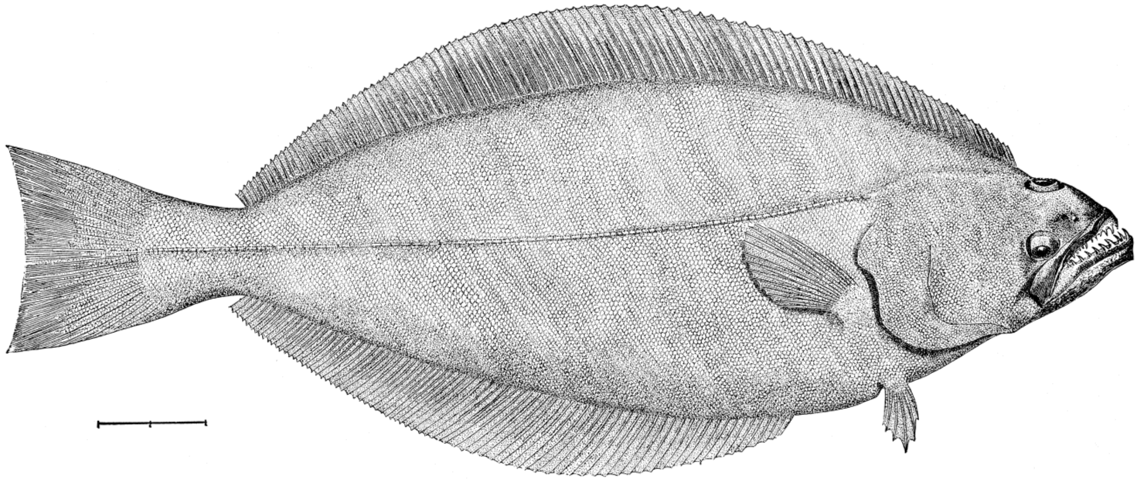
5. Assessment of Greenland turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the model

There were no changes made to the base model which has the same configuration as model 15.1 from 2015 except the addition of catch and size composition data from both the longline and trawl fisheries for 2016 as well as the addition of the 2016 Slope trawl survey index value and size composition data.

To better fit the size composition data and the size bins were combined for composition lengths shorter than 52 cm in Model 16.1.

Residuals for the 2012 and 2016 Slope survey composition data remained problematic in both these models. In addition longline fishery data had substantial residual pattern with an overestimates of larger fish than what was observed. To better fit these data a new block was created for 2011 through 2016 for the Slope survey species composition data and the longline fishery data were allowed to be dome-shaped in Model 16.3.

To simplify data conflicts, a model Model 16.4 in which the ABL longline size composition data were removed was evaluated with the justification that data were aggregated by sex and fit poorly. The lack of fit was likely due to the high degree of sexual dimorphism found in this species (bimodal size distribution when aggregated).

Finally, it was noted that good recruitment appeared to only occur in years where the bottom temperatures were well below the mean. For exploratory purposes we created an environmental index of bottom temperatures, then set a vector to 0 or -1 when temperatures were below 1standard 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_O for years that were deemed "cold" from those that were not.

We adopted the naming convention proposed in September 2015 so that "Model 15.1" represents the configuration and data used in the model accepted in 2015. In this assessment we thus proposed four model configurations:

Model 15.1	Same configuration as Model 15.1 from last year except with the addition of 2016 Slope index and size composition data. Model 15.1 incorporates refined sample size estimates for the slope survey composition data and re-weighted other data. The Shelf survey size composition data and size at age data are used but the age composition data are not. Naïve data fits to the age composition data were available, but the age composition data did not influence model fit. Selectivity for the fixed gear fishery "double normal" to account for the change in fishing behavior in 2008. The 2006 and 2007 trawl fishery size composition data were excluded due to very small sample sizes.
Model 16.1	Same configuration as Model 15.1 except the size bins lower than 50 cm were combined for both sexes.
Model 16.3	Same configuration and data as Model 16.1 except there is an added time block in the slope survey for 2011 – 2016 to account for the change in migration into the area which appears to be density dependent. The Slope survey selectivity curve was also changed to a double normal constrained to be asymptotic by fixing parameters 4 and 6. The longline fishery selectivity was allowed to be dome-shaped by freeing parameters 4 and 6.
Model 16.4	Same configuration as Model 16.3, except the size composition from the ABL longline survey size composition data are excluded from the model.
Model 16.6	Same configuration as Model 16.6, except R_0 is conditioned using bottom temperatures. This model was not considered for management as the vector used in the environmental index has not been vetted.

New data for the assessment included 2016 NMFS slope bottom trawl, NMFS shelf bottom trawl, and ABL longline survey estimates and size compositions. Age composition and size at age data from the 2015 NMFS Shelf survey also became available and were used in this assessment. Fishery catch estimates were updated including projected values for 2016. Data on fishery size composition for 2016 were included.

Summary of Results

Spatial evaluations show that maturing Greenland turbot migrate from the shallow Shelf area onto the deeper slope regions and likely further to the north outside of the NMFS survey area and US zone. The deeper NMFS bottom trawl survey on the EBS slope captured primarily adult Greenland turbot and was most recently conducted in 2016. The 2016 slope survey continues to show a large number of fish consistent with a large pulse of recruitment from 2007-2010. The 2016 numbers were higher than expected given natural mortality alone, but show limited new recruitment post-2010. In addition the shelf survey and fishery data from the shelf show no signs of continued good recruitment. This is not surprising given the high temperatures encountered in 2015 and 2016 on the shelf.

For the fishery data, an apparent shift in the longline fishery to shallower depths occurred in 2010 which resulted in smaller Greenland turbot on average. This change in fishing strategy was taken into account for the current models with a selectivity block in the longline fishery for 2008-2015 in all the models presented allowing temporal changes and dome-shaped selectivity for this gear.

For the model configurations evaluated, the 2007-2010 year classes were consistently estimated to be well above average and contribute to projected biomass increases. However the 2010 year class was much reduced compared to last year's models. The estimates of $B_{100\%}$ ranged between 102,330t and 105,877 t for Models 16.3 and 15.1, respectively. The estimated 2016 spawning stock biomass ranged between 32,507 t (Model 16.1) and 43,476 t (Model 16.3). The 2016 status for the stock was between $B_{32\%}$ for Model 16.1 and $B_{41\%}$ for Model 16.3 compared to $B_{25\%}$ from last year's projection. The projected 2017 estimated total biomass for the models examined ranged between 104,118t (Model 15.1) and 112,349 t (Model 16.3), were both lower than last year's projection for 2017 of 123,494 t.

For all the models presented the stock would be classified as within Tier 3A in 2017 and therefore no reduction in ABC or OFL would be warranted. The corresponding 2017 maximum permissible ABCs from these models were substantially different and ranged from 7,749 t (Model 16.1) to 10,079 t (Model 16.3).

Under Models 15.1 and 16.1 the stock would be considered overfished as the 2016 female SSB was below $B_{35\%}$, and projected not above $B_{35\%}$ in 2026. Under Models 16.3 and 16.4 the stock would not be considered overfished as the 2016 female SSB is above $B_{35\%}$. In all models presented the stock was not approaching an overfished condition as the stock would be above $B_{35\%}$ in 2017 and 2018. Model 16.6 was not considered as it was experimental and not yet ready for management purposes.

Based on model performance in both fit and retrospective analysis Model 16.4 is recommended for management purposes, however we recommend taking a more precautionary approach to setting the ABC for 2017 and 2018. It is likely that the stock will continue to experience poor recruitment for the foreseeable future. For this reason it may be advisable to reduce fishing mortality to below that which is recommended under Model 16.4. Several options are discussed in the Specification of OFL and Maximum Permissible ABC and ABC Recommendation section. The author's preferred method is setting catch to 7,000 t or maximum ABC, whichever is least. The results are summarized in the following table.

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year* for: 2017	2018
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3b	3b	3a	3a
Projected total (age 1+)	114,438	123,494	121,804	122,032
Female spawning biomass	31,028	41,015	50,461	55,347
Projected				
$B_{100\%}$	126,441	126,441	103,097	103,097
$B_{40\%}$	50,577	50,577	41,239	41,239
$B_{35\%}$	44,255	44,255	36,084	36,084
F_{OFL}	0.10	0.14	0.29	0.29
$maxF_{ABC}$	0.08	0.11	0.18	0.18
F_{ABC}	0.08	0.11	0.13	0.12
OFL (t)	4,194	7,416	11,615	12,831
maxABC (t)	3,462	6,132	9,825	10,864
ABC (t)	3,462	6,132	7,000	7,000
EBS (ABC, t)	2,673	4,734	6,111	6,111
Aleutian Islands (ABC, t)	789	1,398	889	889
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

**Based* on Model 16.4 and recommended 7000 t management rule.

Responses to SSC and Plan Team Comments on Assessments in General

None

Responses to SSC and Plan Team Comments Specific to this Assessment

None – No comments specific to this stock in the December 2015 SSC minutes.

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; Fig. 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): Fig. 5.3, Fig. 5.4 Fig. 5.5, and Fig. 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): Fig. 5.7).

Juveniles are generally absent in the Aleutian Islands regions, 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 (Fig. 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 (Fig. 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). Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This 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 4,468 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 1,752 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 2,175 t. In 2016 although the ABC was 3,462 t the TAC was set at

2,873 t and as of September 24, 2016 total catch was at 2,065 t. However the fishery is expected to take the remaining quota by the end of the year.

The majority of the catch over time has been concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (Fig. 5. 5 and Fig. 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 (Fig. 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. For 2008, 2012, 2013 and 2014, Greenland turbot catch in the arrowtooth/Kamchatka fishery has exceeded the directed catch. In 2014 through 2016 commensurate with the reduction in the Greenland turbot TAC, catch in the Aleutian areas has dropped and the highest amounts of catch have once again been observed as dispersed along the shelf edge in the northern part of the Bering Sea (Fig. 5.7).

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 (Fig. 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 fisheries (at about 55% of all sources of Greenland turbot discards during 1992-2003) while Pacific cod fisheries and the “flatfish” fisheries also have contributed substantially to the discard levels (Table 5.2). About 10% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2016. The overall discard rate of Greenland turbot has dropped in recent years from a high of 84% discarded in 1992 down to only 2% in 2011 and 2012. However due to the large numbers of small Greenland turbot encountered in the flatfish and Arrowtooth/Kamchatka fisheries in 2013 and 2014 the discard rate once again rose to 20% in 2013 and 15% in 2014. The discard rate 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 5.4% and as of October 4, 2016 the discard rate for 2016 was 2.8%. In the preliminary 2016 catch data 22.6% (13.3 t of 58.8 t total) of discards came from the Greenland turbot fishery, 19.7% (11.6 t) from the Pacific Halibut fishery, 19.7% (11.6 t) from the Pacific cod fishery, 7.8% of the Greenland turbot discard was from the flatfish fisheries (4.6 t), and 7.0% (4.1 t) has come from the Arrowtooth and Kamchatka fisheries.

Greenland turbot catch in the Aleutian Islands through 2007 was split nearly evenly between trawl and longline, since 2008 the majority of Greenland turbot in the Aleutian Islands has been caught by trawl

(Table 5.4). In the domestic EBS fishery catch of Greenland turbot was predominantly from the Longline fishery except for 1991,1994,2008, 2013, and 2014 (Table 5.3). In 2015 the longline fishery caught 1,093 t and the trawl fishery 997 t. In the preliminary 2016 data the EBS trawl fishery has caught a larger share of EBS quota than longliners (1,115 t vs. 854 t), but this was also true at this time in 2015 and it is expected that the longline fishery will again surpass the trawl fishery by the end of the year. By target fishery, the gain in trawl-fishery has occurred primarily in the Greenland turbot target fishery in 2009 and arrowtooth flounder/Kamchatka fisheries in 2008 - 2015 (Table 5.3). However in 2016 there is a large directed catch of Greenland turbot in the directed fishery (40.7% in 2016 up from 1.7% in 2015).

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 5.8.

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.

Size and age composition

Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2016. The length composition data from the trawl and longline fishery are presented in the Appendix 5.1 (along with the expected values from Model 16.4, http://www.afsc.noaa.gov/REFM/Docs/2016/Gturbot_Appendix5_1.xlsx) and absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2016 are given in Table 5.6

Catch totals from research and other sources

Annual research catches (t, 1977 - 2016) from NMFS longline and trawl surveys are estimated as follows:

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
NMFS BT surveys	62.5	48.3	103.0	123.6	15.0	0.6	175.1	26.1	0.5	18.5	0.6	0.7	11.4	0.9	1.4	8.5	1.4
Longline surveys	3	3	6	11	9	7	8	7	11	6	16	10	10	22	23	23	

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
NMFS BT surveys	1.5	4.6	1.4	1.0	6.6	1.1	6.6	1.1	12.8	0.7	3.0	0.6	4.8	0.4	6.6	1.0	4.9
Longline surveys	1.3	37.43	8.4	18.8	4.1	15.4	3.8	13.1	3.0	8.8	1.8	6.3	1.3	3.1	0.6	3.3	na

Year	2013	2014	2015	2016
NMFS BT surveys	1.0	1.3	0.9	5.6
Longline surveys	Na	Na	Na	Na

Analyses examining the bycatch of Greenland turbot in directed halibut fisheries indicate an average of just over 109 t from 2001-2010 (more recent data are not available) with about 49 t average since 2006 (NMFS Regional Office). Data available on AKFIN and provided by the NMFS Alaska Regional Office on 2010 sport and research Greenland turbot catches are:

Source	t
2010 Aleutian Island Bottom Trawl Survey	0.530
2010 Bering Sea Acoustic Survey	0.000
2010 Bering Sea Bottom Trawl Survey	0.816
2010 Bering Sea Slope Survey	5.210
2010 Northern Bering Sea Bottom Trawl Survey	0.004
Blue King Crab Pot	0.056
IPHC (halibut commission)	2.989
NMFS LL survey	0.364

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 (Fig. 5.9). The slope survey likely under-represents the actual abundance of Greenland turbot and is therefore treated as index of abundance. The survey is thought to under-represent the actual abundance because the species appears to extend beyond the area of the surveys and the ability of the 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. 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 for Model 16.4, 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 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 (Fig. 5.10).

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 39,602 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. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys were presented in Table 5.10. In 2011 and 2010 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 (Fig. 5.9). These observations suggest that the extent of the spatial distribution has remained relatively constant prior to 2010 (with a slight increase) and that these two surveys had both higher densities and broader spatial distribution. The 2014-2016 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 (Fig. 5.10). The 2016 biomass was 22,429 t down from 25,240 t in 2015 and 28,028 t from 2014.

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 2001-2006 (Fig 5.10). 2012-2016 shows the progression of the earlier large year classes, and the lack of any substantial new recruitment into the area.

Survey length-at-age data was available and used for estimating growth and growth variability were previously available from 1982, 1998, and 2003-2015. Gregg et al. (2006) revised age-determination methods for Greenland turbot and although survey age composition data from 1998 and 2003-2015 were included in the model, but were not included in the likelihood function.

Aleutian Islands survey

The 2016 Aleutian Islands bottom trawl survey continued the slow decline in biomass for this area at 2,378 t from 2,529 from 2014, well below the 1991-2012 average level of 12,598 t (Table 5.11) and comparable to the 2012 estimate of 2,600 t. However, 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 489 t (19% of AI biomass) but increased to 965.9 t (40.8 % of AI biomass) in 2016. The estimated proportion of Greenland turbot in the eastern area for 2016 of 40.8% remained below the 1980- 2010 average of 67% of the survey abundance. Only in 2004 and 2012 was the area estimate lower than the other regions. 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 Fig. 5.10.

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 Model 16.4 and Model 16.6 explored in this year's assessment do 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 2016. 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 four of the models explored were similar.

Parameters estimated independently

All independently estimated parameters were the same for all four models presented.

Parameter	Estimate	Source
Natural Mortality	0.112	Cooper et al. (2007)
Length at Age		
L_{min} CV	8%	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 an 8% CV while at age 21 a CV of 7% was assumed. This appears to encompass the observed variability in length-at-age. As with last year, 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 last year's 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, the ABL survey at 60, and the pre-2002 slope surveys set at 25, while 2002 and later set at 400.- were set the sample size for the slope survey were increased to 400 to better balance these surveys with the more frequent shelf survey. The shelf trawl survey sample sizes were set to 200, the 2002 through 2012 slope survey sample sizes were set to 400, while those prior to 2000 were set to 25. The ABL longline sample sizes were set to 60.

Parameters estimated conditionally

The name of key parameters estimated and number of parameters within the four candidate models and exploratory Model 16.6 were:

	Model 15.1	Model 16.1	Model16.3	Model 16.4	Model 16.6
Recruitment					
Early Rec. Devs	(1945-1970) 25	(1945-1970) 25	(1945-1970) 25	(1945-1970) 25	(1945-1970) 25
Main Rec. Devs	(1970-2012) 43	(1970-2012) 43	(1970-2012) 43	(1970-2012) 43	(1970-2012) 43
Future Rec. Devs	(2013-2017) 5	(2013-2017) 5	(2013-2017) 5	(2013-2017) 5	(2013-2017) 5
R_0	1	1	1	1	1
Autocorrelation ρ	1	1	1	1	1
R_0 environmental link	0	0	0	0	1
Naural mortality					
Male	0	0	0	0	0
Female	0	0	0	0	0
Growth					
L_{min} (M and F)	2	2	2	2	2
L_{max} (M and F)	2	2	2	2	2
Von Bert K (M and F)	2	2	2	2	2
Catchability					
q_{shelf}	0	0	0	0	0
q_{slope}	0	0	0	0	0
Selectivity					
Trawl fishery	17	17	15	15	15
Longline fishery	22	22	28	28	28
Shelf survey	17	17	17	17	17
Slope survey	5	5	19	19	19
ABL longline survey	2	2	2	0	0
Total Parameters	72	72	89	87	88

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. Initial analysis 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, in 2011 the 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.

In the models considered this year, 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 Rec. Dev.s) were estimated separately from the post-1970 recruitment deviations (Main Rec. Dev.s). Separating the Rec. Dev.s 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. It should be noted that in the models explored this year the differentiation between the two periods has no effect on model results. This configuration is simply implemented to allow flexibility in exploring other model alternatives in the future.

For exploratory Model 16.6 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 1982-1977, 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 in the Slope Survey

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 ($\log(q_{\text{shelf}}) = -0.4850235$ and $\log(q_{\text{slope}}) = -0.5555418$).

Selectivity

Sex-specific size-based selectivity functions were estimated for the two trawl surveys and the two fisheries. For Model 15.1 time blocks were used to estimate time varying selectivity. The different time blocks for the fisheries and surveys are shown in the table below. For Model 15.1, 16.1, and 16.3 these blocks were the same as those used in the 2014 and 2015 Models. For Model 16.4 and Model 16.6 an additional block was added to the slope survey for 2011-2016. In Model 15.1, 16.1, and 16.3 data from the longline survey are combined hence a sex aggregated size-based selectivity function was used. For Model 16.4 and Model 16.6 the ABL longline survey length composition data were not used.

<table>
<tr><th></th><th colspan="2">Model 15.1</th><th colspan="2">Model 16.1</th><th colspan="2">Model 16.3</th><th colspan="2">Model 16.4</th><th colspan="2">Model 16.6</th></tr>
<tr><th></th><th>Type</th><th>Blocks</th><th>Type</th><th>Blocks</th><th>Type</th><th>Blocks</th><th>Type</th><th>Blocks</th><th>Type</th><th>Blocks</th></tr>
<tr><td>Trawl Fishery</td><td>Double Normal</td><td>1945-1988
1989-2005
2006-2015</td><td colspan="8" rowspan="3">Same as Model 15.1</td></tr>
<tr><td>Longline Fishery</td><td>Double Normal</td><td>1945-1990
1991-2007
2008-2016</td></tr>
<tr><td>Shelf Survey</td><td>Double Normal</td><td>1945-1991
1992-1995
1996-2000
2001-2016</td></tr>
<tr><td>Slope Survey</td><td>Logistic</td><td>1945-2001
2002-2016</td><td colspan="2" rowspan="2">Same as Model 15.1</td><td>Double Normal</td><td>1945-2001
2002-2010
2011-2016</td><td colspan="2">Same as Model 16.3</td><td colspan="2" rowspan="2">Same as Model 16.4</td></tr>
<tr><td>ABL Longline Survey</td><td>Logistic</td><td>None</td><td colspan="2">Same as Model 15.1</td><td>NA</td><td></td></tr>
</table>

If the size selectivity pattern is specified as logistic, then SS3 requires 3 parameters to differentiate the curve from the opposite sex:

p1 is added to the first selectivity parm (inflection)
p2 is added to the second selectivity parm (width of curve)
p3 is the asymptotic selectivity

If the size selectivity pattern is specified as a double normal, then five parameters are needed to differentiate from the opposite sex:

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

Results

Model Evaluation

Model 15.1, Model 16.1, and Model 16.3 all have the same data components and data weighting. Therefore these models can be compared directly for all likelihood components. Model 16.4 and Model 16.6 do not include the ABL longline survey length composition data, so overall likelihoods cannot be compared, but all other components can be. Selection among models was based on model conformance with known biological factors, model likelihood/fit, and retrospective analyses. Figure 5.11 shows the fits to all of the size composition data for all the models across all size bins and years and Figure 5.12 shows the overall fits to the length composition data across all years for the two fisheries and two trawl surveys.

Table 5.16 includes the likelihood values for last year's authors' preferred model and this year's models, key parameter fits, reference points, and key model results. Table 5.17 and Table 5.18 provide measures of model fit to the individual component of all five models including retrospective indices, survey index RMSE, mean effective N for the age and size composition data and the recruitment variability for the candidate models. Figure 5.11 shows results for the models considered, including differences in recruitment, estimates of the spawning biomass in 2016, and spawning biomass time series. Certainty bounds were the standard errors obtained from the inverted Hessian matrix. Although recent recruitments were not substantially different among models, recruitments prior to 1980 show marked differences among models. Model 16.6 recruitments are particularly different from the other models. Differences in spawning biomass was large among models for earlier years, but all the models appear to converge in a relatively narrow estimate for the 2016 female spawning stock biomass. Figure 5.12 shows the overall fit and Figure 5.13 shows the Pearson residuals for each of the length composition data components for Model 15.1, Model 16.1, Model 16.3, and Model 16.4. Differences between Model 15.1 and Model 16.1 were difficult to discern at this scale. Differences in fits between Models 16.1 and Model 16.3 can easily be identified in the fits to the fishery longline data where the over-prediction of larger female fish (> 80cm) was reduced substantially in Model 16.3. Differences in model fits to the species composition data between Model 16.3 and Model 16.4 were not visually discernable. The model residuals are shown in Figure 5.13 showing similar pattern. Fits to the indices can be seen in Figure 5.14 (Shelf survey), Figure 5.18 (Slope survey) and Figure 5.21 (ABL longline survey). The differences in model fits to the indices was subtle, particularly between Model 15.1 and Model 16.1 and between Model 16.3 and Model 16.4. Difference between these two sets of models are more apparent particularly for the Slope survey where the addition of another selectivity block appears to provide a better fit for the 2002 and 2008 slope surveys.

Plots of mean length and model fits can be found in Figure 5.17 (Shelf survey), Figure 5.20 (Slope survey), Figure 5.23 (ABL Longline fishery), Figure 5.26 (Trawl fishery), and Figure 5.29 (Longline fishery). Differences in fit to the Shelf survey and trawl fishery mean length were not readily discernable in these figures, however there were distinct differences in the predicted mean age between Models 15.1 and 16.1 and Models 16.3 and 16.4 with a better prediction for the 2008 and 2012 surveys in the latter two models. The longline fishery data also show a marked improvement in predicting mean length for the latter two models as well, particularly for the 2008 through 2012 data sets.

The difference between Model 15.1 and Model 16.1 was the aggregation of size composition data for both sexes for fish less than 52 cm in Model 16.1. Changes in selectivity due to this model alteration although apparent, were difficult to visually evaluate because they tended to be somewhat subtle (Fig. 5.15, Fig. 5.16, Fig. 5.19, Fig. 5.22, Fig. 5.24, Fig. 5.25, Fig. 5.27 and Fig. 5.28). This improved model likelihood fits to all data components (Table 5.18, Fig. 5.12, and Fig. 5.13) except the longline fishery length composition data which had a reduction in fit by 2.5 log likelihood points, and the shelf survey which had a reduction in fit of 0.02 log likelihood points (Table 5.18 and Fig. 5.14). The overall improvement to the model was 81.47 log likelihood. The recruitment likelihood was also affected with a change from 97.33 in Model 15.1 to 98.96 in Model 16.1. A retrospective analysis was conducted which investigating one measure of retrospective bias by removing data for an entire year back 10 years and then refit the model for each annual removal (Hanselman *et al*. 2013; Fig. 5.30 and Fig. 5.44). In this analysis there was a slight degradation in the Mohn's ρ retrospective value (0.061 to 0.118 for female SSB), but an improvement to both the Woods Hole ρ (from 0.061 to 0.056 for female SSB) and RMSE (0.11 to 0.094 for female SSB) from Model 15.1 to Model 16.1. Overall aggregating the size composition data at less than 52 cm for the two sexes appears to be an improvement to the model.

The major difference in configuration from Model 16.1 to Model 16.3 was in changing the Slope survey selectivity from a logistic to a double normal and adding an additional time block for 2011-2016 for the slope length composition data (Fig.5.19). This time block was justified in that we theorized that there was a density dependent change in selectivity for the slope due the large 2007-2010 year classes. This was evidenced by fish migrating off the shelf at smaller sizes/younger ages than previously observed. This change to the model improved the overall fit by 181.21 log likelihood points with the addition of 17 parameters (Table 5.16). Substantial improvements were attained in fits to the longline fishery, ABL longline, and Slope survey length composition data as well as the Shelf and Slope index data (Table 5.18). Gains were marginal for the Shelf survey composition and the model fit to the Trawl fishery length composition data and ABL longline index data were degraded somewhat. There was a change in the recruitment log likelihood from 98.96 in Model 16.1 to 96.17 in Model 16.3. The retrospective analysis showed an increase in retrospective bias from Model 16.1 to Model 16.3 with Mohn's ρ changing from 0.118 to 0.192, Woods Hole ρ changing from 0.056 to 0.108, and the RMSE from 0.094 to 0.116. Overall Model 16.3 was a better fit model than Model 16.1, however the increase in retrospective bias was reason for concern.

The only difference between Model 16.3 and Model 16.4 was not including the ABL longline survey length composition data. This was justified in that the sexes were not determined for these size composition data. After 52 cm the sizes of the two sexes diverge substantially, the length distribution data therefore was bi-model and were never adequately fit in any of the previous models. The selectivities fit for the two models were not visually distinguishable between the two models for any length composition component. Removing the ABL length composition data improved the fit to all components included in both models by 5 log likelihood points from 1841.72 for Model 16.3 to 1836.72 for Model 16.4. These improvements were primarily in Recruitment (96.17 to 94.12), Trawl Fishery size composition data (105.7 to 102.38), size at age (1150.60 to 1144.47), and ABL longline survey index (8.37 to 7.63). All other components saw some level of decrease in fit, the largest being a 3.83 point increase in log likelihood in the slope length composition data. For the most part the fits to the data components are very similar, the greatest improvement was the change in the retrospective bias. Model 16.4 had an improved Mohn's ρ over Model 16.3 at 0.116 versus 0.192, the Woods Hole ρ improved by -0.095 from 0.108 in Model 16.3 to 0.013 in Model 16.4, and the RMSE changed from 0.116 in Model 16.3 to 0.057 in Model 16.4. Model 16.4 also had Woods Hole ρ and RMSE values closer to zero than with Model 15.1 and Model 16.1. Overall Model 16.4 appears to be an improvement over Model 16.3 with both a slight improvement in overall fit to the data included in the model and a reduction in retrospective bias as measured by the three retrospective indices evaluated.

Model 16.6 was provided as an interesting avenue for future research and shows a possible way in which climate could be introduced into our models. Here R_0 was conditioned on a bottom temperature index which identified extreme cold conditions on the Eastern Bering Sea shelf. This was the only change in the model from Model 16.4 and involved the addition of one parameter. The overall improvement in likelihood from Model 16.4 to Model 16.6 was 30.46 log likelihood points, with the majority of that being in the recruitment which changed from 94.12 in Model 16.4 to 73.10 in Model 16.6. The change between models improved fits to all data components except the Longline fishery size composition (61.6 to 63.38) and shelf survey size at age (1144.47 to 1144.58). In the retrospective analysis both the Mohn's ρ and Woods Hole ρ improved from Model 16.4 to Model 16.6 changing from 0.116 to 0.097 and 0.013 to 0.002, while both the RMSE showed slight degradation changing from 0.057 to 0.067 in Model 16.4 to Model 16.6. Although Model 16.6 appears to be an improvement over Model 16.4, the environmental index used needs to be better vetted and the author's don't think this model is currently ready for management. Results from Model 16.4 and 16.6 were nearly identical.

Although some models were explored this year to evaluate the catchability of the two index surveys, the MCMCs and retrospectives of the models in which these parameters were fit were not stable, tending to make the shelf survey catchability go towards infinity. We therefore did not present any of these models for review by the Plan Team.

For this year the authors would recommend changing to Model 16.4 for the base stock assessment, but consider Model 16.6 with the environmental link on R_0 as an alternative model to be explored further in the 2017 stock assessment cycle. More work should be done on this model in vetting the environmental index used and its relationship to recruitment.

Model 16.4 diagnostics and suggestions for future improvement

Model predicted numbers at size, number at age, and size selectivities for each fishery and survey are presented in an Excel spreadsheet in supplemental Appendix 5.1 ( ).

Survey indices

The Model 16.4 fit to the survey indices was marginally better than last year's model (Fig. 5.14, Fig. 5.18, and Fig. 5.21). As was the case in previous assessments, Model 16.4 fails to fit the high 1994 shelf survey biomass estimate. The model estimated shelf survey biomass follows a general downward trend and with an increase due to the high numbers of small fish observed in the 2008 through 2013 shelf surveys and 2012 and 2016 slope survey. Larger Greenland turbot are thought to migrate off the shelf and this probably varies depending on environmental conditions and population density. This type of variability (due to irregular ontogenetic movement) may support the need for an additional time block starting in 2011 as implemented in Model 16.4.

The Slope survey index used in this year's assessment had six data points which were reasonably fit in the model (Fig. 5.18). Besides issues related to variable ontogenetic movement discussed above, the stock also straddles the US/Russian border. The rate that fish migrate between these regions is unknown. Such migration could affect the population's availability to the US surveys. Additional tagging studies should be conducted to address the issue of adult Greenland turbot movement. The tagging studies should be conducted cooperatively between the US and Russian management agencies if possible.

The fit to the ABL longline survey index of abundance (Fig. 5.21) mimics the 1996 - 2010 index decline with a leveling off in 2011-2014 and an increase in 2015 and 2016 despite the low 2016 estimate. There continues to be a trend in the residuals where the earlier high values tended to be underestimated. It should be noted that the uncertainty used for all of the survey index values in this model was CV = 0.198. Because the 2006 through 2015 values were low compared to the earlier surveys, the uncertainty around these points was also lower. The point estimates for this period are likely less precise than what was assumed. A geostatistical based estimate of variability should be explored for this index which could provide a better starting point for the uncertainty used in our assessment.

Age composition

Even though the shelf survey age composition data were not fit in the model, the age composition predictions matched the data well for both males and females (Fig. 5.31). The model did particularly well for the age compositions prior to 2013. The 2013 and 2014 age composition predictions estimate a somewhat younger size at peak abundance than observed for both males and females for both years. 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.

Length at age

The fits to the length at age data for both males and females were good (Fig. 5.32). There was some annual variability, but this could be due to the lower sample sizes for those age classes and years (the fits lie within the data confidence intervals for the majority of points). There may be some change in growth occurring for the 2005-2015 males and a time varying growth could be explored in future models.

Size composition

Overall Model 16.4 did a reasonable job of capturing the large trends observed in the size composition data (Fig. 5.18 and Fig. 5.19). The Model 16.4 fit shelf survey length composition data was improved over the fit in the 2015 Model configuration particularly for the 2005 through 2010 data that wasn't fit well in previous models. In aggregating the under 52 cm fish the model is better able to fit the small fish, which previous models had difficulty with the males given the inflexible selectivity curves and parameterization. The model also does a better of fitting males when large year classes appear in the data, where Model 15.1 consistently underestimated smaller fish. Model 16.4 provided good fits to the annual mean lengths, however because these populations are bimodal, the fit to the combined mean length may not be a good metric to determine model performance.

The Shelf survey was fit with a double normal selectivity curve with four time blocks Model 16.4 captured the large influx of small fish in 2007 through 2010 (Fig.5.33) It also performed well in following the general trends in size composition over the year. In 1995- 1998 the model tended to overestimate the number of large females, while in 2000-2004 the large females tended to be underestimated. The fits to the mean length over time was indistinguishable from the fit using last year's accepted model, however the likelihood changed by 58.7 points from 321.62 in Model 15.1 to 262.94 in Model 16.4. This improvement in fit was achieved primarily in the aggregation of the sexed data for fish under 52 cm.

The slope survey size composition selectivity was modeled as a double normal with three time blocks and selectivity for males and females. The model fits (Fig. 5.34) were substantially better than last year's Model an overall lower log likelihood (325.38 versus 195.49) and increased effective sample sizes for all recent years (2002-2016). The fits continued to underestimate the peak of the highest abundance size bins, particularly for males (Fig. 5.34). This may therefore, underestimate the number of large males in the population. No other survey or fishery encounters these large males. The model predicts there to have been a larger proportion of males to females (males/female ratio up to 1.6) in the population between 1990 and 2010 for older fish (ages 15 to 30; Fig. 5.35, Fig. 5.36, and Fig. 5.37). In the model and in reality the longline and trawl fisheries disproportionately catch more females, creating this unbalanced population in older fish.

The Auke Bay Laboratory size composition data were not used in this model. In the 2015 model these data were from combined sexes and as such they were very difficult to model using standard selectivity curves. Better model fits were achieved in models presented in 2013 that used splines. These were rejected by the Plan Team and the authors agree that using splines has the problem of overfitting the data and making selectivity curves that are not easily interpretable. Splitting the selectivity for males and females may improve the fit slightly, but short of this or using splined selectivity, there are no further options available for improving the fit to these data. Excluding the data allowed a better overall fit to the other data sources in the model.

The fit to trawl fishery size compositions in Model 16.4 was only slightly improved over Model 15.1 with a change in likelihood of 105.85 to 102.38. The large peaks in the trawl fishery size composition data (Fig. 5.13) were often underestimated in this model for both males and females. The patterns in the residuals for these data remain problematic (Fig.5.13). There was a large shift in the trawl fishery selectivity between the foreign and domestic fisheries (Table 5.19) and another less severe change in 2008 when the Arrowtooth/Kamchatka fishery started. Even with the additional flexibility in fitting the two sexes with time blocked selectivity, there remains patterns in the residuals for females that are problematic in the early years of the size data (1979-1989; Fig. 5.13) where some large year classes may be underestimated. The trawl fishery size composition data are pooled from the directed fishery and from fish caught in other fisheries. The directed fishery targeted the larger fish (predominantly females) on the slope, while the bycatch fishery mostly caught smaller fish (predominantly males) on the shelf resulting in very different expected selectivity patterns for the two sexes. Currently SS3 can't handle such a large difference in selectivity patterns between sexes for the same fishery. In previous years the author attempted to separate out the bycatch trawl data from the targeted trawl fishery data to see if the patterns in the size composition data for these early years can be rectified in future assessments. Since target was not included in the data prior to 2003, this task did not prove possible given the constraints of the data.

With this year's improvements the Model 16.4 fit to the longline data (Fig. 5.39. and Fig. 5.13) appeared reasonable. The double normal used in this year's model allowed the selectivity to become dome-shaped and provided a better fit overall to the longline fishery data. There was a shift in selectivity to smaller fish between the two early time blocks and a larger shift in the later 2008-2015 time block (Fig. 5.28). The ability of the model to fit a lower selectivity for large males while keeping high selectivity for large females ,which are targeted by the fishery, allowed tighter fits to the data. Having higher selectivity for smaller males than females mimics the migration of males to deeper waters at smaller size than females.

Time Series Results

In this section we will present the results from Model 16.4 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 16.4 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 0.607 with a standard deviation of 0.037. The most striking feature of the Model 16.4 recruitment (Fig. 5.40, Table 5.20, and Table 5.21) was the extremely large 1961- 1966 year classes with between 93 and 365 million age 0 recruits. 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 16.4 (like last year's model) 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. The model configuration chosen last year and all models presented this year with the autocorrelation parameter spread these recruitment events out without assuming changes in early productivity. The autocorrelated configuration was rejected by the Plan Team in 2012 because the inclusion of autocorrelation in SS3 had not been thoroughly vetted. However the configuration was accepted in 2014 in light of a study by Thorson et al. (2014) showing improved model performance with the assumption of autcorrelated recruitment deviations.

After 1970, Model 16.4 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 205 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 know 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 for the projection model, used for determining the reference points and setting catch levels, we only use age 1 recruitment from1978 onward.

Recruitment from 1980 through 2006 was low with a mean of 5 million age-0 fish (rec.var = 1.06). The mean Age 0 recruitment for 1977 through 2015 was estimated at 11.6 million fish (rec. var. = 1.26). Recruitment of age 0 fish was estimated in 2007 at 24.9 million, 2008 at 55.48 million, 2009 at 42.67, and 2010 at 8.18 million age 0 fish. Recruitment in 2008 was the largest since 1977. 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 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 (Fig. 5.36 and Fig. 5.37).

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass in Model 16.4 was projected for 2016 at 41,407 t to be increasing from its lowest level of 27,115 t ($B_{26\%}$) in 2013, a drop from a peak of 313,110 t in 1975

($B_{304\%}$; Table 5.22, Table 5.23, Fig. 5.41 and Fig. 5.42). 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 2006 was 4.4 million fish (38% of the overall 1977-2015 mean recruitment). In 1990 the NPFMC cut ABCs to 7,000 t until through 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 steepened post-2008. This decline may be correlated with increased fishing pressure during this period. Between 1986 and 2007 the mean total exploitation was estimated at 0.09 with a maximum total exploitation rate of 0.15 (Table 5.22 and Fig. 5.43). The increased fishing exploitation rate in 2009 and 2010, that may have steepened the most recent decline, was only 0.18. The catch levels in 2009 through 2012 however would have exceeded the OFL control rule levels projected from Model 16.4 (Fig. 5.44). The effects of the incoming 2007-2009 year classes are creating a steep increase in both the total biomass and female spawning biomass estimates. Projections for 2017 and onward predict an increase in spawning biomass as these year classes grow and mature.

The Model 16.4 total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 of 794,690 t to its lowest point in 2010 of 69,475 t (Fig. 5.42). 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 120,900 t in 2016 and projected to be at 121,804 t in 2017. Part of the increase in biomass from last year's assessment is an increase in the average weight at age in this year's model (Table 5.24) with the inclusion of the 2015 length at age data.

<u>Retrospective analysis</u>

The retrospective analysis was conducted in SS3 by removing data systematically by year from all models for 10 years (Fig. 5.45). The largest changes in the retrospectives for all models were between -9 and -8 years (between 2007 to 2008) when the large number of young fish were first observed in the Shelf survey. There is also evident 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 (Fig. 5.30).

In general, Model 16.4 provides better retrospective pattern than last year's model for the overall time series, but doesn't do as well for the more recent data (Model 15.1 Woods Hole $\rho = 0.06$ and Mohn's $\rho = 0.061$ vs. Model 16.4 Woods Hole $\rho = 0.013$ and Mohn's $\rho = 0.116$). This is not unexpected because Model 16.4 has an added time block in the Slope survey which impacts the most recent predictions, following the large year class as it arrives on the Slope, as we peel data away the year classes are overestimated in the model creating a slight positive retrospective model. In both models R_0 is affected by the large year classes, even with a fixed catchability for Model 16.4 an increasing trend is evident as data are removed. Other parameters change with recruitment of the large incoming year classes including shelf and slope selectivity parameters, main recruitment deviations, and growth parameters (Fig. 5.46). von Bertanffy K parameter for both males and females show a slower growth estimated when we include the most recent data, again the change appears to occur with the recruitment of the large 2007-2009 year classes to the shelf survey between years -9 and -8 and may reflect some sort of density dependence effect on growth.

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean recruitment estimated for the period 1978-2014 gives a long-term average female spawning biomass of 41,239 t. The estimated 2016 female spawning biomass was at 41,404 t or $B_{40\%}$, well above the estimate of $B_{35\%}$ (36,084 t). Because the projected spawning biomass in year 2016 (41,404 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. In 2016 a slope survey was conducted and while some areas show lower abundances (i.e., the Aleutian Islands) the signs of recruitment are the best ever seen for this stock. However post-2010 recruitment has been very low. The expectation for the Eastern Bering Sea is continued warming which has been shown to be detrimental to Greenland turbot recruitment. We therefore propose several alternative methods for setting ABC for this long-lived species with intermittent recruitment.

- 7,000 t Rule - a maximum ABC of 7,000 t as used for 1990-1996. Here catch would be limited to 7,000 t or the model maximum ABC whichever was least.

- Warm Climate Model - Model 16.4 projection with average "warm" year recruitment where maximum ABC would be set using projections from Model 16.4, but average recruitment based only on years with annual mean bottom temperatures from the bottom trawl survey higher than 0.5 standard deviations lower than the mean 1982-2016 bottom temperature as calculated by Spencer (2008). Reference points assume a new warm regime.

- Long-term $SSB_{35\%}$ rule - Model 16.4 projection with average warm recruitment as in the Warm Climate model but using $SSB_{100\%}$ as calculated from the full recruitment series 1978-2014 to set a 25-year goal of staying above $SSB_{35\%}$ (36,762 t).

- Long-term $SSB_{20\%}$ rule - Model 16.4 projection with average warm recruitment as in the Warm Climate model but using $SSB_{100\%}$ as calculated from the full recruitment series 1978-2014 to set 25-year goal of staying above $SSB_{20\%}$ (21,007 t).

Each of these alternatives were run forward 25 years to 2040 using the Alaska projection model (Table 5.25 and Fig. 5.47) from Model 16.4 results. For Model 16.4 - Standard and 7,000 t Rule alternatives in the "Warm" scenario catch was reduced to maintain the stock at the standard climate scenario $SSB_{35\%}$ level (36,084 t) to ensure the stock was not overfished. For Model 16.4 – "Warm" alternative $SSB_{100\%}$ was adjusted to a new, lower, level (Warm $SSB_{100\%}$ = 43,778 t) as expected under a warm climate as Greenland turbot productivity would be expected to drop. Under this scenario the catch is set to the warm climate $F_{40\%}$ level. Under the Long-term $B_{20\%}$ alternative the female spawning biomass was allowed to drop below the standard $SSB_{35\%}$, even though this would result in the stock being declared overfished. It should be noted that under the "Warm" climate scenario the mean recruitment drops to 5.48 million fish from 10.68 million fish in the standard climate scenario and long-term expected yield at $F_{40\%}$ would be 2,916 t, a drop from 6,868 t in the standard climate scenario.

Through 2026 catch is nearly the same for both Model 16.4 climate scenarios. Under the Model 16.4 Warm Climate Model alternative catch is maximized over the 40-year period, but the stock becomes overfished in 2026 using the standard climate reference points, but warm average recruitment. To maintain the stock above the currently defined $SSB_{35\%}$ level the Standard Model 16.4 catch is reduced after 2025. Catches in both the Long-term $SSB_{35\%}$ and $SSB_{20\%}$ alternatives are lower than the standard scenario until 2025 when catches under both then begin to exceed the Standard Climate Model 16.4 alternative. The Long-term $B_{35\%}$ alternative results in the greatest lost revenue with 40,045 t less catch through 2026 and 25,485 less through 2040 than the standard model catch. The Warm climate model and long-term $SSB_{20\%}$ model both result in net gains in catch through 2026 (7,688 t and 2,263 t) and 2040 (45,421 t and 38,340 t) over the standard model, however this accepts that the stock will go below the standard $SSB_{35\%}$ level, resulting in the stock being overfished under current rules and reference points. The 7,000 t alternative results in a loss of 4,023 t through 2026 and 4,305 t in catch through 2040 over the standard model catch levels. Again catch is reduced in this alternative after 2026 to maintain the stock above the currently defined $SSB_{35\%}$.

The 7,000 t rule was the authors' preferred alternative because it allowed for an increase in catch as warranted by the new recruitment, however is conservative in that it allows for the stock to remain above $SSB_{35\%}$ through 2029 even with continued low recruitment, as expected in climate forecasts. This alternative also results in a stable fishery with in less forgone catch than the long-term $SSB_{35\%}$ alternative through 2026.

	Recommended ABC (t)		**Female SSB% in 2026**
Alternative	**2017**	**2018**	
Model 16.4 - Standard	9,825	10,635	35.7%
Model 16.4 - "Warm"	9,825	10,635	33.6%
Long-term $B_{20\%}$ rule	8,905	9,712	36.0%
7,000 t Rule	7,000	7,000	39.5%
Long-term $B_{35\%}$ rule	3,280	3,741	55.9%

The projected Greenland turbot maximum permissible ABC, recommended ABC, and OFL levels for 2017 and 2018 are shown below (catch for 2016 was set to 2,186 t):

Year	Catch (for projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2017	7,000	9,825	7,000	11,615	50,461
2018	7,000	10,864	7,000	12,831	56,585

The 2017 estimated overfishing level based on the adjusted $F_{35\%}$ rate is 11,615 t corresponding to a full-selection F of 0.18. 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). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 5.26).

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 22.4%, 10.7%, 8.3% and 9.6%. These average 12.7% which when applied to the BSAI ABC gives the following region-specific allocation:

	2017 ABC	2018 ABC
Aleutian Islands ABC	889	889
Eastern Bering Sea ABC	6,111	6,111
Total	7,000	7,000

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 2015 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2016 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2016 (here assumed to be 2,186 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 2017, 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 2010-2015 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 2016 and above its B_{MSY} level in 2026 under this scenario, then the stock is not overfished.)

Scenario 7: In 2017 and 2018, 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 2018 or 2) above 1/2 of its MSY level in 2018 and expected to be above its MSY level in 2028 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2016 (Table 5.27). Fishing at the maximum permissible rate indicate that the spawning stock (Fig. 5.48) began increasing in 2014 with the incoming large 2007-2009 year classes.

Our projection model run under these conditions indicates that for Scenario 6, the Greenland turbot stock is not overfished based on the first criterion (year 2016 spawning biomass estimated at 41,404 t relative to $B_{35\%}$ = 36,084 t) and will be above its MSY value in 2026 at 36,963 t.

Projections 7 with fishing at the OFL after 2018 results in an expected spawning biomass of 37,614 t by 2028. These projections illustrate the impact of the recent recruitment observed in the surveys and fishery data. For example, under all scenarios, the spawning biomass is expected to continue increasing through 2019 and then drops due to the low recruitments post-2011 and decreasing influence of the 2007-2009 year classes and then levels off as the projection relies on mean recruitment.

Under Scenarios 6 (Fig. 5.49) and 7 of the 2016 Model 16.4 the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

For last year's model with this year's data, Model 15.1, the female spawning stock biomass was projected to be below MSY levels in 2016, but above ½ MSY. The stock was projected be below MSY in 2026 under Scenario 6 ($SSB_{35\%}$ = 37,057 t, SSB_{2016} = 34,468 t, and SSB_{2026} = 36,222 t), but above MSY in 2028 under Scenario 7 (SSB_{2028} = 37,226 t). Using Model 15.1 the stock would be considered overfished, but not approaching an overfished condition. However the authors strongly think that the model configuration in Model 16.4 was an improvement over Model 15.1 in both fitting the data and better capturing the dynamics of turbot migrating from the shelf to the slope.

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 (Fig. 5.50) 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 (Fig. 5.51) 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*; 14,396 t since 1991) and sablefish (*Anoplopoma fimbria*; 5,091 t since 1991), a low impact given the biomass of these species. The non-FMP bycatch are summarized in Table 5.29 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, but at less than 2,500 t per year, 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 3,439 estimated to have been caught since 2003. Northern fulmars (*Fulmarus glacialis*) are the most often captured with a total of 2,797 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

Besides the assessment model improvements suggested above a number of research issues continue to require further consideration. These include:

- An evaluation of possible differential natural mortality between males and females,
- Spatial distribution and migration needs to be better explored through tagging experiments,
- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear.

- Although we understand that a portion of this stock extends into Russian waters, Russian catch is not considered in this assessment. How to take into account this unknown mortality should be explored further.

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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	0.4	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	1,617	6,246	7,863	7,000	7,000
1992	3,665	750	4,414	7,000	7,000
1993	8,361	1,145	9,506	7,000	7,000
1994	3,844	6,427	10,270	7,000	7,000
1995	4,215	3,979	8,193	7,000	7,000
1996	4,900	1,653	6,553	7,000	7,000
1997	5,990	1,210	7,199	9,000	9,000
1998	7,178	1,576	8,754	15,000	15,000
1999	4,020	1,795	5,815	9,000	9,000
2000	5,001	1,947	6,948	9,300	9,300
2001	3,119	2,149	5,268	8,400	8,400
2002	2,500	1,033	3,533	8,000	8,000
2003	2,085	931	3,016	4,000	4,000
2004	1,546	675	2,221	3,500	3,500
2005	1,862	729	2,591	3,500	3,500
2006	1,595	361	1,957	2,740	2,740
2007	1,515	458	1,973	2,440	2,440
2008	963	1,935	2,898	2,540	2,540
2009	1,410	3,080	4,490	7,380	7,380
2010	2,134	1,977	4,111	6,120	6,120
2011	2,043	1,618	3,661	6,140	5,060
2012	2,099	2,613	4,712	9,660	8,660
2013	695	1,045	1,741	2,060	2,060
2014	694	951	1,645	2,124	2,124
2015	1,107	1,095	2,202	3,172	2,648
2016*	868	1,195	2,063	3,462	2,873

*Catch estimated as of October 2016

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by “target” fishery, 1992-2016. 2016 numbers are estimates through October and are not final.

Fishery:	Greenland turbot		Sablefish		Pacific cod		Rockfish		Flatfish		Arrowtooth/Kamchatka		Halibut		Others		Combined	
Year	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard
1992	62	13	202	2,687	135	656	180	103	7	1	6	2			108	262	700	3,724
1993	5,687	332	235	1,916	161	108	572	87	18	183	1	2			10	194	6,683	2,823
1994	6,316	368	195	2,305	149	211	317	37	27	235					38	76	7,040	3,233
1995	5,093	327	157	1,546	145	284	362	25	5	97		5			28	121	5,789	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63					143	140	4,733	1,823
1997	4,709	521	129	619	270	283	202	19	212	92					18	126	5,540	1,660
1998	6,689	290	123	84	281	155	35	1	541	162	40	86			103	167	7,813	945
1999	4,009	227	179	120	180	50	25	2	465	193	131	76			134	61	5,124	729
2000	4,798	177	192	254	130	109	39	1	576	83	262	93			186	75	6,184	791
2001	2,727	89	171	325	203	92	431	30	563	188	201	149			95	47	4,391	921
2002	1,979	73	144	207	210	137	175	18	76	59	225	158			124	50	2,934	701
2003	1,724	44	114	107	178	95	198	5	68	18	129	52	46	158	120	55	2,578	534
2004	1,222	19	78	30	220	83	80	3	134	110	37	18	20	62	91	50	1,882	376
2005	1,530	21	63	21	152	30	136	5	165	26	146	8	13	90	149	49	2,359	249
2006	1,198	14	62	69	65	32	71	8	51	13	141	19	53	10	135	46	1,778	211
2007	1,207	28	60	78	128	91	36	13	54	24	19	0	5	15	197	50	1,705	299
2008	944	3	42	87	16	69	142	1	95	16	762	414	1	10	205	104	2,207	704
2009	2,490	51	76	74	65	21	67	8	49	10	1,158	285	<1	<1	148	14	4,053	461
2010	1,933	19	67	27	97	19	57	2	13	5	1,659	80	1	57	80	8	3,910	217
2011	1,786	8	49	6	165	9	27	1	4	5	1,466	17	<1	30	84	9	3,564	87
2012	1,895	15	36	16	116	9	17	3	47	6	2,269	12	<1	13	239	23	4,624	96
2013	578	13	27	38	13	5	49	10	38	42	635	208	1	24	53	8	1,394	348
2014	626	16	11	36	13	7	40	1	30	52	598	129	<1	3	78	7	1,397	250
2015	1,061	10	1	12	10	15	34	1	72	34	846	24	<1	19	60	6	2,084	120
2016*	1,278	13	0	6	45	12	27	0	58	5	556	4	<1	12	41	7	2,006	59

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2006-2016. Source: NMFS AK Regional Office catch accounting system.

	"Target" fishery	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016*
Longline and pot	Greenland turbot	1,232	743	1,191	1,833	1,790	1,910	589	628	1,052	805
	Sablefish	137	124	149	94	55	52	63	47	12	7
	Pacific cod	129	76	84	111	173	123	16	17	24	46
	Kam/Arrow flounder	16	0	9	49	0	4	0	0	0	0
	Halibut	36	12	9	107	31	13	25	3	20	12
	Others	11	23	1	0	0	1	4	0	0	0
Trawl	Greenland turbot	2	205	1349	118	4	0	3	14	19	487
	Pacific cod	90	9	2	5	0	1	2	2	1	11
	Kam/Arrow flounder	3	1,176	1,434	1,690	1,483	2,277	843	727	870	560
	Atka mackerel	130	201	118	62	64	209	40	45	25	19
	Flathead sole	58	99	49	13	2	46	39	19	60	55
	Pollock	107	86	44	26	29	53	21	41	40	29
	Rockfish	47	142	73	59	28	18	54	41	34	27
	Other Flatfish	12	11	4	1	0	1	4	0	2	2
	Rock sole	8	0	2	3	1	0	2	5	1	0
	yellowfin sole	1	1	4	1	5	6	35	57	43	5
	Sablefish	0	5	1	0	0	0	1	0	0	0
	Others	0	0	0	0	0	1	0	0	0	0

* Through October 2016

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2005-2016.

Area	Gear	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016*
Aleutian Islands	Fixed	167	358	345	110	99	209	90	58	65	36	16	14
	Trawl	301	179	178	712	2,164	1,653	442	1,600	231	133	98	80
	AI Total	468	537	523	822	2,263	1,862	532	1,658	296	169	114	94
EBS	Fixed	1,713	1,270	1,201	867	1,336	1,937	1,959	2,045	632	659	1,093	856
	Trawl	427	183	280	1,222	916	325	1,176	1,012	815	819	997	1,115
	EBS Total	2,140	1,453	1,481	2,089	2,252	2,261	3,134	3,058	1,446	1,478	2,090	1,971
Grand Total		2,608	1,989	2,004	2,911	4,515	4,123	3,666	4,716	1,742	1,647	2,204	2,065

* Estimated through Oct. 2016.

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.

Data source	**Data type**	**Years of data**
Trawl fisheries	Catch	1960-2016
	Size composition	1977-1987, 1989-1991, 1994-2006, 2008-2016
Longline fisheries	Catch	1960-2016
	Size composition	1979-1985, 1993-2016
Shelf Survey	Abundance Index	1987-2016
	Size composition	1982-2016
	Age composition	1998, 2003-2015
Slope Survey	Abundance Index	2002, 2004, 2008, 2010, 2012
	Size composition	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012, 2016
ABL Longline survey	RPN index	1996-2016
	Size composition	1979-2016

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2016. Source: NMFS observer program data. The % female do not include unidentified fish.

	Trawl fishery				**Longline fishery**			
Year	Female	Male	Unident.	%Female	Female	Male	Unident.	%Female
1989	1,405	5,568	947	20%				
1990	3,864	5,762	6,100	40%				
1991	1,851	1,752	9,295	51%				
1992							71	
1993			425		3,921	915	12,464	81%
1994	1,122	1,027	5,956	52%	503	150	1,200	77%
1995	245	363	4,086	40%	1,870	715	5,630	72%
1996	112	390		22%	941	442	7,482	68%
1997					2,393	1,014	14,833	70%
1998	307	696	822	31%	3,510	2,127	22,794	62%
1999	1,044	1,556		40%	8,033	2,899	266	73%
2000	724	1,328	25	35%	6,550	2,962	73	69%
2001	467	892	43	34%	4,054	1,550	271	72%
2002	186	433		30%	4,725	1,811	40	72%
2003	197	325	1	38%	4,624	2,113	2	69%
2004	179	433	10	29%	4,340	2,612	1	62%
2005	118	211		36%	4,650	1,902	43	71%
2006	15	76		16%	3,339	1,474	32	69%
2007	34	23		60%	3,833	2,130	134	64%
2008	421	1,572	1	21%	1,577	1,481		52%
2009	1,017	2,993	26	25%	3,492	2,709	39	56%
2010	298	3,562	174	8%	3,290	2,860	108	53%
2011	853	2,025	37	30%	2,494	1,694	7	60%
2012	1,742	3,153	14	36%	3,141	2,292	69	58%
2013	1,268	1,367	2	48%	1,087	675		62%
2014	1,150	1,578	3	42%	1,022	1,077		49%
2015	928	1,803	1	34%	1,593	1,070	19	60%
2016	421	896	0	32%	1,507	927	36	62%

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, 1979-2016. 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		28,342
1998	34,885		
1999	21,536		
2000	23,184		9,362
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

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 surveys. Note that in 1982-1984, and 1986 the northwestern stations were not sampled.

Year	Total Hauls	Hauls w/ Turbot	Length samples	Otolith sample hauls	Hauls w/age	Otolith Samples	Ages
1982	336	138	1,567	11	11	292	292
1983	407	112	951				
1984	355	60	536	20		263	
1985	356	67	685				
1986	354	59	195				
1987	362	49	377				
1988	373	63	414				
1989	374	69	432				
1990	371	78	548				
1991	388	74	658				
1992	356	73	616	5		7	
1993	375	73	632	7		112	
1994	383	53	536	17		196	
1995	376	49	353				
1996	375	75	450	8		100	
1997	376	66	298	11		79	
1998	375	73	445	25	21	179	127
1999	373	47	207	8		9	
2000	372	61	248	34		112	
2001	400	61	274	45		112	
2002	375	70	455	21		61	
2003	376	71	622	62	62	228	225
2004	375	64	606	45	45	156	156
2005	402	64	442	58	57	164	163
2006	405	56	427	49	48	225	207
2007	376	84	501	68	68	301	278
2008	375	79	406	59	59	184	178
2009	376	104	856	72	71	211	211
2010	376	145	3,199	70	69	280	278
2011	376	156	4,381	61	59	217	212
2012	376	110	2,133	62	62	226	224
2013	376	96	1,160	63	63	198	197
2014	376	96	1,002	59	57	236	228
2015	376	78	771	60	60	219	217
2016	376	80	505	74		171	

Table 5.11. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot biomass (t), 1980-2016.

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
Avg. since 1991	1,423	2,187	7,179	1,419	12,208

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

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	
ABL													
Longline			60	60	60	60	60	60	60	60	60	60	60
Shelf-Age													

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
ABL													
Longline	60	60	60	60	60		60	60	60	60	60	60	60
Shelf-Age									100				

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			
ABL													
Longline	60	60	60	60	60	60	60	60	60	60	60	60	60
Shelf-Age	100	100	100	100	100	100	100	100	100	100	100	100	1

Year	2016
Trawl	50
Longline	50
Shelf	200
Slope	400
ABL	
Longline	60
Shelf-Age	

Table 5.16. Candidate model likelihoods components, main parameters, and results. Please note that the likelihood components are not comparable across all models due to sample size tuning for each and differences in recruitment estimation.

	M15.1	**M16.1**	**M16.3**	**M16.4**	**M16.6**
Likelihoods					
Total	2242.320	2160.850	1979.640	1836.720	1806.260
Survey	-30.152	-27.543	-32.536	-32.149	-32.993
Length Composition	1012.020	927.164	757.584	622.407	616.894
Age Composition	0.000	0.000	0.000	0.000	0.000
Size at Age	1156.580	1155.460	1150.600	1144.470	1144.580
Recruitment	97.334	98.962	96.172	94.122	73.095
Parameter priors	3.982	3.992	3.966	3.997	3.844
Parameters					
LN(R_0)	0.012	0.012	0.014	0.014	0.005
Steepness	0.79	0.79	0.79	0.79	0.79
Natural Mortality	0.112	0.112	0.112	0.112	0.112
q_{Shelf}	0.616	0.616	0.616	0.616	0.616
q_{Slope}	0.573	0.573	0.573	0.573	0.573
Autocor (ρ)	0.601	0.603	0.595	0.607	0.35
L_{max} Female	89.878	89.803	89.456	90.430	90.339
L_{max} Male	71.903	71.847	71.676	71.962	72.021
Von Bert K Female	0.112	0.110	0.115	0.111	0.111
Von Bert K Male	0.186	0.190	0.188	0.187	0.185
Results					
Model					
SSB_{1978} (t)	254,579	262,880	346,327	287,129	280,595
Projection					
$SSB_{100\%}$ (t)	105,877	102,330	105,035	103,097	98,621
SSB_{2016} (t)	34,468	32,507	43,477	41,404	40,964
$SSB_{2016\%}$	32.5	31.8	41.4	40.2	41.5
SSB_{2017}(t)	43,545	41,050	52,360	50,461	50,005
$SSB_{2017\%}$	41.0	40.1	49.9	48.9	50.7
$F_{35\%}$	0.165	0.165	0.216	0.218	0.218
$F_{40\%}$	0.136	0.136	0.181	0.183	0.183
2017					
ABC (t)	8,172	7,749	10,079	9,824	9,743
F_{ABC}	0.136	0.136	0.181	0.183	0.183
OFL (t)	9,836	9,285	11,948	11,615	11,520
F_{OFL}	0.165	0.165	0.216	0.218	0.218
2018					
ABC (t)	8,997	8,540	10,827	10,635	10,564
F_{ABC}	0.136	0.136	0.181	0.183	0.183
OFL (t)	10,820	10,225	12,822	12,561	12,478
F_{OFL}	0.165	0.165	0.216	0.218	0.218

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

	M15.1	M16.1	M16.3	M16.4	M16.6
Retrospective					
Mohn's ρ	0.061	0.118	0.192	0.116	0.097
Woods Hole ρ	0.060	0.056	0.108	0.013	0.002
RMSE	0.110	0.094	0.116	0.057	0.067
Index RMSE					
Shelf	0.222	0.223	0.210	0.208	0.208
Slope	0.203	0.239	0.176	0.183	0.179
ABL Longline	0.374	0.374	0.398	0.394	0.393
Size Comp					
Har. Mean EffN					
Trawl	41.2	37.3	35.1	36.6	36.8
Longline	47.8	45.8	92.48	91.3	88.7
Shelf	64.9	48.6	48.6	48.7	51.3
Slope	38.6	38.3	48.9	47.9	48.1
ABL Longline	26.7	27.7	31.3	NA	NA
Mean input N					
Trawl	12.5	12.5	12.5	12.5	12.5
Longline	25	25	25	25	25
Shelf	50	50	50	50	50
Slope	106.25	106.25	106.25	106.25	106.25
ABL Longline	30	30	30	NA	NA
Rec. Var. (1975-2015)					
Std.dev(ln(No. Age 1))	1.58	1.60	1.55	1.56	1.51

Table 5.18. Likelihood components for each model.

	Length					Size at Age	Index		
	FISHTRW	FISHLL	SHELF	SLOPE	ABL		SHELF	SLOPE	ABL
Model15.1	105.85	106.54	321.62	325.38	152.63	1156.58	-29.34	-4.34	3.53
Model 16.1	102.77	109.04	264.58	302.09	148.68	1155.46	-29.32	-1.69	3.47
Model 16.3	105.70	60.76	261.55	191.66	137.92	1150.60	-32.92	-7.98	8.37
Model 16.4	102.38	61.60	262.94	195.49	0.00	1144.47	-32.74	-7.04	7.63
Model 16.6	100.14	63.38	258.29	195.09	0.00	1144.58	-32.88	-7.42	7.31

Table 5.19. Age-equivalent sex-specific selectivity estimates (as estimated for 2016 Model 16.4) from each gear type for Greenland turbot in the BSAI. Note that selectivity processes are modeled as a function of size and that selectivities-at-length are allowed to vary over time.

	Trawl Fishery		Longline fishery	
Age	Female	Male	Female	Male
1	0.0014	0.0014	0.0000	0.0000
2	0.0015	0.0016	0.0000	0.0000
3	0.0016	0.0044	0.0000	0.0000
4	0.0058	0.0242	0.0000	0.0001
5	0.0348	0.0835	0.0010	0.0029
6	0.1239	0.1859	0.0105	0.0209
7	0.2769	0.3101	0.0484	0.0621
8	0.4518	0.4303	0.1312	0.1162
9	0.5986	0.5302	0.2507	0.1681
10	0.6907	0.6048	0.3804	0.2101
11	0.7268	0.6562	0.4946	0.2411
12	0.7187	0.6896	0.5793	0.2628
13	0.6819	0.7102	0.6320	0.2778
14	0.6295	0.7223	0.6568	0.2881
15	0.5708	0.7292	0.6600	0.2952
16	0.5118	0.7331	0.6484	0.3002
17	0.4558	0.7355	0.6273	0.3040
18	0.4045	0.7372	0.6007	0.3068
19	0.3584	0.7390	0.5716	0.3092
20	0.3174	0.7411	0.5417	0.3112
21	0.2814	0.7437	0.5122	0.3130
22	0.2498	0.7469	0.4839	0.3146
23	0.2221	0.7508	0.4572	0.3162
24	0.1978	0.7553	0.4321	0.3178
25	0.1788	0.7560	0.4096	0.3181
26	0.1647	0.7527	0.3906	0.3172
27	0.1528	0.7500	0.3741	0.3165
28	0.1428	0.7476	0.3598	0.3159
29	0.1343	0.7456	0.3474	0.3154
30	0.1183	0.7428	0.3234	0.3146

Table 5.20. Model 16.4 time series of age-0 recruits (number in 1,000s) with lower (LCI) and upper (UCI) 95% confidence intervals for 1960-2016.

Year	**Age-0 Recruits**	**LCI**	**UCI**	**Year**	**Age-0 Recruits**	**LCI**	**UCI**
1960	56,719	0	149,367	1994	986	406	1,566
1961	93,802	0	257,922	1995	3,839	2,436	5,243
1962	180,190	0	496,630	1996	1,653	781	2,525
1963	335,950	0	801,370	1997	1,679	813	2,545
1964	364,640	0	828,840	1998	2,173	1,050	3,296
1965	204,810	0	544,410	1999	8,442	5,563	11,321
1966	102,680	0	274,098	2000	9,925	6,437	13,413
1967	58,316	0	148,276	2001	12,224	8,720	15,728
1968	39,535	0	95,437	2002	1,839	876	2,801
1969	31,636	0	73,088	2003	675	261	1,088
1970	29,487	0	65,677	2004	599	200	997
1971	31,910	0	68,568	2005	870	365	1,375
1972	40,728	0	83,698	2006	8,039	5,263	10,814
1973	63,350	4,344	122,356	2007	24,928	18,141	31,715
1974	118,800	26,144	211,456	2008	55,475	42,524	68,426
1975	205,060	82,770	327,350	2009	42,670	30,374	54,966
1976	146,080	53,562	238,598	2010	8,183	4,750	11,616
1977	94,192	23,370	165,014	2011	5,459	2,760	8,159
1978	51,564	6,104	97,024	2012	2,633	1,009	4,257
1979	19,231	3,457	35,005	2013	3,755	1,440	6,069
1980	6,862	1,249	12,476	2014	3,719	1,075	6,363
1981	1,180	126	2,234	2015	4,846	864	8,829
1982	2,278	257	4,299	2016	12,667	0	28,331
1983	3,598	824	6,372				
1984	6,452	2,349	10,554				
1985	20,655	13,997	27,313				
1986	5,474	2,777	8,171				
1987	5,899	3,331	8,466				
1988	6,004	3,366	8,641				
1989	15,944	11,543	20,345				
1990	3,951	1,937	5,965				
1991	1,169	467	1,870				
1992	774	296	1,251				
1993	632	232	1,031				

1977-2015 Average 11,550
1977-2015 Standard deviation 18,984

Table 5.21. Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex for Model 16.4.

Females

Yr	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
1977	4.71	6.53	7.82	3.55	1.44	0.71	0.44	0.33	0.30	0.33	0.43	0.66	1.16	1.85	1.46	0.63	0.25	0.11	0.06	0.04	0.38
1978	2.58	4.21	5.70	6.53	2.92	1.18	0.59	0.36	0.27	0.25	0.28	0.36	0.56	0.99	1.58	1.25	0.54	0.21	0.09	0.05	0.37
1979	0.96	2.31	3.65	4.65	5.22	2.33	0.95	0.47	0.29	0.22	0.20	0.23	0.30	0.46	0.82	1.32	1.05	0.45	0.18	0.08	0.36
1980	0.34	0.86	2.00	2.98	3.73	4.18	1.87	0.77	0.38	0.24	0.18	0.17	0.19	0.25	0.39	0.69	1.11	0.89	0.38	0.15	0.37
1981	0.06	0.31	0.74	1.60	2.33	2.90	3.26	1.47	0.61	0.31	0.19	0.15	0.14	0.15	0.20	0.32	0.57	0.92	0.74	0.32	0.44
1982	0.11	0.05	0.26	0.58	1.22	1.78	2.23	2.53	1.15	0.48	0.24	0.16	0.12	0.11	0.12	0.17	0.26	0.47	0.76	0.61	0.64
1983	0.18	0.10	0.05	0.21	0.44	0.93	1.36	1.71	1.96	0.90	0.38	0.20	0.13	0.10	0.09	0.10	0.14	0.22	0.39	0.63	1.05
1984	0.32	0.16	0.09	0.04	0.16	0.34	0.71	1.04	1.33	1.54	0.72	0.30	0.16	0.10	0.08	0.07	0.09	0.11	0.18	0.33	1.42
1985	1.03	0.29	0.14	0.07	0.03	0.13	0.28	0.58	0.87	1.11	1.29	0.60	0.26	0.13	0.09	0.07	0.06	0.07	0.10	0.16	1.52
1986	0.27	0.92	0.25	0.12	0.06	0.02	0.11	0.23	0.50	0.74	0.95	1.11	0.52	0.22	0.12	0.08	0.06	0.06	0.06	0.09	1.46
1987	0.29	0.24	0.82	0.22	0.10	0.05	0.02	0.09	0.20	0.43	0.64	0.83	0.97	0.45	0.19	0.10	0.07	0.05	0.05	0.06	1.37
1988	0.30	0.26	0.22	0.70	0.19	0.09	0.04	0.02	0.08	0.17	0.37	0.56	0.72	0.84	0.40	0.17	0.09	0.06	0.05	0.04	1.25
1989	0.80	0.27	0.23	0.19	0.61	0.16	0.08	0.04	0.02	0.07	0.15	0.32	0.49	0.63	0.74	0.35	0.15	0.08	0.05	0.04	1.15
1990	0.20	0.71	0.24	0.21	0.17	0.54	0.14	0.07	0.03	0.01	0.06	0.13	0.28	0.42	0.54	0.63	0.30	0.13	0.07	0.04	1.04
1991	0.06	0.18	0.64	0.21	0.19	0.15	0.49	0.13	0.06	0.03	0.01	0.05	0.11	0.23	0.35	0.45	0.53	0.25	0.11	0.06	0.95
1992	0.04	0.05	0.16	0.57	0.19	0.17	0.13	0.43	0.11	0.05	0.03	0.01	0.04	0.09	0.20	0.29	0.39	0.46	0.22	0.09	0.88
1993	0.03	0.03	0.05	0.14	0.51	0.17	0.15	0.12	0.39	0.10	0.05	0.02	0.01	0.04	0.08	0.17	0.26	0.34	0.40	0.19	0.86
1994	0.05	0.03	0.03	0.04	0.13	0.46	0.15	0.13	0.11	0.34	0.09	0.04	0.02	0.01	0.03	0.07	0.15	0.22	0.28	0.34	0.89
1995	0.19	0.04	0.03	0.03	0.04	0.11	0.41	0.14	0.12	0.09	0.29	0.07	0.03	0.02	0.01	0.03	0.06	0.12	0.18	0.24	1.05
1996	0.08	0.17	0.04	0.02	0.02	0.03	0.10	0.36	0.12	0.10	0.08	0.25	0.06	0.03	0.01	0.01	0.02	0.05	0.10	0.15	1.10
1997	0.08	0.07	0.15	0.04	0.02	0.02	0.03	0.09	0.32	0.11	0.09	0.07	0.21	0.05	0.02	0.01	0.00	0.02	0.04	0.09	1.07
1998	0.11	0.08	0.07	0.14	0.03	0.02	0.02	0.03	0.08	0.28	0.09	0.08	0.06	0.18	0.04	0.02	0.01	0.00	0.02	0.03	0.97
1999	0.42	0.10	0.07	0.06	0.12	0.03	0.02	0.02	0.02	0.07	0.24	0.08	0.06	0.05	0.15	0.04	0.02	0.01	0.00	0.01	0.83
2000	0.50	0.38	0.09	0.06	0.05	0.11	0.03	0.01	0.02	0.02	0.06	0.21	0.07	0.05	0.04	0.12	0.03	0.01	0.01	0.00	0.71
2001	0.61	0.44	0.34	0.08	0.05	0.05	0.10	0.02	0.01	0.01	0.02	0.05	0.17	0.05	0.04	0.03	0.10	0.02	0.01	0.01	0.59
2002	0.09	0.55	0.40	0.30	0.07	0.05	0.04	0.09	0.02	0.01	0.01	0.01	0.04	0.14	0.05	0.04	0.03	0.08	0.02	0.01	0.51
2003	0.03	0.08	0.49	0.35	0.27	0.06	0.04	0.04	0.08	0.02	0.01	0.01	0.01	0.04	0.12	0.04	0.03	0.02	0.07	0.02	0.44
2004	0.03	0.03	0.07	0.44	0.32	0.24	0.06	0.04	0.03	0.07	0.02	0.01	0.01	0.01	0.03	0.10	0.03	0.03	0.02	0.06	0.39
2005	0.04	0.03	0.03	0.07	0.39	0.28	0.22	0.05	0.03	0.03	0.06	0.01	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.02	0.39
2006	0.40	0.04	0.02	0.02	0.06	0.35	0.25	0.19	0.04	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.02	0.07	0.02	0.02	0.35
2007	1.25	0.36	0.03	0.02	0.02	0.05	0.31	0.23	0.17	0.04	0.03	0.02	0.04	0.01	0.01	0.01	0.01	0.02	0.06	0.02	0.31
2008	2.77	1.11	0.32	0.03	0.02	0.02	0.05	0.28	0.20	0.15	0.03	0.02	0.02	0.04	0.01	0.00	0.00	0.01	0.02	0.05	0.29
2009	2.13	2.48	1.00	0.29	0.03	0.02	0.02	0.04	0.24	0.17	0.13	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.00	0.01	0.29
2010	0.41	1.91	2.22	0.89	0.26	0.02	0.02	0.02	0.04	0.21	0.14	0.10	0.02	0.02	0.01	0.03	0.01	0.00	0.00	0.00	0.26
2011	0.27	0.37	1.71	1.98	0.80	0.23	0.02	0.01	0.01	0.03	0.17	0.12	0.08	0.02	0.01	0.01	0.02	0.00	0.00	0.00	0.23
2012	0.13	0.24	0.33	1.52	1.77	0.71	0.20	0.02	0.01	0.01	0.03	0.14	0.09	0.07	0.01	0.01	0.01	0.02	0.00	0.00	0.19
2013	0.19	0.12	0.22	0.29	1.36	1.58	0.63	0.18	0.02	0.01	0.01	0.02	0.11	0.07	0.05	0.01	0.01	0.01	0.01	0.00	0.16
2014	0.19	0.17	0.11	0.20	0.26	1.22	1.41	0.56	0.16	0.01	0.01	0.01	0.02	0.09	0.06	0.04	0.01	0.01	0.01	0.01	0.15
2015	0.24	0.17	0.15	0.09	0.17	0.23	1.09	1.26	0.50	0.14	0.01	0.01	0.01	0.01	0.08	0.05	0.04	0.01	0.01	0.00	0.14
2016	0.63	0.22	0.15	0.13	0.08	0.16	0.21	0.97	1.11	0.44	0.12	0.01	0.01	0.01	0.01	0.07	0.04	0.03	0.01	0.00	0.12
2017	0.65	0.57	0.19	0.13	0.12	0.08	0.14	0.19	0.86	0.98	0.38	0.11	0.01	0.01	0.00	0.01	0.06	0.04	0.03	0.01	0.11

Table 5.21 (cont.) Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex for Model 16.4.

Males

Yr	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
1977	4.71	6.53	8.07	3.91	1.68	0.85	0.53	0.38	0.33	0.34	0.42	0.61	1.02	1.53	1.18	0.51	0.20	0.09	0.05	0.03	0.13
1978	2.58	4.21	5.79	6.97	3.31	1.40	0.71	0.43	0.31	0.27	0.28	0.34	0.50	0.84	1.26	0.97	0.42	0.17	0.07	0.04	0.13
1979	0.96	2.31	3.73	4.94	5.79	2.70	1.13	0.57	0.35	0.25	0.22	0.22	0.27	0.40	0.67	1.00	0.77	0.33	0.13	0.06	0.14
1980	0.34	0.86	2.04	3.18	4.12	4.75	2.19	0.91	0.46	0.28	0.20	0.17	0.18	0.22	0.32	0.53	0.80	0.61	0.26	0.11	0.15
1981	0.06	0.31	0.76	1.72	2.60	3.30	3.75	1.72	0.71	0.35	0.22	0.16	0.13	0.14	0.17	0.25	0.41	0.62	0.48	0.20	0.20
1982	0.11	0.05	0.27	0.64	1.39	2.06	2.57	2.89	1.32	0.54	0.27	0.16	0.12	0.10	0.10	0.13	0.19	0.31	0.47	0.36	0.31
1983	0.18	0.10	0.05	0.23	0.51	1.09	1.59	1.97	2.21	1.00	0.41	0.20	0.12	0.09	0.08	0.08	0.10	0.14	0.24	0.36	0.51
1984	0.32	0.16	0.09	0.04	0.18	0.40	0.85	1.22	1.50	1.68	0.76	0.31	0.16	0.09	0.07	0.06	0.06	0.07	0.11	0.18	0.66
1985	1.03	0.29	0.14	0.08	0.03	0.15	0.33	0.70	1.00	1.23	1.38	0.62	0.26	0.13	0.08	0.06	0.05	0.05	0.06	0.09	0.68
1986	0.27	0.92	0.26	0.12	0.07	0.03	0.13	0.28	0.59	0.85	1.04	1.16	0.52	0.22	0.11	0.06	0.05	0.04	0.04	0.05	0.65
1987	0.29	0.24	0.82	0.23	0.11	0.06	0.02	0.11	0.24	0.50	0.72	0.89	0.99	0.45	0.19	0.09	0.06	0.04	0.03	0.04	0.60
1988	0.30	0.26	0.22	0.72	0.20	0.09	0.05	0.02	0.09	0.21	0.43	0.62	0.76	0.85	0.38	0.16	0.08	0.05	0.03	0.03	0.54
1989	0.80	0.27	0.24	0.19	0.63	0.17	0.08	0.04	0.02	0.08	0.18	0.37	0.53	0.66	0.73	0.33	0.14	0.07	0.04	0.03	0.50
1990	0.20	0.71	0.24	0.21	0.17	0.56	0.15	0.07	0.04	0.02	0.07	0.15	0.32	0.46	0.57	0.63	0.29	0.12	0.06	0.04	0.45
1991	0.06	0.18	0.64	0.21	0.19	0.15	0.50	0.14	0.06	0.03	0.01	0.06	0.13	0.27	0.39	0.48	0.53	0.24	0.10	0.05	0.41
1992	0.04	0.05	0.16	0.57	0.19	0.17	0.14	0.45	0.12	0.06	0.03	0.01	0.05	0.11	0.23	0.33	0.41	0.46	0.21	0.09	0.40
1993	0.03	0.03	0.05	0.14	0.51	0.17	0.15	0.12	0.40	0.11	0.05	0.03	0.01	0.05	0.10	0.21	0.30	0.36	0.41	0.18	0.43
1994	0.05	0.03	0.03	0.04	0.13	0.46	0.15	0.13	0.11	0.35	0.09	0.04	0.02	0.01	0.04	0.09	0.18	0.26	0.32	0.35	0.54
1995	0.19	0.04	0.03	0.03	0.04	0.11	0.41	0.14	0.12	0.09	0.30	0.08	0.04	0.02	0.01	0.03	0.07	0.15	0.22	0.27	0.75
1996	0.08	0.17	0.04	0.02	0.02	0.03	0.10	0.36	0.12	0.10	0.08	0.26	0.07	0.03	0.02	0.01	0.03	0.06	0.13	0.19	0.87
1997	0.08	0.07	0.15	0.04	0.02	0.02	0.03	0.09	0.32	0.11	0.09	0.07	0.23	0.06	0.03	0.01	0.01	0.03	0.06	0.11	0.92
1998	0.11	0.08	0.07	0.14	0.03	0.02	0.02	0.03	0.08	0.28	0.09	0.08	0.06	0.20	0.05	0.02	0.01	0.00	0.02	0.05	0.90
1999	0.42	0.10	0.07	0.06	0.12	0.03	0.02	0.02	0.02	0.07	0.25	0.08	0.07	0.05	0.17	0.05	0.02	0.01	0.00	0.02	0.81
2000	0.50	0.38	0.09	0.06	0.05	0.11	0.03	0.01	0.02	0.02	0.06	0.22	0.07	0.06	0.05	0.15	0.04	0.02	0.01	0.00	0.72
2001	0.61	0.44	0.34	0.08	0.05	0.05	0.10	0.02	0.01	0.01	0.02	0.05	0.19	0.06	0.05	0.04	0.13	0.03	0.02	0.01	0.61
2002	0.09	0.55	0.40	0.30	0.07	0.05	0.04	0.09	0.02	0.01	0.01	0.02	0.05	0.16	0.05	0.04	0.03	0.11	0.03	0.01	0.53
2003	0.03	0.08	0.49	0.35	0.27	0.06	0.04	0.04	0.08	0.02	0.01	0.01	0.01	0.04	0.14	0.04	0.04	0.03	0.09	0.02	0.47
2004	0.03	0.03	0.07	0.44	0.32	0.24	0.06	0.04	0.03	0.07	0.02	0.01	0.01	0.01	0.03	0.12	0.04	0.03	0.03	0.08	0.43
2005	0.04	0.03	0.03	0.07	0.39	0.28	0.22	0.05	0.03	0.03	0.06	0.01	0.01	0.01	0.01	0.03	0.10	0.03	0.03	0.02	0.44
2006	0.40	0.04	0.02	0.02	0.06	0.35	0.25	0.19	0.04	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.40
2007	1.25	0.36	0.03	0.02	0.02	0.05	0.31	0.23	0.17	0.04	0.03	0.02	0.05	0.01	0.01	0.01	0.01	0.02	0.08	0.03	0.37
2008	2.77	1.11	0.32	0.03	0.02	0.02	0.05	0.28	0.20	0.15	0.03	0.02	0.02	0.04	0.01	0.00	0.01	0.01	0.02	0.07	0.35
2009	2.13	2.48	1.00	0.29	0.03	0.02	0.02	0.04	0.24	0.17	0.13	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.01	0.02	0.35
2010	0.41	1.91	2.22	0.89	0.26	0.02	0.02	0.01	0.04	0.21	0.14	0.11	0.02	0.02	0.01	0.03	0.01	0.00	0.00	0.00	0.30
2011	0.27	0.37	1.71	1.98	0.80	0.23	0.02	0.01	0.01	0.03	0.17	0.12	0.09	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.25
2012	0.13	0.24	0.33	1.52	1.77	0.71	0.20	0.02	0.01	0.01	0.03	0.15	0.10	0.07	0.02	0.01	0.01	0.02	0.00	0.00	0.21
2013	0.19	0.12	0.22	0.29	1.36	1.58	0.63	0.18	0.02	0.01	0.01	0.02	0.12	0.08	0.06	0.01	0.01	0.01	0.01	0.00	0.16
2014	0.19	0.17	0.11	0.20	0.26	1.22	1.41	0.56	0.16	0.01	0.01	0.01	0.02	0.10	0.07	0.05	0.01	0.01	0.01	0.01	0.14
2015	0.24	0.17	0.15	0.09	0.17	0.23	1.08	1.25	0.49	0.14	0.01	0.01	0.01	0.02	0.09	0.06	0.04	0.01	0.01	0.01	0.13
2016	0.63	0.22	0.15	0.13	0.08	0.16	0.21	0.96	1.11	0.43	0.12	0.01	0.01	0.01	0.01	0.08	0.05	0.04	0.01	0.01	0.12
2017	0.65	0.57	0.19	0.13	0.12	0.08	0.14	0.19	0.86	0.98	0.38	0.11	0.01	0.01	0.01	0.01	0.07	0.05	0.03	0.01	0.11

Table 5.22. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the 2015 assessment) for BSAI Greenland turbot, 1977-2018. 2017 through 2018 biomass estimates are from the projection Model 16.4.

				Female Spawning Biomass		Total Age 1+ Biomass	
Year	Apical Fishing Mortality	Total Exploitation	1-SPR	2015 Assessment	Current Assessment	2015 Assessment	Current Assessment
1977	0.09	0.06	0.63	267,900	293,646	464,651	526,159
1978	0.13	0.08	0.74	258,990	287,129	452,383	524,819
1979	0.13	0.08	0.73	240,010	272,096	433,675	519,434
1980	0.17	0.10	0.81	220,630	257,733	420,278	518,606
1981	0.19	0.11	0.84	198,140	242,717	397,450	504,094
1982	0.17	0.11	0.84	177,690	230,738	367,775	477,165
1983	0.17	0.11	0.84	164,710	225,115	338,089	445,485
1984	0.09	0.06	0.63	155,230	219,982	306,788	408,702
1985	0.06	0.04	0.50	156,030	221,225	294,234	389,377
1986	0.04	0.03	0.39	159,280	222,298	285,557	373,056
1987	0.05	0.03	0.41	162,400	221,419	278,288	357,813
1988	0.04	0.02	0.34	162,630	216,656	268,660	340,305
1989	0.07	0.03	0.31	161,010	209,645	259,403	323,640
1990	0.11	0.04	0.45	154,520	197,612	246,749	303,638
1991	0.08	0.03	0.35	143,560	181,529	228,996	278,867
1992	0.03	0.01	0.18	135,050	168,559	215,770	260,042
1993	0.08	0.03	0.36	128,950	158,519	206,456	246,344
1994	0.13	0.05	0.49	118,730	144,745	192,061	227,834
1995	0.11	0.04	0.44	107,780	131,131	174,948	206,921
1996	0.09	0.03	0.39	98,397	119,497	159,857	188,566
1997	0.11	0.04	0.42	90,223	109,373	146,491	172,359
1998	0.14	0.06	0.50	81,553	98,977	132,666	155,960
1999	0.11	0.04	0.44	71,732	87,579	117,672	138,581
2000	0.15	0.06	0.51	64,368	78,823	105,887	124,808
2001	0.13	0.05	0.49	56,137	69,273	93,651	110,722
2002	0.10	0.04	0.41	49,489	61,473	83,899	99,510
2003	0.09	0.03	0.40	44,210	55,153	76,911	91,593
2004	0.08	0.03	0.35	39,608	49,641	71,345	85,627
2005	0.10	0.03	0.41	36,002	45,284	67,256	81,533
2006	0.08	0.03	0.34	32,602	41,338	63,141	77,519
2007	0.08	0.03	0.36	30,270	38,798	59,833	74,334
2008	0.11	0.04	0.47	28,553	37,185	56,719	71,293
2009	0.18	0.07	0.60	26,992	36,061	53,485	68,243
2010	0.18	0.06	0.59	24,572	34,053	51,205	66,197
2011	0.17	0.05	0.57	22,102	31,641	54,035	68,773
2012	0.23	0.06	0.66	19,887	29,295	62,248	75,911
2013	0.08	0.02	0.37	17,613	27,115	72,821	84,526
2014	0.07	0.02	0.32	18,706	28,710	87,580	96,830
2015	0.08	0.02	0.34	23,041	33,665	102,053	108,399
2016	0.06	0.02	0.28	**30,997**	41,405	**114,438**	117,671
2017				**41,015**	**50,461**	**123,494**	**121,804**
2018					**55,347**		**121,325**

Table 5.23. Spawning biomass based on Model 16.4 with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2017 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. 2017 values are from the production model.

Year	Spawning Biomass	LCI	UCI
1977	293,650	195,166	392,134
1978	287,130	195,790	378,470
1979	272,100	187,795	356,405
1980	257,730	180,151	335,309
1981	242,720	171,788	313,652
1982	230,740	166,099	295,381
1983	225,110	166,141	284,079
1984	219,980	166,194	273,766
1985	221,220	172,146	270,294
1986	222,300	177,639	266,961
1987	221,420	180,848	261,992
1988	216,660	179,788	253,532
1989	209,650	176,138	243,162
1990	197,610	167,559	227,661
1991	181,530	154,713	208,347
1992	168,560	144,507	192,613
1993	158,520	136,856	180,184
1994	144,750	125,372	164,128
1995	131,130	113,907	148,353
1996	119,500	104,118	134,882
1997	109,370	95,562	123,178
1998	98,977	86,554	111,400
1999	87,579	76,389	98,769
2000	78,822	68,697	88,947
2001	69,273	60,099	78,447
2002	61,473	53,134	69,812
2003	55,153	47,546	62,760
2004	49,640	42,688	56,592
2005	45,284	38,908	51,660
2006	41,338	35,463	47,213
2007	38,797	33,324	44,270
2008	37,185	32,027	42,343
2009	36,061	31,160	40,962
2010	34,053	29,363	38,743
2011	31,641	27,146	36,136
2012	29,295	24,966	33,624
2013	27,115	22,857	31,373
2014	28,710	24,312	33,108
2015	33,665	28,697	38,633
2016	41,405	35,370	47,440
2017	50,380	42,993	57,767

Table 5.24. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot from the 2015 stock assessment (Barbeaux et al. 2015) and for the 2016 Model 16.4.

	Mid-year length (cm)				Mid-year weight (kg)			
	2015 Reference		2016 M16.4		2015 Reference		2016 M16.4	
Age	Females	Males	Females	Males	Females	Males	Females	Males
1	14.42	13.95	13.61	12.79	0.019	0.018	0.016	0.013
2	22.86	23.10	22.33	22.65	0.087	0.090	0.081	0.084
3	30.29	30.87	30.14	31.17	0.221	0.228	0.218	0.235
4	36.96	37.39	37.13	38.24	0.428	0.421	0.434	0.453
5	42.94	42.86	43.38	44.11	0.703	0.652	0.727	0.716
6	48.32	47.45	48.97	48.98	1.038	0.903	1.085	1.000
7	53.14	51.30	53.98	53.02	1.420	1.158	1.496	1.287
8	57.47	54.53	58.45	56.37	1.838	1.406	1.944	1.565
9	61.36	57.24	62.46	59.15	2.280	1.640	2.418	1.823
10	64.85	59.51	66.04	61.46	2.733	1.854	2.904	2.057
11	67.98	61.42	69.25	63.38	3.190	2.048	3.391	2.266
12	70.80	63.02	72.12	64.97	3.641	2.220	3.872	2.449
13	73.32	64.36	74.69	66.29	4.081	2.371	4.338	2.607
14	75.58	65.49	76.98	67.38	4.504	2.502	4.785	2.742
15	77.62	66.43	79.04	68.29	4.906	2.615	5.206	2.857
16	79.44	67.22	80.88	69.04	5.285	2.711	5.600	2.954
17	81.08	67.89	82.52	69.67	5.638	2.793	5.965	3.035
18	82.55	68.45	83.99	70.19	5.965	2.862	6.300	3.102
19	83.87	68.92	85.31	70.62	6.266	2.920	6.606	3.158
20	85.06	69.31	86.49	70.97	6.541	2.968	6.885	3.204
21	86.12	69.64	87.54	71.27	6.793	3.009	7.137	3.242
22	87.08	69.91	88.48	71.51	7.022	3.042	7.366	3.272
23	87.94	70.15	89.33	71.72	7.230	3.069	7.572	3.297
24	88.71	70.34	90.08	71.89	7.419	3.092	7.759	3.316
25	89.40	70.50	90.76	72.03	7.591	3.112	7.926	3.334
26	90.02	70.64	91.36	72.15	7.744	3.132	8.072	3.352
27	90.57	70.76	91.90	72.24	7.881	3.148	8.201	3.366
28	91.07	70.85	92.39	72.32	8.002	3.162	8.315	3.378
29	91.52	70.93	92.82	72.39	8.110	3.174	8.416	3.388
30	92.45	71.05	93.70	72.48	8.329	3.191	8.614	3.403

Table 5.25. Estimated total Greenland turbot harvest by area, 1977-2016. Values for 2016 are through Oct. 1, 2016 and are preliminary.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1997	6,435	764
1978	37,423	4,766	1998	8,075	682
1979	34,998	6,411	1999	5,386	467
1980	48,856	3,697	2000	5,888	1,086
1981	52,921	4,400	2001	4,253	1,060
1982	45,805	6,317	2002	3,151	485
1983	43,443	4,115	2003	2,412	700
1984	21,317	1,803	2004	1,825	434
1985	14,698	33	2005	2,140	468
1986	7,710	2,154	2006	1,453	537
1987	6,519	3,066	2007	1,481	523
1988	6,064	1,044	2008	2,089	822
1989	4,061	4,761	2009	2,252	2,263
1990	7,702	2,494	2010	2,273	1,872
1991	4,398	3,465	2011	3,120	532
1992	2,462	1,290	2012	3,062	1,658
1993	6,332	2,137	2013	1,449	296
1994	7,143	3,131	2014	1,479	177
1995	5,856	2,338	2015	2,091	114
1996	4,844	1,712	2016*	1,973	95

Table 5.26. Model 16.4 mean spawning biomass and yield projections for Greenland turbot, 2016-2040 from the "Warm" climate scenario for five alternatives for setting ABC.

SSB	**16.4 Standard**	**16.4 Warm**	**Long-term B35%**	**Long-term B20%**	**7,000 t Rule**
2016	41,404	41,404	41,404	41,404	41,404
2017	50,461	50,461	50,461	50,461	50,461
2018	55,347	55,347	58,221	55,750	56,585
2019	57,156	57,156	63,683	58,047	60,287
2020	56,154	56,154	66,655	57,545	61,415
2021	53,271	53,274	67,558	55,107	60,403
2022	49,458	49,477	66,986	51,652	57,844
2023	45,387	45,471	65,477	47,878	54,292
2024	41,407	41,665	63,430	44,203	50,185
2025	37,643	38,247	61,122	40,837	45,841
2026	37,467	35,267	58,725	37,854	41,476
2027	37,312	32,713	56,354	35,258	37,230
2028	37,189	30,539	54,073	33,020	36,913
2029	37,099	28,697	51,925	31,101	36,682
2030	37,038	27,135	49,926	29,457	36,526
2031	37,007	25,818	48,091	28,055	36,439
2032	36,999	24,705	46,412	26,860	36,403
2033	37,024	23,774	44,901	25,851	36,421
2034	37,072	22,997	43,546	24,999	36,479
2035	37,131	22,339	42,325	24,266	36,558
2036	37,191	21,776	41,226	23,629	36,646
2037	37,251	21,290	40,242	23,071	36,739
2038	37,307	20,865	39,360	22,577	36,829
2039	37,306	20,465	38,497	22,109	36,861
2040	37,247	20,090	37,645	21,664	36,834
Catch					
2016	2,186	2,186	2,186	2,186	2,186
2017	9,825	9,825	3,280	8,905	7,000
2018	10,635	10,635	3,741	9,712	7,000
2019	10,635	10,634	3,964	9,791	7,000
2020	10,006	10,002	3,963	9,289	7,000
2021	9,057	9,030	3,804	8,460	7,000
2022	8,080	7,975	3,560	7,532	7,000
2023	7,279	6,996	3,287	6,653	7,000
2024	6,730	6,164	3,021	5,895	7,000
2025	900	5,491	2,782	5,272	7,000
2026	875	4,961	2,575	4,776	7,000
2027	858	4,549	2,400	4,386	829
2028	846	4,229	2,254	4,080	816
2029	839	3,980	2,133	3,840	808
2030	835	3,786	2,032	3,651	805
2031	832	3,636	1,949	3,504	805
2032	832	3,521	1,882	3,390	807
2033	833	3,429	1,826	3,302	811
2034	834	3,353	1,780	3,234	815
2035	835	3,287	1,742	3,179	819
2036	836	3,231	1,709	3,130	822
2037	837	3,181	1,680	3,086	824
2038	836	3,135	1,653	3,044	825
2039	834	3,090	1,629	3,003	825
2040	833	3,047	1,609	2,967	825

Table 5.27. Model 16.4 mean spawning biomass, F, and yield projections for Greenland turbot, 2016-2029. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be **50:50**.

SSB	**Max F_{abc}**	**F_{abc}**	**5-year avg.**	**$F_{75\%}$**	**No Fishing**	**Scenario 6**	**Scenario 7**	**7,000 t rule**
2016	41,404	41,404	41,404	41,404	41,404	41,404	41,404	41,404
2017	50,461	50,461	50,461	50,461	50,461	50,461	50,461	50,461
2018	55,347	55,347	59,181	58,463	59,668	54,564	55,347	56,585
2019	57,156	57,156	65,954	64,252	67,122	55,447	57,156	60,287
2020	56,158	56,158	70,475	67,607	72,472	53,527	55,138	61,419
2021	53,314	53,314	73,035	68,938	75,929	49,898	51,357	60,442
2022	49,715	49,715	74,205	68,929	77,986	45,722	47,006	58,078
2023	46,290	46,290	74,649	68,323	79,249	41,936	43,047	55,126
2024	43,607	43,607	74,904	67,694	80,220	39,087	40,020	52,229
2025	41,849	41,849	75,285	67,355	81,206	37,540	38,265	49,759
2026	41,033	41,033	75,892	67,381	82,316	36,963	37,531	47,860
2027	40,849	40,849	76,694	67,708	83,542	36,968	37,416	46,520
2028	41,011	41,011	77,629	68,239	84,843	37,259	37,614	45,638
2029	41,348	41,348	78,658	68,908	86,197	37,670	37,952	45,090
F								
2016	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2017	0.18	0.18	0.02	0.05	0.00	0.22	0.18	0.13
2018	0.18	0.18	0.02	0.05	0.00	0.22	0.18	0.12
2019	0.18	0.18	0.02	0.05	0.00	0.22	0.22	0.11
2020	0.18	0.18	0.02	0.05	0.00	0.22	0.22	0.12
2021	0.18	0.18	0.02	0.05	0.00	0.22	0.22	0.12
2022	0.18	0.18	0.02	0.05	0.00	0.22	0.22	0.14
2023	0.18	0.18	0.02	0.05	0.00	0.22	0.22	0.15
2024	0.18	0.18	0.02	0.05	0.00	0.20	0.21	0.17
2025	0.17	0.17	0.02	0.05	0.00	0.19	0.19	0.18
2026	0.17	0.17	0.02	0.05	0.00	0.18	0.19	0.19
2027	0.16	0.16	0.02	0.05	0.00	0.18	0.18	0.21
2028	0.16	0.16	0.02	0.05	0.00	0.18	0.18	0.22
2029	0.16	0.16	0.02	0.05	0.00	0.18	0.18	0.23
Catch								
2016	2,186	2,186	2,186	2,186	2,186	2,186	2,186	7,000
2017	9,825	9,825	1,103	2,730	0	11,615	9,825	7,000
2018	10,635	10,635	1,279	3,127	0	12,389	10,635	7,000
2019	10,635	10,635	1,381	3,329	0	12,190	12,550	7,000
2020	10,007	10,007	1,409	3,346	0	11,277	11,597	7,000
2021	9,059	9,059	1,383	3,236	0	10,041	10,312	7,000
2022	8,087	8,087	1,329	3,066	0	8,834	9,056	7,000
2023	7,295	7,295	1,270	2,897	0	7,856	8,063	7,000
2024	6,761	6,761	1,224	2,769	0	6,805	7,061	7,000
2025	6,266	6,266	1,197	2,693	0	6,307	6,486	7,000
2026	6,048	6,048	1,188	2,667	0	6,186	6,310	7,000
2027	6,024	6,024	1,192	2,674	0	6,256	6,345	7,000
2028	6,097	6,097	1,205	2,701	0	6,406	6,470	7,000
2029	6,206	6,206	1,222	2,738	0	6,574	6,621	7,000

Table 5.28. FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991

Year	cod, Pacific (gray)	eels or eel-like fish	flounder, Alaska plaice	flounder, arrowtooth	flounder, general	greenling, atka mackerel	grenadier (rattail)	grenadier, giant	groundfish, general	Kamchatka flounder	octopus, North Pacific	Pacific sleeper shark	perch, Pacific ocean
1991	154			1,085	94	65			107				3
1992	12			4	0.01				10				0.16
1993	115			560	100				529				1
1994	85			1,384	29	1			165				1
1995	111		8	2,007	53	10			533				12
1996	97			492	15	3			232				6
1997	82		1	766	7				278				14
1998	166		2	1,153	23	22			518				3
1999	225	0.4	0.3	1,071	60	133	1,175	219	464			15	32
2000	223	6	1	764	23	5	588	413	326			2	27
2001	110	3		292	15	2	493	4	194			1	52
2002	83			333	4		148	164	122			0.06	1
2003	32		1	368	<0.01	<0.01			5		1	10	1
2004	38		1	256	0.01	0.01			0.02		0.37	3	1
2005	22			185	0.01				1		0.19	3	0.31
2006	56			195	<0.01	0.01			1		0.05	1	0.01
2007	67			235	0.02	0.2			0.02		0.09	1	0.37
2008	83			337	0.01	0.2			0.1		0.32	0.37	166
2009	13			1,339		1			0.01		0.09	0.06	0.23
2010	59		1	574					1		0.04	0.16	0.02
2011	72			223		0.05			4	13	0.05		0.20
2012	79			333					6	239	0.07	0.11	0.30
2013	5			9					3	61	0.14		0.02
2014	6			47	0.04				2	41	0.08	0.04	0.03
2015	37			15		0.01			2	80	0.08		0.02
2016	51		1	367					3	187	0.11		42
Grand Total	2,084	9	15	14,396	423	242	2,403	800	3,504	621	3	36	363

Table 5.28 (Cont.). FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991.

Year	pollock, walleye	rockfish, dark	rockfish, dusky	rockfish, northern	rockfish, rougheye	rockfish, shortraker	rockfish, shortraker/rougheye	rockfish, thornyhead (idiots)	sablefish (blackcod)	sculpin, general	sole, flathead	sole, rex	sole, rock
1991	114	27							504				1
1992	0.05						2	0.01	28				
1993	6		1		0.02		195	38	577		7		0.33
1994	20		10	1	0.22	1	22	35	492		18	18	1
1995	50		65		1	5	28	22	555		57	3	4
1996	32		0.42		0.15	2	19	13	265		52	1	3
1997	56		0.34		1	5	12	10	267		63	18	2
1998	106				4	25	38	45	404		50	12	13
1999	151		0.24		1	11	32	23	380		131	14	54
2000	117		<0.01		8	21	63	28	351		72	22	3
2001	54				0.32	19	28	22	229		69	3	3
2002	13				0.26	2	13	38	170	8	35	13	1
2003	98			2	8	27		80	174	7	76	34	1
2004	64		0.07		4	40		60	89	4	17	5	1
2005	8				2	12		47	99	1	7	6	0.28
2006	1		<0.01	<0.01	5	33		51	93	1	3		0.03
2007	3		0.31	0.15	3	78		55	73	2	0.42	0.13	
2008	32			0.50	0.33	2		37	61	3	1	3	0.44
2009	12				1	4		50	81	2	5	3	
2010	11			0.00	4	29		68	99	1	11	1	0.01
2011	14			0.02	0.12	5		41	23	1	6	0.32	0.01
2012	11		2		1	11		36	28	1	13		
2013	2				0.10	3		17	11	0.30	6	0.40	0.04
2014	2		0.04	0.05		2		25	21	2	8	0.12	0.14
2015	20		0.29	<0.01	0.06	2		29	7	2	11		
2016	126				0.33	5		34	11	21	63	4	0
Grand Total	1,123	27	80	3	44	347	452	902	5,091	55	780	161	89

Table 5.28 (Cont.). FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands area since 1991.

Year	sole, yellowfin	squid, majestic	turbot, Greenland	Sharks and skates	other
1991	0.45	38	3,329		61
1992			75		2
1993		0.34	6,019		43
1994	0.09	19	6,683		63
1995	18	12	5,419		74
1996	0.04	1	3,624		47
1997	9	3	5,230		41
1998	6	1	6,980		80
1999	18	4	4,236		33
2000	4	9	4,976		93
2001	5	2	2,817	1	34
2002		0	2,052	49	16
2003	1	3	1,767	224	1
2004	1	6	1,240	136	0.24
2005		0.42	1,551	168	1
2006	0.08		1,212	123	1
2007			1,235	176	1
2008		4	948	69	0.04
2009		23	2,540	209	0.38
2010		1	1,951	369	3
2011	0.06	0.00	1,794	382	0.33
2012			1,910	357	2
2013	0.05	0.06	591	51	
2014	0.03	1	643	43	0.36
2015	0.29	0.00	1,071	209	0.02
2016		3	1,293	164	0.21
Grand Total	63	131	71,187	2,730	598

Table 5.29. 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.

	Benthic urochordata	Brittle star unidentified	Corals Bryozoans	Eelpouts	Giant Grenadier	Grenadier	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
Longline																				
2003	0.03	0.01	0.06	1.63	35.21	1523.43		0.00	0.51	0.01		2.95	1.18	0.01	0.12	0.00	0.40	0.04	0.10	0.82
2004				2.36	159.18	1168.76			0.13	0.01		1.49	0.40		0.04		0.23	0.01	0.00	0.01
2005	0.00	0.00	0.06	5.50	1099.31	1024.34		0.00	0.12	0.00		1.11	0.36	0.02	0.20	0.00	0.86	0.13	0.01	0.29
2006	0.01	0.00	0.07	3.80	1263.95	216.84		0.03	0.76	0.02		2.06	0.37	0.01	0.08		0.37	0.02	0.01	0.01
2007	0.00	0.01	0.01	2.27	1181.18	234.46		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	0.00	0.01	0.39	0.74	0.00	0.06		1.16	0.02	0.00	0.52
2010	0.01	0.00	0.12	5.75	1815.19	367.18		0.00	1.27	0.02		1.41	0.17	0.01	0.12	0.03	1.13	0.03	0.00	0.33
2011		0.11	0.00	7.67	1603.32	308.22	0.03	0.26	0.86	0.03		1.10	0.30	0.01	1.31	0.08	0.80	0.03	0.02	0.07
2012		0.08	0.01	8.11	1200.60	260.71		0.06	1.17	0.01		1.42	0.23	0.01	0.53		0.92	0.03	0.02	0.09
2013		0.01	0.00	2.07	564.54	5.35		0.25	0.38			0.50	0.07	0.00	0.05		0.44	0.05	0.00	0.13
2014				2.55	315.83	166.33		0.01	1.88	0.01		0.63	0.03		0.00		0.65	0.02		0.22
2015		0.11		4.74	1083.99	21.26			0.30	0.00		0.57	0.01	0.01	0.38		0.48	0.02	0.00	0.03
2016		0.03		2.87	1022.54	0.67		0.08	0.46			0.21	0.05		0.17	0.01	1.27	0.02	0.03	0.05
Pot																				
2004						11.64				0.00							0.04	0.01		

Table 5.30. 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

	Brittle star unidentified	Capelin	Eelpouts	Giant Grenadier	Greenlings	Grenadier	Hermit crab unidentified	Invertebrate unidentified	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	0.00	0.88	4.18	0.00	0.11				0.06	0.00		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					0.00		0.00	
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			0.04				0.04	0.00		0.00		0.00		0.00	0.00
2011			0.12	0.86					0.02		0.04							0.05		0.00	
2013			0.01	0.35							0.08		0.01			0.00		0.00			
2014	0.00		1.14	0.44		0.36			0.03	0.02	0.03		0.89		0.01	0.08		0.02	0.00	0.06	0.00
2015			0.08	6.85							0.03		0.03	0.01		0.35		0.02	0.07		
2016	2.14		0.48	83.42		4.22	0.00		0.95		0.77		19.16	0.13		8.23	0.14	1.01	0.02	0.08	0.00

Table 5.31. 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.

	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
Longline										
1991					81		1	65	51	5
1992					13			8		
1993	29				568		4	2,074	1,164	3
1994			7		325			204	233	13
1995	21				428		8	650	402	50
1996	12				415			579	186	18
1997	14				391		22	362	206	12
1998	32				446		47	1,226	1,497	10
1999	8				428		24	659	838	5
2000	13				570		5	930	1,730	20
2001	1				301		7	537	313	21
2002	64		3		271		45	562	55	6
2003					121					
2004	10		18	151	126		77			
2005		12	13	22	161		41	3		8
2006	31		8	328	84		26	3		13
2007	19			2,438	44		24	34		48
2008	16	7		3	15		29	43		8
2009	85			0	47		15	24		
2010	47	8		179	90		37	85		1
2011				34	41			12		
2012	16		4	26	50			42		
2013					10			5		
2014	5			29	10			8		
2015			18	36	24		35	7		
2016				38	14		70	5		
POT										
1991								71		
1999	21							685	27,768	

Table 5.32. Prohibited species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for Trawl. Crab, herring and salmon are in number of fish, halibut are in tons.

	Bairdi Tanner Crab	Blue King Crab	Chinook 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		927			278,055	6,029	329
1995	3,837				556			52,212	3,027	966
1996	1,089				12			5,594	250	
1997	614				14			6,138	451	
1998	474				14			2,845	125	
1999	1,048				27			2,051	1,198	
2000	1,055				25			2,677	3,327	
2001	497				16			7,189	471	
2002	731				2			2,644	211	
2003					11			1,699		
2004				66	3			66		
2005	88			88	3					
2008				132	3					
2009				747	8					
2010				86	3					
2011				0	1					
2013				0	1					
2014				21	0					
2015				0	0					
2016	1,531			402	1			117		

Table 5.33. 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.

	Birds - Gull	Birds - Kittiwake	Birds - Laysan Albatross	Birds - Northern Fulmar	Birds - Shearwaters	Birds - Short-tailed Albatross	Birds - Unidentified	Birds - Unidentified Albatross	Grand Total
2003				133	21				154
2004		31	21	79				3	134
2005		12	13	151	80				255
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				343	40		15		397
2013				65	60		5		131
2014				55		6			62
2015				17	55				72
2016				34	173				206
Grand Total	20	57	54	2,797	657	6	36	3	

Figures

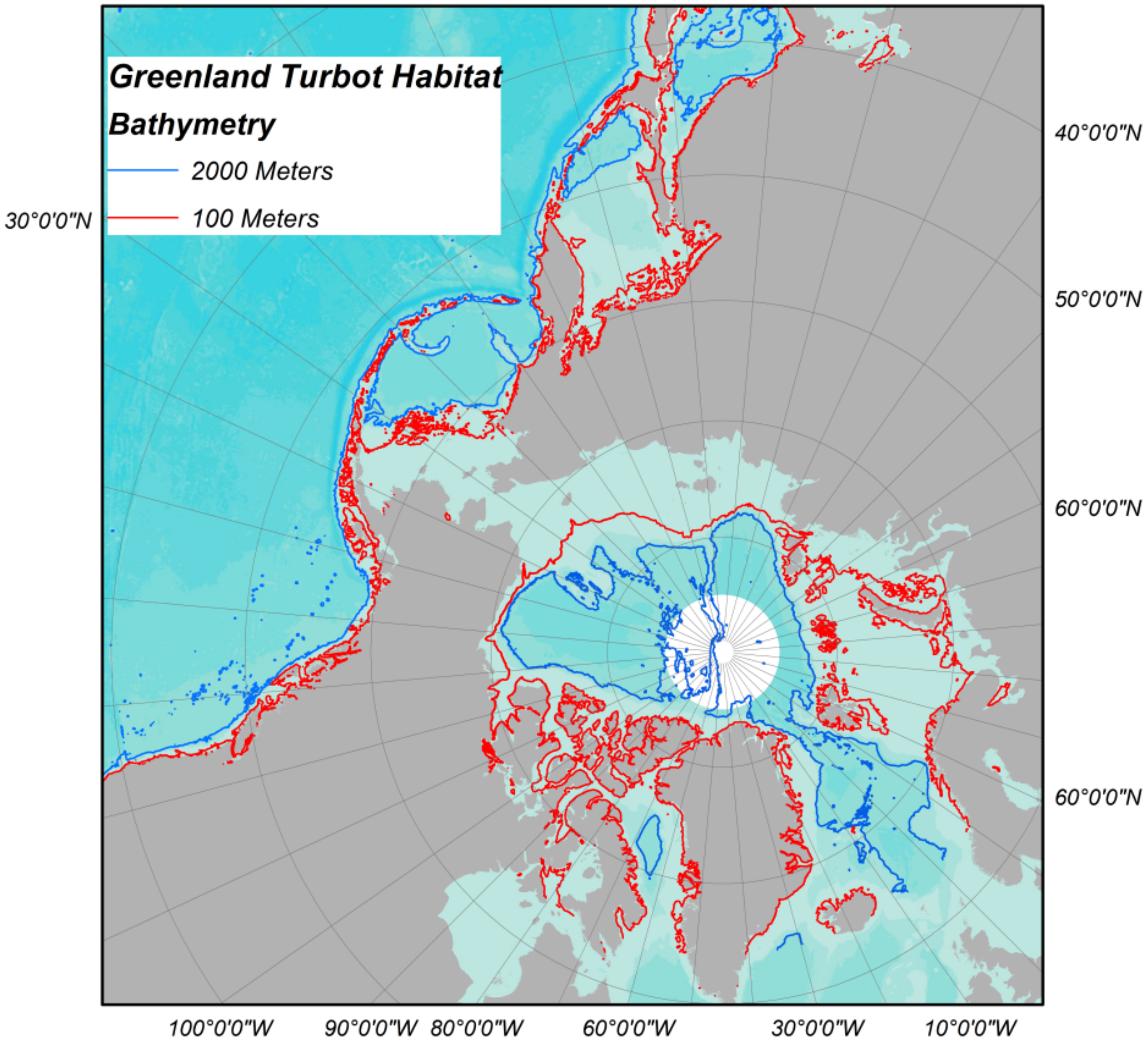


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.

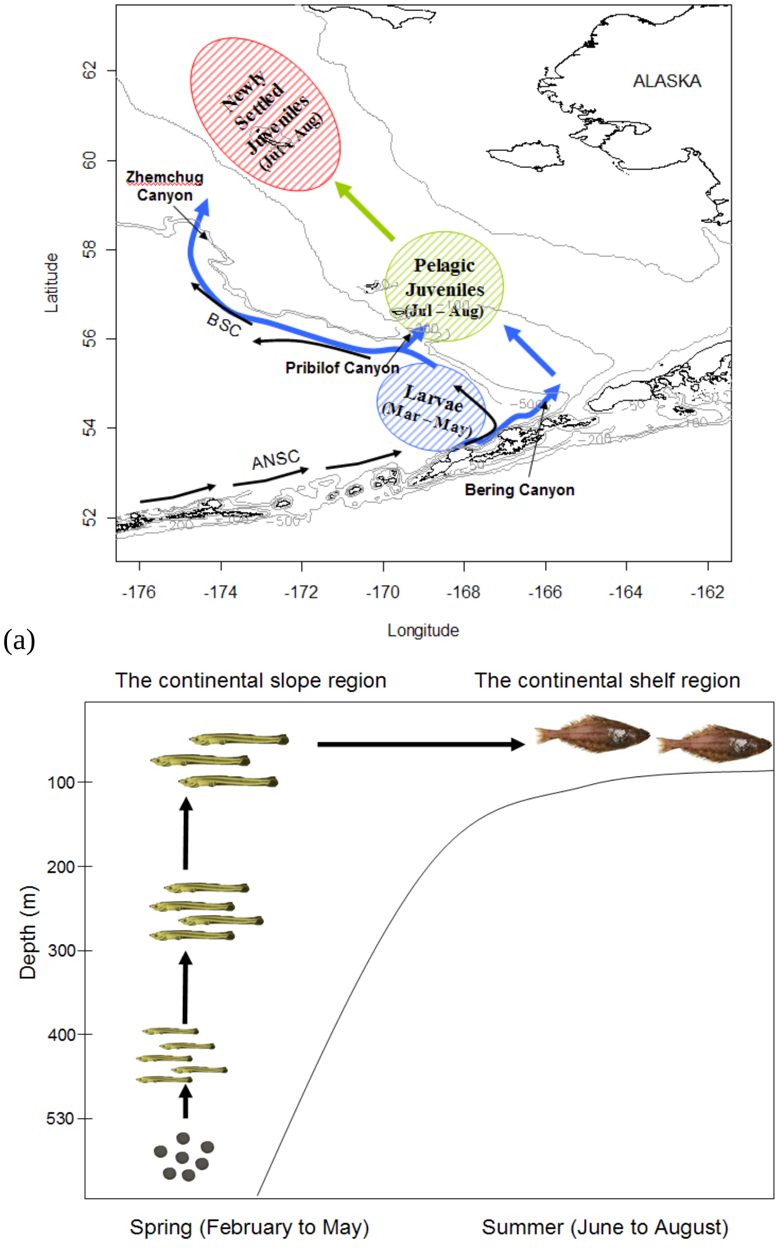


Figure 5.2. Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: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

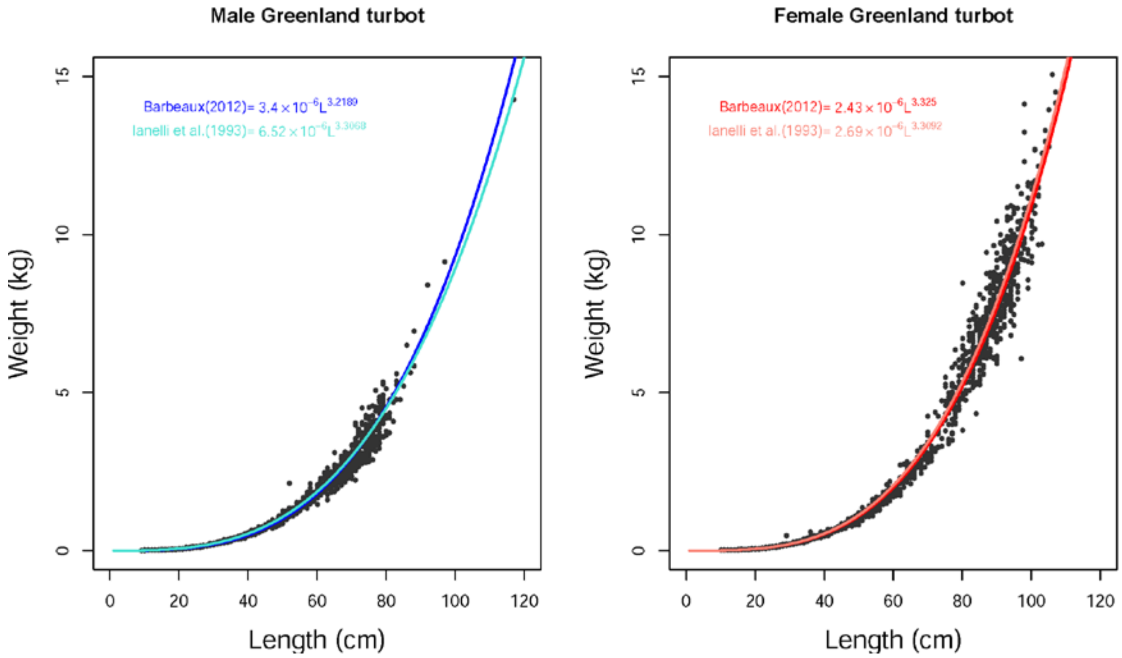


Figure 5. 3. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

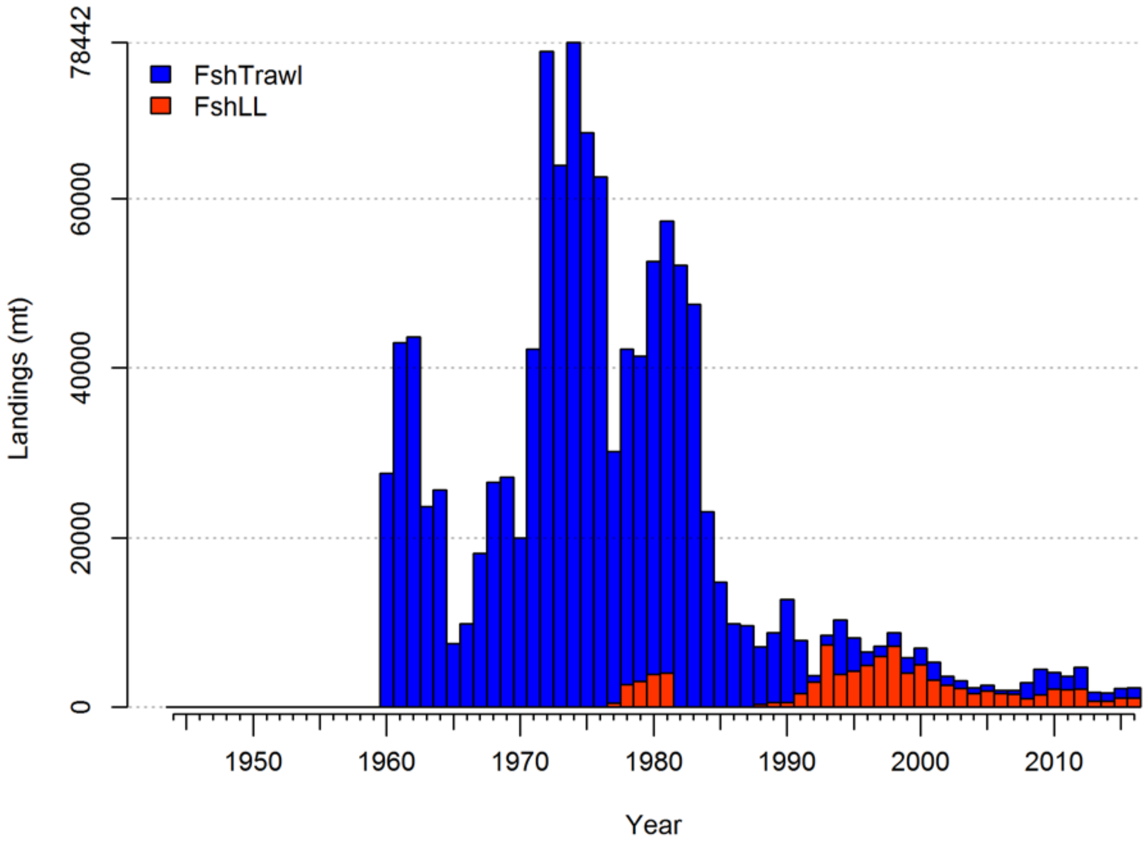


Figure 5. 4. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2015. This data includes targeted catch and bycatch.

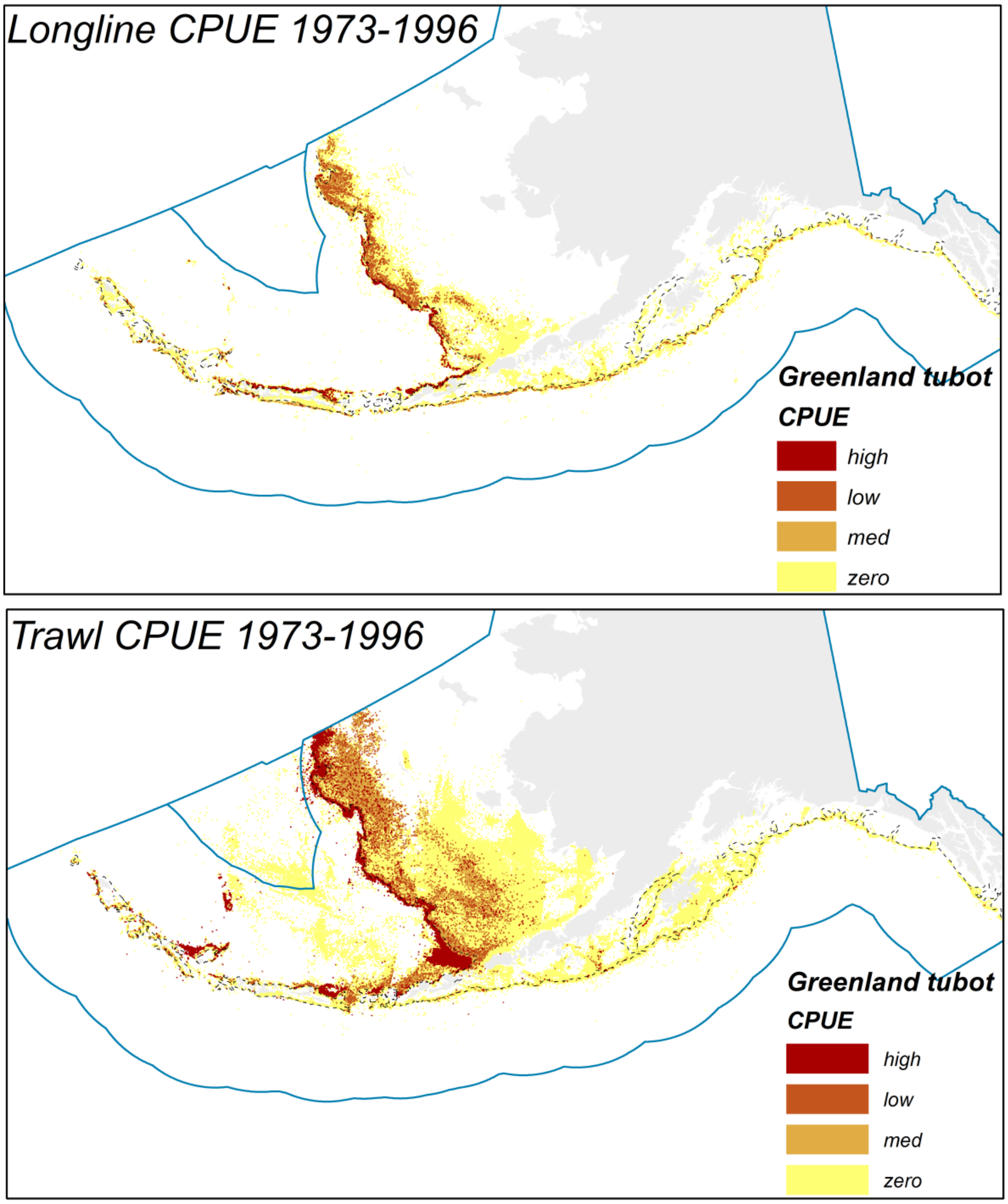


Figure 5.5. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).

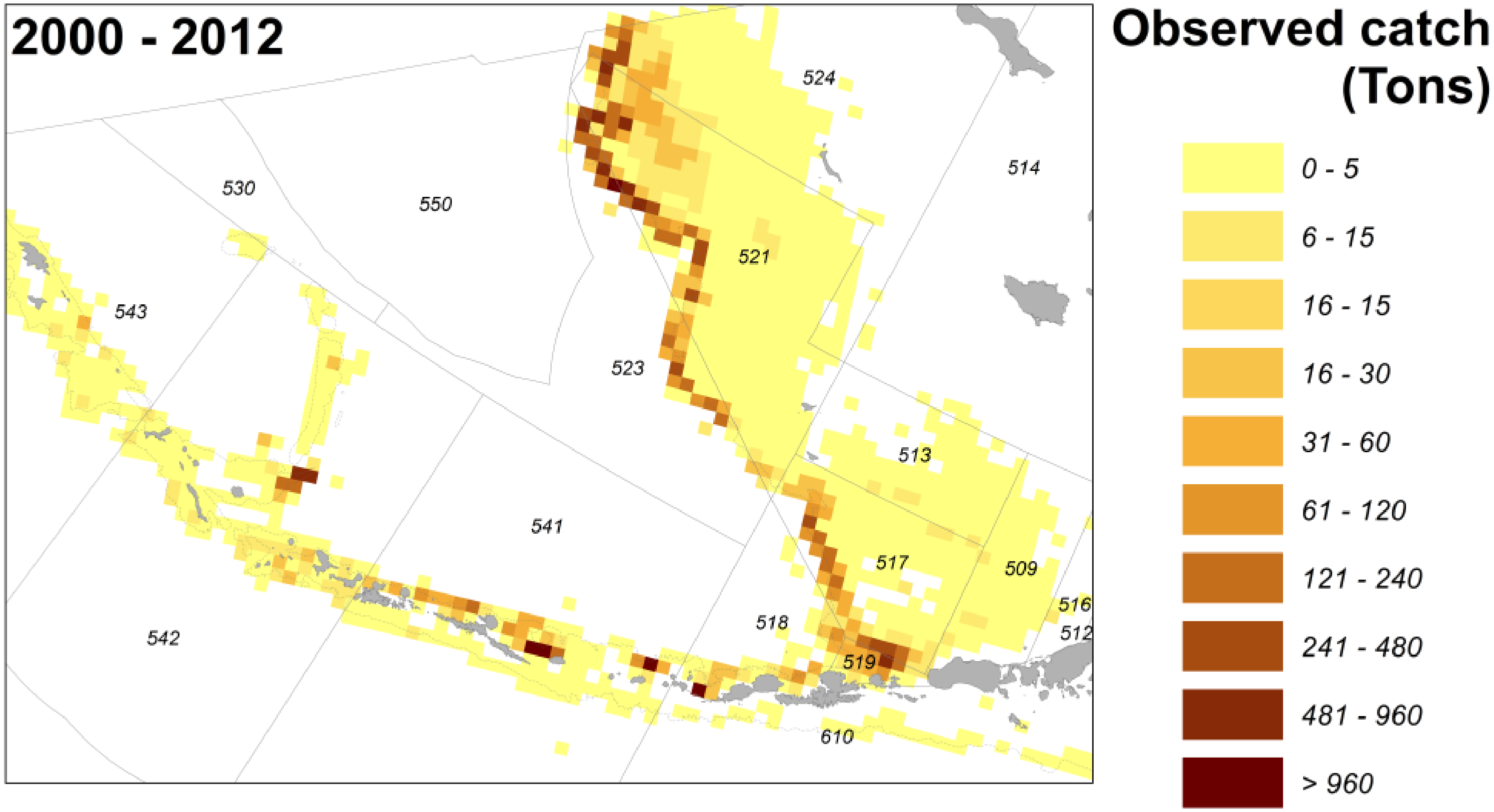


Figure 5.6 All observed catch for 2000 through 2012, data are aggregated spatially at a 400 km^2 grid.

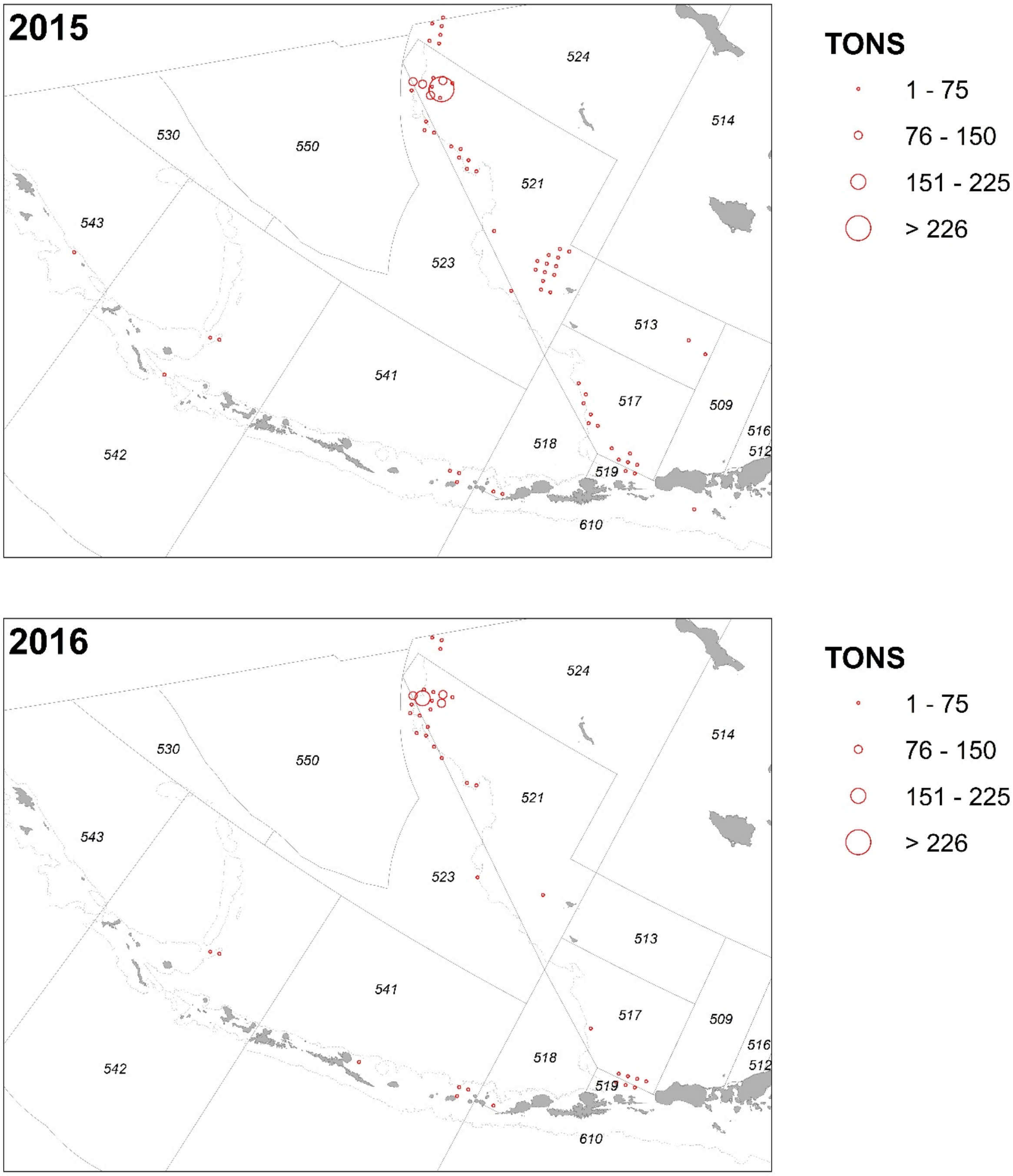


Figure 5.7. All observed Greenland turbot catch for 2015 and 2016. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

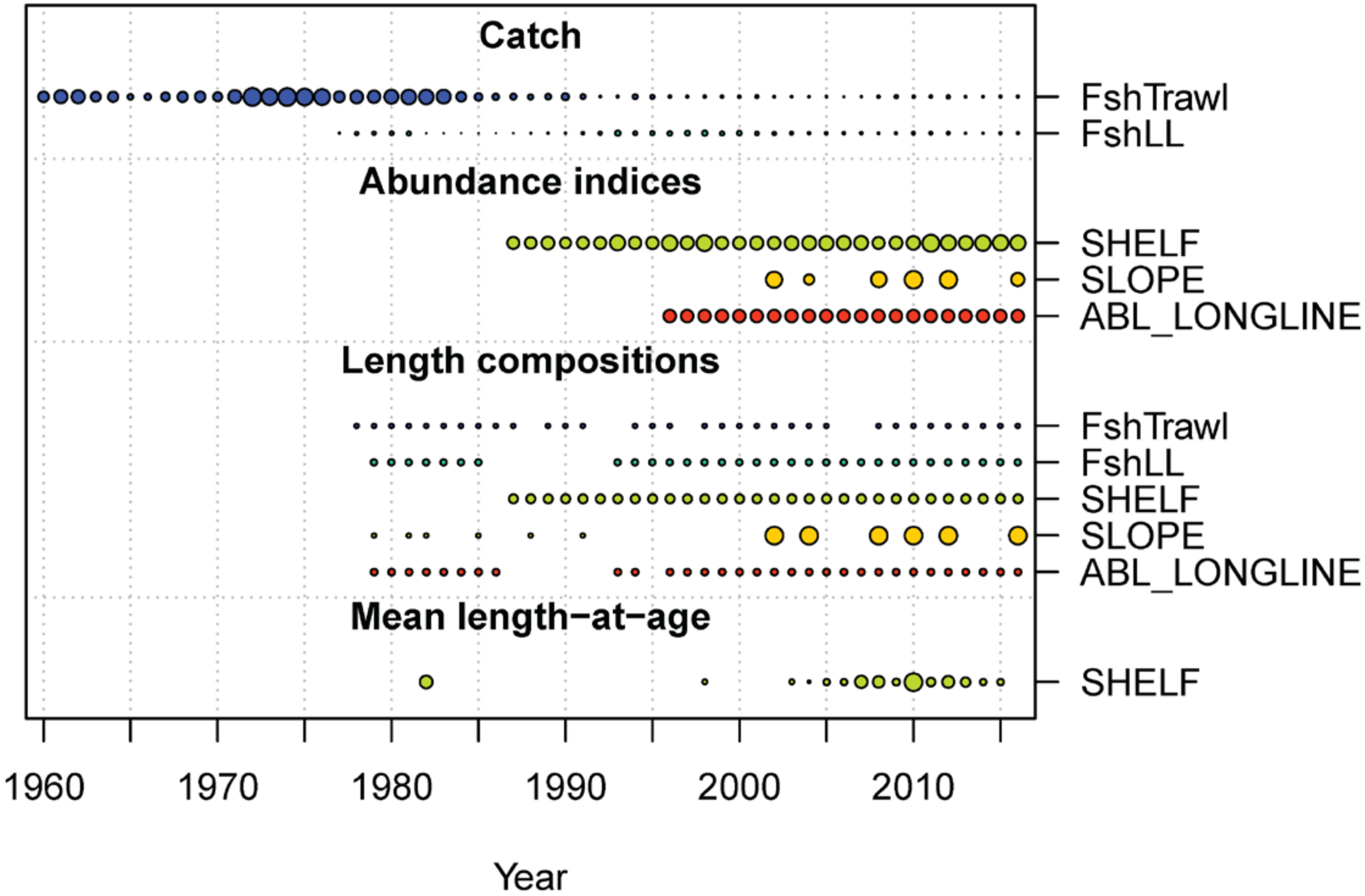


Figure 5.8. Timeline of all data included in models presented. The area of the circle represents the relative precision of the data type. Note that Models16.4 and Model 16.6 do not include ABL_LONGLINE length composition data.

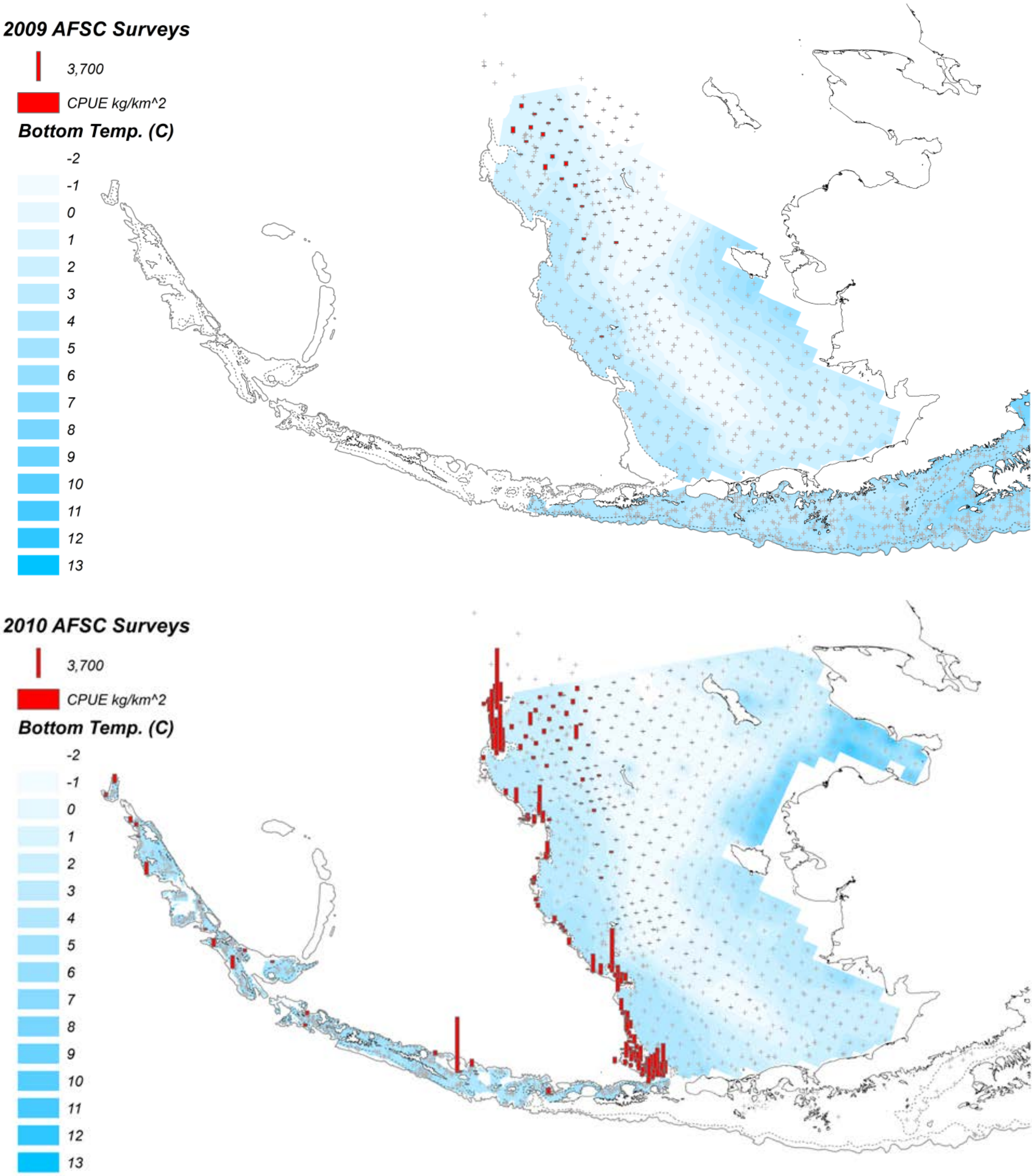
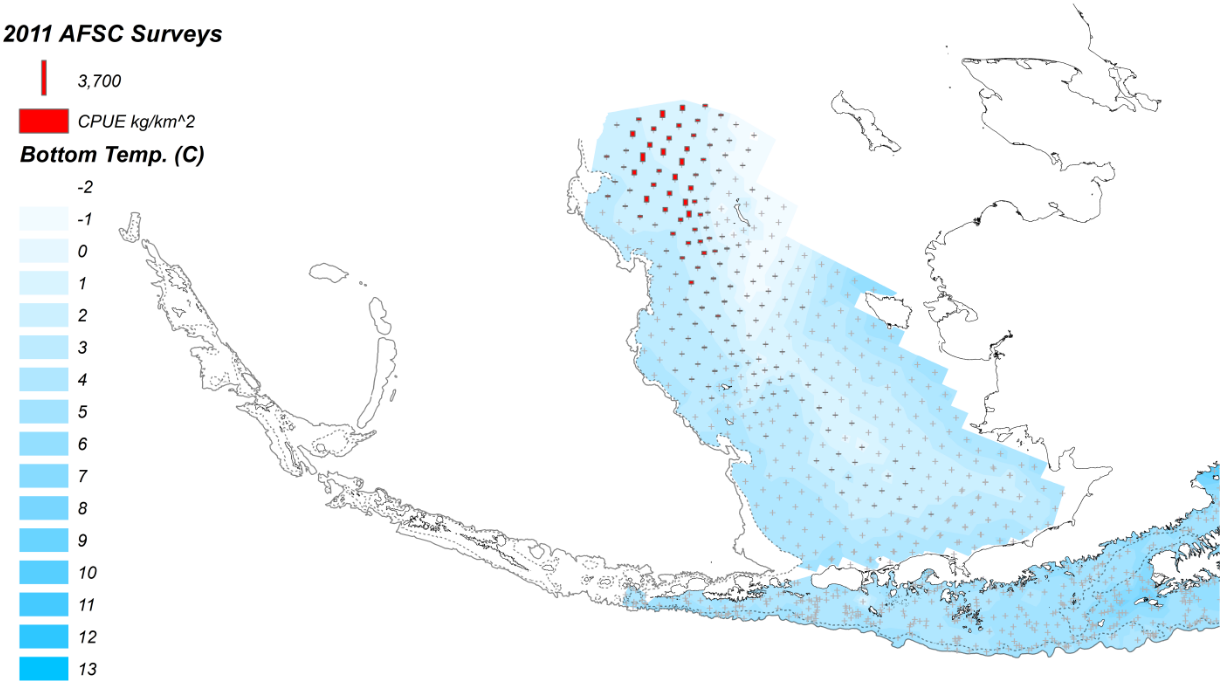


Figure 5.9. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.



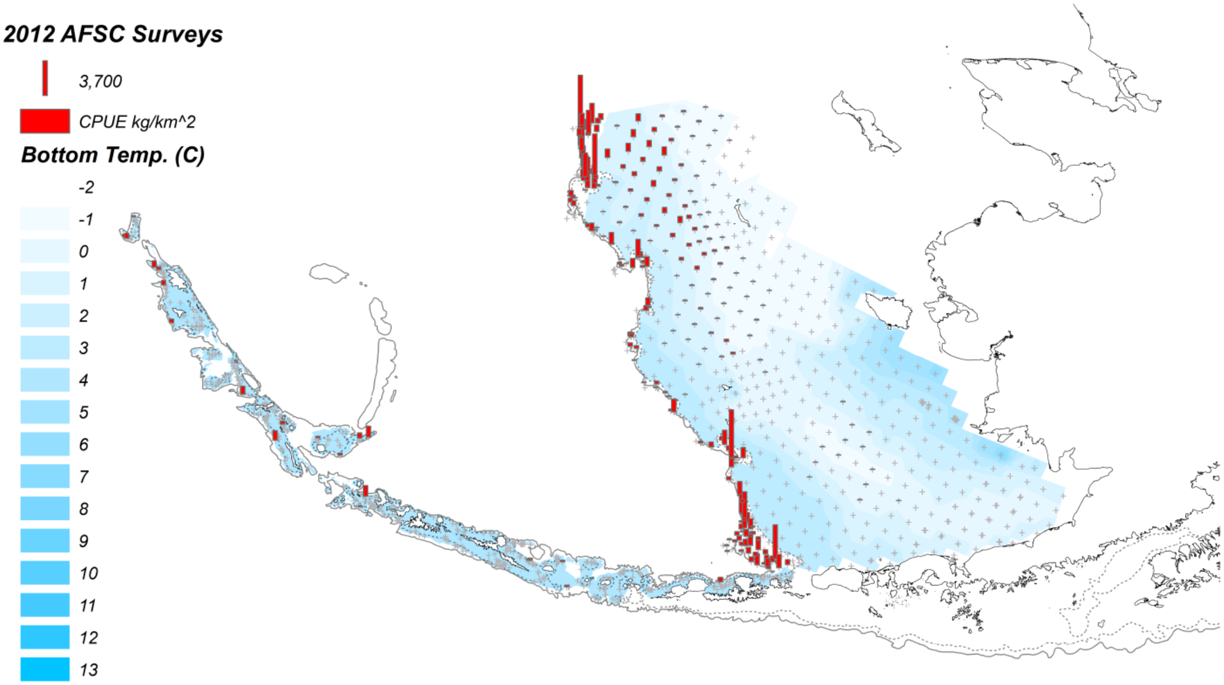
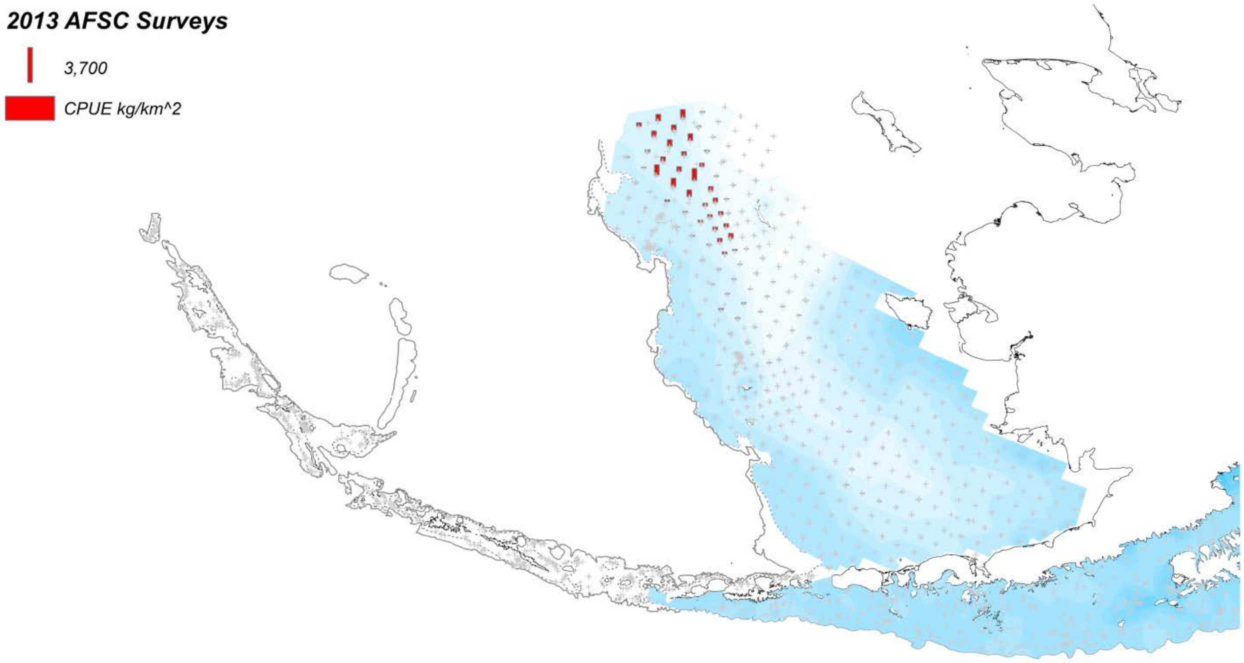


Figure 5.9.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.



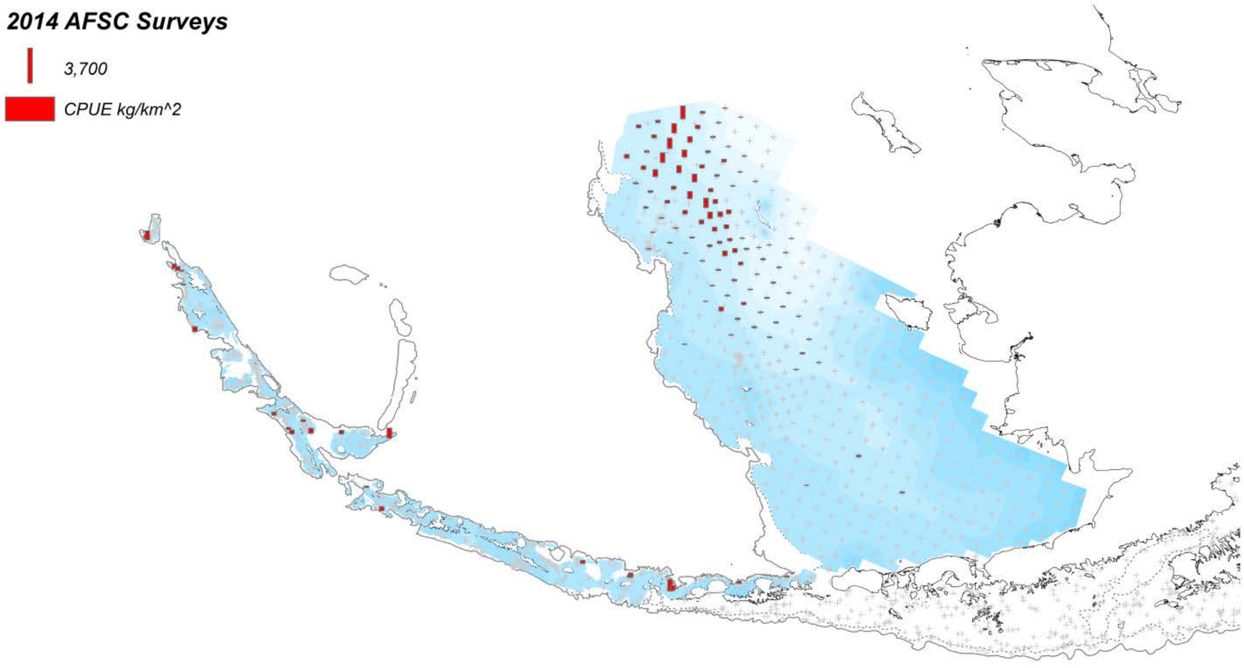


Figure 5.9.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

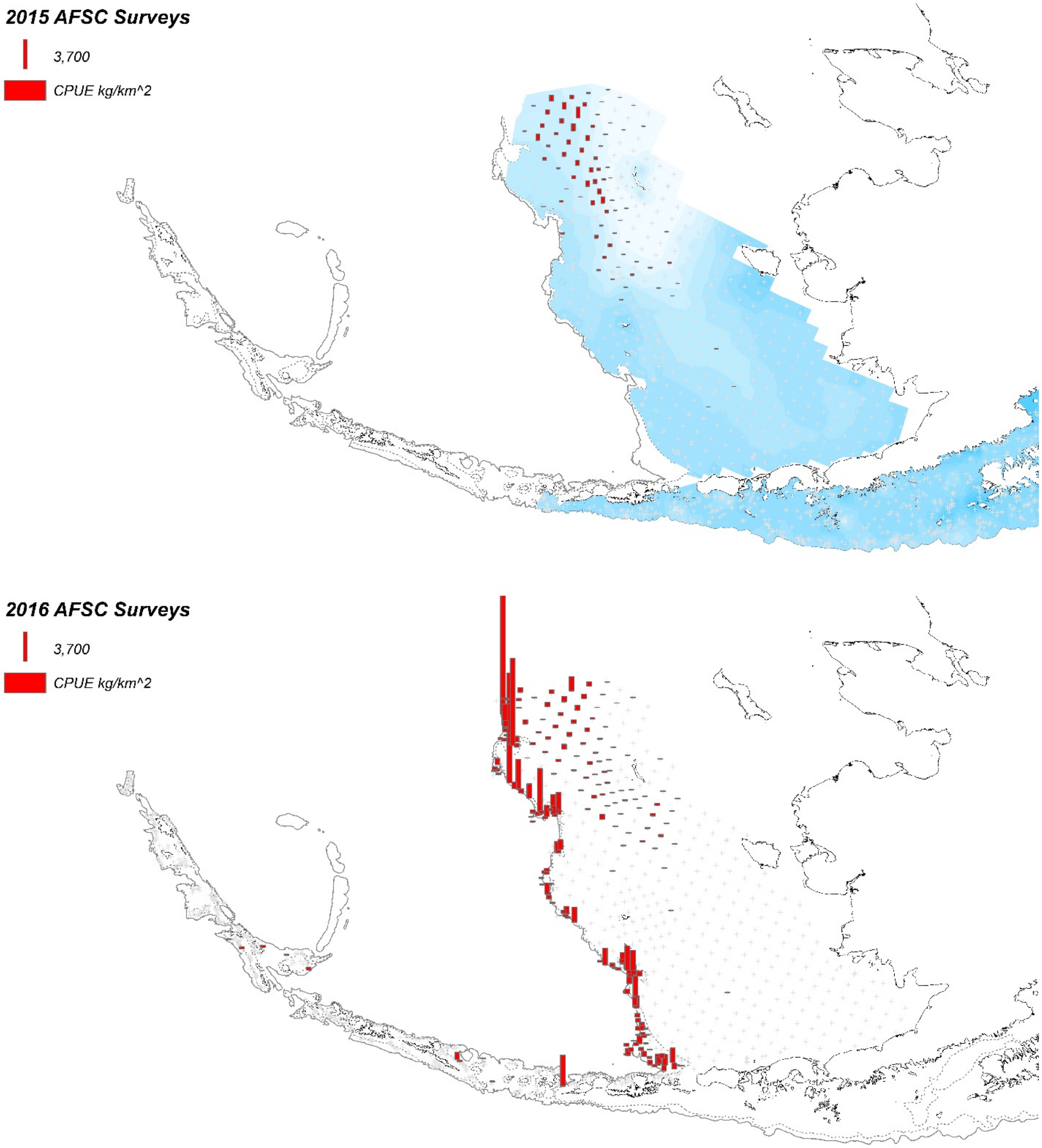


Figure 5.9.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year and 200m (dashed line) and 1000 m (solid gray line) isobaths. Bottom temperatures were not yet available for the 2016 map. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

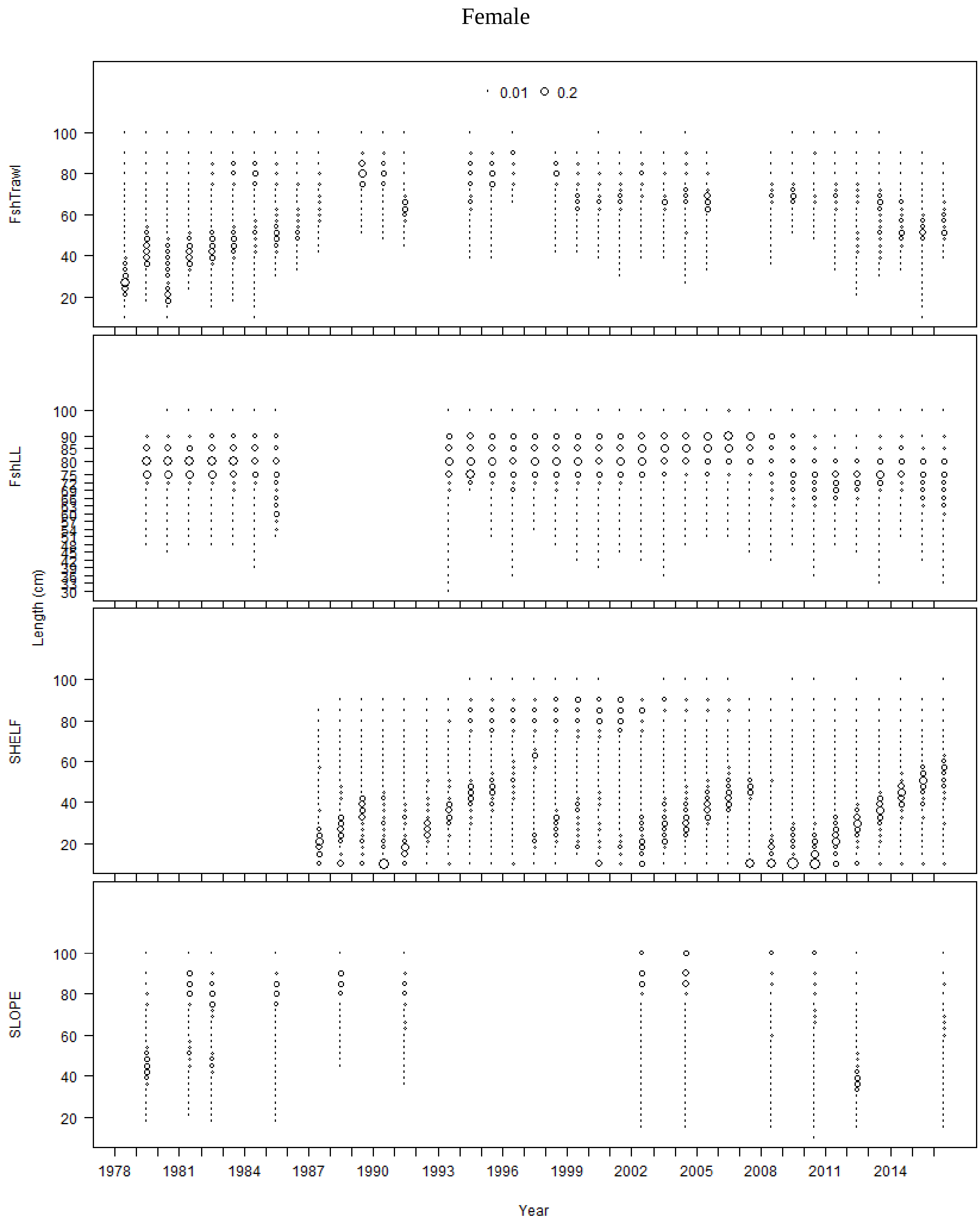


Figure 5.10. Greenland turbot size composition data for females from the Trawl fishery, longline fishery, shelf survey and slope survey.

Male

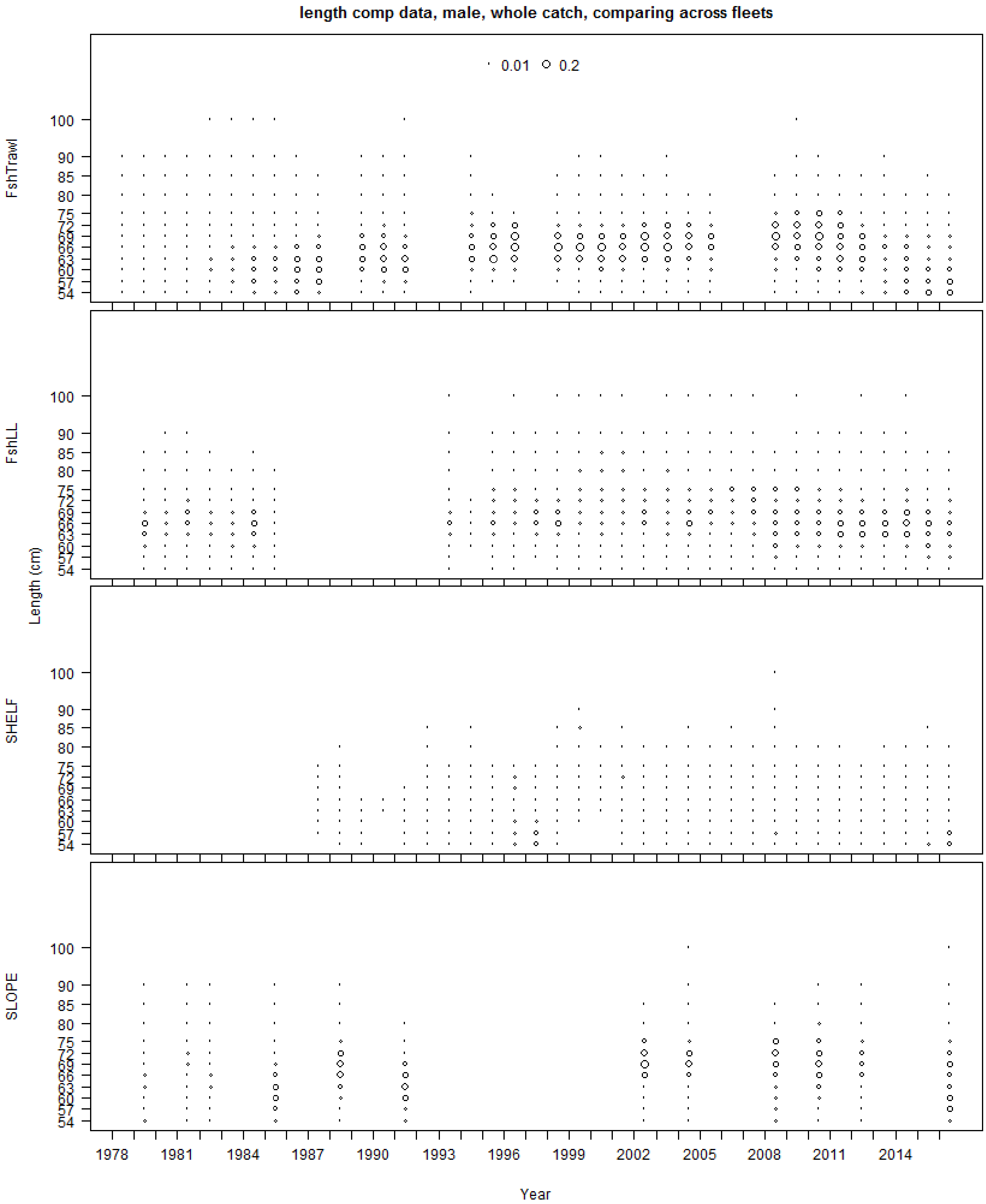


Figure 5.10. (Cont.) Greenland turbot size composition data for males from the trawl fishery, fixed-gear fishery, shelf survey and slope survey.

Figure 5.10. (Cont.) Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.

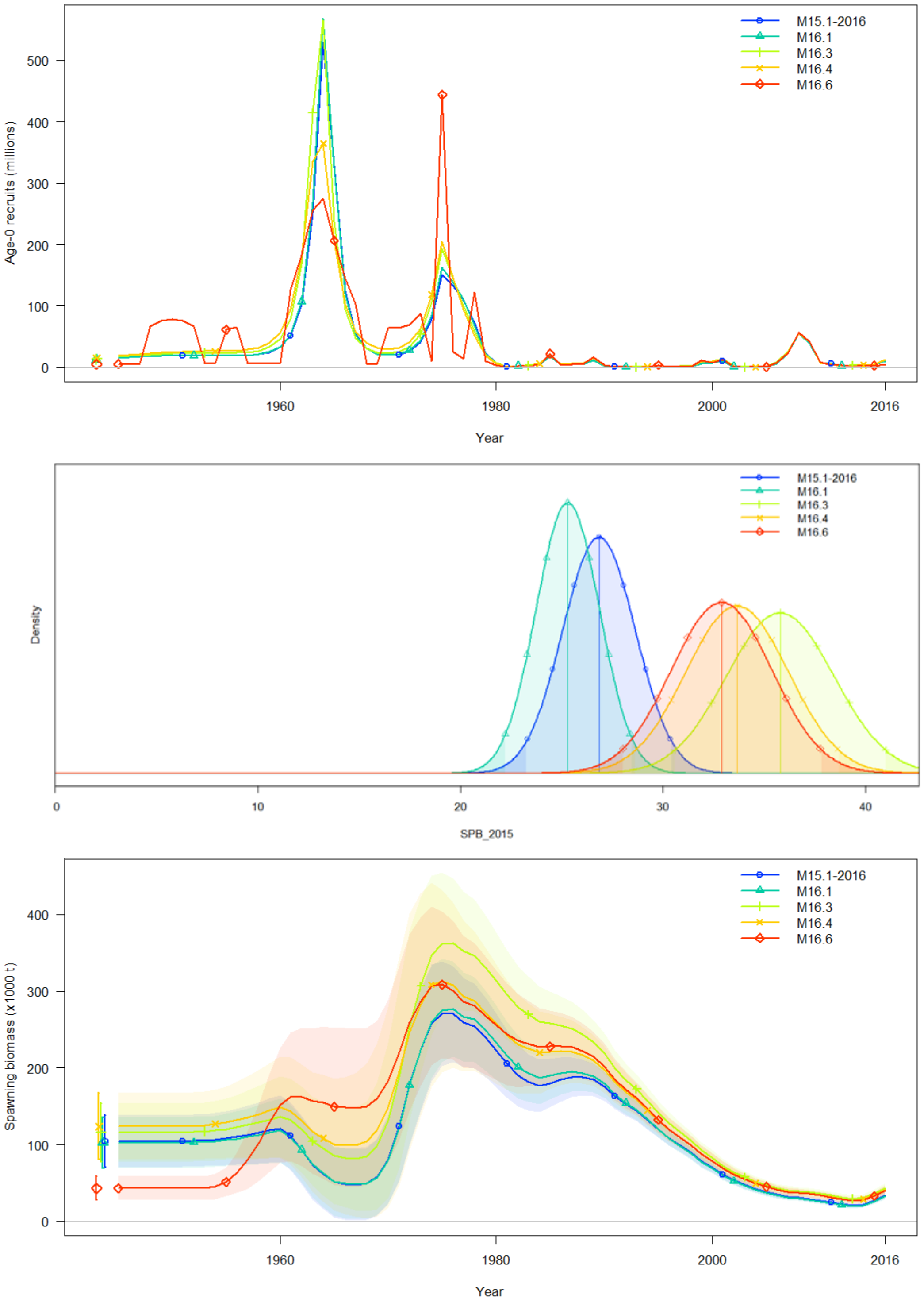


Figure 5.11. Age-0 recruitment (top), 2016 female spawning biomass density (middle), and female spawning biomass (bottom) for the five models evaluated.

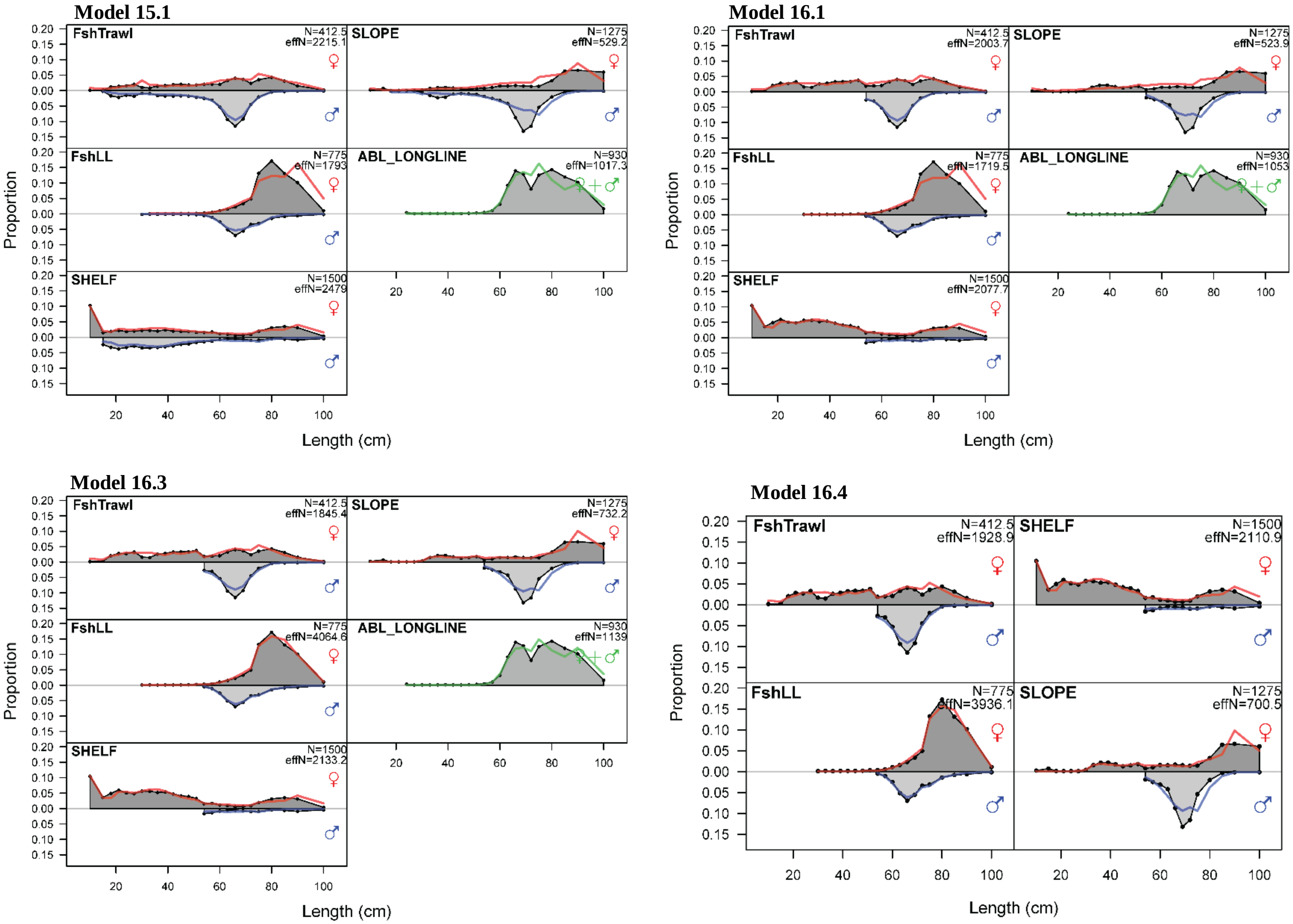
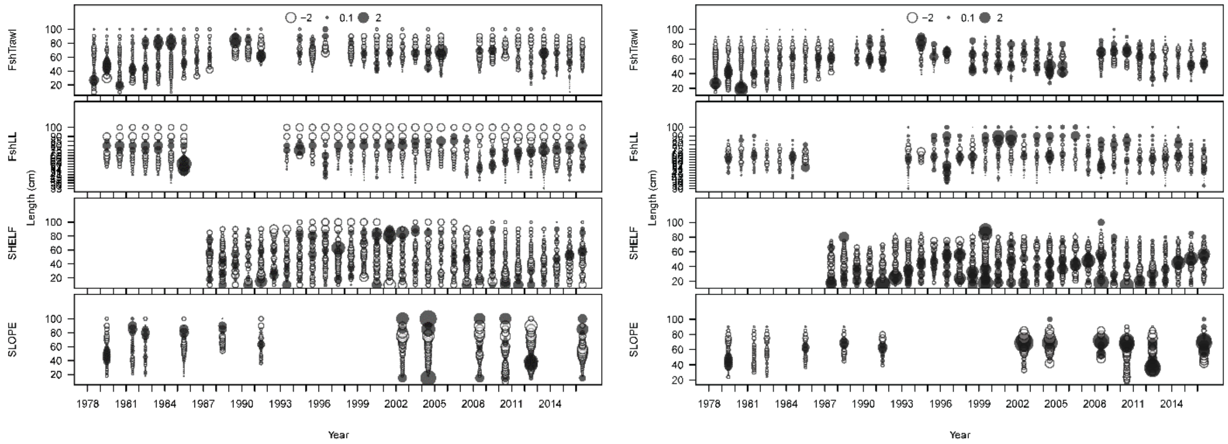
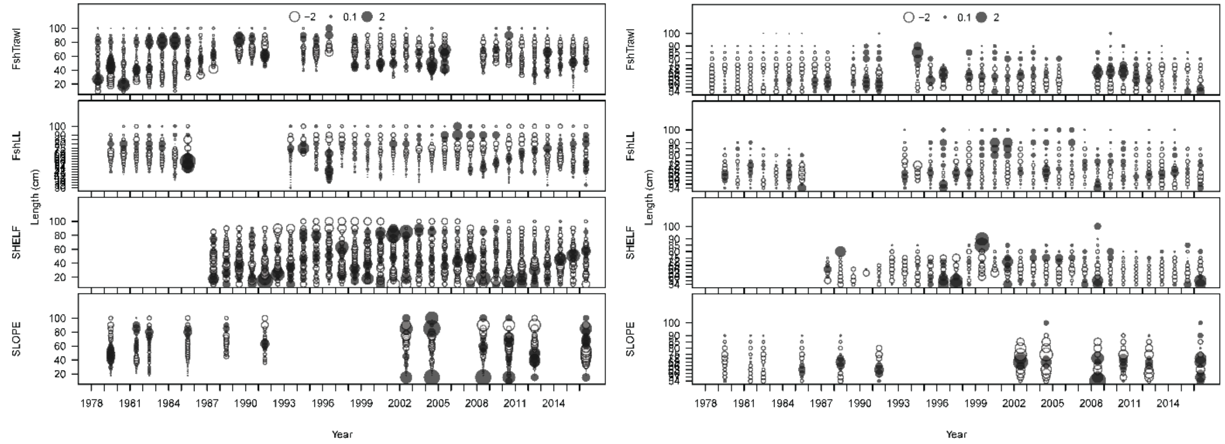


Figure 5.12. All size composition data combined across years and fits (red line female, blue line male) for fisheries and surveys.

Model 15.1



Model 16.3



Model 16.4

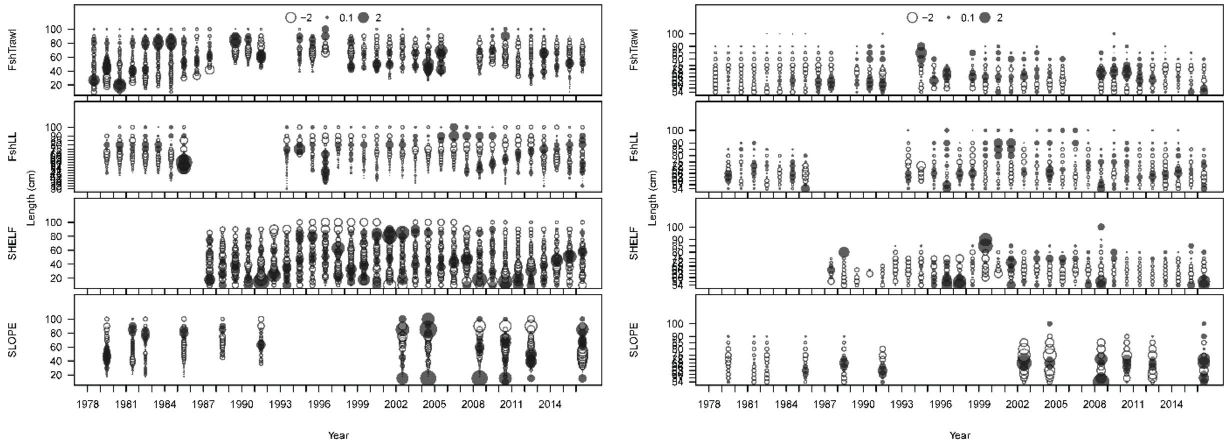


Figure 5.13. Pearson residuals for fisheries and two surveys. Closed bubbles are positive residuals and open bubbles are negative residuals. Note that the scale of the bubble graphs may differ by model.

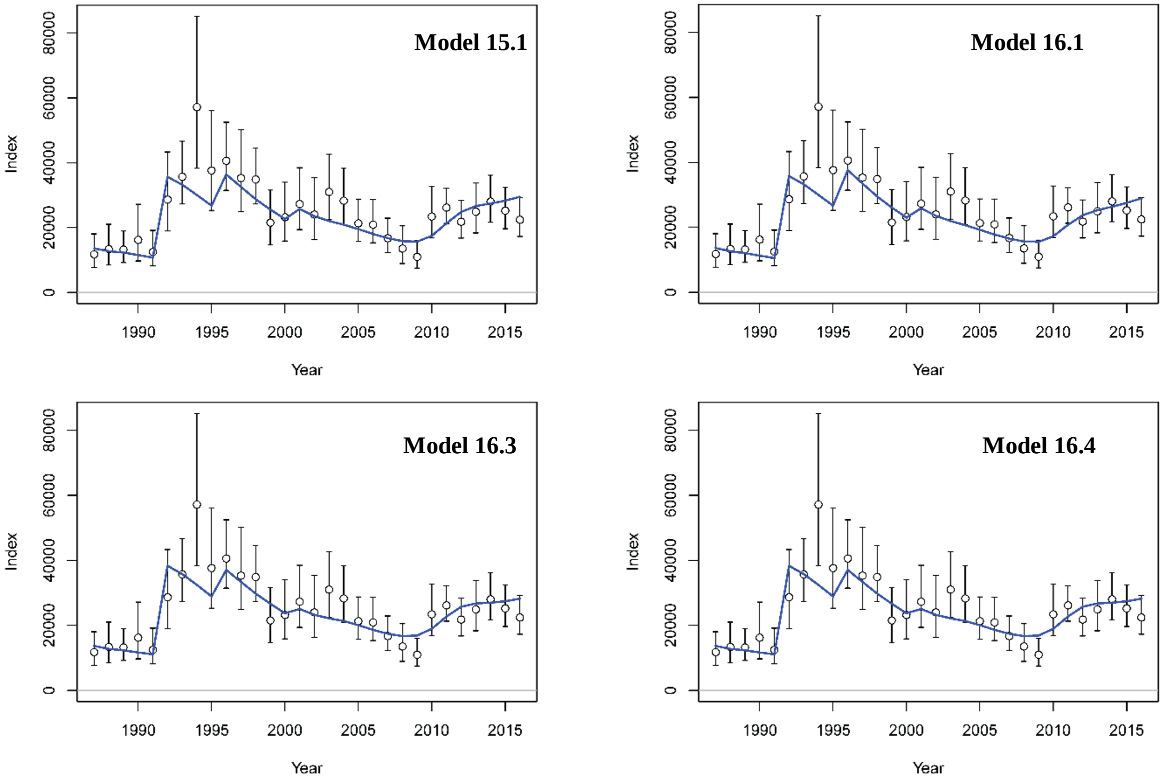
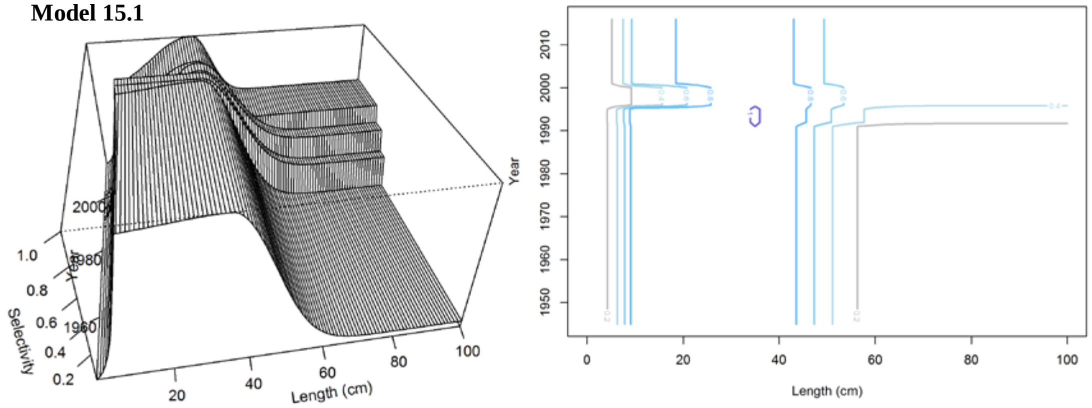
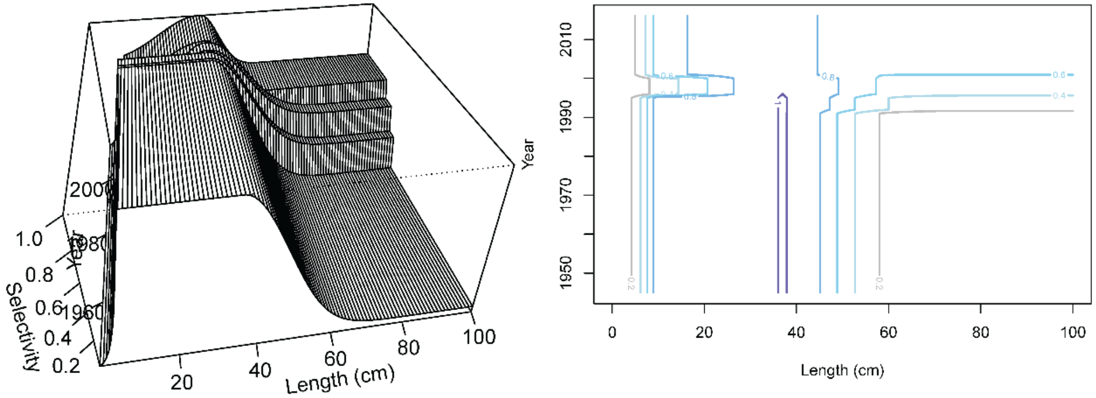


Figure 5.14. Shelf survey index (index values are the total survey biomass in tons) and model fits in blue. Error bars are 95% confidence intervals.

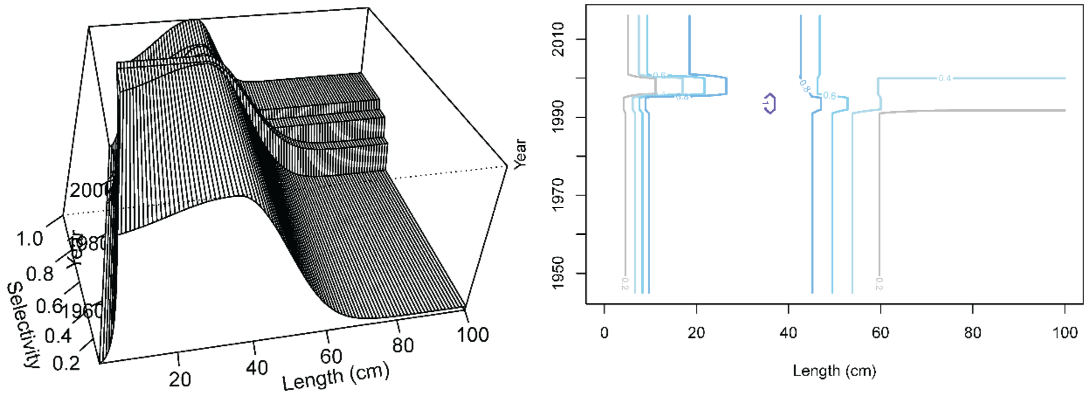
Model 15.1



Model 16.1



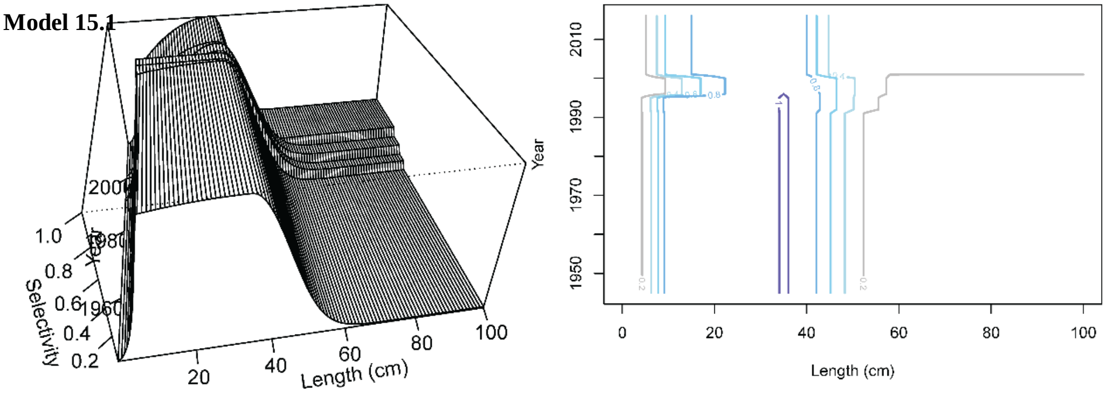
Model 16.3 and Model 16.4



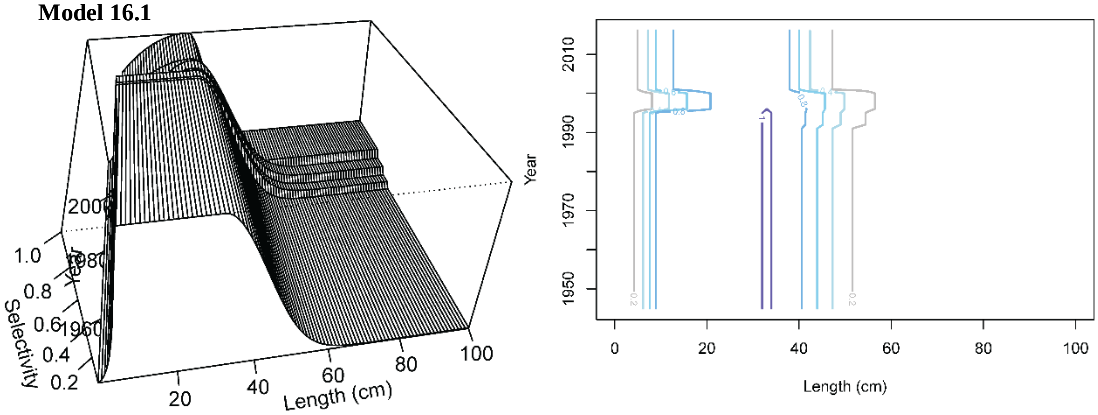
Model 16.4

Figure 5.15. Time-varying selectivity at size for the shelf survey for females.

Model 15.1



Model 16.1



Model 16.3 and Model 16.4

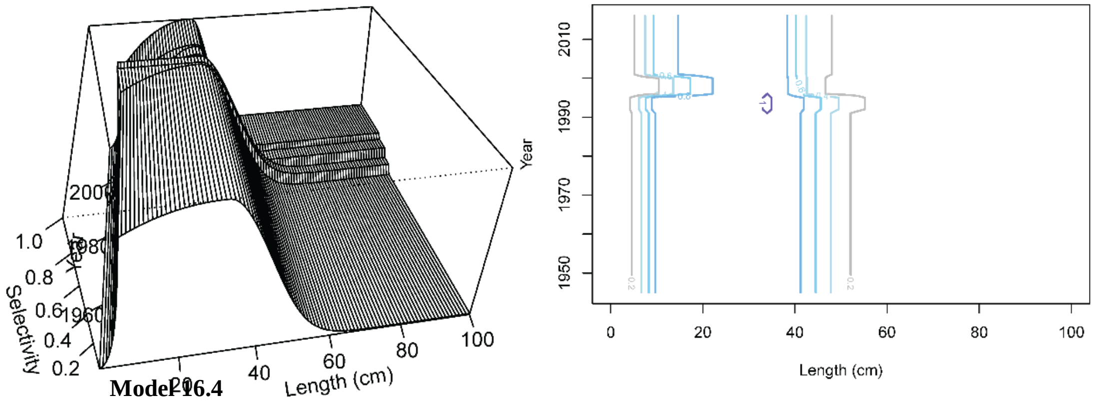


Figure 5.16. Time-varying selectivity at size for the shelf survey for males.

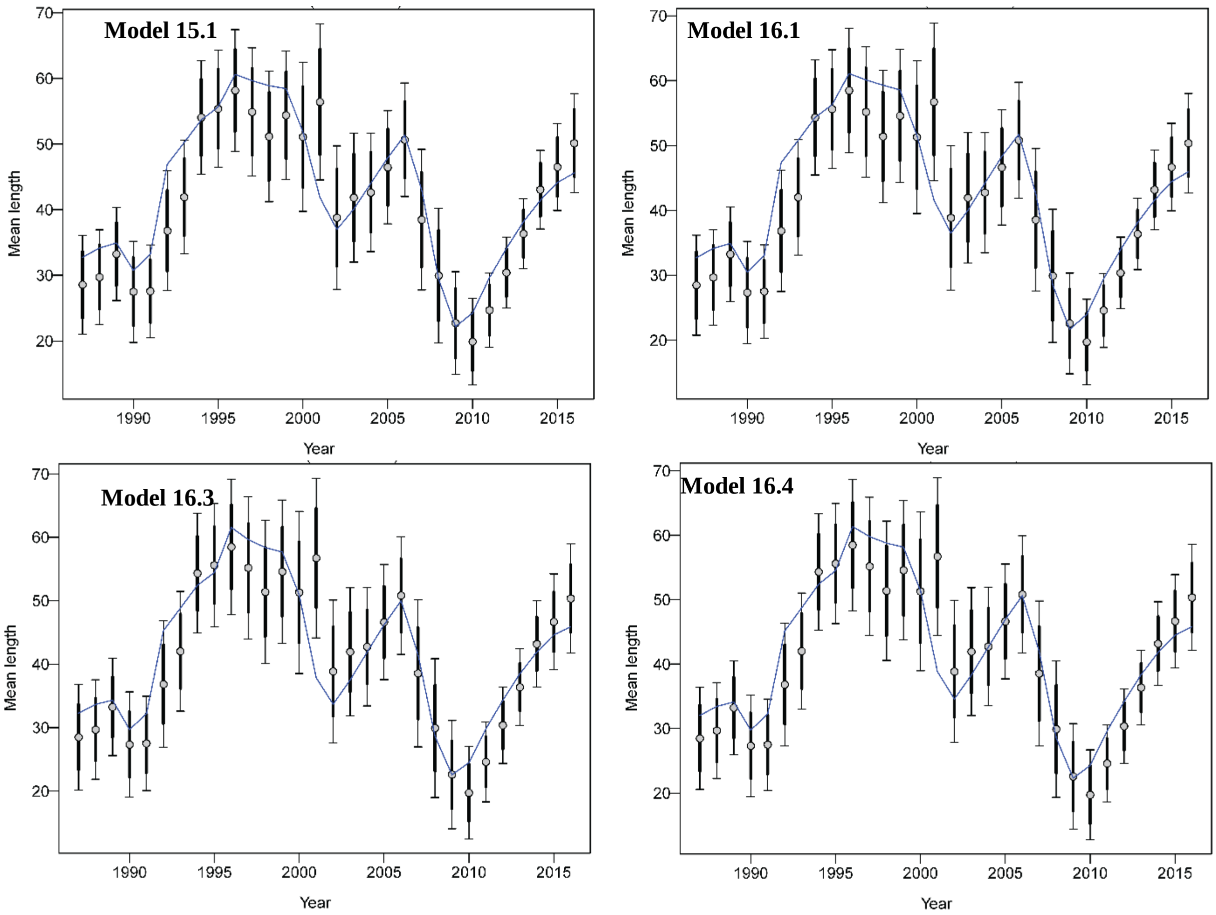


Figure 5.17. Mean length for the Shelf survey and model fit.

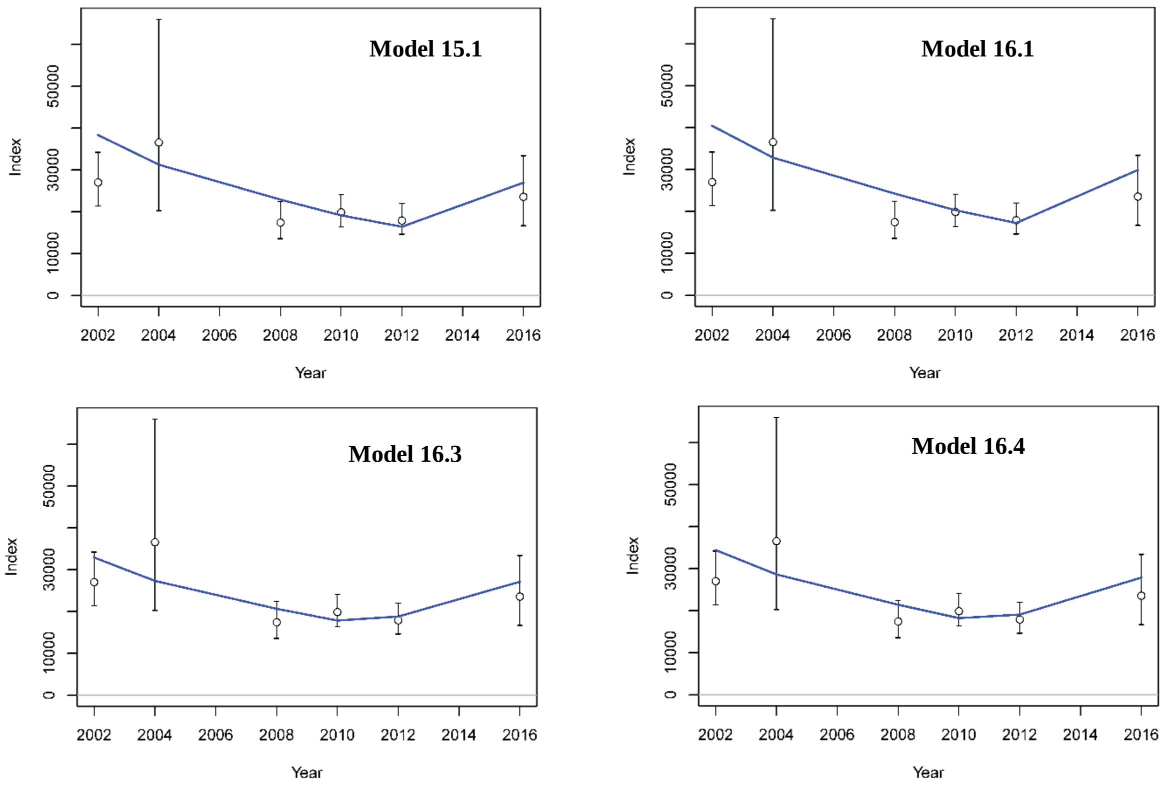


Figure 5.18. Slope survey index (index values are total survey biomass in tons) and model fits. Error bars are 95% confidence intervals.

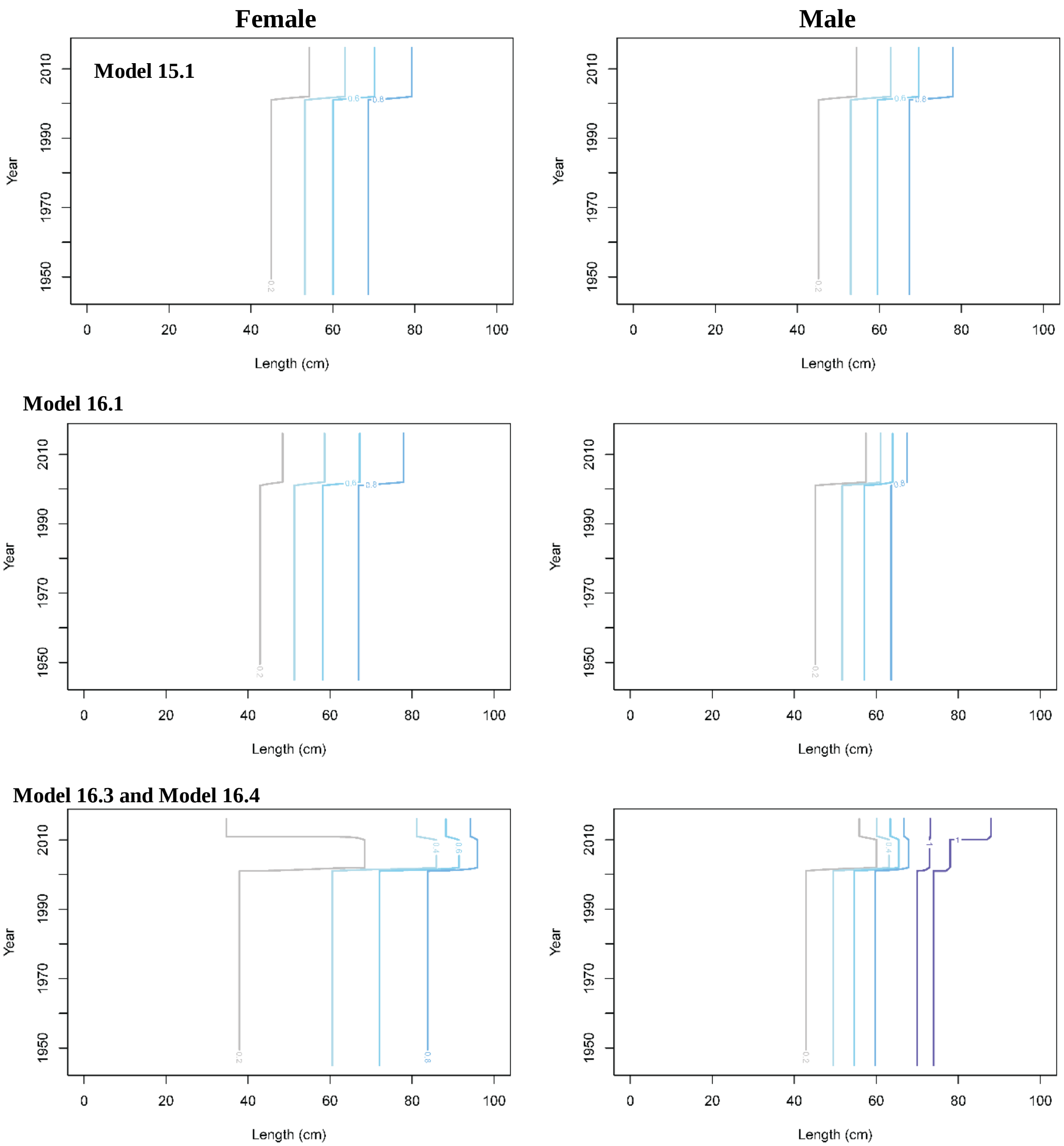


Figure 5.19. Slope survey selectivity by model and sex.

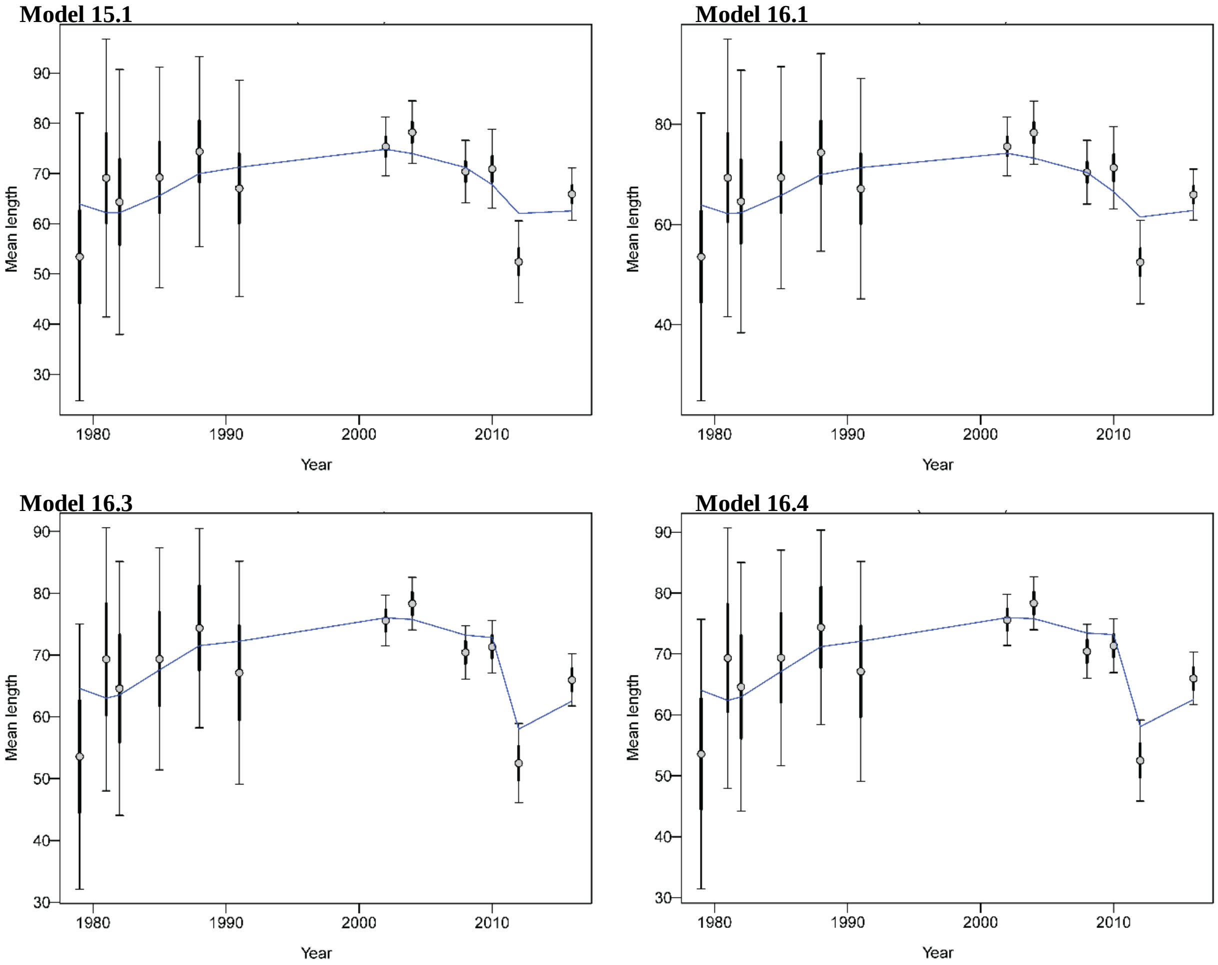
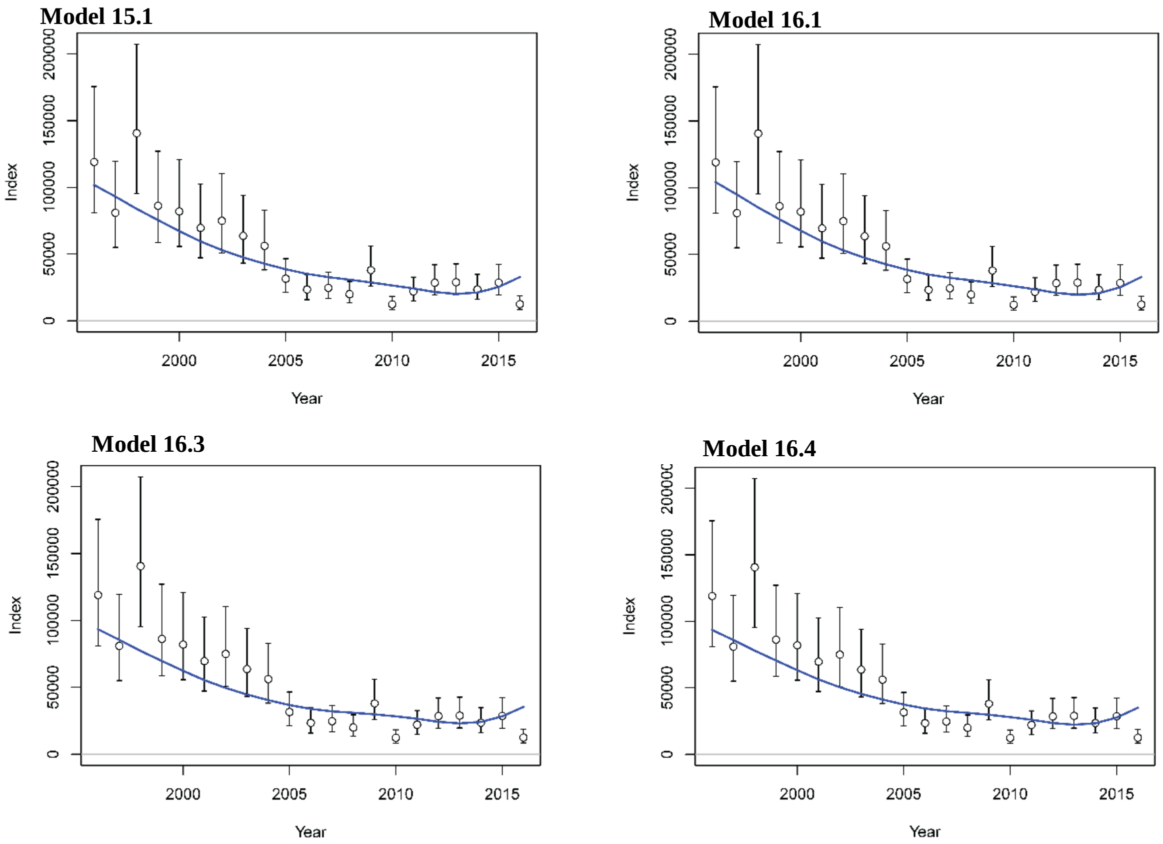


Figure 5.20. Mean size for slope survey and model fits.


Model 15.1

Model 16.1

Model 16.3

Model 16.4

Figure 5.21. The ABL Longline survey index (index values are in relative population numbers (RPN)) and model fits. Error bars are 95% confidence intervals.

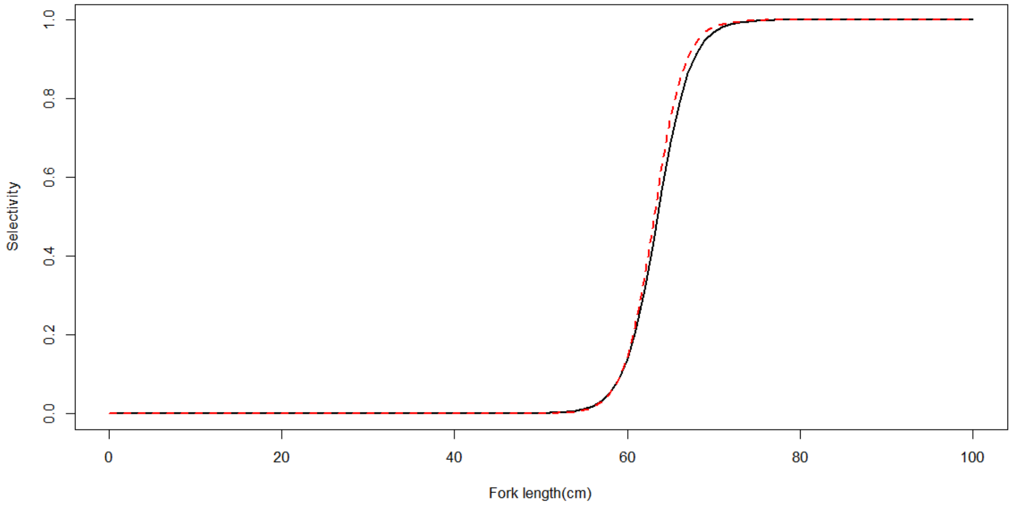


Figure 5.22. ABL longline survey selectivity for Model 15.1 and Model 16.1 (black solid line) and Model 16.3, Model 16.4, and Model 16.6 (red dashed line).

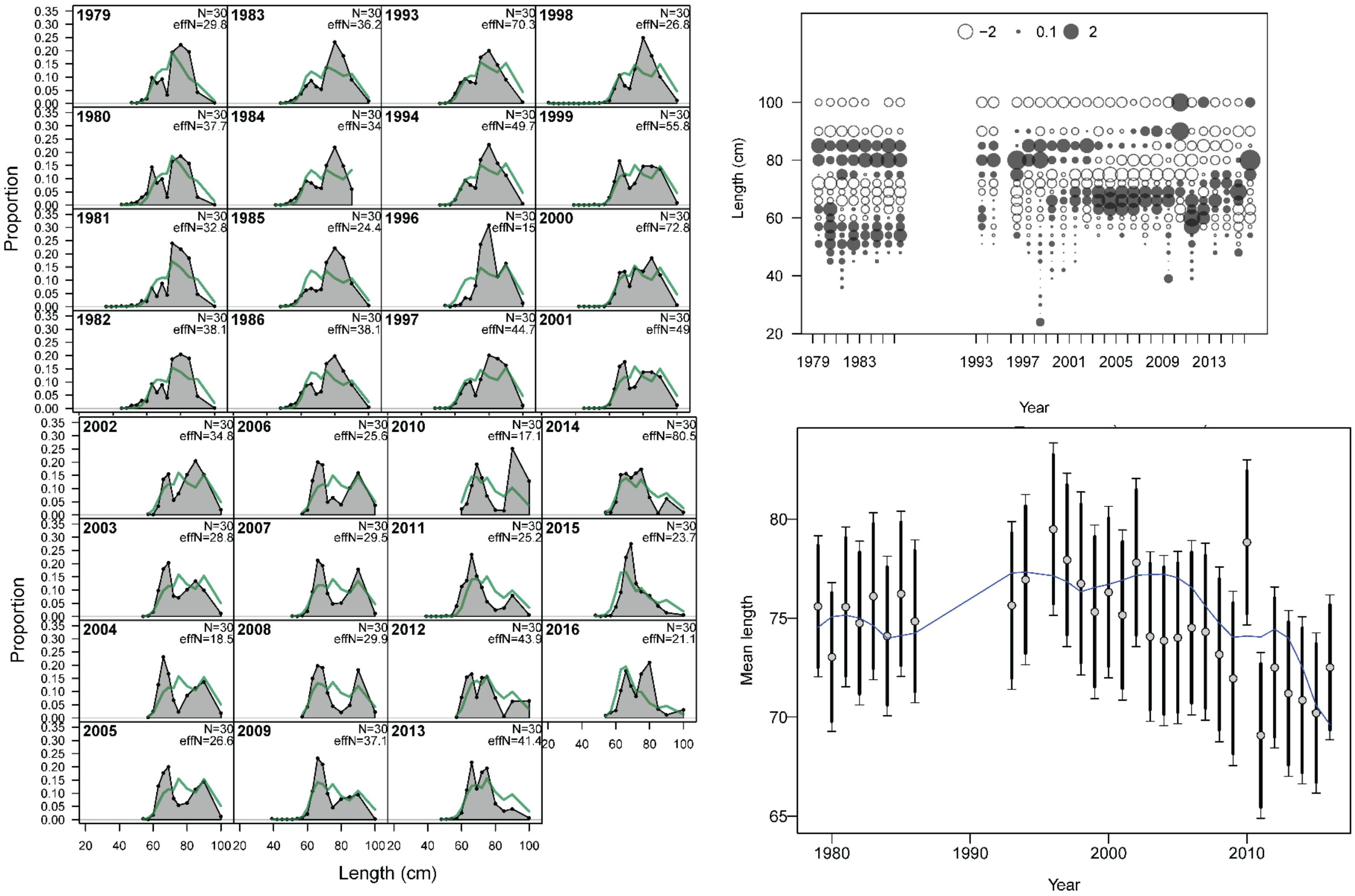
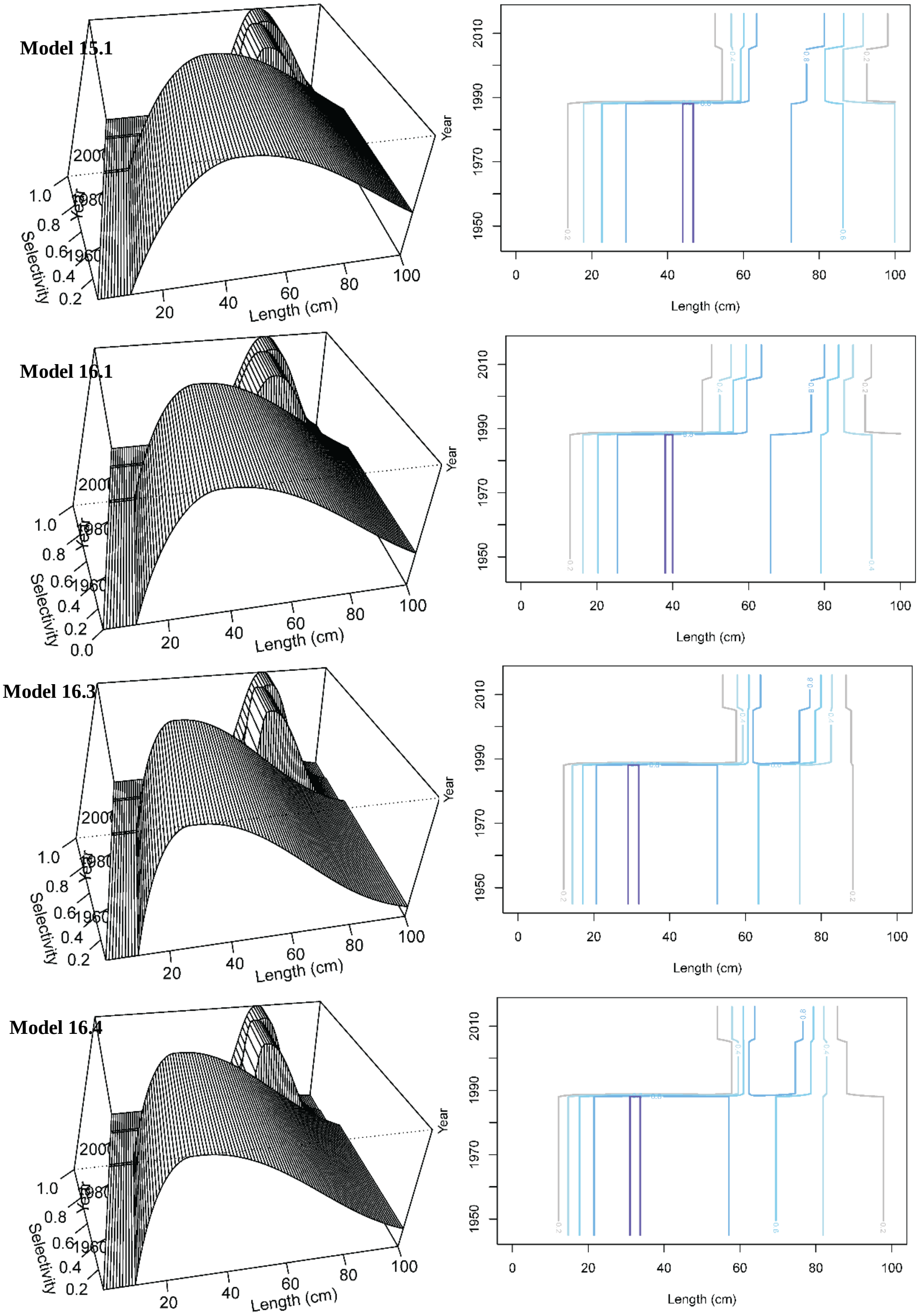


Figure 5.23. Model 16.3 Auke Bay Laboratory Longline survey (Left) size composition data and fits for combined sexes, (top right) slope survey size composition Pearson residuals, and (bottom right) mean length and model fit. **All three models with these data have similar fits.**



Model 15.1

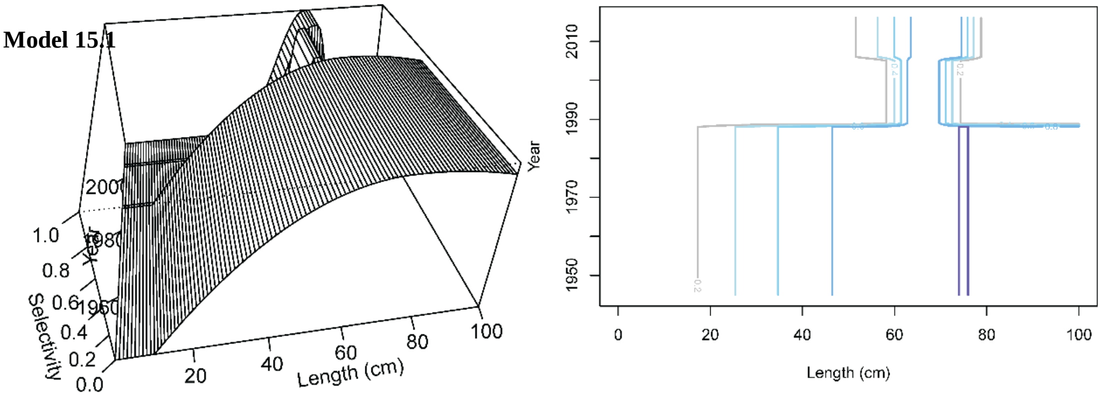
Model 16.1

Model 16.3

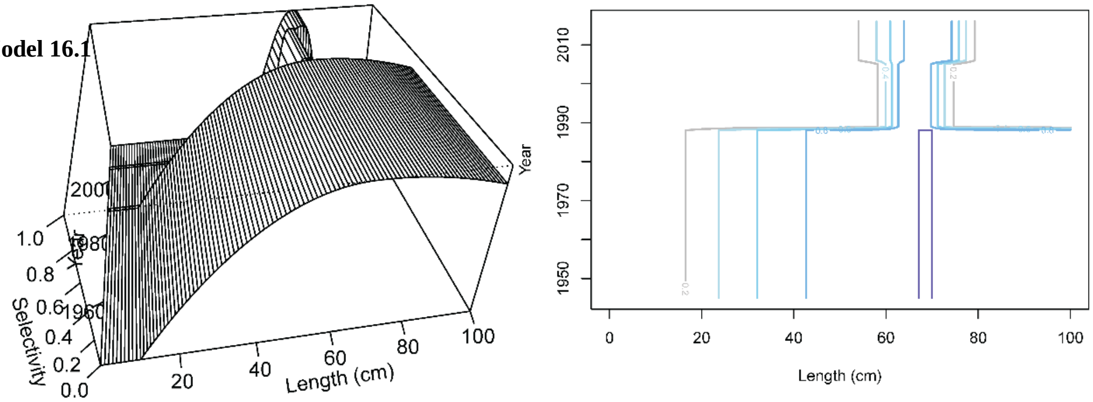
Model 16.4

Figure 5.24. Time-varying selectivity at size for the Trawl fishery for Females.

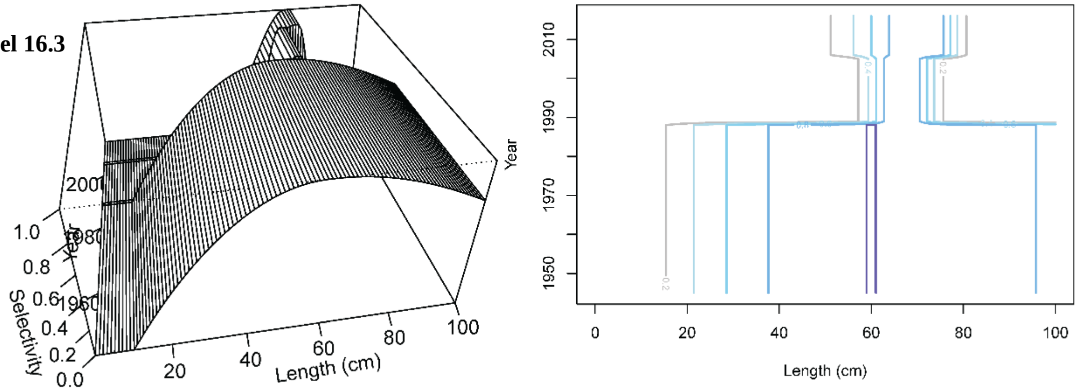
Model 15.1



Model 16.1



Model 16.3



Model 16.4

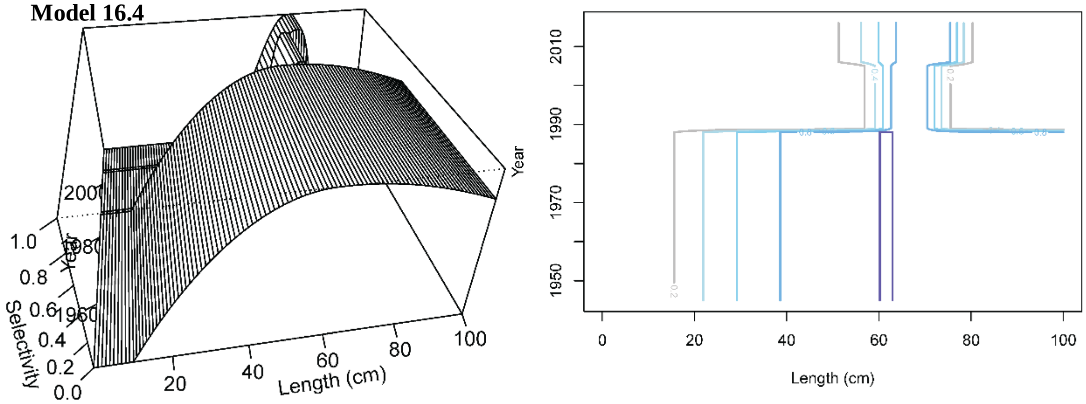
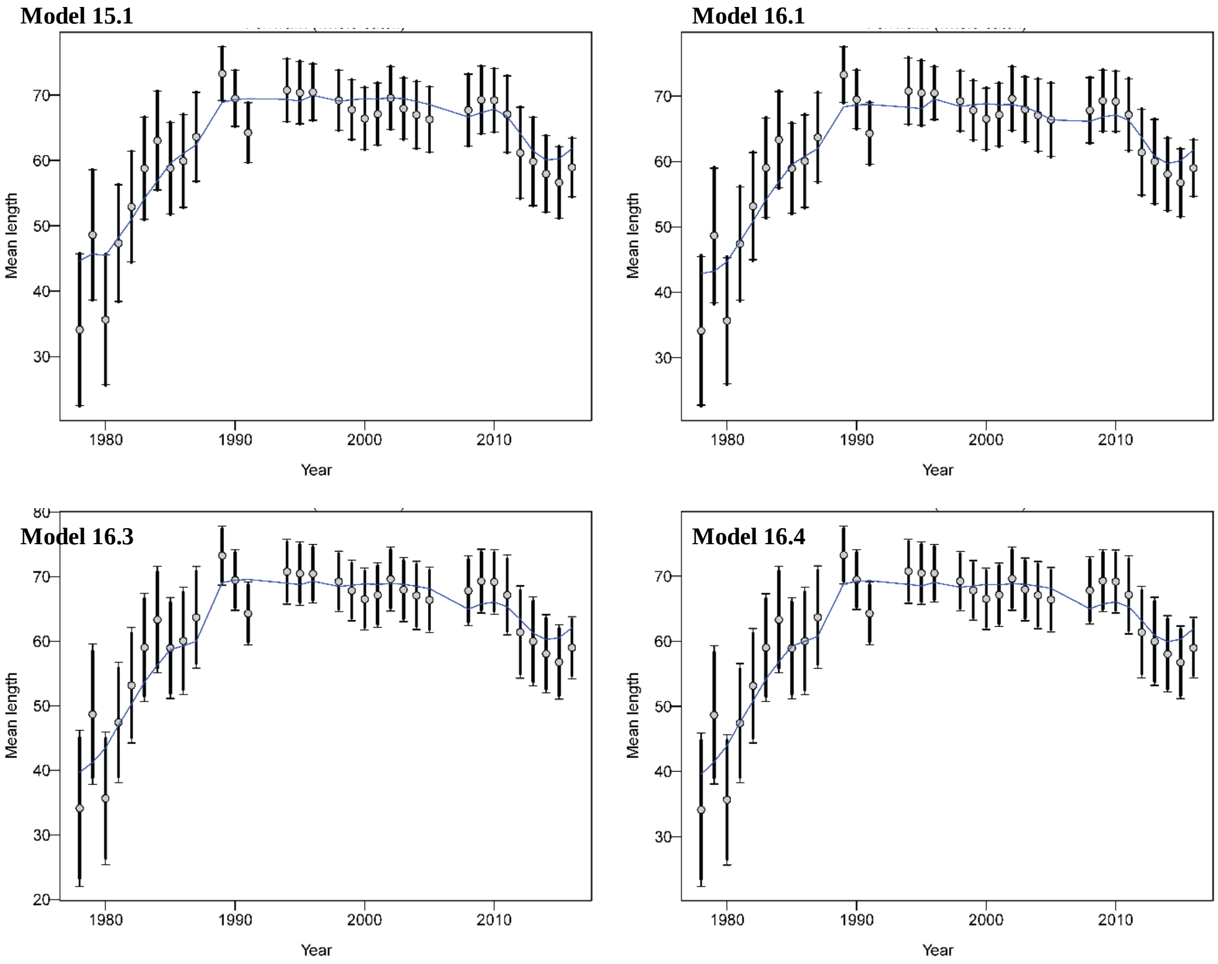


Figure 5.25. Time-varying selectivity at size for the Trawl fishery for males.



Model 15.1

Model 16.1

Model 16.3

Model 16.4

Figure 5.26. Trawl fishery mean length and model fits.

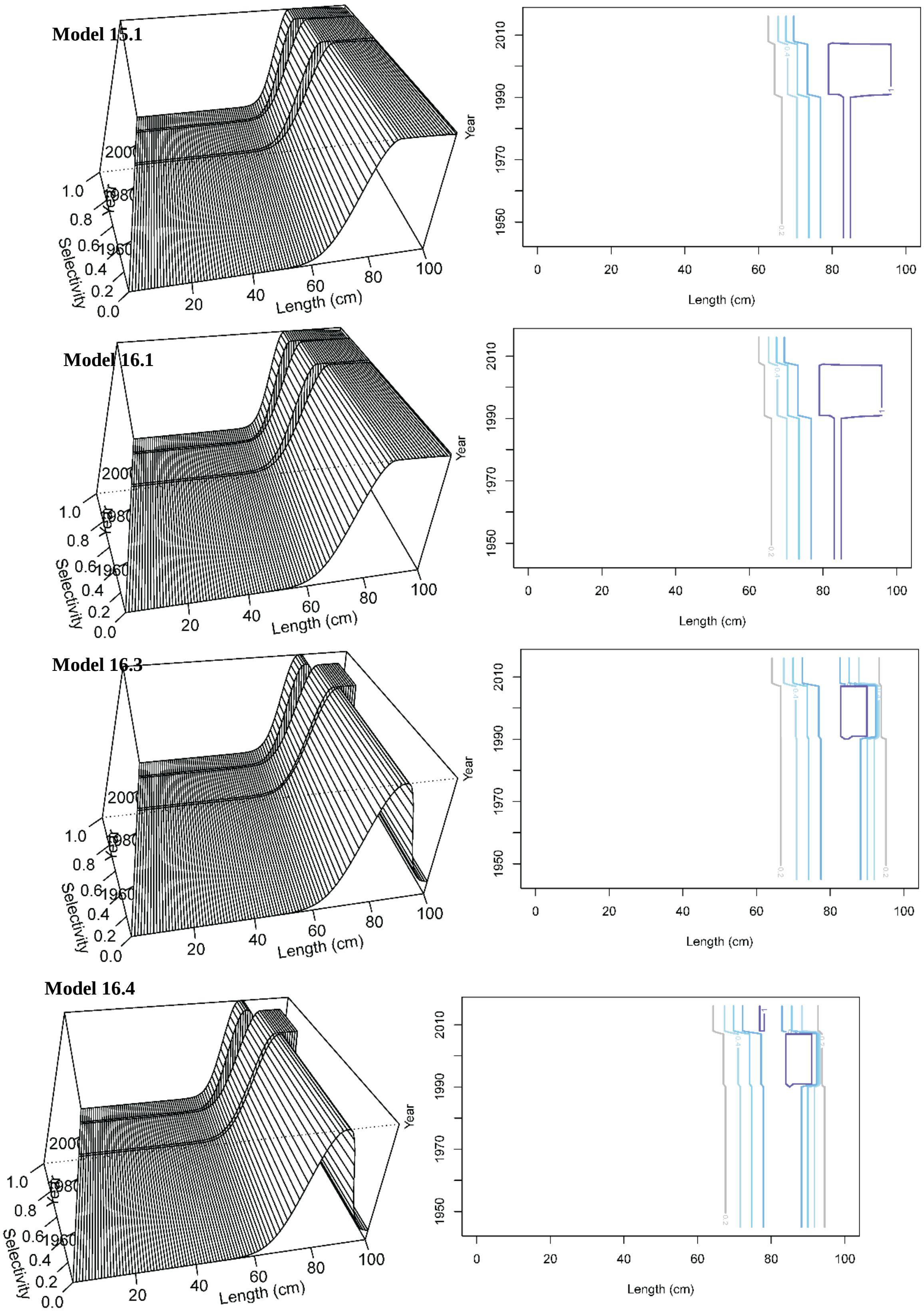


Figure 5.27. Time-varying selectivity at size for the Longline fishery for females.

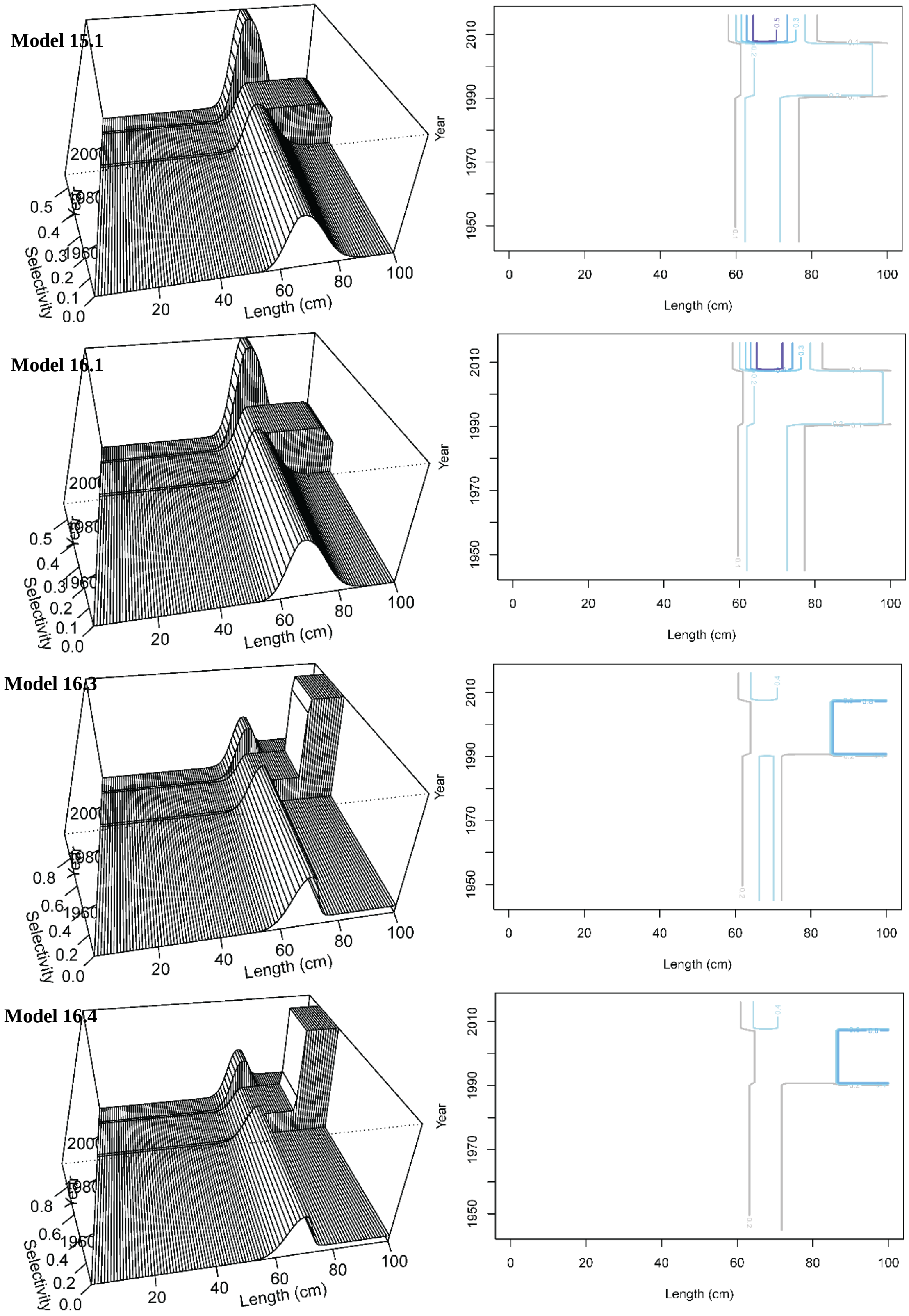


Figure 5.28. Time-varying selectivity at size for the Longline fishery for males.

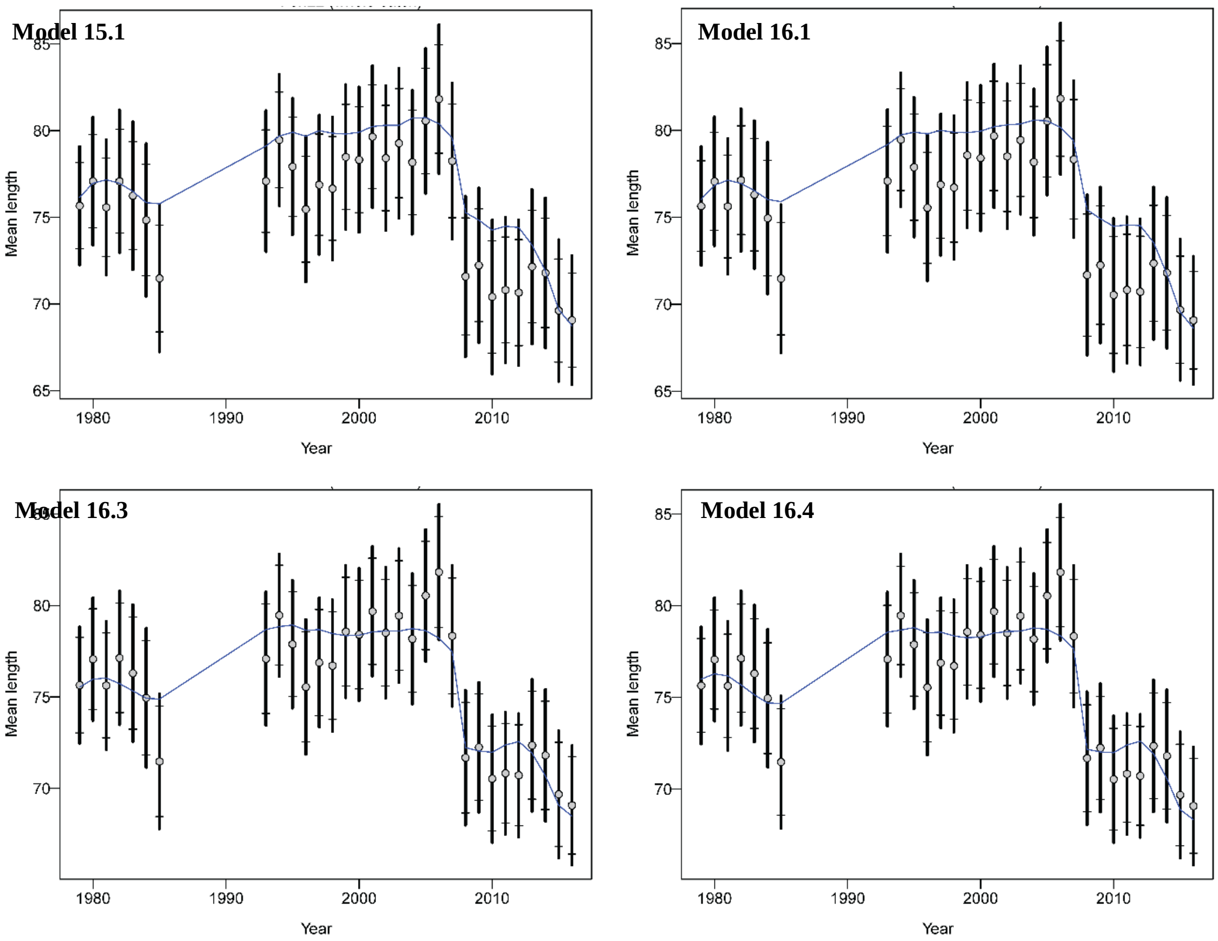
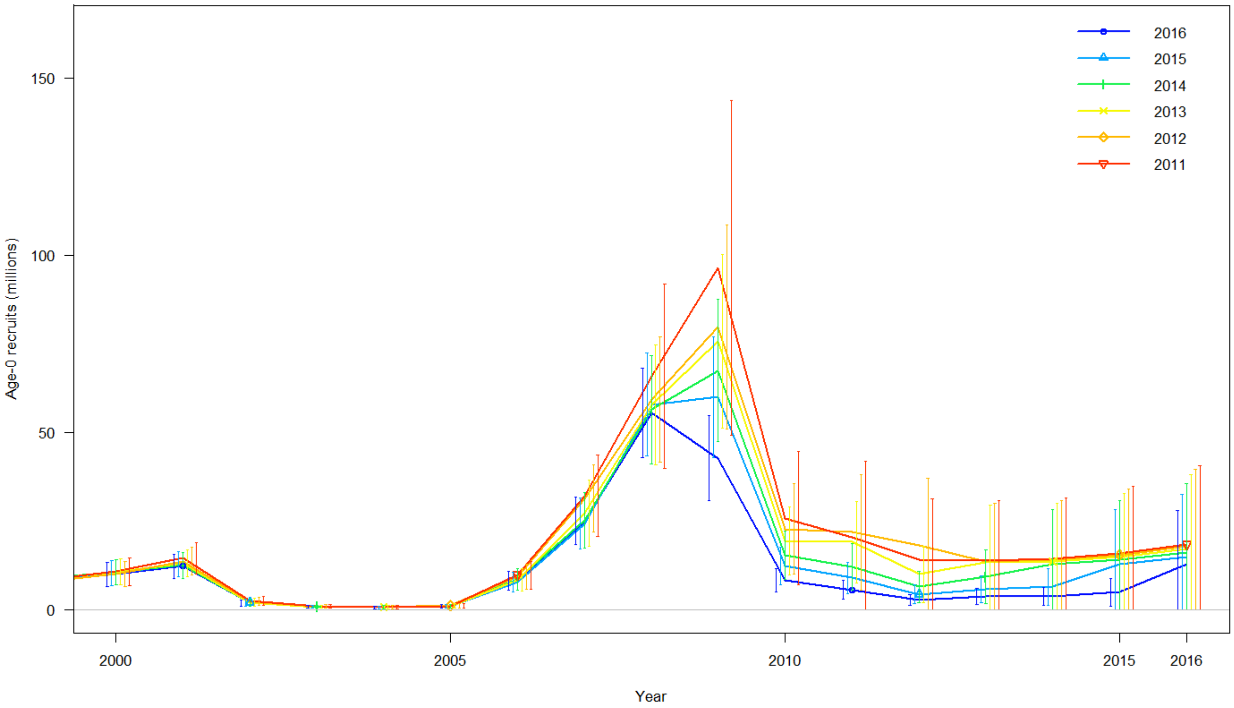


Figure 5.29. Mean length from the Longline fishery and model fits.



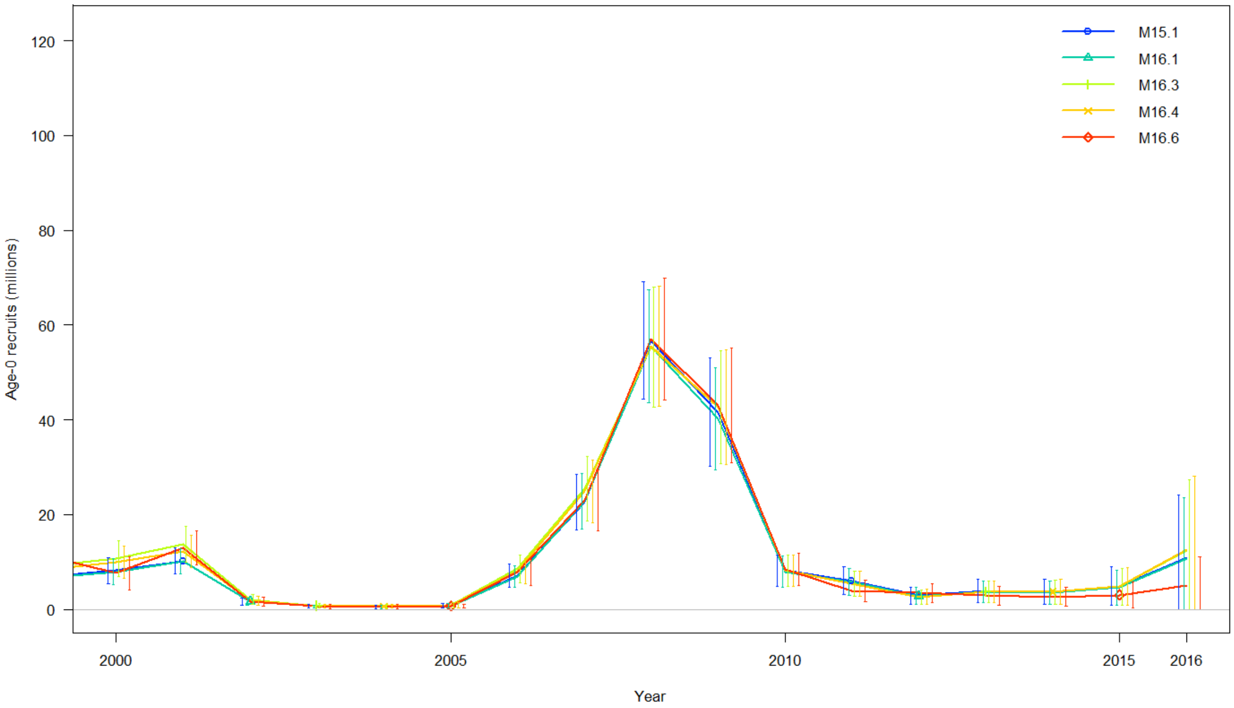


Figure 5.30. Age-0 recruitment from (top) Model 16.4 with data sequentially removed 20016-2011and (bottom) for Models 15.1, 16.1, 16.3,16.4, and 16.6 with all data.

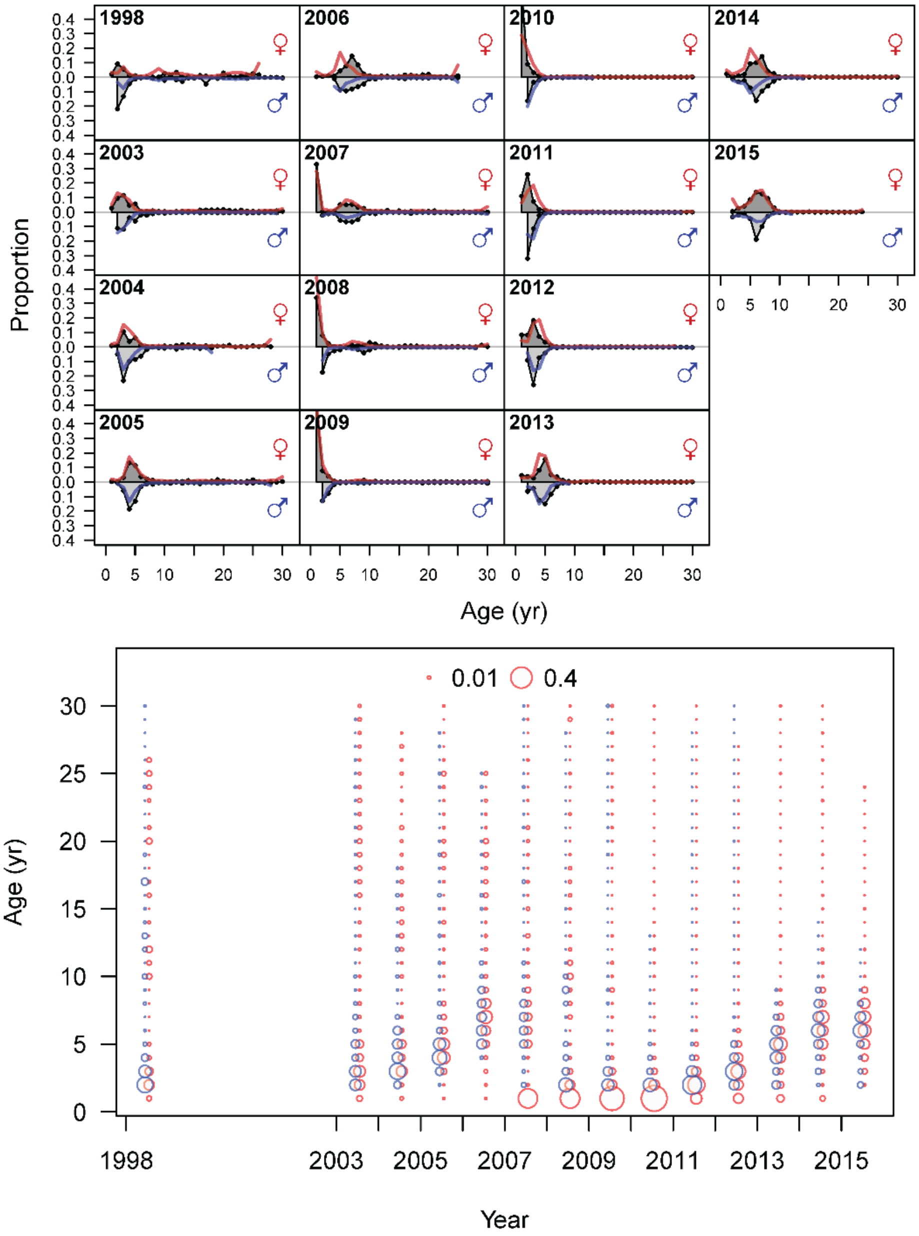


Figure 5.31. Model 16.4 (top) shelf survey age composition data and "ghost" fits (red and blue line) and (bottom) Pearson's residuals for age composition "ghost fits". Closed bubbles are positive residuals and open bubbles are negative residuals. Red bubbles are female and blue are male. "Ghost" fits are projected fits as the likelihood for the age composition data is not included in Model 16.4.

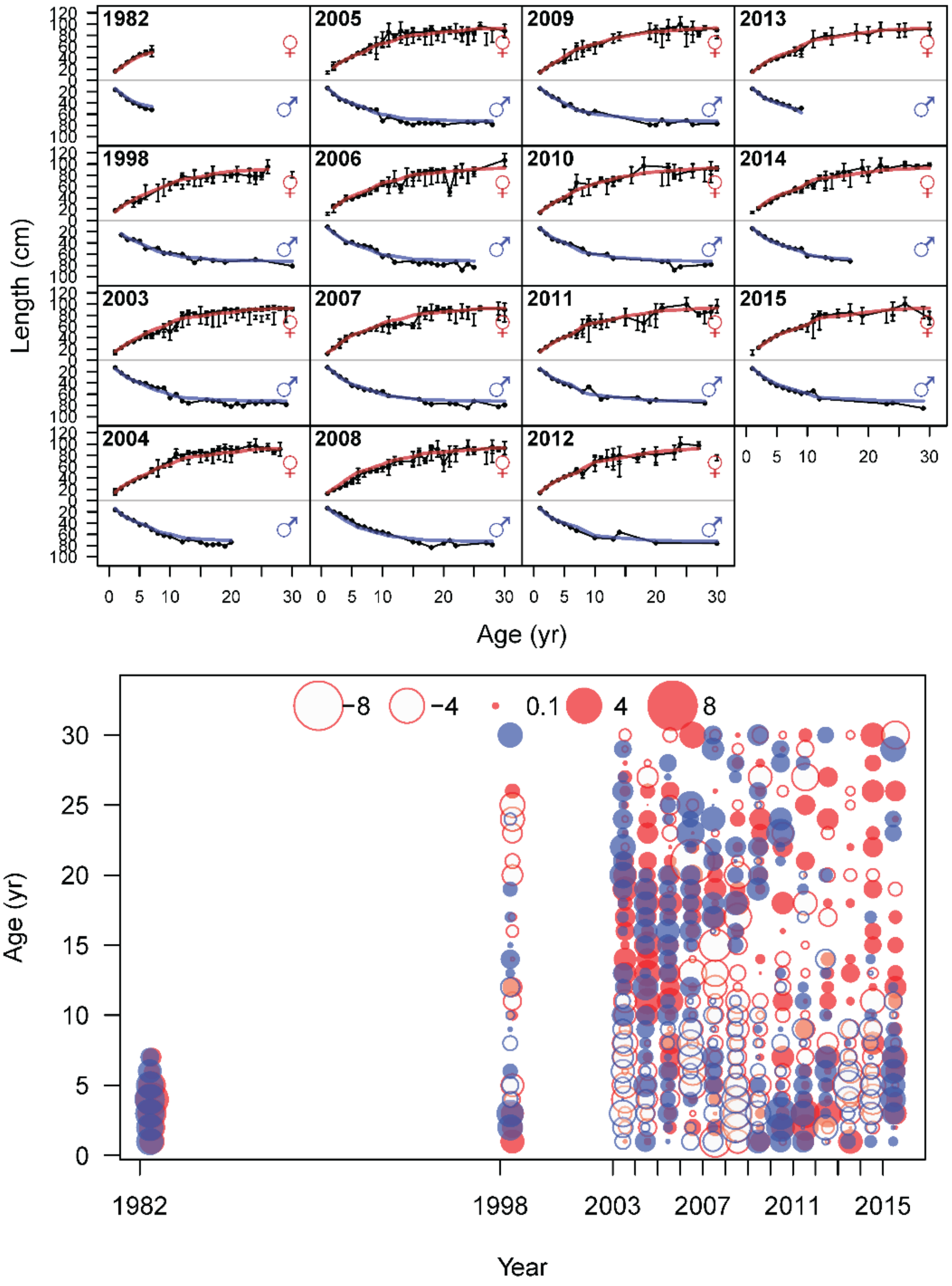


Figure 5.32. (Top) Length at age data and fits (red line). (Bottom) Pearson's residuals for length at age data. Closed bubbles are positive residuals and open bubbles are negative residuals. Red bubbles are female and blue are male.

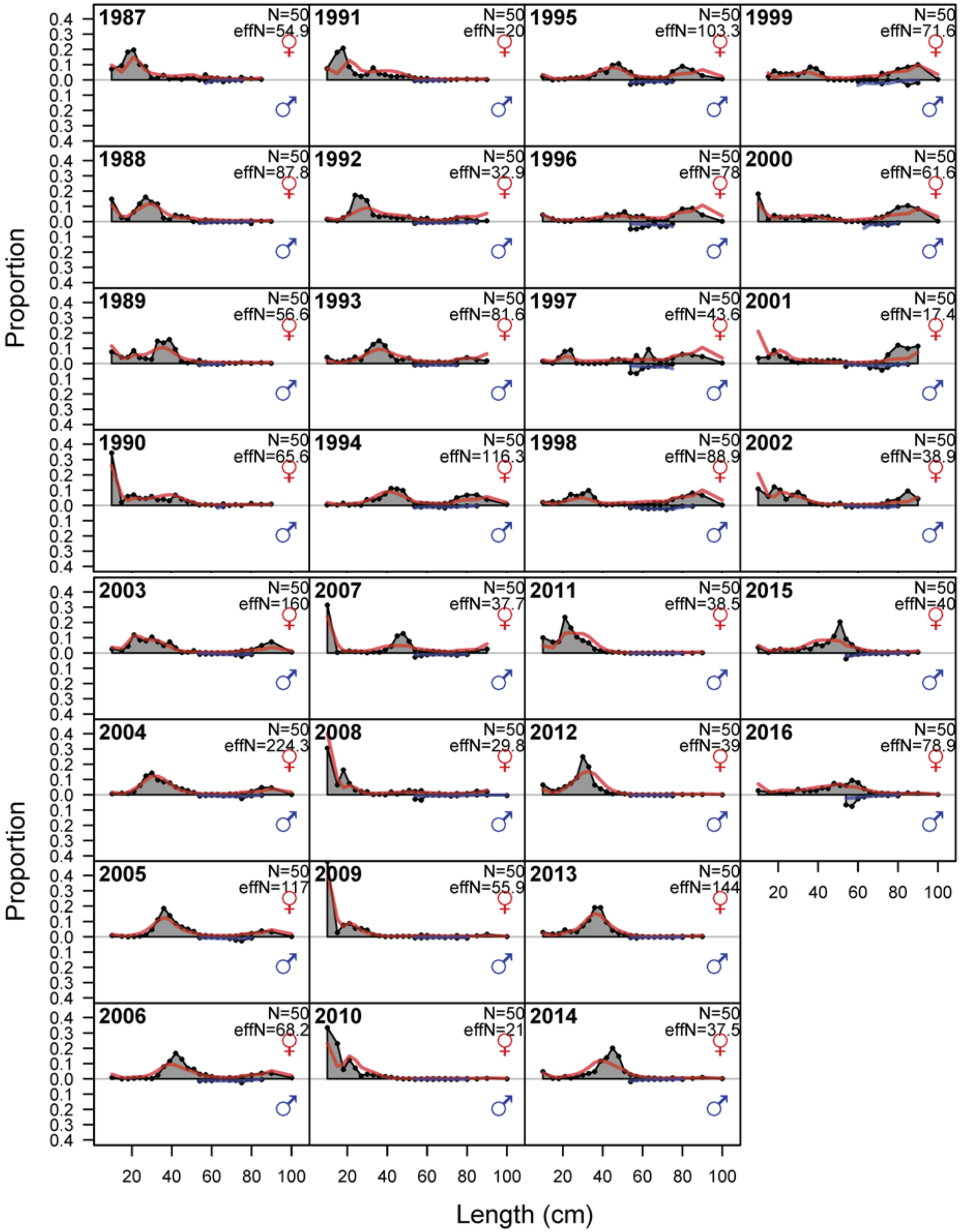


Figure 5.33. Model 16.4 shelf survey size composition data and fits (red line females, blue lines males).

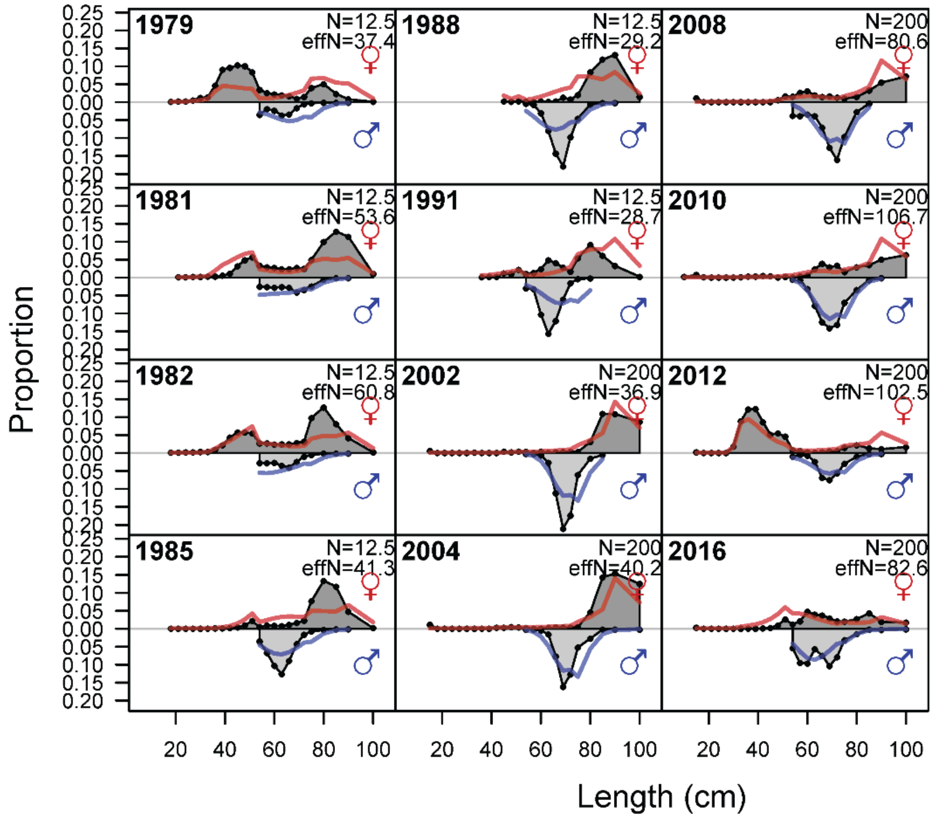


Figure 5.34. Model 16.4 slope survey size composition data and fits (red line for females and blue line for males) for all models.

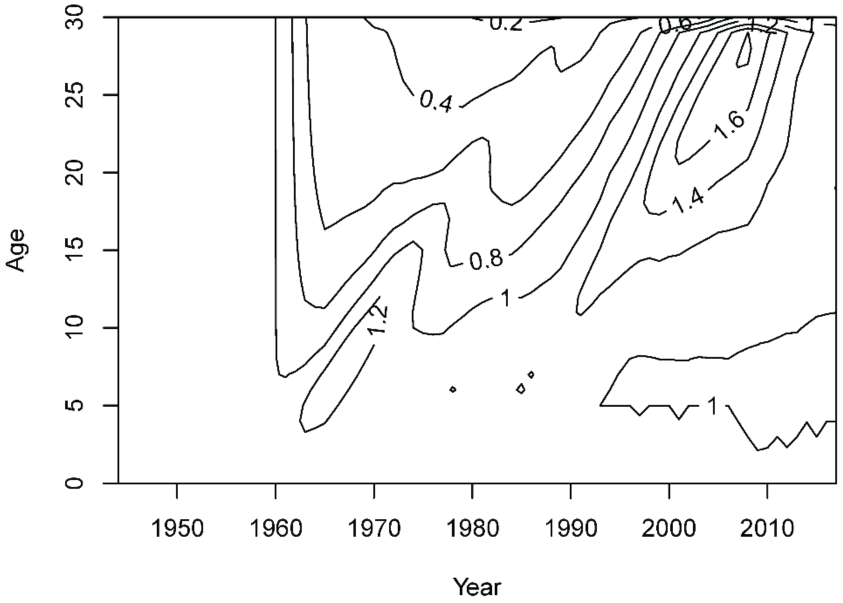
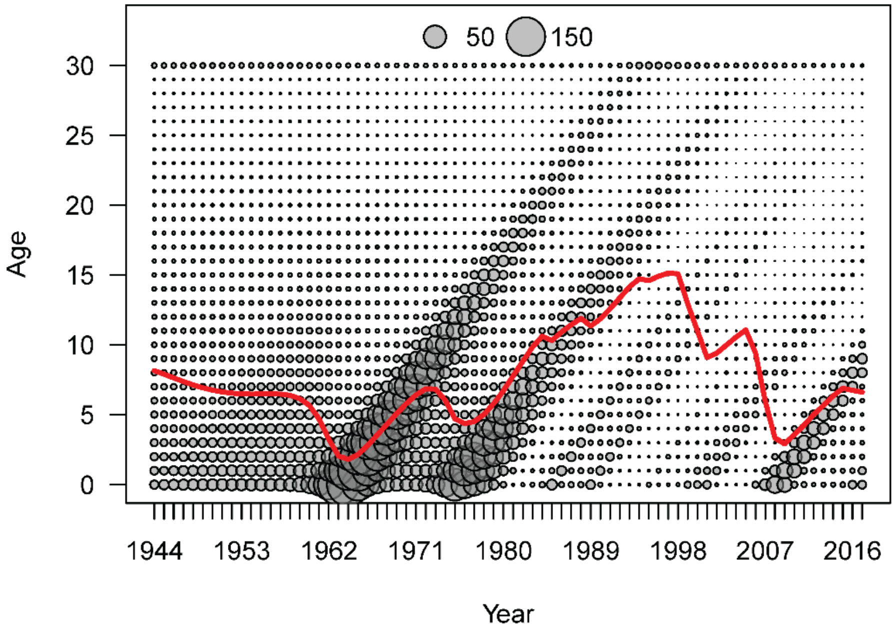


Figure 5.35. Model 16.4 predicted sex ratio (Males/Females).

Beginning of year expected numbers at age of females in (max ~ 182.3 million)



Beginning of year expected numbers at age of males in (max ~ 182.3 million)

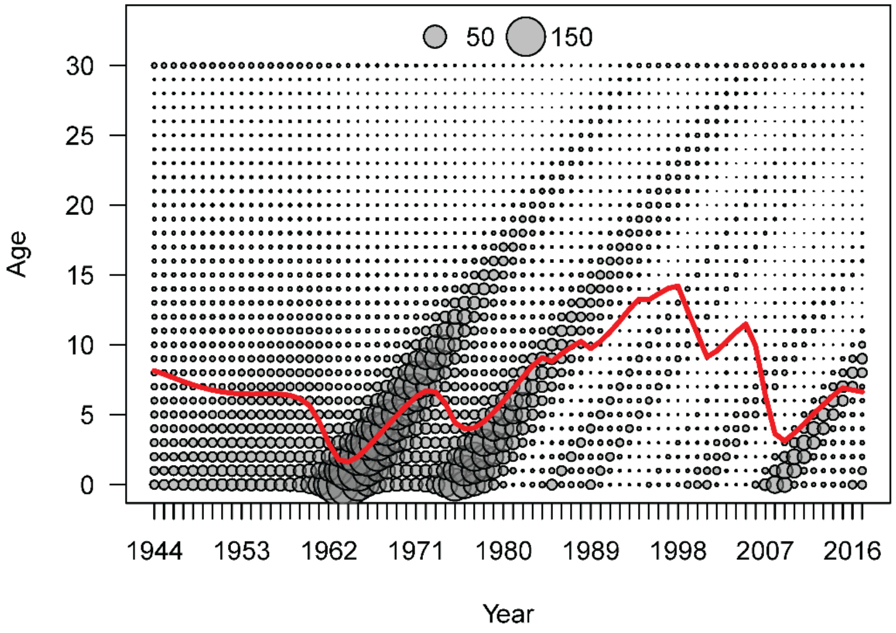
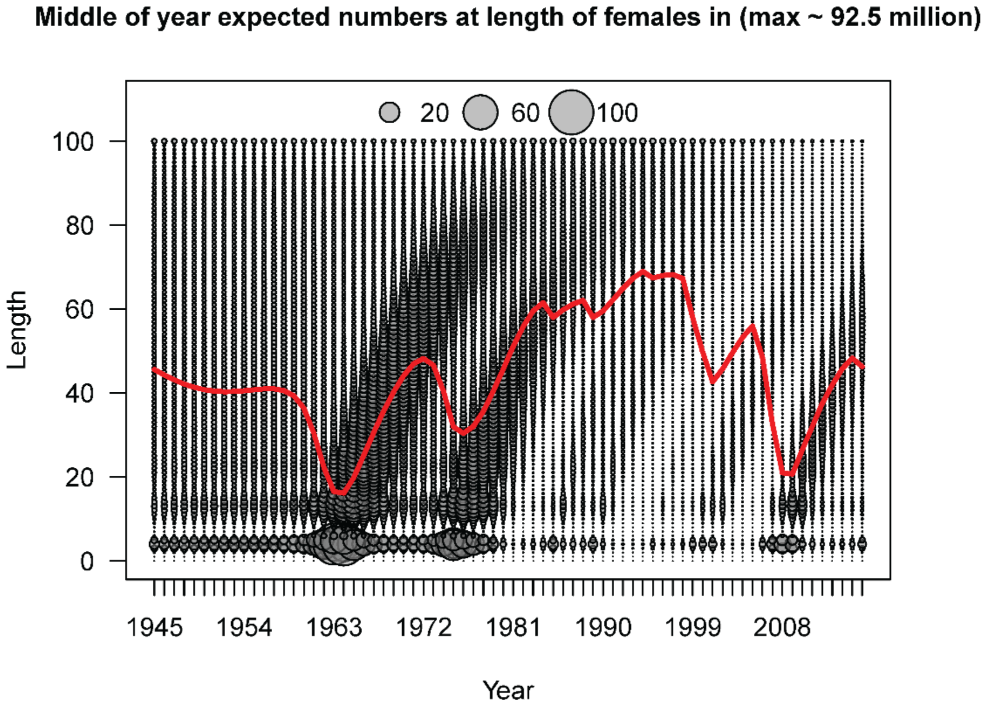


Figure 5.36. Model 16.4 BSAI Greenland turbot numbers at age and mean age by year (red line).



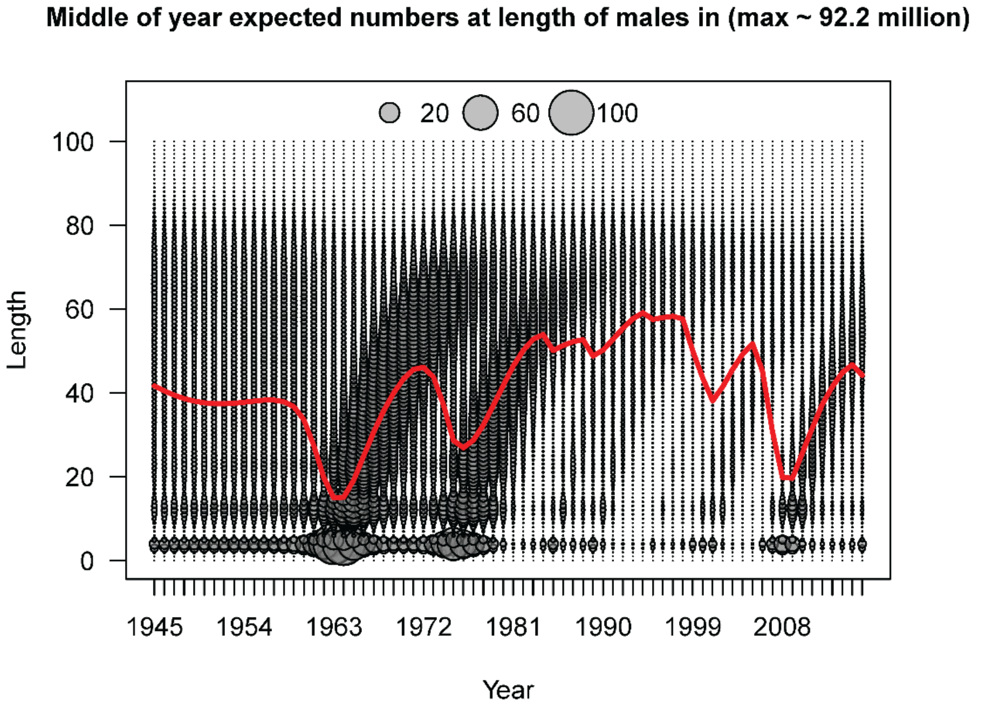


Figure 5.37. Model 16.4 BSAI Greenland turbot numbers at size and mean size by year (red line).

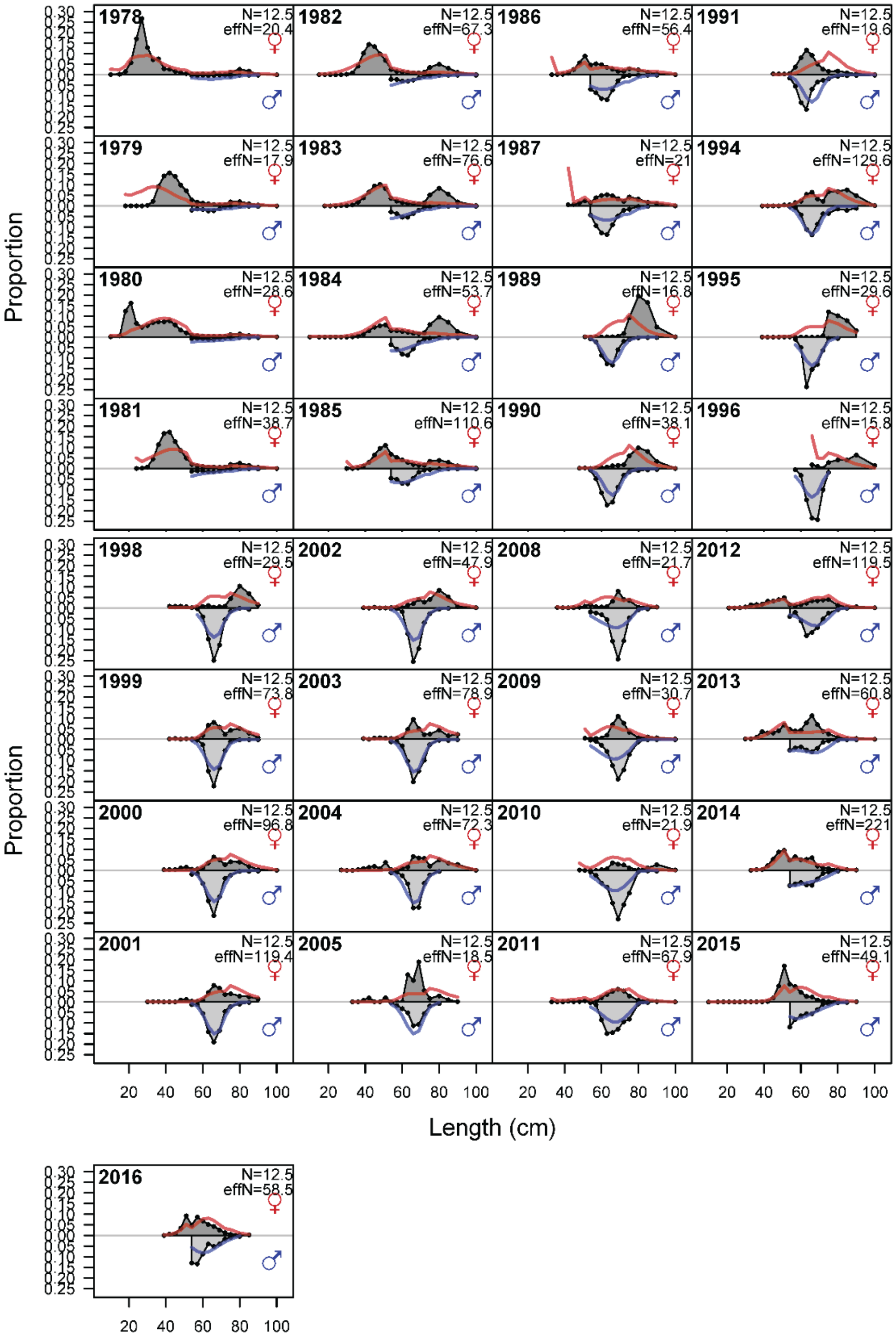


Figure 5.38. Model 16.4 Trawl fishery size composition data and fits (red lines male, blue lines female) .

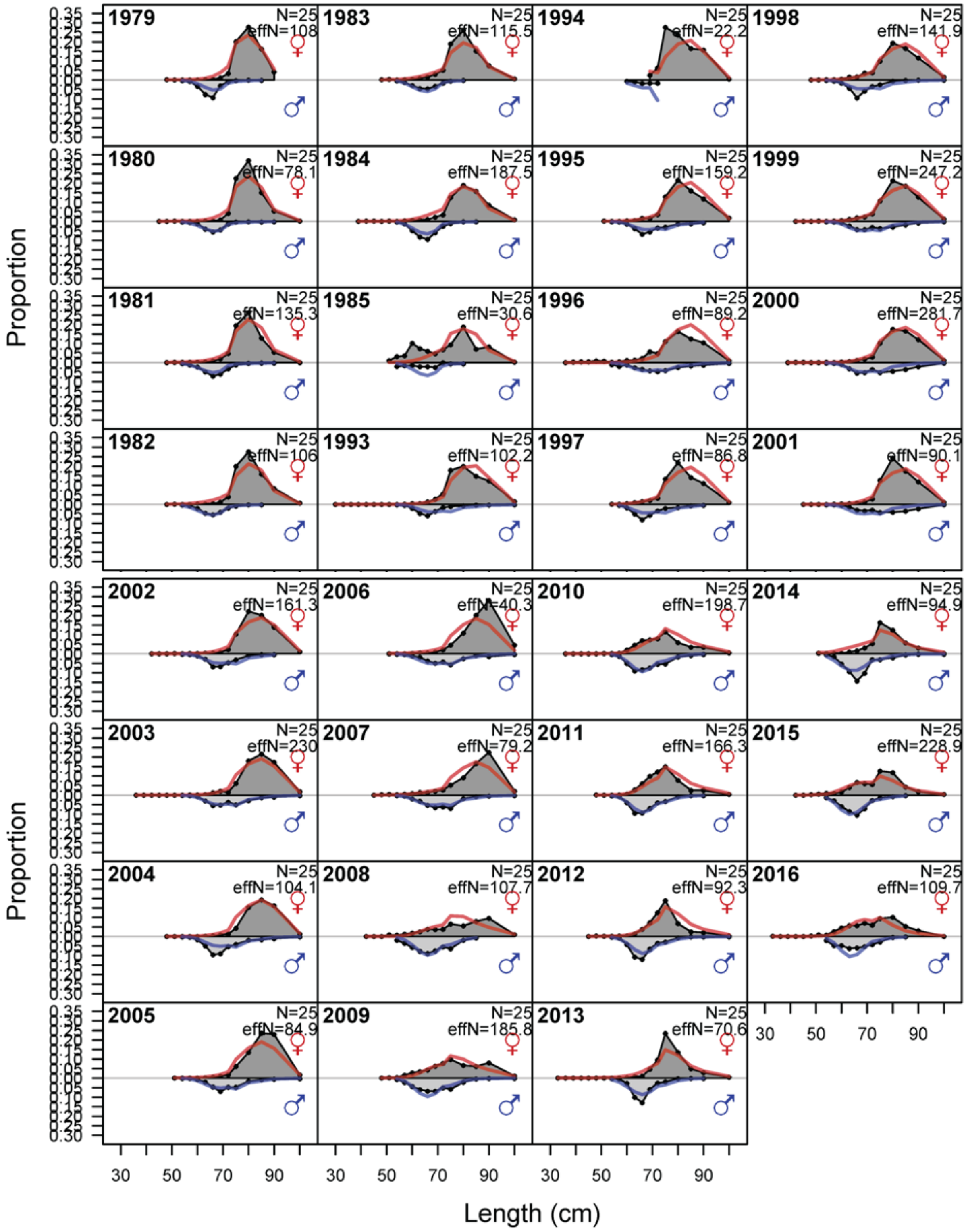


Figure 5.39. Model 16.4 Longline fishery size composition data and fits (red line) for females.

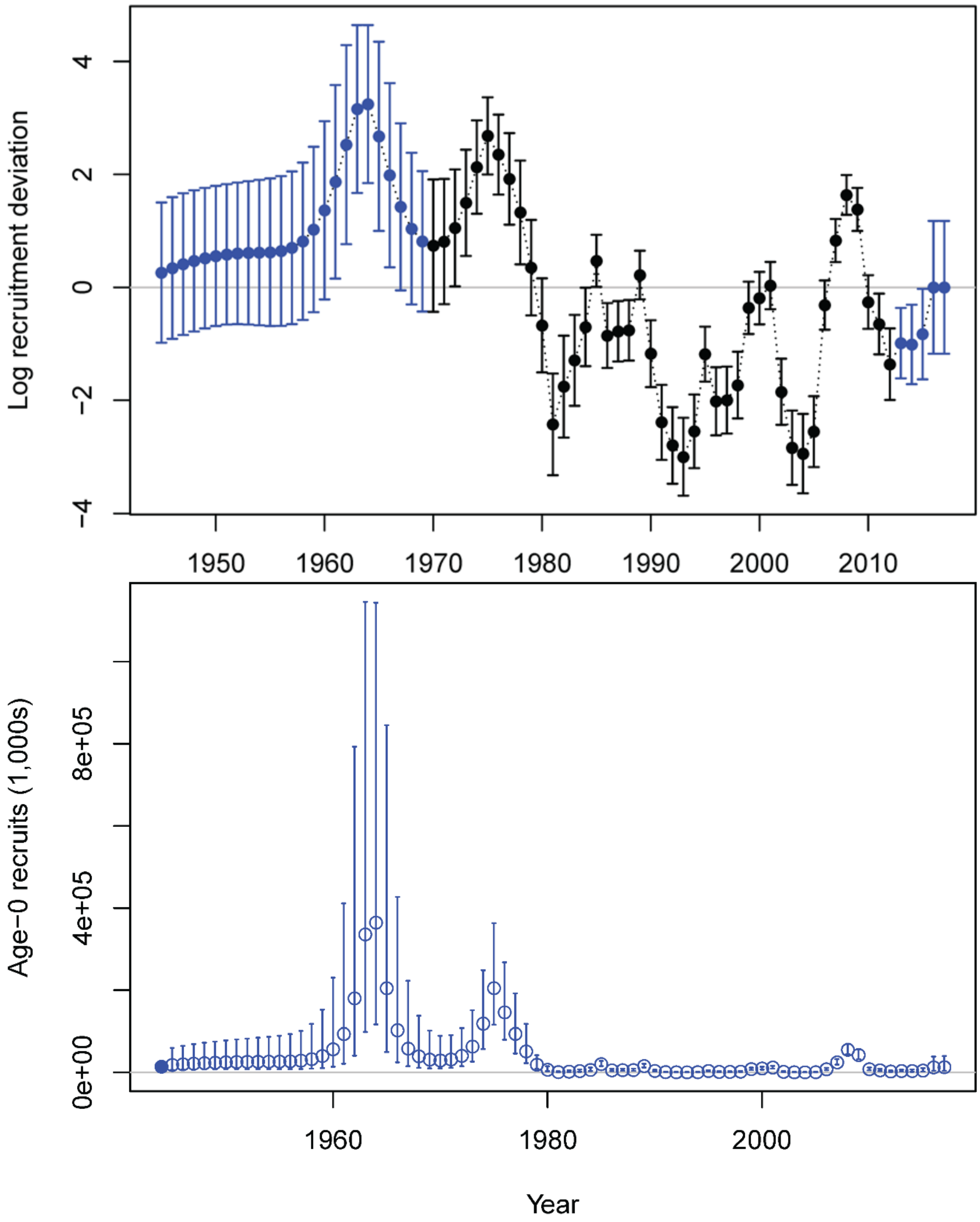


Figure 5.40. Log recruitment deviations (top) and Age-0 recruits (bottom) in thousands for Model 16.4.

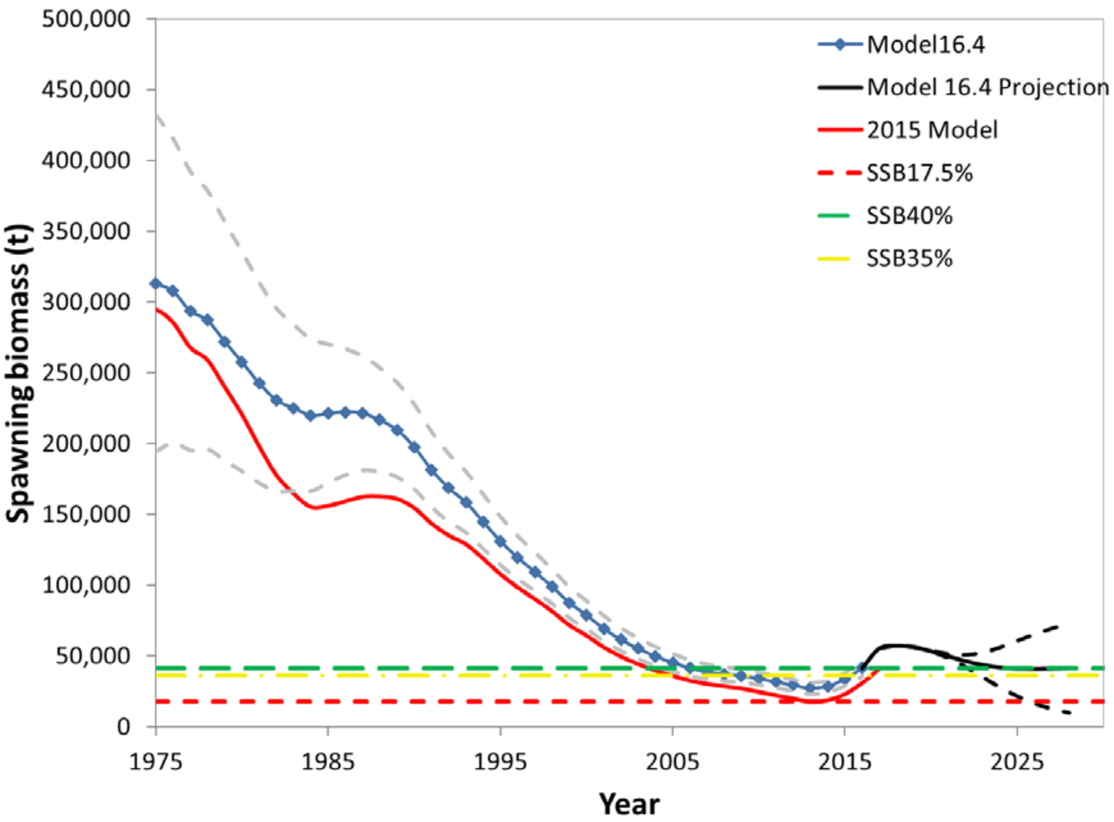


Figure 5.41. Female spawning biomass in tons for BSAI Greenland Turbot for Model 16.4 with reference levels and projection out to 2029 from Alternative 1 F_{40} fishing levels. Model error bars are 95% confidence intervals based on the inverted Hessian, projection error bars are 95% credible intervals based on 1,000 simulations. Red solid line is the spawning biomass time series from last year's model.

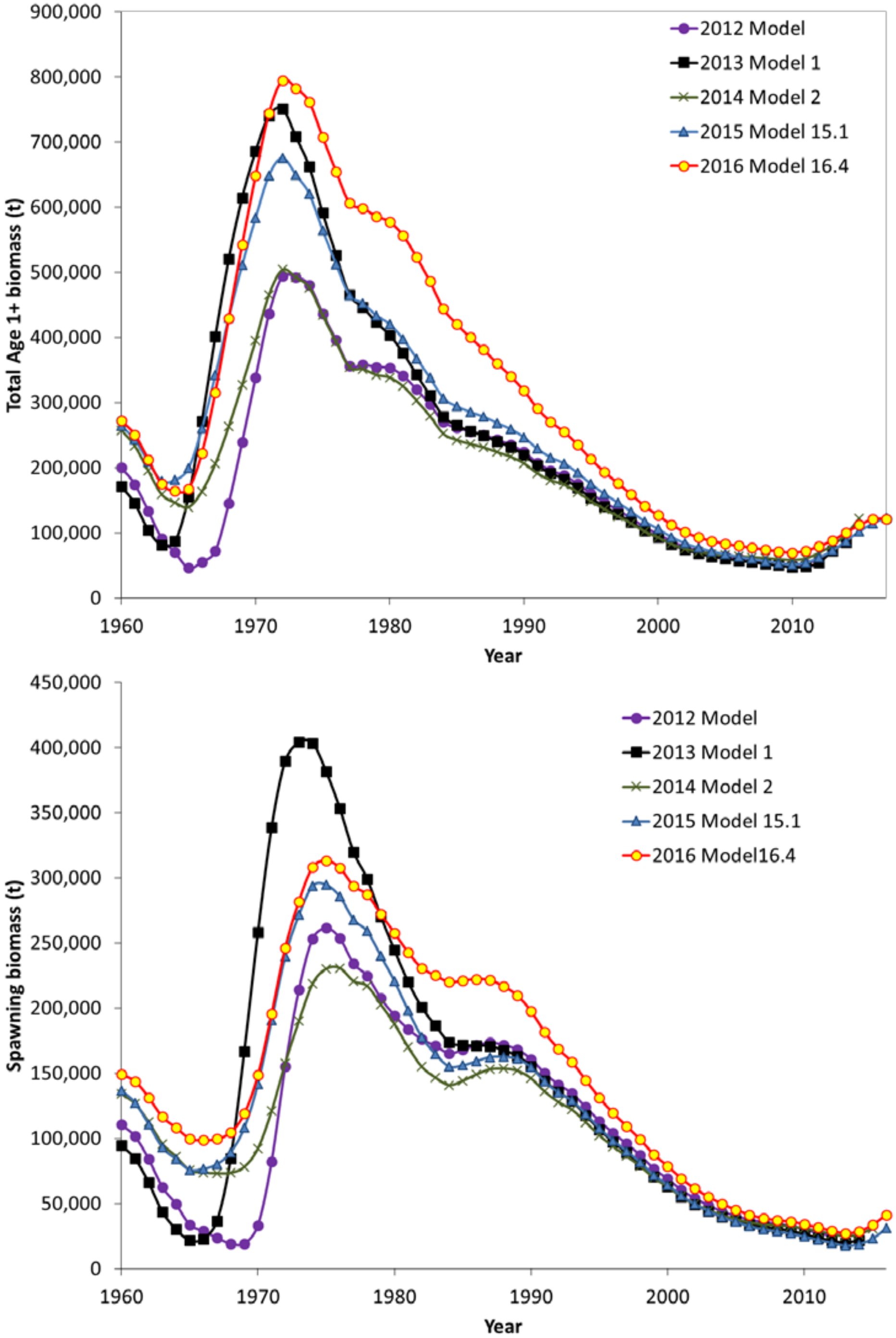


Figure 5.42. Total age +1 biomass (t) and female spawning biomass in tons for BSAI Greenland Turbot for Model 16.4 and previous years' stock assessments.

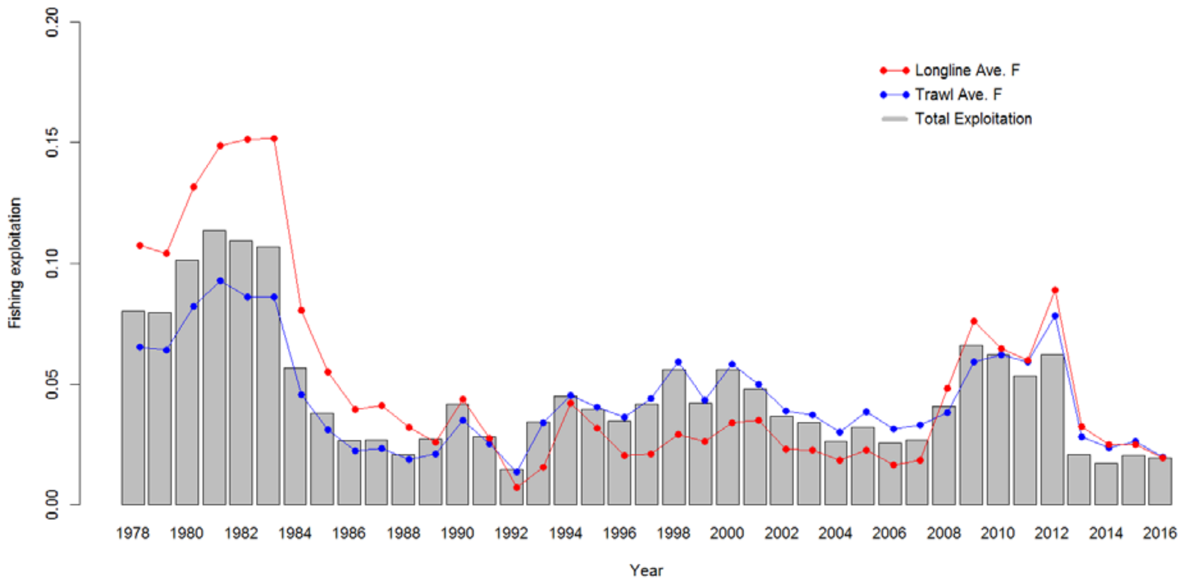


Figure 5.43. BSAI Greenland turbot total exploitation rate (bars) and average Fs for the trawl and longline fisheries for Model 16.4.

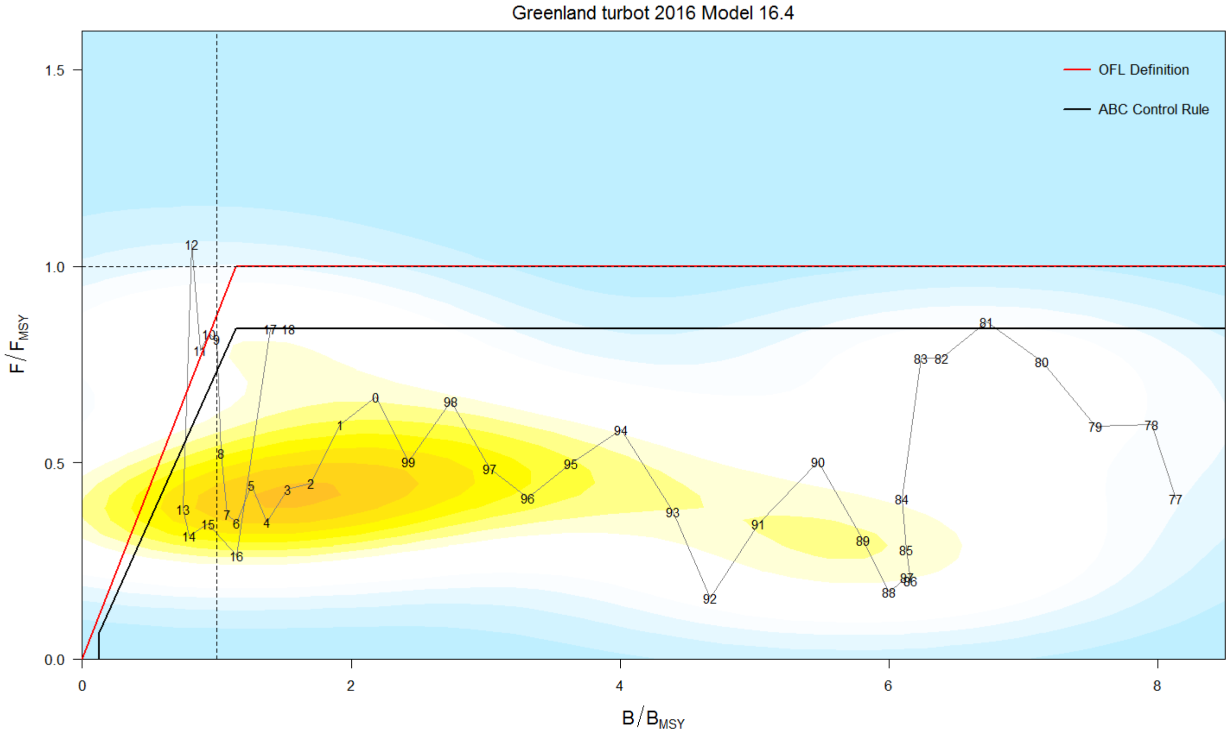


Figure 5.44. For Model 16.4 ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1977-2018. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.

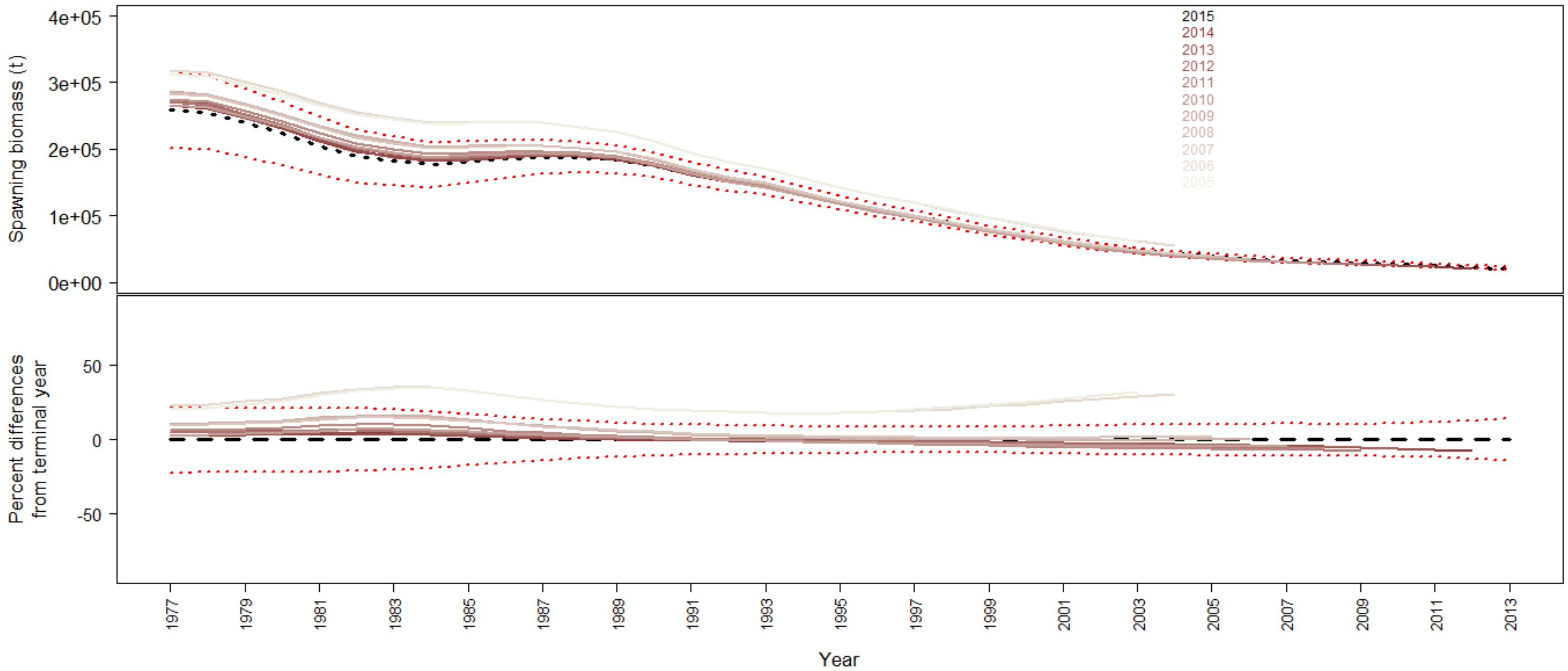


Figure 5.45. Model 15.1 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

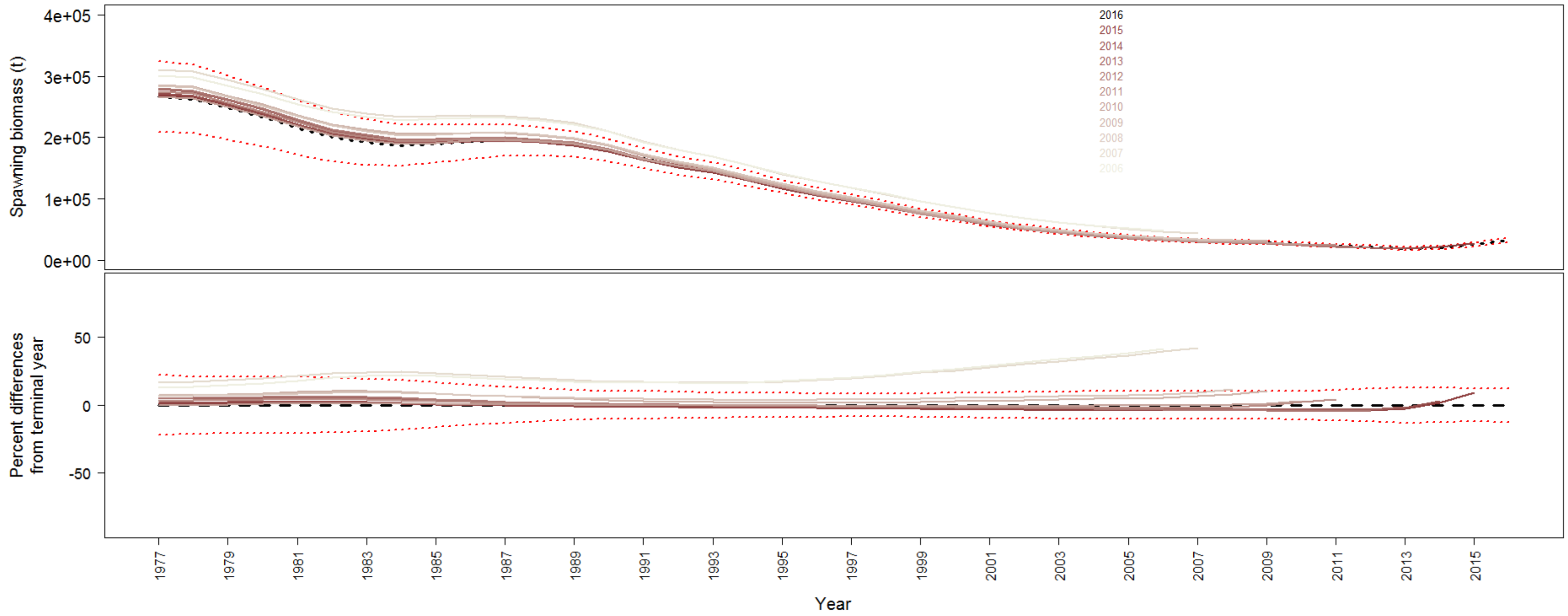


Figure 5.45 (cont.) Model 16.1 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

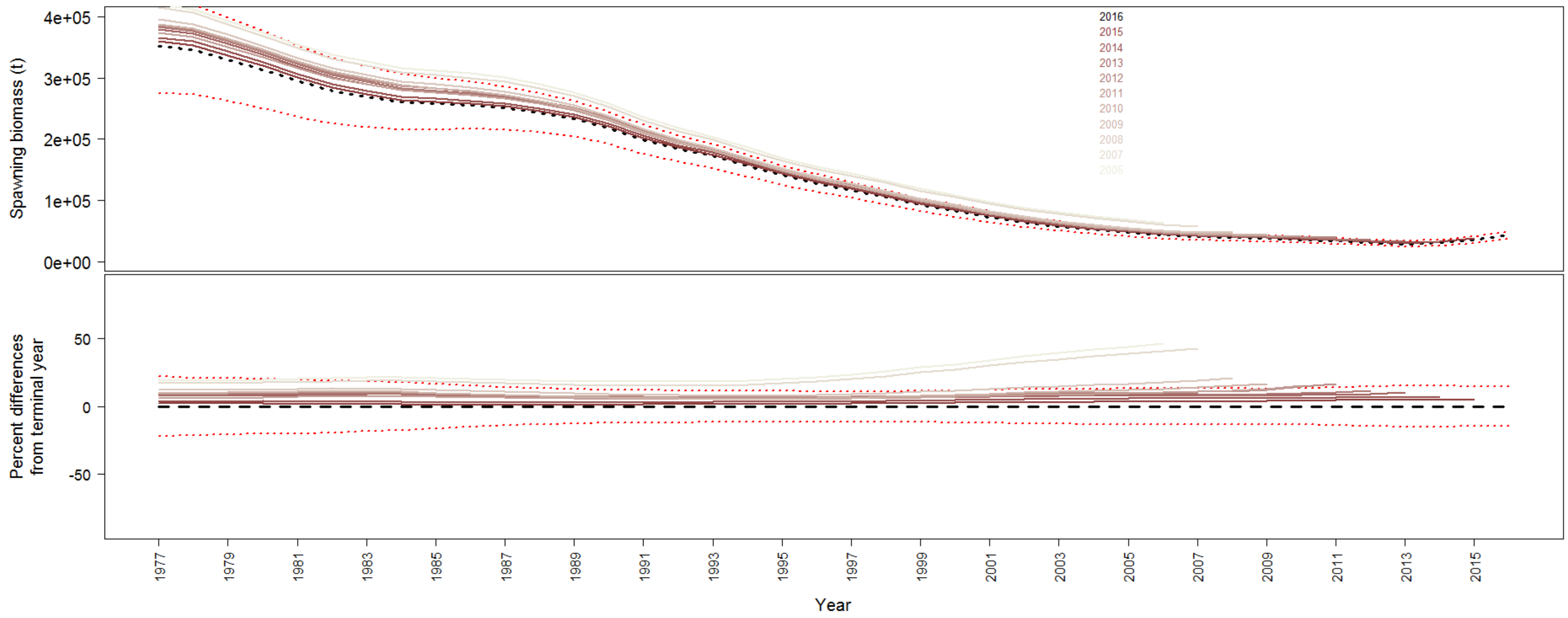


Figure 5.45 (cont.) Model 16.3 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

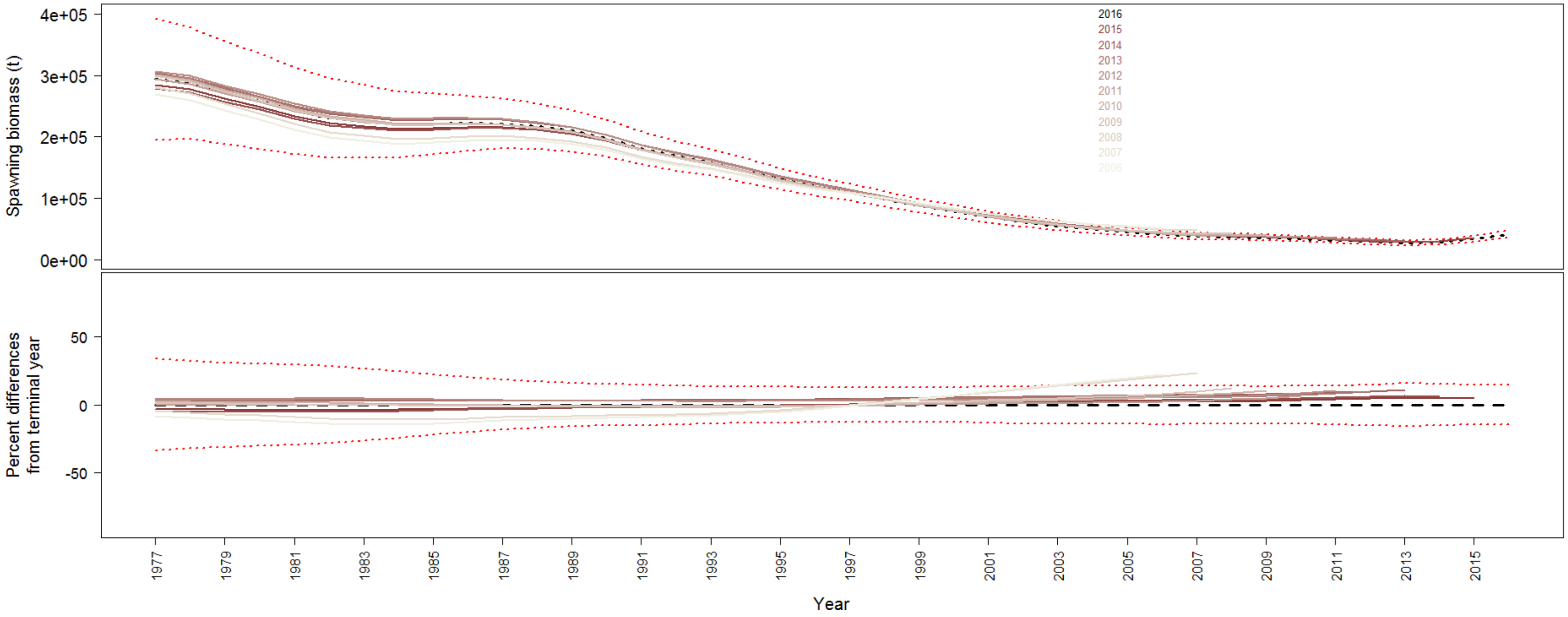


Figure 5.45 (cont.) Model 16.4 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

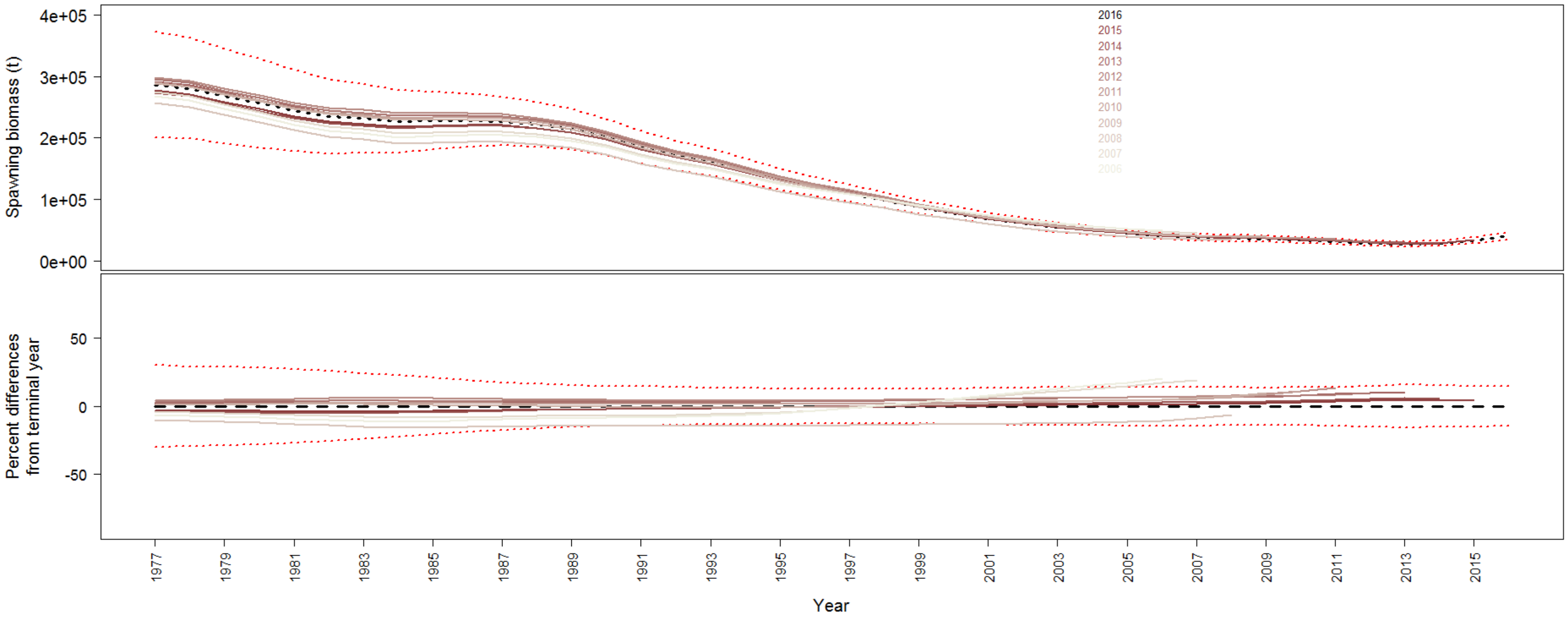


Figure 5.45 (cont.) Model 16.6 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retros pective runs (bottom).

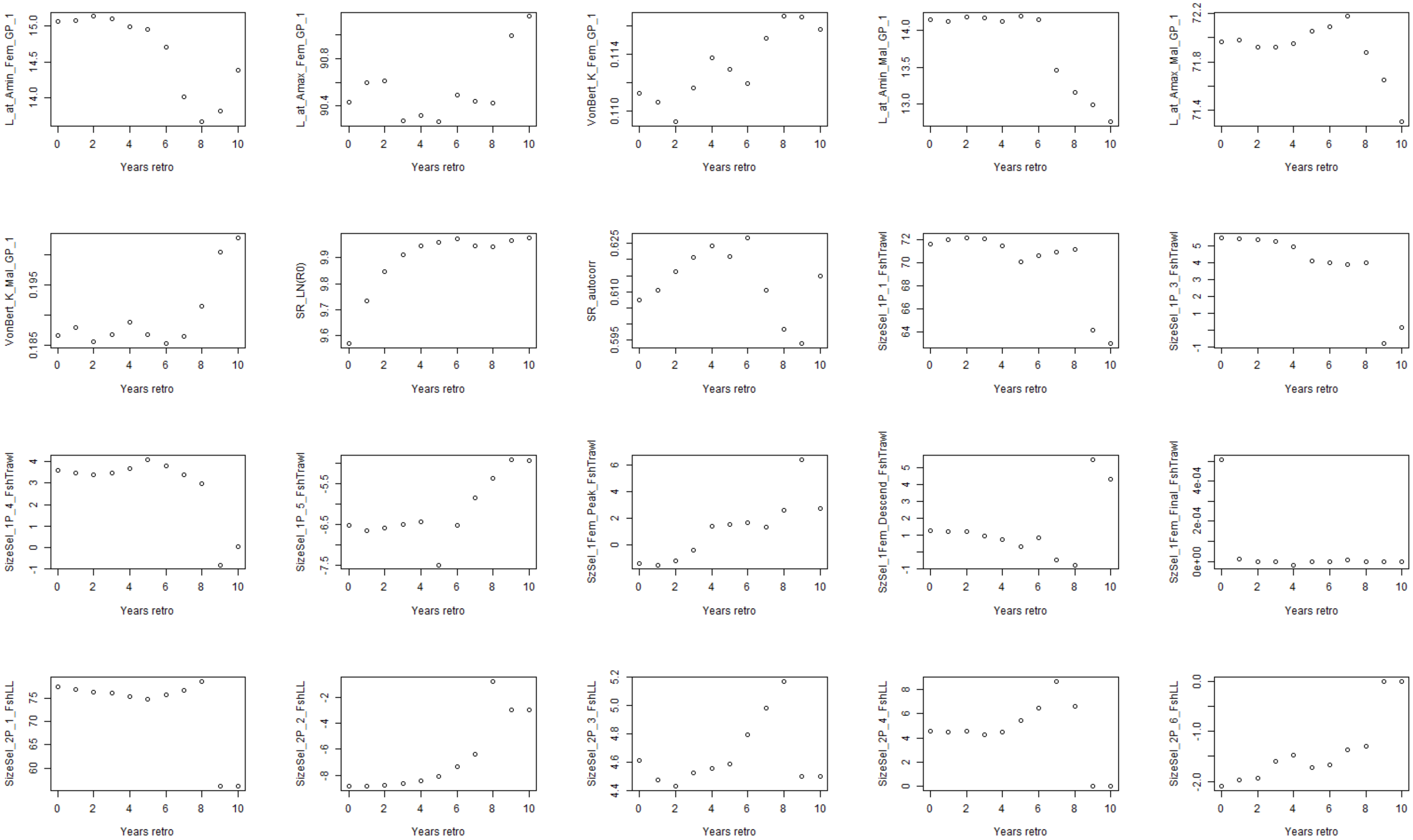


Figure 5.46. Model 15.4 retrospective analysis showing parameter fits by retrospective year.

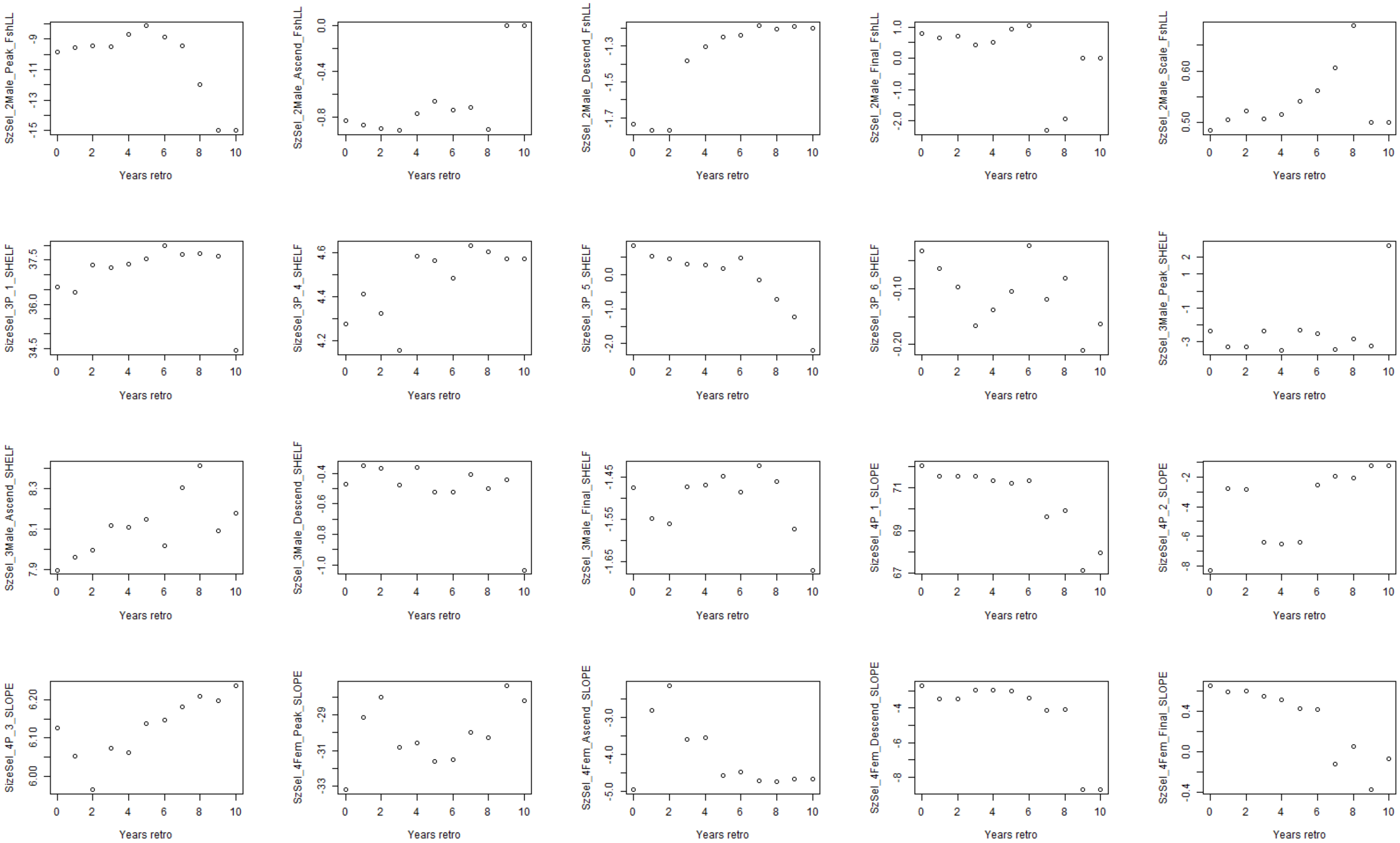


Figure 5.46. (Cont.) Model 15.4 retrospective analysis showing parameter fits by retrospective year.

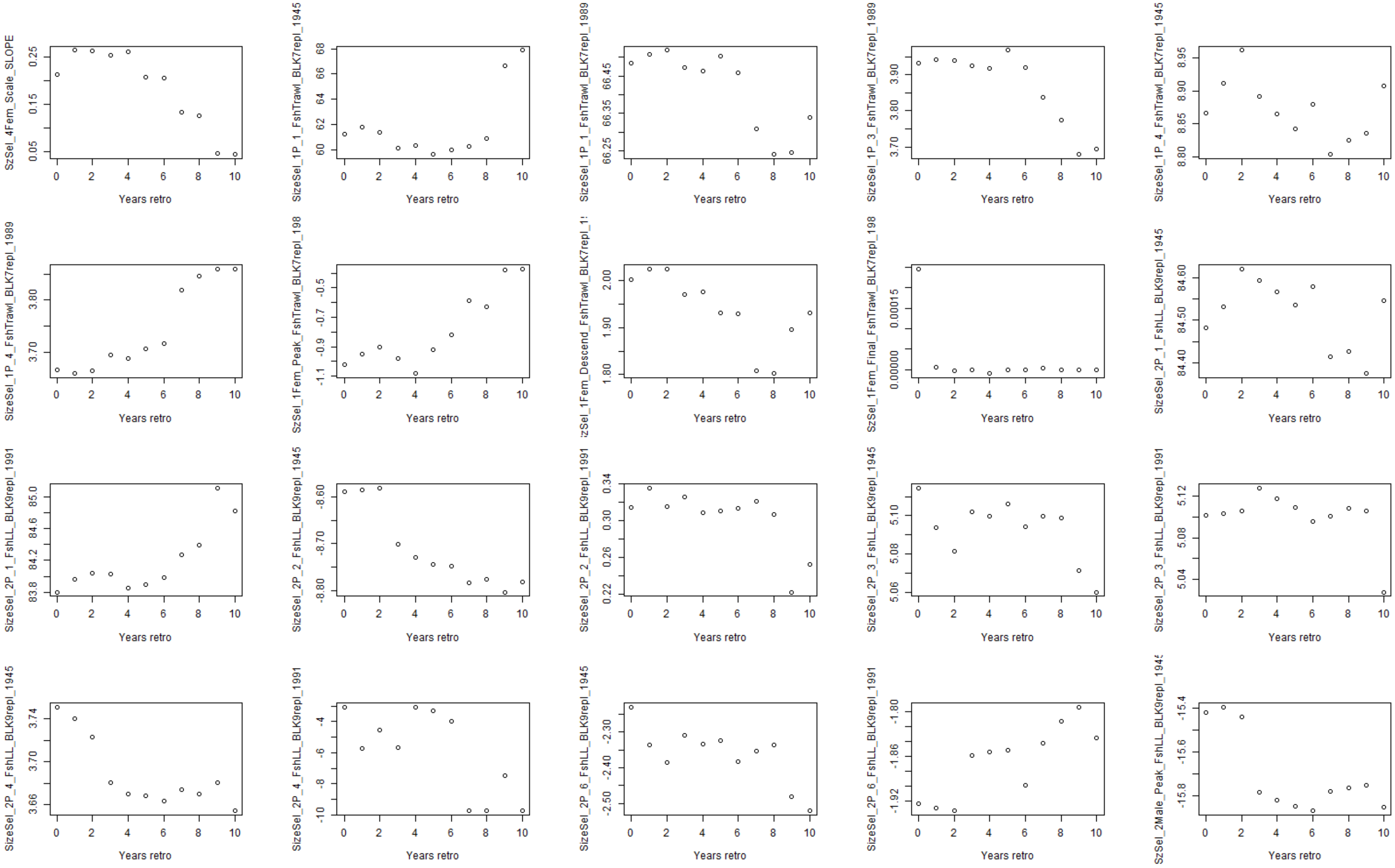


Figure 5.46. (Cont.) Model 15.4 retrospective analysis showing parameter fits by retrospective year.

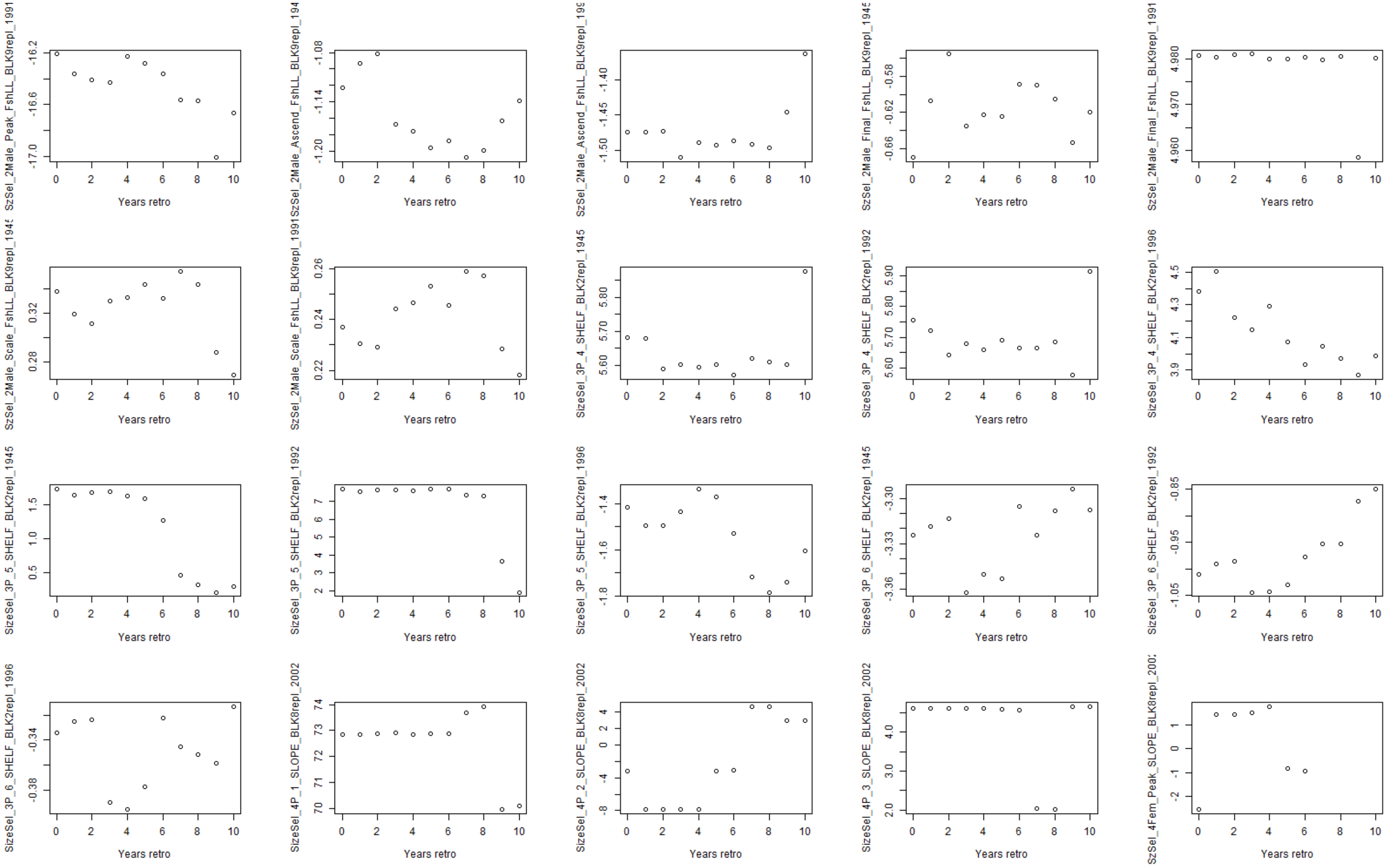


Figure 5.46. (Cont.) Model 15.4 retrospective analysis showing parameter fits by retrospective year.

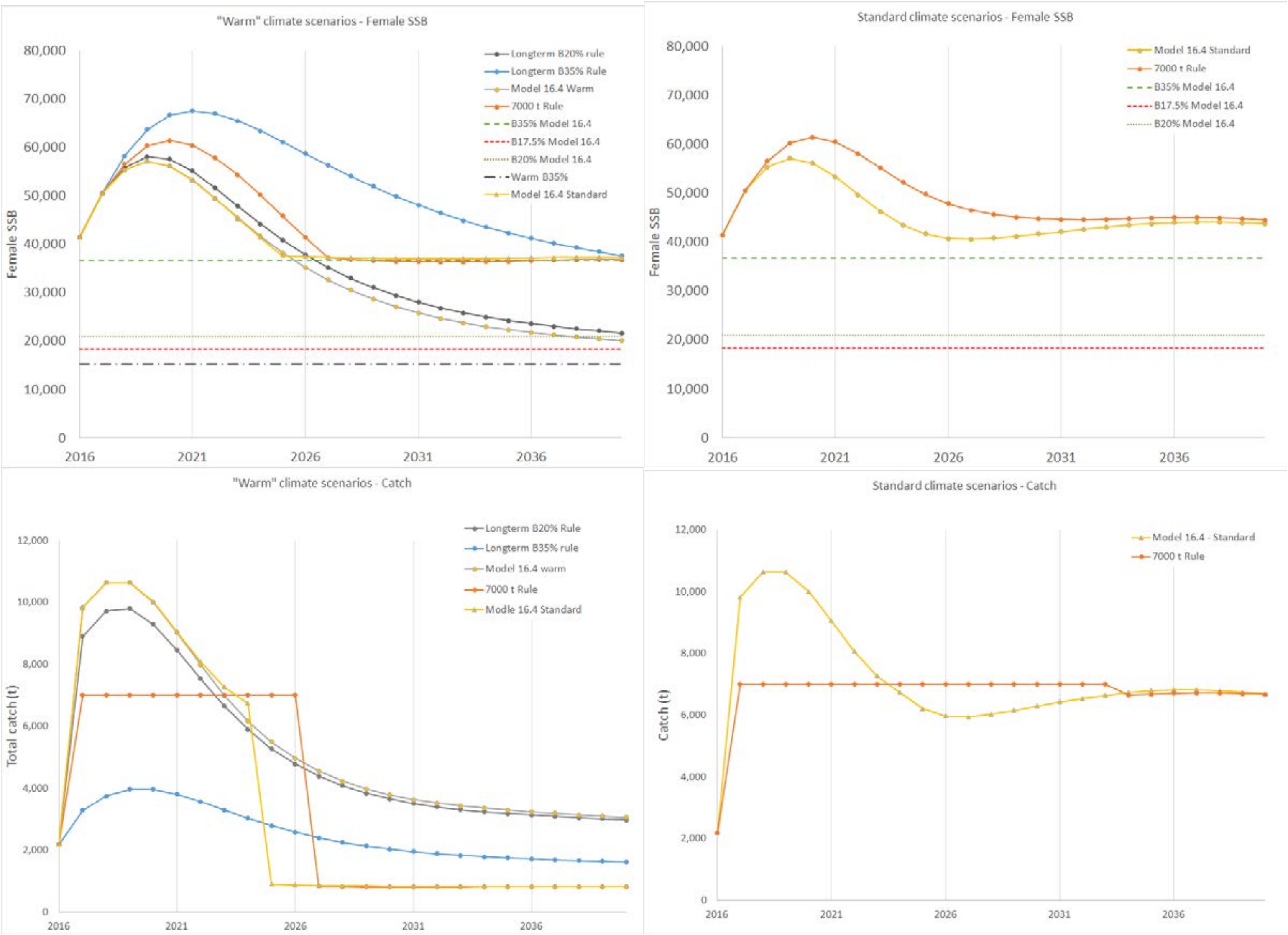


Figure 5.47. Model 16.4 harvest specification alternatives under warm climate (left) and standard climate scenarios (right). The top figures are projections of female spawning stock biomass for 2016-2040 and bottom are catch for 2016-2040.

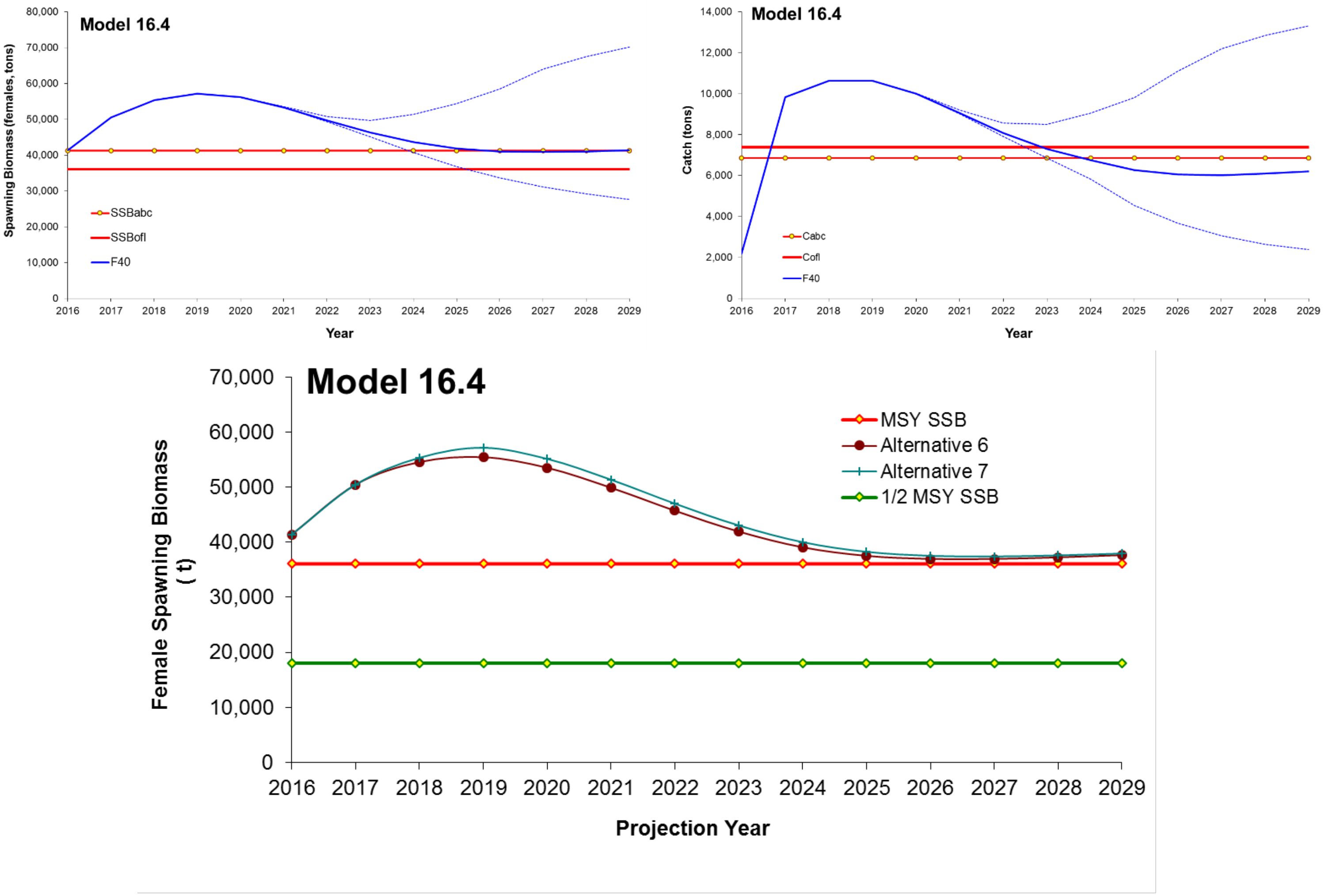


Figure 5.48. Alternative 1 projected (top left) female spawning stock biomass and (top right) catch at F_{40} fishing with long-term expected OFL and ABC reference levels, and (bottom) projected female spawning stock biomass under Alternatives 6 and 7 with SSB_{MSY} and ½ SSB_{MSY} reference levels. $SSB_{35\%}$ is our proxy for SSB_{MSY}.

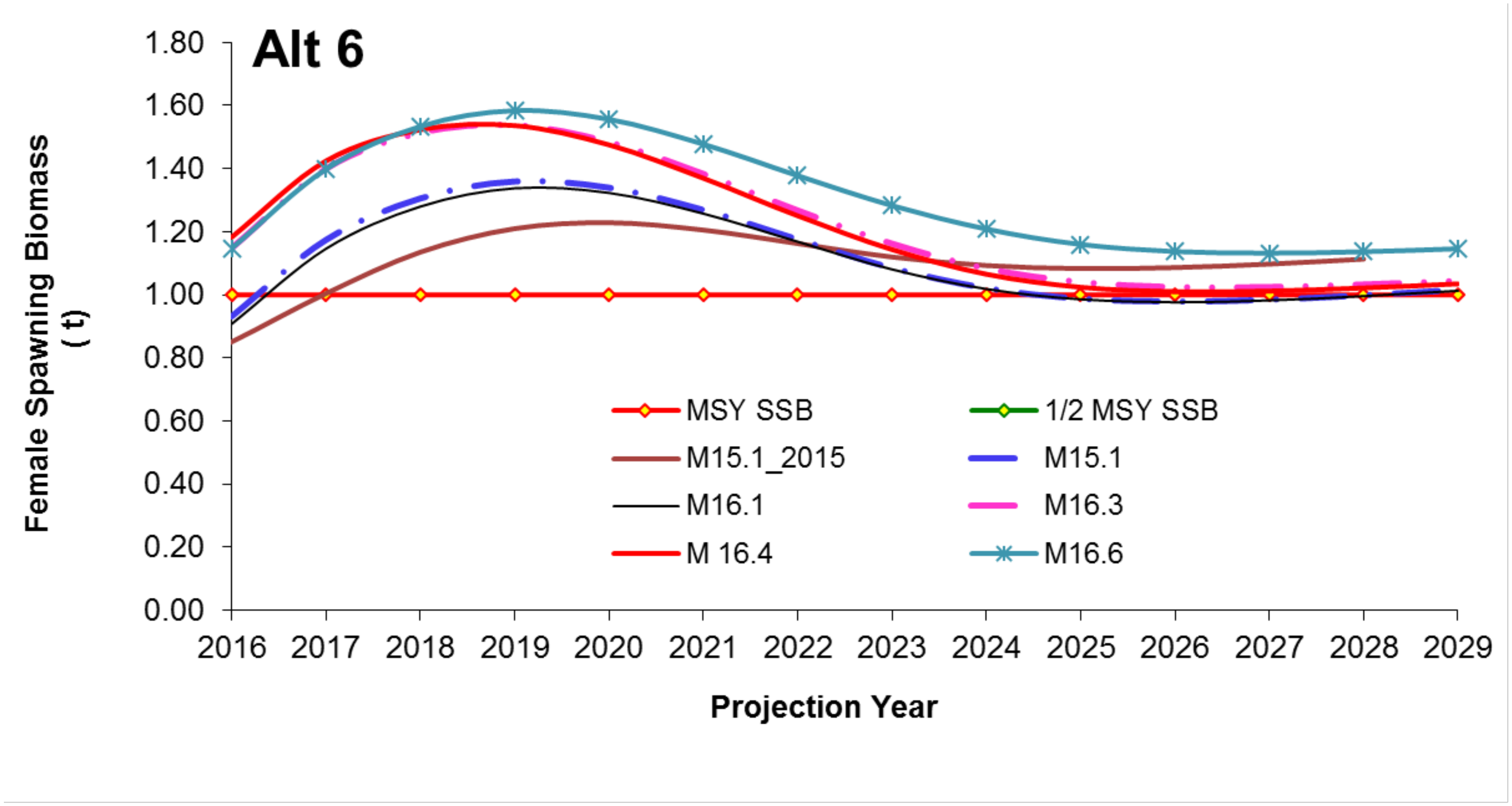


Figure 5.49. Alternative 6 projected female biomass divided by SSB_{MSY} for all models presented. Here catch is set at OFL for all years. The overfished is below ½ SSB_{MSY} (green line) in 2016 or below SSB_{MSY} (red line) in 2026.

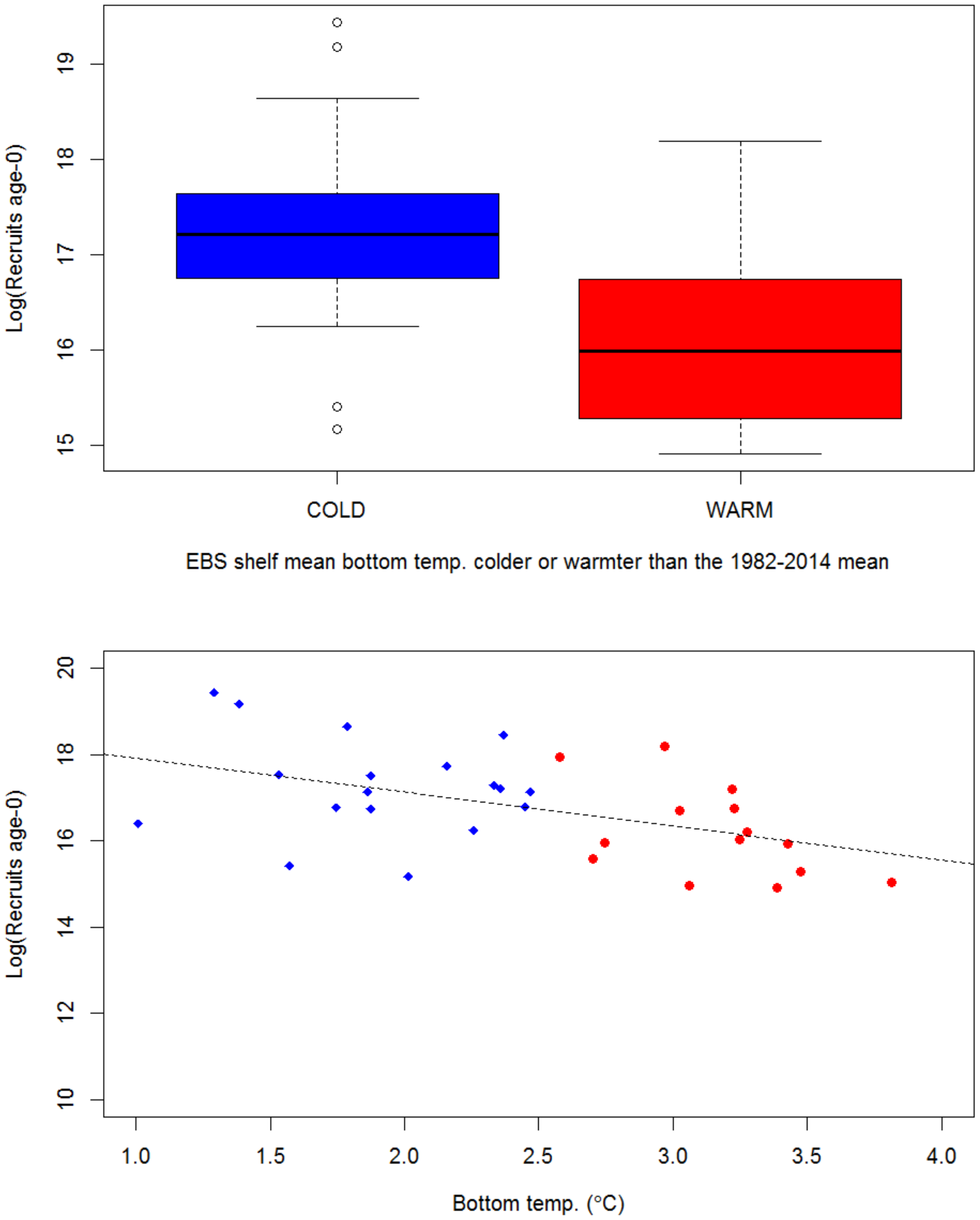


Figure 5.50. Greenland turbot Model 16.4 log recruitment at age-0 and mean bottom temperature from the EBS shelf survey (top) boxplot by above or below the mean temperature from 1982-2014 and (bottom) simple plot by EBS shelf mean bottom temperature (linear regression log(recruits age-0) ~ Temp. df = 31, $R^2 = 0.2389$, p-value = 0.0023).

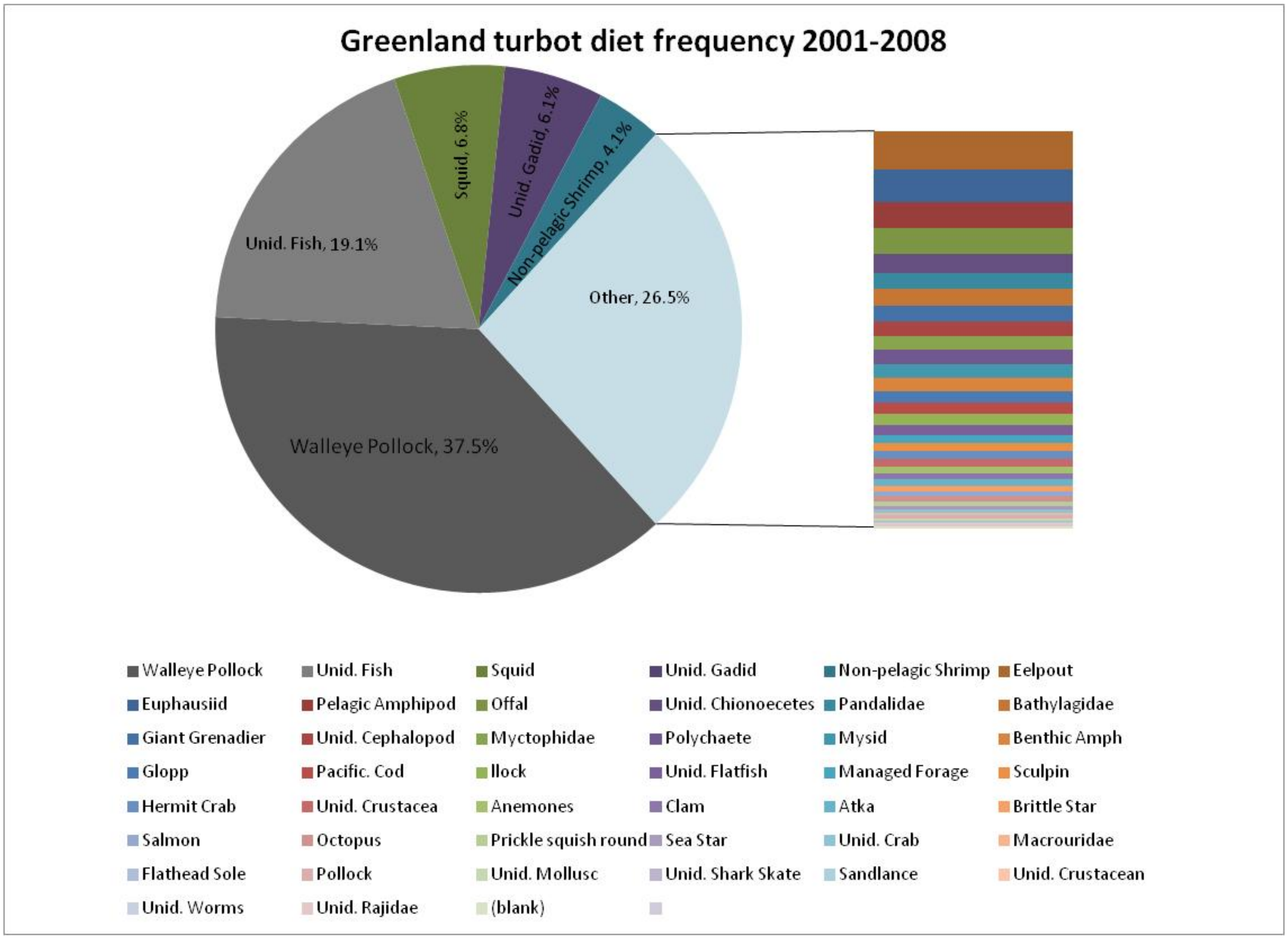


Figure 5.51. Greenland turbot prey items frequency in AFSC diet data for 2001-2008 from the Shelf and Slope bottom trawl survey.

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