Aleutian Islands Pacific cod assessment models September 2021

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Introduction

Several age-structured models have been developed and presented to the BSAI Plan Team since 2012. Four models presented to the September 2021 Plan Team meeting examined sensitivity to natural mortality (M), maturity, and fishery length data (Table 1). In addition, the Tier 5 model will be presented in November 2021, which has been used for the AI cod assessment since 2013. The model and data start in 1991 and run through 2021. A two-fishery model was explored but not presented. This model may be examined following acceptance of a single fishery model.

Data Weighting

Data weighting for age composition data was important because there was some conflict between the survey biomass estimates and the age composition data (Figure 1). The AFSC/NMFS survey catches smaller, younger fish than the fishery. Furthermore, the fishery takes place primarily during spawning season; 81% of fishery catch between 1991-2021 took place during January – April, whereas the survey occurs during summer months.

Weighting age composition data was explored using the methods of McAllister and Ianelli (2007). Statistical data weighting for fishery length likelihoods resulted in unreasonably high weights. Higher age composition likelihood weights decreased survey catchability and reduced biomass estimates. Rather than weight likelihoods, we used weights associated with sample collections to inform compositional data weighting, following Stewart and Monnahan (2017). The annual fishery length composition sample sizes were set to the number of fish lengthed annually, to retain the variability in sample size, and weighted so that the mean was 10. Weights for survey age composition data were set to the number of hauls from which aged collections were taken in each year.

Model 19.0 Basic model

Model 19.0 had the following features:

- One fishery, one gear type, one season per year (single sex).
- External estimation of a single growth curve (vonBertalanffy) for length at age, weight at age.
- Internal estimation of fishing mortality, catchability, and selectivity parameters.
- All parameters constant over time except for recruitment and fishing mortality.
- Recruitment estimated as a mean with lognormally distributed deviations.
- An ageing error matrix for ages 1 through 10+.
- Logistic age-based selectivity for both the fishery and survey.
- Natural mortality was fixed in the basic model using M=0.34 for consistency with previous Aleutian Islands Pacific cod assessments.
- Survey catchability estimated within the model relative to fishery selectivity (fishery catchability fixed at 1).
- Maturity at age in the basic model was estimated using observer data. This is consistent with the Gulf of Alaska Pacific cod assessment.
- Fishery length frequencies were weighted by the relative catch by year in the three NMFS areas (541, 542, and 543).

Model 19.0a Sensitivity to natural mortality

A value of 0.34 was used for the natural mortality rate *M* in all BSAI Pacific cod stock assessments from 2007 (Thompson et al. 2007) through 2015, and replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006 (Thompson et al. 2018). A natural mortality estimate of 0.34 was used in the most recent Aleutian Islands Pacific cod assessment. This value was based on Equation 7 of Jensen (1996) and an age at 50% maturity of 4.9 years (Stark 2007). Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for *M* extends from about 0.30 to 0.38. In proposed models for 2021, EBS natural mortality ranges from 0.309 (Model 21.1) to 0.348 (Model 19.12a). For the Gulf of Alaska, a base natural mortality of 0.47 (SD = 0.41) was proposed for the 2021 model.

A range of natural mortality values were explored using a likelihood profile on the Aleutian Islands cod model on natural mortality values from 0.1 to 0.9. The natural mortality likelihood profile showed some contrast in the results; the fishery length likelihood indicated that the lowest negative log likelihood occurred at *M* = 0.3, whereas the other negative log likelihood components (survey age, survey biomass, and recruitment) were minimized at *M* = 0.8. However, these negative log likelihoods decreased quickly until *M* = 0.3 and remained shallow thereafter (Figure 2). The estimate for Aleutian Islands Pacific cod was 0.36 based on The Barefoot Ecologist tool for estimating natural mortality (Figure 3). To balance the different likelihood components and consider the values for *M* used in other assessments, the value *M* = 0.4 was considered a good starting point. This value also represents the mode of previous estimates (Table 2).

The Plan Team and SSC have expressed concerns over the practice of equating the AI estimate of M with the EBS estimate; therefore a more suitable estimator was examined. The basic model (Model 19.0) and Models 19.0b, 19.0c, as well as the 2020 Tier 5 model used *M* = 0.34. Model 19.0a explored the use of *M* = 0.4.

Model 19.0b Sensitivity to maturity

The maturity-at-age is governed by the relationship:

$Maturity_{age} = \frac{1}{1+e^{-(A+B*age)}}$, where A and B are parameters in the relationship.

A study based on a collection of 129 female fish in February, 2003, from the Unimak Pass area, NMFS area 509, found that 50% of female fish become mature at approximately 4.88 years ($L_{50\%}$) and 58.0 cm, *A* = -4.7143, *B* = 0.9654 (i.e. Tables 2 and 4 in Stark 2007). This maturity ogive is used in the Bering Sea Pacific cod assessment but may not be appropriate for the Aleutian Islands age structured model, because the fish in the sample were not from the Aleutian Islands.

An alternative maturity curve was developed based on observer records of maturity from the Aleutian Islands. This model may be advantageous because it is based on more records and on cod taken from the Aleutian Islands. Observers routinely collect maturity at length from Pacific cod. There are 1,331 records from the Aleutian Islands (Table 3) during the months January – March since 2008. These were used to estimate a maturity ogive by length using the R package *sizeMat*, which estimates the length of fish at gonad maturity. Maturity was considered a binomial response variable and variables were fitted to the logistic function above for maturity, and the length at which 50% of cod are mature is $L_{50\%} = -A/B$. The formula used to fit proportion mature by length was

$$Maturity_{length} = \frac{1}{1+e^{-(A+B*length)}},$$

and the resulting parameters were *A* = -8.0847and *B* = 0.1472. This ogive provided maturity at length which was converted to maturity at age using the length age conversion matrix. The resulting ogive had

$L_{50\%}$, slightly lower than the Stark (2007) estimate. $L_{50\%}$ was estimated to be 54.9 cm, age 4 (Figure 4, Table 4).

Model 19.0c **Sensitivity to fishery length frequency data**

Model 19.0c was not intended for use as an assessment model; rather, it was presented to consider how the models would change in the absence of fishery length frequency data. The fishery length frequencies are notable for differences between cod caught during winter and non-winter months (Figure 5). Here, we define winter as January –April, which corresponds with spawn timing for Pacific cod in Alaska (Neidetcher et al. 2009).

Results

The four age-structured models produced similar fits to survey age frequency (Figure 6) and survey biomass estimates (Figure 7). Selectivity for the fishery and survey, as well as survey catchability, did differ among most models except Model 19.0 and Model 19.0b (Table 5, Figure 8). Model 19.0c indicated the highest survey catchability, and Model 19.0a the lowest. In all models, survey a50 was lower than fishery a50, which is reasonable as the survey catches smaller fish than the fishery (Figure 9).

Several statistical goodness of fit tests were used to examine the four models. The root mean squared deviation (RMSD) was calculated for biomass, and the fit to length and age composition data was measured using the square root of the sum of squared differences (SSD). The RMSD is a measure of the average difference between the observed and predicted total biomass of Pacific cod in the Aleutian Islands, and is similar to a standard deviation. The standard deviation of normalized residuals (SDNRs) was calculated for biomass data (Table 6). Model results did not differ significantly, but the CV of RMSD, the RMSD divided by the mean of the observations) for biomass and SSD for fishery lengths were lowest under Model 19.0a. SDNR values close to 1 are considered better, and plots of the fit to biomass are considered important diagnostic tools as well.

Negative log likelihood components for the four models are shown in Table 7 for recruitment, survey age, survey biomass, catch, fishery length, and total negative log likelihood. Negative log likelihoods were similar regardless of maturity curve, as maturity has no impact on likelihood. The model with the lowest negative log likelihood (highest likelihood) was Model 19.0a, with improvements (lower negative log likelihood) primarily in the survey biomass and fishery lengths.

A retrospective analysis was performed extending back 10 years to evaluate Model 19.0, with data from 2011-2021. The value for Rho for Model 19.0 was 0.157 (Figure 10). There are no AFSC guidelines regarding how large Rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias. However, 0.157 is in the range of values exhibited by many other Alaska groundfish species, and recent values for EBS Pacific cod are shown below.

Year	Model	Rho
2016	16.6	0.147
2017	16.6	0.243
2018	16.6i	0.207
2019	19.12	-0.061
2020	19.12a	-0.021

The spawning biomass of Pacific cod has decreased and increased over the past 10 years and 0.157 represents an average in the differences between adjacent years. Rho for Model 19.0a was 0.103, lower than the basic model, while Rho for Model 19.0b was 0.204 and Model 19.0c was 0.189.

In addition to the four age-structured models presented here, the Tier 5 model is also a consideration for the 2021 AI Pacific cod assessment. As there is no new Aleutian Island survey data since the last full assessment, the Tier 5 reference points would not change from the 2020 assessment.

Tables

Table 1. Age structured models developed for Aleutian Islands Pacific cod, September 2021. In all models, 1990 fishery length frequencies and catch were excluded, and the modeled years were from 1991-2021.

Model name	Data changes from 2019	Model changes from 2019
Model 19.0	2019, 2020, 2021 catch and fishery length frequencies added	None. Basic model with M=0.34, maturity ogive derived from observer collections of maturity values from Aleutian Islands cod.
Model 19.0a	2019, 2020, 2021 catch and fishery length frequencies added	Basic model except M=0.40.
Model 19.0b	2019, 2020, 2021 catch and fishery length frequencies added	Basic model except maturity defined as in Stark (2007).
Model 19.0c	2019, 2020, 2021 catch data added	Basic model with no likelihood component for fishery lengths.

Table 2. Estimates of natural mortality, *M*, for Pacific cod throughout their range. Values marked with asterisks * have been used in stock assessments, and statistics are provided to summarize the estimates. The value mu represents the mean of the log values and sigma is the standard deviation.

Region	Reference Author	Year	M estimate
EBS*	Low	1974	0.375
EBS	Wespestad et al.	1982	0.700
EBS	Bakkala and Wespestad	1985	0.450
EBS	Thompson and Shimada	1990	0.290
EBS	Thompson and Methot	1993	0.370
EBS*	Shimada and Kimura	1994	0.960
EBS*	Shi et al.	2007	0.450
EBS	Thompson et al.	2007	0.340
EBS	Thompson	2016	0.360
GOA	Thompson and Zenger	1993	0.270
GOA	Thompson and Zenger	1995	0.500
GOA	Thompson et al.	2007	0.380
GOA*	Barbeaux et al.	2016	0.470
BC*	Ketchen	1964	0.595
BC*	Fournier	1983	0.650
Korea*	Jung et al.	2009	0.820
Japan*	Ueda et al.	2004	0.200

Statistic	Value
mu:	-0.6666309
sigma:	0.4929505
Arithmetic:	0.5797660
Geometric:	0.5134355
Harmonic:	0.4546938
Mode:	0.4026727
L95%:	0.1953790
U95%:	1.3492544

Table 3. Maturity at length records from Pacific cod from the Aleutian Islands during the months January – March since 2008.

Year	Number
2008	545
2009	35
2010	116
2011	56
2012	129
2013	61
2014	94
2015	78
2016	79
2017	42
2018	26
2019	57
2020	13

Table 4. Proportion mature by age, using Stark (2007) and observer maturity at length data.

Age	Stark 2007	Observer data
1	0.023	0.023
2	0.058	0.058
3	0.140	0.140
4	0.299	0.299
5	0.528	0.528
6	0.746	0.746
7	0.885	0.885
8	0.953	0.953
9	0.982	0.982
10	1.000	0.993

Table 5. Key parameters and the associated standard deviations from the four age-structured models: survey catchability (q), survey selectivity a50 parameter, survey selectivity slope parameter, fishery selectivity a50 parameter, fishery selectivity slope parameter for Model 19.0, Model 19.0a (M = 0.4), Model 19.0b (Stark (2007) maturity ogive, and Model 19.0c (no fishery length likelihood).

	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
Survey Catchability	0.8062 (0.069)	0.6945 (0.065)	0.8062 (0.069)	1.0421 (0.169)
Survey a50	3.0750 (0.143)	3.2408 (0.139)	3.0749 (0.142)	3.496 (0.289)
Survey slope	1.2752 (0.091)	1.2923 (0.084)	1.2752 (0.091)	1.1455 (0.094)
Fishery a50	5.1801 (0.186)	5.2447 (0.188)	5.1801 (0.187)	4.8265 (0.489)
Fishery slope	1.8139 (0.187)	1.8273 (0.180)	1.8139 (0.187)	1.5421 (0.762)

Table 6. Goodness of fit tests for the four models, the coefficient of variation for the RMSD (root mean squared deviation), the RMSD divided by the mean of the observations, for fit to biomass, the square root of the sum of squared differences (SSD) for survey ages, and fishery lengths, the standard deviation of normalized residuals for biomass, as well as survey catchability estimated by the four models, Model 19.0, 19.0a, 19.0b, and 19.0c.

	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
CV of RMSD for biomass	0.2819	0.2698	0.2819	0.2514
SSD for survey age	0.4195	0.4201	0.4195	0.4043
SSD for fishery lengths	0.2281	0.2254	0.2281	0.2937
SDNR	1.6141	1.567	1.6141	1.6638

Table 7. Negative log likelihoods for the age structured models four models presented.

	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
Recruitment	5.153	4.951	5.153	5.054
Survey age	57.933	56.705	57.933	51.267
Survey biomass	12.284	10.954	12.284	10.745
Catch	0.001	0.001	0.001	0.001
Fishery Length	39.54	39.132	39.54	-
Total	114.91	111.743	114.91	67.067

Figures

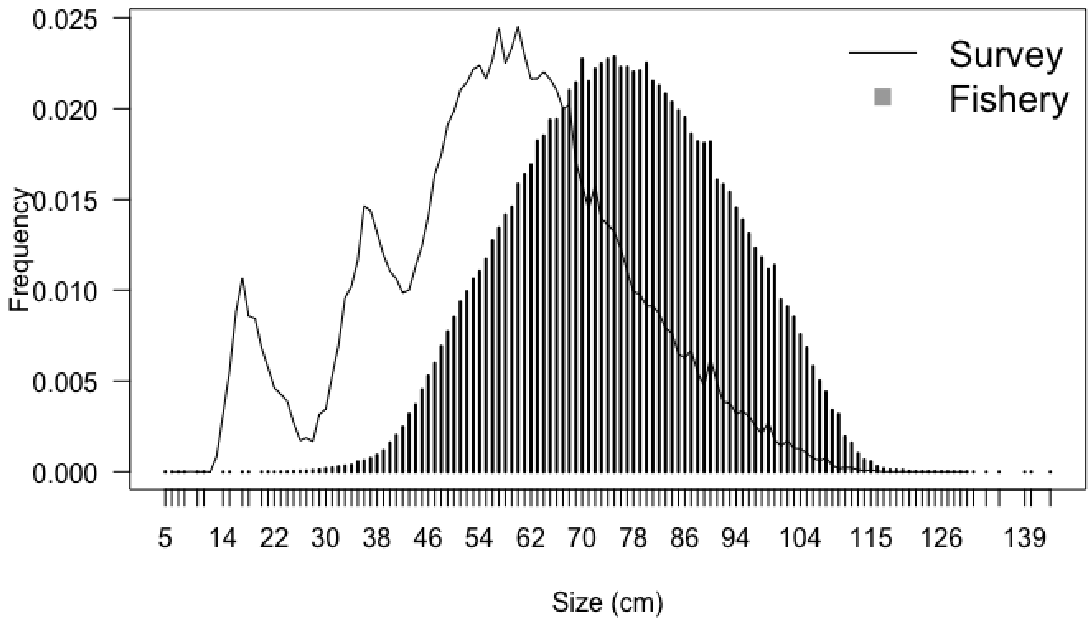

Figure 1. Length frequencies for Pacific cod caught in the Aleutians by fishery (1990-2021) and survey (1991-2018).

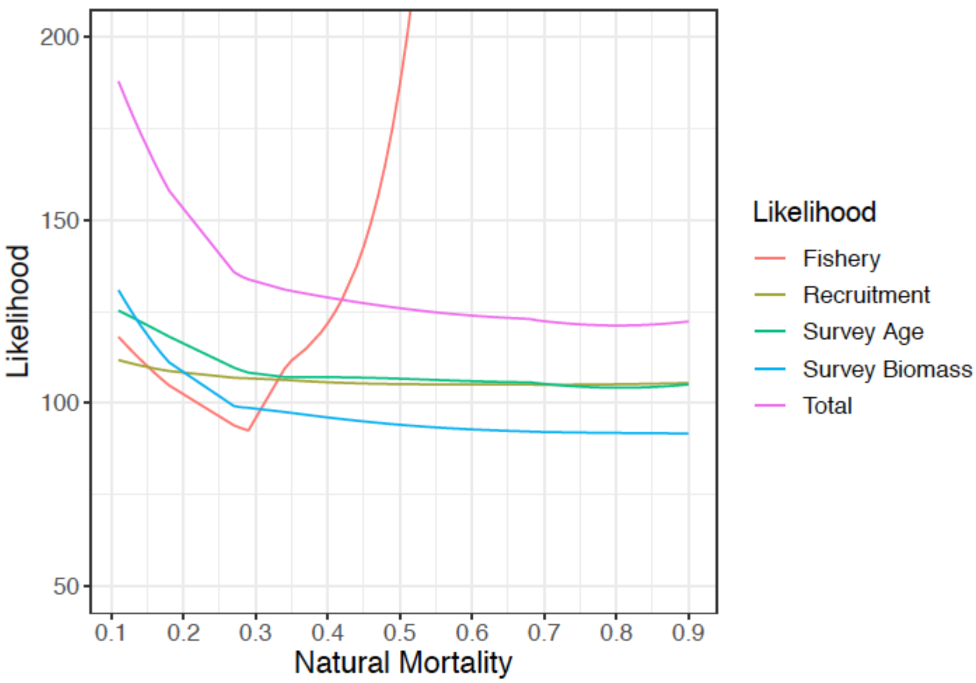

Figure 2. Likelihood profile for natural mortality for fishery length, recruitment, survey biomass, and age likelihood components. Values represent negative log likelihoods.

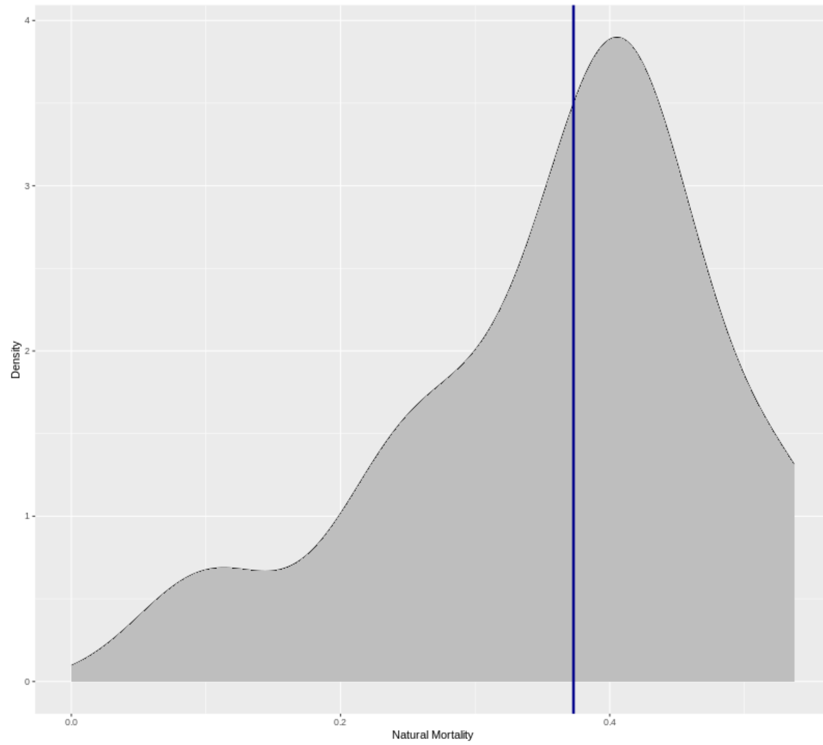

Figure 3. The estimate for Aleutian Islands Pacific cod was 0.36 based on a tool for estimating natural mortality online (http://barefootecologist.com.au/shiny_m.html) that uses life history parameters, and provides a composite estimate of M.

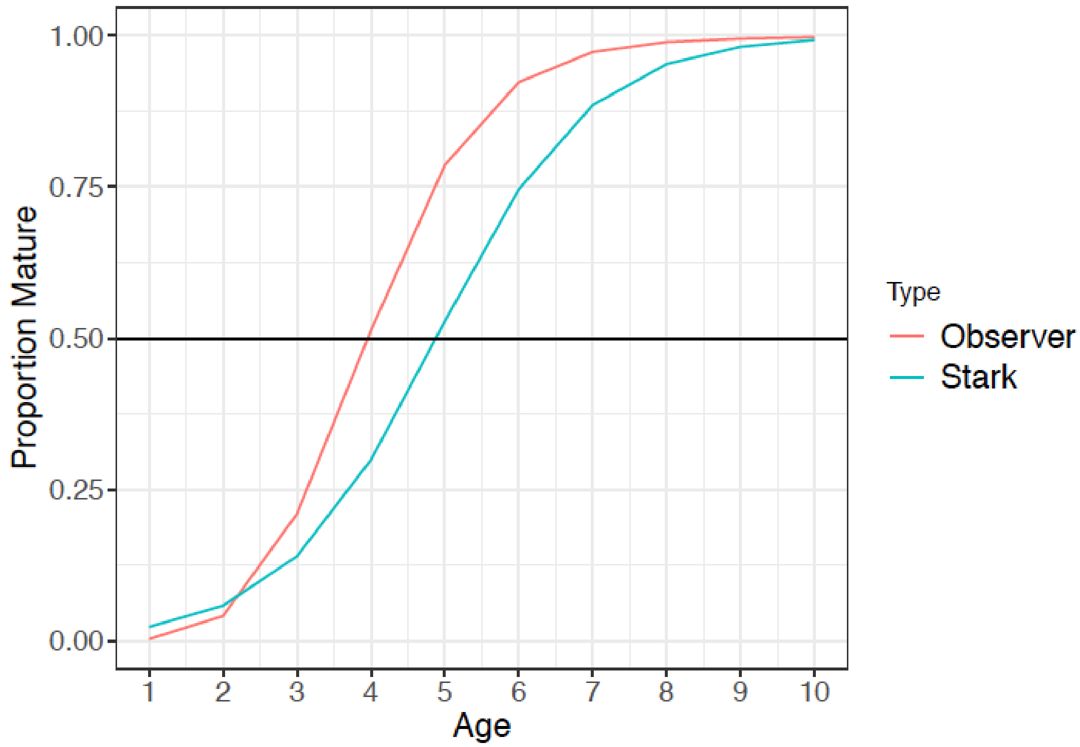

Figure 4. Proportion mature by age, using Stark (2007) and observer maturity at length data.

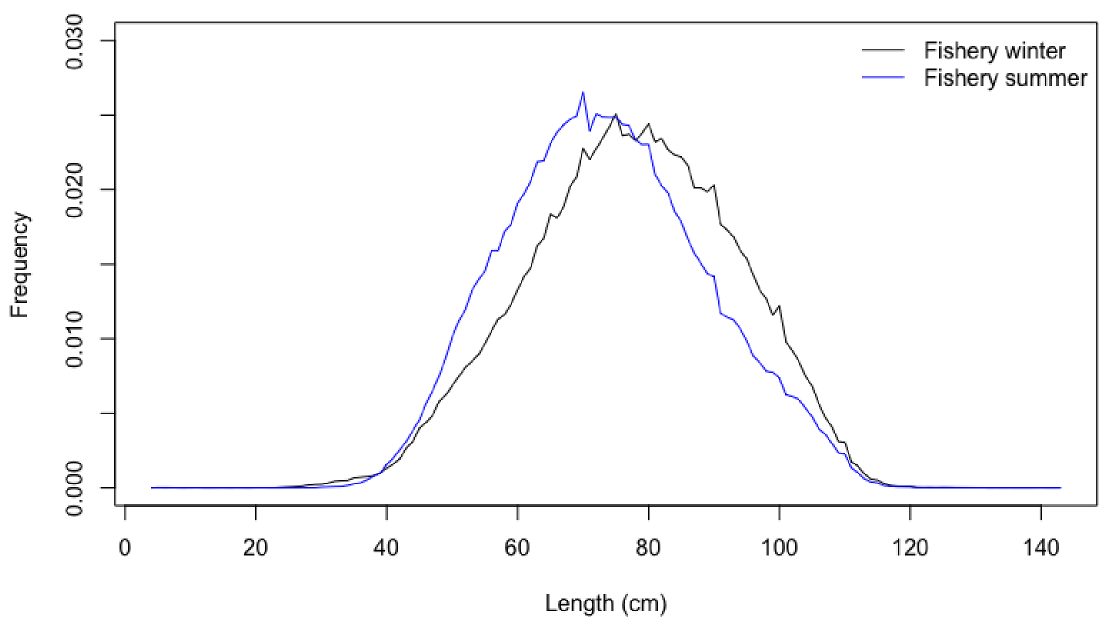

Figure 5. Length frequencies taken by Pacific cod fisheries observers from the Aleutian Islands (NMFS Areas 541, 542, 543) from 1991-2021. Winter is defined as January – April. Summer is defined as all seasons outside of winter (May – December).

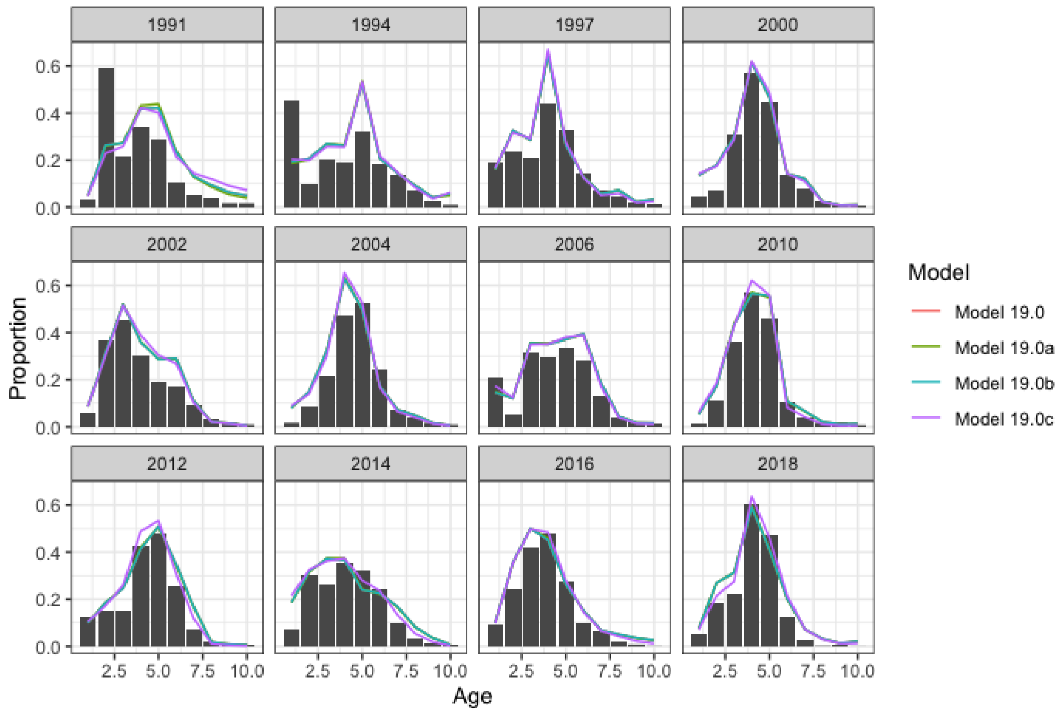

Figure 6. Survey age frequency fit to Model 19.0 (basic model), Model 19.0a (basic model with M = 0.4), Model 19.0b (basic model with Stark 2007 maturity), Model 19.0c (basic model minus fishery length frequency likelihood).

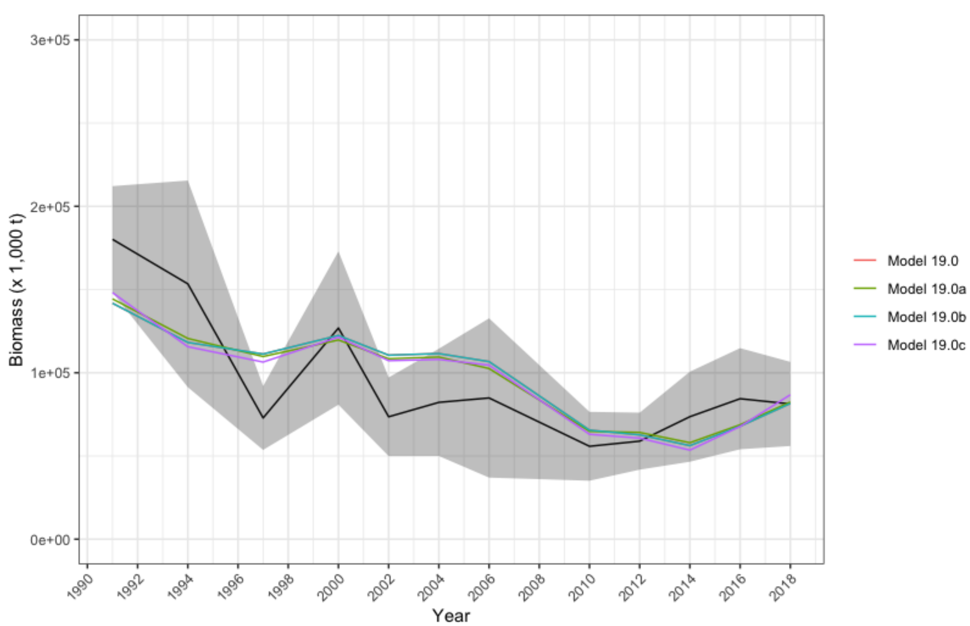

Figure 7. Aleutian Islands survey biomass estimates, from 1991-2018, with 95% confidence intervals and four model estimates of survey biomass, scaled by survey catchability: Model 19.0 (basic model), Model 19.0a (basic model with M = 0.4), Model 19.0b (basic model with Stark 2007 maturity), Model 19.0c (basic model minus fishery length frequency likelihood).

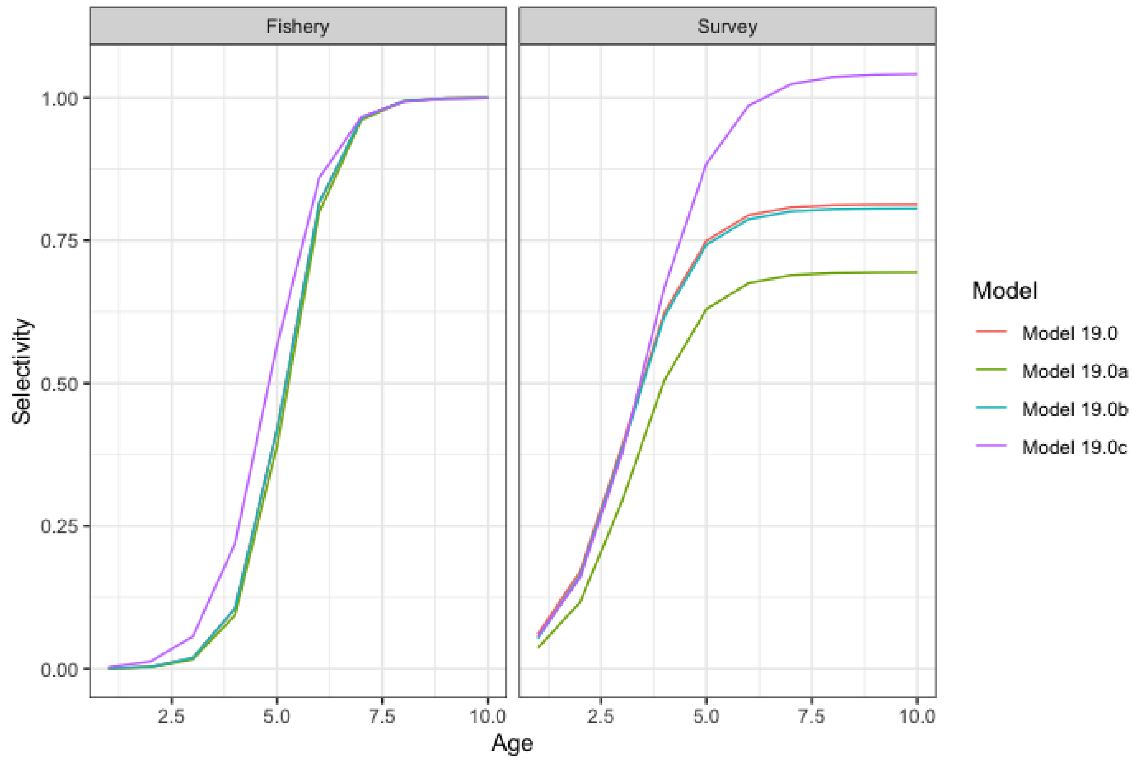

Figure 8. Model estimates of selectivity for the survey and the fishery. The survey selectivity curve is the product of survey catchability and survey selectivity. Note: Model 19.0 and Model 19.0b survey estimates have identical values.

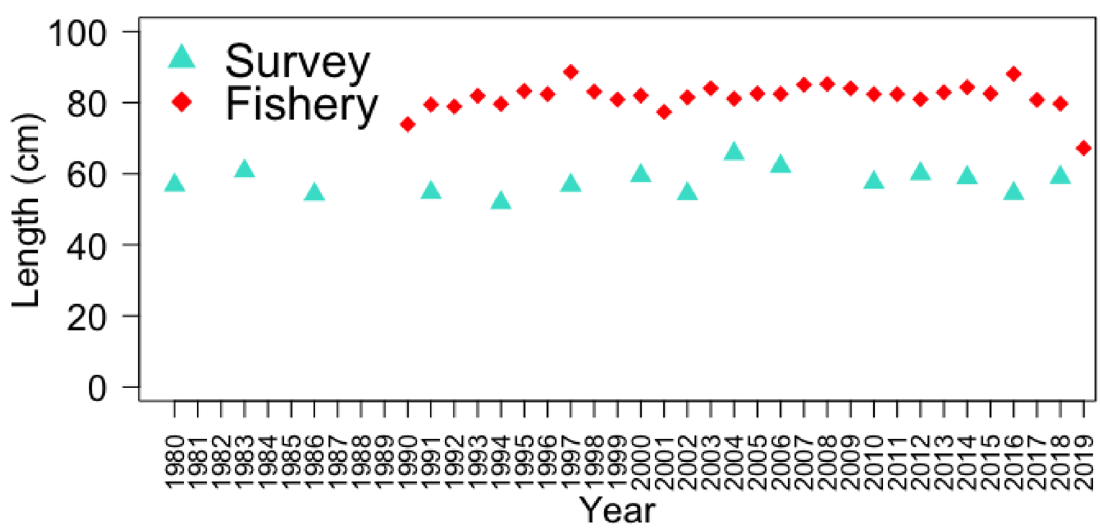

Figure 9. Average length frequencies of fish caught in the survey vs. fishery, 1980-2019.

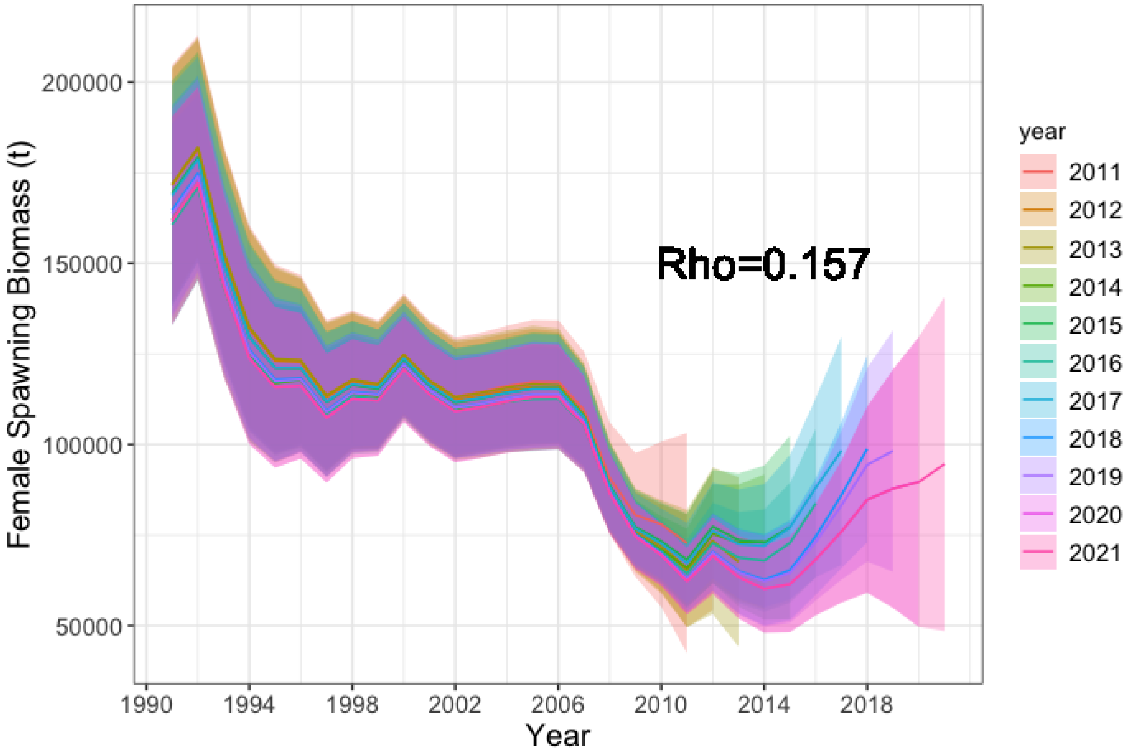

Figure 10. Retrospective plot of female spawning biomass; Rho for Model 19.0 was 0.157, Model 19.0a: 0.103, Model 19.0b: 0.204, Model 19.0c: 0.189.

References

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