PRELIMINARY ASSESSMENT OF THE GREEENLAND TURBOT STOCK IN THE EASTERN BERING SEA AND THE ALEUTIAN ISLANDS

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Introduction

This report represents the preliminary assessment of the Greenland turbot (*Reinhardtius hippoglossoides*) eastern Bering Sea and the Aleutian Islands (BSAI) stock and responses to the recommendation made by the Bering Sea Aleutian Islands (BSAI) Plan Team and the SSC in 2016. The recommendations are listed below followed a response.

Plan Team and SSC 1) the consistency of time blocks across surveys be explored.
A model assuming time invariant selectivity (i.e., no time blocks) was explored. The overall fit to the trawl length composition data degraded, while the overall fit to the longline, shelf survey, and slope survey length data was similar to the base model. The model no longer fit the shelf and ABL longline indices of abundance. This model configuration was not considered reasonable and produced unacceptable results, hence the results are not shown in this report.

Plan Team and SSC 2) a stock structure template be completed.
This was completed and will be presented to the Plan Team during the September, 2018 meeting.

Plan Team and SSC 3) the author explore the use of age comp data in the model.
Otoliths have been collected by the Fisheries Monitoring and Analysis (FMA) Observer Program. Otoliths are available for the majority of years between 1982 and 2018. Approximately 1000 otoliths have been aged from a subset of years (471 from 1982, 55 from 1994, 313 from 2006, and 236 from 2007). Given that so few years are represented in the aged samples, they were not used in the model or explored for use.

Plan Team and SSC 4) the author contact ABL survey staff about getting sex specific lengths collected during future surveys.
The author will do this before the next survey (2019) season.

Data

The data used for this preliminary assessment were the same as those used in the 2016 assessment with several updates (Barbeaux et al. 2016, Figure 1). The data and the updates are briefly summarized here.

Catch was separated into two fleets, trawl (1960 – 2018) and longline (1977 - 2018) (Figure 2). The longline fleet included catch from other fixed gear types, including pots and hook and line. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, the ratio of the two species for the years 1960-64 were assumed to be the same as the mean ratio caught by USSR vessels from 1965-69. The 2017 catch values were used as an estimate of the 2018 catch for the preliminary assessment.

Survey abundance indices from NOAA's Bering Sea Shelf Trawl Survey, NOAA's Bering Sea Slope Trawl Survey, and Auke Bay Laboratory's (ABL) longline survey were used in the assessment (Figure 3). The Shelf Trawl Survey and the ABL longline surveys are conducted annually and represent continuous time-series from 1987 – 2017 and 1996 – 2017, respectively. The 2018 estimates for the shelf and ABL longline survey will be available after the September Plan Team meeting. The Slope Trawl Survey is intended to be a biennial survey and was conducted in 2002, 2004, 2008, 2010, 2012, and 2016. The 2018 slope survey was cancelled.

Length frequency composition data have been collected by the NMFS observer program since 1978. The length composition data from the trawl and longline fishery were included in the assessment (Figure 4). Length composition estimates for the population were also available for the shelf and slope surveys and mean length-at-age from the shelf survey included in the model (Figures 4 and 5).

Model Structure

The 2016 assessment was developed and run using the Stock Synthesis (SS) software package version 3.24 (Methot and Wetzel 2013). This model was transitioned from SS3.24 to the most recent version, SS3.30.12.

Base model

Model 16.4 (Barbeaux et al. 2016) was adopted by the SSC in 2016. This model will be referred to as Model 16.1 in this document. The model was sex-specific, represented ages 0 to 30, and started in 1945.

Growth and natural mortality

Sex-specific growth was assumed to follow the von Bertalanffy growth relationship and was assumed to be constant over time. All growth parameters except the parameters describing the variability in age 1 and age 25 fish were estimated. Length at age 1 was assumed to be the same for both sexes and assumed to have an 15% CV. Age 25 fish were assumed to have a CV of 9% (Gregg et al. 2006).

Natural mortality was assumed to be the same for female and males. It was also assumed to be time invariant and set equal to 0.112 (Cooper et al. 2007).

Maturity

Maturity was assumed to follow a length logistic relationship where the length at 50% maturity was equal to 60 cm and the slope was equal to -0.25 (D'yakov 1982, Cooper et al. 2007). Fecundity was assumed to be equivalent to spawning biomass (SS3 fecundity option 1, where the eggs/kg intercept was equal to 1 and the eggs/kg slope was equal to 0). The maturity curve is shown in Figure 6.

Length-weight relationship

The length-weight relationship parameters were fixed in the model and externally estimated from the combined NMFS survey data. The female alpha and beta parameters to convert length in centimeters to weight in kilograms were set equal to 2.43×10^{-6} and 3.325, respectively, and the male alpha and beta parameters were 3.4x10-6 and 3.2189, respectively (Barbeaux et al. 2012). The length-weight relationship is shown in Figure 6.

Recruitment

Recruitment was assumed to follow the Beverton-Holt stock-recruitment relationship. Steepness (*h*) was fixed and set equal to 0.79 and the variability in recruitment (σ_R) was fixed at 0.6, consistent with values found for Greenland turbot stocks in the North Atlantic and Arctic Ocean (Myers et al. 1999). An autocorrelation parameter was estimated. A prior with a mean of 0.473 and standard deviation 0f 0.265 estimated by Thorson et al. (2014) for Pleuronectidae species was used to estimate the atocorrelation parameter. Recruitment deviations were estimated and separated into early (1945-1970), main (1971-2013), and forecast (2014-2018) recruitment events. Separating the recruitment deviations into these components reduces the influence of the estimation in the early period, which has little data, on the later period.

Catchability

The catchability coefficients for the shelf and slope surveys were fixed in the model. The estimates were from the 2015 Model 14.0 fit without the 2007 through 2015 data. This was meant to eliminate the effects of the 2007 through 2010 year classes ($\log(q_{shelf})$ = -0.4850235 and $\log(q_{slope})$= -0.5555418). The ABL longline catchability was analytically solved for in model 16.1.

Selectivity

Sex-specific, size-based selectivity patterns were estimated for the two trawl surveys and the two fisheries. A double normal pattern was used to model the selectivity of the trawl and longline fisheries and the shelf and slope surveys. Female selectivity estimation for the trawl fishery and the slope survey was offset from the estimated male selectivity and the male selectivity was offset from the female selectivity for the longline fishery and the shelf survey. The double normal pattern is described by 6 parameters describing the peak of the curve, the width of the plateau, the width of the ascending arm of the curve, the width of the descending arm of the curve, the selectivity at the first length bin, and the selectivity at the last length bin. The selectivity of the opposite sex is differentiated by 5 additional parameters:

- p1 is added to the first selectivity parameter (peak)
- p2 is added to the third selectivity parameter (width of ascending side)
- p3 is added to the fourth selectivity parameter (width of descending side)
- p4 is added to the sixth selectivity parameter (selectivity at final size bin)
- p5 is the apical selectivity

The selectivity of the ABL longline survey was assumed to be constant over time and modeled with a logistic pattern, with the length at 50% selectivity and the slope parameter set equal to 63.5993cm and 5.0955, respectively.

Time blocks were used to model time-varying selectivity for all fleets except the ABL longline survey. The time blocks differed among the fleets and are shown relative to the fleet-specific length distributions in Figure 4. Table 1 summarizes which selectivity parameters were fixed or estimated by fleet and time block.

The annual sample sizes for the composition data remained unchanged from the 2016 assessment. For the two fisheries initial sample sizes for each year were set to 50. The annual size composition sample sizes for the shelf survey was set at 200, the ABL survey at 60, and the pre-2002 slope surveys set at 25, while

2002 and later set at 400. The sample size for the slope survey was increased to 400 to better balance this survey with the more frequent shelf survey.

Alternative models

Minor changes were made to model 16.1 to address model stability issues. These changes included the removal of the ABL longline survey index from the model (Model 16.1a) and the estimation of the ABL longline catchability coefficient in the model (Model 16.1b).

During the 2016 assessment season, a model that included an environmental index linked to the estimate of R_0 was presented but not considered for management. This model was explored for the September, 2018 Plan Team meeting. An environmental link parameter was fit to recruitment through a regime parameter, which effectively allowed recruitment to be adjusted for particularly cold years. The mean bottom temperature from the bottom trawl survey from 1982-1977 was calculated, then a vector of 0 and -1 for these years was created and included in the model, with -1 being years in which the mean bottom temperature was below one standard deviation from the time series mean. Prior to 1982 a -1 was set for years with negative average PDO values for 1945-1981. The results were similar between this model and Model 16.1 and Model 16.b and the fits to the indices and composition data were almost identical. There was some improvement in the likelihood, but this improvement was mainly due to minimizing the sum of the recruitment deviations in the data poor regions of the recruitment periods. Hence, the results for this alternative are not included in this document.

Results

Comparison of SS versions

The base model (Model 16.1) was transitioned from SS3.24 to SS3.30.12 to show that the results matched between the two versions. A comparison of the results show that the estimates of key leading parameters were similar between the two SS versions and the estimates of spawning stock biomass (SSB), recruitment, and the estimate of unfished recruitment are essentially identical (Table 2, Figure 7). The fits to the indices and the estimated selectivity patterns were also essentially identical between the versions of SS3 (Figures 8 and 9).

Base model

Comparison to the 2016 assessment

The base model was run with the data updates mentioned in the Data section (above) and compared to the 2016 assessment results. The results were generally similar between the 2016 assessment and Model 16.1 with the data updates. The estimates of growth, ABL longline survey catchability, and autocorrelation in recruitment were similar to the 2016 assessment (Table 3). Similarities were also apparent when comparing the fits to the survey indices and the length composition data (Figures 10, 11, and 12).

One point of departure was the estimate of unfished recruitment (R_0), which was lower than the 2016 assessment's estimate (Table 3). Likelihood profiling was carried out and covered a range of values, (8-10) to evaluate which sources of data may have led to this difference. The likelihood profiles indicate that the survey, length composition, and size-at-age likelihood components were lowest for values of 9.4 and 9.3 for Model 16.1 with data through 2016 and 2018, respectively (Figure 13). Values outside the range shown in Figure 13 led to a lack of convergence characterized by large gradient values and likelihood values equal to NaN.

Estimates of SSB are shown in Figure 14. Unfished SSB and the estimates early in the time series were lower than the 2016 assessment estimates (Figure 14a). The SSB estimates converged in the 1970s and were similar throughout the rest of the time-series. The estimates of recruitment were similar between the two model runs, except the estimate of peak recruitment in the 1960s was larger than the estimate from the 2016 assessment (Figure 14b). The increase in the peak recruitment made up for the initial loss of recruits due to the lower estimate of $R_{0,}$ which was needed to support the observed future catches. There was little difference between the fishing mortality estimates between the two model runs except early in the time-series when fishing mortality associated with the trawl fishery was slightly higher than the estimates from the 2016 assessment (Figure 14d). A slightly higher fishing mortality was needed to achieve the same level of catch given the lower starting conditions.

Model convergence was evaluated by conducting a jitter analysis. The jitter analysis perturbs the initial values so that a broad range of parameter values along the likelihood surface are used as starting values. This ensures that the model converged to a global solution rather than a local minima. Starting values of all estimated parameters were randomly perturbed by 10% and 100 trials were run. Seven of the 100 trials came to a solution (Figure 15). This indicates a certain level of instability in the model; however, when a solution was obtained the parameter estimates were similar and the estimates of SSB and recruitment were similar (Table 4, Figure 16).

Much of the instability in the model was due to the treatment of the ABL longline catchability coefficient. In Model 16.1, the ABL longline survey catchability coefficient was analytically determined. A likelihood profile of the ABL longline survey's catchability (log scale) shows that the survey data, length composition data, and the size-at-age data suggest the value should be below 0 (Figure 17). There are some minor conflicts between the data sources about the exact value, but this suggests the parameter should be estimable. A run was done where the ABL longline index was removed (Model 16.1a) and another run was done while estimating the ABL longline survey catchability (Model 16.1b) to evaluate if an improvement in model stability could be made.

The maximum likelihood estimates of the growth and stock-recruitment parameters were similar among models 16.1, 16.1a, and 16.1b (Table 5). This was also true for the estimate of the ABL longline survey catchability for models 16.1 and 16.1b. Visual inspection of the growth curves, the fits to the indices (RMSE values are shown in Table 6) and length composition data, the estimated fishery and survey selectivities, and the residual patterns in the fits to the length composition data indicate negligible differences between the models (Figures 18-28). The estimates of SSB, recruitment, and fishing mortality were similar among models 16.1, 16.1a, and 16.1b (Figure 29). One noticeable difference was the estimate of R_0 from model 16.1a was lower than the others.

Jitter analyses of 50 runs were done for models 16.1a and 16.1b. The outcomes were almost identical for these models; therefore, the results from model 16.1b are summarized. All of the 50 runs converged to a solution indicating greater stability than model 16.1 (Figure 30). Twenty-five of the iterations were within 10 likelihood units of the maximum likelihood estimate, 8 were within one likelihood unit of the MLE and 4 were iterations resulted in the maximum likelihood estimate (Table 7). The resulting estimates of SSB and recruitment from the top 25 iterations are shown in Figure 31. All but three iterations (9, 40, and 42) are quite similar to the MLE estimates. The author recommends that model 16.1b (estimation of the longline survey catchability coefficient), replace model 16.1 as the base model since the results are similar, there is greater stability in model 16.1b, and it uses all sources of information.

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Tables

Table 1. A summary of the estimated and fixed double normal selectivity parameters by fleet and time block. E – estimated, F – fixed value.

	Trawl fishery			Longline fishery			Shelf survey				Slope survey		
Parameter	Pre-1989	1989-2005	2006-2018	Pre-1991	1991-2007	2008-2018	Pre-1992	1992-1995	1996-2000	2001-2018	Pre-2002	2002-2010	2011-2018
P1: Peak	E	E	E	E	E	E	2001-2018 Est	2001-2018 Est	2001-2018 Est	E	E	E	E
P2: top	F (-4)	F (-4)	F (-4)	E	E	E	F (-7.99)	F (-7.99)	F (-7.99)	F (-7.99)	E	E	E
P3:Ascend width	F (9.99)	E	E	E	E	E	F (6)	F (6)	F (6)	F (6)	E	E	E
P4: Descend width	E	E	E	E	E	E	E	E	E	E	F (10)	F (10)	F (10)
P5:Selex first bin	E	E	E	E	E	F(-999)	E	E	E	E	F (-999)	F (-999)	F (-999)
P6: Selex last bin	F (-999)	F (-999)	F (-999)	E	E	E	E	E	E	E	F (10)	F (10)	F (10)
Offset	Female	Female	Female	Male	Male	Male	Male	Male	Male	Male	Female	Female	Female
P1: Peak	F (-30)	E	E	E	E	E	2001-2018 Est	2001-2018 Est	2001-2018 Est	E	E	E	E
P2: Ascend width	F (0)	F (0)	F (0)	E	E	E	2001-2018 Est	2001-2018 Est	2001-2018 Est	E	E	E	E
P3: Descend width	F (-1)	E	E	F(-999)	F(-999)	F(-999)	2001-2018 Est	2001-2018 Est	2001-2018 Est	E	E	Pre-2002 Est	Pre-2002 Est
P4: Selex last bin	F (0)	E	E	E	E	E	2001-2018 Est	2001-2018 Est	2001-2018 Est	E	E	E	E
P5: Scale	F (1)	F (1)	F (1)	E	E	E	F (1)	F (1)	F (1)	F (1)	E	Pre-2002 Est	Pre-2002 Est

Table 2. Comparison of key parameter estimates from Model 16.1 using SS3.24 and SS3.30.12

	Models	
Parameter	Model 16.1 SS3.24	Model 16.1 SS3.30.12
L_at_Amin (Fem)	15.06	14.97
L_at_Amax (Fem)	90.43	89.47
von Bert k (Fem)	0.11	0.11
L_at_Amin (Male)	14.15	14.12
L_at_Amax (Male)	71.96	71.69
von Bert k (Male)	0.19	0.19
Ln(R0)	9.57	9.51
SR_autocorr	0.61	0.60
LnQ_ABL_LL	-0.49	-0.52

Table 3. Likelihood values and leading parameter estimates from Model 16.1 run with data ending in 2016 and 2018.

Data end year	2016	2018
Model	Model 16.1	Model 16.1
Likelihoods		
Total	1837.5	1940.3
Catch	0.0	0.0
Survey	-32.1	-34.0
Length comp	622.7	654.7
Size at age	1144.9	1211.0
Recruitment	94.4	97.4
Forecast recruitment	3.4	7.1
Leading parameters		
SR_LN(R0)	9.56	9.38
SR_autocorr	0.61	0.61
L_at_Amin_Fem	15.05	15.05
L_at_Amin_Male	14.14	14.09
L_at_Amax_Fem	90.46	90.40
L_at_Amax_Male	71.94	72.01
VonBert_K_Fem	0.11	0.11
VonBert_K_Male	0.19	0.19
Ln q ABL longline	-0.49	-0.51

Table 4. Leading parameter estimates from the jitter analysis of Model 16.1.

	Jitter run						
Parameter	19	33	51	53	55	81	Status
Growth							
Nat M Female	0.112	0.112	0.112	0.112	0.112	0.112	Fixed
L_at_Amin_Fem	15.05	15.05	15.05	15.06	15.05	15.04	Estimated
L_at_Amax_Fem	90.35	90.40	90.40	90.41	90.37	90.22	Estimated
VonBert_K_Fem	0.11	0.11	0.11	0.11	0.11	0.11	Estimated
CV_young_Fem	0.15	0.15	0.15	0.15	0.15	0.15	Fixed
CV_old_Fem	0.09	0.09	0.09	0.09	0.09	0.09	Fixed
NatM_p_1_Male	0.112	0.112	0.112	0.112	0.112	0.112	Fixed
L_at_Amin_Male	14.09	14.09	14.09	14.09	14.08	14.09	Estimated
L_at_Amax_Male	72.09	72.01	72.01	71.99	71.91	72.05	Estimated
VonBert_K_Male	0.19	0.19	0.19	0.19	0.19	0.19	Estimated
CV_young_Male	0.15	0.15	0.15	0.15	0.15	0.15	Fixed
CV_old_Male	0.09	0.09	0.09	0.09	0.09	0.09	Fixed
Stock-recruitment							
SR_LN(R0)	9.38	9.38	9.38	9.38	9.38	9.38	Estimated
SR_BH_steep	0.79	0.79	0.79	0.79	0.79	0.79	Fixed
SR_sigmaR	0.6	0.6	0.6	0.6	0.6	0.6	Fixed
SR_regime	0	0	0	0	0	0	Fixed
SR_autocorr	0.61	0.61	0.61	0.61	0.61	0.61	Estimated

Table 5. Likelihood values and leading parameter estimates from Models 16.1, 16.1a, and 16.1b.

Data end year		2018	2018	2018
Model		16.1	16.1a	16.1b
Likelihoods				
	Total	1940.3	1930.6	1940.3
	Catch	0.0	0.0	0.0
	Survy	-34.0	-38.0	-34.0
	Length comp	654.7	653.5	654.7
	Size at age	1211.0	1208.6	1211.0
	Recruitment	97.4	95.5	97.4
	Forecast recruitment	7.1	6.8	7.1
Leading parameters				
	LN(R0)	9.38	9.43	9.38
	Autocorrelation	0.61	0.60	0.61
	L_at_Amin_Fem	15.05	14.92	15.05
	L_at_Amin_Mal	14.09	13.99	14.09
	L_at_Amax_Fem	90.40	90.53	90.40
	L_at_Amax_Male	72.01	72.05	72.01
	VonBert K Fem	0.11	0.11	0.11
	VonBert K Male	0.19	0.19	0.19
	qshelf	0.62	0.62	0.62
	qslope	0.57	0.57	0.57
	qABL	0.60	-	0.60

Table 6. Root mean square error values for each survey and model.

		Model	
Survey	16.1	16.1a	16.1b
Shelf	0.207	0.216	0.207
Slope	0.178	0.185	0.178
ABL longline	0.389		0.389

Table 7. The resulting total likelihood and component likelihood estimates from the jitter analysis of Model 16.1b. The 25 iterations within 10 likelihood units of the maximum likelihood estimate (indicated by *) are shown.

					Likelihood		
Iter	Total	Catch	Survey	Length_comp	Size_at_age	Recruitment	Forecast_Recruitment
37	1940.29	0.00	-34.00	654.38	1211.21	97.53	7.03
2*	1940.31	0.00	-34.03	654.69	1211.04	97.41	7.06
6*	1940.31	0.00	-34.03	654.70	1211.03	97.41	7.06
11*	1940.31	0.00	-34.03	654.70	1211.03	97.41	7.06
43*	1940.31	0.00	-34.03	654.69	1211.04	97.41	7.06
33	1940.39	0.00	-33.98	654.39	1211.32	97.49	7.03
45	1940.65	0.00	-34.00	654.98	1211.07	97.41	7.05
23	1940.68	0.00	-33.97	655.07	1211.02	97.38	7.05
31	1941.46	0.00	-33.30	653.90	1211.55	97.59	7.54
42	1941.53	0.00	-39.92	657.36	1210.34	101.11	8.39
7	1941.79	0.00	-33.81	656.71	1210.46	97.22	7.07
36	1942.27	0.00	-33.65	654.25	1211.81	98.12	7.57
8	1942.42	0.00	-33.31	654.83	1211.42	97.78	7.52
28	1943.34	0.00	-34.42	657.98	1209.94	98.36	7.33
38	1943.35	0.00	-34.02	656.78	1212.14	97.16	7.14
18	1944.42	0.00	-33.69	659.35	1210.37	97.15	7.09
40	1944.46	0.00	-39.50	657.73	1213.27	100.73	8.01
22	1944.58	0.00	-33.66	657.49	1212.14	97.45	7.02
10	1945.07	0.00	-33.97	659.27	1211.46	96.98	7.17
27	1947.38	0.00	-33.61	661.65	1210.95	97.13	7.11
16	1948.60	0.00	-33.77	662.88	1211.23	96.85	7.25
41	1948.71	0.00	-33.90	663.92	1210.57	96.81	7.17
32	1949.00	0.00	-33.81	662.95	1210.72	97.93	7.07
9	1949.12	0.00	-33.99	653.45	1209.45	110.35	5.76
20	1950.47	0.00	-32.58	662.95	1210.90	97.39	7.61

Figures

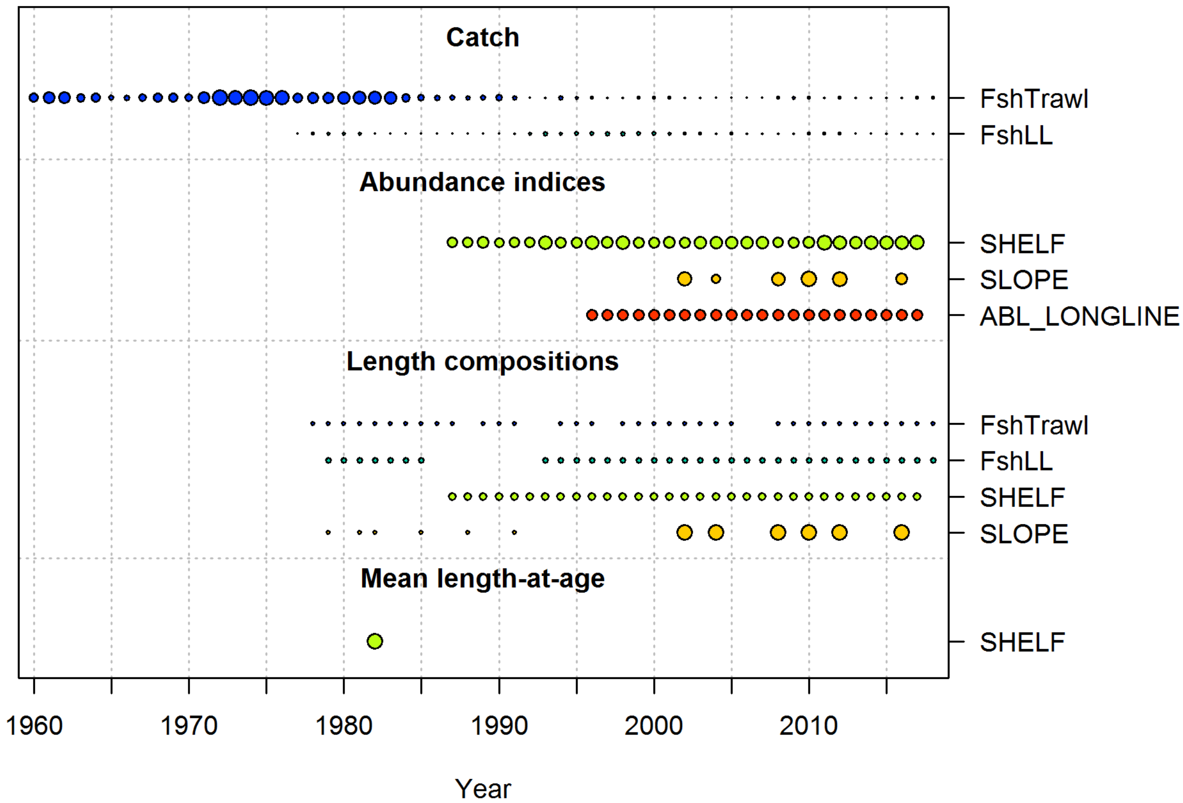


Figure 1. Data presence for the Base Model 16.1 (Model 16.4 in Barbeaux et al. 2016). Circle area is relative within a data type, and proportional to precision for indices and compositions, and absolute catch for catches.

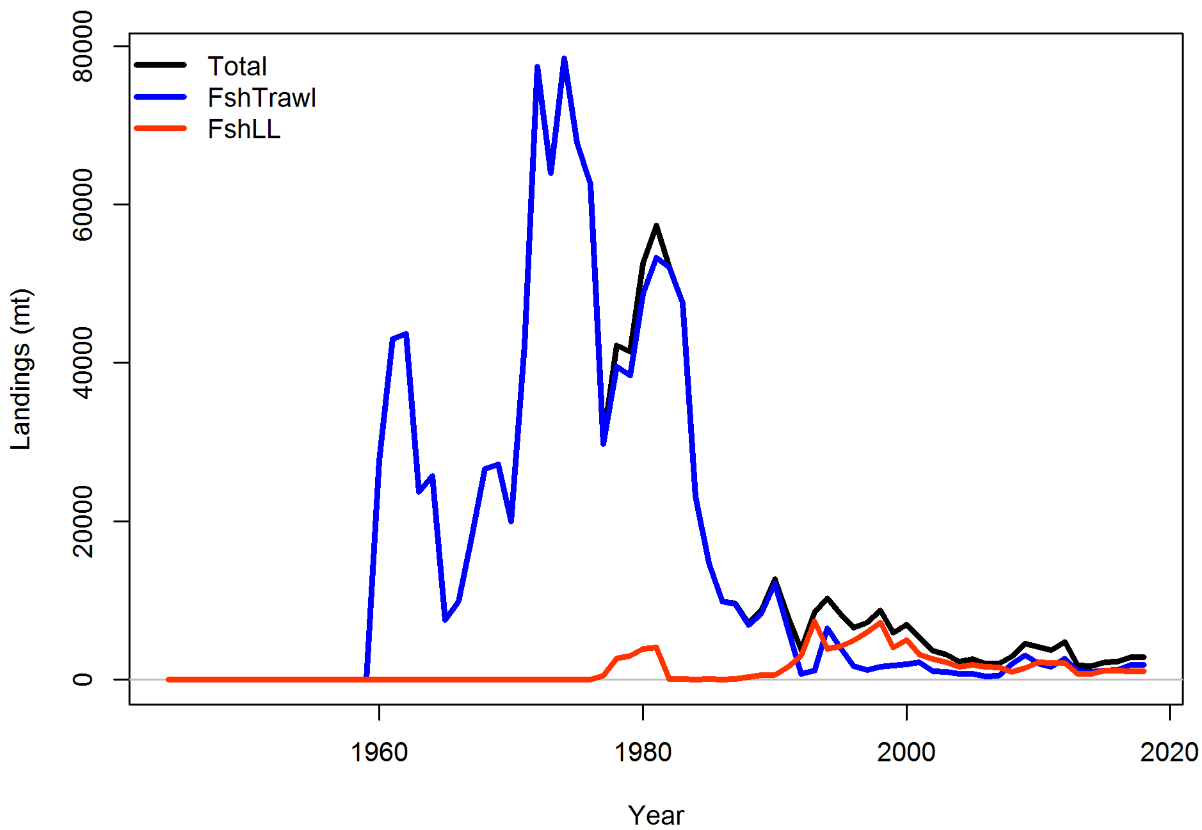
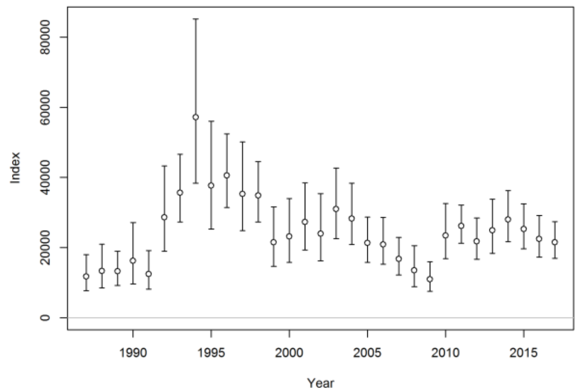


Figure 2. Total (combined trawl and fixed gears), trawl, and longline catch in metric tons (mt).

a)



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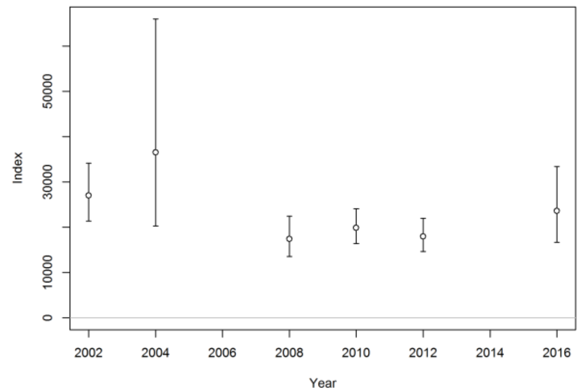

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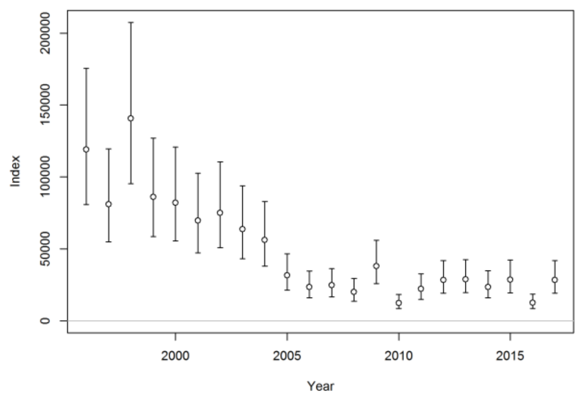


d)

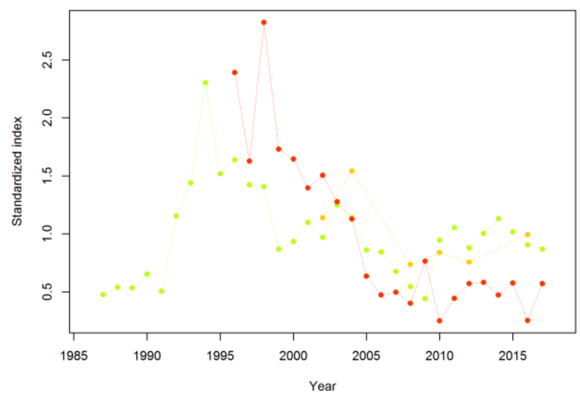


Figure 3. Indices of abundance from the a) shelf survey index, b) slope survey index, c) ABL longline survey, and d) a comparison of all three (shelf – light green points, slope – orange points, and ABL longline – red points).

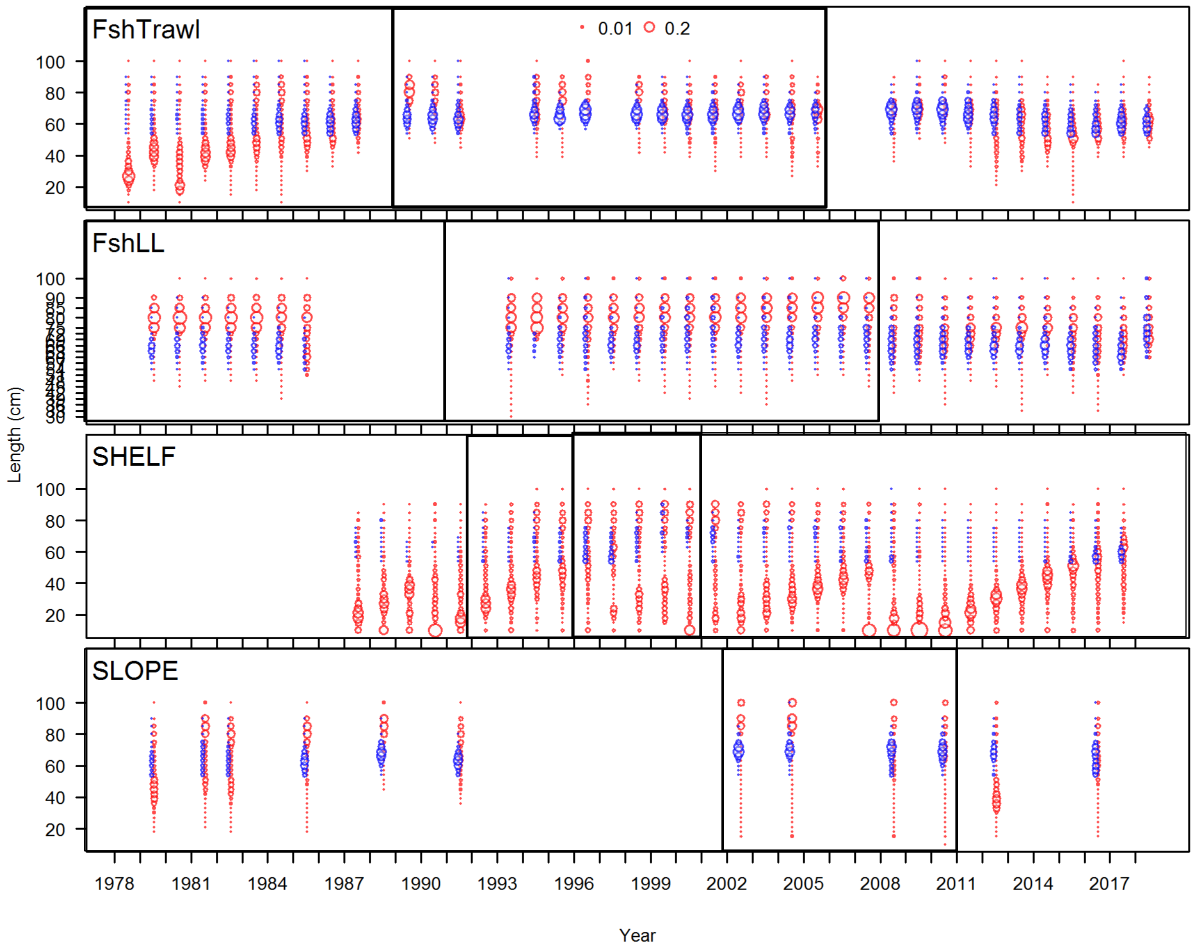


Figure 4. Fleet- and sex-specific length (in cm) composition data. The red and blue circles represent females and males, respectively. Fleet-specific time blocks are shown by the solid, black vertical lines: prior to 1989, 1989-2005, 2005-2018 for the trawl fishery; prior to 1991, 1991-2007, 2008-2018 for the longline fishery; prior to 1992, 1992-1995, 1996-2000, 2001-2018 for the shelf survey; and prior to 2001, 2002-2010, and 2011-2018 for the slope survey.

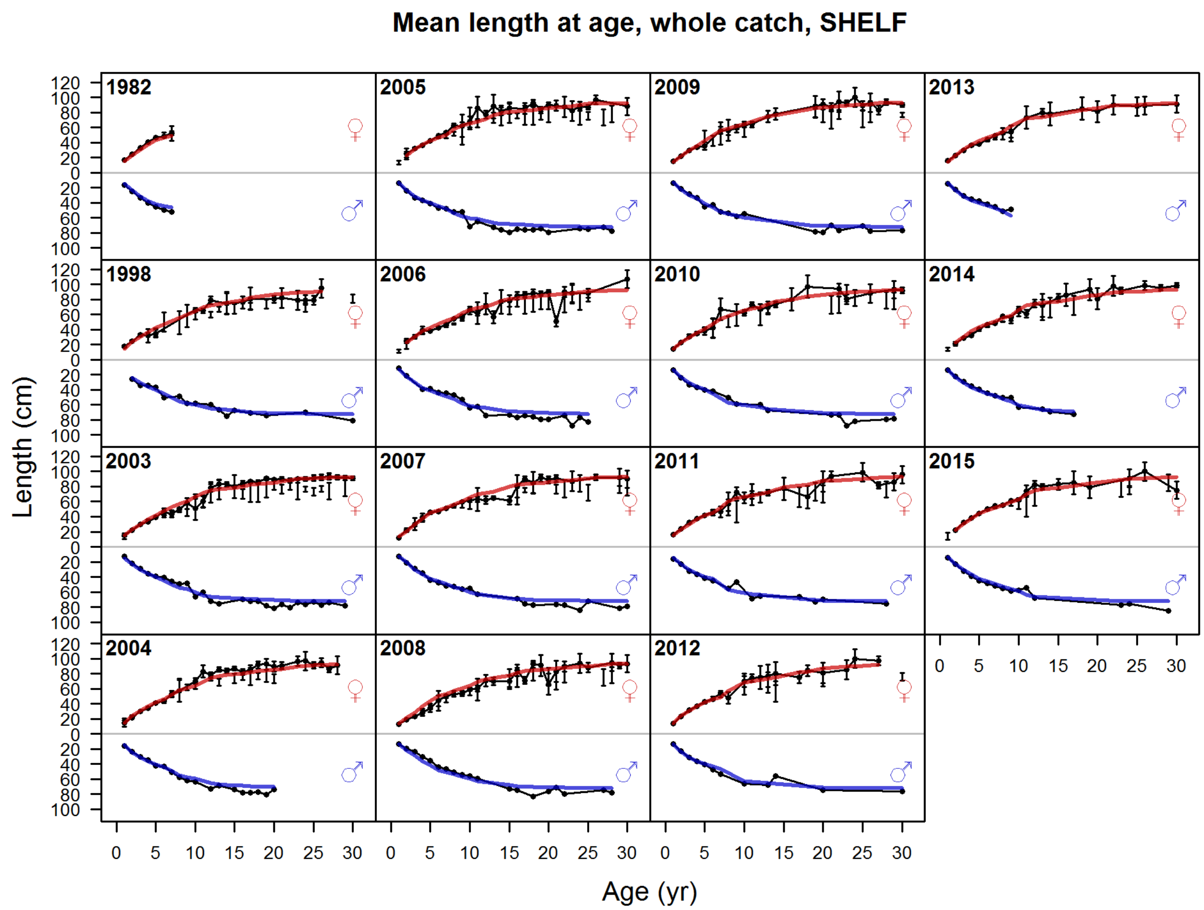


Figure 5. Shelf survey mean length at age data separated by sex. Red (female) and blue (males) lines are the fit of the base model to the data.

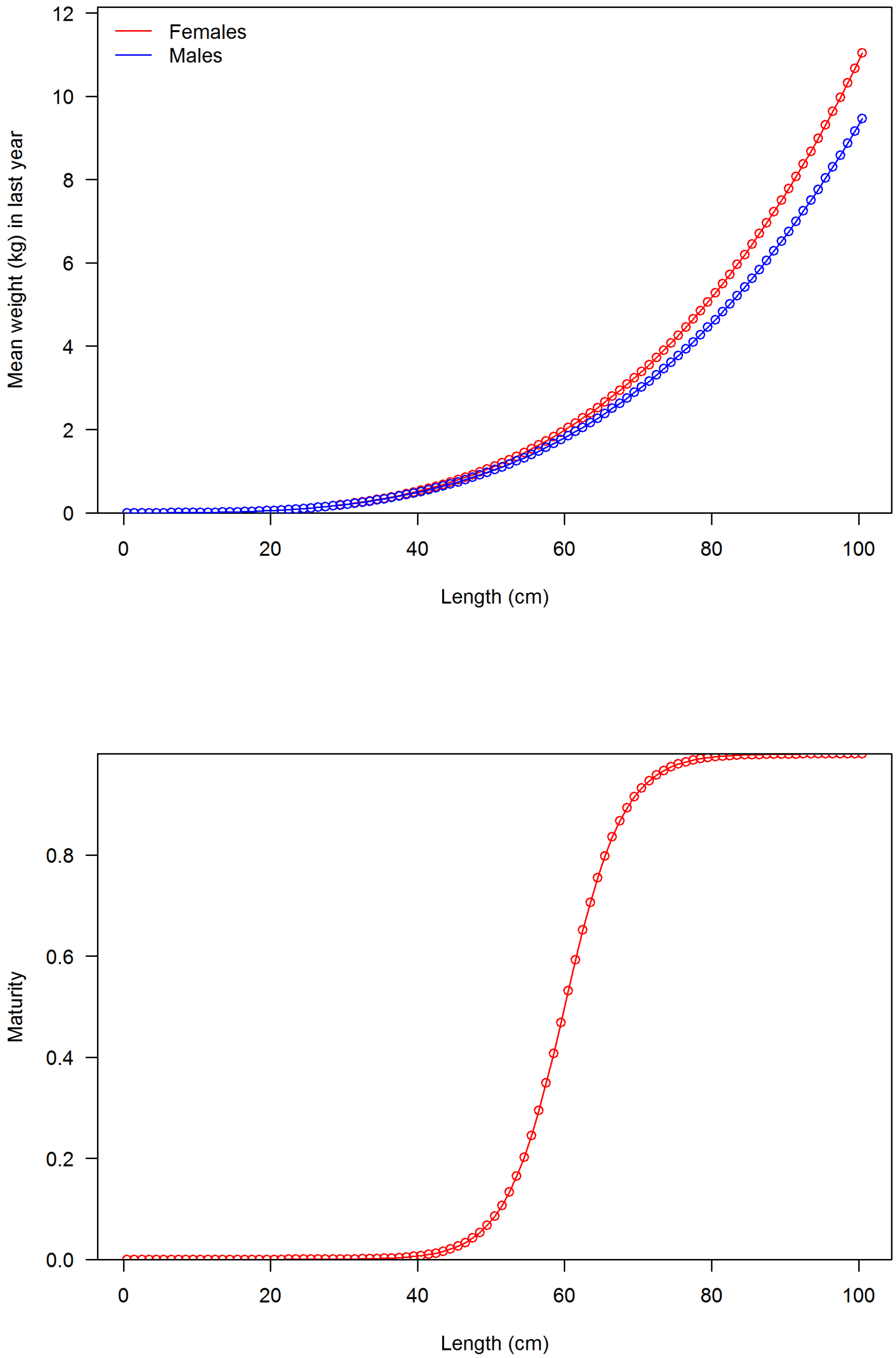


Figure 6. Length-weight and maturity relationships.

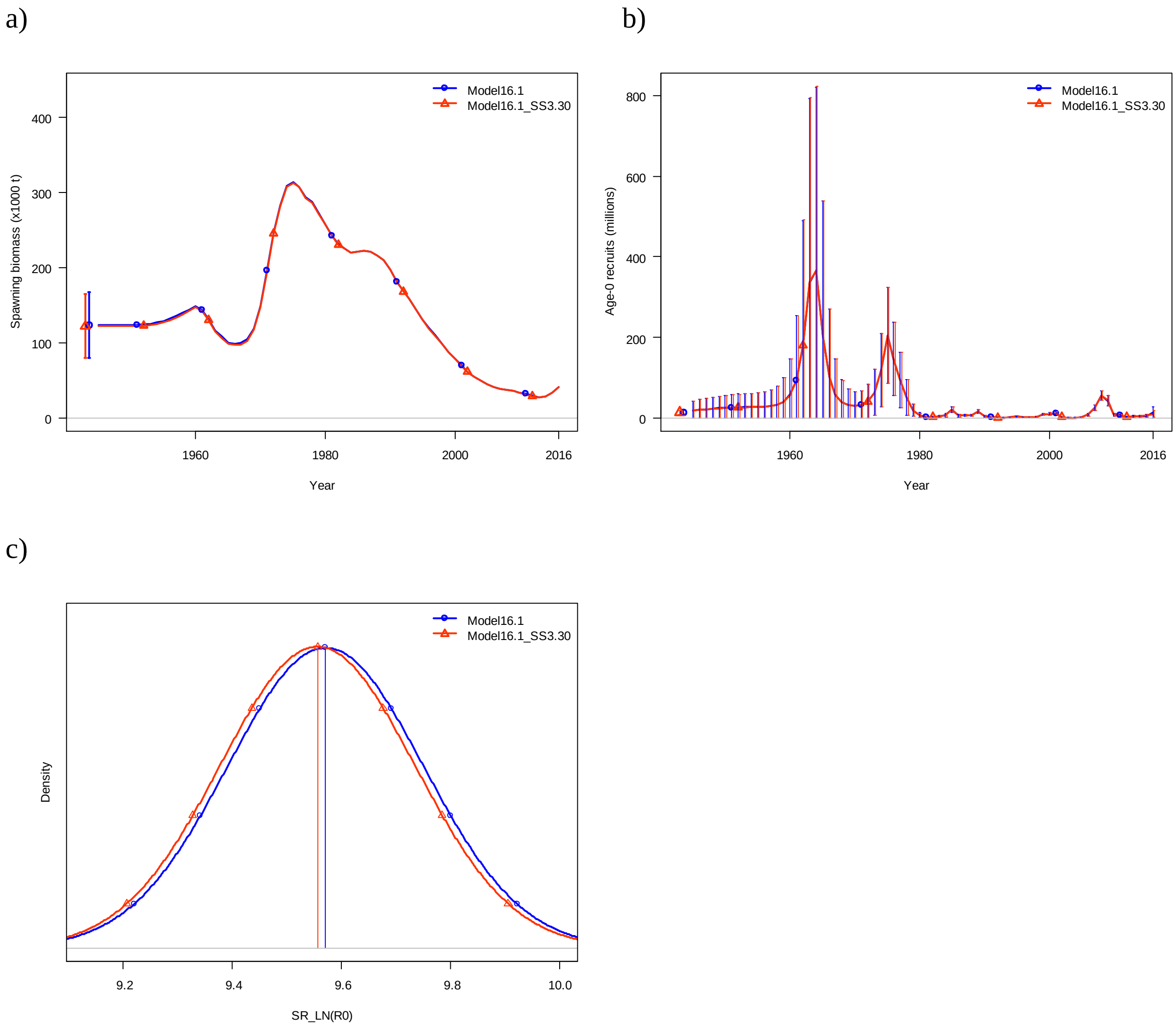
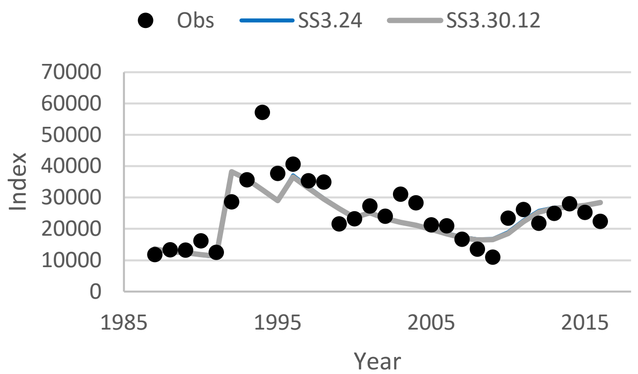
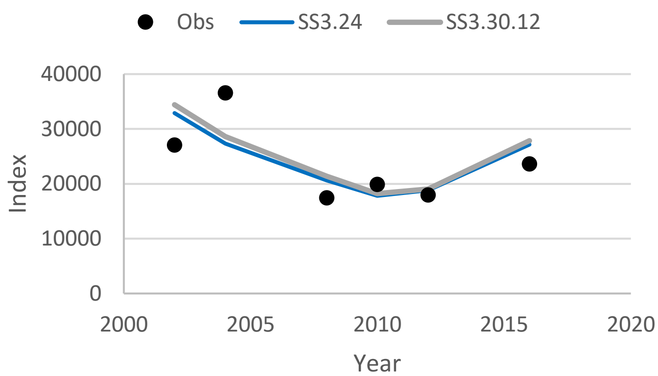


Figure 7. Comparison of Model 16.1 using SS3.24 and SS3.30.12 with data through 2016. a) Spawning stock biomass (SSB), b) recruits (millions), and c) R_0 density.

a)



b)



c)

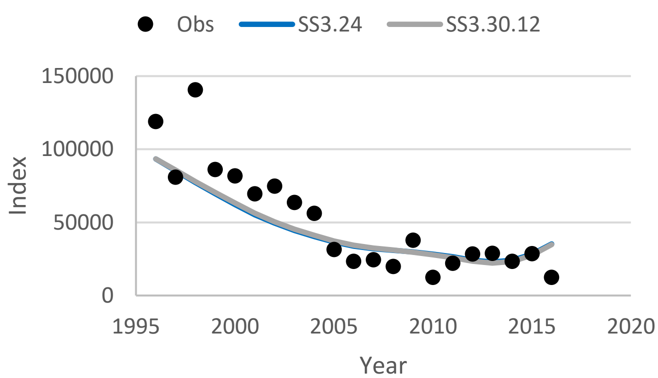


Figure 8. Comparison of Model 16.1 fits to the indices using SS3.24 and SS3.30.12 with data through 2016. a) Shelf survey, b) slope survey, c) ABL longline survey.

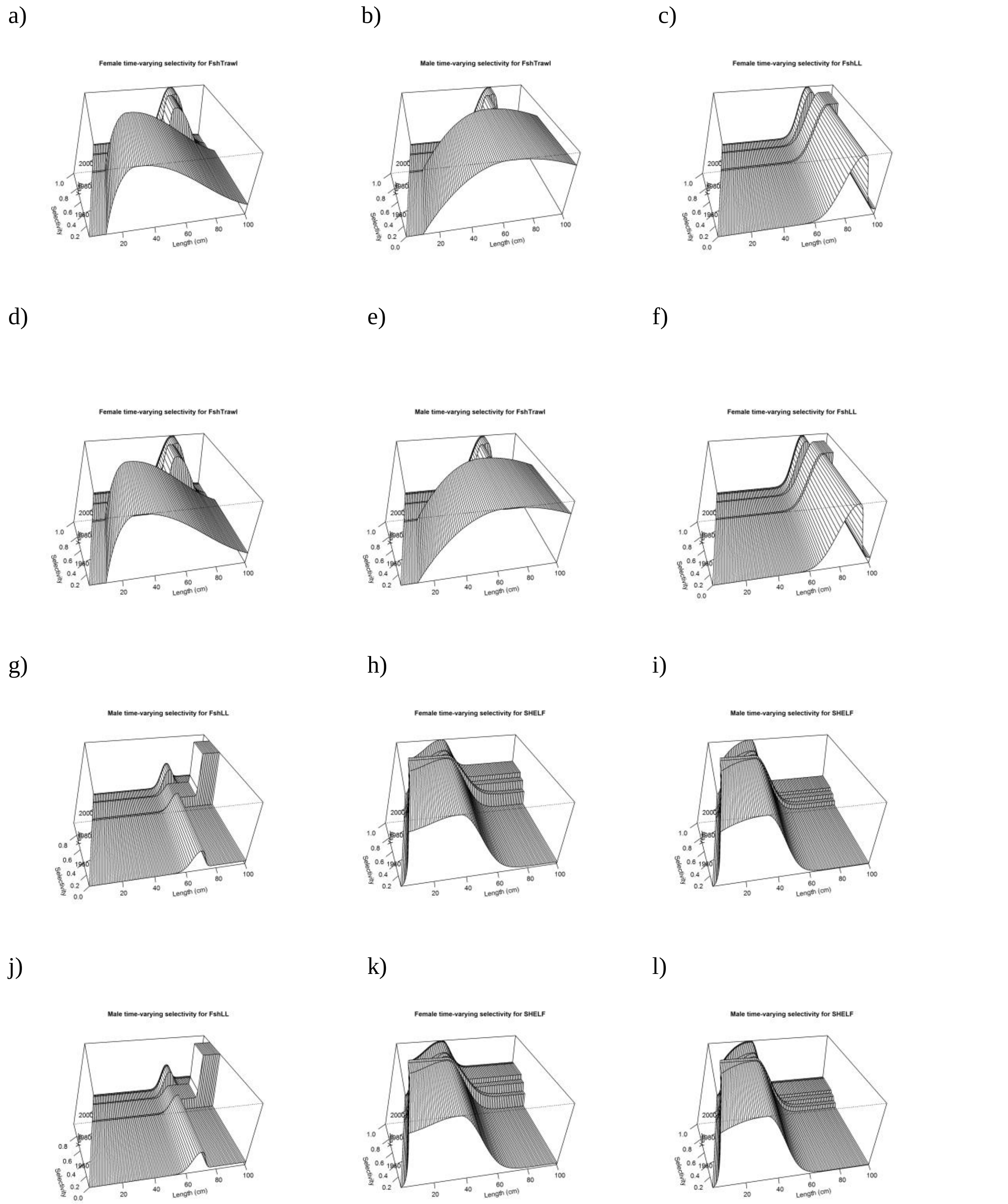
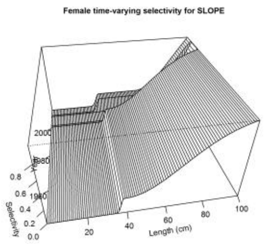
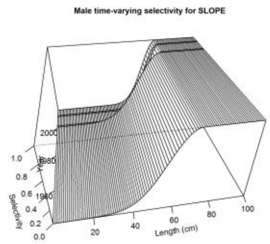


Figure 9. Comparison of Model 16.1 estimated selectivity patterns using a-c, g-i, m-n) SS3.24 and d-f, j-l, o-p) SS3.30.12 with data through 2016.

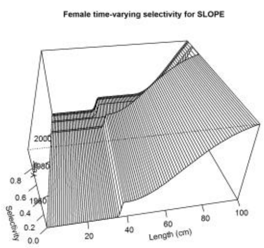
m)



n)



o)



p)

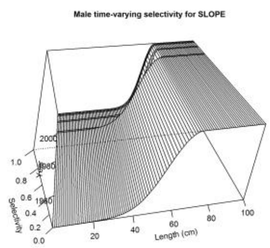
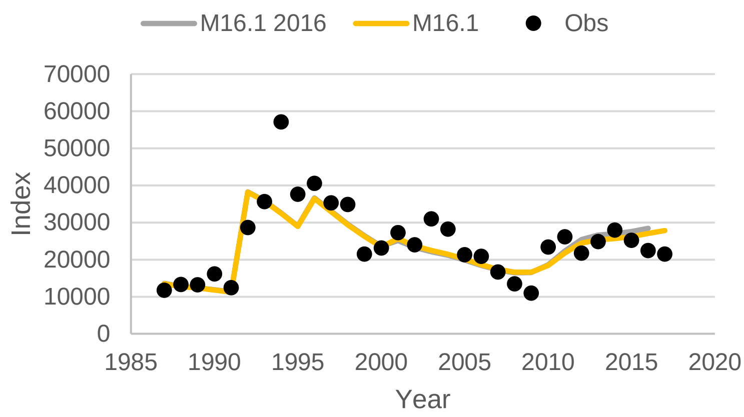
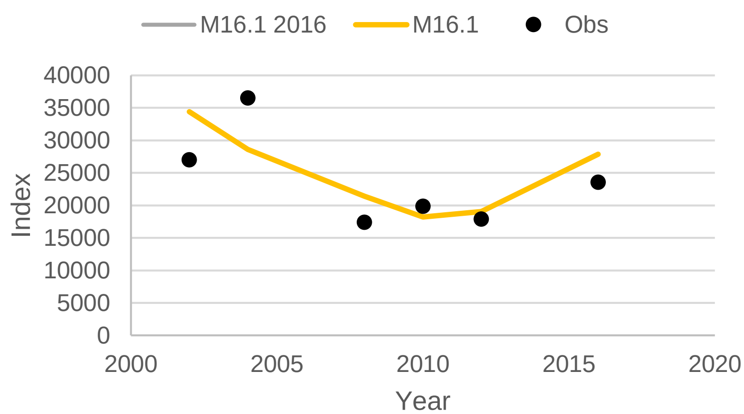


Figure 9- continued. Comparison of Model 16.1 estimated selectivity patterns using a-c, g-i, m-n) SS3.24 and d-f, j-l, o-p) SS3.30.12 with data through 2016.

a)



b)



c)

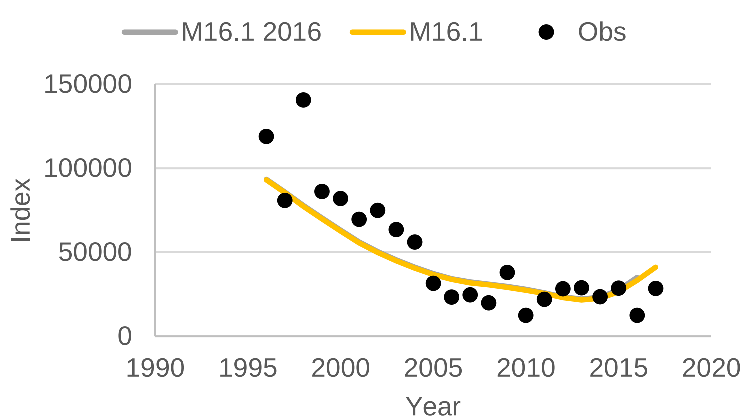
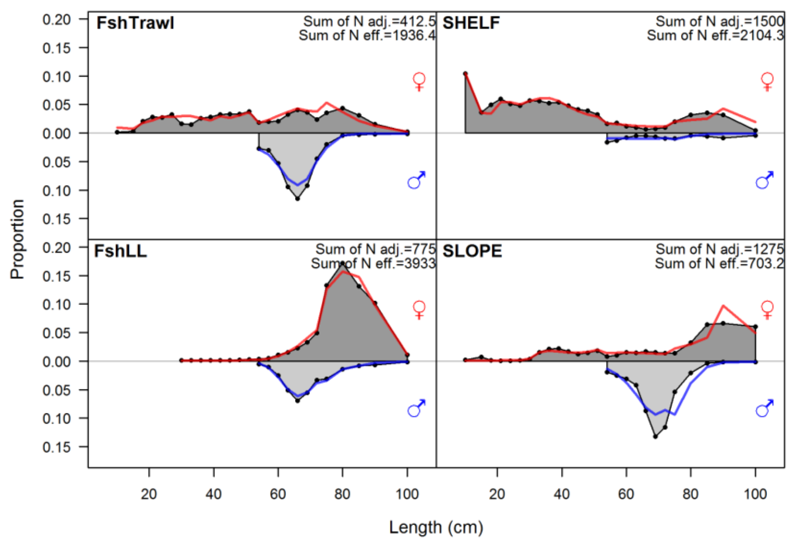


Figure 10. Model fits to the survey biomass estimates from Model 16.1 with data through 2016 and 2018.

a)



b)

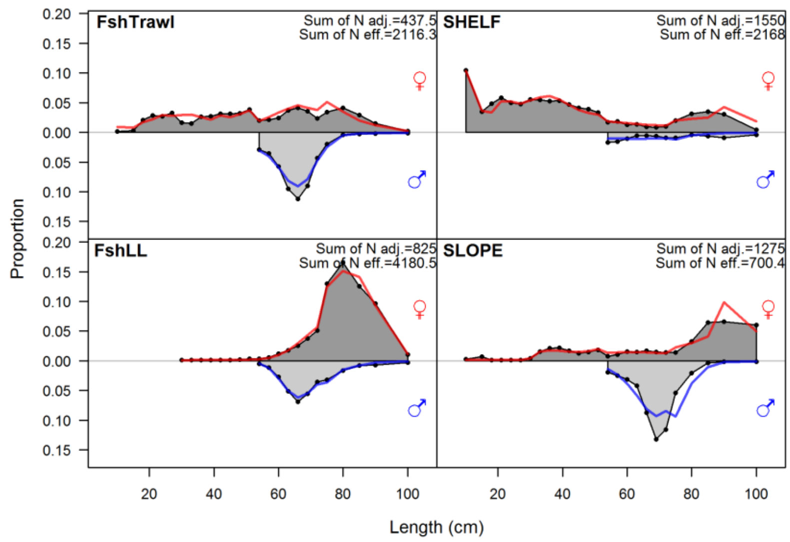
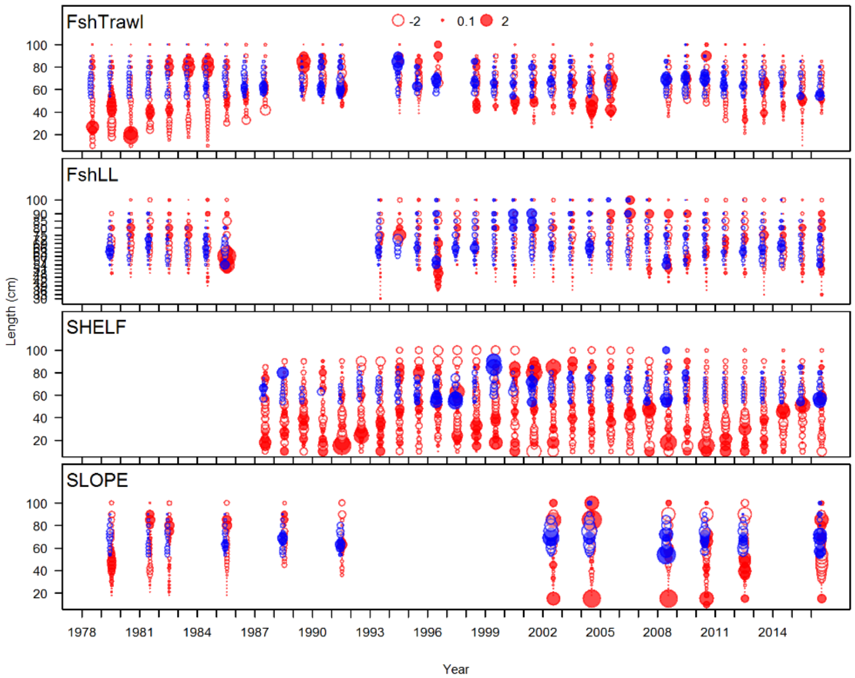


Figure 11 Model fits to the overall length composition data from the 2016 Model 16.1 with data through 2016 and 2018.

a)



b)

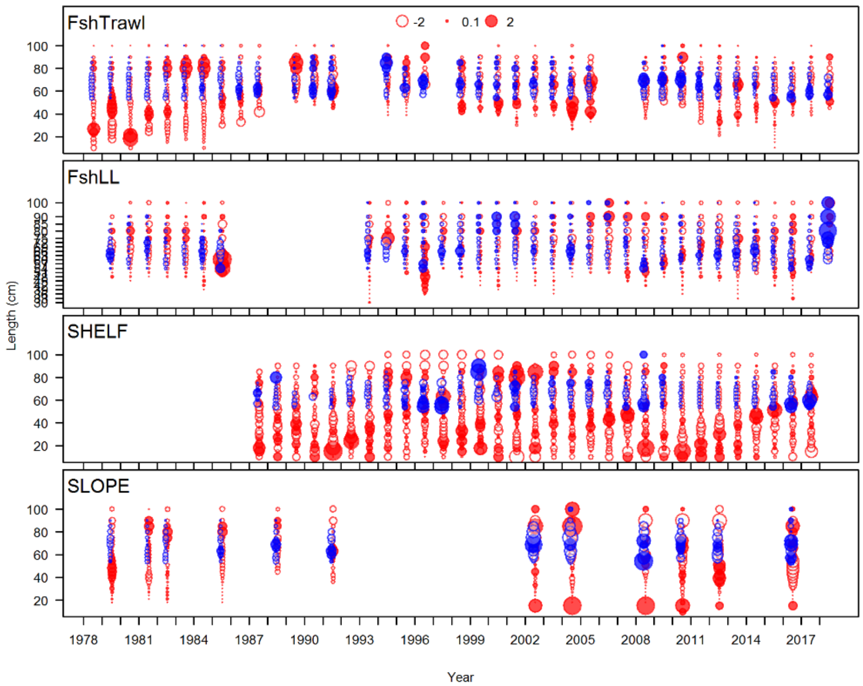
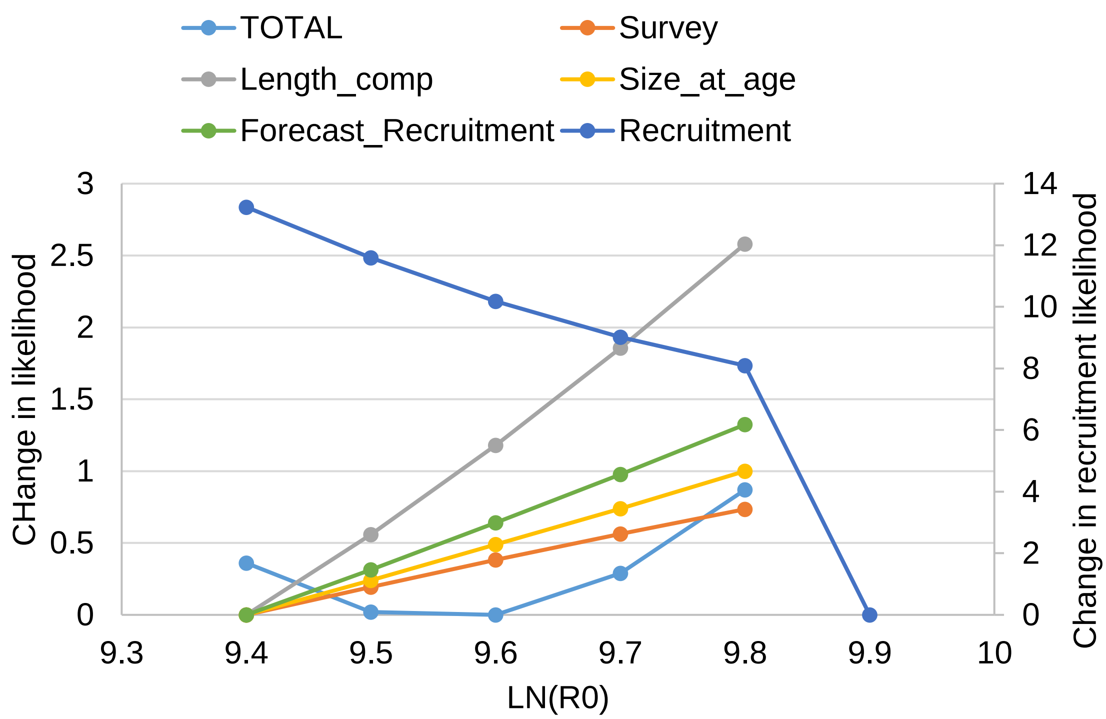


Figure 12. Pearson residuals from the fit to the length composition data from Model 16.1 with data through 2016 and 2018. Solid circles represent a positive residual (observed >expected).

a)



b)

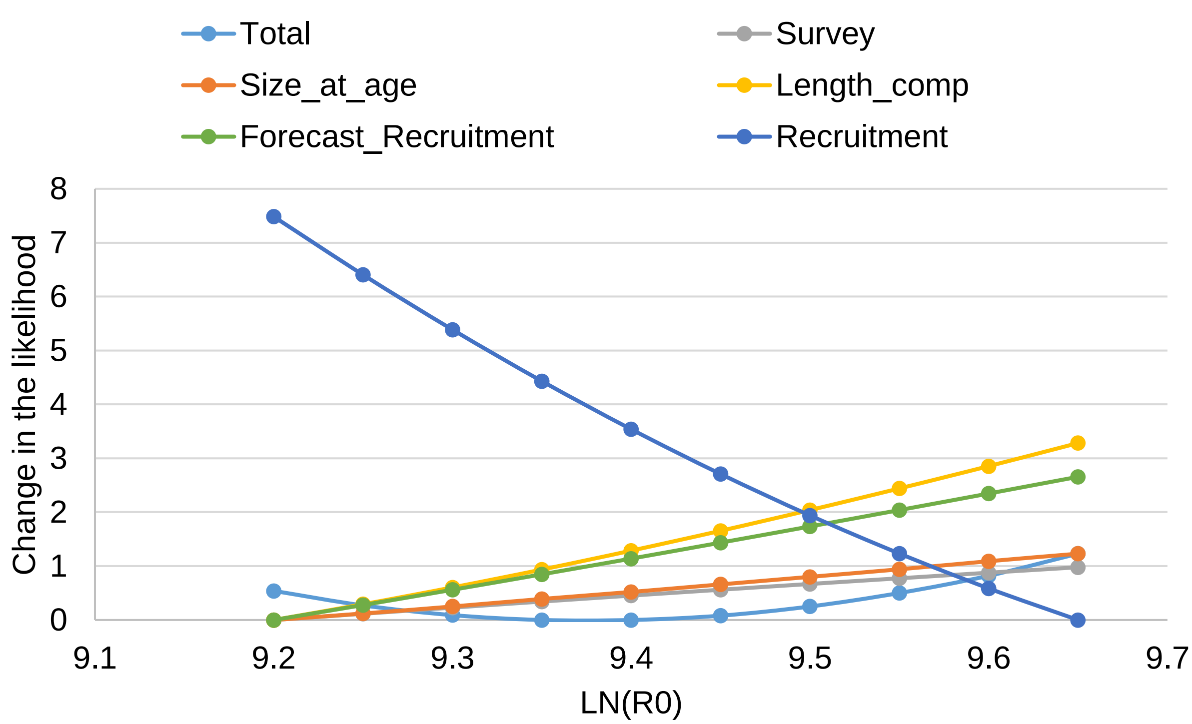


Figure 13. Likelihood profile of R0 from Model 16.1 a) data through 2016 and b) data through 2018.

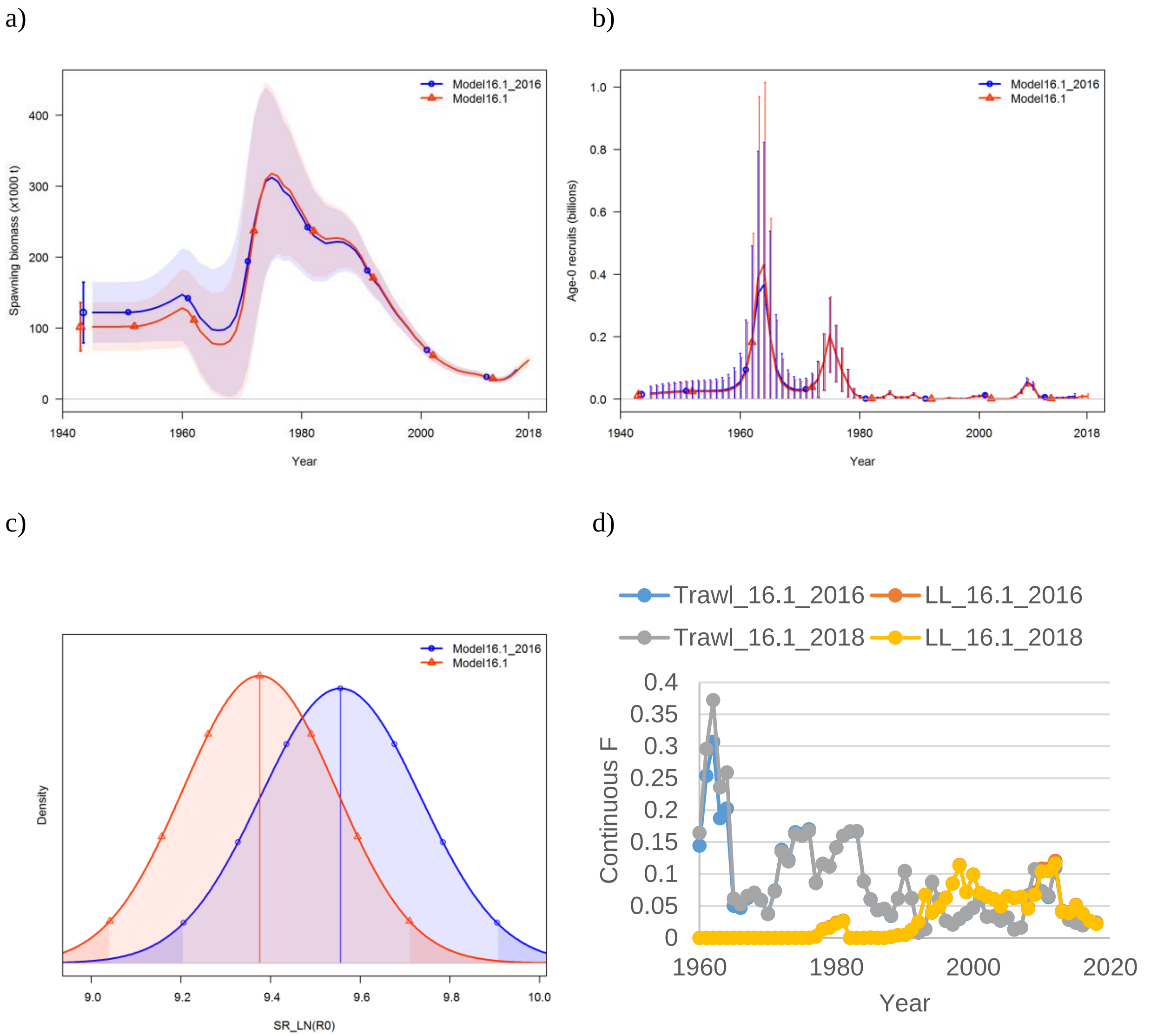


Figure 14. Estimates of a) SSB (mt), b) recruits, c) R0 density, and d) fishing mortality from Model 16.1 with data through 2016 and 2018.

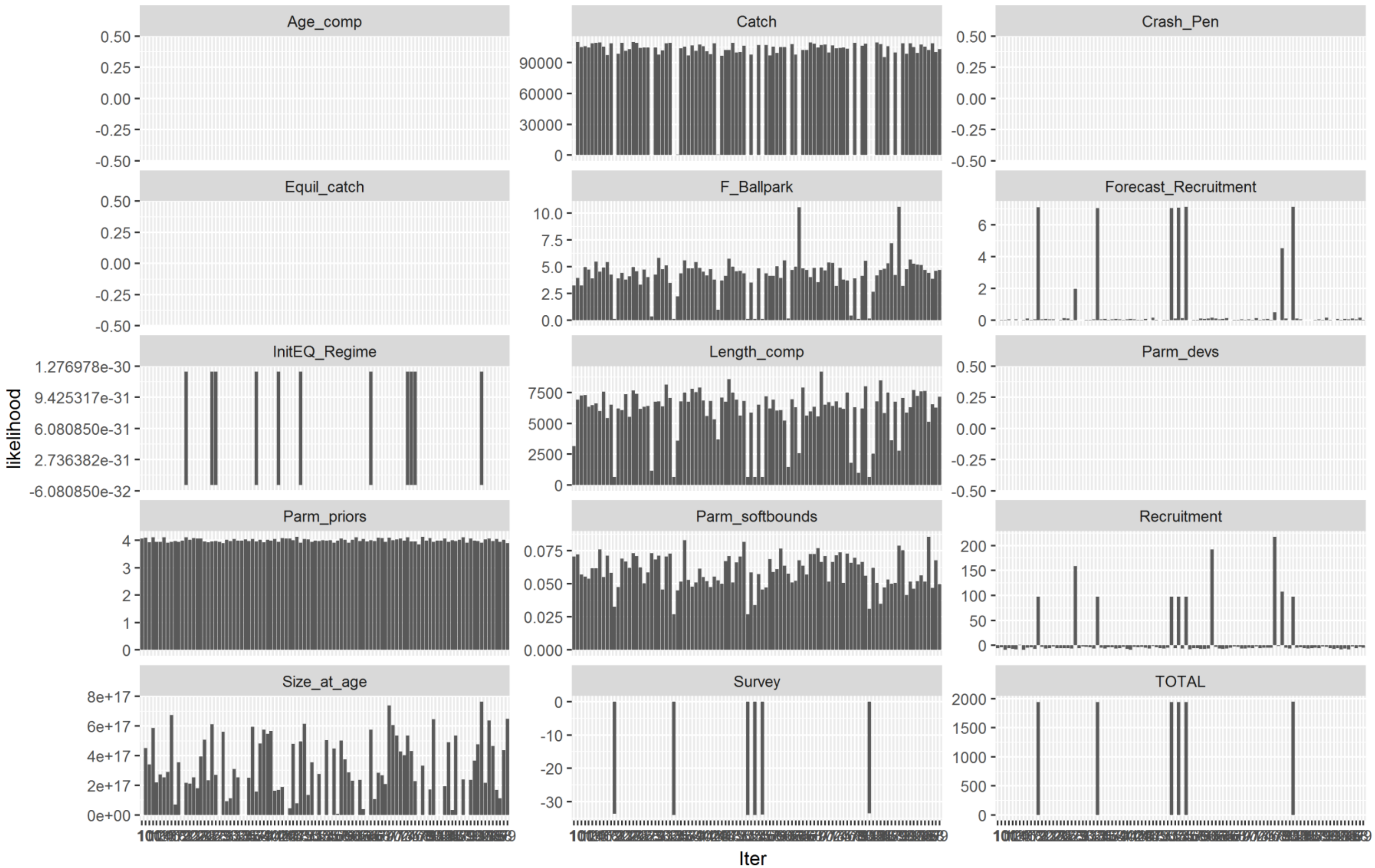
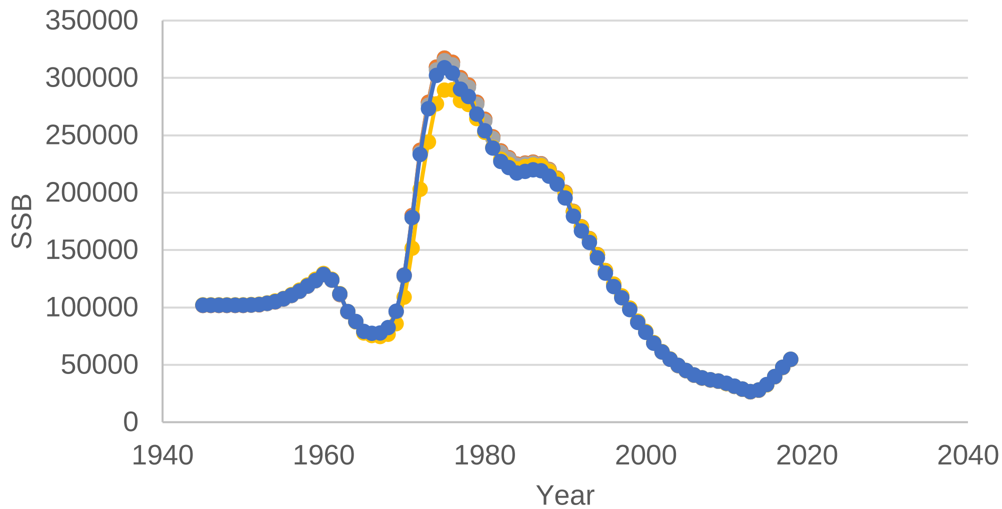


Figure 15. Likelihood estimates from the jitter analysis conducted on Model 16.1. A total of 100 jitter runs were completed.

a)



b)

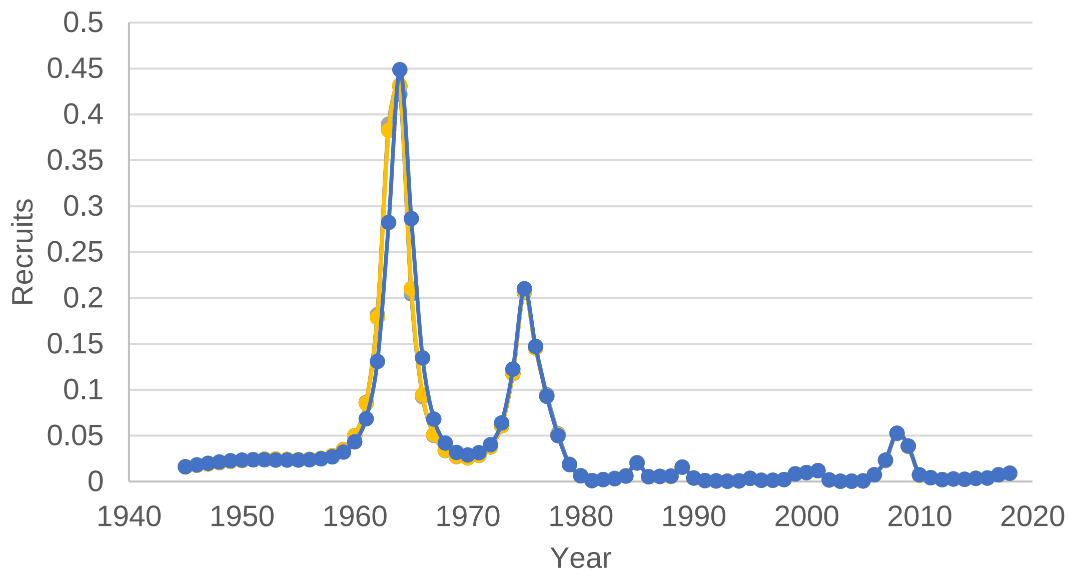


Figure 16. a) SSB and b) recruitment estimates from the Model 16.1 jitter analysis. The results from the 6 iterations that resulted in a solution are shown,

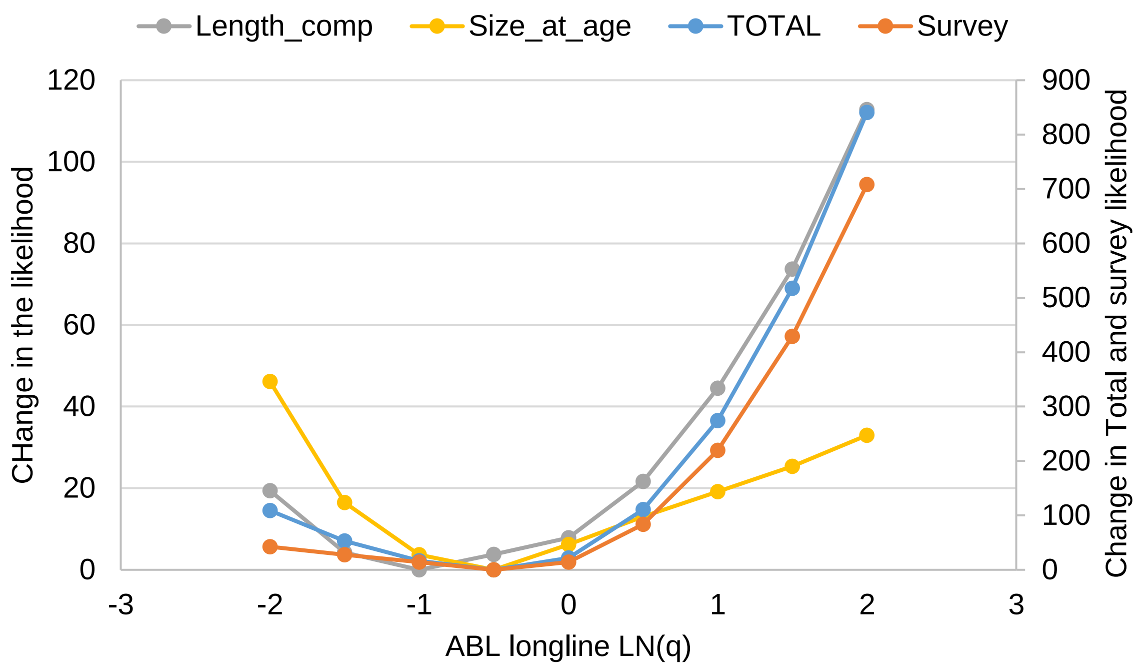
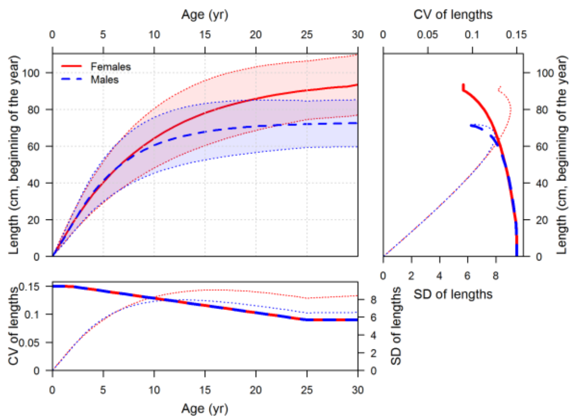
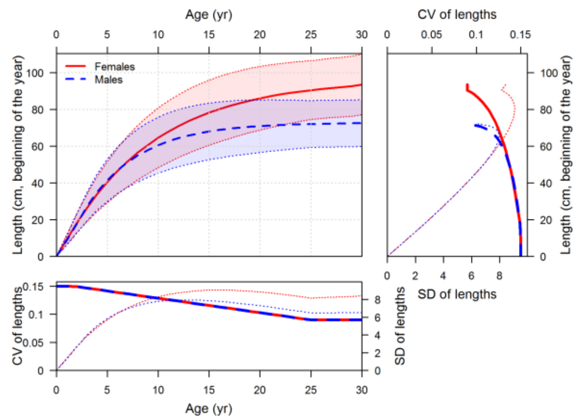


Figure 17. Likelihood profile of the ABL longline catchability coefficient from Model 16.1 with data through 2018.

a)



b)



c)

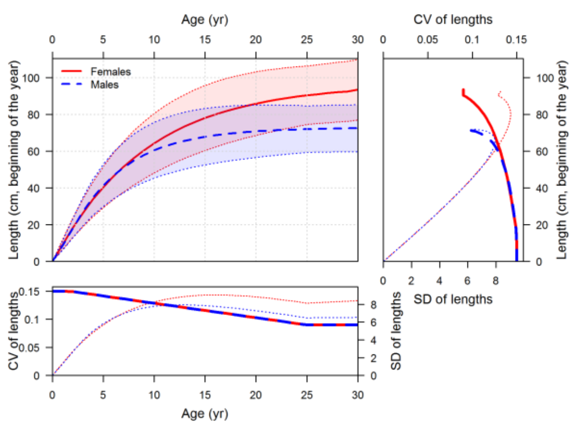
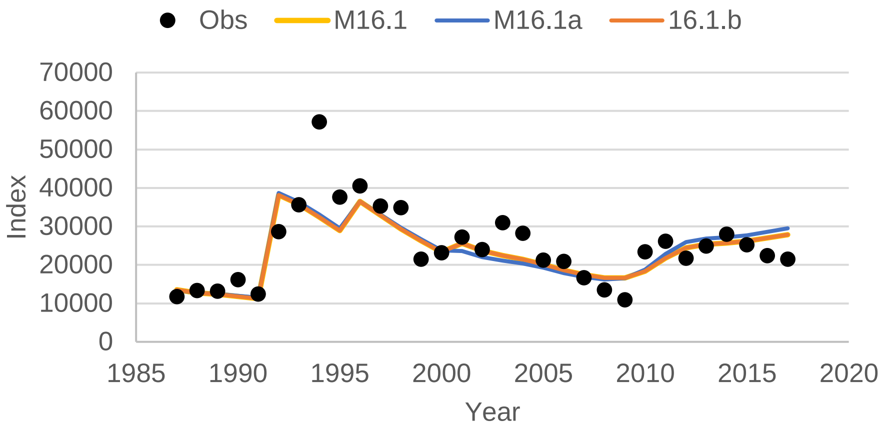
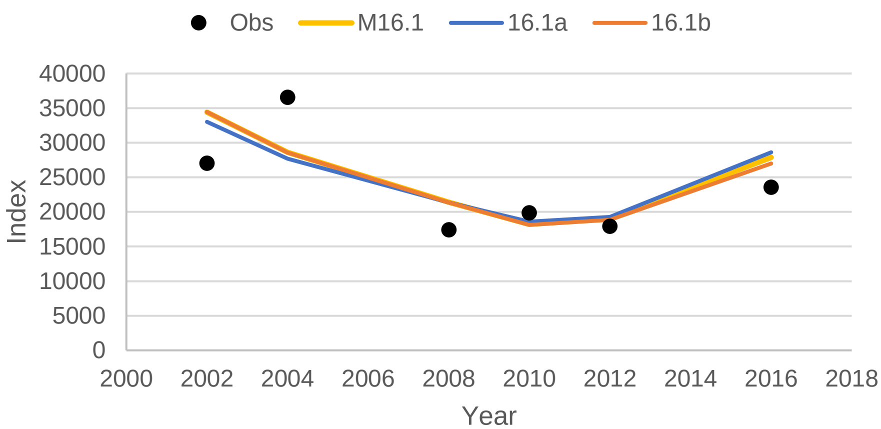


Figure 18. Estimated growth curves from a) Model 16.1, b) Model 16.1a, and c) Model 16.1b

a)



b)



c)

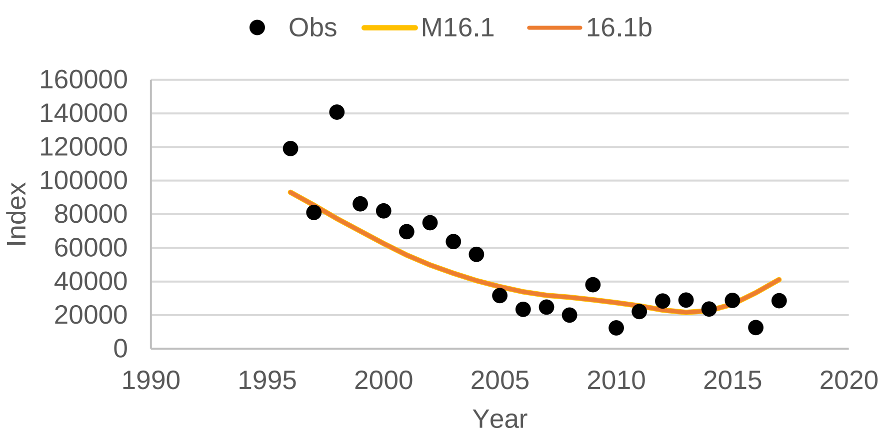
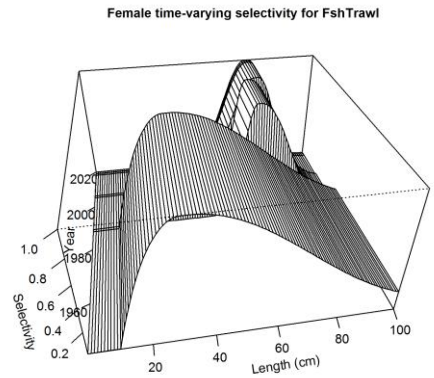
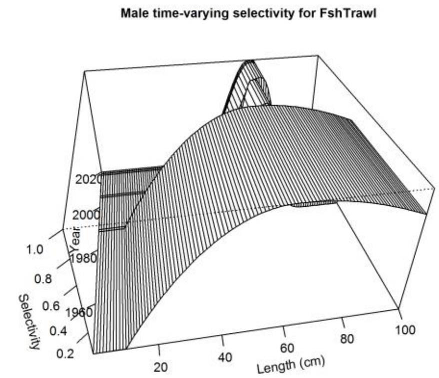


Figure 19. Model fit to the indices a) shelf, b) slope, and c) ABL longline

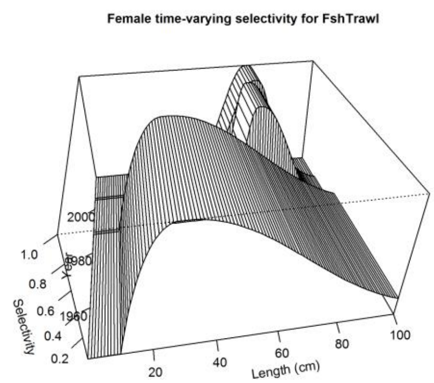
a)



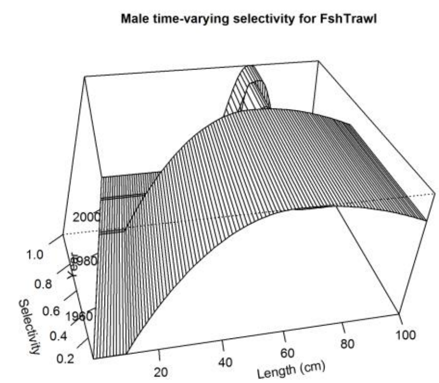
b)



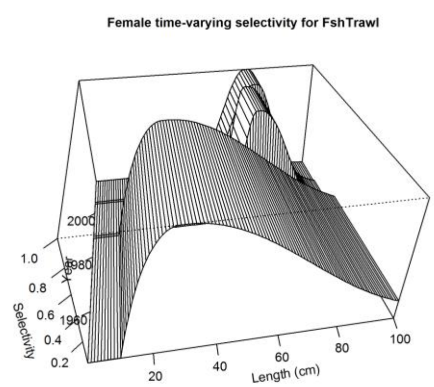
c)



d)



e)



f)

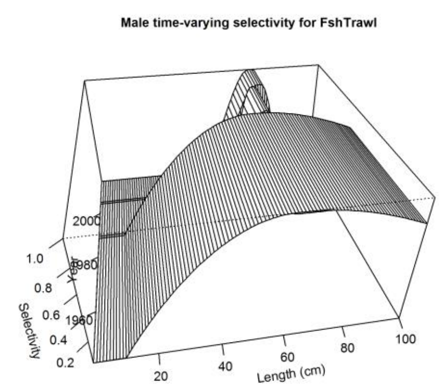
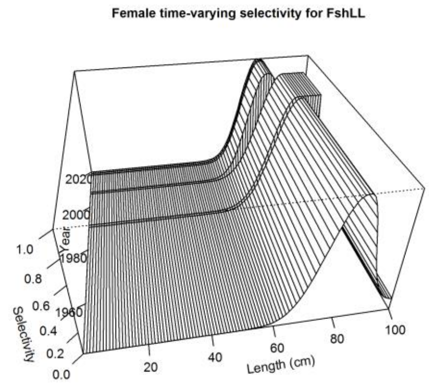
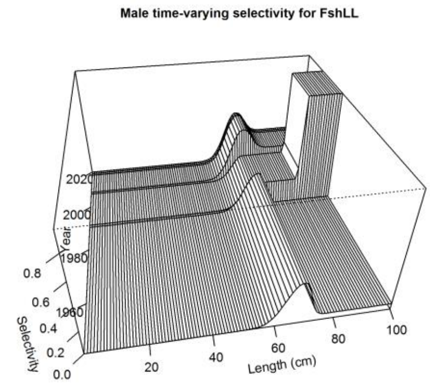


Figure 20. Estimated a,c,e) female and b,d,f) male trawl selectivity.

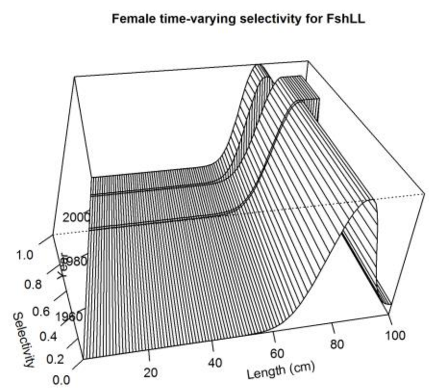
a)



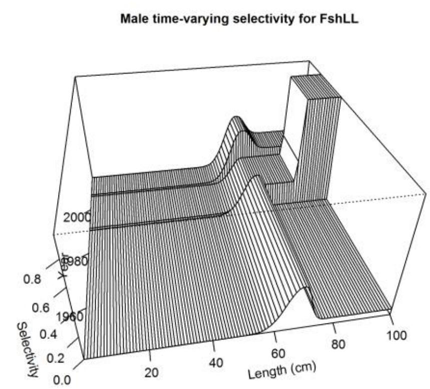
b)



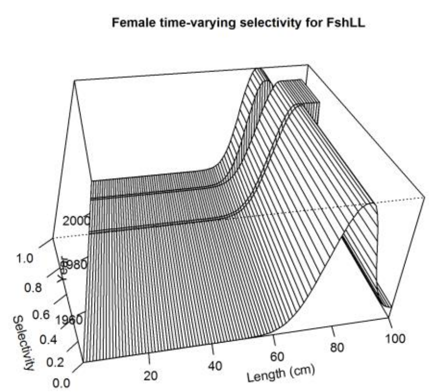
c)



d)



e)



f)

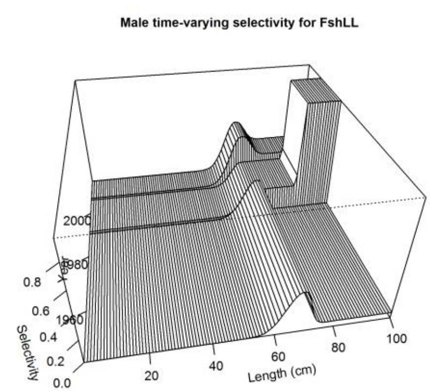
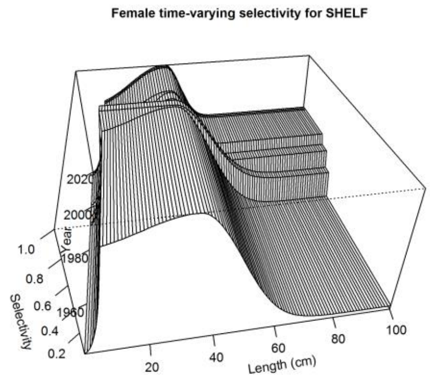
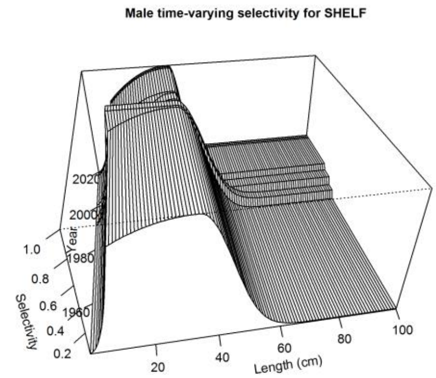


Figure 21. Estimated a,c,e) female and b,d,f) male longline selectivity.

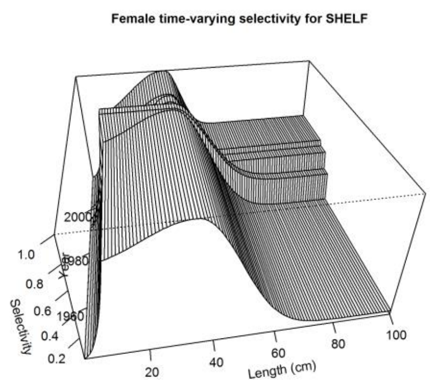
a)



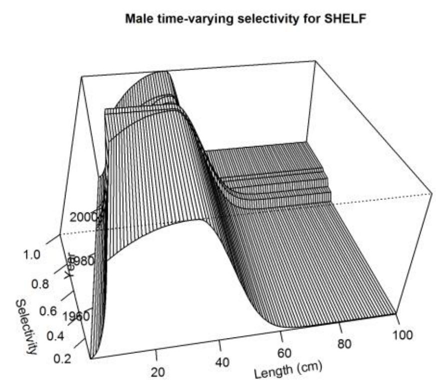
b)



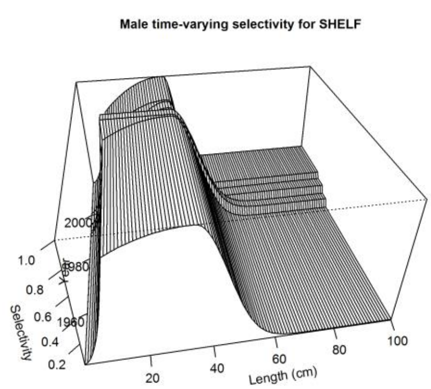
c)



d)



e)



f)

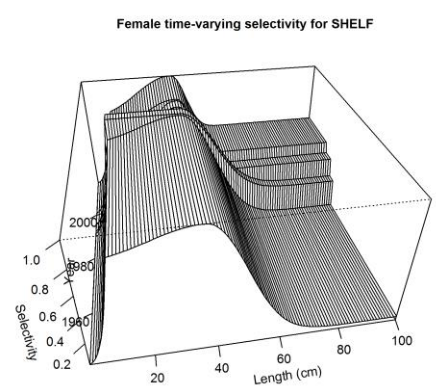


Figure 22.Estimated a,c,e) female and b,d,f) male shelf survey selectivity.

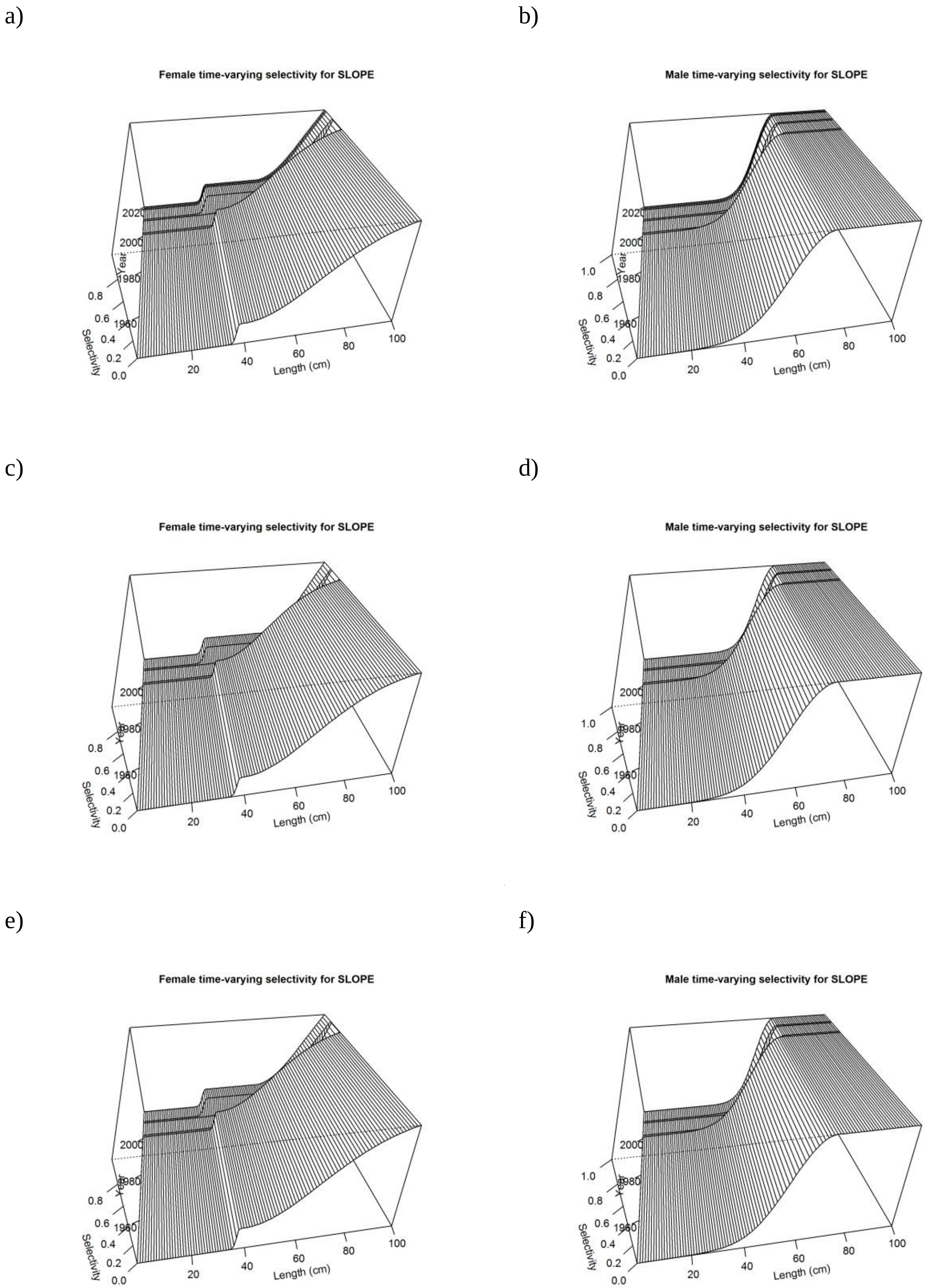
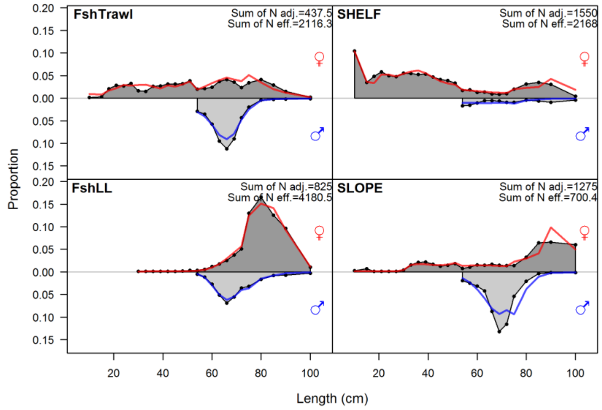
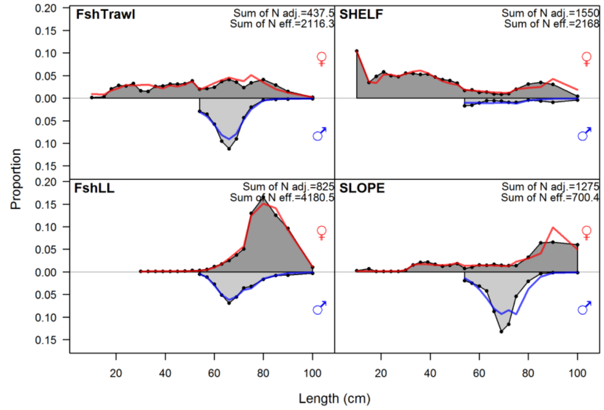


Figure 23. Estimated a,c,e) female and b,d,f) male slope survey selectivity.

a)



b)



c)

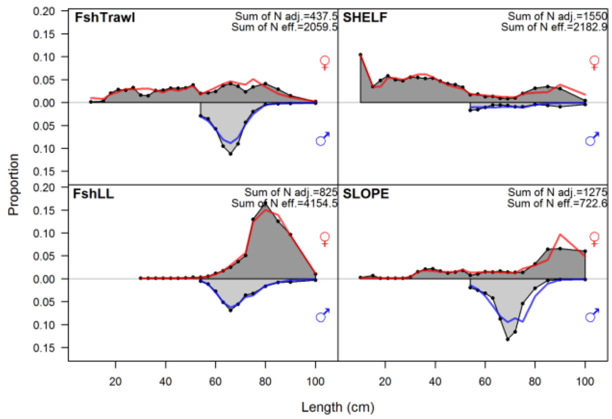


Figure 24. Overall model fit to the length composition data a) Model 16.1, b) Model 16.1a, and c) Model 16.1b.

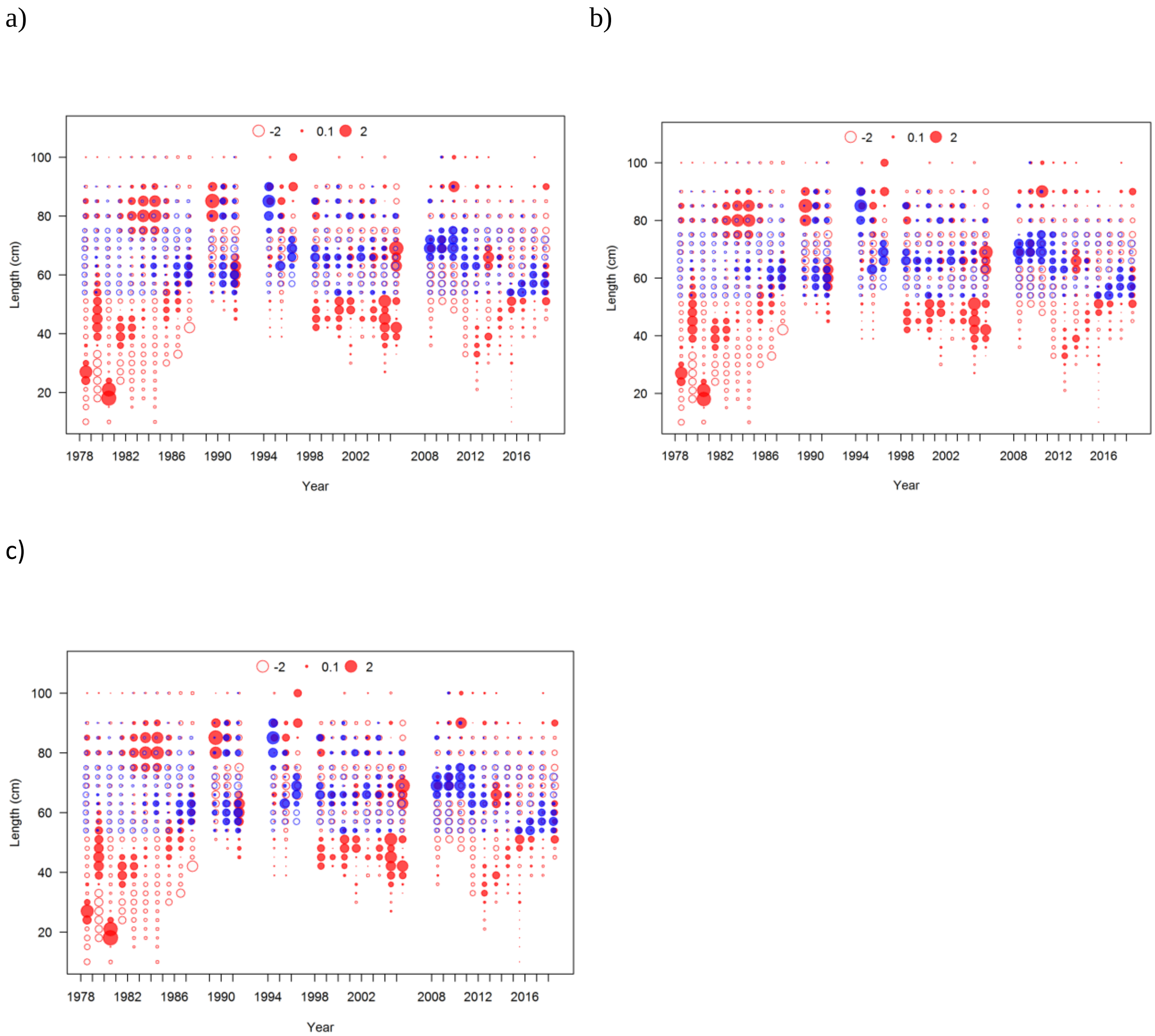
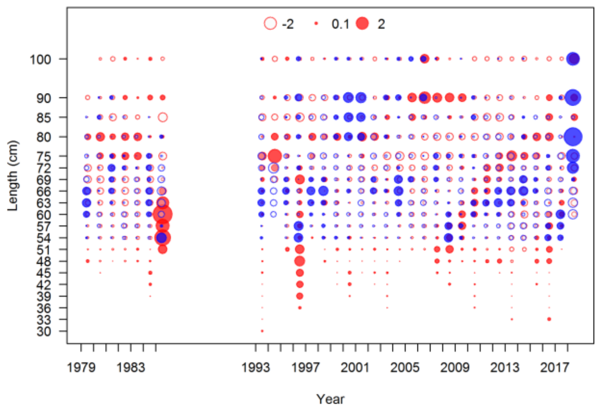
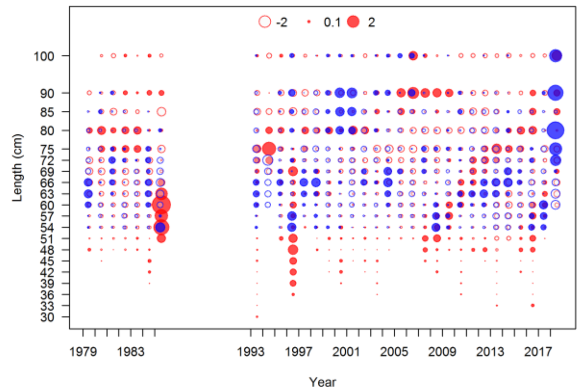


Figure 25. Model fit to the trawl fishery length composition data. a) Model 16.1, b) Model 16.1a, and c) Model 16.1b.

a)



b)



c)

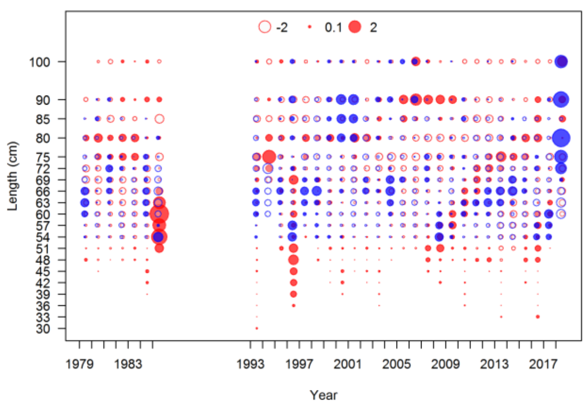
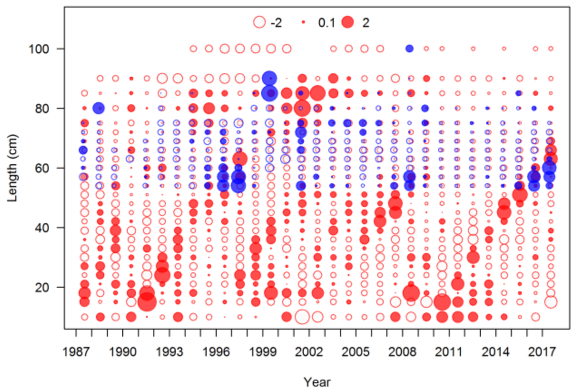
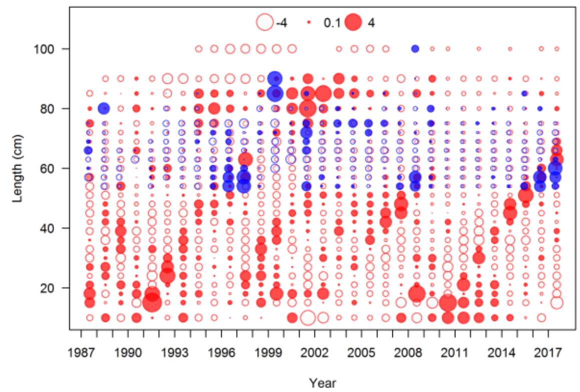


Figure 26. Model fit to the longline fishery length composition data. a) Model 16.1, b) Model 16.1a, and c) Model 16.1b.

a)



b)



c)

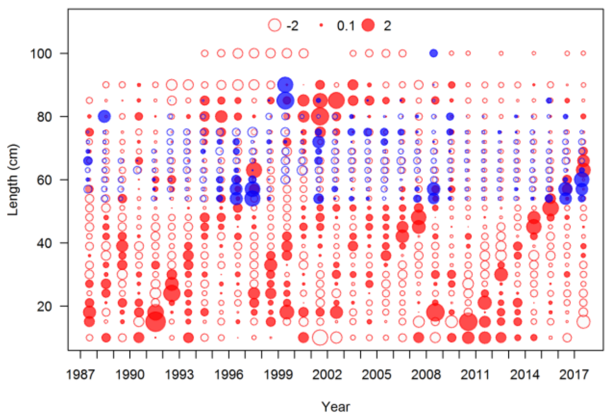
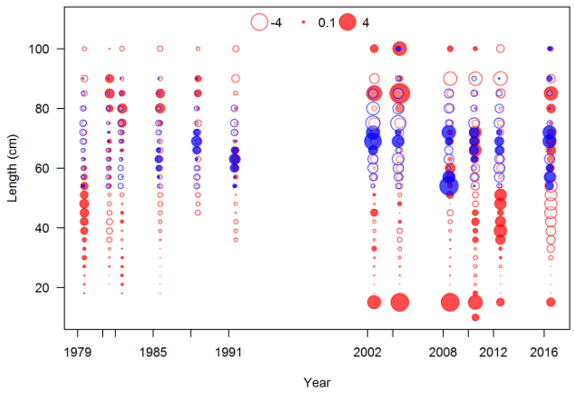
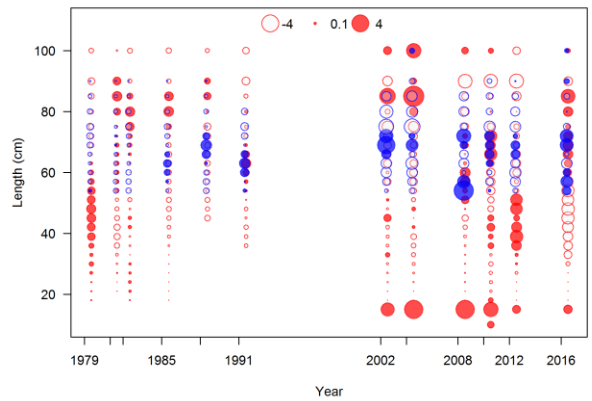


Figure 27. Model fit to the shelf survey length composition data. a) Model 16.1, b) Model 16.1a, and c) Model 16.1b.

a)



b)



c)

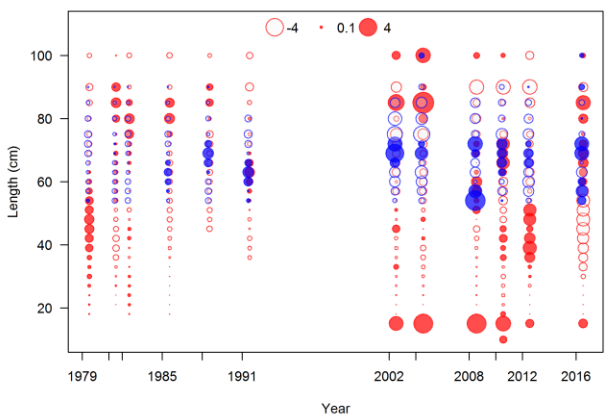


Figure 28. Model fit to the slope survey length composition data. a) Model 16.1, b) Model 16.1a, and c) Model 16.1b.

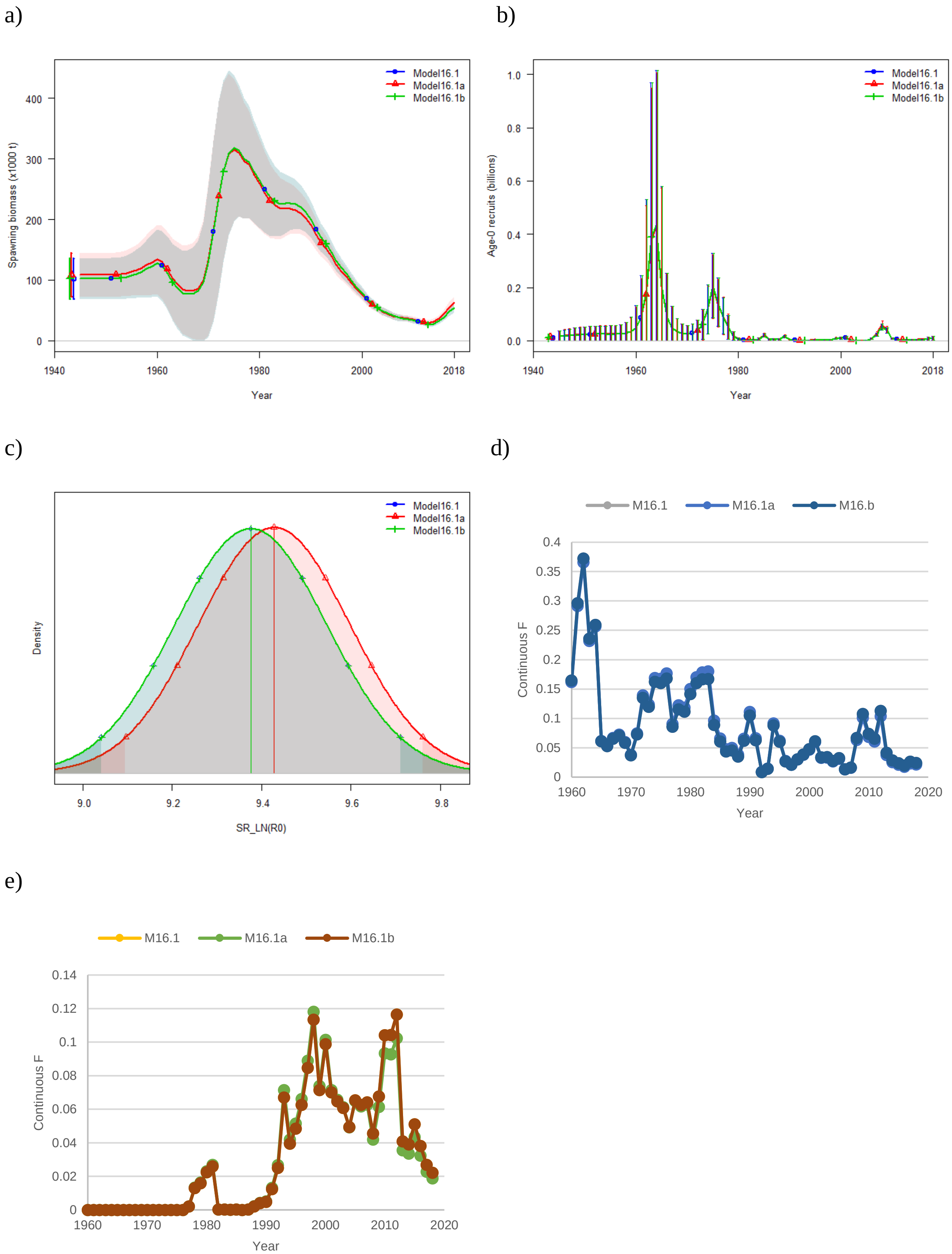


Figure 29. Estimates of a) SSB, c) recruitment, c) R0 density, d) trawl fishing mortality, and d) longline fishing mortality from models 16.1, 16.1a, and 16.1b.

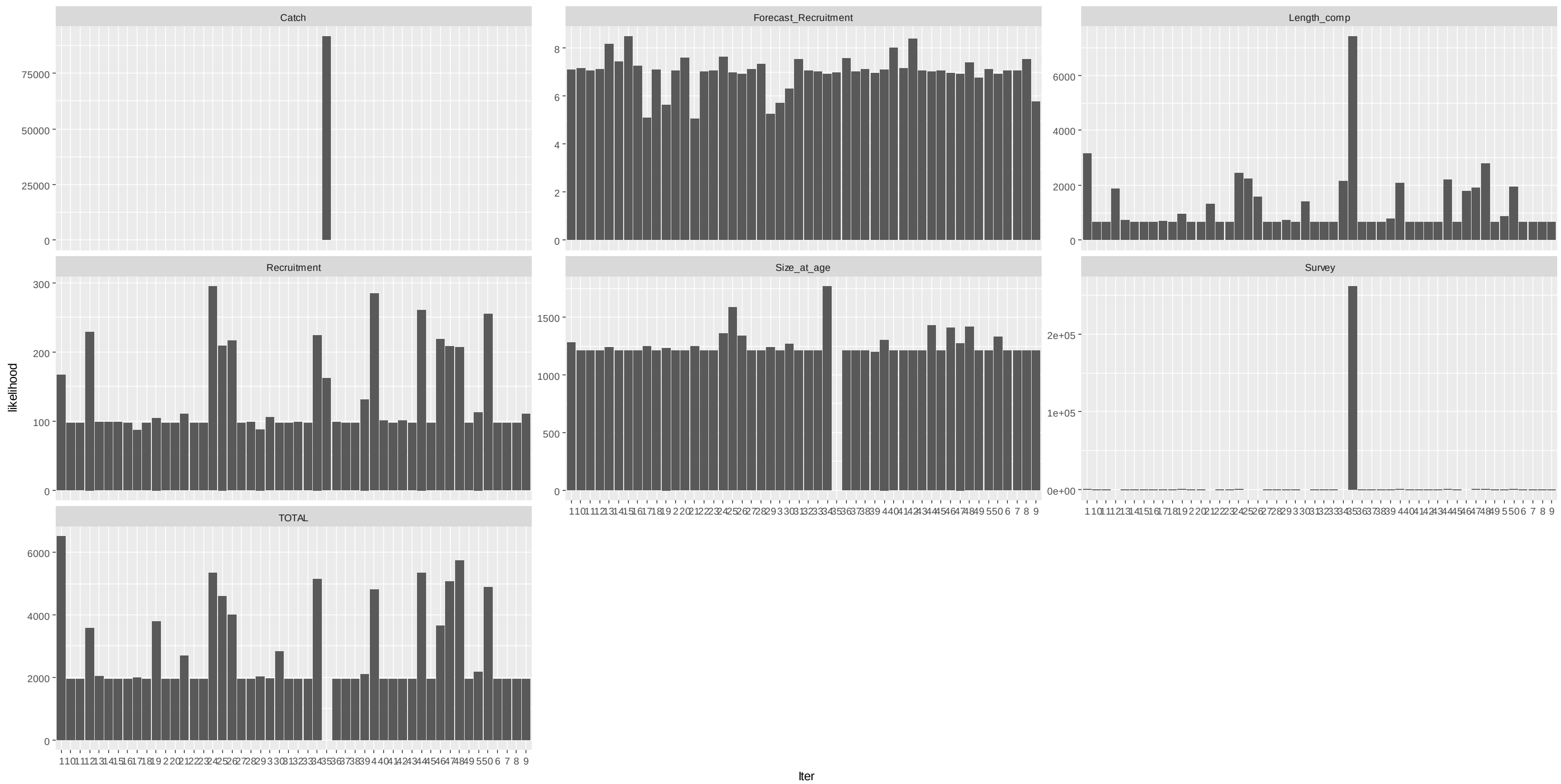


Figure 30. Likelihood estimates from the jitter analysis conducted on Model 16.1b. A total of 50 jitter runs were completed. The catch, forecast recruitment, length composition, recruitment, size-at-age, survey, and total likelihood components are shown. Bars represent an individual likelihood estimate.

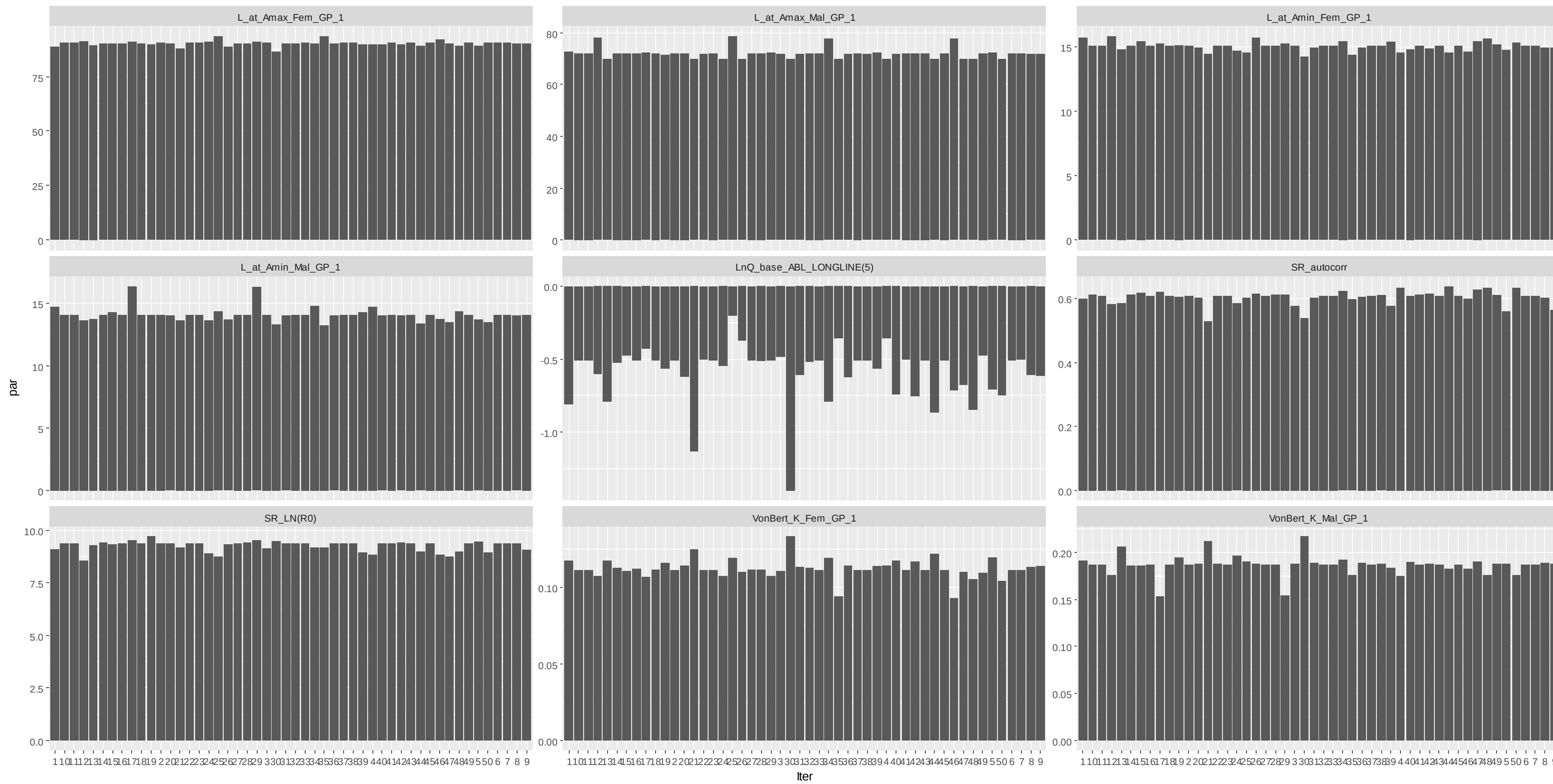
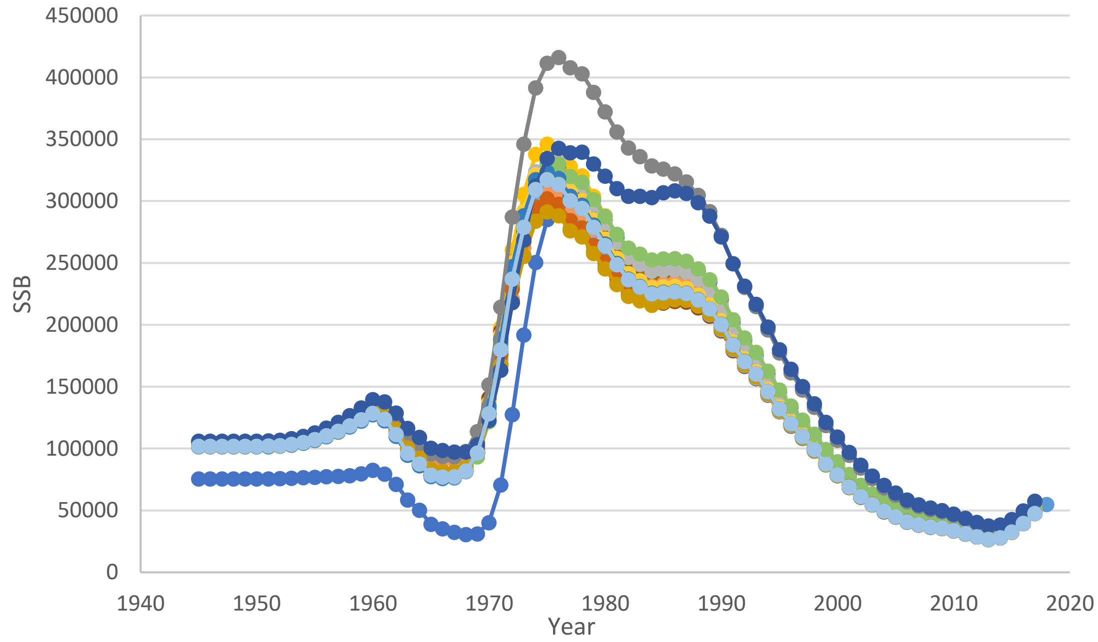


Figure 31. Leading parameter estimates from the jitter analysis conducted on Model 16.1b. Estimates for the length at maximum age (female and male), length at minimum age (female and male), the ABL longline catchability coefficient (log-scale), the stock-recruit autocorrelation parameter, unfished recruitment (R0), and the von Betalanffy growth coefficient are shown. Bars represent an individual parameter estimate.

a)



b)

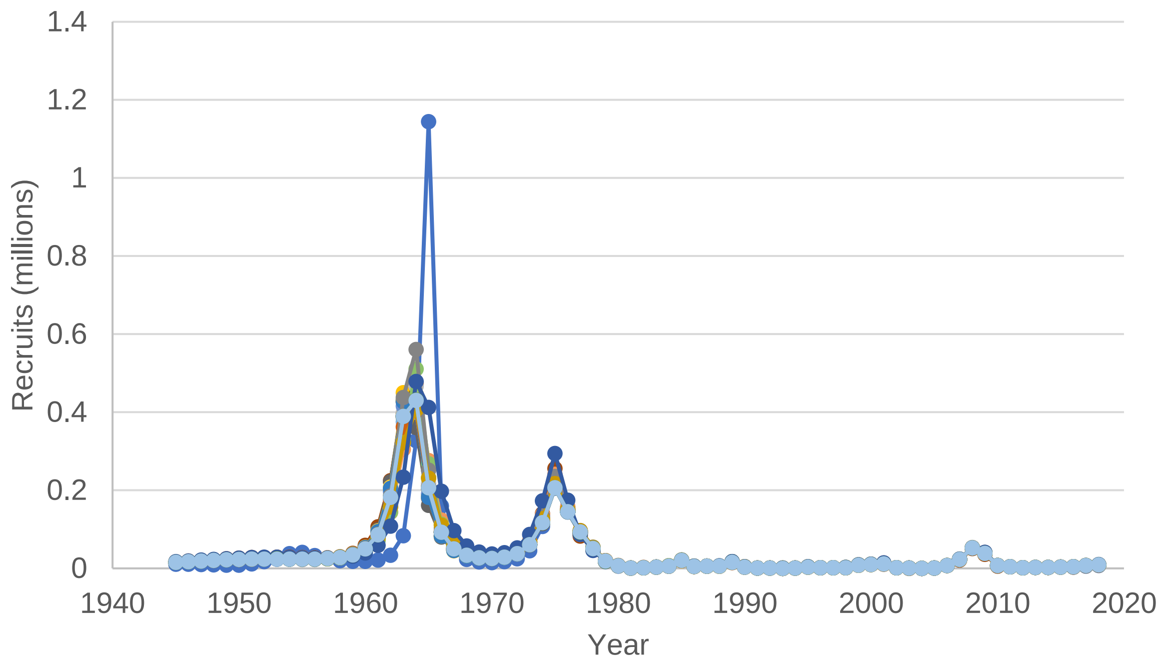


Figure 32. a) SSB and b) recruitment from estimates from the Model 16.1b jitter analysis. The results from the 25 iterations within 10 likelihood units of the MLE are shown.