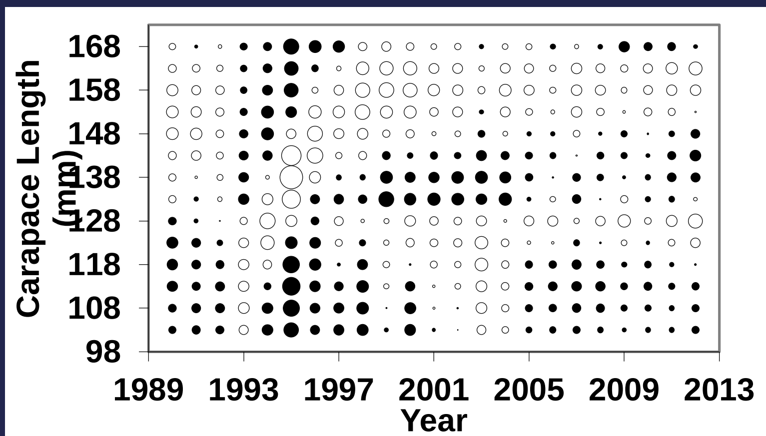
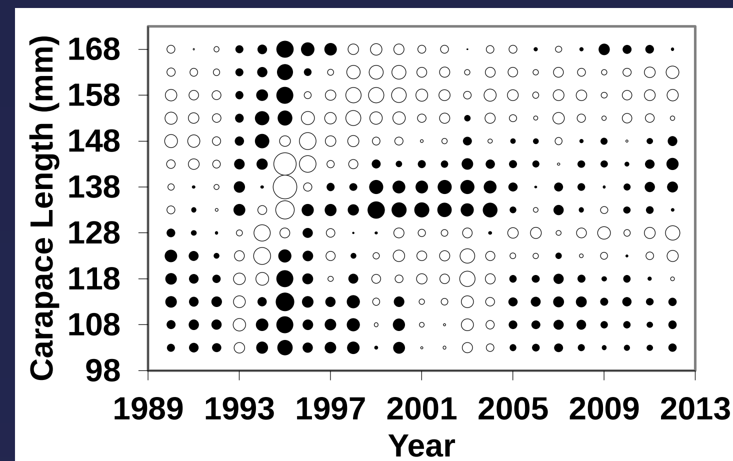


Figure 45. Bubble plots of standardized residuals of total catch length composition for scenarios 1 to 4 fits for WAG golden king crab, 1990/91–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the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

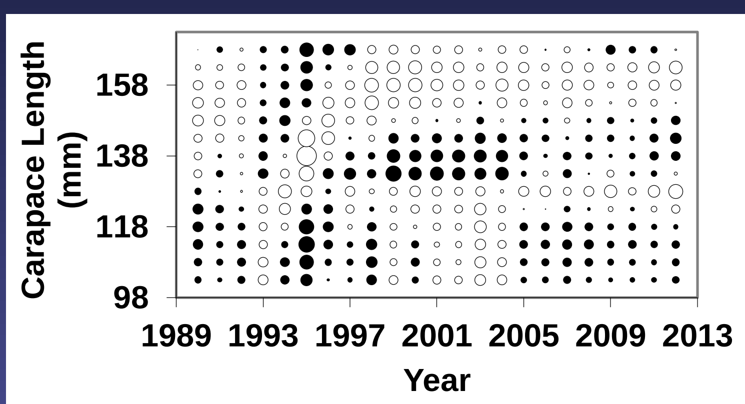
Scenario 1



Scenario 2



Scenario 3



Scenario 4

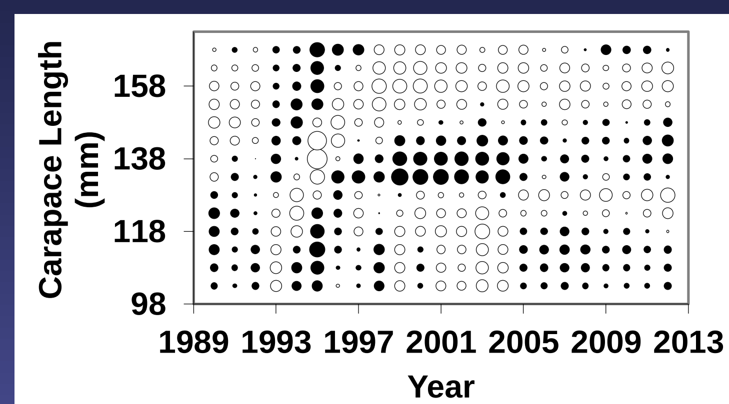
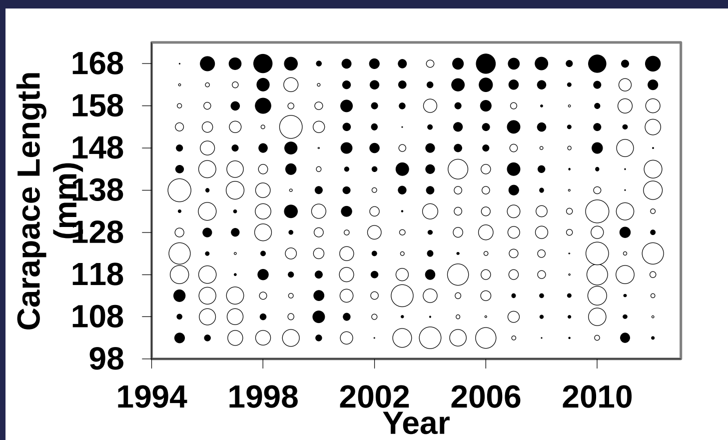
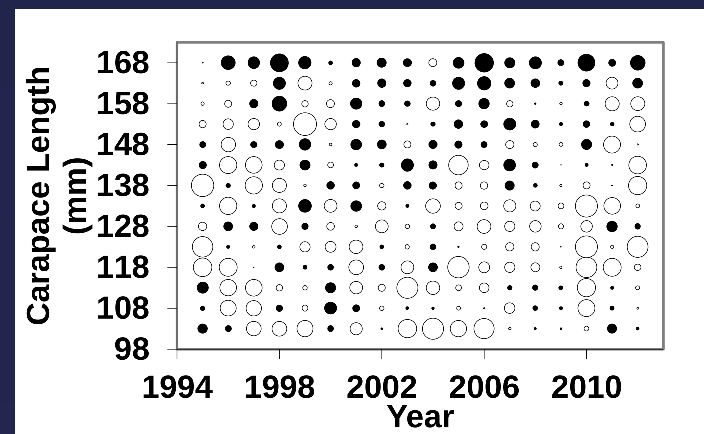


Figure 46. Bubble plots of standardized residuals of groundfish bycatch length composition for scenarios 1 to 4 fits for WAG golden king crab, 1995/96–2012/13. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude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

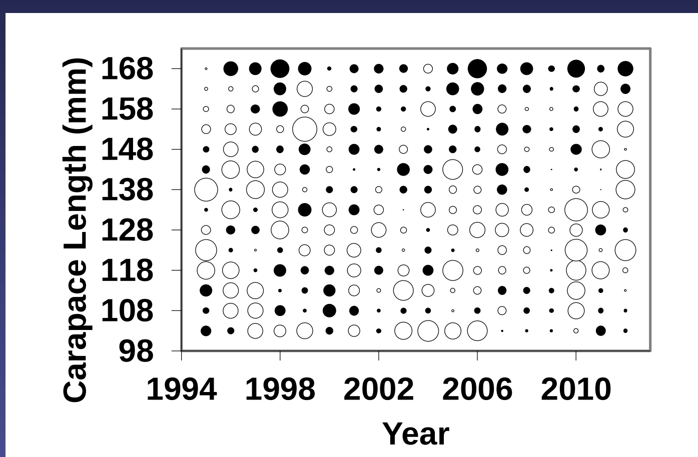
Scenario 1



Scenario 2



Scenario 3



Scenario 4

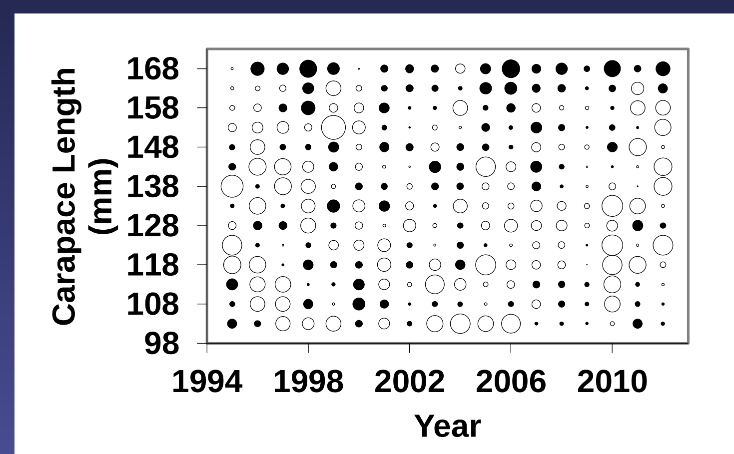


Figure 49. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab assessment model for scenarios 1 to 4 fits in WAG, 1986–2013.

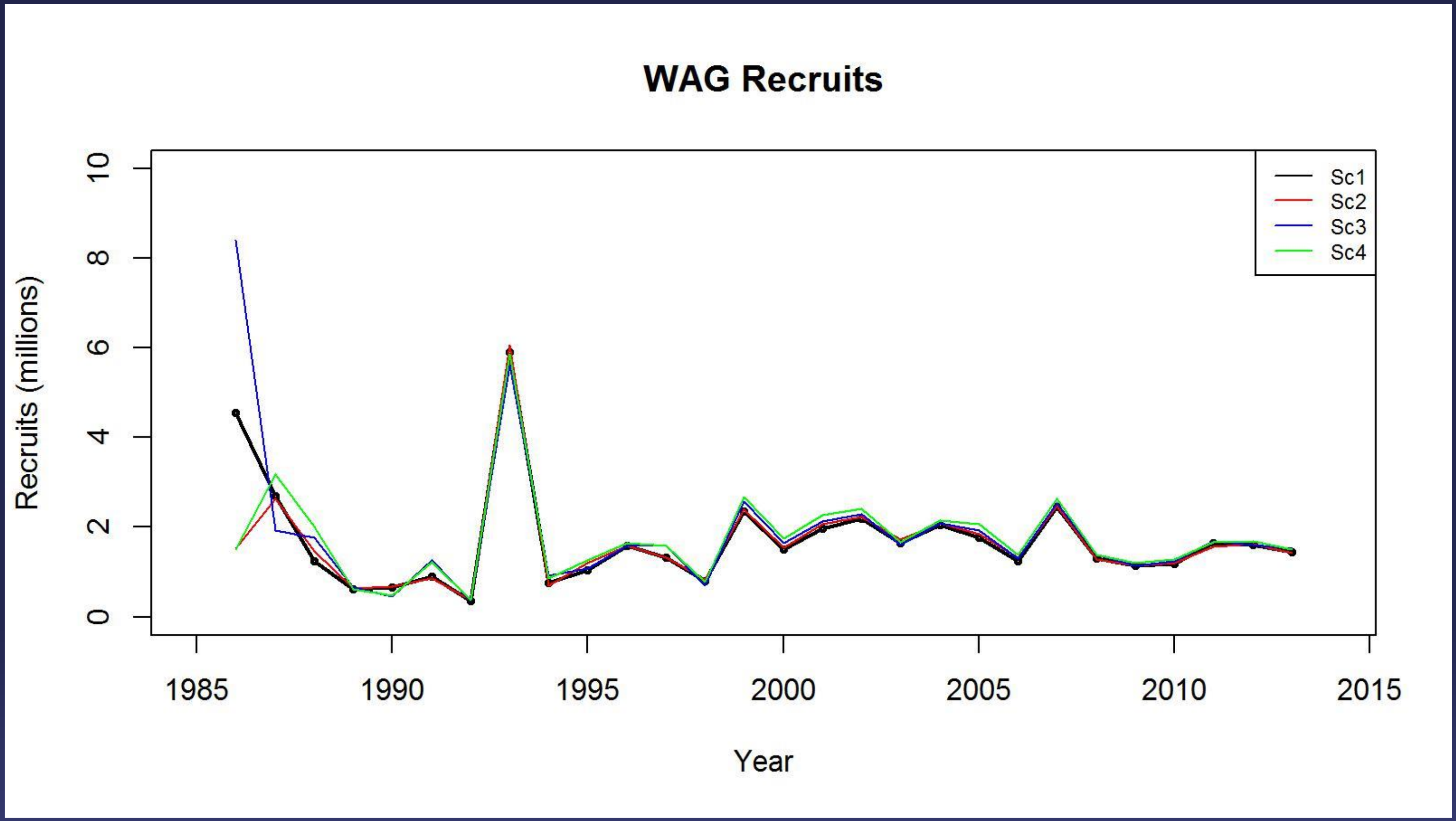


Figure 51. Trends in golden king crab mature male biomass for scenarios 1 to 4 fits in the WAG, 1985/86–2012/13. Mature male crabs are ≥ 121 mm CL. Estimates have one standard error confidence limits.

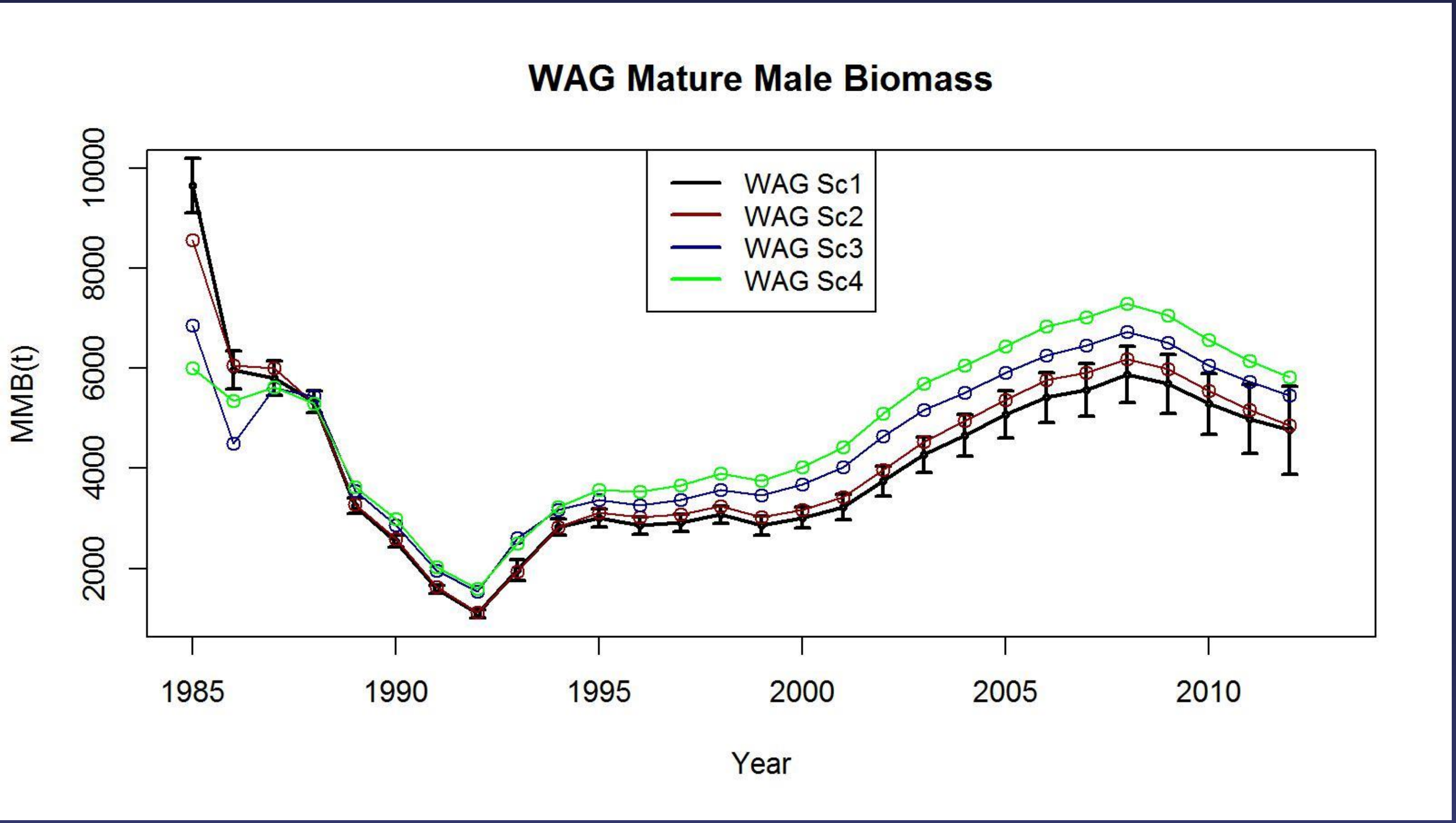


Figure 53. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 1 to 4 fits in the WAG, 1985–2012 (note: 1985 refers to the1985/86 fishery).

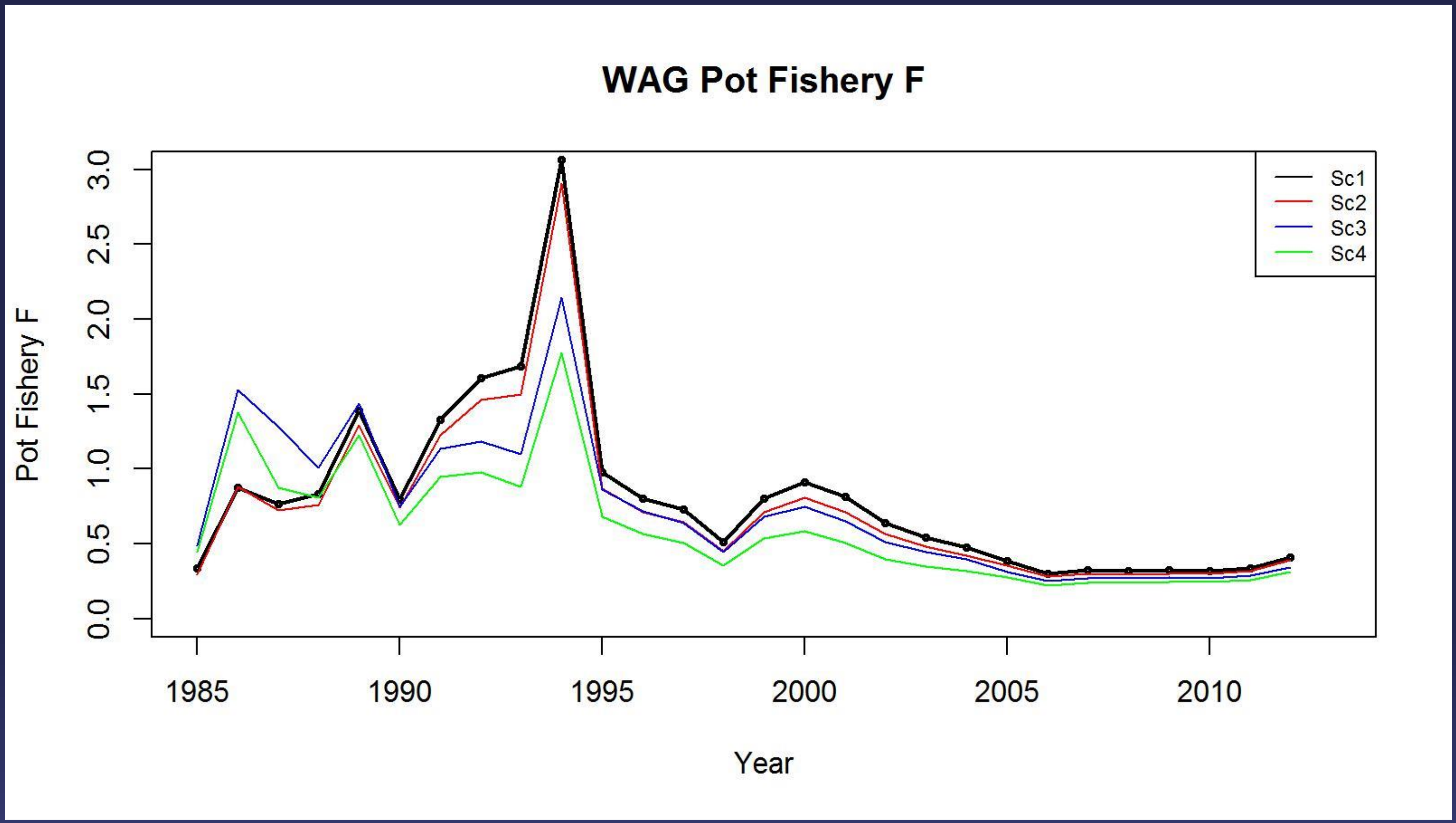


Figure 54. Observed (filled circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 1 to 4 fits in the WAG, 1985–2012. (note: 1985 refers to the1985/86 fishery).

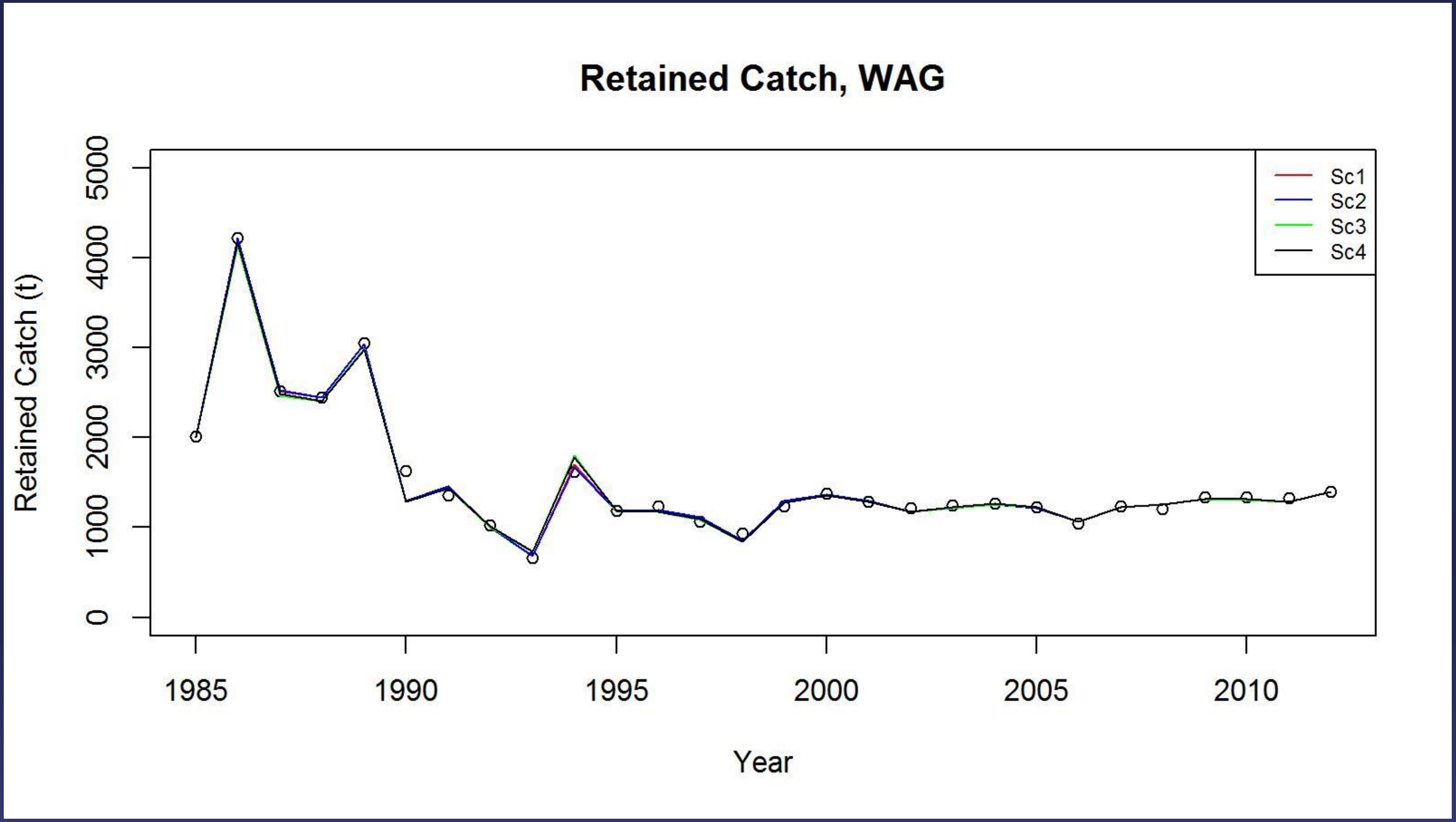


Figure 55. Observed (filled circle) vs. predicted (solid line) total catch of golden king crab for scenarios 1 to 4 fits in the WAG, 1985–2012. A handling mortality rate of 20% was applied to pot discarded catch and it was added to retained catch to get the total catch. (note: 1990 refers to the1990/91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

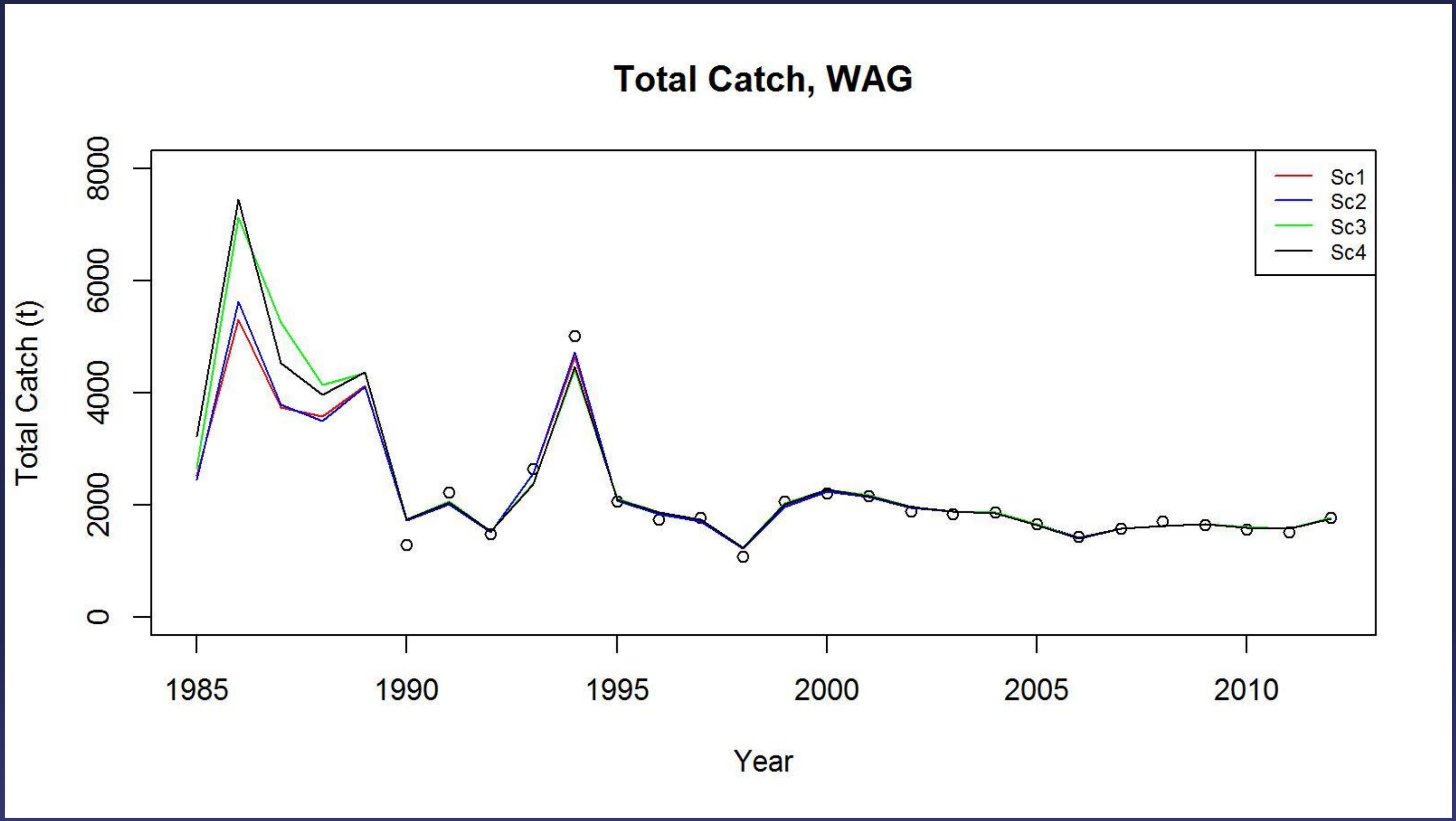


Figure 56. Observed (filled circle) vs. predicted (solid line) groundfish discarded catch of golden king crab for scenarios 1 to 4 fits in the WAG, 1985–2012. An average handling mortality rate of 65% (average of 80% and 50%) was applied to groundfish discard. (note: 1995 refers to the1995/96 fishery).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

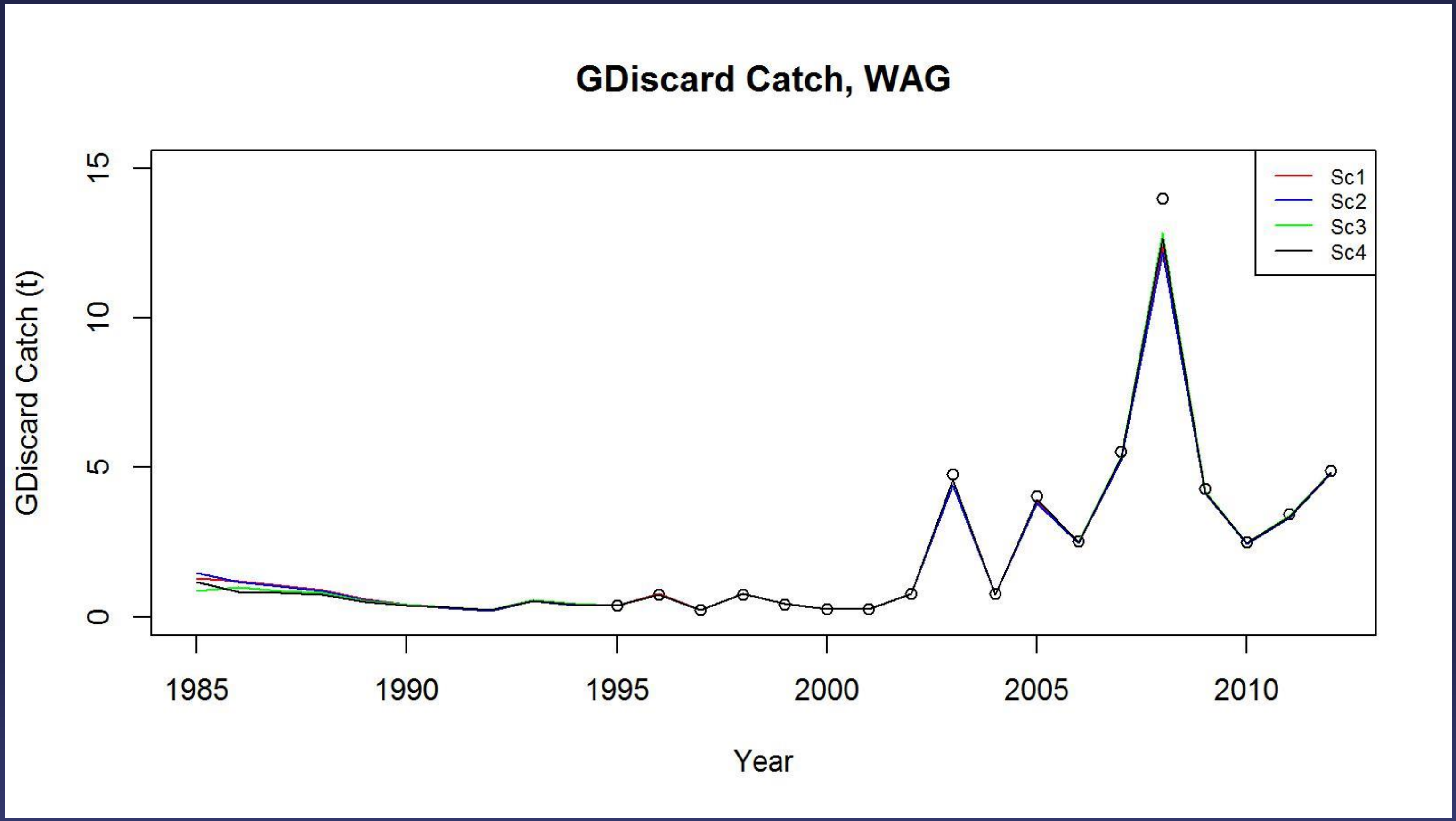
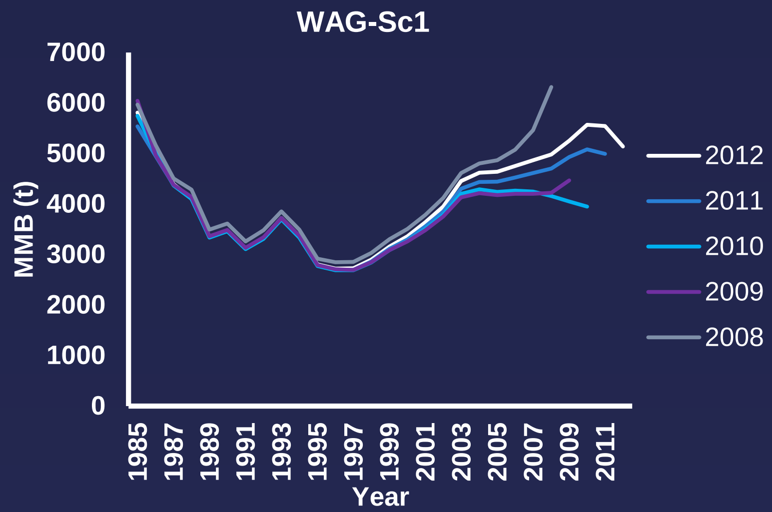
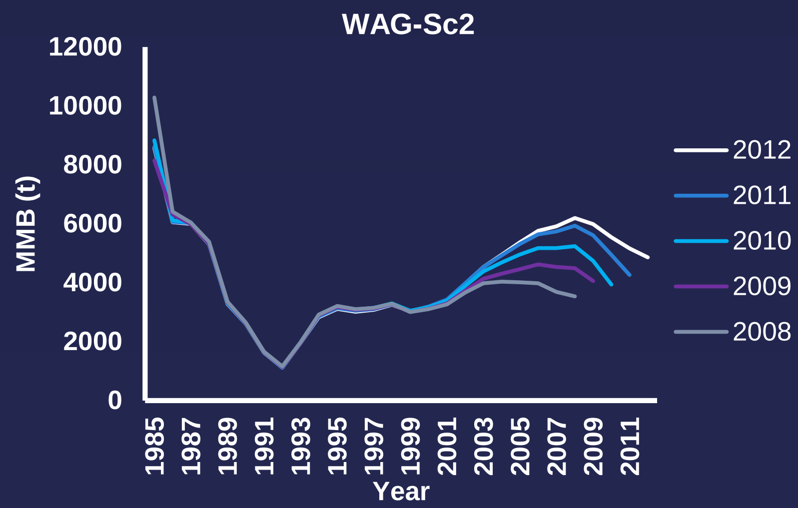


Figure 57. Retrospective fits of mature male biomass by the model when terminal year's data were systematically removed until 2008/09 for scenarios 1 and 2 for golden king crab in the WAG, 1985–2012.





Tier 4 Estimation: B_{ref}, OFL, and ABC

EAG:
Biomass in million pounds

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

WAG:
Biomass in million pounds

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

B_{35}, OFL, and ABC calculation by F_{35} (Discussion paper on the F_{35} approach for Aleutian Islands golden king crab reference points calculation)

EAG:
Biomass in million pounds

Season	Tier	B_{35}	Current MMB	MMB/B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	F_{40}	OFL	ABC (P*=0.49)
1) 2014/15	4a	13.694	15.044	1.10	0.36	2003–2012	0.36	0.28	4.270	4.248
4) 2014/15	4a	14.045	19.746	1.22	0.36	2003–2012	0.36	0.28	5.406	5.373

WAG:
Biomass in million pounds

Season	Tier	B_{35}	Current MMB	MMB/B35	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	F_{40}	OFL	ABC (P*=0.49)
1) 2014/15	4b	11.742	11.083	0.94	0.32	2003–2012	0.34	0.27	2.512	2.500
4) 2014/15	4a	12.145	12.592	1.04	0.34	2003–2012	0.34	0.27	3.303	3.285

Questions? Suggestions?

Our assumptions on the model runs.

- We employed identical methods to analyze the EAG and WAG data.
- We assumed that the groundfish selectivity was 1. This was decided after trial runs to estimate trawl selectivity parameters which produced almost flat selectivity lines. The length composition also indicated full selectivity at all sizes.
- We also set QQ (legal retained rate) to be 1 after trial runs that produced QQ to be 1.

Tier 4 Formula for OFL

- (a) If , $B_t \geq B_{ref}$, $F_{OFL} = \lambda M$
- (b) If $B_t < B_{ref}$ and $B_t > 0.25 B_{ref}$,

$$F_{OFL} = \lambda M \frac{\left(\frac{B_t}{B_{ref}} - \alpha\right)}{(1-\alpha)}$$

- (c) If ,$B_t \ll 0.25 B_{ref}$, $F_{OFL} = 0$