Preliminary assessment of the arrowtooth flounder stock in the Bering Sea and Aleutian Islands

Ingrid Spies
Resource Ecology and Fisheries Management Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE,
Seattle, WA 98115-6349

Introduction

This document represents an effort to respond to comments made by the 2017 Flatfish CIE Review committee, the Bering Sea and Aleutian Islands (BSAI) Plan Team and the Scientific and Statistical Committee (SSC) of the North Pacific Fishery Management Council (NPFMC) regarding the arrowtooth flounder (*Atheresthes stomias*) stock assessment for the BSAI. The comments are provided below, followed by responses and methodology to apply suggestions to the arrowtooth flounder assessment model.

Comments from the 2017 CIE Review

The CIE review committee noted that the arrowtooth assessment model is able to make use of both biomass, age and length composition data in a unified framework. There is also a fairly well established statistical framework in which to estimate the parameters, and the model is supported by comprehensive survey biomass estimates, which should provide high quality estimates of biomass trends.

They provided several suggestions to improve the model. In particular, they felt that the model would be improved with fewer parameters and more age data. They suggested exploring alternatives for male and female natural mortality. In addition, they suggested examining alternatives for integrating the three research surveys that provide biomass estimates for the Aleutian Islands, Bering Sea slope, and Eastern Bering Sea. The committee questioned whether the temperature relationship with catchability on the EBS shelf was significant. They also emphasized the need to understand the stock dynamics immediately preceding the assessment period; one reviewer considered this a major weakness of the assessment.

Comments from the 2016 November Plan Team

The Team recommended the authors consider smoothing the age length conversion matrix and ensure that selectivity parameters are not on bounds without reason.

Comments from 2016 December SSC

Some additional work is indicated for the preferred model for next year's assessment. For instance, the authors were concerned that some selectivity parameters may be at or near their boundaries. They suggested investigating this by considering alternatives for the degree of dome-shaped selectivity curves for the EBS survey. In addition, the PT recommended that the authors consider smoothing the age-length conversion matrix. The SSC supports these explorations.

Seven new models are presented here, to respond to CIE Review, Plan Team, and SSC comments, and general model improvements. The new proposed models include explorations of length-based rather than age-based selectivity for the survey and the fishery, inclusion of an ageing error matrix, and two alternatives to fixed male and female natural mortality. New models are compared to the base model from 2016 (Model 15.1c). All models include a smoothed length age conversion matrix.

Currently the arrowtooth flounder stock assessment has fixed constant natural mortality for males (0.35) and females (0.2). The age composition of the species shows fewer males relative to females as fish increase in age, which suggests higher natural mortality (M) for males (Wilderbuer and Turnock 2009). ifferent options have been explored in the current assessment, which consider natural mortality as a function of the size of the fish (Gislason et al. 2010, Lorenzen 1996). The distribution of ages appears to vary by region and sex; male arrowtooth as old as 36 years have been observed in the Aleutian Islands but are not commonly observed older than age 10 on the Bering Sea shelf. Males were not observed older than age 20 prior to 2005 in the Gulf of Alaska; however, males age 21 have been observed in every survey since that time. The sex ratio of arrowtooth flounder also varies by region. In the Gulf of Alaska, the observed ratio from fishery observer length frequency collections is 69% female, 31% male. Survey length compositions from the Bering Sea indicate that the proportion female is 70% on the Bering Sea shelf, 72% on the Bering Sea slope, and 62% in the Aleutian Islands. In British Columbia catches have been over 70% female since 1996 and the stock is assessed solely based on female numbers (DFO 2015).

Several models investigate consolidating male and female selectivity curves. This is most feasible if selectivity is determined by length, since male and female arrowtooth flounder grow at different rates (females grow larger than males). Length-based selectivity is converted to selectivity at age for age-based calculations in the model, such as numbers at age.

Ageing error in arrowtooth flounder is relatively high compared to walleye pollock and Pacific cod. Therefore, an ageing error transition matrix was incorporated to convert population numbers at age to expected survey numbers at age. The matrix was computed using the estimated percent agreement among two age readers. We used the percent agreement for ages from 1987-2015. The model incorporates a linear increase in the standard deviation of ageing error and assumes that ageing error is normally distributed (Dorn et al. 2003, Methot 2000). Percent agreement is predicted by the sum probability that both readers are correct, that both readers are off by one year in the same direction, and the probability that both age readers are off by two years in the same direction (Methot 2000).

Data

Data in all models was identical to data used in the last full BSAI arrowtooth flounder stock assessment in 2016.

Model structures

The assessment is an age-structured statistical model implemented in the Automatic Differentiation Model Builder (ADMB) framework (Fournier et al. 2012). This framework uses automatic differentiation and allows estimation of highly-parameterized and non-linear models. This age-structured population dynamics model is fit to survey abundance data, survey age data, and survey and fishery length composition data with a harvest control rule to model the status and productivity of these stocks and set quotas. The model is fit to the data by minimizing the objective function, analogous to maximizing the likelihood function. The model implementation language provides the ability to estimate the variance-covariance matrix for all parameters of interest.

Each model was given a different decimal number for consistencyome of the models discussed here resulted in an average difference in spawning biomass that was greater than 0.2, but some did not.

Base model

Model 15.1b was adopted during the last BSAI arrowtooth flounder stock assessment cycle in 2016. Its main features are as follows:

- Male and female natural mortality are fixed at 0.35 and 0.2, respectively.
- The model estimates male and female parameters separately.
- For years in which there is no age data, length data is converted to age via a length-age conversion matrix.
- The model incorporates data from three surveys: the Aleutian Islands, Eastern Bering Sea, and Bering Sea slope.
- Age-based fishery selectivity is estimated non-parametrically and constrained to be monotonically increasing, separately by sex.

- Age-based selectivity for the Aleutian Island and Bering Sea slope surveys is estimated using a two-parameter ascending logistic curve, separately by sex.
- Age-based selectivity for the Eastern Bering Sea survey is estimated using dome shaped selectivity via a two-parameter ascending and a two-parameter descending logistic curve, separately by sex.

In this document, Model 15.1b is run using a smoothed version of the length age conversion matrix and renamed Model 15.1c. All further models are run using this improved length age conversion matrix, as suggested by the BSAI Plan Team and SSC.

Alternative models
Model 15.1c: Base model with smoothed length age conversion matrix (all models considered here use the same smoothed length age conversion matrix).

Model 18.0: This model incorporates survey selectivity at length (rather than at age) for the three surveys. It retains the increasing logistic form for the Aleutian Island and the Bering Sea slope survey data, and the dome shaped form for the Eastern Bering Sea. The parameters for the logistic function are determined by length; therefore, only two parameters are required for the selectivity curve for each survey (rather than four if selectivity is by sex). Logistic selectivity is then converted back to selectivity by age using the length age conversion matrix, separately for each sex.

Model 18.1: This model is the same as Model 18.0, except it also incorporates two-parameter logistic selectivity by sex age for the fishery. It does not incorporate non-parametric fishery selectivity.

Model 18.2: This model is the same as Model 18.0, except it also incorporates survey and fishery selectivity at length (rather than at age). This represents a change from the non-parametric fishery selectivity previously used.

Model 18.3: This model is the same as the base model, except it includes an ageing error matrix.

Model 18.4: This model includes Lorenzen natural mortalities using parameters specified for marine fish species (Lorenzen, K. 1996). The natural mortality for ages 1-5 are set to the natural mortality for age 6 fish.

The Lorenzen (1996) natural mortality equation is as follows:
(1) $M_{age} = aWt_{age}^{b}$, where *a* and *b* are estimated parameters

Model 18.5: Gislason natural mortalityhe natural mortality equation of Gislason et al. (2010) is as follows:
(2) $\ln(M_{age}) = 0.55 - 1.61\ln(L_{age}) + 1.44\ln(L_{¥}) + \ln(K)$, where L_{age} is length at age, and $L_{¥}$ and *K* are parameters from the sex-specific von-Bertalanffy fit to length at age. The mortality in equation is multiplied by W=3 to match the natural mortalities previously established for ATF.

Model 18.6: This model is similar to Model 18.0, with length-based survey selectivity and non-parametric fishery selectivity. It also incorporates the ageing error matrix.

Model evaluation

Models were evaluated using several criteria (Table 1), including survey selectivity likelihood values for the fishery and the three surveys (EBS shelf, Bering Sea slope, and Aleutian Islands), fishery length likelihood, survey length likelihood, survey age likelihood, catch likelihood, and recruitment likelihood.

The total likelihood and the objective function value from the ADMB model output are also presented, as well as the AIC value calculated as described below.

Calculating AIC from the hessian and objective function value (ADMB output)

The hessian, the matrix of second mixed derivatives in transformed space, is created as output from each ADMB model run. The hessian was transformed back into the original parameter space ($Hess_T$) by taking the log of the determinant of the hessian, and the marginal likelihood ($Likelihood_{MAR}$) was estimated (Thorson et al. 2014) as follows, where OFV is the objective function value from the ADMB .par file:

$\text{likelihood}_{MAR} = -0.5 Hess_T - OFV$. Note: log(2pi) not necessary…

The marginal likelihood can be used to calculate AIC, as follows:

$AIC = 2k - 2 * likelihood_{MAR}$, where k is the number of parameters used in the model.

Results

Models 18.0, 18.1, 18.2:
These models incorporated changes in selectivity, by reducing the number of parameters and incorporating selectivity based on length rather than age (Figure 1). These models improve the overall likelihood or reduce the AIC, but they did reduce the number of parameters from 167 in the base model. Model 18.0 reduced the number of parameters by 8, 18.1 by 46 and 18.2 by 48. These models did not improve the survey biomass likelihoods, but they did improve the survey age and length likelihoods, as well as the recruitment likelihood.

Recruitment, biomass, and female spawning biomass for these three models are very similar to the base model (Figures 2, 3, 4).

Model 18.3:
This model was the same as the base model, except it incorporated the ageing error matrix. This resulted in the lowest AIC over all models. In particular, it resulted in the lowest fishery length likelihood and lower survey age and recruitment likelihood. Recruitment, biomass, and female spawning biomass are similar to the base model. Fit to age data was better than the base model (Figure 5).

Models 18.4 and 18.5:

The natural mortality at age for Models 18.4 (Lorenzen), and 18.5 (Gislason) are shown in Figure 6. The first 5 ages were fixed to be the same as the natural mortality at the sixth age for the Lorenzen method, because extremely large natural mortalities in younger fish resulted in much higher recruitment. These estimates for natural mortality conform to observations that there are more females than males in the population (Figure 7).

These models do not currently converge given the parameters provided. Recruitment for the Lorenzen natural mortality appears to be similar to other models, but the Gislason has not converged (Figure 2). Biomass estimates using the Lorenzen, and particularly the Gislason natural mortality are higher than other models (Figure 3). Estimates of female spawning biomass are lowest for these models out of all models considered (Figure 3). These models resulted in a poor fit to age data for the EBS shelf survey (Figure 5).

Conclusions

Models presented here represented an effort to improve the BSAI arrowtooth stock assessment. Overall, the ageing error matrix (Model 18.3) appears to be the best model, considering the lowest AIC and objective function value. The other models that examined selectivity changes (Models 18.0, 18.1, and 18.2) did improve aspects of the model; with lower survey age, survey length, and recruitment likelihoods. Arrowtooth flounder likely move off the Eastern Bering Sea shelf when they attain a certain age, or maturity, rather than a particular length. The EBS shelf survey selectivity curve is specified to be domed shaped for this reason. If selectivity is based on length, it will predict that fewer males will move off the shelf that is biologically likely, since it will only predict movement by only large males.

Differences in the abundance of male and female arrowtooth flounder has been a point of discussion for some time (Wilderbuer and Turnock 2009), and Plan Team, SSC, and CIE reviewers have suggested exploring alternatives for a fixed M that is higher for females than males. Genetic theory indicates that it is unlikely for a natural population to exhibit a skewed sex ratio, as is observed in the arrowtooth flounder. Fisher's principle states that the sex ratio of most species is approximately 1:1 because parents will invest equally in reproduction when competition for mates takes place equally among the entire population. Non-Fisherian populations are those that appear to violate Fisher's principle and have a skewed sex ratio. In species in which individuals undergo sex change throughout their lifetimes, skewed sex ratio is typical (Charnov 1982). However, it is unlikely that arrowtooth flounder change sex in ages 2 or greater because intermediate sexes have not been observed. Flounder of the genus Paralichthys exhibit a mode of sex determination in which male-skewed sex ratios are induced by temperatures lower and higher than average (Luckenbach et al. 2009). High and low temperatures also induce sex reversal in juvenile southern flounder, such that there are 96% males at high temperature and 78% males at low temperature (Luckenbach et al. 2003). Such a mechanism is unlikely in arrowtooth flounder because they have a female skewed sex ratio. The skewed sex ratio in arrowtooth flounder is consistent with research by Beverton (1992) who suggests that natural mortality for male flatfish is approximately 50% higher than that of females. Efforts to improve estimates of natural mortality did not converge with recommended parameters, and different parameterization may improve these models.

Figures and Tables

Figure 1a. Selectivity for the base model (15.1c, and Models 18.0, 18.1, n18.2). In all panels, red is female, blue is male).

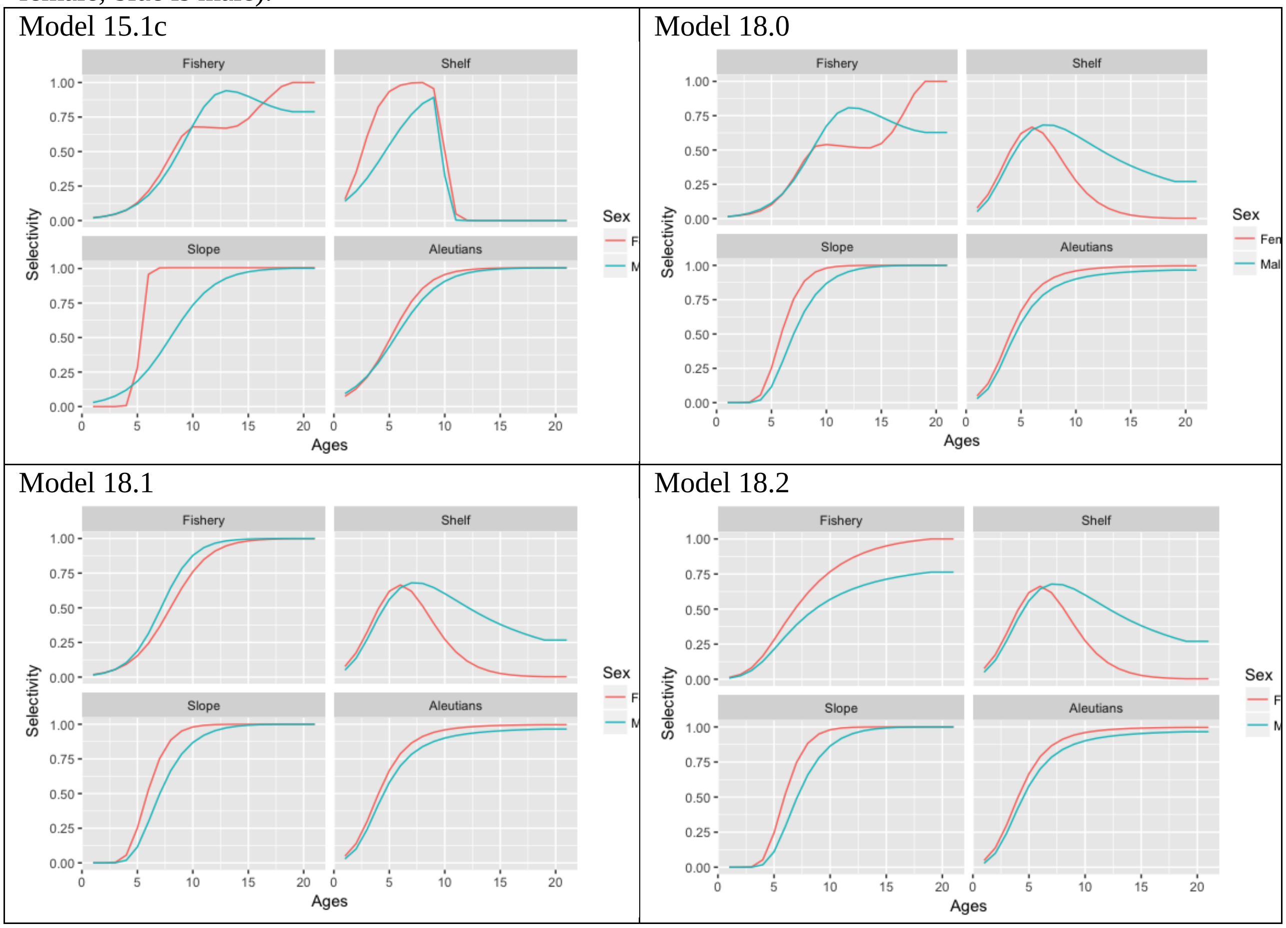

Figure 1b. Selectivity for Models 18.3, 18.4, 18.5, 18.6. In all panels, red is female, blue is male).

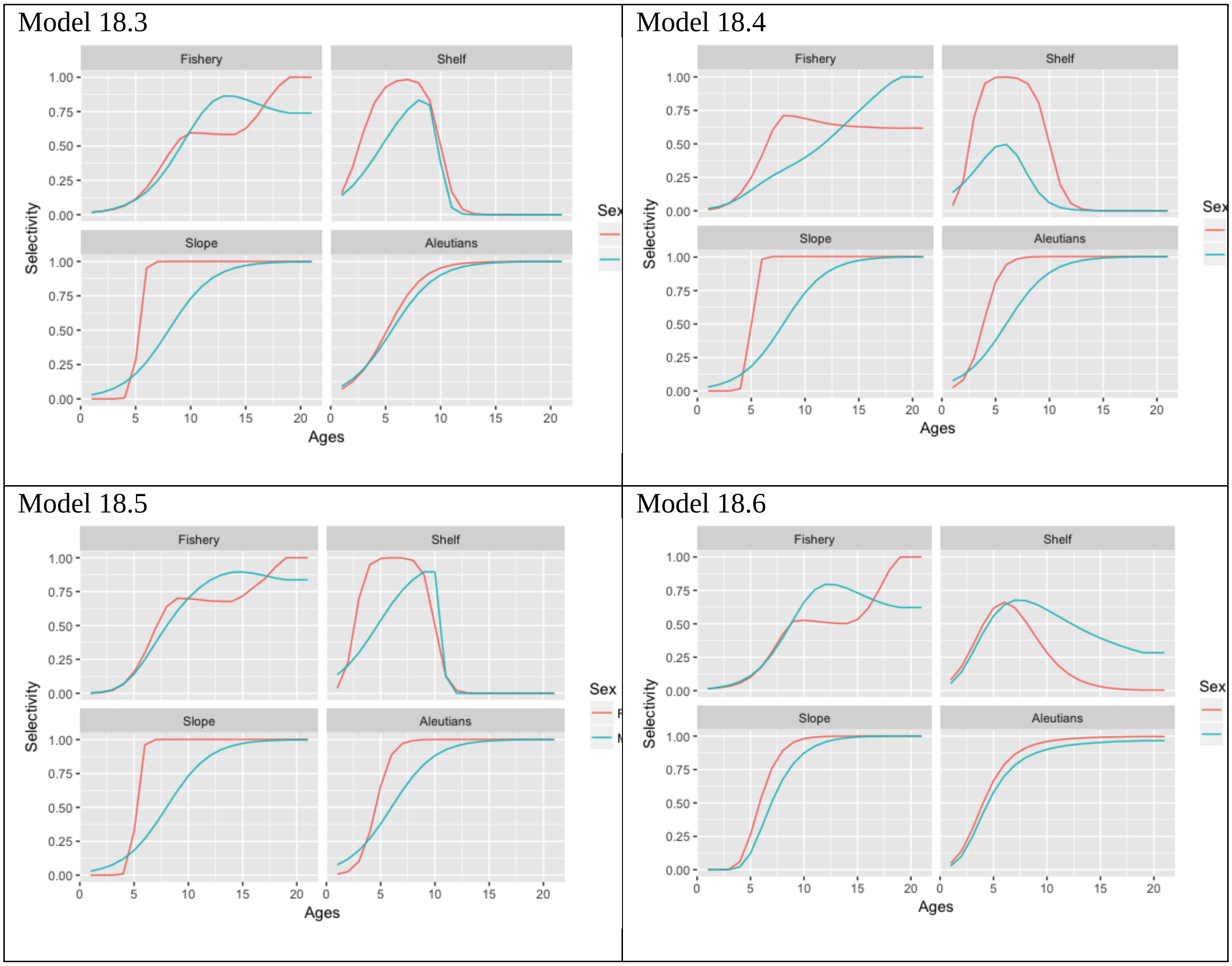

Figure 2. Recruitment estimates from 1976-2011 (5 years prior to the last year of the model) for all models.

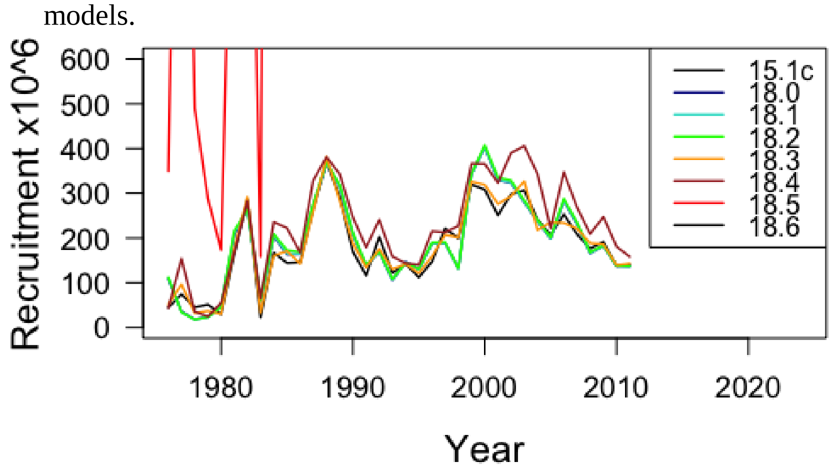

Figure 3. Biomass estimates for 1976-2016 for all models.

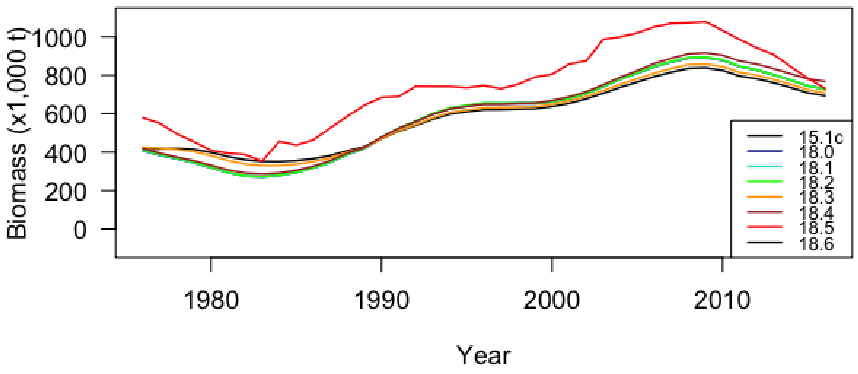
Biomass (x1,000 t)
1000
800
600
400
200
0
1980
1990
2000
2010
Year
15.1c
18.0
18.1
18.2
18.3
18.4
18.5
18.6

Figure 4. Female spawning biomass estimates for all models.

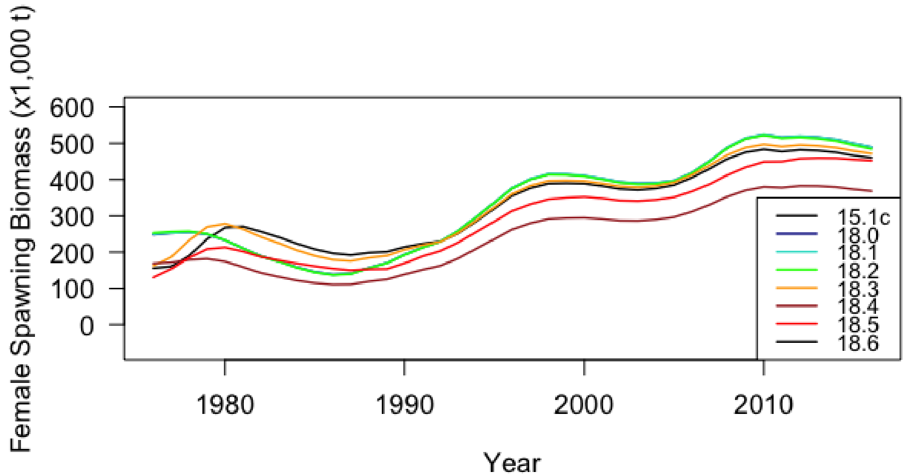

Figure 5. Fit to EBS shelf age data, for Models 15.1c, 18.4, 18.5, and 18.6. Females are red, males are blue.

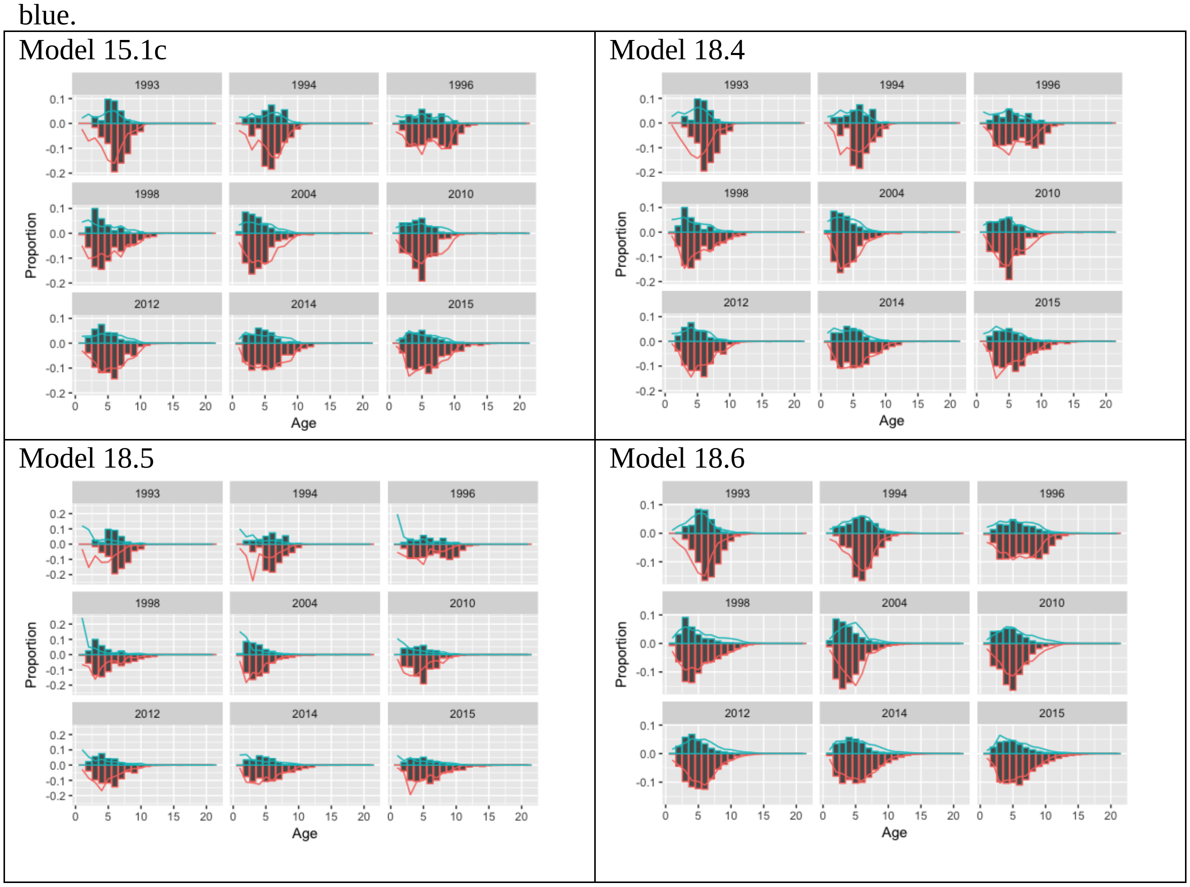

Figure 6. Natural mortality at age for the constant M, Lorenzen, and Gislason natural mortality. In all cases, females are represented by a solid line and males by a dotted line.

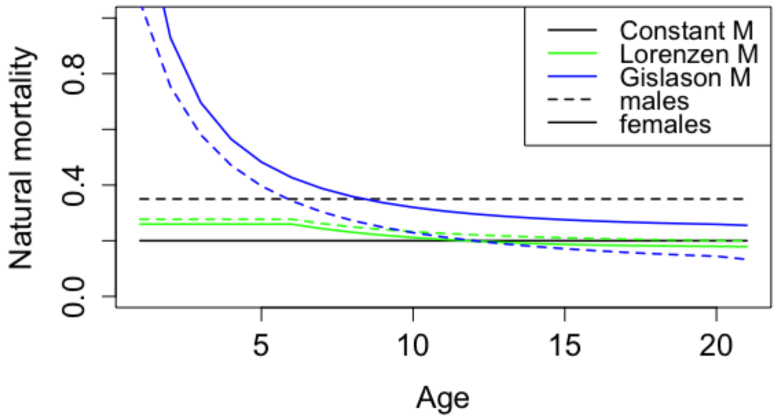

Figure 7. Relative numbers at age for the constant M, Lorenzen, and Gislason natural mortality. In all cases, females are represented by a solid line and males by a dotted line.

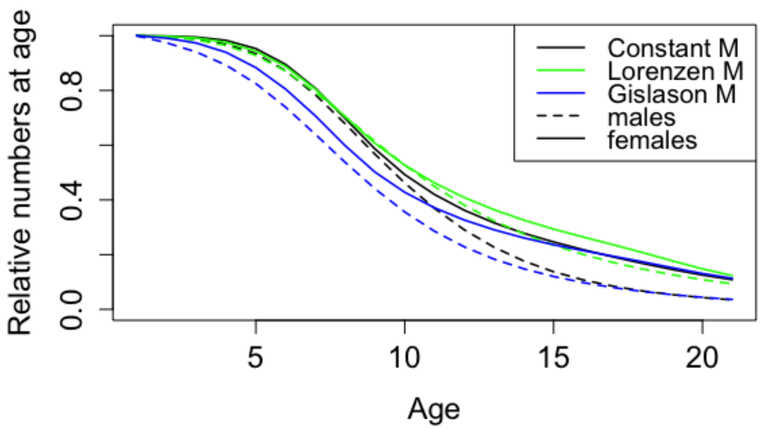

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Table 1. Statistics used to evaluate models. Likelihood (Like.) values are shown for the Eastern Bering Sea survey biomass (EBS Surv. Biom.), the Bering Sea slope survey biomass (Slope Surv. Biom. Like), Aleutian Islands survey biomass (AI Surv. Biom.), Fishery length (Fish. Length), Survey length, Survey age, catch, recruitment (Rec.), fishery selectivity (Fish sel.), Survey selectivity (Surv. Sel.), the number of parameters. The total likelihood and the objective function value from the ADMB model output are also presented, as well as the Akaike Information Criterion (AIC).

Model Number	EBS. Surv. Biom. Like.	Slope Surv. Biom. Like.	AI Surv. Biom. Like.	Fish. Length Like.	Surv. Length Like.	Surv. Age Like.	Rec. Like.	Fish. sel. Like.	Surv. sel. Like.	Number of Parameters	Total Like.	ADSB	Obj. fun.	AIC*
15.1c	24.4	34.8	45.7	479.9	593.8	444.6	50.8	0.83	3.96	167	1674.8	-	3824.5	8078.4
18.0	34.9	71.3	45.9	493.2	544.8	341.0	29.9	1.43	5.53	159	1562.5	0.193	3831.7	8406.3
18.1	35.0	71.4	46.0	498.1	544.9	339.7	29.7	0.00	0.00	121	1564.9	0.194	3831.5	8384.0
18.2	35.1	71.7	46.3	546.9	548.0	343.4	29.8	0.00	0.00	119	1621.2	0.198	3876.1	8459.2
18.3	32.5	62.7	45.6	437.5	538.2	368.5	20.4	2.32	5.93	167	1507.7	0.062	3801.6	7817.8
18.4	37.3	48.7	50.8	498.1	1623.5	898.0	43.9	3.48	17.51	167	3203.7	0.290	6473.3	-Inf
18.5	35.6	71.4	46.0	498.5	532.4	270.3	28.7	0.00	0.00	121	1482.9	0.145	3730.2	-Inf
18.6	35.5	71.2	45.9	493.9	532.2	271.6	28.9	1.47	5.45	159	1480.8	0.196	3730.3	8208.4