10. Assessment of the Alaska Plaice Stock in the Bering Sea and Aleutian Islands

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the input data:

1. Updated catch estimates from 2022-2024 (2024 catch data as of October 5, 2024, the remaining catch in 2024 is estimated by assuming the weekly catch in the remaining 12 weeks equals the average catch from the three weeks prior to October 5)
2. Included new biomass index estimates from the 2024 EBS shelf bottom trawl survey.
3. Included new length-composition data from 2022-2024 from the EBS shelf bottom trawl survey.
4. Updated length-composition data from 2000, 2002-2007 and 2021-2024 from the fishery.

Changes in the assessment methodology:

1. Assessment model transitioned to Stock Synthesis versions 3.30.22 (SS3; Methot and Wetzel (2013))
2. Updated each year's input sample size for the survey age- and length- composition data using a general bootstrap framework implemented in the "surveyISS" Rpackage (Williams and Hulson (2024)).
3. Included age-1 and -2 fish in the fishery and survey age-composition data.
4. Adjusted the maximum age for linear growth from age-1 to age-3 and estimated all growth parameters except the coefficients of variances (CVs).
5. Updated the growth CVs for both males and females with new values determined through likelihood profiles.
6. Updated the length-weight relationship parameter values by estimating them externally using the fishery and survey length-weight data available to 2024.
7. Calculated weight-at-age relationship within SS3.
8. Tuned the variance for the recruitment deviations through SS3.

Summary of Results

For 2025, the recommended maximum allowable ABC from the Tier 3 projection model is 28,745 t. Reference values for BSAI Alaska plaice are summarized in the following table, with the recommended ABC and OFL values for 2025 in bold.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2024	2025	**2025**	2026
M (natural mortality rate)	0.13	0.13	0.13	0.13
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	473,125	481,959	406,051	402,028
Female spawning biomass (t)	158,087	166,827	150,892	148,177
$B_{100\%}$	286,587	286,587	296,407	296,407
$B_{40\%}$	114,635	114,635	118,563	118,563
$B_{35\%}$	100,306	100,306	103,743	103,743
F_{OFL}	0.17	0.17	0.17	0.17
$maxF_{ABC}$	0.17	0.17	0.14	0.14
F_{ABC}	0.14	0.14	0.14	0.14
OFL (t)	42,695	45,182	**34,576**	33,965
maxABC (t)	35,494	37,560	28,745	28,230
ABC (t)	35,494	37,560	**28,745**	28,230
	As determined *last* year for:		As determined *this* year for:	
Status	2022	2023	2023	2024
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Responses to SSC and Plan Team Comments on Assessments in General

None this year.

Responses to SSC and Plan Team Comments Specific to this Assessment

From the December 2021 SSC minutes:
The author continued to investigate biomass in the NBS, noting that over 50% of the survey biomass

currently resides in the NBS. While trawling is prohibited in the Northern Bering Sea Research Area, the spatial distribution of Alaska plaice does not suggest any stock separation. The SSC appreciates the authors' investigation of this issue and recommends examining new models that include the use of the NBS data in a similar manner to many other BSAI stocks, perhaps through a combined EBS+NBS VAST index. The author should also consider the potential for differences in age-at-maturity and size-at-age between the EBS and the NBS as they move forward. Additionally, the SSC suggests that the author examine the utility of estimating catchability (q) within the model rather than relying on a fixed value (1.2).

From the November 2021 BSAI Groundfish Plan Team minutes:
The Team recommends that authors explore the relationship of the southern part of the stock in the EBS to the northern part of the stock in the NBS and consider developing models that include the NBS data.

From the December 2019 SSC minutes:
The SSC … recommends continuing to track survey biomass trends in the NBS. The assessment indicates that sampling in the NBS in 2017 by a NPRB project showed differential age-at-maturity and size-at-age compared to the EBS. For the next full assessment, the SSC requests that the authors investigate differences in length composition and sex ratios between the NBS and EBS surveys. In addition, the SSC recommends analysis of genetic information to inform whether there is evidence of stock structure between the survey regions.

Response to all comments: The goal for this assessment was to transition the model from ADMB code specifically coded for Alaska Plaice to SS3. The intention was to help provide the assessment with more potential alternative models and diagnostic tools that are available to SS3. During the transition process a variety of small errors were discovered and underlining model assumptions were updated. These changes took priority and a lot of time. Unfortunately, there was not sufficient time to explore including data on Alaska Plaice from the Northern Bering Sea (NBS) within the model. There is every intention to explore NBS data on Alaska Plaice in future assessments.

Introduction

Alaska plaice (*Pleuronectes quadrituberculatus*) are primarily distributed on the Eastern Bering Sea continental shelf, with only small amounts found in the Aleutian Islands region. In particular, the summer distribution of Alaska plaice is generally confined to depths < 110 m, with larger fish predominately in deep waters and smaller juveniles (<20 cm) in shallow coastal waters (Zhang *et al.* 1998). The Alaska plaice distribution overlaps with northern rock sole (*Lepidopsetta polyxystra*) and yellowfin sole (*Limanda aspera*), but the center of the distribution is north of the center of the other two species and seems to be positioned further north in warm years and more southern in cold years. Substantial amounts of Alaska plaice were also found between St. Matthew and St. Lawrence Islands in the 2010- 2021 northern expansions of the annual Bering Sea shelf trawl surveys.

Prior to 2002, Alaska plaice were managed as part of the "other flatfish" complex. Since then an age-structured model has been used for the stock assessment allowing Alaska plaice to be managed separately from the "other flatfish" complex as a Tier 3 single species. There has been no research on stock structure for this species.

Fishery and Management History

Since implementation of the Fishery Conservation and Management Act (FCMA) in 1977, Alaska plaice have been lightly harvested in most years since no major commercial target fishery exists for them.

Catches of Alaska plaice increased from approximately 1,000 t in 1971 to a peak of ~ 62,000 t in 1988, the first year of joint venture processing (JVP) (Table 10-1; Figure 10-1). Part of this apparent increase was due to increased species identification and reporting of catches in the 1970s. Because of the overlap of the Alaska plaice distribution with that of yellowfin sole, much of the Alaska plaice catch during the 1960s was likely caught as bycatch in the yellowfin sole fishery (Zhang *et al.* 1998). Since the end of JVP fishing operations in 1991, Alaska plaice have been harvested exclusively by domestic vessels. Catch data from 1980-89 by its component fisheries (JVP, non-U.S., and domestic) are available in (Walters and Wilderbuer 1990).

Alaska plaice was managed as part of the "other flatfish" complex until 2002 when it began being managed as a Tier 3 single species stock. The majority of Alaska plaice bycatch still occurs in the yellowfin yole fishery with the rock sole fishery having the second largest bycatch (Table 10-1). In 2024, the majority of the catch occurred before May or after August. The total 2024 catch is predicted to be 13,755 t (based on a catch of 9,347 t as of October 5, 2024 and an estimated additional catch of ~ 367 t/week for the remaining 12 weeks in 2024). This is well below the 2024 TAC of 21,752 t and ABC of 35,494 t (Table 10-1).

Based on the monitoring of Pacific halibut bycatch, Alaska plaice has been grouped with the rock sole, flathead sole, and other flatfish fisheries under a common prohibited species catch (PSC) limit, with seasonal and total annual bycatch allowances of these flatfish. Before 2008, these fisheries were closed prior to attainment of the TAC due to the bycatch of halibut, and typically were also closed during the first quarter due to a seasonal bycatch cap. Since the implementation of Amendment 80 in 2008 where catch and bycatch shares were assigned to groups of fishing vessels (cooperatives), these fisheries have not been subjected to time and area closures (with the exception of a halibut closure in 2010).

Substantial amounts of Alaska plaice were discarded in various eastern Bering Sea target fisheries in past years due to low market interest. Retained and discarded catches for Alaska plaice were first reported in 2002 with a 3% retention rate (Table 10-1). Similar retention rates were observed for 2003 - 2005 (5%, 5% and 7%, respectively). The discard patterns have changed, with increasing retention rates each year. As of 2015 percent retention has been above 90%. Most of the discards that do occur, occur in the yellowfin sole fishery.

Data

The following table summarizes the data used in the 2024 stock assessment model for Alaska plaice (bold denotes new data for this assessment):

Source	**Data**	**Years**
NMFS Eastern Bering Sea Shelf bottom trawl survey	Survey Biomass	1982-2019, 2021-2024
	Age-Composition	1982, 1988, 1992-1995, 1998, 2000-2002, 2005-2014, 2016-2019, 2021
	Length-Composition	1983-1987, 1989-1991, 1996-1997, 1999, 2003-2004, 2015, 2022-2024
U.S. Trawl Fishery	Catch	1975-2024
	Age-Composition	2000, 2002, 2003

Source	Data	Years
	Length-Composition	1978-89, 1995, 2000-2024

Fishery data

Catch

This assessment uses fishery catches from 1975 through 2024 (Table 10-1). The total 2024 catch is predicted to be 13,755 t (based on a catch of 9,347 t as of October 5, 2024 and an estimated additional catch of ~ 367 t/week for the remaining 12 weeks in 2024).

The catch of Alaska plaice taken in scientific surveys, subsistence fishing, recreational fishing, fisheries managed under other FMPs from 2010–2023 is shown in Table 10-3. 2024 non-commercial catch data is not available yet.

Fishery sex-specific length-compositions from 1978-89, 1995 and 2000-2024 as well as sex-specific age-compositions from 2000, 2002 and 2003 were used in the model as well. The number of ages and lengths collected from BSAI fisheries are shown in Table 10-2.

Because Alaska plaice are usually taken incidentally in target fisheries for other species, CPUE from commercial fisheries is considered unreliable information for determining trends in abundance for these species. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Survey

Large-scale bottom trawl surveys of the Eastern Bering Sea continental shelf have been conducted in 1975 and 1979-2024 by the National Marine Fisheries Service (NMFS). The trawl gear was changed in 1982 from the 400 mesh eastern trawl to the 83-112 trawl, as the latter trawl has better bottom contact. This may contribute to the increase in Alaska plaice seen from 1981 to 1982, as increases between these years were noticed in other flatfish as well. Due to the differences in catchability between these two survey trawls, this assessment only uses the survey estimates from 1982-2024.

Survey estimates of total biomass are shown in Table 10-4 and Figure 10-2. The number of ages and lengths collected from the survey are shown in Table 10-5.

Survey estimates exhibit a relatively stable trend from 1982 to 2012 then start to decline. By 2019 the survey biomass estimates appeared to have leveled off at a lower below average level and has remained around there ever since (Table 10-4 and Figure 10-2).

Assessments for other BSAI flatfish have suggested a relationship between bottom temperature and survey catchability where bottom temperatures are hypothesized to affect survey catchability by affecting either stock distributions and/or the activity level of flatfish relative to the capture process. Temperature was not expected to affect Alaska plaice catchability since they are a “cold loving” species with an anti-freeze protein that inhibits ice formation in their blood (Knight *et al.* 1991). This relationship was investigated in the last full assessments (2021) for Alaska plaice by using the annual temperature anomalies from surveys conducted from 1982 to 2017. Examination of the residuals from the model fit to the bottom trawl survey relative to the annual bottom temperature anomalies did not indicate a positive correlation between the two data series (-0.26 for 2021) (Ormseth 2021a). This was also the result from a past assessment (Spencer *et al.* 1990) where a fit with a LOWESS smoother indicated that little correspondence exists between the two time series, and the cross-correlation coefficient (-0.17) was not significant at the 0.05 level. Thus, the relationship between bottom temperature and survey catchability was not pursued further.

Analytical approach

General Model Structure

The last full assessment for Alaska Plaice was conducted in 2021. It used a sex-specific, age- and length-based population dynamics model (Ormseth 2021a) coded in automatic differentiation model builder (ADMB) (Fournier *et al.* 2012). Model parameters were estimated by minimizing an associated objective function that describes the error structure between model estimates and observed quantities. This model was coded specifically for and only used by Alaska plaice. The sex-specific aspects in this model include 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 length-at-age relationship used a von Bertalanffy growth curve and the weight-at-length relationship used a exponential curve. The logistic age-at-maturity curve is also estimated outside the model and is only determined for females.

Estimated within the 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. Recruitment is determined by estimating annual deviations around mean recruitment. The 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 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 10 cm – 60 cm. The final length bin is a plus group and lengths below 10 cm are excluded. The input sample size for all fishery composition data (age and length) is fixed to 50 while the input sample size for all survey composition data is fixed to 200.

The 2021 assessment model was transitioned to Stock Synthesis versions 3.30.22 (SS3; Methot and Wetzel (2013)) and presented at the 2024 September Plan Team Meeting. The 2024 Alaska Plaice September SAFE details the transition process to SS3 and is in **Appendix A** of this document. **Appendix A** also provides more information about the 2021 assessment model, the equations used in the model and the differences between the 2021 assessment model and the SS3 model.

From the 2024 September Plan Team Meeting, two models were requested to be presented in November. The first is a model called “Base-3”, which is an SS3 model that most closely mirrors the 2021 assessment model. The second is called “Model 24.1” which includes multiple updates to the Base-3 model. These updates included:

1. Updating each year’s input sample size for the survey age-composition data using a general bootstrapping 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. Changing age range to 0-25.
4. Including age-1 and -2 fish in the fishery and survey age-composition data.
5. Adjusting the maximum age for linear growth from age-1 to age-3 and estimating all sex-specific von Bertalanffy growth parameters except the CVs within SS3.

6. Updating the exponential length-weight relationship parameters values by estimating them externally using fishery and survey length-weight data available up to 2024.
7. Updating the growth CVs for both males and females with new values determined through likelihood profiles.
8. Updated the SS3 model to calculate the weight-at-age relationship within SS3.

All of these changes provide improvements to the model by including additional data, updating parameter estimates with new data, and allowing for temporal variability in the statistical weighting of the survey composition data.

Description of Alternative Models

As stated above, the 2024 September Plan Team requested that two models (Base-3 which closely mirrors the 2021 assessment model and Model 24.1 which includes several updates to Base-3) were requested to be presented in November. Two additional alternative models with minor changes are presented in this document.

The first additional model (Model 24.1a), updates the input sample size for the survey length-composition from the number of hauls to values determined from a general bootstrapping framework implemented in the “surveyISS” Rpackage (Williams and Hulson 2024). Then the input sample sizes for both the survey age- and length-composition were re-weighted. This was accomplished by rerunning the model ten times, with each run using the suggested weighting from the Francis data weighting method (Francis 2011) output by SS3 from the previous run. The end result were that the survey length-composition input sample sizes were multiplied by 0.14693 while the survey age-composition input sample sizes were multiplied by 0.2749.

The second additional model (Model 24.1b) mirrors Model 24.1a except that the standard deviation in recruitment deviations (sigmaR) is tuned using the SS3 recommended value. All other models have sigmaR arbitrarily fixed at 1 while Model 24.1b has a tuned sigmaR value of 0.4243. This value was determined by running Model 24.1b 10 times with each run using the suggest SS3 sigmaR from the previous run. The difference between the last two sigmaR values was less than 0.00001.

The SS3 files used to run all four alternative models can be at https://github.com/afsc-assessments/BSAI_Alaska_plaice.git.

Parameters Estimated Outside the Assessment Model

Within all four alternative models, four biological characteristics were estimated external. This included natural mortality, survey catchability, the weight-length relationship and maturity-at-age. For natural mortality (*M*), Zhang (1987) concluded that it varied by sex for Alaska plaice (males = 0.195, females = 0.27). However, past assessments did not use a sex specific *M*. They fixed *M* at 0.25 based on an earlier analysis of natural mortality (Wilderbuer and Walters 1997). In the 2010 assessment, *M* was re-estimated using three methods from the literature based on the life history characteristics of maximum life span (Hoenig 1983), average age (Chapman and Robson 1960) and the relationship between growth and maximum length (Gislason *et al.* 2008). The results suggest a range of *M* values from 0.08 to 0.13 for males and 0.08 to 0.29 for females. For the 2021 assessment, *M* was fixed to 0.13 for both sexes. For the 2024 assessment, a likelihood profile on non-sex specific natural mortality was conducted using Model 24.1b. The results showed that an *M* of 0.13 produced the lowest total likelihood (Figure 10-3).

Herding experiments in the eastern Bering Sea have demonstrated that many of the flatfish encountered in the area between the outer end of the footrope and where the bridles contact the sea floor (outside the trawl path) are herded into the path of the bottom trawl in varying degrees (Somerton and Munro 2001).

The mean herding effect from all seven flatfish species combined resulted in a bridle efficiency of 0.234. Although Alaska plaice were not among the seven flatfish species that were explicitly studied, it is assumed that their behavior is similar to the other studied species which all exhibited herding behavior. Thus, this assessment incorporated a herding effect into the stock assessment model by fixing survey catchability at 1.2, close to the mean value from the combined flatfish species in the herding experiment.

The maturity-at-age matches the values used in the previous full assessment in 2021, which were taken from (TenBrink and Wilderbuer 2015).

The weight-length relationship was determined by fitting an exponential curve to length weight data from both the fishery (1999-2024) and survey (1982, 1988, 1992-1995, 1998, 2000-2002, 2005-2014, 2016-2019, 2021) using the "optim" function in R. Figure 10-4 shows the data and fitted weight-at-length curves. The newly estimated weight-at-length curve is used by all alternative models except Base-3 in which the weight-at-length curve from the 2021 assessment is used.

Parameters Estimated Inside the Assessment Model

A detailed description of the equations used in SS3 can be found in Appendix A of Methot and Wetzel (2013). Table 10-6 list the parameter values, except the recruitment deviations and fishing mortalities, for all four models and whether the parameters are estimated with SS3. Recruitment deviations were estimated up to 2019 because Alaska plaice do not start appearing in composition data until around age five. All estimated parameters were determine by minimizing all the likelihood components. The total number of parameters estimated in each model is listed below.

Source	Base-3	Model 24.1	Model 24.1a	Model 24.1b
Mean Recruitment	1	1	1	1
Recruitment Deviations	45	45	45	45
Initial Population	25	25	25	25
Growth	0	6	6	6
Selectivity	8	8	8	8
Fishing Mortality	50	50	50	50
Total # of Parameters	129	135	135	135

Results

Model Evaluation

Figure 10-5 and Tables 10-7, 10-8 and 10-9 compares the performance of all four models in regards to spawning stock biomass, biomass index, recruitment to age-0 and fishing mortality. All models perform similarly in regards to biomass index and fishing mortality. There are differences when looking at spawning stock biomass and recruitment. For spawning stock biomass, Base-3 has a noticeably separate trajectory than the other models, especially during the middle of the time series. This is most likely do to the dissimilarity in length-at-age (Figure 10-6), weight-at-age (Figure 10-7) and selectivity (Figure 10-8) between Base-3 and the other models. At the beginning of the spawning stock biomass time series, Model 24.1b has a higher spawning stock biomass when compared to the other models. This is most likely caused by Model 24.1b tuning sigmaR to a value of 0.42 while the other models have it fixed at 1. The impact of tuning sigmaR most apparent in the estimation of the recruitment deviations for the initial number-at-age (Figure 10-9, 1950-1975). As for recruitment, model differences occur at the beginning and end of the time series. These discrepancies are caused by the weighting of the composition data and assumptions around sigmaR. The beginning and end of the times series also has the least amount of information in regards to recruitment and is more susceptible to difference in data weighting and model assumptions.

Figure 10-6 shows the length-at-age relationship used in each model. All the models have similar curves with Base-3 looking slightly different. Base-3 is the only model that estimates growth external. The other models estimates growth within SS3 which allows the model to have more flexibility. Figure 10-7 shows the weight-at-age relationship for each model. Again, all models have similar curves except Base-3. Base-3 determines its weight-at-age relationship externally while the other models calculate it within SS3. This ensures that the estimate growth curve within SS3 is used to calculate the weight-at-age relationship.

Figure 10-8 shows the fleet and sex specific age-based selectivity curves used by each model. There is little distinction in the female fleet specific selectivity curves between models. The same is not true of male selectivity. Model 24.1a and 24.1b have male selectivity curves that are shifted to the right of the other model curves for both fleets. This is most likely caused by the Francis re-weighting applied to the survey length-composition data.

A comparison of each models' fit to the fishery length-composition data can be found in Figures 10-10 and 10-11. The aggregated fits shows that Model 24.1a and 24.1b perform better than the other models, especially for the male length-composition data. This could explain the shift in Models' 24.1a and 24.1b male selectivity curves. The Pearson residuals show that Models 24.1, 24.1a and 24.1b tended to have small residuals when compared to Base-3 and thus better fits. As for the fits to the survey length-composition data, the aggregated fits again showed that Model 24.1a and 24.1b performed better than the other models but only slightly (Figure 10-10). Model 24.1a and 24.1b also tended to have small residuals in regards to Pearson residuals when compared to other models (Figure 10-12).

Each models fit to the fishery age-composition data can be found in Figures 10-13 and 10-14. The aggregated fits shows that none of the models fit the data well while the Pearson residuals show no difference between the models. This lack of distinction could be occurring because there is only three years of age-composition data available in the fishery. As for the survey age-composition, the aggregated fits suggest that the Base-3 model performs better than the other models (Figure 10-13) while the Pearson residuals support that Model 24.1a and 24.1b have better fits since they both have smaller residuals when compared to the other models (Figure 10-15).

Overall, this author recommends Model 24.1b as the model for the 2024 assessment. It tends to have better fits to the age- and length-composition data, it has a good fit to the biomass index and it incorporates more standard practices, such as Francis re-weighting of the survey age- and length-composition data and tuning of sigmaR. The remaining diagnostics will therefore only be shown for Model 24.1b.

Figure 10-16 shows expected numbers-at-age and expected mean age in each year for Model 24.1b.

Convergence Status

Convergence for Model 24.1b was determined by successful inversion of the Hessian matrix and a maximum gradient component of less than 1e-4. A jitter analysis revealed that Model 24.1b is insensitive to perturbations of parameter start values on the order of 10% (Figure 10-17). The jitter analysis had 100 runs of which only 11 converged on likelihoods whose difference from the minimal likelihood was greater than six. All parameters were estimated within their pre-specified bounds.

Retrospective Analysis

A ten-year retrospective analysis was conducted by sequential removal of all data annually beginning with 2024 and ending in 2014 (Figure 10-18). The mean terminal spawning biomass estimate from each of these retrospective models lies within the 95% confidence interval of the current base model. Hurtado-Ferro *et al.* (2014) developed suggested ranges for Mohn's ρ values that may arise without the influence of model mis-specification based on a simulation-estimation study. They found that values between -0.15 and 0.20 for longer lived species and values between -0.22 and 0.30 for shorter-lived species could arise without the influence of model mis-specification. With Alaska plaice falling into the longer lived category, the spawning stock biomass Mohn's ρ value of 0.01 for this year's assessment are within the suggested bounds.

Harvest recommendations

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC ($maxF_{ABC}$). The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. The F_{OFL} and F_{ABC} are given in terms of unfished female spawning biomass (F_{SPR}), on fully selected age groups, where unfished female biomass is the average biomass if fishing had not occurred and is estimated as the historical biomass prior to fishing. The reference points are calculated using the long-term average female spawning biomass that would be expected under average estimated recruitment (1977-2018). Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Alaska Plaice in the BSAI are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $B_{35\%}$, equal to 35% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$,equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The 2024 estimates of these reference points are:

Reference Point	Value
Female Spawning Biomass$_{2024}$	150,892
$B_{40\%}$	118,563
$F_{40\%}$	0.14
$maxF_{ABC}$	0.14
$B_{35\%}$	103,743
$F_{35\%}$	0.17
F_{OFL}	0.17

Specification of OFL and Maximum Permissible ABC

The estimated catch level for year 2024 associated with an F_{OFL} of 0.17 is 34,576 t. **The 2024 recommended ABC associated with an F_{ABC} of 0.14 is 28,745 t.**

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Act (MSA). All projection scenarios project the model out for 13 years (till 2037). SS3 was used to run all projections scenarios.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for the next two years, are as follow:

- Scenario 1: In all future years, F is set equal to $maxF_{ABC}$. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
- Scenario 2: In all future years, F is set equal to a constant fraction (1) of $maxF_{ABC}$, where this fraction is equal to the ratio of the F_{ABC} value for 2025 recommended in the assessment, to the $maxF_{ABC}$ for 2025, and catches for 2025 and 2026 are estimated at their most likely values given the 2025 and 2026 recommended ABCs under this scenario. (Rationale: When F_{ABC} is set at a value below $maxF_{ABC}$, it is often set at the value recommended in the stock assessment; also, catch tends not to equal ABC exactly.)
- Scenario 3: In all future years, F is set equal the average F between 2019 to 2023. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
- Scenario 4: In all future years, the upper bound on F_{ABC} is set at a selected fraction (0.75) of F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.).
- Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

- Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2025 or 2026 or 2) above ½ of its MSY level in 2025 and expected to be above its MSY level in 2034 under this scenario, then the stock is not overfished.)
- Scenario 7: In 2025 and 2026, F is set equal to $maxF_{ABC}$, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2026 or 2) above ½ of its MSY level in 2025 and expected to be above its MSY level in 2036 under this scenario, then the stock is not approaching an overfished condition.)

Projected spawning stock biomass, fishing mortality, and catch for the seven standard projection scenarios can be found in Tables 10-10, 10-11 and 10-12.

Risk Table and ABC recommendation

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The following template is used to complete the risk table:

	Assessment-related considerations	***Population dynamics considerations***	***Environmental/ecosystem considerations***	***Fishery Performance***
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 3: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. "Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. "Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. "Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. "Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings."

<u>Assessment considerations</u>

BSAI Alaska plaice have been assessed annually from bottom trawl surveys conducted on the EBS shelf from 1982-2024, with one skipped year in 2020 (due to the coronavirus pandemic). Survey age-compositions are derived from otoliths collected during the surveys which are typically available for the assessment one year after collection. Even though otoliths from the fishery are collected, there are only three years of fishery age-composition data available. The assessment model exhibits good fits to all compositional and abundance data. There is concern about the lack of age-composition data from the fishery but not enough to change the recommended ABC. Recruitment estimates track strong year classes in the most recent years which is consistent with the data. Retrospective analysis of the past 10 years of female spawning biomass estimates from the current assessment model does not indicate a pattern of concern regarding misspecification of the model. Rated Level 1, No Concern.

Population dynamics considerations

The female spawning biomass is projected to remain at levels well-above the $B_{40\%}$ value. There has been above average recruitment from ~2015-2020. The female spawning biomass trend is similar to the total biomass trend with a peak level estimated in 1985 and a slow decline thereafter that continues to the present. Fishing pressure on Alaska plaice has been light as they are mostly caught as bycatch in the yellowfin sole fishery. Fishing mortality estimates have averaged around 0.05 from 1975-2024, well below ABC levels. Projections indicate that the female spawning biomass will remain well-above the B_{MSY} level through 2036. Rated Level 1, No Concern.

Environmental/Ecosystem considerations

Environmental processes:
The eastern Bering Sea (EBS) experienced a prolonged period of above-average thermal conditions from 2014 through 2021. Since 2021, and continuing from August 2023–August 2024, thermal conditions in the EBS have been close to historical baselines of many metrics. There have been no sustained marine heatwaves over the southeastern or northern Bering Sea shelves since January 2021 (Callahan and Lemagie 2024), and observed (Rohan and Barnett 2024b) modeled (Kearney 2024a) EBS bottom temperatures were mostly near-normal over the past year. Sea surface temperatures (SSTs) and bottom temperatures were near the long-term means in all regions by summer 2024. Notable deviations include (i) warm SSTs in the outer domain from fall 2023 through spring 2024 and (ii) unusually warm bottom temperatures in the northern outer domain since spring 2024 that may indicate an intrusion of shelf water (Siddon 2024).

Atmospheric conditions are one of the primary drivers that impact the oceanographic setting in the EBS. Both the North Pacific Index (NPI) and Aleutian Low Index (ALI) provide complementary views of the atmospheric pressure system in the North Pacific. During winter 2023-2024, the NPI was average (Kearney 2024b) and the strength and location of the Aleutian Low Pressure System were both near climatological averages (Overland and Wang 2024). Thus, despite delayed formation of sea ice in fall 2023 (Thoman 2024b), cold winds from the Arctic helped advance sea ice to near-normal extent by mid-winter. Near-normal sea ice extent and thickness (Thoman 2024a,c) may have contributed to a cold pool (<2°C water) of average spatial extent (Kearney 2024b), though the footprint of the coldest waters (<0°C) in 2024 was 75% smaller than in 2023 (Rohan and Barnett 2024a).

Alaska plaice contain a glycol-protein that works to inhibit ice crystal formation in the blood, indicating this species may tolerate colder bottom water temperature. However, the condition of Alaska plaice (based on length-weight residuals) was just below average in the NBS and was at or above average in the SEBS between 2021-2023 (L/W condition information not available for Alaska place in 2024) (Prohaska *et al.* 2024).

For projections into 2025, the National Multi-Model Ensemble (NMME) predicts that SSTs over the EBS are expected to be near normal (anomalies within <0.5°C of the 1982–2010 baseline) (Lemagie 2024). With the expected transition to La Niña, cooler conditions in the EBS may follow. Relatively cool SSTs may contribute to earlier formation of sea ice than has been observed over the last several years (Thoman 2024a).

Prey:
The dominant prey of Alaska plaice are polychaete worms and clam siphons. Direct measurements of infaunal abundance trends are not available, however, abundance trends of motile epifauna that also consume infauna (i.e., indirect measurements) are quantified from the bottom trawl survey. Trends in motile epifauna biomass indicate benthic productivity, although individual species and/or taxa may reflect varying time scales of productivity. The biomass of motile epifauna increased from 2023 to 2024 and remains above the long term mean (Kearney 2024b), indicating that sufficient prey may have been available for Alaska plaice over the southeastern Bering Sea shelf . No direct or indirect measures of prey availability exist for the northern Bering Sea shelf.

Competitors:
Competitors for Alaska plaice prey resources include other benthic foragers, like northern rock sole and yellowfin sole, included in the benthic foragers guild. The trend in biomass of the benthic foragers guild from the standard bottom trawl survey grid increased from 2023 to 2024, but remained below the time series mean. Trends in benthic forager biomass indirectly indicate availability of infauna (i.e., prey of these species), suggesting competition for prey resources remains low in 2024 (Kearney 2024b).

Predators:
Predators of Alaska plaice include Pacific cod, Pacific halibut, and yellowfin sole. The biomass of apex predators, including Pacific cod and Pacific halibut, measured during the standard bottom trawl survey in 2024 was nearly equal to their value in 2023 and below their long term mean. However, the trend in the apex predator guild is largely driven by Pacific cod, which decreased 5.5% from 2023 (Kearney 2024b). The spatial distribution of Pacific halibut overlaps with that of Alaska plaice, suggesting potential increased risk of predation. Examining such spatio-temporal overlaps would better inform the potential predation impacts for Alaska plaice in the EBS. As stated above, the trend in biomass of the benthic foragers guild, including yellowfin sole, increased from 2023 to 2024 but remains below the time series mean (Kearney 2024b).

Summary for Environmental/Ecosystem considerations:

- **Environment:** The EBS shelf experienced oceanographic conditions that were largely average based on historical time series of multiple metrics over the past year (August 2023 - August 2024).
- **Prey:** Sufficient prey may have been available for Alaska plaice over the SEBS based on indirect measurements of motile epifauna.
- **Competition:** The trend in biomass of benthic foragers increased from 2023 to 2024 but remained below the time series mean, indicating competition for prey resources remains low in 2024.
- **Predation:** Predation pressure may be mixed; a decrease in Pacific cod biomass and potential refuge from predation in the inner domain may be countered by the spatial overlap with Pacific halibut in the inner domain of the SEBS. Increases in the benthic forager guild, including Yellowfin sole, may indicate a relative increase in predation pressure from 2023, though the guild overall remains below its long-term mean.

Together, the most recent data available suggest an ecosystem risk Level 1 – Normal: "No apparent ecosystem concerns related to biological status (e.g., environment, prey, competition, predation), or minor concerns with uncertain impacts on the stock."

Fishery performance

Because Alaska plaice are a non-target stock, fishery performance indicators (e.g. CPUE) are not good indicators of population status. Rated Level 1, No Concern.

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: No increased concerns	Level 1: No increased concerns	Level 1: No increased concerns	Level 1: No increased concerns

Status Determination

Under the MSA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This involves answering three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2023) is 15,252 t. This is less than the 2023 OFL of 40,823 t. Therefore, the stock is not being subjected to overfishing.

Is the stock currently overfished? This is determined through Scenario 6. The expected stock size in the current year (2024) of scenario 6 is 147,511 t, which is higher than $B_{35\%}$ (103,743 t). Thus the stock is not currently overfished.

Is the stock approaching an overfished condition? This is determined through Scenario 7. The expected spawning stock size in the year 2036 of scenario 7 (113,528 t) is greater than $B_{35\%}$ (103,743 t); thus, the stock is not approaching an overfished condition.

Estimated fishing mortality is plotted against spawning stock biomass relative to the harvest control rule in Figure 10-19.

Data Gaps and Research Priorities

Currently the suggest model (Model 24.1b) has age-based selectivity for the fishery. There is only three years of age-composition data available from the fishery (2000,2002 and 2003). There are otoliths collected from the fishing in other years (Table 10-2). The survey also has age-based selectivity and uses 25 years of age-composition data to help estimate it. It would be beneficial to have additional years of age-composition data from the fishery to better inform age-based selectivity estimates.

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Tables

Table 10-1. Harvest specifications and catch (t) for Alaska plaice in BSAI from 1975-2024. Retained is the percent of Catch retained.

	Target Fishery							
Year	**Yellowfin Sole**	**Rock Sole**	**other**	**Total Catch**	**Total % Retained**	**TAC**	**ABC**	**OFL**
1975				2,492				
1976				3,620				
1977				2,589				
1978				10,420				
1979				13,672				
1980				6,908				
1981				8,653				
1982				6,811				
1983				10,766				
1984				18,982				
1985				24,888				
1986				46,519				
1987				18,567				
1988				61,638				
1989				14,134				
1990				10,926				
1991				15,003				
1992				18,074				
1993				13,846				
1994				10,822				
1995				19,172				
1996				16,096				
1997				21,236				
1998				14,296				
1999				13,997				
2000				14,497				
2001				8,685				
2002	10,396	621	1,160	12,177	3%			
2003	8,513	402	941	9,857	5%	10,000	137,000	165,000
2004	5,836	1,160	893	7,888	5%	10,000	203,000	258,000
2005	8,712	1,345	1,137	11,194	7%	8,000	189,000	237,000
2006	13,972	1,899	1,447	17,318	15%	8,000	188,000	237,000
2007	16,357	1,805	1,360	19,522	20%	25,000	190,000	241,000
2008	13,512	2,684	1,181	17,377	46%	50,000	194,000	248,000
2009	10,632	2,419	893	13,944	64%	50,000	232,000	298,000
2010	12,044	2,502	1,619	16,164	64%	50,000	224,000	278,000
2011	18,306	3,141	2,209	23,655	70%	16,000	65,100	79,100
2012	13,594	1,606	1,412	16,612	78%	24,000	53,400	64,600
2013	15,979	4,271	3,272	23,522	62%	20,000	55,200	67,000
2014	14,373	3,104	1,971	19,447	81%	24,500	55,100	66,800
2015	11,681	1,444	1,488	14,614	92%	18,500	44,900	54,000
2016	8,164	4,234	987	13,384	85%	14,500	41,000	49,000
2017	12,782	2,744	965	16,491	88%	13,000	36,000	42,800
2018	15,340	4,174	3,826	23,340	91%	16,100	34,590	41,170

Year	Target Fishery					TAC	ABC	OFL
	Yellowfin Sole	Rock Sole	other	Total Catch	Total % Retained			
2019	12,954	1,561	1,736	16,251	96%	18,000	33,600	39,880
2020	16,595	2,482	1,001	20,078	93%	17,000	31,600	37,600
2021	11,798	1,631	2,432	15,862	92%	24,500	31,657	37,924
2022	9,732	830	691	11,253	92%	29,221	32,697	39,305
2023	11,871	2,589	792	15,252	93%	17,500	33,946	40,823
2024*	5,050	3,427	870	9,347	96%	21,752	35,494	42,695

*2024 catch as of October 5, 2024 , sourced October 8, 2024 from the NMFS Alaska Regional Office using the AKFIN database (http://www.akfin.org).

Table 10-2. Number of Alaska plaice lengths and otoliths collected from BSAI fishery.

Lengths			Ages		
Year	# hauls w/ lengths	# Lengths	Year	# Otoliths	# Otoliths Aged
1988	2	197	1982	253	0
1990	4	83	1983	200	0
1991	4	102	1984	327	0
1992	1	178	1985	2,044	0
1993	15	594	1986	1,681	0
1994	2	31	1987	761	0
1995	44	3,908	1988	953	0
1996	1	45	1999	5	0
1997	1	1	2000	167	159
1998	1	68	2001	99	0
1999	7	178	2002	96	93
2000	817	3,918	2003	140	135
2001	484	2,091	2004	115	0
2002	411	2,123	2005	108	0
2003	671	3,100	2006	198	0
2004	492	2,188	2007	232	0
2005	521	2,182	2008	380	0
2006	908	4,458	2009	443	0
2007	1,034	5,330	2010	398	0
2008	1,634	7,459	2011	686	0
2009	1,939	8,763	2012	600	0
2010	1,808	8,770	2013	787	0
2011	2,798	14,320	2014	714	0
2012	2,960	13,604	2015	577	0
2013	3,467	16,640	2016	581	0
2014	3,106	14,362	2017	667	0
2015	2,496	11,891	2018	1,155	0
2016	2,647	12,243	2019	988	0
2017	2,997	14,445	2020	739	0
2018	4,455	24,897	2021	751	0
2019	4,323	21,090	2022	515	0
2020	3,002	16,389	2023	546	0
2021	2,889	16,080			
2022	2,524	11,160			
2023	2,162	11,610			
2024	1,174	6,036			

Table 10-3. Non-commercial catches (t) of Alaska plaice in the BSAI,2010-2023.

Year	**NMFS area**										**Total Catch**
	519	**508**	**509**	**512**	**513**	**514**	**516**	**517**	**521**	**524**	
2010	0.001	0.029	1.426	1.433	2.664	13.744	1.418	0.184	0.571	6.170	27.641
2011	0.000	0.018	1.841	1.288	2.570	9.619	1.591	0.002	0.354	1.188	18.471
2012	0.000	0.022	1.410	1.401	3.552	9.950	1.299	0.120	0.635	1.759	20.147
2013	0.000	0.002	2.858	0.820	4.071	6.407	1.675	0.014	0.542	0.791	17.181
2014	0.000	0.005	1.487	0.990	3.614	6.113	0.957	0.003	0.700	1.661	15.529
2015	0.000	0.030	0.845	0.739	2.922	5.541	0.601	0.001	0.586	1.198	12.464
2016	0.000	0.024	1.259	0.831	3.715	4.686	0.556	0.009	1.848	1.993	14.923
2017	0.000	0.027	1.675	0.908	3.189	13.084	0.938	0.027	2.818	6.090	28.756
2018	0.000	0.018	1.561	0.542	3.334	5.864	0.664	0.010	3.839	3.593	19.425
2019	0.006	0.044	1.176	0.821	2.648	8.785	0.760	0.010	2.876	7.115	24.240
2021	0.000	0.083	0.741	0.987	1.842	10.471	1.198	0.027	0.745	6.829	22.924
2022	0.000	0.084	1.050	1.533	1.386	9.899	1.096	0.001	0.376	7.738	23.163
2023	0.000	0.049	0.783	1.232	1.027	6.480	1.064	0.009	0.180	2.121	12.945

Table 10-4. Estimated biomass, 95% confidence intervals and standard deviations (t) of Alaska plaice from the eastern Bering Sea shelf trawl survey, 1982-2024. No survey occurred in 2020 due to the coronavirus pandemic.

Year	Biomass (t)	Std. Deviation	Lower C.I.	Upper C.I.
1982	718,420	64,912	591,192	845,649
1983	652,948	58,814	537,672	768,223
1984	769,997	112,052	550,374	989,619
1985	580,591	60,908	461,211	699,971
1986	549,242	62,511	426,721	671,764
1987	547,322	55,834	437,888	656,757
1988	678,490	138,348	407,328	949,652
1989	515,627	57,213	403,490	627,764
1990	495,464	46,487	404,350	586,578
1991	535,064	50,429	436,223	633,906
1992	516,889	55,546	408,019	625,758
1993	517,222	50,676	417,897	616,548
1994	624,682	53,422	519,974	729,389
1995	555,314	63,058	431,721	678,908
1996	531,759	67,695	399,076	664,441
1997	632,026	71,700	491,495	772,557
1998	453,200	58,543	338,456	567,944
1999	480,448	40,339	401,383	559,514
2000	445,413	67,275	313,555	577,271
2001	542,820	68,437	408,684	676,957
2002	423,367	53,411	318,682	528,052
2003	460,515	96,742	270,901	650,129
2004	475,592	62,945	352,220	598,963
2005	497,036	55,199	388,846	605,226
2006	640,724	82,834	478,370	803,078
2007	423,047	37,504	349,539	496,555
2008	509,808	47,397	416,909	602,707
2009	531,465	50,501	432,483	630,446
2010	498,756	46,817	406,994	590,518
2011	520,548	73,054	377,362	663,733
2012	582,240	83,256	419,057	745,422
2013	506,261	65,694	377,501	635,021
2014	450,609	48,913	354,739	546,478
2015	355,149	38,723	279,253	431,046
2016	424,065	41,147	343,417	504,713
2017	491,174	52,445	388,381	593,967
2018	415,681	37,112	342,941	488,421
2019	358,710	28,767	302,327	415,093
2021	327,810	28,442	272,064	383,555
2022	376,806	42,125	294,241	459,371
2023	356,239	42,789	272,372	440,105
2024	338,621	36,840	266,415	410,828

Table 10-5. Number of Alaska plaice lengths and otoliths collected from NMFS Eastern Bering Sea Shelf bottom trawl survey. ISS is the input sample size determined through the general bootstrap framework implemented in the "surveyISS" Rpackage

Lengths				Ages			
Year	**# hauls w/ lengths**	**# Collected**	**ISS**	**Year**	**# hauls w/ otoliths**	**# Collected**	**ISS**
1982	152	14,274	2,303	1982	27	298	69
1983	118	11,624	1,740	1988	10	284	57
1984	151	14,026	1,630	1992	10	311	90
1985	168	10,913	1,817	1993	4	183	47
1986	236	12,349	1,614	1994	6	228	63
1987	172	8,533	1,477	1995	11	285	86
1988	170	7,079	715	1998	14	416	123
1989	207	7,741	1,487	2000	16	359	93
1990	215	7,739	1,346	2001	16	335	75
1991	235	8,162	1,585	2002	24	355	92
1992	219	7,583	1,186	2005	20	337	91
1993	240	8,344	1,833	2006	18	362	96
1994	248	9,299	2,036	2007	42	335	101
1995	252	9,917	2,013	2008	35	338	94
1996	254	10,183	1,570	2009	68	590	165
1997	248	10,143	2,179	2010	51	448	115
1998	281	10,101	1,904	2011	59	560	140
1999	268	13,024	3,211	2012	62	475	113
2000	249	9,761	1,401	2013	69	537	133
2001	261	10,990	1,671	2014	51	490	118
2002	249	8,251	1,577	2016	54	468	120
2003	250	8,216	1,302	2017	70	551	116
2004	262	8,570	1,661	2018	59	463	101
2005	262	9,284	1,774	2019	60	517	129
2006	255	12,067	1,725	2021	265	518	142
2007	260	11,630	1,748				
2008	252	12,804	2,093				
2009	233	13,545	2,877				
2010	225	11,366	2,001				
2011	235	11,263	1,702				
2012	240	10,399	1,326				
2013	221	9,705	1,357				
2014	215	7,296	1,377				
2015	222	5,988	1,233				
2016	250	6,310	1,623				
2017	258	8,062	1,667				
2018	280	12,035	2,188				
2019	276	8,957	1,977				
2021	275	8,518	1,770				
2022	252	8,070	1,782				
2023	242	7,080	1,316				
2024	202	8,010	1,563				

Table 10-6. All parameter values and standard deviations (std) from Base-3, Model 24.1, Model 24.1a and Model 24.1b. If the std is NA then the parameter was not estimated in that model.

	Base-3		Model 24.1		Model 24.1a		Model 24.1b	
Label	Value	std	Value	std	Value	std	Value	std
NatM_uniform_Fem_GP_1	0.13		0.13		0.13		0.13	
L_at_Amin_Fem_GP_1	2.00		10.89	1.4963	10.30	1.4468	10.21	1.4411
L_at_Amax_Fem_GP_1	50.0811		49.9535	0.4242	50.1421	0.4258	49.8838	0.4099
VonBert_K_Fem_GP_1	0.13262		0.14443	0.0080	0.14130	0.0076	0.14277	0.0075
CV_young_Fem_GP_1	0.13		0.13		0.13		0.13	
CV_old_Fem_GP_1	0.067		0.071		0.071		0.071	
Wtlen_1_Fem_GP_1	0.005499		0.008007		0.008007		0.008007	
Wtlen_2_Fem_GP_1	3.23350		3.13574		3.13574		3.13574	
Mat50%_Fem_GP_1	9.70203		9.70203		9.70203		9.70203	
Mat_slope_Fem_GP_1	-0.94271		-0.94271		-0.94271		-0.94271	
Eggs/kg_inter_Fem_GP_1	1.00		1.00		1.00		1.00	
Eggs/kg_slope_wt_Fem_GP_1	0.00		0.00		0.00		0.00	
NatM_uniform_Mal_GP_1	0.13		0.13		0.13		0.13	
L_at_Amin_Mal_GP_1	2.23149		14.64100	0.4174	15.54570	0.3895	15.54350	0.3758
L_at_Amax_Mal_GP_1	38.1449		37.6212	0.1835	37.8392	0.2039	37.7307	0.1981
VonBert_K_Mal_GP_1	0.18202		0.19278	0.0069	0.17405	0.0070	0.17638	0.0070
CV_young_Mal_GP_1	0.048		0.048		0.048		0.048	
CV_old_Mal_GP_1	0.048		0.069		0.069		0.069	
Wtlen_1_Mal_GP_1	0.012498		0.014695		0.014695		0.014695	
Wtlen_2_Mal_GP_1	2.98120		2.93648		2.93648		2.93648	
CohortGrowDev	1.00		1.00		1.00		1.00	
FracFemale_GP_1	0.50		0.50		0.50		0.50	
SR_LN(R0)	5.60568	0.0216	5.50995	0.0239	5.51426	0.0286	5.52271	0.0269
SR_BH_steep	1.00		1.00		1.00		1.00	
SR_sigmaR	1.00		1.00		1.00		0.42	
SR_regime	0.00		0.00		0.00		0.00	
SR_autocorr	0.00		0.00		0.00		0.00	
LnQ_base_Survey(2)	0.18232		0.18232		0.18232		0.18232	
Age_DblN_peak_Fishery(1)	13.6416	0.4401	12.9486	0.4837	13.2159	0.4695	13.0485	0.4655
Age_DblN_top_logit_Fishery(1)	30.00		30.00		30.00		30.00	
Age_DblN_ascend_se_Fishery(1)	3.09976	0.1253	2.87147	0.1432	2.88320	0.1347	2.85796	0.1367
Age_DblN_descend_se_Fishery(1)	8.00		8.00		8.00		8.00	
Age_DblN_start_logit_Fishery(1)	-1,003		-1,000		-1,000		-1,000	
Age_DblN_end_logit_Fishery(1)	999		999		999		999	
AgeSel_1Male_Peak_Fishery	3.12696	0.6672	3.91630	0.6523	4.53833	0.6583	4.57141	0.6796
AgeSel_1Male_Ascend_Fishery	0.703961	0.1642	0.917323	0.1642	1.006310	0.1571	1.033090	0.1620
AgeSel_1Male_Descend_Fishery	0.00		0.00		0.00		0.00	
AgeSel_1Male_Final_Fishery	0.00		0.00		0.00		0.00	
AgeSel_1Male_Scale_Fishery	1.00		1.00		1.00		1.00	
Age_DblN_peak_Survey(2)	10.0038	0.2242	9.7439	0.2483	9.9601	0.3367	9.9680	0.3441
Age_DblN_top_logit_Survey(2)	30.00		30.00		30.00		30.00	
Age_DblN_ascend_se_Survey(2)	2.4344	0.0966	2.2904	0.1137	2.2923	0.1486	2.3029	0.1502
Age_DblN_descend_se_Survey(2)	8.00		8.00		8.00		8.00	
Age_DblN_start_logit_Survey(2)	-1,003		-1,000		-1,000		-1,000	
Age_DblN_end_logit_Survey(2)	999		999		999		999	
AgeSel_2Male_Peak_Survey	-0.2104	0.2568	0.2538	0.2940	0.8640	0.3755	0.8317	0.3800
AgeSel_2Male_Ascend_Survey	-0.0372	0.1184	0.2192	0.1350	0.4568	0.1652	0.4530	0.1663
AgeSel_2Male_Descend_Survey	0.00		0.00		0.00		0.00	

Label	Base-3 Value	Base-3 std	Model 24.1 Value	Model 24.1 std	Model 24.1a Value	Model 24.1a std	Model 24.1b Value	Model 24.1b std
AgeSel_2Male_Final_Survey	0.00		0.00		0.00		0.00	
AgeSel_2Male_Scale_Survey	1.00		1.00		1.00		1.00	

Table 10-7. Time series of predicted total biomass, spawning stock biomass, and associated standard deviations from Base-3, Model 24.1, Model 24.1a and Model 24.1b. "Tot Bio" is total biomass for ages 3+, SSB is the spawning stock biomass, and std is the standard deviation of spawning stock biomass.

	Base-3			Model 24.1			Model 24.1a			Model 24.1b		
Year	Tot Bio	SSB	std	Tot Bio	SSB	std	Tot Bio	SSB	std	Tot Bio	SSB	std
1975	395,335	85,122	8,731	341,856	82,331.3	10,128	319,709	80,020.9	10,006	409,811	149,928	11,305
1976	443,204	102,275	8,327	389,835	94,470.2	9,873	369,255	89,537.0	9,911	447,566	155,856	11,032
1977	501,445	130,985	8,233	442,368	116,926.0	10,187	430,835	108,184.0	10,529	497,794	167,472	11,131
1978	552,647	169,942	8,487	496,169	149,939.0	11,038	492,546	137,738.0	11,723	548,850	187,374	11,659
1979	592,486	205,656	8,800	541,177	181,670.0	11,837	544,775	167,716.0	12,713	591,508	207,539	12,322
1980	626,039	233,565	9,001	579,632	207,447.0	12,270	588,607	193,893.0	13,214	626,878	226,532	12,766
1981	658,576	258,771	8,996	617,944	231,709.0	12,311	629,980	220,987.0	13,363	661,206	248,698	12,911
1982	684,404	279,512	8,803	646,981	252,811.0	12,003	660,189	248,295.0	13,283	685,371	271,481	12,852
1983	707,289	302,230	8,507	670,021	277,494.0	11,474	682,604	282,420.0	13,010	702,741	300,770	12,534
1984	723,108	322,817	8,223	682,985	301,698.0	10,857	693,674	315,634.0	12,359	709,384	329,360	11,908
1985	719,345	335,205	8,011	679,793	318,053.0	10,225	687,567	336,209.0	11,445	700,027	346,261	11,129
1986	704,695	338,058	7,819	664,776	323,573.0	9,581	670,018	340,395.0	10,574	679,951	347,782	10,359
1987	668,366	321,617	7,637	626,114	307,892.0	8,982	630,149	320,324.0	9,857	637,891	325,955	9,691
1988	655,689	319,741	7,444	612,448	305,187.0	8,529	615,851	313,603.0	9,335	622,076	317,955	9,194
1989	598,762	287,861	7,245	555,945	271,907.0	8,088	559,810	276,313.0	8,844	564,817	279,792	8,723
1990	596,405	286,532	7,042	549,791	269,055.0	7,753	554,530	270,866.0	8,466	558,412	273,458	8,356
1991	592,642	285,372	6,844	546,362	266,972.0	7,453	551,312	267,110.0	8,134	554,475	269,033	8,033
1992	588,503	279,054	6,632	541,013	260,677.0	7,157	546,125	260,348.0	7,817	548,567	261,857	7,725
1993	580,121	269,509	6,394	533,904	252,027.0	6,846	538,973	252,504.0	7,496	540,840	253,710	7,416
1994	580,986	263,188	6,168	534,200	247,075.0	6,572	538,754	249,169.0	7,244	540,010	250,020	7,174
1995	583,842	260,053	5,972	538,848	245,370.0	6,353	542,157	249,078.0	7,063	542,842	249,572	6,996
1996	579,311	253,626	5,813	536,686	240,071.0	6,183	538,627	244,562.0	6,925	538,552	244,742	6,857
1997	573,490	251,172	5,713	536,006	238,474.0	6,103	536,146	242,813.0	6,893	535,575	242,722	6,819
1998	561,583	246,832	5,659	528,193	234,810.0	6,088	526,546	238,240.0	6,938	525,629	237,943	6,855
1999	555,065	247,891	5,630	524,333	236,666.0	6,106	521,041	239,121.0	7,033	520,040	238,574	6,940
2000	547,891	250,304	5,626	518,077	239,956.0	6,149	513,343	241,401.0	7,171	512,439	240,500	7,066
2001	540,255	252,802	5,646	509,891	243,266.0	6,210	504,278	243,716.0	7,331	503,535	242,381	7,211
2002	538,665	257,999	5,678	507,011	249,135.0	6,277	501,166	248,737.0	7,471	500,602	246,953	7,337
2003	533,835	257,611	5,679	501,075	249,306.0	6,301	495,655	248,215.0	7,535	495,246	246,223	7,389
2004	538,617	255,329	5,628	501,720	247,374.0	6,266	497,883	245,682.0	7,525	497,265	243,791	7,374
2005	551,448	251,884	5,517	510,551	244,013.0	6,158	509,253	241,704.0	7,440	507,925	240,189	7,288
2006	554,466	246,079	5,380	517,369	238,017.0	6,008	518,180	235,117.0	7,313	516,199	234,043	7,165
2007	552,753	237,715	5,241	519,724	229,374.0	5,840	523,338	226,244.0	7,165	520,442	225,503	7,025
2008	548,417	230,664	5,129	519,802	222,178.0	5,689	526,271	219,523.0	7,037	522,330	218,851	6,902
2009	541,192	228,111	5,054	518,593	219,777.0	5,577	527,509	218,391.0	6,951	522,955	217,506	6,818
2010	535,545	231,872	5,039	516,880	224,007.0	5,529	527,914	224,540.0	6,920	523,009	223,086	6,782
2011	522,903	237,959	5,115	507,685	230,885.0	5,578	520,383	233,807.0	6,972	515,717	231,447	6,817
2012	504,338	239,272	5,273	488,619	233,254.0	5,720	502,684	238,714.0	7,099	498,084	235,395	6,925
2013	488,830	241,205	5,423	473,463	236,348.0	5,858	488,241	244,181.0	7,169	483,998	240,101	6,988
2014	463,093	233,791	5,506	448,580	229,996.0	5,908	463,727	239,412.0	7,060	460,234	234,972	6,883
2015	441,869	225,192	5,531	426,310	222,232.0	5,897	441,762	232,393.0	6,889	439,074	228,017	6,715
2016	423,851	216,713	5,501	407,176	214,238.0	5,831	422,818	224,415.0	6,697	421,431	220,559	6,527
2017	417,030	207,245	5,431	392,782	204,897.0	5,716	407,879	214,623.0	6,473	406,965	211,574	6,314
2018	407,135	195,763	5,359	378,312	193,191.0	5,586	391,358	202,219.0	6,225	391,108	199,893	6,082
2019	400,987	180,585	5,322	364,952	177,539.0	5,493	374,273	185,948.0	6,029	373,785	184,170	5,894
2020	399,357	170,415	5,332	362,674	166,758.0	5,466	368,858	174,872.0	5,951	367,853	173,588	5,804
2021	400,334	158,043	5,364	362,880	153,456.0	5,470	365,408	161,347.0	5,943	363,261	160,767	5,780
2022	419,804	150,666	5,498	375,327	144,780.0	5,564	376,001	152,031.0	6,051	369,657	152,085	5,860
2023	437,036	150,909	5,888	394,426	143,340.0	5,884	392,713	148,956.0	6,369	382,373	149,163	6,120
2024	450,583	154,571	6,697	410,452	145,108.0	6,590	407,097	147,754.0	7,016	392,486	147,511	6,657

Table 10-8. Age-0 recruitment estimates and their standard deviations from Base-3, Model 24.1, Model 24.1a and Model 24.1bs. REC is the age-0 recruitment, and std is the standard deviation of age-0 recruitment.

	Base-3		**Model 24.1**		**Model 24.1a**		**Model 24.1b**	
Year	**REC**	**std**	**REC**	**std**	**REC**	**std**	**REC**	**std**
1975	456,422	57,555	477,793	96,261	434,110	159,520	423,883	139,983
1976	421,948	47,705	409,100	73,985	329,039	101,203	330,912	87,958
1977	428,706	41,780	360,765	57,810	292,449	75,879	288,260	66,007
1978	289,848	31,700	239,765	41,702	202,373	55,988	215,093	49,498
1979	318,624	30,817	266,740	39,334	244,371	53,490	244,152	48,095
1980	338,269	30,536	273,622	37,786	249,262	51,898	249,767	47,258
1981	397,094	31,690	335,084	39,246	315,087	54,486	303,111	50,063
1982	166,907	20,807	157,065	27,805	159,746	42,095	178,387	38,928
1983	192,017	21,462	192,564	29,550	216,544	46,870	222,819	43,308
1984	337,100	27,362	321,190	36,341	367,771	58,218	354,399	54,496
1985	207,421	21,665	197,693	29,349	228,041	49,072	236,182	45,813
1986	270,386	24,560	261,907	32,631	284,227	51,560	284,358	48,543
1987	424,876	30,381	377,990	37,427	371,995	54,168	364,709	51,777
1988	239,957	23,146	220,772	28,645	205,790	41,390	216,805	39,575
1989	373,698	28,166	342,053	34,010	334,485	49,390	331,197	47,385
1990	301,233	25,062	290,906	30,965	305,286	47,337	305,414	45,421
1991	432,130	29,177	392,457	34,817	379,574	51,250	373,017	49,231
1992	333,773	25,411	305,292	30,685	296,633	46,816	294,733	44,415
1993	338,838	25,262	312,135	30,496	317,542	47,654	307,985	44,666
1994	174,348	18,138	163,597	22,234	161,920	35,829	173,200	33,331
1995	200,520	19,014	181,362	22,451	167,345	34,563	175,160	32,180
1996	197,801	18,614	172,951	21,515	164,701	34,758	173,539	32,472
1997	233,917	20,005	206,905	23,315	201,049	39,781	205,830	37,116
1998	272,653	21,549	248,832	25,510	260,571	46,363	260,120	43,544
1999	286,539	22,182	265,367	26,350	290,696	49,830	289,611	47,132
2000	296,056	22,738	276,309	26,967	304,279	51,736	303,498	49,151
2001	490,632	29,609	451,375	34,694	490,098	65,548	475,364	62,776
2002	561,937	32,145	528,364	37,897	582,739	71,642	560,051	68,494
2003	226,624	20,762	217,420	24,935	247,723	50,549	251,608	47,072
2004	272,994	22,966	262,687	27,500	290,603	53,333	283,707	48,957
2005	256,123	22,348	246,351	26,668	253,155	48,158	246,459	43,541
2006	122,885	15,501	118,352	18,635	118,446	32,482	136,631	30,022
2007	158,833	17,617	146,211	20,407	137,661	33,631	147,304	30,300
2008	104,799	14,585	97,571	16,996	98,304	29,356	118,414	27,030
2009	255,602	23,857	225,879	26,589	222,785	44,413	206,317	37,792
2010	148,074	19,373	136,588	22,195	145,613	39,636	149,539	33,118
2011	98,804	17,253	88,910	19,273	103,474	35,800	122,383	30,281
2012	155,860	23,919	129,751	25,007	140,075	42,921	144,357	34,441
2013	119,840	23,573	98,644	23,888	109,062	41,097	132,949	34,585
2014	438,510	48,828	357,243	47,166	307,340	63,910	270,681	53,216
2015	310,514	48,204	265,363	47,607	225,684	66,381	234,702	56,792
2016	525,049	76,059	455,180	74,946	387,298	97,186	356,525	80,464
2017	241,369	80,211	220,743	84,407	308,708	115,413	301,400	87,982
2018	368,707	115,526	377,258	116,578	357,083	130,777	337,114	99,613
2019	691,105	191,495	538,166	160,171	596,478	179,951	449,756	128,896
2020	271,966	5,887	247,140	5,905	248,207	7,101	250,312	6,724
2021	271,966	5,887	247,140	5,905	248,207	7,101	250,312	6,724
2022	271,966	5,887	247,140	5,905	248,207	7,101	250,312	6,724
2023	271,966	5,887	247,140	5,905	248,207	7,101	250,312	6,724
2024	271,966	5,887	247,140	5,905	248,207	7,101	250,312	6,724

Table 10-9. Estimated yearly fishing mortality with corresponding standard deviations from Base-3, Model 24.1, Model 24.1a and Model 24.1bs. F is the fishing mortality, and std is the standard deviation of fishing mortality.

	Base-3		Model 24.1		Model 24.1a		Model 24.1b	
Year	**F**	**std**	**F**	**std**	**F**	**std**	**F**	**std**
1975	0.01926	0.00193	0.01969	0.00225	0.02151	0.00256	0.01188	0.00091
1976	0.02399	0.00206	0.02472	0.00249	0.02774	0.00294	0.01647	0.00119
1977	0.01422	0.00108	0.01466	0.00133	0.01679	0.00159	0.01095	0.00075
1978	0.04736	0.00327	0.04873	0.00406	0.05625	0.00490	0.04041	0.00264
1979	0.05270	0.00335	0.05419	0.00414	0.06221	0.00503	0.04859	0.00306
1980	0.02297	0.00131	0.02369	0.00160	0.02669	0.00195	0.02225	0.00132
1981	0.02540	0.00127	0.02629	0.00155	0.02885	0.00185	0.02520	0.00137
1982	0.01812	0.00080	0.01875	0.00098	0.02002	0.00113	0.01806	0.00090
1983	0.02649	0.00106	0.02726	0.00130	0.02835	0.00146	0.02619	0.00120
1984	0.04427	0.00165	0.04513	0.00200	0.04584	0.00219	0.04315	0.00187
1985	0.05632	0.00200	0.05697	0.00236	0.05685	0.00252	0.05432	0.00222
1986	0.10603	0.00366	0.10701	0.00418	0.10591	0.00430	0.10228	0.00387
1987	0.04288	0.00142	0.04349	0.00158	0.04310	0.00159	0.04195	0.00146
1988	0.14856	0.00484	0.15210	0.00544	0.15193	0.00553	0.14849	0.00518
1989	0.03573	0.00116	0.03697	0.00132	0.03724	0.00136	0.03649	0.00128
1990	0.02761	0.00086	0.02884	0.00099	0.02924	0.00103	0.02873	0.00098
1991	0.03817	0.00115	0.04019	0.00134	0.04097	0.00141	0.04032	0.00134
1992	0.04691	0.00139	0.04974	0.00164	0.05085	0.00173	0.05011	0.00165
1993	0.03677	0.00107	0.03914	0.00127	0.04002	0.00136	0.03946	0.00130
1994	0.02923	0.00084	0.03111	0.00101	0.03172	0.00108	0.03128	0.00103
1995	0.05294	0.00153	0.05612	0.00187	0.05708	0.00199	0.05629	0.00191
1996	0.04552	0.00135	0.04797	0.00165	0.04870	0.00175	0.04805	0.00168
1997	0.06131	0.00186	0.06424	0.00227	0.06523	0.00240	0.06441	0.00230
1998	0.04181	0.00130	0.04351	0.00160	0.04433	0.00169	0.04379	0.00162
1999	0.04087	0.00130	0.04225	0.00157	0.04323	0.00168	0.04275	0.00161
2000	0.04218	0.00134	0.04335	0.00162	0.04456	0.00176	0.04412	0.00168
2001	0.02502	0.00079	0.02557	0.00096	0.02639	0.00105	0.02615	0.00101
2002	0.03470	0.00108	0.03537	0.00129	0.03657	0.00144	0.03631	0.00138
2003	0.02800	0.00085	0.02855	0.00100	0.02955	0.00113	0.02939	0.00109
2004	0.02237	0.00065	0.02289	0.00076	0.02370	0.00088	0.02360	0.00085
2005	0.03198	0.00089	0.03289	0.00105	0.03407	0.00122	0.03392	0.00119
2006	0.05067	0.00138	0.05232	0.00164	0.05428	0.00193	0.05397	0.00188
2007	0.05908	0.00162	0.06109	0.00197	0.06351	0.00231	0.06303	0.00224
2008	0.05403	0.00153	0.05577	0.00186	0.05800	0.00216	0.05747	0.00209
2009	0.04376	0.00128	0.04492	0.00157	0.04662	0.00179	0.04616	0.00172
2010	0.05057	0.00154	0.05147	0.00188	0.05316	0.00210	0.05268	0.00202
2011	0.07413	0.00238	0.07471	0.00286	0.07663	0.00313	0.07607	0.00300
2012	0.05201	0.00172	0.05198	0.00203	0.05282	0.00219	0.05260	0.00210
2013	0.07387	0.00247	0.07351	0.00281	0.07389	0.00301	0.07385	0.00290
2014	0.06219	0.00204	0.06194	0.00224	0.06157	0.00239	0.06177	0.00231
2015	0.04774	0.00150	0.04775	0.00163	0.04703	0.00172	0.04730	0.00168
2016	0.04491	0.00137	0.04510	0.00151	0.04419	0.00156	0.04445	0.00154
2017	0.05758	0.00175	0.05815	0.00190	0.05675	0.00195	0.05702	0.00193
2018	0.08695	0.00269	0.08835	0.00293	0.08599	0.00296	0.08623	0.00292
2019	0.06488	0.00210	0.06631	0.00229	0.06449	0.00227	0.06447	0.00224
2020	0.08539	0.00292	0.08785	0.00320	0.08551	0.00313	0.08522	0.00306
2021	0.07144	0.00262	0.07404	0.00287	0.07230	0.00280	0.07180	0.00272
2022	0.05211	0.00203	0.05438	0.00225	0.05353	0.00220	0.05301	0.00212
2023	0.07124	0.00303	0.07448	0.00342	0.07450	0.00333	0.07361	0.00318
2024	0.06354	0.00302	0.06620	0.00347	0.06766	0.00341	0.06690	0.00321

Table 10-10. Projected spawning stock biomass in tons for the seven harvest scenarios listed in the "Harvest Recommendations" section

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2024	147,511	147,511	147,511	147,511	147,511	147,511	147,511
2025	150,892	150,892	150,892	150,892	150,892	150,892	150,892
2026	148,177	148,177	156,878	152,393	165,871	144,620	148,177
2027	148,209	148,209	164,842	156,143	183,086	141,697	148,209
2028	149,721	149,721	173,659	160,973	201,420	140,717	146,211
2029	150,949	150,949	181,649	165,182	219,154	139,821	144,360
2030	149,920	149,920	186,730	166,764	233,964	137,030	140,699
2031	146,510	146,510	188,571	165,516	245,173	132,263	135,176
2032	142,180	142,180	188,498	162,851	253,796	126,988	129,268
2033	137,960	137,960	187,561	159,833	260,703	122,182	123,948
2034	134,320	134,320	186,388	157,023	266,512	118,220	119,576
2035	131,197	131,197	185,037	154,430	271,269	115,018	116,005
2036	128,624	128,624	183,714	152,172	275,280	112,914	113,528
2037	126,529	126,529	182,470	150,240	278,667	111,570	111,939

Table 10-11. Projected catch in tons for the seven harvest scenarios listed in the "Harvest Recommendations" section

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2024	13,755	13,755	13,755	13,755	13,755	13,755	13,755
2025	28,745	28,745	14,557	21,857	0	34,576	28,745
2026	28,230	28,230	15,056	22,018	0	33,222	28,230
2027	28,191	28,191	15,721	22,469	0	32,572	33,924
2028	28,367	28,367	16,439	23,032	0	32,274	33,411
2029	28,518	28,518	17,099	23,533	0	32,019	32,959
2030	28,453	28,453	17,600	23,828	0	31,570	32,332
2031	28,097	28,097	17,892	23,852	0	30,842	31,451
2032	27,493	27,493	17,974	23,625	0	29,900	30,379
2033	26,815	26,815	17,933	23,280	0	28,944	29,317
2034	26,182	26,182	17,844	22,919	0	28,020	28,387
2035	25,612	25,612	17,724	22,565	0	26,576	27,007
2036	25,115	25,115	17,589	22,235	0	25,616	25,879
2037	24,700	24,700	17,456	21,942	0	24,992	25,148

Table 10-12. Projected fishing mortality for the seven harvest scenarios listed in the "Harvest Recommendations" section

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2024	0.067	0.067	0.067	0.067	0.067	0.067	0.067
2025	0.141	0.141	0.070	0.106	0.000	0.172	0.141
2026	0.141	0.141	0.070	0.106	0.000	0.172	0.141
2027	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2028	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2029	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2030	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2031	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2032	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2033	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2034	0.141	0.141	0.070	0.106	0.000	0.172	0.172
2035	0.141	0.141	0.070	0.106	0.000	0.167	0.168
2036	0.141	0.141	0.070	0.106	0.000	0.163	0.164
2037	0.141	0.141	0.070	0.106	0.000	0.161	0.162

Figures

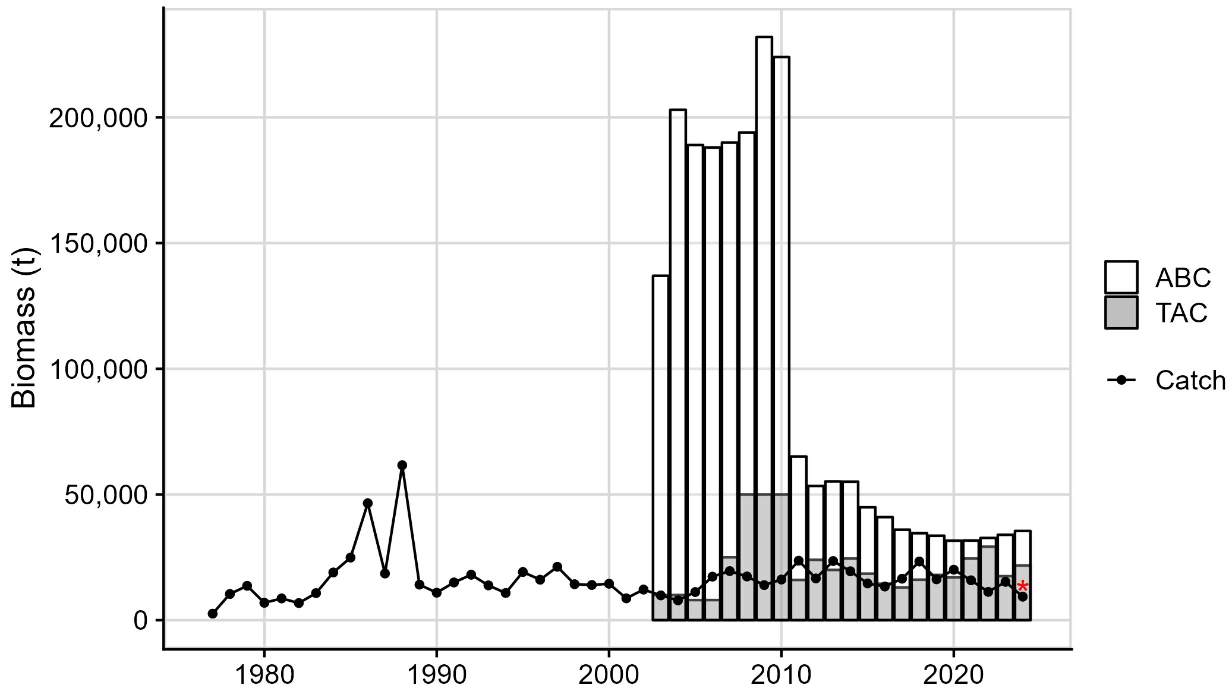

Figure 10-1. Alaska plaice catch, ABC and TAC from 1977-2024, with the projected 2024 catch estimate shown as a red asterisk. Data reflect catch posted through October 5, 2024 (sourced October 8, 2024 from the NMFS Alaska Regional Office using the AKFIN database [http://www.akfin.org])).

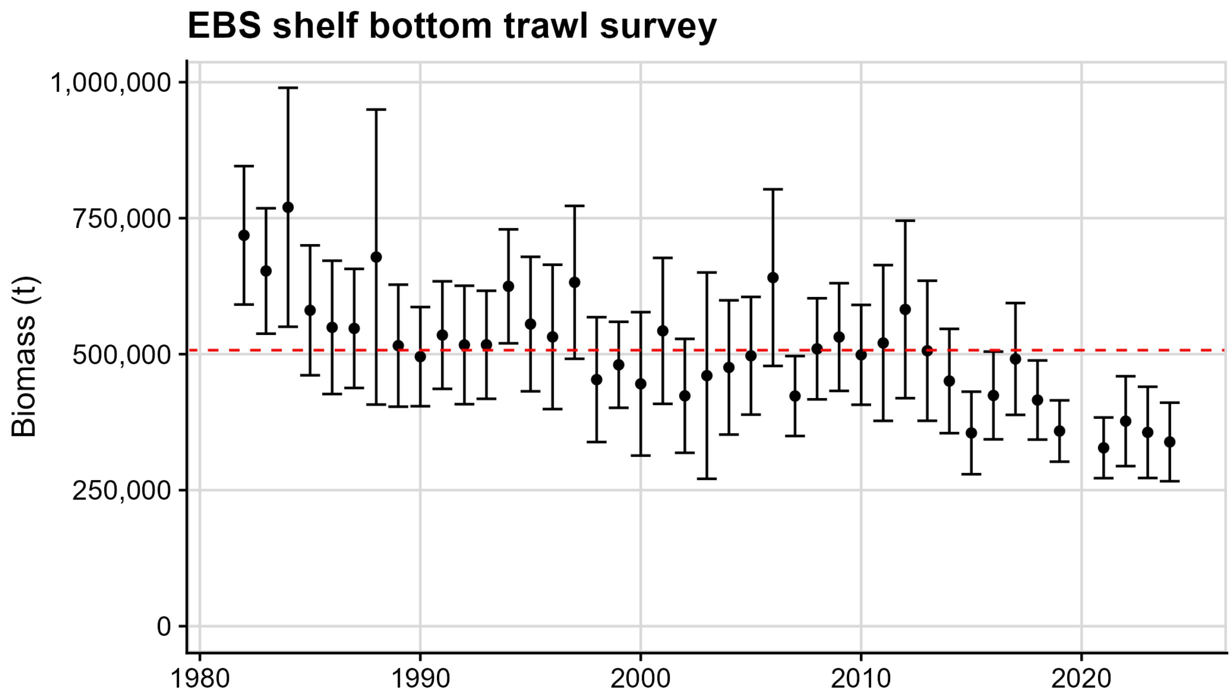

Figure 10-2. Alaska plaice biomass estimates from the EBS shelf trawl survey using the standard grid (no Northern EBS), 1982-2024. No survey was conducted in 2020 due to the COVID-19 pandemic. Data, sourced from the AKFIN database, may differ slightly from previous assessments due to minor modification in the strata definitions. The 1982-2024 long-term average biomass (507,313 t) is shown in the horizontal dashed red line.

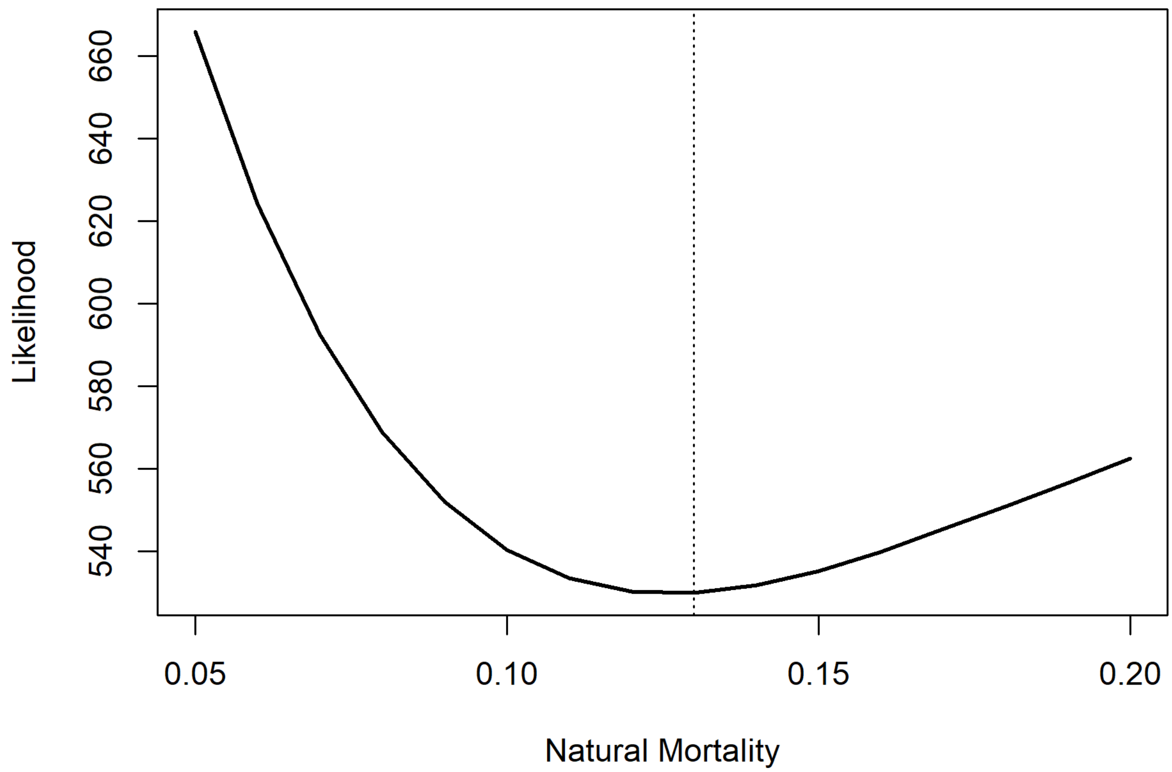

Figure 10-3. Likelihood profile of non-sex specific natural mortality in Model 24.1b. The dotted line indicates the location of 0.13 on the x-axis.

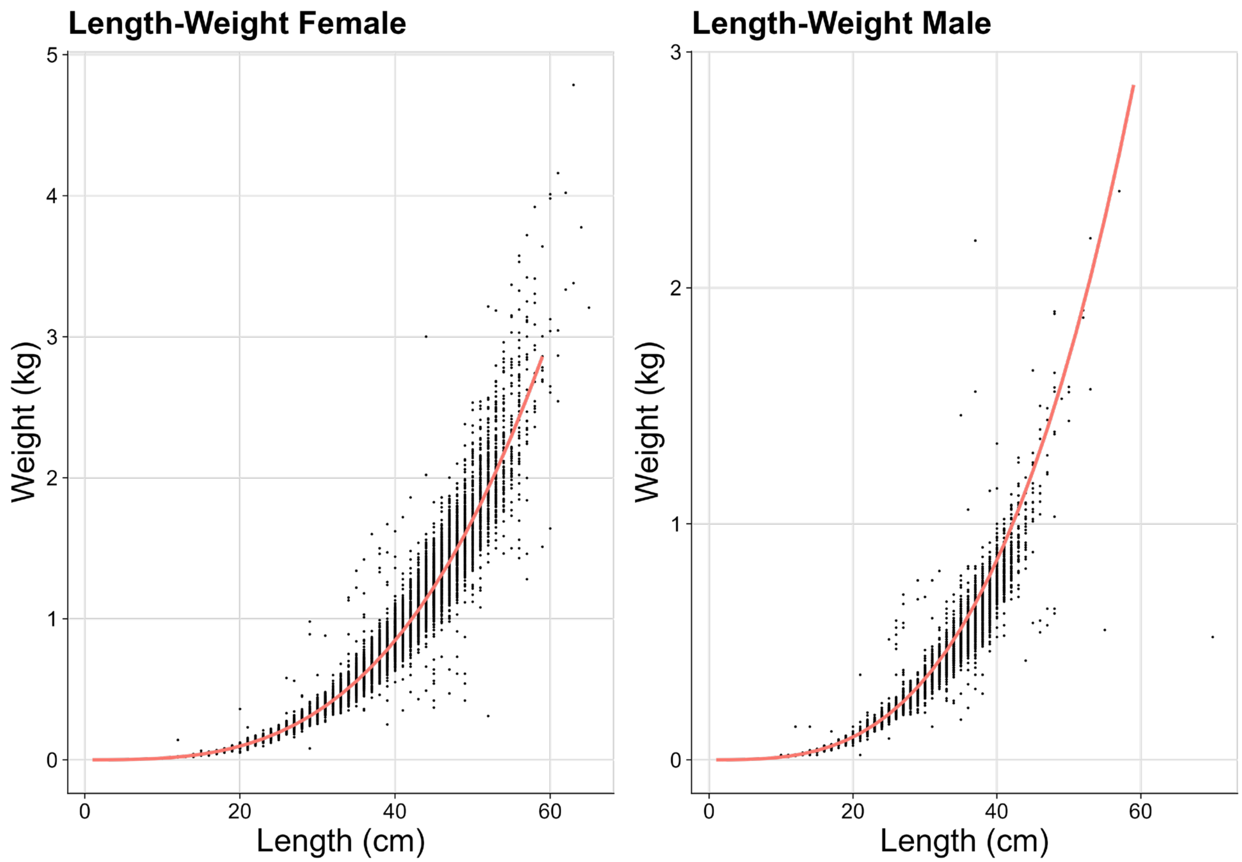

Figure 10-4. Fits to the weight-at-length data from both the survey and fishery. The red line is the fitted weight-at-length curve.

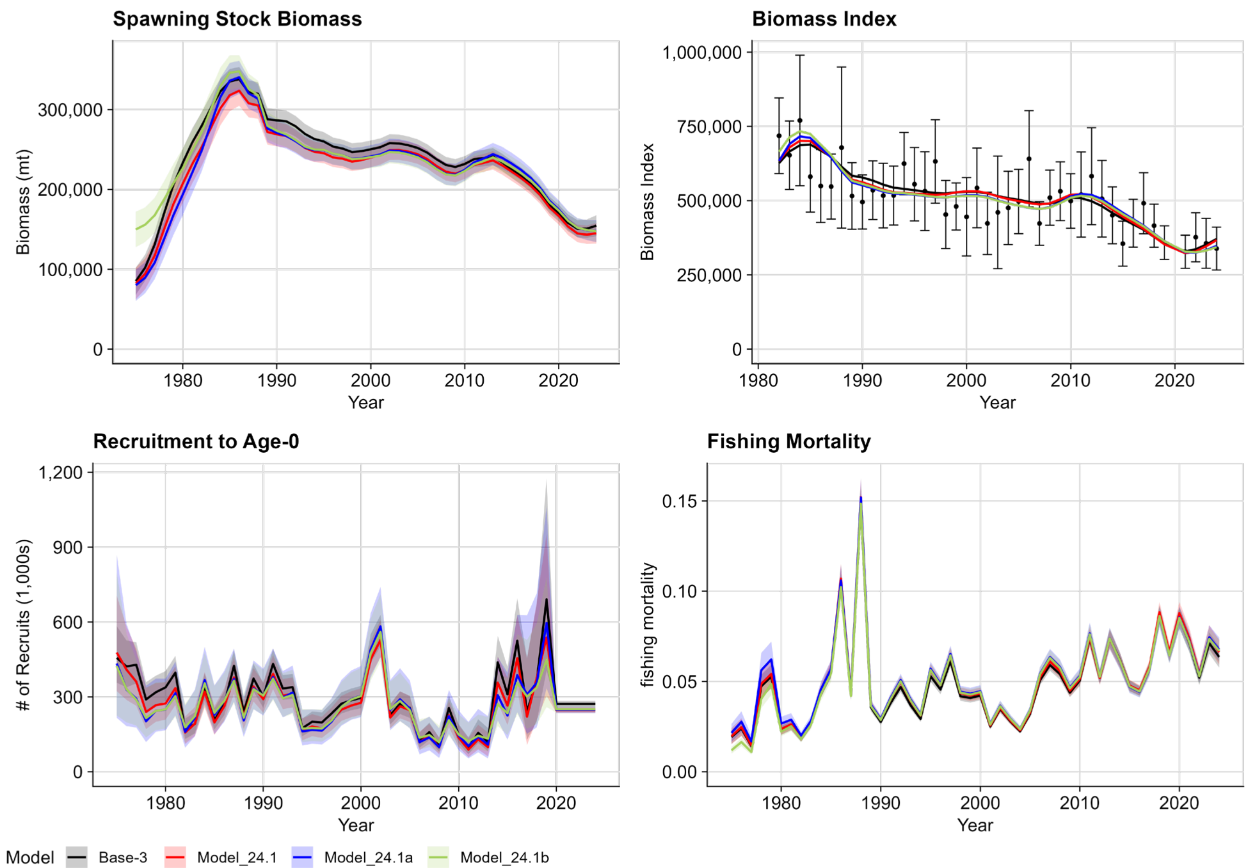

Figure 10-5. A comparison of spawning biomass (top-left), biomass index (top-right), recruits to age-0 (bottom-left) and fishing mortality (bottom-right) between Base-3 (red), Model 24.1 (green), Model 24.1a (blue) and Model 24.1b (purple).

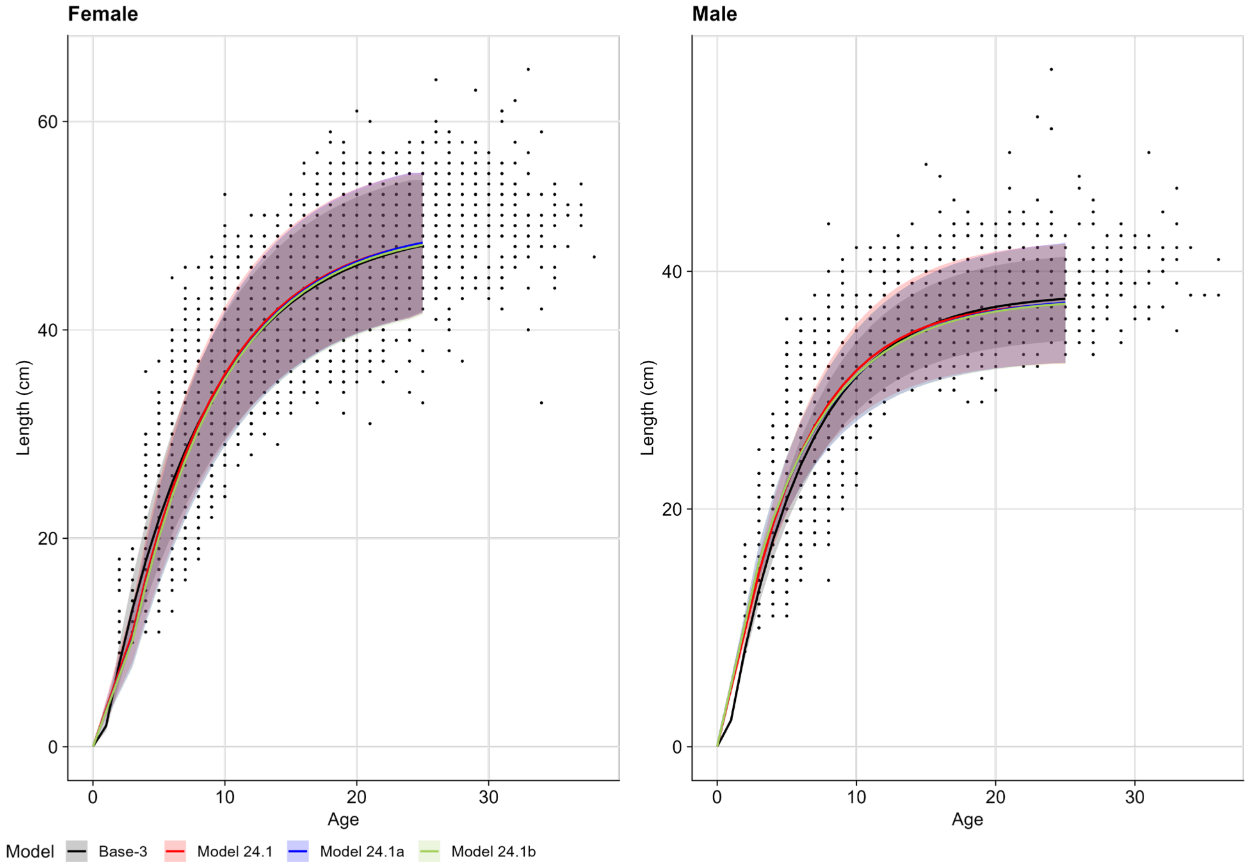

Figure 10-6. A comparison of the sex specific length-at-age between Base-3 (red), Model 24.1 (green), Model 24.1a (blue) and Model 24.1b (purple). The dots are the actual length-at-age data from the fishery (1999-2024) and survey (1982, 1988, 1992-1995, 1998, 2000-2002, 2005-2014, 2016-2019, 2021). Note that the length-at-age data was not used to estimate the length-at-age curve with SS3.

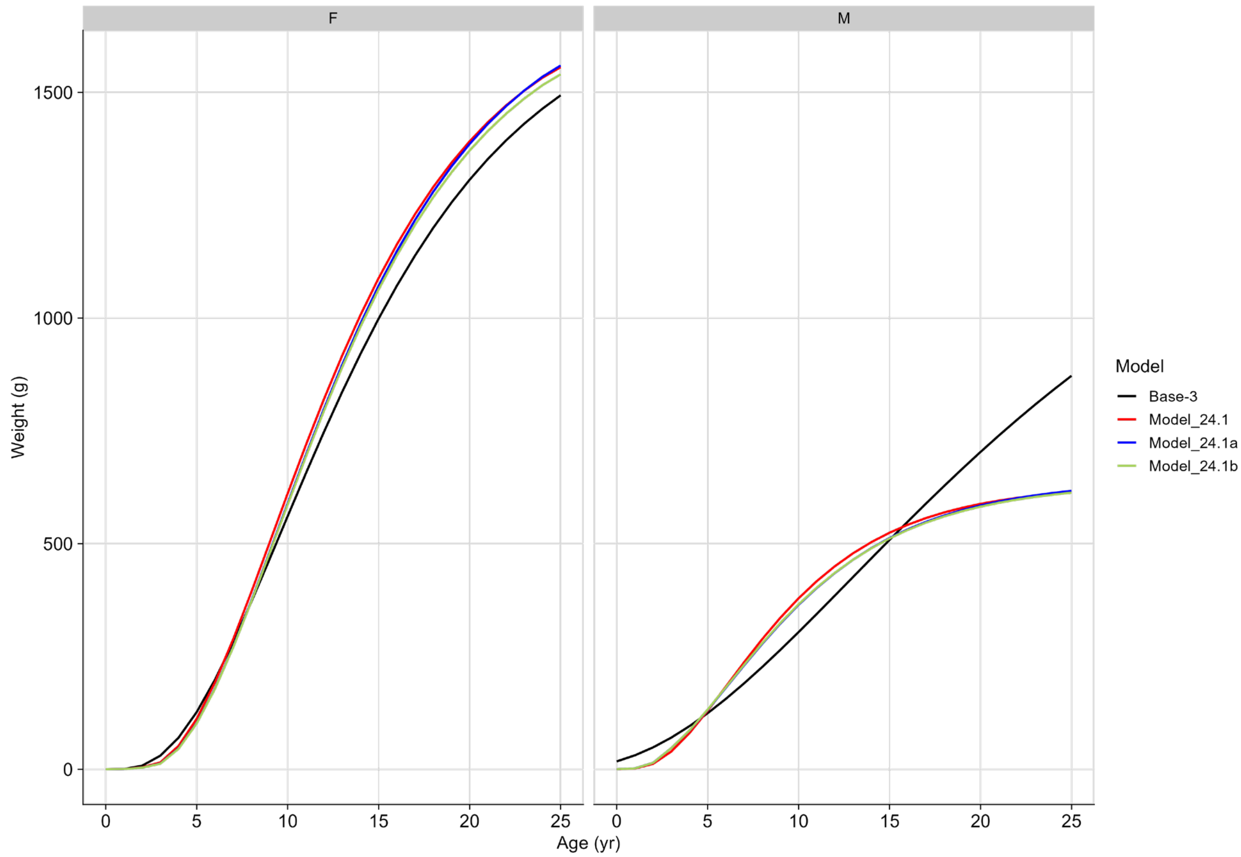

Figure 10-7. A comparison of the sex specific weight-at-age between Base-3 (red), Model 24.1 (green), Model 24.1a (blue) and Model 24.1b (purple).

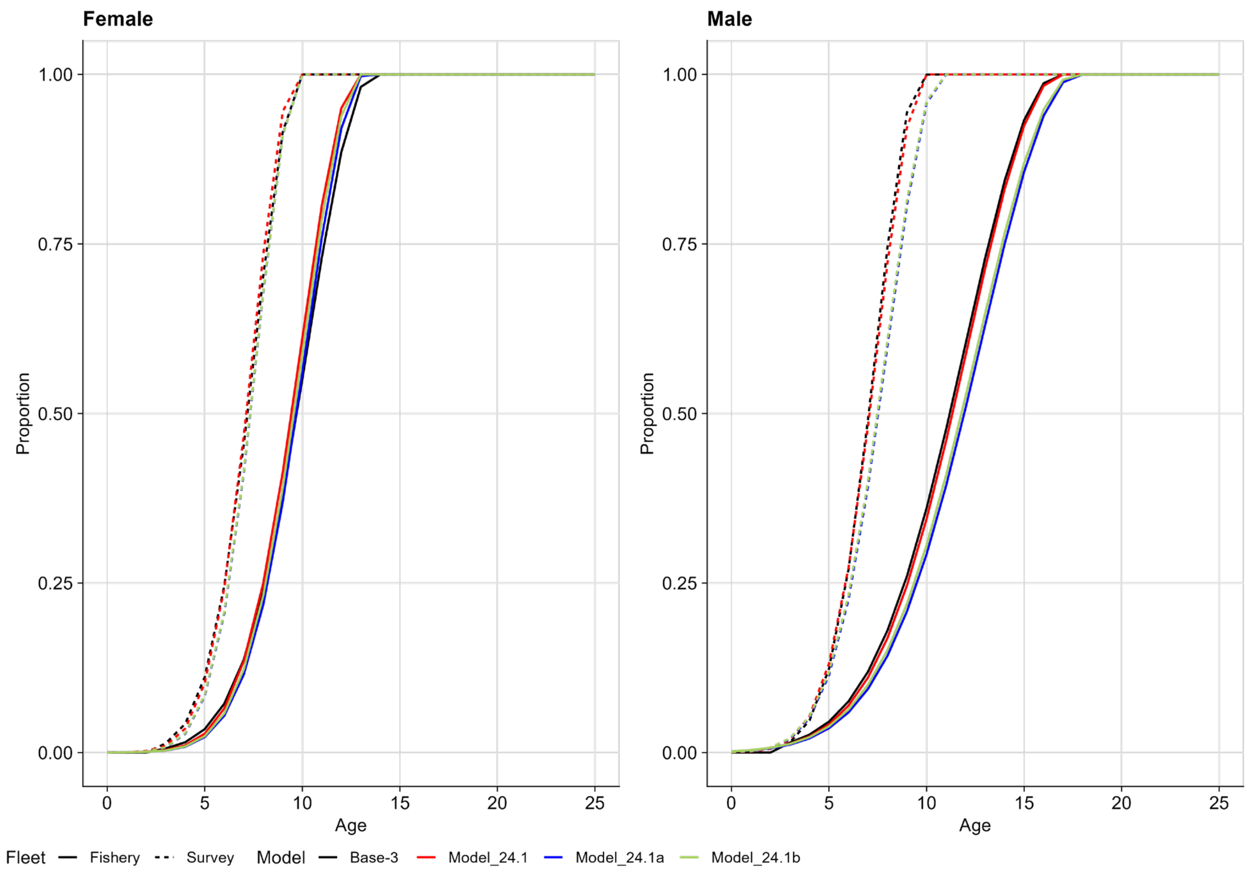

Figure 10-8. A comparison of the fleet and sex-specific selectivity curves used in Base-3 (red), Model 24.1 (green), Model 24.1a (blue) and Model 24.1b (purple). The line type indicates the fleet (solid = Fishery, dashed = Survey)

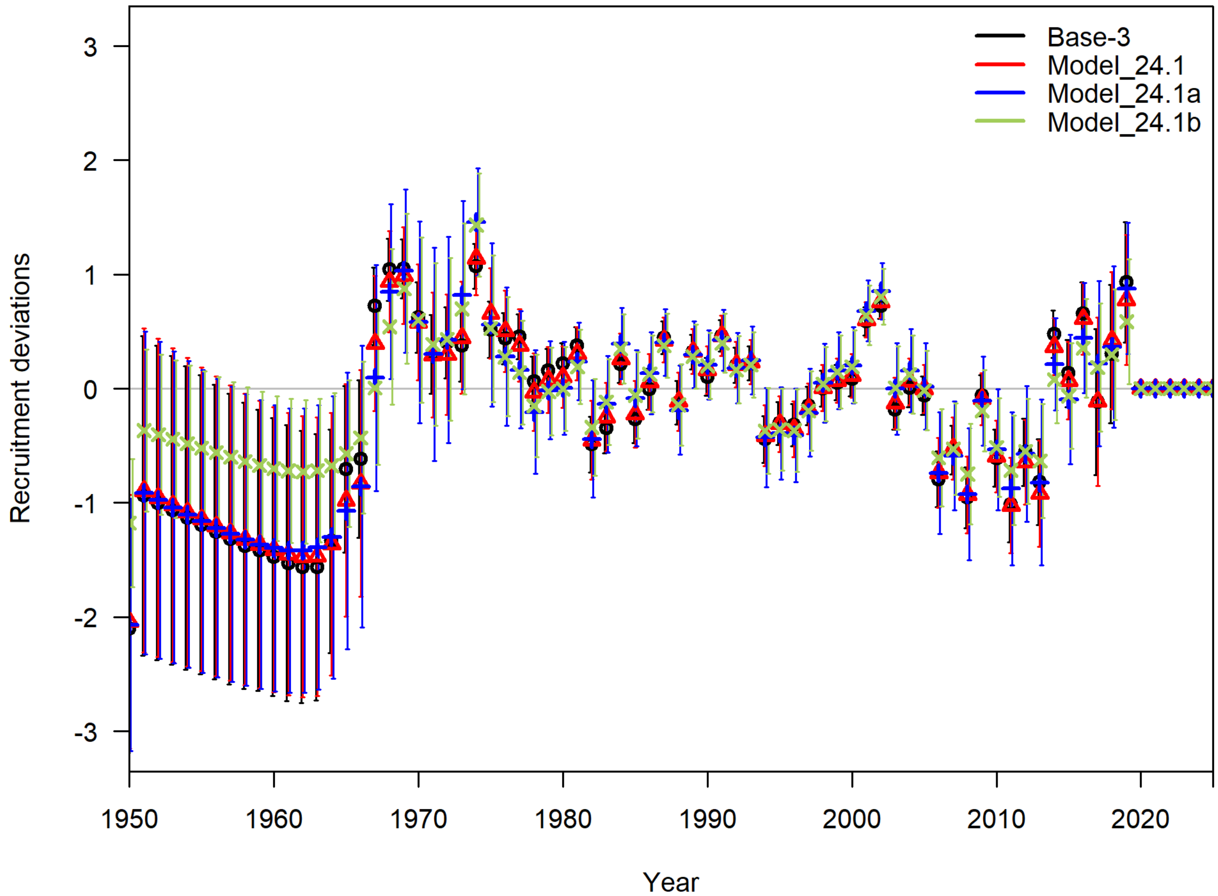

Figure 10-9. A comparison of the estimate recruitment deviations between Base-3 (black), Model 24.1 (red), Model 24.1a (blue) and Model 24.1b (green).

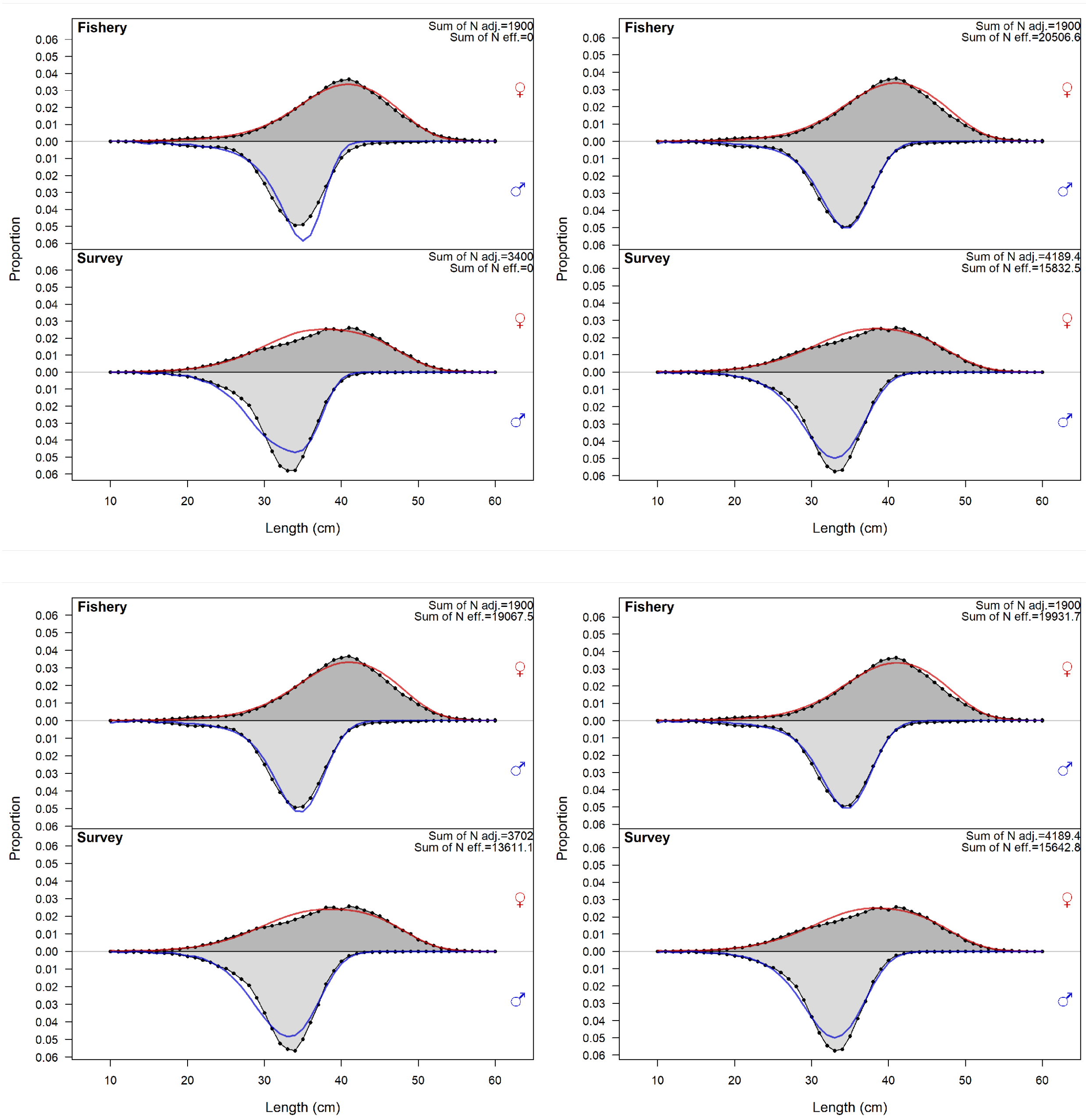

Figure 10-10. A comparison of fits to the sex and fleet specific aggregated length-composition data between Base-3 (top-left), Model 24.1 (bottom-left), Model 24.1a (top-right) and Model 24.1b (bottom-right).

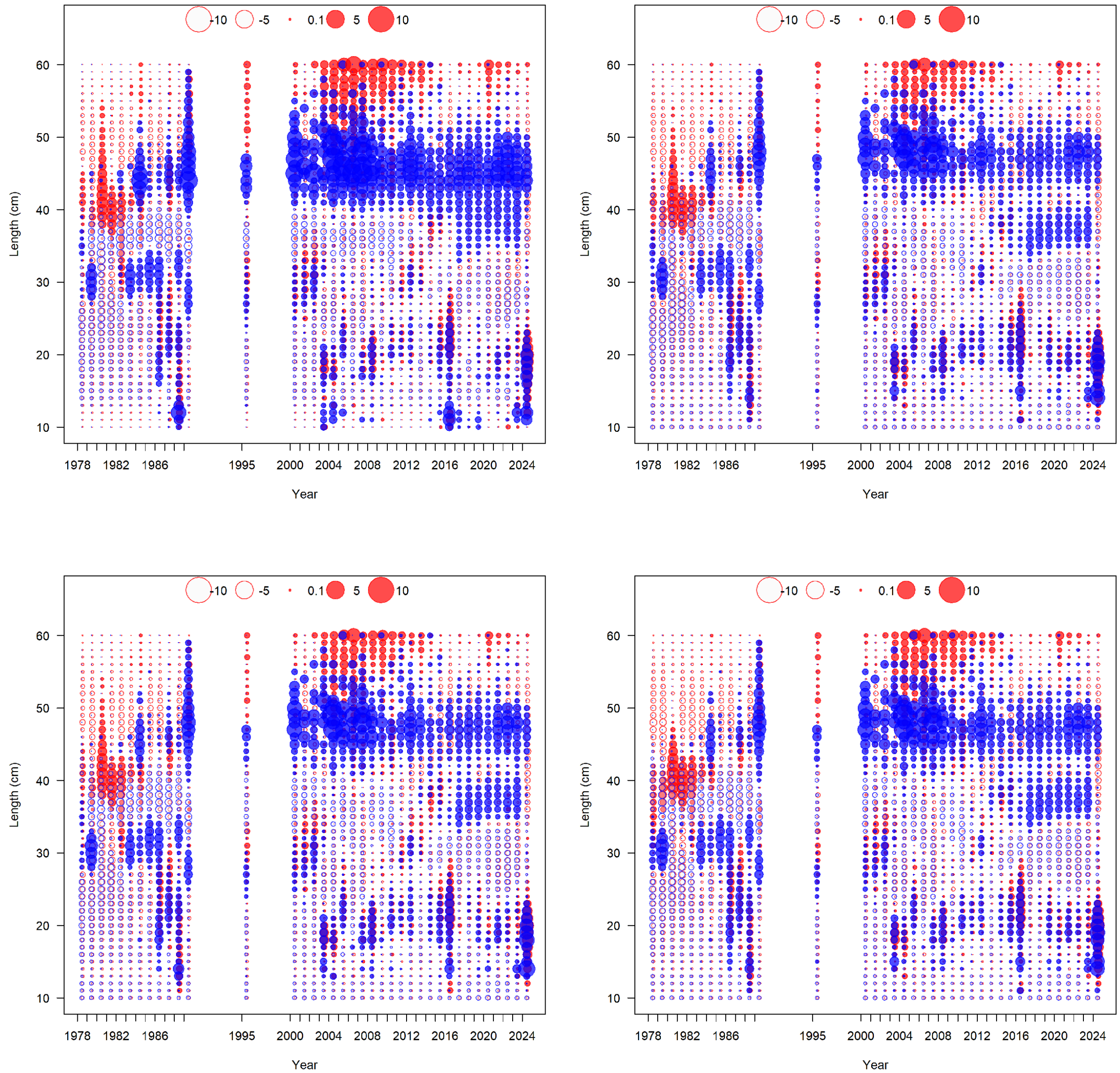

Figure 10-11. A comparison of Pearson residuals for fishery length-composition data between Base-3 (top-left), Model 24.1 (bottom-left), Model 24.1a (top-right) and Model 24.1b (bottom-right). Red bubbles along the top of the plots area legend that show scale. Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females.

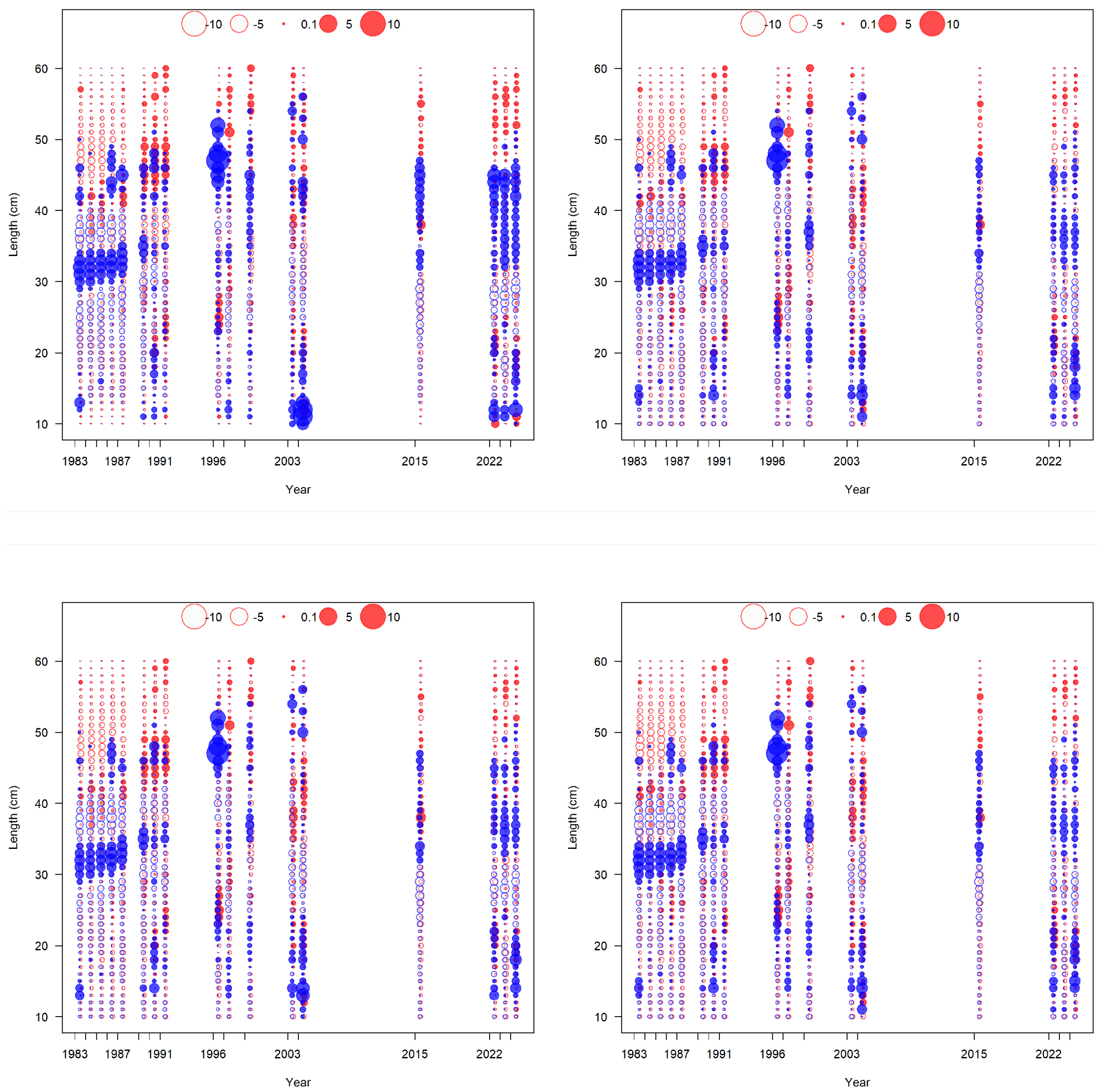

Figure 10-12. A comparison of Pearson residuals for survey length-composition data between Base-3 (top-left), Model 24.1 (bottom-left), Model 24.1a (top-right) and Model 24.1b (bottom-right). Red bubbles along the top of the plots area legend that show scale. Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females.

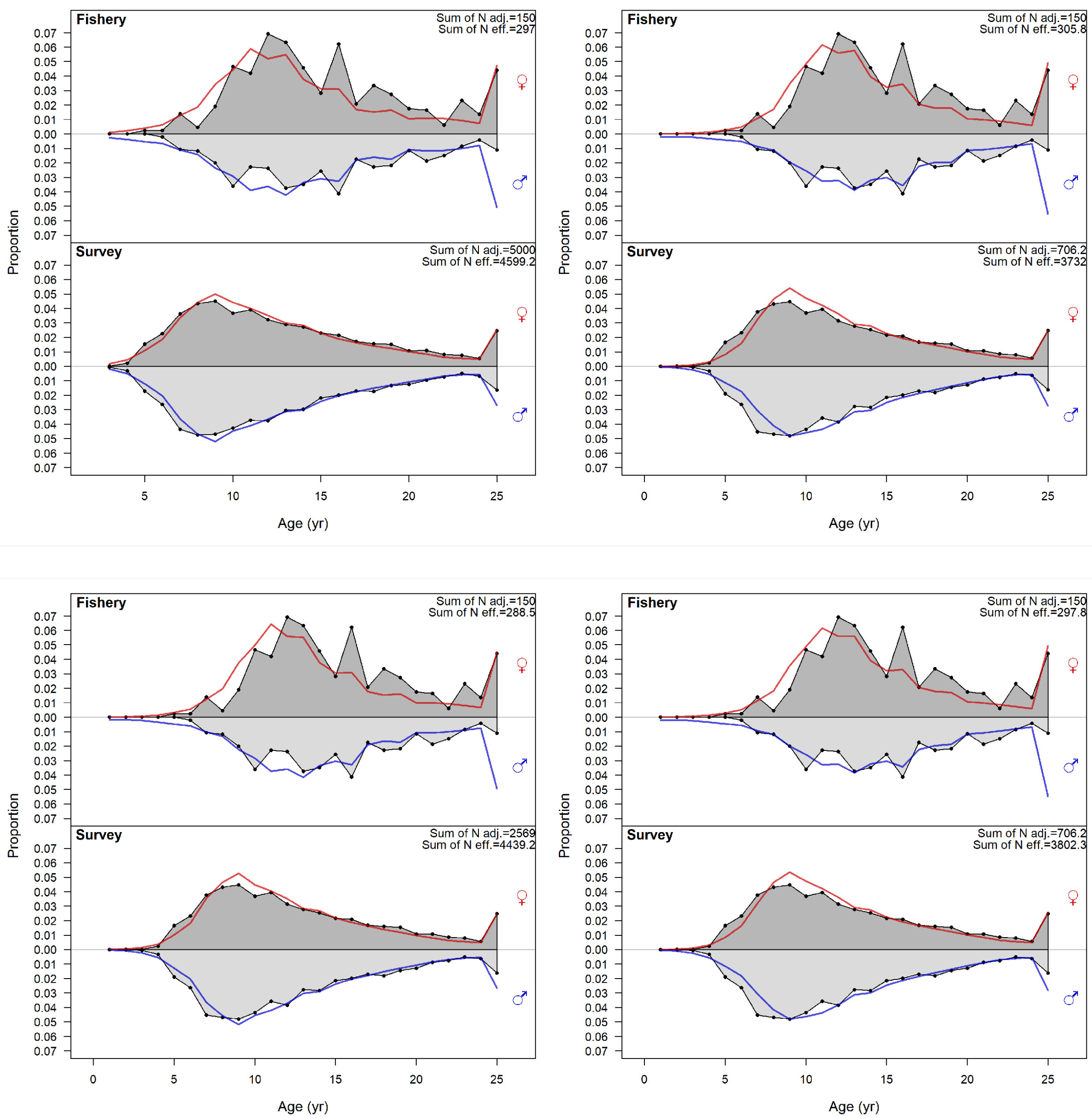

Figure 10-13. A comparison of fits to the fleet and sex specific aggregated age-composition data between Base-3 (top-left), Model 24.1 (bottom-left), Model 24.1a (top-right) and Model 24.1b (bottom-right).

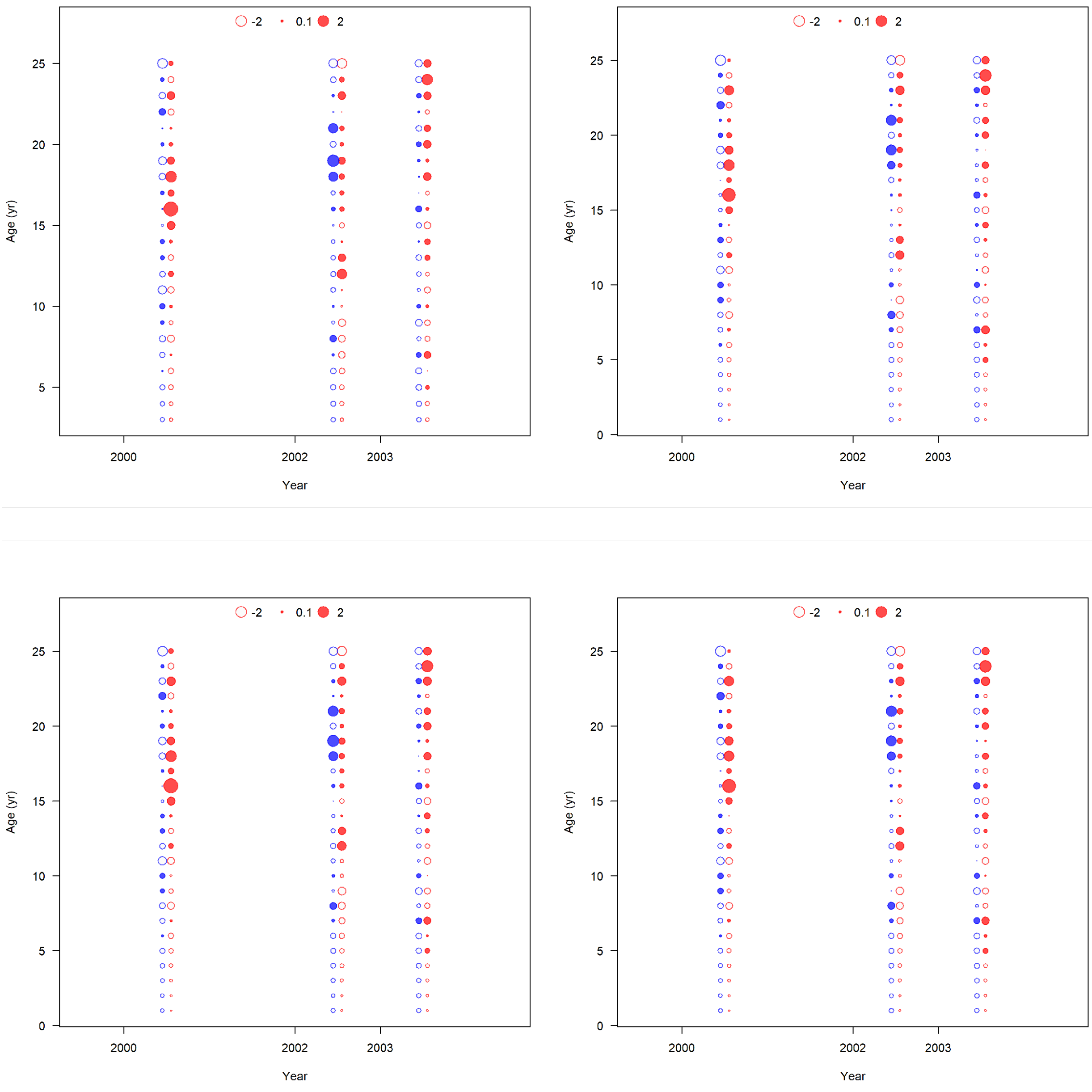

Figure 10-14. A comparison of Pearson residuals for fishery age-composition data between Base-3 (top-left), Model 24.1 (bottom-left), Model 24.1a (top-right) and Model 24.1b (bottom-right). Red bubbles along the top of the plots area legend that show scale. Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females.

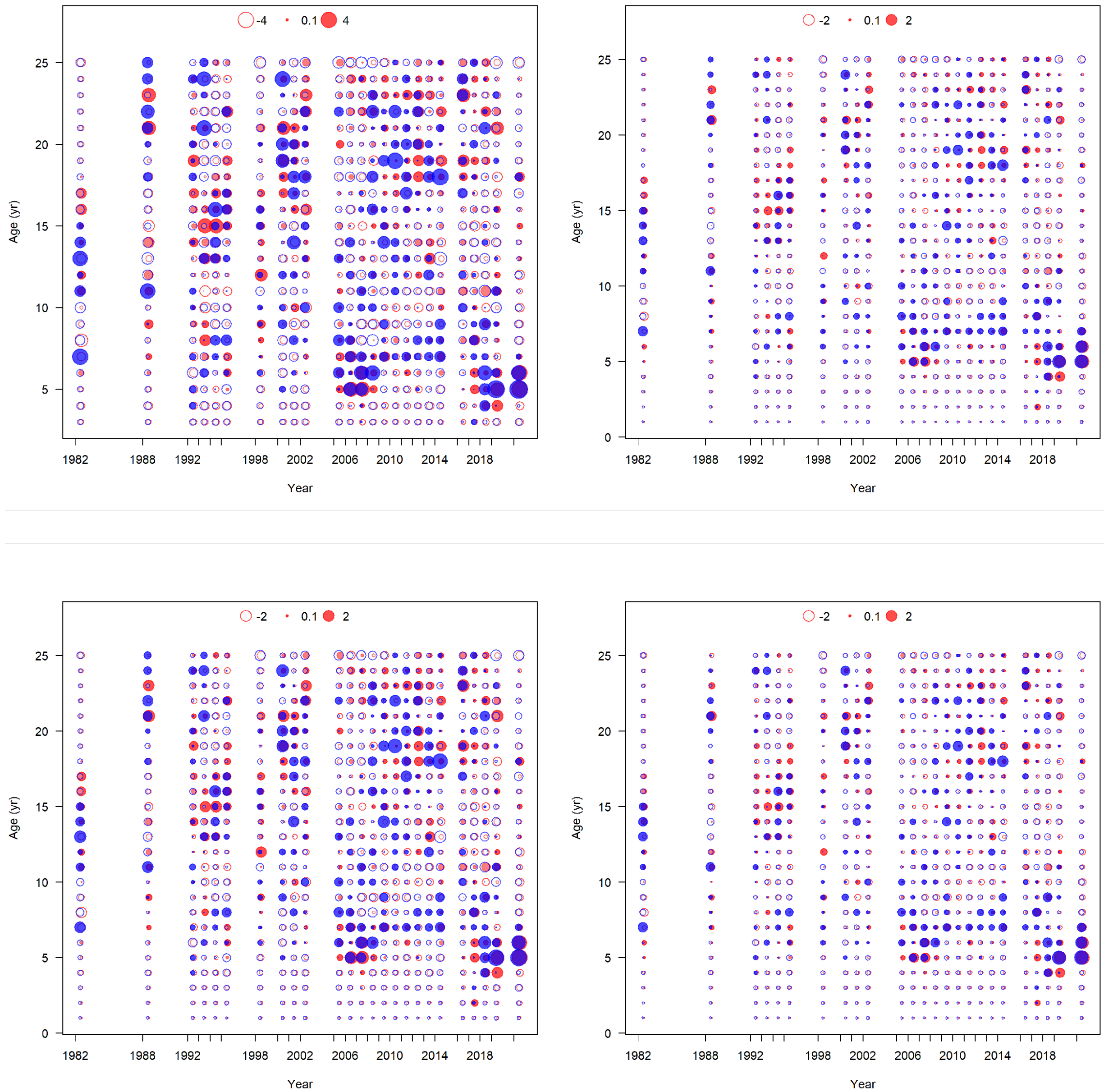

Figure 10-15. A comparison of Pearson residuals for survey age-composition data between Base-3 (top-left), Model 24.1 (bottom-left), Model 24.1a (top-right) and Model 24.1b (bottom-right). Red bubbles along the top of the plots area legend that show scale. Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females.

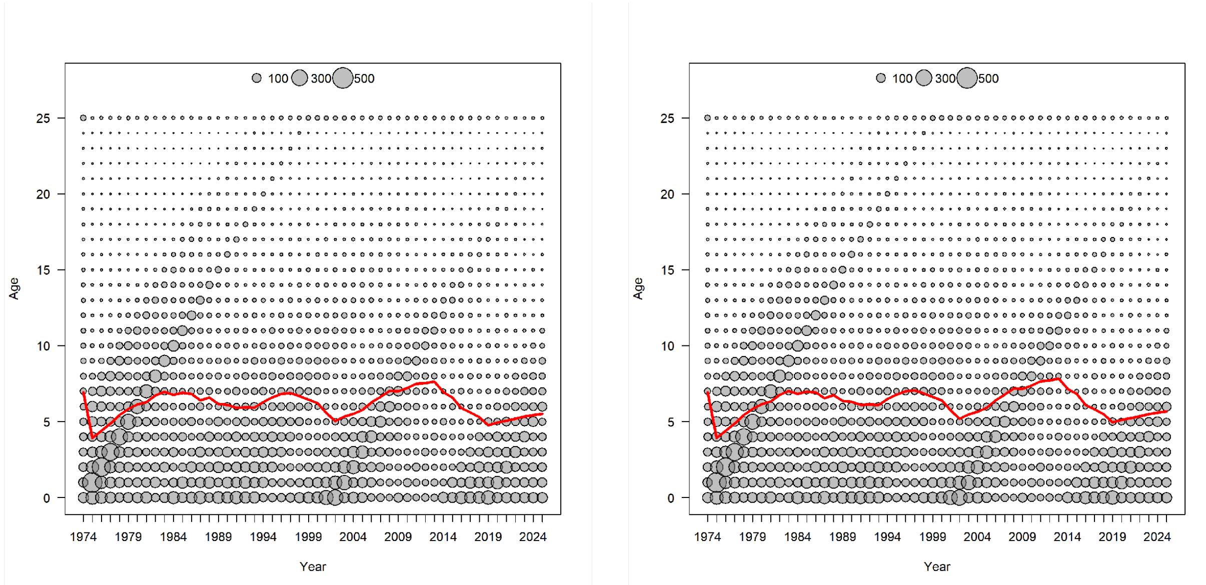

Figure 10-16. Expected numbers-at-age at the beginning of the year for females (left panel) and males (right panel) for Model 24.1b. Red lines show expected mean numbers-at-age

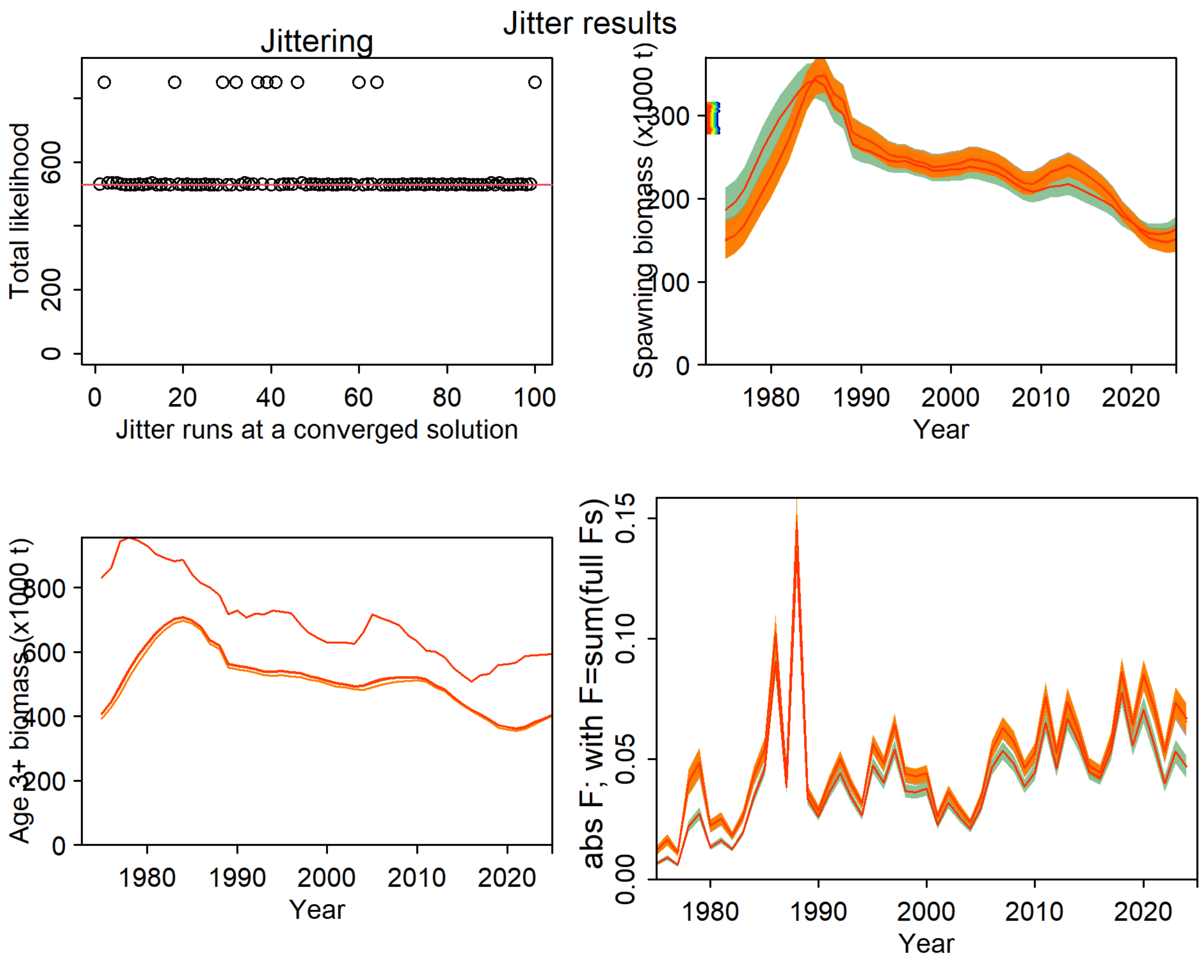

Figure 10-17. Four plots showing the results from a jitter analysis (with 100 runs) on Model 24.1b. The top-left shows the total likelihood, the top-right shows the spawning biomass, the bottom-left shows the age-3+ biomass and the bottom-right showing the fishing mortality. Each plots shows the result from all 100 runs.

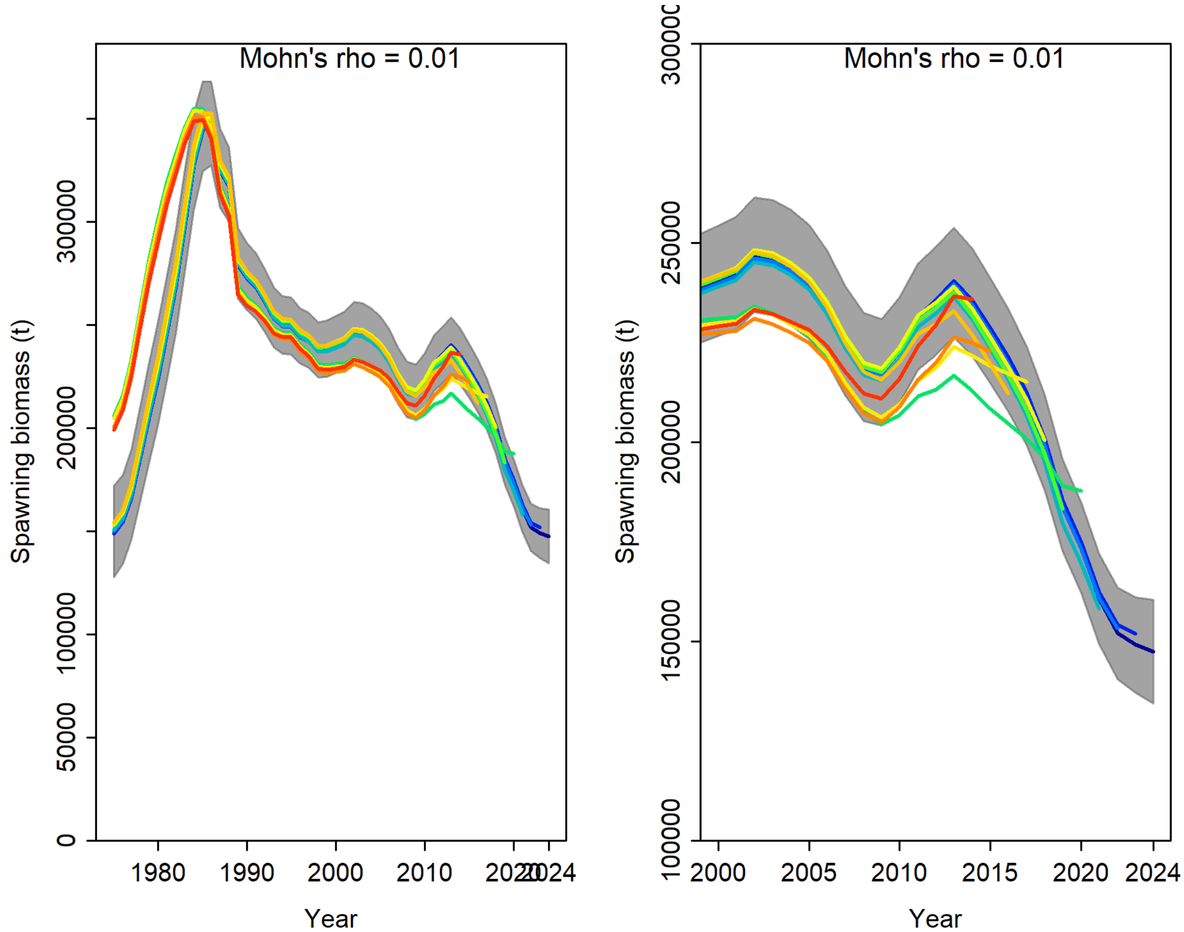

Figure 10-18. Spawning stock biomass from retrospective model runs leaving out 0 to 10 years of the most recent data for Model 24.1b. The grey shaded region represents the 95% confidence interval for the Model 24.1b run with all years of data.

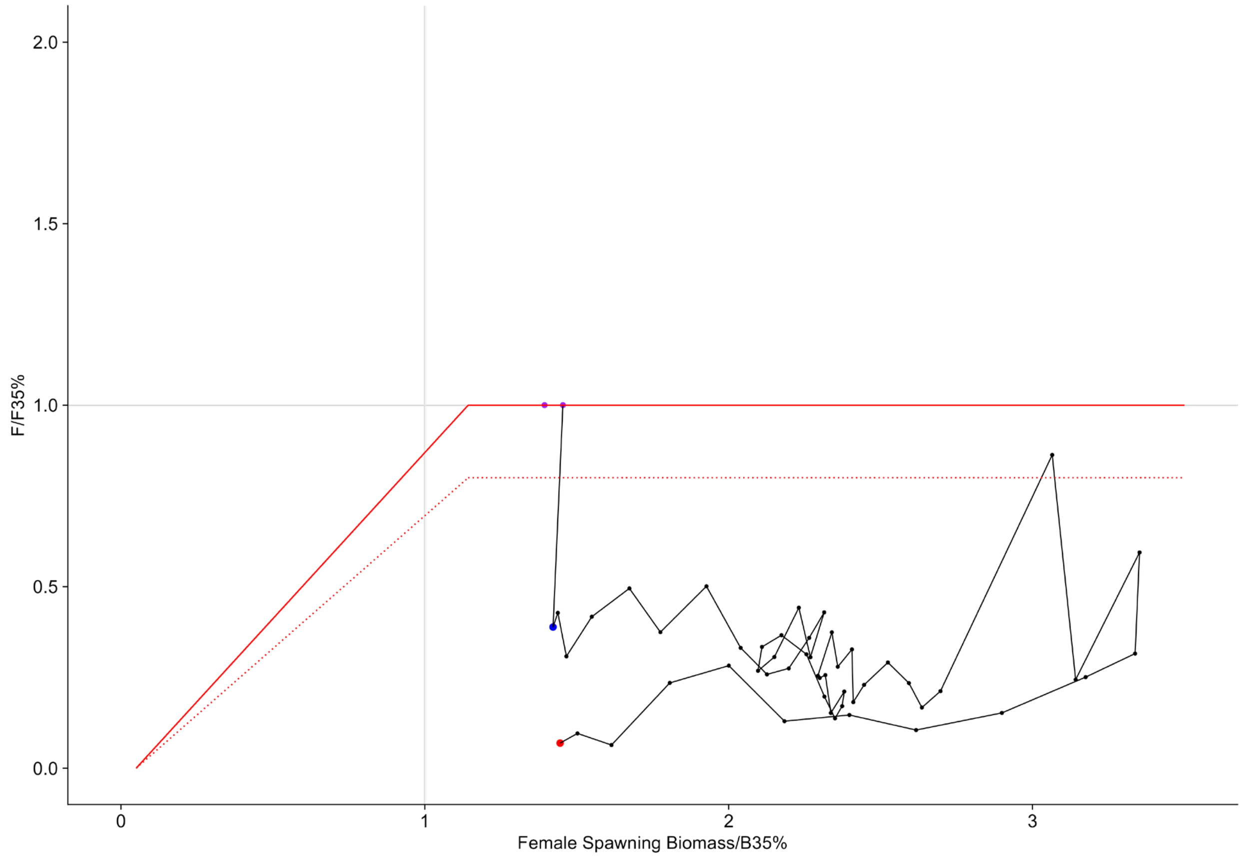

Figure 10-19. Phase-plane diagram of the relative trajectories of female spawning biomass and full-selection fishing mortality. Horizontal axis contains model-estimated female spawning biomass relative to B35%; vertical axis contains model-estimated full-selection fishing mortality relative to F35%. The solid red line shows the OFL Tier 3 control rule and the dotted line shows the ABC Tier 3 control rule. The red dot is the value from 1975, the blue dot is the current-year (2024) value and the purple dots are the projected 2025 & 2026 values.

Appendix 10a: Transitioning the Bering Sea and Aleutian Islands Alaska Plaice Stock Assessment to Stock Synthesis

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 2021b) 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
U.S. Trawl Fishery	Catch	1975-2021
	Age-Composition (by sex)	2000, 2002, 2003
	Length-Composition (by sex)	1978-89, 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 [$R_3 0$] to better mirror the 2021 model mean recruitment (R30), Equation 1 was used:

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

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:

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

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 10-13 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 10-20 and 10-21 show 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 10-20) 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 10-22) 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 10-22). 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 10-23 and 10-24 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 10-25 and 10-26). There are noticeable slight differences in 3+ total biomass and Age-3 recruitment (Figure 10-25). 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 10-14). 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 10-27 and 10-28). There are noticeable slight differences in 3+ total biomass and Age-3 recruitment (Figure 10-27. 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 10-14). 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 10-27 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 10-14). 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	2022-2023
	Length-Composition (by sex)	2022-2023
U.S. Trawl Fishery	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 10-29 and 10-30 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 10-15). 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.

References

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

Ormseth, O.A. (2021a) 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. and Hulson, P. (2024) surveyISS: Survey composition input sample size.

Appendix 10a Tables

Table 10-13. 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 10-14. 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	3,325.2612	1,623.9742	992.067	982.7518	985.5470
Survey	26.7032	-58.9898	-59.209	-58.8731	-58.9021
Length-composition	1,887.7840	1,007.8900	383.985	373.7080	374.8790
Age-composition	1,386.1496	656.7270	648.944	644.9610	645.9870
Recruitment	24.6244	18.3470	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 10-15. 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	Base-4	Model 24.0	Model 24.1
Total	1,010.070	670.014	673.004
Survey	-66.6602	-66.4449	-65.7010
Length-composition	417.408	379.449	380.430
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

Appendix 10a Figures

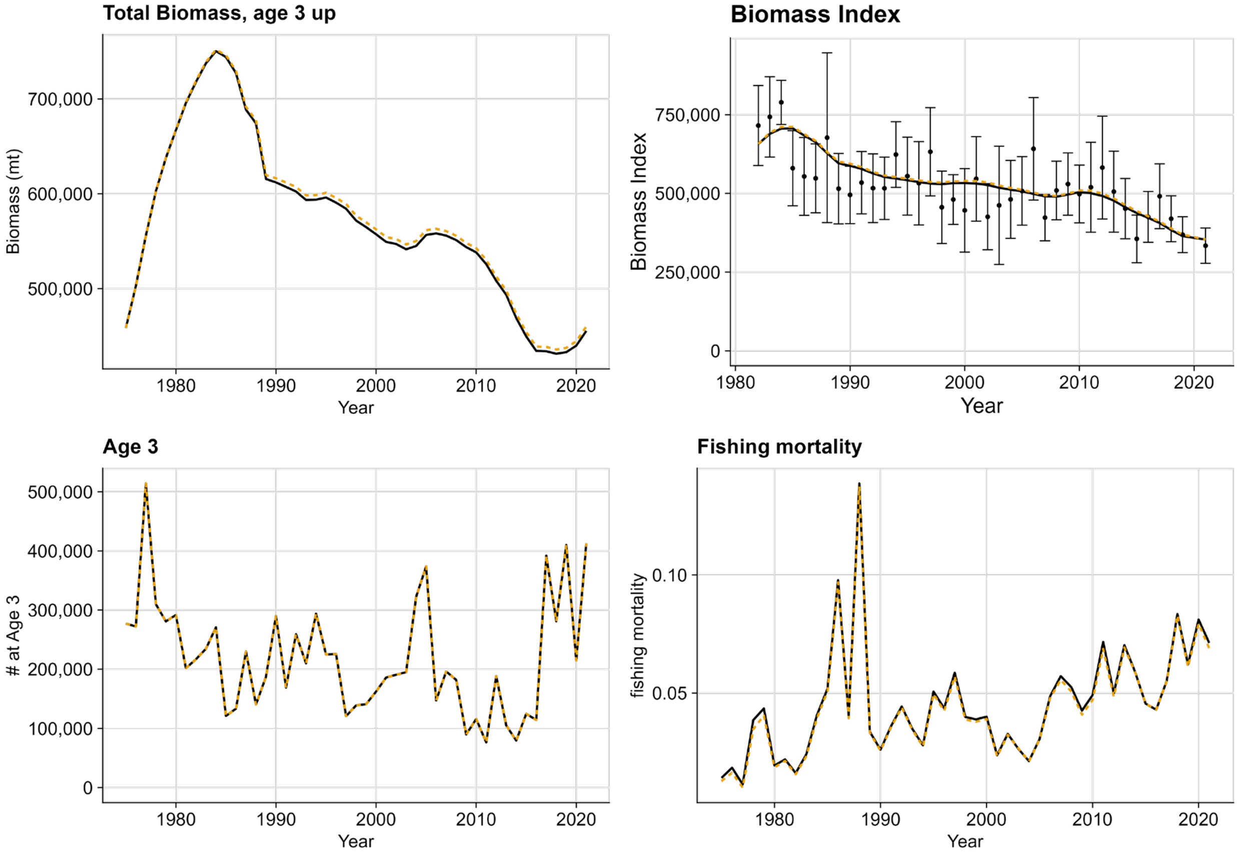

Figure 10-20. Population dynamics plots comparing the 2021 model to the Base-1 model where only selectivity and annual fishing mortality are estimated. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this plot). The top right 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.

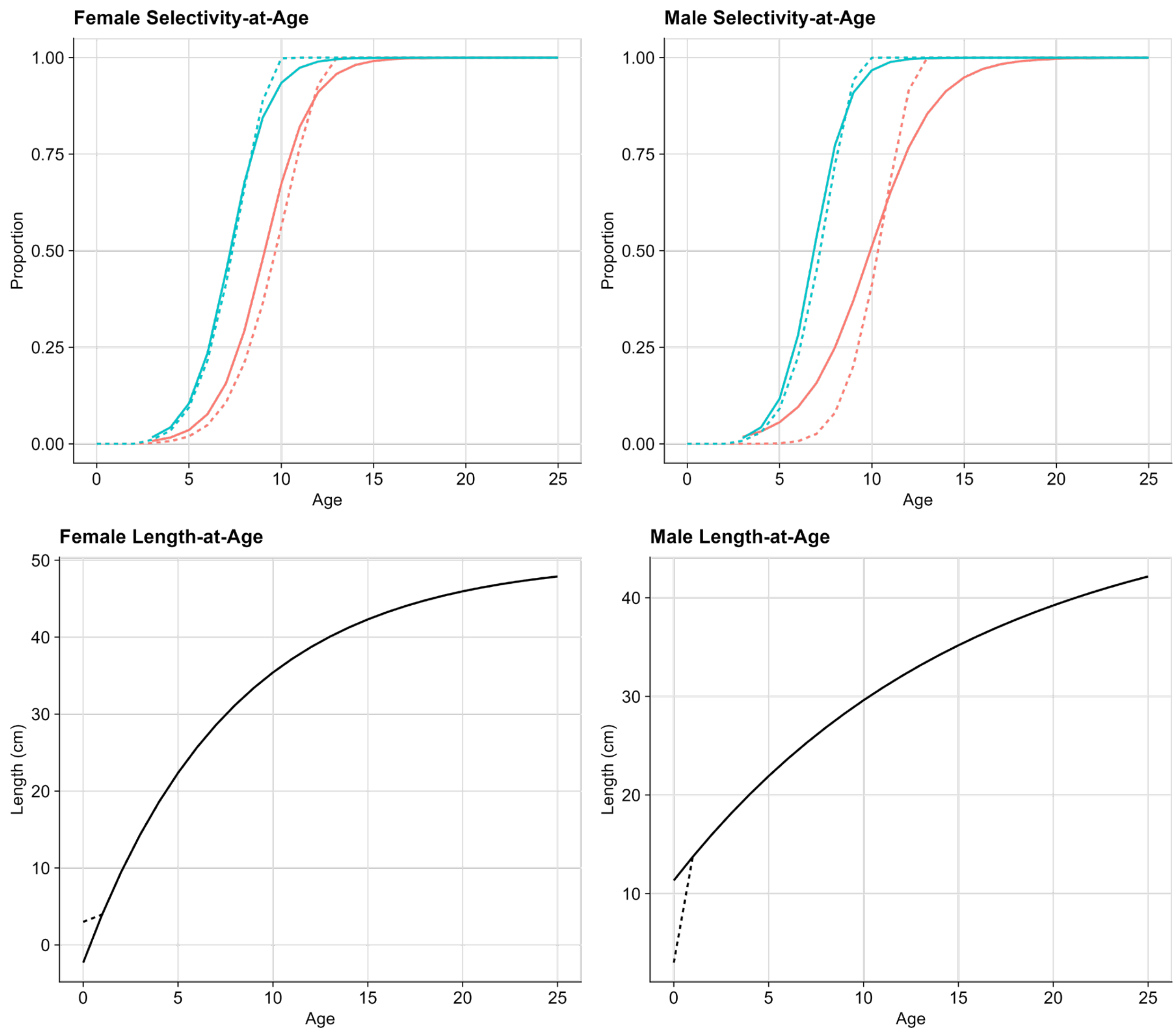

Figure 10-21. Comparison plots between the 2021 model to the Base-1 model where only selectivity and annual fishing mortality are estimated. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom 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.

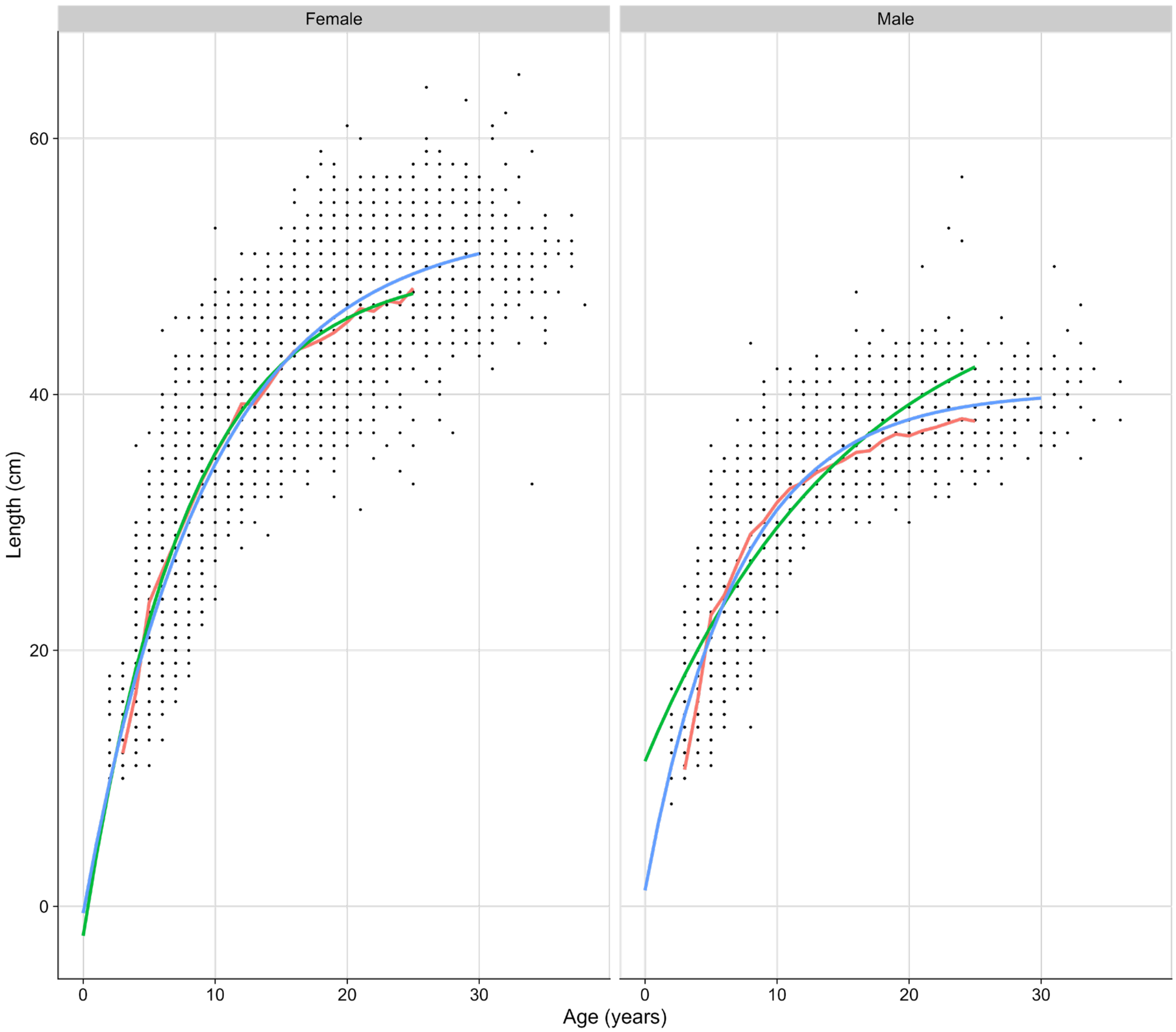

Figure 10-22. Comparison between the von Bertalanffy growth curves used to determine the mean weight-at-age in the 2021 model (green), the mean length-at-age determined from the age-length transition matrix used in 2021 model (red), and the new externally estimated von Bertalanffy growth curves using 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.

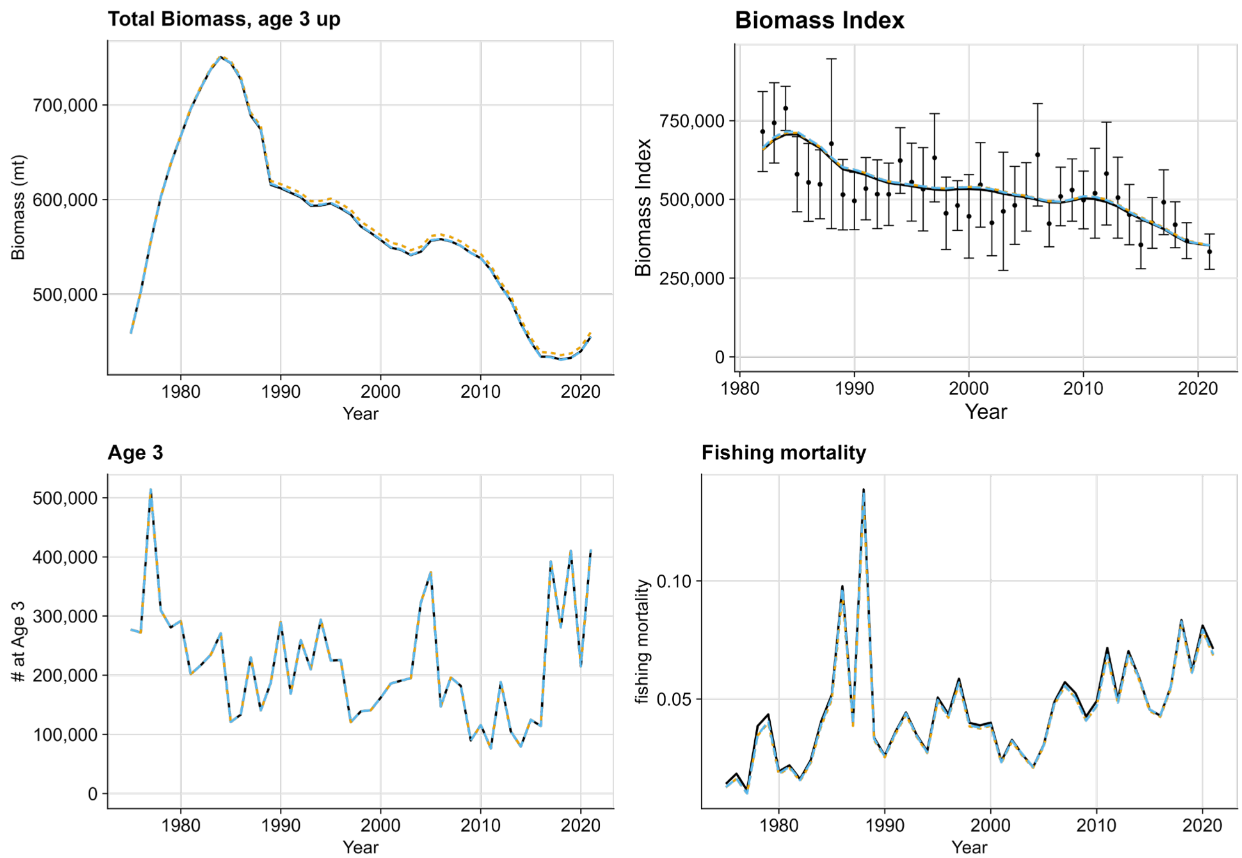

Figure 10-23. Population dynamics plots comparing the 2021 model and the Base-1 model to the Base-2 model with an updated growth curve. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this plot). The top right panel shows the 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.

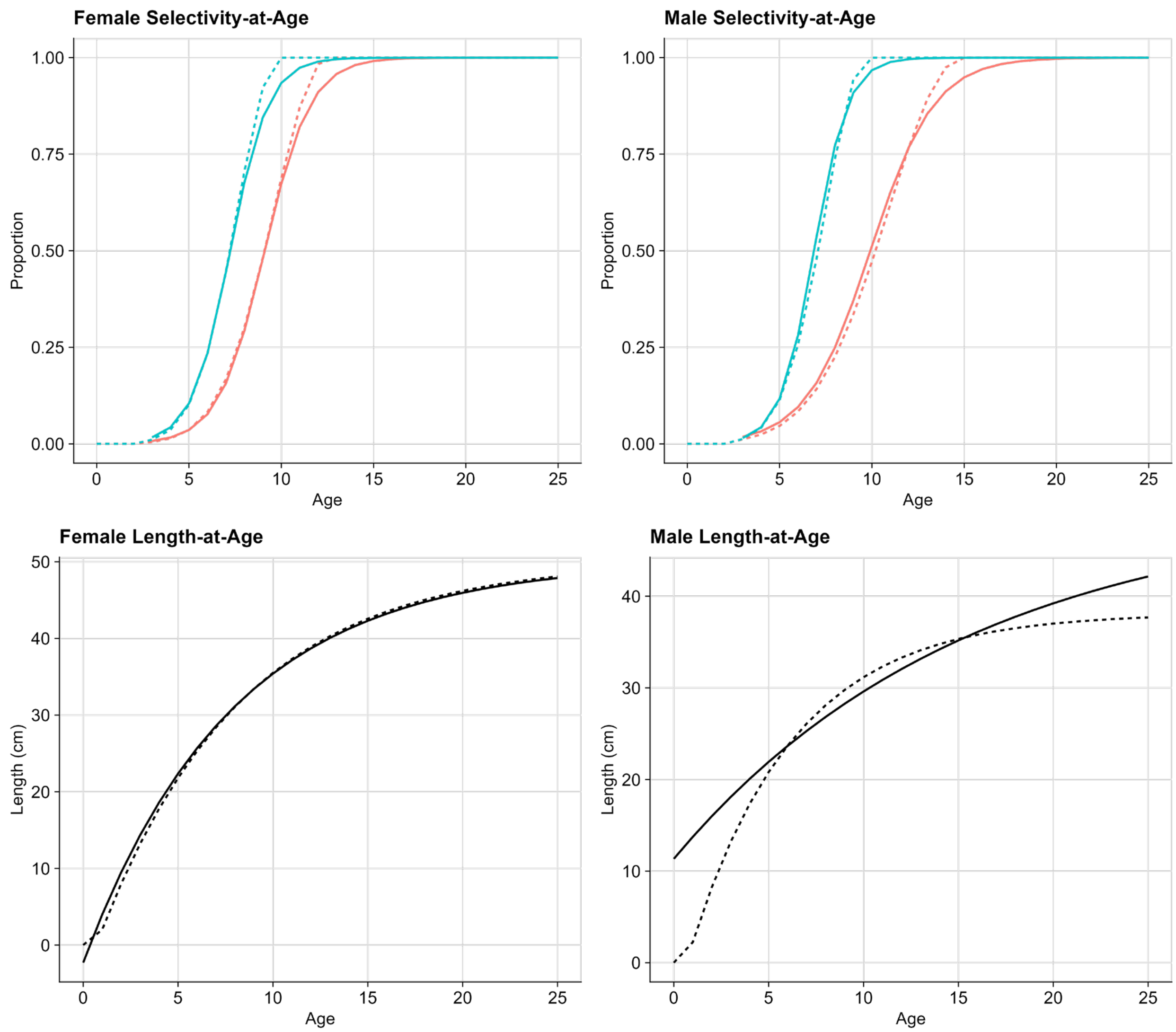

Figure 10-24. Comparison plots between the 2021 model to the Base-2 model with the updated growth curve. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom panels show the growth curves with 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.

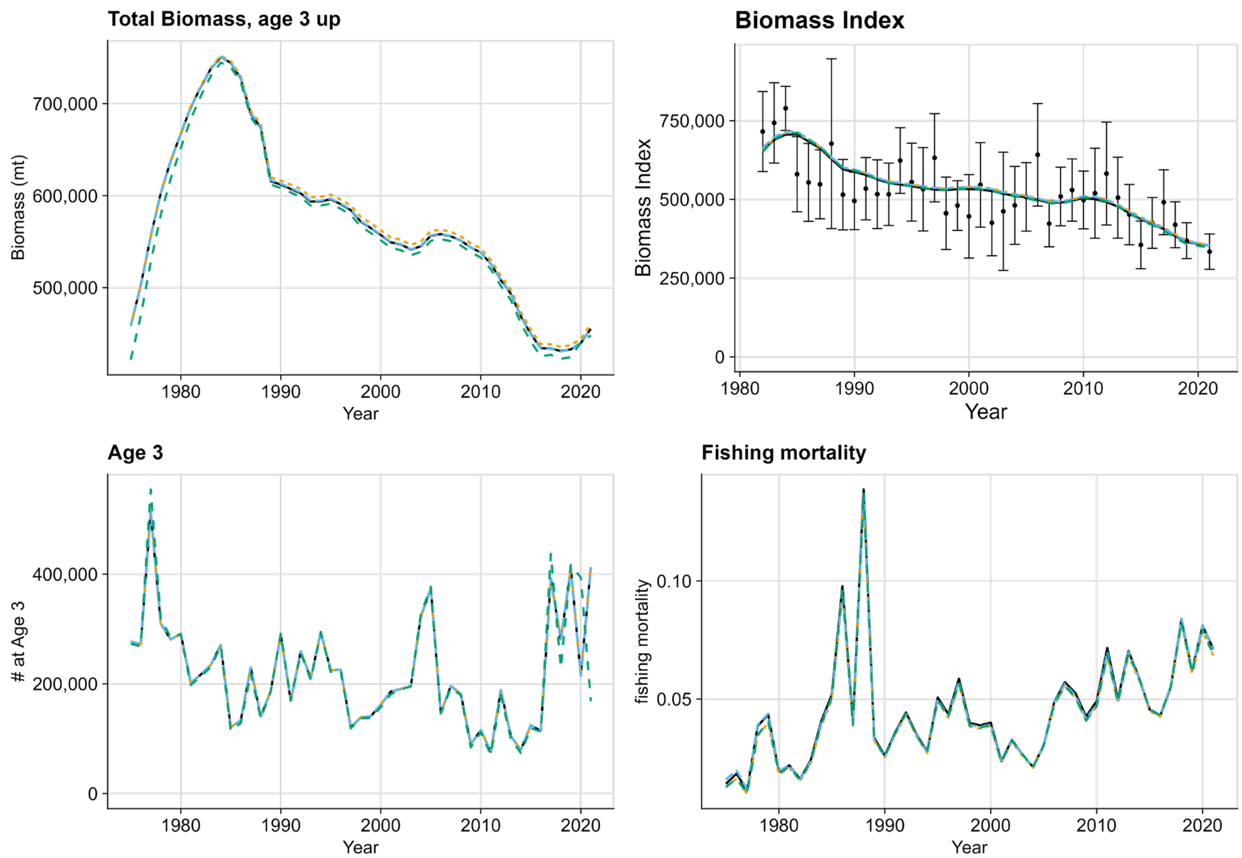

Figure 10-25. Population dynamics plots comparing the 2021, Base-1 and Base-2 models to the Base-3 model where recruitment, fishing mortality and selectivity are estimated. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in this 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.

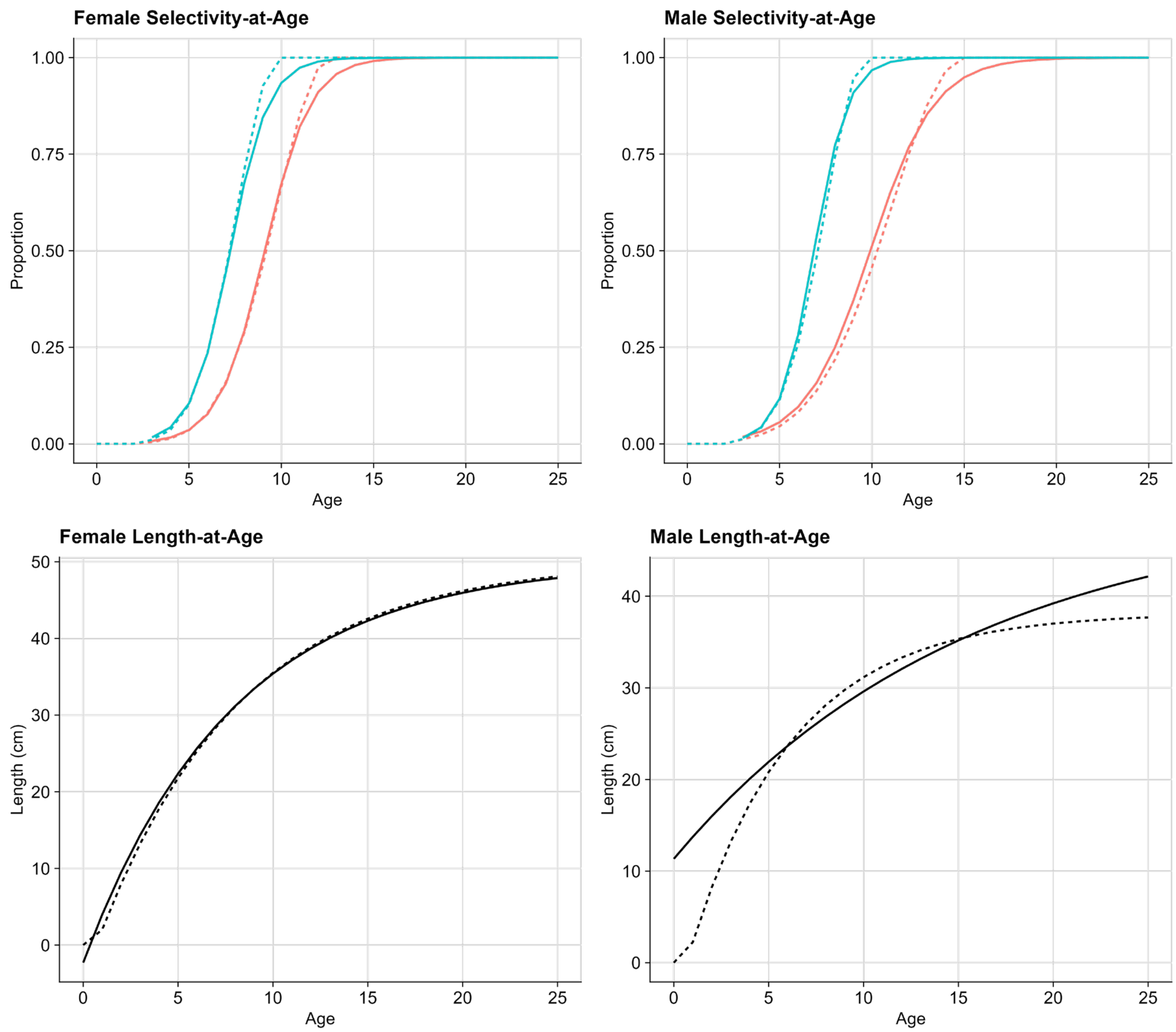

Figure 10-26. Comparison plots between the 2021 model to the Base-3 model where recruitment, fishing mortality and selectivity are estimated. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom 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.

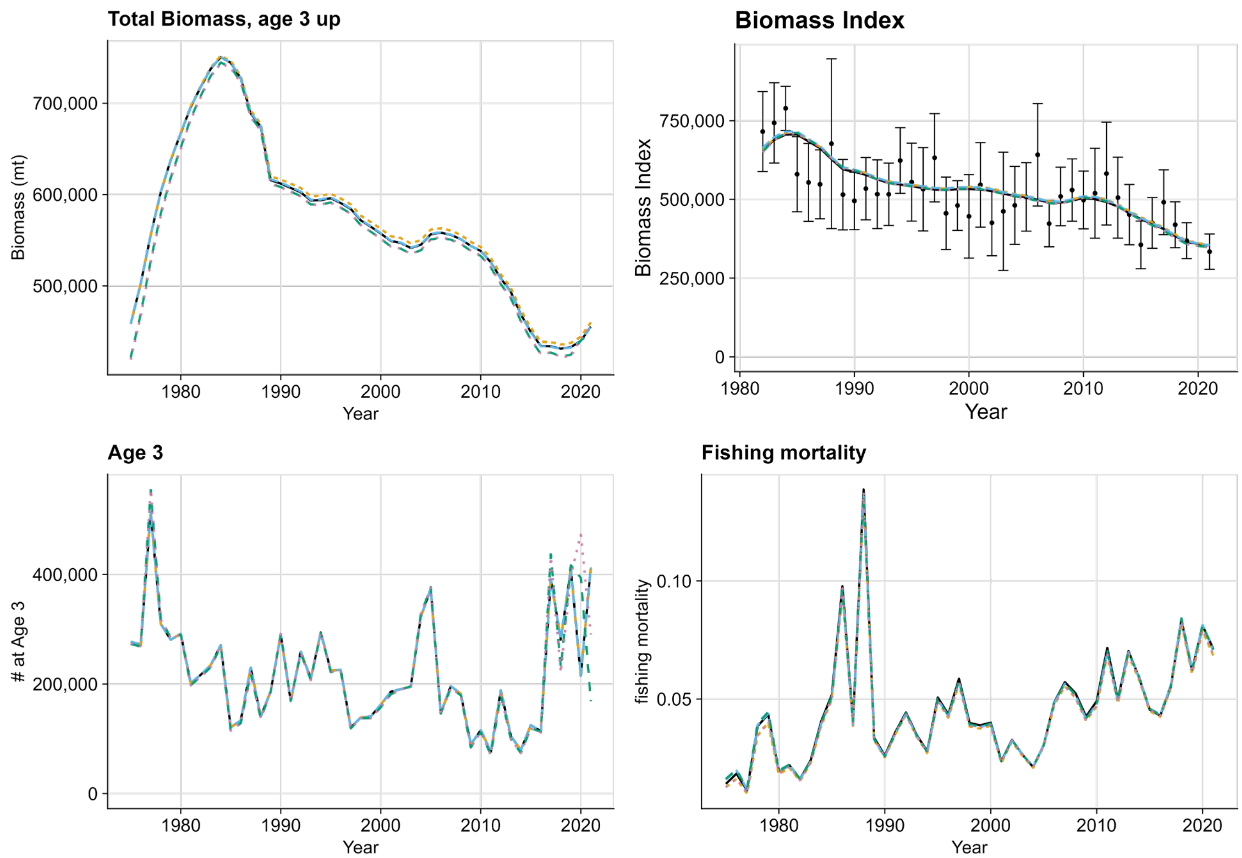

Figure 10-27. Population dynamics plots comparing the 2021, Base-1, Base-2 and Base-3 models to the Base-4 model which mirrors the Base-3 model except that growth is estimated. The top left panel shows the estimated total biomass from age-3 and older (i.e. ages-2 and younger fish are not included in 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.

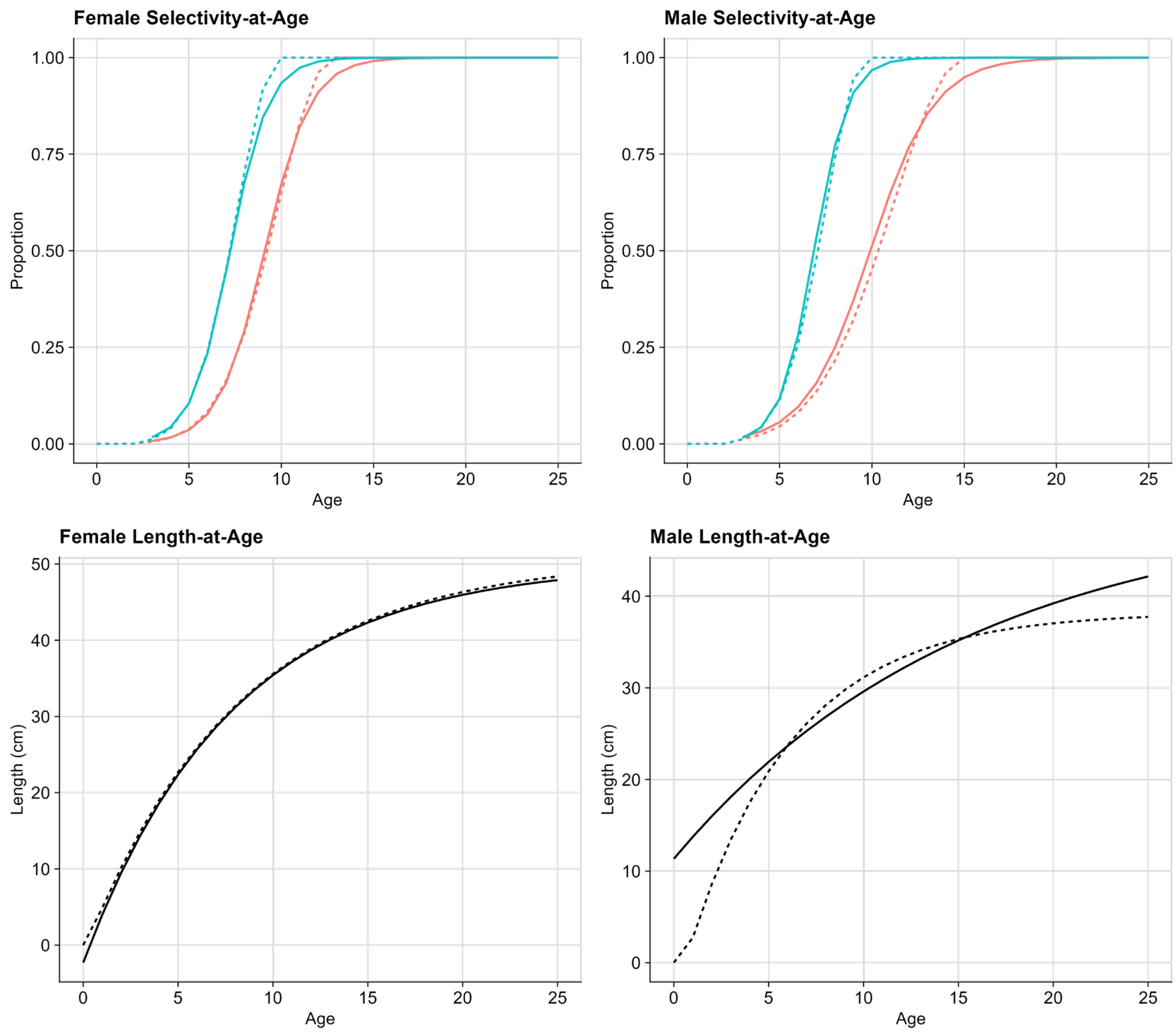

Figure 10-28. Comparison plots between the 2021 model to the Base-4 model which mirrors the Base-3 model except that growth is estimated. The top panels show the estimated selectivity curves from the fishery (red) and survey (blue) fleets with females on the left and males on the right. The bottom panels 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.

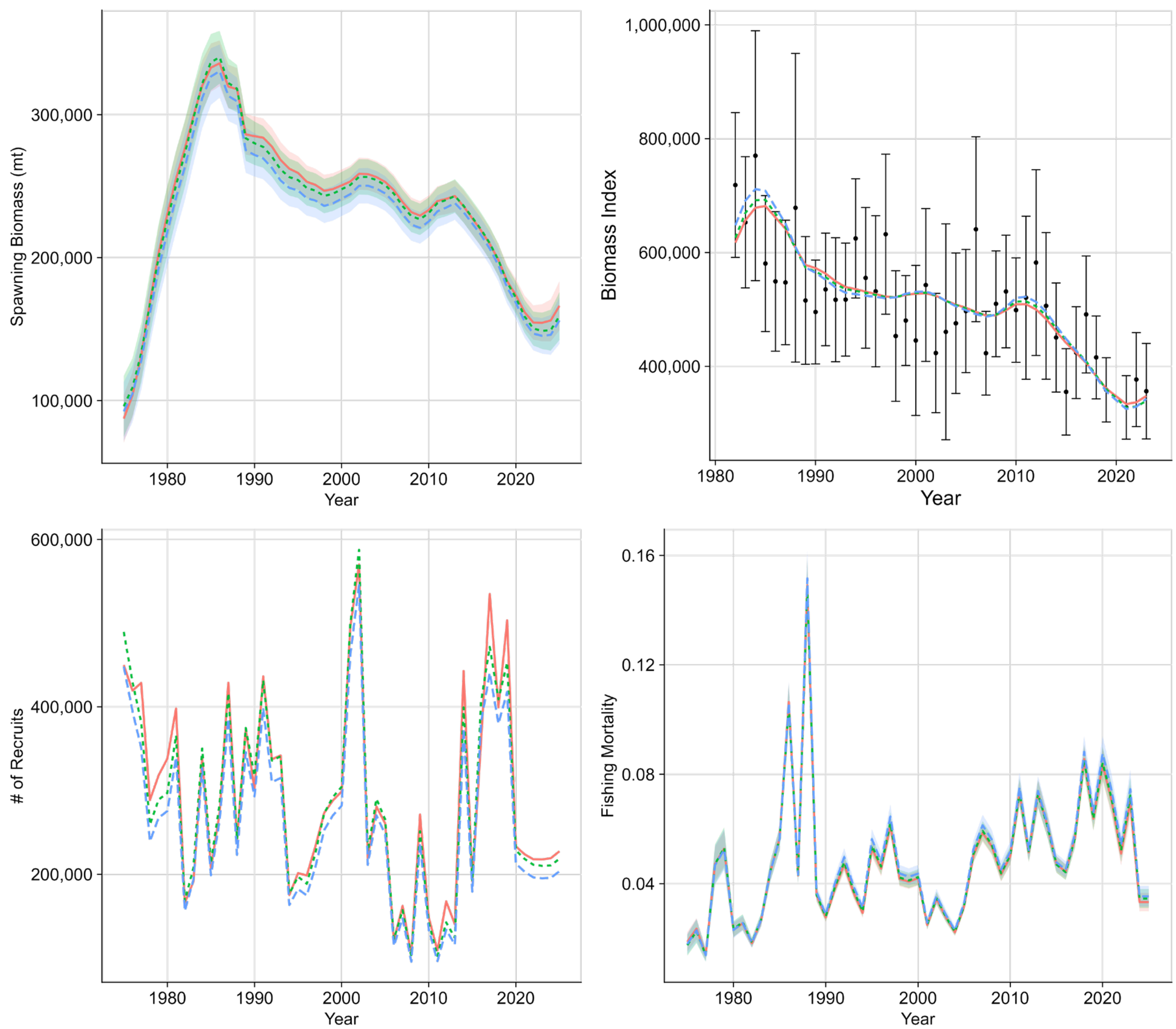

Figure 10-29. Population dynamics plots comparing the Base-4 (red solid), Model 24.0 (green dashed) and Model 24.1 (blue dashed) models. The top left panel shows the estimated spawning biomass. The top right panel shows the estimated biomass index with the black dots with error bars representing that 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.

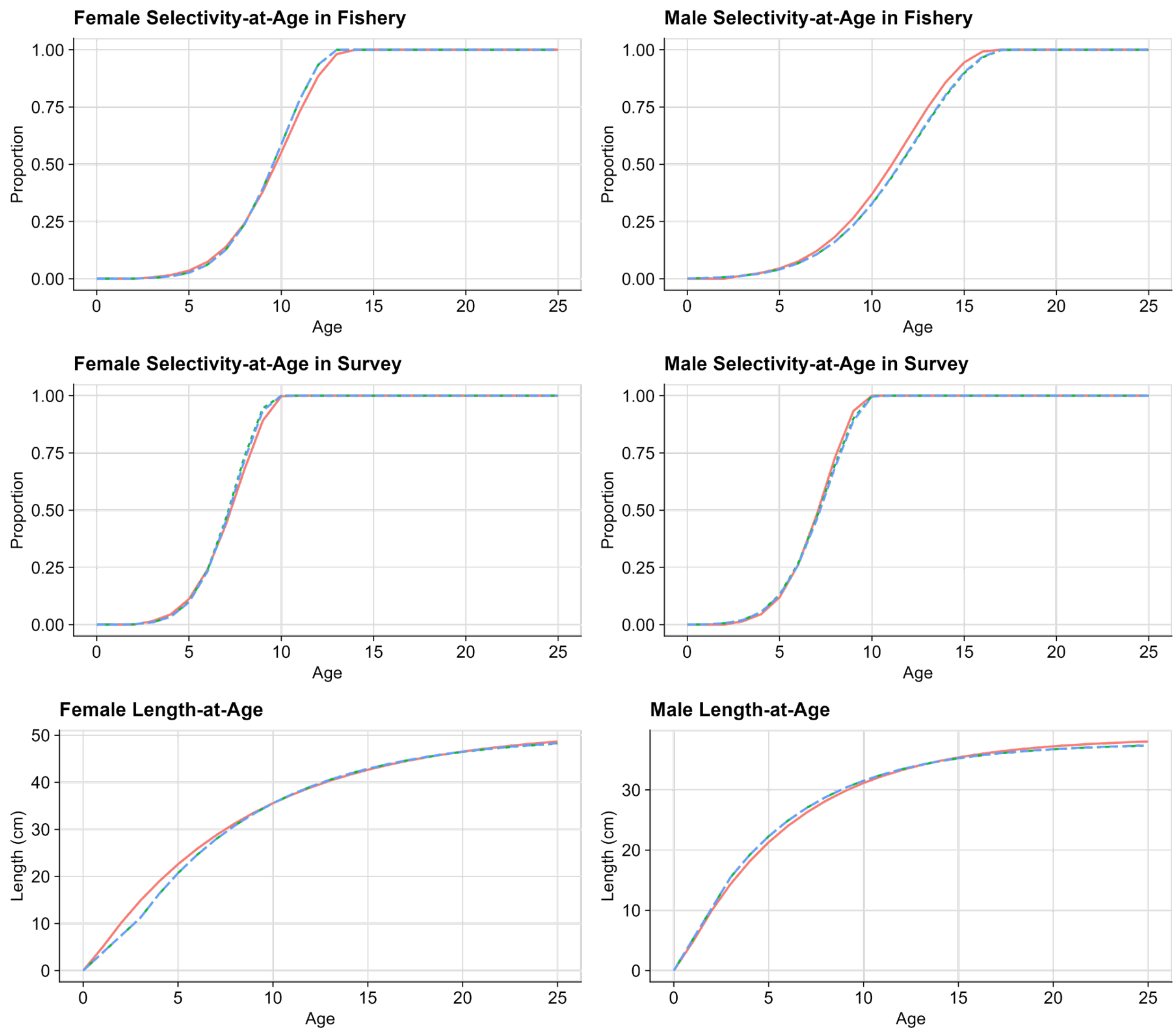

Figure 10-30. Comparison plots between the models Base-4 (red solid), Model 24.0 (green dashed) and Model 24.1 (blue dashed). First row of panels is selectivity in the fishery. The second row is selectivity in the survey and the third row is the length-at-age. The left panels are for female specific curves and the right panels are for male specific curves.