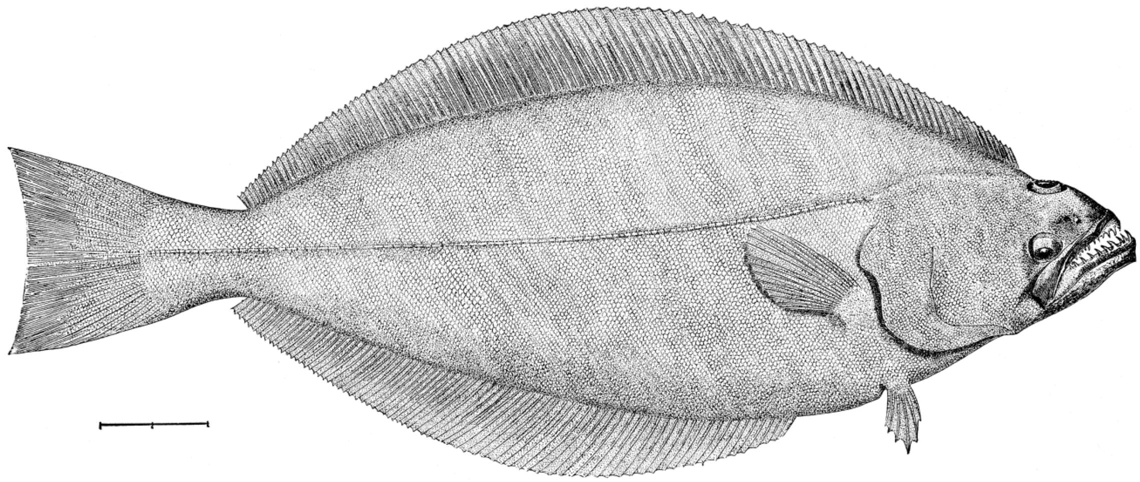
5. Assessment of the Greenland turbot stock in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

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November, 2020

Executive Summary

Summary of Changes in Assessment Inputs

New data for the assessment included the 2019 NMFS shelf bottom trawl survey biomass estimates and size compositions and the Alaska Fisheries Science Center (AFSC) longline survey biomass estimates for 2019 and 2020. Size at age data from the 2018 and 2019 NMFS shelf bottom trawl surveys were also available and were used in this assessment. Fishery catch estimates were also updated and include a preliminary estimate for 2020. Data on fishery size composition from 2019 and 2020 were also included.

Changes in the model

The base model has the same configuration as the 2016 (model 16.4 in Barbeaux et al. 2016) and 2018 (model 16.1b in Bryan et al. 2018) assessments, except for the specified units of AFSC longline index. The AFSC longline relative population numbers (RPNs) are used as an assessment input. In Stock Synthesis, the units (i.e., numbers, weight, fishing mortality, etc.) of the index is explicitly specified. In previous assessments, the specified units for the AFSC longline RPNs were in units of biomass. This was corrected and had minimal impacts on the assessment model results.

The model number used in the 2018 assessment was also in error. Reverting back to the 2016 model nomenclature the current model number is 16.4a (2020) to represent this minor change and the 2018 assessment is referred to as 16.4 (2018) throughout the report.

Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *recommended this* year* for: 2021	2022
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3a	3a	3a	3a
Projected total (age 1+)	106,101	98,532	87,849	79,382
Female spawning biomass	57,094	53,617	51,914	47,197
Projected				
$B_{100\%}$	90,534	90,534	89,054	89,054
$B_{40\%}$	36,213	36,213	35,622	35,622
$B_{35\%}$	31,687	31,687	31,169	31,169
F_{OFL}	0.21	0.21	0.22	0.22
$maxF_{ABC}$	0.18	0.18	0.18	0.18
F_{ABC}	0.18	0.18	0.18	0.18
OFL (t)	11,319	10,006	8,568	7,181
maxABC (t)	9,625	8,510	7,326	6,139
ABC (t)	9,625	8,510	7,326	6,139
Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
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 16.4a (2020) and preliminary catches of 3,321 t was used in place of maximum permissible ABC for 2020. The preliminary catch for 2020 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2015-2019) and the 2020 TAC. The 2021 catch was set equal to max ABC as has been done in the previous Greenland turbot assessments.*

Responses to SSC and Plan Team Comments on Assessments in General

Note: Given the time constraints posed by this year's meeting schedule, the SSC co-chairs have suggested that authors not feel obligated to respond to all of last year's SSC and Team comments in this year's assessments.

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

"…risk tables only need to be produced for goundfish 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 do not recommend ABC be reduced below maximum permissible ABC.

Responses to SSC and Plan Team Comments Specific to this Assessment

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

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.

For November, the Team recommends that the author bring forward the following models: 1) 16.1 2) 16.1b with selectivity estimated 3) 16.1b with environmental covariates included to help explain selectivities. (Plan Team, September 2018)

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. The area of highest density of Greenland turbot in the Pacific Ocean is in the northern Bering Sea. 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; Fig. 5.2). 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) (In Barbeaux et al. (2015): Figure 5.3, Figure 5.4, Figure 5.5, and Figure 5.6). It appears that for years with above average bottom trawl bottom temperatures the larger turbot (> 20 cm) are found at shallower depths (In Barbeaux et al. (2015): Figure 5.7).

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 thousands of kilometers and spend summer periods in deep water in some years and in other years spend time on the shallower EBS shelf region.

Greenland turbot are sexually dimorphic with females achieving a larger maximum size and having a faster growth rate. Data from the AFSC slope and shelf surveys were pooled to obtain weight at length (Figure 5.3). and growth parameters for both male and female Greenland turbot. 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.

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. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Figure 5.4). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 5.1). Trawl harvest declined steadily after 1983 and has remained low. Total catch also declined; however, longline catch started to increase after 1990. The overall decline is due mainly to catch restrictions placed on the fishery 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). For 2013 the 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 2014 ABC remained low at 2,124 t with a total catch of 1,656 t. In 2015, the ABC increased to 3,172 t, but the TAC was limited to 2,648 t and total catch was 2,204 t. 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. The ABC and TAC were increased again in 2018 to 11,132 t and 5,294 and the final catch was 1,835 t. The 2019 ABC was reduced to 9, 658 t and the TAC was 5,294 t. The 2020 ABC and TAC were similar to 2019 and were 9,625 t and 5,300 t, respectively. The fishery generally captures a high proportion of the ABC and TAC annually, with a low of 16% and 35%, respectively, in 2018 (Table 5.2). Approximately 30% and 54% of the ABC and TAC were captured in 2019.

The majority of the catch over time has been concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (Figure 5. 5 and Figure 5. 6), but Greenland turbot has been consistently caught in the shallow water on the shelf as bycatch in the trawl fisheries (Table 5.3 and Table 5.4). 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 (Figure 5.9 from 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 5.3)

For the domestic fishery 1995-2006 the majority (~2/3) of Greenland turbot catch was from the longline fishery. In 2007-2009 and 2012-2014, trawl-caught Greenland turbot exceeded the level of catch by longline vessels (Table 5.4). 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 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 sudden 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 5.13 from Barbeaux et al. 2015). 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. 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 84% 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 23% in 2013 and 20% in 2014. The overall discard rate in 2013 and 2014 were 19% and 17%, respectively. The discard rate appears to have dropped in 2015 and 2016 as Greenland turbot from the more recent abundant year classes migrate off the shelf and out of the range of the shallow water fisheries. The discard rate was 5.8% in 2016, was 4% between 2016 and 2018, and 2% in 2019.

Greenland turbot catch in the Aleutian Islands through 2007 was similar between trawl and longline, since 2008 the majority of Greenland turbot in the Aleutian Islands has been caught by trawl (Table 5.5). Catch of Greenland turbot in the Aleutian Islands declined between 2012 and 2019. In the domestic EBS fishery catch of Greenland turbot was predominantly from the longline fishery except for 1991,1994, 2008, 2013, and 2014 - 2018 (Table 5.3). In 2015 the longline fishery caught 1,093 t and the trawl fishery 999 t. In 2016 the EBS trawl fishery has caught a larger share of EBS quota than longliners (1,122 t vs. 955 t). This trend continued through 2020.

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. The Alaska Fisheries Science Center (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 5.6 and Figure 5.9.

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

Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2020. The length composition data from the trawl and longline fishery are presented in Figure 5.11. The absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2020 are given in Table 5.7.

EBS slope and shelf surveys

There are two bottom trawl surveys included in the Greenland turbot stock assessment. The EBS shelf survey provides abundance estimates of juveniles on the EBS shelf and slope survey provides estimates of older juvenile and adult abundance on the EBS slope (Figure 5.10). 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, and 2012 (Table 5.8). 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. 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) averaged 55,000 t, with a 2004 level of 57,500 t. Although the 2012 EBS slope biomass estimate of 17,984 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. 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 5.9 and Table 5.10). In the 200-400 m strata the population was more than 8 times that of the 2010 survey estimate and the 400-600 m strata was more than double the 2010 estimate. The high numbers and low biomass results are a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007 through 2010 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Figure 5.11).

In the 2016 slope survey Greenland turbot biomass increased to 23,573 t. 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 in Area 6. 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. 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 5.7). From 1987 to 1994 the index shows an increase in biomass to an all-time peak of 57,181 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 10,953t as recruitment remained low throughout the 1990s with only a slight improvement in 1999-2001. In 2010 the index increased to 23,414 t and has since remained relatively stable, between 21,000 t and 28,000 t. The average shelf-survey biomass estimate during the last 20 years (1995-2016) was 25,415 t. Biomass declined in 2018 to 18,017 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys were presented in Table 5.11. 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 5.7, Figure 5.10). 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. The 2014-2018 surveys show a decline in the abundance as the 2007-2010 year classes migrate off the shelf survey area with little replacement from new recruitment (Figure 5.10 and Figure 5.11). The shelf survey biomass has been declining since 2014 and was at 18,017 t in 2018 and 16, 053 t in 2019. The shelf biomass decreased by 11% in 2019 and has declined by 43% since 2014. The numbers of Greenland turbot have been steadily declining since 2011 (Table 5.10).

Survey size composition

A time series of estimated size composition of the population was available for both surveys. The slope survey typically samples more turbot than the shelf trawl survey; consequently, the number of fish measured in the slope surveys is greater. 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 5.11). The progression of the 2007-2011 year classes and the lack of any substantial new recruitment into the area are evident in the 2012-2019 length estimates. In 2019 all measured Greenland turbot were greater than 40cm. The length data from the AFSC's longline survey was included in the model, but not included in the likelihood function (Figure 5.12).

Survey length-at-age used for estimating growth and growth variability were previously available from 1982, 1998, and 2003-2017. Gregg et al. (2006) revised age-determination methods for Greenland turbot and although shelf survey age composition data from 1998 and 2003-2017 were included in the model, they were not included in the likelihood function (Figure 5.13). 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 on the shelf.

Aleutian Islands survey

The 2018 Aleutian Islands bottom trawl survey continued the decline in biomass and declined to 373 t from 2,378 t in 2016 and 2,529 in 2014, well below the 1991-2012 average level of 12,598 t (Table 5.12). 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. 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 low in 2014 at 490 t (19% of AI biomass) followed by an increase to 970t in 2016. We are not certain why there was such a dramatic decline in the Greenland turbot abundance estimate in the Aleutian Islands trawl survey since 2012. 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 Table 5.13 was used as a relative abundance index. It was computed by taking the average RPN from 1996-2020 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 (1996-2016) 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 5.14. 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. In all previous modeling efforts the fit to the AFSC longline size composition data has been rather poor, Valero et al. (2015) in CAPAM's "Good Practices Guide – Selectivity" suggest these data be excluded from the model. For these reasons the assessment does not include the longline size composition data. We plan to further investigate the effects of depredation on this index and evaluate the reasons for poor fits to the size composition data.

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.

Total catch estimates used in the model were from 1960 to 2020. 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 5.5). One minor change was made to the model this year. In Stock Synthesis, the units of survey indices are specified as numbers, biomass, etc. The AFSC longline survey index is an abundance index and should be specified in units of numbers. In previous assessments, it was specified in units of biomass. This has been corrected in this assessment. There was little impact of this change on the assessment model results. The model also uses the Beverton-Holt stock-recruitment curve, and the early recruitment series is carried back to 1945.

Parameters estimated independently

All independently estimated parameters were the same for the two models presented.

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 5.14 and Table 5.15.

Maturation and fecundity

Maturity and fecundity followed the same assumptions as the 2018 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 analysis, 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 5.16).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 (2020)
Recruitment		
	Early Rec. Devs	(1945-1970) 25
	Main Rec. Devs	(1970-2015) 46
	Future Rec. Devs	(2016-2020) 5
	R_0	1
	Autocorrelation ρ	1
Naural mortality		
	Male	0
	Female	0
Growth		
	L_{min} (M and F)	2
	L_{max} (M and F)	2
	Von Bert K (M and F)	2
Catchability		
	q_{shelf}	0
	q_{slope}	0
	q_{ABL}	1
Selectivity		
	Trawl fishery	15
	Longline fishery	28
	Shelf survey	17
	Slope survey	19
	AFSC longline survey	0
	Total Parameters	164

Recruitment and initial conditions

Because there was a large fishery on this stock prior to there being size or age composition data available (1960 – 1977), constraints on recruitment estimation were needed for these earlier years. Previous analyses without constraints resulted in a single, unrealistically large recruitment event being estimated. It seems more probable that the year classes that contributed to the large catches were more diverse (i.e., that a period of good year classes contributed to the biomass that was removed). Consequently, the 2011 assessment was configured to have an estimated R_0 during 1960 through 1969 that differed from the latter period. This resulted in a different mean recruitment being assumed for years 1960 through 1969 and 1970 through 2010 and an assumption of higher productivity in these early years.

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. The length at 50% selectivity and the slope parameter were set equal to 63.5993cm and 5.0955, respectively.

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 - 2020
EBS slope survey	1945 – 2001	2002 – 2010	2011 - 2020
Trawl fishery	1945 – 1988	1989 – 2005	2006 - 2020
Longline fishery	1945 – 1990	1991 – 2007	2008 - 2020

Results

Model Evaluation

The model presented here is the same as the 2018 assessment model, Model 16.4, with one correction, the AFSC longline survey index is specified in numbers rather than biomass and is referred to as Model 16.4a (2020). This correction is appropriate and needed, therefore **Model 16.4a (2020) is the**

recommended model for the current assessment cycle. As such, the model was compared to the 2018 assessment, Model 16.4 (2018), results. Additionally, since a correction was made to the assessment model, a model run was completed using the data from the 2018 assessment to separate its impact of this change from the addition of new data and is referred to as Model 16.4a.

Table 5.17 summarizes the total likelihood and likelihood components for each model run. The likelihood results indicate that Model 16.4a is an improvement on Model 16.4, which is not unexpected since the units of the AFSC longline survey index are correctly specified. This is mainly due to an improvement in the length composition likelihood for Model 16.4a. The likelihood components associated with the shelf survey data improved across the board and improvements were seen in the length composition components associated with the trawl fishery and slope survey. The survey likelihoods for the slope and AFSC longline increased, as did the RMSE (Table 5.18). With the addition of new data (Model 16.4a (2020), the likelihood results for the slope survey and slope length composition increased, indicating the model is fitting these data less well as other time series continue over time.

The parameter estimates for growth and recruitment were similar between model 16.4 (2018), model 16.4a, and model 16.4a (2020) (Table 5.19). The one notable exception is the AFSC longline survey log catchability, which increased substantially. With this change in catchability there were also some subtle differences in selectivity, which will be discussed later.

Model 16.4a’s (2020) fit to the AFSC longline survey is similar to the last assessment and predicted the declining trend in the AFSC longline index, the leveling off between 2011 and 2015, and the increase in 2017 (Figure 5.14). The model generally underestimates the earlier high numbers and overestimates the last few years of the time-series. The model fit to the shelf survey biomass is generally adequate (Figure 5.14). 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.

Model 16.4a’s (2020) fit to the mean size-at-age data is shows similar patterns in the residuals as the previous assessment; however, the fit is slightly better (Figure 5.15). 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. It is noticeable that the male length distributions have a narrower range than the females (Figure 5.16). The fits to the length data were generally adequate (Figure 5.16). The estimated selectivity informed by these data all used a double normal pattern that allowed for dome-shaped selectivity (Figures 5.18 – 5.21).

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 (Figure 5.20). Notably, the models underestimate cohorts from the early 1990s, ~1997, and 2010 (Figure 5.17).

The slope survey size composition selectivity was modeled with a double normal pattern with three time blocks. Selectivity for females was offset from males. The fits continued to underestimate the peak of the distribution and overestimated the highest abundance size bins, particularly for males (Figure 5.16 and Figure 5.17).

The model fit the male length distribution from the longline fishery quite well, but generally underestimated the peak of the female distribution, especially early in the time series (late 1970s and early 1980s) (Figure 5.17). The estimated selectivity curve covering this time period has a dome-shape, but is skewed toward larger turbot, which may help to explain this underestimation (Figure 5.19).

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 5.22). 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 5.23 shows the resulting estimates of recruitment, spawning biomass, the spawning biomass posterior density in 2018 (because Model 16.4a (2020) is being compared to models 16.4 and 16.4a that hve a terminal year of 2018), and apical fishing mortality. Certainty bounds were the standard errors obtained from the inverted Hessian matrix. Tables 5.20 also summarizes these results.

The trends in recruitment, spawning biomass, and fishing mortality were similar between Model 16.4 and Model 16.4a (Figure 5.23). Minor differences included a dampened peak in recruitment during the mid-1960s The peak in recruitment in the mid-1960s was dampened slightly for Model 16.4a and spawning biomass was lower between years 1972 and 1993 for Model 16.4a. The differences occur mainly in the most uncertain portion of the time series, when the data providing information to the model is from the fishery only. Differences between the assessment outcomes from Model 16.4 (2018) and Model 16.4a (2020) were due to the model correction and the inclusion of new data. Similar to Model 16.4a, the largest differences between the last assessment and Model 16.4a (2020) occurs over the time period with greatest uncertainty. The majority of key parameter estimates differed minimally among the models; however, catchability increased and in turn the selectivity differed and was dependent on the data source and time block (Table 5.19, Figures 5.18 – 5.21). In 2018, the authors presented MCMC results indicating that many selectivity parameters were not well determined and could be estimated over a wide range of values that trade-off with catchability and lead to similar results.

Time Series Results

In this section we present the time series results from Model 16.4a (2020) 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 16.4a (2020) fits an autocorrelation parameter for the recruitment deviations with a prior of 0.473 and standard deviation of the prior of 0.265. The posterior autocorrelation parameter has a value of 0.63 with a standard deviation of 0.03. The model predicts extremely large recruitments in 1963- 1967 with between 108 and 424 million age-0 recruits (Table 5.20 and Table 5.24). 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 predicts another large recruitment event in 1974-1977 with an average recruitment of 156 million age-0 fish for these four years with a maximum of 227 million age-0 fish in 1975 (Table 5.20, Figure 5.23). 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. It should be noted that in the projection model used for determining the reference points and setting catch levels, we use age-1 recruitment and the numbers-at-age (age-1 through age 30) from1978 onward.

Recruitment from 1980 through 2006 was low with a mean of 4.9 million age-0 fish. Recruitment of age-0 fish was estimated to be 18.4 million, 42.5 million, 26.3 million, and 4.5 million age-0 fish in 2007, 2008, 2009, and 2010, respectively. 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 (Figure 5.11). 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 (Figures 5.24 and 5.25). The estimated numbers-at-age reflect the strong cohorts in the mid-1960s and late-1970s and from 2007-2010 (Table 5.21, Figure 5.25). Mean length from the longline fishery has been increasing since 2017. There was a noticeable lack of small turbot from the 2019 shelf survey and the mean size on the shelf has steadily increased since 2010 (Figure 5.11 and Figure 5.24). This indicates that there has been a lack of new Greenland turbot recruits on the EBS shelf in recent years.

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass in Model 16.4a (2020) was estimated to be 52,902 t in 2020, which has been increasing from a low of 32,020 t in 2013 (Tables 5.22 and 5.23). The large early 1980s fishery combined with a lack of good recruitment in the mid- to late-1980s and through the 1990s drove the steepest part of the decline in spawning biomass. The mean age-0 recruitment for 1986 to 1999 was 4.1 million fish (43% of the overall 1977-2020 mean recruitment). 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 5.22). The fishing mortality increased between 2008 and 2012 and ranged between 0.18 and 0.24. The effects of the incoming 2007-2009 year classes have created an increase in the female spawning biomass estimates. The projections suggest that spawning biomass will start to decline in 2021(this assumes catch in 2021 is set equal to max ABC, Table 5.25).

The Model 16.4a (2020) total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 of 735,423 t to its lowest point in 2011 of 73,546 t (Table 5.22, Figure 5.26). Since its low point in 2010 total age-1+ biomass is projected to have increased to 98,487 t in 2017 and has slowly declined to 93,849 t in 2020 (Table 5.22). Numbers are also showing declines (Table 5.21, Figure 5.25).

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 positive retrospective bias as data are removed from the model for spawning biomass and recruitment. Data added to the model tends to dampen the strength of the 2007 and 2010 year classes. The Mohn's rho estimate associated with spawning biomass for model 16.4a (2020) was 0.04, which is within the accepted range following Hurtado-Ferro et al. (2014).

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean recruitment estimated for the period 1978-2018 gives a long-term average female spawning biomass of 35,622 t. The estimated 2021 female spawning biomass was at 51,914 t, which is above $B_{40\%}$ and above the estimate of $B_{35\%}$ (31,169 t). Because the projected spawning biomass in year 2021 (51,914 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 5.11). There was also evidence of this recruitment event in the slope data in 2012 and 2016; however, there is no evidence of a good recruitment event after 2010 (Figure 5.11). 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
2021	7,326	7,326	8,568	51,914
2022	6,139	6,139	7,181	47,197

The 2021 estimated overfishing level based on the adjusted $F_{35\%}$ rate is 8,568 t corresponding to a full-selection F of 0.22. 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 5.4).

Stock structure between regions remains uncertain and therefore the policy has been to harvest the "stock" evenly 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%, 12.6%, and 9% and their average is 15.7% (see Table 5.7 for survey biomass estimates). 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:

	2021 ABC	2022 ABC
Aleutian Islands ABC	1150	964
Eastern Bering Sea ABC	6176	5175
Total	7326	6139

<u>Standard harvest scenarios and projections</u>

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 2020 numbers at age estimated in the assessment (age-1+). This vector is then projected forward to the beginning of 2021 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2020 (here assumed to be 3,321 t.). 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 2021, 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 the author's recommend level. Due to current conditions of strong recruitment and a projected increasing biomass, the recommendation is set equal to the maximum permissible ABC.

Scenario 3: In all future years, F is set equal to 50% of $max\ F_{ABC}$. (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 4: In all future years, F is set equal to the 2015-2019 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 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 2021 and 2022, 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 2022 or 2) above 1/2 of its MSY level in 2022 and expected to be above its MSY level in 2030 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 14 years from 2021 (Table 5.25). Fishing at the maximum permissible rate (scenarios 1 and 2) indicate that the spawning stock will decline after 2021, fall below $B_{40\%}$ in 2025, and fall below $B_{35\%}$ in 2026.

Risk Table and ABC Recommendation

<u>Overview</u>

"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 uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	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., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

	considered unreliable.	seen previously, or a very long stretch of poor recruitment compared to previous patterns.	effects on other ecosystem components	

"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. There are some patterns in the length composition residuals indicating some non-stationarity or model mis-specification that have been known properties of the model for some time.

Uncertainty due to missing the EBS slope bottom trawl survey has also 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 assessment model results due to missing the most recent EBS shelf bottom trawl survey was evaluated in Bryan et al. (2020). They found that the direction and magnitude of retrospective bias was an important determinant in the level of expected uncertainty in our stock assessment results. Notably, EBS snow crab exhibited a large, positive retrospective bias and uncertainty was greatest in its stock assessment outcomes. The Greenland turbot assessment exhibits a positive retrospective bias that is much smaller in comparison to EBS snow crab. Therefore, uncertainty is expected to be larger due to missing the shelf survey, but missing this one year does not markedly increase our concern.

We scored this category as Level 1.

Population dynamics considerations

The current Greenland turbot population is dominated by year classes from 2007-2010. As these cohorts have grown and matured, we have seen an increase in total biomass and spawning biomass. However, they are now all fully vulnerable to the fishery and the recent survey data indicates very little to no new recruitment into the population. This stock is characterized by infrequent recruitment events in the past and this concern about a lack of recruitment is not new. Recruitment of this species is thought to be positively correlated with the cold pool extent and is expected to remain low given the general warming of the EBS. Since recruitment is thought to be influenced by environmental conditions, we score this category a Level 1 and address this concern in the Environmental/Ecosystem considerations.

Environmental/Ecosystem considerations

Greenland turbot are considered to be more cold sensitive and distributed at greater depth than similar species arrowtooth flounder and Kamchatka flounder. They are considered more of an Arctic species, but the Northern Bering Sea (NBS) is thought to be shallow enough to create 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. In contrast to the previous 2 years, the 2020 cold pool on the shelf was modeled to be close to average in spatial extent, reflecting the sea ice that built up to mean extent before breaking up rapidly in mid-March. Winter sea surface temperatures in both the EBS and NBS were close to the mean during winter, but warmed to well above the mean during summer. Thus temperature signals do not indicate adverse conditions for turbot on the shelf, especially relative to 2018 and 2019, but there are no survey data to document their summer distribution. The cold pool extent in 2020 indicates average conditions for juvenile recruitment based on a previously established positive correlation between the cold pool and juvenile recruitment. Recent EBS shelf survey data indicates that the length distribution is truncating, with few to no young recruits in 2019. Although 2020 has an average cold pool extent, there is concern that with increased frequency of years with little to no cold pool there will be a continued lack of recruitment in the future.

The two largest identified prey items for this species are walleye pollock (presumably age-1) and squid. Bottom trawl surveys and the EBS walleye pollock stock assessment estimated more age-1 pollock in 2019 compared to 2015-2018, but still much less abundant than the 2012 and 2013 year class. Due to lack of surveys, estimates of age-1 pollock are unknown this year. The squid catch in 2019 was highest since 1981, but this was considered likely to reflect changes in fishing practices rather than abundance (Ormseth 2019). Juvenile turbot likely feed on zooplankton. The latest data available from the Rapid Zooplankton Assessment indicates moderate to low abundances of large copepods in 2018 that decreased in 2019. Taken together these suggest few clear concerns about prey abundance for Greenland turbot.

Arrowtooth flounder, Kamchatka flounder, and Pacific halibut can be considered competitors based on overlap in their ecological niches as large upper-trophic predatory flatfish. Recent assessments for the BSAI show a leveling off of a long-term increasing trend in arrowtooth flounder; recent increases approaching peak biomass for Kamchatka flounder; and recent increases in Pacific halibut. Taken together these indicate that competitors are largely abundant and/or increasing.

Predators of adult turbot are not well known but likely include toothed whales. Predators of juveniles are also not well known but likely include fur seals, arrowtooth flounder, Pacific cod, skates, and sleeper sharks. Thus, trends in predator abundances that would indicate a change in predation impact on turbot are unknown.

Given the uncertainty about future recruitment as it relates to the environment, we score this category as a Level 2.

Fishery performance

The fishery peaked in 1981 with catch equaling 57,531 t (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 35% and 85% of the TAC over this same time period. 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 1	Level 1	Level 2	Level 1

Status Determination

The Greenland turbot stock is neither overfished nor approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2021 of scenario 6 is well above $B_{35\%}$, 31,169 t. With regard to whether the stock is likely to be in an overfished condition in the near future, the expected stock size in the year 2031 of scenario 7 is also greater than $B_{35\%}$. Figure 7-37 shows the relationship between the estimated time-series of female spawning biomass and fishing mortality and the tier 3 control rule for Greenland turbot. The simulation results for the 7 harvest scenarios are shown in Table 7-13. Given the results, Greenland turbot are not currently overfished or approaching overfishing.

The F that would have produced a catch for last year equal to last year's OFL was 0.245.

Status determinations

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 (2019) is 2,850 t. This is less than the 2019 OFL of 11,362 t. Therefore, the BSAI stock is not being subjected to overfishing.
Harvest scenarios 6 and 7 are intended to permit 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 2020:

a. If spawning biomass for 2020 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
b. If spawning biomass for 2020 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2020 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 2030 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 2022 is below ½ B35%, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2022 is above B35%, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2022is above ½ B35% but below B35%, the determination depends on the mean spawning biomass in 2030. If the mean spawning biomass for 2030 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 Tables 5.25 the stock is not being overfished and is not approaching an overfished condition. Spawning biomass in 2020 and 2022 are estimated to be 52,902 t and 47, 197 t which is greater than $B_{35\%}$ = 35,622 t. Figure 5.30 shows the relationship between the ratio of historical fishing mortality and female spawning biomass for Greenland turbot from 1960-2020.

It should be noted that the 2007-2010 cohorts are maturing, growing, and fully 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. These results are summarized in Table 5.27. The results indicate that spawning biomass was at d 33% of the expected unfished level in 1977. This declined to a low of 23% between 2004 and 2006, was relatively stable between 25% and 27% between 2007 and 2014 and rapidly increased to 48% of the expected unfished level in 2020.

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 (see Figure 5.50 in 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 (see Figure 5.51 in Barbeaux et al. 2016) indicate that the most frequent prey for Greenland turbot on the EBS shelf are walleye pollock. 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. The non-FMP bycatch are summarized in Table 5.17 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 3060 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:

- Simplified selectivity time blocks,
- An evaluation of possible differential natural mortality between males and females,
- Spatial distribution and migration needs to be better explored through continued tagging experiments,
- Given the ontogeny of this species, spatial models (e.g., areas-as-fleets) should be explored,
- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear.
- Although we understand that a portion of this stock extends into Russian waters, Russian catch is not considered in this assessment. How to take into account this unknown mortality should be explored further

References

AFS Publication, 1991. Common and Scientific Names of Fishes from the United States and Canada. American Fisheries Society Special Publication 20. C. Richard Robins, Chairman. 183 p. American Fisheries Society, 5410 Grosvenor Lane, Suite 110, Bethesda, MD 20814-2199.

Alton, M.S., R.G. Bakkala, G.E. Walters, and P.T. Munro. +1988. Greenland turbot *Reinhardtius hippoglossoides* of the eastern Bering Sea and Aleutian Islands region. NOAA Tech. Rep., NMFS 71, 31 p.

Barbeaux, S. J., J. Ianelli, D. Nichol, and J. Hoff. 2012. Assessment of the Greenland turbot (Reinhardtius hippoglossoides in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2013. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Barbeaux, S. J., J. Ianelli, D. Nichol, and J. Hoff. 2013. Assessment of the Greenland turbot (Reinhardtius hippoglossoides in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2014. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Barbeaux, S. J., J. Ianelli, D. Nichol, and J. Hoff. 2014. Assessment of the Greenland turbot (Reinhardtius hippoglossoides in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2015. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Barbeaux, S. J., J. Ianelli, D. Nichol, and J. Hoff. 2015. Assessment of the Greenland turbot (Reinhardtius hippoglossoides in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2015. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Barbeaux, S. J., J. Ianelli, D. Nichol, and J. Hoff. 2016. Assessment of the Greenland turbot (Reinhardtius hippoglossoides in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2016. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Bryan, M.D., S. J.Barbeaux, J. Ianelli, D. Nichol, and J. Hoff. 2018. Assessment of the Greenland turbot (Reinhardtius hippoglossoides in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2018. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Chiperzak D. B., F. Saurette, P. Raddi 1995. First Record of Greenland Halibut (*Reinhardtius hippoglossoides*) in the Beaufort Sea (Arctic Ocean) Arctic, 48: 368–371

Cooper, D.W., K.P. Maslenikov, and D.R. Gunderson. 2007. Natural mortality rate, annual fecundity, and maturity at length for Greenland halibut (*Reinhardtius hippoglossoides*) from the northeastern Pacific Ocean. Fishery Bulletin, 105(2): 296-304.

D'yakov, Yu. P. 1982. The fecundity of the Greenland turbot, *Reinhardtius hippoglossoides*, (Pleuronectidae), from the Bering Sea. J. Ichthyol. [Engl. Transl. Vopr. Ikhtiol] 22(5):59-64.

Gregg, J.L., D.M. Anderl, and D.K. Kimura. 2006. Improving the precision of otolith-based age estimates for Greenland halibut (*Reinhardtius hippoglossoides*) with preparation methods adapted for fragile sagittae. Fish. Bull. 104:643–648 (2006).

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1993. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian

Islands region as projected for 1994. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1999. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2000. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Ianelli, J.N., T.K. Wilderbuer, and D. Nichol. 2011. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2000. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Lowe, S., J. Ianelli, and W. Palsson. 2014. Stock assessment of Aleutian Islands Atka mackerel. In Stock Assessment and Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fisheries Management Council, P.O. Box 103136, Anchorage, Alaska, 99510.

Methot, R.D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. *In* Proceedings of the symposium on applications of stock assessment techniques to Gadids. L. Low [ed.]. Int. North Pac. Fish. Comm. Bull. 50: 259-277.

Methot, R. D. Jr. 2012. User Manual for Stock Synthesis Model Version 3.23b. NOAA Fisheries Seattle, WA

Methot, R. D. and C.R. Wetzel. 2013 Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research. 142:86-99.

Myers, R.A., K. G. Bowen, and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56: 2404–2419

Rand, K. M. and E. A. Logerwell. 2011. The first demersal trawl survey of benthic fish and invertebrates in the Beaufort Sea since the late 1970’s. 2011. Polar Biology. 34:475-488.

Sohn D. 2009. Ecology of Greenland Halibut (*Reinhardtius hippoglossoides*) during the Early Life Stages in the Eastern Bering Sea and Aleutian Islands. Master’s thesis. College of Oceanic and Atmospheric Sciences, Oregon State University, Oregon, USA (June, 2009).

Spencer. P. 2008. Density-independent and density-dependent factors affecting temporal changes in spatial distributions of eastern Bering Sea flatfish. Fisheries Oceanography. 17:396-410.

Taylor, I. G. , I. J. Stewart, A. C. Hicks, T. M. Garrison, A. E. Punt, J. R. Wallace, C. R. Wetzel, J. T. Thorson, Y. Takeuchi, K. Ono, C. C. Monnahan, C. C. Stawitz, Z. T. A'mar, A. R. Whitten, K. F. Johnson, R. L. Emmet and other contributors. 2015. r4ss: R code for Stock Synthesis. R package version 1.23.5. https://github.com/r4ss.

Thorson, J. T., O. P. Jensen, and E. F. Zipkin. 2014. How variable is recruitment for exploited marine fishers? A hierarchical model for testing life history theory. Can. J. Fish. Aquat. Sci. 71:973-983.

U.S. Fish and Wildlife Service. 2014. Short-tailed Albatross 5-year Review: Summary and Evaluation. Anchorage Fish and Wildlife Field Office, Anchorage, AK available: http://ecos.fws.gov/docs/five_year_review/doc4445.pdf

Valero, J. M. Maunder, P. Crone, and B. Semmens. 2015. Good Practices Guide – Selectivity (Working Draft). Center for the Advancement of Population Assessment Methodology (CAPAM). NOAA/NMFS Southwest Fisheries Science Center 8901 La Jolla Shores Dr. La Jolla , CA 92037. USA.

Wilderbuer, T.K. and T.M. Sample. 1992. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1993. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

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 proportion of ABC and TAC achieved annually.

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	2,057	3,675	6,140	5,060	60	73
2012	2,613	2,104	4,717	9,660	8,660	49	54
2013	1,045	701	1,746	2,060	2,060	85	85
2014	951	707	1,658	2,124	2,124	78	78
2015	1,095	1,109	2,204	3,172	2,648	69	83
2016	1,229	1,012	2,241	3,462	2,873	65	78
2017	1,839	995	2,834	6,644	4,500	43	63
2018	1,550	285	1,835	11,132	5,294	16	35
2019	2,305	544	2,850	9,658	5,294	30	54
2020*	2,100	1,221	3,321	9,625	5,300	-	-

*Catch estimated as of October 2020. The preliminary catch for 2020 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2015-2019) and the 2020 TAC.

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2020. 2020 numbers are estimates through October and are not final.

Fishery	Arrow-Kamchatka		Greenland turbot		Sablefish		Pacific cod		Pollock		Flatfish		Halibut		Rockfish	
Year	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained	Discard	Retained
1992	2	6	13	62	2121	196	557	135	249	85	1	7	0	0	103	180
1993	2	1	332	5687	880	235	108	161	78	7	183	18	0	0	87	572
1994	0	0	368	6316	2305	195	211	149	62	2	235	27	0	0	37	317
1995	5	0	327	5093	1546	157	284	145	94	1	97	5	0	0	25	362
1996	0	0	173	3451	1026	200	307	170	46	13	63	171	0	0	113	598
1997	0	0	521	4709	619	129	283	270	119	7	92	212	0	0	19	202
1998	86	40	290	6689	84	123	155	281	119	55	162	541	0	0	1	35
1999	76	131	227	4009	120	179	50	180	13	17	193	465	0	0	2	25
2000	93	262	177	4798	254	192	109	130	31	20	83	576	0	0	1	39
2001	149	201	89	2727	325	171	92	203	25	43	188	563	0	0	30	431
2002	158	225	73	1979	207	144	137	210	40	30	59	76	0	0	18	175
2003	52	129	44	1724	107	114	95	178	7	33	18	68	158	46	5	198
2004	19	37	19	1222	30	78	83	220	9	9	109	134	62	20	3	81
2005	8	148	21	1530	21	63	30	156	12	19	26	165	90	13	5	134
2006	19	141	14	1198	69	62	32	66	14	51	13	51	10	53	8	71
2007	0	19	28	1207	78	60	91	128	37	71	24	54	15	5	13	36
2008	414	762	3	944	87	42	69	16	22	63	16	95	10	1	1	142
2009	285	1158	51	2490	74	76	21	65	11	33	10	49	0	0	8	67
2010	80	1658	18	1932	37	68	18	95	7	17	5	13	66	1	2	57
2011	17	1467	8	1809	15	49	9	140	6	22	5	3	30	0	1	27
2012	12	2270	15	1905	15	36	9	105	17	37	5	47	14	0	3	17
2013	208	635	13	578	42	27	5	13	6	15	42	38	24	1	9	49
2014	129	598	16	626	47	11	7	13	7	34	52	30	3	0	1	40
2015	24	846	10	1061	12	1	15	10	5	35	34	72	19	0	1	34
2016	4	559	17	1378	7	1	29	65	5	23	6	59	15	0	0	27
2017	10	506	26	1875	9	2	45	110	1	17	8	142	1	0	0	37
2018	13	273	8	1262	8	7	19	84	2	28	6	31	11	0	2	51
2019	7	500	17	1803	2	11	16	52	3	33	4	233	0	0	6	112
2020	30	1078	6	753	1	10	11	45	9	135	5	46	0	0	9	149

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2007-2020. Source: NMFS AK Regional Office catch accounting system.

Gear	Target fishery	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020*
Fixed	Arrowtooth Flounder/Kamchatka	16	0	9	49	2	4	0	0	0	0	0	0	0	0
	Greenland Turbot - BSAI	1232	743	1191	1832	1812	1920	589	628	1052	907	830	167	478	224
	Halibut	19	12	0	67	31	15	25	3	19	15	1	11	1	0
	Other Flatfish - BSAI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Species	9	22	0	0	0	0	0	0	0	0	0	0	0	0
	Pacific Cod	129	76	84	105	149	113	16	17	24	82	155	99	61	56
	Pollock - bottom	2	10	3	2	1	2	1	1	1	0	1	0	1	0
	Pollock- midwater	105	72	40	20	24	48	18	15	34	17	8	12	18	0
	Rockfish	2	0	1	0	0	1	4	0	0	0	0	0	0	0
	Sablefish	107	111	124	93	57	46	1	66	56	11	6	4	2	3
Trawl	Alaska Plaice - BSAI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Arrowtooth Flounder/Kamchatka	3	1176	1434	1690	1483	2277	843	727	870	563	515	287	507	1109
	Atka Mackerel	130	201	118	62	64	209	40	45	25	46	45	28	49	19
	Flathead Sole	58	99	49	13	2	46	39	19	60	54	115	9	189	15
	Greenland Turbot - BSAI	2	205	1349	118	4	0	3	14	19	487	1071	1103	1341	535
	Other Flatfish - BSAI	12	11	4	1	0	1	4	0	2	2	27	2	42	23
	Other Species	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Pacific Cod	90	9	2	8	0	1	2	2	1	11	0	4	7	0
	Pollock - bottom	0	3	1	1	4	4	2	25	5	11	10	18	18	117
	Pollock - midwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rock Sole - BSAI	8	0	2	3	1	0	2	5	1	0	0	0	0	0
	Rockfish	47	142	73	59	28	18	54	41	34	28	37	53	118	159
	Sablefish	0	5	1	0	0	0	1	0	0	0	1	7	9	9
	Yellowfin Sole - BSAI	1	1	4	1	5	6	35	57	43	8	8	26	6	13

* Through October 2020

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2005-2020. The 2020 values are estimates through October 2020.

Area	Gear	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BS	Fixed	1713.0	1270.0	1201.2	866.5	1335.8	1943.0	1963.4	2046.0	631.6	660.4	1093.3	994.6	991.8	280.9	543.0	281.4
	Trawl	427.1	182.5	280.3	1222.4	915.8	324.8	1175.5	1012.2	814.8	818.6	997.1	1121.0	1719.9	1390.7	2135.2	1354.6
	Total	2140	1453	1481	2089	2252	2268	3139	3058	1446	1479	2090	2116	2712	1672	2678	1636
AI	Fixed	166.5	357.9	344.9	109.9	98.8	215.2	93.7	58.3	69.0	46.1	15.5	17.5	3.7	4.1	1.5	1.2
	Trawl	301.4	178.9	177.8	712.3	2164.2	1652.6	442.0	1600.3	230.6	132.7	97.9	106.7	118.2	158.9	169.6	671.6
	Total	468	537	523	822	2263	1868	536	1659	300	179	113	124	122	163	171	673

Table 5.5. 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	1960-2020
	Size composition	1977-1987, 1989-1991, 1994-2006, 2008-2020
Longline fisheries	Catch	1960-2020
	Size composition	1979-1985, 1993-2020
Shelf Survey	Abundance Index	1987-2019
	Size composition	1982-2019
	Age composition^{+}	1998, 2003-2019
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	1996-2020
	Size composition*	1979-2020

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2020. 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%

Table 5.7. 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 subsequent 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	11,787		
1988	13,353	42,700	
1989	13,209		
1990	16,199		
1991	12,484	40,500	11,925
1992	28,638		
1993	35,692		
1994	57,181		28,235
1995	37,636		
1996	40,611		
1997	35,303		28,343
1998	34,885		
1999	21,536		
2000	23,184		9,359
2001	27,280		
2002	24,000	27,589	9,891
2003	31,010		
2004	28,287	36,557	11,334
2005	21,302		
2006	20,933		20,934
2007	16,723		
2008	13,511	17,901	
2009	10,953		
2010	23,414	19,873	6,758
2011	26,156		
2012	21,792	17,984	2,600
2013	24,907		
2014	28,028		2,529
2015	25,240		
2016	22,429	23,573	2,378
2017	21,519		
2018	18,017		373
2019	16,053		

Table 5.8. Eastern Bering Sea slope survey estimates of Greenland turbot biomass (t), 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

Table 5.9. Eastern Bering Sea slope survey estimates of Greenland turbot numbers, 2002, 2004, 2008, 2010, 2012, and 2016 by depth category.

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

Year	Biomass	Standard Dev	Numbers	Standard Dev
1991	12,484	2,745	33,310,436	4,481,790
1992	28,638	6,113	30,969,139	4,523,389
1993	35,692	4,887	26,420,947	3,318,213
1994	57,181	11,755	23,098,328	4,196,874
1995	37,636	7,735	14,001,981	2,680,442
1996	40,611	5,331	13,796,413	1,733,824
1997	35,303	6,381	12,824,939	2,470,125
1998	34,885	4,360	12,538,736	1,756,591
1999	21,536	4,244	6,723,176	1,314,313
2000	23,184	4,570	7,972,708	1,149,268
2001	27,280	4,819	8,125,773	1,217,839
2002	24,000	4,808	13,521,119	3,175,736
2003	31,010	5,075	16,986,899	2,209,930
2004	28,287	4,430	17,803,889	2,457,932
2005	21,302	3,268	13,645,023	2,338,017
2006	20,933	3,374	11,475,736	1,724,111
2007	16,723	2,692	14,081,178	1,833,181
2008	13,511	2,913	15,129,318	2,061,672
2009	10,953	2,120	22,289,794	2,352,852
2010	23,414	3,986	137,598,240	14,644,412
2011	26,156	2,771	143,597,904	13,948,397
2012	21,792	2,962	61,337,305	6,538,445
2013	24,907	3,914	43,936,598	6,253,129
2014	28,028	3,684	30,240,486	3,831,274
2015	25,240	3,257	21,256,629	2,705,120
2016	22,429	3,007	14,131,789	1,640,226
2017	21,519	2,666	10,517,929	1,279,986
2018	18,017	2,011	7,360,930	801,072
2019	16,053	1,889	5,101,316	597,425

Table 5.11. 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 5.12. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot a) numbers and b) biomass (t), 1980-2018.

a)

Year	Western Aleutian	Central Aleutian	Eastern Aleutian	Southern Bering Sea	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
Avg. since 1991	312,062	457,967	2,093,752	387,920	3,251,701

b)

Year	Western Aleutians	Central Aleutians	Eastern Aleutians	Southern Bering Sea	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
Avg since 1991	1,331	1,963	6,626	1,302	11,222

Table 5.13. Alaska Fisheries Science Center longline survey relative population numbers (RPNs) for Greenland turbot biomass by year and region.

	Bering 4	Bering 3	Bering 2	Bering 1	NE Aleutians	NW Aleutians	SE Aleutians	SW Aleutians	Bering Sea (total)	Aleutians (total)	Combined (/1000)
1996					23,133	7,212	2,142	6,775		39,262	119.05
1997	11,729	6,172	27,936	13,491					59,328		80.99
1998					23,121	7,208	1,791	5,665		37,784	140.63
1999	13,072	6,156	33,848	10,068					63,144		86.20
2000					12,987	4,049	1,201	3,800		22,037	81.96
2001	16,082	5,005	24,766	5,123					50,975		69.58
2002					10,942	3,411	1,397	4,420		20,170	74.91
2003	11,965	3,784	24,660	6,206					46,616		63.64
2004					8,551	2,666	936	2,962		15,115	56.19
2005	3,717	1,826	15,268	2,297					23,107		31.54
2006					3,031	945	566	1,789		6,331	23.46
2007	1,561	1,754	13,523	1,235					18,074		24.67
2008					3,155	984	297	939		5,374	19.99
2009	3,406	640	21,192	2,612					27,850		38.02
2010					2,033	634	163	517		3,347	12.45
2011	1,494	705	12,164	1,821					16,184		22.09
2012					4,714	1,470	350	1,106		7,639	28.44
2013	1,641	3,082	13,473	2,970					21,166		28.89
2014					4,240	1,322	181	573		6,315	23.55
2015	3,104	451	12,737	4,710					21,001		28.67
2016					2,449	764	38	116		3,367	12.59
2017	3,055	1,651	10,039	6,047					20,792		28.17
2018					2,489	776	592	1,815		5,672	21.21
2019	1,422	939	7,935	107					10,403		14.16
2020					4,190	1,307	49	151		5,697	21.30

Table 5.14. 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	16.75	17.67	15.67	15.00			12.17	12.81	15.00	14.08	16.44	14.18	16.09		
2	24.45	24.94	22.37	21.80	25.00	24.33	22.50	18.94	22.05	23.22	23.74	23.28	22.80	21.33	22.45
3	32.70	33.14	29.68	29.90	32.20	30.33	30.00	23.13	29.72	30.23	32.18	32.08	29.25	28.50	32.42
4	40.26	32.00	33.44	34.60	35.95	39.00	39.50	28.50	33.30	34.57	37.06	36.77	36.33	32.60	37.87
5	46.36	35.00	38.96	40.86	42.58	38.00	46.18	34.50	35.50	38.00	41.65	42.35	38.29	40.53	44.25
6	48.11		47.00	43.14	48.85	42.69	47.00	44.00		42.00	46.17	46.00	43.50	46.32	50.36
7	52.50		43.67	53.00	53.33	46.60	50.72	50.14	56.00	67.00	46.50	54.80	48.78	48.74	54.47
8			50.00	57.00	62.50	54.53	54.67	53.25	56.00		57.00	47.50	52.56	57.57	55.09
9			57.50		62.00	57.90	59.75	53.75	59.56		72.00		54.50	56.08	60.83
10		65.80	51.00	70.25	67.50	65.67	62.33	59.00	63.75	62.25	65.00	69.50		66.25	62.44
11		65.00	60.00	83.00	86.00	62.00	63.00	60.25	64.00	73.00	68.67	74.00	73.00	61.00	74.00
12		78.67	78.33	78.25	77.00	71.00	62.00	70.50		67.25		75.00		75.00	82.33
13			83.67	85.60	88.00	56.50	65.00	69.67	74.50	69.50	71.50	77.00	79.33	72.00	79.75
14		75.00	83.20	83.80	81.33	77.00			78.00	73.50		80.00	78.00		
15			80.00	87.17	85.50	78.00	61.67	70.00			77.00			82.00	83.00
16		76.00	84.20	82.00		84.67	80.00	84.50		80.00				86.00	
17		81.00	86.43	85.17	85.00	86.25	90.00	71.00				75.00			85.00
18			85.67	91.67	92.00	88.67	85.00	92.67		97.00	66.00	84.00	85.00		
19			90.67	92.50	84.60	87.60	91.67	91.00	88.00					93.00	79.00
20		80.33	89.56	89.50	90.20	90.33	89.00	66.00	90.50		87.00	81.00	81.00	81.00	
21		82.00	90.00	90.67	89.00	50.50	90.67	83.00	87.67		93.50				
22			88.00		87.00	90.00		89.50	94.00	94.50			90.00	98.00	
23		79.00	90.17	96.50	82.00	88.00	87.00		92.50	80.50		85.00		92.00	
24		79.00	90.00	97.00	88.00			94.00	100.0			100.0			91.00
25		79.00	91.33	91.00	86.75	88.50		88.00	89.00		99.00		88.00		
26		95.00	92.33	94.50	96.50		92.00		93.00	88.00			89.00	98.50	100.00
27			93.67	85.67					83.00		81.67	97.50			
28			92.00	91.00				95.00	93.33					95.33	
29			91.75				92.00	91.00		93.00	86.00				
30			91.00		88.00	107.0	90.00	93.00	89.75	92.00	96.00		91.00	98.75	75.00
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 5.14 continued.

Age	2016	2017	2018	2019
1	14.33333	0	0	0
2	19	0	25	0
3	30.21429	26.66667	31.5	0
4	36	35.57143	36.16667	0
5	44.5625	40.88889	39.42857	44
6	51.55556	44.11111	52.83333	47.66667
7	55.91304	50.42857	59.25	61
8	60.91304	59	61.42857	64
9	59.5	62.86667	66.32	70.92308
10	63.93333	65.79167	66.93103	71.09091
11	65.75	63.61538	71.5	74.47619
12	62.66667	69.6	72.66667	75.25
13	67.5	73.5	80	74.5
14	75.66667	72.5	74	0
15	0	82	84	0
16	83	67	0	70
17	81	82.33333	0	0
18	0	91	85.66667	85
19	0	0	0	92
20	81	0	0	0
21	0	85	0	0
22	88	0	0	0
23	89	73	0	0
24	0	94	97	0
25	87	0	0	0
26	0	0	100	0
27	0	0	0	0
28	99.5	0	0	0
29	92	0	0	0
30	95	0	0	0
Age	2016	2017	2018	2019
1	6	0	0	0
2	3	0	1	0
3	14	3	2	0
4	8	7	6	0
5	16	9	7	1
6	18	9	6	3
7	23	7	4	7
8	23	13	7	3
9	8	15	25	13
10	15	24	29	11
11	8	13	16	21
12	3	10	3	8
13	2	2	1	2
14	3	4	1	0
15	0	3	1	0
16	3	1	0	1
17	1	3	0	0
18	0	1	3	1
19	0	0	0	1
20	1	0	0	0
21	0	1	0	0
22	1	0	0	0
23	1	1	0	0
24	0	1	1	0
25	1	0	0	0
26	0	0	1	0
27	0	0	0	0
28	2	0	0	0
29	1	0	0	0
30	1	0	0	0

Table 5.15. 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	16.61		13.00	16.25	13.50	11.50	12.50	13.10	14.25	14.06	16.10	13.45	14.57	14.00	14.00
2	24.79	25.58	22.15	23.89	24.00	21.00	21.00	19.64	21.93	23.91	23.10	22.48	22.53	22.17	22.70
3	33.67	34.00	28.97	30.30	33.19		28.67	23.36	28.60	33.30	32.09	31.30	30.82	29.24	32.32
4	40.03	33.80	36.06	34.83	36.97	39.50	35.00	30.00	33.27	36.43	36.87	36.72	34.80	35.00	39.00
5	45.70	36.50	38.96	42.55	41.33	38.38	44.40	35.50	45.00	39.75	41.78	40.87	37.90	39.12	44.82
6	50.00	50.00	40.67	43.13	47.10	43.75	47.18	44.00	42.50	42.00	45.33	47.43	41.90	43.94	48.56
7	52.00		46.20	51.20	48.00	44.33	51.70	46.33	52.00			53.00	45.23	47.87	52.15
8		49.00	49.20	58.00	51.83	47.25	52.67	51.00	53.75	50.50	55.50		51.50	50.44	55.08
9		58.00	48.50	61.75	52.00	53.18	56.00	54.57	58.33	59.00	47.00		49.00	50.11	58.50
10		58.33	66.40	63.75	72.00	64.25	55.00	55.67	54.50			66.00		63.00	57.50
11			60.00		64.67	62.25	62.75	59.00			69.00				54.00
12		59.75	72.00	73.20		74.00				60.00	65.50				68.00
13		66.75	76.00	68.67	72.50					67.00		68.00		66.00	
14		75.00			76.00							56.00		69.00	
15		67.50		74.00	79.00	73.00		73.00							
16			70.00	78.00	75.50	77.00	69.00	75.00							
17		71.00	72.00	78.00	76.00	74.00	75.50				66.00			72.00	
18			72.00	77.00	76.00	76.00	77.50	83.00							
19		74.00	78.00	81.00	74.33	79.00			78.50		73.00				
20			81.50	73.50	79.00	79.00		76.00	79.00		70.00	75.00			
21			76.50				76.50	71.00	70.00	73.00					
22			81.00			74.00	77.00	80.00	77.00	73.00					
23			74.00			88.00				88.00					77.00
24		69.50	76.33		74.00	77.00	84.00			82.00					75.50
25			73.00		75.50	83.00	72.00		71.00						
26			77.00						78.00						
27			74.00		73.00			75.00							
28					78.00			78.00		79.00	76.00				
29			78.00				82.00			78.00					85.00
30		81.00					79.00		76.75			76.00			

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 5.15. continued.

Age	2016	2017	2018	2019
1	13	15	15.33333	0
2	18.77778	24	23	0
3	30.6087	29	28	0
4	38.52381	37.5	36.66667	0
5	45.25	38.2	43	39
6	50.68421	42.36364	45.25	48.66667
7	54.33333	47.42857	52.88889	55.91667
8	56.33333	55.75	60.29412	61.75
9	57.23077	58.23077	62.90909	63.5
10	55	61.63636	63	68.5
11	58.83333	57.5	69.33333	62
12	62	60	61	78.5
13	0	58	61	0
14	0	59	78	68
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	83	72	0
19	0	0	0	0
20	79	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	77	0	0
24	0	0	0	0
25	77	0	0	73
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	83	75	0	0

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

Table 5.16. 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**								
Trawl	50	50	50	50	50								
Longline	50	50	50	50	50								
Shelf	200	200	200	200	200								
Slope	400												

Table 5.17. Model a) total likelihoods and c) likelihood components.

a)

	16.4 (2018)		16.4a		16.4a (2020)	
Component	Likelihood	Gradient	Likelihood	Gradient	Likelihood	Gradient
Total	2019.9	3.65e-06	1892.5	3.5e-6	2275.83	3e-4
Catch	5.6E-12		1.6e-12		4.05E-12	
Survey	-30.7		-22.1		-7.6	
Length comp	656.8		530.6		784.3	
Size at age	1276.9		1270.9		1372.4	
Recruitment	101.05		96.4		108.72	

b)

Model	16.4 (2018)				
Fleet/Survey	Trawl	Longline	Shelf	Slope	ABL LL
Likelihood					
Catch	5.6E-12	8.3E-14	0	0	0
Survey	0	0	-32.1	-6.9	8.3
Length comp	105.7	62.9	291.3	196.8	0
Size at age	0	0	1276.9	0	0
	16.4a				
Catch	1.55E-12	8.88E-14	0	0	0
Survey	0	0	-34.2	-5.8	17.8
Length comp	104.4	63.1	288.1	74.9	0
Size at age	0	0	1270.9	0	0
	16.4a (2020)				
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

Table 5.18. Model index RMSE, tuning diagnostics, and recruitment variability for candidate models.

		16.4 (2018)	16.4a	16.4a (2020)
Retrospective				
Mohn's ρ	SSB	0.097	-	0.04
	Recruitment	3.15	-	6.17
	Fishing mortality	-0.04	-	-0.12
Index RMSE				
	Shelf	0.209	0.202	0.207
	Slope	0.176	0.184	0.204
	ABL Longline	0.394	0.433	0.474
Size Comp				
Har. Mean EffN				
	Trawl	37.54	38.31	35.49
	Longline	94.87	94.82	79.40
	Shelf	47.84	50.21	39.49
	Slope	47.51	42.32	45.86
Mean input N				
	Trawl	12.5	12.5	12.5
	Longline	25	25	25
	Shelf	50	50	50
	Slope	106.25	106.25	106.25

Table 5.19. Key parameter estimates and estimated standard deviations.

	16.4 (2018)		16.4a		16.4a (2020)	
Label	Value	StDev	Value	StDev	Value	Stdev
Biology						
L Amin female	15.06	0.24	15.14	0.23	14.92	0.24
L Amax female	90.29	0.43	90.19	0.46	90.34	0.42
von Bert k female	0.11	0.00	0.11	0.00	0.11	0.00
L Amin male	14.13	0.22	14.31	0.22	14.06	0.23
L Amax male	71.99	0.35	73.1	0.45	71.70	0.33
von Bert k male	0.19	0.00	0.18	0.00	0.19	0.00
Recruitment						
SLN(R0)	9.19	0.16	9.19	0.16	9.13	0.17
steepness	0.79	_	0.79	_	0.79	_
σ_R	0.60	_	0.60	_	0.60	_
SR_autocorr	0.61	0.04	0.61	0.04	0.63	0.03
Catchability						
Shelf LN(q)	-0.49	_	-0.49	_	-0.49	_
Slope LN(q)	-0.56	_	-0.56	_	-0.56	_
ABL Longline LN(q)	-0.54	0.07	0.98	0.07	0.79	0.07

Table 5.20. Spawning and total biomass, Age-0 recruits, fishing mortality, exploitation rate, and estimates of 1-SPR for BSAI Greenland turbot, 1960-2020 for models 16.4 and 16.4a (2020).

	16.4(2018)					16.4a (2020)				
Year	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR
1960	112590	46073	0.18	0.12	0.86	111248	32438	0.18	0.12	0.86
1961	108290	82675	0.33	0.20	0.96	107000	48406	0.32	0.20	0.96
1962	96145	185807	0.43	0.24	0.98	94558	86664	0.42	0.25	0.98
1963	80722	437867	0.28	0.17	0.95	78620	184864	0.29	0.17	0.95
1964	71913	484027	0.32	0.19	0.96	69323	383089	0.35	0.21	0.97
1965	62866	204888	0.07	0.05	0.55	58791	424147	0.10	0.07	0.67
1966	61185	85070	0.06	0.05	0.48	56197	231398	0.09	0.07	0.64
1967	61320	44596	0.07	0.06	0.53	54458	108699	0.10	0.09	0.70
1968	65661	29672	0.07	0.07	0.55	54235	58807	0.10	0.10	0.69
1969	80552	24010	0.06	0.05	0.48	58831	39037	0.08	0.07	0.59
1970	114004	23147	0.04	0.03	0.34	74201	32273	0.05	0.04	0.41
1971	169079	26270	0.07	0.06	0.55	107167	32891	0.08	0.08	0.62
1972	230742	35638	0.13	0.11	0.76	153297	41351	0.15	0.12	0.80
1973	276896	59529	0.12	0.09	0.72	196930	65614	0.12	0.10	0.76
1974	310753	119004	0.16	0.11	0.82	236434	127860	0.16	0.13	0.84
1975	320669	209981	0.15	0.11	0.81	257040	227332	0.16	0.12	0.83
1976	318037	147543	0.16	0.11	0.83	265413	161443	0.16	0.11	0.83
1977	305274	93480	0.09	0.05	0.61	262630	105778	0.08	0.06	0.61
1978	299082	49205	0.12	0.08	0.73	264568	58484	0.12	0.08	0.72
1979	283743	17637	0.12	0.08	0.72	256717	20148	0.12	0.08	0.71
1980	268767	6022	0.16	0.10	0.80	248476	6969	0.15	0.10	0.78
1981	253156	1025	0.18	0.11	0.83	239487	1164	0.17	0.11	0.81
1982	240818	1999	0.16	0.11	0.83	233940	2119	0.14	0.10	0.80
1983	235087	3289	0.16	0.10	0.83	234918	3480	0.14	0.10	0.79
1984	229943	6185	0.09	0.05	0.62	236369	6698	0.07	0.05	0.57
1985	231106	20233	0.06	0.04	0.49	243465	22414	0.05	0.03	0.44
1986	231958	5317	0.04	0.03	0.38	249279	5789	0.03	0.02	0.34
1987	230712	5756	0.04	0.03	0.40	251811	6158	0.04	0.02	0.35
1988	225476	5897	0.04	0.02	0.33	249159	6336	0.03	0.02	0.29
1989	217913	15803	0.06	0.03	0.31	243145	16992	0.05	0.02	0.28
1990	205200	3848	0.11	0.04	0.45	231378	4188	0.08	0.03	0.41
1991	188389	1131	0.07	0.03	0.35	215029	1196	0.06	0.02	0.31
1992	174737	743	0.03	0.01	0.18	201287	762	0.03	0.01	0.15
1993	164111	606	0.08	0.03	0.35	190065	600	0.06	0.03	0.31
1994	149741	954	0.12	0.04	0.49	175048	934	0.10	0.12	0.44

Table 5.20. 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 16.4 (2018) and 16.4a (2020).

	16.4 (2018)					16.14a (2020)				
Year	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR	SSB (t)	Age-0 recruits	Apical F	Exploitation rate	1-SPR
1995	135437	3771	0.11	0.04	0.44	160134	3785	0.08	0.04	0.34
1996	123184	1612	0.09	0.03	0.38	146988	1653	0.07	0.03	0.37
1997	112523	1641	0.10	0.04	0.42	135207	1632	0.08	0.03	0.45
1998	101654	2145	0.14	0.05	0.50	123080	2095	0.11	0.03	0.39
1999	89840	8332	0.11	0.04	0.44	109919	8208	0.08	0.05	0.46
2000	80737	9648	0.14	0.05	0.51	99430	9512	0.11	0.03	0.44
2001	70885	11358	0.13	0.05	0.49	88200	11705	0.10	0.04	0.36
2002	62832	1677	0.10	0.04	0.41	78824	1714	0.07	0.04	0.35
2003	56300	614	0.09	0.03	0.40	71013	600	0.07	0.03	0.30
2004	50604	547	0.08	0.03	0.35	64103	492	0.06	0.03	0.35
2005	46087	801	0.10	0.03	0.41	58455	695	0.07	0.02	0.30
2006	41981	7292	0.07	0.03	0.34	53287	6119	0.06	0.03	0.31
2007	39276	22137	0.08	0.03	0.36	49612	18415	0.06	0.02	0.44
2008	37470	48122	0.12	0.04	0.47	46914	42573	0.11	0.02	0.58
2009	36147	33061	0.18	0.07	0.61	44804	26270	0.17	0.03	0.58
2010	33936	6103	0.18	0.06	0.60	41852	4557	0.18	0.06	0.57
2011	31325	4003	0.18	0.06	0.59	38477	3134	0.17	0.06	0.67
2012	28784	1904	0.24	0.07	0.69	35194	1201	0.24	0.05	0.37
2013	26342	2430	0.09	0.02	0.39	32020	1129	0.09	0.06	0.32
2014	27404	2063	0.07	0.02	0.34	32201	909	0.07	0.02	0.35
2015	31312	2458	0.08	0.02	0.36	34940	1066	0.08	0.02	0.30
2016	37430	2168	0.06	0.02	0.30	39500	1136	0.06	0.02	0.30
2017	44447	3182	0.06	0.03	0.29	44725	1347	0.06	0.02	0.18
2018	50465	6041	0.07	0.03	0.33	48898	2162	0.03	0.03	0.27
2019	-	-	-	-	-	52010	4997	0.06	0.02	0.33
2020	-	-	-	-	-	52902	6838	0.07	0.03	0.34

Table 5.21. Estimated beginning of year numbers ($1{\times}10^5$) of female Greenland turbot by age for Model 16.4a (2020).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	528.9	721.7	866.6	380.9	149.4	72.6	45.5	35.8	36.6	48.0	76.2	137.4	213.7	165.1	63.2	20.8	7.9	3.5	1.9	1.4	1.3
1978	292.4	472.9	630.2	724.1	314.7	123.5	60.2	37.8	29.9	30.8	40.5	64.5	116.7	182.1	141.1	54.1	17.9	6.8	3.0	1.7	1.2
1979	100.7	261.4	409.8	515.3	583.4	253.7	99.9	49.0	30.9	24.6	25.4	33.6	53.7	97.4	152.5	118.4	45.5	15.1	5.7	2.5	1.4
1980	34.8	90.1	226.9	336.7	417.5	472.8	206.4	81.7	40.2	25.6	20.4	21.2	28.0	45.0	81.7	128.2	99.7	38.4	12.7	4.8	2.1
1981	5.8	31.2	77.6	182.6	266.3	330.3	375.9	165.0	65.7	32.6	20.8	16.7	17.4	23.1	37.1	67.6	106.3	82.9	32.0	10.6	4.1
1982	10.6	5.2	26.7	61.8	142.6	207.9	259.3	297.0	131.3	52.7	26.3	16.9	13.6	14.2	18.9	30.5	55.7	87.7	68.5	26.5	8.8
1983	17.4	9.5	4.5	21.2	48.1	111.0	162.8	204.4	236.0	105.2	42.5	21.3	13.8	11.2	11.7	15.7	25.4	46.6	73.6	57.7	22.4
1984	33.5	15.6	8.1	3.5	16.6	37.5	87.1	128.6	162.8	189.4	85.1	34.6	17.5	11.4	9.3	9.8	13.1	21.3	39.2	62.1	48.8
1985	112.1	29.9	13.6	6.8	3.0	13.8	31.4	73.0	108.3	137.6	160.7	72.4	29.6	15.0	9.8	8.0	8.4	11.3	18.4	34.0	53.9
1986	28.9	100.2	26.4	11.7	5.8	2.5	11.8	26.8	62.7	93.2	118.7	139.0	62.8	25.7	13.0	8.5	7.0	7.4	9.9	16.1	29.8
1987	30.8	25.9	88.7	22.9	10.1	5.0	2.2	10.2	23.3	54.6	81.3	103.7	121.6	55.0	22.5	11.5	7.5	6.1	6.5	8.7	14.2
1988	31.7	27.5	22.9	76.9	19.8	8.7	4.4	1.9	8.9	20.3	47.5	70.9	90.7	106.5	48.2	19.8	10.1	6.6	5.4	5.7	7.7
1989	85.0	28.3	24.4	20.0	66.9	17.2	7.6	3.8	1.7	7.8	17.8	41.7	62.3	79.7	93.7	42.5	17.4	8.9	5.8	4.8	5.0
1990	20.9	76.0	25.3	21.8	17.9	59.8	15.4	6.7	3.3	1.4	6.7	15.3	35.9	53.7	68.9	81.2	36.9	15.2	7.7	5.1	4.2
1991	6.0	18.7	67.9	22.6	19.5	16.0	53.3	13.6	5.9	2.9	1.2	5.7	12.9	30.3	45.4	58.4	69.1	31.6	13.0	6.7	4.4
1992	3.8	5.3	16.7	60.7	20.2	17.4	14.3	47.3	11.9	5.1	2.5	1.0	4.9	11.1	26.0	39.1	50.5	59.9	27.4	11.3	5.8
1993	3.0	3.4	4.8	15.0	54.3	18.1	15.6	12.7	42.2	10.6	4.5	2.2	0.9	4.3	9.7	22.9	34.4	44.3	52.6	24.1	10.0
1994	4.7	2.7	3.0	4.3	13.4	48.5	16.2	13.9	11.3	37.3	9.3	4.0	1.9	0.8	3.7	8.4	19.6	29.4	37.9	45.0	20.6
1995	18.9	4.2	2.4	2.7	3.8	12.0	43.3	14.3	12.1	9.7	31.7	7.9	3.3	1.6	0.7	3.1	7.0	16.6	24.9	32.2	38.3
1996	8.3	16.9	3.7	2.1	2.4	3.4	10.7	38.4	12.6	10.6	8.4	27.1	6.7	2.8	1.4	0.6	2.6	6.0	14.1	21.3	27.5
1997	8.2	7.4	15.1	3.3	1.9	2.2	3.1	9.5	34.0	11.1	9.2	7.3	23.4	5.8	2.4	1.2	0.5	2.2	5.1	12.1	18.2
1998	10.5	7.3	6.6	13.5	3.0	1.7	1.9	2.7	8.4	30.0	9.7	8.0	6.3	20.0	4.9	2.0	1.0	0.4	1.9	4.3	10.2
1999	41.0	9.4	6.5	5.9	12.1	2.7	1.5	1.7	2.4	7.4	25.9	8.3	6.8	5.3	16.7	4.1	1.7	0.8	0.3	1.6	3.6
2000	47.6	36.7	8.4	5.8	5.3	10.8	2.4	1.4	1.5	2.1	6.4	22.3	7.1	5.8	4.5	14.2	3.4	1.4	0.7	0.3	1.3
2001	58.5	42.5	32.8	7.5	5.2	4.7	9.6	2.1	1.2	1.3	1.8	5.4	18.8	5.9	4.8	3.7	11.8	2.9	1.2	0.6	0.2
2002	8.6	52.3	38.0	29.3	6.7	4.7	4.2	8.6	1.9	1.0	1.1	1.5	4.6	15.8	5.0	4.0	3.1	9.9	2.4	1.0	0.5
2003	3.0	7.7	46.8	34.0	26.2	6.0	4.2	3.8	7.6	1.6	0.9	1.0	1.3	3.9	13.5	4.2	3.4	2.7	8.4	2.1	0.9
2004	2.5	2.7	6.9	41.8	30.4	23.4	5.3	3.7	3.3	6.6	1.4	0.8	0.8	1.1	3.4	11.5	3.6	2.9	2.3	7.2	1.8
2005	3.5	2.2	2.4	6.1	37.4	27.2	20.9	4.8	3.3	2.9	5.8	1.2	0.7	0.7	1.0	2.9	9.9	3.1	2.5	2.0	6.2
2006	30.6	3.1	2.0	2.1	5.5	33.4	24.3	18.6	4.2	2.9	2.5	5.0	1.1	0.6	0.6	0.8	2.5	8.5	2.7	2.1	1.7
2007	92.1	27.4	2.8	1.8	1.9	4.9	29.9	21.6	16.5	3.7	2.5	2.2	4.4	0.9	0.5	0.5	0.7	2.1	7.3	2.3	1.8
2008	212.9	82.3	24.5	2.5	1.6	1.7	4.4	26.6	19.2	14.6	3.3	2.2	1.9	3.8	0.8	0.4	0.5	0.6	1.8	6.2	2.0
2009	131.3	190.3	73.6	21.9	2.2	1.4	1.5	3.9	23.1	16.4	12.3	2.7	1.8	1.6	3.2	0.7	0.4	0.4	0.5	1.6	5.4
2010	22.8	117.4	170.1	65.8	19.5	2.0	1.2	1.3	3.3	19.3	13.4	9.9	2.2	1.5	1.3	2.6	0.5	0.3	0.3	0.4	1.3
2011	15.7	20.4	105.0	152.1	58.8	17.5	1.8	1.1	1.1	2.8	15.9	10.9	8.0	1.8	1.2	1.0	2.1	0.4	0.2	0.3	0.4
2012	6.0	14.0	18.2	93.9	136.0	52.5	15.5	1.5	0.9	1.0	2.3	12.9	8.8	6.4	1.4	1.0	0.8	1.7	0.4	0.2	0.2
2013	5.6	5.4	12.5	16.3	83.9	121.4	46.5	13.5	1.3	0.8	0.8	1.8	10.0	6.8	5.0	1.1	0.8	0.7	1.4	0.3	0.2
2014	4.5	5.0	4.8	11.2	14.6	75.0	108.1	41.2	11.8	1.1	0.7	0.7	1.5	8.5	5.7	4.2	0.9	0.6	0.6	1.2	0.3
2015	5.3	4.1	4.5	4.3	10.0	13.0	66.9	96.0	36.3	10.3	1.0	0.6	0.6	1.3	7.2	4.9	3.6	0.8	0.6	0.5	1.0
2016	5.7	4.8	3.6	4.0	3.8	8.9	11.6	59.4	84.6	31.7	8.9	0.8	0.5	0.5	1.1	6.2	4.2	3.1	0.7	0.5	0.4
2017	6.7	5.1	4.3	3.2	3.6	3.4	8.0	10.3	52.4	74.1	27.5	7.7	0.7	0.4	0.4	0.9	5.3	3.6	2.7	0.6	0.4
2018	10.8	6.0	4.5	3.8	2.9	3.2	3.1	7.1	9.1	45.8	64.2	23.7	6.6	0.6	0.4	0.4	0.8	4.6	3.1	2.3	0.5
2019	25.0	9.7	5.4	4.1	3.4	2.6	2.9	2.7	6.3	8.0	40.1	56.1	20.7	5.8	0.5	0.3	0.3	0.7	4.1	2.8	2.1
2020	34.2	22.3	8.6	4.8	3.6	3.0	2.3	2.5	2.4	5.5	6.9	34.6	48.3	17.8	5.0	0.5	0.3	0.3	0.6	3.6	2.4

Table 5.21. Continued. Estimated beginning of year numbers (1×10[5]) of male Greenland turbot by age for Model 16.4a (2020).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	528.9	721.7	895.7	420.7	173.7	86.3	53.9	41.5	40.2	49.6	75.3	131.1	195.7	144.2	55.4	19.1	7.4	3.3	1.7	1.0	0.8
1978	292.4	472.9	640.7	773.9	356.7	145.6	71.8	44.7	34.3	33.2	40.9	62.2	108.2	161.5	119.0	45.7	15.7	6.1	2.7	1.4	0.9
1979	100.7	261.4	418.8	547.5	645.2	292.9	118.5	58.1	36.0	27.6	26.7	32.9	50.0	86.9	129.8	95.6	36.8	12.7	4.9	2.2	1.1
1980	34.8	90.1	231.7	358.7	458.1	532.1	239.4	96.3	47.1	29.2	22.3	21.6	26.6	40.4	70.2	104.8	77.2	29.7	10.2	4.0	1.8
1981	5.8	31.2	79.6	196.4	295.4	370.5	425.6	190.3	76.3	37.2	23.0	17.6	17.0	20.9	31.8	55.3	82.6	60.9	23.4	8.1	3.1
1982	10.6	5.2	27.5	67.1	160.3	236.3	292.8	334.0	148.7	59.5	29.0	17.9	13.7	13.2	16.3	24.7	43.0	64.2	47.3	18.2	6.3
1983	17.4	9.5	4.6	23.2	54.7	127.9	186.3	229.2	260.5	115.8	46.3	22.5	13.9	10.6	10.3	12.6	19.2	33.4	50.0	36.8	14.2
1984	33.5	15.6	8.4	3.9	18.9	43.7	101.1	146.2	179.3	203.4	90.3	36.1	17.6	10.8	8.3	8.0	9.9	15.0	26.1	39.0	28.7
1985	112.1	29.9	13.8	7.3	3.3	15.9	36.7	84.4	121.9	149.3	169.3	75.2	30.0	14.6	9.0	6.9	6.7	8.2	12.5	21.7	32.5
1986	28.9	100.2	26.7	12.1	6.3	2.8	13.7	31.3	72.0	103.9	127.3	144.3	64.1	25.6	12.5	7.7	5.9	5.7	7.0	10.6	18.5
1987	30.8	25.9	89.3	23.5	10.6	5.5	2.5	11.8	27.1	62.3	89.8	109.9	124.7	55.3	22.1	10.8	6.6	5.1	4.9	6.1	9.2
1988	31.7	27.5	23.1	78.6	20.5	9.2	4.7	2.1	10.2	23.4	53.7	77.5	94.9	107.6	47.8	19.1	9.3	5.7	4.4	4.2	5.2
1989	85.0	28.3	24.6	20.4	69.0	17.9	8.0	4.1	1.9	8.9	20.3	46.7	67.4	82.5	93.6	41.6	16.6	8.1	5.0	3.8	3.7
1990	20.9	76.0	25.3	22.0	18.2	61.7	16.0	7.1	3.6	1.6	7.8	17.7	40.6	58.5	71.6	81.2	36.1	14.4	7.0	4.3	3.3
1991	6.0	18.7	67.9	22.6	19.6	16.3	55.0	14.2	6.2	3.2	1.4	6.6	15.1	34.6	49.8	60.9	69.1	30.7	12.3	6.0	3.7
1992	3.8	5.3	16.7	60.7	20.2	17.5	14.5	48.9	12.5	5.5	2.8	1.2	5.8	13.1	30.0	43.1	52.8	59.9	26.6	10.6	5.2
1993	3.0	3.4	4.8	15.0	54.3	18.1	15.7	13.0	43.6	11.1	4.9	2.4	1.1	5.1	11.6	26.6	38.3	46.8	53.1	23.6	9.4
1994	4.7	2.7	3.0	4.3	13.4	48.5	16.2	14.0	11.6	38.7	9.9	4.3	2.2	0.9	4.5	10.2	23.4	33.6	41.1	46.7	20.7
1995	18.9	4.2	2.4	2.7	3.8	12.0	43.3	14.3	12.3	10.0	33.4	8.5	3.7	1.8	0.8	3.8	8.7	19.9	28.7	35.1	39.8
1996	8.3	16.9	3.7	2.1	2.4	3.4	10.7	38.5	12.6	10.8	8.8	29.0	7.3	3.2	1.6	0.7	3.3	7.5	17.2	24.8	30.3
1997	8.2	7.4	15.1	3.3	1.9	2.2	3.1	9.5	34.1	11.2	9.5	7.7	25.4	6.4	2.8	1.4	0.6	2.9	6.6	15.0	21.6
1998	10.5	7.3	6.6	13.5	3.0	1.7	1.9	2.7	8.4	30.2	9.9	8.3	6.7	22.3	5.6	2.4	1.2	0.5	2.5	5.7	13.1
1999	41.0	9.4	6.5	5.9	12.1	2.7	1.5	1.7	2.4	7.4	26.5	8.6	7.3	5.9	19.3	4.9	2.1	1.1	0.5	2.2	5.0
2000	47.6	36.7	8.4	5.8	5.3	10.8	2.4	1.4	1.5	2.1	6.5	23.1	7.5	6.3	5.1	16.8	4.2	1.8	0.9	0.4	1.9
2001	58.5	42.5	32.8	7.5	5.2	4.7	9.6	2.1	1.2	1.3	1.8	5.7	20.0	6.5	5.4	4.4	14.4	3.6	1.6	0.8	0.3
2002	8.6	52.3	38.0	29.3	6.7	4.7	4.2	8.6	1.9	1.1	1.2	1.6	4.9	17.2	5.6	4.7	3.8	12.4	3.1	1.4	0.7
2003	3.0	7.7	46.8	34.0	26.2	6.0	4.2	3.8	7.6	1.6	0.9	1.0	1.4	4.3	15.0	4.9	4.1	3.3	10.8	2.7	1.2
2004	2.5	2.7	6.9	41.8	30.4	23.4	5.3	3.7	3.3	6.7	1.4	0.8	0.9	1.2	3.7	13.1	4.2	3.6	2.9	9.4	2.4
2005	3.5	2.2	2.4	6.1	37.4	27.2	20.9	4.8	3.3	2.9	5.9	1.3	0.7	0.8	1.1	3.3	11.5	3.7	3.1	2.5	8.3
2006	30.6	3.1	2.0	2.1	5.5	33.4	24.3	18.7	4.2	2.9	2.6	5.2	1.1	0.6	0.7	0.9	2.8	10.0	3.2	2.7	2.2
2007	92.1	27.4	2.8	1.8	1.9	4.9	29.8	21.6	16.6	3.7	2.6	2.3	4.6	1.0	0.5	0.6	0.8	2.5	8.8	2.8	2.4
2008	212.9	82.3	24.5	2.5	1.6	1.7	4.4	26.6	19.2	14.6	3.3	2.3	2.0	4.0	0.9	0.5	0.5	0.7	2.2	7.7	2.5
2009	131.3	190.3	73.6	21.9	2.2	1.4	1.5	3.8	23.1	16.5	12.5	2.8	1.9	1.7	3.4	0.7	0.4	0.4	0.6	1.8	6.5
2010	22.8	117.4	170.1	65.8	19.5	2.0	1.2	1.3	3.3	19.4	13.7	10.3	2.3	1.6	1.4	2.7	0.6	0.3	0.4	0.5	1.5
2011	15.7	20.4	105.0	152.1	58.8	17.4	1.8	1.1	1.1	2.8	16.3	11.4	8.5	1.9	1.3	1.1	2.3	0.5	0.3	0.3	0.4
2012	6.0	14.0	18.2	93.9	136.0	52.5	15.5	1.5	0.9	1.0	2.4	13.6	9.5	7.1	1.6	1.1	0.9	1.9	0.4	0.2	0.2
2013	5.6	5.4	12.5	16.3	83.9	121.2	46.4	13.4	1.3	0.8	0.8	1.9	10.9	7.6	5.6	1.2	0.8	0.7	1.5	0.3	0.2
2014	4.5	5.0	4.8	11.2	14.6	74.9	107.9	41.0	11.8	1.1	0.7	0.7	1.6	9.3	6.5	4.8	1.1	0.7	0.6	1.3	0.3
2015	5.3	4.1	4.5	4.3	10.0	13.0	66.8	95.6	36.1	10.3	1.0	0.6	0.6	1.4	8.1	5.6	4.1	0.9	0.6	0.5	1.1
2016	5.7	4.8	3.6	4.0	3.8	8.9	11.6	59.2	84.3	31.6	9.0	0.9	0.5	0.5	1.2	7.0	4.8	3.6	0.8	0.5	0.5
2017	6.7	5.1	4.3	3.2	3.6	3.4	8.0	10.3	52.3	74.0	27.6	7.8	0.7	0.4	0.4	1.1	6.1	4.2	3.1	0.7	0.5
2018	10.8	6.0	4.5	3.8	2.9	3.2	3.1	7.1	9.1	45.8	64.5	24.0	6.8	0.6	0.4	0.4	0.9	5.2	3.6	2.7	0.6
2019	25.0	9.7	5.4	4.1	3.4	2.6	2.9	2.7	6.3	8.0	40.2	56.5	21.0	5.9	0.6	0.3	0.3	0.8	4.6	3.2	2.4
2020	34.2	22.3	8.6	4.8	3.6	3.0	2.3	2.5	2.4	5.5	6.9	34.9	48.9	18.2	5.1	0.5	0.3	0.3	0.7	4.0	2.7

Table 5.22. Spawning and total biomass compared with the 2018 assessment and fishing mortality, exploitation rate, and 1-SPR from the current assessment for BSAI Greenland turbot, 1977-2022. The 2021 and 2022 biomass estimates are from the Model 16.4a (2020) projections. The projections assume catch in 2021 and 2022 is equal to maximum ABC.

	SSB (t)		Total biomass (age1+)				
Year	2018	Current	2018	Current	Apical F	Exploitation rate	1-SPR
1977	305,274	262,630	548,852	517,074	0.08	0.06	0.61
1978	299,082	264,568	546,301	526,469	0.12	0.08	0.72
1979	283,743	256,717	539,868	532,363	0.12	0.08	0.71
1980	268,767	248,476	538,157	542,857	0.15	0.10	0.78
1981	253,156	239,487	522,807	539,134	0.17	0.11	0.81
1982	240,818	233,940	495,039	521,651	0.14	0.10	0.80
1983	235,087	234,918	462,520	497,395	0.14	0.10	0.79
1984	229,943	236,369	424,885	466,143	0.07	0.05	0.57
1985	231,106	243,465	404,683	450,445	0.05	0.03	0.44
1986	231,958	249,279	387,423	436,071	0.03	0.02	0.34
1987	230,712	251,811	371,177	421,379	0.04	0.02	0.35
1988	225,476	249,159	352,624	403,380	0.03	0.02	0.29
1989	217,913	243,145	334,902	385,414	0.05	0.02	0.28
1990	205,200	231,378	313,813	363,383	0.08	0.03	0.41
1991	188,389	215,029	287,964	336,135	0.06	0.02	0.31
1992	174,737	201,287	268,139	314,567	0.03	0.01	0.15
1993	164,111	190,065	253,572	297,937	0.06	0.03	0.31
1994	149,741	175,048	234,223	276,483	0.10	0.04	0.44
1995	135,437	160,134	212,424	252,549	0.08	0.03	0.39
1996	123,184	146,988	193,287	231,044	0.07	0.03	0.34
1997	112,523	135,207	176,407	211,651	0.08	0.03	0.37
1998	101,654	123,080	159,417	192,111	0.11	0.05	0.45
1999	89,840	109,919	141,516	171,679	0.08	0.03	0.39
2000	80,737	99,430	127,299	155,018	0.11	0.04	0.46
2001	70,885	88,200	112,819	138,197	0.10	0.04	0.44
2002	62,832	78,824	101,258	124,445	0.07	0.03	0.36
2003	56,300	71,013	93,004	114,172	0.07	0.03	0.35
2004	50,604	64,103	86,688	106,020	0.06	0.02	0.30
2005	46,087	58,455	82,241	99,905	0.07	0.03	0.35
2006	41,981	53,287	77,875	93,979	0.06	0.02	0.30
2007	39,276	49,612	74,360	88,990	0.06	0.02	0.31
2008	37,470	46,914	70,995	84,192	0.11	0.03	0.44
2009	36,147	44,804	67,514	79,178	0.17	0.06	0.58
2010	33,936	41,852	64,684	74,547	0.18	0.06	0.58
2011	31,325	38,477	65,839	73,546	0.17	0.05	0.57
2012	28,784	35,194	70,832	76,034	0.24	0.06	0.67
2013	26,342	32,020	76,786	79,219	0.09	0.02	0.37

Table 5.22. Continued. Spawning and total biomass compared with the 2018 assessment and fishing mortality, exploitation rate, and 1-SPR from the current assessment for BSAI Greenland turbot, 1977-2022. The 2021 and 2022 biomass estimates are from the Model 16.4a (2020) projections. The projections assume catch in 2021 and 2022 is equal to maximum ABC.

	SSB (t)		Total biomass (age1+)				
Year	2018	Current	2018	Current	Apical F	Exploitation	1-SPR
2014	27,404	32,201	86,267	85,934	0.07	0.02	0.32
2015	31,312	34,940	95,068	92,031	0.08	0.02	0.35
2016	37,430	39,500	101,777	96,170	0.06	0.02	0.30
2017	44,447	44,725	106,426	98,487	0.06	0.03	0.30
2018	50,465	48,898	108,433	98,362	0.03	0.02	0.18
2019	54,244	52,010	105,930	97,392	0.06	0.03	0.27
2020	52,743	52,902	98,876	93,970	0.07	0.04	0.33
2021	-	51,914	-	87,849	-	-	-
2022	-	47,197	-	79,382	-	-	-

Table 5.23. Spawning biomass from Model 16.4a (2020) 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	Year	SSB	LCI	UCI
1977	262,630	168,978	356,282	2021	51,914	51,914	51,914
1978	264,568	174,786	354,350	2022	47,197	47,197	47,197
1979	256,717	171,395	342,039				
1980	248,476	167,864	329,088				
1981	239,487	163,816	315,158				
1982	233,940	163,024	304,856				
1983	234,918	168,337	301,499				
1984	236,369	173,905	298,833				
1985	243,465	185,065	301,865				
1986	249,279	195,024	303,534				
1987	251,811	201,671	301,951				
1988	249,159	202,931	295,387				
1989	243,145	200,627	285,663				
1990	231,378	192,781	269,975				
1991	215,029	180,164	249,894				
1992	201,287	169,730	232,844				
1993	190,065	161,469	218,661				
1994	175,048	149,225	200,871				
1995	160,134	136,919	183,349				
1996	146,988	126,108	167,868				
1997	135,207	116,391	154,023				
1998	123,080	106,111	140,049				
1999	109,919	94,609	125,229				
2000	99,430	85,581	113,279				
2001	88,200	75,664	100,736				
2002	78,824	67,454	90,195				
2003	71,013	60,677	81,349				
2004	64,103	54,695	73,511				
2005	58,455	49,867	67,043				
2006	53,287	45,421	61,153				
2007	49,612	42,347	56,876				
2008	46,914	40,145	53,682				
2009	44,804	38,477	51,131				
2010	41,852	35,926	47,777				
2011	38,477	32,918	44,035				
2012	35,194	29,958	40,431				
2013	32,020	27,005	37,035				
2014	32,201	27,197	37,204				
2015	34,940	29,623	40,256				
2016	39,500	33,570	45,430				
2017	44,725	38,055	51,395				
2018	48,898	41,550	56,245				
2019	52,010	44,153	59,866				
2020	52,902	44,741	61,064				

Table 5.24. Age-0 recruits based on Model 16.4a (2020) 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.

Year	Age-0 Recruits	LCI	UCI
1977	105,778	30,874	180,682
1978	58,484	10,610	106,358
1979	20,148	4,102	36,195
1980	6,969	1,363	12,576
1981	1,164	142	2,185
1982	2,119	269	3,969
1983	3,480	822	6,137
1984	6,698	2,527	10,868
1985	22,414	15,421	29,407
1986	5,789	3,022	8,555
1987	6,158	3,548	8,768
1988	6,336	3,643	9,030
1989	16,992	12,346	21,638
1990	4,188	2,110	6,266
1991	1,196	500	1,892
1992	762	307	1,218
1993	600	230	970
1994	934	399	1,470
1995	3,785	2,451	5,119
1996	1,653	822	2,484
1997	1,632	828	2,436
1998	2,095	1,057	3,133
1999	8,208	5,537	10,879
2000	9,512	6,293	12,731
2001	11,705	8,534	14,875
2002	1,714	856	2,573
2003	600	245	956
2004	492	178	805
2005	695	312	1,077
2006	6,119	4,144	8,094
2007	18,415	13,768	23,062
2008	42,573	33,590	51,556
2009	26,270	19,170	33,370
2010	4,557	2,783	6,331
2011	3,134	1,727	4,541
2012	1,201	524	1,877
2013	1,129	488	1,771
2014	909	355	1,463
2015	1,066	445	1,687
2016	1,136	537	1,735
2017	1,347	595	2,098
2018	2,162	852	3,472
2019	4,997	1,159	8,836
2020	6,838	1,188	12,489

Table 5.25. Model 16.4a (2020) mean spawning biomass, yield, and F projections for Greenland turbot, 2018-2031. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be 50:50. $B_{40\%}$ is 35,622 t and $B_{35\%}$ is 31,169 t.

Spawning biomass (t)							
Year	*Max ABC*	*Author's recommended F*	*50% max F_{abc}*	*Avg F*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2021	51,914	51,914	51,914	51,914	51,914	51,914	51,914
2022	47,197	47,197	50,333	50,508	51,864	46,409	47,197
2023	42,396	42,396	48,114	48,445	51,049	41,021	42,396
2024	37,879	37,879	45,575	46,035	49,714	36,105	37,305
2025	33,911	33,911	43,022	43,584	48,141	31,891	32,932
2026	30,848	30,848	40,791	41,429	46,669	28,852	29,683
2027	28,911	28,911	39,197	39,889	45,648	26,985	27,661
2028	28,005	28,005	38,385	39,118	45,279	26,157	26,711
2029	27,914	27,914	38,320	39,088	45,595	26,127	26,582
2030	28,409	28,409	38,901	39,704	46,557	26,649	27,022
2031	29,332	29,332	40,049	40,893	48,133	27,561	27,865
2032	30,518	30,518	41,625	42,519	50,213	28,693	28,940
2033	31,740	31,740	43,422	44,375	52,610	29,827	30,026
2034	32,764	32,764	45,186	46,208	55,072	30,729	30,889
Catch (t)							
Year	*Max ABC*	*Author's recommended F*	*50% max F_{abc}*	*Avg F*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2021	7,326	7,326	2,398	2,124	0	8,568	7,326
2022	6,139	6,139	2,149	1,910	0	7,055	6,139
2023	5,099	5,099	1,901	1,696	0	5,763	5,966
2024	4,259	4,259	1,682	1,505	0	4,744	4,905
2025	3,480	3,480	1,512	1,357	0	3,601	3,838
2026	2,881	2,881	1,411	1,268	0	2,965	3,129
2027	2,674	2,674	1,384	1,245	0	2,771	2,890
2028	2,732	2,732	1,424	1,281	0	2,874	2,962
2029	2,971	2,971	1,516	1,363	0	3,164	3,233
2030	3,339	3,339	1,644	1,477	0	3,592	3,646
2031	3,747	3,747	1,793	1,611	0	4,072	4,110
2032	4,159	4,159	1,946	1,749	0	4,527	4,557
2033	4,510	4,510	2,083	1,873	0	4,920	4,941
2034	4,735	4,735	2,191	1,972	0	5,154	5,168

Table 5.25. Continued. Model 16.4a (2020) mean spawning biomass, yield, and F projections for Greenland turbot, 2018-2031. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be 50:50. $B_{40\%}$ is 35,622 t and $B_{35\%}$ is 31,169 t.

Fishing mortality							
Year	*Max ABC*	*Author's recommended F*	*50% max F_{abc}*	*Avg F*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2021	0.18	0.18	0.06	0.05	0.00	0.22	0.18
2022	0.18	0.18	0.06	0.05	0.00	0.22	0.18
2023	0.18	0.18	0.06	0.05	0.00	0.22	0.22
2024	0.18	0.18	0.06	0.05	0.00	0.22	0.22
2025	0.18	0.18	0.06	0.05	0.00	0.19	0.20
2026	0.16	0.16	0.06	0.05	0.00	0.17	0.18
2027	0.15	0.15	0.06	0.05	0.00	0.16	0.17
2028	0.14	0.14	0.06	0.05	0.00	0.16	0.16
2029	0.14	0.14	0.06	0.05	0.00	0.15	0.16
2030	0.14	0.14	0.06	0.05	0.00	0.15	0.16
2031	0.14	0.14	0.06	0.05	0.00	0.16	0.16
2032	0.14	0.14	0.06	0.05	0.00	0.16	0.16
2033	0.15	0.15	0.06	0.05	0.00	0.16	0.17
2034	0.15	0.15	0.06	0.05	0.00	0.17	0.17

Table 5.26. Dynamic B_0 results from model 16.4a (2020). SSB_0 is the expected spawning biomass in the absence of fishing. Depletion is SSB/SSB_0

Year	SSB_0	SSB	Depletion
1977	792,546	262,630	0.33
1978	823,333	264,568	0.32
1979	838,486	256,717	0.31
1980	844,315	248,476	0.29
1981	848,584	239,487	0.28
1982	857,637	233,940	0.27
1983	872,468	234,918	0.27
1984	888,873	236,369	0.27
1985	900,801	243,465	0.27
1986	903,379	249,279	0.28
1987	894,319	251,811	0.28
1988	873,814	249,159	0.29
1989	843,655	243,145	0.29
1990	806,343	231,378	0.29
1991	764,572	215,029	0.28
1992	720,712	201,287	0.28
1993	676,315	190,065	0.28
1994	632,328	175,048	0.28
1995	588,965	160,134	0.27
1996	546,452	146,988	0.27
1997	505,554	135,207	0.27
1998	466,513	123,080	0.26
1999	429,329	109,919	0.26
2000	394,046	99,430	0.25
2001	360,787	88,200	0.24
2002	329,712	78,824	0.24
2003	300,898	71,013	0.24
2004	274,383	64,103	0.23
2005	250,231	58,455	0.23
2006	228,185	53,287	0.23
2007	208,548	49,612	0.24
2008	191,263	46,914	0.25
2009	175,881	44,804	0.25
2010	161,902	41,852	0.26
2011	148,978	38,477	0.26
2012	137,129	35,194	0.26
2013	126,864	32,020	0.25
2014	119,213	32,201	0.27
2015	115,028	34,940	0.30
2016	113,789	39,500	0.35
2017	113,994	44,725	0.39
2018	114,080	48,898	0.43
2019	113,183	52,010	0.46
2020	110,993	52,902	0.48

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

	Arrowtooth Flounder	Atka Mackerel	BSAI Alaska Plaice	BSAI Kamchatka Flounder	BSAI Other Flatfish	BSAI Rougheye Rockfish	BSAI Shortraker Rockfish	BSAI Skate	BSAI Squid	Demersal Shelf Rockfish	Flathead Sole	Flounder	Greenland Turbot
1991	1,085	65										94	3,329
1992	4											0.01	75
1993	560									0.10		107	6,019
1994	1,384	1										67	6,683
1995	2,007	10									57		5,419
1996	492	3									52		3,624
1997	766										63		5,230
1998	1,153	22									50		6,980
1999	1,071	133									131		4,236
2000	764	5									72		4,976
2001	292	2									69		2,817
2002	333										35		2,052
2003	368	<0.01	1		40				3		76		1,767
2004	256	0.01	1		5	4	40		6		17		1,240
2005	185				7	2	12		0		7		1,551
2006	195	0.01			1	5	33				3		1,212
2007	235	0.20			0.27	3	78				0		1,235
2008	337	<0.01			3	0.33	2		4		1		948
2009	1,339	1			4	1	4		23		5		2,540
2010	572		1		1	4	28		1		11		1,946
2011	223	0.05		13	4	0.12	5	382			6		1,794
2012	333			239	6	1	11	357			13		1,910
2013	9			61	3	0.10	3	51			6		591
2014	47			41	2		2	43			8		643
2015	15	0.01		80	2	0.06	2	209			11		1,071
2016	370		1	203	7	0.35	5	194			65		1,394
2017	603		0.25	380	53	1	16	198			138		1,901
2018	162			453	68	2	46	94			223		1,240
2019	247			946	215	7.5	55	123			495		1819
2020	153			298	46	5.3	5	99			177		759

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	Pelagic Shelf Rockfish	Pollock	Rock Sole	Sablefish
1991				107		61		154	3		114	1	504
1992				10		2		12	0.16		0.05		28
1993				529		77		115	1	0.04	6	0.33	577
1994				165		96		85	1		20	1	492
1995				533	64	96		111	12		50	4	555
1996				232	16	59		97	6		32	3	265
1997				278	27	51		82	14		56	2	267
1998				518	37	125		166	3		106	13	404
1999	1,411			464	74	56		225	32		151	54	380
2000	1,007			328	47	121		223	27		117	3	351
2001	500			197	18	56		110	52		54	3	229
2002	312			179	17	55		83	1		13	1	170
2003		2				79	240	32	1		98	1	174
2004						60	143	38	1		64	1	89
2005						48	172	22	0.31		8	0.28	99
2006		<0.01				52	125	56	0.01		1	0.03	93
2007		0.15				56	179	67	0.37		3		73
2008		0.50				37	72	83	166		32	0.44	61
2009						50	210	13	0.23		12		81
2010		<0.01				70	370	59	0.02		11	0.01	98
2011		0.02	0.05			41		72	0.20		14	0.01	23
2012			0.07			40		79	0.30		11		28
2013			0.14			17		5	0.02		2	0.04	11
2014		0.05	0.08			25		6	0.03		2	0.14	21
2015		<0.01	0.08			29		37	0.02		20		7
2016			0.12			38		61	42		131	0.01	16
2017		0.01	1			54		53	37		227	1	120
2018			1			50		32	111		173	0.02	121
2019						308		42	150				633
2020						17		18	32			2	194

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

	Sculpin	Shark	Sharpchin/Northern Rockfish	Shortraker Rockfish	Shortraker/Rougheye Rockfish	Shortraker/Rougheye/Sharpchin/Northern Rockfish	Squid	Thornyhead Rockfish	Yellowfin Sole
1991						27	38		0.45
1992					2			0.01	
1993					123	73	0.34	0.01	
1994			11		14	10	19		0.09
1995			65		18	16	12		18
1996					12	10	1		<0.01
1997					2	17	3		9
1998					38	29	1		6
1999					10	34	4		18
2000			<0.01		46	45	9		4
2001					43	5	2		5
2002					16		0.17		
2003				0.35	35			1	1
2004									1
2005									
2006									0.08
2007									
2008									
2009									
2010									
2011	1						<0.01		0.06
2012	1	0.11							
2013	0.27						0.06		0.05
2014	2	0.04					1		0.03
2015	2						<0.01		0.29
2016	21						3		
2017	33	0.01					14		1
2018	30						22		0.10
2019	27								
2020	22	2.7							

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.

Year	Benthic urochordata	Brittle star unidentified	Corals Bryozoans - Corals Bryozoans Unidentified	Eelpouts	Giant Grenadier	Grenadier - Rattail Grenadier Unidentified	Gunnels	Invertebrate unidentified	Large Sculpins	Large Sculpins - Bigmouth Sculpin	Large Sculpins - Great Sculpin	Large Sculpins - Yellow Irish Lord	Misc crabs	Misc fish	Other Sculpins	Scypho jellies	Sea anemone unidentified	Sea pens whips	Sea star	Snails	Sponge unidentified	urchins dollars cucumbers
2003	0.03	0.01	0.06	1.59	44.44	1,503.57			0.51				0.01	2.95	1.18	0.01	0.12		0.40	0.04	0.10	0.80
2004				2.36	135.79	1,164.08			0.13				0.01	1.48	0.40		0.04		0.23	0.01		0.01
2005			0.06	5.53	1,105.29	1,029.74			0.12				0.00	1.11	0.36	0.02	0.20		0.86	0.13	0.01	0.29
2006				3.95	1,300.83	216.84		0.03	0.76				0.02	2.08	0.37	0.01	0.08		0.38	0.02	0.01	0.02
2009				5.41	1,775.30	46.88		0.01		0.11	0.04			0.39	0.74		0.06		1.16	0.02		0.52
2010	0.01		0.12	5.73	3,174.76	1,014.30		0.00					0.18	1.40		0.01	0.12	0.03	1.12	0.03		0.33
2011		0.15		7.74	2,084.61	352.99	0.03	0.26					0.16	1.10		0.01	1.46	0.08	0.81	0.03	0.02	0.07
2012		0.08		8.15	1,393.03	292.74		0.06					0.06	1.42			0.53		0.92	0.03	0.02	0.09
2013				2.07	539.05								0.12	0.50					0.44			0.13
2014				2.55	297.24								0.17	0.63					0.65			
2015				4.74	1,016.39								0.16	0.57			0.38		0.48	0.02		
2016		0.09		3.55	1,104.69								0.16	0.24			0.32		1.35	0.02	0.03	0.06
2017				1.47	1,087.63	51.12							0.15	0.08			0.10	0.03	1.35	0.01	0.01	0.11
2018					346.68														0.10			0.03
2019				0.10	366.33														0.15	0.01		
2020																						

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.

Year	Benthic urochordata	Brittle star unidentified	Corals Bryozoans - Corals Bryozoans Unidentified	Eelpouts	Giant Grenadier	Grenadier - Rattail Grenadier Unidentified	Hermit crab unidentified	Large Sculpins	Misc crabs	Misc crustaceans	Misc fish	Misc inverts (worms etc)	Other Sculpins	Pandalid shrimp	Polychaete unidentified	Scypho jellies	Sea anemone unidentified	Sea pens whips	Sea star	Snails	Sponge unidentified	Squid	Stichaeidae	urchins dollars cucumbers
2003				27.85		25.24					1.26	0.04	4.79	0.01			0.77	0.02	4.63	0.51				
2004				10.70		25.95		4.18			0.11					0.06			1.96	0.14				
2005																								
2008																								
2009				3.42	365.00	48.84					0.20		0.43	0.01			0.13		0.06	0.01	0.10			0.03
2010																								
2011																								
2013																								
2014																								
2015																								
2016				0.89	83.43						0.77			0.13			8.28		1.02					
2017		0.48		7.33	450.14				0.15		1.43			0.67			20.23	0.33	4.37	0.17	1.16			
2018	0.30			4.68	364.22				0.56		2.17			0.60		0.40	35.36		4.17	0.12	0.20			
2019		2.73	0.28	37.68	446.35	62.32	0.04		2.86	0.03	2.44			0.52	0.02	2.59	20.46	0.03	21.12	0.38	1.03	65.07		6.04
2020		0.87		2.43	397.27				1.40		2.05			0.39			28.72	0.13	5.12	0.13	1.74	29.38		

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					81		1	136	51	5
1992					13			8		
1993	29				568		4	2074	1164	3
1994			7		325			204	233	13
1995	21				428		8	650	402	50
1996	12				415			579	186	18
1997	14				391		22	362	206	12
1998	32				446		47	1226	1497	10
1999	28				428		24	1344	28606	5
2000	13				570		5	930	1730	20
2001	1				301		7	537	313	21
2002	64		3		271		45	562	55	6
2003	53		9	136	120		20	25		
2004	10		18	151	85		77			
2005		12	13	22	137		41	3		8
2006	28		8	328	27		26			13
2007	19			2438	17		24	34		48
2008	16	7		3	8		26	43		8
2009	85				17		15	24		
2010	47	8		180	53		37	85		
2011			4	34	45			12		
2012	16		4	26	38			42		
2013					7			5		
2014	5			29	10			8		
2015			18	36	23		34	7		
2016				38	30		70	12		
2017			6		31		36	8		
2018			3	4	6		6	19		
2019			7		3		23	9		
2020							25			

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

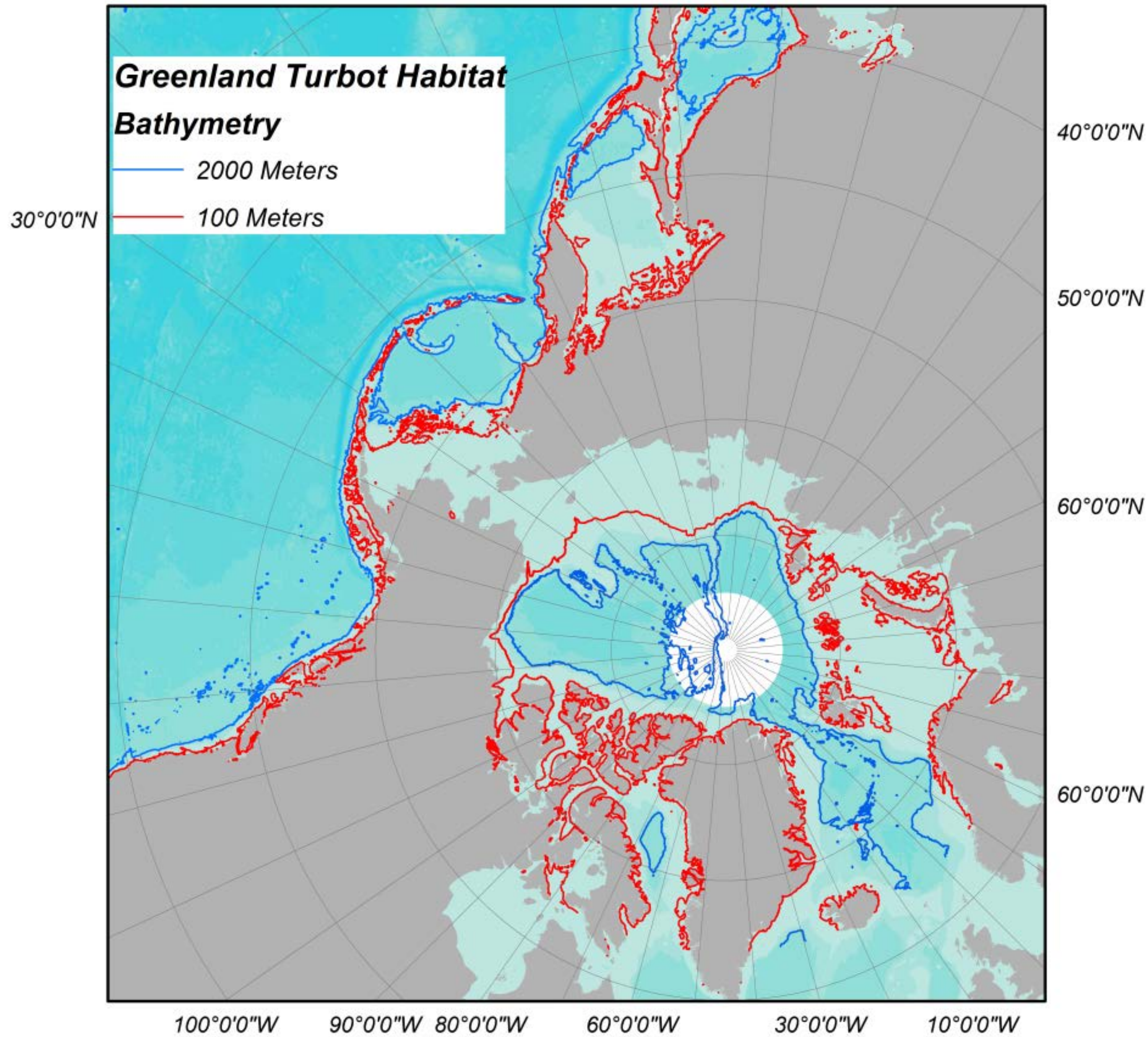
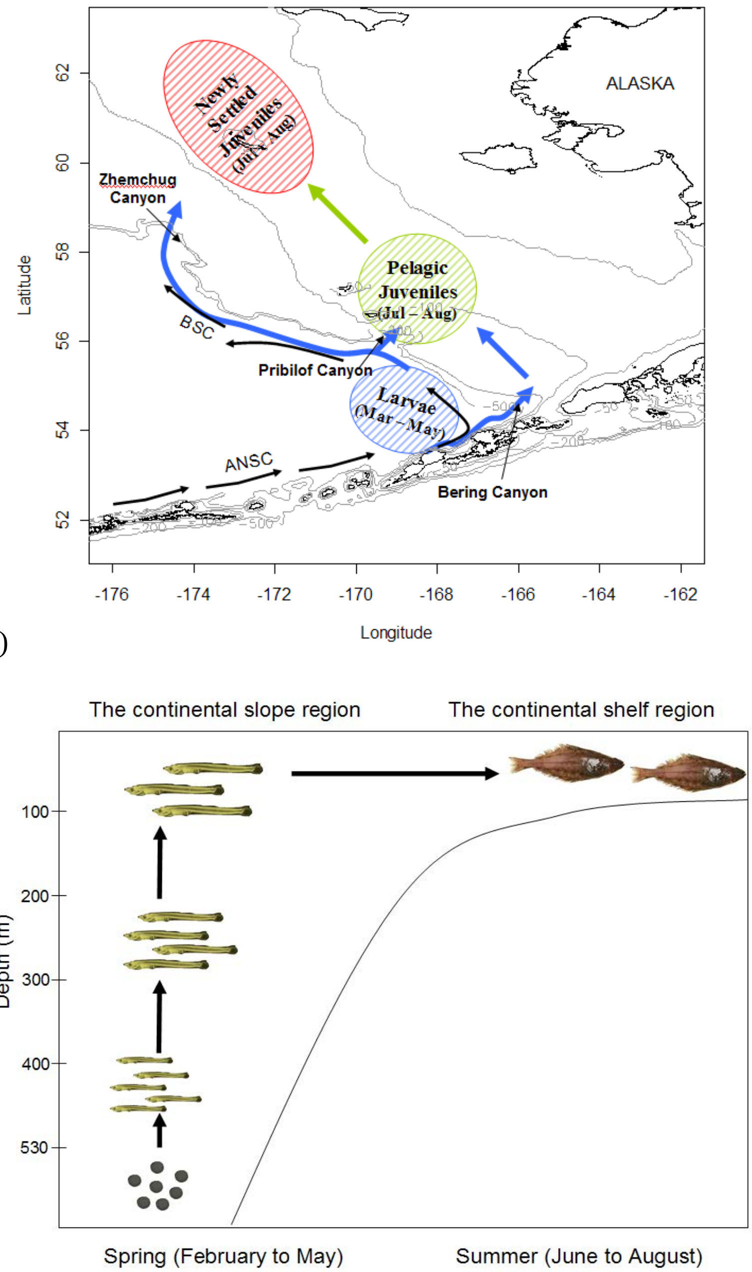


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.



(a)

(b)

Figure 5.2. Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: settlement ground). Blue arrows: possible larval transport routes from slope to shelf. (b) Vertically changed distribution as they develop. ***Source: Sohn (2009).***

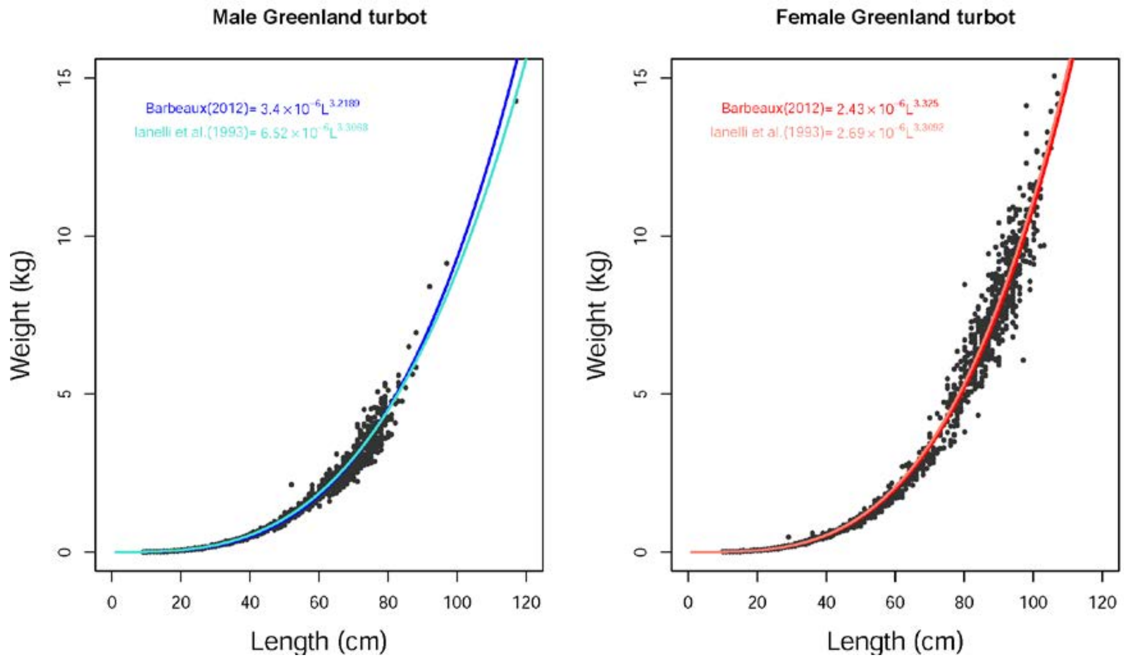


Figure 5. 3. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

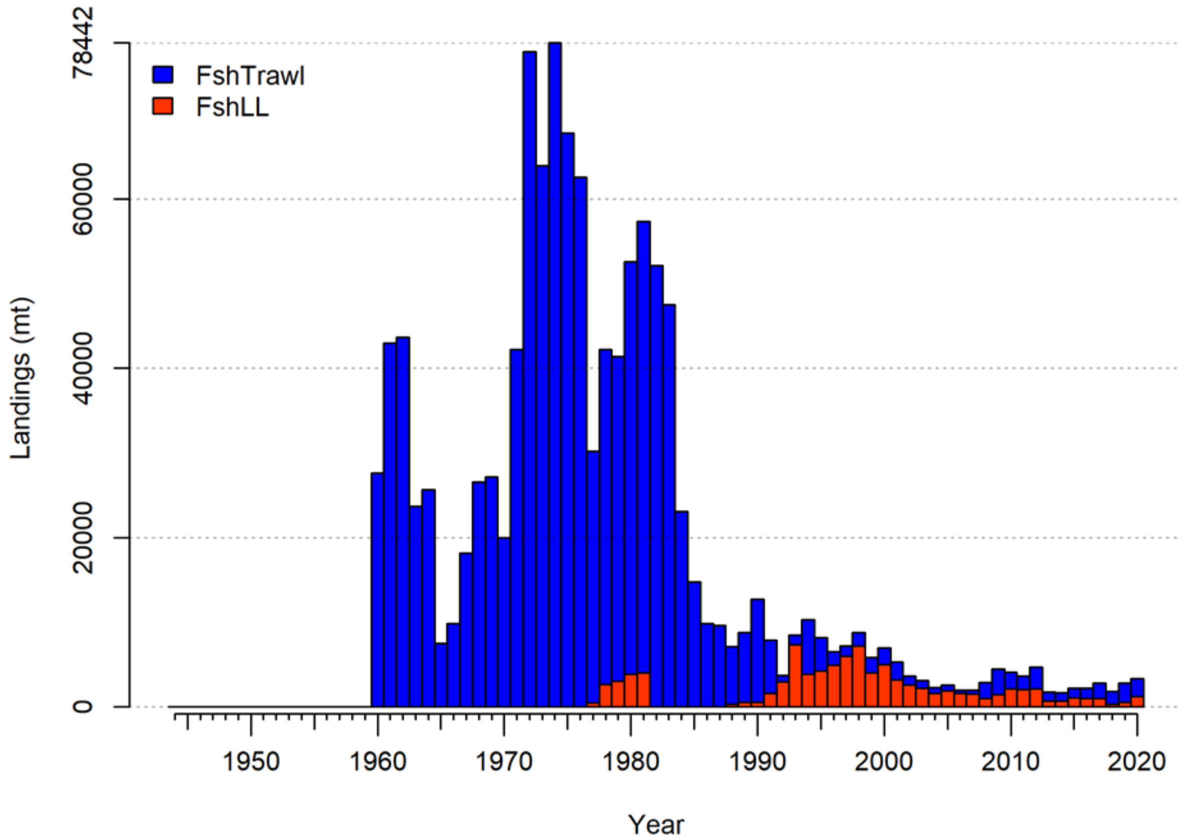


Figure 5. 4. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2020. This data includes targeted catch and bycatch.

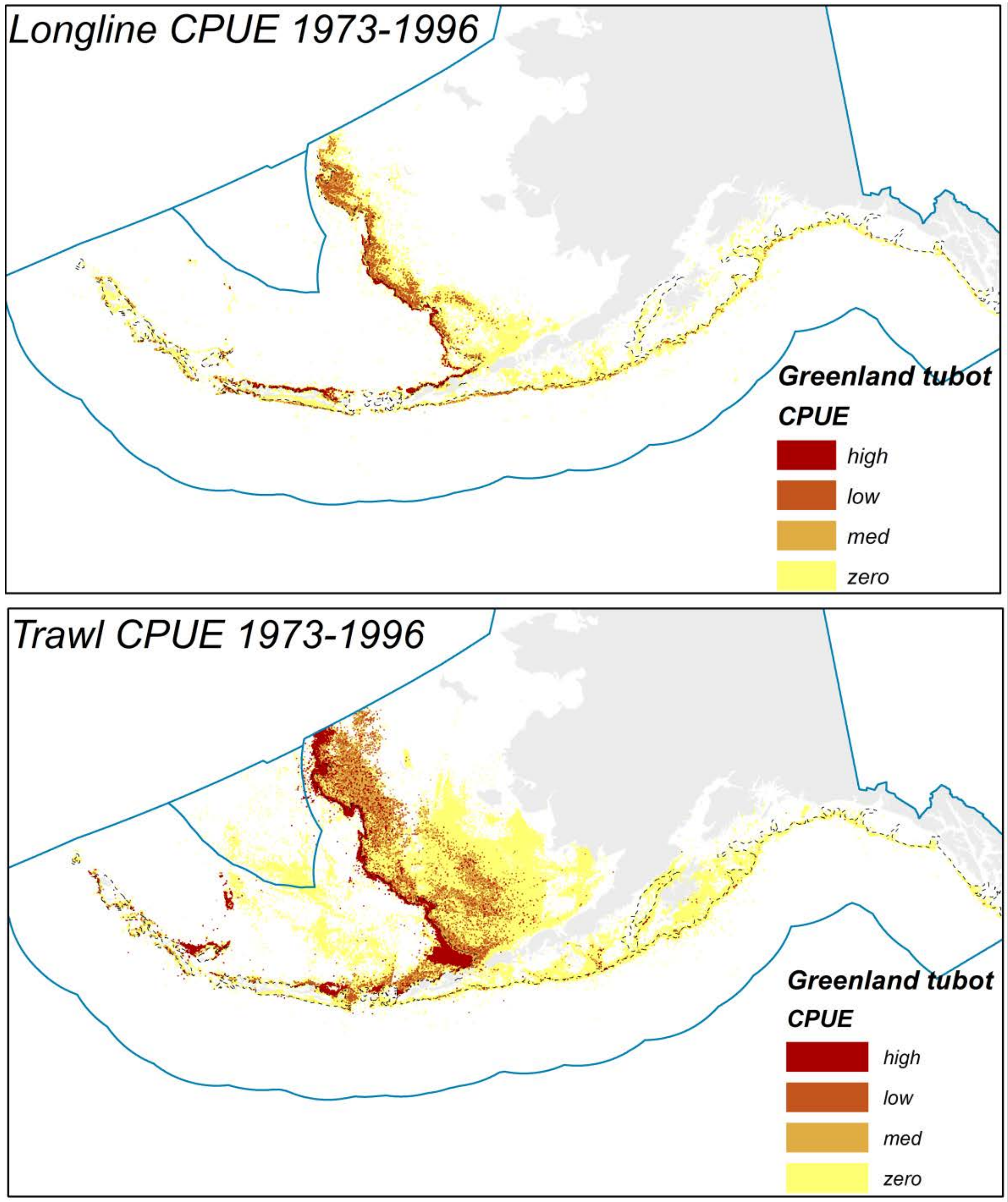


Figure 5.5. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).

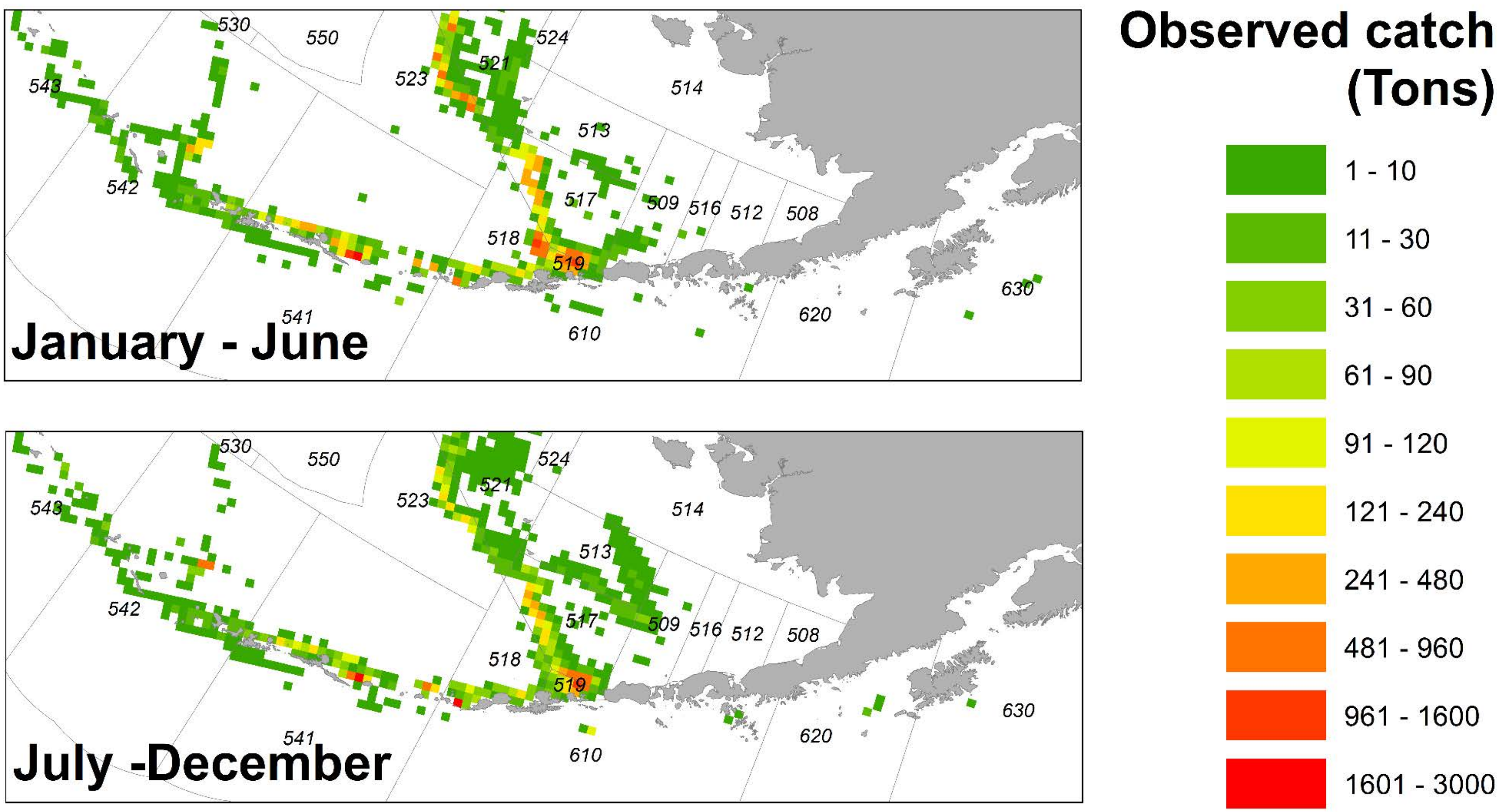


Figure 5.6 All observed catch for 2000 through 2018, data are aggregated spatially at a 400 km^2 grid.

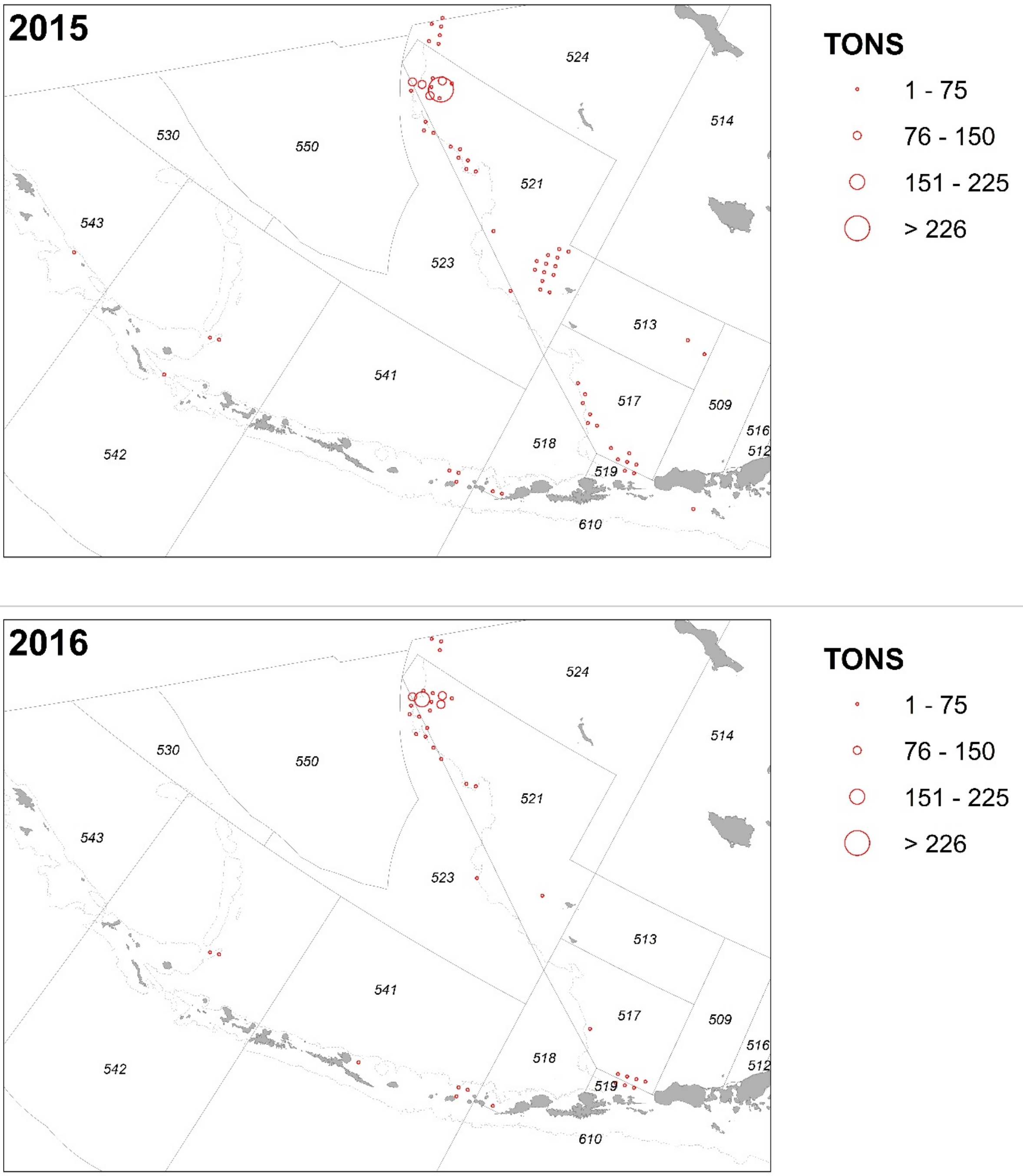


Figure 5.7. All observed Greenland turbot catch for 2015 and 2016. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

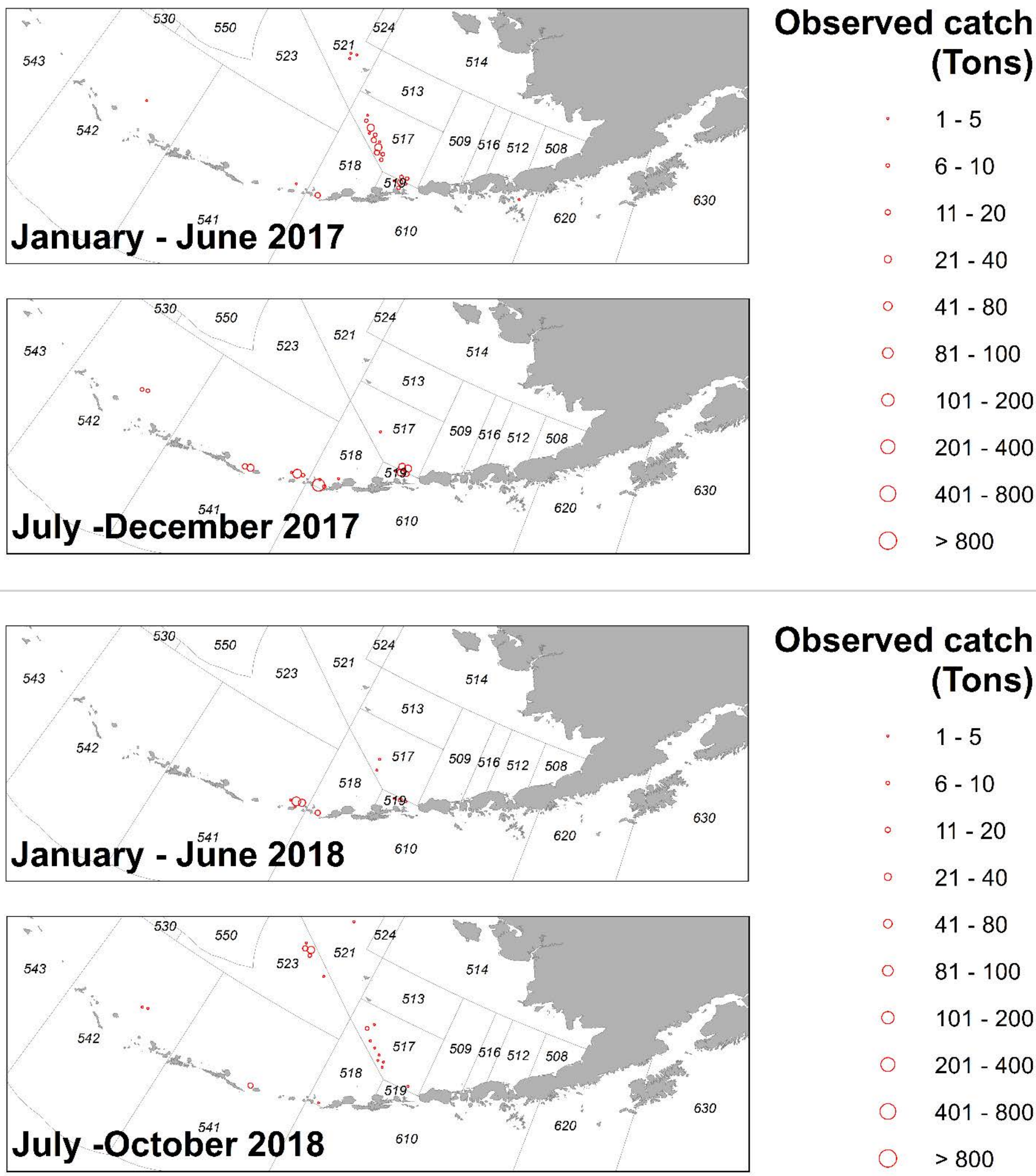


Figure 5.8. All observed Greenland turbot catch for 2017 and 2018. Data are aggregated for at 400 km^2. Note that areas with less than 1t are not shown.

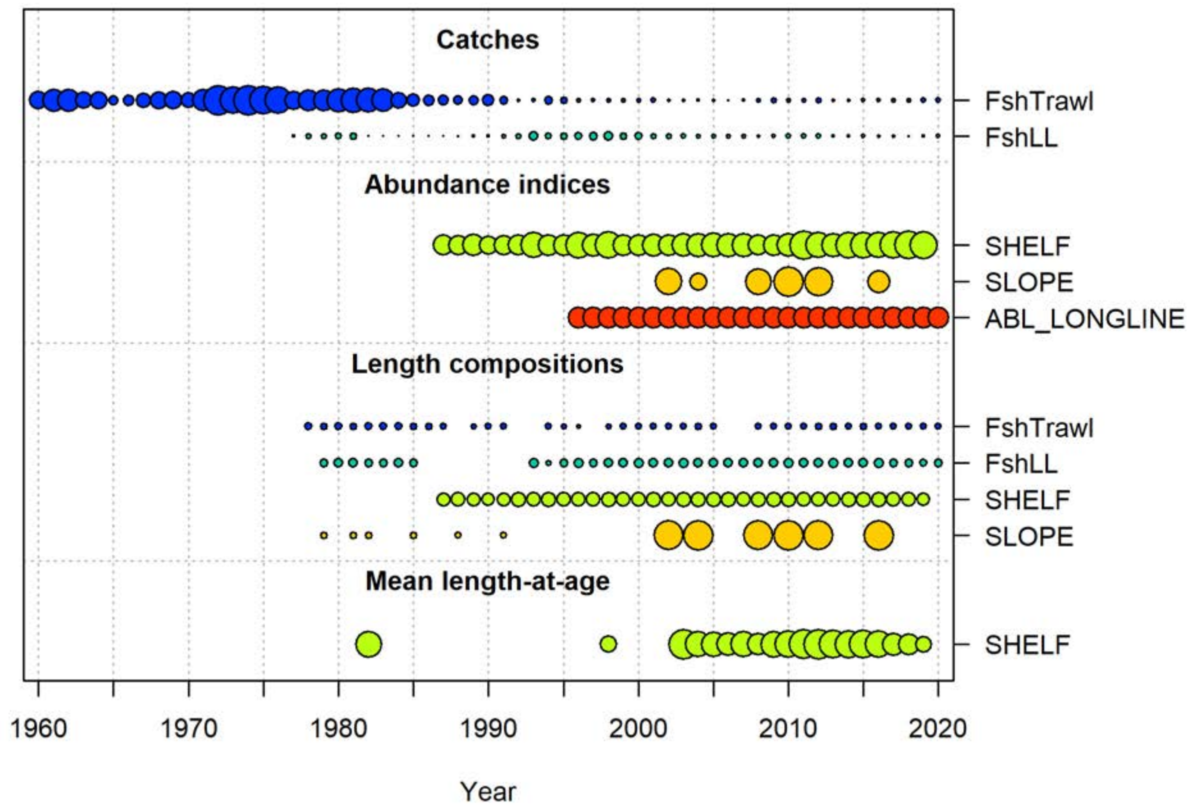


Figure 5.9. Timeline of all data included in model. Circle area is relative within a data type and scaled to the maximum. Circles are proportional to total catch for catches, proportional to precision for indices, and tot sample size for composition data.

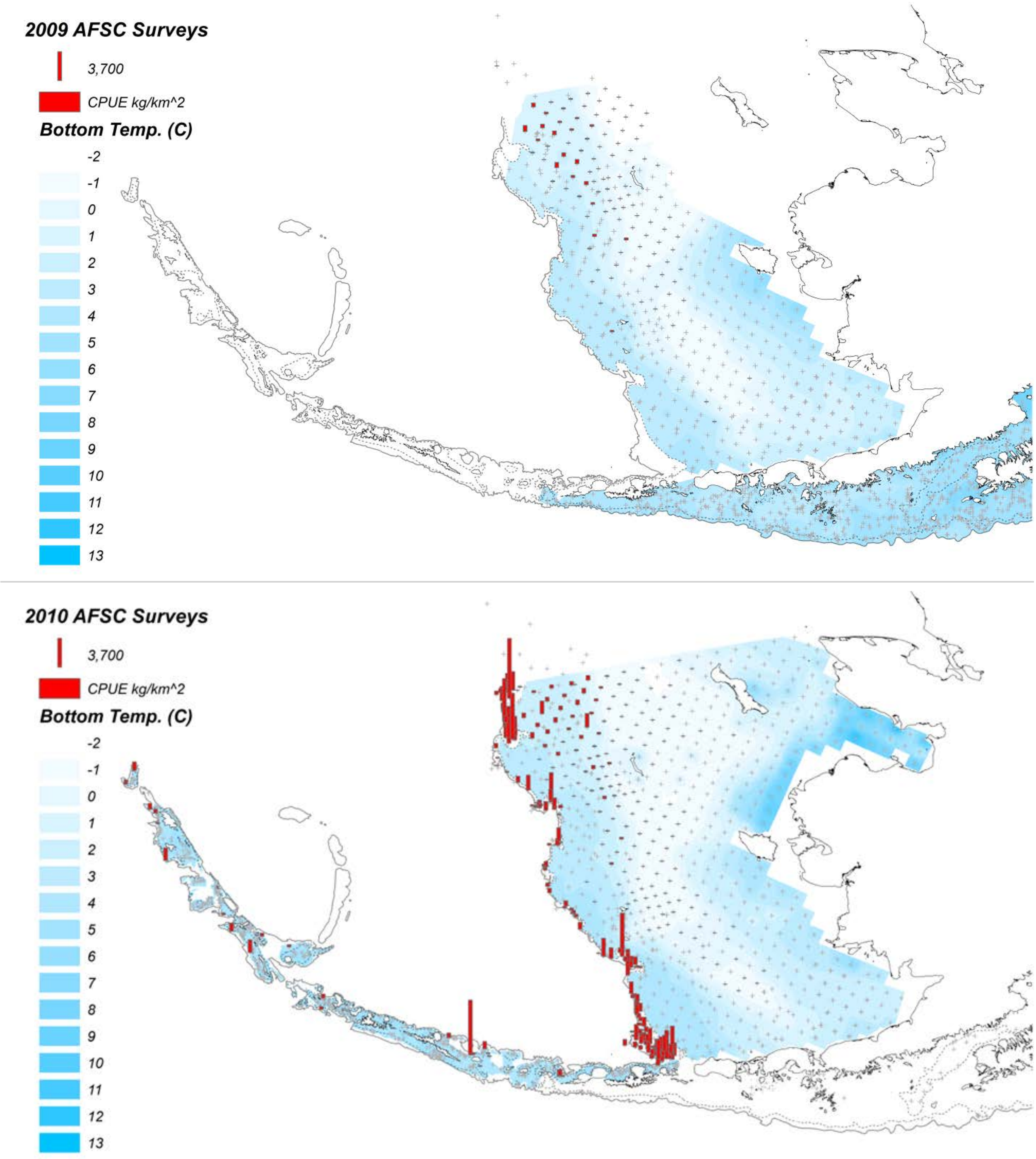
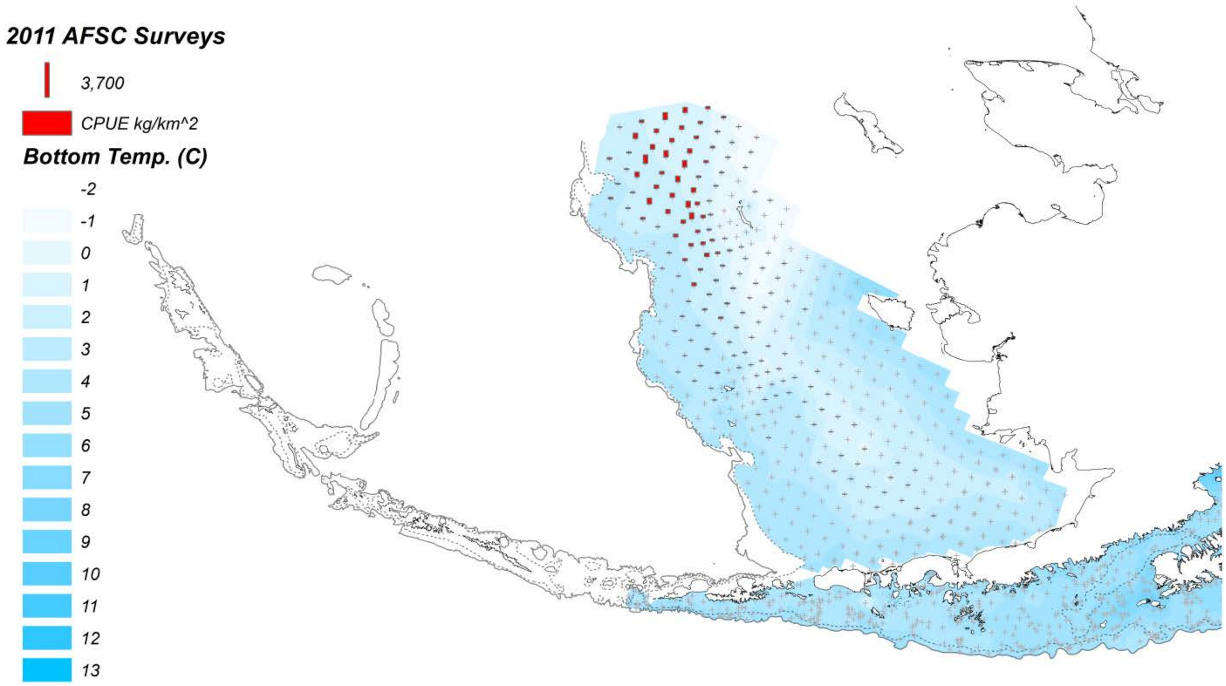


Figure 5.10. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.



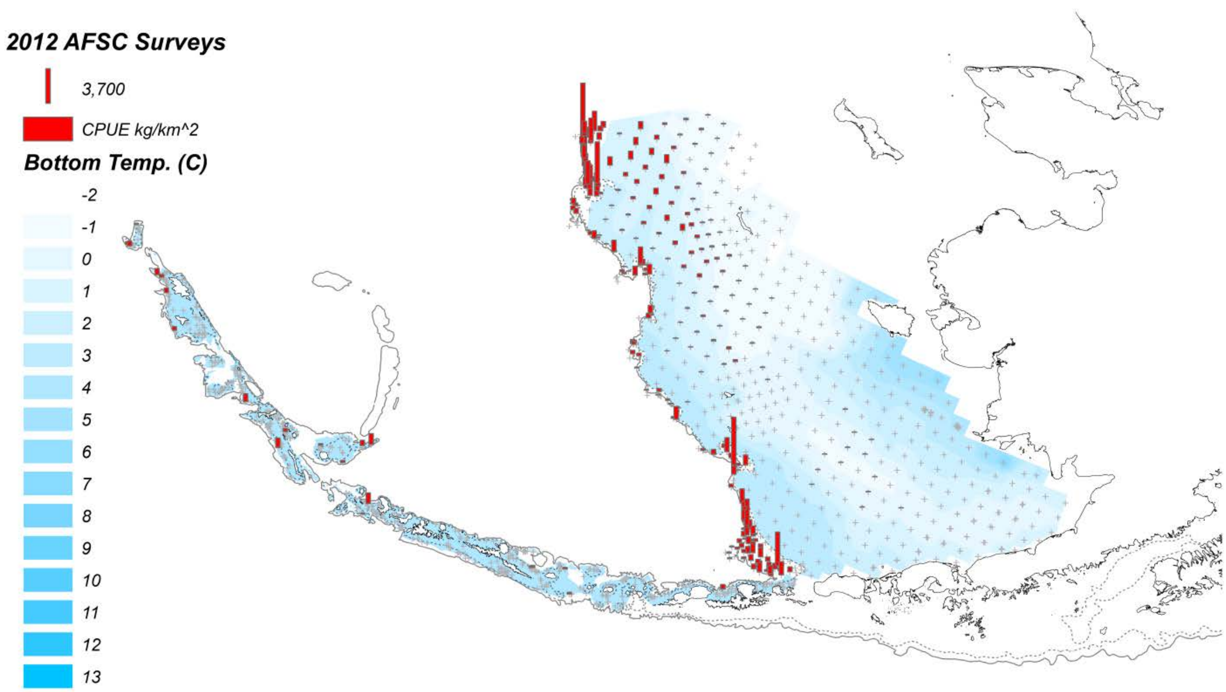
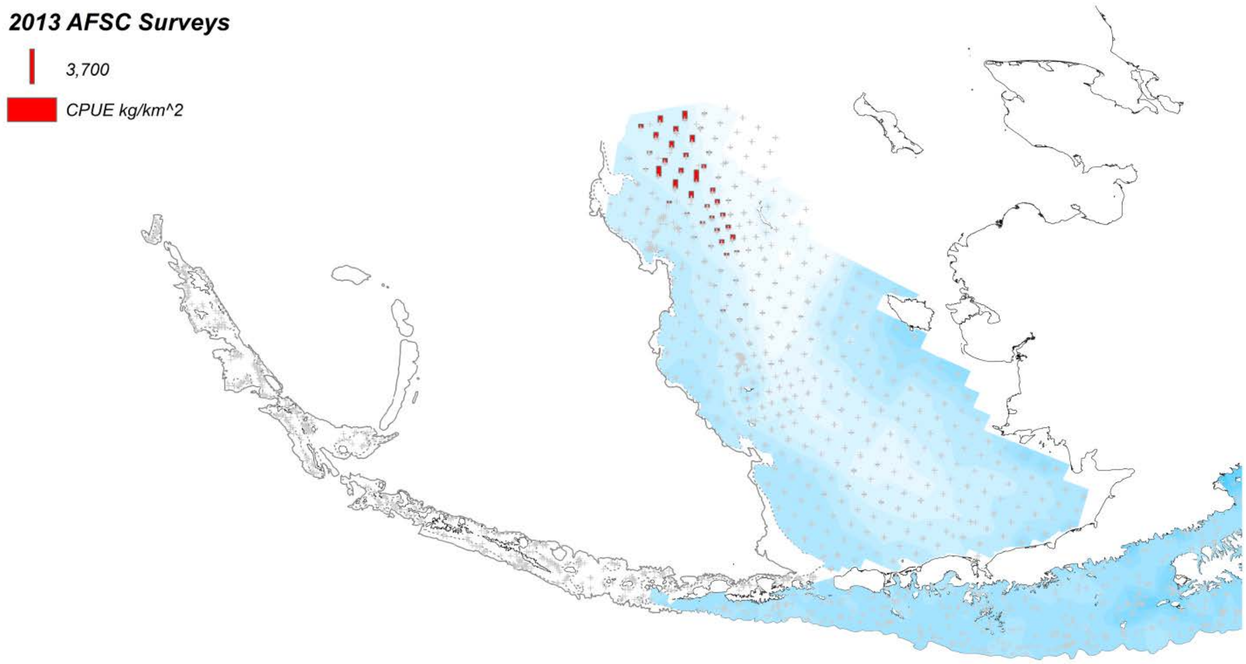


Figure 5.10.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.



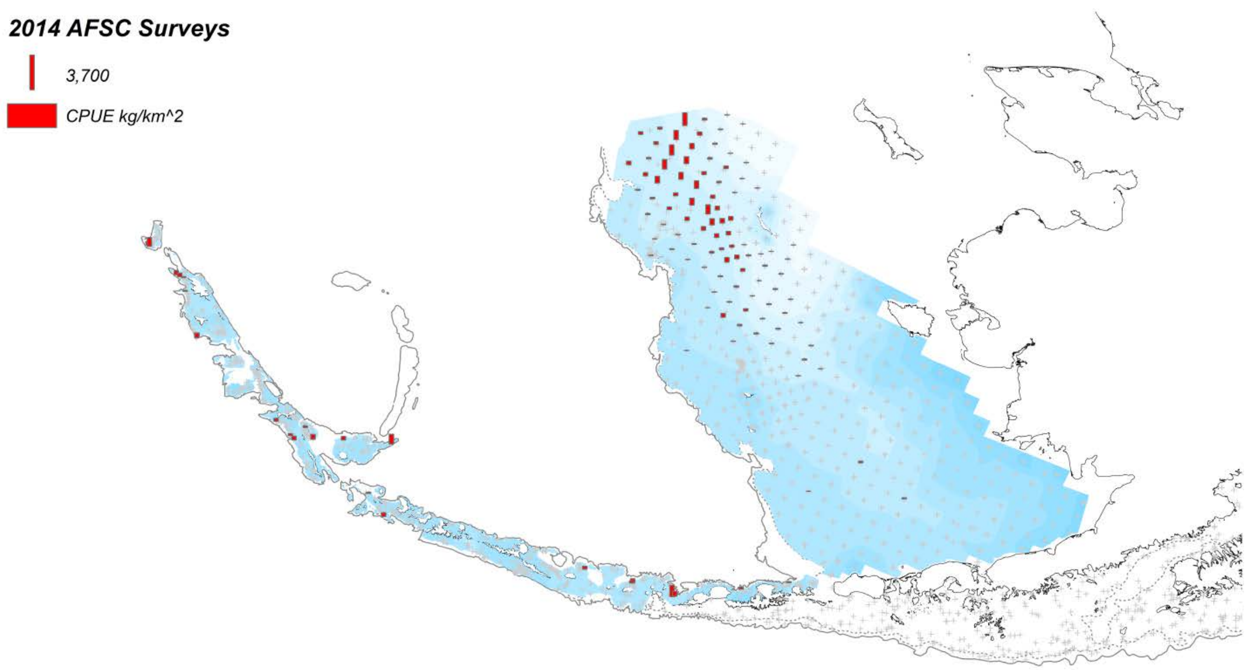
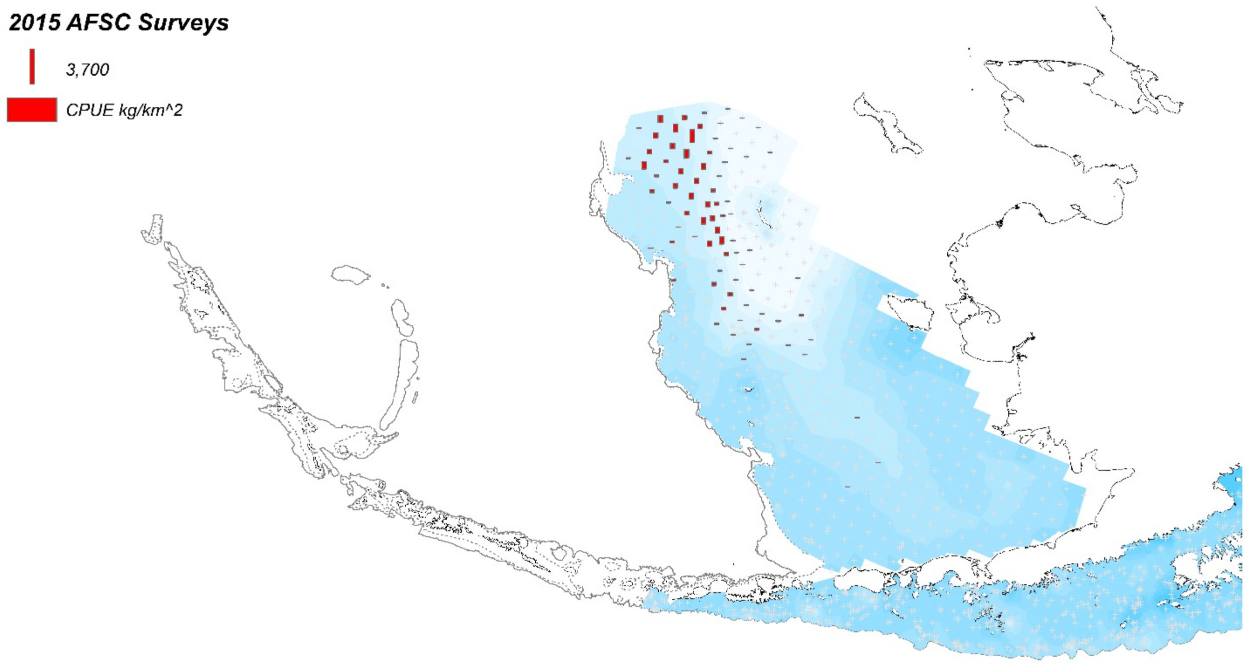


Figure 5.10.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.



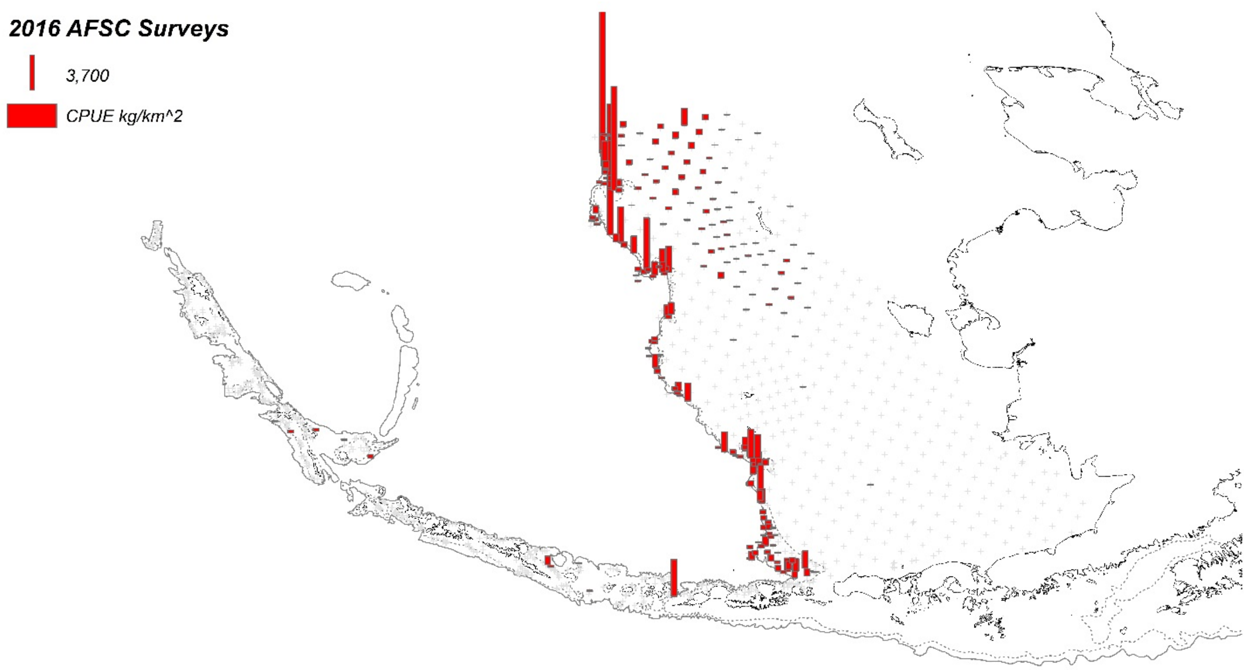


Figure 5.10.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year and 200m (dashed line) and 1000 m (solid gray line) isobaths. Bottom temperatures were not yet available for the 2016 map. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

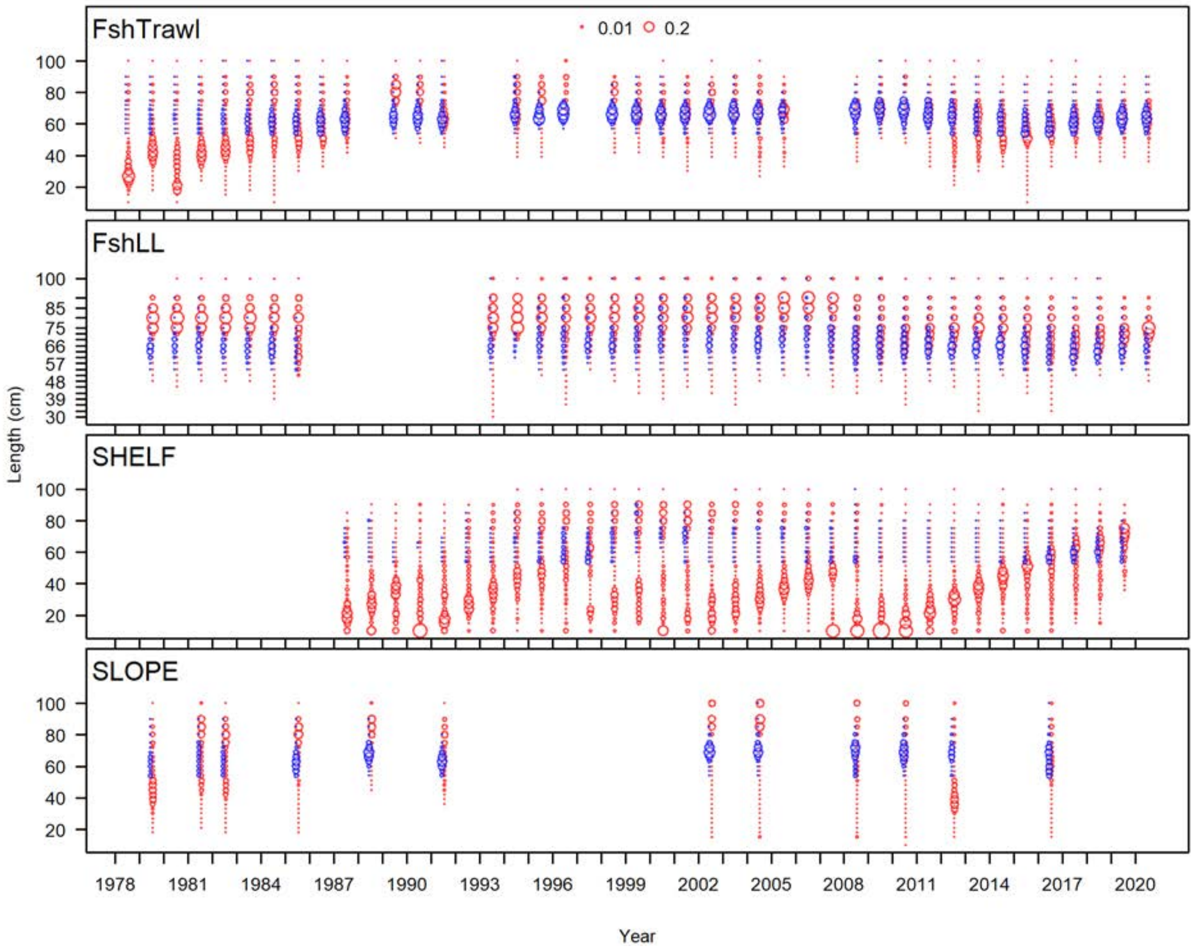


Figure 5.11. Greenland turbot size composition data from the trawl fishery, longline fishery, shelf survey and slope survey.

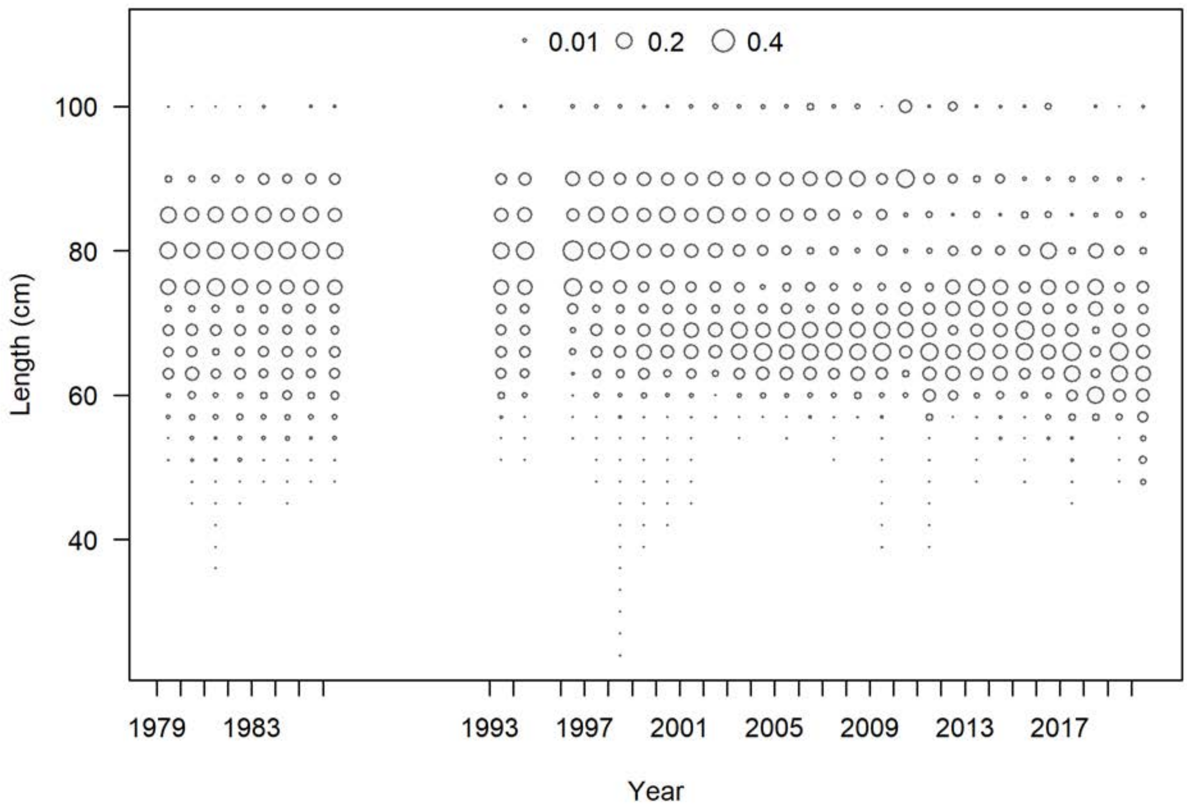


Figure 5.12. Greenland turbot size composition data for combined sexes from the Alaska Fisheries Science Center longline survey.

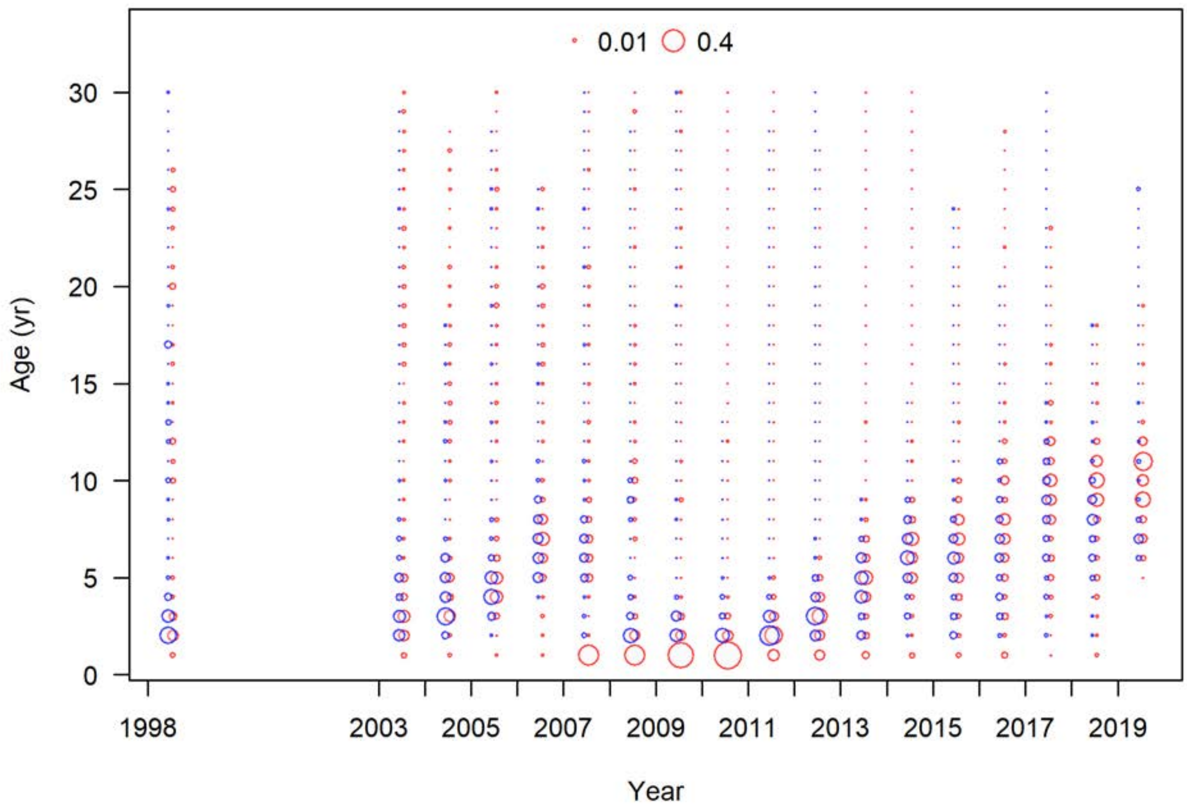


Figure 5.13. (Cont.) Greenland turbot age composition data for females (red) and males (blue) from the EBS shelf bottom trawl survey. These data were included in the model but not included in the likelihood.

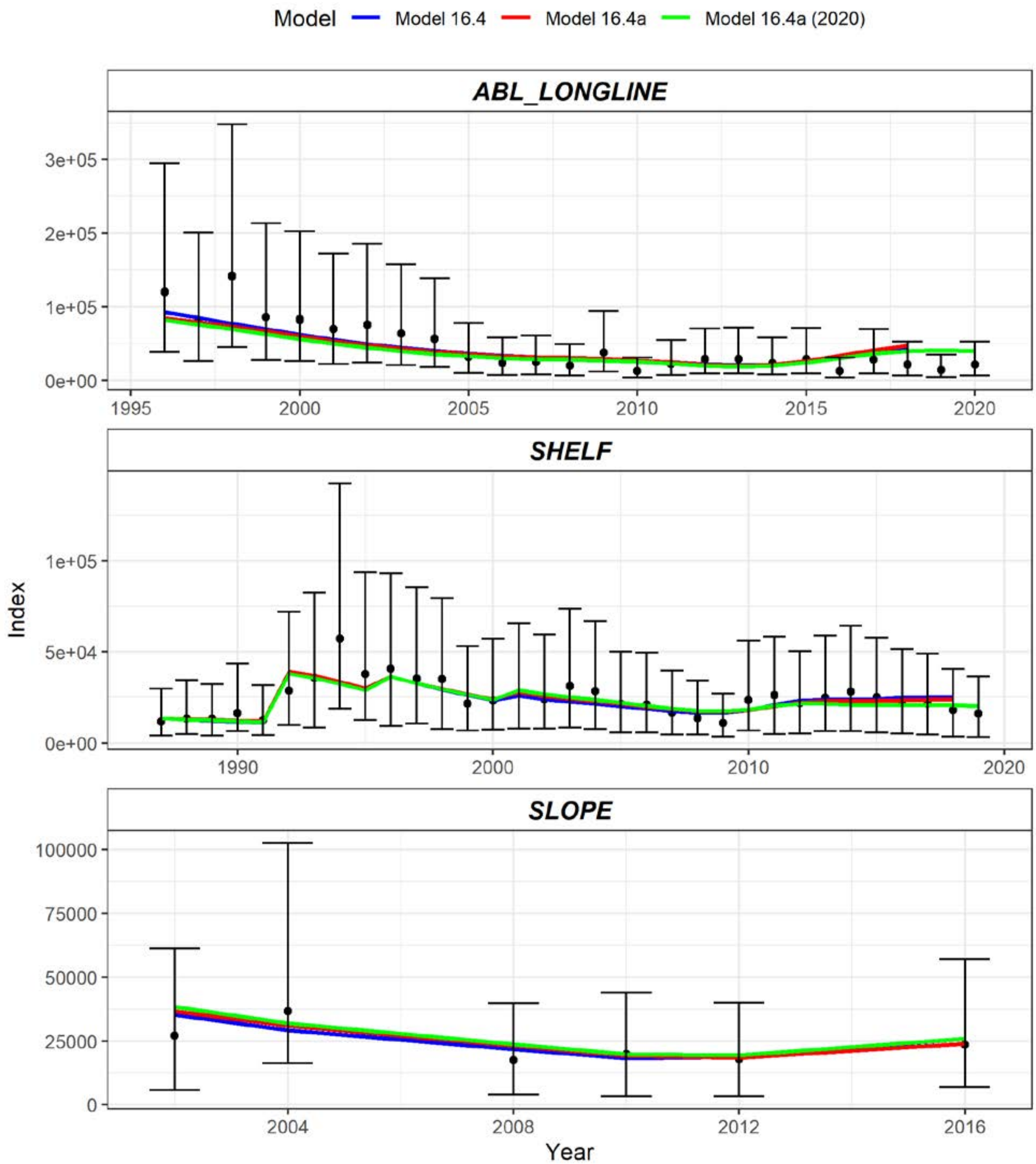
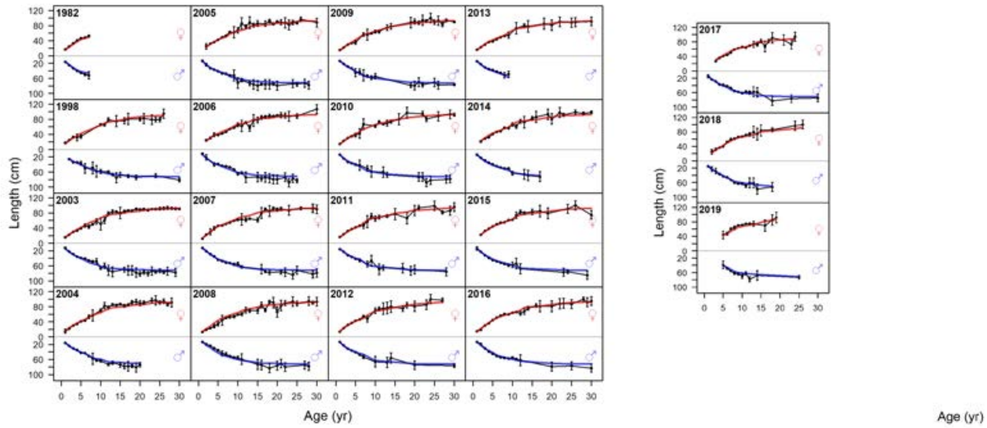


Figure 5.14. Survey indices (index values are the total survey biomass in tons) and model fits. Error bars are 95% confidence intervals.

a)



b)

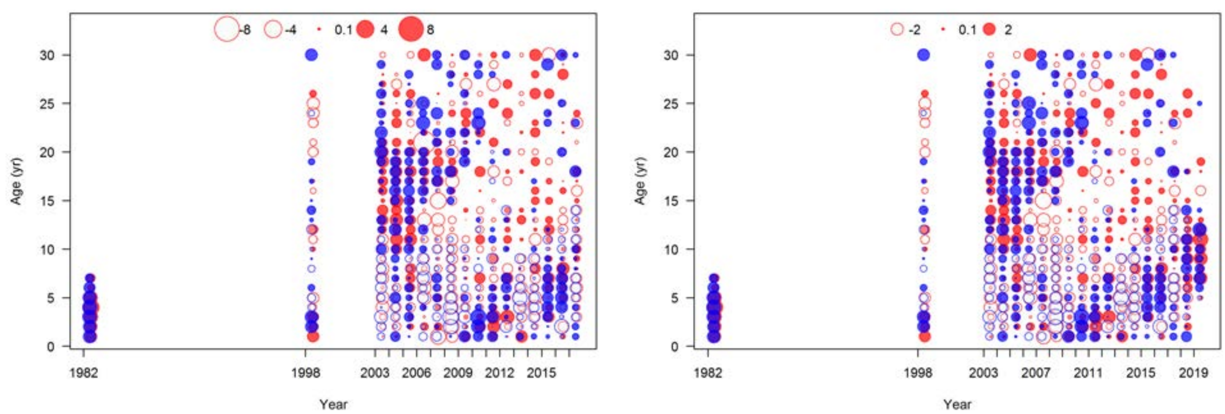
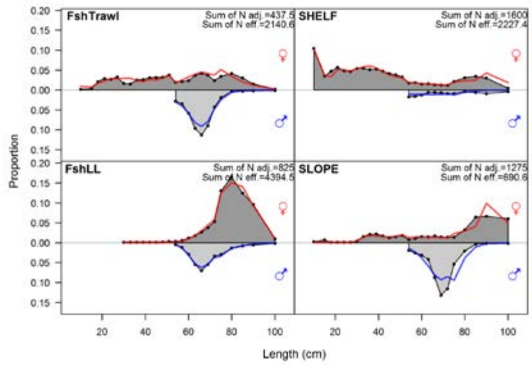
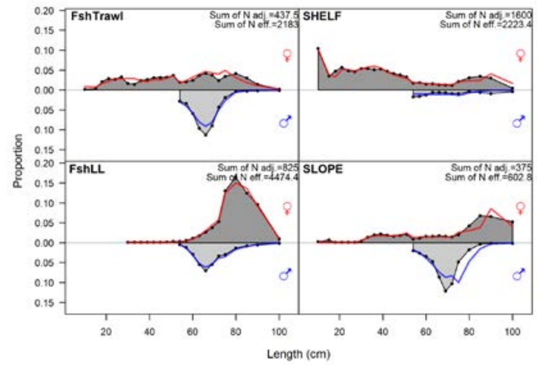


Figure 5.15. a) Length at age data and fit (females - red line, males – blue line) by Model 16.4a (2020) and b) the standardized residuals from Model 16.4 (left) and Model 16.4a (2020) (right). The closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation). Red bubbles are female and blue are male.

a)



b)



c)

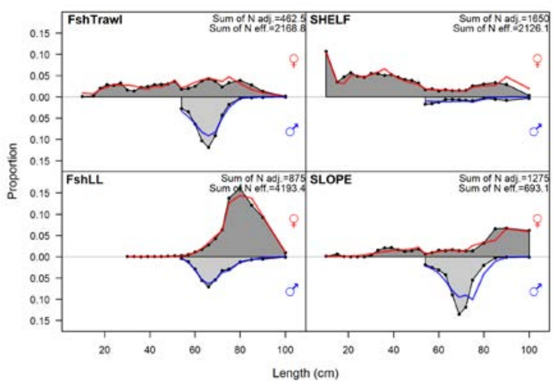


Figure 5.16. All size composition data combined across years and fits (red line female, blue line male) for fisheries and surveys. a) Model 16.4, b) model 16.4a, c) model 16.4a (2020)

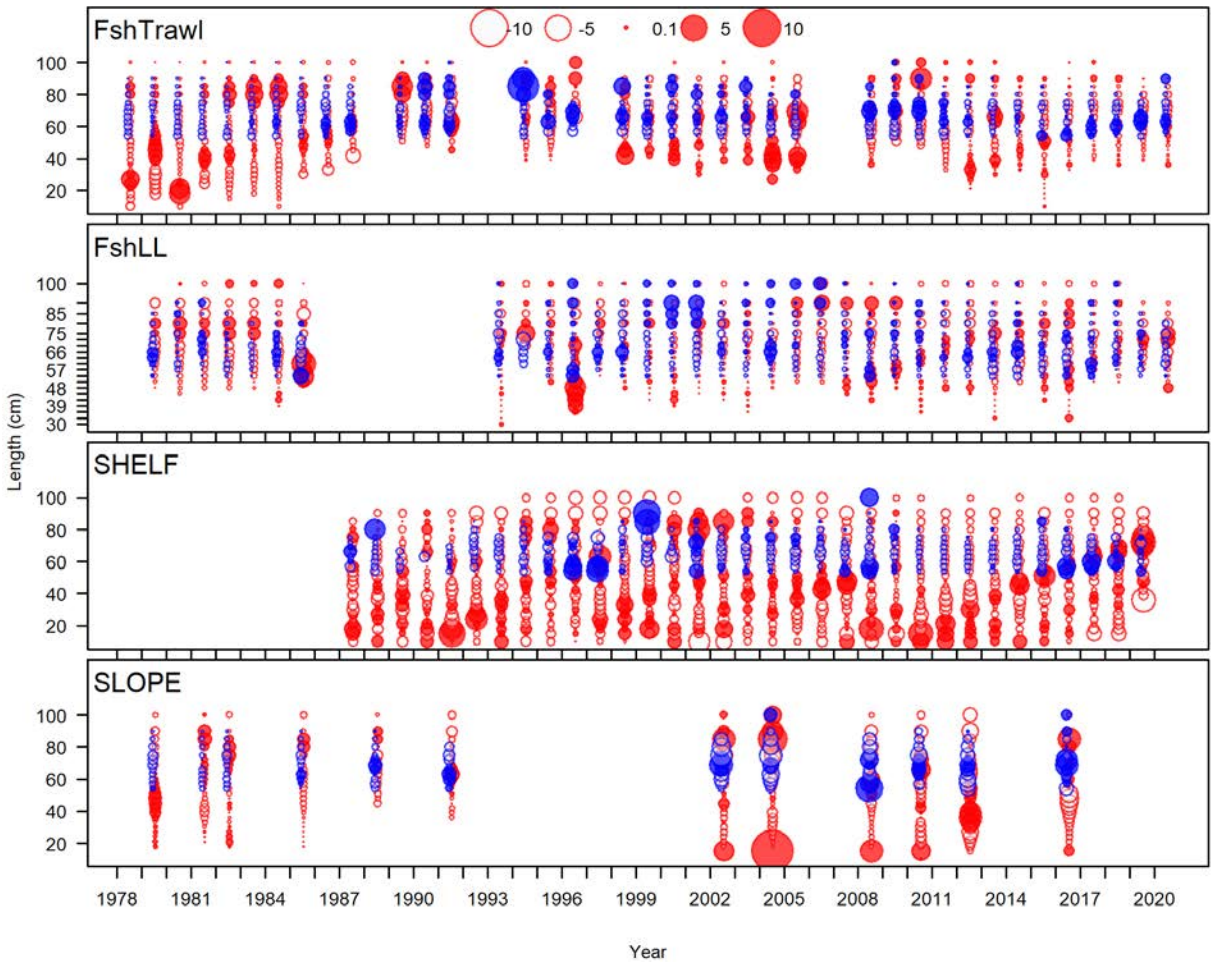
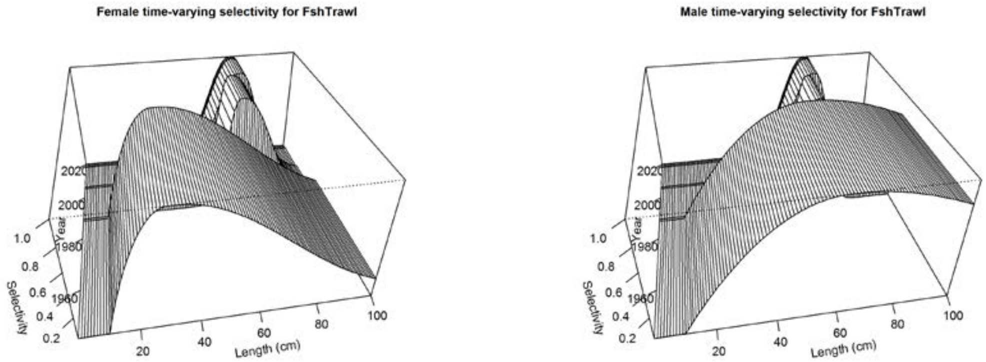
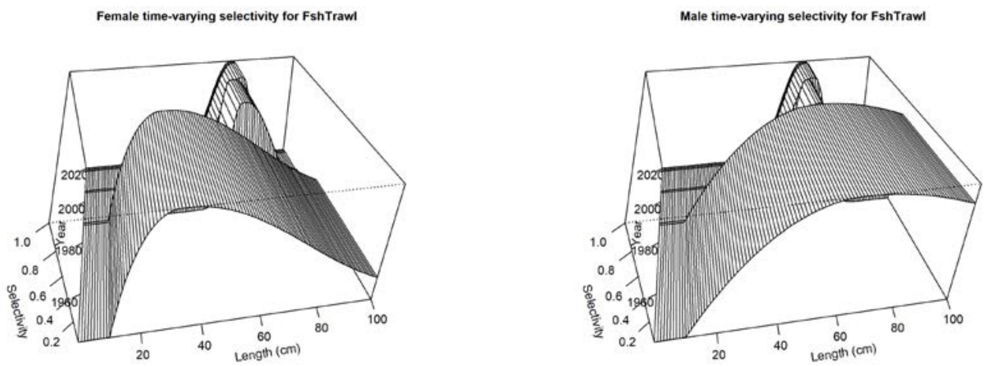


Figure 5.17. Pearson residuals for the trawl and longline fisheries and the EBS shelf and EBS slope bottom trawl surveys, Mode; 16.4a (2020). Closed bubbles are positive residuals (obs-expected, underestimation) and open bubbles are negative residuals (overestimation). Note that the scale of the bubble graphs may differ by model.

a)



b)



c)

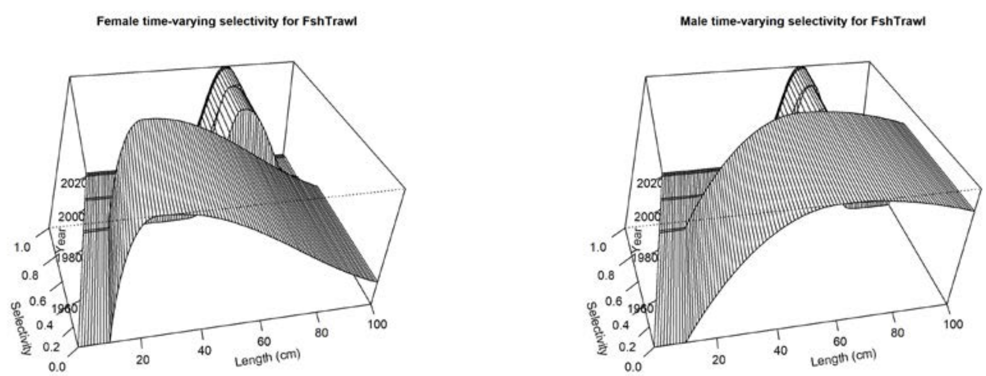
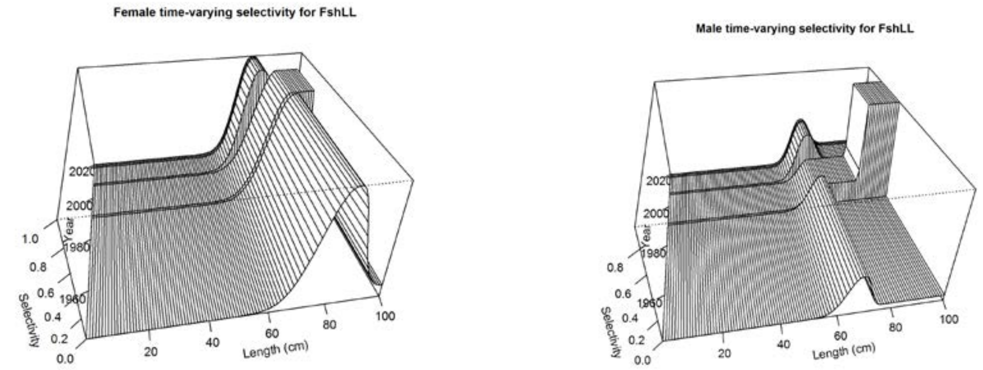
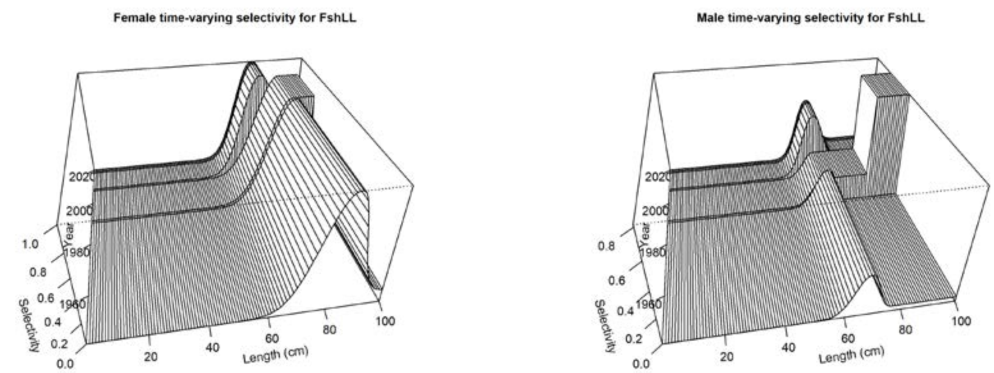


Figure 5.18. Time-varying selectivity at size for the Trawl fishery for both sexes (female - left panels, males – left panels). a) Model 16.4 (2018), b) model 16.4a, and c) model 16.4a (2020).

a)



b)



c)

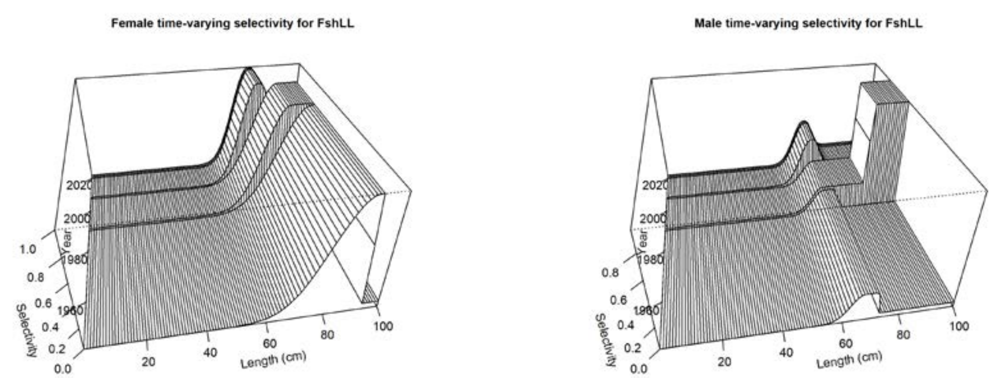
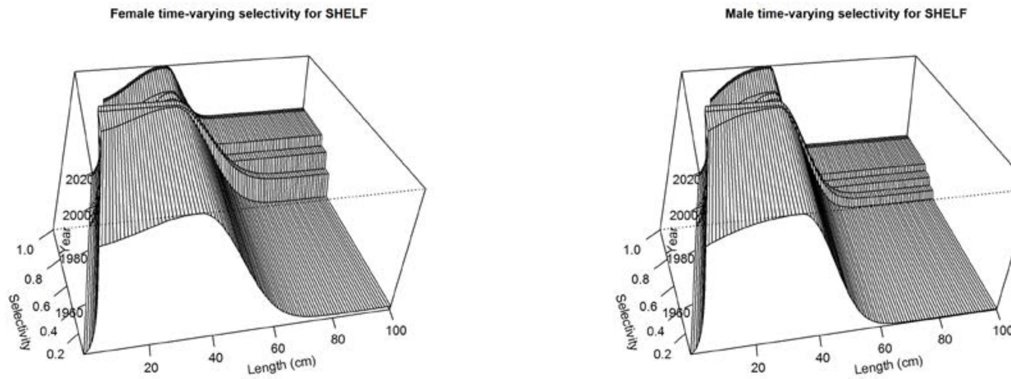
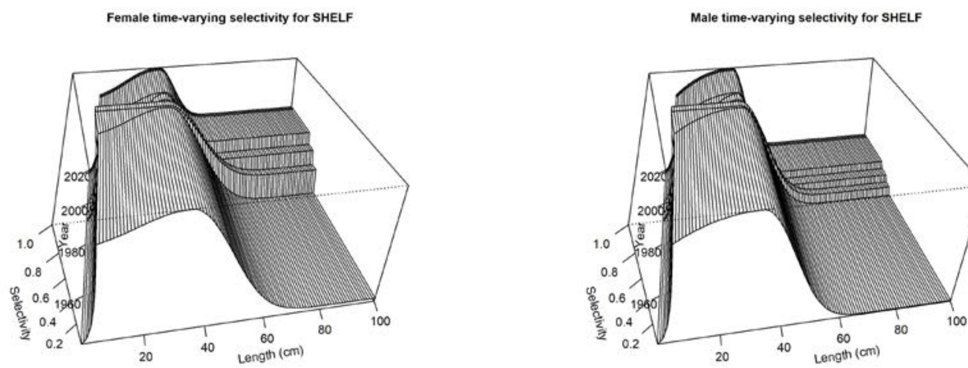


Figure 5.19. Time-varying selectivity at size for the Longline fishery for both sexes (female - right panels, males – left panels). a) Model 16.4, b) Model 16.4a, and c) model 16.4a (2020).

a)



b)



c)

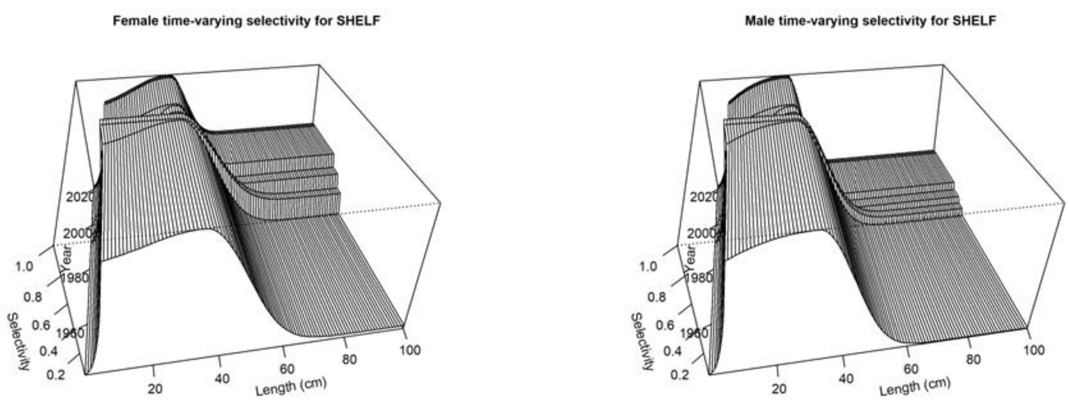
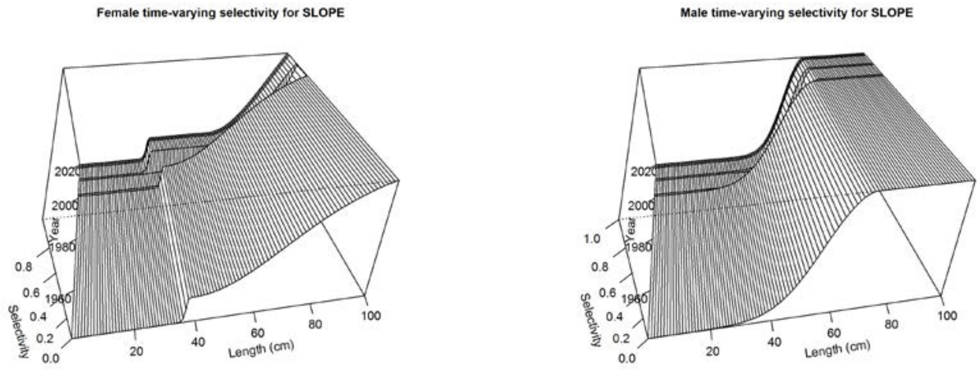
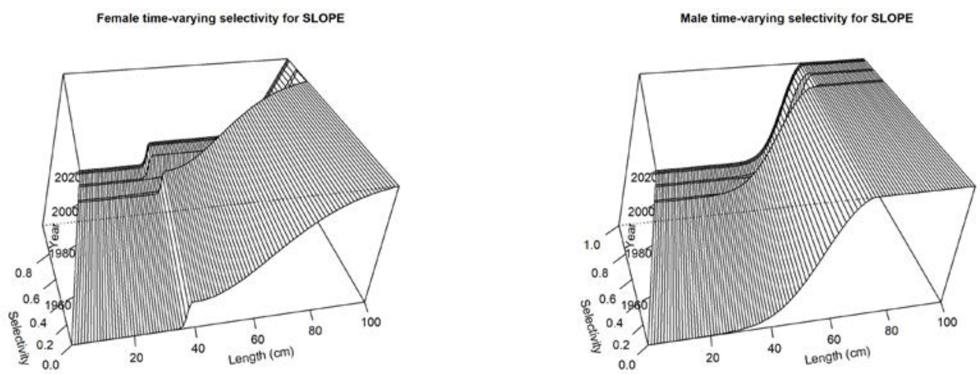


Figure 5.20. Time-varying selectivity at size for the shelf survey. sexes (female - right panels, males – left panels). a) Model 16.4, b) model 16.4a, and c) model 16.4a (2020).

a)



b)



c)

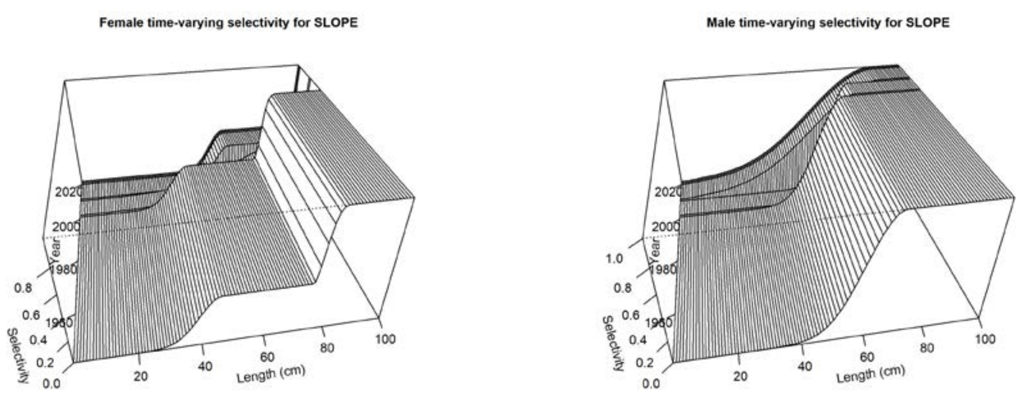
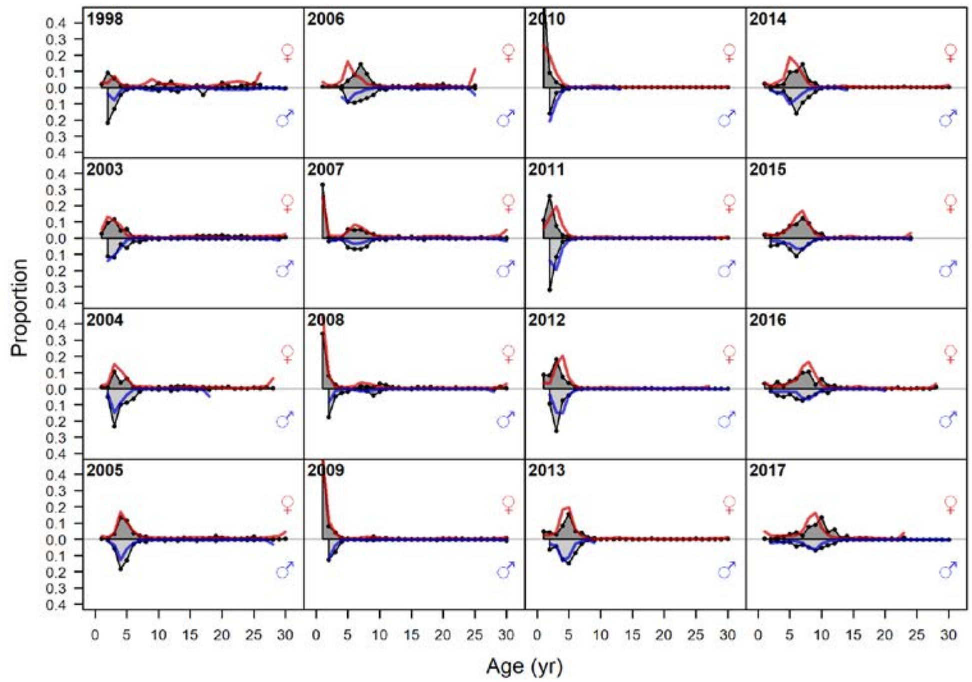
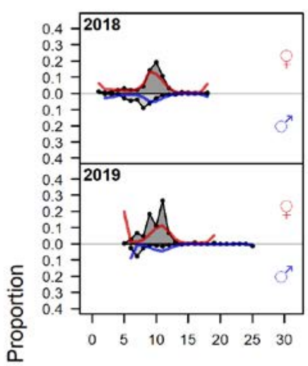


Figure 5.21. Slope survey selectivity by model for females (left panels) and males (right panels) and a, b) model 16.4 and c, d) model 16.4a (2020).





Age (yr)

Figure 5.22. Model 16.4a (2020) shelf survey age composition data and "ghost" fits (red and blue line "Ghost" fits are projected fits as they are not fit to the likelihood for the age composition.

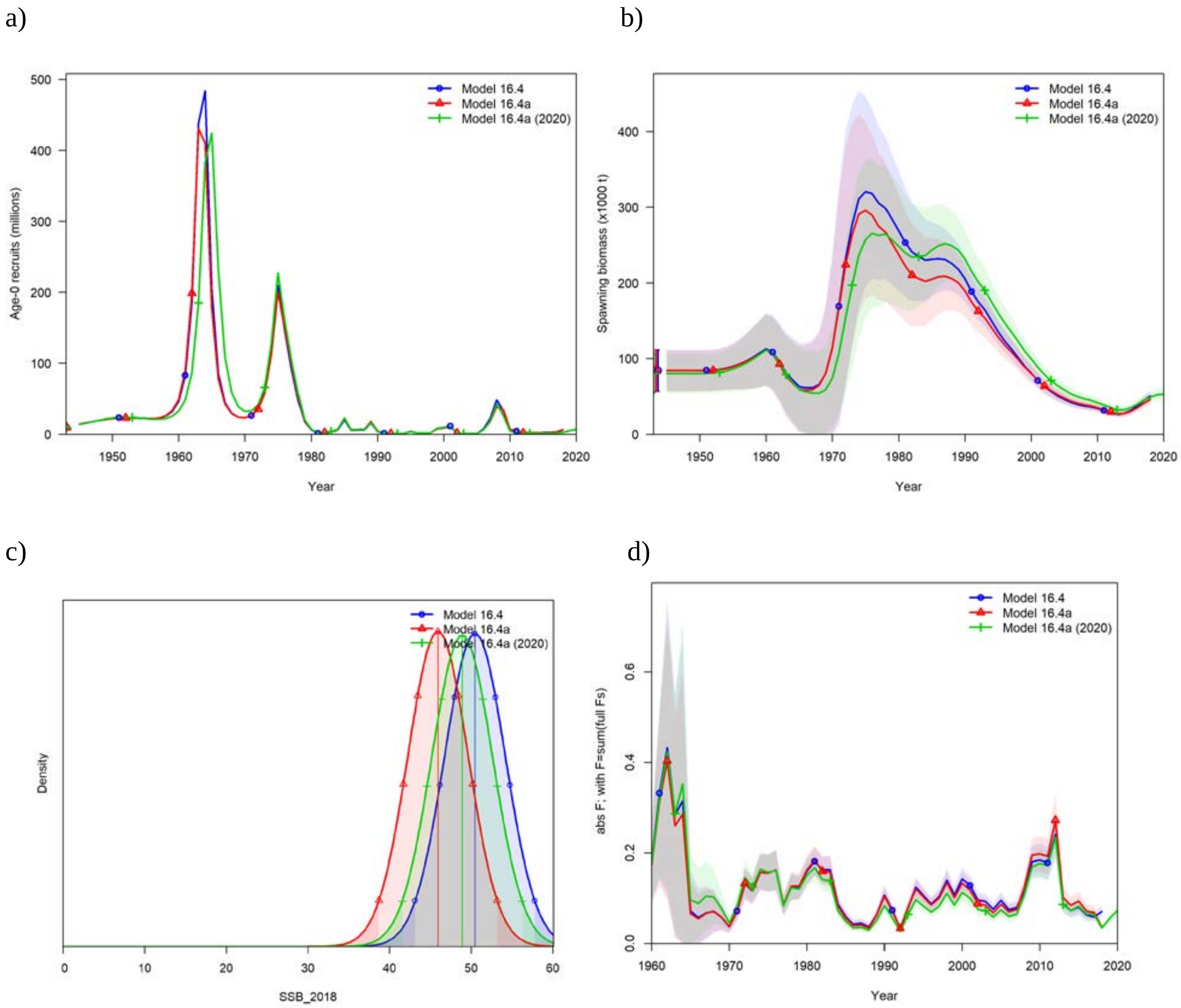


Figure 5.23. a) Age-0 recruitment, b) female spawning biomass, c) the posterior density of spawning biomass in 2018, and d) fishing mortality for models 16.4 (2018), 16.4a, and 16.4a (2020).

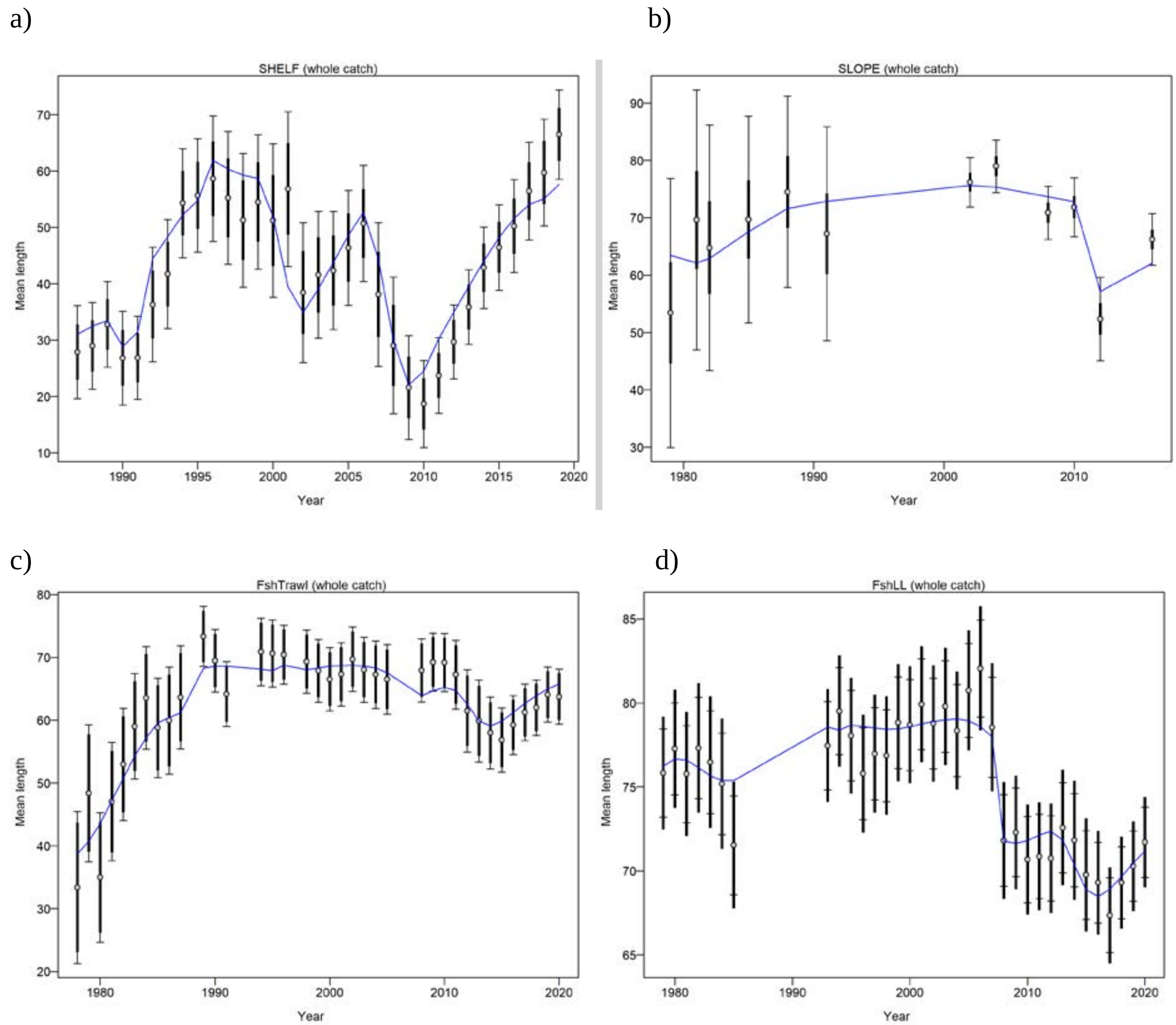
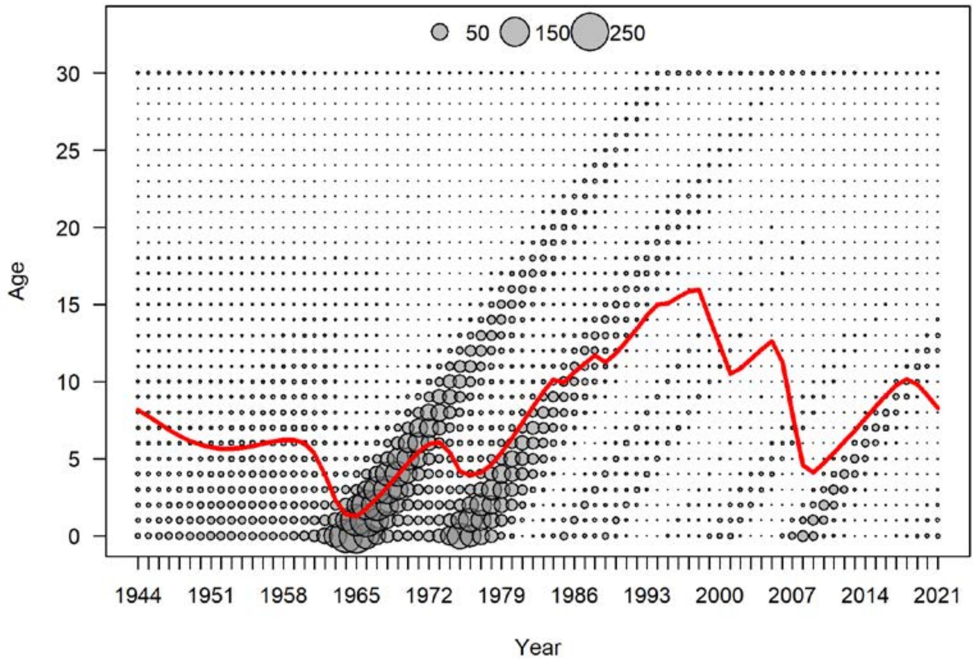


Figure 5.24. Observed and expected mean length from the a) trawl survey, b) the slope survey, c) the trawl fishery, and d) the longline fishery.

a)



b)

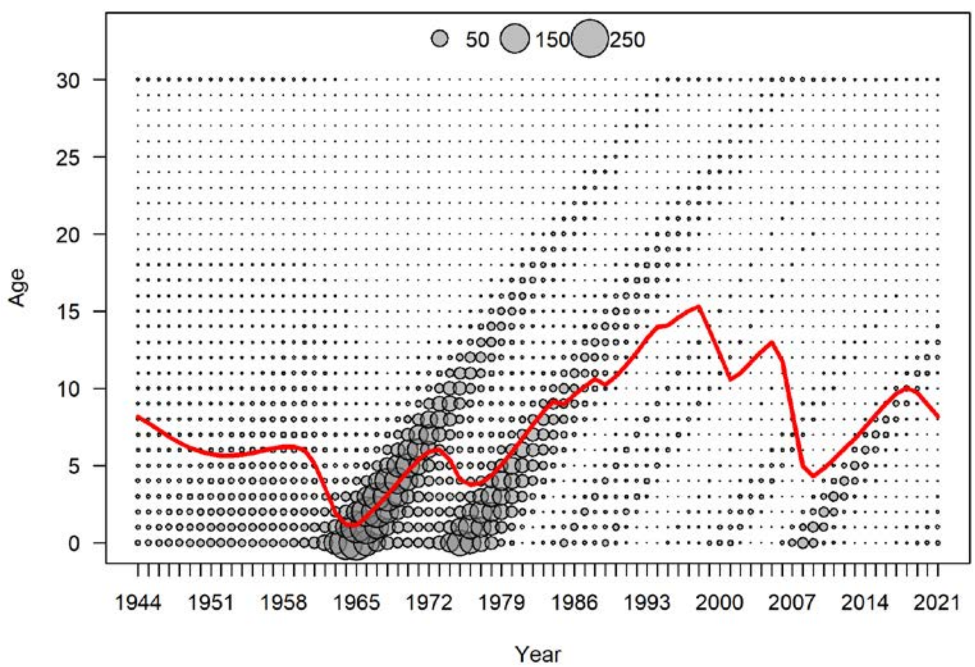


Figure 5.25. BSAI Greenland turbot numbers at age and mean age by year (red line), a) female and b) male.

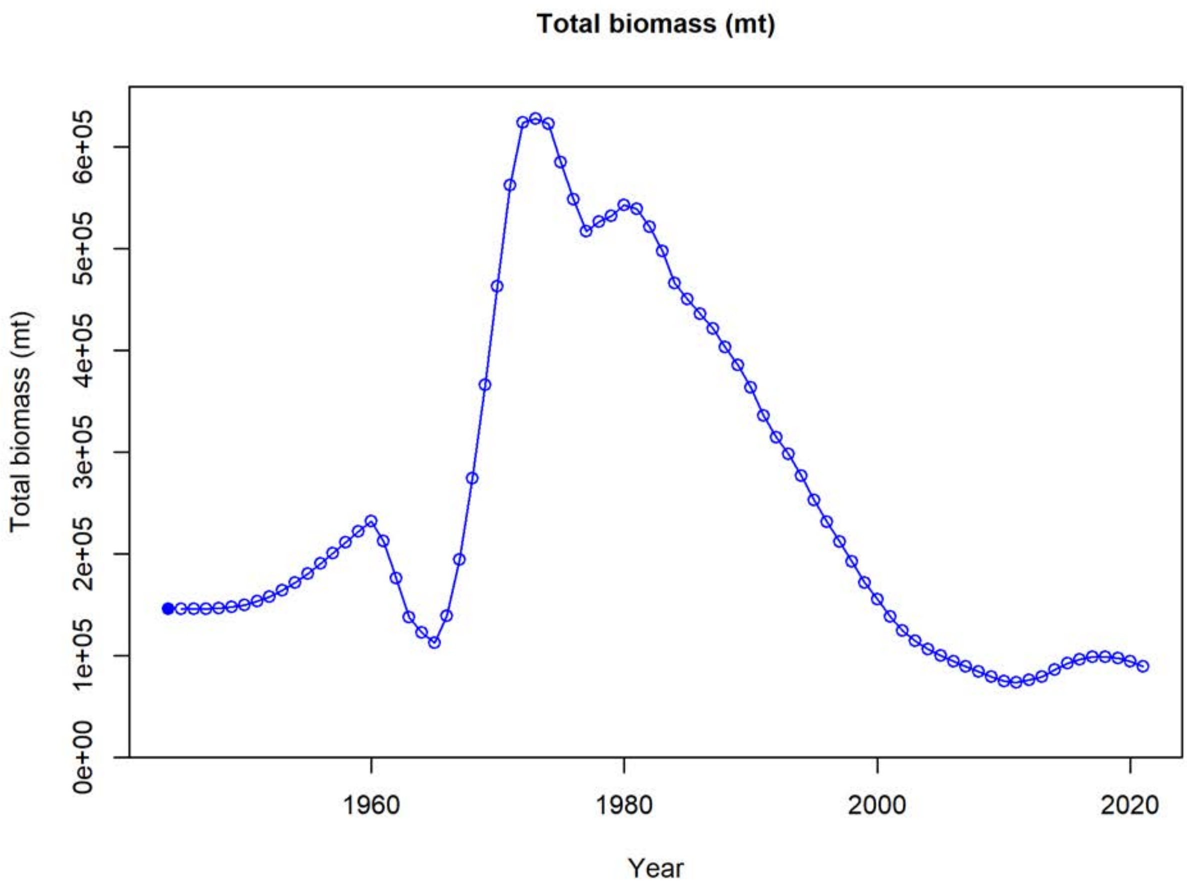


Figure 5.26. Total age 1+ biomass (t) from model 16.4a (2020).

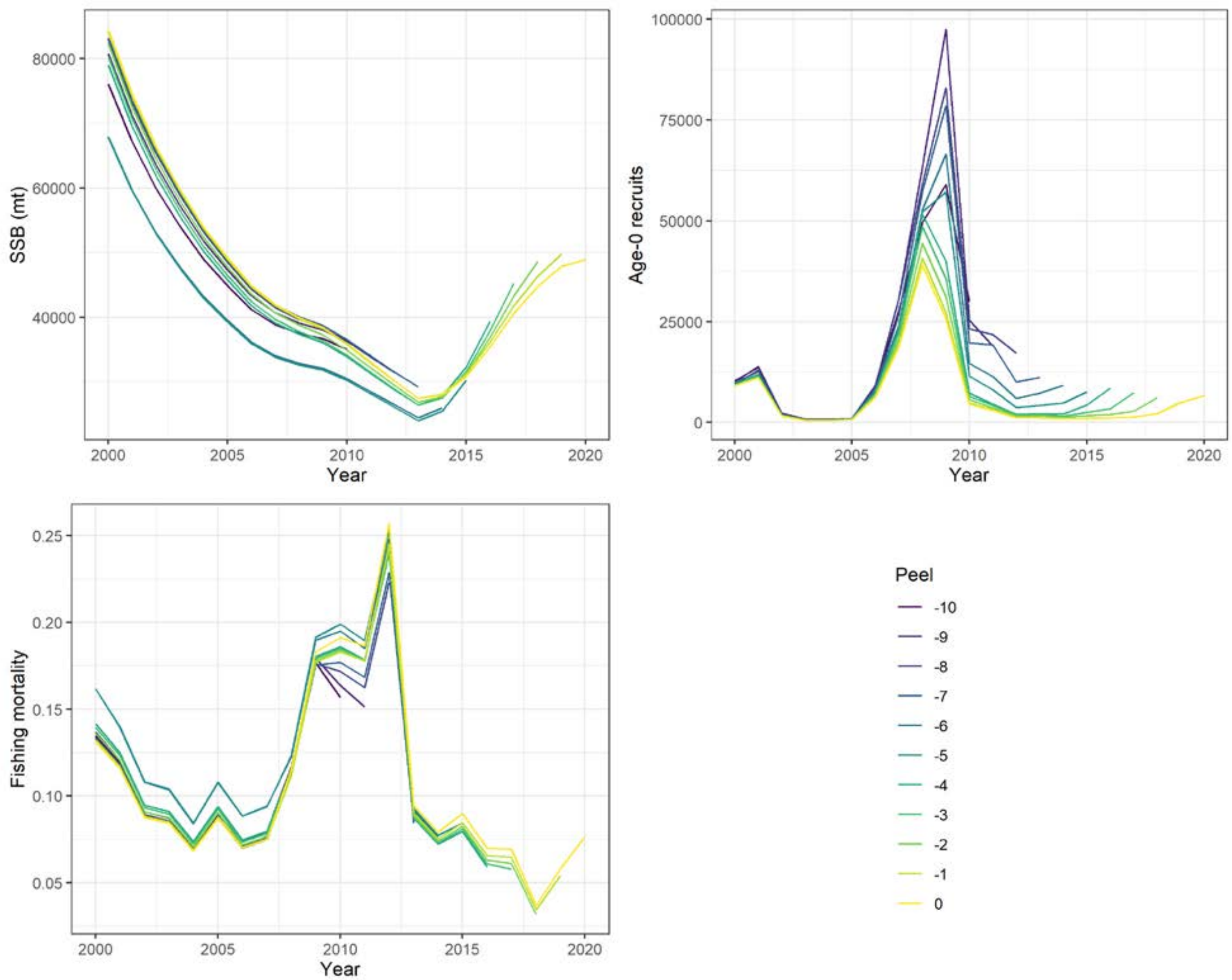


Figure 5.27. Retrospective plots of female spawning biomass (top left), age-0 recruits (top right), and fishing mortality (bottom left) with data sequentially removed from 2020 to 2010.

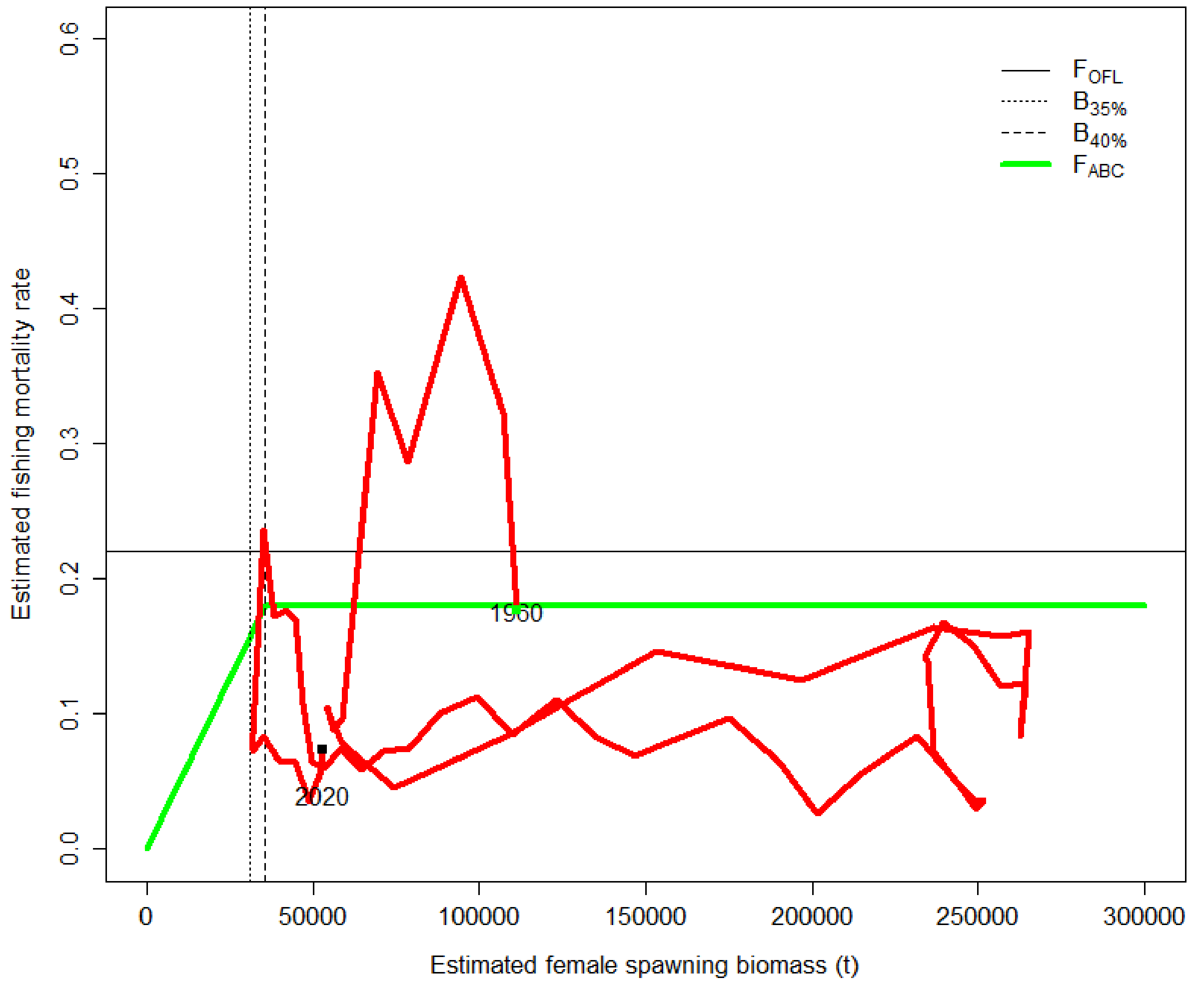


Figure 5.28. For Model 16.4a (2020) ratio of historical fishing mortality versus female spawning biomass for BSAI Greenland turbot, 1960-2020. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.