Preliminary Assessment of Greenland turbot (Reinhardtius hippoglossoidea) in the Bering Sea and Aleutian Islands

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Introduction

The main goal in preparation for the September Groundfish Plan Team meeting was to evaluate the impact of data updates on the assessment, consider new methods for deriving the AFSC longline survey Relative Population Numbers (RPNs) for inclusion in the assessment, and evaluate assessment model assumptions.

Data

The following data sources were used in the 2022 BSAI Greenland turbot assessment and used for the model runs in this document:

Source	Data	Years
NMFS Groundfish survey:	EBS shelf BTS length composition	1987-2022
	EBS shelf BTS mean length at age	1982, 1998-2019, 2021
	EBS slope BTS biomass	2002, 2004, 2008, 2010, 2012, 2016
	EBS slope BTS length composition	Same as above and 1979, 1981-1982, 1985, 1988, 1991
	EBS slope BTS mean length at age	2002, 2004, 2008, 2010, 2012, 2016
AFSC longline survey	Relative population numbers	1996-2022
	Length composition	1979-2022
U.S. fisheries	Catch	1960-2022
	Length Composition: Trawl	1978-1991, 1994-1996, 1998-2021
	Fixed Gear	1979-1985, 1993-2020

Fishery Data

Catch data were updated to ensure there were no differences between the data retrieved as of July, 2024 and the catch data used in 2022 (*Figure 1*).

Survey Data

EBS slope bottom trawl survey biomass

The EBS slope bottom trawl survey data were updated by the Groundfish Assessment Program. Briefly, the Bering Sea slope stratum areas were updated (*Table 1*). This mostly affected the strata in Bering Slope Subarea 5 (consisting of strata 51-55). Similar to what was done in 2022 for the Bering Sea shelf areas, the Bering slope biomass and length composition tables were recalculated using the new updated stratum areas for all Bering slope survey years. The difference in the survey biomass estimates were small (Figure *2*). There was an apparent change in the length distribution, where the length distribution generally shifted towards smaller fish (*Figure 3*). Working with the GAP survey team, we realized that a formatting error has persisted in the assessment over time. The proportions at 100 cm was included in the data file between the 10cm and 15cm size bins. This error then shifted length bin 15cm and larger to the next larger length bin. This error has been fixed and the corrected data were used for all model runs. We note that this change had little impact on the model outcome compared to the last accepted model (*Figure A. 1*).

It should be noted that length composition data from a slope survey conducted as part of a U.S.-Japan cooperative agreement in the 1970s and 80s are included in the assessment. The length data prior to the AFSC EBS slope bottom trawl survey have been included in the assessment since 2001 and are intended to provide some information about the size and age composition of the population in the late 1960s to early 1970s. The length estimates from this earlier survey were not updated, since they are not part of the modern survey.

AFSC longline survey RPNs

Since 1996, the domestic AFSC longline survey for sablefish has conducted biennial sampling in the Aleutian Islands and biennial sampling in the Bering Sea since 1997. The combined time series has been included in the assessment as a relative abundance index (Figure *2*). The RPN index for Greenland turbot has been computed by taking the average RPN (from 1996-2022 in the last accepted assessment model) for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI}\frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS}\frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator function (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions are given here by each area as: p^{AI} and p^{EBS} . Note that with each new year data added to this time series, the estimate of the combined index changes in all years. Additionally, it has been assumed that the log standard error is the same for all years and has been set equal to 0.198.

The status quo approach for computing the combined BSAI is problematic because it relies on long-term average RPNs interpolate between years. This often results in abrupt changes in the index that are believed to be an artifact of the interpolation method and not actual changes in the population. For 2024, we recommend a new linear approximation approach to obtain region-specific estimates in off-survey years, provide a more statistically sound continuous survey index, and to obtain annual coefficient of variance (CV) estimates (Longline Survey Team, personal comms Jan 2024). The off-survey year, area-specific RPN estimates were obtained using a linear interpolation approach executed using the na.approx function in the zoo R package (Zeileis and Grothendieck 2005). The off-year estimate was interpolated from the two nearest data points and the end years were set equal to the nearest year, resulting in a continuous area-specific time series. This was done for the Aleutian Islands and the Bering Sea separately. The annual, area-specific RPNs were then summed to derive a single BSAI RPN time series. The same process was done for the area-specific CVs. Given that the status quo approach results in continuously changing time series, the linear approximation approach seems to be a reasonable and statistically appropriate method to derive the index. Therefore, we conducted sensitivity runs using the new linear approximated AFSC longline RPN time series.

The RPNs from the status quo approach are highly variable in the first four years of the time series and again in the latter half of the time series (*Table 2, Figure 2*). The linear interpolation approach smooths this variability, but also provides realistic uncertainty estimates, which includes inter-annual variation in the uncertainty. Uncertainty is low at the beginning of the RPN time series from the linear interpolation method and then ranges between 0.14 and 0.21. The higher uncertainty estimates correspond to a period of time when RPNs declined and then leveled off. During this period of time, the rate of killer whale depredation on the survey longline sets increased in the Bering Sea (*Figure 4*). Given this moderately strong relationship between killer whale depredation and the RPNs, the variance estimates from the linear interpolation approach seems to more adequately describe the uncertainty of this index than assuming a constant CV.

Length composition multinomial sample size

There is always difficulty in determining the appropriate multinomial sample size for the size composition data (Hulson et al. 2023). In the last accepted model initial annual sample sizes for each year and fishing fleet were set to 50. The annual size composition sample sizes for the shelf survey were set at 200, 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 these surveys with the more frequent shelf survey.

A new bootstrapping approach to determine the input sample size for the AFSC bottom trawl surveys has been advocated (Williams and Hulson, 2024). An R package has been developed to generate bootstrap replicates of the standard design-based indices of length composition from the AFSC bottom trawl survey data. The bootstrap replicates are then used to estimate the input sample size (ISS) for these data sources. The general bootstrap framework is described in Hulson et al. (2023) for age and length composition from AFSC bottom trawl surveys. This method was used for the EBS shelf survey and EBS slope survey as an alternative to what has been used in the past. A comparison between what has been used in the past and the values from this new method are summarized in *Table 3.* The sample sizes output from the afscISS package exhibit considerable inter-annual variability compared to what has been used in previous assessments. Currently this approach is not available for the fishery data; therefore, we continued using the static input sample size for the lengths from the fishery fleets.

Analytic Approach

A version of Stock Synthesis 3 (SS3) has been used for this assessment since 1994 (Methot and Wetzel, 2013). In the last accepted model, total catch from 1960 to 2022 was used as an input. The model included two fisheries, those using fixed gear (longline and pots) and those using trawls, and up to three surveys covering various years (see table on page 1).

Several parameters are from outside the model and used as fixed parameters:

Parameter	Estimate	Source
Natural Mortality	0.112	Cooper et al. (2007)
Length at Age		
L_{min} CV	15%	Gregg et al. (2006)
L_{max} CV	7%	Gregg et al. (2006)
Maturity and Fecundity		
Length 50% mature	60	D'yakov (1982), Cooper et al. (2007)
Maturity curve slope	-0.25	D'yakov (1982), Cooper et al. (2007)
Eggs/kg intercept	1	D'yakov (1982), Cooper et al. (2007)
Eggs/kg slope	0	D'yakov (1982), Cooper et al. (2007)
Length-weight		
Male		
Alpha	3.4×10^{-6}	1977-2011 NMFS Survey data
Beta	3.2189	1977-2011 NMFS Survey data
Female		
Alpha	2.43×10^{-6}	1977-2011 NMFS Survey data
Beta	3.325	1977-2011 NMFS Survey data
Recruitment		
Steepness	0.79	Myers et al. (1999)
Sigma R	0.6	Ianelli et al. (2011)

The name and number of the key parameters estimated in the last accepted assessment model is as follows:

		2022 assessment
Recruitment		
	Early Rec. Devs	(1945-1970) 25
	Main Rec. Devs	(1970-2018) 49
	Future Rec. Devs	(2019-2022) 4
	R_0	1
	Autocorrelation ρ	1
Natural mortality		
	Male	0
	Female	0
Growth		
	L_{min} (M and F)	2
	L_{∞} (M and F)	2
	von Bert K (M and F)	2
Catchability		
	q_{shelf}	0
	q_{slope}	0
	q_{ABL}	1
Selectivity		
	Trawl fishery	15
	Longline fishery	28
	EBS shelf bottom trawl survey	17
	EBS slope bottom trawl	19
	AFSC longline survey	2
	Total Parameters	168

Model assumptions

Growth assumptions

Sex-specific growth was estimated internally to the SS3 model using the von Bertalanffy growth curve. Length at age 1 is assumed to be the same for both sexes and the variability in length at age 1 was assumed to have a CV of 15% while at the maximum age a CV of 9% was assumed. Growth has been assumed to be time-invariant.

Evidence of time-varying growth was evaluated by fitting VBGF to the length-at-age data from Bering Sea shelf and slope bottom trawl surveys one year at a time. The data were obtained from the gap_products specimen table. Parameter estimates for L_{inf}, K, and t_0 were deemed to show no apparent temporal patterns (*Figure 5*). There is a slight jump up in K and t_0 in recent years, but given the declining number of samples, we determine it was appropriate to model growth without temporal variability.

Stock recruitment relationship

A single R_0 was assumed for all years in the last assessment model. The stock-recruitment relationship was assumed to follow Beverton-Holt stock recruitment dynamics with steepness (*h*) set to 0.79 and σ_R set to 0.6, values consistent with those estimated found for Greenland turbot stocks in the North Atlantic and Arctic Ocean (Myers et al. 1999). The model start year was set to 1945 allowing some flexibility in estimating a variety of age classes in the model given the assumed natural mortality of 0.112. Recruitment deviations for 1945-1970 (early recruitment deviations) were estimated separately from the post-1970 recruitment deviations (main recruitment deviations). Separating the recruitment deviations can be used to reduce the influence of recruitment estimation in the early period when there is little data on the later period in some model configurations.

An autocorrelation parameter was also estimated where the prior component due to stock-recruitment residuals (ε_i) is

$\pi_R = \frac{{\varepsilon_1}^2}{2\sigma_R^2} + \sum_{i=2}^{n} \frac{\left(\varepsilon_i - \rho\varepsilon_{i-1}\right)^2}{2\sigma_R^2\left(1-\rho^2\right)}$, where ρ is the autocorrelation coefficient and σ_R^2 is the assumed stock recruitment variance term. The model uses a prior of 0.473 (SD=0.265) estimated by Thorson *et al.* (2014) for Pleuronectidae species. The estimation of the autocorrelation parameter was first implemented in the 2013 accepted assessment model. This practice is now discouraged (see SS3 user manual, page 216). A simulation experiment showed that SS3 poorly estimates the autocorrelation parameter (Johnson et al. 2019). It is now recommended to use an external estimate the autocorrelation from the recruitment deviations and fix it in the model, if there is evidence of autocorrelation. Therefore, we conducted model runs assuming there was no autocorrelation in recruitment. Additional model runs used a fixed autocorrelation parameter value of 0.45 in the model.

Selectivity and the evaluation of fleet specific time blocks

Selectivity in the last accepted model used the logistic selectivity pattern for the AFSC longline survey, where the length at 50% selectivity and the slope parameter were estimated. Selectivity for the AFSC longline survey is not sex-specific because prior to 2021 sex-specific lengths were not collected.

Sex-specific size-based selectivity functions were estimated for the two trawl surveys and the two fisheries and modeled using a double normal pattern. The double normal selectivity 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 female selectivity for the trawl fishery and the slope survey was offset from the estimated male selectivity because the ratio of males in the length composition is generally higher than females. The male selectivity was offset from the female selectivity for the longline fishery and the shelf survey since the proportion of females caught is generally higher than males. 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 estimated fleet-specific selectivity parameters from the last accepted model are as follows:

Fleet / sex	Estimated parameters
Trawl fishery	
Male	Peak, ascending limb, descending limb, start logit
Female	Peak, descending limb, final selectivity
Fixed gear fishery	
Male	Peak, ascending limb, descending limb, final selectivity, scale
Female	Peak, top logit, ascending limb, descending limb, final selectivity
EBS shelf BTS	
Male	Peak, ascending limb, descending limb, final selectivity
Female	Peak, descending limb, first bin selectivity, final bin selectivity
EBS slope BTS	
Male	Peak, top logit, ascending limb
Female	Peak, ascending limb, descending limb, final selectivity, scale

Using time blocks on selectivity to allow for changes over time has been a longstanding feature of the Greenland turbot assessment. The time blocks used in the last assessment were as follows:

Fleet/survey			
EBS shelf survey	1945 – 1991	1992 – 1995	1996-2000, 2001 - 2022
EBS slope survey	1945 – 2001	2002 – 2010	2011 - 2022
Trawl fishery	1945 – 1988	1989 – 2005	2006 - 2022
Longline fishery	1945 – 1990	1991 – 2007	2008 - 2022

The positioning of the time blocks on selectivity parameters in the last accepted model was evaluated with respect to spatial shifts in the mean annual center of gravity of Greenland turbot encounters by fleets. This analysis was conducted on fleet-specific length data. For each fleet, centers of gravity of Greenland turbot encounters were calculated as the means of latitude and longitude of all tows (or fishing events) by year, weighted by the frequency of occurrence. Data were summarized by sex and length class, with lengths (in cm) being grouped into the following classes, based on Vihtakari et al. (2021): <30 cm; 30-60 cm; >60cm.

Spatial shifts of Greenland turbot over time were not apparent from the Bering Sea shelf survey data (*Figure 6*). Likewise, centers of gravity did not shift location for the slope survey data, except for a moderate shift northward and westward following the first two years of the survey (*Figure 7*). Spatial shifts were observed for the trawl fishery data center of gravity, with the fishery shifting southward and eastward in 1988 and then back northwards around 2005, consistently with the block structure (*Figure 8, Figure 9*). The longline fishery generally shifted north and west over time, where the center of gravity has been more consistent since around 2010 (*Figure 10*). We also see a shift toward smaller female around 2008 (Figure 9). Overall, the time block structure from the last accepted model was consistent with past spatial shifts and changes in the observed length composition data of the fisheries, but not of the surveys. No sex-specific differences were observed for any fleet and hence are not shown here.

The EBS slope bottom trawl survey is a short time series and the last time block in the last accepted assessment model includes two years of data. Given the limited temporal scope of this survey, we evaluated removing the slope survey time blocks. Justification for using time blocks on the EBS shelf bottom trawl survey selectivity in this model is discussed below.

Potential for time-varying EBS shelf bottom trawl survey catchability

There was evidence of temporal variability in the area occupied by turbot in the survey length data. For example, *Figure 11* and *Figure 12* are maps of frequency of encounter in space of, respectively, females and males <30 cm. Range expansion or contraction over time may indicate episodic recruitment and / or changes in survey catchability. In previous models, including the last accepted model, temporal variability in the shelf bottom trawl survey had been addressed, in part, by imposing time blocks on survey selectivity. This assumes that temporal variability is due to changes in size-specific availability. Identifying clean time blocks for this survey is difficult and designing time blocks based on availability may require an even finer-scale for the 2001-2022 block. This fine-scale block structure, as well as the assumption of time-varying survey catchability as an alternative, were explored as sensitivity runs.

Catchability

Catchability for the EBS shelf and EBS slope surveys were fixed in the last accepted assessment model. Since the 2015 assessment, the catchability values used in the model were $\log(q_{shelf}) = -0.485$ and $\log(q_{slope}) = -0.556$. The survey-specific catchability values were estimated from the 2015 Model 14.0 fit without the 2007 - 2015 data. This was meant to eliminate the effects of the 2007 through 2010 year classes. During the CIE review in 2021, the CIE reviewers indicated that the "practice of using estimates from an older model run is not recommended, because it uses the first part of the data twice". As an alternative, we used the float option in SS3 where the model derives an analytical solution (i.e., model estimated vulnerable biomass/ model estimated survey biomass) for the survey-specific catchability.

Additionally we explored estimating time-varying catchability for the EBS shelf bottom trawl survey, as an alternative to using time blocks on selectivity to account for changes due to spatial variability over time due to episodic recruitment events. We explored two options, 1) estimating a vector of deviations, and 2) adding additional time blocks every five years. We have excluded these as viable options at this point in time because the model over fit the index, effectively down weighting the index, when estimating deviations. When implementing additional time blocks many parameter bounds were encountered.

Variance adjustment

This assessment has used the following variance adjustment for the length composition data for many years:

Fleet	Sample size	Variance adjustment
Trawl fishery	50	0.25
Longline fishery	50	0.5
EBS shelf survey	200	0.25
EBS slope survey	400	0.5
AFSC longline survey	60	0.5

We conducted a sensitivity run to evaluate the impact of not including variance adjust on the length composition data on the assessment outcomes. From this sensitivity run, we then carried out Francis reweighting to update the variance adjustment values and determine whether the reweighting priority was similar to the currently used scheme.

Description of Alternative Models

A large number of model runs were conducted to evaluate the uncertainty in the assessment model given particular model assumptions and to develop a set of recommended models. The model runs that will be the focus of this report are summarized below:

Model	Description
m1	Updated slope data
m2	m1+No EBS slope survey time block
m3	m1+Analytical solution for survey catchability values
m8	m1+New survey multinomial sample size
m9	m1+No variance adjustment of length composition data
m9a	m1+Francis reweighting on length composition
m10	m1+Linear interpolation method AFSC LL RPN
m11	m1+No SRR autocorrelation
m15	m1+Fixed SRR autocorrelation (rho = 0.45)
m17	Analytical solution for survey catchability values No SRR autocorrelation New survey multinomial sample size No variance adjustment of length composition data Linear interpolation method AFSC LL RPN
m18	m17 + fixed SRR autocorrelation
m19	Analytical solution for survey catchability values No SRR autocorrelation No EBS slope survey time block New survey multinomial sample size No variance adjustment of length composition data Linear interpolation method AFSC LL RPN
m20	m19 + fixed SRR autocorrelation

Results

Modeling time-invariant selectivity for the EBS slope bottom trawl survey (m2) and using the AFSC longline survey RPNs and variance estimates from the linear interpolation method (m10) resulted in minor differences when compared to model m1 (*Figure A. 2*). We will therefore, focus on the remaining models listed in the table above. Comparisons will be made looking at the fits to the data, root mean square error estimates for the survey indices, likelihoods when appropriate and other diagnostics. Total likelihoods, likelihood components, and fleet specific likelihoods for each likelihood component are reported in Table *4* and Table *5*.

Base model sensitivity runs (m3 – m15): fits to data

The suite of sensitivity runs were done to determine the impact of changing individual model assumptions.

Fits to the bottom trawl survey biomass and AFSC longline RPNs followed similar trends for all model runs (Figure *13*). Examination of the likelihood components make some differences apparent. The survey likelihood results indicate that using the analytical solution for catchability (m3) improved the overall survey likelihood and fleet-specific survey likelihood components, but more so for the shelf and longline surveys when compared to model m1 (*Table 4, Table 5*). Using the analytical solution to estimate catchability also increased the catchability estimate for all surveys (*Table 6*). Model m3 also led to improved fit to the length composition data for the shelf and longline surveys. Fits to the shelf and slope surveys were similar between models m1 and m11 (SRR autocorrelation was assumed equal to 0), while fit to the AFSC longline survey was a bit poorer (5 likelihood units difference). The fit to survey biomass was similar for all survey fleets when comparing models m1 and m15 (SRR autocorrelation was assumed equal to 0.45). Model m15 led to a better fit to the shelf survey length data as well, which was not unexpected given that this is the main source of recruitment information and autocorrelation is evident in the data.

The likelihoods of models m1, m8, m9, and m9a are not directly comparable because the differences in data weighting effectively altering the data inputs; however, the RMSE values associated with each survey can provide a comparison (*Table 6*). Changing the length composition weights through new multinomial sample size or variance adjustments had mixed impacts on the model fit to the survey biomass. The fit to the EBS shelf survey biomass was similar between model m1 and models m8 and m9a; however not applying variance adjustment to the length composition (model m9) led to a poorer fit to the EBS shelf survey biomass (*Table 6, Figure 13*). The fit to the slope survey biomass was similar among models m1, m8, m9, and m9a. The fit to the AFSC longline survey was poorer when including inter-annually varying, multinomial sample size for the bottom trawl surveys (m8) and when not including variance adjustment on the length composition data (m9); however, the fit improved when Francis-reweighting was used to iteratively determine the variance adjustment values (m9a). The reweighting reduced the weight on the AFSC longline allowing for improved fit to the index.

The fits to the overall length composition data and the patterns in length composition residuals were similar among the majority of model runs (*Figure 14*, *Figure 15*). The size of the Pearson residuals differed due to changes in the treatment of the data (e.g., no variance adjustment or updated Francis reweighting). When variance adjustment of the length composition was not implemented (m9), we see that the fit to the EBS shelf survey length composition improves as compared to m1; the smaller lengths are better estimated and the overestimation of the larger fish is improved (*Figure 14*). The overestimation of the larger fish observed in the AFSC longline survey is also lessened in model m9 as compared to the other models. We also see some improvement to the shelf survey length composition data for model m8 that relies on inter-annually varying sample sizes.

Updated variance adjustments using Francis reweighting (m9a) resulted in new multinomial sample sizes as compared to model m1. All fleets were down weighted, but the relative order among fleets changed where the EBS slope survey and longline fishery were more equally weighted and the weight of the EBS shelf survey bottom trawl survey and the AFSC longline survey were much reduced:

	Sample size	Sample size after adjustment	
Fleet		m1	m9a
Trawl fishery	50	12.5	8.5
Longline fishery	50	25	22
EBS shelf survey	200	50	4
EBS slope survey	400	200	26
AFSC longline survey	60	30	10.5

Under model m9a, more weight was put on data from a non-random fishing process than on the survey length composition data. The EBS shelf survey length composition is our main source of information about recruitment and therefore down weighting this data set is a counter intuitive result. Down weighting these data results in a poorer fit to the female and male length composition data from the EBS shelf and slope bottom trawl surveys. More specifically small females in the slope survey are overestimated and larger females are underestimated more so than the other models, whereas for the EBS shelf survey we see a greater underestimation of smaller females and 75cm-80cm females and overestimation of the largest females (Figure *14*). It also results in a poorer fit to the AFSC longline length composition data where we overestimate larger individuals. Estimates of the EBS shelf survey's and EBS slope survey's selectivities also were considerably altered under model m9a, as compared to other model runs (Figure *16*).

Models m17 - m20: fits to data

Models m17 – m20 accumulate the individual changes that were evaluated in the sensitivity analysis. The key data changes are the updated slope survey data and the use of the AFSC longline RPNs estimated from the linear approximation approach (m17 – m20). The structural changes are the analytical estimation of catchability (m17-m20), assuming that recruitment is not autocorrelated (m17 and m19), recruitment is autocorrelated (ρ = 0.45), and no time blocks on the EBS slope survey selectivity (m19 and m20).

The fit of models m17 – m20 to the three survey indices capture the general trends (Figure *17*). The RMSE estimates and fits to the EBS shelf indicate some similarities between runs in comparison to model m1 (*Table 7*). Any misfit to the shelf survey biomass is mainly in the early period of the survey (1992-1995). The RMSE values associated with the slope survey are larger indicating a poorer fit (more so for models m19 and m20), especially in the first year and second to last year of this short time series. Conversely, the fit to the AFSC longline survey improves (smaller RMSE values) where models m17 – m20 fit the earlier portion of the AFSC longline index, the main index informing the model about the adult population, better than the previously accepted model.

Overall, the fits to the shelf length composition data for both males and females is improved by models m17-m20 than compared to model m1 (*Figure 18)*. Additionally, for the AFSC longline survey, the estimated proportions at larger lengths are better estimated (i.e., there is a reduction in overestimation) under models m17-m20 than model m1. Improving the fit to the shelf survey length composition helps to improve out estimates of recent recruitment. Additionally improving the fit to the AFSC longline index and length composition helps to improve our estimates of numbers that reflect the main source of fishery-independent information we have about the adult population.

The survey and length likelihoods indicate there is a trade-off in fitting the EBS slope survey data and the AFSC longline and EBS shelf survey data. Improvement in the fit to the AFSC longline RPNS and shelf survey biomass lead to a worse fit to the slope survey biomass when comparing among models m17 – m20 (Table *5*, *Figure 17*). Models m18 and m20 (models including autocorrelation in recruitment) have lower survey likelihoods for the longline and shelf surveys and higher likelihood for the slope survey than either models m17 or m19. The fits to the length composition data are also better (i.e., lower likelihood) for the shelf and longline surveys for model m18 when compared to m17 and m20 when compared to m19.

Francis reweighting was not conducted for models m17-m20 because it led to the under weighting the shelf survey length composition and poorer fits to the length composition data for all surveys. The Pearson residuals are larger for models m17-m20 than m1; however, the residual patterns overtime are similar among the model runs (*Figure 19*). The residuals demonstrate there is a consistent underestimation of the peak of the male length distribution from the slope survey over time, there is some underestimation of cohorts in the shelf survey, and the bimodal peaks of the AFSC longline survey are also underestimated over time. Similar to the base sensitivity runs estimates of selectivity were fairly consistent among model runs for the two commercial fishery fleets and the AFSC longline (*Figure 20*). The EBS shelf survey selectivity became more domed for both females and males, thereby reducing the selectivity of larger individuals and for the 1996-2000 time block increasing the selectivity of smaller fish. A comparison of fits to the annual length composition data shows that model m18 and m20, better fit the 1996-2001 data than m1 (*Figure 21*). The EBS slope survey selectivity for males was fairly consistent among runs. Models m19 and m20 did not include time blocks on the slope survey selectivity and the resulting male selectivity was similar among runs, while female selectivity was reduced between ~45cm and 75cm compared to the first time block of the other models. The misfit of the male slope length composition data suggests that the peak of the selectivity curve may be too larger. Potentially fixing the width parameter of the selectivity curve may help to improve the fit to the male and female length composition data from the slope survey.

Estimates of catchability for the EBS shelf survey increased to a value greater than 1 for model runs m17-m20, while increasing to ~3 for the AFSC longline survey (*Table 7*). This is high compared to previous assessments. Studies have shown that trawl surveys often have a catchability greater than one for flatfish due to their antipredator behavior of delayed movement to remain cryptic until predators are at a close distance (Ryer 2008, Bryan et al. 2014). This effectively allows for close contact with the fishing gear and herding of flatfish by the sweep of the trawl net as they try to move away. The catchability estimate for the AFSC longline survey, although larger, is within the realm of possibility; the longline catchability estimate for sablefish is ~6 (Goethel et al., 2023).

In an effort to increase the stability in the EBS shelf survey selectivity estimates, we explored removing the time blocks and modeling the temporal variability due to potential changes in the area occupied within the survey domain as time-varying catchability. Removing the time blocks, led to an extremely poor fit to the EBS shelf survey biomass especially in the first decade of the time series (*Figure 22*). Therefore, either time-varying catchability or time blocks are needed if the priority is to fit the early part of the time series. Modeling time-varying catchability over fit the biomass index (effectively down weighting the data), and including more time blocks resulted in a number of parameter bound issues; therefore, we excluded these models from consideration at this time.

Time series results

The majority of sensitivity runs had similar initial conditions and converged to a similar end point (*Figure 23*). There is considerable variability in the assessment model outcomes between 1960 and 1980, when catch data is the main source of information in the model. During this period, we see considerable variability in the estimate of age-0 recruits. This is partially driven by our assumptions about autocorrelation in recruitment. When we assume there is no autocorrelation in recruitment (m11), we see three sharp peaks in recruitment during this early time period which are then seen in SSB several years later (*Figure 23*). Similarly, when we fix the autocorrelation parameter (m15) to a value closer to the prior mean used in model m1 (rho ~0.45), which is lower than the model estimate ~0.69, we see a prominent peak in the early 1960s, similar to model m11, followed a period of prolonged recruitment in the late 1970s. We also see a difference in the scale of the population when the analytical solution for catchability (m3) is used. Using this option to model catchability led to an increase in the catchability estimates, which effectively indicates the scale of the population should be lower than we previously expected. This is most obvious for the time period where we have survey information. Given that catch is the same among the models the expectation of having a smaller population leads to higher estimates of fishing mortality (*Figure 23*).

The trend in the time series from models m17 – m20 is similar to what we see for the sensitivity runs (*Figure 24*). Assuming that recruitment is not autocorrelated (m17 and m19) results in several sharp peaks in recruitment before 1980, which are then seen in SSB several years later and leads to higher SSB estimates than model m1 in the l960s and 1970s. The previous assessment model estimates wider, more smooth periods of recruitment over this time frame. Models m18 and m20 assumed that recruitment is autocorrelated and similar to model m15, we see one less peak in recruitment and the peaks are slightly wider than model m17 and m19 (*Figure 24*). A commonality among all, is that the model estimates an initially small population and then needs to estimate large recruitment deviations early in the time series to support the large catches observed in the 1960s –late 1970s (*Figure 25*).

The scale of the population is another difference between model m1 and models m17-m20. Models m17-m20 use the analytical solution for catchability, which increased our estimates of this parameter, especially for the EBS shelf bottom trawl survey and the AFSC longline survey. An increase in catchability effectively reduces the scale of the population, which we see in the estimate of SSB in 2022, the majority of the later time period of the model, and the first 5-10 years of the model (*Figure 24*). Given that catch is the same among the models the expectation of having a smaller population leads to higher estimates of fishing mortality. The exception is for models m17 and m19 between 1960 and 1965 when the population is larger due to a large estimated recruitment in the 1950s.

The initial population in models m17 - m20 are lower than model m1. Estimates of $log(R_0)$ are 8.83, 8.65, and 8.63 for models m1, m18, and m20, respectively (*Table 8*). When exponentiated, that is an approximately 16% and 18% reduction in the R_0 estimate compared to model m1. Likelihood profiles show that the length data are the main determinant of R_0 and the length data from the EBS shelf bottom trawl survey are particularly informative (*Figure 26*). This makes intuitive sense, given that the EBS shelf survey samples juvenile habitat and is essentially an index of recruitment. The likelihood profiles demonstrate that the length composition data from the EBS shelf survey indicates R_0 should be lower than other length data sources, which are seeming flat in comparison. We will note that values below 8.4 led to convergence issues; hence, the left side of the profile is not shown here. Francis reweighting was not carried out for models m17-m20and the input sample sizes from the shelf survey are relatively larger in models m17-m20 than model m1. Given that more weight is place on the EBS shelf survey length composition data in model m17-m20, this helps to explain why these models estimate a lower R_0 than m1.

Retrospective analysis and leave one out analysis

The Mohn's rho for spawning stock biomass from the sensitivity models were low, similar to model m1 (the last accepted model with updated slope survey length data). Models m17-m20, which aggregated the changes in model assumptions, led to larger positive rho values, ~0.2 or greater (Table *9*). Unlike many of the sensitivity runs, models m17-m20 do not fix the EBS shelf and slope bottom trawl survey catchability values and catchability is derived as an analytical solution within SS3. With each retrospective peel, the shelf survey catchability declines, which would indicate biomass should be higher and helps to explain this increase in Mohn's rho (*Figure 27*).

The initial estimates of SSB from all models also exhibit a strong retrospective pattern where unfished SSB increased with each peel (*Figure 27*). Likelihood profiles on R_0 show that the EBS shelf bottom trawl survey length composition data is a strong determinant of R_0 in the model (*Figure 26*). Over the last decade or more, there has been a paucity of small/young Greenland turbot in the length data from the EBS shelf survey, which helps to explain successively smaller estimates of R_0 as new data are added to the model. This is turn would lead to lower estimates of unfished SSB.

A leave one out analysis was conducted to evaluate the impact of removing the particular data source from the model. We did this separately for each survey by removing the survey index and length composition data from the model. The leave one out analysis using model m1 further demonstrates the impact of removing the EBS shelf bottom trawl survey data has on the initial population estimates and the population scale of the model (*Figure 28*). When the EBS shelf bottom trawl survey is removed from the assessment, R_0 and SSB are initially larger and fishing mortality is initially lower.

Jitter analysis

A jitter analysis was conducted using a step of 0.05. A total of 100 jitters were carried out for each model. The number of converged runs per model is as follows:

Model	Number of runs converged
m1	94
m17	53
m18	60
m19	39
m20	60

Models m17 – m20 had less converged models from the jitter analysis. Of the iterations that converged they the likelihoods were similar to the maximum likelihood estimate. Including autocorrelation in the assessment model increased the number of converged iterations for models m18 and m20. The major difference between m1 and the other models is that the length composition data in m17-m20 are not down weighted (i.e., variance adjustments are not applied). Given that the length data is providing more information to the model this is causing more movement in the selectivity parameters during the jitter analysis and reduces the number of converged runs. If time permits, the authors would like to explore ways to stabilize selectivity between September and November. For example, the parameter controlling the width of the double normal selectivity curve is estimated for most of the fleets. Fixing this to a reasonable negative number, may help stabilize selectivity and the model.

Model start year

The initial conditions of this model are a key uncertainty. All models explored estimate a small initial population size and large positive recruitment deviations around 1950, the early 1960s, and the early to mid-1970s (*Figure 25*). When plotted with total catch, we see that each large, positive recruitment deviation precedes a large peak in catch by several years. The early recruitment deviations are largely informed by the catch data alone. Additionally the retrospective analysis shows that the initial population estimates decline as new data are added to the model corroborating this uncertainty.

As an experiment we conducted a model run starting in 1986. The period after 1986 is marked by much lower catch and is the start of the data rich period of the assessment. Equilibrium catch was set equal to the average of catch from 1960-1985 and initial fishing morality was estimated, so that the impact of historical removals was accounted for in the model. It should be noted that these early catches included Greenland turbot and arrowtooth flounder together. To separate them, the ratio of the two species for the years 1960-64 was assumed to be the same as the mean ratio caught by USSR vessels from 1965-69 and are therefore uncertain. Using these estimates to inform equilibrium catch and estimating initial fishing mortality may be a better assumption moving forward with this model in the future.

Early recruitment deviations were estimated to determine the initial age compositions. Selectivity time blocks were modified to either remove completely (EBS slope survey) or modified to match the new start year. The model results indicate that the initial estimate of R_0 and SSB would be larger than what is currently estimated by the assessment model (*Figure 29*). We were not able to fully evaluate this model for consideration as an alternative model given time constraints. The results do emphasize our uncertainty about whether this population was initially small that then produced large recruitment events to support the catch or is a large population that has experience higher exploitation rates. This model should be considered further in the future and the uncertainty about the initial stock size should be considered when developing management advice this year.

Recommendations

The authors consider models m18 or m20 to be viable options for November. The main justification for this is that the models improve some model assumptions:

1. Both models move us away from assuming that catchability is fixed. The catchability values that have been used in this assessment were from a model run removing some of the EBS shelf data, estimated catchability, and then re-ran the model using the estimate as a fixed value. This effectively uses the data twice and was discouraged by CIE reviewers.
2. Estimating autocorrelation in recruitment within SS3 is discouraged (Johnson 2016, Methot et al. 2020). There is evidence that there is autocorrelation in recruitment; therefore, the autocorrelation parameter is fixed to 0.45 (Thorson, 2014).
3. Model 20 removed the time blocks on the EBS slope trawl selectivity, given that the time series is short and there is little evidence for implementing the time block.
4. Both models use the recommended input sample size approach for bottom trawl surveys (Williams and Hulson 2024).

They also demonstrated improved fits to the EBS survey length composition data, which is an important source of information about recruitment in the model. Additionally models m18 and m20 have improved fits to the AFSC longline survey RPNs and they reduce the overestimation of larger fish observed in AFSC longline survey length composition data, which is currently the main source of fishery-independent information we have about the adult Greenland turbot population.

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Tables

Table 1. EBS slope bottom trawl survey, stratum specific area estimates from 2002 and the 2023 update.

STRATUM	AREA (KM2, 2002 VERSION)	AREA (KM2, 2023 UPDATE)	Percent difference
11	4012.41	4012.409	0.00
12	4062.77	4062.774	0.00
13	1741.66	1741.656	0.00
14	1354.74	1354.74	0.00
15	1106.89	1106.891	0.00
21	1157.635	1157.635	0.00
22	705.075	705.075	0.00
23	591.273	591.274	0.00
24	552.734	552.734	0.00
25	535.671	535.671	0.00
31	903.783	903.783	0.00
32	886.107	886.107	0.00
33	910.262	910.262	0.00
34	732.352	732.352	0.00
35	675.523	675.523	0.00
41	1236.274	1236.274	0.00
42	730.35	730.35	0.00
43	693.954	693.954	0.00
44	707.59	707.59	0.00
45	662.419	662.419	0.00
51	423.712	441.315	4.15
52	425.725	614.546	44.35
53	431.829	582.775	34.96
54	551.99	480.639	-12.93
55	570.139	421.937	-25.99
61	2595.79	2595.792	0.00
62	1705.756	1705.756	0.00
63	917.491	917.491	0.00
64	645.173	645.173	0.00
65	496.416	496.415	0.00

Table 2. AFSC longline survey RPN and SE estimates from the status quo approach and the linear interpolation method. Sampling is conducted in the Aleutian Islands in even years and the Bering Sea in odd years.

	Status quo approach		**Linear approach**		
Year	RPN	SE	RPN	SE	Percent difference in RPN
1996	115,681	0.198	90,656	0.056	-28
1997	80,481	0.198	91,884	0.069	12
1998	124,177	0.198	94,095	0.102	-32
1999	83,247	0.198	87,450	0.119	5
2000	71,400	0.198	76,416	0.108	7
2001	73,663	0.198	72,298	0.100	-2
2002	66,480	0.198	67,911	0.142	2
2003	63,322	0.198	61,830	0.187	-2
2004	49,844	0.198	48,636	0.166	-2
2005	32,967	0.198	33,856	0.140	3
2006	22,245	0.198	26,659	0.164	17
2007	23,940	0.198	22,885	0.194	-5
2008	18,338	0.198	26,683	0.203	31
2009	36,212	0.198	29,950	0.212	-21
2010	10,762	0.198	23,278	0.204	54
2011	20,523	0.198	19,485	0.182	-5
2012	23,099	0.198	23,715	0.189	3
2013	27,408	0.198	25,614	0.198	-7
2014	19,300	0.198	25,787	0.193	25
2015	29,441	0.198	25,201	0.196	-17
2016	10,247	0.198	23,537	0.201	56
2017	28,439	0.198	24,328	0.192	-17
2018	18,185	0.198	20,342	0.203	11
2019	13,997	0.198	14,975	0.208	7
2020	16,576	0.198	17,455	0.187	5
2021	21,628	0.198	19,233	0.170	-12
2022	10,108	0.198	15,750	0.161	36

Table 3. Input sample size options for bottom trawl surveys.

Fleet	Year	Previous	New	Fleet	Year	Previous	New
Shelf	1987	200	94	Shelf	2011	200	1190
Shelf	1988	200	105	Shelf	2012	200	711
Shelf	1989	200	114	Shelf	2013	200	434
Shelf	1990	200	193	Shelf	2014	200	355
Shelf	1991	200	199	Shelf	2015	200	329
Shelf	1992	200	181	Shelf	2016	200	242
Shelf	1993	200	273	Shelf	2017	200	192
Shelf	1994	200	181	Shelf	2018	200	150
Shelf	1995	200	158	Shelf	2019	200	100
Shelf	1996	200	234	Shelf	2021	200	68
Shelf	1997	200	72	Shelf	2022	200	55
Shelf	1998	200	208	Slope	1979	25	25
Shelf	1999	200	70	Slope	1981	25	25
Shelf	2000	200	128	Slope	1982	25	25
Shelf	2001	200	139	Slope	1985	25	25
Shelf	2002	200	148	Slope	1988	25	25
Shelf	2003	200	290	Slope	1991	25	25
Shelf	2004	200	261	Slope	2002	400	446
Shelf	2005	200	223	Slope	2004	400	372
Shelf	2006	200	211	Slope	2008	400	484
Shelf	2007	200	212	Slope	2010	400	495
Shelf	2008	200	157	Slope	2012	400	482
Shelf	2009	200	284	Slope	2016	400	541
Shelf	2010	200	755				

Table 4. Total likelihood and likelihood component estimates from each model, base model sensitivity runs (top table) and the update models (bottom). Likelihoods for the update models are not directly comparable to models < m15, because the lack of variance adjustment.

	Model			
Likelihood	2022_assess	m1_2022_corr	m3_qfloat	m8_Srv_ninput
TOTAL	3526.5	3547.2	3537.0	3567.9
Survey	-3.8	-1.2	-12.5	13.6
Length_comp	1163.4	1188.1	1179.2	1205.1
Size_at_age	2249.5	2234.6	2236.3	2244.9
	Model			
Likelihood	m9_noVarAdj	m9a_FrancisRewgt	m11_noSRRautocorr	m15_SRRautocorrFixed
TOTAL	5720.7	2539.8	3642.7	3560.9
Survey	34.1	-14.4	4.0	0.6
Length_comp	3123.6	416.2	1192.2	1182.1
Size_at_age	2359.3	2098.4	2236.7	2235.3

	Model					
Likelihood	2022_assess	m1_2022_corr	m17	m18	m19	m20
TOTAL	3526.5	3547.2	5667.0	5562.5	5795.5	5688.0
Survey	-3.8	-1.2	-10.5	-15.8	-1.6	-5.5
Length_comp	1163.4	1188.1	3003.3	2985.8	3092.4	3071.6
Size_at_age	2249.5	2234.6	2380.7	2380.5	2408.5	2408.8

Table 5. Fleet specific likelihood estimates for each likelihood component and model.

			Fleet				
Model	Likelihood	ALL	1	2	3	4	5
m1 2022_corr	Survey	-1.2	0.0	0.0	-22.9	-6.5	28.1
	Length	1188.1	131.2	106.6	467.8	290.0	192.4
	Size at age	2234.6	0.0	0.0	1668.4	566.2	0.0
m2 no slope time blocks	Survey	7.7	0.0	0.0	-20.0	-2.4	30.1
	Length	1244.4	126.5	108.1	460.1	352.3	197.3
	Size at age	2271.7	0.0	0.0	1667.0	604.7	0.0
m3 qfloat	Survey	-12.5	0.0	0.0	-24.2	-5.9	17.6
	Length	1179.2	131.4	106.6	463.8	290.0	187.3
	Size at age	2236.3	0.0	0.0	1664.7	571.5	0.0
m8 Srv_ninput	Survey	13.6	0.0	0.0	-21.2	-5.0	39.8
	Length	1205.1	130.6	108.1	443.7	330.2	192.6
	Size at age	2244.9	0.0	0.0	1661.3	583.6	0.0
m9 no Var adjust	Survey	34.1	0.0	0.0	-9.3	-4.5	47.9
	Length	3123.6	495.5	216.7	1522.7	513.7	374.9
	Size at age	2359.3	0.0	0.0	1741.4	617.9	0.0
m9a FrancisRewgt	Survey	-14.4	0.0	0.0	-17.8	-6.0	9.3
	Length	416.2	89.7	91.6	97.7	60.1	77.1
	Size at age	2098.4	0.0	0.0	1570.5	528.0	0.0
m10 AFSC LL linear approx	Survey	-32.3	0.0	0.0	-22.2	-6.2	-3.9
	Length	1191.4	130.6	106.4	470.7	290.2	193.5
	Size at age	2234.3	0.0	0.0	1669.3	564.9	0.0
m11 noSRRautocorr	Survey	4.0	0.0	0.0	-22.6	-6.4	33.0
	Length	1192.2	130.6	106.8	466.8	294.7	193.2
	Size at age	2236.7	0.0	0.0	1668.5	568.1	0.0
m15 SRRautocorrFixed	Survey	0.6	0.0	0.0	-22.9	-6.3	29.8
	Length	1182.1	130.0	106.0	463.6	290.5	192.0
	Size at age	2235.3	0.0	0.0	1668.5	566.8	0.0
m17	Survey	-10.5	0.0	0.0	-21.2	-4.0	14.6
	Length	3003.3	476.9	159.3	1404.3	588.4	374.3
	Size at age	2380.7	0.0	0.0	1732.5	648.1	0.0
m18	Survey	-15.8	0.0	0.0	-22.5	-2.7	9.4
	Length	2985.8	475.7	159.6	1396.3	584.0	370.2
	Size at age	2380.5	0.0	0.0	1731.2	649.2	0.0
m19	Survey	-1.6	0.0	0.0	-19.2	0.4	17.2
	Length	3092.4	466.9	161.3	1390.3	690.4	383.5
	Size at age	2408.5	0.0	0.0	1733.1	675.4	0.0
m20	Survey	-5.5	0.0	0.0	-20.8	2.2	13.1
	Length	3071.6	465.5	161.1	1382.2	683.2	379.6
	Size at age	2408.8	0.0	0.0	1732.1	676.8	0.0

Table 6. Survey specific catchability estimates and root mean square error estimates for base model sensitivity runs.

Model	Fleet	Q	RMSE
2022_assess	SHELF	0.616	0.265
2022_assess	SLOPE	0.574	0.196
2022_assess	AFSC LL	2.223	0.439
m1_2022_corr	SHELF	0.616	0.255
m1_2022_corr	SLOPE	0.574	0.182
m1_2022_corr	AFSC LL	2.423	0.457
m3_qfloat	SHELF	0.963	0.256
m3_qfloat	SLOPE	0.672	0.196
m3_qfloat	AFSC LL	3.285	0.422
m8_Srv_ninput	SHELF	0.616	0.256
m8_Srv_ninput	SLOPE	0.574	0.193
m8_Srv_ninput	AFSC LL	2.098	0.493
m9_noVarAdj	SHELF	0.616	0.305
m9_noVarAdj	SLOPE	0.574	0.198
m9_noVarAdj	AFSC LL	2.122	0.516
m9a_FrancisRewgt	SHELF	0.616	0.271
m9a_FrancisRewgt	SLOPE	0.574	0.193
m9a_FrancisRewgt	AFSC LL	2.501	0.393
m11_noSRRautocorr	SHELF	0.616	0.258
m11_noSRRautocorr	SLOPE	0.574	0.181
m11_noSRRautocorr	AFSC LL	2.384	0.472
m15_SRRautocorrFixed	SHELF	0.616	0.256
m15_SRRautocorrFixed	SLOPE	0.574	0.182
m15_SRRautocorrFixed	AFSC LL	2.404	0.462

Table 7. Survey specific catchability estimates and root mean square error estimates for models m17 - m20.

Model	Fleet	Q	RMSE
2022_assess	SHELF	0.616	0.265
2022_assess	SLOPE	0.574	0.196
2022_assess	AFSC LL	2.223	0.439
m1_2022_corr	SHELF	0.616	0.255
m1_2022_corr	SLOPE	0.574	0.182
m1_2022_corr	AFSC LL	2.423	0.457
m17	SHELF	1.207	0.270
m17	SLOPE	0.644	0.205
m17	AFSC LL	3.192	0.381
m18	SHELF	1.348	0.268
m18	SLOPE	0.682	0.218
m18	AFSC LL	3.344	0.365
m19	SHELF	1.233	0.274
m19	SLOPE	0.648	0.249
m19	AFSC LL	3.203	0.393
m20	SHELF	1.370	0.271
m20	SLOPE	0.681	0.265
m20	AFSC LL	3.333	0.380

Table 8. Parameter estimates and standard deviation.

	Model								
	m1			m18			m20		
Parameter	Value	Parm_ StDev	Gradient	Value	Parm_ StDev	Gradient	Value	Parm_ StDev	Gradient
L_at_Amin_Fem_GP_1	15.65	0.14	0	15.37	0.14	0	15.37	0.14	0
L_at_Amax_Fem_GP_1	93.84	0.46	0	91.86	0.32	0	92.01	0.33	0
VonBert_K_Fem_GP_1	0.11	0	0	0.12	0.00	0	0.12	0	0
L_at_Amin_Mal_GP_1	15.08	0.13	0	14.65	0.11	0	14.64	0.11	0
L_at_Amax_Mal_GP_1	71.33	0.27	0	70.45	0.20	0	70.59	0.2	0
VonBert_K_Mal_GP_1	0.18	0	0	0.20	0.00	0	0.19	0	0
SR_LN(R0)	8.83	0.18	0	8.65	0.08	0	8.63	0.07	0
SR_autocorr	0.7	0.03	0	0.45	_	_	0.45	_	_
LnQ_base_SHELF	-0.49	_	_	0.30	_	_	0.31	_	_
LnQ_base_SLOPE	-0.56	_	_	-0.38	_	_	-0.38	_	_
LnQ_base_ABL_LONGLINE	0.89	0.07	0	1.21	_	_	1.2	_	_
Size_DblN_peak_FshTrawl	67.61	1.59	0	68.21	0.90	0	68.12	0.89	0
Size_DblN_top_logit_FshTrawl	-4	_	_	-4.00	_	_	-4	_	_
Size_DblN_ascend_se_FshTrawl	4.92	0.24	0	4.95	0.12	0	4.94	0.12	0
Size_DblN_descend_se_FshTrawl	4.47	0.64	0	4.55	0.39	0	4.51	0.38	0
Size_DblN_start_logit_FshTrawl	-5.47	0.9	0	-5.79	0.51	0	-5.93	0.54	0
Size_DblN_end_logit_FshTrawl	-999	_	_	-999.00	_	_	-999	_	_
SzSel_Fem_Peak_FshTrawl	0.63	1.65	0	0.91	0.82	0	1.11	0.81	0
SzSel_Fem_Ascend_FshTrawl	0	_	_	0.00	_	_	0	_	_
SzSel_Fem_Descend_FshTrawl	-0.06	0.74	0	-0.05	0.42	0	0.04	0.4	0
SzSel_Fem_Final_FshTrawl	0	111.8	0	0.00	_	_	0	_	_
SzSel_Fem_Scale_FshTrawl	1	_	_	1.00	_	_	1	_	_
Size_DblN_peak_FshLL	77.04	2	0	76.68	1.09	0	76.72	1.08	0
Size_DblN_top_logit_FshLL	-8.18	35.86	0	-8.86	25.28	0	-9.01	22.6	0
Size_DblN_ascend_se_FshLL	4.61	0.27	0	4.50	0.16	0	4.49	0.16	0
Size_DblN_descend_se_FshLL	2.86	1.37	0	4.11	0.60	0	4.12	0.58	0
Size_DblN_start_logit_FshLL	-999	_	_	-999.00	_	_	-999	_	_
Size_DblN_end_logit_FshLL	-0.75	0.32	0	-1.39	0.38	0	-1.47	0.39	0
SzSel_Male_Peak_FshLL	-9.86	2.87	0	-8.45	2.52	0	-8.86	2.53	0
SzSel_Male_Ascend_FshLL	-0.69	0.49	0	-0.51	0.40	0	-0.56	0.42	0
SzSel_Male_Descend_FshLL	0.01	2.81	0	-3.60	6.00	0	-2.76	4.85	0
SzSel_Male_Final_FshLL	0.89	0.77	0	1.68	0.65	0	1.71	0.59	0
SzSel_Male_Scale_FshLL	0.44	0.09	0	0.44	0.09	0	0.42	0.09	0
Size_DblN_peak_SHELF	35.32	2.43	0	13.12	2.09	0	13.03	2.34	0
Size_DblN_ascend_se_SHELF	6	_	_	6.00	_	_	6	_	_
Size_DblN_descend_se_SHELF	3.88	0.71	0	6.42	0.14	0	6.47	0.15	0
Size_DblN_start_logit_SHELF	8.76	6.9	0	10.40	14.98	0	10.31	16.85	0

Table 8. Continued

	Model								
	m1			m18			m20		
Parameter	Value	Parm_ StDev	Gradient	Value	Parm_ StDev	Gradient	Value	Parm_ StDev	Gradient
Size_DblN_end_logit_SHELF	0.2	0.15	0	-0.76	0.08	0	-0.75	0.08	0
SzSel_Male_Peak_SHELF	2.34	2.07	0	15.28	2.02	0	15.5	2.24	0
SzSel_Male_Ascend_SHELF	7.72	42.32	0	-2.15	0.46	0	-2.05	0.46	0
SzSel_Male_Descend_SHELF	-0.98	0.38	0	-1.21	0.15	0	-1.22	0.15	0
SzSel_Male_Final_SHELF	-0.99	0.14	0	-1.01	0.08	0	-1.06	0.08	0
SzSel_Male_Scale_SHELF	1	_	_	1.00	_	_	1	_	_
Size_DblN_peak_SLOPE	72.2	8.03	0	72.00	5.72	0	74.5	1.07	0
Size_DblN_top_logit_SLOPE	-2.97	160.44	0	-2.77	180.79	0	-3.8	118.43	0
Size_DblN_ascend_se_SLOPE	6.24	0.58	0	6.24	0.42	0	6.37	0.06	0
Size_DblN_descend_se_SLOPE	10	_	_	10.00	_	_	10	_	_
Size_DblN_start_logit_SLOPE	-999	_	_	-999	_	_	-999	_	_
Size_DblN_end_logit_SLOPE	10	_	_	10.00	_	_	10	_	_
SzSel_Fem_Peak_SLOPE	-9.53	20.02	0	-4.98	14.16	0	22.5	3.41	0
SzSel_Fem_Ascend_SLOPE	-0.4	1.78	0	-0.13	1.11	0	0.95	0.11	0
SzSel_Fem_Descend_SLOPE	0.04	197.44	0	0.08	193.53	0	0	201.23	0
SzSel_Fem_Final_SLOPE	0.52	89.55	0	0.00	_	_	0	_	_
SzSel_Fem_Scale_SLOPE	0.64	0.06	0	0.73	0.05	0	0.76	0.06	0
Size_inflection_ABL_LONGLINE	62.9	0.39	0	63.17	0.28	0	63.2	0.29	0
Size_95%width_ABL_LONGLINE	6.03	0.58	0	6.18	0.42	0	6.21	0.42	0
Size_DblN_peak_FshTrawl_BLK7repl_1945	67.1	7.17	0	71.70	3.83	0	73	3.84	0
Size_DblN_peak_FshTrawl_BLK7repl_1989	66.3	1.25	0	66.46	0.62	0	66.5	0.57	0
Size_DblN_ascend_se_FshTrawl_BLK7repl_1945	9.99	_	_	9.99	_	_	9.99	_	_
Size_DblN_ascend_se_FshTrawl_BLK7repl_1989	3.64	0.47	0	3.75	0.23	0	3.79	0.22	0
Size_DblN_descend_se_FshTrawl_BLK7repl_1945	8.45	0.45	0	8.41	0.27	0	8.45	0.28	0
Size_DblN_descend_se_FshTrawl_BLK7repl_1989	3.96	0.45	0	3.88	0.22	0	3.81	0.21	0
SzSel_Fem_Peak_FshTrawl_BLK7repl_1945	-30	_	_	-30.00	_	_	-30	_	_
SzSel_Fem_Peak_FshTrawl_BLK7repl_1989	-1.1	1.75	0	-1.81	0.94	0	-1.92	0.95	0
SzSel_Fem_Descend_FshTrawl_BLK7repl_1945	-1	_	_	-1.00	_	_	-1	_	_
SzSel_Fem_Descend_FshTrawl_BLK7repl_1989	1.6	0.45	0	1.76	0.23	0	1.88	0.22	0
SzSel_Fem_Final_FshTrawl_BLK7repl_1945	0	_	_	0	_	_	0	_	_
SzSel_Fem_Final_FshTrawl_BLK7repl_1989	0	111.8	0	0	_	_	0	_	_

Table 8. Continued

	Model								
	m1			m18			m20		
Parameter	Val	Stdev	Grad				Val	Stdev	Grad
Size_DblN_peak_FshLL_BLK9repl_1945	85.76	1.84	0	85.45	1.22	0	86.08	0.58	0
Size_DblN_peak_FshLL_BLK9repl_1991	84.19	2.63	0	83.81	2.01	0	83.86	2.05	0
Size_DblN_top_logit_FshLL_BLK9repl_1945	-3.42	5.42	0	-2.79	1.75	0	-8.96	23.48	0
Size_DblN_top_logit_FshLL_BLK9repl_1991	0.29	1.18	0	0.26	0.66	0	0.31	2.01	0
Size_DblN_ascend_se_FshLL_BLK9repl_1945	5.29	0.21	0	5.26	0.14	0	5.28	0.12	0
Size_DblN_ascend_se_FshLL_BLK9repl_1991	5.15	0.32	0	5.21	0.24	0	5.23	0.24	0
Size_DblN_descend_se_FshLL_BLK9repl_1945	-0.37	2.69	0	-1.00	2.34	0	-0.95	2.44	0
Size_DblN_descend_se_FshLL_BLK9repl_1991	-3.79	71.28	0	-1.34	13.03	0	-2.58	71.58	0
Size_DblN_end_logit_FshLL_BLK9repl_1945	-1.05	0.46	0	-1.04	0.31	0	-1.09	0.3	0
Size_DblN_end_logit_FshLL_BLK9repl_1991	-1.6	0.53	0	-1.26	0.40	0	-1.3	0.4	0
SzSel_Male_Peak_FshLL_BLK9repl_1945	-15.64	3.08	0	-15.55	1.98	0	-16.4	2.03	0
SzSel_Male_Peak_FshLL_BLK9repl_1991	-13.79	3.84	0	-12.88	3.14	0	-13.23	3.2	0
SzSel_Male_Ascend_FshLL_BLK9repl_1945	-1.01	0.65	0	-1.02	0.44	0	-1.15	0.39	0
SzSel_Male_Ascend_FshLL_BLK9repl_1991	-0.99	0.71	0	-0.93	0.56	0	-0.96	0.58	0
SzSel_Male_Final_FshLL_BLK9repl_1945	-0.76	1.12	0	-0.78	0.77	0	-0.15	0.59	0
SzSel_Male_Final_FshLL_BLK9repl_1991	9.41	14.92	0	9.53	12.41	0	9.54	12.11	0
SzSel_Male_Scale_FshLL_BLK9repl_1945	0.36	0.1	0	0.32	0.06	0	0.32	0.06	0
SzSel_Male_Scale_FshLL_BLK9repl_1991	0.31	0.05	0	0.28	0.03	0	0.25	0.03	0
Size_DblN_descend_se_SHELF_BLK2repl_1945	5.71	0.3	0	6.70	0.12	0	6.68	0.14	0
Size_DblN_descend_se_SHELF_BLK2repl_1992	5.93	0.43	0	6.80	0.15	0	6.79	0.16	0
Size_DblN_descend_se_SHELF_BLK2repl_1996	4.03	0.8	0	6.71	0.19	0	6.71	0.19	0
Size_DblN_start_logit_SHELF_BLK2repl_1945	2.11	2.44	0	8.15	19.99	0	8.16	19.89	0
Size_DblN_start_logit_SHELF_BLK2repl_1992	7.73	27.4	0	8.02	22.40	0	8.04	21.99	0
Size_DblN_start_logit_SHELF_BLK2repl_1996	-1.06	0.67	0	-8.72	7.78	0	-8.67	9.19	0
Size_DblN_end_logit_SHELF_BLK2repl_1945	-3.52	0.3	0	-4.46	0.29	0	-4.44	0.28	0
Size_DblN_end_logit_SHELF_BLK2repl_1992	-1.22	0.17	0	-2.32	0.12	0	-2.34	0.12	0
Size_DblN_end_logit_SHELF_BLK2repl_1996	-0.55	0.14	0	-1.42	0.10	0	-1.47	0.1	0

Table 8. continued

	Model								
	m1			m18			m20		
Parameter	Val	Stdev	Grad				Val	Stdev	Grad
Size_DblN_peak_SLOPE_BLK8repl_2002	72.4	1.2	0	71.83	0.84	0			
Size_DblN_peak_SLOPE_BLK8repl_2011	84.4	6.88	0	78.09	2.82	0			
Size_DblN_top_logit_SLOPE_BLK8repl_2002	2.11	35.25	0	-3.98	111.28	0			
Size_DblN_top_logit_SLOPE_BLK8repl_2011	-2.99	156.92	0	-2.99	157.68	0			
Size_DblN_ascend_se_SLOPE_BLK8repl_2002	5.78	0.11	0	5.67	0.09	0			
Size_DblN_ascend_se_SLOPE_BLK8repl_2011	7.59	0.29	0	6.94	0.13	0			
SzSel_Fem_Peak_SLOPE_BLK8repl_2002	24	3.4	0	23.68	2.63	0			
SzSel_Fem_Peak_SLOPE_BLK8repl_2011	27	_	_	27.00	_	_			
SzSel_Fem_Ascend_SLOPE_BLK8repl_2002	1.16	0.18	0	1.23	0.14	0			
SzSel_Fem_Ascend_SLOPE_BLK8repl_2011	1.12	0.23	0	1.04	0.10	0			
SzSel_Fem_Final_SLOPE_BLK8repl_2002	-4.98	_	_	-4.98	_	_			
SzSel_Fem_Final_SLOPE_BLK8repl_2011	0	_	_	0.00	_	_			

Table 9. Mohn's rho estimates for each model run.

Model	Model description	SSB	Recruitment	Fishing mortality	Bratio
m1	Updated slope length data	0.092	9.220	-0.123	-0.478
m2	m1+No EBS slope survey time block	0.081	9.555	-0.111	-0.476
m3	m1+Analytical solution for survey catchability values	0.147	10.940	-0.136	-0.501
m8	m1+New survey multinomial sample size	0.013	5.958	-0.076	-0.370
m9	m1+No variance adjustment of length composition data	0.064	12.806	-0.066	-0.510
m10	m1+Linear interpolation method AFSC LL RPN	0.131	9.586	-0.158	-0.471
m11	m1+No SRR autocorrelation	0.147	9.416	-0.164	-0.305
m15	m1+Fixed SRR autocorrelation (rho = 0.45)				
m17	Analytical solution for survey catchability values No SRR autocorrelation New survey multinomial sample size No variance adjustment of length composition data Linear interpolation method AFSC LL RPN	0.297	13.034	-0.217	-0.098
m18	m17 + Fixed SRR autocorrelation	0.211	11.525	-0.159	-0.266
m19	Analytical solution for survey catchability values No EBS slope survey time block No SRR autocorrelation New survey multinomial sample size No variance adjustment of length composition data Linear interpolation method AFSC LL RPN	0.294	12.413	-0.211	-0.098
m20	m19 + Fixed SRR autocorrelation	0.203	11.676	-0.148	-0.272

Figures

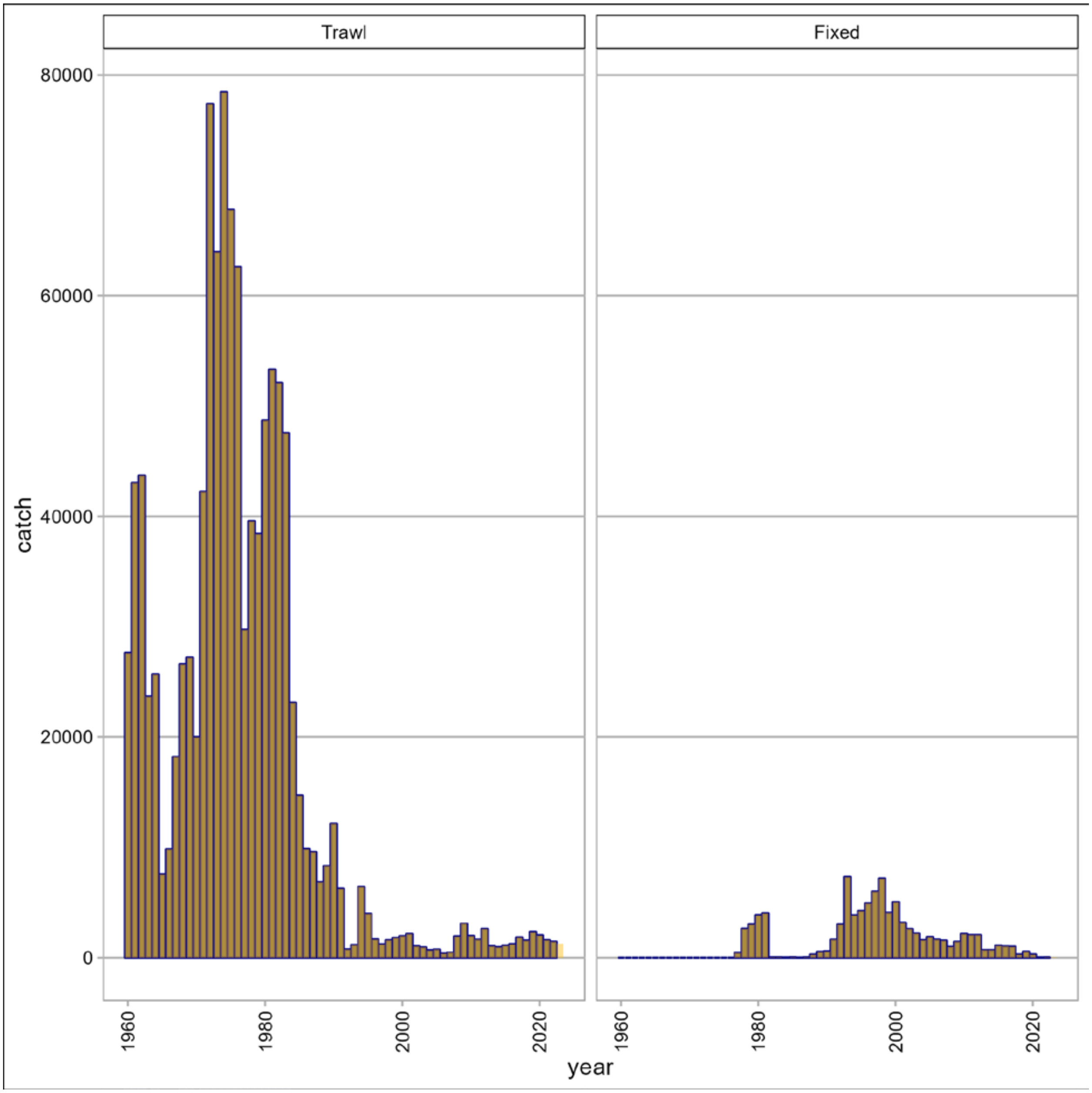


Figure 1. Catch by fleet 1960-2023. Yellow is data retrieved from the comprehensive blend tables in 2024 and the dark blue is the catch data retrieved in 2022.

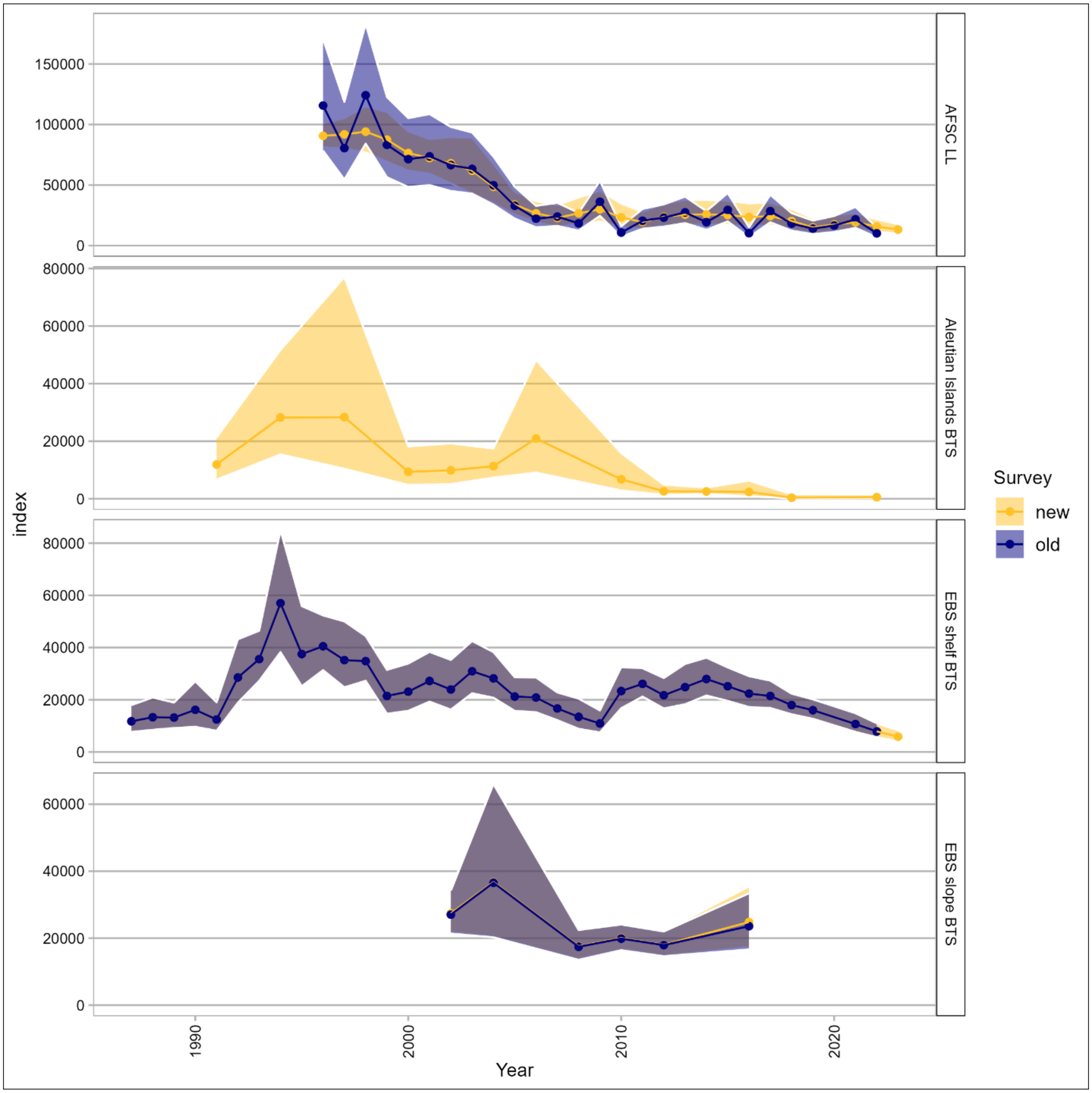
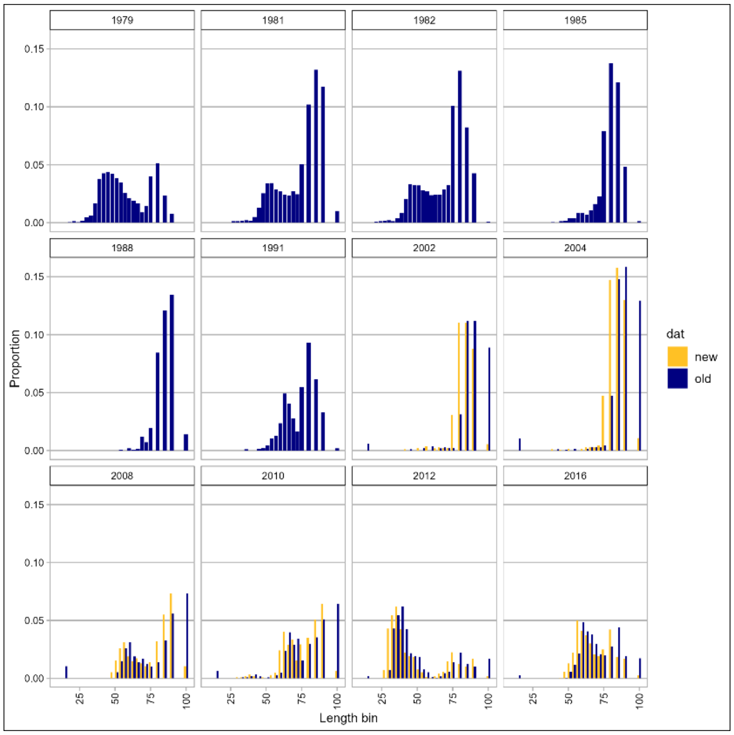


Figure 2. Survey indices by data source. The bottom trawl surveys are in units of metric tons and the AFSC LL represents relative population numbers. The Aleutian Islands BTS biomass is not used in the assessment, but shown here since it is used to apportion ABC between the Bering Sea and AI in November. Yellow is data retrieved from the gap_products akfin_biomass tables in 2024 and the dark blue is the survey data retrieved in 2022.

a)



b)

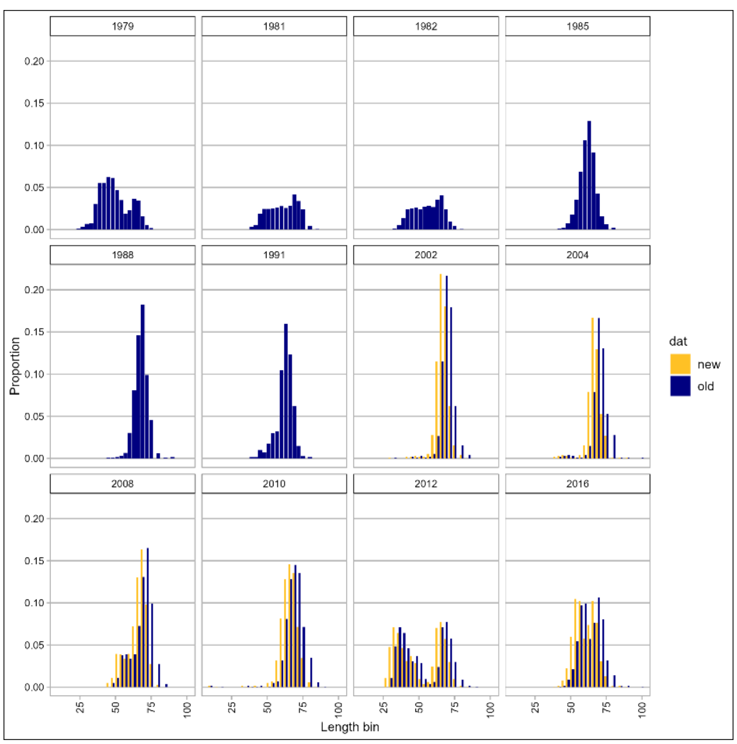


Figure 3. EBS slope bottom trawl survey length composition data a) female and b) male. Yellow is data retrieved from the gap_products sizecomp tables in 2024 and the dark blue is the survey data retrieved in 2022. Data prior to 2002 were not impacted by the GAP data update.

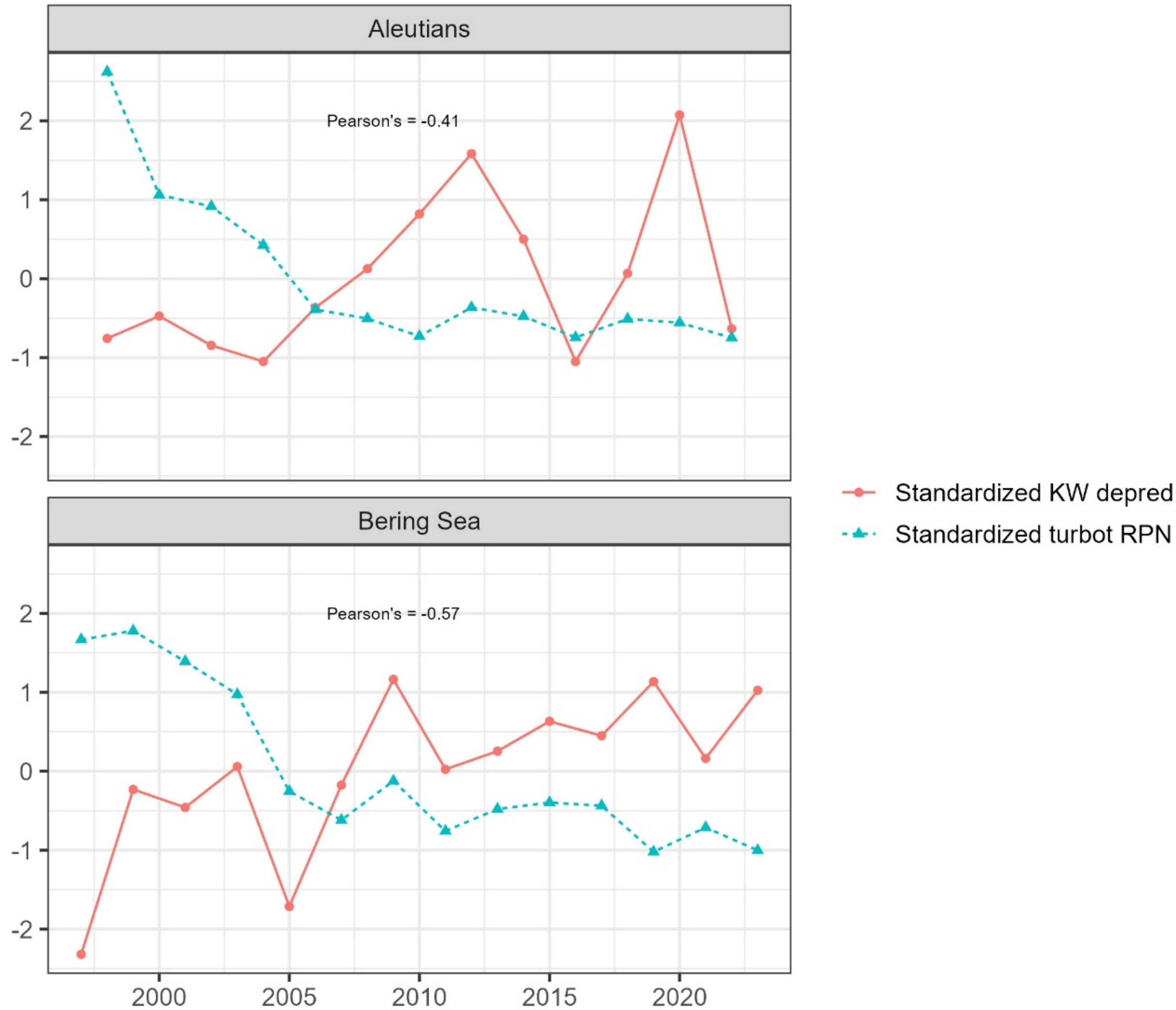


Figure 4. AFSC longline survey RPN estimates and killer whale depredation rates for the Aleutain Islands (top) and Bering Sea (bottom).

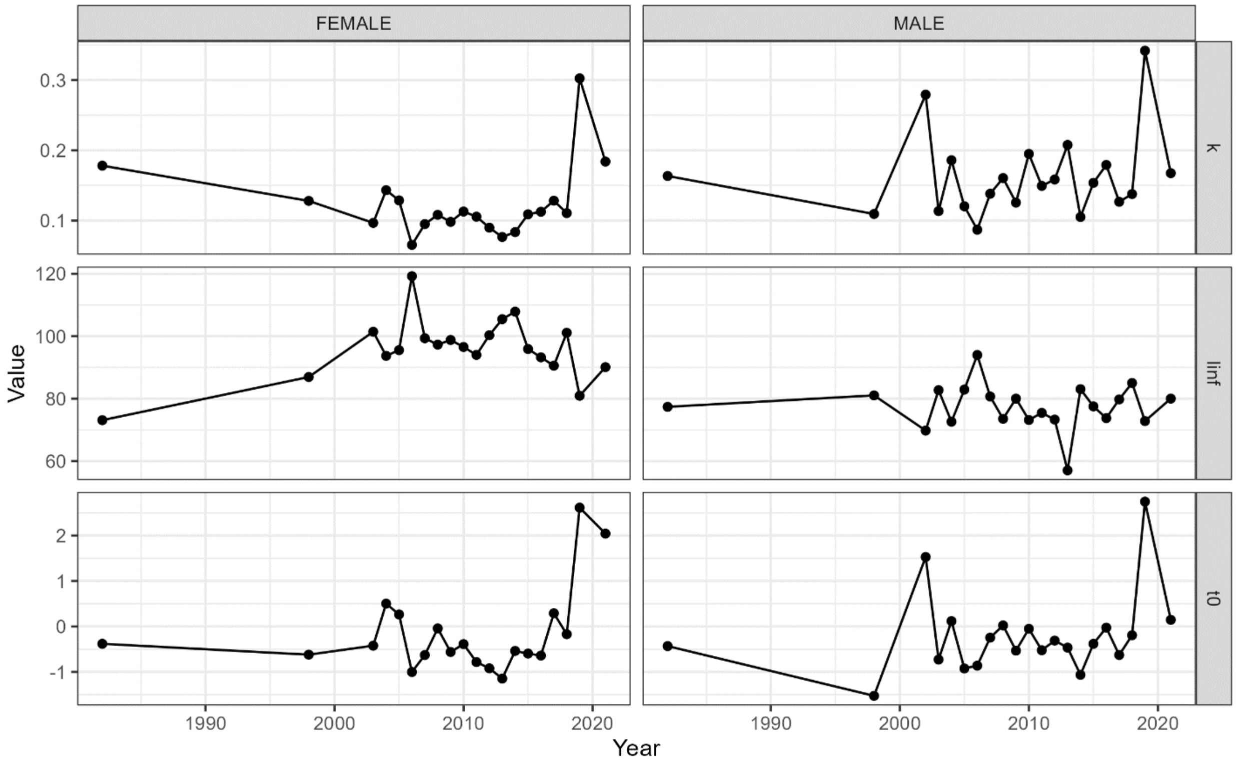


Figure 5. Von Bertalanffy growth function parameter estimates for Greenland turbot by year.

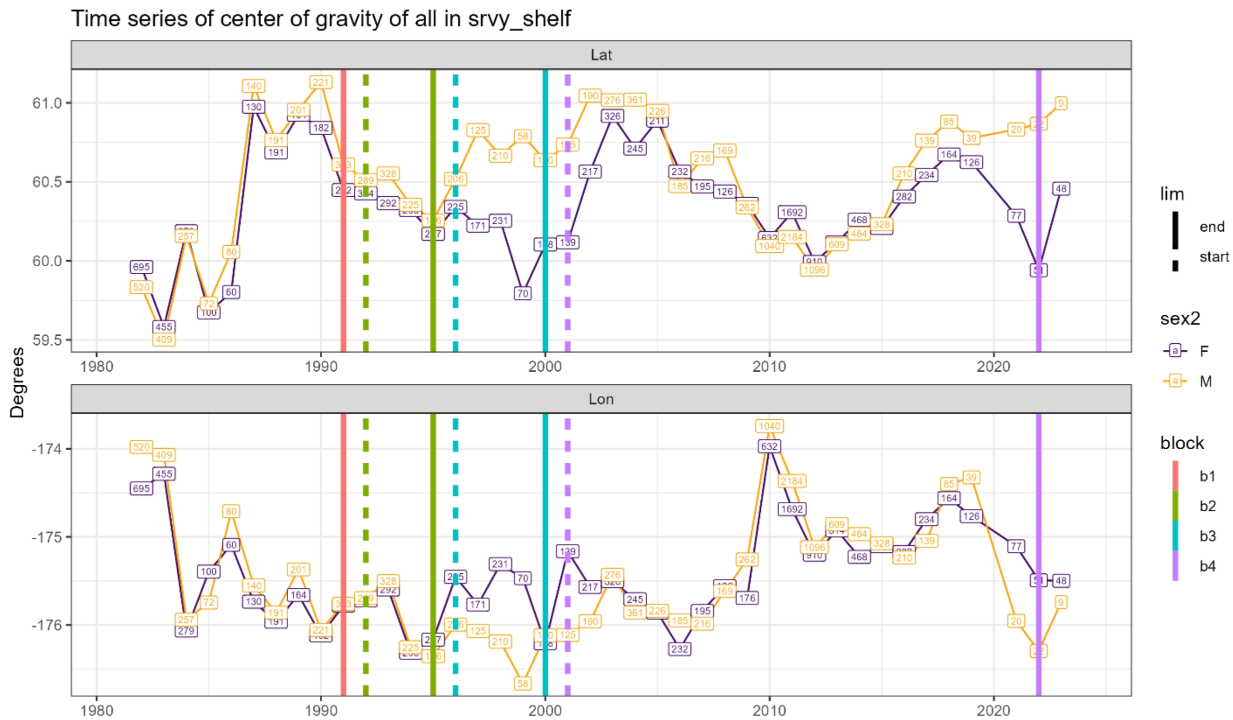


Figure 6. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the Bering Sea shelf survey data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning (dashed) and end (solid) of the time blocks on the selectivity parameters for this fleet.

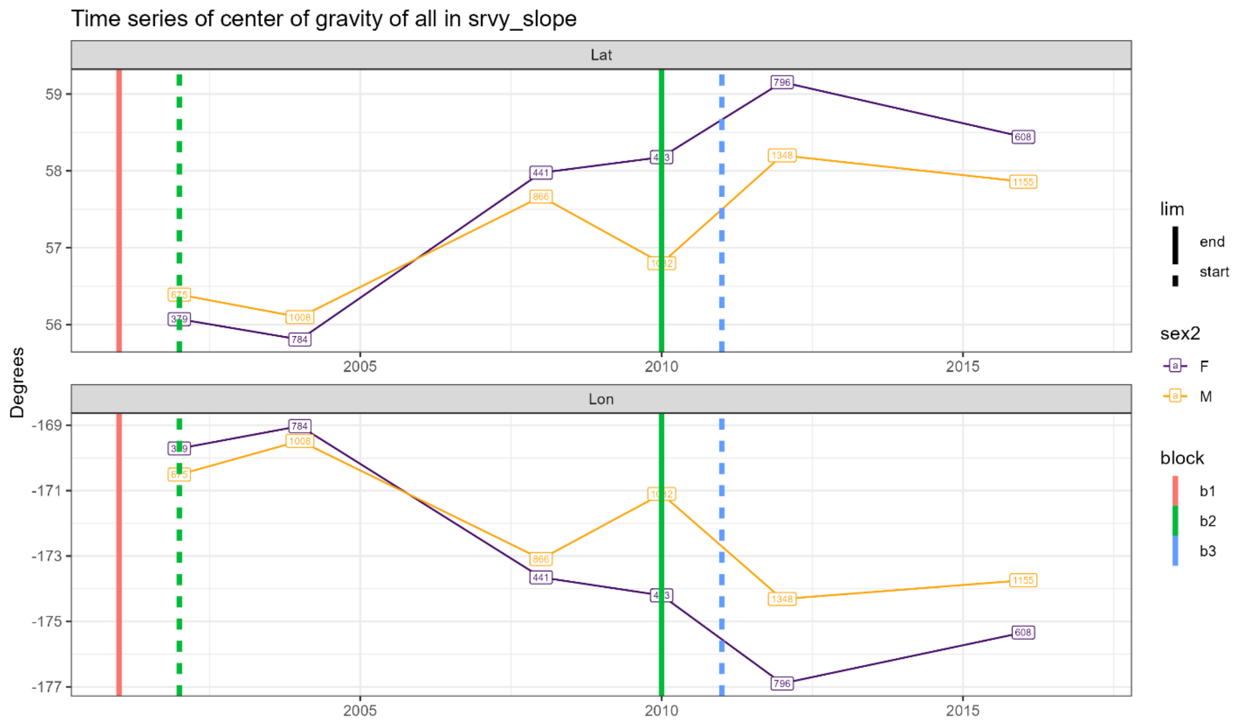


Figure 7. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the Bering Sea slope survey data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning (dashed) and end (solid) of the time blocks on the selectivity parameters for this fleet.

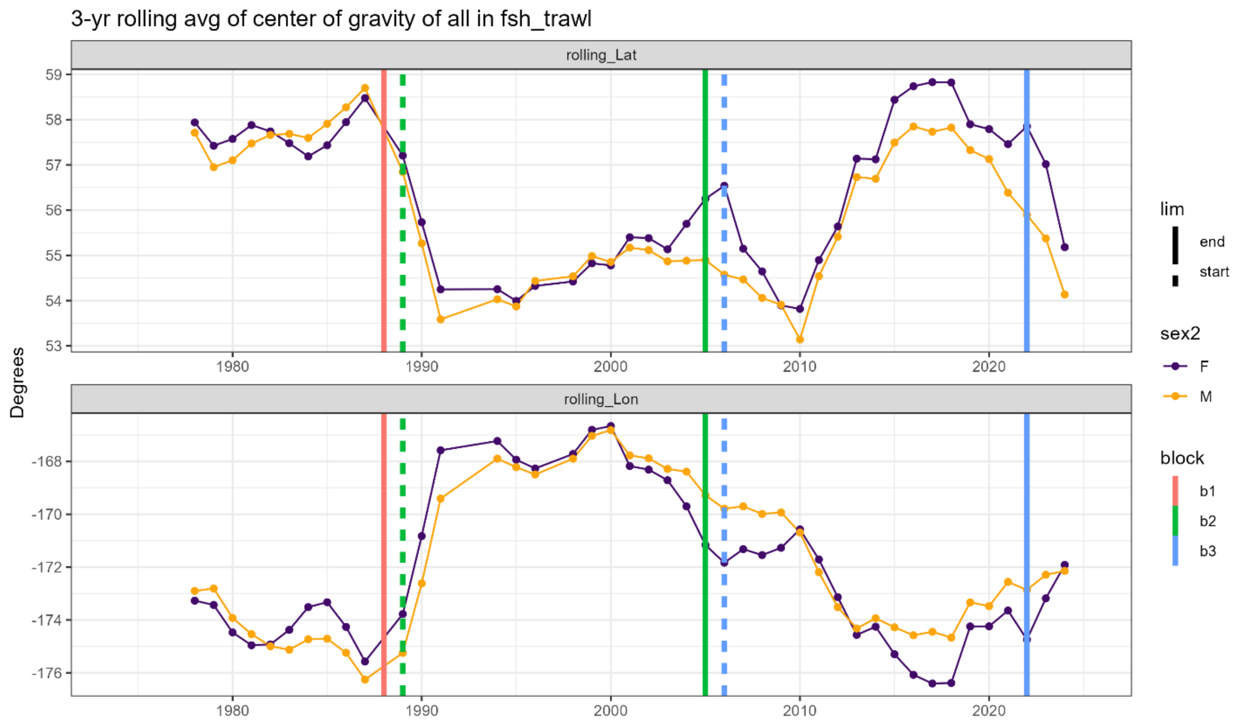


Figure 8. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the trawl fishery data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning (dashed) and end (solid) of the time blocks on the selectivity parameters for this fleet.

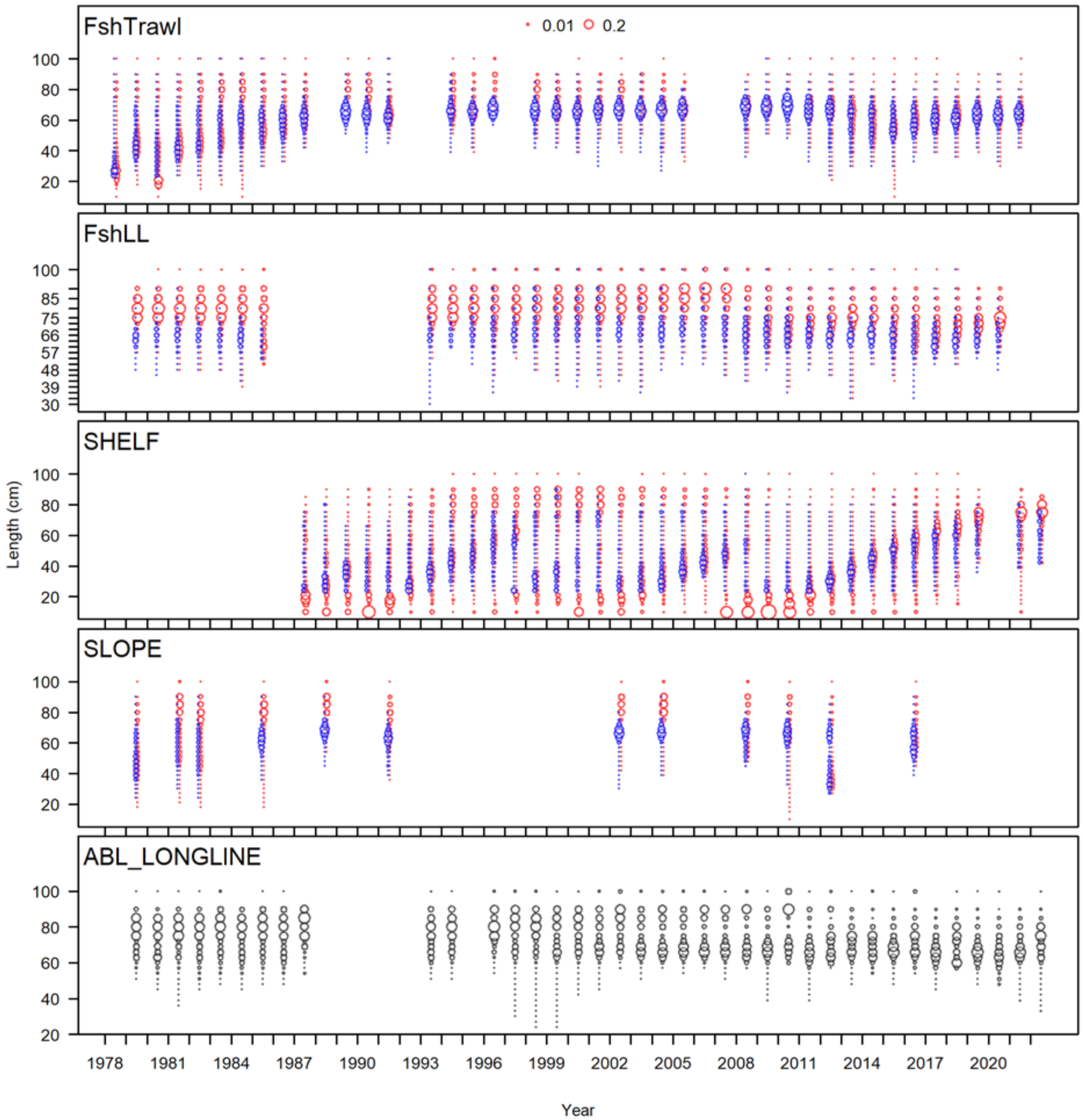


Figure 9. Length composition data from each fleet. Red represents females, blue represents males, and black represents combined sex. The bubbles represent the proportion at each length.

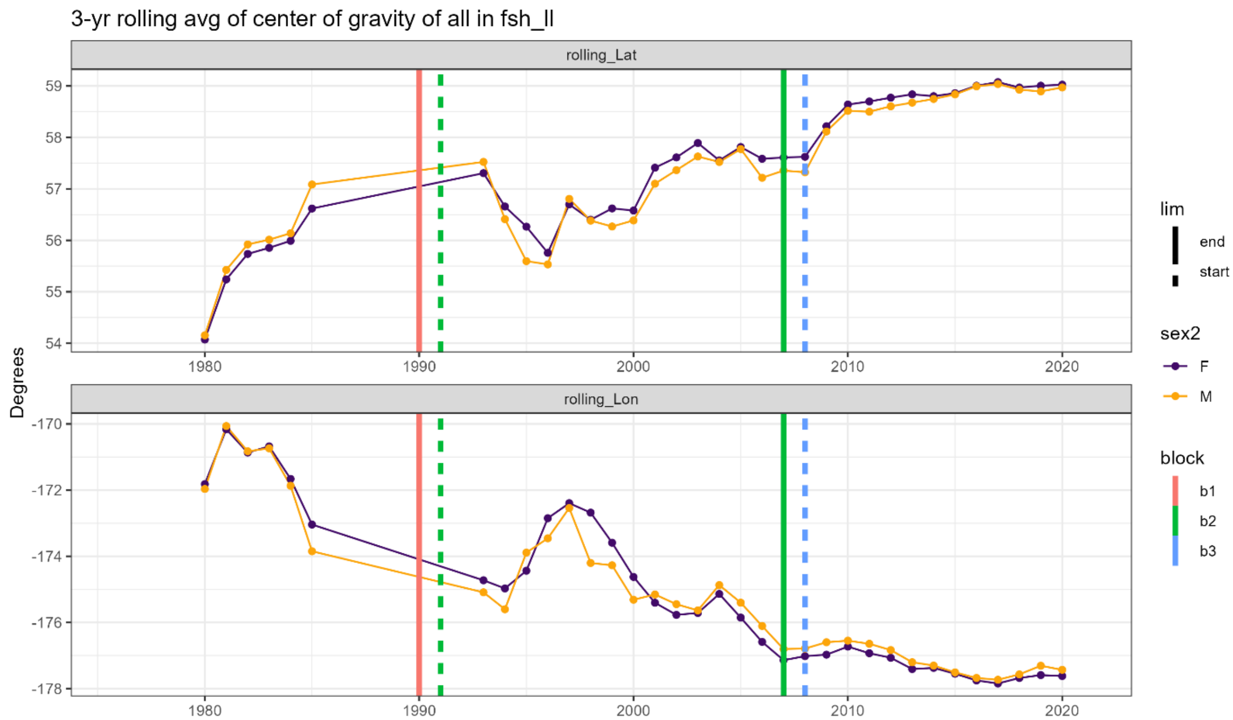


Figure 10. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the longline fishery data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning (dashed) and end (solid) of the time blocks on the selectivity parameters for this fleet.

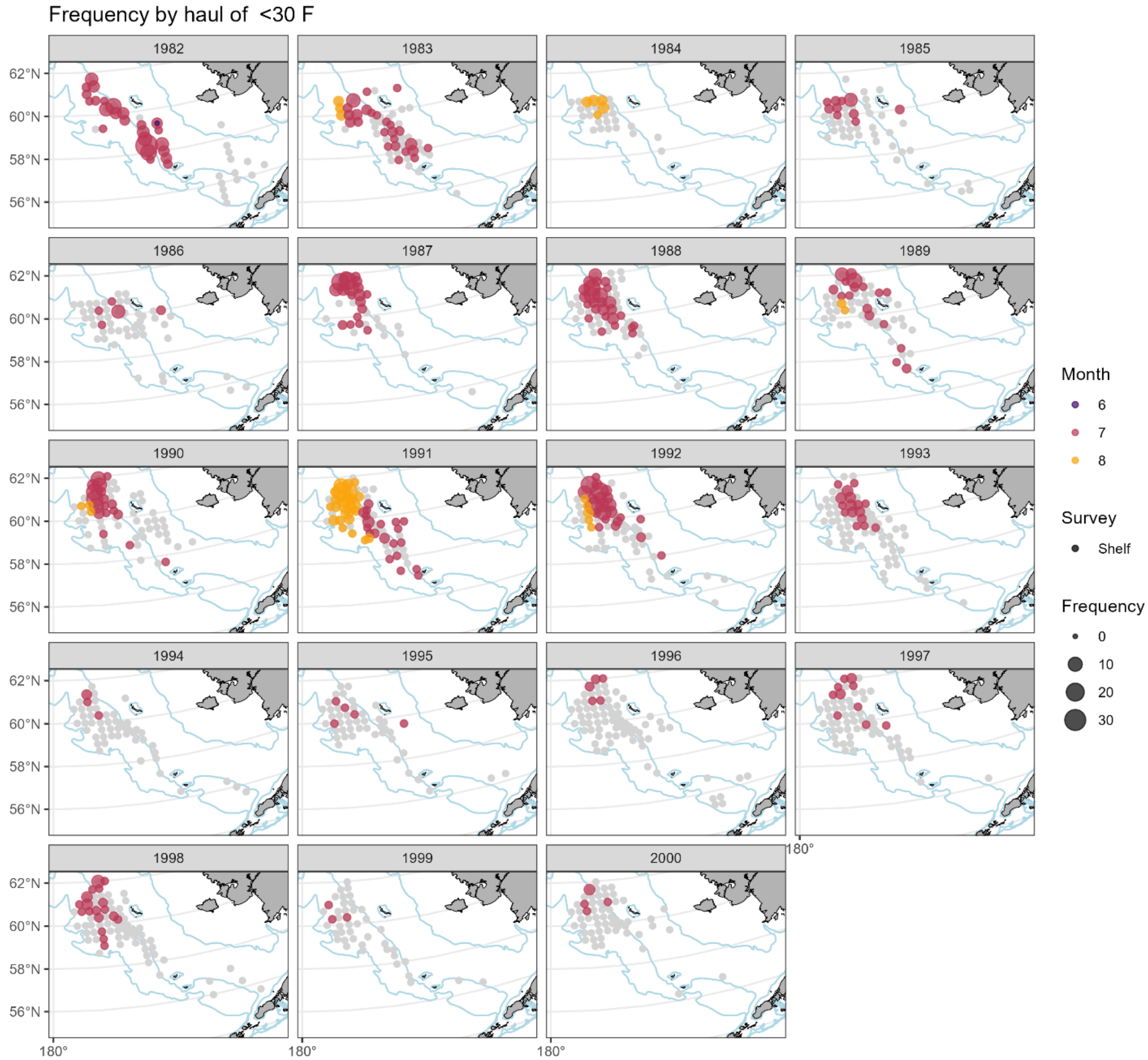


Figure 11. Maps of frequency of encounter of <30 cm female Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf; squares: slope).

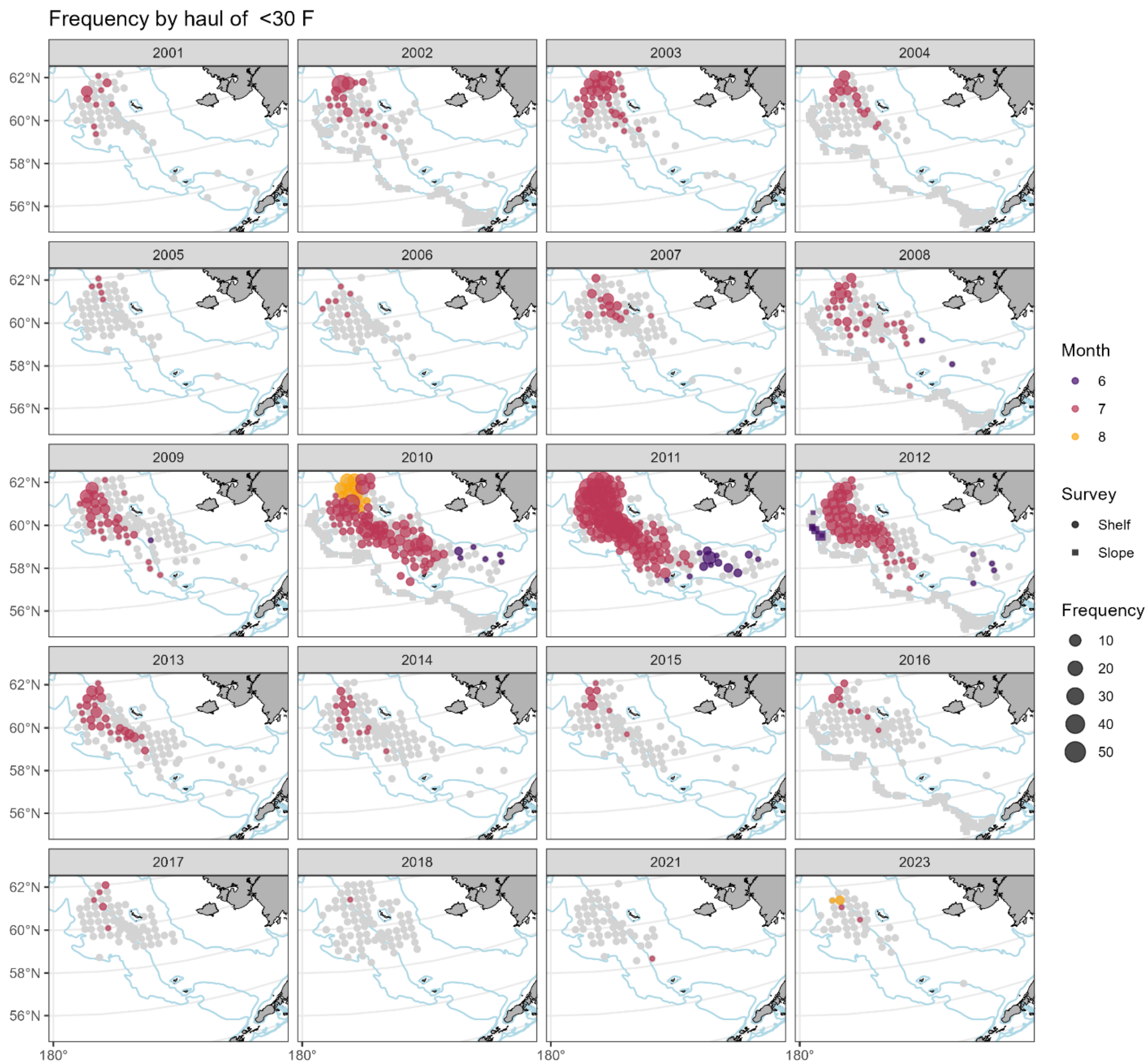


Figure 11. Continued.

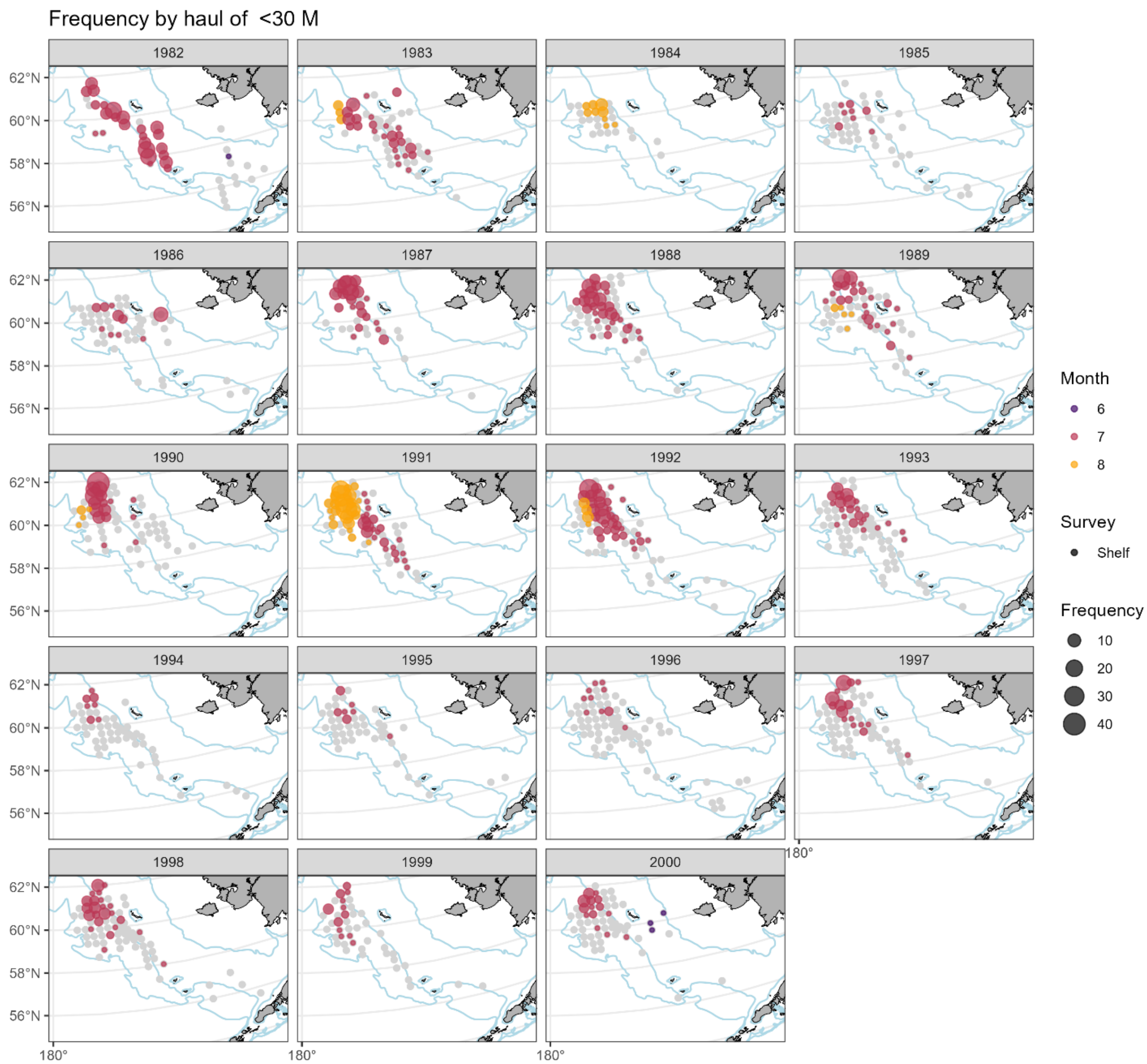


Figure 12. Maps of frequency of encounter of <30 cm male Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf; squares: slope).

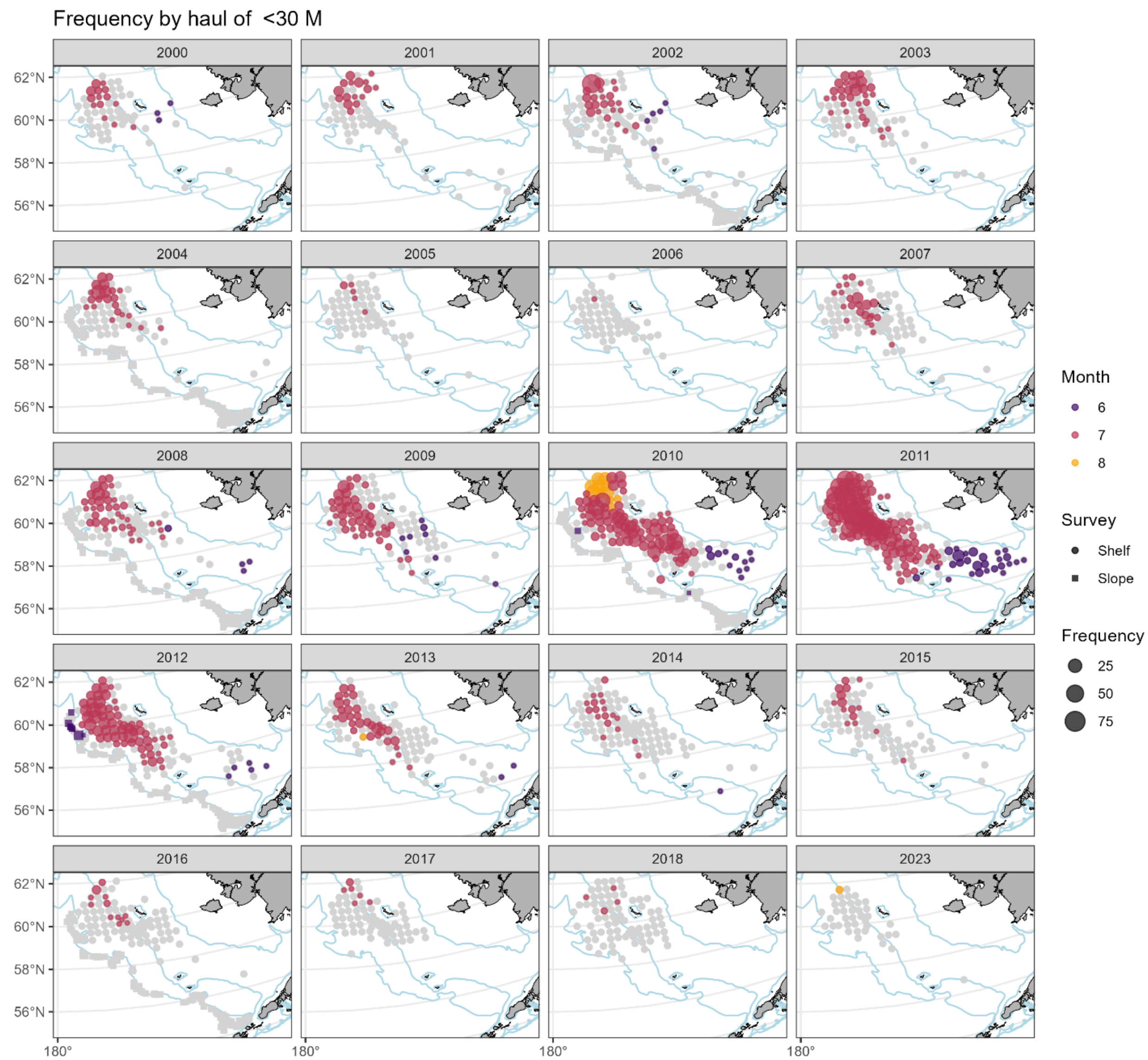


Figure 12 Continued.

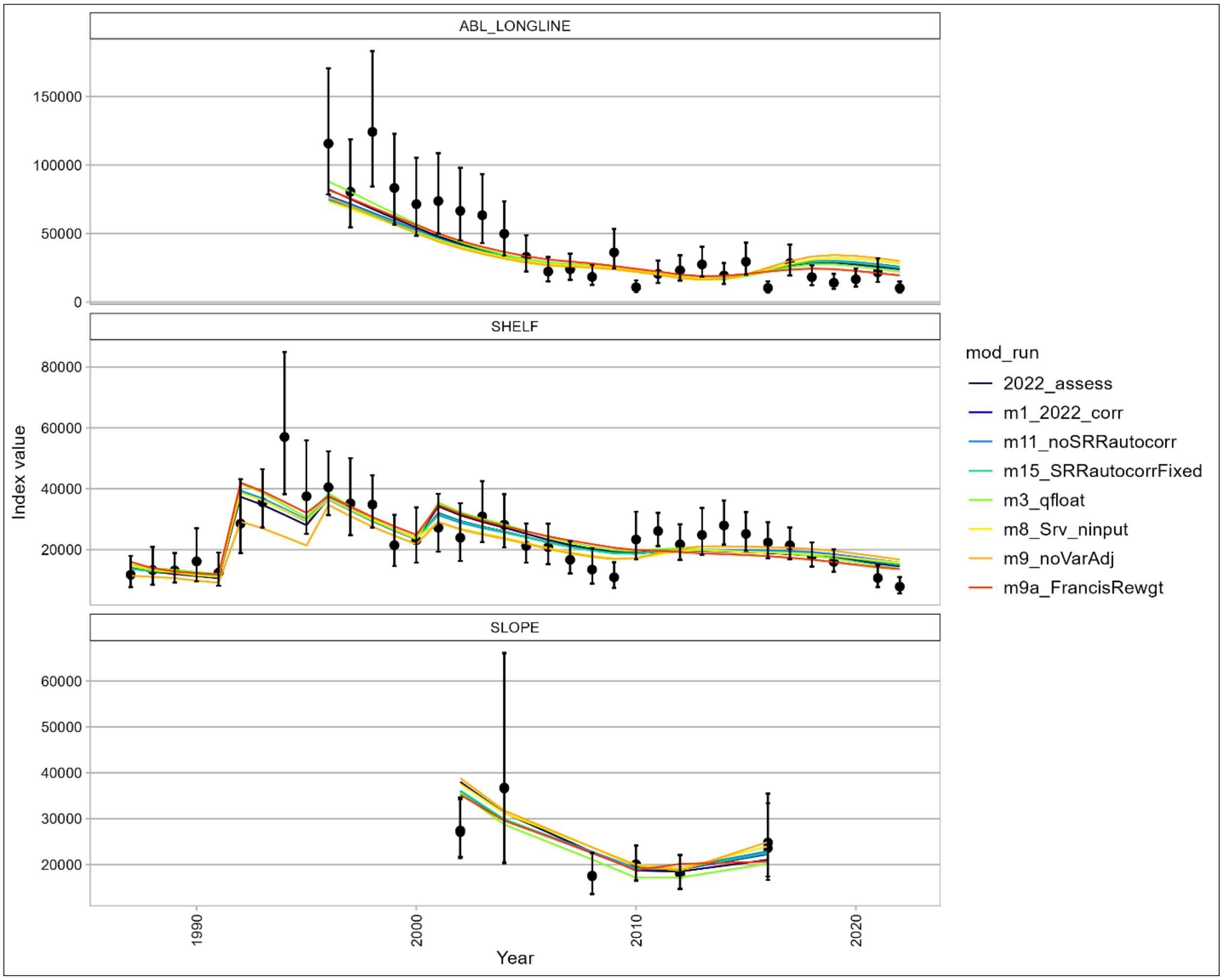
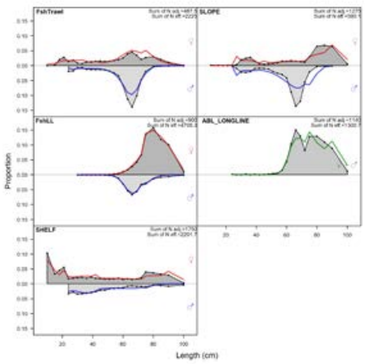
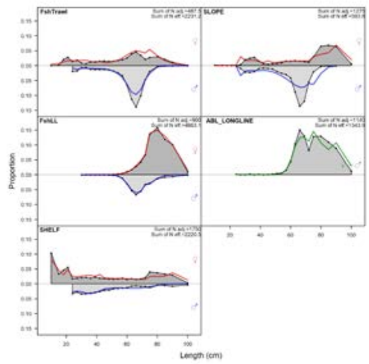


Figure 13. Model fit to AFSC longline survey RPNs and EBS shelf and slope bottom trawl survey biomass from base model sensitivity runs.

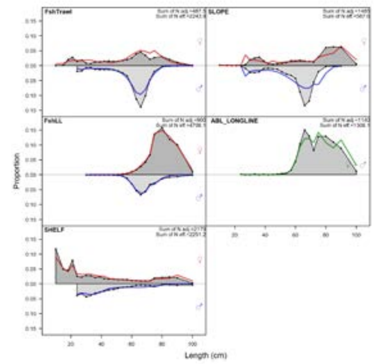
m1



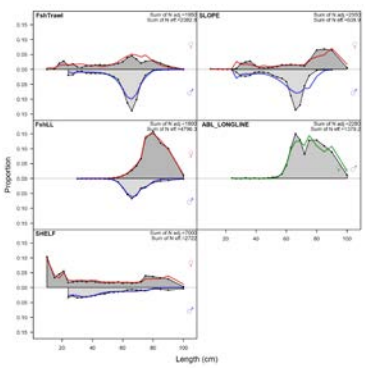
m3



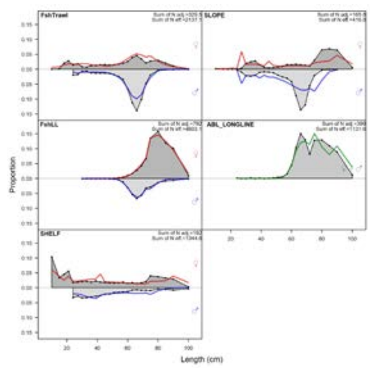
m8



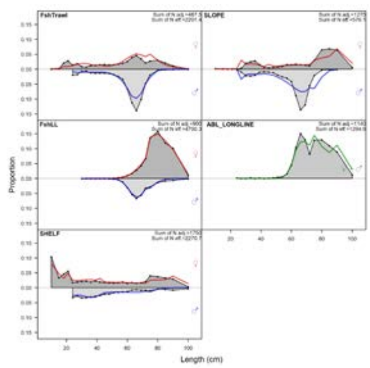
m9



m9a



m11



m15

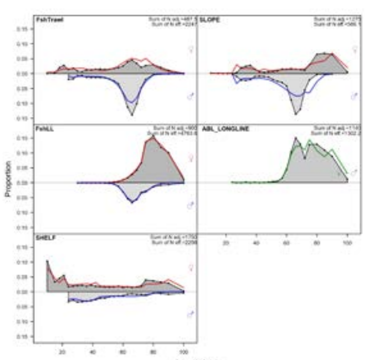
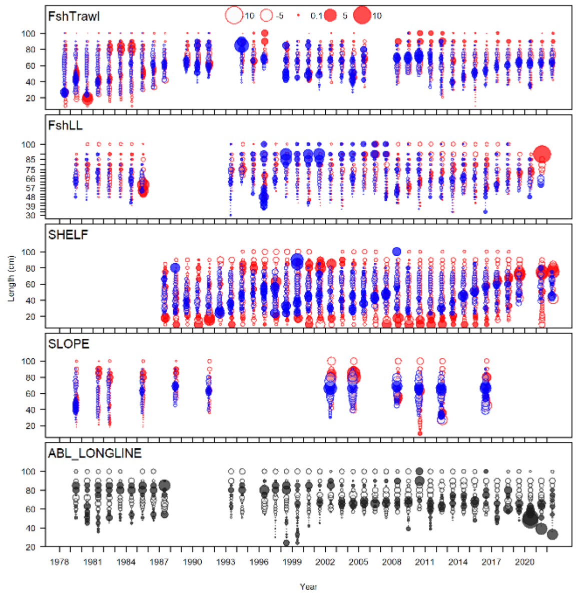
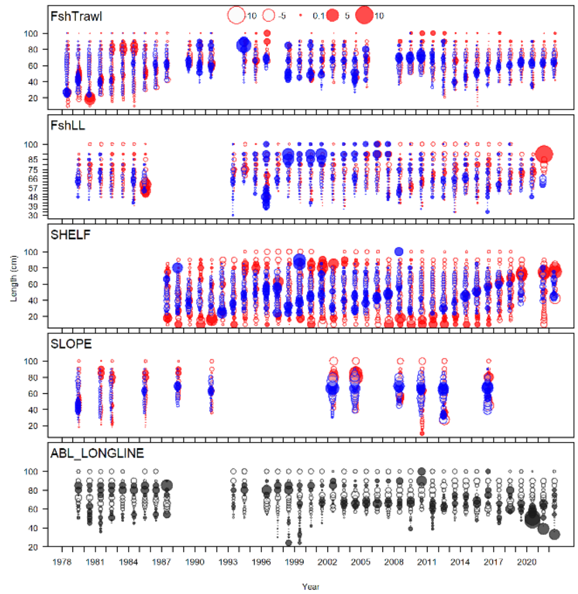


Figure 14. Model fit to fleet specific aggregated length composition data for individual model runs indicated by the alpha-numeric label.

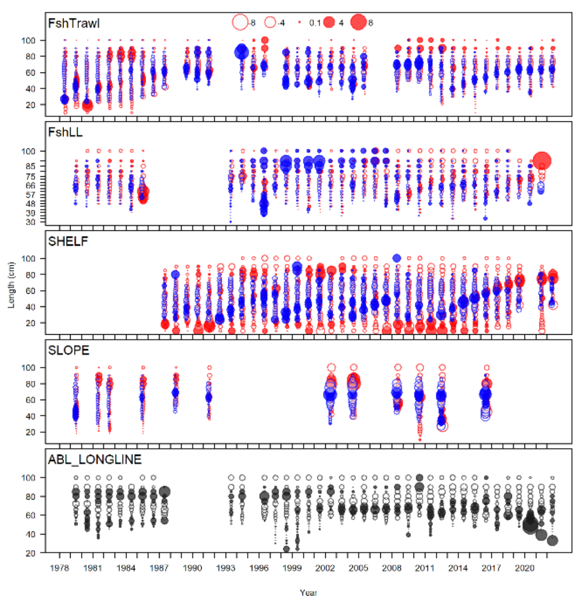
m1



m3



m8



m9

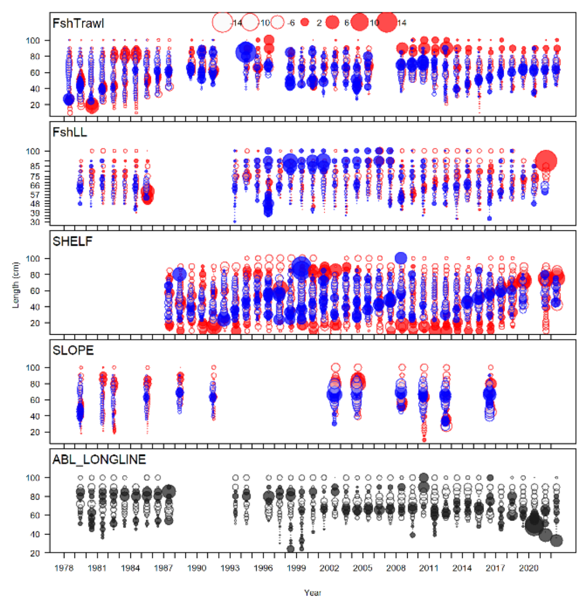
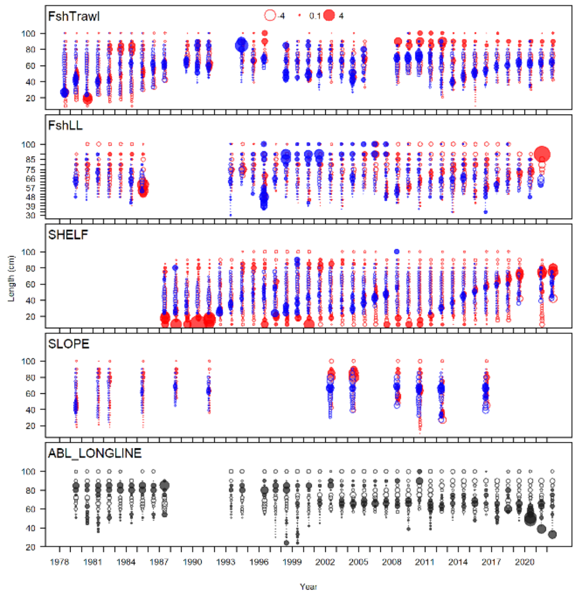
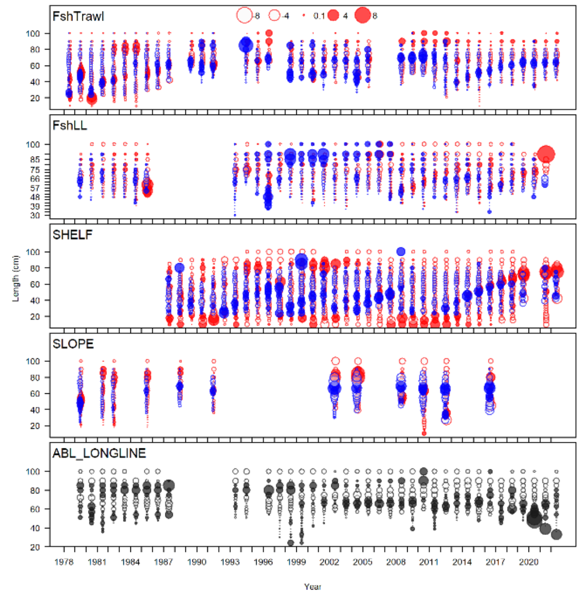


Figure 15. Pearson residuals across fleets for individual model runs indicated by the alpha-numeric label. Blue bubbles represent males, red represents females, and black represents combined sex.

m9a



m11



m15

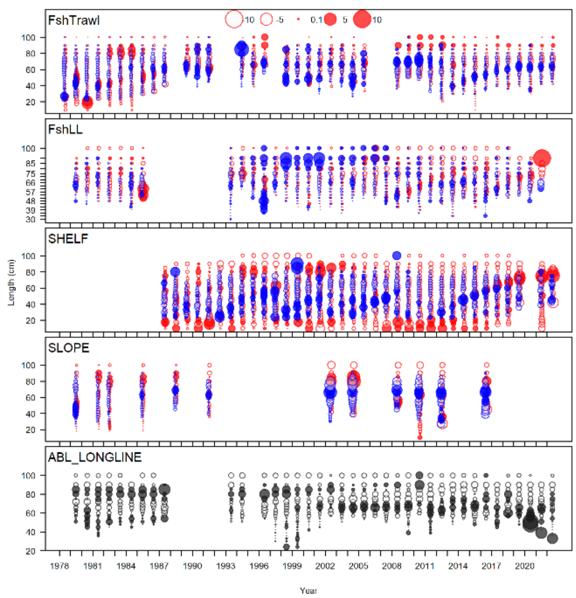


Figure 15 continued

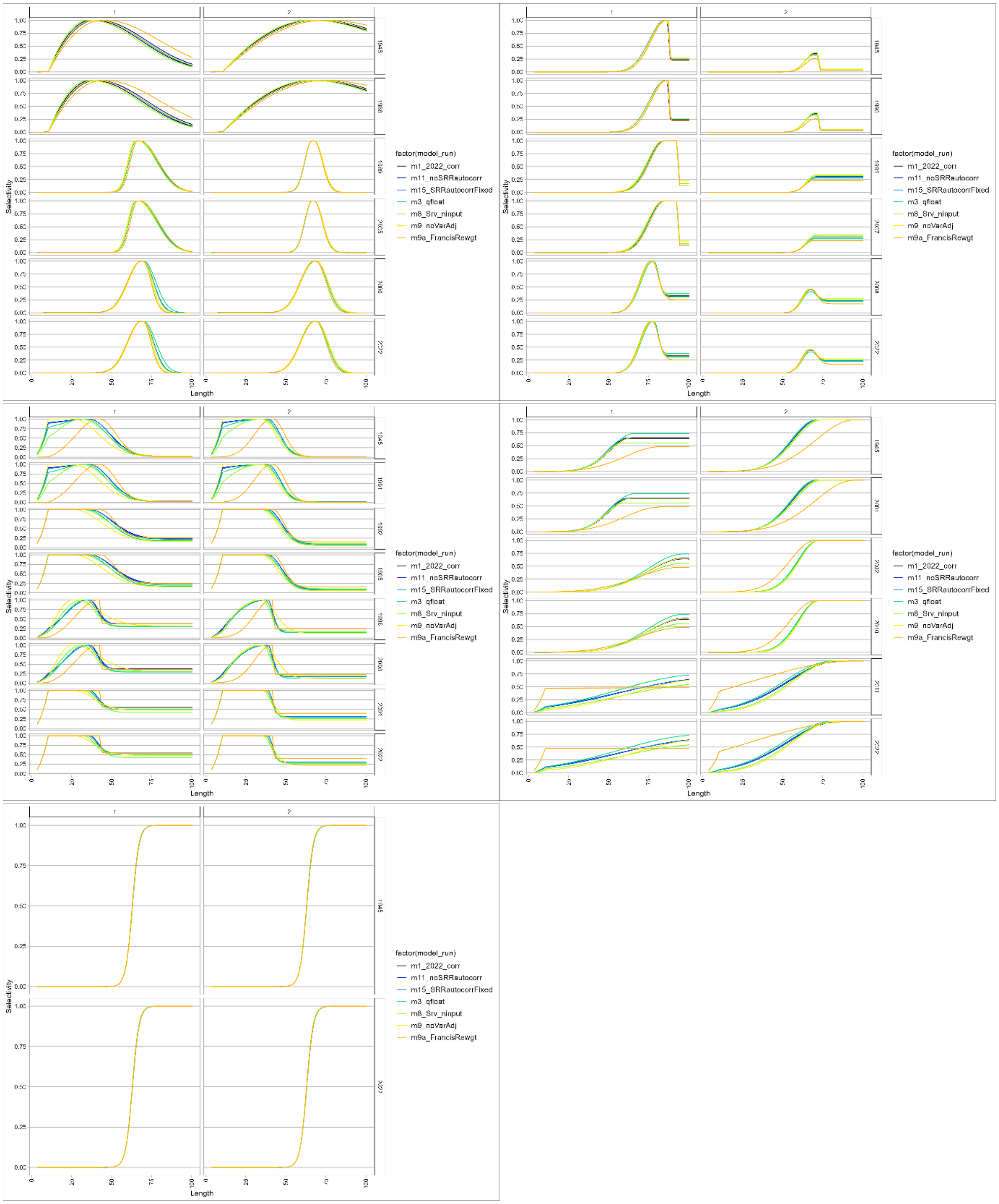


Figure 16. Fleet-specific selectivity for base model sensitivity runs. Trawl fishery (top left), Longline fishery (top right), EBS shelf bottom trawl survey (middle left), EBS slope bottom trawl survey (middle right), and AFSC longline survey (bottom row). Female selectivity is in columns labeled 1 and males are labeled 2.

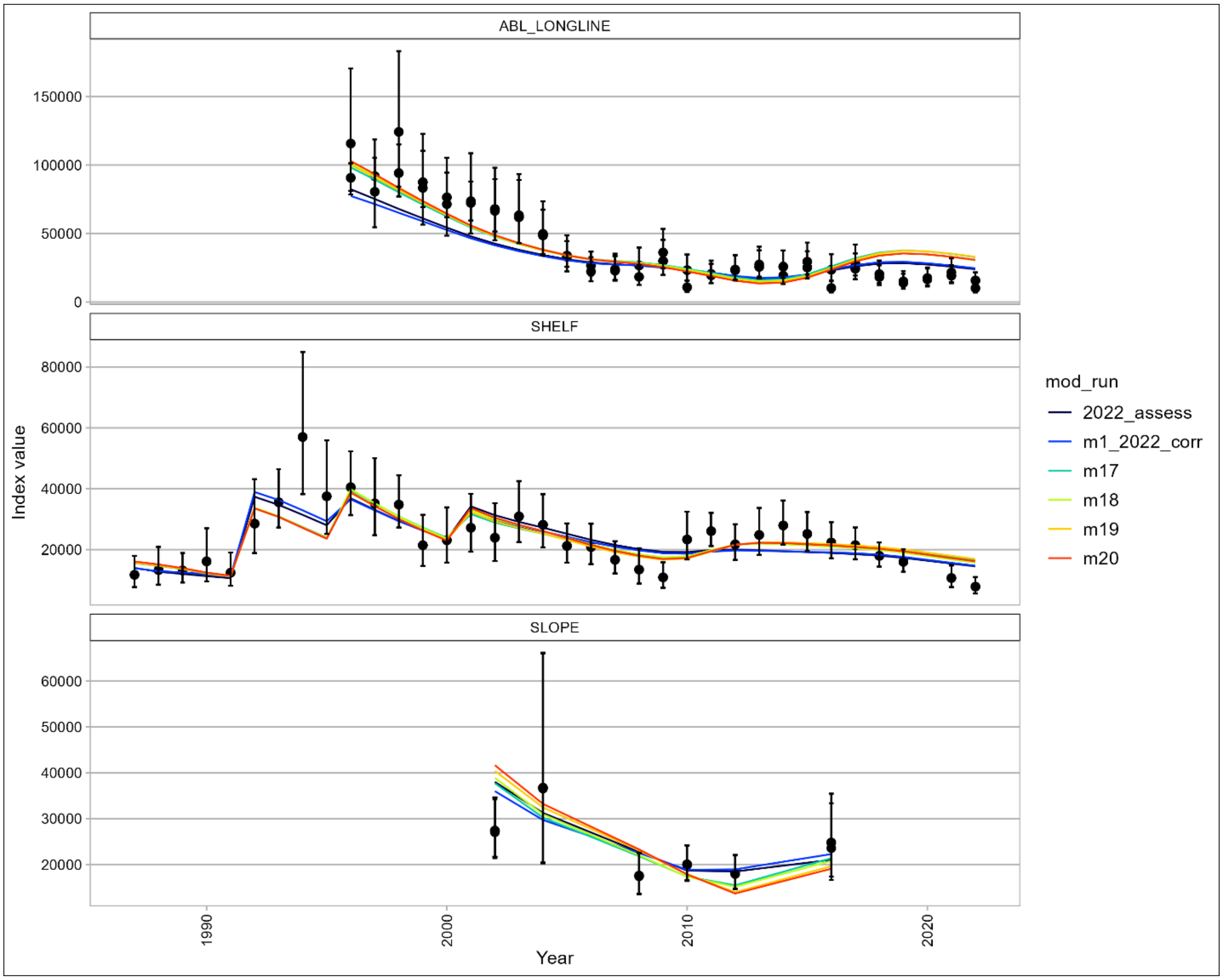
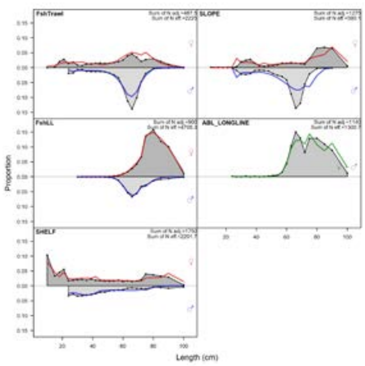
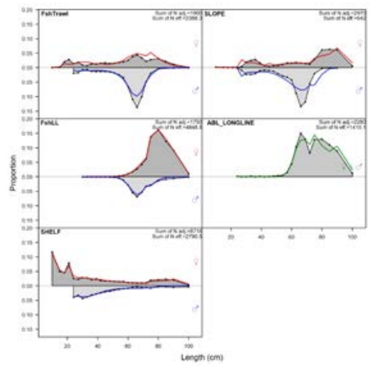


Figure 17. Model fit to AFSC longline survey RPNs and EBS shelf and slope bottom trawl survey biomass from model runs m17 - m20.

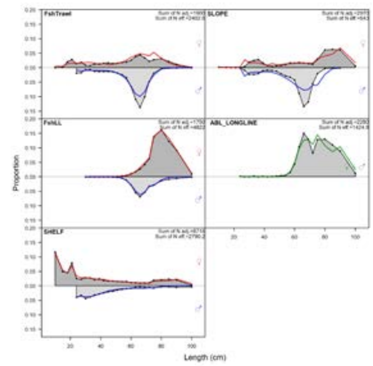
m1



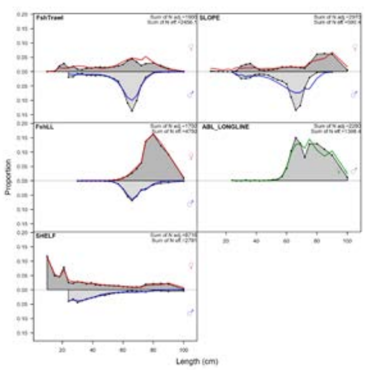
m17



m18



m19



m20

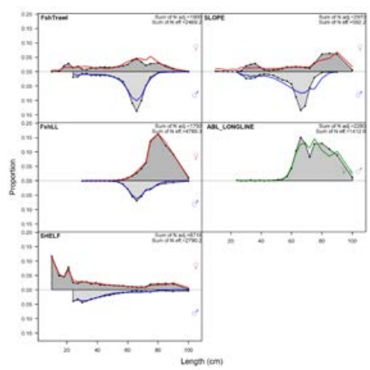
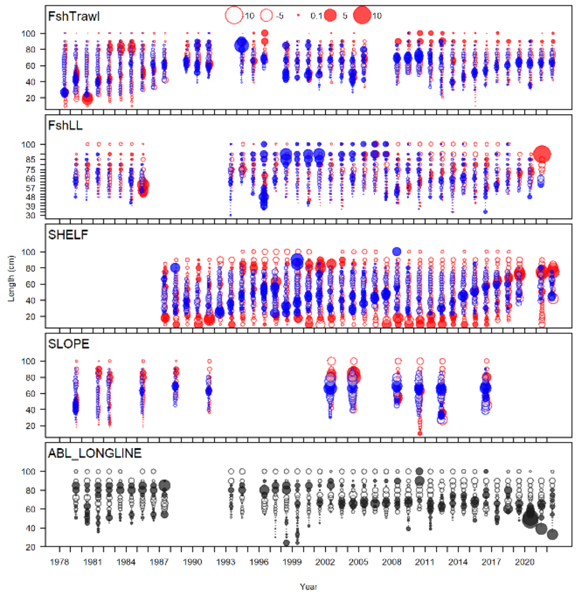
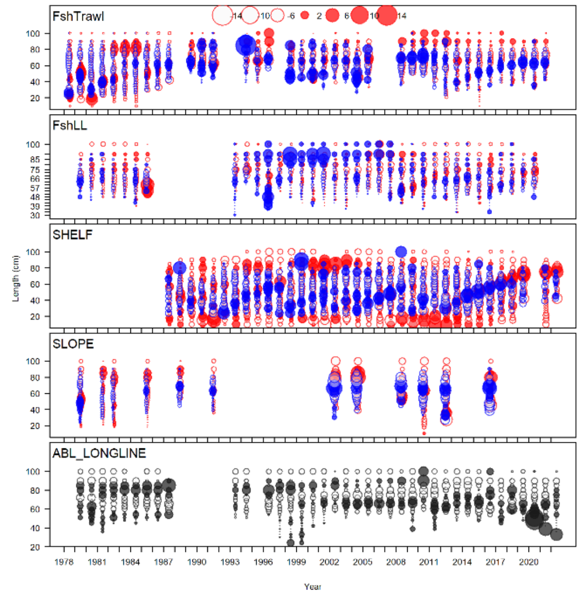


Figure 18. Model fit to fleet specific aggregated length composition data for individual model runs indicated by the alpha-numeric label.

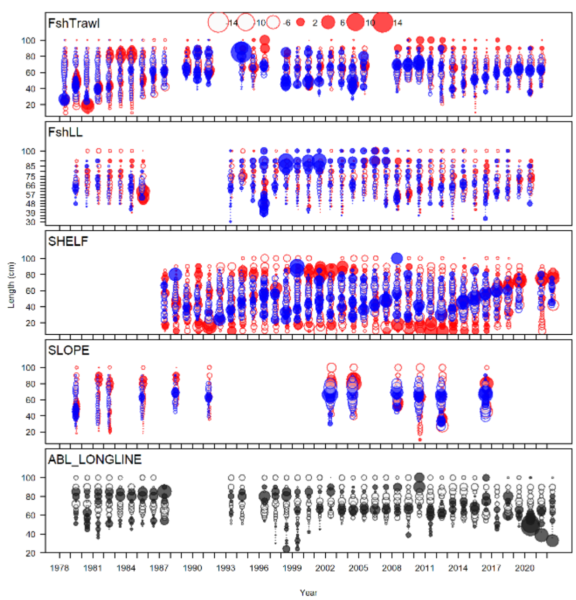
m1



m17



m18



m19

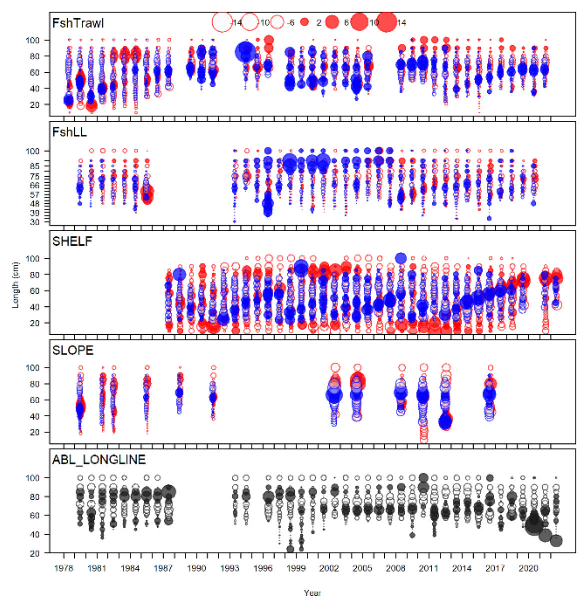


Figure 19. Pearson residuals across fleets for individual model runs indicated by the alpha-numeric label. Blue bubbles represent males, red represents females, and black represents combined sex.

m20

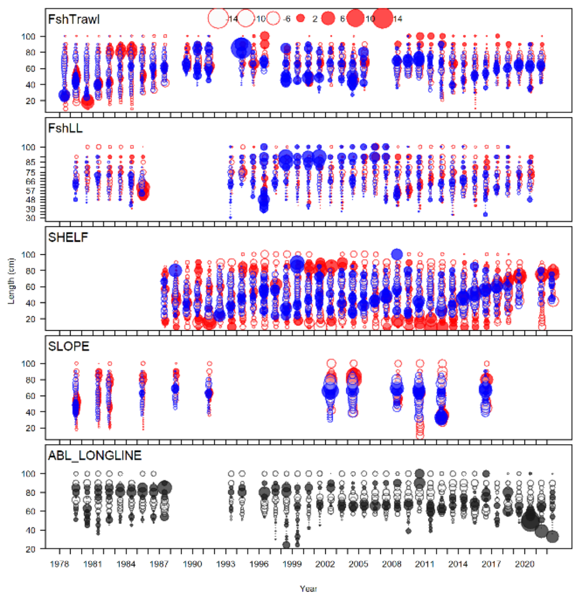


Figure 19 continued

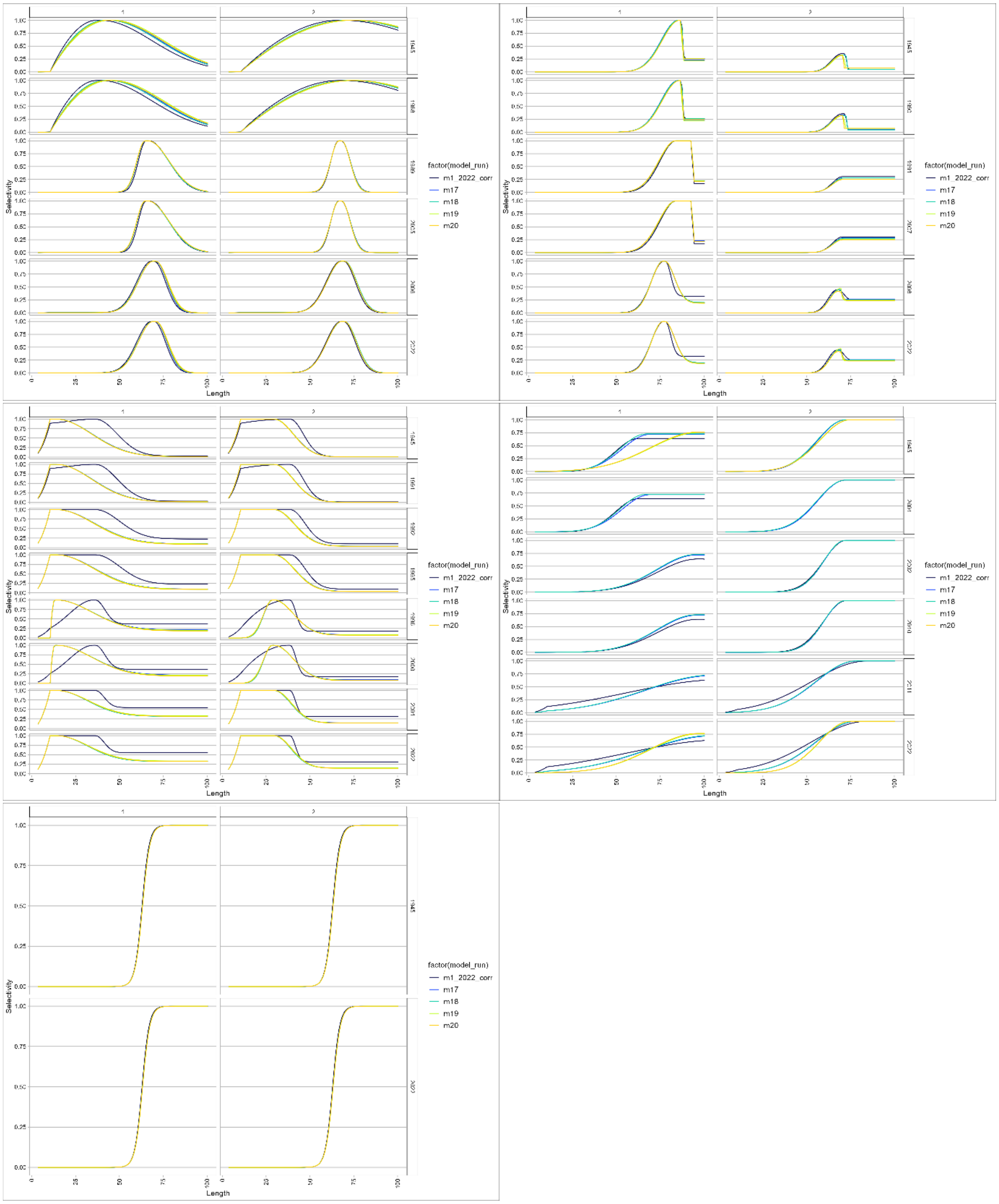
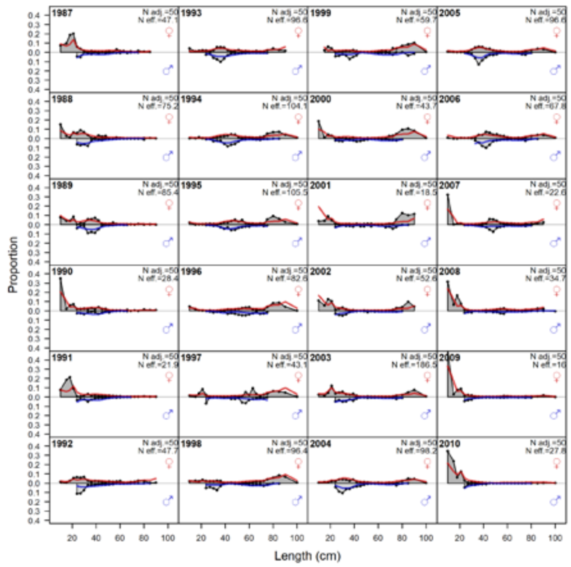
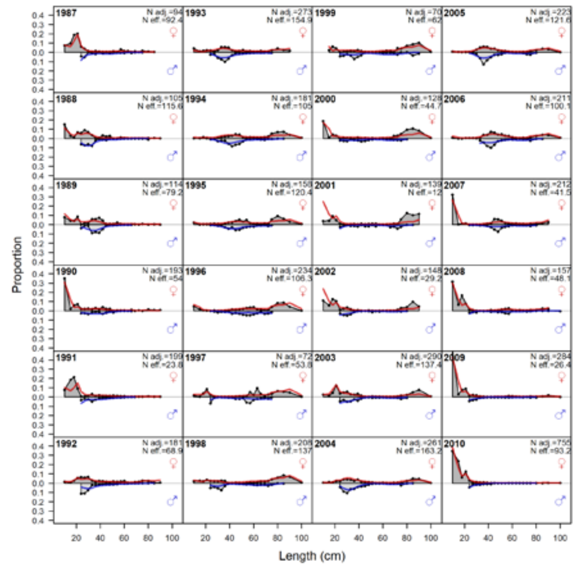


Figure 20. Fleet-specific selectivity for models m17-20. Trawl fishery (top left), Longline fishery (top right), EBS shelf bottom trawl survey (middle left), EBS slope bottom trawl survey (middle right), and AFSC longline survey (bottom row). Female selectivity is in column labeled 1 and males are labeled 2.

m1



m18



m20

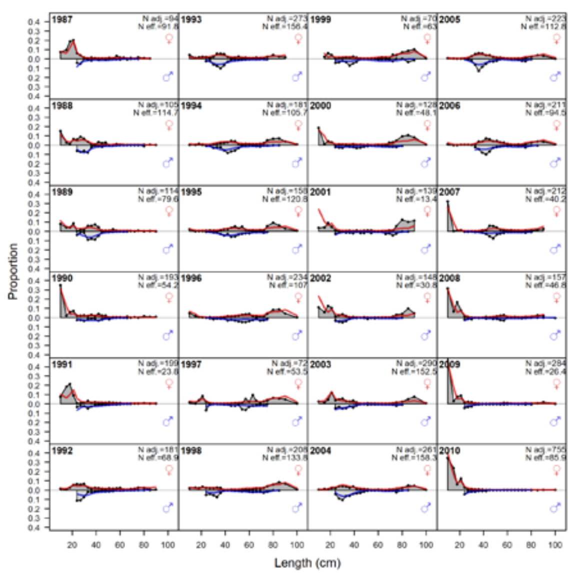


Figure 21. Model fits to the annual EBS shelf bottom trawl survey length composition data for models m1, m18, and m20.

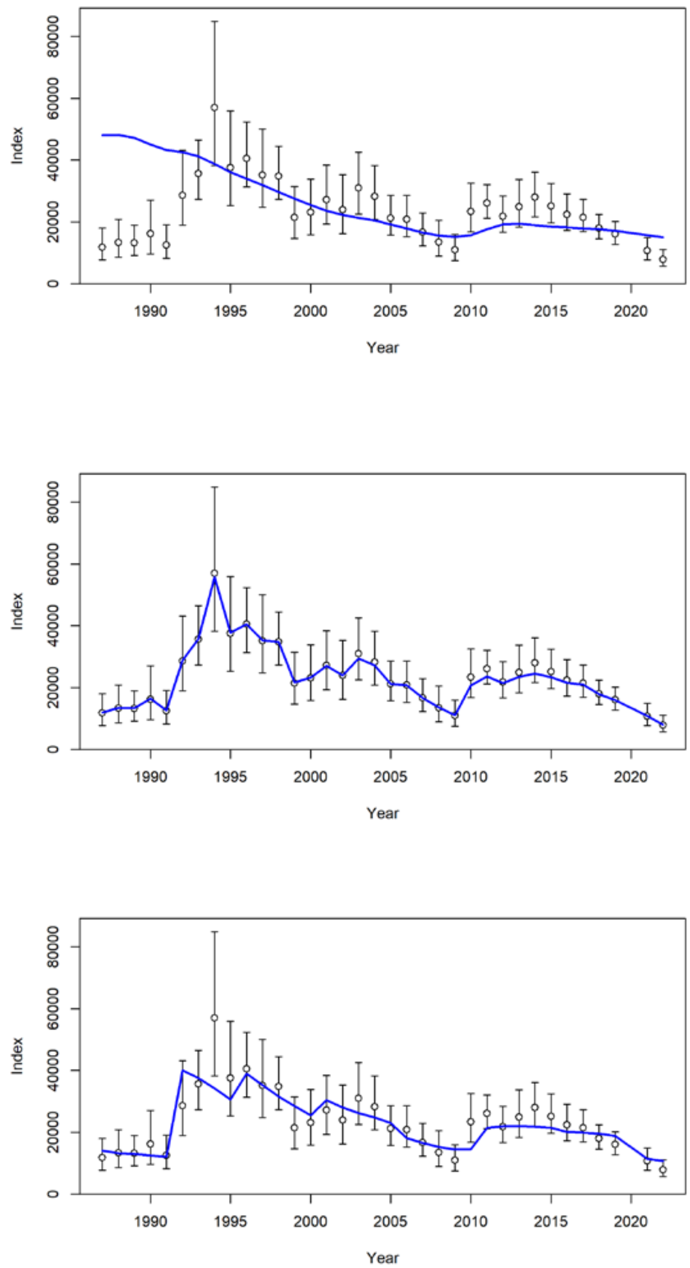


Figure 22. Fit to the EBS shelf bottom trawl survey when time blocks are removed (top), catchability is time-varying (middle), and ~5 year time blocks are implemented throughout the time series (bottom).

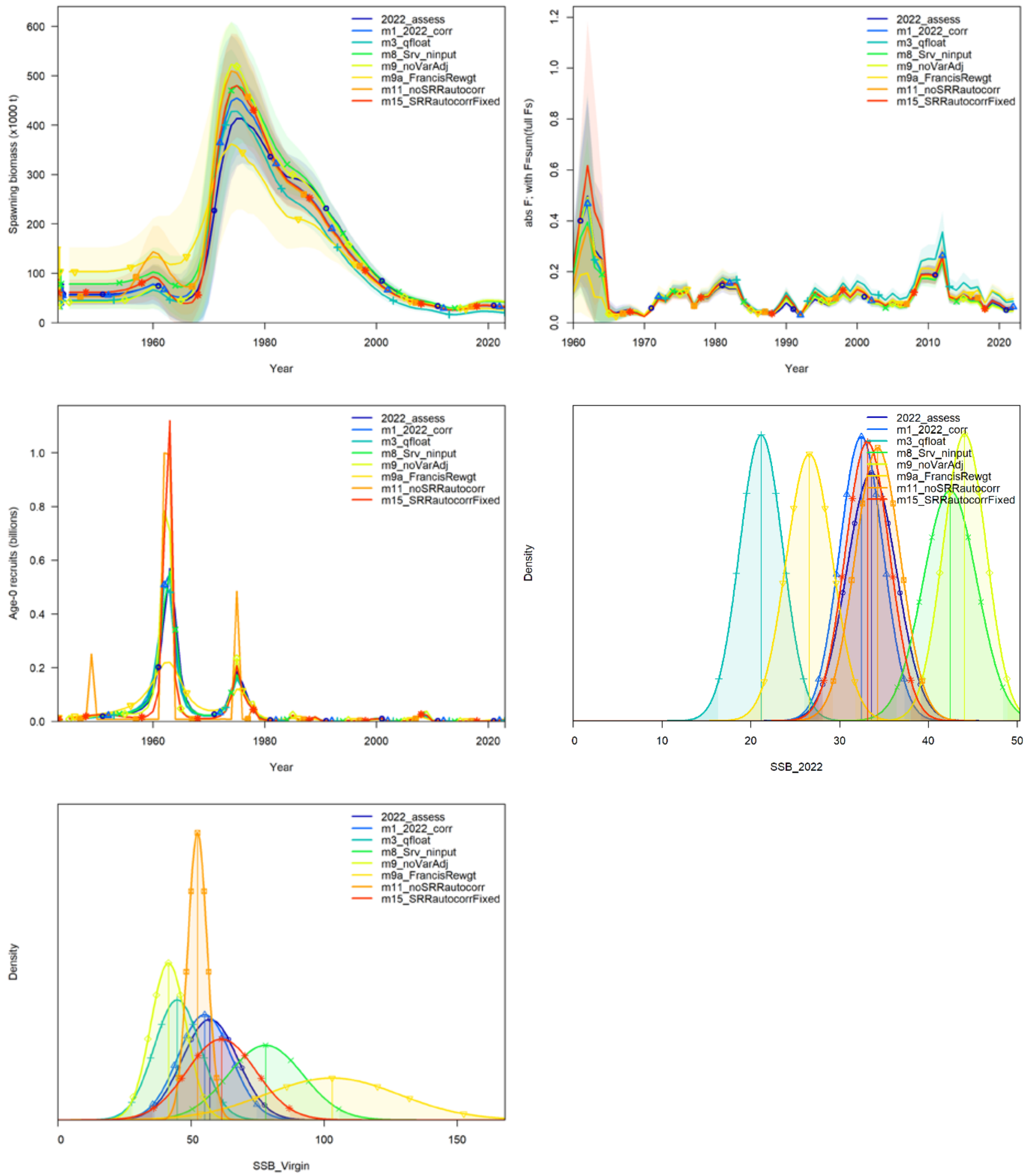


Figure 23. Comparison of SSB (top left), annual fishing mortality (top right), age-0 recruits (center left), SSB in 2022 (center right), and unfished SSB(bottom left) from the base model sensitivity runs.

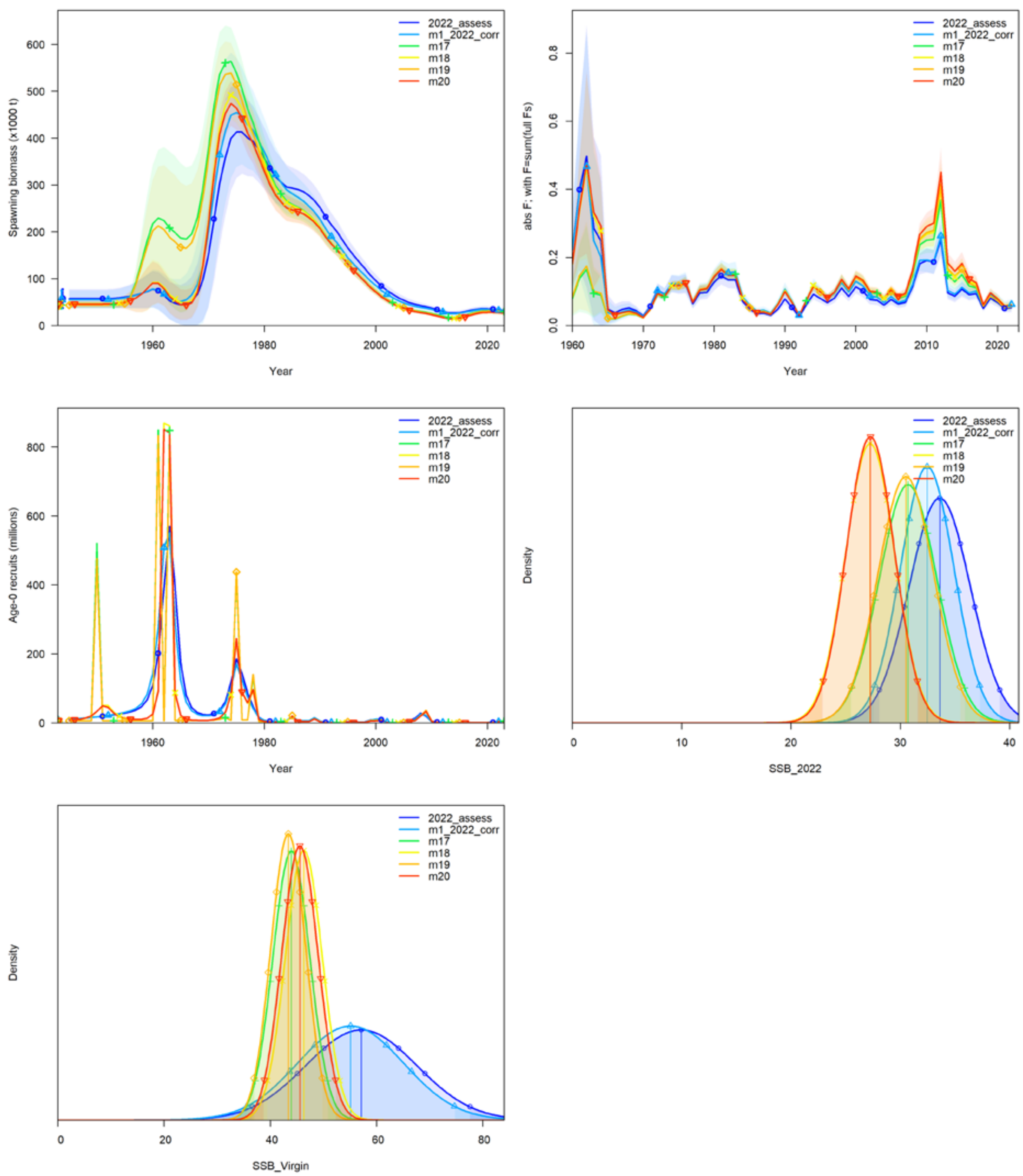


Figure 24. Comparison of SSB (top left), annual fishing mortality (top right), age-0 recruits (center left), SSB in 2022 (center right), and unfished SSB(bottom left). Update models.

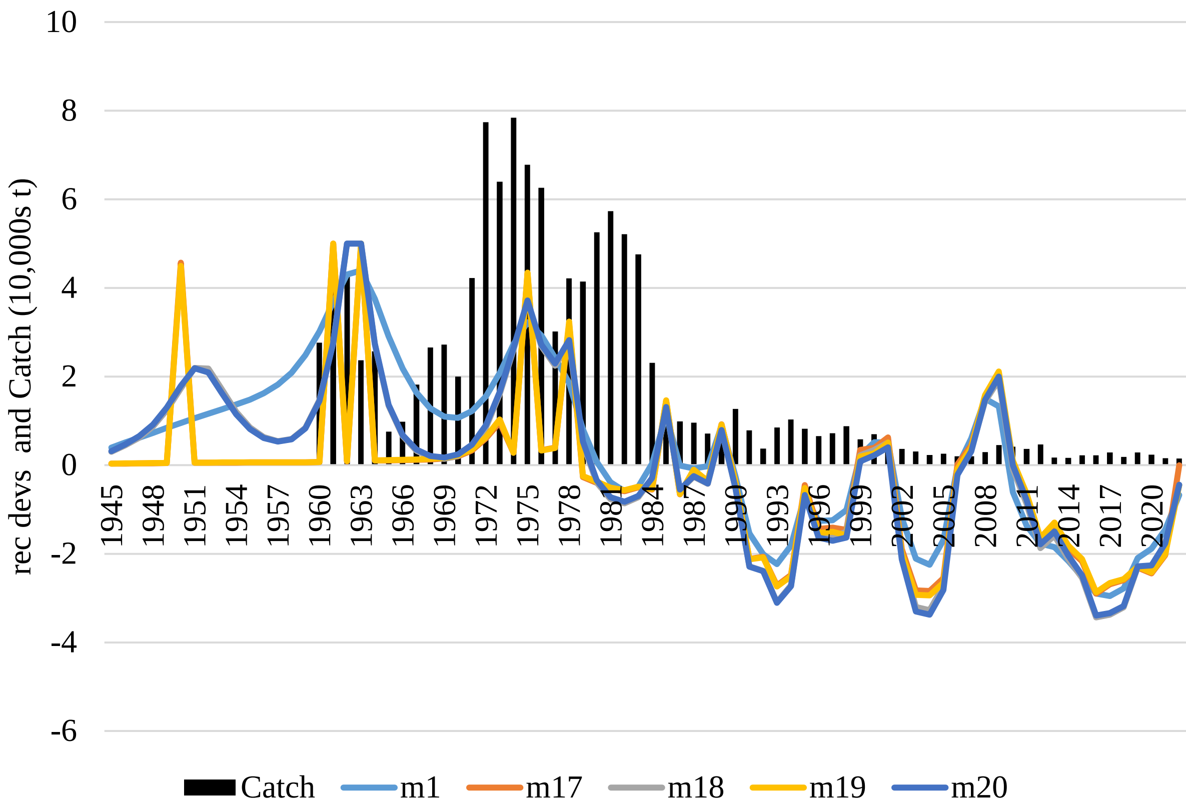


Figure 25. Recruitment deviations and total catch in (10,000s t).

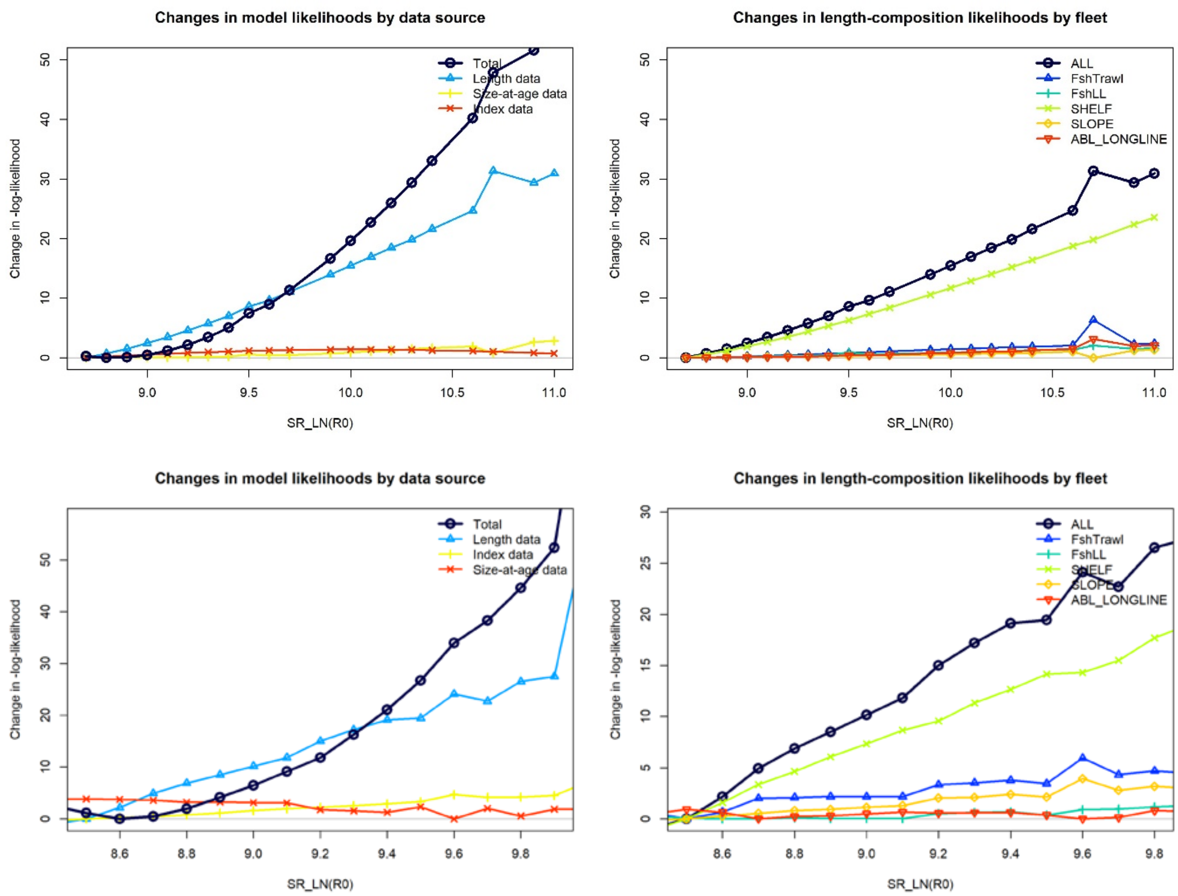


Figure 26. R_0 likelihood profile, total likelihood plot and fleet-specific length composition likelihood plots, for model m1 (top row), m20 (bottom row).

m1 m18

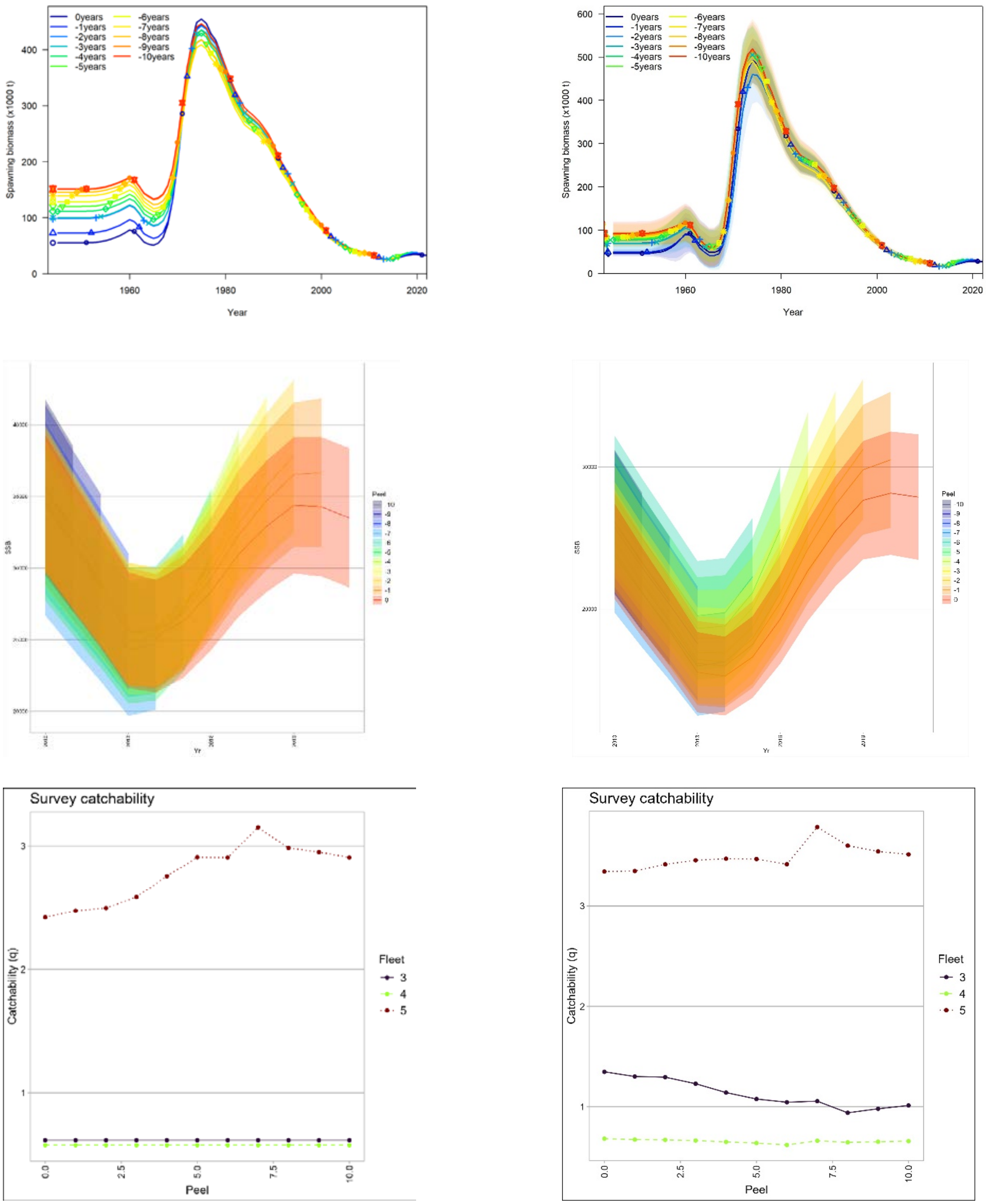
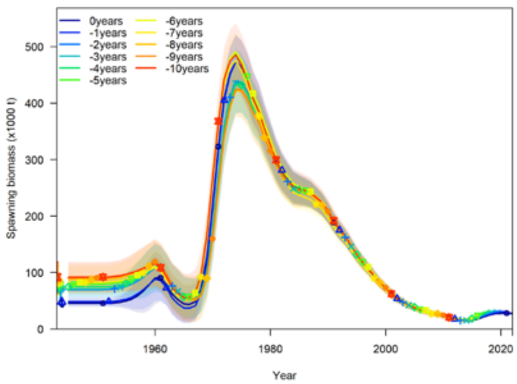
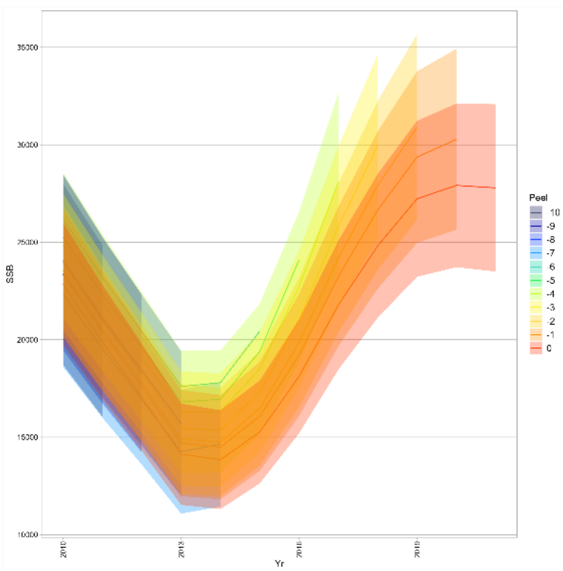


Figure 27. Retrospective plots of SSB (full time series and last 20 years) and change in catchability. Models are indicated by the alpha-numeric label. The EBS shelf bottom trawl survey is fleet 3, the EBS slope bottom trawl survey is fleet 4, and the AFSC longline survey is fleet 5.

m20





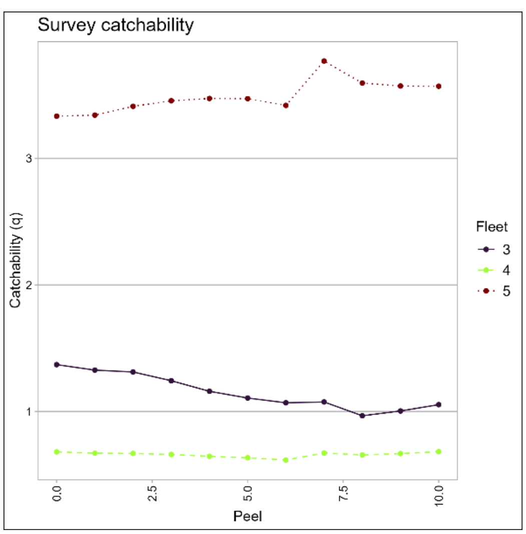


Figure 27 continued.

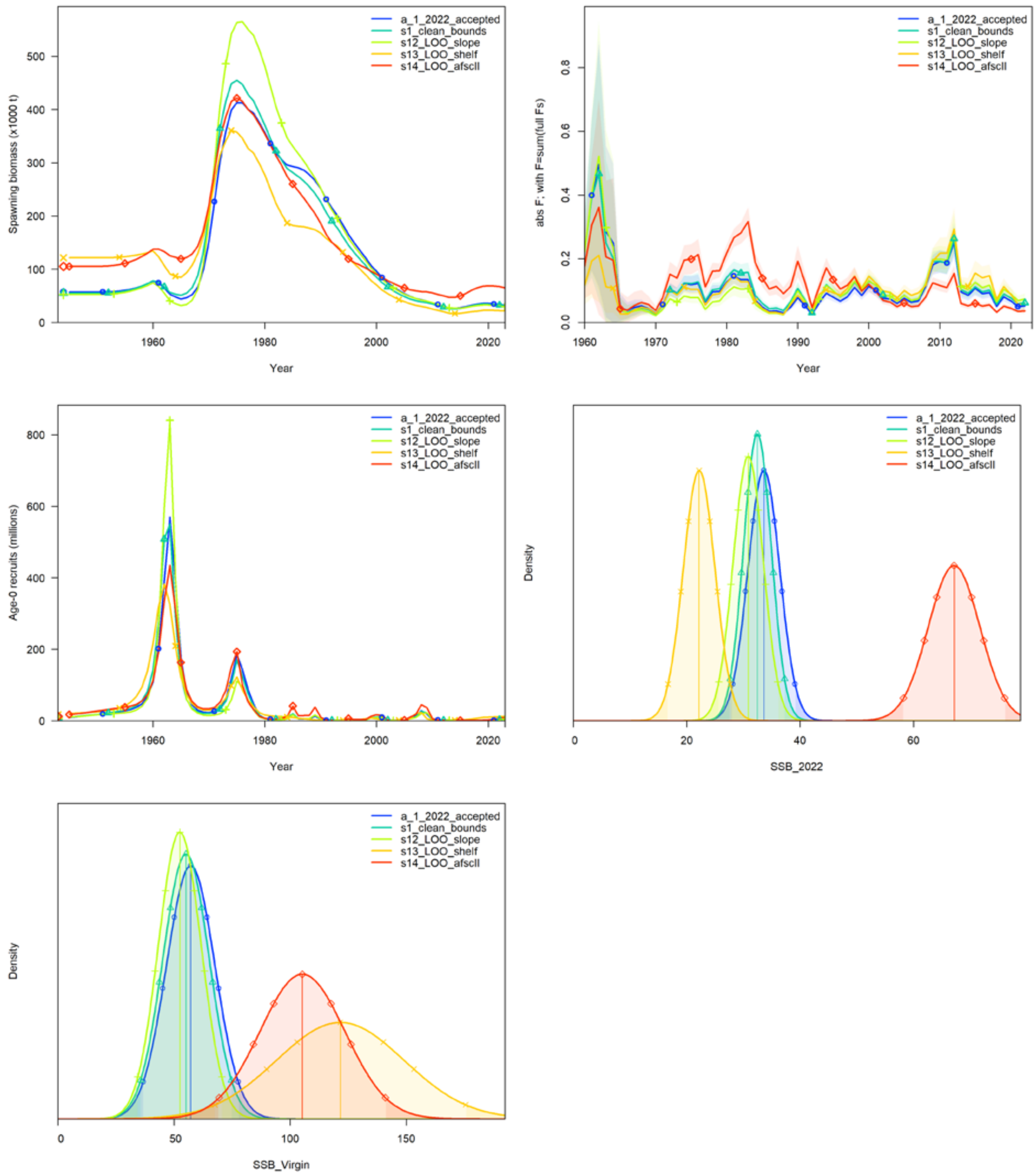


Figure 28. Leave one out analysis for model m1.

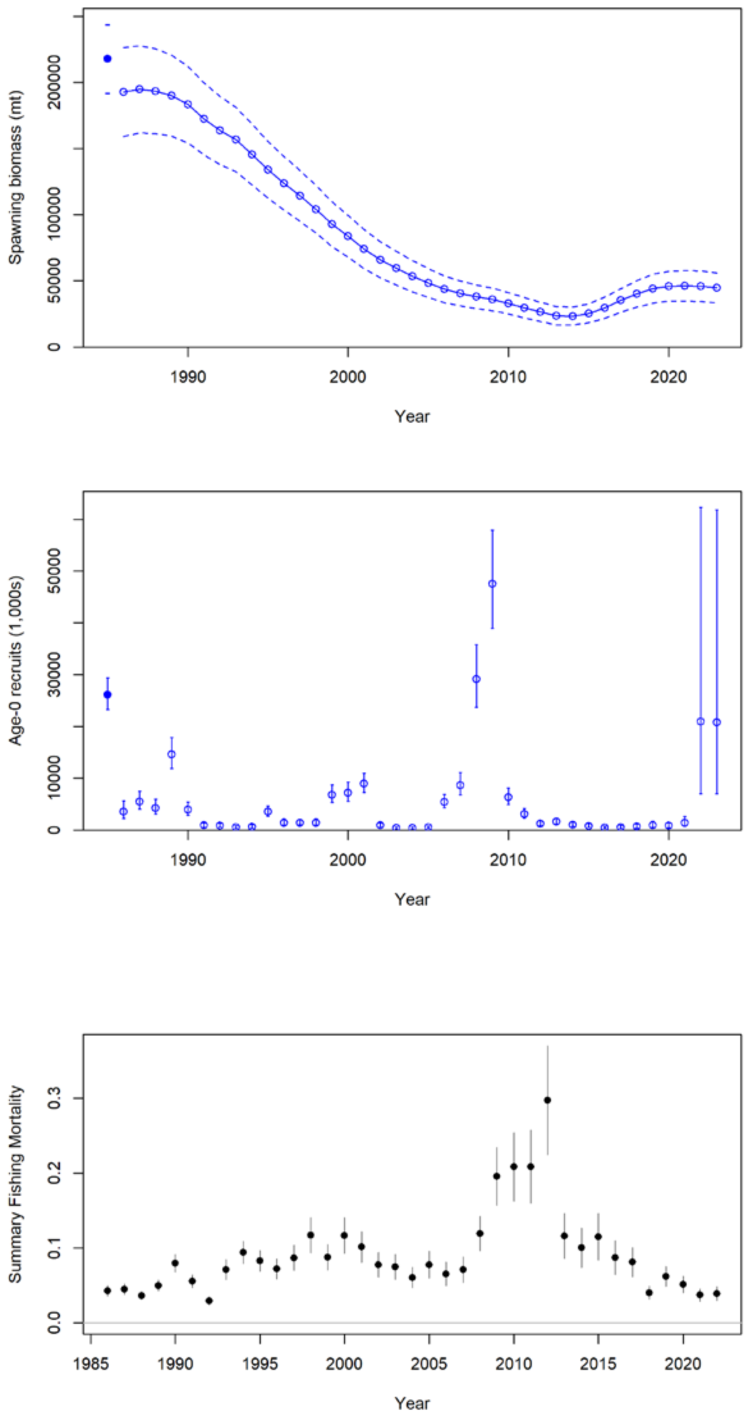


Figure 29. SSB, age-0 recruits, and annual fishing mortality from an experimental model run starting in 1986.

Appendix

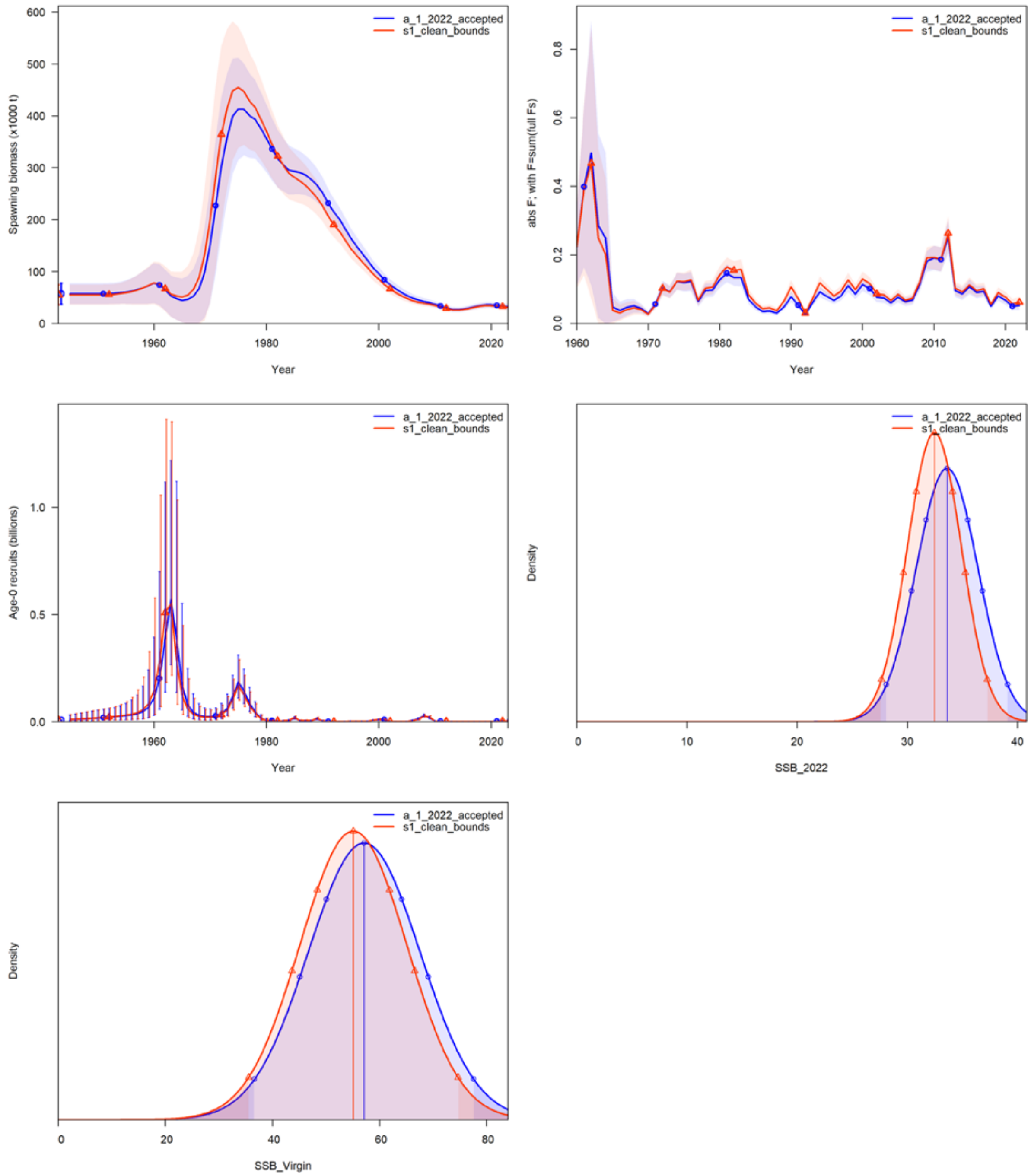


Figure A. 1 Comparison of SSB (top left), annual fishing mortality (top right), age-0 recruits (center left), SSB in 2022 (center right), and unfished SSB(bottom left) from the last accepted model (blue) and the model with corrected slope length distributions (red).

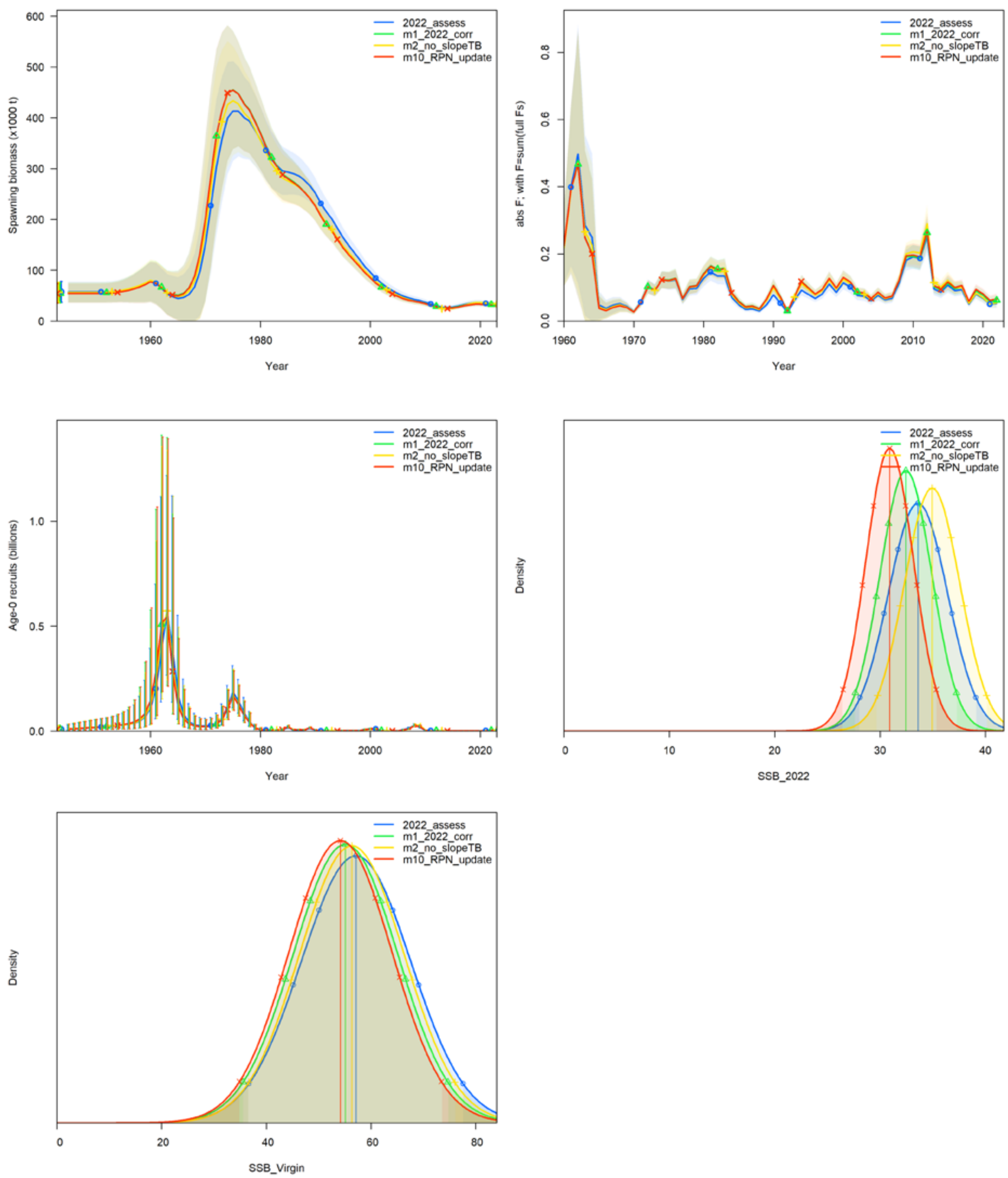

2022_assess
m1_2022_corr
m2_no_slopeTB
m10_RPN_update
Spawning biomass (x1000 t)
Year
abs F; with F=sum(full Fs)
Age-0 recruits (billions)
Density
SSB_2022
SSB_Virgin

Figure A. 2