Updated Maturity at Age for Female Sablefish
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Background

The current female age-at-maturity model used in the Alaska stock assessment was estimated using macroscopic maturity determination methods on samples collected during summer surveys from 1978-1983 (Sasaki, 1985). There are many factors that may make these maturity data outdated or an inaccurate estimate of maturity. Macroscopic evaluations of maturity can be inaccurate because the stage of oocytes can be difficult to discern without the aid of histology (Hunter et al., 1992). In addition, these maturity data were categorized by fish length, which were later converted to ages for the stock assessment. It has also been observed that maturity determination for sablefish collected during the summer, 6-8 months prior to the winter spawning season (Sigler et al. 2001; Rodgveller et al. 2016), can be too early for accurate determinations of maturity during some months, because oocytes have not started to mature in all fish that will spawn (Rodgveller 2018).

To obtain more up-to-date maturity estimates and explore changes in sablefish maturity among years, sablefish ovaries were collected in December 2011 and 2015 in the Central Gulf of Alaska (GOA) for a study of age at maturity and fecundity (Rodgveller et al. 2016). Additionally, in the summer of 2015 female sablefish were collected on the Alaska Fisheries Science Center summer longline survey. Fish caught earlier than August did not consistently show signs of development towards spawning and skip spawners and immature fish could not reliably be differentiated from spawning fish. Fish collected in August did show signs of development towards spawning and immature fish could be separated because there was a gap in oocyte development between the immature and developing fish. Therefore, for the summer longline survey we've only included samples from August in this analysis. Using histological (microscopic) methods, skip spawning female sablefish (i.e. mature fish that will not spawn) were identified for the first time. Estimates of age at maturity and spawning stock biomass were affected by whether or not skip spawning fish were considered in maturity models (Rodgveller et al. 2018). Skipping rates of mature fish, those that have spawned in the past and are not in the current season, differed between these sampling years (a high of 21% in 2011 and 2-6% in 2015).

When skip spawning is present, logistic regression will generally fail to accurately represent the true proportion mature at a given age (Trippel and Harvey 1991). There have been some recent advancements to address skip spawning using the gonadosomatic index (Flores et al., 2014) or splines (Head et al., 2020), in this examination we are utilizing generalized additive models (GAM), which are akin to the methods of Head et al. (2020). In this study simulation analysis is used to generate maturity curves with skip spawning to examine both the effects of skip spawning on maturity estimation using generalized additive models and the potential effects of not addressing the presence of skip spawning. The sablefish samples from 2011 and 2015 were then examined for appropriate methods for incorporating skip spawning and the effects on estimates of spawning stock biomass (SSB) are presented.

Methods

Simulations

Parameters for female maturity at age, maturity at length, length at age and weight at age were obtained from the 2020 sablefish stock assessment and fishery evaluation (SAFE, Goethel et al., 2020). A Bernoulli random variable was generated ten thousand times for each simulated age, where a value of 1 is mature and 0 is immature, using the probability of being mature-at-age (m_a)from the SAFE (page 40). Similarly, a Bernoulli random variable was generated for 2, 5, and 10% skip spawning between ages 5 and 22, which is the age range where fish were found to skip spawn in collections made in 2011 and 2015, where a value of 1 indicates skip spawning and the functional maturity is 0 (immature). Maturity was estimated using logistic regression (GLM) and a GAM with a logit link on 250 randomly sampled individuals by age, length, or age and length. Additionally, the true maturity-at-age (length) was estimated by summing the number mature by the sample size using the full dataset (10,000 x number of ages). Resulting maturity curves were examined graphically. Additionally, the root mean squared error is provided.

Sablefish

Sablefish maturity was estimated using all samples from the 2011 and 2015 collections with a GLM and a GAM on age, length, and age-length models using a binomial family with a logit link; knots were unconstrained for GAMs. The age-length models used the following forms:

GLM: maturity ~ age x length

GAM: maturity ~ s(age) + s(length).

The resulting maturity curves for sablefish were incorporated into the stock assessment model for examination of any changes to spawning biomass estimates.

Results

Simulations

Note that for clarity only simulations based upon 5% skip spawning are presented. Based upon simulation analysis, if skip spawning is present and a GLM is used to determine maturity-at-age then the maturity rate of younger fish will typically be overestimated followed by an underestimation of the true maturity rate. A GAM more accurately reflects the true maturity rate (Figure 1). This same trend holds true for maturity-at-length (Figure 2). Maturity models that account for age and length provide similar results (Figure 3). If only age or length is accounted for in the model then the GAM performs best (Figure 4), if the model is based upon age and length then either the GAM or GLM perform equally well for this scenario (Figure 5).

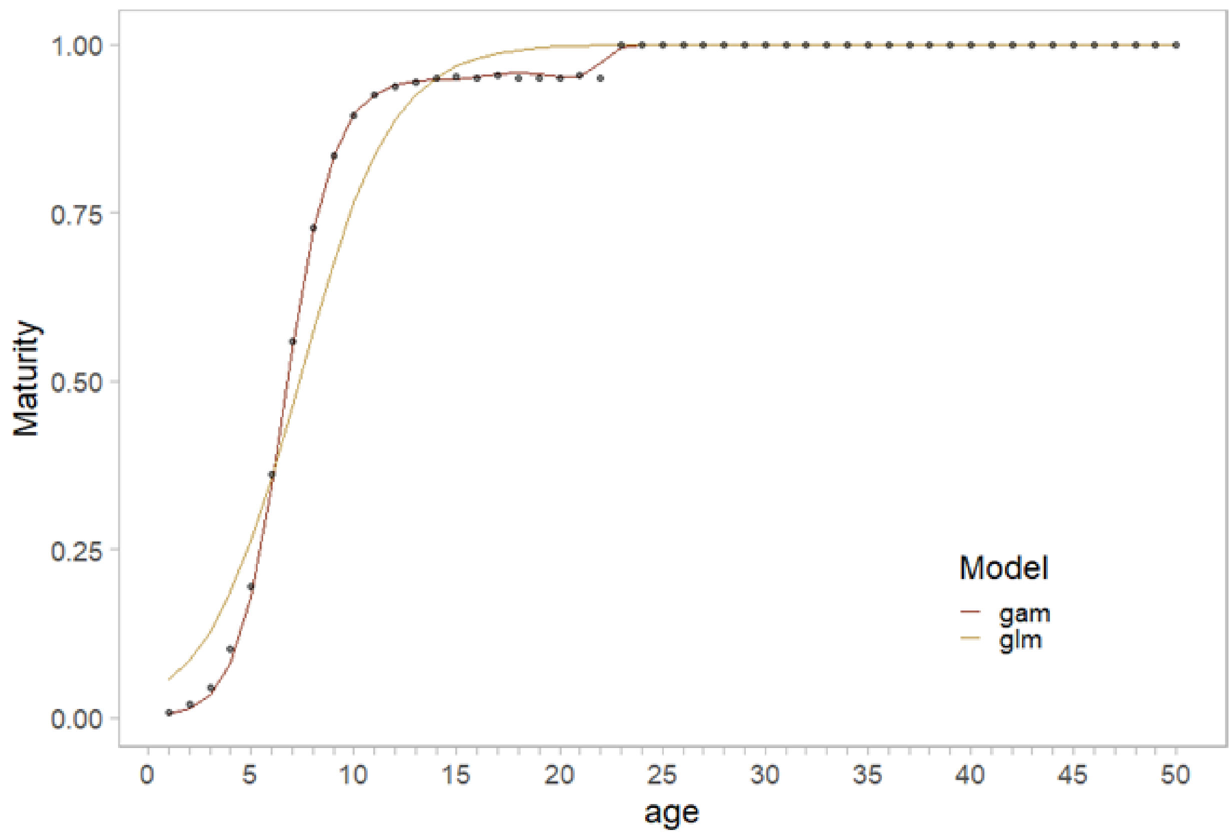


Figure 1. Maturity-at-age based upon simulated maturity with 5% skip spawning between ages 5-22. The true maturity at age from the simulated data is represented by dots.

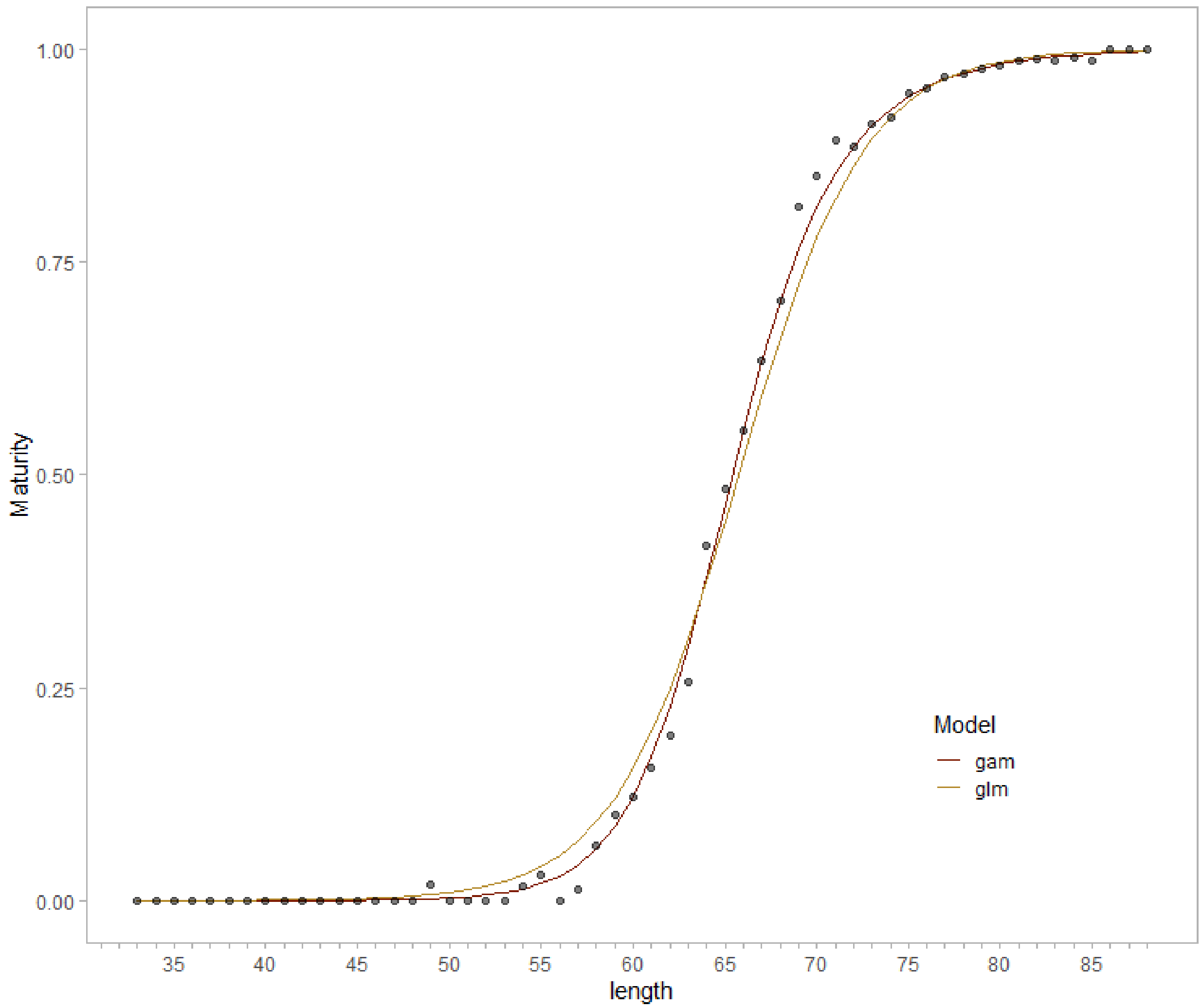


Figure 2. Maturity-at-length based upon simulated maturity with 5% skip spawning between ages 5-22. The true maturity-at-length rate is represented by dots.

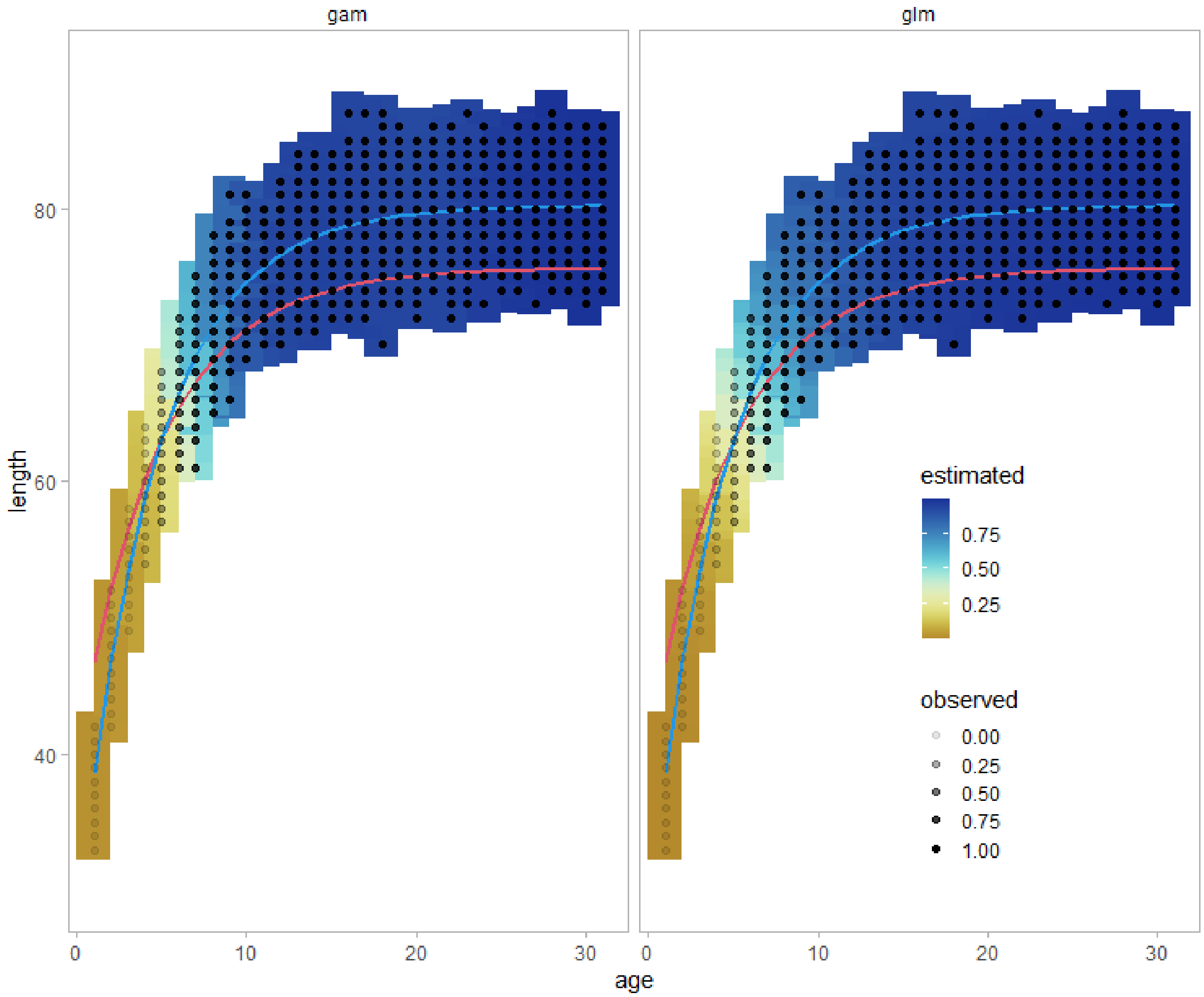


Figure 3. Maturity-at-length and age based upon simulated maturity with 5% skip spawning between ages 5-22. The coloring indicates the modeled proportion mature at a given length for each age. The true maturity-at-length for each age rate is represented by dots, the shading of the dot indicates the proportion mature. The red line is the 1960-1995 growth curve and the blue line is the 1996-present growth curve from the SAFE.

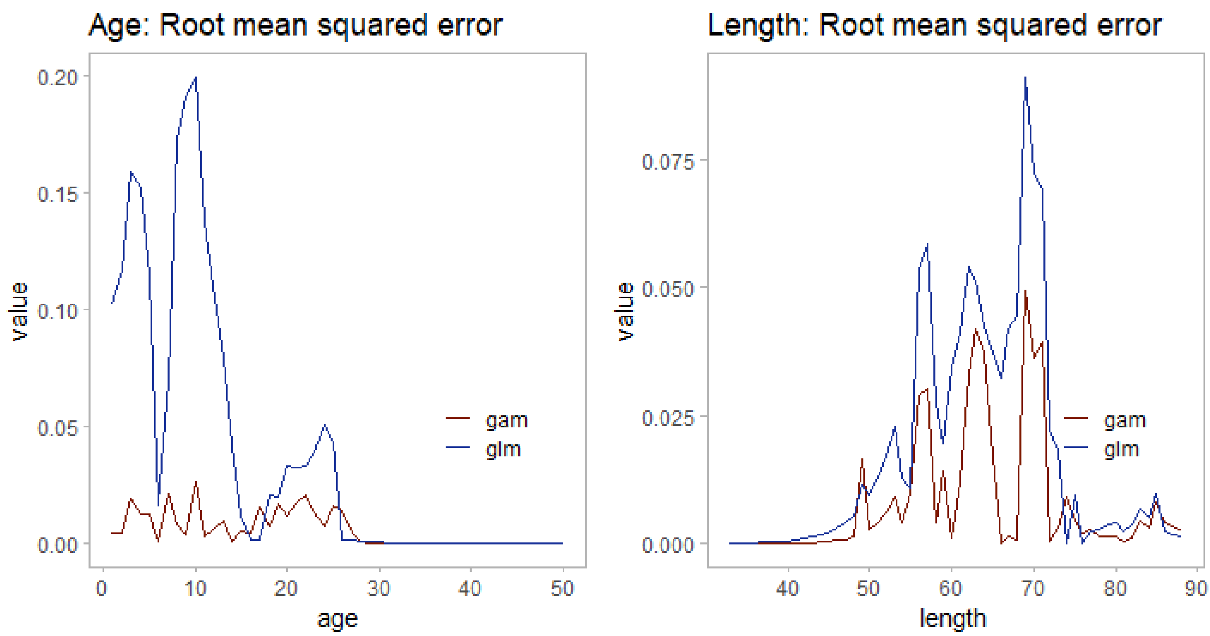


Figure 4. The root mean square error of maturity estimates by age and length compared to the true maturity at age or length.

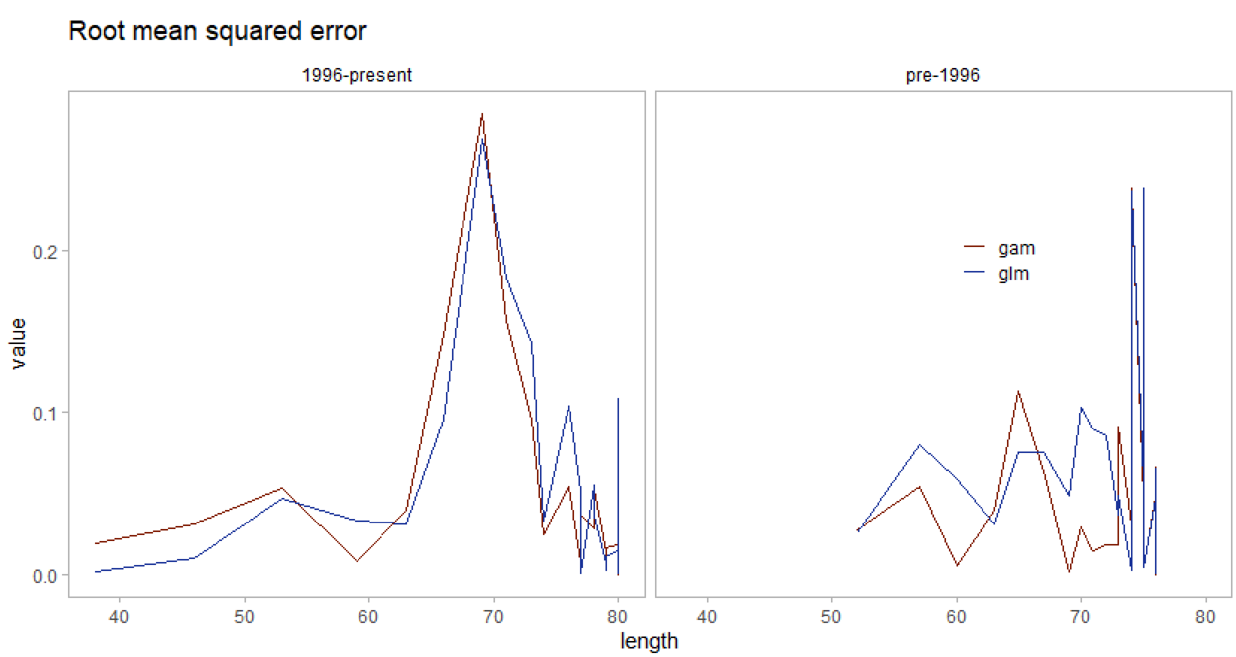


Figure 5. The root mean square error of maturity estimates by age-length compared to the true maturity at age-length for the two female growth curves provided in the SAFE.

Sablefish

Maturity curves at age show a substantial difference between the GAM, GLM and current models (Figure 6). When converted to maturity at age, the length-based maturity models are more similar, though discrepancies still arise (Figure 7). The age/length GAM and GLM models provide similar results, which include a reduction in maturity-at-age for pre-1996 lengths from the current model and similar results for 1996-present (Figure 8). Of note is the reduction in maturity at age of ages <5 for 1996-present, which has implications for SSB estimates. All of the updated maturity curves generally produce a reduction in SSB (Figure 9). However, since the age-based GLM is particularly different from the current model (Figure 6) it produces substantial shifts in SSB relative to all the other models (Figure 9). As such it has the greatest percent deviation and root mean square error from the base model (Figures 10 & 11).

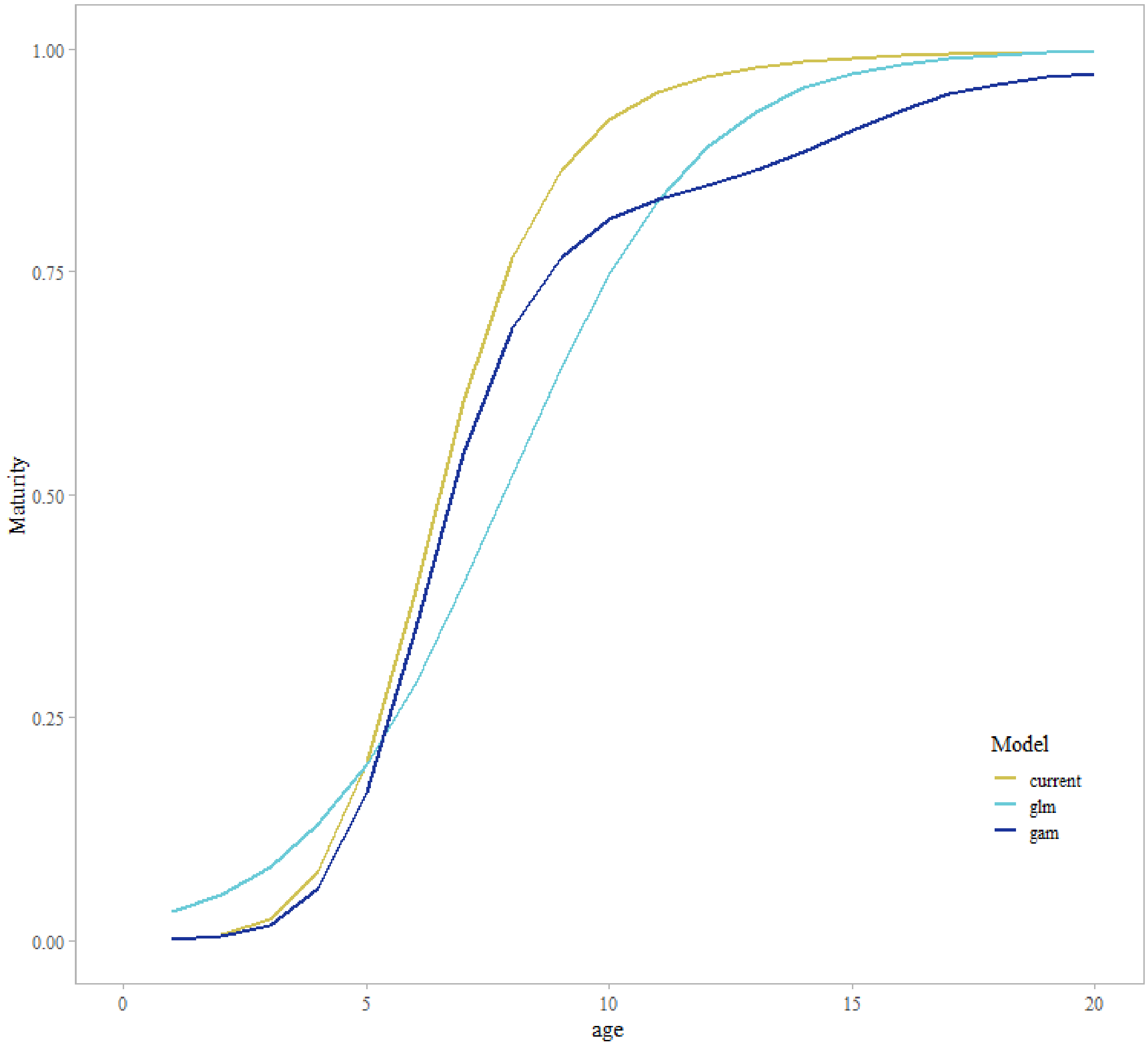


Figure 6. Age-based sablefish maturity showing the current maturity curve and GLM and GAM based curves estimated using functional maturity. The current maturity curve is from Sasaki (1985).

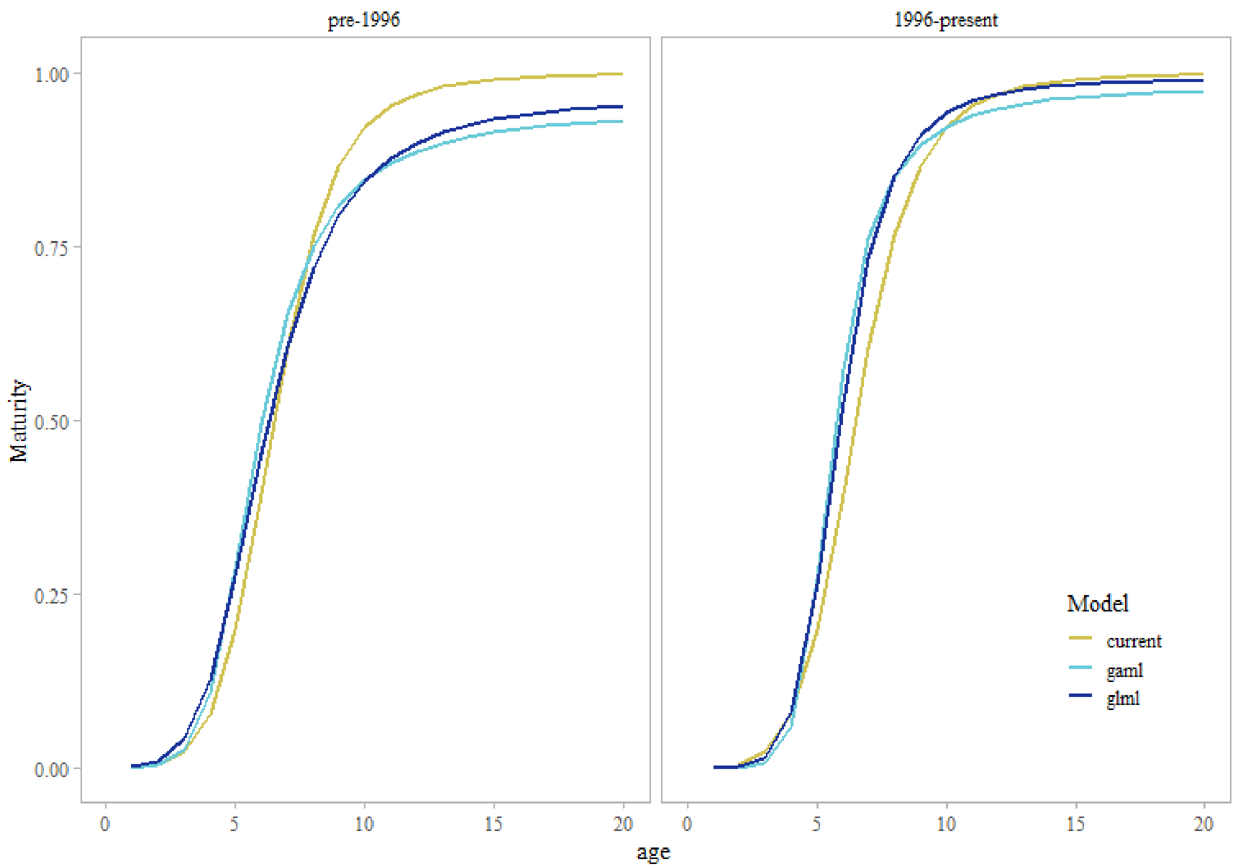


Figure 7. Length-based sablefish maturity showing the current maturity curve and GLM and GAM based curves estimated using functional maturity. The two time periods are for different growth rates in the SAFE (Goethel et al., 2020). The current maturity curve is from Sasaki (1985).

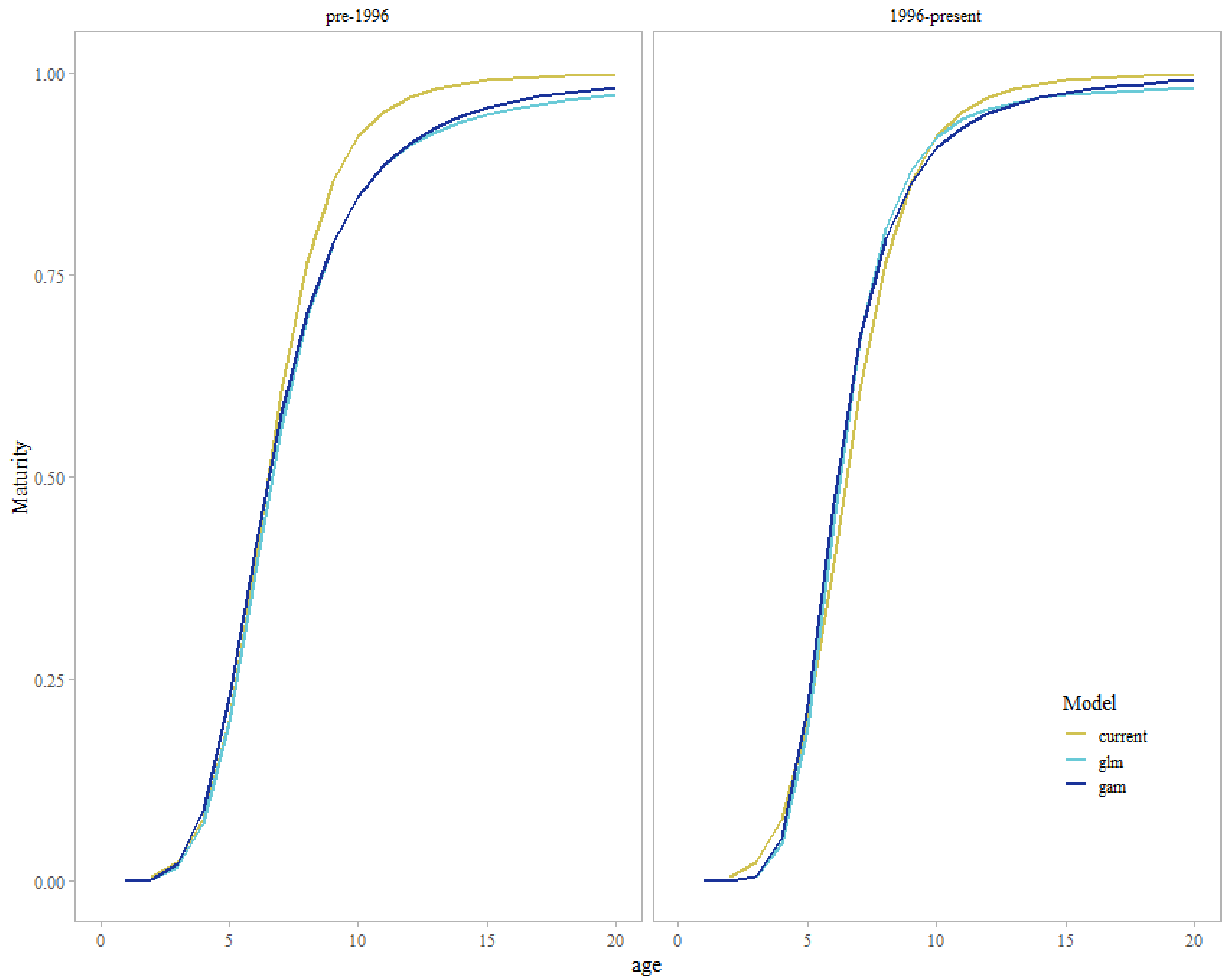
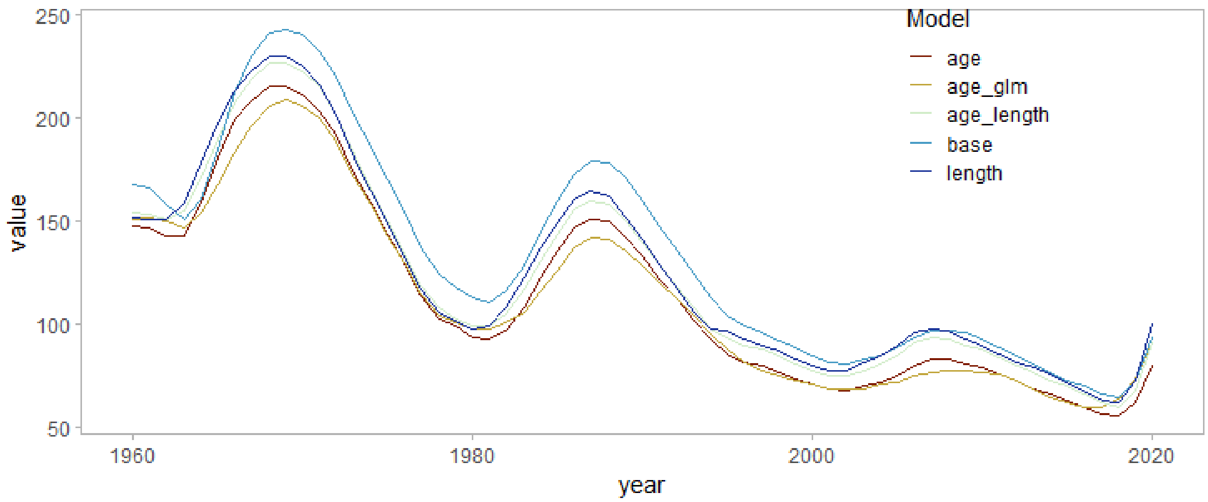


Figure 8. Age/length-based sablefish maturity showing the current maturity curve and GLM and GAM based curves estimated using functional maturity. The two time periods are for different growth rates in the SAFE (Goethel et al. 2020). The current maturity curve is from Sasaki (1985).



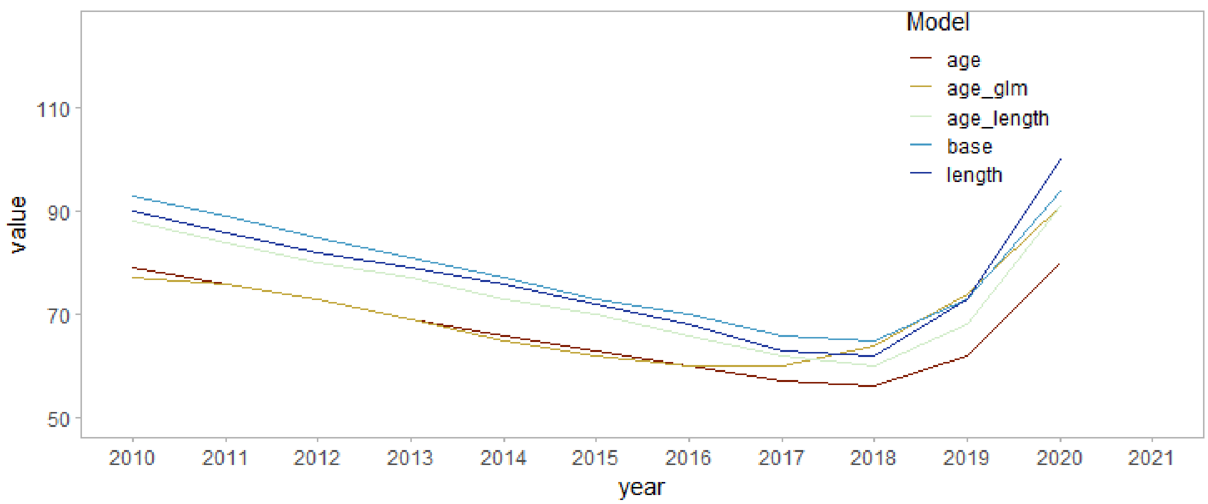


Figure 9. Spawning stock biomass (SSB) estimates from the stock assessment and from three GAM (age, length, age_length) estimated and one GLM (age_glm) estimated alternate maturity models. The base model uses the current maturity curve.

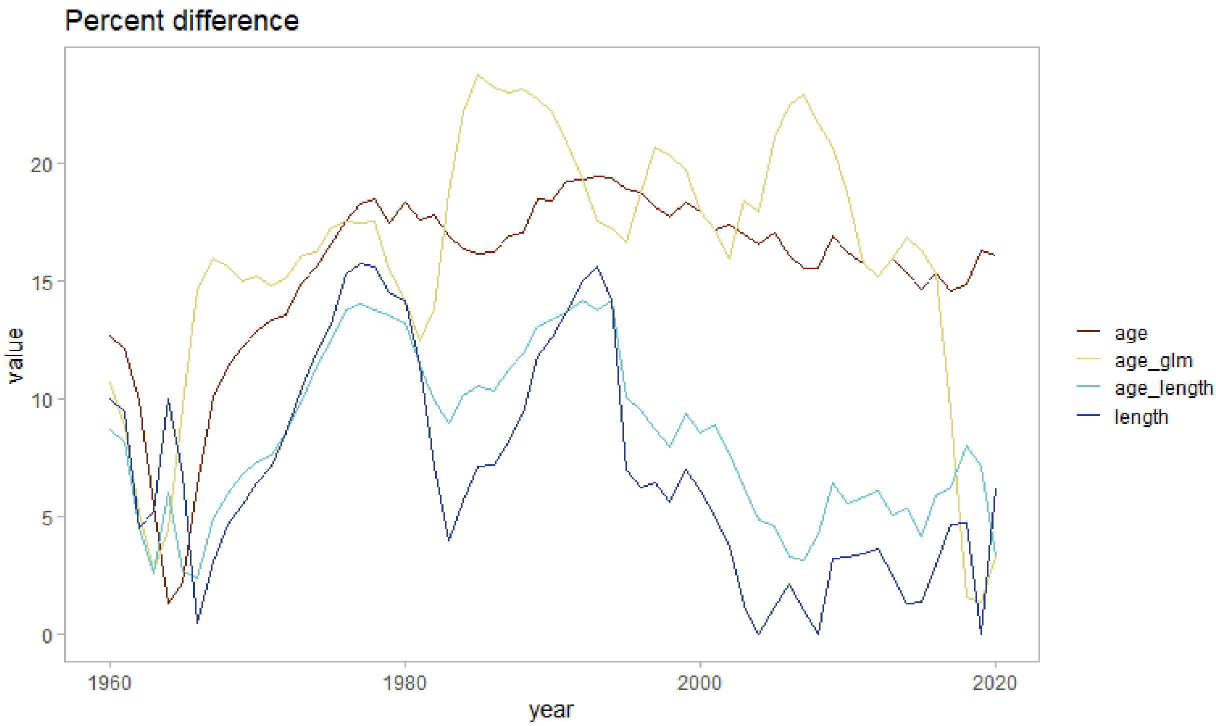


Figure 10. The percent difference between the base stock assessment spawning stock biomass (SSB) and SSB from three alternate GAM (age, length, age_length) maturity models and an age-based GLM (age_glm).

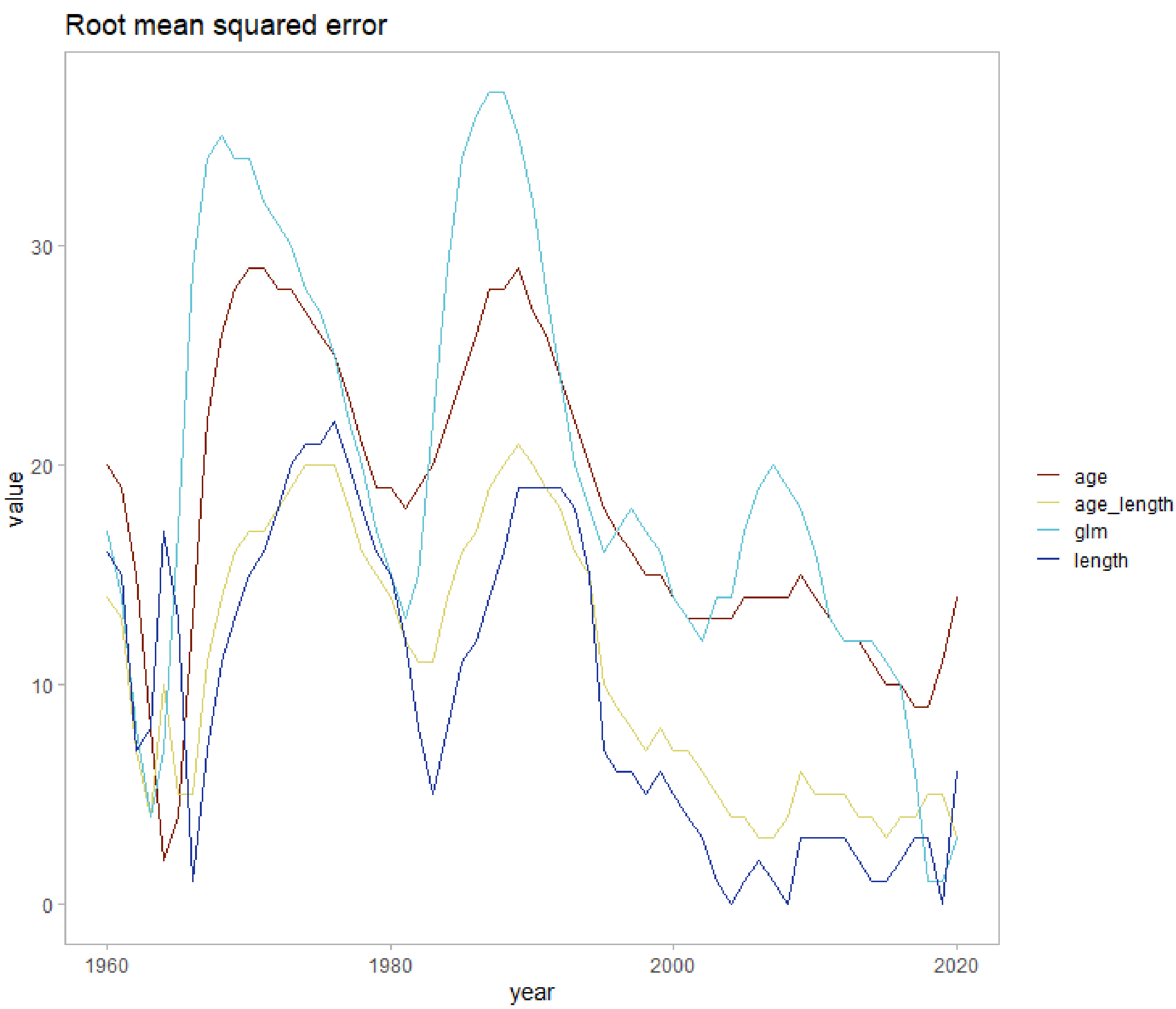


Figure 11. The annual root mean squared error between the base stock assessment spawning stock biomass (SSB) and SSB three alternate GAM (age, length, age_length) maturity models and an age-based GLM (age_glm).

Discussion

The incorporation of skip spawning redefines maturity as "functionally mature", as opposed to "biologically mature" (Head et al. 2020), where functional maturity includes only those fish that are reproducing in the current season. Considering skip spawning fish as not functionally mature makes a meaningful difference in the shape of the maturity curve. The shape of the curve in turn affects the overall SSB generated from the assessment model. Given that a GLM cannot adequately estimate maturity from data that includes skip spawning it seems prudent to not use this type of model structure. Therefore calling the Sasaki (1985) maturity data, which is currently used in the assessment, into question as it was collected in the summer, was evaluated macroscopically, and did not include a code for skip spawning, which may all be problematic (Rodgveller 2016, 2018). The current maturity curve may be overestimating the number of spawners at younger ages as evidenced by the age, length and age-length models for the 1996-present growth curve (Figures 7 & 8). The response at older ages is generally an overestimate as well.

If skip spawning is regularly present then the assessment would be well served to include this information. However, though many species world-wide have been observed to skip spawn the spatial and temporal aspects of skip spawning of sablefish in Alaskan waters has not been evaluated. If skip spawning occurs intermittently and for short periods of time it is likely unnecessary to consider it for stock assessment purposes, assuming the percent of fish at a given age is limited. If the amount of skip spawning is consistent then it may be possible to leave it unaddressed and note that there is a bias in the assessment, though it should act simply as a scalar of biological reference points. However, the limited information currently available (2 years) indicates variability is present in the annual amount of skip spawning (Rodgveller et al. 2018) and therefore should be researched further to understand the variation. Last, the maturity data were sampled from a small spatial area, which may not reflect the larger population condition. There are plans to obtain samples from the fishery in the Aleutian Islands, Central GOA, and the Eastern GOA in 2022 when it opens in the spring, which is likely close to spawning season and ovaries will show evidence of past or imminent spawning. We hope to gather spatial data on maturity, skip spawning, and energetics for the first time. More years of data will be needed to evaluate the maturity and skip spawning rates for the population over time. Longline survey data from August in the Central GOA could be utilized more in the future with tissue collections and histological analysis of maturity status.

Overall our recommendation would be to include skip spawning, preferably through the age/length model and prioritize research to address temporal and spatial data gaps. Adopting this model will provide a measure of maturity that incorporates changes in growth (Echave et al. 2012) and does not appear to have a substantial impact relative to the current estimate of SSB.

References

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