Transitioning the Bering Sea and Aleutian Islands Alaska Plaice Stock Assessment to Stock Synthesis

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Introduction

This document outlines a proposed change of switching the Bering Sea and Aleutian Islands (BSAI) Alaska Plaice (*Pleuronectes quadrituberculatus*) stock assessment model to Stock Synthesis versions 3.30.22 (SS3; Methot and Wetzel 2013). Once a base SS3 model that best mirrors the previous Alaska Plaice assessment model from 2021 was established, alternative SS3 model configurations were explored for 2024 assessment cycle using all available new data.

Past Alaska Plaice assessments used a sex-specific, age- and length-based population dynamics model coded in automatic differentiation model builder (ADMB) (referred to as "the 2021 model"). This model was coded specifically for and only used for Alaska Plaice. The sex-specific aspects in this model are the length-at-age relationship, weight-at-length relationship, weight-at-age relationship, age-length transition matrix and selectivity curves. All the sex-specific aspects are estimated outside the model except the selectivity curves. The age-at-maturity is also estimated outside the model and is only determined for females. Estimated within the 2021 model are the log of mean recruitment, numbers at age in the initial population, annual recruitment deviations, log of mean fishing mortality, annual fishing mortality deviations and sex-specific selectivity parameters. The 2021 model has two fleets; fishery and survey (Eastern Bering Sea (EBS) shelf bottom trawl survey). Both used sex-specific age-based logistic selectivity. Fixed within the 2021 model is natural mortality (0.13, same for males and females) survey catchability (1.2) and the sex-ratio at recruitment (0.5). The age range is 3-25 with age-25 being a plus group and ages below 3 are excluded. The length bins are 1cm long and ranged from 10cm – 60cm. The final length bin is a plus group and lengths below 10cm are excluded.

SS3 is a more flexible assessment model framework then the 2021 model. It is better documented, continually updated, and has a wide variety of external resources such as the r4ss package that allows for easier exploration of alternative models. What makes the 2021 model more rigid is that it was coded specifically for Alaska Plaice. This means exploring alternative model configurations requires manually changing the ADMB code which is time consuming and prone to potential human error. In addition, since the model is coded specifically for Alaska Plaice, few people interact with the model which makes is it harder to catch potential mistakes within the ADMB code.

Data bridging

An important difference between the 2021 model and SS3 occurs within the population dynamics age-classes. The youngest possible age-class in the 2021 model is age-3, while SS3 always begin at age-0. The inputted age-composition data in SS3 can start at ages larger than zero, however the first age-bin is considered a plus group ranging from 0 to the minimum age from the age-composition data. The same

applies to length-composition data with the smallest length-bin being a plus group ranging from 0 to the upper limit of the smallest length-bin. The 2021 model omits data on ages 0-2 and excluded lengths smaller than the lower end of the smallest length-bin. Ignoring this difference between models will result in differences between expected and observed age- and length-compositions for the youngest age and smallest length-bins when selectivity at these ages and lengths is estimated to be greater than 0 in SS3. In addition, information on younger ages and smaller lengths can be valuable since it informs selectivity estimates at the younger ages (even if they are zero) and can improve recruitment estimates in the most recent years.

For the bridging process, the same data used in the 2021 model (Ormseth 2021) are used to transition to SS3. This means that the age-composition data excluded age 0-2 individuals and the length-composition data excluded individuals smaller than 10 cm even though there is data available in both excluded groups. The table below lists the data use during the bridging process.

Source	Data	Years
NMFS Eastern Bering Sea shelf bottom trawl survey	Biomass Index	1982-2021; no survey was conducted in 2020 due to the COVID
	Age Composition (by sex)	1982, 1988, 1992-1995,1998, 2000-2002, 2005-2014, 2016-2019
	Length-Composition (by sex)	1983-1987, 1989-1991, 1996-1997, 1999, 2003, 2004, 2015, 2021
Fisheries	Catch	1975-2021
	Age-Composition (by sex)	2000, 2002, 2003
	Length-Composition (by sex)	1978-1989, 1995, 2001, 2008-2020

Note that for the EBS bottom trawl survey age- and length- composition data there are no overlapping years. This is because the two data types are not independent since the length-composition data is used to calculate the age-composition data with a separate age-length transition matrix.

Differences in analytic approach

There are several fundamental differences between the 2021 model and SS3 that prevent the two from fully matching each other.

Recruitment

The 2021 model assumes that new recruits are added to age-3 while SS3 adds new recruits to age-0.The 2021 model assumes that the selectivity for fish younger than age-3 is zero and SS3 has an option to specify the minimaum age of selected fish (*i.e.* age-3). Therefore, to have the mean recruitment from SS3 ($R_0 0$) to better mirror the 2021 model mean recruitment ($R_3 0$), Equation 1 was used:

$$R_0 0 = R_3 0 * e^{3M} \quad (1)$$

where *M* is natural mortality. Equation 1 was only used when mean recruitment was fixed in SS3.

Selectivity

In the 2021 model, selectivity is an age-based sex-specific logistic curve. SS3 can have a length-based sex-specific logistic curve but not an age-based one. It can have a sex-specific age-based double normal selectivity curve that can be modified to behave similarly to the logistic selectivity curve. In SS3, the double normal selectivity curve is defined by six parameters; *Peak*, *Top*, *ascending width*, *descending width*, *initial* and *final*. By fixing *Top* to 30, *descending width* to 8, *initial* to -1003 (note that the 3 ensures that selectivity below age-3 is zero) and *finale* to 999 and only modify/estimate *Peak* and *ascending width* then the double normal selectivity curve will behave similarly to a logistic selectivity curve.

Growth

The 2021 model incorporates growth in two ways; mean weight-at-age and age-length transition matrix. Both are sex-specific and are estimated independently of each other. The mean weight-at-age is calculated externally by multiplying the mean length-age by the mean weight-at-length. The mean length-at-age is estimated externally with a von-Bertalanffy growth curve for each sex. Both growth curves were last updated in 2016 using the EBS bottom trawl survey age-length data. The weight-at-length relationship is estimated externally as sex-specific curves using the following equation:

$$Weight = a_s(Length)^{b_s} \quad (2)$$

where a_s and b_s are parameters that define the weight-at-length relationship for sex s. The weight-at-length relationship was last updated in 2016 using the EBS bottom trawl survey weight-length data. Neither the estimated age-length relationship nor the weight-length relationship are directly inputted into the 2021 model.

The sex-specific age-length transition matrices used in the 2021 models are estimated completely separately from the length-at-age relationship. They are estimated directly from the length-at-age data from the EBS bottom trawl survey by determining the proportion in each length-bin for a given age-class. These matrices have not been updated since at least 2003.

SS3 uses a modified version of the length-at-age von-Bertalanffy growth curve in which younger ages (defined by the user) are assumed to have a linear age-length relationship while older ages follow a von-Bertalanffy growth curve. The younger and older growth curves each have their own coefficient of variance (CV). The growth parameters and associate CVs can be estimated or fixed to specific values in SS3 and be sex-specific. The age-length transition matrix in SS3 is calculated internally using the von-Bertalanffy growth parameters and CVs. This matrix cannot be manually entered.

The differences in growth estimation between the 2021 model and SS3 make it hard for growth curves and age-length transition matrices to perfectly match. However, the weight-at-age relationship can be either calculated internally or entered manually within SS3. Thus the weight-at-age relationship in SS3 can perfectly match the 2021 model.

Model bridging

A variety of alternative models were explored to try and bridge the 2021 model to SS3. Below are four models that demonstrate how the best bridging SS3 model was chosen:

- Base-1 was a deterministic SS3 model that aimed to have all the characteristics and parameter values from the 2021 model. Mean recruitment, recruitment deviations, mean weight-at-age and parameters for the sex-specific length-at-age curve, female length-at-maturity vector, natural mortality, and survey catchability were all fixed to the values from the 2021 model. The younger age linear growth curve was set between age-0 to age-1 and the age-1 length-at-age was set to the age-1 length determined from the von Bertalanffy growth curve defined by the growth parameters estimated externally for the 2021 model. The younger and older age sex-specific growth CVs were visually estimated from the age-length transition matrix used in 2021 model then fixed in SS3. The age-length transition matrix could not be copied from the 2021 model and, therefore, was internally calculated in SS3 (described above). The only things estimated in the Base-1 model are the annual fishing mortalities and the sex-specific age-based selectivity curves for the fishery and survey fleets. The selectivity curves were estimated in Base-1 to try and get the double normal selectivity curves in SS3 to match the logistic selectivity curves from 2021 as best as possible.
- Base-2 updated the Base-1 model by changing the old age von Bertalanffy growth parameters (for males and females) with newly externally estimated sex-specific von Bertalanffy growth parameters that were estimated using the survey and fishery age-length data through 2021. These updated growth parameters were fixed in SS3.
- Base-3 updated the Base-2 model by estimated mean recruitment, annual recruitment deviations in addition to mean fishing mortality, fishing morality deviations, and selectivity. The growth parameters were fixed to the updated growth parameters used in Base-2.
- Base-4 model is a modified version of the Base-3 model with the difference being that growth is estimated within SS3. Specifically, the sex-specific maximum length, sex-specific growth rate and male length at age-1, used to define the maximum length for the younger age linear growth curve, were estimated within SS3. The female length at age-1 was fixed to the value used in Base-3.

Table 10.1 describes the number of parameters in each population dynamics process and whether they were estimated in each bridging model and the 2021 model.

Bridging results

Figure 10.1 and 10.2 shows comparisons plots between Base-1 and 2021 models. Overall, Base-1 model performs very similarly to the 2021 model. However, the goal of using a deterministic model is to ensure that if all the parameter values match up then the two models should produce identical results. Unfortunately that did not happen. There are slight differences especially in the age 3+ total biomass (Figure 10.1) with the Base-1 model having a larger total biomass after 1990. The main issue causing this difference is growth. As described above, the 2021 model incorporates growth in two independent ways (mean weight-at-age and the age-length transition matrix). When comparing the mean length-at-age from the weight-at-age calculation and the age-length transition matrix in the 2021 model (green and red lines in Figure 10.3) it is apparent that they don't match for either sex. Thus, the 2021 model uses two separate growth curves for each sex when there should only be one for each sex.

The growth curves in the Base-1 model only matches the growth curves used to calculate the mean weight-at-age in the 2021 model. This means the age-length transition matrix in SS3 does not match the age-length transition matrix in 2021 model. There is no underlining growth curve defining the 2021 model age-length transition matrix so it cannot be used in SS3. To improve the growth curve in the Base-1 model, new sex-specific von Bertalanffy growth curves were externally estimated using the age-length data up to 2021

from the survey and fishery (blue line in Figure 10.3). The newly estimated growth curves ended up closely mirroring the mean age-at-length from the age-length transition matrix from the 2021 model. The Base-2 model is the same as the Base-1 model but with the updated growth curve. Figure 10.4 and 10.5 show comparison plots between the Base-2, Base-1 and 2021 models. The results reveals that the Base-2 model matches the 2021 model much better that Base-1.

The Base-3 model is a modified version of the Base-2 model in that mean recruitment and recruitment deviations are estimated. The intention is to estimate the same set of parameters as the 2021 model. The Base-3 model matches the 2021 model fairly well (Figure 10.6 and 10.7). There are noticeable slight differences in 3+ total biomass and Age-3 recruitment (Figure 10.6). The Age-3 recruitment difference occur predominantly at the tail end of the time series. This is most likely do to the lack of information on new recruits in the composition data at the end of the time series. Younger fish don't start appearing in the age-composition data from the survey until around age-5. Interestingly the Base-3 model has the lowest total likelihood value when compared to the Base-1 and Base-2 models suggesting an overall better fit to the data (Table 10.2). However, the recruitment component of the Base-3 total likelihood is larger than Base-1 and Base-2 recruitment component. This implies that the better fit to the composition data is driving the differences in recruitment deviations between the Base-3 and Base-1 and -2 models.

The Base-4 model mirrors the Base-3 model except that growth is estimated instead of fixed. The Base-4 model matched the 2021 model well (Figure 10.8 and 10.9). There are noticeable slight differences in 3+ total biomass and Age-3 recruitment (Figure 10.8). The Age-3 recruitment difference occur predominantly at the tail end of the time series which is most likely do to the lack of information on new recruits in the composition data at the end of the time series. The total likelihood for the Base-4 model is lower than the Base-1 and -2 models suggesting an overall better fit to the data (Table 10.2). However, the Base-3 total likelihood is smaller than Base-4's.

When determining the new base model for the 2024 Alaska Plaice assessment, I would recommend the Base-4 model over the Base-3 model. The differences in the models ability to estimate total biomass, biomass index, age-3 recruits and fishing mortality is small (Figure 10.8) with the largest difference occurring in age-3 recruits at the tail end of the time series. The likelihood components suggest that the Base-3 model fit the data better, but this difference is small (Table 10.2). I would argue that it is better to estimate growth within the model because it provides the model with more flexibility and ensures that growth is re-estimated for each full assessment. This is especially important given that growth was a big issue in the 2021 model.

2024 assessment

Before exploring alternative models for the 2024 assessment, all available data was updated. See the table below for all the updated data.

Source	Data	Years
NMFS Eastern Bering Sea shelf bottom trawl survey	Biomass Index	2023-2023
	Length-Composition (by sex)	2022-2023
Fisheries	Catch	2022-2024 (up to August 1st, 2024)
	Length-Composition (by sex)	2000, 2002-2007, 2021-2024

With the data updated, two alternative SS3 models are proposed to address some limitations in the Base-4 model. The first alternative model (Model 24.0) include the following changes:

1. Updating each year's input sample size for the survey age-composition data using a general bootstrap framework implemented in the "surveyISS" Rpackage (Williams and Hulson 2024).
2. Updating each year's input sample size for the survey length-composition data with the number of hauls.
3. Including age-1 and -2 fish in the fishery and survey age-composition data.
4. Adjusting the maximum age for linear growth from age-1 to age-3 and estimating all growth parameters except the CVs.
5. Updating the parameters values for the length-weight relationship by estimating them externally using the fishery and survey length-weight data available up to 2024.
6. Updating the old age growth CVs for both males and females with new values determined through likelihood profiles.

The second alternative model (Model 24.1) has all the same changes as Model 24.0 with the addition of calculating the weight-at-age relationship within SS3 instead of externally. This ensures that the weight-at-age relationship is derived from the growth parameters estimated within SS3 instead of being calculated externally from a separate growth curve that is not guaranteed to match the estimated SS3 growth curve.

2024 Results

Figure 10.10 and 10.11 show that the three models (Base-4, Model 24.0, and Model 24.1) behave relatively similarly with the major (yet small) differences occurring when estimating the spawning biomass and number of recruits to age-0. Model 24.0 and Model 24.1 have much better fits to the data when compared to the Base-4 model, with Model 24.0 having the lowest total likelihood value (Table 10.3). This is because Model 24.0 and 24.1 do a better job at fitting the length- and age- composition data when compared to the Base-4 model.

Overall, I would recommend Model 24.1 as the assessment model for 2024. Though Model 24.0 has a better likelihood value, I would argue that is it better to calculate the weight-at-age relationship within SS3. This ensures that the weight-at-age relationship is derived directly from the estimated growth parameters instead of being calculated externally from a separate growth curve that is not guaranteed to match the estimated SS3 growth curve.

Literature Cited

Methot, R. D. and C. R. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research **142**:86-99.

Ormseth, O.A. (2021) Assessment of the alaska plaice stock in the bering sea and aleutian islands. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea and Aleutian Islands regions*. North Pacific Fishery Management Council, Anchorage, AK.

Williams B, Hulson P (2024). *surveyISS: Survey composition input sample size*. R package version 1.0.0, https://benwilliams-noaa.github.io/surveyISS/, https://github.com/BenWilliams-NOAA/surveyISS/.

Tables

Table 10.1. Lists the number of parameters for each population dynamics process and whether they were estimated in each bridging model and the 2021 model.

Population Dynamics Process	2021 Model	Base-1	Base-2	Base-3	Base-4
Recruitment Mean	1 – Estimated	1 - Fixed	1 - Fixed	1 - Estimated	1 - Estimated
Recruitment Deviations	47 – Estimated; years 1975-2021	47 – Fixed; years 1975-2021	47 – Fixed; years 1975-2021	47 – Estimated; years 1975-2021	47 – Estimated; years 1975-2021
Growth	Fixed; mean weight-at-age and age-length transition matrix	10 – Fixed; 2021 weight-at-age parameters	10 – Fixed; Update growth curve	10 – Fixed; Update growth curve	5 – Estimated, 5 Fixed
Selectivity	8 – Estimated; logistic, sex and fleet specific	8 – Estimated, 14 – Fixed; double normal, sex and fleet specific	8 – Estimated, 14 – Fixed; double normal, sex and fleet specific	8 – Estimated, 14 – Fixed; double normal, sex and fleet specific	8 – Estimated, 14 – Fixed; double normal, sex and fleet specific
Survey Catchability	1 – Fixed	1 - Fixed	1 - Fixed	1 - Fixed	1 - Fixed
Mean Fishing Mortality	1 – Estimated	1 – Estimated	1 – Estimated	1 – Estimated	1 – Estimated
Fishing Mortality Deviations	47 – Estimated; Years 1975-2021	47 – Estimated; Years 1975-2021	47 – Estimated; Years 1975-2021	47 – Estimated; Years 1975-2021	47 – Estimated; Years 1975-2021
Natural Mortality	1 - Fixed	1 - Fixed	1 - Fixed	1 - Fixed	1 - Fixed

Table 10.2. Components of the objective function, the number of parameters estimated and the derived 2021 total biomass for the bridging and 2021 models. Note that the likelihood components in the 2021 model are not comparible to the bridging models.

Likelihood Component	2021 Model	Base-1	Base-2	Base-3	Base-4
Total	3325.2612	1623.974	992.067	982.7518	985.547
Survey	26.7032	-58.9898	-59.209	-58.8731	-58.9021
Length-composition	1887.784	1007.89	383.985	373.708	374.879
Age-composition	1386.1496	656.727	648.944	644.961	645.987
Recruitment	24.6244	18.347	18.347	22.9559	23.5831
# of Parameters	104	56	56	104	109
2021 Biomass (mt)	455,329	460,007	455,106	447,986	456,572

Table 10.3. Components of the objective function, the number of parameters estimated and the derived 2024 total biomass and spawning biomass for the Base-4, Model 24.0 and Model 24.1 models.

Likelihood Component	Base-4	Model 24.0	Model 24.1
Total	1010.07	670.014	673.004
Survey	-66.6602	-66.4449	-65.701
Length-composition	417.408	379.449	380.43
Age-composition	633.643	335.088	335.743
Recruitment	25.6784	21.9209	22.5315
# of Parameters	109	109	109
2024 Total Biomass (mt)	452,628	437,532	413,477
2024 Spawning Biomass (mt)	156,061	149,321	145,993

Figures

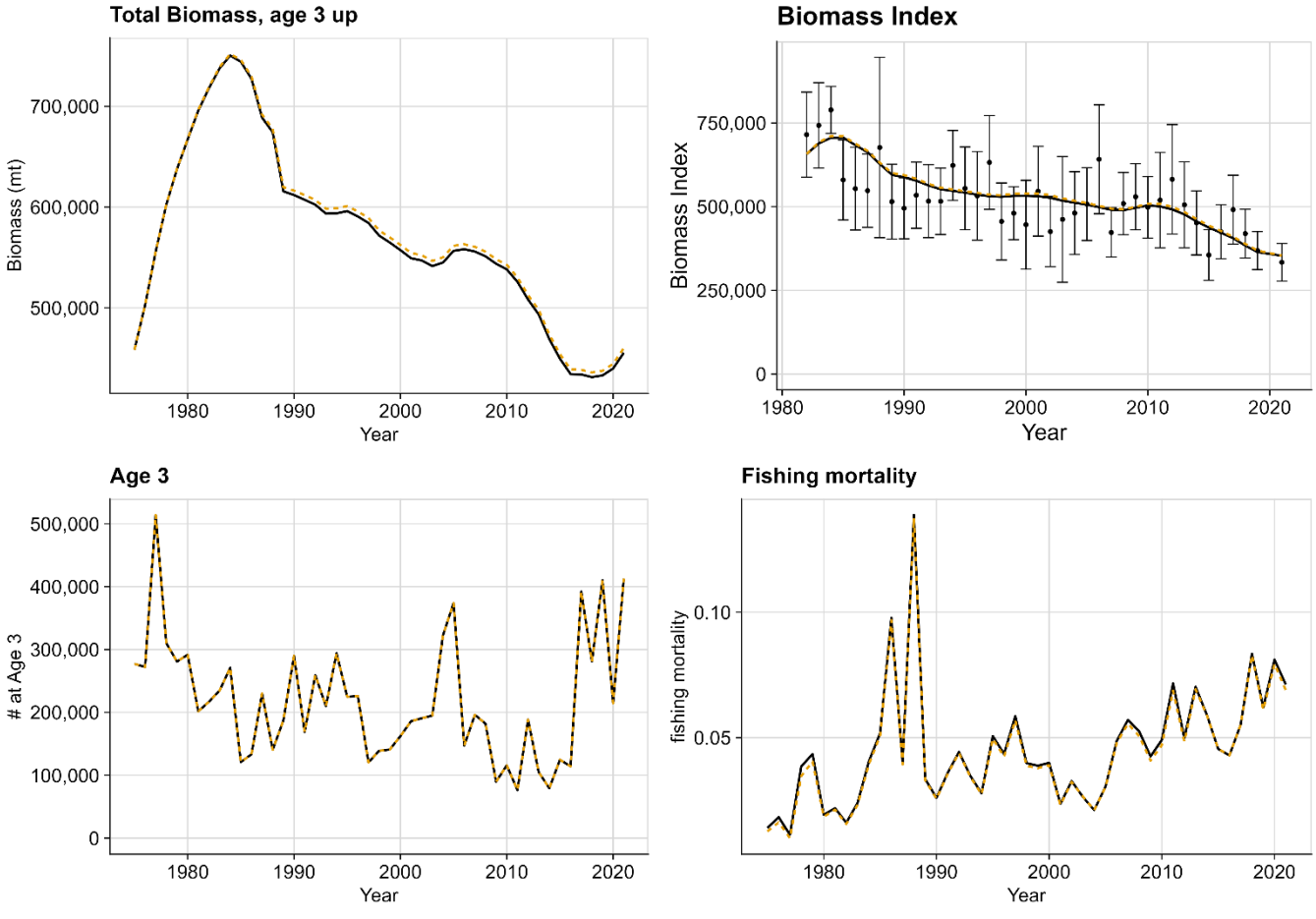

Figure 10.1. Population dynamics plots comparing the 2021 model to the Base-1 model where only selectivity and annual fishing mortality are estimated. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this plot). The top right panel shows the estimated biomass index with the black dots with error bars representing that actual biomass index data. The bottom left panel shows the number of individuals at age-3. The bottom right panel shows the estimated fishing mortality. In each panel the solid black line represents the 2021 model and the dashed yellow line represents the Base-1 model.

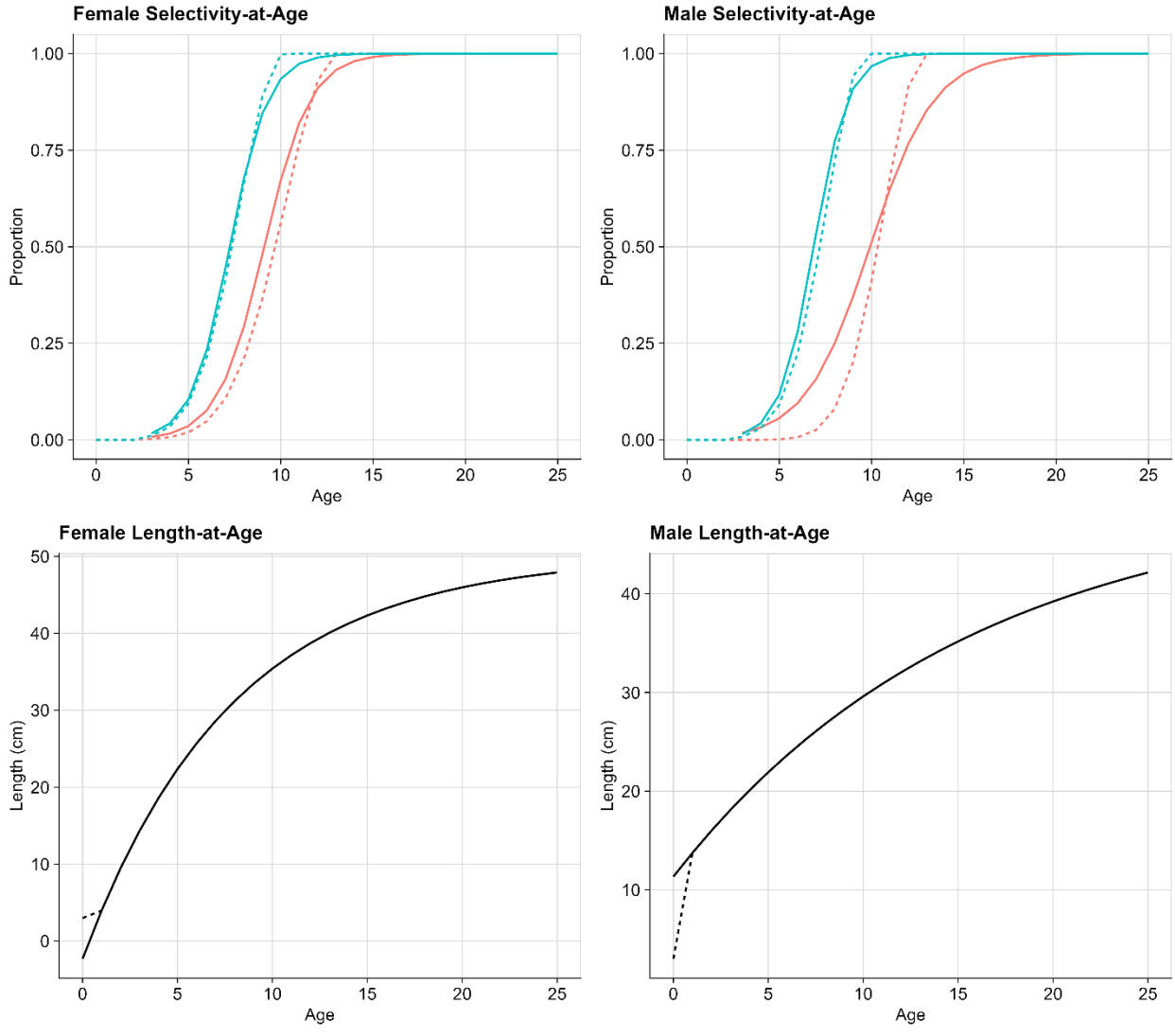

Figure 10.2. Comparison plots between the 2021 model to the Base-1 model where only selectivity and annual fishing mortality are estimated. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom panels show the growth curves with females on the left and males on the right. In all the panels, the solid line represents the 2021 model and the dashed line represents the Base-1 model.

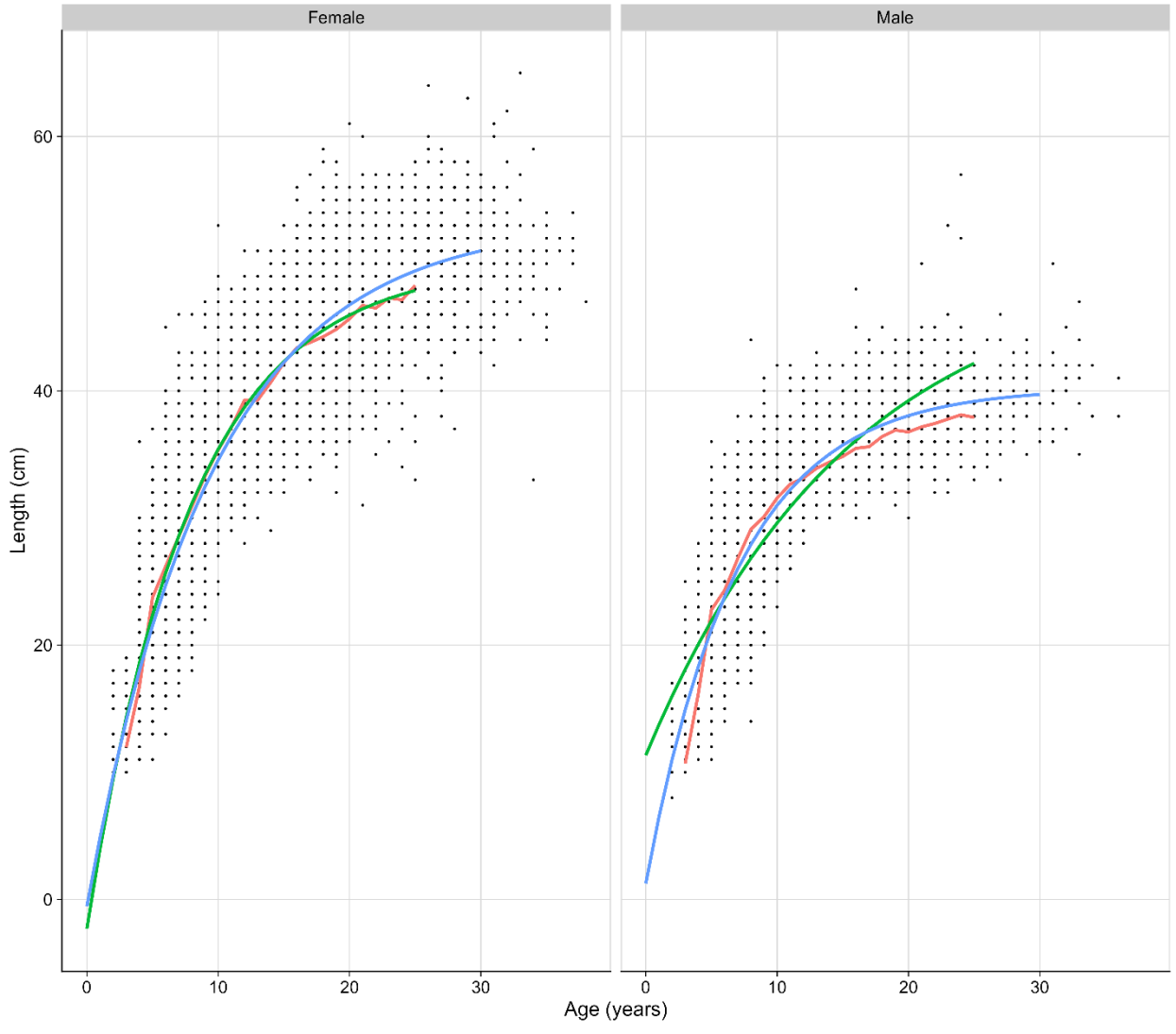

Figure 10.3. Comparison between the von Bertalanffy growth curves used to determine the mean weight-at-age in the 2021 model (green), the mean length-at-age determined from the age-length transition matrix used in 2021 model (red), and the new externally estimated von Bertalanffy growth curves using the age-length data up to 2021 from the survey and fishery (blue). The black dots represent the age-length data up to 2021 from the survey and fishery. The left panels shows the female growth curves and data points while the right panel shows the male growth curves and data points.

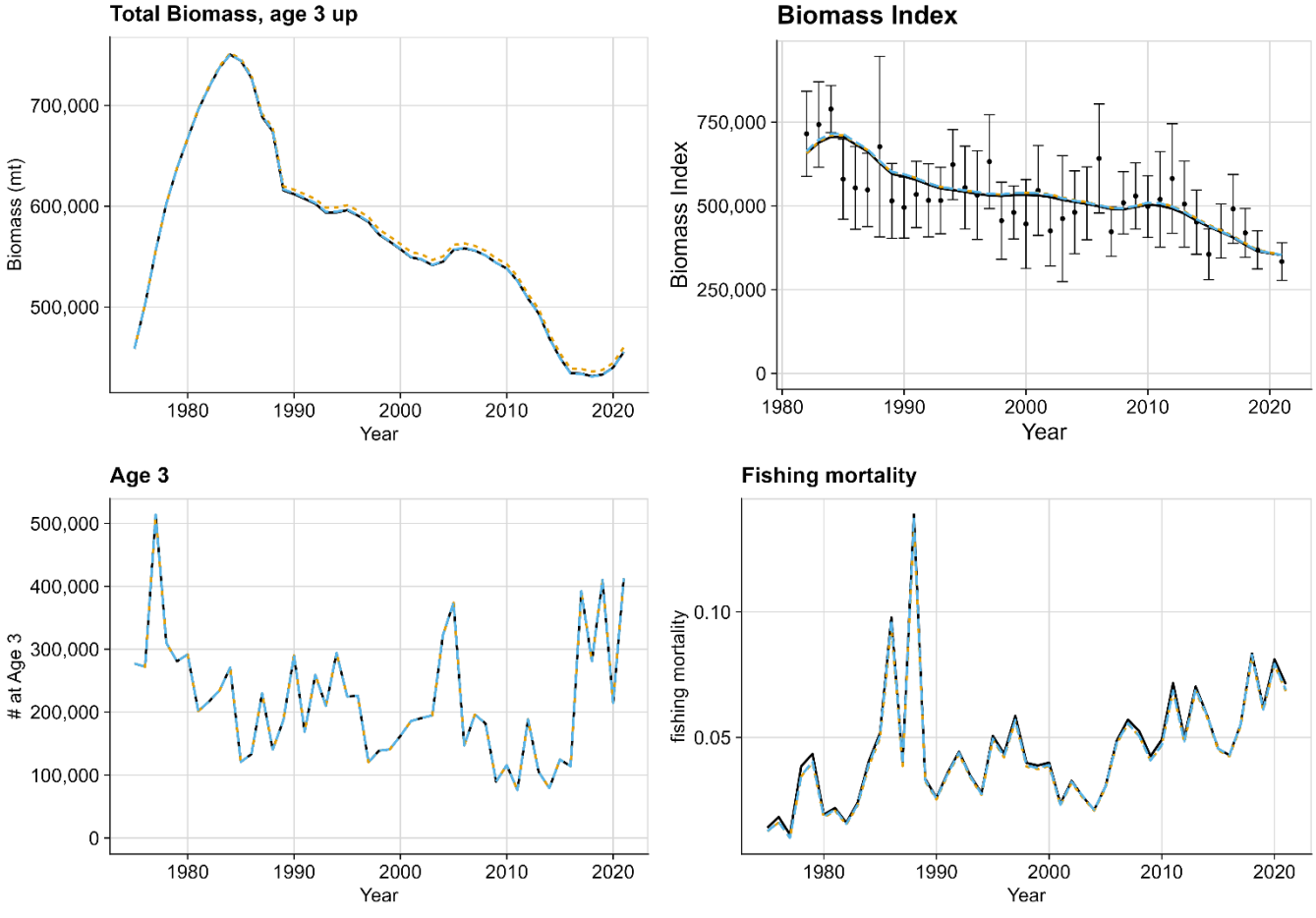

Figure 10.4. Population dynamics plots comparing the 2021 model and the Base-1 model to the Base-2 model with an updated growth curve. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this plot). The top right panel shows the estimated biomass index with the black dots with error bars representing that actual biomass index data. The bottom left panel shows the number of individuals at age-3. The bottom right panel shows the estimated fishing mortality. In each panel the solid black line represents the 2021 model, the dashed yellow line represents the Base-1 model and the dashed blue line represents the Base-2 model.

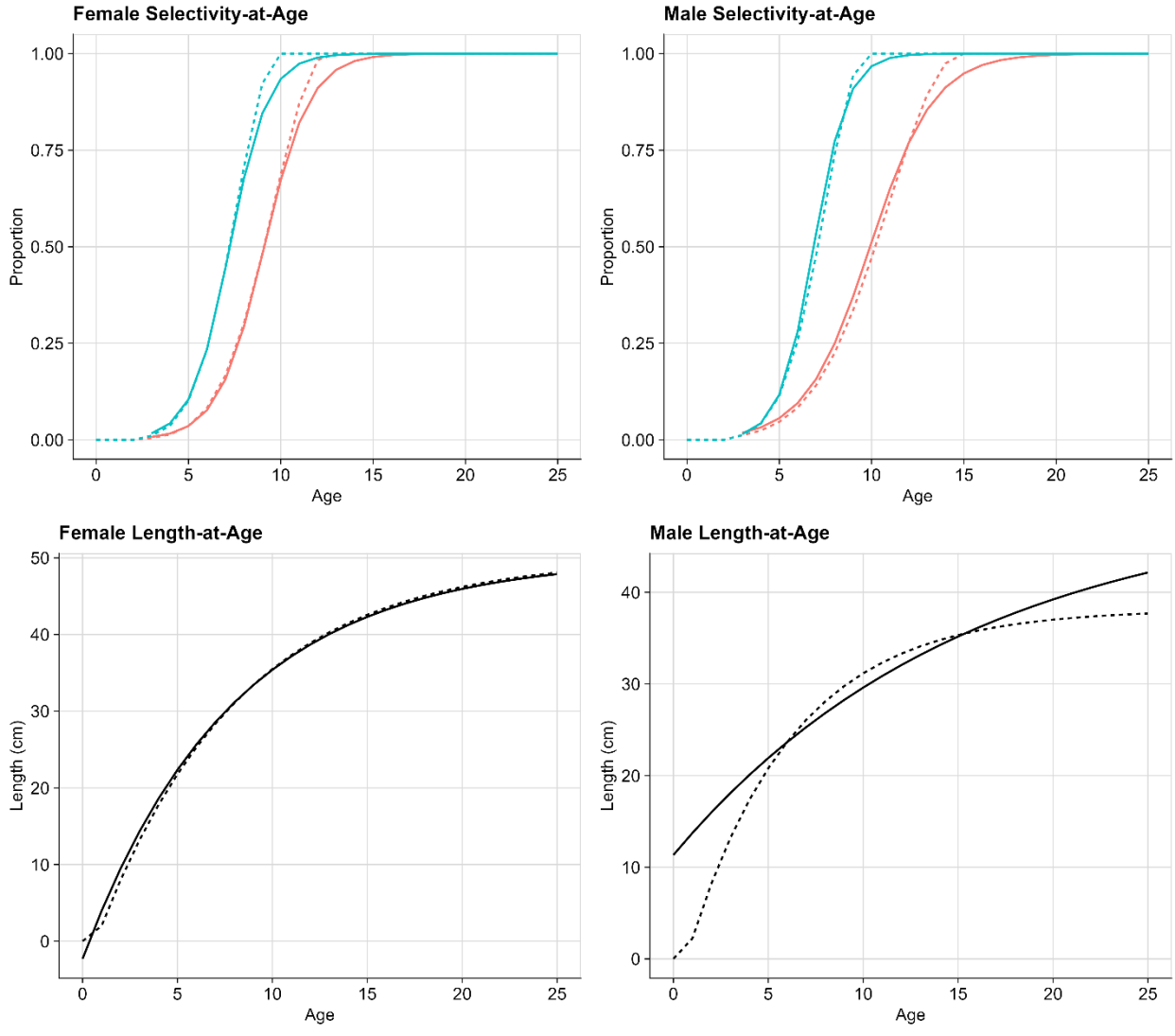

Figure 10.5. Comparison plots between the 2021 model to the Base-2 model with the updated growth curve. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom panels show the growth curves with females on the left and males on the right. In all the panels, the solid line represents the 2021 model and the dashed line represents the Base-2 model.

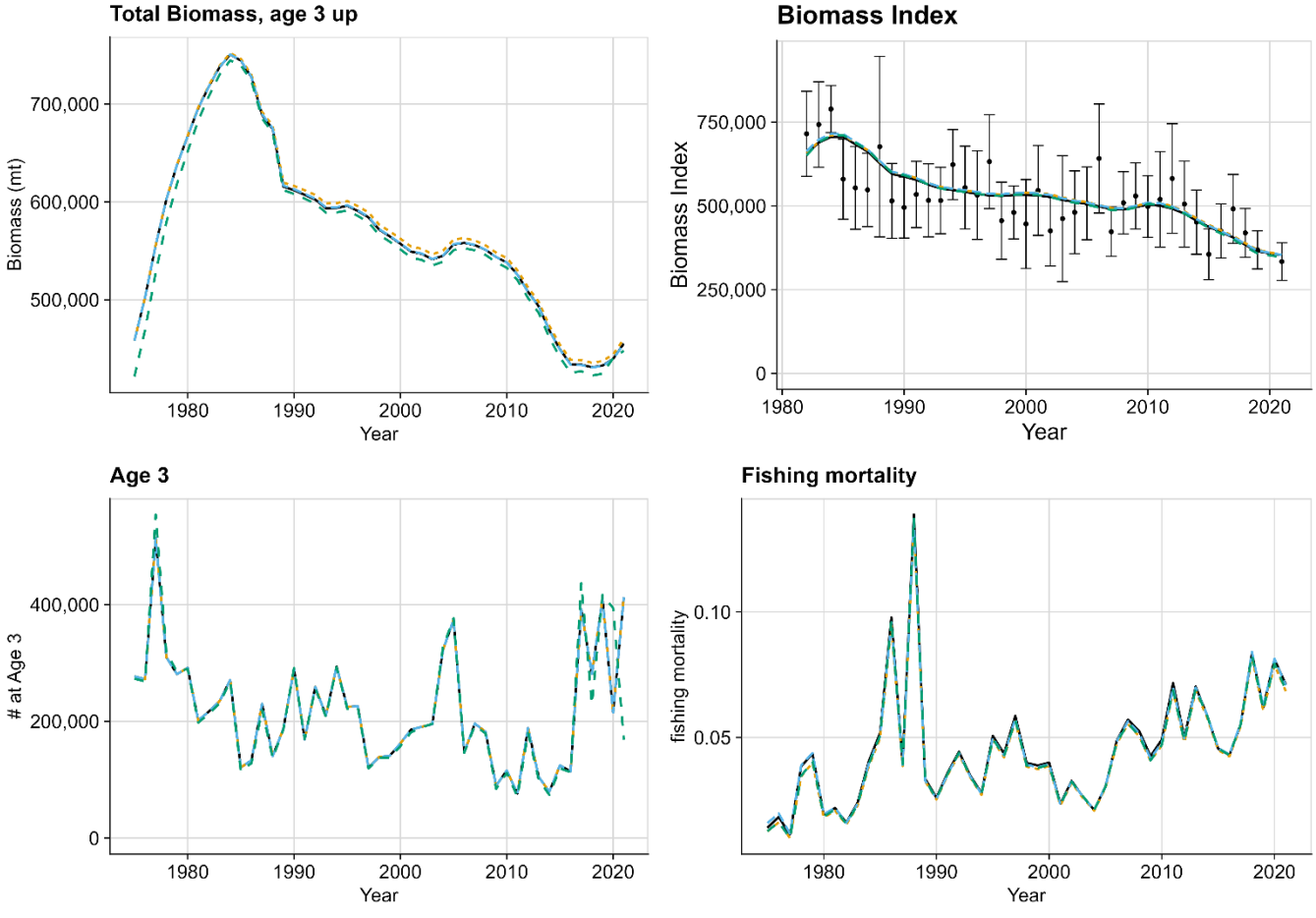

Figure 10.6. Population dynamics plots comparing the 2021, Base-1 and Base-2 models to the Base-3 model where recruitment, fishing mortality and selectivity are estimated. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this plot). The top right panel shows the estimated biomass index with the black dots with error bars representing that actual biomass index data. The bottom left panel shows the number of individuals at age-3. The bottom right panel shows the estimated fishing mortality. In each panel the solid black line represents the 2021 model, the dashed yellow line represents the Base-1 model, the dashed blue line represents the Base-2 model and the dashed green line represents the Base-3 model.

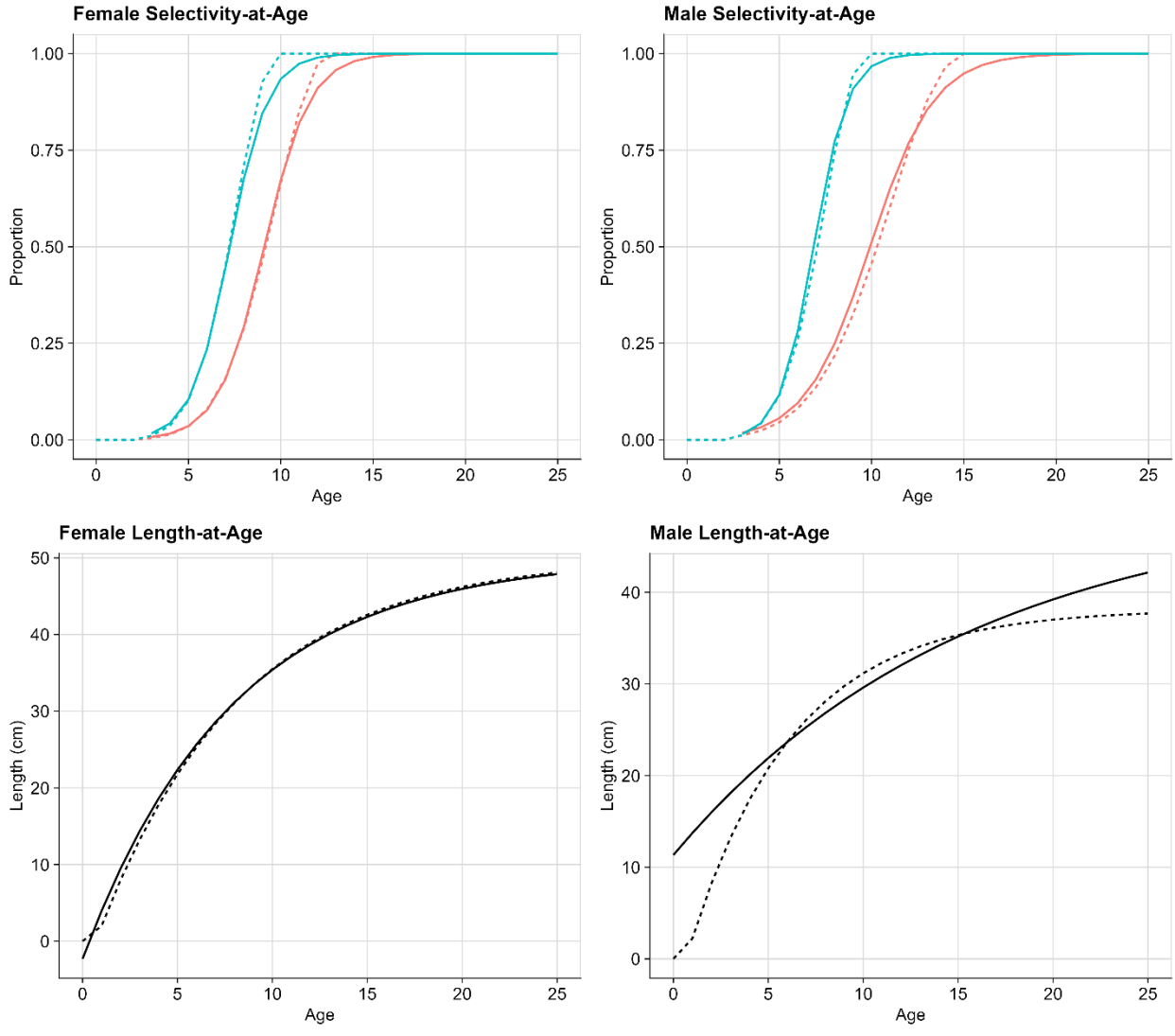

Figure 10.7. Comparison plots between the 2021 model to the Base-3 model where recruitment, fishing mortality and selectivity are estimated. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom panels show the growth curves with females on the left and males on the right. In all the panels, the solid line represents the 2021 model and the dashed line represents the Base-3 model.

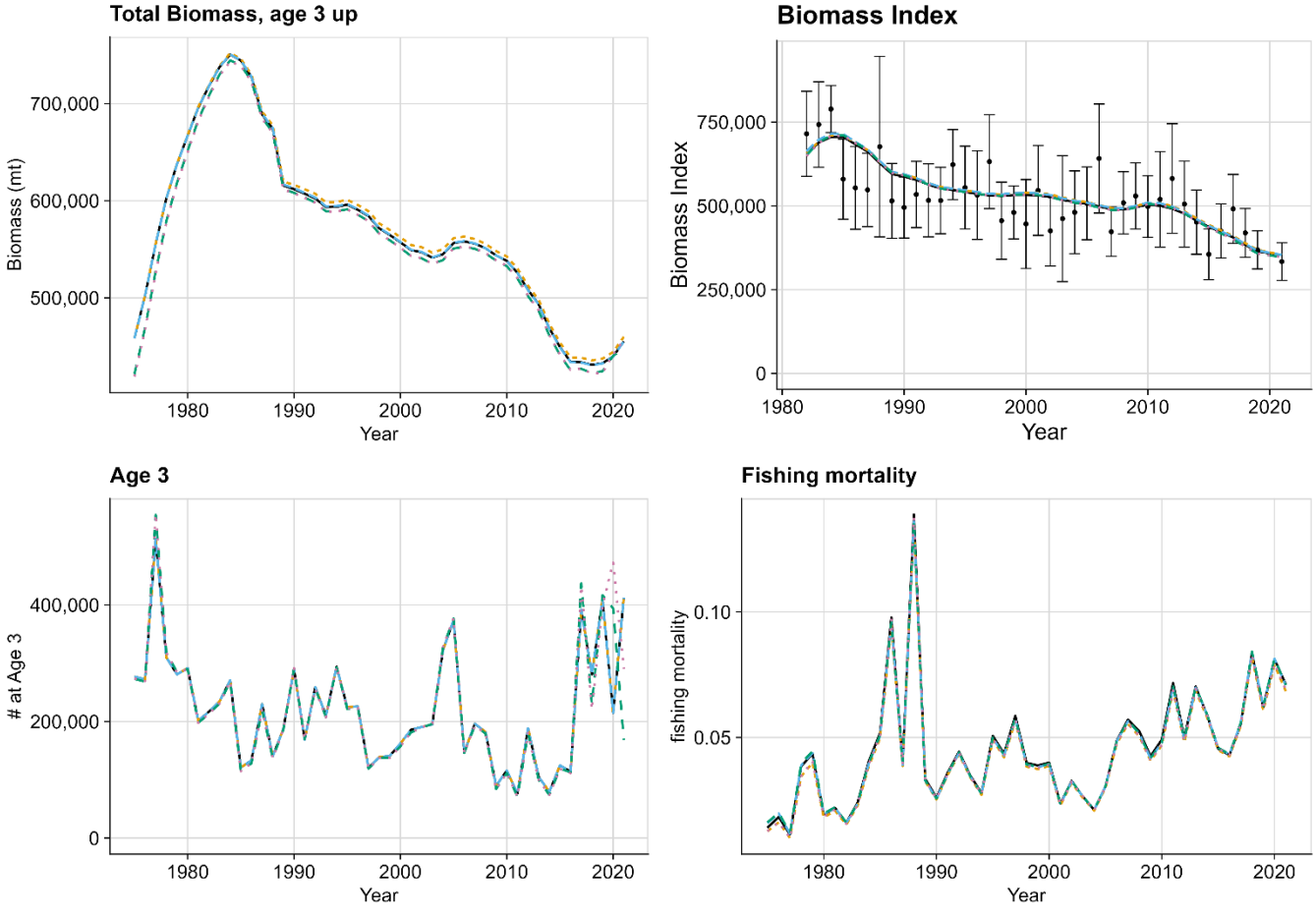

Figure 10.8. Population dynamics plots comparing the 2021, Base-1, Base-2 and Base-3 models to the Base-4 model which mirrors the Base-3 model except that growth is estimated. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this plot). The top right panel shows the estimated biomass index with the black dots with error bars representing that actual biomass index data. The bottom left panel shows the number of individuals at age-3. The bottom right panel shows the estimated fishing mortality. In each panel the solid black line represents the 2021 model, the dashed yellow line represents the Base-1 model, the dashed blue line represents the Base-2 model, the dashed green line represents the Base-3 and the dashed pink line represents the Base-4 model.

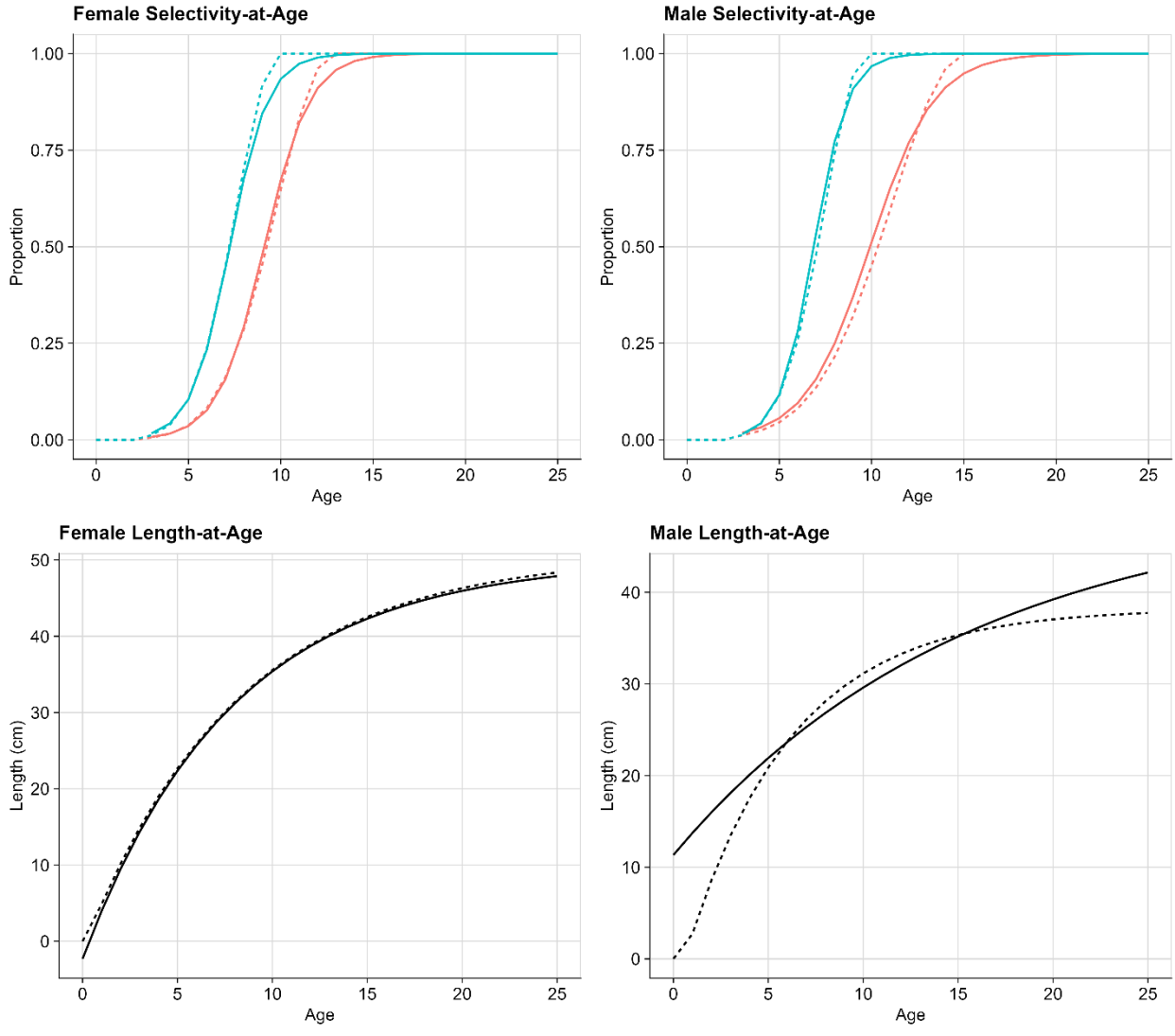

Figure 10.9. Comparison plots between the 2021 model to the Base-4 model which mirrors the Base-3 model except that growth is estimated. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom panels show the growth curves with females on the left and males on the right. In all the panels, the solid line represents the 2021 model and the dashed line represents the Base-4 model.

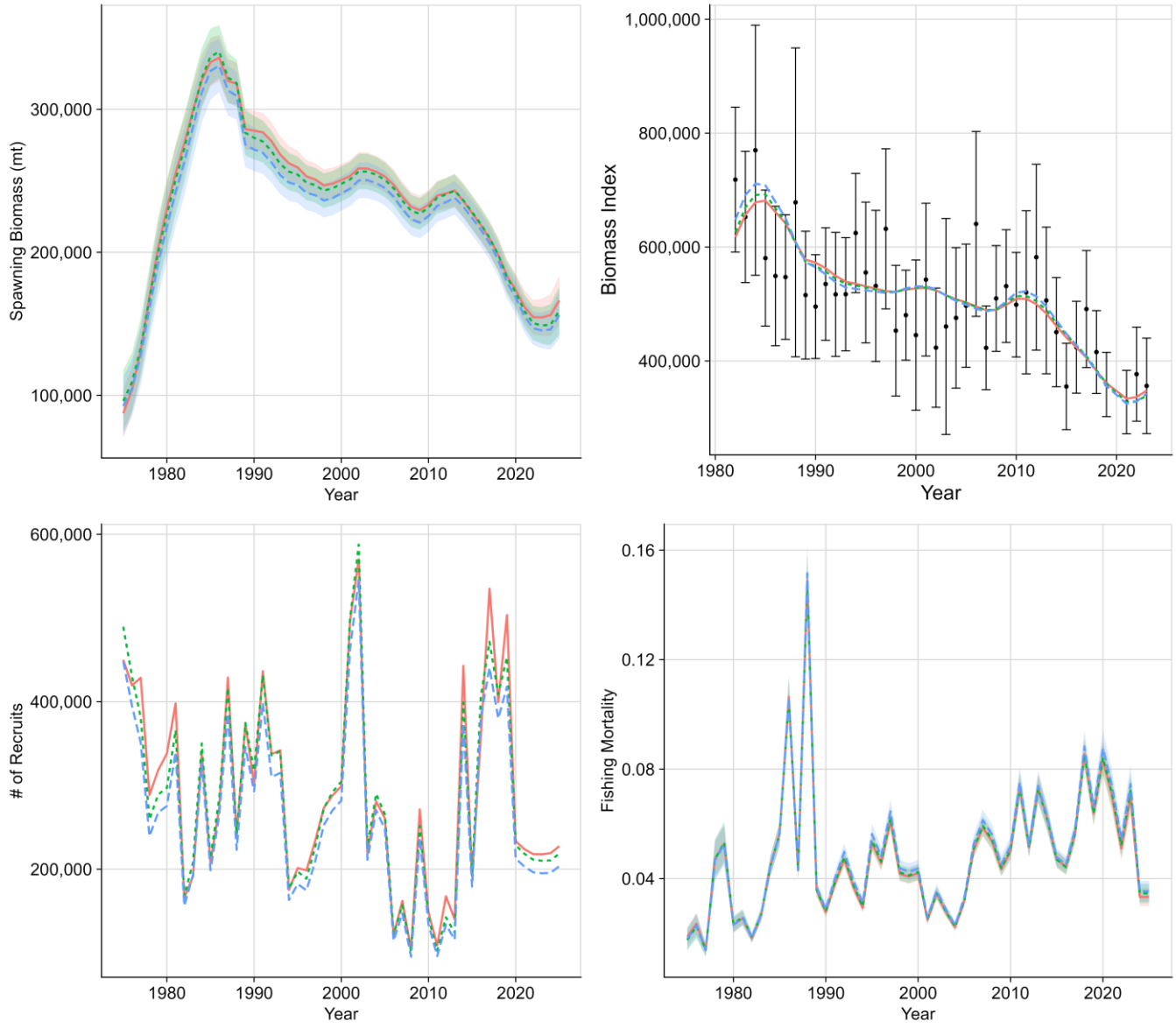

Figure 10.10. Population dynamics plots comparing the Base-4 (red solid), Model 24.0 (green dashed) and Model 24.1 (blue dashed) models. The top left panel shows the estimated spawning biomass. The top right panel shows the estimated biomass index with the black dots with error bars representing that actual biomass index data. The bottom left panel shows the number of age-0 recruits. The bottom right panel shows the estimated fishing mortality. The shaded regions in the top left and bottom right panels represent the 95% confidence interval for the associated color.

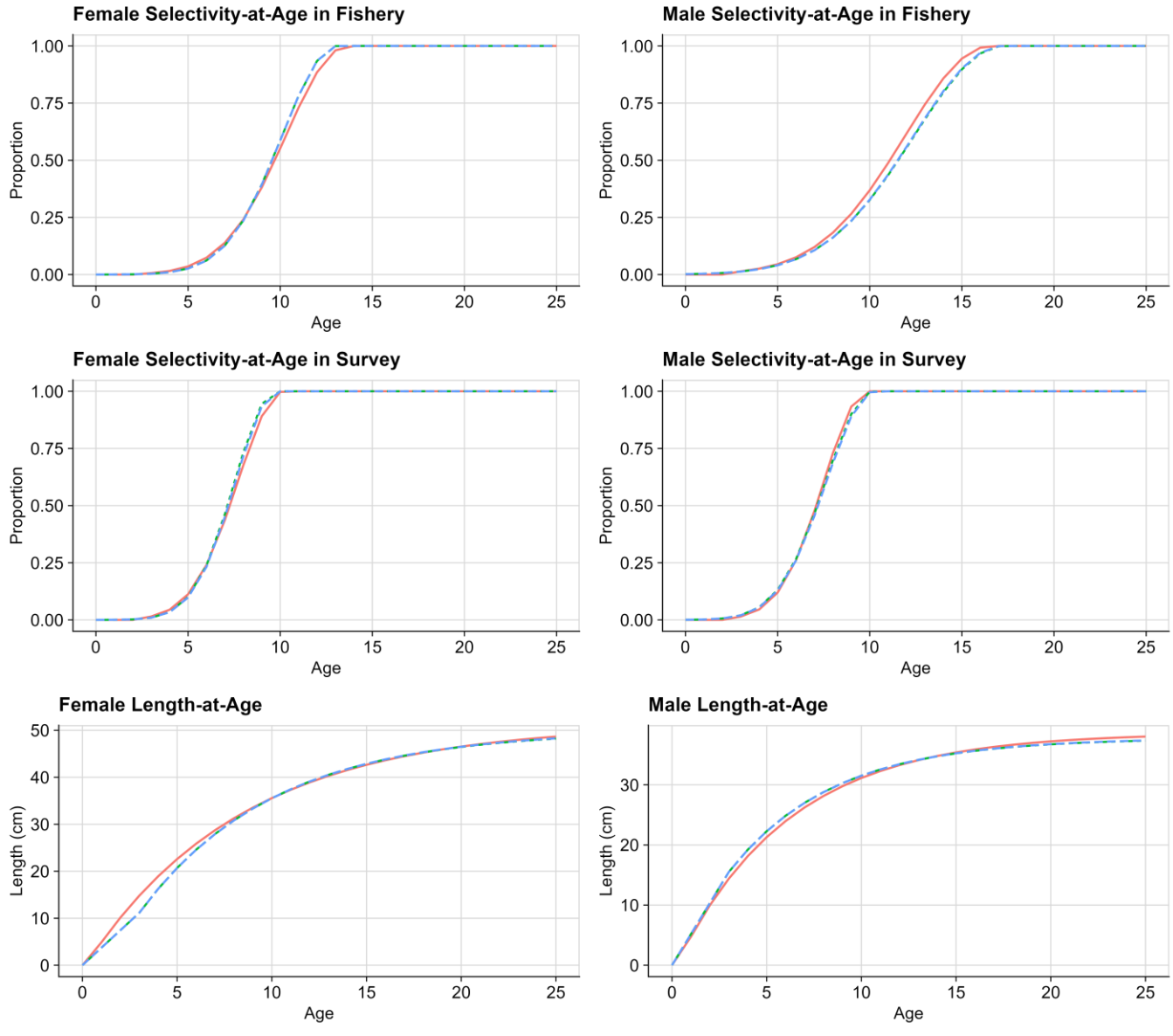

Figure 10.11. Comparison plots between the models Base-4 (red solid), Model 24.0 (green dashed) and Model 24.1 (blue dashed). First row of panels is selectivity in the fishery. The second row is selectivity in the survey and the third row is the length-at-age. The left panels are for female specific curves and the right panels are for male specific curves.