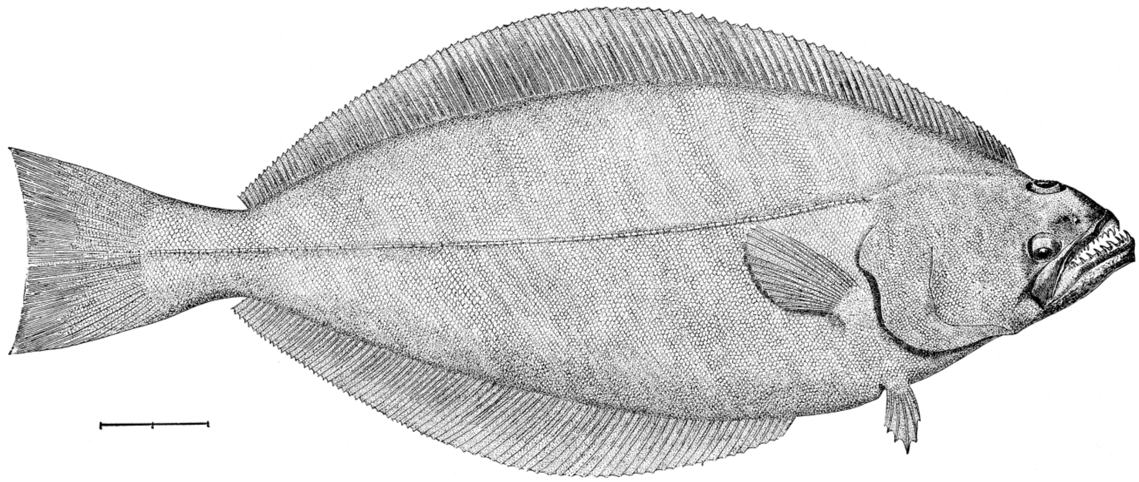
5. Assessment of Greenland turbot in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

Meaghan D. Bryan., Steven J. Barbeaux, James Ianelli, Dan Nichol and Jerry Hoff

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA 98115-6349

Executive Summary

Summary of Changes in Assessment Inputs

New data for the assessment included 2018 NMFS shelf bottom trawl survey and ABL longline survey estimates and size compositions. Age composition and size at age data from the 2017 NMFS shelf bottom trawl survey also became available and were used in this assessment. Fishery catch estimates were updated including projected values for 2018. Data on fishery size composition for 2018 were included.

Changes in the model

The base model has the same configuration as the 2016 assessment model (model 16.4 in Barbeaux et al. 2016, model 16.1 in this report), but the ABL longline survey catchability parameter was estimated. This model was presented during the September plan team meeting (model 16.1b) and helped to address model instability issues that were apparent in the results from a jitter analysis conducted on model 16.1. The resulting assessment outcomes between models 16.1 and 16.1b were the same, so only the results from model 16.1b are presented in this report.

During the 2016 assessment cycle and again during the September Plan Team meeting in 2018, it was noted that good recruitment appeared to occur in years where the bottom temperatures were well below the mean. Therefore, a model linking an environmental index to recruitment through R_0 was explored and evaluated for the November Plan Team meeting. This was model 16.6 in Barbeaux et al. 2016 and will be referred to as 16.1c throughout this report. An index of bottom temperatures where 0s indicated warm years and -1s indicated cold years. Cold years were defined as those with temperatures below 1 standard deviation from the 1982-2016 mean as calculated in Spencer (2006).Years prior to 1982 were set to -1 when the annual average PDO was negative, as bottom temperatures were not available. We fit a parameter that in effect changed R_0 for years that were deemed “cold” from those that were not.

Quantity	As estimated or *specified last* year for: 2018	2019	As estimated or *recommended this* year* for: 2019	2020
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3a	3a	3a	3a
Projected total (age 1+)	126,417	127,021	105,930	98,876
Female spawning biomass	58,035	61,878	54,244	52,743
Projected				
$B_{100\%}$	103,097	103,097	90,534	90,534
$B_{40\%}$	41,239	41,239	36,213	36,213
$B_{35\%}$	36,084	36,084	31,687	31,687
F_{OFL}	0.22	0.22	0.21	0.21
$maxF_{ABC}$	0.18	0.18	0.18	0.18
F_{ABC}	0.18	0.18	0.18	0.18
OFL (t)	13,148	13,540	11,362	10,476
maxABC (t)	11,132	11,473	9,658	8,908
ABC (t)	11,132	11,473	9,658	8,908
Status	As determined *last* year for: 2016	2017	As determined *this* year for: 2017	2018
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 16.1b and estimated catches of 3,758 t used in place of maximum permissible ABC for 2018. The final catch for 2018 was estimated as the product of the average proportion of the TAC captured over the previous 5 years (2013-2017) and the 2018 TAC.*

Responses to SSC and Plan Team Comments on Assessments in General

The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity. (SSC, October 2017)

To facilitate a coordinated response to this request, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from stock assessment program leadership at the AFSC, have suggested that authors address it by using the previous year’s Ecosystem Status Report (ESR) as follows:

> “No later than the summer of each year, the lead author of each assessment should review the previous year’s ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where “severe decline” means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely and if that decline was not anticipated in the most recent stock assessment,

> he or she should summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become available after the document is produced but prior to the October Council meeting of that year, the document should be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary."

Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible. (SSC, December 2017)

To help coordinate author responses to this request, a committee was established earlier this year, consisting of all Ecosystem Status Report (ESR) and assessment authors who currently report fish condition. The committee agreed that the "weight-length residual" method currently used in the ESR should be the standard. Chris Rooper has offered to share his R code for doing the necessary calculations and making plots. Of course, assessment authors are *not* required to report fish condition, but if they choose to do so, conforming to the weight-length residual method will ensure that this SSC request is satisfied.

Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration. (SSC, December 2017)

SSMA and MESA leadership will facilitate coordinated responses to this request by issuing specific guidance and individual tasking.

"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern." (SSC October 2017)

This request was recently clarified by the SSC by replacing the terms "ecosystem status" and "stock assessment status" with "Ecosystem Status Report information" and "Stock Assessment Information," where the potential determinations for each will consist of "Okay" and "Not Okay," and by issuing the following guidance (emphasis added):

- "The SSC clarifies that "stock assessment status" is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.
- "Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the "Okay" or "Not Okay" determinations.
- "The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be

useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.

- "Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC.
- "In consideration of this request to examine stock status information and ecosystem status report information, the leadership of the joint Teams recommended that a group be formed to work with the editors of the ecosystem status report to develop these ecosystem thresholds for action. Moreover, they asked the SSC to assign members to participate in this effort. If the workgroup is formed, the SSC nominates the following SSC members to participate in this workgroup: Franz Mueter and George Hunt.
- "Finally, one SSC member indicated that there were multiple groups doing this or a very similar exercise (i.e., trying to explicitly use ecosystem data to anticipate changes in stock status) at present, with several products in the pipeline. The SSC requests that the Alaska Fisheries Science Center coordinate these efforts so as to avoid duplication of efforts, and determine whether a new group is necessary."

The iterative process described in the final bullet above was scheduled to begin at this year's September meeting of the Joint BSAI and GOA Plan Teams. However, no formal criteria for these categorizations were developed by the Plan Teams.

"The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification." (SSC December 2017)

Clarification: *"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."* (SSC June 2018)

We will continue to provide documentation of model evaluation and logical bases of all recommended model complexity changes for Greenland turbot.

Responses to SSC and Plan Team Comments Specific to this Assessment

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)

1) A model assuming time invariant selectivity (i.e., no time blocks) was explored. The overall fit to the trawl length composition data degraded, while the overall fit to the longline, shelf survey, and slope survey length data was similar to the base model. The model no longer fit the shelf and ABL longline indices of abundance. This model configuration was not considered reasonable and produced unacceptable results, hence the results are not shown in this report. This issue will be explored further during the next assessment cycle.
2) A stock structure template was completed and presented to the Plan Team during the September, 2018 meeting.
3) Otoliths have been collected by the Fisheries Monitoring and Analysis (FMA) Observer Program. Otoliths are available for the majority of years between 1982 and 2018. Approximately 1000 otoliths have been aged from a subset of years (471 from 1982, 55 from 1994, 313 from 2006, and 236 from 2007). Given that so few years are represented in the aged samples, they were not used in the model or explored for use.

4) The author contact the ABL survey staff before the next survey (2019) season to request sex specific lengths be collected.

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)

Models 16.1, 16.1b, and 16.1c (environmental covariate model) are summarized in this report.

The Team also requests that dynamic B0 output be displayed. . (Plan Team, September 2018)

This output is summarized in this report in the stock status determination section.

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 have life history characteristics that complicate assessment surveys in the Eastern Bering Sea and Aleutian Islands region. There continues to be issues in rectifying inconsistencies between the NMFS Shelf surveys and NMFS Slope surveys.

Life History

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. As of October, 2018 the catch was 1,823 t.

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 5.2 and Table 5.3). 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 5.3). 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. In 2015 the overall discard rate was 5.8% and has been consistently 4% since 2016.

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 5.4). Catch of Greenland turbot in the Aleutian Islands has been declining since 2012. 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 has continued through 2018.

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 Auke Bay Laboratory (ABL) Longline survey has been conducted by the ABL out of Juneau, Alaska. The type of data and relevant years from each can be found in Table 5.5 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 were assumed to be the same as the mean ratio caught by USSR vessels from 1965-69.

<u>Size and age composition</u>

Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2018. 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 1989-2016 are given in Table 5.6

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 survey to tend bottom in the deeper waters may be compromised. Similarly the shelf trawl survey may also under-represent juvenile Greenland turbot abundance on the shelf, particularly given the variability of the extent of the cold pool in recent years. 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 5.7). 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 5.8 and Table 5.9). 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 5.10. In 2010 and 2011 the abundance estimates from the shelf surveys indicated a significant increase of Greenland turbot recruitment and an increase in the proportion of tows with Greenland turbot present (Table 5.7, 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). The 2018 biomass was 18,017 t down from 21,519 t in 2017 and 22,429 t from 2016.

Survey size composition

A time series of estimated size composition of the population was available for both surveys. The slope surveys typically sample 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 (Fig 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 2012-2018 length estimates. The length data from the Auke Bay Lab'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).

Aleutian Islands survey

The 2018 Aleutian Islands bottom trawl survey continued the decline in biomass for this area at 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 5.11). Abundance in 2018 dropped to 54,327 from 920,007 in 2016. Abundance dropped by 87% drop in abundance 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) abundance estimate had a sharp drop 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) and has continued to decline. We are not certain why there was such a dramatic decline in the Greenland turbot abundance estimate in the Aleutian Islands trawl survey in 2012 and 2014. 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 Auke Bay Laboratory Longline survey for sablefish alternates years between the Aleutian Islands and the Eastern Bering Sea slope region. The combined time series Table 5.12 was used as a relative abundance index. It was computed by taking the average RPN from 1996-2016 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 ABL longline survey extends back to the cooperative longline survey and is shown in Figure 5.11.

Discussions with the survey managers have revealed whale depredation on this survey in recent years. This would bias the index low and when included in the stock assessment force the model to estimate a lower Greenland turbot abundance for the more recent years affected by whale depredation. Further it is unknown what the effects of whale predation has on size composition. In all previous modeling efforts the fit to the ABL 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 ABL longline 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 2018. 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, together with up to three surveys covering various years (Table 5.5). Only minor changes to the models were explored this year. All models explored continue to use the Beverton-Holt stock-recruitment curve, and the early recruitment series is carried back to 1945. The results from two of the models explored were similar.

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 5.13 and Table 5.14.

Maturation and fecundity

Maturity and fecundity followed the same assumptions as the 2016 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 devised using the combined data from all surveys conducted by the Alaska Fisheries Science Center in the Bering Sea and Aleutian Islands. From 2003 to 2011 the Greenland turbot stock assessment models used the same weight at length relationship for males and females ($w = 2.44 \times 10^{-6} L^{-3.34694}$, where L = length in cm, and w = weight in kilograms). Given the great deal of sexual dimorphism observed in this species it was thought that having separate weight at length relationships for males and females would better capture the diversity in this stock. Starting in 2012 and continuing with this year's models $w = 2.43 \times 10^{-6} L^{3.325}$ is used for females and $w = 3.40 \times 10^{-6} L^{3.2189}$ for males. This relationship is similar to the weight at length relationship observed by Ianelli et al. (1993) and used in the Greenland turbot stock assessment prior to 2002. The weight at length analysis was presented at the September 2012 Plan team and SSC meetings (Barbeaux et al. 2012, Appendix 5.1).

Size composition multinomial sample size

There is always difficulty in determining the appropriate multinomial sample size for the size composition data. For the two fisheries initial sample sizes for each year were set to 50 (Table 5.15).The annual size composition sample sizes for the shelf survey was set at 200, and the pre-2002 slope surveys set at 25, while 2002 and later set at 400. The sample size for the slope survey was increased to 400 to better balance these surveys with the more frequent shelf survey. The slope sample sizes prior to 2000 were set to 25.

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

		Model 16.1b	Model 16.1c
Recruitment			
	Early Rec. Devs	(1945-1970) 25	(1945-1970) 25
	Main Rec. Devs	(1970-2012) 43	(1970-2012) 43
	Future Rec. Devs	(2013-2019) 7	(2013-2019) 7
	R_0	1	1
	Autocorrelation ρ	1	1
	R_0 environmental link	0	1
Naural mortality			
	Male	0	0
	Female	0	0
Growth			
	L_{min} (M and F)	2	2
	L_{max} (M and F)	2	2
	Von Bert K (M and F)	2	2
Catchability			
	q_{shelf}	0	0
	q_{slope}	0	0
	q_{ABL}	1	1
Selectivity			
	Trawl fishery	15	15
	Longline fishery	28	28
	Shelf survey	17	17
	Slope survey	19	19
	ABL longline survey	0	0
	Total Parameters	90	91

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.

A single R_0 was assumed for all years and fit using an uninformative log normal prior. The models were fit to 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. As in last year's accepted model, this year's models use a prior of 0.473 (SD=0.265) estimated by Thorson *et al.* (2014) for Pleuronectidae species. For all models the 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.

Model 16.1c (model 16.6 in Barbeaux et al. 2016) was not presented in September, but explored for the November Plan Team meeting. Model 16.1c differs from model 16.1b in that an environmental link parameter was fit to R_0 which effectively allowed a separate R_0 for particularly cold years. We calculated the mean bottom temperature from the bottom trawl survey from 1982-2018, we then set a vector of 0 and -1 for these years, with -1 being years in which the mean bottom temperature was below one standard deviation from the time series mean. Prior to 1982 we set a -1 for years with negative average PDO values for 1945-1981.

Catchability

As in last year's accepted model, for all models presented this year, we selected catchabilities for the shelf and slope from the 2015 Model 14.0 fit without the 2007 through 2015 data. This was meant to eliminate the effects of the 2007 through 2010 year classes (log(q_{shelf}) = -0.4850235 and log(q_{slope})= -0.5555418). During the September Plan Team meeting, the authors presented model diagnostics (i.e., jitter and mcmc results) that indicated the 2016 assessment model was fairly unstable. The authors showed that the stability of the model improved when the catchability coefficient for the ABL longline survey was estimated. This parameter was estimated in both 16.b and 16.1c.

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 ABL 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 - 2018
EBS slope survey	1945 – 2001	2002 – 2010	2011 - 2018
Trawl fishery	1945 – 1988	1989 – 2005	2006 - 2018
Longline fishery	1945 – 1990	1991 – 2007	2008 - 2018

Results

Model Evaluation

Models were evaluated based on model conformance with known biological factors, model likelihood/fit, and retrospective analyses. Table 5.16 summarizes the total likelihood and likelihood components for each model. The likelihood of model 16.1c improved by 21 units with one additional parameter. This improvement was mainly due to the lower likelihood of the recruitment likelihood component. The survey and mean size-at-age likelihood components were similar between the models (Table 5.16, Figures 5.14 and 5.15). The root mean square error estimates also indicate that the fits to survey biomass were quite similar (Table 5.17).

Both models predicted the declining trend in the ABL longline index, the leveling off between 2011 and 2015 and an increase thereafter even though the biomass estimates have been relatively stable (Figure 5.14). The models generally underestimated the earlier high values of biomass and overestimated the last three years of the time-series. The models fit to the shelf survey biomass followed the general declining trend with an increase generally captured the trends in the data increase due to the high numbers of small fish observed in the 2008 through 2013 shelf surveys and 2012 and 2016 slope survey. Although the overall trend was captured the models grossly underestimated the high shelf biomass value in 1994. The models also predicted that the increasing trend in these estimates would continue in 2017 and 2018 even though the index has been declining for a few years (Figure 5.14). The slope survey index was not updated in 2018 due to the cancellation of the survey. The models fit this index reasonably well.

There was an improvement in the length composition likelihood component for model 16.c. A closer look at the individual likelihood values within the length composition component indicates there is a trade-off in the fit to the length composition data (Table 5.16b). The improvement in Model 16.1c's length composition likelihood was due to an improved fit to the fisheries trawl and shelf survey length composition data, which was difficult to visually determine (Figures 5.16 and 5.17). This is not surprising given these data sources contain greater information about smaller Greenland turbot than the longline fishery or slope survey. Meanwhile, model 16.1b had better fits to the longline fishery and the slope survey data. Figure 5.17 shows the residuals from the fits to the length composition data. The patterns in the residuals are similar between the two models.

The trade-off in the model fit to the length composition data was a result of the differing selectivities between the models (Figures 5.18 – 5.21). The fits to the fishery trawl data early in the time-series were somewhat improved in model 16.1c. The residuals were smaller at smaller sizes for females in the first few years and at larger sizes in 1982-1984 than those from model 16.1b (Figure 5.17). This corresponds to differing estimated selectivity in the first time block (1945 – 1989), where the selectivity had a dome shape in model 16.1b and the estimated relationship in model 16.1c was asymptotic (Figure 5.18). Fishery trawl selectivity was similar for the other time blocks between models. The patterns in the residuals indicate male lengths were overestimated in 1978-82 and then the peaks were underestimated for the majority of subsequent years. The residuals also indicate that the cohort represented in the 2012-2018 was underestimated.

The longline fishery selectivity for both sexes differed between models; however the new curves reflect that the longline fishery captured larger females than males (Figure 5.19). The estimated selectivity curves were generally dome-shaped for the all time blocks. The exception was the estimated male selectivity in the second time block. The patterns in the residuals were similar and indicate models fit the longline length composition relatively well, but the residuals were slightly smaller for model 16.1b.

The male fishery length composition data has a narrower range than the females and the model initially overestimates the proportions at length and then generally underestimates the lengths. The model also initially (i.e., first three years) overestimated the male proportion at length in the slope data and then generally underestimated the peak of the distribution.

The shelf survey was fit with a double normal selectivity pattern, where male selectivity was offset from the estimated female selectivity. This allowed for dome-shaped selectivity. Selectivity was assumed to vary over time with four time blocks The estimated patterns were all dome-shaped and similar between the models, except in the first time block when the selectivity of the smallest size bins increased in model 16.1c (Figure 5.20). Notably, the models underestimate cohorts in 1990-1997 and 2010-2018. Also, in 1995- 1998 the models tended to overestimate the number of large females, while in 2000-2004 the large females tended to be underestimated.

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 slope survey selectivity patterns were similar between models (Figure 5.21). The fits continued to underestimate the peak of the highest abundance size bins, particularly for males.

It should be noted that in September the authors presented MCMC results indicating that many of the selectivity parameters were poorly determined. This issue has not been resolved, but should be addressed in the future. Possible avenues of investigation include simplifying or reducing the time blocks.

The shelf survey age composition data were included in the model but not fit to the age composition likelihood. The model 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, and 2014 and expected the peak of the distribution to occur at an older age in 2011 and 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, and apical fishing mortality. Certainty bounds were the standard errors obtained from the inverted Hessian matrix. Tables 5.19, 5. 22, and 5.23 also summarize all or portions of these results. Recruitment after 1980 was similar between the two models; however, prior to 1980 there were obvious differences and the estimate of unfished recruitment R_0 from model 16.1c was lower than from model 16.1b (Table 5.19). Average recruitment from 1977- 2018 was 10 million and 9.4 million for models 16.1b and 16.1c, respectively. Differences in spawning biomass were large prior to 1960 and again between 1971 and 1995, but the model estimates converge in 1996 with a similar estimate of spawning biomass in 2018 (Figure 5.23b and c). The model does not have catch records before 1960, so the initial differences in SSB are due to the estimated starting conditions. The difference in fishing mortality between models was greatest from 1960 to 1965, where model 16.1b had higher *F*s and explains why the spawning biomass estimate from model 16.1b is lower than model 16.1c (Figure 5.23d). The 1971-1995 spawning biomass estimates from model 16.1b were higher than the estimates from model 16.1c even though fishing mortality was higher. Some of the highest catches were during this time and caught by the trawl fishery (Figure 5.4). The estimated selectivity for the majority of this time period was estimated to be dome-shaped for model 16.1b, whereas it was estimated to be asymptotic by model 16.1c. The dome-shaped selectivity allowed for a greater number of mature females to accumulate in the population leading to higher spawning biomass estimates (Tables 5.20 and 5.21, Figure 5.28).

Retrospective analyses were conducted to determine the level bias in the assessment by removing data one year at a time for 10 years and then refit the model for each annual removal. The Mohn's rho statistic was calculated to measure the severity of the retrospective pattern and to provide a measure of comparability between models. Overall, the retrospective bias in spawning biomass was low for both models (Figures 5.29 and 5.30). The Mohn's rho statistic was 0.097 and 0.045 for models 16.1b and 16.1c, respectively (Table 5.17).

Model 16.1c was presented at the November, 2016 Plan Team meeting as an exploratory model to show a possible way in which climate could be introduced in our models. R_0 was conditioned on a bottom temperature index which identified extreme cold conditions on the Eastern Bering Sea shelf. This was the only difference in the two models presented here and involved the addition of one parameter. Although the likelihood and retrospective statistics suggest that the including an environmental variable linked to recruitment through R_0 is an improvement in the model, this approach has not been well tested. When this model was first configured the only option was to link the environmental index to R_0. This can rescale the stock-recruitment relationship in every year. New options in SS3 allow environmentally driven changes in recruitment without changing R_0, which should be evaluated. Additionally, the results were similar between models resulting in similar harvest advice. **Therefore, for this year the authors would recommend Model 16.1b for the base stock assessment**. We strongly recommend that models incorporating the link between recruitment and the environment be explored in the future for its application to the Greenland turbot assessment. Attention should be paid to how the index is implemented (i.e., binary versus temperature estimates) and whether the expected changes should be modeled as long term regime shifts or annual deviations.

Time Series Results

In this section we will present the results from Model 16.1b and predicted time series. 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 16.1b 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 0.613 with a standard deviation of 0.038. The model predicts extremely large recruitments in 1961- 1966 with between 83 and 484 million age 0 recruits (Tables 5.19 and 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. Model 16.1.b fits autocorrelation in recruitment forcing 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, Model 16.1b predicts another large recruitment event in 1973-1978 with an average recruitment of 113 million age-0 fish for these six years with a maximum of 210 million age-0 fish in 1975. 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) from1977 onward.

Recruitment from 1980 through 2006 was low with a mean of 4.7 million age-0 fish. Recruitment of age-0 fish was estimated to be 22.1 million, 48.1 million, 33million, and 6 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. 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 5.28). The estimated numbers-at-age reflect the strong cohorts in the late 1970s and from 2007-2010 (Table 5.20).

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass in Model 16.1b was projected to be 50,465 t in 2018, which has been increasing from a low of 26,342 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 (40% of the overall 1977-2018 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 that more than doubled the catch of Greenland turbot in 2008 and continued to double the catch of Greenland turbot 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 0.09 with a maximum of 0.14 (Table 5.22). The fishing mortality increased between 2009 and 2012 and ranged between 0.18 and 0.24.This may have steepened the most recent decline. The effects of the incoming 2007-2009 year classes have created a steep increase in both the total biomass and female spawning biomass estimates. The projections suggest that spawning biomass will start to decline in 2020 (Table 5.25). The retrospective analysis indicates that with each new year of data the influence of the 2007-2010 recruitment event is dampened and helps to explain why the spawning biomass estimates in recent years from this assessment are lower than the 2016 assessment (Table 5.22).

The Model 16.1b 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 2010 of 64,684 t (Figure 5.29). The difference is that the total biomass shows the impact of the 2007- 2010 recruitments starting in 2011. Since its low point in 2010 total age-1+ biomass is projected to have increased to 108,433 t in 2018 and projected to be at 105,937 t in 2019 and 98,923 t in 2020 (Table 5.22).

Retrospective analysis

A retrospective analysis was conducted in SS3 by removing data systematically by year from all models for 10 years (Figures 5.26a and 5.27a). There is a positive retrospective bias as data are removed from the model. Data added to the model tends to estimate a substantial decrease in the strength of the 2009 and

2010 year classes (Figure 5.27a). The Mohn's rho estimate associated with spawning biomass for model 16.1b was 0.09, 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 1978-2016 gives a long-term average female spawning biomass of 36,213 t. The estimated 2019 female spawning biomass was at 54,244 t, which is above $B_{40\%}$ and above the estimate of $B_{35\%}$ (31,687 t). Because the projected spawning biomass in year 2019 (54,244 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 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 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.

Due to this concern about recruitment, model 16.1c was evaluated. The projection results from model 16.1c were similar to those from 16.1b (Tables 5.26 and 5.27). The projected Greenland turbot maximum permissible ABC, recommended ABC, and OFL levels from model 16.1b for 2019 and 2020 are shown below:

Year	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2019	9,658	9,658	11,362	54,244
2020	8,908	8,908	10,476	52,743

The 2019 estimated overfishing level based on the adjusted $F_{35\%}$ rate is 11,362 t corresponding to a full-selection F of 0.21. 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. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

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).

Recent research on recruitment processes holds promise for clearer understanding (e.g., Sohn 2009). 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 past four surveys (when both areas were covered) were 14.5% and 10% and their average is 12.7%. The reduction in the percentage is due to a steep declining trend in the Aleutian Island biomass estimates (Table 5.7). The BSAI ABC was split between the EBS and the Aleutian Islands assuming 8% of the biomass is in the Aleutian Islands and gives the following region-specific allocation:

	2019 ABC	2020 ABC
Aleutian Islands ABC	1,227	1,131
Eastern Bering Sea ABC	8,431	7,777
Total	9,658	8,908

Standard harvest scenarios and projections

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

For each scenario, the projections begin with the vector of 2018 numbers at age estimated in the assessment (age-1+). This vector is then projected forward to the beginning of 2019 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2018 (here assumed to be 3,758 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 2019, 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 the 2013-2017 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 4: In all future years, F is set equal to the $F_{75\%}$. (Rationale: This scenario was developed by the NMFS Regional Office based on public feedback on alternatives.

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 2019 and 2020, 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 2020 or 2) above 1/2 of its MSY level in 2020 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 13 years from 2018 (Table 5.25). Fishing at the maximum permissible rate (scenarios 1 and 2) indicate that the spawning stock will decline after 2019, fall below $B_{40\%}$ in 2025, and fall below $B_{35\%}$ in 2027. The projection results from model 16.1c are reported for completeness. The projection results from model 16.1c when fishing under the maximum permissible spawning biomass has a similar trend to model 16.1b (Table 5.26).

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 (2017) is 2,834 t. This is less than the 2018 OFL of 13,148 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 2018:

a. If spawning biomass for 2018 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
b. If spawning biomass for 2018 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2018 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 2028 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 2020 is below ½ B35%, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2020 is above B35%, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2020 is 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 2018 and 2020 are estimated to be 50,465 t and 52,743 t which is greater than $B_{35\%}$ = 31,687 t. Figure 5.30 shows the relationship between the ratio of historical fishing mortality and female spawning biomass for Greenland turbot from 1960-2018.

It should be noted that the 2007-2010 cohorts are maturing, growing, and becoming more 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 37% of the expected unfished level in 1977. This declined to a low of 20% between 2004 and 2006, was relatively stable between 21% and 25% between 2007 and 2014 and rapidly increased to 44% of the expected unfished level in 2018.

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 (Figure 5.31) 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 (Figure 5.32) 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 5.28. 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 5.16 and Table 5.30, bycatch of prohibited species are summarized in Table 5.31 and Table 5.32. 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 5.33). 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 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.
- An evaluation of non-binary environmental indices and methods for linking environmental covariates to recruitment
- 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

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Tables

Table 5.1. Catch estimates of Greenland turbot by gear type (t; including discards) and ABC and TAC values since implementation of the MFCMA.

Year	Trawl	Longline & Pot	Total	ABC	TAC
1977	29,722	439	30,161	40,000	
1978	39,560	2,629	42,189	40,000	
1979	38,401	3,008	41,409	90,000	
1980	48,689	3,863	52,552	76,000	
1981	53,298	4,023	57,321	59,800	
1982	52,090	32	52,122	60,000	
1983	47,529	29	47,558	65,000	
1984	23,107	13	23,120	47,500	
1985	14,690	41	14,731	44,200	
1986	9,864	0	9,864	35,000	33,000
1987	9,551	34	9,585	20,000	20,000
1988	6,827	281	7,108	14,100	11,200
1989	8,293	529	8,822	20,300	6,800
1990	12,119	577	12,696	7,000	7,000
1991	6,246	1,618	7,863	7,000	7,000
1992	749	3,003	3,752	7,000	7,000
1993	1,145	7,325	8,470	7,000	7,000
1994	6,427	3,846	10,272	7,000	7,000
1995	3,979	4,216	8,194	7,000	7,000
1996	1,653	4,903	6,556	7,000	7,000
1997	1,210	5,990	7,200	9,000	9,000
1998	1,576	7,181	8,757	15,000	15,000
1999	1,795	4,058	5,853	9,000	9,000
2000	1,947	5,027	6,974	9,300	9,300
2001	2,149	3,164	5,312	8,400	8,400
2002	1,033	2,603	3,636	8,000	8,000
2003	931	2,181	3,111	4,000	4,000
2004	675	1,583	2,259	4,740	3,500
2005	729	1,880	2,608	3,930	3,500
2006	361	1,628	1,989	2,740	2,740
2007	458	1,546	2,004	2,440	2,440
2008	1,935	976	2,911	2,540	2,540
2009	3,080	1,435	4,515	7,380	7,380
2010	1,977	2,146	4,123	6,120	6,120
2011	1,618	2,051	3,668	6,140	5,060
2012	2,613	2,103	4,716	9,660	8,660
2013	1,045	697	1,742	2,060	2,060
2014	951	704	1,656	2,124	2,124
2015	1,095	1,109	2,204	3,172	2,648
2016	1,187	1,085	2,272	3,462	2,873
2017	1,839	995	2,834	6,644	4,500
2018*	1,548	275	1,823	11,132	5,294

*Catch estimated as of October 2018

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2018. 2018 numbers are estimates through October and are not final.

Fishery	Greenland turbot		Sablefish		Pacific Cod		Rockfish		Arrowtooth/Kamchatka		Halibut		Flatfish		Others	
Year	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain
1992	13	62	2,121	196	557	135	103	180	2	6			1	7	261	108
1993	332	5,687	880	235	108	161	87	572	2	1			183	18	194	10
1994	368	6,316	2,305	195	211	149	37	317	0	0			235	27	75	38
1995	327	5,093	1,546	157	284	145	25	362	5	0			97	5	105	28
1996	173	3,451	1,026	200	307	170	113	598	0	0			63	171	135	143
1997	521	4,709	619	129	283	270	19	202	0	0			92	212	125	18
1998	290	6,689	84	123	155	281	1	35	86	40			162	541	163	87
1999	227	4,009	120	179	50	180	2	25	76	131			193	465	56	134
2000	177	4,798	254	192	109	130	1	39	93	262			83	576	75	186
2001	89	2,727	325	171	92	203	30	431	149	201			188	563	47	95
2002	73	1,979	207	144	137	210	18	175	158	225			59	76	50	124
2003	44	1,724	107	114	95	178	5	198	98	129	158	46	18	68	55	120
2004	19	1,222	30	78	83	220	3	81	39	37	62	20	109	134	50	91
2005	21	1,530	21	63	30	156	5	134	21	148	90	13	26	165	49	149
2006	14	1,198	69	62	32	66	8	71	72	141	10	53	13	51	46	135
2007	28	1,207	78	60	91	128	13	36	5	19	15	5	24	54	50	197
2008	3	944	87	42	69	16	1	142	415	762	10	1	16	95	104	205
2009	51	2,490	74	76	21	65	8	67	285	1,158	0	0	10	49	14	148
2010	18	1,928	36	67	19	97	2	57	81	1,658	66	1	5	13	8	80
2011	8	1,786	15	49	9	164	1	27	7	897	36	0	5	3	9	84
2012	15	1,895	16	36	9	115	3	17	9	923	13	0	5	47	23	239
2013	13	578	41	27	5	13	10	49	176	593	24	1	42	38	8	53
2014	16	626	47	11	7	13	1	40	127	499	3	0	52	30	7	78
2015	10	1,061	12	1	17	10	1	34	25	760	19	0	34	72	6	60
2016	17	1,377	8	1	29	65	0	27	4	464	14	0	6	59	7	68
2017	26	1,875	9	3	45	110	0	37	5	222	1	0	8	141	2	61
2018	8	1,262	8	7	13	81	2	51	6	121	10	0	6	31	8	50

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2007-2018. Source: NMFS AK Regional Office catch accounting system.

Gear	Target fishery	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fixed	Arrowtooth Flounder/Kamchatka	16	0	9	49	0	4	0	0	0	0	0	0
	Greenland Turbot - BSAI	1232	743	1191	1828	1790	1910	589	628	1052	907	830	167
	Halibut	19	12	0	67	37	13	25	3	19	15	1	10
	Other Flatfish - BSAI	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
	Pacific Cod	129	76	84	111	173	123	16	17	24	82	155	91
	Pollock - bottom	0	0	0	0	0	0	0	0	0	0	0	0
	Rockfish	2	0	1	0	0	1	4	0	0	0	0	0
	Sablefish	137	124	149	103	63	52	67	58	12	8	10	8
Trawl	Alaska Plaice - BSAI	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
	Atka Mackerel	130	201	118	62	64	209	40	45	25	46	45	27
	Flathead Sole	58	99	49	13	2	46	39	19	60	55	115	9
	Greenland Turbot - BSAI	2	205	1349	118	4	0	3	14	19	487	1071	1103
	Other Flatfish - BSAI	12	11	4	1	0	1	4	0	2	2	26	2
	Other Species	0	0	0	0	1	0	0	0	0	0	0	0
	Pacific Cod	90	9	2	5	0	1	2	2	3	11	0	4
	Pollock - bottom	2	13	4	5	5	6	3	26	6	11	10	18
	Pollock - midwater	105	72	40	20	24	48	18	15	34	18	8	13
	Rock Sole - BSAI	8	0	2	3	1	0	2	5	1	0	0	0
	Rockfish	47	142	73	59	28	18	54	41	34	28	37	53
	Sablefish	0	5	1	0	0	0	1	0	0	0	1	7
	Yellowfin Sole - BSAI	1	1	4	1	5	6	35	57	43	8	8	26

* Through October 2018

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2005-2018. The 2018 values are estimates through October 2016.

Area	Gear	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
EBS	Fixed	1713	1270	1201	867	1336	1943	1966	2046	632	661	1093	995	991	271
	Trawl	427	183	280	1222	916	325	1176	1012	815	819	999	1122	1720	1390
	Total	2140	1453	1481	2089	2252	2268	3142	3058	1446	1480	2092	2117	2712	1662
AI	Fixed	167	358	345	110	99	215	97	58	68	46	15	17	4	4
	Trawl	301	179	178	712	2164	1653	442	1600	231	133	98	107	118	158
	Total	468	537	523	822	2263	1868	539	1658	299	179	113	124	122	162

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 ABL 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	1960-2018
	Size composition	1977-1987, 1989-1991, 1994-2006, 2008-2018
Longline fisheries	Catch	1960-2018
	Size composition	1979-1985, 1993-2018
Shelf Survey	Abundance Index	1987-2018
	Size composition	1982-2018
	Age composition^{+}	1998, 2003-2017
Slope Survey	Abundance Index	2002, 2004, 2008, 2010, 2012, 2016
	Size composition	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, 2016
ABL Longline survey	RPN index	1996-2018
	Size composition*	1979-2018

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2018. Source: NMFS observer program data. The % female do not include unidentified fish.

	Trawl				Longline			
Year	Female	Male	Unid	% Female	Female	Male	Unid	% Female
1989	1405	5568	1017	20%				
1990	3864	5762	6100	40%				
1991	1851	1752	9295	51%				
1992					0	0	71	
1993			425		3921	915	12464	81%
1994	1122	1027	5956	52%	503	150	1200	77%
1995	245	363	4114	40%	1870	715	5630	72%
1996	112	390		22%	941	442	7482	68%
1997					2393	1014	14833	70%
1998	307	696	822	31%	3510	2127	22794	62%
1999	1044	1556		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		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		36%	4650	1902	43	71%
2006	15	76		16%	3339	1474	32	69%
2007	34	23		60%	3833	2130	134	64%
2008	421	1572	1	21%	1577	1481		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%
2014	1150	1571	3	42%	1022	1077		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	1229	1952		39%	662	388		63%

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, 1979-2018. 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

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. 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

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

a)

Year	Western Aleutian	Central Aleutian	Eastern Aleutian	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	842	2,351	5,703	467	9,362
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	984	424	970	2,378
2018	320	53	0	0	373
Avg. since 1991	1,331	2,010	6,581	1,301	11,222

b)

Year	Western Aleutians	Central Aleutians	Eastern Aleutians	Southern Bering Sea	Total
1991	500420	712719	1796765	316486	3326390
1994	881506	929025	3994288	1952614	7757433
1997	498354	896440	8493220	81841	9969855
2000	181735	593387	1816919	146309	2738350
2002	120372	432377	2404722	138672	3096143
2004	471895	742596	758643	990203	2963337
2006	440137	349587	4054808	349346	5193878
2010	276593	332759	1198540	136532	1944424
2012	189068	215029	57716	25824	487637
2014	147713	142076	126252	152591	568632
2016	0	132234	423147	364626	920007
2018	36955	17372	0	0	54327

Table 5.12. Auke Bay 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	119.08
1997	11,729	6,172	27,936	13,491					59,328		80.98
1998					23,121	7,208	1,791	5,665		37,784	140.66
1999	13,072	6,156	33,848	10,068					63,144		86.19
2000					12,987	4,049	1,201	3,800		22,037	81.98
2001	16,082	5,005	24,766	5,123					50,975		69.58
2002					10,942	3,411	1,397	4,420		20,170	74.93
2003	11,965	3,784	24,660	6,206					46,616		63.63
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	23.47
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	12.46
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									20,638		28.06
2018										5672	21.4

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

Age	1982	1998	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	16.75	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. 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. 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
Trawl	50	50	50
Longline	50	50	50
Shelf	200	200	200
Slope	400		

Table 5.16. Model a) total likelihoods and c) likelihood components. Please note that the total likelihood is not comparable between models because model 16.1c includes an environmental link on recruitment.

a)

Component	16.1b Likelihood	Gradient	16.1c Likelihood	Gradient
Total	2019.9	3.65e-06	1998.0	0.00151
Catch	5.6E-12		2.0E-13	
Survey	-30.7		-30.4	
Length comp	656.8		653.9	
Size at age	1276.9		1277.2	
Recruitment	101.05		79.03	

b)

Model	16.1b					16.1c				
Fleet/Survey	Trawl	Longline	Shelf	Slope	ABL LL	Trawl	Longline	Shelf	Slope	ABL LL
Likelihood										
Catch	5.6E-12	8.3E-14	0	0	0	1.1E-13	9.7E-14	0	0	0
Survey	0	0	-32.1	-6.9	8.3	0	0	-31.6	-6.6	7.7
Length comp	105.7	62.9	291.3	196.8	0	102.3	64.9	286.5	200.3	0
Size at age	0	0	1276.9	0	0	0	0	1277.2	0	0

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

		16.1b	16.1c
Retrospective			
Mohn's ρ	SSB	0.097	0.045
	Recruitment	3.15	2.49
	Fishing mortality	-0.04	-0.05
Index RMSE			
	Shelf	0.209	0.211
	Slope	0.176	0.179
	ABL Longline	0.394	0.392
Size Comp			
Har. Mean EffN			
	Trawl	37.54	38.91
	Longline	94.87	104.5
	Shelf	47.84	50.32
	Slope	47.51	44.54
Mean input N			
	Trawl	12.5	12.5
	Longline	25	25
	Shelf	50	50
	Slope	106.25	106.25
	Rec. Var. (1975-2018)		
	Std.dev(ln(No. Age 1))	1.55	1.51

Table 5.18. Key parameter estimates and estimated standard deviations.

	16.1b		16.1.c	
Label	Value	StDev	Value	Stdev
Biology				
L Amin female	15.06	0.24	15.19	0.23
L Amax female	90.29	0.43	90.70	0.41
von Bert k female	0.11	0.00	0.11	0.00
L Amin male	14.13	0.22	14.17	0.22
L Amax male	71.99	0.35	71.97	0.35
von Bert k male	0.19	0.00	0.19	0.00
Recruitment				
SLN(R0)	9.19	0.16	8.44	0.17
steepness	0.79	_	0.79	_
σ_R	0.60	_	0.60	_
SR_autocorr	0.61	0.04	0.44	0.06
SR_LN(R0)_ENV_add	-	-	-1.99	0.28
Catchability				
Shelf LN(q)	-0.49	_	-0.49	_
Slope LN(q)	-0.56	_	-0.56	_
ABL Longline LN(q)	-0.54	0.07	-0.51	0.07

Table 5.19. Spawning and total biomass, Age-0 recruits, fishing mortality, exploitation rate, and estimates of 1-SPR for BSAI Greenland turbot, 1960-2018 for models 16.1b and 16.1c.

	16.1b					16.1c				
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	119206	7320	0.11	0.10	0.78
1961	108290	82675	0.33	0.20	0.96	121116	71729	0.18	0.16	0.90
1962	96145	185807	0.43	0.24	0.98	111020	127112	0.22	0.19	0.93
1963	80722	437867	0.28	0.17	0.95	96239	264792	0.14	0.12	0.85
1964	71913	484027	0.32	0.19	0.96	88619	415344	0.16	0.15	0.88
1965	62866	204888	0.07	0.05	0.55	78333	224937	0.04	0.04	0.51
1966	61185	85070	0.06	0.05	0.48	76508	107820	0.04	0.05	0.51
1967	61320	44596	0.07	0.06	0.53	75095	61898	0.06	0.06	0.60
1968	65661	29672	0.07	0.07	0.55	76229	7024	0.07	0.07	0.64
1969	80552	24010	0.06	0.05	0.48	85524	6028	0.06	0.06	0.58
1970	114004	23147	0.04	0.03	0.34	110114	37901	0.04	0.04	0.44
1971	169079	26270	0.07	0.06	0.55	154155	41465	0.07	0.07	0.65
1972	230742	35638	0.13	0.11	0.76	203995	49218	0.12	0.12	0.82
1973	276896	59529	0.12	0.09	0.72	238840	66899	0.11	0.10	0.78
1974	310753	119004	0.16	0.11	0.82	264402	15496	0.14	0.13	0.85
1975	320669	209981	0.15	0.11	0.81	266150	347969	0.13	0.12	0.83
1976	318037	147543	0.16	0.11	0.83	257121	40070	0.13	0.12	0.84
1977	305274	93480	0.09	0.05	0.61	239795	22005	0.07	0.06	0.64
1978	299082	49205	0.12	0.08	0.73	233383	115901	0.11	0.09	0.73
1979	283743	17637	0.12	0.08	0.72	218758	10160	0.11	0.09	0.73
1980	268767	6022	0.16	0.10	0.80	205235	3446	0.14	0.11	0.80
1981	253156	1025	0.18	0.11	0.83	190758	502	0.16	0.12	0.83
1982	240818	1999	0.16	0.11	0.83	180770	1510	0.12	0.12	0.82
1983	235087	3289	0.16	0.10	0.83	177771	2697	0.12	0.11	0.82
1984	229943	6185	0.09	0.05	0.62	175254	5044	0.06	0.06	0.62
1985	231106	20233	0.06	0.04	0.49	180883	20907	0.04	0.04	0.49
1986	231958	5317	0.04	0.03	0.38	187079	4235	0.03	0.03	0.38
1987	230712	5756	0.04	0.03	0.40	191386	5318	0.03	0.03	0.38
1988	225476	5897	0.04	0.02	0.33	191097	5084	0.02	0.02	0.31
1989	217913	15803	0.06	0.03	0.31	187965	15590	0.06	0.03	0.30
1990	205200	3848	0.11	0.04	0.45	180093	3507	0.10	0.04	0.43
1991	188389	1131	0.07	0.03	0.35	167488	999	0.07	0.03	0.33
1992	174737	743	0.03	0.01	0.18	157157	688	0.03	0.01	0.18
1993	164111	606	0.08	0.03	0.35	149116	422	0.08	0.03	0.36
1994	149741	954	0.12	0.04	0.49	137064	1584	0.12	0.05	0.48

Table 5.19. Continued. Spawning and total biomass, Age-0 recruits, fishing mortality, exploitation rate, and estimates of 1-SPR for BSAI Greenland turbot, 1960-2018 for models 16.1b and 16.1c.

	16.1b					16.1c				
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	124816	3498	0.11	0.04	0.44
1996	123184	1612	0.09	0.03	0.38	114189	1459	0.09	0.03	0.38
1997	112523	1641	0.10	0.04	0.42	104803	1622	0.11	0.04	0.43
1998	101654	2145	0.14	0.05	0.50	94965	1492	0.15	0.06	0.51
1999	89840	8332	0.11	0.04	0.44	84030	10402	0.11	0.04	0.44
2000	80737	9648	0.14	0.05	0.51	75679	7565	0.15	0.06	0.52
2001	70885	11358	0.13	0.05	0.49	66486	11704	0.13	0.05	0.50
2002	62832	1677	0.10	0.04	0.41	59007	1472	0.10	0.04	0.42
2003	56300	614	0.09	0.03	0.40	52939	536	0.10	0.03	0.41
2004	50604	547	0.08	0.03	0.35	47592	505	0.08	0.03	0.35
2005	46087	801	0.10	0.03	0.41	43495	667	0.10	0.03	0.42
2006	41981	7292	0.07	0.03	0.34	39618	7050	0.08	0.03	0.35
2007	39276	22137	0.08	0.03	0.36	37122	20314	0.09	0.03	0.37
2008	37470	48122	0.12	0.04	0.47	35546	48202	0.12	0.04	0.48
2009	36147	33061	0.18	0.07	0.61	34395	32086	0.18	0.07	0.61
2010	33936	6103	0.18	0.06	0.60	32362	6126	0.19	0.07	0.61
2011	31325	4003	0.18	0.06	0.59	29898	2771	0.18	0.06	0.60
2012	28784	1904	0.24	0.07	0.69	27462	2632	0.25	0.07	0.69
2013	26342	2430	0.09	0.02	0.39	25057	1843	0.09	0.02	0.40
2014	27404	2063	0.07	0.02	0.34	26024	1614	0.08	0.02	0.35
2015	31312	2458	0.08	0.02	0.36	29750	2045	0.08	0.02	0.37
2016	37430	2168	0.06	0.02	0.30	35664	1665	0.07	0.02	0.31
2017	44447	3182	0.06	0.03	0.29	42521	2253	0.06	0.03	0.30
2018	50465	6041	0.07	0.03	0.33	48435	3925	0.07	0.04	0.34

Table 5.20. Estimated beginning of year numbers (1×10^7) of female Greenland turbot by age for Model 16.1b.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	46.74	65.96	80.33	35.91	13.81	6.404	3.738	2.672	2.359	2.559	3.38	5.645	11.95	24.88	18.48	5.72	1.734	0.627	0.301	0.197	2.4
1978	24.6026	41.79	57.66	67.3	29.64	11.38	5.29	3.102	2.228	1.977	2.155	2.86	4.795	10.19	21.28	15.85	4.919	1.494	0.542	0.26	2.3
1979	8.8184	22	36.25	47.22	53.99	23.73	9.14	4.275	2.523	1.824	1.628	1.784	2.377	4.002	8.534	17.88	13.37	4.159	1.267	0.46	2.2
1980	3.01099	7.884	19.1	29.76	38.01	43.38	19.13	7.409	3.487	2.071	1.505	1.35	1.485	1.986	3.354	7.174	15.08	11.3	3.524	1.076	2.2
1981	0.5126	2.692	6.792	15.33	23.3	29.68	34.02	15.11	5.898	2.797	1.672	1.222	1.101	1.217	1.634	2.77	5.945	12.53	9.421	2.947	2.8
1982	0.99933	0.458	2.308	5.376	11.8	17.88	22.89	26.44	11.85	4.664	2.229	1.341	0.986	0.892	0.99	1.335	2.272	4.894	10.36	7.809	4.8
1983	1.64473	0.893	0.392	1.818	4.111	8.993	13.7	17.69	20.63	9.339	3.713	1.791	1.086	0.804	0.733	0.818	1.109	1.896	4.099	8.703	10.7
1984	3.09272	1.47	0.765	0.309	1.39	3.134	6.891	10.59	13.8	16.26	7.435	2.983	1.451	0.887	0.661	0.606	0.68	0.925	1.588	3.445	16.4
1985	10.1165	2.765	1.285	0.639	0.254	1.142	2.581	5.701	8.804	11.54	13.67	6.28	2.531	1.236	0.758	0.567	0.521	0.586	0.799	1.374	17.2
1986	2.65835	9.045	2.433	1.097	0.54	0.214	0.965	2.189	4.852	7.52	9.891	11.76	5.417	2.189	1.071	0.658	0.493	0.454	0.511	0.698	16.3
1987	2.87775	2.377	7.995	2.105	0.941	0.463	0.184	0.831	1.889	4.198	6.523	8.6	10.25	4.729	1.915	0.938	0.578	0.433	0.399	0.45	15.0
1988	2.94857	2.573	2.1	6.905	1.803	0.806	0.397	0.158	0.716	1.632	3.636	5.664	7.485	8.935	4.132	1.675	0.822	0.507	0.38	0.351	13.6
1989	7.90159	2.636	2.279	1.828	5.974	1.559	0.698	0.344	0.137	0.623	1.423	3.177	4.957	6.56	7.839	3.629	1.473	0.724	0.446	0.335	12.3
1990	1.92422	7.064	2.357	2.038	1.634	5.34	1.393	0.621	0.303	0.12	0.538	1.22	2.717	4.239	5.62	6.735	3.127	1.273	0.627	0.388	11.2
1991	0.56554	1.72	6.315	2.106	1.821	1.461	4.769	1.236	0.542	0.26	0.101	0.448	1.013	2.255	3.53	4.701	5.663	2.644	1.082	0.536	10.1
1992	0.37143	0.506	1.538	5.645	1.883	1.628	1.305	4.244	1.089	0.472	0.224	0.086	0.382	0.862	1.922	3.015	4.026	4.864	2.277	0.934	9.3
1993	0.30276	0.332	0.452	1.375	5.047	1.684	1.455	1.166	3.785	0.969	0.418	0.198	0.076	0.335	0.756	1.683	2.639	3.523	4.256	1.993	9.0
1994	0.47688	0.271	0.297	0.404	1.229	4.512	1.505	1.299	1.037	3.346	0.85	0.364	0.171	0.065	0.286	0.643	1.429	2.236	2.984	3.606	9.4
1995	1.88565	0.426	0.242	0.265	0.361	1.099	4.03	1.336	1.138	0.891	2.827	0.709	0.302	0.141	0.054	0.237	0.533	1.188	1.867	2.501	11.1
1996	0.80592	1.686	0.381	0.216	0.237	0.323	0.982	3.586	1.177	0.988	0.764	2.398	0.597	0.253	0.118	0.045	0.198	0.447	0.999	1.573	11.6
1997	0.82028	0.721	1.507	0.341	0.193	0.212	0.289	0.876	3.181	1.036	0.861	0.66	2.056	0.509	0.215	0.1	0.038	0.167	0.378	0.844	11.2
1998	1.07239	0.733	0.644	1.347	0.305	0.173	0.19	0.257	0.777	2.8	0.902	0.743	0.564	1.741	0.428	0.18	0.083	0.032	0.139	0.315	10.2
1999	4.16602	0.959	0.656	0.576	1.205	0.272	0.154	0.169	0.228	0.68	2.416	0.768	0.624	0.468	1.434	0.351	0.147	0.068	0.026	0.114	8.7
2000	4.82424	3.725	0.857	0.586	0.515	1.077	0.243	0.138	0.149	0.199	0.588	2.067	0.651	0.525	0.392	1.198	0.293	0.122	0.057	0.022	7.5
2001	5.67908	4.313	3.33	0.766	0.524	0.46	0.962	0.217	0.121	0.13	0.171	0.496	1.723	0.538	0.431	0.32	0.977	0.238	0.1	0.046	6.2
2002	0.83826	5.077	3.856	2.977	0.685	0.468	0.411	0.856	0.191	0.105	0.111	0.144	0.414	1.429	0.444	0.355	0.264	0.806	0.197	0.083	5.3
2003	0.30677	0.749	4.539	3.447	2.661	0.612	0.419	0.367	0.758	0.167	0.091	0.095	0.123	0.351	1.206	0.374	0.299	0.222	0.678	0.166	4.6
2004	0.27353	0.274	0.67	4.058	3.081	2.379	0.547	0.373	0.325	0.665	0.145	0.079	0.081	0.104	0.297	1.017	0.315	0.252	0.187	0.572	4.1
2005	0.40049	0.245	0.245	0.599	3.628	2.755	2.126	0.488	0.331	0.286	0.581	0.126	0.068	0.07	0.089	0.253	0.866	0.268	0.214	0.16	4.0
2006	3.64624	0.358	0.219	0.219	0.535	3.243	2.462	1.895	0.432	0.291	0.248	0.499	0.107	0.057	0.059	0.075	0.213	0.728	0.226	0.18	3.6
2007	11.0684	3.26	0.32	0.195	0.196	0.479	2.897	2.195	1.684	0.382	0.255	0.216	0.432	0.092	0.049	0.05	0.064	0.181	0.619	0.192	3.3
2008	24.061	9.896	2.914	0.286	0.175	0.175	0.428	2.582	1.948	1.485	0.334	0.221	0.186	0.37	0.079	0.042	0.043	0.054	0.153	0.525	3.0
2009	16.5303	21.51	8.846	2.605	0.256	0.156	0.156	0.378	2.251	1.671	1.255	0.279	0.184	0.154	0.307	0.065	0.035	0.036	0.046	0.13	3.0
2010	3.05164	14.78	19.23	7.907	2.329	0.228	0.139	0.137	0.324	1.884	1.366	1.008	0.222	0.146	0.122	0.244	0.053	0.028	0.029	0.037	2.7
2011	2.00139	2.728	13.21	17.19	7.068	2.08	0.203	0.122	0.119	0.275	1.559	1.108	0.806	0.176	0.115	0.097	0.195	0.042	0.023	0.024	2.3

Table 5.20. Continued. Estimated beginning of year numbers (1×10^7) of female Greenland turbot by age for Model 16.1b.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
2012	0.95177	1.789	2.439	11.81	15.36	6.314	1.852	0.179	0.106	0.101	0.228	1.271	0.891	0.643	0.14	0.092	0.078	0.157	0.034	0.019	2.0
2013	1.21482	0.851	1.599	2.18	10.56	13.72	5.605	1.621	0.153	0.088	0.081	0.179	0.977	0.68	0.49	0.107	0.071	0.061	0.123	0.027	1.7
2014	1.03139	1.086	0.761	1.43	1.949	9.432	12.23	4.972	1.425	0.133	0.076	0.069	0.151	0.825	0.574	0.414	0.091	0.06	0.052	0.106	1.5
2015	1.22915	0.922	0.971	0.68	1.278	1.742	8.417	10.87	4.39	1.247	0.115	0.065	0.059	0.129	0.703	0.489	0.354	0.078	0.052	0.045	1.4
2016	1.0839	1.099	0.824	0.868	0.608	1.142	1.555	7.487	9.61	3.844	1.08	0.099	0.055	0.05	0.109	0.597	0.416	0.302	0.067	0.044	1.3
2017	1.59123	0.969	0.982	0.737	0.776	0.543	1.02	1.384	6.631	8.447	3.352	0.935	0.085	0.048	0.043	0.094	0.513	0.358	0.26	0.058	1.2
2018	3.02046	1.423	0.866	0.878	0.659	0.694	0.485	0.907	1.224	5.817	7.355	2.901	0.806	0.073	0.041	0.037	0.081	0.443	0.31	0.226	1.1

Table 5.20 Continued. Estimated beginning of year numbers (1×10^7) of male Greenland turbot by age for Model 16.1b

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	46.74	65.96	82.75	39.31	15.93	7.58	4.43	3.09	2.60	2.65	3.32	5.28	10.63	21.07	15.62	5.04	1.61	0.60	0.27	0.15	0.71
1978	24.60	41.79	58.54	71.55	33.36	13.36	6.31	3.67	2.56	2.14	2.18	2.73	4.35	8.75	17.34	12.86	4.15	1.32	0.49	0.23	0.71
1979	8.82	22.00	37.00	50.03	59.64	27.36	10.84	5.08	2.94	2.05	1.71	1.75	2.18	3.47	6.99	13.85	10.27	3.31	1.06	0.39	0.75
1980	3.01	7.88	19.48	31.67	41.80	49.04	22.27	8.77	4.10	2.37	1.64	1.37	1.40	1.75	2.78	5.60	11.09	8.22	2.65	0.85	0.91
1981	0.51	2.69	6.96	16.48	25.98	33.61	38.93	17.54	6.87	3.20	1.84	1.28	1.07	1.09	1.36	2.16	4.35	8.63	6.40	2.06	1.37
1982	1.00	0.46	2.37	5.85	13.37	20.60	26.27	30.16	13.51	5.27	2.45	1.41	0.98	0.82	0.83	1.04	1.65	3.32	6.59	4.88	2.62
1983	1.64	0.89	0.40	1.99	4.73	10.55	16.02	20.24	23.11	10.32	4.02	1.87	1.07	0.74	0.62	0.63	0.79	1.26	2.53	5.02	5.72
1984	3.09	1.47	0.79	0.34	1.61	3.73	8.20	12.34	15.51	17.66	7.87	3.07	1.42	0.82	0.57	0.47	0.48	0.60	0.96	1.93	8.19
1985	10.12	2.77	1.30	0.68	0.29	1.34	3.10	6.77	10.16	12.76	14.51	6.47	2.52	1.17	0.67	0.47	0.39	0.40	0.49	0.79	8.31
1986	2.66	9.04	2.46	1.14	0.59	0.24	1.14	2.62	5.73	8.58	10.77	12.24	5.46	2.12	0.99	0.57	0.39	0.33	0.33	0.42	7.68
1987	2.88	2.38	8.06	2.16	0.99	0.51	0.21	0.98	2.25	4.91	7.36	9.23	10.50	4.68	1.82	0.84	0.49	0.34	0.28	0.29	6.94
1988	2.95	2.57	2.12	7.08	1.88	0.86	0.44	0.18	0.84	1.93	4.21	6.30	7.90	8.98	4.00	1.56	0.72	0.42	0.29	0.24	6.19
1989	7.90	2.64	2.29	1.87	6.19	1.64	0.74	0.38	0.16	0.73	1.67	3.64	5.45	6.83	7.76	3.46	1.35	0.62	0.36	0.25	5.55
1990	1.82	6.68	2.23	1.94	1.58	5.23	1.38	0.62	0.31	0.13	0.59	1.33	2.89	4.32	5.42	6.16	2.75	1.07	0.50	0.29	4.62
1991	0.57	1.72	6.31	2.11	1.83	1.49	4.94	1.30	0.58	0.29	0.12	0.54	1.23	2.66	3.97	4.98	5.66	2.52	0.98	0.46	4.52
1992	0.37	0.51	1.54	5.64	1.88	1.64	1.33	4.40	1.15	0.51	0.25	0.10	0.47	1.06	2.29	3.42	4.29	4.88	2.17	0.85	4.29
1993	0.30	0.33	0.45	1.37	5.05	1.68	1.46	1.19	3.93	1.02	0.45	0.22	0.09	0.41	0.94	2.03	3.03	3.80	4.32	1.93	4.55
1994	0.48	0.27	0.30	0.40	1.23	4.51	1.50	1.31	1.06	3.48	0.91	0.40	0.20	0.08	0.36	0.82	1.78	2.66	3.33	3.78	5.67
1995	1.89	0.43	0.24	0.27	0.36	1.10	4.03	1.34	1.15	0.92	3.00	0.77	0.34	0.17	0.07	0.31	0.70	1.51	2.25	2.81	8.00
1996	0.81	1.69	0.38	0.22	0.24	0.32	0.98	3.59	1.18	1.01	0.80	2.59	0.67	0.29	0.14	0.06	0.26	0.60	1.29	1.93	9.27
1997	0.82	0.72	1.51	0.34	0.19	0.21	0.29	0.88	3.19	1.05	0.89	0.70	2.27	0.58	0.26	0.13	0.05	0.23	0.52	1.12	9.74
1998	1.07	0.73	0.64	1.35	0.30	0.17	0.19	0.26	0.78	2.82	0.92	0.78	0.61	1.98	0.51	0.22	0.11	0.04	0.20	0.45	9.43
1999	4.17	0.96	0.66	0.58	1.20	0.27	0.15	0.17	0.23	0.69	2.47	0.80	0.67	0.53	1.71	0.44	0.19	0.09	0.04	0.17	8.48
2000	4.82	3.72	0.86	0.59	0.51	1.08	0.24	0.14	0.15	0.20	0.60	2.15	0.70	0.58	0.46	1.48	0.38	0.17	0.08	0.03	7.46
2001	5.68	4.31	3.33	0.77	0.52	0.46	0.96	0.22	0.12	0.13	0.17	0.52	1.85	0.60	0.50	0.39	1.26	0.32	0.14	0.07	6.40
2002	0.84	5.08	3.86	2.98	0.68	0.47	0.41	0.86	0.19	0.11	0.11	0.15	0.45	1.58	0.51	0.43	0.34	1.08	0.27	0.12	5.52
2003	0.31	0.75	4.54	3.45	2.66	0.61	0.42	0.37	0.76	0.17	0.09	0.10	0.13	0.39	1.38	0.44	0.37	0.29	0.93	0.24	4.88
2004	0.27	0.27	0.67	4.06	3.08	2.38	0.55	0.37	0.33	0.67	0.15	0.08	0.09	0.11	0.34	1.19	0.38	0.32	0.25	0.81	4.44
2005	0.40	0.24	0.25	0.60	3.63	2.75	2.13	0.49	0.33	0.29	0.59	0.13	0.07	0.08	0.10	0.29	1.04	0.34	0.28	0.22	4.58
2006	3.65	0.36	0.22	0.22	0.54	3.24	2.46	1.90	0.43	0.29	0.25	0.52	0.11	0.06	0.07	0.09	0.25	0.90	0.29	0.24	4.16
2007	11.07	3.26	0.32	0.20	0.20	0.48	2.90	2.19	1.68	0.38	0.26	0.22	0.45	0.10	0.05	0.06	0.08	0.22	0.79	0.25	3.84
2008	24.06	9.90	2.91	0.29	0.17	0.18	0.43	2.58	1.95	1.49	0.34	0.23	0.19	0.40	0.09	0.05	0.05	0.07	0.19	0.69	3.57
2009	16.53	21.51	8.85	2.61	0.26	0.16	0.16	0.38	2.25	1.68	1.27	0.29	0.19	0.16	0.33	0.07	0.04	0.04	0.06	0.16	3.57
2010	3.05	14.78	19.23	7.91	2.33	0.23	0.14	0.14	0.32	1.89	1.39	1.04	0.23	0.16	0.13	0.27	0.06	0.03	0.03	0.04	3.01
2011	2.00	2.73	13.21	17.19	7.07	2.08	0.20	0.12	0.12	0.28	1.59	1.16	0.86	0.19	0.13	0.11	0.22	0.05	0.03	0.03	2.50

Table 5.20 Continued. Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex for Model 16.1b

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+

2012	0.95	1.79	2.44	11.81	15.36	6.31	1.85	0.18	0.11	0.10	0.23	1.33	0.96	0.71	0.16	0.10	0.09	0.18	0.04	0.02	2.07
2013	1.21	0.85	1.60	2.18	10.55	13.70	5.59	1.61	0.15	0.09	0.08	0.19	1.06	0.76	0.56	0.13	0.08	0.07	0.14	0.03	1.65
2014	1.03	1.09	0.76	1.43	1.95	9.43	12.21	4.95	1.42	0.13	0.08	0.07	0.16	0.91	0.65	0.48	0.11	0.07	0.06	0.12	1.44
2015	1.23	0.92	0.97	0.68	1.28	1.74	8.41	10.84	4.37	1.24	0.12	0.07	0.06	0.14	0.79	0.56	0.42	0.09	0.06	0.05	1.35
2016	1.08	1.10	0.82	0.87	0.61	1.14	1.55	7.47	9.57	3.83	1.08	0.10	0.06	0.05	0.12	0.68	0.49	0.36	0.08	0.05	1.21
2017	1.59	0.97	0.98	0.74	0.78	0.54	1.02	1.38	6.61	8.43	3.36	0.95	0.09	0.05	0.05	0.10	0.59	0.42	0.31	0.07	1.09
2018	3.02	1.42	0.87	0.88	0.66	0.69	0.48	0.91	1.22	5.81	7.38	2.93	0.82	0.08	0.04	0.04	0.09	0.51	0.37	0.27	1.01

Table 5.20. Estimated beginning of year numbers (1×10^7) of female Greenland turbot by age for Model 16.1c.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	11.0	17.9	138.2	5.2	18.1	10.4	7.0	5.1	0.7	0.6	4.8	7.1	12.4	19.4	10.5	4.1	1.8	0.1	0.1	0.1	2.0
1978	58.0	9.8	16.0	120.3	4.4	15.1	8.8	5.8	4.2	0.5	0.5	4.0	5.9	10.4	16.3	8.8	3.5	1.5	0.1	0.1	1.7
1979	5.1	51.8	8.8	13.8	100.1	3.6	12.4	7.2	4.8	3.5	0.4	0.4	3.3	4.8	8.5	13.2	7.2	2.8	1.2	0.1	1.5
1980	1.7	4.5	46.1	7.6	11.5	82.6	3.0	10.2	5.9	3.9	2.9	0.4	0.4	2.7	3.9	6.9	10.8	5.8	2.3	1.0	1.3
1981	0.3	1.5	4.0	39.5	6.2	9.3	66.4	2.4	8.2	4.7	3.1	2.3	0.3	0.3	2.1	3.1	5.5	8.5	4.6	1.8	1.8
1982	0.8	0.2	1.4	3.4	31.9	4.9	7.3	52.6	1.9	6.5	3.7	2.5	1.8	0.2	0.2	1.7	2.4	4.2	6.6	3.6	2.8
1983	1.3	0.7	0.2	1.2	2.8	25.3	3.9	5.8	41.5	1.5	5.1	3.0	2.0	1.4	0.2	0.2	1.3	1.9	3.4	5.2	5.1
1984	2.5	1.2	0.6	0.2	0.9	2.2	20.0	3.1	4.6	32.9	1.2	4.1	2.3	1.6	1.1	0.1	0.1	1.0	1.5	2.7	8.2
1985	10.5	2.3	1.1	0.5	0.1	0.8	1.8	16.8	2.6	3.9	27.6	1.0	3.4	2.0	1.3	0.9	0.1	0.1	0.9	1.3	9.1
1986	2.1	9.3	2.0	0.9	0.5	0.1	0.7	1.6	14.4	2.2	3.3	23.7	0.9	2.9	1.7	1.1	0.8	0.1	0.1	0.8	8.9
1987	2.7	1.9	8.3	1.8	0.8	0.4	0.1	0.6	1.4	12.5	1.9	2.9	20.6	0.7	2.6	1.5	1.0	0.7	0.1	0.1	8.4
1988	2.5	2.4	1.7	7.4	1.6	0.7	0.3	0.1	0.5	1.2	10.9	1.7	2.5	17.9	0.6	2.2	1.3	0.8	0.6	0.1	7.4
1989	7.8	2.3	2.1	1.5	6.5	1.4	0.6	0.3	0.1	0.4	1.0	9.5	1.5	2.2	15.7	0.6	1.9	1.1	0.7	0.5	6.5
1990	1.8	7.0	2.0	1.9	1.3	5.8	1.2	0.6	0.3	0.1	0.4	0.9	8.2	1.3	1.9	13.5	0.5	1.7	1.0	0.6	6.2
1991	0.5	1.6	6.2	1.8	1.7	1.2	5.2	1.1	0.5	0.2	0.1	0.3	0.8	6.8	1.1	1.6	11.4	0.4	1.4	0.8	6.0
1992	0.3	0.4	1.4	5.6	1.6	1.5	1.1	4.6	1.0	0.4	0.2	0.1	0.3	0.6	5.8	0.9	1.4	9.8	0.4	1.2	6.0
1993	0.2	0.3	0.4	1.3	5.0	1.5	1.4	1.0	4.1	0.8	0.4	0.2	0.0	0.2	0.6	5.1	0.8	1.2	8.6	0.3	6.3
1994	0.8	0.2	0.3	0.4	1.1	4.5	1.3	1.2	0.9	3.6	0.7	0.3	0.1	0.0	0.2	0.5	4.3	0.7	1.0	7.2	5.7
1995	1.7	0.7	0.2	0.2	0.3	1.0	4.0	1.2	1.1	0.7	3.1	0.6	0.3	0.1	0.0	0.2	0.4	3.6	0.6	0.8	10.9
1996	0.7	1.6	0.6	0.2	0.2	0.3	0.9	3.5	1.0	0.9	0.6	2.6	0.5	0.2	0.1	0.0	0.1	0.3	3.0	0.5	10.0
1997	0.8	0.7	1.4	0.6	0.1	0.2	0.3	0.8	3.1	0.9	0.8	0.5	2.2	0.4	0.2	0.1	0.0	0.1	0.3	2.6	8.9
1998	0.7	0.7	0.6	1.2	0.5	0.1	0.2	0.2	0.7	2.8	0.8	0.7	0.5	1.9	0.4	0.2	0.1	0.0	0.1	0.2	9.7
1999	5.2	0.7	0.6	0.5	1.1	0.5	0.1	0.2	0.2	0.6	2.4	0.7	0.6	0.4	1.6	0.3	0.1	0.1	0.0	0.1	8.1
2000	3.8	4.7	0.6	0.6	0.5	1.0	0.4	0.1	0.1	0.2	0.5	2.0	0.6	0.5	0.3	1.3	0.3	0.1	0.0	0.0	7.0
2001	5.9	3.4	4.2	0.5	0.5	0.4	0.9	0.4	0.1	0.1	0.2	0.5	1.7	0.5	0.4	0.3	1.1	0.2	0.1	0.0	5.8
2002	0.7	5.2	3.0	3.7	0.5	0.5	0.4	0.8	0.3	0.1	0.1	0.1	0.4	1.4	0.4	0.3	0.2	0.9	0.2	0.1	4.9
2003	0.3	0.7	4.7	2.7	3.3	0.4	0.4	0.3	0.7	0.3	0.1	0.1	0.1	0.3	1.2	0.3	0.3	0.2	0.7	0.1	4.3
2004	0.3	0.2	0.6	4.2	2.4	3.0	0.4	0.4	0.3	0.6	0.2	0.1	0.1	0.1	0.3	1.0	0.3	0.2	0.2	0.6	3.8
2005	0.3	0.2	0.2	0.5	3.7	2.2	2.7	0.3	0.3	0.3	0.5	0.2	0.0	0.1	0.1	0.2	0.9	0.2	0.2	0.1	3.8
2006	3.5	0.3	0.2	0.2	0.5	3.3	1.9	2.4	0.3	0.3	0.2	0.5	0.2	0.0	0.1	0.1	0.2	0.7	0.2	0.2	3.3
2007	10.2	3.2	0.3	0.2	0.2	0.4	3.0	1.7	2.1	0.3	0.3	0.2	0.4	0.2	0.0	0.0	0.1	0.2	0.6	0.2	3.0
2008	24.1	9.1	2.8	0.2	0.2	0.2	0.4	2.7	1.5	1.9	0.2	0.2	0.2	0.3	0.1	0.0	0.0	0.0	0.1	0.5	2.7
2009	16.0	21.5	8.1	2.5	0.2	0.1	0.1	0.3	2.3	1.3	1.6	0.2	0.2	0.1	0.3	0.1	0.0	0.0	0.0	0.1	2.8
2010	3.1	14.3	19.3	7.3	2.3	0.2	0.1	0.1	0.3	1.9	1.1	1.3	0.2	0.1	0.1	0.2	0.1	0.0	0.0	0.0	2.5
2011	1.4	2.7	12.8	17.2	6.5	2.0	0.2	0.1	0.1	0.2	1.6	0.9	1.0	0.1	0.1	0.1	0.2	0.1	0.0	0.0	2.1
2012	1.3	1.2	2.4	11.5	15.4	5.8	1.8	0.2	0.1	0.1	0.2	1.3	0.7	0.8	0.1	0.1	0.1	0.1	0.1	0.0	1.8
2013	0.9	1.2	1.1	2.2	10.2	13.7	5.2	1.6	0.1	0.1	0.1	0.2	1.0	0.5	0.6	0.1	0.1	0.1	0.1	0.0	1.6
2014	0.8	0.8	1.1	1.0	2.0	9.2	12.3	4.6	1.4	0.1	0.1	0.1	0.1	0.8	0.4	0.5	0.1	0.1	0.0	0.1	1.4

Table 5.21. Continued. Estimated beginning of year numbers (1×10^7) of female Greenland turbot by age for Model 16.1c.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
2015	1.0	0.7	0.7	0.9	0.9	1.7	8.2	10.9	4.0	1.2	0.1	0.1	0.1	0.1	0.7	0.4	0.4	0.1	0.1	0.0	1.3
2016	0.8	0.9	0.6	0.7	0.8	0.8	1.6	7.3	9.6	3.5	1.0	0.1	0.1	0.0	0.1	0.6	0.3	0.4	0.0	0.0	1.2
2017	1.1	0.7	0.8	0.6	0.6	0.8	0.7	1.4	6.4	8.5	3.1	0.9	0.1	0.0	0.0	0.1	0.5	0.3	0.3	0.0	1.1
2018	2.0	1.0	0.7	0.7	0.5	0.5	0.7	0.6	1.2	5.7	7.4	2.7	0.8	0.1	0.0	0.0	0.1	0.5	0.2	0.3	1.0

Table 5.21. Continued. Estimated beginning of year numbers (1×10^7) of male Greenland turbot by age for Model 16.1c.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	11.00	17.91	138.04	5.17	17.81	10.30	6.87	5.01	0.65	0.64	4.79	7.06	12.44	19.54	10.60	4.14	1.83	0.14	0.09	0.06	2.05
1978	57.95	9.84	15.95	119.65	4.37	14.94	8.63	5.76	4.20	0.55	0.54	4.02	5.92	10.44	16.40	8.90	3.48	1.53	0.12	0.07	1.77
1979	5.08	51.81	8.75	13.70	99.33	3.59	12.26	7.08	4.73	3.45	0.45	0.44	3.30	4.87	8.57	13.47	7.31	2.86	1.26	0.10	1.52
1980	1.72	4.54	46.10	7.52	11.40	81.89	2.95	10.09	5.83	3.89	2.84	0.37	0.36	2.72	4.01	7.06	11.10	6.02	2.35	1.04	1.33
1981	0.25	1.54	4.04	39.19	6.14	9.18	65.85	2.37	8.11	4.69	3.13	2.28	0.30	0.29	2.19	3.22	5.68	8.93	4.85	1.89	1.91
1982	0.75	0.22	1.37	3.41	31.58	4.88	7.28	52.21	1.88	6.43	3.71	2.48	1.81	0.23	0.23	1.73	2.56	4.51	7.09	3.85	3.02
1983	1.35	0.67	0.20	1.15	2.74	25.01	3.85	5.76	41.28	1.49	5.09	2.94	1.96	1.43	0.19	0.18	1.38	2.03	3.58	5.63	5.45
1984	2.52	1.21	0.60	0.17	0.93	2.17	19.82	3.05	4.56	32.75	1.18	4.04	2.34	1.56	1.14	0.15	0.15	1.09	1.62	2.85	8.83
1985	10.45	2.25	1.07	0.52	0.14	0.78	1.83	16.65	2.57	3.84	27.53	0.99	3.40	1.97	1.31	0.96	0.12	0.12	0.92	1.36	9.83
1986	2.12	9.35	2.01	0.94	0.45	0.12	0.67	1.57	14.29	2.20	3.29	23.64	0.85	2.92	1.69	1.13	0.82	0.11	0.11	0.79	9.62
1987	2.66	1.89	8.34	1.77	0.82	0.39	0.11	0.58	1.36	12.42	1.91	2.86	20.55	0.74	2.54	1.47	0.98	0.72	0.09	0.09	9.06
1988	2.54	2.38	1.69	7.36	1.55	0.71	0.34	0.09	0.51	1.18	10.79	1.66	2.49	17.87	0.65	2.21	1.28	0.85	0.62	0.08	7.96
1989	7.79	2.27	2.12	1.50	6.46	1.35	0.62	0.30	0.08	0.44	1.04	9.44	1.46	2.18	15.64	0.57	1.93	1.12	0.75	0.55	7.04
1990	1.75	6.97	2.03	1.90	1.34	5.77	1.21	0.56	0.26	0.07	0.39	0.90	8.18	1.26	1.88	13.53	0.49	1.67	0.97	0.65	6.58
1991	0.50	1.57	6.23	1.82	1.70	1.19	5.15	1.07	0.49	0.23	0.06	0.33	0.76	6.92	1.07	1.59	11.44	0.41	1.42	0.82	6.13
1992	0.34	0.45	1.40	5.57	1.62	1.52	1.07	4.59	0.95	0.43	0.20	0.05	0.28	0.66	5.98	0.92	1.37	9.88	0.36	1.22	6.02
1993	0.21	0.31	0.40	1.25	4.98	1.45	1.36	0.95	4.09	0.85	0.38	0.18	0.05	0.25	0.58	5.30	0.81	1.22	8.75	0.32	6.41
1994	0.79	0.19	0.27	0.36	1.12	4.45	1.30	1.21	0.85	3.63	0.75	0.34	0.15	0.04	0.22	0.51	4.64	0.71	1.07	7.67	5.89
1995	1.75	0.71	0.17	0.25	0.32	1.00	3.97	1.15	1.06	0.74	3.12	0.64	0.29	0.13	0.03	0.19	0.43	3.93	0.61	0.90	11.51
1996	0.73	1.56	0.63	0.15	0.22	0.29	0.89	3.54	1.02	0.93	0.64	2.70	0.55	0.25	0.11	0.03	0.16	0.37	3.38	0.52	10.66
1997	0.81	0.65	1.40	0.57	0.13	0.20	0.25	0.80	3.14	0.90	0.82	0.56	2.36	0.48	0.21	0.10	0.03	0.14	0.32	2.94	9.73
1998	0.75	0.72	0.58	1.25	0.51	0.12	0.18	0.23	0.71	2.78	0.79	0.72	0.49	2.06	0.42	0.19	0.09	0.02	0.12	0.28	11.01
1999	5.20	0.67	0.65	0.52	1.12	0.45	0.11	0.16	0.20	0.62	2.43	0.69	0.62	0.42	1.78	0.36	0.16	0.07	0.02	0.10	9.71
2000	3.78	4.65	0.60	0.58	0.47	1.00	0.40	0.10	0.14	0.18	0.55	2.11	0.60	0.54	0.37	1.54	0.31	0.14	0.06	0.02	8.47
2001	5.85	3.38	4.16	0.53	0.52	0.42	0.89	0.36	0.08	0.12	0.15	0.47	1.82	0.51	0.46	0.31	1.31	0.27	0.12	0.05	7.25
2002	0.74	5.23	3.02	3.72	0.48	0.46	0.37	0.79	0.32	0.07	0.11	0.13	0.40	1.55	0.44	0.39	0.27	1.12	0.23	0.10	6.24
2003	0.27	0.66	4.68	2.70	3.32	0.43	0.41	0.33	0.70	0.28	0.06	0.09	0.12	0.35	1.35	0.38	0.34	0.23	0.97	0.20	5.49
2004	0.25	0.24	0.59	4.18	2.42	2.97	0.38	0.37	0.29	0.62	0.25	0.06	0.08	0.10	0.30	1.17	0.33	0.30	0.20	0.84	4.93
2005	0.33	0.23	0.21	0.53	3.74	2.16	2.65	0.34	0.33	0.26	0.55	0.22	0.05	0.07	0.09	0.27	1.02	0.29	0.26	0.18	5.04
2006	3.52	0.30	0.20	0.19	0.47	3.34	1.93	2.37	0.30	0.29	0.23	0.48	0.19	0.04	0.06	0.08	0.23	0.88	0.25	0.22	4.52
2007	10.16	3.15	0.27	0.18	0.17	0.42	2.98	1.72	2.10	0.27	0.25	0.20	0.42	0.16	0.04	0.05	0.07	0.20	0.77	0.22	4.14
2008	24.10	9.08	2.82	0.24	0.16	0.15	0.37	2.66	1.53	1.86	0.23	0.22	0.18	0.37	0.14	0.03	0.05	0.06	0.18	0.67	3.80
2009	16.04	21.55	8.12	2.52	0.21	0.14	0.14	0.33	2.31	1.31	1.58	0.20	0.19	0.15	0.31	0.12	0.03	0.04	0.05	0.15	3.75
2010	3.06	14.34	19.26	7.26	2.25	0.19	0.13	0.12	0.28	1.94	1.09	1.30	0.16	0.15	0.12	0.25	0.10	0.02	0.03	0.04	3.14
2011	1.39	2.74	12.82	17.22	6.48	2.01	0.17	0.11	0.10	0.24	1.63	0.90	1.07	0.13	0.13	0.10	0.20	0.08	0.02	0.03	2.60
2012	1.32	1.24	2.45	11.46	15.39	5.79	1.78	0.15	0.10	0.09	0.20	1.36	0.75	0.88	0.11	0.10	0.08	0.17	0.07	0.01	2.16
2013	0.92	1.18	1.11	2.19	10.24	13.71	5.11	1.55	0.13	0.08	0.07	0.16	1.09	0.59	0.70	0.09	0.08	0.06	0.13	0.05	1.71
2014	0.81	0.82	1.05	0.99	1.96	9.14	12.20	4.52	1.36	0.11	0.07	0.06	0.14	0.93	0.51	0.60	0.07	0.07	0.05	0.11	1.50

Table 5.21. Continued. Estimated beginning of year numbers (1×10[7]) of male Greenland turbot by age for Model 16.1c.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
2015	1.02	0.72	0.74	0.94	0.88	1.75	8.15	10.83	3.99	1.19	0.10	0.06	0.05	0.12	0.80	0.44	0.51	0.06	0.06	0.05	1.39
2016	0.83	0.91	0.64	0.66	0.84	0.79	1.56	7.23	9.55	3.49	1.04	0.08	0.05	0.05	0.10	0.69	0.38	0.44	0.05	0.05	1.24
2017	1.13	0.74	0.82	0.58	0.59	0.75	0.71	1.38	6.40	8.40	3.06	0.91	0.07	0.05	0.04	0.09	0.60	0.33	0.38	0.05	1.12
2018	1.96	1.01	0.67	0.73	0.52	0.53	0.67	0.63	1.22	5.62	7.35	2.67	0.79	0.06	0.04	0.03	0.08	0.52	0.28	0.33	1.01

Table 5.21. Spawning and total biomass compared with the 2016 assessment and fishing mortality, exploitation rate, and 1-SPR from the current assessment for BSAI Greenland turbot, 1977-2020. The 2019 and 2020 biomass estimates are from the Model 16.1b projections.

	SSB (t)		Total biomass (age1+)				
Year	2016	Current	2016	Current	Apical F	Exploitation rate	1-SPR
1977	293,646	305274	526,159	548,852	0.09	0.05	0.61
1978	287,129	299082	524,819	546,301	0.12	0.08	0.73
1979	272,096	283743	519,434	539,868	0.12	0.08	0.72
1980	257,733	268767	518,606	538,157	0.16	0.10	0.80
1981	242,717	253156	504,094	522,807	0.18	0.11	0.83
1982	230,738	240818	477,165	495,039	0.16	0.11	0.83
1983	225,115	235087	445,485	462,520	0.16	0.10	0.83
1984	219,982	229943	408,702	424,885	0.09	0.05	0.62
1985	221,225	231106	389,377	404,683	0.06	0.04	0.49
1986	222,298	231958	373,056	387,423	0.04	0.03	0.38
1987	221,419	230712	357,813	371,177	0.04	0.03	0.40
1988	216,656	225476	340,305	352,624	0.04	0.02	0.33
1989	209,645	217913	323,640	334,902	0.06	0.03	0.31
1990	197,612	205200	303,638	313,813	0.11	0.04	0.45
1991	181,529	188389	278,867	287,964	0.07	0.03	0.35
1992	168,559	174737	260,042	268,139	0.03	0.01	0.18
1993	158,519	164111	246,344	253,572	0.08	0.03	0.35
1994	144,745	149741	227,834	234,223	0.12	0.04	0.49
1995	131,131	135437	206,921	212,424	0.11	0.04	0.44
1996	119,497	123184	188,566	193,287	0.09	0.03	0.38
1997	109,373	112523	172,359	176,407	0.10	0.04	0.42
1998	98,977	101654	155,960	159,417	0.14	0.05	0.50
1999	87,579	89840	138,581	141,516	0.11	0.04	0.44
2000	78,823	80737	124,808	127,299	0.14	0.05	0.51
2001	69,273	70885	110,722	112,819	0.13	0.05	0.49
2002	61,473	62832	99,510	101,258	0.10	0.04	0.41
2003	55,153	56300	91,593	93,004	0.09	0.03	0.40
2004	49,641	50604	85,627	86,688	0.08	0.03	0.35
2005	45,284	46087	81,533	82,241	0.10	0.03	0.41
2006	41,338	41981	77,519	77,875	0.07	0.03	0.34
2007	38,798	39276	74,334	74,360	0.08	0.03	0.36
2008	37,185	37470	71,293	70,995	0.12	0.04	0.47
2009	36,061	36147	68,243	67,514	0.18	0.07	0.61
2010	34,053	33936	66,197	64,684	0.18	0.06	0.60
2011	31,641	31325	68,773	65,839	0.18	0.06	0.59
2012	29,295	28784	75,911	70,832	0.24	0.07	0.69
2013	27,115	26342	84,526	76,786	0.09	0.02	0.39

Table 5.22. Continued. Spawning and total biomass compared with the 2016 assessment and fishing mortality, exploitation rate, and 1-SPR from the current assessment for BSAI Greenland turbot, 1977-2020. The 2019 and 2020 biomass estimates are from the Model 16.1b projections.

	SSB (t)		Total biomass (age1+)				
Year	2016	Current	2016	Current	Apical F	Exploitation	1-SPR
2014	28,710	27404	96,830	86,267	0.07	0.02	0.34
2015	33,665	31312	108,399	95,068	0.08	0.02	0.36
2016	41,405	37430	117,671	101,777	0.06	0.02	0.30
2017	50,461	44447	121,804	106,426	0.06	0.03	0.29
2018	55,347	50465	121,325	108,433	0.07	0.03	0.33
2019	-	54,244	-	105,937	-	-	-
2020	-	52,743	-	98,923	-	-	-

Table 5.22. Spawning biomass from Model 16.1b with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2018 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. The 2019 and 2020 values are from the projection model.

Year	SSB	LCI	UCI
1977	305,274	203,682	903,611
1978	299,082	205,461	885,283
1979	283,743	197,704	839,879
1980	268,767	189,877	795,550
1981	253,156	181,298	749,342
1982	240,818	175,595	712,821
1983	235,087	175,810	695,858
1984	229,943	176,038	680,631
1985	231,106	182,052	684,074
1986	231,958	187,407	686,596
1987	230,712	190,303	682,908
1988	225,476	188,790	667,409
1989	217,913	184,593	645,022
1990	205,200	175,326	607,392
1991	188,389	161,726	557,631
1992	174,737	150,821	517,222
1993	164,111	142,559	485,769
1994	149,741	130,458	443,233
1995	135,437	118,304	400,894
1996	123,184	107,894	364,625
1997	112,523	98,812	333,068
1998	101,654	89,331	300,896
1999	89,840	78,751	265,927
2000	80,737	70,713	238,980
2001	70,885	61,811	209,820
2002	62,832	54,592	185,981
2003	56,300	48,791	166,647
2004	50,604	43,749	149,787
2005	46,087	39,808	136,418
2006	41,981	36,204	124,263
2007	39,276	33,906	116,255
2008	37,470	32,424	110,910
2009	36,147	31,365	106,995
2010	33,936	29,366	100,449
2011	31,325	26,956	92,721
2012	28,784	24,590	85,200
2013	26,342	22,229	77,973
2014	27,404	23,197	81,114
2015	31,312	26,670	92,684
2016	37,430	31,995	110,792
2017	44,447	38,045	131,564
2018	50,465	43,138	149,377
2019	54,244	54,244	54,244
2020	52,743	52,743	52,743

Table 5.23. Age-0 recruits based on Model 16.1b with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2018 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error.

Year	Age-0 Recruits	LCI	UCI
1977	93480	23,984	162,976
1978	49205.1	5,714	92,696
1979	17636.8	3,166	32,108
1980	6021.97	1,090	10,954
1981	1025.19	110	1,940
1982	1998.66	233	3,764
1983	3289.47	758	5,821
1984	6185.44	2,286	10,085
1985	20233	13,792	26,674
1986	5316.69	2,733	7,900
1987	5755.5	3,286	8,225
1988	5897.15	3,349	8,445
1989	15803.2	11,529	20,077
1990	3848.45	1,912	5,785
1991	1131.08	461	1,801
1992	742.849	290	1,196
1993	605.528	227	984
1994	953.755	400	1,507
1995	3771.3	2,417	5,125
1996	1611.84	775	2,448
1997	1640.55	808	2,473
1998	2144.78	1,058	3,232
1999	8332.04	5,567	11,097
2000	9648.47	6,346	12,951
2001	11358.2	8,153	14,564
2002	1676.52	819	2,535
2003	613.542	245	982
2004	547.067	190	904
2005	800.976	349	1,253
2006	7292.49	4,888	9,697
2007	22136.7	16,425	27,848
2008	48122	37,741	58,503
2009	33060.6	24,075	42,047
2010	6103.29	3,690	8,516
2011	4002.78	2,116	5,890
2012	1903.54	833	2,974
2013	2429.65	1,247	3,612
2014	2062.79	1,000	3,126
2015	2458.29	1,178	3,738
2016	2167.8	936	3,400
2017	3182.45	1,197	5,168
2018	6040.92	1,171	10,911

Table 5.24. Model 16.1b 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 36,213 t and $B_{35\%}$ is 31,687 t.

Spawning biomass (t)							
Year	*Max ABC*	*Author's recommended F*	*Avg F*	*F75%*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2018	50465	50465	50465	50465	50465	50465	50465
2019	54244	54244	54244	54244	54244	54244	54244
2020	52743	52743	55828	56532	58035	51814	52743
2021	49561	49561	55673	57124	60286	47797	49561
2022	45543	45543	54293	56451	61261	43124	44696
2023	41344	41344	52181	54955	61274	38470	39844
2024	37481	37481	49831	53106	60722	34336	35522
2025	34395	34395	47743	51401	60074	31301	32211
2026	32478	32478	46270	50206	59707	29580	30293
2027	31638	31638	45510	49647	59791	28921	29486
2028	31542	31542	45354	49645	60309	28965	29415
2029	31885	31885	45644	50071	61190	29399	29756
2030	32450	32450	46229	50790	62343	30002	30287
2031	33086	33086	46980	51685	63679	30635	30861
Catch (t)							
Year	*Max ABC*	*Author's recommended F*	*Avg F*	*F75%*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2018	3758	3758	3758	3758	3758	3758	3758
2019	9658	9658	4017	2733	0	11362	9658
2020	8908	8908	3923	2703	0	10295	8908
2021	7890	7890	3681	2569	0	8956	9277
2022	6825	6825	3366	2379	0	7615	7880
2023	5866	5866	3044	2176	0	6446	6659
2024	5119	5119	2767	1997	0	5268	5610
2025	4388	4388	2574	1870	0	4355	4582
2026	3973	3973	2477	1805	0	3995	4153
2027	3897	3897	2466	1798	0	3996	4108
2028	4016	4016	2515	1832	0	4196	4277
2029	4220	4220	2598	1891	0	4472	4531
2030	4444	4444	2695	1960	0	4751	4793
2031	4654	4654	2790	2030	0	4998	5028

Table 5.25. Continued. Model 16.1b 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 36,213 t and $B_{35\%}$ is 31,687 t.

			Fishing mortality				
Year	*Max ABC*	*Author's recommended F*	*Avg F*	*F75%*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2018	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2019	0.18	0.18	0.07	0.05	0.00	0.21	0.18
2020	0.18	0.18	0.07	0.05	0.00	0.21	0.18
2021	0.18	0.18	0.07	0.05	0.00	0.21	0.21
2022	0.18	0.18	0.07	0.05	0.00	0.21	0.21
2023	0.18	0.18	0.07	0.05	0.00	0.21	0.21
2024	0.18	0.18	0.07	0.05	0.00	0.20	0.21
2025	0.17	0.17	0.07	0.05	0.00	0.18	0.19
2026	0.16	0.16	0.07	0.05	0.00	0.17	0.17
2027	0.15	0.15	0.07	0.05	0.00	0.16	0.17
2028	0.15	0.15	0.07	0.05	0.00	0.16	0.16
2029	0.14	0.14	0.07	0.05	0.00	0.16	0.16
2030	0.14	0.14	0.07	0.05	0.00	0.16	0.16
2031	0.15	0.15	0.07	0.05	0.00	0.16	0.16

Table 5.25. Model 16.1c 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 33,953 t and $B_{35\%}$ is 29,709 t.

			Spawning biomass (t)				
Year	*Max ABC*	*Author's recommended F*	*Avg F*	*F75%*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2018	48562	48562	48562	48562	48562	48562	48562
2019	52225	52225	52225	52225	52225	52225	52225
2020	50750	50750	53789	54454	55918	49838	50750
2021	47605	47605	53628	54999	58083	45874	47605
2022	43619	43619	52238	54278	58971	41249	42787
2023	39430	39430	50095	52717	58881	36622	37963
2024	35547	35547	47678	50770	58193	32483	33638
2025	32410	32410	45487	48934	57373	29378	30261
2026	30424	30424	43901	47600	56821	27605	28294
2027	29546	29546	43041	46913	56726	26920	27466
2028	29432	29432	42801	46800	57074	26958	27393
2029	29764	29764	43015	47122	57790	27389	27736
2030	30304	30304	43514	47729	58767	27975	28253
2031	30903	30903	44174	48506	59922	28578	28800
			Catch (t)				
Year	*Max ABC*	*Author's recommended F*	*Avg F*	*F75%*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2018	3758	3758	3758	3758	3758	3758	3758
2019	9430	9430	3875	2662	0	11103	9430
2020	8691	8691	3786	2634	0	10048	8691
2021	7681	7681	3550	2501	0	8719	9039
2022	6617	6617	3240	2311	0	7379	7642
2023	5650	5650	2918	2105	0	6199	6411
2024	4881	4881	2634	1919	0	5057	5394
2025	4160	4160	2430	1783	0	4098	4321
2026	3715	3715	2322	1710	0	3713	3867
2027	3623	3623	2301	1695	0	3702	3810
2028	3734	3734	2343	1723	0	3895	3973
2029	3929	3929	2418	1776	0	4161	4218
2030	4142	4142	2508	1841	0	4428	4469
2031	4337	4337	2595	1905	0	4658	4688

Table 5.26. Continued. Model 16.1c 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 33,953 t and $B_{35\%}$ is 29,709 t.

			Fishing mortality				
Year	*Max ABC*	*Author's recommended F*	*Avg F*	*F75%*	*F = 0*	*Fofl*	*Max ABC for 2 years and then OFL*
2018	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2019	0.18	0.18	0.07	0.05	0.00	0.21	0.18
2020	0.18	0.18	0.07	0.05	0.00	0.21	0.18
2021	0.18	0.18	0.07	0.05	0.00	0.21	0.21
2022	0.18	0.18	0.07	0.05	0.00	0.21	0.21
2023	0.18	0.18	0.07	0.05	0.00	0.21	0.21
2024	0.18	0.18	0.07	0.05	0.00	0.20	0.21
2025	0.17	0.17	0.07	0.05	0.00	0.18	0.19
2026	0.16	0.16	0.07	0.05	0.00	0.17	0.17
2027	0.15	0.15	0.07	0.05	0.00	0.16	0.17
2028	0.15	0.15	0.07	0.05	0.00	0.16	0.16
2029	0.15	0.15	0.07	0.05	0.00	0.16	0.16
2030	0.15	0.15	0.07	0.05	0.00	0.16	0.16
2031	0.15	0.15	0.07	0.05	0.00	0.16	0.16

Table 5.26. Dynamic B_0 results from model 16.1b. SSB_0 is the expected spawning biomass in the absence of fishing. Depletion is SSB/SSB_0

Year	SSB_0	SSB	Depletion
1977	819,778	305,274	0.37
1978	829,784	299,082	0.36
1979	827,514	283,743	0.34
1980	818,872	268,767	0.33
1981	810,776	253,156	0.31
1982	808,833	240,818	0.30
1983	813,884	235,087	0.29
1984	821,993	229,943	0.28
1985	827,476	231,106	0.28
1986	825,732	231,958	0.28
1987	814,507	230,712	0.28
1988	793,767	225,476	0.28
1989	764,911	217,913	0.28
1990	730,047	205,200	0.28
1991	691,534	188,389	0.27
1992	651,489	174,737	0.27
1993	611,379	164,111	0.27
1994	571,188	149,741	0.26
1995	530,940	135,437	0.26
1996	492,097	123,184	0.25
1997	455,183	112,523	0.25
1998	420,141	101,654	0.24
1999	386,840	89,840	0.23
2000	355,259	80,737	0.23
2001	325,486	70,885	0.22
2002	297,661	62,832	0.21
2003	271,856	56,300	0.21
2004	248,118	50,604	0.20
2005	226,504	46,087	0.20
2006	206,772	41,981	0.20
2007	189,232	39,276	0.21
2008	173,851	37,470	0.22
2009	160,222	36,147	0.23
2010	147,852	33,936	0.23
2011	136,408	31,325	0.23
2012	125,941	28,784	0.23
2013	117,047	26,342	0.23
2014	110,914	27,404	0.25
2015	108,584	31,312	0.29
2016	109,626	37,430	0.34
2017	112,374	44,447	0.40
2018	114,973	50,465	0.44

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

Table 5.28 (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

Table 5.28 (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

Table 5.28. Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for longline and pot vessels since 2003. Species with catch < 0.01 t have been excluded.

	Species																				
Year	Benthic urochordata	Brittle star unidentified	Corals Bryozoans Unidentified	Eelpouts	Giant Grenadier	Pacific Grenadier	Ratail Grenadier Unidentified	Gunnels	Invertebrate unidentified	Large Sculpins	Misc crabs	Misc crustaceans	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		1503.57			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		1164.08			0.13	0.01		1.48	0.40		0.04		0.23	0.01		0.01
2005			0.06	5.53	1105.29		1029.74			0.12			1.11	0.36	0.02	0.20		0.86	0.13	0.01	0.29
2006	0.01		0.07	3.95	1300.83		216.84		0.03	0.76	0.02		2.08	0.37	0.01	0.08		0.38	0.02	0.01	0.02
2007		0.01	0.01	2.27	1181.18	0.01	234.45		0.02	0.32	0.01		0.43	1.29		0.03		0.78	0.03	0.50	0.02
2008			0.00	2.85	686.76		20.90			0.36	0.03		1.74	0.37		0.04		1.42	0.02	0.01	0.01
2009		0.03	0.00	5.41	1775.30		46.88		0.01	0.15		0.01	0.39	0.74		0.06		1.16	0.02		0.52
2010	0.01		0.12	5.74	1807.84		366.98		0.00		0.19		1.40		0.01	0.12	0.03	1.12	0.03		0.33
2011		0.11	0.00	7.67	1603.34		308.23	0.03	0.26		0.15		1.10		0.01	1.31	0.08	0.80	0.03	0.02	0.07
2012		0.08	0.01	8.11	1200.31		260.63		0.06		0.06		1.41		0.01	0.53		0.92	0.03	0.02	0.09
2013		0.01		2.07	565.33		5.35		0.25		0.11		0.50			0.05		0.44	0.05		0.13
2014				2.55	315.87		166.33		0.01		0.15		0.63			0.00		0.65	0.02		0.22
2015		0.11		4.74	1067.48		21.25				0.15		0.57		0.01	0.38		0.48	0.02		0.03
2016		0.09		3.55	1232.18		0.67		0.08		0.15		0.24			0.32	0.13	1.35	0.02	0.03	0.06
2017				1.47	1169.48		48.77				0.12		0.08			0.10	0.03	1.35	0.01	0.01	0.11
2018				0.25	341.96		5.32				0.04		0.02		0.02			0.08			0.03

Table 5.29. Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for trawlers since 2003. Species with catch < 0.01 t have been excluded

	Species																							
Year	Benthic urochordata	Brittle star unidentified	Capelin	Corals Bryozoans Unidentified	Eelpouts	Giant Grenadier	Greenlings	Grenadier	Hermit crab unidentified	Invertebrate unidentified	Lanternfishes (myctophidae)	Large Sculpins	Misc crabs	Misc fish	Misc inverts (worms etc)	Other Sculpins	Pandalid shrimp	Scypho jellies	Sea anemone unidentified	Sea pens whips	Sea star	Snails	Sponge unidentified	urchins dollars cucumbers
2003		0.03			27.85			25.24	0.01				0.01	1.26	0.04	4.79	0.01		0.77	0.02	4.63	0.51		
2004			0.01		10.70			25.95		0.88		4.18		0.11				0.06			1.96	0.14		
2005					1.00		0.18	0.47				0.27		0.27		0.15					0.25			
2008					0.27	67.46						1.56		0.11		0.64								
2009					3.42	365.00		49.64				0.80		0.20		0.43	0.01		0.13		0.06	0.01	0.10	0.03
2010					0.04	58.75		5.66																
2011					0.12	0.86								0.04							0.05			
2013					0.01	0.35								0.08										
2014					1.14	0.44		0.36					0.02	0.03				0.01	0.08		0.02		0.06	
2015					0.08	6.85								0.03			0.01		0.35		0.02	0.07		
2016		2.14			0.48	83.43		4.22						0.77			0.13		8.23	0.14	1.01	0.02	0.08	
2017	0.03	0.48		0.02	7.33	450.14		0.01		0.01			0.15	1.43			0.67		20.23	0.33	4.37	0.17	1.16	0.01
2018	0.35				5.15	358.13	0.57				0.01		1.49	2.04			0.63	0.47	35.37	0.03	3.03	0.09	0.17	0.01

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.

	Species										
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
1993	29					568		4	2,074	1,164	3
1994			7		45	325			204	233	13
1995	21				81	428		8	650	402	50
1996	12				91	415			579	186	18
1997	14				43	391		22	362	206	12
1998	32				54	446		47	1,226	1,497	10
1999	28				81	428		24	1,344	28,606	5
2000	13				114	570		5	930	1,730	20
2001	1				54	301		7	537	313	21
2002	64		3		49	271		45	562	55	6
2003	53		9	136	22	121		20	25		
2004	10		18	151	19	125		77	0		
2005		12	13	22	24	160		41	3		8
2006	28		8	328	12	78		26	0		13
2007	19			2,438	6	44		24	34		48
2008	16	7		3	1	10		26	43		8
2009	85	0		0	6	47		15	24		
2010	47	8		180	10	89		37	84		1
2011				34	4	41			12		
2012	16		4	26	5	50			42		
2013				0	1	10			5		
2014	5			29	1	10			8		
2015			18	36	3	23		34	7		
2016				38	3	30		70	12		

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.

	Species										
Year	Bairdi Tanner Crab	Blue King Crab	Chinook Salmon	Golden (Brown) King Crab		Halibut	Herring	Non-Chinook Salmon	Opilio Tanner (Snow) Crab	Other King Crab	Red King Crab
1991	14,919		71			373		5	237,955	11,160	1,398
1993						0			80		
1994	1,916		58		371	927			278,055	6,029	329
1995	3,837				267	556			52,212	3,027	966
1996	1,089				6	12			5,594	250	
1997	614				9	14			6,138	451	
1998	474				10	14			2,845	125	
1999	1,048				19	27			2,051	1,198	
2000	1,055				21	25			2,677	3,327	
2001	497				11	16			7,189	471	
2002	731				1	2			2,644	211	
2003	2,884			99	8	11			1,800		
2004				66	2	3			66		
2005	88			88	2	3					
2008				132							
2009				747	6	8					
2010				86	2	3					
2011					1	1					
2013					1	1					
2014				21							
2015											
2016	1,531			464	4	1			117		

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

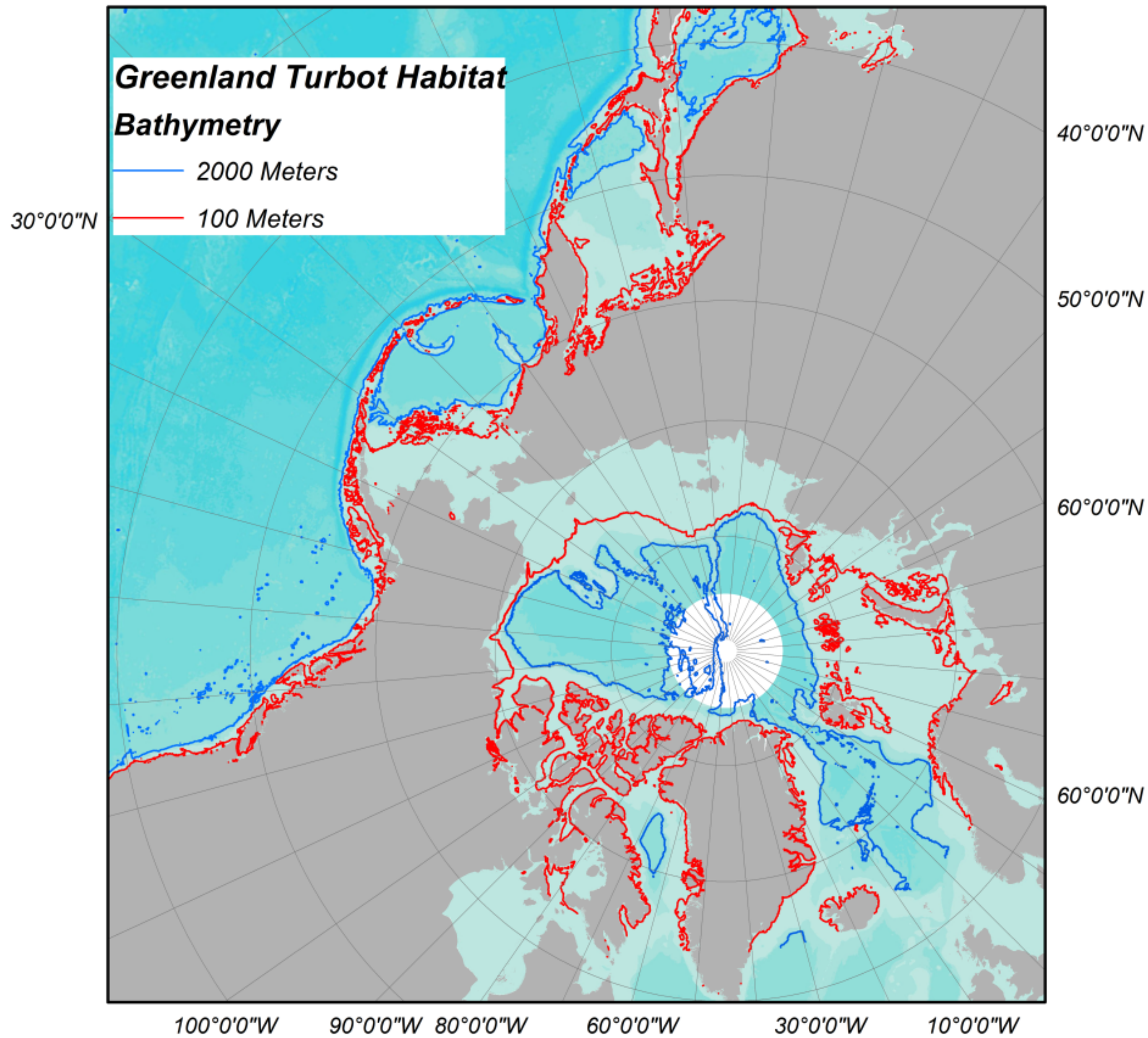
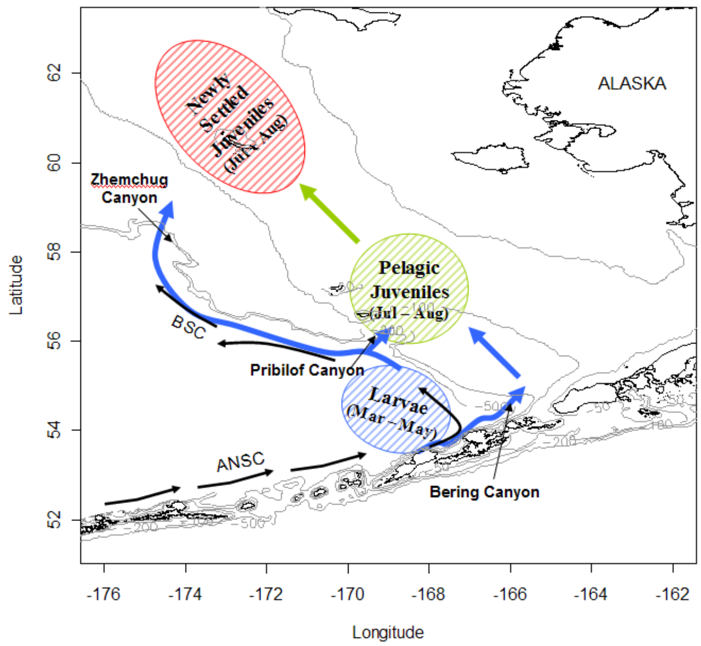
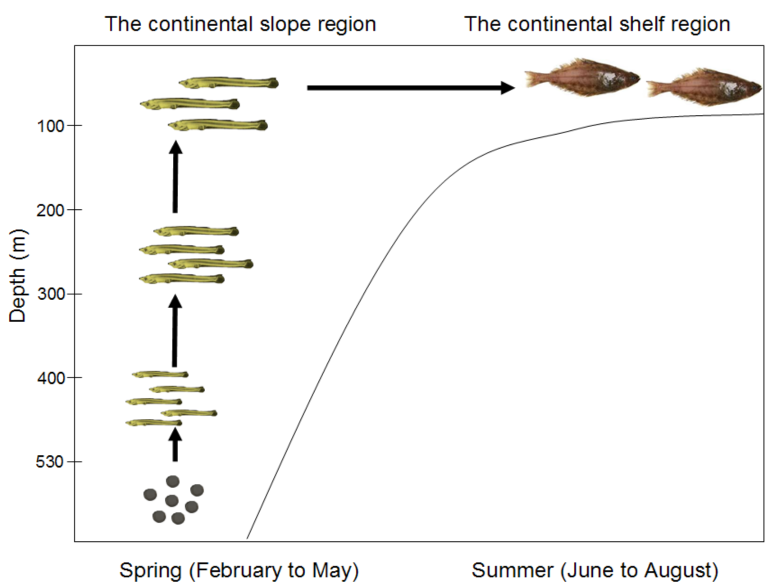


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.



(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).***

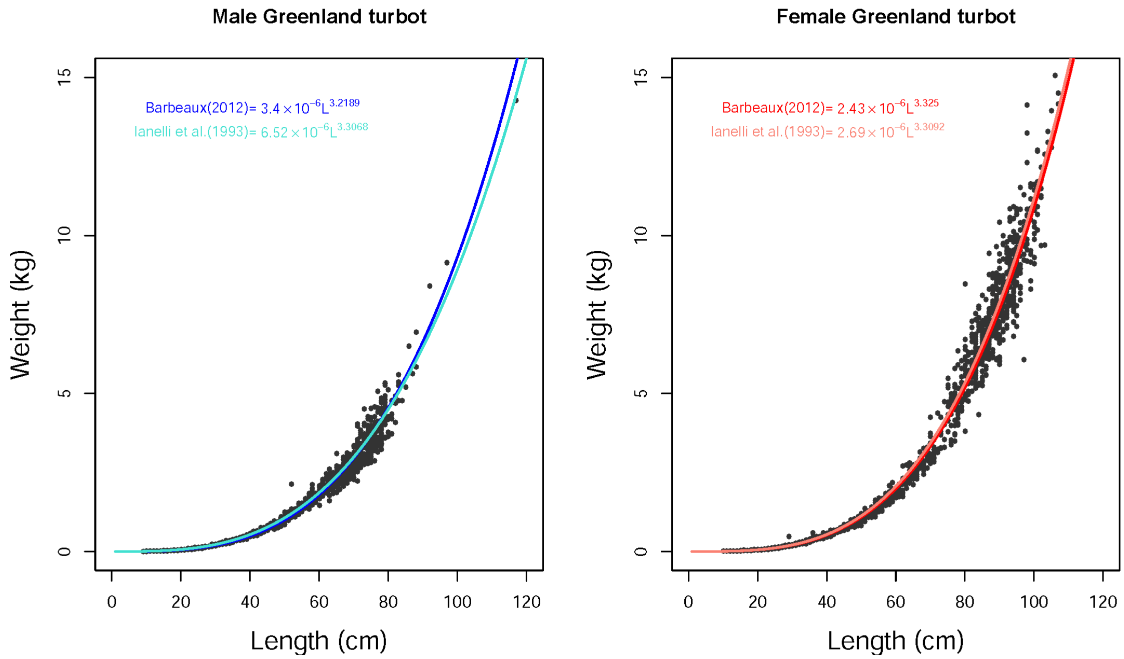


Figure 5. 3. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

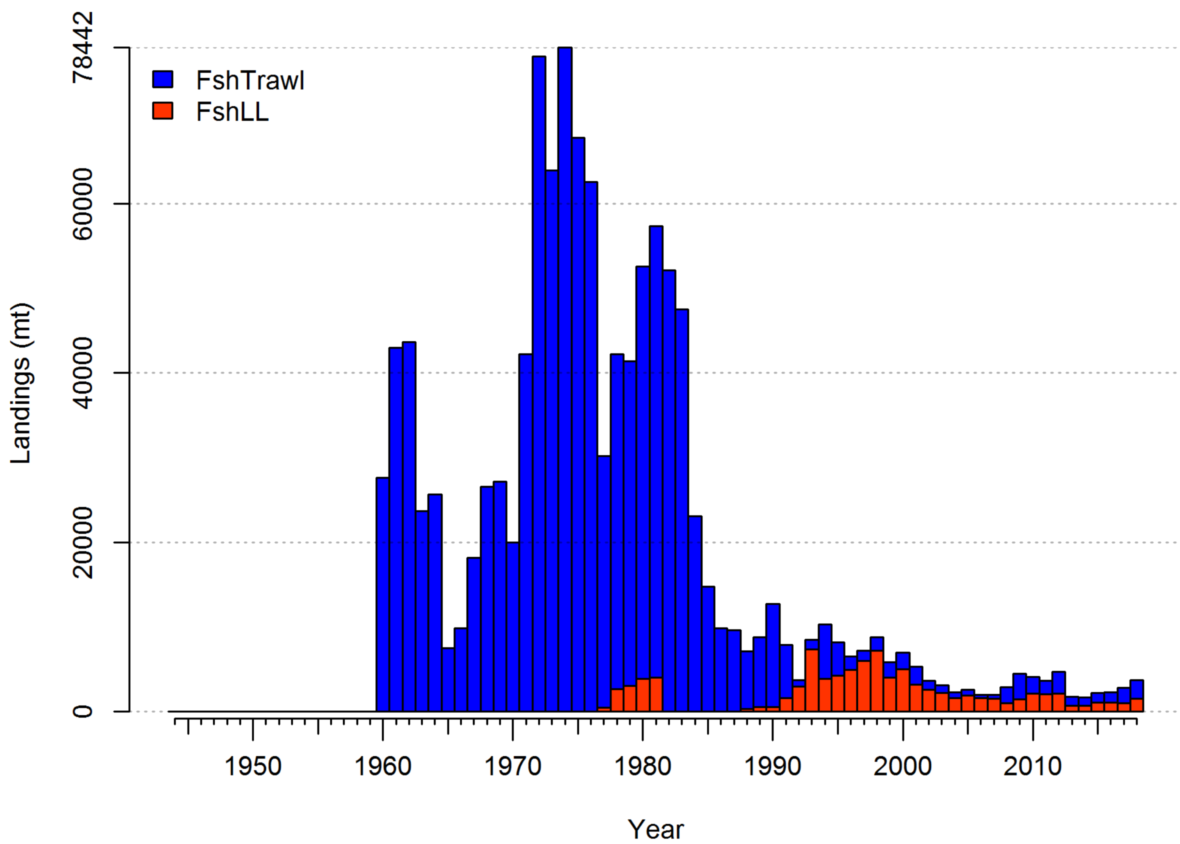


Figure 5. 4. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2018. This data includes targeted catch and bycatch.

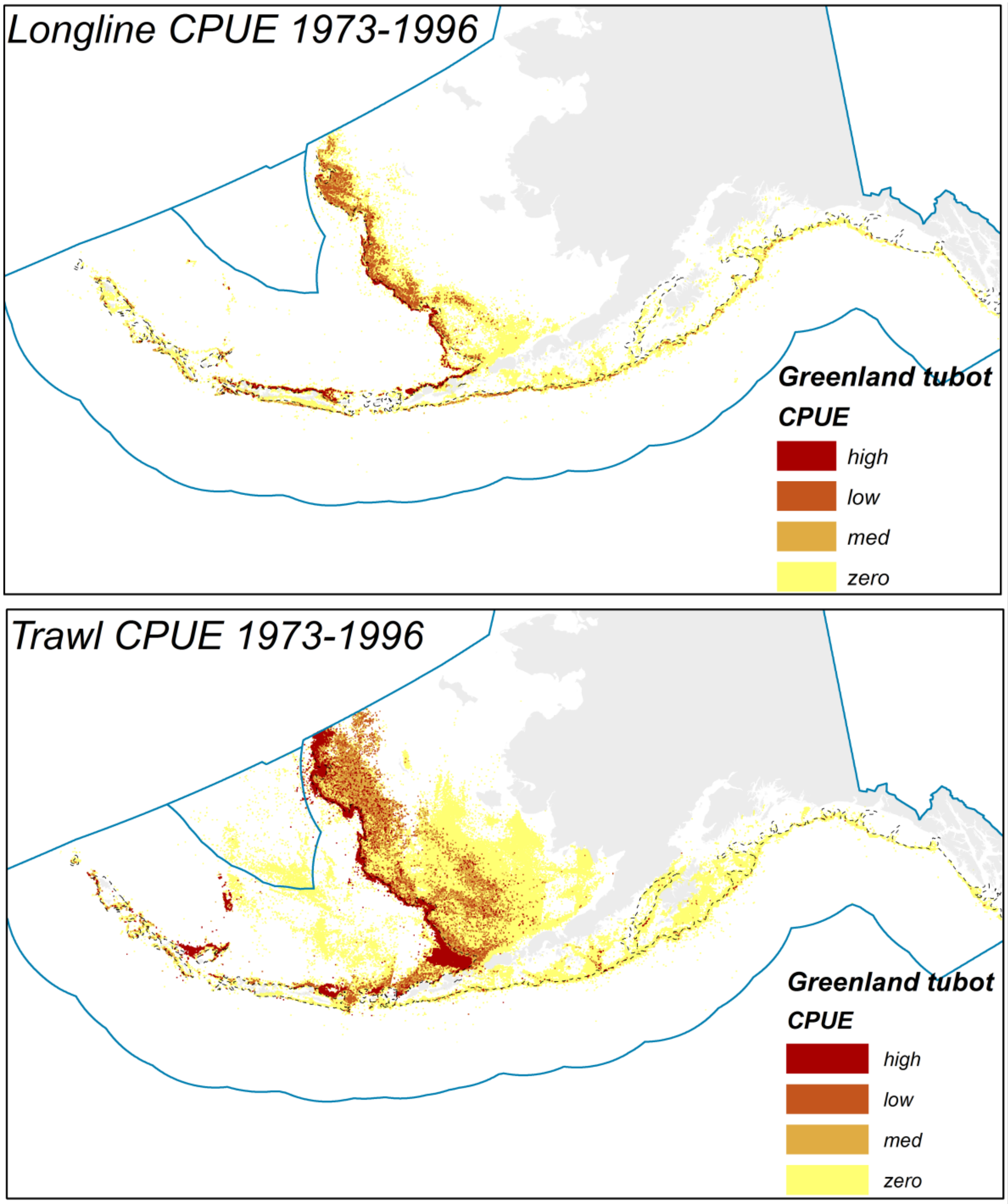


Figure 5.5. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).

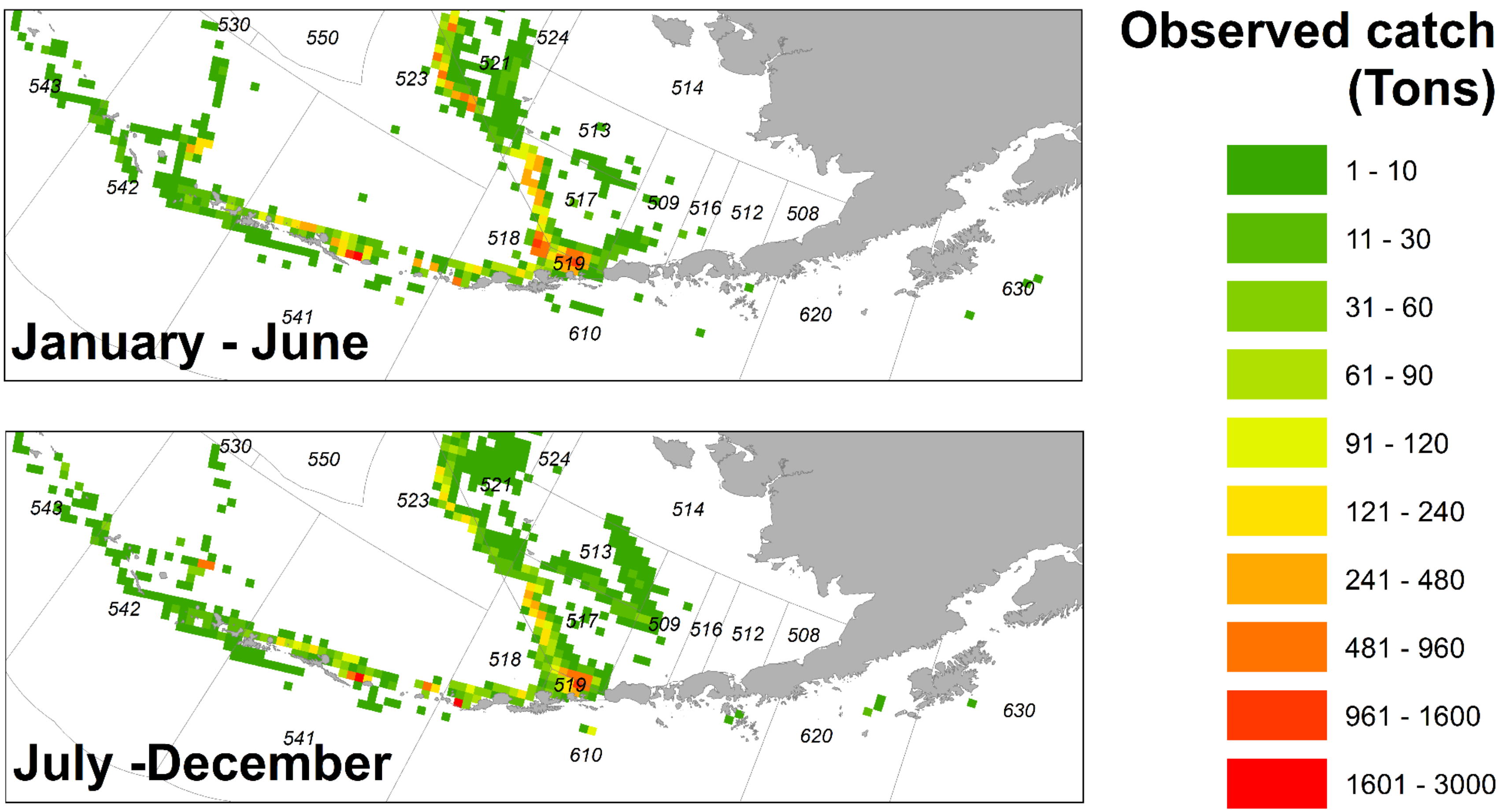


Figure 5.6 All observed catch for 2000 through 2018, data are aggregated spatially at a 400 km^2 grid.

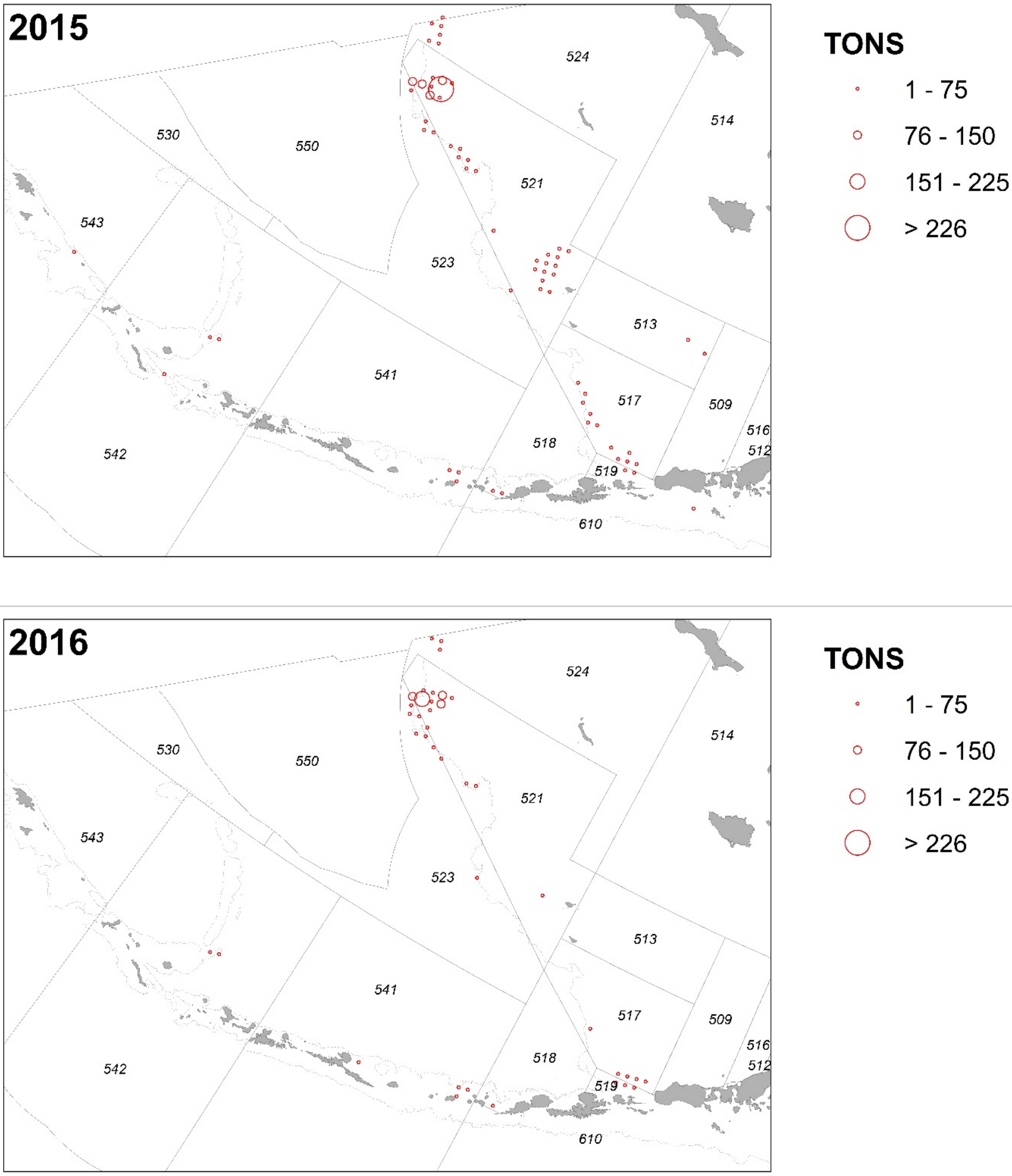


Figure 5.7. All observed Greenland turbot catch for 2015 and 2016. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

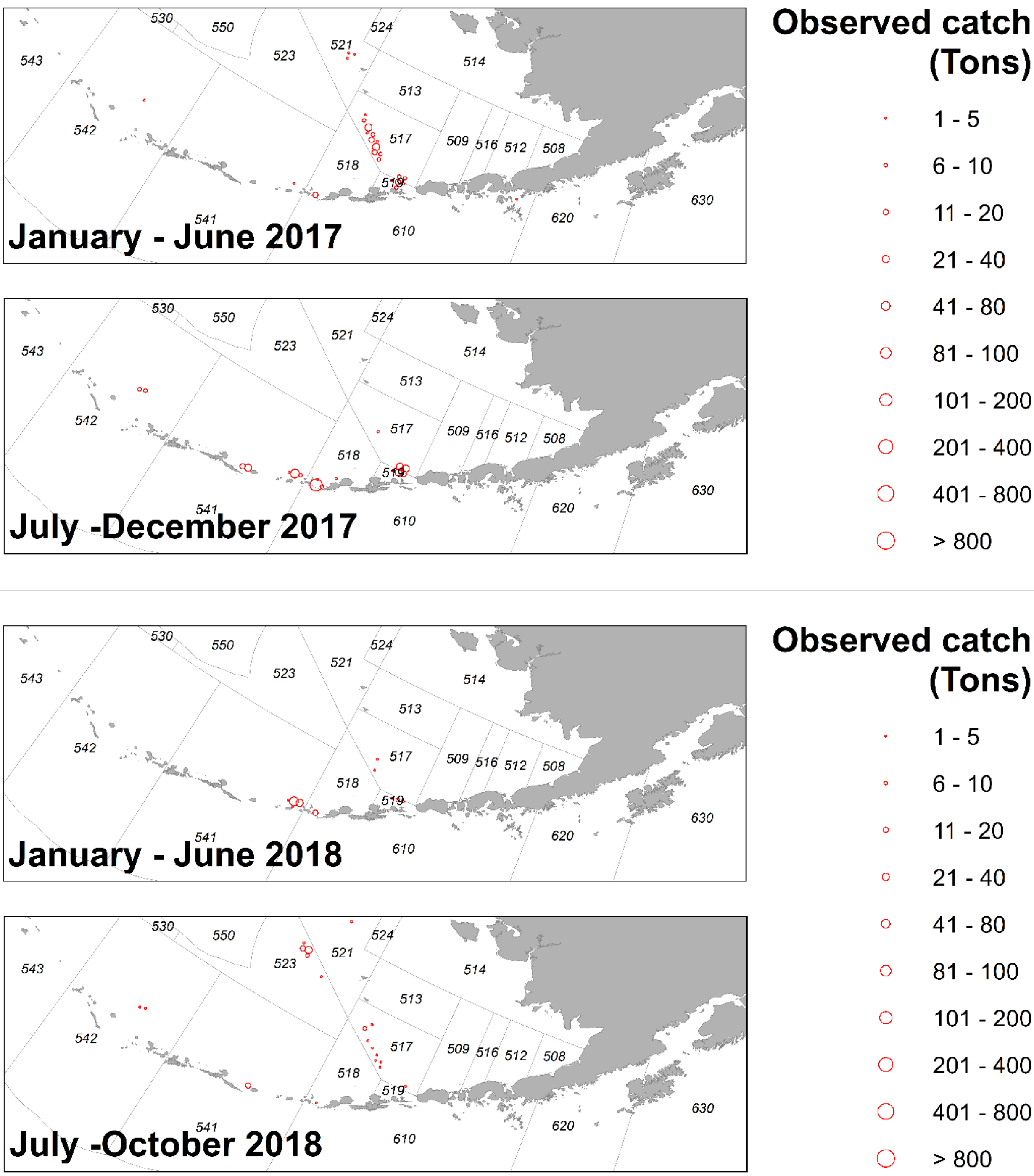


Figure 5.8. All observed Greenland turbot catch for 2017 and 2018. Data are aggregated for at 400 km^2. Note that areas with less than 1t are not shown.

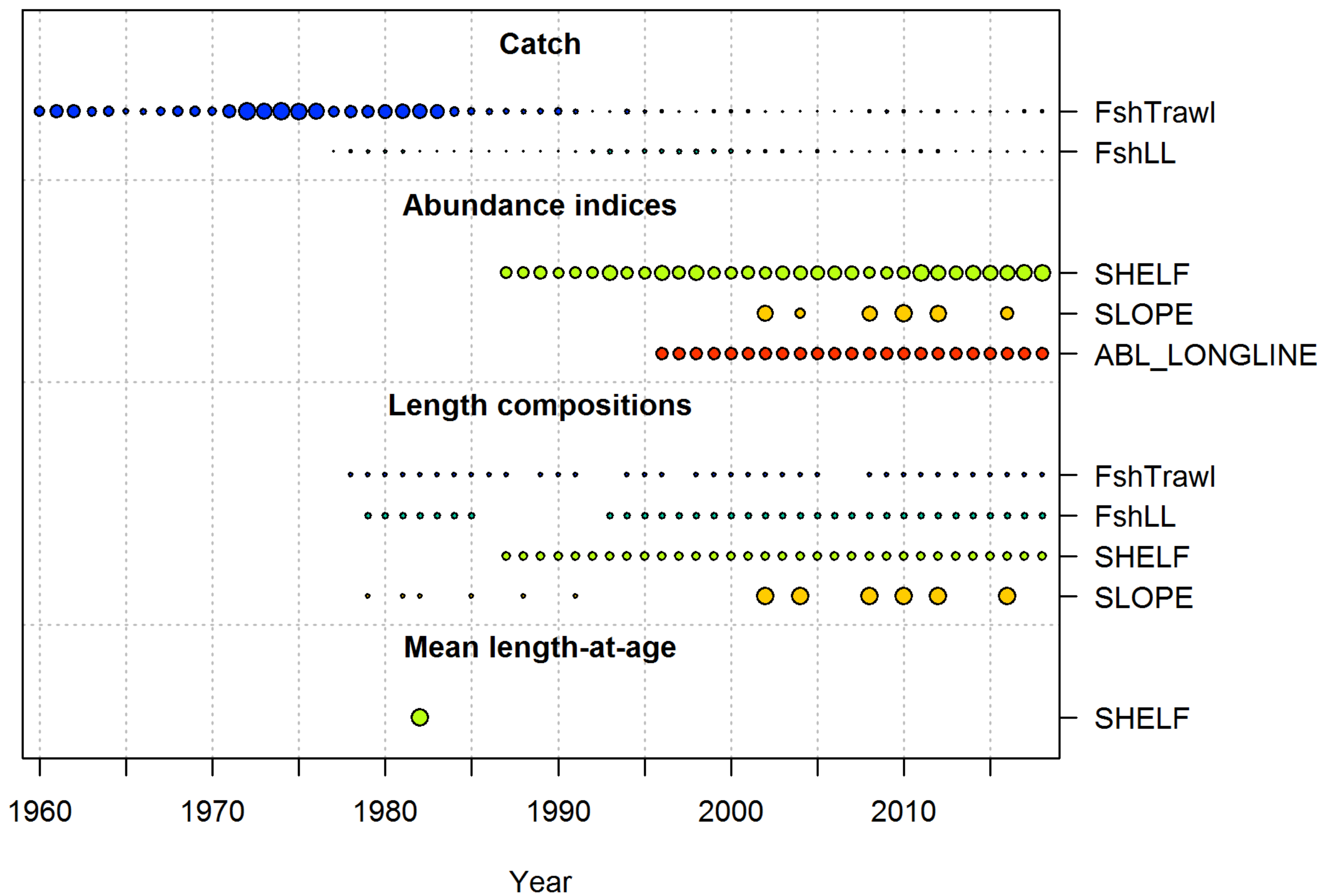


Figure 5.9. Timeline of all data included in models presented. The area of the circle represents the relative precision of the data type.

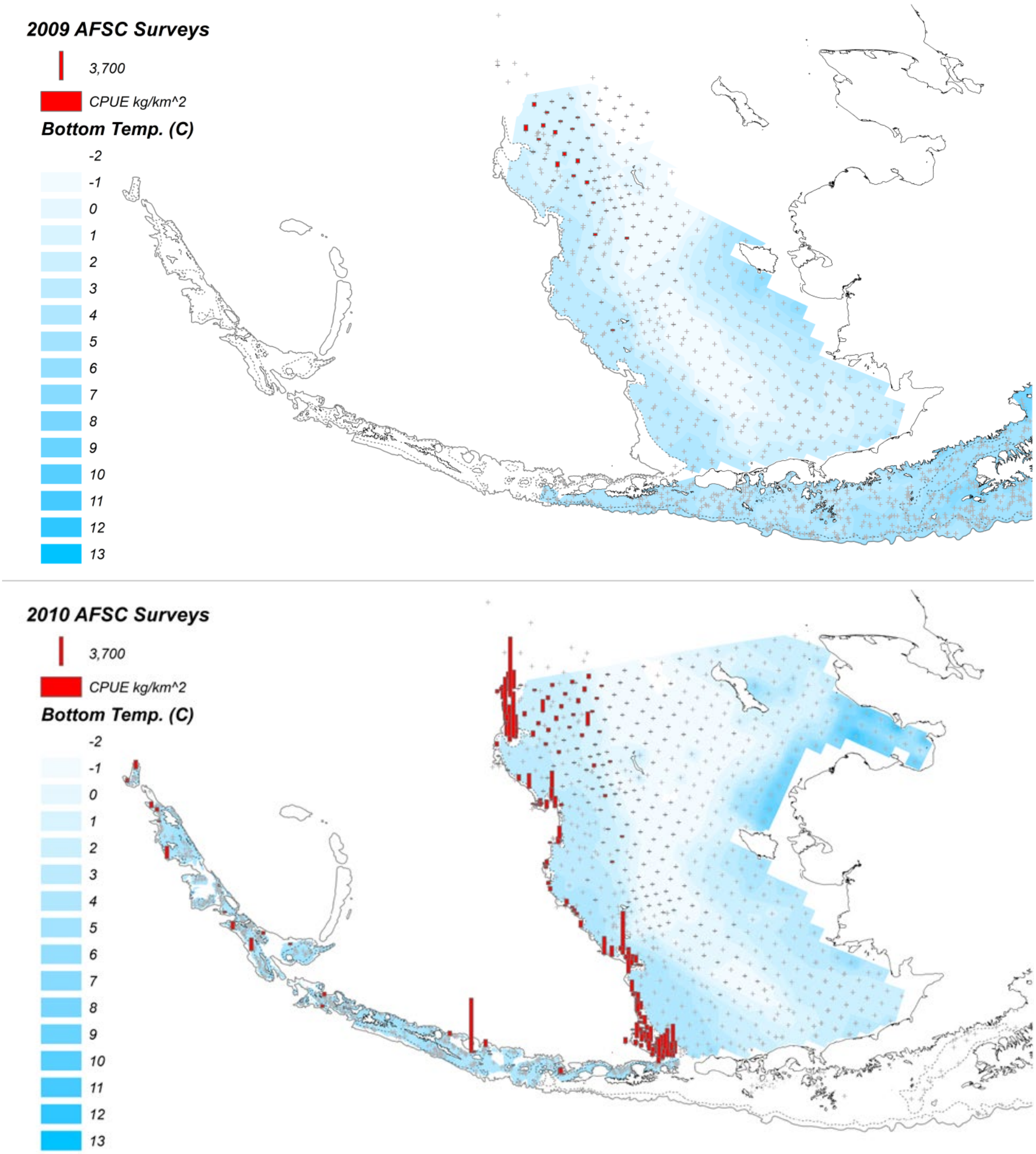
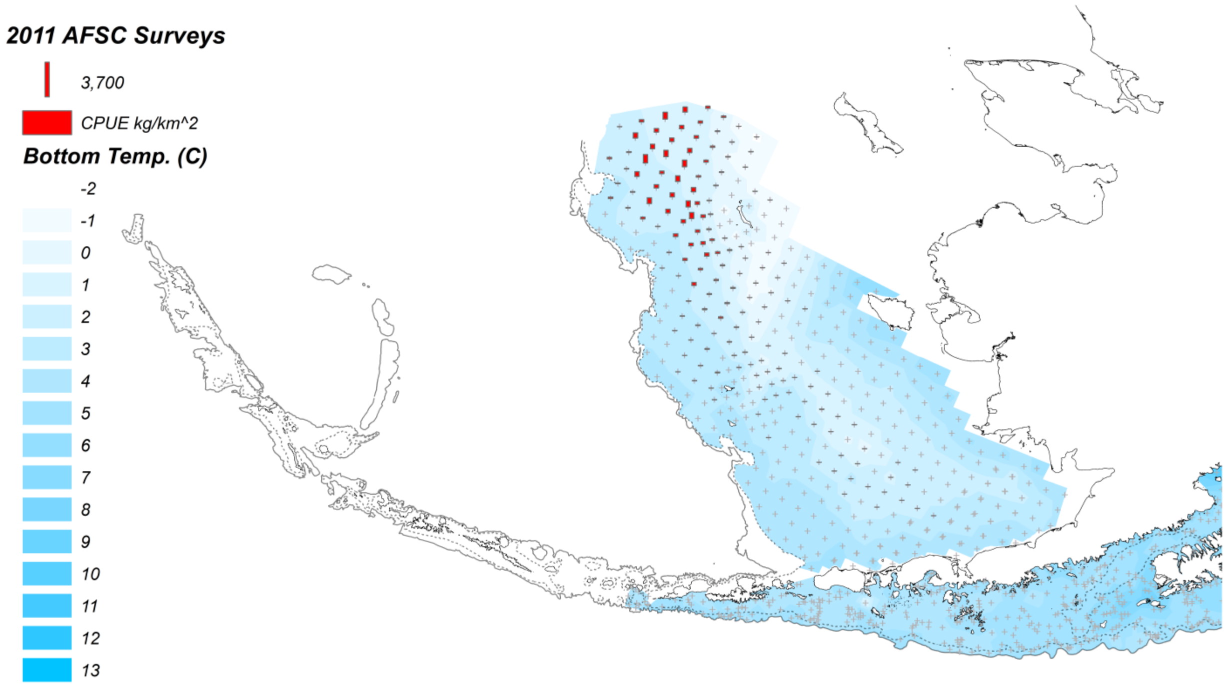


Figure 5.10. Greenland turbot CPUE kg/km[2] for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars.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



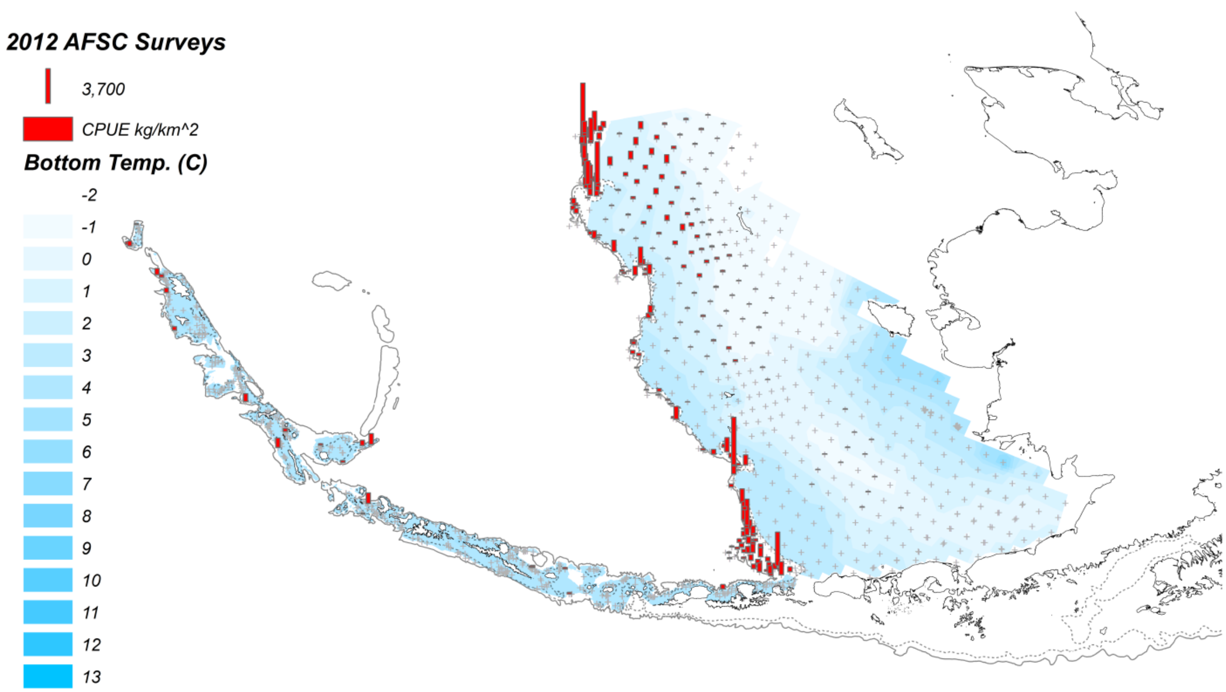
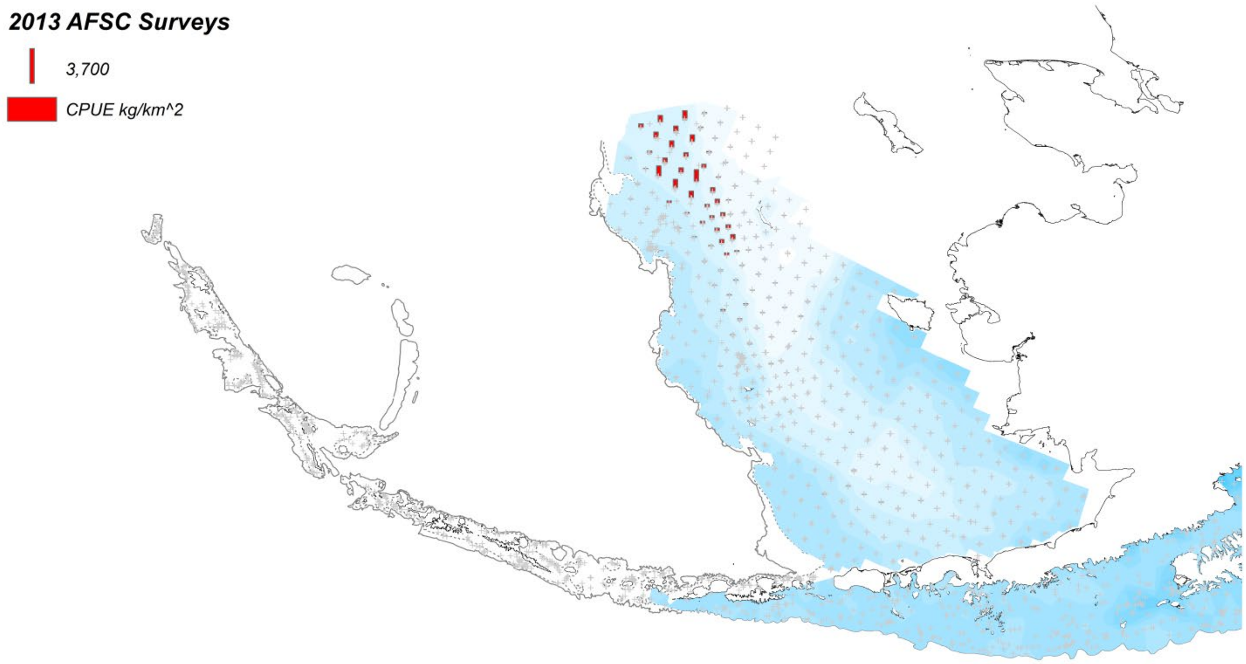


Figure 5.10.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with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



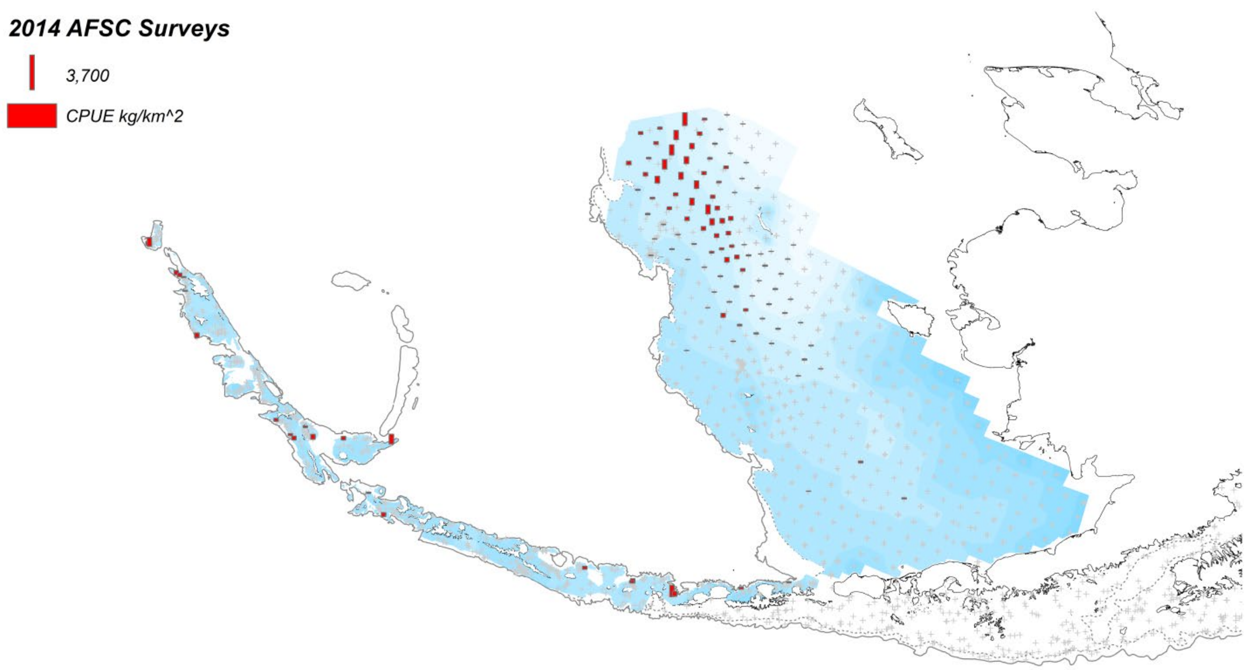
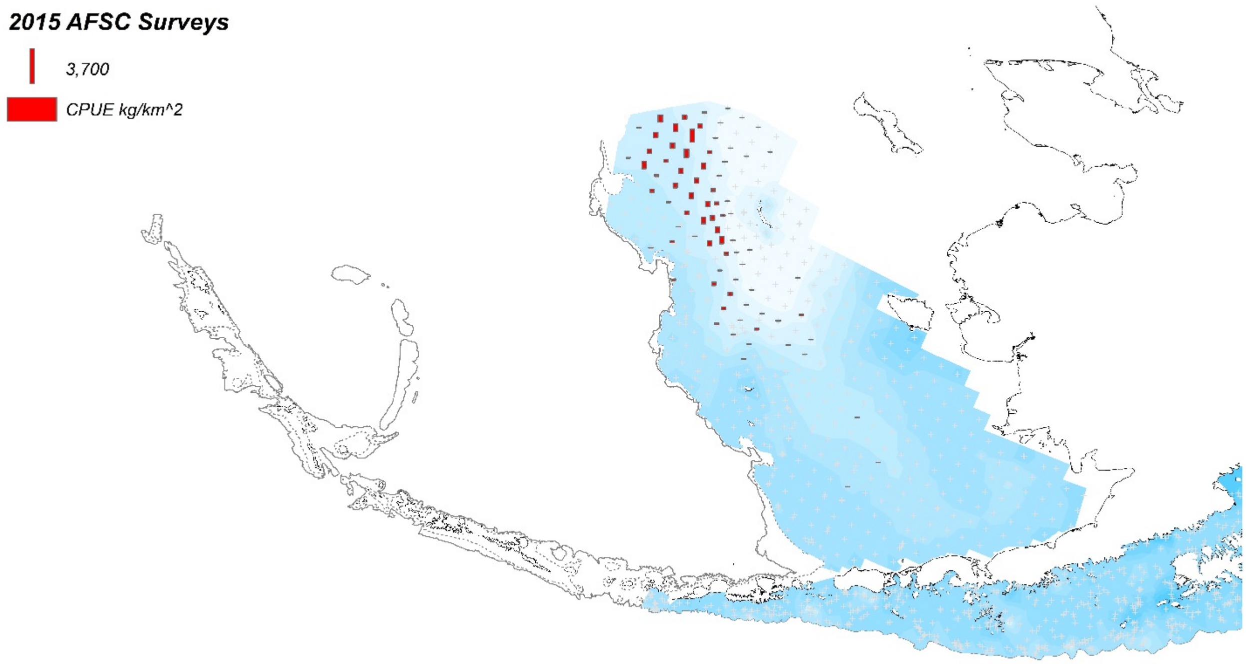


Figure 5.10.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with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



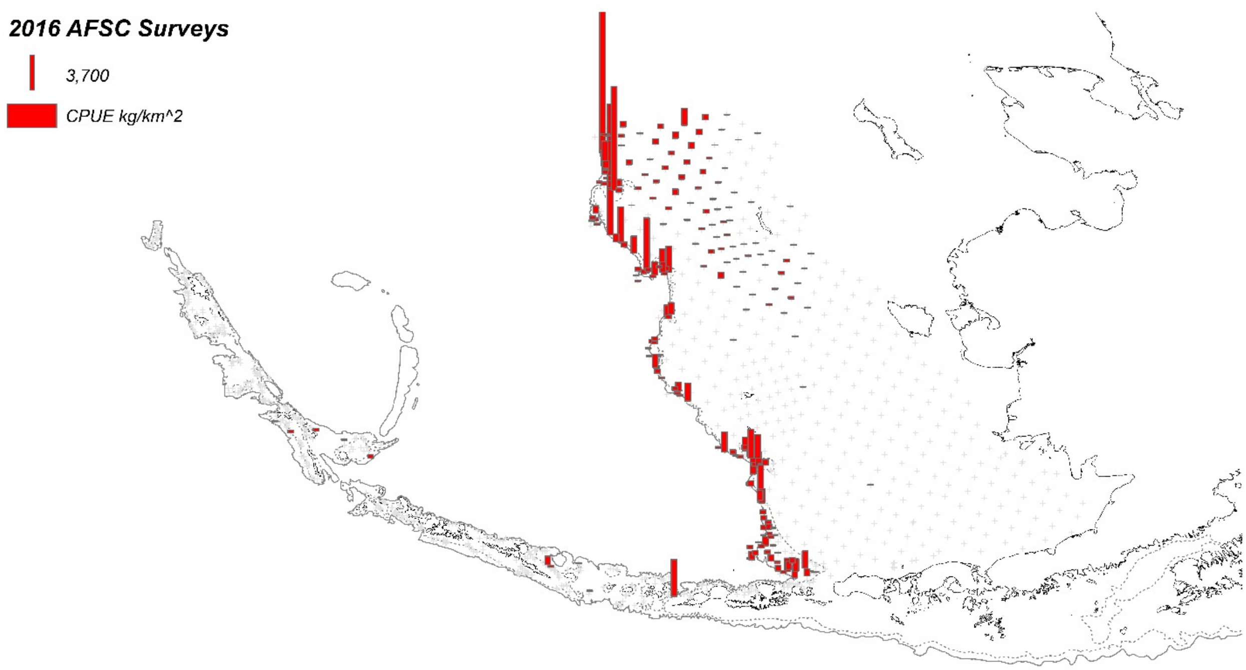


Figure 5.10.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year and 200m (dashed line) and 1000 m (solid gray line) isobaths. Bottom temperatures were not yet available for the 2016 map. Surveyed locations are marked with gray +, while areas with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

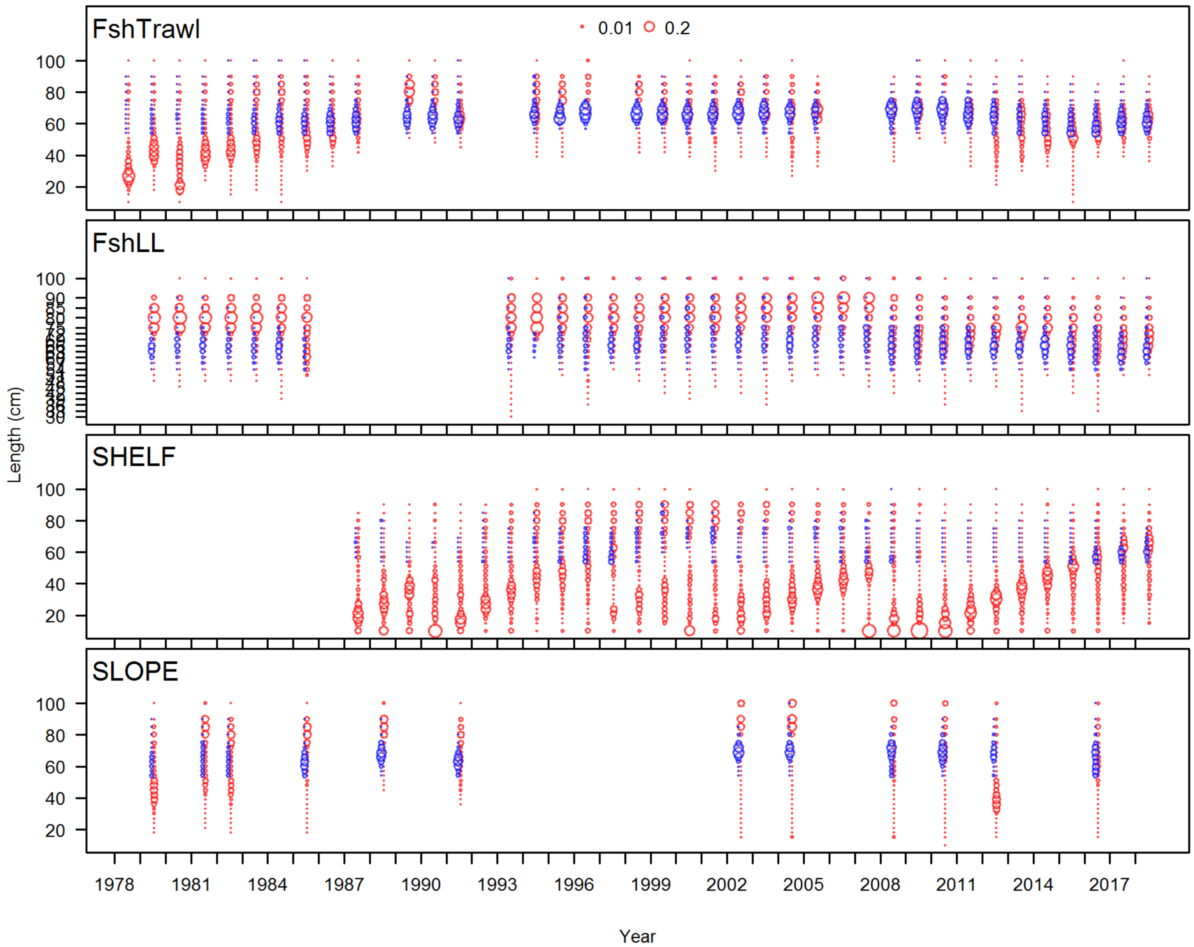


Figure 5.11. Greenland turbot size composition data from the Trawl fishery, longline fishery, shelf survey and slope survey.

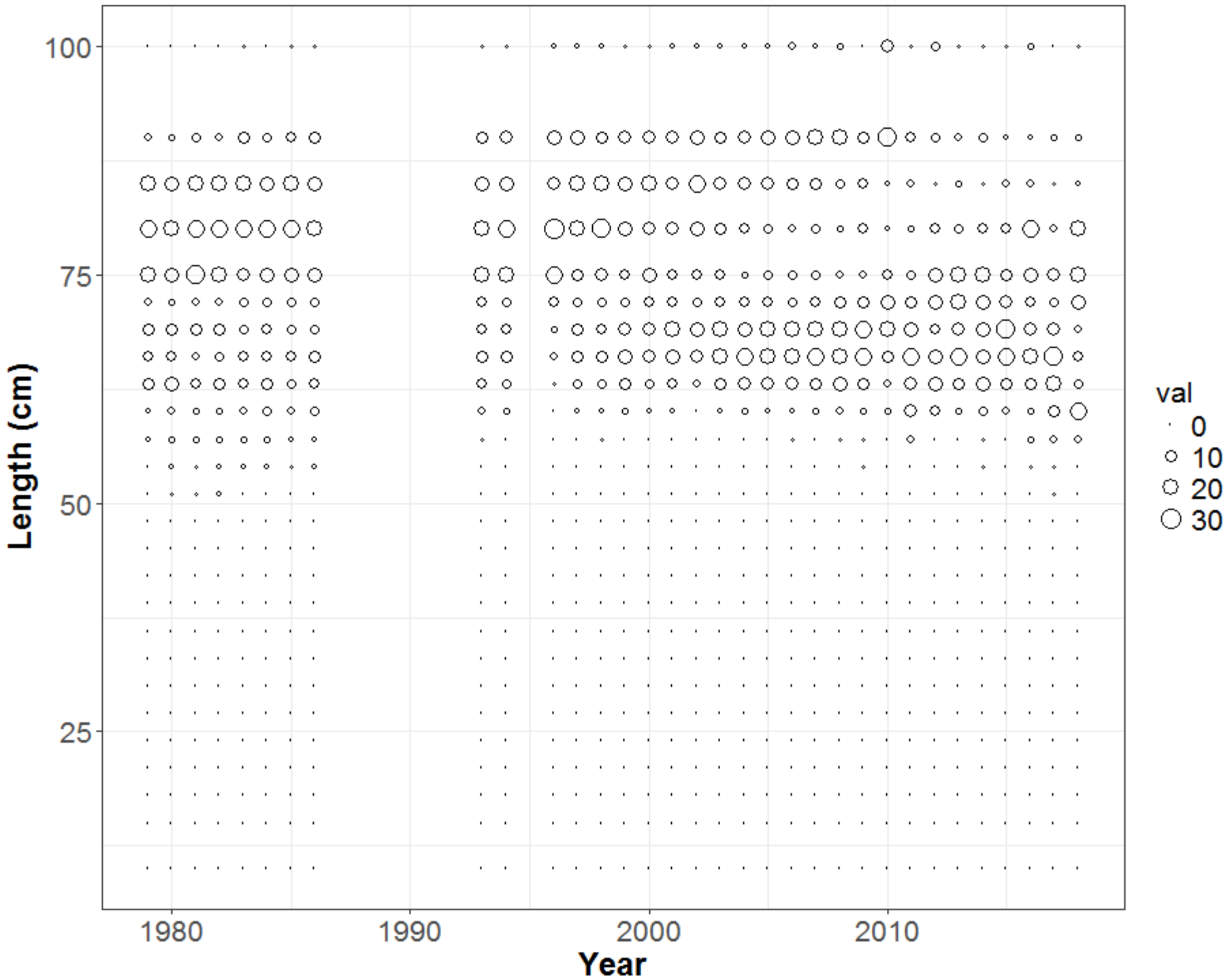


Figure 5.12. Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.

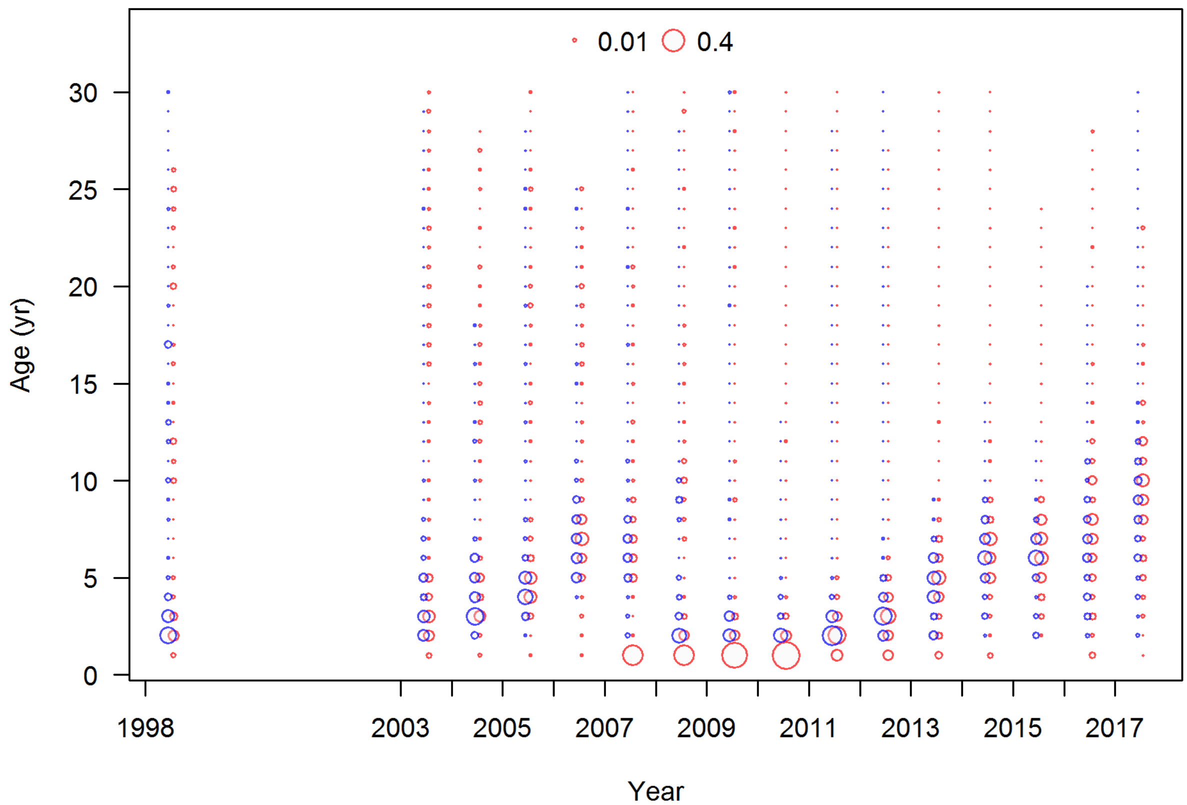


Figure 5.13. (Cont.) Greenland turbot age composition data for females (red) and males (blue) from the EBS shelf bottom trawl survey. These data were included in the model but not included in the likelihood.

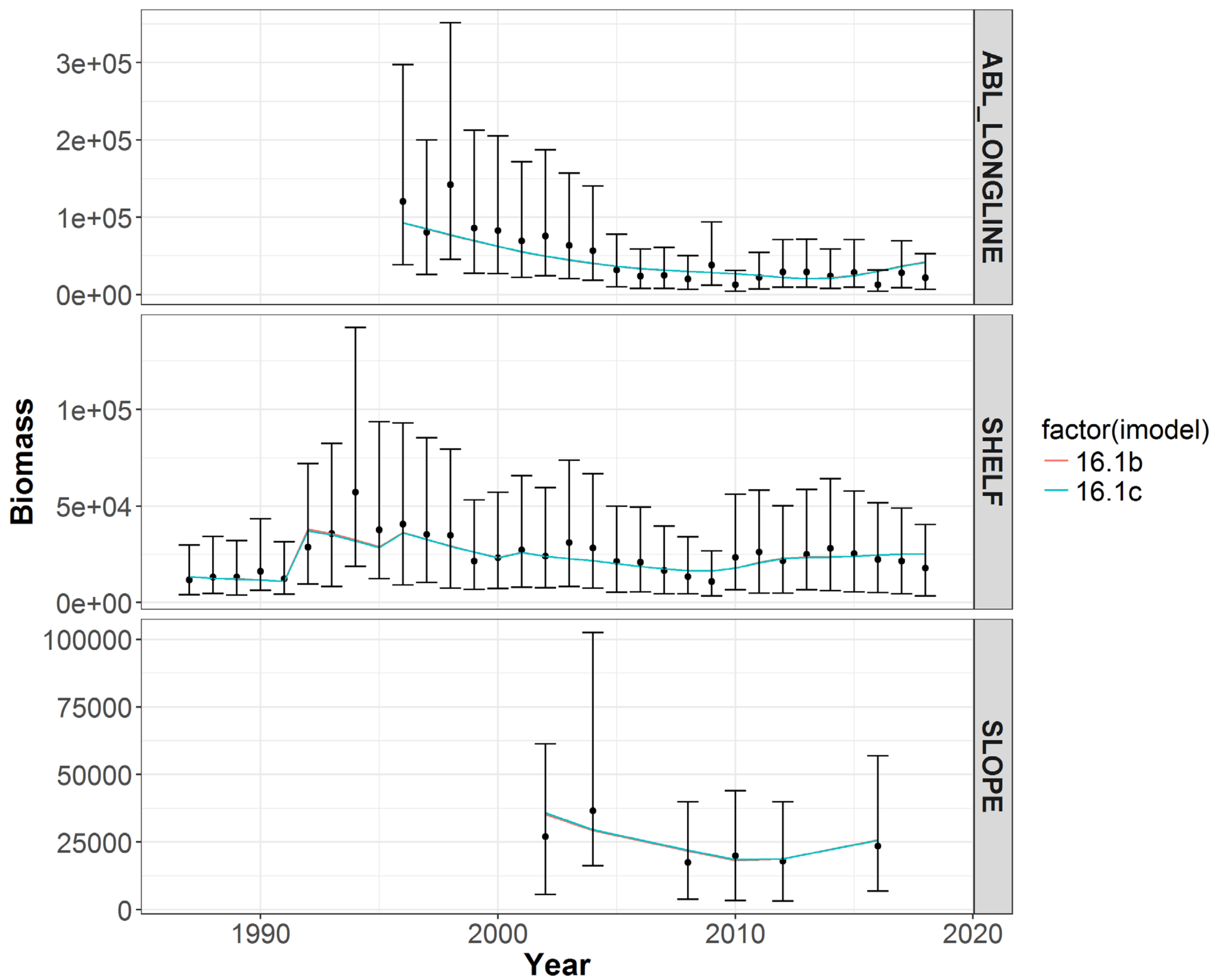


Figure 5.14. Survey indices (index values are the total survey biomass in tons) and model fits. Error bars are 95% confidence intervals.

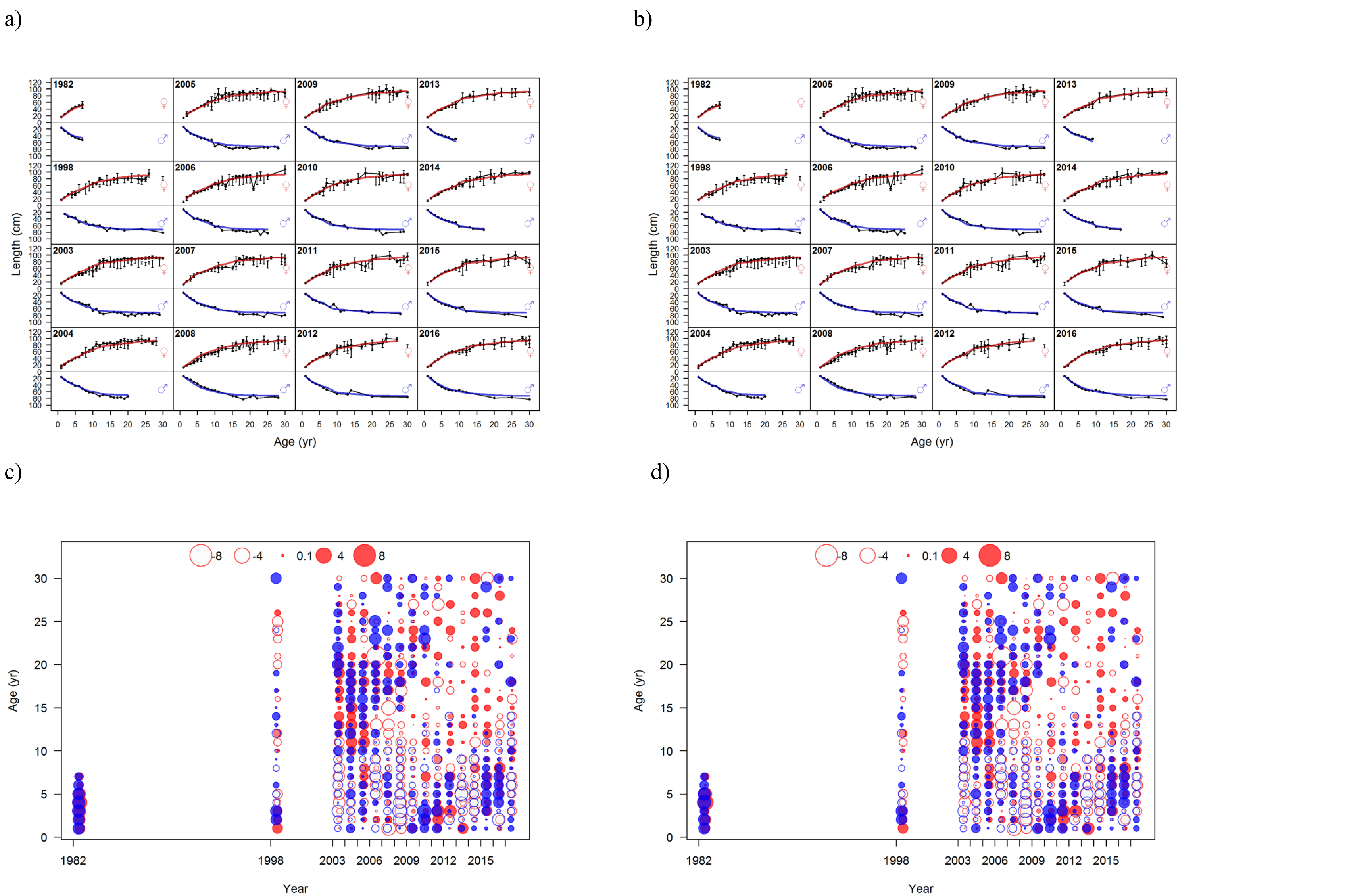
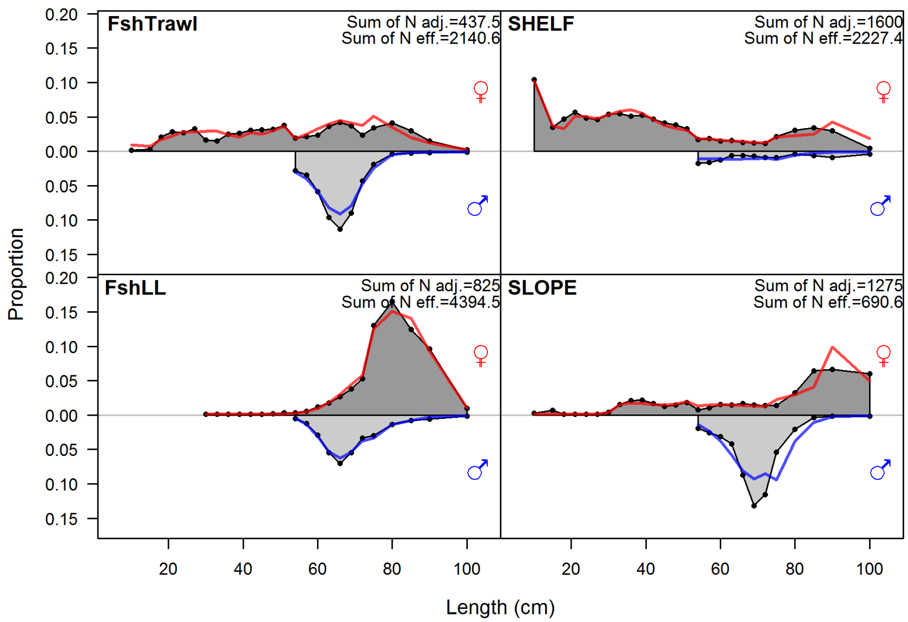


Figure 5.15. Length at age data and fits (females - red line, males – blue line), a) model 16.1b and b) model 16.1c. Closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation), c) model 16.1b and d) model 16.1c.. Red bubbles are female and blue are male.

a)



b)

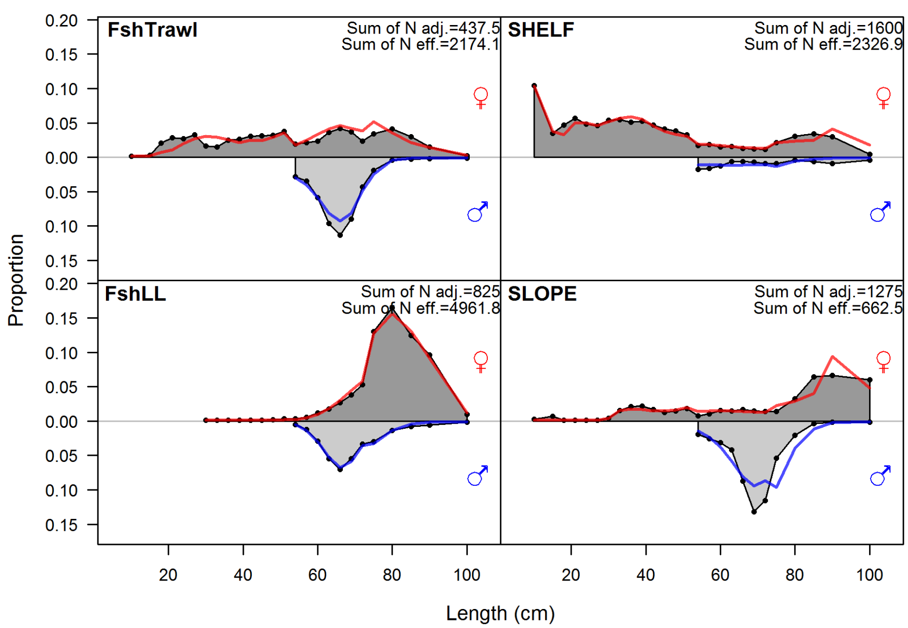
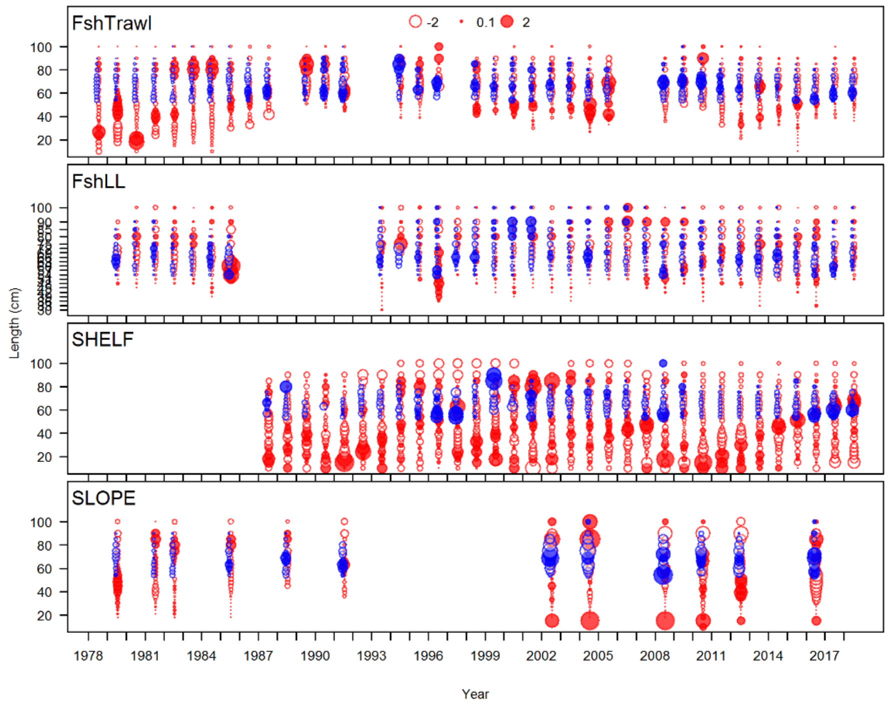


Figure 5.16. All size composition data combined across years and fits (red line female, blue line male) for fisheries and surveys. Model 16.1b and b) Model 16.1c

a)



b)

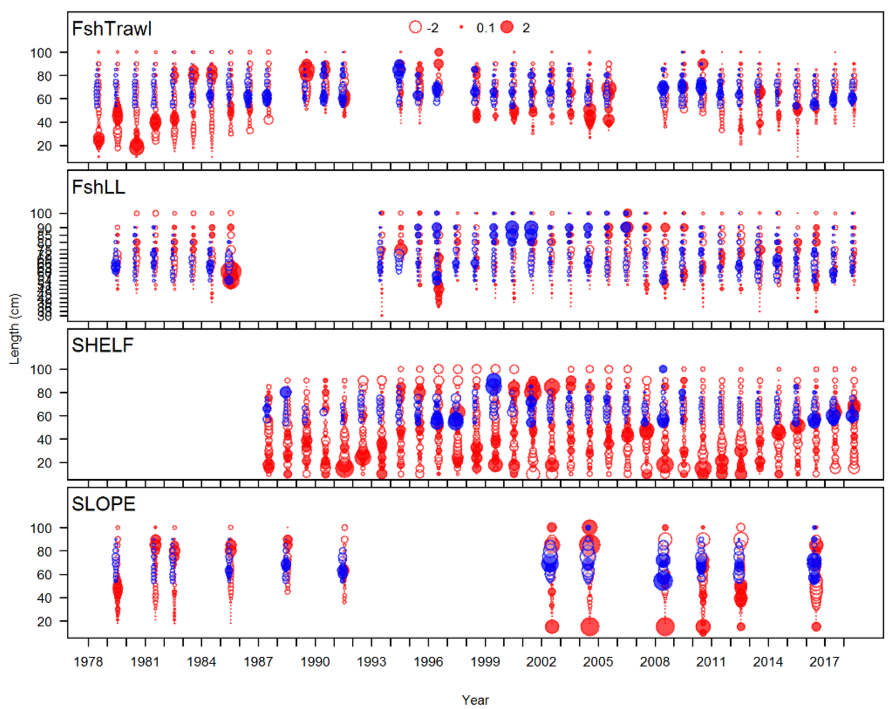
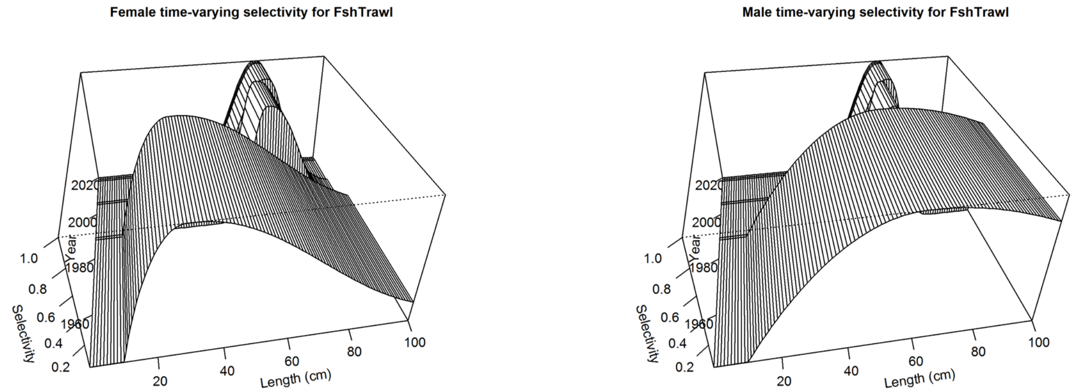


Figure 5.17. Pearson residuals for fisheries and two surveys. Closed bubbles are positive residuals (underestimation) and open bubbles are negative residuals (overestimation). Note that the scale of the bubble graphs may differ by model.

a)



b)

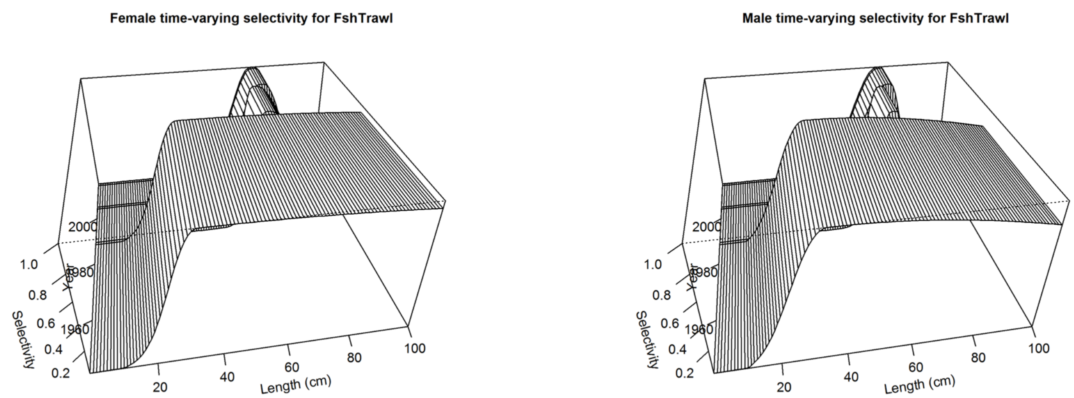
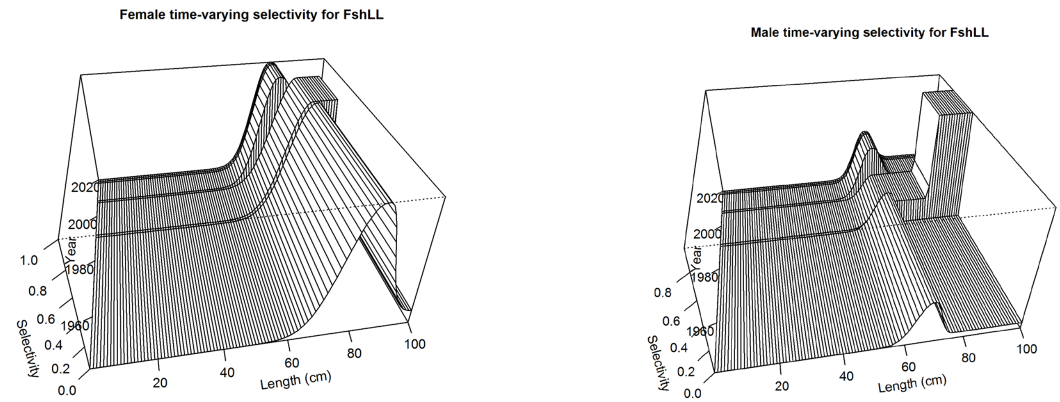


Figure 5.18. Time-varying selectivity at size for the Trawl fishery for both sexes (female - left panels, males – left panels). a) Model 16.1b and b) model 16.1c.

a)



b)

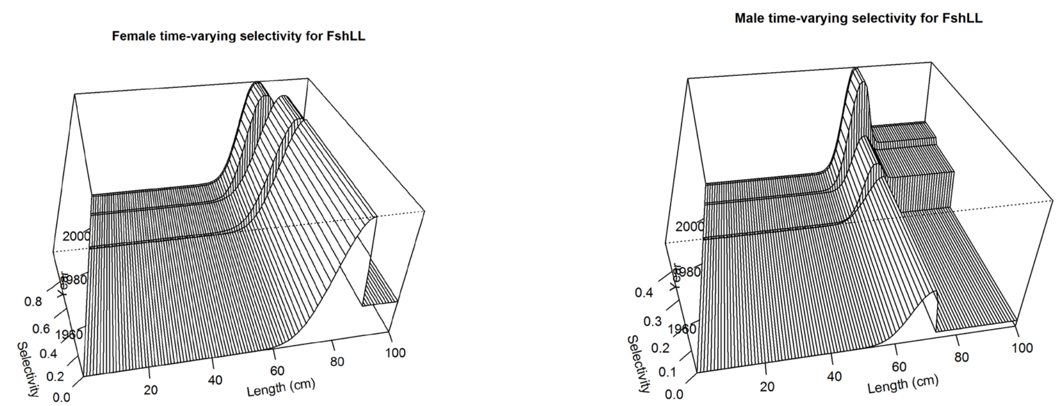
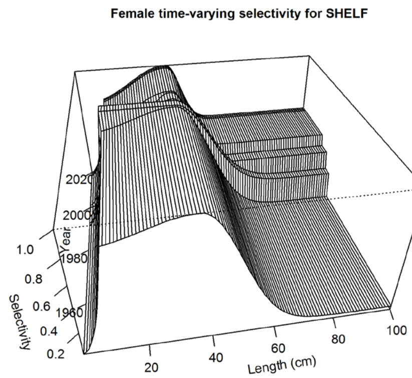
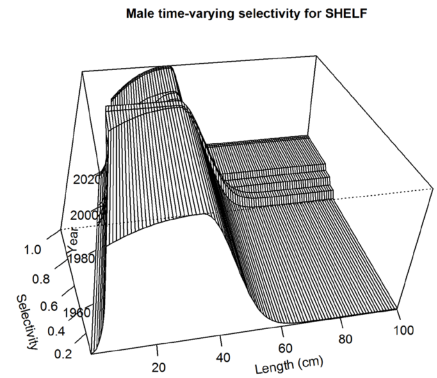


Figure 5.19. Time-varying selectivity at size for the Longline fishery for both sexes (female - right panels, males – left panels). a) Model 16.1b and b) model 16.1c

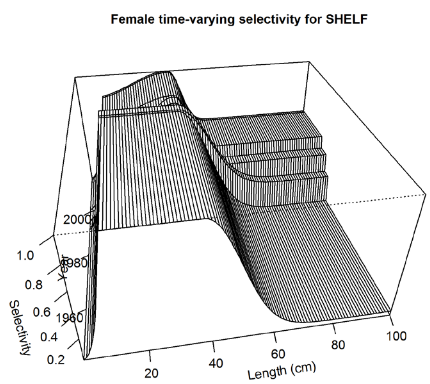
a)



b)



c)



d)

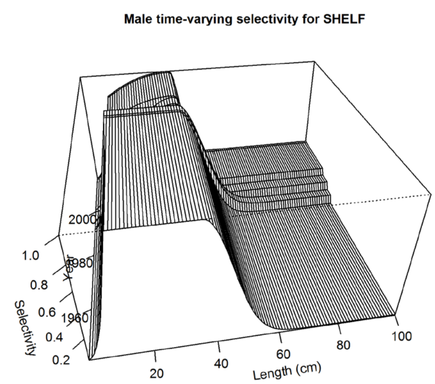
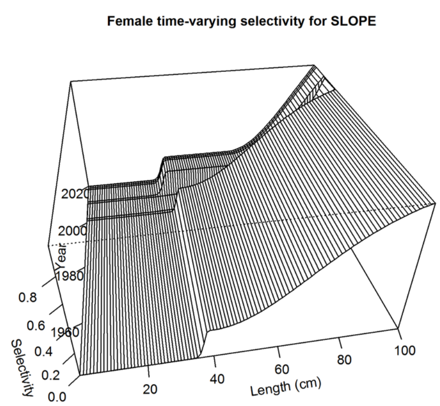
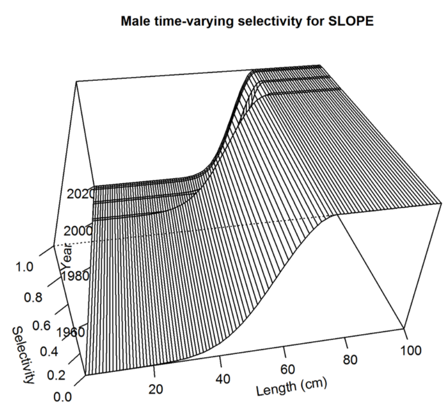


Figure 5.20. Time-varying selectivity at size for the shelf survey. sexes (female - right panels, males – left panels). a) Model 16.1b and b) model 16.1c

a)



b)



c) d)

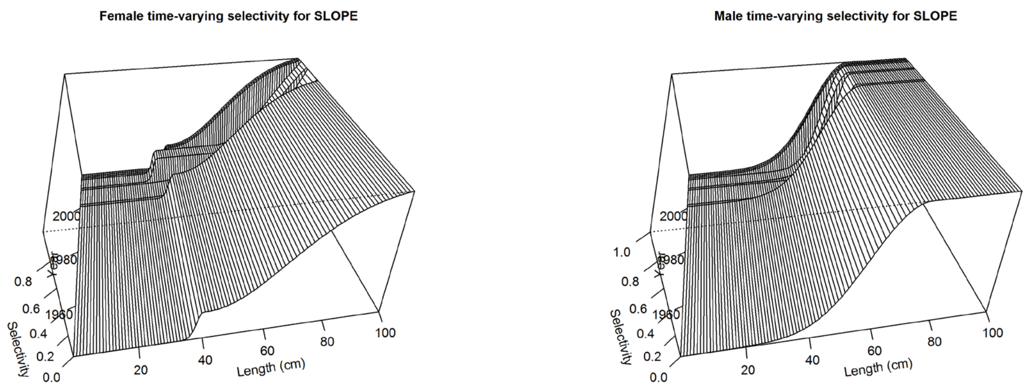


Figure 5.21. Slope survey selectivity by model for females (left panels) and males (right panels) and a, b) model 16.1b and c, d) model 16.2.

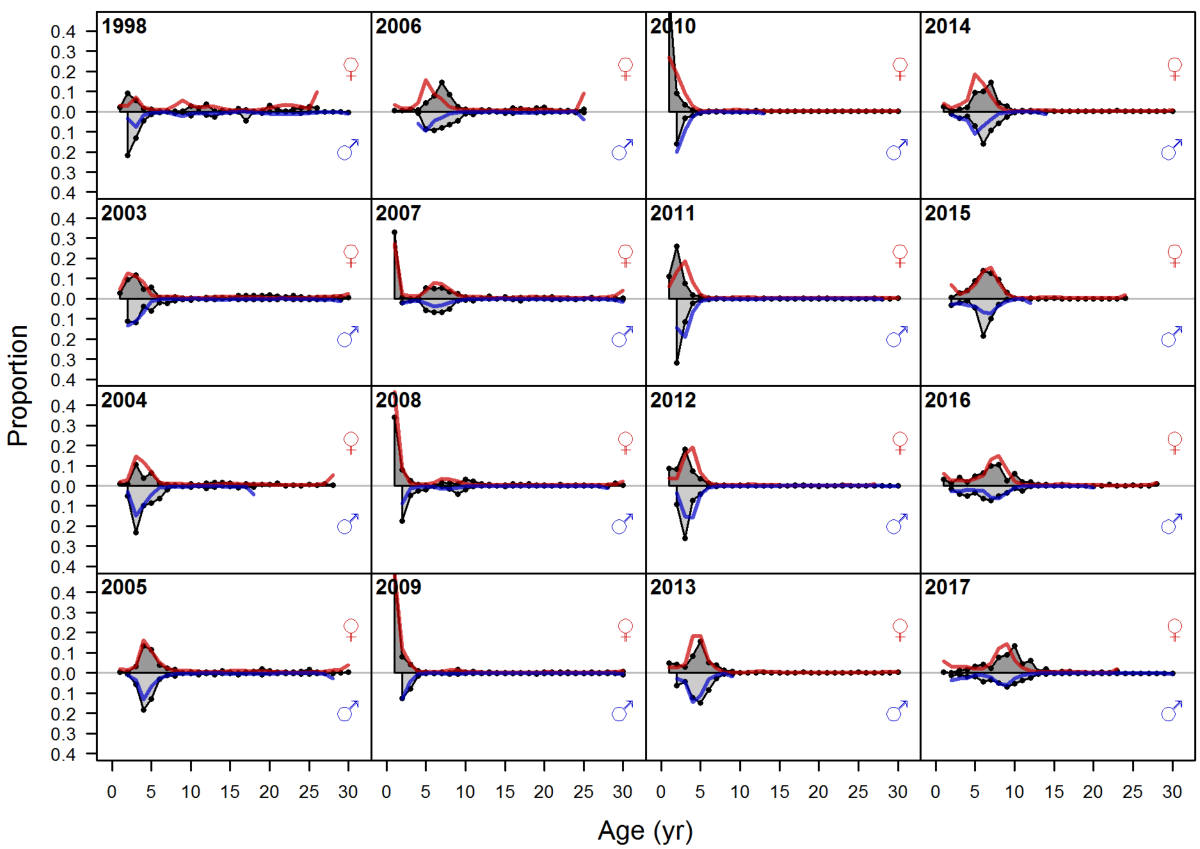


Figure 5.22. Model 16.1b shelf survey age composition data and "ghost" fits (red and blue line "Ghost" fits are projected fits as they are not fit to the likelihood for the age composition.

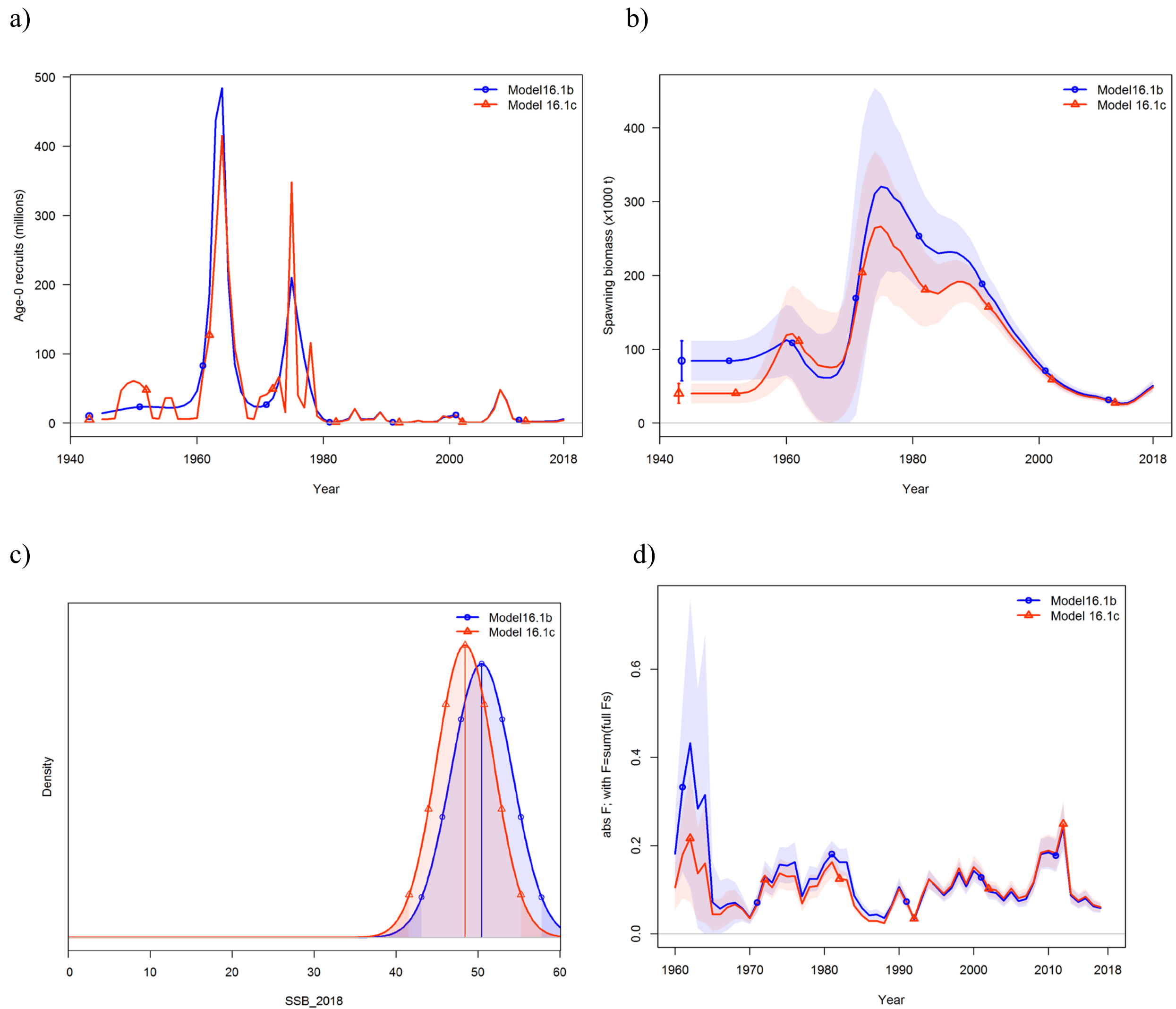
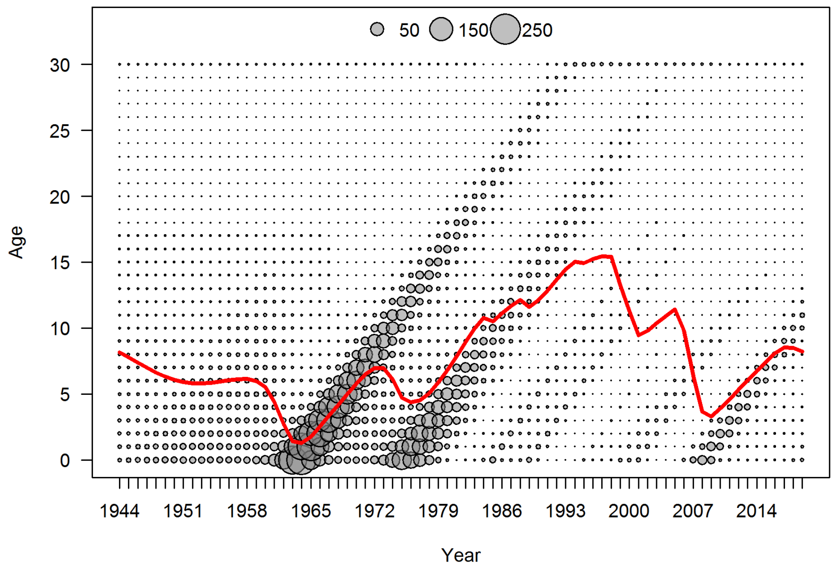


Figure 5.23. a) Age-0 recruitment, b) female spawning biomass, c) the posterior density of spawning biomass in 2018, and d) fishing mortality for models 16.1b and 16.1c.

a)



b)

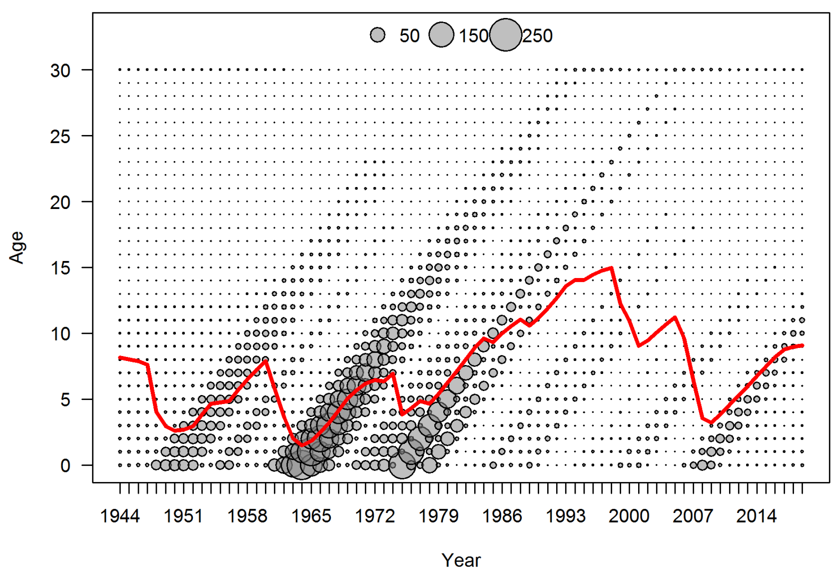
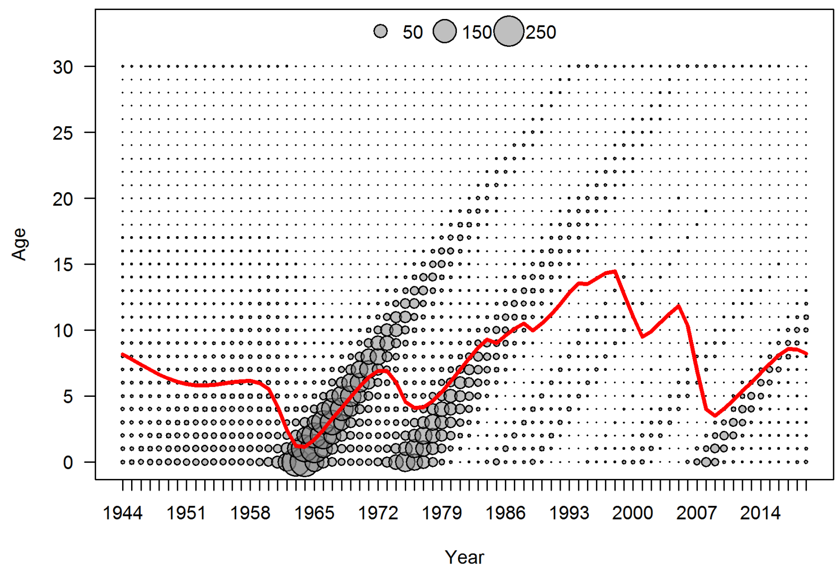


Figure 5.24. Female BSAI Greenland turbot numbers at age and mean age by year (red line), a) model 16.1b and b) 16.1c.

a)



b)

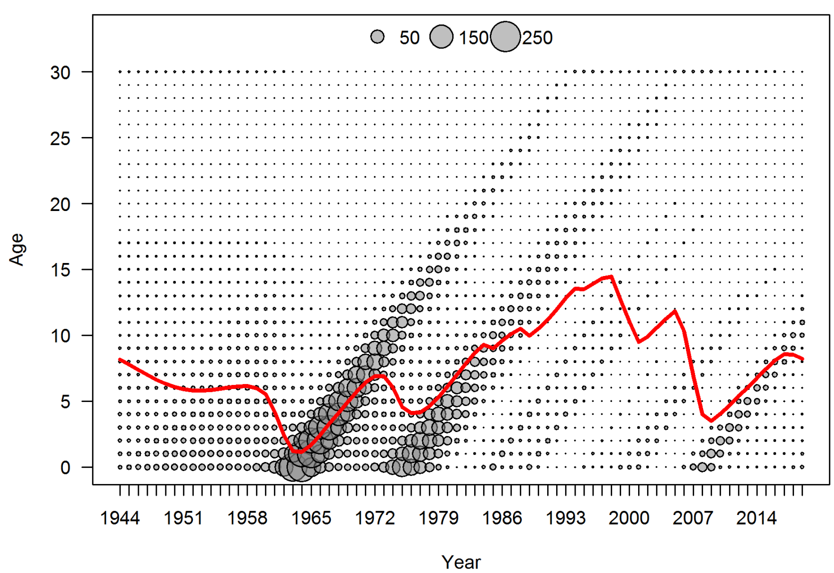
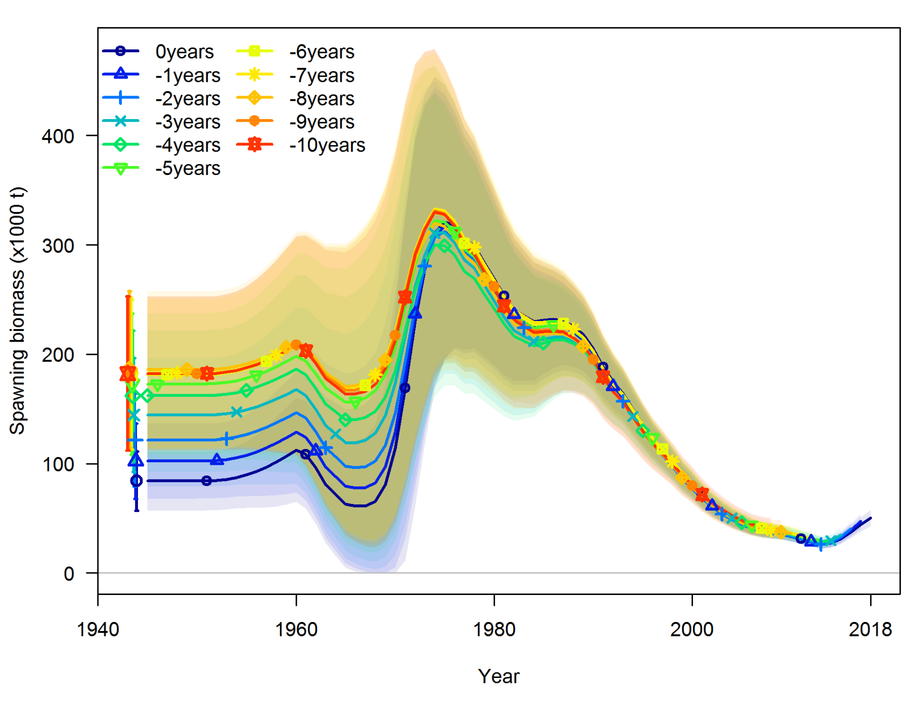


Figure 5.25. Male BSAI Greenland turbot numbers at age and mean age by year (red line), a) model 16.1b and b) 16.1c.

a)



b)

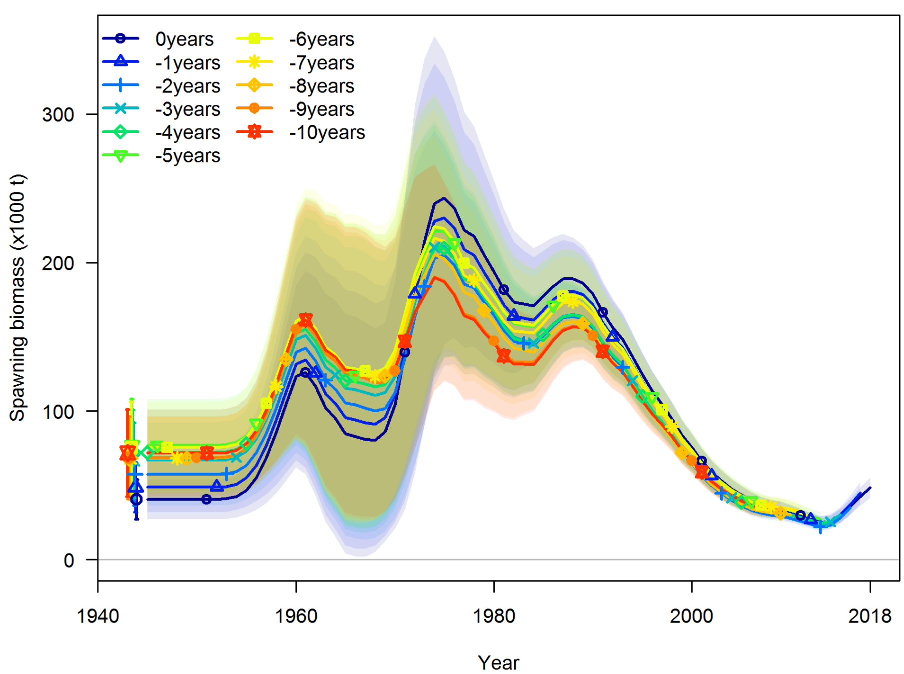
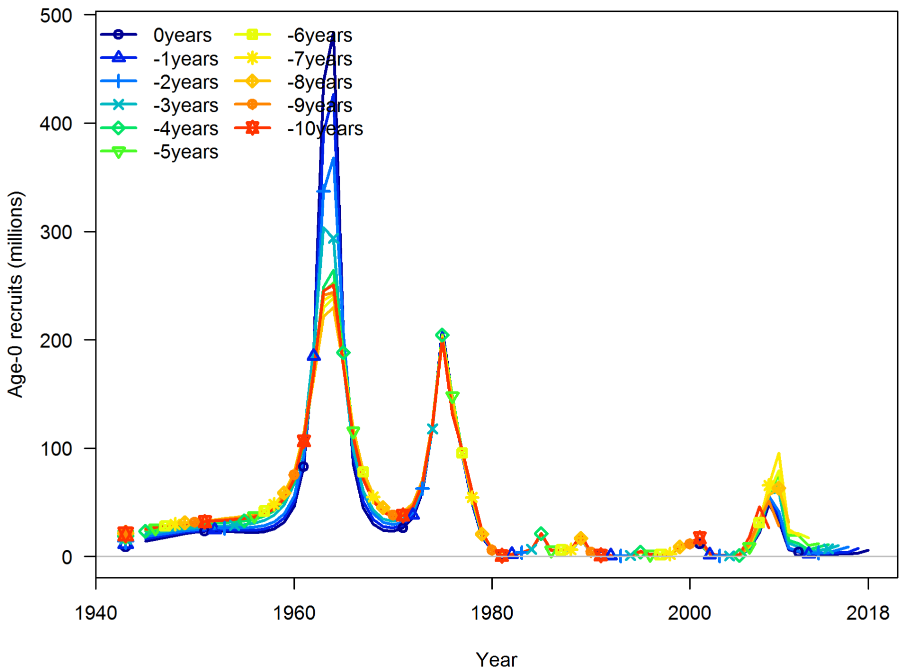


Figure 5.26. Female spawning biomass from (top) Model 16.1b and (bottom) Model 16.1c with data sequentially removed 2018-2008.

a)



b)

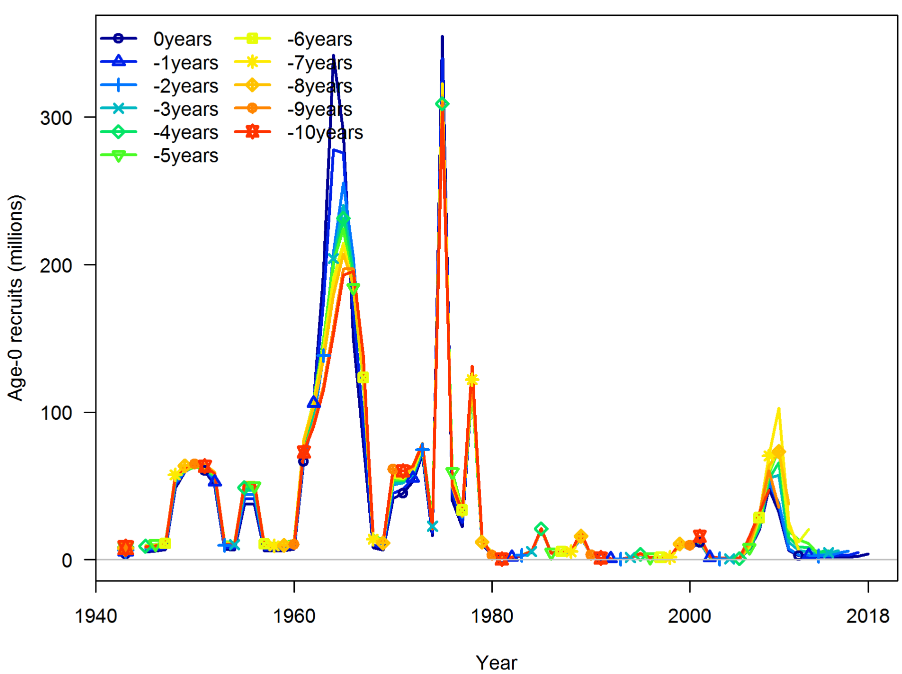


Figure 5.27. Age-0 recruits from a) model 16.1b and b) model 16.1c with data sequentially removed 2018-2008.

a) b)

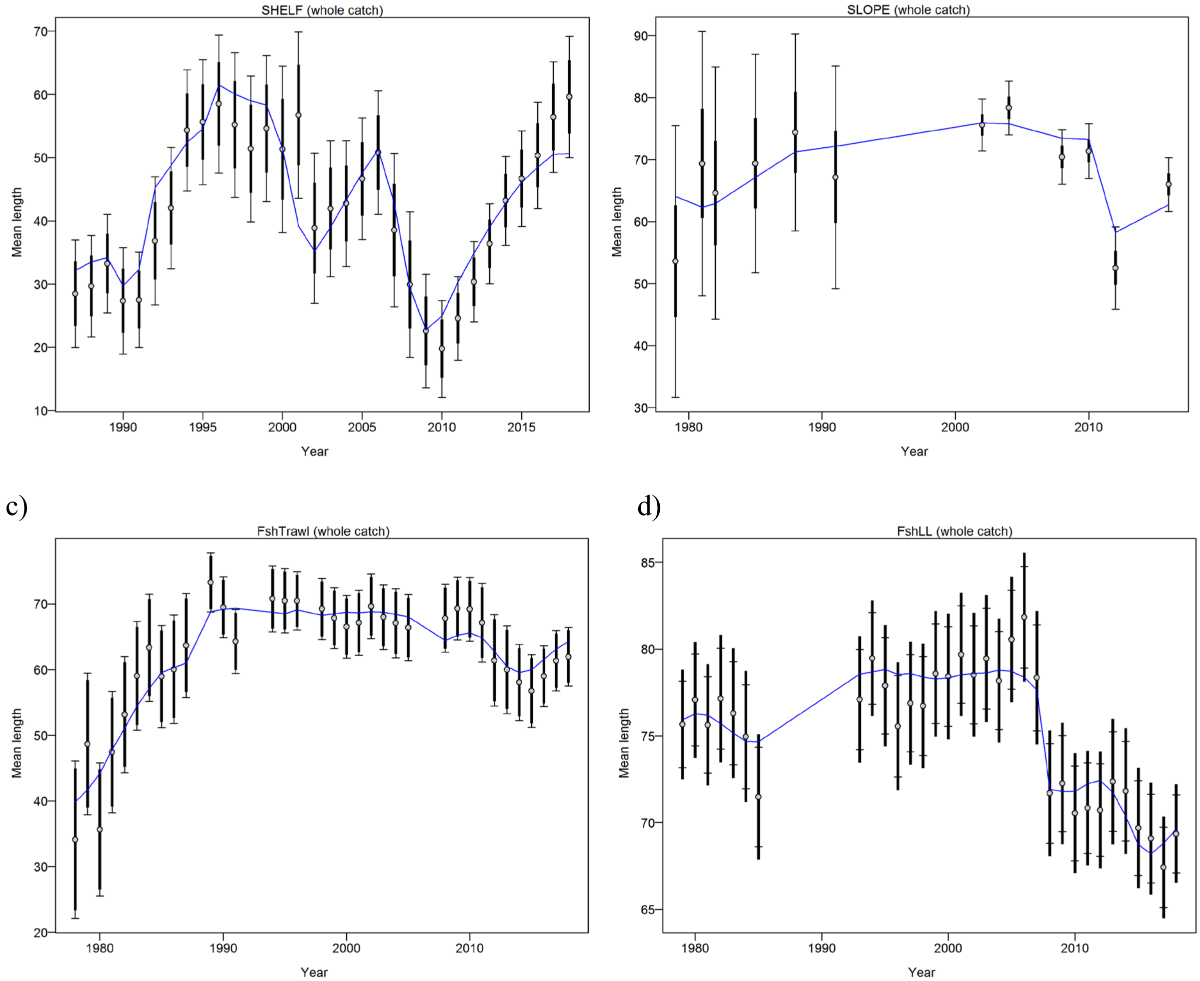


Figure 5.28. Mean length and model fit for the a) Shelf survey, b) slope survey, c) trawl fishery, and d) longline fishery for model 16.1b.

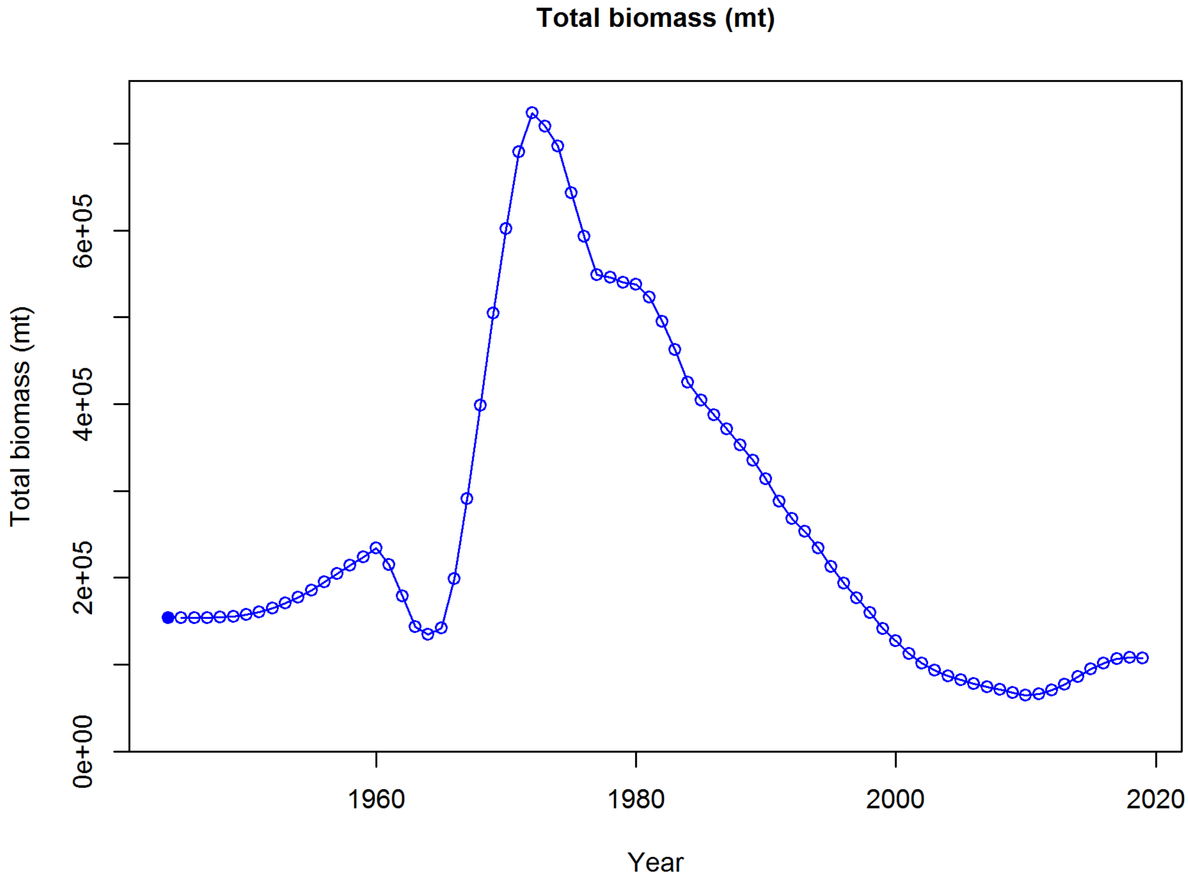


Figure 5.29. Total age 1+ biomass (t) from model 16.1b.

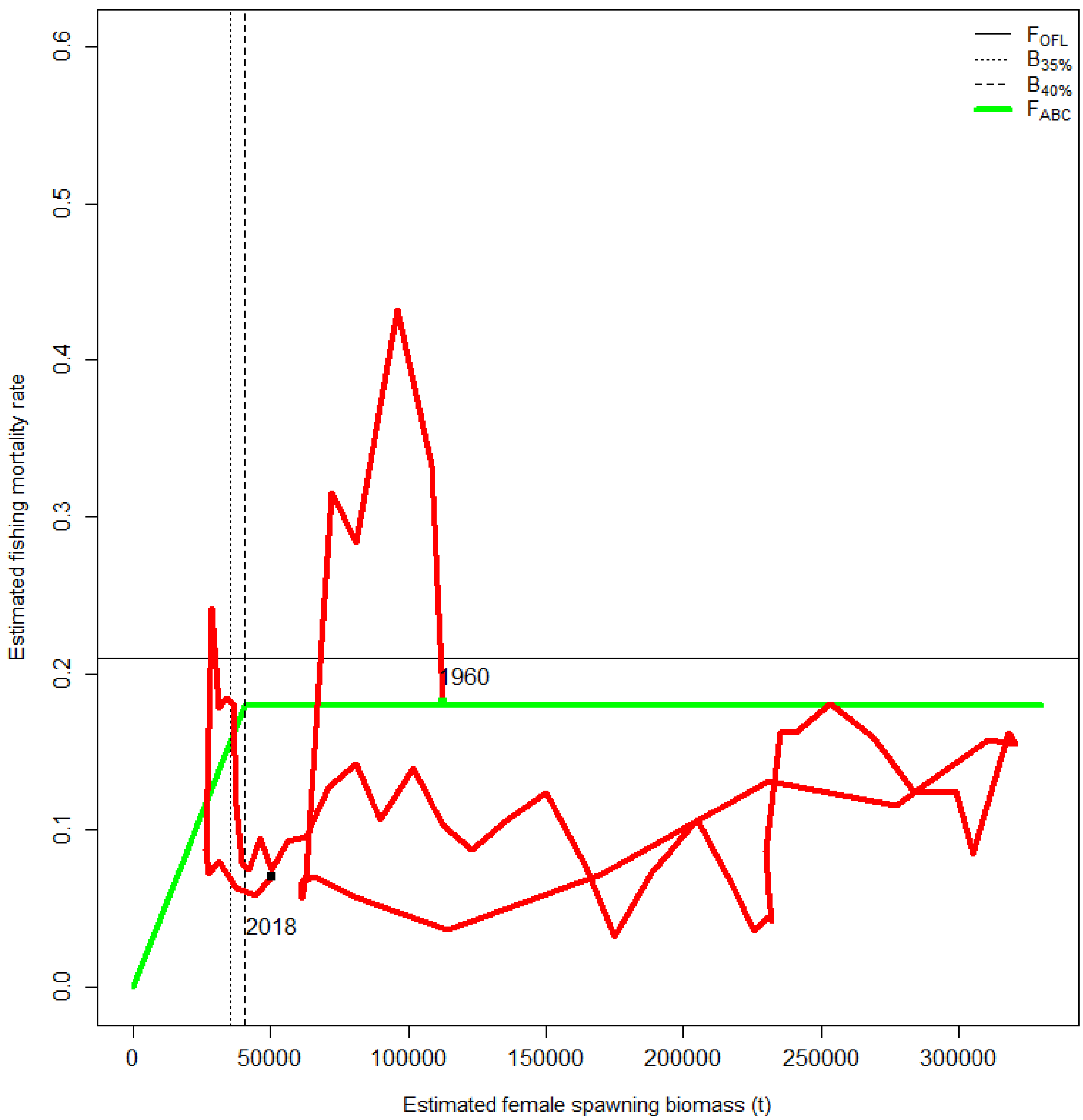
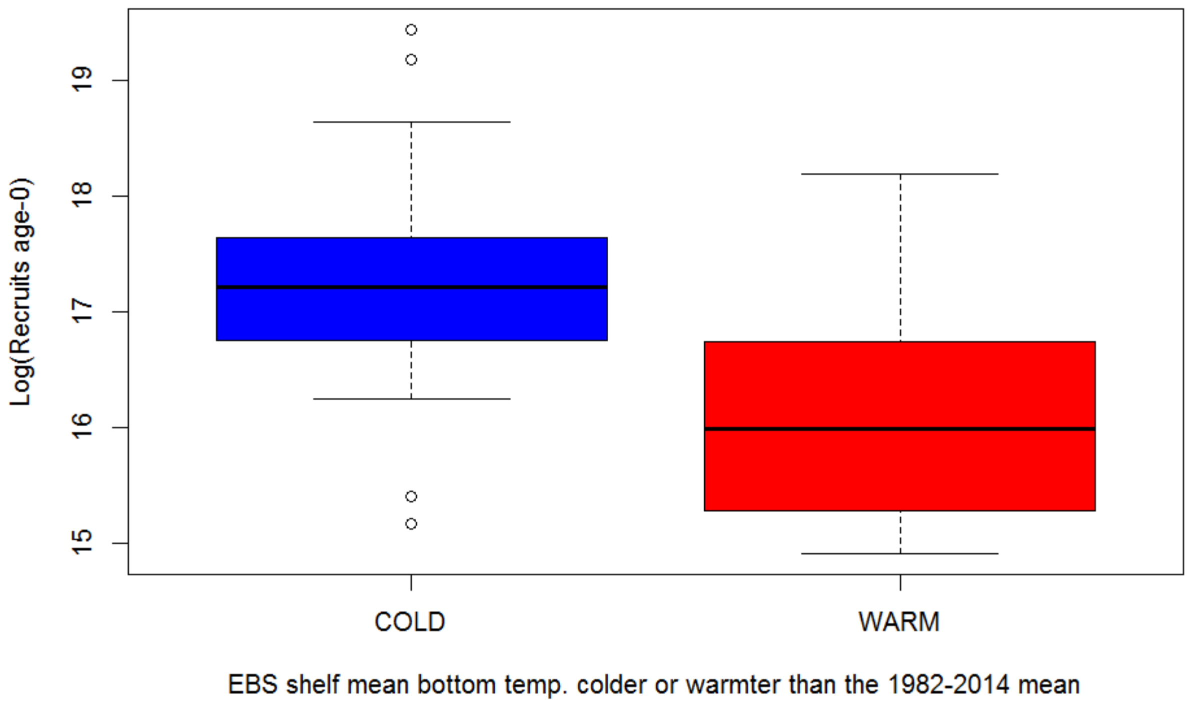


Figure 5.30. For Model 16.1b ratio of historical fishing mortality versus female spawning biomass for BSAI Greenland turbot, 1960-2018. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.



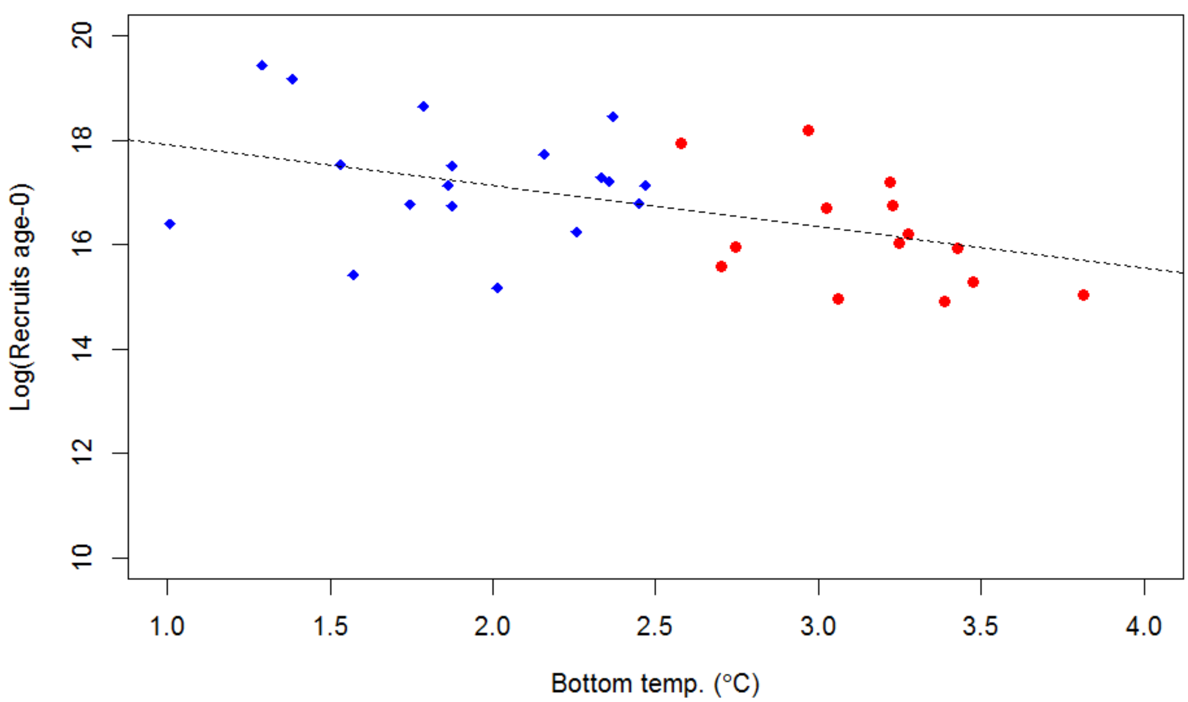


Figure 5.31. Greenland turbot Model 16.4 log recruitment at age-0 and mean bottom temperature from the EBS shelf survey (top) boxplot by above or below the mean temperature from 1982-2014 and (bottom) simple plot by EBS shelf mean bottom temperature (linear regression log(recruits age-0) ~ Temp. df = 31, $R^2 = 0.2389$, p-value = 0.0023).

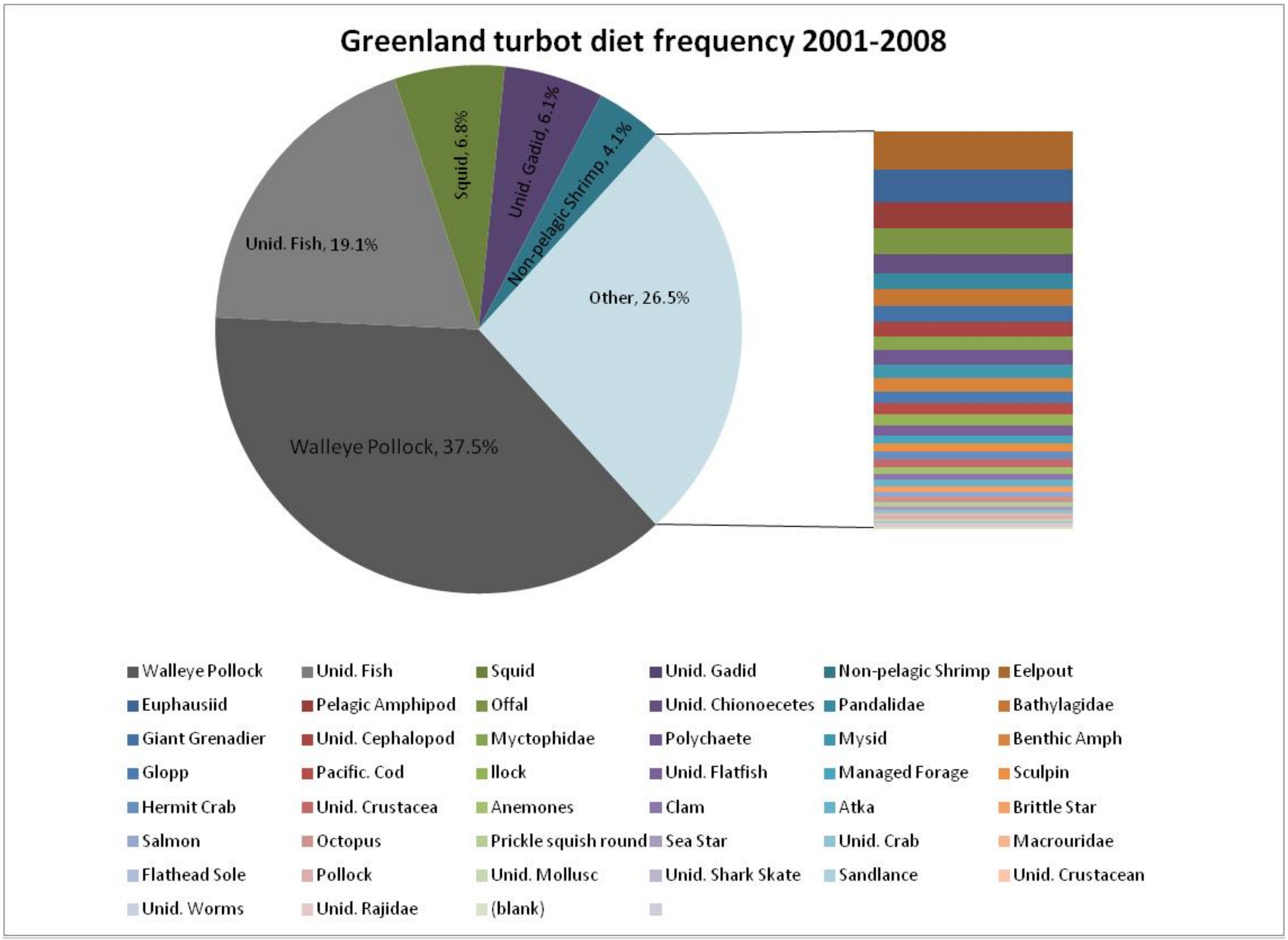


Figure 5.32. Greenland turbot prey items frequency in AFSC diet data for 2001-2008 from the Shelf and Slope bottom trawl survey.