Evaluation of potential alternative models for BSAI northern rockfish

by

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Executive summary

Sex-specific differences in weight at age were found for BSAI northern rockfish, and the proportion female in the Aleutian Islands (AI) trawl survey abundance estimates was approximately 62% rather than the 50% assumed with a combined-sex model. Examination of observed sex-specific age and length frequency distributions indicate a distribution of similar shape (i.e., variance) with a slightly larger mean age or length for females. In split-sex models, the sex-specific differences in AI selectivity curves were relatively minor and the estimated natural mortality for males was approximately 20% larger than that for females. The retrospective results were generally similar between the combined-sex and split-sex models.

The differences in the growth curves between spatial regions appears to be larger than the differences between sexes. Because the spatial distribution of sampled fish not necessarily be representative of the population abundance or fishery catch (particularly with length-stratified sampling), spatially-weighted averages are used to obtain the appropriate spatial weighting. However, the sampling of fish in the survey and fishery is random with respect to sex. Consequently, combined-sex age and length compositions inherently incorporate the appropriate sex ratio and lead to similar results as the split-sex models since sex-specific natural mortality and selectivity were similar.

Models with time-varying AI survey catchability fit the AI survey biomass estimates better, as expected. However, the retrospective patterns were worse than the previously accepted model (Model 21(2023)). Given the survey design and strict protocols followed by the AI survey, evidence that catchability would be changing systematically over time is lacking. Similarly, models with time-varying AI survey selectivity (with some constraint) only showed minor differences in survey selectivity between the time blocks, and produced retrospective patterns and estimated biomass similar to the previously accepted model.

In conclusion, we recommend continuing with the previously accepted model.

Introduction

In their December 2023 meeting, the Scientific and Statistical Committee of the North Pacific Fishery Management Council made the following request for the BSAI northern rockfish stock assessment:

Investigate whether information on sex ratio, that might indicate different mortalities between sexes, or the inclusion of time blocks for survey selectivity and/or catchability may be informative in resolving the retrospective pattern.

The purpose of this document is to evaluate split-sex models, and models with time-varying survey selectivity or catchability, for BSAI northern rockfish.

Data

The years of catch, age and size composition data, and AI survey biomass estimates to be fit by the model were chosen to be identical to that used in the 2023 assessment, as not all age compositions that will be in the 2025 final assessment have been completed as the time of this analysis. The following table summarizes the data fit within assessment models in this evaluation:

Component	BSAI
Fishery catch	1977-2023
Fishery age composition	2000-2009, 2011, 2013, 2015, 2017, 2019-2021
Fishery size composition	1977-1978, 1996, 1998-1999, 2010, 2012, 2014, 2016, 2018, 2022
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022

Weight-at-age is estimated outside the assessment model, and were re-estimated for split-sex models in order to obtain sex-specific values. The re-estimation was based on all the available data on length-at-age and length-weight relationships at the time of the analysis, which includes observations from the newly available 2024 AI survey. The number of otoliths read, and the number of hauls from which they were obtained, are shown in Tables 1 and 2 for the BSAI fishery and the AI trawl survey, respectively. Smaller number of otoliths were obtained in the EBS region for both the fishery and the survey. Spatially averaged estimates of length-at-age are used in the model, and data from the EBS are lightly weighted due to the reduced fishery catch and survey abundance estimates in this area (Spencer and Lamon 2023).

Fishery Data

The fishery age compositions in the 2019 and subsequent assessments were produced by applying area-specific age-length keys to the fishery length composition from each area (each combined across sexes), and weighting the resulting subarea age compositions by the extrapolated catch number by subarea from the North Pacific Groundfish Observer Program.

Sex-specific length frequency data was obtained by multiplying the sex-specific length frequency within each subarea and year (which sums to 1 across both sexes) by the extrapolated catch number from the North Pacific Groundfish Observer Program, and combining across areas. In years with read otoliths, sex-specific estimates of fishery age compositions were calculated in a similar manner to the sex-aggregated data, but with sex-specific age-length keys and length compositions for each subarea and year. Observer age and length samples are obtained randomly with respect to sex, and the length frequencies applied to the sex-specific age-length keys reflect the sex ratio in the catch. The sex-specific age compositions were weighted across the spatial areas by the extrapolated catch number by subarea from the North Pacific Groundfish Observer Program.

The fishery age compositions are relatively similar between the sexes. The age frequencies are plotted as cumulative distributions (Figure 1), which allow visualization of sex-specific differences. Females show slightly larger proportions at age at the older ages in several of the recent years (2000, 2008-2011, and since 2015); however, this pattern is reversed in some years (2004, 2005), and in some years the compositions appear nearly identical (2003, 2006, 2007, 2013).

The fishery length compositions also show slightly larger proportions at length for females for most years, with larger differences observed in 1996 and 1998 (Figure 2).

For the fishery age and length compositions, the relative sample size in each year is proportional to the number of hauls with aged fish and length data, respectively. Reduced sampling rates prior to 2010 will lead to these years being weighted less strongly in the assessment model, even if large differences occur in the sex-specific age compositions.

Age-length keys were used to produce estimates of sex-specific mean length at age by year and spatial region, which were fit with von Bertalanffy growth curves for each subarea. Fishery sex-specific weight at age relationships were obtained by estimating and applying sex-specific length-weight relationships to the fitted von Bertalanffy length-age relationships from each subarea. The subarea lengths and weight at age were averaged across spatial areas by the extrapolated catch number by subarea from the North Pacific Groundfish Observer Program.

Boxplots of the data available on weight at age, obtained by applying the length-weight relationships to the estimates of mean length at age, are shown in Figure 3, and indicate in each region that females attain larger weights than males.

The estimated fishery weights-at-age growth curve by subarea, across all years, indicate a cline from small fish in WAI to larger fish in the EAI and SBS areas (Figure 4). Additionally, within each subarea, the estimated weight at age for females older than 15 years is larger than that for males.

The proportion female in the fishery age and length composition has been near 50% since 2010; the proportion female was more variable prior to 2010. The average proportion female in the fishery age composition data was 53%, whereas the average proportion female in the length composition data was 49% (Figure 5).

A conversion matrix was created to convert the modeled numbers at age to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. The expected size at age for the conversion matrix is an average of the yearly fishery size at age curves from 1990-2025 described above. The conversion matrix was created by fitting a power relationship to the observed standard deviation in length at each age (obtained from the aged fish in the fishery from 1998-2025), and the predicted relationship was used to produce variation around the predicted size at age from the von Bertalanffy relationship. For split-sex models, separate conversion matrices were produced for males and females, using sex-specific estimates of length at age and its standard deviation.

Survey data

Sex-specific age and length compositions from the AI trawl survey was obtained in a similar manner to the fishery data. Sex-specific length frequency by subarea were obtained from the length distribution of estimated population size produced by AFSC RACE GAP, and were applied to sex-specific age-length keys for each survey year. The sex-specific age compositions were weighted across the spatial areas by the survey abundance estimates by area (after smoothing the survey abundance estimates with a random effects model). Estimates of spatially-averaged, sex-specific, survey lengths and weights at age were obtained in an identical method used for the fishery estimates, with weighting by the smoothed estimates of subarea survey abundance.

Similar to the fishery age compositions, the survey age compositions are relatively similar between the sexes (Figure 6). Females show slightly larger proportions at ages ≥ 10 in most of the years since 2004, with the exception of 2006 and 2014, in which similar proportions between the sexes were observed at younger ages. In other years, such as 1997 and 2002, the cumulative distributions by sex are very similar to each other. In both the fishery and survey age compositions, years with differing cumulative distributions by sex have similar slopes of the cumulative distributions, which indicates that the difference is in the mean age, rather than the shape, of the distribution.

Boxplots of the data available on survey weight at age, obtained by applying the length-weight relationships to the estimates of mean length at age, are shown in Figure 7, and indicate in each region that females attain larger weights than males.

The estimated survey weights-at-age growth curve by subarea, across all years, indicate a similar cline as seen in the fishery data, with small fish in WAI to larger fish in the EAI and SBS areas, with females older than 15 years being larger than for males (Figure 8). The subarea length and weight at age were averaged across spatial areas by smoothed estimates of sex-specific survey abundance from the AI trawl survey.

The proportion female in the AI survey abundance estimates has exceeded 55% since 1991, and has averaged 62% from 1991 to 2024 (Figure 9).

Analytical Approach

Model structure

The existing combined-sex BSAI age-structured model is described in Spencer and Laman (2023). Time-invariant fishery and survey curves were modeled, each with logistic curves. Prior distributions were used for the survey catchability, and the natural mortality rate *M*. A lognormal distribution was used for *M*, with the mean set to 0.06, the value used in previous assessments, based upon expected relationships between *M* and longevity identified in Then et al. (2015), with the CV set to 0.15. The standard deviation of log recruits, σ_r, was fixed at 0.75. Similarly, the prior distribution for survey catchability followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.001, essentially fixing survey catchability at 1.0.

In the 2019 assessment, a penalty has been placed on the estimated selectivity at age 15 to force it to be relatively close to 1. Model runs without this penalty indicated survey selectivity substantially below 1 for all ages, with larger estimated biomass than seen in previous assessments. In the 2021 and subsequent assessments, the penalty was changed from age 15 to age 30, and selectivity was at age 30 was set for ages > 30. The removal of this constraint also indicated larger estimated biomass than seen in previous assessments. Relaxing this constraint is considered in several of the models below.

Description of alternative models

The alternative models considered in this report explore combined-sex and split-sex models that remove the constraint on survey selectivity, relax the prior on survey catchability, and include either time-varying catchability or selectivity:

Model	Description
Model 21 (2023)	The final 2023 assessment model
Effect of removing survey selectivity constraint on existing model	
Model 25_1	Model 21(2023), but removal of survey selectivity constraint and not fixing survey selectivity for ages > 30.
Split-sex models, with and without the survey selectivity constraint	
Model 25_2	Split-sex model, with same priors and constraints as in Model 21(2023)
Model 25_3	Split-sex model, but removal of survey selectivity constraint and not fixing survey selectivity for ages > 30.
Combined-sex models that relax AI survey catchability prior, and/or model time-varying AI survey catchability and/or AI survey selectivity	
Model 25_4	Model 21(2023), but the coefficient of variation on prior distribution for AI survey catchability is increased from 0.001 to 0.4.
Model 25_5	Model 21(2023), but the coefficient of variation on prior distribution for AI survey selectivity is increased from 0.001 to 0.4, and 5-year time blocks are used for AI catchability (i.e., bin start years of 1977, 1996, 2001, 2006, 2011, and 2016).
Model 25_6	Model 21(2023), but 5-year time blocks are used for AI survey selectivity.
Split-sex models that relax AI survey catchability prior, and/or model time-varying AI survey catchability and/or AI survey selectivity	
Model 25_7	Model 25_2, but the coefficient of variation on prior distribution for AI survey catchability is increased from 0.001 to 0.4.
Model 25_8	Model 25_2, but the coefficient of variation on prior distribution for AI survey selectivity is increased from 0.001 to 0.4, and 5-year time blocks are used for AI catchability.
Model 25_9	Model 25_2, but 5-year time blocks are used for AI survey selectivity.

For models with time-varying survey selectivity or catchability, time variation in parameters was produced by lognormally distributed deviations:

$$x_i = xe^{\epsilon_i}$$

where x_i is the value of the parameter for time block i, x is the median value of the parameter across the time blocks, and ϵ_i is the lognormally-distributed deviation from the median. The lognormal deviations ϵ_i were penalized in the likelihood function with a coefficient of variation of 0.10.

Results

Model Evaluation

The overall likelihoods between the split-sex models and the combined-sex model cannot be compared to each other because of the differences in the input data; however, the likelihoods can be compared within each of these groups, as well as some components that are common to both sets of models (i.e., the AI survey biomass estimates). The best fit to the AI survey biomass is obtained in model 25_5 and 25_8, which are combined-sex and split-sex models, respectively, in which time blocks are used for survey catchability (Table 3). The root mean squared error (RMSE) is a useful metric for evaluating how well the model is fitting data, and RMSE for the AI survey biomass is also lowest for models 25_5 and 25_8. The estimated survey catchability across the time blocks is similar for these models, and is < 1 for most of the years since 1991 (Figure 10). For these models, a decrease in survey catchability prior to 2010 allows better fits to relatively low survey biomass during these years, and a better fit is also obtained to the high 2014 biomass estimate due to a jump in catchability (Figure 11).

The RMSE values for the age and length composition data are similar within the sets of combined- and split-sex models, indicating that the alternatives for modeling survey selectivity have little effect on fitting the composition data. However, the RMSE values indicate that composition data were fit slightly better in the split-sex models. For example, the RMSE for the fishery age compositions, fishery length compositions, and AI survey age compositions were 0.0158, 0.0286, and 0.0173 in Model 21(2023), whereas these values were 0.0094, 0.0170, and 0.0109 in Model 25_2 (i.e., a split-species version of Model 21(2023)). The fits to the composition data, aggregated across years and weighted by the yearly sample size, are shown in (Figures 12-15). Neither the combined-sex or the split-sex models strongly fit the variations between age or length bins in the composition data. For example, although the combined-sex models fit the fishery age compositions better than the survey age compositions, the aggregated numbers at age in the fishery for ages 20-22 and ages 28 – 32 are underestimated by the modeled aggregated numbers at age (Figure 12). Similar lack of fits to the age compositions are observed for the split-sex models (Figure 13). In the fits to the fishery length compositions, the gain from the split-sex models relative to the combined-sex models comes mainly from the fits to the female length composition data (Figures 14 and 15).

The estimation of survey selectivity and catchability interact to affect the estimated scale of population biomass. For combined-sex models with time-invariant survey selectivity, models with strong priors on survey catchability and on the asymptote of the survey selectivity curve (i.e., models 2021(2023), 25_4, and 25_5) all estimate nearly identical survey selectivity curves (Figure 16), but the estimated biomass is larger for models 25_4 and 25_5 (Figure 17) because the estimated survey catchability for these models has been reduced from 1 to 0.76 and 0.94, respectively (Table 3). For the combined-sex model with time-varying survey selectivity (Model 25_6), the estimated selectivity curves between the time blocks are very similar to each other (Figure 16), and the estimated biomass is very similar to the current Model 21(2023) (Figure 17). Removing the survey selectivity constraint (Model 25_1) results in lower selectivity across all ages, and a substantial increase in biomass relative to the current Model 21(2023).

Similar patterns are observed in split-sex models with time-invariant survey selectivity, where the constraint on survey selectivity results in the nearly identical selectivity curves across models 25_2, 25_7, and 25_8, with little difference between the curves for males and females (Figure 18). Relaxing the constraint on survey selectivity for the split-sex model 25_3 resulted in substantially lower selectivity for both males and females, and the largest estimate of 2023 biomass (768 kt) of any of the models considered (Table 3, Figure 17). The split-sex model with time-varying survey selectivity (Model 25_9) shows only slight differences between the time blocks, with males showing slightly lower selectivity than females, similar to its combined-sex model counterpart (Model 25_6). Fishery selectivity curves were similar between the models (Figure 19).

For combined-sex models, the value of *M* was at or below the prior median of 0.06, ranging from 0.051 to 0.060 (Table 3). For split-sex models, the estimated natural morality of males ranged from 0.059 to 0.066, and was larger than the estimated *M* for females (range of 0.049 to 0.058). The combination of higher female survey selectivity and lower female *M* allows the split-sex models to fit the higher proportion of females in the AI survey age composition data (Figure 20).

Retrospective analysis

Retrospective estimates of spawning stock biomass, using 10-year peels, was conducted for all models. The Mohn's rho for the current model 21(2023) is -0.156, whereas the Mohn's rho for the other models (excluding model 25_3) ranged from -0.079 to -0.171 (Table 3, Figure 21). Model 25_3 is the split-sex model without constraints on the survey selectivity curve, and estimates of AI survey selectivity at age were progressively lower as the number of recent years peeled from the model increased. The lowest (in absolute terms) value of Mohn's rho was -0.079 and was obtained with model 25_4, which is a combined-sex model with in which the CV for the prior distribution on AI survey catchability was increased to 0.4. The estimated catchability for this model was 0.76, the lowest of the models considered and a 24% reduction from the value of 1 in the current model 21(2023) (Table 3).

Conclusions

Sex-specific differences in weight at age were found for BSAI northern rockfish, and the proportion female in the Aleutian Islands (AI) trawl survey abundance estimates was approximately 62% rather than the 50% assumed with a combined-sex model. Examination of observed sex-specific age and length frequency distributions indicate a distribution of similar shape (i.e., variance) with a slightly larger mean age or length for females. In split-sex models, the sex-specific differences in AI selectivity curves were relatively minor and the estimated natural mortality for males was approximately 20% larger than that for females. The retrospective results were generally similar between the combined-sex and split-sex models.

The differences in the growth curves between spatial regions appears to be larger than the differences between sexes. Because the spatial distribution of sampled fish not necessarily be representative of the population abundance or fishery catch (particularly with length-stratified sampling), spatially-weighted averages are used to obtain the appropriate spatial weighting. However, the sampling of fish in the survey and fishery is random with respect to sex. Consequently, combined-sex age and length compositions inherently incorporate the appropriate sex ratio and lead to similar results as the split-sex models since sex-specific natural mortality and selectivity were similar.

Models with time-varying AI survey catchability fit the AI survey biomass estimates better, as expected. However, the retrospective patterns were worse than the previously accepted model (Model 21(2023)). Given the survey design and strict protocols followed by the AI survey, evidence that catchability would be changing systematically over time is lacking. Similarly, models with time-varying AI survey selectivity (with some constraint) only showed minor differences in survey selectivity between the time blocks, and produced retrospective patterns and estimated biomass similar to the previously accepted model.

In conclusion, we recommend continuing with the previously accepted model.

References

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Table 1. Number of otoliths read, and the number of hauls, by area and sex in the AI trawl survey.

	WAI						CAI					
	Otolliths read			Hauls (otoliths read)			Otolliths read			Hauls (otoliths read)		
Year	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined
1991							113	130	243	5	5	5
1994	78	102	180	6	7	8	31	30	61	3	3	3
1997	111	114	225	19	19	23	99	112	211	19	19	23
2000	107	120	227	24	26	32	134	141	275	21	20	26
2002	38	50	88	20	23	25	36	38	74	12	15	19
2004	83	110	193	19	23	23	72	84	156	13	17	17
2006	88	107	195	18	18	19	67	81	148	11	12	13
2010	90	105	195	20	19	21	93	93	186	19	19	21
2012	87	119	206	19	29	30	72	84	156	17	15	18
2014	89	112	201	24	22	25	64	83	147	10	12	13
2016	96	192	288	54	70	73	72	95	167	36	40	42
2018	93	196	289	53	69	73	69	81	150	29	33	38
2022	88	196	284	48	57	59	64	127	191	29	36	39
2024	137	168	305	55	57	61	65	127	192	28	37	39

	EAI						EBS					
	Otolliths read			Hauls (otoliths read)			Otolliths read			Hauls (otoliths read)		
Year	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined
1991	59	100	159	7	7	7	21	33	54	2	2	2
1994	62	65	127	7	6	7	24	17	41	1	1	1
1997	91	103	194	16	17	22						
2000	92	107	199	21	21	27	12	9	21	6	6	7
2002	28	38	66	8	13	13	17	14	31	11	7	12
2004	51	69	120	15	15	20	21	25	46	4	4	5
2006	40	73	113	13	14	18	34	43	77	5	6	7
2010	62	77	139	14	20	21	8	10	18	5	8	9
2012	68	92	160	12	15	16	32	20	52	3	3	3
2014	70	80	150	16	13	17	26	26	52	5	4	5
2016	36	70	106	17	26	27	3	12	15	3	4	4
2018	33	85	118	22	29	29	5	25	30	4	7	7
2022	57	90	147	24	29	31	13	12	25	6	5	6
2024	45	68	113	20	20	23	23	31	54	9	11	11

Table 2. Number of otoliths read, and the number of hauls, by area and sex in the BSAI fishery.

	WAI						CAI					
	Otoliths read			Hauls (otoliths read)			Otoliths read			Hauls (otoliths read)		
Year	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined
2000	28	26	54	14	15	16	36	26	62	16	13	17
2001	22	24	46	13	16	18	21	27	48	17	17	22
2002	38	51	89	19	21	26	40	33	73	19	20	25
2003	81	92	173	49	48	63	43	53	96	21	22	27
2004	42	68	110	27	33	40	22	30	52	13	14	15
2005	33	26	59	22	16	26	15	11	26	7	7	8
2006	31	31	62	17	19	24	60	67	127	26	29	30
2007	28	35	63	17	21	28	39	51	90	20	24	29
2008	54	49	103	36	33	48	26	77	103	22	44	50
2009	33	58	91	24	36	43	24	41	65	15	21	26
2011	45	67	112	35	48	56	59	103	162	35	39	42
2013	47	51	98	35	36	54	122	134	256	62	64	79
2015	112	132	244	74	90	121	80	79	159	58	50	75
2017	65	99	164	53	77	112	58	94	152	50	78	106
2019	181	192	373	149	148	245	69	104	173	59	85	113
2020	158	130	288	131	114	209	80	97	177	67	80	126
2021	153	174	327	127	142	225	54	114	168	47	89	116

	EAI						EBS					
	Otoliths read			Hauls (otoliths read)			Otoliths read			Hauls (otoliths read)		
Year	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined
2000	11	18	29	6	10	10	14	8	22	6	3	6
2001	17	17	34	14	9	16	4	2	6	2	1	2
2002	5	11	16	5	5	5	7	8	15	3	3	4
2003	26	13	39	14	9	17	2	7	9	2	3	3
2004	13	8	21	8	5	10	8	5	13	3	3	4
2005	8	12	20	5	6	6	6	6	12	2	4	4
2006	8	4	12	5	3	7	17	12	29	9	7	10
2007	37	33	70	24	20	32	3	2	5	1	1	1
2008	23	26	49	17	18	27						
2009	19	27	46	15	16	23	15	29	44	8	9	11
2011	27	22	49	21	17	28	61	77	138	46	51	74
2013	90	63	153	47	41	65	41	48	89	32	34	53
2015	63	73	136	50	48	69	24	11	35	22	11	29
2017	31	29	60	28	27	48	27	31	58	25	27	42
2019	83	67	150	67	56	109	71	36	107	62	33	86
2020	50	36	86	43	33	67	16	24	40	14	21	32
2021	73	42	115	63	36	88	38	32	70	34	28	56

Table 3. Negative log likelihood of model components, root mean squared errors, and estimates of key quantities.

	Model 21 (2023)	Model 25_1	Model 25_2	Model 25_3	Model 25_4	Model 25_5	Model 25_6	Model 25_7	Model 25_8	Model 25_9
	Combined-sex	Combined-sex	Split-sex	Split-sex	Combined-sex	Combined-sex	Combined-sex	Split-sex	Split-sex	Split-sex
Negative log-likelihood										
Data components										
AI survey biomass	8.77	9.32	8.84	10.15	8.82	4.54	9.64	8.84	4.65	9.74
Catch biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fishery age comp	257.77	251.12	432.73	423.62	257.99	257.67	257.94	433.28	432.84	432.61
Fishery length comp	84.10	81.93	112.06	104.17	84.08	84.08	84.92	111.85	111.97	112.78
AI survey age comp	198.34	190.83	330.78	308.53	198.24	198.42	188.60	330.13	330.56	321.16
Maturity	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21
Proportion female										
Priors and penalties										
Recruitment	-2.91	-2.27	-3.58	-1.68	-3.23	-3.02	-3.72	-3.99	-3.76	-4.68
Prior on survey q	0.00	0.00	0.00	0.00	0.13	0.82	0.00	0.33	0.93	0.00
Prior on M	0.35	0.00	0.77	0.47	0.17	0.37	0.45	0.56	0.69	0.85
survey sel constraint	1.54	0.00	2.56	0.00	1.46	1.50	1.06	2.42	2.47	1.81
Fishing mortality penalty	5.91	5.58	5.53	4.85	5.86	5.75	5.92	5.40	5.42	5.55
Time-varying survey sel constraint	410.91	410.91	153.33	153.33	410.91	410.91	414.17	153.33	153.33	157.88
Total negative log-likelihood	561.08	543.73	896.90	857.32	560.73	557.34	555.27	896.02	892.99	891.59
Parameters	139	139	144	144	139	144	151	144	149	168
Root mean square error										
AI survey biomass	0.355	0.333	0.365	0.327	0.351	0.310	0.384	0.355	0.313	0.391
Recruitment	0.622	0.636	0.631	0.651	0.620	0.619	0.604	0.626	0.628	0.608
Combined sexes										
Fishery age comp	0.0158	0.0155			0.0158	0.0158	0.0158			
Fishery length comp	0.0286	0.0284			0.0286	0.0286	0.0288			
AI survey age comp	0.0173	0.0167			0.0173	0.0173	0.0168			
Split sexes										
Fishery age comp			0.0094	0.0093				0.0094	0.0094	0.0094
Fishery length comp			0.0170	0.0166				0.0170	0.0170	0.0171
AI survey age comp			0.0109	0.0102				0.0109	0.0109	0.0108
Estimated key quantities										
Mohn's rho	-0.156	-0.171	-0.144	0.295	-0.079	-0.164	-0.142	-0.118	-0.163	-0.135
M (combined)	0.052	0.060			0.054	0.052	0.051			
M (females)			0.049	0.058				0.051	0.050	0.049
M (males)			0.060	0.066				0.061	0.060	0.059
AI survey q	1.000	1.000	1.000	1.000	0.755	0.935	1.000	0.668	0.895	1.000
2023 total biomass	308,010	524,000	297,660	768,120	415,490	370,630	306,640	459,870	366,150	298,520
standard deviation	32,138	81,604	29,844	145,890	154,230	79,501	32,451	162,050	76,101	30,433
CV	0.10	0.16	0.10	0.19	0.37	0.21	0.11	0.35	0.21	0.10

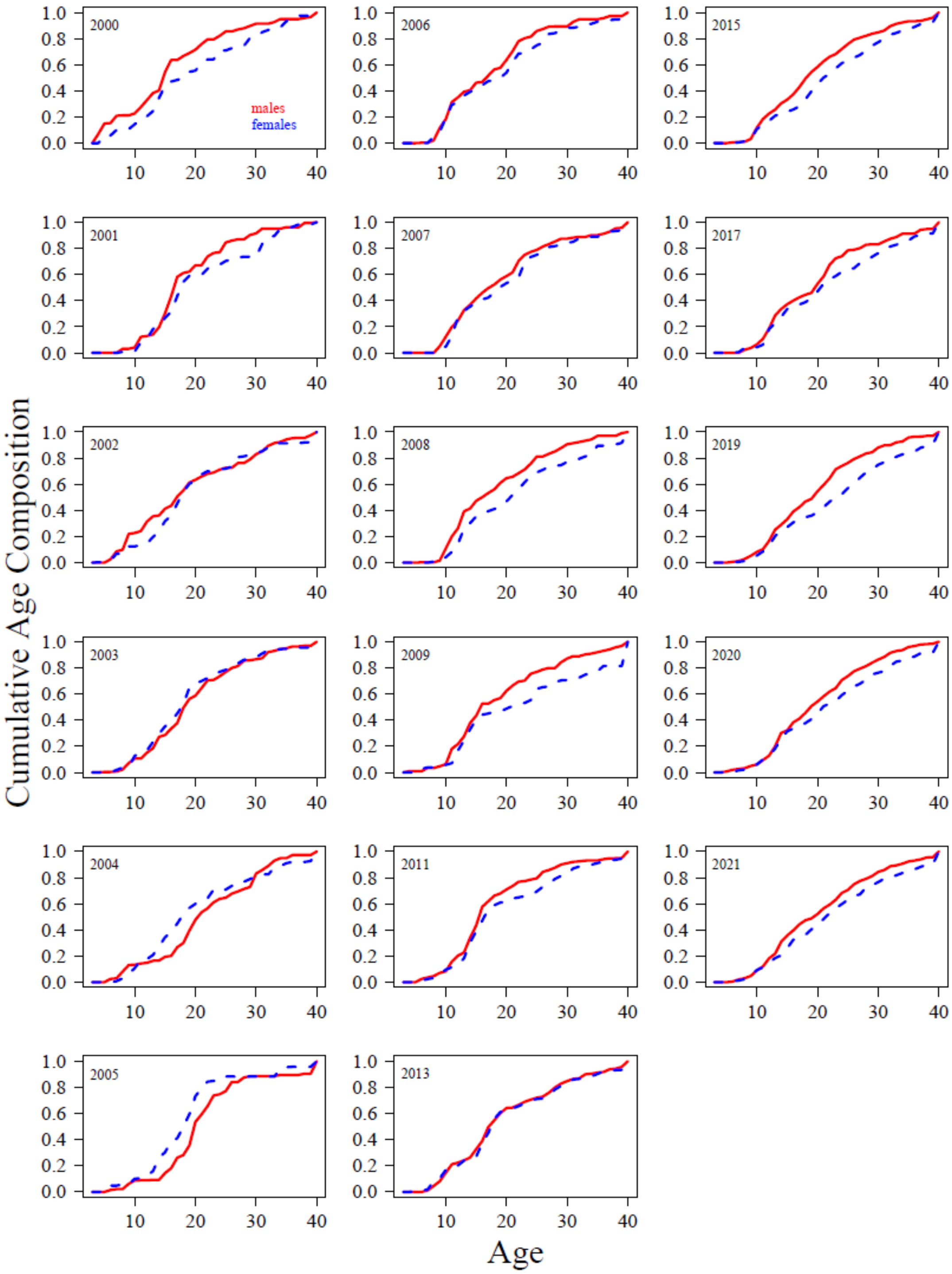

Figure 1. Cumulative age frequency distributions of northern rockfish in the BSAI fishery, by sex.

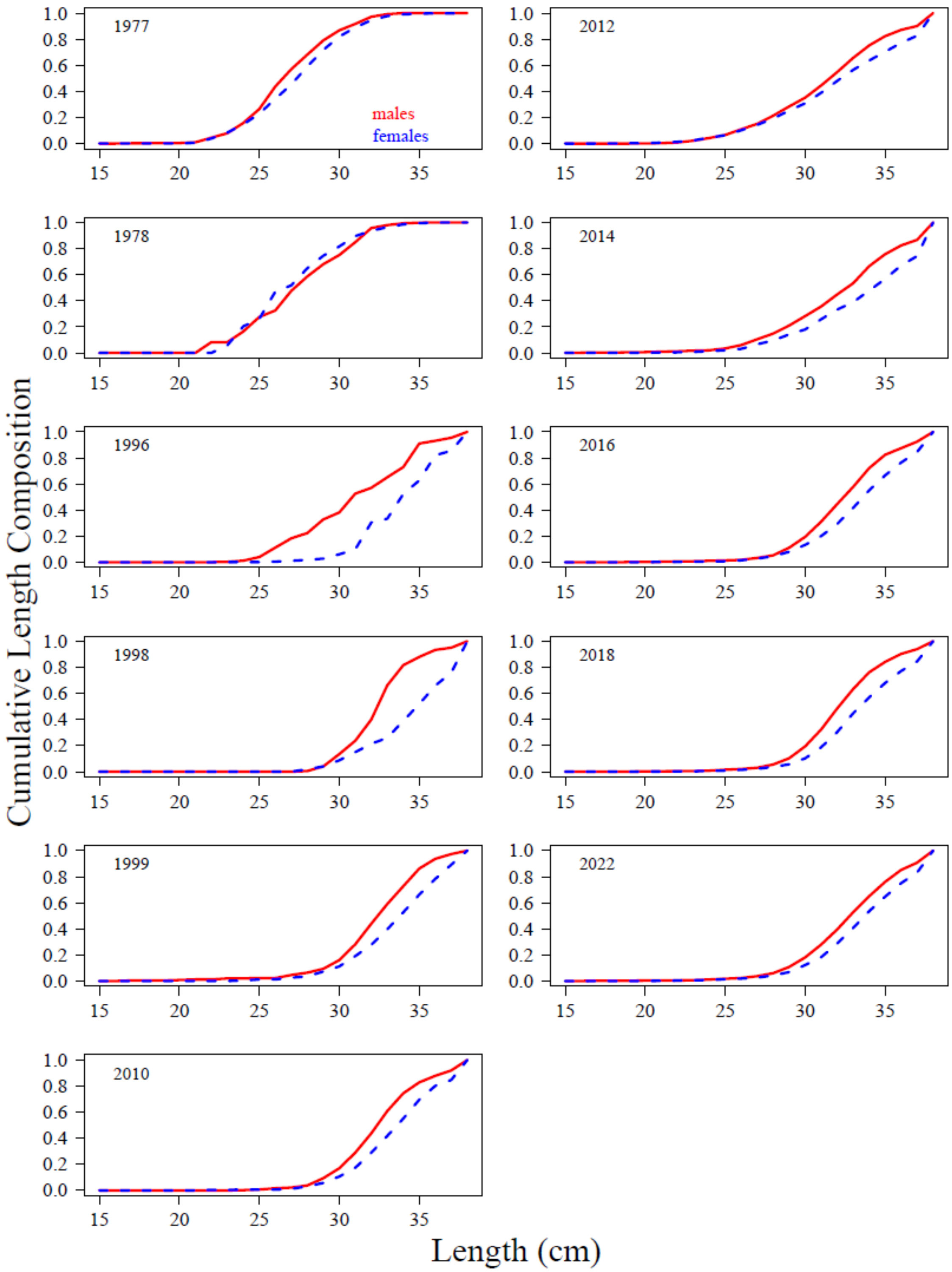

Figure 2. Cumulative length frequency distributions of northern rockfish in the BSAI fishery, by sex.

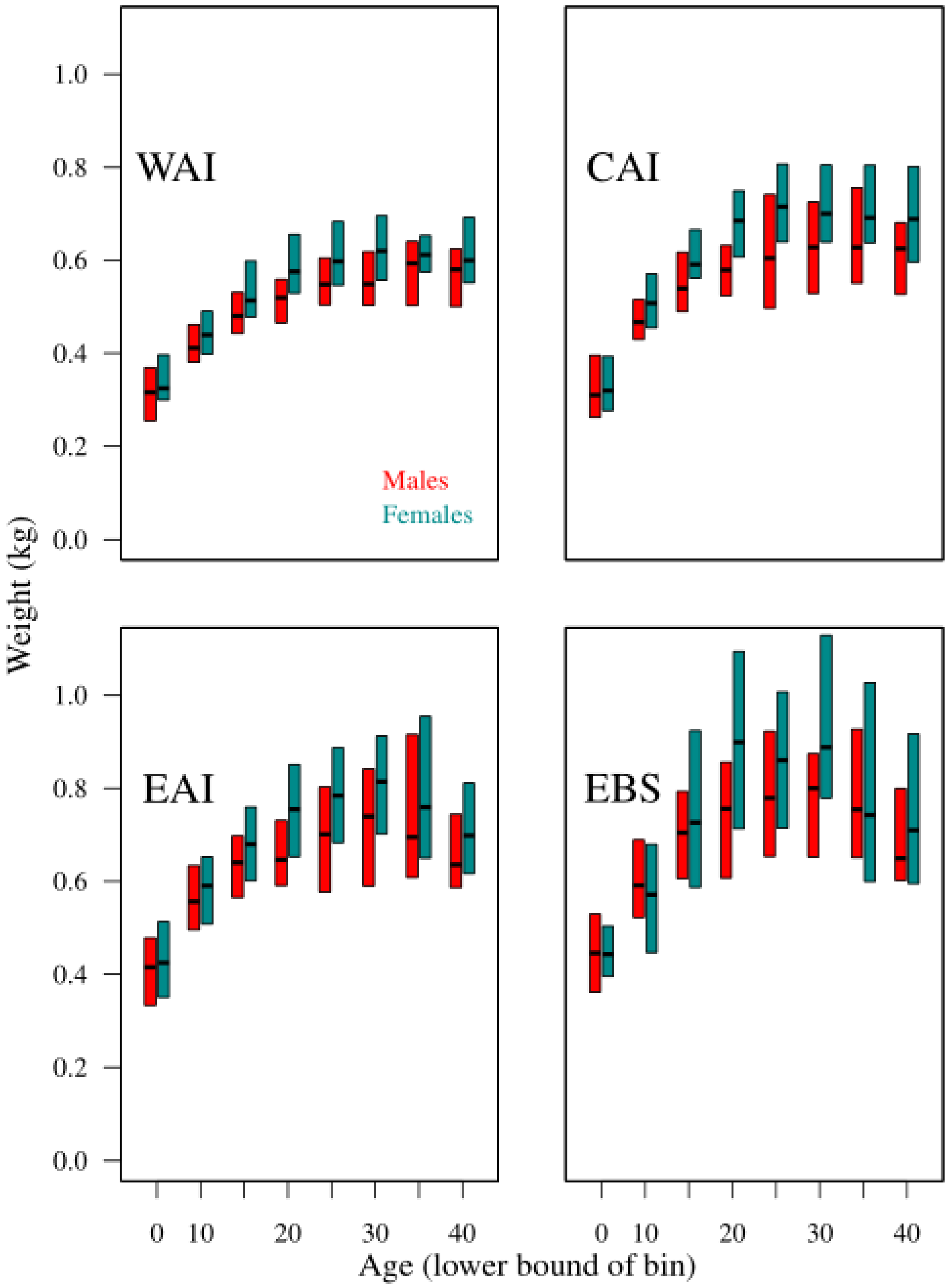

Figure 3. Estimated fishery weights at age, obtained from applying fitted length-weight relationships to estimates of mean length at age per year and spatial region.

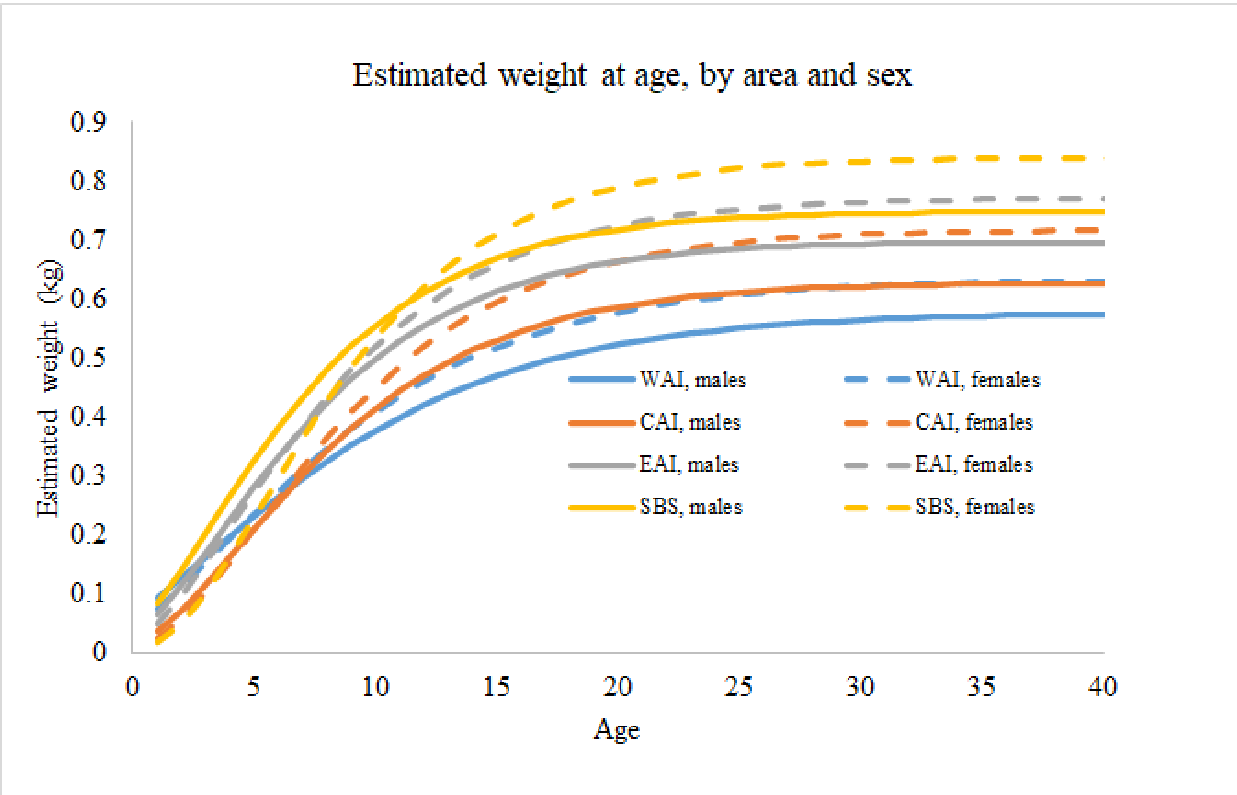

Figure 3. Estimated weight at age of northern rockfish in the BSAI fishery, by area and sex.

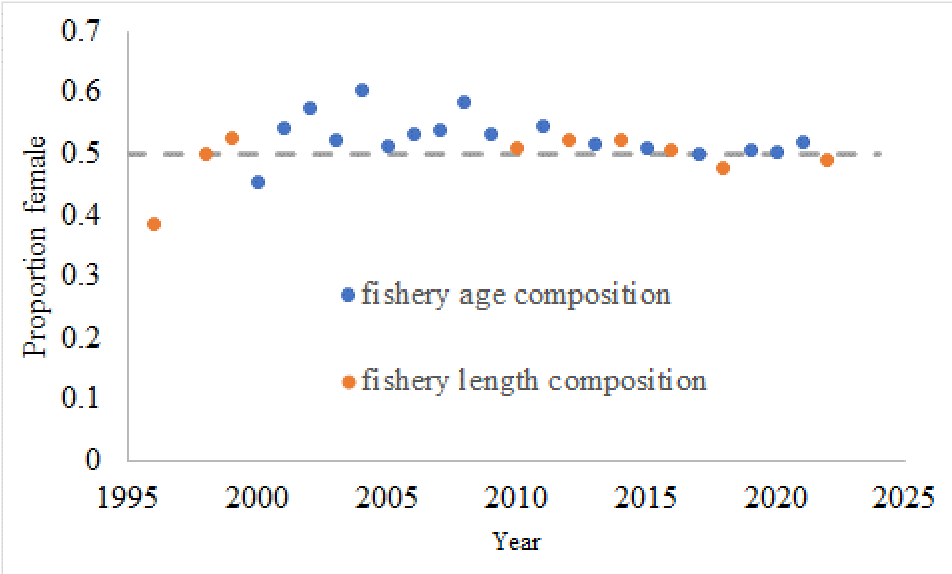

Figure 5. Estimated proportion female in the BSAI fishery length and age compositions.

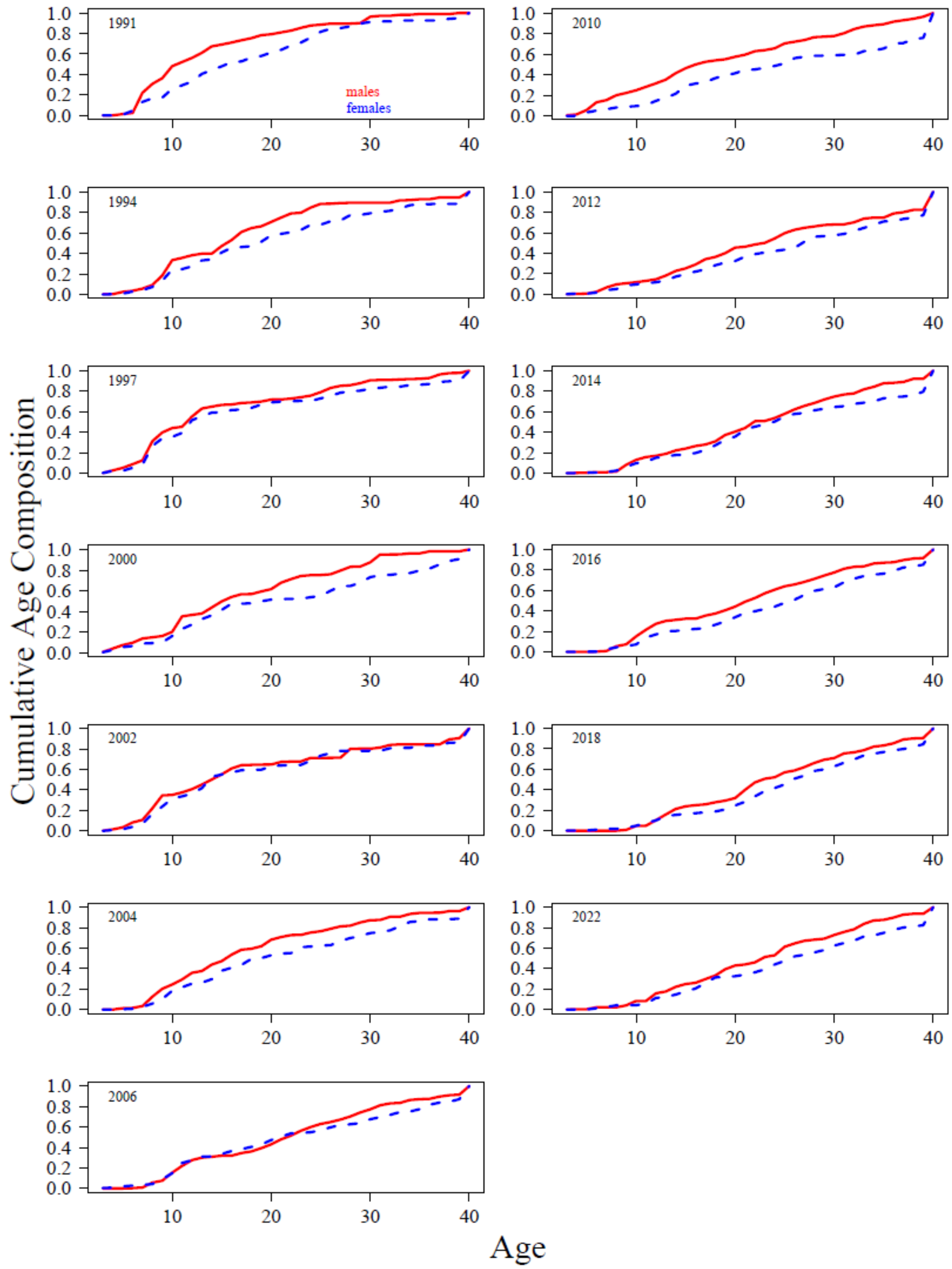

Figure 6. Cumulative age frequency distributions of northern rockfish in the AI survey, by sex.

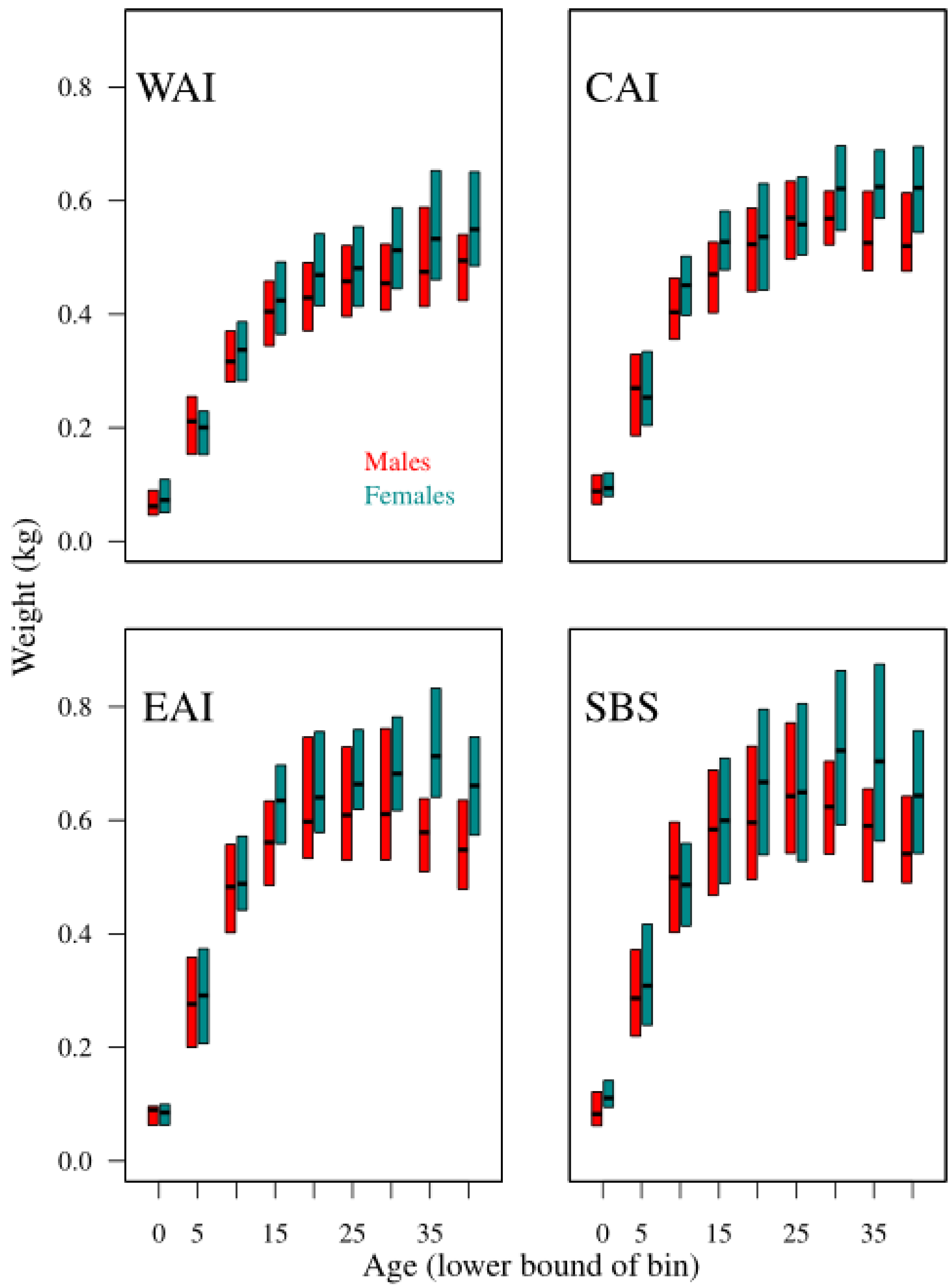

Figure 7. Estimated AI survey weights at age, obtained from applying fitted length-weight relationships to estimates of mean length at age per year and spatial region.

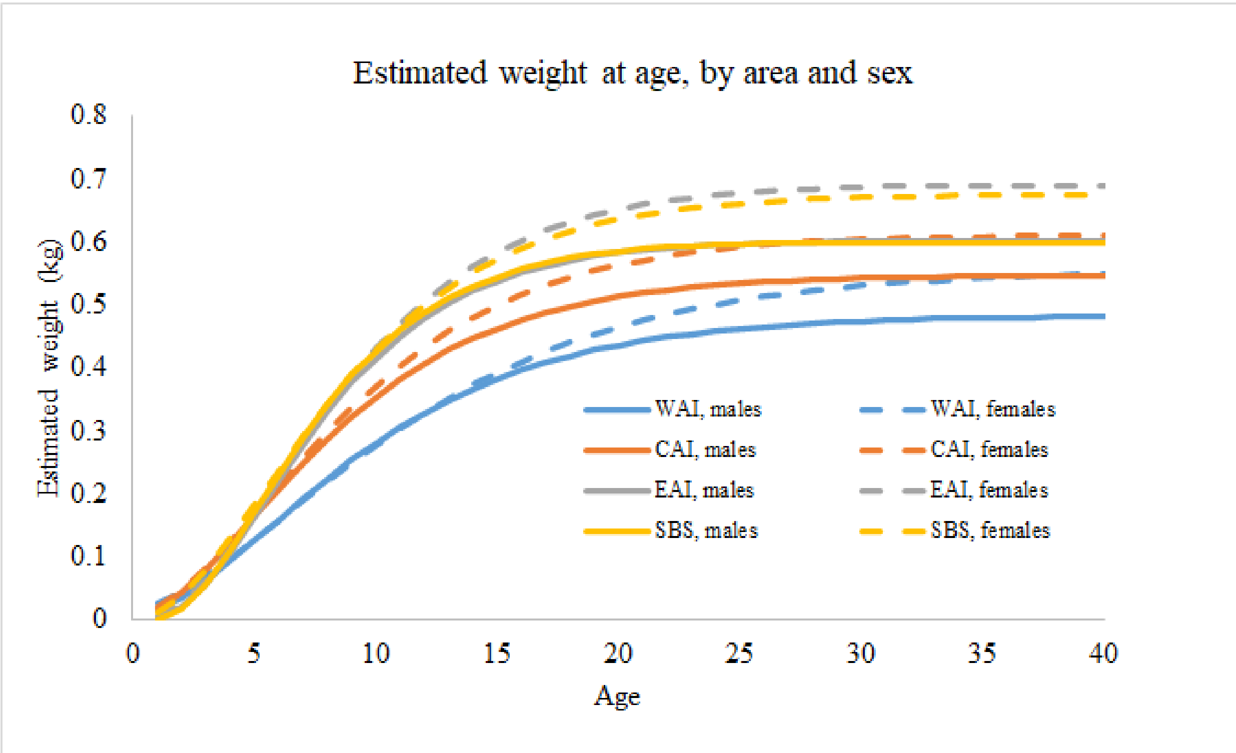

Figure 8. Estimated weight at age of northern rockfish in the AI survey, by area and sex.

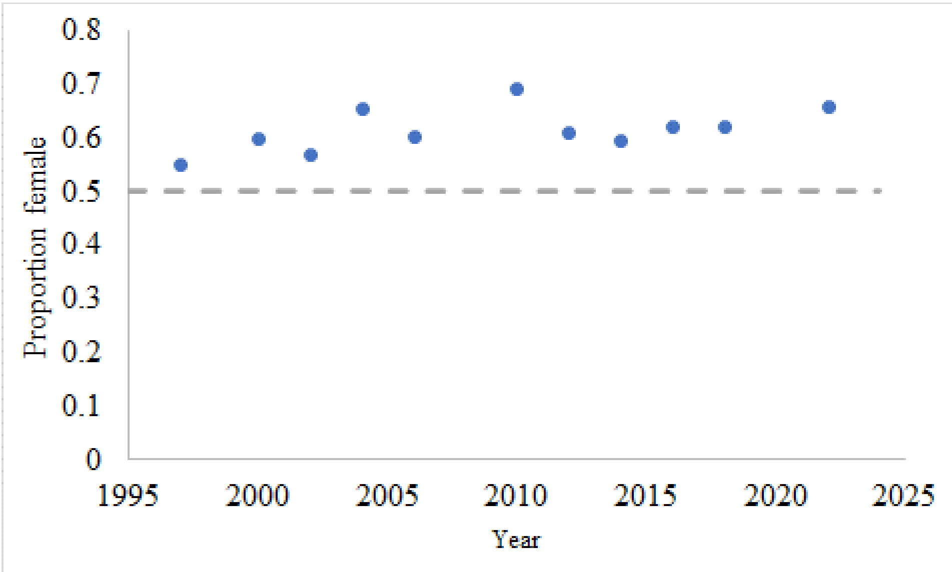

Figure 9. Estimated proportion female in the AI survey age compositions.

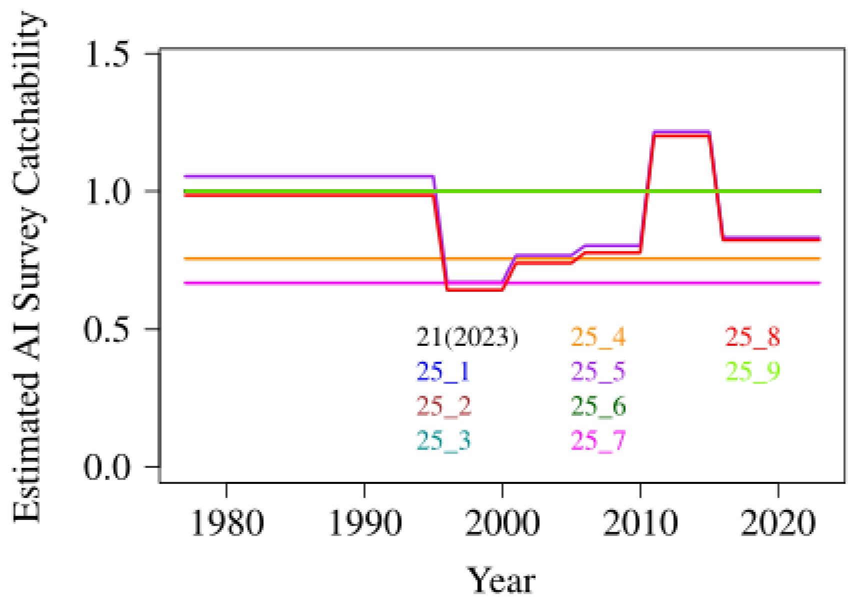

Figure 10. Estimates of AI survey catchability, by model.

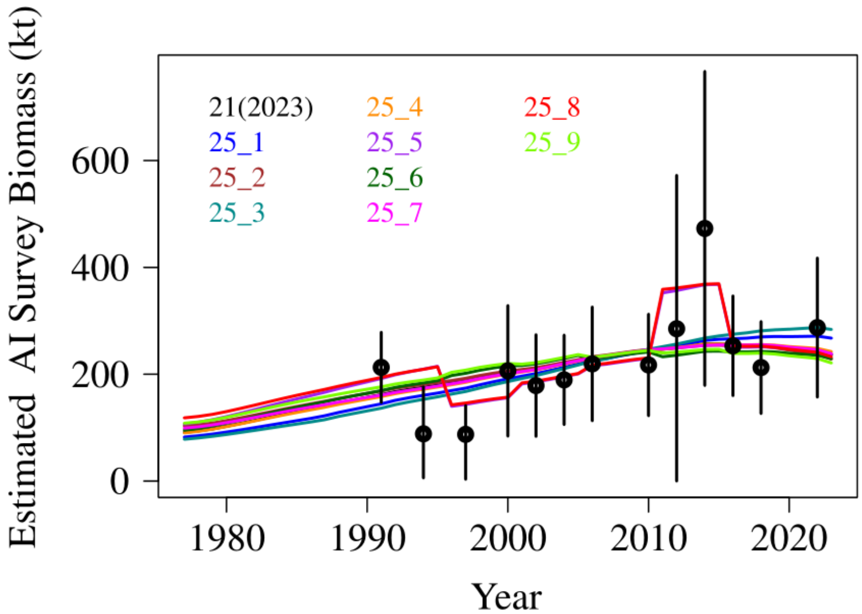

Figure 11. Model fits to the AI survey biomass estimates.

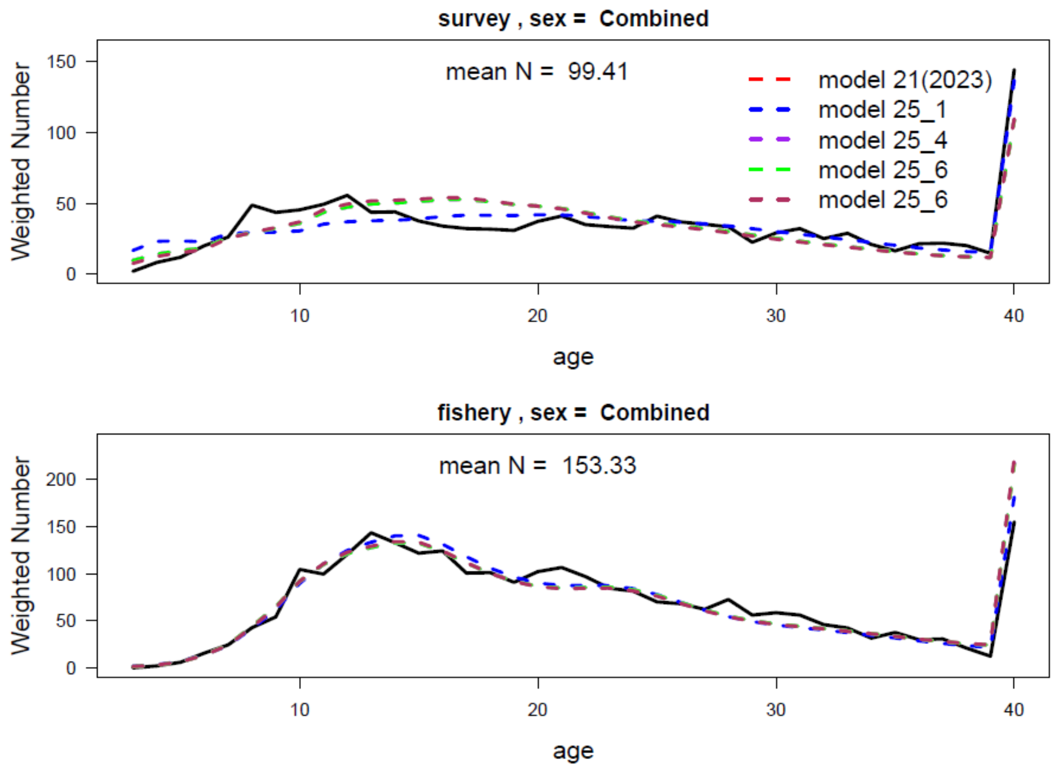

Figure 12. Estimated aggregated observed and estimated age compositions, across the combined-sex models.

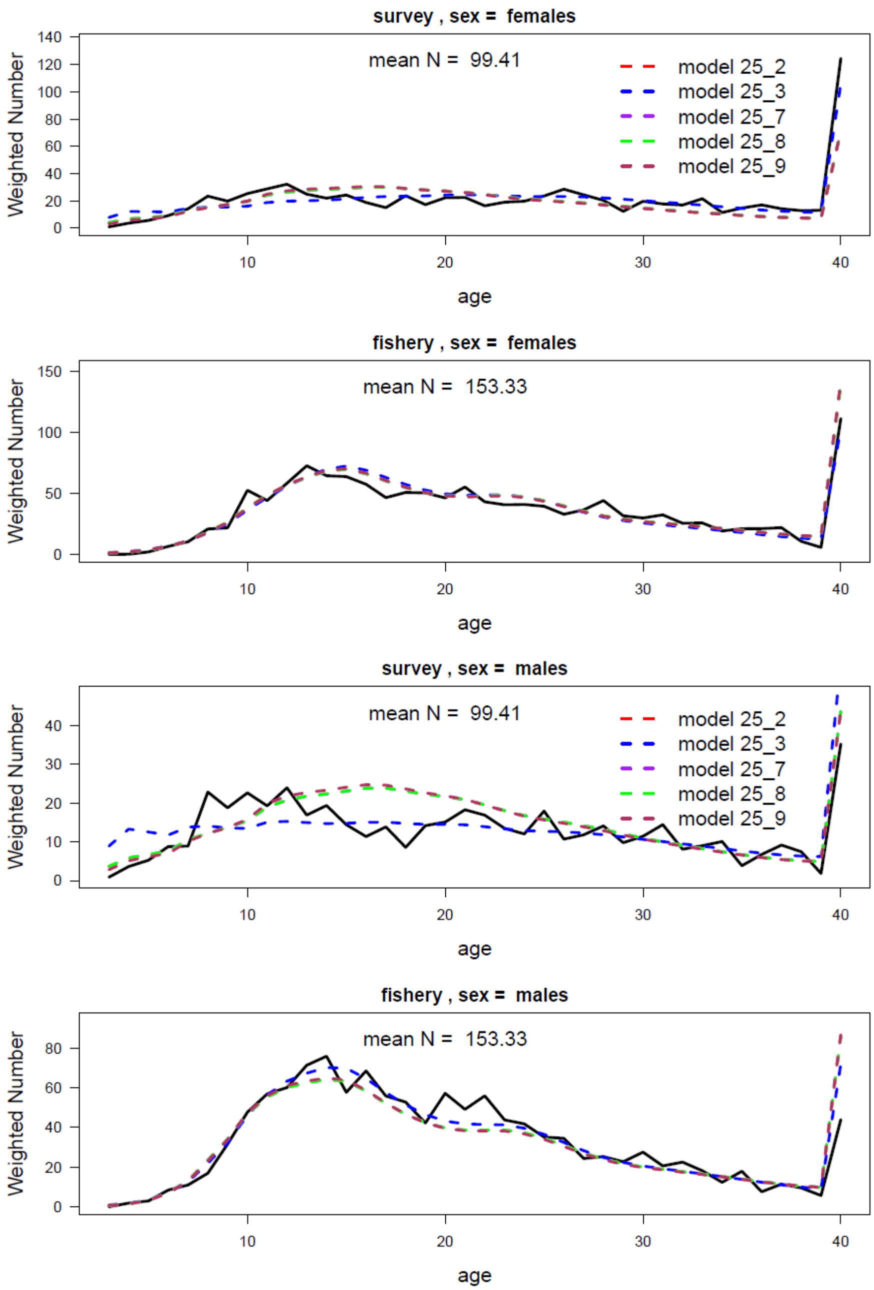

Figure 13. Estimated aggregated observed and estimated age compositions, across the split--sex models.

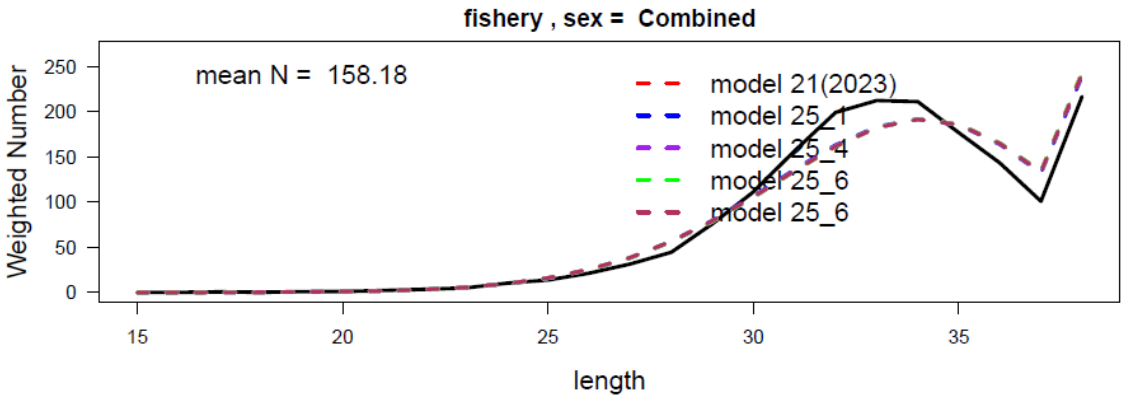

Figure 14. Estimated aggregated observed and estimated fishery length compositions, across the split--sex models.

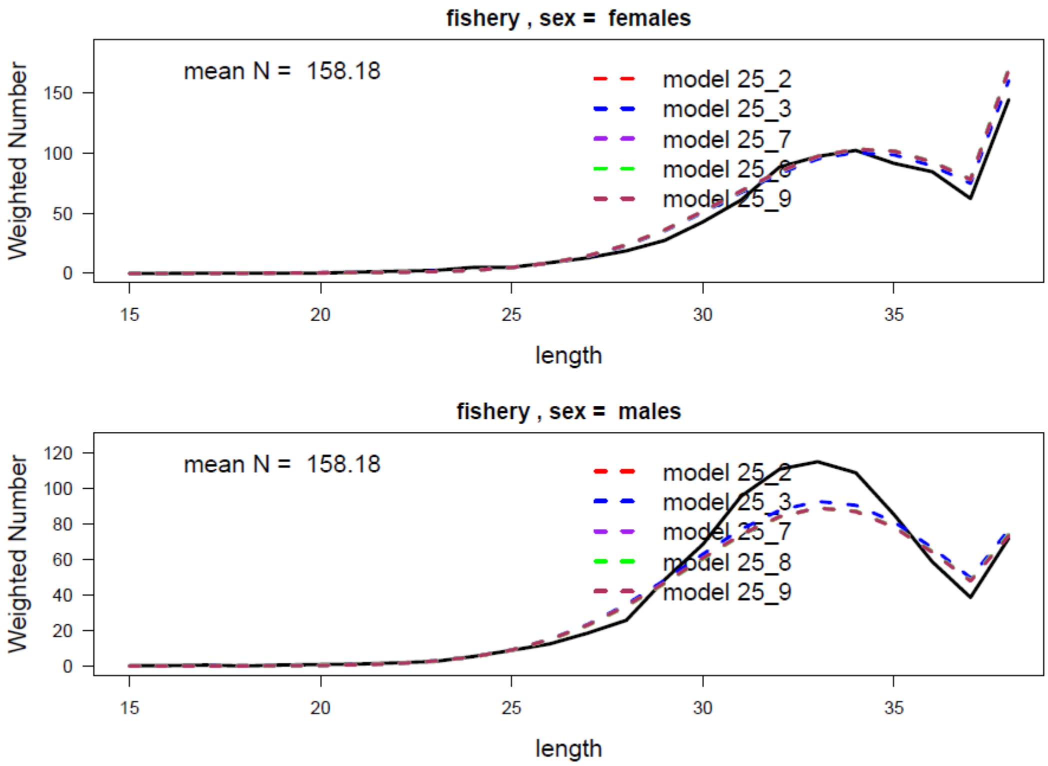

Figure 15. Estimated aggregated observed and estimated fishery length compositions, across the split--sex models.

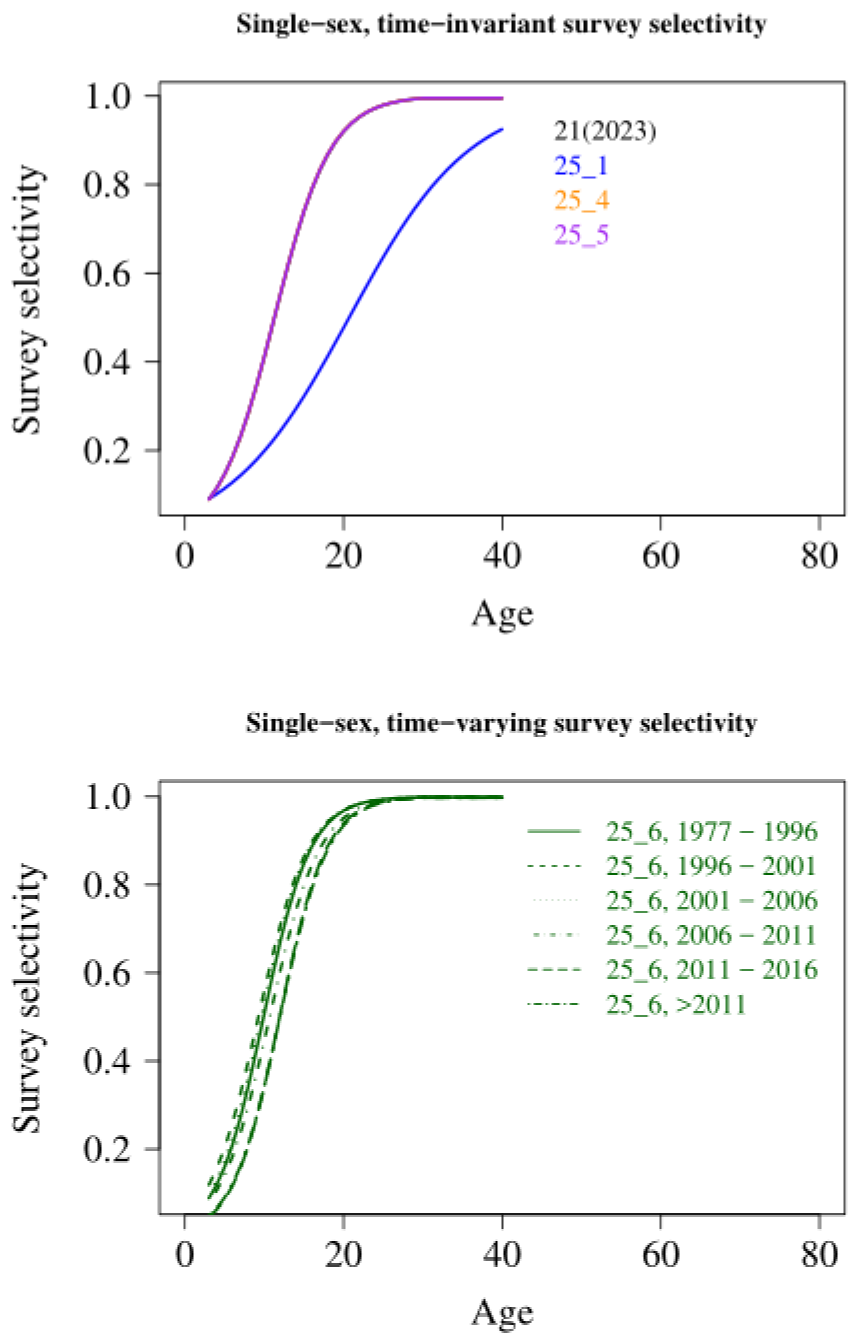

Figure 16. Estimated time-invariant (top panel) and time-varying (bottom panel) AI survey selectivity for combined-sex models.

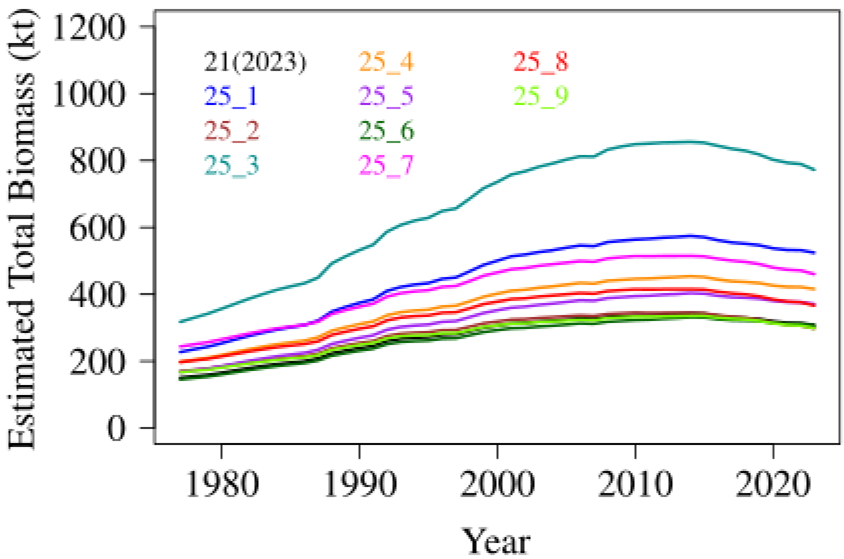

Figure 17. Estimated total biomass, by model.

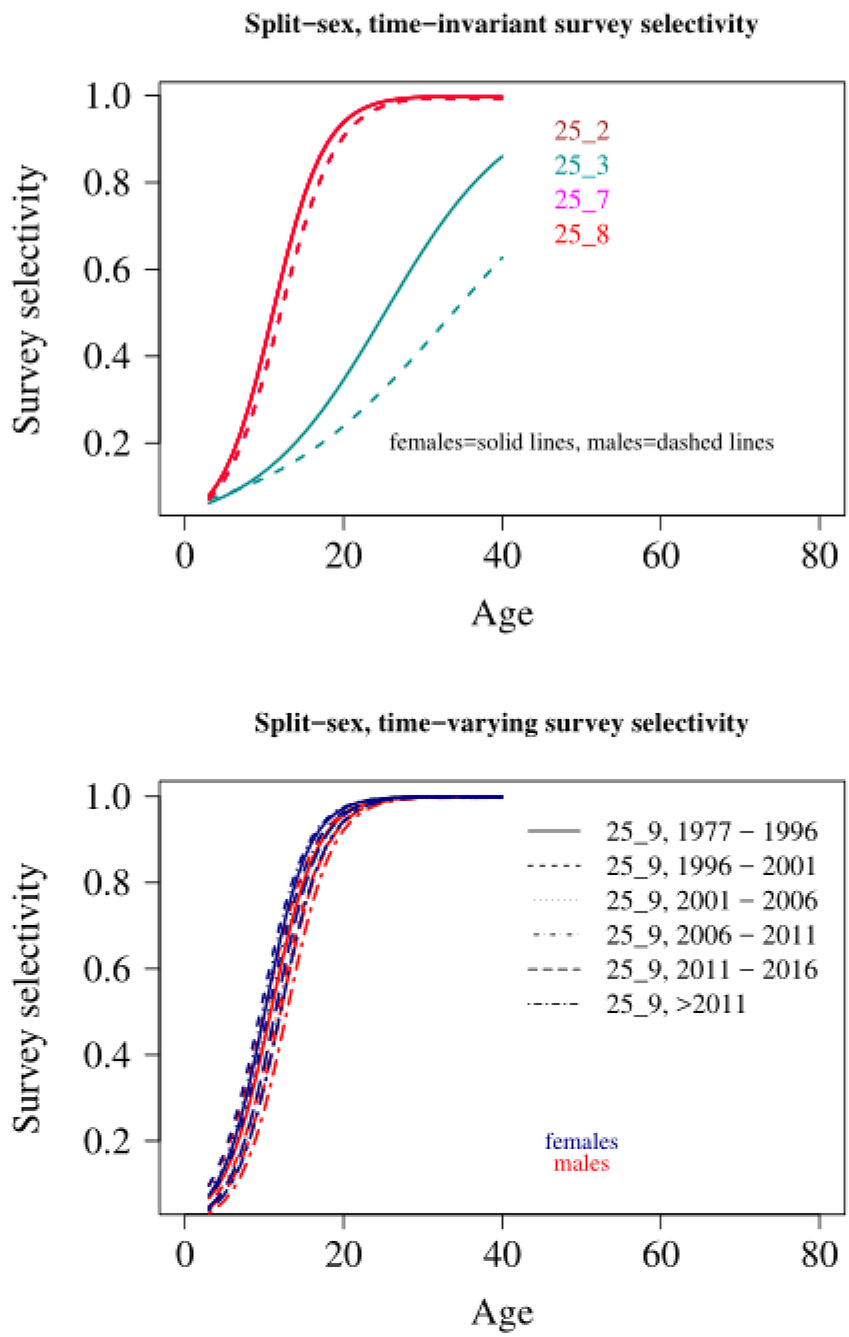

Figure 18. Estimated time-invariant (top panel) and time-varying (bottom panel) AI survey selectivity for split-sex models.

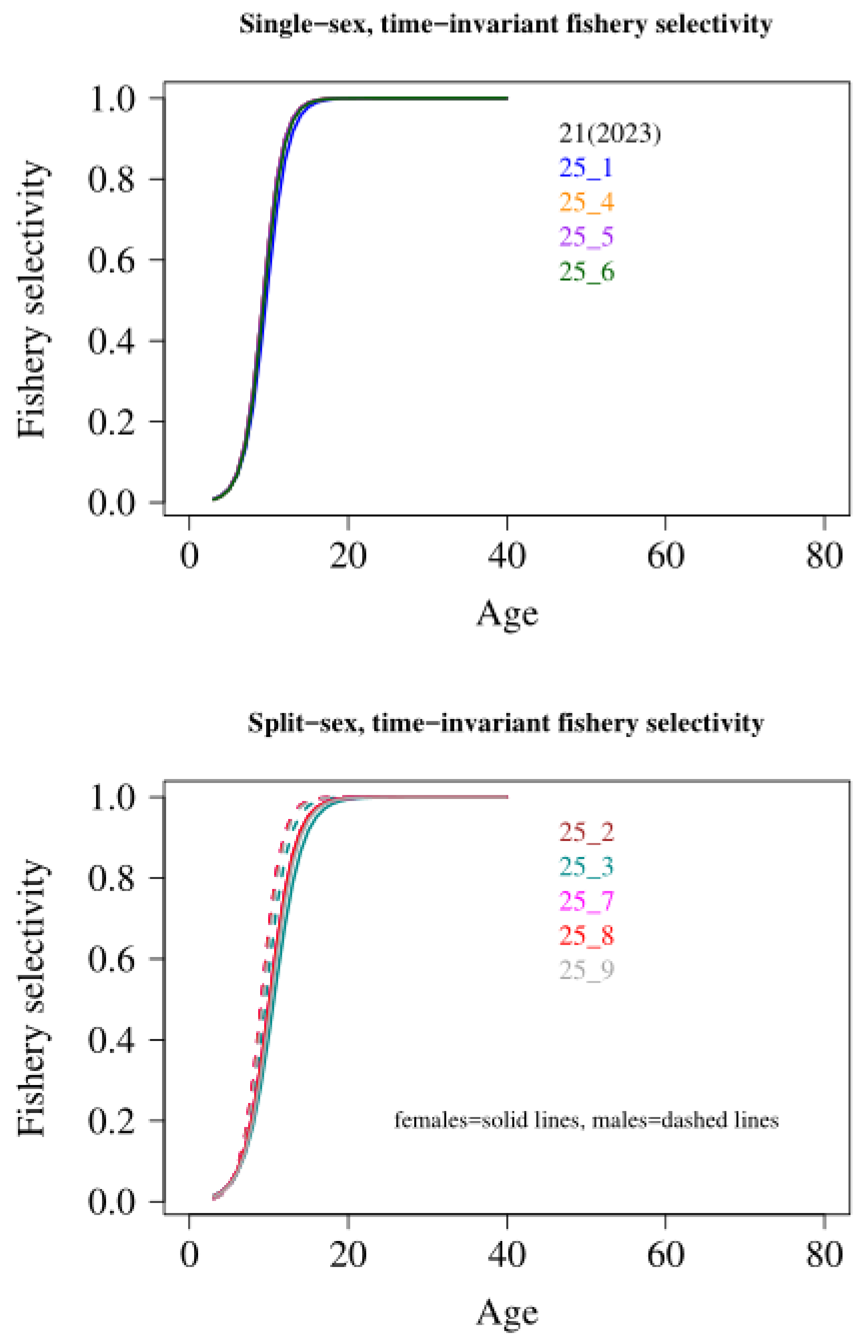

Figure 19. Estimated time-invariant (top panel) and time-varying (bottom panel) fishery selectivity.

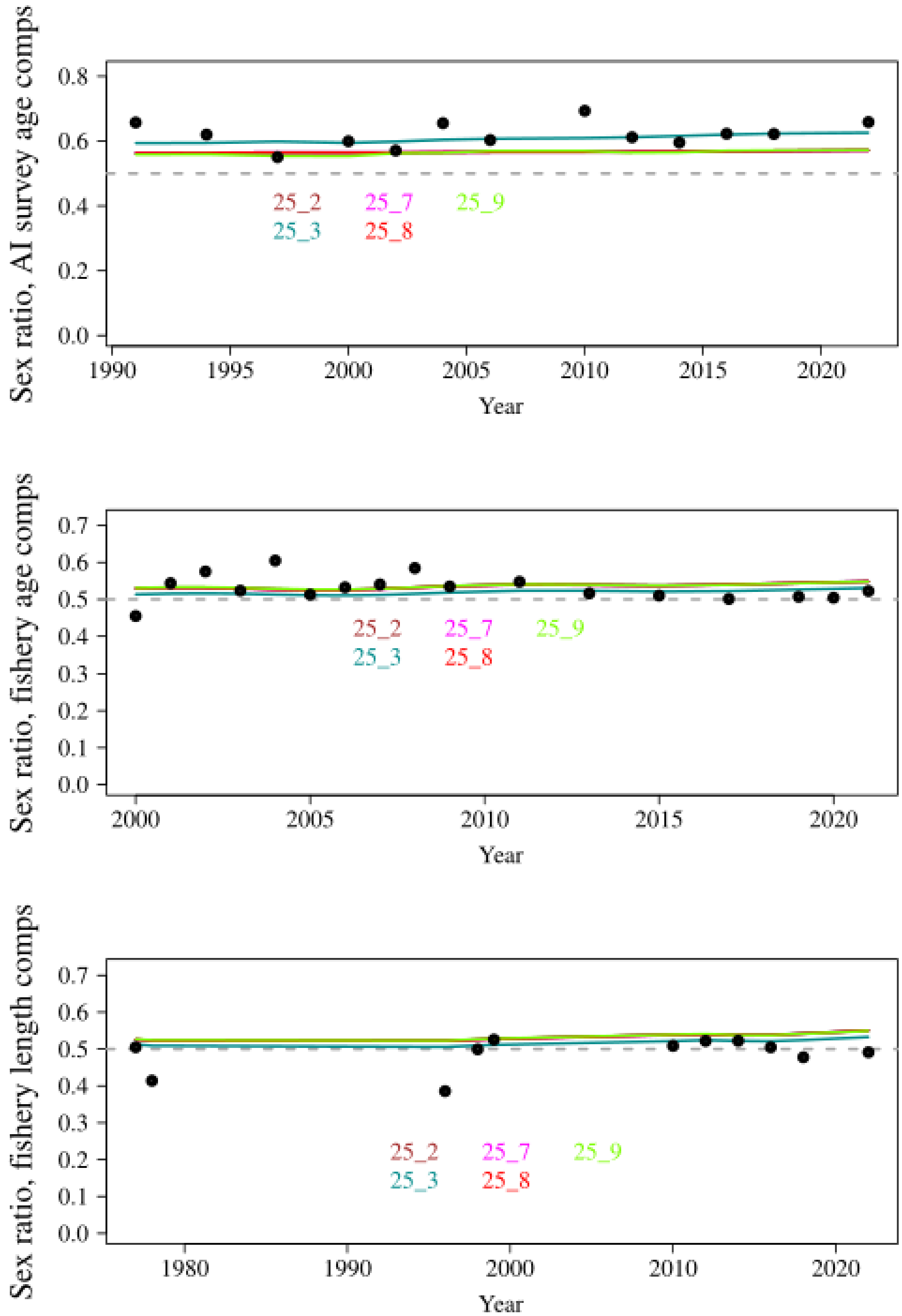

Figure 20. Estimated and observed proportion females in the age and length composition data, by models.

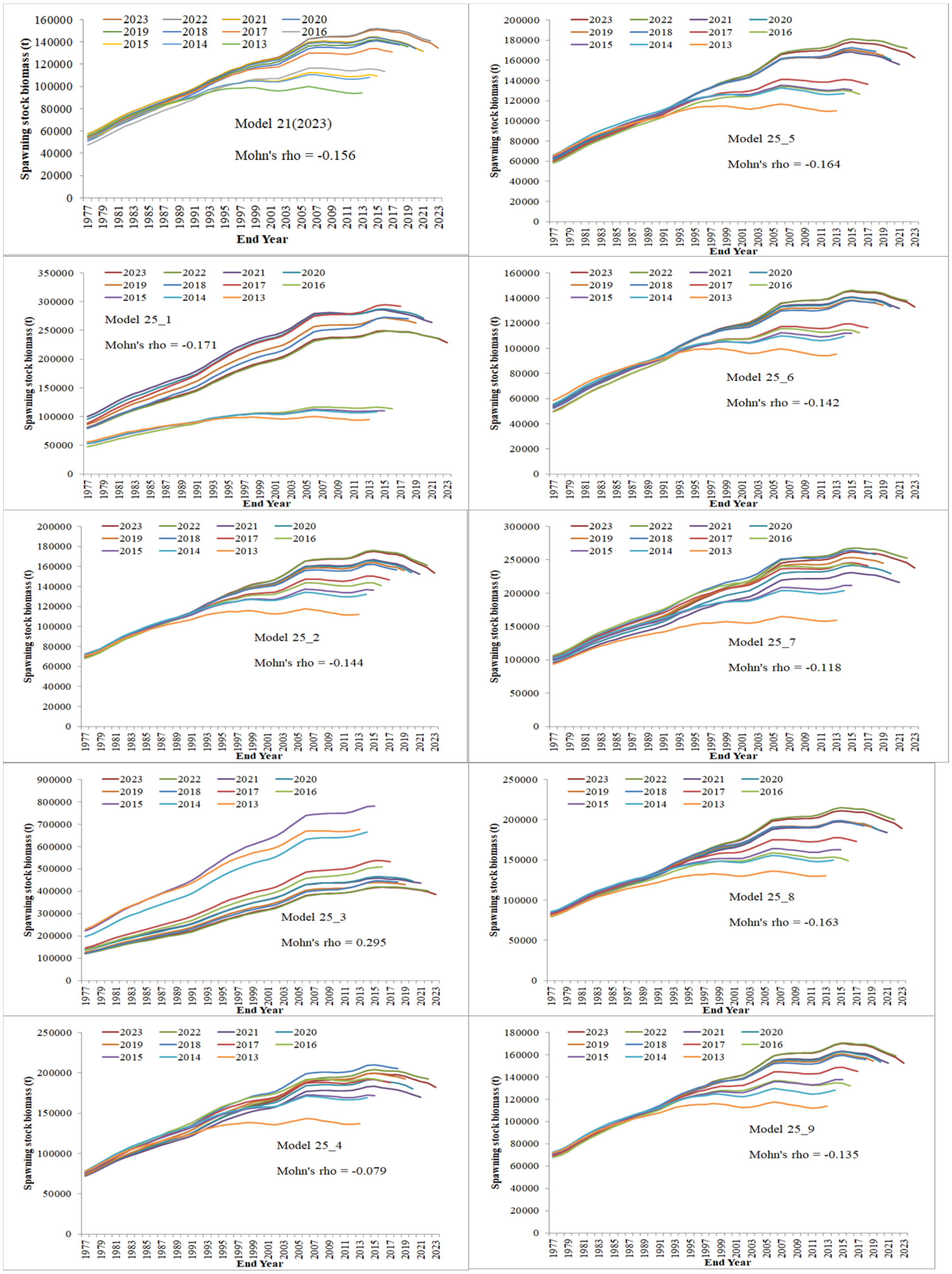

Figure 21. Retrospective estimates of spawning stock biomass, by model.