Preliminary stock assessment for the Gulf of Alaska northern and southern rock soles

Authors: Meaghan Bryan and Kimberly Fitzpatrick

Executive Summary

The northern and southern rock sole stock assessments are on a 4-year assessment cycle and are scheduled for a full operational model in 2025. Relative to the last full assessment in 2021, (Models 21.2 and 21.1 for northern and southern rock sole, respectively) incremental data changes are made to a 2-area growth morph model for northern rock sole and a structural single area model is proposed for southern rock sole. Analyses are modeled using Stock Synthesis 3.

The following incremental data changes are made to 2-area growth morph model with Model 21.2c and d recommended for review in November for northern rock sole.

- Model 21.2: Base northern rock sole model,
- Model 21.2a: Revised length-weight relationship,
- Model 21.2b: Revised catch estimated,
- Model 21.2c: Revised survey length composition input sample size
- Model 21.2d: Francis reweighting of Model 21.2c

For southern rock sole, the 2-area growth model is changed to a single-area model based on re-evaluating the length-at-age data. As such, the model numbering is changed to Model 25. The following changes have been made with Models 25.1c and 25.1d recommended for review in November for southern rock sole.

- Model 21.1: Base southern rock sole model,
- Model 25.1a: Single area model with 50% catch split,
- Model 25.1b: Revised catch estimated,
- Model 25.1c: Uncertainty in length-at-age modeled as a CV,
- Model 25.1d: Revised survey length composition input sample size
- Model 25.1e: Fixed female peak survey selectivity parameter of Model 21.1d.

Introduction

2021 assessment models

The northern and southern rock sole assessment models accepted for management in 2021were 2-area growth morph models configured in Stock Synthesis 3 (SS3). The morphs represent areas, where the areas were defined as central-eastern GOA (CEGOA) and western GOA (WGOA). The models covered ages 0 – 30, age-0s represented recruits and age-30 represented a plus group. The models were sex-specific and started in 1977. Each model had four fleets defined by area and fleet type: CEGOA fishery, WGOA fishery, CEGOA bottom trawl survey, and WGOA bottom trawl survey. Fishery catch are reported as undifferentiated rock sole and was evenly split between the two stocks and by area.

The biological parameters were sex and area-specific. Maturity was assumed to be the same in both areas. The length-weight relationship was assumed to be the same for females and males and in both areas. Female natural mortality was fixed at 0.2 for both areas and male natural mortality was estimated. Growth was assumed to follow von Bertalanffy growth and the parameters were estimated for both sexes and areas.

The stock recruitment relationship was assumed to be the mean level of recruitment, where steepness was fixed at 1, recruitment variability was fixed equal to 0.6. Mean recruitment was estimated and the regime parameter that acts as an offset to equilibrium recruitment was also estimated. Early recruitment deviations were estimated to initialize the numbers at age, the main recruitment deviations were estimated for 1977-2028, and the late recruitment deviations were set equal to 0 so that recruitment was set equal to mean recruitment.

Sex-specific, size-based selectivity functions were estimated for the fishery and survey fleets and assumed to be constant over time. A double normal selectivity pattern was used for the fishery and the survey.

Area-specific fishery and survey selectivity was assumed to by logistic. The parameters associated with the descending side of the double normal curve and the selectivity of the final size bin were fixed to accommodate this assumption for the fishery and survey fleets. Male selectivity was estimated as an offset of female selectivity for all fleets. When using a double normal pattern, five additional parameters are required to differentiate from the opposite sex. These parameters are length at peak selectivity, the ascending and descending limbs, and the selectivity at the final length bin. An additional parameter represents the apical selectivity for males. It was assumed that apical selectivity was 1 for all fleets. The peak and ascending offset parameters were estimated and all other offset parameters were fixed.

Area-specific, survey catchability was fixed equal to 1 in all model configurations.

The following data were used in the models:

Data source	**Years**
Fishery catch (assumed 50% NRS, 50% SRS)	1977-2021
NMFS GOA groundfish survey biomass and SE	1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021
Fishery length composition	1997-2021
NMFS GOA groundfish survey length composition	1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019
NMFS GOA groundfish survey CAAL (2019 age data were not available for NRS, but have been aged since the 2021 assessment and will be added to the model for November, as well as the 2023 CAAL)	1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2017, 2019*

2025 rock sole models

We present several data updates and implement them in the models. The first is a new approach to estimating species-specific catch from the total rock sole catch data. Catch is not reported by species and it has been assumed that catch is evenly split between species. This has been questioned by the Plan Team and SSC in the past; therefore, we use the NMFS Observer Program data that has species-specific observations to split the aggregate rock sole catch and implement the new estimates in the assessment models. We also update the input sample size for the bottom trawl survey length composition data.

Since 2021, a new method for spatial differences in growth has become available. We re-evaluate the length-at-age data using two approaches to identify whether there are spatial differences in growth for each of these species and validate where there are differences in growth. Given the results from this analysis, we move forward with the data updates for the 2-area northern rock sole model (model 21.2) and develop a single area model for southern rock sole.

Lastly, in 2021, the Plan Team requested that we look at the outcome of splitting the other shallow water flatfish survey biomass and into WGOA and CEGOA regions and evaluate the uncertainty introduced with this split. This analysis is in Appendix A and we do not recommend a spatial portioning of the data.

Spatial growth analysis and data updates

The growth morphs from the 2021 assessment were defined as central-eastern Gulf of Alaska (GOA) and western GOA. We re-analyzed the GOA bottom trawl survey specimen data using the fishmethods package in Program R (Nelson 2021). The growthlrt function was used to test several hypotheses:

H0: Growth is not equal between areas

H1: L∞ value are equal

H2: Growth coefficients are equal

H3: Size at age 0 (t0) values are equal

H4: Growth is equal

The data were queried from the gap_products specimen table and the analysis was completed separately for each species. The analysis was also done separately for each sex given these species exhibit dimorphic growth. The separation of the data into the western GOA and the central-eastern GOA was done based on visual inspection of the data and the difference in the area-specific growth curves are greater for northern rock sole than southern rock sole (Figure 1).

The AIC results suggest there is substantial evidence for differences in growth between the western GOA and the central-eastern GOA for both species. The model where all growth parameters differ among areas has the lowest AIC for northern rock sole and given the delta AIC there is strong support for this model for northern rock sole females (Table 1b). Differences in growth are also supported for male northern rock sole, but a model with the von Bertalanffy growth coefficient equal in both areas and a model with the size at age-0 equal in both areas are also supported. The model assuming an equal growth coefficient receives the strongest support for female southern rock sole (Table 1a). The models assuming the same t_0 parameter and differing growth also receive substantial support. The model with the lowest AIC for male southern rock sole is the model where the t_0 parameter is set equal among areas; however, there is substantial support for the models assuming an equal growth coefficient and differing growth (Table 1a). The results suggest that there is some difference in growth for southern rock sole.

We applied the method described in Kapur et al. (2020) using the growthbreaks R package (https://github.com/afsc-assessments/growthbreaks). This was applied to both the female and male length-at-age specimen data for both rock sole species to validate that the separation between the western GOA and the central-eastern GOA is statistically detectable.

The results suggest that the estimated growth break for southern rock sole does not match the assumed break in the data in the assessment model, which is ~159° (Figure 2 - Figure 3). The estimated breaks for southern rock sole were further to the east. A break in the male length-at-age data closer to the assumed central-east and western breaks seems to be identified; however, the difference in female growth is expected to have a bigger impact on SSB. Given the results for female and male southern rock sole from the "growthbreaks" analysis, the AIC results, and the qualitative minimal differences in the von Bertalanffy growth estimates (estimated external to the assessment model), we explored a single area model (Model 25.1a) for southern rock sole.

The estimated growth breaks for northern rock sole using the growthbreak R package were more similar to the assumed break in the length-at-age data in the 2-area assessment model (Figure 4 - Figure 5). The estimated breaks for northern rock sole for especially age-4s and age-7s females are similar to the western GOA and central-eastern GOA break (~160°) that is used in the assessment. This pattern seems consistent between males and females. Breaks were detected at 161° for age-4, 159° for age-7, and 156° and 149 for age-10 and age-15 female northern rock sole (Figure 4). For male northern rock sole breaks were detected at 150 and 156 for age-4s, 159 for age-7s, and 164 for age-10s (Figure 5). Given that there is some consistency in the female growth breaks for northern rock sole and the AIC analysis strongly supports the model assuming differing growth between the areas, the 2-area growth morph model that was accepted in 2021 is retained.

Observed proportion of northern and southern rock soles

The Plan team and SSC have requested for better accounting of northern and southern rock sole catch in the assessment models. Northern and southern rock sole have been consistently identified by the NMFS Observer Program since 1997. The proportion of northern and southern rock sole from 1997 – 2021 was derived using the extrapolated haul weights for northern and southern rock sole contained in the obsint.debriefed_spcomp and obsint_debriefed_haul tables:

$$CP_{y,s} = \frac{\sum_{1}^{H} w_{y,s,h}}{\sum_{s=1}^{S}\sum_{h=1}^{H} w_{y,s,h}},$$

where *CP* is the year and species-specific catch proportion, *y* is year, *s* is species, *h* is haul. This is the same method for separating arrowtooth flounder and Kamchatka flounder catch in the BSAI (Bryan et al. 2022 and Shotwell et al. 2022).

The assessment models have assumed that annual fishery catch of rock sole is evenly split between northern and southern rock sole; however, the relative catch of the two species varies over time (Figure 6). Annual species-specific catch for 1997-2021 was then the product of the catch proportion and the total rock sole catch.

As the two species were not distinguished within the fishery until 1997, annual species-specific catch prior to 1997 was estimated as the total rock sole catch multiplied by the proportion of the catch belonging to each species averaged across the first five years of species-specific data (1997-2001). These average proportions were estimated as 45% northern rock sole and 55% southern rock sole. This assumed that catch proportions between 1977 and 1996 were more similar to the beginning of the time series than the full time series. While on average the total catch was close to evenly divided between species (47% northern rock sole and 53% southern rock sole), the proportion of the catch that was southern rock sole peaked at 76% in 2004 while 81% of the catch was northern rock sole in 2016 (Figure 6). The catch prior to 1997 remains relatively unchanged since the average proportions are close to 50% (Figure 7). After 1997, we see the variability in the observed proportions reflected in the catch estimates.

Area specific catch

The area specific catch estimates for the growth morph models were updated from the new species-specific catch estimates. The area specific catch estimates for each species was derived as the product of the species-specific catch and the average proportion of catch coming from the western GOA or central-eastern GOA (3% and 97%, respectively; Figure 8). For this assessment, we derived the area-specific proportion of rock sole catch by from (1998 – 2021) from the comprehensive blend table which are then applied to the species specific catch (Figure 9). The average area-specific proportion from 1998 – 2002 was then applied to the species-specific catch for years 1977-1997 (Model 21.2b and Model 25.1b).

Input sample size

Previous rock sole assessment models have use the number of hauls with length-at-age specimens to weight the length composition data. This has been updated to use the number of hauls with length data for several of the updated model runs (Table 3). We do this as an intermediate step before implementing the input sample sizes from the surveyISS package in the future (Model 21.2c and Model 25.1d).

Input sample size for the fishery length composition data remains the same as previous assessment, number of hauls with length data. The input sample size for the survey conditional-age-at-length data also remains the same and is:

$$ISS_{lbin,year}^{CAAL} = Nages_{lbin}\left(\frac{Nhauls\ with\ ages_{year}}{Nages_{year}}\right),$$

where the input samples size for length bin (lbin) and year is the product of number of ages in each length bin scaled by the ratio of the number of hauls with ages ($Nhauls\ with\ ages_{year}$) in a year and the number of ages samples in a given year ($Nages_{year}$).

Model runs

Southern rock sole

The 2021 assessment model for GOA southern rock sole was 21.1 and is compared to the model runs presented for September 2025. The previous rock sole assessments used the length-weight relations from Turner et al. (2011). The previous length-weight parameters were estimated using combined northern and southern rock sole length-weight survey from the GOA bottom trawl survey. This has been updated for this assessment (Figure 10).

The single area model makes the same general assumptions as the 2-area model as described in *2021 assessment models*, but data are aggregated and represent the entire GOA. Catch inputs were revised to split total rock sole catch by the observed proportion of southern rock sole from 1997-2021. Input sample size for the survey length composition were also updated to reflect the number of hauls with length composition samples.

The single area models are numbered as follows:

Model	Change in model
25.1a	Single area model with 50% catch split
25.1b	Revised southern rock sole catch estimates
25.1c	Uncertainty in length-at-age modeled as CV similar to the 2-area model
25.1d	Updated survey length composition input sample size
25.1e	Updated survey length composition input sample size with fixed female peak selectivity parameter for the survey

Results

Data, fleet specific, and total likelihoods are reported in Table 4. The single area models fit the combined GOA wide survey biomass fairly well, but similar to the 2-area model, misses the peak in 2009 (Figure 12). Model 25.1a might have a subtly better fit to the surveys than Model 21.1. The single area models fit the fishery and survey length composition data equivalent to Model 21.1 (Figure 13 - Figure 18). Both models tend to underestimate the peaks of the length distributions in a similar way, which is true for the fishery and survey.

Selectivity estimation was similar across the single area models, but changing the input sample size for the survey length composition led to an unexpected result (Figure 19). When the number of hauls with length data is used as the data weight rather than the number of hauls with specimen data, the fishery selectivity curve shifts to the right and the parameter describing the size at peak selectivity is estimated at the upper bound of the parameter range (~65cm), which is close to the maximum size in the model. We did a likelihood profile over this parameter and found that the survey length likelihood conflicts with the fishery length likelihood and the survey length-at-age likelihood (Figure 20). The survey length likelihood is minimized when the fishery peak selectivity is estimated at the upper bound whereas the fishery length likelihood and the survey size-at-age likelihoods are minimized at a lower value for this peak parameter. Model 25.1e fixes this parameter to 57cm (similar to what is estimated in the other single area models) to address this issue for now. We also conducted Francis iterative reweighting (not presented here) to determine if this would rectify the issue. Iterative reweighting led to the down weighting of the fishery length composition data while not adjusting the survey length composition data and did not resolve the issue. Using the number of hauls with length composition data (Model 25.1d) rather than the number of hauls with the specimen data (Models 25.1a – m25.1c) to weight the length data better reflects the scale of length sampling. We will work to see if we can better understand why this weighting scheme has led to the higher estimation of the peak parameter for November.

Growth estimation was similar across the single area models and was between the 2-area estimates from Model 21.2 (Table 5, Figure 20). The confidence bounds of the two growth curves also overlap significantly, giving support for using a single-area model.

The single-area model produces similar outcomes as the 2-area model for GOA southern rock sole (Figure 21). There was very little difference in SSB and recruitment. Fishing mortality was estimated to be somewhat lower. **Given the similarities between model 21.2 and the single area models, the overlap in the CIs of the growth curve estimates and the spatial growth analysis results, at a minimum, we recommend bringing model 25.1c forward to November. Model 25.1c reflects several cumulative changes across models 25.1a -25.1c and the performance of the three models is similar. We also recommend bringing forward 25.1d in November, if we can identify the source of why using the number of hauls with length data causes the peak parameter to be estimated at its upper bound.**

Northern rock sole

The 2021 assessment model for GOA northern rock sole was 21.2 and is compared to the model runs presented for September 2025.

The 2-area, growth morph model for GOA northern rock sole was updated as follows:

Model	Change in model
21.2a	Revised length-weight relationship
21.2b	Revised catch estimated
21.2c	Revised input sample size for length composition
21.2d	21.c with Francis reweighting

The previous rock sole assessments used the length-weight relations from Turner et al. (2011). The previous length-weight parameters were estimated using combined northern and southern rock sole length-weight survey from the GOA bottom trawl survey. This has been updated for this assessment and the estimated length-weight parameters were sex-specific and area-specific (Figure 11). This had a minimal impact on the model results. The annual, area-specific catch inputs and annual input sample sizes for the survey length data were revised as mentioned above (Figure 9a, Table 3). Iterative reweighting of the composition data was carried out using the Francis method.

Results

The model runs for the GOA northern rock sole were relatively similar with regard to fits to data (Figure 23 - Figure 27), estimates of selectivity (Figure 28 - Figure 29) and growth (Figure 30), and ultimately the derived quantities (e.g., spawning stock biomass; Figure 31). The total likelihood, likelihoods associated with different data sources and fleet specific likelihoods are reported in (Table 6).

Updating the input sample size for the survey length composition to the number of hauls with length data led to a subtle improvement in the fits to the length composition data, as expected given the increase in weight with little change to the fits to survey biomass (Table 7, Figure 23 - Figure 27). Francis reweighting improved the fit to survey biomass by down weighting the CEGOA fishery length composition data (variance adjustment = 0.12) and the WGOA bottom trawl survey data (variance adjustment 0.26) while the WGOA fishery length composition and CEGOA bottom trawl survey length composition ISS were not adjusted (Table 7, Figure 23). This leads to the CEGOA length composition to have the highest relative weight followed by the WGOA survey, the CEGOA fishery, and the WGA fishery. The fits to the length composition seemed unchanged with the iterative reweighting.

Growth estimates were consistent across the models (Table 8 , Figure 30). One unresolved issue is that the growth relationships for the WGOA seem to be underestimate the length-at-age for later ages (> age-12), while estimating the CGOA quite well. The original impetus of using the growth morph model was because when the two areas were aggregated the growth curve underestimated length-at-age in general, but especially for those observations associated with the CGOA. The underestimation of growth at older ages in the WGOA may be due to the lower sample size. We also looked at correlation with other parameters. There is some correlation with some selectivity parameters, especially for WGOA females (Table 9). **During the next full assessment we will evaluate model sensitivity to selectivity and its impact on growth.**

The recruitment distribution parameter is estimated in the model and determines the proportion of the population found in the western Gulf. The range in estimates for the distribution parameter is between 0.69 and 0.73 (Table 4.15), which is slightly higher than the proportion of survey biomass from the western Gulf (63%). This parameter is positively correlated with male natural mortality in the western Gulf. The models estimate a male natural mortality value that provides a fairly reasonable estimate distribution of the population. Given the positive correlation between male natural mortality and asymptotic length, for growth to be more reasonably estimated male natural mortality would have to be higher. The estimate of male mortality is constrained by the fixed value of female natural mortality. **During the next full assessment evaluating the model's ability to estimate natural mortality for females and males will be the priority.**

The resulting SSB from the models had overlapping confidence intervals; however, the SSB estimates from model 21.2c and 21.2d was lower between 1977 and 1998 while the remainder of the times series was more similar (Figure 31a).

We recommend bringing forward models 21.2c and 21.2d forward depending on the discussion about data weighting with the Plan Team.

Tables

Table 1. AIC results from the growth analysis comparing the western GOA and central-eastern GOA for a) southern rock sole and b) northern rock sole.

a)

Stock	Hypothesis	AIC	Delta AIC
Southern rock sole: female	H2: growth coefficient equal	23401.34	0
	H3: t0 equal	23401.55	0.21
	H0: Growth not equal	23403.22	1.88
	H1: Linfinity equal	23446.51	45.17
	H4: Growth equal	23764.76	363.416
Southern rock sole: male	H3: t0 equal	12846.69	0
	H2: growth coefficient equal	12847.25	0.56
	H0: Growth not equal	12848.62	1.93
	H1: Linfinity equal	12851.66	4.97
	H4: Growth equal	12920.02	73.334

b)

Stock	Hypothesis	AIC	Delta AIC
Northern rock sole: female	H0: Growth not equal	17845.01	0
	H2: growth coefficient equal	17862.32	17.31
	H3: t0 equal	17866.64	21.63
	H1: Linfinity equal	17885.92	40.91
	H4: Growth equal	18775.82	930.813
Northern rock sole: male	H2: growth coefficient equal	11675.81	0
	H0: Growth not equal	11676.9	1.09
	H3: t0 equal	11677.16	1.35
	H1: Linfinity equal	11718.55	42.74
	H4: Growth equal	12123.98	448.172

Table 2. Number of age samples from the GOA bottom trawl survey for a) southern and b) northern rock sole.

a)

Female	WGOA	CGOA	EGOA	Total
1996	83	98	0	181
1999	89	134	0	223
2001	91	339	0	430
2003	112	240	0	352
2005	108	118	32	258
2007	111	158	0	269
2009	98	190	2	290
2011	105	135	0	240
2013	114	126	26	266
2015	113	123	11	247
2017	111	248	66	425
2019	181	275	16	472
2021	277	231	27	535
Male	WGOA	CGOA	EGOA	Total
1996	28	59	0	87
1999	43	89	0	132
2001	63	204	0	267
2003	69	150	0	219
2005	73	66	12	151
2007	79	93	0	172
2009	75	141	1	217
2011	66	76	0	142
2013	77	81	20	178
2015	79	69	3	151
2017	77	173	43	293
2019	79	103	14	196
2021	149	106	8	263

Table 2. continued.

b)

Male	CEGOA	WGOA	Total
1996	38	56	94
1999	45	110	155
2001	115	125	240
2003	77	129	206
2005	42	124	166
2007	49	146	195
2009	91	131	222
2011	56	114	170
2013	89	82	171
2015	105	93	198
2017	159	72	231
Female	CEGOA	WGOA	Total
1996	65	71	136
1999	64	163	227
2001	180	170	350
2003	114	184	298
2005	69	150	219
2007	77	180	257
2009	121	164	285
2011	76	162	238
2013	100	121	221
2015	129	124	253
2017	251	109	360

Table 3. Input sample size for GOA bottom trawl survey length composition data.

a)

		SRS input sample size	
Year	Fleet	21.2	25.1d
1996	GOA survey	39	277
1999	GOA survey	36	254
2001	GOA survey	107	232
2003	GOA survey	67	348
2005	GOA survey	61	322
2007	GOA survey	75	332
2009	GOA survey	56	333
2011	GOA survey	71	256
2013	GOA survey	62	210
2015	GOA survey	46	275
2017	GOA survey	81	187
2019	GOA survey	124	202
2021	GOA survey	138	217

Table 3. Continued

b)

Year	Fleet	NRS input sample size 21.1	21.1c	Adjusted sample size 21.1d
1996	CEGOA	9	71	71
1999	survey	11	79	79
2001		60	106	106
2003		32	128	128
2005		19	134	134
2007		36	141	141
2009		30	135	135
2011		31	105	105
2013		26	91	91
2015		29	111	111
2017		46	76	76
2019		22	74	74
2021		19	67	67
1996	WGOA survey	13	123	31.98
1999		20	100	26
2001		41	91	23.66
2003		33	165	42.9
2005		36	122	31.72
2007		41	146	37.96
2009		24	141	36.66
2011		42	116	30.16
2013		35	97	25.22
2015		22	110	28.6
2017		28	87	22.62
2019		36	81	21.06
2021		29	72	18.72

Table 4. a) Likelihood values for the GOA southern rock sole models and b) fleet specific likelihoods. Model 21.2 is not directly comparable to the other models because it is a 2-area model. Models 25.1d and 25.1e use different input sample size values for the survey length composition data.

a)

Likelihood	21.2	25.1a	25.1b	25.1c	25.1d	25.1f
Npars	115	99	99	99	99	99
TOTAL	1371.73	1124.48	1124.97	1123.95	1250.53	1271.02
Catch	0.00	0.00	0.00	0.00	0.00	0.00
Survey	-31.39	-20.07	-19.85	-19.85	-18.71	-18.38
Length_comp	622.78	569.68	569.89	568.46	691.29	711.33
Age_comp	776.24	571.66	571.61	572.03	574.04	570.34
Recruitment	-2.23	-2.23	-2.13	-2.14	-1.82	-1.76

b)

model	Likelihood	All	Fishery	Survey
25.1a	Age_like	571.66	0	571.66
25.1b	Age_like	571.61	0.00	571.61
25.1d	Age_like	574.04	0.00	574.04
25.1f	Age_like	570.34	0.00	570.34
25.1a	Catch_like	0.00	0.00	0.00
25.1b	Catch_like	0.00	0.00	0.00
25.1d	Catch_like	0.00	0.00	0.00
25.1f	Catch_like	0.00	0.00	0.00
25.1a	Length_like	569.68	512.96	56.72
25.1b	Length_like	569.89	513.05	56.85
25.1d	Length_like	691.29	535.42	155.87
25.1f	Length_like	711.33	535.72	175.61
25.1a	Surv_like	-20.07	0.00	-20.07
25.1b	Surv_like	-19.85	0.00	-19.85
25.1d	Surv_like	-18.71	0.00	-18.71
25.1f	Surv_like	-18.38	0.00	-18.38

Table 5. Key parameter estimates for the southern rock sole models.

Parameter	Model 21.2	m25.1a	m25.1b	m25.1d	m25.1f
L_at_Amax_Fem_GP_1	51.57	48.89	48.89	48.01	48.70
L_at_Amin_Fem_GP_1	15.37	14.24	14.24	14.85	14.76
VonBert_K_Fem_GP_1	0.16	0.18	0.18	0.18	0.17
SD_old_Fem_GP_1		5.18	5.18		
CV_young_Fem_GP_1	0.16			0.14	0.15
L_at_Amax_Fem_GP_2	46.01				
L_at_Amin_Fem_GP_2	12.38				
VonBert_K_Fem_GP_2	0.20				
CV_young_Fem_GP_2	0.19				
L_at_Amax_Mal_GP_1	41.48	40.60	40.59	39.15	39.86
L_at_Amin_Mal_GP_1	16.03	15.09	15.09	15.44	15.19
VonBert_K_Mal_GP_1	0.18	0.20	0.20	0.21	0.20
CV_young_Mal_GP_1	0.13			0.12	0.13
L_at_Amax_Mal_GP_2	37.17				
L_at_Amin_Mal_GP_2	12.92				
VonBert_K_Mal_GP_2	0.27				
SD_old_Mal_GP_1		5.26	5.26		
CV_young_Mal_GP_2	0.18				
NatM_uniform_Mal_GP_1	0.25	0.27	0.27	0.28	0.28
NatM_uniform_Mal_GP_2	0.27				
InitF_seas_1_flt_1Fishery		0.03	0.03	0.04	0.03
SR_LN(R0)	12.43	12.36	12.36	12.46	12.39
SR_regime_BLK1add_1976	-0.09	-0.08	-0.07	-0.11	-0.11

Table 6. a) Likelihood values for the GOA northern rock sole models and b) fleet specific likelihoods. Models 21.1c and 21.1d have a different input sample size than the other models.

a)

	Model				
Likelihood	21.1	21.1a	21.1b	21.1c	21.1d
Npar	108	108	108	108	108
Age_comp	624.64	624.60	624.67	631.85	617.82
Length_comp	569.97	570.12	569.82	736.64	265.12
Recruitment	-3.49	-1.67	-4.45	-4.95	-6.78
Survey	-14.55	-14.60	-15.35	-15.97	-19.17
TOTAL	1184.54	1184.65	1181.15	1358.62	867.78

b)

Model	Likelihood	ALL	Fishery_Central	Fishery_West	Survey_Central	Survey_West
21.1	Age_like	624.64	0.00	0.00	315.58	309.06
21.1a	Age_like	624.60	0.00	0.00	315.51	309.09
21.1b	Age_like	624.67	0.00	0.00	315.52	309.15
21.1c	Age_like	631.85	0.00	0.00	317.82	314.03
21.1d	Age_like	617.82	0.00	0.00	**311.23**	**306.60**
21.1	Length_like	569.97	410.35	**88.46**	**30.41**	40.75
21.1a	Length_like	570.12	410.50	**88.46**	**30.36**	40.80
21.1b	Length_like	569.82	410.73	**88.45**	**30.09**	40.55
21.1c	Length_like	736.64	422.31	90.21	93.51	130.60
21.1d	Length_like	265.12	**58.72**	88.67	79.90	**37.83**
21.1	Surv_like	-14.55	0.00	0.00	-4.47	-10.08
21.1a	Surv_like	-14.60	0.00	0.00	-4.50	-10.10
21.1b	Surv_like	-15.35	0.00	0.00	-5.48	-9.86
21.1c	Surv_like	-15.97	0.00	0.00	-5.94	-10.03
21.1d	Surv_like	-19.17	0.00	0.00	**-7.69**	**-11.48**

Table 7. Survey root mean square error estimates for the northern rock sole models.

Model	RMSE	fleetname
21.1	0.35	Survey_Central
	0.27	Survey_West
21.1b	0.34	Survey_Central
	0.27	Survey_West
21.1c	0.34	Survey_Central
	0.26	Survey_West
21.1d	0.32	Survey_Central
	0.23	Survey_West

Table 8. Key parameter estimates from the northern rock sole models.

Parameter	Model 21.1	21.1a	21.1b	21.1c	21.1d
NatM male CEGOA	0.23	0.23	0.23	0.24	0.25
NatM male WGOA	0.25	0.25	0.25	0.24	0.25
InitF flt_1Fishery_Central	0.10	0.10	0.10	0.10	0.10
Init F flt_2Fishery_West	0.00	0.00	0.00	0.00	0.00
L_at_Amax_Fem_GP_1	50.38	50.36	50.32	49.86	49.08
L_at_Amin_Fem_GP_1	10.38	10.38	10.39	10.19	9.98
VonBert_K_Fem_GP_1	0.23	0.23	0.23	0.24	0.24
CV_young_Fem_GP_1	0.23	0.23	0.23	0.24	0.26
L_at_Amax_Mal_GP_1	41.27	41.25	41.22	40.57	39.72
L_at_Amin_Mal_GP_1	10.95	10.95	10.97	10.39	10.19
VonBert_K_Mal_GP_1	0.28	0.29	0.29	0.31	0.32
CV_young_Mal_GP_1	0.20	0.20	0.20	0.21	0.23
L_at_Amax_Fem_GP_2	40.40	40.40	40.41	40.36	40.45
L_at_Amin_Fem_GP_2	10.07	10.07	10.08	10.06	10.21
VonBert_K_Fem_GP_2	0.23	0.23	0.23	0.22	0.23
CV_young_Fem_GP_2	0.22	0.22	0.22	0.22	0.22
L_at_Amax_Mal_GP_2	33.36	33.36	33.36	32.22	33.15
L_at_Amin_Mal_GP_2	9.37	9.37	9.38	8.74	9.38
VonBert_K_Mal_GP_2	0.34	0.34	0.34	0.39	0.35
CV_young_Mal_GP_2	0.20	0.20	0.20	0.21	0.20
SR_LN(R0)	11.65	11.62	11.64	11.58	11.56
SR_regime_BLK1add_1976	-0.02	-0.02	-0.02	-0.03	-0.04
Recruitment Distrib WGOA*	0.96	0.98	0.99	0.94	0.82

*Recruitment distribution indicates the proportion of the recruits settling in the western GOA and is parameterized as *exp(est)/(exp(est)+1)*.

Table 9. Correlation estimates for the western GOA northern rock sole growth parameters a) western GOA females and b) western GOA males.

a)

	WGOA Female			
Parameter	L_at_Amin_Fem_GP_2	L_at_Amax_Fem_GP_2	VonBert_K_Fem_GP_2	CV_young_Fem_GP_2
L_at_Amin_Fem_GP_2	1.00			
L_at_Amax_Fem_GP_2	0.35	1.00		
VonBert_K_Fem_GP_2	-0.63	-0.81	1.00	
CV_young_Fem_GP_2	-0.59	-0.23	0.28	1.00
NatM_uniform_Mal_GP_1	0.00	0.00	0.00	0.00
L_at_Amin_Mal_GP_1	0.01	0.00	0.00	0.00
L_at_Amax_Mal_GP_1	0.00	0.00	0.00	0.00
VonBert_K_Mal_GP_1	0.00	0.00	0.00	0.00
CV_young_Mal_GP_1	0.00	0.00	0.00	0.00
NatM_uniform_Mal_GP_2	0.07	-0.01	-0.13	-0.01
L_at_Amin_Mal_GP_2	0.01	0.00	-0.02	0.00
L_at_Amax_Mal_GP_2	0.02	0.02	-0.05	0.00
VonBert_K_Mal_GP_2	-0.02	-0.01	0.05	0.00
CV_young_Mal_GP_2	-0.01	0.00	0.01	0.00
RecrDist_GP_2_area_2_month_1	0.10	-0.14	-0.12	-0.02
SR_LN(R0)	0.09	-0.13	-0.12	-0.01
SR_regime_BLK1add_1976	-0.01	-0.01	0.01	0.00
InitF_seas_1_flt_1Fishery_Central	0.01	0.00	0.00	-0.01
InitF_seas_1_flt_2Fishery_West	-0.01	-0.34	0.19	-0.02
Size_DblN_peak_Fishery_Central(1)	0.00	0.00	0.00	0.00
Size_DblN_top_logit_Fishery_Central(1)	0.00	0.00	0.00	0.00
Size_DblN_ascend_se_Fishery_Central(1)	0.00	0.00	0.00	0.00
SzSel_Male_Peak_Fishery_Central(1)	0.00	0.00	0.00	0.00
SzSel_Male_Ascend_Fishery_Central(1)	0.00	0.00	0.00	0.00
Size_DblN_peak_Fishery_West(2)	-0.04	-0.48	0.31	-0.01
Size_DblN_top_logit_Fishery_West(2)	0.00	0.00	0.00	0.00
Size_DblN_ascend_se_Fishery_West(2)	-0.07	-0.44	0.31	0.01
SzSel_Male_Peak_Fishery_West(2)	0.04	0.26	-0.18	0.00
SzSel_Male_Ascend_Fishery_West(2)	0.06	0.31	-0.22	-0.01
Size_DblN_peak_Survey_Central(3)	0.00	0.00	-0.01	0.00
Size_DblN_ascend_se_Survey_Central(3)	0.00	0.00	-0.01	0.00
SzSel_Male_Peak_Survey_Central(3)	0.00	0.00	0.00	0.00
SzSel_Male_Ascend_Survey_Central(3)	0.00	0.00	0.00	0.00
Size_DblN_peak_Survey_West(4)	0.11	-0.17	-0.01	-0.06
Size_DblN_ascend_se_Survey_West(4)	-0.01	-0.20	0.11	0.00
SzSel_Male_Peak_Survey_West(4)	-0.09	0.15	-0.01	0.06
SzSel_Male_Ascend_Survey_West(4)	0.01	0.14	-0.07	0.00

Table 9. Continued

b)

Parameter	WGOA Male NatM_uniform_Mal_GP_2	L_at_Amin_Mal_GP_2	L_at_Amax_Mal_GP_2	VonBert_K_Mal_GP_2	CV_young_Mal_GP_2
NatM_uniform_Mal_GP_2	1.00				
L_at_Amin_Mal_GP_2	0.04	1.00			
L_at_Amax_Mal_GP_2	0.22	0.39	1.00		
VonBert_K_Mal_GP_2	-0.13	-0.68	-0.81	1.00	
CV_young_Mal_GP_2	-0.06	-0.61	-0.27	0.36	1.00
RecrDist_GP_2_area_2_month_1	0.51	0.06	0.06	-0.12	-0.04
SR_LN(R0)	0.50	0.06	0.08	-0.13	-0.04
SR_regime_BLK1add_1976	0.00	0.00	0.00	0.00	0.00
InitF_seas_1_flt_1Fishery_Central	0.00	0.00	-0.01	0.01	0.00
InitF_seas_1_flt_2Fishery_West	-0.10	-0.02	-0.08	0.06	0.01
Size_DblN_peak_Fishery_Central(1)	0.00	0.00	0.01	-0.01	0.00
Size_DblN_top_logit_Fishery_Central(1)	0.00	0.00	0.00	0.00	0.00
Size_DblN_ascend_se_Fishery_Central(1)	0.00	0.00	0.00	-0.01	0.00
SzSel_Male_Peak_Fishery_Central(1)	0.00	0.00	0.00	0.00	0.00
SzSel_Male_Ascend_Fishery_Central(1)	0.00	0.00	0.00	0.00	0.00
Size_DblN_peak_Fishery_West(2)	0.05	0.00	-0.04	0.01	-0.01
Size_DblN_top_logit_Fishery_West(2)	0.00	0.00	0.00	0.00	0.00
Size_DblN_ascend_se_Fishery_West(2)	0.03	0.00	-0.03	0.01	0.00
SzSel_Male_Peak_Fishery_West(2)	-0.28	-0.06	0.08	0.03	0.05
SzSel_Male_Ascend_Fishery_West(2)	-0.15	-0.04	0.11	-0.01	0.04
Size_DblN_peak_Survey_Central(3)	0.00	0.01	0.01	-0.01	0.00
Size_DblN_ascend_se_Survey_Central(3)	0.00	0.01	0.01	-0.01	0.00
SzSel_Male_Peak_Survey_Central(3)	0.00	0.00	0.00	0.00	0.00
SzSel_Male_Ascend_Survey_Central(3)	0.00	0.00	0.00	0.00	0.00
Size_DblN_peak_Survey_West(4)	0.37	0.05	0.09	-0.11	-0.03
Size_DblN_ascend_se_Survey_West(4)	0.22	0.03	0.05	-0.06	-0.02
SzSel_Male_Peak_Survey_West(4)	-0.39	-0.02	-0.16	0.13	0.01
SzSel_Male_Ascend_Survey_West(4)	-0.23	-0.09	-0.16	0.17	0.05

Figures

a)

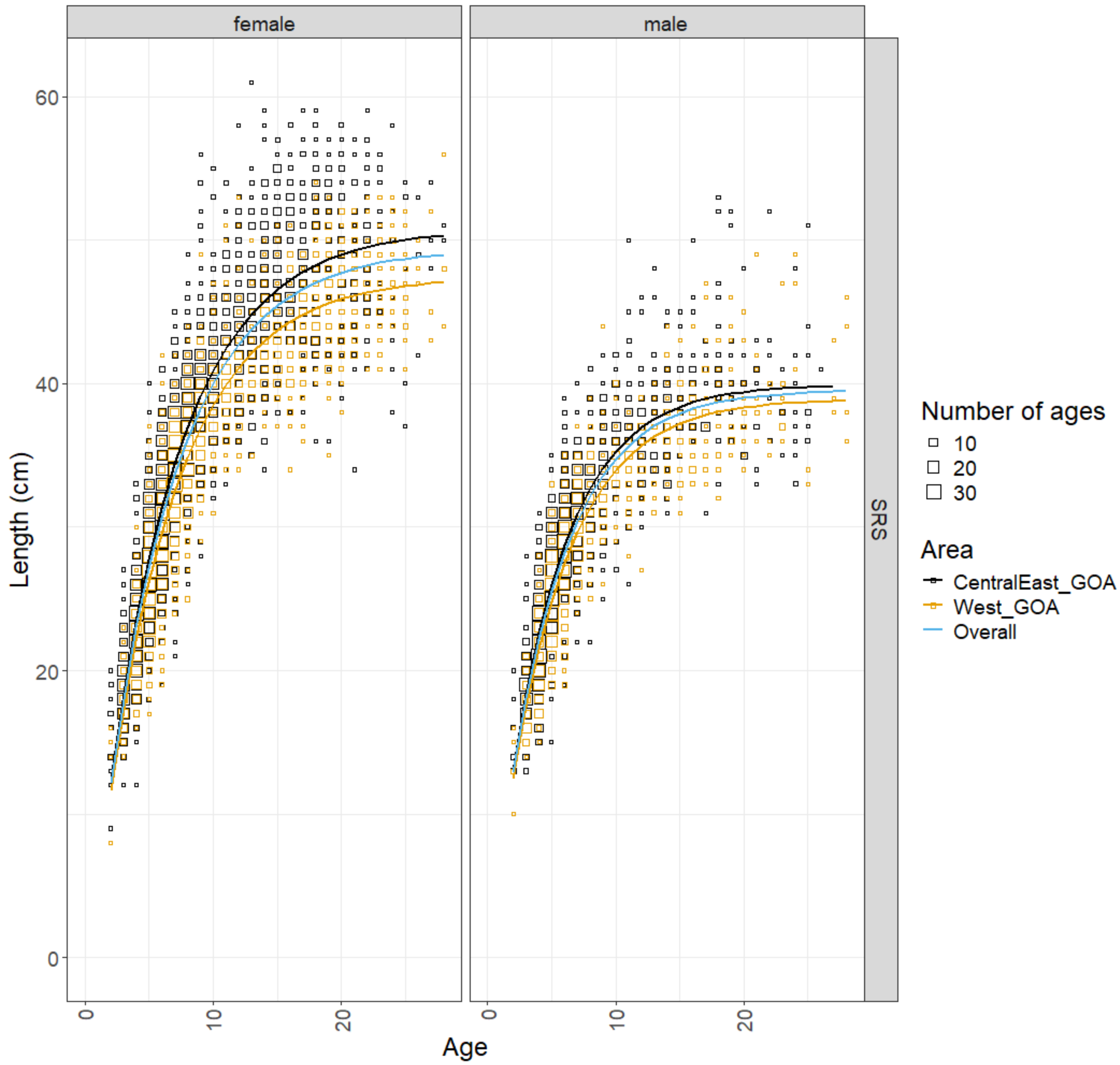


Figure 1. Area-specific, central-east and western GOA specimen data and von Bertlanffy growth curves estimated outside the assessment model and fit to the aggregated data (blue), central-east GOA (black) and western GOA (yellow) for a) southern rock sole and b) northern rock sole.

b)

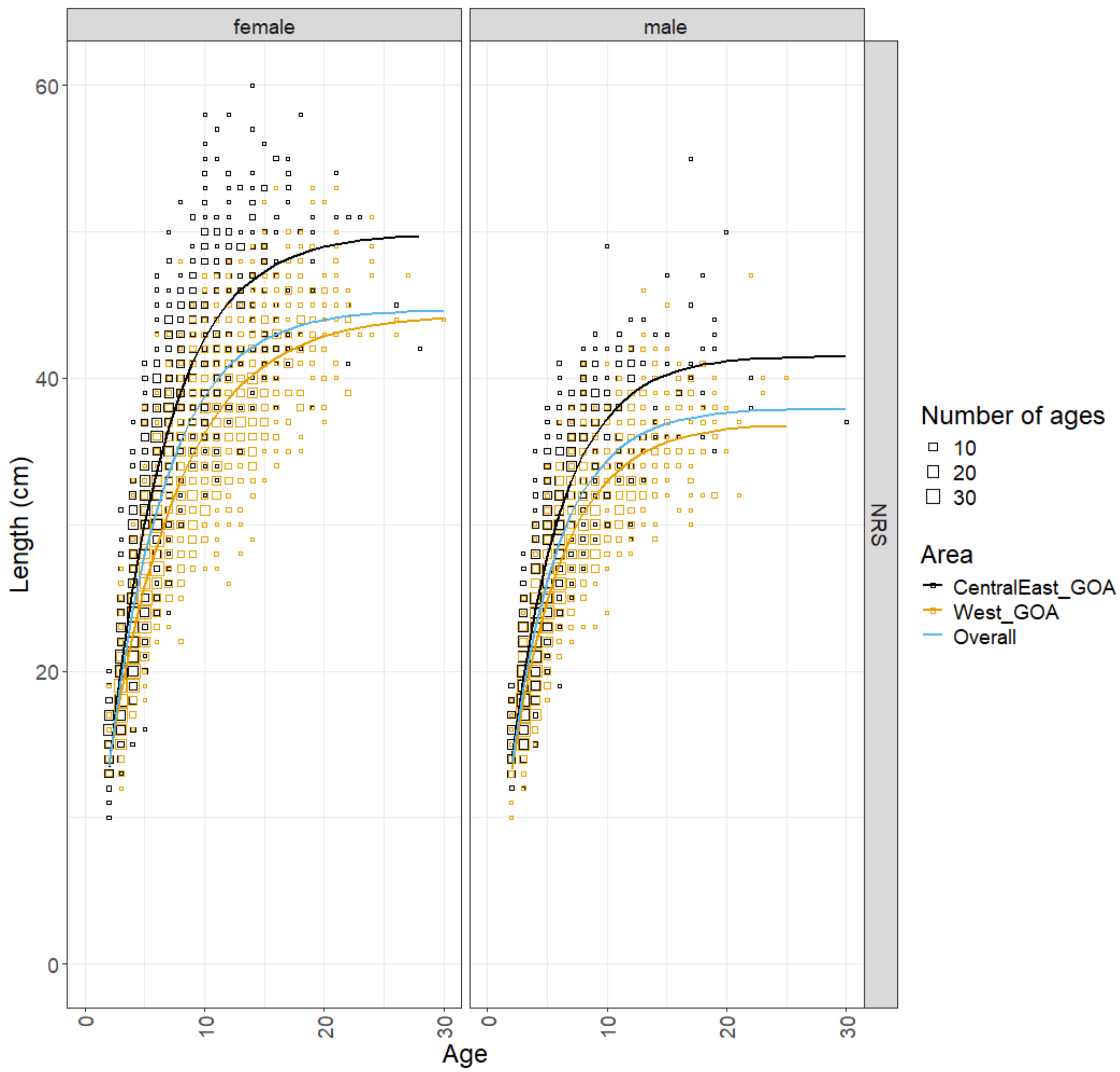


Figure 1. Continued. Northern rock sole length-at-age data and growth curves. Externally estimated from assessment model.

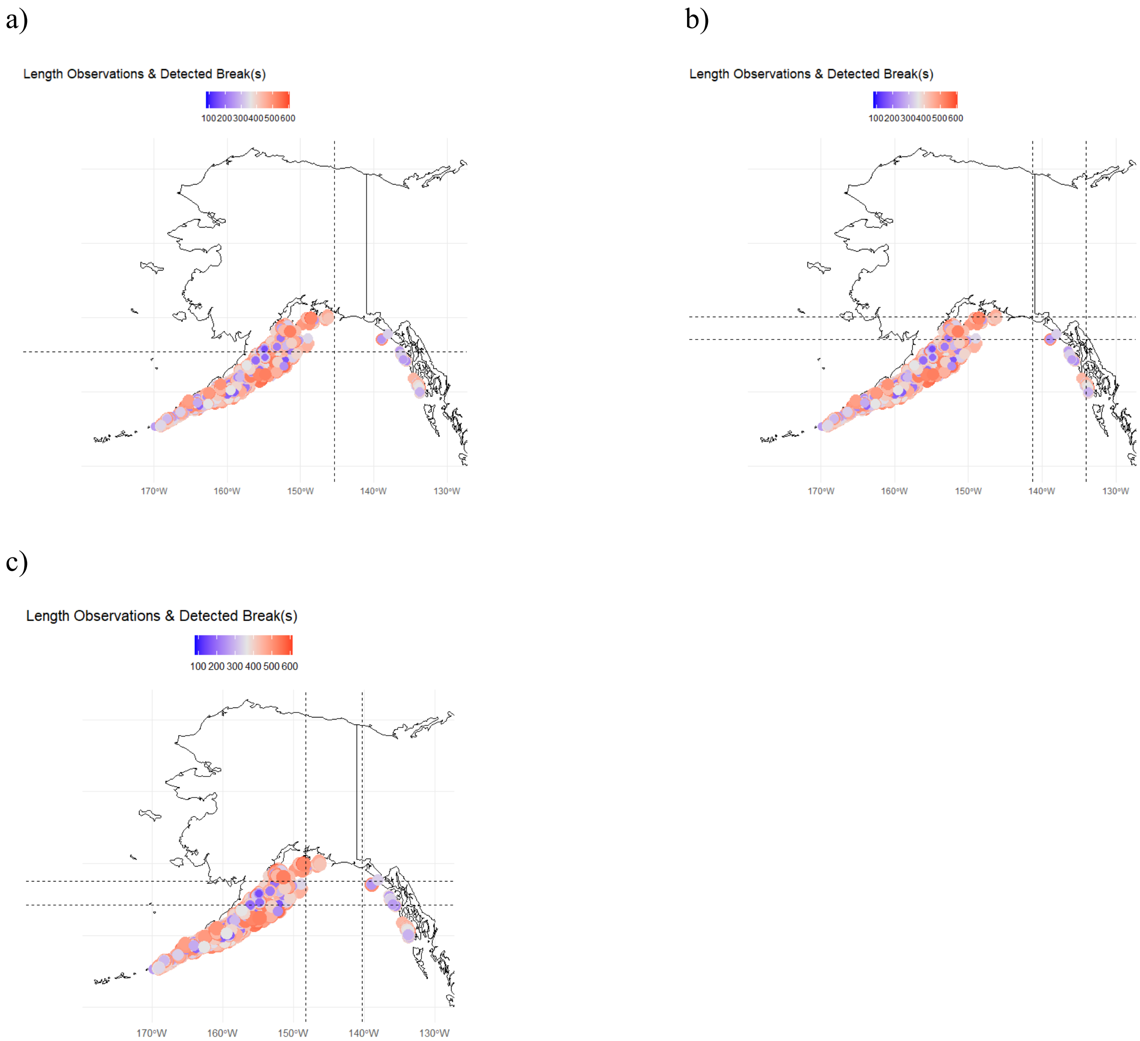


Figure 2. Detected spatial breaks in growth using the growthbreaks R package for female southern rock sole. Several age classes are presented a) age-5, b) age-8, and c) age-10.

a) b)

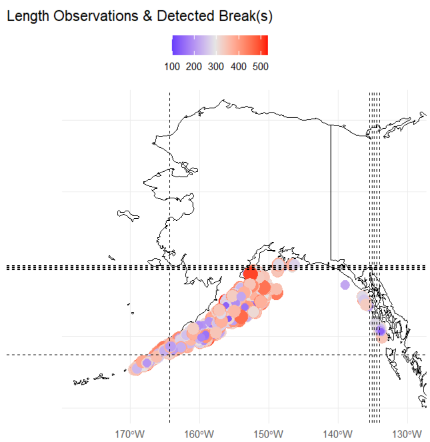
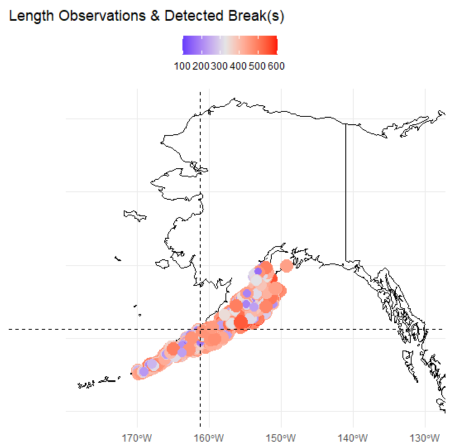
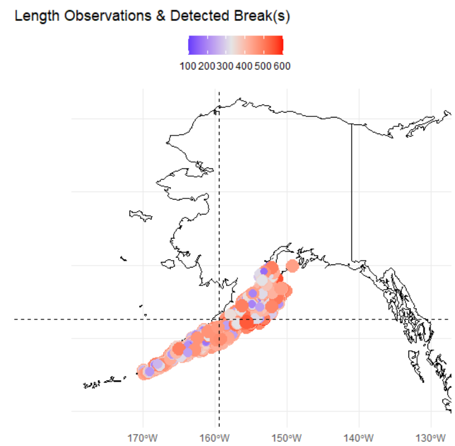


Figure 3. Detected spatial breaks in growth using the growthbreaks R package for male southern rock sole. Several age classes are presented a) age-8, and b) age-10.

a)



b)



c)

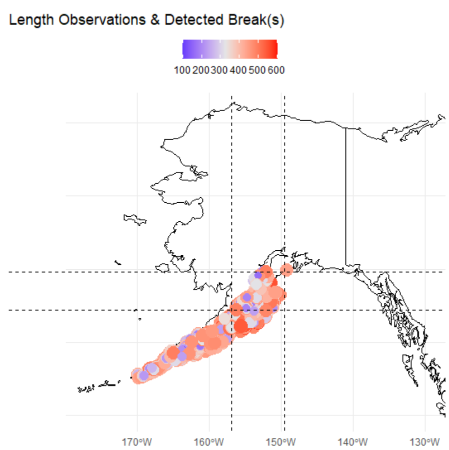
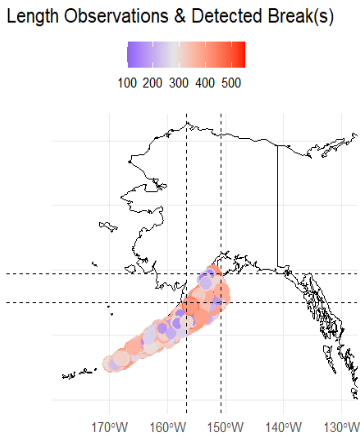
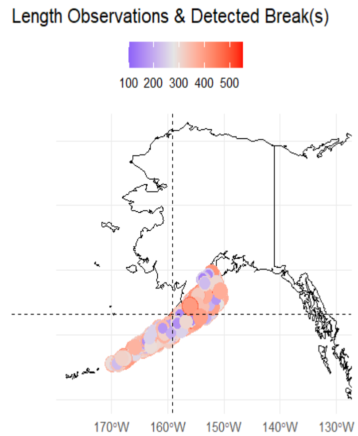


Figure 4. Detected spatial breaks in growth using the growthbreaks R package for female northern rock sole. Several age classes are presented a) age-4 , b) age-7 , and c) age-10.

a)



b)



c)

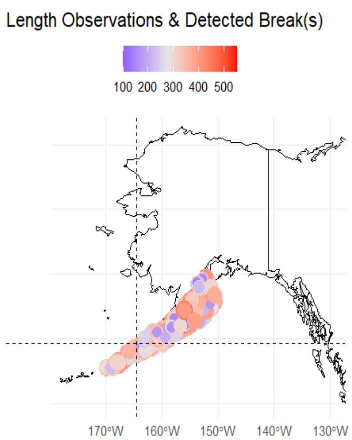


Figure 5. Detected spatial breaks in growth using the growthbreaks R package for male northern rock sole. Several age classes are presented a) age-4, b) age-7, and c) age-10.

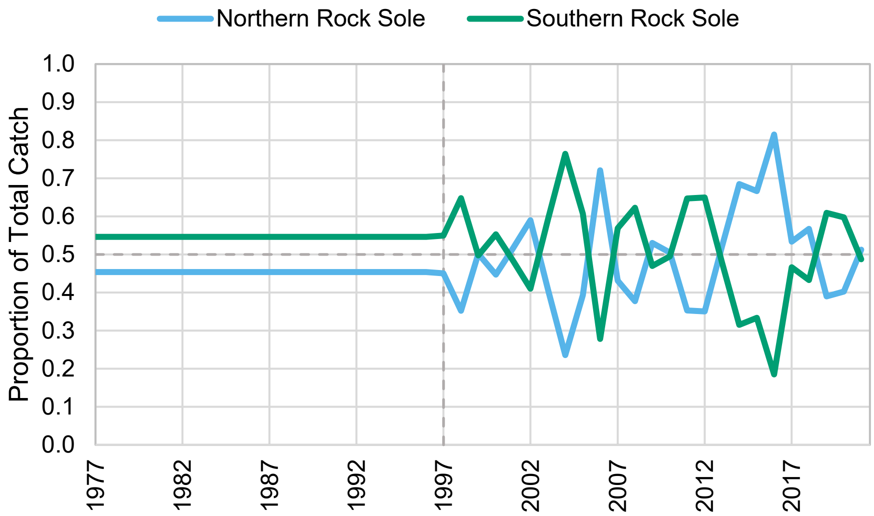
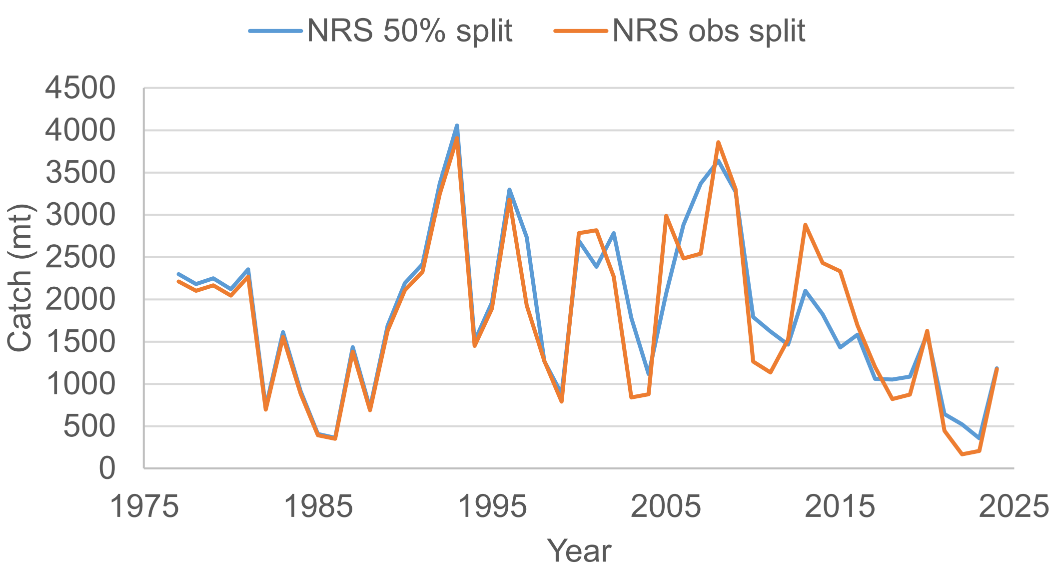


Figure 6. Estimated proportions of annual total fishery catch of rock sole for northern (blue) and southern (green) rock sole. Proportions prior to 1997 (vertical dashed line) are based on the average of the first five years of species-specific data (1997-2001). Dashed horizontal line represents the previous assumed even split in fishery catch between species.

a)



b)

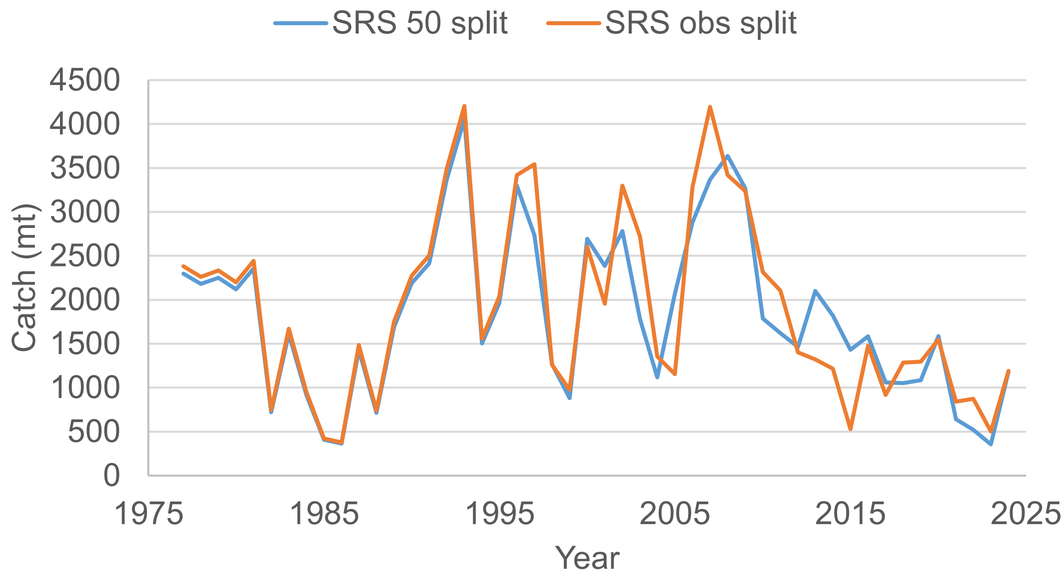


Figure 7. Total rock sole catch assuming an even split and using the derived annual and species-specific ratios for a) northern rock sole and b) southern rock sole.

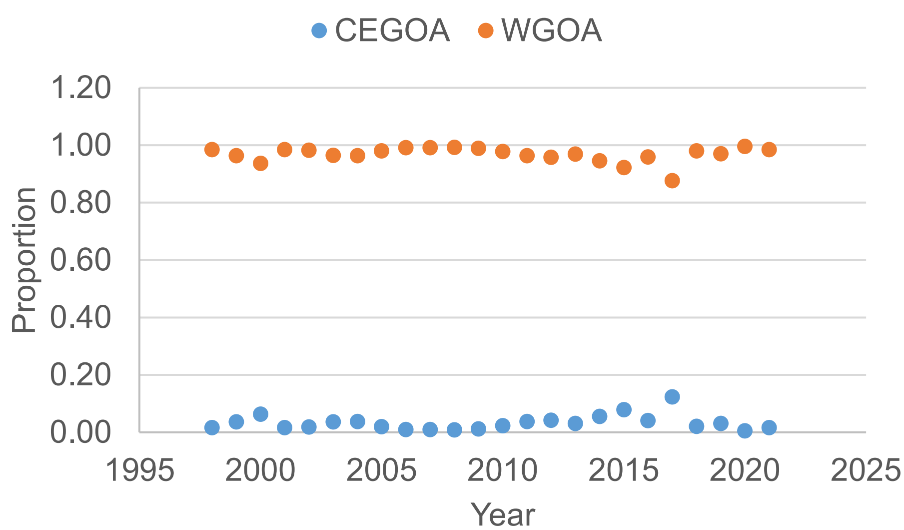
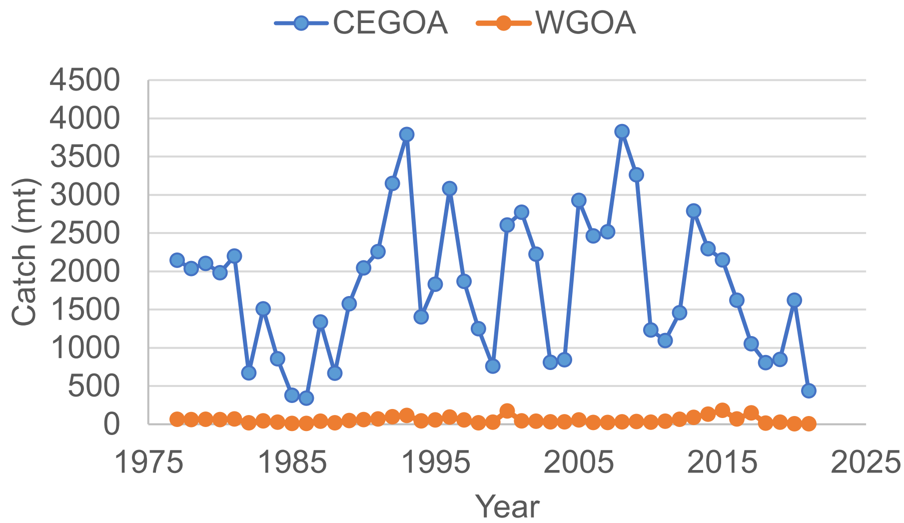


Figure 8. Area-specific proportions of rock sole catch from comprehensive_blend table.

a)



b)

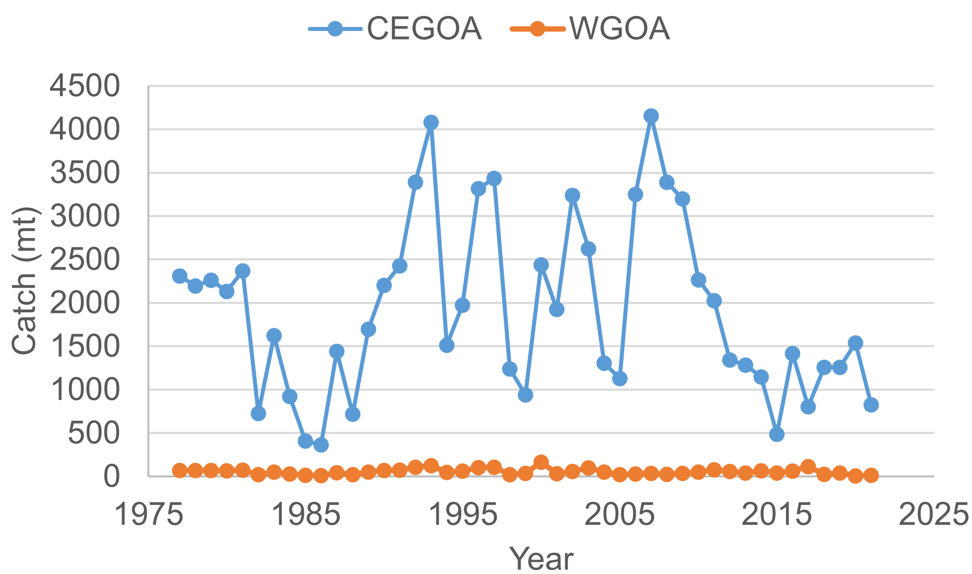
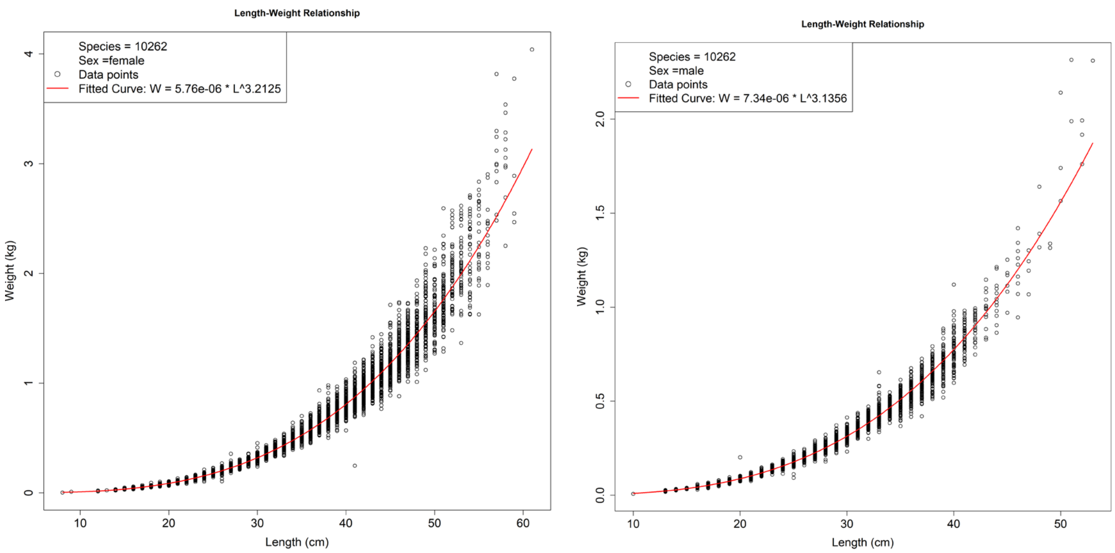


Figure 9. Area-specific catch for a) northern rock sole and b) southern rock sole.

a)



b)

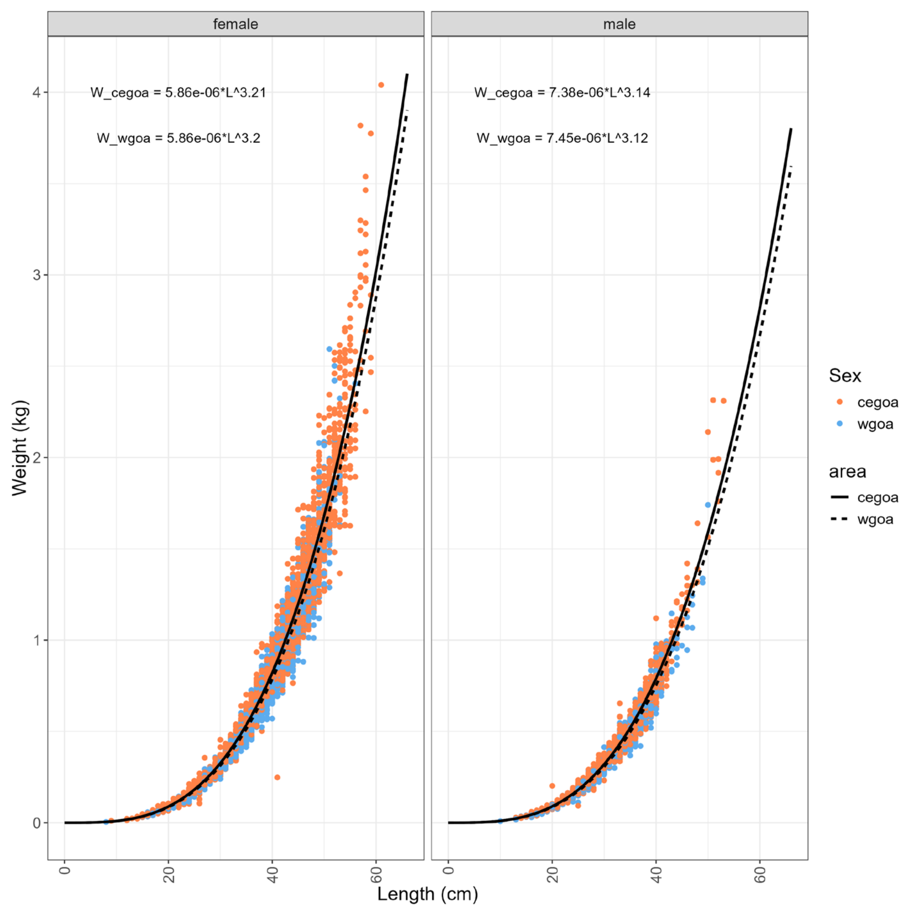


Figure 10. Updated length-weight relationships for southern rock sole; a) all GOA (female-left, male-right) and b) area-specific: Central-eastern GOA (CEGOA) and western GOA (WGOA).

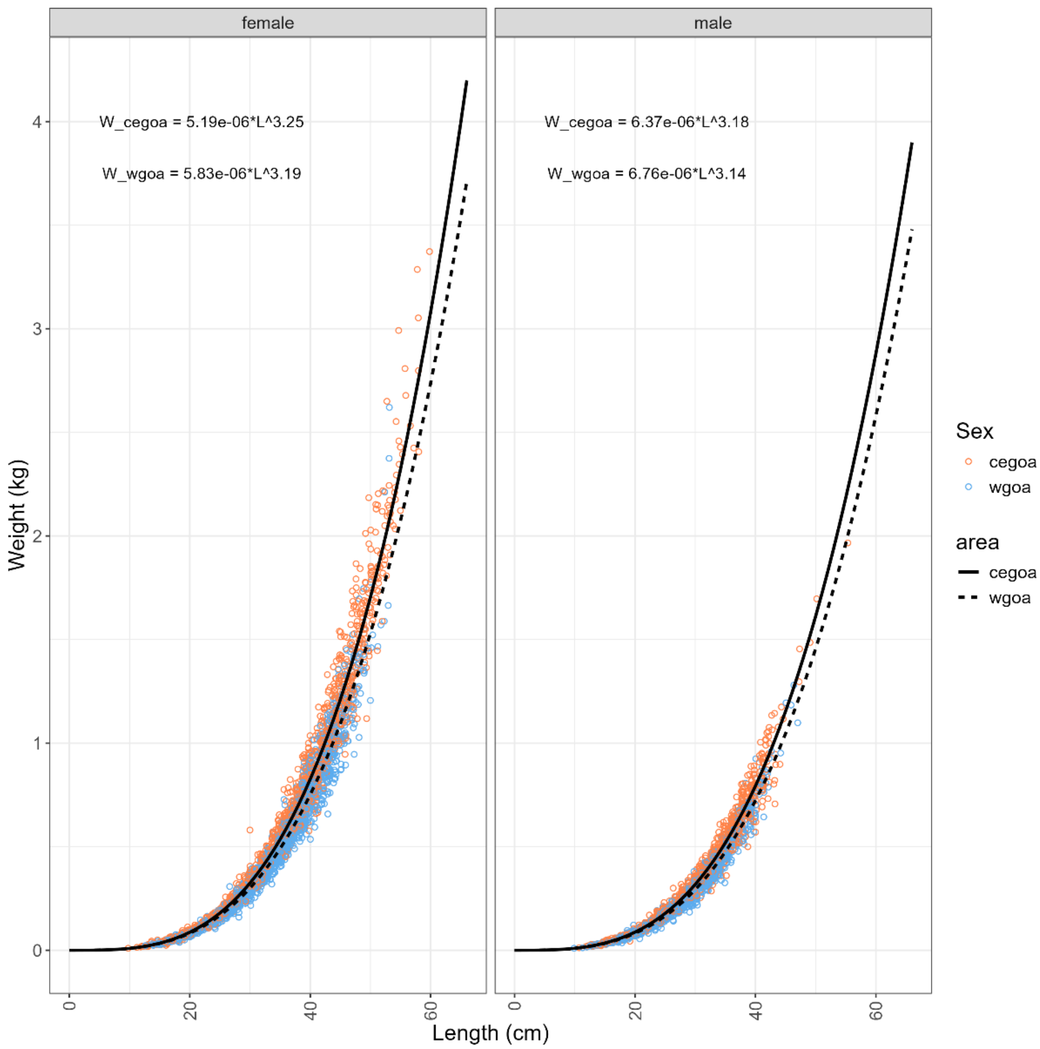


Figure 11. Updated sex and area-specific length-weight relationships for northern rock sole.

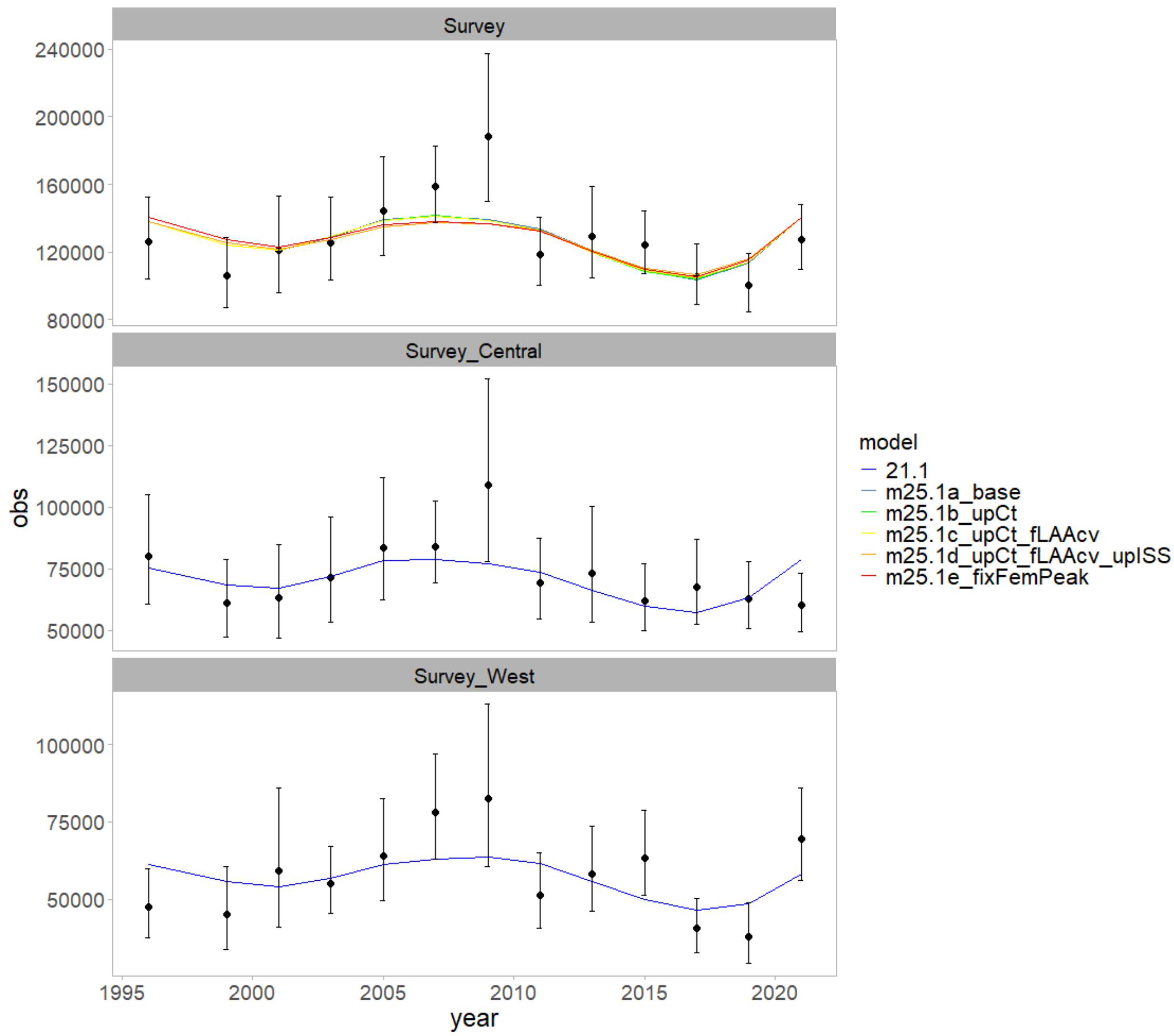
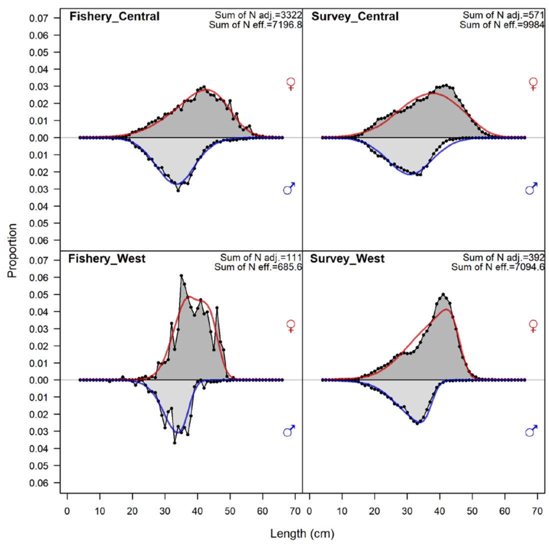
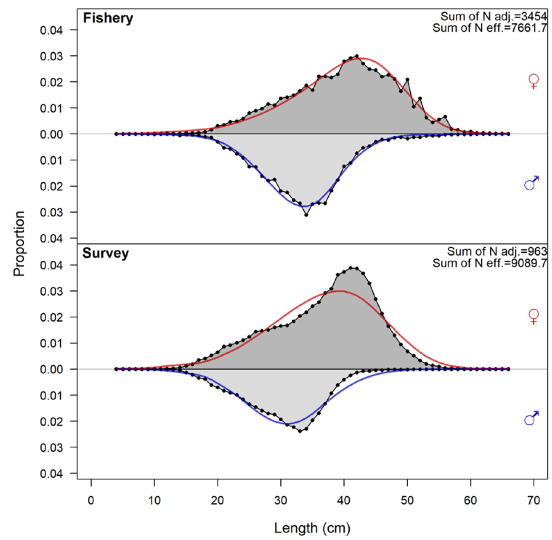


Figure 12. Model fits to the southern rock sole GOA bottom trawl survey data.

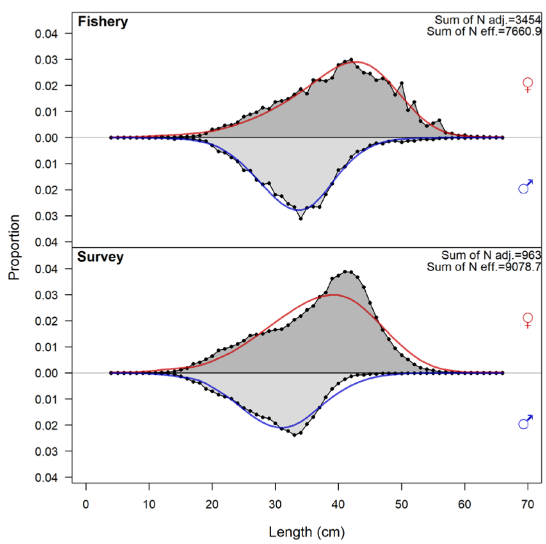
a)



b)



c)



d)

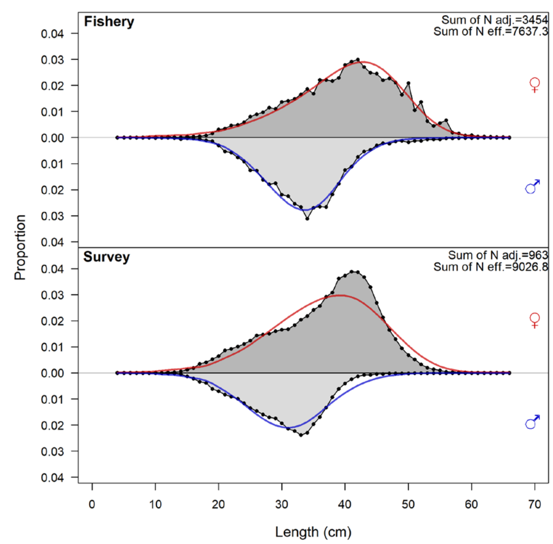
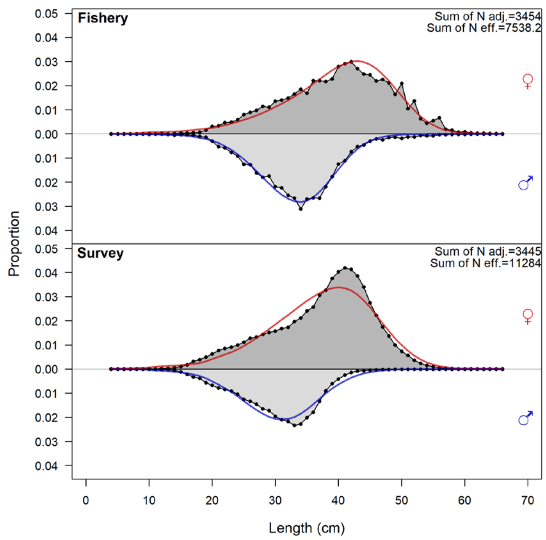


Figure 13. Fits to aggregate length composition data: models a) 21.1 and b) 25.1a, c) 25.1b, d) 25.1c, e) 25.1d, and f) 25.1e.

e)



f)

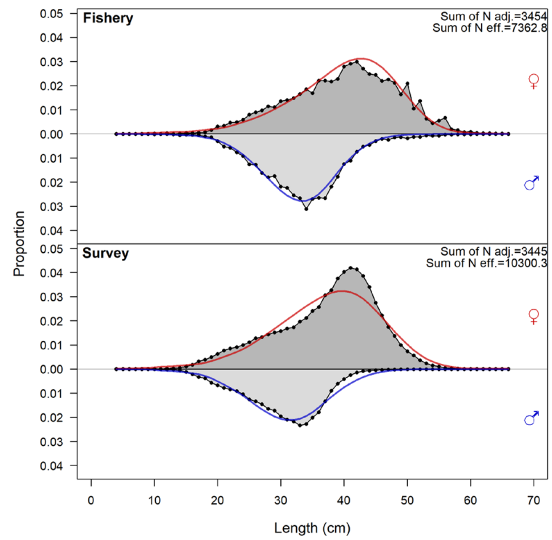


Figure 13. Continued.

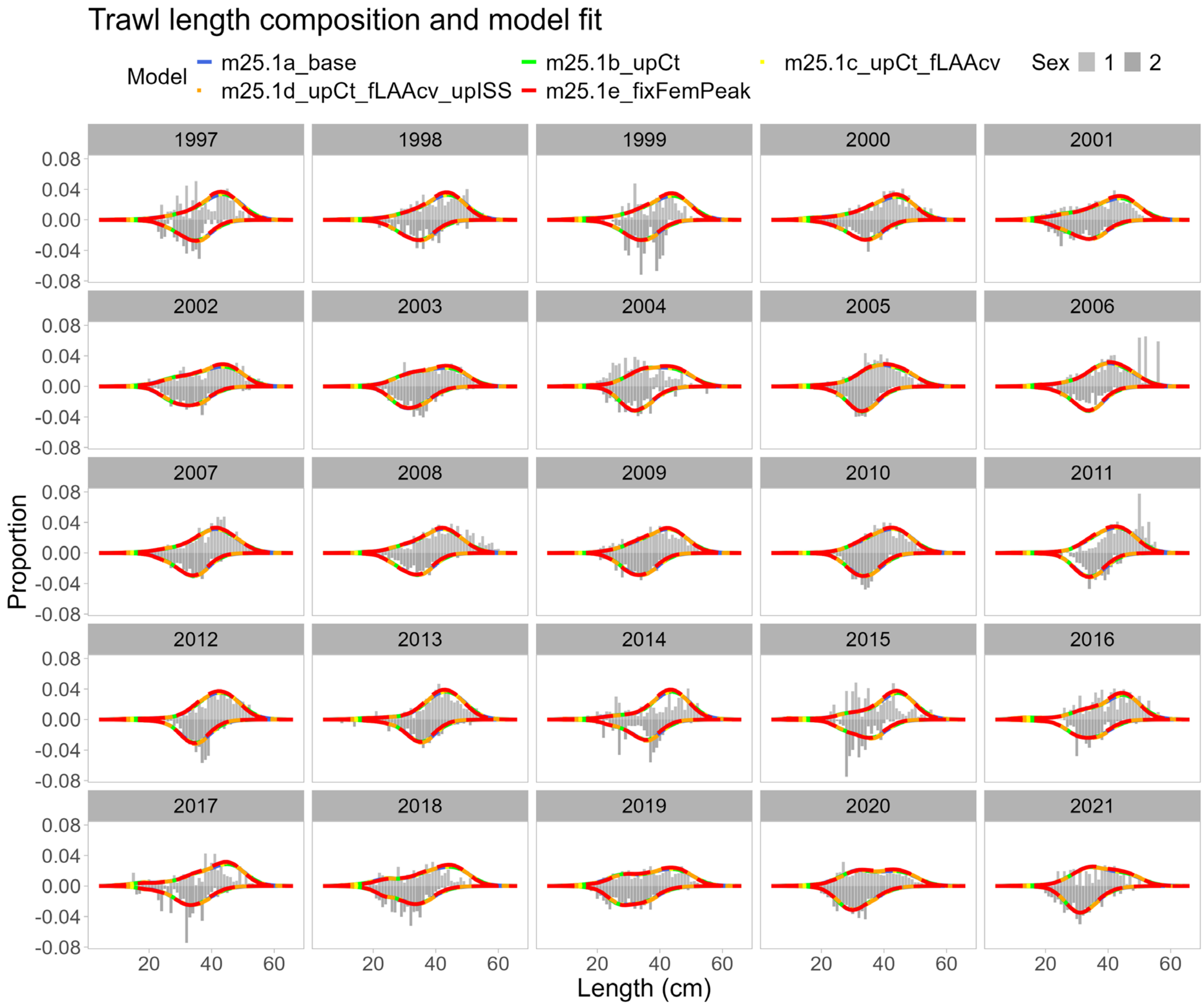


Figure 14. Model 25.1 – 25.1e fits to the southern rock sole GOA fishery length composition data.

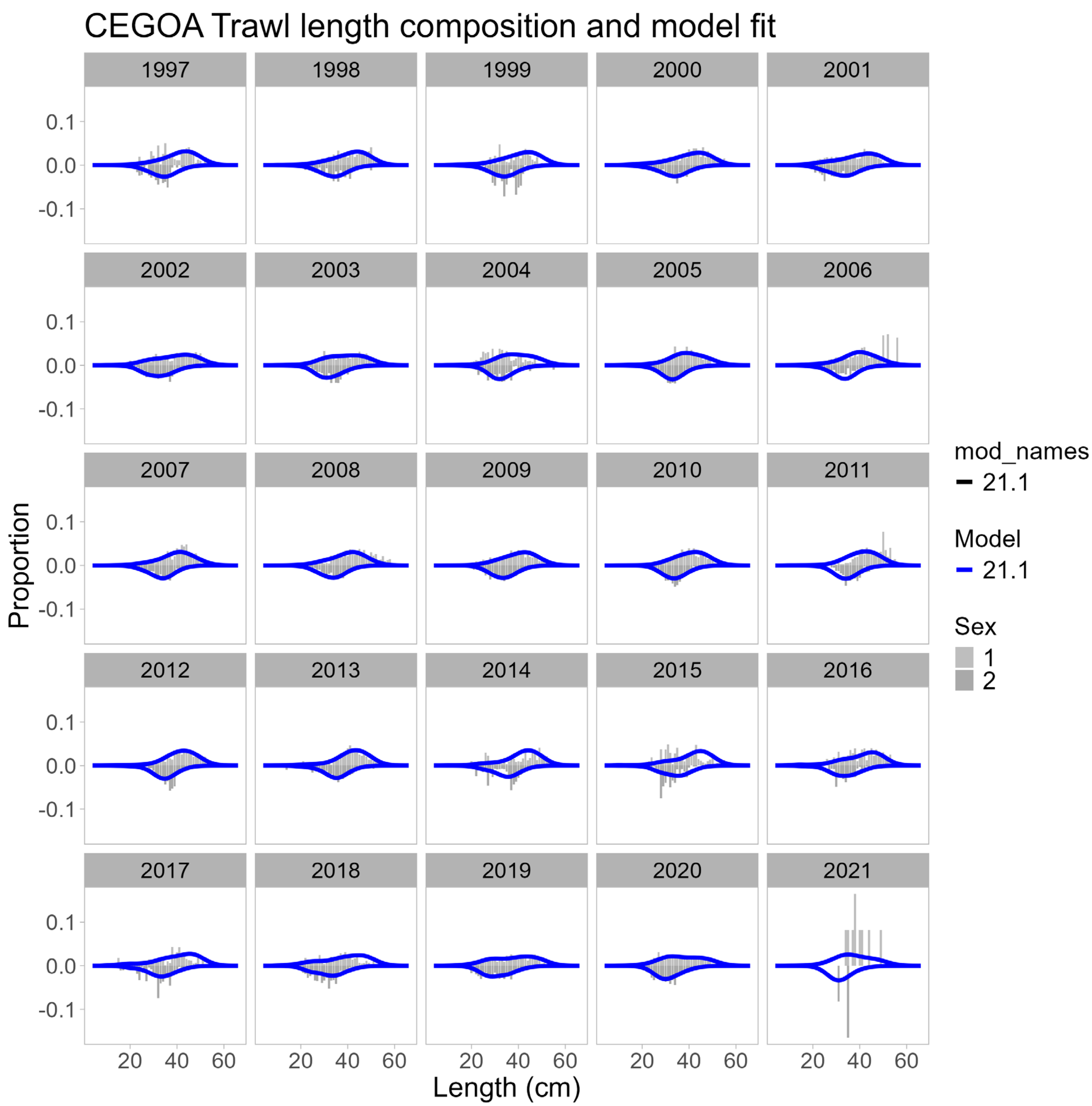


Figure 15. Model 21.1 fits to the southern rock sole central-eastern GOA fishery length composition data.

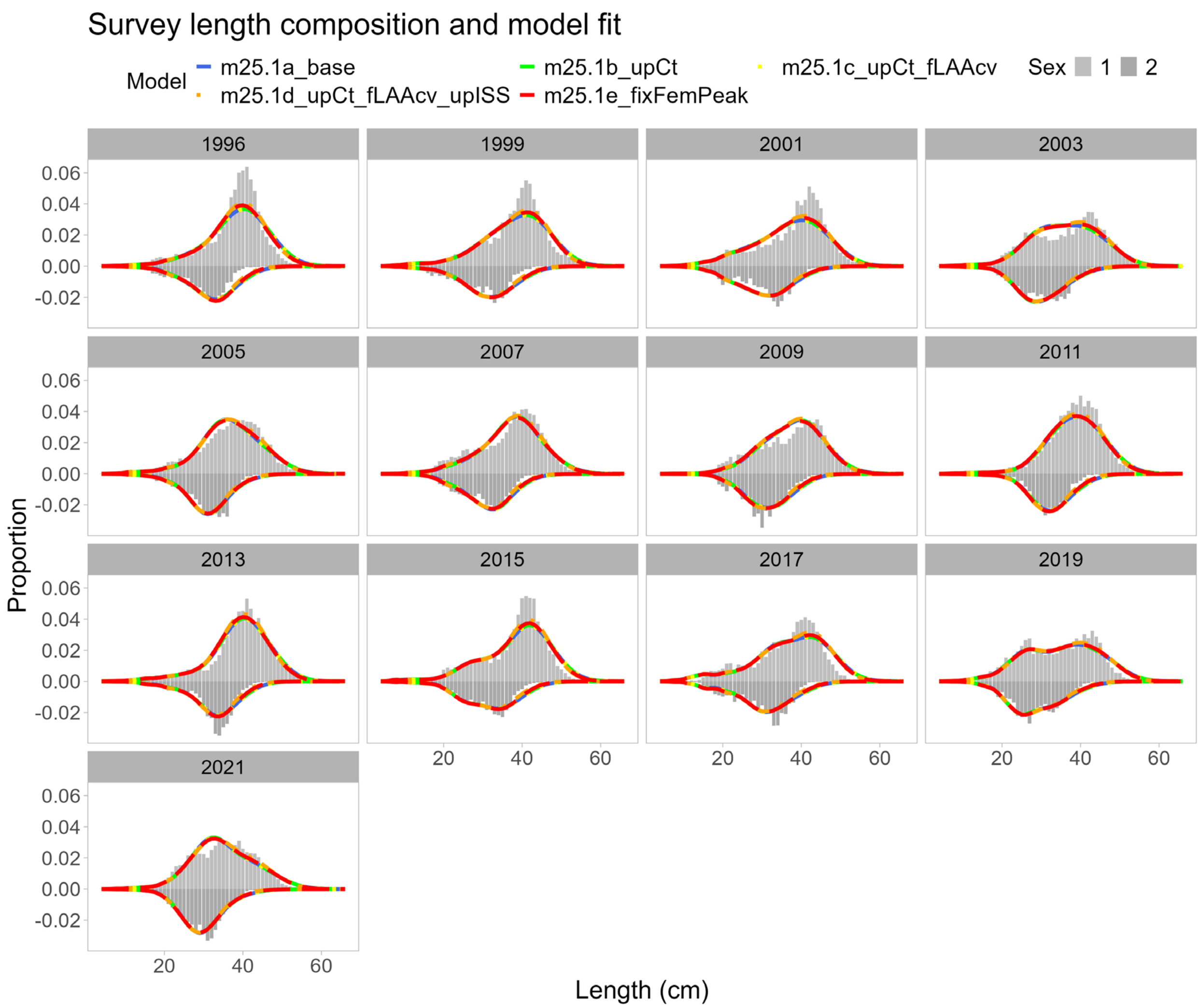


Figure 16. Model 25.1a – 25.1e fits to the southern rock sole GOA survey length composition data.

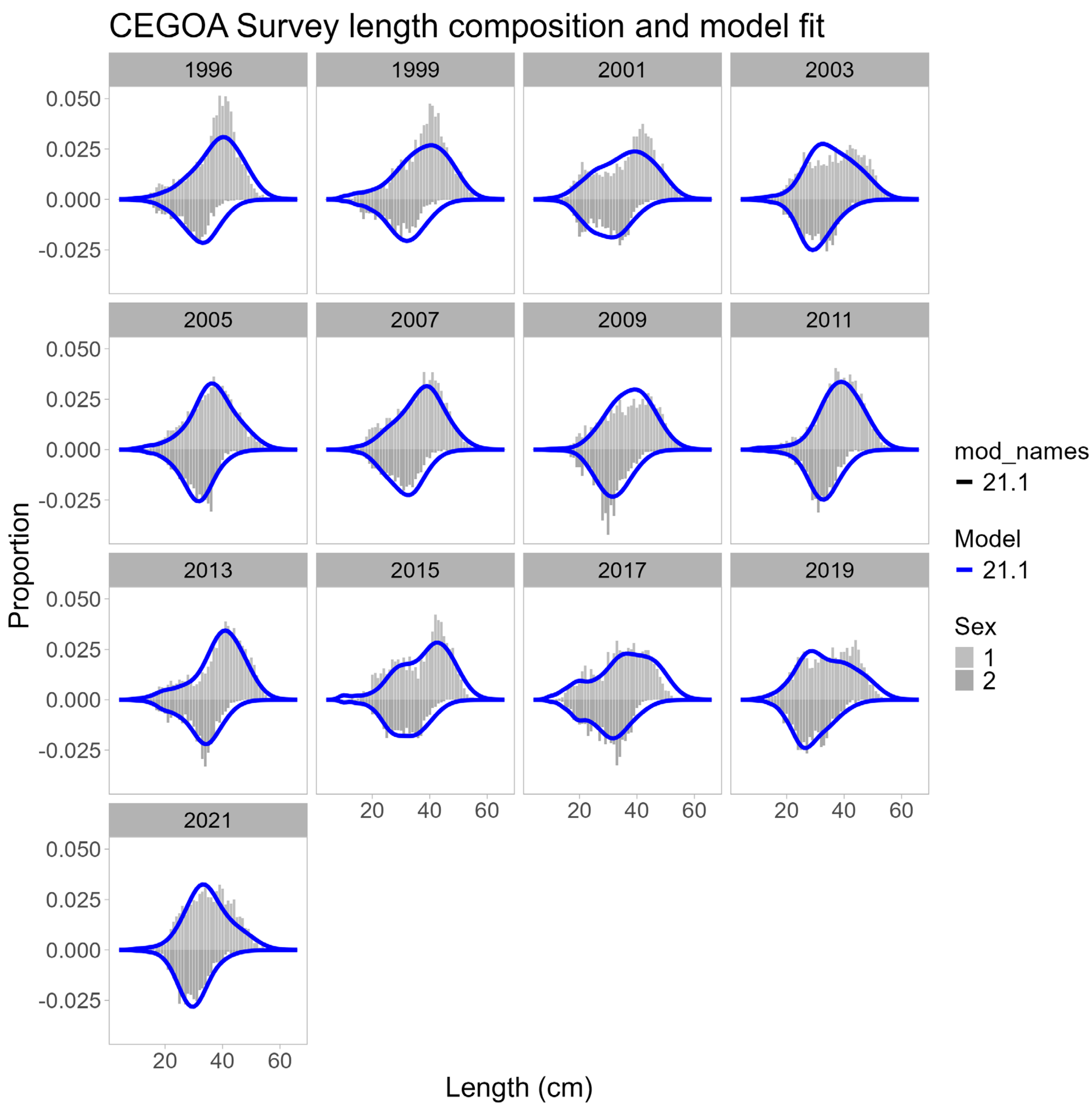


Figure 17. Model 21.1 fits to the southern rock sole central-eastern GOA survey length composition data.

Figure 18. Model 21.1 fits to the southern rock sole western GOA survey length composition data.

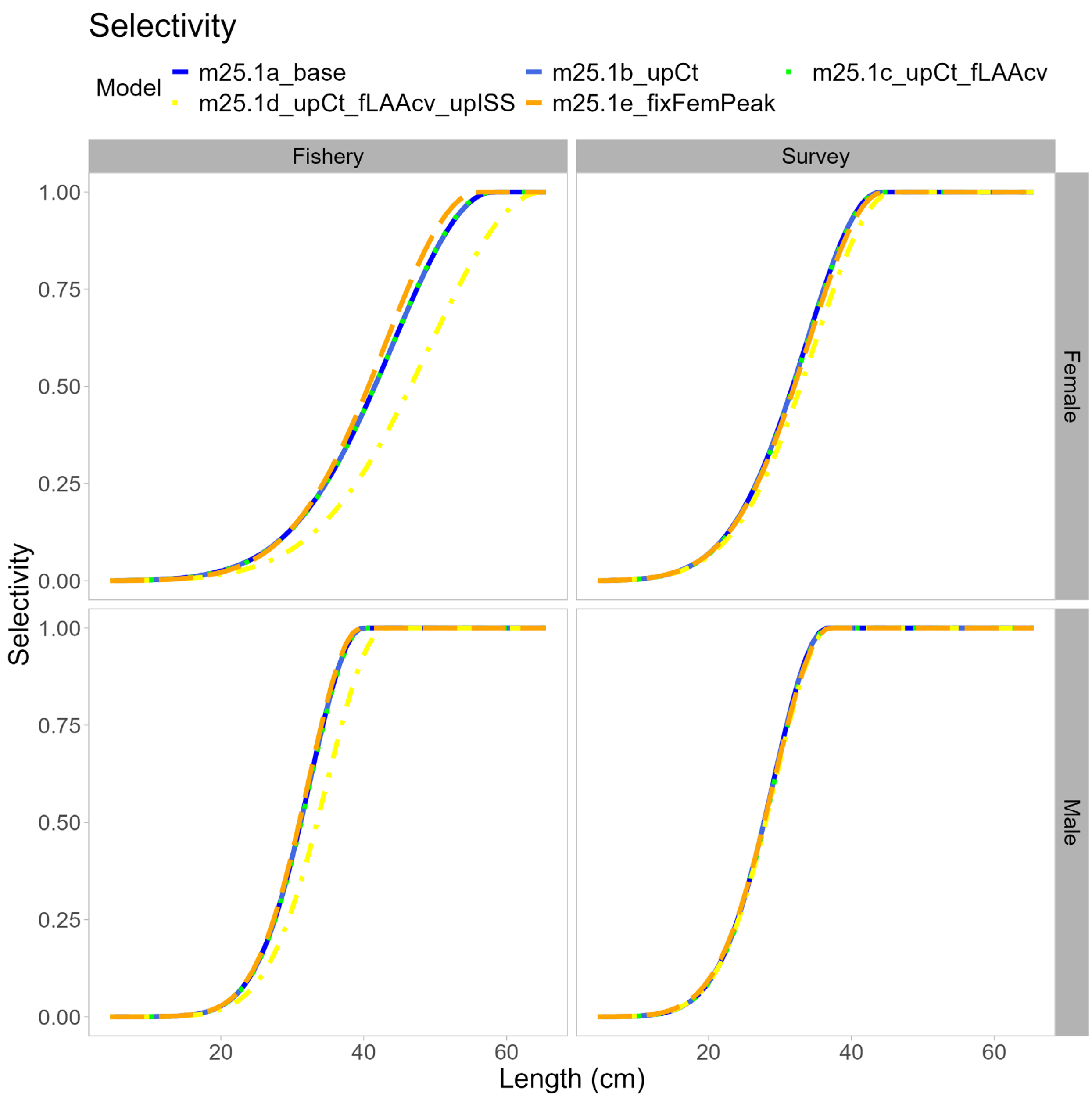
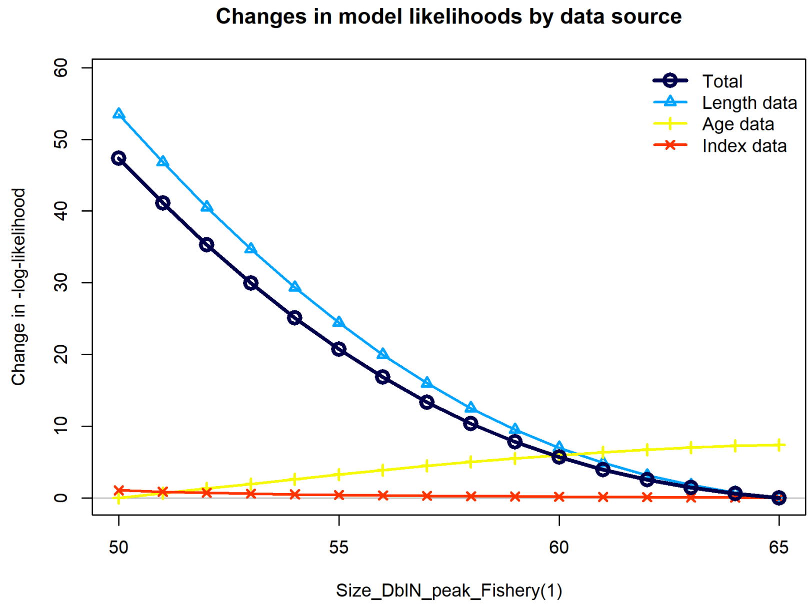


Figure 19. Southern rock sole selectivity for the single area models (m25.1a-e).

a)



b)

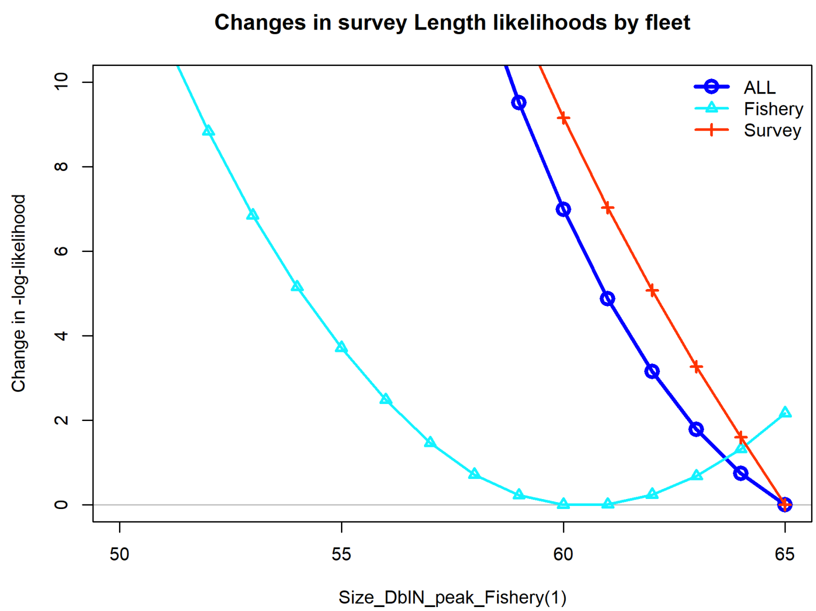


Figure 20. Likelihood profile on female fishery selectivity peak parameter (size at which selectivity reaches it maximum). a) total likelihoods and b) fleet-specific length likelihoods.

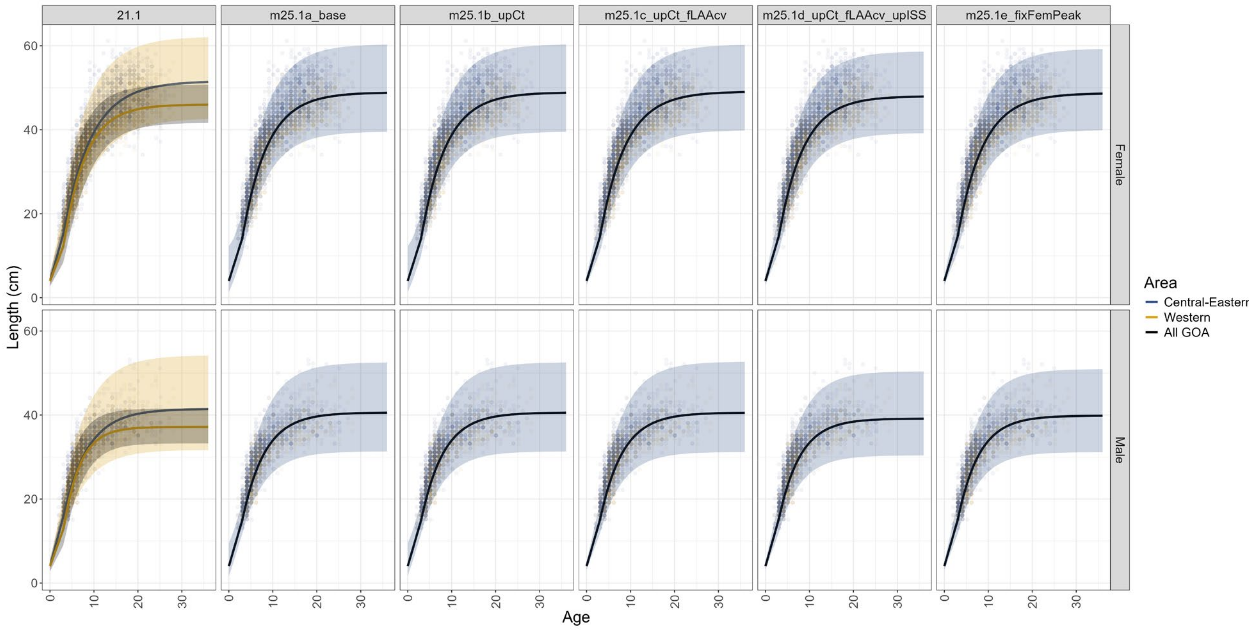


Figure 21. Southern rock sole growth estimated by each model.

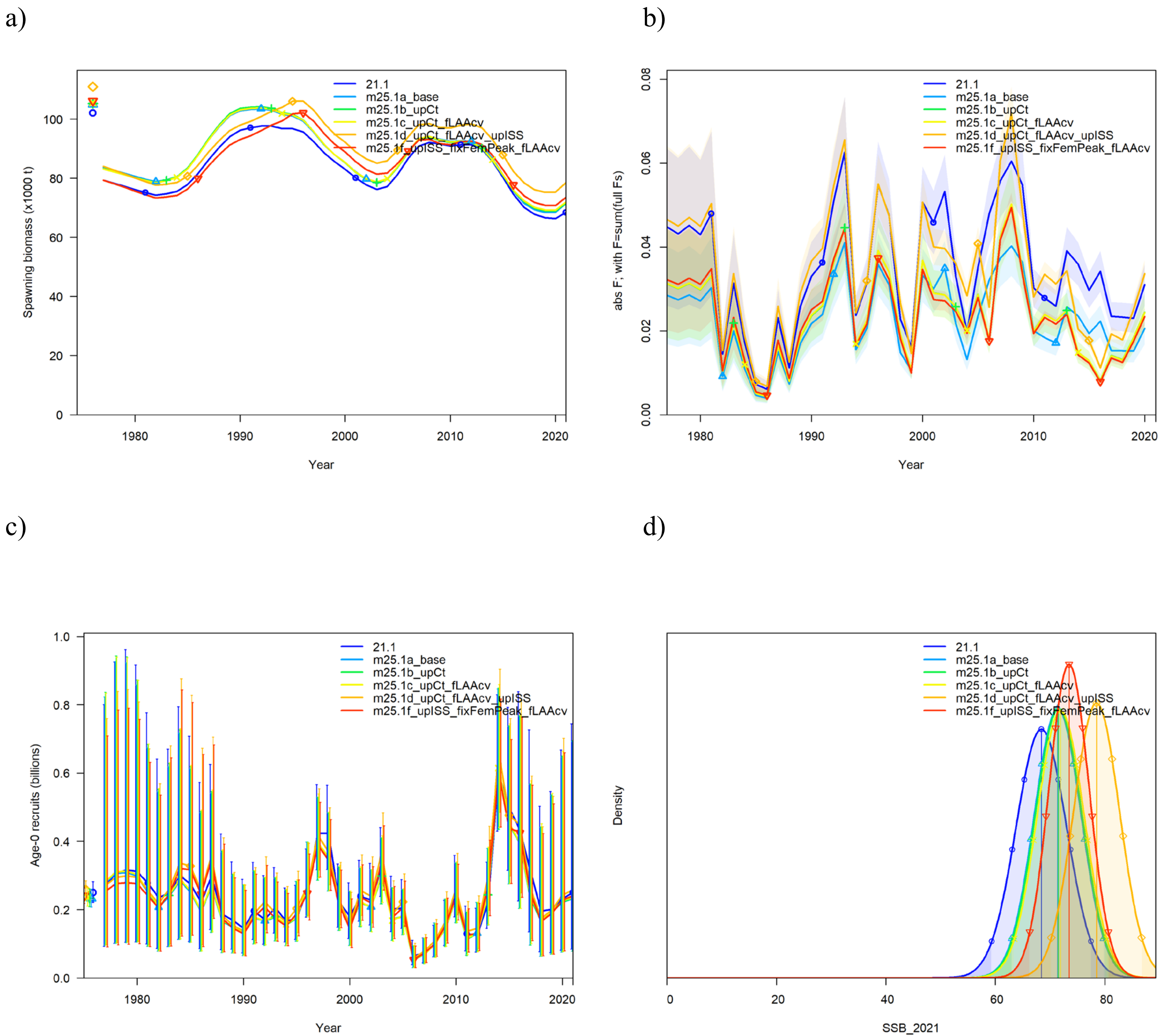


Figure 22. Southern rock sole spawning stock biomass (SSB), fishing mortality, recruitment, and density of SSB in 2021. Shaded areas and bars represent 95% confidence intervals.

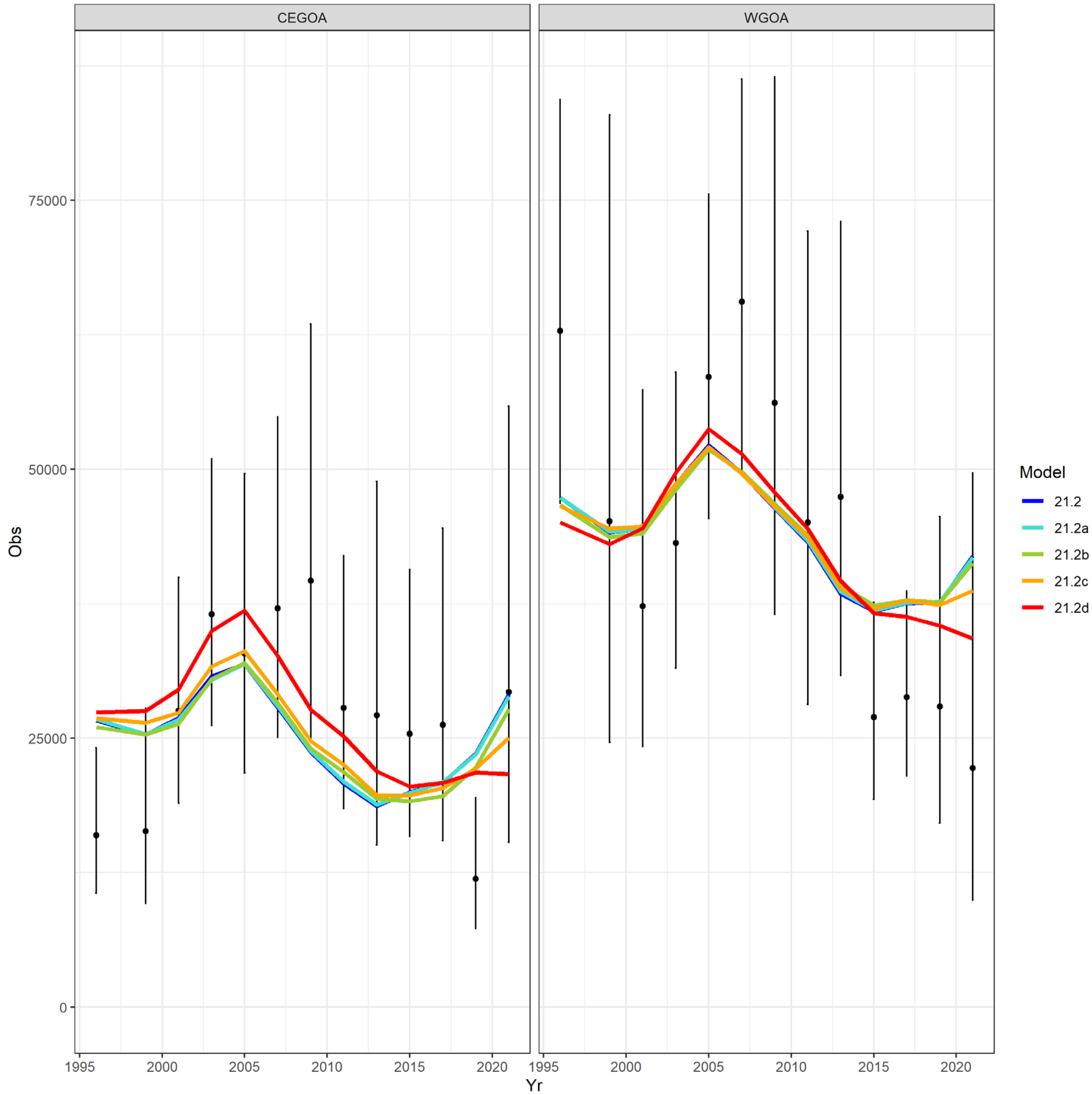
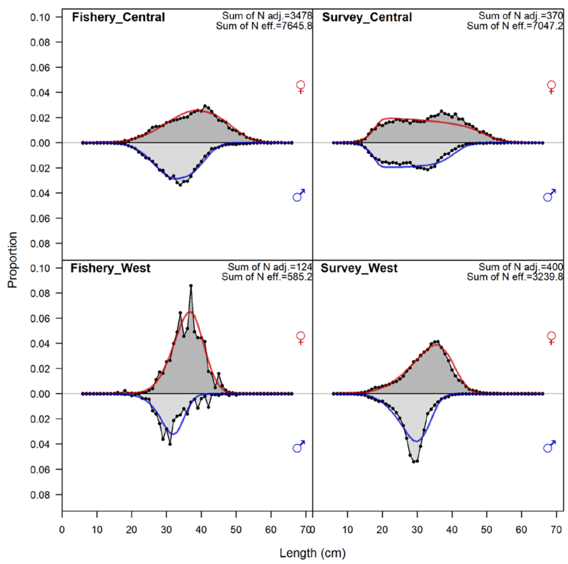
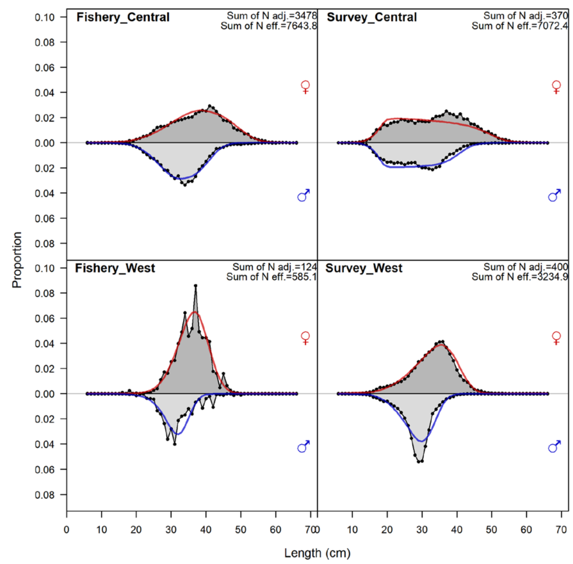


Figure 23. Model fits to the northern rock sole GOA bottom trawl survey data.

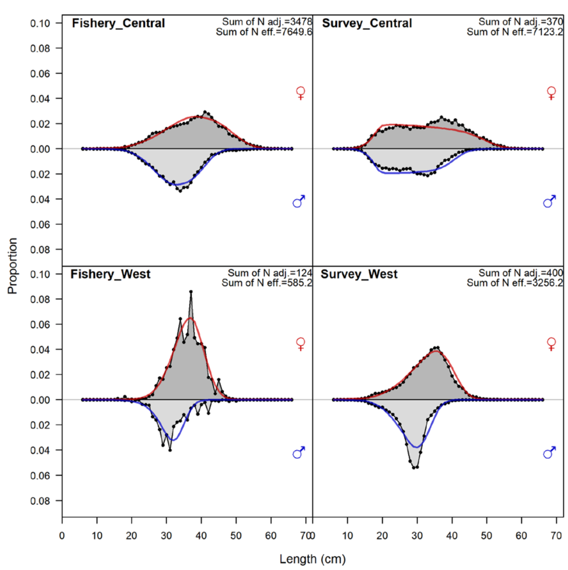
a)



b)



c)



d)

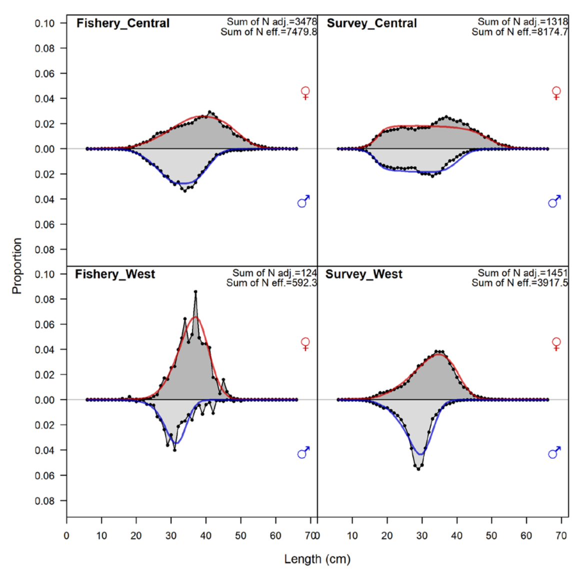


Figure 24. Fits to aggregate length composition data: models a) 21.2, b) 21.2a, c) 21.2b, d) 21.2c, e) 21.2d

e)

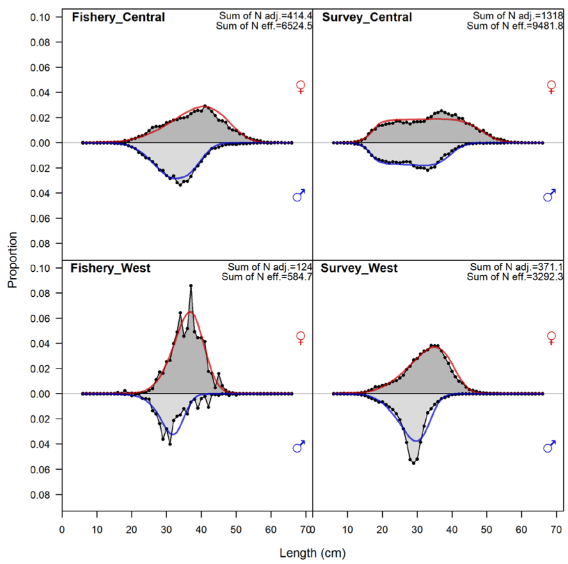


Figure 24. Continued.

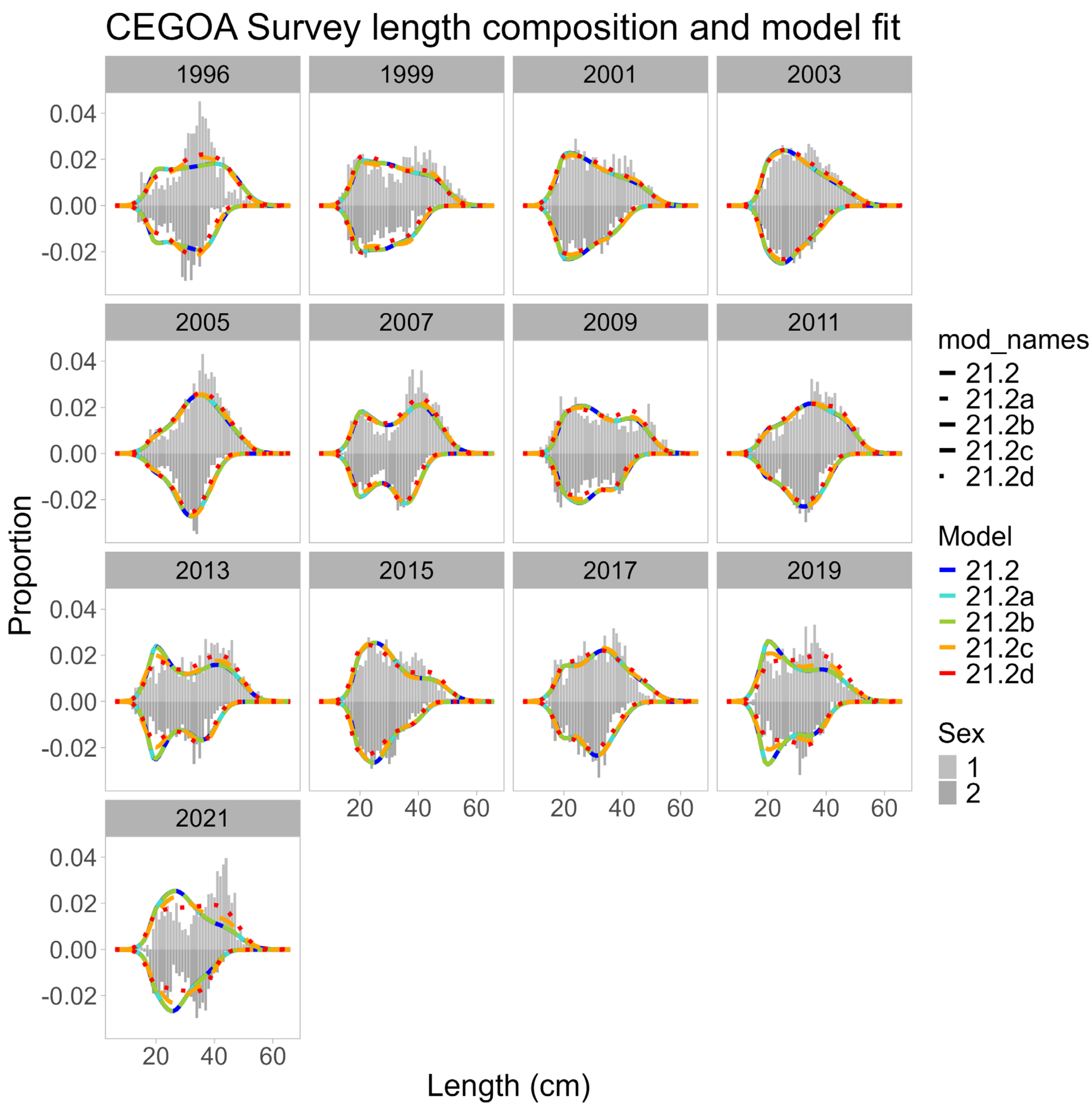


Figure 25. Model fits to the northern rock sole central-eastern GOA survey length composition data.

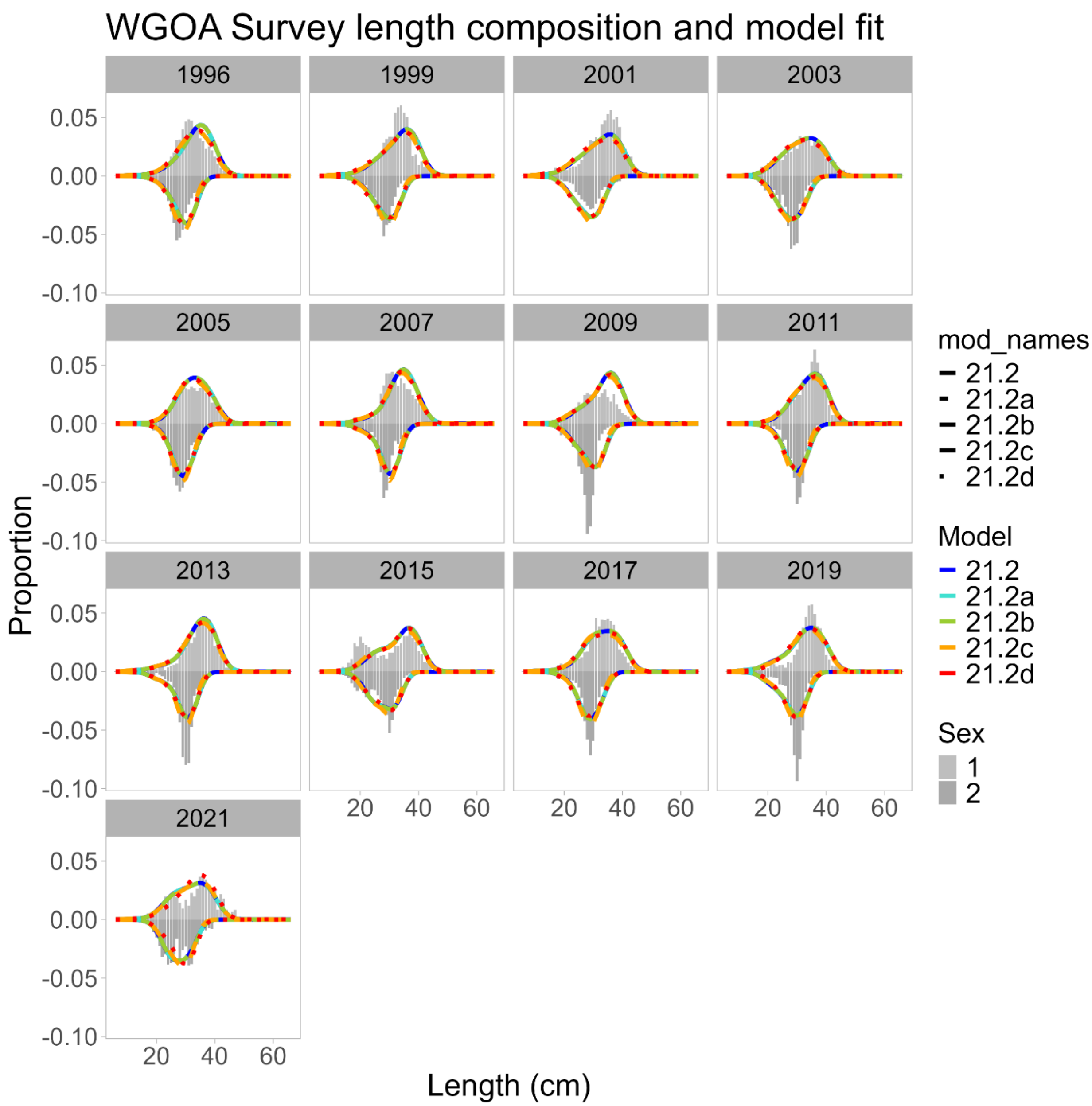


Figure 26. Model fits to the northern rock sole western GOA survey length composition data.

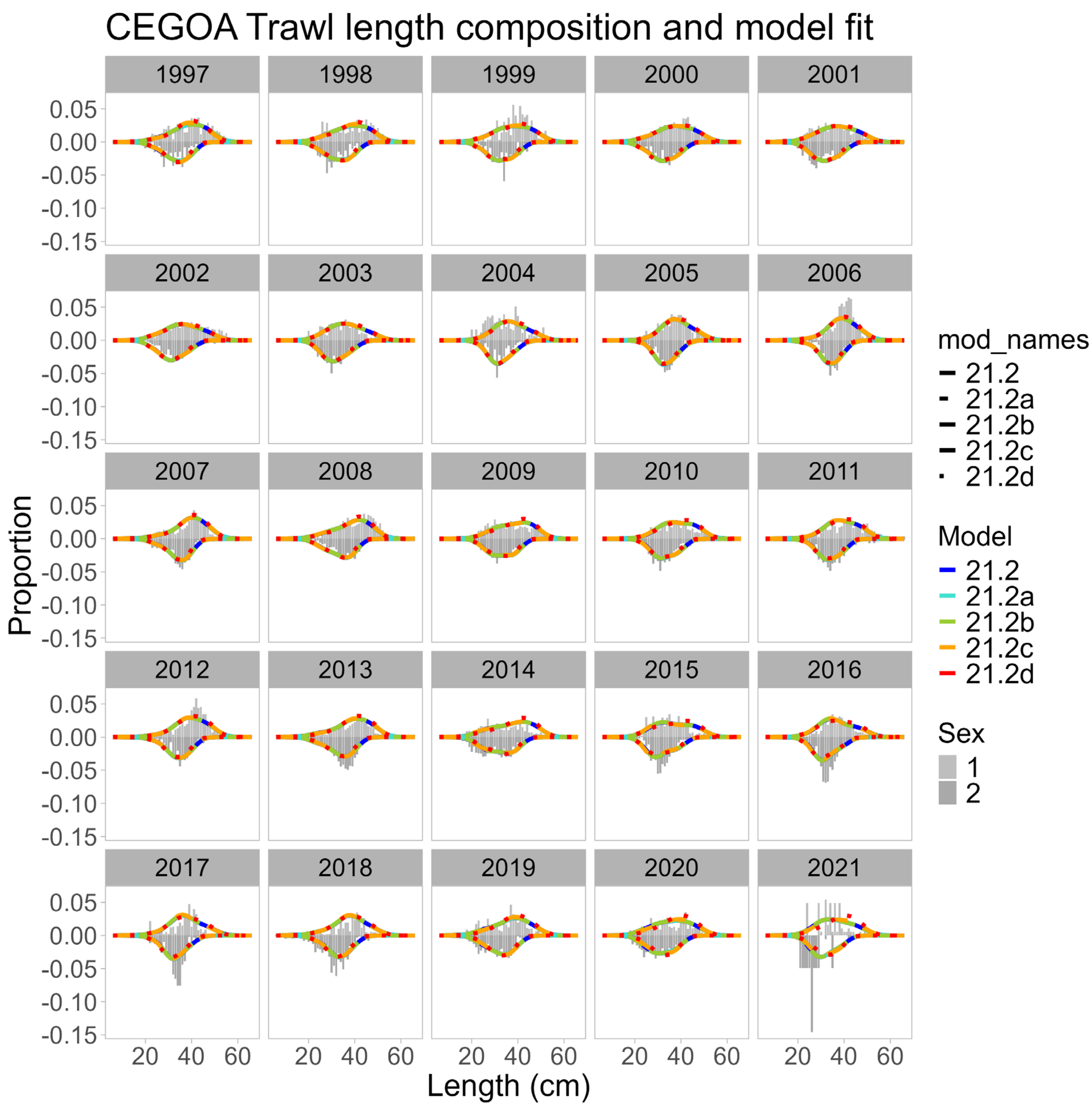


Figure 27. Model fits to the northern rock sole central-eastern GOA fishery length composition data.

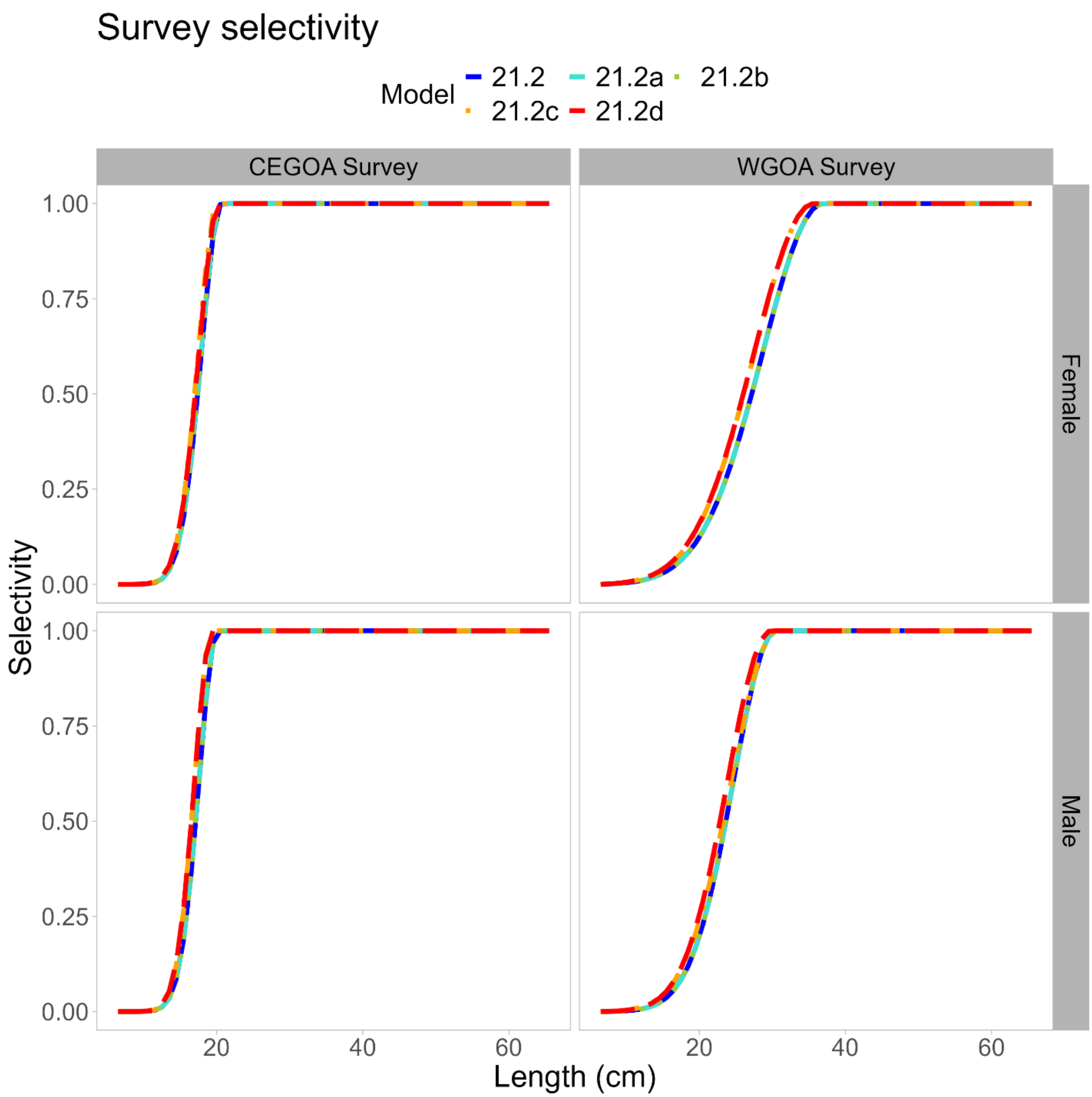


Figure 28. Estimates of northern rock sole bottom trawl survey selectivity by area and sex.

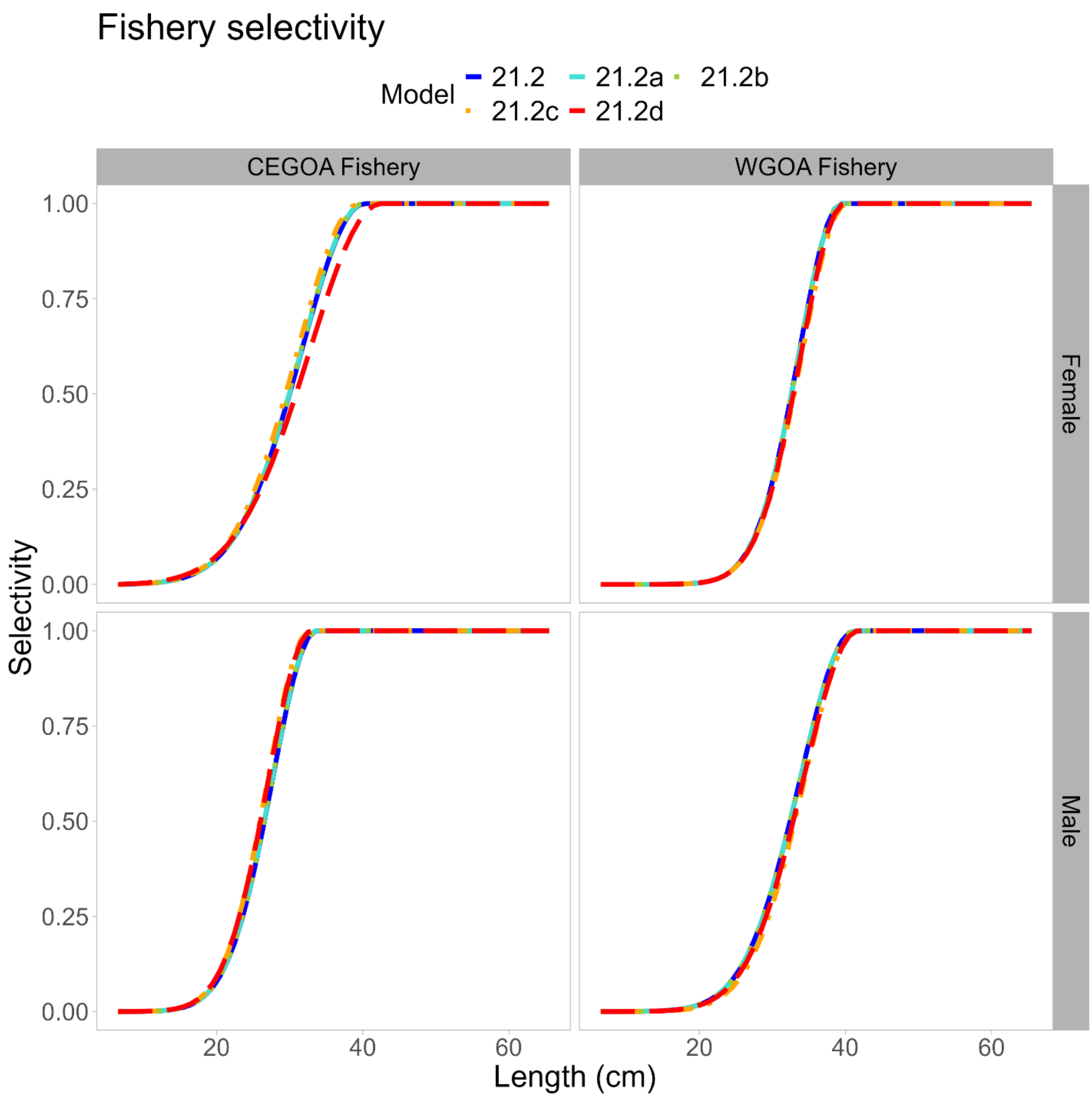


Figure 29. Estimates of northern rock sole fishery selectivity by area and sex.

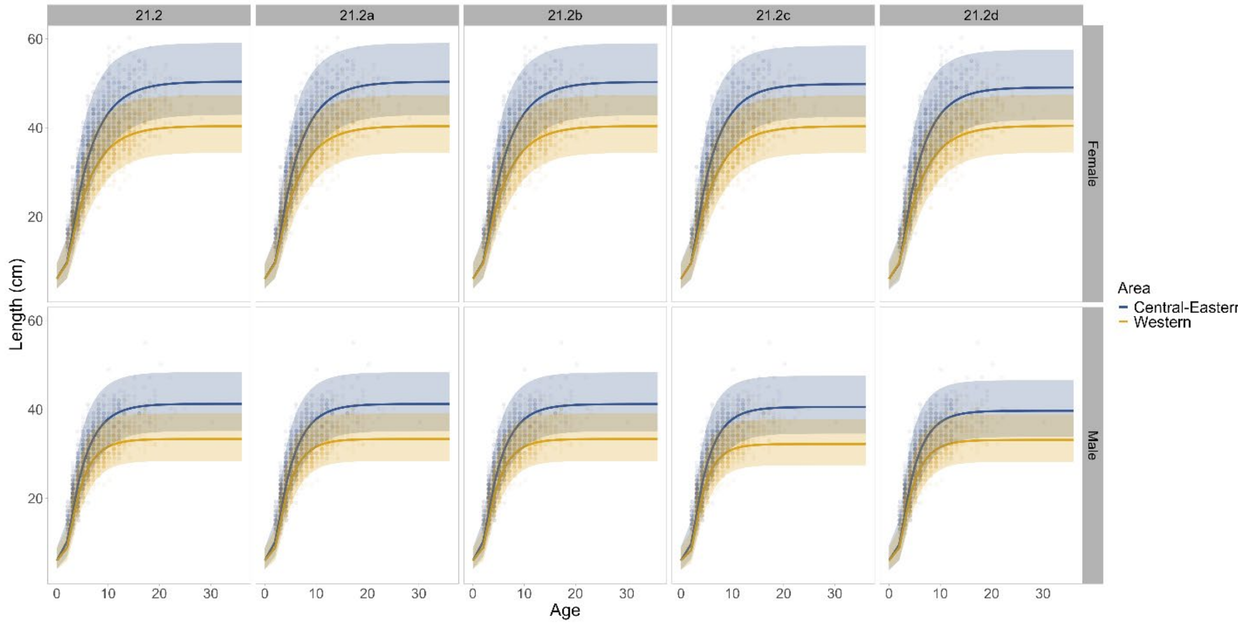


Figure 30. Growth estimates for northern rock sole.

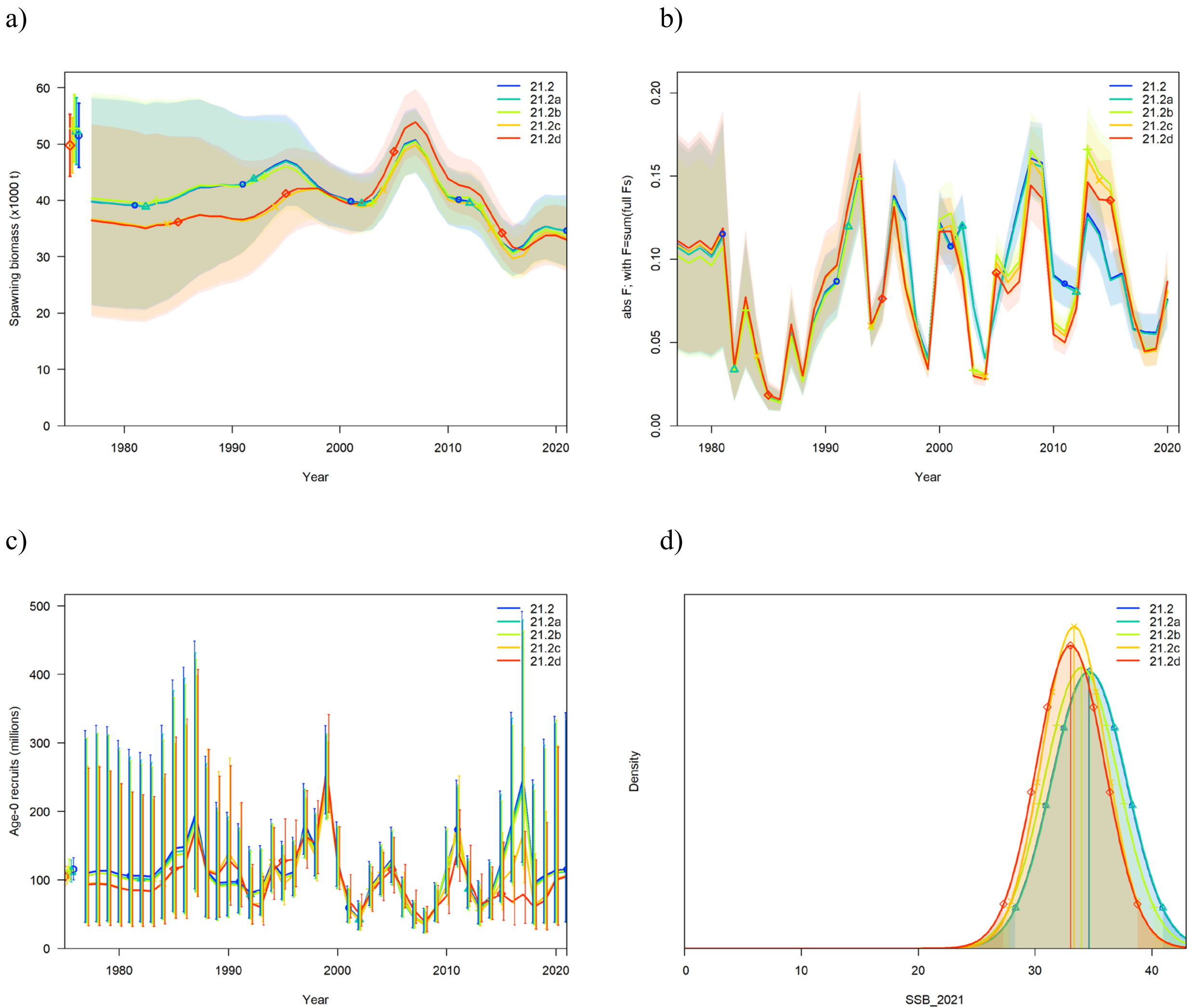


Figure 31. Northern rock sole spawning stock biomass (SSB), fishing mortality, recruitment, and density of SSB in 2021. Shaded areas and bars represent 95% confidence intervals.

Appendix A. Area-specific other shallow water flatfish

Shallow water flatfish are modeled using a single area REMA model; yet, there is evidence that some species may display different dynamics across the GOA and those species may benefit from a multi-area model. For example, northern rock sole appears to have different growth patterns in the central-eastern GOA than the western GOA (Bryan et al. 2021). The survey data for each shallow water flatfish species was examined for evidence of regional differences and to determine if there was sufficient data to support a two-area model (central-eastern vs. western GOA).

Most of the shallow water flatfish species are annually encountered in less than 10% of all survey trawls and splitting the data by area would substantially increases the uncertainty of the survey indices due to the lower sample size (). Switching to a two-area model would primarily impact survey estimates in the western GOA as the biomass for most species is concentrated in the central-eastern GOA. Only northern and southern rock sole were consistently present in a sufficient number of hauls in each region to potentially support a two-area model (≥20 hauls). For the remaining species, splitting by region would lead to an increase in the CVs associated with the survey indices, many of which already have large CV (e.g., CV > 0.3). This increase is, on average, by 0.05 for the central-eastern GOA and 0.15 for the western GOA. English sole and sand sole had the greatest average annual increase in CVs (0.30 and 0.25) for the western GOA resulting in average regional CVs of 0.61 and 0.80 respectively.

We recommend continuing to use single area REMA models for the other shallow-water flatfish.

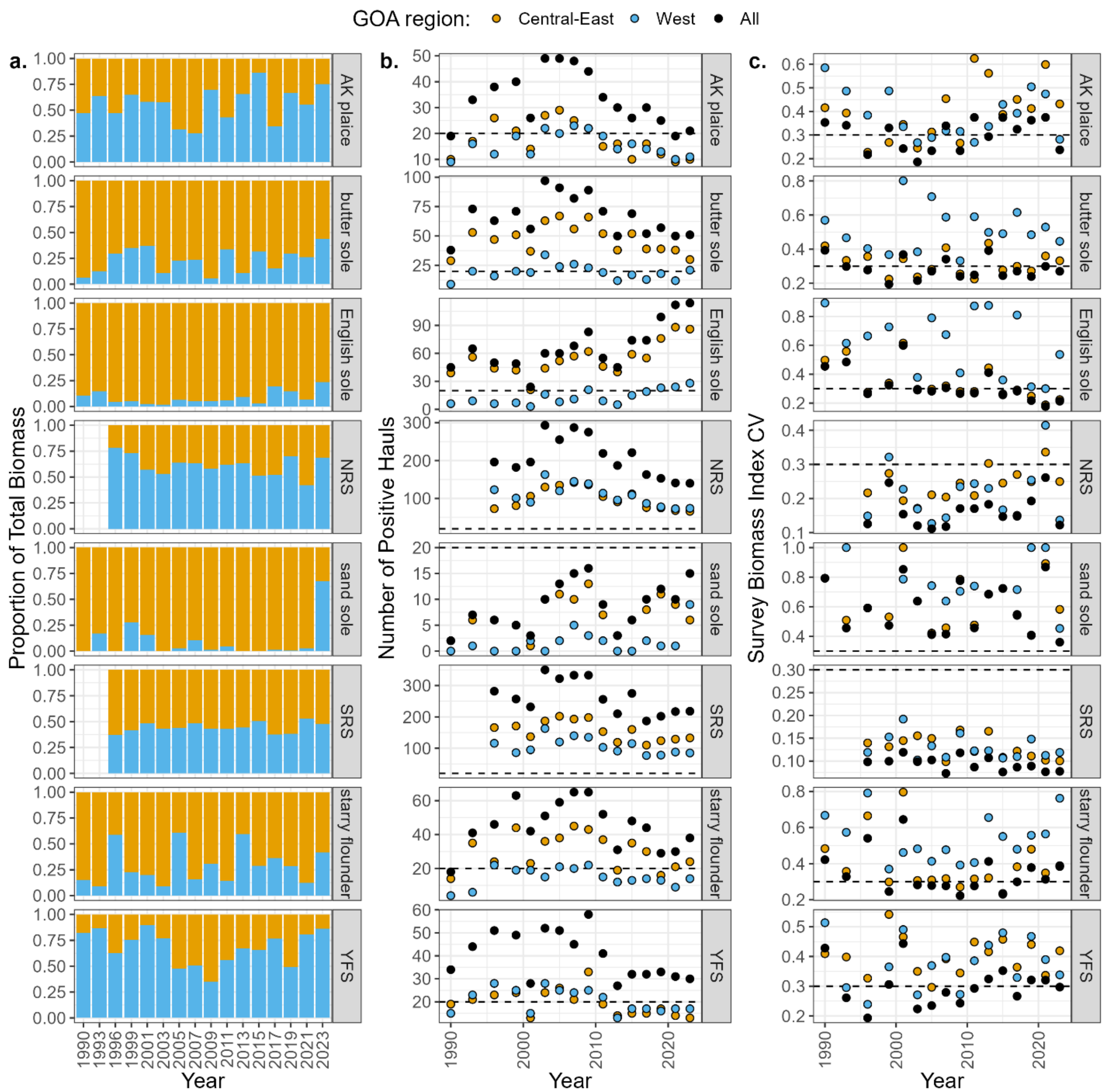


Figure A.1. Annual shallow-water flatfish bottom-trawl survey data based on GOA region (orange, central-eastern; blue, western; black, all of GOA): (a) the proportion of proportion of the annual estimated total biomass from the survey for each species, (b) the number of survey hauls with positive counts for each species by region (487-831 BTS trawls per year; dashed line represents 20 hauls), (c) the CVs associated with the annual survey biomass index (dashed line represents a 0.3 CV). Note variable y-axes among panes. Species names: AK plaice, Alaska plaice; NRS, northern rock sole; SRS, southern rock sole; YFS, yellowfin sole.