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

M.S.M. Siddeek, J. Zheng, and D. Pengilly

Alaska Department of Fish and Game, Juneau and Kodiak

May CPT presentation: September 16, 2015

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, 1985/86–2014/15 fisheries.

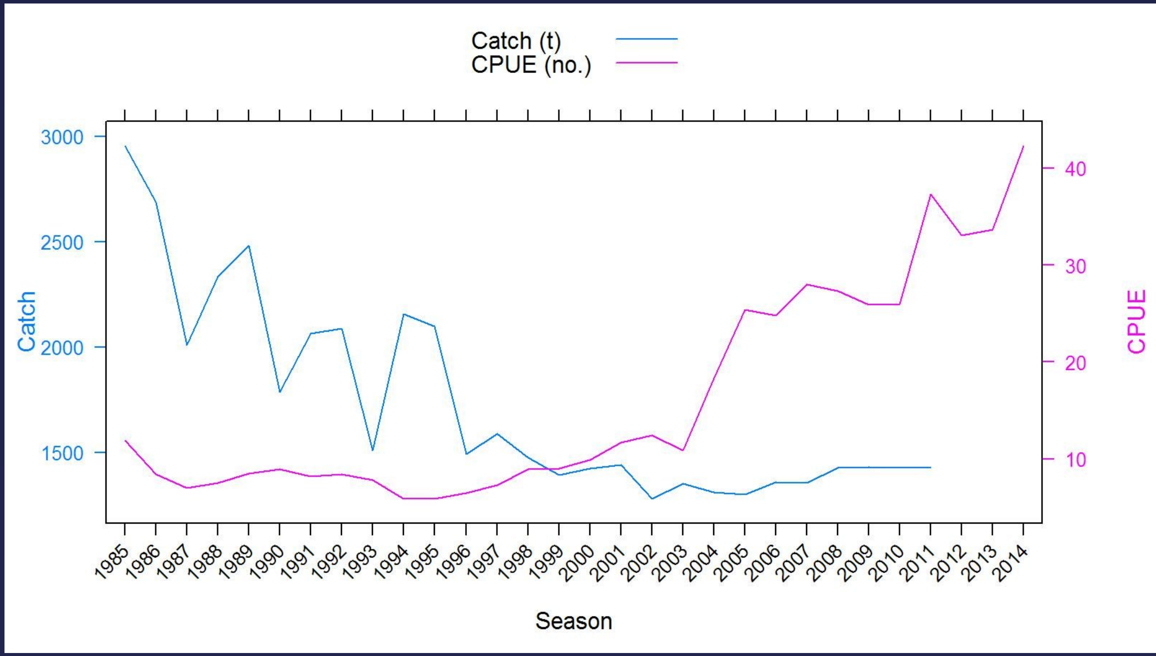
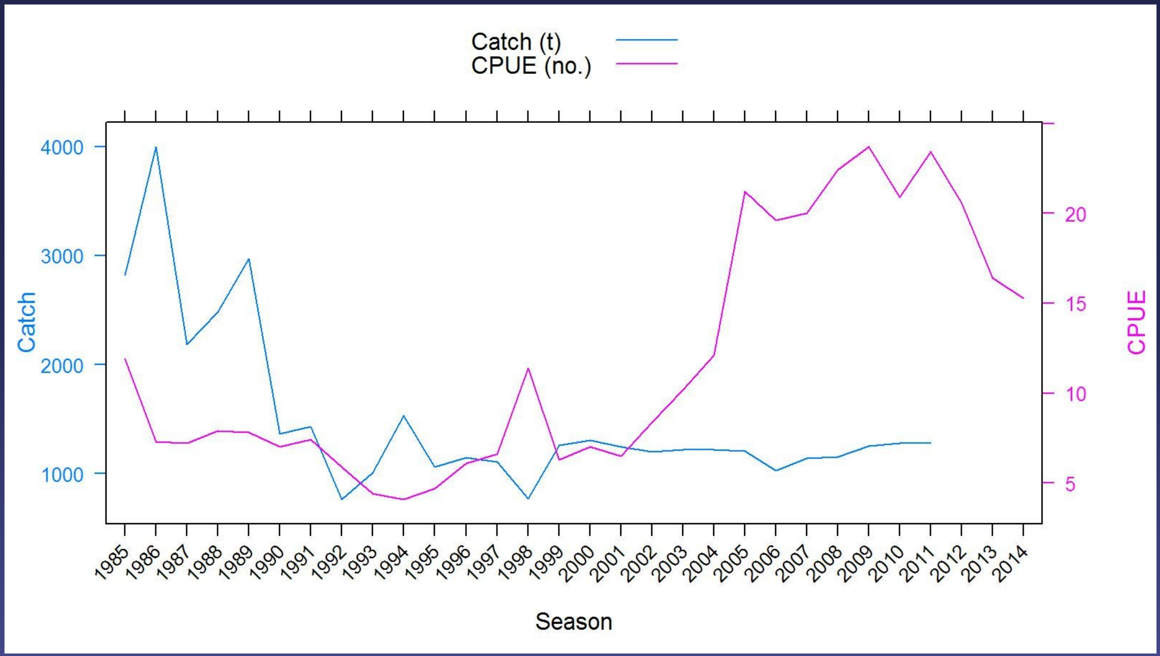


Figure 2. Historical commercial harvest (from fish ticket and in metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2014/15 fisheries



Goals

- Address CPT 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 Tier 4 and Tier 3 assessment methods to determine OFL and ABC for EAG and WAG.

Approach

- We developed an integrated model to analyze data from pot fishery retained and total catch , standardized legal size CPUE from observer data, groundfish fishery bycatch, and tag release-recapture lengths and time-at-liberty. We also used the standardized fish ticket retained CPUE index in one scenario.
- We used the Tier 4 and Tier 3 approaches to determine overfishing levels (OFL) and allowable biological catches (ABC) separately for EAG and WAG.
- We considered 12 scenarios for EAG and 11 scenarios for WAG for exploratory analysis, but picked up six and five scenarios for detail consideration for EAG and WAG, respectively.
- 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; component likelihoods; and retrospective fits to mature male biomass.

Responses to May 2015 CPT comments/recommendations

- Comment: Include results from the CPUE standardization in the assessment document.
- *Response: we have included CPUE diagnostic plots (Figures 8-10 for EAG and 36-38 for WAG).*
- Comment: Use the improved set of equations for fishing mortality for all models.
- *Response: We have modified the Z formula (Appendix A). We compared the F and MMB distributions between the old and the modified formulas. Differences are minor (Figure 67).*
- Comment: Standardize the commercial fishery CPUE using available information.
- *Response: We have scoped a number of predictor variables (e.g., Year, Vessel, Captain, Area, and Month) in the model selection by lognormal GLM.*

Responses to May 2015 CPT comments– continued

- Comment: Total catch estimates should be given weights based on the observer sample sizes when model fitting.
- *Response*: *We have used the number of pots sampled scaled to a maximum of 300 as weights in the total catch biomass likelihood.*
- Comment: If possible do profile on current MMB and not catchability. Since MMB is model output and not a parameter, this is usually done by forcing the model to fit a pseudo survey in the final year and varying the survey values.
- *Response: We have investigated the component likelihoods against terminal MMB (Figure 34 for EAG and Figure 63 for WAG).*
- Comment: Provide a sensitivity analysis to potential changes in catchability and selectivity in the CPUE time series. Results should be compared for the following alternatives: Alternative 1—no changes in selectivity or catchability, Alternative 2—One break in catchability/selectivity for post rationalization period, Alternative 3—Two catchability/selectivity breaks, one break in 1999 and another post-rationalization. Provide likelihood profiles as described above for each alternative.
- *Response: We followed the suggestions as different scenarios and provide component likelihoods for preferred scenarios .*

Responses to May 2015 CPT comments– continued

- Comment: Provide additional plots to evaluate the fit to the tagging data:
- *Response*: *We provide observed vs. predicted number of recaptures for different time at large and observed mean length and predicted mean length of recaptures for each release size for different time at large. .*
- Comment: Provide confidence intervals assuming log-normality for the quantity of interest .
- *Response: We used the ln(1+CV^2) for variance of ln(CPUE) and ln(MMB) as suggested by Burnham et al. (1987).*
- Comment: Provide an analysis of sensitivity to the F penalty in model fitting. During estimation phases, relax the F penalty earlier than the final phase. Evaluate the effect of different mean F values in the F penalty term (from low to high).
- *Response: We relaxed the F penalty to an earlier phase (selectivity phase) and investigated different mean F in the F penalty (scenario 7)(Table 31).*
- Comment: The model currently initializes by estimating the abundance by length category in the first year. Compare this method to an approach that assumes some average level of recruitment to populate the initial size composition.
- *Response:We considered equilibrium condition in one scenario for EAG and all scenarios for WAG.*

Table 4. Scenarios 1 to 12 for the EAG assessment

Scenario		Likelihood/Penalty Weights	Maximum Effective Sample Size
1	Data: Retained Catch, Total Catch, Groundfish Bycatch, tag recaptures, observer CPUE indices. Parameters: q1 and q2; Total Selectivity 1, Total Selectivity 2; Retention Curve 1; F_t ; R_t ; Size transition matrix from tag recaptures, fixed M = 0.18, Groundfish fishery selectivity = 1.	Retained catch = 500 , total catch = number of pots sampled scaled to a maximum of 300, groundfish discard catch = 1 , recruitment deviation = 2.0 , pot fishery F deviation (initial) = 1000 (later 0.001), mean F (initial) = 1000 (later 0.001), groundfish bycatch F deviation (initial) = 1000 (later 0.001), posfunction = 1000.	Retained catch = 200, total catch = 150, groundfish bycatch = 25
2	Scenario 1, but q1, q2, q3, Total Select 1, Total Select 2, Total Select 3 for 1985/86 – 1998/99, 1999/90 – 2004/05, and 2005/06-2014/15.	Scenario 1.	Scenario 1.
3	Scenario 1, but 1985–1998 fishery retained CPUE indices are used as an additional likelihood .	Scenario 1.	Scenario 1.
4	Scenario 1, but without molt probability model.	Scenario 1.	Scenario 1.
5	Scenario 1, but total catch and length frequency from 1996/97 onward are used in the likelihoods	Scenario 1.	Scenario 1.
6	Scenario 1, but effective sample sizes are iteratively estimated.	Scenario 1.	Iteratively estimated
7	Scenario 1, but evaluated the effect of different mean F values (0.09, 0.18, 0.45) in the mean F-penalty .	Scenario 1.	Scenario 1.
8	Scenario 1, but used initial size composition from equilibrium condition.	Scenario 1.	Scenario 1.
9	Scenario 1 and explored the component likelihoods for varying terminal MMB.	Scenario 1.	Scenario 1.
10	Scenario 1 and explored the component likelihoods for varying values of the q pair.	Scenario 1.	Scenario 1.
11	Scenario 1, but used observer CPUE indices for 1995/96-2014/15 with one q.	Scenario 1.	Scenario 1.
12	Scenario 1, but groundfish bycatch data are not used. A mean bycatch F of 0.000148 is used..	Same as scenario 1.	Same as scenario 1.

WAG scenarios

- Table 19. Scenarios 1 to 12 for the WAG assessment are similar to those for EAG, but with few changes

	EAG	WAG
Scenario		
8	Initial size composition from equilibrium condition	Explore MMB
9	Explore MMB	WAG tagging data
10	Explore q	NA
11		Indexing jump from 9 to 11 to be the same as EAG scenario 11
12	Groundfish bycatch data are not used. A mean bycatch F of 0.000148 is used..	Groundfish bycatch data are not used. mean bycatch F of 0.000332

Equilibrium estimate of initial size composition is used in all scenarios.

Input Data for EAG and WAG (page 10)

Data set	Years	Data type(s)
Retained pot catch	1985/86–2014/15	Catch by length
Total pot catch	1990/91–2014/15	Catch by length (Observer nominal total CPUE with effort were used to estimate total pot catch)
Groundfish male discard mortality	1989/90–2013/14	by length
Observer legal size crab CPUE	1995/96–2014/15	Independently estimated annual CPUE index with standard error (by negative binomial GLM) (Fox and Weisberg 2011)
Pot Fishery retained catch CPUE	1985/86–1998/99	Independently estimated annual CPUE index with standard error (by lognormal GLM). This series is used in the model for scenario 3
Tag-recapture data	EAG: 1991, 1997, 2000, 2003, 2006	Release-recapture length and time-at-large - 1717 records
	WAG: 1980s	- 64 records

CPUE standardization

Observer legal size male CPUE index:

null model:

- ln(? ? ? ? ?) ? ? ? ?? ? ? ??

Full model for stepwise selection by GLM with negative binomial model :

- Ú Æ ? ? ? ? ? ? ? ? ?? ? ? ? (? ? ? ? ?? ? ? ?) ? ? ? ? h? ? ? ? ? ? ? ? ? ? ? ? ? ? ?? ?
  ? ? ? ? ? ?? ? ? ? ? ? ? ? ? ? ? (? ? ? ? h? ? ? ?) ? ? Æ ? ? ? ? ? ? ? ? ? ? ? ? ? ??

Fish ticket retained male CPUE index:

null model:

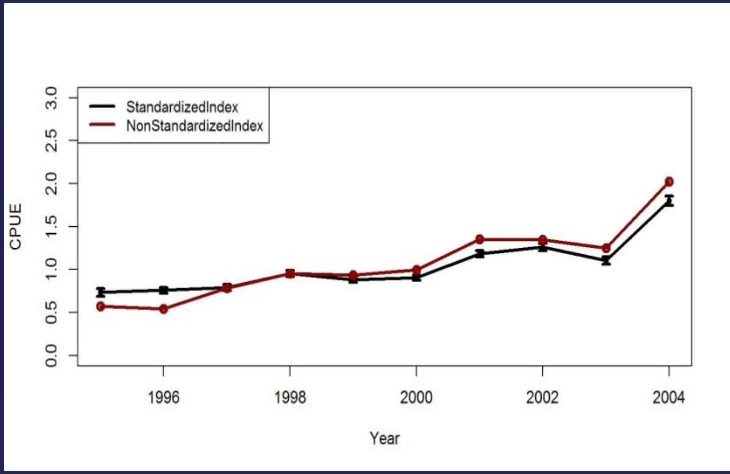
- Ú (? ? ? ? ?) ? ? ? ?? ? ? ??

Full model for stepwise selection by GLM with lognormal model:

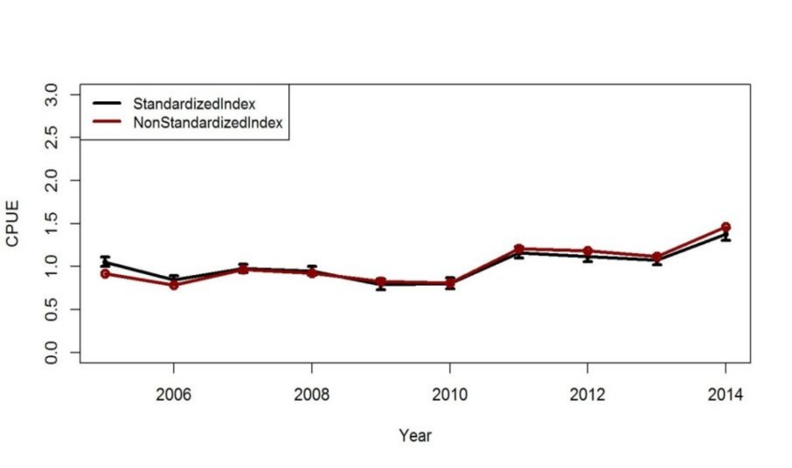
- Ú Æ ? ? ? ? ? ? ? ? ?? ? ? ? ? ? h? ? ? ? ? ? ? ? ? ? ? ? ? ?? ? ? ? ? ? ? ?? ? ? ??

Figure 7. Trends in non-standardized and standardized (negative binomial GLM) observer CPUE indices with +/- 2 SE for EAG golden king crab. Standardized indices: black line and non-standardized indices: red line.

1995/96–2004/05



2005/06–2014/15



1995/96–2014/15

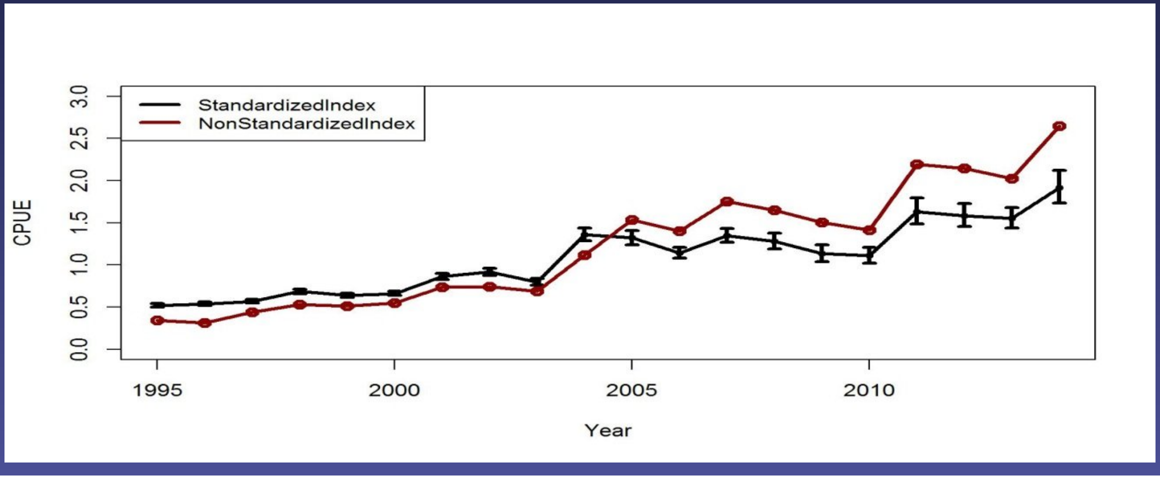
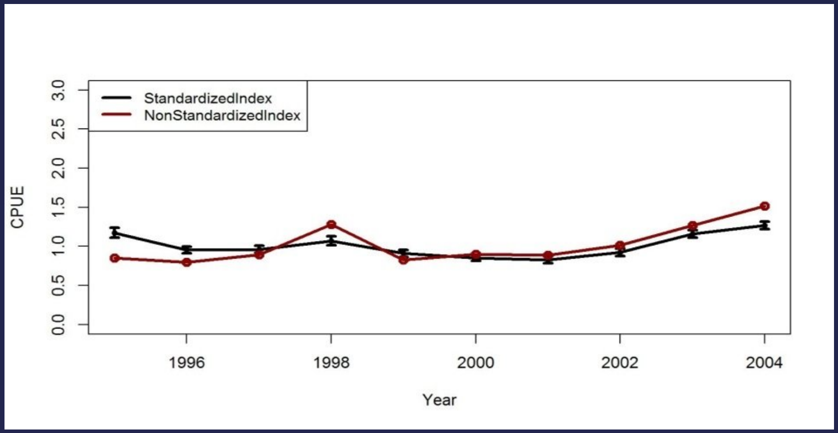
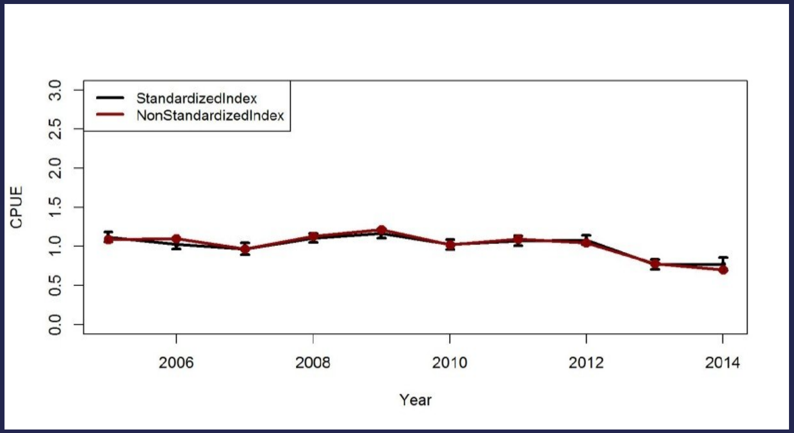


Figure 35. Trends in non-standardized and standardized (negative binomial GLM) observer CPUE indices with +/- 2 SE for WAG golden king crab. Standardized indices: black line and non-standardized indices: red line.

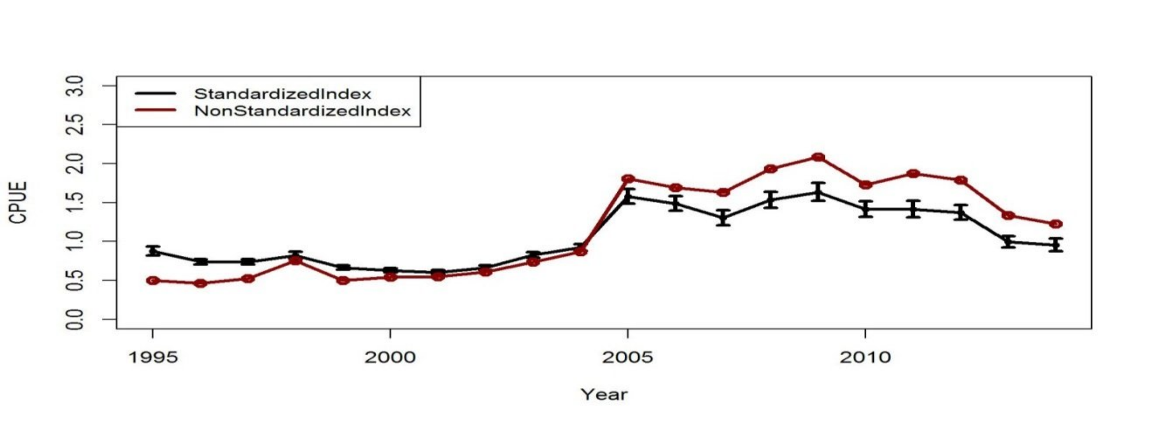
1995/96–2004/05



2005/06–2014/15

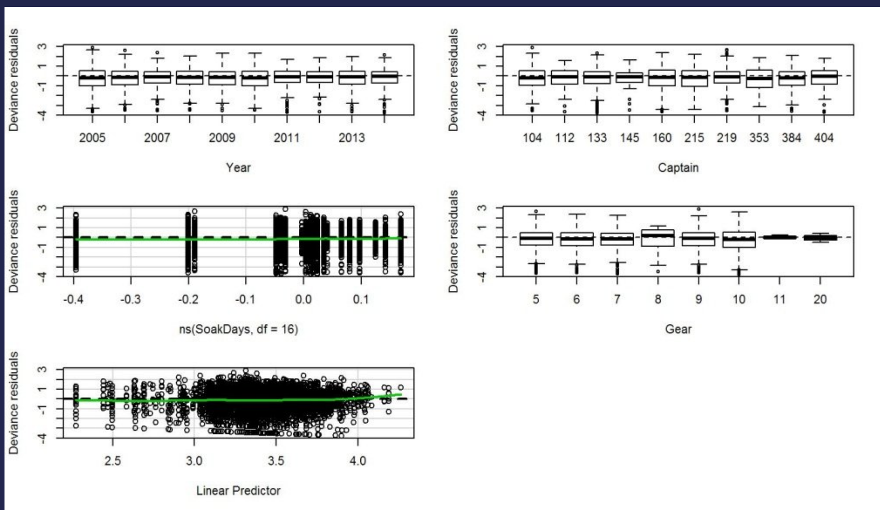


1995/96–2014/15

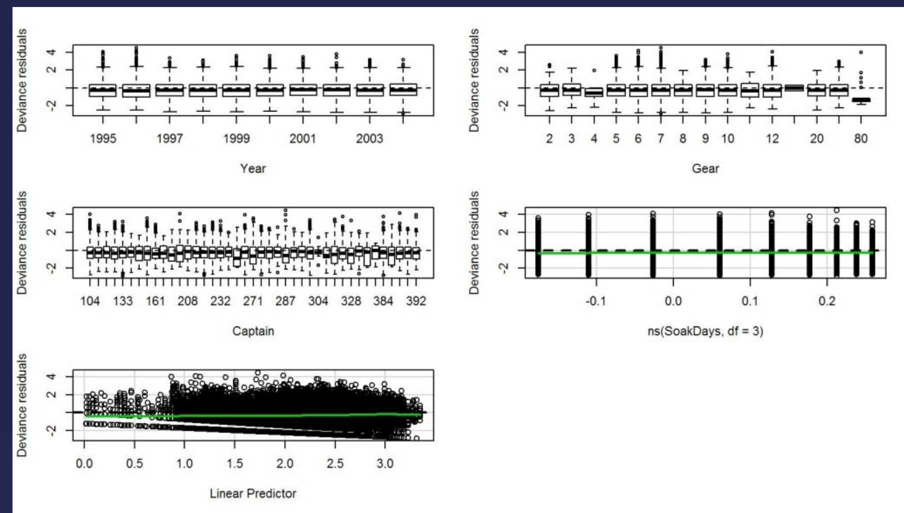


Figures 8 and 9. Deviance residuals vs. explanatory and response variables of the best fit model for EAG CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. The solid green lines are the loess smoother through the plotted values.

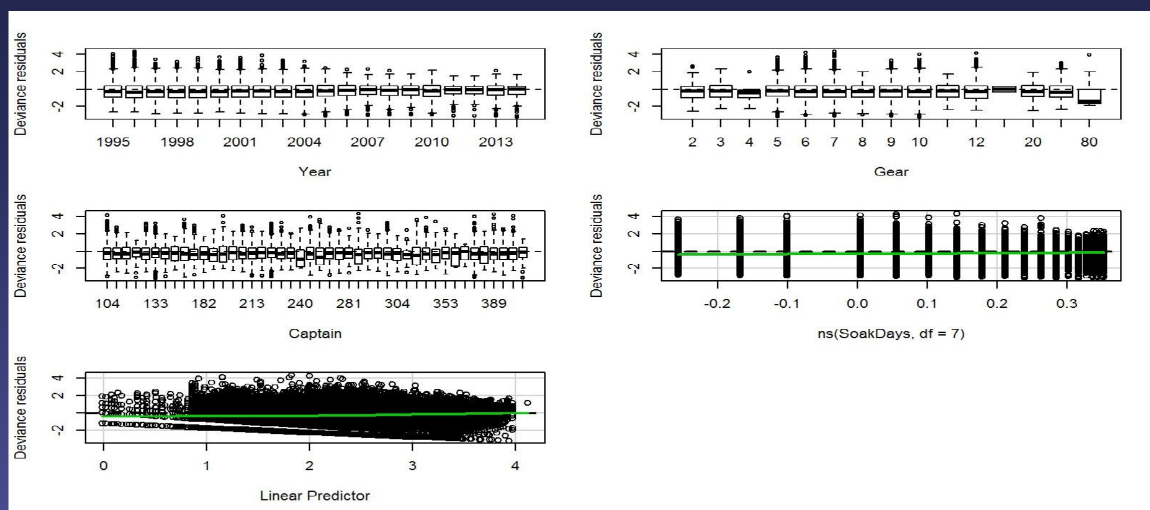
1995/96–2004/05



2005/06–2014/15

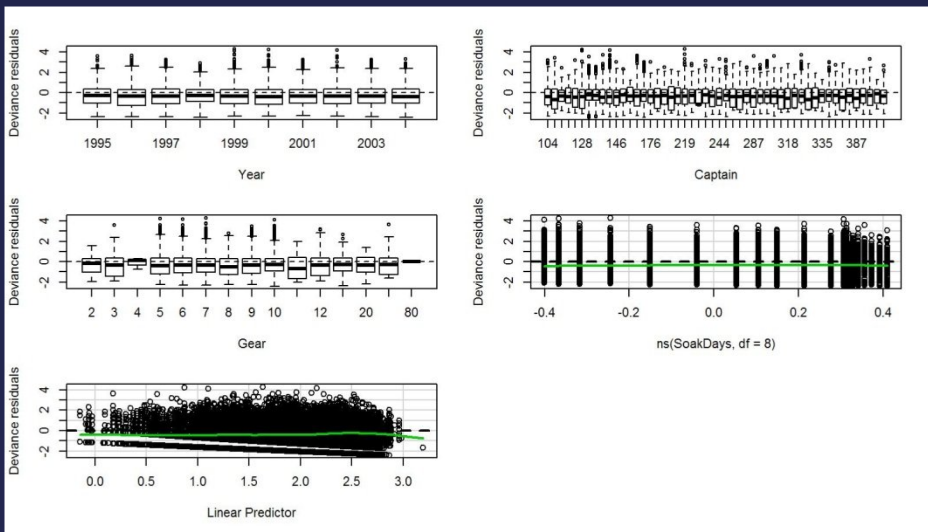


1995/96–2014/15

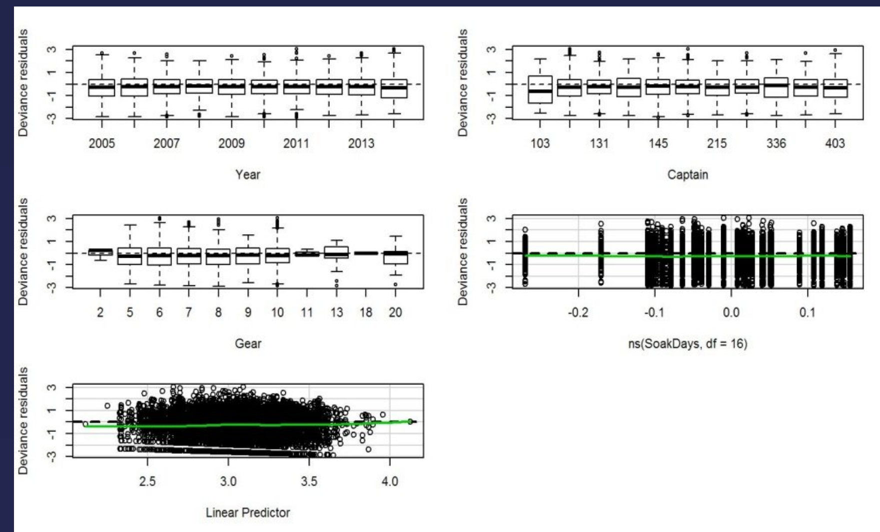


Figures 36 and 37. Deviance residuals vs. explanatory and response variables of the best fit model for WAG CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x-axis for soak time variable. The solid green lines are the loess smoother through the plotted values.

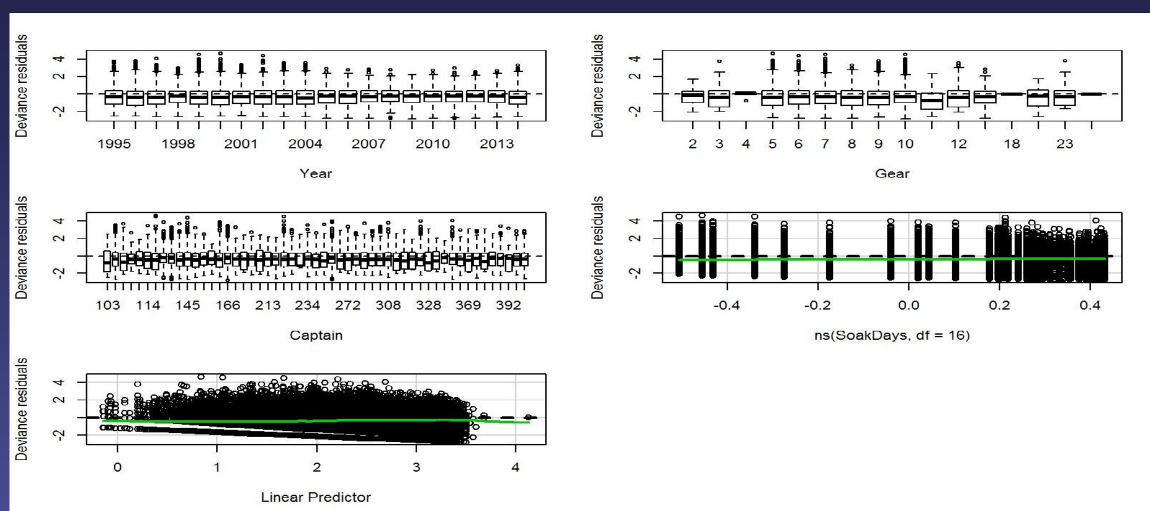
1995/96–2004/05

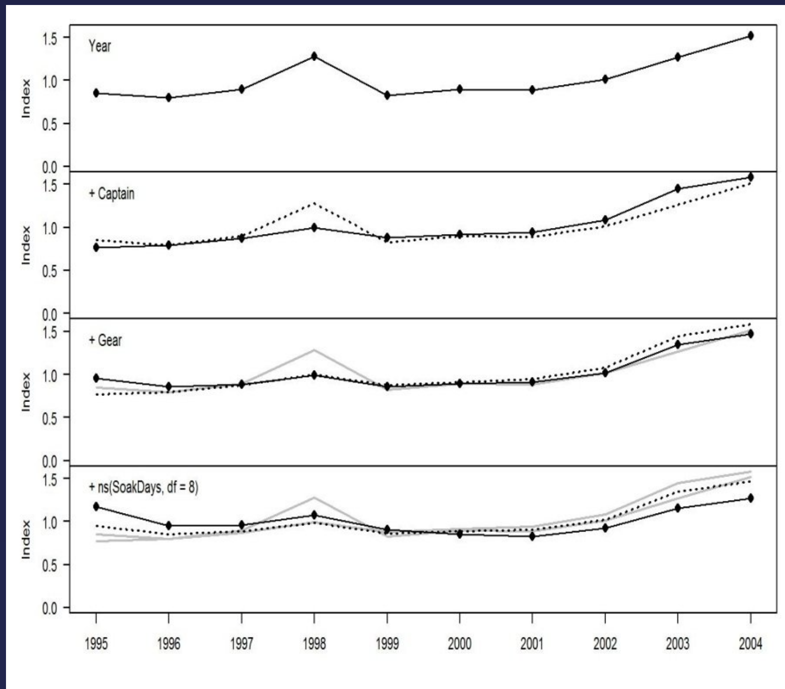


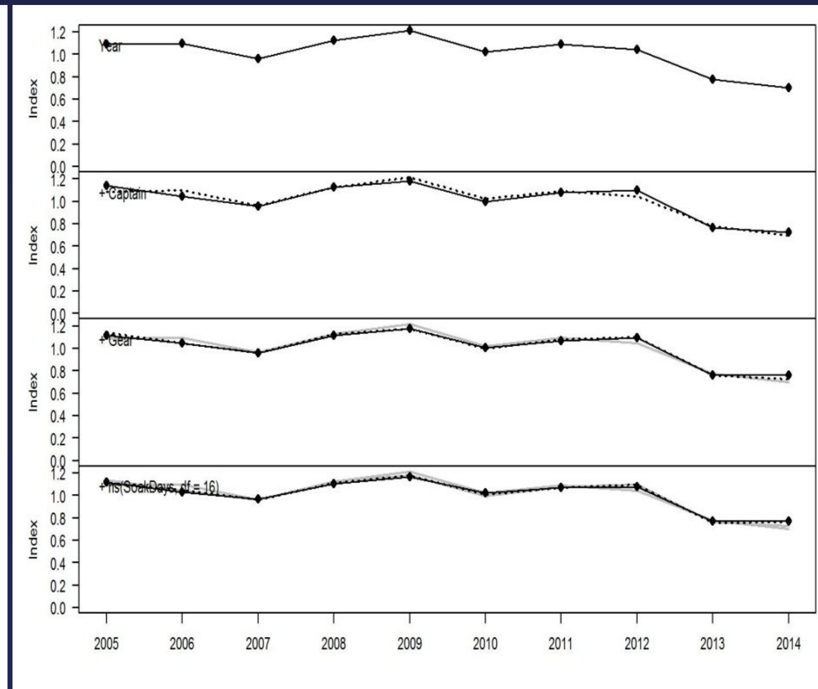
2005/06–2014/15



1995/96–2014/15



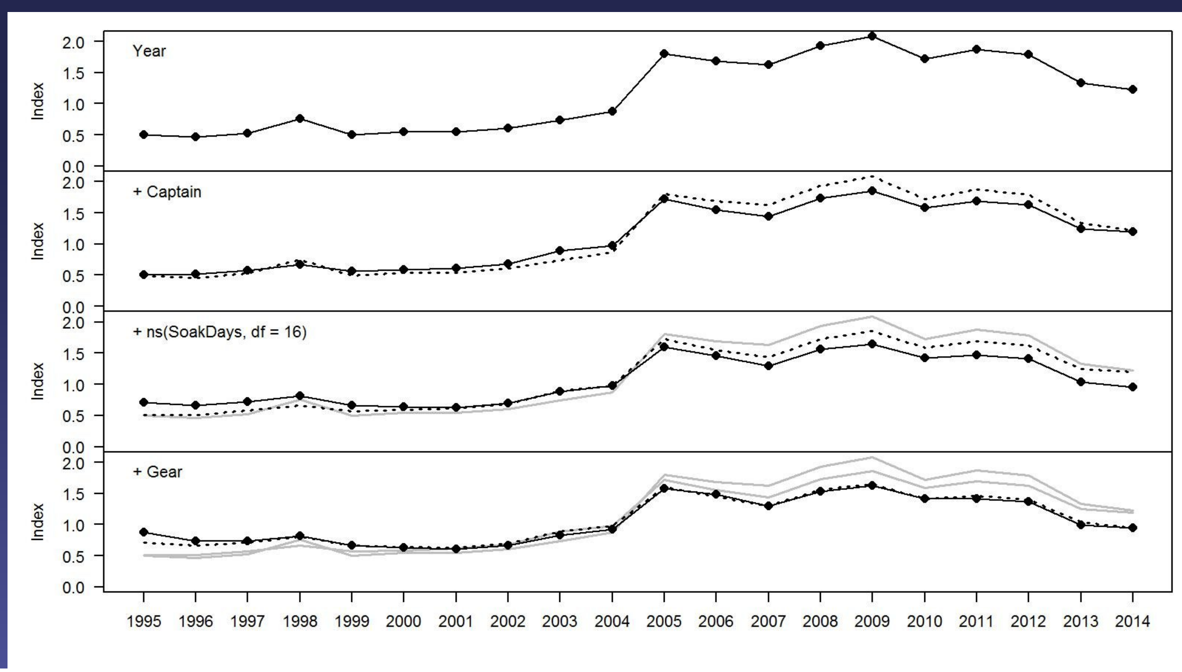




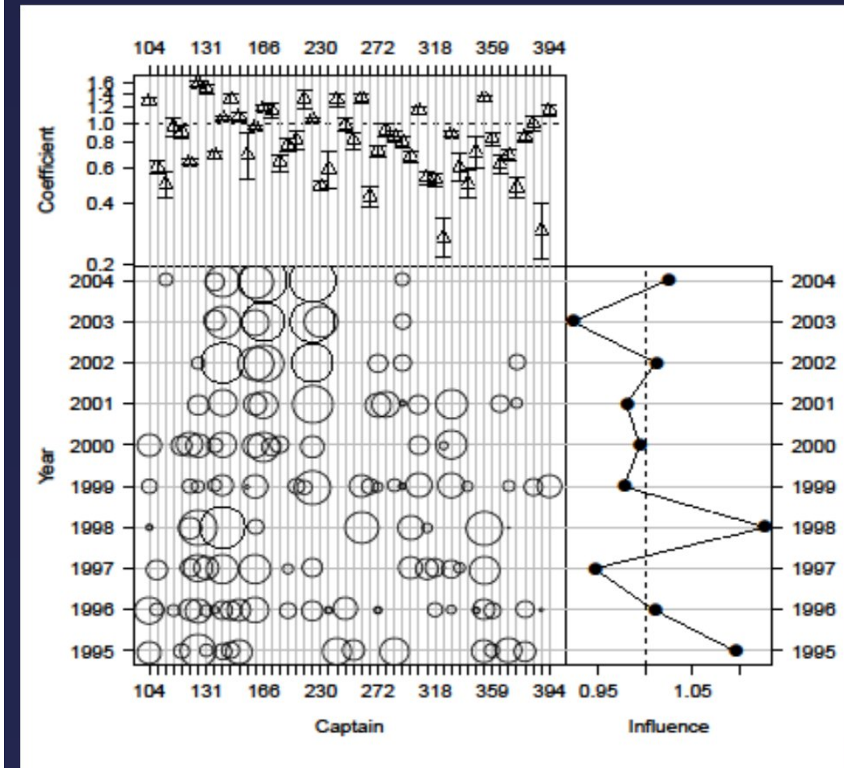
WAG

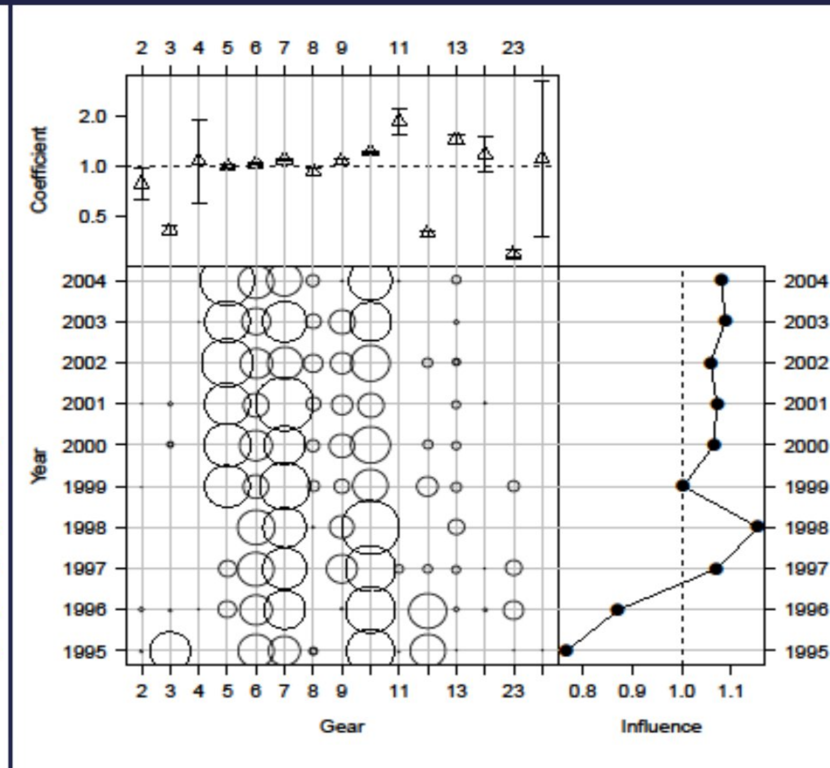
95-04

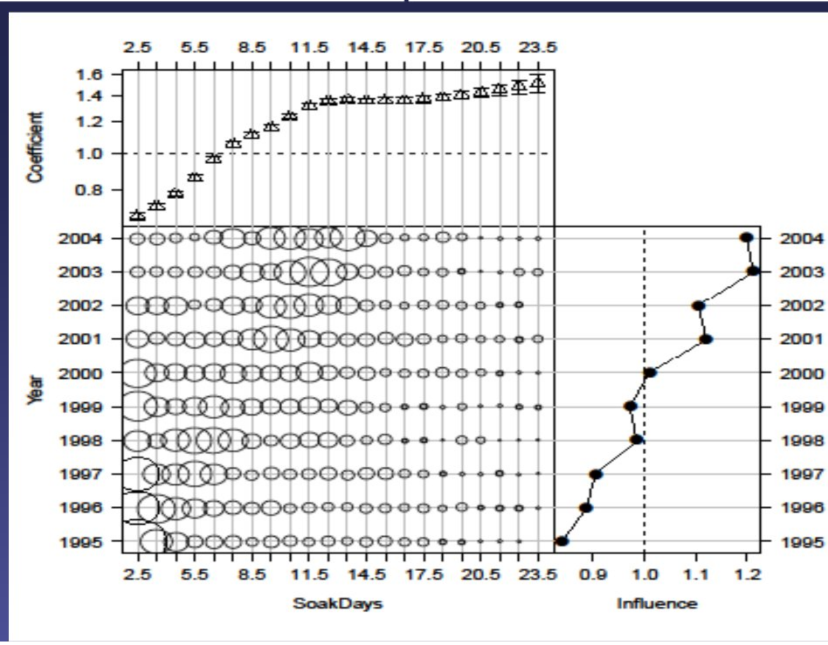
05-14



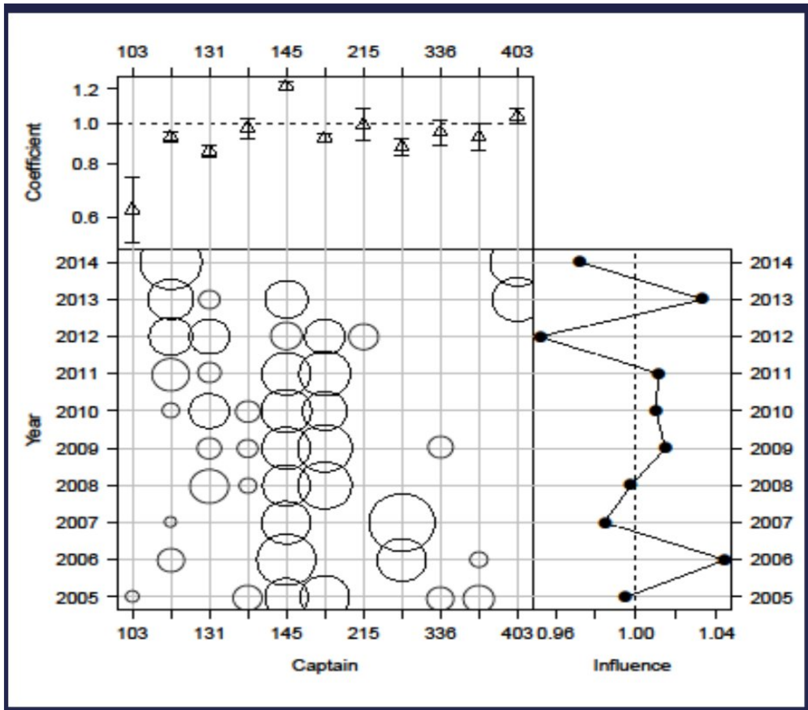
95-14

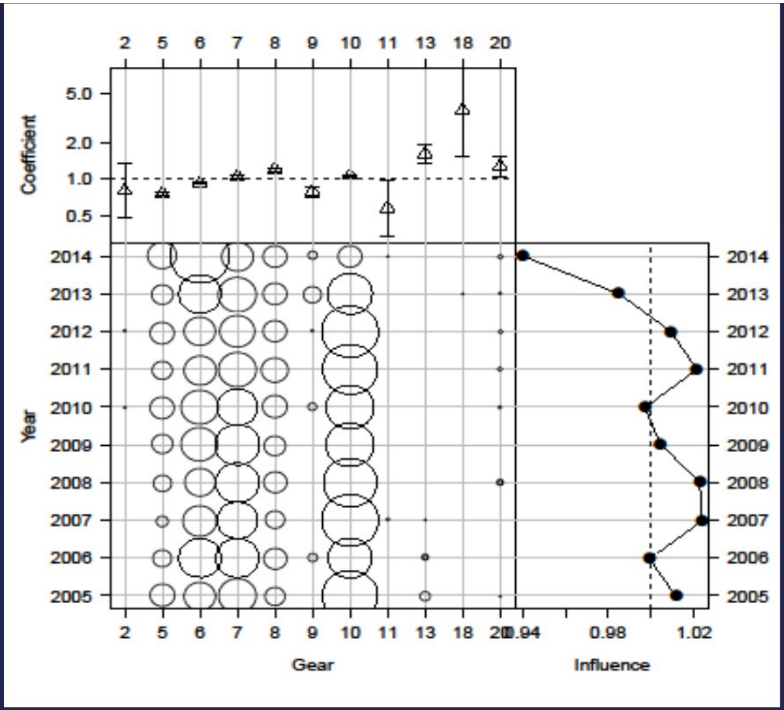


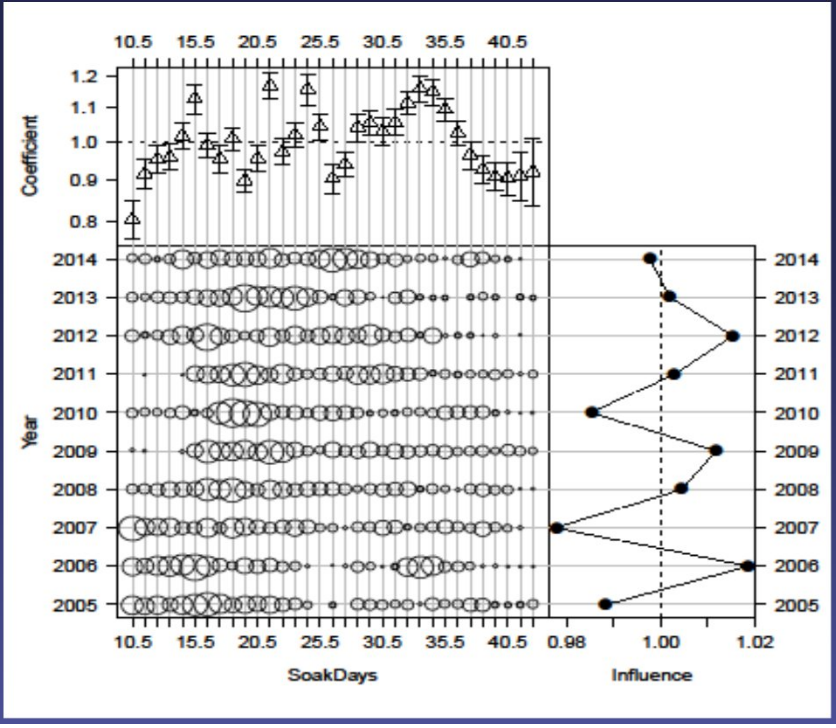




WAG 1995/96-2004/05







WAG 2005/06-2014/15

Revised catch equations

- $\hat{T}_{??}temp = \frac{??\,?^{?}_{??}}{?_{??}} N_{??}e^{??\,?_{?}?} (1 - e^{??\,??})$
- $\hat{C}_{??} = \frac{??\,?^{?}_{??}\,?^{?}_{??}}{?_{??}} N_{??}e^{??\,?_{?}?} (1 - e^{??\,??})$
- $\hat{D}_{??} = 0.2(\hat{T}_{??}temp - \hat{C}_{??})$
-
- $\hat{T}_{??} = \hat{C}_{??} + \hat{D}_{??}$
- $Z_{??} = F_{?}s^{?}_{??}s^{?}_{??} + 0.2F_{?}s^{?}_{??}(1 - s^{?}_{??}) + 0.65\,F^{??}_{?}s^{??}_{?}$

Previous Z formula:

- $Z_{??} = F_{?}s^{?}_{??} + F^{??}_{?}s^{??}_{?}$

Initial condition

1. Initial condition (t=1985) :

? ???? ? ? ???? ? ∈? ∑? ? ∈? (4)

-

2. Equilibrium initial condition:

- The equilibrium stock abundance is

  N = X.S.N + R (5)

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

- The equilibrium N is

  ? Æ − ? ? ? ? ? (6)

  where *I* is the identity matrix.

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

Likelihood components

- $LL_{?}^{??\,???} = \lambda_{?} \sum_{?}\{\ln(\sum_{?} \hat{C}_{?\,?} w_{?} + c) - \ln(\sum_{?} C_{?\,?} w_{?} + c)\}^{?}$ (12a)
- $LL_{?}^{??\,???} = \lambda_{?} \sum_{?}\{\ln(\sum_{?} \hat{T}_{?\,?} w_{?} + c) - \ln(\sum_{?} T_{?\,?} w_{?} + c)\}^{?}$ (12b)
-
- $LL_{?\,?}^{??\,???} = \lambda_{?\,?} \sum_{?}\{\ln(\sum_{?} \widehat{Tr}_{?\,?} w_{?} + c) - \ln(\sum_{?} Tr_{?\,?} w_{?} + c)\}^{?}$ (12c)
- $LL_{?}^{??\,???} = \lambda_{?} \sum_{?}\{\ln(\sum_{?} \hat{C}_{?\,?} w_{?} + c) - \ln(\sum_{?} C_{?\,?} w_{?} + c)\}^{?}$ [X: 1981/82 to 1984/85 retained catch for equilibrium initial composition calculation]

Likelihood components

- $LL_{?}^{????} =$
  $$\lambda_{?????}\left\{0.5\sum_{?} \ln\left[2\pi\left(\sigma_{??}^{?} + \sigma_{?}^{?}\right)\right] + \sum_{?} \frac{\left(?? Æ ????_{?}^{?}??\ ?\ ?? Æ ???_{?}^{?}??\right)^{?}}{?\left(?_{??}^{?}?\ ?_{?}^{?}\right)}\right\}$$
  (13)

$$\widehat{CPUE}_{?}^{?} = q_{?} \sum_{?} S_{?}^{?} S_{?}^{?} \left(N_{??} - 0.5\left[\widehat{C}_{??} + \widehat{D}_{??} + \widehat{Tr}_{??}\right]\right)e^{???}$$

$$\sigma_{??}^{?} = \ln(1 + CV_{??}^{?})$$

(15)

Likelihood components

- Robust normal likelihood function for length composition data (retained, total, groundfish discard mortality)(Equation 16).
- Multinomial likelihood function for tagging data (Equation 19)

- Penalty functions:

(a) pot F_dev (Equation 22)

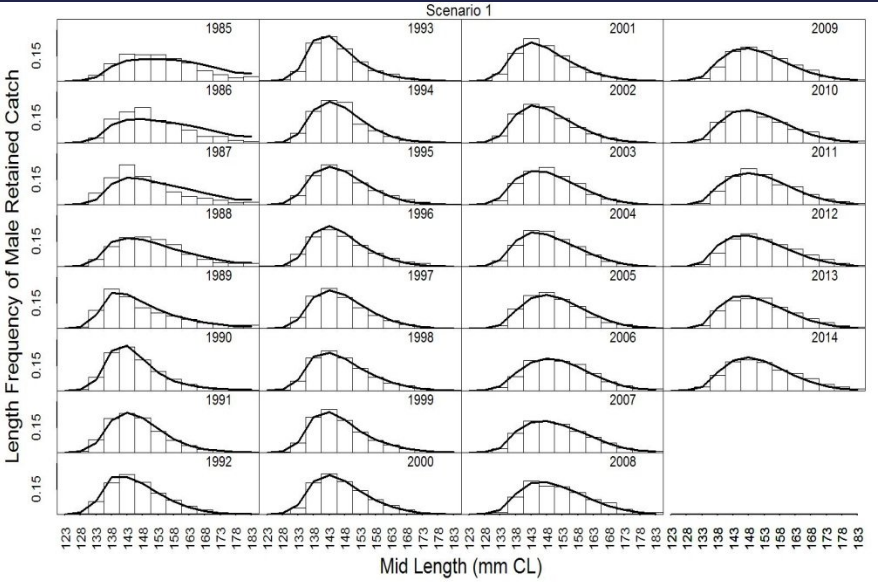
(b) groundfish bycatch F_dev (Equation 22)

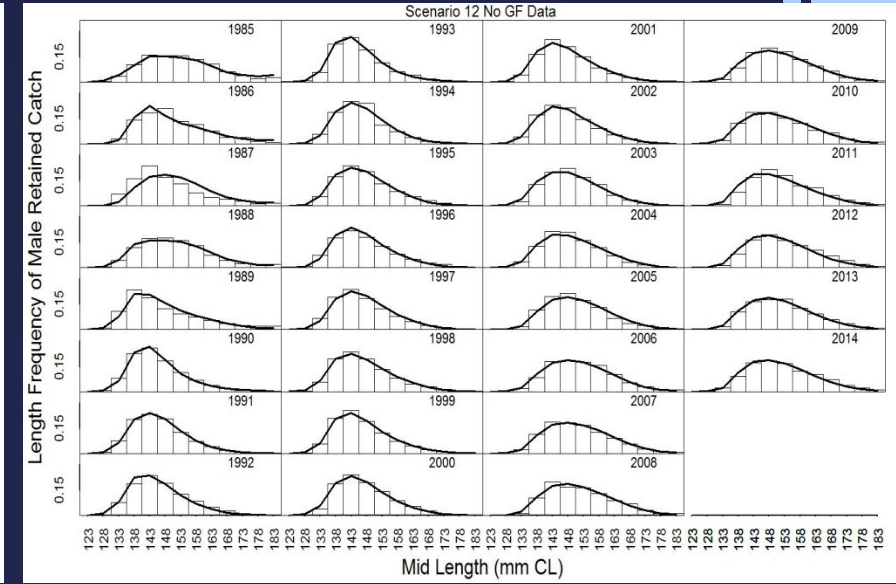
(c) R_dev (Equation 23)

(d) average F about a fixed F (Equation 24)

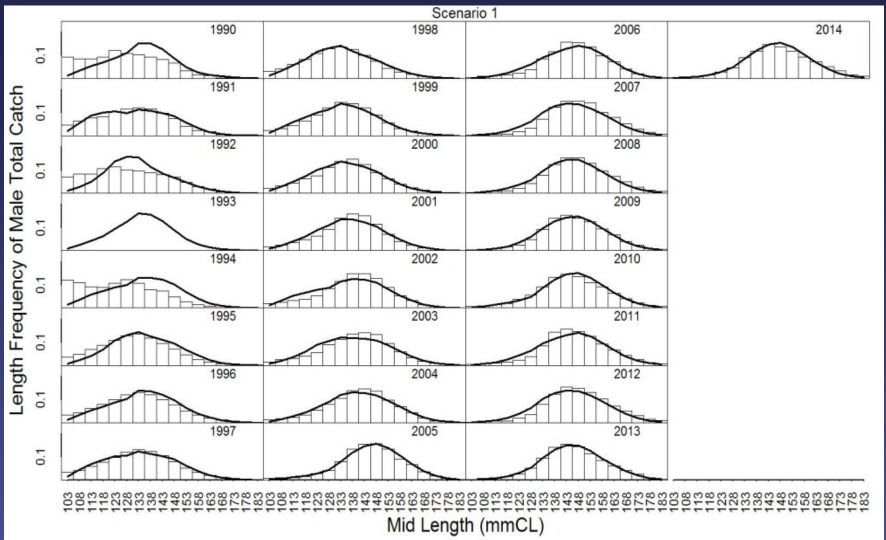
(e) posfunction (Equation 25)

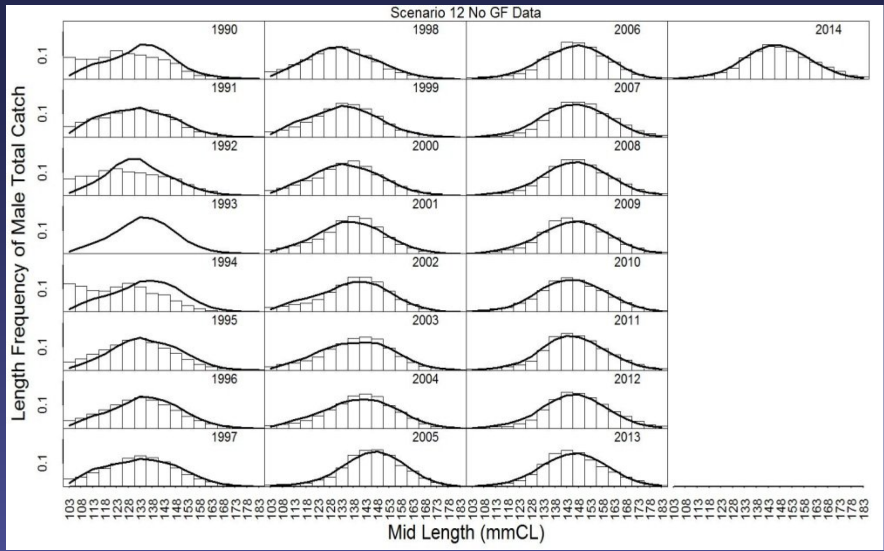
Figures 69a & 70a. Predicted (line) vs. observed (bar) retained catch length composition for scenarios 1 (left) and 12 (right) for EAG.



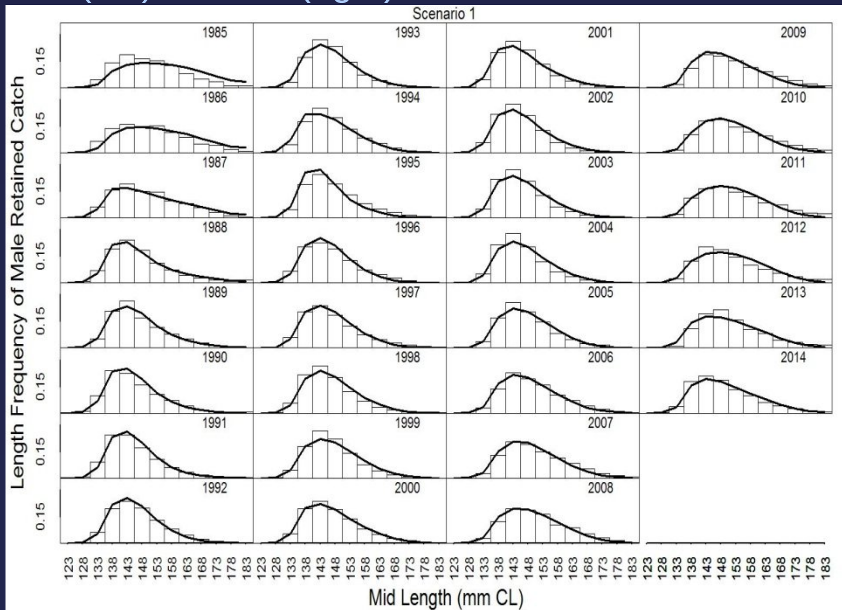


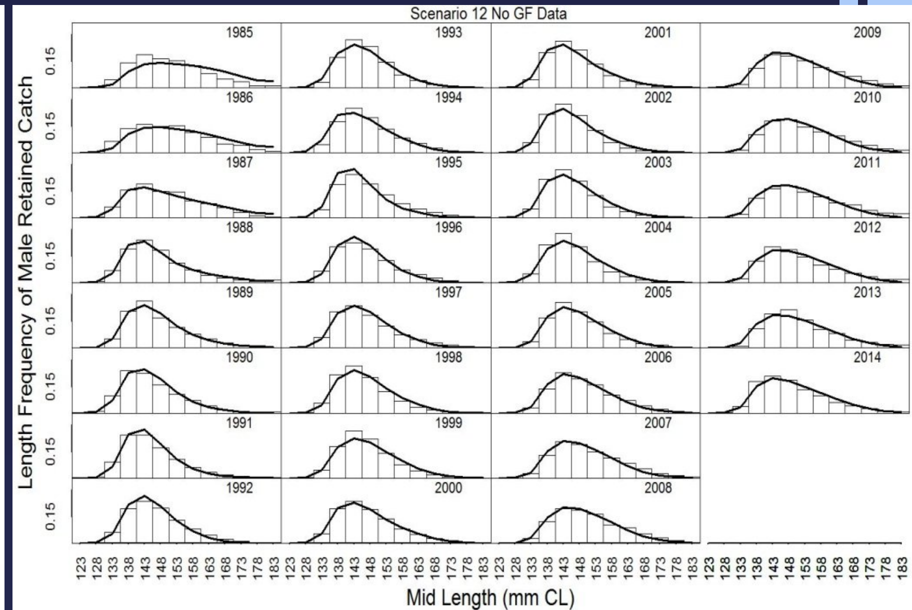
Figures 69b & 70b. Predicted (line) vs. observed (bar) total catch length composition for scenarios 1 (left) and 12 (right) for EAG.



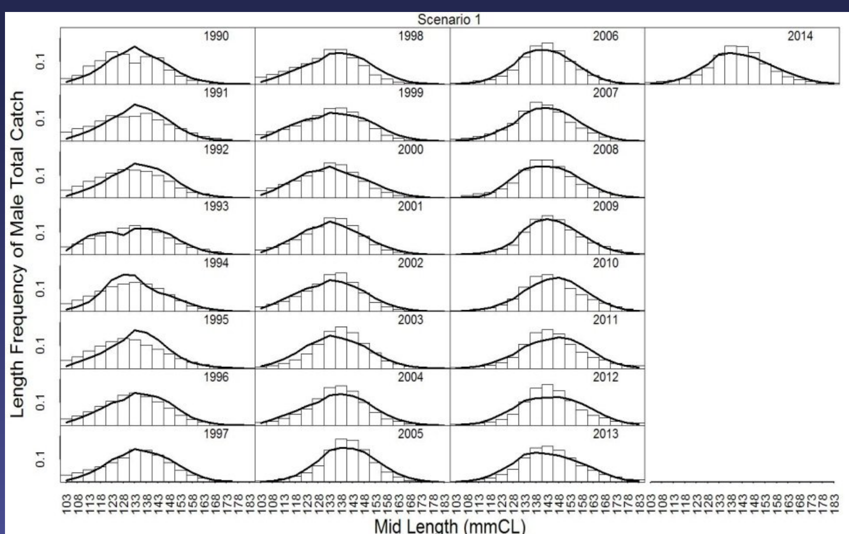


Figures 39 & 71a. Predicted (line) vs. observed (bar) retained catch length composition for scenarios 1 (left) and 12 (right) for WAG.





Figures 41 & 71b. Predicted (line) vs. observed (bar) total catch length composition for scenarios 1 (left) and 12 (right) for WAG.



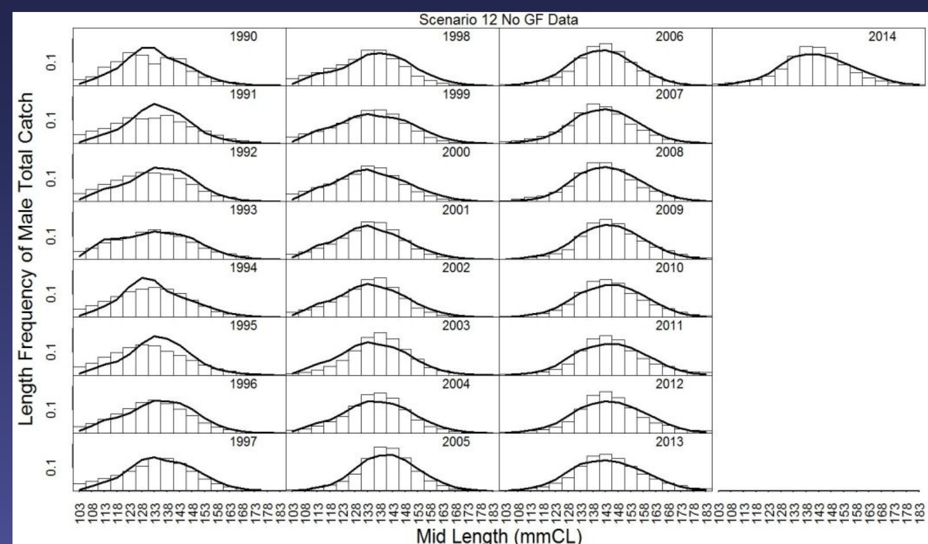


Figure 23. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios 1, 2, 3, 4, 5, 6, 8, 11, and 12 fits to EAG data,

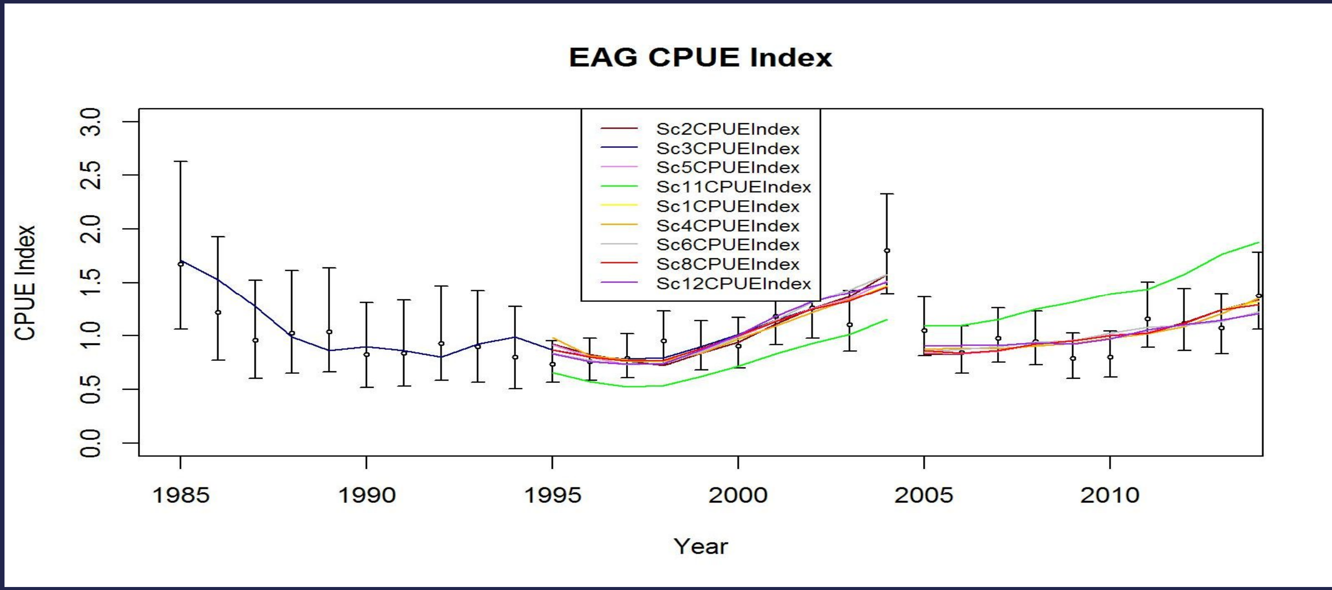


Figure 53. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios 1, 2, 3, 4, 5, 6, 9, 11, and 12 fits for WAG data.

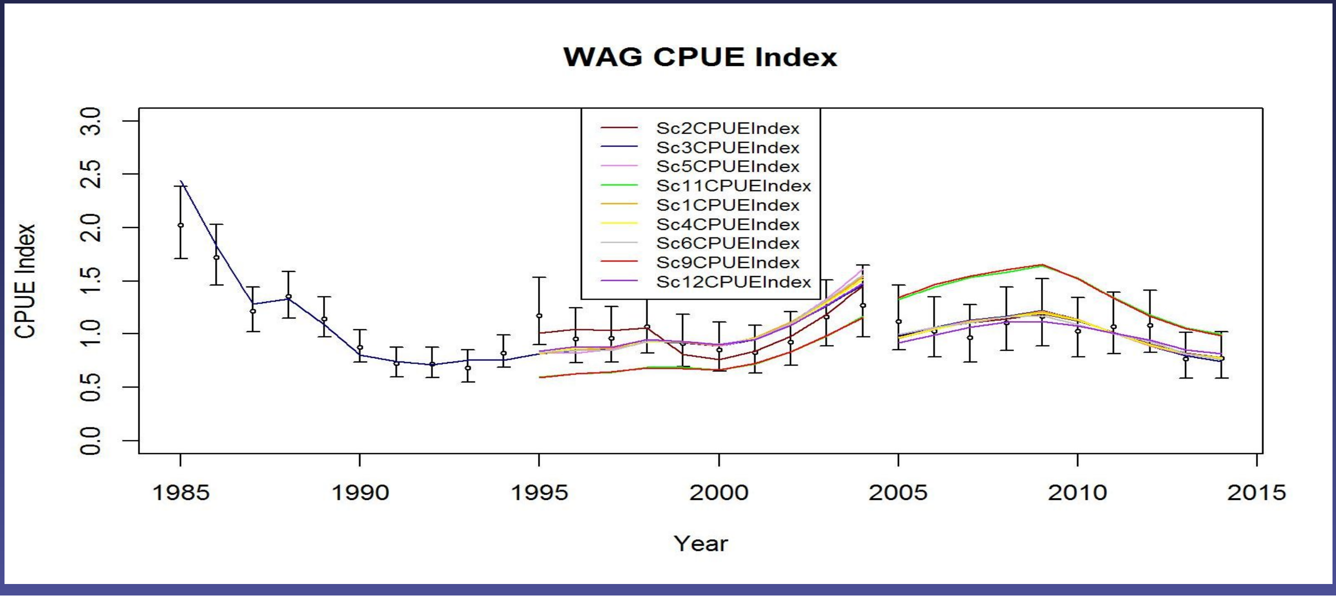


Figure 21. Observed tag recaptures (open circle) vs. predicted tag recaptures (solid line) by size bin for years 1 to 6 recaptures for scenario 1 model fit to EAG data.

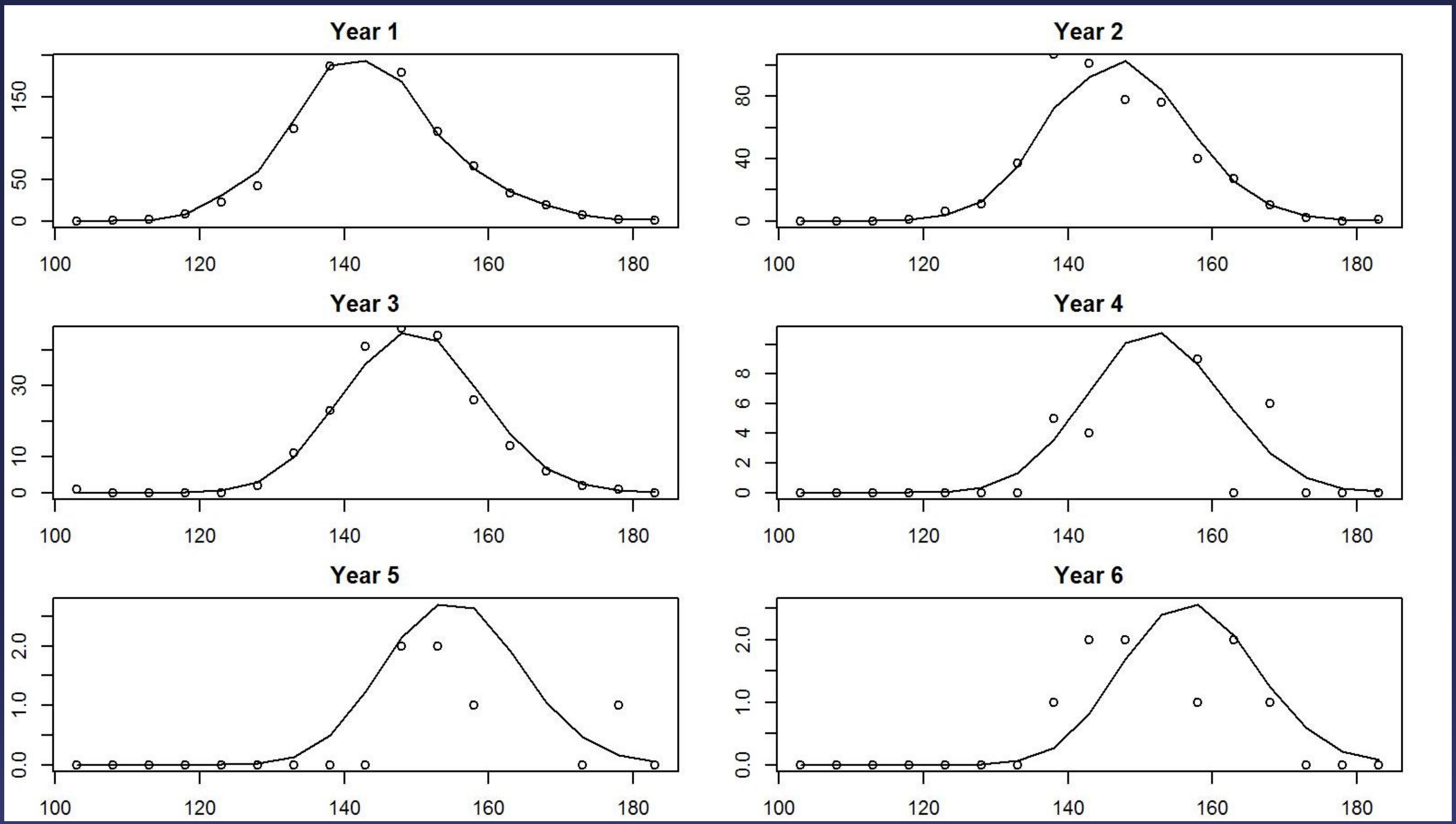
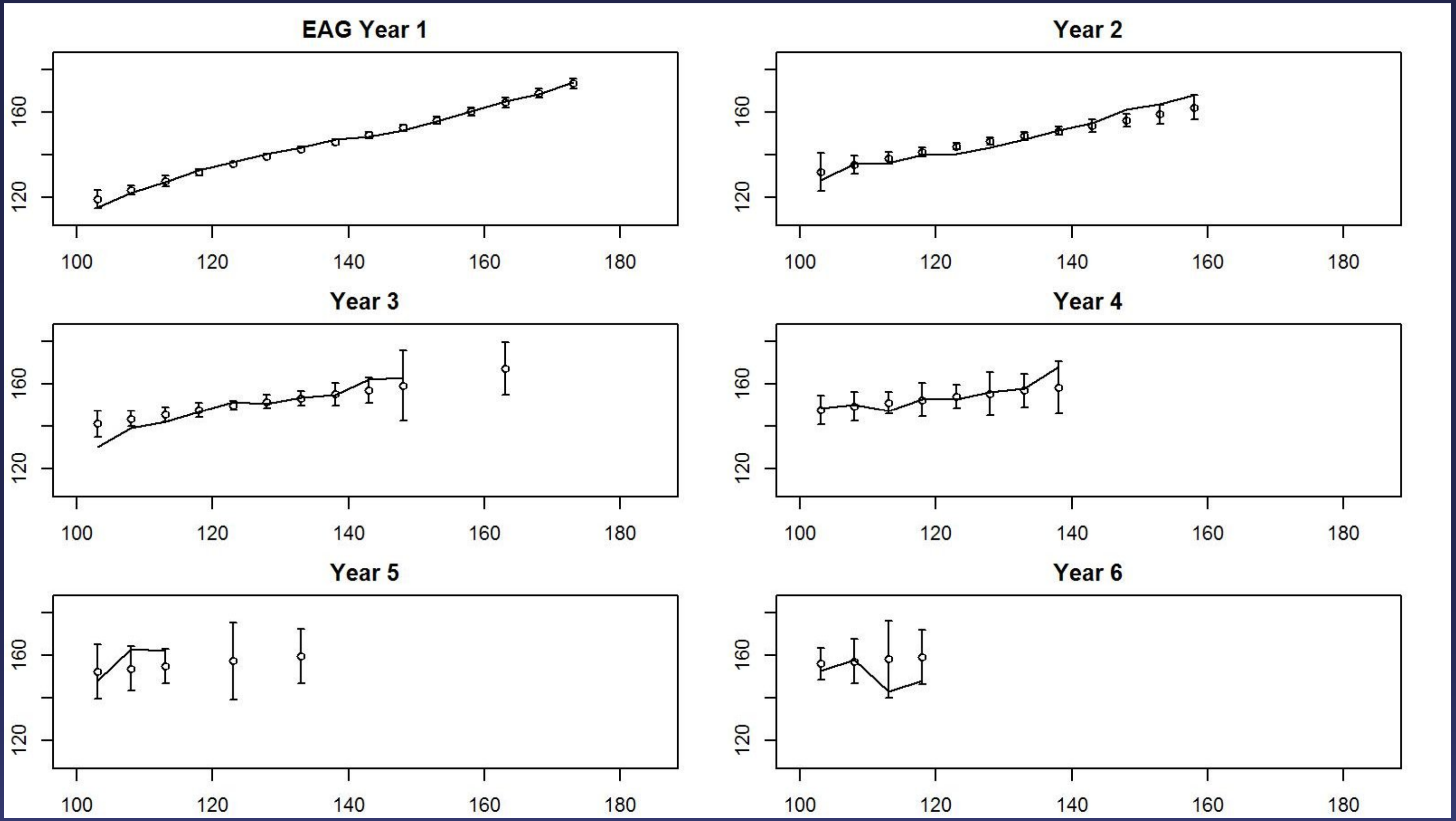
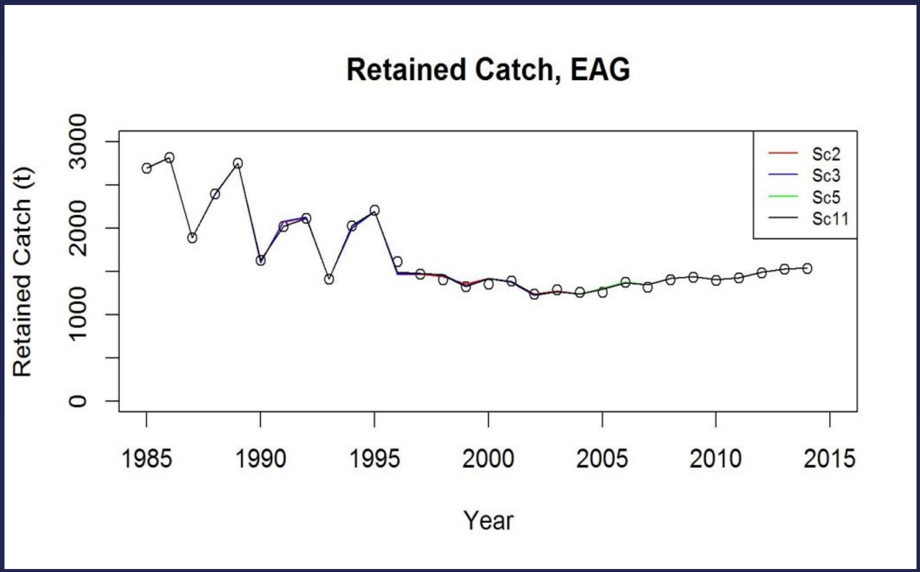
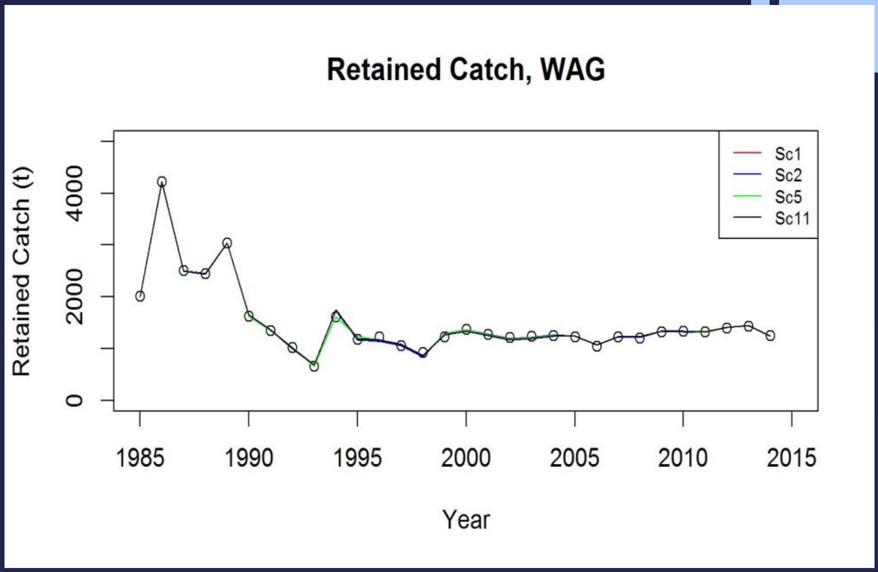


Figure 22. Observed and predicted mean length (with two SE) of recaptures vs. release length for years 1 to 6 recaptures for scenario 1 model fit to EAG data.

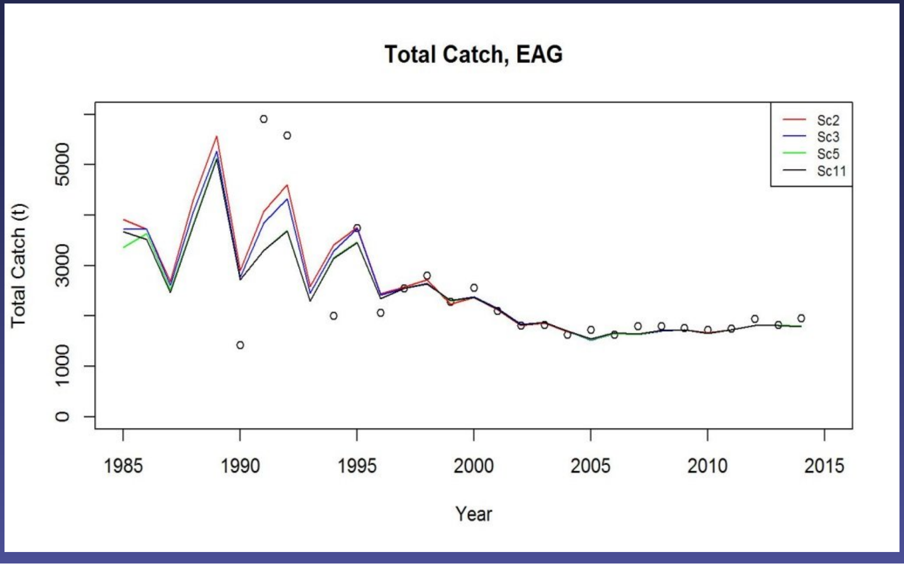


Figures 29 and 59. Observed (open circle) vs. predicted (solid line) retained catch for Sc 2, 3, 5, and 11 fits for EAG (left) and Sc 1, 2, 5, and 11 model fits for WAG (right)





Figures 30 & 60. Observed (open circle) vs. predicted (solid line) total catch for Sc 2, 3, 5, and 11 fits for EAG (left) and Sc 1, 2, 5, 11 fits for WAG model fits (right).



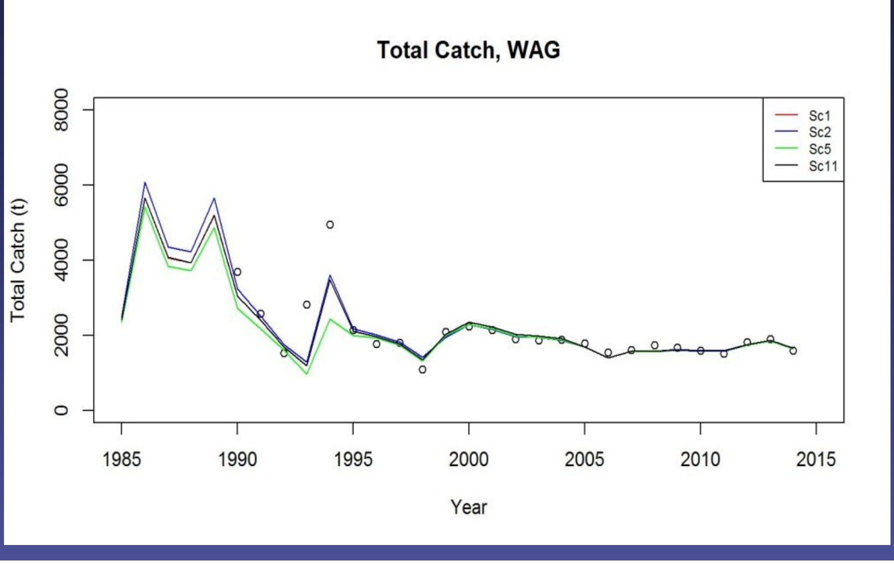


Table 15. Negative log-likelihood values of sc. 1, 2, 3, 5, 11, and 12 fits to EAG data.

Likelihood Component	Scenario 1	Scenario 2	Scenario 3	Scenario 5	Scenario 11	Scenario 12
Number of free parameters	121	124	122	121	120	95
like_retlencomp	-890.50	-891.04	-890.40	-889.84	-891.27	-890.07
like_totallencomp	-867.59	-870.66	-868.06	-732.45	-732.46	-868.74
like_gdiscdlencomp	-647.84	-649.40	-647.80	-648.59	-649.23	-
like_retcpue	-12.15	-10.50	-12.50	-10.98	-11.11	-13.23
like_retdcatchB	8.08	8.28	8.74	5.94	5.92	7.65
like_totalcatchB	31.53	30.86	32.25	11.75	11.60	30.67
like_gdiscdcatchB	0.00	0.00	0.00	0.00	0.00	-
like_rec_dev	5.05	5.56	4.84	4.89	5.03	2.94
like_meanFpot	0.00	0.00	0.00	0.00	0.00	0.00
like_F	0.01	0.01	0.01	0.01	0.01	0.01
like_gF	0.02	0.02	0.02	0.02	0.02	-
like_Tag	2691.67	2688.62	2691.78	2690.57	2690.46	2690.01
like_finalF	0.00	0.00	0.00	0.00	0.00	0.00
like_fpen	0.00	0.00	0.00	0.00	0.00	0.00
LikefishtickCPUE			-0.83			
Total	318.28	311.75	318.06	431.32	428.98	959.24

Table 30. Negative log-likelihood values of Sc 1, 2, 5, 11, and 12 fits to WAG data.

Likelihood Component	Scenario 1	Scenario 2	Scenario 5	Scenario 11	Scenario 12
Number of free parameters	108	111	108	107	82
like_retlencomp	-1001.90	-1007.05	-1016.08	-1002.04	-1004.28
like_totallencomp	-985.01	-991.24	-834.84	-984.84	-984.48
like_gdiscdlencomp	-566.41	-566.61	-567.54	-567.39	-
like_retcpue	-10.92	-19.16	-10.19	-8.86	-13.19
like_retdcatchB	10.77	11.98	6.64	10.78	10.66
like_totalcatchB	49.73	48.43	16.48	49.80	48.44
like_gdiscdcatchB	0.00	0.00	0.00	0.01	-
like_rec_dev	6.33	6.88	5.58	6.61	4.33
like_meanFpot	0.00	0.00	0.00	0.00	0.00
like_F	0.03	0.03	0.03	0.03	0.03
like_gF	0.03	0.03	0.03	0.11	-
like_Tag	2689.34	2687.11	2687.71	2689.31	2688.95
like_finalF	0.00	0.00	0.00	0.00	0.00
like_fpen	0.00	0.00	0.00	0.00	0.00
Total	191.99	170.41	287.81	193.52	750.47

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

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

Figure 32. Retrospective fits of MMB by the model for removal of terminal year's data for scenarios 2 and 5 model fits for EAG.

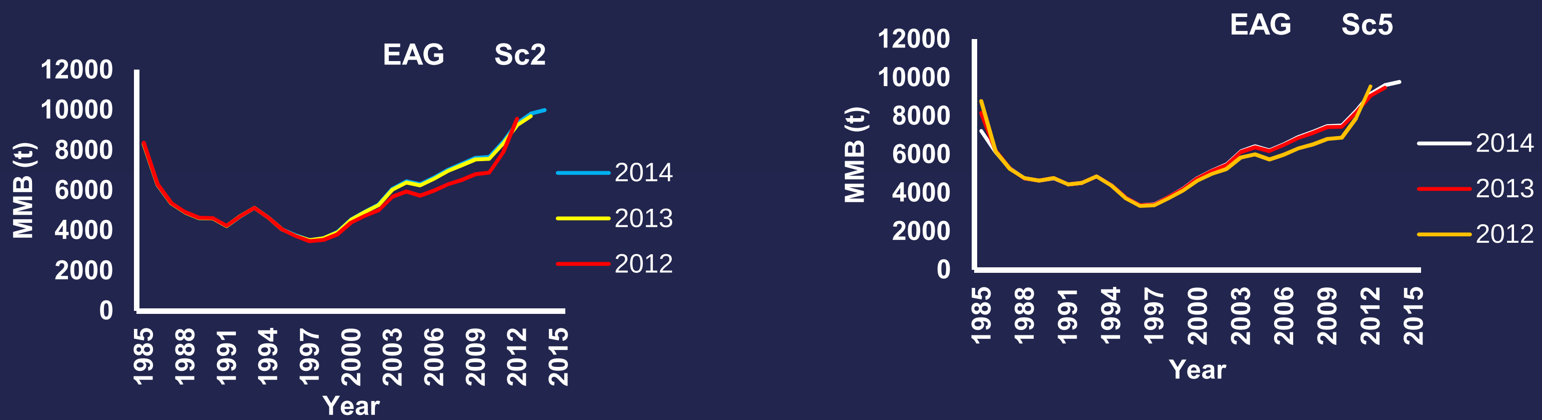


Figure 62. Retrospective fits of MMB by the model for removal of terminal year's data for scenarios 1 and 5 model fits for WAG.

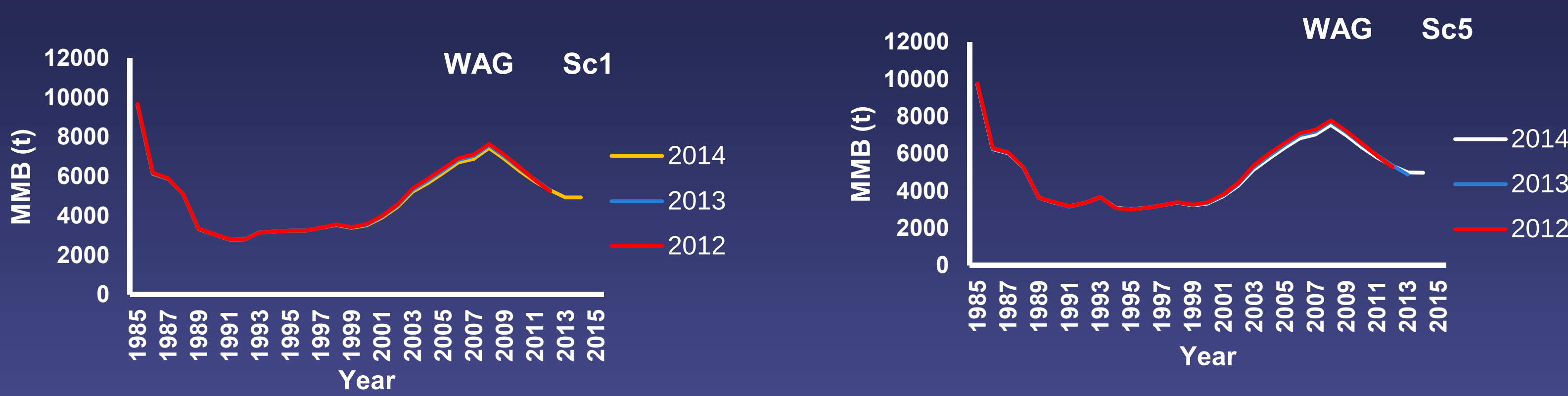


Figure 33. Total negative log-likelihood and the components of it vs. fraction of the estimated pair of catchability coefficients for scenario 1 model fit to EAG data (all zero adjusted).

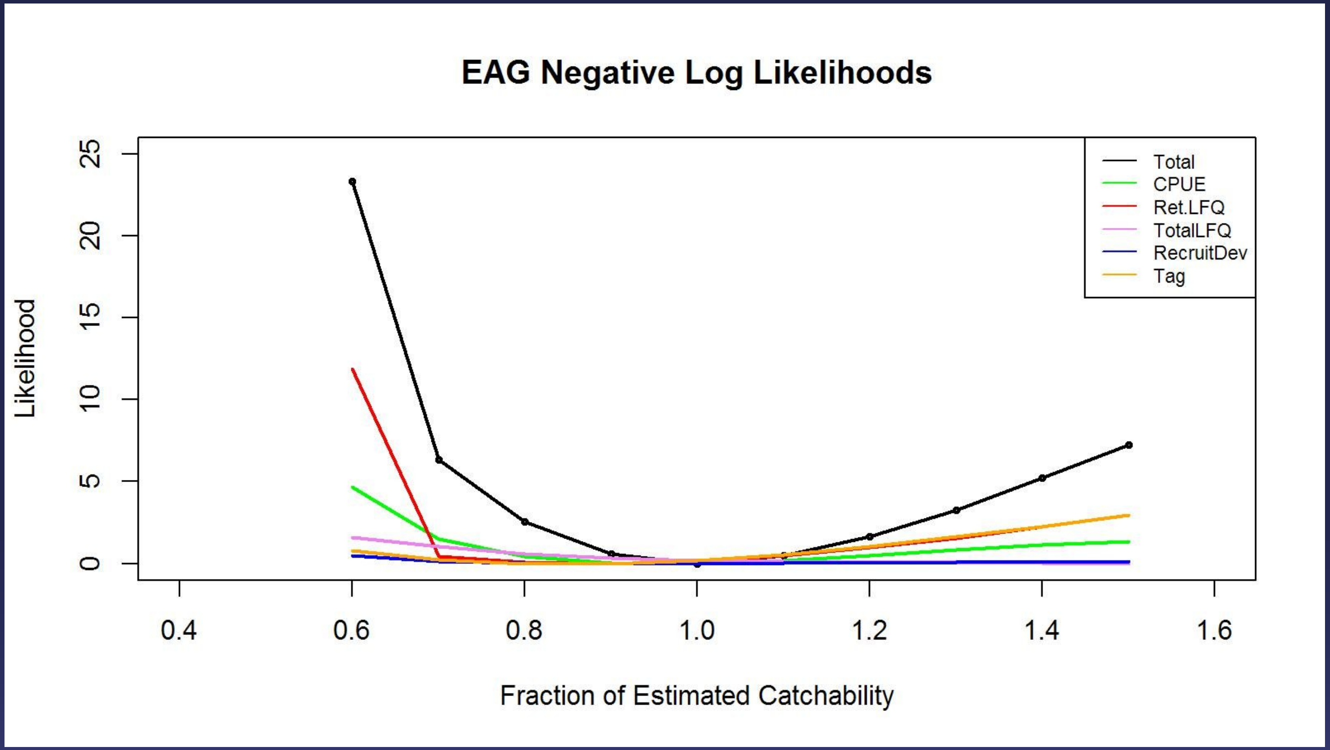


Figure 34. Total negative log-likelihood and components of it vs. fraction of the estimated terminal MMB for scenario 1 model fit to EAG data (all zero adjusted).

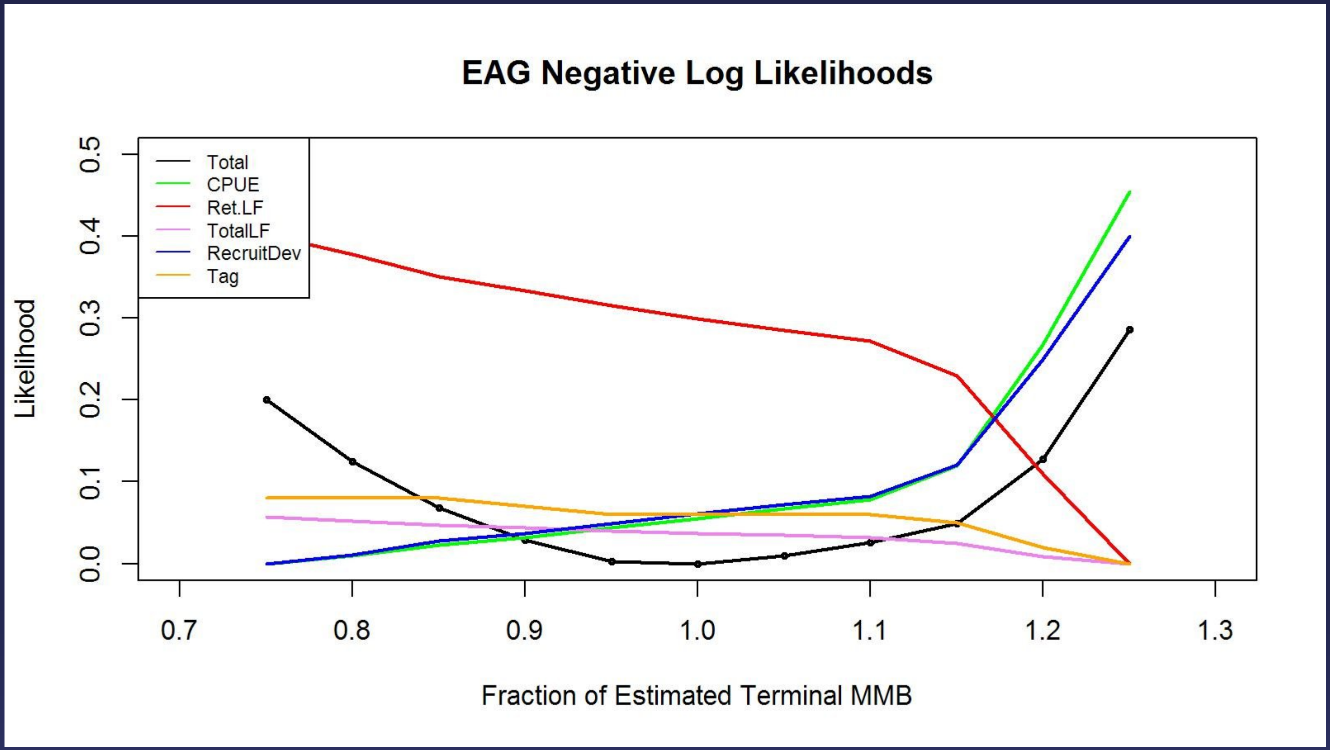


Figure 63. Total negative log-likelihood and components of it vs. fraction of the estimated terminal MMB for scenario 1 model fit to WAG data (all zero adjusted).

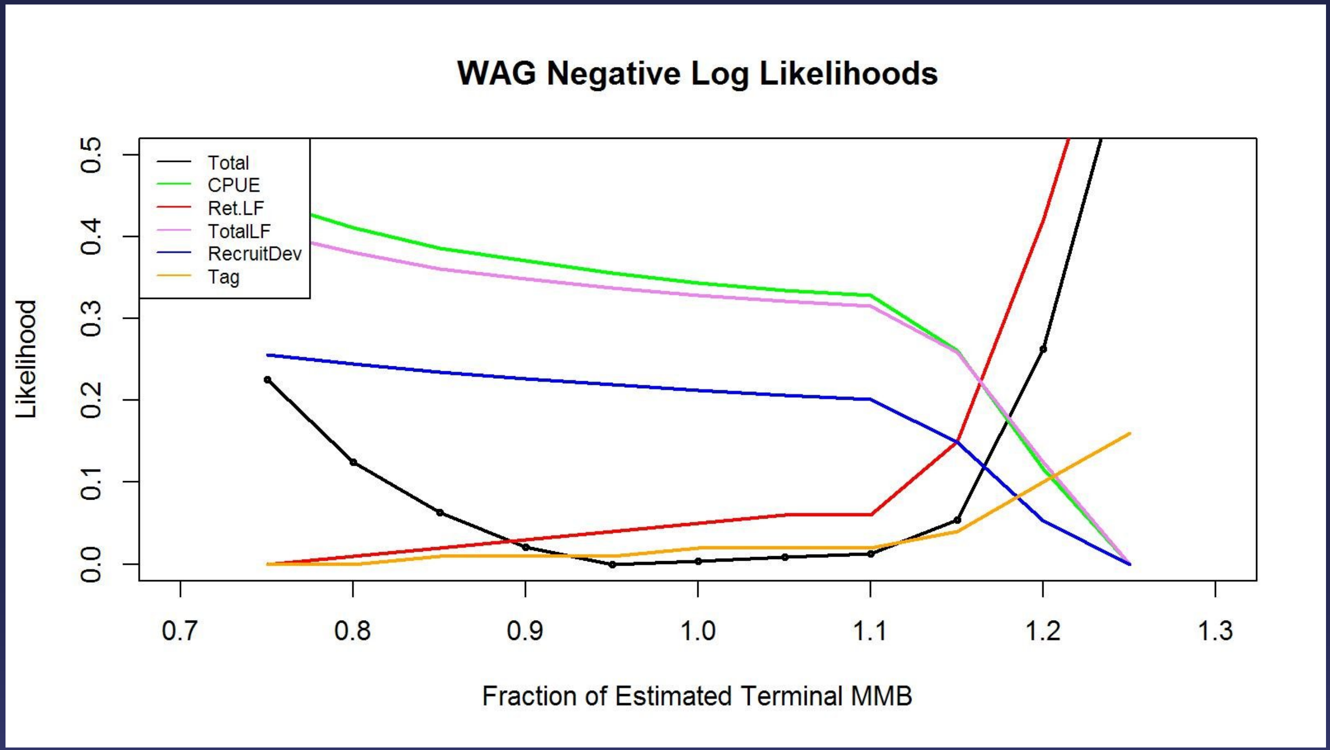


Figure 68. Equilibrium and 1985 size compositions for scenario 1 model fit for EAG (top) and WAG (bottom).

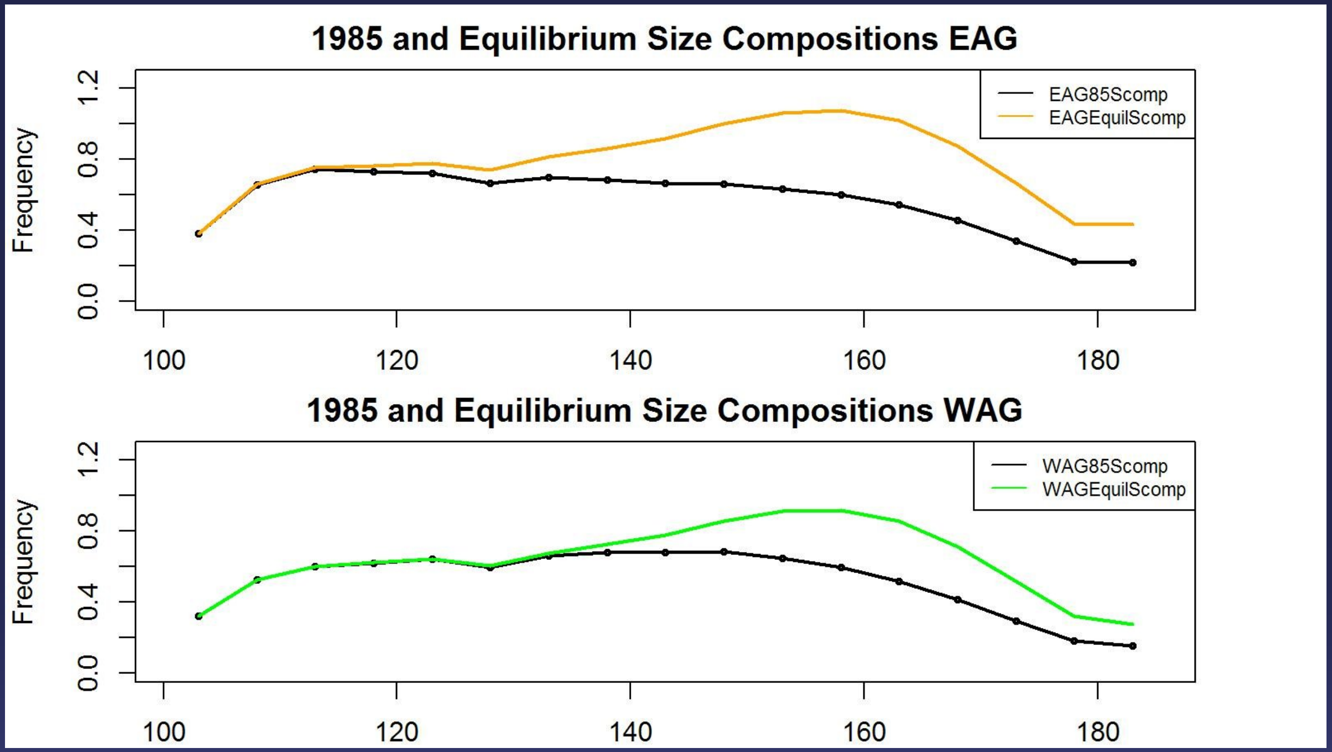


Figure 67. Comparison of F (top) and MMB (bottom) estimates between using the old Z formula (i.e. in May 2015 CPT draft document) and the revised Z formula for scenario 1 model fit to WAG data.

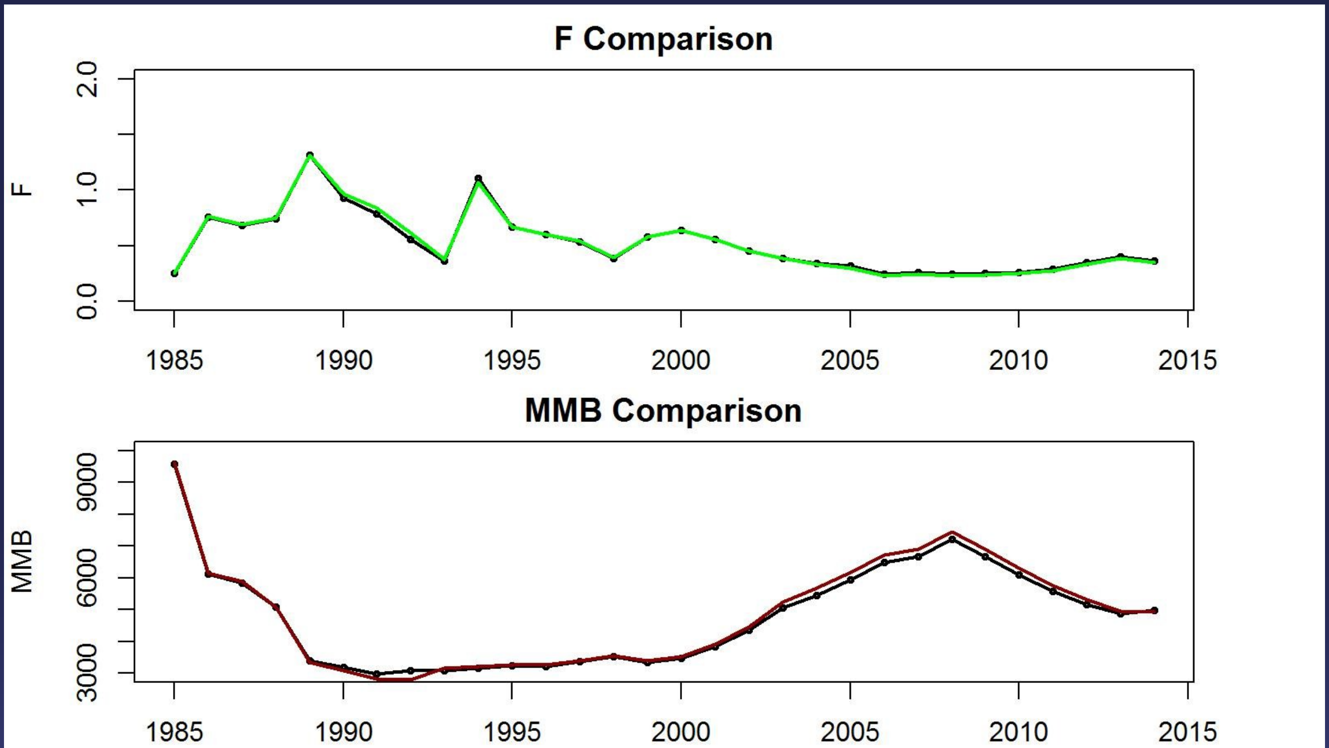


Figure 28. Pot fishery total F for Sc 1, 2, 3, 5, 11, and 12 fits to EAG data.

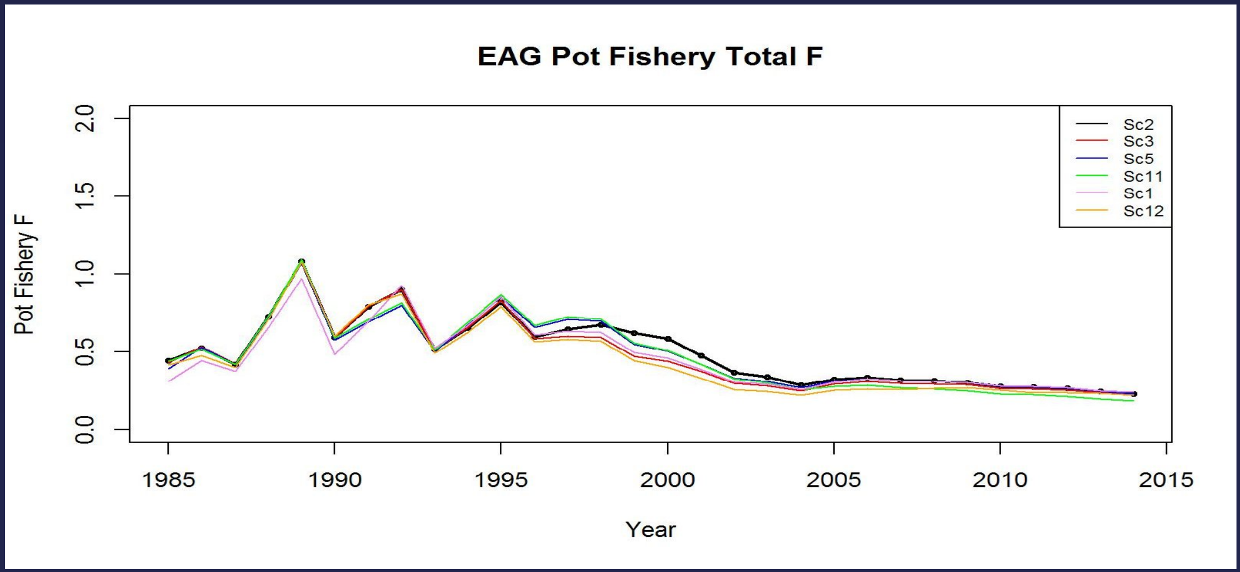


Figure 58. Pot fishery total F for Sc 1, 2, 5, 11, and 12 fits to WAG data.

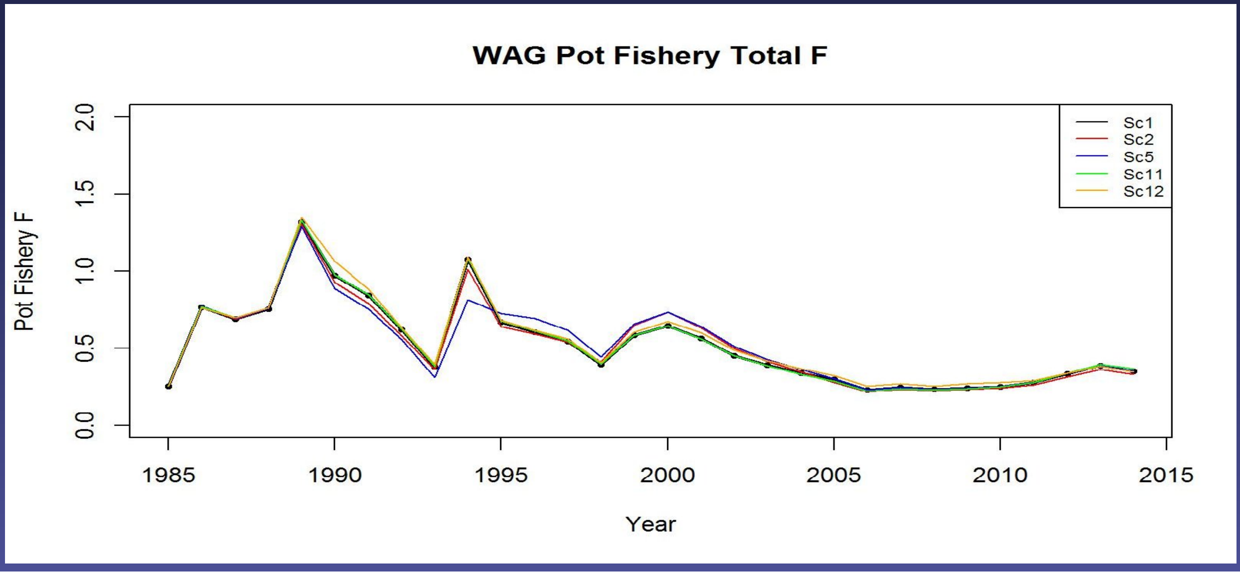


Figure 24. Number of male recruits to the model for Sc 2, 3, 5, and 11 model fits to EAG data.

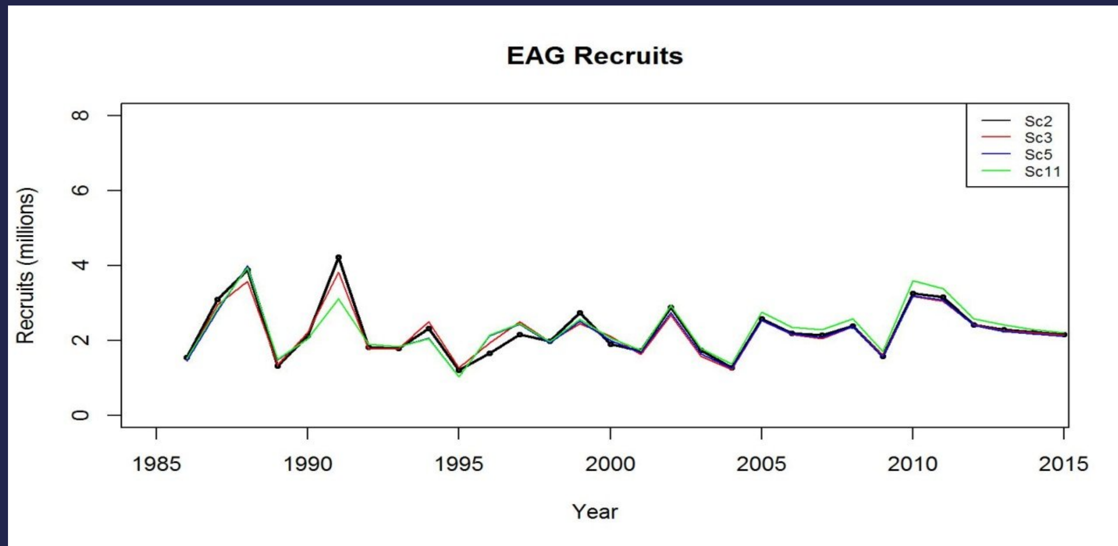


Figure 54. Number of male recruits to the model for Sc 1, 2, 5, and 11 model fits to WAG data.

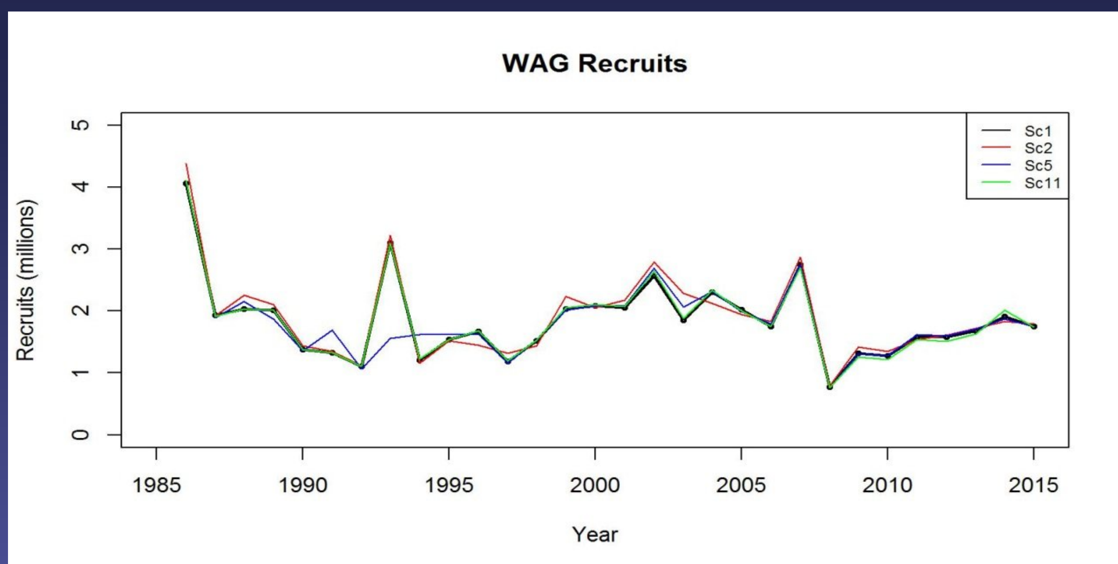


Figure 26. Trends in MMB for Sc 1, 2, 3, 4, 5, 6, 8, 11, and 12 model fits for EAG ,

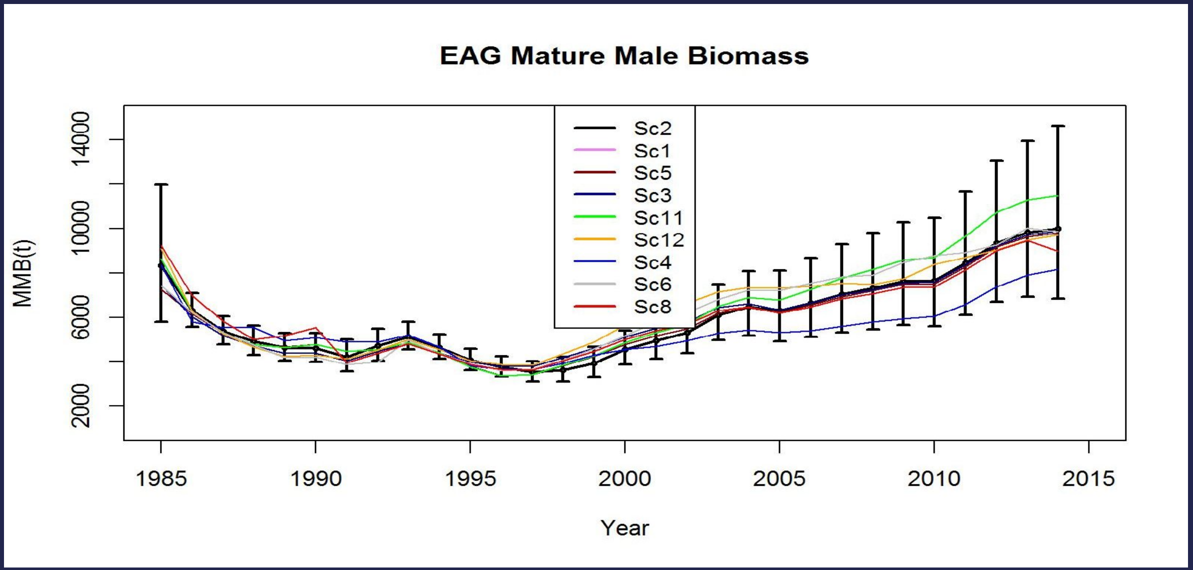
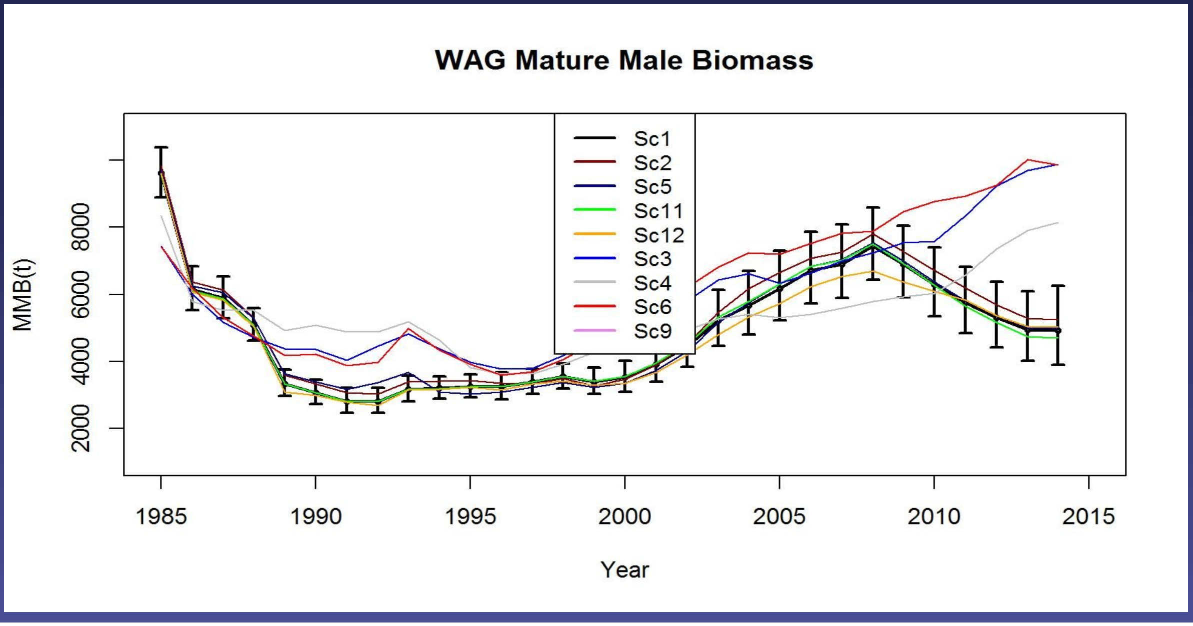


Figure 56. Trends in MMB for Sc 1, 2, 3, 4, 5, 6, 9, 11, and 12 model fits for WAG .



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

EAG:
Biomass, total OFL, and ABC in million pounds

Season	Tier	B_{ref}	Current MMB	MMB/ MMB_{ref}	F_{OFL}	Years to define B_{ref}	M	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
1) 2015/16	4a	13.012	21.464	1.65	0.18	1986–2015	0.18	2.937	2.922	2.643
2) 2015/16	4a	13.174	22.045	1.67	0.18	1986–2015	0.18	2.907	2.890	2.616
3) 2015/16	4a	13.164	21.792	1.66	0.18	1986–2015	0.18	3.008	2.993	2.707
5) 2015/16	4a	12.976	21.595	1.66	0.18	1986–2015	0.18	2.915	2.900	2.624
11) 2015/16	4a	14.032	25.318	1.80	0.18	1986–2015	0.18	3.545	3.533	3.191
12) 2015/16	4a	13.875	21.433	1.54	0.18	1986–2015	0.18	3.000	2.984	2.700

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

WAG:
Biomass, total OFL, and ABC in million pounds

Season	Tier	B_{ref}	Current MMB	MMB/MMB_{ref}	F_{OFL}	Years to define B_{ref}	M	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
1) 2015/16	4a	10.740	10.880	1.01	0.18	1986–2015	0.18	1.612	1.607	1.451
2) 2015/16	4a	11.255	11.574	1.03	0.18	1986–2015	0.18	1.683	1.678	1.515
5) 2015/16	4a	10.894	11.004	1.01	0.18	1986–2015	0.18	1.593	1.589	1.434
11) 2015/16	4b	10.742	10.355	0.96	0.179	1986–2015	0.18	1.549	1.545	1.394
12) 2015/16	4a	10.376	11.102	1.07	0.18	1986–2015	0.18	1.635	1.631	1.471

Tier 3 estimation: B_{35}, OFL, and ABC calculation by F_{35}

EAG:
Biomass, total OFL, and ABC in million pounds

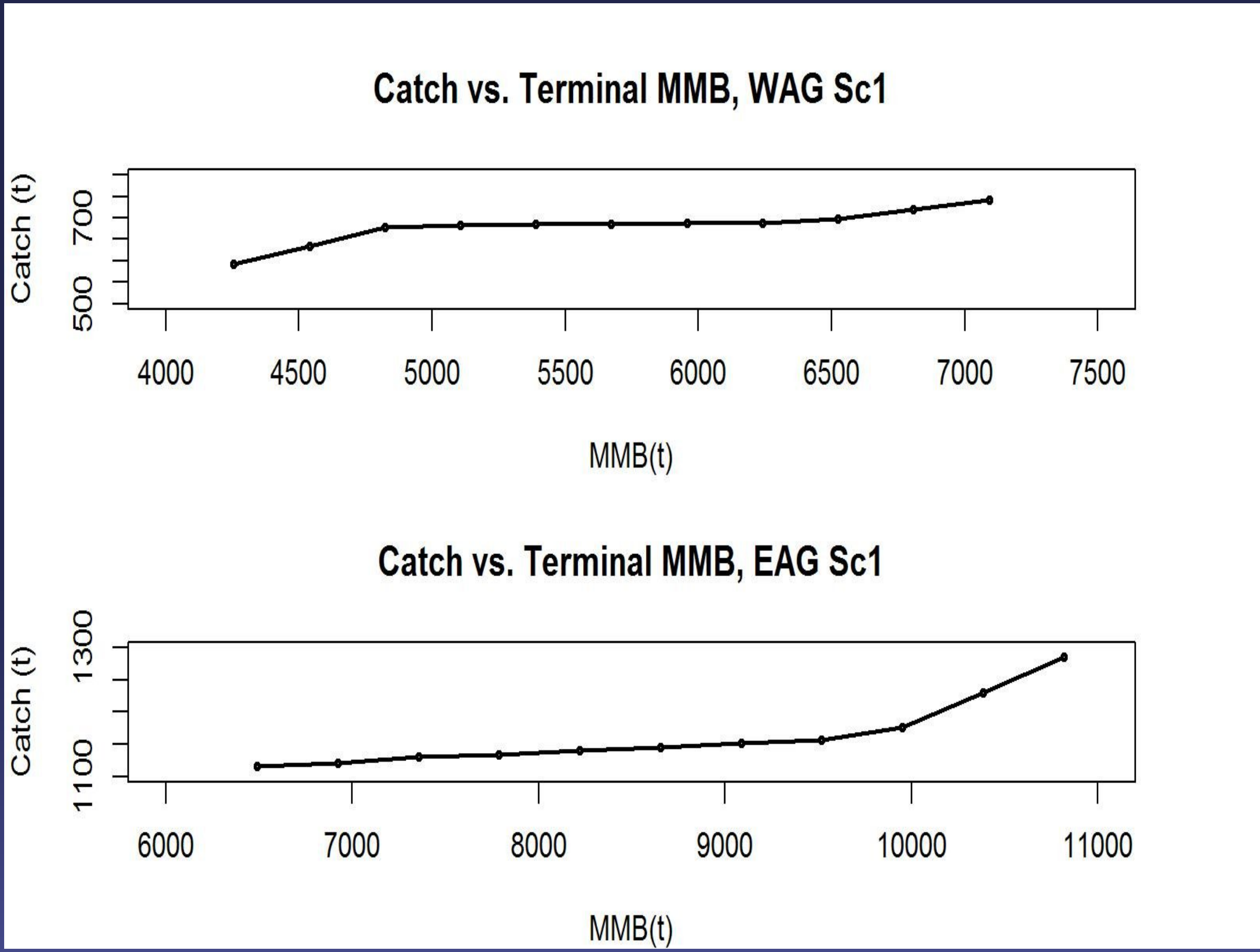
Season	Tier	B_{35}	Current MMB	MMB/B_{35}	F_{OFL}	Recruitment Years to define B_{ref}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
1) 2015/16	3a	15.807	19.677	1.24	0.37	1986–2015	0.37	5.593	5.565	5.034
2) 2015/16	3a	15.987	20.092	1.26	0.39	1986–2015	0.39	5.795	5.762	5.216
3) 2015/16	3a	15.831	19.885	1.26	0.37	1986–2015	0.37	5.726	5.698	5.153
5) 2015/16	3a	15.599	19.731	1.26	0.38	1986–2015	0.38	5.681	5.651	5.113
11) 2015/16	3a	16.408	22.630	1.38	0.36	1986–2015	0.36	6.581	6.558	5.923
12) 2015/16	3a	16.021	19.676	1.23	0.36	1986–2015	0.36	5.574	5.545	5.017

Tier 3 estimation: B_{35}, OFL, and ABC calculation by F_{35}

WAG:
Biomass, total OFL, and ABC in million pounds

Season	Tier	B_{35}	Current MMB	MMB/ B_{35}	F_{OFL}	Recruitment Years to Define B_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.9*OFL)
1) 2015/16	3b	12.987	11.407	0.88	0.28	1986–2015	0.32	2.384	2.378	2.146
2) 2015/16	3b	13.151	11.848	0.90	0.29	1986–2015	0.33	2.620	2.614	2.358
5) 2015/16	3b	12.742	11.436	0.90	0.29	1986–2015	0.33	2.474	2.467	2.227
11) 2015/16	3b	12.914	11.026	0.85	0.27	1986–2015	0.32	2.228	2.222	2.005
12) 2015/16	3b	13.047	11.586	0.89	0.28	1986–2015	0.32	2.438	2.428	2.194

Figure 66. Estimated catch by Tier 4 formula vs. terminal MMB for WAG (top) and EAG (bottom).



Some discussion points

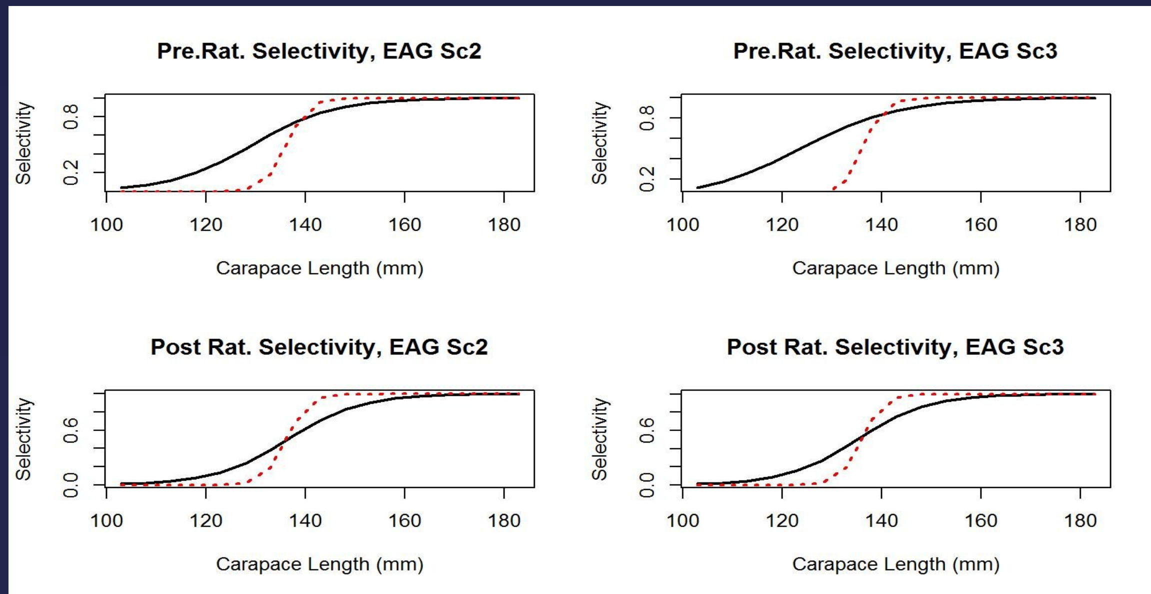
- *Tier 4 rule produced a very conservative estimate of OFL. Under Tier 3, the OFL F were 0.36-0.39 for EAG and 0.27 - 0.29 for WAG for various scenarios indicating that using 0.18 as a maximum OFL under Tier 4 may be overly- conservative and that using a γ value of 2 in the Tier 4 formula may be more appropriate.*
- The trends in F and MMB did not vary much compared to status quo results when mean F penalty was removed and the F estimation phase was changed to an earlier phase.
- The output did not change much from other scenarios' results when we disregarded the groundfish data in the model fit.

Good place to stop here. Thanks.
Any Question

Table 32. Observer legal size male crab CPUE data for EAG for 1995/96–2004/05, 2005/06–2013/14, and 1995/96–2013/14 time periods. R^2 determines the relative merit of each fit. ns = cubic splines, df = degree of freedom, and θ = dispersion parameter of the negative binomial model. (Source: 2015 Sea Grant Symposium).

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

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



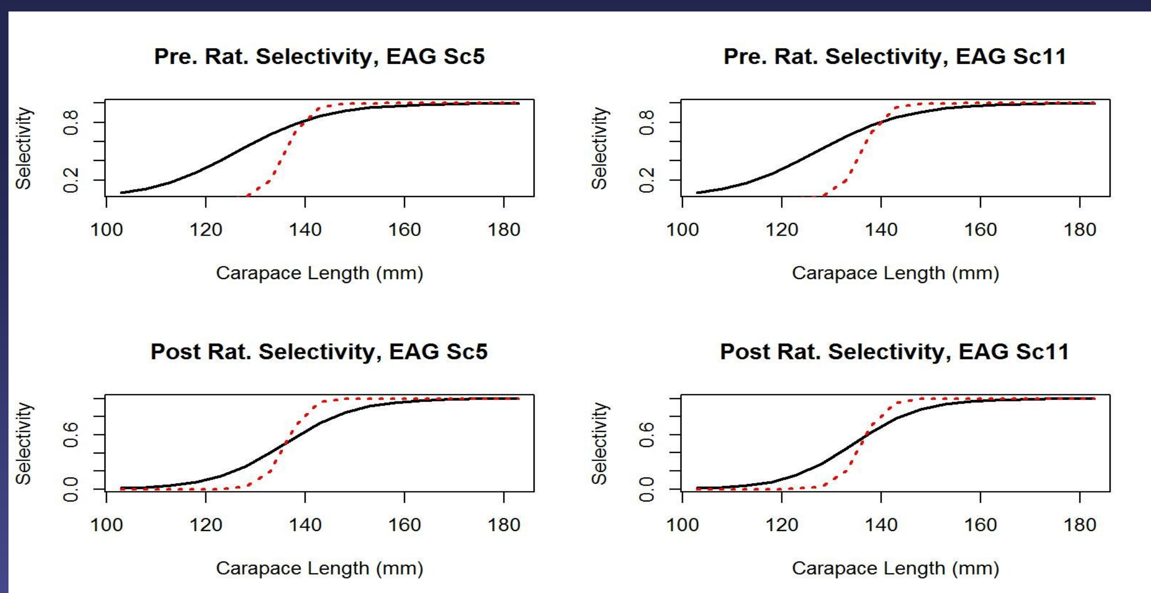


Figure 48. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post-rationalization periods under Sc 1, 2, 5, and 11 model fits to WAG data.

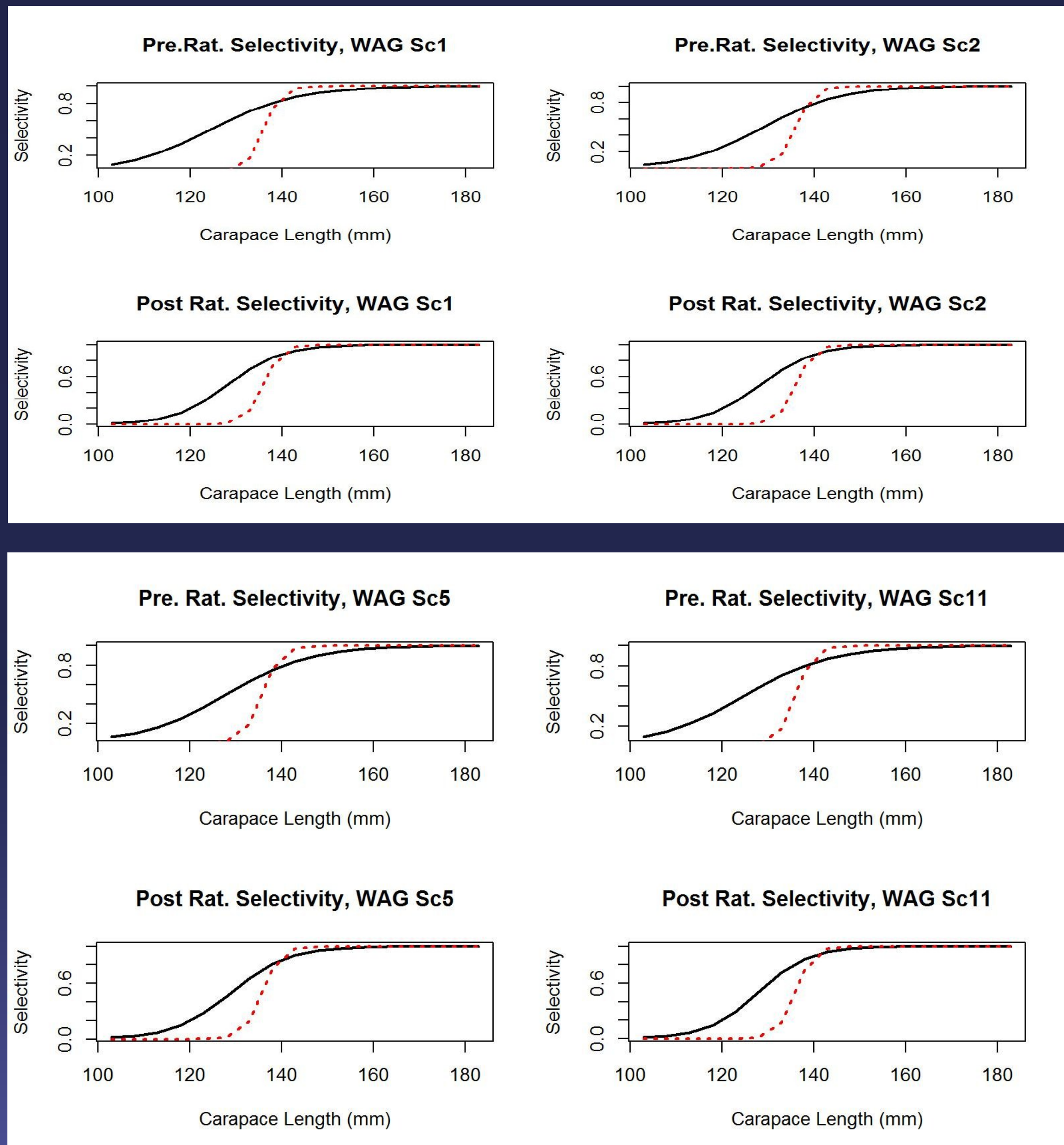


Figure 65. Estimated molt probability vs. carapace length of golden king crab under scenario 1 for EAG (black line) and WAG (green line).

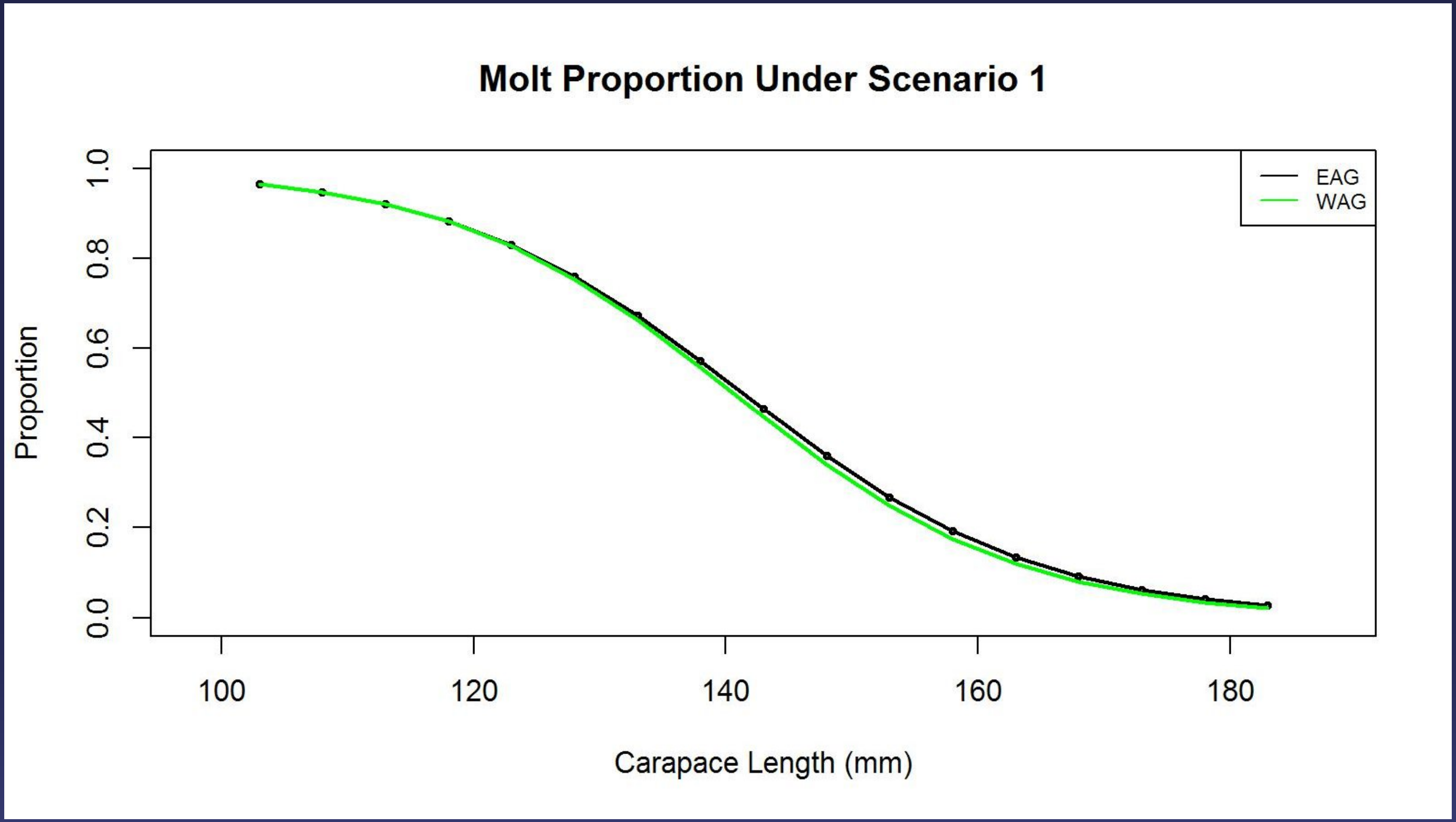


Figure 64. Predicted effective sample size vs. input calculated effective sample size for retained catch length composition for scenarios 6 fit (iterative estimation of effective sample size following Francis, 2011) to golden king crab data in the EAG and WAG, 1985/96 – 2014/15.

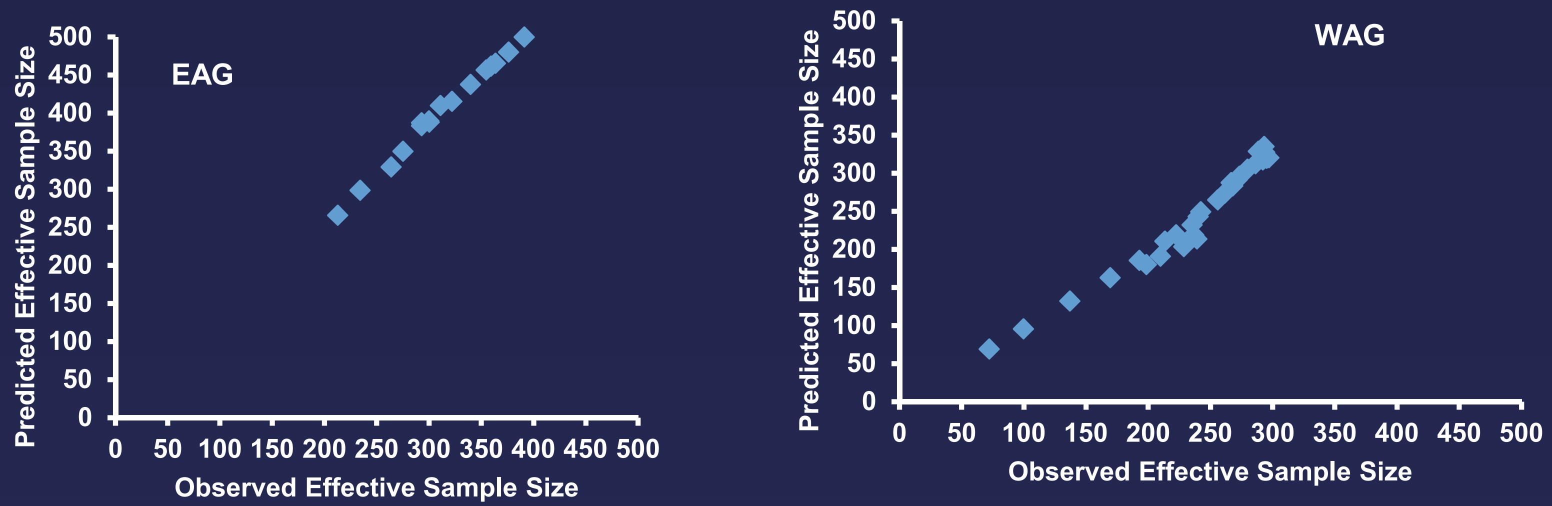


Table 1. Retained catch (number and weight of crabs), estimated total male catch (number and weight of crabs on the deck), pot fishery effort (number of pot lifts), and estimated groundfish fishery discard mortality (number and weight of crabs) for the EAG golden king crab stock. The crab numbers are for the size range 101–170+ mm CL. NA: no observer sampling to compute total catch. The directed fishery data included cost-recovery beginning in 2013/14.

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

Table 2. Pot fishery retained, observer retained, and observer total CPUE (number of crabs per pot lift), observer sample size (number of sampled pots), and observer CPUE Index for the EAG golden king crab stock.

Year	Pot Fishery Nominal Retained CPUE	Obs. Nominal Retained CPUE	Obs. Nominal Total CPUE	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	8.898	2.167	13.000	138	
1991	8.199	17.357	36.911	377	
1992	8.364	10.427	38.522	199	
1993	7.786	5.074	20.815	31	
1994	5.892	2.540	12.911	127	
1995	5.888	5.063	16.981	6388	0.734
1996	6.451	5.168	13.806	8360	0.758
1997	7.336	7.126	18.248	4670	0.791
1998	8.875	9.170	25.766	3616	0.954
1999	8.964	9.251	20.773	3851	0.884
2000	9.849	9.922	25.390	5043	0.907
2001	11.655	11.140	22.479	4626	1.184
2002	12.372	11.992	22.593	3980	1.261
2003	10.921	11.022	19.431	3960	1.105
2004	18.295	17.732	28.483	2206	1.802
2005	25.397	29.439	38.475	1193	1.053
2006	24.836	25.203	33.520	1098	0.844
2007	27.954	31.088	40.373	998	0.977
2008	27.260	29.733	38.178	613	0.949
2009	25.853	26.643	35.891	408	0.789
2010	25.956	26.052	36.763	436	0.802
2011	37.333	38.793	51.691	361	1.161
2012	33.018	38.000	47.744	438	1.116
2013	33.674	35.827	46.162	499	1.077
2014	42.293	46.959	59.997	376	1.374

Table 16. 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) for the WAG golden king crab stock. The crab numbers are for the size range 101–170+ mm CL.

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

Table 17. Pot fishery retained, observer retained, and observer total CPUE (number of crabs per pot lift), observer sample size (number of sampled pots), and observer CPUE Index for the WAG golden king crab stock.

Year	Pot Fishery Nominal Retained CPUE	Obs. Nominal Retained CPUE	Obs. Nominal Total CPUE	Obs. Sample Size (no.pot lifts)	Obs. CPUE Index
1990	6.980	11.833	26.667	340	
1991	7.428	7.778	19.175	857	
1992	5.895	6.393	16.829	690	
1993	4.425	6.542	17.232	174	
1994	4.080	6.714	19.234	1270	
1995	4.647	4.964	14.279	5598	1.174
1996	6.074	5.424	13.537	7194	0.952
1997	6.561	6.520	15.027	3985	0.962
1998	11.397	9.415	23.085	1876	1.070
1999	6.321	5.926	14.485	4523	0.909
2000	6.970	6.402	16.644	4740	0.853
2001	6.509	5.993	14.657	4454	0.827
2002	8.418	7.465	17.373	2509	0.924
2003	10.215	9.289	18.170	3334	1.157
2004	12.058	11.141	22.449	2619	1.267
2005	21.230	23.741	35.939	1365	1.116
2006	19.640	23.963	33.408	1183	1.029
2007	20.053	21.041	32.461	1082	0.968
2008	22.430	24.592	38.174	979	1.106
2009	23.720	26.533	34.047	892	1.163
2010	20.879	22.339	29.029	867	1.023
2011	23.403	23.811	31.121	837	1.068
2012	20.568	22.821	30.760	1109	1.079
2013	16.419	16.949	24.960	1223	0.769
2014	15.291	15.277	22.669	1137	0.772

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass with standard deviation (t), and mature male biomass with standard deviation (t) for the scenario 2 model for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of biological year) and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	Standard Deviation	Legal Male Biomass (≥ 136 mm CL)	Standard Deviation
1985	NA	8328	1528	8373	1111
1986	1.54	6284	382	8057	734
1987	3.10	5358	317	6203	366
1988	3.89	4911	331	5306	290
1989	1.32	4622	308	4736	279
1990	2.13	4600	324	4312	271
1991	4.23	4219	362	4445	295
1992	1.82	4707	363	4115	325
1993	1.78	5125	314	4418	320
1994	2.32	4646	277	4933	281
1995	1.20	4067	237	4519	249
1996	1.65	3755	225	3891	224
1997	2.16	3524	226	3647	216
1998	1.98	3624	272	3422	222
1999	2.73	3928	332	3477	269
2000	1.90	4562	383	3789	329
2001	1.73	4945	444	4356	379
2002	2.88	5310	511	4774	436
2003	1.73	6096	629	5201	499
2004	1.27	6457	723	5894	602
2005	2.57	6311	787	6294	696
2006	2.18	6649	884	6233	764
2007	2.14	7036	986	6483	852
2008	2.38	7321	1076	6856	950
2009	1.58	7621	1150	7156	1040
2010	3.25	7662	1207	7427	1114
2011	3.16	8431	1380	7552	1178
2012	2.42	9348	1573	8219	1329
2013	2.28	9823	1739	9082	1516
2014	2.22	10000	1916	9610	1688
2015	2.15	10289	4852	9821	1865

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 on July 1 (start of biological year) and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available. 1985 refers to the 1985/86 fishery.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 121 mm CL)	Standard Deviation	Legal Male Biomass (≥ 136 mm CL)	Standard Deviation
1985	NA	9624	373	10841	362
1986	4.06	6146	329	9437	358
1987	1.93	5885	312	6084	306
1988	2.03	5083	239	5701	275
1989	2.01	3340	199	4977	216
1990	1.38	3071	177	3264	177
1991	1.33	2810	184	2989	163
1992	1.11	2806	187	2755	173
1993	3.10	3170	189	2762	176
1994	1.20	3211	167	3198	172
1995	1.54	3254	172	3092	154
1996	1.67	3251	198	3200	163
1997	1.19	3390	185	3216	182
1998	1.52	3549	187	3332	176
1999	2.03	3396	194	3522	178
2000	2.08	3525	229	3370	185
2001	2.05	3913	280	3471	217
2002	2.57	4459	337	3850	265
2003	1.85	5228	418	4416	321
2004	2.31	5669	472	5145	396
2005	2.02	6177	515	5626	451
2006	1.75	6716	533	6114	492
2007	2.75	6907	548	6648	512
2008	0.77	7441	541	6878	526
2009	1.32	6899	533	7305	522
2010	1.28	6296	510	6854	518
2011	1.58	5749	489	6245	495

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

Figure 14. Predicted effective sample size vs. input effective sample size for retained catch length composition for Sc 2, 3, 5, and 11 fits to golden king crab data in the EAG, 1985/86 to 2014/15. The red line is the 45^0 line passing through the origin.

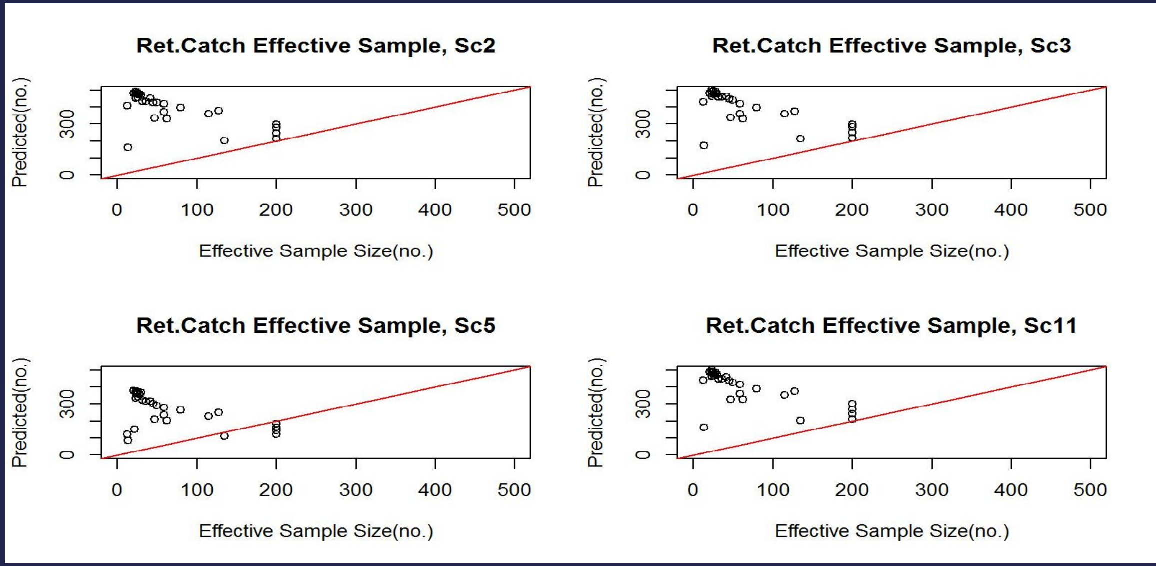


Figure 45. Predicted effective sample size vs. input effective sample size for retained catch length composition for Sc 1, 2, 5, and 11 fits to golden king crab data in the WAG, 1985/96 – 2014/15. The red line is the 45^0 line passing through the origin.

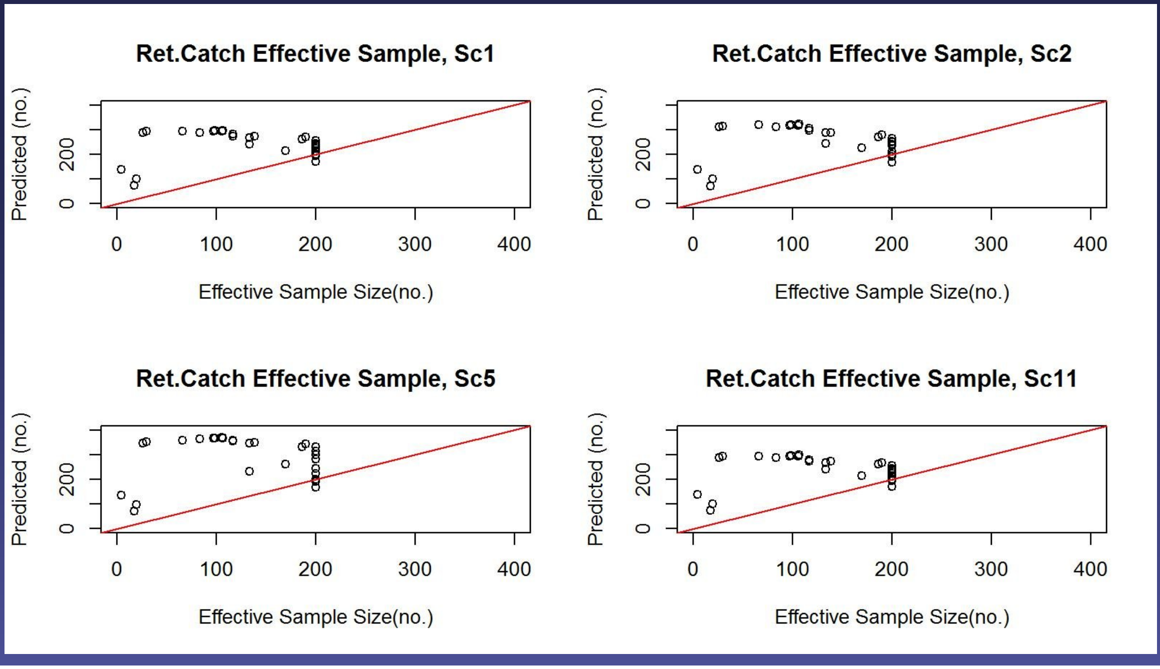


Figure 15. Predicted effective sample size vs. input effective sample size for total catch length composition for Sc 2, 3, 5, and 11 fits to golden king crab data in the EAG, 1990/91 to 2014/15. The red line is the 45^0 line passing through the origin.

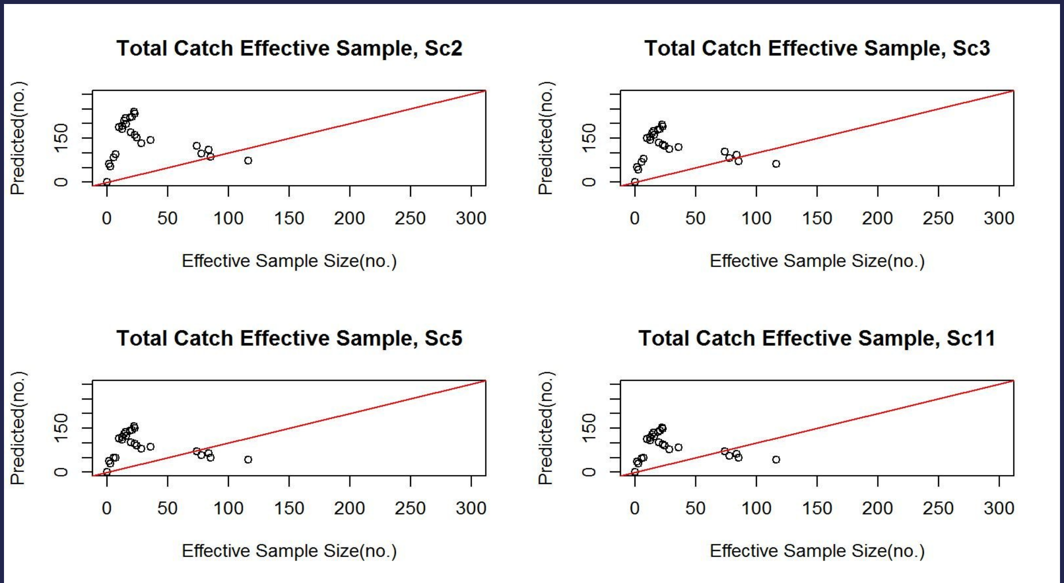


Figure 46. Predicted effective sample size vs. input effective sample size for total catch length composition for Sc 1, 2, 5, and 11 fits to golden king crab data in the WAG, 1990/91 – 2014/15. The red line is the 45^0 line passing through the origin.

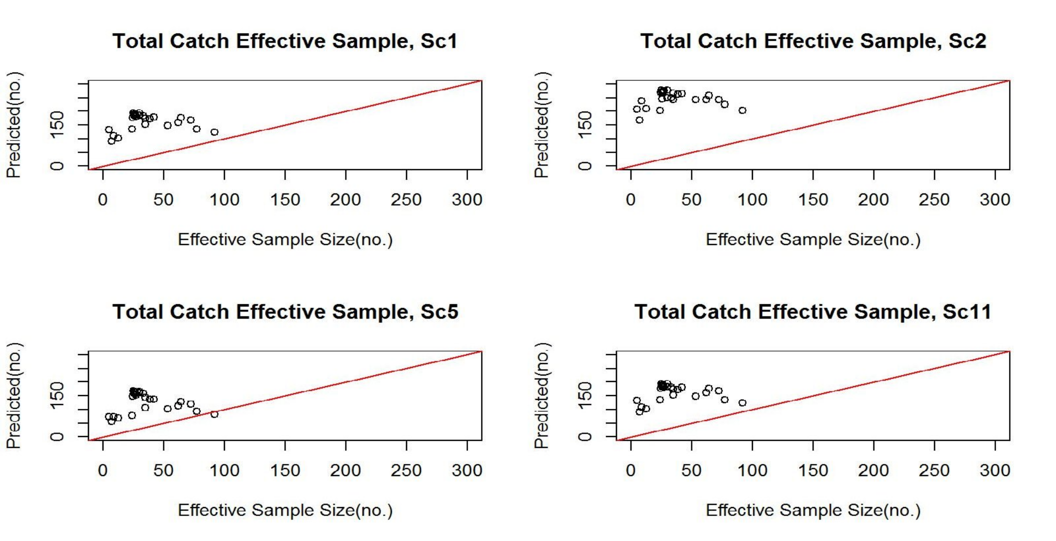


Figure 16. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for Sc 2, 3, 5, and 11 fits to golden king crab data in the EAG, 1989/90 to 2014/15. The red line is the 45⁰ line passing through the origin.

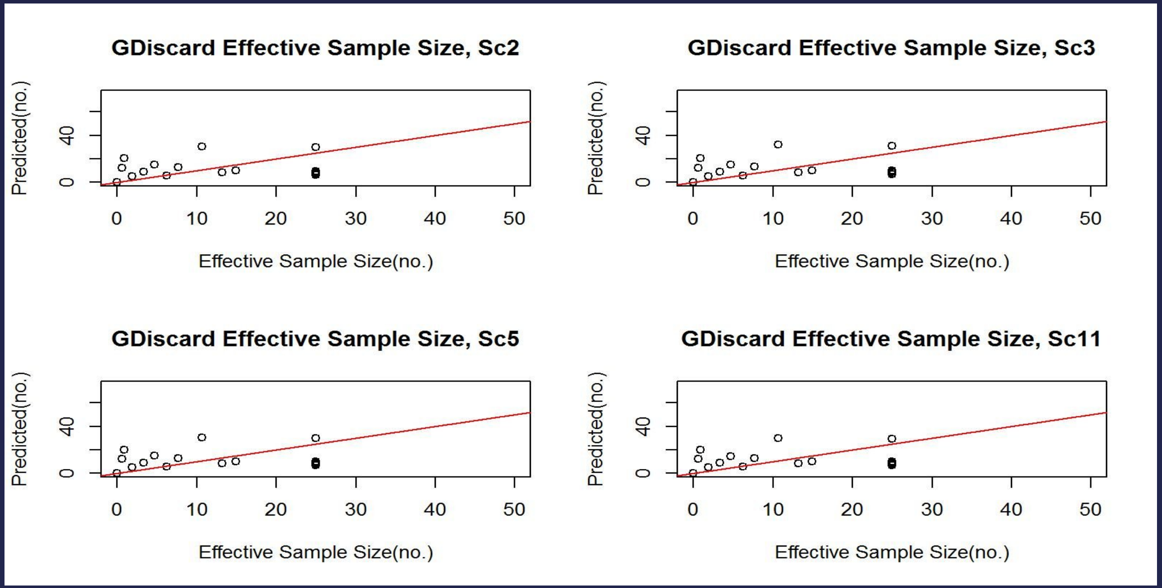


Figure 47. Predicted effective sample size vs. input effective sample size for groundfish discarded catch length composition for Sc 1, 2, 5, and 11 fits to golden king crab data in the WAG, 1995/96 – 2013/14. The red line is the 45⁰ line passing through the origin.

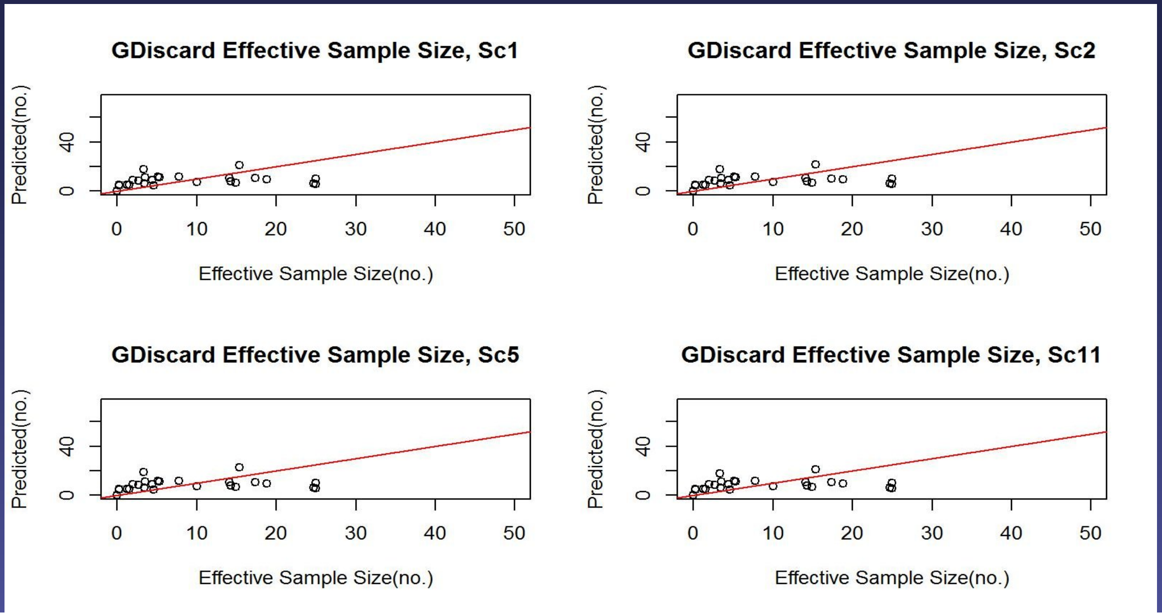
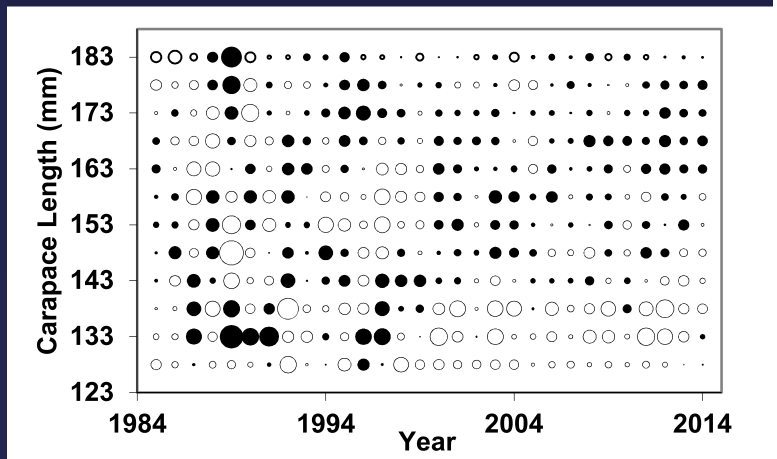
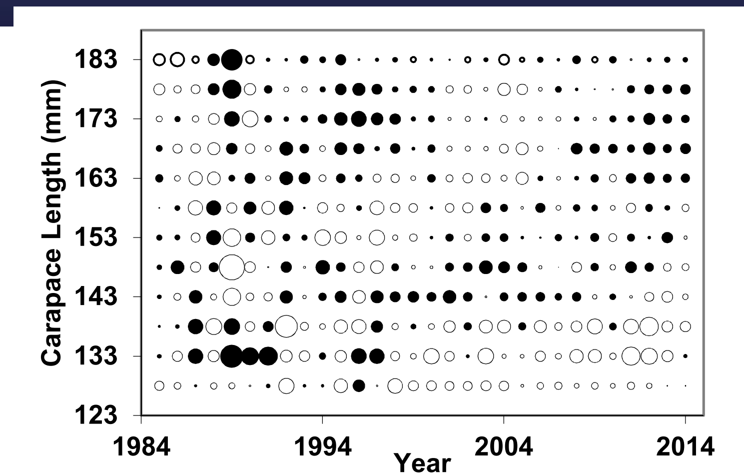


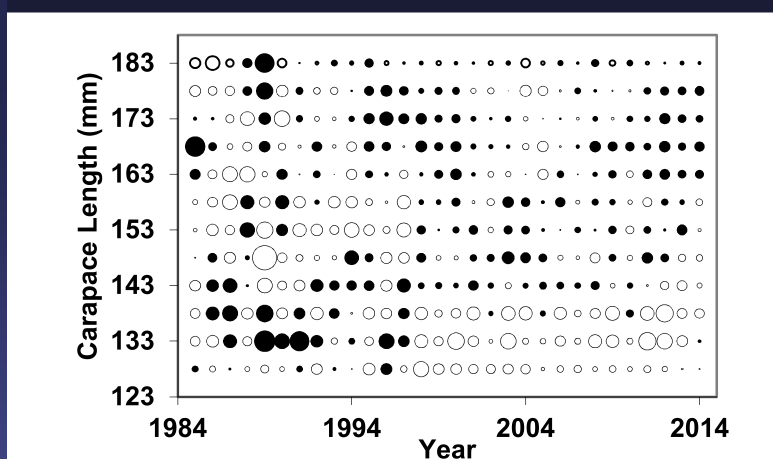
Figure 18. Bubble plots of standardized residuals of retained catch length composition for scenarios 2, 3, 5, and 11 fits for EAG golden king crab, 1985/86–2014/15. Filled circles are the positive and unfilled circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



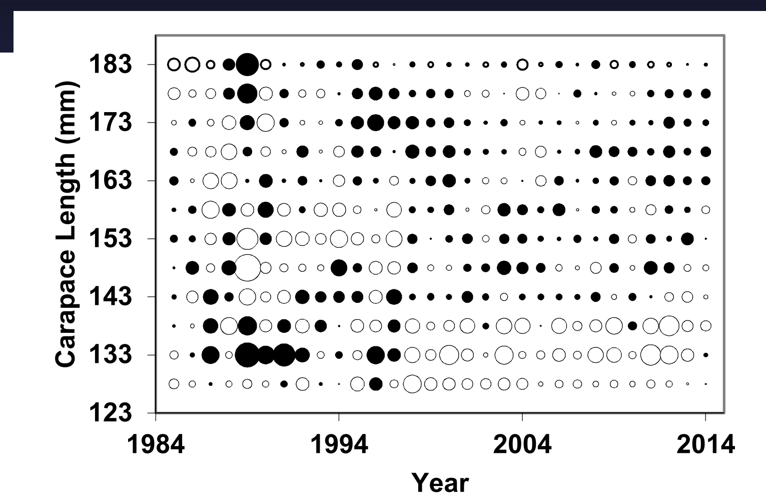
Scenario 2
Sc 2



Sc 3
Scenario 3



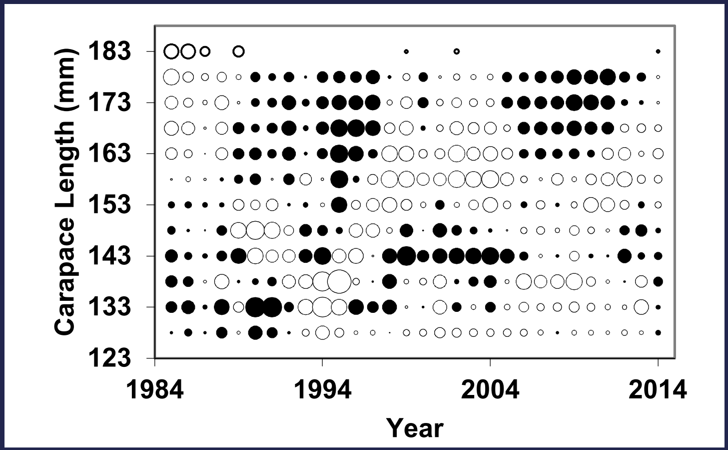
Scenario 5
Sc 5



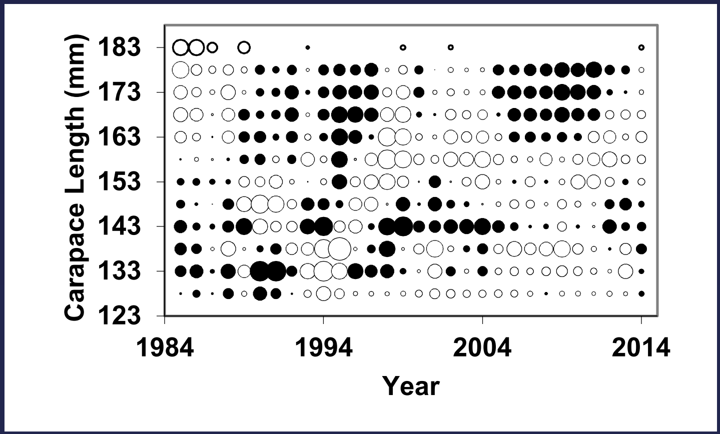
Sc 11
Scenario 11

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

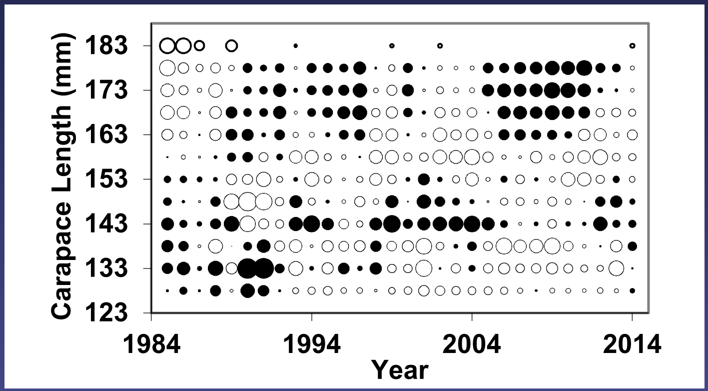
Scenario 1



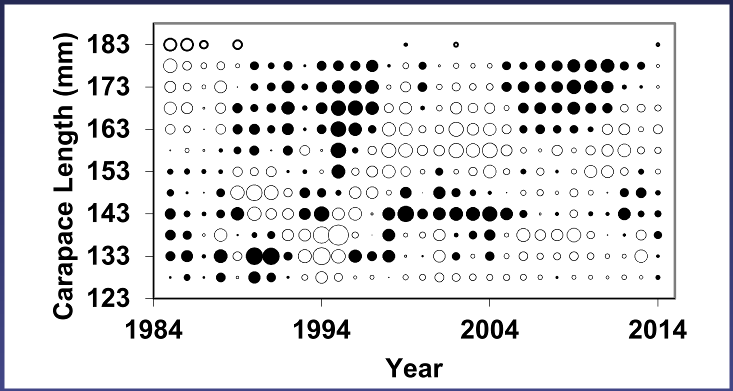
Scenario 2



Scenario 5



Scenario 11



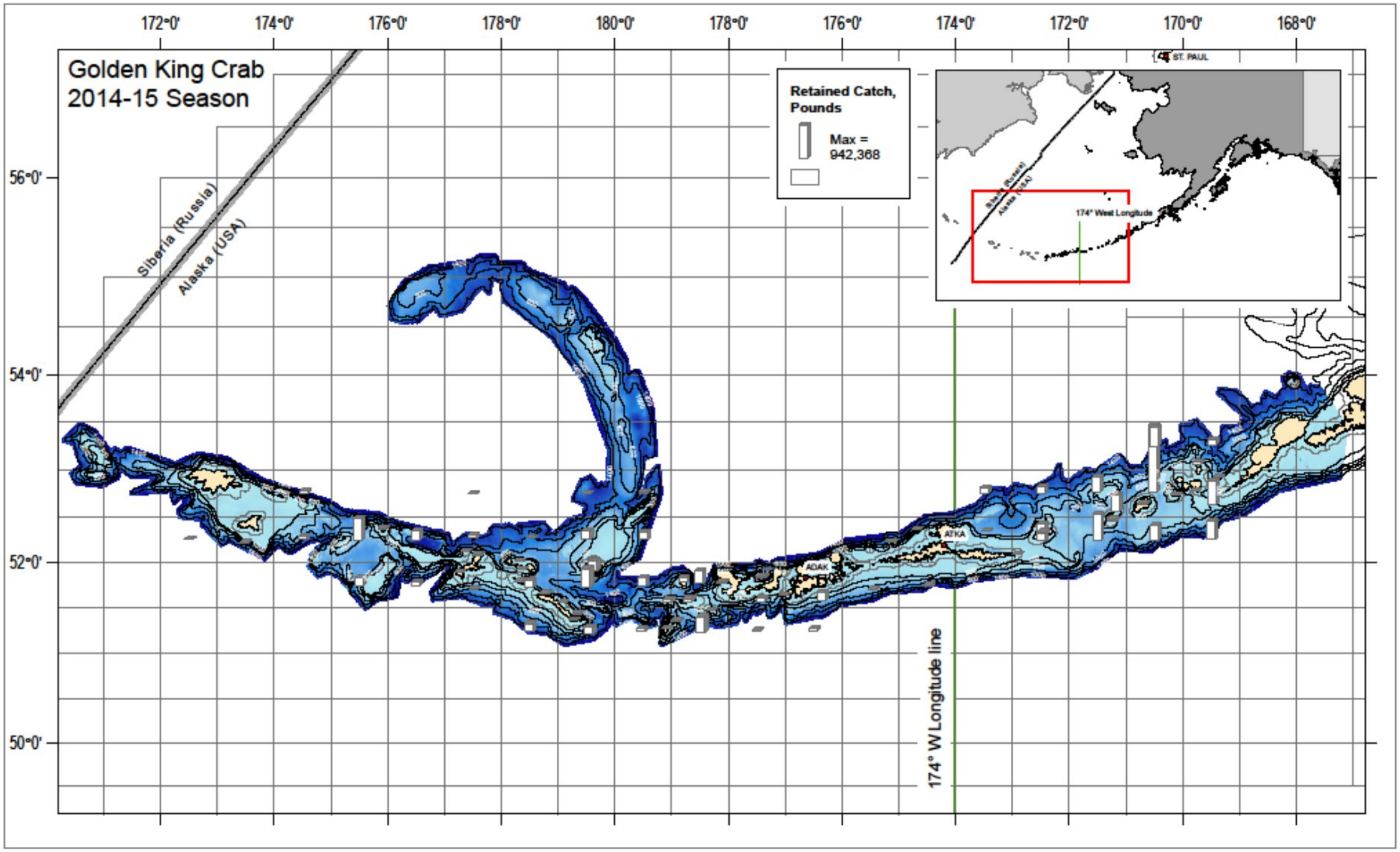
	103	108	113	118	123	128	133	138	143	148	153	158	163	168	173	178	183 +
103	0.06	0.02	0.21	0.47	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
108		0.08	0.02	0.23	0.46	0.19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
113			0.11	0.03	0.24	0.44	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
118				0.15	0.03	0.25	0.42	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
123					0.21	0.03	0.25	0.38	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
128						0.28	0.04	0.25	0.34	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
133							0.36	0.04	0.23	0.29	0.08	0.00	0.00	0.00	0.00	0.00	0.00
138								0.44	0.04	0.21	0.24	0.06	0.00	0.00	0.00	0.00	0.00
143									0.54	0.04	0.19	0.20	0.04	0.00	0.00	0.00	0.00
148										0.63	0.03	0.16	0.15	0.03	0.00	0.00	0.00
153											0.71	0.03	0.13	0.11	0.02	0.00	0.00
158												0.78	0.03	0.10	0.08	0.01	0.00
163													0.84	0.02	0.08	0.06	0.01
168														0.88	0.02	0.06	0.04
173															0.92	0.01	0.07
178																0.94	0.06
183 +																	1.00

Table 7. Size transition matrix for scenario 2, EAG.

Fixed parameter values (page 10)

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

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



Data Gap and Research Priorities

- We 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.
-
- An independent estimate of *M* is needed for this stock. Tagging is one possibility.
-
- 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.
-
- An arbitrary 20% handling mortality rate on discarded males was used. An experimentally-based independent estimate of handling mortality is needed for golden king crab.

Tier 4 Formula for OFL

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

$$F_{???} = \lambda M \frac{\left(\frac{??}{?\,???} - ??\right)}{(???)}$$

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

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
Length specific equilibrium abundance ? ??	n
Fishing mortalities F_t	
Pot fishery, $\bar{F}$	1985/86–2014/15
Mean pot fishery fishing mortality, F_t^{Tr}	1
Trawl fishery, $\bar{F}^{Tr}$	1989/90–2013/14 (the mean F for 1989/90 to 1994/95 (5-year mean, 1991/92 no data) was used to project back the trawl discards up to 1985/86.
Mean trawl fishery fishing mortality,	1
Selectivity and retention	
Pot fishery total selectivity ? ???	2 (1985/86–2004/05; 2005/06–2014/15)
Pot fishery total selectivity difference, ?????? ?	2 (1985/86–2004/05; 2005/06–2014/15)
Trawl fishery selectivity ? ????	1
Trawl fishery selectivity difference ?????? ??	1
Pot fishery retention ? ???	2 (1985/86–2004/05; 2005/06–2014/15)
Pot fishery retention difference ?????? ?	2 (1985/86–2004/05; 2005/06–2014/15)
Growth	
Expected growth increment, ω_1, ω_2	2
Variability in growth increment, ?	1
Molt probability (size transition matrix with tag data) a	1
Molt probability (size transition matrix with tag data) b	1