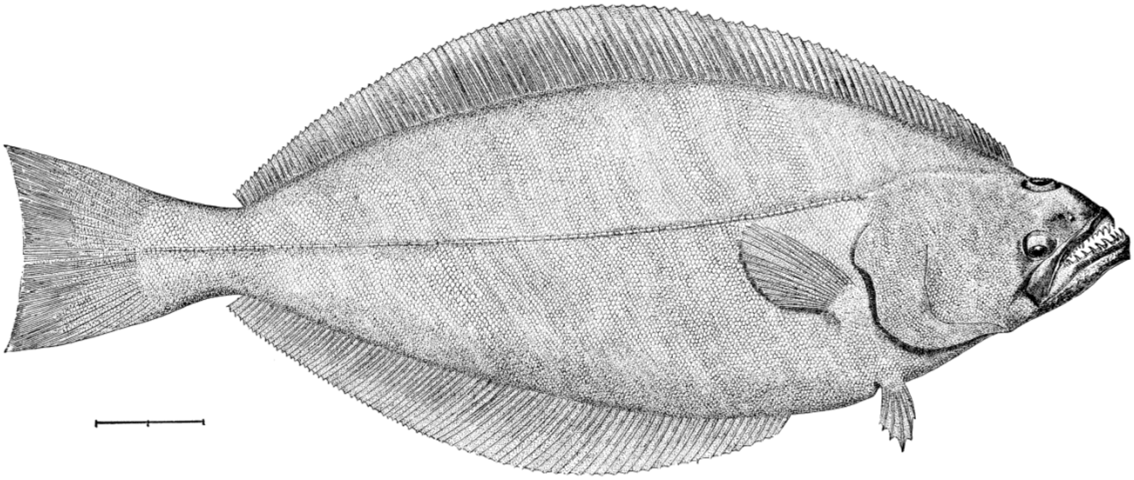
5. Assessment of the Greenland turbot stock in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

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Executive Summary

Summary of Changes in Assessment Inputs

New data for the assessment included the 2021 and 2022 NMFS shelf bottom trawl survey biomass estimates and size compositions and the Alaska Fisheries Science Center (AFSC) longline survey relative population numbers for 2021 and 2022. Length at age data from the 2021 and 2022 NMFS shelf bottom trawl surveys were also available and were used in this assessment. Fishery catch estimates were updated and include a preliminary estimate for 2022. Data on fishery size composition from 2021 and 2022 were also included.

Summary of Changes in Assessment Model

Model changes were minor. The AFSC longline survey length data were included in models 16.4b and 16.4c and its selectivity was estimated. The EBS slope bottom trawl survey mean length at age data were also included in Model 16.4c.

Quantity	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year* for: 2023	2024
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3a	3a	3a	3a
Projected total (age 1+)	84,341	80,404	53,907	48,850
Female spawning biomass	50,361	47,376	33,554	30,484
Projected				
$B_{100\%}$	89,054	89,054	67,647	67,647
$B_{40\%}$	35,622	35,622	27,058	27,058
$B_{35\%}$	31,169	31,169	23,676	23,676
F_{OFL}	0.22	0.22	0.20	0.20
$maxF_{ABC}$	0.18	0.18	0.17	0.17
F_{ABC}	0.18	0.18	0.17	0.17
OFL (t)	7,687	6,698	4,645	3,947
maxABC (t)	6,572	5,724	3,960	3,364
ABC (t)	6,572	5,724	3,960	3,364
Status	As determined *last* year for: 2020	2021	As determined *this* year for: 2021	2022
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 2,918 t was used in place of maximum permissible ABC for 2023. The preliminary catch for 2023 and 2024 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2017-2021) and the 2022 TAC.*

Responses to SSC and Plan Team Comments on Assessments in General

"The SSC requests that all authors fill out the risk table in 2019…" (SSC December 2018)

"…risk tables only need to be produced for groundfish assessments that are in 'full' year in the cycle." (SSC, June 2019)

"The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table." (SSC, October 2019)

"The SSC requests the GPTs, as time allows, update the risk tables for the 2020 full assessments.

…..The SSC recommends dropping the overall risk scores in the tables.

…..The SSC requests that the table explanations be included in all the assessments which include a risk table for completeness.

….The SSC notes that the risk tables provide important information beyond ABC-setting which may be useful for both the AP and the Council and welcomes feedback to improve this tool going forward." (SSC December 2019)

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 length-at-maturity that is not accounted for in the assessment model and due to uncertainty about future recruitment.

Responses to SSC and Plan Team Comments Specific to this Assessment

"…, we recommend a more realistic alternative than the maximum ABC be used for two-year harvest projections, as only roughly one third of the ABC was caught in 2019." (SSC, December 2020).

A more realistic catch estimate was used for the projections. The preliminary catch for 2023 and 2024 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2017-2021) and the 2022 TAC.

"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 is currently working on a project to address this suggestion. The results from his work will be evaluated during the next full assessment.

"With regard to maturity, recent information (Cooper et al. 2007) suggests that the maturity at size may be larger than estimated from a previous study in the early 1980s, though this recent study had limited samples at smaller sizes. The SSC suggests that pooling the data from these two studies might provide a more defensible approach than the approximation of the D'yakov 1982 results presented in the assessment." (SSC, December 2020).

It is not possible to pool the data from Cooper et al. (2007) study with more current samples, so this suggestion cannot be addressed. A sensitivity analysis on the length at 50% maturity was conducted and the uncertainty in maturity is considered in the risk table.

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).

This will be addressed during the next assessment cycle.

The SSC agrees with the Plan Team's recommendations that: 1) the consistency of time blocks across surveys be explored 2) a Stock Structure template be completed 3) the author explore the use of age comp data in the model. 4) the author contact ABL survey staff about getting sex specific lengths collected during future surveys (Plan Team, November 2016, also in SSC, December 2016 and 2018)

This will be addressed during the next assessment cycle.

Sometime after the current assessment cycle, the Team recommends that the author consider excluding pre-1977 data. (Plan Team, September 2018)

This will be explored for the next assessment cycle.

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

This will be addressed further during the next assessment cycle.

Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) is a Pleuronectidae (right eyed) flatfish that has a circumpolar distribution inhabiting the North Atlantic, Arctic and North Pacific Oceans. 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 (< 100 m) and colder shelf waters (< 0°C). The larger specimens were in higher concentrations in deeper (> 100 m), warmer waters (> 0°C) (Barbeaux et al. 2015). 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. In this assessment, Greenland turbot found in the two regions are assumed to represent a single management stock. 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 5.2). 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.

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).

Fishery

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 5.3). 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 have been 1,775 t between 2008 and 2021. Catch by the longline fishery started to increase after 1990 and then declined after 1998 (Figure 5.2). Catch by the longline fleet has been less than 300 t since 2018.

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 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 have been increasing since 2016, while catch remains low. The fishery has generally captured a high proportion of the ABC and TAC annually, with lows of 16% in 2018 and 26% in 2021, respectively (Table 5.1). Since 2018, an average of 41% of the TAC and 25% of the ABC has been captured.

The majority of the catch over time has been concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (Figures 5.3 and 5.4), but Greenland turbot has been consistently caught in the shallow water on the shelf as bycatch in the trawl fisheries (Tables 5.1 and 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).

For the domestic fishery, the trawl fishery took the majority of the catch until 1992 (Table 5.1). The longline fishery took the majority (~69%) 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 has captured approximately 68% of the catch between 2012 and 2021.

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 from 356 fathoms, from 1995 to 2009, up to 296 fathoms, on average, from 2010 to 2015 (Figure 5.6). This change in depth was preceded by a decrease in average length of Greenland turbot in this fishery of ~10 cm between 2007 and 2008 continuing to the present (Figure 5.6). There was also a northward trend in mean fishing latitude starting at 56.5°N in 1995 to 59°N by 2009. 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 5.2). The overall discard rate of Greenland turbot has dropped in recent years from a high of 82% discarded in 1992 down to only 3% in 2011 and 2012. 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 5% over the years 2015-present.

Greenland turbot catch has primarily been from the Bering Sea; however, catch levels were similar in 1991, 2009, and 2010 (Table 5.3). Catch of Greenland turbot in the Aleutian Islands declined between 2012 and 2019.

Data

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 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 Table 5.4 and Figure 5.7.

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 2022. The length composition data from the trawl and longline fishery are presented in Figure 5.8. The absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2022 are given inTable 5.5.

EBS slope and shelf surveys

There are two bottom trawl surveys included in the Greenland turbot stock assessment. The EBS shelf survey primarily provides abundance estimates of juveniles and the slope survey provides estimates of older juvenile and adult abundance on the EBS slope (Figures 5.8 and 5.9). 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 had been 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 (Table 5.6). 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 estimates 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. 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 (comparable since similar depths were sampled by both surveys) averaged 45,898 t, with a 2004 level of 64,756 t. Although the 2012 EBS slope biomass estimate of 17,992 t was down from 2010 estimate of 19,873 t, the population numbers in 2012 of 11,839,700 fish was more than double the 2010 estimate of 5,839,126 fish (Table 5.7). 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 5.7). 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 5.8).

In the 2016 slope survey Greenland turbot biomass increased to 23,573 t (Figure 5.10). In the 2016 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 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 5.8). 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 (expanded areas 8 and 9). For consistency the index of abundance used in this stock assessment only includes data post-1987 and included data from the expanded area (Figure 5.10). The shelf survey is a measure of juvenile fish and appears to be highly influenced by occasional large recruitment events. The shelf survey index shows a steep decline in biomass from initial biomass estimates in 1982 of 39,603 t as the large recruitments during the late 1970s migrated off the shelf down to an all-time low of 5,654 t in 1986 (Table 5.6). From 1987 to 1994 the index shows an increase in biomass 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, 2011 and 2017. The average shelf-survey biomass estimate during the last 20 years (1995-2017) was 25,168 t.

Biomass has been declining since 2018 17,966 t. Shelf biomass declined by 33% between 2019 and 2021 and declined by 26% in 2022. The 2022 shelf biomass is the lowest observed since 1982.

The number of hauls and the levels of Greenland turbot sampling in the shelf surveys were presented in Table 5.10. In 2010 and 2011 the abundance estimates from the shelf surveys indicated a significant increase of Greenland turbot recruitment and an increase in the proportion of tows with Greenland turbot present (Table 5.10, Figures 5.8 and 5.9). These observations suggest that the extent of the spatial distribution has remained relatively constant prior to 2010 (with a slight increase) and that these two surveys had both higher densities and broader spatial distribution. Biomass and abundance have been declining since 2012. This is due to the 2007-2010 year classes migrate off the shelf survey area and in recent years with little replacement from new recruitment (Figures 5.8 and 5.9).

Survey size composition
A time series of estimated size composition of the population was available for both surveys. The shelf survey appears to be useful for detecting recruitment patterns that are consistent with the trends in biomass. In 2007 through 2011 signs of recruits (Greenland turbot less than about 40 cm) were clear after an absence of small fish during 2003-2006 (Figure 5.8). 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 40cm. A small proportion of fish less than 40 cm were observed in 2021. The length data from the AFSC’s longline survey was also included in the model (Figure 5.8). The lengths from the longline survey are not sex-specific and generally range between 50cm and 100cm. There is a clear shift in the AFSC longline size distributions after 2002.

Survey length-at-age used for estimating growth and growth variability were previously available from 1998, 2003-2019, and 2021. 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 5.9). 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 in 2019 and 2021 on the shelf.

Aleutian Islands survey
The 2022 Aleutian Islands biomass and numbers increased from 2018 (Table 5.6). Biomass was up to 512 t from 373 t and abundance was 177,309 from 54,327 (Table 5.11). This followed a declining trend between 2006 and 2018. The 2018 biomass declined to 373 t from 2,378 t in 2016 and 2,529 in 2014, well below the 1991-2022 average level of 10,398 t. Abundance in 2018 dropped to 54,327 from 920,007 in 2016. Abundance dropped by 87% in the Central Aleutians Islands area and Greenland turbot were not caught in the Eastern AI or the Southern Bering Sea. Abundance in the Western AI area increased in 2018 to 36,955 from zero in 2016. Abundance of Greenland turbot in the AI survey increased from 568,632 in 2014 to 920,007 in 2016 as fish were recruiting to the Aleutian Islands area in 2016.

Biomass in the Aleutian Islands is generally highest in the eastern AI, followed by the central AI, except in 2018. The breakdown of area specific survey biomass for the Aleutian Islands region shows that the eastern Aleutian Islands area (Area 541) biomass estimate dropped sharply from 3,695 t in 2010 (59% of AI biomass) to 181 t (7% of AI biomass) in 2012 and remained relatively low since. The trawl-survey area-swept data for the Aleutian Islands component of the Greenland turbot stock is not presently included in the stock assessment model.

Longline survey
The AFSC longline survey for sablefish alternates years between the Aleutian Islands and the Eastern Bering Sea slope region. The combined time series was used as a relative abundance index. Area based

RPNs are in Table 5.12. It was computed by taking the average RPN from 1997-2022 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 (1996-2022) 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. The time series of size composition data from the AFSC longline survey extends back to the cooperative longline survey and is shown in Figure 5.10. The RPNs declined between 1998 and 2008 and have remained at low numbers since.

Discussions with the survey managers have revealed whale depredation on this survey may affect the index. Data affected by depredation are removed from the RPN analysis but due to the overall magnitude, sample sizes are reduced and unknown effects of whale depredation may introduce bias to this index. Further it is unknown what the effects of whale depredation has on size composition. We will further investigate the impact of whale depredation on the index during the next full assessment.

Analytic approach

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 2022. 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 (Table 5.4). The assessment model also uses the Beverton-Holt stock-recruitment curve, and the early recruitment series is carried back to 1945. Minor changes in the assessment were reviewed in September and included in this model. Changes were including the AFSC longline length data and estimating this survey’s selectivity and including the EBS slope survey mean length at age data. There was little impact of this change on the assessment model results when compared to the 2020 assessment.

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	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)

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. 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 age 21 a CV of 7% was assumed. This appears to encompass the observed variability in length-at-age. As with the previous assessment, size-at-age information from the methods described by Gregg et al. (2006) were used and this information is summarized in Table 5.4, Table 5.13, and Table 5.14.

Maturation and fecundity

Maturity and fecundity followed the same assumptions as the 2020 model with the female length at 50% mature at 60 cm as per D'yakov (1982). Recent studies on the fecundity of Greenland turbot indicate that estimates at length may be somewhat higher than most estimates from other studies and areas (Cooper et al., 2007). In particular, the values were higher than that found from D'yakov's (1982) study. The data for proportion mature at length from the new study suggest a larger length at 50% maturity but data were too limited to provide revised estimates and may be biased large due to the lack of smaller fish in the study. 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. This is based on an approximation from D'yakov's (1982) study.

Weight at length relationship

The weight at length relationship was derived using the combined data from all surveys conducted by the Alaska Fisheries Science Center in the Bering Sea and Aleutian Islands. 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 and continuing with this year's models $w = 2.43 \times 10^{-6} L^{3.325}$ is used 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 presented at the September 2012 Plan team and SSC meetings (Barbeaux et al. 2012, Appendix 5.1).

Size composition multinomial sample size

There is always difficulty in determining the appropriate multinomial sample size for the size composition data. For the two fisheries initial sample sizes for each year were set to 50 (Table 5.15). The annual size composition sample sizes for the shelf survey was 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.

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

		Model 16.4a	**Models 16.4b and 16.4c**
Recruitment			
	Early Rec. Devs	(1945-1970) 25	(1945-1970) 25
	Main Rec. Devs	(1970-2018) 49	(1970-2018) 49
	Future Rec. Devs	(2019-2022) 4	(2019-2022) 4
	R_0	1	1
	Autocorrelation ρ	1	1
Naural mortality			
	Male	0	0
	Female	0	0
Growth			
	L_{min} (M and F)	2	2
	L_{max} (M and F)	2	2
	Von Bert K (M and F)	2	2
Catchability			
	q_{shelf}	0	0
	q_{slope}	0	0
	q_{ABL}	1	1
Selectivity			
	Trawl fishery	15	15
	Longline fishery	28	28
	Shelf survey	17	17
	Slope survey	19	19
	AFSC longline survey	0	2
	Total Parameters	166	168

Recruitment and initial conditions

For this assessment, a single R_0 was assumed for all years and fit using an uninformative log normal prior. 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 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 model starting 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.

Catchability

The catchabilities for the shelf and slope were fixed in the model and the values are from the 2015 Model 14.0 fit without the 2007 through 2015 data. This was meant to eliminate the effects of the 2007 through 2010 year classes. The values used in the model were $\log(q_{shelf}) = -0.485$ and $\log(q_{slope}) = -0.556$. The catchability coefficient for the AFSC longline survey was estimated.

Selectivity

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 and the male selectivity was offset from the female selectivity for the longline fishery and the shelf survey. 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 AFSC longline survey selectivity was assumed to be constant over time and modeled with a logistic pattern in Model 16.4a. The length at 50% selectivity and the slope parameter were set equal to 63.5993cm and 5.0955, respectively in Model16.4a. Models 16.4b and 16.4c estimate selectivity.

Time blocks were used to estimate time varying selectivity for the fishery and the shelf and slope bottom trawl surveys. The time blocks 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

Results

Model Evaluation

The model presented here is the same as the 2020 assessment model, Model 16.4a, but the AFSC longline length composition data were inputs and its selectivity was estimated in Model 16.4b. Model 16.4c was the same as Model 16.4b and also included the EBS slope survey mean length at age data as inputs. Models 16.4b and 16.4c are compared to the 2020 assessment model 16.4a. **Model 16.4c (2020) is the recommended model for the current assessment cycle.**

Table 5.16 summarizes the total likelihood and likelihood components for each model run. The total likelihood results are not directly comparable since the data inputs differed among the models. They are reported for completeness. The data were the same for the survey component likelihoods and can be compared. The survey component likelihoods and the index RMSE results indicate that model 16.4a had the best fit to the EBS shelf survey biomass, Model 16.4b had an improved fit to the EBS slope survey biomass, and Model 16.4c had an improved fit to the AFSC longline RPN time series (Table 5.17).

The fit to the AFSC longline survey is similar to the last assessment in the beginning of the time series but is much improved for the last 6 years of the data. The models predict the declining trend in the AFSC longline index and the leveling off for the remainder of years (Figure 5.10). The model generally underestimates the earlier high numbers. The model fit to the shelf survey biomass is generally adequate (Figure 5.10). The model estimates the first several years of the survey quite well and the initial increase in biomass between 1991 and 1993. The model then greatly underestimates the high shelf biomass value in 1994 and then seems to fit the remaining years fairly well with some underestimation towards the end of the time series. The slope survey index has not been updated since 2016. The model fits this index reasonably well and the 2022 model fit the slope biomass than the 2020 assessment.

The parameter estimates for growth were similar among the models (Table 5.18). All models estimated unfished recruitment to be lower than the 2020 assessment and were similar among the models. Models 16.4a and 16.4b were ~5% higher than Model 16.4c. Autocorrelation in recruitment was similar among the models. The AFSC longline survey log catchability was also similar among the models.

All models fit the mean length at age data similarly (Figures 5.11-5.13). The length composition data from the trawl and longline fisheries and the EBS shelf and slope trawl surveys were data inputs that contributed to the likelihood. The fits to the length data were generally adequate (Figures 5.14 – 5.15). The estimated selectivity informed by these data all used a double normal pattern that allowed for dome-shaped selectivity (Figures 5.16 – 5.19).

The shelf survey was fit with a double normal selectivity pattern, where male selectivity was offset from the estimated female selectivity. Selectivity was assumed to vary over time with four time blocks. The estimated patterns were all dome-shaped and consistent among the models (Figure 5.18). Notably, the models underestimate cohorts from the early 1990s, ~1997, and 2010 (Figure 5.15).

The slope survey size selectivity was modeled with a double normal pattern with three time blocks. Selectivity for females was offset from males. Estimated male selectivity was similar among the models. Female selectivity for the 2011-2022 time block flattened and the model estimated full selection at a much higher size than the 2020 assessment. The fits continued to underestimate the peak of the male distribution and overestimated the highest abundance size bins, particularly for males (Figure 5.14 and Figure 5.15).

The model fit the female and male length distributions from the longline fishery quite well (Figures 5.14 and 5.15). Estimated selectivity was similar among the models, except 16.4a (2020). This is due to the improved parameterization of the double normal in SS3.3.19 (Figure 5.17). The model fit to the trawl size composition data was similar among the models. The fit to the data is adequate; however, the peak of the overall male distribution is underestimated (Figure 5.14).

The shelf survey age composition data were included in the model but not included in the age composition likelihood. The age composition predictions matched the data fairly well for both males and females (Figure 5.20). The model expected somewhat younger individuals in 2006, 2013, 2014, and 2017 and expected the peak of the distribution to occur at an older age in 2011 than the observed male and female distributions. The high numbers of age-1 fish observed in the shelf survey for 2007 through 2010 were consistent with the size composition data and were fit well by the model.

Figure 5.21 shows the resulting estimates of recruitment, spawning biomass, the spawning biomass posterior density in 2020 (because the 2022 models are being compared to the 2020 assessment model results), and apical fishing mortality. Certainty bounds were the standard errors obtained from the inverted Hessian matrix. Table 5.18 also summarizes these results.

The trends in recruitment, spawning biomass, and fishing mortality were similar among the models (Figure 5.21). The differences among the models occur mainly in the most uncertain portion of the time series, when the data providing information to the model is from the fishery only. More specifically, Model 16.4a estimated lower recruitment in the early 1960s than Models 6.4b and 16.4c. Also, recruitment in the late 1970s and 2010 was estimated to be lower in Models 164.b and 16.4c than by Model 16.4a. Model 16.4b. Starting spawning stock biomass estimated to be lower y the 2022 stock models than the 2020 assessment. Additionally spawning stock biomass in the most recent years is also estimated to be lower by Models 16.4a, 16.4b, and 16.4c than Model 16.4a (2020). This is due to declining survey biomass on the EBS shelf and those models better fitting the AFSC LL RPNs in the most recent years. The majority of key parameter estimates differed minimally among the models (Table 5.18).

Model 16.4c is the recommended model to provide management advice. This model performs similarly to model 16.4a and 16.b, uses the AFSC longline data to estimate selectivity, and uses all of the available information to model growth.

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 0.71with a standard deviation of 0.03. The model predicts extremely large recruitments in 1963- 1967 with between 182 and 570 million age-0 recruits (Table 5.19). This is an artifact of the model as there were no size or age composition data prior to 1977 to steer recruitment in these early years. A larger than average abundance was needed for the large 1960’s fishery and to leave enough large fish in the 1970s and 1980s to account for the large fish observed in the size composition data. The estimated autocorrelation in recruitment forces the model to create several large year classes throughout the 60s. In SS3, due to how the recruitment deviations likelihood is specified, if autocorrelation is not allowed the model will always fit a single large recruitment instead of multiple events when it does not have composition or index data to inform the model. This configuration was accepted in 2014 in light of a study by Thorson et al. (2014) showing improved model performance with the assumption of auto-correlated recruitment deviations.

After 1970, the model estimates another large recruitment event in 1974-1977 with an average recruitment of 135 million age-0 fish for these four years with a maximum of 186 million age-0 fish in 1975 (Table 5.19, Figure 5.20). As there were no size composition data prior to 1977, the basis for these large year classes was the existence of many large fish in the early longline fishery. Because Greenland turbot appear to reach a terminal size, the exact ages were not known and therefore the exact years for these recruitment events were not known and may change in future models under different configurations. The large pulse of fish during this period is well documented and can be traced from the trawl fishery through to the longline fishery and surveys.

Recruitment from 1980 through 2006 was low with a mean of 4.6 million age-0 fish. Recruitment of age-0 fish was estimated to be 13.5 million, 29.0 million, 19.3 million, and 3.4 million age-0 fish in 2007, 2008, 2009, and 2010, respectively (Table 5.19 andTable 5.23). Recruitment in 2008 was the largest since 1978. These recent 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 2013 in the trawl fishery (Figures 5.8 and 5.9). The 2014 longline fishery data show large year classes beginning to enter the size composition data. The influx of new recruits in 2007 through 2009 cause a sharp drop in the predicted population mean size and mean age (Figure 5.26). The estimated numbers-at-age reflect the strong cohorts in the mid-1960s and late-1970s and from 2007-2010 (Table 5.20, Figure 5.21). Mean length from the trawl and longline fishery has been increasing since 2015 and 2017, respectively (Figures 5.22 and 5.23). There has also been a noticeable lack of small turbot from the shelf survey since 2019. The mean size on the shelf has steadily increased since 2010 (Figure 5.24). This indicates that there has been a lack of new Greenland turbot recruits on the EBS shelf in recent years. Mean length on the slope noticeably declined in 2012 when the 2007-2009 cohorts moved onto the slope and increased in as the cohorts grew (Figure 5.25).

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass was estimated to be 35,257 t in 2022 by Model 16.4c (Table 5.22). Spawning stock biomass increased between 2014 and 2020 and declined in 2021 and 2022. 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 3.9 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 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 0.07 with a maximum of 0.11 (Table 5.21). The fishing mortality increased between 2008 and 2012 and ranged between 0.11 and 0.24. The effects of the incoming 2007-2010 year classes led to an increase in the female spawning biomass estimates and has exhibited some decline in 2021 and 2022.

The Model 16.4c total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 to a low point in 2013 of 66,338t (Table 5.21, Figure 5.26).

Since 2013, total age-1+ biomass is projected to have increased to 73,428 t in 2017 and has declined to 58,349 t in 2022 (Table 5.21). Numbers are also showing declines (Table 5.20).

Retrospective analysis

A retrospective analysis was conducted in SS3 by removing data systematically by year from all models for 10 years (Figure 5.27). There is a small positive retrospective bias as data are removed from the model for spawning biomass and recruitment. The Mohn's rho estimate associated with spawning biomass for model 16.4a (2020) was 0.04 and increased for all models with the updated 2022 data. The rho was 0.09, 0.11, and 0.1 for Models 16.4a, 16.4b, and 16.4c, respectively. All are within the accepted range following Hurtado-Ferro et al. (2014).

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean age-1 recruitment estimated for the period 1978-2020 gives a long-term average female spawning biomass of 23,676 t. The estimated 2023 female spawning biomass was at 33,554 t, which is above $B_{40\%}$ and above the estimate of $B_{35\%}$ (27,058 t). Because the projected spawning biomass in year 2023 (33,554 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 and ABC Recommendation

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 indicate that there was strong recruitment between 2007 and 2010 (Figure 5.8). There was also evidence of this recruitment event in the slope data in 2012 and 2016; however, there is little evidence of a strong recruitment event after 2010 (Figure 5.8). The expectation for the Eastern Bering Sea is continued warming which has been shown to be detrimental to Greenland turbot recruitment.

Year	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2023	3,960	3,960	4,645	33,554
2024	3,364	3,364	3,947	30,484

The 2023 estimated overfishing level based on the adjusted $F_{35\%}$ rate is 3,960 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.

Subarea Allocation

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:

	2023 ABC	2024 ABC
Aleutian Islands ABC	622	528
Eastern Bering Sea ABC	3,338	2,836
Total	3,960	3,364

Standard harvest scenarios and projections

A standard set of projections for population status under alternatives were conducted to comply with Amendment 56 of the FMP. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the 2022 numbers at age estimated in the assessment (age-1+). This vector is then projected forward to the beginning of 2023 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2022 (here assumed to be 1,468 t.). Since this fishery has not caught the TAC or ABC in several years a more realistic estimate of catch was used for 2023 as well. The preliminary catch for 2023 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2017-2021) and the 2022 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 of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2023, are as follow ("*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 F_{ABC}.

Scenario 3: In all future years, *F* is set equal to the 2017-2021 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: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$ (Rationale: This scenario provides a likely lower bound on FABC that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.).

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 expected to be above half of its B_{MSY} level in 2018 and above its B_{MSY} level in 2031 under this scenario, then the stock is not overfished.)

Scenario 7: In 2023 and 2024, F is set equal to max FABC, and in all subsequent years, F is set equal to FOFL. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2023 or 2) above 1/2 of its MSY level in 2023 and expected to be above its MSY level in 2035 under this scenario, then the stock is not approaching an overfished condition.)

Alternatives 1 through 7 were projected 14 years from 2022 (Table 5.24). SSB in 2023 and 2024 are above $B_{35\%}$; therefore, this stock is not considered to be approaching overfishing. Fishing at the maximum permissible rate (scenarios 1 and 2) indicate that the spawning stock will decline below $B_{35\%}$ by 2026.

Risk Table and ABC Recommendation

Overview

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

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e.,	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types

	uncertainty; strong retrospective bias.	recruitment patterns.	predators and prey of the stock)	
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

“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, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

“Assessment 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.

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

“Environmental/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.

“Fishery performance—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.”

Assessment considerations

The BSAI Greenland turbot assessment does not show a strong retrospective bias and fits to the data are seemingly adequate. However, two key uncertainties are still present in the model. First, uncertainty due to missing the EBS slope bottom trawl survey has been a consistent concern. The EBS slope survey was last conducted in 2016 when the 2007-2010 year classes were moving onto the slope. Therefore, there is some uncertainty about the adult portion of this stock on the slope.

Uncertainty in size at maturity is currently not accounted for in the assessment model. The current assessment uses a maturity relationship developed in the 1980s, and it is assumed that length at 50% maturity is 60 cm. The development of mature ovaries in Greenland turbot is unusual in that they simultaneously develop two cohorts of oocytes (Rideout *et al.* 2012). A larger, advanced cohort is for spawning within the year and a smaller developing cohort is for spawning the following year. Although fish with only a developing cohort are mature, updated maturity analyses have considered them "functionally immature" because they would not spawn within the year. Updated maturity ogives accounting for this has led to an increase in Greenland turbot length at 50% maturity in East Greenland (Kennedy *et al.* 2014). We conducted a sensitivity analysis where length at 50% maturity was assumed to be greater than the current assumption and set equal to 65 cm, 67 cm, and 70 cm. This range is based on the maturity estimates from Cooper *et al.* (2007). The results are summarized in Table 5.26 and Figure 5.29. As expected, an increase in length at 50% maturity resulted in a reduction in spawning stock biomass compared to the recommended model. The average reduction in SSB between 1978 and 2022 was 6%, 9% and 13% when assuming length at 50% maturity was 65cm, 67 cm, and 70 cm, respectively. Larger length at 50% maturity reduces the proportion of the population that is mature, which in turn would lead to a reduction in the biomass and fishing mortality reference points as compared to the projection results from the recommended model.

Given the unaccounted for uncertainties in the assessment model, we scored this category as Level 2.

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 have not been observed in the EBS shelf bottom trawl survey data since 2018.

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

Environmental/Ecosystem considerations

The extended warm phase experienced in the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022). Sea surface temperature (SST) was within one standard deviation of the long term average and marine heatwaves were relatively weak and short-lived compared to recent years. Estimates of bottom temperature derived from the ROMS model suggest that bottom temperatures in the northern Bering Sea (NBS) over the past year were within normal ranges while the southeastern Bering Sea (SEBS) was significantly cooler than average. The Bering Sea ice extent was generally higher than average throughout much of the 2021-2022 winter. Ice advanced rapidly in November, though there was an abrupt springtime retreat beginning in mid-April. These cool-to-normal winter conditions were favorable to cold pool formation, though not to the areal extent in the years preceding 2014 (Hennon et al., 2022).

Greenland turbot are considered to be more cold-adapted and distributed at greater depth than arrowtooth flounder and Kamchatka flounder. They are 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. Drastically reduced cold pool extents were observed in 2018, 2019, and 2021. The 2020 cold pool on the shelf was modeled (i.e., ROMS output) to be close to average in spatial extent and the 2022 cold pool (observed and modeled) was near the historical average and resembled other average-to-cool years, most similar to 2017 (Hennon et al., 2022). The 2022 cold pool extent indicates average conditions for juvenile recruitment based on a previously established positive correlation between the cold pool and juvenile recruitment (Barbeaux et al., 2016).

Prey:

Juvenile Greenland turbot likely feed on zooplankton. Zooplankton abundances (copepods and euphausiids) over the southeastern Bering Sea shelf were surveyed in spring and late-summer 2022. 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. Relative to the last cold period which ended in 2012, large copepod abundances were reduced, though abundances were increased from 2021. Small copepod numbers remained elevated compared to abundances during the cold period from 2006-2012 and were also increased from 2021. Euphausiid estimates remained low, as is common during the spring, and were decreased from 2021 (Kimmel et al., 2022).

The two predominant identified prey items of adult turbot are walleye pollock (presumably age-1) and squid. Observations of the 2021 pollock year-class are not available (no age-0 BASIS survey occurred). The 2022 age-0 pollock relative biomass estimates from the BASIS survey in the northeastern and southeastern regions of the Bering Sea are less than estimates during the recent warm period (2014-2018), and are slightly greater than the cold period from 2007-2013 (Andrews et al., 2022).

Condition factor has 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 the apex predator guild increased from 2021 to 2022 over the southeastern Bering Sea and is nearly equal to their long term mean. The trend in this guild is largely driven by Pacific cod and arrowtooth flounder, both of whom have increased from 2021 (Whitehouse, 2022). The increase in abundance of potential competitors (to their long-term mean) may be countered by spatial refuge as turbot prefer deeper habitats than arrowtooth and Kamchatka flounder, for example. 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. Fur seal abundance has been steadily declining, as measured by pup counts at St. Paul Island through 2021 (Siddon, 2022). Pacific cod abundance increased over the southern shelf from 2021 to 2022 (Whitehouse, 2022). Indirect evidence of killer whale presence in the Bering Sea is available based on depredation noted during the NOAA AFSC longline survey. While rates of depredation increased from 1997-2009, depredation interactions remained relatively consistent between 2009-2021 (Siwicke, pers. comm.). Taken together, trends in predator abundances would indicate no increased predation concern for turbot.

Summary for *Environmental/Ecosystem considerations:*

- Environment: The extended warm phase experienced by the eastern Bering Sea (EBS) that began in approximately 2014 has largely relaxed to normal conditions over the past year (August 2021 - August 2022).
- Recruitment: The 2022 cold pool extent indicates average conditions for juvenile recruitment based on a previously established positive correlation between the cold pool and juvenile recruitment.
- Prey: Indicators of prey availability suggest few clear concerns about prey abundance for Greenland turbot.

- Trends in potential competitors do not indicate substantially increased competition for habitat or prey resources.
- Trends in predator abundances would indicate no increased predation concern for turbot.

Together, the most recent data available suggest an ecosystem risk Level 1 – Normal: "No apparent environmental/ecosystem concerns."

Fishery performance

The fishery peaked in 1981 (Table 5.1). 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 relatively stable and quite low compared to 1970 and 1980s levels since 2013. Over this time TAC has been specified to be ~65% of ABC, on average, due to concerns about low future recruitment. Catch has been between 26% and 83% of the TAC since 2013. In 2021 only 26% of the TAC was caught. The longline fishery has not been fishing for Greenland turbot over the last several years due to whale interactions. Given that the fishery catch has remained relatively stable over the past 10 years or so and below TAC, we score this category as Level 1.

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 2	Level 2	Level 1	Level 1

A reduction in maximum ABC may be warranted given the uncertainty about length at 50% maturity in the assessment model and its direct impacts on the derivation of reference points, OFL, and ABC. The sensitivity analysis that was conducted provides a range of percent reduction estimates in SSB for three levels of assumed length at 50% maturity values that are higher than the assumed value in the recommended model. The range of percent reduction should be considered.

Status Determination

The *F* that would have produced a catch for last year equal to last year's OFL was 0.284.

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 (2021) is 1,582 t. This is less than the 2021 OFL of 8, 568 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 2022:

a. If spawning biomass for 2022 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
b. If spawning biomass for 2022 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2022 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 2024 is below ½ B35%, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2024 is above B35%, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2024 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 5.24 the stock is not being overfished and is not approaching an overfished condition. Spawning biomass in 2022 and 2024 are estimated to be 35,257t and 30,484 t, which are greater than $B_{35\%}$ = 27,058 t. Figure 5.28 shows the relationship between the ratio of historical fishing mortality and female spawning biomass for Greenland turbot from 1960-2022.

It should be noted that the 2007-2010 fully are vulnerable to the fishery. Given the fishery selectivities, the numbers-at-age and spawning biomass are expected to continue to decline in the absence of good recruitment in the future.

The Plan Team requested that the dynamic B_0 results from SS3 be reported in 2020. These results are summarized in Table 5.25. The results indicate that spawning biomass was at 41% of the expected unfished level in 1977. This declined to a low of 25% between 2004 and 2006, was relatively stable between 25% and 27% between 2007 and 2014 and has increased to 43% of the expected unfished level in 2022.

Ecosystem Effects

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 is 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 5.27. 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 follows arrowtooth and sablefish. The non-FMP bycatch are summarized in Table 5.28 and Table 5.29, bycatch of prohibited species by gear type are summarized in Table 5.30 and Table 5.31. 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 5.32). 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. These include:

- 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) are submitting a research proposal in 2022 to fund this study.
- Simplified selectivity time blocks,
- An evaluation of possible differential natural mortality between males and females
- Inclusion of a combined EBS slope bottom trawl survey and AFSC longline survey abundance index in the assessment model will be evaluated during the next full assessment.

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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 October 2022.

Year	Trawl	Longline & Pot	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
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*	1,445	24	1,468	6,572	6,572	-	-

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2022. 2022 numbers are estimates through October and are not final.

	Atka Mackerel		Flat		Greenland turbot		Halibut		KamArr		Pacific Cod		Pollock - bottom		Pollock - midwater		Rockfish		Sablefish	
Year	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained
1992													49	24					2121	196
1993	116	2	183	18	332	5687					108	161	12	7	66	0	87	572		
1994	13	32	235	27	368	6316							13	0					2305	195
1995	10	27	97	5	327	5093					284	145	37	0	57	1	25	362		
1996	88	129			173	3451					307	170	20	0			113	598	1026	200
1997	7	12	92	212	521	4709					283	270	19	0			19	202	619	129
1998	44	27	162	541					86	40	155	281	31	14	88	41	1	35		
1999	42	112	193	465	227	4009			76	131	50	180	2	2	11	15	2	25	120	179
2000	43	161	83	576	177	4798			93	262	109	130	9	1						
2001	21	50			89	2727			149	201	92	203	4	13	21	30			325	171
2002	10	94	59	76					158	225	137	210	32	8	8	22				
2003	48	87	18	68	44	1724	158	46	52	129	95	178	0	2	7	31			107	114
2004	41	82					62	20			83	220	0	0	9	9			30	78
2005	37	130					90	13			30	156		1	12	18				
2006	32	85			14	1198	10	53			32	66		1	14	50			69	62
2007	12	118	24	54	28	1207	15	5			91	128	0	2	36	68				
2008	82	119	16	95	3	944	10	1	414	762	69	16	2	11	20	52	1	142	87	42
2009	2	116	10	49	51	2490			285	1158	21	65					8	67		
2010	1	61	5	13	18	1932	66	1	80	1658	18	95					2	57		
2011	3	61			8	1806	30	0	17	1467	9	140	0	5	6	18	1	27	15	49
2012	7	203			14	1860	12	0	12	2269	9	103	0	6	17	31	3	17		
2013	2	38					25	1	208	635	5	12	1	3	5	12	10	49	33	26
2014	0	44					3	0	129	598			4	22	3	12				
2015	0	24			10	1051	19	0	24	846					5	30				
2016	1	45	6	59	17	1373	17	0	4	559			1	11	4	13				
2017	0	45			26	1875	1		10	506	45	110			1	6	0	37	9	
2018	5	23			8	1262	11		13	273	19	84	1	17	1	11				
2019	6	43			17	1808	1	0					0	18	3	15				12
2020	4	15	5	46	6	755	0	0	30	1078					8	21	15	150	1	10
2021	4	53	3	255	4	347			17	741					0	1				2
2022	1	23	9	329	12	278	4	0	18	572	17	0	0	22	0	0	3	72	6	91

Table 5.3. Estimates of Greenland turbot catch by area based on NMFS Regional Office estimates, 2005-2022. The 2022 values are estimates through October 2022.

Year	AI	BS
1991	3,465	4,398
1992	1,290	2,462
1993	2,137	6,332
1994	3,131	7,141
1995	2,339	5,856
1996	1,712	4,844
1997	764	6,435
1998	682	8,075
1999	467	5,386
2000	1,086	5,888
2001	1,060	4,253
2002	485	3,151
2003	700	2,412
2004	434	1,825
2005	468	2,140
2006	537	1,453
2007	523	1,481
2008	822	2,089
2009	2,263	2,252
2010	1,868	2,268
2011	535	3,136
2012	1,657	3,010
2013	294	1,434
2014	165	1,470
2015	105	2,082
2016	122	2,113
2017	122	2,711
2018	163	1,671
2019	174	2,686
2020	678	1,648
2021	467	1,130
2022	434	1,024

Table 5.4. Data sets used in the stock synthesis (SS3) model for Greenland Turbot in the EBS. All size and age data except for the AFSC longline survey are specified by sex. + Mean size-at-age data are used. * Used as ghost data.

Data source	**Data type**	**Years of data**
Trawl fisheries	Catch	1960-2022
	Size composition	1977-1987, 1989-1991, 1994-2006, 2008-2022
Longline fisheries	Catch	1960-2022
	Size composition	1979-1985, 1993-2020
Shelf Survey	Abundance Index	1987-2019, 2021-2022
	Size composition	1982-2019, 2021 - 2022
	Age composition⁺	1998, 2003-2019, 2021
Slope Survey	Abundance Index	2002, 2004, 2008, 2010, 2012, 2016
	Size composition	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, 2016
AFSC Longline survey	RPN index	1996-2022
	Size composition*	1979-2022

Table 5.5. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1991-2022. Source: NMFS observer program data. The % female do not include unidentified fish.

	Trawl				Longline			
Year	F	M	U	% Female	F	M	U	% 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	1122	1027	5956	52%	503	150	1200	77%
1995	245	363	4086	40%	1870	715	5630	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%	3833	2130	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	716	2184	1	25%	401	119	0	77%
2021	1483	2961	80	33%				
2022	565	943						

Table 5.6. Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1979-2019. The 1982-1985 shelf estimates were did not include survey areas 8 and 9 and therefore were not included in assessment models. The 1988 and 1991 slope estimates are from 200-800 m whereas the other slope estimates are from 200 - 1,000m. However only 2002 through 2016 slope survey index values are used in the stock assessment models. The Aleutian Islands surveys prior to 1990 used different operational protocols and may not compare well with ubsequent surveys, the Aleutian Islands survey is not used in the stock assessment model.

	Eastern Bering Sea		Aleutian Islands
Year	Shelf	Slope	Survey
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	27,028	9,891
2003	30,916		
2004	28,199	36,557	11,334
2005	21,230		
2006	20,858		20,934
2007	16,670		
2008	13,464	17,426	
2009	10,919		
2010	23,339	19,873	6,758
2011	26,095		
2012	21,733	17,922	2,600
2013	24,836		
2014	27,953		2,529
2015	25,176		
2016	22,357	23,573	2,378
2017	21,452		
2018	17,966		373
2019	16,008		
2021	10,690		
2022	7,869		512

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

Depth (m)	**2002**	**2004**	**2008**	**2010**	**2012**	**2016**
200-400	4,081	2,889	4,553	1,166	2,420	860
400-600	14,174	25,360	6,707	10,352	10,268	14,405
600-800	4,709	5,303	4,373	5,235	3,822	5,277
800-1000	2,189	1,800	1,487	2,041	1,018	1,279
1000-1200	1,959	1,206	781	1,079	456	1,752
Total	27,113	36,557	17,901	19,873	17,984	23,573

Depth (m)	**2002**	**2004**	**2008**	**2010**	**2012**	**2016**
200-400	993,994	745,401	1,740,599	421,257	3,374,545	339,322
400-600	3,668,882	4,885,557	1,913,410	3,428,133	7,055,925	6,378,043
600-800	1,070,165	998,631	1,196,717	1,330,889	1,089,539	1,558,064
800-1000	504,257	360,764	273,120	432,937	228,151	337,375
1000-1200	374,192	224,570	126,498	225,910	91,540	413,958
Total	6,611,490	7,214,922	5,250,344	5,839,126	11,839,700	9,026,762

Table 5.8. Eastern Bering Sea slope survey estimates of Greenland turbot biomass in numbers by stratum in 2002, 2004, 2008, 2010, 2012, and 2016 by depth category.

	Population biomass						Pop numbers (millions)					
Year	1	2	3	4	5	6	1	2	3	4	5	6
02	15,565	2,313	1,721	2,315	895	4,221	3.56	0.73	0.43	0.59	0.31	0.98
04	24,792	2,186	1,062	1,732	548	6,238	4.65	0.61	0.24	0.43	0.11	1.17
08	6,253	2,239	896	1,362	404	6,272	1.43	0.74	0.19	0.30	0.14	2.45
10	7,460	2,171	838	2,056	506	6,842	1.97	0.66	0.25	0.51	0.19	2.26
12	5,600	1,990	696	1,060	564	8,012	1.71	0.74	0.23	0.39	0.20	8.38
16	5,524	2,437	1,266	2,636	3,172	8,539	1.74	0.78	0.33	0.83	1.54	3.81

Table 5.9. EBS shelf survey biomass (t) and abundance (numbers) estimates and the corresponding standard deviations.

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

Table 5.10. 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	200	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	203			248	191
2019	376	113			153	109

Table 5.11. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot a) numbers and b) biomass (t), 1980-2022.

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

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

Table 5.12. 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

Table 5.13 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.

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
Age	**1982**	**1998**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	20	3	3	1	0	0	18	16	6	38	9	17	11	0	0
2	33	18	30	5	1	3	4	17	41	54	76	40	30	3	11
3	33	7	37	29	10	3	1	8	29	22	33	49	16	10	12
4	38	1	16	10	38	2	2	2	10	7	16	31	24	10	23
5	14	2	24	21	31	11	17	2	2	2	17	23	41	30	28
6	9	0	3	7	13	16	17	1	0	1	6	13	20	25	22
7	4	0	3	3	9	25	18	7	3	1	2	5	18	38	30
8	0	0	6	1	6	19	15	4	1	0	1	2	9	23	23
9	0	0	2	0	1	10	12	4	9	0	2	0	2	12	12
10	0	5	1	4	2	3	6	7	4	4	2	2	0	4	9
11	0	5	2	2	1	1	1	4	4	4	3	3	1	3	2
12	0	3	3	4	3	6	3	2	0	8	0	1	0	3	3
13	0	0	3	5	1	2	7	3	2	2	4	1	3	1	4
14	0	1	5	5	3	1	0	0	2	4	0	1	1	0	0
15	0	0	1	6	2	2	3	2	0	0	1	0	0	3	2
16	0	2	5	4	0	3	1	2	0	1	0	0	0	1	0
17	0	1	7	6	2	4	4	3	0	0	0	2	0	0	1
18	0	0	6	3	3	3	1	3	0	1	1	2	1	0	0
19	0	0	6	2	5	5	3	1	1	0	0	0	0	1	1
20	0	3	9	2	5	6	3	1	2	0	1	1	1	1	0
21	0	1	5	3	2	2	3	1	3	0	2	0	0	0	0
22	0	0	4	0	1	2	0	2	1	2	0	0	1	1	0
23	0	1	6	2	1	1	1	0	4	2	0	1	0	3	0
24	0	2	5	1	2	0	0	1	1	0	0	1	0	0	1
25	0	2	3	3	4	2	0	2	2	0	1	0	1	0	0
26	0	1	3	2	2	0	3	0	1	1	0	0	1	2	1
27	0	0	3	3	0	0	0	0	2	0	3	2	0	0	0
28	0	0	4	1	0	0	0	1	3	0	0	0	0	3	0
29	0	0	4	0	0	0	1	3	0	1	1	0	0	0	0
30	0	0	5	0	1	1	1	1	4	3	1	0	1	4	1

Table 5.13 continued.

Age	**2016**	**2017**	**2018**	**2019**	**2021**
1	14.3	0.0	0.0	0.0	0.0
2	19.0	0.0	25.0	0.0	0.0
3	30.2	26.7	31.5	0.0	0.0
4	36.0	35.6	36.2	0.0	0.0
5	44.6	40.9	39.4	44.0	42.0
6	51.6	44.1	52.8	47.7	0.0
7	55.9	50.4	59.3	61.0	51.0
8	60.9	59.0	61.4	64.0	56.0
9	59.5	62.9	66.3	70.9	61.0
10	63.9	65.8	66.9	71.1	72.1
11	65.8	63.6	71.5	74.5	74.2
12	62.7	69.6	72.7	75.3	75.3
13	67.5	73.5	80.0	74.5	78.6
14	75.7	72.5	74.0	0.0	79.8
15	0.0	82.0	84.0	0.0	83.0
16	83.0	67.0	0.0	70.0	82.5
17	81.0	82.3	0.0	0.0	82.0
18	0.0	91.0	85.7	85.0	0.0
19	0.0	0.0	0.0	92.0	76.0
20	81.0	0.0	0.0	0.0	0.0
21	0.0	85.0	0.0	0.0	0.0
22	88.0	0.0	0.0	0.0	0.0
23	89.0	73.0	0.0	0.0	0.0
24	0.0	94.0	97.0	0.0	0.0
25	87.0	0.0	0.0	0.0	0.0
26	0.0	0.0	100.0	0.0	92.0
27	0.0	0.0	0.0	0.0	0.0
28	99.5	0.0	0.0	0.0	0.0
29	92.0	0.0	0.0	0.0	0.0
30	95.0	0.0	0.0	0.0	90.0

Age	**2016**	**2017**	**2018**	**2019**	**2021**
1	6	0	0	0	0
2	3	0	1	0	0
3	14	3	2	0	0
4	8	7	6	0	0
5	16	9	7	1	2
6	18	9	6	3	0
7	23	7	4	7	1
8	23	13	7	3	8
9	8	15	25	13	1
10	15	24	29	11	8
11	8	13	16	21	16
12	3	10	3	8	19
13	2	2	1	2	8
14	3	4	1	0	4
15	0	3	1	0	1
16	3	1	0	1	2
17	1	3	0	0	1
18	0	1	3	1	0
19	0	0	0	1	1
20	1	0	0	0	0
21	0	1	0	0	0
22	1	0	0	0	0
23	1	1	0	0	0
24	0	1	1	0	0
25	1	0	0	0	0
26	0	0	1	0	1
27	0	0	0	0	0
28	2	0	0	0	0
29	1	0	0	0	0
30	1	0	0	0	1

Table 5.14. 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.

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	13.5	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
Age	**1982**	**1998**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	23	0	3	4	2	2	26	21	12	48	21	22	7	2	1
2	43	19	34	9	2	1	8	36	73	57	90	44	30	6	27
3	30	11	38	40	16	0	6	11	47	27	44	60	17	17	22
4	31	5	18	18	35	2	4	4	11	14	15	25	35	10	15
5	10	2	27	20	27	16	15	4	1	4	9	23	41	17	22
6	3	1	9	15	10	20	22	2	2	1	3	7	21	35	34
7	1	0	10	10	5	15	23	3	1	0	0	3	13	23	20
8	0	1	5	1	6	16	15	9	4	2	2	0	2	18	12
9	0	1	2	4	1	11	4	7	3	1	1	0	2	9	4
10	0	3	5	4	1	4	3	3	2	0	0	1	0	3	2
11	0	0	2	0	3	4	4	1	0	0	1	0	0	0	1
12	0	4	1	5	0	1	0	0	0	1	2	0	0	0	1
13	0	4	1	3	2	0	0	0	0	2	0	1	0	1	0
14	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0
15	0	2	0	2	1	1	0	1	0	0	0	0	0	0	0
16	0	0	2	2	4	2	1	1	0	0	0	0	0	0	0
17	0	3	1	1	1	1	4	0	0	0	1	0	0	1	0
18	0	0	1	3	1	1	2	1	0	0	0	0	0	0	0
19	0	2	1	1	3	1	0	0	2	0	1	0	0	0	0
20	0	0	2	2	1	1	0	1	1	0	1	1	0	0	0
21	0	0	2	0	0	0	2	1	1	1	0	0	0	0	0
22	0	0	2	0	0	1	1	1	2	1	0	0	0	0	0
23	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1
24	0	2	3	0	1	1	1	0	0	1	0	0	0	0	2
25	0	0	2	0	2	2	1	0	1	0	0	0	0	0	0
26	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0
27	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0
28	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
29	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1
30	0	2	0	0	0	0	1	0	4	0	0	2	0	0	0

Table 5.14. continued.

Age	**2016**	**2017**	**2018**	**2019**	**2021**
1	13.0	15.0	15.3	0.0	0.0
2	18.8	24.0	23.0	0.0	0.0
3	30.6	29.0	28.0	0.0	0.0
4	38.5	37.5	36.7	0.0	39.0
5	45.3	38.2	43.0	39.0	0.0
6	50.7	42.4	45.3	48.7	0.0
7	54.3	47.4	52.9	55.9	54.0
8	56.3	55.8	60.3	61.8	57.0
9	57.2	58.2	62.9	63.5	61.0
10	55.0	61.6	63.0	68.5	67.0
11	58.8	57.5	69.3	62.0	71.0
12	62.0	60.0	61.0	78.5	0.0
13	0.0	58.0	61.0	0.0	0.0
14	0.0	59.0	78.0	68.0	0.0
15	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	74.0
18	0.0	83.0	72.0	0.0	0.0
19	0.0	0.0	0.0	0.0	70.0
20	79.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	82.0
23	0.0	77.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	80.0
25	77.0	0.0	0.0	73.0	78.0
26	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0
30	83.0	75.0	0.0	0.0	0.0

Age	**2016**	**2017**	**2018**	**2019**	**2021**
1	6	1	3	0	0
2	9	4	1	0	0
3	23	6	1	0	0
4	21	6	3	0	1
5	12	5	7	1	0
6	19	11	12	6	0
7	21	7	9	12	1
8	12	12	17	4	3
9	13	13	11	4	4
10	5	11	6	2	3
11	6	6	3	3	1
12	1	3	1	2	0
13	0	1	1	0	0
14	0	1	1	1	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	1
18	0	1	1	0	0
19	0	0	0	0	1
20	1	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	1
23	0	1	0	0	0
24	0	0	0	0	1
25	1	0	0	2	1
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	1	1	0	0	0

Table 5.15. Starting multinomial sample sizes for size composition data by fishery and survey for all models

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						200	200	200	200	200	200	200	200
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	200	200	200	200	200	200	200	200	200	200	200	200	200
Slope													400

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	200	200	200	200	200	200	200	200	200	200	200	200	200
Slope		400				400		400		400			

Year	2016	2017	2018	2019	2020	2021	2022
Trawl	50	50	50	50	50	50	50
Longline	50	50	50	50	50	50	50
Shelf	200	200	200	200	200	200	200
Slope	400						

Table 5.16. Model a) total likelihoods and c) likelihood components.

a)

	16.4a (2020)		16.4a (2022)		16.4b		16.4c	
Component	Likelihood	Gradient	Likelihood	Gradient	Likelihood	Gradient	Likelihood	Gradient
Total	2275.83	3e-4	2626.28	0	2878.05	0	3550.58	0
Catch	4.05E-12		7.11e-12		8.93e-11		3.21e-11	
Survey	-7.6		5.28081		10.86		-5.59	
Length comp	784.3		880.841		1115.29		1167.78	
Size at age	1372.4		1623.58		1635.43		2250.46	
Recruitment	108.72				95.32		96.85	

b)

Model	16.4a (2020)				
Fleet/Survey	Trawl	Longline	Shelf	Slope	ABL LL
Likelihood					
Catch	3.97E-12	7.64E-14	0	0	0
Survey	0	0	-34.7	-4.07	31.1
Length comp	121.7	76.4	348.3	237.9	0
Size at age	0	0	1372.4	0	0
	16.4a (2022)				
Catch	7.00e-12	1.019e-13	0	0	0
Survey	0	0	-24.41	-5.05	34.74
Length comp	129.7	78.05	409.91	263.61	0
Size at age	0	0	1623.58	0	0
	16.4b				
Catch	8.92e-11	9.38e-14	0	0	0
Survey	0	0	-23.60	-6.78	41.24
Length comp	131.78	77.39	401.60	269.03	235.50
Size at age	0	0	1635.43	0	0
	16.4c				
Catch	3.20e-11	1.02e-13	0	0	0
Survey	0	0	-21.958	-5.83	22.1983
Length comp	129.5	78.54	418.84	312.80	228.113
Size at age	0	0	1672.55	577.91	

Table 5.17. Model index RMSE, tuning diagnostics, and recruitment variability for candidate models.

		16.4a (2020)	16.4a (2022)	16.4b	16.4c
Retrospective					
Mohn's ρ	SSB	0.04	0.09	0.11	0.10
	Recruitment	6.17	10.1	9.43	9.0
	Fishing mortality	-0.12	-0.15	-0.16	-0.13
Index RMSE					
	Shelf	0.207	0.250	0.254	0.264
	Slope	0.204	0.192	0.175	0.185
	AFSC LL	0.474	0.477	0.497	0.438
Size Comp					
Har. Mean EffN					
	Trawl	35.49	35.10	34.25	35.65
	Longline	79.40	82.584	84.03	86.90
	Shelf	39.49	33.65	34.40	33.03
	Slope	45.86	39.81	40.56	39.34
	AFCS LL			27.97	28.60
Mean input N					
	Trawl	12.5	12.5	12.5	12.5
	Longline	25	25	25	25
	Shelf	50	50	50	50
	Slope	106.25	106.25	106.25	106.25
	AFSC LL			30	30

Table 5.18. Key parameter estimates and estimated standard deviations.

	16.4a (2020)		16.4a (2022)		16.4b		16.4c	
Label	Value	Stdev	Value	Stdev	Value	Stdev	Value	Stdev
Biology								
L Amin female	14.92		15.88	0.147	15.85	0.15	15.92	0.142
L Amax female	90.34		91.50	0.390	89.90	0.334	89.13	0.274
von Bert k female	0.11		0.11	0.002	0.11	0.002	0.110	0.002
L Amin male	14.06		15.21	0.135	15.21	0.130	15.31	0.128
L Amax male	71.70		72.13	0.33	71.92	0.320	70.75	0.263
von Bert k male	0.19		0.18	0.003	0.18	0.003	0.179	0.003
Recruitment								
LN(R0)	9.13		8.91	0.183	8.91	0.178	8.86	0.182
steepness	0.79	-	0.79	-	0.79	-	0.79	-
σ_R	0.60		0.60	-	0.60	-	0.60	-
SR_autocorr	0.63		0.71	0.029	0.70	0.030	0.71	0.030
Catchability								
Shelf LN(q)	-0.49	-	-0.49	-	-0.49	-	-0.49	-
Slope LN(q)	-0.56	-	-0.56	-	-0.56	-	-0.56	-
ABL Longline LN(q)	0.79		0.74	0.073	0.73	0.076	0.75	0.085

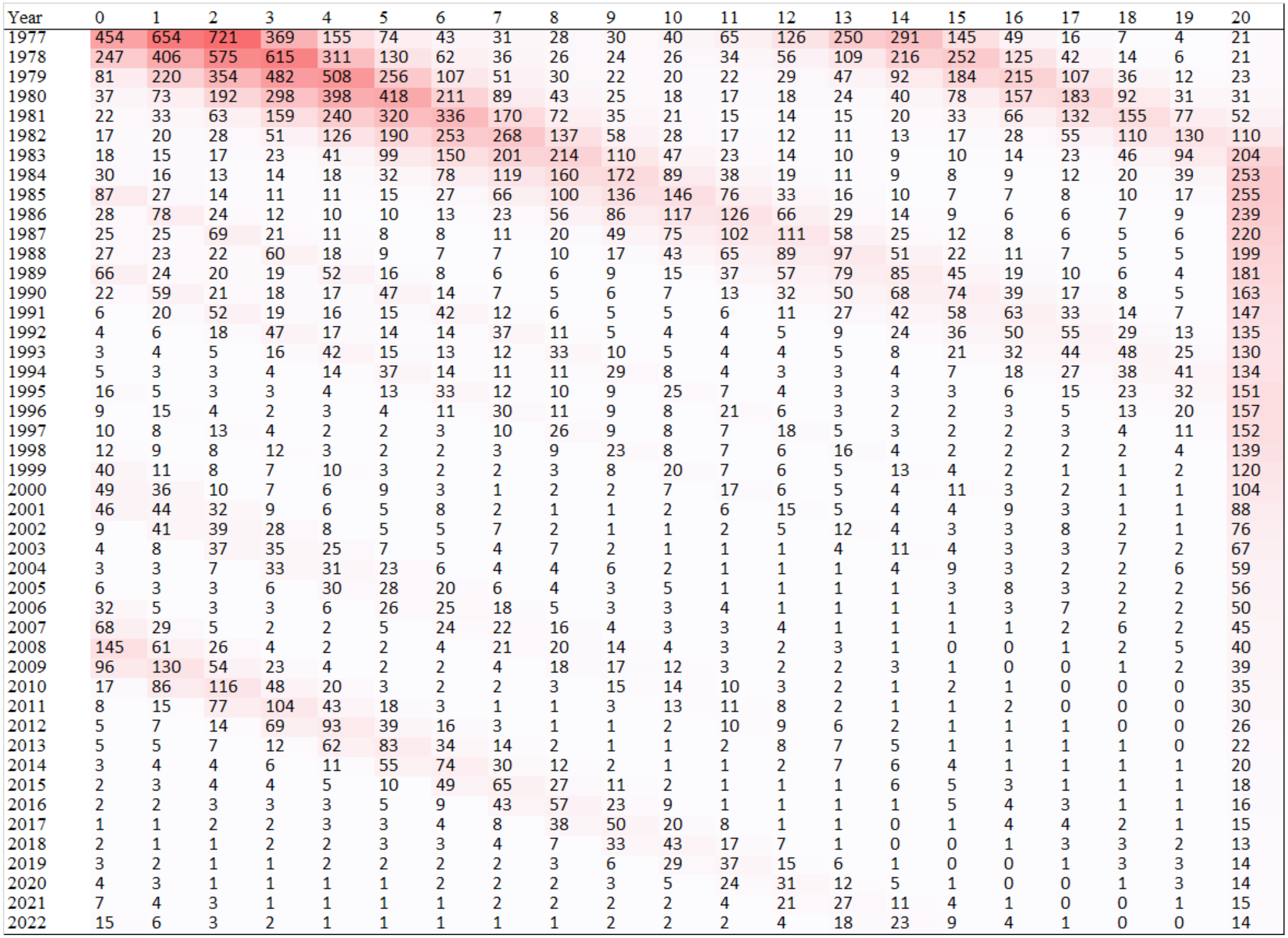
Table 5.19. Spawning and total biomass, Age-0 recruits, fishing mortality, exploitation rate, and estimates of 1-SPR for BSAI Greenland turbot, 1960-2020 for models 16.4c and 16.4a (2020).

	16.4(2020)					16.4c				
Year	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR
1960	111248	32438	0.18	0.12	0.86	78470	102939	0.22	0.15	0.91
1961	107000	48406	0.32	0.2	0.96	74788	191342	0.40	0.25	0.98
1962	94558	86664	0.42	0.25	0.98	64693	377743	0.50	0.31	0.99
1963	78620	184864	0.29	0.17	0.95	52761	570494	0.29	0.20	0.95
1964	69323	383089	0.35	0.21	0.97	47533	408690	0.26	0.19	0.94
1965	58791	424147	0.1	0.07	0.67	43653	182298	0.05	0.04	0.44
1966	56197	231398	0.09	0.07	0.64	45434	82766	0.04	0.04	0.37
1967	54458	108699	0.1	0.09	0.7	51028	44902	0.05	0.05	0.43
1968	54235	58807	0.1	0.1	0.69	65205	29823	0.05	0.05	0.46
1969	58831	39037	0.08	0.07	0.59	95752	23940	0.04	0.04	0.41
1970	74201	32273	0.05	0.04	0.41	148908	22917	0.03	0.03	0.29
1971	107167	32891	0.08	0.08	0.62	223474	26232	0.06	0.05	0.49
1972	153297	41351	0.15	0.12	0.8	300401	36389	0.10	0.08	0.70
1973	196930	65614	0.12	0.1	0.76	356976	61265	0.09	0.07	0.65
1974	236434	127860	0.16	0.13	0.84	398380	116907	0.12	0.09	0.75
1975	257040	227332	0.16	0.12	0.83	413010	186765	0.12	0.08	0.74
1976	265413	161443	0.16	0.11	0.83	413088	146396	0.12	0.08	0.75
1977	262630	105778	0.08	0.06	0.61	401162	90885	0.06	0.04	0.52
1978	264568	58484	0.12	0.08	0.72	394337	49320	0.09	0.06	0.64
1979	256717	20148	0.12	0.08	0.71	376617	16252	0.10	0.06	0.64
1980	248476	6969	0.15	0.1	0.78	358019	7321	0.13	0.08	0.73
1981	239487	1164	0.17	0.11	0.81	337481	4363	0.14	0.09	0.78
1982	233940	2119	0.14	0.1	0.8	319578	3410	0.13	0.08	0.77
1983	234918	3480	0.14	0.1	0.79	308543	3640	0.13	0.08	0.77
1984	236369	6698	0.07	0.05	0.57	299019	5997	0.07	0.04	0.55
1985	243465	22414	0.05	0.03	0.44	296954	17440	0.05	0.03	0.43
1986	249279	5789	0.03	0.02	0.34	294963	5573	0.03	0.02	0.33
1987	251811	6158	0.04	0.02	0.35	290990	5085	0.03	0.02	0.34
1988	249159	6336	0.03	0.02	0.29	283003	5356	0.03	0.02	0.28
1989	243145	16992	0.05	0.02	0.28	272640	13114	0.05	0.02	0.28
1990	231378	4188	0.08	0.03	0.41	257166	4483	0.07	0.03	0.41
1991	215029	1196	0.06	0.02	0.31	237554	1246	0.05	0.02	0.31
1992	201287	762	0.03	0.01	0.15	220818	785	0.02	0.01	0.15
1993	190065	600	0.06	0.03	0.31	206789	642	0.06	0.03	0.31
1994	175048	934	0.1	0.12	0.44	188689	1011	0.09	0.04	0.44

Table 5.19. Continued. Spawning and total biomass, Age-0 recruits, fishing mortality, exploitation rate, and estimates of 1-SPR for BSAI Greenland turbot, 1960-2020 for models 16.4a (2020) and 16.4c.

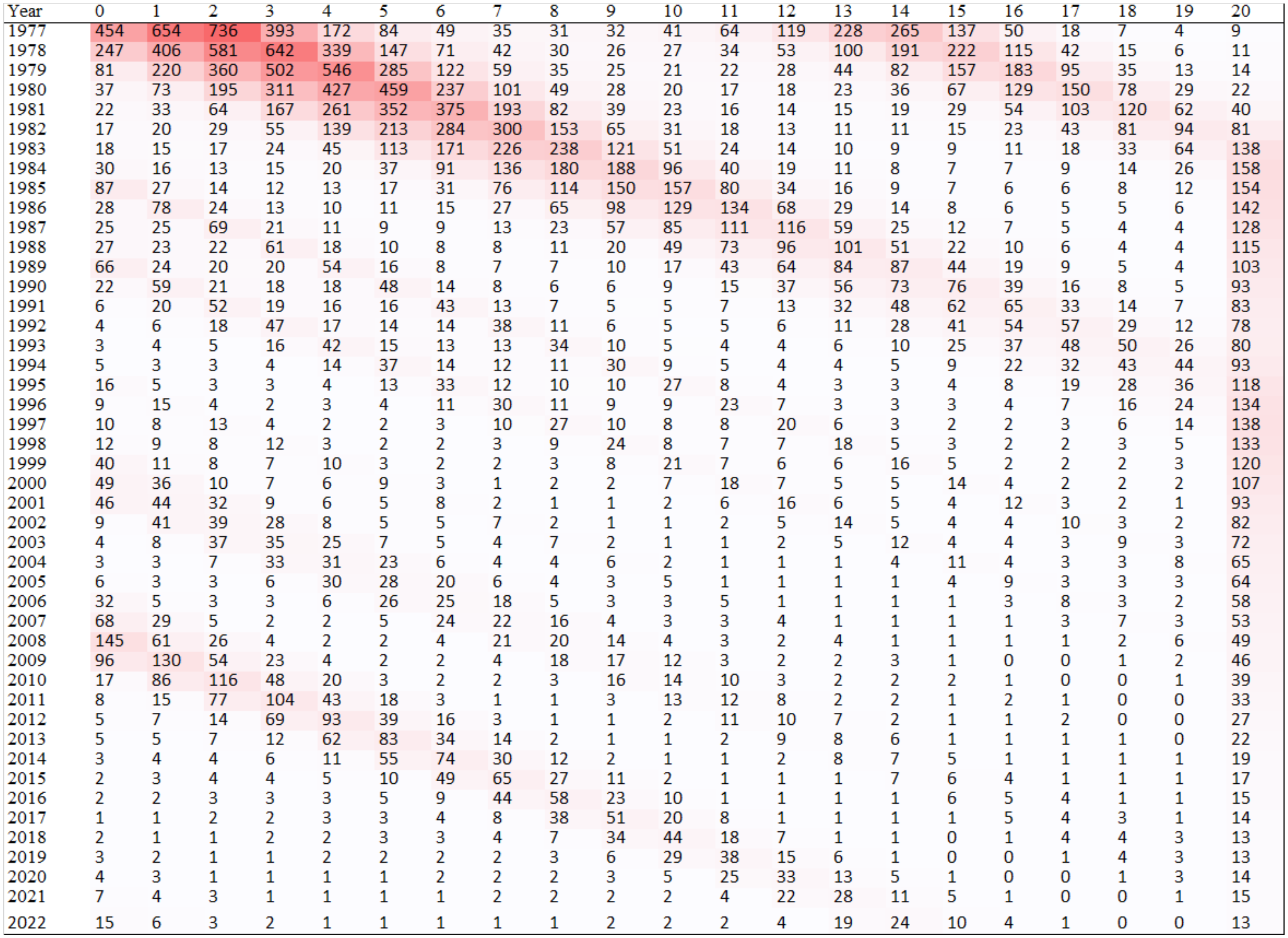
	16.4 (2020)					16.4c				
Year	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR
1995	160134	3785	0.08	0.04	0.34	170672	3257	0.08	0.03	0.39
1996	146988	1653	0.07	0.03	0.37	154794	1894	0.06	0.03	0.34
1997	135207	1632	0.08	0.03	0.45	140685	1924	0.08	0.03	0.37
1998	123080	2095	0.11	0.03	0.39	126606	2455	0.11	0.05	0.45
1999	109919	8208	0.08	0.05	0.46	111859	7950	0.08	0.03	0.40
2000	99430	9512	0.11	0.03	0.44	100265	9844	0.11	0.05	0.47
2001	88200	11705	0.1	0.04	0.36	88184	9269	0.10	0.04	0.45
2002	78824	1714	0.07	0.04	0.35	78218	1744	0.07	0.03	0.37
2003	71013	600	0.07	0.03	0.3	70005	733	0.07	0.03	0.36
2004	64103	492	0.06	0.03	0.35	62827	646	0.06	0.02	0.31
2005	58455	695	0.07	0.02	0.3	56995	1180	0.07	0.03	0.36
2006	53287	6119	0.06	0.03	0.31	51645	6403	0.06	0.02	0.31
2007	49612	18415	0.06	0.02	0.44	47718	13539	0.06	0.02	0.33
2008	46914	42573	0.11	0.02	0.58	44684	29035	0.11	0.04	0.47
2009	44804	26270	0.17	0.03	0.58	42182	19290	0.17	0.06	0.62
2010	41852	4557	0.18	0.06	0.57	38898	3392	0.18	0.06	0.61
2011	38477	3134	0.17	0.06	0.67	35385	1658	0.18	0.05	0.60
2012	35194	1201	0.24	0.05	0.37	32072	1071	0.24	0.07	0.70
2013	32020	1129	0.09	0.06	0.32	28711	957	0.09	0.03	0.41
2014	32201	909	0.07	0.02	0.35	28135	684	0.08	0.02	0.38
2015	34940	1066	0.08	0.02	0.3	29176	485	0.10	0.03	0.43
2016	39500	1136	0.06	0.02	0.3	31274	317	0.09	0.03	0.39
2017	44725	1347	0.06	0.02	0.18	33907	293	0.09	0.04	0.41
2018	48898	2162	0.03	0.03	0.27	35856	337	0.05	0.03	0.27
2019	52010	4997	0.06	0.02	0.33	37352	665	0.08	0.04	0.38
2020	52902	6838	0.07	0.03	0.34	37204	851	0.07	0.04	0.35
2021	-	-	-	-	-	36380	1359	0.05	0.03	0.28
2022	-	-	-	-	-	35257	3028	0.05	0.03	0.29

Table 5.20. Estimated beginning of year numbers (1×10^5) of female Greenland turbot by age for Model 16.4c.



Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	454	654	721	369	155	74	43	31	28	30	40	65	126	250	291	145	49	16	7	4	21
1978	247	406	575	615	311	130	62	36	26	24	26	34	56	109	216	252	125	42	14	6	21
1979	81	220	354	482	508	256	107	51	30	22	20	22	29	47	92	184	215	107	36	12	23
1980	37	73	192	298	398	418	211	89	43	25	18	17	18	24	40	78	157	183	92	31	31
1981	22	33	63	159	240	320	336	170	72	35	21	15	14	15	20	33	66	132	155	77	52
1982	17	20	28	51	126	190	253	268	137	58	28	17	12	11	13	17	28	55	110	130	110
1983	18	15	17	23	41	99	150	201	214	110	47	23	14	10	9	10	14	23	46	94	204
1984	30	16	13	14	18	32	78	119	160	172	89	38	19	11	9	8	9	12	20	39	253
1985	87	27	14	11	11	15	27	66	100	136	146	76	33	16	10	7	7	8	10	17	255
1986	28	78	24	12	10	10	13	23	56	86	117	126	66	29	14	9	6	6	7	9	239
1987	25	25	69	21	11	8	8	11	20	49	75	102	111	58	25	12	8	6	5	6	220
1988	27	23	22	60	18	9	7	7	10	17	43	65	89	97	51	22	11	7	5	5	199
1989	66	24	20	19	52	16	8	6	6	9	15	37	57	79	85	45	19	10	6	4	181
1990	22	59	21	18	17	47	14	7	5	6	7	13	32	50	68	74	39	17	8	5	163
1991	6	20	52	19	16	15	42	12	6	5	5	6	11	27	42	58	63	33	14	7	147
1992	4	6	18	47	17	14	14	37	11	5	4	4	5	9	24	36	50	55	29	13	135
1993	3	4	5	16	42	15	13	12	33	10	5	4	4	5	8	21	32	44	48	25	130
1994	5	3	3	4	14	37	14	11	11	29	8	4	3	3	4	7	18	27	38	41	134
1995	16	5	3	3	4	13	33	12	10	9	25	7	4	3	3	3	6	15	23	32	151
1996	9	15	4	2	3	4	11	30	11	9	8	21	6	3	2	2	3	5	13	20	157
1997	10	8	13	4	2	2	3	10	26	9	8	7	18	5	3	2	2	3	4	11	152
1998	12	9	8	12	3	2	2	3	9	23	8	7	6	16	4	2	2	2	2	4	139
1999	40	11	8	7	10	3	2	2	3	8	20	7	6	5	13	4	2	1	1	2	120
2000	49	36	10	7	6	9	3	1	2	2	7	17	6	5	4	11	3	2	1	1	104
2001	46	44	32	9	6	5	8	2	1	1	2	6	15	5	4	4	9	3	1	1	88
2002	9	41	39	28	8	5	5	7	2	1	1	2	5	12	4	3	3	8	2	1	76
2003	4	8	37	35	25	7	5	4	7	2	1	1	1	4	11	4	3	3	7	2	67
2004	3	3	7	33	31	23	6	4	4	6	2	1	1	1	4	9	3	2	2	6	59
2005	6	3	3	6	30	28	20	6	4	3	5	1	1	1	1	3	8	3	2	2	56
2006	32	5	3	3	6	26	25	18	5	3	3	4	1	1	1	1	3	7	2	2	50
2007	68	29	5	2	2	5	24	22	16	4	3	3	4	1	1	1	1	2	6	2	45
2008	145	61	26	4	2	2	4	21	20	14	4	3	2	3	1	0	0	1	2	5	40
2009	96	130	54	23	4	2	2	4	18	17	12	3	2	2	3	1	0	0	1	2	39
2010	17	86	116	48	20	3	2	2	3	15	14	10	3	2	1	2	1	0	0	0	35
2011	8	15	77	104	43	18	3	1	1	3	13	11	8	2	1	1	2	0	0	0	30
2012	5	7	14	69	93	39	16	3	1	1	2	10	9	6	2	1	1	1	0	0	26
2013	5	5	7	12	62	83	34	14	2	1	1	2	8	7	5	1	1	1	1	0	22
2014	3	4	4	6	11	55	74	30	12	2	1	1	2	7	6	4	1	1	1	1	20
2015	2	3	4	4	5	10	49	65	27	11	2	1	1	1	6	5	3	1	1	1	18
2016	2	2	3	3	3	5	9	43	57	23	9	1	1	1	1	5	4	3	1	1	16
2017	1	1	2	2	3	3	4	8	38	50	20	8	1	1	0	1	4	4	2	1	15
2018	2	1	1	2	2	3	3	4	7	33	43	17	7	1	0	0	1	3	3	2	13
2019	3	2	1	1	2	2	2	2	3	6	29	37	15	6	1	0	0	1	3	3	14
2020	4	3	1	1	1	1	2	2	2	3	5	24	31	12	5	1	0	0	1	3	14
2021	7	4	3	1	1	1	1	2	2	2	2	4	21	27	11	4	1	0	0	1	15
2022	15	6	3	2	1	1	1	1	1	2	2	2	4	18	23	9	4	1	0	0	14

Table 5.20. Continued. Estimated beginning of year numbers (1×10^5) of male Greenland turbot by age for Model 16.4c.



Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	454	654	736	393	172	84	49	35	31	32	41	64	119	228	265	137	50	18	7	4	9
1978	247	406	581	642	339	147	71	42	30	26	27	34	53	100	191	222	115	42	15	6	11
1979	81	220	360	502	546	285	122	59	35	25	21	22	28	44	82	157	183	95	35	13	14
1980	37	73	195	311	427	459	237	101	49	28	20	17	18	23	36	67	129	150	78	29	22
1981	22	33	64	167	261	352	375	193	82	39	23	16	14	15	19	29	54	103	120	62	40
1982	17	20	29	55	139	213	284	300	153	65	31	18	13	11	11	15	23	43	81	94	81
1983	18	15	17	24	45	113	171	226	238	121	51	24	14	10	9	9	11	18	33	64	138
1984	30	16	13	15	20	37	91	136	180	188	96	40	19	11	8	7	7	9	14	26	158
1985	87	27	14	12	13	17	31	76	114	150	157	80	34	16	9	7	6	6	8	12	154
1986	28	78	24	13	10	11	15	27	65	98	129	134	68	29	14	8	6	5	5	6	142
1987	25	25	69	21	11	9	9	13	23	57	85	111	116	59	25	12	7	5	4	4	128
1988	27	23	22	61	18	10	8	8	11	20	49	73	96	101	51	22	10	6	4	4	115
1989	66	24	20	20	54	16	8	7	7	10	17	43	64	84	87	44	19	9	5	4	103
1990	22	59	21	18	18	48	14	8	6	6	9	15	37	56	73	76	39	16	8	5	93
1991	6	20	52	19	16	16	43	13	7	5	5	7	13	32	48	62	65	33	14	7	83
1992	4	6	18	47	17	14	14	38	11	6	5	5	6	11	28	41	54	57	29	12	78
1993	3	4	5	16	42	15	13	13	34	10	5	4	4	6	10	25	37	48	50	26	80
1994	5	3	3	4	14	37	14	12	11	30	9	5	4	4	5	9	22	32	43	44	93
1995	16	5	3	3	4	13	33	12	10	10	27	8	4	3	3	4	8	19	28	36	118
1996	9	15	4	2	3	4	11	30	11	9	9	23	7	3	3	3	4	7	16	24	134
1997	10	8	13	4	2	2	3	10	27	10	8	8	20	6	3	2	2	3	6	14	138
1998	12	9	8	12	3	2	2	3	9	24	8	7	7	18	5	3	2	2	3	5	133
1999	40	11	8	7	10	3	2	2	3	8	21	7	6	6	16	5	2	2	2	3	120
2000	49	36	10	7	6	9	3	1	2	2	7	18	7	5	5	14	4	2	2	2	107
2001	46	44	32	9	6	5	8	2	1	1	2	6	16	6	5	4	12	3	2	1	93
2002	9	41	39	28	8	5	5	7	2	1	1	2	5	14	5	4	4	10	3	2	82
2003	4	8	37	35	25	7	5	4	7	2	1	1	2	5	12	4	4	3	9	3	72
2004	3	3	7	33	31	23	6	4	4	6	2	1	1	1	4	11	4	3	3	8	65
2005	6	3	3	6	30	28	20	6	4	3	5	1	1	1	1	4	9	3	3	3	64
2006	32	5	3	3	6	26	25	18	5	3	3	5	1	1	1	1	3	8	3	2	58
2007	68	29	5	2	2	5	24	22	16	4	3	3	4	1	1	1	1	3	7	3	53
2008	145	61	26	4	2	2	4	21	20	14	4	3	2	4	1	1	1	1	2	6	49
2009	96	130	54	23	4	2	2	4	18	17	12	3	2	2	3	1	0	0	1	2	46
2010	17	86	116	48	20	3	2	2	3	16	14	10	3	2	2	2	1	0	0	1	39
2011	8	15	77	104	43	18	3	1	1	3	13	12	8	2	2	1	2	1	0	0	33
2012	5	7	14	69	93	39	16	3	1	1	2	11	10	7	2	1	1	2	0	0	27
2013	5	5	7	12	62	83	34	14	2	1	1	2	9	8	6	1	1	1	1	0	22
2014	3	4	4	6	11	55	74	30	12	2	1	1	2	8	7	5	1	1	1	1	19
2015	2	3	4	4	5	10	49	65	27	11	2	1	1	1	7	6	4	1	1	1	17
2016	2	2	3	3	3	5	9	44	58	23	10	1	1	1	1	6	5	4	1	1	15
2017	1	1	2	2	3	3	4	8	38	51	20	8	1	1	1	1	5	4	3	1	14
2018	2	1	1	2	2	3	3	4	7	34	44	18	7	1	1	0	1	4	4	3	13
2019	3	2	1	1	2	2	2	2	3	6	29	38	15	6	1	0	0	1	4	3	13
2020	4	3	1	1	1	1	2	2	2	3	5	25	33	13	5	1	0	0	1	3	14
2021	7	4	3	1	1	1	1	2	2	2	2	4	22	28	11	5	1	0	0	1	15
2022	15	6	3	2	1	1	1	1	1	2	2	2	4	19	24	10	4	1	0	0	13

Table 5.21. Spawning and total biomass compared with the 2020 assessment and fishing mortality, exploitation rate, and 1-SPR from the current assessment for BSAI Greenland turbot, 1977-2022. The 2023 and 2024 biomass estimates are from the Model 16.4c projections. The projections assume catch in 2021 and 2022 is equal to maximum ABC.

	SSB (t)		Total biomass (age1+)				
Year	2020	Current	2020	Current	Apical F	Exploitation rate	1-SPR
1977	262,630	398,380	517,074	722,445	0.06	0.04	0.52
1978	264,568	413,010	526,469	712,367	0.09	0.06	0.64
1979	256,717	413,088	532,363	696,237	0.10	0.06	0.64
1980	248,476	401,162	542,857	683,858	0.13	0.08	0.73
1981	239,487	394,337	539,134	658,025	0.14	0.09	0.78
1982	233,940	376,617	521,651	620,918	0.13	0.08	0.77
1983	234,918	358,019	497,395	580,468	0.13	0.08	0.77
1984	236,369	337,481	466,143	536,207	0.07	0.04	0.55
1985	243,465	319,578	450,445	510,129	0.05	0.03	0.43
1986	249,279	308,543	436,071	487,249	0.03	0.02	0.33
1987	251,811	299,019	421,379	465,420	0.03	0.02	0.34
1988	249,159	296,954	403,380	441,121	0.03	0.02	0.28
1989	243,145	294,963	385,414	417,521	0.05	0.02	0.28
1990	231,378	290,990	363,383	390,655	0.07	0.03	0.41
1991	215,029	283,003	336,135	359,232	0.05	0.02	0.31
1992	201,287	272,640	314,567	333,676	0.02	0.01	0.15
1993	190,065	257,166	297,937	313,198	0.06	0.03	0.31
1994	175,048	237,554	276,483	287,940	0.09	0.04	0.44
1995	160,134	220,818	252,549	260,701	0.08	0.03	0.39
1996	146,988	206,789	231,044	236,509	0.06	0.03	0.34
1997	135,207	188,689	211,651	214,989	0.08	0.03	0.37
1998	123,080	170,672	192,111	193,776	0.11	0.05	0.45
1999	109,919	154,794	171,679	172,067	0.08	0.03	0.40
2000	99,430	140,685	155,018	154,529	0.11	0.05	0.47
2001	88,200	126,606	138,197	137,138	0.10	0.04	0.45
2002	78,824	111,859	124,445	123,049	0.07	0.03	0.37
2003	71,013	100,265	114,172	112,452	0.07	0.03	0.36
2004	64,103	88,184	106,020	103,864	0.06	0.02	0.31
2005	58,455	78,218	99,905	97,224	0.07	0.03	0.36
2006	53,287	70,005	93,979	90,792	0.06	0.02	0.31
2007	49,612	62,827	88,990	85,374	0.06	0.02	0.33
2008	46,914	56,995	84,192	80,301	0.11	0.04	0.47
2009	44,804	51,645	79,178	75,037	0.17	0.06	0.62
2010	41,852	47,718	74,547	69,722	0.18	0.06	0.61
2011	38,477	44,684	73,546	66,993	0.18	0.05	0.60
2012	35,194	42,182	76,034	66,631	0.24	0.07	0.70
2013	32,020	38,898	79,219	66,338	0.09	0.03	0.41

Table 5.21. Continued. Spawning and total biomass compared with the 2020 assessment and fishing mortality, exploitation rate, and 1-SPR from the current assessment for BSAI Greenland turbot, 1977-2022. The 2023 and 2024 biomass estimates are from the Model 16.4c projections. The projections assume catch in 2021 and 2022 is equal to maximum ABC.

	SSB (t)		Total biomass (age1+)				
Year	2020	Current	2020	Current	Apical F	Exploitation	1-SPR
2014	32,201	28,135	85,934	69,348	0.08	0.02	0.38
2015	34,940	29,176	92,031	72,019	0.10	0.03	0.43
2016	39,500	31,274	96,170	73,285	0.09	0.03	0.39
2017	44,725	33,907	98,487	73,428	0.09	0.04	0.41
2018	48,898	35,856	98,362	71,834	0.05	0.03	0.27
2019	52,010	37,352	97,392	70,018	0.08	0.04	0.38
2020	52,902	37,204	93,970	66,219	0.07	0.04	0.35
2021	51,914	36,380	87,849	62,174	0.05	0.03	0.28
2022	47,197	35,257	79,382	58,349	0.05	0.03	0.29
2023	-	33,554	-	53,907	-	-	-
2024	-	30,484	-	48,850	-	-	-

Table 5.22. Spawning biomass from Model 16.4c with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2020 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. The 2021 and 2022 values are from the projection model.

Year	SSB	LCI	UCI
1977	401,162	316,994	485,330
1978	394,337	315,748	472,926
1979	376,617	303,429	449,805
1980	358,019	289,996	426,042
1981	337,481	274,590	400,372
1982	319,578	261,427	377,729
1983	308,543	254,495	362,591
1984	299,019	248,535	349,503
1985	296,954	249,612	344,296
1986	294,963	250,626	339,300
1987	290,990	249,544	332,436
1988	283,003	244,305	321,701
1989	272,640	236,563	308,717
1990	257,166	223,735	290,597
1991	237,554	206,624	268,484
1992	220,818	192,157	249,479
1993	206,789	180,226	233,352
1994	188,689	164,159	213,219
1995	170,672	148,068	193,276
1996	154,794	133,946	175,642
1997	140,685	121,441	159,929
1998	126,606	108,847	144,365
1999	111,859	95,491	128,227
2000	100,265	85,196	115,334
2001	88,184	74,332	102,037
2002	78,218	65,493	90,942
2003	70,005	58,313	81,696
2004	62,827	52,081	73,572
2005	56,995	47,100	66,891
2006	51,645	42,507	60,784
2007	47,718	39,227	56,210
2008	44,684	36,748	52,619
2009	42,182	34,737	49,627
2010	38,898	31,898	45,899
2011	35,385	28,814	41,957
2012	32,072	25,901	38,244
2013	28,711	22,864	34,558
2014	28,135	22,484	33,785
2015	29,176	23,519	34,833
2016	31,274	25,426	37,122
2017	33,907	27,776	40,039
2018	35,856	29,459	42,252
2019	37,352	30,776	43,928
2020	37,204	30,563	43,844
2021	36,380	29,784	42,976
2022	35,257	28,798	41,716

Table 5.23. Age-0 recruits based on Model 16.4c with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2022 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error.

Year	Age-0 Recruits	LCI	UCI
1977	90,885	34,647	147,124
1978	49,320	14,188	84,452
1979	16,252	3,586	28,917
1980	7,321	1,412	13,229
1981	4,363	896	7,831
1982	3,410	843	5,976
1983	3,640	1,156	6,125
1984	5,997	2,522	9,473
1985	17,440	11,790	23,090
1986	5,573	3,117	8,029
1987	5,085	2,992	7,178
1988	5,356	3,164	7,547
1989	13,114	9,465	16,764
1990	4,483	2,511	6,455
1991	1,246	567	1,925
1992	785	335	1,235
1993	642	265	1,020
1994	1,011	462	1,560
1995	3,257	1,989	4,526
1996	1,894	977	2,812
1997	1,924	997	2,851
1998	2,455	1,255	3,655
1999	7,950	5,151	10,750
2000	9,844	6,486	13,203
2001	9,269	6,270	12,268
2002	1,744	825	2,663
2003	733	301	1,165
2004	646	266	1,027
2005	1,180	556	1,803
2006	6,403	4,211	8,595
2007	13,539	9,345	17,733
2008	29,035	21,937	36,132
2009	19,290	13,797	24,783
2010	3,392	1,882	4,902
2011	1,658	830	2,487
2012	1,071	484	1,657
2013	957	429	1,484
2014	684	289	1,079
2015	485	187	783
2016	317	106	528
2017	293	93	492
2018	337	115	560
2019	665	295	1,035
2020	851	411	1,290
2021	1,359	599	2,119
2022	3,028	670	5,385

Table 5.24. 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 50:50.

Alternative 1

Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	4,440
2023	2,918	53,907	33,554	0.12	4,645	3,960
2024	2,918	48,850	30,484	0.15	3,947	3,364
2025	2,813	44,981	27,201	0.17	3,301	2,813
2026	2,062	42,020	23,933	0.15	2,422	2,062
2027	1,568	40,475	21,284	0.13	1,844	1,568
2028	1,294	40,186	19,262	0.12	1,524	1,294
2029	1,223	41,347	17,971	0.11	1,441	1,223
2030	1,329	43,453	17,454	0.11	1,566	1,329
2031	1,549	45,975	17,615	0.11	1,824	1,549
2032	1,875	48,564	18,297	0.11	2,207	1,875
2033	2,268	50,960	19,371	0.11	2,668	2,268
2034	2,646	53,436	20,686	0.12	3,111	2,646
2035	3,008	55,599	22,053	0.12	3,535	3,008
2036	3,270	57,360	23,269	0.13	3,842	3,270

Alternative 2

Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	4,440
2023	2,918	53,907	33,554	0.12	4,645	3,960
2024	2,918	48,850	30,484	0.15	3,947	3,364
2025	2,813	44,981	27,201	0.17	3,301	2,813
2026	2,062	42,020	23,933	0.15	2,422	2,062
2027	1,568	40,475	21,284	0.13	1,844	1,568
2028	1,294	40,186	19,262	0.12	1,524	1,294
2029	1,223	41,347	17,971	0.11	1,441	1,223
2030	1,329	43,453	17,454	0.11	1,566	1,329
2031	1,549	45,975	17,615	0.11	1,824	1,549
2032	1,875	48,564	18,297	0.11	2,207	1,875
2033	2,268	50,960	19,371	0.11	2,668	2,268
2034	2,646	53,436	20,686	0.12	3,111	2,646
2035	3,008	55,599	22,053	0.12	3,535	3,008
2036	3,270	57,360	23,269	0.13	3,842	3,270

Alternative 3

Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	1,553
2023	2,918	53,907	33,554	0.12	4,645	1,384
2024	2,918	48,850	30,484	0.15	3,947	1,175
2025	982	44,981	27,201	0.06	3,301	982
2026	860	43,967	25,191	0.06	2,696	860
2027	768	43,576	23,296	0.06	2,226	768
2028	717	43,916	21,688	0.06	1,939	717
2029	716	45,395	20,601	0.06	1,869	716
2030	767	47,683	20,186	0.06	1,993	767
2031	862	50,397	20,442	0.06	2,284	862
2032	989	53,279	21,282	0.06	2,726	989
2033	1,136	56,149	22,629	0.06	3,240	1,136
2034	1,289	59,325	24,364	0.06	3,792	1,289
2035	1,431	62,398	26,303	0.06	4,312	1,431
2036	1,552	65,275	28,243	0.06	4,744	1,552

Table 5.24 continued.

Alternative 4						
Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	1,271
2023	2,918	53,907	33,554	0.12	4,645	1,132
2024	2,918	48,850	30,484	0.15	3,947	961
2025	803	44,981	27,201	0.05	3,301	803
2026	707	44,157	25,314	0.05	2,724	707
2027	634	43,917	23,517	0.05	2,270	634
2028	594	44,376	21,985	0.05	1,994	594
2029	595	45,948	20,956	0.05	1,931	595
2030	638	48,316	20,588	0.05	2,061	638
2031	716	51,107	20,888	0.05	2,361	716
2032	822	54,074	21,777	0.05	2,814	822
2033	945	57,045	23,184	0.05	3,339	945
2034	1,074	60,341	24,994	0.05	3,903	1,074
2035	1,194	63,557	27,025	0.05	4,438	1,194
2036	1,297	66,594	29,073	0.05	4,886	1,297
Alternative 5						
Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	0
2023	2,918	53,907	33,554	0.12	4,645	0
2024	2,918	48,850	30,484	0.15	3,947	0
2025	0	44,981	27,201	0	3,301	0
2026	0	45,010	25,866	0	2,849	0
2027	0	45,470	24,523	0	2,476	0
2028	0	46,494	23,355	0	2,254	0
2029	0	48,529	22,615	0	2,229	0
2030	0	51,300	22,486	0	2,395	0
2031	0	54,486	23,011	0	2,741	0
2032	0	57,884	24,147	0	3,236	0
2033	0	61,363	25,857	0	3,815	0
2034	0	65,266	28,044	0	4,442	0
2035	0	69,197	30,540	0	5,052	0
2036	0	73,053	33,141	0	5,589	0
Alternative 6						
Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	5,207
2023	4,645	53,907	33,554	0.20	4,645	4,645
2024	3,789	47,064	29,319	0.20	3,789	3,789
2025	2,903	42,379	25,486	0.19	2,903	2,903
2026	2,084	39,484	22,240	0.16	2,084	2,084
2027	1,571	38,089	19,672	0.14	1,571	1,571
2028	1,298	37,973	17,752	0.13	1,298	1,298
2029	1,242	39,305	16,569	0.12	1,242	1,242
2030	1,388	41,565	16,152	0.12	1,388	1,388
2031	1,651	44,198	16,392	0.12	1,651	1,651
2032	2,026	46,849	17,126	0.12	2,026	2,026
2033	2,486	49,251	18,215	0.13	2,486	2,486
2034	2,913	51,665	19,504	0.13	2,913	2,913
2035	3,316	53,710	20,807	0.14	3,316	3,316
2036	3,599	55,309	21,927	0.14	3,599	3,599

Table 5.24. Continued.

			Alternative 7			
Year	Catch	Total biomass	SSB	F	OFL	ABC
2022	1,469	57,624	35,257	0.05	5,207	5,207
2023	3,960	53,907	33,554	0.17	4,645	4,645
2024	3,283	47,772	29,781	0.17	3,852	3,852
2025	3,091	43,580	26,275	0.20	3,091	3,091
2026	2,205	40,410	22,862	0.17	2,205	2,205
2027	1,653	38,823	20,176	0.15	1,653	1,653
2028	1,357	38,564	18,168	0.13	1,357	1,357
2029	1,288	39,787	16,916	0.12	1,288	1,288
2030	1,424	41,958	16,444	0.12	1,424	1,424
2031	1,681	44,520	16,637	0.12	1,681	1,681
2032	2,052	47,109	17,330	0.12	2,052	2,052
2033	2,506	49,458	18,384	0.13	2,506	2,506
2034	2,929	51,828	19,642	0.13	2,929	2,929
2035	3,328	53,837	20,919	0.14	3,328	3,328
2036	3,608	55,407	22,017	0.14	3,608	3,608

Table 5.25. Dynamic B_0 results from model 16.4c. SSB_0 is the expected spawning biomass in the absence of fishing. Depletion is SSB/SSB_0

Year	SSB_0	SSB	Depletion
1977	967,949	401,162	0.41
1978	972,029	394,337	0.41
1979	962,450	376,617	0.39
1980	945,278	358,019	0.38
1981	927,077	337,481	0.36
1982	913,113	319,578	0.35
1983	904,798	308,543	0.34
1984	899,440	299,019	0.33
1985	892,468	296,954	0.33
1986	879,897	294,963	0.34
1987	859,664	290,990	0.34
1988	831,658	283,003	0.34
1989	797,039	272,640	0.34
1990	757,593	257,166	0.34
1991	715,323	237,554	0.33
1992	672,072	220,818	0.33
1993	628,801	206,789	0.33
1994	585,227	188,689	0.32
1995	542,224	170,672	0.31
1996	501,005	154,794	0.31
1997	462,028	140,685	0.30
1998	425,275	126,606	0.30
1999	390,615	111,859	0.29
2000	357,987	100,265	0.28
2001	327,414	88,184	0.27
2002	298,966	78,218	0.26
2003	272,681	70,005	0.26
2004	248,574	62,827	0.25
2005	226,636	56,995	0.25
2006	206,658	51,645	0.25
2007	188,788	47,718	0.25
2008	172,989	44,684	0.26
2009	158,907	42,182	0.27
2010	146,154	38,898	0.27
2011	134,432	35,385	0.26
2012	123,704	32,072	0.26
2013	114,262	28,711	0.25
2014	106,672	28,135	0.26
2015	101,415	29,176	0.29
2016	98,202	31,274	0.32
2017	96,170	33,907	0.35
2018	94,325	35,856	0.38
2019	92,064	37,352	0.41
2020	89,124	37,204	0.42
2021	85,559	36,380	0.43
2022	81,503	35,257	0.43

Table 5.26. Spawning stock biomass estimates from the maturity at age sensitivity analysis.

	Length at 50% maturity			
Year	60cm	65cm	67cm	70cm
1978	394,337	366,725	351,484	323,620
1979	376,617	354,124	341,768	318,843
1980	358,019	337,908	327,441	308,208
1981	337,481	317,201	307,634	290,791
1982	319,578	297,334	287,700	271,745
1983	308,543	284,221	273,968	257,688
1984	299,019	274,144	263,436	246,588
1985	296,954	272,504	261,506	243,947
1986	294,963	272,422	261,715	244,120
1987	290,990	271,361	261,500	244,711
1988	283,003	266,742	258,129	242,914
1989	272,640	259,523	252,249	238,944
1990	257,166	246,839	240,920	229,763
1991	237,554	229,391	224,666	215,581
1992	220,818	213,940	210,024	202,463
1993	206,789	200,664	197,261	190,741
1994	188,689	183,210	180,230	174,589
1995	170,672	165,754	163,135	158,228
1996	154,794	150,239	147,870	143,498
1997	140,685	136,434	134,244	130,257
1998	126,606	122,782	120,788	117,165
1999	111,859	108,613	106,873	103,678
2000	100,265	97,586	96,102	93,324
2001	88,184	86,022	84,800	82,471
2002	78,218	76,418	75,403	73,452
2003	70,005	68,423	67,550	65,876
2004	62,827	61,366	60,588	59,120
2005	56,995	55,521	54,787	53,444
2006	51,645	49,979	49,226	47,925
2007	47,718	45,689	44,835	43,450
2008	44,684	42,297	41,300	39,740
2009	42,182	39,699	38,617	36,914
2010	38,898	36,648	35,605	33,917
2011	35,385	33,477	32,545	30,983
2012	32,072	30,419	29,613	28,231
2013	28,711	27,047	26,318	25,107
2014	28,135	25,852	24,988	23,676
2015	29,176	25,828	24,629	22,943
2016	31,274	26,885	25,250	22,975
2017	33,907	28,987	27,001	24,136
2018	35,856	31,094	28,999	25,811
2019	37,352	33,127	31,116	27,885
2020	37,204	33,759	32,008	29,047
2021	36,380	33,664	32,206	29,631
2022	35,257	33,142	31,953	29,774

Table 5.27. FMP species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991

Year	Arrowtooth Flounder	Atka Mackerel	BSAI Alaska Plaice	BSAI Kamchatka Flounder	BSAI Other Flatfish	BSAI Rougheye Rockfish	BSAI Shortraker Rockfish	BSAI Skate and GOA Skate, Other	BSAI Squid	Flathead Sole	Flounder
1991	1,033	0	0	0	0	0	0	0	0	0	93
1993	7	0	0	0	0	0	0	0	0	0	5
1994	1,297	0	0	0	0	0	0	0	0	0	67
1995	1,856	0	0	0	0	0	0	0	0	57	0
1996	228	0	0	0	0	0	0	0	0	51	0
1997	385	0	0	0	0	0	0	0	0	62	0
1998	336	22	0	0	0	0	0	0	0	43	0
1999	556	133	0	0	0	0	0	0	0	121	0
2000	278	0	0	0	0	0	0	0	0	70	0
2001	168	0	0	0	0	0	0	0	0	68	0
2002	157	0	0	0	0	0	0	0	0	29	0
2003	206	0	0	0	35	0	0	0	3	71	0
2004	81	0	0	0	5	0	5	0	6	14	0
2005	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0
2009	1,145	1	0	0	4	1	2	0	23	1	0
2010	123	0	0	0	0	0	0	0	1	0	0
2011	1	0	0	1	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0
2016	355	0	0	135	4	0	0	9	0	58	0
2017	596	0	0	342	53	0	15	61	0	137	0
2018	165	0	0	451	68	0	46	51	0	226	0
2019	241	0	0	937	215	0	55	65	0	497	0
2020	144	0	0	298	42	0	5	59	0	177	0
2021	101	0	0	122	58	0	26	29	0	60	0
2022	82	0	0	167	97	0	7	16	0	65	0

Table 5.27 (Cont.). FMP species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991.

Year	Non TAC Species	Northern Rockfish	Octopus	Other	Other Flatfish	Other Rockfish	Other Species	Pacific Cod	Pacific Ocean Perch	Pollock	Rock Sole	Rougheye Rockfish	Sablefish
1991	0	0	0	92	0	39	0	81	2	114	1	0	172
1993	0	0	0	0	0	0	0	0	0	0	0	0	1
1994	0	0	0	96	0	67	0	45	1	20	0	0	346
1995	0	0	0	98	62	70	0	50	12	49	0	0	308
1996	0	0	0	19	16	19	0	9	6	23	3	0	54
1997	0	0	0	43	26	10	0	7	14	53	2	0	28
1998	0	0	0	19	36	18	0	24	3	94	12	0	31
1999	0	0	0	43	73	3	0	87	32	146	23	0	115
2000	9	0	0	35	46	31	0	41	26	111	3	0	62
2001	0	0	0	29	18	24	0	0	52	49	3	0	66
2002	0	0	0	26	16	31	0	0	0	0	0	0	43
2003	0	0	0	0	0	0	19	14	0	94	0	0	26
2004	0	0	0	0	0	20	12	0	1	64	0	0	12
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	4	21	0	0	11	0	0	23
2010	0	0	0	0	0	1	2	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	10	42	116	0	0	2
2017	0	0	1	0	0	21	0	23	37	219	1	1	93
2018	0	0	1	0	0	43	0	12	111	172	0	2	98
2019	0	0	7	0	0	302	0	13	150	268	0	7	591
2020	0	0	0	0	0	10	0	14	32	109	2	5	130
2021	0	0	0	0	0	40	0	4	109	68	0	2	121
2022	0	0	1	0	0	148	0	0	28	58	0	2	210

Table 5.27 (Cont.). FMP species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991.

Year	Sculpin	Shark	Sharpchin/Northern Rockfish	Shortraker/Rougheye Rockfish	Shortraker/Rougheye/Sharpchin/Northern Rockfish	Squid	Yellowfin Sole
1991	0	0	0	0	19	38	0
1993	0	0	0	0	0	0	0
1994	0	0	0	5	7	19	0
1995	0	0	0	0	3	12	18
1996	0	0	0	0	4	1	0
1997	0	0	0	0	2	3	0
1998	0	0	0	0	0	1	6
1999	0	0	0	0	7	4	18
2000	0	0	0	0	32	9	4
2001	0	0	0	0	0	2	0
2002	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0
2016	20	0	0	0	0	3	0
2017	33	0	0	0	0	14	1
2018	30	0	0	0	0	22	0
2019	27	0	0	0	0	0	0
2020	22	3	0	0	0	0	0
2021	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0

Table 5.28. 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.

Species group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Benthic urochordata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Gull	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Kittiwake	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Laysan Albatross	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Northern Fulmar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Other Alcid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Shearwaters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Short-tailed Albatross	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Unidentified Albatross	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brittle star unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Capelin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corals Bryozoans - Corals Bryozoans Unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corals Bryozoans - Red Tree Coral	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eelpouts	29	13	0	4	2	0	9	0	0	8	0	0	0	4	9	0	38	2	2	11
Eulachon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Giant Grenadier	44	136	1,105	1,301	1,181	0	2,140	0	0	1,365	0	0	0	1,187	1,538	711	814	599	444	270
Greenlings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grenadier - Pacific Grenadier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grenadier - Rattail Grenadier Unidentified	1,529	0	0	217	234	21	96	0	342	288	0	0	0	0	0	0	0	0	0	0
Gunnels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit crab unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Invertebrate unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lanternfishes (myctophidae)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins	1	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins - Bigmouth Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins - Great Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins - Yellow Irish Lord	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc crabs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3
Misc crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc deep fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc fish	4	2	0	2	0	0	1	1	0	1	0	0	0	1	2	0	0	2	1	1
Misc inverts (worms etc)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other osmerids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Sculpins	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pacific Sand lance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandalid shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Polychaete unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	7
Scypho jellies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea anemone unidentified	0	0	0	0	0	0	0	0	1	1	0	0	0	9	20	0	0	0	22	5
Sea pens whips	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea star	5	0	0	0	1	0	0	0	0	1	0	0	0	2	6	4	21	5	3	7
Snails	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sponge unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	1	0
Squid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	29	14	15
Stichaeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
urchins dollars cucumbers	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5

Table 5.29. 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 group	2003	2004	2005	2008	2009	2010	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Benthic urochordata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Northern Fulmar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Birds - Shearwaters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brittle star unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1	0
Capelin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corals Bryozoans - Corals Bryozoans Unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eelpouts	28	11	0	0	3	0	0	0	0	0	1	7	5	38	2	2	11
Eulachon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Giant Grenadier	0	0	0	0	365	0	0	0	0	0	83	450	364	447	397	444	270
Greenlings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grenadier - Pacific Grenadier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grenadier - Rattail Grenadier Unidentified	25	26	0	0	49	0	0	0	0	0	0	0	0	62	0	0	0
Hermit crab unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Invertebrate unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lanternfishes (myctophidae)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins - Bigmouth Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Sculpins - Yellow Irish Lord	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc crabs	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	1	3
Misc crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc deep fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc fish	1	0	0	0	0	0	0	0	0	0	1	1	2	2	2	1	1
Misc inverts (worms etc)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other osmerids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Sculpins	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pacific Sand lance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandalid shrimp	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Polychaete unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	7
Scypho jellies	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Sea anemone unidentified	0	0	0	0	0	0	0	0	0	0	8	20	35	21	29	22	5
Sea pens whips	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea star	5	2	0	0	0	0	0	0	0	0	1	4	4	21	5	3	7
Snails	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sponge unidentified	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	1	0
Squid	0	0	0	0	0	0	0	0	0	0	0	0	0	65	29	14	15
Stichaeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
urchins dollars cucumbers	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	5

Table 5.30. 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	14919		71		373		5	237955	11160	1398
1993					0			80		
1994	1916		58		927			278055	6029	329
1995	3837				556			52212	3027	966
1996	1089				12			5594	250	
1997	614				14			6138	451	
1998	474				14			2845	125	
1999	1048				27			2051	1198	
2000	1055				25			2677	3327	
2001	497				16			7189	471	
2002	731				2			2644	211	
2003	2884			99	11			1800		
2004				66	3			66		
2005	88			88	3					
2008				132						
2009				747	8					
2010				86	3					
2011					1					
2013					1					
2014				21						
2015										
2016	1531			464	10			117		
2017	3262			2370	90			2040		
2018	808			1291	35			78		
2019	1495			7834	97		583	816		
2020	4861			1334	31			3062		

Table 5.31. 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.

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	14,919	0	71	0	373	0	0	237,955	11,160	1,398
1993	0	0	0	0	0	0	0	0	0	0
1994	1,916	0	58	0	927	0	0	278,055	6,029	329
1995	3,837	0	0	0	556	0	0	52,212	3,027	966
1996	0	0	0	0	12	0	0	5,594	0	0
1997	0	0	0	0	14	0	0	6,138	0	0
1998	0	0	0	0	14	0	0	0	125	0
1999	1,048	0	0	0	27	0	0	2,051	1,198	0
2000	0	0	0	0	0	0	0	0	3,327	0
2001	497	0	0	0	16	0	0	7,189	471	0
2002	0	0	0	0	0	0	0	0	0	0
2003	2,884	0	0	99	11	0	0	1,800	0	0
2004	0	0	0	66	3	0	0	66	0	0
2005	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	747	8	0	0	0	0	0
2010	0	0	0	86	3	0	0	0	0	0
2011	0	0	0	0	1	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0
2016	1,531	0	0	464	10	0	0	117	0	0
2017	3,262	0	0	2,370	90	0	0	2,040	0	0
2018	808	0	0	1,291	35	0	0	78	0	0
2019	1,495	0	0	7,863	97	0	583	816	0	0
2020	4,861	0	0	1,334	31	0	0	3,062	0	0
2021	1,045	0	0	1,783	5	0	0	162	0	0
2022	0	0	0	876	17	0	0	0	0	0

Table 5.32. Bird species catch (number) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands in the longline fisheries, trawl fisheries registered no bird catch. Note that these are extrapolated from the observed catch records and not the official numbers used in protected species management.

Year	Gull	Kittiwake	Laysan Albatross	Northern Fulmar	Shearwaters	Short-tailed Albatross	Unidentified	Unidentified Albatross	Grand Total
2003				133	21				154
2004		31	21	80				3	135
2005		12	13	152	81				258
2006			3	212					215
2007		10	2	243	119				374
2008				247					247
2009	4	4	10	548	69		4		639
2010	17			170	4		11		202
2011			5	499	38				543
2012				354	40		15		409
2013				65	60		5		131
2014				55		6			62
2015				17	55				72
2016				82	174				256
2017		9		130	14				153
2018			3	70					73
Grand Total	20	66	57	3060	674	6	36	3	3922

Figures

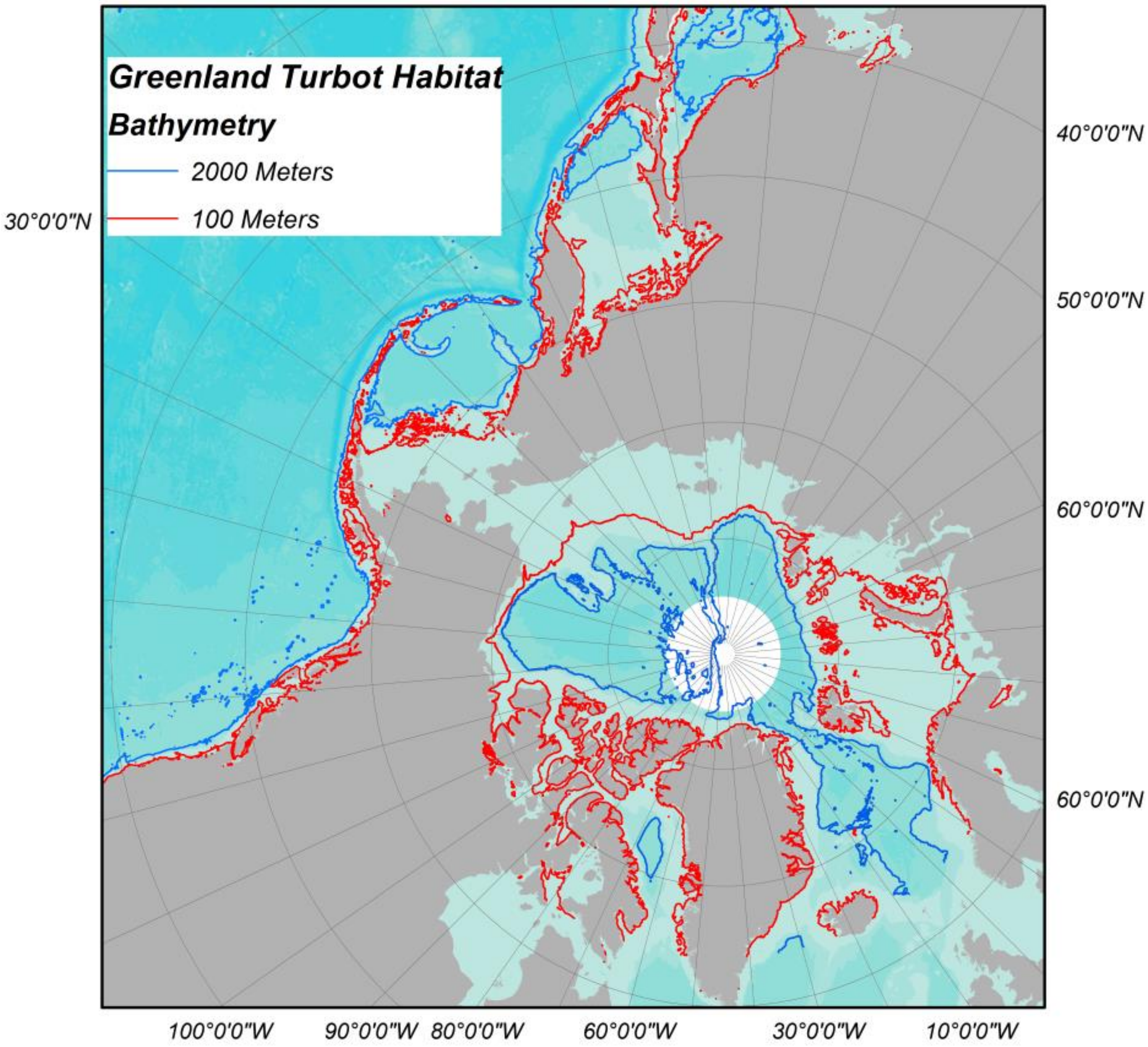


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.

(a)

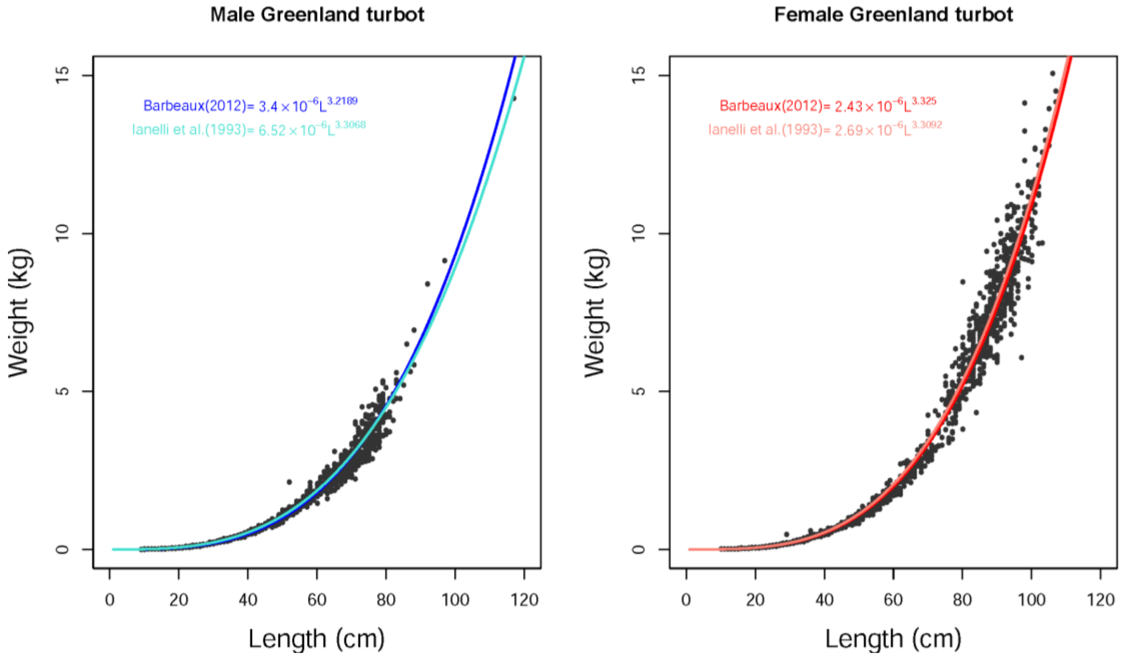


Figure 5.2. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

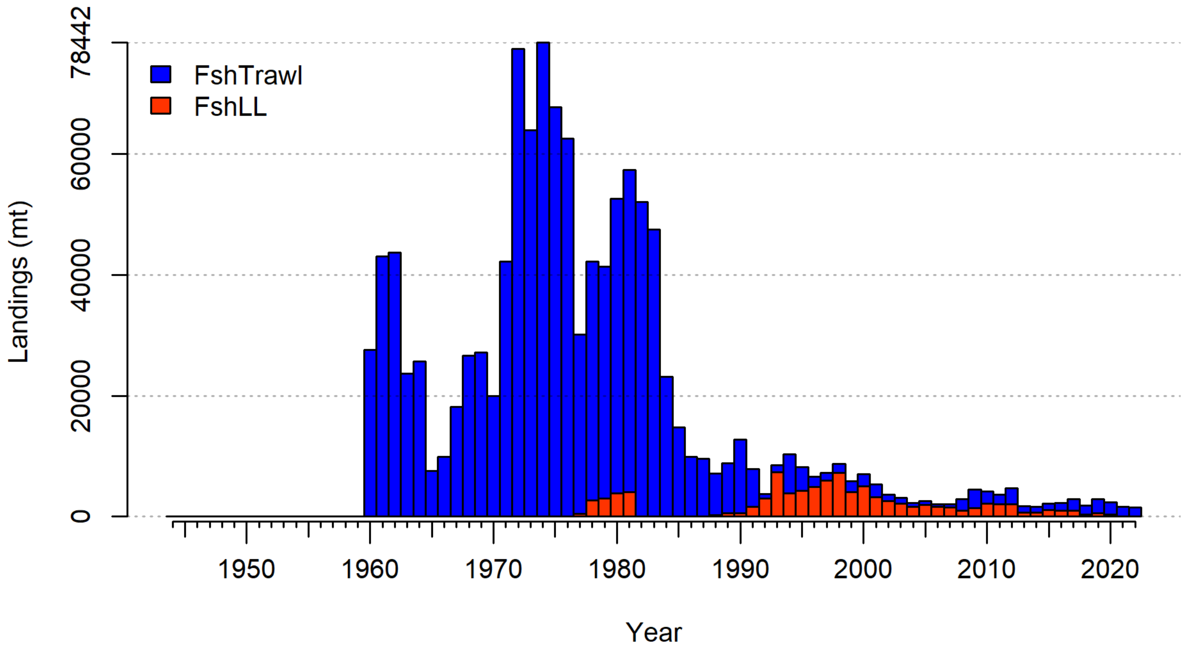
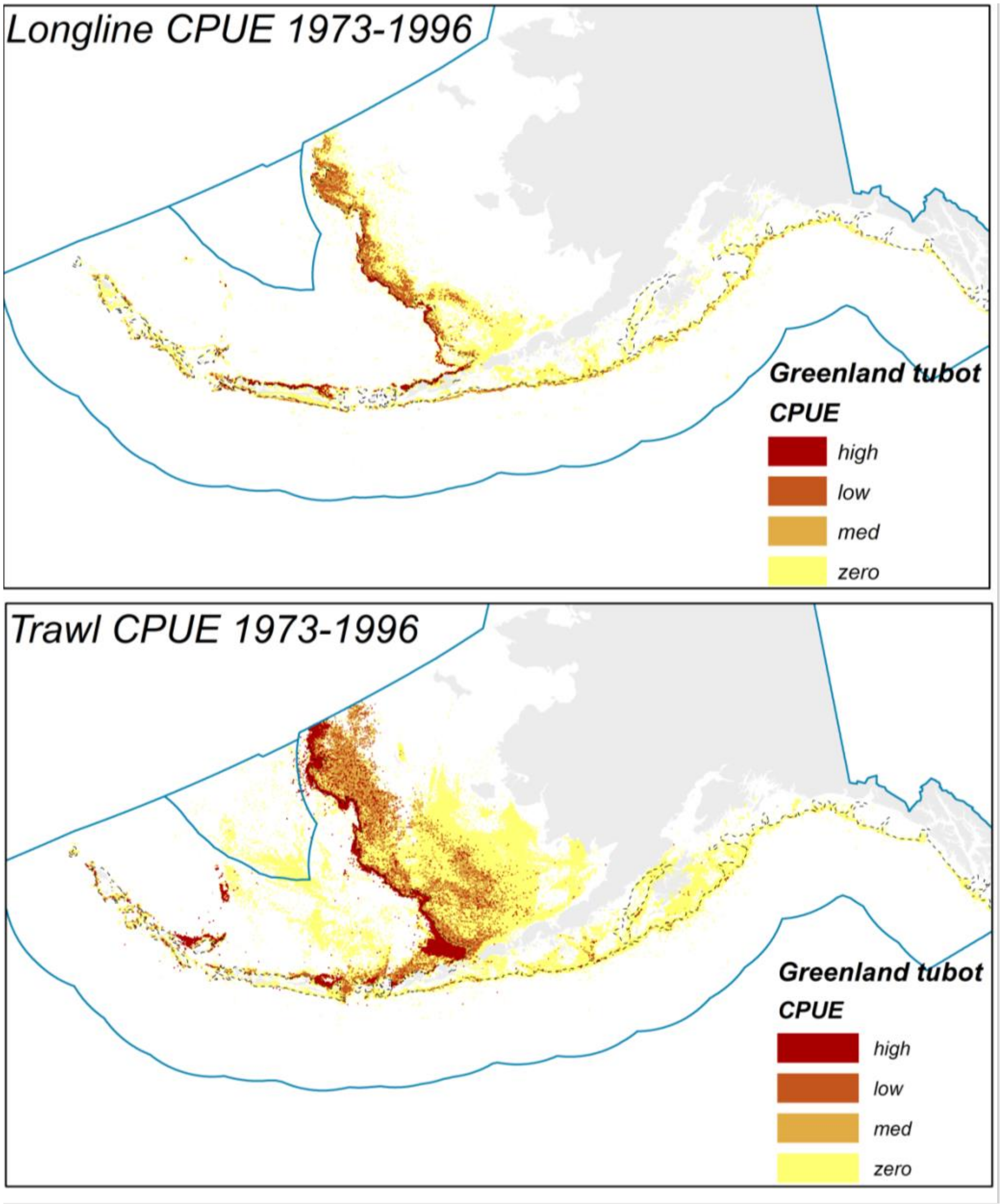


Figure 5.3. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2022. This data includes targeted catch and bycatch.



Longline CPUE 1973-1996

Trawl CPUE 1973-1996

Figure 5.4. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).

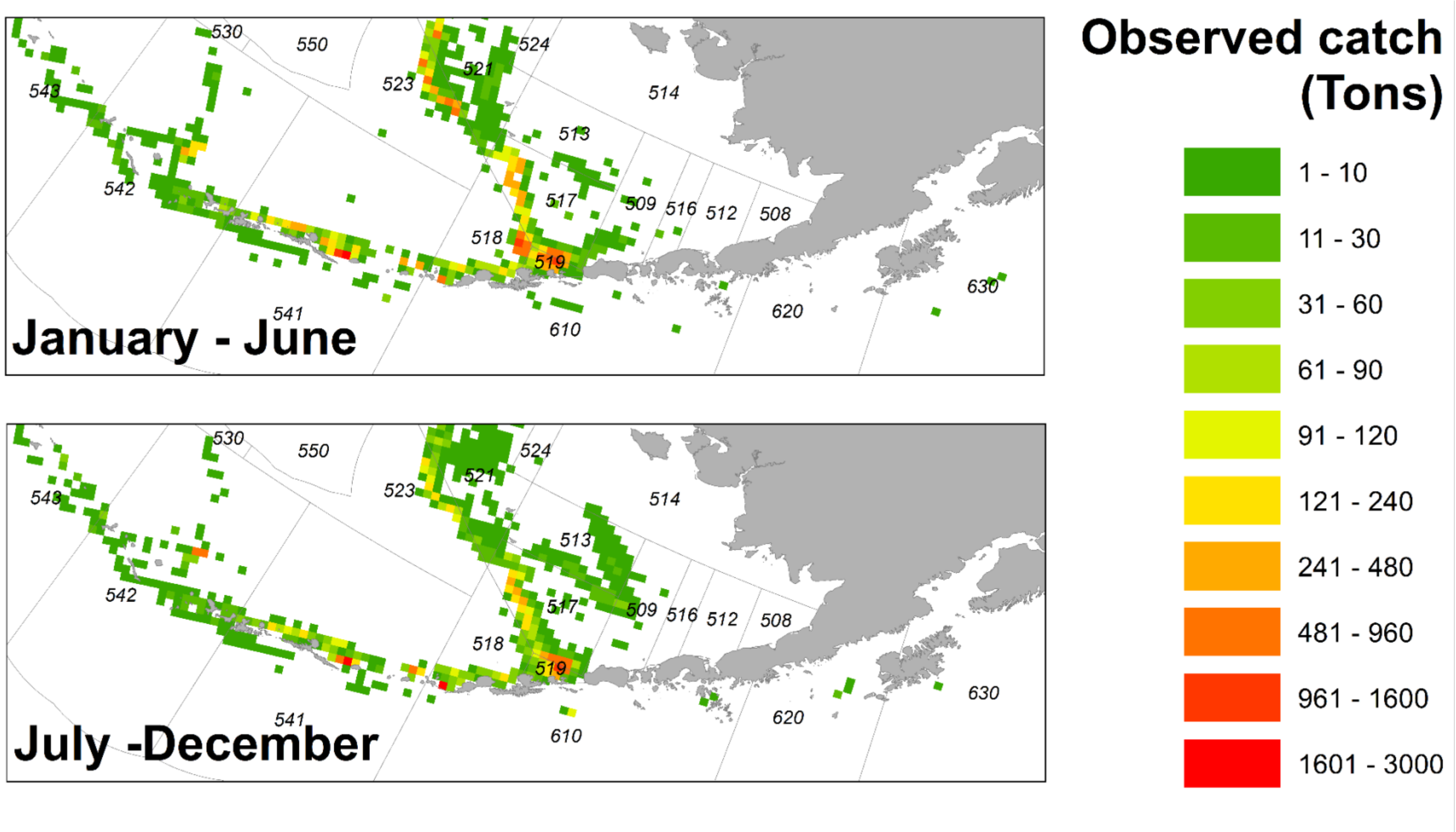


Figure 5.5. All observed catch for 2000 through 2018, data are aggregated spatially at a 400 km^2 grid.

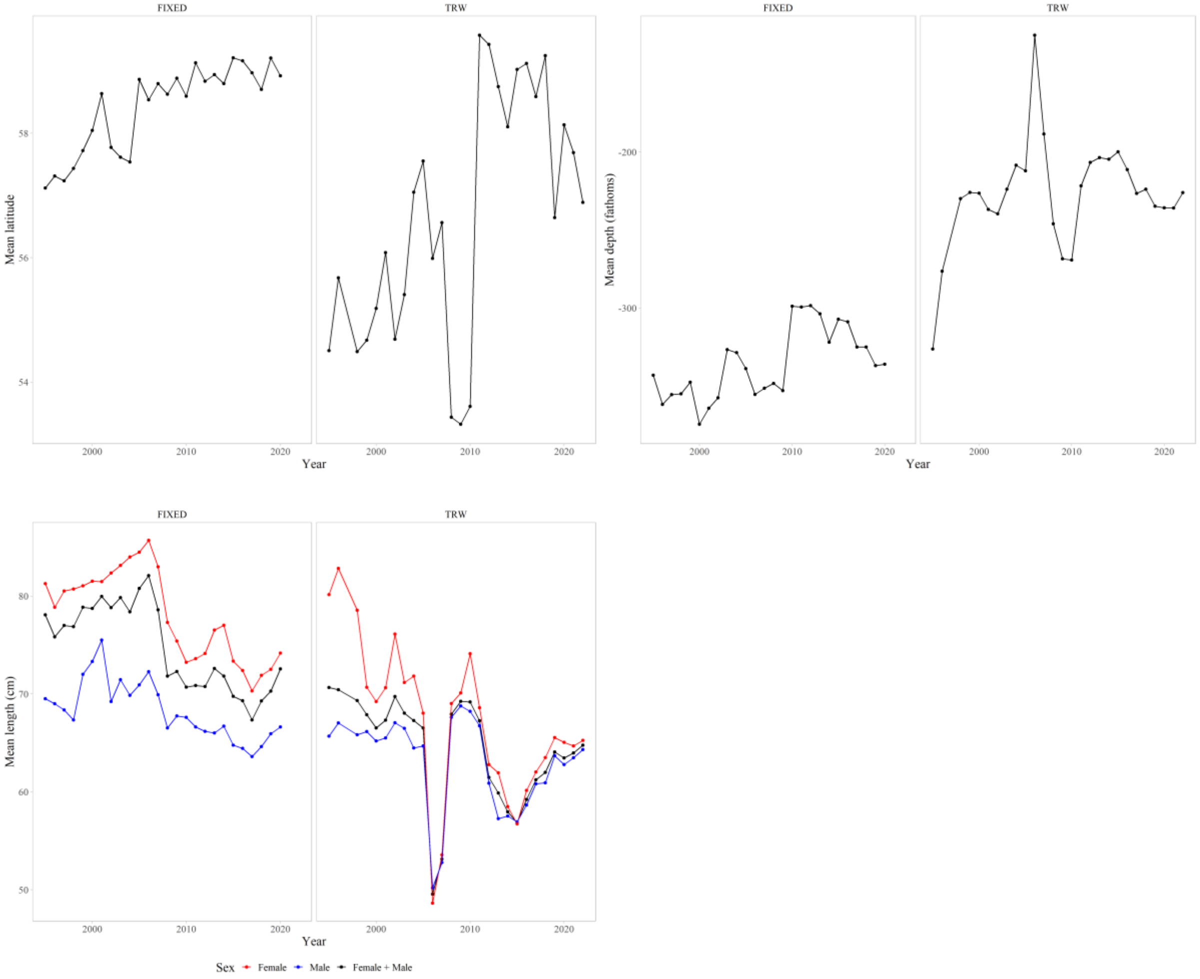


Figure 5.6. Mean latitude (top left) and depth (top right) of fishing and mean length (bottom left) of captured Greenland turbot by gear type.

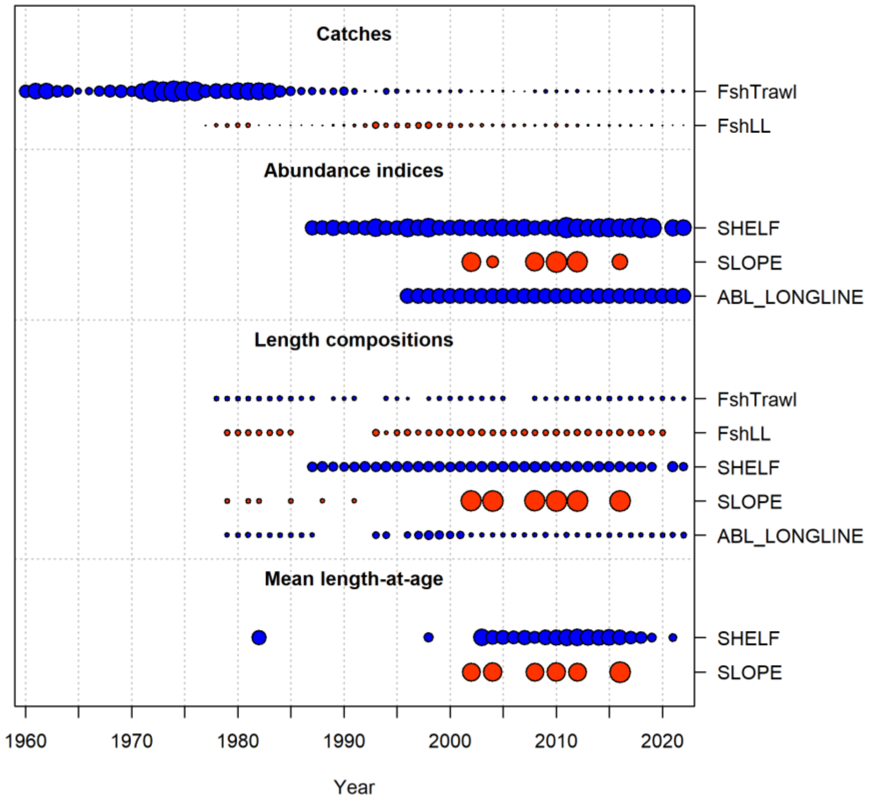


Figure 5.7. Timeline of all data included in models 16.4b and 16.4c. The mean length-at-age from the slope is not included in model 16.4a. Circle area is relative within a data type and scaled to the maximum. Circles are proportional total catch for catches, proportional to precision for indices, and tot sample size for composition data.

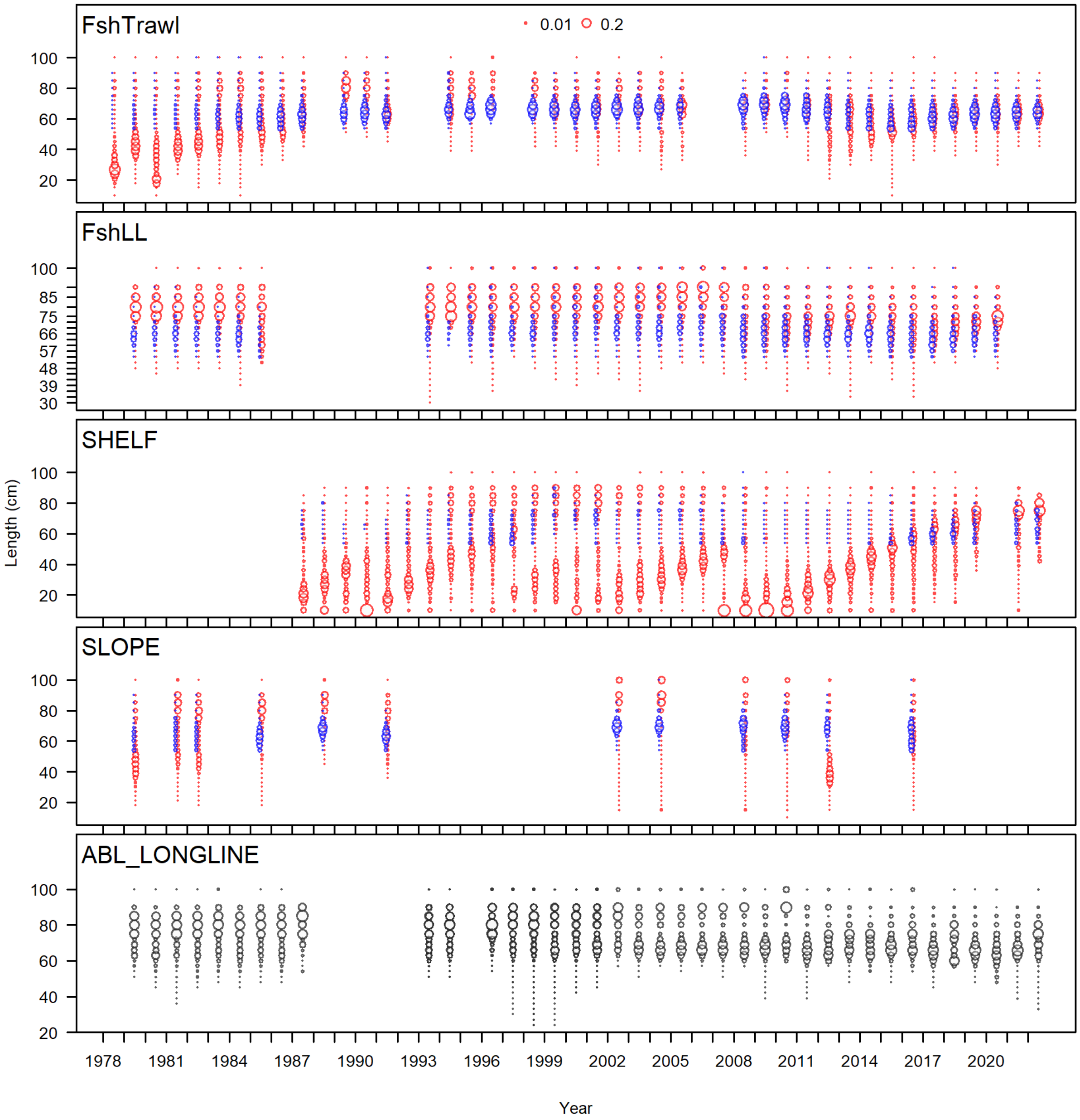


Figure 5.8. Greenland turbot size composition data from the trawl fishery, longline fishery, shelf survey and slope survey.

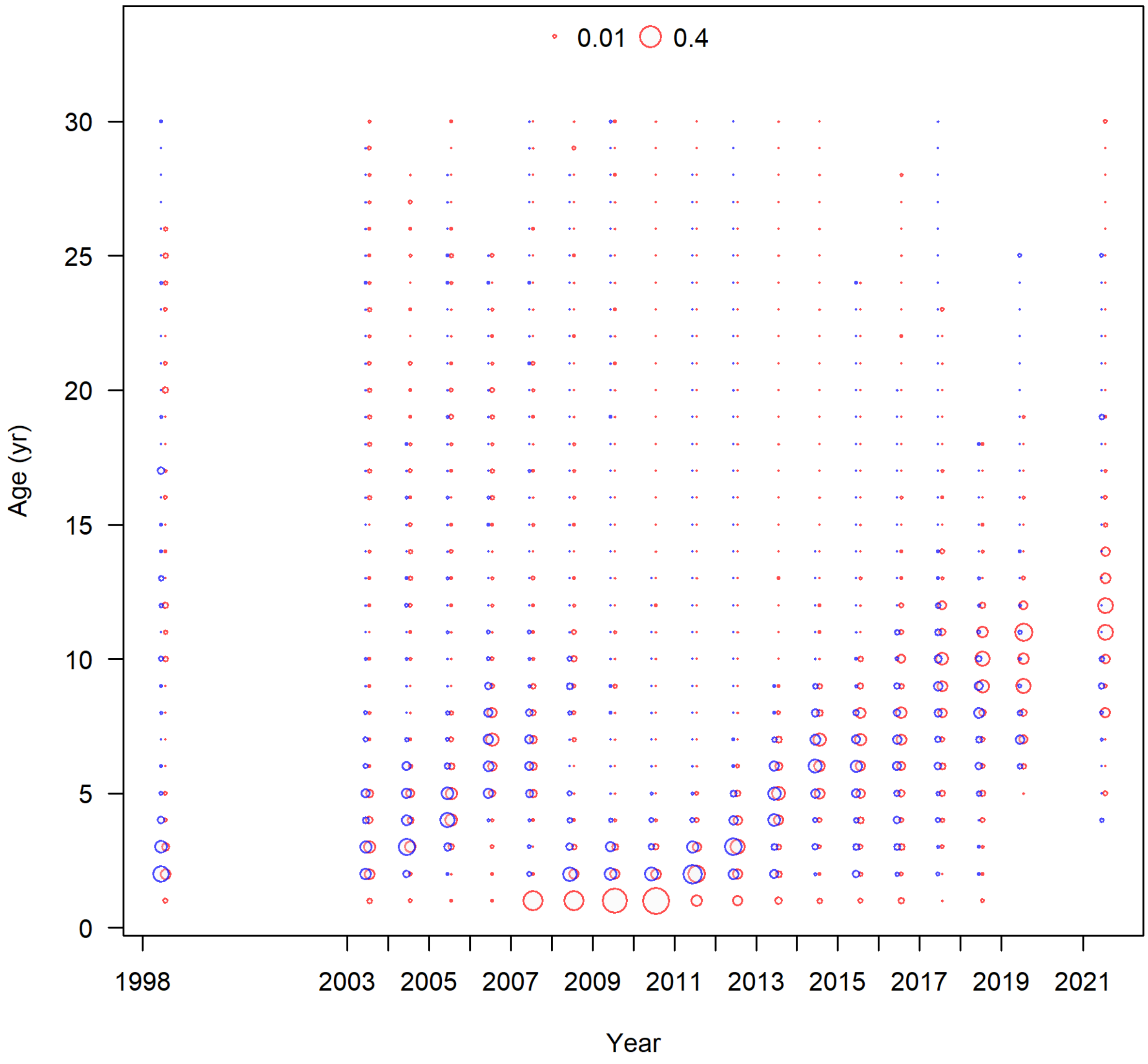


Figure 5.9. Greenland turbot age composition data for females (red) and males (blue) from the EBS shelf bottom trawl survey. These data were included in the model but not included in the likelihood.

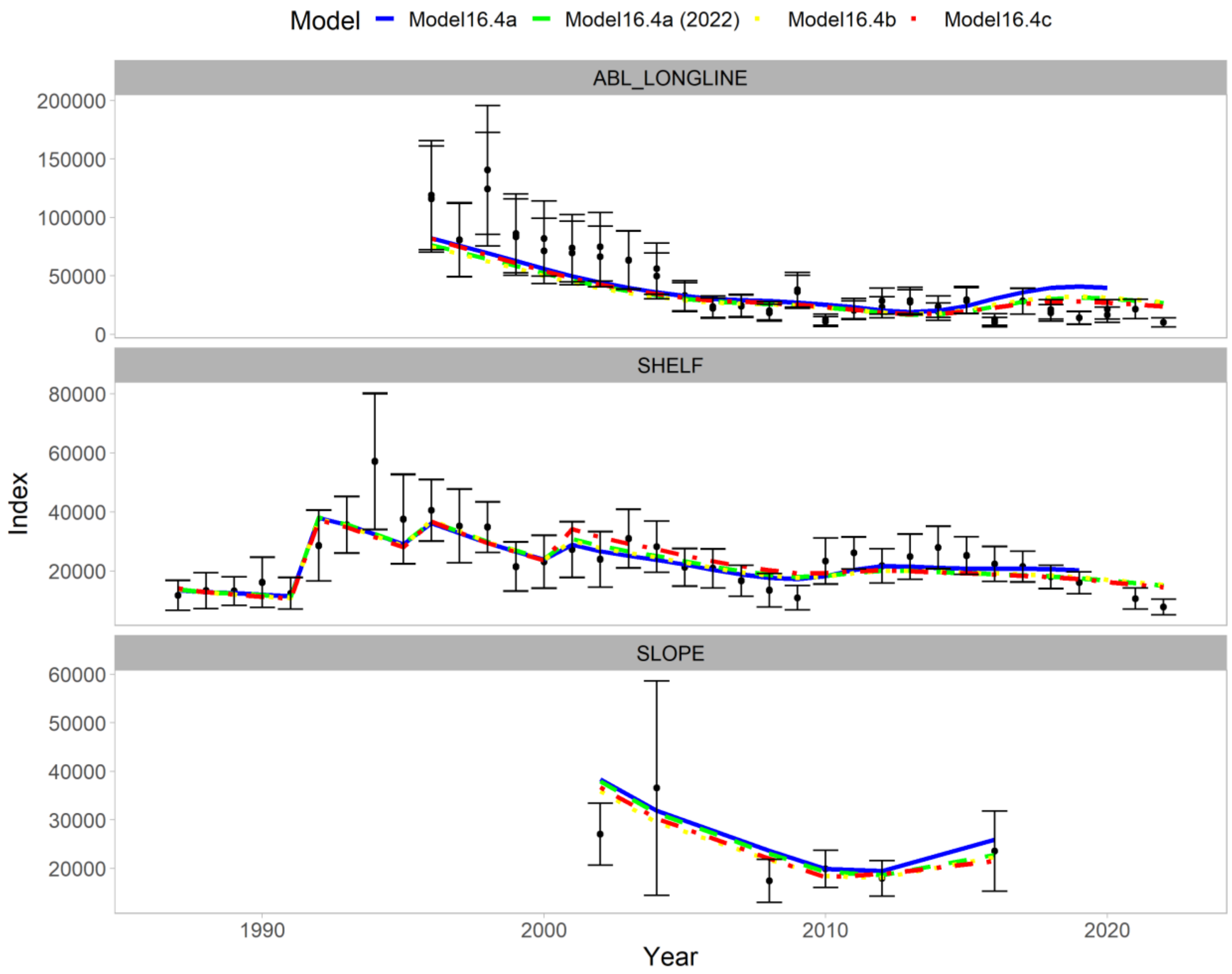


Figure 5.10. Survey indices (index values are the total survey biomass in tons) and model fits. Error bars are 95% confidence intervals.

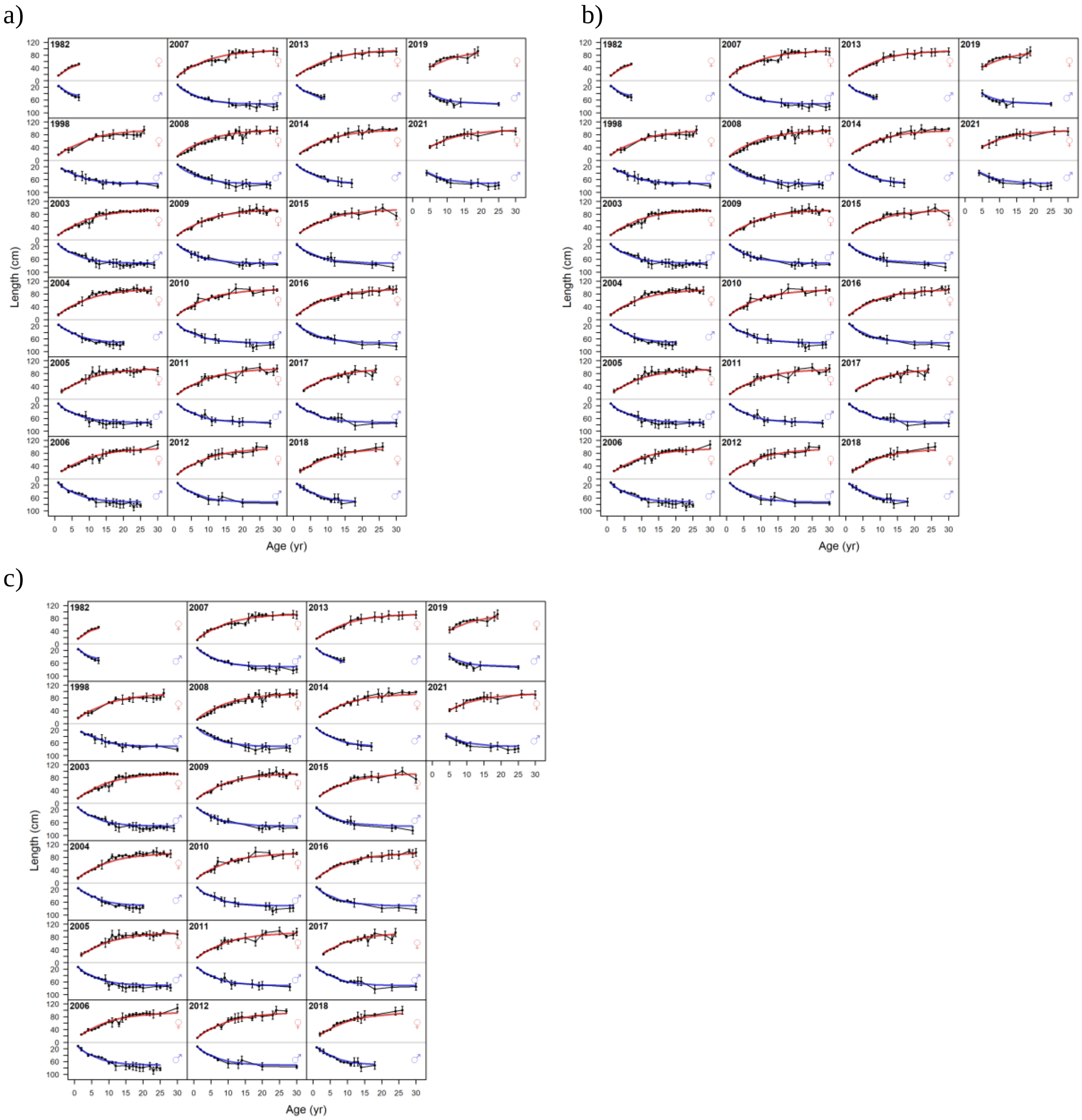


Figure 5.11. EBS shelf bottom trawl survey length at age data and fit (females - red line, males – blue line) by a) Model 16.4a and b) Model 16.4b, and c) Model 16.4c

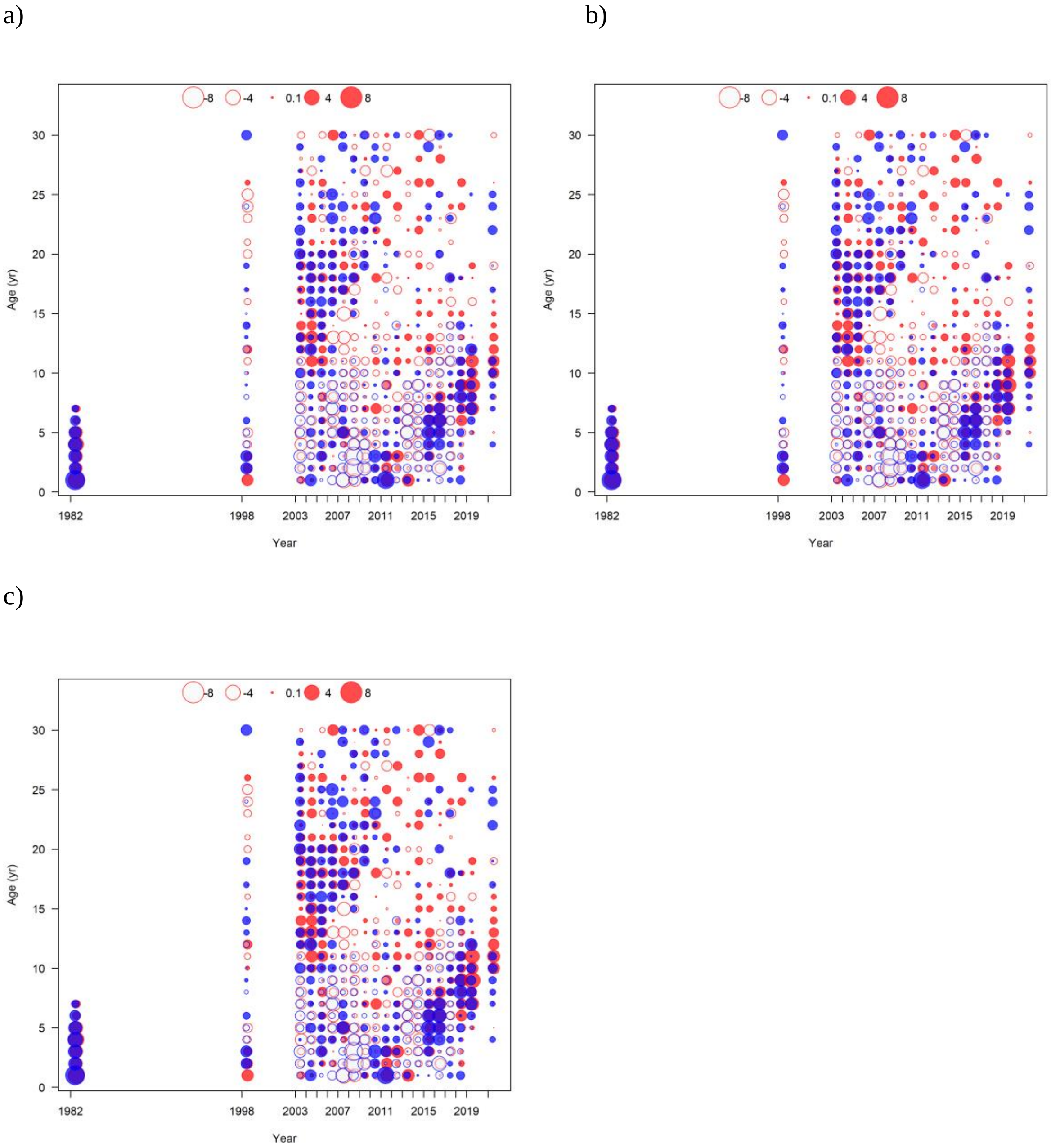


Figure 5.12. a) The standardized residuals from a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c. The closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation). Red bubbles are female and blue are male.

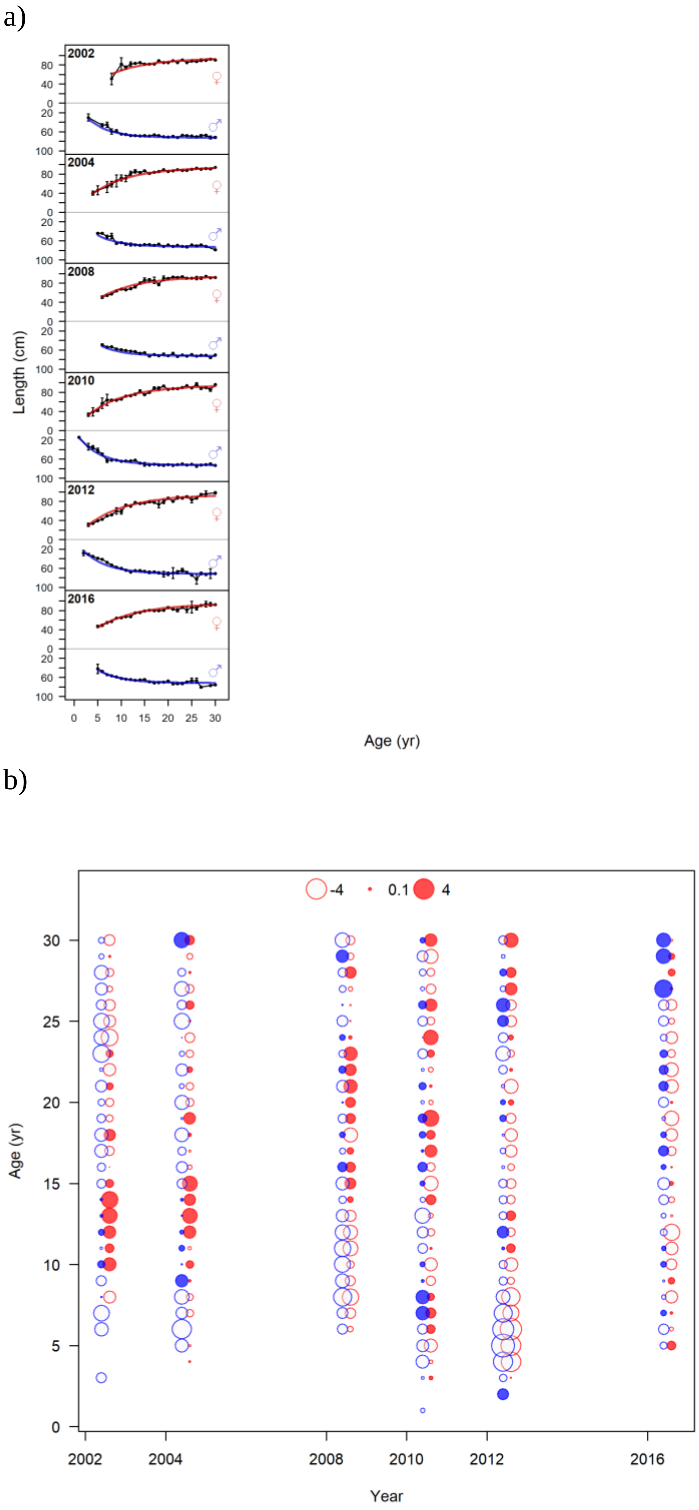


Figure 5.13. a) EBS slope bottom trawl survey length at age data and fit (females - red line, males – blue line) and b) standardized residuals from Model 16.4c. The closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation). Red bubbles are female and blue are male.

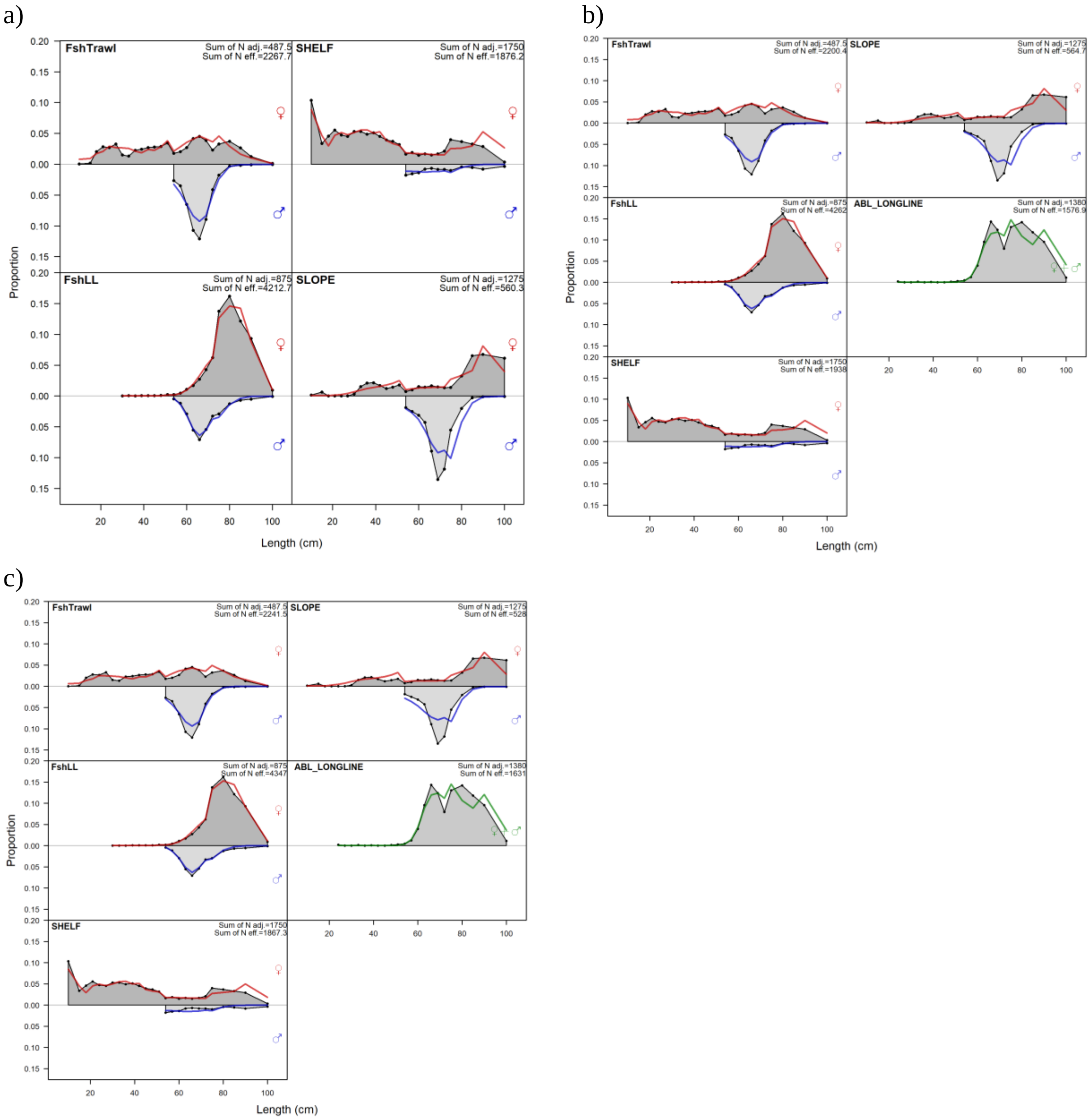


Figure 5.14. All size composition data combined across years and fits (red line female, blue line male, green line unsexed) for fisheries and surveys. a) Model 16.4a (2022), b) model 16.4.b, c) model 16.4c.

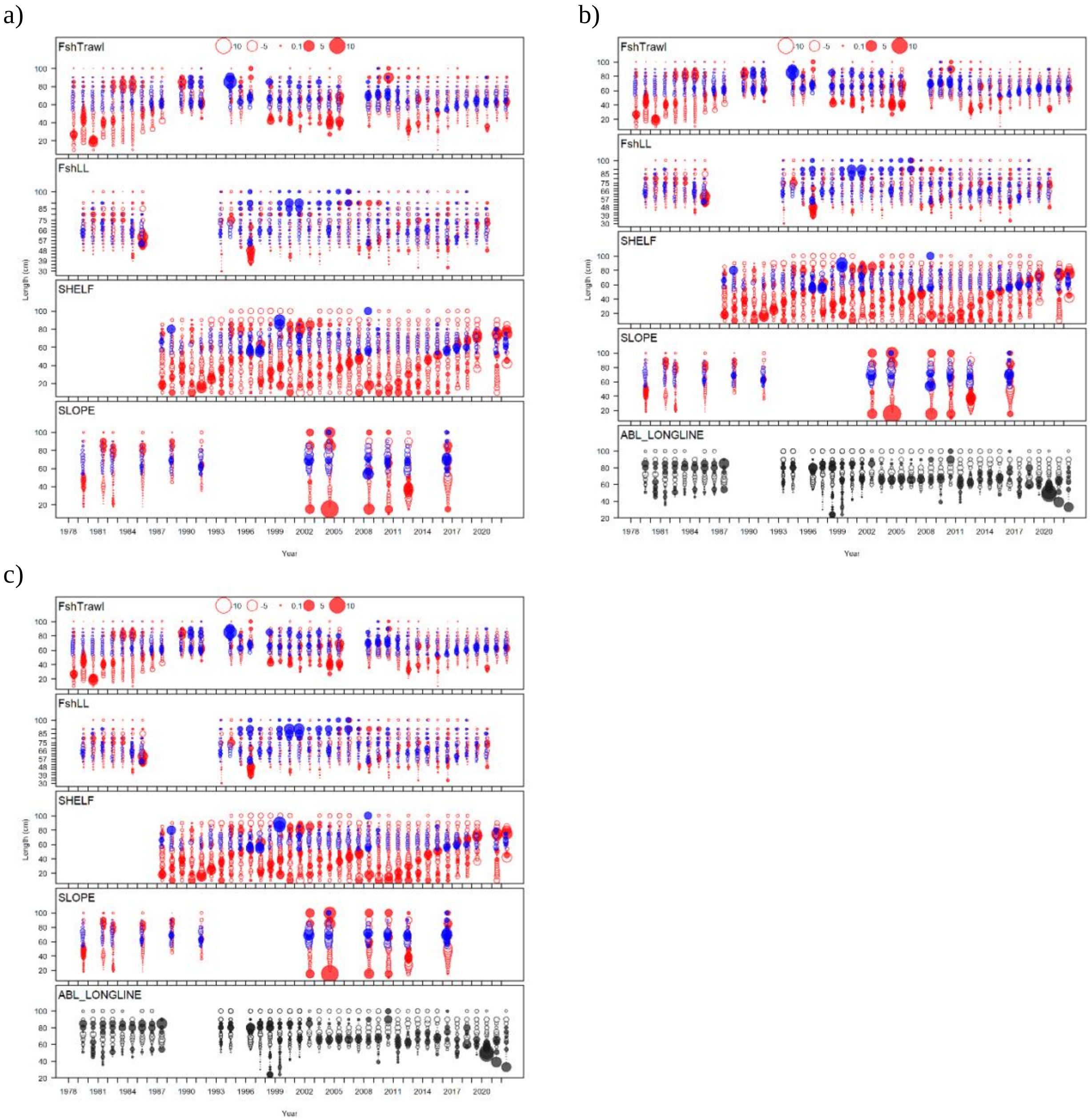


Figure 5.15. Pearson residuals for the trawl and longline fisheries and the EBS shelf and EBS slope bottom trawl surveys, a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c. Closed bubbles are positive residuals (obs-expected, underestimation) and open bubbles are negative residuals (overestimation). Note that the scale of the bubble graphs may differ by model.

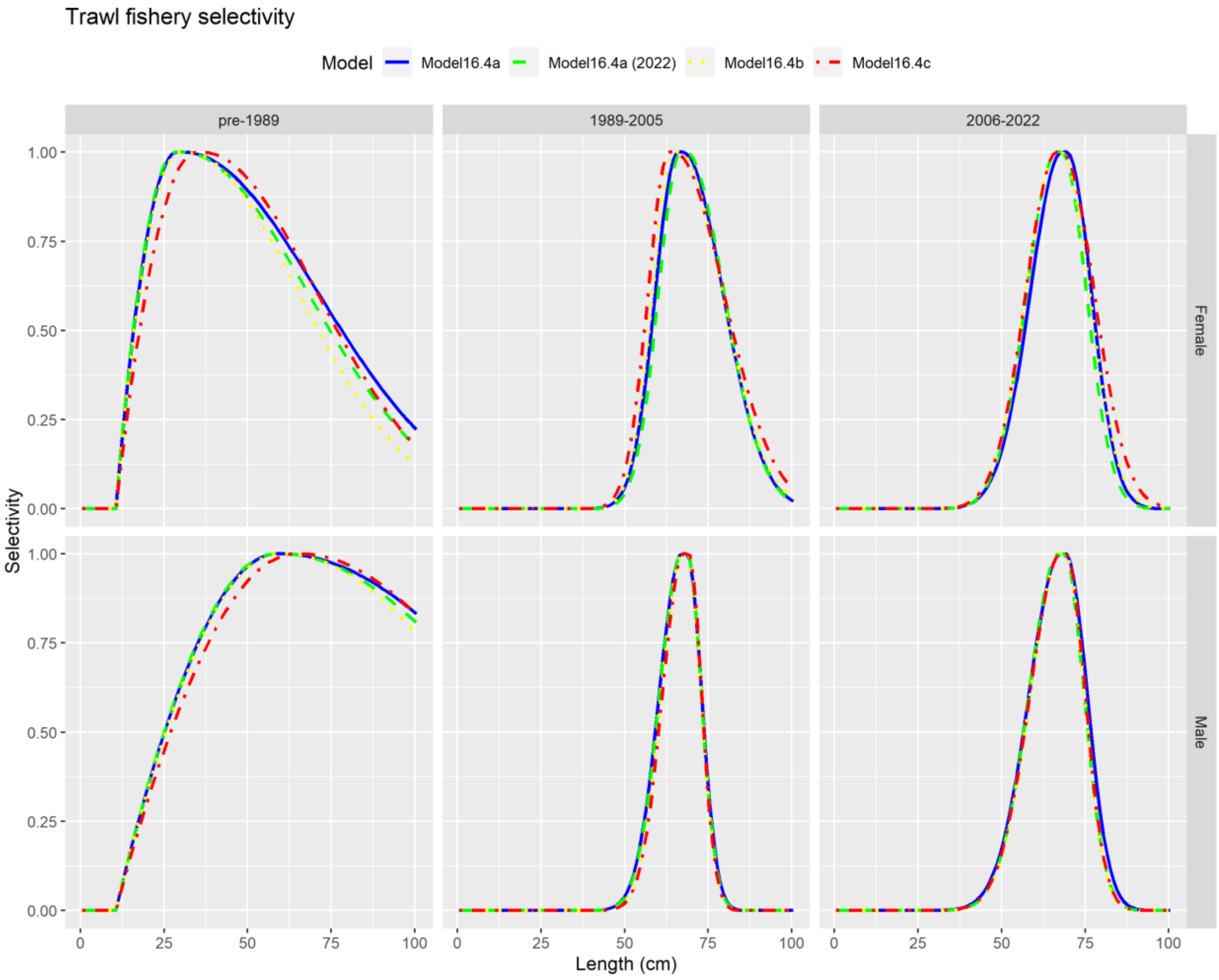


Figure 5.16. Time-varying selectivity at size for the trawl fishery for both sexes (

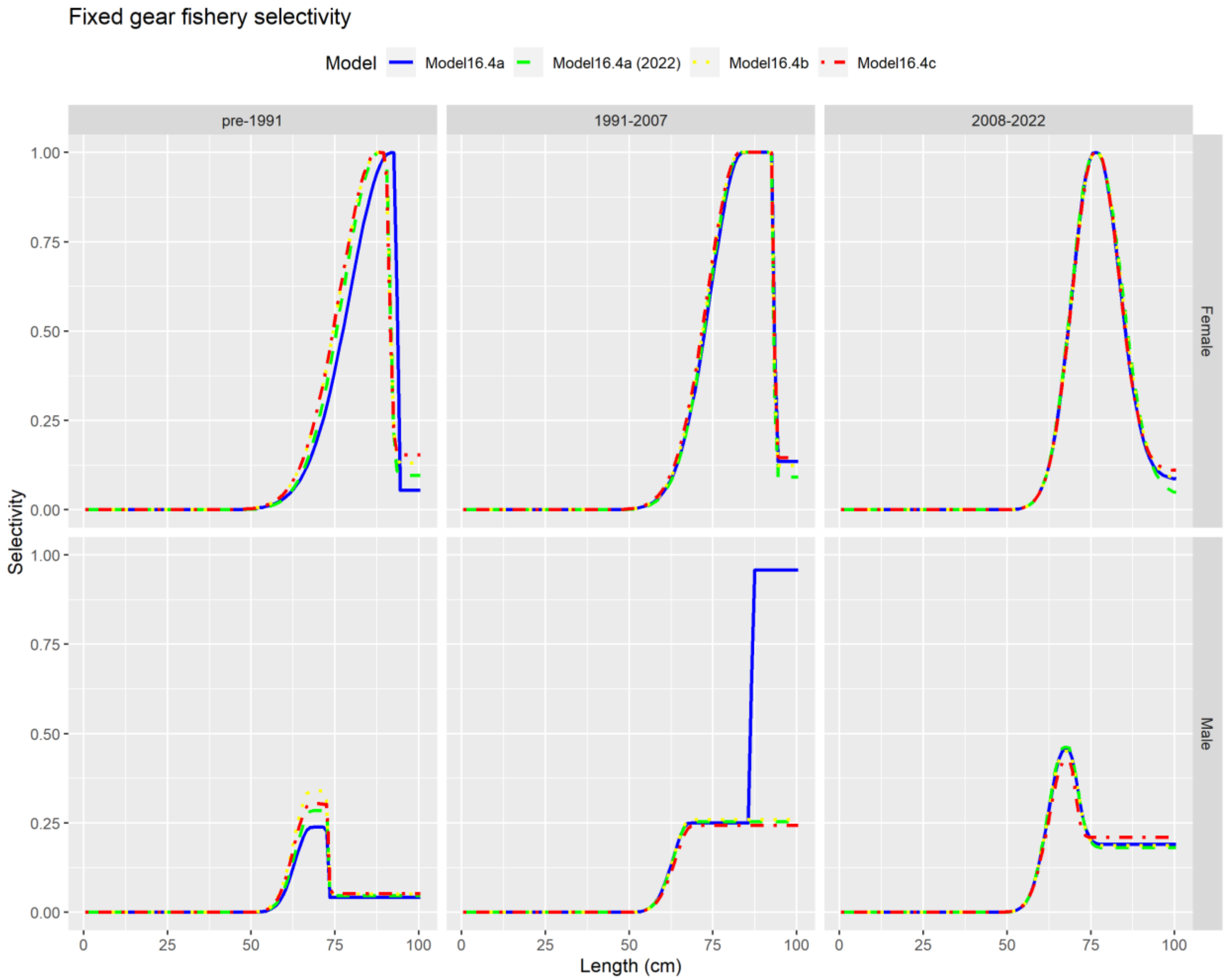


Figure 5.17. Time-varying selectivity at size for the longline fishery for both.

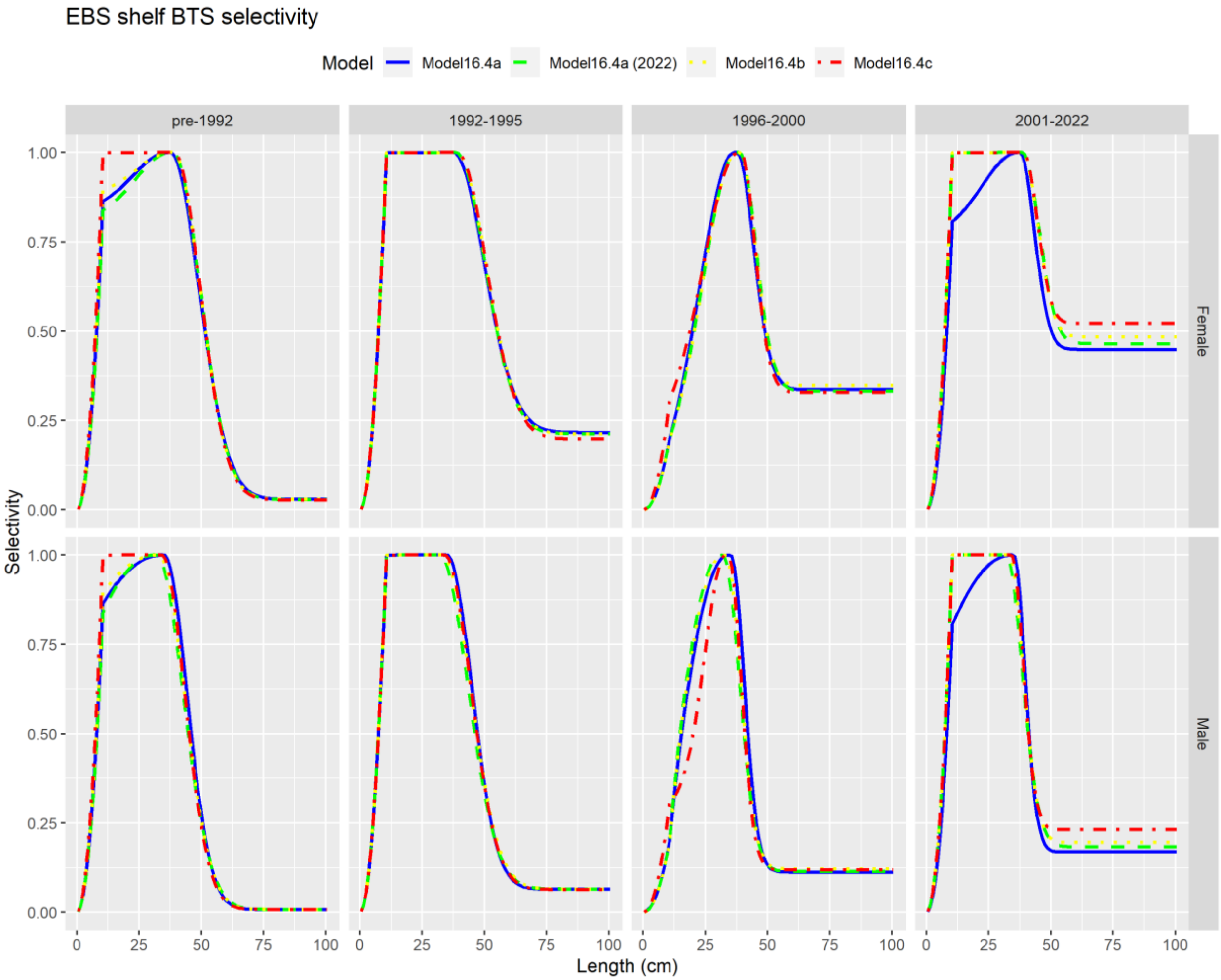


Figure 5.18. Time-varying selectivity at size for the shelf survey.

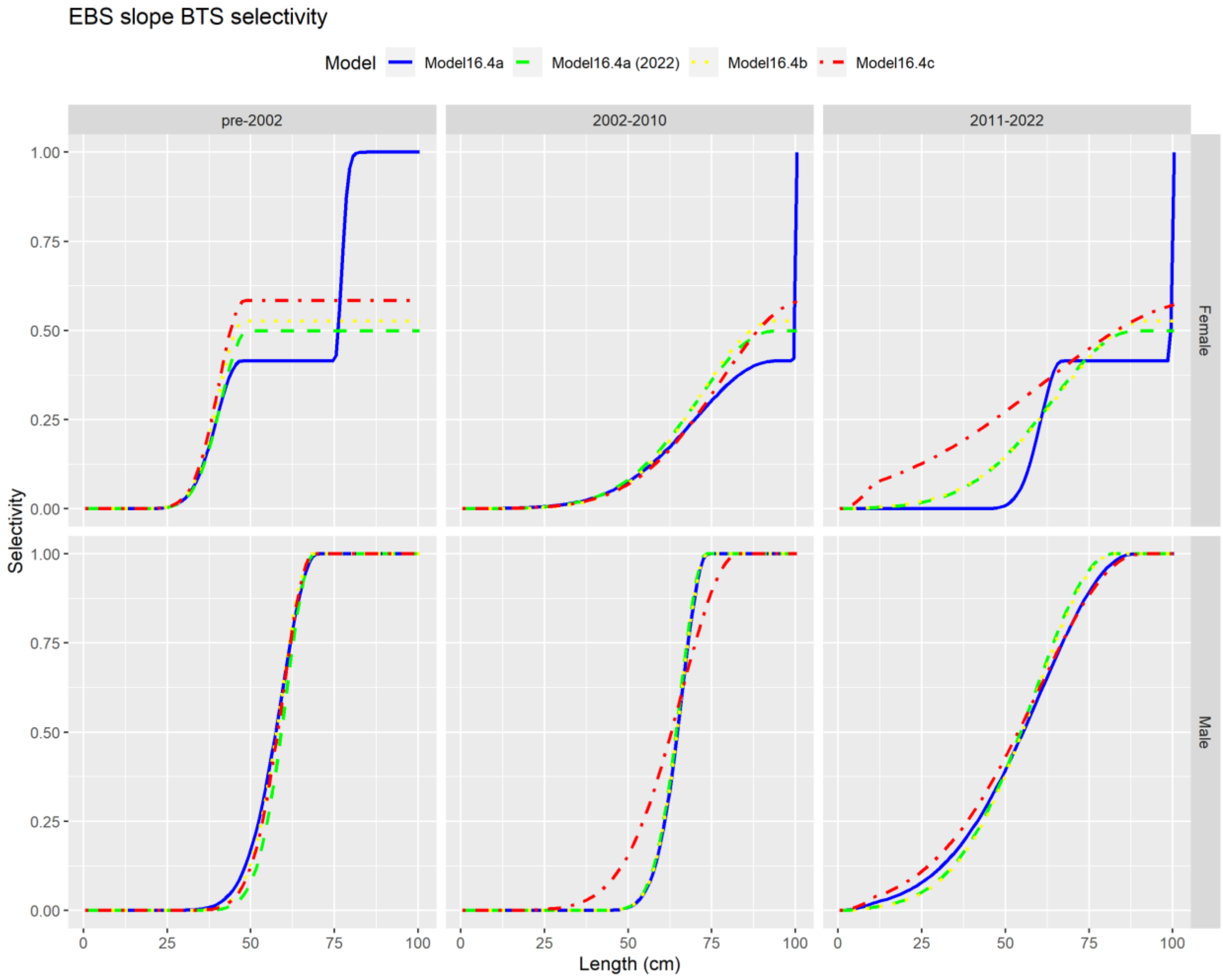


Figure 5.19. Time-varying selectivity at size for the slope survey.

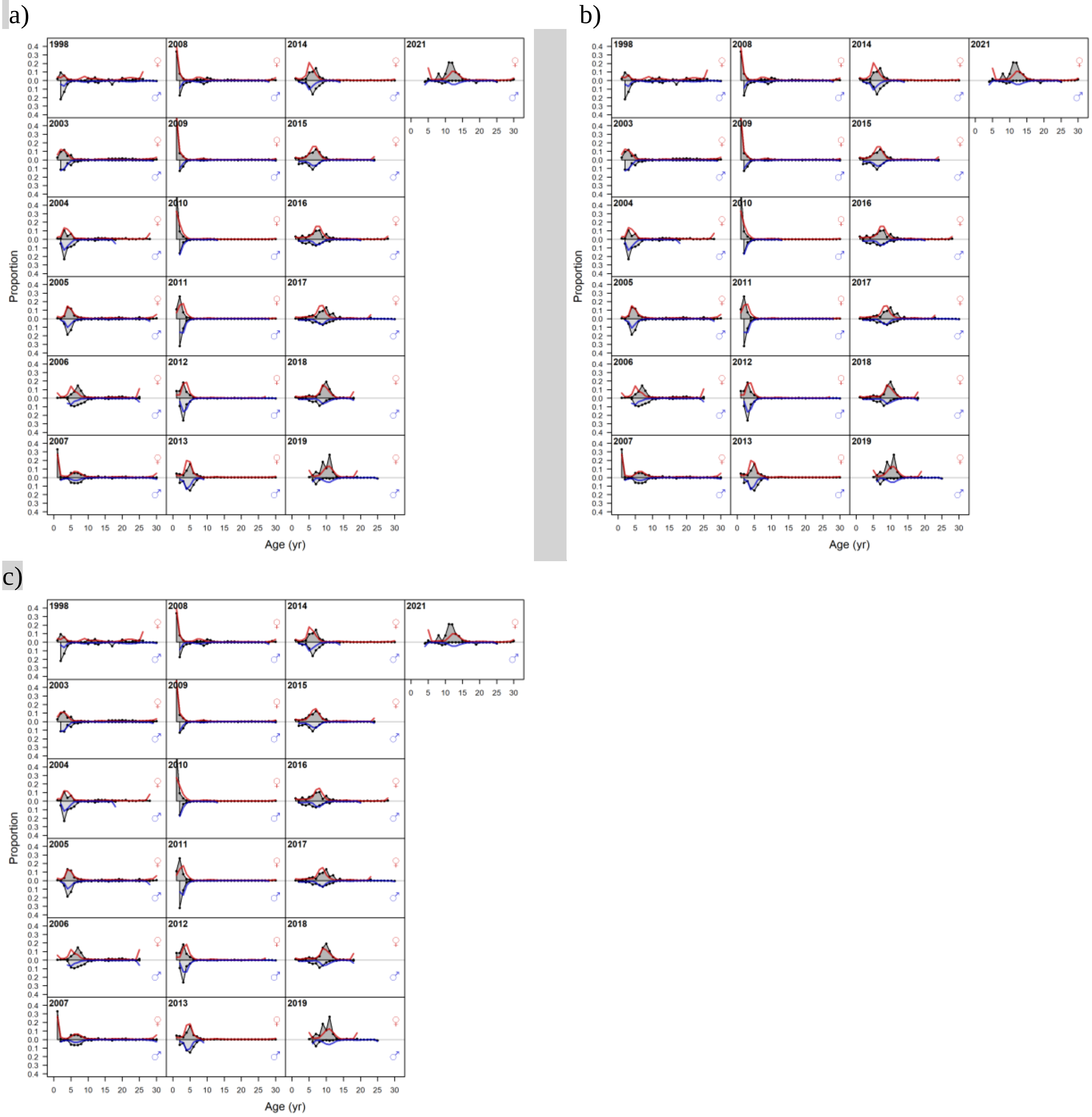


Figure 5.20. EBS shelf survey age composition data and model fits (red and blue line). Data were included as "ghost" data and not included in the likelihood. a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c

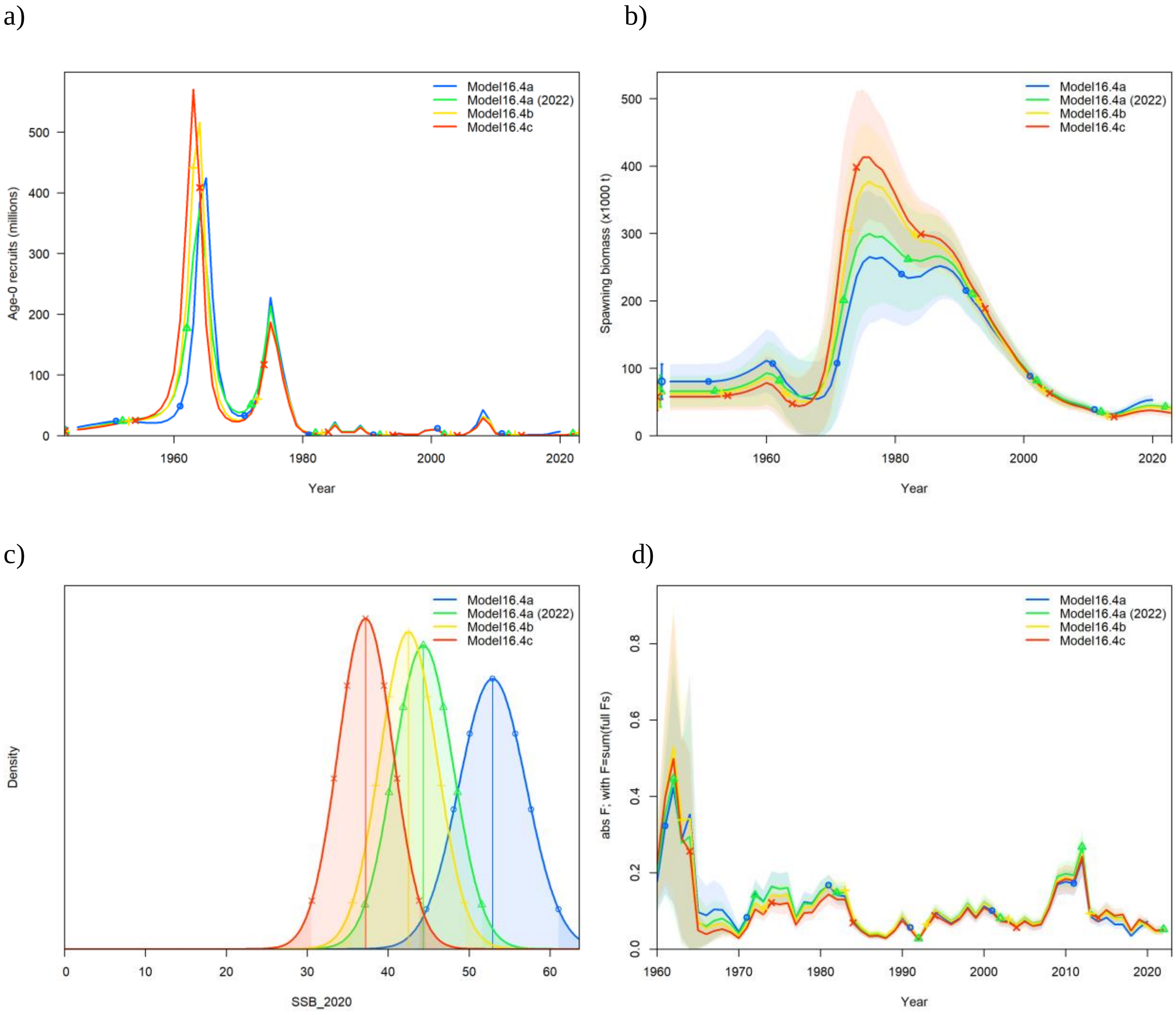
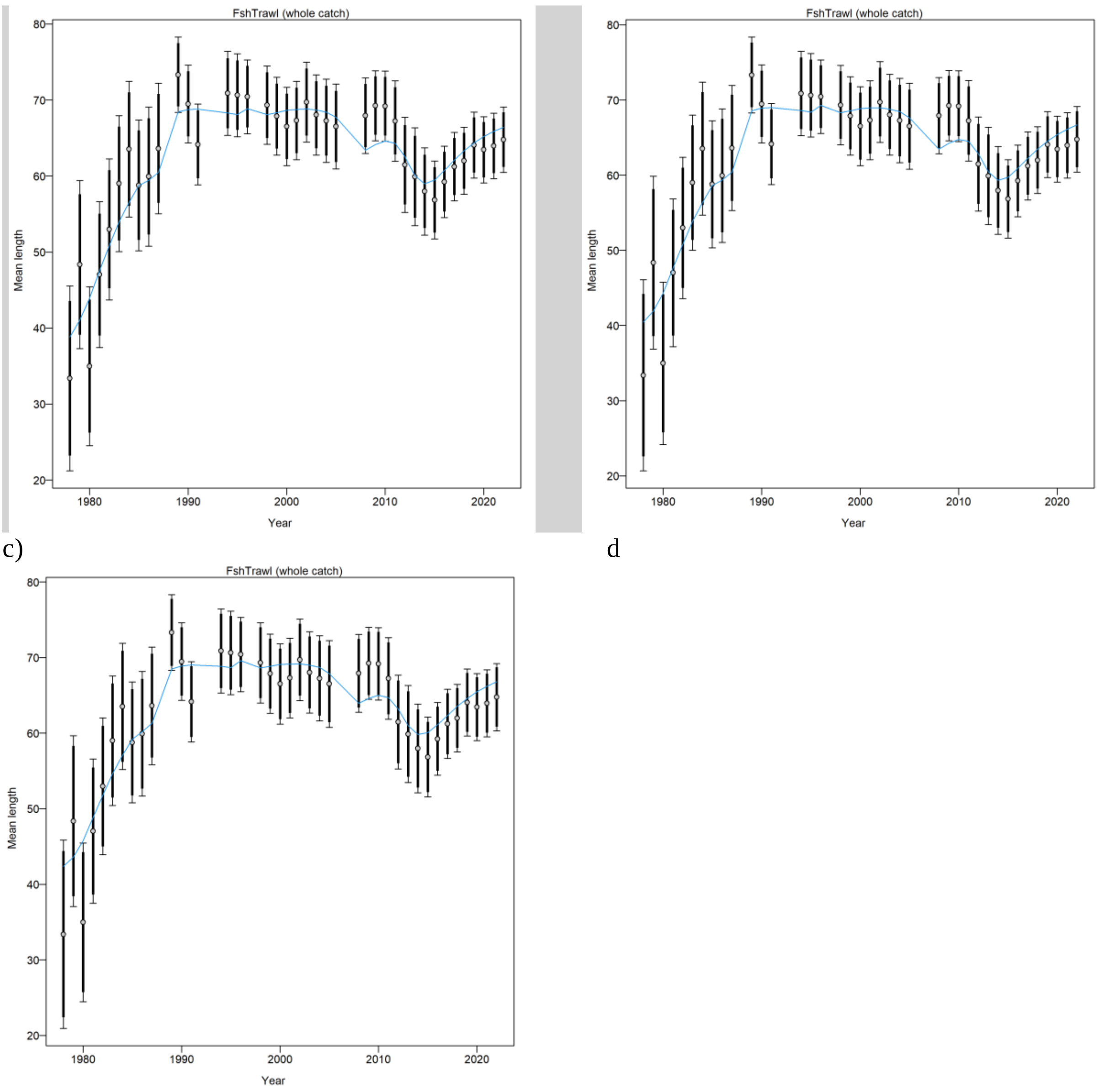


Figure 5.21. a) Age-0 recruitment, b) female spawning biomass, c) the posterior density of spawning biomass in 2020, and d) fishing mortality for models 16.4a (2020), 16.4a (2022), 16.4b, and 16.4c.



a)

b)

c)

d

Figure 5.22. Observed and expected mean length from the trawl fishery, a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c.

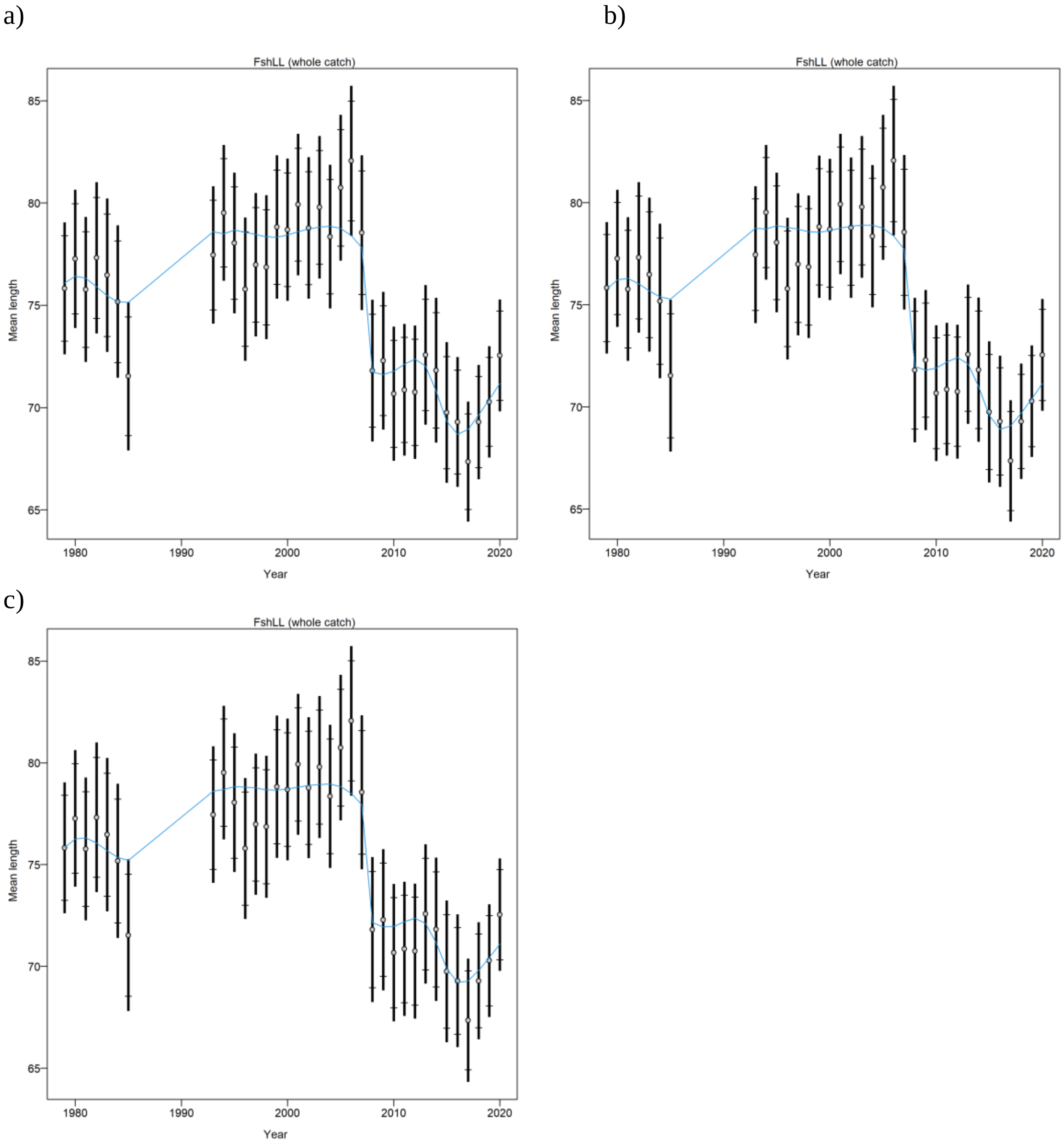
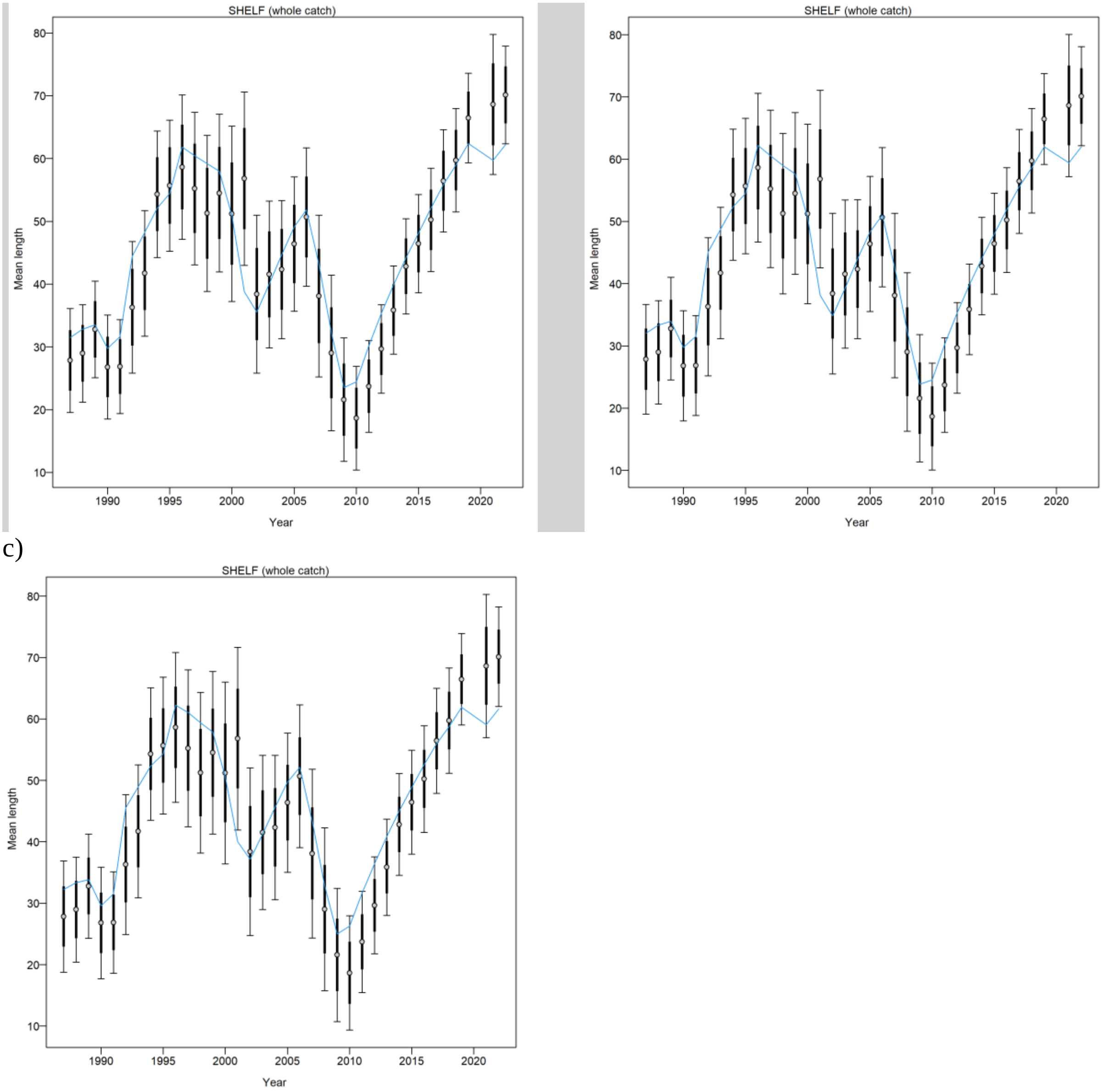


Figure 5.23. Observed and expected mean length from the longline fishery, a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c.



a) b) c)

Figure 5.24. Observed and expected mean length from the shelf survey, a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c.

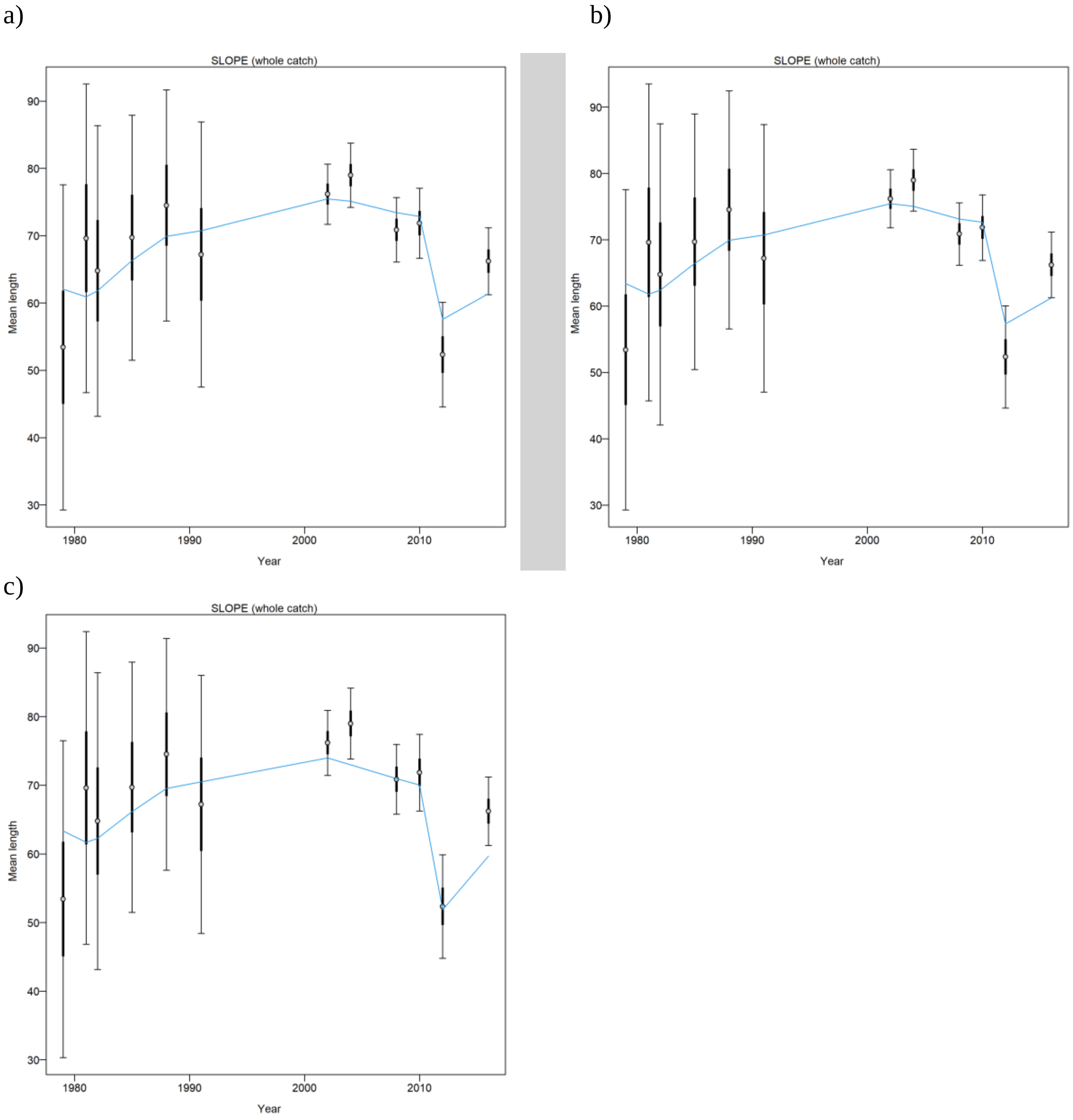


Figure 5.25. Observed and expected mean length from the slope trawl survey, a) Model 16.4a, b) Model 16.4b, and c) Model 16.4c.

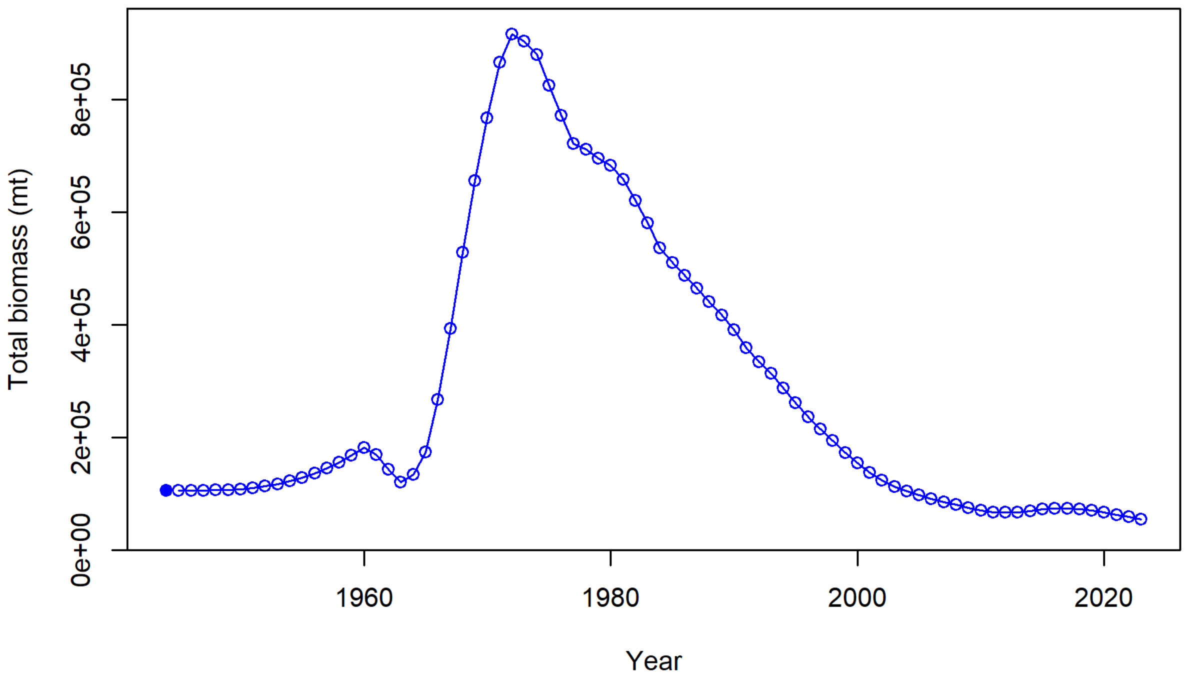


Figure 5.26. Total biomass estimate from Model 16.4c.

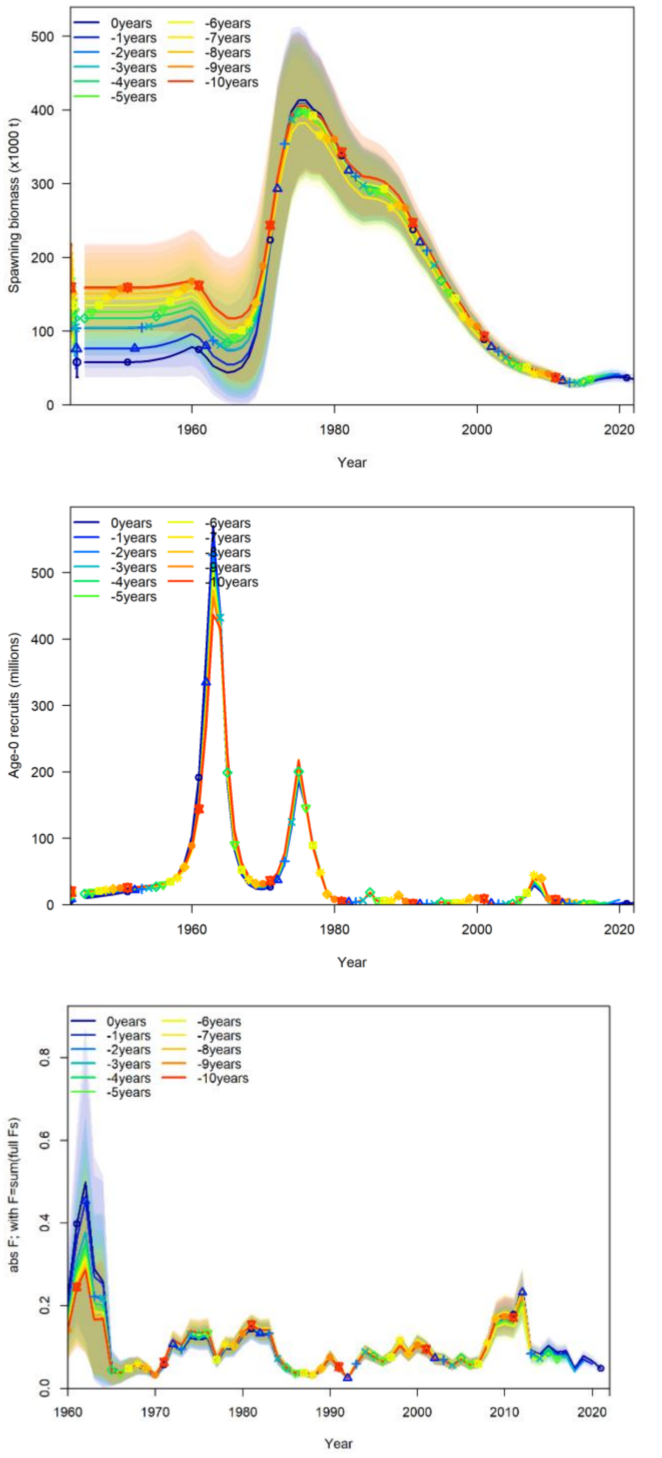


Figure 5.27. Retrospective plots of female spawning biomass (top), age-0 recruits (middle), and fishing mortality (bottom) with data sequentially removed from 2022 to 2012.

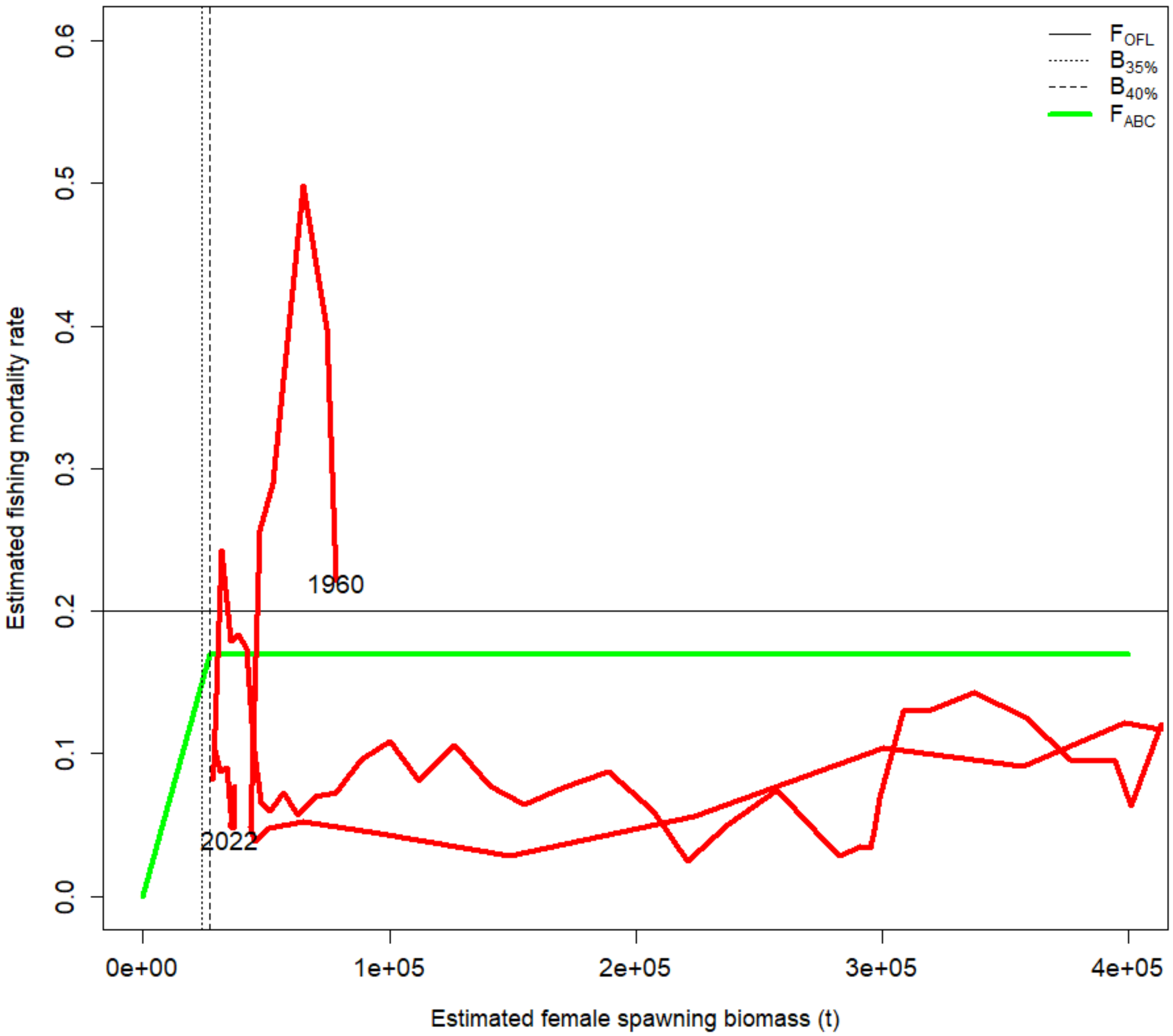


Figure 5.28. Ratio of historical fishing mortality versus female spawning biomass for BSAI Greenland turbot, 1960-2022, Model 16.4c. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets

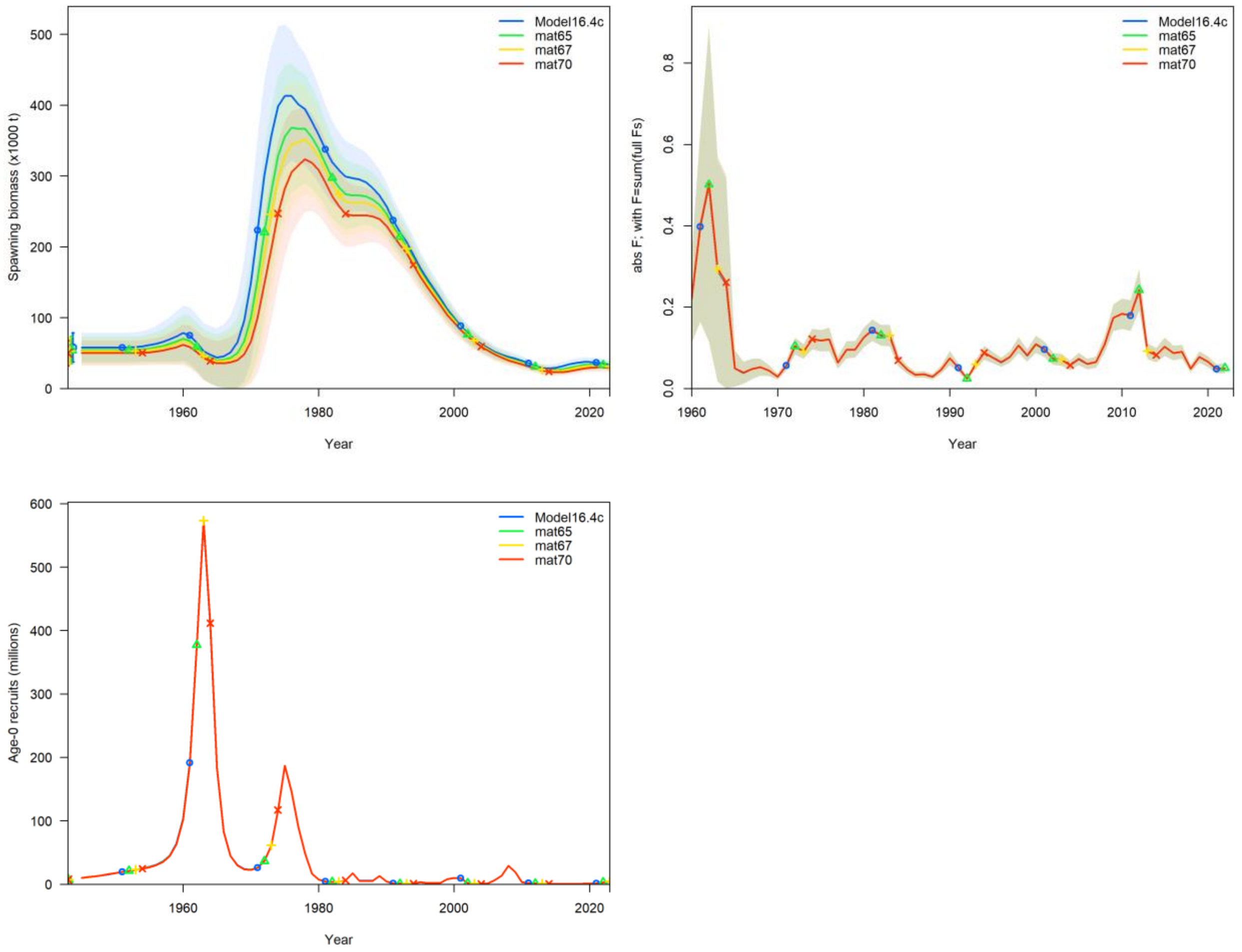


Figure 5.29. Spawning stock biomass (top left), fishing mortality (top right), and recruitment (bottom left) from the recommended model (Model 16.4c) and the model runs from the maturity at age sensitivity analysis.