5. Assessment of the Greenland turbot stock in the Bering Sea and Aleutian Islands

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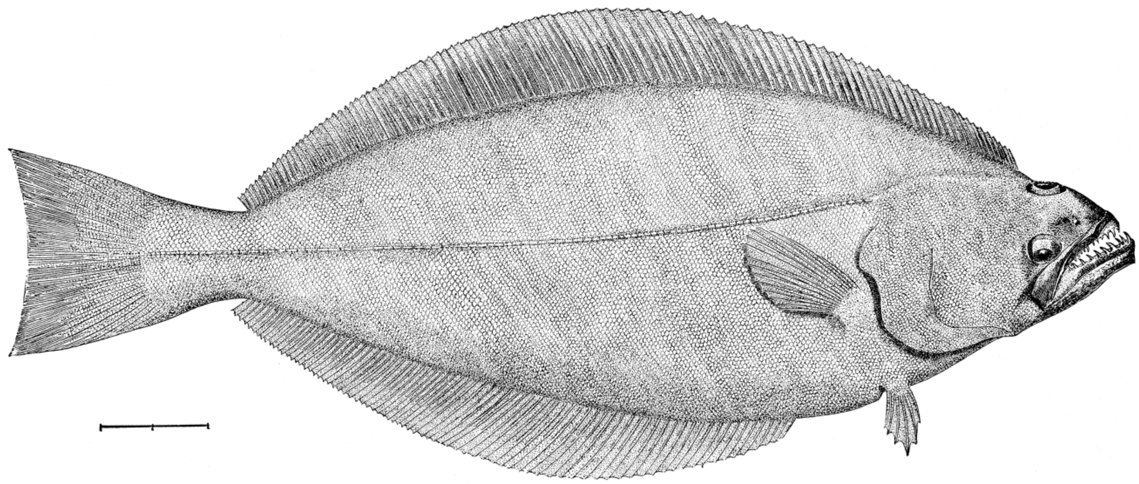

THE GREENLAND TURBOT.

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Executive Summary

Summary of Changes in Assessment Inputs

New data for the assessment included the 2023 and 2024 NMFS shelf bottom trawl survey biomass estimates and size compositions and the Alaska Fisheries Science Center (AFSC) longline survey relative population numbers and size compositions for 2023. Length at age data from the 2022 and 2023 NMFS shelf bottom trawl survey were also available and were used in this assessment. Fishery catch estimates were updated and include a preliminary estimate for 2024. Data on fishery size composition from 2023 and 2024 from the trawl fishery were also included in the model.

Summary of Changes in Assessment Model

The authors recommended Model 16.4c for management, which is the recommended and approved model used in the last full assessment; therefore, changes were not made to the model and this is considered an update operational assessment. Alternative models were explored and are discussed in the chapter. The authors did not recommend any of the alternative models because of concerns about model stability and an increase in the retrospective pattern.

Quantity	As estimated or *specified last* year for: 2024	2025	As estimated or *recommended this* year* for: 2025	2026
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3a	3a	3a	3a
Projected total (age 1+)	50,278	47,854	37,615	35,877
Female spawning biomass	31,653	29,439	23,999	22,061
Projected				
$B_{100\%}$	67,647	67,647	58,812	58,812
$B_{40\%}$	27,058	27,058	23,525	23,525
$B_{35\%}$	23,676	23,676	20,584	20,584
F_{OFL}	0.18	0.18	0.20	0.20
$maxF_{ABC}$	0.15	0.15	0.17	0.17
F_{ABC}	0.15	0.15	0.15	0.15
OFL (t)	3,705	3,185	2,598	2,059
maxABC (t)	3,188	2,740	2,237	1,771
ABC (t)	3,188	2,740	2,013	1,594
	As determined *last* year for:		As determined *this* year for:	
Status	2022	2023	2023	2024
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

** Projections are based on model 16.4c and preliminary catches of 1,143 t was used in place of maximum permissible ABC for 2025 and 2026 to provide OFL and maximum ABC estimates. The preliminary catch for 2025 and 2026 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2019-2023), 36%, and the 2024 TAC, 3,188 t. The authors recommended ABC be reduced from maximum ABC by 10%, which is reflected in the table.*

Responses to Comments

Responses to SSC and Plan Team Comments on Assessments in General

"*The Team recommended as a best practice that appendices be linked in the front of the document (as with the sablefish assessment) to allow for an easier review of the appendices.*" (Plan Team, November 2023)

Combined recommendations on the risk table:

"The SSC continues to support a three-category risk table with categories normal, increased, and extreme, and requests that the category descriptions be revised to cover the range covered by the original table."

"The SSC reiterates that only fishery performance indicators that provide some inference regarding biological status of the stock should be used."

"The SSC recommends that the risk tables consider potential future risks when these can be anticipated."

"When risk scores are reported, the SSC requests that a brief justification for each score be provided, even when that score indicates no elevated risk."

(SSC, December 2023)

A risk table is presented in the Harvest Recommendations. After completing this exercise, we suggest that a reduction in maximum ABC may be warranted given uncertainty in stock status, future recruitment, and declining catch with a declining population.

"*The SSC requests that when Bayesian model output is reported, basic convergence diagnostics are also presented.*" (SSC, December 2023)

Responses to SSC and Plan Team Comments Specific to this Assessment

"The SSC suggests that it might be useful for the author to explore the use of VAST for the EBS slope and longline surveys, given the recent cancelations and relative paucity of trawl surveys of the slope." (SSC, December 2020).

A UAF Masters student, Tristan Sebens, advised by Dr. Curry Cunningham evaluate methods to do this. For this to be used we will need a similar method to combine length data so that selectivity can be estimated. The authors will consider this for the next full assessment.

The SSC agrees with PT and author recommendations regarding further improvements to the model. Specifically, we encourage the author to investigate (1) the use of selectivity blocks if an appropriate rationale can be developed for these time blocks, (2) spatial distribution and migration to better understand changes in the proportion of the stock extending into Russian waters, and (3) approaches to incorporating Russian catches into the assessment (SSC, December 2018).

We evaluated the rationale of the selectivity time-blocks during this cycle. Given spatial shifts in the fishery and corresponding changes in the length distribution, the fishery time blocks on selectivity were deemed appropriate. The authors also evaluated removing the selectivity time blocks for the EBS shelf bottom trawl survey. When removed the model greatly overestimated biomass in the early years. Therefore, the authors decided to keep the EBS shelf survey time blocks used in previous assessments.

Sometime after the current assessment cycle, the Team recommends that the author consider excluding pre-1977 data.

This was explored, but a fully developed assessment model was not ready for September. The authors will address this during the next full assessment.

Efforts to improve model stability by reducing parameters that are not well estimated is encouraged for future assessments. (SSC, October 2018)

This is an ongoing effort for this model.

"*The Team recommended the authors revise the interpolation method used to combine the BS and AI longline survey relative population numbers, either based on linear interpolation or new methods under development at the University of Alaska Fairbanks.*" (BSAI Plan Team, November 2022)

"*The BSAI GPT also recommended that the authors revise the interpolation method used to combine the EBS and AI longline survey relative population numbers, continue exploration of killer whale depredation impacts on longline survey abundance estimates, and present newly available sex-structured length composition data from the longline survey. The SSC agrees with these recommendations.*" (SSC, December 2022)

The authors see the value is using the linear approximation approach to derived the AFSC longline RPNs. They were used in the alternative models presented in this report. Model 16.4c presented in September did not include the RPNs using the linear approximation approach and is the recommended model for management. The authors will ensure the linear approximation approach is used for the next full assessment.

Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) is a Pleuronectidae flatfish that has a circumpolar distribution inhabiting the North Atlantic, Arctic and North Pacific Oceans (Figure 5.1). The American Fisheries Society uses "Greenland halibut" as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, the common name Greenland turbot, which is also the "official" market name in the US and Canada (AFS 1991), is retained.

In the Pacific Ocean, Greenland turbot have been found from the Sea of Japan to the waters off Baja California. Specimens have been found across the Arctic in both the Beaufort (Chiperzak et al. 1995) and Chukchi seas (Rand and Logerwell 2011). This species primarily inhabits the deeper slope and shelf waters (between 100 m to 2000 m; Figure 5.1) in bottom temperatures ranging from -2°C to 5°C. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988; Sohn 2009). Adult Greenland turbot distribution in the Bering Sea appears to be dependent on size and maturity as larger more mature fish migrate to deeper warmer waters. In the annual summer shelf trawl surveys conducted by the Alaska Fisheries Science Center (AFSC) the distribution by size shows a clear preference by the smaller fish for shallower (< 200 m) and colder shelf waters (between -2°C and +2°C). The larger specimens are in higher concentrations in deeper (> 200 m), warmer waters (between 0°C and 4°C) (Figure 5. 2). It appears that for years with above average bottom trawl bottom temperatures the larger turbot (> 20 cm) are found at shallower depths (Barbeaux et al. 2015).

Juveniles are generally absent in the Aleutian Islands region, suggesting that the population in the Aleutians originates from the EBS or elsewhere (Bryan, 2018). In this assessment, Greenland turbot found in the two regions are assumed to represent a single management stock. The lack of small individuals suggests the Aleutian Islands and Bering Sea are a single stock. The NMFS initiated a tagging study in 1997 to supplement earlier international programs. Results from conventional and archival tag return data suggest that individuals can range distances of several hundreds of kilometers and spend summer periods in deep water in some years and in other years spend time on the shallower EBS shelf region (Siwicke and Coutre 2020). The archival release and recovery information can be found here: https://apps-afsc.fisheries.noaa.gov/maps/tagmap/tagmap-v2/combined.php.

Greenland turbot are sexually dimorphic with females achieving a larger maximum size and having a faster growth rate. Data from the AFSC slope and shelf surveys were pooled to obtain weight at length (Figure 5.3). Growth parameters are estimated within the stock assessment model for both male and female Greenland turbot and differs between males and females. This sexually dimorphic growth is consistent with trends observed in the North Atlantic. Collections in the North Atlantic suggest that males may have higher mortality than females. Evidence from the Bering Sea shelf and slope surveys suggest males reach a maximum size much smaller than females, but that mortality may not be higher than in females. Sexually dimorphic spawning behaviors are also prevalent for this species. Siwicke et al. (2022), using archival tagging data, determined males exhibited multiple rises for an average of 20 days, while females exhibited a single spawning rise occurring at annual intervals between January and February.

Fishery and Management History

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. Combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Figure 5. 4). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 5.1). Trawl harvest declined steadily after 1983, with the lowest catch in 2007 (458 t). Catch increased in 2008 and has remained low. The average catch for the trawl fishery has been 1,722 t between 2008 and 2024. Catch by the longline fishery started to increase after 1990 and then declined after 1998. Catch by the longline fleet has been under 50 t since 2021.

Total catch declined in the early 1980s (Table 5.1). Catch restrictions were placed on the fishery in the 1990s because of apparent low levels of recruitment. From 1990-1995 the Council set the ABC's (and TACs) to 7,000 t as an added conservation measure citing concerns about recruitment. Between 1996 and 2012 the ABC levels varied but averaged 6,540 t (with catch for that period averaging 4,482 t). The 2013 ABC was lowered to 2,060 to correct for changes in the stock assessment model and total catch for 2013 was 1,742 t. The ABC and TAC remained low between 2014 and 2016. In 2016, although the ABC was 3,462 t the TAC was set at 2,873 t and total catch was at 2,272 t. In 2017, the ABC was increased to 6,644 t, the TAC was set to 4,500 t and total catch was 2,834 t. ABC and TAC increased between 2017 and 2018 and have been declining since 2019. The fishery has generally captured a high proportion of the ABC and TAC annually, with lows of 16% in 2018 and 22% in 2022, respectively (Table 5.1). Catch has been low since 2018 and an average of 24% and 36% of the ABC and TAC have been retained between 2018 and 2023.

Historically the majority of the catch over time was concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (e.g., Figure 5. 5 and Figure 5.5 in Bryan 2022), but Greenland turbot has been consistently caught in the shallow water on the shelf as bycatch in the trawl fisheries (Table 5.2). Catch of Greenland turbot is generally dispersed along the shelf and shelf edge in the northern most portion of the management area. However, between 2008 and 2012 at a 400km^2 resolution the cells with highest amounts of catch were observed in the Eastern Aleutian Islands (Barbeaux *et al.* 2013), suggesting high densities of Greenland turbot in these areas. These areas of high Greenland turbot catch in the Aleutians are coincident with the appearance of the Kamchatka and arrowtooth flounder fishery. This fishery has the highest catch of Greenland turbot outside of the directed fishery (Table 5.2, Figure 5.6).

For the domestic fishery, the trawl fishery took the majority of the catch, 96%, until 1992 (Table 5.1). The longline fishery took the majority (~71%) of Greenland turbot catch from 1992-2007. In 2008 and 2009 the trawl fishery captured more Greenland turbot than the longline fishery. The shift in the proportion of catch by sector was due in part to changes arising from Amendment 80 passed in 2007. Amendment 80 to the BSAI Fishery Management Plan (FMP) was designed to improve retention and utilization of fishery resources. The amendment extended the American Fisheries Act (AFA) Groundfish Retention Standards to all vessels and established a limited access privilege program for the non-AFA trawl catcher/processors. This authorized the allocation of groundfish species quotas to fishing cooperatives and effectively provided better means to reduce bycatch and increase the value of targeted species. The trawl fishery captured approximately 57% of the catch between 2008 and 2017 and has captured an average of 91% of the catch since 2018.

The longline fleet generally targets pre-spawning aggregations of Greenland turbot; the fishery opens May 1, but usually occurs June-August in the EBS to avoid killer whale predation. Catch information prior to 1990 included only the tonnage of Greenland turbot retained by Bering Sea fishing vessels or processed onshore (as reported by PacFIN). In 2010, there was a shift in the mean depth of the targeted Greenland turbot longline fishery fished at 667m, from 1995 to 2009, up to 555m, on average, from 2010 to 2015 (Figure 5. 7). There has been a northwest trend in mean fishing latitude over time for the longline fishery (Figure 5. 8). The trawl gear fishery exhibited a southward shift in fishing at the end of the 1980s, but has operated across the shelf over time (Figure 5. 9). On average the trawl fishery operated at deeper depths between 1980 and 1998 and has operated at ~400 m since 2000 (Figure 5.7).

The overall discard rate of Greenland turbot has dropped in recent years from a high of 82% discarded in 1992 (Table 5.2). The lowest discard rate of 2% has occurred in 2012 and 2019. Discard levels of Greenland turbot have typically been highest in the sablefish fishery while Pacific cod fisheries and the “flatfish” fisheries also have contributed substantially to the discard levels (Table 5.2b,c). However due to the large numbers of small Greenland turbot encountered in the flatfish and arrowtooth/Kamchatka fisheries in 2013 and 2014 the discard rate once again rose to 20% in 2013 and 15% in 2014. The discard rate has varied between 2% and 6% since 2015.

Greenland turbot catch has primarily been from the Bering Sea; however, catch levels were similar in 1991, 2009, and 2010 (Table 5.3). Since 1991, an average of 78% of Greenland turbot catch has been from the Bering Sea and 22% from the Aleutian Islands.

Catch of Greenland turbot has been low since 2013 and has been generally declining (Table 5.1).

Data

The following data sources were used in the 2024 BSAI Greenland turbot assessment and used for the model runs in this document:

Source	Data	Years
NMFS Groundfish survey:	EBS shelf BTS biomass	1987-2024
	EBS shelf BTS length composition	1987-2024
	EBS shelf BTS mean length at age	1982, 1998-2019, 2021-2023
	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
AFSC longline survey	EBS slope BTS mean length at age	2002, 2004, 2008, 2010, 2012, 2016
	Relative population numbers	1996-2023
U.S. fisheries	Length composition	1979-2023
	Catch	1960-2024
	Trawl length composition	1978-1991, 1994-1996, 1998-2024
	Fixed Gear length composition	1979-1985, 1993-2021

Fisheries data in this assessment were split into the longline (including all fixed gear) and trawl fisheries. Both the trawl and longline data include observations and catch from targeted catch and bycatch. There are also data from three surveys. The shelf and slope surveys are bottom trawl surveys conducted by the Resource Assessment and Conservation Engineering (RACE) Division of the Alaska Fisheries Science Center (AFSC). The AFSC longline survey has been conducted by the Auke Bay Laboratory (ABL) out of Juneau, Alaska. The type of data and relevant years from each can be found in Figure 5.10.

Fishery data

Catch
The catch data were used as presented above for both the longline and trawl fisheries. The 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.

Size and age composition
Length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2024. The length composition data from the trawl and longline fishery are presented in Figure 5.11. The absolute sample sizes for the period of the domestic fishery by sex and fishery from 1991-2024 are given in Table 5.4. Very few samples were collected from the longline/fixed gear fishery in 2021-2024 and corresponds to low catch and Greenland turbot not being a predominant species in this fishery in recent years.

Early in the time series, late 1970s to early 1980s, the trawl fishery captured a higher proportion of smaller turbot (Figure 5.11). After 1984, there was a noticeable shift towards larger fish, where the size distribution of males caught during this time period has been fairly consistent. The longline/fixed gear fishery has consistently captured higher proportions of larger Greenland turbot over time. A higher proportion of females greater than 70 cm were caught prior to 2008 followed by a shift towards females less than 70 cm.

Survey Data

<u>EBS slope and shelf surveys</u>
Data from two bottom trawl surveys are included in the Greenland turbot stock assessment. Due to the ontogenetic shift in turbot spatial distributions from the shelf to the slope, the EBS shelf bottom trawl survey primarily provides abundance estimates of juveniles and the slope bottom trawl survey provides estimates of older juvenile and adult abundance on the EBS slope (Figure 5.11). The slope survey likely under-represents the actual abundance of Greenland turbot and is therefore treated as index of abundance. The survey is thought to under-represent the actual abundance because the species appears to extend beyond the area of the surveys and the ability of the net to maintain bottom contact in the deeper waters may be compromised. The shelf survey biomass estimates are also treated as a relative index.

The EBS slope was surveyed every third year from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. From 1979-1985, the slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency. In 1988, the NOAA ship Miller Freeman was used to survey the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side experiments with the Miller Freeman for calibration purposes. However, the Miller Freeman sampled a smaller area and fewer stations in 1988 than the previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1000 m. In 2002, the AFSC re-established the bottom trawl survey of the upper continental slope of the eastern Bering Sea and a second survey was conducted in 2004. Planned biennial slope surveys lapsed (the 2006 survey was canceled) but resumed in the summer of 2008, 2010, 2012, and 2016. A 2014 survey was planned, but was cancelled due to contracting difficulties. A 2016 survey was conducted although fewer stations were conducted than planned (88% of planned stations) due to contracted vessel mechanical issues. All missed tows were in the Bering Canyon (subarea 1) region where 53 of 75 planned stations were completed. The 2018 survey was cancelled due to contracting difficulties. This area is where we expected a large number of Greenland turbot, so 2016 abundance may be underestimated. The slope survey has not been conducted since 2016. Although the size composition data for surveys prior to 2002 were used in this assessment, abundance estimates were considered inappropriate for use due to differences in survey consistency, vessel power, gear used, and uncertainty on the extent of survey gear bottom contact.

The estimated biomass of Greenland turbot in this region has fluctuated over the years (Figure 5.12). When US-Japanese slope surveys were conducted in 1979, 1981, 1982 and 1985, the combined survey biomass estimates from the shelf and slope indicate a decline in EBS abundance. After 1985, the combined shelf plus slope biomass estimates averaged 47,169 t, with a 2004 level of 64,958 t. Although the 2012 EBS slope biomass estimate of 18,019 t was down from 2010 estimate of 20,046 t, the population numbers in 2012 of 11,839,700 fish were more than double the 2010 estimate of 5,839,126 fish (Table 5. 6). The 2012 slope survey abundance estimate in numbers was the highest population estimate since the slope survey was reinstated in 2002. For 2012, most of the change in population estimates was due to the changes in Greenland turbot abundance found in the two shallowest strata between 200 and 600 m depth strata (Table 5. 6). In the 200-400 m strata the population was more than 7 times that of the 2010 survey estimate and the 400-600 m strata was more than double the 2010 estimate. The high numbers and low biomass results are a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007 through 2010 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Figure 5.11). In the 2016 slope survey, Greenland turbot biomass increased to 24,803 t (Table 5.5).

In the 2016 slope survey, most of the biomass (83.5% of biomass and 87.9% of abundance) was located in depths between 400 and 800 meters consistent with the growing 2007-2010 year classes moving downslope. For all regions except Area 1 (1.4% decrease) there was an increase in Greenland turbot biomass in the 2016 survey compared to 2012, as expected with the growth of the large 2007-2010 year classes. The 2016 slope survey also saw an increase in abundance in all regions except Area 6 which experienced a 54.5% decline in abundance. Areas 5, 4, and 3 saw a 657.1%, 112.1%, and 44.3% increases in abundance consistent with Greenland turbot migrating south as they grow.

Although the 2016 slope survey continued to see the highest abundance in area the highest proportion of fish were located in the furthest north strata with 42.2% and 36.2% of the fish by abundance and biomass, respectively, in Area 6 (Table 5.7). This compared to the 2012 survey which saw 71.9% and 44.7% of the abundance and biomass in Area 6. Area 6 had an overall 54.5% decrease in abundance from 2012 to 2016. This demonstrates the expected southward migration of the 2007-2010 year classes into Areas 5, 4, and 3 with 657%, 112%, and 44% increases in abundance in these areas. The number of fish in areas 1 and 2 remained relatively stable with only 1.6% and 5.5% increases.

The shelf trawl survey has been conducted by the AFSC annually since 1979. Beginning in 1987 NMFS expanded the standard survey area farther to the northwest. For consistency the index of abundance used in this stock assessment only includes data post-1987 and included data from the expanded area (Figure 5. 13). The shelf survey is a measure of juvenile fish and appears to be highly influenced by occasional large recruitment events (Figure 5.11, Figure 5.12). The shelf survey index shows a steep decline in biomass from initial biomass estimates in 1982 of 39,603 t to a low of 5,654 t in 1986 (Table 5.5). From 1987 to 1994 biomass increased to an all-time peak of 56,997 t in 1994 following two larger than average recruitment events in the mid and late 1980s. After 1994, the shelf index once again declined steadily through 2009 to 10,919 t as recruitment remained low throughout the 1990s with only a slight improvement in 1999-2001. In 2010, the index increased to 23,339 t and was relatively stable between

2011 and 2017. The average shelf-survey biomass estimate during the last 20 years (2004 - 2024) was 18,382 t. Biomass has been declining since 2014 and in 2024 the survey biomass estimate was 4,959 t. The 2024 EBS shelf bottom trawl survey biomass estimate is at an all-time low and the lowest estimate in the past three years. This is followed by the 2023, 1986, and 2022 estimates which were 5,857 t, 5,654 t, and 7,869 t, respectively (Table 5.5). In 2010 and 2011, the abundance estimates from the shelf surveys indicated a significant increase of Greenland turbot due to an increase in recruitment in 2009 and 2010 and an increase in the proportion of tows with Greenland turbot present (Table 5.8, Table 5.9).

Survey data show that the extent of the spatial distribution of turbot on the shelf and upper slope presents temporal variation, possibly expanding as recruitment events occur (Figure 5.15, Figure 5.16). For example, occurrences of small (< 30 cm) fish have remained relatively constant prior to 2010, albeit with some interannual variability. Between 2010 and 2012, the bottom trawl surveys detected larger numbers of small fish distributed throughout the continental shelf. Biomass and abundance on the EBS shelf have been declining since 2014. This is due to the migration of the 2007-2010 year classes off the shelf survey area (Figure 5.17, Figure 5.18), and a lack of replacement from new recruitment over the last decade (Figure 5.11).

Bottom trawl survey size composition
A time series of estimated size composition of the population was available for the EBS shelf and slope surveys. The shelf survey appears to be useful for detecting recruitment patterns that are consistent with the trends in biomass. Signs of recruitment (Greenland turbot less than about 30 cm) were clear between 2007 and 2011 after an absence of small fish between 2003 and 2006 (Figure 5.11). The progression of the 2007-2010 year classes and the lack of any substantial new recruitment into the area are evident in length estimates since. In 2019 and 2022, all measured Greenland turbot were greater than 40 cm. A small proportion of fish less than 30 cm were observed in 2021. In 2023 and 2024, there is some indication of small fish on the EBS shelf; however, the cohort strength between 2023 and 2024 appears small.

Survey length-at-age used for estimating growth and growth variability were previously available from 1998, 2003-2019, and 2021-2023. Gregg et al. (2006) revised age-determination methods for Greenland turbot and although shelf survey age composition data were included in the model, they were not included in the likelihood function (Figure 5.14). The age composition data are not included in the likelihood to avoid using the data twice given that in all years the mean length-at-age data and length data from the same source are used. It is worth noting that the age data show evidence of the 2007-2010 cohort ageing overtime and a noticeable lack of turbot less than 5 years old on the EBS shelf since 2019.

<u>Aleutian Islands bottom trawl survey</u>

The Aleutian Islands bottom trawl survey is not presently included in the stock assessment model. Given the depth constraints of this survey (i.e., maximum depth of 500 m) and Greenland turbot rarely occurring in the survey, the biomass estimates are not used as a relative index of abundance in the assessment model. We report on trends as it is used to allocate the ABC between the Bering Sea and Aleutians in years when the slope survey and the Aleutians Islands survey overlapped.

Biomass was highly variable between 1980 and 2006 with a high of 31,759 t and then consistently declined to a low 373 t in 2018. Biomass increased to 539 t in 2022 and 604 t in 2024 (Table 5.5, Table 5.10). The index in numbers showed a similar trend and declined to a low of 54,327 in 2018 and increased to 177,309 in 2022 and 229,622 in 2024. Biomass in the Aleutian Islands was generally highest in the eastern AI, followed by the central AI (Table 5.10).

Longline survey

The domestic AFSC longline survey for sablefish has conducted biennial sampling in the Aleutian Islands and biennial sampling in the Bering Sea since 1996. Area-based RPNs are in Table 5.11. The combined time series has been included in the assessment as a relative abundance index (Figure 5.12). The RPN index for Greenland turbot was computed for model 16.4c and all previous assessments by taking the average RPN from 1997-2024 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 (1996-2024) are given here by each area as: p^{AI} and p^{EBS}. Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years and that this approach assumes that the population proportion in these regions is constant. 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 interpolated 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. This alternative index is included in models m24.1, m24.1a, m24.1, and m24.2a.

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 (Figure 5.12). 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.

Discussions with the survey managers have revealed whale depredation on this survey may affect the index and as such, data affected by depredation are removed from the RPN analysis. We evaluated the killer whale depredation rates with respect to the RPN index. This evaluation shows that as the rate of killer whale depredation on the survey longline sets increased and leveled off in the Bering Sea the RPN index declines and levels off to a low level (Figure 5.19). 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.

The length data from the AFSC longline survey were also included in the model (Figure 5.11). The length data included in the model are not sex-specific and generally range between 50 cm and 100 cm. There is a clear shift in the AFSC longline size distributions after 2002 to more prevalent smaller sizes, although there is some evidence of larger sizes in the most recent surveys.

Analytic approach

General Model Structure

A version of the Stock Synthesis program (Methot 1990) has been used to model the eastern Bering Sea component of Greenland turbot since 1994. The software and assessment model configuration has changed over time, particularly in the past seven years as newer versions have become available. Stock Synthesis version 3.30.19 was used for this assessment.

Total catch estimates used in the model were from 1960 to 2024. Model parameters were estimated by maximizing the log posterior distribution of the predicted observations given the data. The model included two fisheries, those using fixed gear (longline and pots) and those using trawls, and up to three surveys covering various years. The assessment model also uses the Beverton-Holt stock-recruitment curve, and the early recruitment series is carried back to 1945.

Description of Alternative Models

Several alternative models were reviewed in September and the following models were evaluated for November. The table below provides a snapshot of the differences, which will be further explained within this section.

Model	**Description**
m16.4c	2022 assessment model with updated data
m24.1	M16.4c with the following changes: 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
m24.1a	m24.1 and same variance adjustment as m16.4c
m24.2	m24.1 with SRR autocorrelation fixed = 0.45
m24.2a	m24.2 and same variance adjustment as m16.4c

Age Structured Model Results

Parameters estimated independently

All independently estimated parameters were the same for the models and are as follows:

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	9%	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	3.43×10^{-6}	1982, 1998, 2003-2023 EBS bottom trawl survey data
Beta	3.2189	1982, 1998, 2003- 2023 EBS bottom trawl survey data
Female		
Alpha	2.44×10^{-6}	1982, 1998, 2003- 2023 EBS bottom trawl survey data
Beta	3.325	1982, 1998, 2003- 2023 EBS bottom trawl survey data
Recruitment		
Steepness	0.79	Myers et al. (1999)
Sigma R	0.6	Ianelli et al. (2011)
Autocorrelation	0.45	Thorson et al. (2014), for model m24.2 only

Natural mortality and length at age

The natural mortality of Greenland turbot was assumed to be 0.112 based on Cooper et al. (2007). This is also more consistent with re-analyses of age structures that suggest Greenland turbot live beyond 30 years (Gregg et al. 2006).

Parameters describing length-at-age are estimated within the model. The reference age for the first size at age 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 maximum age a CV of 9% was assumed. This appears to encompass the observed variability in length-at-age. Mean size-at-age data from the EBS shelf and slope bottom trawl surveys were used in this assessment (Table 5.12, Table 5.13).

Maturation and fecundity

Maturity and fecundity followed the same assumptions as the 2022 model with the female length at 50% mature at 60 cm as per D'yakov (1982). For this assessment a logistic maturity-at-size relationship was used with 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively.

Weight at length relationship

The weight at length relationship was derived using the combined data from the Bering Sea bottom trawl surveys conducted by the Alaska Fisheries Science Center. From 2003 to 2011 the Greenland turbot stock assessment models used the same weight at length relationship for males and females ($w = 2.44 \times 10^{-6} L^{-3.34694}$, where L = length in cm, and w = weight in kilograms). Given the great deal of sexual dimorphism observed in this species it was thought that having separate weight at length relationships for males and females would better capture the diversity in this stock. Starting in 2012 the relationship was updated to $w = 2.43 \times 10^{-6} L^{3.325}$ for females and $w = 3.40 \times 10^{-6} L^{3.2189}$ for males. This relationship is similar to the weight at length relationship observed by Ianelli et al. (1993) and used in the Greenland turbot stock assessment prior to 2002. The weight at length analysis was first presented at the September 2012 Plan team and SSC meetings (Barbeaux et al. 2012, Appendix 5.1) and has been updated and remained similar since (Figure 5.3).

<u>Size composition multinomial sample size</u>

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, model 16.4c, the 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 (Table 5.4).

A new bootstrapping approach to determine the input sample size for the AFSC bottom trawl surveys has been advocated (Hulson and Williams 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 to obtain the input sample size for the EBS shelf survey and EBS slope survey length composition data for models m24.1, m24.1a, m24.2, and m24.2a 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 5.14. The sample size 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 in model 24.1, 24.1a, 24.2, and 24.2a.

The name of key parameters estimated and number of parameters within the candidate models were:

		Model 16.4c	Model 24.1 and 24.1a	Model 24.2 and 24.2a
Recruitment				
	Early Rec. Devs	(1945-1970) 26	(1945-1970) 26	(1945-1970) 26
	Main Rec. Devs	(1971-2020) 50	(1971-2020) 50	(1971-2020) 50
	Future Rec. Devs	(2021-2024) 4	(2021-2024) 4	(2021-2024) 4
	R_0	1	1	1
	Autocorrelation ρ	1	0	0 (ρ= 0.45)
Naural mortality				
	Male	0	0	0
	Female	0	0	0
Growth				
	L_{min} (M and F)	2	2	2
	L_{max} (M and F)	2	2	2
	Von Bert K (M and F)	2	2	2
Catchability				
	q_{shelf}	0 (fixed)	0 (float)	0 (float)
	q_{slope}	0 (fixed)	0 (float)	0 (float)
	q_{ABL}	1	0 (float)	0 (float)
Selectivity				
	Trawl fishery	15	15	15
	Longline fishery	28	28	28
	Shelf survey	17	17	17
	Slope survey	17	7	7
	AFSC longline survey	2	2	2
	Total Parameters	169	156	156

Recruitment and initial conditions

For all models, a single R_0 was assumed for all years. The model used the Beverton-Holt stock recruitment curve with steepness (*h*) set to 0.79 and σ_R set to 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 used in model m16.4c where the prior component due to stock-recruitment residuals (ε_i) is:

$$\pi_R = \frac{\varepsilon_1{}^2}{2\sigma_R^2} + \sum_{i=2}^{n} \frac{\left(\varepsilon_i - \rho\varepsilon_{i-1}\right)^2}{2\sigma_R^2\left(1-\rho^2\right)}$$

, and ρ is the autocorrelation coefficient and σ_R^2 is the assumed stock recruitment variance term. Model 16.4c uses a prior of 0.437 (SD=0.265) estimated by Thorson *et al.* (2014) for Pleuronectidae species. Models m24.1 and m24.1a do not assume recruitment is autocorrelated (ρ = 0), while models m24.2 and m24.2a assume recruitment is autocorrelated at a fit value (ρ = 0.45). Both alternatives were evaluated because a simulation experiment showed that SS3 poorly estimates the autocorrelation parameter (Johnson et al. 2019). It is now recommended to use an external estimate for the autocorrelation from the recruitment deviations and fix it in the model.

The first year of the models 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.

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”. Models m24.1, m24.1a, m24.2, and m24.2a, used the float option in SS3 where the model derives an analytical solution for survey-specific catchability.

Selectivity

Selectivity for the AFSC longline survey was modeled using the logistic selectivity pattern, 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. All models treat the AFSC longline survey selectivity in the same way.

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. 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

Time blocks were used to estimate time varying selectivity for the fishery and the shelf and slope bottom trawl surveys. This is a longstanding feature of the Greenland turbot model and in doing so, it is assumed that selectivity changes over time due to changing availability of certain size classes (e.g., when there is a recruitment event). The time blocks used in Model 16.4c are as follows:

Fleet/survey			
EBS shelf survey	1945 – 1991	1992 – 1995	1996-2000, 2001 - 2024
EBS slope survey	1945 – 2001	2002 – 2010	2011 - 2024
Trawl fishery	1945 – 1988	1989 – 2005	2006 - 2024
Longline fishery	1945 – 1990	1991 – 2007	2008 - 2024

In September, time blocks in the last accepted model (Model 16.4c) were 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 (see Figures 6-8 in Appendix B). We showed that the time block structure in model 16.4c was consistent with past spatial shifts and changes in the observed length composition data of the fishery fleets; therefore, we retained the fishery selectivity time blocks in all models.

We also reviewed the time blocks used to model the bottom trawl survey selectivity in September. We determined that the EBS shelf survey time blocks should be retained in all models. Without allowing for time-varying selectivity, the model has tremendous difficulty fitting the early data points of the relative biomass index. The EBS slope bottom trawl survey is a short time series and the last time block in Model 16.4c includes two years of data. Given the limited temporal scope of this survey, we removed the EBS slope bottom trawl survey time blocks in Models 24.1, 24.1a, 24.2, and 24.2a.

<u>Variance adjustment of length composition data</u>
Model 16.4c used the following variance adjustment for the length composition data:

Fleet	Sample size (same in all years)	Variance adjustment	Adjusted sample size
Trawl fishery	50	0.25	12.5
Longline fishery	50	0.5	25
EBS shelf survey	200	0.25	100
EBS slope survey	400	0.5	200
AFSC longline survey	60	0.5	30

Models 24.1 and 24.2 do not implement variance adjustment. The Plan Team requested we use Francis-reweighting to determine variance adjustment values for Models 24.1 and 24.2. As we discussed in September, Francis reweighting led to unreasonable down weighting of the EBS shelf and slope bottom trawl survey length composition data and extremely poor fits to the length data, especially for the EBS slope survey. Therefore, we applied the variance adjustment values from Model 16.4c in Models 24.1a and 24.2a.

Evaluation of Model(s) and Associated Uncertainty
The likelihood results for all model runs are reported in Table 5.15. Given that there are differences in some of the data components between Model 16.4c and the alternative models they are not all directly comparable, but do provide a general overview of how well the models fit the data components.

All models estimated similar growth patterns (Table 5.16, Figure 5.20). Model fits to the separate data sources, EBS shelf survey and EBS slope survey, indicate that the models underestimate the mean length at ages above 20 years old, somewhat consistently; however, the estimated growth relationships describe the raw length-at-age data well (Figure 5.20, Figure 5.21, Figure 5.22, Figure 5.23).

The fit to the EBS shelf bottom trawl survey biomass index was similar among the models when comparing root mean square error values and visually (Table 5.17, Figure 5.24). There is some trade-off between fitting the slope and AFSC longline indices. The EBS slope bottom trawl survey biomass index was fit best by Model 16.4c (lowest RMSE value), whereas the alternative models overestimated the first data point and underestimated the last two data points more so than Model 16.4c (Figure 5.24). The biggest difference in the fit to the slope survey is in the last two years of the time series. This lack of fit may be partially explained by the removal of the selectivity time block that cover these years in Model 16.4c. Conversely, the AFSC longline RPN index was better fit by the alternative models (lower RMSE values) when using the RPN derived from the linear approximation method than Model 16.4c. The alternative models were able to better estimate the declining trend in the RPN index between 1996 and 2007 than Model 16.4c (Figure 5.24).

The estimates of catchability differed greatly when comparing the alternative models to Model 16.4c (Table 5.16). The fixed value used in Model 16.4c for the EBS shelf survey was log(-0.49) or 0.61, whereas the alternative models all estimate log(q) to be a positive number and greater than 1 when exponentiated. 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. Catchability in Model 16.4c for the EBS slope survey is set equal to 0.57 (log q = -0.56). The estimate from the alternative models were between 0.6 and 0.69, indicating that all models expect the slope survey to underestimate population biomass. The catchability estimate for the AFSC longline survey was ~2.4 from Model 16.4c and ~3 for the alternative models. The estimates seem to be in the realm of possibility given that the longline catchability estimate for sablefish is ~6 (Goethel et al., 2023).

The fit to the aggregated fishery, trawl and longline/fixed gear, length composition data was relatively similar among the models with some improvement to the fit in the alternative models with variance-adjusted sample sizes (Figure 5.25). The fit to the aggregated, female EBS shelf length composition data improved in the alternative models as compared to Model 16.4c, whereas the fit to the male length composition was similar among models. This is in part due to better fits in years with higher sample sizes (e.g., 2010 and 2011, Figure A. 3). Fit to the aggregate EBS slope survey length composition was similar among models for female lengths greater than 50cm, with a slightly better fit to smaller lengths by the alternative models. All models underestimated the peak of the male length distribution (Figure 5.25). Fit to the aggregate AFSC longline length composition was similar among models with some improved fit to the descending limb of the length distribution by the alternative models. The fleet-specific residual patterns were similar among models; however, the magnitude of the residuals was generally higher for models 24.1 and 24.2 that did not variance-adjust the sample size (Figure 5.26). Notable patterns include a general underestimation of the cohorts (e.g., late 1980s, 2008-2010) in the EBS shelf survey data, a consistent underestimation of the peak of the male length distribution from the slope survey over time, and consistent underestimation of ~80 cm fish between 1979 – 2002 and then a shift to underestimation ~60 cm fish in 2003 –present in the AFSC longline data.

Estimates of selectivity were fairly consistent among models for the two fishery fleets (Figure 5.27, Figure 5.28). The estimate of selectivity for the first time block of the trawl fleet had the greatest difference between Model 16.4c and the alternative models and had the same dome shape but was shifted towards smaller fish. The EBS shelf survey selectivity showed the greatest differences among models (Figure 5.29). Models 24.1 and 24.2 had more domed selectivity than Model 16.4c, but still had higher selectivity of smaller fish than Models 24.1a and 24.2a. Model 24.1 and 24.2 generally had better fits to the pre-1992 data than the other models. The alternative models estimated more domed selectivity for the 1992-1995 time block, but fits to the length data were similar among models. 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. This increased the selectivity for smaller females and decreased the selectivity of smaller males. The EBS slope survey selectivity for males estimated by the alternative models (shown in the 1945 plotting facet of Figure 5.30) was similar to the estimated selectivity for first two time blocks in Model 16.4c and had slightly higher selectivity for smaller fish than Model 16.4c's estimated selectivity in the third time block (Figure 5.30). The alternative models fit to the male length distribution in 2012 was poorer than in Model 16.4c. Female selectivity was higher for 60 cm – 100 cm females in the first time block than the later time blocks (Figure 5.30). Female selectivity for the slope survey was similar to the selectivity estimated for the 2002-2010 time block by Model 16.4c. The alternative models' fit to the 1979, 1982, and 1985 female length distributions was somewhat poorer than Model 16.4c. The AFSC longline selectivity was consistent among models (Figure 5.31).

Assuming that recruitment is not autocorrelated, Models 24.1 and 24.1a, resulted in a sharp peak in recruitment in the 1950s (Model 24.1 > Model 24.1a), several sharp peaks in the 1960s, and two sharp peaks in the late 1970s, which are seen in the SSB timeseries several years later and leads to higher estimates than all other models prior to 1980 (Figure 5.32). Models 16.4c, 24.2, and 24.2a assume that recruitment is autocorrelated and estimate wider, more smooth periods of recruitment over this time frame. 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. All models estimate a declining trend in SSB after the late 1970s and converge to lower SSB estimates in 2022 than the last assessment, with Model 16.4c estimating the highest biomass, followed by Models 24.1 and 24.1a, then 24.2 and 24.2a.

Retrospective analysis (within model)
A retrospective analysis was completed for all models and was conducted in SS3 by removing data systematically by year for 10 years. All models have a positive pattern indicating that with each new year of data the estimates of SSB are less optimistic than the previous assessment. Model 16.4c had the smallest retrospective pattern in SSB of all the models (Figure 5.33). Mohn's rho was 0.14 for Model 16.4c, whereas the alternative models had Mohn's rho values of $\geq$ 0.32 (Table 5.17). This larger retrospective pattern was largely driven by the solution for the EBS shelf bottom trawl survey catchability that declined with each peel effectively increasing the estimate of SSB (Figure 5.34).

The retrospective pattern for Model 16.4c (Figure 5.33) was larger than the pattern estimated in 2022. Mohn's rho increased to 0.14 for model 16.4c (2024) from 0.1 in 2022.

Convergence Status and Criteria
A jitter analysis was also conducted to determine the stability of the candidate models. Starting from the parameter file the parameters were jittered by a 0.02 increment for 100 iterations. Model 16.4c had the greatest stability with 79 converged iterations as compared to 16, 48, 32, and 41 out of 100 for models 24.1, 24.1a, 24.2, and 24.2a, respectively. The reduced stability of the alternative models is a concern.

The alternative models incorporate several improvements to the model including use of AFSC longline RPNs from the linear approximation method, fixing the level of autocorrelation in recruitment (recommended by the SS3 developers), and uses the analytical solution for catchability. The increased retrospective pattern and the relative instability of the alternative models are concerning and lead us to recommend **Model 16.4c to provide management advice.** The authors would like to stress that the suggested improvements that were evaluated this year should be re-evaluated in 2026, while investigating methods to increase the stability of the model.

The instability of the alternative models appeared to be most often due to difficulty in estimating the selectivity parameters. The double-normal selectivity option in Stock Synthesis requires estimating six parameters. The number of fleets using this option, combined with the number of time blocks and the resulting time-varying parameters being estimated (often with a sex-specific offset), resulted in a relatively complex parametrization for fishery selectivity. Future work may attempt to simplify this parametrization by simplifying the time block structure (e.g., removing blocks from the slope survey), and fixing the parameters for selectivity at the first and last size bin and the width of the plateau. Initial simplified selectivity parametrizations were explored during this assessment cycle, but time was insufficient to satisfactorily evaluate these new model formulations.

Variance adjustment appeared to be a second source of model instability. It is generally recommended that Francis reweighting be applied to determine the data weights for variance adjustment. However, Francis reweighting led to down weighting of the trawl survey data and to poor fits to the length data. One possible reason for this was that length data from different sources contain competing information on population length structure, with shelf surveys capturing mostly smaller fish, and slope and longline surveys and fisheries sampling larger individuals. Additionally, possible size-selective killer whale depredation affecting longline surveys and fisheries, combined with the lack of slope survey data after 2016, means that little recent information is available on the length structure of the adult population. Future work could further explore some of these conflicts in the data and identify a variance adjustment method that weights different data sources more appropriately.

Future work should explore alternative model start dates. Initializing the model in 1945 allows it to capture years of high historical catch (1960-1980). However, there is no other data to inform population abundance and size structure during this early period (e.g., the first available length data from the fishery is from 1978, and from surveys 1987). Preliminary explorations were conducted to evaluate the effects on the model of using a later start date (1986). This led to model estimates of stock biomass in recent years that were close to those from the models initialized in 1945, but to a higher estimate of B_0, and therefore to different current stock status. More broadly, this reflects the uncertainty around whether the large historical catches reflect a relatively small population that had some very successful recruitment events between 1960 and 1980 (the current assumption), or an originally larger population that has since declined.

Time Series Results

In this section we present the time series results from Model 16.4c the recommended model. In all instances in this section "total biomass" refers to age 1+ biomass, spawning biomass is the female spawning biomass, and recruitment is age-0 numbers from the model unless otherwise specified.

Recruitment

Model 16.4c estimates an autocorrelation parameter for the recruitment deviations with a prior of 0.473 and standard deviation of the prior of 0.265. The estimated value for the autocorrelation parameter is 0.70 with a standard deviation of 0.028. The model predicts extremely large recruitments between 1960 and 1965 (Table 5.18). After 1970, the model estimates another large recruitment event in 1974-1976 with an average recruitment of 129 million age-0 fish for these three years with a maximum of 164 million age-0 fish in 1975 (Table 5.18). The current model estimates a small unfished population followed by large recruitment events to support the large early catch history. As there were no size composition prior to 1979, these early large recruitments are mainly informed by the early catches.

Recruitment from 1980 through 2007 was low with a mean of 5.1 million age-0 fish. Recruitment of age-0 fish was estimated to be 23.4 million, 19.2 million, and 2.7 million age-0 fish in 2008, 2009, and 2010, respectively (Table 5.18). Recruitment in 2008 was the largest since 1978. These recruitment events were captured over multiple years in the shelf survey size and age composition data, in the size composition from the last two slope surveys, and in the size composition data from 2012 and 2016 in the trawl fishery (Figure 5.11). The influx of new recruits in 2007 through 2009 cause a sharp drop in the predicted population mean size and mean age (Figure 5.35). The estimated numbers-at-age reflect the strong cohorts in the mid-1960s and late-1970s and from 2007-2009 (Table 5.18, Table 5.19, Figure 5.35). There was a noticeable lack of small turbot from the EBS shelf bottom trawl survey through 2022. The mean size on the shelf has steadily increased between 2010 and 2022 (Figure 5.36). Mean length declined in 2023 with a somewhat higher proportion of small fish and then increased due to a relatively higher proportion of larger fish in the observations. In general, the length data from the EBS shelf trawl survey indicates a general lack of recruitment over the last decade.

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass was estimated to be 25,594 t in 2024 by Model 16.4c (Table 5.20, Table 5.21). Spawning stock biomass increased between 2014 and 2020 and has been declining since 2021. The large early 1980s fishery combined with a lack of good recruitment in the mid- to late-1980s and through the 1990s drove the steepest part of the decline in spawning biomass. The mean age-0 recruitment for 1986 to 1999 was 4.1 million fish. In 1990 the NPFMC cut the ABC to 7,000 t until 1996 to account for low recruitment; however the ABCs were exceeded in 5 of the 7 years (Table 5.1). The stock continued to decline in the 1990s as poor recruitment continued. In 1997, the NPFMC started managing the stock as a Tier 3 stock and the ABCs were allowed to increase (Table 5.1). The mean ABC between 1997 and 2002 was 9,783 t, the mean catch however was lower and averaged about 6,355 t per year over this period. From 2003 to 2008 the ABC levels remained relatively low with a high of 4,000 t in 2003 and a low of 2,440 t in 2007. The catch dropped even lower to an average of just 2,417 t per year in this period. In 2008, with Amendment 80, an arrowtooth/ Kamchatka fishery emerged and catch increased in 2009 and remained relatively high through 2012. The average catch for 2008 through 2012 was 3,988 t. The ABCs during this period, due to a clerical error in the projection model, went from 2,500 t in 2008 to 7,380 in 2009. From 2009 to 2012 the ABC averaged 7,325 t with a high at 9,660 t in 2012. Although the decline in spawning biomass began to slow in 2005 through 2007, the decline in spawning biomass again continued after 2008. This decline may be correlated with increased fishing pressure during this period. Between 1986 and 2007 the mean fishing mortality was estimated at 0.08 with a maximum of 0.13 (Table 5.18). The fishing mortality increased between 2008 and 2012 and ranged between 0.12 and 0.28. The effects of the incoming 2007-2010 year classes led to an increase in the female spawning biomass estimates between 2016 and 2019 has exhibited a declining trend since 2020.

The Model 16.4c total age 1+ biomass estimates declined between 1977 and 2013 to 56,068 t (Table 5.18, Figure 5.37). After 2013, total age-1+ biomass increased to 61.691 t in 2016 and has declined to 40,194 t in 2024 (Table 5.18). Numbers at length and age are also showing declines (Figure 5.35).

Projections and Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean age-1 recruitment estimated for the period 1978-2022 gives a long-term average female spawning biomass of 23,525 t. The estimated 2025 female spawning biomass was at 23,999 t, which is above $B_{40\%}$ and above the estimate of $B_{35\%}$ (20,584 t). Because the projected spawning biomass in year 2025 (23,999 t) is above $B_{40\%}$, Greenland turbot ABC and OFL levels will be determined at Tier 3a of Amendment 56.

Specification of OFL and Maximum Permissible ABC

In the past several years, the ABC has been set to max ABC, but had been previously set below the maximum permissible estimates. For example, in 2008 the ABC recommendation was 21% of the maximum permissible level. The rationale for these lower values were generally due to concerns over stock structure uncertainty, lack of apparent recruitment, and modeling issues. The shelf survey length composition data indicated that there was strong recruitment between 2007 and 2010 (Figure 5.11). There was also evidence of this recruitment event in the slope data in 2012 and 2016; however, there has been little evidence of a strong recruitment event after 2010. The expectation for the Eastern Bering Sea is continued warming which has been shown to be detrimental to Greenland turbot recruitment. Given the scores in the risk table due to uncertainty about future recruitment in addition to uncertainty about stock status and well as fishery performance, the author’s recommend that ABC should be lower than maximum ABC. We specifically suggest a 10% reduction.

Year	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2025	2,237	2,013	2,598	23,999
2026	1,771	1,594	2,059	22,061

The 2025 estimated overfishing level based on the adjusted $F_{35\%}$ rate is 2,598 t corresponding to a full-selection *F* of 0.20. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) -specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is unallocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendments 56. This set of projections encompasses harvest scenarios designed to satisfy the requirements of Amendments 56, the National Environmental Policy Act, and the Magnuson-Stevens Act (MSA).

For each scenario, the projections begin with the 2024 numbers at age estimated in the assessment (age-1+). This vector is then projected forward to the beginning of 2025 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2024 (here assumed to be 751 t.). Since this fishery has not caught the TAC or ABC in several years a more realistic estimate of catch was used for 2025 as well. The preliminary catch for 2025 and 2026 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2019-2023) and the 2024 TAC. In each subsequent year, the fishing mortality rate is prescribed based on the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five harvest scenarios are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2025 and are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, *F* is set equal to max F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to a constant fraction ("author's *F*") of max F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for *2025* recommended in the assessment, to the maxF_{ABC} for *2025*, and catches for *2025 and 2026* are estimated at their most likely values given the assessment *2025 and 2026* recommended ABCs under this scenario. (Rationale: When F_{ABC} is set at a value below max F_{ABC}, it is often set at the value recommended in the stock assessment; also, catch tends not to equal ABC exactly.)

Scenario 3: In all future years, *F* is set equal to the *2019* to *2023* average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4 (optional): In all future years, the upper bound on F_{ABC} is set at a selected fraction of F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.). This scenario is optional and is up to the author's discretion.

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in *2025* or 2) above 1/2 of its MSY level in *2025* and expected to be above its MSY level in *2034* under this scenario, then the stock is not overfished.)

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

Alternatives 1 through 7 were projected to year 2036 (Table 5.22). SSB in 2025 and 2026 are above $B_{35\%}$; therefore, this stock is not considered to be overfished or approaching an overfished condition.

Risk Table and ABC Recommendation

Overview

"The following template is used to complete the risk table:

Risk Table Levels of Concern

	Assessment-related considerations	*Population dynamics considerations*	*Ecosystem considerations*	*Fishery-informed stock considerations*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are typical for the stock and recent trends are within normal range.	No apparent ecosystem concerns related to biological status (e.g., environment, prey, competition, predation), or minor concerns with uncertain impacts on the stock.	No apparent concerns related to biological status (e.g., stock abundance, distribution, fish condition), or few minor concerns with uncertain impacts on the stock.
Level 2: Increased concern	Substantially increased assessment uncertainty/ unresolved issues, such as residual patterns and substantial retrospective	Stock population dynamics (e.g., recruitment, growth, natural mortality) are unusual; trends increasing or decreasing faster than has	Indicator(s) with adverse signals related to biological status (e.g., environment, prey, competition, predation).	Several indicators with adverse signals related to biological status (e.g., stock abundance, distribution, fish condition).

	patterns, especially positive ones.	been seen recently, or patterns are atypical.		
Level 3: Extreme Concern	Severe assessment problems; very poor fits to important data; high level of uncertainty; very strong retrospective patterns, especially positive ones.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are extremely unusual; very rapid changes in trends, or highly atypical patterns compared to previous patterns.	Indicator(s) showing a combined frequency (low/high) and magnitude(low/high) to cause severe adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock) that are likely to impact the stock.	Multiple indicators with strong adverse signals related to biological status (e.g., stock abundance, distribution, fish condition), a) across different sectors, and/or b) different gear types.

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

1. "Assessment-related considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. "Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. "Ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

4. "Fishery-informed stock considerations—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings."

<u>Assessment-related considerations</u>
A key uncertainty in this assessment model is the starting biomass of this population. The model starts in 1945 to allow for the explicit inclusion of the early, large catch history (1960 – 1980) and to estimate the population age structure assuming no fishing pressure prior to 1960. The model estimates an initially small population in 1945 followed by large recruitment events to support the early catch history. During the September Plan Team meeting the authors showed that the large recruitment events are largely driven by the large observed catches between 1960 -1980 given that the first available length data is not until 1978 in the trawl fishery and 1987 from the EBS shelf bottom trawl survey (Appendix B, Figure 25). Additionally, the authors presented an exploratory model that initiated the population in 1986, which represents the start of the more data rich period of the model, and used the average catch from 1960 -

1985 to get initial estimated of fishing mortality. This exploratory model run demonstrated that the model would estimate the initial population to be much larger than what is currently being estimated (Appendix B, Figure 29). This suggests that there is considerable uncertainty in the estimate of initial population size and in turn stock status.

The data time series that have surveyed the adult portion of this stock and used in this assessment are becoming inconsistent. The lack of EBS slope bottom trawl survey data since 2016 and the impact of killer whale depredation on the AFSC longline survey, and the cancellation of the AFSC longline survey in 2023 add uncertainty in our understanding of the adult Greenland turbot population estimates.

All the candidate models showed positive retrospective patterns, highlighting that each new year of data resulted in a lower biomass estimate for this stock (Figure 5.36). In addition, jitter analyses and likelihood profiles highlighted considerable model instability. While these concerns were alleviated in the recommended model (m16.4c) compared to the alternative models, model diagnostics suggested that there are some substantial structural uncertainties.

Given the unaccounted for uncertainties in the assessment model, the retrospective patterns, and the concerns for model structural uncertainty and instability, we scored this category as Level 3.

Population dynamics considerations

The BSAI Greenland turbot stock is characterized by infrequent recruitment events. The last relatively strong cohorts in the population are from 2007-2009. As they have grown and matured, we saw an increase in total biomass and spawning biomass, which is now starting to decline. Given the frequency of past recruitment events, we would have expected another in recent years. However, recruitment has been below average since 2012 and fish younger than 4 years old had not been observed in the EBS shelf bottom trawl survey between 2018 and 2022. In 2023 and 2024 we see small individuals in the data and in the age database there are observations of age-1 unsexed fish in 2023. Since we do not have 2024 age data, it will be another year before we have a better understanding of cohort strength. The 2024 length composition data suggests that the strength of this potential cohort is likely small.

We score this category as Level 2 given the uncertainty in future recruitment levels.

Ecosystem considerations

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

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

Greenland turbot are considered to be more cold-adapted and distributed at greater depth than arrowtooth flounder and Kamchatka flounder. They are also considered more of an Arctic species, but the NBS is thought to be shallow enough that it creates a physical barrier to their northward movement during warm years. One hypothesis is that they will move deeper with warmer conditions over time, but current survey designs may not observe this well. The 2024 cold pool over the southern shelf was of average spatial extent, which indicates average conditions for juvenile recruitment based on a previously established positive correlation between the cold pool and juvenile recruitment (Barbeaux et al., 2016).

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

Metrics of ocean acidification include Ω_{arag} and pH. Summer 2024 bottom water Ω_{arag} conditions were similar to 2023 while pH was slightly more acidic; the most corrosive bottom waters were found in slope waters and over the northwest shelf (Pilcher et al., 2024).

Prey:
Juvenile Greenland turbot likely feed on zooplankton. Spring trends are likely more important for small life stages of turbot, as by late-summer the fish have settled out of the pelagic environment. The Rapid Zooplankton Assessment in the southeastern Bering Sea (SEBS) in spring noted moderate abundance of small copepods, but low abundance of large copepods along the middle shelf (higher in the outer shelf) and near-zero abundance of euphausiids in the RZA, which is typical for the spring (Kimmel et al., 2024).

The two predominant identified prey items of adult turbot are walleye pollock (presumably age-1) and squid. The estimated abundance of larval pollock sampled in spring increased from near the end of the last cold stanza (2012) through the warm stanza (2014, 2016, 2018) to a time-series maximum in 2024 (Rogers et al., 2024). By late summer, age-0 pollock CPUE estimates in the middle domain of the SEBS and NBS regions were lower than estimates from the recent warm period (2014–2021) but slightly higher than estimates from the cold period (2007–2013). In the inner domain, pollock were the most numerous non-salmonid species collected in the ADF&G nearshore survey (Garcia et al., 2024). In the NBS, CPUE estimates have remained low compared to the SEBS (Andrews et al., 2024). Since 2022, with cooler SSTs, pollock weights and energy density have been low while % lipid has been average (Page et al., 2024).

Condition metrics have not been regularly estimated for turbot during the bottom trawl survey, however, indicators of prey availability suggest few clear concerns about prey abundance for Greenland turbot.

Competitors:
Arrowtooth flounder, Kamchatka flounder, and Pacific halibut can be considered competitors based on overlap in their ecological niches as large upper-trophic predatory flatfish. These species are included within the apex predator guild. The biomass of apex predators measured during the standard bottom trawl survey in 2024 was nearly equal to their value in 2023 and below their long term mean (Siddon, 2024). Within that guild, turbot and Pacific halibut biomass declined while arrowtooth flounder increased 26% from 2023 to 2024 (Siddon, 2024). The increase in abundance of potential competition from arrowtooth flounder may be countered by spatial refuge as turbot prefer deeper habitats than arrowtooth flounder.

Taken together, trends in potential competitors do not indicate substantially increased competition for habitat or prey resources.

Predators:
Predators of juvenile turbot are not well known, but likely include fur seals, arrowtooth flounder, Pacific cod, skates, and sleeper sharks. Predators of adult turbot are also not well known, but likely include toothed whales. The apex predator guild includes Pacific cod and arrowtooth flounder and in 2024 was nearly equal to their value in 2023 and below their long term mean. Within the guild, Pacific cod decreased 5.5% from 2023 while arrowtooth flounder increased 26% (Siddon, 2024). Other predators of turbot include northern fur seals, skates, sleeper sharks, and toothed whales; unfortunately, no indicators of population trends for these species were available. Based on limited information available, trends in predator abundances suggest no increased predation concern for turbot in the southeastern Bering Sea.

Summary for *Environmental/Ecosystem considerations:*

- **Environment:** The EBS shelf experienced oceanographic conditions that were largely average based on historical time series of multiple metrics over the past year (August 2023 - August 2024). The cold pool was average in extent over the shelf.
- **Prey:** Indicators of prey availability suggest sufficient prey may have been available for Greenland turbot.
- **Competition:** Trends in potential competitors do not indicate substantially increased competition for habitat or prey resources.
- **Predation:** Based on limited information available, trends in predator abundances suggest no increased predation concern for turbot in the southeastern Bering Sea.

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

Fishery-informed stock considerations
The fishery for Greenland turbot peaked in 1981 (Table 5.1). Following this period, catch declined with increasing management regulations and lowering population biomass. The lowest TAC, 2,060 t, was specified in 2013 after several years of relatively high fishing. Catch has been quite low compared to 1970 and 1980s levels since 2013 and has been declining since 2020.

TAC was specified to be ~67% of ABC, on average, between 2015 and 2021 due to concerns about low future recruitment. In 2022 and 2023, TAC was set equal to ABC. Catch has been between 26% and 83% of the TAC since 2015. A total of 26%, 22%, and 32% of the TAC was caught in 2021-2023, respectively. The longline industry has reported that they have not been fishing for Greenland turbot over the last several years due to whale interactions which may help to explain why TAC is not achieved. Conversely, the trawl fleet has obtained between 81% and 99% of the Greenland turbot catch since 2019. Catch from the trawl fleet has been declining since 2019 and follows the decline population biomass; therefore, we score this category as Level 2.

Summary and ABC recommendation
Summarize the results of the previous subsections in a table.

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance considerations*
Level 3	Level 2	Level 1	Level 2

A reduction in maximum ABC may be warranted given the uncertainty about stock status, the loss of fishery-independent data in areas where the adult population is found, model structural uncertainty, uncertainty about future recruitment, and declining catch with a declining population. We suggest a 10% reduction in ABC from maximum ABC.

Area Allocation of ABC

In this assessment, the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions was adopted. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, the length compositions from the Aleutian Islands surveys appear to have few small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Since 2005 the majority of the catch has been from the EBS (Table 5.3).

Stock structure between regions remains uncertain and therefore the policy has been to harvest the "stock" proportionately by specifying region-specific ABCs. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportions of the adult biomass in the Aleutian Islands region over the surveys since 2010 when the last strong cohort was present in the population are 25% (2010), 12.6% (2012), and 9.0% (2016) and their average is 15.7%. The BSAI ABC was split between the EBS and the Aleutian Islands assuming 15.7% of the biomass is in the Aleutian Islands and gives the following region-specific allocation:

	2025 ABC	2026 ABC
Aleutian Islands ABC	316	250
Eastern Bering Sea ABC	1,697	1,344
Total	2,013	1,594

Status Determination

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

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2023) is 1,281 t. This is less than the 2023 OFL of 3,705 t. Therefore, the BSAI stock is not being subjected to overfishing.

Harvest scenarios 6 and 7 are intended to permit the determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest Scenarios 6 and 7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2025:

a. If spawning biomass for 2025 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
b. If spawning biomass for 2025 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2025 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$ the stock's status relative to MSST is determined by referring to the harvest scenario 6. If the mean spawning

biomass for 2036 is below $B_{35\%}$ the stock is below its MSST. Otherwise the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to the harvest scenario 7:

a. If the mean spawning biomass for 2026 is below ½ B35%, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2026 is above B35%, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2026 is above ½ B35% but below B35%, the determination depends on the mean spawning biomass in 2036. If the mean spawning biomass for 2036 is below B35%, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and projection results presented in Table 5.22, the stock is not being overfished and is not approaching an overfished condition. Spawning biomass in 2025 and 2026 is estimated to be 23,999 t and 22,061 t, which are greater than $B_{35\%}$ = 20,584 t. Figure 5.38 shows the relationship between the ratio of historical fishing mortality and female spawning biomass for Greenland turbot from 1960-2024.

F_{limit}

The F that would have produced a catch for last year equal to last year's (2023) OFL was 0.212.

Ecosystem Considerations

Ecosystem Effects on the Stock

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970's. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, the plausibility of this scenario is speculation. Several major predators on the shelf were at relatively low stock sizes during the late 1970's (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid-1980's. Perhaps this shift in abundance has reduced the survival of juvenile Greenland turbot in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

The most recent large recruitment events 2007-2009 occurred during a series of years (2006-2013) in which the average bottom temperatures on the shelf were measurably colder on average and the area of cold water (< 2°C) on the Bering Sea Shelf was large (Zador *et al.* 2014). A simple Student's T test of the log recruitment by mean bottom temperatures on the EBS shelf (Barbeaux et al. 2016) as calculated by Spencer (2008) show a significant correlation (df = 31, $R^2 = 0.2389$, p-value = 0.0023) suggesting that favorable recruitment of Greenland turbot is dependent on colder overall bottom temperatures or larger areas with colder temperatures. Greenland turbot suitable settlement habitat is likely increased with the increase in the size of the area of the shelf < 2°C. Whether this is due to lessening competition, increased prey, or decreased predation is unknown. Foods habits data collected between 2001 and 2008 that the most frequent prey for Greenland turbot on the EBS shelf are walleye Pollock (Barbeaux et al. 2016) indicate. However temperature may be a much better predictor for Greenland turbot recruitment than pollock recruitment.

Fishery Effects on the Ecosystem

The Greenland turbot fishery has been rather small, less than 5,000 t annually since 2002, in comparison with the major Bering Sea longline and trawl gadid and yellowfin sole fisheries. The direct impact of the fishery on the ecosystem besides catch of Greenland turbot is through bycatch. FMP managed species bycatch in the Greenland turbot fishery can be found in Table 5.23. The highest bycatch has been of arrowtooth flounder (*Atheresthes stomias*) and sablefish (*Anoplopoma fimbria*), a low impact given the biomass of these species. Bycatch of Kamchatka flounder (*A. evermanni*) follows arrowtooth and sablefish. The non-FMP bycatch are summarized in Table 5.24 and Table 5.25. Bycatch of prohibited species by gear type are summarized in Table 5.26 and Table 5.27. Grenadiers have been the highest non-FMP bycatch species in the Greenland turbot fishery, the impact to the ecosystem is thought to be minimal. Bird bycatch in the Greenland turbot fishery is limited to the longline fishery with a total of 3,922 estimated to have been caught since 2003. Northern fulmars (*Fulmarus glacialis*) are the most often captured with a total of 3,060 estimated to have been caught since 2003 (Table 5.24, Table 5.25). It is estimated that 6 endangered short-tailed albatross (*Phoebastria albatrus*) were killed incidental to the Bering Sea Greenland turbot hook-and-line fishery in 2014 based on the observed take of 2 short-tailed albatross (NMFS CAS). Despite documented interactions in the Bering Sea and Aleutian Islands groundfish fisheries, the short-tailed albatross population has been increasing at an estimated rate of 5.2 to 9.4 percent per year since 2000 (USFWS 2014) and interactions in the fishery appear to be extremely rare. NMFS monitors the fisheries for interactions with short-tailed albatross and requires use of seabird avoidance gear in the hook and line fisheries to make it unlikely that the fisheries will reduce the recovery of the short-tailed albatross population.

Data Gaps and Research Priorities

A number of assessment and research issues continue to require further consideration:

- The authors suggest continued exploration of the modeling assumptions presented in alternative models 24.1 and 24.2, while improving stability. The instability of the alternative models appeared to be most often due to difficulty in estimating the selectivity parameters. Therefore, continued effort to simplify selectivity is recommended.
- Future work should explore alternative model start dates to obtain a better understanding about our uncertainty in stock status and as a potential for improved model fit to the data sources.
- The afscISS R package should be used to provide initial input sample size for survey composition data during the next full assessment.
- Updating the maturity ogives is a priority for this stock. Funding to conduct an updated maturity study was secured in 2020, but was cancelled due to the global pandemic. The lead author and Todd TenBrink (AFSC, REFM, Age and Growth Program) had a special project supported by the NMFS Observer Program in 2024 where observers collected maturity specimens. The number of samples collected is unknown at this time.
- The survey data for this the adult portion of this stock is becoming more inconsistent. The eastern Bering Sea slope survey has not been conducted since 2016 and the AFSC longline survey was not conducted in 2024. Continued loss of data collected in adult habitat will further increase the uncertainty in the stock status of this population.

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Tables

Table 5.1. Catch estimates of Greenland turbot by gear type (t; including discards), ABC and TAC values since implementation of the MFCMA, and the annual proportion of ABC and TAC achieved. *Catch estimated as of September 2024.

Year	Trawl	Longline/Fixed gear	Total	ABC	TAC	Percent ABC	Percent TAC
1977	29,722	439	30,161	40,000	-	75	-
1978	39,560	2,629	42,189	40,000	-	105	-
1979	38,401	3,008	41,409	90,000	-	46	-
1980	48,689	3,863	52,552	76,000	-	69	-
1981	53,298	4,023	57,321	59,800	-	96	-
1982	52,090	32	52,122	60,000	-	87	-
1983	47,529	29	47,558	65,000	-	73	-
1984	23,107	13	23,120	47,500	-	49	-
1985	14,690	41	14,731	44,200	-	33	-
1986	9,864	0	9,864	35,000	33,000	28	30
1987	9,551	34	9,585	20,000	20,000	48	48
1988	6,827	281	7,108	14,100	11,200	50	63
1989	8,293	529	8,822	20,300	6,800	43	130
1990	12,119	577	12,696	7,000	7,000	181	181
1991	6,246	1,618	7,863	7,000	7,000	112	112
1992	749	3,003	3,752	7,000	7,000	54	54
1993	1,145	7,325	8,470	7,000	7,000	121	121
1994	6,427	3,846	10,272	7,000	7,000	147	147
1995	3,979	4,216	8,194	7,000	7,000	117	117
1996	1,653	4,903	6,556	7,000	7,000	94	94
1997	1,210	5,990	7,200	9,000	9,000	80	80
1998	1,576	7,181	8,757	15,000	15,000	58	58
1999	1,795	4,058	5,853	9,000	9,000	65	65
2000	1,947	5,027	6,974	9,300	9,300	75	75
2001	2,149	3,164	5,312	8,400	8,400	63	63
2002	1,033	2,603	3,636	8,000	8,000	45	45
2003	931	2,181	3,111	4,000	4,000	78	78
2004	675	1,583	2,259	4,740	3,500	48	65
2005	729	1,880	2,608	3,930	3,500	66	75
2006	361	1,628	1,989	2,740	2,740	73	73
2007	458	1,546	2,004	2,440	2,440	82	82
2008	1,935	976	2,911	2,540	2,540	115	115
2009	3,080	1,435	4,515	7,380	7,380	61	61

Table 5.1 continued.

Year	Trawl	Longline & Pot	Total	ABC	TAC	Percent ABC	Percent TAC
2010	1,977	2,158	4,136	6,120	6,120	68	68
2011	1,618	2,054	3,671	6,140	5,060	60	73
2012	2,613	2,054	4,667	9,660	8,660	48	54
2013	1,045	683	1,728	2,060	2,060	84	84
2014	951	684	1,635	2,124	2,124	77	77
2015	1,095	1,092	2,187	3,172	2,648	69	83
2016	1,228	1,008	2,236	3,462	2,873	65	78
2017	1,838	995	2,833	6,644	4,500	43	63
2018	1,550	285	1,834	11,132	5,294	16	35
2019	2,316	545	2,860	9,658	5,294	30	54
2020	2,035	291	2,326	9,625	5,300	24	44
2021	1,582	14	1,596	7326	6,025	22	26
2022	1,454	24	1,478	6,572	6,572	22	22
2023	1,235	46	1,281	3,960	3,960	32	32
2024*	740	12	751	3,188	3,188	-	-

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates a) overall and b and c) by "target" fishery, 1992-2024. 2024 numbers are estimates through October and are not final.

a)

Year	Discarded	Retained	Total	Discard rate
1991	2504	5360	7863	0.32
1992	3059	694	3752	0.82
1993	1787	6683	8470	0.21
1994	3232	7040	10272	0.31
1995	2405	5789	8195	0.29
1996	1823	4733	6556	0.28
1997	1660	5540	7200	0.23
1998	945	7813	8757	0.11
1999	729	5124	5853	0.12
2000	791	6184	6974	0.11
2001	921	4391	5312	0.17
2002	701	2934	3636	0.19
2003	534	2578	3111	0.17
2004	376	1882	2259	0.17
2005	249	2359	2608	0.10
2006	211	1778	1989	0.11
2007	299	1705	2004	0.15
2008	704	2207	2911	0.24
2009	461	4053	4515	0.10
2010	235	3901	4136	0.06
2011	94	3577	3671	0.03
2012	94	4573	4667	0.02
2013	345	1383	1728	0.20
2014	251	1384	1635	0.15
2015	113	2074	2187	0.05
2016	84	2152	2236	0.04
2017	100	2733	2833	0.04
2018	75	1760	1834	0.04
2019	62	2798	2860	0.02
2020	82	2244	2326	0.04
2021	47	1549	1596	0.03
2022	75	1404	1478	0.05
2023	71	1210	1281	0.06
2024	19	724	743	0.03

Table 5.2 continued

b) Trawl

	Arrowtooth Flounder		Kamchatka		Flathead Sole		Greenland turbot	
Year	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained
1991	198	233					185	2499
1992		6						
1993							3	9
1994							283	5173
1995					20	2	213	2962
1996					42	141	49	290
1997					85	212	33	449
1998	86	40			63	453	57	293
1999	76	131			56	359	66	627
2000	93	260			67	510		586
2001	149	201			171	515	21	296
2002	118	225			22	64	26	116
2003	52	129			13	64		206
2004	19	37			86	103	1	57
2005	8	146			14	136		24
2006	5	16			2	27		
2007		3			16	42	0	2
2008	414	762			8	91		205
2009	285	1150			7	42	30	1320
2010	80	1610			2	11		118
2011	6	886	11	580	0	2	0	4
2012	8	919	4	1347	1	45		
2013	175	560	33	76	15	24	0	3
2014	127	497	2	101	13	5	0	14
2015	24	760	0	86	13	47	0	19
2016	4	464	0	95	1	53	3	484
2017	5	217	5	288	1	114	12	1059
2018	6	113	8	160	2	7	7	1096
2019	2	172	5	331	3	186	13	1334
2020	4	247	27	832	0	15	5	530
2021	2	230	15	511	2	169	4	347
2022	1	63	17	509	8	295	12	278
2023	2	100	8	514	1	152	1	40
2024	1	102	1	123	0	10	0	8

Table 5.2 continued

Trawl

	Other Flatfish		Rock Sole		Yellowfin Sole		Atka Mackerel	
Year	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained
1991	0						28	23
1992	0	4		3			11	23
1993	152	16	26	2	5		116	2
1994	191	16	39	11	5		13	32
1995	10		3		64	3	10	27
1996	14	26		3	6	2	88	129
1997		1	2		4		7	12
1998	65	17	0	1	33	70	44	27
1999	121	52		0	16	54	42	112
2000	9	48	1	1	6	17	43	161
2001	6	11	5	10	6	27	21	50
2002	36	11			2	0	10	94
2003	3	1		1	1	3	48	87
2004	22	27	0	4			41	82
2005	4	29	1		6	0	37	130
2006		1	3	24	8		32	85
2007	5	7	3	5	1		12	118
2008		4			0	0	82	119
2009		4	1		2	2	2	116
2010		1	2		0	1	1	61
2011			1	0	4	2	3	61
2012			0		4	2	7	203
2013		4	2	0	25	10	2	38
2014			3	2	35	22	0	44
2015	0	2	0	0	20	22	0	24
2016	0	2	0		4	4	1	45
2017	1	26			7	2	0	45
2018	1	1			3	23	5	23
2019	1	43			0	6	6	43
2020	0	23			4	8	4	15
2021	1	82			1	4	4	53
2022	0	31			2	3	1	23
2023	0	70			4	7	0	3
2024	0	5			0	1	1	59

Table 5.2 continued

b) Trawl

Year	Pacific Cod		Pollock - bottom		Pollock - midwater		Rockfish		Sablefish	
	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain
1991	34	1	132	13	59	4	20	4		
1992	67	15	49	24	201	61	101	180		
1993	41	23	12	7	66	0	78	566		
1994	44	17	12	0	48	1	33	315	182	12
1995	85	4	37		57	1	25	359	71	4
1996	85	2	20		26	13	96	597		
1997	30	44	19		99	6	4	202		
1998	93	18	31	14	88	41	0	21		
1999	9	14	2		11	15	2	23		
2000	34	24	9	1	23	17	1	38		
2001	25	56	4	13	21	30	30	429	39	11
2002	26	27	32	8	8	22	17	169		
2003	42	37	0	2	7	31	5	198		
2004	50	31	0	0	9	9	2	81		12
2005	12	4		1	12	18	5	134		
2006	15	6		1	14	50	8	66		
2007	56	34		2	36	68	13	34		
2008	8	2	2	11	20	52	1	142		5
2009	1	1		4	11	29	6	66		
2010	3	5		3	7	14	2	56		
2011	0	0		5	6	18	1	27		
2012	1	0		6	17	31	2	17		
2013	2	0	1	3	5	12	6	48		
2014	2		4	22	3	12	1	40		
2015	0	1		6	5	30	1	34		
2016	0	11		11	4	13	0	27	0	
2017				10	1	6	0	37	0	
2018	4		1	17	1	11	2	51	0	7
2019	0	7	0	18	3	15	6	112	0	9
2020			2	117	8	21	15	150	0	9
2021	0		1	38	0	1	4	111	0	2
2022	3		1	22		0	5	87	1	91
2023	7	0		34	0	4	2	166	2	118
2024				11	0	5	3	160	4	238

Table 5.2 continued

c) Fixed gear

Year	Greenland Turbot Discard	Greenland Turbot Retain	Halibut Discard	Halibut Retain	Pacific Cod Discard	Pacific Cod Retain	Rockfish Discard	Rockfish Retain	Sablefish Discard	Sablefish Retain
1991	40	6			365	14	1	1	13	2
1992	3	8			569	174	2	1	167	105
1993	122	243			213	134	11	8	265	136
1994	28	50			375	225	5	2	264	181
1995	74	114			410	127	3	8	173	102
1996	70	111			431	131	12	6	179	124
1997	84	132			530	119	4	2	138	102
1998	132	263			346	228	3	3	59	50
1999	64	173			268	172	1	7	97	98
2000	94	172			330	243		2	158	142
2001	41	104			399	251		2	131	122
2002	43	88			291	253	13	6	158	170
2003	60	109	81	45	271	301	1		120	90
2004	33	85	54	29	283	192	2	3	102	109
2005	33	78	29	15	206	249	1	3	80	94
2006	32	74	32	22	202	141	3	3	114	74
2007	38	54	28	10	187	129	1	1	113	58
2008	10	41	74	7	332	44			94	59
2009	41	67		2	246	135	1	1	166	98
2010	54	99	75	6	155	76	1	2	119	91
2011	22	65	45	4	272	109		1	115	80
2012	41	75	48	1	109	81	1	1	83	82
2013	26	31	216	9	82	23	2	3	70	66
2014	22	24	49	3	189	33	2	2	54	16
2015	38	40	71	2	226	34	2		15	10
2016	41	46	392	3	488	43	2	2	47	4
2017	46	55	73		463	169			58	7
2018	14	23	303		319	183		1	44	3
2019	12	22	156	1	224	141		2	30	3
2020	10	20	94	2	283	102		1	52	3
2021			2	2	135	13		1	50	1
2022			158	1	144	6			142	1
2023			128	1	200	23			229	4
2024			21	2	71	7			55	

Table 5.3. Estimates of Greenland turbot catch (t) by area based on NMFS Regional Office estimates, 1991-2024. The 2024 values are estimates through October 2024.

Year	AI	BS	Grand Total
1991	3,465	4,398	7,863
1992	1,290	2,462	3,752
1993	2,137	6,332	8,470
1994	3,131	7,141	10,272
1995	2,338	5,856	8,194
1996	1,712	4,844	6,556
1997	764	6,435	7,200
1998	682	8,075	8,757
1999	467	5,386	5,853
2000	1,086	5,888	6,974
2001	1,060	4,253	5,312
2002	485	3,151	3,636
2003	700	2,412	3,111
2004	434	1,825	2,259
2005	468	2,140	2,608
2006	537	1,453	1,989
2007	523	1,481	2,004
2008	822	2,089	2,911
2009	2,263	2,252	4,515
2010	1,868	2,268	4,136
2011	535	3,136	3,671
2012	1,657	3,010	4,667
2013	294	1,434	1,728
2014	165	1,470	1,635
2015	105	2,082	2,187
2016	122	2,113	2,236
2017	122	2,711	2,833
2018	163	1,671	1,834
2019	174	2,686	2,860
2020	678	1,648	2,326
2021	467	1,130	1,596
2022	440	1,038	1,478
2023	484	797	1,281
2024*	300	442	743

Table 5.4. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1991-2024. Source: NMFS observer program data. The % female do not include unidentified fish.

	Trawl				Fixed			
Year	Female	Male	Unknown	%Female	Female	Male	Unknown	%Female
1991	1851	1752	9295	51	0	0	0	
1992	0	0	0		0	0	71	
1993	0	0	425		3921	915	12464	81
1994	1024	1027	5150	50	503	150	1200	77
1995	245	363	3528	40	1870	715	5316	72
1996	112	390	0	22	941	442	7482	68
1997	0	0	0		2393	1014	14833	70
1998	307	696	822	31	3510	2127	22794	62
1999	1044	1556	0	40	7875	2877	266	73
2000	724	1328	25	35	6550	2962	73	69
2001	467	892	43	34	4054	1550	271	72
2002	186	433	0	30	4725	1811	40	72
2003	197	325	1	38	4624	2113	2	69
2004	179	433	10	29	4340	2612	1	62
2005	118	211	0	36	4650	1902	43	71
2006	15	76	0	16	3339	1474	32	69
2007	34	23	0	60	3816	2127	134	64
2008	421	1572	1	21	1577	1481	0	52
2009	1017	2993	26	25	3492	2709	39	56
2010	298	3562	174	8	3290	2860	108	53
2011	853	2025	37	30	2494	1694	7	60
2012	1742	3153	14	36	3141	2292	69	58
2013	1268	1367	2	48	1087	675	0	62
2014	1150	1571	3	42	1022	1077	0	49
2015	928	1803	1	34	1593	1070	19	60
2016	1011	2057	2	33	1702	1069	36	61
2017	1486	3342	625	31	1185	947	2	56
2018	1256	1980	5	39	662	388	0	63
2019	995	3616	3	22	808	449	0	64
2020	806	2451	1	25	401	119	0	77
2021	1483	2961	80	33	7	2	0	78
2022	713	1535	0	32	0	0	3	
2023	343	1487	2	19	0	0	0	
2024*	212	741	0	22	0	0	0	

Table 5.5. Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands, 1979-2024. The Aleutian Islands surveys prior to 1990 used different operational protocols and may not compare well with subsequent surveys, the Aleutian Islands survey is not used in the stock assessment model.

Year	Shelf	Slope	Aleutian Islands
1979		123,000	
1980			3,598*
1981		99,600	
1982	39,603	90,600	
1983	24,557		9,684*
1984	17,791		
1985	10,990	79,200	
1986	5,654		31,759*
1987	11,745		
1988	13,306	42,700	
1989	13,173		
1990	16,145		
1991	12,440	40,500	11,925
1992	28,542		
1993	35,566		
1994	56,997		28,235
1995	37,516		
1996	40,496		
1997	35,196		28,343
1998	34,793		
1999	21,459		
2000	23,101		9,359
2001	27,199		
2002	23,917	27,409	9,891
2003	30,916		
2004	28,199	36,759	11,334
2005	21,230		
2006	20,858		20,934
2007	16,670		
2008	13,464	17,581	
2009	10,919		
2010	23,339	20,046	6,758
2011	26,095		
2012	21,733	18,019	2,600
2013	24,836		
2014	27,953		2,529
2015	25,176		
2016	22,357	24,803	2,378
2017	21,452		
2018	17,966		373
2019	16,008		
2021	10,690		
2022	7,869		539
2023	5,857		
2024	4,959		604

Table 5.6 Eastern Bering Sea slope survey estimates of Greenland turbot biomass (t) and numbers by depth category in 2002, 2004, 2008, 2010, 2012, and 2016.

Depth (m)	2002	2004	2008	2010	2012	2016
200-400	4,082	2,889	4,423	1,170	2,279	860
400-600	14,527	25,562	6,679	10,524	10,367	15,528
600-800	4,736	5,316	4,276	5,235	3,897	5,421
800-1000	2,173	1,800	1,448	2,038	1,019	1,256
1000-1200	1,891	1,192	755	1,079	456	1,738
Total	27,409	36,759	17,581	20,046	18,019	24,803

Depth (m)	2002	2004	2008	2010	2012	2016
200-400	994,449	745,401	1,740,600	422,725	3,186,079	339,322
400-600	3,794,888	4,927,418	1,967,103	3,491,729	7,080,826	6,997,625
600-800	1,074,403	1,000,540	1,200,519	1,330,888	1,110,855	1,591,302
800-1000	501,459	360,764	272,578	432,120	233,422	332,886
1000-1200	360,811	222,697	126,497	225,909	91,540	410,917
Total	6,726,010	7,256,820	5,307,297	5,903,371	11,702,722	9,672,052

Table 5.7. Eastern Bering Sea slope survey estimates of Greenland turbot biomass and numbers by stratum in 2002, 2004, 2008, 2010, 2012, and 2016.

	Population biomass (t)						Population numbers (millions)					
Year	1	2	3	4	5	6	1	2	3	4	5	6
2002	15,565	2,313	1,721	2,315	1,275	4,221	3.56	0.73	0.43	0.59	0.44	0.98
2004	24,792	2,186	1,062	1,732	750	6,238	4.65	0.62	0.24	0.43	0.15	1.17
2008	6,253	2,239	896	1,362	558	6,272	1.43	0.74	0.19	0.30	0.19	2.45
2010	7,460	2,171	838	2,056	680	6,842	1.97	0.66	0.25	0.51	0.25	2.26
2012	5,600	1,990	696	1,060	661	8,012	1.71	0.74	0.23	0.39	0.25	8.38
2016	5,524	2,437	1,266	2,636	4,402	8,539	1.74	0.78	0.33	0.83	2.18	3.81

Table 5.8. EBS shelf bottom trawl survey total haul count, catch count, biomass (t) and abundance (numbers) estimates and the corresponding standard deviations, and number of hauls with length samples.

Year	Haul Count	Catch Count	Biomass	Stdev	Numbers	Stdev	Number of hauls with length samples
1987	357	45	11,745	2,570	21,916,509	3,013,516	33
1988	373	63	13,306	3,098	29,102,468	5,708,312	58
1989	374	69	13,173	2,455	25,456,908	3,281,791	56
1990	371	78	16,145	4,328	28,842,650	4,048,350	62
1991	372	73	12,440	2,734	33,208,464	4,465,508	65
1992	356	73	28,542	6,090	30,877,550	4,505,782	64
1993	375	73	35,566	4,867	26,349,976	3,306,628	73
1994	375	53	56,996	11,711	23,022,217	4,180,691	52
1995	376	49	37,516	7,706	13,954,145	2,670,244	49
1996	375	75	40,496	5,314	13,755,784	1,727,589	75
1997	376	66	35,196	6,358	12,787,256	2,461,010	64
1998	375	73	34,793	4,347	12,504,380	1,751,108	73
1999	373	47	21,459	4,228	6,700,783	1,309,319	43
2000	372	61	23,101	4,552	7,946,335	1,145,103	57
2001	375	58	27,199	4,801	8,104,076	1,213,682	58
2002	375	70	23,917	4,787	13,485,063	3,167,251	70
2003	376	71	30,916	5,056	16,952,448	2,205,570	71
2004	375	64	28,199	4,414	17,761,824	2,452,894	64
2005	373	63	21,230	3,255	13,609,758	2,332,141	61
2006	376	56	20,858	3,361	11,439,309	1,717,369	56
2007	376	84	16,670	2,682	14,039,039	1,827,161	84
2008	375	79	13,464	2,902	15,089,018	2,056,510	78
2009	376	104	10,919	2,112	22,218,702	2,343,873	103
2010	376	145	23,339	3,970	137,268,464	14,593,549	144
2011	376	156	26,094	2,761	143,299,587	13,903,499	155
2012	376	110	21,733	2,951	61,188,158	6,515,801	109
2013	376	96	24,836	3,899	43,820,855	6,232,076	96
2014	376	96	27,953	3,672	30,159,806	3,819,879	95
2015	376	78	25,176	3,246	21,207,584	2,696,365	78
2016	376	80	22,357	2,997	14,089,149	1,635,006	80
2017	376	67	21,452	2,658	10,486,627	1,276,258	67
2018	376	77	17,966	2,005	7,340,786	798,778	77
2019	376	66	16,008	1,883	5,087,813	595,898	66
2021	376	48	10,690	1,801	2,747,987	420,328	48
2022	376	38	7,869	1,349	1,988,411	298,030	38
2023	376	40	5,857	1,048	3,742,560	737,924	40
2024	350	26	4,959	1,085	1,594,616	287,903	26

Table 5.9. Biological sampling statistics for Greenland turbot from the EBS shelf survey. Note that in 1982-1984, and 1986 the northwestern stations were not sampled.

Year	Total hauls	Length samples	Hauls with otoliths	Hauls with ages	Number of otoliths	Number ages
1982	334	1228	11	11	292	292
1983	353	951				
1984	355	536	20		263	
1985	356	200				
1986	354	195				
1987	357	290				
1988	373	414				
1989	374	376				
1990	371	544				
1991	372	658				
1992	356	616	5		7	
1993	375	632	7		179	
1994	375	530	17		196	
1995	376	343				
1996	375	450	8		100	
1997	376	298	11		79	
1998	375	445	25	21	178	127
1999	373	128	8		11	
2000	372	248	34		188	
2001	375	270	43		215	
2002	375	455	21		71	
2003	376	622	62	62	435	407
2004	375	606	45	45	290	280
2005	373	441	57	56	293	277
2006	376	427	48	48	260	239
2007	376	501	68	68	334	311
2008	375	406	59	59	245	235
2009	376	856	72	71	351	344
2010	376	3199	70	69	362	358
2011	376	3721	61	59	427	381
2012	376	2133	62	62	418	408
2013	376	1160	63	63	382	374
2014	376	973	59	57	359	340
2015	376	771	60	60	380	368
2016	376	505	74	71	335	316
2017	376	373	43	42	234	217
2018	376	249			203	191
2019	376	165			117	109
2021	376	97			96	92
2022	376	73			70	66
2023	376	127			84	75
2024	350	53				

Table 5.10. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot a) numbers and b) biomass (t), 1980-2024.

a)

Year	Western Aleutians	Central Aleutians	Eastern Aleutians	Southern Bering Sea	Grand Total
1980	0	232,804	924,561	9,881	1,167,246
1983	118,107	820,058	1,591,480	280,410	2,810,055
1986	593,934	519,528	7,122,791	2,614,622	10,850,875
1991	500,420	712,719	1,796,765	316,486	3,326,390
1994	881,506	929,025	3,994,288	1,952,614	7,757,433
1997	498,354	896,440	8,493,220	81,841	9,969,855
2000	181,735	593,387	1,816,919	146,309	2,738,350
2002	120,372	432,377	2,404,722	138,672	3,096,143
2004	471,895	742,596	758,643	990,203	2,963,337
2006	440,137	349,587	4,054,808	349,346	5,193,878
2010	276,593	332,759	1,198,540	136,532	1,944,424
2012	189,068	215,029	57,716	25,824	487,637
2014	147,713	142,076	126,252	152,591	568,632
2016	0	132,234	423,147	364,626	920,007
2018	36,955	17,372	0	0	54,327
2022	32,852	65,176	69,721	9,560	177,309
2024	8,887	109,380	98,278	13,077	229,622

b)

Year	Western Aleutians	Central Aleutians	Eastern Aleutians	Southern Bering Sea	Grand Total
1980	0	799	2,720	79	3,598
1983	525	2,328	5,737	1,094	9,684
1986	1,747	2,495	19,580	7,937	31,759
1991	2,195	3,320	4,607	1,803	11,925
1994	2,401	4,007	15,862	5,966	28,235
1997	2,146	3,130	22,708	359	28,343
2000	839	2,351	5,703	467	9,359
2002	793	1,658	6,996	444	9,891
2004	2,588	2,948	2,564	3,234	11,334
2006	1,973	1,937	15,742	1,282	20,934
2010	1,071	1,507	3,695	486	6,758
2012	1,091	1,231	181	98	2,600
2014	553	989	490	497	2,529
2016	0	424	970	984	2,378
2018	321	53	0	0	373
2022	62	169	260	21	512
2024	18	320	235	32	604

Table 5.11. Alaska Fisheries Science Center longline survey relative population numbers (RPNs) for Greenland turbot biomass by year and region.

Year	Bering 1 slope	Bering 2 slope	Bering 3 slope	Bering 4 slope	NE Aleutians slope	NW Aleutians slope	SE Aleutians slope	SW Aleutians slope
1996					0	0	2,535	7,772
1997	13,002	27,180	7,121	9,913				
1998					20,749	6,473	2,133	6,541
1999	9,600	31,445	6,951	11,186				
2000					11,529	3,596	1,356	4,158
2001	4,905	27,095	6,337	14,032				
2002					9,571	2,986	1,638	5,022
2003	5,956	24,982	4,270	9,810				
2004					7,512	2,343	1,120	3,433
2005	2,165	15,624	2,433	3,215				
2006					2,751	858	694	2,128
2007	1,199	12,313	2,256	1,251				
2008					2,885	900	373	1,143
2009	2,495	19,651	643	2,956				
2010					1,751	546	200	613
2011	1,768	10,600	795	1,427				
2012					3,919	1,222	378	1,158
2013	2,836	12,070	3,149	1,430				
2014					3,570	1,114	220	675
2015	4,393	13,355	546	2,636				
2016					2,126	663	42	130
2017	5,931	9,128	2,602	2,557				
2018					2,075	647	623	1,911
2019	108	7,795	852	1,197				
2020					3,467	1,081	60	184
2021	1,458	11,008	1,791	1,119				
2022					1,795	560	140	428
2023	92	7,134	1,101	1,952				

Table 5.12 Summary of the length-at-age information of females used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods). Top is average length and bottom is sample number.

	EBS Shelf														
	Year														
Age	1982	1998	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	16.8	17.7	15.7	15.0	0.0	0.0	12.2	12.8	15.0	14.1	16.4	14.2	16.1	0.0	0.0
2	24.5	24.9	22.4	21.8	25.0	24.3	22.5	18.9	22.0	23.2	23.7	23.3	22.8	21.3	22.5
3	32.7	33.1	29.7	29.9	32.2	30.3	30.0	23.1	29.7	30.2	32.2	32.1	29.3	28.5	32.4
4	40.3	32.0	33.4	34.6	35.9	39.0	39.5	28.5	33.3	34.6	37.1	36.8	36.3	32.6	37.9
5	46.4	35.0	39.0	40.9	42.6	38.0	46.2	34.5	35.5	38.0	41.6	42.3	38.3	40.5	44.3
6	48.1	0.0	47.0	43.1	48.8	42.7	47.0	44.0	0.0	42.0	46.2	46.0	43.5	46.3	50.4
7	52.5	0.0	43.7	53.0	53.3	46.6	50.7	50.1	56.0	67.0	46.5	54.8	48.8	48.7	54.5
8	0.0	0.0	50.0	57.0	62.5	54.5	54.7	53.3	56.0	0.0	57.0	47.5	52.6	57.6	55.1
9	0.0	0.0	57.5	0.0	62.0	57.9	59.8	53.8	59.6	0.0	72.0	0.0	54.5	56.1	60.8
10	0.0	65.8	51.0	70.3	67.5	65.7	62.3	59.0	63.8	62.3	65.0	69.5	0.0	66.3	62.4
11	0.0	65.0	60.0	83.0	86.0	62.0	63.0	60.3	64.0	73.0	68.7	74.0	73.0	61.0	74.0
12	0.0	78.7	78.3	78.3	77.0	71.0	62.0	70.5	0.0	67.3	0.0	75.0	0.0	75.0	82.3
13	0.0	0.0	83.7	85.6	88.0	56.5	65.0	69.7	74.5	69.5	71.5	77.0	79.3	72.0	79.8
14	0.0	75.0	83.2	83.8	81.3	77.0	0.0	0.0	78.0	73.5	0.0	80.0	78.0	0.0	0.0
15	0.0	0.0	80.0	87.2	85.5	78.0	61.7	70.0	0.0	0.0	77.0	0.0	0.0	82.0	83.0
16	0.0	76.0	84.2	82.0	0.0	84.7	80.0	84.5	0.0	80.0	0.0	0.0	0.0	86.0	0.0
17	0.0	81.0	86.4	85.2	85.0	86.3	90.0	71.0	0.0	0.0	0.0	75.0	0.0	0.0	85.0
18	0.0	0.0	85.7	91.7	92.0	88.7	85.0	92.7	0.0	97.0	66.0	84.0	85.0	0.0	0.0
19	0.0	0.0	90.7	92.5	84.6	87.6	91.7	91.0	88.0	0.0	0.0	0.0	0.0	93.0	79.0
20	0.0	80.3	89.6	89.5	90.2	90.3	89.0	66.0	90.5	0.0	87.0	81.0	81.0	81.0	0.0
21	0.0	82.0	90.0	90.7	89.0	91.0	90.7	83.0	87.7	0.0	93.5	0.0	0.0	0.0	0.0
22	0.0	0.0	88.0	0.0	87.0	90.0	0.0	89.5	94.0	94.5	0.0	0.0	90.0	98.0	0.0
23	0.0	79.0	90.2	96.5	82.0	88.0	87.0	0.0	92.5	80.5	0.0	85.0	0.0	92.0	0.0
24	0.0	79.0	90.0	97.0	88.0	0.0	0.0	94.0	100.0	0.0	0.0	100.0	0.0	0.0	91.0
25	0.0	79.0	91.3	91.0	86.8	88.5	0.0	88.0	89.0	0.0	99.0	0.0	88.0	0.0	0.0
26	0.0	95.0	92.3	94.5	96.5	0.0	92.0	0.0	93.0	88.0	0.0	0.0	89.0	98.5	100.0
27	0.0	0.0	93.7	85.7	0.0	0.0	0.0	0.0	83.0	0.0	81.7	97.5	0.0	0.0	0.0
28	0.0	0.0	92.0	91.0	0.0	0.0	0.0	95.0	93.3	0.0	0.0	0.0	0.0	95.3	0.0
29	0.0	0.0	91.8	0.0	0.0	0.0	92.0	91.0	0.0	93.0	86.0	0.0	0.0	0.0	0.0
30	0.0	0.0	91.0	0.0	88.0	107.0	90.0	93.0	89.8	92.0	96.0	0.0	91.0	98.8	75.0
N1	20	3	3	1	0	0	18	16	6	38	9	17	11	0	0
N2	33	18	30	5	1	3	4	17	41	54	76	40	30	3	11
N3	33	7	37	29	10	3	1	8	29	22	33	49	16	10	12
N4	38	1	16	10	38	2	2	2	10	7	16	31	24	10	23
N5	14	2	24	21	31	11	17	2	2	2	17	23	41	30	28
N6	9	0	3	7	13	16	17	1	0	1	6	13	20	25	22
N7	4	0	3	3	9	25	18	7	3	1	2	5	18	38	30
N8	0	0	6	1	6	19	15	4	1	0	1	2	9	23	23
N9	0	0	2	0	1	10	12	4	9	0	2	0	2	12	12
N10	0	5	1	4	2	3	6	7	4	4	2	2	0	4	9
N11	0	5	2	2	1	1	1	4	4	4	3	3	1	3	2
N12	0	3	3	4	3	6	3	2	0	8	0	1	0	3	3
N13	0	0	3	5	1	2	7	3	2	2	4	1	3	1	4
N14	0	1	5	5	3	1	0	0	2	4	0	1	1	0	0
N15	0	0	1	6	2	2	3	2	0	0	1	0	0	3	2
N16	0	2	5	4	0	3	1	2	0	1	0	0	0	1	0
N17	0	1	7	6	2	4	4	3	0	0	0	2	0	0	1
N18	0	0	6	3	3	3	1	3	0	1	1	2	1	0	0
N19	0	0	6	2	5	5	3	1	1	0	0	0	0	1	1
N20	0	3	9	2	5	6	3	1	2	0	1	1	1	1	0
N21	0	1	5	3	2	2	3	1	3	0	2	0	0	0	0
N22	0	0	4	0	1	2	0	2	1	2	0	0	1	1	0
N23	0	1	6	2	1	1	1	0	4	2	0	1	0	3	0
N24	0	2	5	1	2	0	0	1	1	0	0	1	0	0	1
N25	0	2	3	3	4	2	0	2	2	0	1	0	1	0	0
N26	0	1	3	2	2	0	3	0	1	1	0	0	1	2	1
N27	0	0	3	3	0	0	0	0	2	0	3	2	0	0	0
N28	0	0	4	1	0	0	0	1	3	0	0	0	0	3	0
N29	0	0	4	0	0	0	1	3	0	1	1	0	0	0	0
N30	0	0	5	0	1	1	1	1	4	3	1	0	1	4	1

Table 5.12 continued.

	EBS Shelf							EBS slope					
	Year							Year					
Age	2016	2017	2018	2019	2021	2022	2023	2002	2004	2008	2010	2012	2016
1	14.3	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0	0.0	0.0	0.0	0.0
2	19.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	30.2	26.7	31.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.0	31.0	0.0
4	36.0	35.6	36.2	0.0	0.0	0.0	0.0	0.0	40.0	0.0	39.0	33.5	0.0
5	44.6	40.9	39.4	44.0	42.0	0.0	0.0	0.0	46.0	0.0	41.8	39.0	46.5
6	51.6	44.1	52.8	47.7	0.0	0.0	0.0	0.0	0.0	51.0	57.0	42.8	49.2
7	55.9	50.4	59.3	61.0	51.0	0.0	0.0	0.0	53.0	54.1	64.0	49.5	54.9
8	60.9	59.0	61.4	64.0	56.0	65.5	0.0	51.0	59.0	57.3	63.2	51.6	56.9
9	59.5	62.9	66.3	70.9	61.0	0.0	59.3	0.0	66.0	63.5	63.5	60.0	63.6
10	63.9	65.8	66.9	71.1	72.1	66.8	69.4	82.0	72.0	67.5	65.8	58.0	64.4
11	65.8	63.6	71.5	74.5	74.2	74.1	66.0	74.8	71.0	66.0	71.9	71.9	67.2
12	62.7	69.6	72.7	75.3	75.3	77.7	75.5	81.7	81.3	68.5	73.0	70.3	67.0
13	67.5	73.5	80.0	74.5	78.6	81.1	76.8	83.1	85.8	72.5	75.8	77.5	74.6
14	75.7	72.5	74.0	0.0	79.8	78.8	76.0	85.1	83.0	79.8	82.2	75.3	76.1
15	0.0	82.0	84.0	0.0	83.0	79.2	75.3	82.0	86.8	86.3	74.7	76.4	79.2
16	83.0	67.0	0.0	70.0	82.5	78.0	78.0	82.1	81.5	86.3	79.9	79.1	80.7
17	81.0	82.3	0.0	0.0	82.0	79.0	75.0	81.8	83.4	86.0	88.8	78.1	80.0
18	0.0	91.0	85.7	85.0	0.0	0.0	82.0	88.5	85.1	77.4	87.8	74.0	79.9
19	0.0	0.0	0.0	92.0	76.0	0.0	0.0	84.7	88.8	90.3	93.0	79.7	80.1
20	81.0	0.0	0.0	0.0	0.0	0.0	88.0	85.1	85.3	89.7	86.3	86.7	86.0
21	0.0	85.0	0.0	0.0	0.0	0.0	0.0	88.6	86.8	92.6	87.9	80.3	82.7
22	88.0	0.0	0.0	0.0	0.0	0.0	0.0	85.2	89.1	91.8	87.7	88.0	80.3
23	89.0	73.0	0.0	0.0	0.0	0.0	85.0	90.4	87.6	93.9	90.3	86.9	86.3
24	0.0	94.0	97.0	0.0	0.0	0.0	0.0	84.9	87.8	90.1	93.8	89.8	81.5
25	87.0	0.0	0.0	0.0	0.0	0.0	0.0	87.9	90.2	90.3	89.0	83.0	87.0
26	0.0	0.0	100.0	0.0	92.0	0.0	0.0	87.6	92.3	90.7	96.7	86.8	85.3
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.0	89.9	90.5	88.4	94.6	90.9
28	99.5	0.0	0.0	0.0	0.0	0.0	0.0	90.0	91.8	94.6	90.3	96.0	93.5
29	92.0	0.0	0.0	0.0	0.0	0.0	0.0	92.1	91.0	91.1	85.3	0.0	93.0
30	95.0	0.0	0.0	0.0	90.0	0.0	0.0	90.2	93.8	91.7	95.9	98.4	92.0
N1	6	0	0	0	0	0	2	0	0	0	0	0	0
N2	3	0	1	0	0	0	0	0	0	0	0	0	0
N3	14	3	2	0	0	0	0	0	0	0	2	2	0
N4	8	7	6	0	0	0	0	0	2	0	1	18	0
N5	16	9	7	1	2	0	0	0	1	0	5	20	4
N6	18	9	6	3	0	0	0	0	0	4	1	17	5
N7	23	7	4	7	1	0	0	0	1	7	1	12	7
N8	23	13	7	3	8	2	0	1	2	21	5	11	28
N9	8	15	25	13	1	0	4	0	1	18	13	2	23
N10	15	24	29	11	8	4	5	1	2	13	20	3	25
N11	8	13	16	21	16	8	1	4	2	10	15	7	34
N12	3	10	3	8	19	7	8	3	3	8	13	11	19
N13	2	2	1	2	8	11	4	9	4	6	6	8	16
N14	3	4	1	0	4	5	3	12	6	6	5	15	15
N15	0	3	1	0	1	5	3	13	9	3	9	12	21
N16	3	1	0	1	2	3	1	15	8	4	7	7	17
N17	1	3	0	0	1	1	2	18	16	2	5	9	10
N18	0	1	3	1	0	0	3	8	15	5	4	2	12
N19	0	0	0	1	1	0	0	13	13	3	8	3	15
N20	1	0	0	0	0	0	1	10	13	7	10	7	7
N21	0	1	0	0	0	0	0	20	21	8	16	6	12
N22	1	0	0	0	0	0	0	12	15	8	7	4	4
N23	1	1	0	0	0	0	1	9	8	8	11	7	6
N24	0	1	1	0	0	0	0	17	12	8	13	6	2
N25	1	0	0	0	0	0	0	18	20	11	12	2	1
N26	0	0	1	0	1	0	0	7	10	3	3	6	3
N27	0	0	0	0	0	0	0	4	16	4	5	7	7
N28	2	0	0	0	0	0	0	8	9	8	11	2	2
N29	1	0	0	0	0	0	0	7	7	12	4	0	3
N30	1	0	0	0	1	0	0	10	27	34	10	5	17

Table 5.13 Summary of the length-at-age information of males used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods). Top is average length and bottom is sample number.

	EBS Shelf														
	Year														
Age	1982	1998	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	16.6	0.0	13.0	16.3	16.0	11.5	12.5	13.1	14.3	14.1	16.1	13.5	14.6	14.0	14.0
2	24.8	25.6	22.1	23.9	24.0	21.0	21.0	19.6	21.9	23.9	23.1	22.5	22.5	22.2	22.7
3	33.7	34.0	29.0	30.3	33.2	0.0	28.7	23.4	28.6	33.3	32.1	31.3	30.8	29.2	32.3
4	40.0	33.8	36.1	34.8	37.0	39.5	35.0	30.0	33.3	36.4	36.9	36.7	34.8	35.0	39.0
5	45.7	36.5	39.0	42.6	41.3	38.4	44.4	35.5	45.0	39.8	41.8	40.9	37.9	39.1	44.8
6	50.0	50.0	40.7	43.1	47.1	43.8	47.2	44.0	42.5	42.0	45.3	47.4	41.9	43.9	48.6
7	52.0	0.0	46.2	51.2	48.0	44.3	51.7	46.3	52.0	0.0	0.0	53.0	45.2	47.9	52.2
8	0.0	49.0	49.2	58.0	51.8	47.3	52.7	51.0	53.8	50.5	55.5	0.0	51.5	50.4	55.1
9	0.0	58.0	48.5	61.8	52.0	53.2	56.0	54.6	58.3	59.0	47.0	0.0	49.0	50.1	58.5
10	0.0	58.3	66.4	63.8	72.0	64.3	55.0	55.7	54.5	0.0	0.0	66.0	0.0	63.0	57.5
11	0.0	0.0	60.0	0.0	64.7	62.3	62.8	59.0	0.0	0.0	69.0	0.0	0.0	0.0	54.0
12	0.0	59.8	72.0	73.2	0.0	74.0	0.0	0.0	0.0	60.0	65.5	0.0	0.0	0.0	68.0
13	0.0	66.8	76.0	68.7	72.5	0.0	0.0	0.0	0.0	67.0	0.0	68.0	0.0	66.0	0.0
14	0.0	75.0	0.0	0.0	76.0	0.0	0.0	0.0	0.0	0.0	0.0	56.0	0.0	69.0	0.0
15	0.0	67.5	0.0	74.0	79.0	73.0	0.0	73.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	70.0	78.0	75.5	77.0	69.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	71.0	72.0	78.0	76.0	74.0	75.5	0.0	0.0	0.0	66.0	0.0	0.0	72.0	0.0
18	0.0	0.0	72.0	77.0	76.0	76.0	77.5	83.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	74.0	78.0	81.0	74.3	79.0	0.0	0.0	78.5	0.0	73.0	0.0	0.0	0.0	0.0
20	0.0	0.0	81.5	73.5	79.0	79.0	0.0	76.0	79.0	0.0	70.0	75.0	0.0	0.0	0.0
21	0.0	0.0	76.5	0.0	0.0	0.0	76.5	71.0	70.0	73.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	81.0	0.0	0.0	74.0	77.0	80.0	77.0	73.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	74.0	0.0	0.0	88.0	0.0	0.0	0.0	88.0	0.0	0.0	0.0	0.0	77.0
24	0.0	69.5	76.3	0.0	74.0	77.0	84.0	0.0	0.0	82.0	0.0	0.0	0.0	0.0	75.5
25	0.0	0.0	73.0	0.0	75.5	83.0	72.0	0.0	71.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	77.0	0.0	0.0	0.0	0.0	0.0	78.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	74.0	0.0	73.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	78.0	0.0	0.0	78.0	0.0	79.0	76.0	0.0	0.0	0.0	0.0
29	0.0	0.0	78.0	0.0	0.0	0.0	82.0	0.0	0.0	78.0	0.0	0.0	0.0	0.0	85.0
30	0.0	81.0	0.0	0.0	0.0	0.0	79.0	0.0	76.8	0.0	0.0	76.0	0.0	0.0	0.0
N1	23	0	3	4	1	2	26	21	12	48	21	22	7	2	1
N2	43	19	34	9	2	1	8	36	73	57	90	44	30	6	27
N3	30	11	38	40	16	0	6	11	47	27	44	60	17	17	22
N4	31	5	18	18	35	2	4	4	11	14	15	25	35	10	15
N5	10	2	27	20	27	16	15	4	1	4	9	23	41	17	22
N6	3	1	9	15	10	20	22	2	2	1	3	7	21	35	34
N7	1	0	10	10	5	15	23	3	1	0	0	3	13	23	20
N8	0	1	5	1	6	16	15	9	4	2	2	0	2	18	12
N9	0	1	2	4	1	11	4	7	3	1	1	0	2	9	4
N10	0	3	5	4	1	4	3	3	2	0	0	1	0	3	2
N11	0	0	2	0	3	4	4	1	0	0	1	0	0	0	1
N12	0	4	1	5	0	1	0	0	0	1	2	0	0	0	1
N13	0	4	1	3	2	0	0	0	0	2	0	1	0	1	0
N14	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0
N15	0	2	0	2	1	1	0	1	0	0	0	0	0	0	0
N16	0	0	2	2	4	2	1	1	0	0	0	0	0	0	0
N17	0	3	1	1	1	1	4	0	0	0	1	0	0	1	0
N18	0	0	1	3	1	1	2	1	0	0	0	0	0	0	0
N19	0	2	1	1	3	1	0	0	2	0	1	0	0	0	0
N20	0	0	2	2	1	1	0	1	1	0	1	1	0	0	0
N21	0	0	2	0	0	0	2	1	1	1	0	0	0	0	0
N22	0	0	2	0	0	1	1	1	2	1	0	0	0	0	0
N23	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1
N24	0	2	3	0	1	1	1	0	0	1	0	0	0	0	2
N25	0	0	2	0	2	2	1	0	1	0	0	0	0	0	0
N26	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0
N27	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0
N28	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
N29	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1
N30	0	2	0	0	0	0	1	0	4	0	0	2	0	0	0

Table 5.13. continued.

	EBS Shelf							EBS slope					
	Year							Year					
Age	2016	2017	2018	2019	2021	2022	2023	2002	2004	2008	2010	2012	2016
1	13.0	15.0	15.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.5	0.0	0.0
2	18.8	24.0	23.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0	0.0
3	30.6	29.0	28.0	0.0	0.0	0.0	0.0	30.0	0.0	0.0	34.0	31.0	0.0
4	38.5	37.5	36.7	0.0	39.0	0.0	0.0	0.0	0.0	0.0	35.5	35.4	0.0
5	45.3	38.2	43.0	39.0	0.0	45.0	0.0	0.0	43.8	0.0	42.0	38.7	42.0
6	50.7	42.4	45.3	48.7	0.0	45.7	0.0	46.0	44.3	49.3	49.6	41.8	47.0
7	54.3	47.4	52.9	55.9	54.0	59.0	0.0	45.0	51.3	53.7	63.0	47.8	54.3
8	56.3	55.8	60.3	61.8	57.0	63.0	0.0	59.5	49.5	53.1	62.4	53.2	56.6
9	57.2	58.2	62.9	63.5	61.0	55.7	0.0	58.3	65.3	58.1	61.9	58.0	59.5
10	55.0	61.6	63.0	68.5	67.0	65.5	58.0	64.9	63.9	59.5	64.3	60.1	62.3
11	58.8	57.5	69.3	62.0	71.0	63.0	0.0	65.3	66.6	60.9	63.7	63.8	63.9
12	62.0	60.0	61.0	78.5	0.0	0.0	0.0	67.6	67.5	62.6	64.0	67.9	64.3
13	0.0	58.0	61.0	0.0	0.0	71.0	67.5	68.2	68.0	63.7	62.4	65.1	65.9
14	0.0	59.0	78.0	68.0	0.0	0.0	0.0	69.0	69.1	67.2	68.1	65.2	65.5
15	0.0	0.0	0.0	0.0	0.0	80.0	72.0	67.7	67.9	65.4	70.7	66.5	64.7
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.9	67.7	72.4	72.2	68.5	69.6
17	0.0	0.0	0.0	0.0	74.0	0.0	0.0	66.6	69.3	69.7	70.9	68.4	71.6
18	0.0	83.0	72.0	0.0	0.0	0.0	0.0	67.9	67.2	71.8	72.1	69.8	70.7
19	0.0	0.0	0.0	0.0	70.0	76.0	0.0	70.0	71.3	69.0	73.0	72.5	70.0
20	79.0	0.0	0.0	0.0	0.0	0.0	0.0	70.7	68.6	71.7	71.4	71.7	67.8
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.2	71.5	67.3	72.8	70.0	73.6
22	0.0	0.0	0.0	0.0	82.0	0.0	0.0	71.8	69.1	73.3	71.8	68.3	73.1
23	0.0	77.0	0.0	0.0	0.0	0.0	0.0	67.3	71.6	70.7	70.1	63.7	73.0
24	0.0	0.0	0.0	0.0	80.0	0.0	0.0	68.0	72.3	73.0	72.2	68.8	70.0
25	77.0	0.0	0.0	73.0	78.0	0.0	0.0	68.7	68.7	69.5	70.6	74.4	67.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.3	70.3	72.5	74.3	83.0	67.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.3	68.1	71.3	72.3	70.8	80.4
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.4	71.3	71.0	71.6	73.2	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	71.7	0.0	76.1	70.0	71.0	76.9
30	83.0	75.0	0.0	0.0	0.0	0.0	0.0	71.8	78.5	70.5	73.3	71.1	75.8
N1	6	1	3	0	0	0	0	0	0	0	2	0	0
N2	9	4	1	0	0	0	0	0	0	0	0	1	0
N3	23	6	1	0	0	0	0	1	0	0	1	4	0
N4	21	6	3	0	1	0	0	0	0	0	2	23	0
N5	12	5	7	1	0	1	0	0	6	0	2	23	1
N6	19	11	12	6	0	3	0	3	7	4	5	12	7
N7	21	7	9	12	1	1	0	2	3	9	3	13	16
N8	12	12	17	4	3	3	0	2	2	11	15	13	32
N9	13	13	11	4	4	6	0	4	9	12	37	11	39
N10	5	11	6	2	3	2	2	12	10	17	16	9	28
N11	6	6	3	3	1	1	0	12	5	16	14	14	19
N12	1	3	1	2	0	0	0	13	4	14	10	13	23
N13	0	1	1	0	0	1	2	10	9	6	9	13	23
N14	0	1	1	1	0	0	0	11	8	6	9	6	13
N15	0	0	0	0	0	1	1	10	17	8	3	10	9
N16	0	0	0	0	0	0	0	16	12	7	9	4	9
N17	0	0	0	0	1	0	0	8	12	7	8	5	12
N18	0	1	1	0	0	0	0	13	11	10	7	5	11
N19	0	0	0	0	1	1	0	13	8	5	10	2	9
N20	1	0	0	0	0	0	0	11	19	13	12	3	6
N21	0	0	0	0	0	0	0	11	17	4	11	1	5
N22	0	0	0	0	1	0	0	12	10	7	8	3	8
N23	0	1	0	0	0	0	0	14	12	7	9	3	5
N24	0	0	0	0	1	0	0	9	4	7	9	5	4
N25	1	0	0	2	1	0	0	16	16	6	11	7	2
N26	0	0	0	0	0	0	0	9	6	6	4	1	2
N27	0	0	0	0	0	0	0	4	8	6	15	4	5
N28	0	0	0	0	0	0	0	5	8	9	8	6	0
N29	0	0	0	0	0	0	0	3	0	7	7	1	7
N30	1	1	0	0	0	0	0	5	6	31	14	24	10

Table 5.14. Starting and adjusted (parentheses) multinomial sample sizes for size composition data by fishery and survey for a) m16.4c, b) m24.1 and m24.2, c) m24.1a and m24.2b.

a) m16.4c

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Trawl	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)		50 (12.5)
Longline			50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)				
Shelf						200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)
Slope			25 (12.5)		25 (12.5)	25 (12.5)			25 (12.5)			25 (12.5)	

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Trawl	50 (12.5)	50 (12.5)			50 (12.5)	50 (12.5)	50 (12.5)		50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)
Longline				50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)
Shelf	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)
Slope													400 (200)

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Trawl	50 (12.5)	50 (12.5)	50 (12.5)			50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)
Longline	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)
Shelf	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)
Slope		400				400 (200)		400 (200)		400 (200)			

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024
Trawl	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)
Longline	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)				
Shelf	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	200 (50)	201 (50)	202 (50)
Slope	400 (200)								

b) m24.1 and m24.2

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Trawl	50	50	50	50	50	50	50	50	50	50	50		50
Longline			50	50	50	50	50	50	50				
Shelf						170	376	227	78	96	92	106	113
Slope			25		25	25			25			25	

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Trawl	50	50			50	50	50		50	50	50	50	50
Longline				50	50	50	50	50	50	50	50	50	50
Shelf	191	193	182	270	189	158	236	71	209	70	127	139	149
Slope													450

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Trawl	50	50	50			50	50	50	50	50	50	50	50
Longline	50	50	50	50	50	50	50	50	50	50	50	50	50
Shelf	290	270	219	217	206	153	299	741	1200	686	438	345	338
Slope		358				486		488		472			

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024
Trawl	50	50	50	50	50	50	50	50	50
Longline	50	50	50	50	50				
Shelf	237	193	153	94		65	53	64	49
Slope	534								

c) m24.1a and m24.b

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Trawl	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)		50 (12.5)
Longline			50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)				
Shelf											92 (23)	106 (26.5)	113 (28.25)
Slope			25 (12.5)		25 (12.5)	25 (12.5)			25 (12.5)			25 (12.5)	

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Trawl	50 (12.5)	50 (12.5)			50 (12.5)	50 (12.5)	50 (12.5)		50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)
Longline				50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)
Shelf	191 (47.7)	193 (39.5)	182 (45.5)	270 (67.5)	189 (47.3)	158 (39.5)	236 (59)	71 (17.8)	209 (52.3)	70 (17.5)	127 (31.8)	139 (34.75)	149 (37.3)
Slope													450 (225)

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Trawl	50 (12.5)	50 (12.5)	50 (12.5)			50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)
Longline	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)
Shelf	290 (72.5)	270 (67.5)	219 (54.8)	217 (54.3)	206 (51.5)	153 (38.3)	299 (74.8)	741 (185.3)	1200 (300)	686 (171.5)	438 (109.5)	345 (86.3)	338 (84.5)
Slope		358 (179)				486 (243)		488 (244)		472 (236)			

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024
Trawl	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50 (12.5)	50(12.5)
Longline	50 (25)	50 (25)	50 (25)	50 (25)	50 (25)				
Shelf	237 (59.3)	193 (48.3)	153 (38.3)	94 (23.5)		65 (16.3)	53 (13.3)	64 (16)	49 (12.3)
Slope	534 (267)								

Table 5.15. Model a) total likelihoods and c) likelihood components.

a)

Component	16.4c (2024)	24.1	24.1a	24.2	24.2a
Total	3732.96	6122.42	3861.35	5990.64	3755.72
Catch	4.94E-12	6.09E-13	5.30E-13	1.58E-11	3.15E-09
Survey	8.78	10.44	-9.12	3.33	-17.68
Length comp	1282.87	3305.19	1294.6	3276.19	1261.72
Size at age	2314.61	2492.13	2357.83	2492.21	2354.6

b)

	16.4c (2024)				
	Trawl	Longline/Fixed	Shelf Survey	Slope Survey	AFSC Longline Survey
Catch	4.81e-12	1.34e-13			
Survey			-7.87	-6.02	22.67
Length comp	161.95	106.53	503.78	290.50	220.11
Size at age			1749.11	565.50	
	24.1				
Catch	3.12E-13	2.96E-13			
Survey			-5.41	2.58	13.27
Length comp	598.67	161.29	1423.81	684.07	437.35
Size at age			1816.50	675.63	
	24.1a				
Catch	2.86E-13	2.44E-13			
Survey			-6.03	-0.23	-2.87
Length comp	153.76	78.70	447.85	391.23	223.07
Size at age			1734.38	623.45	
	24.2				
Catch	1.54E-11	3.78E-13			
Survey			-9.31	4.62	8.02
Length comp	597.40	161.68	1407.46	677.09	432.56
Size at age			1815.10	677.11	
	24.2a				
Catch	3.15E-09	3.02E-13			
Survey			-10.60	1.30	-8.38
Length comp	155.23	77.85	424.70	383.43	220.51
Size at age			1728.89	625.71	

Table 5.16. Key parameter estimates and estimated standard deviations.

	16.4c (2022)		16.4c (2024)		24.1		24.2	
Label	Value	Stdev	Value	Stdev	Value	Stdev	Value	Stdev
Biology								
L Amin female	15.92	0.142	15.64	0.141	15.41	0.133	15.57	0.141
L Amax female	89.13	0.274	93.81	0.458	91.89	0.341	93.63	0.457
von Bert k female	0.11	0.002	0.11	0.002	0.12	0.001	0.12	0.002
L Amin male	15.31	0.128	15.07	0.127	14.63	0.109	14.92	0.125
L Amax male	70.75	0.263	71.33	0.265	70.63	0.195	71.26	0.254
von Bert k male	0.179	0.003	0.18	0.002	0.195	0.002	0.19	0.002
Recruitment								
LN(R0)	8.86	0.182	8.96	0.176	8.49	0.103	8.73	0.074
steepness	0.79	-	0.79	-	0.79	-	0.79	-
σ_R	0.6	-	0.6	-	0.6	-	0.6	-
SR_autocorr	0.71	0.030	0.70	0.028	0	-	0	-
Catchability								
Shelf LN(q)	-0.49	-	-0.49	-	0.30	-	0.07	-
Slope LN(q)	-0.56	-	-0.56	-	-0.40	-	-0.51	-
ABL Longline LN(q)	0.75	0.085	0.88	0.070	1.18	-	1.14	-

	24.1a		24.1b	
Label	Value	Stdev	Value	Stdev
Biology				
L Amin female	15.40	0.132	15.77	0.151
L Amax female	91.93	0.321	93.77	0.466
von Bert k female	0.12	0.001	0.12	0.002
L Amin male	14.63	0.109	14.65	0.128
L Amax male	70.62	0.193	71.23	0.249
von Bert k male	0.20	0.002	0.19	0.002
Recruitment				
LN(R0)	8.64	0.074	8.82	0.179
steepness	0.79	-	0.79	-
σ_R	0.6	-	0.6	-
SR_autocorr	0.45	-	0.45	-
Catchability				
Shelf LN(q)	0.42	-	0.33	-
Slope LN(q)	-0.36	-	-0.48	-
ABL Longline LN(q)	1.22	-	1.17	

Table 5.17 Model index RMSE and Mohn's rho (measuring retrospective pattern) for the candidate models.

		16.4c (2024)	24.1	24.1a	24.2	24.2a
Retrospective						
Mohn's ρ	SSB	0.14	0.37	0.45	0.32	0.35
	Recruitment	11.5	14.5	7.9	14.8	8.9
	Fishing mortality	-0.29	0.02	-0.02	-0.10	-0.11
Index RMSE						
	Shelf	0.31	0.33	0.32	0.32	0.31
	Slope	0.19	0.27	0.26	0.29	0.28
	AFSC LL	0.44	0.37	0.32	0.36	0.30

Table 5.18. Spawning and total biomass, Age-0 recruits, fishing mortality, and exploitation rate for BSAI Greenland turbot, 1960-2022 for models 16.4c (2022) and 16.4c (2024).

	16.4c (2022)				16.4c (2024)			
Year	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	SSB (t)	Age-0 recruits	Apical F	Exploitation rate
1960	78470	102939	0.22	0.15	86392	138346	0.21	0.14
1961	74788	191342	0.4	0.25	83340	262610	0.36	0.23
1962	64693	377743	0.5	0.31	74265	476642	0.43	0.26
1963	52761	570494	0.29	0.2	63801	532656	0.23	0.15
1964	47533	408690	0.26	0.19	59962	298253	0.19	0.14
1965	43653	182298	0.05	0.04	57815	132888	0.04	0.03
1966	45434	82766	0.04	0.04	61899	64801	0.03	0.03
1967	51028	44902	0.05	0.05	72290	37821	0.04	0.04
1968	65205	29823	0.05	0.05	95563	26458	0.05	0.04
1969	95752	23940	0.04	0.04	139318	21820	0.04	0.04
1970	148908	22917	0.03	0.03	205917	21032	0.03	0.02
1971	223474	26232	0.06	0.05	289122	23871	0.05	0.04
1972	300401	36389	0.1	0.08	366504	32495	0.10	0.08
1973	356976	61265	0.09	0.07	416949	53690	0.09	0.07
1974	398380	116907	0.12	0.09	450221	100607	0.12	0.08
1975	413010	186765	0.12	0.08	456300	164401	0.12	0.08
1976	413088	146396	0.12	0.08	448811	122929	0.13	0.08
1977	401162	90885	0.06	0.04	430374	75123	0.07	0.04
1978	394337	49320	0.09	0.06	417993	42828	0.10	0.06
1979	376617	16252	0.1	0.06	395213	15101	0.11	0.06
1980	358019	7321	0.13	0.08	371894	7236	0.14	0.08
1981	337481	4363	0.14	0.09	346490	4520	0.16	0.09
1982	319578	3410	0.13	0.08	323116	3642	0.15	0.09
1983	308543	3640	0.13	0.08	305852	3950	0.16	0.09
1984	299019	5997	0.07	0.04	289573	6514	0.08	0.05
1985	296954	17440	0.05	0.03	281150	19491	0.06	0.03
1986	294963	5573	0.03	0.02	273601	6266	0.04	0.02
1987	290990	5085	0.03	0.02	265215	5833	0.05	0.02
1988	283003	5356	0.03	0.02	254071	6099	0.04	0.02
1989	272640	13114	0.05	0.02	241762	14997	0.07	0.02
1990	257166	4483	0.07	0.03	225303	4931	0.11	0.04
1991	237554	1246	0.05	0.02	205610	1338	0.07	0.03
1992	220818	785	0.02	0.01	189612	836	0.03	0.01
1993	206789	642	0.06	0.03	176772	664	0.07	0.03
1994	188689	1011	0.09	0.04	160336	999	0.12	0.04

Table 5.18. Continued. Spawning and total biomass, Age-0 recruits, fishing mortality, and exploitation rate for BSAI Greenland turbot, 1960-2024 for models 16.4c (2022) and 16.4c (2024).

	16.4c (2022)				16.4c (2024)			
	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	SSB (t)	Age-0 recruits	Apical F	Exploitation rate
1995	170672	3257	0.08	0.03	144385	3011	0.10	0.04
1996	154794	1894	0.06	0.03	130756	1717	0.08	0.03
1997	140685	1924	0.08	0.03	118940	1722	0.09	0.04
1998	126606	2455	0.11	0.05	107128	2142	0.13	0.05
1999	111859	7950	0.08	0.03	94572	7114	0.10	0.04
2000	100265	9844	0.11	0.05	84866	9569	0.13	0.05
2001	88184	9269	0.1	0.04	74539	9854	0.12	0.05
2002	78218	1744	0.07	0.03	66062	1811	0.09	0.04
2003	70005	733	0.07	0.03	59142	705	0.08	0.03
2004	62827	646	0.06	0.02	53085	606	0.07	0.03
2005	56995	1180	0.07	0.03	48213	1038	0.09	0.03
2006	51645	6403	0.06	0.02	43739	5256	0.07	0.03
2007	47718	13539	0.06	0.02	40601	9775	0.07	0.03
2008	44684	29035	0.11	0.04	38290	23355	0.12	0.04
2009	42182	19290	0.17	0.06	36407	19202	0.20	0.07
2010	38898	3392	0.18	0.06	33676	2756	0.20	0.07
2011	35385	1658	0.18	0.05	30648	1271	0.19	0.06
2012	32072	1071	0.24	0.07	27738	832	0.28	0.08
2013	28711	957	0.09	0.03	24623	755	0.11	0.03
2014	28135	684	0.08	0.02	24071	546	0.10	0.03
2015	29176	485	0.1	0.03	24887	377	0.12	0.04
2016	31274	317	0.09	0.03	26574	246	0.10	0.04
2017	33907	293	0.09	0.04	28715	206	0.11	0.05
2018	35856	337	0.05	0.03	30199	187	0.06	0.03
2019	37352	665	0.08	0.04	31321	205	0.10	0.05
2020	37204	851	0.07	0.04	30927	282	0.09	0.04
2021	36380	1359	0.05	0.03	29980	787	0.07	0.03
2022	35257	3028	0.05	0.03	28839	4018	0.07	0.03
2023	-	-	-	-	27315	3127	0.07	0.03
2024	-	-	-	-	25594	4608	0.05	0.02

Table 5.19. Age-0 recruits based on Model 16.4c with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2024 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error.

Year	Age-0 Recruits	LCI	UCI
1977	75,123	27,605	122,641
1978	42,828	12,314	73,341
1979	15,101	3,291	26,912
1980	7,236	1,360	13,113
1981	4,520	900	8,140
1982	3,642	876	6,409
1983	3,950	1,217	6,683
1984	6,514	2,647	10,382
1985	19,491	13,147	25,836
1986	6,266	3,484	9,048
1987	5,833	3,415	8,251
1988	6,099	3,567	8,632
1989	14,997	10,755	19,239
1990	4,931	2,725	7,136
1991	1,338	601	2,075
1992	836	352	1,321
1993	664	269	1,060
1994	999	452	1,547
1995	3,011	1,845	4,177
1996	1,717	889	2,545
1997	1,722	899	2,544
1998	2,142	1,105	3,179
1999	7,114	4,622	9,605
2000	9,569	6,328	12,810
2001	9,854	6,837	12,871
2002	1,811	849	2,773
2003	705	289	1,122
2004	606	246	967
2005	1,038	486	1,589
2006	5,256	3,475	7,037
2007	9,775	6,709	12,841
2008	23,355	17,857	28,854
2009	19,202	14,329	24,075
2010	2,756	1,526	3,987
2011	1,271	628	1,913
2012	832	373	1,292
2013	755	337	1,173
2014	546	229	863
2015	377	142	613
2016	246	79	413
2017	206	60	352
2018	187	53	322
2019	205	61	350
2020	282	107	457
2021	787	406	1,168
2022	4,018	2,421	5,615
2023	3,127	1,531	4,724
2024	4,608	1,128	8,089

Table 5.20. Spawning and total biomass compared with the 2022 assessment and fishing mortality, exploitation rate from the current assessment for BSAI Greenland turbot, 1977-2024. The 2025 and 2026 biomass estimates are from the Model 16.4c projections. The preliminary catch for 2025 and 2026 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2019-2023), 36%, and the 2024 TAC, 3,188 t.

	SSB (t)		Total biomass (age1+)			
Year	2022	Current	2022	Current	Apical F	Exploitation rate
1977	398,380	430,374	722,445	741,545	0.07	0.04
1978	413,010	417,993	712,367	720,901	0.10	0.06
1979	413,088	395,213	696,237	693,251	0.11	0.06
1980	401,162	371,894	683,858	669,146	0.14	0.08
1981	394,337	346,490	658,025	632,021	0.16	0.09
1982	376,617	323,116	620,918	584,806	0.15	0.09
1983	358,019	305,852	580,468	535,951	0.16	0.09
1984	337,481	289,573	536,207	485,075	0.08	0.05
1985	319,578	281,150	510,129	454,399	0.06	0.03
1986	308,543	273,601	487,249	428,607	0.04	0.02
1987	299,019	265,215	465,420	405,318	0.05	0.02
1988	296,954	254,071	441,121	380,884	0.04	0.02
1989	294,963	241,762	417,521	358,276	0.07	0.02
1990	290,990	225,303	390,655	333,261	0.11	0.04
1991	283,003	205,610	359,232	304,305	0.07	0.03
1992	272,640	189,612	333,676	281,932	0.03	0.01
1993	257,166	176,772	313,198	264,992	0.07	0.03
1994	237,554	160,336	287,940	243,505	0.12	0.04
1995	220,818	144,385	260,701	220,104	0.10	0.04
1996	206,789	130,756	236,509	199,708	0.08	0.03
1997	188,689	118,940	214,989	181,809	0.09	0.04
1998	170,672	107,128	193,776	163,996	0.13	0.05
1999	154,794	94,572	172,067	145,446	0.10	0.04
2000	140,685	84,866	154,529	130,660	0.13	0.05
2001	126,606	74,539	137,138	115,717	0.12	0.05
2002	111,859	66,062	123,049	103,688	0.09	0.04
2003	100,265	59,142	112,452	94,881	0.08	0.03
2004	88,184	53,085	103,864	87,912	0.07	0.03
2005	78,218	48,213	97,224	82,741	0.09	0.03
2006	70,005	43,739	90,792	77,690	0.07	0.03
2007	62,827	40,601	85,374	73,551	0.07	0.03
2008	56,995	38,290	80,301	69,596	0.12	0.04
2009	51,645	36,407	75,037	65,197	0.20	0.07
2010	47,718	33,676	69,722	60,287	0.20	0.07
2011	44,684	30,648	66,993	57,509	0.19	0.06
2012	42,182	27,738	66,631	56,832	0.28	0.08
2013	38,898	24,623	66,338	56,068	0.11	0.03

Table 5.20. Continued. Spawning and total biomass compared with the 2022 assessment and fishing mortality, exploitation rate from the current assessment for BSAI Greenland turbot, 1977-2024. The 2025 and 2026 biomass estimates are from the Model 16.4c projections. The preliminary catch for 2025 and 2026 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2019-2023), 36%, and the 2024 TAC, 3,188 t.

	SSB (t)		Total biomass (age1+)			
Year	2022	Current	2022	Current	Apical F	Exploitation
2014	28,135	24,071	69,348	58,543	0.10	0.03
2015	29,176	24,887	72,019	60,750	0.12	0.04
2016	31,274	26,574	73,285	61,691	0.10	0.04
2017	33,907	28,715	73,428	61,651	0.11	0.05
2018	35,856	30,199	71,834	60,027	0.06	0.03
2019	37,352	31,321	70,018	58,292	0.10	0.05
2020	37,204	30,927	66,219	54,690	0.09	0.04
2021	36,380	29,980	62,174	50,909	0.07	0.03
2022	35,257	28,839	58,349	47,383	0.07	0.03
2023	33,554	27,315	53,907	43,703	0.07	0.03
2024	30,484	25,594	48,850	40,194	0.05	0.02
2025	-	23,999	-	37,615	-	-
2026	-	22,061	-	35,877	-	-

Table 5.21. Spawning biomass from Model 16.4c with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2024 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. The 2025 and 2026 values are from the projection model.

Year	SSB	LCI	UCI	Year	SSB	LCI	UCI
1977	430,374	338,566	522,182	2021	29,980	25,556	34,405
1978	417,993	333,888	502,098	2022	28,839	24,498	33,181
1979	395,213	318,025	472,401	2023	27,315	23,107	31,522
1980	371,894	301,022	442,766	2024	25,594	21,558	29,630
1981	346,490	281,669	411,311	2025	23,999	-	-
1982	323,116	263,919	382,313	2026	22,061	-	-
1983	305,852	251,663	360,041				
1984	289,573	239,860	339,286				
1985	281,150	235,459	326,841				
1986	273,601	231,665	315,537				
1987	265,215	226,775	303,656				
1988	254,071	218,842	289,300				
1989	241,762	209,496	274,028				
1990	225,303	196,000	254,606				
1991	205,610	179,076	232,144				
1992	189,612	165,527	213,697				
1993	176,772	154,921	198,623				
1994	160,336	140,621	180,051				
1995	144,385	126,639	162,131				
1996	130,756	114,733	146,779				
1997	118,940	104,428	133,452				
1998	107,128	93,963	120,293				
1999	94,572	82,617	106,527				
2000	84,866	73,977	95,755				
2001	74,539	64,617	84,460				
2002	66,062	57,007	75,117				
2003	59,142	50,865	67,418				
2004	53,085	45,514	60,656				
2005	48,213	41,273	55,152				
2006	43,739	37,363	50,116				
2007	40,601	34,710	46,493				
2008	38,290	32,814	43,766				
2009	36,407	31,311	41,502				
2010	33,676	28,929	38,422				
2011	30,648	26,220	35,076				
2012	27,738	23,597	31,879				
2013	24,623	20,722	28,525				
2014	24,071	20,312	27,831				
2015	24,887	21,134	28,641				
2016	26,574	22,696	30,452				
2017	28,715	24,644	32,786				
2018	30,199	25,942	34,457				
2019	31,321	26,931	35,710				
2020	30,927	26,483	35,371				

Table 5.22. Model 16.4c mean total biomass, spawning biomass, yield, and F projections for Greenland turbot, 2022-2036 for the seven alternatives. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be 96% and 4%, respectively.

Alternative 1						
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.09	1,143	2,599	2,237
2026	22,061	35,877	0.10	1,143	2,059	1,771
2027	20,122	38,012	0.15	1,375	1,600	1,375
2028	18,193	42,570	0.13	1,095	1,275	1,095
2029	16,832	49,352	0.12	1,039	1,211	1,039
2030	16,409	57,998	0.12	1,365	1,592	1,365
2031	17,476	67,859	0.12	2,261	2,636	2,261
2032	20,224	78,705	0.13	3,586	4,177	3,586
2033	24,292	89,886	0.13	5,059	5,887	5,059
2034	29,070	100,749	0.14	6,474	7,529	6,474
2035	33,995	111,322	0.14	7,707	8,958	7,707
2036	38,690	120,989	0.15	8,707	10,117	8,707
Alternative 2						
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.09	1,143	2,599	2,237
2026	22,061	35,877	0.10	1,143	2,059	1,771
2027	20,122	38,012	0.15	1,375	1,600	1,375
2028	18,193	42,570	0.13	1,095	1,275	1,095
2029	16,832	49,352	0.12	1,039	1,211	1,039
2030	16,409	57,998	0.12	1,365	1,592	1,365
2031	17,476	67,859	0.12	2,261	2,636	2,261
2032	20,224	78,705	0.13	3,586	4,177	3,586
2033	24,292	89,886	0.13	5,059	5,887	5,059
2034	29,070	100,749	0.14	6,474	7,529	6,474
2035	33,995	111,322	0.14	7,707	8,958	7,707
2036	38,690	120,989	0.15	8,707	10,117	8,707
Alternative 3						
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.09	1,143	2,599	1,039
2026	22,061	35,877	0.10	1,143	2,059	877
2027	20,122	38,012	0.08	747	1,600	747
2028	18,553	43,280	0.08	681	1,344	681
2029	17,398	50,470	0.08	708	1,315	708
2030	17,098	59,377	0.08	908	1,730	908
2031	18,286	69,543	0.08	1,333	2,815	1,333
2032	21,288	81,028	0.08	1,955	4,433	1,955
2033	25,924	93,435	0.08	2,684	6,301	2,684
2034	31,713	106,236	0.08	3,426	8,204	3,426
2035	38,121	119,439	0.08	4,110	9,961	4,110
2036	44,710	132,305	0.08	4,703	11,489	4,703

Table 5.22 Continued. Model 16.4c mean total biomass, spawning biomass, yield, and F projections for Greenland turbot, 2022-2036 for the seven alternatives. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be 96% and 4%, respectively.

Alternative 4						
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.09	1,143	2,599	667
2026	22,061	35,877	0.10	1,143	2,059	563
2027	20,122	38,012	0.05	480	1,600	480
2028	18,705	43,583	0.05	443	1,374	443
2029	17,668	51,015	0.05	465	1,367	465
2030	17,466	60,135	0.05	596	1,807	596
2031	18,753	70,538	0.05	874	2,922	874
2032	21,898	82,356	0.05	1,282	4,578	1,282
2033	26,780	95,273	0.05	1,768	6,512	1,768
2034	32,965	108,813	0.05	2,270	8,514	2,270
2035	39,939	122,996	0.05	2,742	10,393	2,742
2036	47,255	137,059	0.05	3,159	12,057	3,159
Alternative 5						
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.09	1,143	2,599	0
2026	22,061	35,877	0.10	1,143	2,059	0
2027	20,122	38,012	0.00	0	1,600	0
2028	18,976	44,125	0.00	0	1,428	0
2029	18,156	52,006	0.00	0	1,465	0
2030	18,136	61,537	0.00	0	1,954	0
2031	19,612	72,400	0.00	0	3,124	0
2032	23,028	84,860	0.00	0	4,853	0
2033	28,376	98,752	0.00	0	6,914	0
2034	35,324	113,717	0.00	0	9,105	0
2035	43,410	129,825	0.00	0	11,223	0
2036	52,187	146,289	0.00	0	13,161	0
Alternative 6						
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.20	2,599	2,599	2,599
2026	21,187	34,238	0.18	1,856	1,856	1,856
2027	18,851	35,672	0.16	1,352	1,352	1,352
2028	16,986	40,421	0.14	1,075	1,075	1,075
2029	15,699	47,388	0.13	1,037	1,037	1,037
2030	15,349	56,196	0.13	1,416	1,416	1,416
2031	16,476	66,169	0.13	2,457	2,457	2,457
2032	19,237	77,009	0.14	3,999	3,999	3,999
2033	23,222	87,988	0.15	5,685	5,685	5,685
2034	27,788	98,434	0.16	7,269	7,269	7,269
2035	32,378	108,402	0.17	8,625	8,625	8,625
2036	36,640	117,326	0.17	9,697	9,697	9,697

Table 5.22 Continued. Model 16.4c mean total biomass, spawning biomass, yield, and F projections for Greenland turbot, 2022-2036 for the seven alternatives. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be 96% and 4%, respectively.

			Alternative 7			
Year	SSB	Total biomass	F	Catch	OFL	ABC
2025	23,999	37,615	0.17	2,237	2,599	2,599
2026	21,406	34,645	0.16	1,639	1,905	1,905
2027	19,193	36,299	0.16	1,416	1,416	1,416
2028	17,277	40,931	0.15	1,121	1,121	1,121
2029	15,949	47,808	0.13	1,073	1,073	1,073
2030	15,565	56,544	0.13	1,450	1,450	1,450
2031	16,663	66,454	0.14	2,487	2,487	2,487
2032	19,396	77,238	0.14	4,022	4,022	4,022
2033	23,356	88,171	0.15	5,701	5,701	5,701
2034	27,900	98,579	0.16	7,280	7,280	7,280
2035	32,472	108,517	0.17	8,633	8,633	8,633
2036	36,719	117,417	0.17	9,702	9,702	9,702

Table 5.23. FMP species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991

Year	Arrowtooth Flounder	BSAI Alaska Plaice	BSAI Kamchatka Flounder	BSAI Other Flatfish	Flathead Sole	Other Flatfish	Rock Sole	Yellowfin Sole
1991	1085						1	0
1992	4							
1993	560						0	
1994	1384						1	0
1995	2007				57	64	4	18
1996	492				52	16	3	0
1997	766				63	27	2	9
1998	1153				50	37	13	6
1999	1071				131	74	54	18
2000	764				72	47	3	4
2001	292				69	18	3	5
2002	333				35	17	1	
2003	368	1		40	76		1	1
2004	256	1		5	17		1	1
2005	185			7	7		0	
2006	195			1	3		0	0
2007	235			0	0			
2008	337			3	1		0	
2009	1339			4	5			
2010	572	1		1	11		0	
2011	247		18	4	6		0	0
2012	348		272	6	12			
2013	11		81	3	5		0	0
2014	62		52	2	8		0	0
2015	21		112	2	11			0
2016	378	1	227	7	65		0	
2017	605	0	398	53	138		1	1
2018	168		462	68	227		0	0
2019	248		956	216	498		0	0
2020	157	1	299	46	177		2	0
2021	101		122	58	60		0	
2022	82		167	97	65		0	
2023	5		13	6	11			
2024			4	1	5			

Table 5.23 Continued. FMP species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991.

Year	Atka Mackerel	Pacific Cod	Pollock	Sablefish	Shortraker rockfish	Pacific Ocean Perch	Other Rockfish
1991	65	154	114	504	27	3	61
1992		12	0	28	2	0	2
1993		115	6	577	196	1	77
1994	1	85	20	492	35	1	96
1995	10	111	50	555	98	12	96
1996	3	97	32	265	22	6	59
1997		82	56	267	19	14	51
1998	22	166	106	404	67	3	125
1999	133	225	151	380	44	32	56
2000	5	223	117	351	91	27	121
2001	2	110	54	229	48	52	56
2002		83	13	170	16	1	55
2003	0	32	98	174	35	1	79
2004	0	38	64	89	40	1	60
2005		22	8	99	12	0	48
2006	0	56	1	93	33	0	52
2007	0	67	3	73	78	0	56
2008	0	83	32	61	2	166	37
2009	1	13	12	81	4	0	50
2010		57	11	98	27	0	70
2011	0	78	14	31	7	0	44
2012		77	10	27	14	0	39
2013		5	2	11	6	0	17
2014		6	2	21	6	0	25
2015	0	37	20	7	4	0	29
2016		61	133	16	7	42	38
2017		53	227	120	16	37	54
2018		58	175	128	46	111	54
2019	1	42	272	637	55	150	311
2020		18	109	199	5	32	18
2021	17	4	68	121	26	109	40
2022		1	58	210	7	28	148
2023		0	3	31	1	1	7
2024			0	3	0	1	1

Table 5.23 Continued. FMP species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991.

Year	BSAI Skate and GOA Skate, Other	BSAI Squid	Octopus	Sculpin	Shark	Squid
1991						37.79
1992						
1993						0.34
1994						18.97
1995						12.14
1996						0.65
1997						3.2
1998						1.27
1999						3.6
2000						9.11
2001						1.99
2002						0.17
2003		3.463				
2004		6.045				
2005		0.417				
2006						
2007						
2008		4.176				
2009		22.656				
2010		0.87853				
2011	382.785823		0.0455864	0.67710535	0.42331	0.00347
2012	352.177955		0.07708533	1.47350879	0.10424016	
2013	49.8775951		0.1544667	0.27542278		0.06446
2014	42.6468392		0.07471727	2.45141722	0.03531306	0.60317
2015	207.593814		0.09142496	2.02913053		0.00165656
2016	193.731203		0.1381254	21.3391836		3.32749
2017	198.052323		1.35194397	33.4761423	0.00768	14.0354505
2018	99.7415836		0.74455622	29.8452353		22.3714203
2019	122.951325		6.78657977	26.8372254	0.11431513	
2020	101.421385		0.43688649	21.8841901	2.77159	
2021	28.7413		0.4917			
2022	16.11364		0.96806			
2023	3.73948		0.00463			
2024	0.16751		0.03103			

Table 5.24 Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for longline and pot vessels since 2003. Species with catch < 0.01 t have been excluded.

Weight	Year						
Species	2003	2004	2005	2006	2007	2008	2009
Benthic urochordata	0.03		0.00	0.01	0.00		
Bivalves	0.00		0.00				0.00
Brittle star unidentified	0.01		0.00	0.00	0.01		0.03
Corals Bryozoans - Corals Bryozoans Unidentified	0.06		0.06	0.07	0.01	0.00	0.00
Corals Bryozoans - Red Tree Coral	0.00					0.00	
Eelpouts	1.59	2.36	5.53	3.95	2.27	2.85	5.41
Giant Grenadier	44.44	135.79	1105.29	1300.83	1181.18	686.76	1775.30
Greenlings							
Grenadier - Pacific Grenadier			0.00		0.01		
Grenadier - Rattail Grenadier Unidentified	1503.57	1164.08	1029.74	216.84	234.45	20.90	46.88
Gunnels							
Hermit crab unidentified	0.00		0.00		0.00		0.00
Invertebrate unidentified	0.00		0.00	0.03	0.02		0.01
Large Sculpins	0.51	0.13	0.12	0.76	0.32		
Large Sculpins - Bigmouth Sculpin						0.28	0.11
Large Sculpins - Great Sculpin						0.07	0.04
Large Sculpins - Yellow Irish Lord						0.01	
Misc crabs	0.01	0.01	0.00	0.02	0.01	0.03	0.00
Misc crustaceans							0.01
Misc fish	2.95	1.48	1.11	2.08	0.43	1.74	0.39
Misc inverts (worms etc)							
Other Sculpins	1.18	0.40	0.36	0.37	1.29	0.37	0.74
Scypho jellies	0.01		0.02	0.01			0.00
Sea anemone unidentified	0.12	0.04	0.20	0.08	0.03	0.04	0.06
Sea pens whips	0.00		0.00				
Sea star	0.40	0.23	0.86	0.38	0.78	1.42	1.16
Snails	0.04	0.01	0.13	0.02	0.03	0.02	0.02
Sponge unidentified	0.10	0.00	0.01	0.01	0.50	0.01	0.00
urchins dollars cucumbers	0.80	0.01	0.29	0.02	0.02	0.01	0.52

Table 5. 24 Continued.

Weight											
Species	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Benthic urochordata	0.01									0.00	
Bivalves							0.00		0.01	0.00	
Brittle star unidentified	0.00	0.05	0.04	0.01		0.12	0.09	0.00		0.00	0.00
Corals Bryozoans - Corals Bryozoans Unidentified	0.12	0.00	0.01	0.00					0.00		
Corals Bryozoans - Red Tree Coral											
Eelpouts	5.73	7.61	7.80	2.04	2.50	4.70	3.52	1.47	0.30	0.10	0.05
Giant Grenadier	1836.14	2067.53	1364.64	534.95	294.11	1009.10	1103.25	1087.53	346.64	366.31	201.81
Greenlings		0.00									
Grenadier - Pacific Grenadier											
Grenadier - Rattail Grenadier Unidentified	697.22	341.66	288.47	16.77	173.71	10.54	2.29	51.09	64.37	13.30	0.07
Gunnels		0.03									
Hermit crab unidentified	0.00						0.00				
Invertebrate unidentified	0.00	0.26	0.06	0.25	0.01		0.15			0.00	
Large Sculpins											
Large Sculpins - Bigmouth Sculpin											
Large Sculpins - Great Sculpin											
Large Sculpins - Yellow Irish Lord											
Misc crabs	0.18	0.21	0.08	0.13	0.20	0.19	0.20	0.22	0.06	0.09	0.04
Misc crustaceans											
Misc fish	1.40	1.09	1.34	0.50	0.82	0.56	0.25	0.08	0.05	0.01	0.02
Misc inverts (worms etc)	0.00										
Other Sculpins											
Scypho jellies	0.01	0.01	0.01	0.00		0.00		0.00	0.03	0.00	0.00
Sea anemone unidentified	0.12	1.45	0.50	0.04	0.00	0.38	0.31	0.10	0.02	0.00	0.00
Sea pens whips	0.03	0.08					0.15	0.07			
Sea star	1.12	0.80	0.88	0.43	0.64	0.47	1.34	1.35	0.10	0.15	0.02
Snails	0.03	0.03	0.03	0.05	0.02	0.02	0.02	0.01	0.00	0.01	0.00
Sponge unidentified	0.00	0.02	0.01	0.00		0.00	0.03	0.01	0.00		
urchins dollars cucumbers	0.33	0.04	0.15	0.13	0.22	0.02	0.06	0.12	0.03	0.01	0.01

Table 5.25 Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for trawlers since 2003. Species with catch < 0.01 t have been excluded.

Species	2003	2004	2005	2008	2009	2010
Benthic urochordata						
Birds - Northern Fulmar						
Birds - Shearwaters						
Bivalves						
Brittle star unidentified	0.03					
Capelin		0.01				
Corals Bryozoans - Corals Bryozoans Unidentified						0.00
Eelpouts	27.85	10.70	1.00	0.27	3.42	0.04
Eulachon						
Giant Grenadier				67.46	365.00	66.40
Greenlings			0.18			
Grenadier - Pacific Grenadier					0.80	
Grenadier - Rattail Grenadier Unidentified	25.24	25.95	0.47		48.84	5.66
Hermit crab unidentified	0.01	0.00				
Invertebrate unidentified		0.88				
Lanternfishes (myctophidae)						
Large Sculpins		4.18	0.27			
Large Sculpins - Bigmouth Sculpin				1.56	0.72	
Large Sculpins - Yellow Irish Lord					0.08	
Misc crabs	0.01	0.00				0.00
Misc crustaceans						
Misc deep fish						
Misc fish	1.26	0.11	0.27	0.11	0.20	
Misc inverts (worms etc)	0.04					
Other osmerids						
Other Sculpins	4.79		0.15	0.64	0.43	
Pacific Sand lance			0.00			
Pandalid shrimp	0.01				0.01	0.00
Polychaete unidentified						
Sculpin						
Scypho jellies		0.06				
Sea anemone unidentified	0.77	0.00			0.13	0.00
Sea pens whips	0.02					
Sea star	4.63	1.96	0.25	0.00	0.06	0.00
Snails	0.51	0.14			0.01	
Sponge unidentified				0.00	0.10	0.00
Squid						
Stichaeidae						
urchins dollars cucumbers					0.03	0.00

Figure 5.25 Continued.

Species	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Benthic urochordata					0.00	0.03	0.30	0.86	0.07	0.03	0.00	0.02	0.00
Birds - Northern Fulmar								0.00					
Birds - Shearwaters								0.00			0.00		
Bivalves								0.00	0.02	0.00	0.00	0.00	
Brittle star unidentified			0.00		2.14	0.48	0.00	2.73	0.87	0.53	0.02	0.03	0.00
Capelin													
Corals Bryozoans - Corals Bryozoans Unidentified		0.00				0.02	0.02	0.28	0.02		0.01	0.00	
Eelpouts	0.12	0.01	1.14	0.08	0.89	7.33	4.68	37.76	2.43	2.49	11.44	0.27	0.19
Eulachon						0.00							
Giant Grenadier	0.86	0.58	0.44	6.85	83.43	450.14	364.22	447.22	397.27	443.71	269.59	71.53	22.42
Greenlings							0.59	0.00	0.01		0.00		
Grenadier - Pacific Grenadier													
Grenadier - Rattail Grenadier Unidentified			0.36		4.22	0.01		62.32	13.86		1.88		
Hermit crab unidentified					0.00	0.00	0.00	0.05	0.05	0.00	0.05	0.01	0.00
Invertebrate unidentified						0.01	0.00	0.00		0.00			
Lanternfishes (myctophidae)			0.00			0.00	0.01	0.01	0.00		0.00	0.00	
Large Sculpins													
Large Sculpins - Bigmouth Sculpin													
Large Sculpins - Yellow Irish Lord													
Misc crabs			0.02		0.00	0.15	0.56	2.86	1.42	0.57	3.17	0.08	0.00
Misc crustaceans								0.03	0.07	0.00	0.00	0.01	0.00
Misc deep fish								0.01					
Misc fish	0.04	0.08	0.03	0.03	0.77	1.43	2.17	2.46	2.05	1.16	1.28	0.23	0.03
Misc inverts (worms etc)						0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.00
Other osmerids								0.00					
Other Sculpins													
Pacific Sand lance													
Pandalid shrimp				0.01	0.13	0.67	0.60	0.52	0.39	0.22	0.05	0.01	0.01
Polychaete unidentified						0.00	0.00	0.02	0.06	0.00	0.00	0.00	0.00
Sculpin										13.95	7.19	0.39	0.01
Scypho jellies			0.01			0.00	0.40	2.60	0.32	0.01	0.01	0.01	0.00
Sea anemone unidentified		0.00	0.08	0.35	8.28	20.23	35.36	20.50	28.72	21.76	5.44	0.31	0.08
Sea pens whips					0.14	0.33	0.01	0.03	0.13	0.06	0.01	0.01	0.00
Sea star	0.05	0.00	0.02	0.02	1.02	4.37	4.17	21.20	5.12	2.70	6.98	0.31	0.47
Snails			0.00	0.07	0.02	0.17	0.12	0.39	0.13	0.06	0.20	0.02	0.00
Sponge unidentified	0.00		0.06		0.08	1.16	0.20	1.03	1.74	1.18	0.02	0.01	0.00
Squid								65.50	29.38	13.82	15.47	4.13	0.09
Stichaeidae							0.00						
urchins dollars cucumbers			0.00		0.00	0.01	0.02	6.33	0.11	0.15	5.48	0.05	1.31

Table 5.26. Prohibited species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for fixed gear. Crab, herring and salmon are in number of fish, halibut are in tons.

Year	Bairdi Tanner Crab	Blue King Crab	Chinook Salmon	Golden (Brown) King Crab	Halibut	Herring	Non-Chinook Salmon	Opilio Tanner (Snow) Crab	Other King Crab	Red King Crab
1991							1.43	136.22	50.77	5.3
1992								7.61		
1993	29						4	2074	1164	3
1994			7		45			204	233	13
1995	21				81		8	650	402	50
1996	12				91		0	579	186	18
1997	14				43		22	362	206	12
1998	32				54		47	1226	1497	10
1999	28				81		24	1344	28606	5
2000	13				114		5	930	1730	20
2001	1				54		7	537	313	21
2002	64		3		49		45	562	55	6
2003	53	0	9	136	22	0	20	25		0
2004	10	0	18	151	13	0	77	0		0
2005	0	12	13	22	21	0	41	3		8
2006	28	0	8	328	5	0	26	0		13
2007	19	0	0	2438	2	0	24	34		48
2008	16	7	0	3	1	0	26	43		8
2009	85	0	0	0	2	0	15	24		0
2010	48	8	0	180	6	0	37	87		1
2011	1	1	4	58	5	0	77	20		4
2012	15	0	4	28	4	0	124	48		0
2013	0	0	0	0	1	0	22	15		0
2014	6	0	0	39	1	0	49	21		0
2015	0	0	17	47	3	0	34	7		0
2016	19	0	0	47	3	0	69	31		0
2017	7	0	6	0	2	0	36	11		0
2018	1	1	3	4	0	0	6	65		5
2019	0	0	7	0	0	0	23	9		0
2020	0	0	0	0	0	0	25	2		0

Table 5.27. Prohibited species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for Trawl. Crab, herring and salmon are in number of fish, halibut are in tons.

	Bairdi Tanner Crab	Blue King Crab	Chinook	Golden (Brown) King Crab	Halibut	Herring	Non-Chinook Salmon	Opilio Tanner (Snow) Crab	Other King Crab	Red King Crab
1991	14919		71			0.01	4.9	237955	11160	1398
1993								80		
1994	1916		58		371	0.00		278055	6029	329
1995	3837				267	0.02		52212	3027	966
1996	1089				6	0.09		5594	250	
1997	614				9	0.16		6138	451	
1998	680				10	0.04	1	24534	125	
1999	1048				19	0.34		2051	1198	
2000	1063				21	0.01		2689	3327	
2001	497				11	0.04		7189	471	
2002	731				1	0.01		2644	211	
2003	2884	0	0	99	8	0.02	0	1800		0
2004	0	0	0	66	2	0	0	66		0
2005	88	0	0	88	2	0	0	0		0
2008	0	0	0	132	2	0	0	0		0
2009	0	0	0	747	6	0	0	0		0
2010	0	0	0	86	2	0	0	0		0
2011	0	0	0	0	0.99	0	0	0		0
2013	0	0	0	0	0.80	0	0	0		0
2014	0	0	0	21	0	0	0	0		0
2015	0	0	0	0	0	0	0	0		0
2016	1531	0	0	464	4	0	0	117		0
2017	3262	0	0	2370	38	0.06	0	2040		0
2018	808	0	0	1291	11	0	0	78		0
2019	1495	0	0	7863	37	0.00	583	816		0
2020	4861	0	0	1334	11	0	0	3062		0
2021	1045	0	0	1783	3	0	0	162		0
2022	0	0	0	876	13	0	0	0		0
2023	0	0	0	146	0.17	0	0	0		0
2024	0	0	0	0	0.01	0	0	0		0

Figures

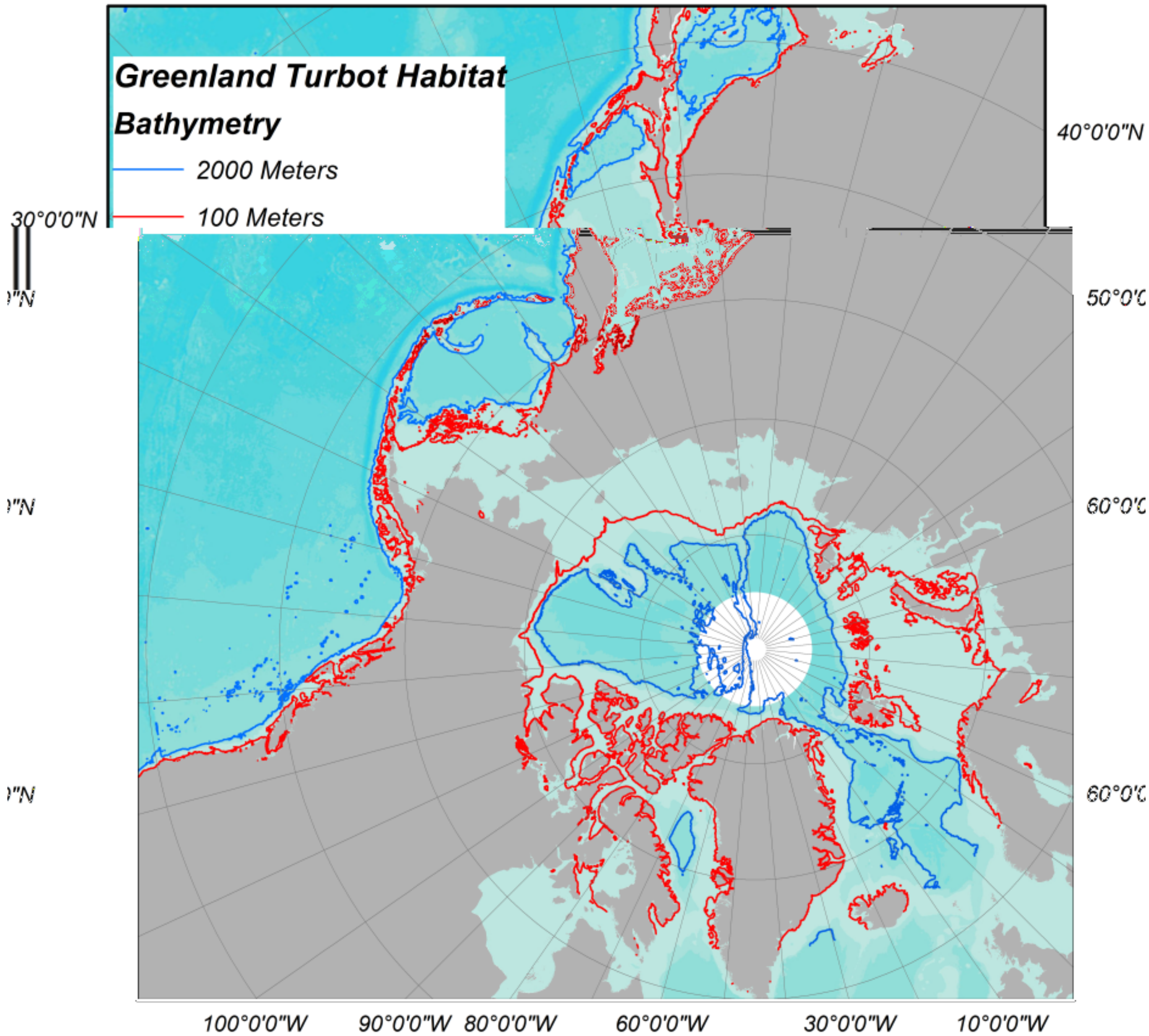


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.

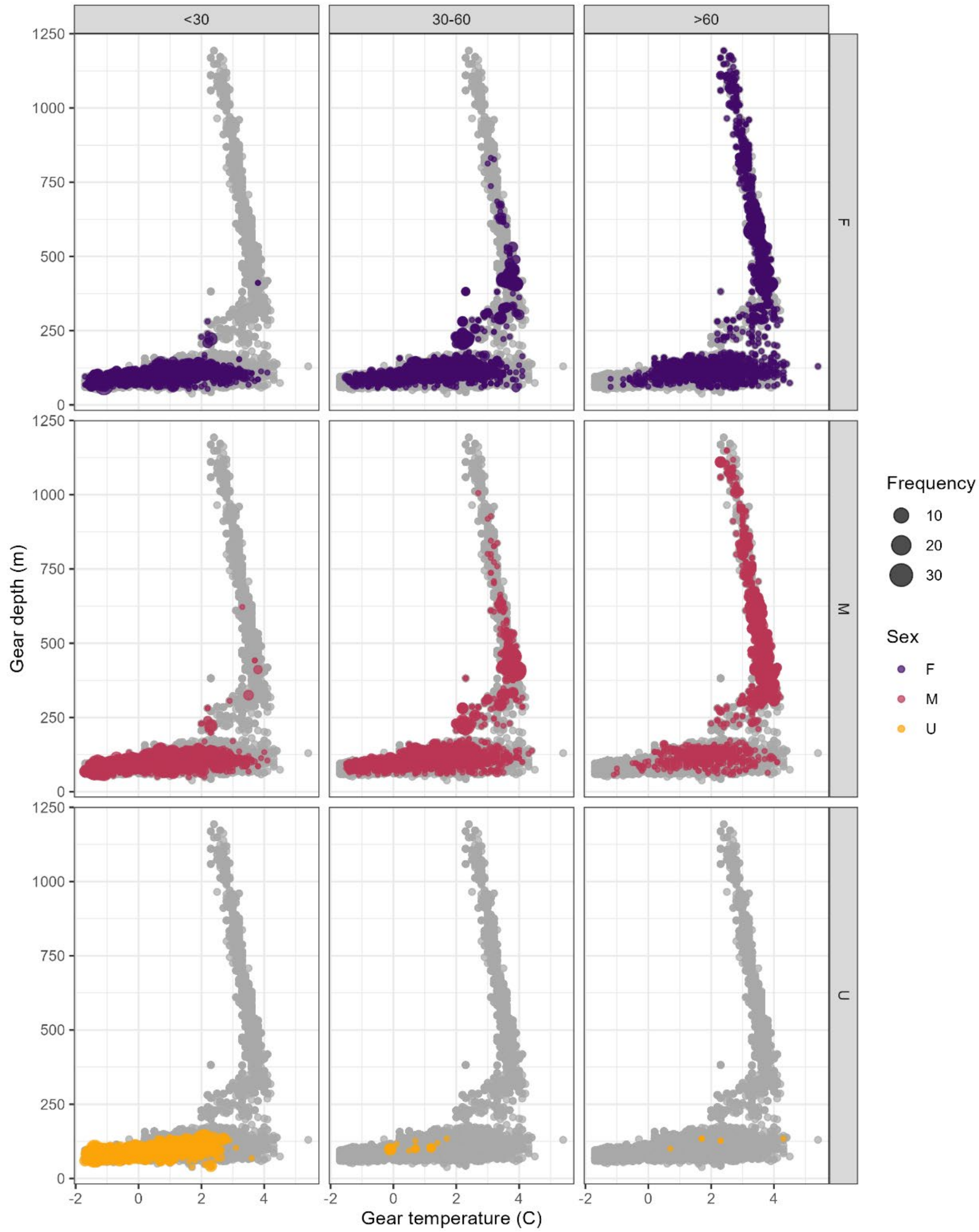


Figure 5.2. Frequency of occurrence of Greenland turbot by gear temperature and depth in the AFSC bottom trawl survey data, for all years combined. Columns indicate size class (in cm), rows indicate sex (females, males, undetermined). The size of the bubbles indicates frequency by haul.

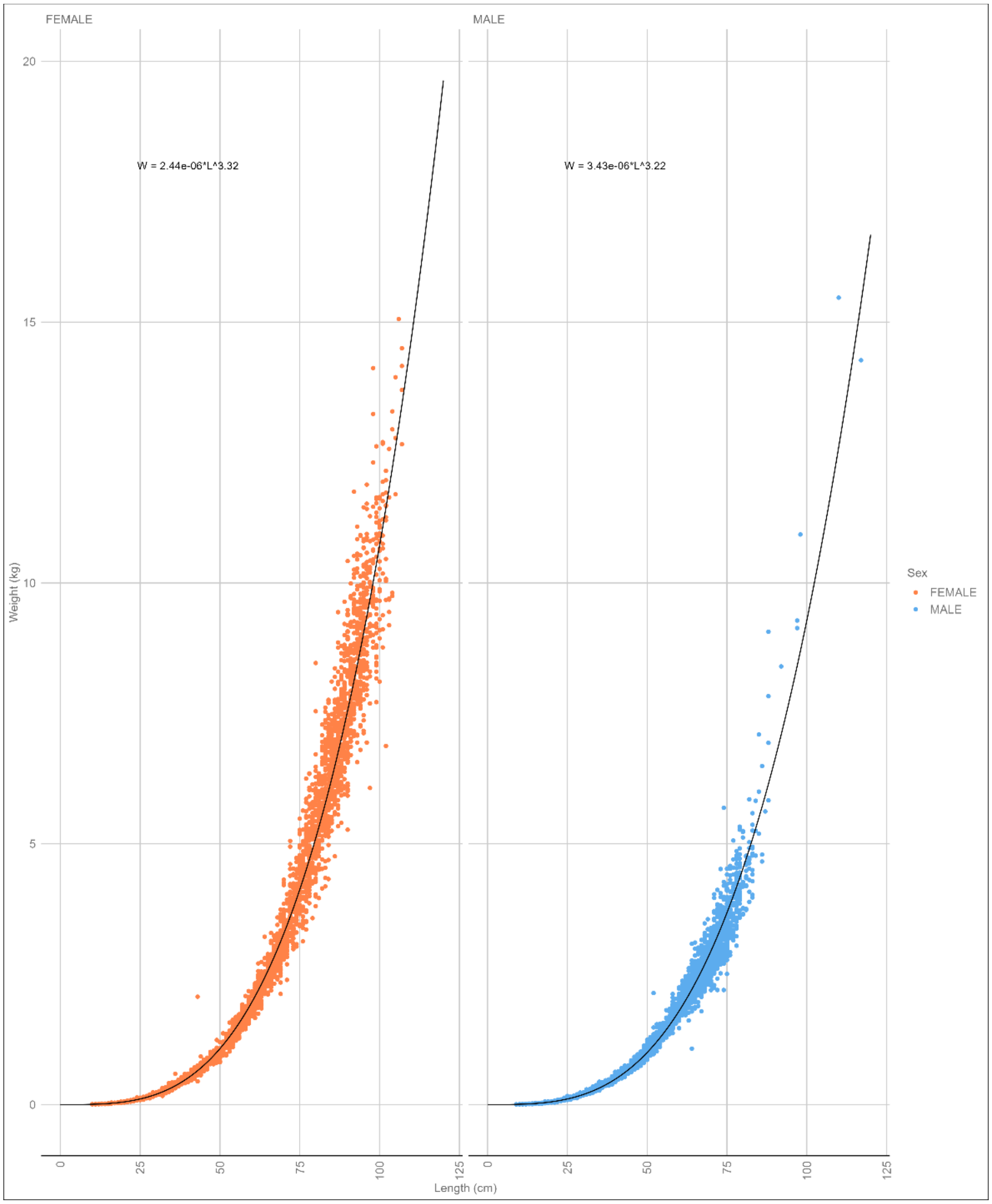


Figure 5.3. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area.

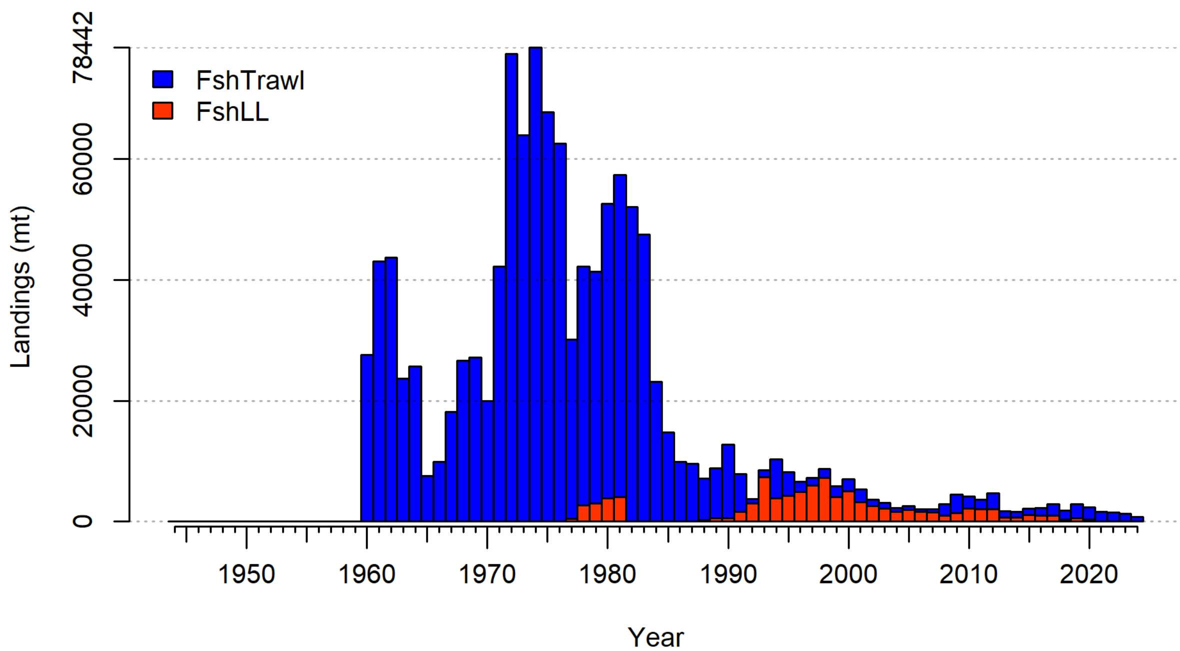


Figure 5.4. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2024. This data includes targeted catch and bycatch.

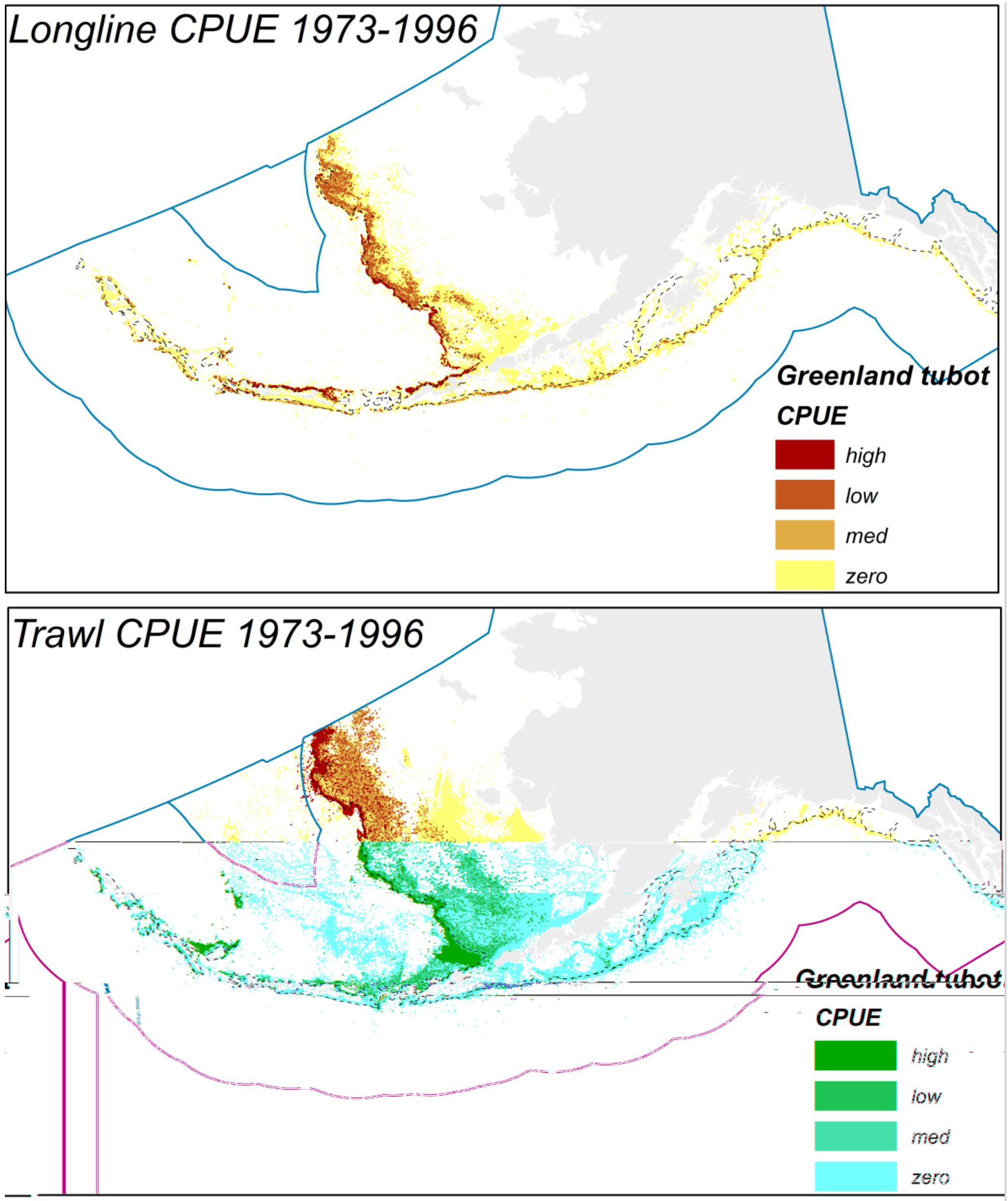


Figure 5.5. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).

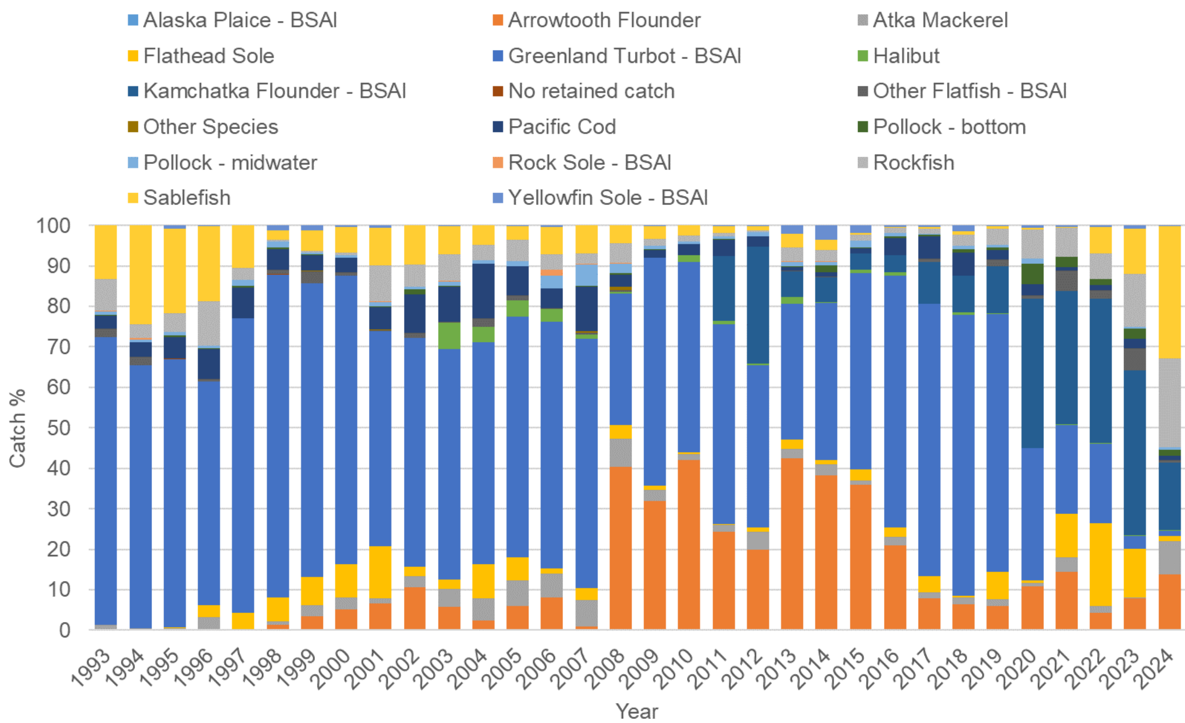


Figure 5.6. Percent catch of Greenland turbot per trip target species, 1993 – 2024.

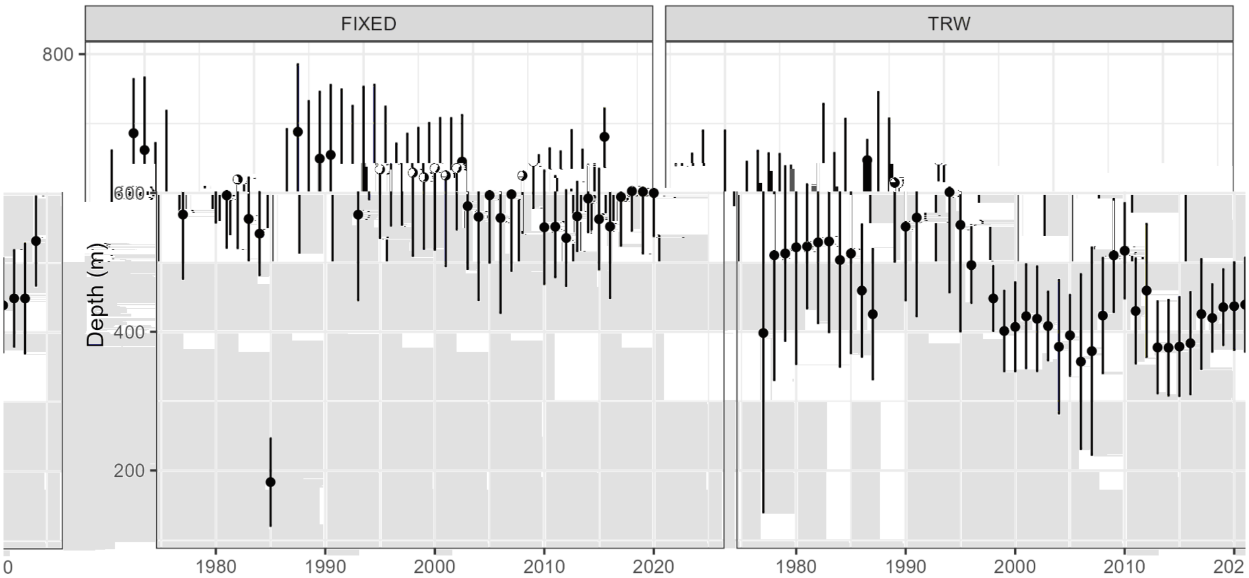


Figure 5.7 Operating depth (m) of the fixed and trawl gear fisheries for Greenland turbot in the EBS and AI combined. Bars represent standard deviation.

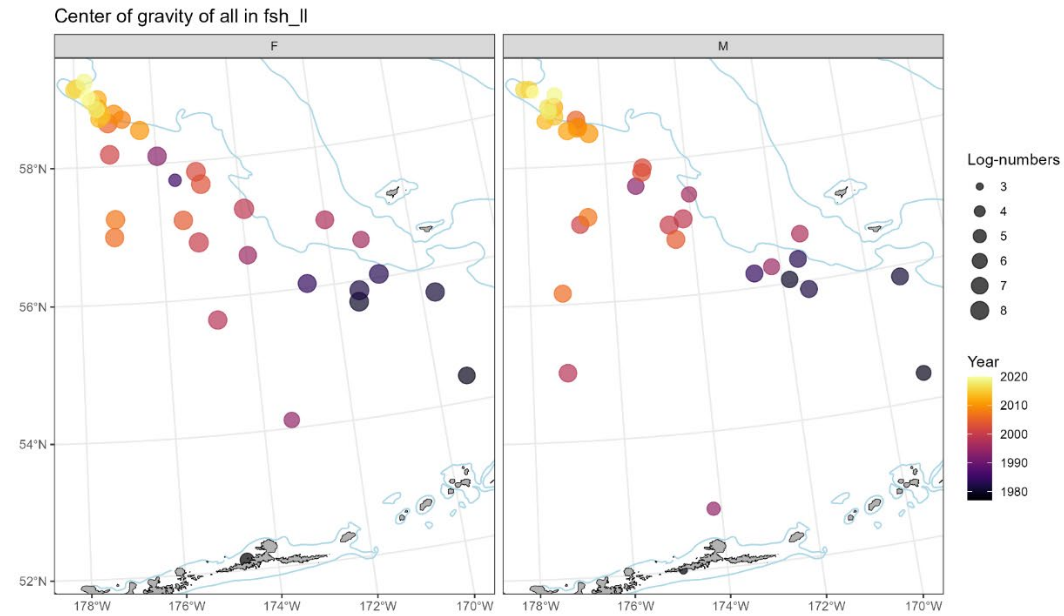


Figure 5.8. Mean annual center of gravity of the longline fishery for Greenland turbot by sex. The size of the bubbles indicates the log-numbers of fished individuals, colors indicate the year.

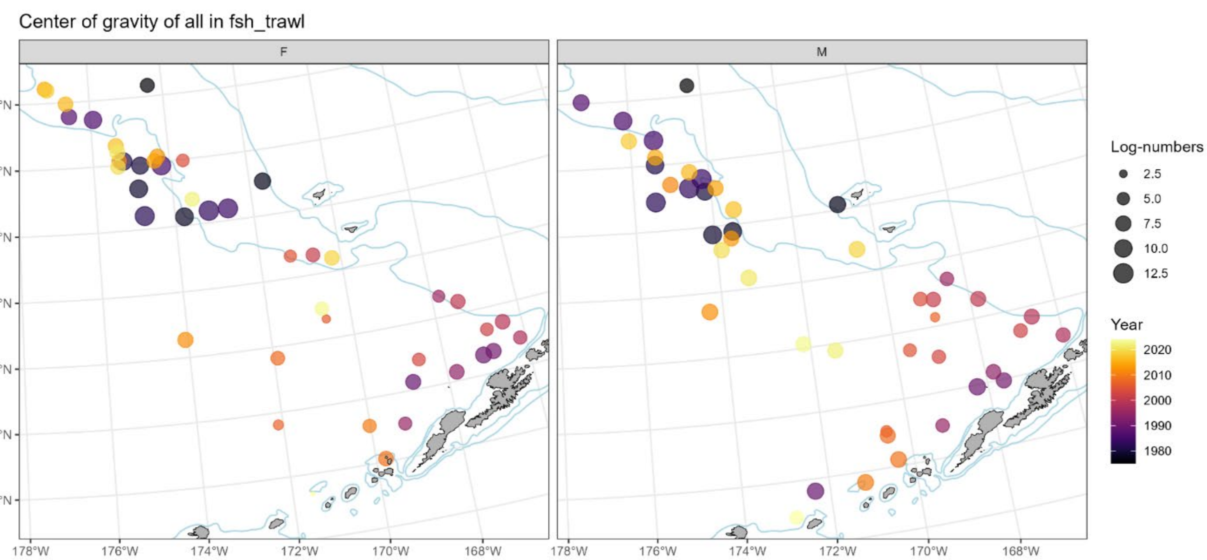


Figure 5.9 Mean annual center of gravity of the trawl fishery for Greenland turbot by sex. The size of the bubbles indicates the log-numbers of fished individuals, colors indicate the year.

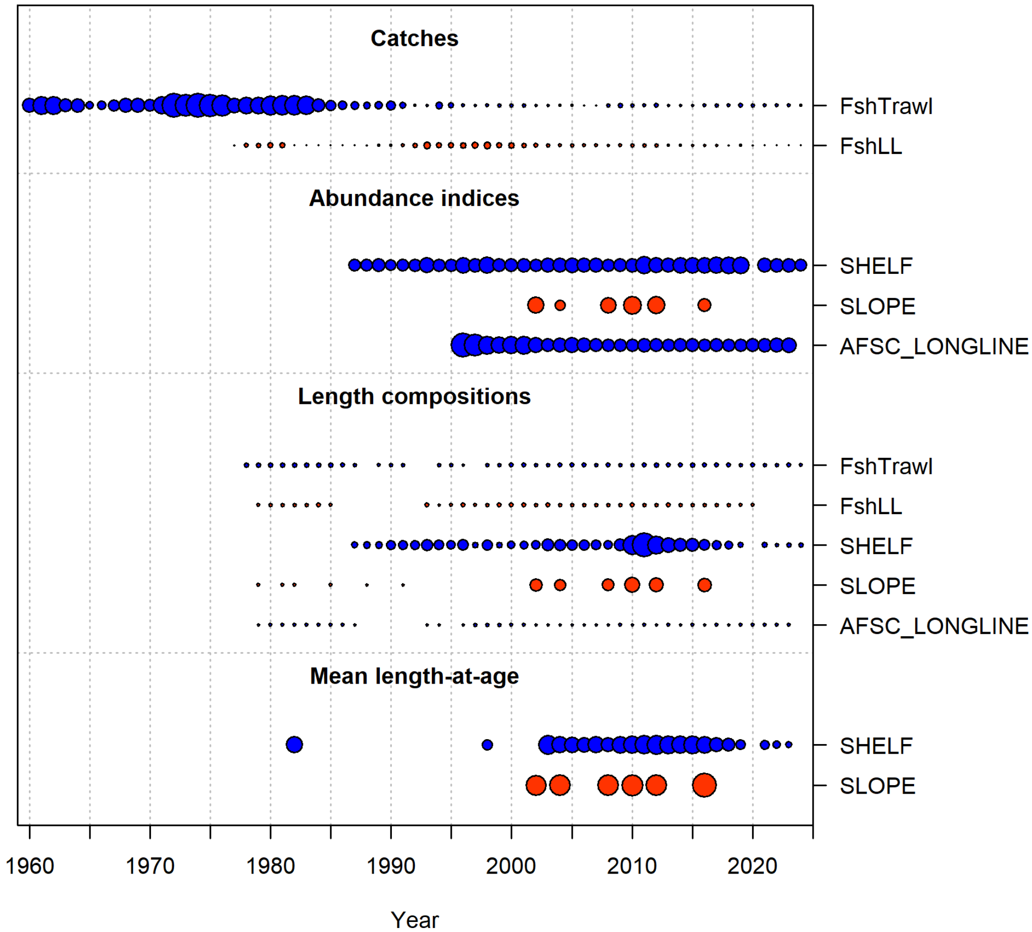


Figure 5.10. Timeline of all data included in models. Circle area is relative within a data type and scaled to the maximum. Circles are proportional total catch for catches, proportional to precision for indices, and tot sample size for composition data.

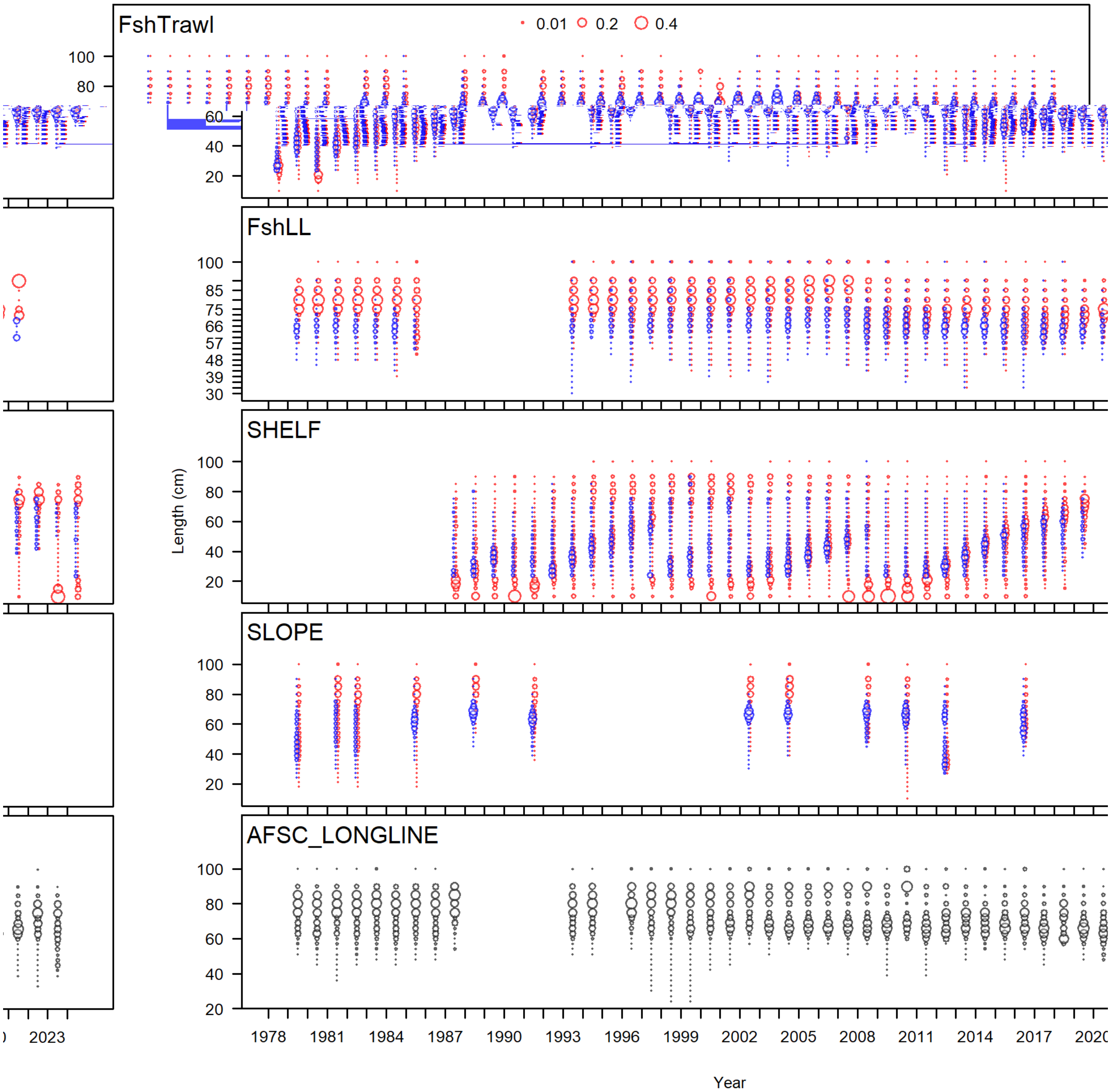


Figure 5.11. Greenland turbot size composition data from the trawl fishery, longline fishery, shelf survey, slope survey, and longline survey. Blue: males; red: females; black: combined sex.

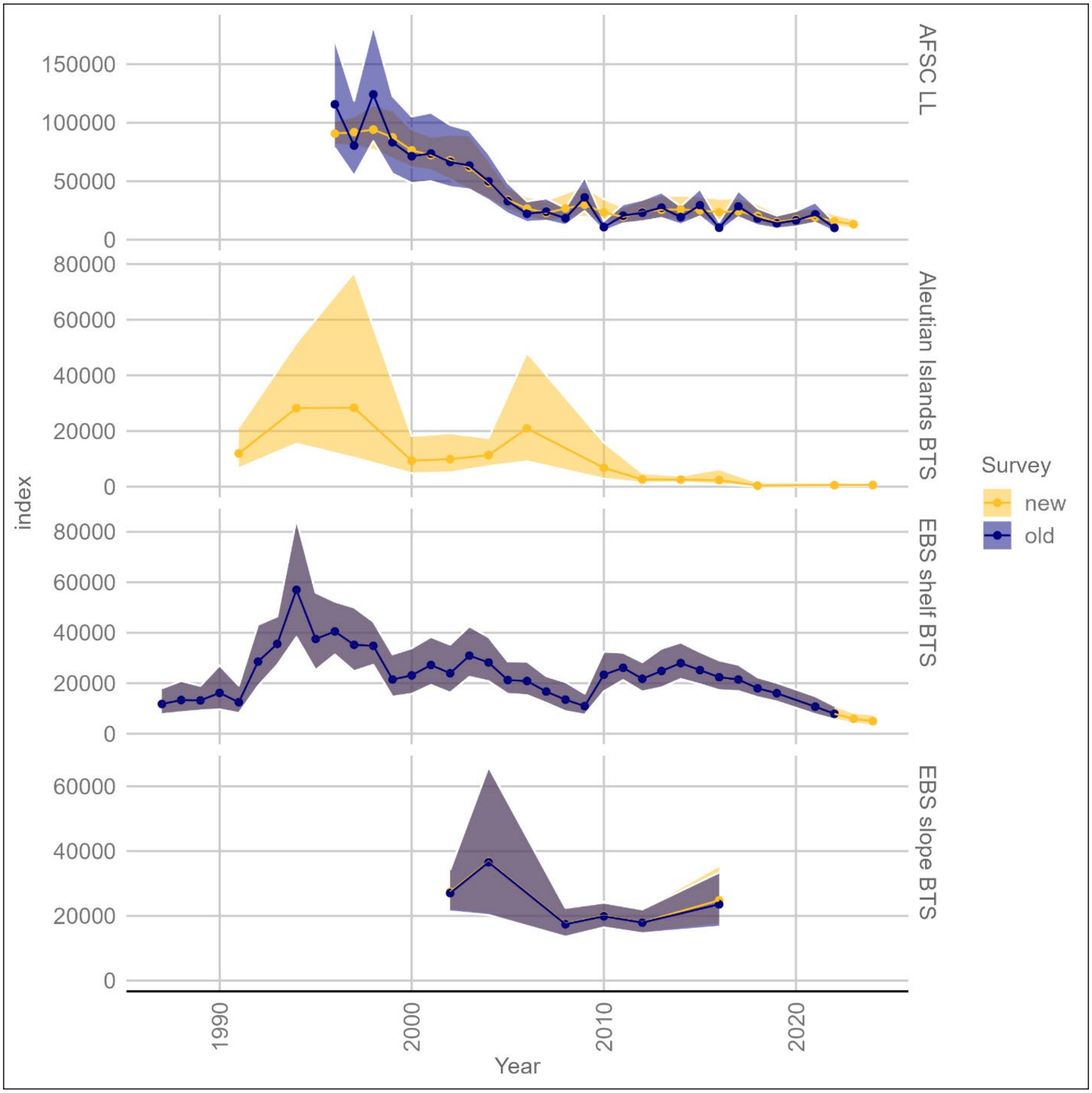


Figure 5.12. Survey indices used in the 2022 assessment and those used in the 2024 assessment models. The ‘old’ AFSC longline RPN index is used in model m16.4c (2024) and the ‘new’ index is used in the alternative models.

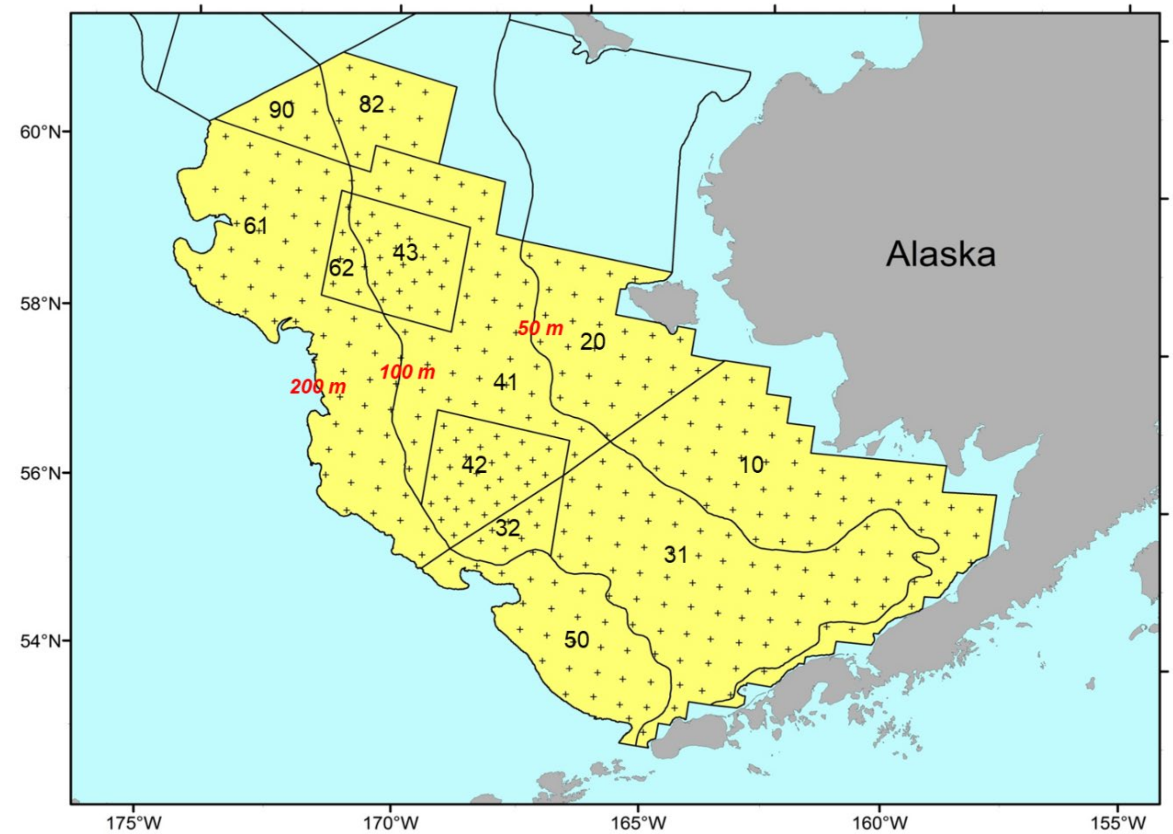


Figure 5.13. Map of Eastern Bering Sea bottom trawl survey areas.

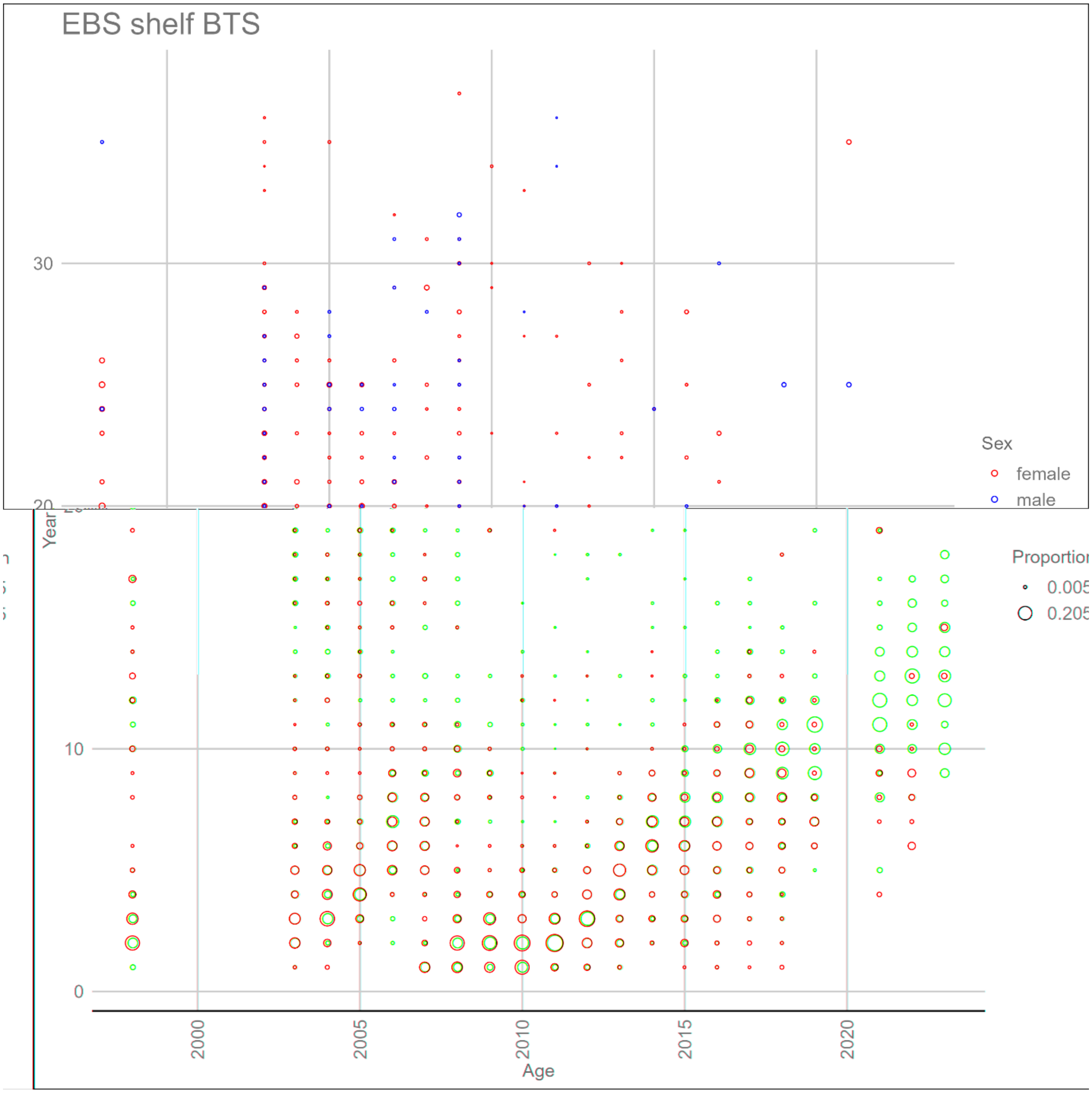


Figure 5.14. Greenland turbot age composition data for females (red) and males (blue) from the EBS shelf bottom trawl survey. These data were included in the model but not included in the likelihood.

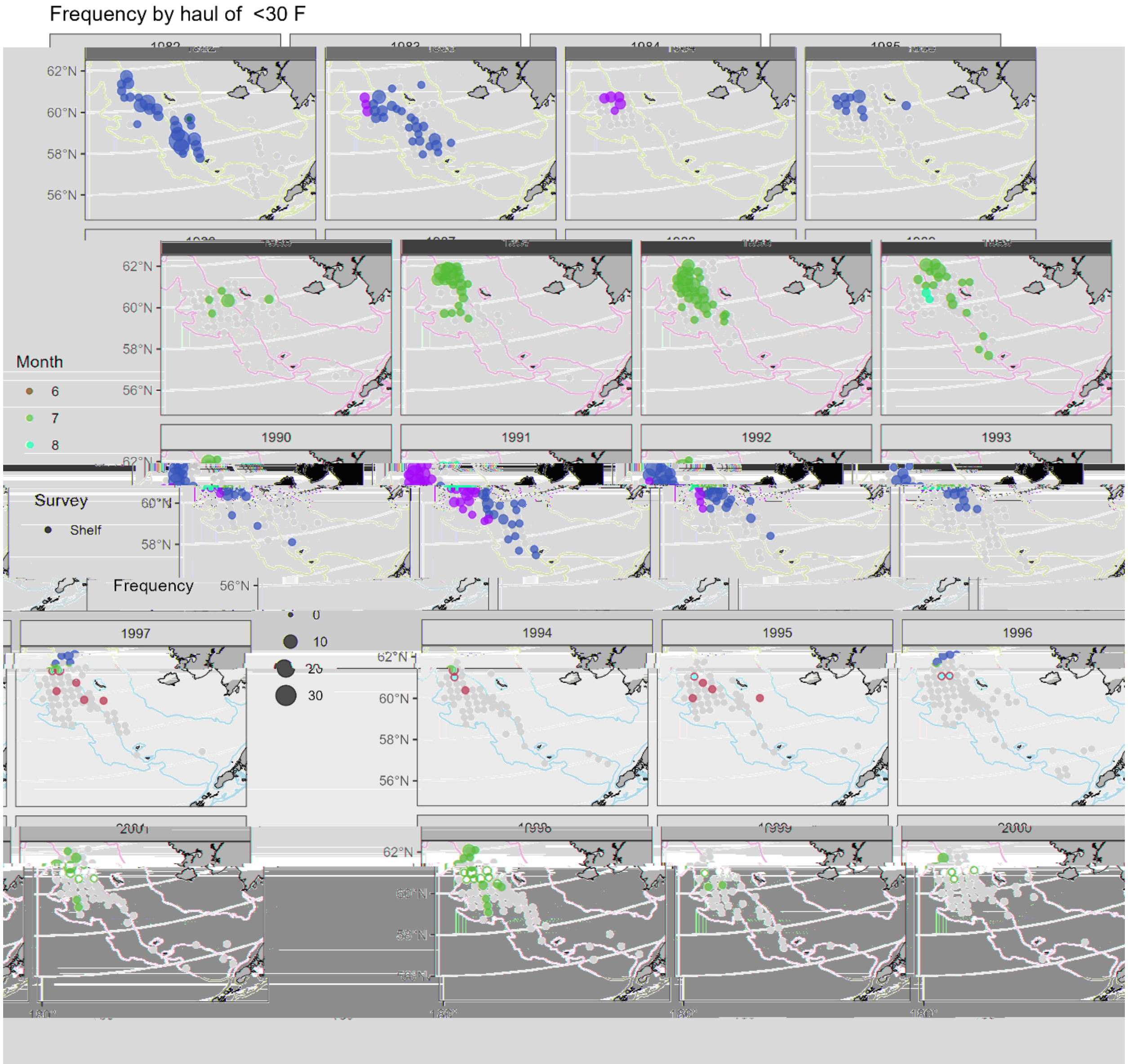


Figure 5.15. Maps of frequency of encounter of <30 cm female Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf).

Figure 5.15. Continued.

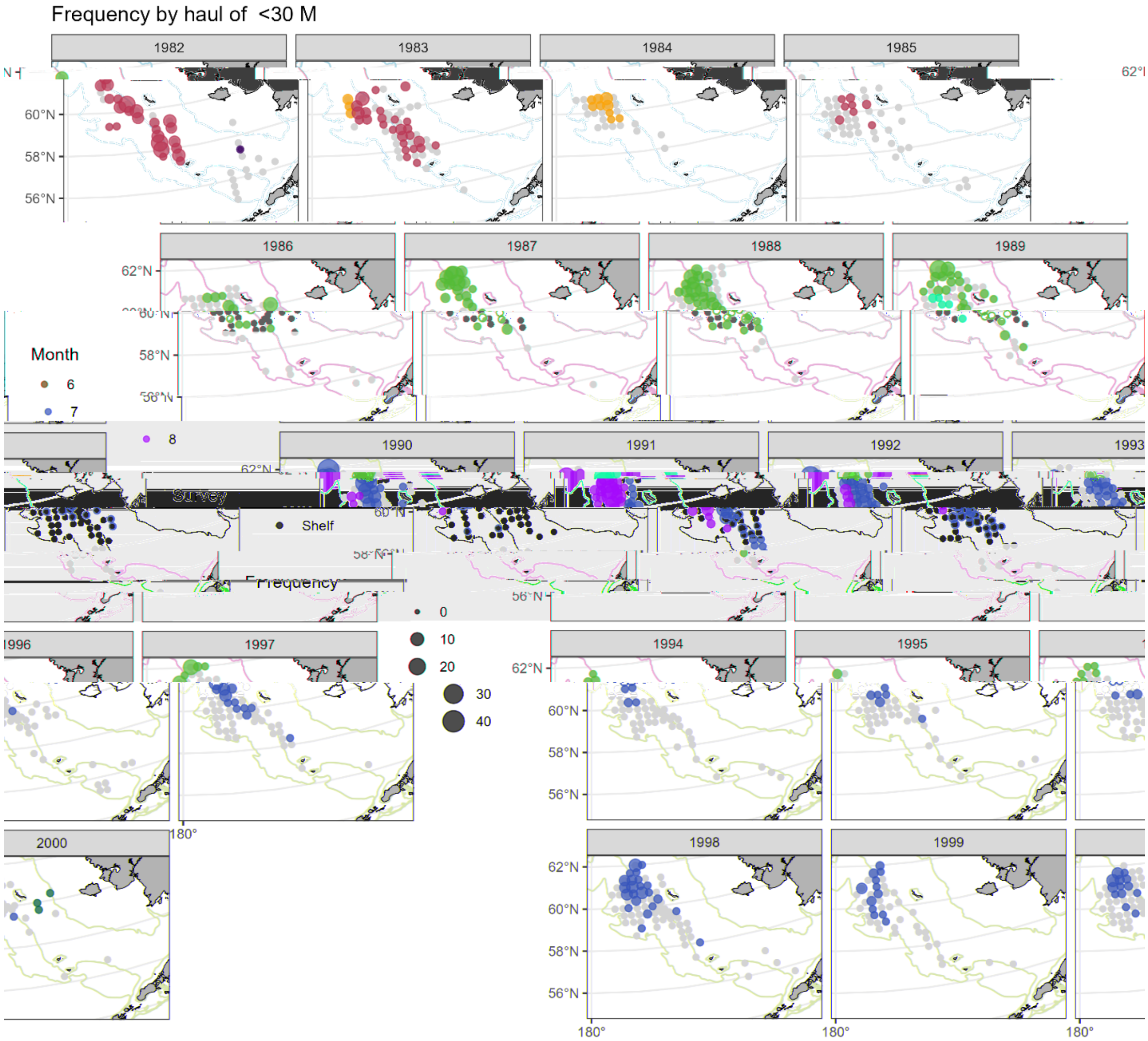


Figure 5.16. Maps of frequency of encounter < 30 cm male Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf).

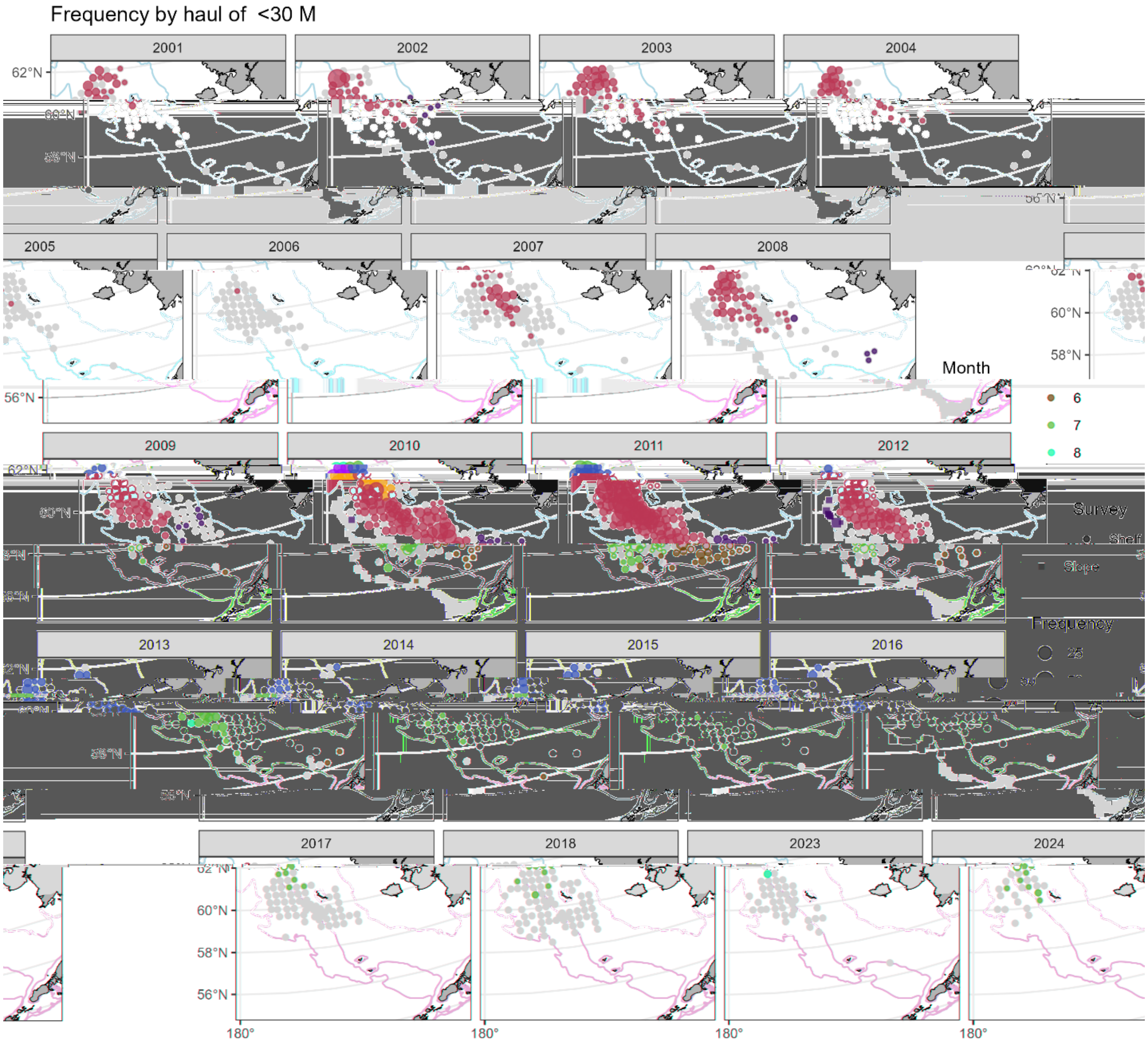


Figure 5.16. Continued.

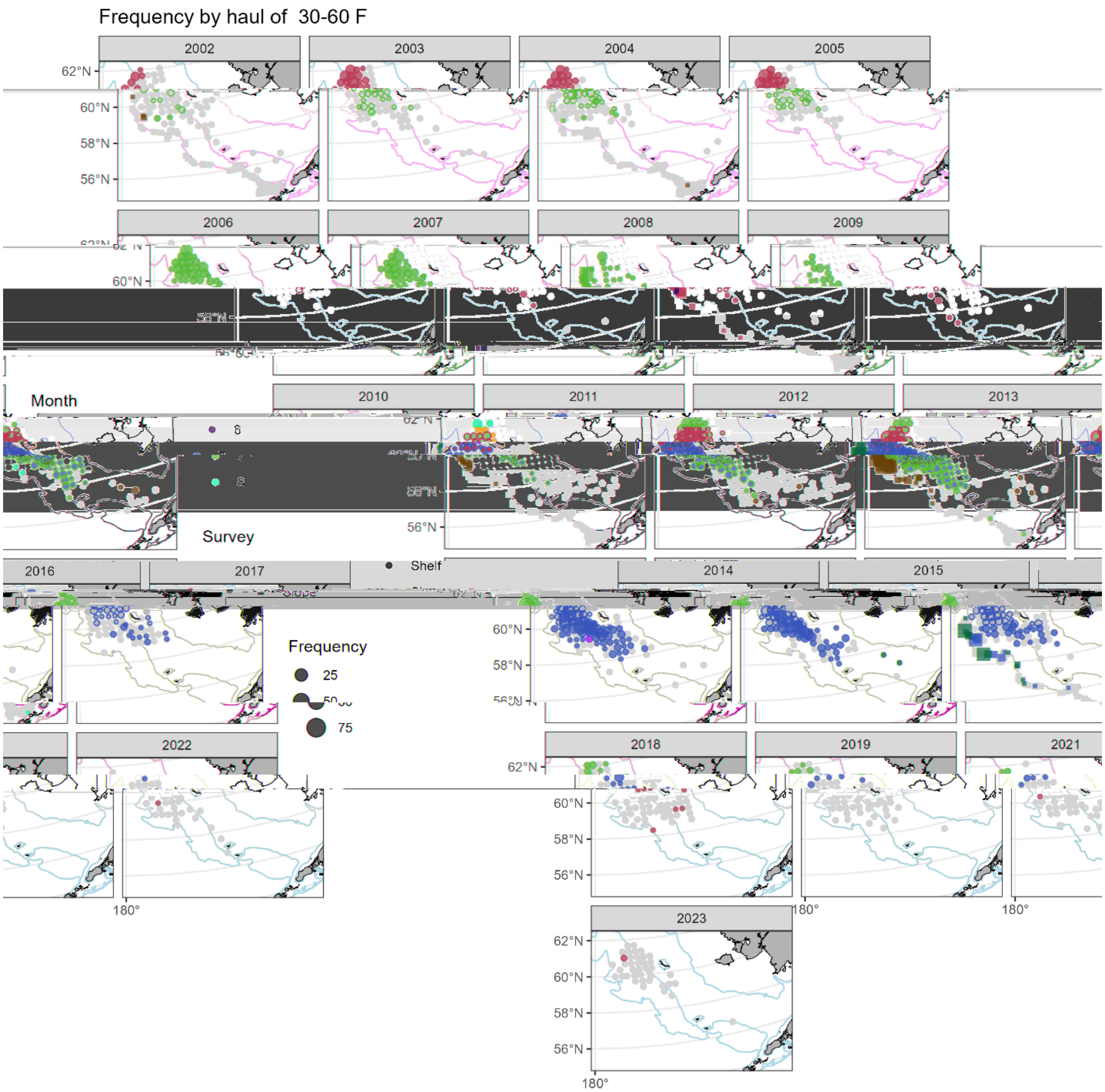


Figure 5.17. Maps of frequency of encounter of 30-60 cm female Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf; squares: slope). Only years after 2002 are shown.

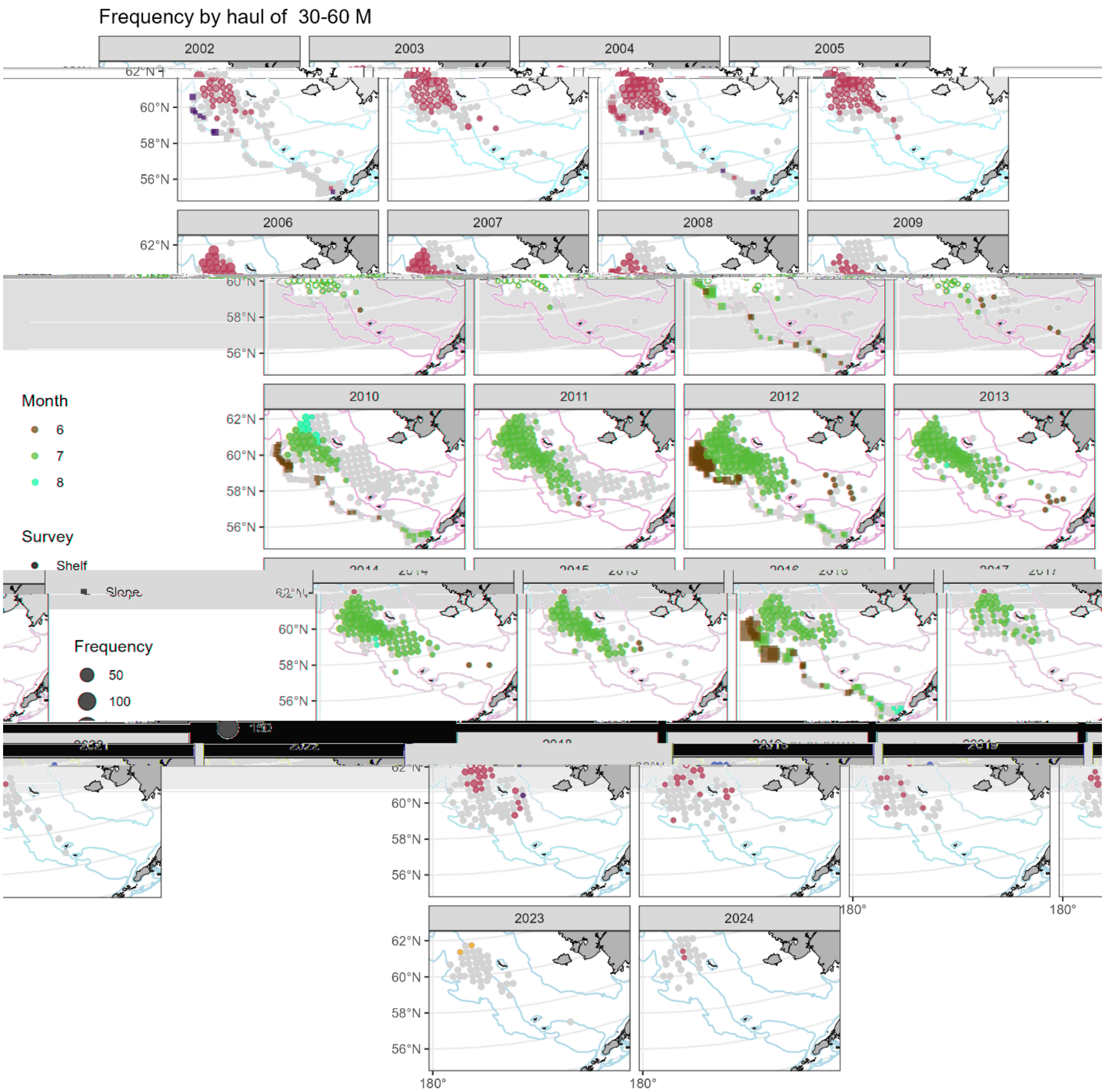


Figure 5.18. Maps of frequency of encounter of 30-60 cm female Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf; squares: slope). Only years after 2002 are shown.

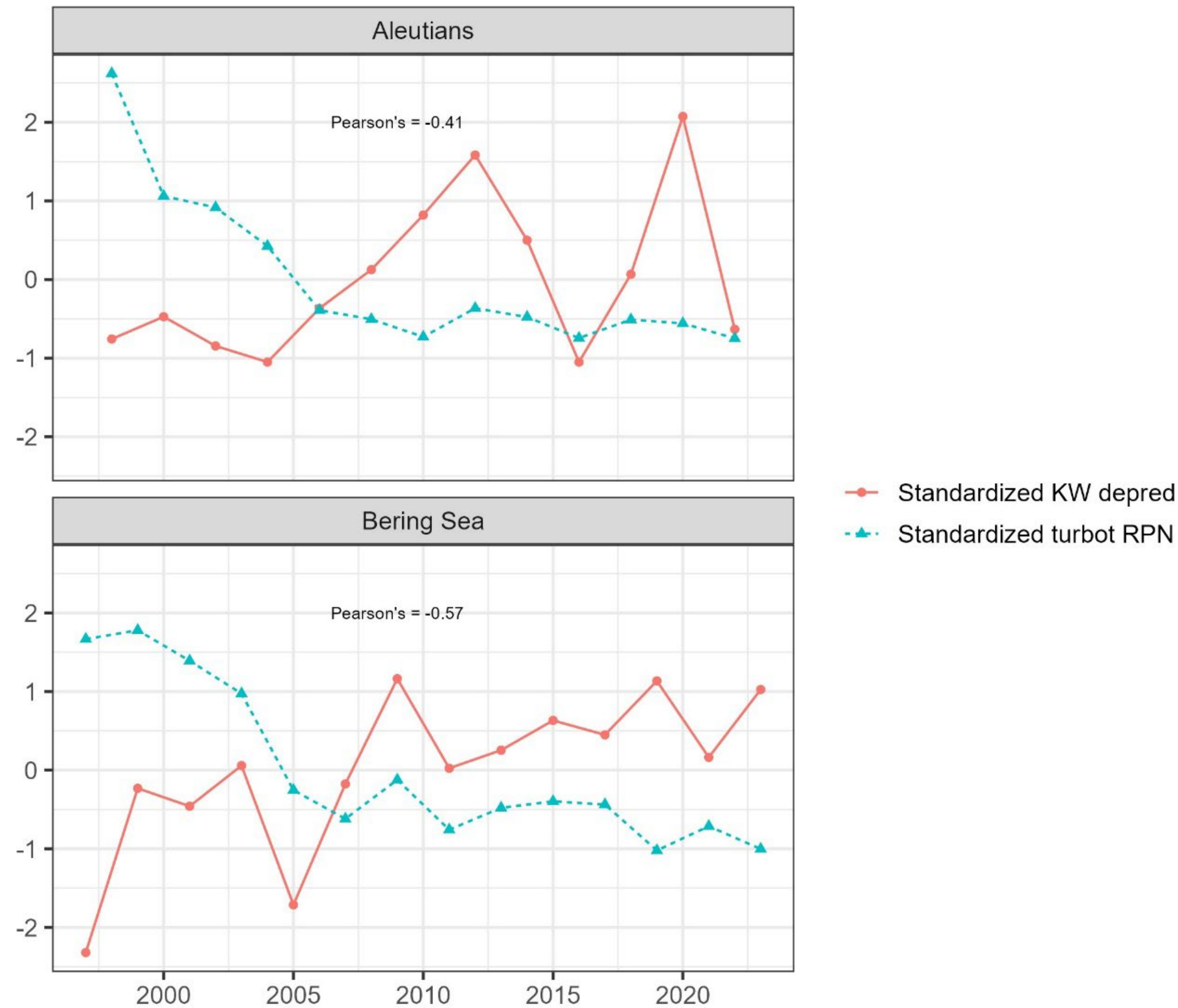


Figure 5.19. AFSC longline survey RPN estimates and killer whale depredation rates for the Aleutain Islands (top) and Bering Sea (bottom).

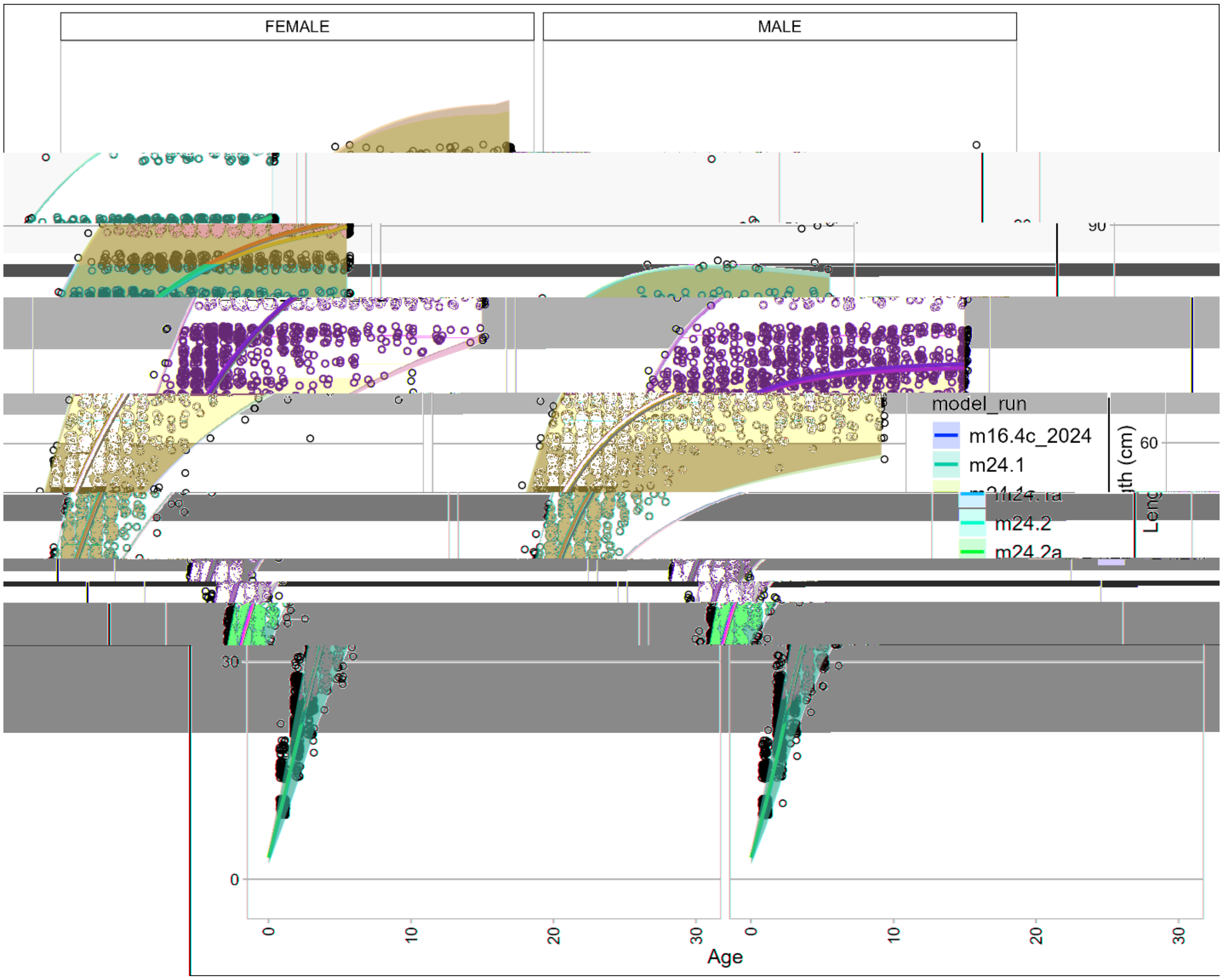
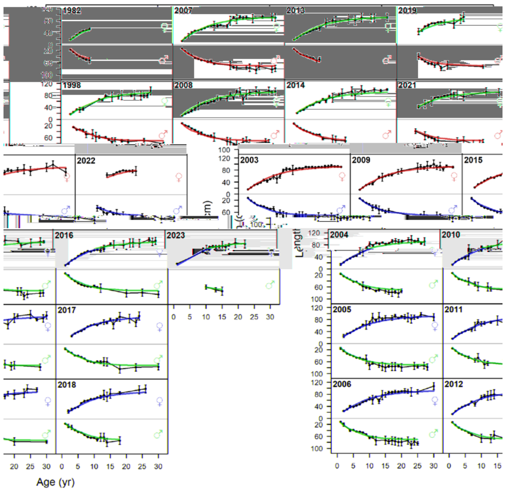
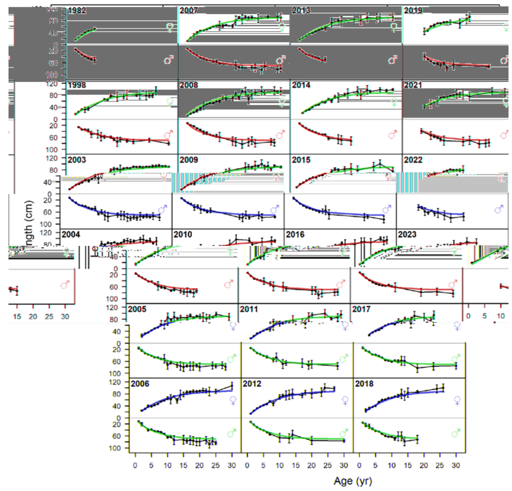


Figure 5.20. Estimated growth curves and uncertainty from each model plotted against the raw length at age observations from the gap_products specimen table.

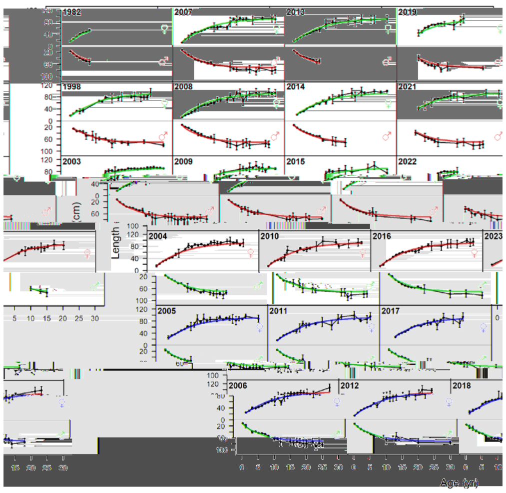
a)



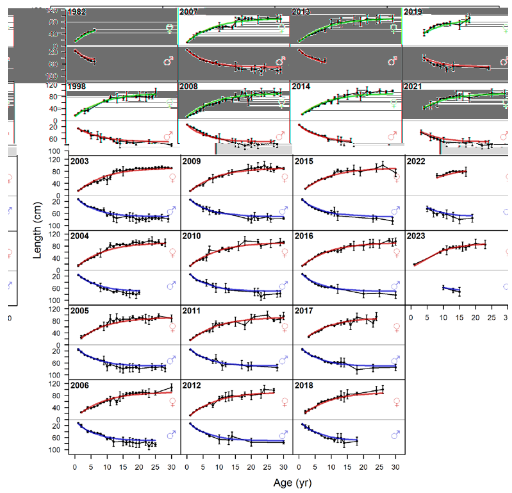
b)



c)



d)



e)

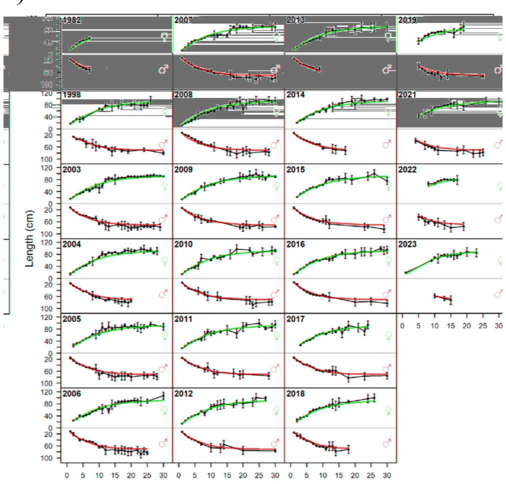


Figure 5.21. EBS shelf bottom trawl survey length at age data and fit (females - red line, males – blue line) by a) Model 16.4c and b) Model 24.1, and c) Model 24.1a, d) 24.2, and e) 24.2a.

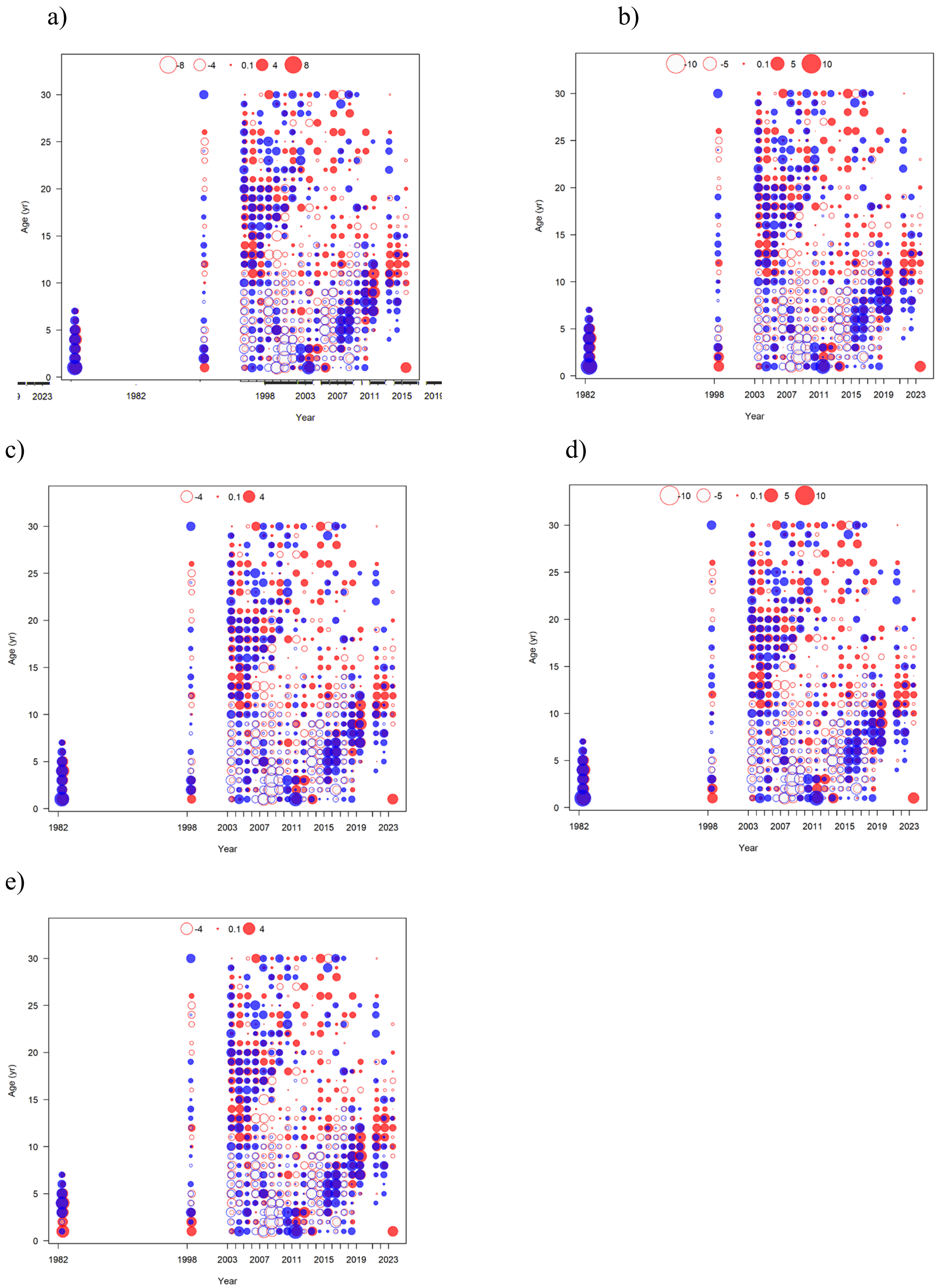
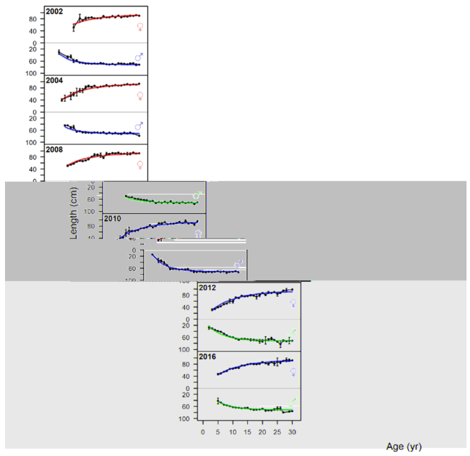
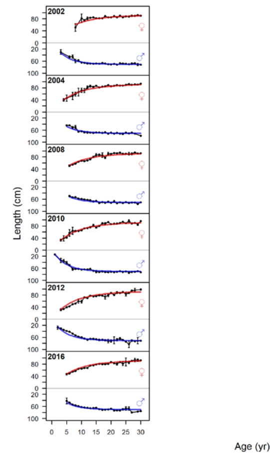


Figure 5.22. a) The standardized residuals for the fit to the mean length at age data from a) Model 16.4c and b) Model 24.1, and c) Model 24.1a, d) 24.2, and e) 24.2a. The closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation). Red bubbles are female and blue are male.

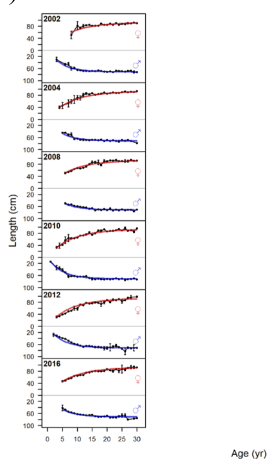
a)



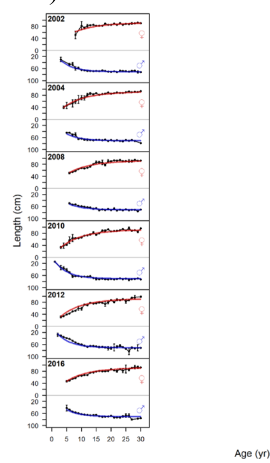
b)



c)



d)



e)

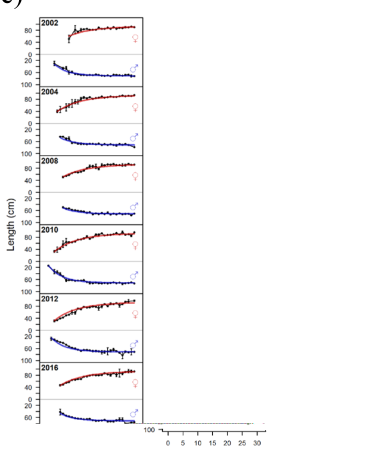


Figure 5.23. a) EBS slope bottom trawl survey length at age data and fit (females - red line, males – blue line) and b) standardized residuals from a) Model 16.4c and b) Model 24.1, and c) Model 24.1a, d) 24.2, and e) 24.2a. The closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation). Red bubbles are female and blue are male.

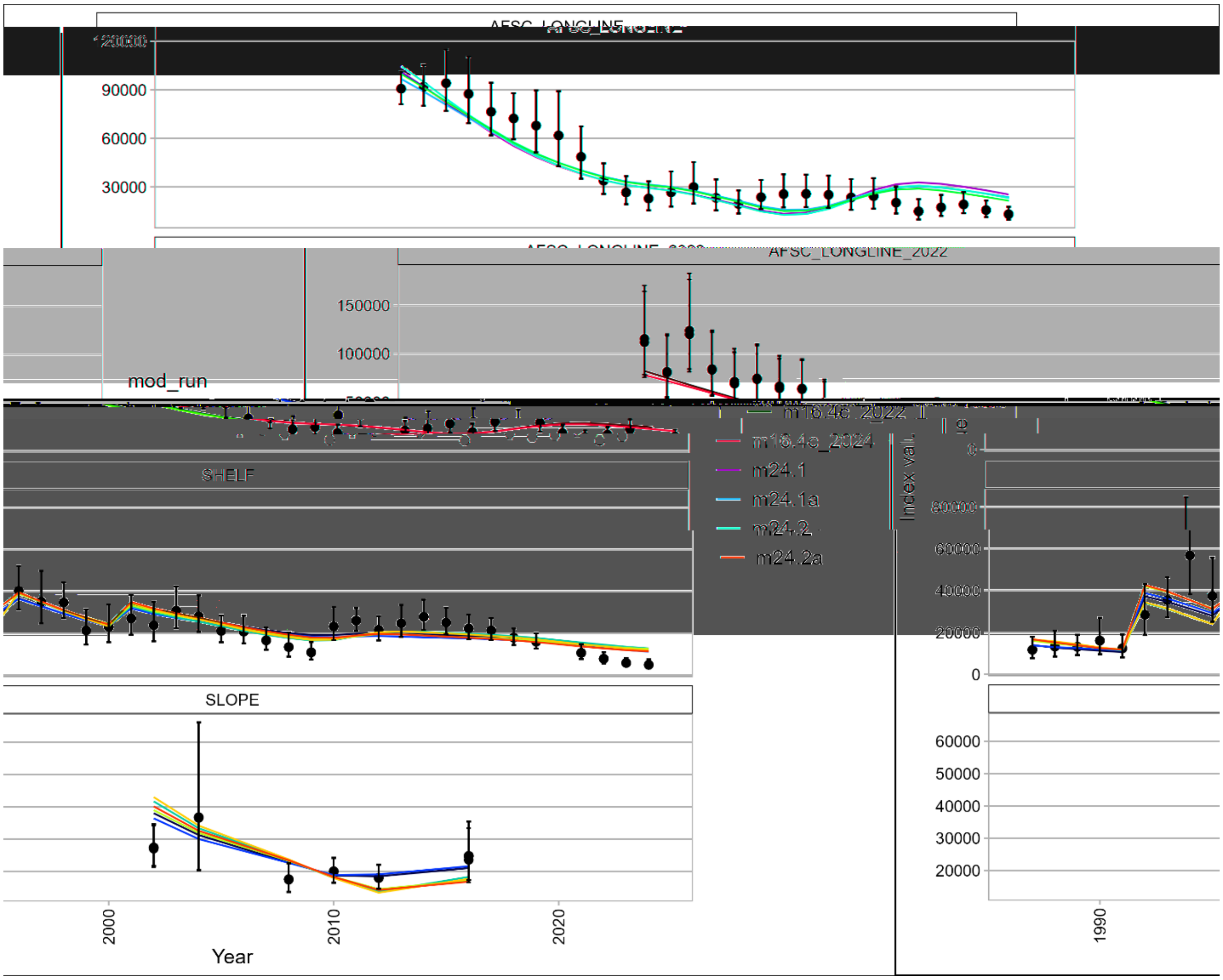


Figure 5.24. Survey indices (index values are the total survey biomass in tons) and model fits. Error bars are 95% confidence intervals. The AFSC longline facet is for model fit to the RPNs from the linear approximation method and the AFSC_LONGLINE_2022 is for the model fit to the status quo RPN approach.

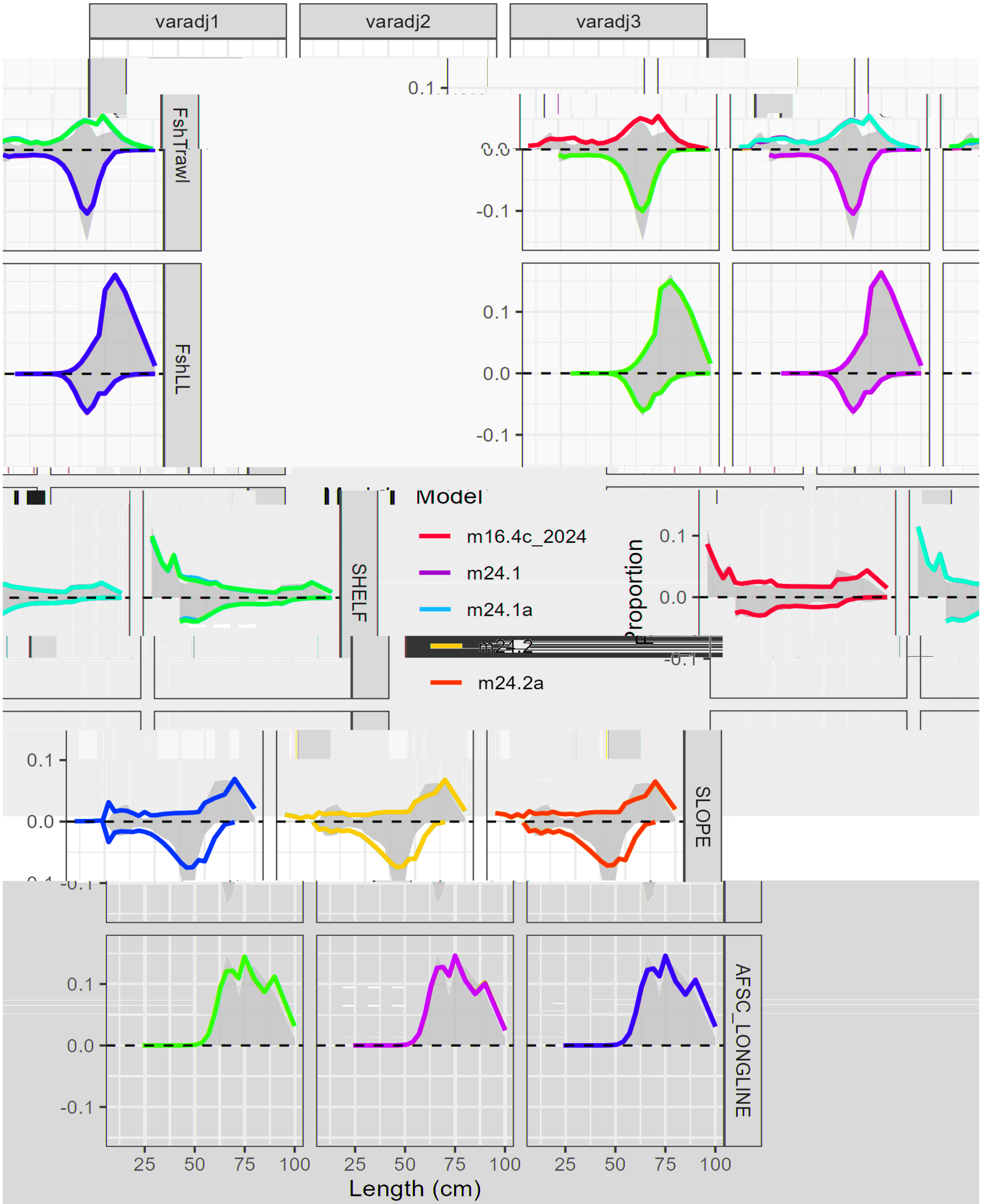


Figure 5.25. Fit to the aggregated length composition data by fleet, model, and assumption about the combination of input sample size and variance adjustment. Varadj2 represents the afscISS sample size for bottom trawl surveys reported in Table 5.14 and no variance adjustment, varadj3 represents the afscISS sample size and m16.4c variance adjustments inputs.

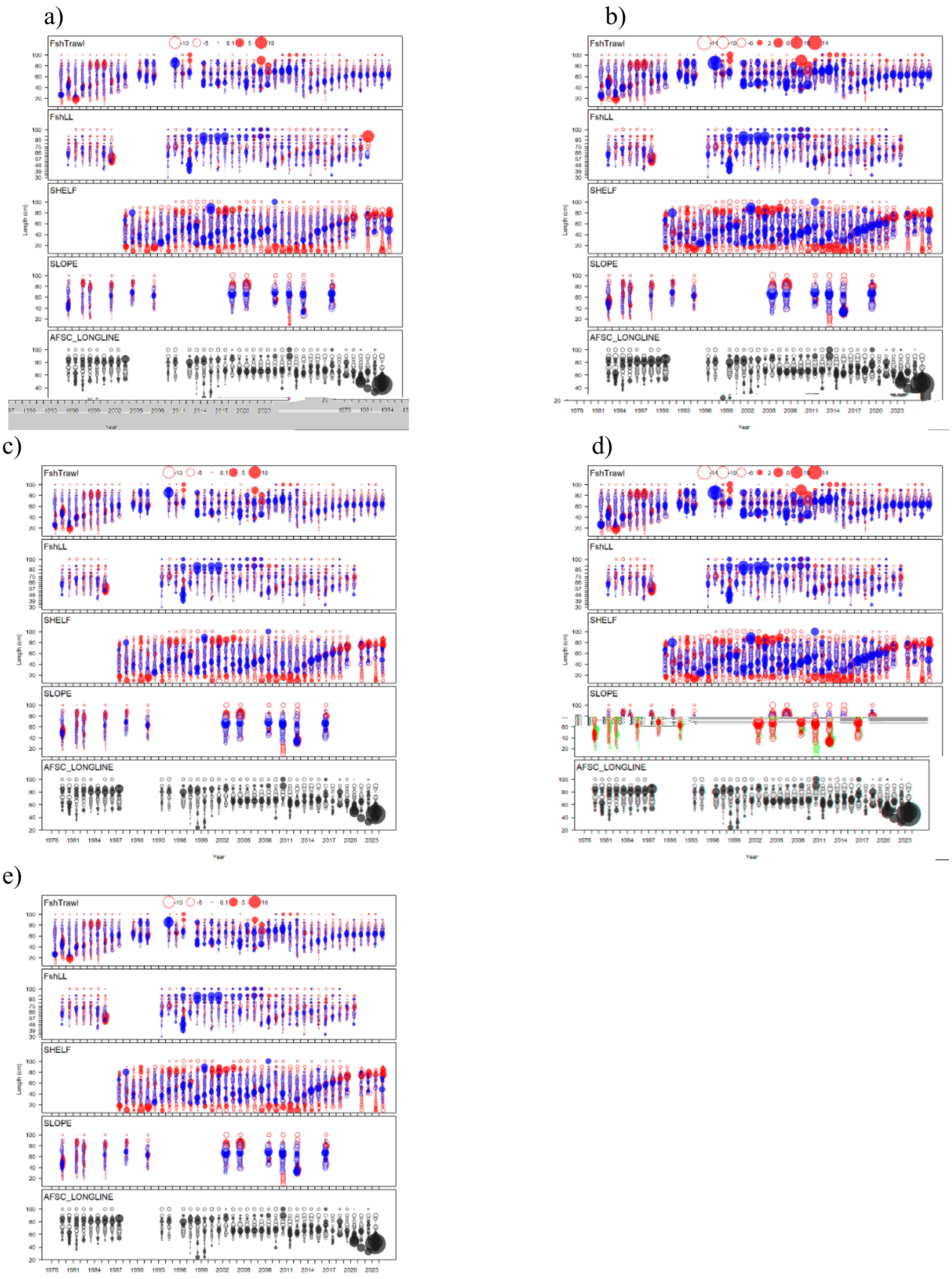


Figure 5.26. Pearson residuals for the trawl and longline fisheries and the EBS shelf and EBS slope bottom trawl surveys, a) Model 16.4c and b) Model 24.1, and c) Model 24.1a, d) 24.2, and e) 24.2a. Closed bubbles are positive residuals (obs-expected, underestimation) and open bubbles are negative residuals (overestimation). Note that the scale of the bubble graphs may differ by model.

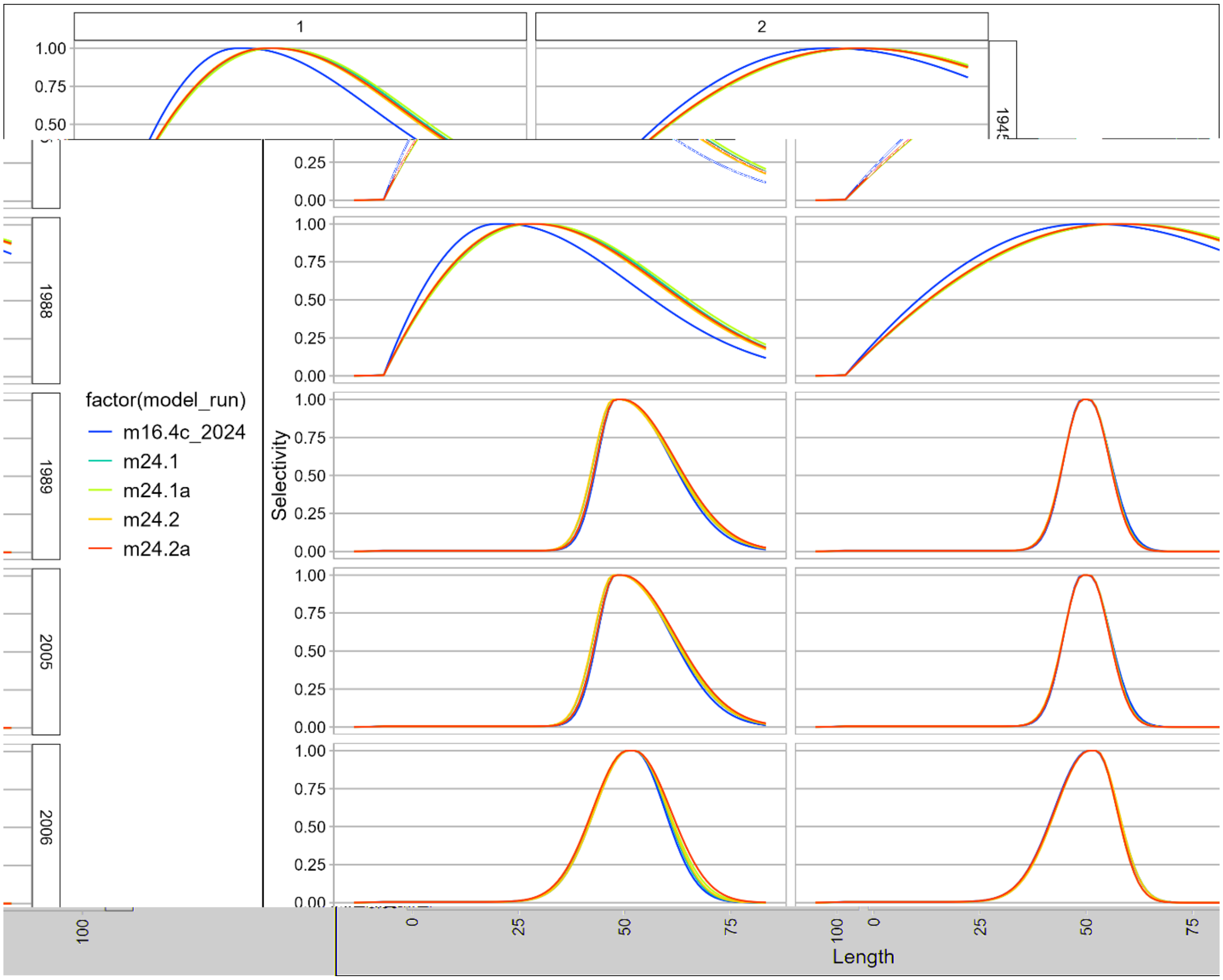


Figure 5.27. Time-varying selectivity at size for the trawl fishery for both sexes. The value 1 represents females and 2 represents males.

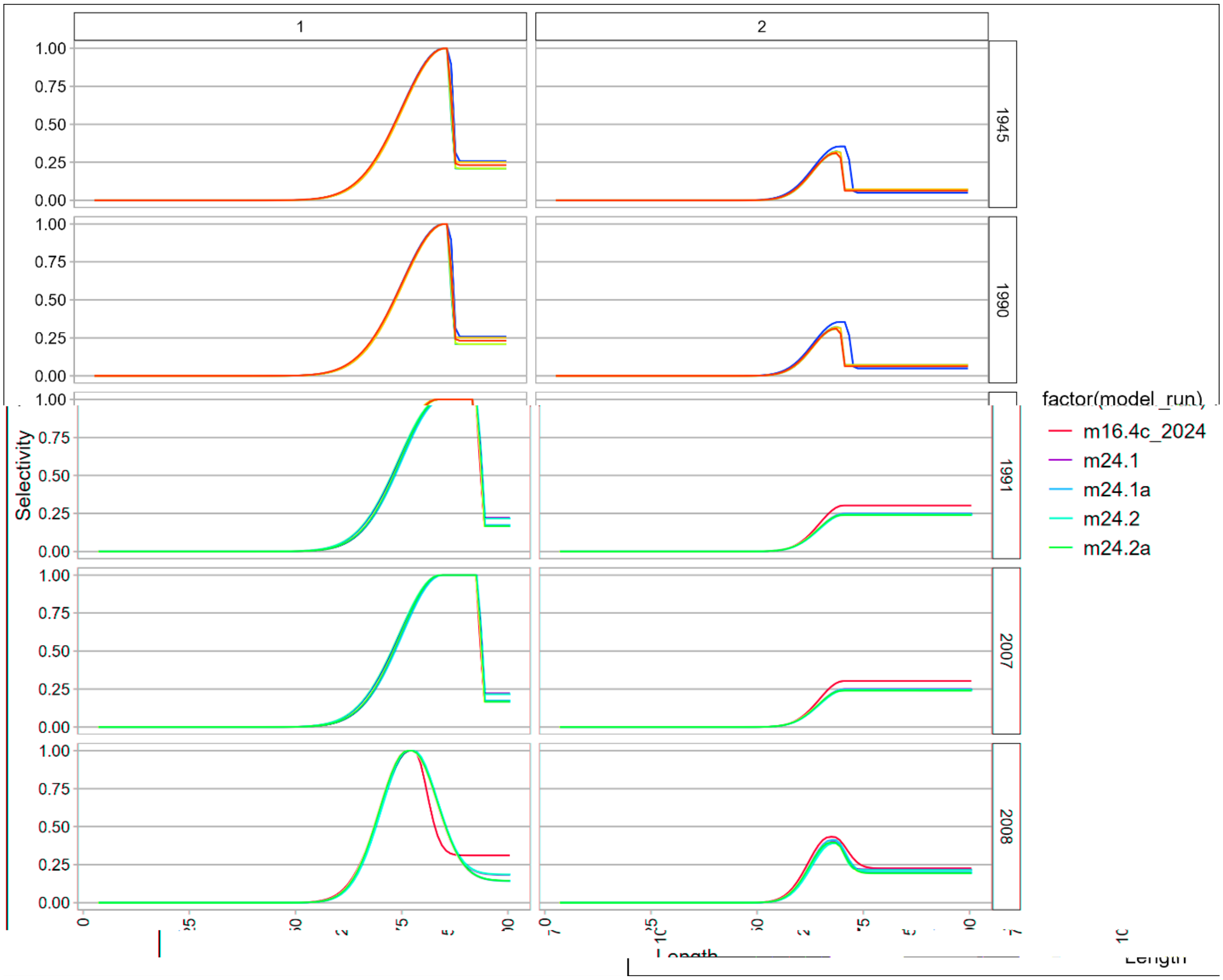


Figure 5.28. Time-varying selectivity at size for the longline fishery for both sexes. The value 1 represents females and 2 represents males.

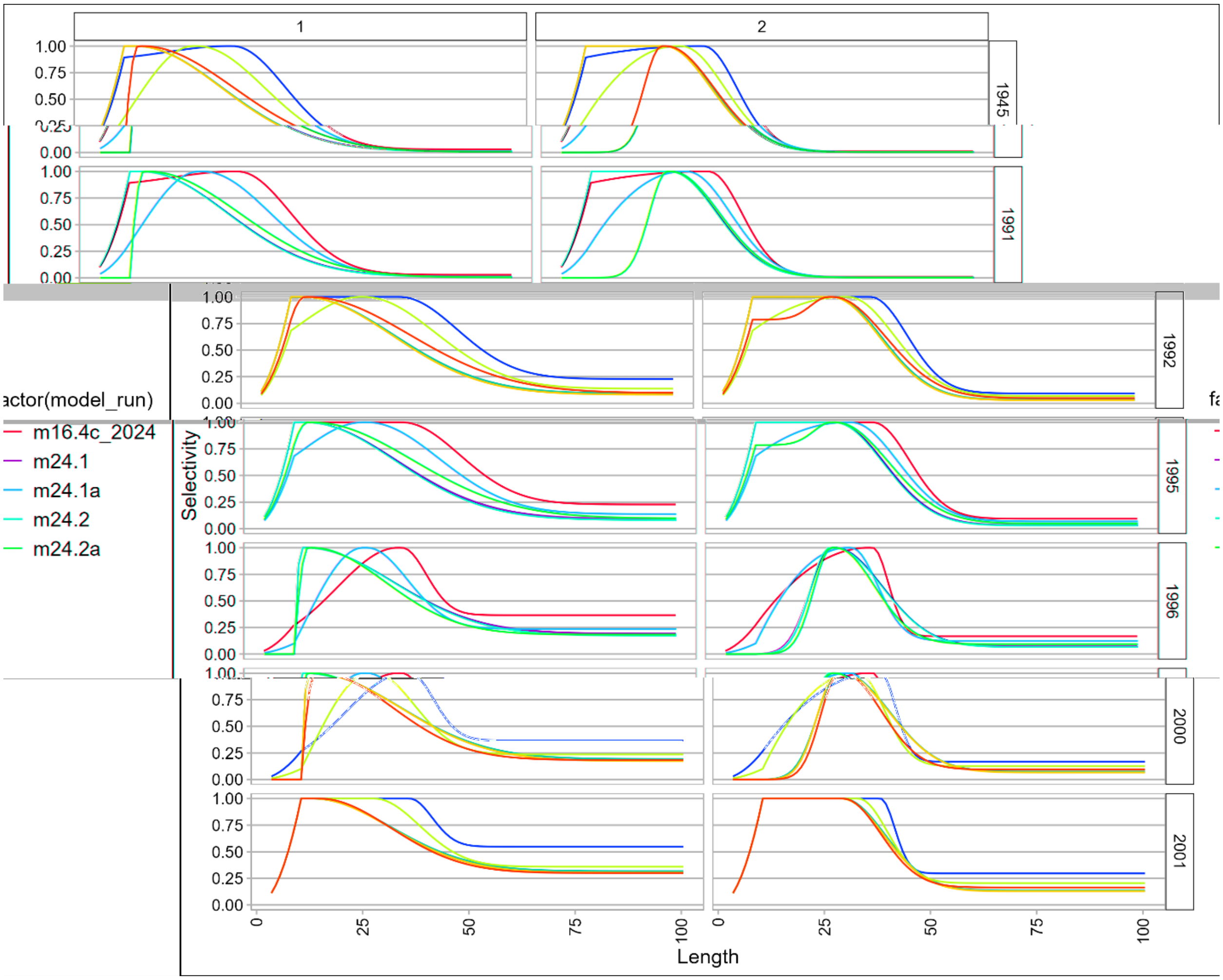


Figure 5.29. Time-varying selectivity at size by sex for the shelf survey. The value 1 represents females and 2 represents males.

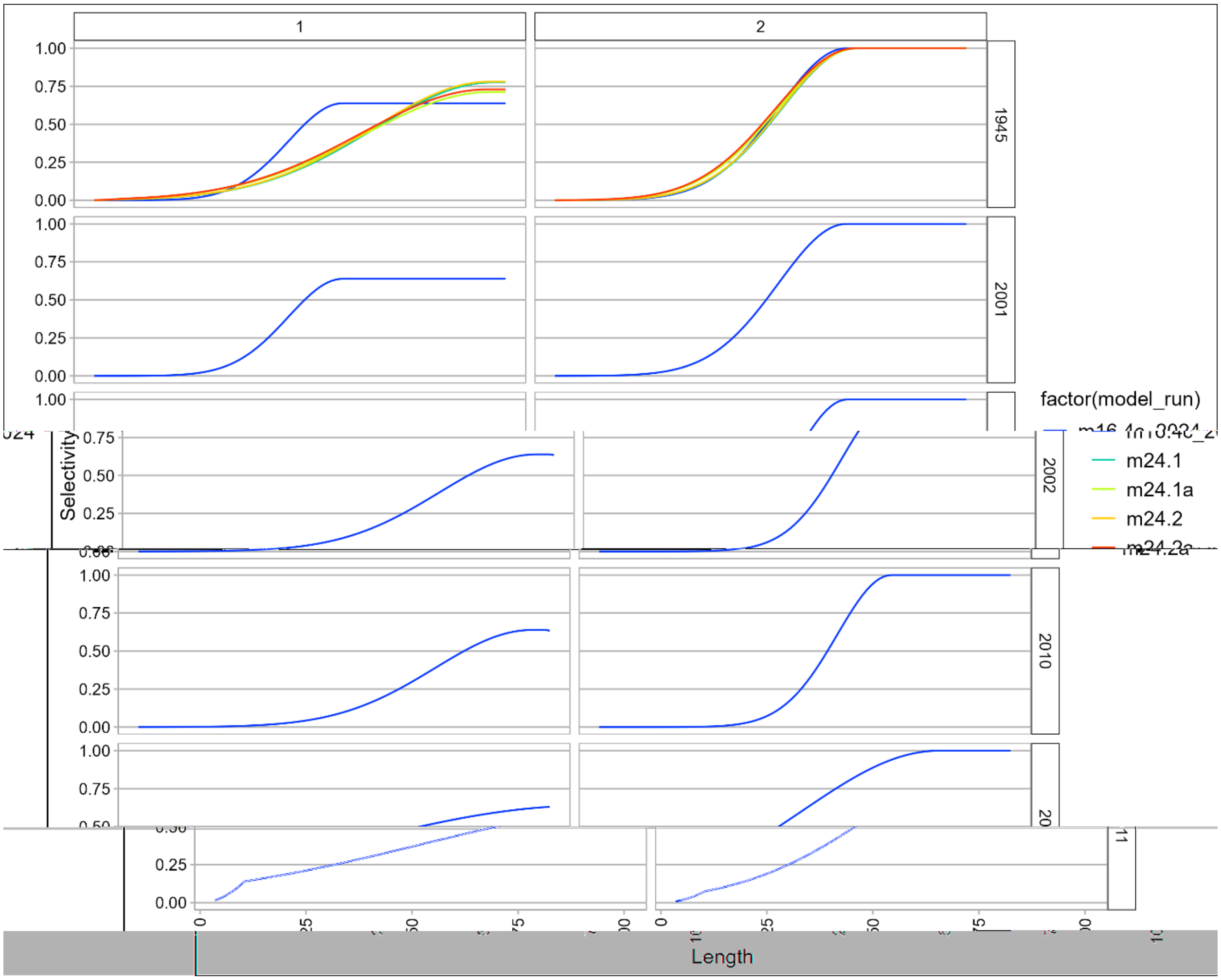


Figure 5.30. Time-varying selectivity at size by sex for the EBS slope bottom trawl survey. The estimated selectivity for Models 24.1, 24.1a, 24.2, and 24.2a was not time-varying and plotted in the 1945 facet. The value 1 represents females and 2 represents males.

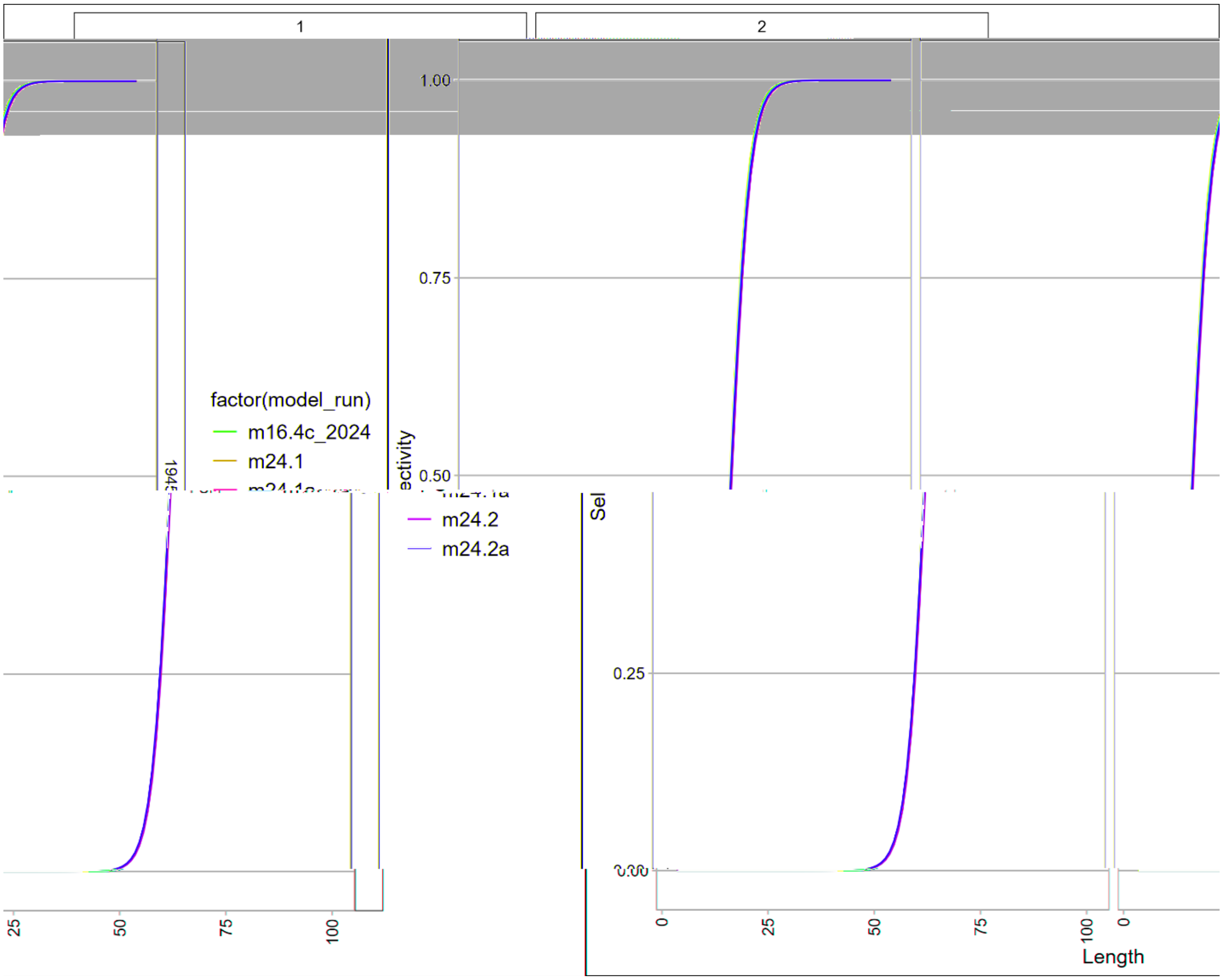


Figure 5.31. AFSC longline survey selectivity for females (1) and males (2).

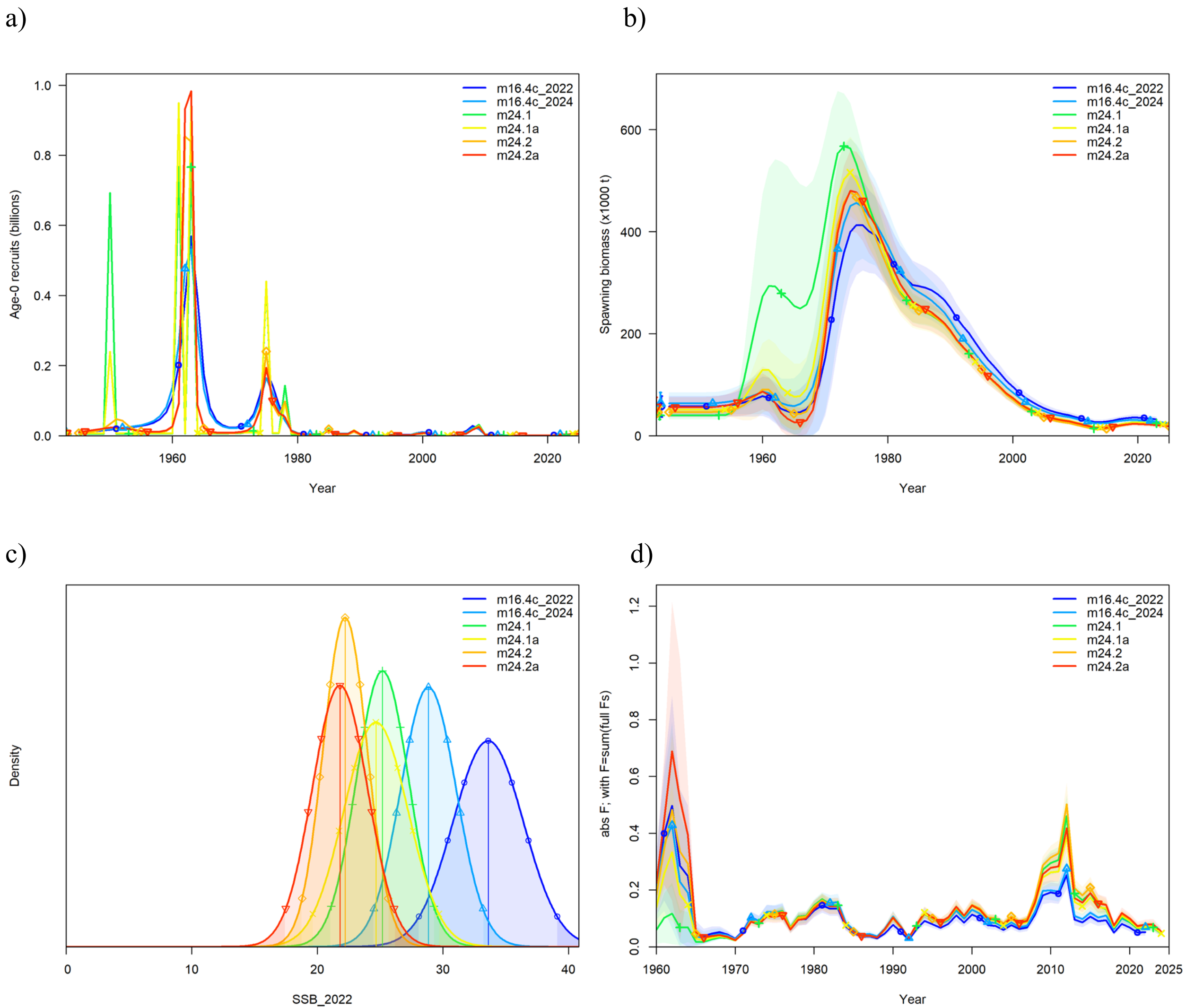


Figure 5.32. a) Age-0 recruitment, b) female spawning biomass, c) the posterior density of spawning biomass in 2020, and d) fishing mortality for models 16.4c (2022), 16.4c (2024), 24.1, 24.1a, 24.2, 24.2a.

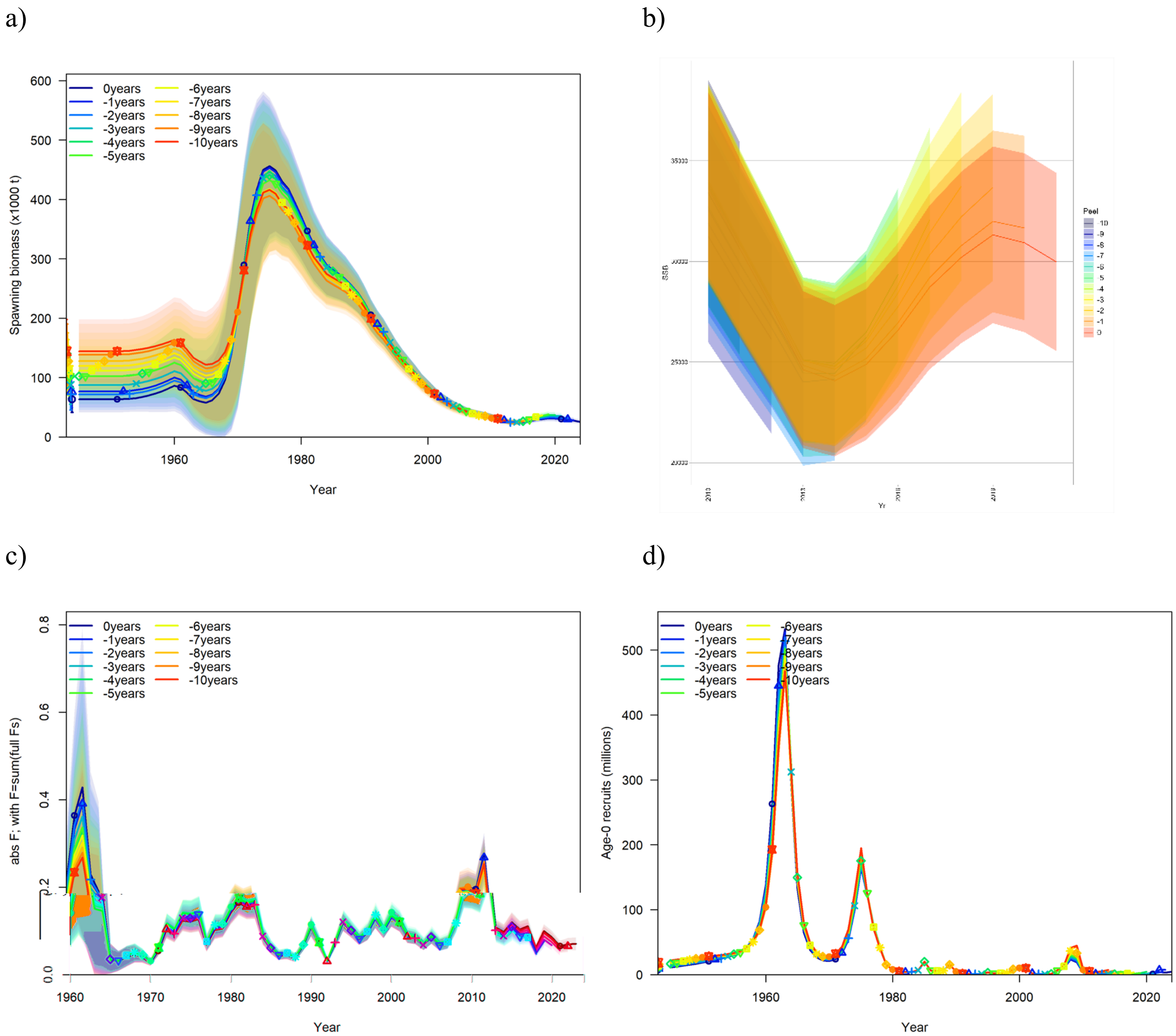
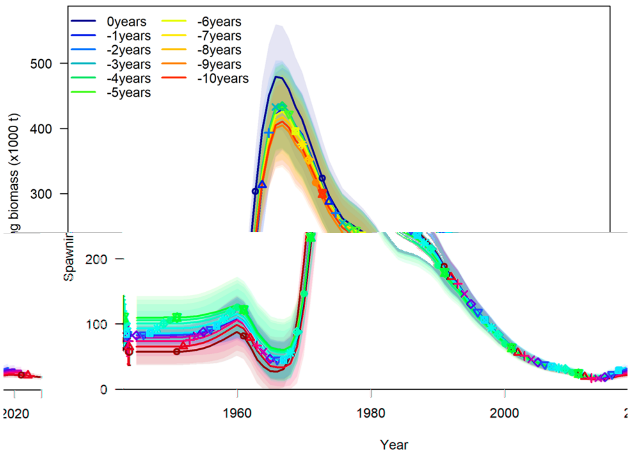
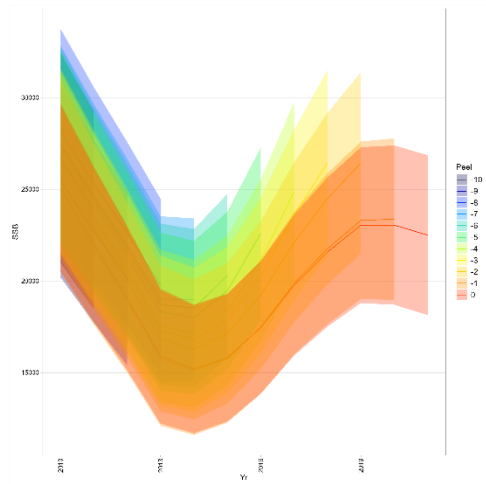


Figure 5.33. Retrospective plots of a) female spawning biomass (fulltime series), b) female spawning biomass (last 10 years), c) age-0 recruits, and d) fishing mortality (bottom) with data sequentially removed from 2024 to 2014 for model 16.4c.

a)



b)



c)

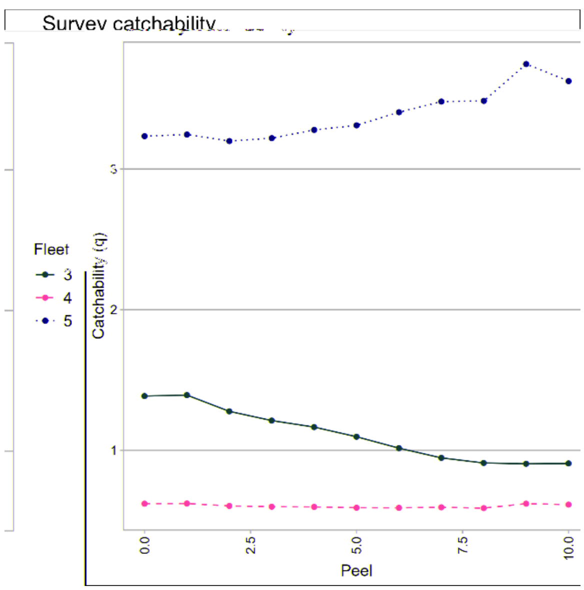
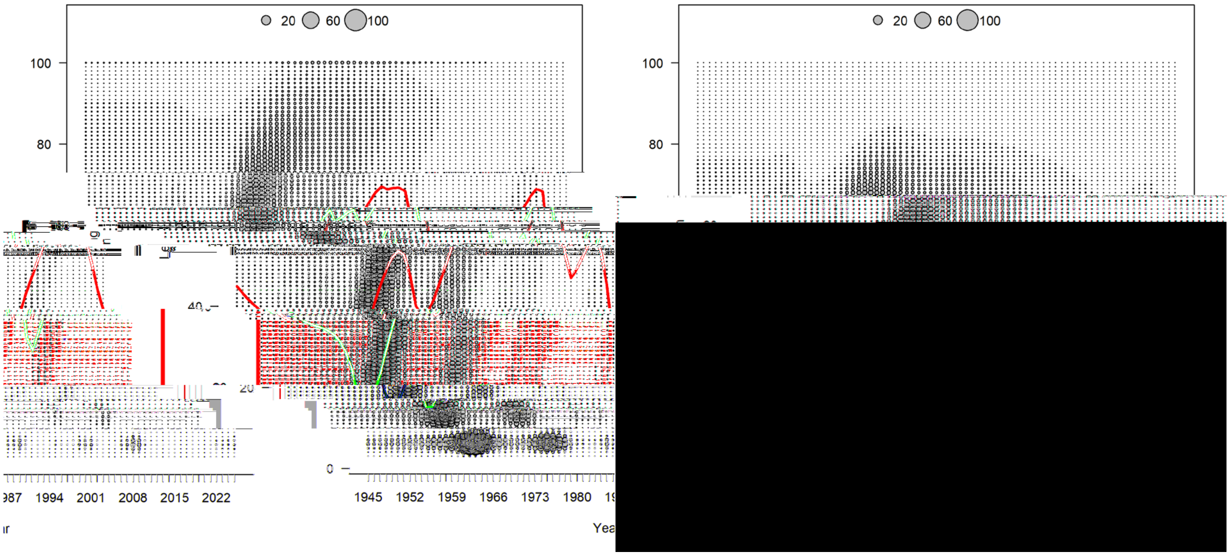


Figure 5.34. Retrospective plots for alternative model 24.2a as an example of the retrospective patterns in the alternative models. a) Female spawning biomass (full time series) b) female spawning biomass (last 10 years of the model), and c) survey catchability where Fleet 3 ~ EBS shelf bottom trawl survey, fleet 4 ~ EBS slope bottom trawl survey, and fleet 5 ~ AFSC longline survey.

a)



b)

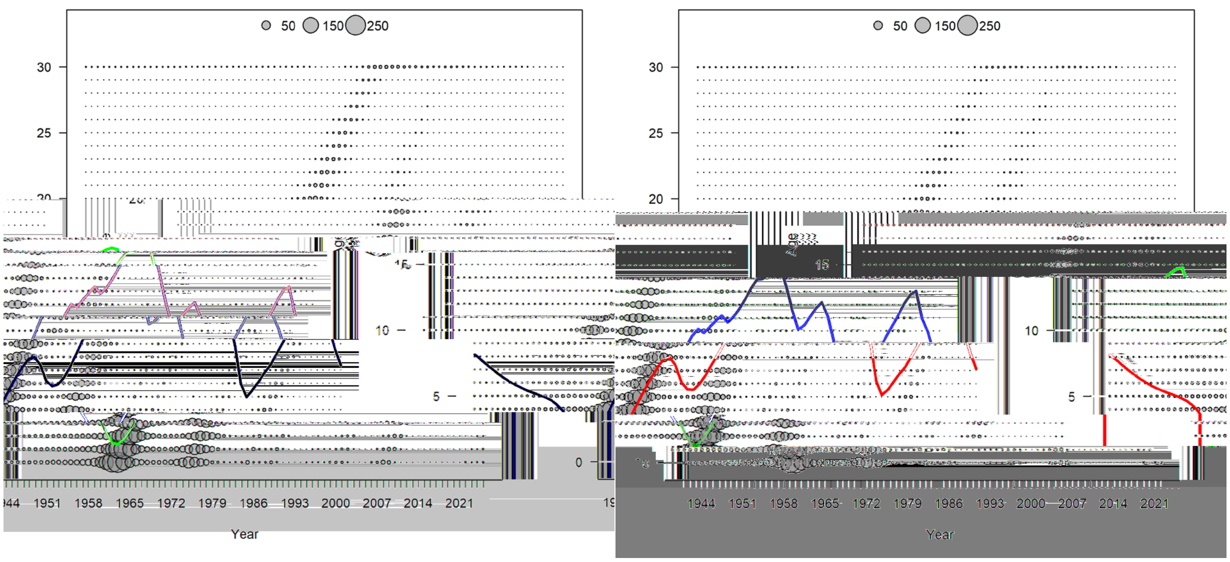


Figure 5.35. a) Numbers at length in the beginning of the year and mean length (red line) and b) numbers at age in the beginning of the year and mean age for females (left) and males (right).

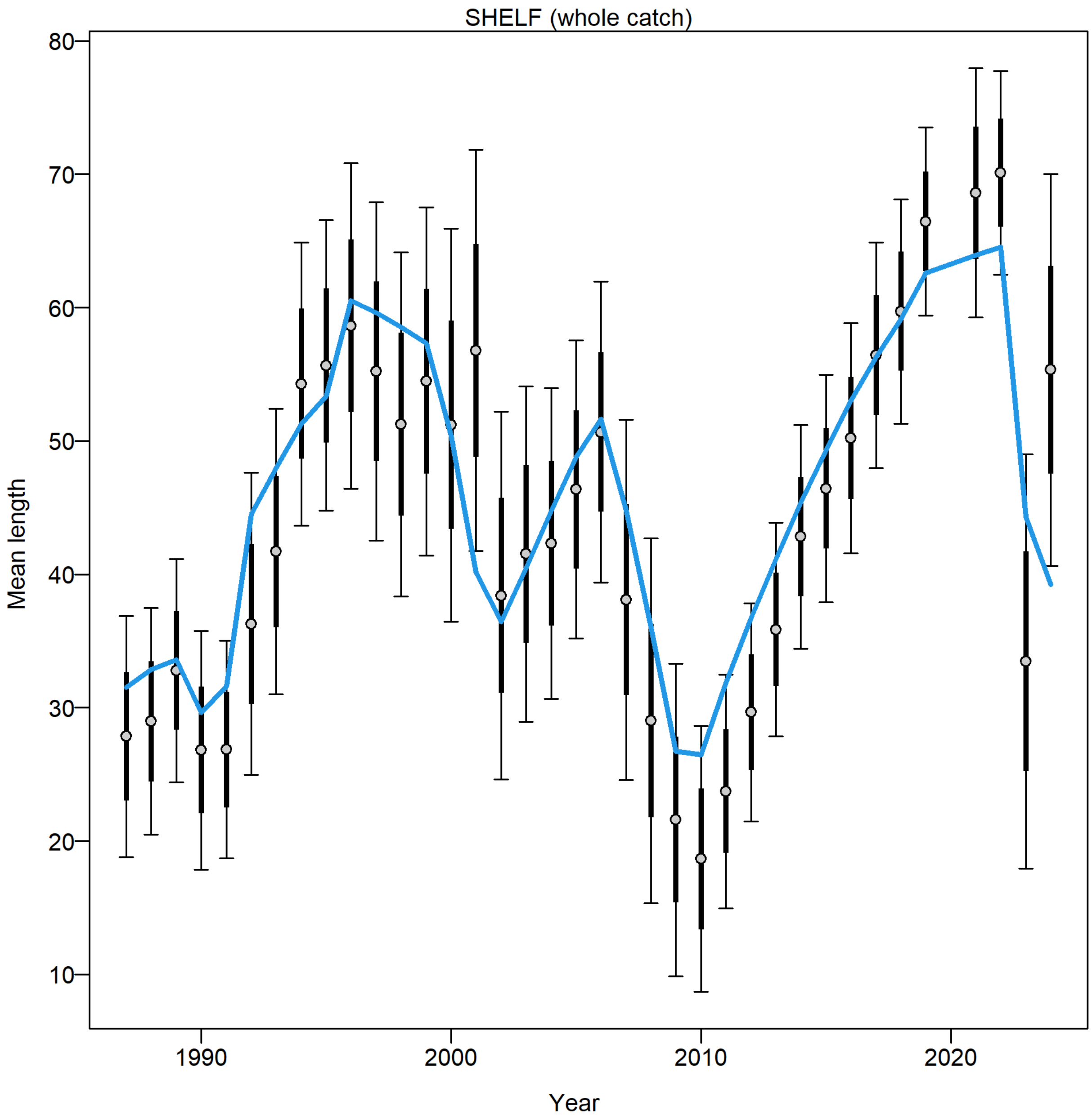


Figure 5.36. Mean length for the EBS shelf bottom trawl survey with 95% confidence intervals based on current sample sizes.

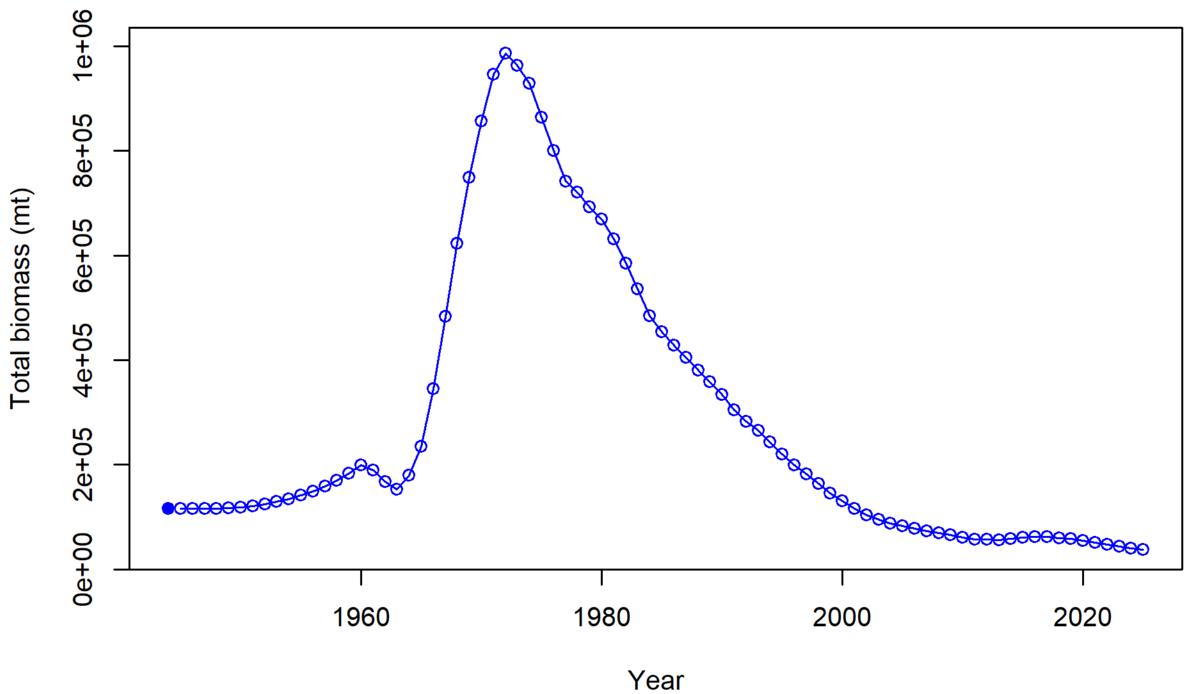


Figure 5.37. Total biomass estimate from Model 16.4c.

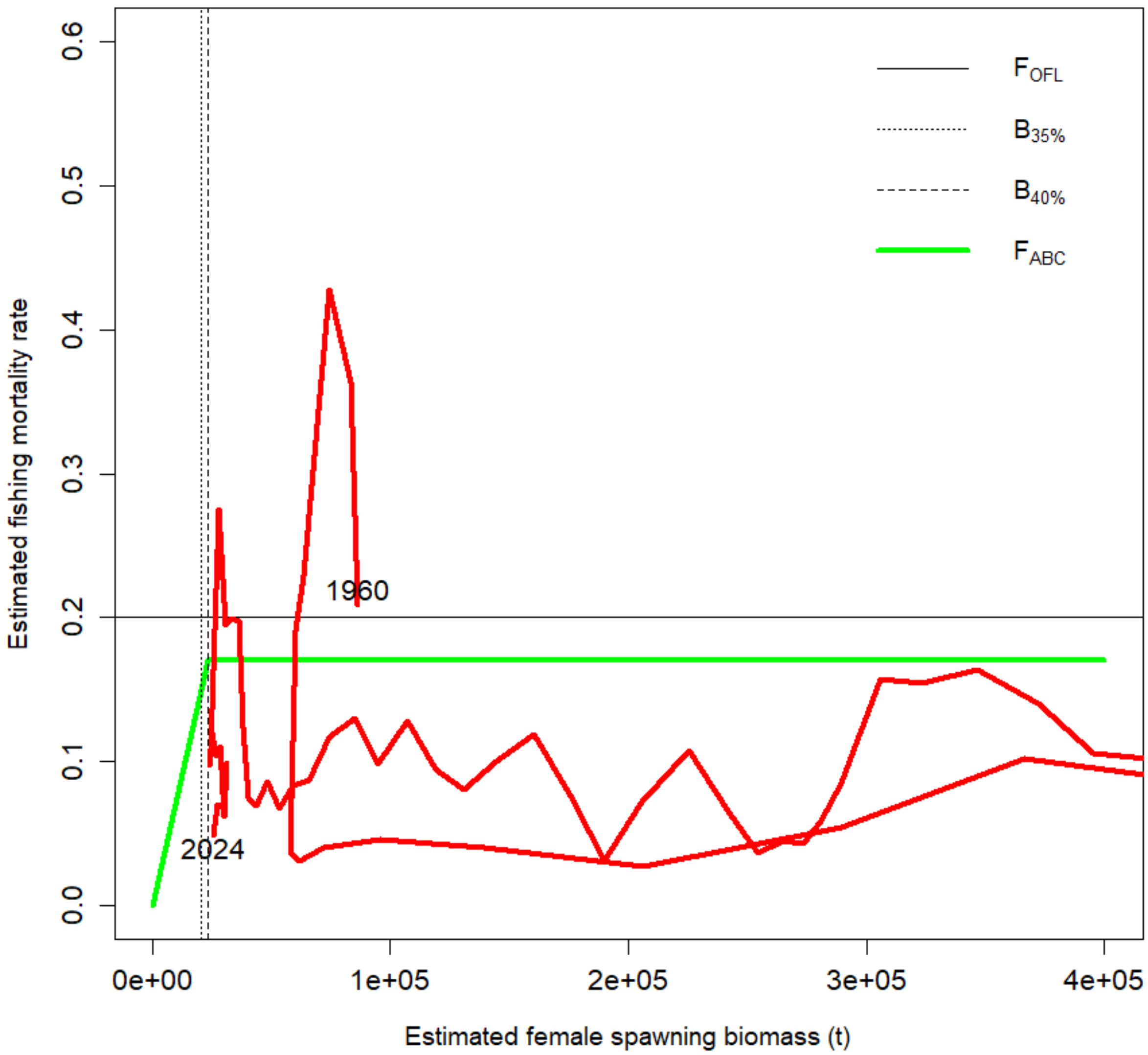


Figure 5.38. Ratio of historical fishing mortality versus female spawning biomass for BSAI Greenland turbot, 1960-2024, Model 16.4c. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.

Appendix A.

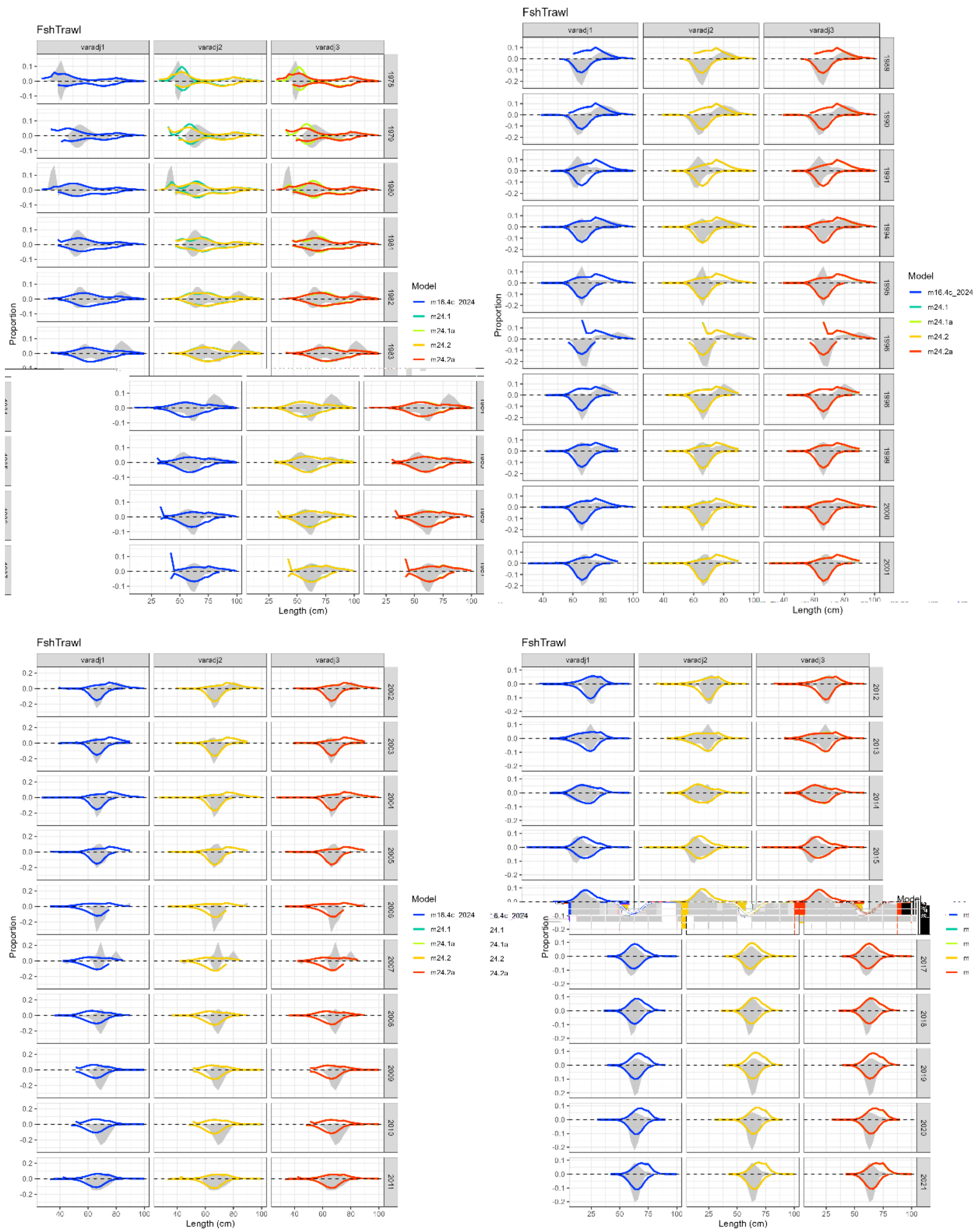


Figure A.1. Trawl fishery annual length data and model fits.

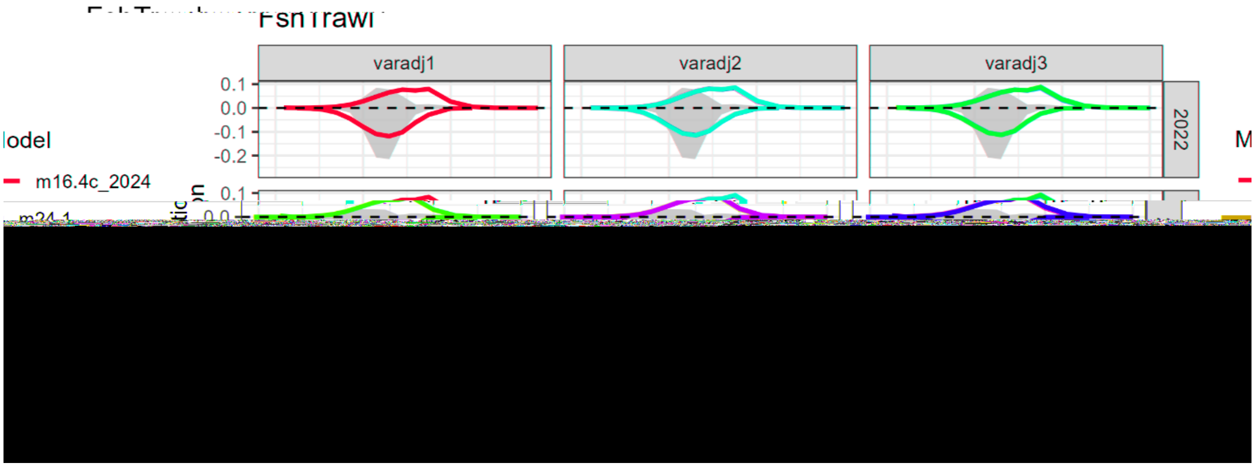


Figure A.1. Continued.

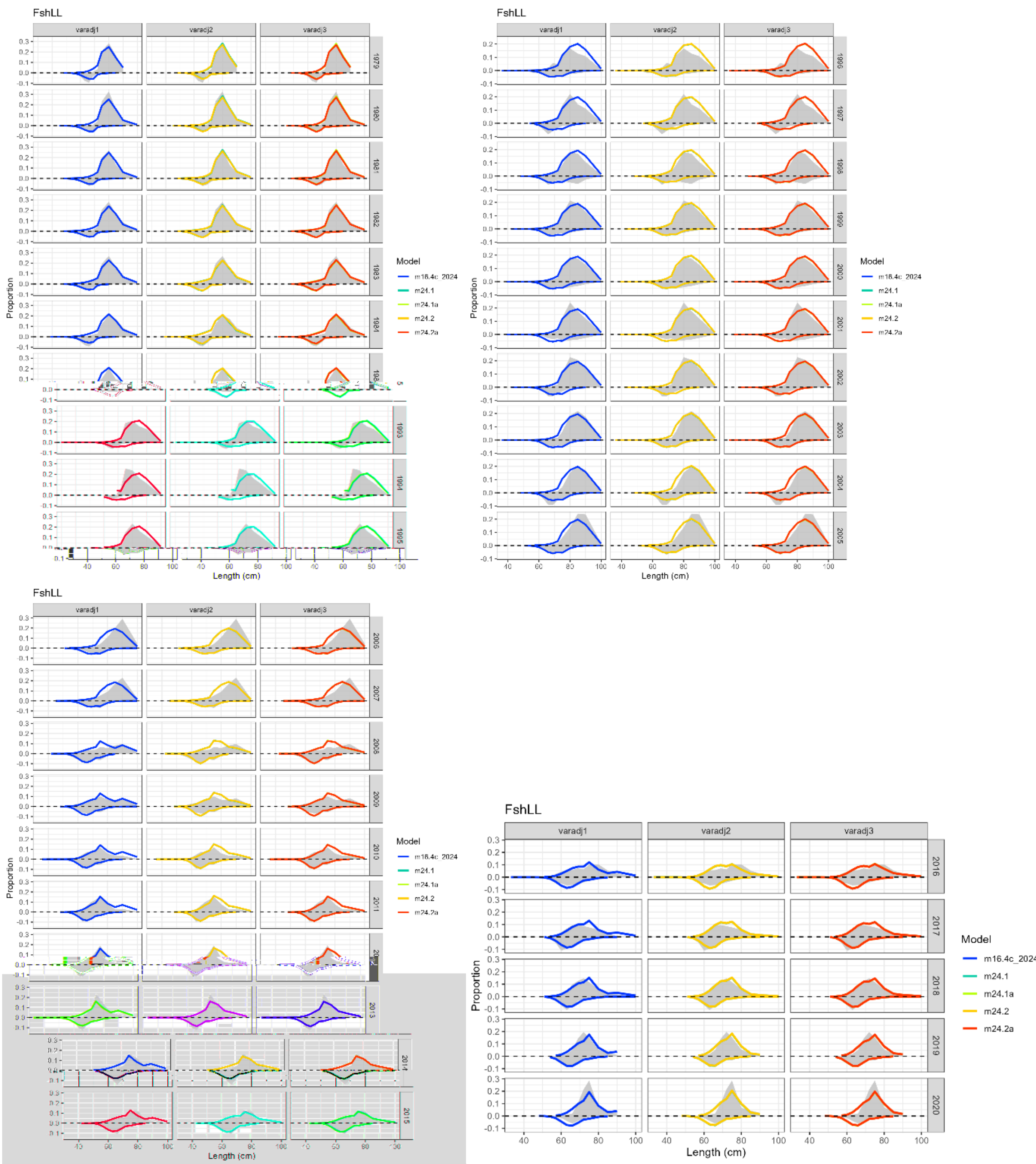


Figure A.2. Longline fishery annual length data and model fits.

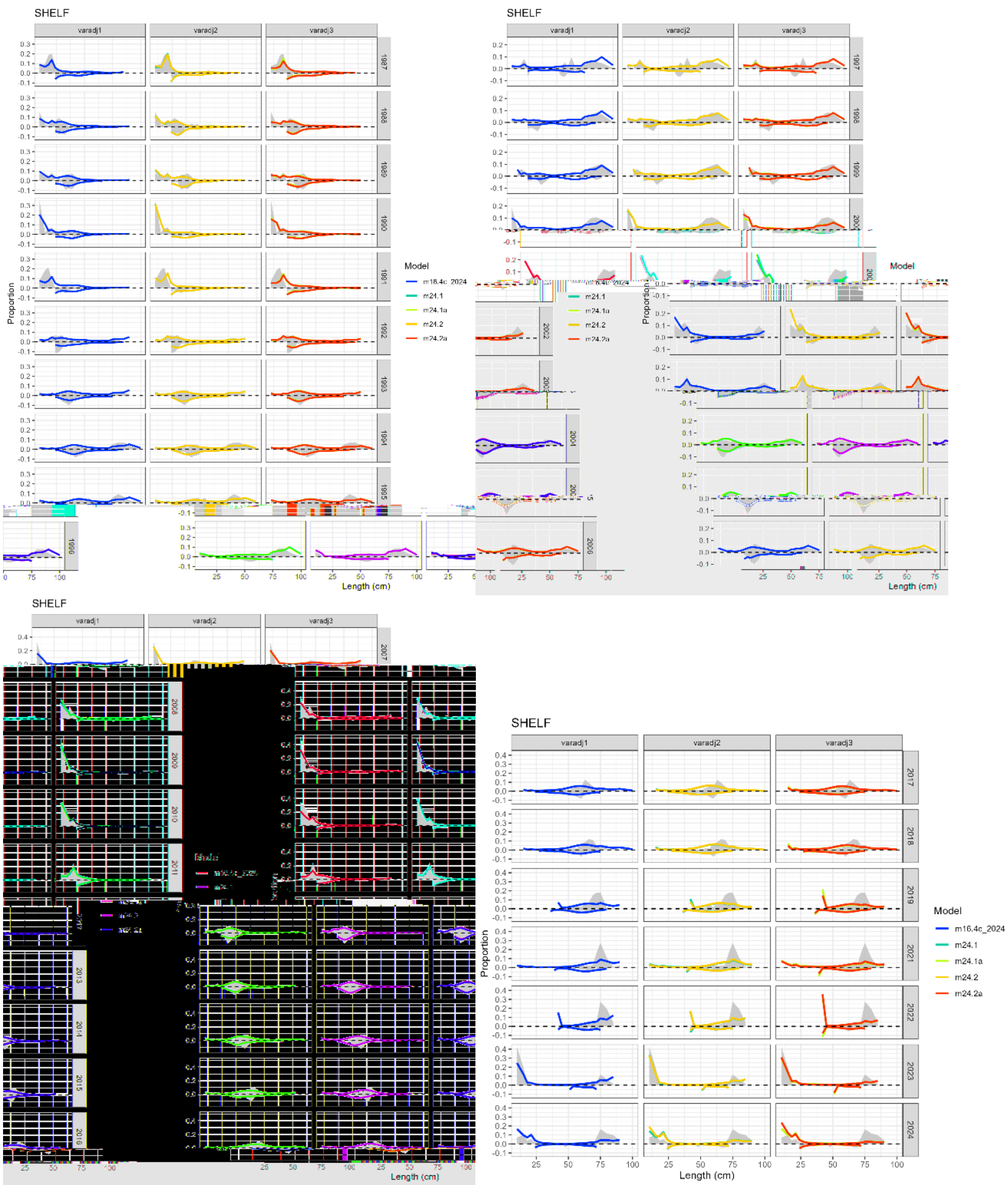


Figure A.3. EBS shelf bottom trawl survey annual length data and model fits.

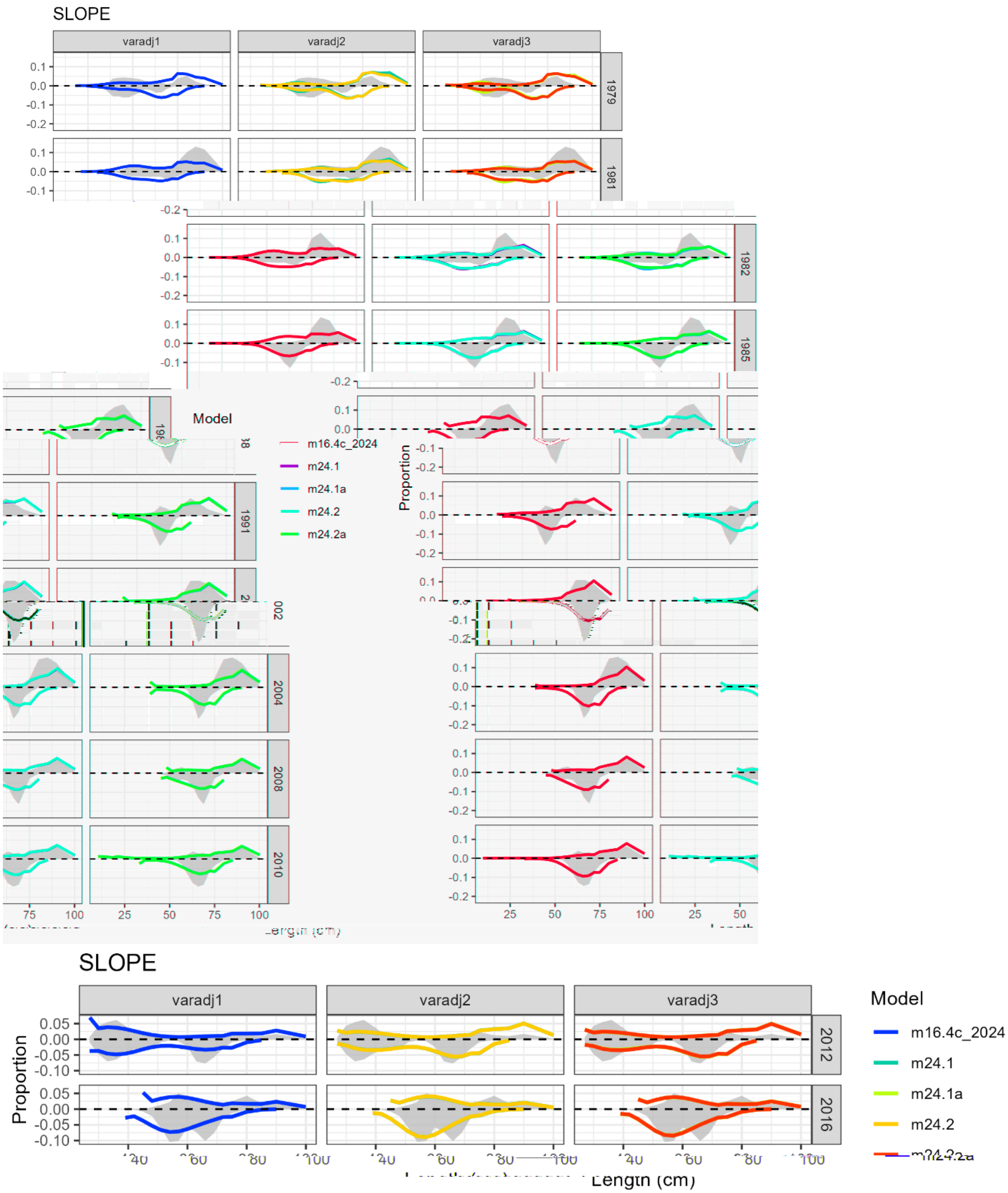


Figure A.4. EBS slope bottom trawl survey annual length data and model fits.

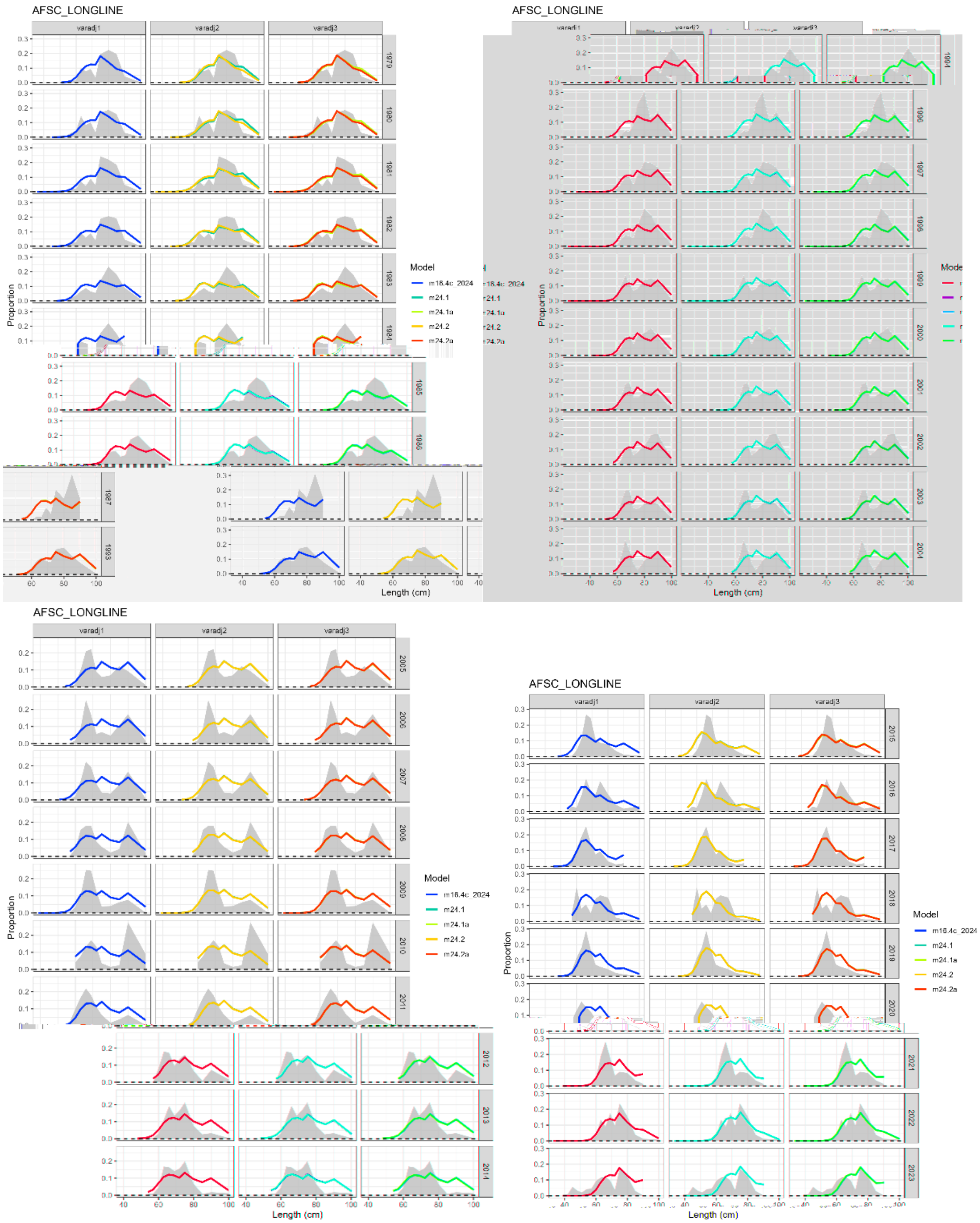


Figure A.5. AFSC longline survey annual length data and model fits.

Appendix B. September 2024 Report

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

Meaghan D. Bryan and Alberto Rovellini

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 ($\rho = 0.45$), 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 (

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

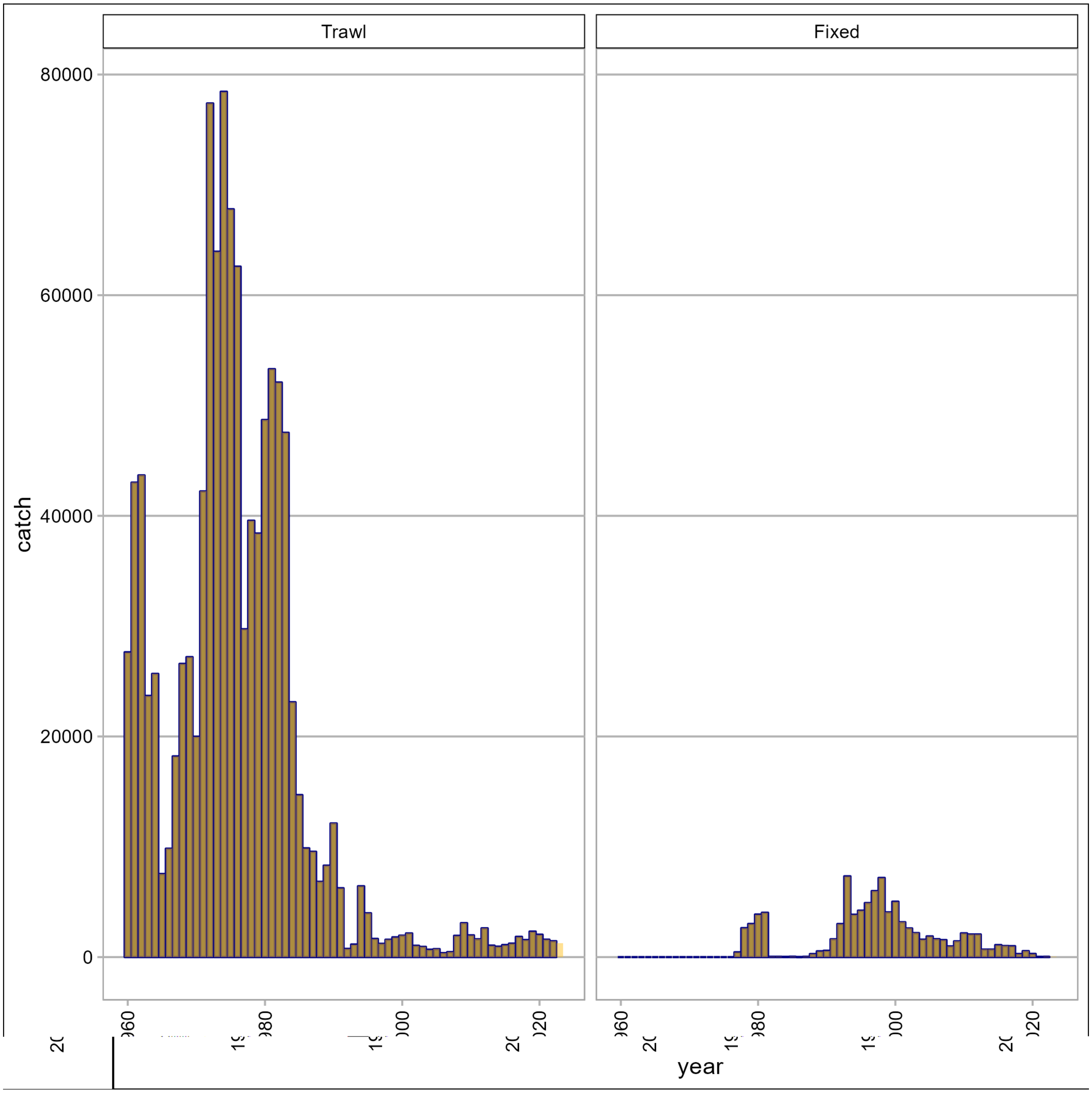


Figure 1. Catch by fleet 1960-2023. Yellow is data retrieved from the comprehensive blend tables in 2024 and the dark blue is the catch data retrieved in 2022.

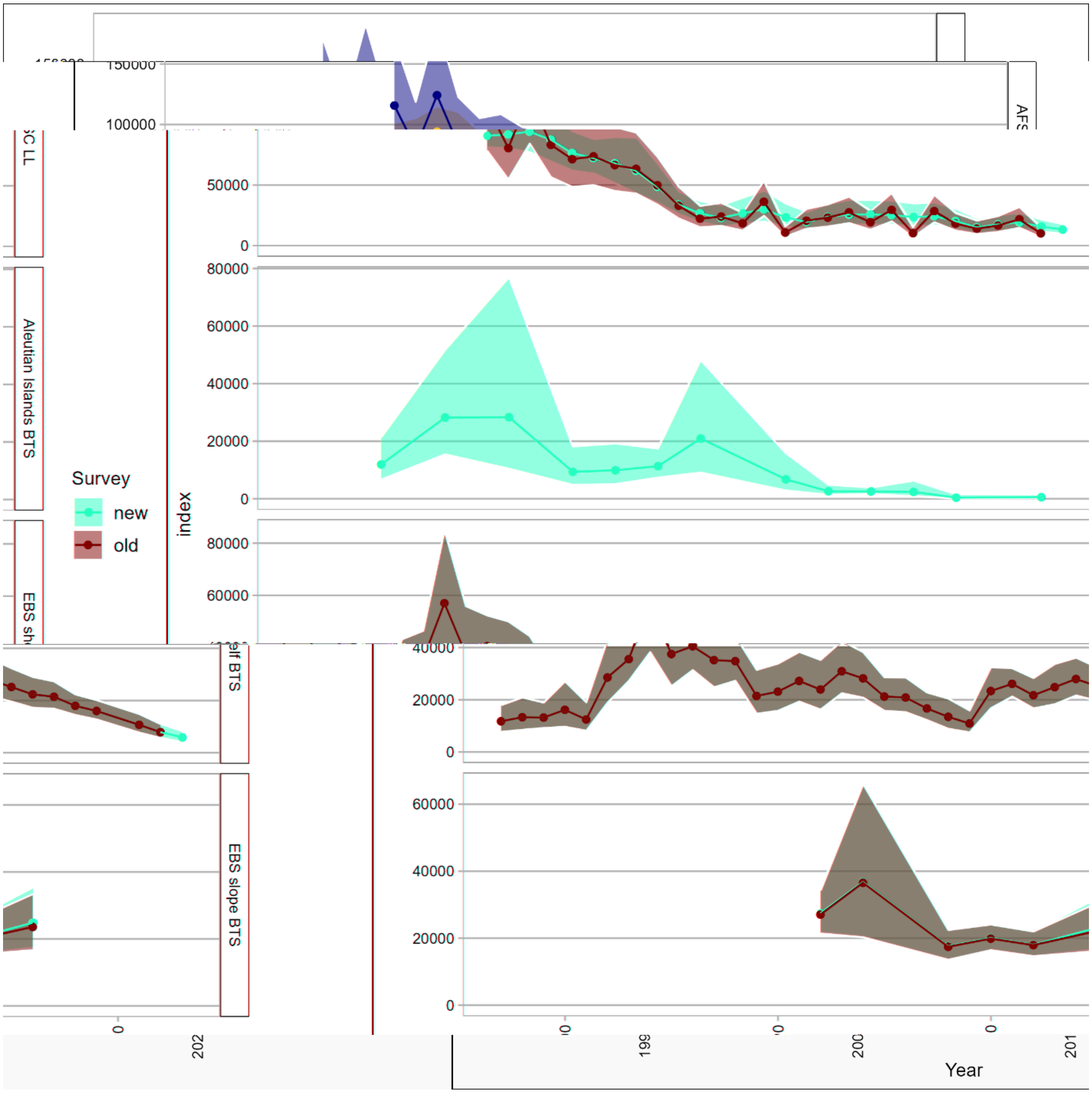
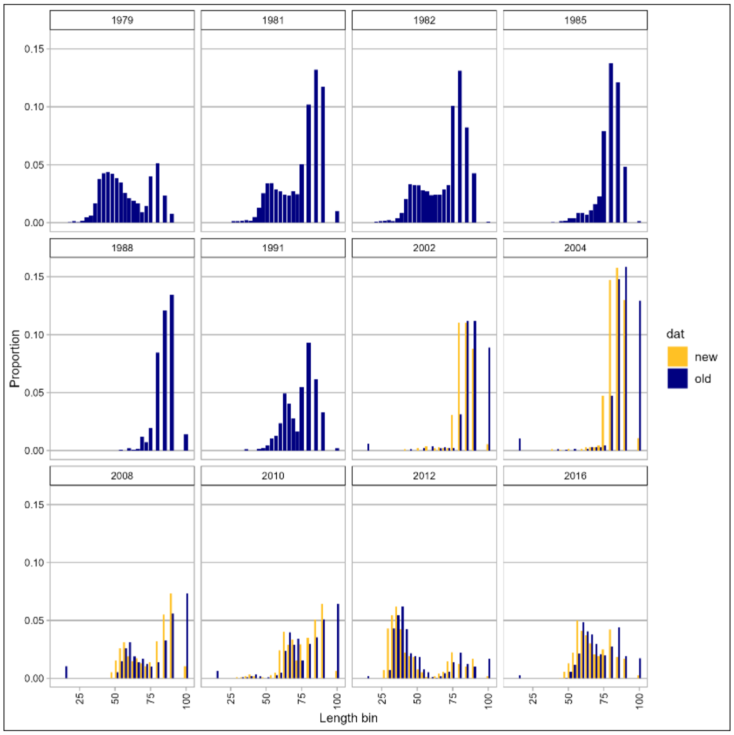


Figure 2. Survey indices by data source. The bottom trawl surveys are in units of metric tons and the AFSC LL represents relative population numbers. The Aleutian Islands BTS biomass is not used in the assessment, but shown here since it is used to apportion ABC between the Bering Sea and AI in November.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


1979
1981
1982
1985
1988
1991
2002
2004
2008
2010
2012
2016
Proportion
Length bin
dat
new
old

b)

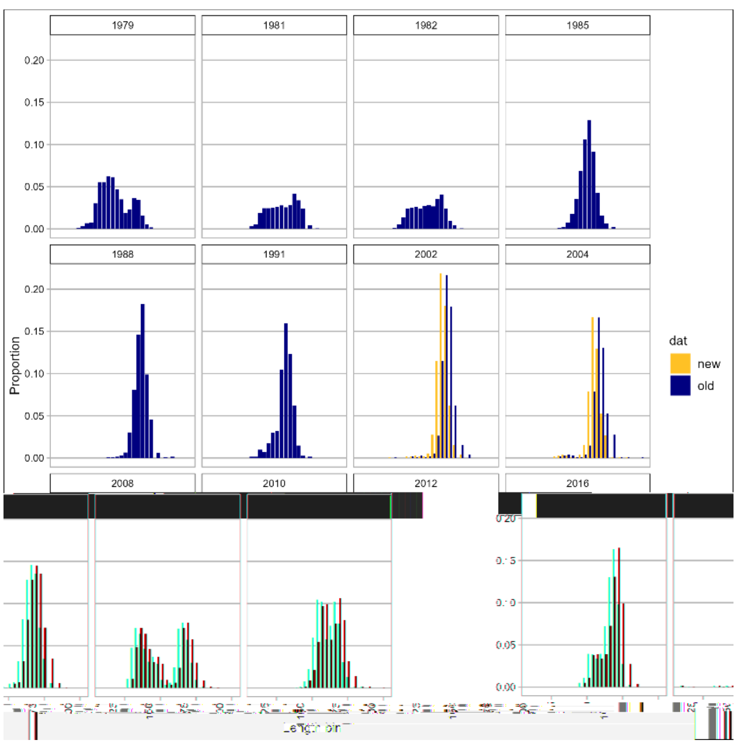

1979
1981
1982
1985
1988
1991
2002
2004
2008
2010
2012
2016
Proportion
dat
new
old

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.

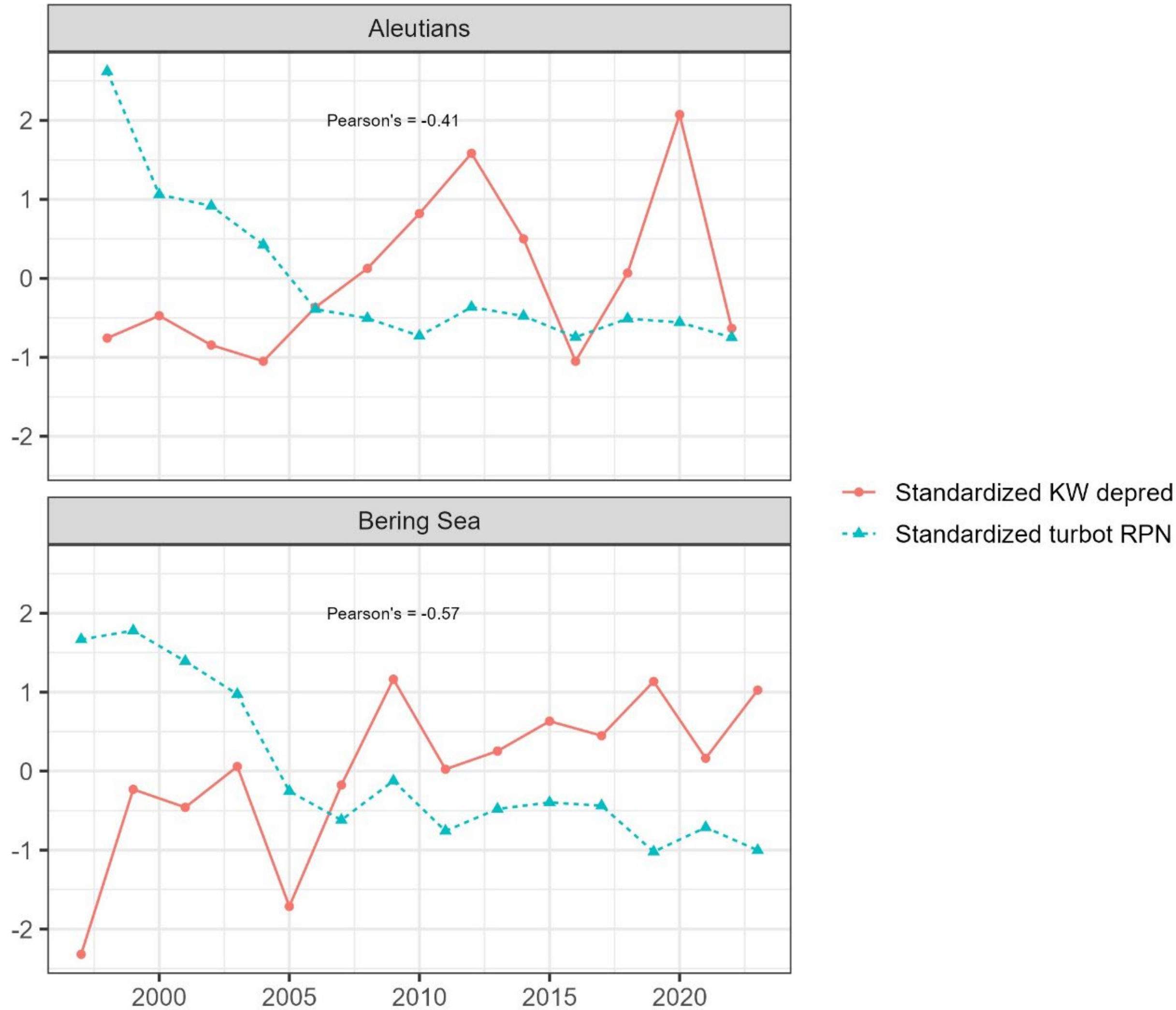


Figure 4. AFSC longline survey RPN estimates and killer whale depredation rates for the Aleutain Islands (top) and Bering Sea (bottom).

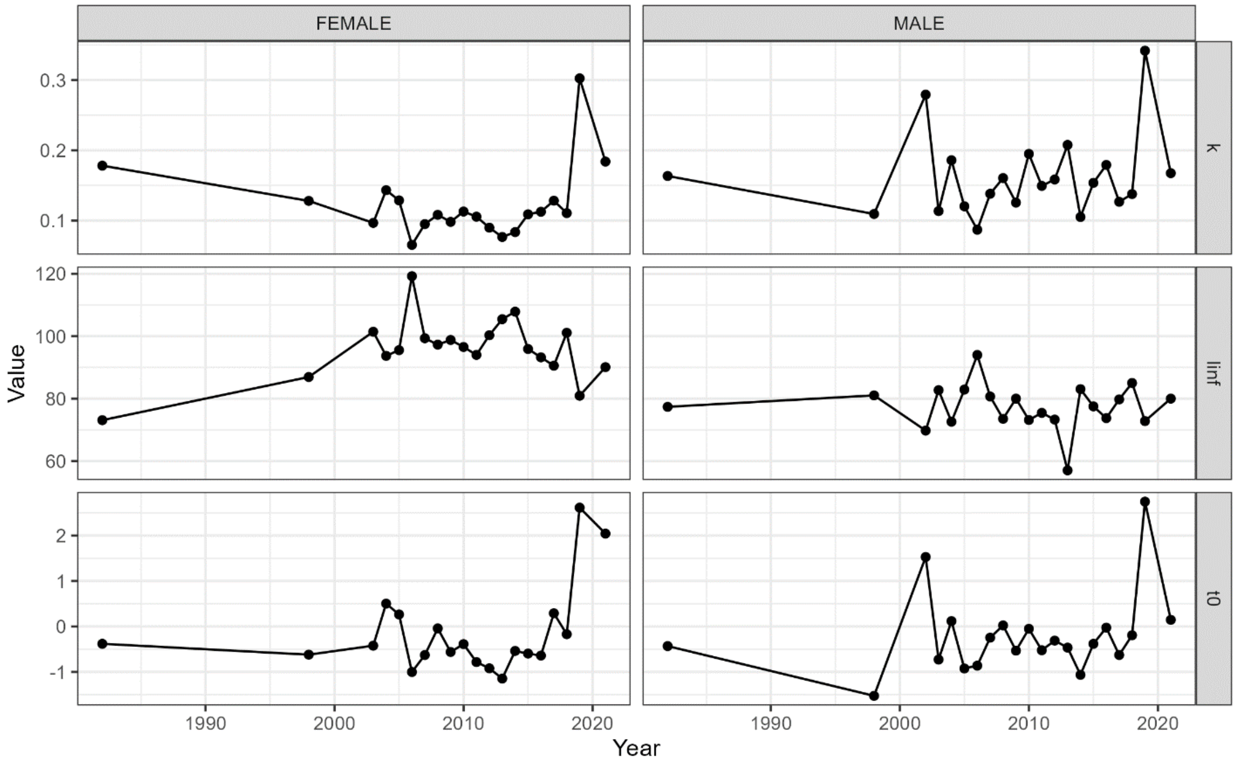


Figure 5. Von Bertalanffy growth function parameter estimates for Greenland turbot by year.

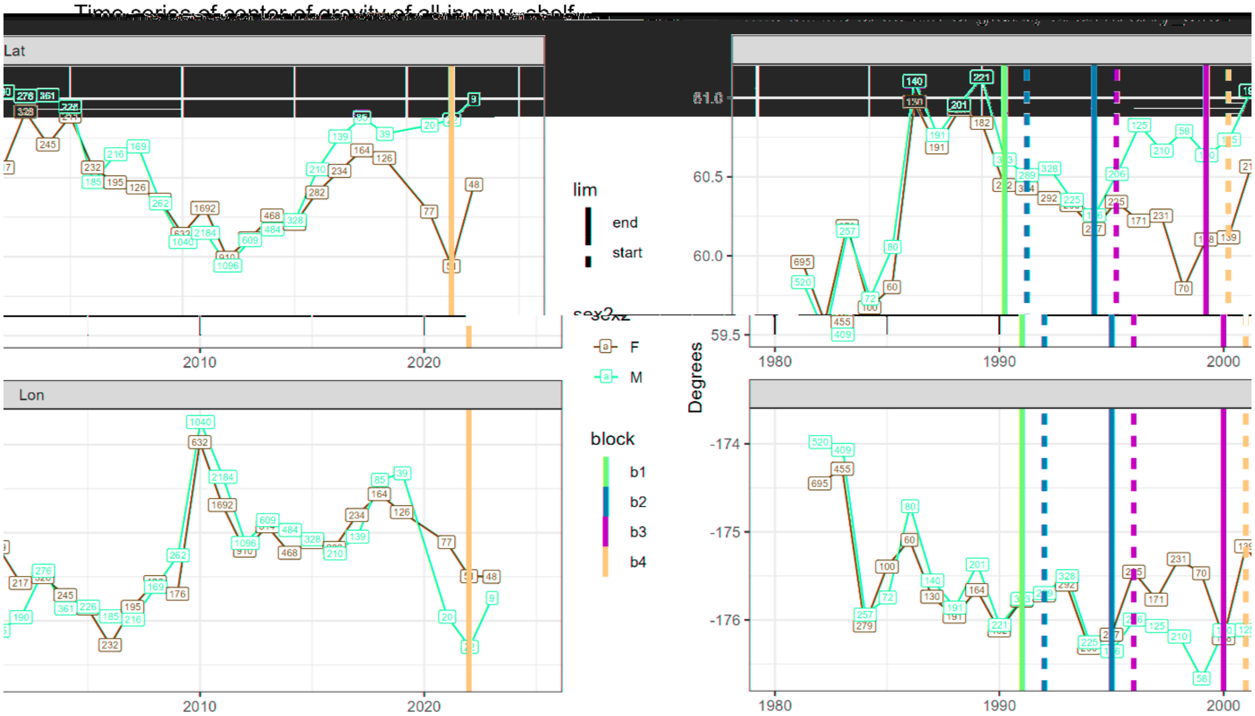


Figure 6. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the Bering Sea shelf survey data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning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

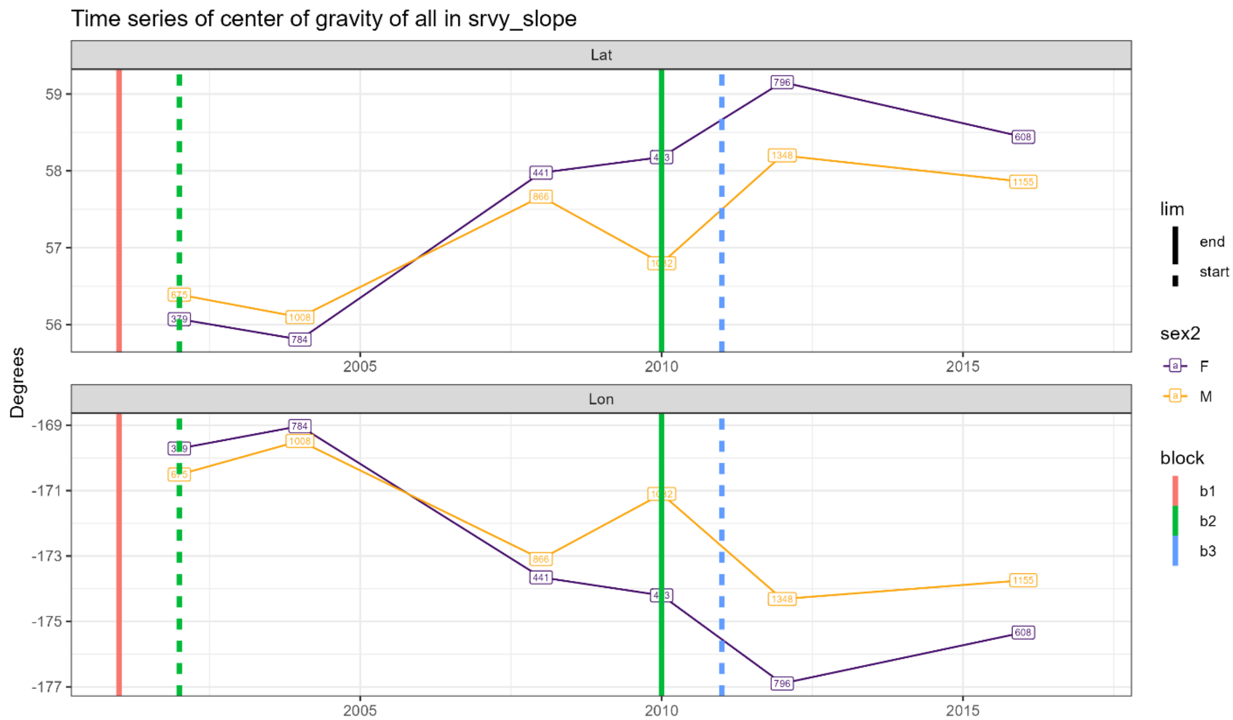


Figure 7. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the Bering Sea slope survey data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning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

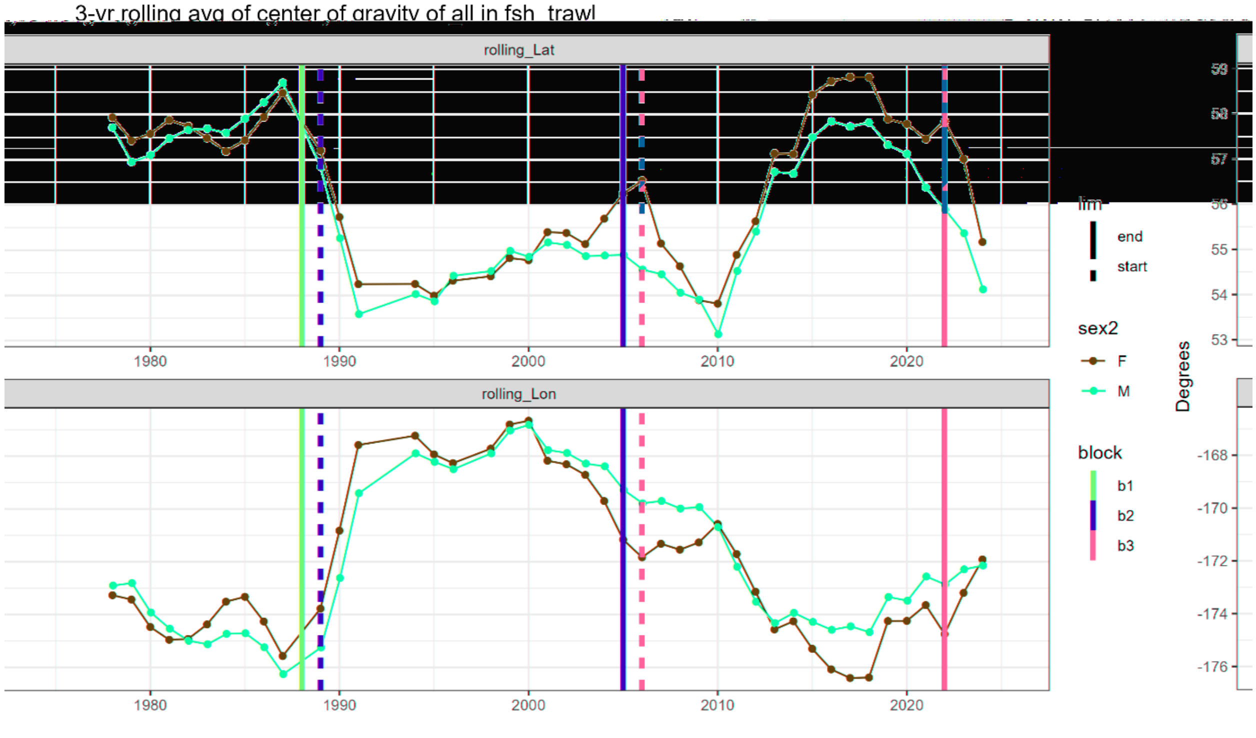


Figure 8. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the trawl fishery data. All length classes aggregated. Males in yellow, females in purple. Numbers

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.

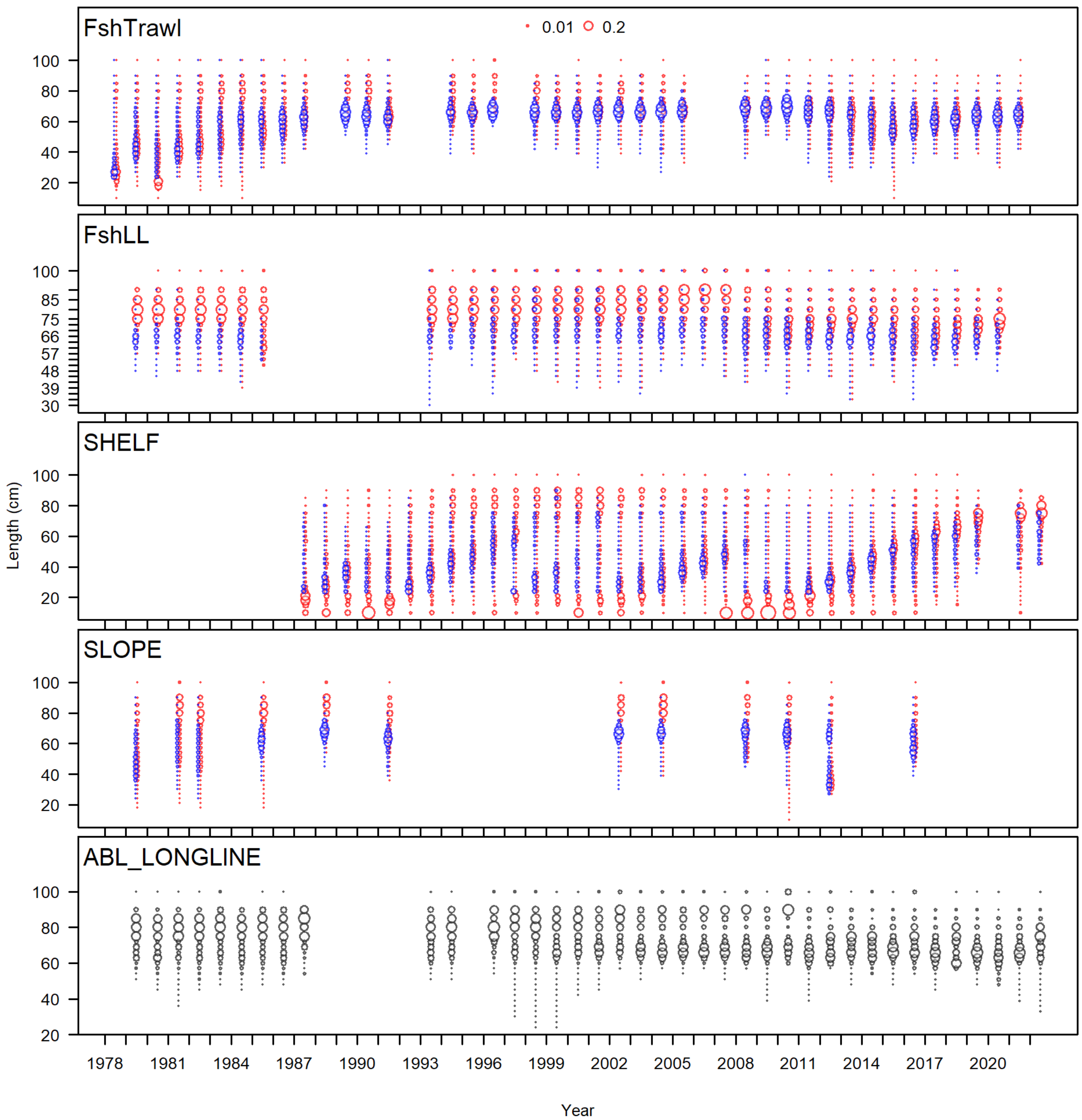


Figure 9. Length composition data from each fleet. Red represents females, blue represents males, and black represents combined sex. The bubbles represent the proportion at each length.

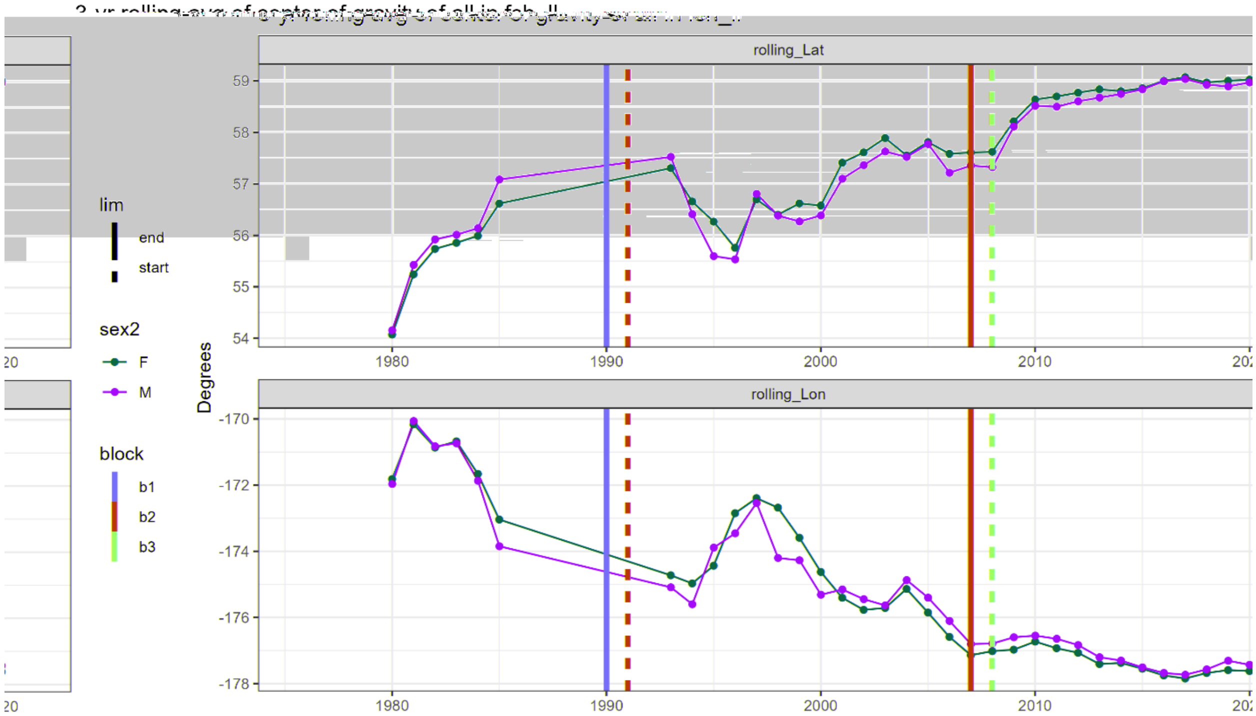


Figure 10. Time series of latitude (top) and longitude (bottom) of the center of gravity of Greenland turbot in the longline fishery data. All length classes aggregated. Males in yellow, females in purple. Numbers indicate sample size (sum of length frequency). Vertical bars indicate the beginning (dashed)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

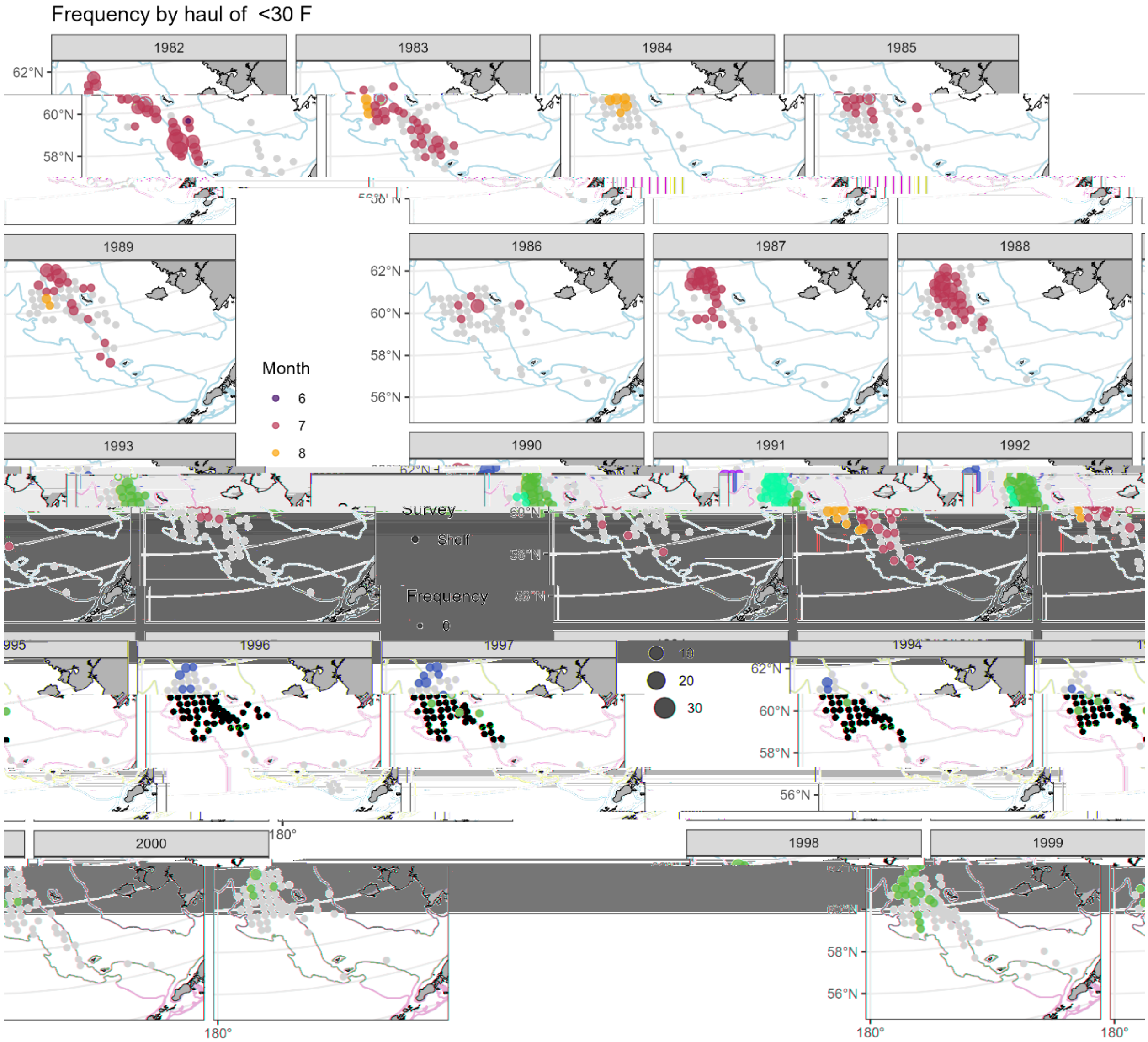


Figure 11. Maps of frequency of encounter of <30 cm female Greenland turbot in the Bering Sea surveys, plotted with each year as a facet. Colors indicate months, bubble size indicates frequency, and shape indicates survey (circles: shelf; squares: slope).

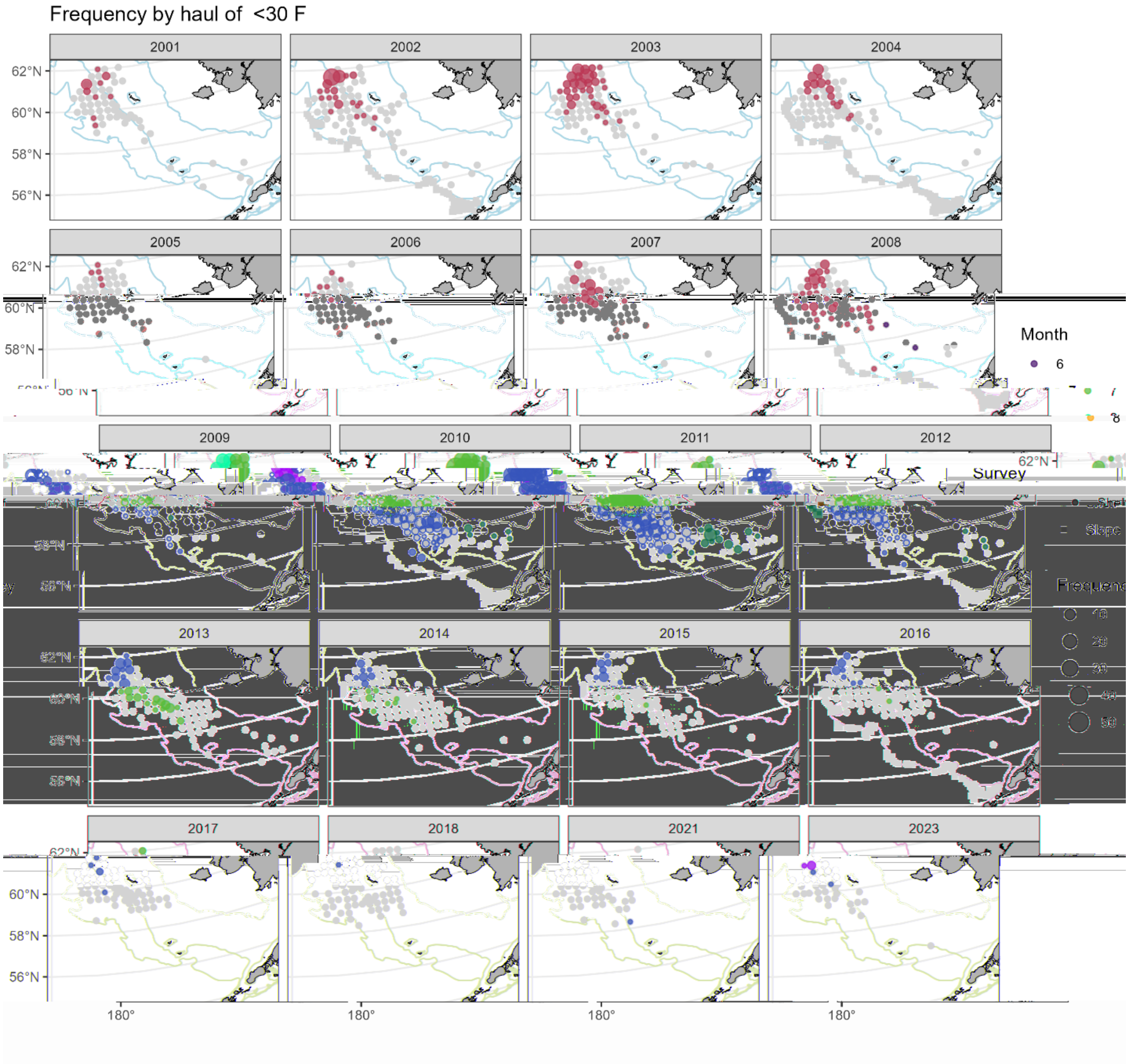


Figure 11. Continued.

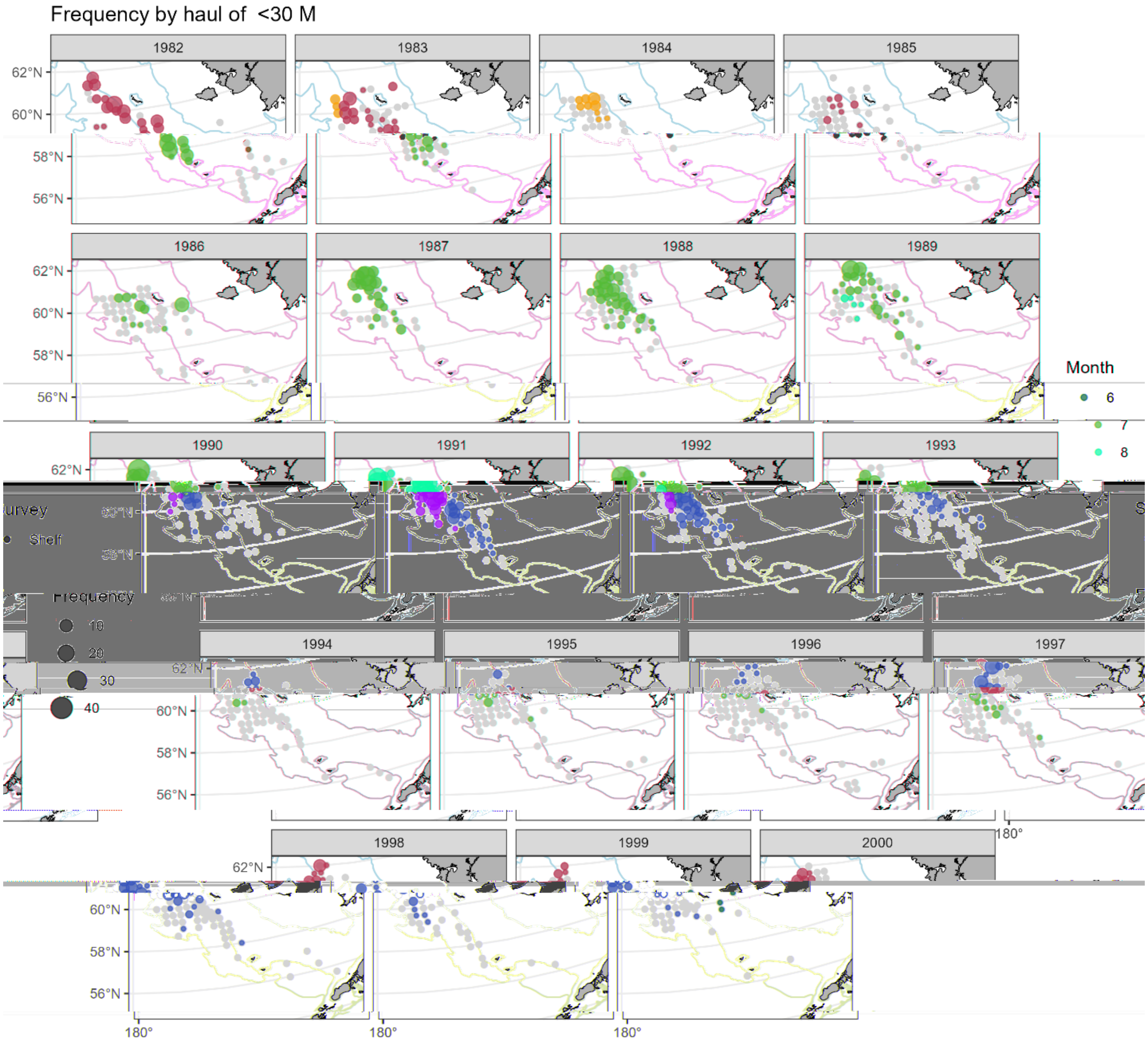

Frequency by haul of <30 M
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
62°N
60°N
58°N
56°N
180°
Month
6
7
8
Shelf
Frequency
10
20
30
40

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).

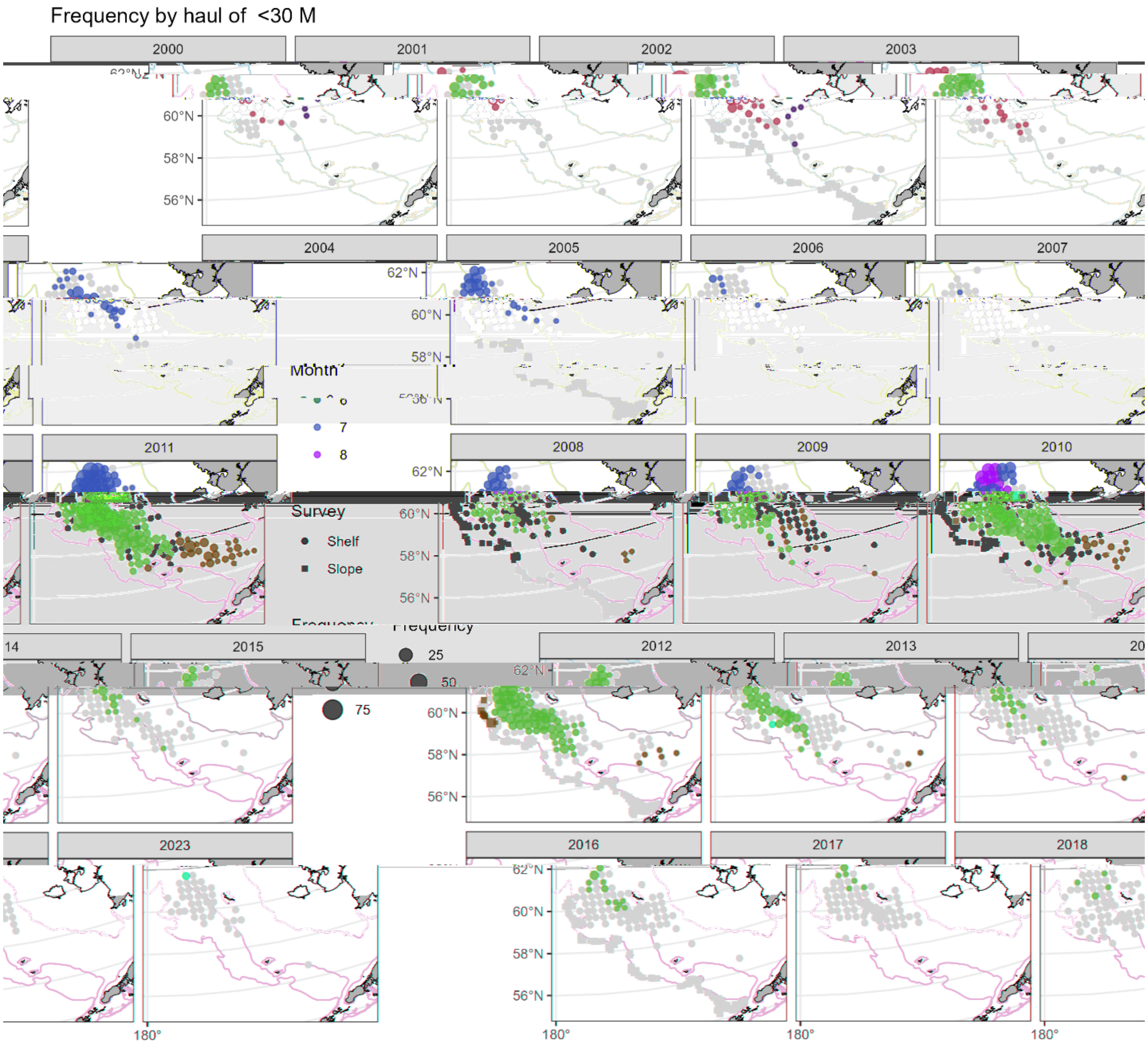


Figure 12 Continued.

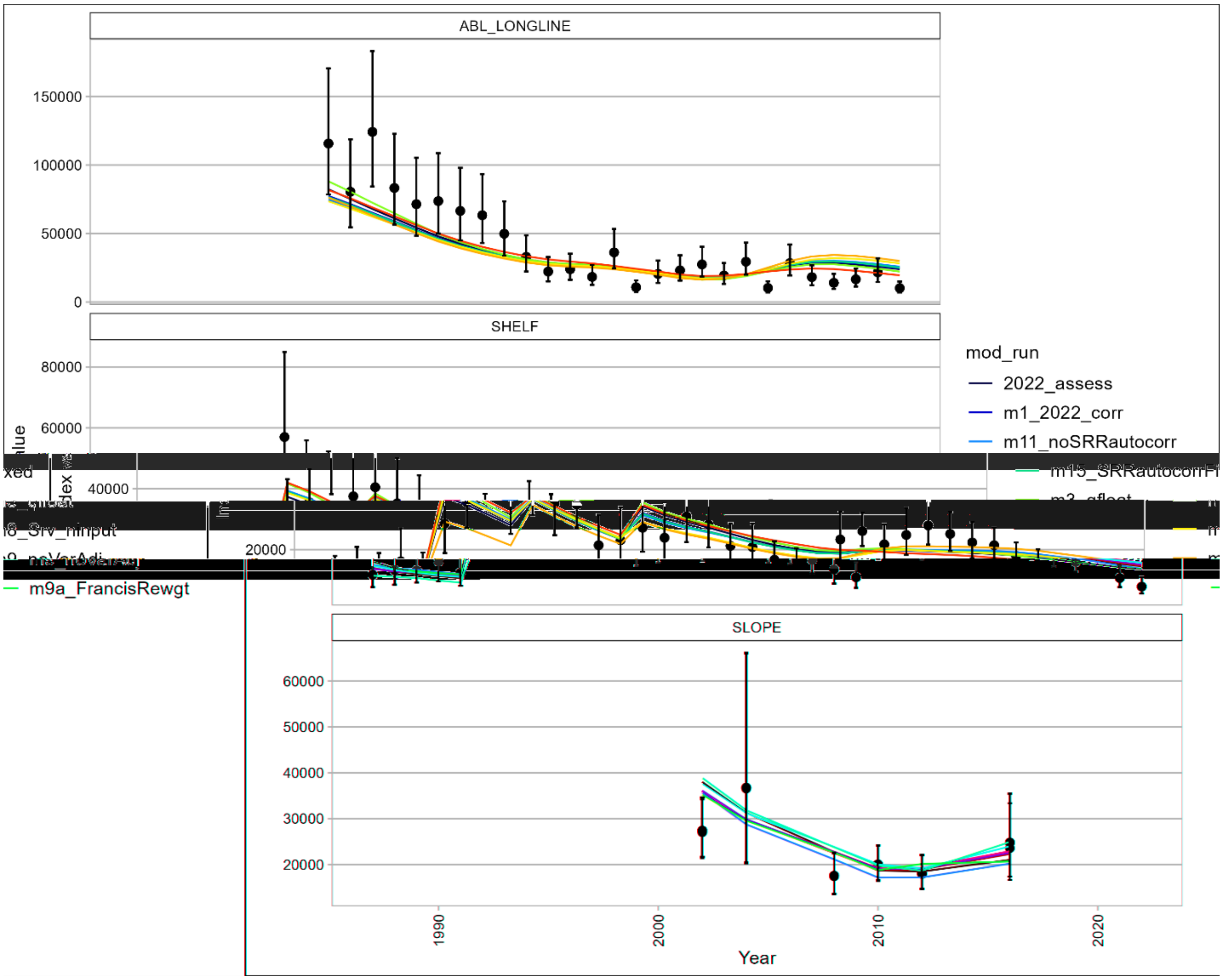


Figure 13. Model fit to AFSC longline survey RPNs and EBS shelf and slope bottom trawl survey biomass from base model sensitivity runs.

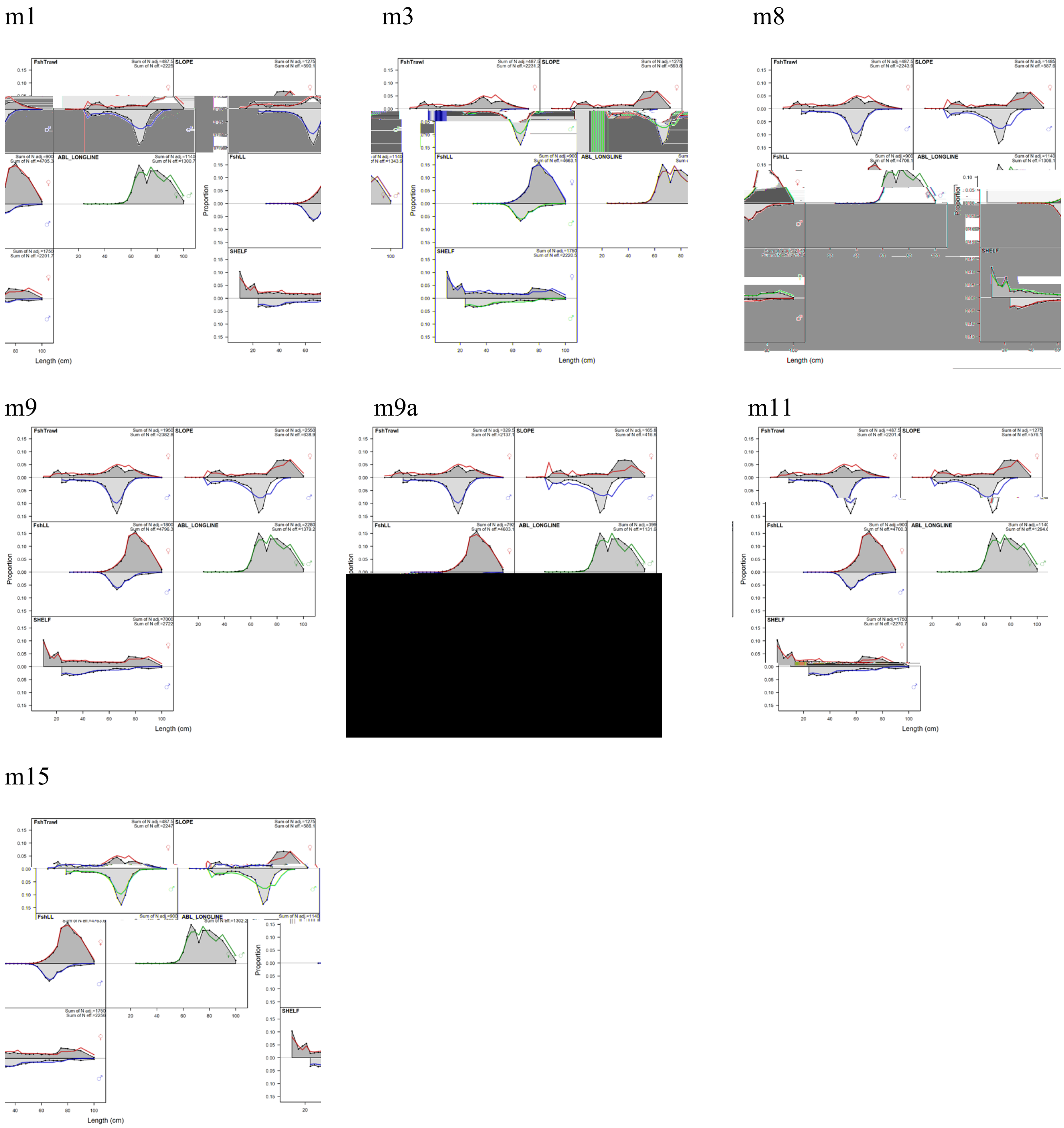
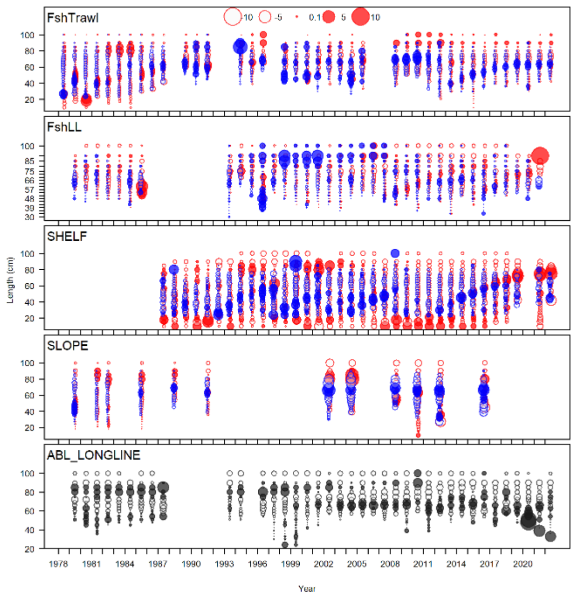
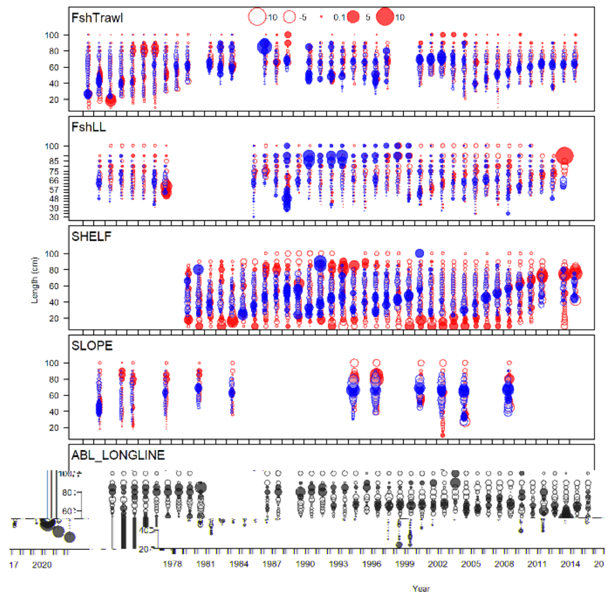


Figure 14. Model fit to fleet specific aggregated length composition data for individual model runs indicated by the alpha-numeric label.

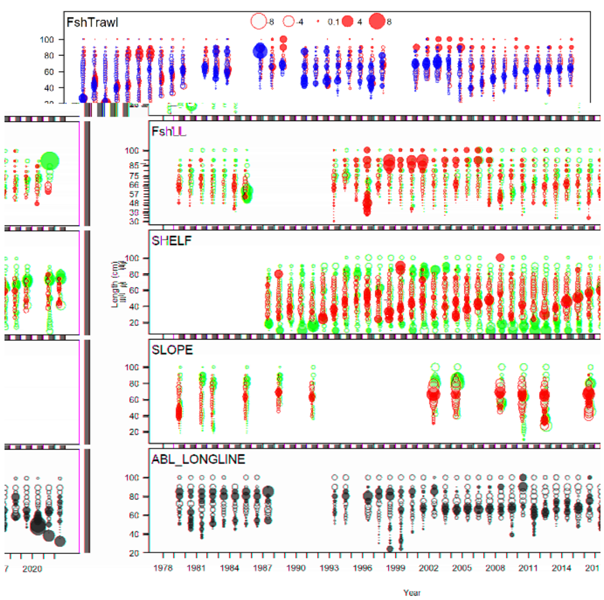
m1



m3



m8



m9

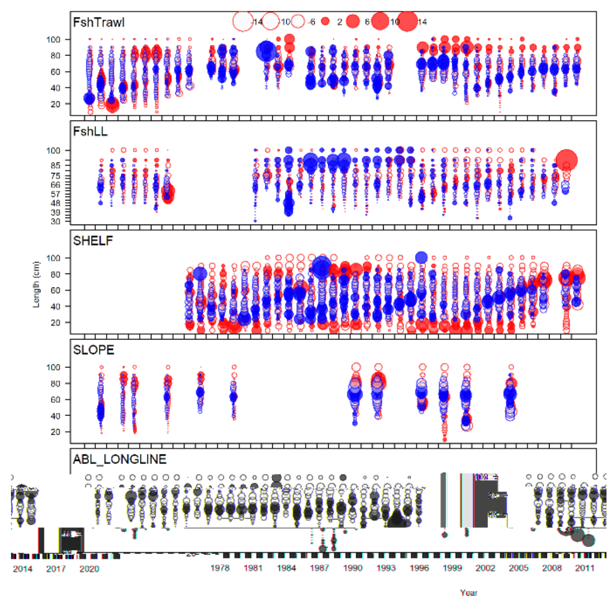
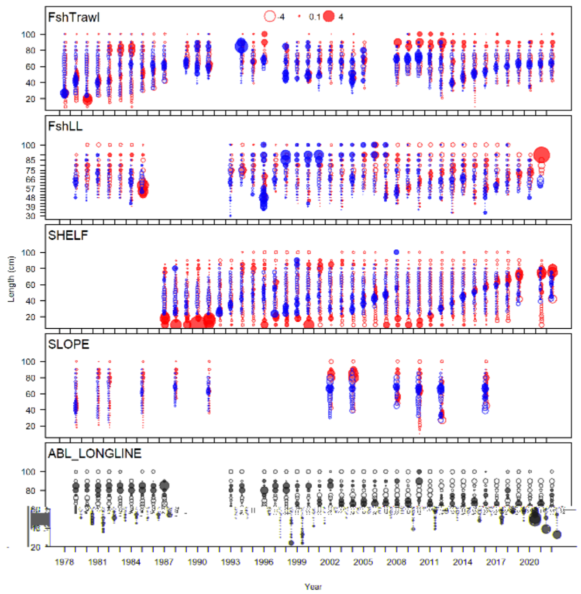
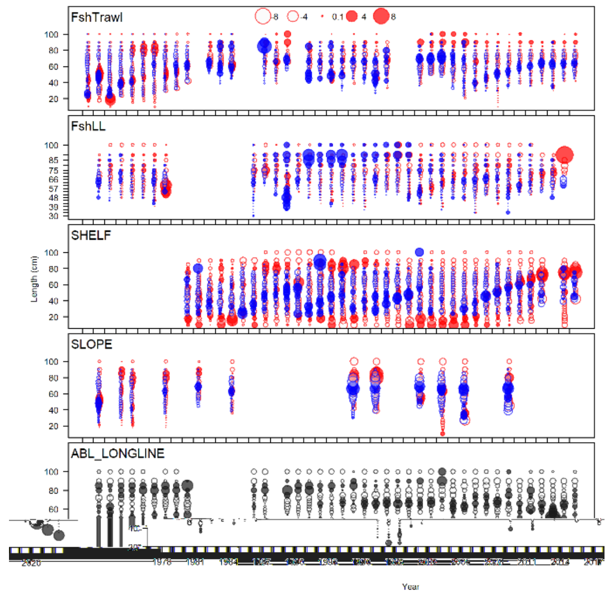


Figure 15. Pearson residuals across fleets for individual model runs indicated by the alpha-numeric label. Blue bubbles represent males, red represents females, and black represents combined sex.

m9a



m11



m15

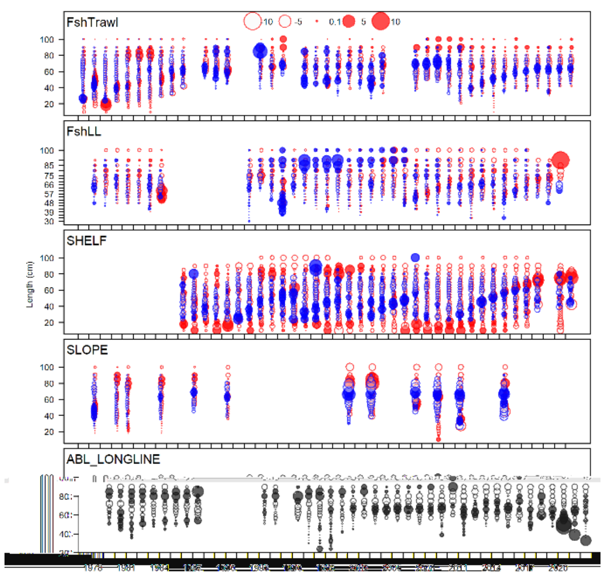


Figure 15 continued

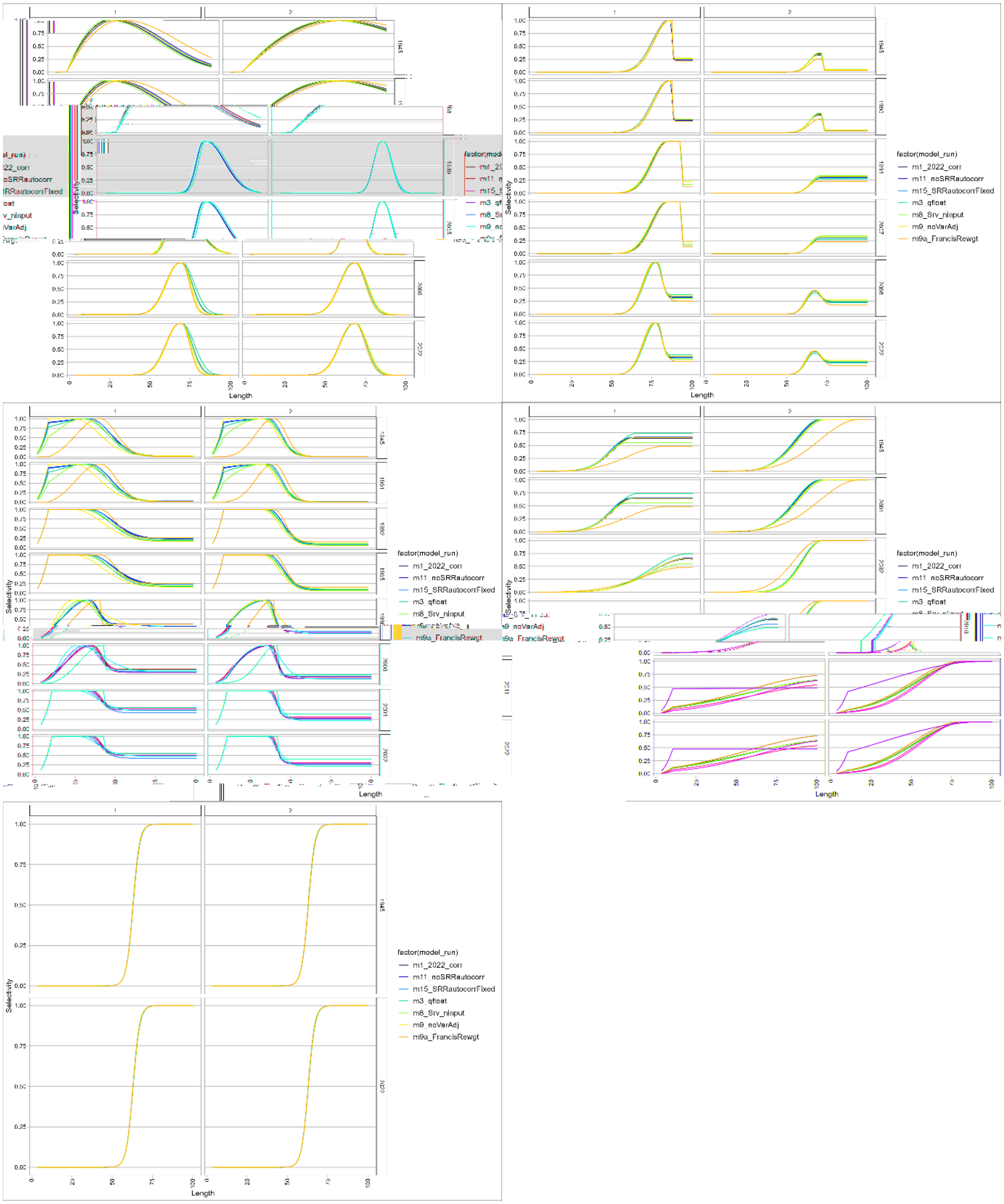


Figure 16. Fleet-specific selectivity for base model sensitivity runs. Trawl fishery (top left), Longline fishery (top right), EBS shelf bottom trawl survey (middle left), EBS slope bottom trawl survey (middle right), and AFSC longline survey (bottom row). Female selectivity is in columns labeled 1 and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

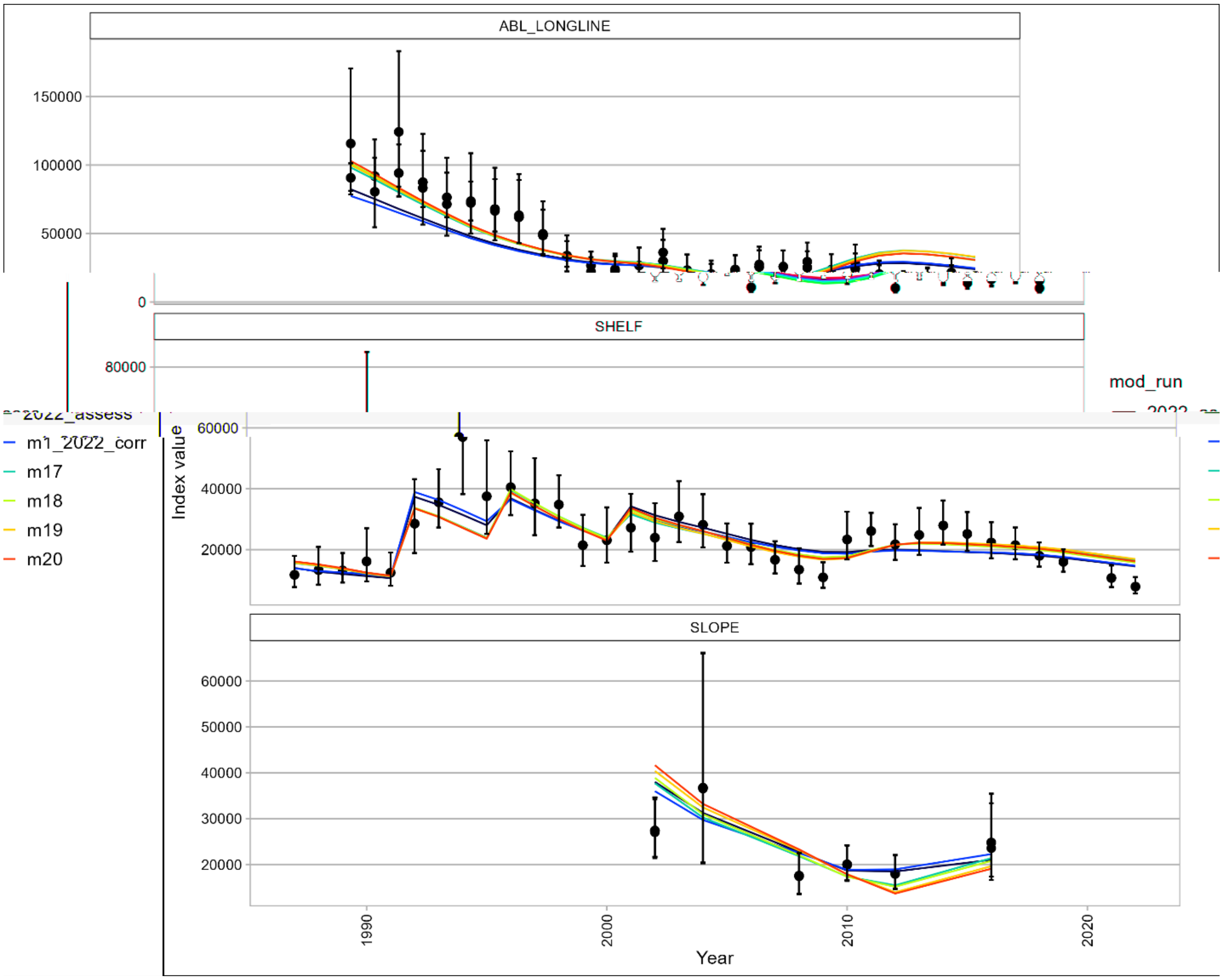
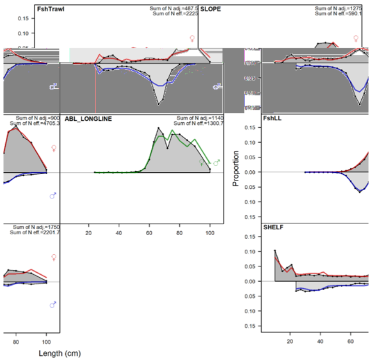
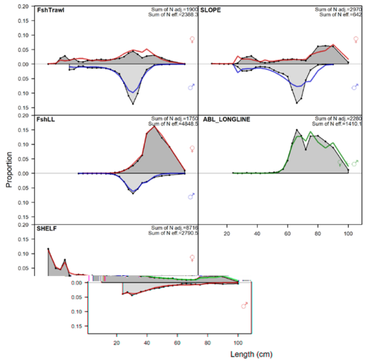


Figure 17. Model fit to AFSC longline survey RPNs and EBS shelf and slope bottom trawl survey biomass from model runs m17 - m20.

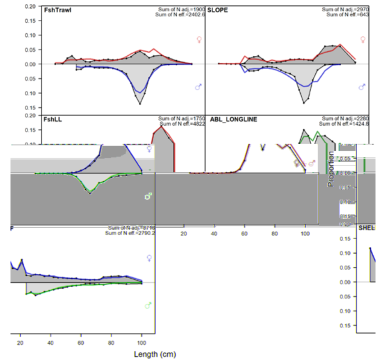
m1



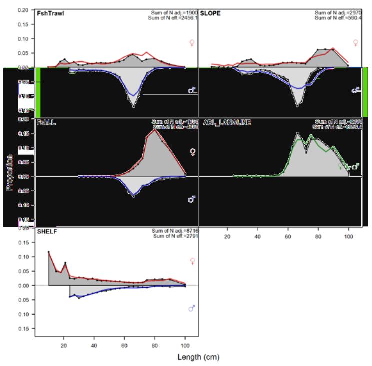
m17



m18



m19



m20

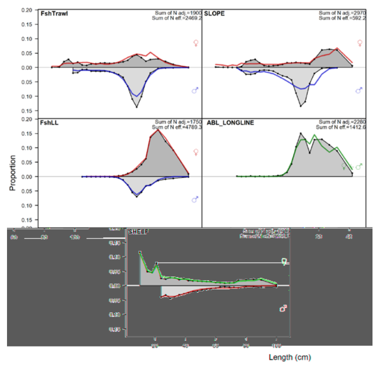


Figure 18. Model fit to fleet specific aggregated length composition data for individual model runs indicated by the alpha-numeric label.

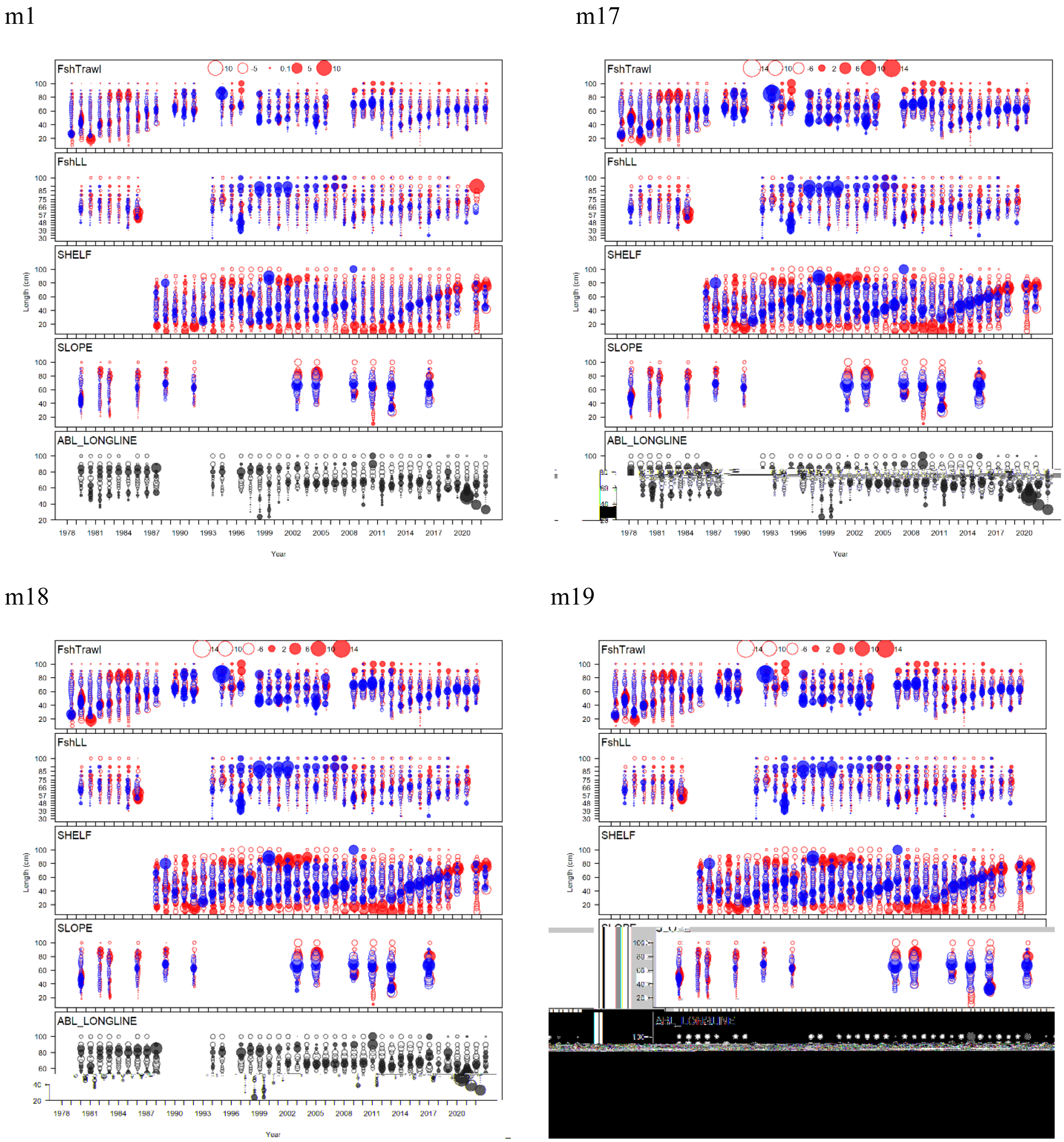


Figure 19. Pearson residuals across fleets for individual model runs indicated by the alpha-numeric label. Blue bubbles represent males, red represents females, and black represents combined sex.

m20

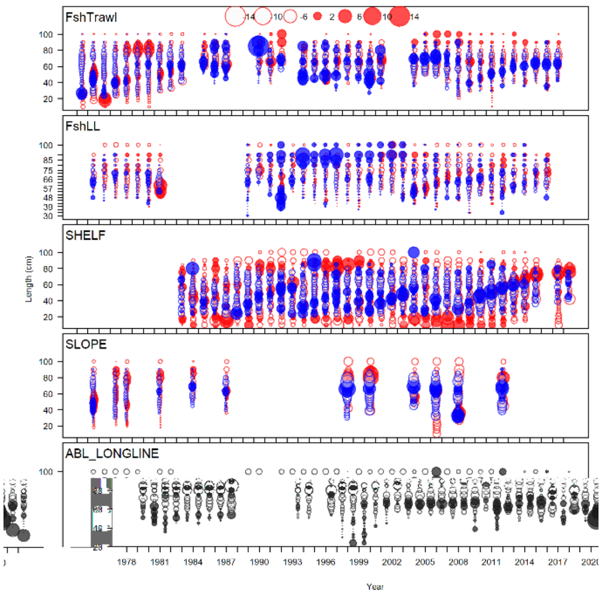


Figure 19 continued

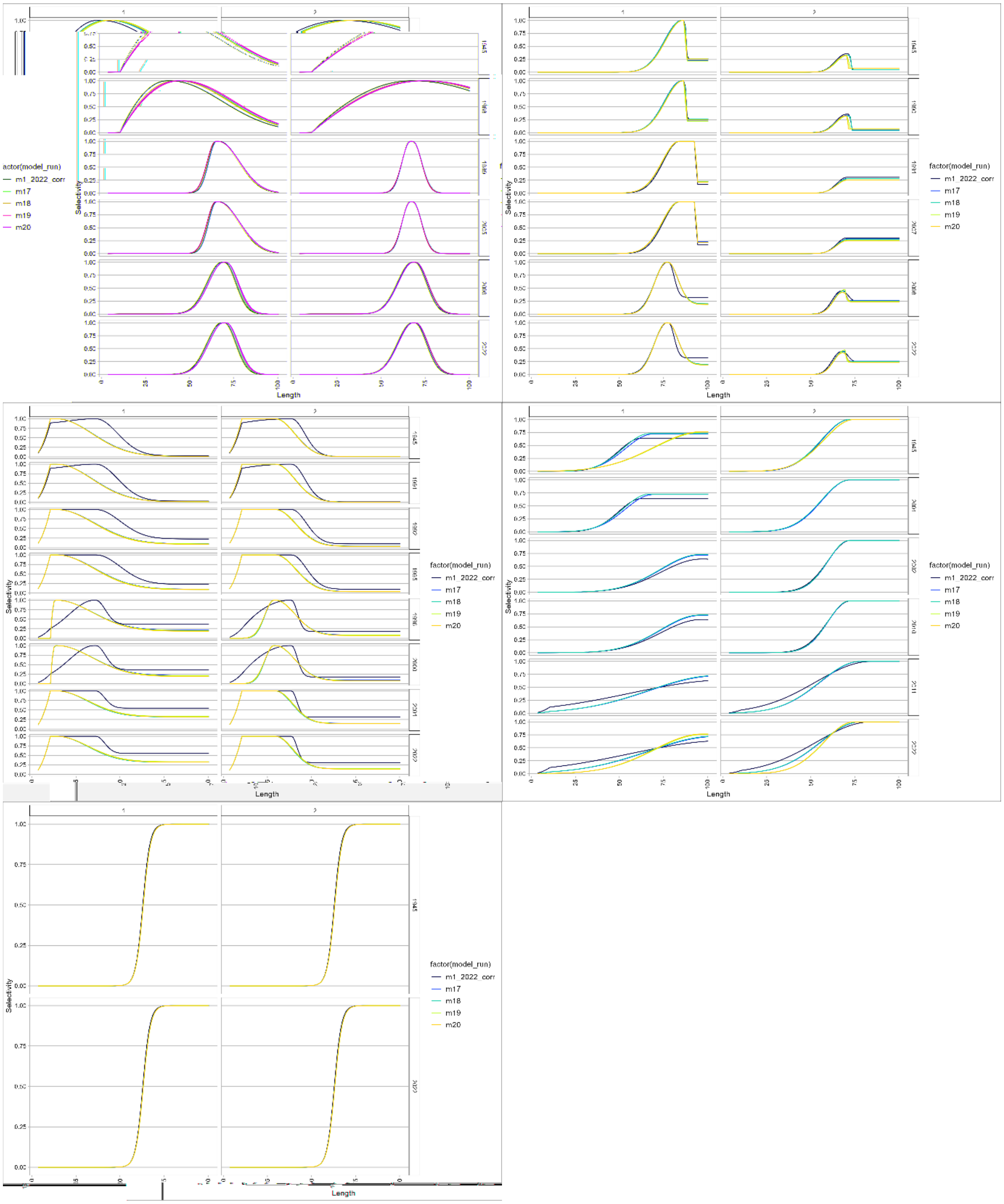
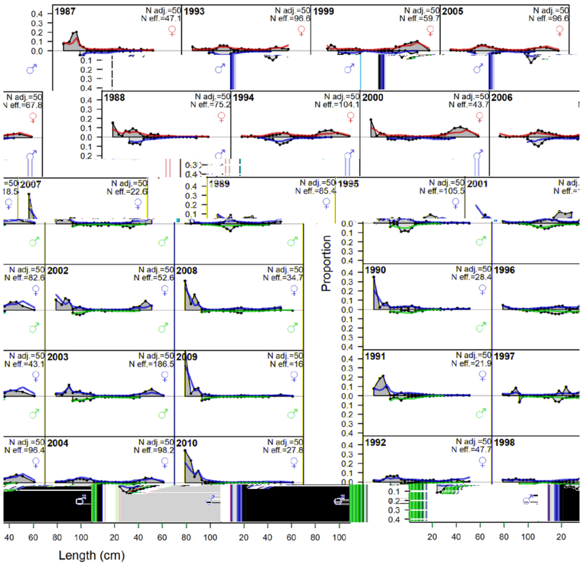
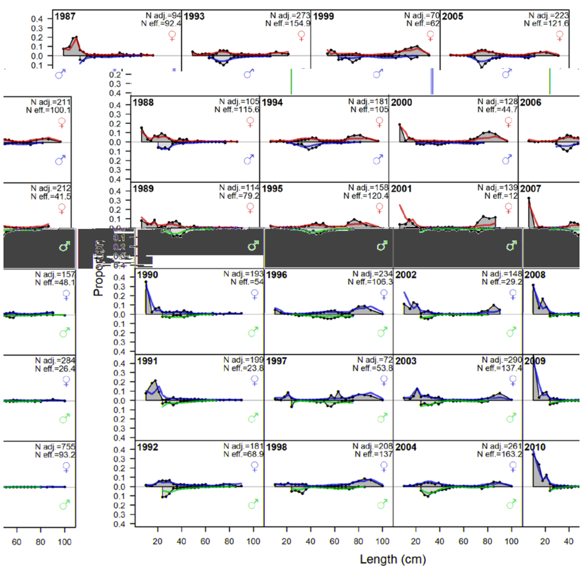


Figure 20. Fleet-specific selectivity for models m17-20. Trawl fishery (top left), Longline fishery (top right), EBS shelf bottom trawl survey (middle left), EBS slope bottom trawl survey (middle right), and AFSC longline survey (bottom row). Female selectivity is in column labeled 1 and males are labeled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

m1

m18





m20

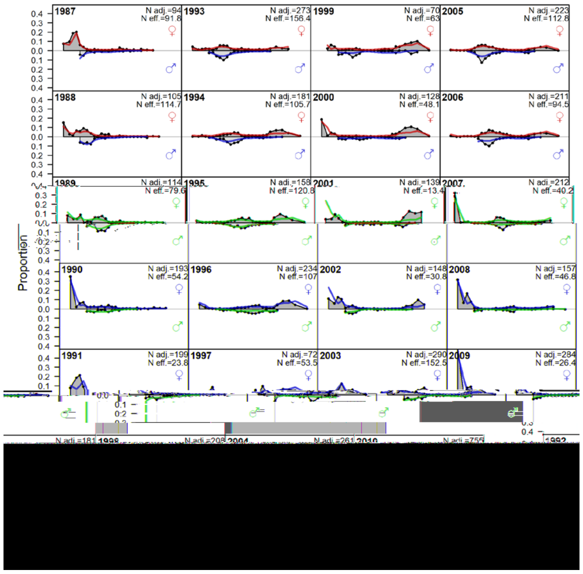
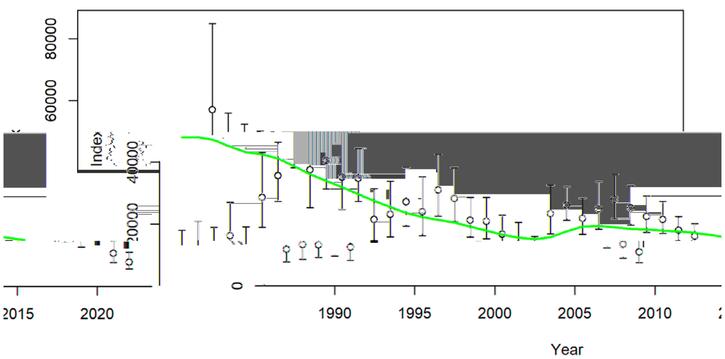


Figure 21. Model fits to the annual EBS shelf bottom trawl survey length composition data for models m1, m18, and m20.



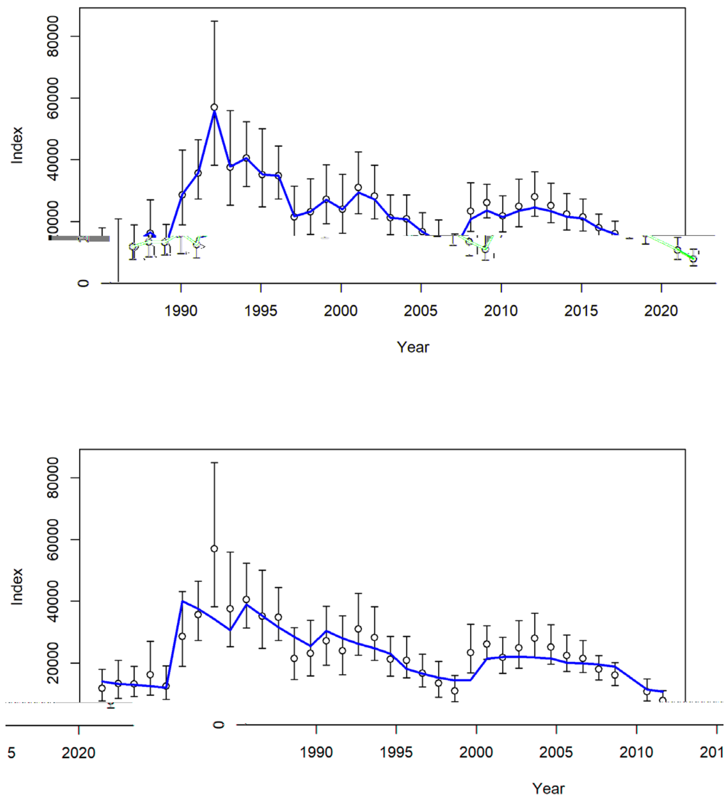


Figure 22. Fit to the EBS shelf bottom trawl survey when time blocks are removed (top), catchability is time-varying (middle), and ~5 year time blocks are implemented throughout the time series (bottom).

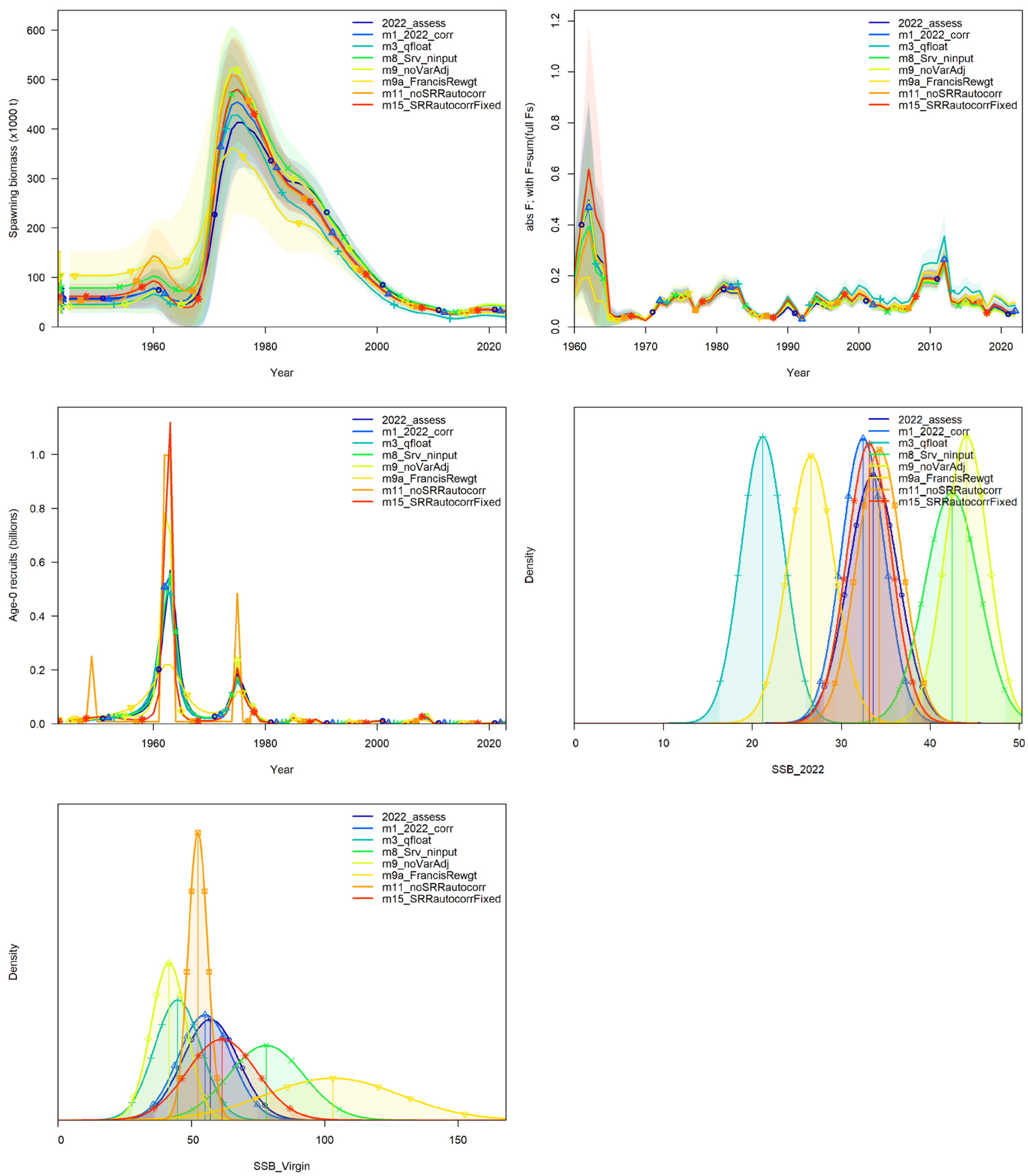

2022_assess
m1_2022_corr
m3_qfloat
m8_Srv_ninput
m9_noVarAdj
m9a_FrancisRewgt
m11_noSRRautocorr
m15_SRRautocorrFixed
Spawning biomass (x1000 t)
Year
abs F; with F=sum(full Fs)
Year
Age-0 recruits (billions)
Year
Density
SSB_2022
Density
SSB_Virgin

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.

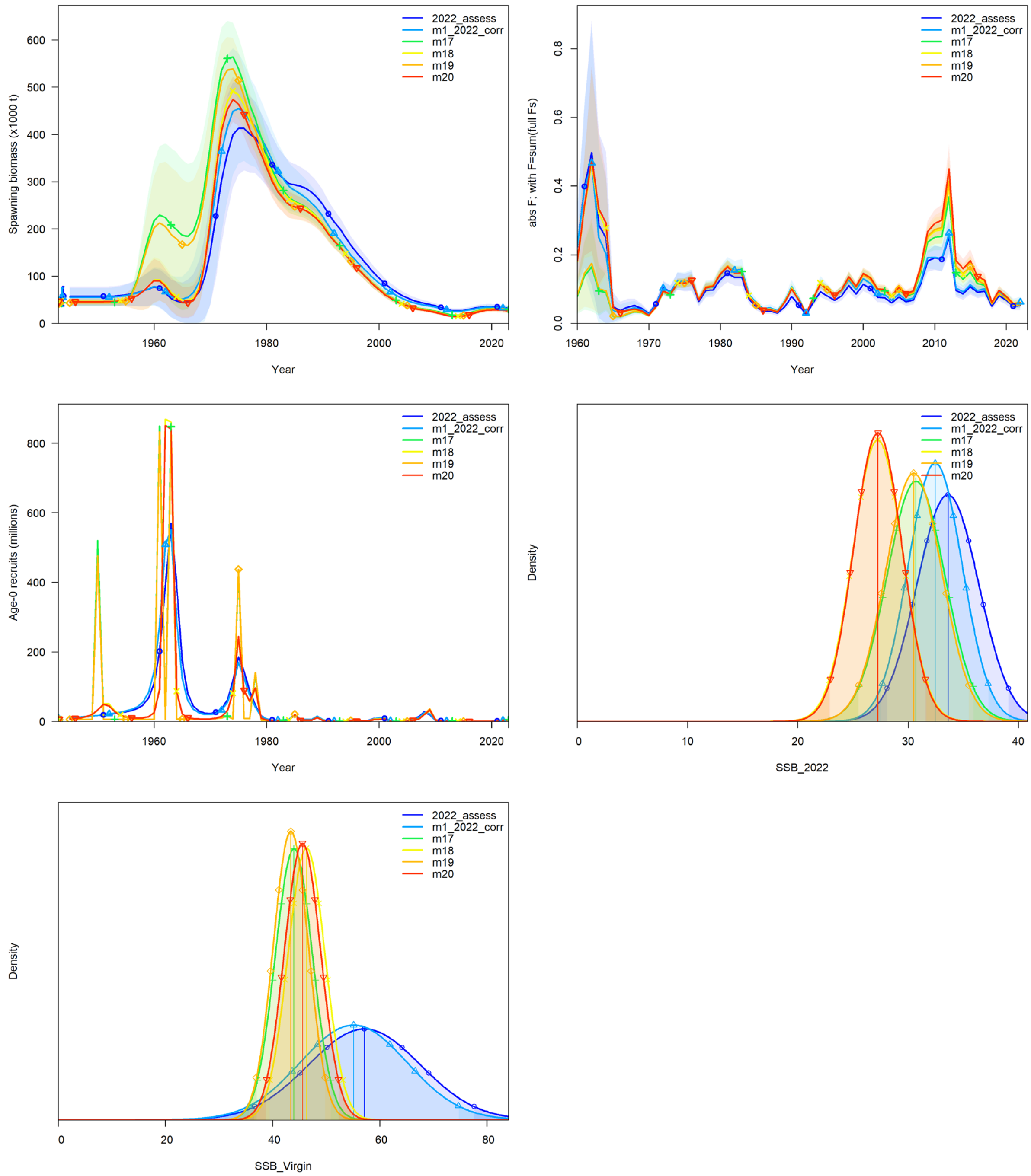


Figure 24. Comparison of SSB (top left), annual fishing mortality (top right), age-0 recruits (center left), SSB in 2022 (center right), and unfished SSB(bottom left). Update models.

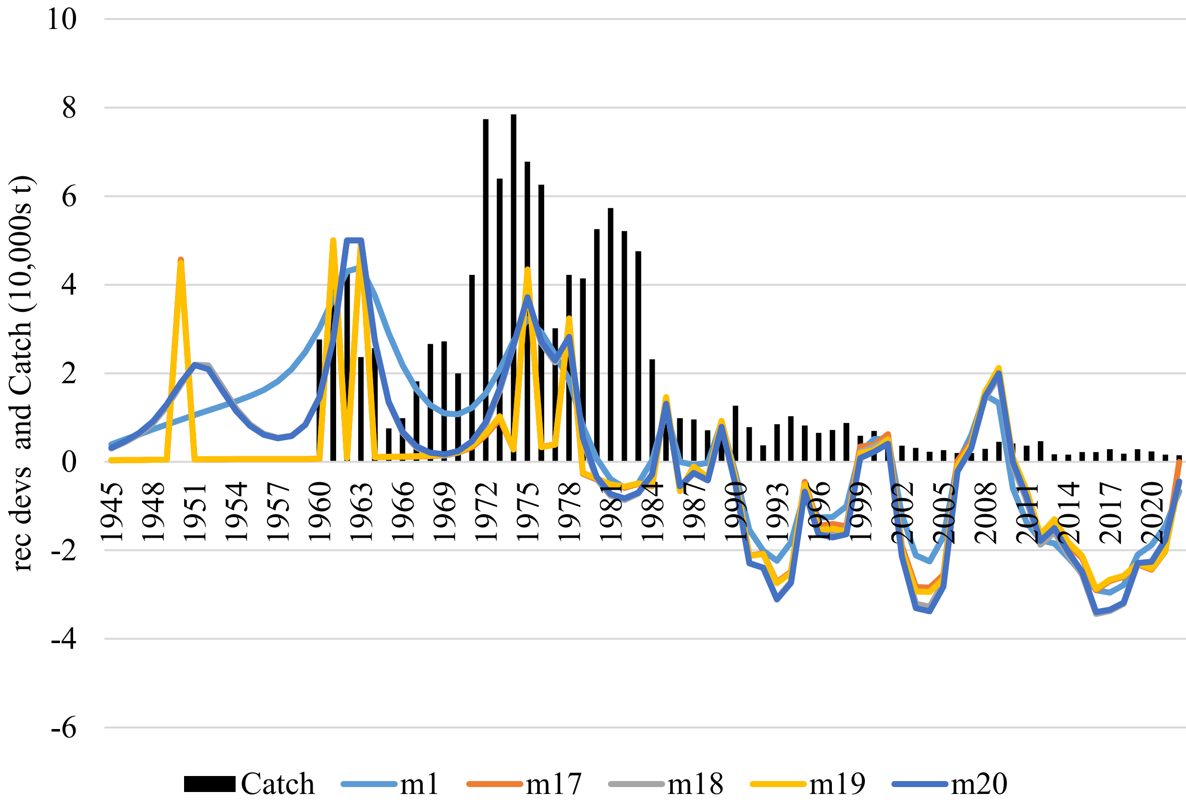


Figure 25. Recruitment deviations and total catch in (10,000s t).

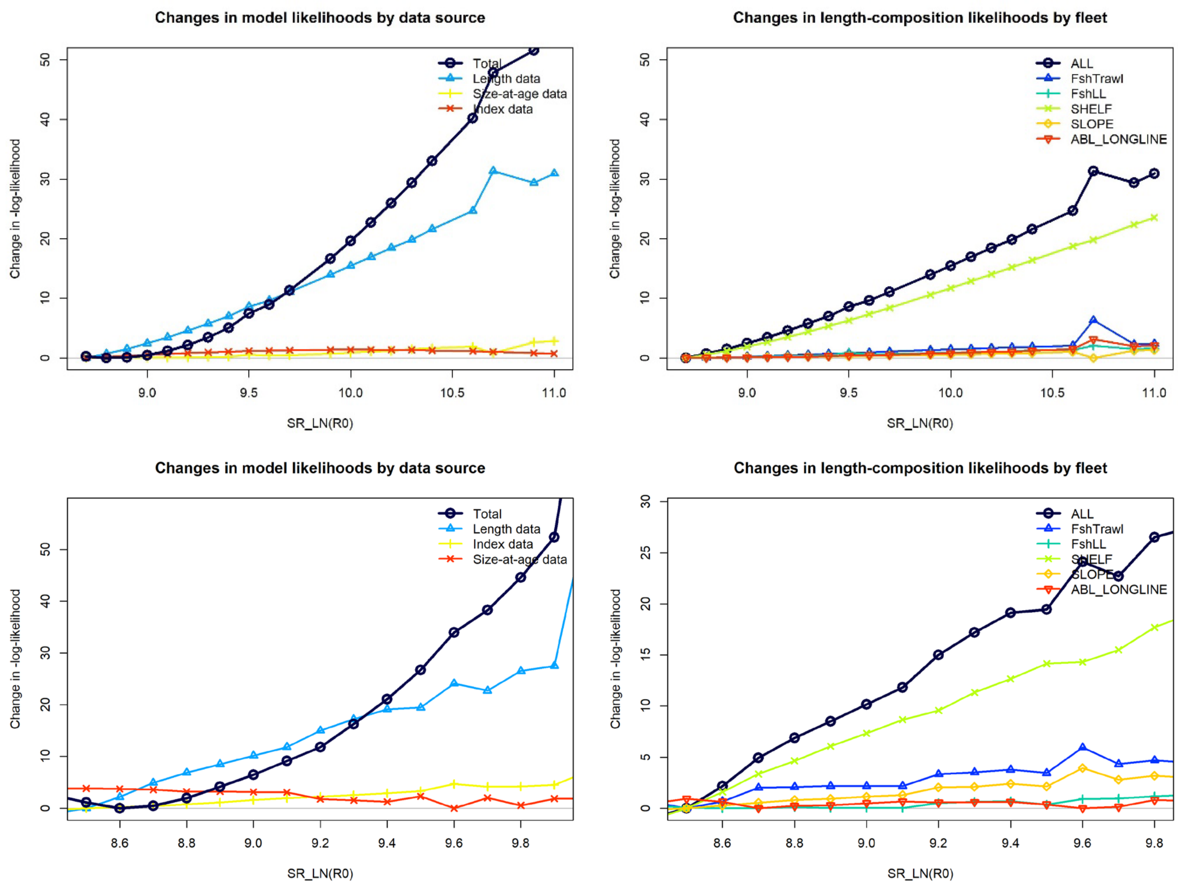
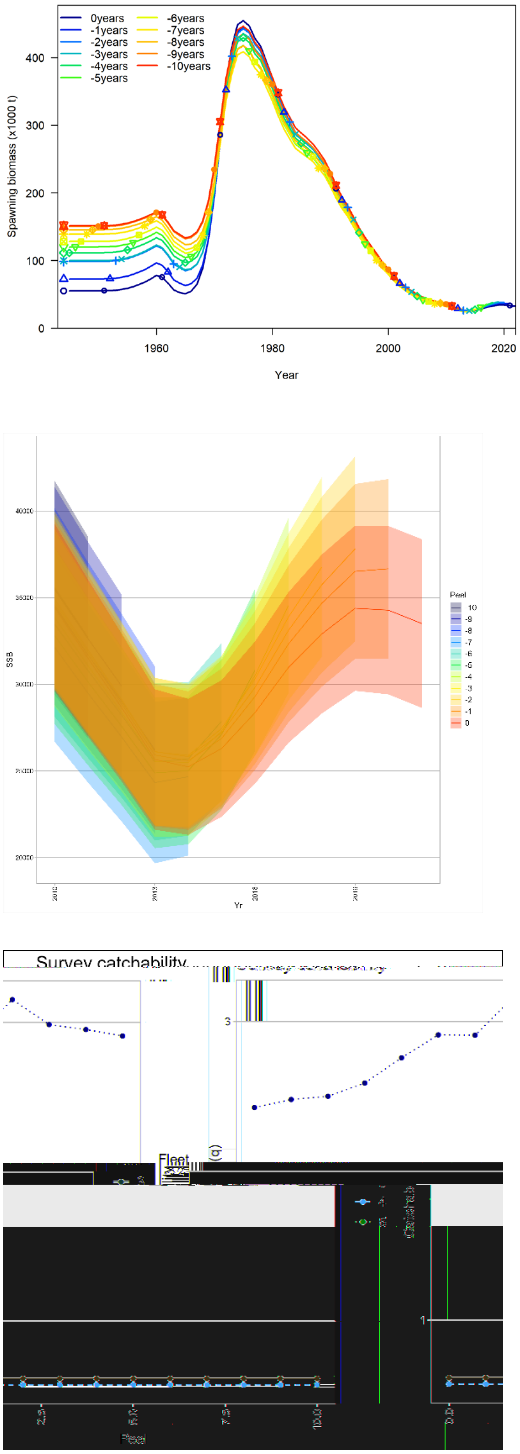


Figure 26. R_0 likelihood profile, total likelihood plot and fleet-specific length composition likelihood plots, for model m1 (top row), m20 (bottom row).

m1



m18

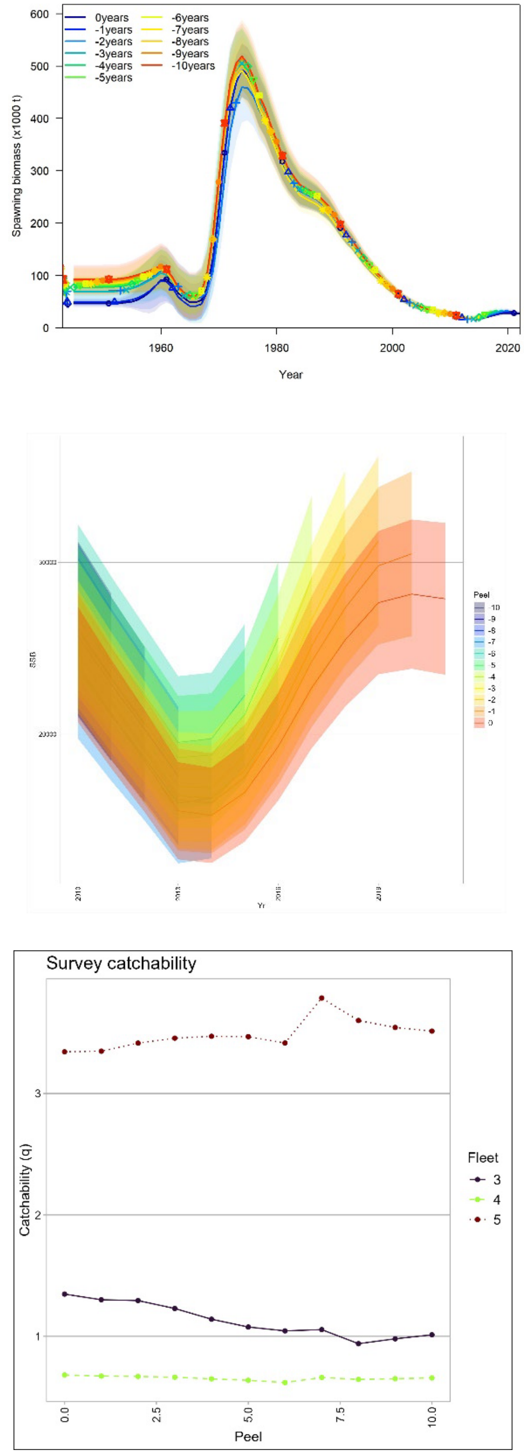


Figure 27. Retrospective plots of SSB (full time series and last 20 years) and change in catchability. Models are indicated by the alpha-numeric label. The EBS shelf bottom trawl survey is fleet 3, the EBS slope bottom trawl survey is fleet 4, and the AFSC longline survey is fleet 5.

m20

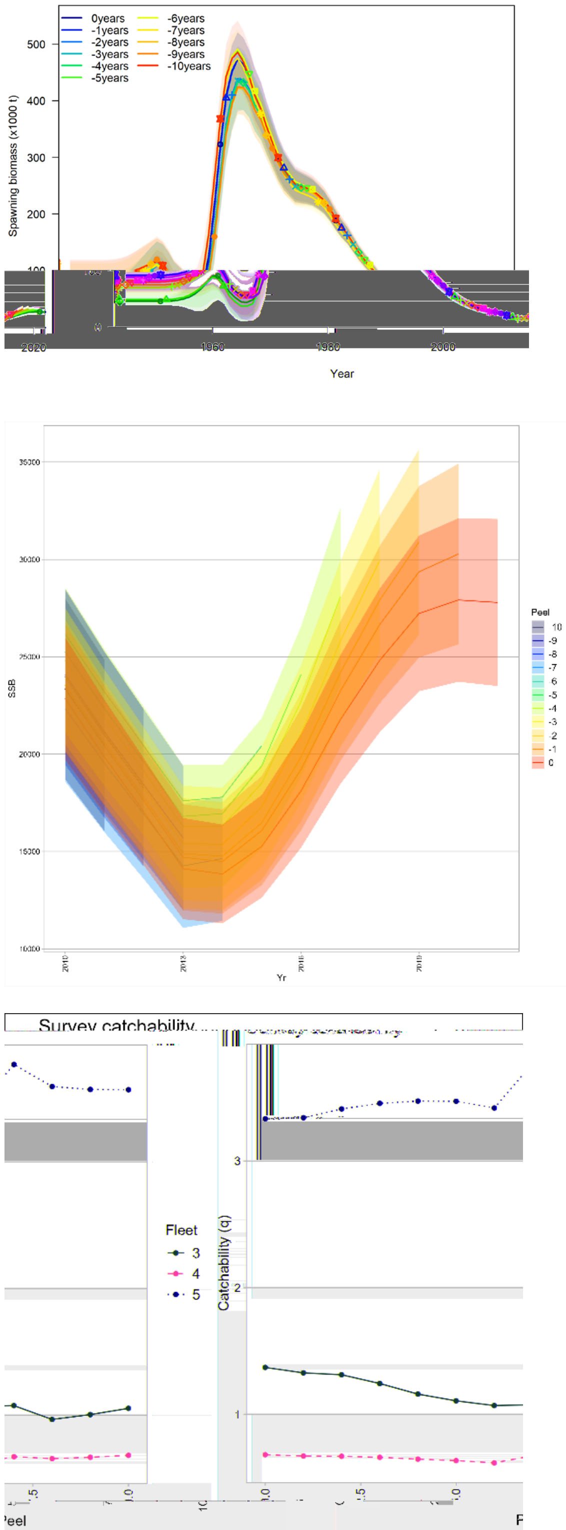


Figure 27 continued.

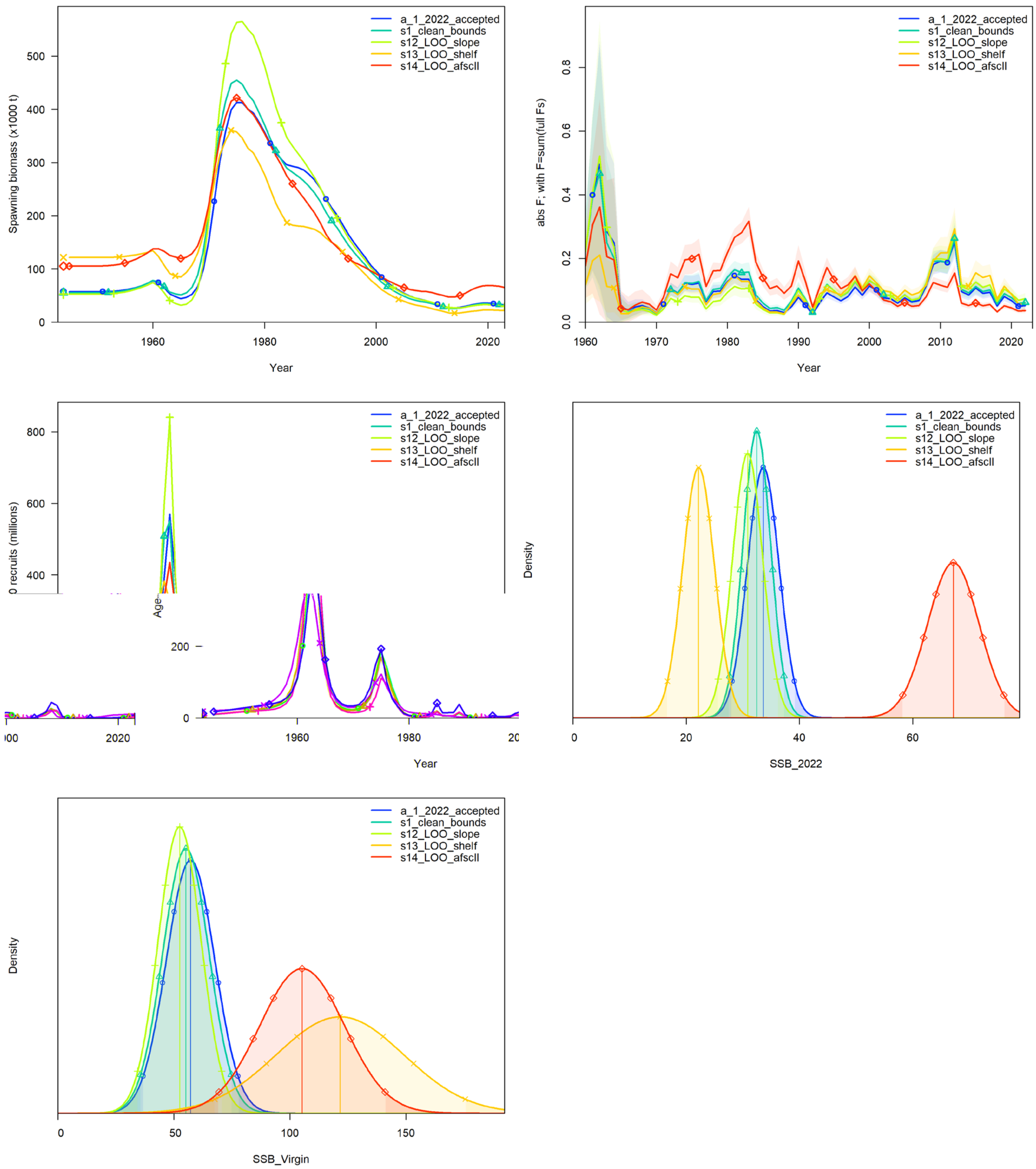


Figure 28. Leave one out analysis for model m1.

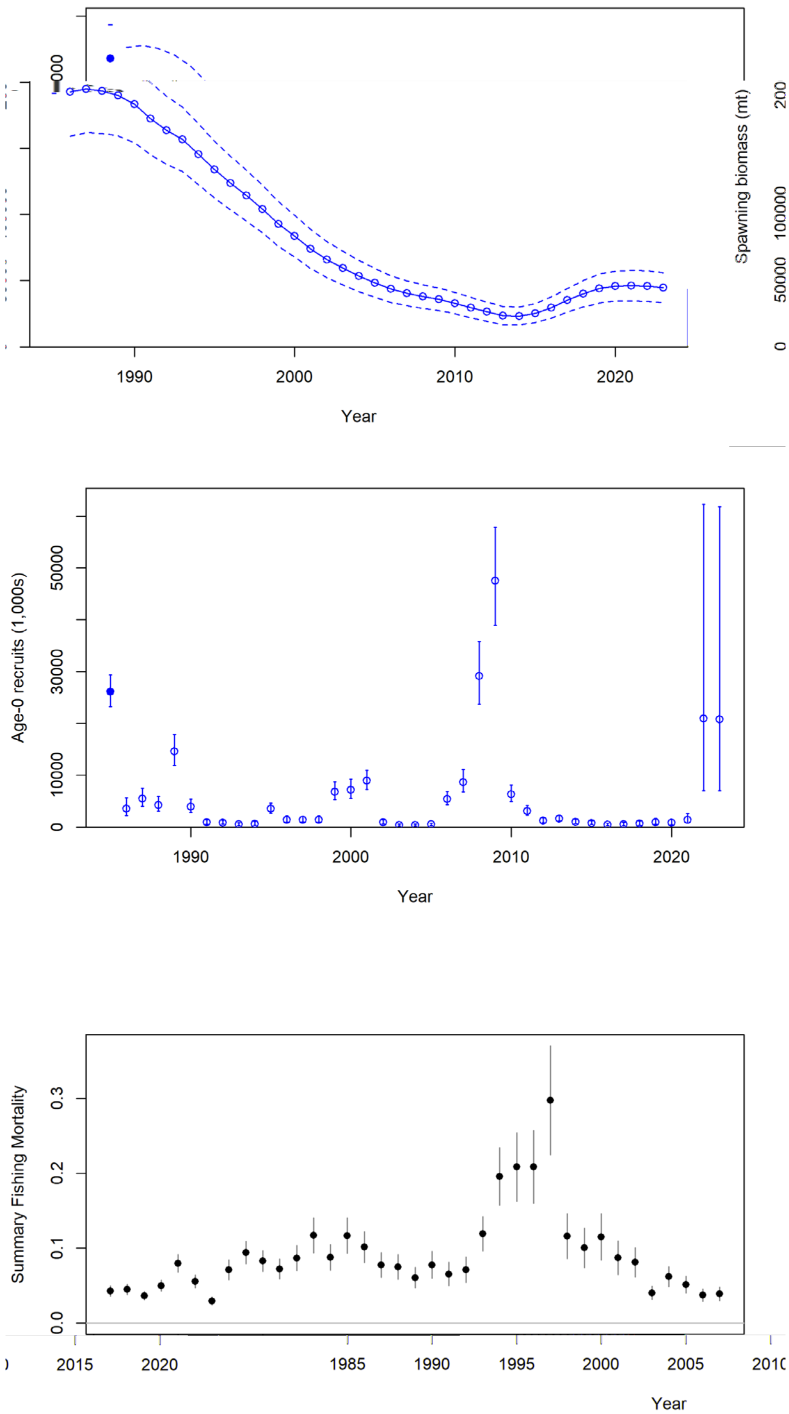


Figure 29. SSB, age-0 recruits, and annual fishing mortality from an experimental model run starting in 1986.

Appendix

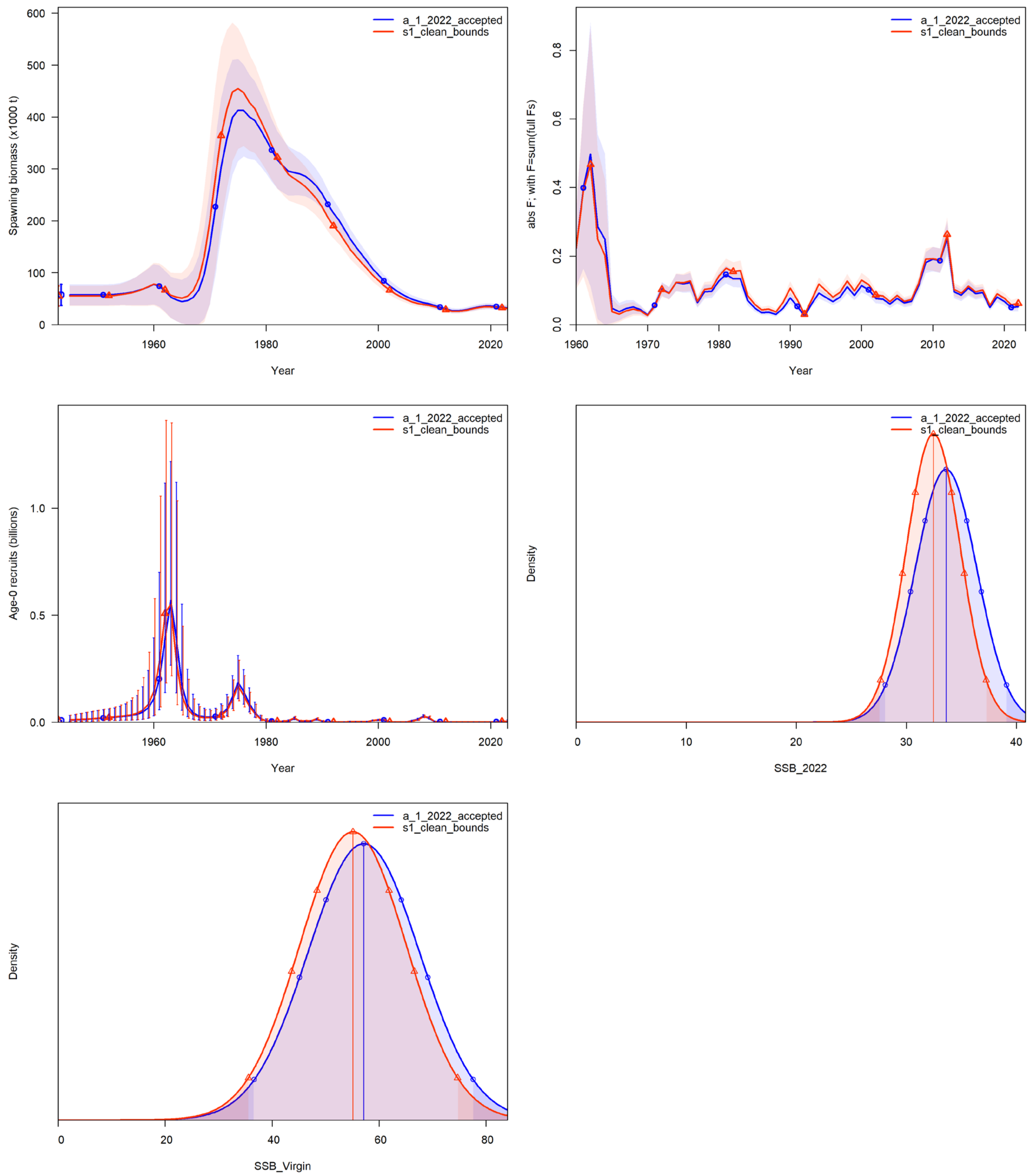


Figure A. 6 Comparison of SSB (top left), annual fishing mortality (top right), age-0 recruits (center left), SSB in 2022 (center right), and unfished SSB (bottom left) from the last accepted model (blue) and the model with corrected slope length distributions (red).

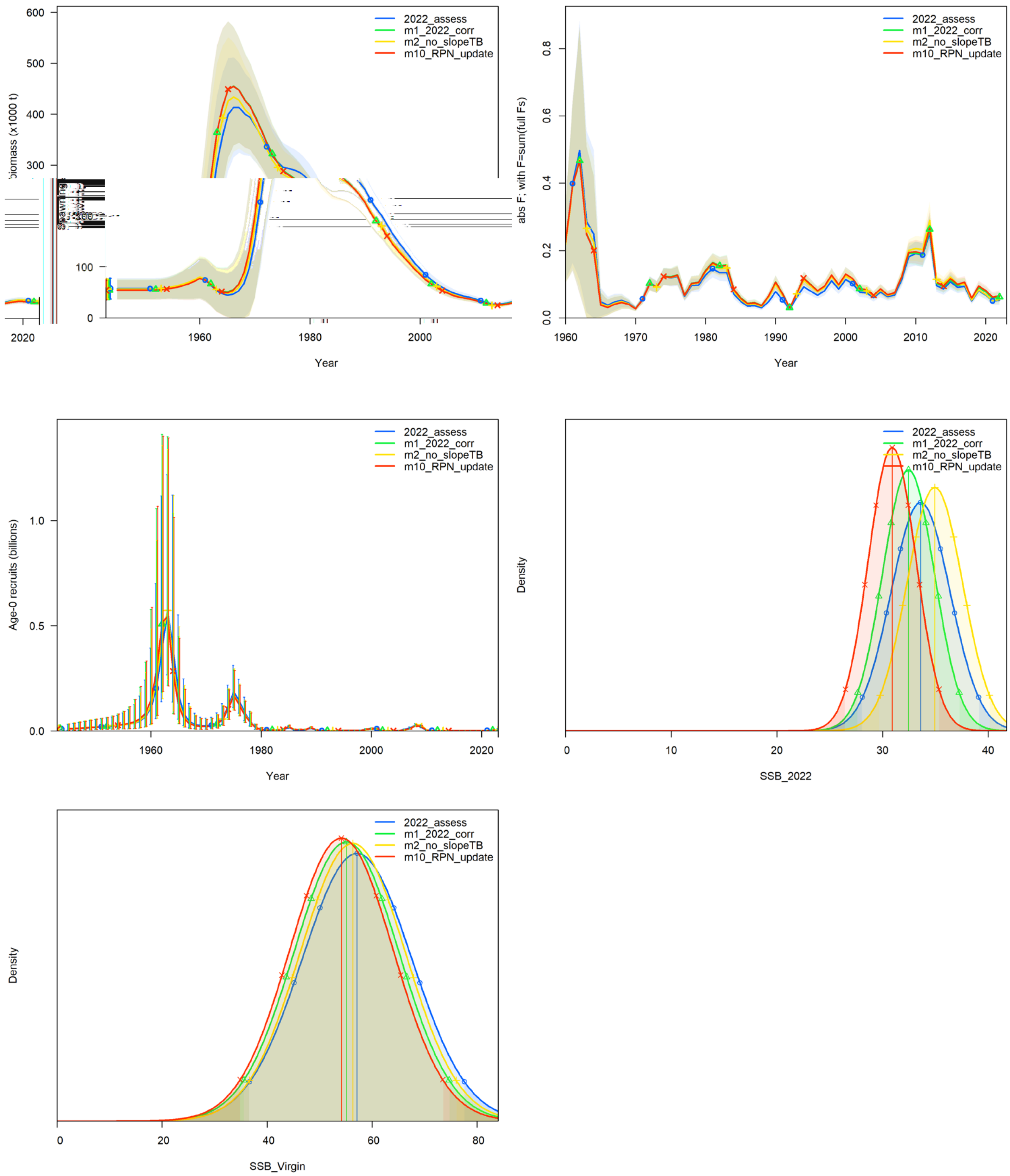


Figure A. 7 Spawning stock biomass (SSB), fishing mortality, age-0 recruits, SSB estimates in 2022, and unfished SSB estimates by model.