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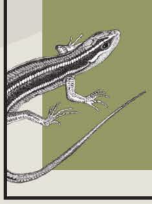

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Application of age data to the Oregon data-moderate assessments for Copper and Quillback rockfishes

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ABSTRACT

In 2021, the Pacific Fisheries Management Council conducted stock assessments for Copper (*Sebastes caurinus*) and Quillback rockfishes (*S. maliger*) off Oregon using a length-based data-moderate assessment approach. This approach excludes direct incorporation of age data for these two assessments. This project re-runs these assessment models, but incorporates the available age data for each species, to evaluate the ability to estimate key aspects of their population dynamics, including growth and recruitment. Two model configurations were explored for each species, one with and one without estimation of annual recruitment deviations. These modeling attempts were largely unsuccessful, but for different reasons. For Quillback Rockfish, the limited age data (n = 951) appeared to be insufficient in quantity to estimate growth and recruitment deviations simultaneously, which will be addressed for future assessments by ageing the existing collection of age samples. For Copper Rockfish, a relatively substantial age dataset was available (n = 2,631), but still did not provide enough information to estimate growth and recruitment deviations within the model simultaneously. The Copper Rockfish models explored appeared to be particularly sensitive to the treatment of the commercial data, consistent with the 2021 adopted data-moderate assessment.

INTRODUCTION

Copper (*Sebastes caurinus*) and Quillback (*S. maliger*) rockfishes in Oregon waters were assessed during the 2021 – 2022 Pacific Fisheries Management Council (PFMC) assessment cycle (Langseth et al., 2021; Wetzel et al., 2021). In preparation for the 2021 - 2022 cycle, Oregon Department of Fish and Wildlife (ODFW) aged a total of 2,631 Copper Rockfish otoliths collected from recreational and commercial fisheries. For Quillback Rockfish, 951 otoliths had been read for age determination for previous research projects. A new length-based data-moderate assessment approach was approved for use in the 2021 - 2022 assessment cycle where catch and length composition data were utilized in the Stock Synthesis (SS3) integrated assessment framework (SS3-CL, Rudd et al., 2021). This new data-moderate approach may facilitate the assessment of many groundfish species managed by the PFMC with variable levels of data quantity and quality. Additionally, there is limited capacity to conduct and review PFMC groundfish stock assessments. Data-moderate assessments for species that have limited data reduces workload and review needs relative to full assessments, increasing the throughput of advice for management. The Scientific and Statistical Committee (SSC), the scientific advisory body to the PFMC, provides guidelines regarding the data types and sources that could be used and the treatment of biological parameters within SS3-CL models, designed to simplify the assessment and review process. The PFMC selected multiple species with which to implement this new SS3-CL framework for the 2021 assessment cycle. At the time, the PFMC categorized Copper and Quillback rockfishes as data-moderate assessments due to the limited data and data types available at the coastwide level, as opposed to the finer scale spatial delineation ultimately used in each assessment (state or sub-state level). This modeling decision excluded using available age data collected from Oregon fisheries directly within the assessment model (i.e., noting that age data were used for estimation of growth outside the model, "Terms of Reference for the Groundfish and Coastal Pelagic Species Stock Assessment Review Process for 2021-2022," 2020). The goal of this project was to integrate the ODFW age datasets in the adopted data-moderate assessments to better understand the importance of these data to the estimation of stock status of Copper and Quillback rockfishes in Oregon and the estimation of key parameters within the assessment model, such as growth, natural mortality (*M*), and annual recruitment deviations for each species, if possible.

METHODS

Major characteristics of the data-moderate assessments

SS3 is an integrated statistical catch-at-age modeling framework that is the primary platform used to assess West coast groundfish species managed by the PFMC (Methot and Wetzel, 2013). SS3 is a highly flexible modeling platform that can be structured to a simple population model (e.g., an age-structured population model with fixed growth, selectivity, and with deterministic recruitment) or structured to capture highly complicated population and fishery dynamics (e.g., time-varying biology, movement, multiple distinct growth curves). To date, SS3 has been used across species with a range of available data to provide advice to management. In 2020, the PFMC SSC approved the use of data-moderate assessment approach using only catch and length data (i.e., fishery-independent indices of abundance, if available, could also be included) where simulation analysis indicated that models using catch and length data in SS3 are generally able provide similar estimates of stock status compared to full assessments (Rudd et al., 2021). The data-moderate assessment approach of using only catch and length data within SS3 was termed a SS3-CL assessment.

Copper and Quillback rockfishes were assessed in 2021 using the SS3-CL modeling approach where only catches and length data from recreational and commercial fisheries in Oregon to estimate stock status and provide advice to management. The general structures of the data-moderate assessments for both species (Table 1) were retained for certain models, and alternative model configurations (e.g., additional data, estimation or fixing of parameters) were evaluated. More details on the adopted data-moderate assessment structures are included in the 2021 stock assessment documents (Langseth et al., 2021; Wetzel et al., 2021). In the 2021 stock assessment of Copper Rockfish, growth was estimated externally to the assessment model using length-at-age data collected from Oregon and Washington fisheries (only recreational fishing is allowed in Washington for Copper Rockfish) that were combined with a California growth study that provided mean length-at-age and standard deviation used to simulate age data for young fish (i.e., fish age 3 or less, Lea et al., 1999). The resulting growth curve indicated sex-specific growth with females growing to a slightly larger size than males. The estimated sex-specific growth parameters were then utilized in the assessment model as fixed parameters. For Quillback Rockfish, fishery-dependent data from Oregon and Washington and data from the coastwide West Coast Groundfish Bottom Trawl survey were utilized to develop external growth estimates. There were fewer samples from which to develop a growth curve for Quillback Rockfish and, given the lack of difference in growth observed between males and females, a single-sex model was developed for this species for the sake of parsimony.

Table 1. General model characteristics of the Oregon Copper Rockfish and Quillback Rockfish adopted data-moderate assessment models (Langseth et al., 2021; Wetzel et al., 2021).

Model Characteristic	Copper Rockfish	Quillback Rockfish
Treatment of sex	Two-sex model	Single-sex model
Growth	Estimated outside model and fixed	Estimated outside model and fixed
Fleet Structure	Commercial; Recreational	Commercial; Recreational
Selectivity Shape	Asymptotic; Domed	Asymptotic; Domed
Recruitment	Deterministic	Stochastic
Data Weighting Method	McAllister-Ianelli (1997)	Francis (2011)

Both assessments utilized a double-normal parameterization in selectivity, a highly flexible parameterization which allows for asymptotic or dome shaped selectivity for each of the two fleets (commercial and recreational) and the estimation of a dome shaped selectivity curve for the recreational fleets. Annual recruitment deviations were able to be estimated within the Quillback Rockfish assessment model but not within the Copper Rockfish model. The Quillback Rockfish assessment utilized Francis (Francis, 2011) data weighting, which is one of three data weighting methods approved for use by the SSC. The McAllister-Ianelli (McAllister and Ianelli, 1997) data weighting method was used for the Copper Rockfish assessment, because it resulted in a more stable model based on suggested data-weights between the commercial and recreational fleets. In Copper Rockfish, Francis data weighting gave little weight to the commercial fishery length data in the model, resulting in inconsistent and unrealistic estimates in the selectivity from the commercial fleet. In contrast, the McAllister-Ianelli method suggest a larger data weighting, but still relatively low weight overall, for this fleet that led to a more stable model with an estimated selectivity curve that better reflected the *a priori* expected selectivity based on understood size-selectivity of the fleet.

Age data and ageing error matrices

For both species, age data were formatted as conditional-age-at-length (CAAL) samples to be added into the stock assessment model files. Input sample sizes were set equal to the number of ages from each year, fleet, length bin, and sex. Lengths were binned in two-centimeter bins in each of the assessment models. Additionally, an ageing error matrix was developed using otolith double reads to estimate ageing error and/or bias by age using the nwfscAgeingError *R* package (Thorson et al., 2012), available on GitHub, for each species. For Copper Rockfish, there were a total of 339 ages from the commercial fleet and 2,292 from the recreational fleet, all aged by a single reader at ODFW. Age estimates ranged from 4 to 51 years old. These ages were used in the development of the growth parameters used in the data-moderate model. Additionally, there were 539 double reads (sample size (n) = 73 commercial and n = 466 recreational) from which an ageing error matrix was developed, again all from ODFW. For Quillback Rockfish, there were 783 ages from the recreational fleet and 168 from the commercial fleet, with read ages ranging from 5 to 40 years old from a single reader at ODFW. Again, these data were used in the development of the growth parameters for the data-moderate model. There were no available otolith double reads for Quillback Rockfish to support estimation of an ageing error matrix from Oregon data. Hence, double read samples collected from California fisheries and aged by the NWFSC Cooperative Ageing Program on Quillback Rockfish were used to develop the ageing error matrix (n = 143). These were collected from a variety of sources, including recreational fisheries (n = 21), commercial fisheries (n = 6), and several other fishery-independent sources (n = 116) and read by the NWFSC Cooperative Ageing Program lab (P. MacDonald, NWFSC; pers. comm.). All other ages were read by ODFW (M. Terwilliger, ODFW).

Modeling considerations

For each species, the age data and ageing error matrix were integrated into the existing data-moderate assessment models (termed "base models") adopted for management by the PFMC, and then models with variable structures were explored to determine which parameters could be estimated reliably, followed by various fine-tuning approaches (e.g., data weighting, adjusting parameter bounds). Figure 1 illustrates a generalized approach to the modeling process, though it differed by species. Model explorations were undertaken with the most recent Stock Synthesis executable version (3.30.19; Methot and Wetzel, 2013). Models were developed for each species with the desired attributes and key results were compared to the base model. Diagnostics were performed on selected models. The r4ss package (version 1.43.2; Taylor et al., 2021), available on GitHub, was used to visualize model results and the nwfscDiag *R* package (https://github.com/nwfsc-assess/nwfscDiag) was used to run model diagnostics. It is worth noting that none of the models discussed here have been reviewed and vetted for use in management, and therefore they should be considered exploratory only.

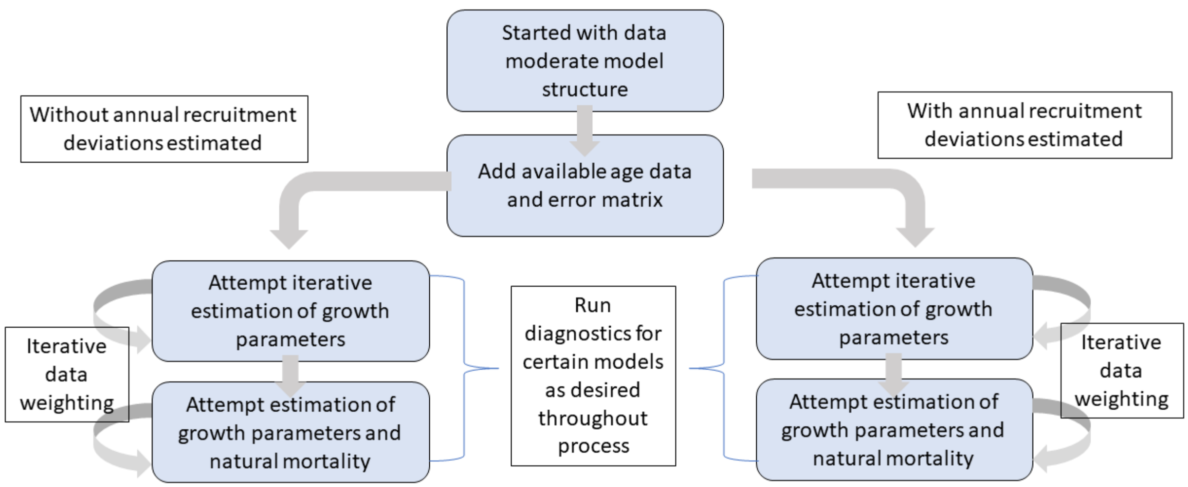

Figure 1. An illustration of the general approach to the model exploration process used. Note that the specific approach differed by species and is detailed in the Results section.

RESULTS

Copper Rockfish

First, the CAAL data and ageing error matrix were added to the base model. This was then followed by the development of a series of models that estimated annual recruitment deviations for subsets of years within the model, iterative exploration of the estimation of select growth parameters and *M* for each sex and updating the data weighting as appropriate. The estimate of the peak commercial selectivity parameter, the initial length that fish are fully selected, was relatively unstable across model configurations. Similar model sensitivity and uncertainty around this parameter had been identified in the adopted base model. For many models in this series, allowing estimation of the peak commercial selectivity shifts the selectivity curve rightward (e.g., maximum selectivity occurring at larger sizes), to a point where it was deemed unrealistic given the regulations in place for the commercial fishery. Therefore, this parameter was fixed at an intermediate value that was considered reasonable based on the knowledge of the commercial fishery fishing behavior throughout the iterative addition of estimated growth parameters. Models that estimated this parameter were run periodically during model exploration and development.

Growth was estimated using the von Bertalanffy growth parameters, and estimation of the maximum length (L_{MAX}), the Brody growth coefficient (*k*), the minimum length or first size-at-age (L_{MIN}), and the coefficient of variation in growth of young and old fish (CV_{young} and CV_{old}) were tested. Initial testing showed that the estimation of L_{MIN} was relatively uncertain (CV > 15%), and this parameter was fixed at the external estimate used in the data-moderate assessment during model exploration. Since the variation in growth of young fish is associated with the L_{MIN}, CV_{young} was also fixed, and estimation not explored. There are no fish under four years old in the dataset and estimates of initial growth parameters may not be supported by the data (e.g., L_{MIN}, the CV of young fish, and even potentially *k*, although estimation was explored). All estimates of the three remaining growth parameters above were reasonable (i.e., close to the values used in the data-moderate assessment) and reasonably precise (i.e., individual parameter CVs < 5%).

The addition of the CAAL data and the ageing error matrix to the base model markedly decreased the 2021 relative stock status (the fraction of spawning biomass in 2021 relative to unfished, SB_{2021}/SB_0; “Ages Only” model in Figure 2) through a reduced estimate of unfished recruitment (R_0). When annual recruitment deviations were turned on, the relative stock status decreased further, relative to the model with CAAL data added and deterministic recruitment (“Ages + Recs” versus “Ages Only” in Figure 2) and the residuals in the age compositions increased. The overall recruitment pattern with annual deviations estimated indicated at least two recruitment events that influence the trajectory of the population, one series of high recruitment years prior to 2000 and another smaller event in the year 2012. Similar years with well above average recruitment were seen in other rockfish models developed in 2021, including Vermilion Rockfish (Cope and Whitman, 2021) and Quillback Rockfish (Langseth et al., 2021).

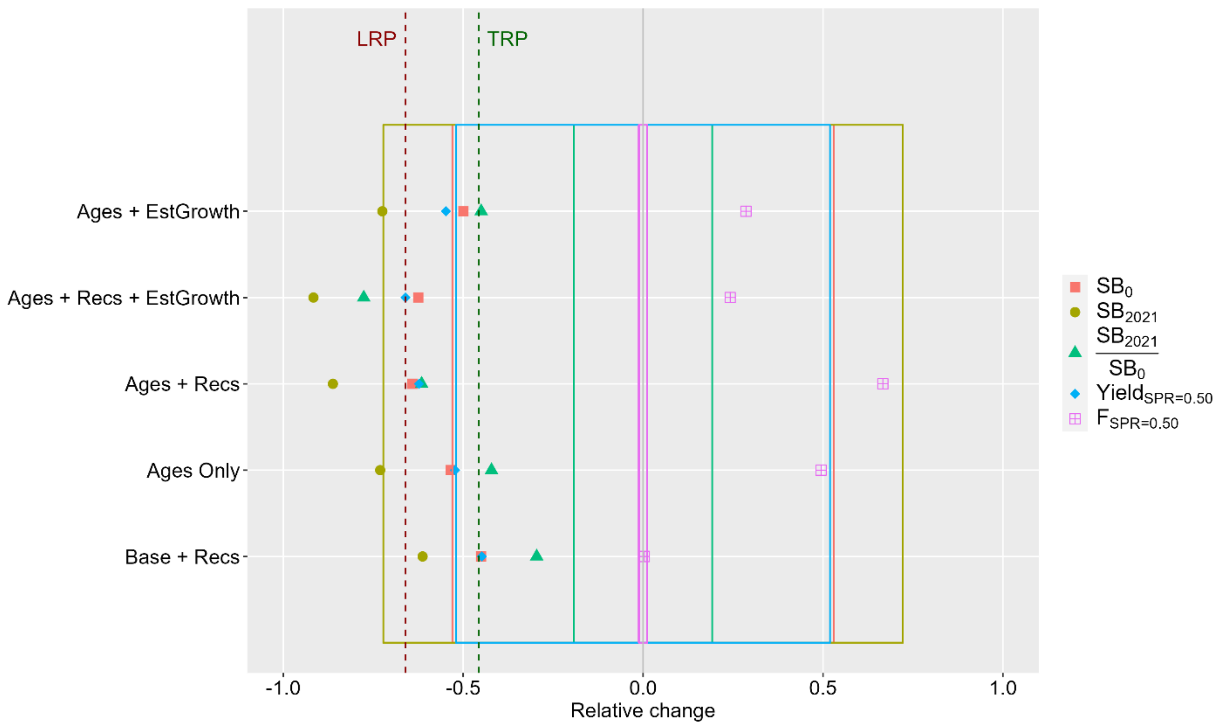

Figure 2 Comparison of the relative change in estimated management quantities (Cope and Gertseva, 2020) for key models (y-axis) within the Copper Rockfish model series relative to the data-moderate assessment adopted for management ("Base"; Wetzel et al., 2021) with recruitment deviations estimated in the base model ("Base + Recs"), age data added to the base model with recruitment deviations ("Ages + Recs"), and age data added to the base model with estimated growth and recruitment deviations ("Ages + Recs + EstGrowth") or age data added to the base model with deterministic recruitment ("Ages Only") and age data added to the base model with estimated growth and deterministic recruitment ("Ages + EstGrowth"). TRP is Target Reference Point and LRP is Limit Reference Point, and both apply to relative stock status (triangles) only. The quantities compared are the estimate of unfished spawning biomass (SB_0), spawning biomass in 2021 (SB_{2021}), the stock status (SB_{2021}/SB_0), the yield based on a spawner per recruit harvest rate ($Yield_{SPR=0.50}$), and the fishing mortality at that harvest rate ($F_{SPR=0.50}$). The colored boxes indicate 95 percent confidence interval around the point estimate of the quantity from the data-moderate model where each color corresponds with a specific quantity in the legend. A model with matching estimates as the base model would reflect a relative change of 0, a model with estimates less than the base model would have a negative relative change, and a model with estimates greater than the base model would have a positive relative change.

Francis data weighting was attempted but after multiple iterations, weights for the age data for each fleet did not appear to stabilize (i.e., the suggested data weights continued to vary after each data weighting iteration rather than stabilizing at a constant value). The McAllister-Ianelli data weighting approach stabilized after two iterations and was used in subsequent models. A lack of stability in data weighting has been observed in other groundfish assessments and is often considered as a signal that one or more of the datasets may not be informative to the parameters being estimated (i.e., data lacks contrast across time or sample sizes may be low).

Estimating L_{MAX} for both females and males resulted in reasonable estimates (i.e., close to the fixed values from the 2021 data-moderate assessment) that were precise (i.e., estimated parameter CVs < 1%) and in some improvement to the overall negative log-likelihood (NLL) (i.e., a decrease of 11 NLL units, with the two additional growth parameters estimated) when compared to the data-moderate model with ages added but no additional growth parameters estimated. Fit to the length compositions were improved but no difference was observed in the fit to the age compositions. Allowing the model to estimate sex-specific L_{MAX} parameters also resulted in a decrease in the selectivity of older fish by the recreational fishery and a continued decline in recent relative stock status. When the female and male *k* parameters were also estimated, the estimated sex-specific L_{MAX} parameters both increased and the recreational selectivity for larger fish continued to decline (e.g., became more deeply domed). Estimated values of *k* were generally lower than the fixed values used in the data-moderate assessment (e.g., for females, estimates range from 0.17 – 0.20 yr^{-1} when the fixed value = 0.206 yr^{-1}). Given the absence of fish aged between 0-3 years of age in the data, the estimated *k* parameters are being informed by the change in growth of fish 4+, which would be expected to vary from that if fish from all ages were available in the model. Estimating the *k* parameter of the growth curve resulted in a decline in the estimated relative stock status, and also resulted in a decrease in the NLL relative to the data moderate model with ages and no growth estimation (i.e., decrease in the NLL by 32 units, with four additional estimated parameters). There was also some improvement to the commercial age composition fit but not the fit to the recreational age compositions or the length compositions. When also estimating CV_{old} for both sexes, the descending limb of the peak selectivity parameter for the recreational fleet stabilized at a higher, more realistic level given the known fishery behavior. The overall NLL improved further (i.e., decrease of NLL by 189 units, when compared to a similarly weighted model with age data and recruitment but no growth estimation, noting the addition of six estimated growth parameters) and the fits to the age composition data, primarily for the commercial fleet, was improved as well. This was also the first model in the progression where a reasonable estimate of the peak commercial selectivity parameter was obtained with a reasonable CV (4.4%).

Adding estimation of *M* for both sexes at this point did not improve the NLL or fits to any of the major data sources. Estimates were both reasonable (female M = 0.12 yr^{-1}; male M = 0.11 yr^{-1}), though slightly higher than the median of the prior (e.g., 0.108 yr^{-1}). The estimated relative stock status increased when *M* was estimated for either sex; however, the male *M* was found to be highly correlated with R_0. The estimated peak of commercial selectivity was reasonable and more uncertain (CV > 5%). Convergence issues were encountered with this model failing to consistently identify the global best fit when attempting to estimate the three sex-specific growth parameters, *M* values, and annual recruitment deviations together.

Diagnostics were run on multiple models in the series, including jittering to evaluate model convergence and likelihood profiles on parameters of interest. Generally, diagnostics revealed that there was limited information in the data to inform several parameters, including R_0 (Figure 3), the peak of commercial selectivity (Figure 4) and *M* (Figure 5). The estimated recruitment deviations strongly influence the estimate of R_0 compared to the information in the length or age data (Figure 3). The recreational length data supports lower R_0 values while the recreational ages indicate support for higher R_0 values, though with both the commercial length and age data having limited information to inform R_0. Estimating recruitment deviations drives a lower estimate of R_0 compared to the adopted base model (Figure 3 versus Figure 32 in Wetzel et al., 2021).

The likelihood profile for the peak of commercial selectivity parameter indicated limited information in the commercial length and age data, with a relatively wide range of values having similar support in the data (i.e., within 2 NLL units; Figure 4). The limited change in the likelihood across a range of values for the peak of the commercial selectivity resulted in a range of parameter estimates given the model structure, especially when recruitment deviations were estimated within the model.

There appeared to be limited information in the length or age data to inform the estimate of female *M* (Figure 5). Generally, age data are expected to contain some level of information on *M*, although noting that this parameter, even with considerable age data, can be challenging to estimate. The recreational ages had little to no information on *M* with even less information in the commercial age data within the model when estimating select growth parameters and recruitment deviations.

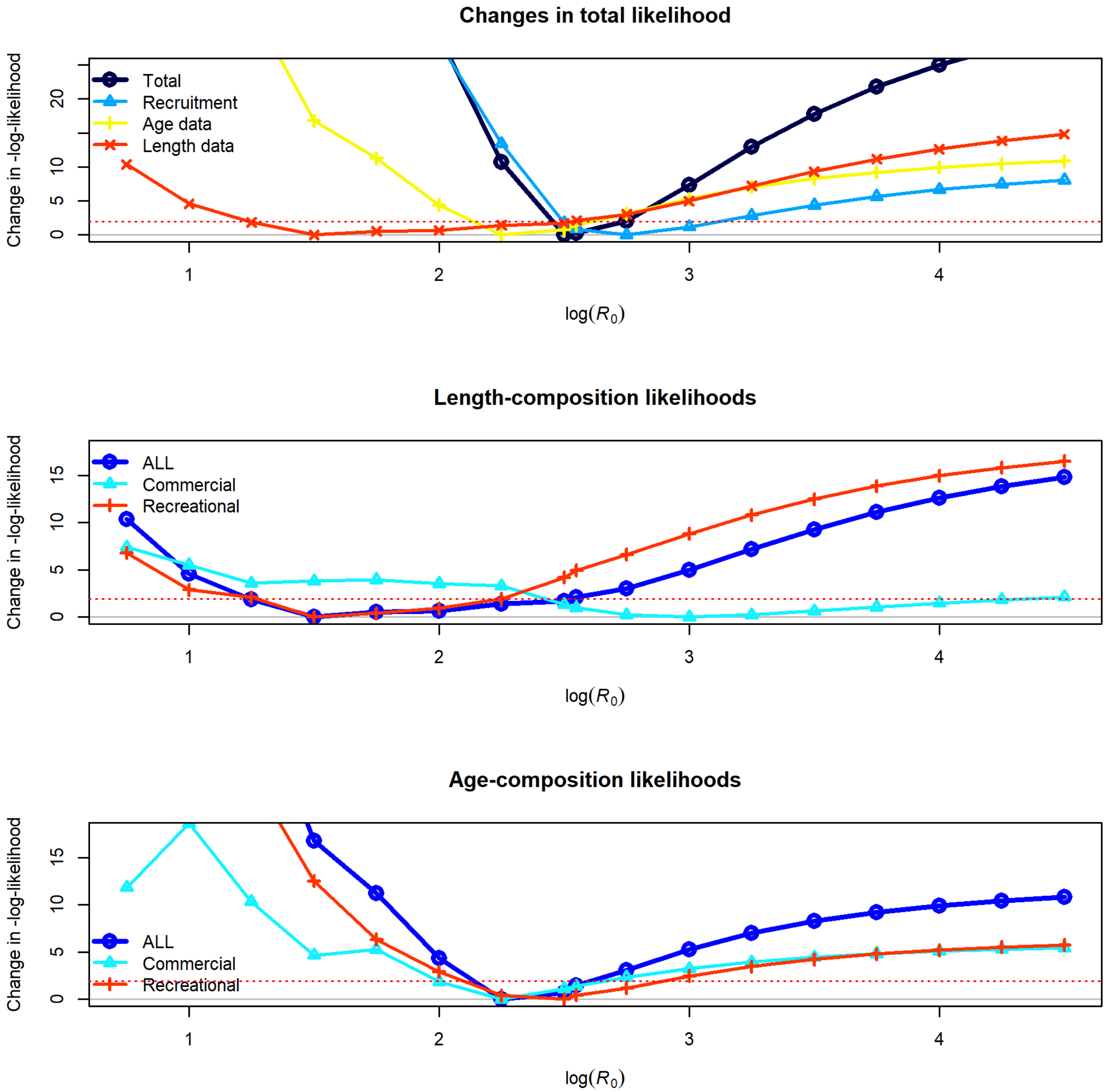

Figure 3. Example of a likelihood profile across values for R_0. This model estimated recruitment and three growth parameters (corresponding to the "Ages + Recs + EstGrowth" model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

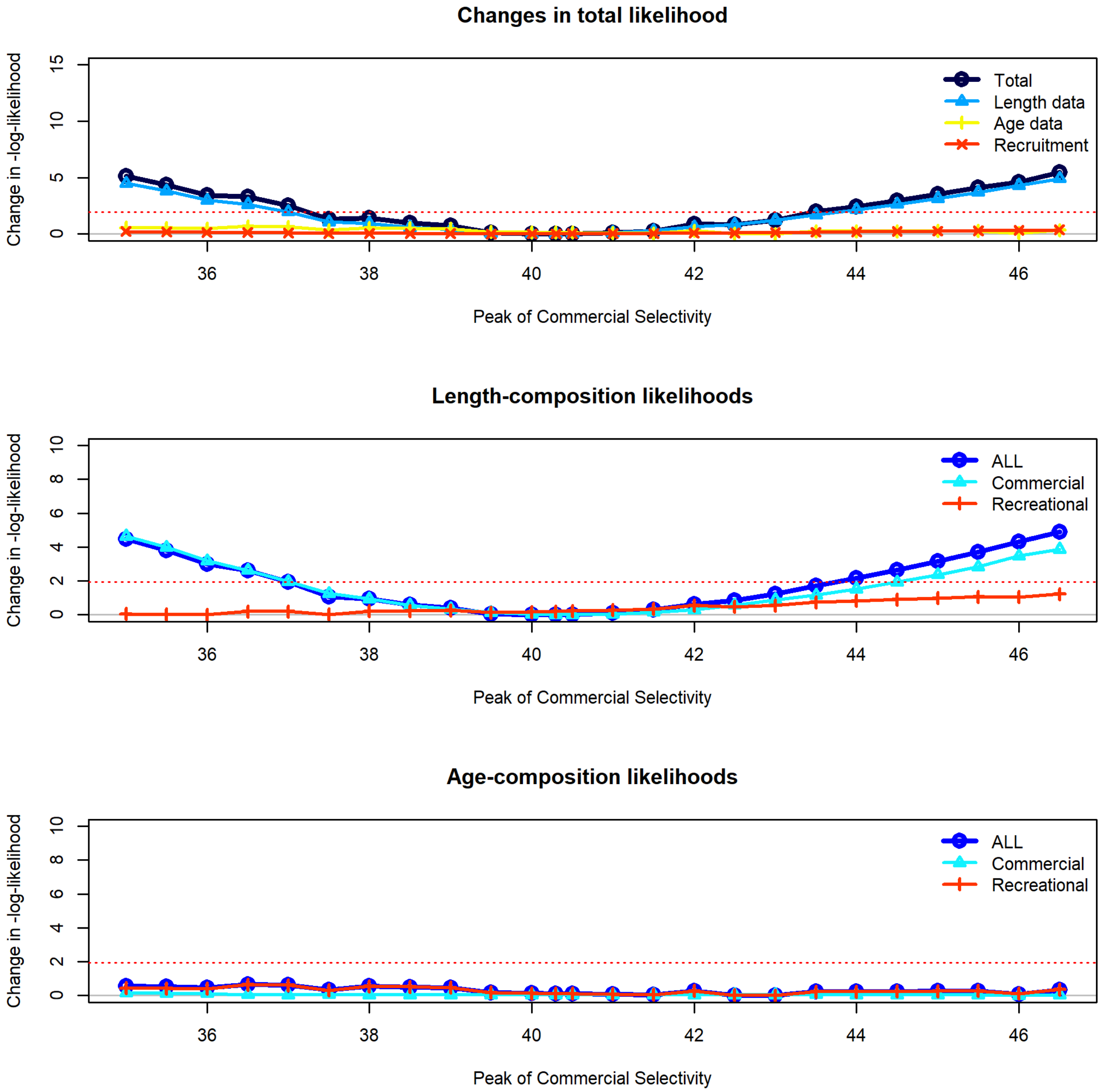

Figure 4. Example of an uninformative likelihood profile across values for the peak of commercial selectivity. This model estimated recruitment and three growth parameters (corresponding to the "Ages + Recs + EstGrowth" model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

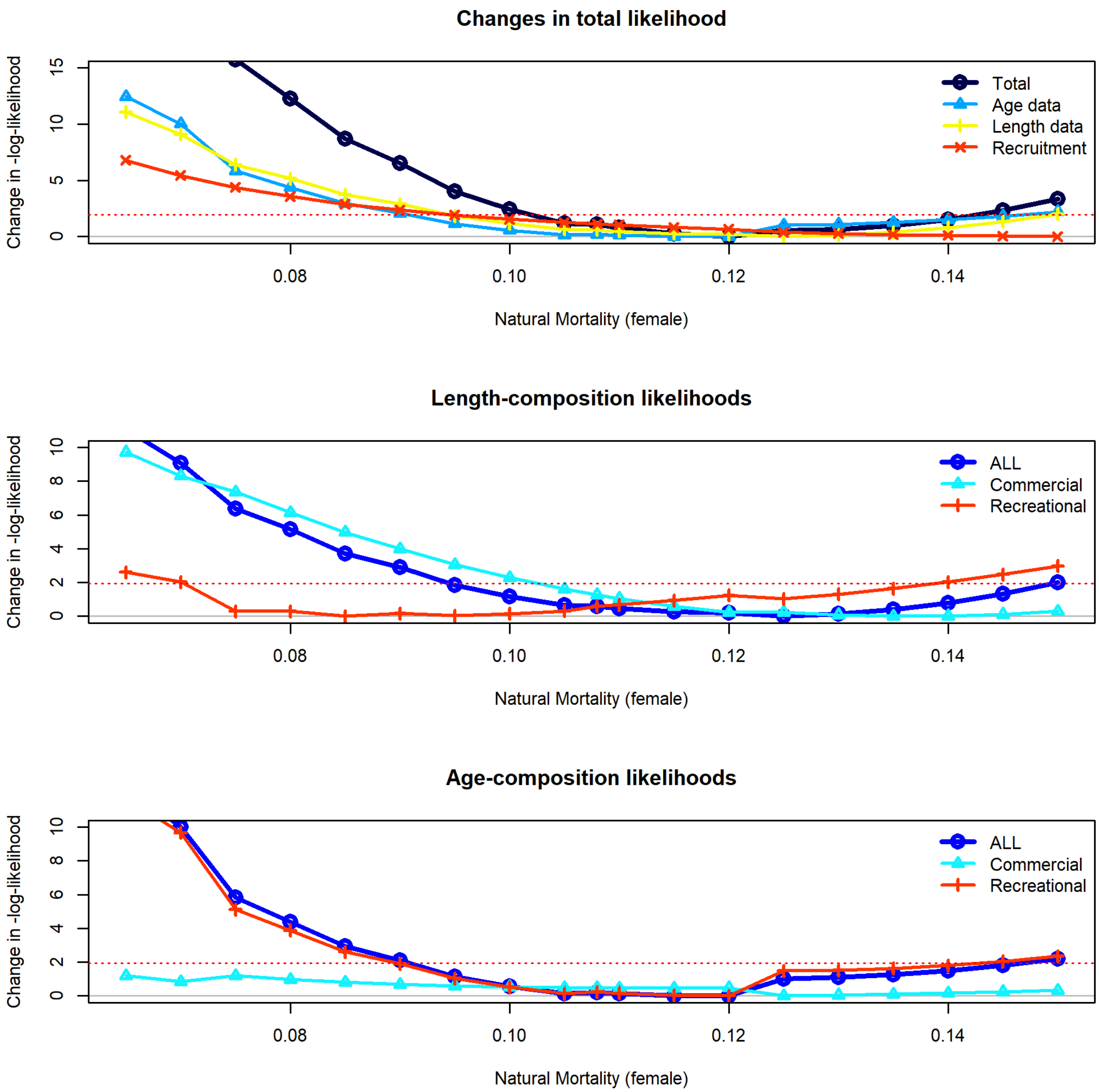

Figure 5. Example of an uninformative likelihood profile across female *M* value. This model estimated recruitment and three growth parameters (corresponding to the “Ages + Recs + EstGrowth” model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

A similar series of models were run without annual recruitment deviations being estimated (i.e., deterministic recruitment) and included the same modeling series that iteratively turned on estimation of specific growth parameters and *M*. Results from these models were generally similar to the series with annual recruitment deviations, though the trajectory of the population did not include the large estimated population swings (i.e., the marked decline in the recent relative stock status) but the addition of the age data resulted in a more depleted estimate of the stock compared to the base model (Figure 2, models "Ages Only" and "Ages + EstGrowth"). Fits to the length- and age-composition data were generally worse than those models that estimated recruitment deviations, as would be expected from a model with significantly less flexibility with fewer estimated parameters. The estimation of annual recruitment deviations provides significant model flexibility and the estimated deviations may reflect both variation in recruitment and some degree of model mis-specification. However, when deterministic recruitment was assumed, the peak of commercial selectivity was able to be more reliably estimated at a value that was considered reasonable given the dynamics of the fishery. This result is consistent with the behavior of the adopted base model which opted for deterministic recruitment to improve model stability (Wetzel et al., 2021). There were no significant correlations among parameters with models where growth was estimated (L_{MAX}, k, and CV_{old}). Again, McAllister-Ianelli data weighting was applied. Multiple growth parameters were able to be estimated reliably (individual parameter CVs ≤ 5%). Relative stock status and the descending limb of recreational selectivity were also not as volatile as those models with annual recruitment deviations. Estimating *M,* though reasonable estimates were obtained, created some level of correlations among commercial selectivity parameters.

Diagnostics were run on two deterministic models, one that estimated both male and female L_{MAX} values and one that estimated L_{MAX}, *k*, and CV_{old} for both sexes. Jitter analyses confirmed good convergence for both of these models. However, the profiles on R_0 indicated significant uncertainty to the range of values supported in the data (support in the data for log(R0) values between approximately 2.75-3.10, Figure 6). Additional profiles on the three estimated growth parameters (L_{MAX}, *k*, and CV_{old}) showed increased information in the data when this less flexible model structure was assumed compared to the models that estimated annual recruitment deviations (Figures 7 – 9). In particular, the recreational age compositions were generally more informative in the estimation of R_0 and growth parameters compared to models with recruitment deviations estimated. However, across models, length and age composition data were highly informative for all estimated parameters when compared to similar models with estimated recruitment deviations. The growth curve from the model that estimated all three growth parameters was similar to the fixed growth curve from the data-moderate assessment, though the estimated L_{MAX} for both males and females was slightly larger compared to the assumed L_{MAX} parameters in the base model (Figure 10). The fixed L_{MAX} values within the base model were estimated externally using age data from both Oregon and Washington to construct an average growth curve for this portion of the Copper Rockfish stock off the U.S. West Coast, where there were differences in the age-at-length observed with sampled fish in Oregon reaching larger sizes compared to fish from Washington waters.

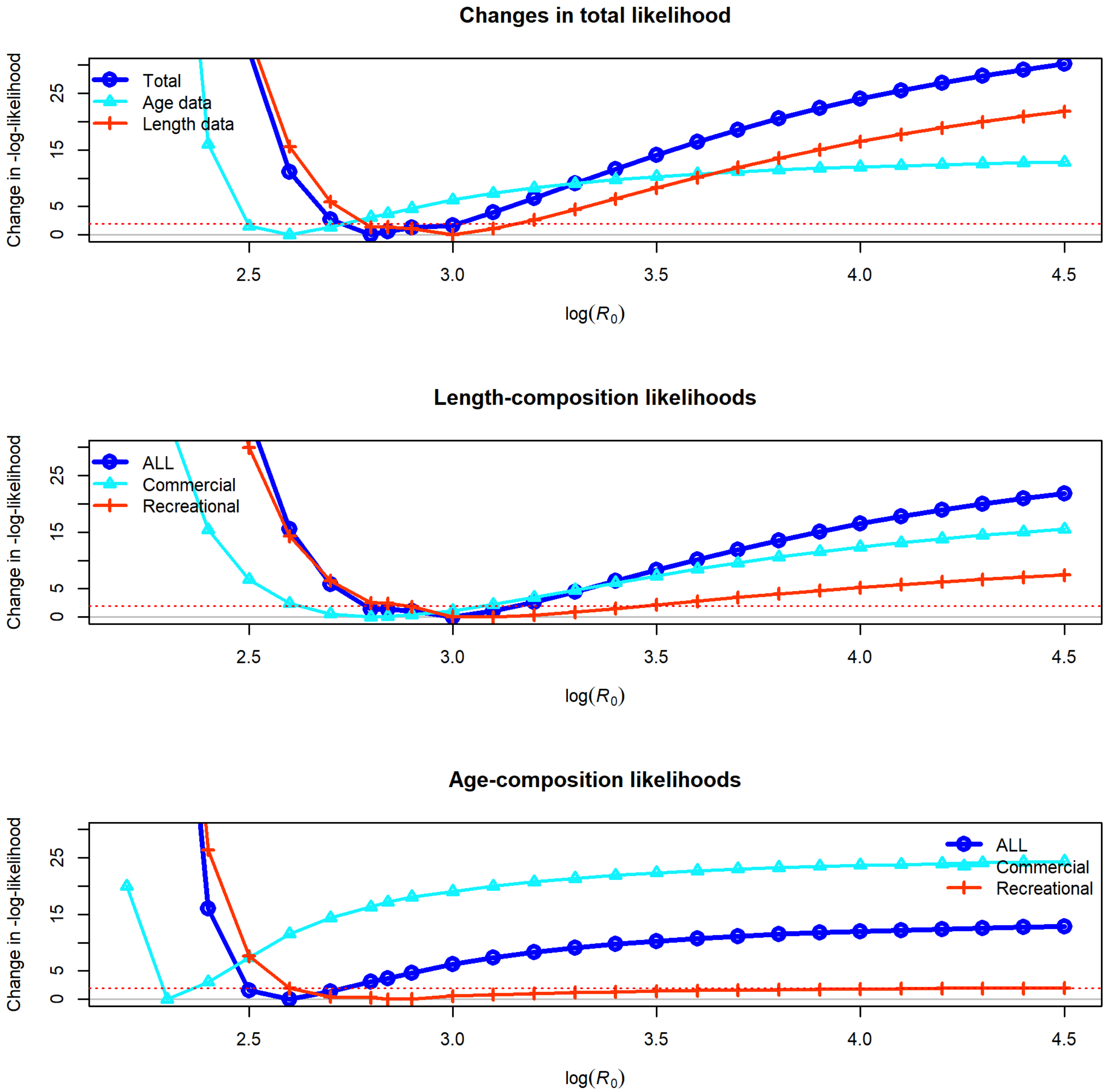

Figure 6. Likelihood profile across values for R_0. This model estimated three growth parameters (corresponding to the "Ages + EstGrowth" model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

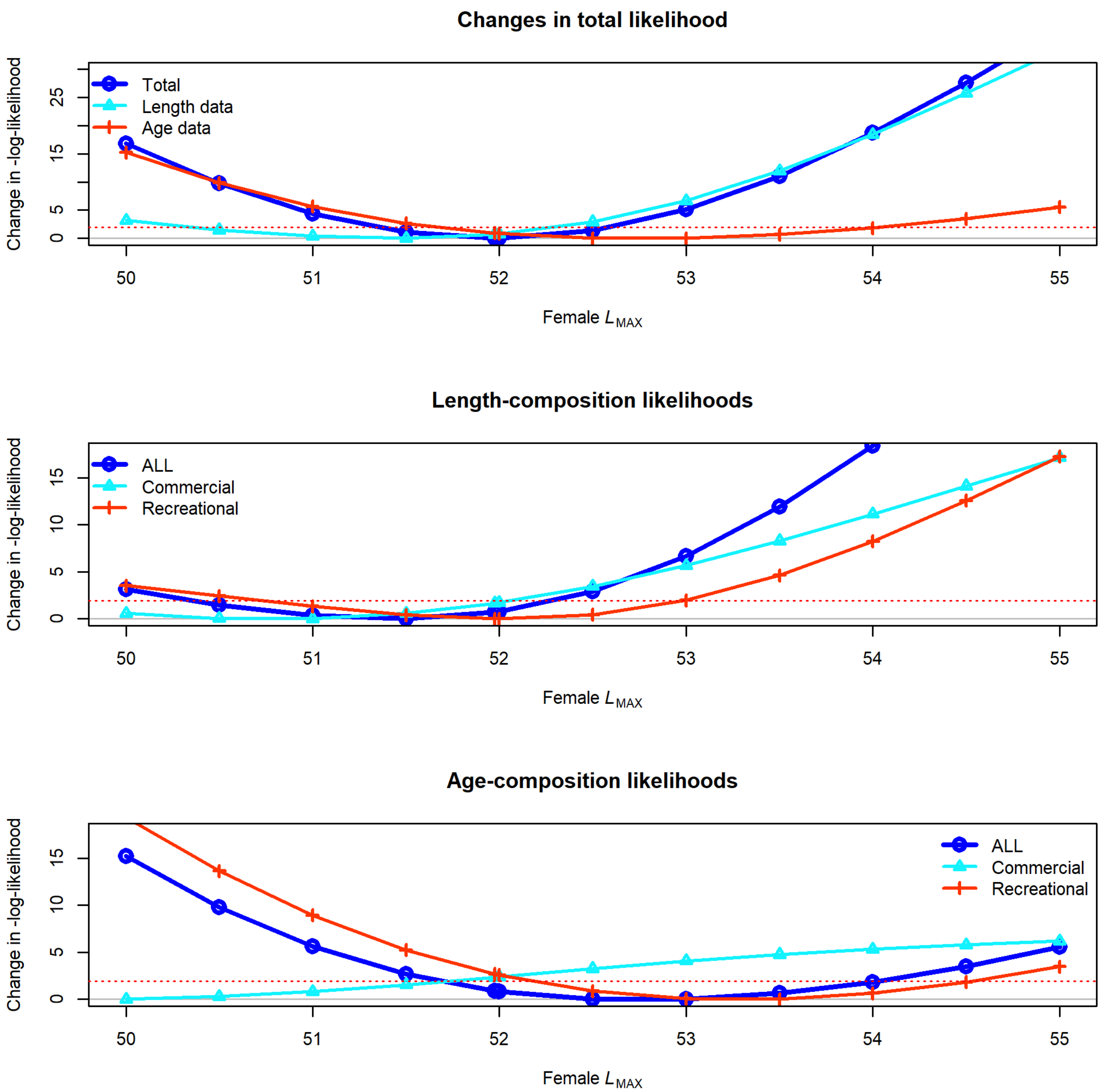

Figure 7. Likelihood profile across values for female L_{MAX}. This model estimated three growth parameters (corresponding to the "Ages + EstGrowth" model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

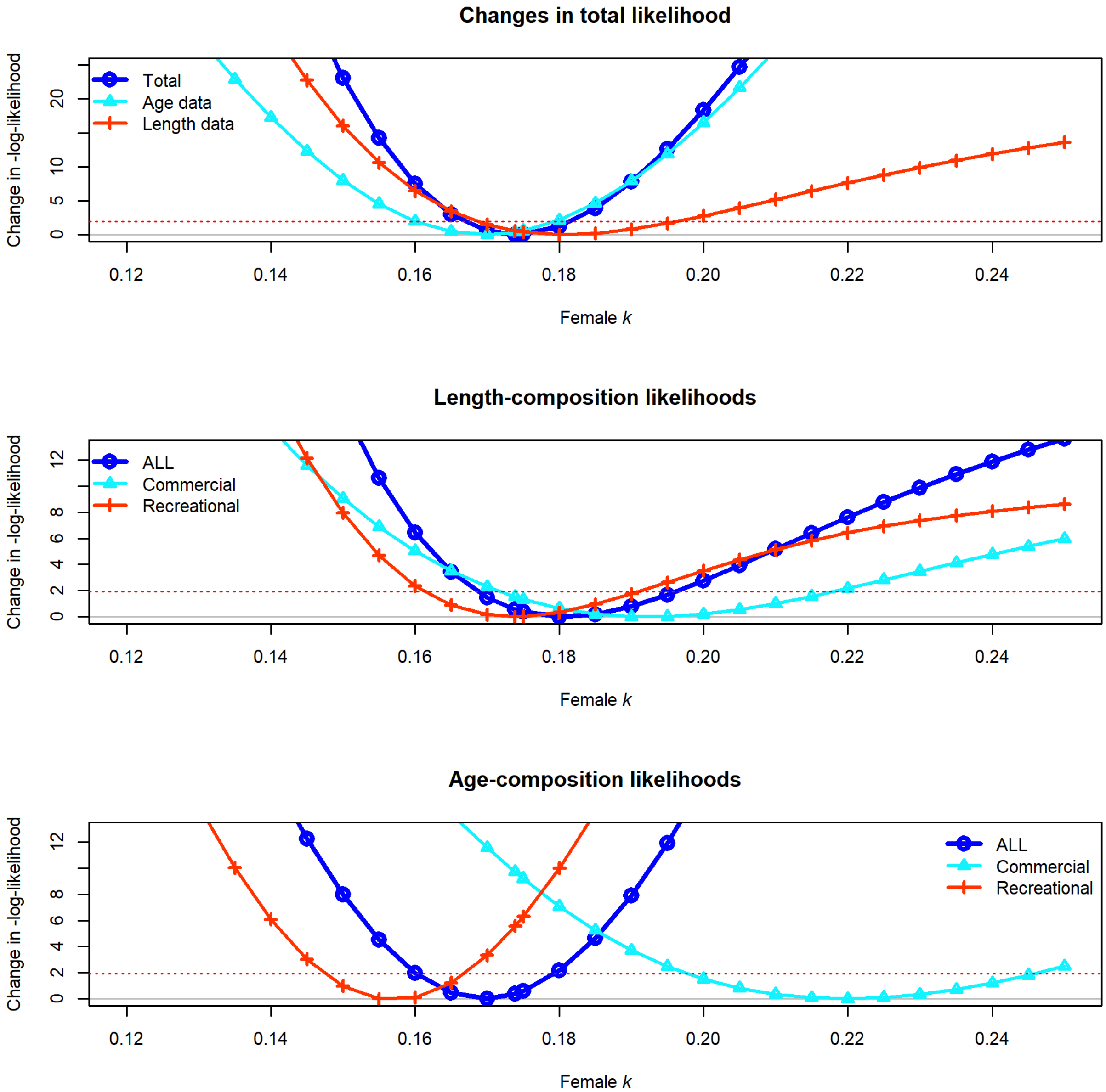

Figure 8. Likelihood profile across a range of values for female *k*. This model estimated three growth parameters (corresponding to the "Ages + EstGrowth" model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

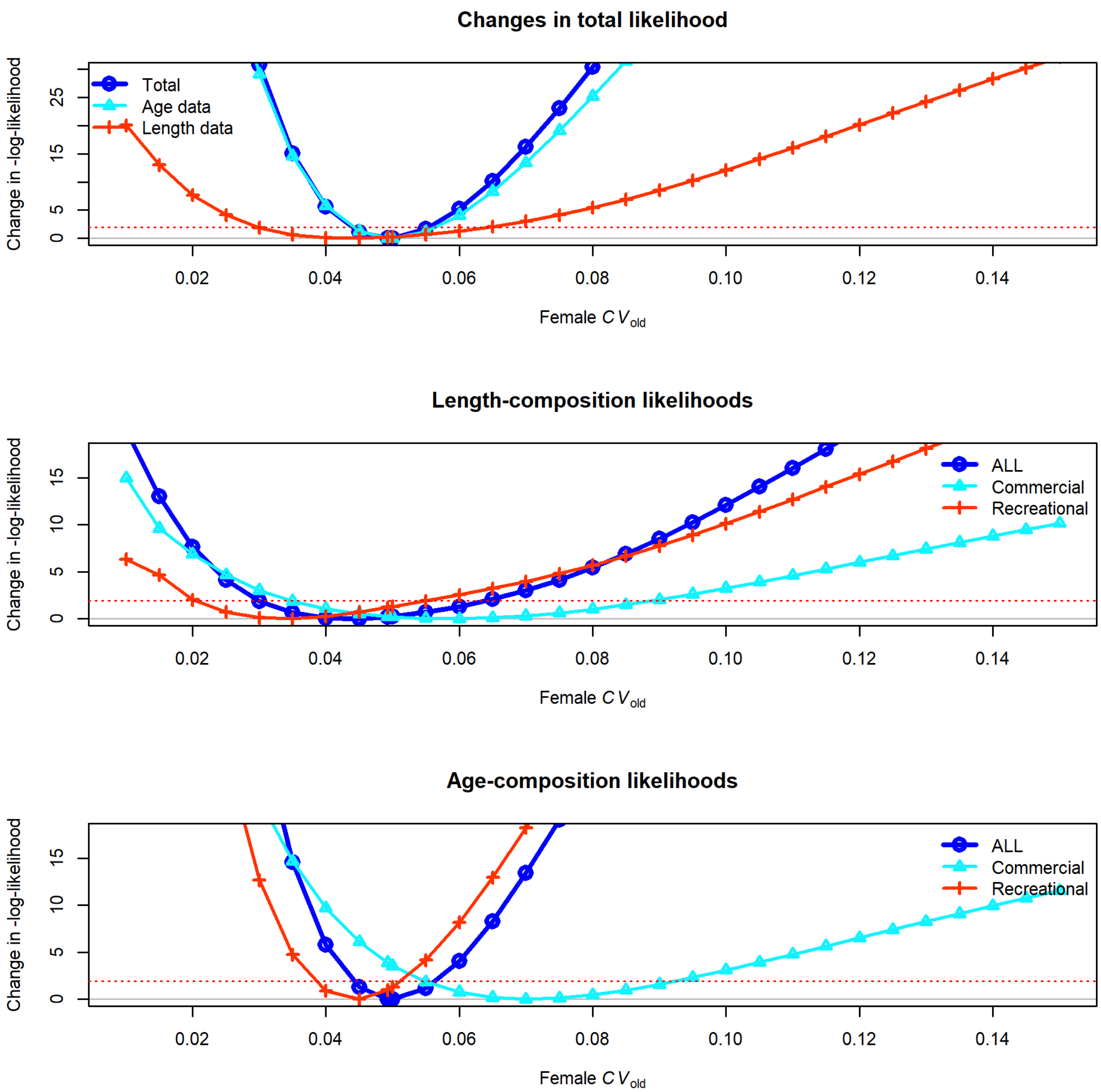

Figure 9. Likelihood profile across a range of values for female CV_{old}. This model estimated three growth parameters (corresponding to the “Ages + EstGrowth” model in Figure 2). The horizon dashed red line indicates changes in the negative log-likelihood of 1.92 units which one-half of the 95% critical value for a chi-squared distribution with one degree of freedom, generally used to identify parameter value ranges with similar support given the data.

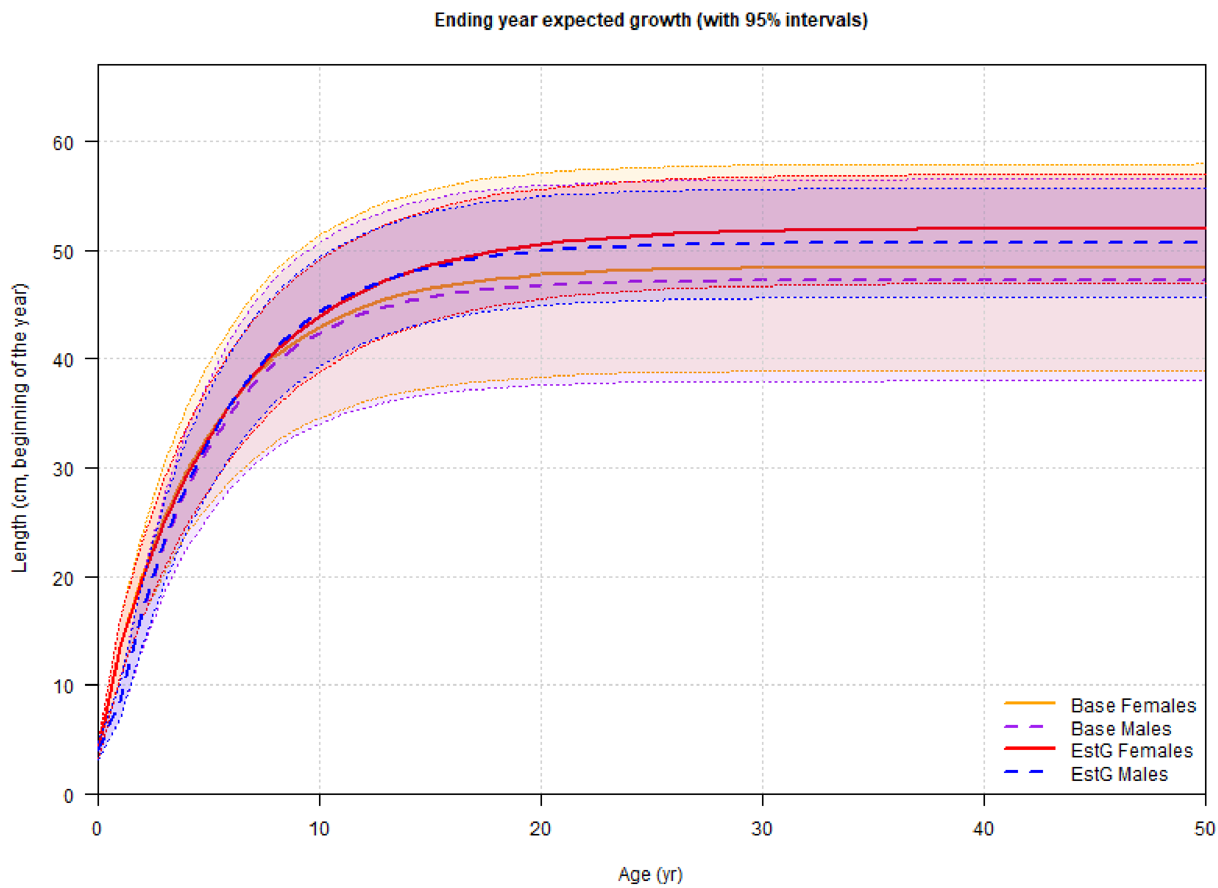

Figure 10. Comparison of growth curves for males and females for the data-moderate base model (lines corresponding to "Base" females/males) and a model that estimated three growth parameters (corresponding to the "Ages + EstGrowth" model in Figure 2, with lines "EstG" for females and males above).

Quillback Rockfish

Similar to Copper Rockfish, two series of models were run for Quillback Rockfish, ones with and without annual recruitment deviations estimated, following the addition of the CAAL data and the ageing error matrix. As observed with Copper Rockfish, the addition of the age data, without any other changes to the model structure, decreased the relative stock status (SB_{2021}/SB_0) compared to the data-moderate base model (Figure 11), though not outside of the estimate 95 percent uncertainty interval of the base model. Francis data weighting did not stabilize in either model series after four iterations. However, McAllister-Ianelli suggested data weighting stabilized after three model weighting iterations. This is a departure from the original Quillback Rockfish data-moderate model, which applied Francis data weighting.

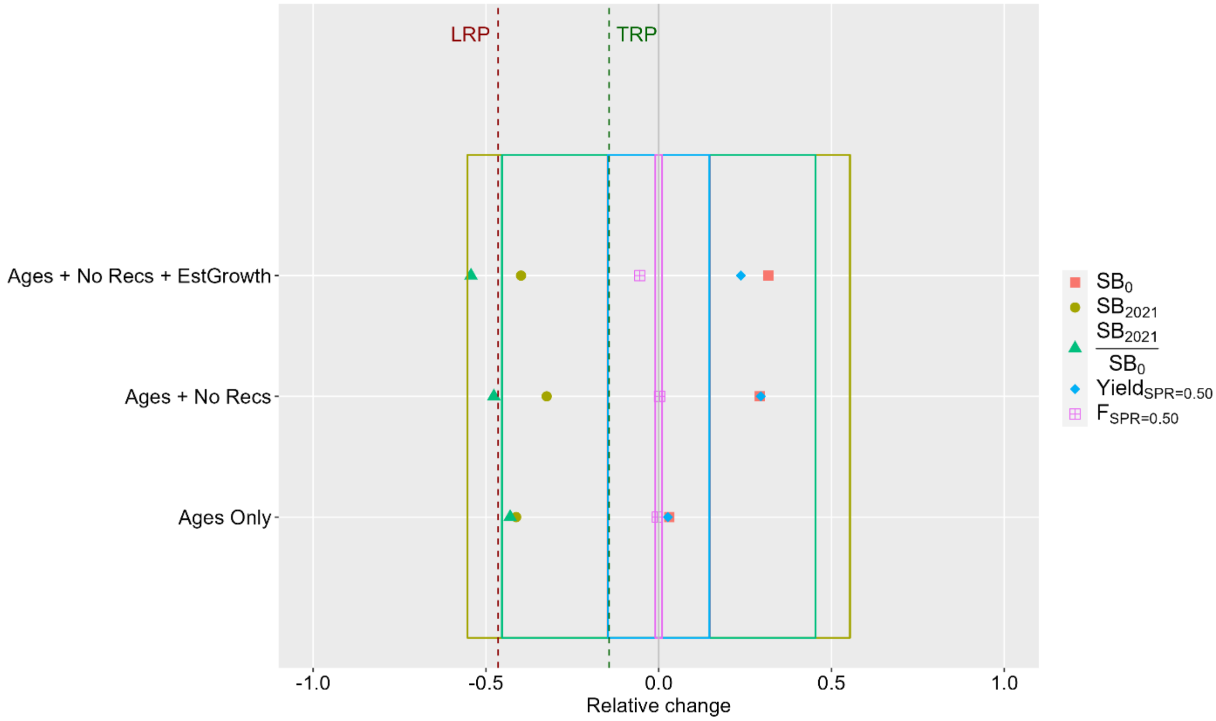

Figure 11. Comparison of the relative change in estimated management quantities (Cope and Gertseva, 2020) as compared to the data-moderate assessment (Langseth et al., 2021) for selected models within the Quillback Rockfish model series (y-axis) with ages added to the base model ("Ages + No Recs"), ages added to the base model with recruitment deviations estimated ("Ages Only"), and ages added to the base model with growth parameters and no recruitment deviations ("Ages + No Recs + EstGrowth"). Note the data-moderate assessment estimated recruitment and "Ages Only" model includes estimation of annual recruitment deviations. TRP is Target Reference Point and LRP is Limit Reference Point. The quantities compared are the estimate of unfished spawning biomass (SB_0), spawning biomass in 2021 (SB_{2021}), the stock status (SB_{2021}/SB_0), the yield based on a spawner per recruit harvest rate ($Yield_{SPR=0.50}$), and the fishing mortality at that harvest rate ($F_{SPR=0.50}$). The colored boxes indicate the 95 percent confidence interval around the point estimate of the quantity from the data-moderate model where each color corresponds with a specific quantity in the legend. A model with matching estimates as the base model would reflect a relative change of 0, a model with estimates less than the base model would have a negative relative change, and a model with estimates greater than the base model would have a positive relative change.

With models that estimated annual recruitment deviations, none of the growth parameters (e.g., L_{MAX}, *k*, and L_{MIN}) were able to be estimated reliably for multiple reasons. Estimating L_{MAX} and *k*, though precision was good (i.e., individual parameter CVs < 5%), resulted in a concurrent deterioration of the precision in estimated selectivity parameters, specifically the logit parameter that defines asymptotic or dome selectivity for the recreational fleet and the peak selectivity for both fleets. These three problematic selectivity parameters were fixed within the model at the values from the data-moderate assessment, and then the above three growth parameters were attempted to be estimated again. Growth parameters and the remaining unfixed selectivity parameters were able to be estimated with good precision again (i.e., CVs < 10%) and estimates for L_{MAX} and *k* were close to the original fixed values in the data-moderate assessment. However, selectivity for both fleets continued to be unstable or unrealistic. Estimating L_{MIN} did not result in instability in selectivity but had high uncertainty in the estimated parameter (CV = 48.8%), and so was excluded from further model exploration. There were no diagnostics run on these models, as the overall model performance and behavior was deemed untenable.

Models with deterministic recruitment were more stable, with multiple growth parameters able to be estimated with reasonable precision (individual CVs ≤ 5%) and values close to the fixed values used in the 2021 data-moderate assessment without concurrent deterioration in selectivity parameter estimates. These included L_{MAX}, *k*, and the growth CV_{old}. The L_{MIN} parameter when attempted to be estimated hit the lower parameter bound and was again fixed within the model. Again, with relatively limited information regarding young fish in the age compositions (for Quillback Rockfish, no fish under age five), there is some question that despite relative precision (CV = 3.1%), values for the estimates of *k* would not be as accurate if collections reflected the full range of ages. The estimated relative stock status (SB_{2021}/SB_0) continued to decline as estimated parameters were added ("Ages + NoRecs + EstGrowth" in Figure 11) but selectivity appeared to be stable. Diagnostics were run on a model that included estimation of the three growth parameters: L_{MAX}, *k*, and CV_{old}. Jitter analyses indicated good convergence of the model that estimated all three of these parameters. However, when likelihood profiles were run on these three parameters, the age data were generally shown not to be as informative as the length compositions and the two data sources often supported conflicting parameter values (as an example, Figure 12). When growth was estimated, the growth curve was similar to the fixed growth utilized in the base model, but with the L_{MAX} at a slightly higher value when estimated (Figure 13). In contrast to the profiles conducted on the Copper Rockfish model for the L_{MAX} parameter, where the recreational age compositions seemed to be the most influential, the most influential data source for Quillback Rockfish were the commercial lengths rather than either length or age data from the recreational fleet (Figure 9).

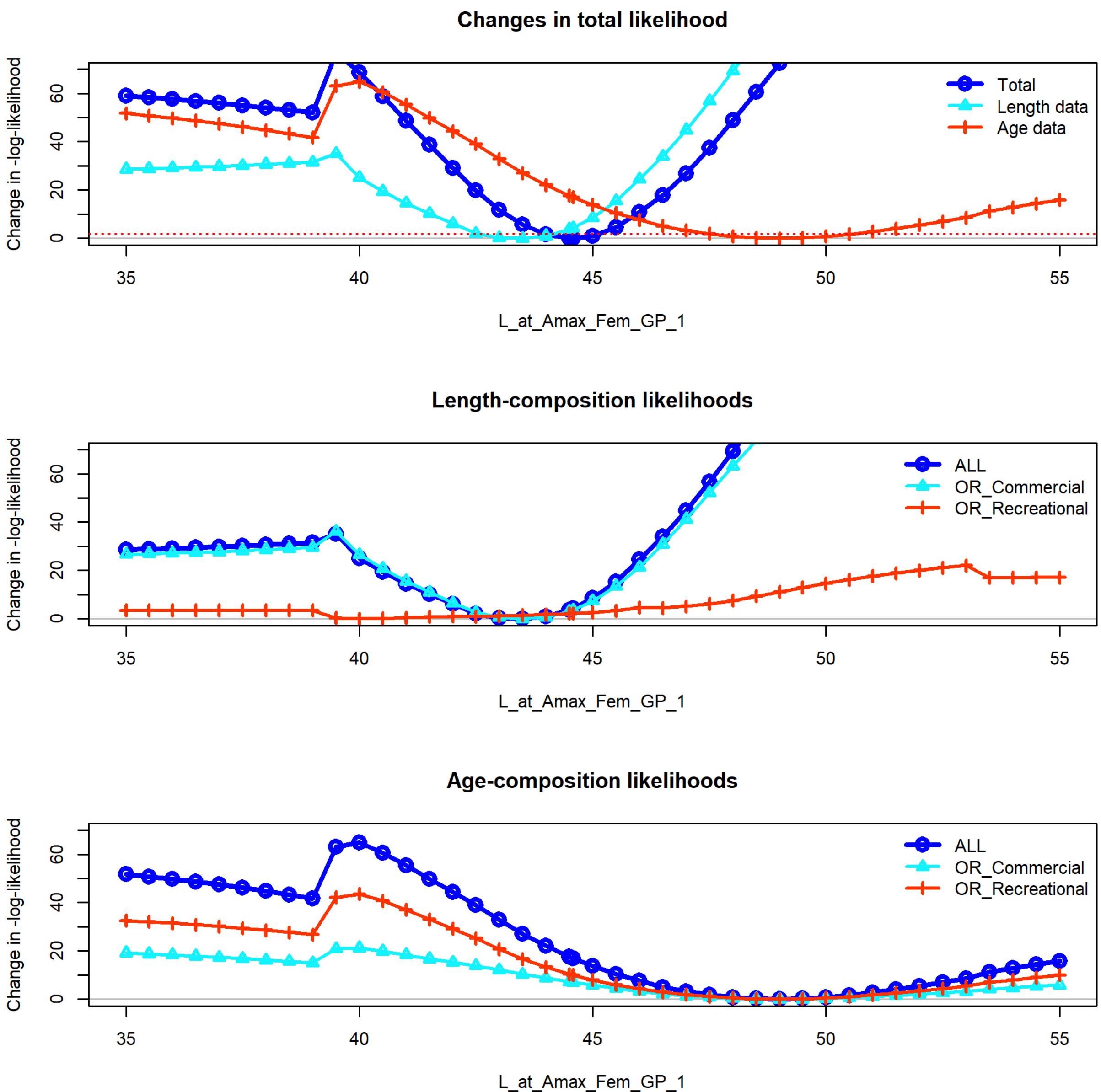

Figure 12. Example of a likelihood profile across a range of values for L_{MAX} (L_at_Amax_Fem_GP_1). This model estimated three growth parameters (corresponding to the "Ages + NoRecs + EstGrowth" model in Figure 11).

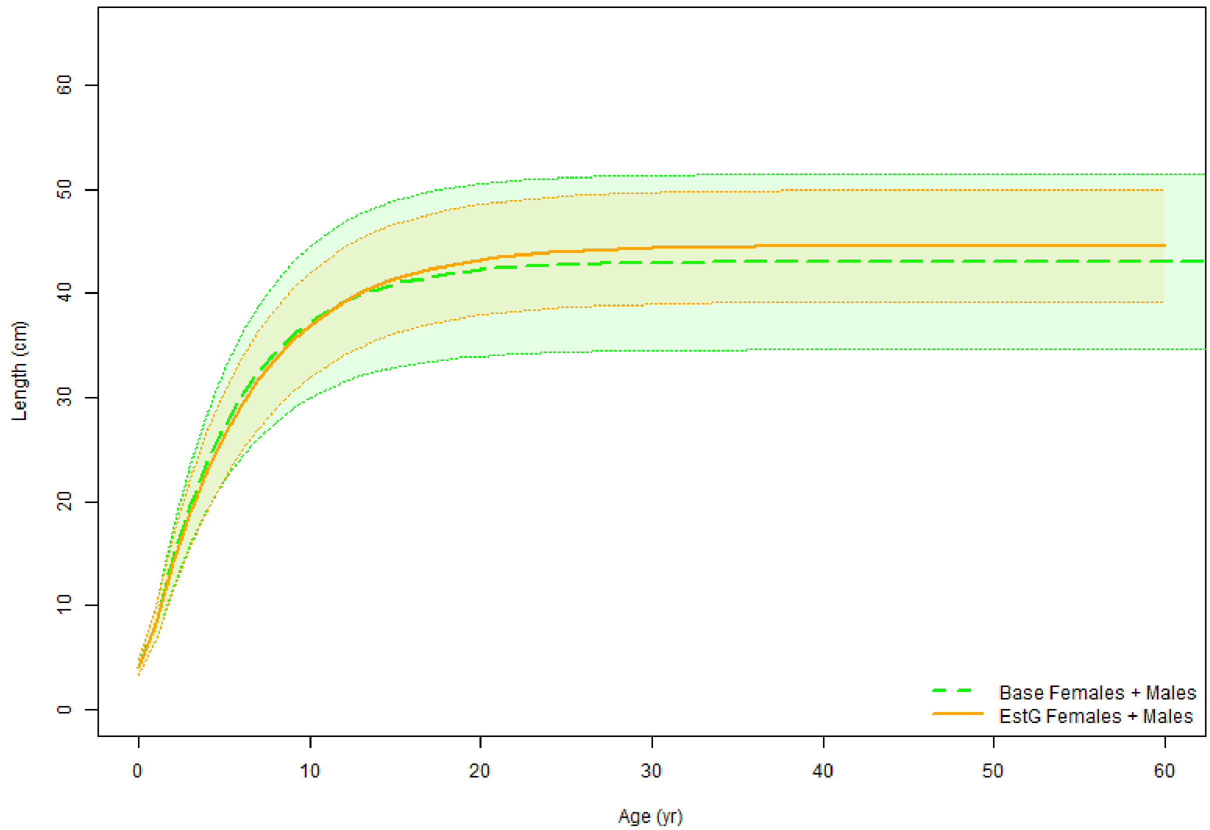

Figure 13. Comparison of growth curves for males and females combined for the Quillback Rockfish data-moderate base model and a model that estimated three growth parameters (corresponding to the "Ages + NoRecs + EstGrowth" model in Figure 11).

DISCUSSION

Available age data were incorporated into both data-moderate assessments, but generally did not result in better informed assessment models in terms of estimating all growth parameters, more informed recruitment deviations, or an overall reduction in model uncertainty. For Copper Rockfish, estimating growth and recruitment deviations were highly desired improvements to the data-moderate model, yet the addition of a relatively substantial age dataset did not provide sufficient information to do both in concert. Additionally, the model that included recruitment deviations while retaining fixed growth parameter had very similar performance to the sensitivity in the 2021 data-moderate assessment that used only length data (Wetzel et al., 2021). However, without recruitment deviations estimated, some growth parameters were able to be estimated using data exclusive to Oregon and the age data appeared to be informative for certain parameters (e.g., R_0). For Quillback Rockfish, the data-moderate model was able to estimate annual recruitment deviations. However, the addition of the limited age data did not allow for growth to be estimated while also estimating recruitment deviations. With recruitment deviations not estimated, certain growth parameters were able to be estimated. For both species, the estimated growth curve was different than the fixed curves used in each of the data moderate assessments. The decline in the estimated relative stock status relative to the adopted base models for both species following the addition of the age data while retaining the same structure is notable, though this was more extreme for Copper Rockfish than Quillback Rockfish.

Assessment models can be highly sensitive to the specification of growth within an assessment (e.g., growth sensitivities in Langseth et al., 2021 and Wetzel et al., 2021). Additionally, in order to estimate all growth parameters within an assessment model, age data from both young and old fish need to be available. While the ages collected from commercial and recreational fisheries did include some older fish, there were no ages from young fish (i.e., age-0 to age-3) due to the fisheries selectivity. In the absence of composition data from young fish, the estimation of the curvature of growth across ages (*k*) can be difficult and may lead to bias in estimates of maximum length (L_{MAX}) if incorrect. Many West coast groundfish assessments rely upon data collected by surveys which have an increased selectivity on young fish to support estimation of growth; however, many nearshore species, such as Copper and Quillback rockfishes, are not commonly encountered by the large-scale fishery-independent surveys on the West coast. New data that could be brought forward for either of these species are relatively limited. The main exception would be ageing the remainder of the existing collection of Quillback Rockfish otoliths (n = 5,985 from both commercial and recreational sampling). However, the age data that were included in this exploration constitute the entirety of ODFW's collection for Copper Rockfish through 2020, though additional sampling of the commercial fleet may be helpful. Special collection of specifically young fish or fish across lengths outside of commercial or recreational fishery activities would be helpful to produce informed growth curves, as previous nearshore assessments have utilized (Berger et al., 2015; Cope et al., 2019).

Simulation analysis looking at the performance of the data-moderate SS3-CL approach examined the impact of time-series length and annual effective sample sizes on performance (Rudd et al., 2021). This analysis showed that a time series of 20 years with an annual effective sample size of 50 lengths per year, the scenario most similar but with slightly more data compared to the existing data within Oregon for Copper and Quillback rockfishes, that stock status could be estimated with limited bias but somewhat imprecisely if the biology and population dynamics were specified correctly. However, in real world assessments, there is a reasonable likelihood some population parameters may be specified incorrectly or the model mis-specified in some way due to lack of comprehensive data and knowledge around population processes. Robust data collections from fishery-dependent and –independent sampling to support the estimation of population parameters (growth, natural mortality, recruitment deviations) and limit the number of fixed parameters within a model can provide more informed population estimates and better capture the uncertainty around those estimates that can support management decisions.

In terms of additional data, there are several fishery-dependent datasets that have typically been used to develop indices of abundance in other nearshore assessments that could be evaluated for both species. These include recreational dockside sampling, the nearshore commercial logbook, and the state onboard charter observer data, though there is some question about how influential these indices could be within the models. Other fishery-independent data sources were explored for both species for the 2021 data-moderate assessments. The Quillback Rockfish data-moderate assessment included an independent estimate of population size from Remotely Operated Vehicle (ROV) data. However, Copper Rockfish did not have sufficient ROV data to create a similar population estimate. Additionally, ODFW's Marine Reserves Program hook and line survey within Oregon marine reserves encountered very few Copper Rockfish. While the adopted 2021 data-moderate assessments for both species indicated a relative stock status above the management target level, ODFW has taken proactive actions to further limit the harvest of both species and are actively pursuing alternative data collection avenues outside of fishery harvests to support future assessments.

These models were considered exploratory and have not been reviewed for management purposes. The data-moderate assessments continue to represent the best available science, as they have been reviewed through the standard PFMC process. The addition of the age data to the Copper Rockfish model appeared to exacerbate issues surrounding the estimation of the commercial selectivity in the data-moderate model and illustrated a classic, though frustrating example of a "data-rich and information-poor" species (e.g., the most recent Oregon Black Rockfish (*S. melanops*) assessment, Cope et al., 2015), where there appear to be sufficient data available to develop full age-structured assessment models yet the data do not provide enough information to meet certain benchmarks, such as reliable estimates of growth or recruitment.

The 2021 data-moderate assessments of Copper Rockfish estimated that portions of the stock off the West Coast to have spawning biomass levels below the PFMC management target of 40 percent (e.g., two stocks in California) and either select portions or the entire coastwide stock (i.e., four separate area-based models) are likely to be re-assessed in 2023 using all available data (i.e., the data-moderate assessments included only catch, fishery-independent indices from surveys conducted by the Northwest Fisheries Science Center, and length data). The analysis conducted here for Copper and Quillback rockfishes indicated that adding age data would not resolve all of the major sources of uncertainty (e.g., growth, selectivity, and annual recruitment deviations) from the 2021 models, suggesting that trade-offs in model structure might still be necessary when assessing these species, increasing perceived uncertainty in these assessments over time. These results provide guidance to determine additional data collections that could resolve uncertainties in existing data streams. Further investigation of commercial selectivity or alternative commercial fleet structures might be useful for future assessments of Copper Rockfish in Oregon. Quillback Rockfish was identified as a species that will strongly be considered to be reassessed in 2025 by the PFMC (see PFMC June 2022 Decision Document; https://www.pcouncil.org/june-2022-decision-summary-document/), at which point, Oregon's full collection of samples will have been aged, addressing a key data deficiency for that species, potentially paving the way for a full age-structured assessment.

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