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

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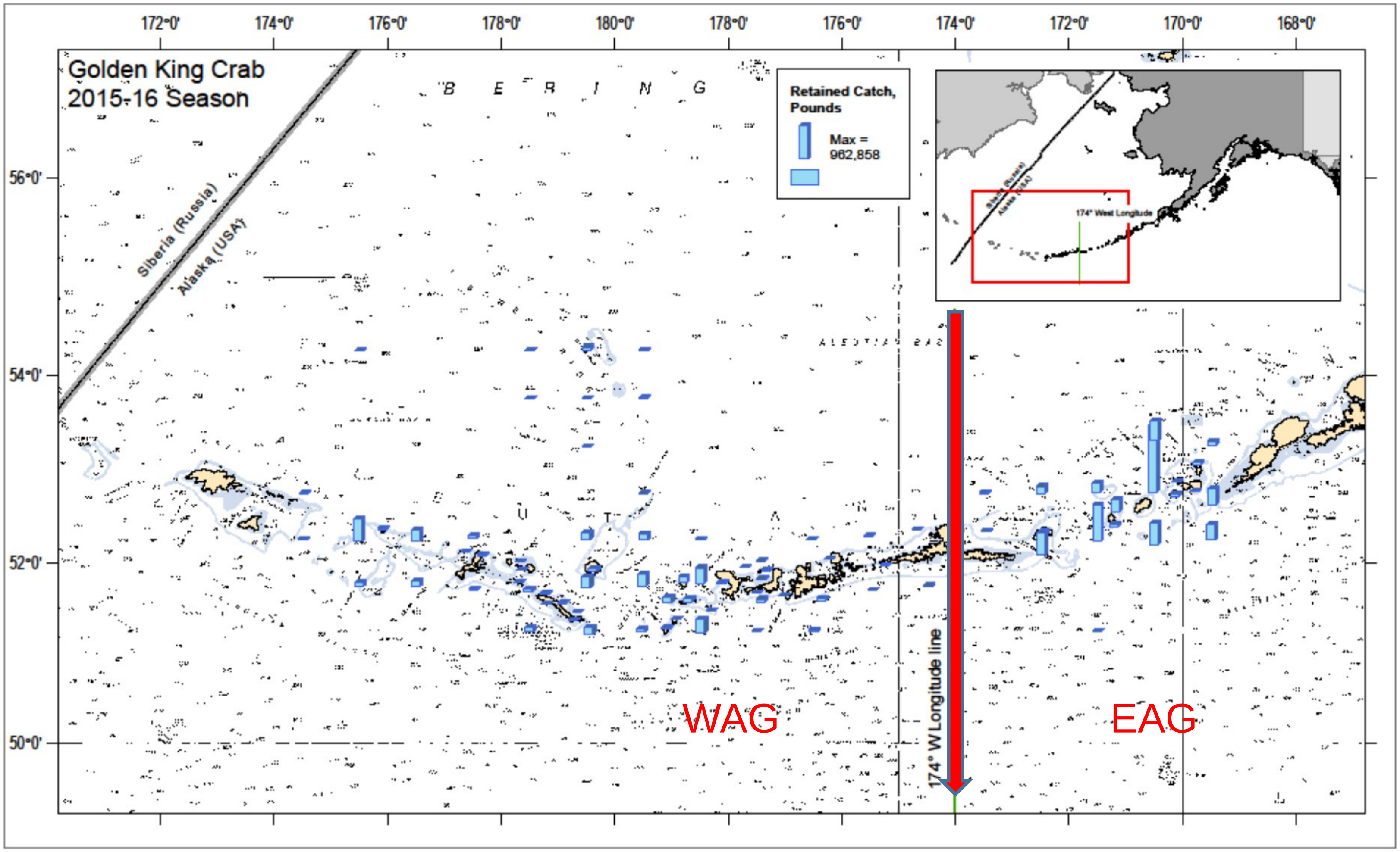
Aleutian Islands golden king crab stocks in the two management regions (EAG and WAG) are currently managed under constant harvest policy through Tier 5 assessment.



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

Figure 3

EAG

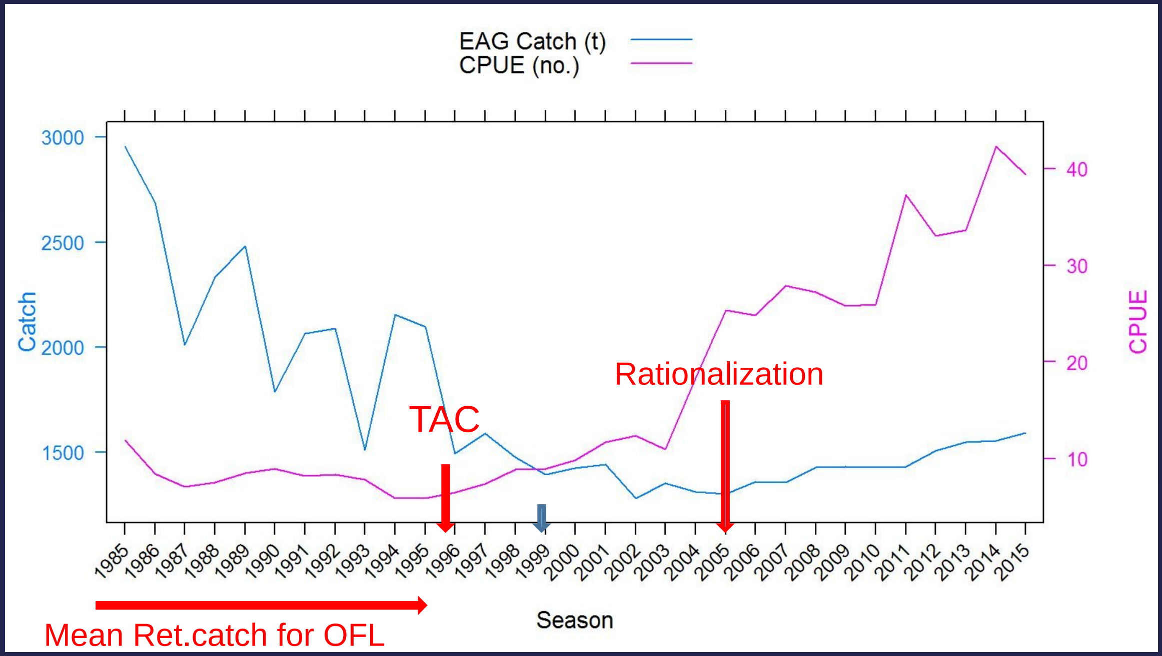
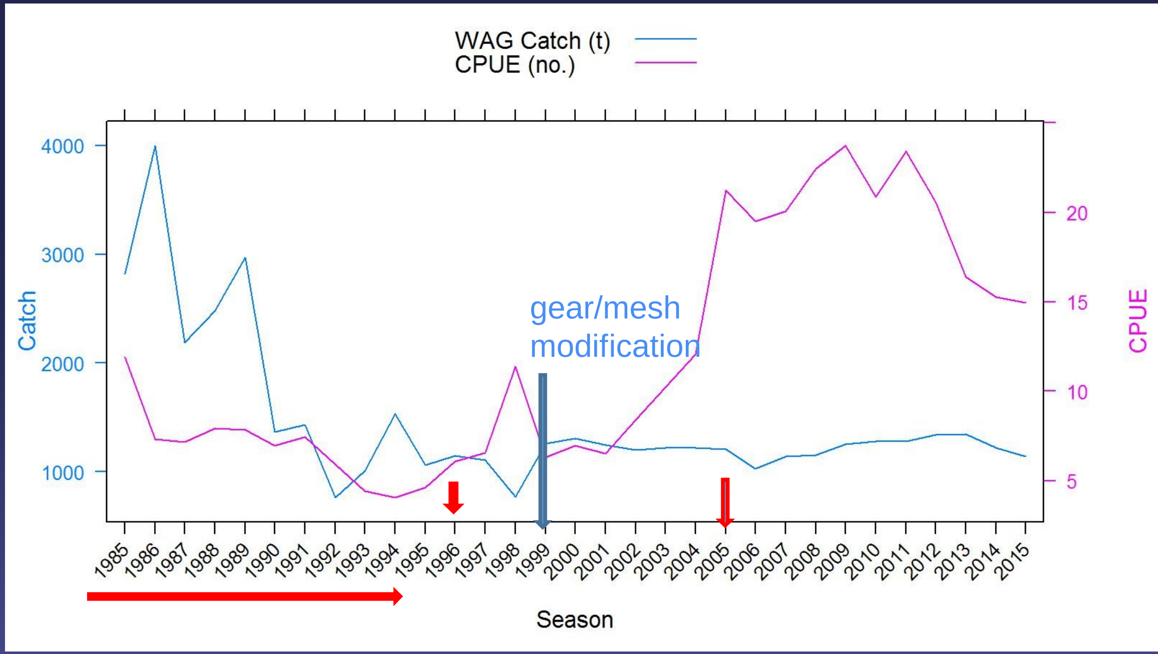


Figure 4

WAG



CPUE standardization history

2008-2011	(a) Nominal retained catch CPUE, triennial pot survey CPUE (EAG). (b) Observer nominal retained CPUE were standardized in relation to pot survey CPUE. (c) Zhou and Shirley (1997) non-linear soak time model was fitted to CPUE vs. Soak time and predicted yearly CPUE based on mean soak time.
2012-2013	CPUE standardization by GLM: (a) GLM with a Log-normal model for positive catches, a binomial model for zero catches and the two indices were combined to get the combined CPUE indices with standard errors, latter estimated by bootstrap sampling. (b) Error distributions appeared not adequate for the combined indices fit and a negative binomial model provided a better error distribution and also ease the fitting procedure without having to do bootstrapping.
CPT/SSC recommendations on CPUE estimation for model use in 2013	(a) Estimate CPUE indices separately for the pre- and post-rationalization time periods with soak time either selected or enforced. (b) Use the negative binomial model in the GLM.

Topics

- Address the May 2016 CPT and June 2016 SSC comments.
- Provide Tier 4 and Tier 3 OFL and ABC for EAG and WAG.

Approach

- An integrated length-based model. This is the only FMP crab stock modelled with fishery dependent catch and CPUE data without survey information.

- 34 scenarios were run for EAG and WAG for exploratory work:
- ❖ Scenarios were run with *M* estimated and *M* fixed at $0.18yr^{-1}$.
- ❖ Scenarios were run with dome shaped or logistic selectivity.
- ❖ Scenarios that used number of length measurements as Stage-1 effective sample sizes were scaled relative to some maximum values.
- 13 scenarios were selected for this presentation that address the CPT questions in May 2016 and SSC questions in June 2016.

Some points to note on the analysis and presentation:

- Tag release-recapture lengths and time duration for recaptures were used for size transition matrices and total mortality estimation.

- The recommended 8 out of 13 representative scenarios are:

  1a (base, Stage-1 effective sample size is the scaled number of length measurements),

  1c (base, Stage-1 effective sample size is the number of fishing trips),

  2a (1a with fish ticket CPUE likelihood),

  2c (1c with fish ticket CPUE likelihood),

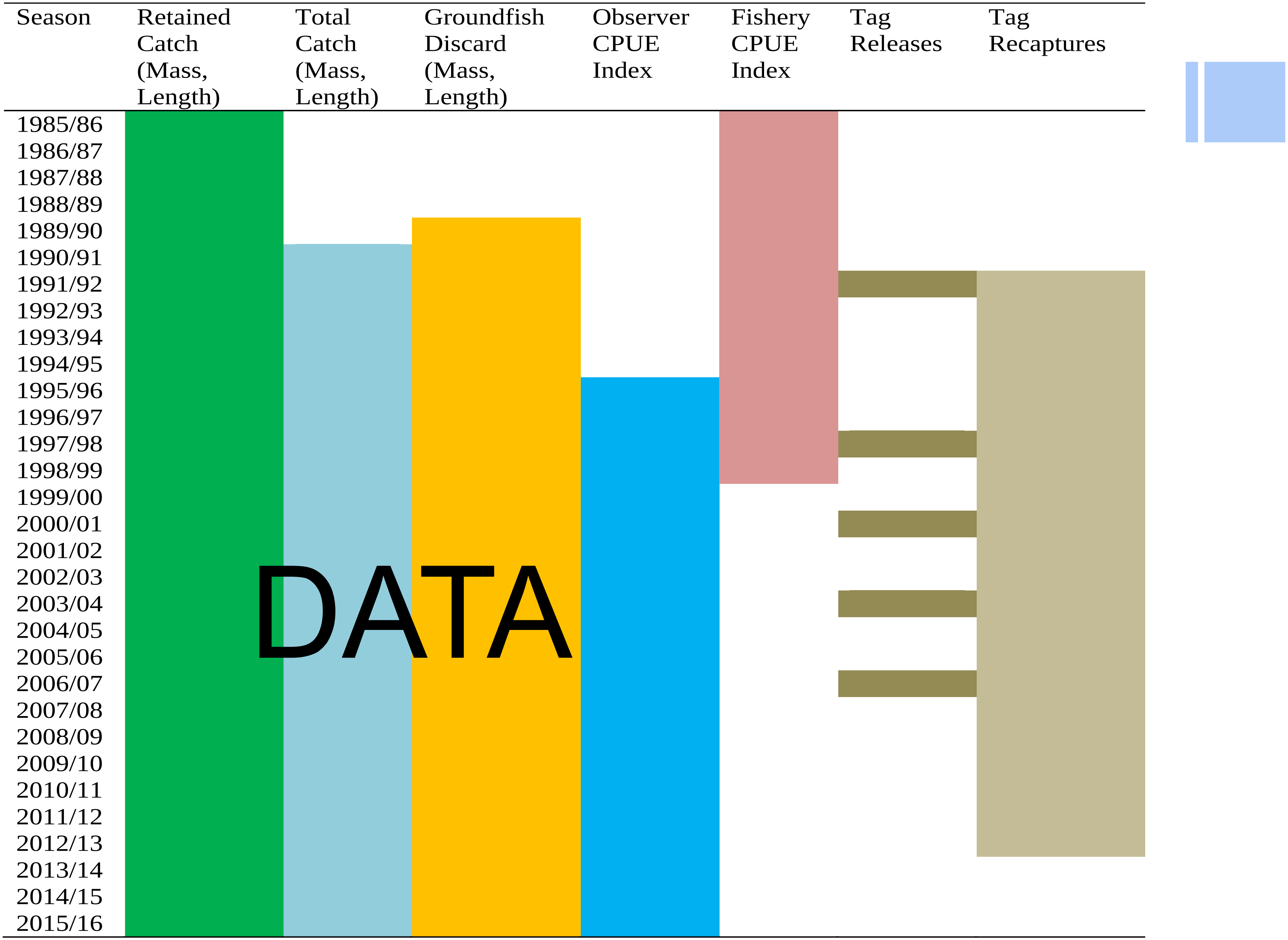
  6a (1a with iteratively estimated Stage-2 effective sample sizes),

  6c (1c with iteratively estimated Stage-2 effective sample sizes),

  8a (1a with dome shaped selectivity), and

  8c (1c with dome shaped selectivity)

- All scenarios fit the data equally well.


Season
Retained Catch (Mass, Length)
Total Catch (Mass, Length)
Groundfish Discard (Mass, Length)
Observer CPUE Index
Fishery CPUE Index
Tag Releases
Tag Recaptures
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93
1993/94
1994/95
1995/96
1996/97
1997/98
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
2013/14
2014/15
2015/16
DATA

May 2016 CPT Comments / Recommendations

- Comment 1. **Bring forward a Tier 3 assessment in addition to Tier 4 as *M* may not be stable.**

Response:

We are providing the Tier 3 assessment in addition to the Tier 4 assessment.

- Comment 2: **Use the equilibrium model as it better tracked the variability in the initial size classes. The author should provide a plot of the full time series to show the pattern in depletion relative to removals prior to the start of the model.**

- Response:

We considered only the equilibrium model scenarios. We provide the full time series (1960 onward) of MMB and their retrospective patterns (Figures 19 and 22 for EAG; 35 and 38 for WAG).

CPT Comments / Recommendations continued

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

- Response:

(a) Did not find any computational errors on the profile of CPUE for WAG.

(b) We estimated an average *Z* yr^{-1} using the tagging data. *Z* = 0.99 yr^{-1}, which accounts for additional tagging related loss rates as well. An *M* value higher than $0.18 yr^{-1}$ is feasible

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

CPT Comments / Recommendations continued

- Comment 4. **Drop the groundfish bycatch weight due to poor fits to the groundfish bycatch length frequency data (e.g. scenario 7). A scenario should be provided with the groundfish data removed.**

Response:

- Scenarios 4c and 4a eliminated the likelihood for groundfish data (size composition and bycatch) for EAG and WAG, respectively. The rate of reduction of terminal MMB from the initial MMB did not change appreciably from other scenarios for EAG. However, the rate of reduction for WAG was slightly large (Table 29).

CPT Comments / Recommendations continued

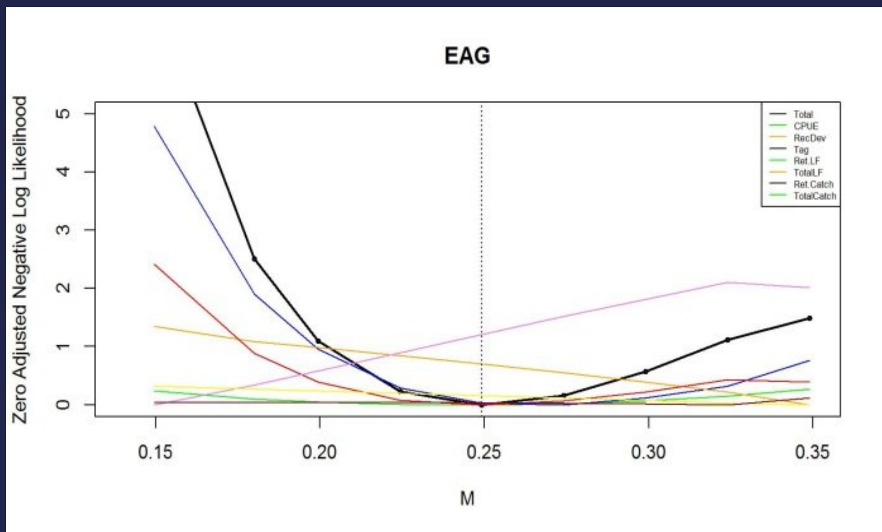
- Comment 5. **Continue with the dome shaped selectivity and do an *M* profile with the dome shaped selectivity.**

Response:

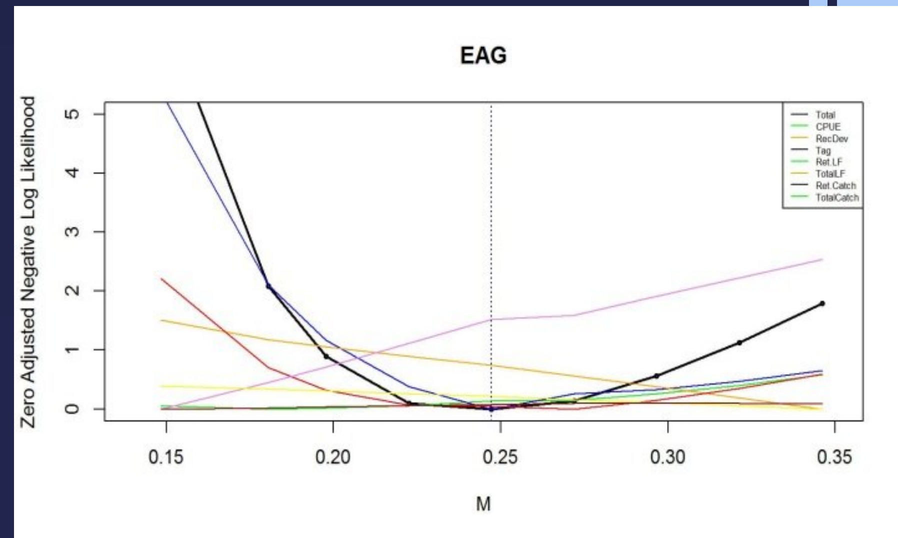
We provide a number of *M* profile plots in Figures 1 (EAG) and 2 (WAG) below in response to various CPT comments, which included the dome shaped selectivity (bottom right plots).

Figure 1.

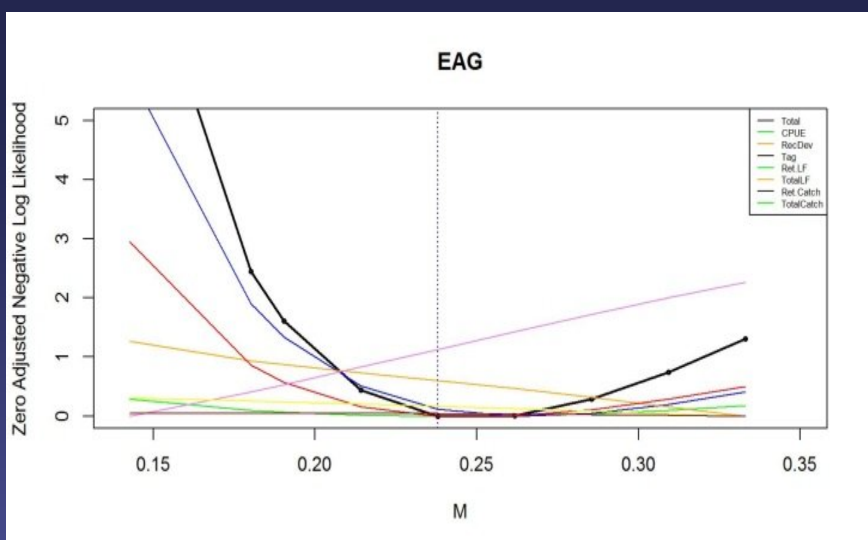
EAG data



EAG+WAG data + Fish Ticket CPUE



EAG+WAG data



EAG data with dome shaped selectivity

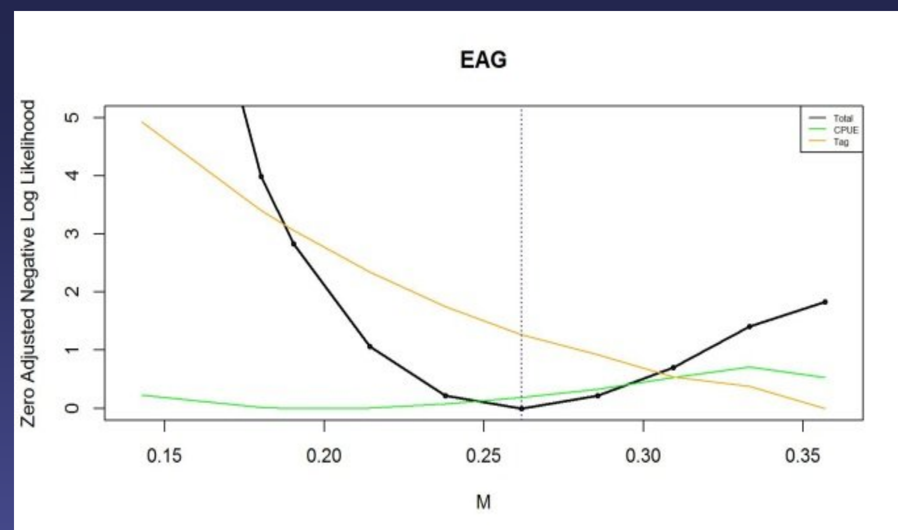
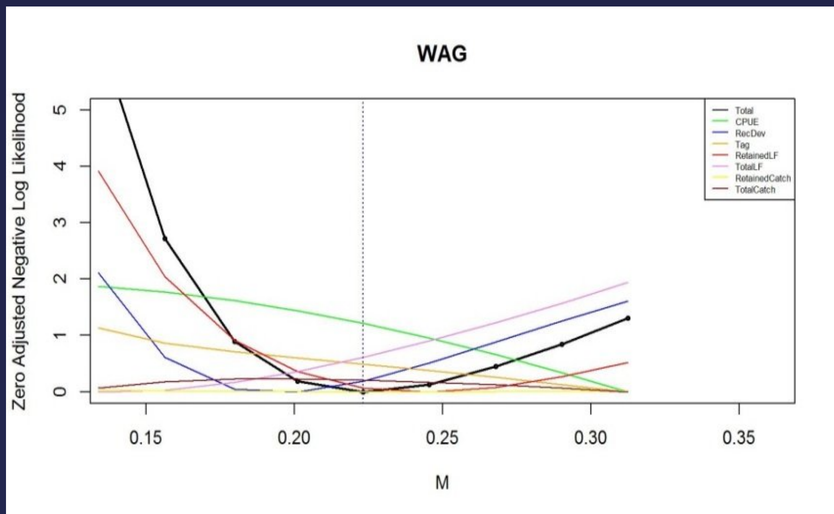
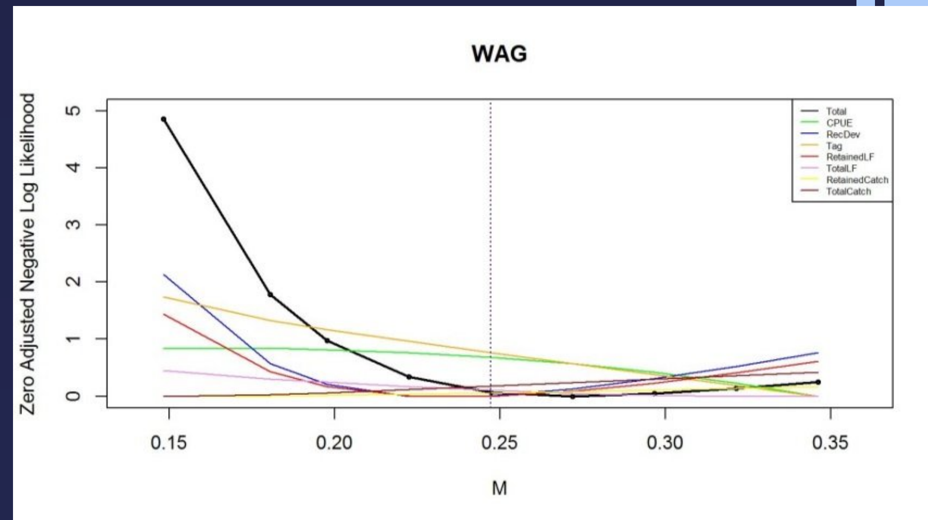


Figure 2.

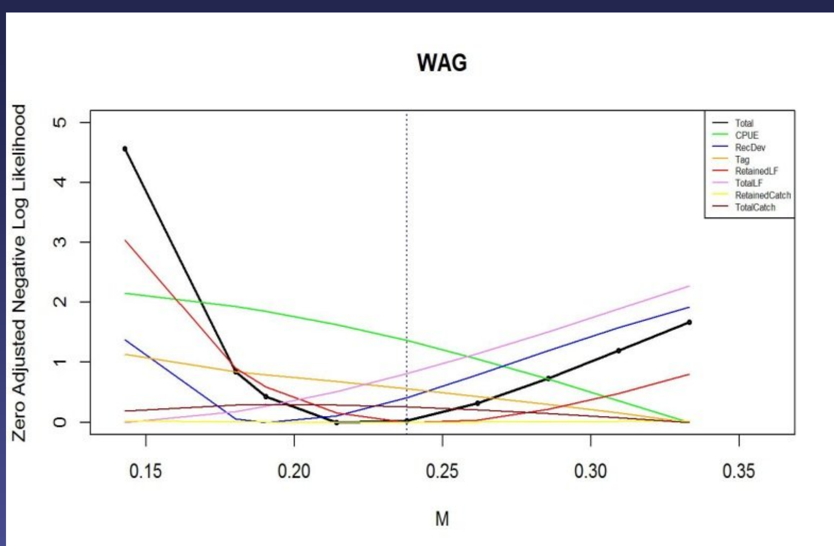
WAG data



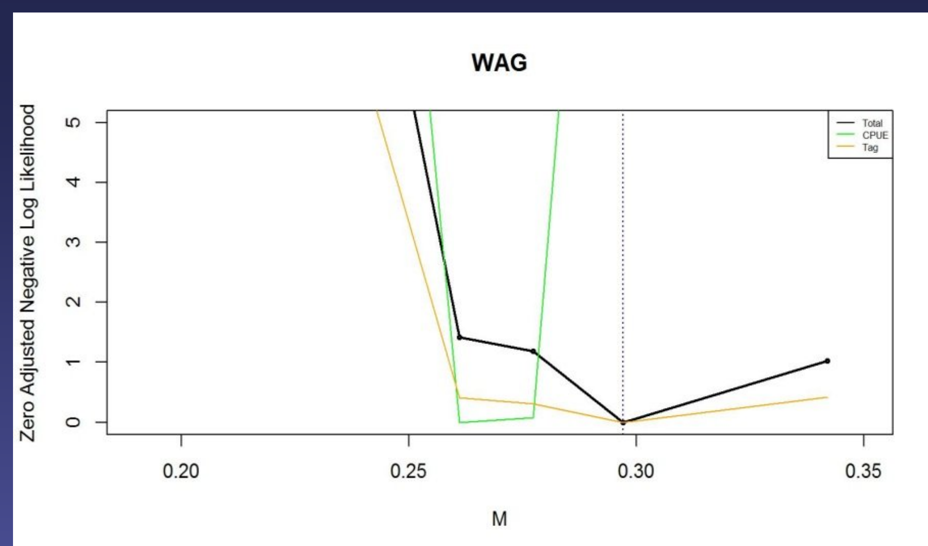
WAG+EAG data + Fish Ticket CPUE



WAG+EAG data



WAG data with dome shaped selectivity



CPT Comments / Recommendations continued

Comment 6: **In iterative fitting of effective sample sizes, put a bound (e.g. 200) and reconsider using the weighting without increasing above the observed. The author should bring forward scenario 3 with appropriate reweighting using the Francis (2011) method.**

Response:

(a) In the May 2016 CPT document , we misidentified the McAllister and Ianelli (1997) method as Francis (2011) method. In this report we followed only Francis method.

(b) Francis (*in press*, 2016) recommends setting no bounds to sample sizes in the iteration process. So, we did not enforce bounds.

(c) The criterion we chose to stop the iterations was – no appreciable change in terminal MMB and retained catch OFL.

CPT Comments / Recommendations continued

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

Response:

In this analysis, we did not pursue this task.

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

Response:

In this analysis, we did not pursue this task.

CPT Comments / Recommendations continued

General Comment 9: **Provide CVs instead of SDs throughout analysis.**

Response:

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

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

Response:

Please see our response to Comment 8.

CPT Comments / Recommendations continued

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

Response:

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

CPT Comments / Recommendations continued

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

Response:

- For catch and bycatch biomasses, the weights were based on best fit criteria (details on pages 16 and 17). For total catch biomass weight, the number of vessels sampled by observers was scaled to a maximum of 250 (half of 500 assigned for retained catch biomass).
- (b.1) If the effective sample sizes are number of length measurements, they were scaled to given maxima for Stage-1 sample size estimation. No scaling was done for Stage-2 sample size computation.
- (b.2) If the effective sample size is number of fishing trips made by the sampled vessels, no scaling was done for either Stage-1 or Stage-2 sample size estimation.

June 2016 SSC Comments / Recommendations

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

Response:

- (a) We reconsidered the approach to estimating *M* by using only the EAG or WAG data and the combined data with and without fish ticket CPUE in the integrated model.

(b) We tested the difference in the *M* estimates between the combined and individual data sets using Wald Statistic: ? (?) (? ? ? ?)? / ???Æ which follows χ^2 with 1 df. The differences were not statistically significant.

- (c) The profile plots (Figures 1 and 2) indicate that there were sufficient data to estimate *M*.
- (d) As an additional precaution, we estimated the *M* from the combined data with a prior *M* of 0.18yr^{-1} , which was based on life history parameters (Equation C.1).

SSC Comments / Recommendations continued

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

Response:

- Scenarios 11a (WAG) and 11c (EAG) were run with *M* fixed at 0.18yr^{-1} and selectivity set to asymptotic. Scenarios 16a (WAG) and 16c (EAG) were run for the same *M*, but with the dome shaped selectivity. The dome shaped selectivity reduced the rate of reduction of terminal MMB from the initial MMB for EAG, but did not change the rate of reduction for WAG (Table 29). Figures 1 and 2 show that the total negative log likelihood minima were attained at higher values than *M* of 0.18yr^{-1} for dome shaped selectivity.

SSC Comments / Recommendations continued

- Comment 3. **Conduct further analysis on area-shrinkage and standardization of CPUE. Further support is necessary to determine whether the assumption that CPUE is proportional to abundance is warranted. The effect of area-shrinkage may be informed by in-depth examination of spatial data.**

Response:

- We have not yet completed this task.

SSC Comments / Recommendations continued

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

Response:

- We included Year:Captain and Year:Gear interaction terms in the CPUE standardization because Year and Gear were the selected predictor variables in most cases (Appendix B). When levels of factors that had indeterminate parameter estimates (NA) were eliminated, interaction terms were not significant.

SSC Comments / Recommendations continued

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

Response:

- (a) We considered number of fishing trips as Stage-1 effective sample size in scenarios ending with c and d. Although the management parameters (MMB and OFL) for EAG did not change when number of trips was used for Stage-1 effective sample sizes in place of the scaled number of length measurements, they did for the WAG (Table 29).
- (b) Stage-1 input sample sizes listed in Tables 6 and 20 were used (in general) in all scenarios for EAG and WAG, respectively.

SSC Comments / Recommendations continued

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

Response:

- The area of the circle depicts the relative size of the standardized residuals (scale is not linear), but we have not yet added the scale. We will improve on this in the next cycle of model runs.

SSC Comments / Recommendations continued

- Comment 7. **The fit to the groundfish bycatch length frequencies was relatively poor. It appeared that the selectivity curve for this fleet was fixed in the model runs, which could cause lack of fit in other aspects of the model. Estimation of the selectivity and/or addressing data weighting for this component should be evaluated further.**

Response:

- (a) We estimated groundfish selectivity in scenarios 3 a and 3c for EAG and WAG, respectively. Estimated selectivity parameters had unreasonably high CVs and the selection curves were flat near 1. Hence, we left selectivity fixed to 1 for all other scenarios.
- (b) We considered scenarios 4a, 4c, 14a, and 14c, that omit groundfish data likelihoods. We have not yet considered down weighting of the groundfish length frequency likelihood.

SSC Comments / Recommendations continued

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

Response:

- We considered additional model runs (34 scenarios) as a result of CPT and SSC questions and brought forward 13 representative scenarios for discussion at this meeting.

SSC Comments / Recommendations continued

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

Response:

- We considered both P*=0.49, as used in last assessment, and 20% in the Tier 4 and Tier 3 ABC estimation.

Biomass scaling approaches to address the OFL and ABC estimates issues

- Estimate *M* in the model (assessment model document);
- Project the abundance from unfished equilibrium in 1960 to initialize the 1985 abundance (assessment model document); and
- Use dome shaped total selectivity (assessment model document).

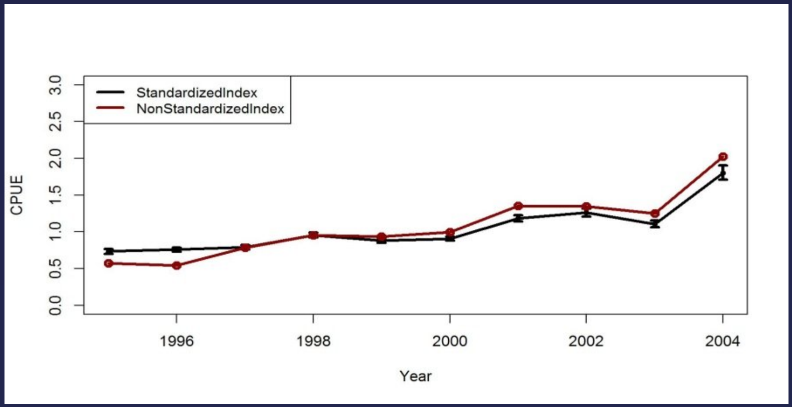
Table E

Sc.	Size-composition weighting	Catchability and total selectivity sets	Total selectivity type	CPUE data type	GLM predictor variable selection criterion	Treatment of trawl/total size composition and catch data	Natural mortality (M yr^{-1})
1a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
1b	Stage-1:Number of lengths	2	logistic	Observer	AIC	Trawl bycatch size-composition data included	0.2339
1c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
1d	Stage-1:Number of trips	2	logistic	Observer	AIC	Trawl bycatch size-composition data included	0.2339
2a	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
2b	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	AIC	Trawl bycatch size-composition data included	0.2426
2c	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
2d	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	AIC	Trawl bycatch size-composition data included	0.2426
3a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included, groundfish selectivity estimated	0.2339
3c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included, groundfish selectivity estimated	0.2339
4a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Dropped trawl bycatch & size-composition data	0.2339
4c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Dropped trawl bycatch & size-composition data	0.2339
5a	Stage-1:Number of lengths	3	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
5c	Stage-1:Number of trips	3	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
6a	Stage-2:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
6c	Stage-2:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
7a	Stage-2:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
7c	Stage-2:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.2426
8a	Stage-1:Number of lengths	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
8c	Stage-1:Number of trips	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.2339
9a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2339
9c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2339
10a	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2426
10c	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Total size composition and catch data started from 1996/97 (EAG) or -1995/96 (WAG)	0.2426
11a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.18
11c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Trawl bycatch size-composition data included	0.18
12a	Stage-1:Number of lengths	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.18
12c	Stage-1:Number of trips	2	logistic	Observer & Fish ticket	R-squared	Trawl bycatch size-composition data included	0.18
14a	Stage-1:Number of lengths	2	logistic	Observer	R-squared	Dropped trawl bycatch size-composition data	0.18
14c	Stage-1:Number of trips	2	logistic	Observer	R-squared	Dropped trawl bycatch size-composition data	0.18
16a	Stage-1:Number of lengths	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.18
16c	Stage-1:Number of trips	2	dome shaped	Observer	R-squared	Trawl bycatch size-composition data included	0.18
19a	Stage-1:Number of lengths	2	logistic	Observer	R-squared, Interaction	Trawl bycatch size-composition data included	0.2339
19c	Stage-1:Number of trips	2	logistic	Observer	R-squared, Interaction	Trawl bycatch size-composition data included	0.2339

Figures B1 & B2. Trends in non-standardized and standardized (negative binomial GLM) observer CPUE indices with +/- 2 SE for EAG. Standardized indices: black line and non-standardized indices: red line. R^2 (top panels) and CAIC (bottom panels) criteria are used for variable selection.

1995/96–2004/05

2005/06–2015/16



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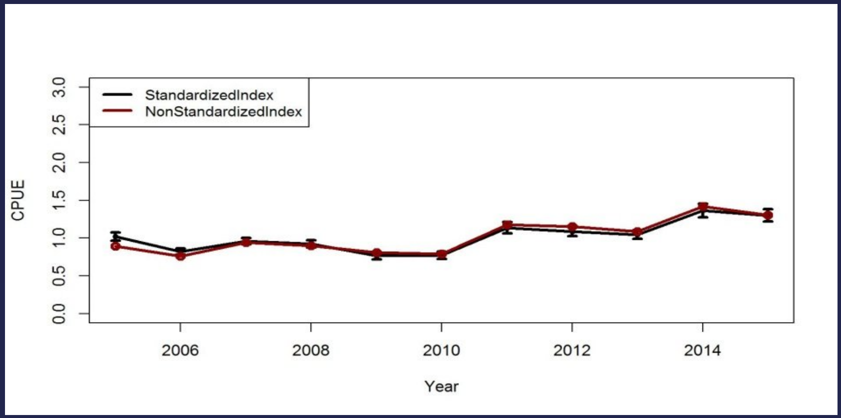

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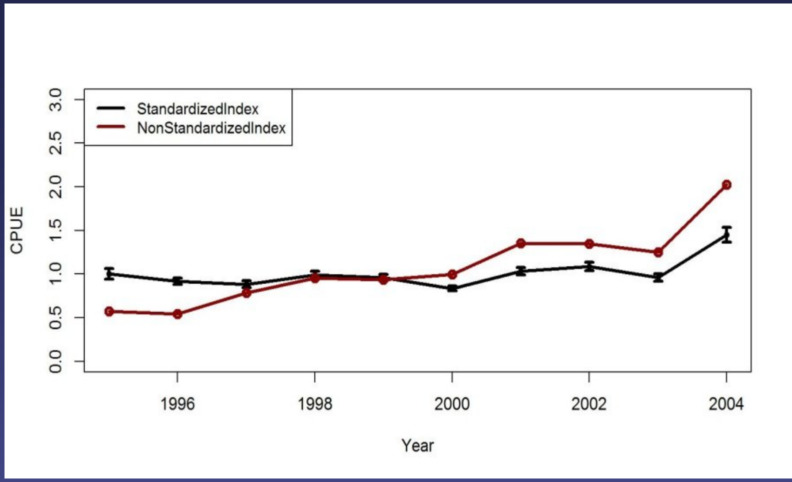

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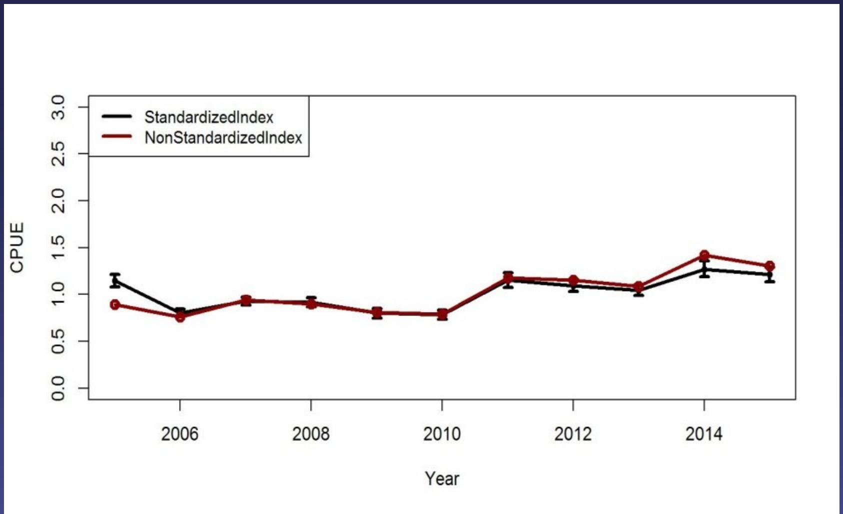

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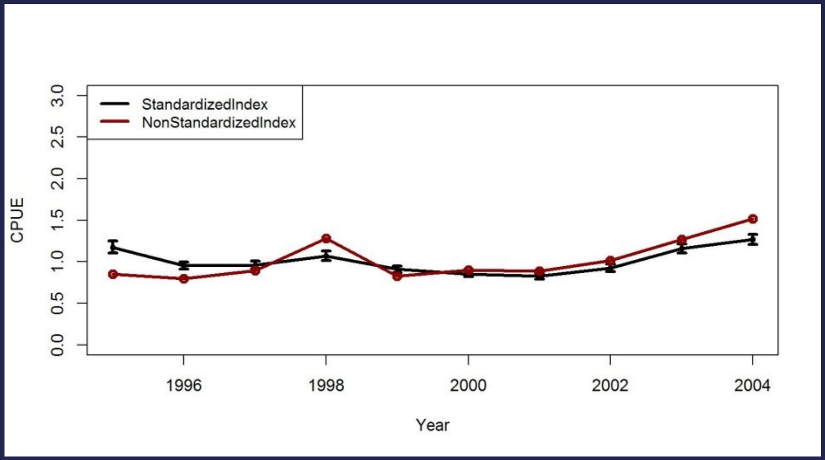
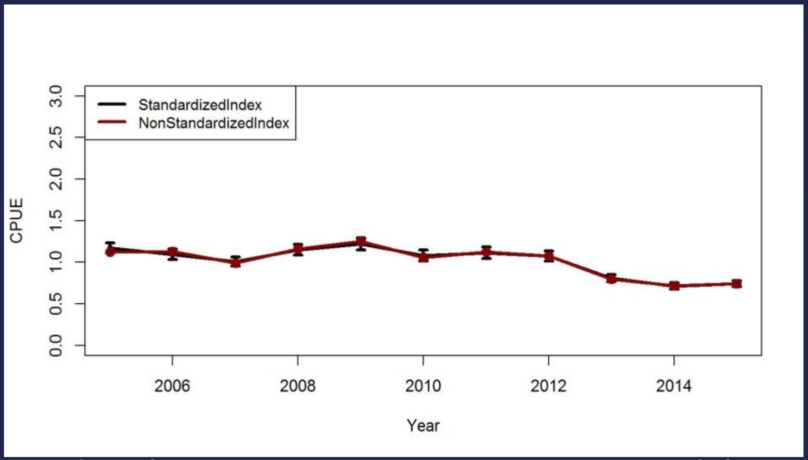
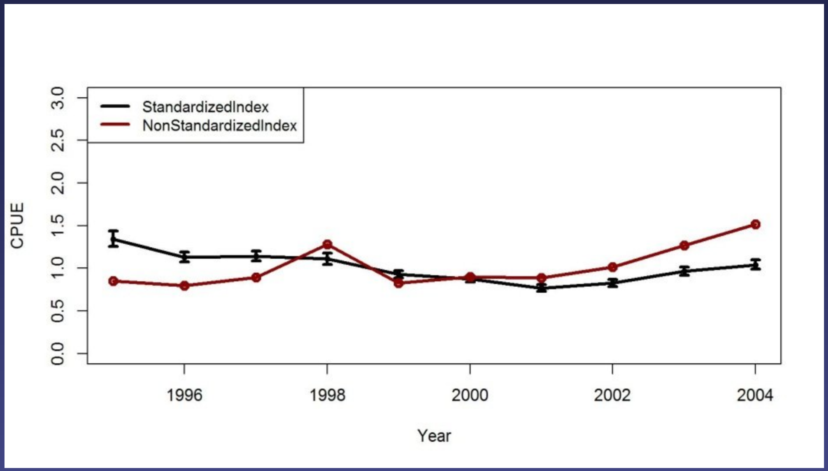
Figures B1 & B2. Trends in non-standardized and standardized (negative binomial GLM) observer CPUE indices with +/- 2 SE for WAG. Standardized indices: black line and non-standardized indices: red line. R^2 (top panels) and CAIC (bottom panels) criteria are used for variable selection.

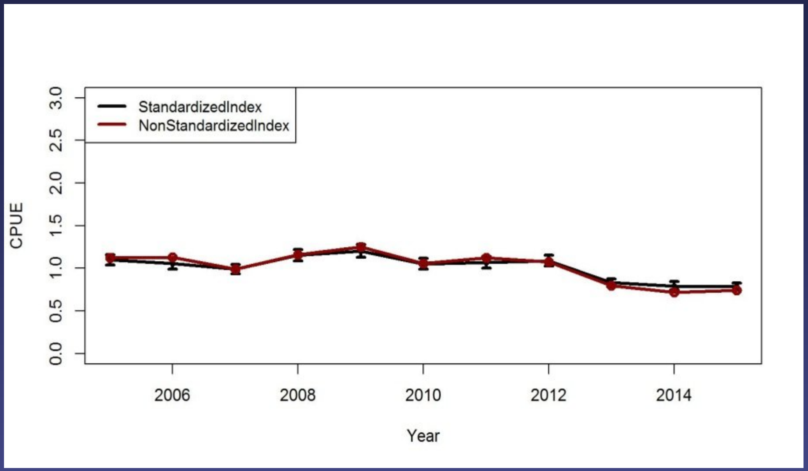
1995/96–2004/05

2005/06–2015/16





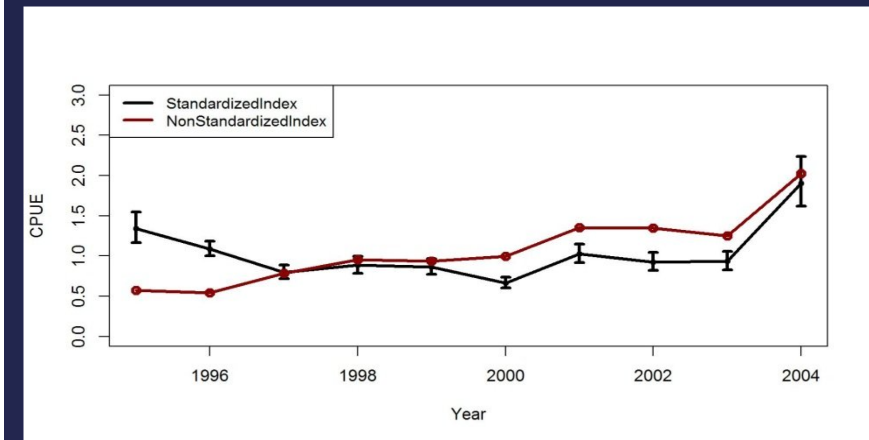


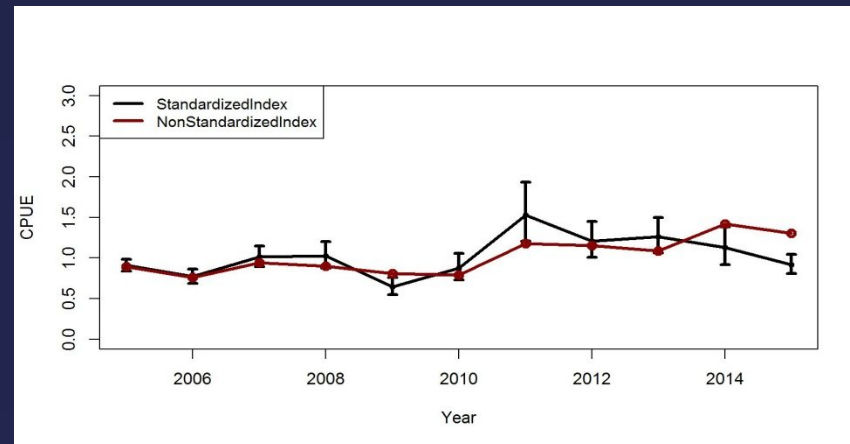


Figures B9 & B17. Trends in non-standardized and standardized (negative binomial GLM) observer CPUE indices with +/- 2 SE for the Year:Captain interaction model. Standardized indices: black line and non-standardized indices: red line. R^2 criterion is used for variable selection.

1995/96–2004/05

2005/06–2015/16





EAG

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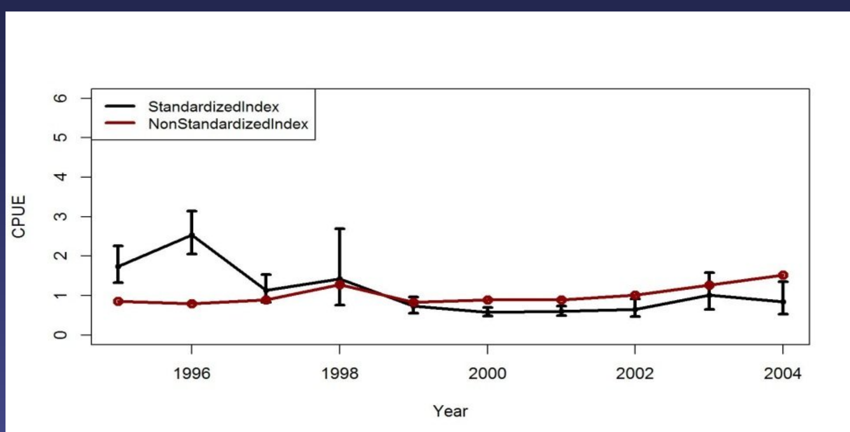
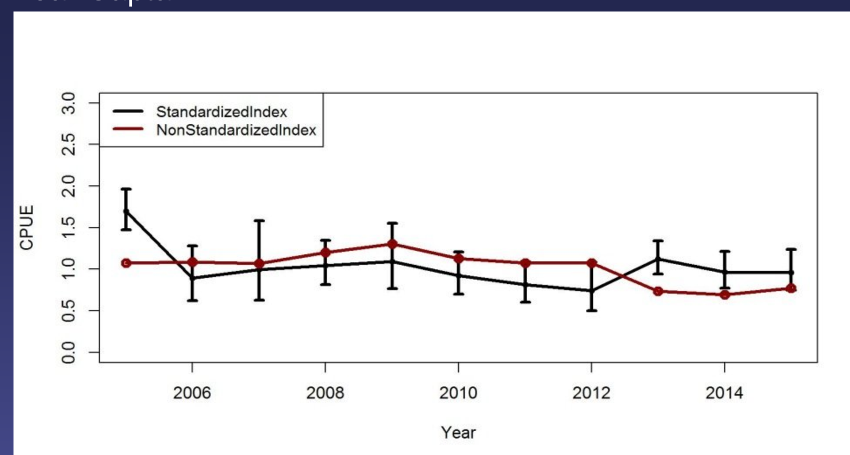
Year:Captain



WAG



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Figures 16 and 32. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) for Scs 1a, 1c, 2a, 2c, 4a, 4c, 6a, 6c, 7a, 7c, 8a, 8c, 11a, 11c, 16 a, and 16c fits,

EAG

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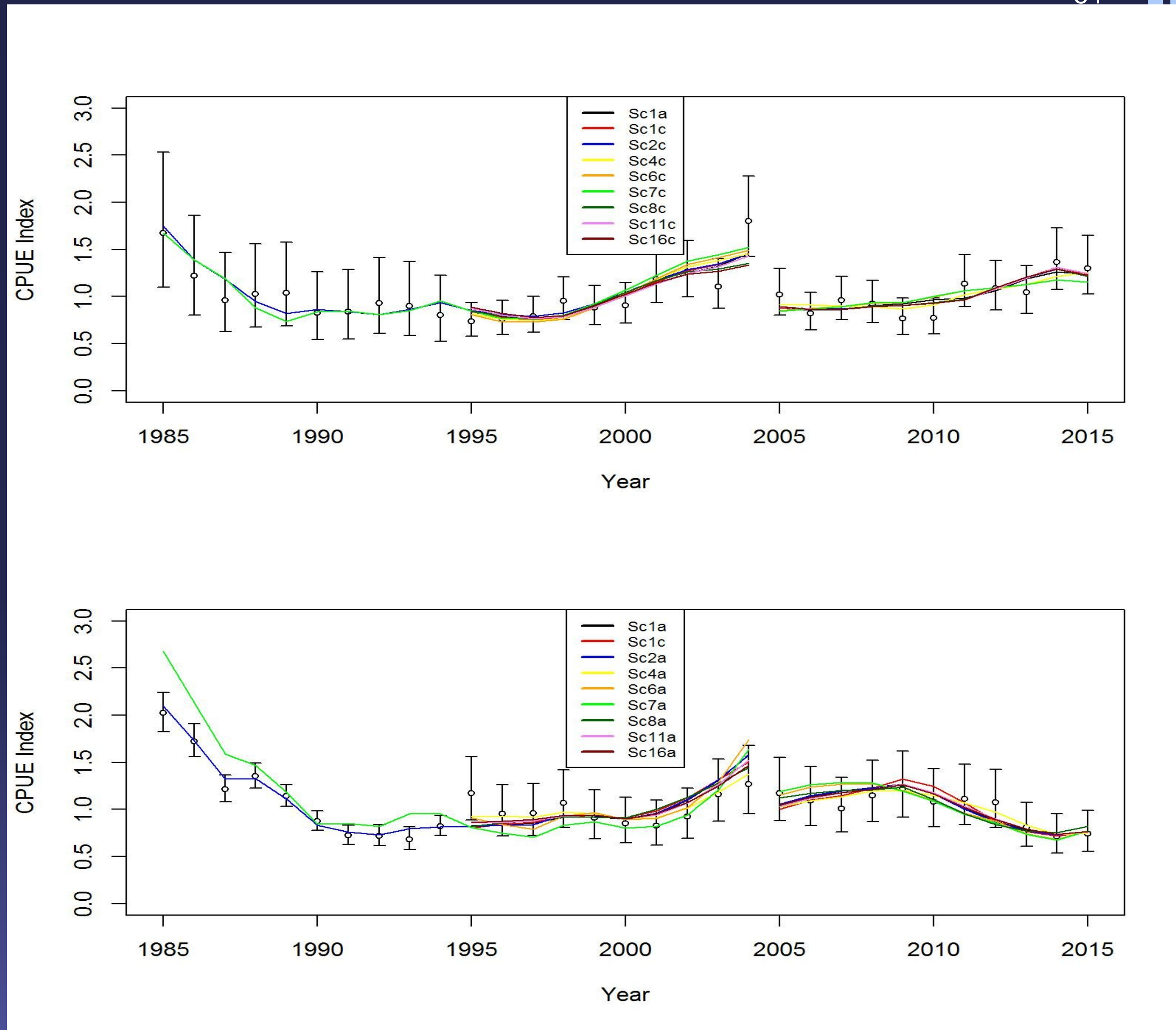
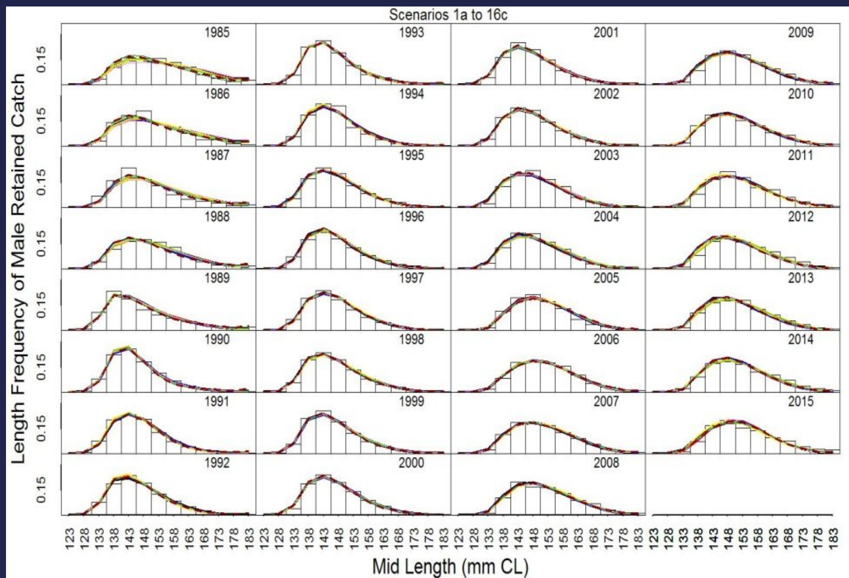
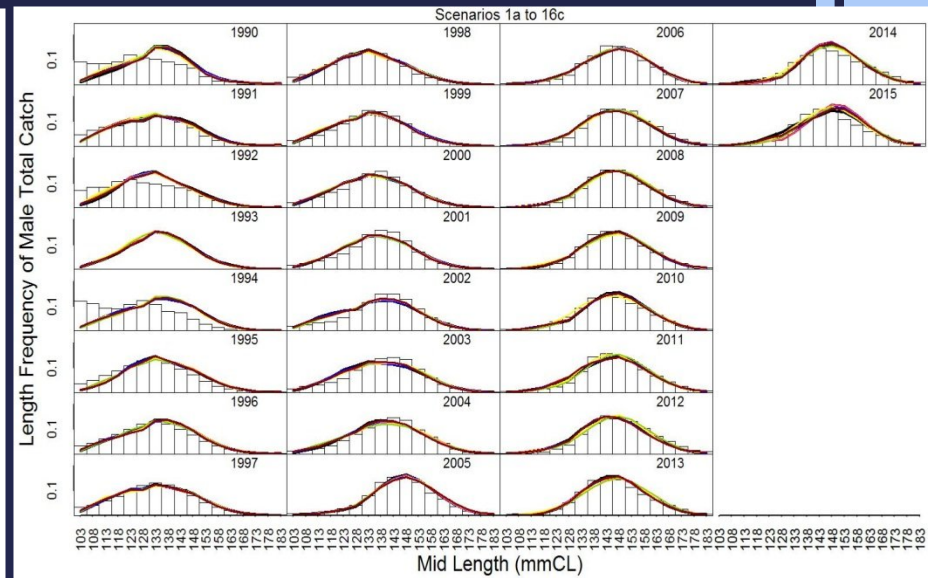
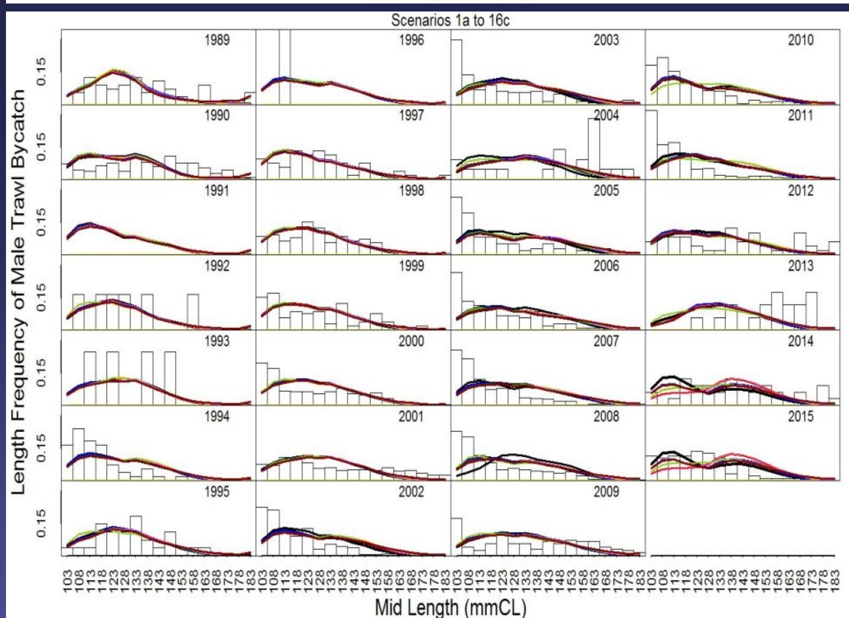


Figures 6, 7, and 8. Predicted (line) vs. observed (bar) retained (top left), total (top right), and groundfish discard (bottom left) catch length compositions for Scs 1a, 1c, 2c, 4c, 6c, 7c, 8c, 11c, and16c fits.

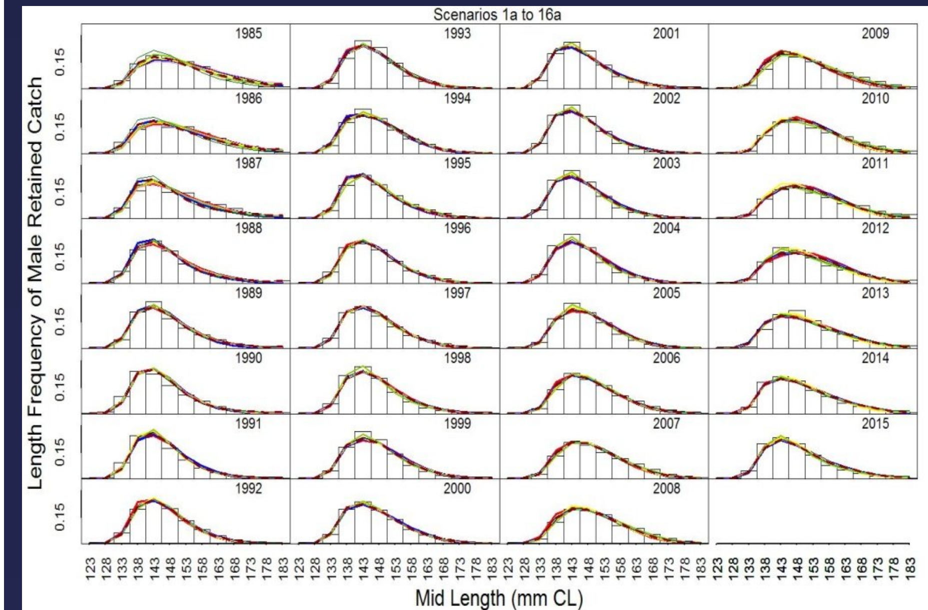


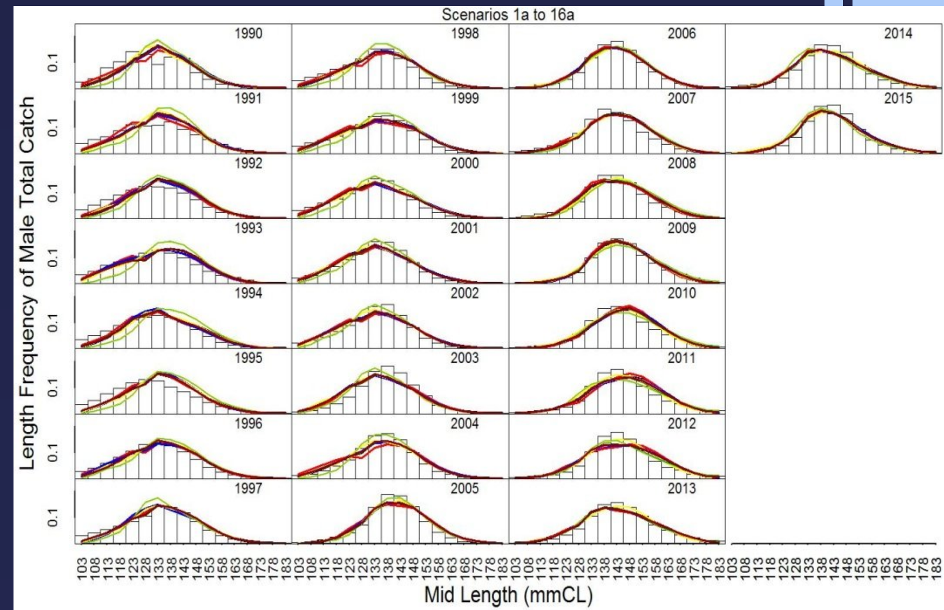


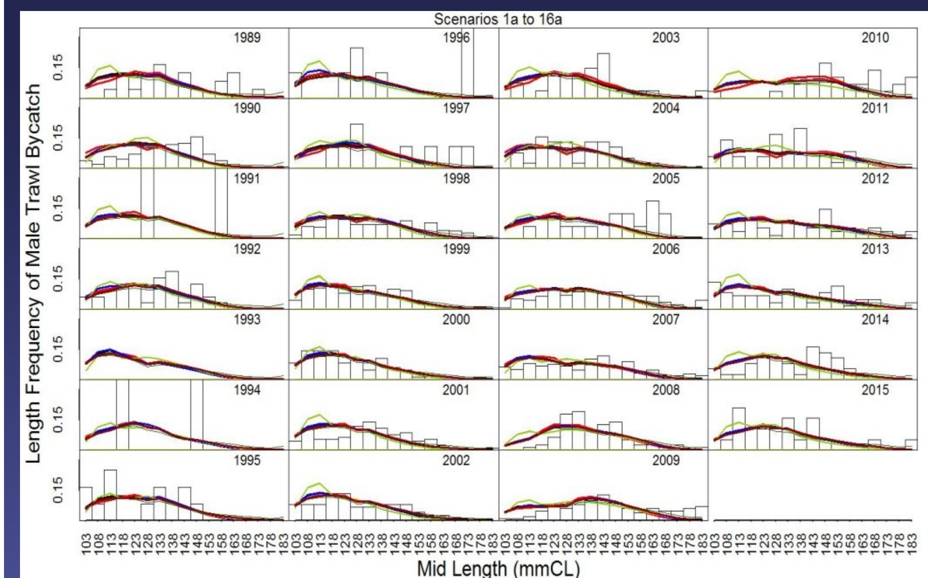


EAG

Figures 24, 25, and 26. Predicted (line) vs. observed (bar) retained (top left), total (top right), and groundfish discard (bottom left) catch length compositions for Scs 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and16a fits.







WAG

Figures 9 and 27. Total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios (Sc) 1a, 1c, 2a, 2c, 4a, 4c, 6a, 6c, 7a, 7c, 8a, 8c, and 16a, 16c fits.

EAG | WAG

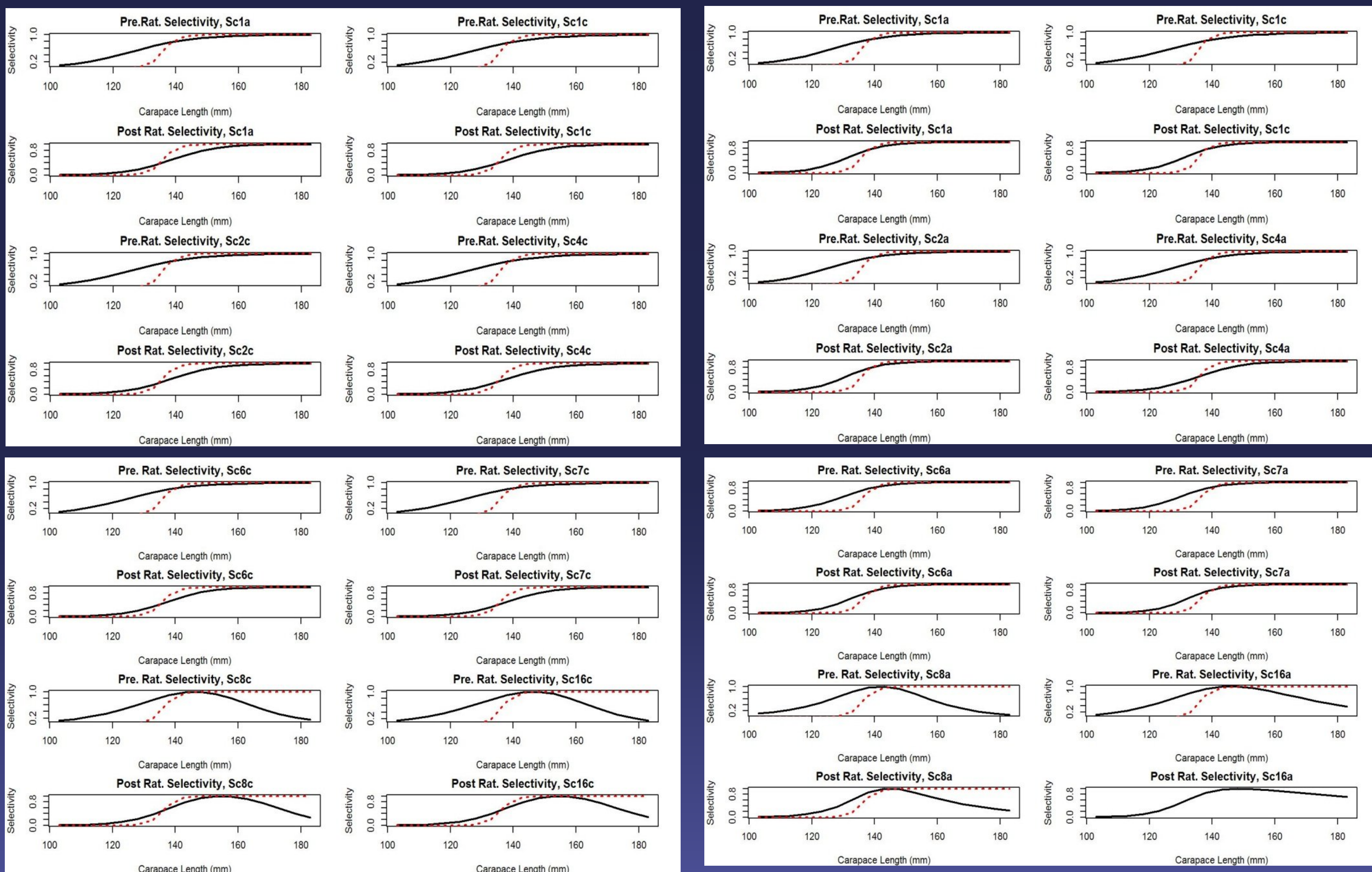
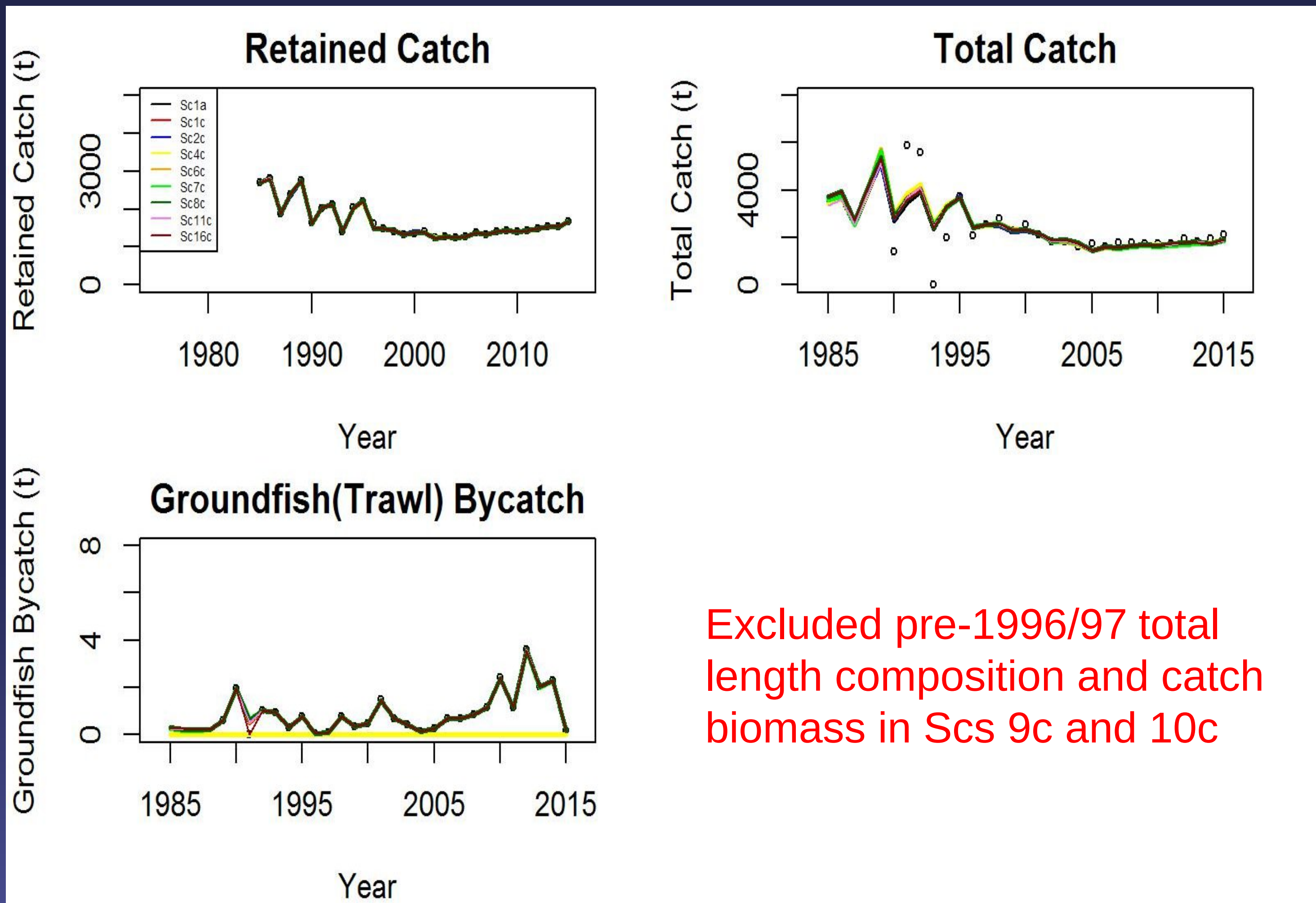


Figure 21. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) for Scs 1, 1c, 2c, 4c, 6c, 7c, 8c, and 16c fits.

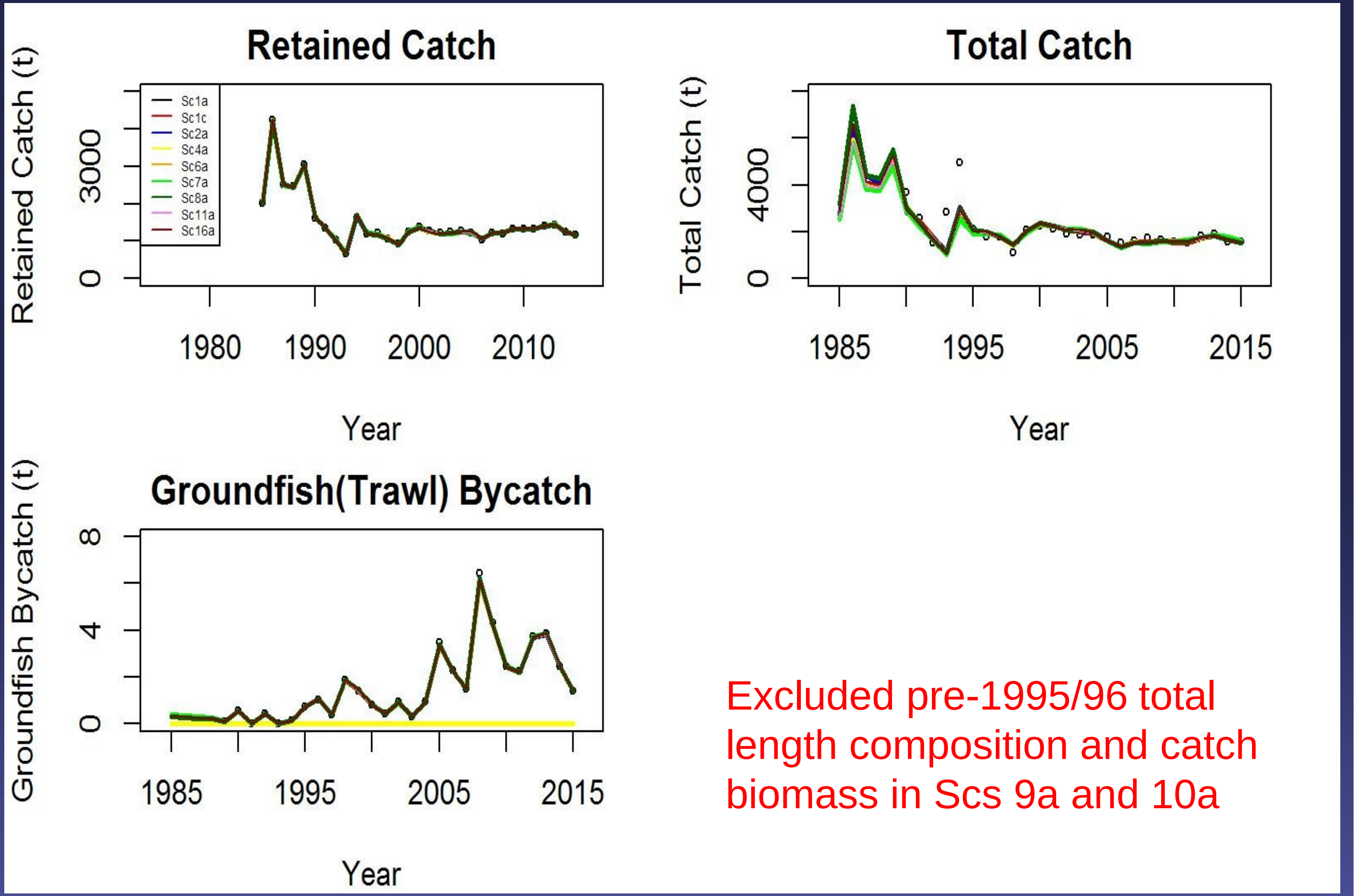
EAG



Excluded pre-1996/97 total length composition and catch biomass in Scs 9c and 10c

Figure 37. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) for Scs 1a, 1c, 2a, 4a, 6a, 7a, 8a, 11a, and 16a fits.

WAG



Excluded pre-1995/96 total length composition and catch biomass in Scs 9a and 10a

Figure 22. Retrospective fits of MMB by the model when terminal year's data were systematically removed until 2011/12 for scenarios (Sc) 1a, 1c, 2c, 6c, 7c, 8c, 11c, and 16c fits, 1960–2015.

EAG

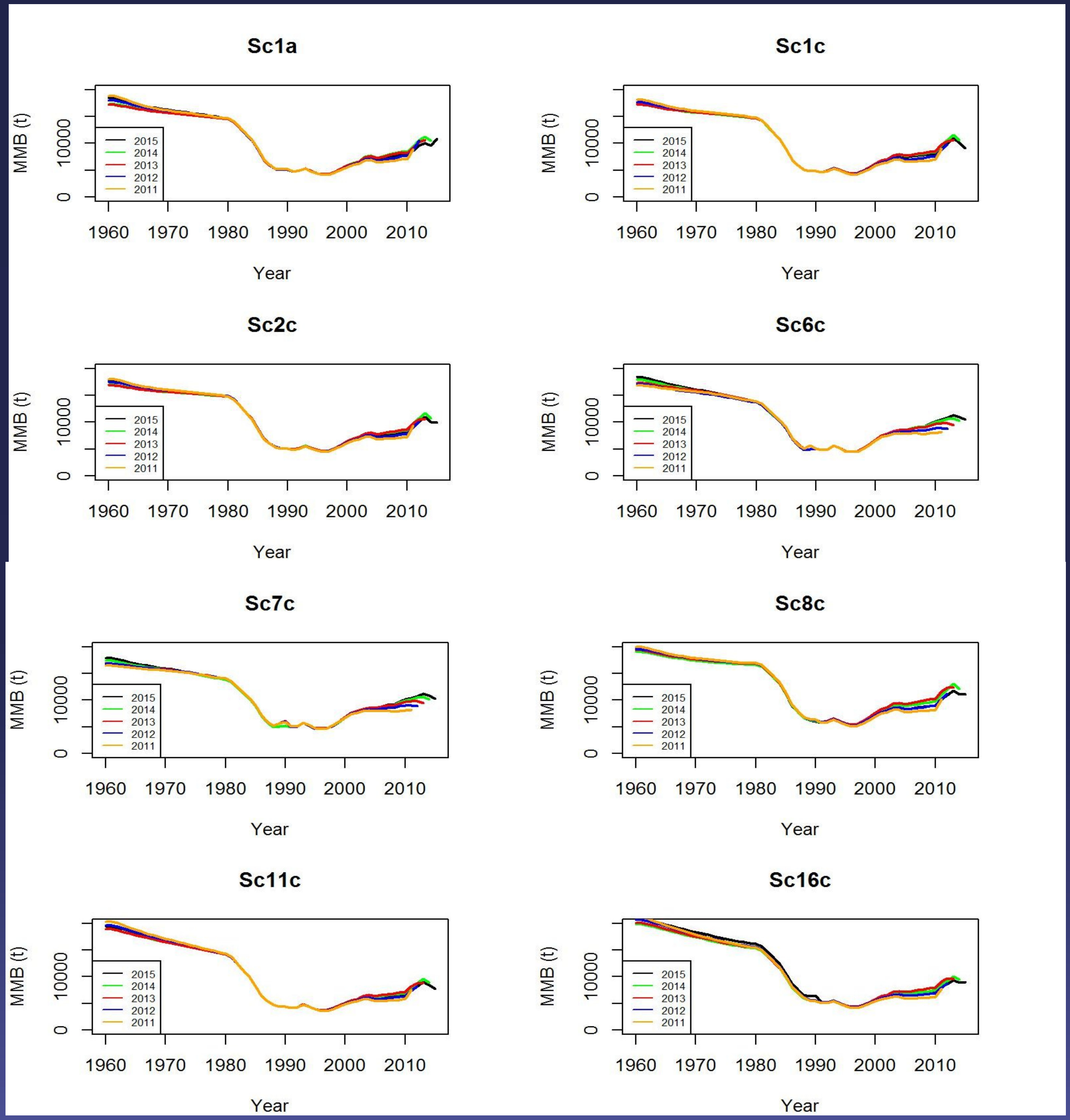
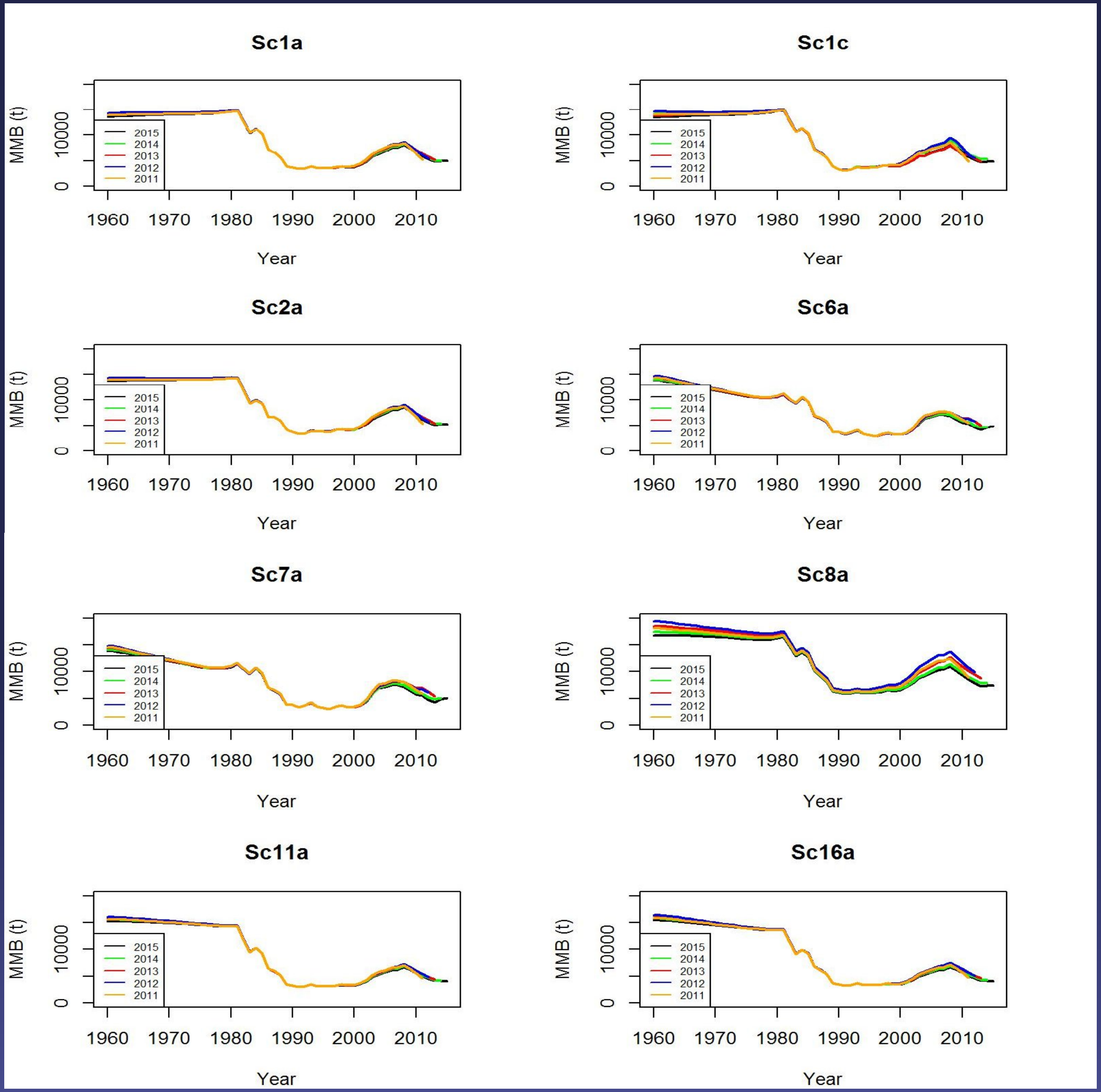


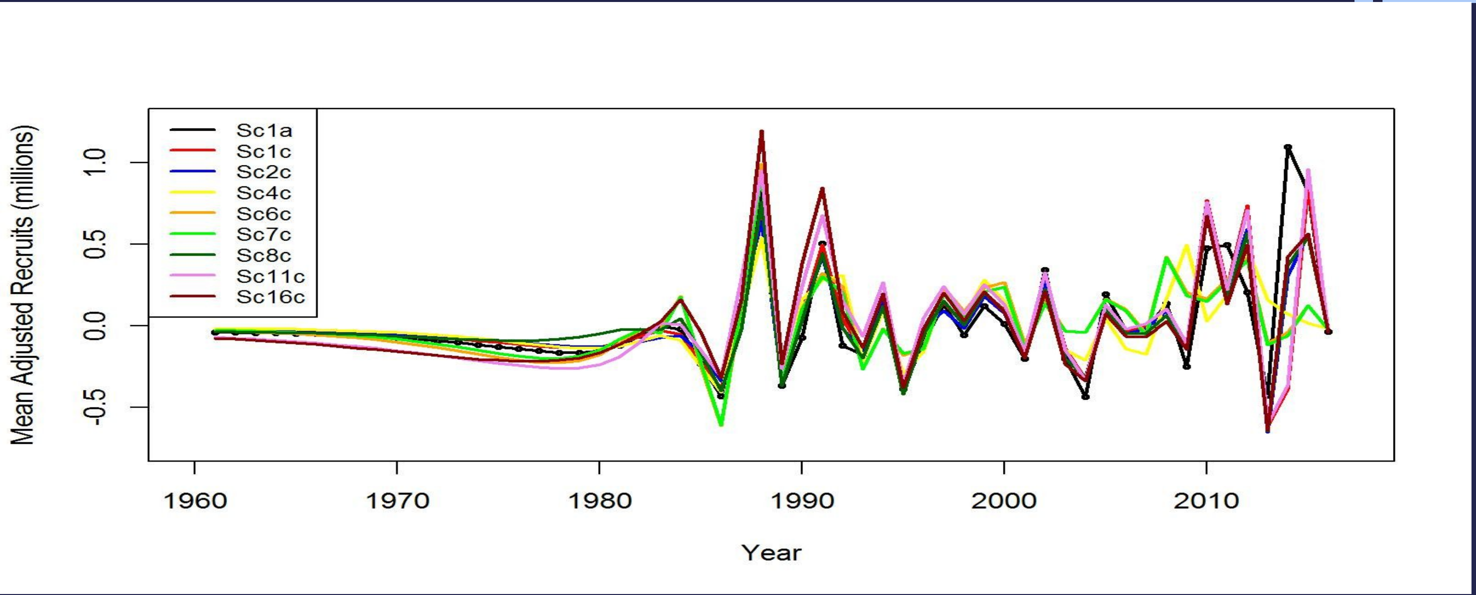
Figure 38. Retrospective fits of MMB by the model when terminal year's data were systematically removed until 2011/12 for scenarios (Sc) 1a, 1c, 2a, 6a, 7a, 8a, 11a, and 16a fits, 1960–2015.

WAG

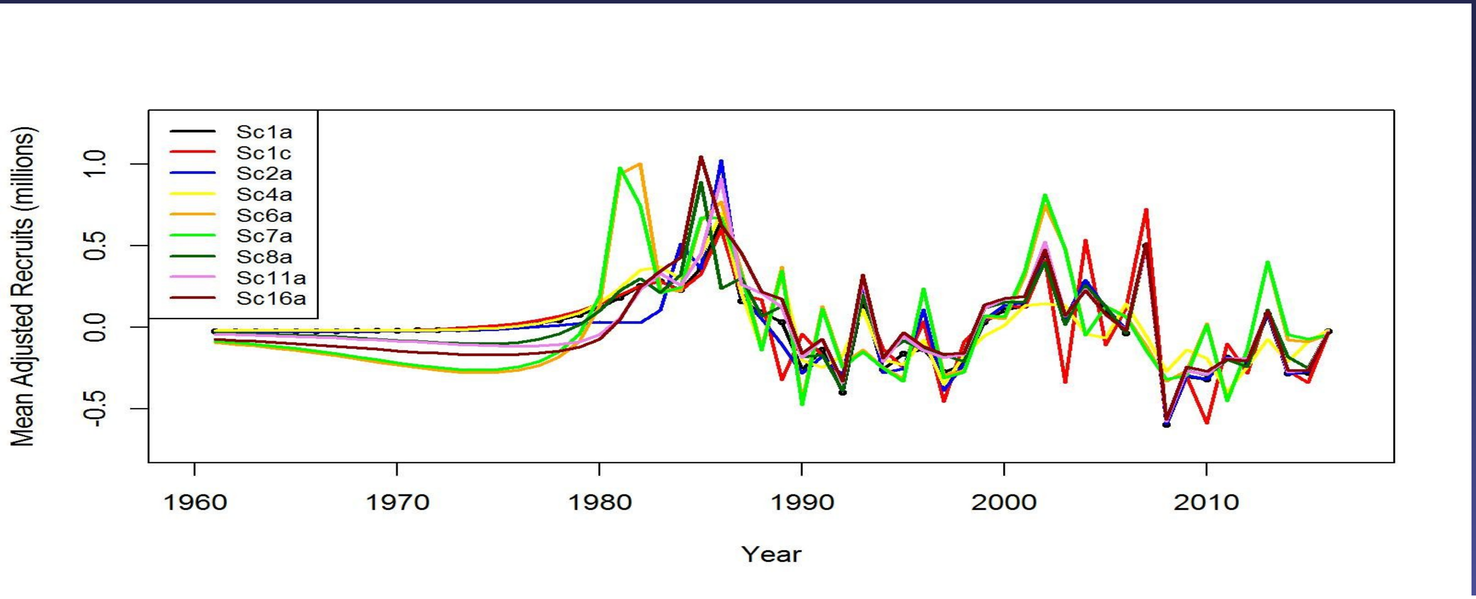


Figures 17 and 33. Number of male recruits for scenarios (Sc) 1a, 1c, 2a, 2c, 4a, 4c, 6a, 6c, 7a, 7c, 8a, 8c, 11a, 11c, 16a, and 16c fits , 1961–2016.

EAG

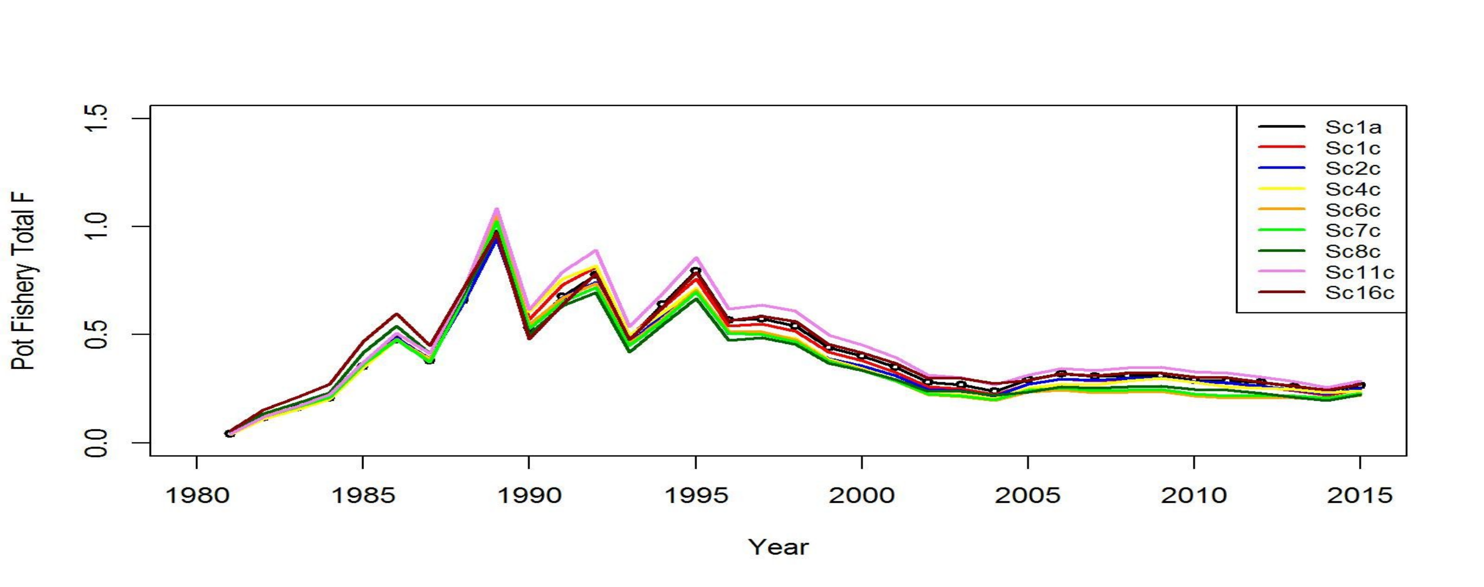


WAG

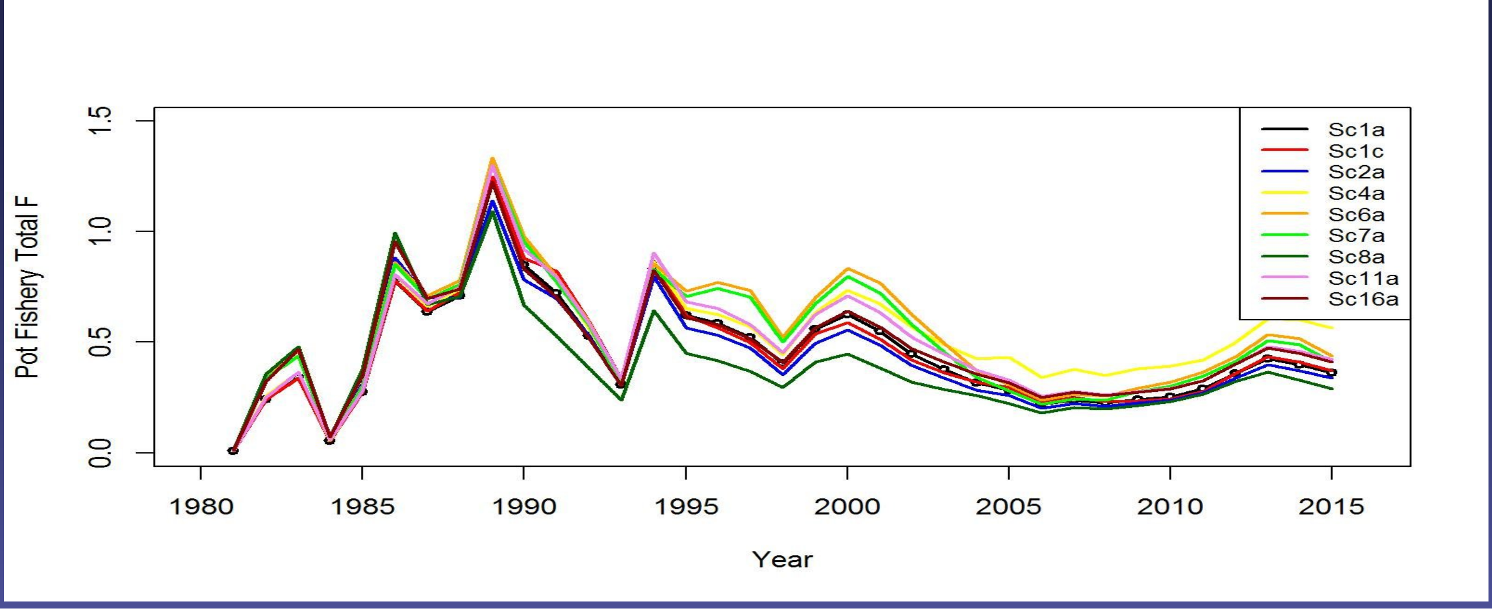


Figures 20 and 36. Trends in total pot fishery F for scenarios (Sc) 1a, 1c, 2a, 2c, 4a, 4c, 6a, 6c, 7a, 7c, 8a, 8c, 11a, 11c, 16a, and 16c fits, 1981–2015.

EAG

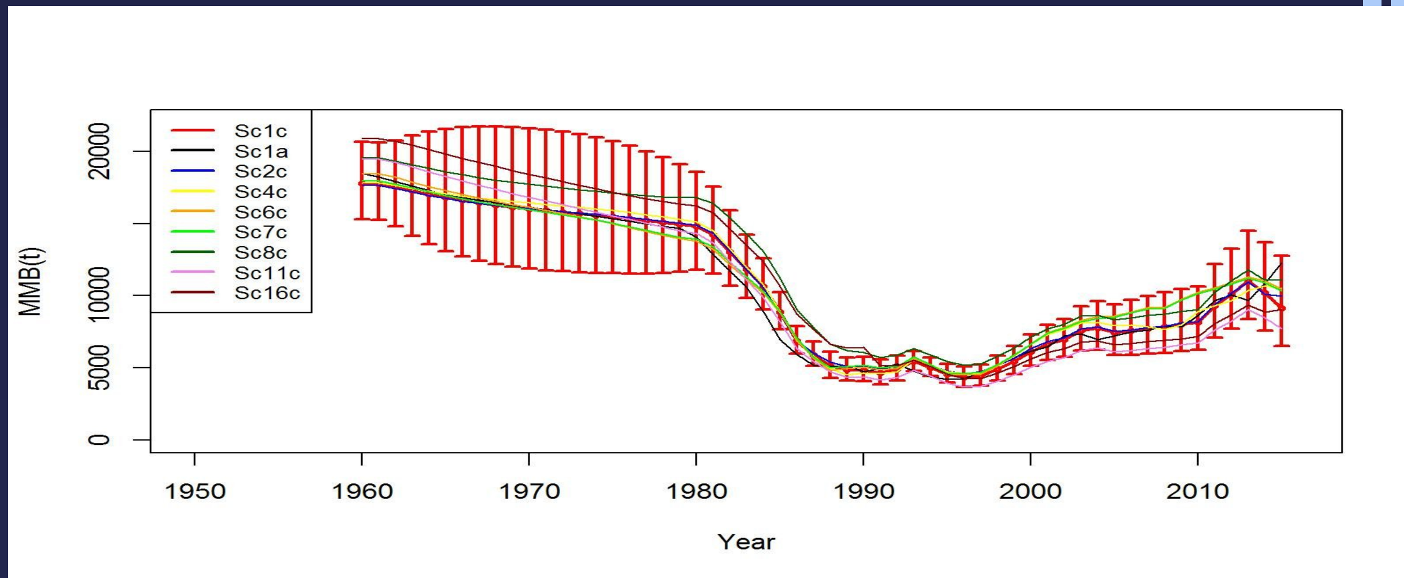


WAG



Figures 19 and 35. Trends in MMB for scenarios (Sc) 1a, 1c, 2a, 2c, 4a, 4c, 6a, 6c, 7a, 7c, 8a, 8c, 11a, 11c, 16a, and 16c fits, 1960/61–2015/16.

EAG



WAG

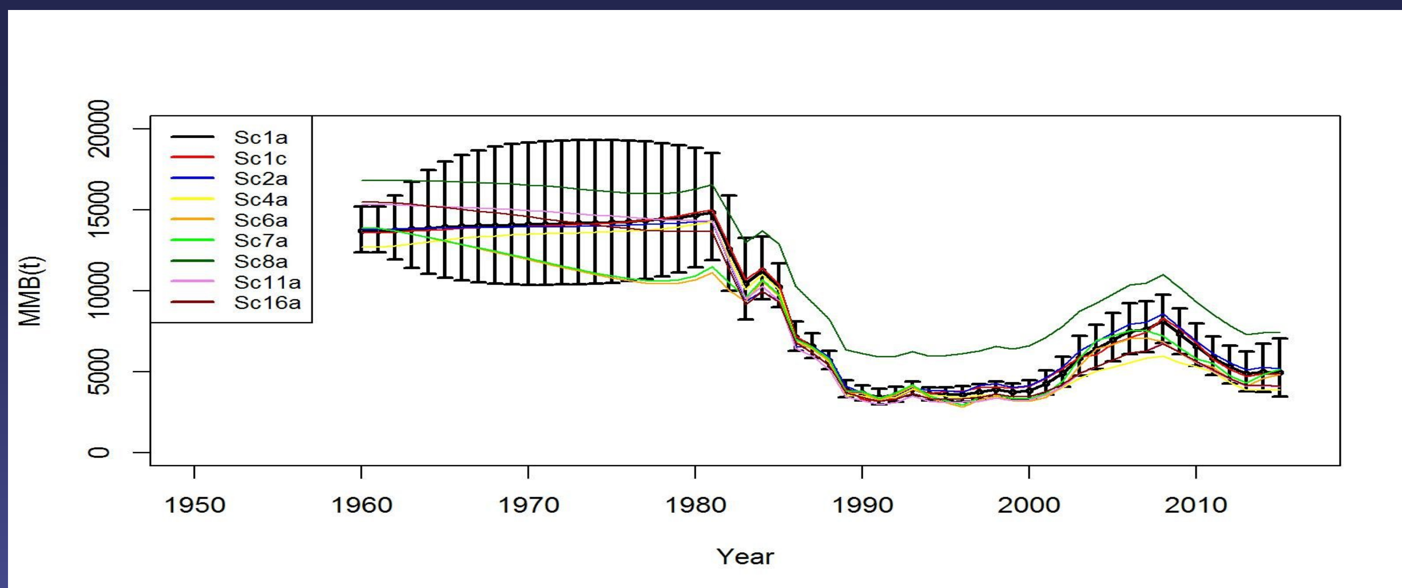


Table 29.

	EAG				WAG				
Sc	Tier 4 Total Catch OFL (t)	Tier 3 Total Catch OFL (t)	MMB_{2016} / $MMB_{initial}$	Sc	Tier 4 Total Catch OFL (t)	Tier 3 Total Catch OFL (t)	MMB_{2016} / $MMB_{initial}$	M yr^{-1}	Remarks
1a	1,669	3,799	0.66		822	1,484	0.38	0.2339	Equilibrium initial condition, asymptotic selectivity, ESS= no. of length measurements
1b	1,175	2,907	0.60		967	1,752	0.40	0.2339	Same as Sc1a, but CPUE predictor variables were selected by AIC
1c	1,506	3,822	0.56		785	1,431	0.37	0.2339	Same as Sc1a, but ESS = number of trips made by sampled vessels
1d	1,062	2,647	0.53		883	1,614	0.39	0.2339	Same as Sc1c, but CPUE predictor variables were selected by AIC
2a	1,696	3,866	0.64		894	1,644	0.39	0.2426	Sc1a with fish ticket CPUE
2b	1,323	3,268	0.63		1,043	1,904	0.41	0.2426	Same as Sc2a, but CPUE predictor variables were selected by AIC
2c	1,624	4,036	0.60		728	1,346	0.36	0.2426	Same as Sc2a, but ESS = number of trips made by sampled vessels
2d	1,158	2,884	0.55		939	1,762	0.40	0.2426	Same as Sc2c, but CPUE predictor variables were selected by AIC
3c	1,506	3,403	0.56	3a	646	1,254	0.38	0.2339	Estimate groundfish selectivity
4c	1,662	3,763	0.57	4a	594	1,140	0.37	0.2339	Drop groundfish bycatch and bycatch LF
5c	1,435	3,216	0.58	5a	814	1,298	0.37	0.2339	Three catchability and asymptotic total selectivity 1985/86–1994/95, 1995/96–2004/05, and 2005/06–
6c	1,730	3,745	0.55	6a	784	1,465	0.39	0.2339	Francis iterative estimation of ESS
7c	1,722	3,898	0.56	7a	861	1,654	0.41	0.2426	Francis iterative estimation of ESS with fish ticket CPUE
8c	1,764	3,579	0.60	8a	988	2,073	0.45	0.2339	Dome shaped selectivity
9c	1,452	3,368	0.55	9a	820	1,547	0.38	0.2339	Total catch & LF started from 1996/97 for EAG or 1995/96 for WAG.
10c	1,610	3,693	0.57	10a	933	1,782	0.40	0.2426	Sc 9.. with fish ticket CPUE
11c	1,049	2,138	0.45	11a	579	812	0.30	0.18	Same as Sc1a or Sc1c with lower M
12c	1,086	2,165	0.46	12a	621	880	0.30	0.18	Same as Sc2a or Sc2c with lower M
14c	1,238	2,468	0.47	14a	444	615	0.29	0.18	Drop groundfish bycatch and bycatch LF with lower M
16c	1,151	2,199	0.48	16a	576	807	0.30	0.18	Dome shaped selectivity with lower M
19c	1,204	2,771	0.52	19a	1,082	1,936	0.41	0.2339	Same as Sc1a or Sc1c, but CPUE predictor variables set contains the Year:Captain interaction term

EAG

Tier 4 Assessment: Tier level, MMB_{ref}, OFL, and ABC (million pounds)

Scenario	Tier	MMB_{ref}	Current MMB	MMB / MMB_{ref}	F_{OFL}	Years to define MMB_{ref}	M	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1 a (base)	4a	14.672	27.037	1.84	0.23	1986–2016	0.2339	3.679	3.660	2.493
1c (base)	4a	15.043	21.876	1.45	0.23	,,	0.2339	3.319	3.302	2.655
2a	4a	15.315	25.808	1.69	0.24	,,	0.2426	3.739	3.721	2.991
2c	4a	15.387	23.411	1.52	0.24	,,	0.2426	3.581	3.563	2.865
6a	4a	15.431	23.952	1.55	0.23	,,	0.2339	3.610	3.593	2.888
6c	4a	16.362	22.356	1.37	0.23	,,	0.2339	3.814	3.797	3.051
8a (dome shaped)	4a	16.189	27.286	1.69	0.23	,,	0.2339	3.958	3.935	3.167
8c (dome shaped)	4a	17.509	25.781	1.47	0.23	,,	0.2339	3.890	3.870	3.112

EAG

Tier 3 Assessment: Tier level, MMB_{ref}, OFL, and ABC (million pounds)

Sc.	Tier	MMB_{35}	Current MMB	MMB / MMB_{35}	F_{OFL}	Years to define MMB_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1 a (base)	3a	13.720	22.773	1.66	0.61	1986–2016	0.61	8.374	8.332	6.699
1c (base)	3a	13.342	18.080	1.36	0.61	,,	0.61	7.503	7.465	6.002
2a	3a	13.540	21.483	1.59	0.64	,,	0.64	8.523	8.482	6.818
2c	3a	13.283	19.184	1.44	0.65	,,	0.65	8.254	8.214	6.603
6a	3a	13.640	19.797	1.45	0.61	,,	0.61	8.186	8.148	6.549
6c	3a	13.842	18.319	1.32	0.58	’’	0.58	8.256	8.221	6.605
8a (dome shaped)	3a	14.284	23.590	1.65	0.53	,,	0.53	8.029	7.982	6.423
8c (dome shaped)	3a	14.544	22.148	1.52	0.53	,,	0.53	7.891	7.852	6.313

WAG

Tier 4 Assessment: Tier level, MMB_{ref}, OFL, and ABC (million pounds) 48

Scenario	Tier	MMB_{ref}	Current MMB	MMB / MMB_{ref}	F_{OFL}	Years to define MMB_{ref}	M	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1 a (base)	4b	11.766	11.428	0.97	0.23	1986–2016	0.2339	1.813	1.792	1.450
1c (base)	4b	11.789	11.148	0.95	0.22	,,	0.2339	1.730	1.709	1.384
2a	4b	12.219	11.794	0.97	0.23	,,	0.2426	1.970	1.948	1.576
2c	4b	11.486	10.492	0.91	0.22	,,	0.2426	1.605	1.586	1.284
6a	4a	10.760	11.851	1.10	0.23	,,	0.2339	1.728	1.720	1.382
6c	4b	11.255	10.359	0.92	0.21	,,	0.2339	1.524	1.507	1.219
8a (dome shaped)	4b	17.615	16.669	0.95	0.22	,,	0.2339	2.179	2.155	1.743
8c (dome shaped)	4b	14.200	11.991	0.84	0.19	,,	0.2339	1.429	1.413	1.072

WAG

Tier 3 Assessment: Tier level, MMB_{ref}, OFL, and ABC (million pounds)

Sc.	Tier	MMB_{35}	Current MMB	MMB / MMB_{35}	F_{OFL}	Years to define MMB_{35}	F_{35}	OFL	ABC (P*=0.49)	ABC (0.8*OFL)
1 a (base)	3b	10.697	10.033	0.94	0.45	1986–2016	0.48	3.271	3.248	2.617
1c (base)	3b	10.615	9.784	0.92	0.44	,,	0.48	3.156	3.131	2.525
2a	3b	10.737	10.215	0.95	0.47	,,	0.50	3.624	3.599	2.899
2c	3b	10.396	9.191	0.88	0.44	,,	0.51	2.967	2.947	2.374
6a	3b	10.573	10.414	0.98	0.48	,,	0.49	3.229	3.207	2.583
6c	3b	10.324	9.137	0.89	0.43	''	0.49	2.802	2.781	2.242
8a (dome shaped)	3a	12.892	14.384	1.12	0.51	,,	0.51	4.569	4.545	3.655
8c (dome shaped)	3b	11.504	10.507	0.91	0.44	,,	0.49	2.983	2.961	2.387

Tier 4 Assessment: Aleutian Islands OFL and ABC (pooled from EAG and WAG estimates)

Sc.	OFL (million pounds)	ABC (P*=0.49) (million pounds)	ABC (0.8*OFL) (million pounds)	OFL (1,000 t)	ABC (P*=0.49) (1,000 t)	ABC (0.8*OFL) (1,000 t)
1a (base)	5.492	5.452	4.393	2.491	2.473	1.993
1c (base)	5.049	5.011	4.039	2.290	2.273	1.832
2a	5.709	5.669	4.567	2.590	2.572	2.072
2c	5.186	5.149	4.149	2.352	2.336	1.882
6a	5.338	5.313	4.27	2.421	2.410	1.937
6c	5.338	5.304	4.27	2.421	2.406	1.937
8a (dome shaped)	6.137	6.09	4.91	2.784	2.763	2.227
8c (dome shaped)	5.319	5.283	4.184	2.412	2.397	1.898

Tier 3 Assessment: Aleutian Islands OFL and ABC (pooled from EAG and WAG estimates)

Sc.	OFL (million pounds)	ABC (P*=0.49) (million pounds)	ABC (0.8*OFL) (million pounds)	OFL (1,000 t)	ABC (P*=0.49) (1,000 t)	ABC (0.8*OFL) (1,000 t)
1a (base)	11.645	11.580	9.316	5.282	5.252	4.226
1c (base)	10.659	10.596	8.527	4.835	4.806	3.868
2a	12.147	12.081	9.717	5.510	5.480	4.408
2c	11.221	11.161	8.977	5.090	5.063	4.072
6a	11.415	11.355	9.132	5.178	5.151	4.142
6c	11.058	11.002	8.847	5.016	4.991	4.013
8a (dome shaped)	12.598	12.527	10.078	5.714	5.682	4.572
8c (dome shaped)	10.874	10.813	8.700	4.932	4.905	3.946

Conclusions

- The biomass scaling issue is adequately addressed by the

(a) equilibrium initial condition, (b) higher estimated *M*, and

(c) dome shaped total selectivity.

- The MMB trends reflect the CPUE trends in EAG and WAG.

- If the model is accepted, we recommend the OFL and ABC estimates for any one of scenarios:

1a (base, effective sample size is the scaled number of length measurements),

1c (base, effective sample size is the number of fishing trips),

2a (1a with fish ticket CPUE likelihood),

2c (1c with fish ticket CPUE likelihood),

6a (1a with iteratively estimated effective sample sizes),

6c (1c with iteratively estimated effective sample sizes),

8a (1a with dome shaped selectivity), and

8c (1c with dome shaped selectivity) under Tier 3 or Tier 4 estimation procedure.

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.

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.
- We have been using the length-weight relationship established based on 1997 data for golden king crab. The research foundation program can help us to update this relationship by collecting new length weight information.

Thank You.
Any Questions?
Suggestions?