17. Evaluation of aspects of the Bering Sea/Aleutian Islands Atka mackerel stock assessment model and data

Sandra Lowe and James Ianelli

Introduction

Responses to SSC and Plan Team Comments Specific to the Atka Mackerel Assessment

The Bering Sea/Aleutian Islands (BSAI) Plan Team recommended a list of items to be addressed in future assessments at their November, 2018 meeting. The SSC agreed (December, 2018 SSC minutes) with the Plan Team recommendations listed below. The elements in bold are addressed in this document. Items 6 and 8 will be addressed in the final (November, 2018) assessment.

From the November 2017 Plan Team minutes: *The Team recommends that the authors undertake the following during one or more future assessments (as this is a long list, the Team does not expect all items to be addressed by next September, and understands that the authors can prioritize the list as they see fit):*

1. **Investigate which parameters (including derived quantities) are changing in the retrospective peels that might contribute the relationship between historical scale and number of peels.**
2. **Consider dropping the 1986 age composition from the analysis, to be consistent with the policy of not using pre-1991 survey data.**
3. **Improve documentation for the process of using Francis weights to tune the constraint governing the amount of time variability in fishery selectivity.**
4. **Continue to investigate fishery selectivity time blocks, with blocks linked to identifiable changes in the fishery.**
5. **Evaluate the sensitivity of model results to an assumed average sample size of 100 for the fishery age composition data, or better yet (if possible), find a way to tune the sample size and the constraint governing the amount of time variability in fishery selectivity simultaneously.**
6. Investigate whether a larger number of survey otoliths can be collected in a representative fashion.
   Note: Random sampling was adopted for the 2018 AI survey, with a scheme to sample approximately 300 otoliths per area, with an overall target of otoliths from 1,000 Atka mackerel.
7. **Continue the investigation of age-dependent natural mortality.**
8. Continue to include (and update) Figure 17.5.
   This will be included in the November 2018 assessment.

Evaluations

Data used for these evaluations were identical to those used in the 2017 assessment. References to last year's (2017) assessment are based on model runs with last year's accepted model (Model 16.0b, Lowe *et al*. 2017).

This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisheries Service and should not be construed to represent any agency determination or policy.

Retrospective pattern investigations

The Plan Team requested investigation of which parameters might be causing the apparent downward shift in biomass for retrospective "assessments" after about 2013 (Figure 1). Because there appears to be a scale shift in the biomass estimates, initial evaluations examined the survey catchability coefficient and the mean recruitment parameter. Extracting these values indicates that in more recent terminal-year assessment runs the value of the survey catchability was higher which, according to how the model is specified, scales the population to be lower (Figure 1), but only results in slightly lower mean recruitment estimates (Figure 2). Model fits to the survey data for these retrospective runs show that the 2 lowest survey estimates in time series (2012 and 2016), likely dropped the overall biomass estimates (and increased values of catchability) following the three relatively high biomass estimates between 2002 and 2010 (Figure 3). The 2002, 2004, and 2010 estimates represented the three highest survey biomass estimates in the time series. We also evaluated the impact of these survey data as they entered in to the retrospective assessments. For the survey index, the negative log-likelihood shows how historical biomass estimates become more or less consistent with model estimates with a large jump in cumulative negative log likelihood after the 2012 survey was included (Figure 4). Figure 4 also shows the relative impact of adding survey age compositions. The retrospective peels are fairly consistent with expected jumps after the recent 2012 and 2014 survey age compositions were added. Although jumps in the cumulative survey age negative log likelihoods occurred after the 2012 and 2014 survey data were added, these increases were much less than the survey index, and are comparable with adding in past years of survey age compositions (Figure 4). The robust fishery age data which is generally well fit, prevents the model from fitting the 2012 and 2016 large drops in survey biomass. In conclusion, the observed pattern reflects the addition of recent survey estimates, and in general, seems to be consistent with the uncertainty estimates of biomass for a species that is relatively patchily distributed, and trawl survey estimates that have a high level of variability.

Dropping the 1986 survey age compositions

Because of inconsistencies in the 1980s survey data (see *Survey abundance indices* in Lowe *et al*. 2017), the 1980s survey biomass data are omitted, but the 1986 survey age composition are included. The 1986 survey age data were thought to provide useful information on relative year-class strengths. We explored this further with simulations with and without the 1986 survey age composition. The impact of dropping the 1986 survey age composition reduced recruitment estimates by nearly 3.6% (mean recruitment is 658 million with those data included compared to 634 million without; Figure 5). The 2017 spawning biomass estimate was similarly affected with a slightly lower estimate when the 1986 survey age composition was excluded. Relative to survey fit, dropping the 1986 data degraded the fit to the data slightly (negative log likelihood for the survey index of 8.18 versus 8.32 without the 1986 age compositions). Between these two models runs, the estimate of survey catchability also differed, which explains some of the change in recruitment and spawning biomass levels (1.17 for Model 16.0b and 1.29 for the same model without the 1986 survey age composition).

In last year's assessment we also conducted a sensitivity analyses of time-varying selectivity for the survey as suggested by the BSAI Plan Team. Initial explorations allowed for a separate selectivity pattern for 1986 and included the 1986 survey biomass estimate (The 1986 survey was the most comprehensive of the 1980s surveys). Although the 1986 survey age data may provide useful information on relative year-class strengths, the different survey protocols during the 1980s may warrant allowing a selectivity change for that year. This was tested but failed to improve the model fit to the survey biomass and also had minimal impact on results.

In conclusion, we suggest that that there is no real benefit to including the 1986 survey age composition, and that including these data is inconsistent given that the model does not include the 1986 survey index. We propose to exclude the 1986 survey age composition in future assessments.

Further evaluations of the Francis weights and selectivity changes

In this section we attempt to address SSC and Plan Team requests 3, 4, and 5 (above) all dealing with aspects of fishery selectivity variability. For item 3 (documenting the procedure for tuning the time-varying selectivity variability), we distinguish the tuning of the sample sizes given constant or other rigid selectivity/separable fishing mortality patterns, from the method introduced last year in which the allowance for time-varying selectivity variability (σ_{f_sel}) was tuned using the Francis weighting method (Francis 2011, equation TA1.8) on the fishery age composition data. This is analogous to the tuning with Francis weights that were used to determine samples sizes in Lowe *et al*. (2017). This was done in an effort to satisfy the request to arrive at a statistical approach for specifying the degree of time-varying selectivity. While this requires fixing the assumption that the input fishery sample sizes have a mean value of 100, we argue that this is a reasonable way to arrive at a balance between process and observation error. We consider that the mean input sample size for the fishery age composition is reasonable (mean=100) and that the lack of fit (or potential overfitting) could be adjusted by finding the appropriate level of interannual variability in selectivity. The procedure for tuning the degree of time-varying selectivity variability given input samples sizes was done iteratively by simply adjusting the variance term for selectivity variability (σ_{f_sel}) to achieve a "Francis weight" of 1.0 (or nearly). Typically, this was achieved in 3-4 iterations, and was done by manually editing the variance terms (which could differ by year, but for this case, were set to be the same for each year within a trial run). The original documentation for the smoothness (second differencing) penalty (L_2) was provided in Appendix Table C-3 of the 2017 (and previous) assessments as:

$$L_2 = \sum_l \lambda_2^l \sum_{j=1}^{A} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2 ,$$

where λ is the weight for the prior on smoothness for selectivities. The index l is equal to s or f for survey or fishery selectivity respectively (in this case it is f). The index j denotes age with A being the maximum age modeled. The parameter η is the age effect for fishery selectivity.

However, in previous assessments we omitted discussion of how the σ_{f_sel} parameter relates to this equation. The relationship between σ_{f_sel} and λ_2^l is:

$$\lambda_2^l = \frac{1}{2\sigma_{f_sel}^2}.$$

Regarding selectivity variability adjustments relative to results, we suggest that tuning by adjusting the σ_{f_sel} term provides a defensible statistical approach to setting the degree of selectivity variability (and thereby perhaps better track age-specific fishing mortality), assuming the effective sample size (to include overdispersion) is approximately correct. In contrast, other approaches, e.g., constant or blocked selectivity specifications, would require downweighting the fishery age composition data, thereby implicitly accepting that the "model is correct" and the data are problematic. We consider the fishery age data to be the most robust of the data inputs.

Item 4, (request to continue to examine periods where fishery selectivity could reasonably assumed to be the same) was initially explored in the 2017 assessment. We addressed previous SSC and Plan Team comments to turn off time-varying selectivity and apply time blocks for fishery selectivity together in a preliminary sensitivity analysis (Lowe *et al*. 2017, Model 16.0c), using blocks of years within which selectivity was time-invariant for the periods:

1977-1983 Foreign fishery
1984-1991 Joint venture fishery
1992-1998 Domestic fishery and 3-subarea split

1999-2010 Steller sea lion regulations
2011-2014 Steller sea lion RPAs
2015-2017 revised Steller sea lion RPAs

These periods were identified as ones having different management measures and spatial closures. However, the model performance was relatively low given model fits (e.g., to survey data) and assumptions about the level of observer sampling. Results from preliminary investigations implementing blocked selectivity were unsatisfactory and appeared to miss age-specific targeting and recruitment events (Lowe *et al*. 2017). Results of the estimated selectivity patterns for the time blocks selected tended to obscure confirmed significant recruitment events, and or the selectivity for the block was based on a pattern that was only evident in the fishery catches for a short time period (less than the number of years in the block). We continued the exploration of time blocks adding an additional time block within the 1999-2010 time period to account for changes in the fishery from Amendments 78 and 80:

1999-2005 Steller sea lion regulations
2006-2010 Steller sea lion regulations, Amendments 78 and 80

Amendment 78 to the BSAI Groundfish FMP closed a large portion of the Aleutian Islands (AI) subarea to nonpelagic trawling. The Amendment 78 closures to nonpelagic trawling included the AI Habitat Conservation Area (AIHCA), the AI Coral Habitat Protection Areas, and the Bowers Ridge Habitat Conservation Zone, located in the northern portion of Area 542 and 543. These closures were implemented on July 28, 2006. These closures were in addition to the Steller sea lion protection measures and, in combination, substantially limited the locations available for nonpelagic trawling in the AI subarea. Amendment 80 to the BSAI Groundfish FMP was adopted by the Council in June 2006 and implemented for the 2008 fishing year. This action allocated several BSAI non-pollock trawl groundfish species (including Atka mackerel) among trawl fishery sectors, facilitated the formation of harvesting cooperatives in the non-American Fisheries Act (non-AFA) trawl catcher/processor sector, and established a limited access privilege program (also referred to as a catch share program). BSAI Atka mackerel is one of the groundfish species directly affected by Amendment 80.

As expected, the fits to the fishery age composition were degraded when time-varying selectivity was dropped and replaced with periods where selectivity was held constant for specific periods. Adding an additional "time block" to the blocked selectivity model resulted in only minor (negligible) improvements to the fit to the fishery age compositions (Figure 6 compared to Figure 7). The fit to the survey was slightly worse and the spawning biomass and apical fishing mortality rates differed significantly compared to last year's model (Model 16.0b) with time-varying selectivity (Figure 8). The selectivity patterns can have a large impact on the reference fishing mortality rates, and Atka mackerel have been shown to be sensitive to assumptions about selectivity (Lowe *et al*. 2008, Lowe *et al*. 2013). For example, previous investigations incorporating annual time-varying approach for fishery selectivity allowed the model flexibility to better reflect the fishery age composition data and provided results consistent with fishery age distributions (Lowe *et al*. 2013). Also, it seems reasonable that some selectivity variability would occur given year-class variability (SigmaR= 45-50% in recent years), and the fact that the fishery may seek out higher catch-rate areas where such strong year-classes may be present (and hence have higher peak fishing mortalities as shown in Figure 8). Therefore, we suggest that the time varying selectivity option be retained. Further explorations of statistical aspects of tuning the time-varying selectivity variance term (σ_{f_sel}) with the Francis (2011) method are provided below.

For request 5 listed above, the Plan Team suggested looking at how tuning the selectivity variability parameter affects results if a higher or lower sample size was assumed for the fishery. The 2017 model assumed a mean sample size of 100 for the time period of observer data 1991-2016 (scaled based on the number of tows sampled). To fulfill this request we rescaled all the input sample sizes to half (50) and

double (200) that assumption. Tuning the selectivity variability parameter for these two new cases resulted in expected differences in the amount of selectivity variability in the fishery (Figures 9, 10, and 11). These runs also affected recruitment estimates i.e., when a higher sample size was specified, the selectivity varied more (Figure 11) and interannual variability of recruitment increased (Figure 12). For the most part, recruitment estimates for sample sizes of 50 and 100 were relatively similar, but increasing the sample size to 200 significantly lowered recruitment estimates (Figure 12). This is consistent with the expectation that greater "targetting" of specific year-classes results in higher values for the above-average year-classes compared to separable assumptions that selectivity/availability of cohorts are more even.

The relative impact expected in projections is explored by comparing the estimated recent 5-year average selectivities assuming mean fishery sample sizes equal to 50, 100, and 200. Figure 13 shows that the tuned models under different fishery sample size assumptions result in different age-specific selectivity estimates, particularly for ages between 3 and 8 years. The fishery catches essentially consist of fish 3-11 years old. Fish older than age 9 make up a very small percentage of the population each year, and the differences in the selectivity assumptions for older ages are not likely to have a large impact. However, differences in selectivity for ages 3-8 can have a significant impact. These differences will impact the F_{SPR} estimates and consequently the ABC and OFL values. Higher sample size result in shifts in selectivity to the right, relative to maturity-at-age, which is associated with higher F_{SPR} reference rates. For example, the $F_{40\%}$ value for the higher input sample size was 0.43 compared to 0.42 and 0.40 for input mean sample sizes of 100 and 50, respectively. Comparing projections for these three scenarios show the spawning biomass as being highest for the low input sample size resulting in higher catches based on the ABC control rules (Figure 14).

Age-specific natural mortality

We previously conducted preliminary explorations of alternative formulations of age-specific natural mortality (M) specified outside the assessment model (Lowe and Ianelli 2016; unpublished data). Alternatives included the Lorenzen model (Lorenzen, 1996), and the M-at-age formulation suggested in the report of the Natural Mortality Workshop held in 2009 (the "best ad-hoc mortality model" in that report [see Brodziak *et al.* 2011]). In response to request 7 (continue investigation of age-specific natural mortality), we include a third method (Gislason, 2010) in a further investigation of age-specific M, and use a rescaled average vector of M for model evaluation. These three methods are initially based on theoretical life history and or ecological relationships that are then evaluated using meta-analysis, resulting in an empirical equation relating M to more easily measured quantities of length and weight. The three methods used in this analysis are:

Brodziak et al. (2011)—Age–specific M is given by

$$M(a) = \begin{cases} M_c \dfrac{L_{mat}}{L(a)} & for \quad a < a_{mat} \\ M_c & for \quad a \geq a_{mat} \end{cases}$$

where L_{mat} is the length at maturity = 36.77 cm (age 5, 90% maturity), M_c = 0.30 is the specified natural mortality at L_{mat} , L(a) is mean length at age for the 2010-2016 Aleutian Islands summer bottom trawl surveys.

Lorenzen (1996)—Age-specific M for ocean ecosystems is given by

$$M\,(a) = 3.69\ W^{-0.305},$$

where W is the mean weight at age from the 2010-2016 Aleutian Islands summer bottom trawl surveys.

Gislason et al. (2010)—Age specific M is given by

$$\ln(M) = 0.55 - 1.61 \ln(L) + 1.44 \ln(L_\infty) + \ln(K),$$

where L_∞ = 43.23 cm, and K = 0.384 were estimated by fitting the von Bertalanffy growth curve using age data from the 2010-2016 Aleutian Islands summer bottom trawl surveys.

Results of age-specific natural mortality estimates from the three methods described above were relatively consistent and suggested higher mortality rates for age classes younger than the age at maturity, particularly for ages 1-2 (Table 1). To obtain an age-specific natural mortality schedule for further investigation, we used an ensemble approach and averaged the results for all three methods. We then used the method recommended by Clay Porch in Brodziak *et al*. (2011) to rescale the average age-specific values so that the average M for a range of ages equals a specified value (Porch, 2011). The average age-specific values were rescaled so that natural mortality for fish greater than or equal to age 4.5, the age at 90% maturity, was equal to 0.3, the value of natural mortality used in previous Atka mackerel assessments (Table 1). This rescaled average schedule was used to explore the impact of higher age-specific mortality for the younger ages.

Spawning biomass for the age-specific natural mortality shows a shift to higher totals relative to the 2017 assessment model (Figure 15). Projections from the age-specific natural mortality model run showed minor increases in ABC (<3%), which on investigation, was consistent with the relatively minor differences in natural mortality between the two models for the "most" selected age groups (Figure 16). Notably, the biggest difference was for age-1 recruits which are impacted by higher values of M but have low impact to stock dynamics given selectivity and maturity schedules (Figure 17).

The following table of negative log-likelihood values compares components between last year's assessment model and one modified with age-specific natural mortality.

	2017Assessment	Age-specific natural mortality
Fishery age composition	160.38	127.14
Selectivity regularity	140.08	99.09
Survey index	8.43	8.2
Survey age composition	28.29	27.87
Stock recruitment	4.15	-5.77
Prior on survey q	1.47	0.44

In summary, the implementation of age-specific natural mortality improved model fits for some components, particularly the fishery age composition and stock recruitment components. The largest impacts of age-specific M is on the younger ages, particularly for ages 1 and 2 with estimated values of M of 1.04 and 0.56, respectively (Table 1). The model has a lot of flexibility for age 1 recruitment, and the high estimated M for age 1 is accommodated by greatly inflated estimates of age 1 recruitment (Figure 17). Although spawning biomass estimates are scaled higher relative the the 2017 assessment with constant M, biological reference rates and the associated ABC and OFL reflect only minor increases. The age at 50% selectivity for both models is about age 4.5, natural mortality and selectivity schedules are nearly indentical for ages greater than age 4 (Figure 16). Although estimates of age 1 recruitment differ greatly between the 2 models, age 1 recruits have low impact to stock dynamics given selectivity and

maturity schedules for Atka mackerel (Figure 16). As such, we are not clear that a model configuration with age-specific mortality is an improved representation for Atka mackerel stock dynamics than the currently accepted model with constant M=0.3. The natural mortality estimate of 0.3 is a conservative assumption and based on a previous meta-analysis (Lowe and Fritz, 1997). This value seems to fit reasonably well with other key estimated parameters (e.g. survey catchability and selectivity). We suggest continuing with the current accepted model (Model 16.0b) with the assumption of fixed constant M=0.3, and to focus our efforts on other aspects of the Atka mackerel assessment model.

Literature Cited

Brodziak, J., Ianelli, J., Lorenzen, K., and Methot R.D. Jr. (eds) (2011) Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119, 38 p.

Francis, R.I.C.C 2011. Data weighting in statistical fisheries stock assessment models. Can. Journ. Fish. Aquat. Sci. 1138: 1124-1138.

Gislason, H., N. Daan, J. C. Rice and J. G. Pope. 2010. Size, growth, temperature and natural mortality of marine fish. Fish and Fisheries 11:149-158.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49:627-647.

Lowe, S. and J. Ianelli. 2016. *Unpublished report*. Assessment evaluations for the Atka mackerel stock in the Bering Sea/Aleutian Islands. Alaska Fisheries Science Center, 7600 Sand Point Way NE, Building 4, REFM, Seattle, WA 98115

Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2008. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2013. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S., J. Ianelli, W. Palsson. 2017. Stock assessment of Aleutian Islands Atka mackerel. *In* Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Lowe, S.A. and L.W. Fritz. 1997. Atka mackerel. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions as Projected for 1999. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, AK.

Porch, C. 2011. Abstract #12: Rescaling the Lorenzen natural mortality curve: issues from the Southeast Data Assessment and Review. *In* Brodziak, J., Ianelli, J., Lorenzen, K., and Methot R.D. Jr. (eds) (2011) Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119, 38 p.

Tables

Table 1. Schedule of alternative approaches to specifying specific natural mortality rates-at-age. The "Rescaled Average" was used for evaluations.

Age	Length (cm)	Weight (g)	Brodziak *et al*. (2011)	Lorenzen (1996)	Gislason *et al*. (2010)	Average	Rescaled Ave.
1	14.09	45	0.76	1.00	2.13	1.30	1.04
2	23.38	168.25	0.46	0.69	0.94	0.70	0.56
3	29.71	391	0.36	0.54	0.64	0.51	0.41
4	34.02	538.5	0.31	0.49	0.52	0.44	0.35
5	36.96	663	0.30	0.46	0.45	0.40	0.32
6	38.96	725.5	0.30	0.45	0.41	0.39	0.31
7	40.32	837.75	0.30	0.43	0.39	0.37	0.30
8	41.25	934.5	0.30	0.42	0.38	0.37	0.29
9	41.88	918.5	0.30	0.42	0.37	0.36	0.29
10	42.31	893.75	0.30	0.42	0.36	0.36	0.29
11+	42.60	1024.25	0.30	0.41	0.36	0.36	0.29

Figures

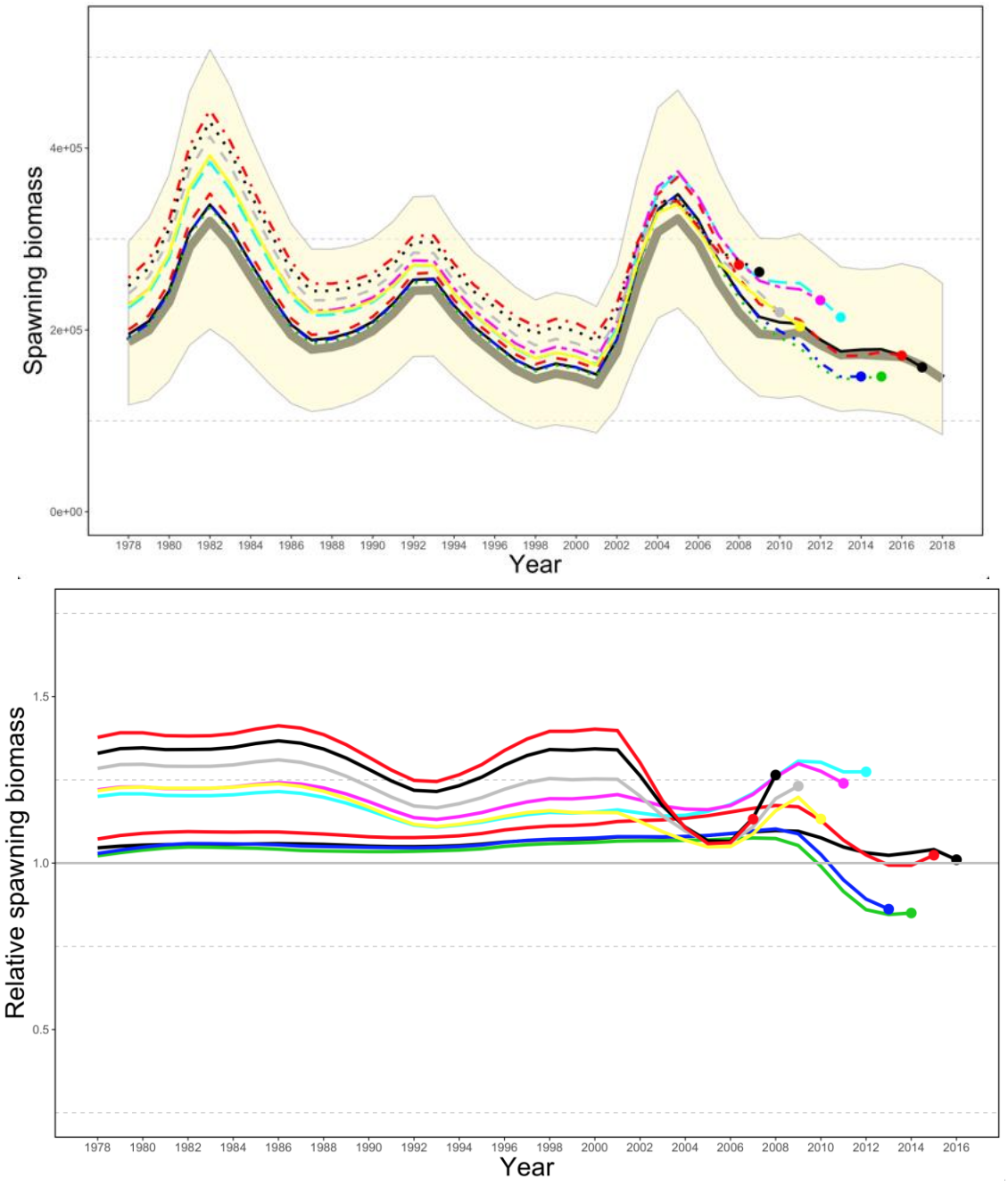


Figure 1. Retrospective plots showing the BSAI Atka mackerel spawning biomass over time (top) and the relative difference (bottom) over 10 different "peels".

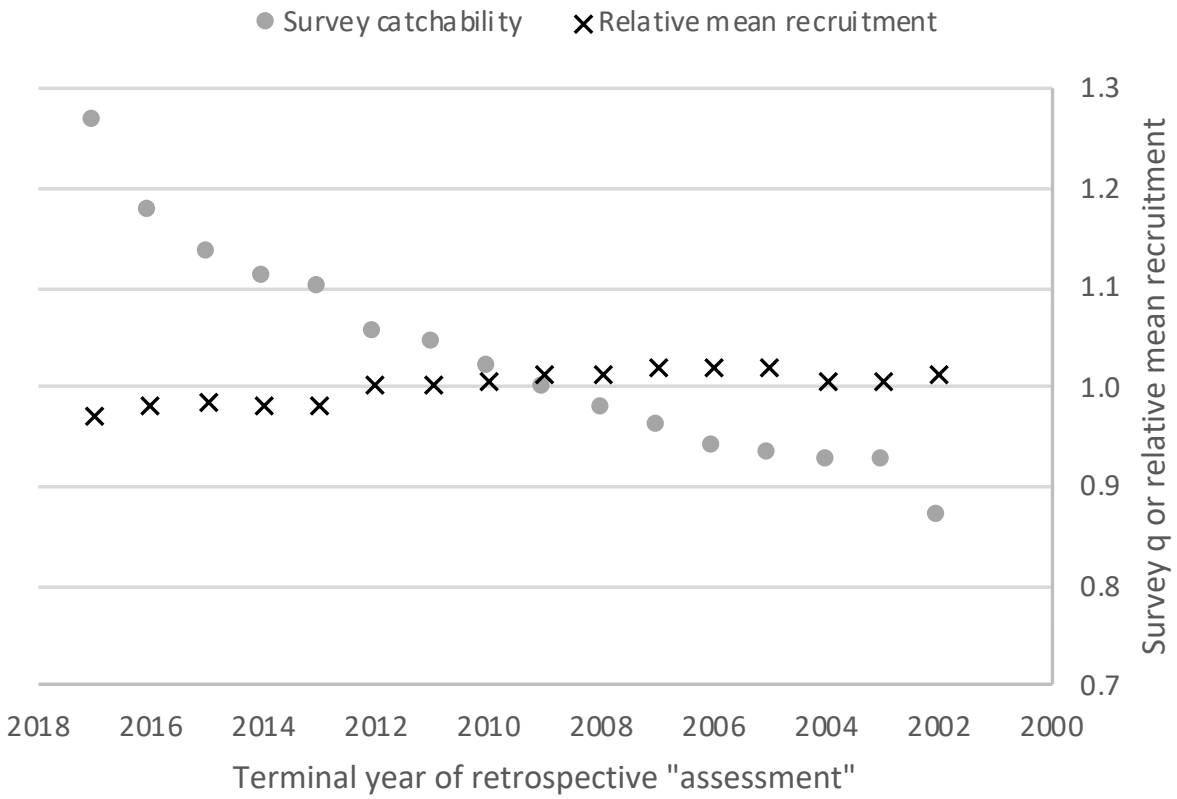


Figure 2. Atka mackerel Aleutian Islands bottom trawl survey catchability (q) and mean recruitment (rescaled to have mean of 1.0) over different retrospective model runs. Horizontal axis (in reverse order) represents the terminal year of the retrospective model run.

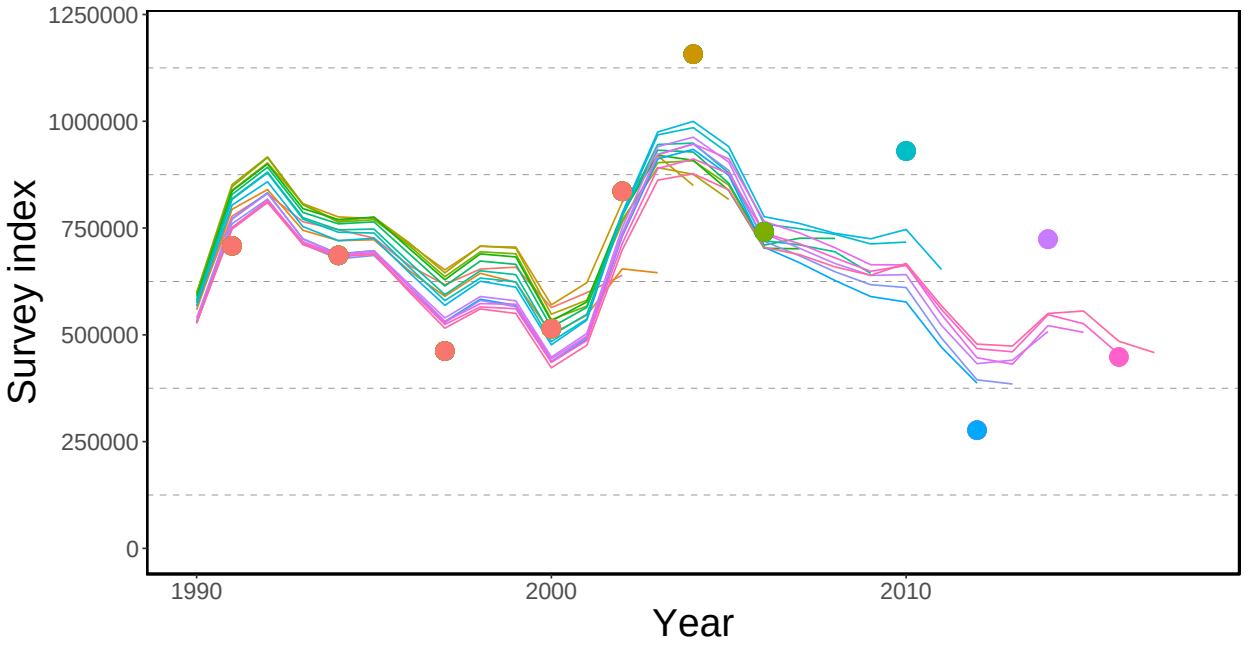


Figure 3. Fit to survey data (dots) relative to retrospective run model fits (lines). Note that each run estimates survey catchability (and age-specific selectivity) independently, hence the pattern may or may not reflect changes in absolute biomass estimates.

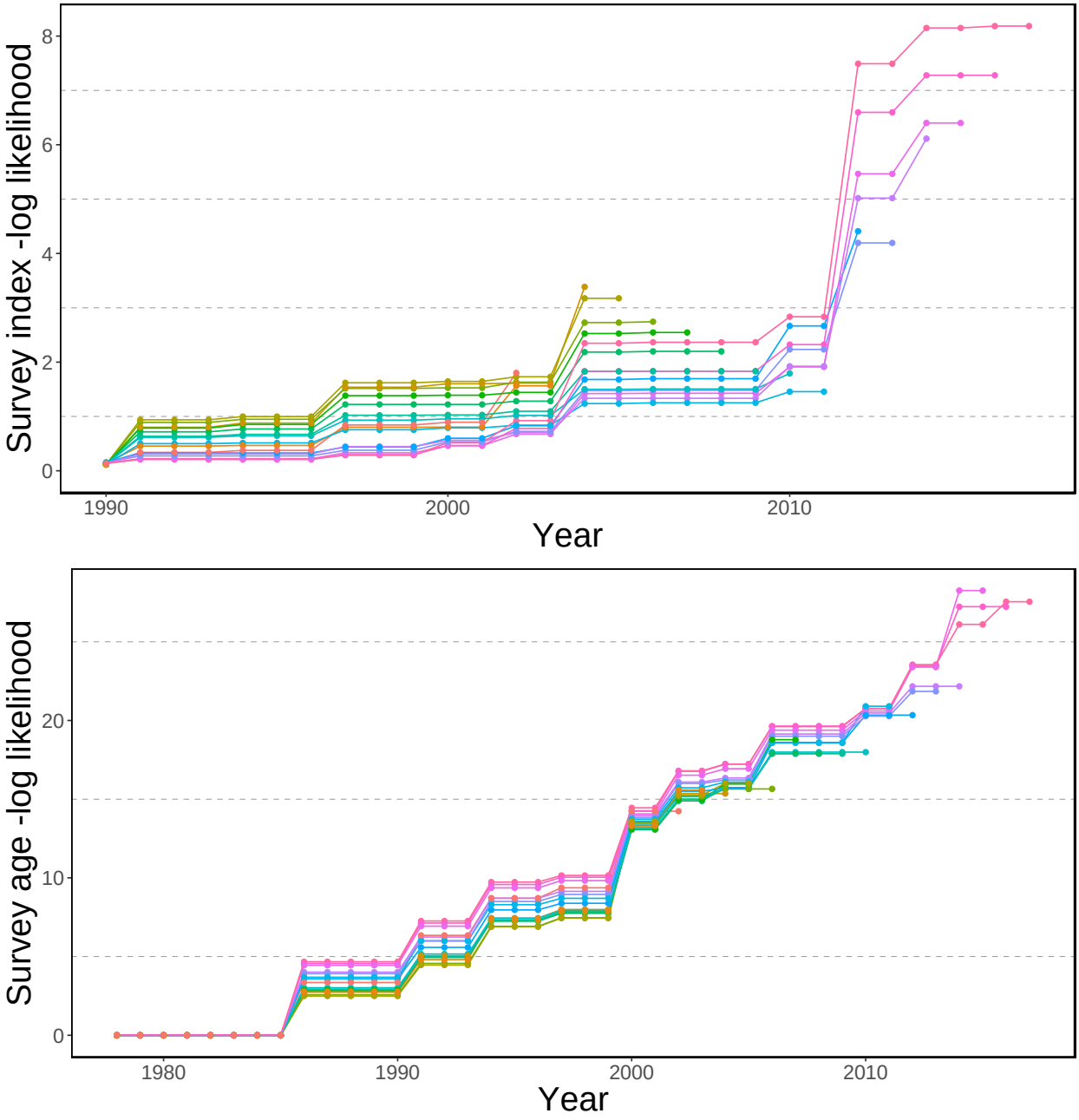


Figure 4. Cumulative negative log-likelihood for survey index data (top), and survey age composition (bottom) for retrospective model runs.

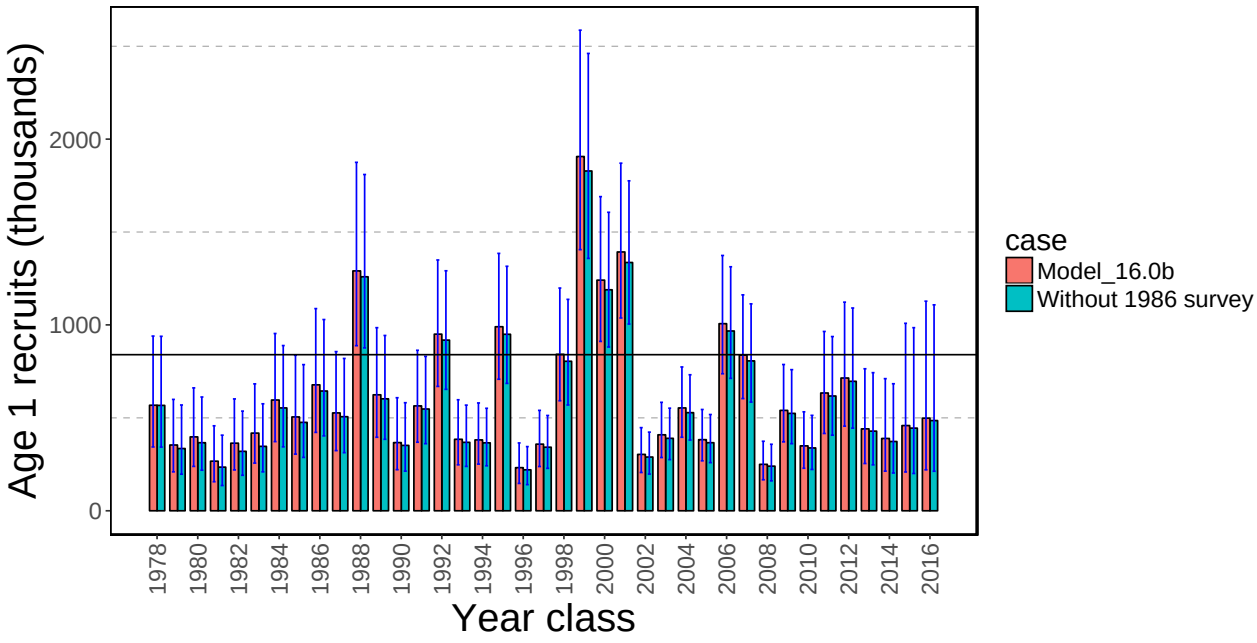


Figure 5. Recruitment estimates (age 1) with, and without the 1986 survey age composition included. Model 16.0b is last year's model configuration including the 1986 survey age composition. The solid line is the mean recruitment estimate for Model 16.0b.

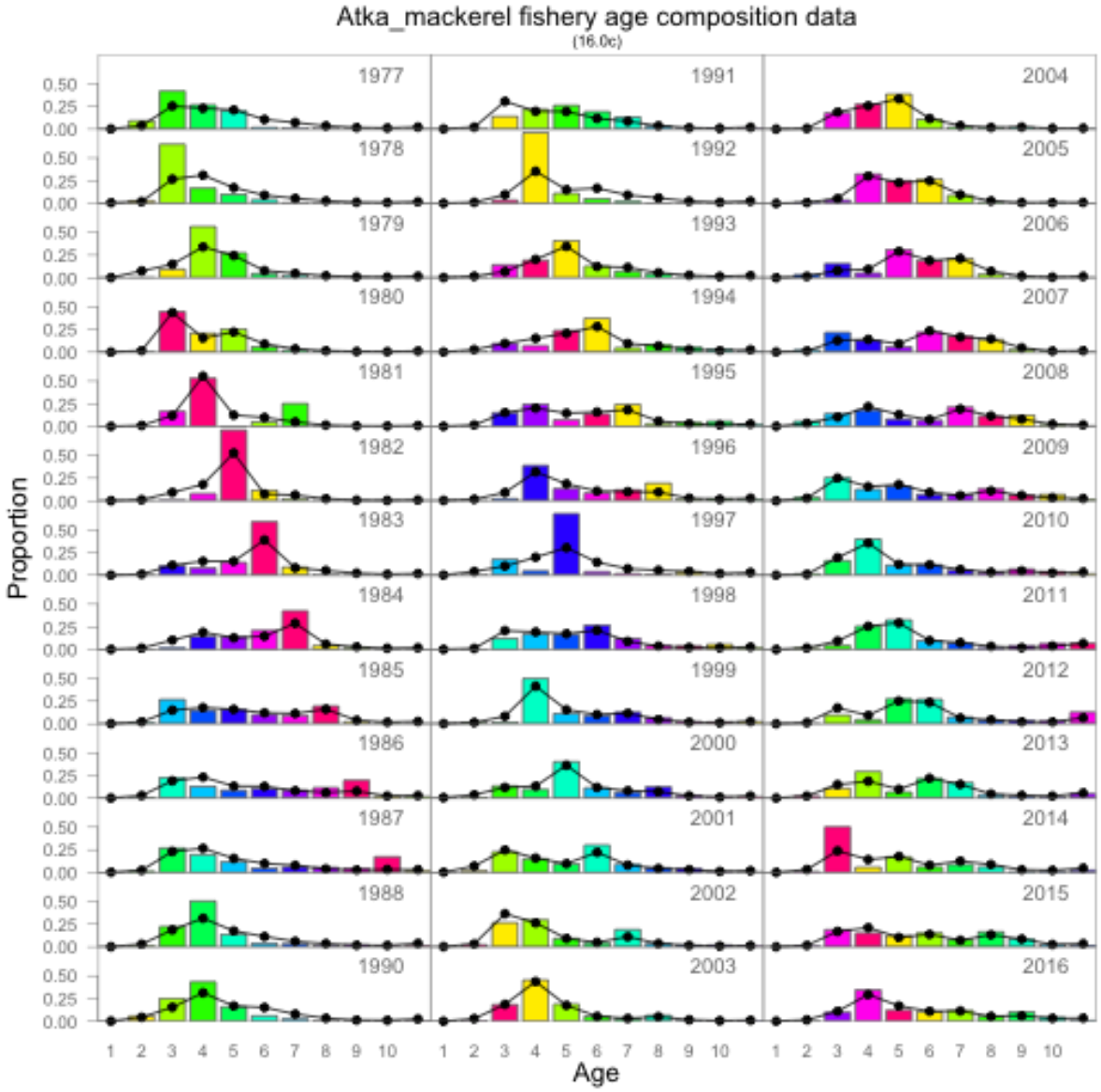


Figure 6. Model fits for configuration 16.0c as in the 2017 assessment, without an added block of selectivity in 2000-2005 period for BSAI Atka mackerel.

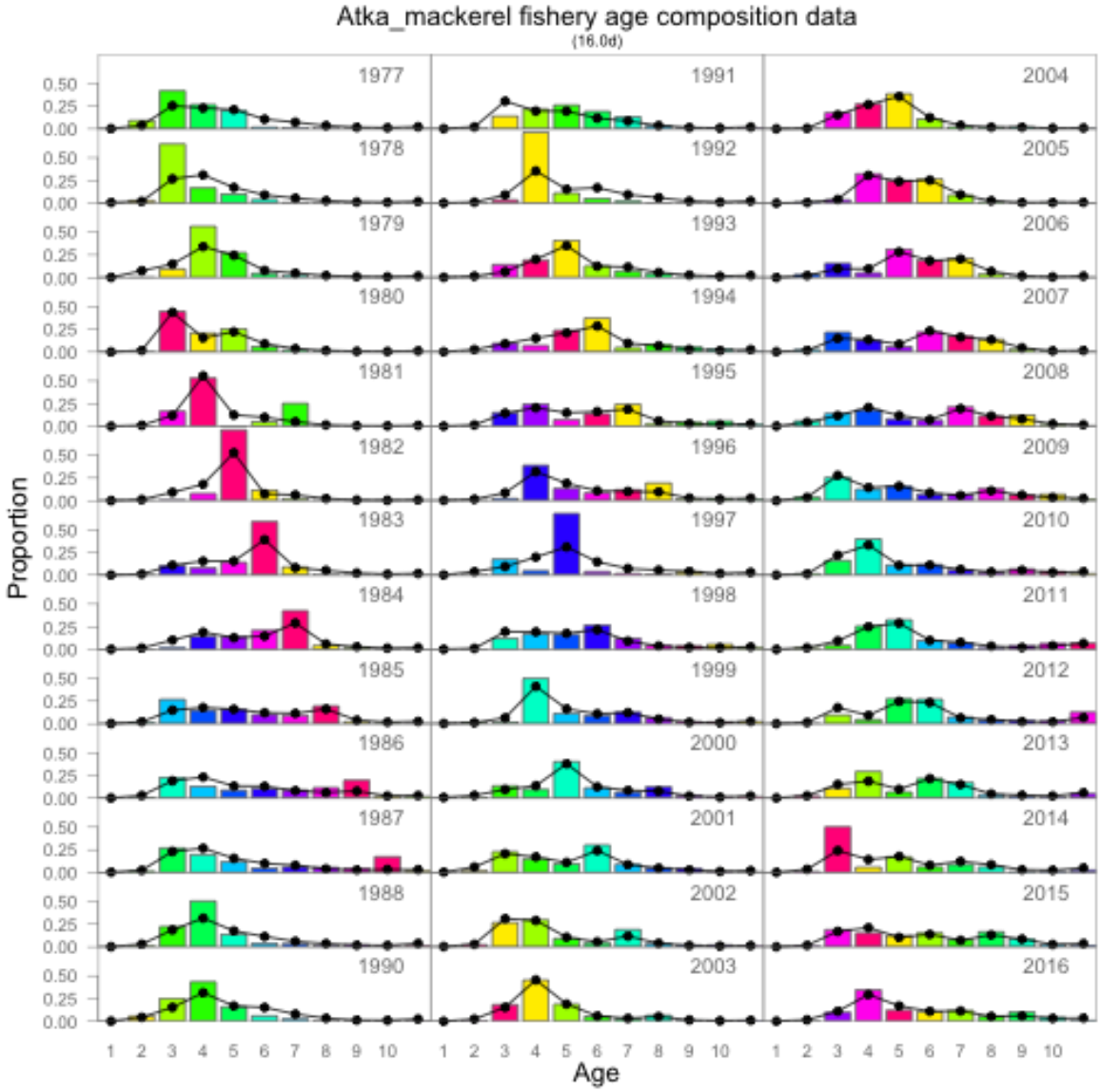


Figure 7. Model fits for configuration 16.0d with an added block of selectivity in the 2000-2005 period for BSAI Atka mackerel.

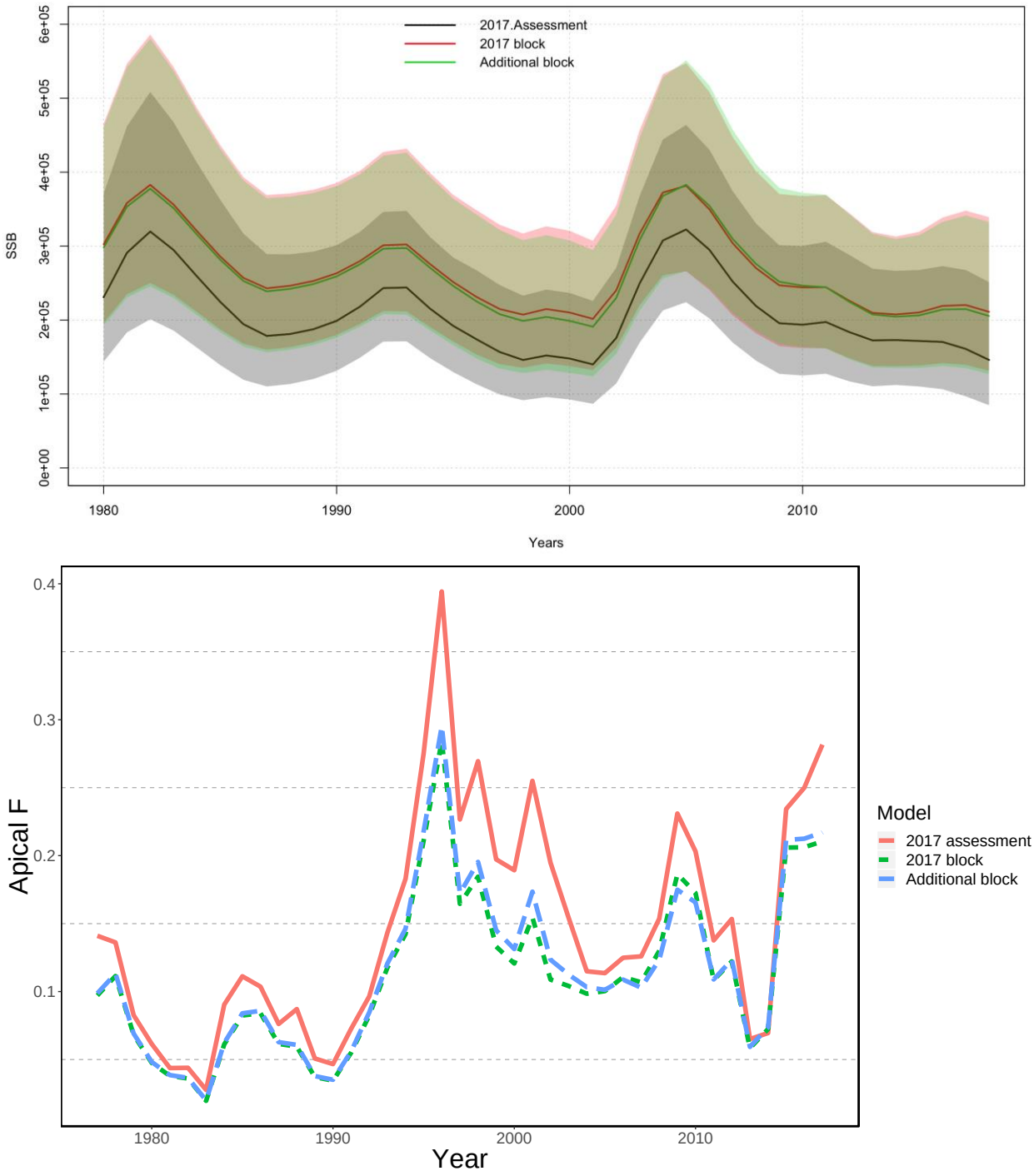


Figure 8. Spawning biomass (top) and apical fishing mortality (bottom) for the 2017 selected assessment model configuration (Model 16.0b) with time-varying fishery selectivity, and alternative selectivity blocking schemes.

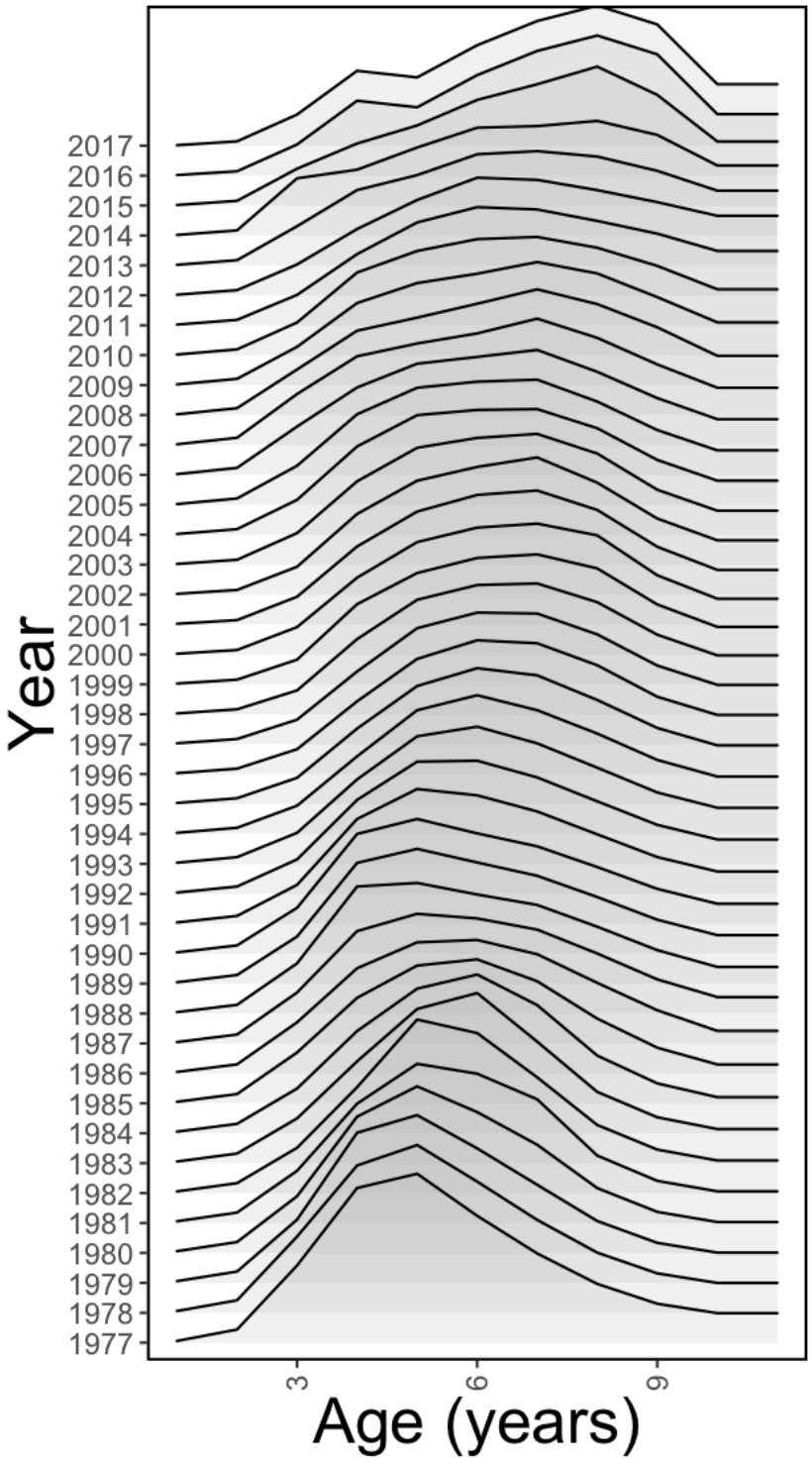


Figure 9. Selectivity estimates with mean 1991-2016 sample size equal to 50 and Francis (2011) weights tuned to approximately 1.0.

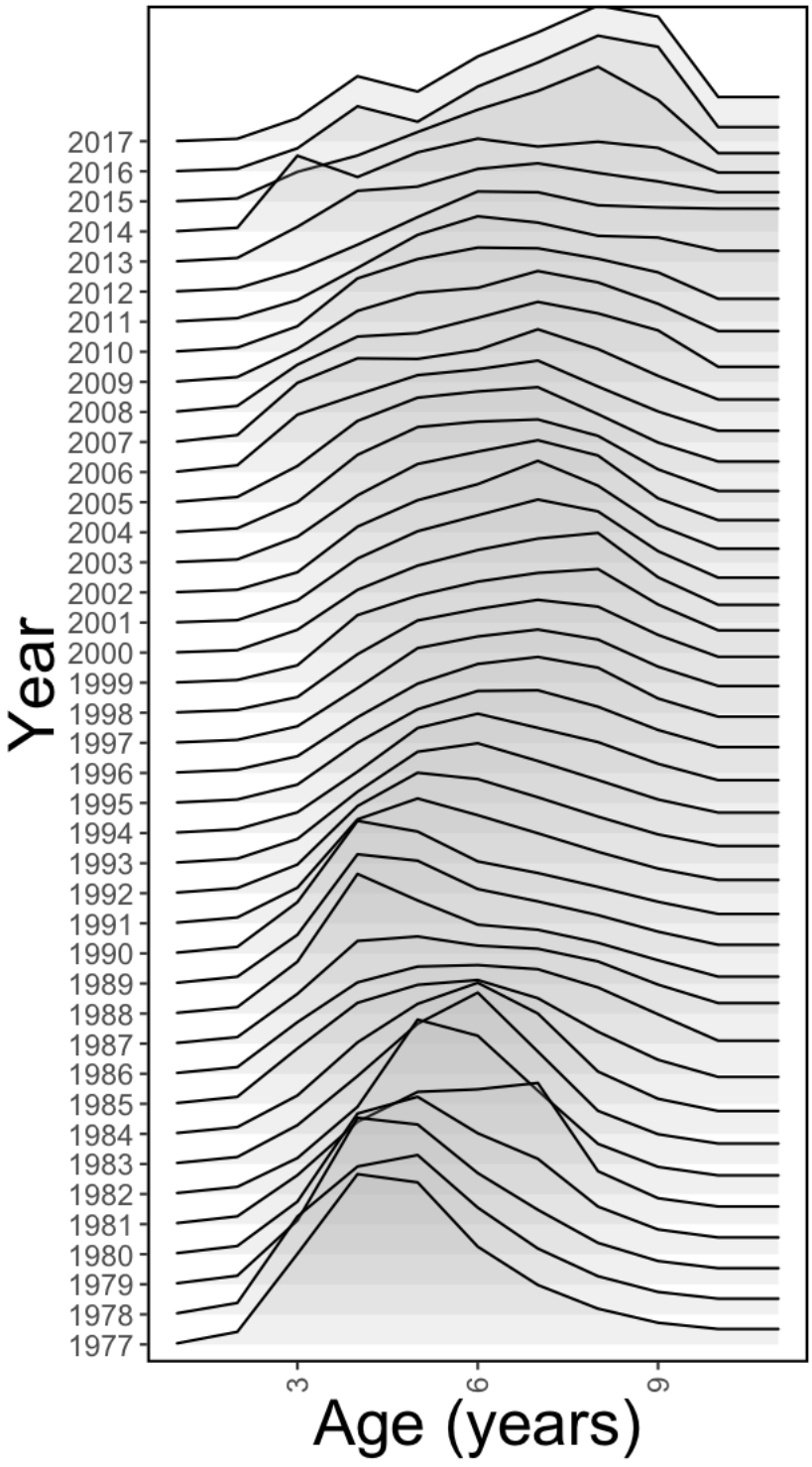


Figure 10. Selectivity estimates with mean 1991-2016 sample size equal to 100 and Francis (2011) weights tuned to approximately 1.0 (Model 16.0b used in 2017 assessment).

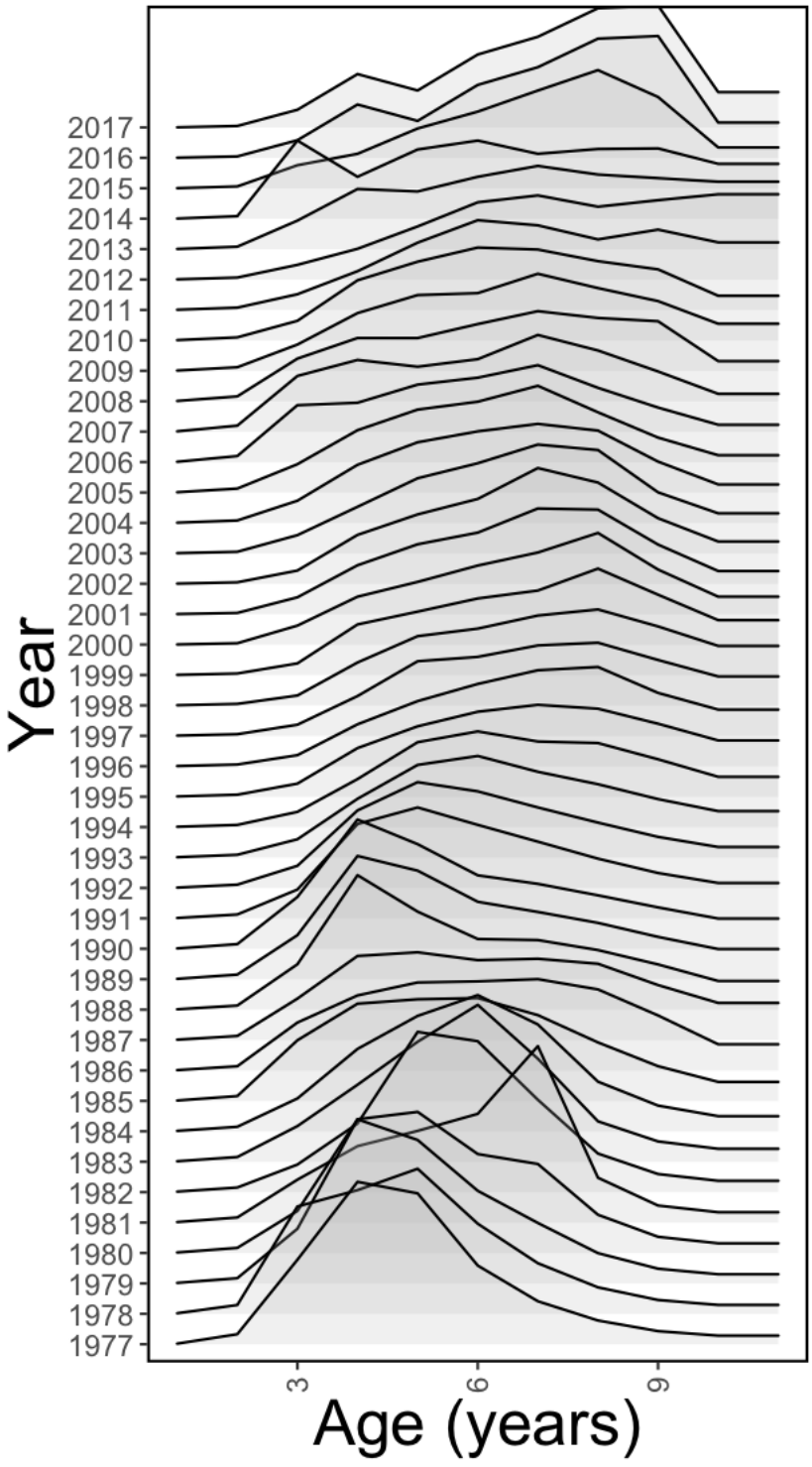


Figure 11. Selectivity estimates with mean 1991-2016 sample size equal to 200 and Francis (2011) weights tuned to approximately 1.0.

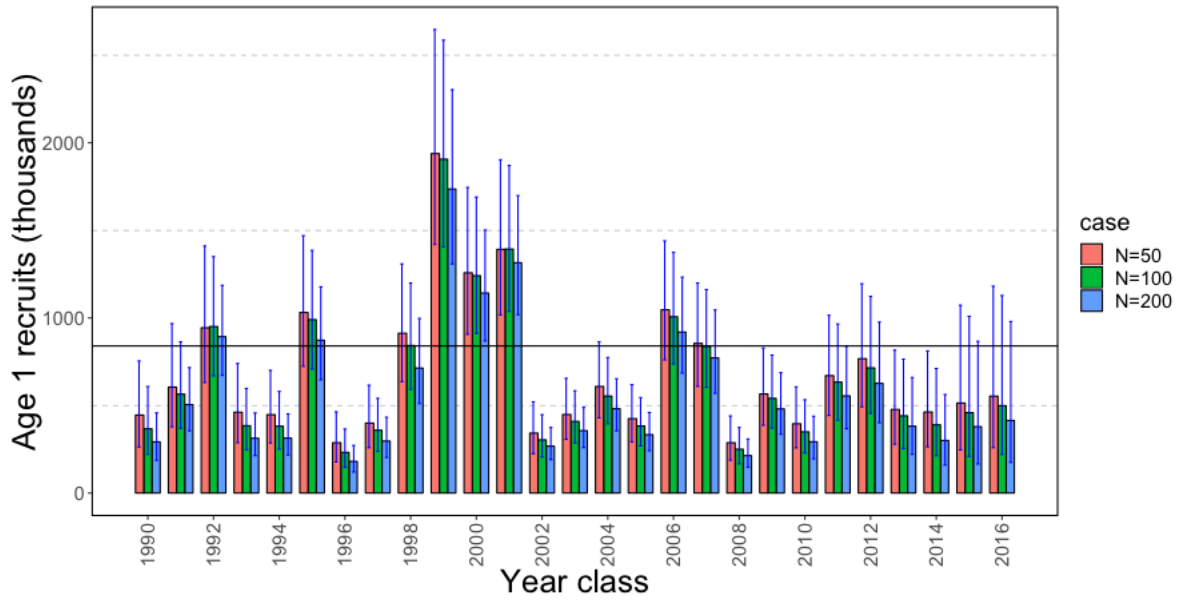


Figure 12. Estimated BSAI Atka mackerel age 1 recruitment under different assumptions about mean 1991-2016 fishery sample sizes comparing values of 100 (used in the 2017 assessment), and alternative mean 1991-2016 sample sizes equal to 50 and 200, and Francis weights tuned to approximately 1.0

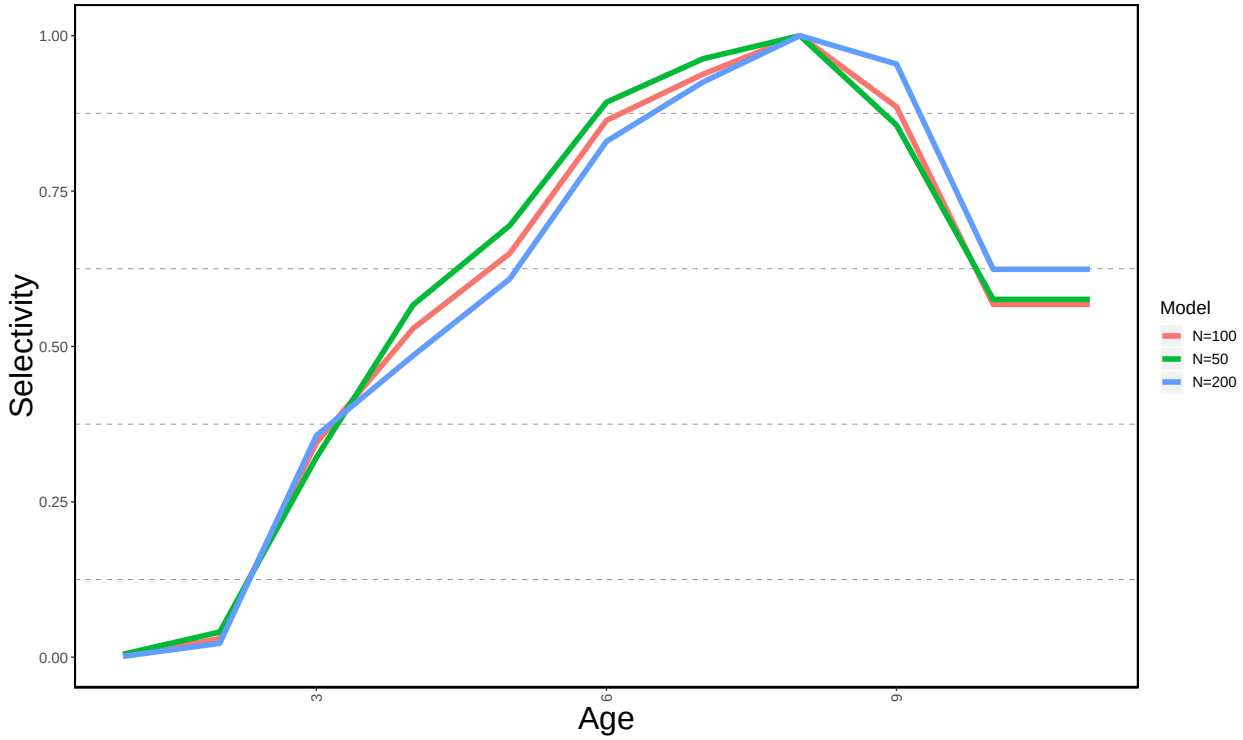


Figure 13. Average (2012-2016) selectivity at age estimates for different tuned model runs with mean 1991-2016 fishery sample sizes equal to 100 (used in the 2017 assessment), and alternatives with selectivity variability tuned to mean 1991-2016 fishery sample sizes equal to 50 and 200.

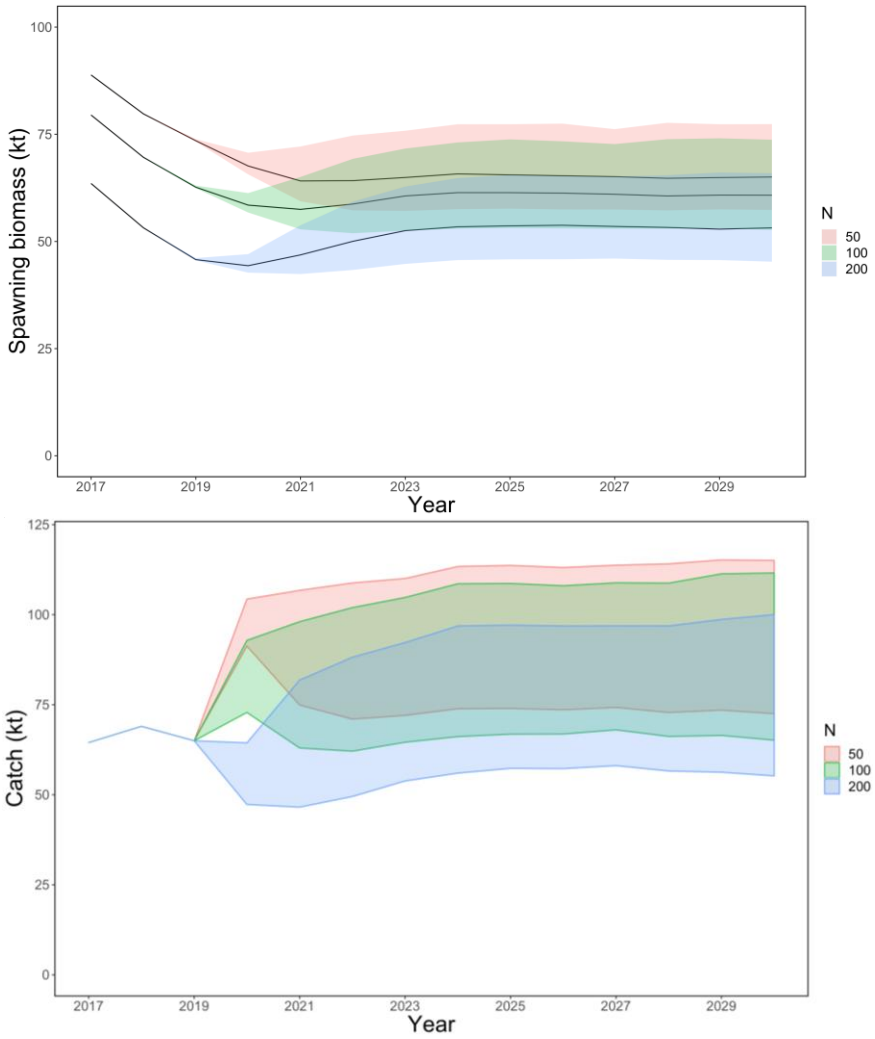


Figure 14. Projections of spawning biomass (top) and fishery catch (bottom) for different tuned model runs with mean 1991-2016 fishery sample sizes N=100 (used in 2017 assessment) and alternatives with time-varying selectivity variability tuned to mean fishery sample sizes of N=50 and N=200.

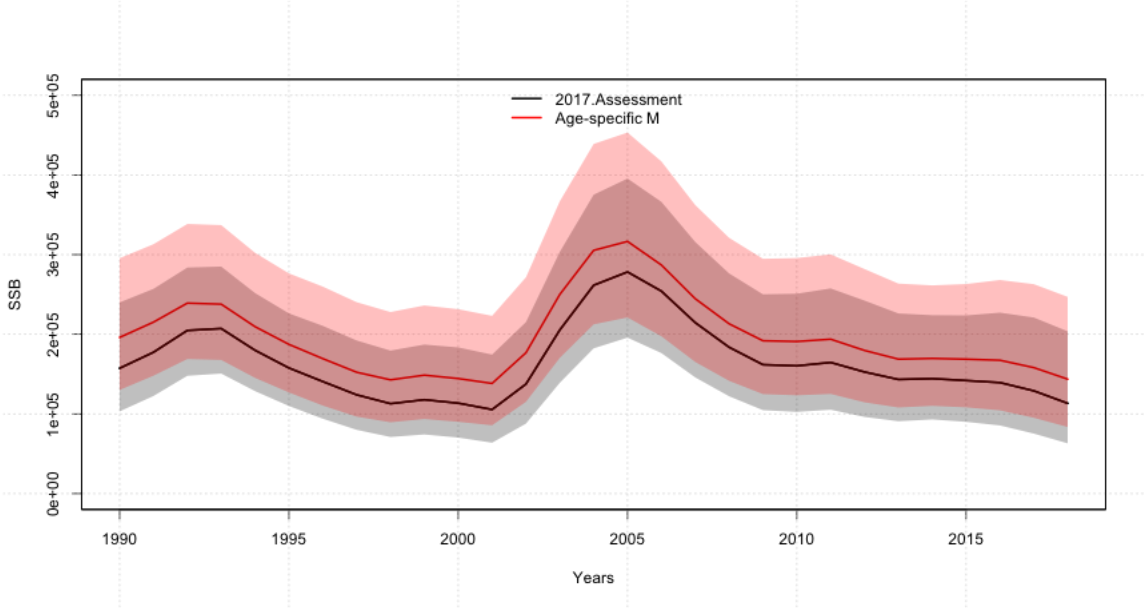


Figure 15. Comparison of Atka mackerel spawning biomass for last year's Model 16.0b (2017 assessment) and one with age-specific natural mortality (*M*) specified.

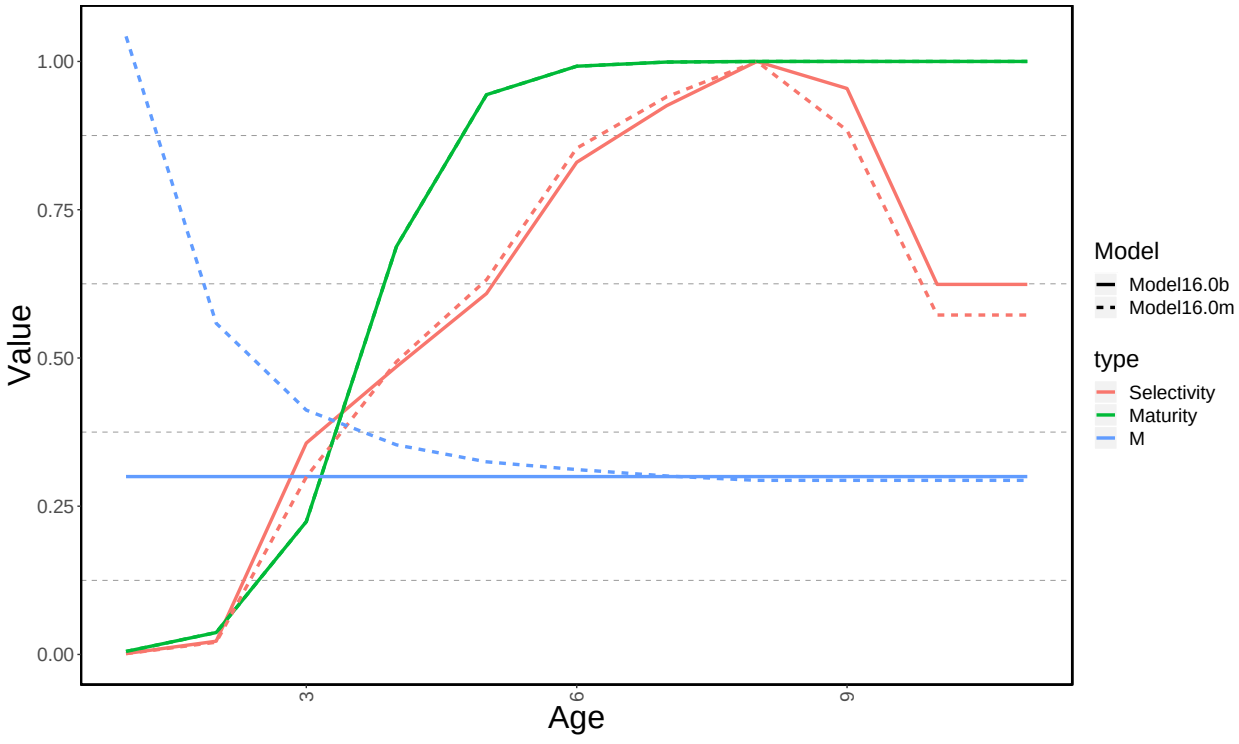


Figure 16. Age-specific schedules for Atka mackerel for the 2017 assessment model (Model 16.0b) and the one with age-specific natural mortality (Model 16.0m).

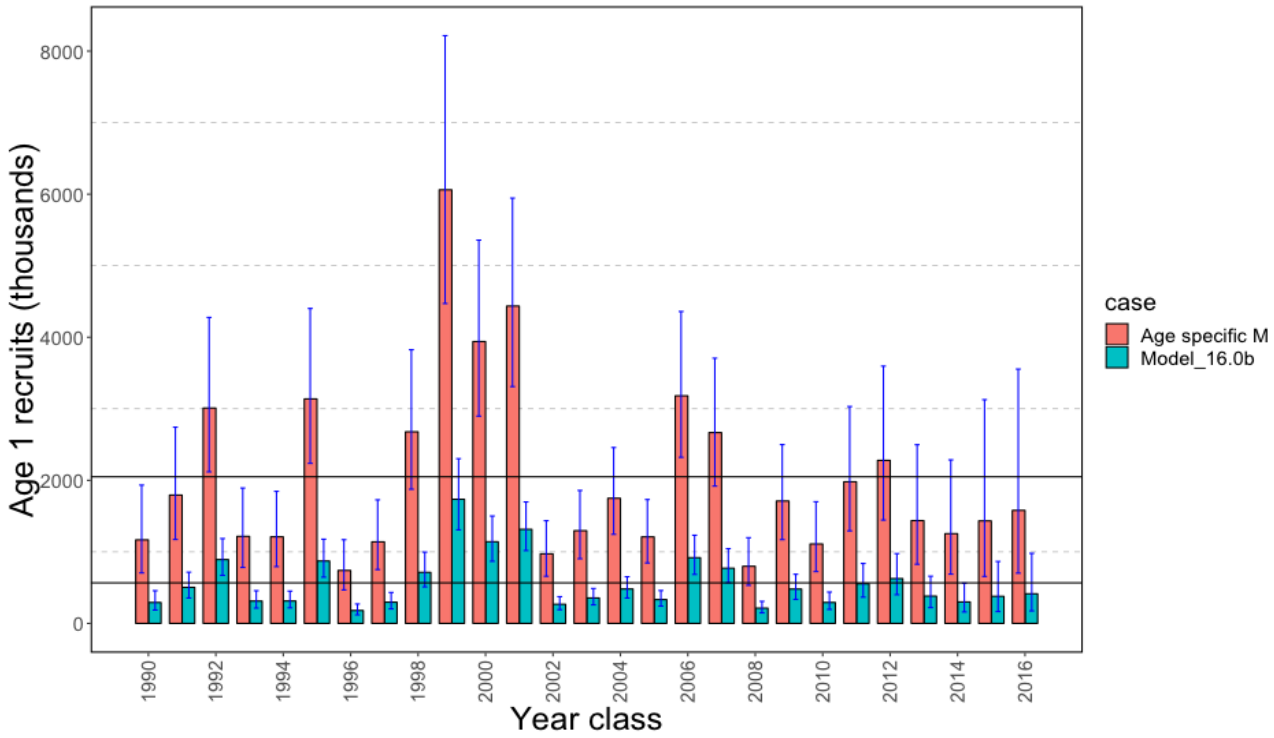


Figure 17. Age 1 recruitment estimates for BSAI Atka mackerel from the 2017 assessment (Model 16.0b, constant M =0.3, and the one with age-specific natural mortality (Model 16.0m).