Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment in Spring 2017

Draft report for the May 2017 Crab Plan Team Meeting

M.S.M. Siddeek, J. Zheng, C. Siddon, and B. Daly

Alaska Department of Fish and Game, Juneau and Kodiak, Alaska

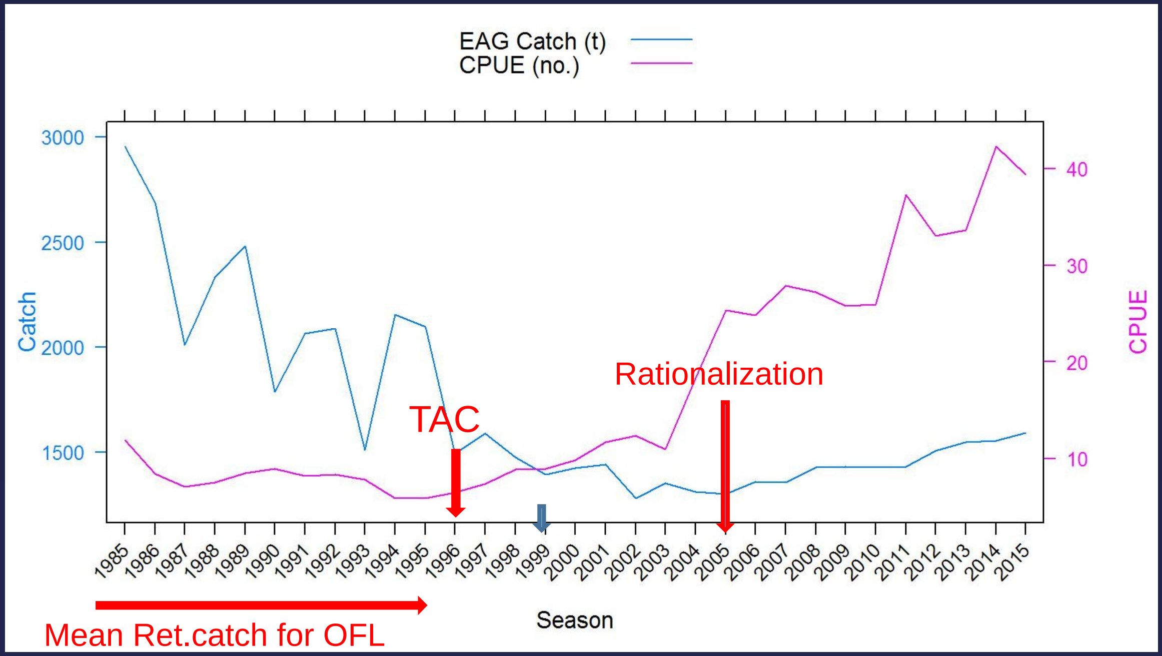
May 3, 2017, Juneau, Alaska

Topics

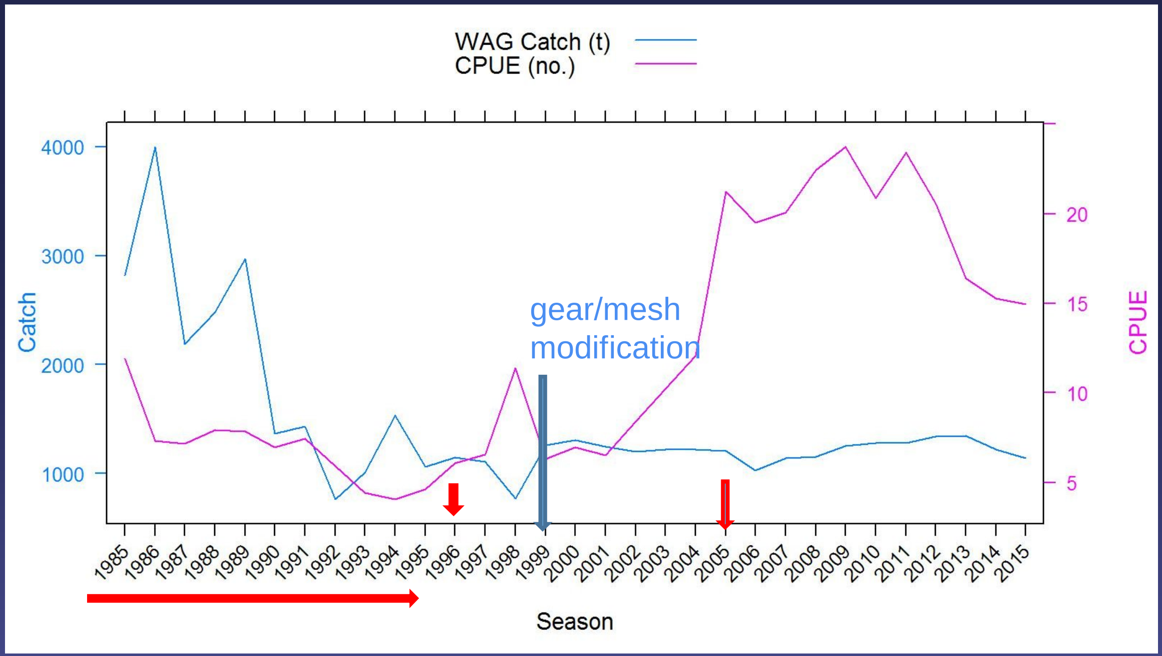
- Introduction
- Responses to September 2016, January 2017 CPT, and February 2017 SSC comments
- CPUE Standardization results
- Length based stock assessment results
- Tier 3 OFL and ABC

Catch (t) and CPUE (number of crab per pot lift) in 1985/86–2015/16 .

EAG



WAG



September 2016 CPT comments

- **Comment 1: The CPT recommended bringing likelihood profile on *M*, mean MMB, and MMB depletion to the May 2017 CPT meeting.**

- *Response:*

- M profiles are in Figs. 4 to 6, mean MMB profile is in Fig. 7 and MMB depletion profile is in Fig. 8. The penalty functions are in Appendix A.

-We used finer incremental steps (0.025) for the M profile calculation.

- **Comment 2: Tables 1 (EAG) and 15 (WAG) should be modified to provide the retained catch, pot bycatch breakdown by males and females (make clear if mortality applied) and trawl bycatch followed by total catch.**

- *Response:*

We included Table 1a: retained catch, bycatch (males and females lumped together), groundfish discard catch (males and females lumped together), and the total catch with details of what rates of mortality were applied during the 1990/91–2015/16 period for the entire Aleutian Islands.

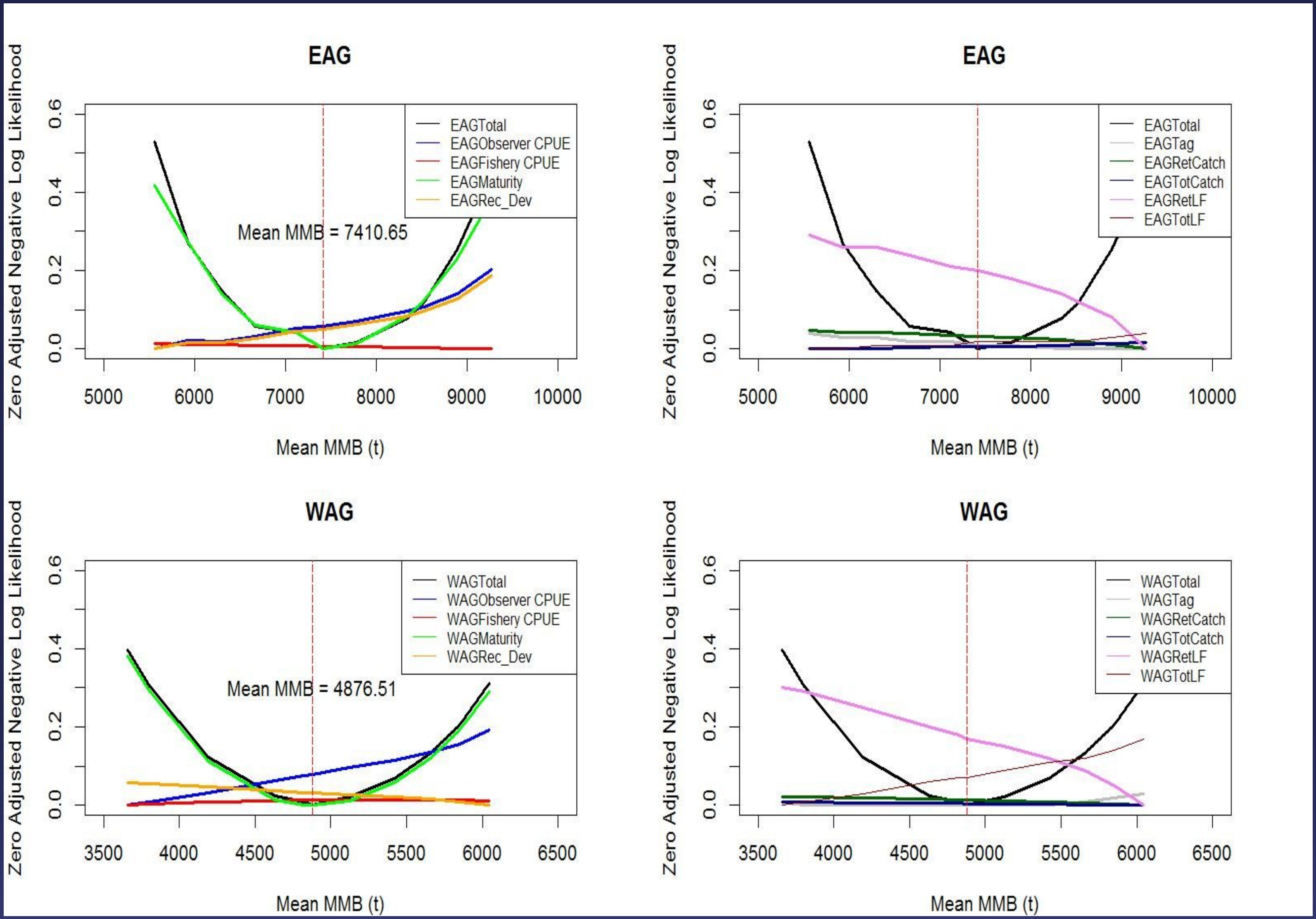


Figure 7. Total and components negative log-likelihoods vs. mean *MMB* for **scenario 1** model fit to EAG and WAG data.

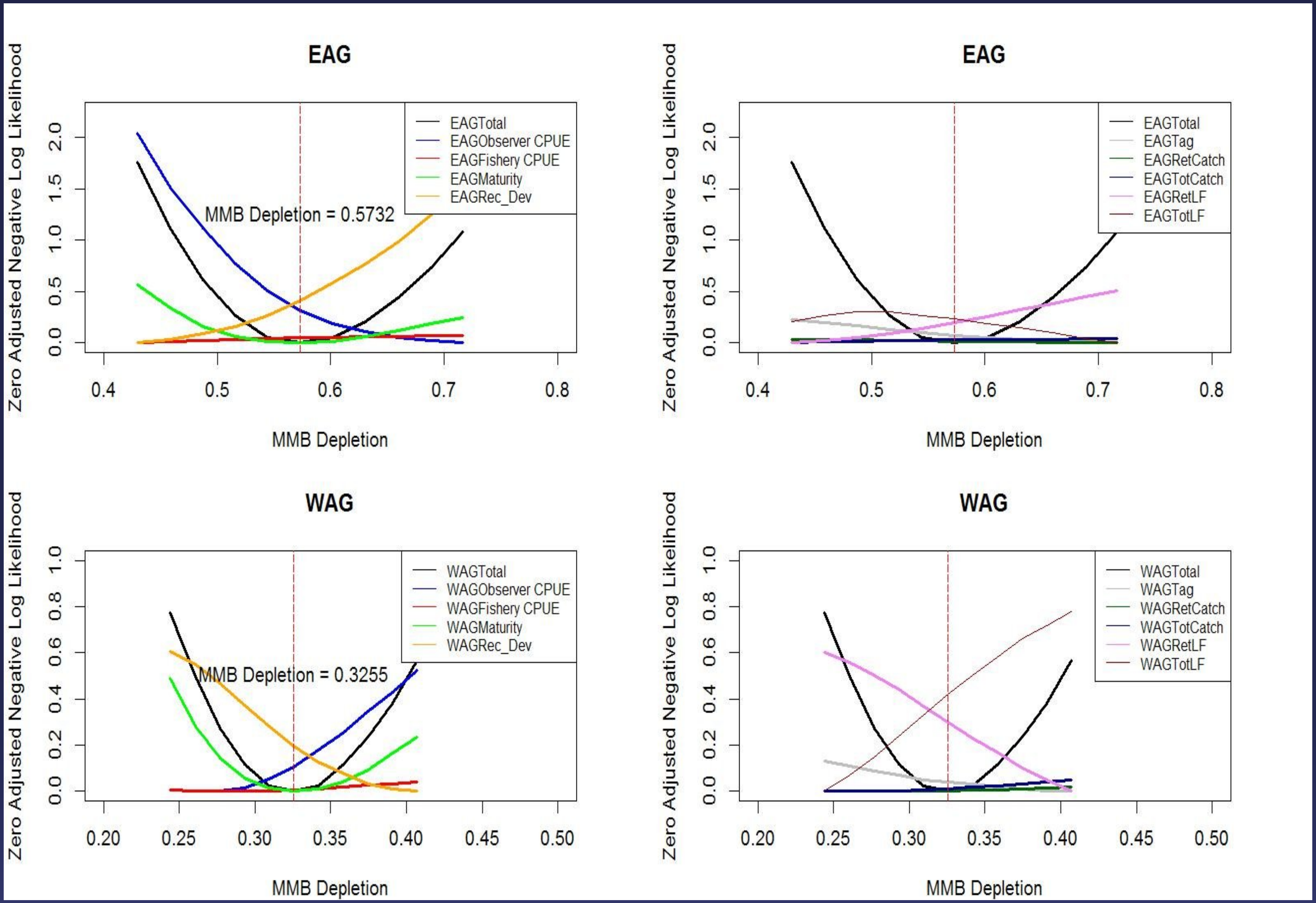


Figure 8. Total and components negative log-likelihoods vs. MMB depletion for **scenario 1** model fit to EAG and WAG data.

September 2016 CPT comments continued

- **Comment 3: The plots showing estimated selectivity curves should include both the estimates for pre- and post-rationalization periods.**
- *Response: Done (Fig. 13 for EAG and Fig. 32 for WAG).*
- **Comment 4. Continue the development of a spatial model that could be used to explore the implications of changed in fishing locations.**
- *Response: Appendix F provides the detail.*

January 2017 CPT comments

- **Comment 1: While the CPT accepts the approach of using a combined EAG/WAG model to estimate natural mortality, the team would also like to see evidence that tests have been done to show that the combined model gives precisely the same results as the two individual models, since only the individual models have undergone technical review.**

Response:

We provided M profiles in Figures 4 (scenario 0a considered M penalty), 5 (scenario 0b disregarded M penalty), and 6 (scenario 1b disregarded M penalty and used separate EAG and WAG data sets). It appears that all results were close.

- **Comment 2: The likelihood profiles by data components for natural mortality showed that the WAG CPUE had a different profile than other data components, showing a strong improvement in fit at lower values of natural mortality. It would be good to confirm that this is correct.**

Response:

The total likelihood fits for EAG and WAG attained minimum around 0.224 . The CPUE likelihoods for EAG and WAG behaved similarly although they did not attain the minima at the total likelihood minimum value.

- **Comment 3: Start the observer CPUE time series in 1995 and include the retained catch CPUE time series for 1985–1998 in the base model.**

Response:

  - *We considered the 1995/96–2015/16 observer CPUE time series in the base and most scenarios.*
- *- As per CPT suggestion, we considered Sc 3 that included observer CPUE index from 1991–1994.*

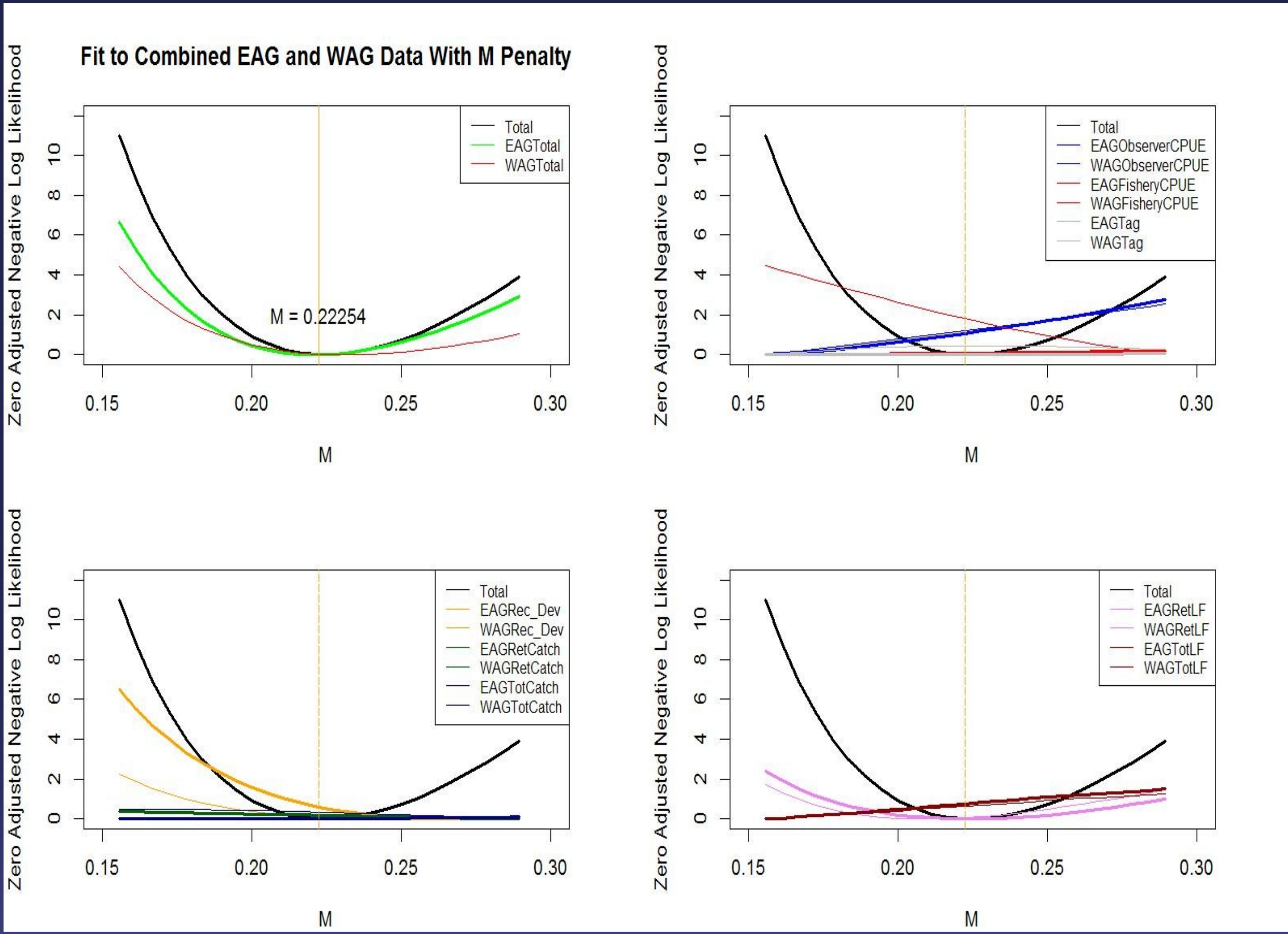


Figure 4. Total and components negative log-likelihoods vs. *M* for **scenario 0a** model fit for EAG and WAG combined data. *M* = 0.2225 yr^{-1} ($\pm$ 0.0191 yr^{-1}).

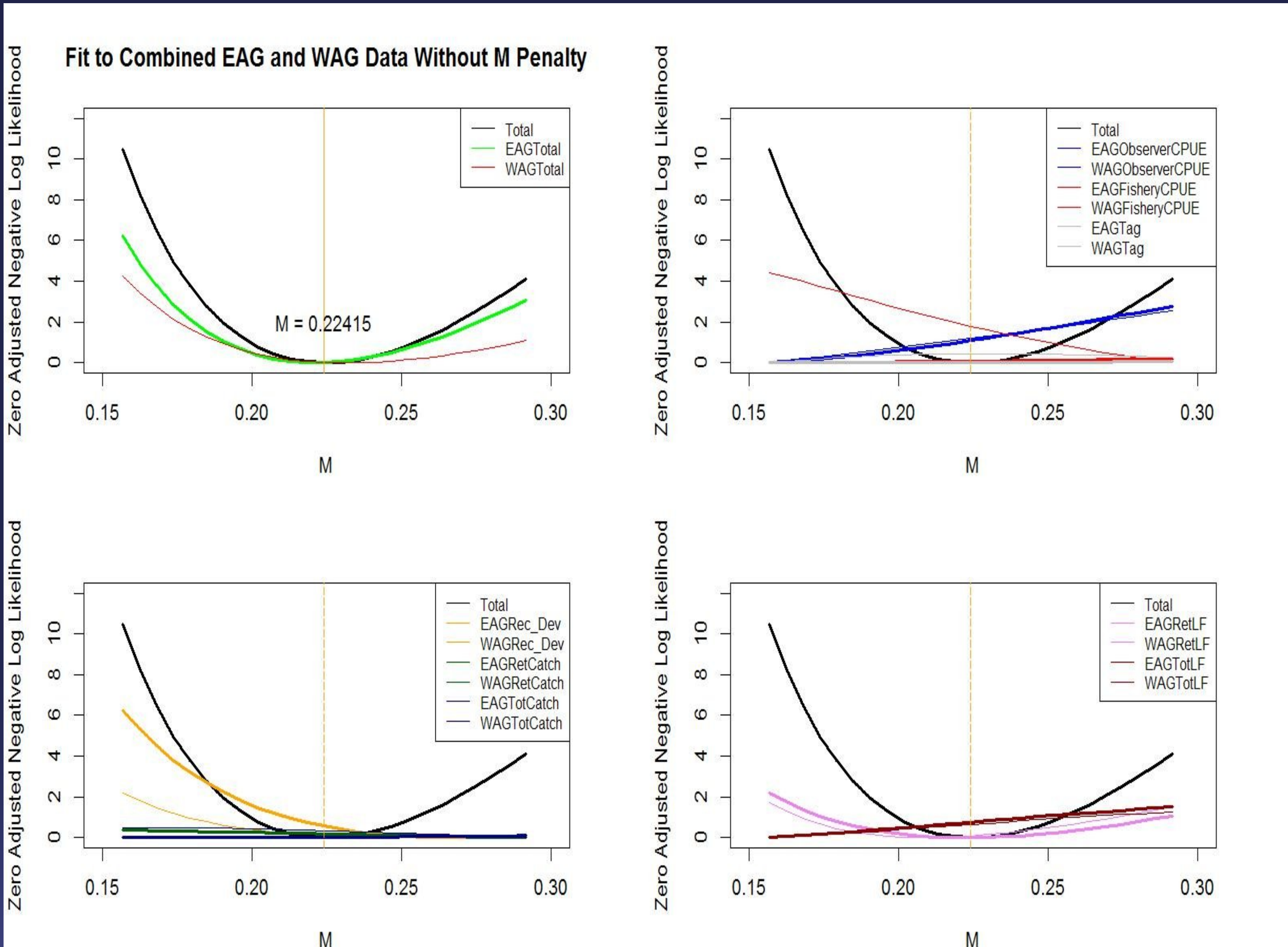


Figure 5. Total and components negative log-likelihoods vs. *M* for **scenario 0b** model fit for EAG and WAG combined data. *M* = 0.2242 yr-1 ($\pm$ 0.0196 yr^{-1}).

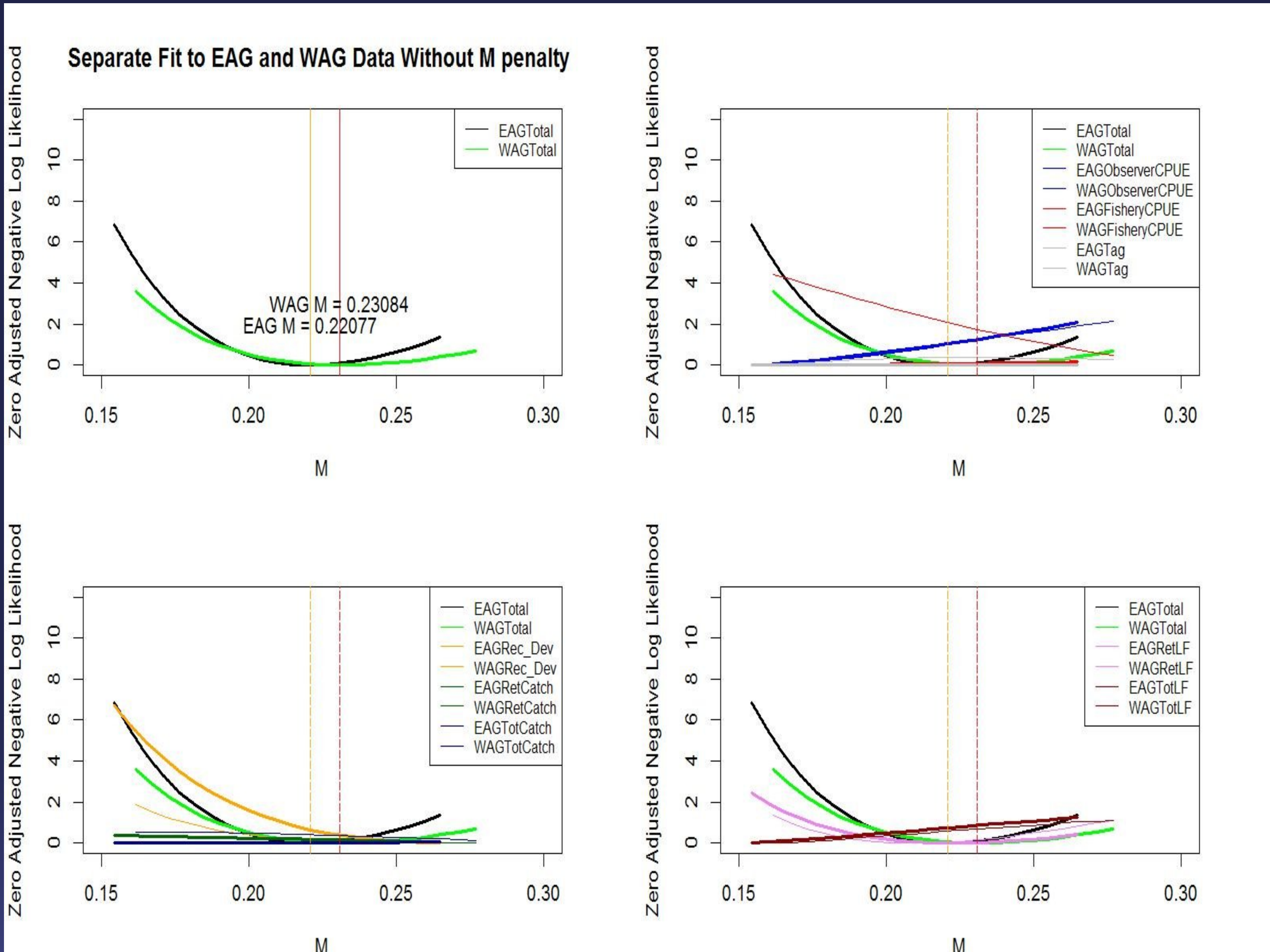


Figure 6. Total and components negative log-likelihoods vs. *M* for **scenario 1b** model separate fit to EAG and WAG data. EAG *M* = 0.2208 yr^{-1} (± 0.0238 yr^{-1}), WAG *M* = 0.2308 yr^{-1} (± 0.0350yr^{-1}).

January 2017 CPT comments continued

- **Comment 4: CVs for the recruitment estimates be examined and that only those recruitment estimates that are informed by data (i.e., recruit CVs less than sigma R) be used to obtain mean recruitment to initialize the model.**

Response:

- *We examined the recruit standard deviation pattern (Figure 9) and selected the time period 1987–2012 based on recruit standard deviation values < 70% sigma R for mean number of recruits estimation to initialize the model.*

- **Comment 5: The dome-shaped selectivity models not be carried forward for the May meeting.**

Response: Done

- **Comment 6: The CPT agrees with the author's recommendation that the Francis method be adopted as the preferred approach for selecting weights for length-composition data for AIGKC.**

Response:

- *We applied Francis re-weighting method for selecting weights for length composition data for all scenarios (Appendix D).*

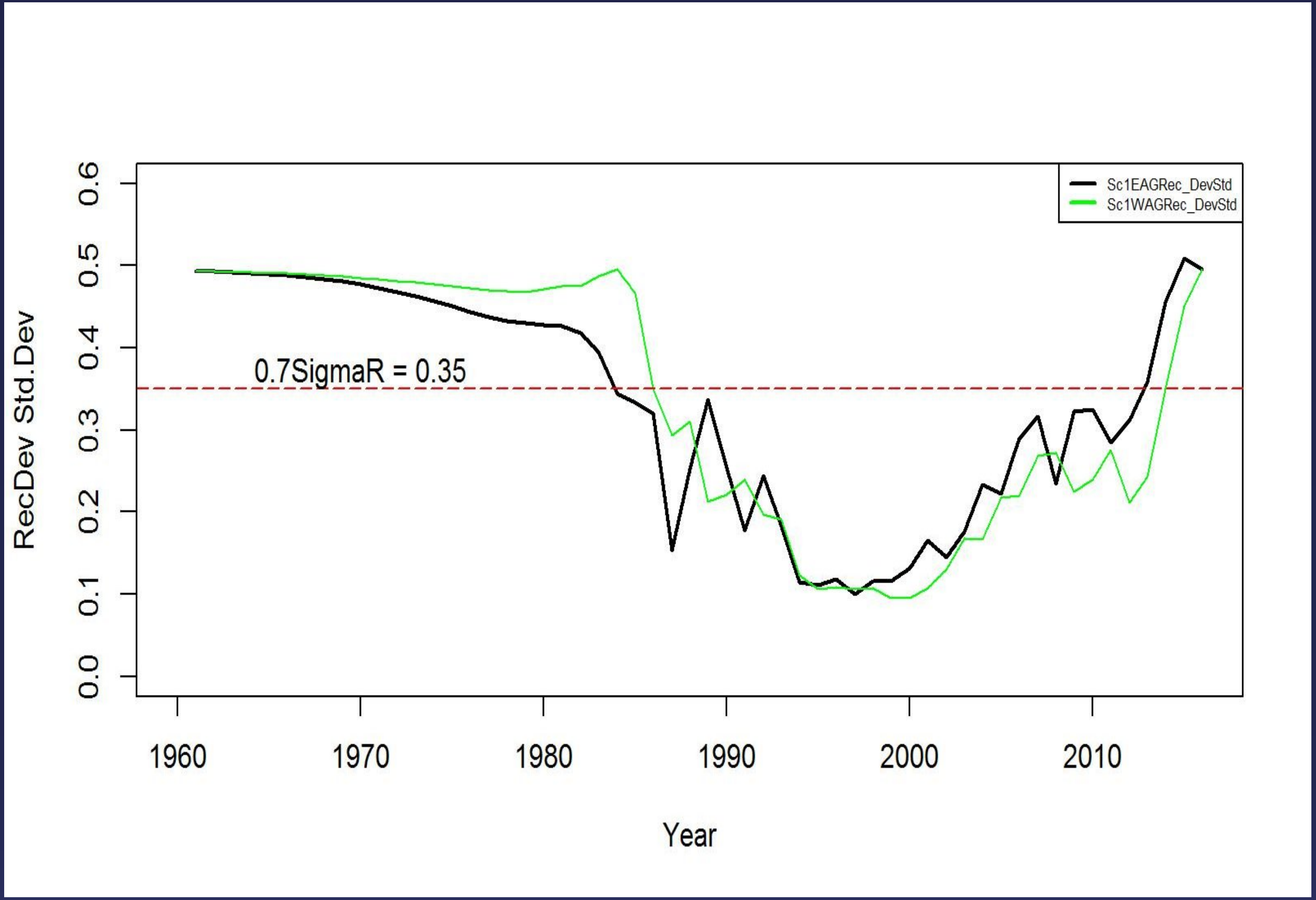


Figure 9. Standard deviation of recruit_dev plot for EAG and WAG. The mean recruit for years with standard deviation less than 0.7 sigma R was used to initialize the models. We selected the 1987–2012 period for mean recruit estimation.

January 2017 CPT comments continued

- **Comment 7: The changes in the spatial pattern of fishing be evaluated further for the May CPT meeting based on plots by year (or blocks of years).**

Response:

- *Appendix F provides the spatial pattern of observer sample, effort , catch, and productivity in core and non-core areas by year during 1990–2015. We also estimated CPUE indices, catch, F, and MMB trends using core data and compared those values with the full data set model results.*

- **Comment 8: An F35% calculation requires vectors for maturity, selectivity, and natural mortality—all of which are available for AIGKC. Therefore the CPT recommends that AIGKC be placed in Tier 3. If the SSC agrees with this recommendation in February, there would be no need to develop OFL/ABC tables for Tier 4 in the May assessment document.**

Response: Done

- **Comment 9: These maturity data be re-evaluated for the May CPT meeting to determine whether a maturity curve can be estimated reliably.**

Response:

- *We used the maturity proportions by size estimated from1991 ADFG pot survey maturity data in the model. It appears that a reliable maturity curve can be fitted (Appendix C).*

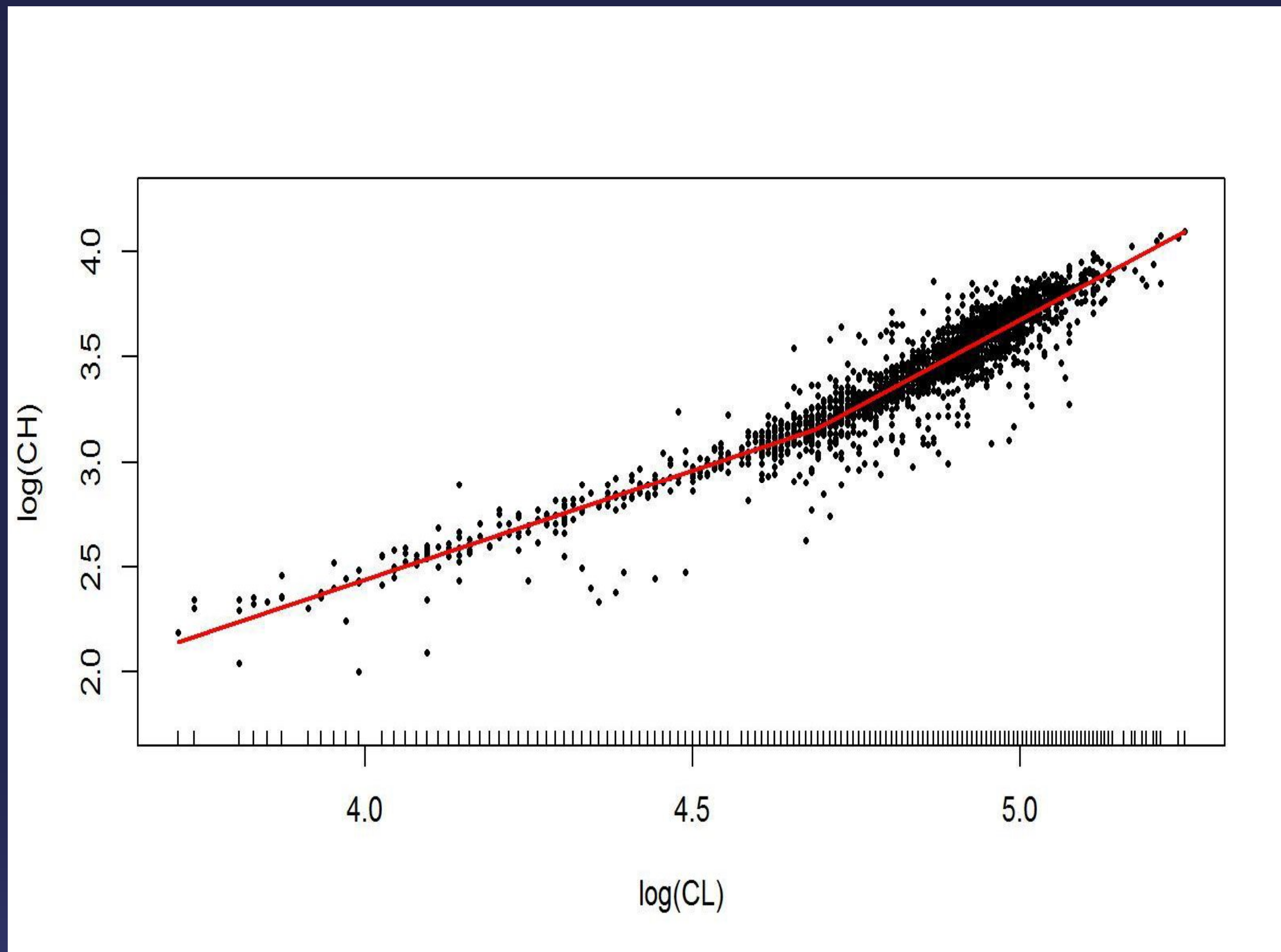


Figure C.1. Segmented linear regression fit to ln(CH) vs. ln(CL) data of male golden king crab in EAG. Break Point L50% = 108.53 ± 1.01 mm CL, n = 2457, Adjusted R-squared: 0.91.

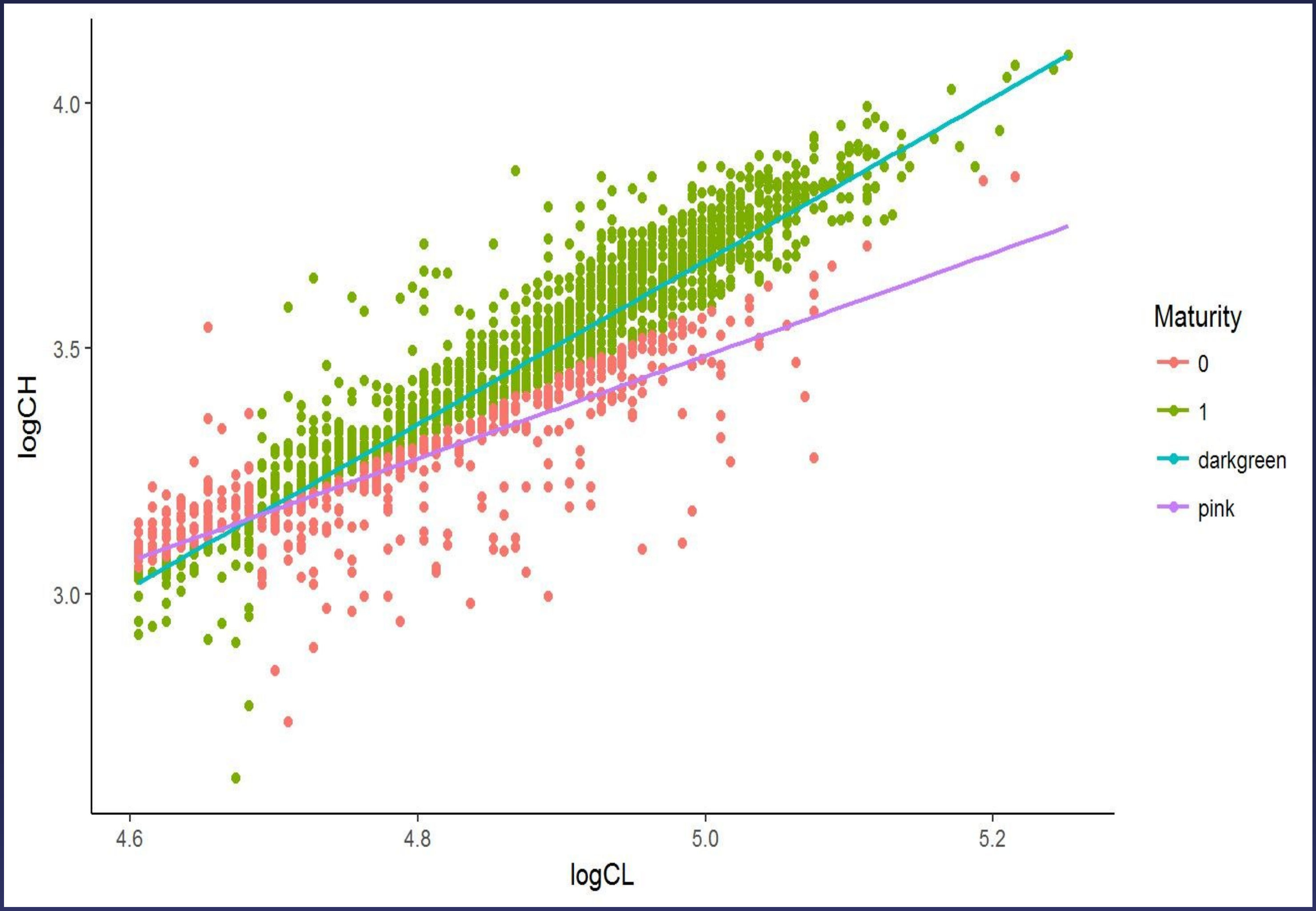


Figure C.2. Segmented linear regression fit to ln(CH) vs. ln(CL) data of male golden king crab in EAG with classification of mature (code 1, darkgreen) and immature (code 0, red) data points.

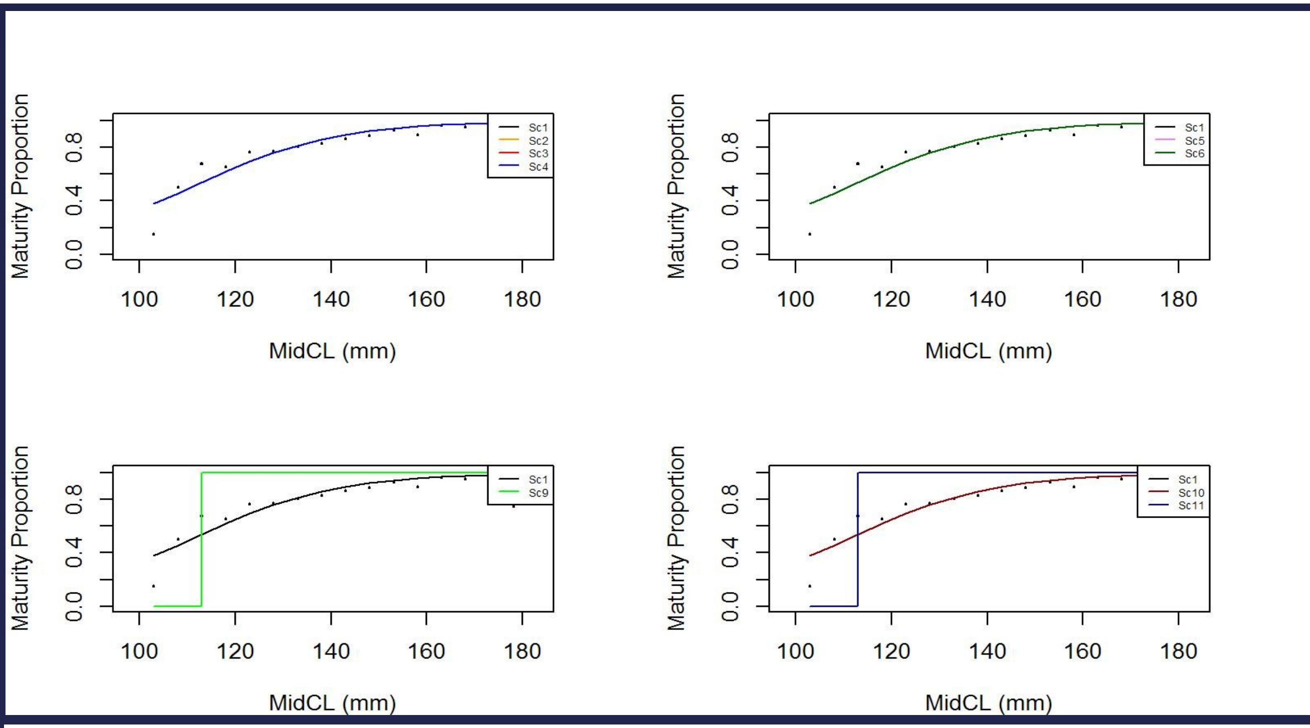


Figure 18. Estimated maturity probability vs. CL for scenarios (Sc) 1 to 11, EAG.

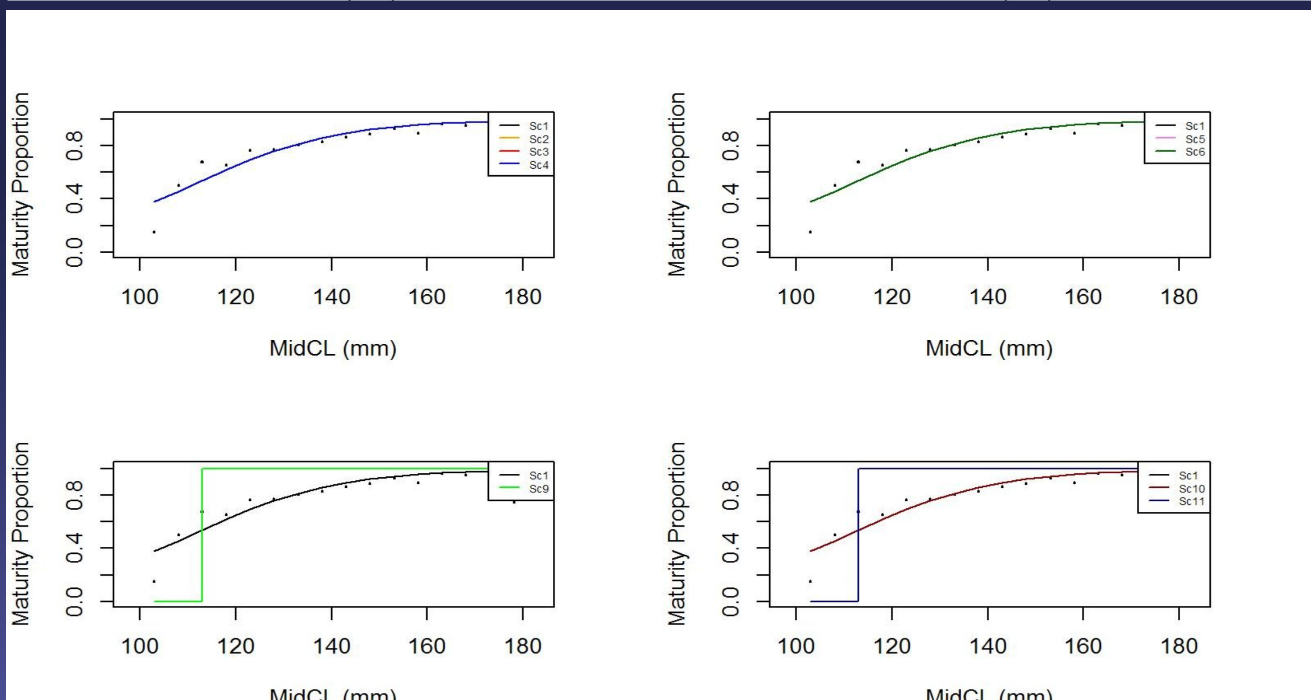


Figure 37. Estimated maturity probability vs. CL for scenarios (Sc) 1 to 11, WAG.

January 2017 CPT comments continued

- **Comment 10: The CPT discussed whether the primary abundance index for AIGKC as calculated from fishery data should be considered in recommending a Tier level. The CPT regards this as an important factor in assessment uncertainty, but recommends that this be considered when recommending a buffer for the ABC, not in determining the Tier level.**

Response:

Because of uncertainty in fisheries data, we provided the 20% and 25% buffer options for ABC calculation. The CPT in May 2017 selected the 20% buffer.

- **Comment 11: CPT would prefer to see similar runs grouped together for May, as it is hard to compare 15 model runs on one graph (for example, Figure 29 on p. 95).**

Response:

- *We grouped the plots into four and also used a fixed color scheme to display.*

February 2017 SSC comments

- **Comment 1: Pending completion of the CPT and SSC requests, the authors bring forward a Tier 3 analysis for AIGKC for consideration at the May CPT and June SSC meetings.**

Response:

- *We did only the Tier 3 analysis.*

- **Comment 2: Strongly encourages future efforts to develop a fishery-independent survey for this resource, in addition to continuing efforts to better understand the CPUE data through investigation of the annual spatial distribution of the fishery and changes in individual vessel participation.**

Response:

- *We are making every effort to expand the fishery independent survey currently being conducted only in the EAG area.*
- *Appendix F provides the spatial pattern of observer sample, effort , catch, and productivity in core and non-core areas by year during 1990–2015. We have provided a few model fitting results on core data as well.*

February 2017 SSC comments continued

- **Comment 3: The SSC generally supports the CPT recommendations, but recommends a slightly revised approach to the treatment of M. The author prepares a likelihood profile using a finer resolution (smaller step-size). The author makes a run using both EAG and WAG data sets combined that includes a prior on natural mortality (0.18) with a CV of 50%.**

- **When the final preferred model has been developed, the SSC requests one additional run that does not use this prior on M in order to evaluate its effect.**

Response:

- *(a) We considered two options: 1. Including the M prior and 2. Not including the M prior. The results appear not significantly different (Figures 4 to 6). So, we opted to using the M estimate obtained without the M prior in all scenarios.*
- *(b) We used the smaller step-size of 0.025 to calculate M profiles.*

- **Comment 4: Finally, the author to perform jitter runs to avoid unexpected model behavior.**

Response:

- *We conducted 100 jitter runs for scenarios 1 and 9. The convergence did not deviate from the original optimized positions for most runs (Appendix E).*

February 2017 SSC comments continued

- **Comment 5: The SSC notes that the tuning of input-to-effective sample sizes for the McAllister-Ianelli method appears to have been conducted at the level of individual year's observations. This is not consistent with general practice. The SSC supports the CPT recommendation to use the Francis method for future analyses.**

Response:

(a) We used the harmonic mean as a single multiplier for the time series of input effective sample sizes under McAllister and Ianelli method.

(b) In the current runs, we used only the Francis method of iterated weighting of effective sample sizes for all scenarios.

- **Comment 6: Recruitments that are included in the B_{MSY} calculations should have an estimated variance << sigma R, and should generally not include the terminal year's estimates (2016) unless specifically warranted by informative data. The SSC recommends the CPT and authors review the GPT guidance on making these calculations.**

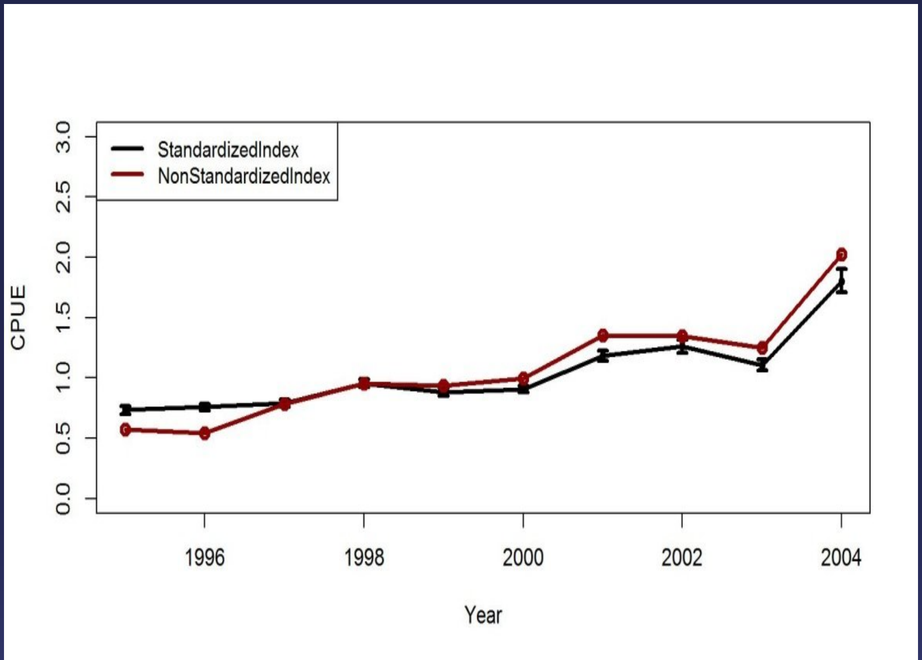
Response:

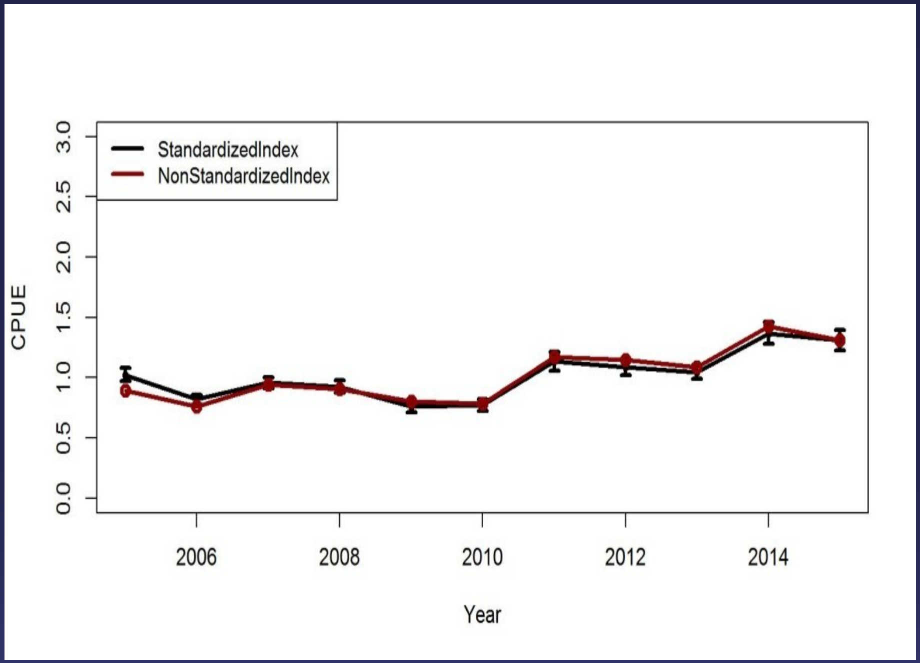
We used a subset of recruitment estimates that excluded the terminal and initial year's R for equilibrium abundance and B_{MSY} reference points estimation (1987–2012).

Trends in non-standardized and standardized CPUE indices with +/- 2 SE for EAG. Standardized indices: black line and non-standardized indices: red line.

1995/96 – 2004/05

2005/06 – 2015/16





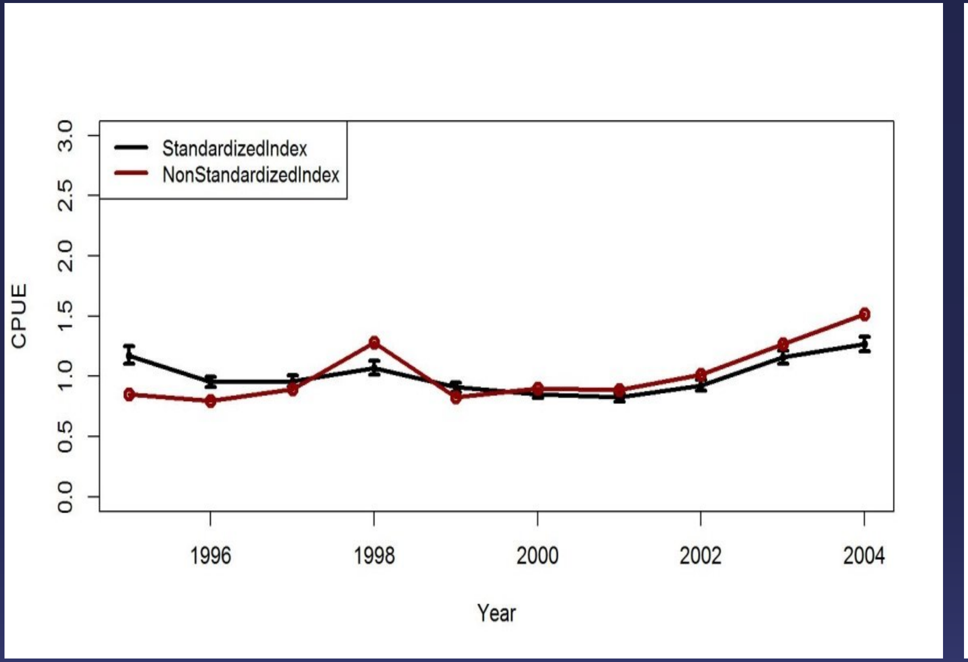
Ln(CPUE) = Year + Gear + Captain + ns(Soak, df=3) *forced in*,
family = negative binomial (theta = 1.33)

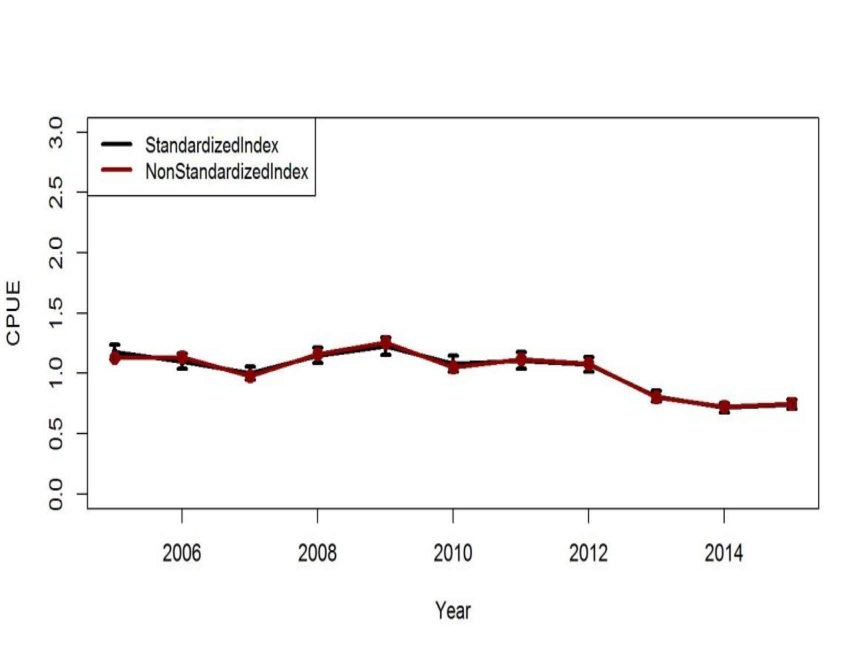
Ln(CPUE) = Year + Captain + ns(Soak, df=16) + Gear,
family = negative binomial (theta = 2.29)

Trends in non-standardized and standardized CPUE indices with +/- 2 SE for WAG. Standardized indices: black line and non-standardized indices: red line.

1995/96 – 2004/05

2005/06 – 2015/16

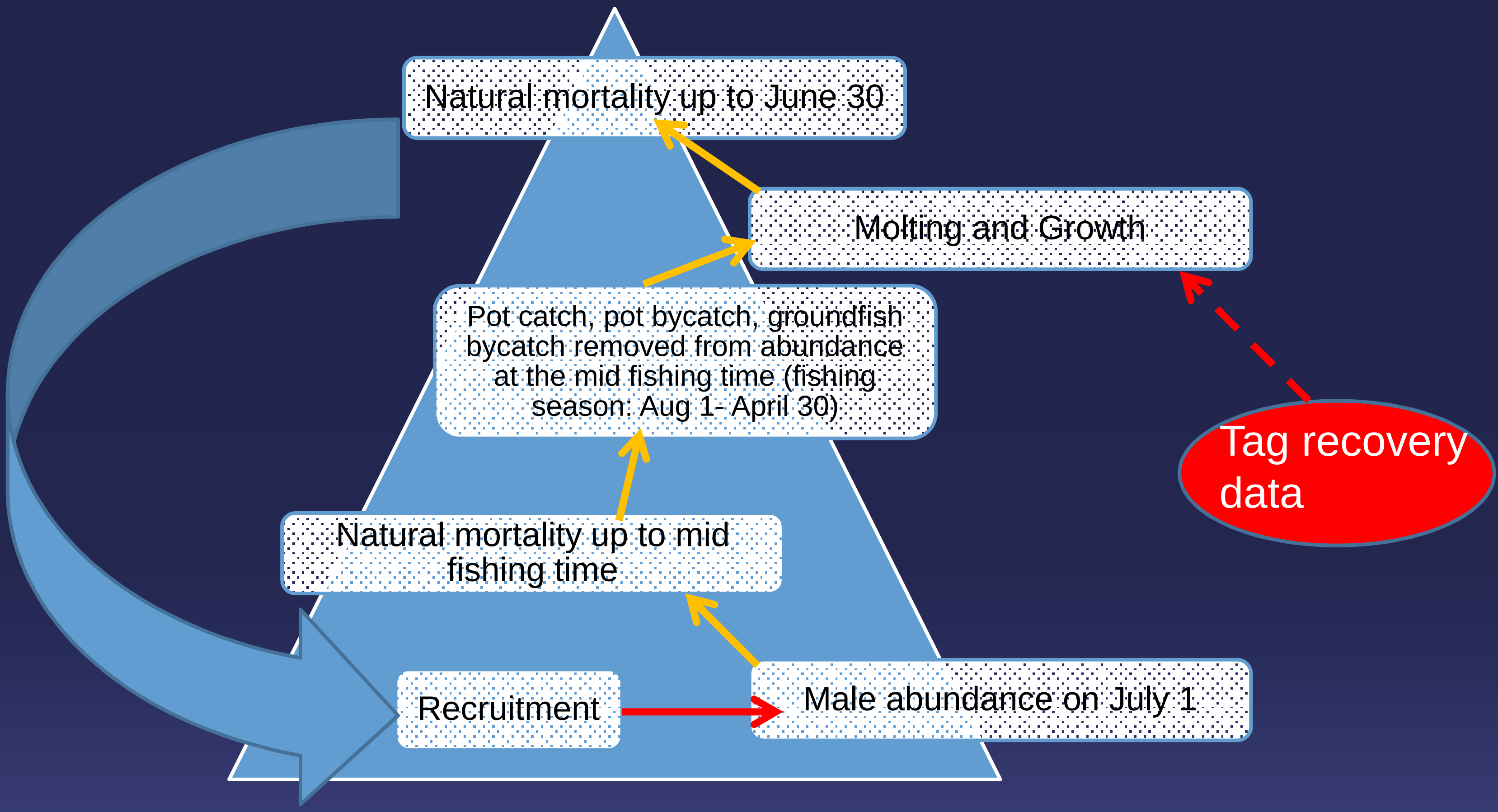




Ln(CPUE) = Year + Captain + Gear + ns(Soak, df=8),
family = negative binomial (theta = 0.98)

Ln(CPUE) = Year + Gear +ns(Soak, df=17) ,
family = negative binomial (theta = 1.13)

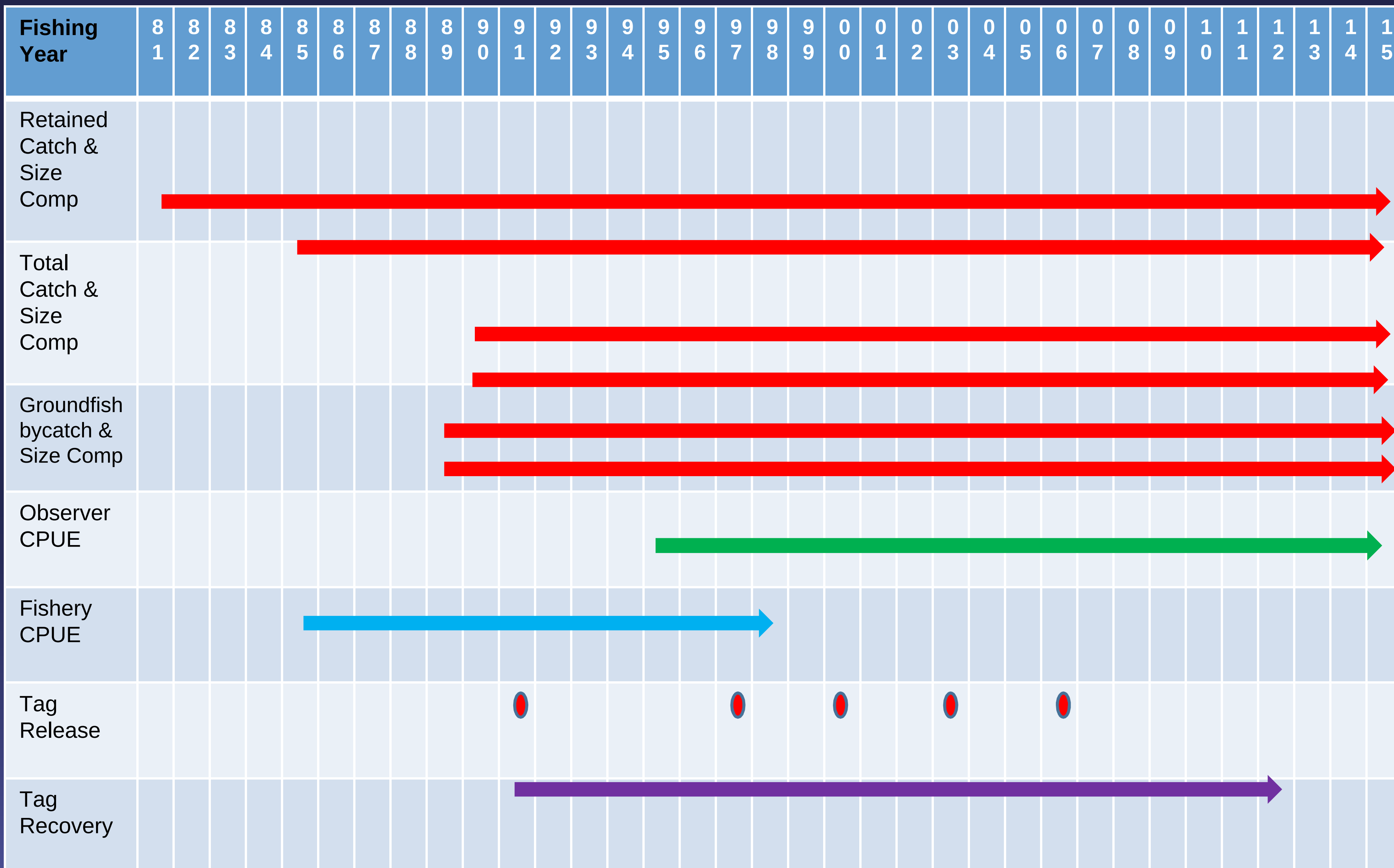
Conceptual length based model



Length based modeling approach

- An integrated length based model. This is the only FMP crab stock modelled with fishery dependent catch and CPUE data without survey information.
- Estimated *M* in the model.
- Projected the abundance from unfished equilibrium in 1960 to initialize the 1985 abundance.
- Eleven scenarios were run for EAG and WAG.
- Francis re-weighting method was used for Stage-2 effective sample sizes calculation for all scenarios.

Data


Fishing Year
81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
Retained Catch & Size Comp
Total Catch & Size Comp
Groundfish bycatch & Size Comp
Observer CPUE
Fishery CPUE
Tag Release
Tag Recovery

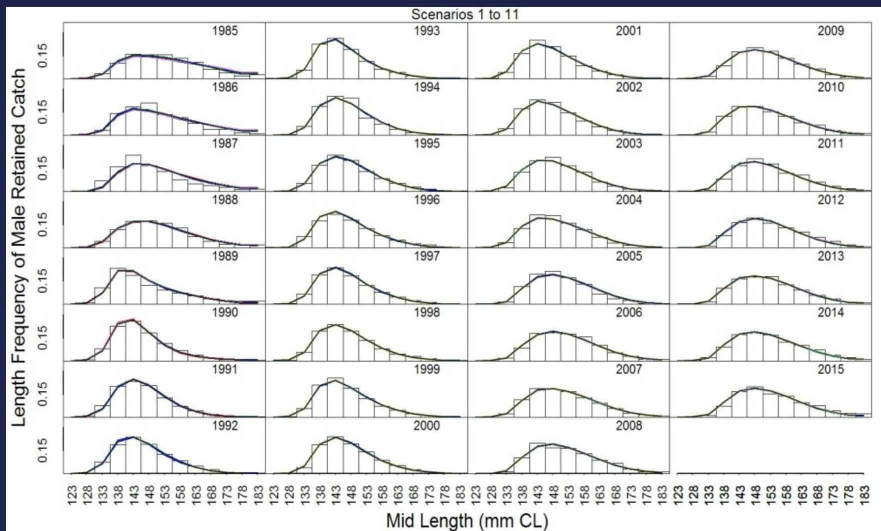
EAG and WAG scenarios (Sc.)

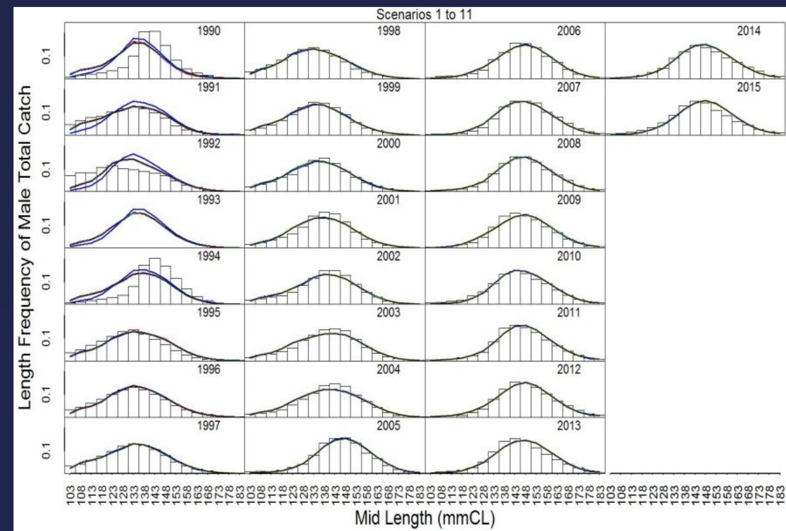
Scenario	Size-composition weighting	Catchability and logistic total selectivity sets	Maturity	CPUE data type	Treatment of M and Tier 3 B_{MSY} reference points	Natural mortality (M yr^{-1})
0a	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer from 1995/96–2015/16 & Fish Ticket from 1985/86–1998/99	Estimate a common M using the combined EAG and WAG data with an M prior	0.223
0b	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer from 1995/96–2015/16 & Fish Ticket from 1985/86–1998/99	Estimate a common M using the combined EAG and WAG data without an M prior	0.224
1b	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer from 1995/96–2015/16 & Fish Ticket from 1985/86–1998/99	Estimate separate M for each area using individual EAG or WAG data without an M prior	EAG: 0.221 WAG: 0.231
1	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer from 1995/96–2015/16 & Fish Ticket from 1985/86–1998/99	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	0.224
2	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Omit Fish Ticket CPUE likelihood	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	0.224
3	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer CPUE from 1991/92–2015/16 & Fish Ticket	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	0.224
4	Stage-1:Number of days/trips Stage-2: Francis method	3	Logistic curve	Observer & Fish Ticket	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	0.224
5	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer & Fish ticket	Low bracketing value of M; B_{MSY} reference points based on average recruitment from 1987–2012	0.189
6	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer & Fish ticket	High bracketing value of M; B_{MSY} reference points based on average recruitment from 1987–2012	0.266
7	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer & Fish ticket	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1982–2016	0.224

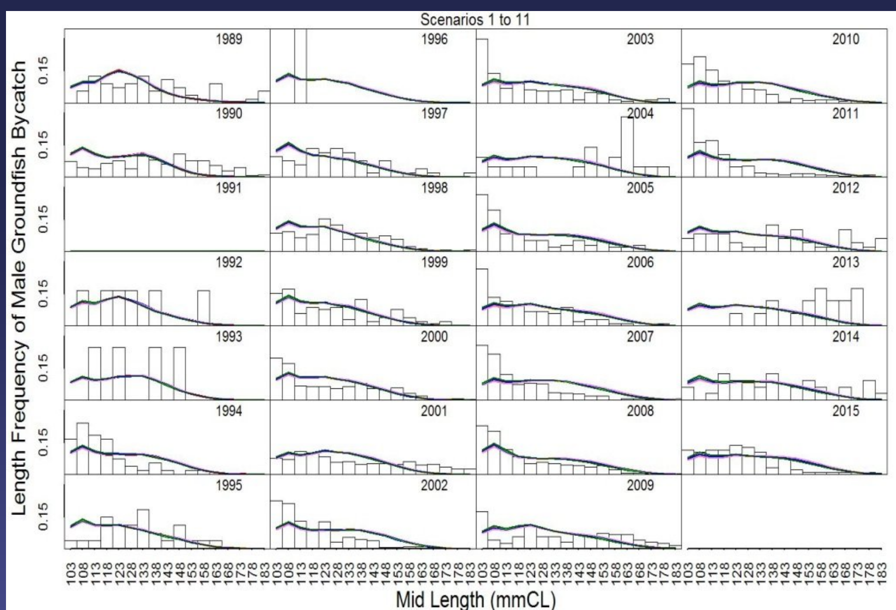
EAG and WAG scenarios (Sc.)

Scenario	Size-composition weighting	Catchability and logistic total selectivity sets	Maturity	CPUE data type	Treatment of M and Tier 3 B_{MSY} reference points	Natural mortality (M yr^{-1})
8	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer & Fish ticket	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1996–2016	0.224
9	Stage-1:Number of days/trips Stage-2: Francis method	2	Knife-edge 111 mmCL	Observer & Fish Ticket	Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	0.224
9**	Stage-1:Number of days/trips Stage-2: Francis method	2	Knife-edge 111 mmCL	Observer & Fish Ticket	Considered only for WAG for Approach 2 OFL and ABC calculation; Single M from combined EAG and WAG data; B_{MSY} reference points based on average recruitment from 1993–1997	0.224
10	Stage-1:Number of days/trips Stage-2: Francis method	2	Logistic curve	Observer & Fish Ticket	Separate M from EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	EAG: 0.221 WAG: 0.231
11	Stage-1:Number of days/trips Stage-2: Francis method	2	Knife-edge 111 mmCL	Observer & Fish Ticket	Separate M from EAG and WAG data; B_{MSY} reference points based on average recruitment from 1987–2012	EAG: 0.221 WAG: 0.231

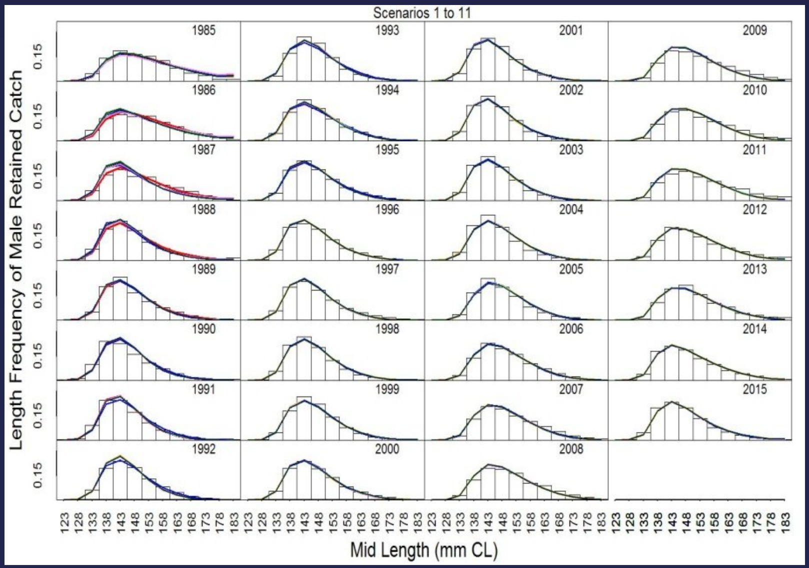
Figs. 10, 11, and 12. Predicted (line) vs. observed (bar) retained (top right), total (top left), and groundfish discarded (bottom left) catch length compositions for scenarios 1 to 11 fits to EAG data, 1985/86–2015/16.

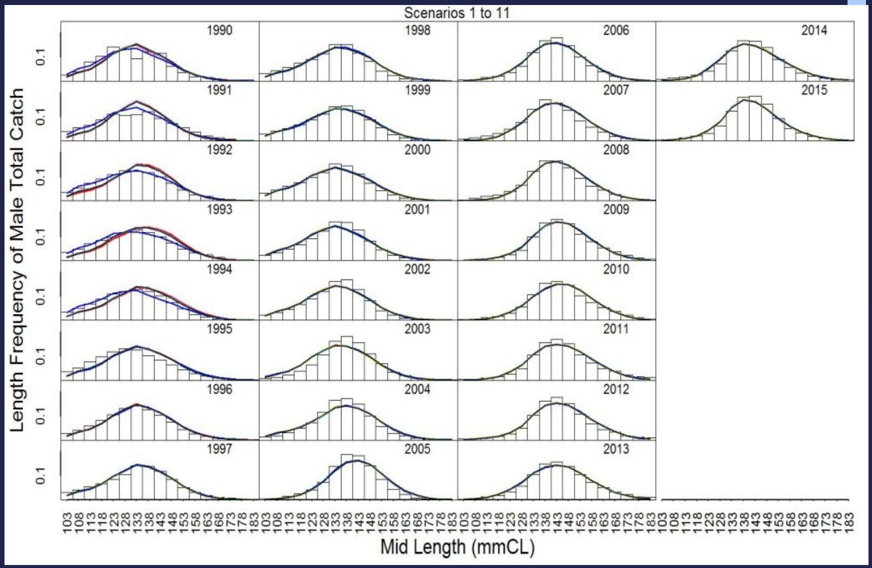






Figs. 29, 30, and 31. Predicted (line) vs. observed (bar) retained (top right), total (top left), and groundfish discarded (bottom left) catch length compositions for scenarios 1 to 11 fits to WAG data, 1985/86–2015/16.





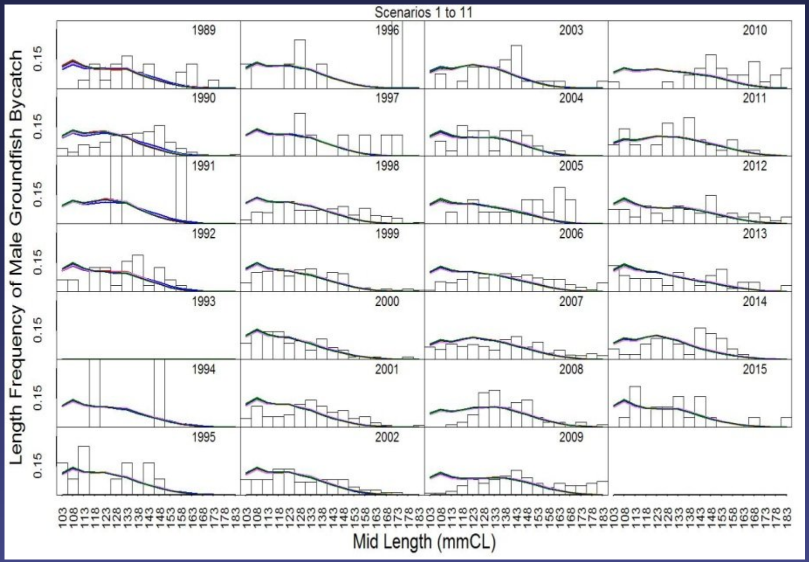


Fig. 13. Total (black solid line) and retained selectivity (red dotted line) for pre- and post-rationalization periods under scenarios (Sc) 1 to 11 fits to EAG data, 1985/86 – 2015/16.

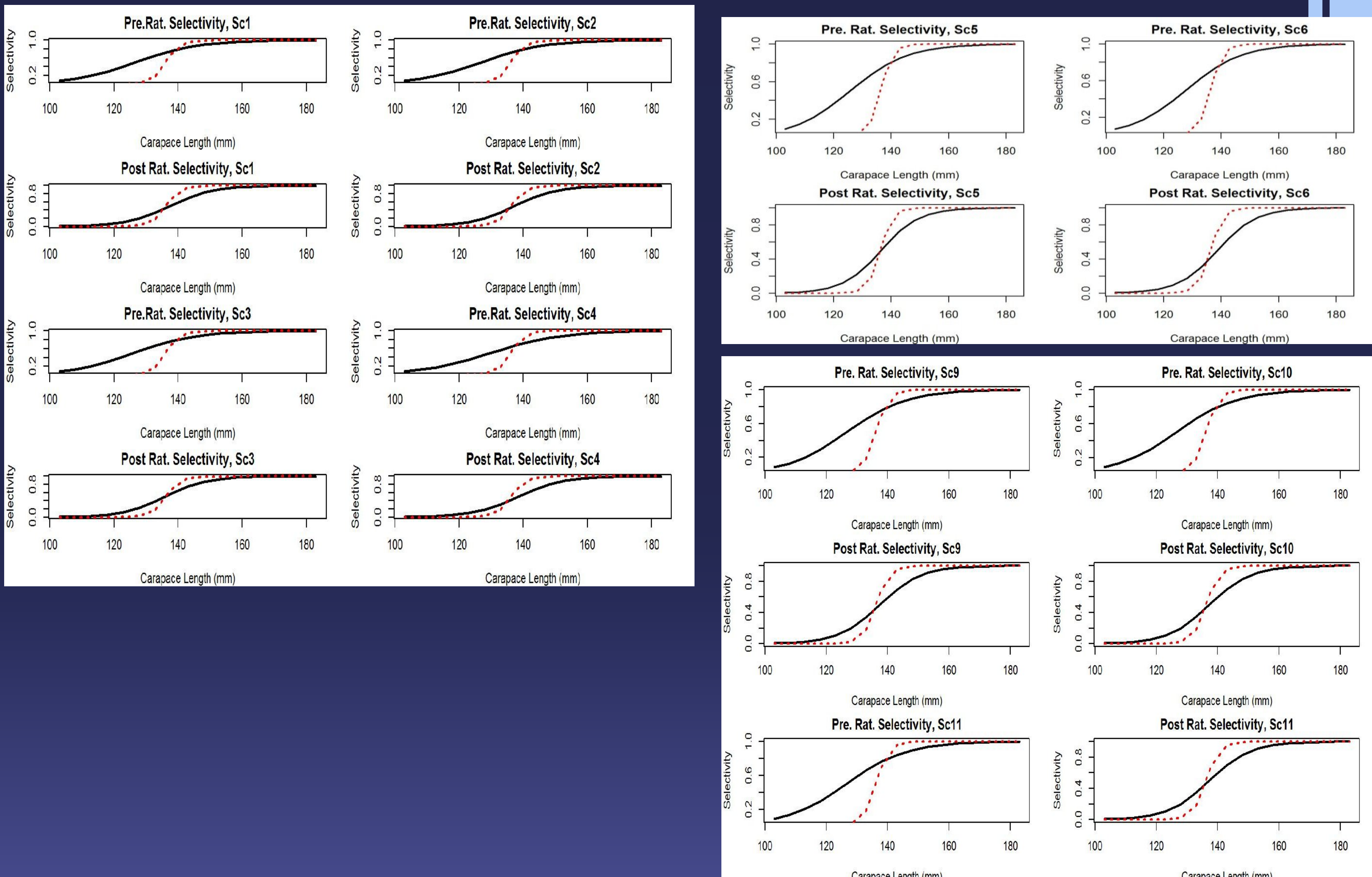
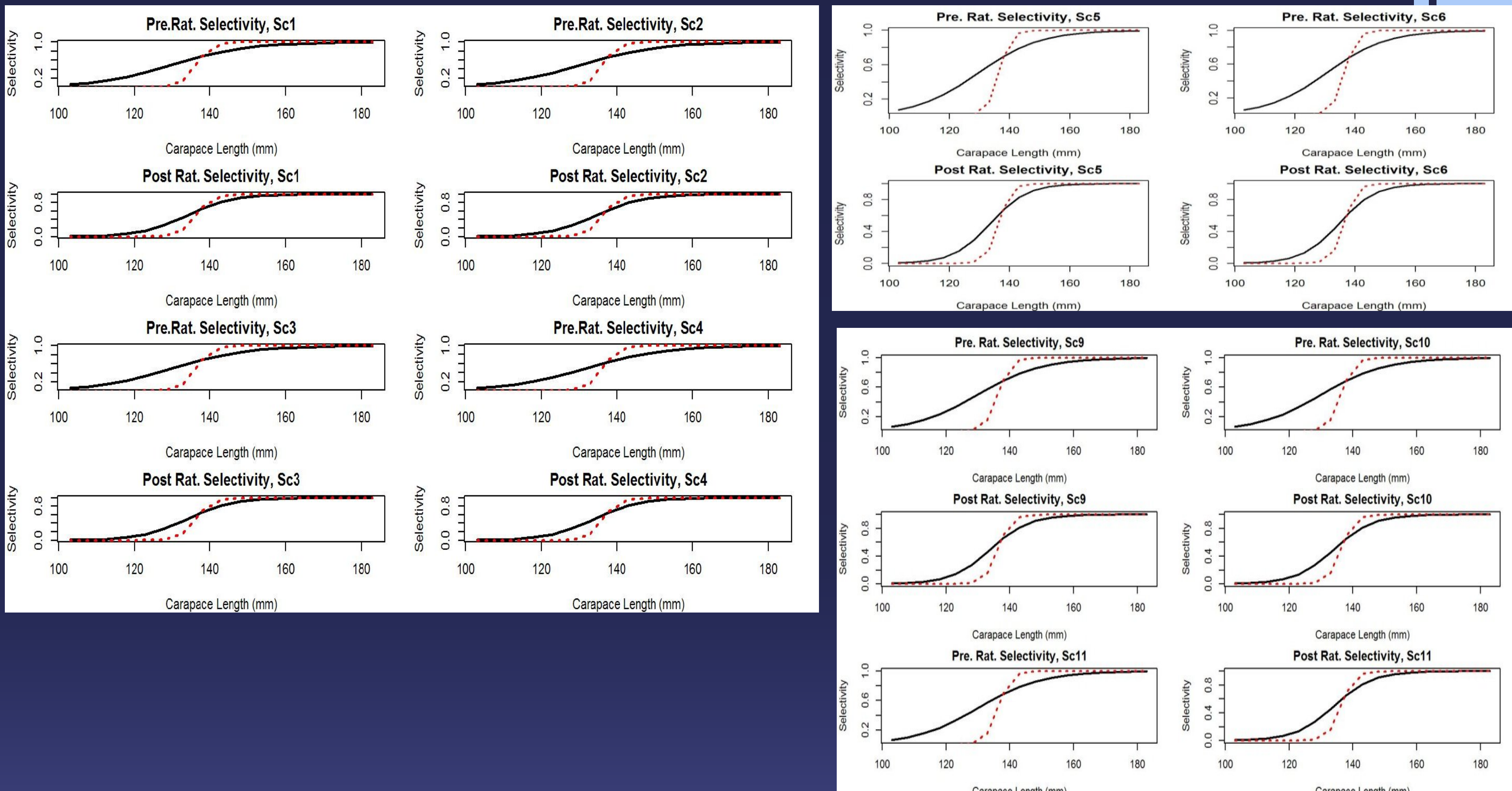
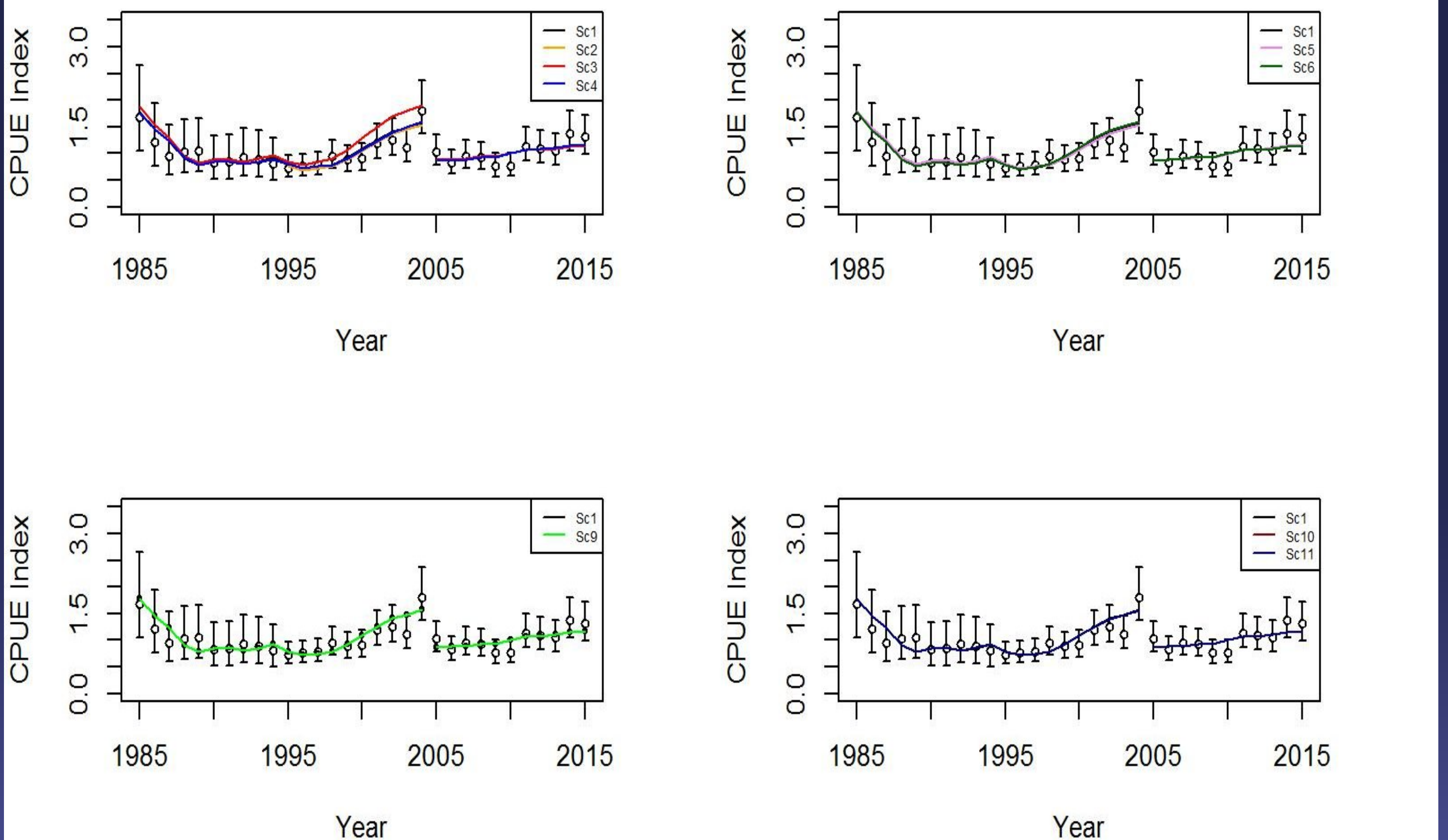


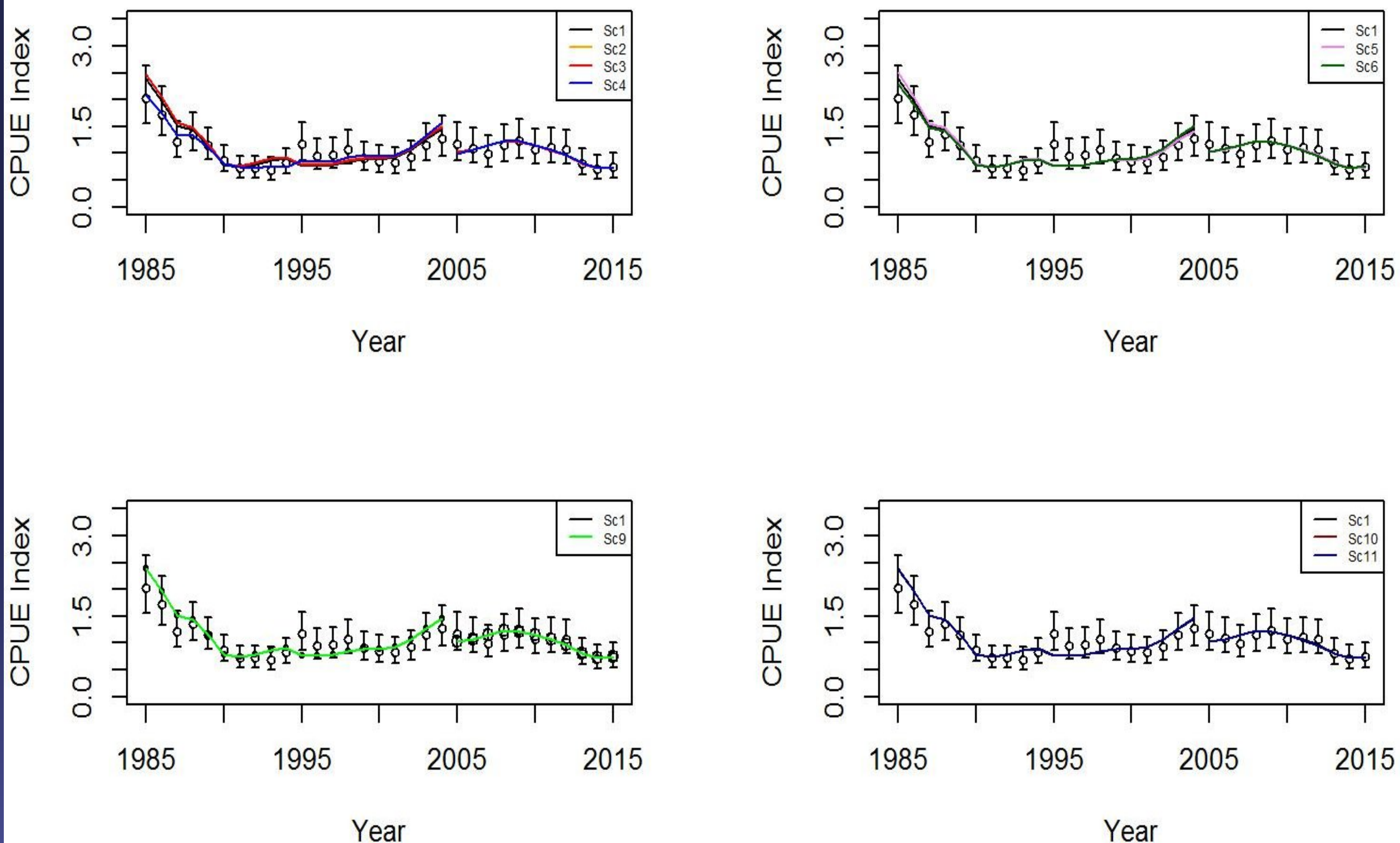
Fig. 32. Total (black solid line) and retained selectivity (red dotted line) for pre- and post-rationalization periods under scenarios (Sc) 1 to 11 fits to WAG data, 1985/86 – 2015/16.



Figs. 26. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc.) 1 to 11 fits to EAG data 1985/86 – 2015/16



Figs. 45. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for scenarios (Sc.) 1 to 11 fits to WAG data 1985/86 – 2015/16



Figs. 15 and 34. Number of male recruits for scenarios (Sc) 1 to 11 fits to EAG (top) and WAG (bottom) data, 1961 – 2016. The numbers were mean adjusted for comparison.

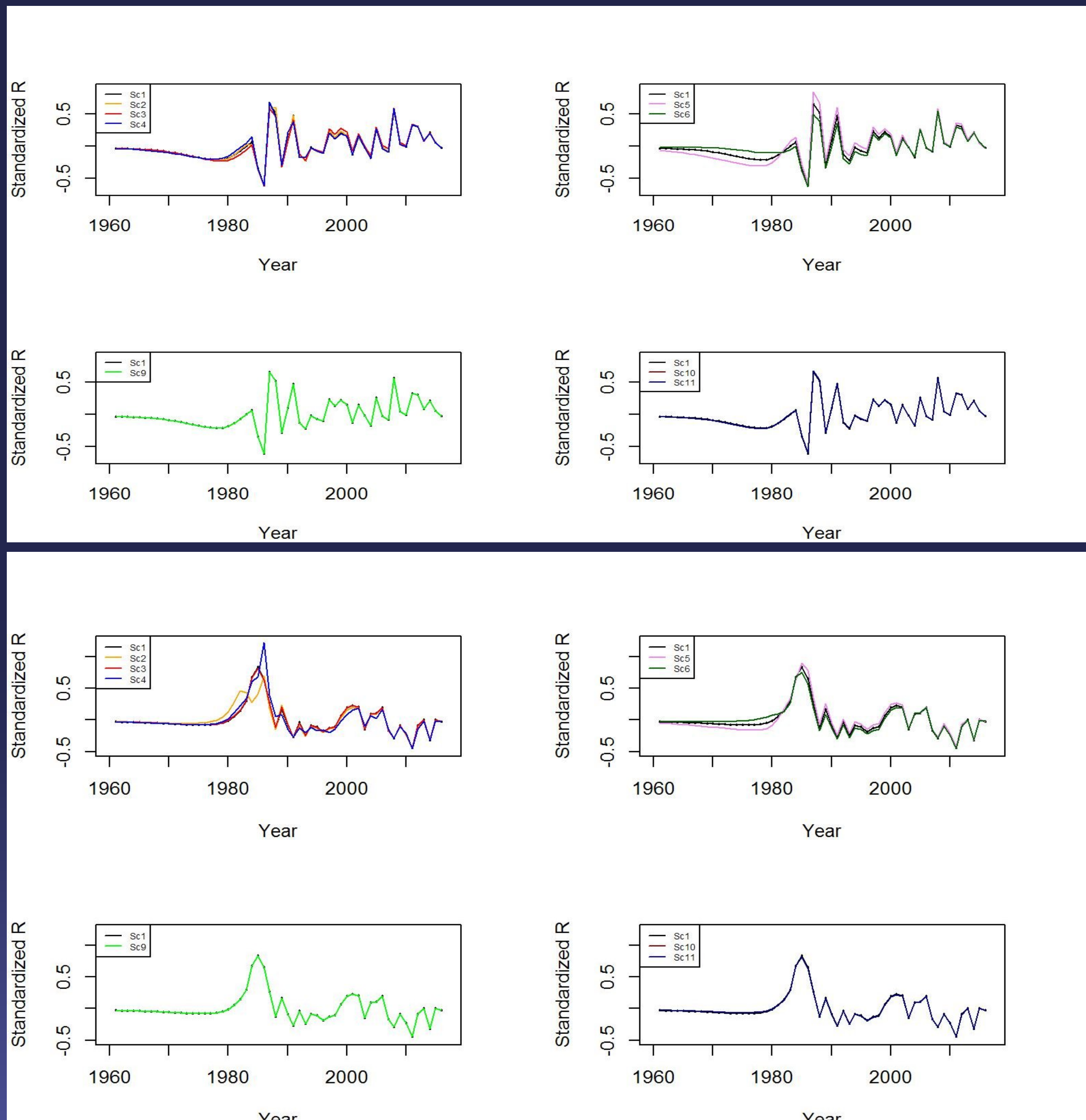


Fig. 25. Retrospective fits of MMB by the model for removal of terminal year's data for scenarios (Sc) 1, 2, 3, 4, and 9 fits for golden king crab in the EAG, 1960–2015.

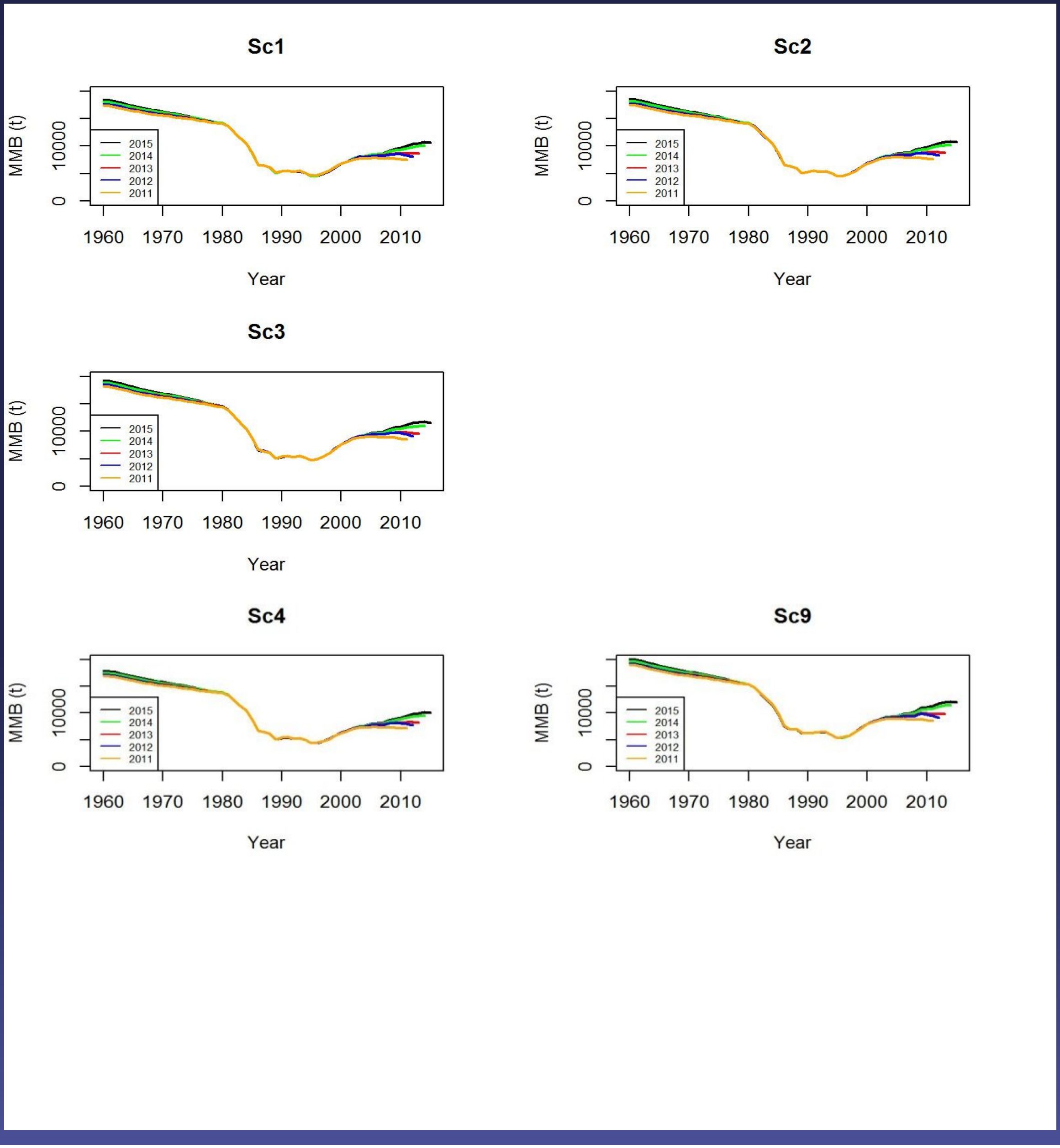
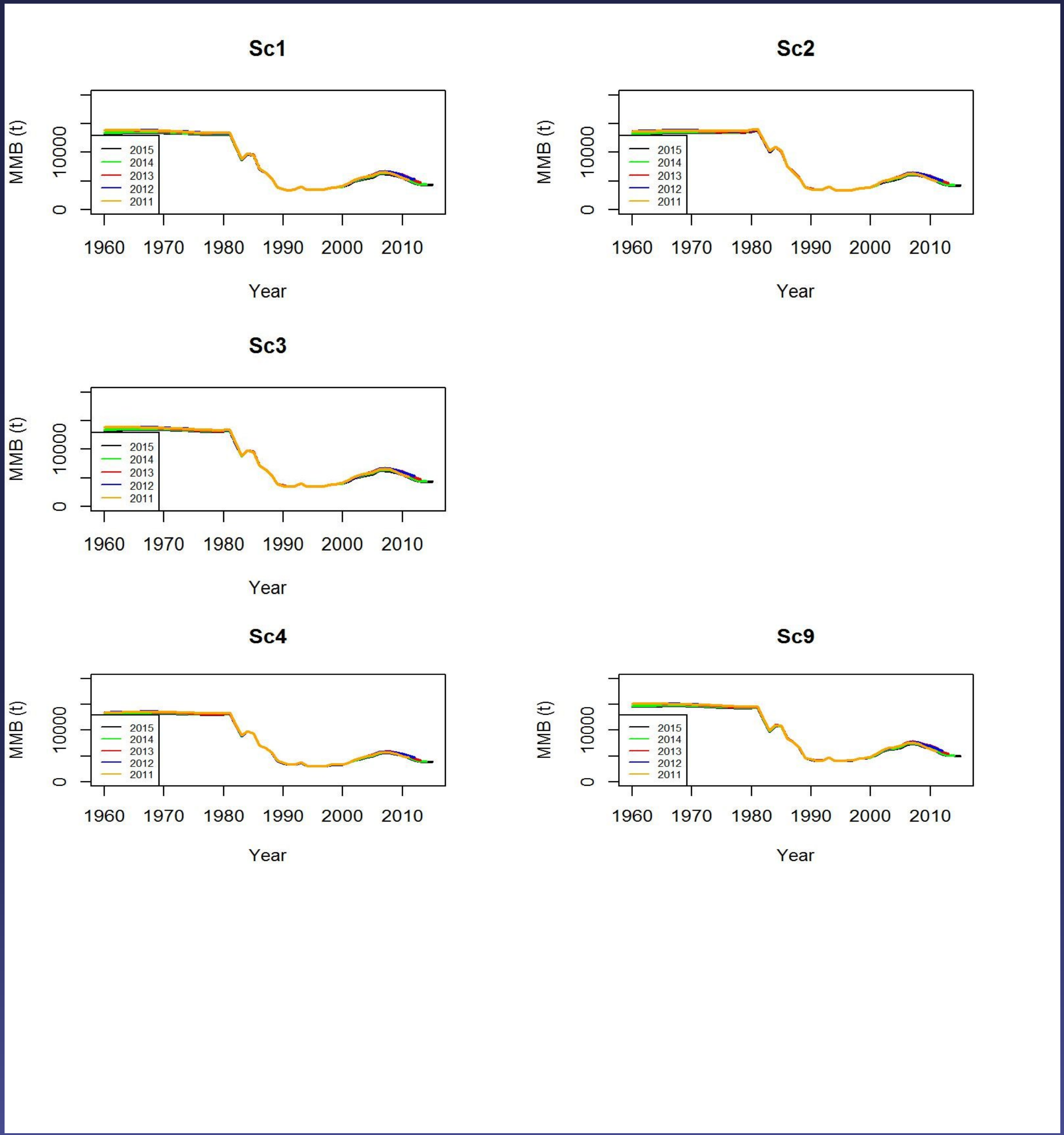
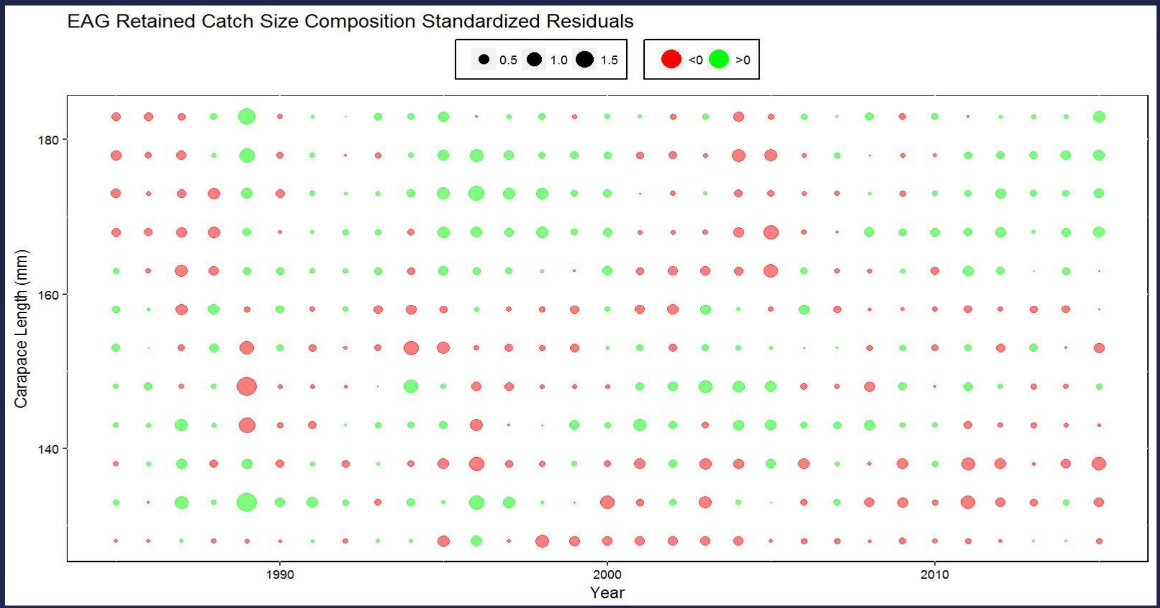
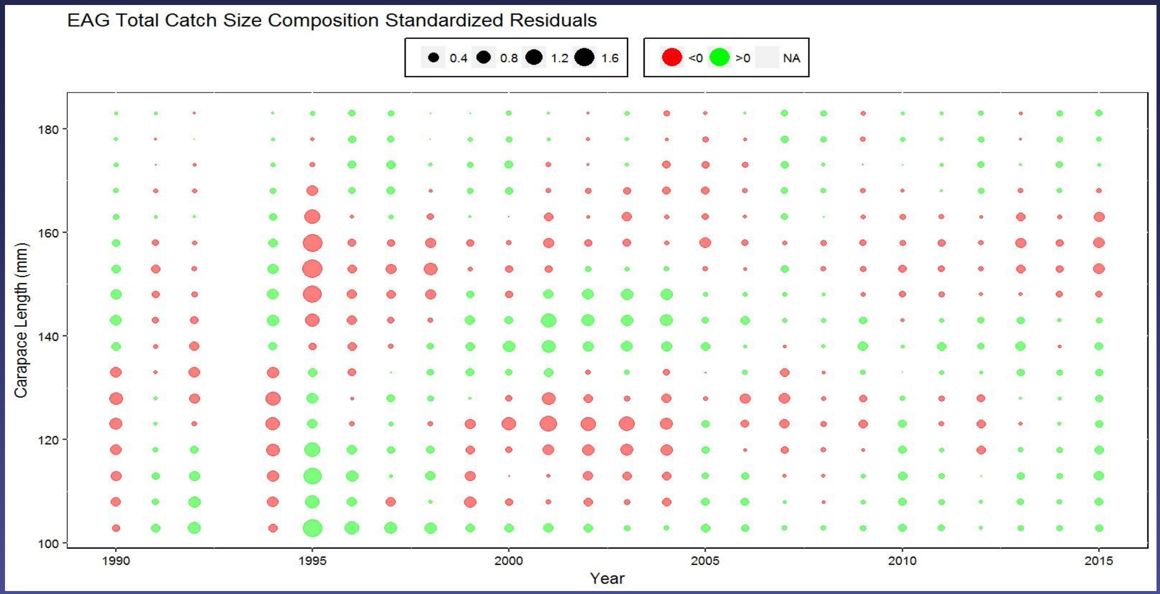


Fig. 44. Retrospective fits of MMB by the model for removal of terminal year's data for scenarios (Sc) 1, 2, 3, 4, and 9 fits for golden king crab in the WAG, 1960–2015.

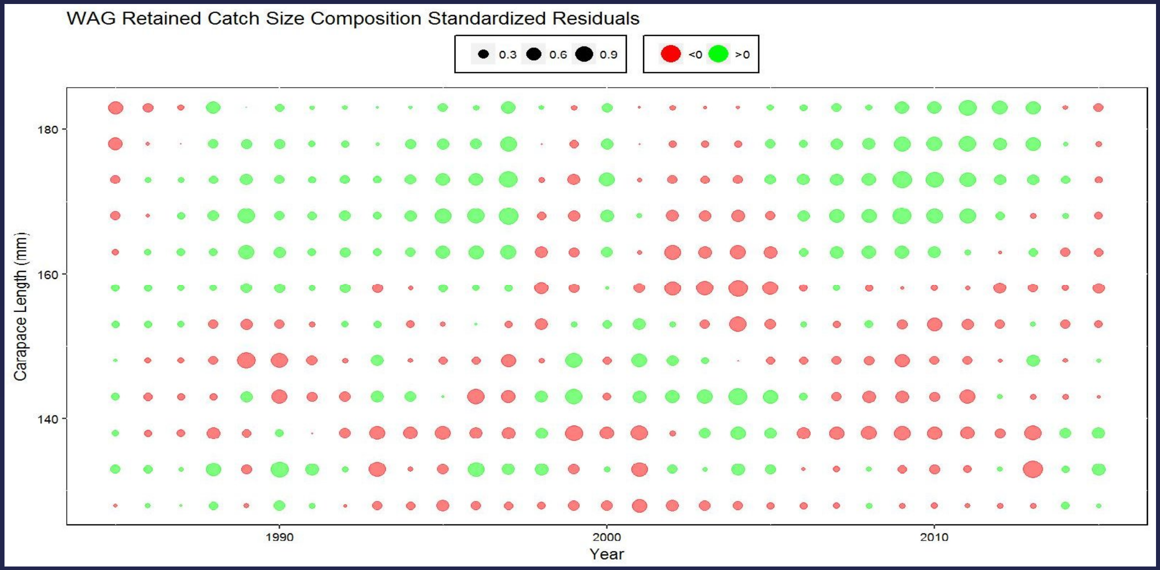


Figs. 21 and 22. Bubble plots of standardized residuals of retained (top) and total (bottom) catch length compositions for scenario 1 fit to EAG data.





Figs. 40 and 41. Bubble plots of standardized residuals of retained (top) and total (bottom) catch length compositions for scenario 1 fit to WAG data.



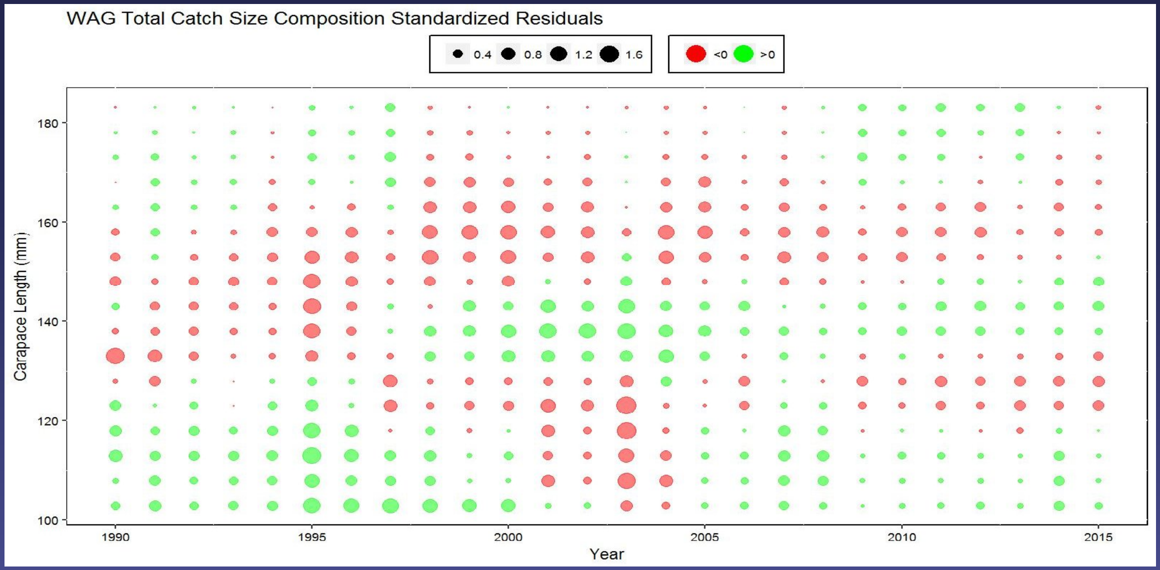


Figure 19. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios (Sc) 1 to 11, in EAG, 1985–2015.

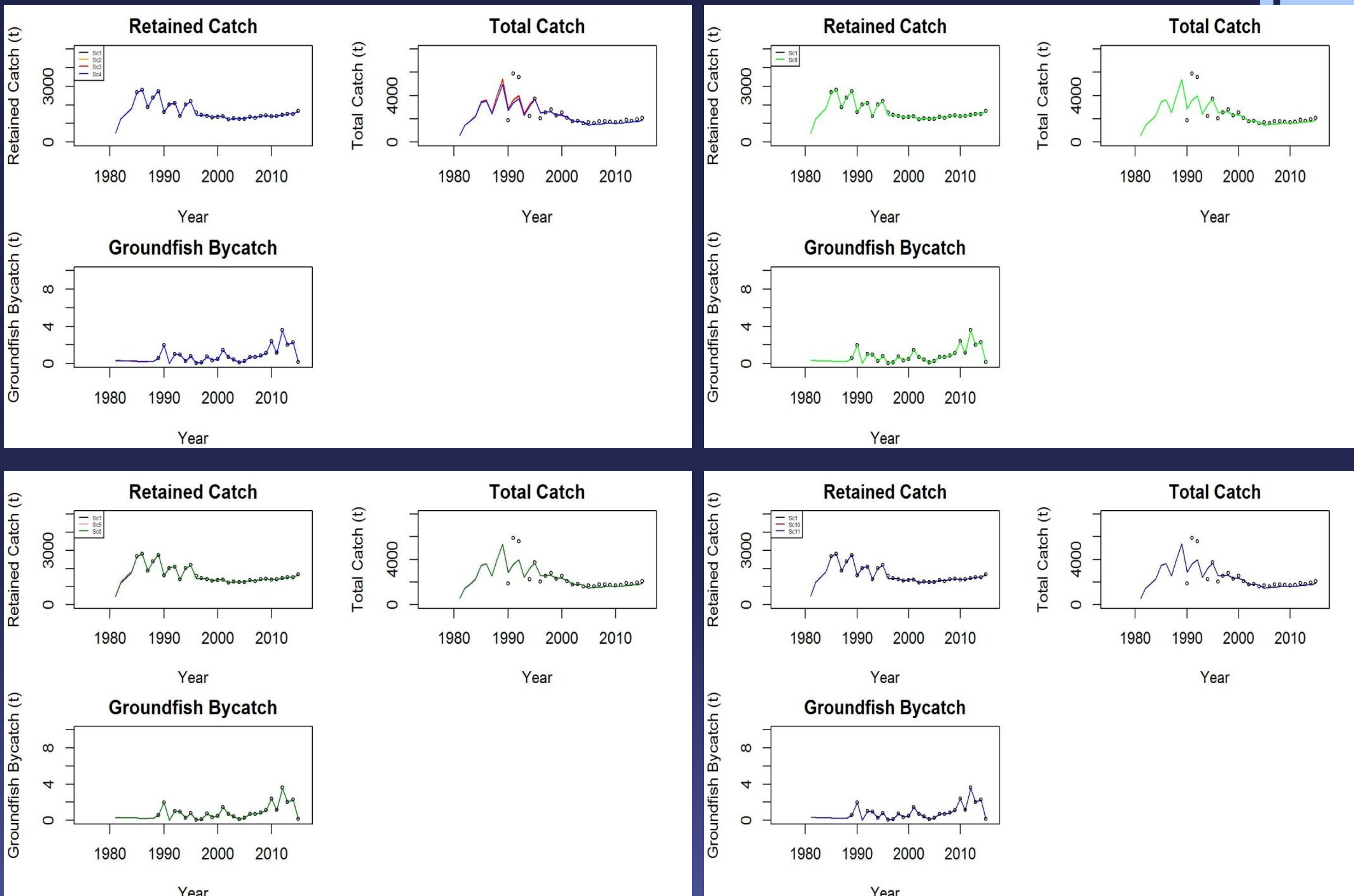


Figure 38. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios (Sc) 1 to 11, in WAG, 1985–2015.

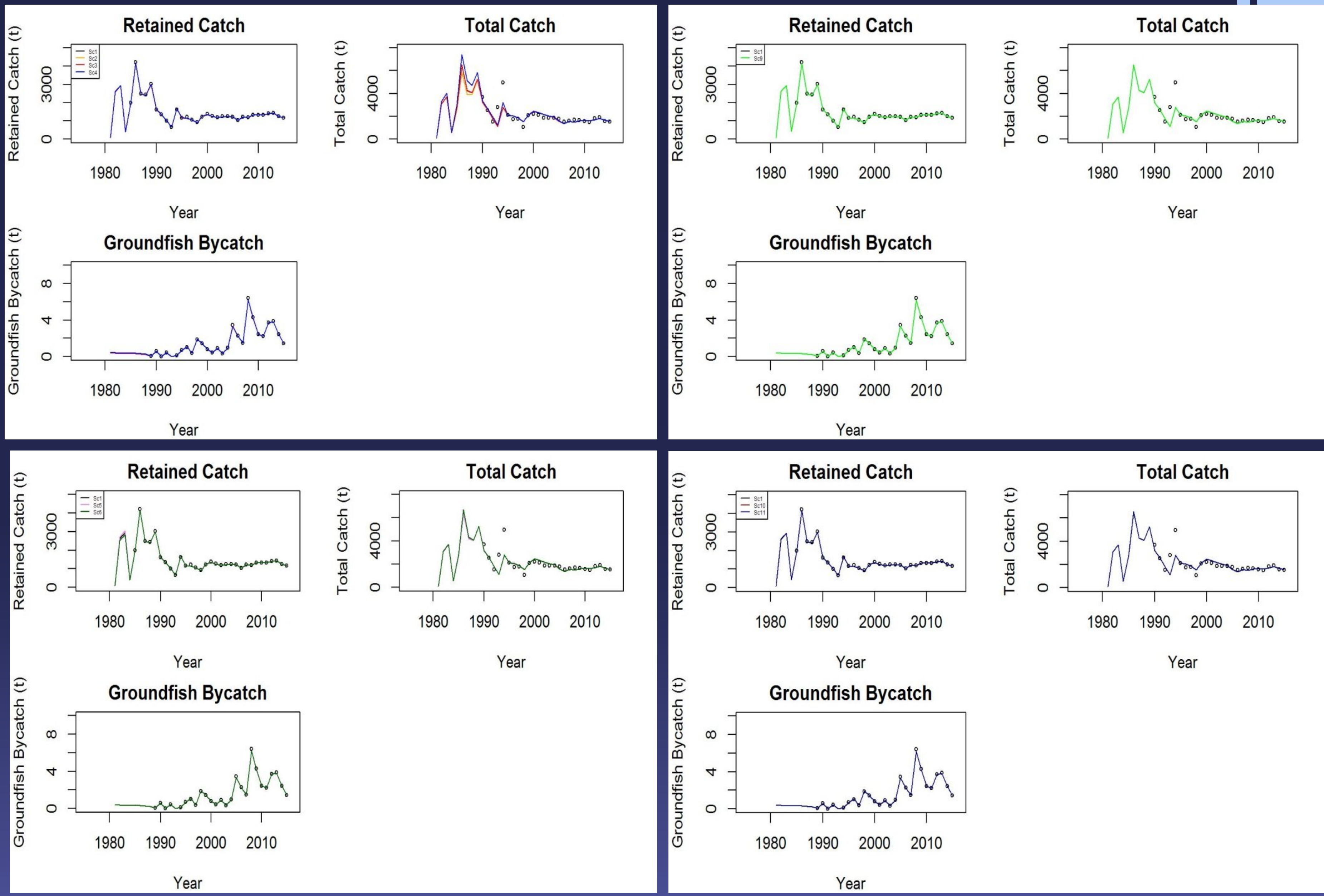


Figure 27. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 11 model fits in the EAG, 1981–2015.

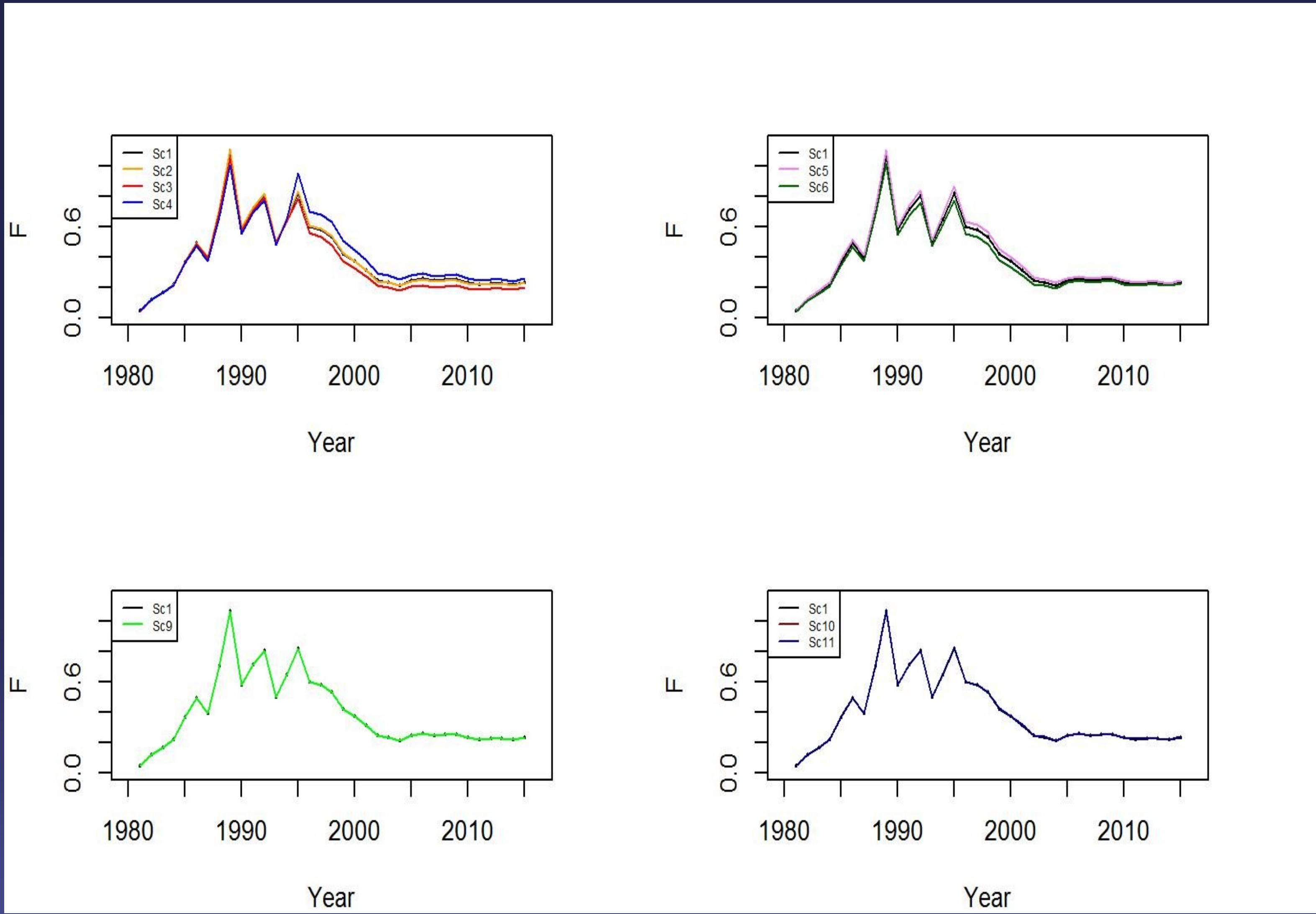


Figure 46. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 11 model fits in the WAG, 1981–2015.

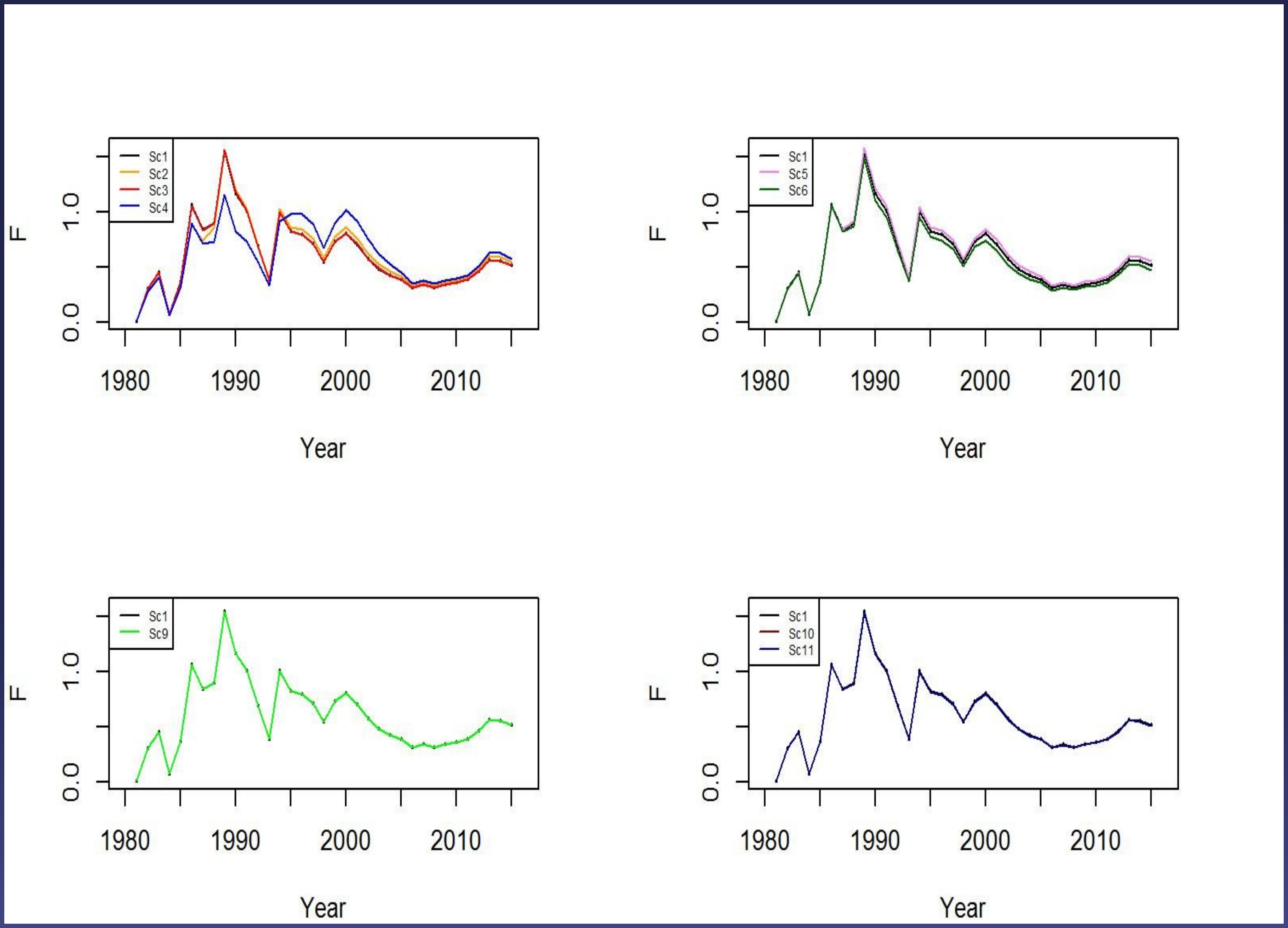


Figure 28. Trends in mature male biomass for scenarios (Sc) 1 to 11 fits in the EAG, 1960/61–2015/16. Scenario 1 estimates have two standard errors confidence limits.

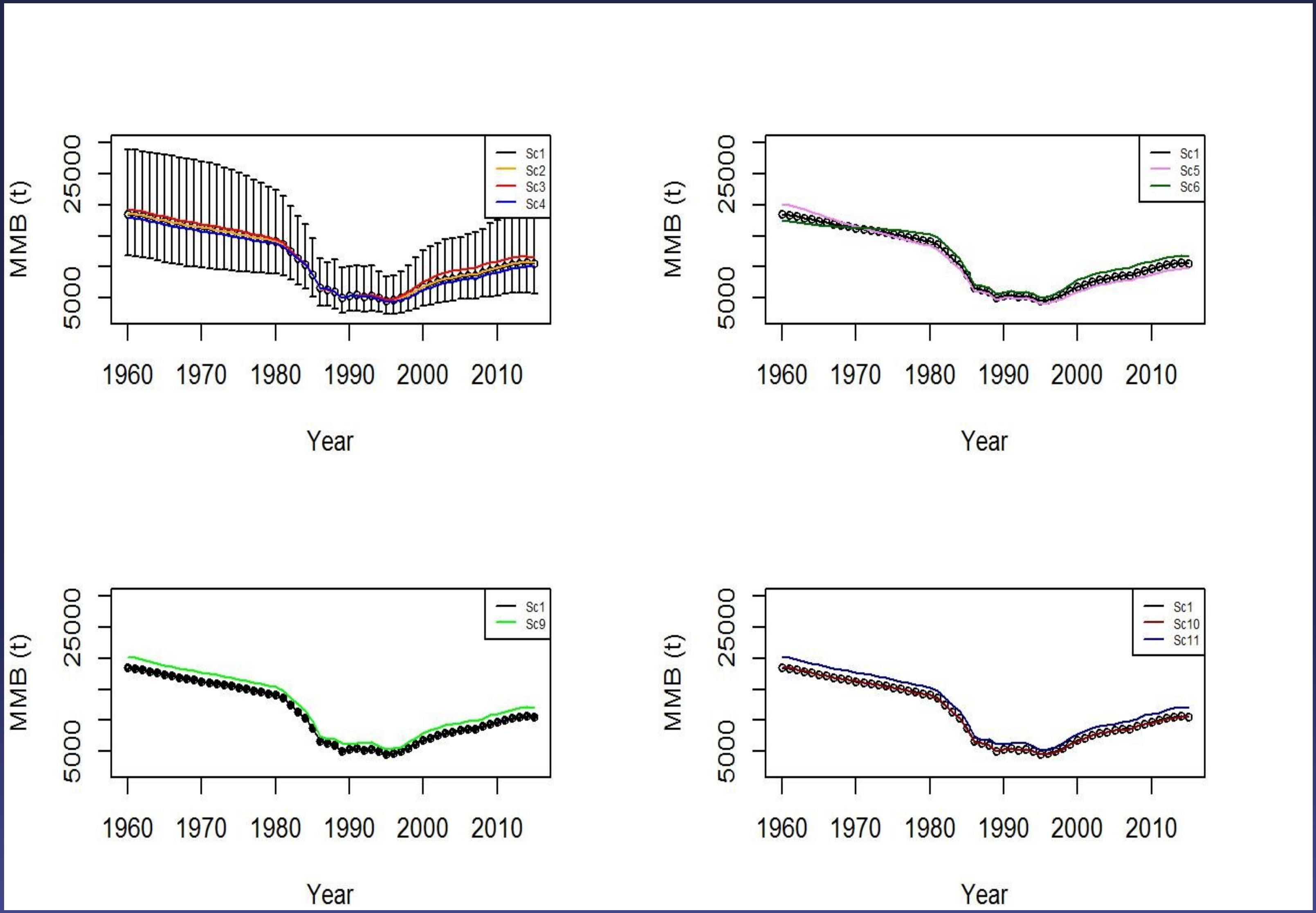


Figure 47. Trends in mature male biomass for scenarios (Sc) 1 to 11 fits in the WAG, 1960/61–2015/16. Scenario 1 estimates have two standard errors confidence limits.

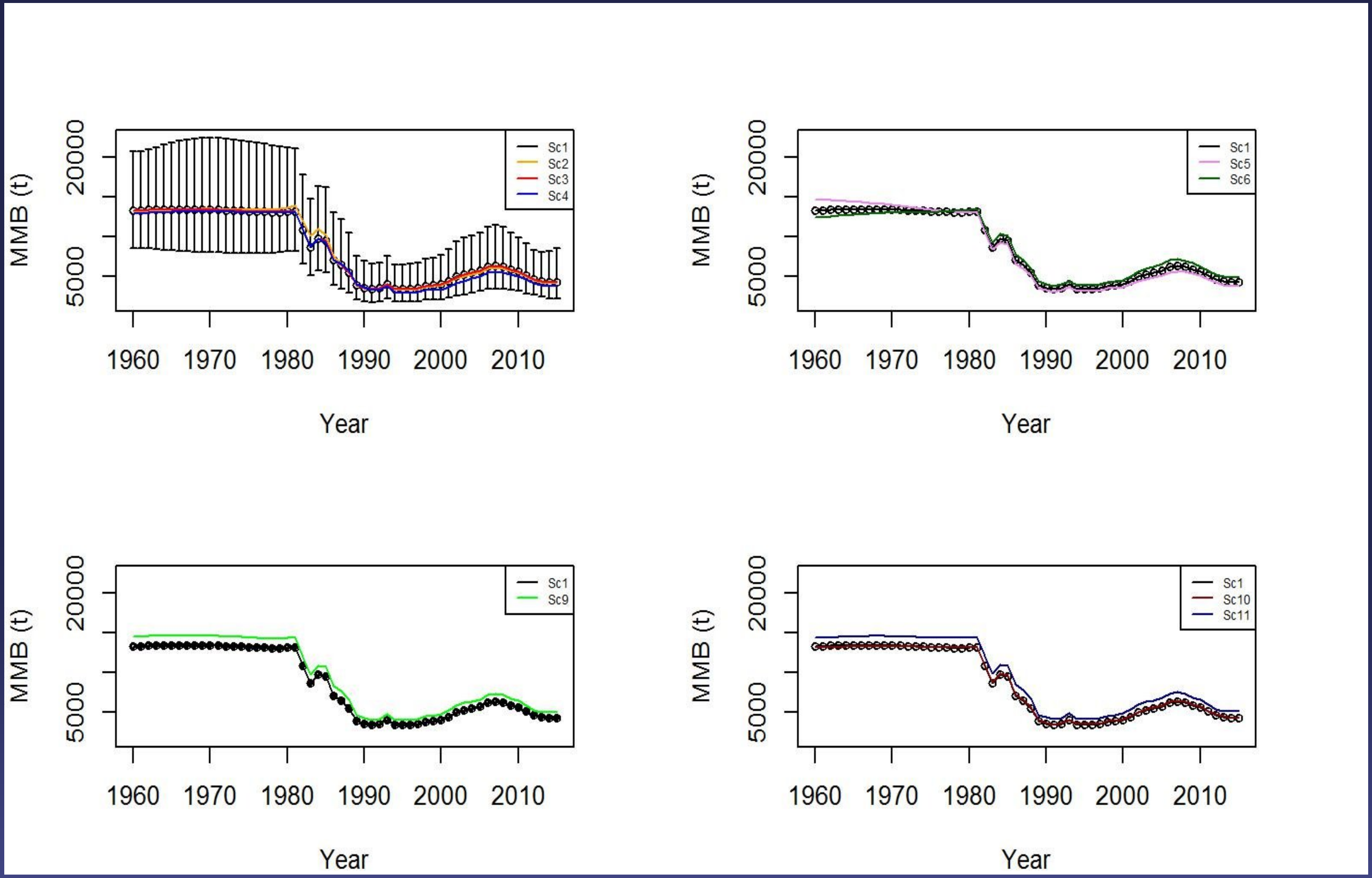
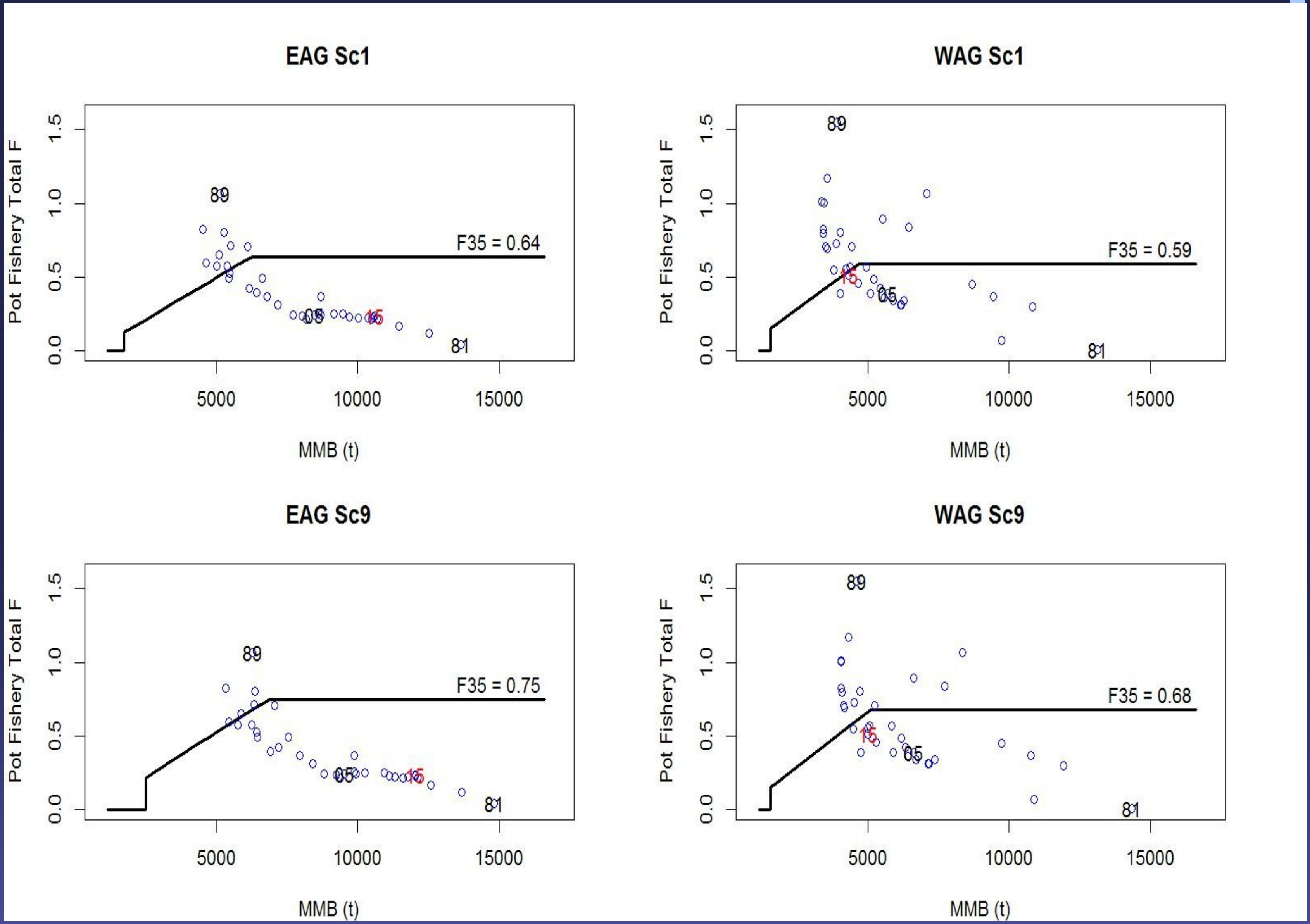


Figure 48. Relationships between full fishing mortalities and mature male biomass during 1985–2015 under scenarios 1 and 9 for EAG and WAG.



EAG

Likelihood Component	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 9	Sc 10	Sc11	Sc3– Sc 1	Sc 5 – Sc 1	Sc 6 – Sc 1	Sc 10 – Sc 1	Sc 11 – Sc 9
Number of free para.	139	138	139	142	139	139	137	139	137					
Data	base	base	base	base	base	base	base	base	base					
Retained LF	-1152.09	-1151.47	-1150.71	-1164.02	-1148.80	-1152.06	-1152.09	-1151.96	-1151.96	1.38	3.29	0.03	0.13	0.13
Total LF	-1201.41	-1199.97	-1213.01	-1194.82	-1204.80	-1198.51	-1201.41	-1201.65	-1201.65	-11.6	-3.39	2.9	-0.24	-0.24
Observer cpue	-11.92	-11.86	-5.96	-12.21	-12.62	-10.93	-11.92	-11.99	-11.99	5.96	-0.7	0.99	-0.07	-0.07
Retd. catch	7.08	6.85	7.46	7.14	7.22	6.94	7.08	7.09	7.09	0.38	0.14	-0.14	0.01	0.01
Total catch	20.12	19.99	20.30	20.47	20.14	20.14	20.12	20.12	20.12	0.18	0.02	0.02	0.00	0.00
Gdiscd catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rec_dev	5.77	6.10	6.13	5.83	7.50	5.20	5.77	5.86	5.86	0.36	1.73	-0.57	0.09	0.09
Pot F_dev	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Gbyc_F_dev	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Tag	2690.70	2690.59	2690.35	2688.91	2690.67	2690.72	2690.70	2690.70	2690.70	-0.35	-0.03	0.02	0.00	0.00
Fishery cpue	-0.52	-	-2.54	-0.68	-0.57	-0.45	-0.52	-0.52	-0.52	-2.02	-0.05	0.07	0.00	0.00
Maturity	0.17	0.17	0.17	0.17	0.17	0.17	-	0.17	-	0.00	0.00	0.00	0.00	-
Total	357.95	360.43	352.23	350.83	358.96	361.25	357.78	357.87	357.70	-5.72	1.01	3.3	-0.08	-0.08

WAG

Likelihood Component	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 9	Sc 10	Sc11	Sc3– Sc 1	Sc 5 – Sc 1	Sc 6 – Sc 1	Sc 10 – Sc 1	Sc 11 – Sc 9
Number of free para.	139	138	139	142	139	139	137	139	137					
Data	base	base	base	base	base	base	base	base	base					
Retained LF	-1103.6	-1106.21	-1106.66	-1113.50	-1102.73	-1101.23	-1103.60	-1103.42	-1103.42	-3.06	0.87	2.37	0.18	0.18
Total LF	-1347.65	-1342.09	-1345.97	-1333.15	-1349.49	-1346.04	-1347.65	-1347.34	-1347.34	1.68	-1.84	1.61	0.31	0.31
Observer cpue	-10.48	-12.22	-12.22	-13.04	-11.09	-9.71	-10.48	-10.36	-10.36	-1.74	-0.61	0.77	0.12	0.12
Retd. catch	4.76	5.47	4.92	4.86	4.79	4.74	4.76	4.75	4.75	0.16	0.03	-0.02	-0.01	-0.01
Total catch	43.03	43.59	43.24	34.40	43.18	42.71	43.03	42.99	42.99	0.21	0.15	-0.32	-0.04	-0.04
Gdiscd catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rec_dev	4.59	4.25	4.57	5.22	5.13	4.48	4.59	4.54	4.54	-0.02	0.54	-0.11	-0.05	-0.05
Pot F_dev	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00
Gbyc_F_dev	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00
Tag	2692.35	2692.91	2692.40	2698.88	2692.25	2692.23	2692.35	2692.34	2692.34	0.05	-0.1	-0.12	-0.01	-0.01
Fishery cpue	-7.96	-	-6.43	-18.11	-6.63	-9.29	-7.96	-8.20	-8.20	1.53	1.33	-1.33	-0.24	-0.24
Maturity	0.17	0.17	0.17	0.17	0.17	0.17	-	0.17	-	0.00	0.00	0.00	0.00	-
Total	275.26	285.93	274.08	265.78	275.65	278.13	275.10	275.54	275.37	-1.18	0.39	2.87	0.28	0.27

Million pounds

Tier 3 EAG

Sc.	Tier	$B_{35\%}$	Current MMB	MMB/ $B_{35\%}$	F_{OFL}	Recruitment Years to define $B_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)	ABC (0.8*OFL)
1	3a	14.177	18.820	1.33	0.64	1987–2012	0.64	8.787	8.753	6.591	7.030
2	3a	14.309	19.050	1.33	0.63	1987–2012	0.63	8.873	8.837	6.654	7.098
3	3a	14.818	20.203	1.36	0.61	1987–2012	0.61	9.641	9.601	7.231	7.713
4	3a	13.791	17.987	1.30	0.66	1987–2012	0.66	8.301	8.268	6.226	6.641
9	3a	15.539	20.515	1.32	0.75	1987–2012	0.75	9.890	9.852	7.417	7.912
10	3a	14.265	18.840	1.32	0.62	1987–2012	0.62	8.556	8.523	6.417	6.845
11	3a	15.577	20.507	1.32	0.73	1987–2012	0.73	9.672	9.635	7.254	7.738

Tier 3 WAG

Sc.	Tier	$B_{35\%}$	Current MMB	MMB/ $B_{35\%}$	F_{OFL}	Recruitment Years to Define $B_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)	ABC (0.8*OFL)
1	3b	10.214	9.671	0.95	0.54	1987–2012	0.57	2.862	2.842	2.146	2.289
2	3b	10.099	9.535	0.94	0.54	1987–2012	0.58	2.767	2.747	2.075	2.213
3	3b	10.226	9.680	0.95	0.54	1987–2012	0.57	2.861	2.840	2.145	2.288
4	3b	9.866	9.031	0.92	0.49	1987–2012	0.54	2.445	2.427	1.834	1.956
9	3b	11.111	10.863	0.98	0.66	1987–2012	0.68	3.378	3.355	2.534	2.702
9**	3a	9.937	10.800	1.09	0.68	1993–1997	0.68	3.443	3.428	2.582	2.754
10	3b	10.049	9.704	0.97	0.59	1987–2012	0.61	3.115	3.093	2.336	2.492
11	3b	11.025	10.928	0.99	0.71	1987–2012	0.72	3.616	3.591	2.712	2.893

Million pounds

Tier 3 AI

Aleutian Islands (AI) Total OFL and ABC for the next fishing season in million pounds.				
Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)	ABC (0.8*OFL)
1	11.649	11.595	8.737	9.319
2	11.64	11.584	8.729	9.311
3	12.502	12.441	9.376	10.001
4	10.746	10.695	8.06	8.597
9	13.268	13.207	9.951	10.614
9**	13.333	13.280	9.999	10.666
10	11.671	11.616	8.753	9.337
11	13.288	13.226	9.966	10.631

Million pounds

Aleutian Islands AI

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[e]
2013/14	N/A	N/A	6.290	6.38	7.04	12.54	11.28
2014/15	N/A	N/A	6.290	6.11	6.79	12.53	9.40
2015/16	N/A	N/A	6.290	6.016	6.775	12.53	9.40
2016/17	N/A	N/A	5.545	Fishing[b]	Fishing[b]	12.53	9.40
2017/18[c]	13.325	31.378				13.268	10.614
2017/18[d]	13.325	31.315				13.333	10.666

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. Fishing in progress
c. Approach 1
d. Approach 2
e. The last two ABC estimates are based on 20% buffer whereas the other estimates are based on 25% buffer

Data Gap and Research Priorities

Tagging experiments:

a. Extensive tagging experiments or resource surveys are needed to investigate stock distributions.

b. An independent estimate of *M* is needed for this stock. Tagging is one possibility.

c. An extensive tagging study for molting probability and growth study is needed.

Handling mortality study:

- An experimentally based independent estimate of handling mortality is needed.

Survey:

- The Aleutian King Crab Research Foundation has recently initiated crab survey programs in the Aleutian Islands. This program needs to be strengthened and continued for golden king crab research to address some of the data gap.

Acknowledgement

David Barnard, Miranda Westphal, Leland Hulbert, Ethan Nichols, Robert Foy, Vicki Vanek, Andrew Nault, Andre Punt, Martin Dorn, William Stockhausen, Sherri Dressel, Chris Siddon, Joel Webb, Ben Daly, Hamazaki Hamachan, William Bechtol, and Karla Bush, CPT members, industry personnel, and industry consultants.

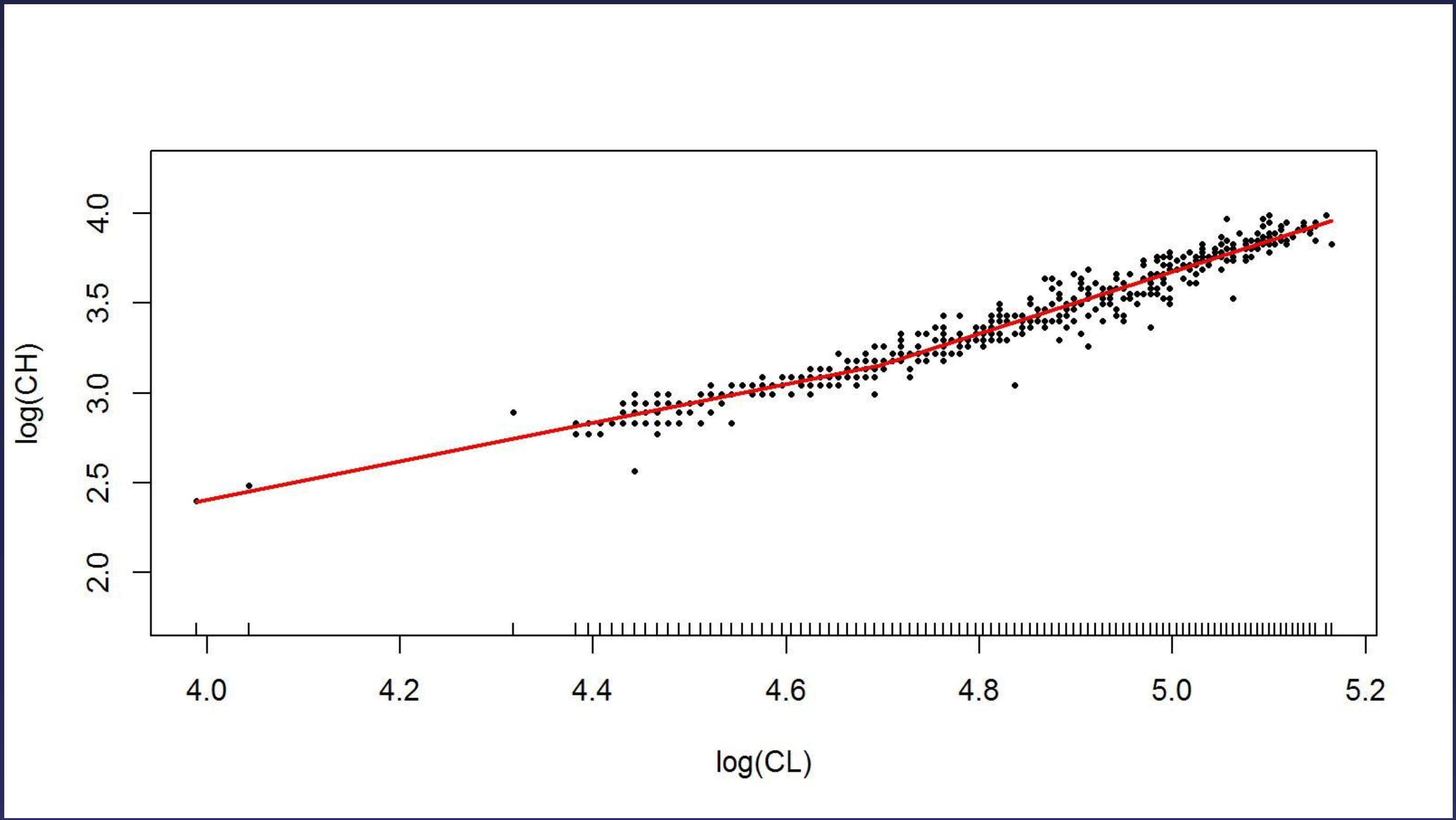


Figure X. Segmented linear regression fit to ln(CH) vs. ln(CL) data of male golden king crab in Bowers Ridge, WAG. Break Point L50% = 109.51 ± 1.02 mmCL, n =508, Adjusted R-squared: 0.96.

Initial condition

1. Equilibrium initial condition:

- The equilibrium stock abundance is

  N = X.S.N + R

  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 – ? ? ? ? ?

  where *I* is the identity matrix.
-
- We used the mean number of recruits from 1987 to 2012 to obtain the equilibrium solution under *M* in year 1960, and then projected the equilibrium abundance with constant *M* and estimated yearly recruitment up to 1985 with removal of retained catches during 1981/82 to 1984/85.

Francis method

- Observed mean length for year *t*,
- ?? ∑??? ??? ó ??? (1)
-
- Predicted mean length for year *t*,
- ?? ∑??? ??? ó ??? (2)
-
- Variance of the predicted mean length in year *t*,
- ??? (??) ∑??? ???(??? ??)? / ?? (3)
-
- Francis' reweighting parameter *W*,
- ? ? / ???{(?? ? ??) / √(???(??))} (4)

- ?? is related to the initial (Stage-1) effective sample size according to:
- ??? ? ???? (5)

Likelihood components

- $LL_{?}^{??\,???} = \lambda_{?} \sum_{?}\{\ln(\sum_{?} \hat{C}_{?\,?} w_{?} + c) - \ln(\sum_{?} C_{?\,?} w_{?} + c)\}^{?}$
- $LL_{?}^{??\,???} = \lambda_{?} \sum_{?}\{\ln(\sum_{?} \hat{T}_{?\,?} w_{?} + c) - \ln(\sum_{?} T_{?\,?} w_{?} + c)\}^{?}$
- $LL_{?\,?}^{??\,???} = \lambda_{?\,?} \sum_{?}\{\ln(\sum_{?} \widehat{Tr}_{?\,?} w_{?} + c) - \ln(\sum_{?} Tr_{?\,?} w_{?} + c)\}^{?}$
- $LL_{?}^{??\,???} = \lambda_{?} \sum_{?}\{\ln(\sum_{?} \hat{C}_{?\,?} + c) - \ln(\sum_{?} C_{?\,?} + c)\}^{?}$ [x: 1981/82 to 1984/85 retained catch for equilibrium initial composition calculation]
- $LL_{?\ ?\,??\,????} = \lambda_{?\ ?\,??\,????} \sum_{?}\left(\hat{P}_{?} - P_{?}\right)^{?}$
- C=0.001

Likelihood components

- $LL^{????}_{?} = \lambda_{?????}\left\{0.5\sum_{?}\ln\left[2\pi\left(\sigma^{?}_{??} + \sigma^{?}_{?}\right)\right] + \right.$

$\left.\sum_{?}\frac{\left(?? Æ ???{}^{?}_{?}?? ? \; ?? Æ ??? ??{}^{?}_{?}?? \right)^{?}}{?\left(?^{?}_{??}? \; ?^{?}_{?}\right)}\right\}$

$$\widehat{CPUE}^{?}_{?} = q_{?}\sum_{?} S^{?}_{?} S^{?}_{?}\left(N_{??} - 0.5\left[\widehat{C_{??}} + \widehat{D_{??}} + \widehat{Tr_{??}}\right]\right)e^{????}$$

$$\sigma^{?}_{??} = \ln(1 + CV^{?}_{??})$$

C=0.001

Likelihood components

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

- Penalty functions:

  pot fishery F_dev

  groundfish fishery bycatch F_dev

  R_dev

  posfunction

Tier 3 Formula for overfishing level fishing mortality F_{OFL}

- (a) If $B_{?} > B_{??\%}$, $F_{???} = F_{\text{ÊËÅ}}$
- (b) If $B_{?} \leq B_{??\%}$ and $B_{?} > 0.25B_{??\%}$,

$$F_{???} = F_{\text{ÊËÅ}} \frac{\left(\frac{??}{?\,??\%}??\right)}{(???)}$$

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

Currently $\alpha = 0.1$.

$B_{?}$ is the terminal year mature male biomass (MMB).

Number of crab vessels before (red) and after crab rationalization (IFQ quota management)

Fishing Season	EAG	WAG
2002	19	6
2003	18	6
2004	19	6
2005	7	3
2006	6	3
2007	4	3
2008	3	3
2009	3	3
2010	3	3
2011	3	3
2012	3	4
2013	3	3
2014	3	2
2015	3	2

Tag release and recapture summary (101 to 185 mm CL), EAG

Total Release	27131	Number of Recoveries by Year
	Year1	1005
	Year2	497
	Year3	216
	Year4	51
	Year5	13
	Year6	12
	Overall % recovery	6.61

Description of observer data collection

- Data collected since 1988
- Initial years' data are not comprehensive, so a shorter time series of data for the period 1995/96–2015/16 was selected.
- During 1990/91–1994/95, observers were only deployed on catcher-processor vessels. During 1995/96–2004/05, observers were deployed on all fishing vessels. Since 2005/06, observers have been deployed on all fishing vessels, but catcher-only vessels are required to carry observers for a minimum of 50% of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity.
- Observers count and measure all crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot.
- Prior to the 2009/10 season, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured.
- One sampled pot data is treated as a single CPUE record because the unit of effort is one pot lift. CPUE standardization was done using over 110,000 records.
- Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season

CPUE standardization of observer data by GLM

Negative binomial model

- $\ln(CPUE_i) = Year_{y?}$ Null model

- $\ln(CPUE_i) = Year_{y?} + ns(Soak_{si}, df) + Month_{m?} + Area_{ai} + Vessel_{vi} + Captain_{ci} + Gear_{gi} + ns(Depth_{di}, df) + ns(VesSoak_{vsi}, df)$

Maximum set of model terms

ns = piecewise-cubic splines; df = degree of freedom