Evaluation of recruitment estimates in the Bering Sea/Aleutian Islands Blackspotted/Rougheye rockfish assessment, and their management implications

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Executive Summary

Bering Sea/Aleutian Islands blackspotted rougheye rockfish is assessed with an age-structured model for the Aleutian Islands portion of the stock, and a non-age-structured model for the eastern Bering Sea portion of the stock. The following is a list of our concerns or observations regarding the input data, models presented in the 2018 assessment (Spencer et al. 2018), and alternative models considered in this report, for AI portion of the stock.

Drop in abundance of older fish: The number of older fish in the recent AI surveys and fishery catch is less than previous years. The percentage decline of survey abundance of 5 sets of age groups older than 21 years (i.e., ages 21-25, 26-30, 31-35, 36-40, and 40+) ranged between 52% (for ages 40+) and 87% (for ages 21-25) from the 2012 survey to the 2014 survey. Prior to 2015, the proportion of fish aged 23 and older in the fishery catch ranged from 42% (2009) to 92% (2007). In 2015 and 2017, these proportions were reduced to 19% and 9%, respectively.

Mismatch in data vs model total mortality: Cohort-specific mortality rates from the 2018 model are smaller than those estimated directly from survey data (via catch curves), indicating that the model does not have a mechanism for explaining less than expected number of older fish in recent years.

Poor residual pattern: The fit and residual pattern to the AI survey estimate is poor in the 2018 model, with the large biomass estimates from 2000, 2002, and 2012 not well fit by the model.

Mismatch in model versus survey trend: There is an overall decreasing trend in the AI survey biomass trend, yet the 2018 population model shows a strong increase in recent total biomass (i.e., a factor of 4 since ~ 2000).

Changes in magnitude of year-class estimates: The estimate of the 1998 year class has declined from 23.1 million in the 2014 assessment to 7.8 million in the 2018 assessment, indicating an example of the uncertainty in early recruitment estimates.

Population shifts younger: The 2018 model estimates that the current population is young and consists of a relatively small number of year classes with low survey selectivity, with 80% of the 2018 numerical abundance at or below age 16 (ages which have less than 20% survey selectivity). The large year class for 2002 comprises 19% of the 2018 total biomass, and the 2002, 1998, and 1999 year classes comprise about 37% of the total 2018 biomass.

Large inter-assessment changes: Because surveys and full assessment do not occur annually, projected population biomass and harvest specifications in off years or non-survey years are not updated with new survey information that may reduce uncertainty of key year class strengths. The concentration of the

estimated 2018 population into a small number of year classes results in sharp increases in the post-2018 ABC and OFL as the estimated population has grown in size and become more available to the fishery. The 2020 maximum ABC was a 29% increase from the 2019 ABC, and the projected 2021 maximum ABC (from the 2019 partial assessment) is 28% larger than the projected 2020 maximum ABC. These increases are unusual for a long-lived stock, particularly in the absence of major changes to the input data and without a definitive increase in survey biomass estimates.

Positive retrospective bias in recruitment estimates: Models with relatively stronger emphasis on fitting the age/length composition data (i.e., the 2018 model, and exploratory models in this report) did poorly in retrospective analyses with positive biases for recruitment and spawning stock biomass.

A data-weighting method to improve fit to survey index: Alternative data-weighting procedures, such as that proposed by Francis (2011), improve the retrospective bias and produce trends in abundance more consistent with the observed trends in survey biomass.

Our investigation of these issues in this document lead us to recommend that for the November 2020 assessment we pursue:

1) Updating the estimate of natural mortality. Recent research by Then et al. (2015) estimates natural mortality of approximately 0.045 for blackspotted/rougheye rockfish, higher than the estimate of 0.032 used in the 2018 assessment.
2) Updating the ageing error matrix with likelihood-based estimates, based on the method described in Punt et al. (2008).
3) Using Francis (2011) for the weighting composition data in order to reduce retrospective bias for recruitment and spawning stock biomass, and reduce the influence of uncertain estimates of year class strength on assessment results and projected harvest specifications.

Introduction

Bering Sea/Aleutian Islands blackspotted rougheye rockfish is assessed with an age-structured model for the Aleutian Islands (AI) portion of the stock, and a non-age-structured model for the eastern Bering Sea portion of the stock. The current assessment of AI portion of the stock is characterized by a strong conflict between the AI survey biomass estimates and the age/length composition data. The survey biomass estimates show a generally decreasing trend, although the model fits (influenced by the age/length composition data) suggest the stock has been rapidly increasing in recent years. In the 2018 assessment two methods of weighting the composition data were considered (models 18.1 and 18.2). Model 18.1 uses the McAllister-Ianelli (1997) weighting method, and gives relatively greater emphasis on fitting the composition data, whereas Model 18.2 uses the Francis (2011) method and gives relatively less emphasis on fitting the composition data and more emphasis to the survey biomass estimates. The SSC selected Model 18.1 for management, which projects rapid population, and consequently ABC and OFL, increases. The BSAI Plan Team had three suggestions following the 2018 assessment:

(BSAI Plan Team, November 2018) *For the next assessment, the Team recommends:*

- *updating the age error matrix, as this has helped with the corresponding model in the GOA.*
- *evaluating dome-shaped selectivity for the survey, to better account for the survey's difficulty in sampling large/old fish accurately.*
- *examining larger bounds on M and investigating a profile of M and its subsequent impacts on model results.*

The main purpose of this document is to further evaluate the reliability of recruitment estimates for AI blackspotted/rougheye rockfish. First, we review the data and the fits of models considered in 2018 and present some additional graphs for displaying the results. Second, we evaluate the effect of each of three suggestions from the PT and SSC (updating the aging error matrix, updating the prior distribution mean and variance for natural mortality, and dome-shaped survey selectivity) on estimated recruitment and fits to survey biomass. Third, we evaluate the retrospective patterns in recruitment estimates for exploratory models that incorporate changes in both the natural mortality prior distribution and ageing error matrix, with alternative composition data weighting schemes (as was done in models 18.1 and 18.2). Additionally, we consider a model in which the number year class estimates is reduced. That is, we examine how sensitive model estimates are when the number of near-term recruits are set to a mean value instead of freely estimated. We conclude with recommendations for the November 2020 assessment.

Review of data and the fits of previous models

Decline in older/larger fish in recent years

The proportion of older and smaller blackspotted/rougheye rockfish has declined substantially in recent Aleutian Islands trawl surveys. From 1991 to 2012, the size composition of the survey was comprised mostly of fish greater than 38 cm, with the mode of the distribution increasing slightly over time (Figure 1). For example, the proportion of the size composition $\geq$ 38 cm ranged between 68% and 88% in the 2004 – 2012 surveys for the combined WAI-CAI-EAI areas. In contrast, this proportion sharply decreased in the 2014-2018 surveys, ranging between 36% and 39%.

The declines in the large fish in the AI survey are consistent with declines in older fish. The estimated number of blackspotted/rougheye rockfish, binned by groups comprising 5 age classes, are shown in Figure 2. The percentage decline of survey abundance of 5 sets of age groups older than 21 years (i.e., ages 21-25, 26-30, 31-35, 36-40, and 40+) ranged between 52% (for ages 40+) and 87% (for ages 21-25) from the 2012 survey to the 2014 survey. The survey abundance of these age groups in the 2016 AI survey was similar to those in the 2014 survey. Coincident with the declines of older fish in the survey are increases in younger fish, particularly for ages 11-15 and 16-20, although note that comparisons across these younger age groups is complicated due to unequal survey selectivity. For each of the ages from 3-5, very low or zero values of abundance were observed in surveys from 1991-2000, with relatively high values observed on the 2014 and 2016 surveys.

The proportion of older fish in the AI fishery has also declined in recent years (Figure 3). Fishery age compositions from 2004-2005, 2007-2009, 2011, 2015, and 2017 are used in the assessment model. Prior to 2015, the proportion of fish aged 23 and older in these data ranged from 42% (2009) to 92% (2007). In 2015 and 2017, these proportions were reduced to 19% and 9%, respectively. These compositions are scaled to the extrapolated number from fishery Observer data in Figure 3, and indicate that these proportions represents a both a numerical decline in the number of older fish caught as well as an increase in the catch of younger fish.

The absence of older/larger fish in recent surveys imply mortality rates that are higher than those estimated in the stock assessment. Simple mortality rates were estimated directly from the survey data via catch curves and compared to the mortality rates estimated within the assessment. Catch curves applied to cohorts where fish are fully selected to the fishery (i.e., ages > 20) and extending past 2000 indicate total mortality rates between 0.14 and 0.19 (Figure 4). In contrast, the mortality rates for these cohorts from the accepted 2018 assessment model ranged between 0.08 – 0.09.

Several key parameters and population processes in the AI blackspotted/rougheye model are tightly constrained (i.e., natural mortality and survey catchability), resulting in a limited set of options the model has available to fit the decline in the older fish. The assessment model could produce higher mortality rates if the prior distribution for natural mortality had a larger mean (which is currently 0.03). However, a range of estimates of natural mortality based on current life-history methods indicates an *M* of ~0.045 (Table 1), higher than what is currently used in the assessment but likely not large enough to account for the pattern in the observed survey data. Alternatively, the decline in older fish may be due to dome-shaped survey selectivity. Models evaluating each of these hypotheses are considered later in this document. Finally, the decline in older fish could be explained by higher fishing mortality, but in this case one would expect the fishery catch to be larger in recent years. The population process that has the most flexibility in the model to explain these data is recruitment, even if the actual mechanisms are something other than recruitment. Note also that the pattern of lower abundance is apparent in both the fisheries and survey data, and only in recent years, which hinders attempts to obtain a simple explanatory mechanism.

Examination of catch curves from survey data can be a useful check for the model; because the model is attempting track the mortality and dynamics of these cohorts, one would expect consistency between the catch curves and the model results. Both the catch curves and the composition data indicate that the number of older/larger fish in recent years is less than expected. There is not currently an explanation of this pattern in the assessment model, as indicated by the discrepancy between the cohort mortality rates estimated from the model and those obtained from direct examination of the survey data.

Conflict between the composition data and survey biomass estimates

Considerable tension exists in the assessment model in fitting the survey biomass estimates and the age and length composition data. This was described in the 2018 assessment, with Model 18.2 (with the Francis weights) showing a lower RMSEs (root mean squared error) (i.e., better fit) to the survey biomass estimates and larger RMSEs (i.e., degraded fits) for each of the composition data types relative to model 18.1 (with McAllister-Ianelli weighting) (Figure 5). As noted in the 2018 assessment (Spencer et al.

2018), Model 18.1 estimated a population comprised of large recent year classes which causes the stock to increase rapidly, with the 2018 estimated total biomass at an all-time maximum and about 4 times the estimated biomass for 2000 (Figure 6). Many of these young fish are also largely missing from the survey data. The differences in survey biomass and total biomass between the two options for data-weighting indicate the level of tension between the biomass and composition data.

Uncertainty in estimates of recruitment

The uncertainty in the models considered in 2018 can be explored through further examination of the retrospective results. Model 18.1 estimates large recruitment for a relatively small number of year classes. Specifically, the estimates for the 2002, 2008, and 2010 year classes are 19.4 million, 16.9 million, and 17.1 million, respectively; each of these values is a least twice the value of any other year class. Additionally, the retrospective analysis indicates that these recruitment estimates have not been consistent between the retrospective peels. For example, the 2002 year class was estimated at 1.7 million in the 2008 retrospective peel, increased to 22.5 million in the 2012 peel, declined to 12.4 million in the 2014 peel, and has since increased to 19.4 million in the 2018 model (Figure 7).

The Francis weighting in model 18.2 resulted in more stability in the recruitment estimates, as the downweighting of the composition data avoids the need to estimate very large recruitments in the recent year classes. The maximum of retrospective recruitment estimates for the post-1998 year classes is 8 million for Model 18.2 (as compared to 33 million for Model 18.1). The percentage changes in recruitment estimates between the retrospective peels is shown in Figure 8. The downscaling of recruitment estimates results in a total rate of biomass increase (Figure 6) that is more consistent with the trend of the observed survey biomass estimates. The retrospective results for model 18.2 are shown in rescaled y-axes in Figure 9.

Additionally, Model 18.2 has reduced uncertainty in the recruitment estimates between the retrospective peels relative to model 18.1, as indicated by a reduction in Mohn's rho to 0.22 from a value of 0.58 in Model 18.2 (Table 1).

The variability in recruitment estimates revealed by the retrospective analysis are consistent with the variability observed between actual assessments. For example, in the 2014 assessment the 1998 year class was estimated at 23.1 million, but this has been reduced to 7.8 million in the 2018 assessment.

Management Implications of Large and Uncertain Recruitment Estimates

Estimation of ABC and OFL levels are currently based on the estimated number at age in 2018 from model 18.1, which reflect the scale of estimated recruitments for the year classes present in 2018. Model 18.1 shows a large proportion of young fish in relatively few age classes that have not been fully observed in the survey; 80% of the 2018 numerical abundance is at or below age 16, and these ages have less than 20% survey selectivity (Figure 10). The large year class for 2002 comprises 19% of the 2018 total biomass, and the 2002, 1998, and 1999 year classes comprise about 37% of the total 2018 biomass.

As these young fish increase in age and grow larger, they become more selected by the fishery and the ABC increases. The 2020 maximum ABC was a 29% increase from the 2019 ABC, and the projected 2021 maximum ABC (from the 2019 partial assessment) is 28% larger than the projected 2020 maximum ABC. These increases are unusual for a long-lived stock, particularly in the absence of major changes to the input data and without a definitive increase in survey biomass estimates.

Given the reduction in estimated recruitment for year classes previously estimated to be large (i.e., 1998 and 1999), it is likely that year classes currently estimated as strong would be revised downward in future assessments as more data on year class strength becomes available. However, the uncertainty in initial numbers at age are not considered in the standard projection model used for obtaining ABC and OFL. Additionally, new information on year class strength from the AI survey typically comes only every two years (and given that the 2020 survey was cancelled there could be a 4 year gap). If these projected model numbers-at-age are overestimated, then the ABC and OFL levels may require larger downward adjustments when more information becomes available.

Model explorations

In this section, we consider 3 model specifications suggested by either the BSAI PT and/or the SSC: 1) updating the aging error matrix; 2) updating the prior distribution for natural mortality; and 3) dome-shaped survey selectivity. The effect of each of these model changes, with respect to estimated recruitment, survey biomass, and total biomass and relative to model 18.1, was considered for each change separately. We first describe the methodology of each of the modeling alternatives, and then compare the estimated recruitment, survey biomass, and total biomass to Model 18.1.

BSAI blackspotted/rougheye rockfish comprise a complex of two species, and it is possible that both the ageing error and natural mortality could differ between these species. However, the abundance is dominated by blackspotted rockfish, particularly in the Aleutian Islands subarea where the age-structured model is applied.

Update aging error matrix

An aging error matrix was estimated using software developed by the Northwest Fisheries Science Center (NWFSC; https://github.com/nwfsc-assess/nwfscAgeingError), which is based on the methodology described in Punt et al. (2008). The method requires a set of fish with age reading from multiple readers for each fish, and the mean and standard deviation of the read ages for each reader was estmated based on the likelihood of observing the read age for each fish given the true age. The true ages are unobserved, and maximum likelihood estimates are obtained by integrating across all possible values for the true age. It was assumed that the readers had equal variation in the read ages and were unbiased. Additionally, the coefficient of variation of the read ages was modeled as constant with age (i.e., the standard deviation of increases linearly with age).

This estimation procedure differs from that used to generate the ageing error matrix in the 2018 model, which is not based on fitting data on individual fish but rather fits the percent agreement for each age (and weights each age equally regardless of differences in sample size). Additionally, the data used for the current ageing error matrix was sampled in the Gulf of Alaska, whereas the Punt et al. (2008) methodology was applied to 2341 double readings of blackspotted/rougheye rockfish from the BSAI sampled during 1986 – 2017.

The updated ageing error shows higher CVs in read ages than was estimated for the 2018 model, with the CV from the Punt et al. (2008) methodology estimated at 0.121 whereas the CV used in the 2018 assessment estimated at 0.065 (for older ages) (Figure 11). Application of the estimation procedure used for the 2018 ageing error matrix to the updated BSAI data (not shown) indicates that the differences in the estimated CV results primarily from changes in the estimation procedure, not the input data.

Update prior and variance for natural mortality

Estimates of natural mortality based on life-history parameters were obtained from the online application (http://barefootecologist.com.au/shiny_m.html) developed by Dr. Jason Cope (Fisheries Research Scientist, NWFSC). The app calculates natural mortality from a variety of methods based on the available input data (i.e., maximum age, von Bertalannfy growth parameters, etc.). Three natural mortality models developed by Then et al (2015) based on maximum age (t_{max}) were considered, which Then et al. (2015) recommend as the preferred methodology. The observed maximum age for BSAI blackspotted/rougheye rockfish is 121, and estimates of natural mortality for each model were obtained from values of t_{max} of 100, 125, and 150. The estimates of natural mortality ranged from 0.034 to 0.072, which are higher than values of *M* estimated in Alaska blackspotted/rougheye assessments (i.e., 0.032 and 0.036 for BSAI and GOA, respectively). The mean of the prior distribution for *M* was increased to 0.045 (from 0.03 in the 2018 model), along with an increase in the CV to 0.10 (from 0.05 in the 2018 model). Recognizing the uncertainty of the estimates in Table 1, the value of 0.045 represents a value within the range of values in Table 1 rather than a numerical average, and also corresponds to the center of a range considered (0.035 – 0.055) for British Columbia rougheye/blackspotted rockfish (Dr. Paul Starr, Canadian Groundfish Research and Conservation Society, pers. comm.)

Evaluate dome-shaped survey selectivity

Dome-shaped survey selectivity was evaluated in the assessment model, with the standard double normal curve (Wallis 2014) modified with an offset parameter *d* as follows:

$$sel(a) = \begin{cases} e^{-(a-\mu)^2/2\sigma_1^2}, & a \leq \mu \\ 1, & \mu \leq a \leq \mu + d \\ e^{-(a-(\mu+d))^2/2\sigma_2^2}, & a \geq \mu + d \end{cases}$$

The offset parameter *d* allows the peak of the selectively curve, which is scaled to equal 1 and occurs at age μ, to extend across multiple ages; setting *d*=0 would produce a standard double normal curve with the slope of the ascending and descending limbs governed by σ_1 and σ_2, respectively.

Effect of the exploratory model specifications on the estimated recruitment and biomass

The updated natural mortality prior distribution resulted in increasing recruitment for all age classes, whereas the updated ageing error matrix resulted in increased recruitment for several year classes, including 2002, 2006, and 2010 (Figure 12). Specifically, the estimate of the 2002 year class is increased 47% and 134% with updated *M* prior distribution and ageing error, respectively, and the estimate of the 2010 year class is 63% and 69% larger, respectively. Each of these results is expected; increased values of *M* results in larger estimated recruitments in order to compensate for larger natural mortality, and increased ageing error allows the model to estimate larger recruitments in order to account for the additional “smearing” of these year class strengths with more ageing error.

The updated ageing error matrix resulted in very similar total biomass estimates relative to model 18.1 for 2010 and earlier, with biomass increasing at a faster rate in recent years due to increased recent year classes (Figure 13). The model with an updated *M* prior distribution resulted in larger total biomass for the entire time series relative to model 18.1. The fit to the survey biomass data was very similar between the model with the updated ageing error and model 18.1, whereas the model with the updated prior distribution for natural mortality resulted in larger survey biomass in the 1990s, and lower survey biomasses after 2010, relative to model 18.1 (Figure 14). The updated prior distribution for *M* resulted in an *M* estimate of 0.092, which seems implausibly large for a long-lived stock such as blackspotted/rougheye rockfish.

In contrast, the effect of dome shaped selectivity lowered recruitment from the 2018 model; for example, the 2020 year class was reduced from 19.4 million to 14.4 million, and the 2008 year class was reduced from 16.9 million to 12.5 million. The AI double normal AI survey selectivity curve was similar to the logistic curve estimated in 2018, with the exception of a sharp reduction in the selectivity for the age 45+ group (Figure 15). The reduction in the plus group selectivity increased estimated total biomass prior to 2015, and decreased estimated total biomass after 2010, relative to model 18.1. The model with the dome-shaped survey selectivity produced larger estimates of survey biomass for 2010 and earlier.

In summary, the issues present in model 18.1 (i.e., estimated large year classes based on limited data, a rapidly increasing population based on strong year classes of young fish not completely observed in the survey, and a poor residual pattern in the fit to the survey biomass estimates) have not been resolved by these exploratory model alternatives. For example, none of these exploratory models fit the large survey biomass estimates in 2000, 2002, and 2012.

Retrospective recruitment estimates for models with updated ageing error and prior distribution for natural mortality

We now evaluate the retrospective recruitment patterns for models that incorporate both the updated ageing error matrix and the updated prior distribution for natural morality distribution. Although the analysis above indicates that the updated prior distribution for *M* produced a very large *M* estimate, the same prior distribution was retained for this retrospective analysis in order to explore the scale and direction of the effect on model estimates. Additionally, we re-iterate the age/length compositions weight for both the McAllister-Ianelli and Francis methods.

Finally, an additional model we consider is extending the number of year classes where recruitment is not estimated from 3 in model 18.1 to 14 (the recruitment for these year classes is set to the estimated mean recruitment). Specifically, most year classes are estimated as

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where μ_R is the log-scale mean of recruitment and ν_t is a log-scale time-variant deviation with a mean of 0 and a standard deviation (σ_R) of 0.75. For the recent years, the recruitment would be set to the estimated mean:

$$N_{t,3} = e^{(\mu_R + \sigma_R^2/2)}$$

The original rationale for not estimating the most recent 3 recruitments was that no data were available (the age of recruitment is 3), and this has been extended to reflect that recent estimates of recruitment are likely unreliable. The value of 14 was chosen to represent an extended period exceeding a decade for which we may have a retrospective bias in recruitment estimates. A table describing the model names and differences from model 18.1 is shown below.

ae_m_McIan	Updated ageing error, updated natural mortality prior distribution, updated McAllister-Ianelli data weights
ae_m_Francis	Updated ageing error, updated natural mortality prior distribution, updated Francis data weights
ae_m_drop14	Updated ageing error, updated natural mortality prior distribution, set most recent 14 year classes to the estimated mean recruitment, and with the same weights as model *ae_m_Francis*

Retrospective patterns in recruitment

As with the models evaluated in 2018, the McAllister-Ianelli weighting shows the strongest retrospective pattern (Figure 16). The 2002 year class, estimated to be a strong component of the population, increased from an estimated 2.5 million in the 2008 peel to 58.5 in the 2018 peel, and the retrospective estimates do not appear to have stabilized. The 1998 year class was estimated as strong in the 2010-2013 peels (ranging from 70.1 – 76.4 million), but has since declined to the 17.8 million. Recent year classes have been lower in scale, but still show a retrospective pattern when plotted as percentage change from the initial estimate (Figure 17).

Use of the Francis weighting results in reduced retrospective pattern, with a reduced range of recruitment estimates (Figure 16). The 1998 year class shows the same general pattern seen with the McAllister-Ianelli weighting, but the peak of the recruitment estimates has been reduced to 12.9 million. The 2002 year class shows a reduced increase over time, from 1.5 million in the 2008 peel to 5.2 million in the 2018 peel. A comparison of the retrospective estimates on the same scale as those with the McAllister-Ianelli weighting is shown in Figure 16, and the retrospective estimates with the Francis weighting plotted with rescaled y-axes are shown in Figure 18.

The retrospective pattern in the ae_m_drop14 model also showed a reduced retrospective pattern relative to using the McAllister-Ianelli weights (Figure 16). In this case, recruitment for multiple year classes are set to the same estimated mean value. The range of the recruitment estimates for the 1998 year class is 1.8 million to 6.3 million, even further reduced than with the Francis weights. The retrospective estimates for the ae_m_drop14 model plotted with rescaled y-axes are shown in Figure 19.

Similar to the 2018 models, the Mohn's rho for the McAllister-Ianelli weighting had the largest absolute value among the alternative model considered (0.22), with the Mohn's rho decreasing to 0.17 with the Francis weighting and -0.16 for the ae_m_drop14 model (Table 2). The negative sign of Mohn's rho in the ae_m_drop14 model indicates that recruitment is higher in the most recent peel relative to most other peels. The retrospective recruitment estimates sometimes increased in the years prior to the set of years where they are set to the estimated mean (Figure 20), as if the model is estimating high recruitment for these years to compensate for an extended period of constant recruitment in the most recent 14 years.

Discussion and recommendations

The estimated ageing error matrix is based on a likelihood procedure that fits data from each observed fish with multiple reads, and the data is also updated to use the most recent BSAI data. The aging error matrix shows higher variability in read ages around the given true age, which is consistent with blackspotted/rougheye being a relatively difficult rockfish to age. In comparison with model 18.1, the effect of the ageing error matrix is seen most in the recruitment estimates for very recent years, as the scale of recruitment estimates for other years are constrained by prior distributions on survey catchability and natural mortality. *We recommend using the updated ageing error matrix.*

The most recent research relating natural mortality to life-history parameters (Then et al. 2015) suggests that M is ~0.045 for blackspotted/rougheye rockfish, higher than the value of 0.032 used in the current assessment. The estimates of M for the 2018 peel in the 3 exploratory runs (with the increased mean and variance on the prior distribution) ranged from 0.052 in Model ae_m_drop14 to 0.091 in model ae_m_McIan. Although the exploratory runs were useful to examine the direction of M estimates with alternative priors, these values are generally larger than those suggested by the research of Then at al. (2015). *We recommend bringing forward a model with M either set at 0.045, or with an informative prior distribution centered on this value.*

The most defining feature of the current BSAI blackspotted/rougheye assessment model is the conflict between the age/length composition data and the trend in the survey biomass estimates. The causes for this conflict within the model are unclear, and we hypothesize that two processes might be relevant. First, there has been an increase in the number of observed young fish in the AI survey in recent years. These young ages still comprise a small percentage of the survey age composition, so the estimated survey selectivity is low. In order to account for observation of these young fish, the recruitment has to be large to overcome the low survey selectivity. Second, the model may be trying to model the decline in older fish via variation in recruitment strength. For any given survey year, an increase in the estimated proportion of young fish would decrease the estimated proportion of older fish.

By definition, data conflicts force a consideration of which data to emphasize in the estimation procedure because the model results are sensitive to data weighting. For BSAI blackspotted/rougheye rockfish, we recommend giving more weight to the survey biomass trends and less weight to the age/length composition data than what was used for the accepted 2018 model. As noted in the 2018 assessment, the use of the McAllister-Ianelli weights produces variability in estimated recruitment strengths between assessments, which is further supported by the strong retrospective patterns observed in this paper. This also has management implications, as uncertain estimates of year class strength are projected forward and have produced substantial percentage increases in the ABC and OFL since the 2018 assessment. Without a definitive increase in the survey biomass estimates or more reliable estimates of year class strength, these percentage increases in ABC and OFL may not be warranted for a long-lived stock the has exhibited less than expected older fish in recent surveys and fishery catch.

Both the Francis weighting and setting the most recent 14 year classes to the estimated mean recruitment down-weight the composition data and produced similar absolute values for Mohn's rho for recruitment in the exploratory models considered here. However, the latter method has the unusual feature of ramping up recruitment in the years before the mean value is used. *We recommend using the Francis (2011) weighting procedure*, which has a stronger theoretical foundation than other *ad-hoc* methods because it accounts for correlations within each given year of composition data that reduces the amount of informative data in the observed compositions.

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Table 1. Estimates of natural mortality for BSAI blackspotted/rougheye rockfish.

		Maximum Age		
Method	Model	100	125	150
$Then_{nls}$	$M = at_{max}^{b}$	0.072	0.059	0.050
$Then_{lm}$	$\log(M) = a + b * \log(t_{\max})$	0.051	0.041	0.034
$Then_{1parm}$	$M = a/t_{max}$	0.053	0.042	0.035

Table 2. Mohn’s rho for recruitment and spawning stock biomass for the models considered in the 2018 assessment, and the exploratory models considered in the document.

	Mohn’s rho	
Model	*Recruitment*	*SSB*
18.1	0.59	0.77
18.2	0.22	0.47
ae_m_McIan	0.22	0.59
ae_m_Francis	0.17	0.44
ae_m_drop14	-0.16	0.36

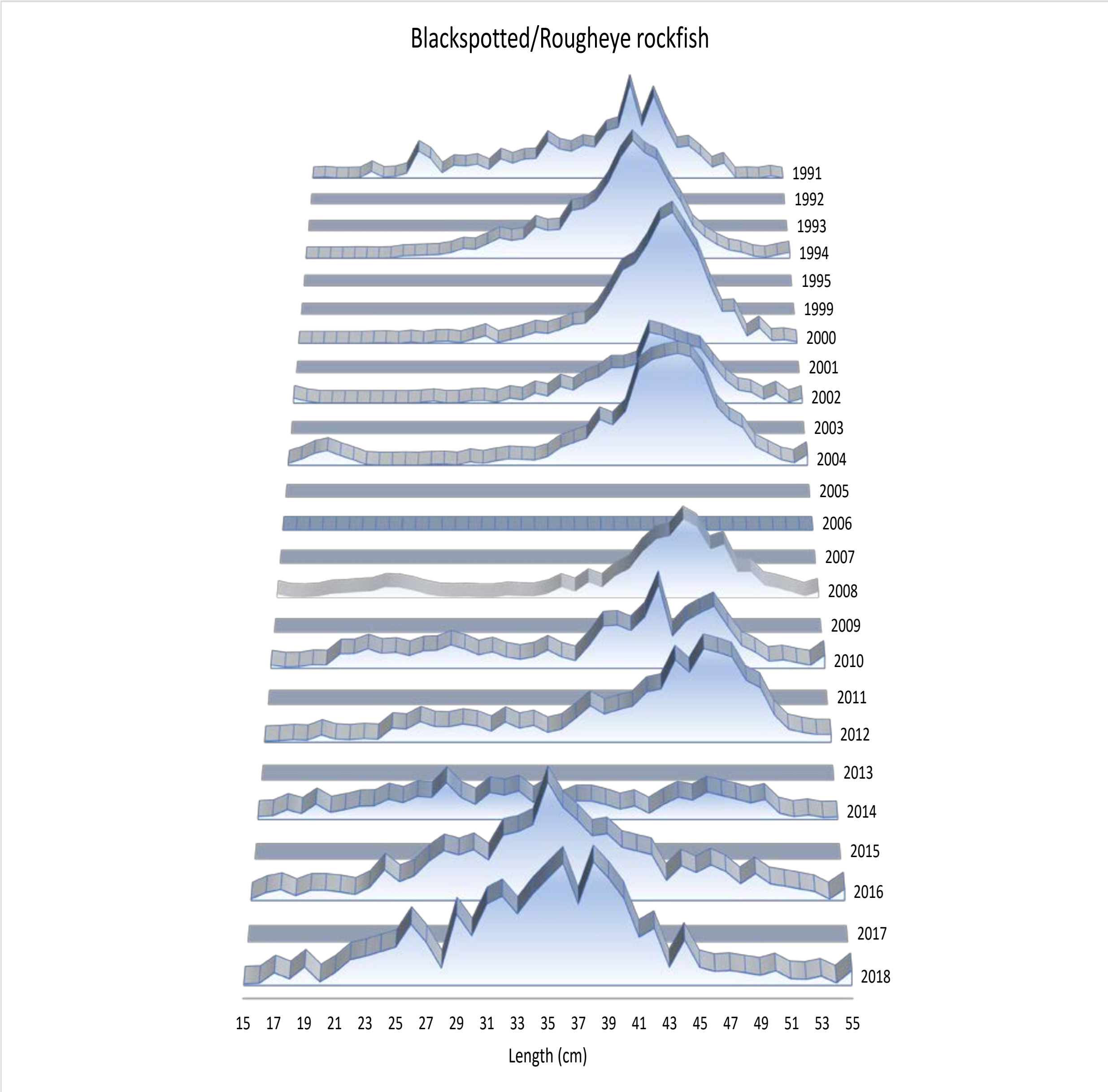

Figure 1. Abundance at size for blackspotted/rougheye rockfish from the AI surveys (excluding the SBS area).

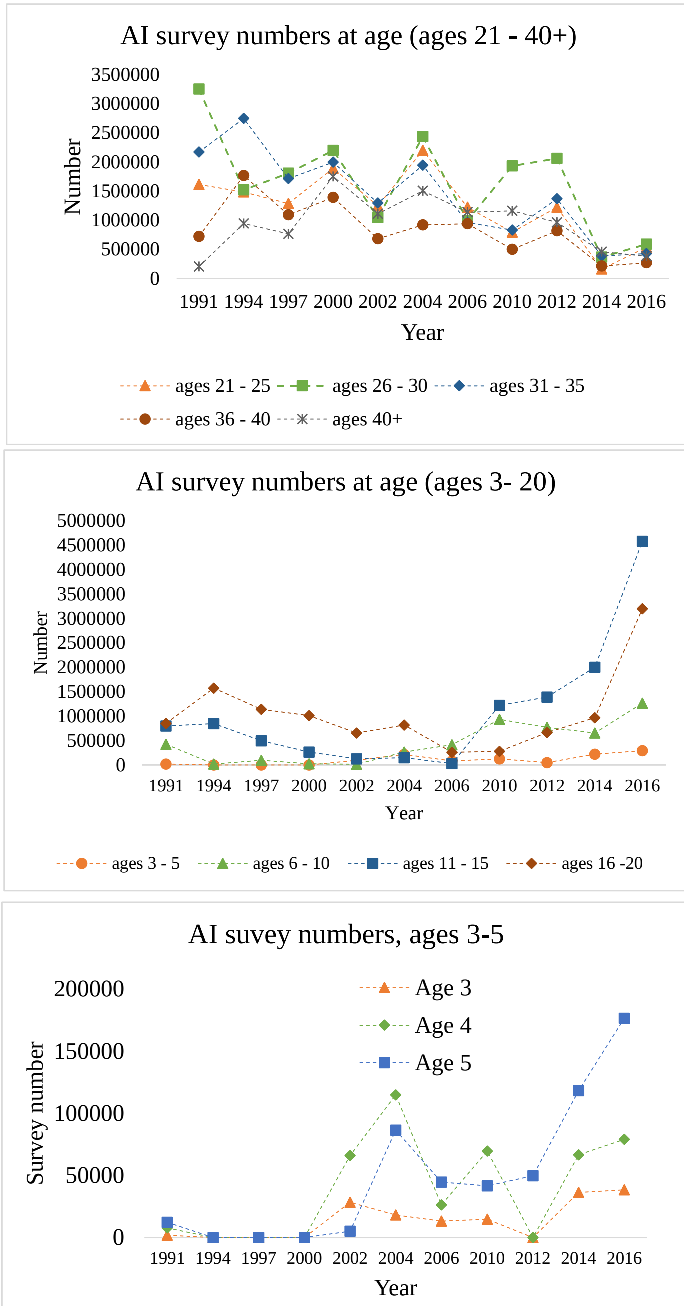

Figure 2. Abundance by age group blackspotted/rougheye rockfish from the AI survey (excluding the SBS area)

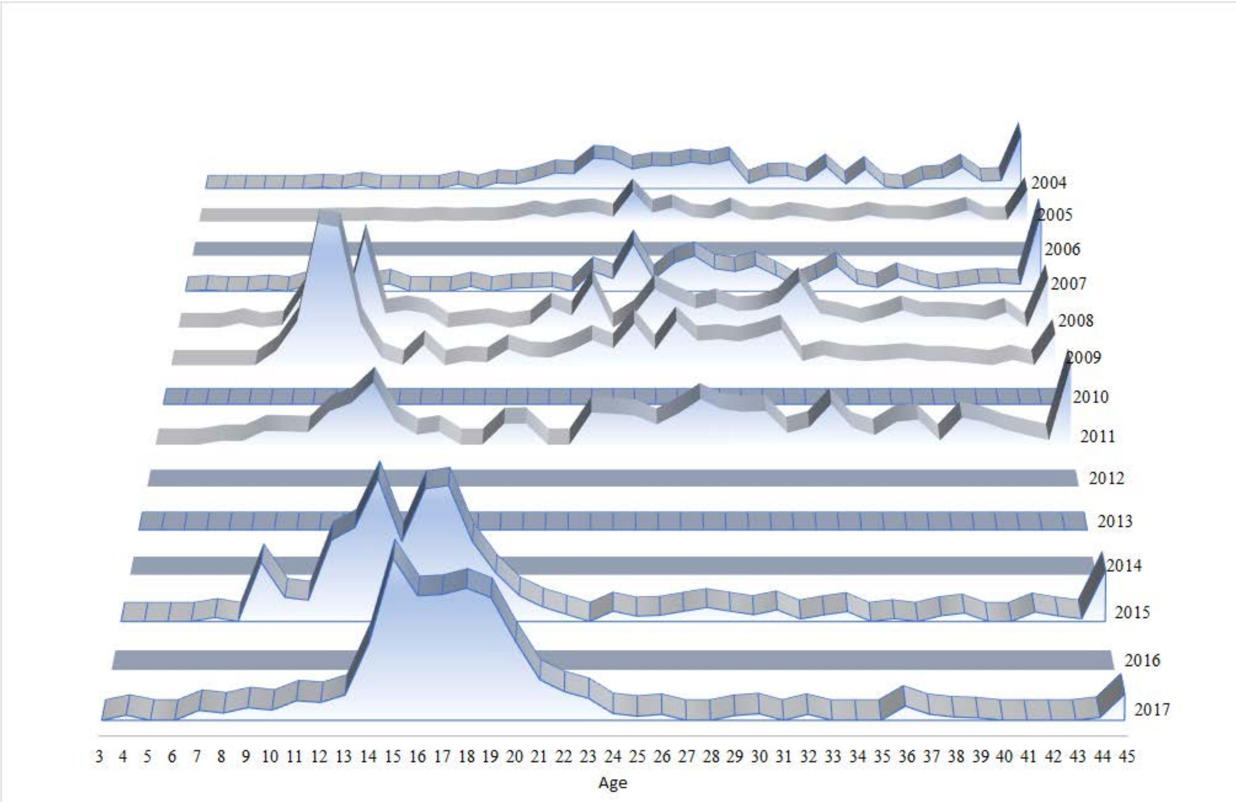

Figure 3. Aleutian Islands estimated fishery catch by age (with observations scaled to the extrapolated number from the Observer sampling program).

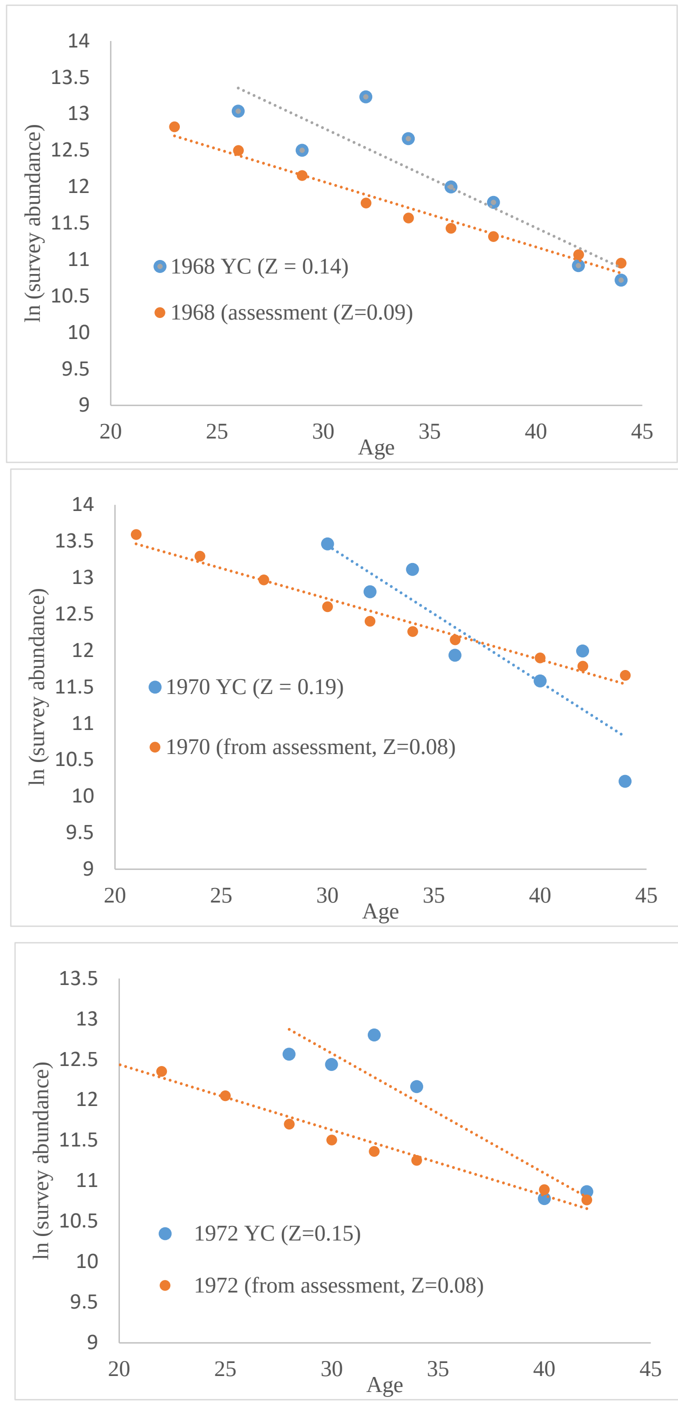

Figure 4. Log abundance for selected cohorts of blackspotted/rougheye rockfish from the AI survey (excluding the SBS area) and estimated from 2018 assessment model.

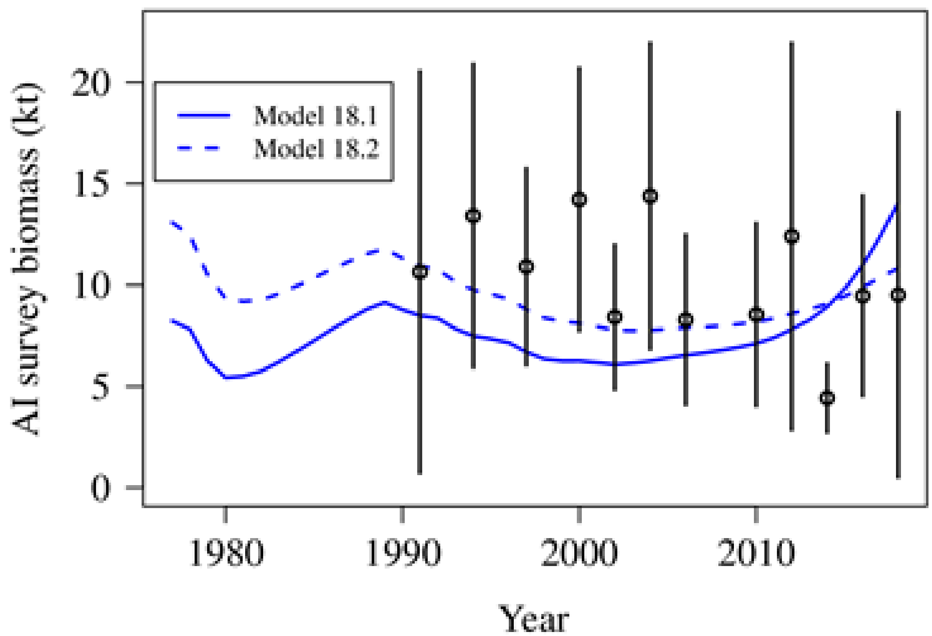

Figure 5. Fits to AI survey biomass from the 2018 assessment; model 18.1 has McAllister-Ianelli weighting (i.e., more emphasis on fitting the composition data) of the compositions data whereas model 18.2 has Francis weighting.

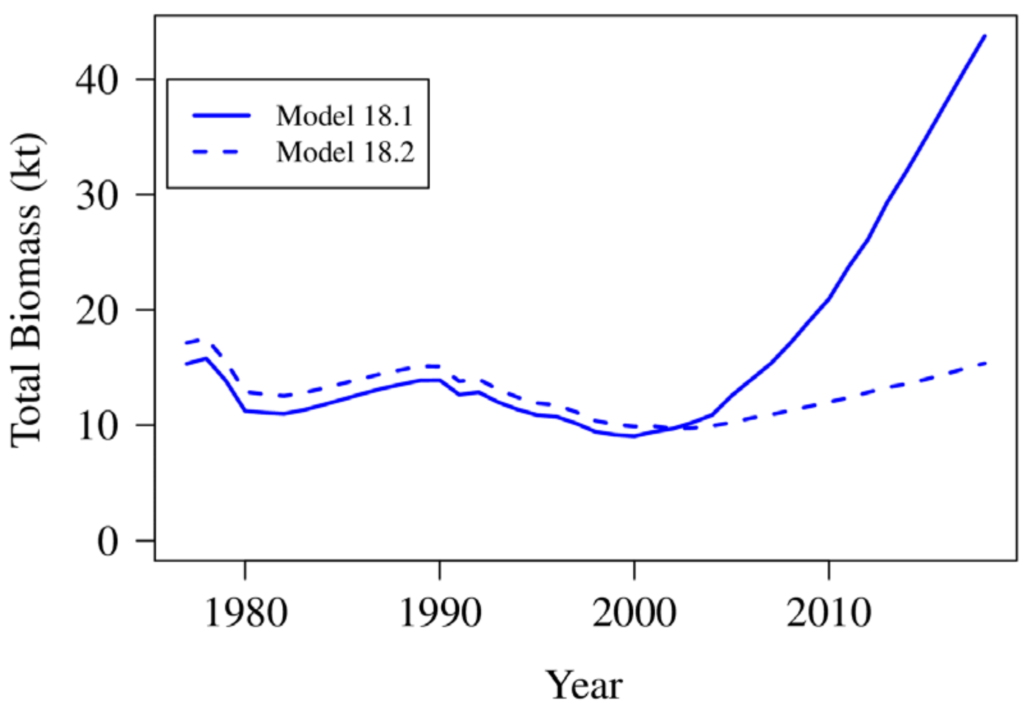

Figure 6) Estimated total biomass from the 2018 assessment; model 18.1 has McAllister-Ianelli weighting (i.e., more emphasis on fitting the composition data) of the compositions data whereas model 18.2 has Francis weighting.

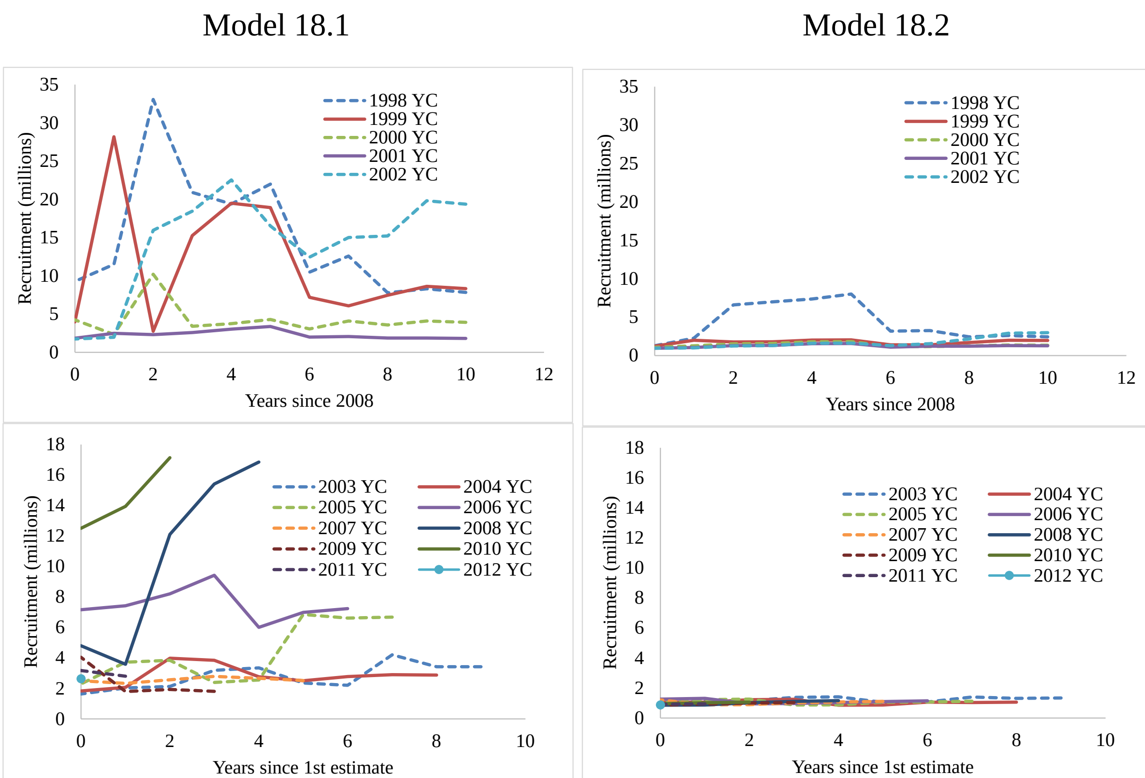

Figure 7). Retrospective estimates of recruitment from the 2018 assessment model, for the 1998 – 2012 year classes, as a function of the years since either the first estimate or 2008 (whichever is later).

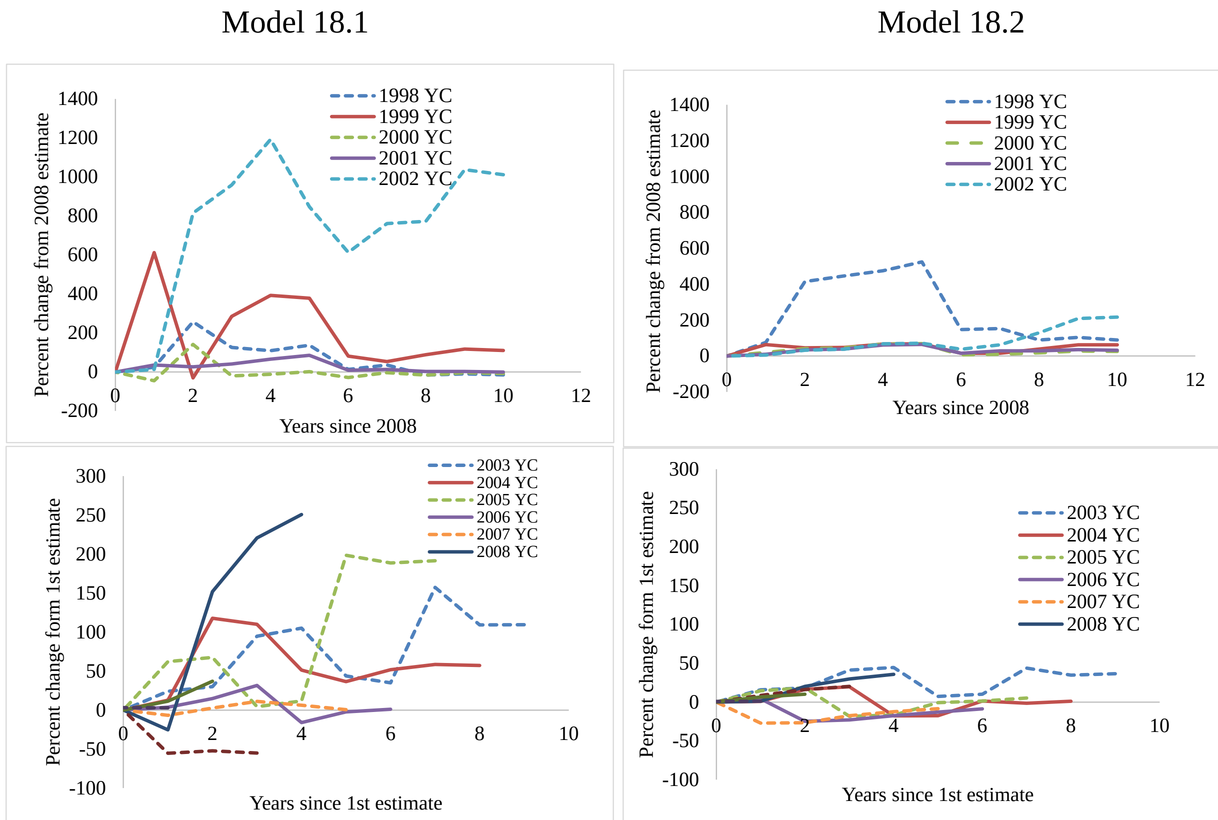

Figure 8) Percent change in the retrospective estimates of recruitment from the 2018 assessment model, for the 1998 – 2012 year classes, from either the first estimate or 2008 (whichever is later).

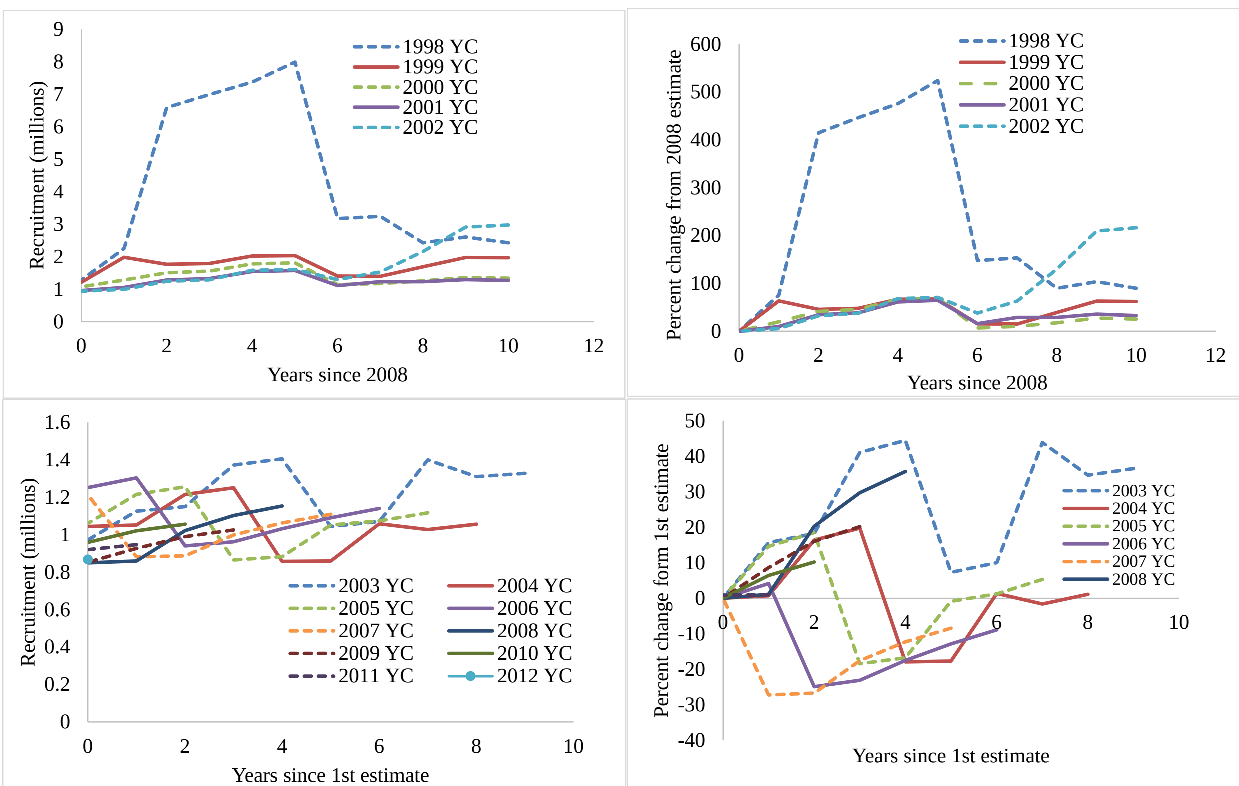

Figure 9. Retrospective estimates of recruitment from model 18.2, and percent changes from either the first estimate or 2008 (whichever is later), with rescaled y-axes.

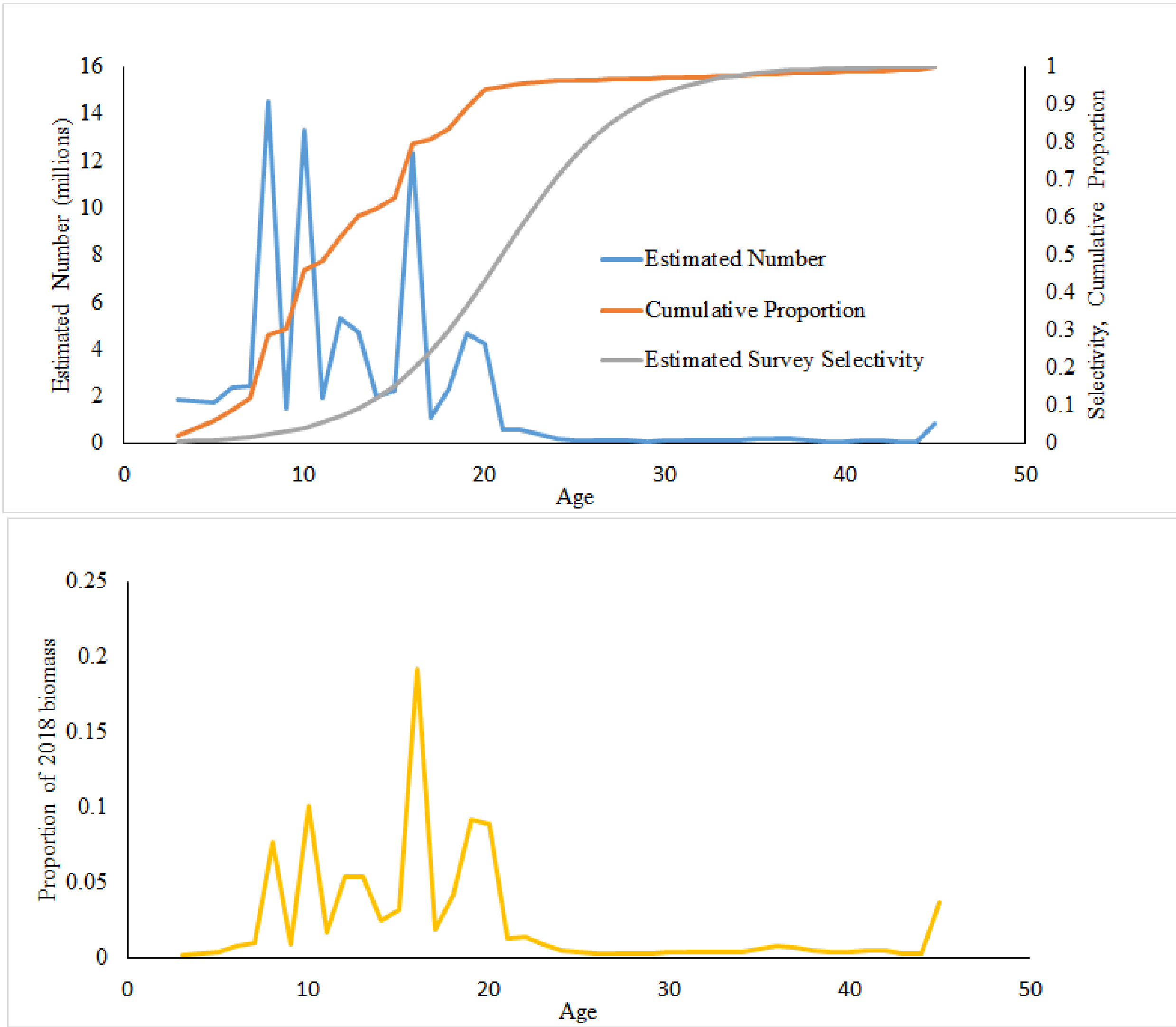

Figure 10. Estimated 2018 numbers at age, their cumulative proportion, estimated survey selectivity, and biomass by age from the 2018 assessment.

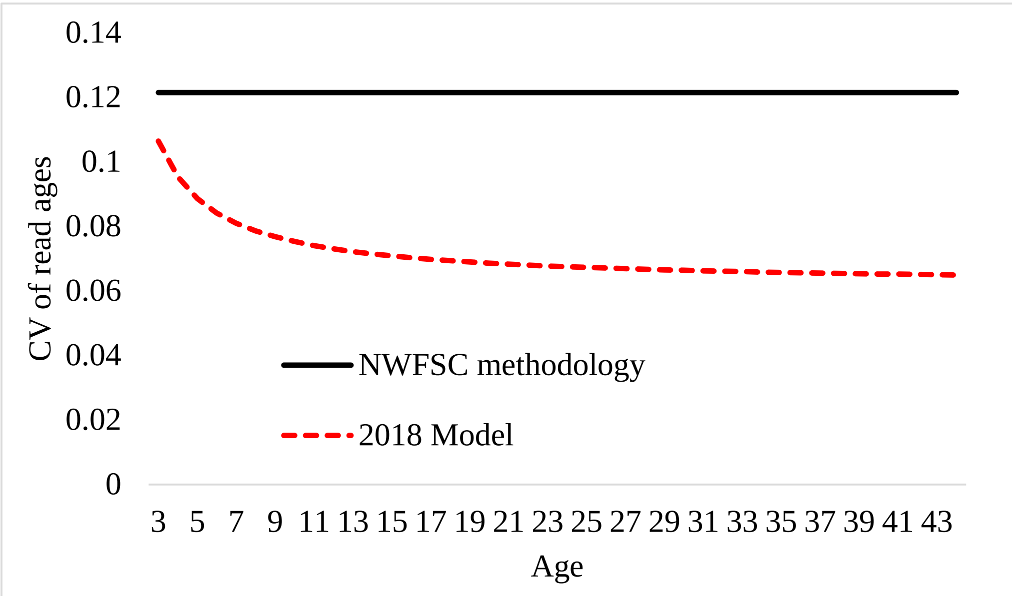

Figure 11. The coefficient of variation (CV) in read ages around a true age, estimated from the NWFSC method in Punt et al. (2008) and used in the 2018 assessment.

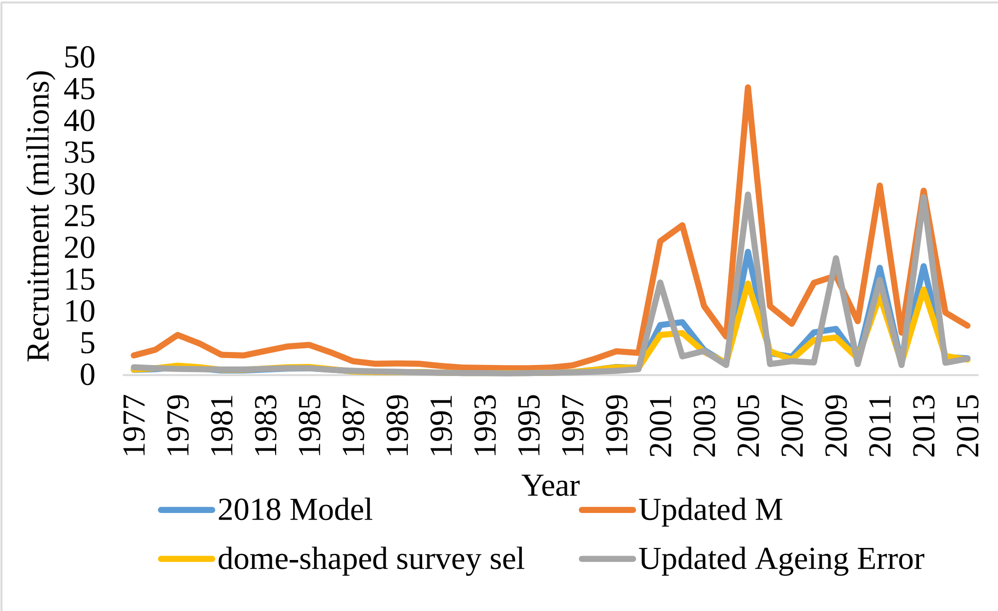

Figure 12. Estimated recruitment as a function of three separate model changes from the 2018 assessment model.

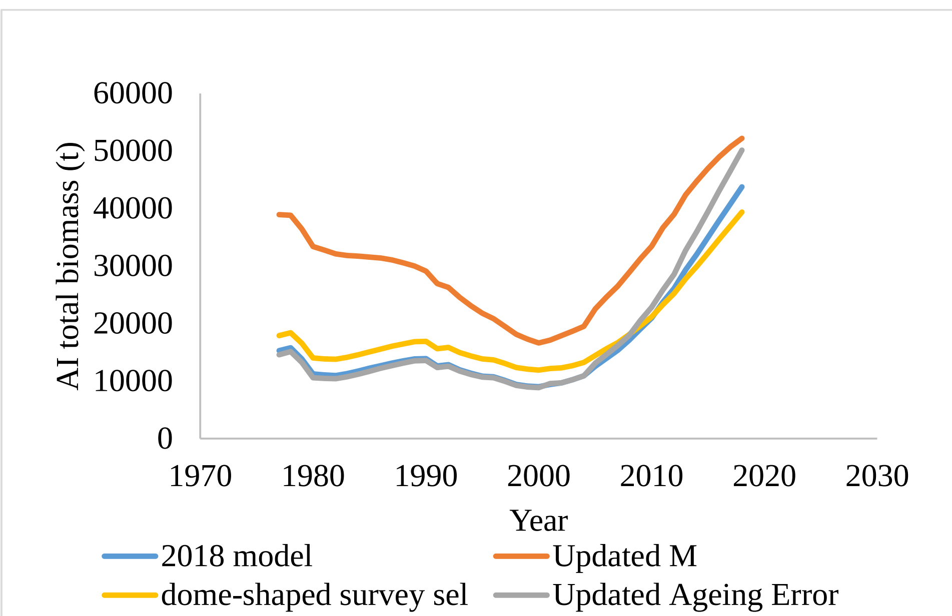

Figure 13. Estimated total biomass as a function of three separate model changes from the 2018 assessment model.

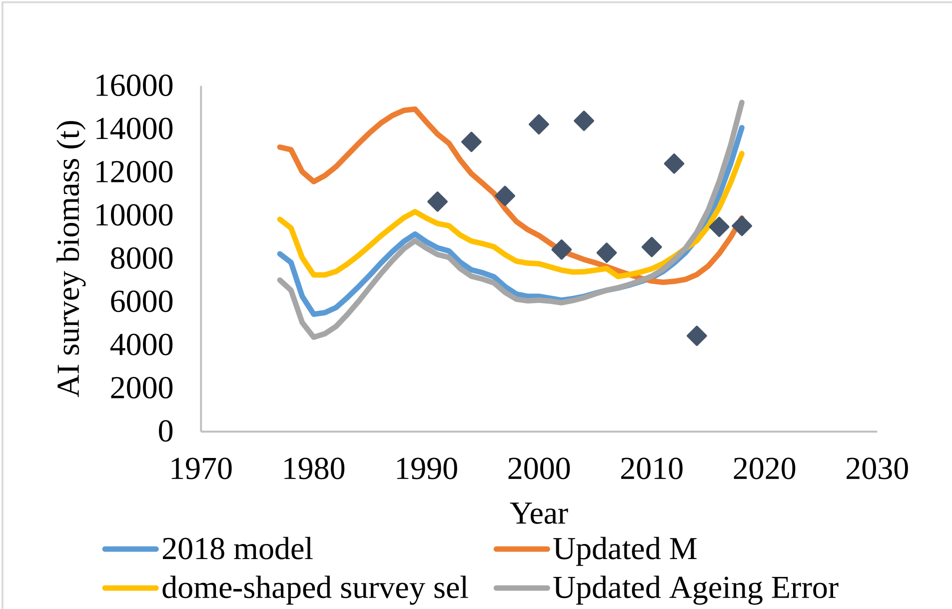

Figure 14. Estimated survey selectivity as a function of three separate model changes from the 2018 assessment model.

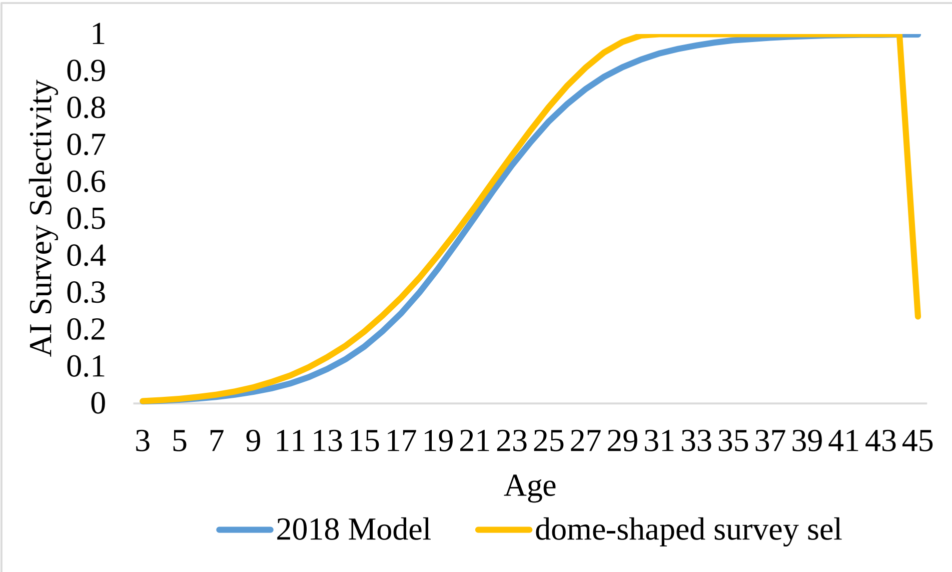

Figure 15. Estimated dome-shaped survey selectivity (for a model allowing double-normal AI survey selectivity but otherwise identical to model 18.1).

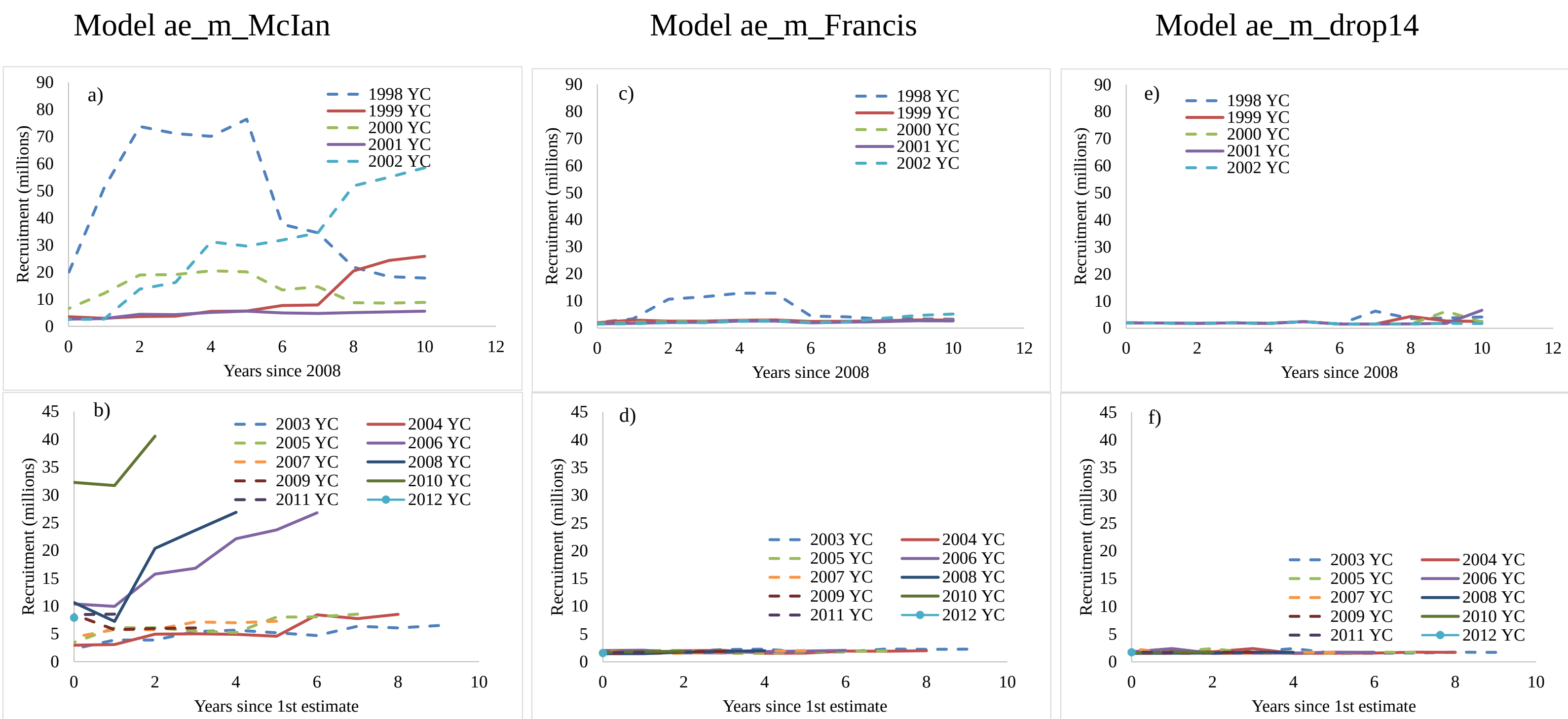

Figure 16. Retrospective estimates of recruitment from 3 exploratory models for the 1998 – 2012 year classes, as a function of the years since either the first estimate or 2008 (whichever is later).

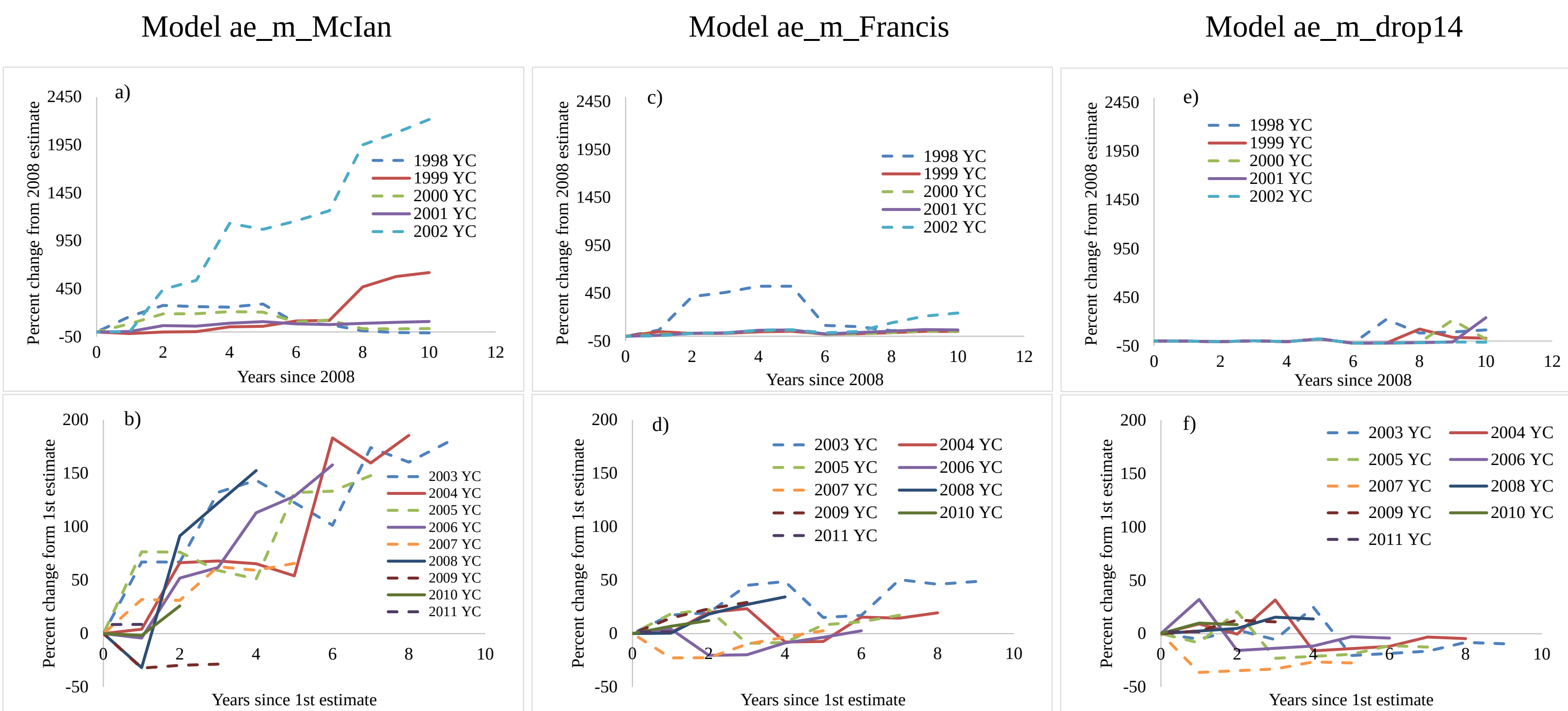

Figure 17. Percent change in the retrospective estimates of recruitment from three exploratory models, for the 1998 – 2012 year classes, from either the first estimate or 2008 (whichever is later).

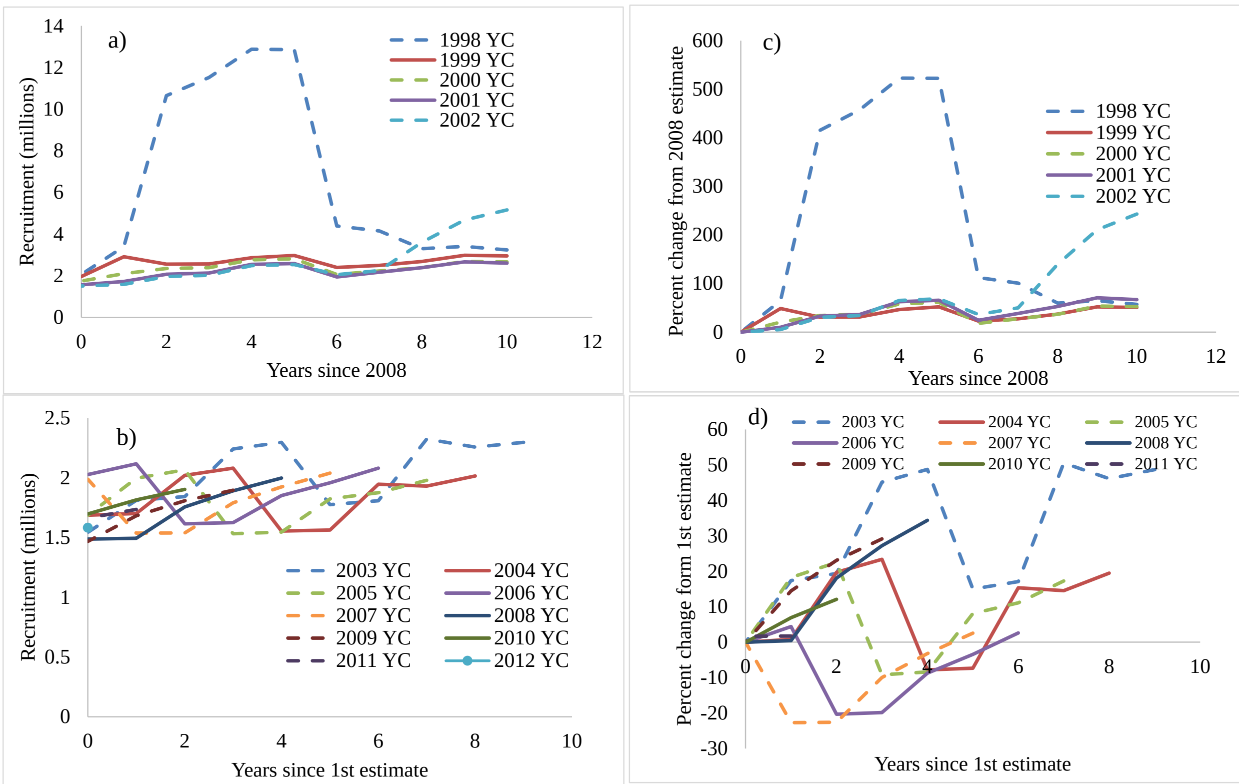

Figure 18. Retrospective estimates of recruitment from model ae_m_Francis, and percent changes from either the first estimate or 2008 (whichever is later), with rescaled y-axes.

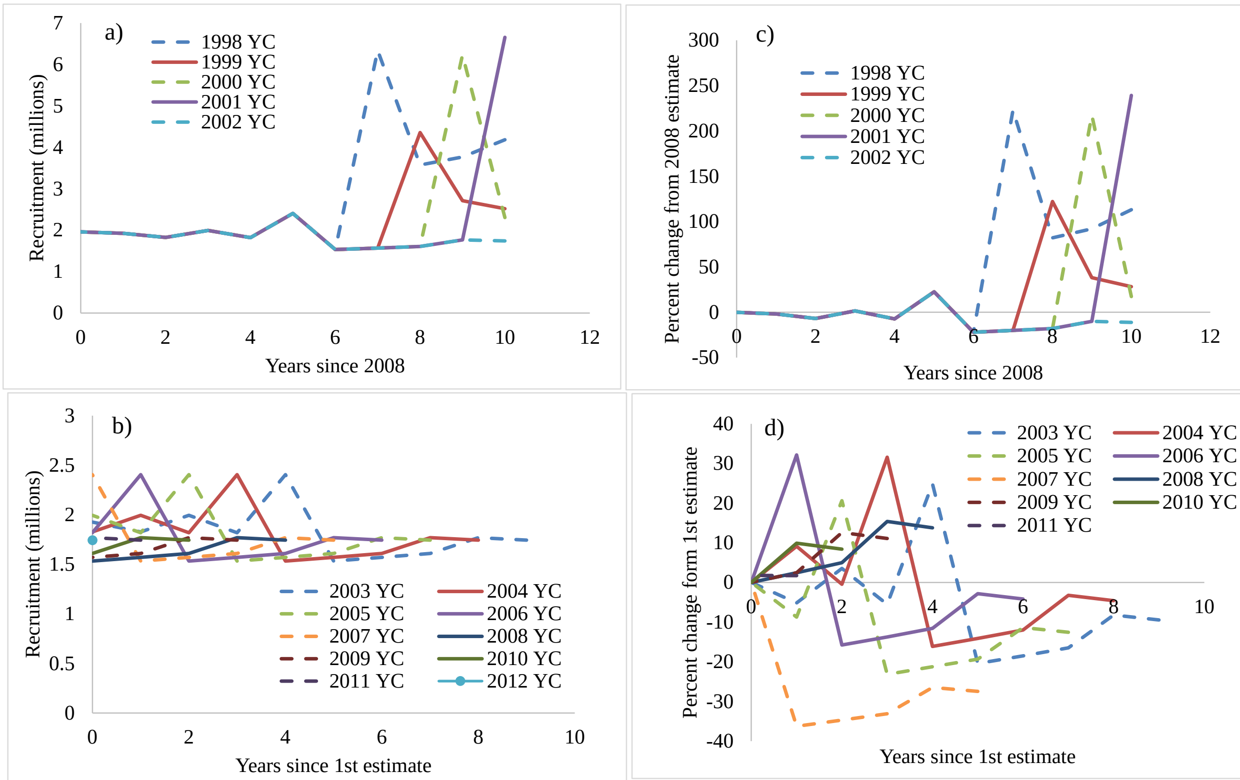

Figure 19. Retrospective estimates of recruitment from model ae_m_drop14, and percent changes from either the first estimate or 2008 (whichever is later), with rescaled y-axes.

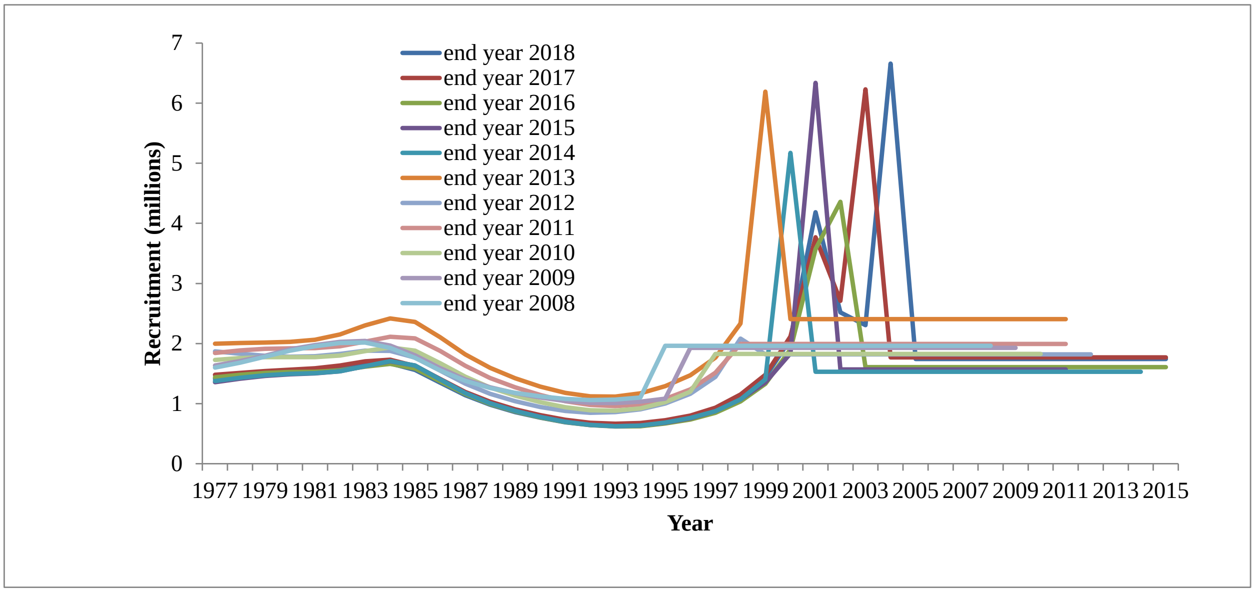

Figure 20. Retrospective estimates of recruitment from model ae_m_drop14, by year.