Gulf of Alaska Pacific cod

Notes for September Plan Team
Steven Barbeaux

CIE Review

"The review panel recognized the tremendous amount of effort by the staff in preparing the assessment and the excellence of the documentation. The presentations were of the same high quality. The additional analyses requested by the panel during the meeting were done very competently and quickly." - Dr. Henrik Sparholt

On 1-4 May 2018 a review of the Gulf of Alaska Pacific cod stock assessment was conducted by Dr. Jean-Jacques Maguire, Dr. Henrik Sparholt, and Dr. Kevin Stokes. These scientists were contracted through the Center of Independent Experts (CIE) with the terms of reference provided in Appendix A of this document along with the three reviews. The terms of reference related to the following issues: 1) Whether the IPHC longline survey should be included in the assessment, 2) Whether the ADFG trawl surveys should be included in the assessment model, 3) the level of complexity necessary in the assessment model, 4) data weighting, 5) time variability and appropriate fishery and survey selectivity, 6) whether to include environmental indices for natural mortality, and 7) whether the temperature-catchability relationship for the AFSC longline survey was modeled appropriately.

They noted that the assessment document was complete and of high quality. The data used and modeling approaches were appropriate for this stock. They agreed that the IPHC survey should be included, but it would be necessary for length data on Pacific cod to be collected so that selectivity could be appropriately modeled[1]. Exploratory models including the IPHC data (assuming the same selectivity as the AFSC bottom trawl survey) were presented to the CIE reviewers and included in Appendix B.

Opinions differed among reviewers on whether ADFG trawl survey data should be included. Exploratory models on using these data are presented to the CIE review (Appendix B).

The question of model complexity was interpreted differently by the three reviewers. However all three appeared to agree that simpler models are generally preferred and that the simple models presented in 2016 should continue to be run in order to set a baseline while more complex (moderately complex) models should be developed to explore specific features and questions. All warned that adding model complexity may improve model precision it also increases the probability of overfitting the data and the odds of being precisely wrong.

All agreed that the data weighting applied in the models presented appeared sensible and to the generally accepted standards for assessment models. The discussion during the CIE review highlighted the current lack of consensus among stock assessors in this area and the need for continued research and model sensitivity analyses in respect to model weighting.

---

[1] *Pacific cod length data are being collected this year by the IPHC and will be included in next year (2019) assessment.*

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

The reviewers noted that adding environmental covariates within assessment models requires care and validation on the processes being hypothesized. Two of the three reviewers had doubts about the increased natural mortality of GOA Pacific cod during the marine heatwave and suggested that we should more fully explore other possibilities such as overfishing, disease (*although this would manifest as increased natural mortality*), migration from the surveyed and fished region, and under-reporting of Pacific cod catch. Given that there was ample evidence for the decline in GOA Pacific cod abundance in the managed area with some uncertainty as to the process involved in generating the decline, the precautionary approach suggests an assumption of increased mortality during the heatwave was a prudent management measure.

All reviewers agreed that using temperature in modeling catchability of the AFSC longline survey appeared appropriate as the longline survey does not full cover the shallowest habitat of Pacific cod and the depth distribution of cod shows a shifting distribution with changing temperatures. There were several explanations given as to why this might occur, but all agreed that adding this improved the model.

Pacific cod aging bias

Although not part of the CIE review's terms of reference an issue was discovered this year concerning GOA Pacific cod otolith aging which suggests possible aging bias in otoliths read prior to 2009 and presented during the CIE review. The otoliths used in Stark (2007) were reread using the current methods and reading criteria. Results indicated Pacific cod were younger at length than previously estimated (Fig. 1). Examining length at age over time indicated a shift to larger sizes after 2007 for ages 2 through (Fig. 2). During the CIE review this issue was noted as a concern. Consequently several models additional model configurations were explored.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

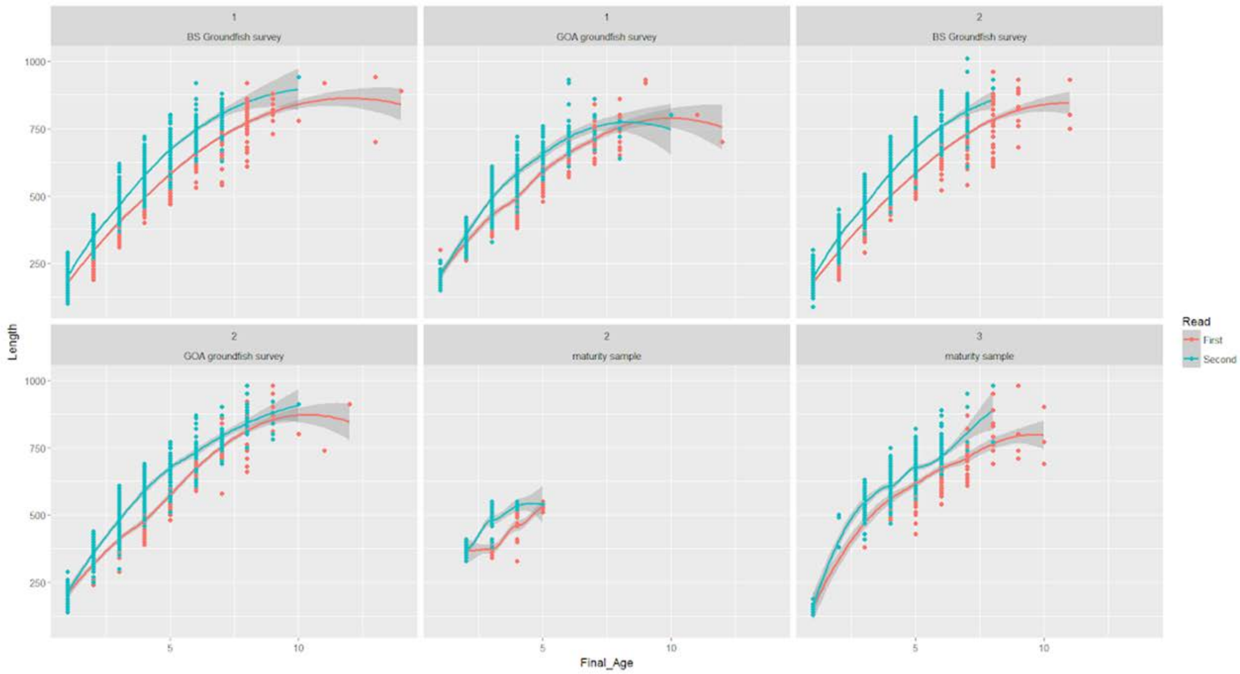


Figure 1. Length-at-age for otoliths from Stark (2007) analysis of Pacific cod growth and maturity showing the age from the original read (red) and a reread of the otoliths using the latest methods and criteria (blue).

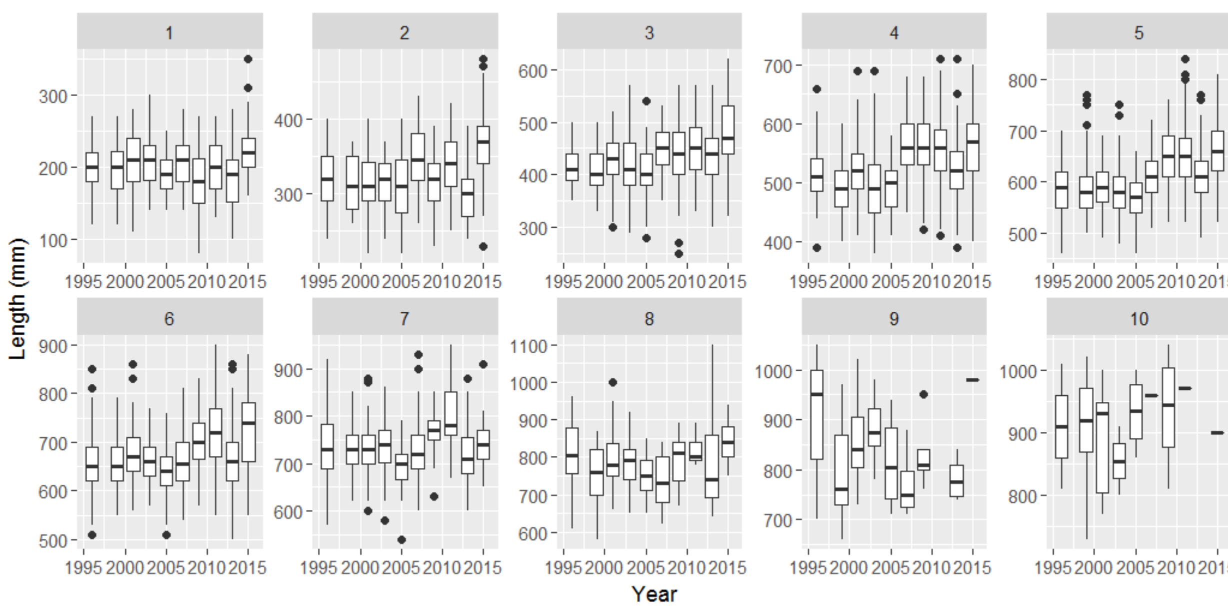


Figure 2. Length-at-age by year for each age 1 through 10 for Pacific cod otoliths collected during the summer bottom trawl surveys showing an increase in median length in 2007 for ages 2 through 6.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

CIE review models

Besides the models presented in 2016 and 2017 assessments there were 5 additional models presented during the review which addressed specific questions (Fig. 3 and Fig. 4). Model18.09.38 was the same as the 2017 reference model, Model 17.09.35, except length-based maturity (Fig. 5) was used instead of age-based maturity considering the reread of the Stark (2007) otoliths. The length at 50% maturity was calculated using the *morp_mature* function in the **sizeMat** R package (Torrejon-Magallanes 2017). Model 18.09.39 was the same model as Model18.09.38 except pre-2007 age data were excluded and the prior cv on natural mortality was changed from 0.1 to the prior cv of 0.41 for both the regular and 2015-2016 block. Model18.09.40 was the same as Model18.09.39 except all age composition data were excluded from the model. Model 18.09.41 was the same configuration as Model18.09.39 except pre-2007 age data were included with aging error implemented, the growth parameters were fixed, and aging bias was added for Pre-2007 age data based on the re-read of the Stark (2007) otoliths (*At the time of the CIE review it was discovered that stock synthesis did not allow time varying aging error or bias*). Model18.09.42 was the same as Model 18.08.41 except the western ADFG trawl survey index was included (*note that this model did not converge properly*). Model descriptions and synopsis of results can be found in Appendix B.

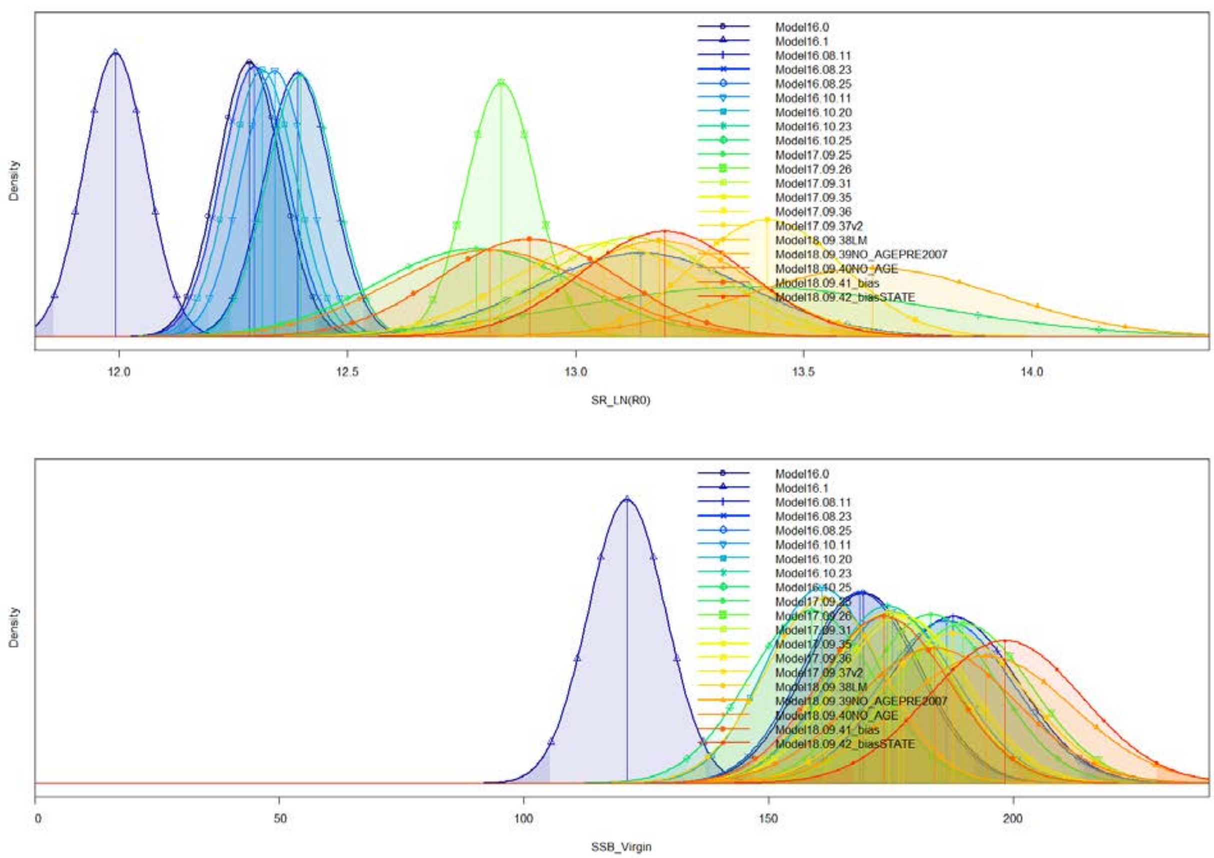


Figure 3. (Top) the log R_0 in thousands and (bottom) SSB_0 in thousands of tons for all models presented in the CIE Review.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

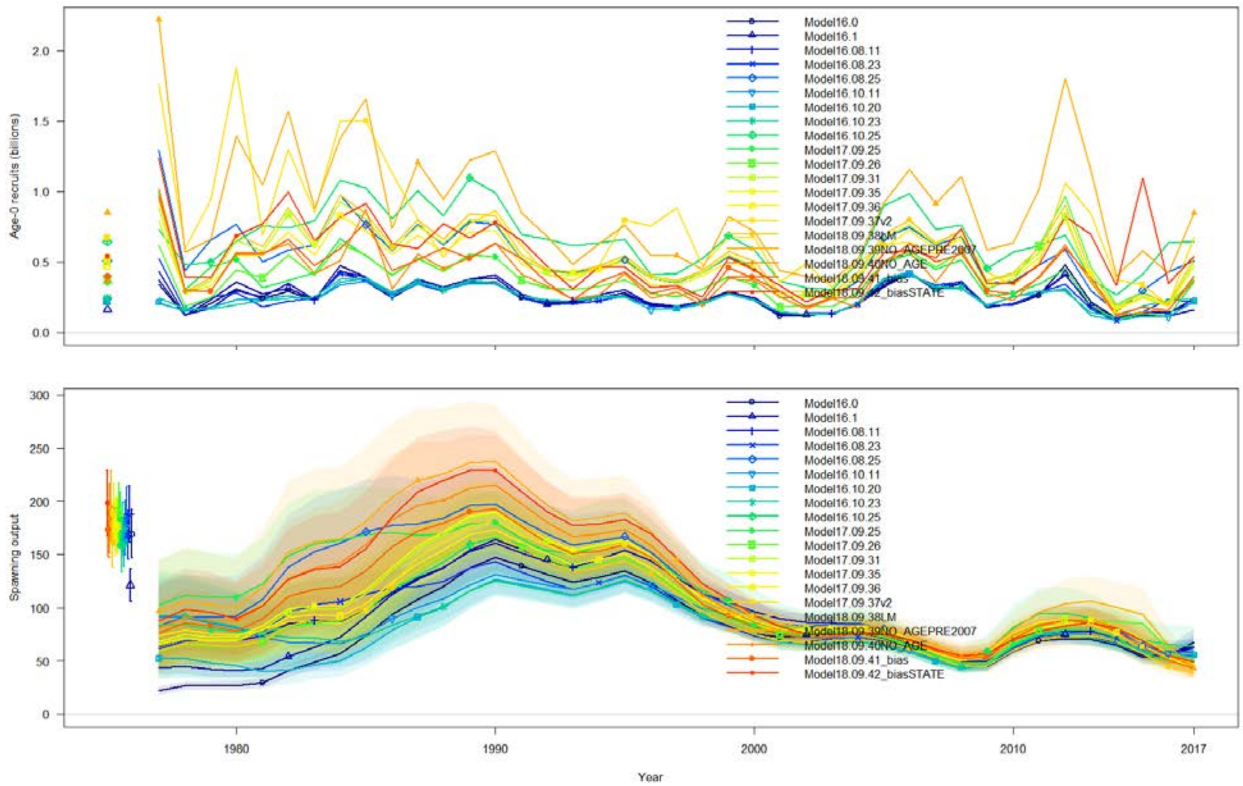
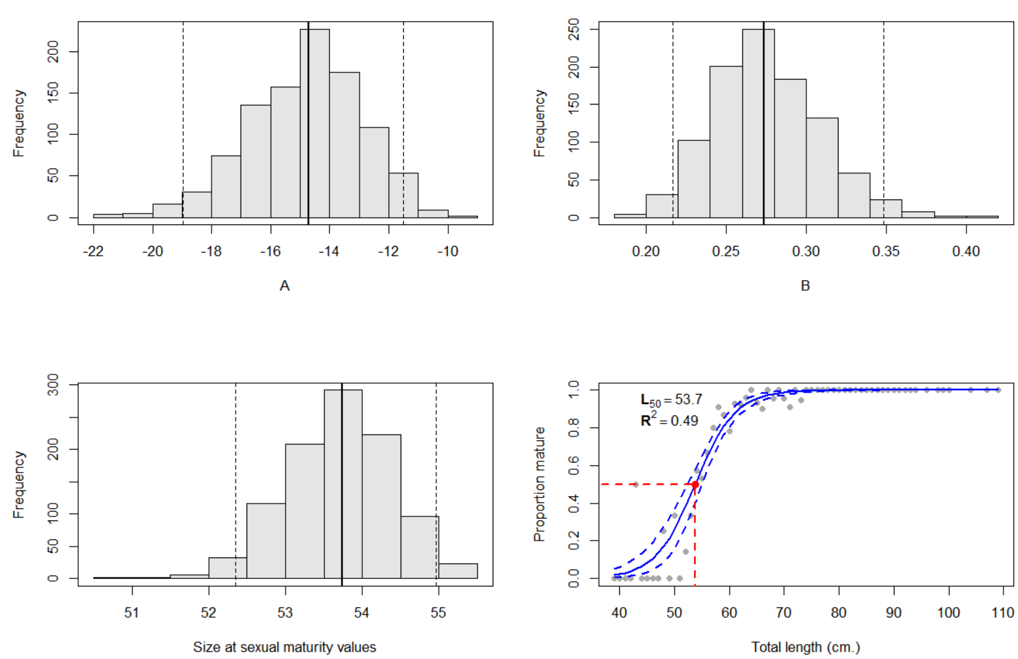


Figure 4. (Top) number of Pacific cod at Age-0 in billions and (bottom) female spawning stock biomass (thousands of tons) for all models presented during the CIE review.



Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

Figure 5. Bootstrapped (n=1000) parameters and results for the logistic length-based maturity using Stark (2007) reread otolith and maturity data. Proportion mature $P = {}^{1}/_{1+e^{-(A+BL)}}$ and L_{50} = A/-B

Use of resampling for model selection when scaling model parameters to environmental indices

A new method for assessing the inclusion of environmental indices in the model was also presented at the CIE. For all models developed after Model 17.09.26 (the 17.09.31 and 17.09.35, 17.09.36 and 17.09.37 and all of the 18.xx.xx models) the AFSC longline survey catchability included a parameter, P, which was used to additively adjust annual catchability values based on an annual temperature index, Iy, as $\log(Q_y) = (\bar{Q} + PI_y)$ where Q_y is catchability for a given year, and Q is the expected catchability across all time. The AFSC longline survey catchability was thought to be influenced by shelf temperature as Pacific cod distribution is shown to change due to temperature (Fig. 6), with shifts as much as 30 meters for some size categories and the longline survey starting depth at 125M is near the mean distribution of cod for the larger fish during warm years, but deeper than the mean in cold years.

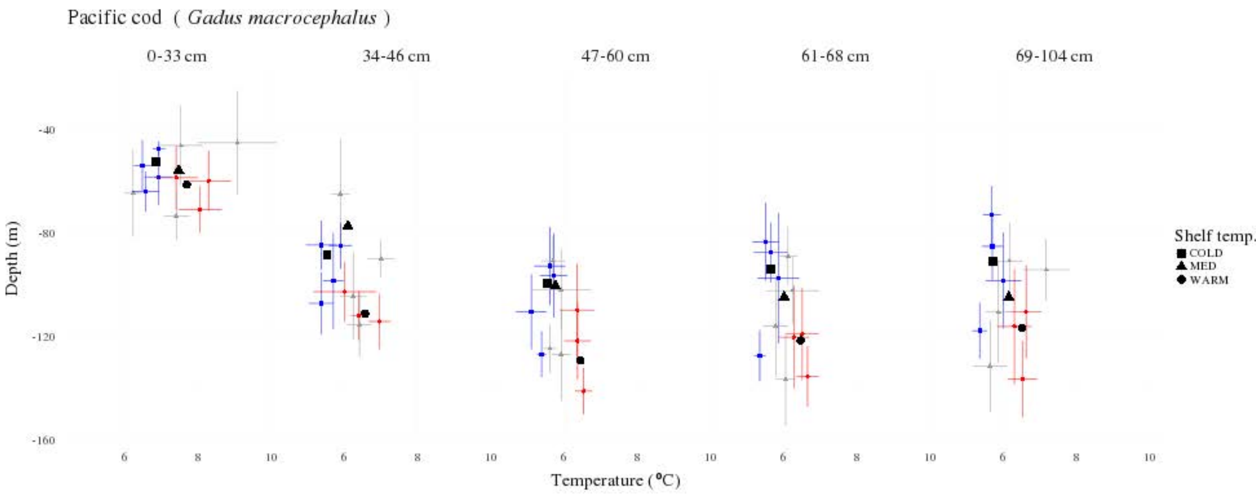


Figure 6. Distribution of Pacific cod by length category by depth and temperature for cold years (blue, square shows mean for all cold years) and warm years (red, circle shows mean for all warm years) from the AFSC bottom trawl survey 1993-2017.

For this examination we used an index of mean annual temperature at depth for cod developed from the Climate Forecast System Reanalysis (CFSR) as our temperature index, I. CFSR is the latest version of the National Centers for Environmental Prediction (NCEP) climate reanalysis. The oceanic component of CFSR includes the Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 4 (MOM4) with an iterative sea-ice (Saha et al. 2010). It uses 40 levels in the vertical with a 10-meter resolution from surface down to about 262 meter. The zonal resolution is 0.5° and a meridional resolution of 0.25° between 10°S and 10°N, gradually increasing through the tropics until becoming fixed at 0.5° poleward of 30°S and 30°N.

To make the index the CFSR reanalysis grid points were co-located with the AFSC bottom trawl survey stations. The co-located CFSR oceanic temperature profiles were then linearly interpolated to obtain the temperatures at the depths centers of gravity for Pacific cod at 10 cm to 70 cm at 10 cm intervals as determined from the AFSC bottom trawl survey. All co-located grid points were then averaged to get the time series of CFSR temperatures over the period of 1979-2016 (Fig. 7)

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

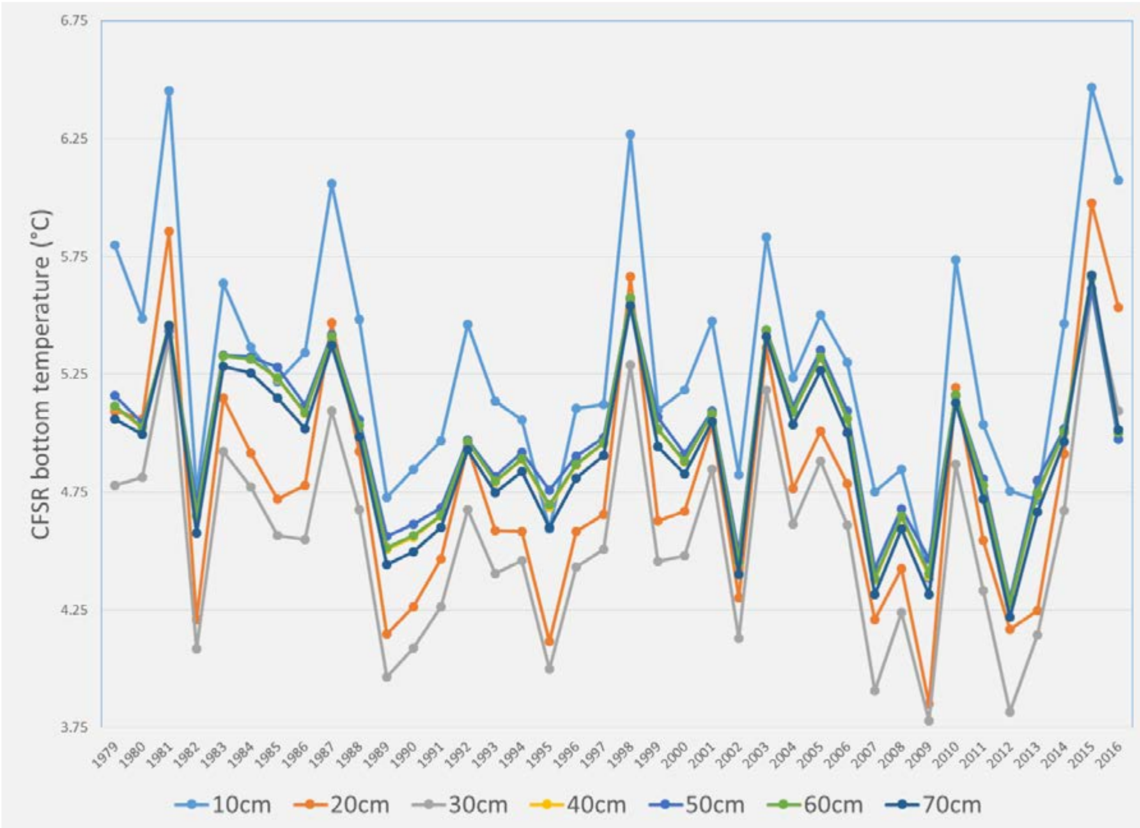


Figure 7. CFSR time series of bottom temperature for the mean depth of Pacific cod at different sizes.

The mean depth of Pacific cod at 10 cm and 40cm was found to be 47.9 m and 103.4 m in the Central GOA and 41.9 m and 64.07 m in the Western GOA. The temperatures of the 10 cm and 40 cm Pacific cod in the CSFR indices are highly correlated (R^2 = 0.88) with the larger fish in deeper and slightly colder waters 7.49 °C vs. 6.00 °C in the Central GOA and 4.78 °C vs. 4.75 °C in the Western GOA. The shallower index is more variable (CV_{10cm} 0.10 vs. CV_{40cm}=0.07). There are high peaks temperature in 1981, 1987, 1998, 2015 and 2016 with 2015 being the highest in both the 10 cm and 40 cm indices. There are low valleys in temperature in 1982, 1989, 2009, 2012, and 2013. The coldest temperature in the 10cm index was in 2009 and in the 40 cm index in 2012. There isn't a significant trend in either of these indices over the entire time period.

The addition of parameter P may improve model fit through the addition of model flexibility and spurious correlations with the temperature time series. Model selection methods such as Akaike's information Criterion (AIC; Akaike 1998) are often employed for determining whether the addition of a given parameter improves a model, however AIC has been shown to select over-fit models (Bozdogan 1987). In addition many of the parameters considered in modern stock assessment models are in reality pseudo-parameters of deviations set with constraints and therefore should not be considered as true parameters, potentially violating the conditions necessary to use AIC for model selection.

In our case to test whether adding the scaling parameter (P) on longline survey catchability to a model provides an improvement we chose to perform a randomization test. There are two ways we propose implementing this method. One method for auto-correlated time series and another for models without significant autocorrelation. In the case where the time series is auto-correlated we propose evaluating the attributes of the time series using an ARMA process and then conducting multiple simulations of a time series of the same length using the ARMA attributes and then fitting the assessment model to the multiple simulated time series. For an independent time series, simple random sampling without replacement of the actual time series can be used to generate multiple new simulated time series of the same length. The assessment model is then refit to the newly generated time series.

In both these cases the repeated fitting of the model to the simulated time series generates a distribution of scaling parameters. If the catchability parameter does not have a constraining prior or is not fixed the distribution of the scaling parameter should be centered on 0. In assessment models where the main parameter (Q in this case) has a constraining prior or at the extreme is fixed, the scaling parameter will not be centered on 0, but rather will be centered on the difference between the constrained parameter and its estimate had it been unconstrained. A two-tailed test to determine the significance of the parameter is derived by calculating the number of scaling parameters that exceed the absolute value obtained when fitting to the "true" index. This value would be a non-parametric P-value which can be assessed against a previously determined α.

This type of resampling method shares many similarities to Monte Carlo simulations. We generate a large number of simulated samples from the original CFSR temperature index. Here we begin with the assumption that there is some population data generating process (DGP) that produced the CFSR index, but this process remains unobserved. Now, we draw a new "sample" of data that consists of a different mix of the cases in the original sample and repeat this many times so that we have a lot of new simulated "samples." The fundamental assumption is that all information about the DGP contained in the original sample of data is also contained in the distribution of these simulated samples, except their order. If so, then resampling from the one sample we have is equivalent to generating completely new random samples from the population of data generated by the DGP, but in a random order. Therefore how extreme the scaling parameter is in comparison with the simulated distribution is a measure of how much the order of the measurements drive the initial scaling parameter estimate and how well changes in catchability are explained by changes in the CFSR index as filtered through all the other assumptions of the assessment model.

For this test the CFSR index was tested for autocorrelation using an autocorrelation function with α =0.05. No significant autocorrelation was detected in this index and therefore we chose to use the simple randomization approach (Fig. 8).

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

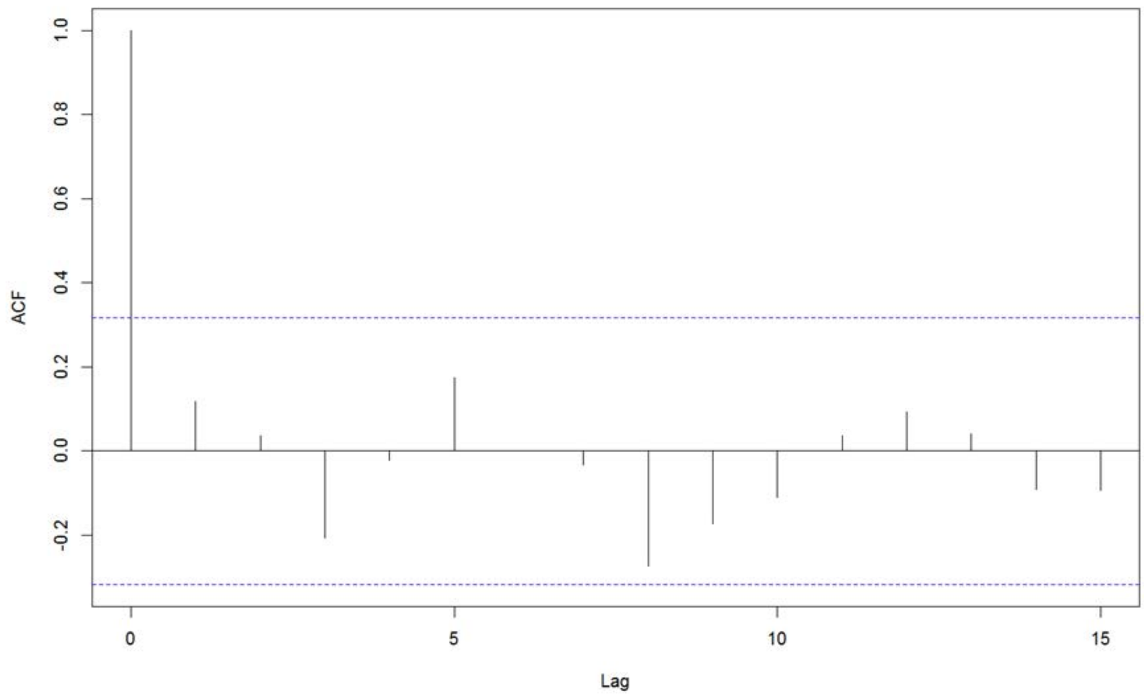


Figure 8. ACF of the CFSR time series of bottom temperature for the mean depth of 10 cm Pacific cod.

Results

We resampled the CFSR index 999 times generating 999 simulations (Fig. 9) and chose α=0.05. The model was rerun on each simulation generating a relatively normal distribution (Fig. 10) with a mean of -0.005 and standard deviation of 0.129. The distribution of the scaling factor exceeded the estimated scaling factor parameter in 12 of the 999 simulations generating a P-value of 0.012 or 1.2% (Fig. 11). This suggests that a mode which includes scaling the longline catchability by the CFSR index is an improvement over a model naïve to bottom temperature.

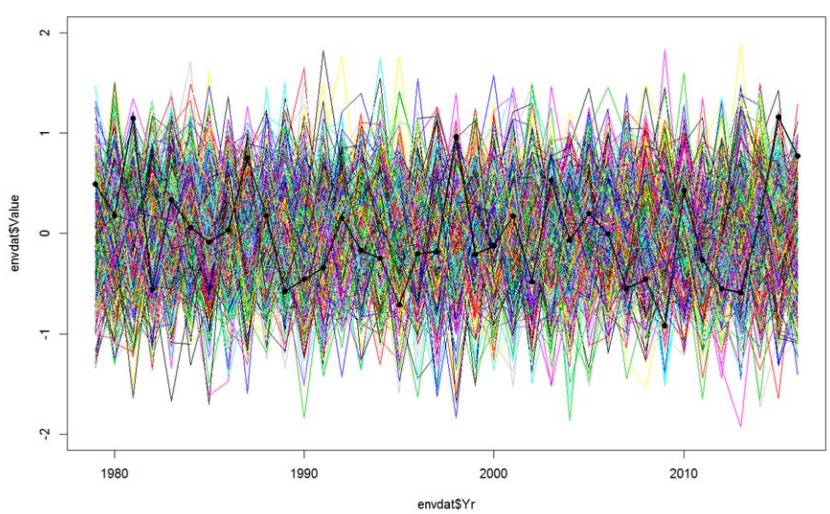


Figure 9. 1000 resamples of the CFSR index of bottom temperature for 10 cm Pacific cod.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

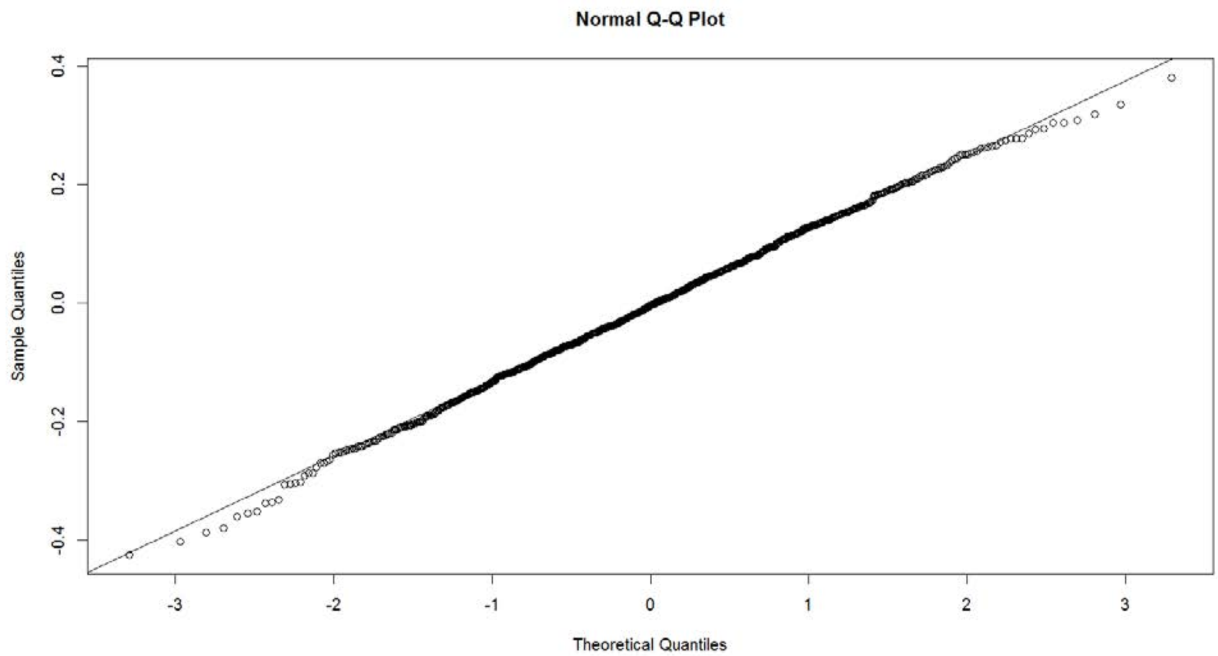


Figure 10. QQplot of AFSC longline survey catchability scaling parameter from the resampled CFSR index.

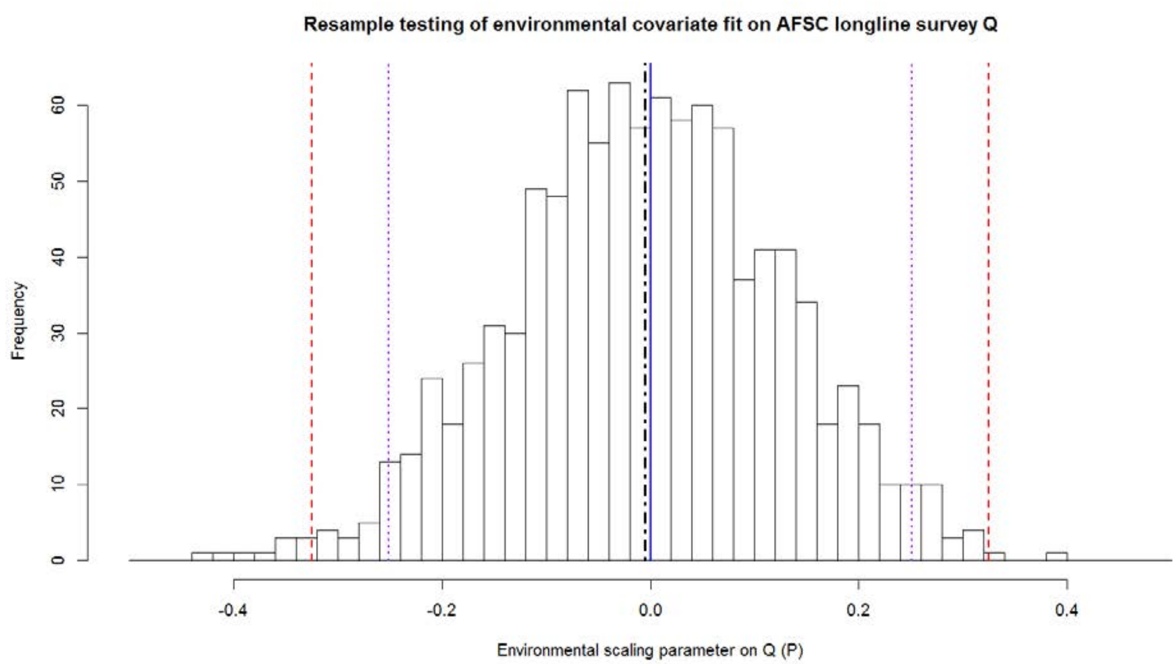


Figure 11. Distribution of the AFSC longline survey catchability scaling parameter from the resampled CFSR index showing the absolute value of the scaling parameter from the fit to the true CFSR index (red dashed line), the 95% confidence interval (purple dotted line), the mean of the distribution (blue dot-dashed line) and 0.00 (black solid line).

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

Post-CIE models for management consideration

The difference in the models considered following the review dealt with transitioning to the latest version of SS3.30 which is planned for the analysis in the 2018 SAFE report chapter. Seven models are planned including ones with length-based maturity, aging bias within the model, removal of pre-2007 age data, removal of all age data, changing the prior on M, and using a prior on the growth parameters based on 2007-2015 AFSC trawl survey length at age data.

Model	Data	SS version	Maturity	Aging bias	Marine heatwave index for M	Prior CV on M	VB prior (l_{inf}/K)
17.09.35	Same as 2017	2.24	Age-based			0.10	Uniform
17.09.35	Same as 2017	3.30	Age-based			0.10	Uniform
18.09.38	Same as 2017	3.30	Length-based			0.10	Uniform
18.09.45	Same as 2017	3.30	Length-based	✓		0.10	Uniform
18.10.38	No age data pre-2007	3.30	Length-based			0.10	Uniform
18.10.43	No age data pre-2007	3.30	Length-based		✓	0.10	Uniform
18.10.44	No age data pre-2007	3.30	Length-based			0.41	Normal 99.46/0.197
18.10.46	No age data pre-2007	3.30	Length-based		✓	0.41	Normal 99.46/0.197
18.11.38	No age data	3.30	Length-based			0.10	Normal 99.46/0.197

	Model 17.09.35	Model 18.09.35/38	Model 18.09.45	Model 18.10.38	Model 18.10.43	Model 18.10.44	Model 18.10.46	Model 18.11.38
Parameters	202	202	202	202	202	202	202	202
Likelihood								
TOTAL	1560.06	1451.71	1659.67	1061.42	1058.57	1047.91	1063.17	877.95
Survey	1.01	-4.05	-12.02	-11.64	-15.51	-16.67	-16.30	-15.73
Length_comp	1006.30	1004.82	1009.44	989.15	986.72	985.27	988.37	978.69
Age_comp	540.44	539.79	759.29	173.53	190.87	176.33	193.62	0.00
Parm_priors	11.68	11.92	2.01	8.33	1.42	2.29	0.36	8.86
Results								
R_0 millions	531.16	562.55	561.64	421.30	947.81	629.01	743.80	392.58
NatM	0.490	0.498	0.431	0.459	0.527	0.485	0.486	0.444
NatM 2015-2016	0.714	0.715	1.011	0.668	NA	0.983	NA	0.673
NatM MHV parameter	NA	NA	NA	NA	0.00185	NA	0.00183	NA
AFSC survey q	1.381	1.341	1.100	1.316	0.979	1.080	0.968	1.146
L_{inf}	124.06	123.93	101.21	105.89	108.95	99.46	99.46	99.46
VonBert K	0.113	0.114	0.142	0.154	0.148	0.170	0.172	0.175
SSB_0 (1,000 t)	177.38	176.52/160.54	208.42	173.37	238.03	202.77	244.39	189.90
Bratio 2017	0.267	0.264/0.235	0.197	0.235	0.197	0.215	0.194	0.250
SPRratio 2016	0.769	0.778/0.856	0.459	0.855	0.503	0.523	0.516	0.785

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

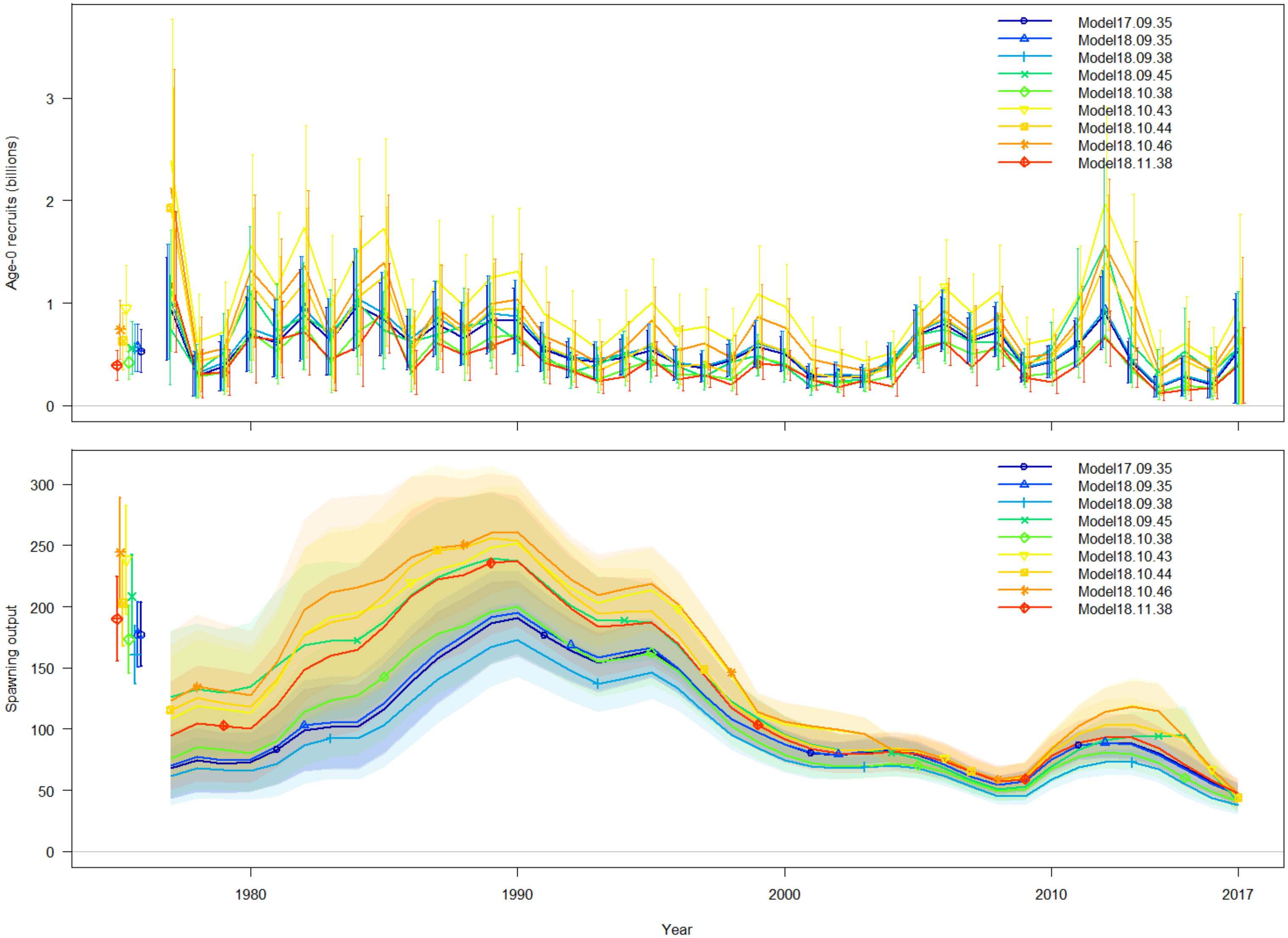


Figure 12. (Top) Age-0 recruits in billions and (bottom) female spawning biomass in thousands of tons for the 2017 reference and all new 2018 models.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

Table 2. Likelihoods by fleet for all models. Red indicates highest likelihood for the likelihood component while green is lowest. Likelihoods for the age components are not comparable among models.

Label	ALL	FshTrawl	FshLL	FshPot	Srv	LLSrv	MODEL
Age_like	540.44				540.44		Model17.09.35
Age_like	539.79				539.79		Model18.09.35/38
Age_like	759.29				759.29		Model18.09.45
Age_like	173.53				173.53		Model18.10.38
Age_like	190.87				190.87		Model18.10.43
Age_like	176.33				176.33		Model18.10.44
Age_like	193.62				193.62		Model18.10.46
Age_like	0.00				0.00		Model18.11.38
Catch_like	3.93E-10	1.23E-10	1.39E-10	1.32E-10			Model17.09.35
Catch_like	4.10E-10	1.27E-10	1.46E-10	1.37E-10			Model18.09.35/38
Catch_like	1.05E-11	3.24E-12	3.56E-12	3.68E-12			Model18.09.45
Catch_like	5.84E-11	1.87E-11	2.08E-11	1.89E-11			Model18.10.38
Catch_like	8.33E-13	2.67E-13	2.75E-13	2.91E-13			Model18.10.43
Catch_like	1.25E-12	4.35E-13	4.11E-13	4.07E-13			Model18.10.44
Catch_like	6.46E-13	2.06E-13	2.13E-13	2.27E-13			Model18.10.46
Catch_like	5.39E-12	1.73E-12	1.89E-12	1.77E-12			Model18.11.38
Length_like	1006.30	274.14	200.95	207.83	132.97	190.41	Model17.09.35
Length_like	1004.82	273.96	199.80	207.68	133.00	190.38	Model18.09.35/38
Length_like	1009.44	276.65	200.70	205.58	139.16	187.35	Model18.09.45
Length_like	989.15	266.71	199.35	206.41	131.61	185.07	Model18.10.38
Length_like	986.72	268.02	197.25	207.40	130.36	183.69	Model18.10.43
Length_like	985.27	267.93	198.31	204.46	132.85	181.72	Model18.10.44
Length_like	988.37	269.69	198.16	206.06	131.71	182.75	Model18.10.46
Length_like	978.69	269.82	200.29	203.46	124.75	180.38	Model18.11.38
Surv_like	1.01				0.57	0.44	Model17.09.35
Surv_like	-4.05				0.50	-4.55	Model18.09.35/38
Surv_like	-12.02				-1.57	-10.45	Model18.09.45
Surv_like	-11.64				-1.88	-9.76	Model18.10.38
Surv_like	-15.51				-5.42	-10.09	Model18.10.43
Surv_like	-16.67				-5.56	-11.11	Model18.10.44
Surv_like	-16.30				-5.11	-11.18	Model18.10.46
Surv_like	-15.73				-3.15	-12.58	Model18.11.38

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

Model18.09.35

This model is the same as Model17.09.35 except it has been implemented in SS V3.30. The results show a slight difference in model results. Differences in overall likelihood are due to how the two model versions handle annual selectivity deviates and not large differences in model fit. The differences in the annual selectivity deviate configuration has caused minor changes in the trawl and longline fishery selectivities for 1977-1989.

Likelihood component	Model 17.09.35	Model 18.09.35	Model 18.09.38		Summary Parameters/results	Model 17.09.35	Model 18.09.35	Model 18.09.38
TOTAL	1560.06	1451.71	1451.71					
Catch	3.93E-10	4.10E-10	4.10E-10		Recr_Virgin_millions	531.163	562.549	562.549
Equil_catch	1.65E-03	1.42E-03	1.42E-03		LN(R0)	13.1828	13.2402	13.2402
Survey	1.01	-4.05	-4.05		NatM	0.490292	0.498182	0.498182
Length_comp	1006.30	1004.82	1004.82		NatM 2015-2016	0.714160	0.715361	0.715361
Age_comp	540.44	539.79	539.79		L_{inf}	124.064	123.925	123.925
Recruitment	-7.28	-7.41	-7.41		VonBert K	0.113425	0.113662	0.113662
Forecast_Recruitment	3.09	3.18	3.18		SSB_Virgin_thousand_mt	177.3805	176.8190	160.539
Parm_priors	11.68	11.92	11.92		Bratio 2017	0.266542	0.264378	0.234918
Parm_softbounds	2.13E-02	2.23E-02	2.23E-02		SPRratio 2016	0.769416	0.778445	0.855893
Parm_devs	4.81	-96.58	-96.58					

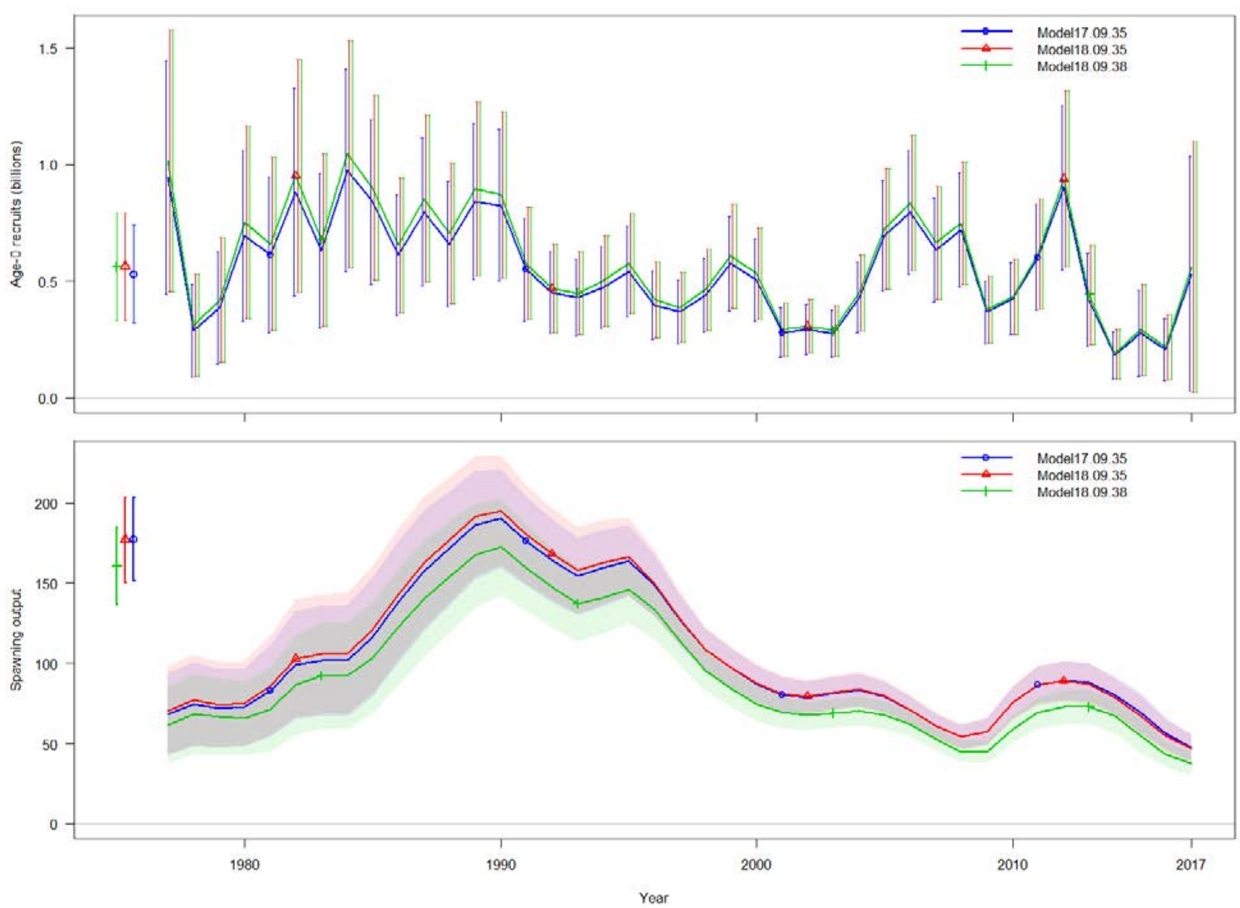


Figure 13. (Left) Age 0 recruits in billions and female spawning biomass in thousands of tons from Model 17.09.35, Model 18.09.35, and Model 18.09.38.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

Model18.09.38

This model is the same as Model18.09.35 except maturity is length-based instead of age-based as presented during the CIE review. The change from age-based to length-based maturity made no difference in the model fit or total biomass estimates. It did however decrease the estimates of spawning biomass as the size at maturity was larger than expected under the estimated age-at-maturity.

Model18.10.38

This model is the same as Model18.09.38 except all age data read before 2007 are excluded from the data. This model differs from Model17.09.39 presented at the CIE review in that it has now been implemented in SS v3.30. The pre-2007 data were removed from the model due to aging bias observed in these data. Removing these data, as expected, improves the fit to both the survey indices and length composition data. L_{inf} decreases and the von Bertalanffy K increases, the generic natural mortality decreases as well as natural mortality for the 2015-2016 time block. Because of the change in natural mortality and growth overall recruitment drops, however the overall recruitment trend remains very similar (except for 1984 and 1985 which appear to exchange prominence). Also because of the change in growth and natural mortality estimates of female spawning biomass overall are slightly higher in Model 18.10.38 with the difference greater in years prior to 2000. It should be noted that in all models the uncertainty in the biomass estimates are higher prior to 2000. The retrospective (Fig. 15) remains about the same as last year's model with a Mohn's rho of 0.09

Likelihood component	**Model 18.09.38**	**Model 18.10.38**	**Model 18.11.38**		**Summary Parameters/results**	**Model 18.09.38**	**Model 18.10.38**	**Model 18.11.38**
TOTAL	1451.71	1061.42	877.95					
Catch	4.10E-10	5.84E-11	5.39E-12		**Recr_Virgin_millions**	562.549	421.299	392.577
Equil_catch	1.42E-03	9.10E-04	5.21E-04		**LN(R0)**	13.2402	12.9511	12.8805
Survey	-4.05	-11.64	-15.73		**NatM**	0.498182	0.459117	0.444331
Length_comp	1004.82	989.15	978.69		**NatM 2015-2016**	0.715361	0.668266	0.673349
Age_comp	539.79	173.53	0.00		**L_{inf}**	123.925	105.892	99.46
Recruitment	-7.41	-5.14	-2.15		**VonBert K**	0.113662	0.153856	0.174615
Forecast_Recruitment	3.18	3.33	3.75		**SSB_Virgin_thousand_mt**	176.8190	173.3715	189.9045
Parm_priors	11.92	8.33	8.86		**Bratio 2017**	0.264378	0.235378	0.250488
Parm_softbounds	2.23E-02	2.00E-02	1.88E-02		**SPRratio 2016**	0.778445	0.854948	0.784996
Parm_devs	-96.58	-96.15	-95.48					

Model 18.11.38

This model is the same as Model 18.10.38 except all age data has been removed and the growth parameter priors were parameterized based on a regression of the 2007-2015 AFSC trawl survey length-at-age data. The model shows a better fit to both surveys over Model 18.09.38 and Model 18.10.38 as all age data were removed. Overall length composition data fits were better. The improvements to the length composition data were within the pot fishery and the two surveys. Natural mortality is lower in this model than the two similar models with age data. This suggests a conflict in the age data and the other data sources.

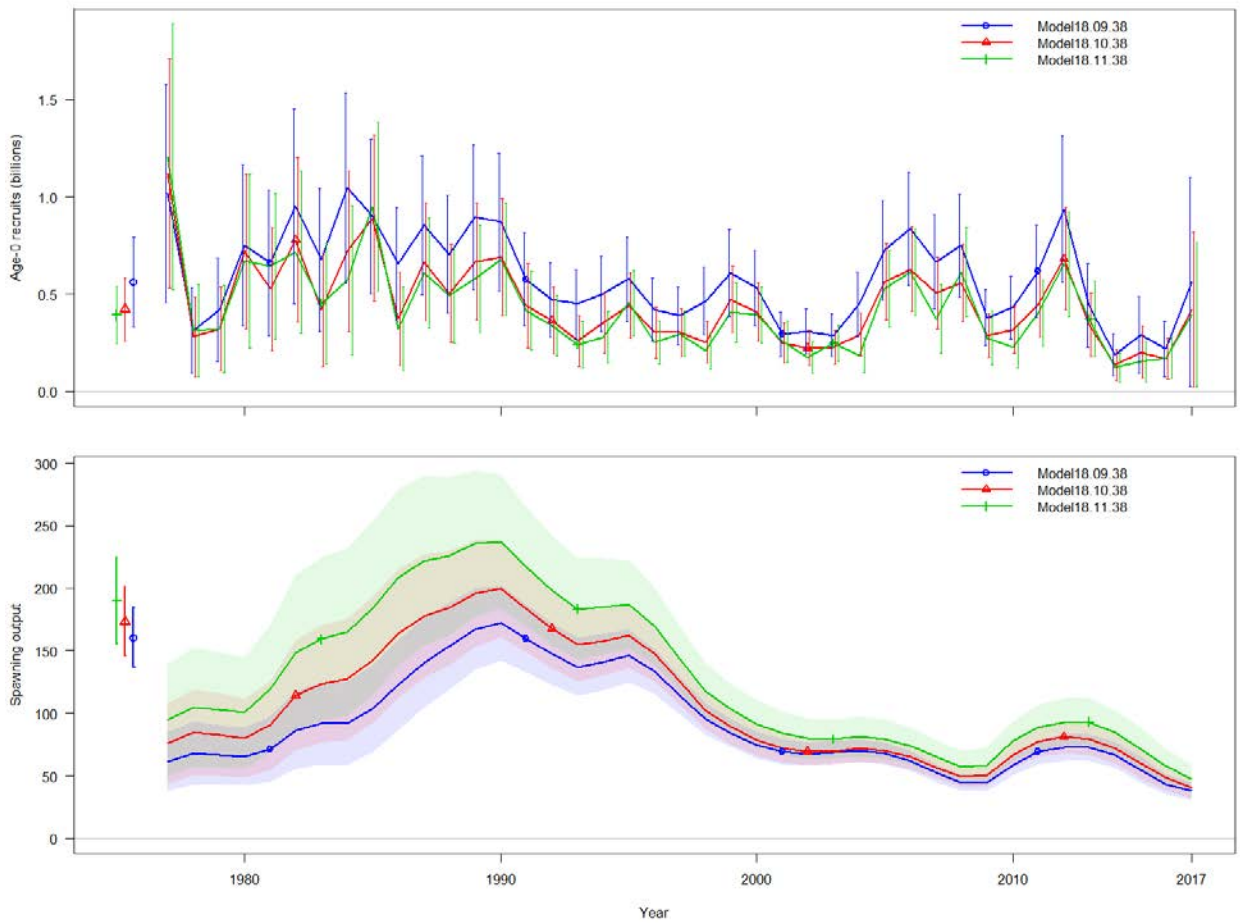


Figure 14. (Top) Age-0 recruits in billions and (bottom) female spawning biomass in thousands of tons for Model 18.09.38, Model 18.10.38, and Model 18.11.38.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

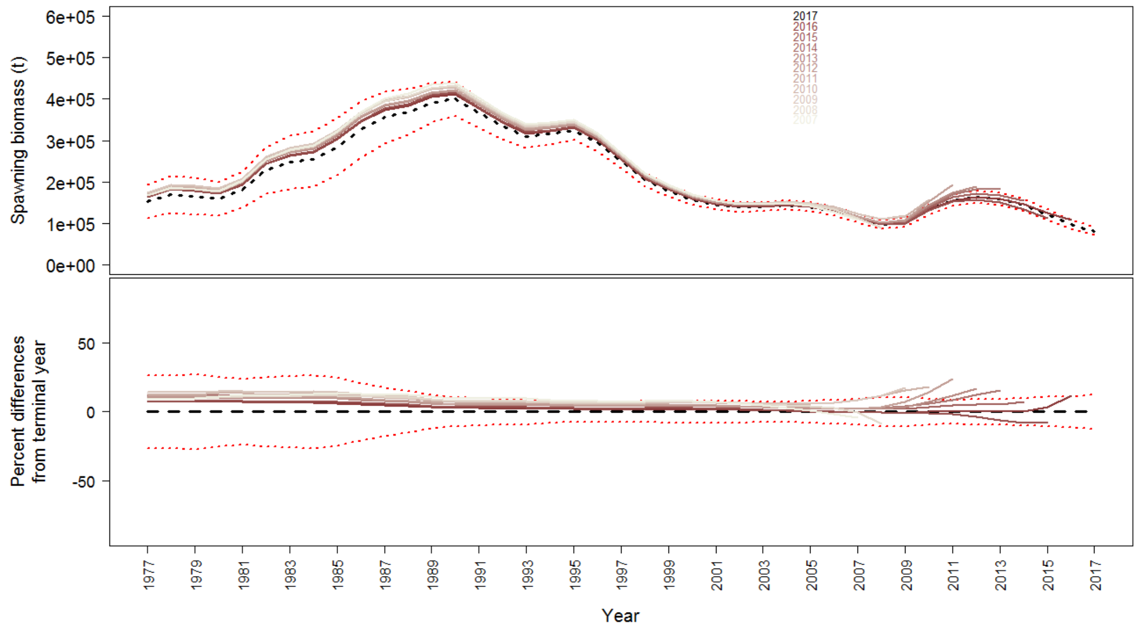


Figure 15. Retrospective analysis on female spawning biomass for Model 18.10.38.

Model 18.10.43

This model is the same as Model18.10.38 except instead of a separate natural mortality block for 2015-2016, a uniform parameter is used to scale natural mortality with a Central GOA winter marine heatwave index. The daily sea surface temperatures for 1981 through June 2018 were retrieved from the NOAA High-resolution Blended Analysis Data database (Reynolds et al. 2007) and filtered to only include data from the central Gulf of Alaska between 145°W and 160°W longitude for waters less than 300m in depth. The overall daily mean sea surface temperature was then calculated for the entire region. The daily mean sea surface temperatures were processed through the R package heatwaveR (Schlegel and Smit 2018) to obtain the marine heatwave cumulative intensity (MHWCI; Hobday et al. 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the 1 January 1983 through 31 December 2012 time series. The MHWCI were summed for each year to create an annual index of MHWCI (Fig.16) and summed for each year for the months of January through March, November, and December to create an annual winter index of MHWCI.

Overall the introduction of the heatwave index improves the fit to all but the conditional length at age data. The increase in natural mortality in this model for 2014-2016 is substantial and for all ages. This requires the model to increase recruitment (Fig. 17) in previous years (2006-2011) that doesn't match the age data and which cannot be mitigated by changes in growth as there is a narrow prior on the growth parameters in this model. It is likely that mortality during these heat waves may impact younger fish mortality more than older fish., increasing natural mortality across all ages requires the model to compensate by increasing recruitment in previous years which although provides a better fit across most components requires a worse fit to age composition data.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

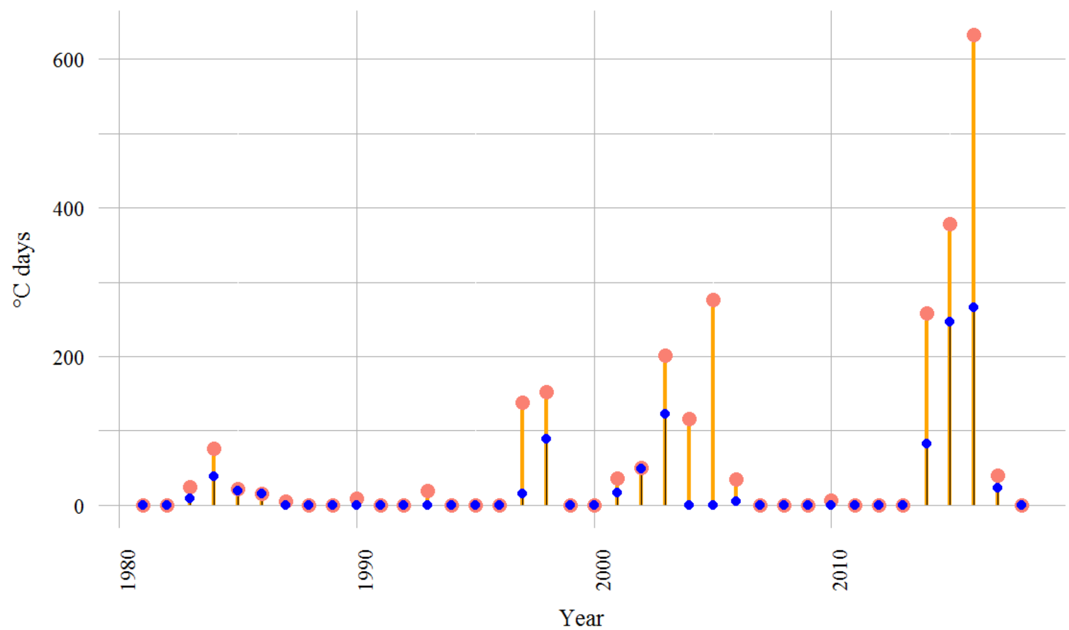


Figure 16. Index of the sum of the annual marine heatwave cumulative intensity (℃ days) for 1981-2018 (larger red points) and index of the sum of the annual winter marine heatwave cumulative intensity for 1981-2018 (smaller blue points) from the daily mean sea surface temperatures NOAA high resolution blended analysis data for the Central Gulf of Alaska. The 2018 index value is the sum through 22 June 2018.

Likelihood component	Model 18.10.38	Model 18.10.43	Model 18.10.44		Summary Parameters/results	Model 18.10.38	Model 18.10.43	Model 18.10.44
TOTAL	1061.42	1058.57	1047.91					
Catch	5.84E-11	8.33E-13	1.25E-12		**Recr_Virgin_millions**	421.299	947.81	629.01
Equil_catch	9.10E-04	2.24E-04	1.99E-04		**LN(R0)**	12.9511	13.76	13.35
Survey	-11.64	-15.51	-16.67		**NatM**	0.459117	0.53	0.49
Length_comp	989.15	986.72	985.27		**NatM 2015-2016**	0.668266		0.98
Age_comp	173.53	190.87	176.33		**NatM MHV parameter**		0.00185	
Recruitment	-5.14	-10.37	-4.89		**L_{inf}**	105.892	108.95	99.46
Forecast_Recruitment	3.33	1.75	1.46		**VonBert K**	0.153856	0.15	0.17
Parm_priors	8.33	1.42	2.29		**SSB_Virgin_thousand_mt**	173.3715	238.03	202.77
Parm_softbounds	2.00E-02	2.03E-02	2.08E-02		**Bratio 2017**	0.235378	0.20	0.21
Parm_devs	-96.15	-96.34	-95.90		**SPRratio 2016**	0.854948	0.50	0.52

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

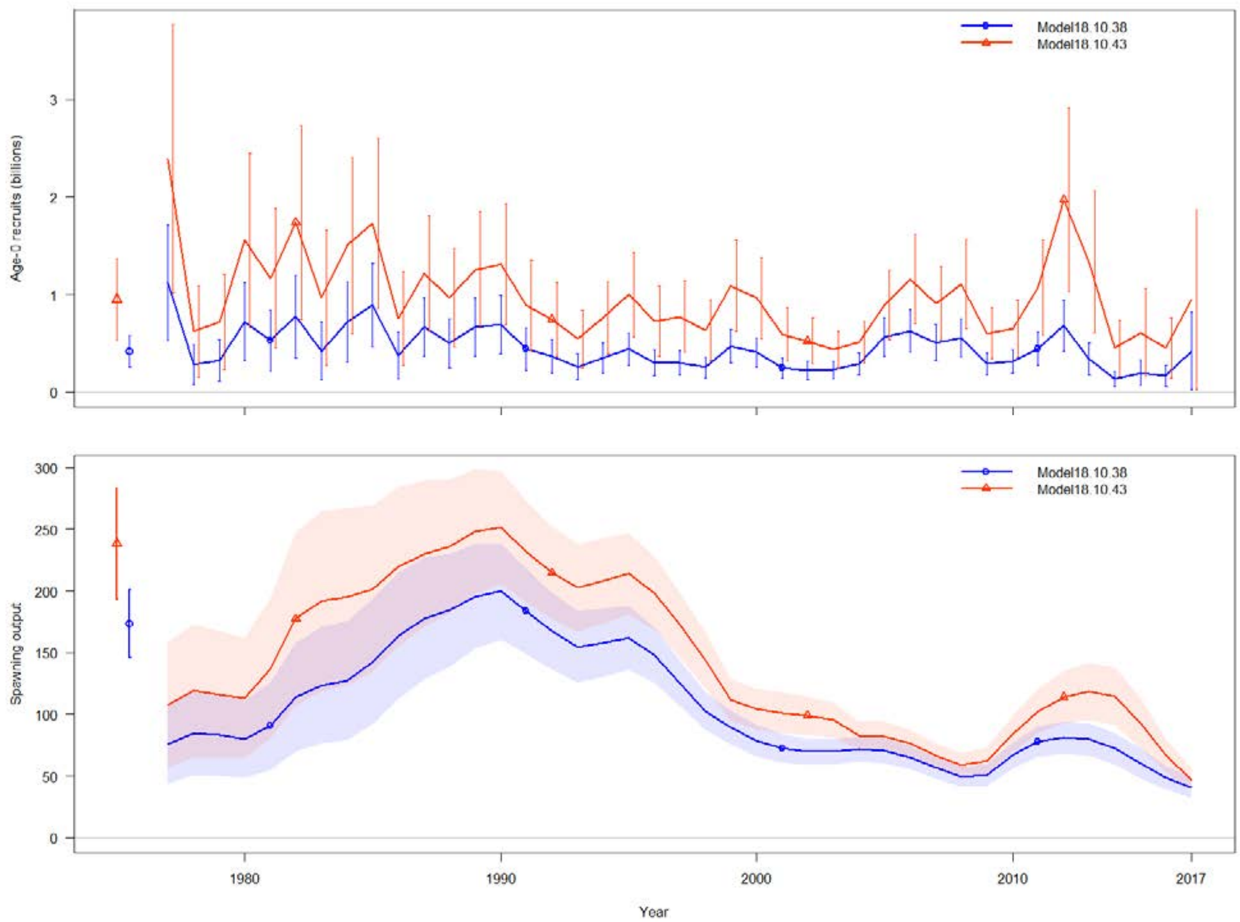


Figure 17. (Top) Age-0 recruits in billions and (bottom) female spawning biomass in thousands of tons for Model 18.10.38, and Model 18.10.43.

Model18.10.44

This model is the same as Model18.10.38 except the CV of the prior on natural mortality is set to 0.41 instead of 0.1 and the growth parameter priors were parameterized based on a regression of the 2007-2015 AFSC trawl survey length-at-age data (Fig. 18). The fits between Model18.10.38 and Model 18.10.44 are close with minor improvements in fits to the survey indices, primarily in the post-2015 data. The fits to the survey and trawl length composition, as well as the survey age composition data were poorer under Model 18.10.44. The largest change between these two models was an increase in natural mortality for both blocks and a decrease in the AFSC trawl survey catchability. This resulted in an overall increase in the estimated biomass (Fig. 19). Like all the models presented the retrospective pattern was minimal with a slight improvement over Model 18.10.38 with a Mohn's rho of 0.06.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

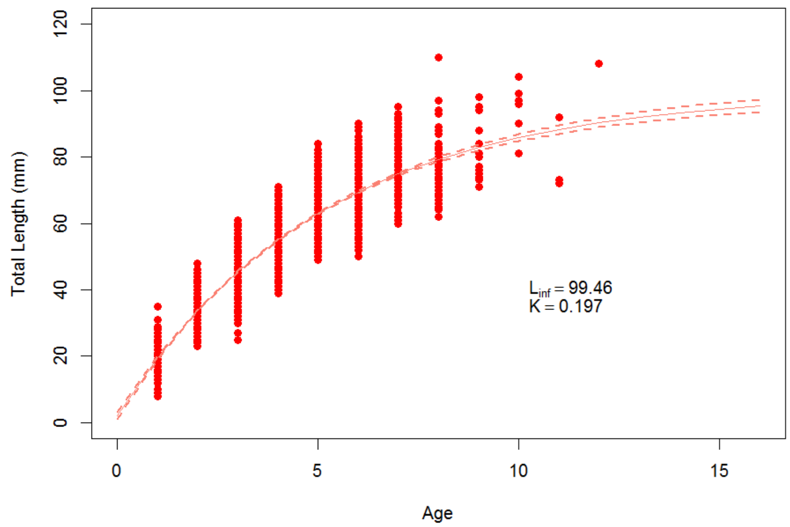


Figure 18. Fit to von Bertalanffy growth model for 2007-2015 length at age data from the AFSC bottom trawl surveys.

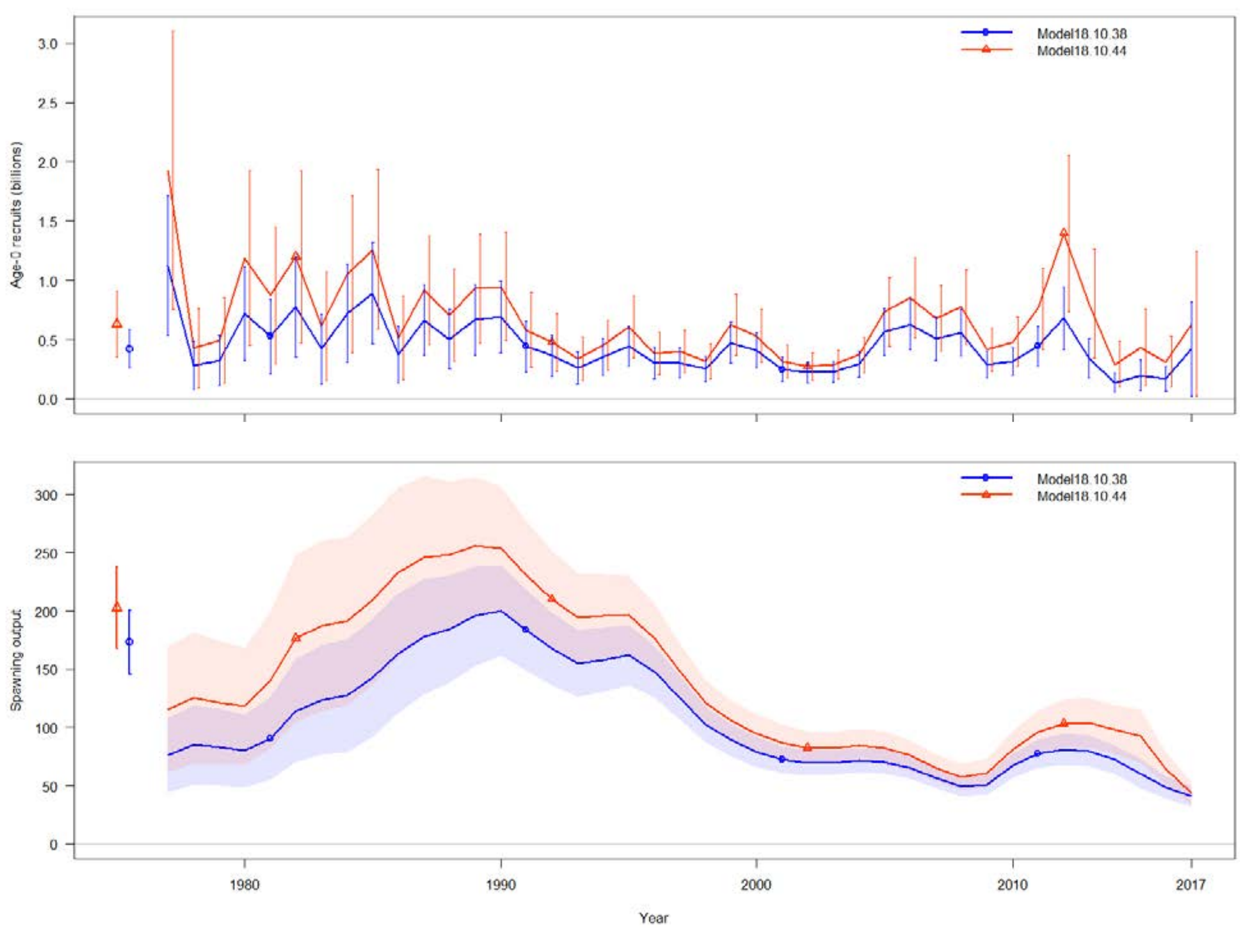


Figure 19. (Top) Age-0 recruits in billions and (bottom) female spawning biomass in thousands of tons for Model 18.10.38, and Model 18.10.44.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

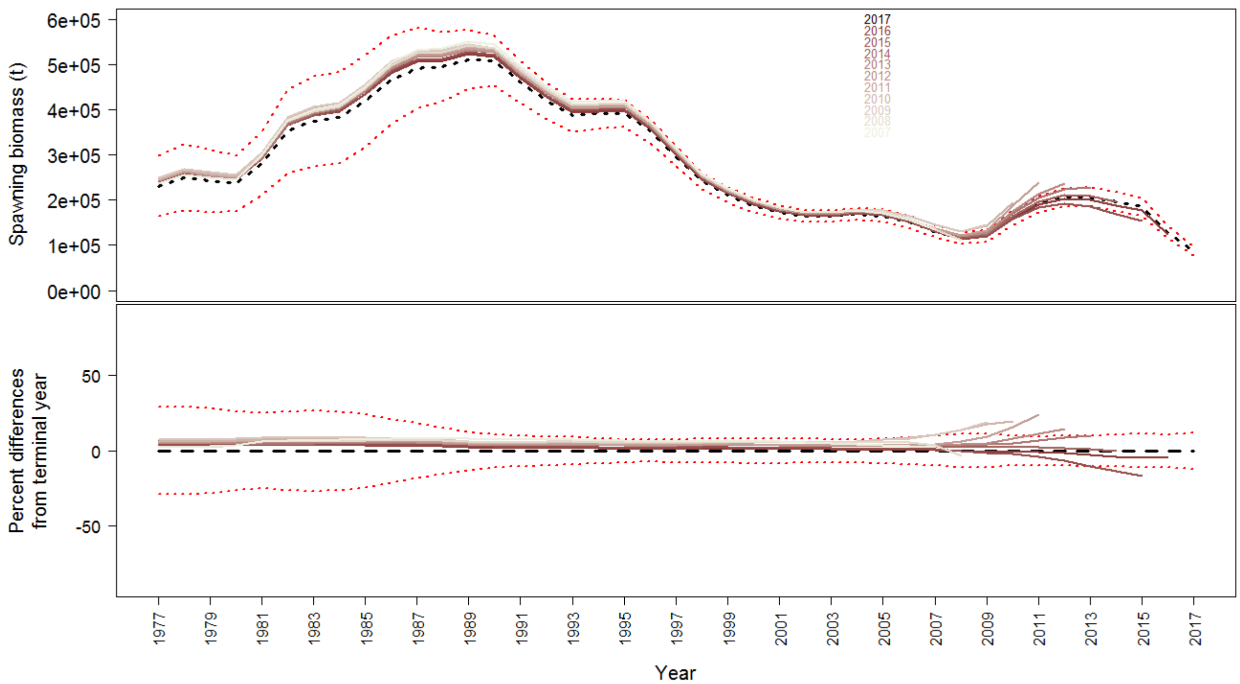


Figure 20. Retrospective analysis on female spawning biomass for Model 18.10.44.

Model18.09.45

This model is the same as Model18.09.38 except aging bias is implemented for age data prior to 2007 and the CV of the prior on natural mortality is set to 0.41 instead of 0.1. The correct specification of aging bias in the model should result in a better fit to the AFSC bottom trawl survey length composition data. However in this model the fit to the AFSC bottom trawl survey data length composition is worse. This suggests the aging bias is mis-specified. The increasing the CV on natural mortality allows natural mortality to increase and therefore the model to fits both surveys better. In addition, catchability for the bottom trawl survey decreased to 0.983 with the increasing natural mortality. Due to the misspecification in the aging bias, this model needs more work and is not yet ready for use in management.

Gulf of Alaska Pacific cod September Plan Team Submission September 18, 2018

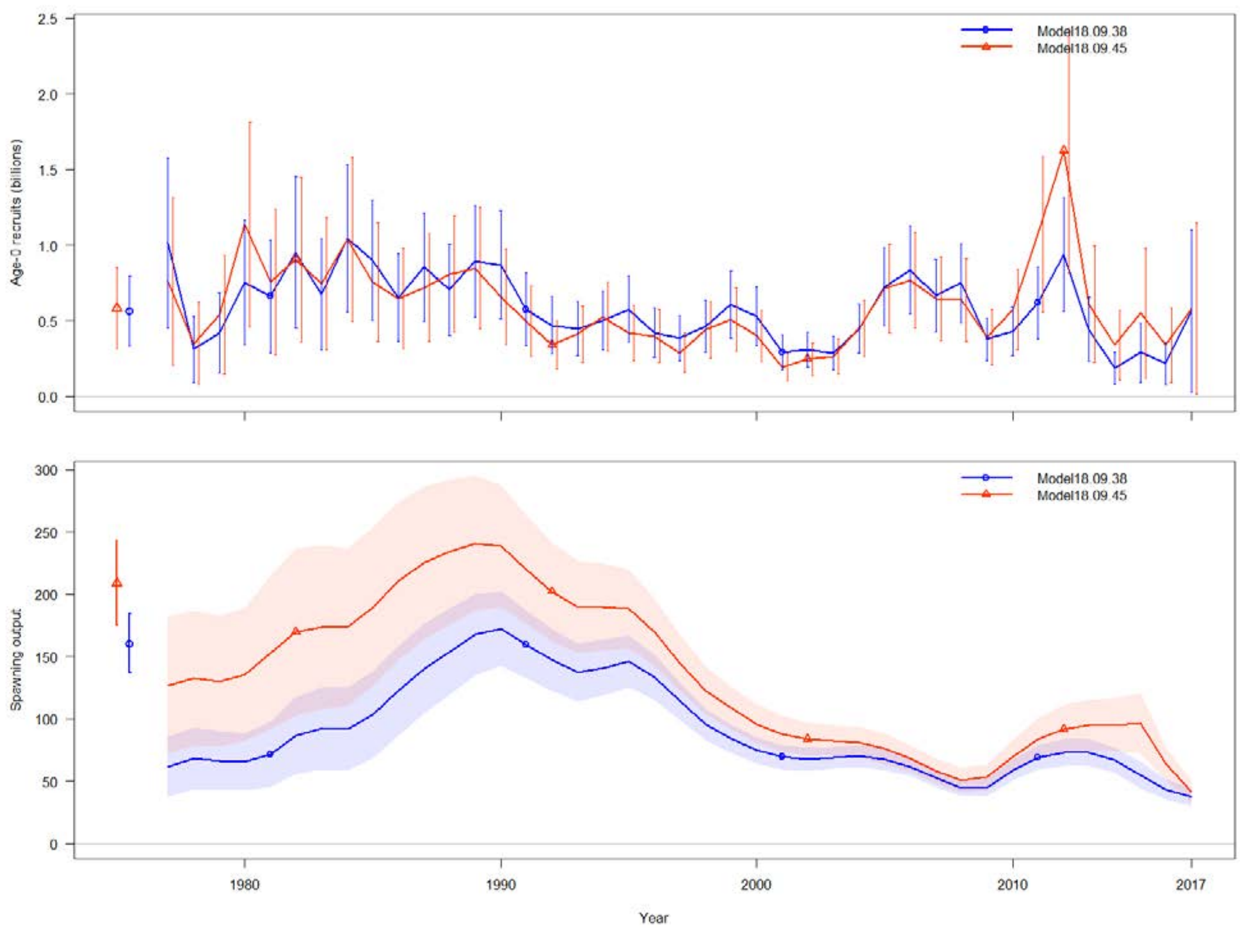


Figure 21. (Top) Age-0 recruits in billions and (bottom) female spawning biomass in thousands of tons for Model 18.10.38, and Model 18.10.44.

Akaike, H. (1998). Information theory and an extension of the maximum likelihood principle. In *Selected Papers of Hirotugu Akaike* (pp. 199-213). Springer, New York, NY.

Bozdogan, H. (1987). Model selection and Akaike's information criterion (AIC): The general theory and its analytical extensions. *Psychometrika*, *52*(3), 345-370.

Hobday, A.J., Alexander, L.V., Perkins, S.E., Smale, D.A., Straub, S.C., Oliver, E.C., Benthuysen, J.A., Burrows, M.T., Donat, M.G., Feng, M. and Holbrook, N.J., 2016. A hierarchical approach to defining marine heatwaves. Progress in Oceanography, (141), pp.227-238.

Reynolds, Richard W., Thomas M. Smith, Chunying Liu, Dudley B. Chelton, Kenneth S. Casey, Michael G. Schlax, 2007: Daily High-Resolution-Blended Analyses for Sea Surface Temperature. J. Climate, 20, 5473-5496. Reynolds, Richard W., Thomas M. Smith, Chunying Liu, Dudley B. Chelton, Kenneth S. Casey, Michael G. Schlax, 2007: Daily High-Resolution-Blended Analyses for Sea Surface Temperature. J. Climate, 20, 5473-5496.

Saha, S., and Coauthors, (2010), The NCEP climate forecast system reanalysis. Bull. Amer. Meteor. Soc., 91, 1015-1057.

Schlegel, R. W. and A. J. Smit. 2018. heatwaveR: Detect heatwaves and cold-spells. R package version 0.3.0. https://CRAN.R-project.org/package=heatwaveR

Torrejon-Magallanes, J. (2017). sizeMat: Estimate Size at Sexual Maturity. R package version 0.3.0. https://CRAN.R-project.org/package=sizeMat

Gulf of Alaska Pacific cod September Plan Team Submission Appendix A: CIE review

CIE Review Documents

Dr. Jean-Jackues Maguire:

https://www.st.nmfs.noaa.gov/Assets/Quality-Assurance/documents/peer-review-reports/2018/2018_07_Maguire_GOA_Pacific_cod.pdf

Dr. Henrick Sparholt:

https://www.st.nmfs.noaa.gov/Assets/Quality-Assurance/documents/peer-review-reports/2018/2018_07_%20Sparholt_GOA_Pacific_cod.pdf

Dr. Kevin Stokes:

https://www.st.nmfs.noaa.gov/Assets/Quality-Assurance/documents/peer-review-reports/2018/2018_07_Stokes_GOA_Pacific_cod.pdf

Gulf of Alaska Pacific cod September Plan Team Submission

Appendix B: CIE review model results

Label	Model16.0	Model16.1	Model16.08.11	Model16.08.23	Model16.08.25	Model16.10.11	Model16.10.20
# Parameters	83	94	332	115	127	332	86
AIC	3639.16	4323.3	3861.98	3919.44	3598.22	2085.04	1690.32
TOTAL_like	1736.58	2067.65	1598.99	1844.72	1672.11	710.52	759.16
Survey_like	61.4847	69.4912	73.9424	43.6485	8.22203	29.14	31.8916
Length_comp_like	1104.69	1376.69	931.659	1220.42	1125.75	281.613	322.602
Age_comp_like	544.726	571.459	565.467	552.724	539.48	399.882	406.651
Parm_priors_like	0	0	0	0	0.509041	0	0
SSB0 millions	216.612	161.442	240.772	218.856	510.507	228.855	222.77
SR_LN(R0)	12.2859	11.9919	12.3916	12.2962	13.1432	12.3408	12.3139
SR_BH_steep	1	1	1	1	1	1	1
M	0.38	0.38	0.38	0.38	0.4809	0.38	0.38
M 2015-2016	NA	NA	NA	NA	NA	NA	NA
M Kt Age 1	NA	NA	NA	NA	NA	NA	NA
M Kt Age 5	NA	NA	NA	NA	NA	NA	NA
M para	NA	NA	NA	NA	NA	NA	NA
L_at_Amax	113.273	104.534	108.653	109.29	127.586	107.635	99.6111
VonBert_K	0.12874	0.146941	0.140409	0.137141	0.109335	0.141521	0.159732
SSB_t	169.329	121.0035	187.551	168.608	186.2675	175.2125	160.8005
Bratio_2017	0.400298	0.518913	0.343933	0.330637	0.313641	0.317693	0.343372
SPRratio_2016	1.09573	1.07711	1.07651	1.10954	0.99722	1.08781	1.06055
Tuned?	No	No	No	No	No	Francis TA18 Tuned	Francis TA18 Tuned
Data notes	Trawl, longline, and pot fishery composition, and AFSC Trawl survey index< note that these models have been fit with the 2017 data, not what is in the stock assessments. Proportioning of fishery data are per 2017 protocols and addition of 2017 fishery and survey data	Same as 16.0, Add AFSC longline survey index and size composition	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1
Model notes	Fixed M=0.38, Fixed Q=1, Asymtotic selectivity for all but pot fishery	Fixed M=0.38, Fixed Q=1, Asymtotic selectivity for all but pot fishery	Same as Model 16.6.1 except annually varying fishery selectivity all allowed to be dome-shaped	Same as Model 16.08.1 excepth blocked fishery and survey selectivity	Same as Model16.08.23 except M fit with prior of 0.38 cv=0.1, Trawl survey catchability fit with uniform prior	Same as Model 16.08.11	Same as Model 16.1

Gulf of Alaska Pacific cod September Plan Team Submission

Appendix B: CIE review model results

Label	Model16.10.23	Model16.10.25	Model17.09.25	Model17.09.26	Model17.09.31	Model17.09.35	Model17.09.36	Model17.09.37v2
# Parameters	117	127	134	192	195	202	202	203
AIC	1647.454	1608.402	3613.18	3580.68	3580.68	3524.12	2774.7	3502.28
TOTAL_like	706.727	677.201	1672.59	1598.34	1595.34	1560.06	1185.35	1548.14
Survey_like	11.1282	-10.5032	24.84	8.40794	-0.237298	1.00726	2.37867	-3.50705
Length_comp_like	298.522	285.532	1102.86	1047.31	1045.43	1006.3	643.049	1002.2
Age_comp_like	408.723	412.177	547.62	538.336	538.017	540.439	533.997	537.674
Parm_priors_like	0	0.865754	0.00	1.3068	10.0982	11.6759	9.76094	3.46401
SSB0 millions	242.296	647.977	355.93	375.988	501.121	531.163	470.604	673.597
SR_LN(R0)	12.3979	13.3816	12.78	12.8373	13.1246	13.1828	13.0618	13.4204
SR_BH_steep	1	1	1.00	1	1	1	1	1
M	0.38	0.509254	0.44	0.437793	0.483928	0.490292	0.476532	0.75
M 2015-2016	NA	NA	NA	0.902882	0.691736	0.71416	0.688286	NA
M Kt Age 1	NA	NA	NA	NA	NA	NA	NA	0.454498
M Kt Age 5	NA	NA	NA	NA	NA	NA	NA	0.494567
M para	NA	NA	NA	NA	NA	NA	NA	1.03937
L_at_Amax	99.8024	90.0247	1.24E+02	120.828	124.25	124.064	123.977	126.419
VonBert_K	0.15822	0.187201	1.15E-01	0.118628	0.113522	0.113425	0.11338	0.110307
SSB_t	174.233	158.705	1.83E+02	189.691	176.513	177.3805	174.5245	187.5365
Bratio_2017	0.306313	0.401076	2.74E-01	0.216972	0.266759	0.266542	0.253802	0.250151
SPRratio_2016	1.08193	0.834801	1.09E+00	0.609787	0.797406	0.769416	0.823987	1.00354
Tuned?	Francis TA18 Tuned	Francis TA18 Tuned	No	No	No	No	Francis TA18 Tuned	No
Data notes	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1	Same as Model 16.1
Model notes	Same as Model 16.08.23	Same as Model 16.08.25	Same as Model 16.08.25 except selectivity for all fisheries and surveys allowed to be dome-shaped	Same as Model 17.08.25 except for block on M for 2015-2016 and Selectivity for fisheries allowed to vary annually with CV 0.2 of interannual devs	Same as Model 17.09.26 except Longline catchability fit with covariate on temperature and M prior cv = 0.1	Same as Model 17.09.31 except block on Longline and trawl fishery selectivity for 2005-2006	Same as Model 17.09.35	Same as Model 17.09.35 except annually and age varying M

Gulf of Alaska Pacific cod September Plan Team Submission

Appendix B: CIE review model results

Label	Model18.09.38LM	Model18.09.39NO_AGEPRE2007	Model18.09.40NO_AGE	Model18.09.41_bias	Model18.09.42_biasSTATE
Number of Parameters	202	202	202	201	207
AIC	3524.12	2742.36	2374.374	4314.9	4917.72
TOTAL_like	1560.06	1169.18	985.187	1956.45	2251.86
Survey_like	1.00726	-9.2501	-10.9703	-6.86513	24.4275
Length_comp_like	1006.3	986.256	980.755	1005.94	1251.62
Age_comp_like	540.439	190.704	0	947.201	963.18
Parm_priors_like	11.6759	2.28509	8.97933	7.44393	13.6833
Recr_Virgin_millions	531.163	847.751	366.546	399.818	537.581
SR_LN(R0)	13.1828	13.6503	12.8119	12.8988	13.1948
SR_BH_steep	1	1	1	1	1
Natural Mortality	0.490292	0.539888	0.444227	0.463675	0.48477
Natural Mortality for 2015-2016 Block	0.71416	1.04587	0.679619	0.654238	0.750296
Natural Mortality Knot Age 1	NA	NA	NA	NA	NA
Natural Mortality Knot Age 5	NA	NA	NA	NA	NA
Natural Mortality scaling parameter	NA	NA	NA	NA	NA
L_at_Amax	124.064	110.861	102.076	99.816	99.816
VonBert_K	0.113425	0.143415	0.168963	0.182506	0.188957
SSB_Virgin_thousand_mt	161.3825	194.2345	183.813	173.523	198.2405
Bratio_2017	0.237174	0.220957	0.245129	0.247745	0.245543
SPRratio_2016	0.846562	0.506212	0.802274	0.857974	0.738271
Tuned?	No	No	No	No	No
Data notes	Same as Model 16.1	Same as Model 16.1 except no age data pre-2007	Same as Model 16.1 except no age data	Same as Model 16.1	Same as Model 16.1 except ADFG Western Large Mesh survey Index and length composition added
Model notes	Model17.09.35 but with L50 instead of M50 for maturity	Same as Model18.09.38 except sd on the M prior was changed from 0.1 to 0.41 for both Ms	Same as Model18.09.39	Same as Model18.09.39 but with aging error and bias added for age Pre-2007	Same as Model18.09.41
General notes on new models		Substantial improvement to index and length composition fits with removal of old ages, suggest some disagreement among data sources. M fit better in this model so I loosened the assumptions on the prior	Similar to Model18.09.39, except only slight improvement with the removal of the 2007 and newer ages.	Appears to have improved fit to indices, but didn't improve fits to length composition.	Adding state data seems to show disagreement between that and other data. Recruitment changes, but doesn't improve model to include these data.

Gulf of Alaska Pacific cod September Plan Team Submission

Appendix B: CIE review model results