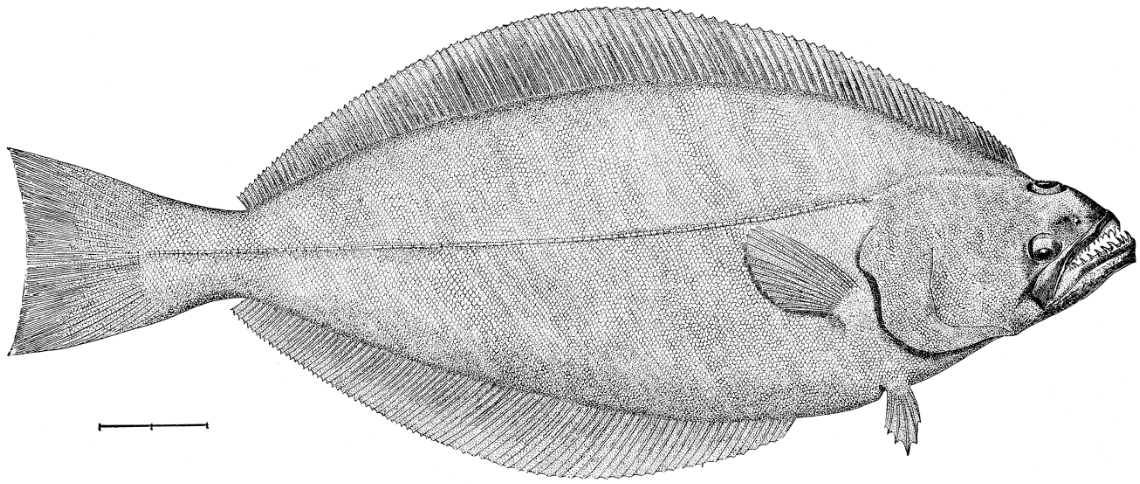
5. Assessment of Greenland turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in the model

Analyses of new data (namely size and age composition data for 2013 – 2015) made available in September 2015 exacerbated a data conflict with the NMFS EBS Shelf and Slope trawl surveys necessitating unexpected model configuration changes to resolve what are clear structural mis-specifications. The EBS shelf survey provides a reasonable index of young fish but as they age, they clearly exit the survey area. The EBS slope survey provides an index of adult fish and typically occurs every other year (except that the 2014 survey was dropped so the most recent data is from 2012). Initial runs of the 2014 Model with the new data (Model 14.0) suggested that recent high recruitment estimates (2007-2010) are closer to average, likely reflecting a change in the availability of these fish to the Shelf survey gear. Re-weighting shelf and slope survey composition data to better account for shifts in distribution relative to survey gear appears to improve model diagnostics while acknowledging that Greenland turbot are distributed to a large degree outside the survey areas and are affected by thermal conditions (shifting further north in warmer years in the EBS).

To simplify data conflicts, a model in which the ABL longline 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). Another factor in defense of omitting these data was that whale depredation in recent years in the EBS for Greenland turbot specifically has increased substantially and likely affects the reliability of this as an index. We adopted the naming convention proposed in September 2015 so that “Model 14.0” represents the configuration and data types used in the model accepted in 2014 with 2015 data additions. In this assessment we thus proposed three model configurations:

Model 14.1 Uses refined sample size estimates for the slope survey composition data and re-weighted other data. In this configuration the Shelf survey size composition data and size at age data were used but the age composition data were not. Naïve data fits to the age composition data are available, but the age composition data did not influence model fit.

Model 15.1 Same configuration as Model 14.1 except the selectivity for the fixed gear fishery was changed from an asymptotic logistic to the “double normal” to account for the change in fishing behavior in 2008; also the 2006 and 2007 trawl fishery size composition data were excluded due to very small sample sizes.

Model 15.3 Same configuration and data as Model 15.1 except the fisheries and shelf and slope survey selectivity was specified to be annually varying using a penalized random walk process (SD = 0.1). This feature is intended to reflect the variable availability of the Greenland turbot stock in the survey area. In this model, the trawl and longline fishery selectivities were also annually variable between 1980 and 2015 with less constraint on the random walk (SD = 0.5).

New data for the assessment included 2015 NMFS shelf bottom trawl survey and ABL longline survey estimates and size compositions. Age composition and size at age data from the 2013 and 2014 NMFS Shelf surveys also became available and were used in this assessment. Fishery catch estimates were updated including projected values for 2015. Data on fishery size composition for 2015 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 2012. In the 2014 model configuration the 2012 Slope survey size composition data were offset to some degree by subsequent Shelf survey size and age composition data (with constant selectivity). Data weights were thus re-evaluated in light of clear changes in the spatial distribution and growth of Greenland turbot on the shelf and slope regions.

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 explored in Models 15.1 and 15.3 by allowing temporal changes and dome-shaped selectivity for this gear. Initial explorations revealed undesirable residual patterns which led to developing Model 15.3 which allowed for annually varying selectivity parameters.

For the model configurations evaluated, the 2007-2010 year classes were consistently estimated to be well above average and contribute to projected biomass increases. The estimates of $B_{100\%}$ ranged between 109,893 t and 154,536 t for Models 14.0 and 15.3, respectively. The estimated 2015 spawning stock biomass ranged between 29,918 t (Model 14.1) and 37,374 t (Model 15.3). The 2015 status for the stock ranged between $B_{18\%}$ (Model 15.1) and $B_{25\%}$ (Model 14.0) compared to $B_{30\%}$ from last year’s projection. The projected 2016 estimated total biomass for the models examined ranged between 110,832 t (Model 14.1) and 151,150 t (Model 15.3), bracketing last year’s projection for 2016 of 132,666 t.

For the models evaluated the stock was classified as within Tier 3B for 2016 and therefore the ABC and OFL recommendations are reduced by the descending portion in the harvest control rule. The corresponding 2016 maximum permissible ABCs ranged from 3,462 t (Model 15.1) to 8,815 t (Model 15.3).

If Model 14.0 were to be retained the stock would be considered overfished but not approaching an overfished condition as the stock was below B_{MSY}, but above ½ B_{MSY} in 2015, however under Scenario 6 in Model 14.0 the stock would be below B_{MSY} in 2025. The models indicated that the stock is not considered overfished in 2014, overfishing did not occur in 2015, and the stock is not approaching an overfished condition (though under Model 14.0 scenario 6, which assumes future catches would be set to the OFL, the stock failed to rebuild to B_{MSY} by 2025). Based on trade-offs in model complexity and refinements to data weightings assumed, Model 15.1 is recommended for management purposes as summarized in the following table.

Quantity	As estimated or *specified last* year for: 2015	2016	As estimated or *recommended this* year* for: 2016	2017
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass (t)	122,298	132,666	114,438	123,494
Female spawning biomass (t)	30,853	38,848	31,028	41,015
Projected				
$B_{100\%}$	130,123	130,123	126,441	126,441
$B_{40\%}$	52,049	52,049	50,577	50,577
$B_{35\%}$	45,543	45,543	44,255	44,255
F_{OFL}	0.12	0.18	0.10	0.14
$maxF_{ABC}$	0.10	0.15	0.08	0.11
F_{ABC}	0.10	0.15	0.08	0.11
OFL (t)	3,903	6,453	4,194	7,416
maxABC (t)	3,172	5,248	3,462	6,132
ABC (t)	3,172	5,248	3,462	6,132
EBS	2,448	4,050	2,673	4,734
Aleutian Islands	724	1,198	789	1,398
Status	As determined *last* year for: 2013	2014	As determined *this* year for: 2014	2015
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 15.1

Responses to SSC and Plan Team Comments on Assessments in General

None

Responses to SSC and Plan Team Comments Specific to this Assessment

From December 2014: “The Team recommends fitting Model 1 with recruitments since at least 2007 estimated freely in order to confirm or reject the supposition that the large increase in survey q is attributable to the recruitment dispersion and/or autocorrelation parameters”.

Models were explored fitting both natural mortality and catchability of the two surveys in the model. Catchability for the Shelf survey becomes greater than 1 in these model runs, and MCMCs were unstable with one-way slide of the catchability estimates towards infinity. The retrospective pattern of these model were degraded (biased high) as fits to natural mortality and catchability changed substantially when data were removed from the model. The Shelf age data from 2012 through 2014 appear to inform the model on natural mortality adjusting it to a higher value as the more recent data include the large 2007-2010 year classes and therefore younger fish. None of these models were considered as alternatives for this year because of model performance based on poor retrospective performance and lack of convergence.

Introduction

Greenland turbot have life history characteristics that complicate assessment surveys in the Eastern Bering Sea and Aleutian Islands region. Model developments to improve input data and assumptions continued to present challenges with the addition 2015 data. In particular, this assessment continued to re-evaluate relative weighting input data, details are presented in the relevant sections below.

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) (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 (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. 5.8). 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. 5.9). 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 1752 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. As of October 10, 2015 total catch was at 2,194 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. 10 and Fig. 5. 11), 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 and 2015 comensurate 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. 12).

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 between 1995-2009 up to 296 fathoms on average between 2010-2015 (Fig. 5. 13). 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 2004-2015. 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 be dropping in 2015 as Greenland turbot from the more recent abundant year classes migrate off the shelf and out of the range of the shallow water fisheries. As of October 10, the discard rate was 5%. In the preliminary 2015 catch data 28% of the Greenland turbot discard was from the flatfish fisheries (32 t) and 21% (24 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 the preliminary 2015 data the EBS trawl fishery has caught a larger share of EBS quota than longliners (1,089 t vs. 995 t). 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).

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 5.14.

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 2015. The length composition data from the trawl and longline fishery are presented in the Appendix 5.1 (along with the expected values from Model 15.1, http://www.afsc.noaa.gov/REFM/Docs/2015/Greenland_turbot_Appendix_5.1_2015_Model_15.1_Data_and_Prediction.xlsx) and absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2015 are given in Table 5.6

Catch totals from research and other sources

Annual research catches (t, 1977 - 2015) 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
NMFS BT surveys	1.0	1.3	0.9
Longline surveys	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 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. 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 (the next slope survey is planned for 2016). Although the size composition data for surveys prior to 2002 were used in this assessment, abundance estimates were considered inappropriate for use due to differences in survey consistency, vessel power, gear used, and uncertainty on the extent of survey gear bottom contact (Table 5.8).

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. The average shelf-survey biomass estimate during the last 20 years (1995-2015) was 25,557 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys were presented in Table 5.8. 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. 5.15). These observations suggest that the extent of the spatial distribution has remained relatively constant prior to 2010 (with a slight increase) and that the most recent surveys have both higher densities and broader spatial distribution. The 2013-2015 surveys show a decline in the abundance of the 2007-2010 year classes as they migrate out of the shelf survey area (Fig. 5.16).

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 suvey was reinstated in 2002. Most of the change in population estimates is due to the changes in Greenland turbot abundance found in the two shallowest strata between 200 and 600 m depth strata (Table 5.9 and Table 5.10). In the 200-400 m strata the population was more than 8 times that of the 2010 survey estimate and the 400-600 m strata was more than double the 2010 estimate. These high numbers, but low biomass is a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007 through 2009 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Fig. 5.16).

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 averge 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.

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 the last 8 years signs of recruits (Greenland turbot less than about 40 cm) are clear after an absence of small fish during 2004-2006 (Fig 5.16).

Survey size-at-age data was available and used for estimating growth and growth variability were previously available from 1979-1982. Gregg et al. (2006) revised age-determination methods for Greenland turbot and this year survey age composition data from 2003-2014 were included.

Aleutian Islands survey

The 2014 Aleutian Islands bottom trawl survey estimate was 2,529 t, well below the 1991-2012 average level of 12,598 t (Table 5.11) and comparable to the 2012 estimate of 2,600 t. The distribution of Greenland turbot in 2014 indicate much lower abundance in the survey compared to pre-2012 surveys (Fig. 5.11). 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). The estimated proportion of Greenland turbot in the eastern area for 2014 of 19% is far 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 tubot abundance estimate in the Aleutian Islands trawl survey in 2012 and 2014. For 2012 we speculated that lower bottom temperatures in the shallow areas in the eastern area may have been a contributing factor (Lowe *et al*. 2014), but that did not hold true for 2014 where we see an increase in bottom temperatures. 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 1996-2015 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 (1996-2015) 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. 5.16.

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 15.3 explored in this year's assessment do not include the ABL longline index or 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 2015. 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 initial annual size composition sample sizes for the surveys were set at the same values as those used in previous assessments for Model 14.0. However, in the alternative models 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 were:

	Model 14.0 and 14.1	Model 15.1	Model 15.3
Recruitment			
Early Rec. Devs	(1945-1970) 25	(1945-1970) 25	(1945-1970) 25
Main Rec. Devs	(1970-2012) 43	(1970-2012) 43	(1970-2012) 43
Future Rec. Devs	(2013-2017) 5	(2013-2017) 5	(2013-2017) 5
R_0	1	1	1
Rho	1	1	1
Naural mortality			
Male	0	0	0
Female	0	0	0
Growth			
L_{min} (M and F)	2	2	2
L_{max} (M and F)	2	2	2
Von Bert K (M and F)	2	2	2
Catchability			
q_{shelf}	0	0	0
q_{slope}	0	0	0
Selectivity			
Trawl fishery	21	21	9
Random Walk 80-15			324
Longline fishery	13	30	10
Random Walk 80-15			324
Shelf survey	17	17	8
Random Walk 83-15			264
Slope survey	2	2	5
Random Walk 80-12			165
ABL longline survey	2	2	0
Total Parameters	136	153	1190

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 all periods a Beverton-Holt stock recruitment curve with steepness set to 0.9 with σ_R (log-scale recruitment variability) set to 0.6.

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.

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 a Model 14.0 fit without the 2007 through 2015 data. This was meant to eliminate the effects of the 2007 through 2010 year classes ($\log(q_{shelf})$ = -0.4850235 and $\log(q_{slope})$= -0.5555418).

Selectivity

Sex-specific size-based selectivity functions were estimated for the two trawl surveys and the two fisheries. For Model 14.0, 14.1 and 15.1 time blocks were used to estimate time varying selectivity while for Model 15.3 a random walk was used to estimate annually varying selectivity for specified periods (Methot and Wetzel, 2013). The different time blocks for the fisheries and surveys are shown in the table below. For Model 14.0, 14.1 and 15.1 these blocks were the same as those used in the 2014 Model. Data from the longline survey are combined hence a sex aggregated size-based selectivity function was used.

	Model 14.0and Model 14.1		Model 15.1		Model 15.3.2	
	Type	Blocks	Type	Blocks	Type	Blocks
Trawl Fishery	Double Normal	1945-1988 1989-2005 2006-2015	Double Normal	1945-1988 1989-2005 2006-2015	Double Normal	Random Walk 1980-2015
Longline Fishery	Logistic	1945-1990 1991-2007 2007-2015	Double Normal	1945-1990 1991-2007 2008-2015	Double Normal	Random Walk 1980-2015
Shelf Survey	Double Normal	1945-1991 1992-1995 1996-2000 2001-2015	Double Normal	1945-1991 1992-1995 1996-2000 2001-2015	Double Normal	Random Walk 1983-2015
Slope Survey	Logistic	None	Logistic	None	Logistic	Random Walk 1980-2012
ABL Longline Survey	Logistic	None	Logistic	None		

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

Model 14.0 and Model 14.1 use a logistic selectivity model for the longline fishery data. A change in fishing in 2008 resulted in the fishery targeting shallower depths and therefore the largest and deeper fish were no longer caught in the fishery. The fits to the 2008-2015 data remained poor in these models. To address this issue a double normal model which allowed dome-shaped selectivity was tested in Model 15.1 and Model 15.3. In Model 15.3 we tested annually varying selectivity instead of blocked selectivity for all size composition data. This was implemented through a random walk as described by Methot and Wetzel (2013) on all selectivity parameters.

Results

Model Evaluation

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. The tuning of the size and age composition sample size for last year's model were different from this year's and therefore direct comparisons of size and age composition likelihood estimates were not possible. 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 5.17 shows results for the models considered including differences in recruitment, 2015 spawning biomass estimates, and spawning biomass time series. Certainty bounds were the standard errors obtained from the inverted Hessian matrix.

Model 14.0 has different size composition sample sizes and model weightings than the other models and therefore can not be compared directly to the other models using likelihoods. However, the other three models have the same data and the same data weighting and therefore can be compared directly in this manner. Selection this model was based on model conformance with known biological factors, model likelihood/fit, and retrospective analyses. Figure 5.18 shows the fits to all of the size composition data for all the models across all size bins and years and Figure 5.19 shows the Pearson's residuals for the fits to the two fisheries and two trawl surveys.

Because the difference between Model 14.0 and 14.1 are solely due to data weighting differences, an analysis of differences in the full model likelihoods would not be a valid comparison. The main difference between these two models is the change in sample size of the slope survey composition data from 100 to 400 for the 2002-2012 surveys, no longer including the shelf age composition data fits in the model likelihood, and a change in model weighting for the size composition data. The change in fits to the indices as measured by the index RMSE was minimal for all three surveys. Fits to the ABL longline survey size composition data, as measured by the harmonic mean of the effective sample size show a substantial improvement to the fits to the slope survey composition data over Model 14.0, a minor improvement to the shelf survey, and a worse fit to both fishery's composition data, particularly to the longline fishery data with a decrease from an effective sample size of 61.6 to 52.7. These changes reflected the change in the input sample size and weighting with a decrease in input sample size for the fisheries and an increase for the slope survey. The model was therefore performing as directed. The fishery and shelf survey size composition data weighting was adjusted through a single iteration using the Francis (2011) method as implemented in the R package *r4ss (*Taylor *et al.* 2015*).* The shelf survey index shows little change from Model 14.0 to 14.1 (Fig. 5.20), selectivity for females (Fig. 5.21) and males (Fig. 5.22) for the shelf composition data show some small changes in the descending slope for both males and females for the later survey data. Graphs of the shelf size composition data mean length at age (Fig. 5.23) show both models fit the mean length equally well. Fits to the slope survey index appear to the degraded somewhat in Model 14.1 (Fig. 5.24). Selectivity between these two models did not change substantially from Model 14.0 to 14.1 (Fig. 5.25), however the fit to the mean size shows a tighter fit to the mean length showing a closer fit to a drop in the 2012 mean length (Fig. 5.26). The ABL longline survey was the most affected with a change of -0.04 RMSE from Model 14.0 to 14.1, however this change in RMSE was rather minor and is barely discernible in graphs of the data and fit (Fig. 5.27). Differences among ABL longline selectivity models is likewise barely noticeable, although Model 14.1 shows a slight shift to larger fish (Fig. 5.28). ABL longline size composition data residuals and fits to the mean length are not differentiable among models with very little change from models 14.0 to 14.1 (Fig. 5.29). Most of the changes observed in the Trawl fishery selectivity occur for the females (Fig. 5.30) for the 1989-2005 time period with an increase in the selectivity peak and a sharper descending slope on the larger fish. Selectivity for the males remained the same (Fig. 5.31). Overview of the mean length at age fits reveal little difference in model fits (Fig. 5.32). Differences between the Model 14.0 and 14.1 Longline fishery selectivity curves for Model 14.0 and 14.1 are indistinguishable for the females (Fig. 5.33), while the male curve (Fig. 5.34) shows a distinct shift with lower selectivity on younger fish in the 1991-2009 time period. Model 14.1 appears to fit the mean length at age more closely than Model 14.0, but the differences are subtle (Fig. 5.35).

Model 14.1 showed an improvement over Model 14.0 in the retrospective analysis with a decrease in the Mohn's ρ , Woods Hole ρ, and retrospective RMSE from 0.211 to 0.196, 0.089 to 0.059, and 0.124 to 0.113, respectively (Table 5.17). Including the 2013 -2015 data in Model 14.0 greatly influence the estimates of 2007-2010 recruitments (Fig. 5.36). The Estimates of 2009 Age-0 recruits increased by 45% when the 2013-2015 were removed from Model 14.0. Model 14.1 2009 estimates of Age-0 recruits were nearly the same as those estimated from Model 14.0 without the 2013-2015 data (76.4 vs. 77.4 million Age-0 fish).

Model 14.1 and Model 5.1 have the same data, data sample sizes, and data weighting. It therefore can be compared using likelihood methods. Model 15.1 only differs from Model 14.1 by having a double normal selectivity on the Longline fishery size composition data. This change resulted in an improvement in the model fit of change the longline fishery selectivity from a logistic curve to a double normal. Using AIC to compare models, Model 15.1 has a -112.6 point improvement over Model 14.1 with the additional 13 parameters. The greatest improvement was in the fishery size composition data for both fisheries and the slope survey with decreases in log likelihoods and increases in effective sample sizes. The changes in fit to the shelf size composition were equivocal with increased in log likelihood, but a small increase in the effective sample size as well. The fit to eh ABL longline composition was degraded slightly with a < 1 change in effective sample size and <3 point increase in the log likelihood. The effect of the addition of the double normal to the longline size composition selectivity to the index fits were equivocal as well with minor increases to all three likelihoods and an increase to the RMSE for the shelf and slope surveys survey of <0.01 but the ABL index RMSE was the same. The retrospective analysis showed an improvement from Model 14.1 to Model 15.1 with the Mohn's ρ, Woods Hole ρ, and retrospective RMSE decreasing from 0.196 to 0.171, 0.059 to 0.047, and 0.113 to 0.101, respectively. These values indicate an improvement in the retrospective in the most recent years and over the entire time series. The Hanselman's ϕ is >1 for both models, but slightly higher for Model 15.1 indicating the retrospective bias occurs across the whole timeline for both models.

The most substantial changes from last year's model are found in Model 15.3. The model no longer includes the ABL longline data and selectivity is allowed to be annually variable through a restricted random walk. Because the data are different overall comparisons using AIC are not viable, however because sample size and weights remain the same between Models 15.1 and 15.3 comparisons of individual likelihood components and data fits are useful. The likelihoods suggest that the fit to the two indices included in the model were improved. The shelf survey negative log-likelihood decreased by 15.3 and the slope decreased by 2.45. However the index RMSE for the shelf survey and slope survey changed from 0.23 to 0.14 and from 0.21 to 0.24 from Model 15.1 to 15.3. Overall size composition fits improved by -239.8 LL, with improvements to all size composition data. This is also reflected in the increase in Effective sample sizes for all components, particularly the longline fishery where the longline fishery size composition effective sample size changed from 78.83 in Model 15.1 to 288.86 in Model 15.3. The sum of the size composition and index likelihoods, excluding the ABL Longline survey differed by 403 points between Model 15.1 and Model 15.3.1, however this improvement came at the cost of an additional 1,037 random walk pseudo-parameters. A method to quantify the addition of random walk pseudo-parameters for model selection and measuring this against improvements to the fit as measured by the likelihood has not yet been developed, however, Valero et al. 2015 in CAPAM Good Practices Guide – Selectivity" recommend employing time-varying selectivity. They found that static selectivities perform poorly when selectivities change, but varying selectivity performs reasonably well even when selectivity is actually static.

Although models with penalized random walk parameters are inappropriate for AIC comparisons, they do add considerable complexity to the model. One of the drawbacks of fitting the data so well is that the retrospective analysis shows a substantial degradation in the retrospective performance. From Model 15.1 to Model 15.3 the Mohn's ρ increased from 0.171 to 0.354, the Woods Hole ρ increased from 0.047

to 0.088 and the RMSE increased from 0.101 to 0.148. The doubling of the Mohn's ρ indicate a particularly troubling tendency of the model to substantially decrease the estimate of recent female spawning biomass as data are added to the model, even more than observed in Model 14.0. The Wood's Hole ρ for Model 15.3 is comparable to that observed in Model 14.0 indicating that both models have a similar level of retrospective bias across the entire time series. However review of the retrospective graphs of spawning biomass show that Model 14.0 has a high positive bias in the most recent years and lessening bias further back in time. Model 15.3 has a very high positive bias in the most recent years and a not as high, but substantial negative bias further back in time.

The improvement to the model from Model 14.0 to 14.1 are clear in that the newly proposed data weighting better balances the Slope and Shelf survey data. The addition of the double normal to the fishery selectivity in Model 15.1 also shows a marked improvement in model performance in both fits to the data and retrospective performance. The addition of annual variability to selectivity in the model greatly improves the fit to the data, however the retrospective performance in substantially degraded.

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 15.1 for the official stock assessment, but consider Model 15.3 with the random walk as an alternative model to be explored further in the 2016 stock assessment cycle. More work should be done on this model in exploring how the retrospective could be improved by changing the standard deviation of the random walk. Reducing this value for the selectivity parameters will likely improve the retrospective pattern while retaining fits to the data; however we did not have time to fully explore these attributes in this year's assessment cycle.

Model 15.1 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 15.1 fit to the survey indices is approximately the same as the fit to last year's model (Fig. 5.20, Fig. 5.24, and Fig. 5.27). Model 15.1 fails to fit the high 1994 shelf survey biomass estimate. In addition the model fit ifor the 2003 and 2004 biomass estimates are outside the confidence bounds of the survey, not fitting this short increase, but instead fitting a simple slope from the high biomass in 2001 through to the low biomass in 2009. The model estimated shelf survey biomass follows the general trend and shows an increase due to the high numbers of small fish observed in the 2008 through 2013 shelf surveys and 2012 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 time-varying selectivity curves as used in Model 15.3.

The slope survey index used in this year's assessment comprises only 5 points, however Model 15.1 only fits three of the five reasonably well (Fig. 5.24). The 2002 and 2008 model estimates are substantially higher than the observed values. The fit to these data is nearly a straight negatively sloped line through the points. 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. 5.27) mimics the 1996 - 2010 index decline. Instead of showing a sharp decline from earlier years and slight incline in the latest survey data, given the high uncertainty in these data, the model prefers to fit a shallow decline throughout the data series with a slight leveling off in recent years. There is a trend in the residual where the earlier high values tended to be underestimated. The RPN index values are rather stable since 2011. 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. If these data are to be used in the assessment 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. 5.37). The model did particularly well for the age compositions prior to 2013. The 2013 and 2014 age composition predictions for 2014 estimate a somewhat younger size at peak abundance than observed for both males and females for both years. The high numbers of young 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 fit of the length at age data for both males and females was good (Fig. 5.38). 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 2005-2014 males and a time varying growth should be explored in future models.

Size composition

Overall Model 15.3 did a reasonable job of capturing the large trends observed in the size composition data (Fig. 5.18 and Fig. 5.19). The Model 15.1 fit to the shelf survey data was only marginally improved over the fit to the 2014 Model configuration. The models perform poorly in 1999 through 2005 when there were a higher proportion of large female fish on the shelf than previously or later (Fig. 5.39). In this case the model consistently underestimates the proportion of larger females than observed. The model also does a poor job of fitting males when large year classes appear in the data, consistently underestimating the smaller fish as they age. This may be a problem with this survey only seeing younger fish; the model therefore underestimates their abundance because they do not occur in the shelf data in later years because they have migrated off the shelf. Model 15.3 with annually varying selectivity does an even poorer job of fitting these younger fish. Model 15.1 provided a very good fit 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 slope survey size composition selectivity was modeled as a logistic model with no time blocks, but separate selectivity for males and females. The model fits (Fig. 5.40) were substantially better than last year’s Model with increased effective sample sizes for all years. The fits continued to understimated the peak of the highest abundance size bins, particularly for males (Fig. 5.40). This may therefore underestimate the 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 1.6:1) in the population between for older fish (Fig. 5.41). between 50 cm and 70 cm (Fig. 5.42).

The Auke Bay Laboratory size composition data were from combined sexes and as such they are 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. There is no real improvement to the model fit from last year. Model 15.1 has a slightly higher log likelihood and lower average effective sample size for these data than Model 14.0. We fit the model using a single logistic curve (Fig. 5.28), but these data were bimodal and the model tends to fit a single mode to these data resulting (Fig. 5.29). in overfitting between the male and female peaks and underfitting the two peaks for all years. 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. In Model 15.3 we have not fit these data in the model, this data choice tends to increase the overall biomass estimates for recent years which suggests the index might be biased low.

The large peaks in the trawl fishery size composition data (Fig. 5.43) are often underestimated in this model for both males and females. The patterns in the residuals for these data remain problematic (Fig.19). 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. 5.19) 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. 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 15.1 fit to the longline data (Fig. 5.44. and Fig. 5.19) 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. 5.33 and Fig 5.34). 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. Comparison with the annually varying selectivities fit in Model 15.3 suggest that the time blocks selected in Model 15.1 could potentially be affecting model performance as selectivity patterns differ considerably as selectivity becomes more dome-shaped in recent times in the annually varying model for both males and females.

Time Series Results

In this section we will present the results from Model 15.1 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.

<u>Recruitment</u>

Model 15.1 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 0.634 with a standard deviation of 0.036. The most striking feature of the Model 15.1 recruitment (Fig. 5.45, Table 5.20, and Table 5.21) is the extremely large 1960- 1966 year classes with between 64 and 350 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 15.1 fits autocorrelation in recruitment forcing the model to create several large year classes throughout the 60s. 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 recent study by Thorson et al (2014) showing improved model performance with the assumption of autcorrelated recruitment deviations.

After 1970, Model 15.1 predicts another large recruitment event in 1973-1979 with an average recruitment of 75.38 million age 0 fish for these seven years with a maximum of 120.36 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 from1977 onward.

Recruitment from 1980 through 2006 was low with a mean of 4.9 million age-0 fish (rec.var=1.11). The mean Age 0 recruitment for 1977 through 2015 was estimated at 13.2 million fish (rec. var. = 1.41). Recruitment of age 0 fish was estimated in 2007 at 14.59 million, 2008 at 54.22 million, 2009 at 78.52 million, and 2010 at 12.1 million age 0 fish. Recruitment in 2009 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 the last two years 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 2010 cause a sharp drop in the predicted population mean size and mean age (Fig. 5.41 and Fig. 5.42).

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass in Model 15.1 was projected for 2016 at 30,997 t to be increasing from its lowest level of 17,613 t ($B_{14\%}$) in 2013, a drop from a peak of 294,610 t in 1975 ($B_{233\%}$; Table 5.22, Table 5.23, Fig. 5.46 and Fig. 5.47). 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 3.7 million fish (28% 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 0.04 with a maximum total exploitation rate of 0.14 (Table 5.22 and Fig. 5.48). The increased fishing exploitation rate in 2009 and 2010, that may have steepened the most recent decline, was only 0.08. The catch levels in 2008 through 2013 however would have exceeded the OFL control rule levels projected from Model 15.1 (Fig. 5.49). The effects of the incoming 2007-2010 year classes are creating a steep increase in both the total biomass and female spawning biomass estimates. Projections for 2016 and onward predict an increase in spawning biomass as these year classes grow and mature.

The Model 15.1 total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 of 675,710 t to its lowest point in 2010 of 51,205 t (Fig. 5.47). 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 102,053 in 2015 and projected to be at 114,438 t in 2016. The decrease in the estimated total biomass and spawning biomass from last year's assessment is mostly due to a decrease in estimated recruits with the inclusion of the new 2013 and 2014 age composition data, and 2015 shelf size composition data, and the new ABL longline survey coming in lower than expected. Model runs with the ABL longline survey not included have higher estimated biomass levels. If whale depredation on Greenland turbot during this survey is substantial, this survey index should be excluded from the assessment as it would likely be biasing estimates low. In addition, the 2013 and 2014 weight at age data changed the growth parameters such that females up to age 18 and all males were smaller than in last year's model (Table 5.24).

Retrospective analysis

The retrospective analysis was conducted in SS3 by removing data systematically by year from all models for 10 years (Fig. 5.50). The largest changes in the retrospectives for all models were between -8 and -7 years (from 2007 to 2008). The maturing fish are likely migrating out of the shelf survey area. In essence the model is "skeptical" of the new large year classes as they are not observed in the ABL longline composition data and none of the more recent indices show a large increase in biomass that would be expected if they remained in the area. This highlights the problem with missing the 2014 slope survey for this stock as the migrating turbot should be evident in this region.

In general, Model 15.1 with new slope size composition weights and double normal selectivity on the Longline fishery provides better retrospective pattern than last year's model (Model 14.0 Mohn's ρ = 0.211 vs. Model 15.1 Mohn's ρ = 0.171). This is not unexpected because Model 15.1 downplays the effects of the larger fish migrating off the shelf and out of the shelf survey area. In both models R_0 is affected by the large year classes, even with a fixed catchability for Model 15.1 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. 5.51). The shift in both slope survey selectivity parameters is dramatic with the exclusion of the 2012 composition data between year -2 and -3. The main recruitment deviations post-1984 show an increasing trend as data are removed. VonBertanffy K parameter for females shows a slower growth estimated when we include the most recent data, again the change appears to occur with the recruitment of the large 2007-2010 year classes to the shelf survey between years -8 and -7.

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean recruitment estimated for the period 1977-2015 gives a long-term average female spawning biomass of 50,577t. The estimated 2015 female spawning biomass is at 23,042 t or $B_{18\%}$,well below the estimate of $B_{35\%}$ (44,255 t). Because the projected spawning biomass in year 2015 is below $B_{40\%}$ Greenland turbot ABC and OFL levels will be determined at Tier 3b 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 2012 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. Therefore we recommend that the ABC be set to the maximum permissible.

The projected Greenland turbot maximum permissible ABC and OFL levels for 2016 and 2017 are shown below (catch for 2015 was set to 2,186 t):

Year	Catch (for projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2016	3,462	3,462	3,462	4,194	31,028
2017	6,131	6,132	6,132	7,416	41,015

The 2016 estimated overfishing level based on the adjusted $F_{35\%}$ rate is 4,194 t corresponding to a full-selection F of 0.10. 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 5.25).

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 50.0%, 22.4%, 10.7%, and 8.3%. These average 22.8% which when applied to the BSAI ABC gives the following region-specific allocation:

	2016 ABC	2017 ABC
Aleutian Islands ABC	789	1,398
Eastern Bering Sea ABC	2,673	4,734
Total	3,462	6,132

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 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2015 (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 2016, 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 2009-2014 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 B_{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 2015 and above its B_{MSY} level in 2025 under this scenario, then the stock is not overfished.)

Scenario 7: In 2016 and 2017, F is set equal to max F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its B_{MSY} level in 2018 or 2) above 1/2 of its B_{MSY} level in 2017 and expected to be above its B_{MSY} level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2015 (Table 5.26). Fishing at the maximum permissible rate indicate that the spawning stock (Fig. 5.52) 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 2015 spawning biomass estimated at 23,042 t relative to $0.5B_{35\%}$ = 22,127 t) and will be above its B_{MSY} value (44,255 t) in 2025 at 46,101 t.

Projections 7 with fishing at the OFL after 2018 results in an expected spawning biomass of 46,183 t by 2027. 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 2020 and then levels off as the influence of the 2007-2010 year classes wane and the projection relies on mean recruitment.

Under Scenarios 6 and 7 of the 2015 Model 15.1 the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

For Model 14.0 the female spawning stock biomass was projected to be below B_{MSY} levels in 2015, but above ½ B_{MSY}. The stock was projected be below B_{MSY} in 2025 under Scenario 6 (Fig. 5.53), but above B_{MSY} in 2027 under Scenario 7. Using Model 14.0 the stock would be considered in an overfished condition, but not approaching an overfished condition. This was, in the opinion of the authors completely a factor of the model not being properly balanced between the slope and shelf survey size composition weights. As shelf data were added to the model that showed the large 2007-2010 year classes disappearing from the survey, the model reduced recruitment on these year classes to compensate for these missing fish in the latest surveys.

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 2007-2010 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. 5.54) as calculated by Spencer (2008) show a significant correlation (df=31, $R^2 = 0.289$, p-value=0.0012) 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. 5.55) indicate that the most frequent prey for Greenland turbot on the EBS shelf are walleye pollock. However temperature is a much better predictor for Greenland turbot recruitment than pollock recruitment.

Fishery effects on the ecosystem

The Greenland turbot fishery has been rather small, less than 5,000 t annually since 2002, in comparison with the major Bering Sea longline and trawl gadid and yellowfin sole fisheries. The direct impact of the fishery on the ecosystem besides catch of Greenland turbot is through bycatch. FMP managed species bycatch in the Greenland turbot fishery can be found in Table 5.27. The highest bycatch has been of arrowtooth flounder (*Atheresthes stomias*; 14,029 t since 1991) and sablefish (*Anoplopoma fimbria*; 5,080 t since 1991), a low impact given the biomass of these species. The non-FMP bycatch are summarized in Table 5.28 and Table 5.29, bycatch of prohibited species are summarized in Table 5.30 and Table 5.31.

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 2,776 estimated to have been caught since 2003 (Table 5.32). It is estimated that 6 endangered short-tailed albatross (*Phoebastria albatrus*) were killed incidental to the Bering Sea Greenland turbot hook-and-line fishery in 2014 based on the observed take of 2 short-tailed albatross (NMFS CAS). Despite documented interactions in the Bering Sea and Aleutian Islands groundfish fisheries, the short-tailed albatross population has been increasing at an estimated rate of 5.2 to 9.4 percent per year since 2000 (USFWS 2014) and interactions in the fishery appear to be extremely rare. NMFS monitors the fisheries for interactions with short-tailed albatross and requires use of seabird avoidance gear in the hook and line fisheries to make it unlikely that the fisheries will reduce the recovery of the short-tailed albatross population.

Data Gaps and Research Priorities

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.
- The 2016 slope survey is desperately needed to verify the large 2007-2010 year classes and rebalance the assessment model.

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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	6,246	1,617	7,863	7,000	7,000
1992	749	3,003	3,752	7,000	7,000
1993	1,145	7,325	8,470	7,000	7,000
1994	6,427	3,846	10,272	7,000	7,000
1995	3,979	4,216	8,194	7,000	7,000
1996	1,653	4,903	6,556	7,000	7,000
1997	1,210	5,990	7,200	9,000	9,000
1998	1,576	7,181	8,757	15,000	15,000
1999	1,795	4,058	5,853	9,000	9,000
2000	1,947	5,027	6,974	9,300	9,300
2001	2,149	3,164	5,313	8,400	8,400
2002	1,033	2,602	3,635	8,000	8,000
2003	931	2,615	3,546	4,000	4,000
2004	675	1,583	2,258	3,500	3,500
2005	729	1,879	2,608	3,500	3,500
2006	361	1,625	1,986	2,740	2,740
2007	458	1,544	2,002	2,440	2,440
2008	1,935	988	2,923	2,540	2,540
2009	3,080	1,431	4,511	7,380	7,380
2010	1,977	2,160	4,138	6,120	6,120
2011	1,618	2,028	3,646	6,140	5,060
2012	2,612	2,107	4,720	9,660	8,660
2013	1,046	700	1,745	2,060	2,060
2014	951	704	1,656	2,124	2,124
2015*	1,090	1,105	2,194	3,172	2,648

*Catch estimated as of October 2015

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2015. 2015 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			23	12	700	3,724
1993	5,687	332	235	1,916	161	108	572	87	18	183	1	2			2	116	6,683	2,823
1994	6,316	368	195	2,305	149	211	317	37	27	235					36	15	7,040	3,233
1995	5,093	327	157	1,546	145	284	362	25	5	97		5			27	27	5,789	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63					129	94	4,733	1,823
1997	4,709	521	129	619	270	283	202	19	212	92					12	7	5,540	1,660
1998	6,689	290	123	84	281	155	35	1	541	162	40	86			49	48	7,813	945
1999	4,009	227	179	120	180	50	25	2	465	193	131	76			117	48	5,124	729
2000	4,798	177	192	254	130	109	39	1	576	83	262	93			165	43	6,184	791
2001	2,727	89	171	325	203	92	431	30	563	188	201	149			52	22	4,391	921
2002	1,979	73	144	207	210	137	175	18	76	59	225	158			95	10	2,934	701
2003	1,724	44	114	107	178	95	198	5	68	18	129	52			87	48	2,578	534
2004	1,222	19	78	30	220	83	80	3	134	110	37	18	46	158	82	41	1,882	376
2005	1,534	21	63	21	152	30	136	5	165	26	146	8	20	62	131	37	2,359	249
2006	1,199	14	62	69	65	32	71	8	51	13	141	19	13	90	85	32	1,778	211
2007	1,207	28	60	78	128	91	36	13	54	24	19	0	53	10	127	13	1,705	299
2008	944	3	42	87	16	69	142	1	95	16	762	414	5	15	142	82	2,207	704
2009	2,490	51	76	74	65	21	67	8	49	10	1,158	285	1	10	116	2	4,053	461
2010	1,932	19	71	28	97	19	57	2	13	5	1,659	80	<1	<1	61	1	3,910	235
2011	1,769	8	49	8	165	9	27	1	4	5	1,466	17	1	74	61	3	3,564	89
2012	1,899	15	36	16	116	9	17	3	47	6	2,269	12	<1	30	203	7	4,624	96
2013	579	13	27	38	12	5	49	10	38	42	635	208	<1	13	38	2	1,394	351
2014	626	16	11	44	13	7	40	1	30	52	598	129	<1	3	78	7	1,397	259
2015*	1,062	10	1	12	10	11	32	<1	72	32	846	24	<1	19	58	6	2,081	113

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2006-2014. Source: NMFS AK Regional Office catch accounting system.

	"Target" fishery	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015*
Longline and pot	Greenland turbot	1,212	1,232	743	1,191	1,833	1,773	1,914	589	628	1,053
	Sablefish	132	137	124	149	100	57	52	63	55	12
	Pacific cod	77	129	76	84	111	174	123	15	17	20
	Kam/Arrow flounder	140	16	0	9	49	0	4	0	0	0
	Halibut	63	19	12	0	74	30	13	28	3	19
	Others	5	11	22	1	0	0	1	4	<1	<1
Trawl	Greenland turbot	0	2	205	1,349	118	4	0	3	14	19
	Pacific cod	21	90	9	2	5	0	1	2	2	1
	Kam/Arrow flounder	21	3	1,176	1,434	1,690	1,483	2,277	843	727	870
	Atka mackerel	117	130	201	118	62	64	209	40	45	23
	Flathead sole	28	58	99	49	13	2	46	39	19	60
	Pollock	65	107	86	44	26	29	53	21	41	41
	Rockfish	74	47	142	73	59	28	18	54	41	33
	Other Flatfish	1	12	11	4	1	0	1	4	<1	2
	Rock sole	27	8	0	2	3	1	0	3	5	1
	yellowfin sole	8	1	1	4	1	6	6	35	57	40
	Sablefish	0	0	5	1	0	0	0	1	0	0
	Others	0	0	0	0	0	0	0	0	0	0

* Through October 2015

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2004-2015.

Area	Gear	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Aleutian Islands	Fixed	238	167	358	345	110	99	220	90	58	66	44	15
	Trawl	196	301	179	178	712	2,164	1,653	442	1,600	231	133	95
	AI Total	700	434	468	537	523	822	2,263	1,872	532	1,658	177	110
EBS	Fixed	1,346	1,713	1,270	1,201	867	1,336	1,948	1,944	2,050	634	660	1,089
	Trawl	479	427	183	280	1,222	916	325	1,176	1,012	815	819	995
	EBS Total	2,412	1,825	2,140	1,453	1,481	2,089	2,252	2,273	3,120	3,062	1,479	2,084
Grand Total		3,111	2,259	2,608	1,989	2,004	2,911	4,515	4,145	3,652	4,720	1,656	2,194

* Estimated through Oct. 2015.

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	1960-2014
	Size composition	1977-1987, 1989-1991, 1994-2006, 2008-2015
Longline fisheries	Catch	1960-2015
	Size composition	1979-1985, 1993-2015
Shelf Survey	Abundance Index	1987-2015
	Size composition	1982-2015
	Age composition	1998, 2003-2014
Slope Survey	Abundance Index	2002, 2004, 2008, 2010, 2012
	Size composition	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010, 2012
ABL Longline survey	RPN index	1996-2015
	Size composition	1979-2015

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2015. 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	770	1,432	1	35%	830	493		63%

Table 5.7. Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1979-2015. 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 2012 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		

Table 5.8. 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	367	46	1,567	11	11	292	292
1983	442	55	951				
1984	460	27	536	20		263	
1985	417	72	685				
1986	388	53	195				
1987	393	39	377				
1988	441	58	414				
1989	444	61	432				
1990	404	62	548				
1991	406	65	658				
1992	361	64	616	5		7	
1993	396	73	632	7		179	
1994	436	56	536	17		196	
1995	537	51	353				
1996	382	75	450	8		100	
1997	382	64	298	11		79	
1998	616	73	445	25	21	200	127
1999	426	47	207	8		11	
2000	423	57	248	34		188	
2001	426	61	274	45		217	
2002	404	70	455	21		71	
2003	408	71	622	62	62	435	407
2004	413	64	606	45	45	290	280
2005	417	62	442	58	57	294	278
2006	457	56	427	49	48	262	239
2007	443	84	501	68	68	334	311
2008	432	78	406	59	59	245	235
2009	422	103	856	72	71	351	344
2010	415	144	3,199	70	69	362	358
2011	422	155	4,381	61	59	427	381
2012	451	109	2,133	62	62	418	408
2013	455	96	1,160	63	63	382	374
2014	428	95	1,002	59	57	359	340
2015	440	78	771	60		380	

Table 5.9. Eastern Bering Sea slope survey estimates of Greenland turbot biomass (t), 2002, 2004, 2008, 2010, and 2012 by depth category.

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

Table 5.10. Eastern Bering Sea slope survey estimates of Greenland turbot numbers, 2002, 2004, 2008, 2010, and 2012 by depth category.

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

Table 5.11. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot biomass (t), 1980-2014.

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
Avg. since 1991	1,565	1,464	2,308	7,855	13,191

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	112.5
1997	11,729	6,172	27,936	13,491					59,328		82.75
1998					23,121	7,208	1,791	5,665		37,784	132.89
1999	13,072	6,156	33,848	10,068					63,144		88.07
2000					12,987	4,049	1,201	3,800		22,037	77.45
2001	16,082	5,005	24,766	5,123					50,975		71.1
2002					10,942	3,411	1,397	4,420		20,170	70.79
2003	11,965	3,784	24,660	6,206					46,616		65.02
2004					8,551	2,666	936	2,962		15,115	53.08
2005	3,717	1,826	15,268	2,297					23,107		32.23
2006					3,031	945	566	1,789		6,331	22.17
2007	1,561	1,754	13,523	1,235					18,074		25.21
2008					3,155	984	297	939		5,374	18.89
2009	3,406	640	21,192	2,612					27,850		38.85
2010					2,033	634	163	517		3,347	11.77
2011	1,494	705	12,164	1,821					16,184		22.57
2012					4,714	1,470	350	1,106		7,639	26.87
2013	1,641	3,082	13,473	2,970					21,166		29.52
2014					4,240	1,322	181	573		6,315	22.25
2015	3,104	451	12,737	4,710					21,001		29.29

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
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
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
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
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
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
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
8			50.00	57.00	62.50	54.53	54.67	53.25	56.00		57.00	47.50	52.56	57.57
9			57.50		62.00	57.90	59.75	53.75	59.56		72.00		54.50	56.08
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
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
12		78.67	78.33	78.25	77.00	71.00	62.00	70.50		67.25		75.00		75.00
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
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
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		
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
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		
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
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

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

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**
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
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
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
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
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
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
7	52.00		46.20	51.20	48.00	44.33	51.70	46.33	52.00			53.00	45.23	47.87
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
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
10		58.33	66.40	63.75	72.00	64.25	55.00	55.67	54.50			66.00		63.00
11			60.00		64.67	62.25	62.75	59.00			69.00			
12		59.75	72.00	73.20		74.00				60.00	65.50			
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				
24		69.50	76.33		74.00	77.00	84.00			82.00				
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				
30		81.00					79.00		76.75			76.00		
Age	**1982**	**1998**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
1	23	0	3	4	2	2	26	21	12	48	21	22	7	2
2	43	19	34	9	2	1	8	36	73	57	90	44	30	6
3	30	11	38	40	16	0	6	11	47	27	44	60	17	17
4	31	5	18	18	35	2	4	4	11	14	15	25	35	10
5	10	2	27	20	27	16	15	4	1	4	9	23	41	17
6	3	1	9	15	10	20	22	2	2	1	3	7	21	35
7	1	0	10	10	5	15	23	3	1	0	0	3	13	23
8	0	1	5	1	6	16	15	9	4	2	2	0	2	18
9	0	1	2	4	1	11	4	7	3	1	1	0	2	9
10	0	3	5	4	1	4	3	3	2	0	0	1	0	3
11	0	0	2	0	3	4	4	1	0	0	1	0	0	0
12	0	4	1	5	0	1	0	0	0	1	2	0	0	0
13	0	4	1	3	2	0	0	0	0	2	0	1	0	1
14	0	1	0	0	1	0	0	0	0	0	0	1	0	1
15	0	2	0	2	1	1	0	1	0	0	0	0	0	0
16	0	0	2	2	4	2	1	1	0	0	0	0	0	0
17	0	3	1	1	1	1	4	0	0	0	1	0	0	1
18	0	0	1	3	1	1	2	1	0	0	0	0	0	0
19	0	2	1	1	3	1	0	0	2	0	1	0	0	0
20	0	0	2	2	1	1	0	1	1	0	1	1	0	0
21	0	0	2	0	0	0	2	1	1	1	0	0	0	0
22	0	0	2	0	0	1	1	1	2	1	0	0	0	0
23	0	0	1	0	0	1	0	0	0	1	0	0	0	0
24	0	2	3	0	1	1	1	0	0	1	0	0	0	0
25	0	0	2	0	2	2	1	0	1	0	0	0	0	0
26	0	0	3	0	0	0	0	0	1	0	0	0	0	0
27	0	0	1	0	1	0	0	1	0	0	0	0	0	0
28	0	0	0	0	1	0	0	1	0	1	1	0	0	0
29	0	0	1	0	0	0	1	0	0	1	0	0	0	0
30	0	2	0	0	0	0	1	0	4	0	0	2	0	0

Table 5.15. Starting multinomial sample sizes for size composition data by fishery and suvey for Model 14.1, 15.1, and 15.3. Note Model 14.0 2002-2012 slope survey size composition sample size was 100.

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	
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	

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.

	M14.0	M14.1	M15.1	M15.3
Likelihoods				
Total	2535.02	2352.18	2278.88	1800.01
Survey	-31.41	-34.35	-33.24	-46.3153
Length Composition	1151.70	1035.43	961.30	591.312
Age Composition	107.98	0.00	0.00	0
Size at Age	1233.55	1273.46	1272.34	1126.65
Recruitment	67.52	72.67	70.17	52.86
Parameter priors	3.97	4.03	4.05	3.94162
Parameters				
$LN(R_0)$	9.55	9.62	9.65	10.03
Steepness	0.79	0.79	0.79	0.79
Natural Mortality	0.11	0.11	0.11	0.11
q_{Shelf}	0.62	0.62	0.62	0.62
q_{Slope}	0.57	0.57	0.57	0.57
Autocor (ρ)	0.60	0.62	0.63	0.59
L_{max} Female	88.03	88.68	88.93	90.18
L_{max} Male	73.98	70.43	70.34	72.75
Von Bert K Female	0.11	0.11	0.11	0.11
Von Bert K Male	0.15	0.18	0.18	0.17
Results				
Model				
SSB_{1978} (t)	206,390	232,240	258,990	148,270
Projection				
$SSB_{100\%}$ (t)	109,893	124,798	126,441	154,536
SSB_{2015} (t)	27,303	22,919	23,041	37,374
$SSB_{2015\%}$	0.248	0.184	0.182	0.242
SSB_{2016}(t)	32,577	30,584	30,997	48,144
$SSB_{2016\%}$	0.296	0.245	0.245	0.312
$F_{35\%}$	0.24	0.16	0.17	0.25
$F_{40\%}$	0.20	0.13	0.14	0.21
2016				
ABC (t)	4,447	3,534	3,462	8,815
F_{ABC}	0.13	0.08	0.08	0.16
OFL (t)	5,465	4,261	4,193	10,429
F_{OFL}	0.16	0.10	0.10	0.19
2017				
ABC (t)	6,390	5,959	6,132	12,935
F_{ABC}	0.15	0.11	0.11	0.20
OFL (t)	7,847	7,174	7,416	15,274
F_{OFL}	0.19	0.13	0.14	0.25

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

		M14.0	M14.1	M15.1	M15.3
Retrospective					
	Rho	0.211	0.196	0.171	0.354
	WH_Rho	0.089	0.059	0.047	0.088
	RMSE	0.124	0.113	0.101	0.168
Index RMSE					
	Shelf	0.23	0.22	0.23	0.14
	Slope	0.20	0.20	0.21	0.24
	ABL Longline	0.37	0.33	0.33	NA
Size Comp					
Har. Mean EffN					
	Trawl	33.83	30.30	37.80	90.07
	Longline	61.62	52.72	78.83	288.86
	Shelf	62.60	64.29	64.55	72.29
	Slope	25.45	35.62	36.96	60.32
	ABL Longline	31.50	30.82	30.76	NA
Mean input N					
	Trawl	31	12.5	12.5	12.5
	Longline	60	25	25	25
	Shelf	50	50	50	50
	Slope	23.64	97.73	97.73	97.73
	ABL Longline	30.0	30.0	30	NA
Age Comp					
	Har. Mean EffN	41.33	34.26	33.98	30.93
	Mean input N	30.0	0	0	0
	Rec. Var. (1975-2015)				
	Std.dev(ln(No. Age 1))	1.40	1.50	1.50	1.31

Table 5.18. Likelihood components for each model. Model 14.0 has different weights on the size composition data and therefore the likelihoods are not comparable with the other models.

	Length					Age	Size at Age	Index		
	FISHTRW	FISHLL	SHELF	SLOPE	ABL	SHELF	SHELF	SHELF	SLOPE	ABL
Model14.0	348.93	208.43	356.66	107.98	127.48	108.12	1233.55	-26.89	-7.07	2.55
Model14.1	154.31	100.19	363.96	288.28	128.69	0.00	1273.46	-25.40	-4.10	-4.85
Model15.1	109.94	74.03	365.59	281.59	130.15	0.00	1272.34	-25.18	-3.37	-4.70
Model15.3	49.37	21.91	335.64	184.40	NA	0.00	1126.65	-40.50	-5.82	NA

Table 5.19. Age-equivalent sex-specific selectivity estimates (as estimated for 2015 Model 15.1) 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	0.0067	0.0067	0.0000	0.0000
2	0.0070	0.0070	0.0000	0.0000
3	0.0099	0.0105	0.0000	0.0000
4	0.0236	0.0267	0.0000	0.0000
5	0.0592	0.0691	0.0006	0.0011
6	0.1192	0.1432	0.0080	0.0142
7	0.1926	0.2412	0.0433	0.0590
8	0.2629	0.3478	0.1264	0.1367
9	0.3184	0.4488	0.2507	0.2288
10	0.3543	0.5347	0.3908	0.3177
11	0.3718	0.6015	0.5234	0.3944
12	0.3743	0.6497	0.6363	0.4568
13	0.3663	0.6820	0.7265	0.5061
14	0.3516	0.7020	0.7959	0.5446
15	0.3331	0.7131	0.8481	0.5747
16	0.3129	0.7181	0.8870	0.5982
17	0.2925	0.7192	0.9158	0.6169
18	0.2728	0.7181	0.9372	0.6319
19	0.2541	0.7158	0.9530	0.6440
20	0.2368	0.7131	0.9648	0.6539
21	0.2209	0.7104	0.9736	0.6620
22	0.2064	0.7082	0.9802	0.6689
23	0.1933	0.7066	0.9852	0.6746
24	0.1814	0.7057	0.9889	0.6795
25	0.1711	0.7012	0.9911	0.6825
26	0.1625	0.6933	0.9923	0.6838
27	0.1550	0.6862	0.9932	0.6849
28	0.1485	0.6800	0.9940	0.6858
29	0.1428	0.6746	0.9945	0.6866
30	0.1317	0.6656	0.9956	0.6878

Table 5.20. Model 15.1 time series of age-0 recruits (number in 1,000s) with lower (LCI) and upper (UCI) 95% confidence intervals for 1960-2015.

Year	**Age-0 Recruits**	**LCI**	**UCI**	**Year**	**Age-0 Recruits**	**LCI**	**UCI**
1960	63,921	0	151,296	1994	973	418	1,528
1961	110,790	0	263,833	1995	2,934	1,771	4,096
1962	212,890	0	483,017	1996	1,635	802	2,468
1963	349,610	9,472	689,748	1997	1,670	828	2,511
1964	301,680	0	634,116	1998	2,014	982	3,046
1965	152,850	0	345,871	1999	6,605	4,256	8,953
1966	74,884	0	167,371	2000	7,902	5,029	10,775
1967	42,599	0	92,242	2001	8,022	5,373	10,671
1968	28,482	0	59,887	2002	1,542	675	2,409
1969	22,467	0	46,081	2003	652	248	1,057
1970	20,618	0	41,335	2004	601	225	976
1971	21,967	981	42,953	2005	1,078	467	1,689
1972	27,529	2,970	52,088	2006	6,216	3,894	8,538
1973	41,394	7,935	74,853	2007	14,589	9,312	19,866
1974	72,101	21,568	122,634	2008	54,229	38,974	69,484
1975	120,360	49,808	190,912	2009	78,522	57,734	99,310
1976	106,260	43,987	168,533	2010	12,056	6,012	18,100
1977	88,058	34,903	141,213	2011	6,461	2,737	10,184
1978	70,983	31,315	110,651	2012	4,646	1,546	7,746
1979	28,513	11,848	45,178	2013	5,646	1,662	9,630
1980	14,341	6,378	22,304	2014	5,643	1,067	10,219
1981	5,509	2,368	8,649	2015	11,970	0	26,374
1982	5,235	2,511	7,959				
1983	6,209	3,340	9,078				**1977-2014 Average 13,264**
1984	6,029	3,260	8,798				
1985	19,697	14,293	25,101				
1986	5,614	3,020	8,208				
1987	5,327	3,069	7,585				
1988	5,301	3,024	7,577				
1989	12,873	9,307	16,439				
1990	4,116	2,217	6,014				
1991	1,162	491	1,833				
1992	780	308	1,252				
1993	639	244	1,035				

Table 5.21. Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex for Model 15.1.

Females

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	4.38	4.67	4.67	2.43	1.19	0.66	0.43	0.33	0.30	0.33	0.44	0.69	1.15	1.33	0.71	0.28	0.12	0.06	0.03	0.02	0.06
1978	3.56	3.92	4.16	4.12	2.11	1.02	0.56	0.36	0.28	0.25	0.27	0.36	0.56	0.93	1.07	0.57	0.23	0.10	0.05	0.02	0.06
1979	1.42	3.18	3.48	3.65	3.54	1.78	0.84	0.45	0.29	0.22	0.20	0.21	0.28	0.43	0.71	0.82	0.44	0.17	0.07	0.03	0.06
1980	0.72	1.27	2.83	3.05	3.14	2.98	1.47	0.68	0.36	0.23	0.17	0.15	0.16	0.21	0.33	0.55	0.63	0.33	0.13	0.06	0.07
1981	0.28	0.64	1.13	2.46	2.59	2.59	2.40	1.16	0.53	0.28	0.17	0.13	0.11	0.12	0.16	0.24	0.40	0.45	0.24	0.10	0.09
1982	0.26	0.25	0.57	0.98	2.07	2.11	2.05	1.85	0.87	0.39	0.20	0.12	0.09	0.08	0.08	0.11	0.17	0.28	0.32	0.17	0.13
1983	0.31	0.24	0.22	0.49	0.82	1.68	1.66	1.57	1.39	0.64	0.28	0.15	0.09	0.06	0.06	0.06	0.08	0.12	0.19	0.22	0.21
1984	0.31	0.28	0.21	0.19	0.41	0.67	1.33	1.28	1.18	1.03	0.47	0.20	0.10	0.06	0.05	0.04	0.04	0.05	0.08	0.13	0.30
1985	1.00	0.27	0.25	0.18	0.16	0.35	0.56	1.10	1.05	0.96	0.83	0.38	0.16	0.08	0.05	0.04	0.03	0.03	0.04	0.06	0.34
1986	0.29	0.90	0.24	0.22	0.16	0.14	0.30	0.48	0.93	0.88	0.80	0.69	0.31	0.14	0.07	0.04	0.03	0.03	0.03	0.03	0.33
1987	0.27	0.26	0.80	0.22	0.20	0.14	0.12	0.26	0.41	0.79	0.75	0.68	0.59	0.27	0.11	0.06	0.04	0.03	0.02	0.02	0.31
1988	0.27	0.24	0.23	0.71	0.19	0.17	0.12	0.11	0.22	0.35	0.68	0.64	0.58	0.50	0.22	0.10	0.05	0.03	0.02	0.02	0.28
1989	0.66	0.24	0.22	0.20	0.63	0.17	0.15	0.11	0.09	0.19	0.30	0.59	0.55	0.50	0.43	0.19	0.08	0.04	0.03	0.02	0.26
1990	0.21	0.59	0.22	0.19	0.18	0.56	0.15	0.13	0.10	0.08	0.17	0.27	0.51	0.48	0.43	0.37	0.17	0.07	0.04	0.02	0.24
1991	0.06	0.19	0.53	0.19	0.17	0.16	0.50	0.13	0.12	0.08	0.07	0.15	0.23	0.43	0.40	0.37	0.31	0.14	0.06	0.03	0.22
1992	0.04	0.05	0.17	0.47	0.17	0.15	0.14	0.45	0.12	0.10	0.07	0.06	0.13	0.20	0.38	0.35	0.32	0.27	0.12	0.05	0.21
1993	0.03	0.04	0.05	0.15	0.42	0.15	0.14	0.13	0.40	0.11	0.09	0.07	0.06	0.11	0.17	0.33	0.31	0.28	0.24	0.11	0.24
1994	0.05	0.03	0.03	0.04	0.13	0.38	0.14	0.12	0.12	0.36	0.09	0.08	0.06	0.05	0.10	0.15	0.29	0.27	0.25	0.21	0.30
1995	0.15	0.04	0.03	0.03	0.04	0.12	0.34	0.12	0.11	0.10	0.31	0.08	0.07	0.05	0.04	0.09	0.13	0.25	0.23	0.21	0.43
1996	0.08	0.13	0.04	0.02	0.03	0.03	0.11	0.30	0.11	0.10	0.09	0.27	0.07	0.06	0.04	0.04	0.07	0.11	0.21	0.20	0.55
1997	0.08	0.07	0.12	0.03	0.02	0.02	0.03	0.10	0.27	0.10	0.09	0.08	0.24	0.06	0.05	0.04	0.03	0.06	0.10	0.19	0.65
1998	0.10	0.07	0.07	0.11	0.03	0.02	0.02	0.03	0.08	0.24	0.09	0.08	0.07	0.21	0.05	0.05	0.03	0.03	0.06	0.09	0.73
1999	0.33	0.09	0.07	0.06	0.09	0.03	0.02	0.02	0.02	0.08	0.21	0.08	0.07	0.06	0.18	0.05	0.04	0.03	0.02	0.05	0.70
2000	0.39	0.29	0.08	0.06	0.05	0.08	0.02	0.01	0.02	0.02	0.07	0.18	0.07	0.06	0.05	0.16	0.04	0.04	0.02	0.02	0.65
2001	0.40	0.35	0.26	0.07	0.05	0.05	0.08	0.02	0.01	0.01	0.02	0.06	0.16	0.06	0.05	0.05	0.14	0.04	0.03	0.02	0.57
2002	0.08	0.36	0.31	0.23	0.06	0.05	0.04	0.07	0.02	0.01	0.01	0.02	0.05	0.14	0.05	0.04	0.04	0.12	0.03	0.03	0.51
2003	0.03	0.07	0.32	0.28	0.21	0.06	0.04	0.04	0.06	0.02	0.01	0.01	0.01	0.04	0.12	0.04	0.04	0.03	0.10	0.03	0.46
2004	0.03	0.03	0.06	0.28	0.25	0.19	0.05	0.04	0.03	0.05	0.02	0.01	0.01	0.01	0.04	0.11	0.04	0.03	0.03	0.09	0.42
2005	0.05	0.03	0.03	0.05	0.25	0.22	0.17	0.05	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.03	0.09	0.03	0.03	0.03	0.45
2006	0.31	0.05	0.02	0.02	0.05	0.23	0.20	0.15	0.04	0.03	0.03	0.04	0.01	0.01	0.01	0.01	0.03	0.08	0.03	0.02	0.41
2007	0.73	0.28	0.04	0.02	0.02	0.04	0.20	0.18	0.13	0.04	0.03	0.02	0.04	0.01	0.01	0.01	0.01	0.03	0.07	0.03	0.38
2008	2.71	0.65	0.25	0.04	0.02	0.02	0.04	0.18	0.16	0.12	0.03	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.02	0.06	0.35
2009	3.92	2.42	0.58	0.22	0.03	0.02	0.02	0.03	0.16	0.14	0.10	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.01	0.02	0.35
2010	0.60	3.51	2.16	0.52	0.20	0.03	0.02	0.01	0.03	0.14	0.12	0.09	0.02	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.30
2011	0.32	0.54	3.13	1.93	0.46	0.18	0.03	0.01	0.01	0.03	0.12	0.10	0.07	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.24
2012	0.23	0.29	0.48	2.80	1.73	0.41	0.16	0.02	0.01	0.01	0.02	0.10	0.08	0.06	0.02	0.01	0.01	0.01	0.00	0.00	0.20
2013	0.28	0.21	0.26	0.43	2.50	1.54	0.37	0.14	0.02	0.01	0.01	0.02	0.08	0.07	0.05	0.01	0.01	0.01	0.01	0.00	0.16
2014	0.28	0.25	0.18	0.23	0.38	2.24	1.38	0.33	0.12	0.02	0.01	0.01	0.02	0.07	0.06	0.04	0.01	0.01	0.01	0.01	0.14
2015	0.59	0.25	0.22	0.16	0.21	0.34	2.00	1.22	0.29	0.11	0.02	0.01	0.01	0.01	0.06	0.05	0.03	0.01	0.01	0.01	0.13
2016	0.63	0.53	0.22	0.20	0.15	0.18	0.30	1.78	1.09	0.26	0.09	0.01	0.01	0.01	0.01	0.05	0.04	0.03	0.01	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 15.1.

Males

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	4.38	4.67	4.62	2.34	1.11	0.61	0.40	0.32	0.30	0.35	0.50	0.84	1.48	1.83	1.03	0.43	0.18	0.09	0.05	0.03	0.19
1978	3.56	3.92	4.14	4.02	2.01	0.95	0.52	0.34	0.27	0.25	0.30	0.42	0.70	1.25	1.54	0.87	0.36	0.16	0.08	0.04	0.18
1979	1.42	3.18	3.46	3.56	3.39	1.67	0.78	0.42	0.28	0.22	0.21	0.24	0.34	0.58	1.02	1.26	0.71	0.29	0.13	0.06	0.19
1980	0.72	1.27	2.80	2.97	3.00	2.82	1.38	0.64	0.35	0.23	0.18	0.17	0.20	0.28	0.47	0.83	1.02	0.57	0.24	0.10	0.20
1981	0.28	0.64	1.12	2.38	2.45	2.44	2.27	1.11	0.51	0.28	0.18	0.14	0.14	0.16	0.22	0.37	0.66	0.81	0.45	0.19	0.24
1982	0.26	0.25	0.56	0.94	1.94	1.96	1.93	1.79	0.87	0.40	0.22	0.14	0.11	0.11	0.12	0.17	0.29	0.51	0.62	0.35	0.33
1983	0.31	0.24	0.22	0.47	0.77	1.55	1.54	1.51	1.40	0.68	0.32	0.17	0.11	0.09	0.08	0.10	0.13	0.22	0.40	0.49	0.53
1984	0.31	0.28	0.21	0.18	0.38	0.61	1.22	1.21	1.18	1.10	0.53	0.25	0.13	0.09	0.07	0.06	0.07	0.11	0.18	0.31	0.80
1985	1.00	0.27	0.25	0.18	0.15	0.32	0.51	1.02	1.01	0.99	0.92	0.45	0.21	0.11	0.07	0.06	0.05	0.06	0.09	0.15	0.92
1986	0.29	0.90	0.24	0.22	0.16	0.13	0.28	0.44	0.87	0.87	0.85	0.78	0.38	0.18	0.10	0.06	0.05	0.05	0.05	0.08	0.92
1987	0.27	0.26	0.80	0.21	0.19	0.14	0.12	0.24	0.38	0.76	0.75	0.74	0.68	0.33	0.15	0.08	0.05	0.04	0.04	0.05	0.86
1988	0.27	0.24	0.23	0.71	0.19	0.17	0.12	0.10	0.21	0.33	0.66	0.65	0.64	0.59	0.29	0.13	0.07	0.05	0.04	0.03	0.79
1989	0.66	0.24	0.22	0.20	0.62	0.16	0.15	0.10	0.09	0.18	0.29	0.58	0.57	0.56	0.52	0.25	0.12	0.06	0.04	0.03	0.72
1990	0.21	0.59	0.22	0.19	0.18	0.55	0.15	0.13	0.09	0.08	0.16	0.25	0.49	0.49	0.48	0.44	0.21	0.10	0.05	0.04	0.65
1991	0.06	0.19	0.53	0.19	0.17	0.16	0.50	0.13	0.11	0.08	0.07	0.13	0.21	0.41	0.40	0.40	0.37	0.18	0.08	0.05	0.59
1992	0.04	0.05	0.17	0.47	0.17	0.15	0.14	0.44	0.12	0.10	0.07	0.06	0.11	0.18	0.35	0.34	0.34	0.31	0.15	0.07	0.55
1993	0.03	0.04	0.05	0.15	0.42	0.15	0.14	0.13	0.39	0.10	0.09	0.06	0.05	0.10	0.15	0.30	0.30	0.29	0.27	0.13	0.54
1994	0.05	0.03	0.03	0.04	0.13	0.38	0.14	0.12	0.11	0.35	0.09	0.08	0.05	0.04	0.09	0.13	0.26	0.25	0.25	0.23	0.57
1995	0.15	0.04	0.03	0.03	0.04	0.12	0.34	0.12	0.11	0.10	0.30	0.08	0.06	0.04	0.04	0.07	0.11	0.21	0.21	0.21	0.67
1996	0.08	0.13	0.04	0.02	0.03	0.03	0.11	0.30	0.11	0.09	0.09	0.25	0.06	0.05	0.04	0.03	0.06	0.09	0.18	0.18	0.74
1997	0.08	0.07	0.12	0.03	0.02	0.02	0.03	0.10	0.27	0.10	0.08	0.07	0.22	0.06	0.05	0.03	0.02	0.05	0.08	0.15	0.77
1998	0.10	0.07	0.07	0.11	0.03	0.02	0.02	0.03	0.08	0.23	0.08	0.07	0.06	0.19	0.05	0.04	0.03	0.02	0.04	0.06	0.76
1999	0.33	0.09	0.07	0.06	0.09	0.03	0.02	0.02	0.02	0.07	0.20	0.07	0.06	0.05	0.15	0.04	0.03	0.02	0.02	0.03	0.67
2000	0.39	0.29	0.08	0.06	0.05	0.08	0.02	0.01	0.02	0.02	0.06	0.18	0.06	0.05	0.04	0.13	0.03	0.03	0.02	0.01	0.58
2001	0.40	0.35	0.26	0.07	0.05	0.05	0.08	0.02	0.01	0.01	0.02	0.05	0.15	0.05	0.04	0.04	0.11	0.03	0.02	0.01	0.49
2002	0.08	0.36	0.31	0.23	0.06	0.05	0.04	0.07	0.02	0.01	0.01	0.02	0.05	0.12	0.04	0.04	0.03	0.09	0.02	0.02	0.41
2003	0.03	0.07	0.32	0.28	0.21	0.06	0.04	0.04	0.06	0.02	0.01	0.01	0.01	0.04	0.10	0.04	0.03	0.03	0.07	0.02	0.36
2004	0.03	0.03	0.06	0.28	0.25	0.19	0.05	0.04	0.03	0.05	0.02	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.02	0.06	0.32
2005	0.05	0.03	0.03	0.05	0.25	0.22	0.17	0.05	0.03	0.03	0.05	0.01	0.01	0.01	0.01	0.03	0.07	0.03	0.02	0.02	0.33
2006	0.31	0.05	0.02	0.02	0.05	0.23	0.20	0.15	0.04	0.03	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.06	0.02	0.02	0.29
2007	0.73	0.28	0.04	0.02	0.02	0.04	0.20	0.18	0.13	0.04	0.03	0.02	0.03	0.01	0.01	0.01	0.01	0.02	0.05	0.02	0.26
2008	2.71	0.65	0.25	0.04	0.02	0.02	0.04	0.18	0.16	0.12	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.01	0.02	0.04	0.24
2009	3.92	2.42	0.58	0.22	0.03	0.02	0.02	0.03	0.16	0.14	0.10	0.03	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.24
2010	0.60	3.51	2.16	0.52	0.20	0.03	0.02	0.01	0.03	0.13	0.11	0.08	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.20
2011	0.32	0.54	3.13	1.93	0.46	0.18	0.03	0.01	0.01	0.03	0.11	0.09	0.06	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.17
2012	0.23	0.29	0.48	2.80	1.73	0.41	0.16	0.02	0.01	0.01	0.02	0.09	0.07	0.05	0.01	0.01	0.01	0.01	0.00	0.00	0.14
2013	0.28	0.21	0.26	0.43	2.50	1.54	0.37	0.14	0.02	0.01	0.01	0.02	0.07	0.05	0.04	0.01	0.01	0.01	0.01	0.00	0.11
2014	0.28	0.25	0.18	0.23	0.38	2.24	1.38	0.33	0.12	0.02	0.01	0.01	0.01	0.06	0.05	0.03	0.01	0.01	0.00	0.01	0.09
2015	0.59	0.25	0.22	0.16	0.21	0.34	2.00	1.23	0.29	0.11	0.02	0.01	0.01	0.01	0.05	0.04	0.03	0.01	0.00	0.00	0.09
2016	0.63	0.53	0.22	0.20	0.15	0.18	0.31	1.78	1.08	0.25	0.09	0.01	0.01	0.01	0.01	0.04	0.03	0.02	0.01	0.00	0.08

Table 5.22. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the 2014 assessment) for BSAI Greenland turbot, 1977-2017. 2016 through 2017 biomass estimates are from the projection Model 15.1.

				Female Spawning Biomass		Total Age 1+ Biomass	
Year	Apical Fishing Mortality	Total Exploitation	1-SPR	2014 Assessment	Current Assessment	2013 Assessment	Current Assessment
1977	0.11	0.06	0.59	220,707	267,900	354,323	464,651
1978	0.16	0.09	0.71	216,994	258,990	351,340	452,383
1979	0.17	0.10	0.73	202,766	240,010	342,498	433,675
1980	0.23	0.13	0.81	187,714	220,630	338,430	420,278
1981	0.27	0.14	0.85	170,056	198,140	324,898	397,450
1982	0.26	0.14	0.85	154,920	177,690	303,115	367,775
1983	0.25	0.14	0.85	146,680	164,710	279,206	338,089
1984	0.13	0.08	0.66	140,905	155,230	252,111	306,788
1985	0.09	0.05	0.51	144,250	156,030	242,469	294,234
1986	0.06	0.03	0.40	149,145	159,280	236,353	285,557
1987	0.06	0.03	0.40	153,092	162,400	231,233	278,288
1988	0.05	0.03	0.32	153,590	162,630	223,876	268,660
1989	0.07	0.03	0.36	151,975	161,010	216,911	259,403
1990	0.11	0.05	0.48	146,043	154,520	206,711	246,749
1991	0.07	0.03	0.37	135,926	143,560	191,342	228,996
1992	0.04	0.02	0.21	127,908	135,050	180,666	215,770
1993	0.09	0.04	0.38	122,021	128,950	174,067	206,456
1994	0.12	0.05	0.50	112,379	118,730	162,668	192,061
1995	0.11	0.05	0.45	102,350	107,780	148,580	174,948
1996	0.09	0.04	0.40	93,809	98,397	136,386	159,857
1997	0.11	0.05	0.43	86,418	90,223	125,728	146,491
1998	0.15	0.07	0.51	78,581	81,553	114,551	132,666
1999	0.11	0.05	0.45	69,676	71,732	102,184	117,672
2000	0.15	0.07	0.52	62,993	64,368	92,879	105,887
2001	0.13	0.06	0.50	55,516	56,137	83,051	93,651
2002	0.10	0.04	0.42	49,540	49,489	75,638	83,899
2003	0.09	0.04	0.41	44,875	44,210	70,934	76,911
2004	0.08	0.03	0.36	40,923	39,608	67,760	71,345
2005	0.10	0.04	0.42	38,006	36,002	66,010	67,256
2006	0.08	0.03	0.36	35,446	32,602	64,081	63,141
2007	0.08	0.03	0.38	34,051	30,270	62,749	59,833
2008	0.09	0.05	0.50	33,315	28,553	61,342	56,719
2009	0.15	0.08	0.64	32,612	26,992	59,651	53,485
2010	0.15	0.08	0.62	30,921	24,572	58,390	51,205
2011	0.15	0.07	0.61	28,835	22,102	60,747	54,035
2012	0.21	0.08	0.71	26,865	19,887	69,331	62,248
2013	0.08	0.02	0.46	24,931	17,613	80,929	72,821
2014	0.07	0.02	0.41	26,342	18,706	97,442	87,580
2015	0.07	0.02	0.43	**30,853**	23,041	**122,298**	102,053
2016				**38,848**	**30,997**	**132,666**	**114,438**
2017					**41,015**		**123,494**

Table 5.23. Spawning biomass with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2016 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. 2016 values are from the production model.

Year	Spawning Biomass	LCI	UCI
1977	267,900	209,968	325,832
1978	258,990	205,317	312,663
1979	240,010	190,414	289,606
1980	220,630	174,788	266,472
1981	198,140	156,076	240,204
1982	177,690	139,262	216,118
1983	164,710	129,632	199,788
1984	155,230	123,298	187,162
1985	156,030	126,673	185,387
1986	159,280	132,408	186,152
1987	162,400	137,900	186,900
1988	162,630	140,376	184,884
1989	161,010	140,771	181,249
1990	154,520	136,242	172,798
1991	143,560	127,179	159,941
1992	135,050	120,306	149,794
1993	128,950	115,669	142,231
1994	118,730	106,909	130,551
1995	107,780	97,365	118,195
1996	98,397	89,191	107,603
1997	90,223	82,056	98,390
1998	81,553	74,295	88,811
1999	71,732	65,266	78,198
2000	64,368	58,554	70,182
2001	56,137	50,888	61,386
2002	49,489	44,715	54,263
2003	44,210	39,844	48,576
2004	39,608	35,603	43,613
2005	36,002	32,316	39,688
2006	32,602	29,202	36,002
2007	30,270	27,118	33,422
2008	28,553	25,608	31,498
2009	26,992	24,218	29,766
2010	24,572	21,918	27,226
2011	22,102	19,555	24,649
2012	19,887	17,438	22,336
2013	17,613	15,227	19,999
2014	18,706	16,281	21,131
2015	23,041	20,210	25,872
2016	30,997	27,101	34,893

Table 5.24. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot from the 2014 stock assessment (Barbeaux et al. 2014) and for the 2015 Model 15.1.

	Mid-year length (cm)				Mid-year weight (kg)			
	2014 Reference		2015 M15.1		2014 Reference		2015 M15.1	
Age	Females	Males	Females	Males	Females	Males	Females	Males
1	14.19	13.84	14.42	13.95	0.02	0.02	0.019	0.018
2	22.13	22.27	22.86	23.10	0.08	0.08	0.087	0.090
3	30.11	30.44	30.29	30.87	0.22	0.22	0.221	0.228
4	37.20	37.33	36.96	37.39	0.44	0.42	0.428	0.421
5	43.48	43.15	42.94	42.86	0.73	0.67	0.703	0.652
6	49.06	48.06	48.32	47.45	1.09	0.94	1.038	0.903
7	54.00	52.21	53.14	51.30	1.50	1.23	1.420	1.158
8	58.39	55.71	57.47	54.53	1.94	1.51	1.838	1.406
9	62.28	58.66	61.36	57.24	2.40	1.77	2.280	1.640
10	65.74	61.16	64.85	59.51	2.86	2.02	2.733	1.854
11	68.80	63.26	67.98	61.42	3.32	2.25	3.190	2.048
12	71.51	65.04	70.80	63.02	3.77	2.46	3.641	2.220
13	73.92	66.53	73.32	64.36	4.19	2.64	4.081	2.371
14	76.06	67.80	75.58	65.49	4.60	2.80	4.504	2.502
15	77.96	68.87	77.62	66.43	4.98	2.94	4.906	2.615
16	79.64	69.77	79.44	67.22	5.33	3.06	5.285	2.711
17	81.13	70.53	81.08	67.89	5.65	3.16	5.638	2.793
18	82.45	71.17	82.55	68.45	5.94	3.24	5.965	2.862
19	83.63	71.71	83.87	68.92	6.21	3.32	6.266	2.920
20	84.67	72.17	85.06	69.31	6.45	3.38	6.541	2.968
21	85.59	72.56	86.12	69.64	6.66	3.43	6.793	3.009
22	86.41	72.88	87.08	69.91	6.86	3.48	7.022	3.042
23	87.14	73.16	87.94	70.15	7.03	3.51	7.230	3.069
24	87.78	73.39	88.71	70.34	7.19	3.54	7.419	3.092
25	88.35	73.59	89.40	70.50	7.33	3.57	7.591	3.112
26	88.86	73.75	90.02	70.64	7.46	3.60	7.744	3.132
27	89.31	73.89	90.57	70.76	7.57	3.62	7.881	3.148
28	89.71	74.01	91.07	70.85	7.67	3.64	8.002	3.162
29	90.06	74.11	91.52	70.93	7.76	3.65	8.110	3.174
30	90.74	74.26	92.45	71.05	7.92	3.68	8.329	3.191

Table 5.25. Estimated total Greenland turbot harvest by area, 1977-2015. Values for 2015 are through Oct. 17th, 2015 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*	2,084	110
1996	4,844	1,712			

Table 5.26. Model 15.1 mean spawning biomass, F, and yield projections for Greenland turbot, 2015-2028. 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
2015	23,042	23,042	23,042	23,042	23,042	23,042	23,042
2016	31,028	31,028	31,028	31,028	31,028	31,028	31,028
2017	41,015	41,015	41,898	41,824	42,408	40,723	41,015
2018	49,913	49,913	52,774	52,587	54,071	49,094	49,913
2019	55,481	55,481	61,865	61,518	64,292	53,878	54,613
2020	57,729	57,729	68,476	67,929	72,349	55,134	55,830
2021	57,418	57,418	72,832	72,059	78,361	53,859	54,492
2022	55,725	55,725	75,624	74,619	82,896	51,350	51,908
2023	53,707	53,707	77,580	76,352	86,572	48,749	49,204
2024	52,013	52,013	79,213	77,782	89,829	46,980	47,326
2025	51,045	51,045	80,776	79,163	92,886	46,101	46,364
2026	50,705	50,705	82,319	80,545	95,792	45,877	46,076
2027	50,765	50,765	83,823	81,907	98,537	46,032	46,183
2028	51,042	51,042	85,263	83,220	101,112	46,370	46,483
F							
2015	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2016	0.08	0.08	0.03	0.03	0.00	0.10	0.08
2017	0.11	0.11	0.03	0.03	0.00	0.13	0.11
2018	0.14	0.14	0.03	0.03	0.00	0.16	0.17
2019	0.14	0.14	0.03	0.03	0.00	0.17	0.17
2020	0.14	0.14	0.03	0.03	0.00	0.17	0.17
2021	0.14	0.14	0.03	0.03	0.00	0.17	0.17
2022	0.14	0.14	0.03	0.03	0.00	0.17	0.17
2023	0.14	0.14	0.03	0.03	0.00	0.16	0.16
2024	0.13	0.13	0.03	0.03	0.00	0.15	0.15
2025	0.13	0.13	0.03	0.03	0.00	0.14	0.14
2026	0.12	0.12	0.03	0.03	0.00	0.14	0.14
2027	0.12	0.12	0.03	0.03	0.00	0.14	0.14
2028	0.12	0.12	0.03	0.03	0.00	0.13	0.13
Catch							
2015	2,186	2,186	2,186	2,186	2,186	2,186	2,186
2016	3,462	3,462	1,262	1,446	0	4,194	3,462
2017	6,132	6,132	1,697	1,941	0	7,317	6,132
2018	9,045	9,045	2,113	2,413	0	10,585	10,918
2019	10,058	10,058	2,438	2,779	0	11,823	11,963
2020	10,315	10,315	2,649	3,011	0	11,940	12,071
2021	10,118	10,118	2,760	3,131	0	11,525	11,642
2022	9,706	9,706	2,809	3,178	0	10,844	10,988
2023	9,275	9,275	2,829	3,194	0	9,708	9,856
2024	8,653	8,653	2,846	3,207	0	8,919	9,023
2025	8,208	8,208	2,869	3,228	0	8,497	8,570
2026	7,983	7,983	2,900	3,259	0	8,334	8,387
2027	7,903	7,903	2,936	3,297	0	8,322	8,360
2028	7,910	7,910	2,975	3,337	0	8,392	8,420

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

	flounder, arrowtooth	sablefish (blackcod)	groundfish, general	skate, other	grenadier (rattail)	cod, Pacific (gray)	pollock, walleye	rockfish, thornyhead (idiots)	grenadier, giant	sole, flathead	rockfish, other	rockfish, shortraker/rougheye	Kamchatka flounder	flounder, general
1991	1,085	504	107			154	114				61			94
1992	4	28	10			12	0	0			2	2		0
1993	560	577	529			115	6	38		7	36	195		100
1994	1,384	492	165			85	20	35		18	61	22		29
1995	2,007	555	533			111	50	22		57	73	28		53
1996	492	265	232			97	32	13		52	46	19		15
1997	766	267	278			82	56	10		63	41	12		7
1998	1,153	404	518			166	106	45		50	79	38		23
1999	1,071	380	464		1,175	225	151	23	219	131	32	32		60
2000	764	351	326		588	223	117	28	413	72	92	63		23
2001	292	229	194		493	110	54	22	4	69	33	28		15
2002	333	170	122	49	148	83	13	38	164	35	16	13		4
2003	368	174	5	223		32	98	80		76	0			0
2004	256	89	0	136		38	64	60		17	0			0
2005	185	99	1	168		22	8	47		7	0			0
2006	195	93	1	121		56	1	51		3	1			0
2007	235	73	0	176		67	3	55		0	0			0
2008	337	61	0	69		83	32	37		1				0
2009	1,339	81	0	209		13	12	50		5	0			
2010	574	99	1	363		59	11	68		11	0			
2011	223	23	4	382		72	14	41		6	0		13	
2012	333	28	6	355		79	11	36		13	1		239	
2013	9	11	3	51		5	2	17		6			61	
2014	47	21	2	43		6	2	25		8	0		41	0
2015	15	7	2	210		37	20	29		11	0		80	
Grand Total	14,029	5,080	3,501	2,553	2,403	2,033	997	868	800	717	576	452	434	423

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

	rockfish, shortraker	perch, Pacific ocean	greenling, atka mackerel	sole, rex	squid, majestic	sole, rock	rockfish, dusky	sole, yellowfin	rockfish, rougheye	Pacific sleeper shark	sculpin, general	rockfish, dark	flounder, Alaska plaice	Other
1991		3	65		38	1		0				27		0
1992		0												0
1993		1			0	0	1		0					3
1994	1	1	1	18	19	1	10	0	0					3
1995	5	12	10	3	12	4	65	18	1				8	2
1996	2	6	3	1	1	3	0	0	0					0
1997	5	14		18	3	2	0	9	1				1	0
1998	25	3	22	12	1	13		6	4				2	1
1999	11	32	133	14	4	54	0	18	1	15			0	3
2000	21	27	5	22	9	3	0	4	8	2			1	7
2001	19	52	2	3	2	3		5	0	1				5
2002	2	1		13	0	1			0	0	8			1
2003	27	1	0	34	3	1		1	8	10	7		1	5
2004	40	1	0	5	6	1	0	1	4	3	4		1	0
2005	12	0		6	0	0			2	3	1			1
2006	33	0	0			0	0	0	5	1	1			3
2007	78	0	0	0			0		3	1	2			1
2008	2	166	0	3	4	0			0	0	3			1
2009	4	0	1	3	23				1	0	2			0
2010	29	0		1	1	0			4	0	1		1	9
2011	5	0	0	0	0	0		0	0		1			1
2012	11	0					2		1	0	1			2
2013	3	0		0	0	0		0	0		0			0
2014	2	0		0	1	0	0	0		0	2			0
2015	2	0	0		0		0	0	0		2			0
Grand Total	342	321	242	157	128	89	80	63	43	36	34	27	14	48

Table 5.28. Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for longline and pot vessels since 2003.

	Benthic urochordata	Bivalves	Brittle star unidentified	Corals Bryozoans	Eelpouts	Giant Grenadier	Grenadier	Gunnels	Hermit crab unidentified	Invertebrate unidentified	Large Sculpins	Misc crabs	Misc crustaceans	Misc fish	Misc inverts (worms etc)	Other Sculpins
Longline																
2003	0.032	0.001	0.010	0.056	1.588	44.439	1503.568		0.000	0.000	0.5	0.009		2.949		1.182
2004					2.355	135.787	1160.075				0.1	0.007		1.482		0.400
2005	0.001	0.001	0.003	0.056	5.531	1105.290	1029.744		0.000	0.000	0.1	0.002		1.106		0.359
2006	0.010		0.001	0.066	3.951	1300.829	216.837			0.034	0.8	0.018		2.079		0.374
2007	0.004		0.006	0.013	2.268	1181.184	234.462		0.003	0.016	0.3	0.010		0.430		1.286
2008				0.004	2.848	686.763	20.900				0.4	0.026		1.740		0.368
2009		0.000	0.026	0.002	5.409	1775.300	46.882		0.001	0.013	0.1	0.005	0.009	0.387		0.744
2010	0.010		0.000	0.120	5.745	1815.194	367.177		0.003	0.004	1.3	0.009		1.408	0.001	0.175
2011			0.110	0.002	7.674	1603.849	308.216	0.031		0.260	0.9	0.031		1.097		0.299
2012			0.077	0.010	8.113	1200.596	260.715			0.064	1.2	0.009		1.415		0.231
2013			0.008	0.001	2.069	564.542	5.349			0.248	0.4			0.504		0.074
2014					2.546	315.825	166.326			0.006	1.9	0.008		0.627		0.031
2015			0.115		4.740	1084.230	21.335				0.3	0.001		0.570		0.013
POT																
2004							4.009					0.004				

Table 5.28 Cont. Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for longline and pot fisheries since 2003.

	Scypho jellies	Sea anemone unidentified	Sea pens whips	Sea star	Snails	Sponge unidentified	urchins dollars cucumbers
Longline							
2003	0.013	0.124	0.002	0.395	0.039	0.095	0.803
2004		0.043		0.225	0.011	0.005	0.006
2005	0.017	0.197	0.002	0.864	0.133	0.008	0.286
2006	0.006	0.078		0.376	0.024	0.014	0.019
2007		0.027		0.779	0.035	0.497	0.024
2008		0.038		1.415	0.020	0.005	0.010
2009	0.003	0.060		1.157	0.022	0.001	0.520
2010	0.007	0.117	0.025	1.129	0.033	0.003	0.329
2011	0.007	1.308	0.082	0.805	0.026	0.019	0.067
2012	0.007	0.528		0.916	0.028	0.016	0.089
2013	0.004	0.045		0.436	0.054	0.004	0.134
2014		0.001		0.650	0.017		0.221
2015	0.007	0.380		0.483	0.020	0.002	0.025
Pot							
2004				0.004	0.001		

Table 5.29. Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for trawlers since 2003.

	Brittle star unidentified	Capelin	Corals Bryozoans	Eelpouts	Giant Grenadier	Greenlings	Grenadier	Hermit crab unidentified	Invertebrate unidentified	Lanternfishes (myctophidae)	Large Sculpins	Misc crabs	Misc fish	Misc inverts (worms etc)	Other Sculpins	Pacific Sand lance	Pandalid shrimp	Scypho jellies
Trawl																		
2003	0.031			27.85			25.24	0.00				0.00	1.25	0.03	4.		0.00	
2004		0.01		10.70			25.95	0.00	0.87		4.	0.00	0.10					0.06
2005				0.998		0.18	0.466				0.		0.27		0.	0.00		
2008				0.268	67.461						1.		0.11		0.			
2009				3.420	365.00		49.63				0.		0.20		0.		0.00	
2010			0.00	0.041	58.753		5.657				0.				0.		0.00	
2011				0.118	0.858						0.		0.04					
2013			0.00	0.010	0.349								0.07		0.			
2014	0.001			1.143	0.438		0.357			0.00	0.	0.01	0.02		0.			0.00
2015				0.085	6.848								0.03		0.		0.00	

Table 5.29 Cont. Non-FMP species catch (kg) in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for trawlers.

	Sea anemone unidentified	Sea pens whips	Sea star	Snails	Sponge unidentified	urchins dollars cucumbers
Trawl						
2003	0.769	0.016	4.633	0.512		
2004	0.004		1.964	0.142		
2005			0.250			
2008			0.001		0.002	
2009	0.128		0.063	0.006	0.098	0.031
2010	0.001		0.000		0.005	0.000
2011			0.050		0.002	
2013	0.002		0.001			
2014	0.075		0.021	0.004	0.061	0.001
2015	0.345		0.020	0.069		

Table 5.30. Prohibited species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for fixed gear.

	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					81.50		0.00	0.07	0.05	0.01
1992					12.80			0.01		
1993	0.03				568.36		0.00	2.07	1.16	0.00
1994			0.01		325.41			0.20	0.23	0.01
1995	0.02				428.12		0.01	0.65	0.40	0.05
1996	0.01				415.25		0.00	0.58	0.19	0.02
1997	0.01				390.87		0.02	0.36	0.21	0.01
1998	0.03				445.91		0.05	1.23	1.50	0.01
1999	0.01				427.63		0.02	0.66	0.84	0.01
2000	0.01				570.44		0.00	0.93	1.73	0.02
2001	0.00				301.08		0.01	0.54	0.31	0.02
2002	0.06		0.00		271.05		0.05	0.56	0.06	0.01
2003	52.79	0.00	8.71	135.92	121.15	0.00	20.28	25.18		0.00
2004	10.35	0.00	17.64	151.25	125.65	0.00	76.92	0.00		0.00
2005	0.00	12.27	13.35	21.57	161.15	0.00	41.01	2.90		8.05
2006	31.42	0.00	8.19	327.84	83.53	0.00	25.81	3.00		12.64
2007	18.70	0.00	0.00	2437.57	43.58	0.00	23.89	34.26		47.86
2008	16.07	6.79	0.00	3.19	14.51	0.00	29.21	42.71		8.14
2009	84.83	0.00	0.00	0.00	47.32	0.00	15.01	23.70		0.00
2010	46.85	8.33	0.00	179.35	89.75	0.00	35.88	84.66		1.22
2011	0.00	0.00	0.00	34.43	40.68	0.00	77.98	11.70		0.00
2012	15.82	0.00	4.07	26.21	50.24	0.00	127.02	41.68		0.00
2013	0.00	0.00	0.00	0.00	9.96	0.00	22.21	4.66		0.00
2014	4.69	0.00	0.00	28.52	10.03	0.00	50.42	8.40		0.00
2015	0.00	0.00	17.64	35.59	23.83	0.00	34.57	7.16		0.00
POT										
1991								0.07		
1999	0.02				0.18			0.68	27.77	
2002					0.00					
2004	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00		0.00

Table 5.31. Prohibited species catch in the Greenland turbot fishery for the Eastern Bering Sea and Aleutian Islands for Trawl.

	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	14.92		0.07		372.95	0.01	0.00	237.96	11.16	1.40
1993					0.02			0.08		
1994	1.92		0.06		926.64	0.00		278.05	6.028	0.33
1995	3.84				556.26	0.012		52.21	3.03	0.97
1996	1.09				12.35	0.09		5.59	0.25	
1997	0.61				14.38	0.16		6.14	0.45	
1998	0.47				13.58	0.04		2.84	0.13	
1999	1.05				26.66	0.34		2.05	1.20	
2000	1.05				25.32	0.01		2.68	3.33	
2001	0.50				15.80	0.04		7.19	0.47	
2002	0.73				1775.19	0.01		2.64	0.21	
2003	2.88	0.00	0.00	98.54	0.01	0.00	0.00	1.80		0.00
2004	0.00	0.00	0.00	66.12	2.96	0.00	0.00	66.12		0.00
2005	87.55	0.00	0.00	87.55	2.99	0.00	0.00	0.00		0.00
2008	0.00	0.00	0.00	132.00	2.81	0.00	0.00	0.00		0.00
2009	0.00	0.00	0.00	746.97	8.17	0.00	0.00	0.00		0.00
2010	0.00	0.00	0.00	86.00	2.75	0.00	0.00	0.00		0.00
2011	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00		0.00
2013	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00		0.00
2014	0.00	0.00	0.00	20.99	0.00	0.00	0.00	0.00		0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

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

	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	80				3	135
2005		12	13	152	81				258
2006			3	212					215
2007		10	2	243	119				374
2008				247					247
2009	4	4	10	548	69		4		639
2010	17			170	4		11		202
2011			5	498	38				542
2012				354	40		15		409
2013				65	60		5		131
2014				55		6			62
2015				17	55				72
Grand Total	20	57	54	2,776	486	6	36	3	3,439

Figures

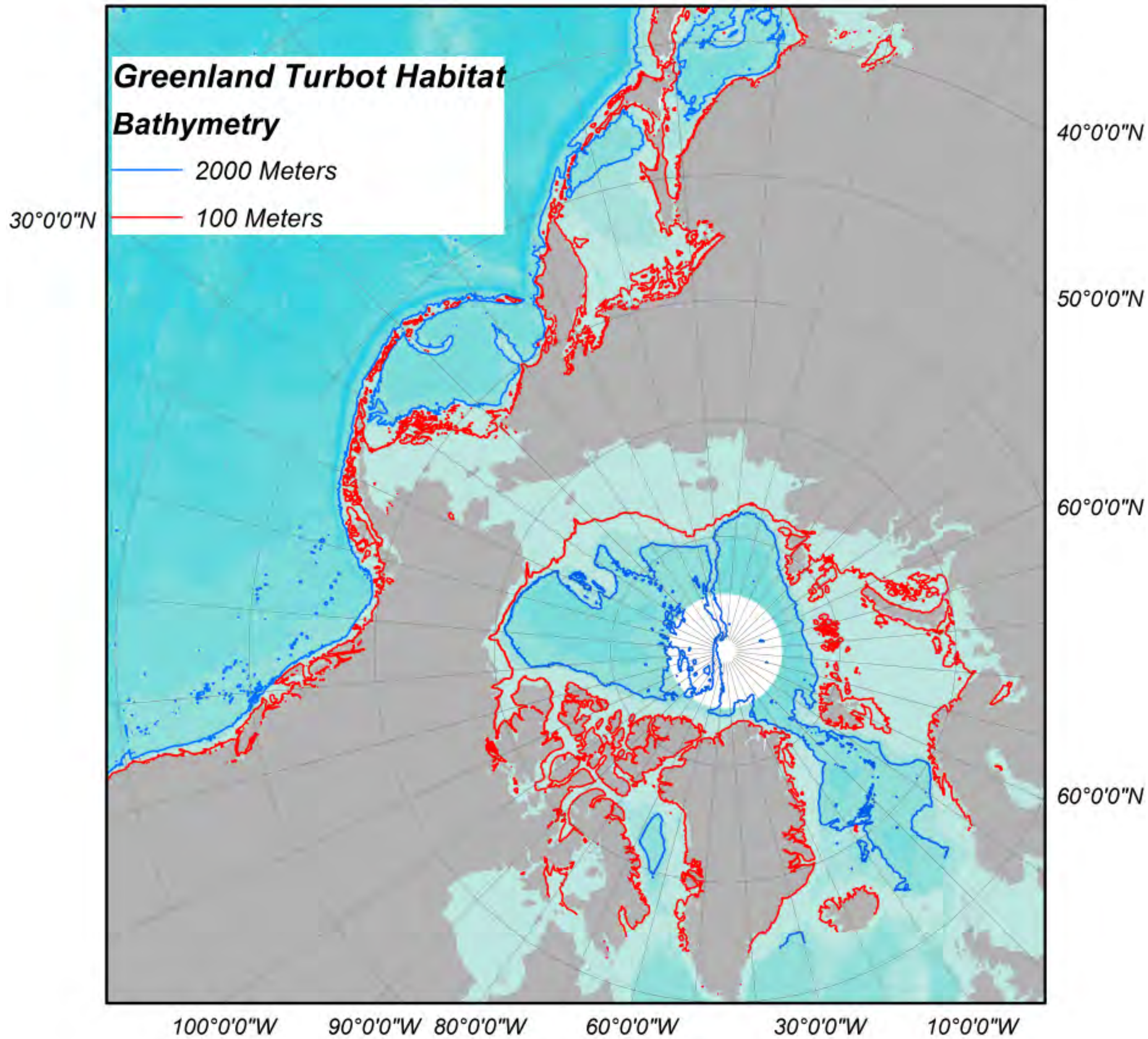


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.

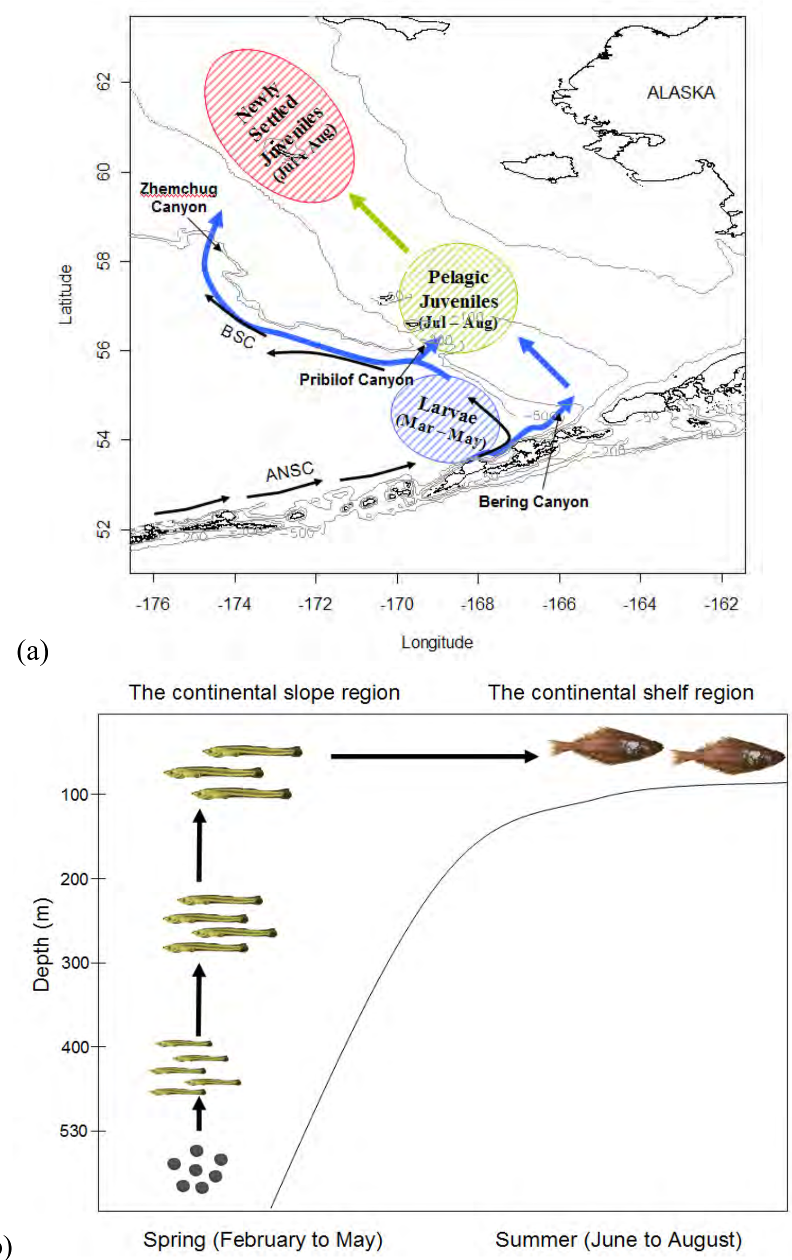


Figure 5.2. Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: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

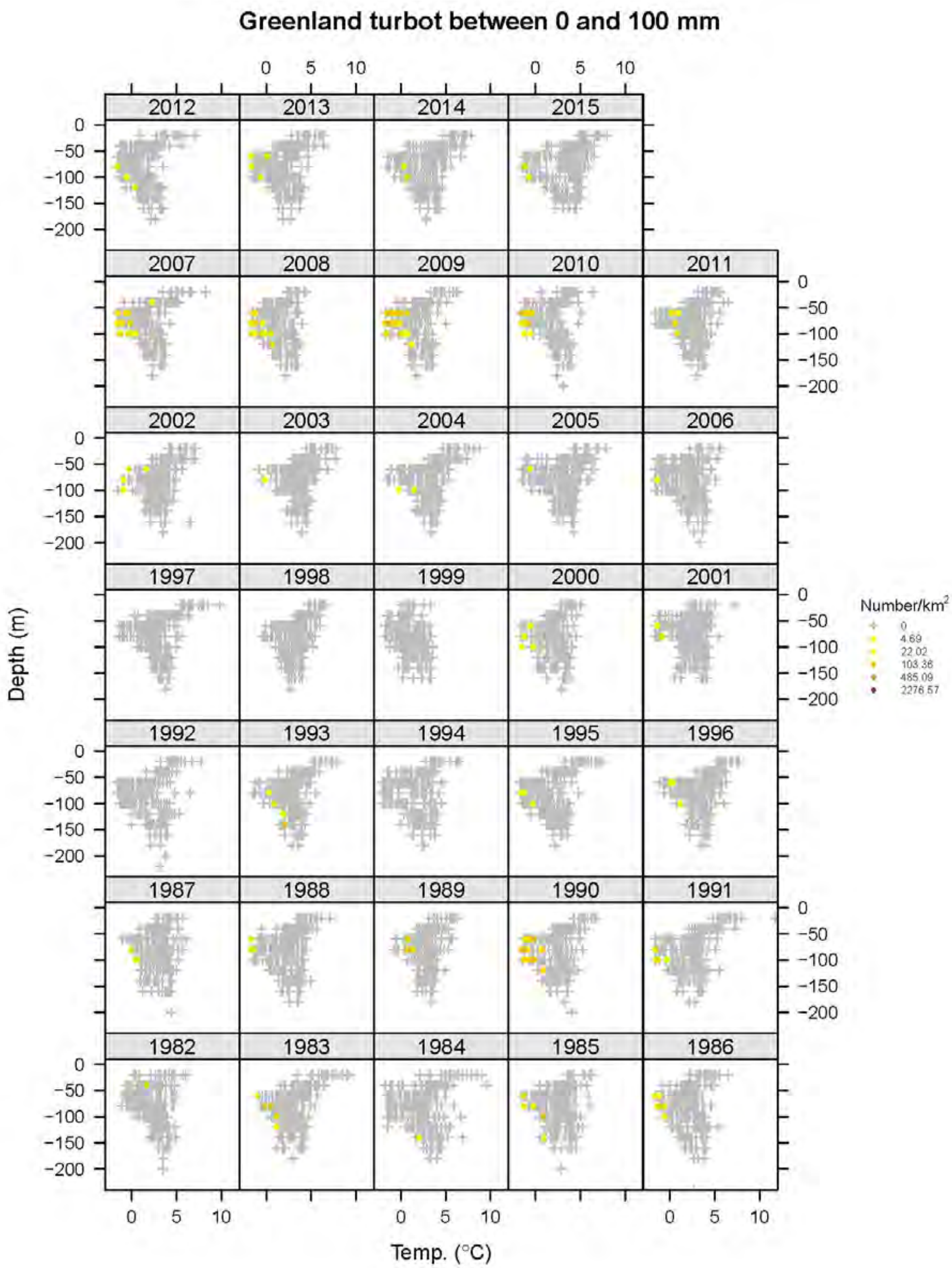


Figure 5.3. Greenland turbot (0-100 mm) density distribution by temperature and depth (left) for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

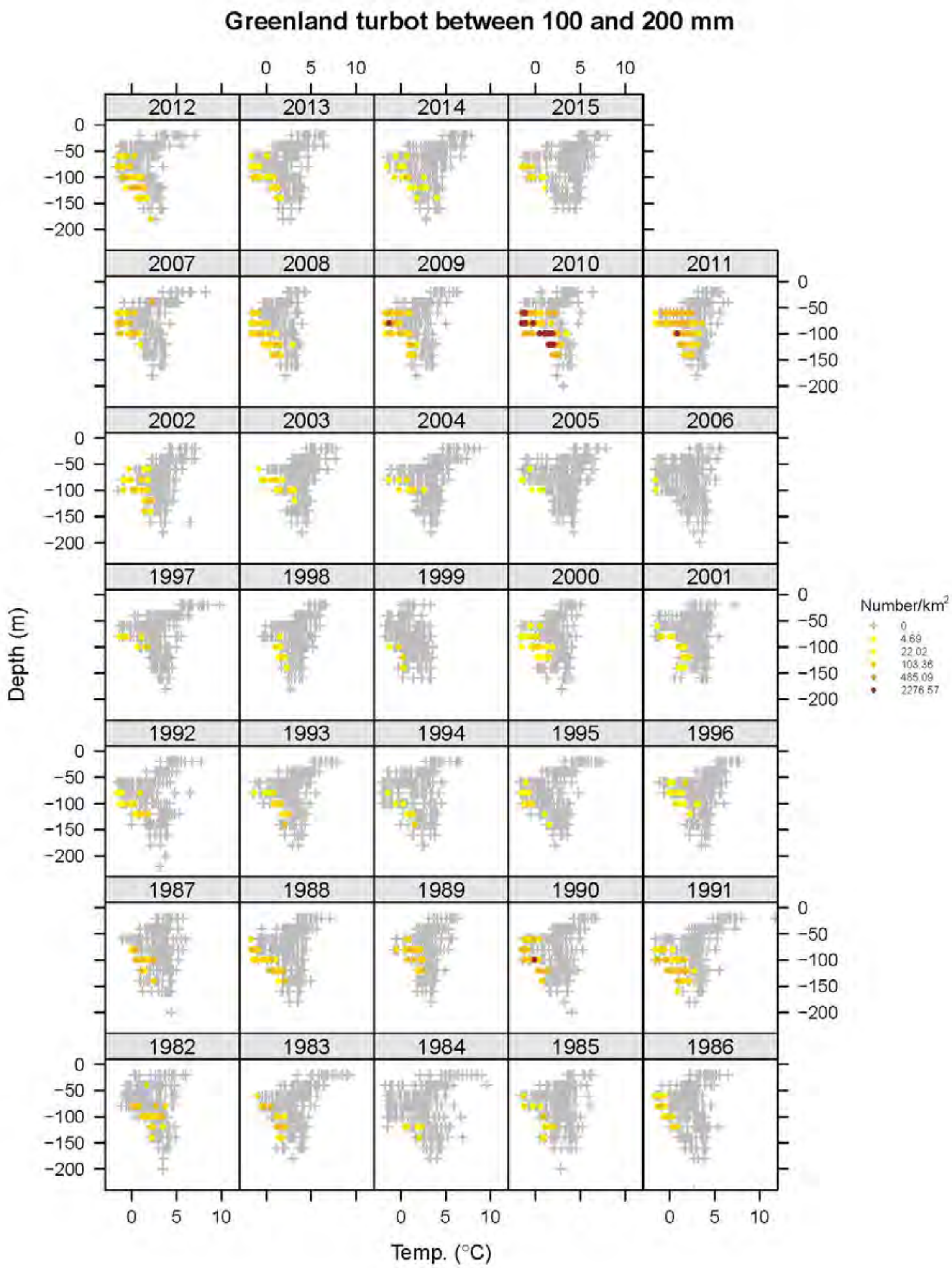


Figure 5.3. (Cont.) Greenland turbot (100-200 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

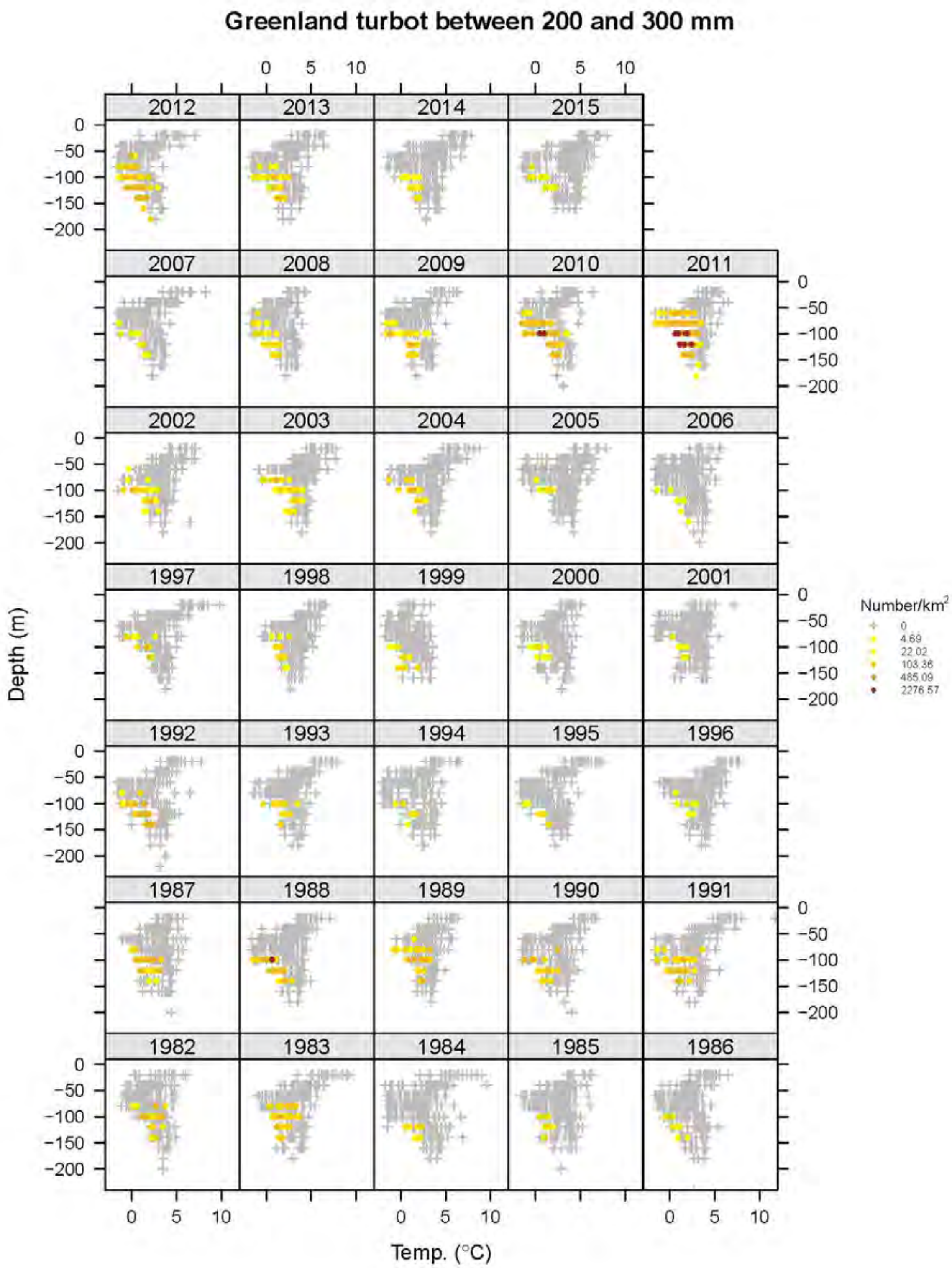


Figure 5.3. (Cont.) Greenland turbot (200-300 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

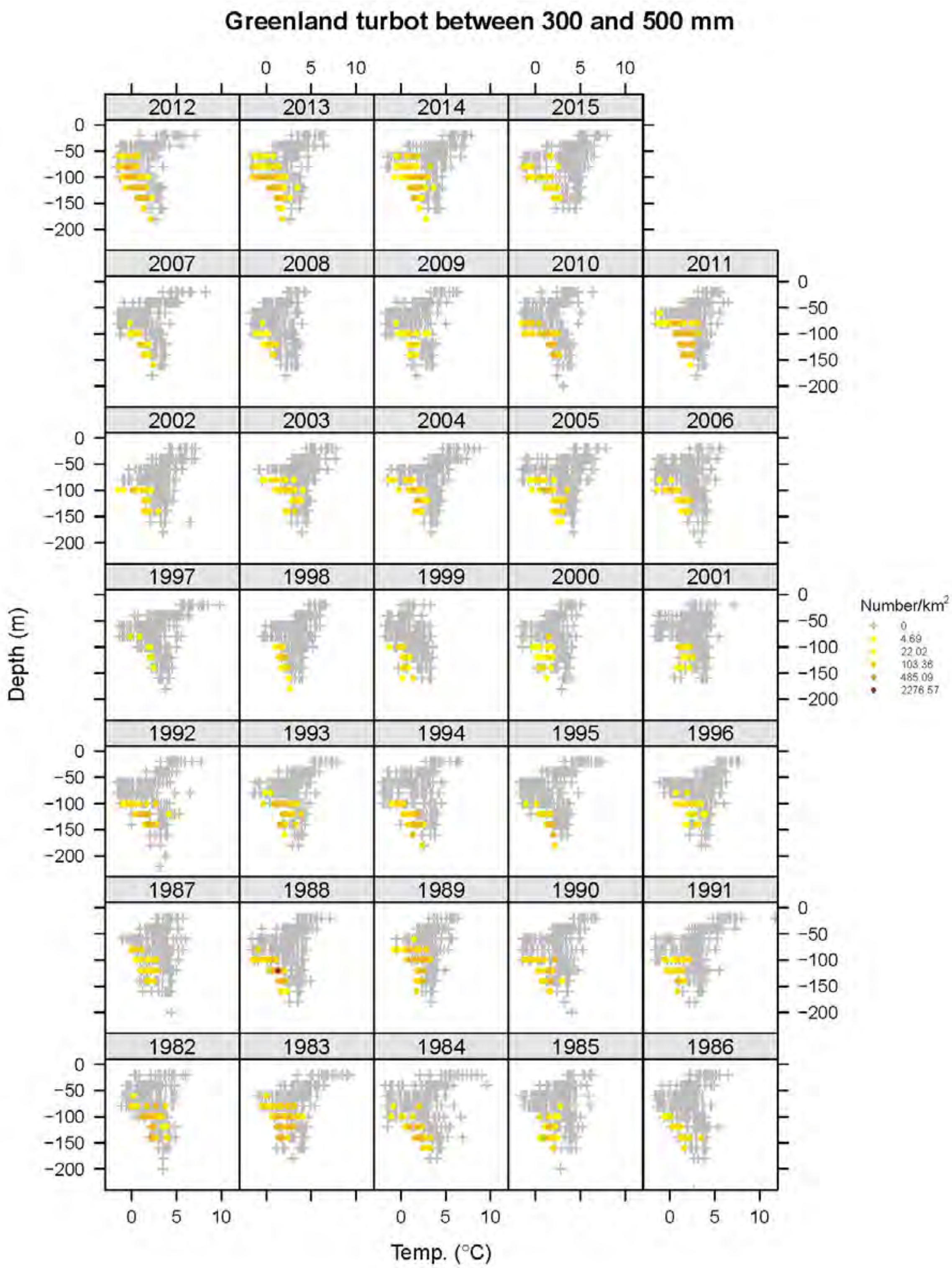


Figure 5.3. (Cont.) Greenland turbot (300-500 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

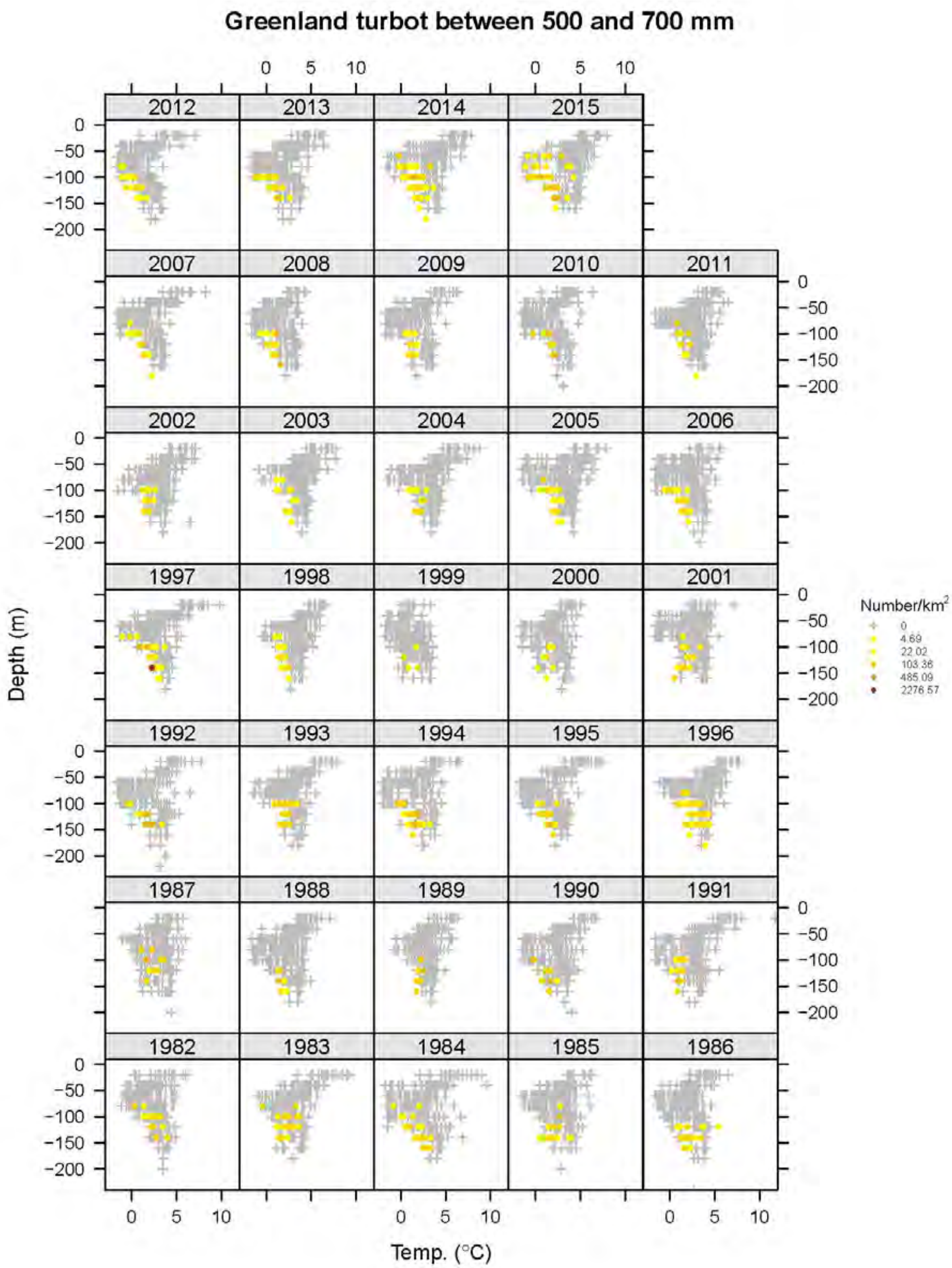


Figure 5.3. (Cont.) Greenland turbot (500-700 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

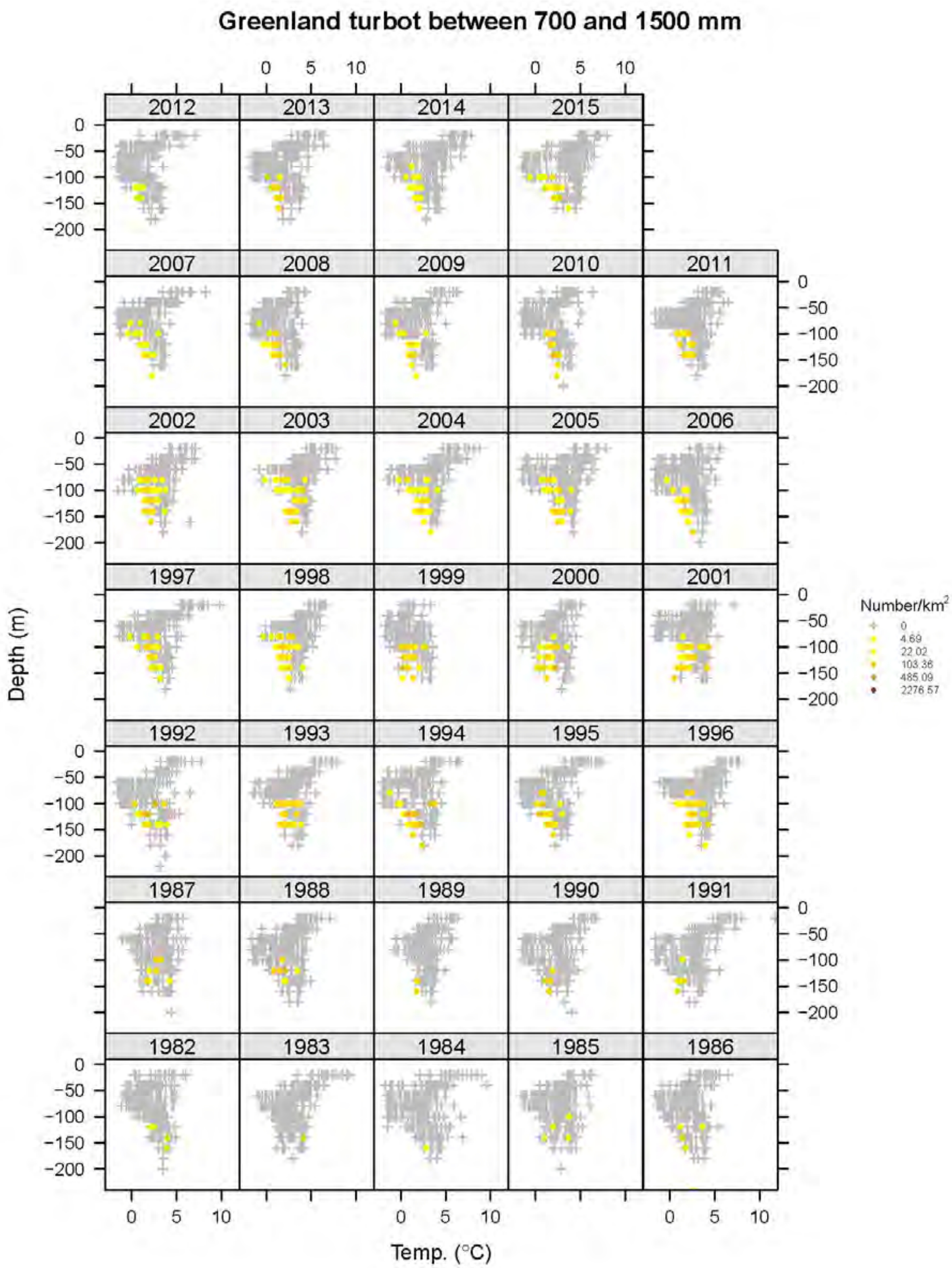


Figure 5.3. (Cont.) Greenland turbot (700-1500 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

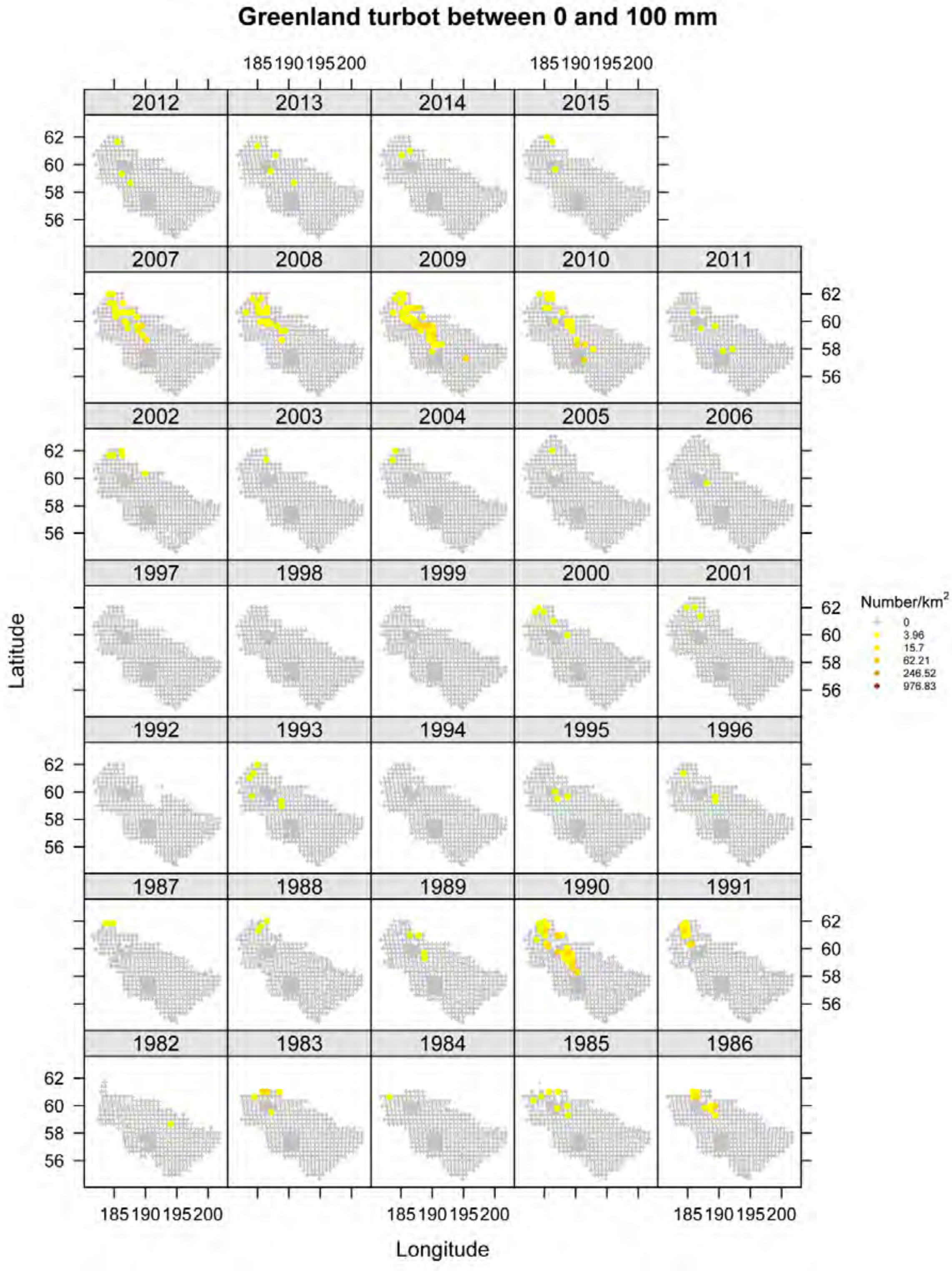


Figure 5.4. Greenland turbot (0-100 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

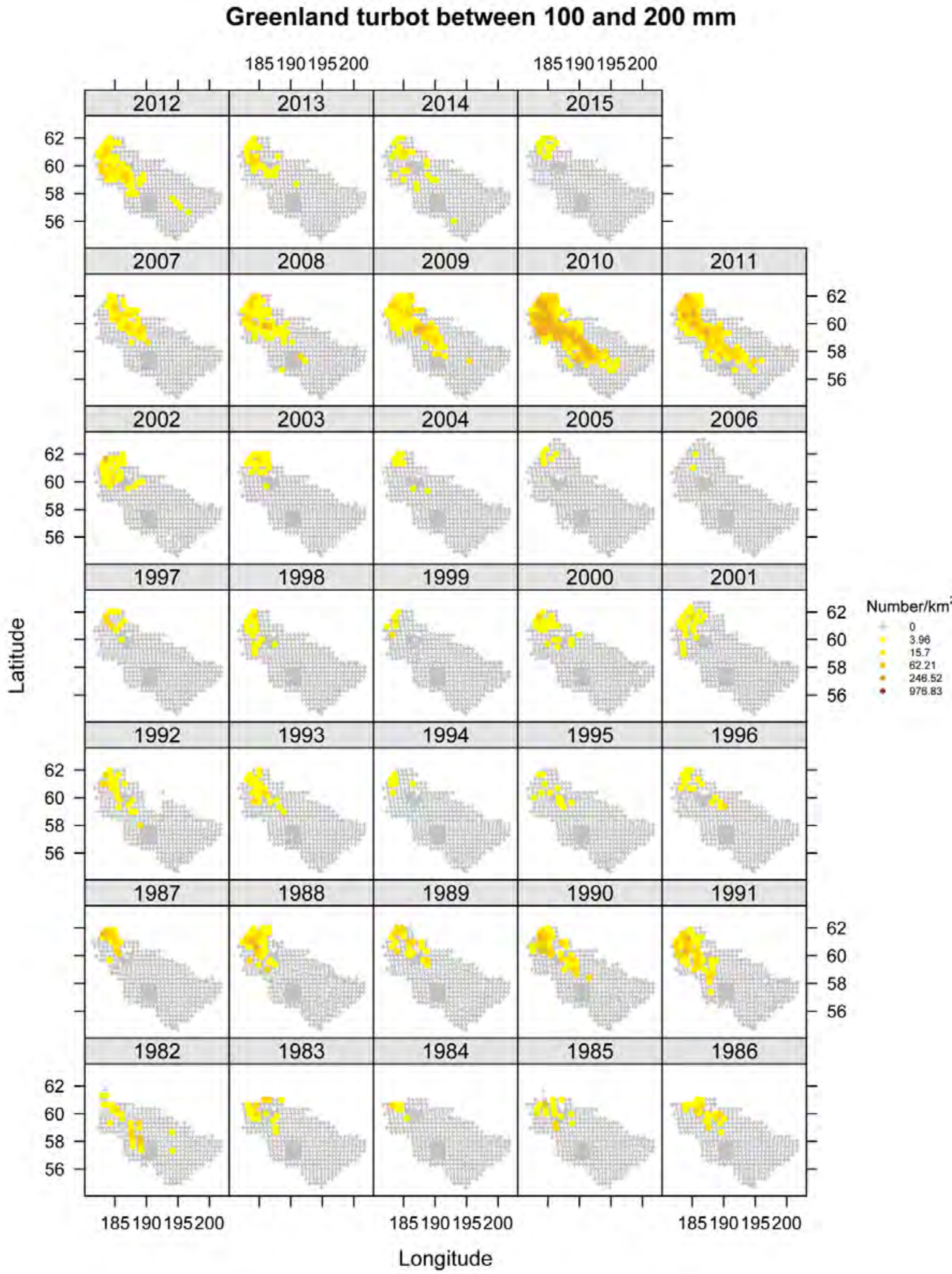


Figure 5.4. (Cont.) Greenland turbot (100-200 cm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

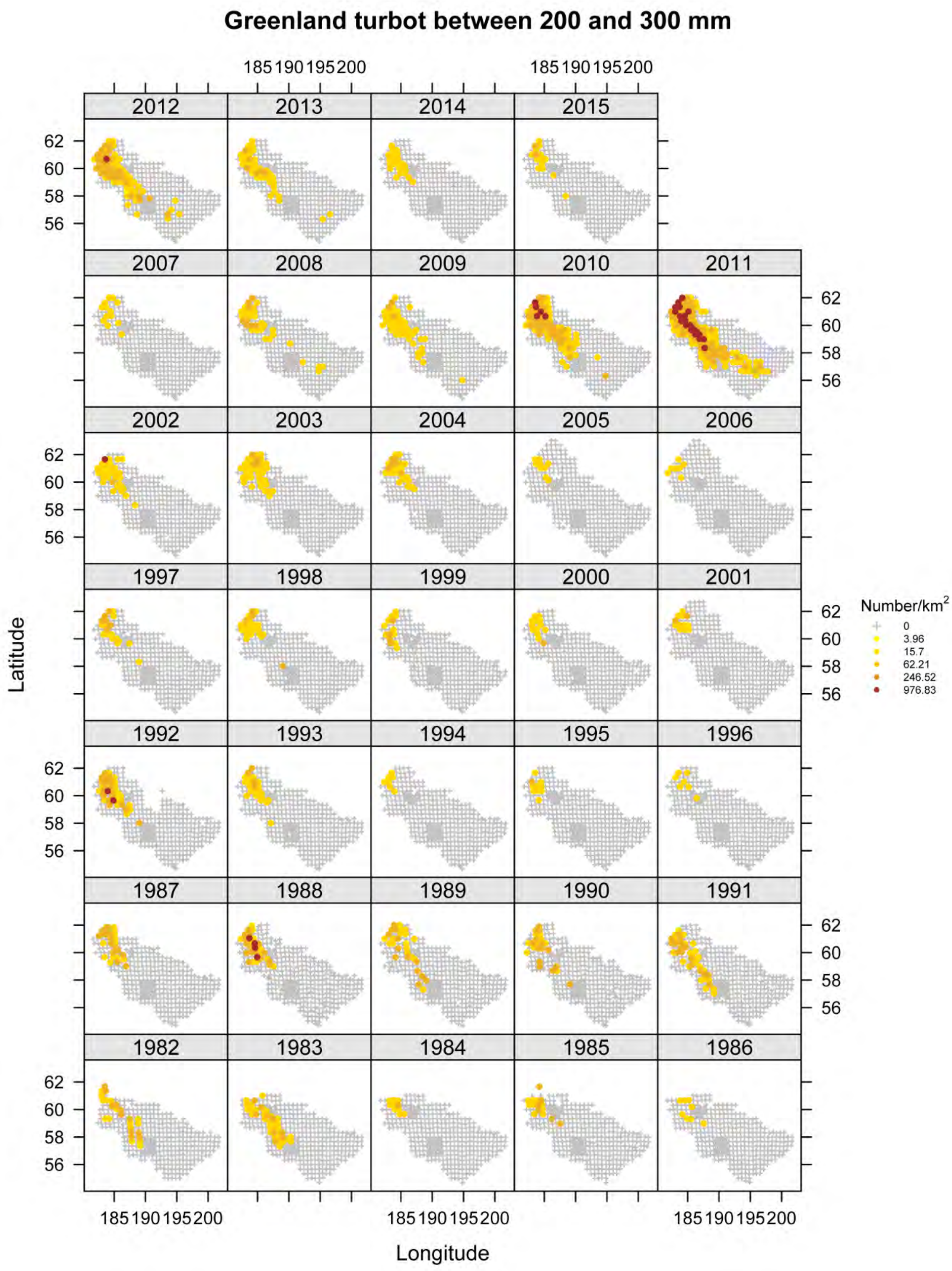


Figure 5.4.(Cont.) Greenland turbot (200-300 cm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

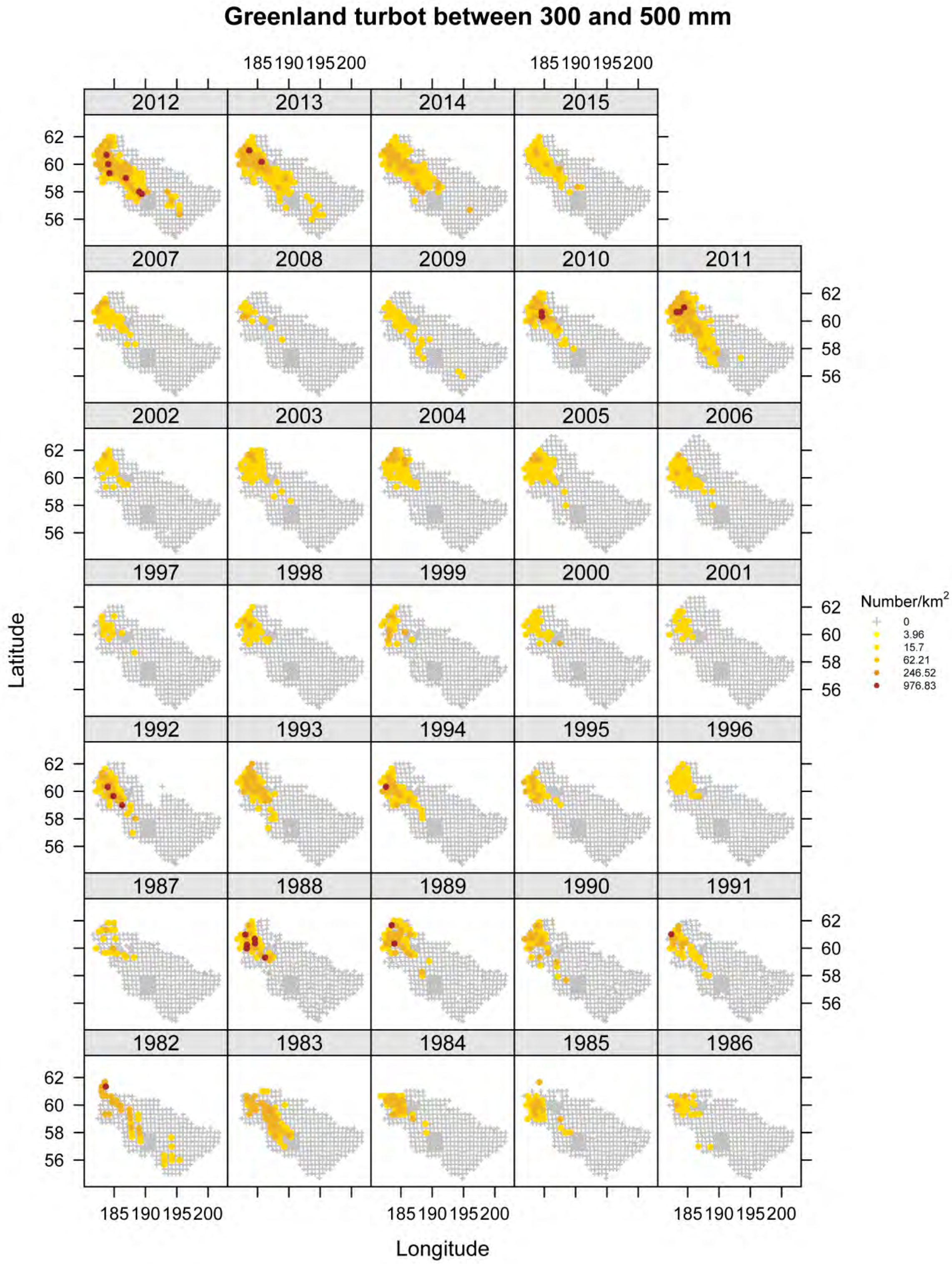


Figure 5.4. (Cont.) Greenland turbot (300- 500 mm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

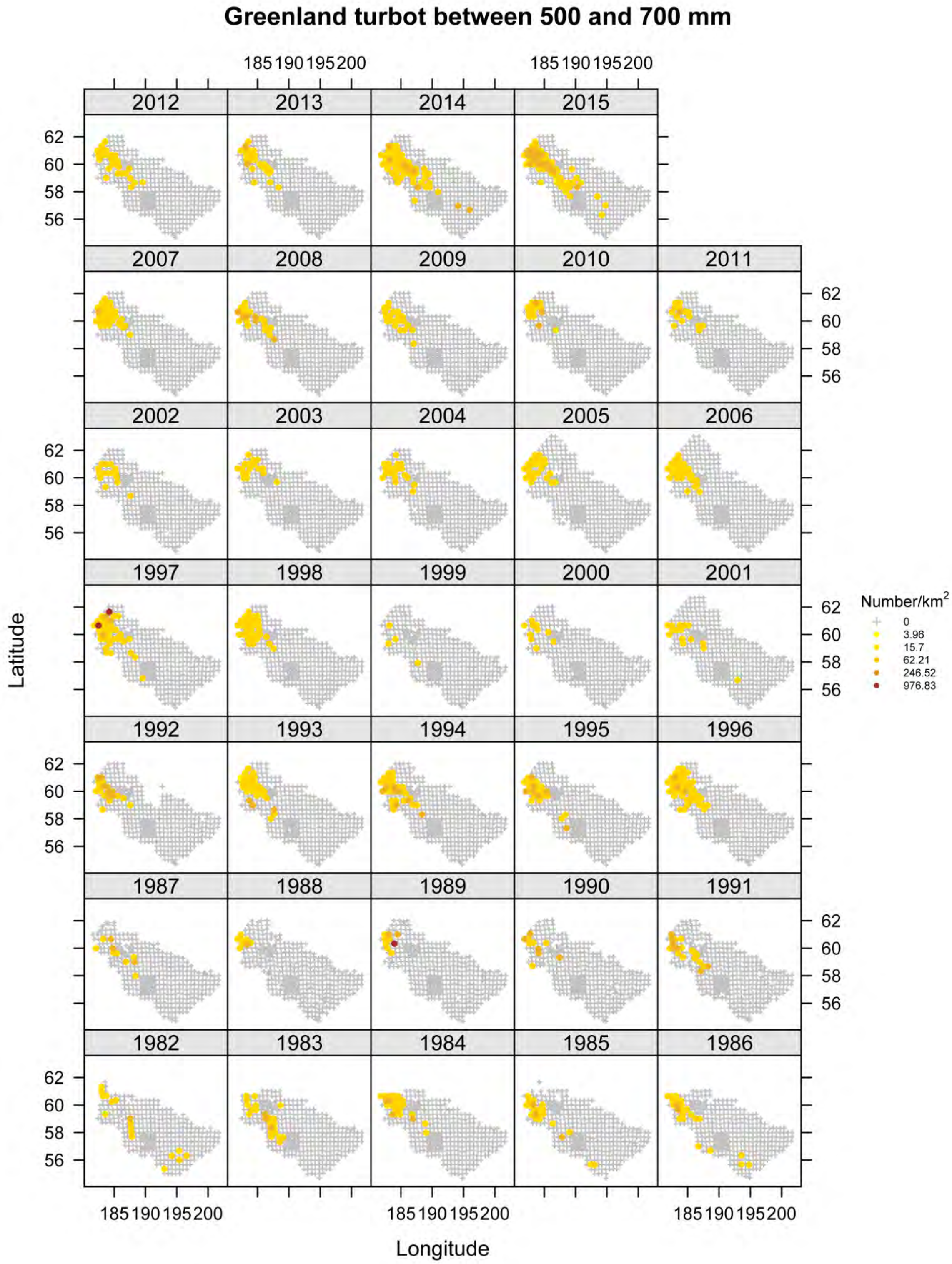


Figure 5.4.(Cont.) Greenland turbot (500- 700 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

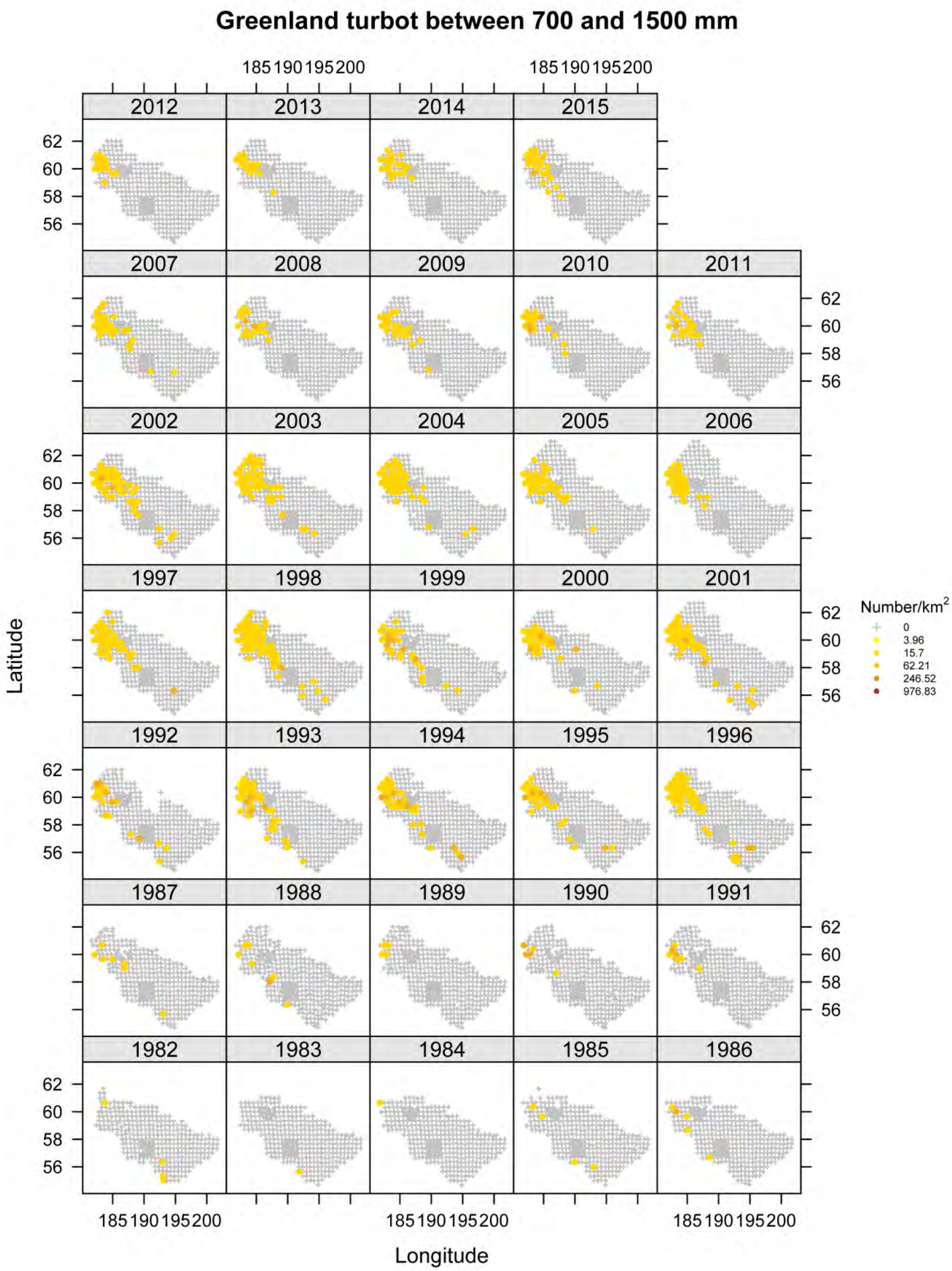
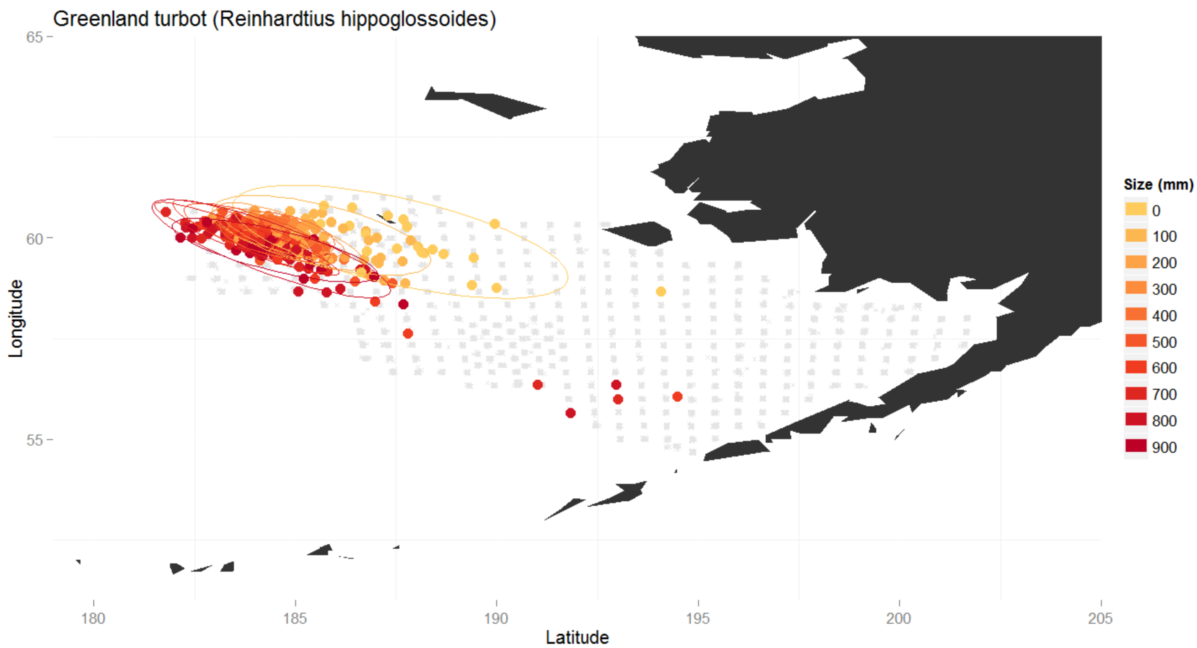


Figure 5.4.(Cont.) Greenland turbot (700- 1500 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.



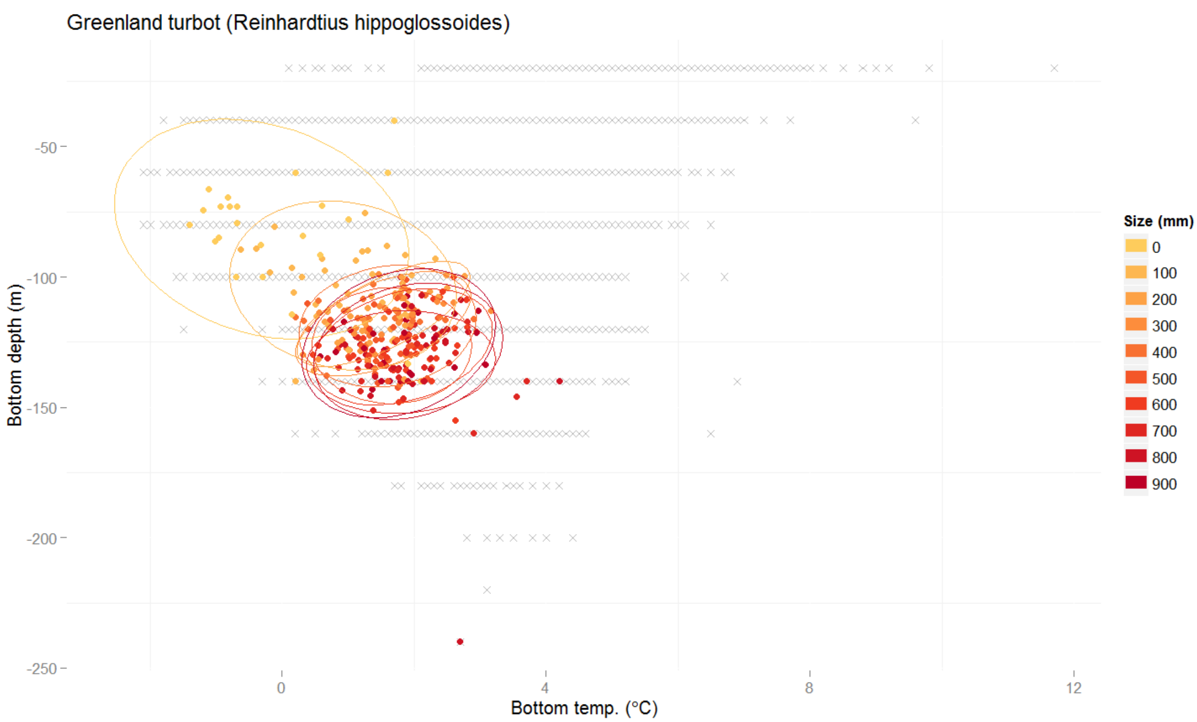


Figure 5.5. Greenland turbot centroids of abundance by size category for 1982 – 2015 Shelf bottom trawl survey by (top) location and (bottom) depth and temperature. Ellipses are bounds surrounding 90% of the centroids.

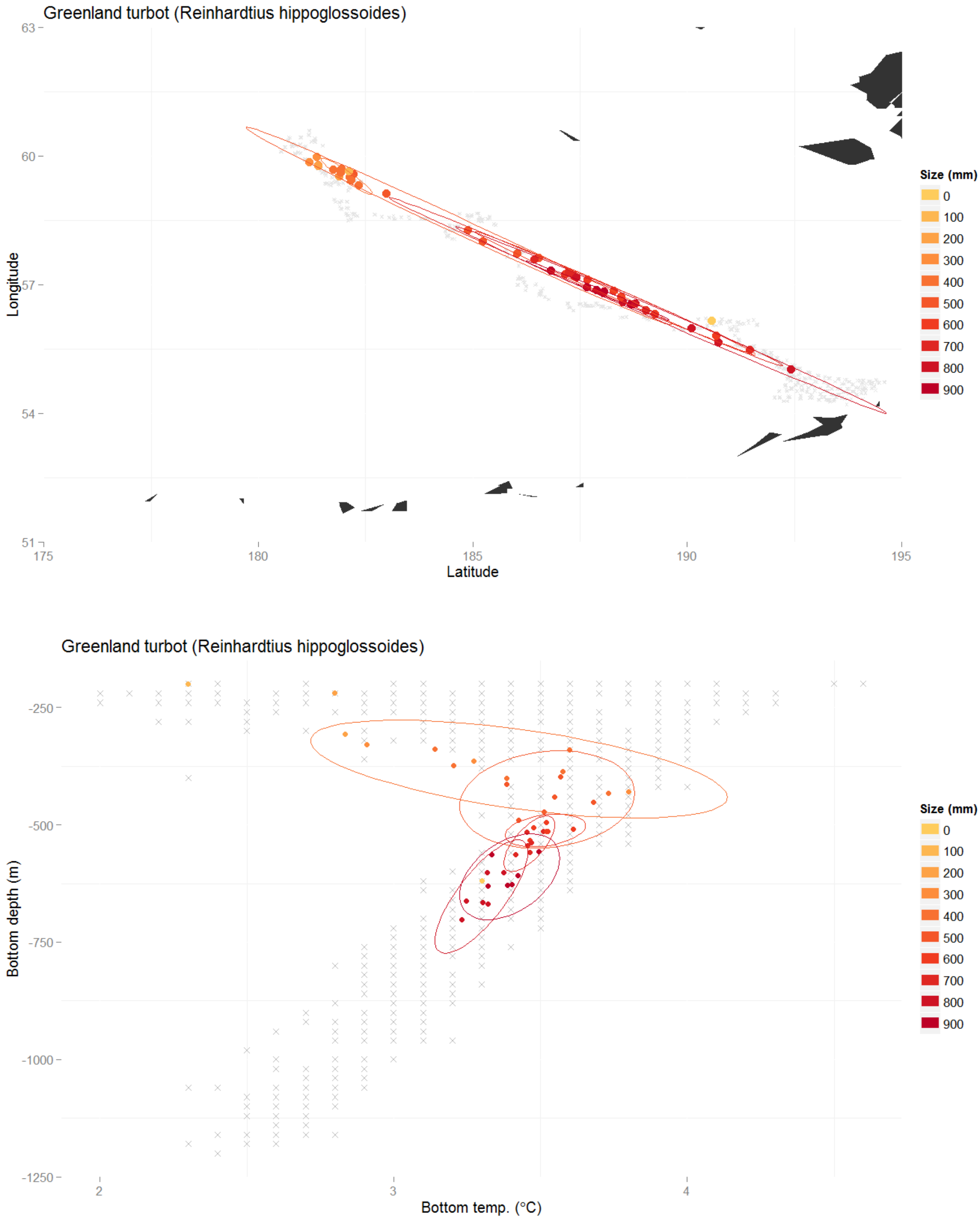
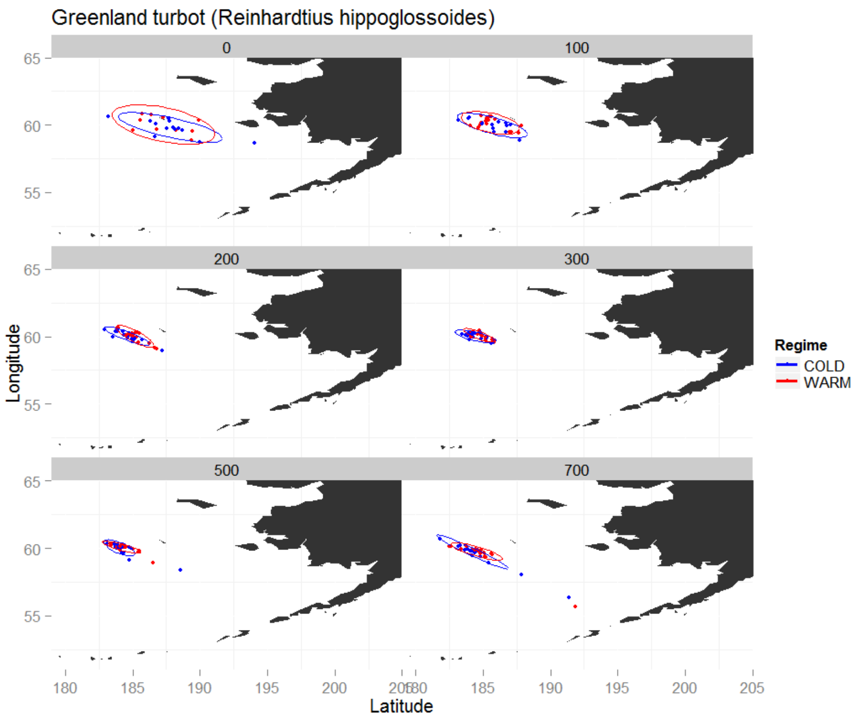


Figure 5.6. Greenland turbot centroids of abundance by size category for 2000 – 2015 slope bottom trawl survey by (top) location and (bottom) depth and temperature. Ellipses are bounds surrounding 90% of the centroids for that size category.



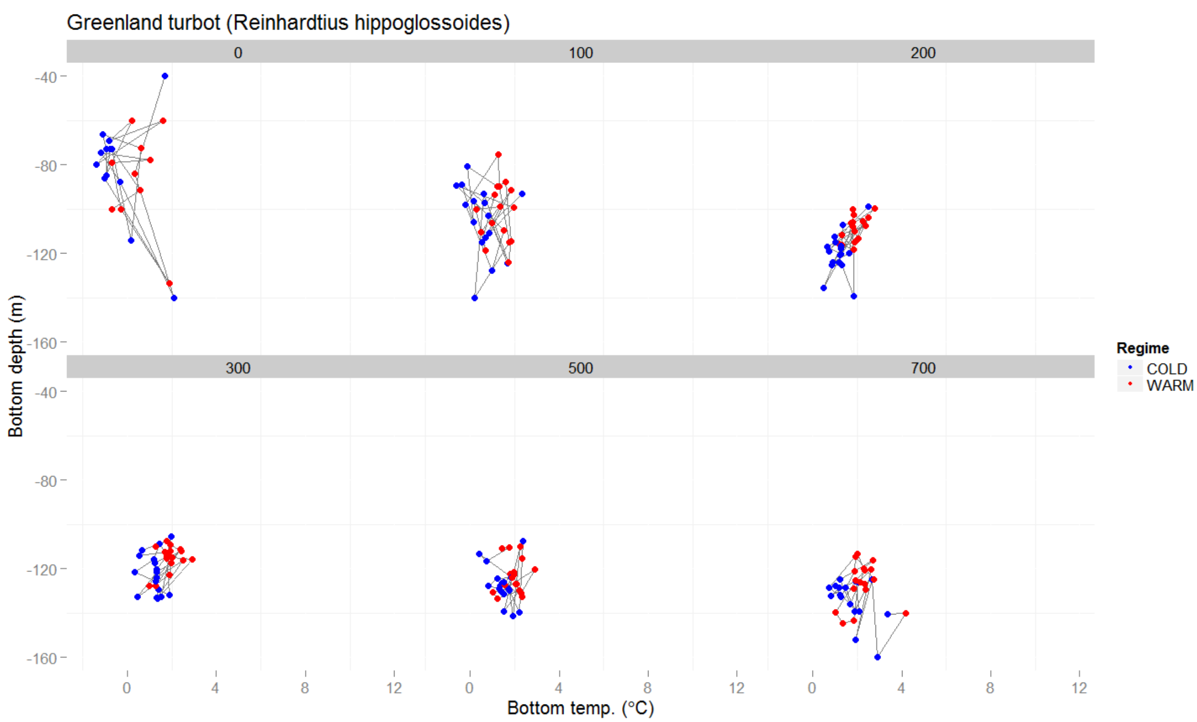


Figure 5.7. Greenland turbot centroids of abundance by size category and year for 1982 – 2015 shelf bottom trawl survey (top) location and (bottom) depth and temperature colored by year above average (red) or below average (blue) temperatures for the time period. Ellipses are bounds surrounding 90% of the centroids.

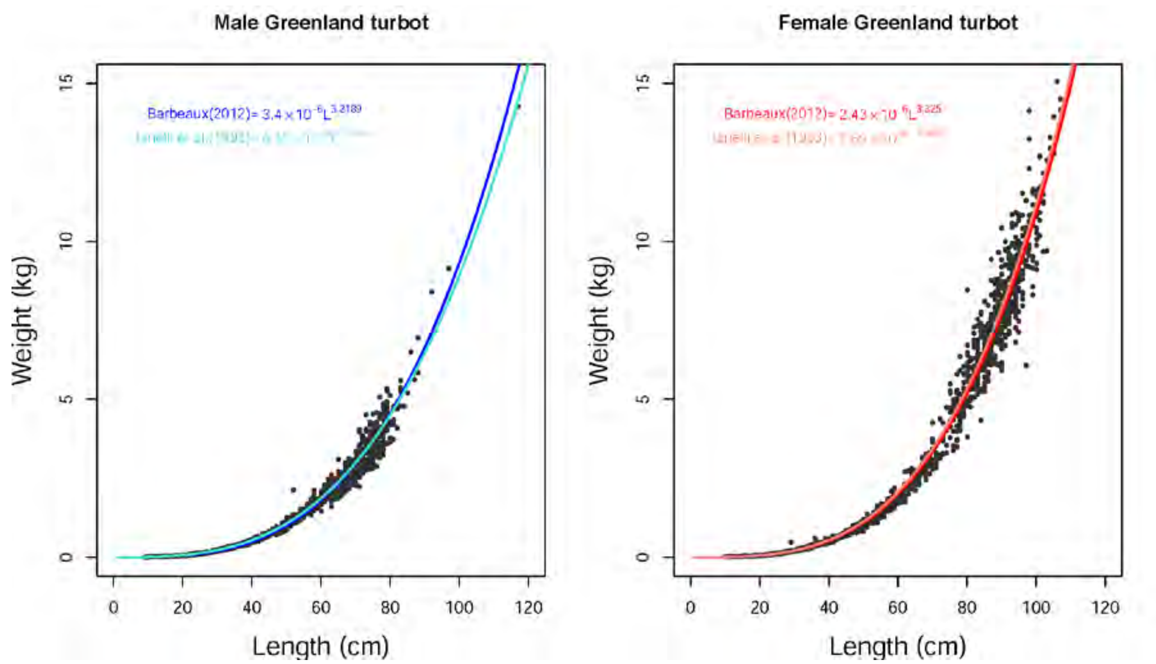


Figure 5. 8. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

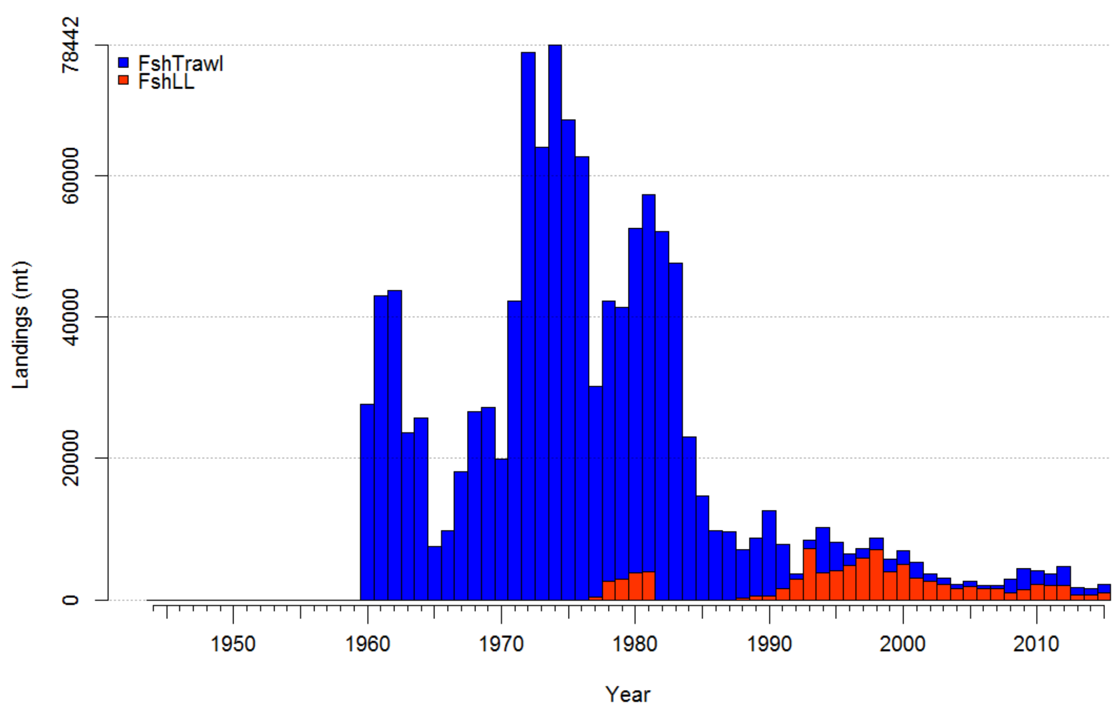


Figure 5. 9. Greenland turbot longline and trawl catch in the Bering Sea and Aleutian Islands area from 1960 through 2015. This data includes targeted catch and bycatch.

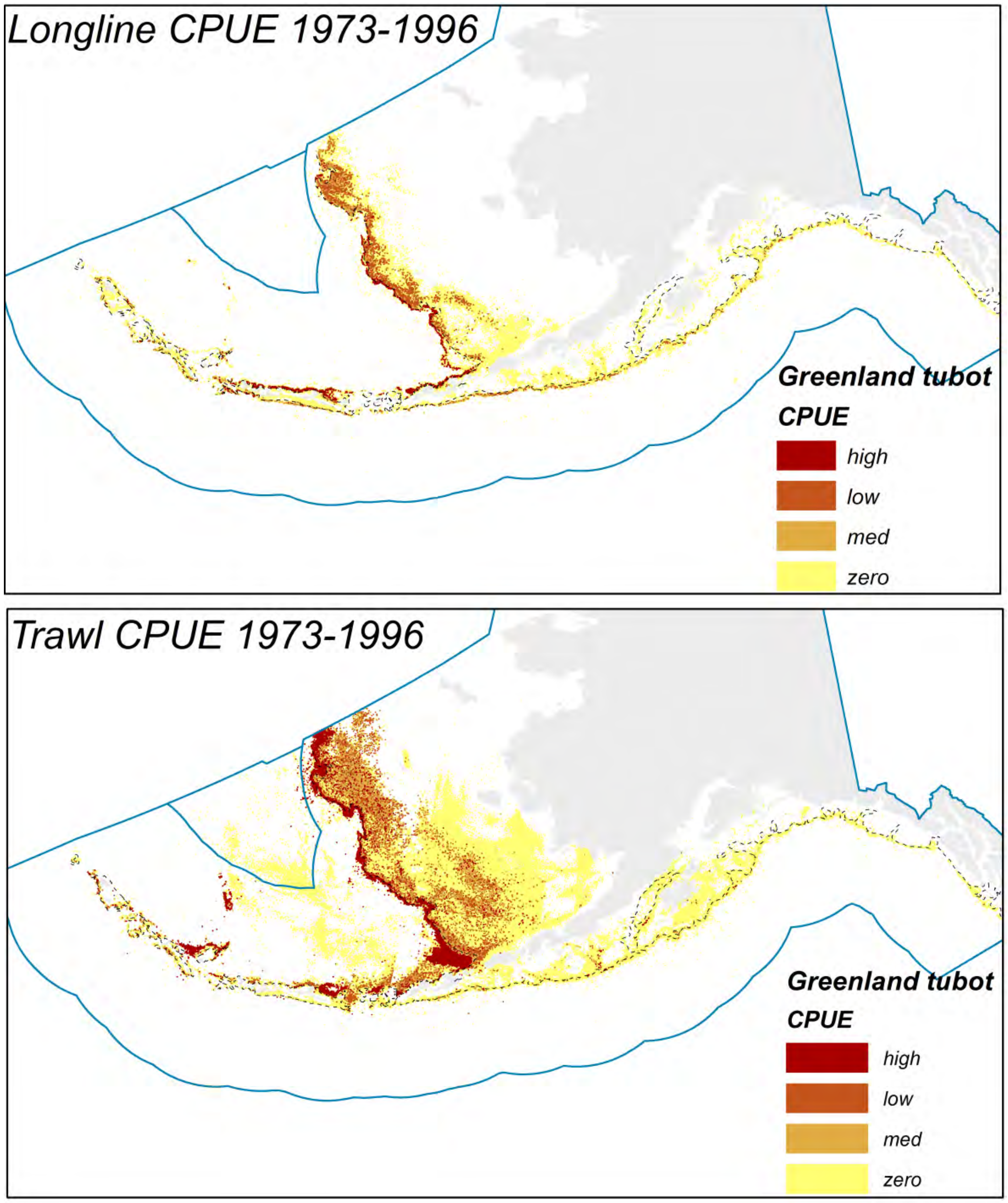


Figure 5.10. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al 1998).

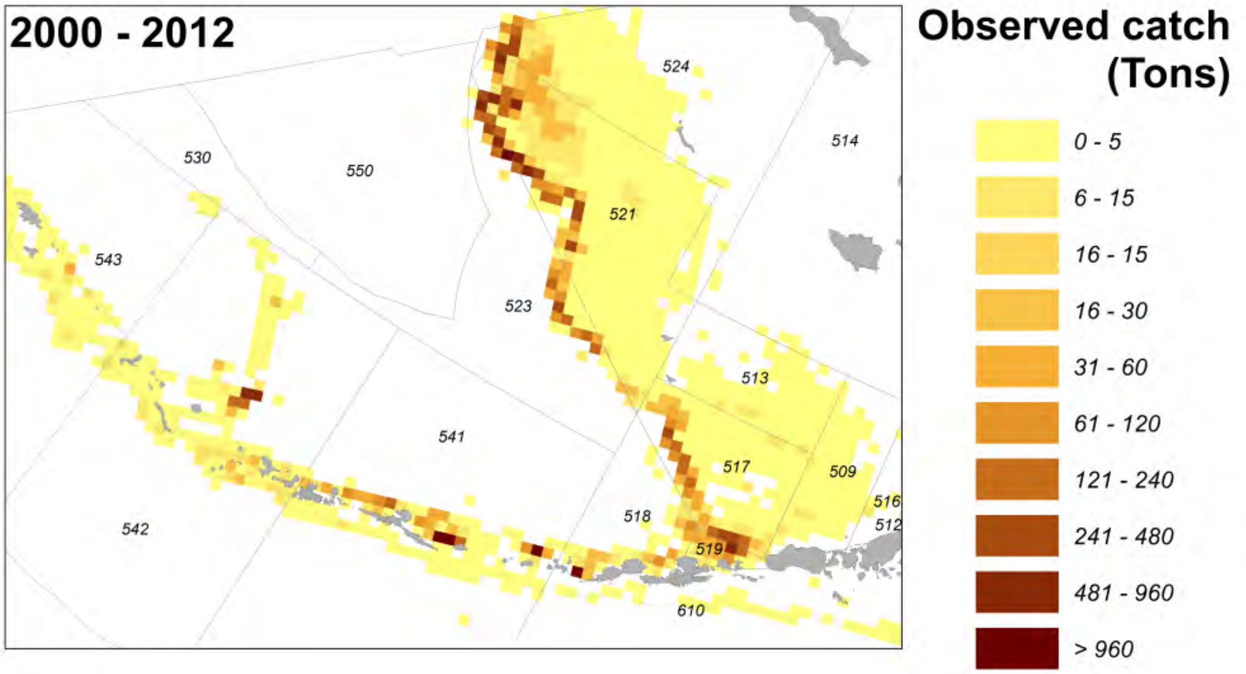


Figure 5.11 All observed catch for 2000 through 2012, data are aggregated spatially at a 400 km^2 grid.

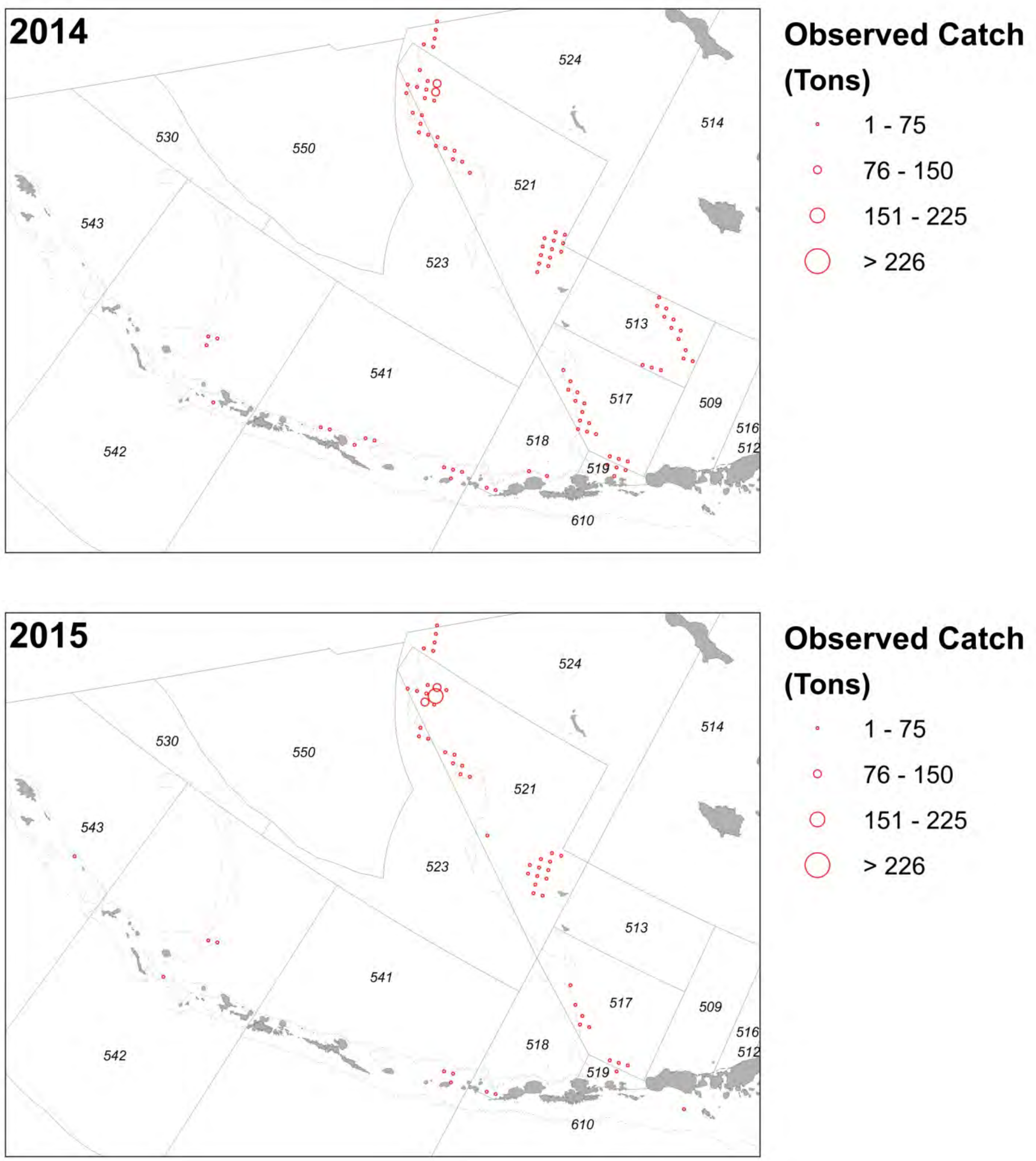


Figure 5.12. All observed Greenland turbot catch for 2014 and 2015. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

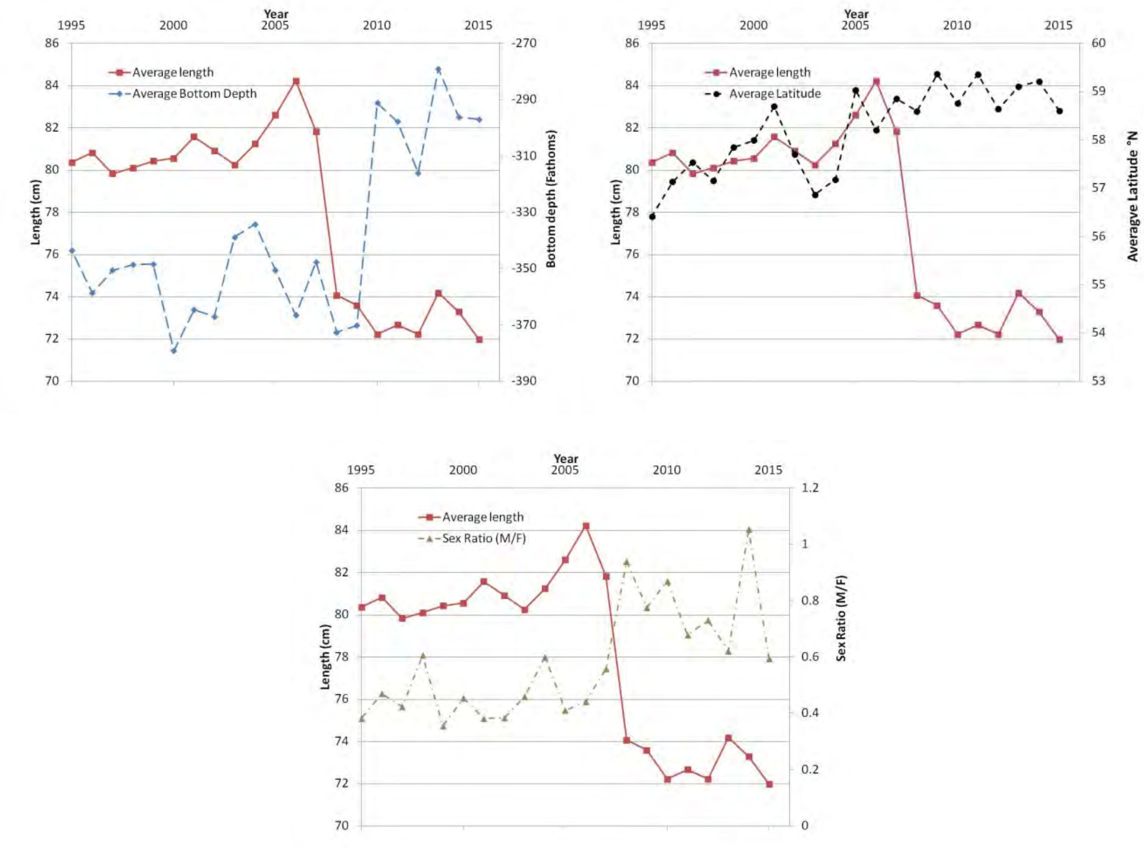


Figure 5.13. Average bottom depth in fathoms and average length of Greenland turbot (top left) and average latitude and average length of Greenland turbot (top right), and Sex ration males/females and averatel length of Greenland turbot (bottom) for the Greenland turbot longline fishery (defined as longline strings with >1 t of turbot catch) from observed data.

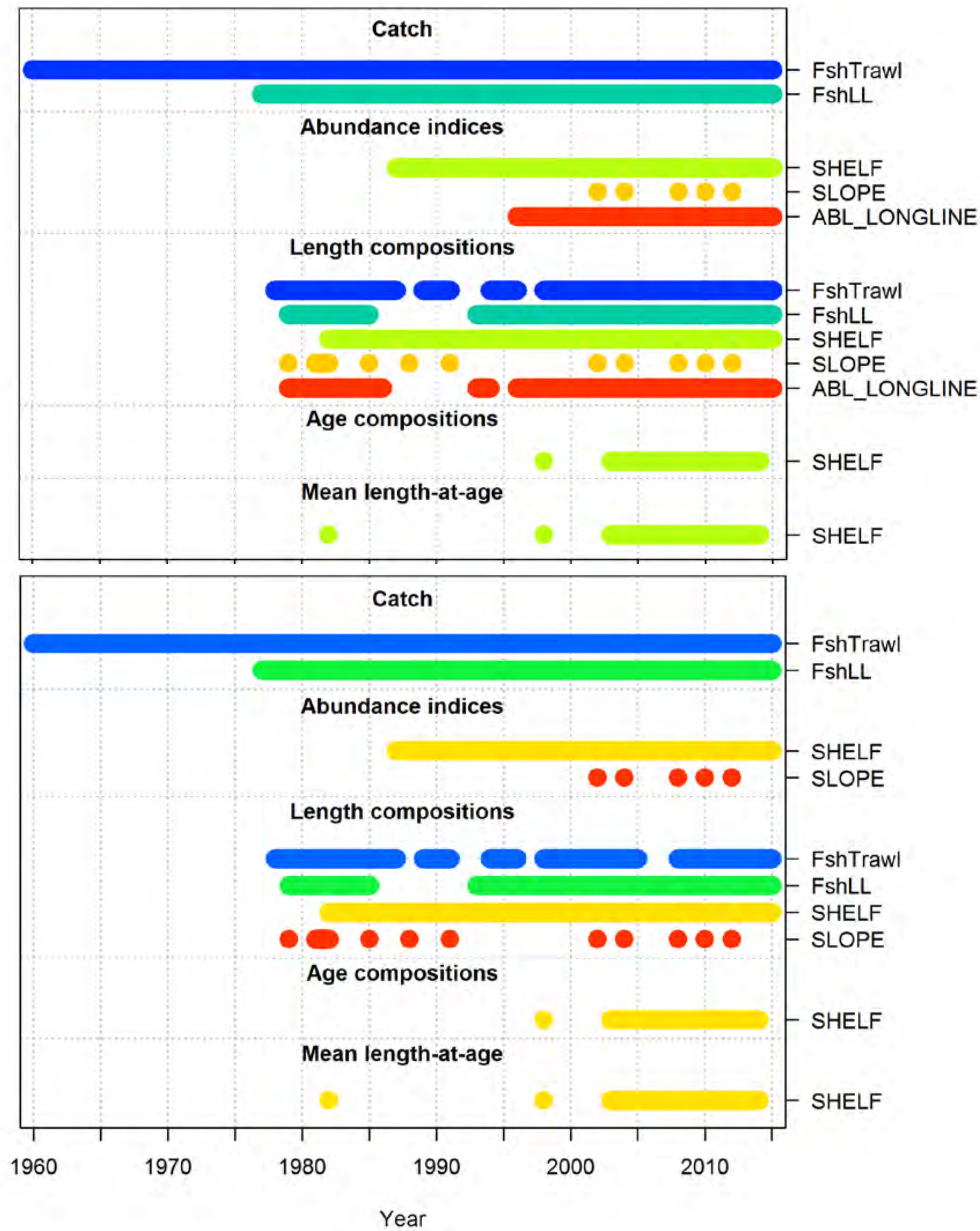


Figure 5.14. Timeline of all data included in (top) Model 14.0 and (bottom) all other models presented.

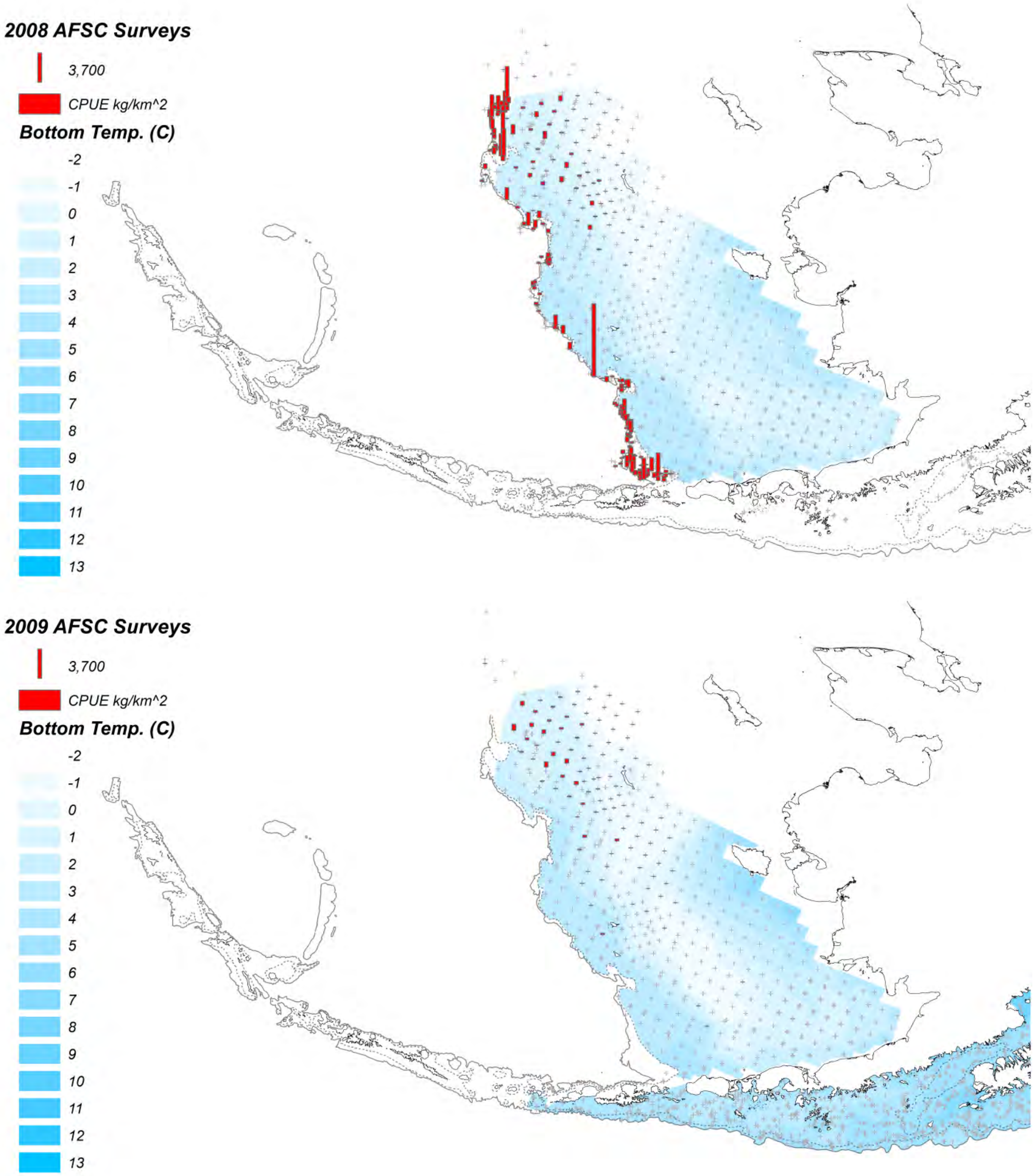


Figure 5.15. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

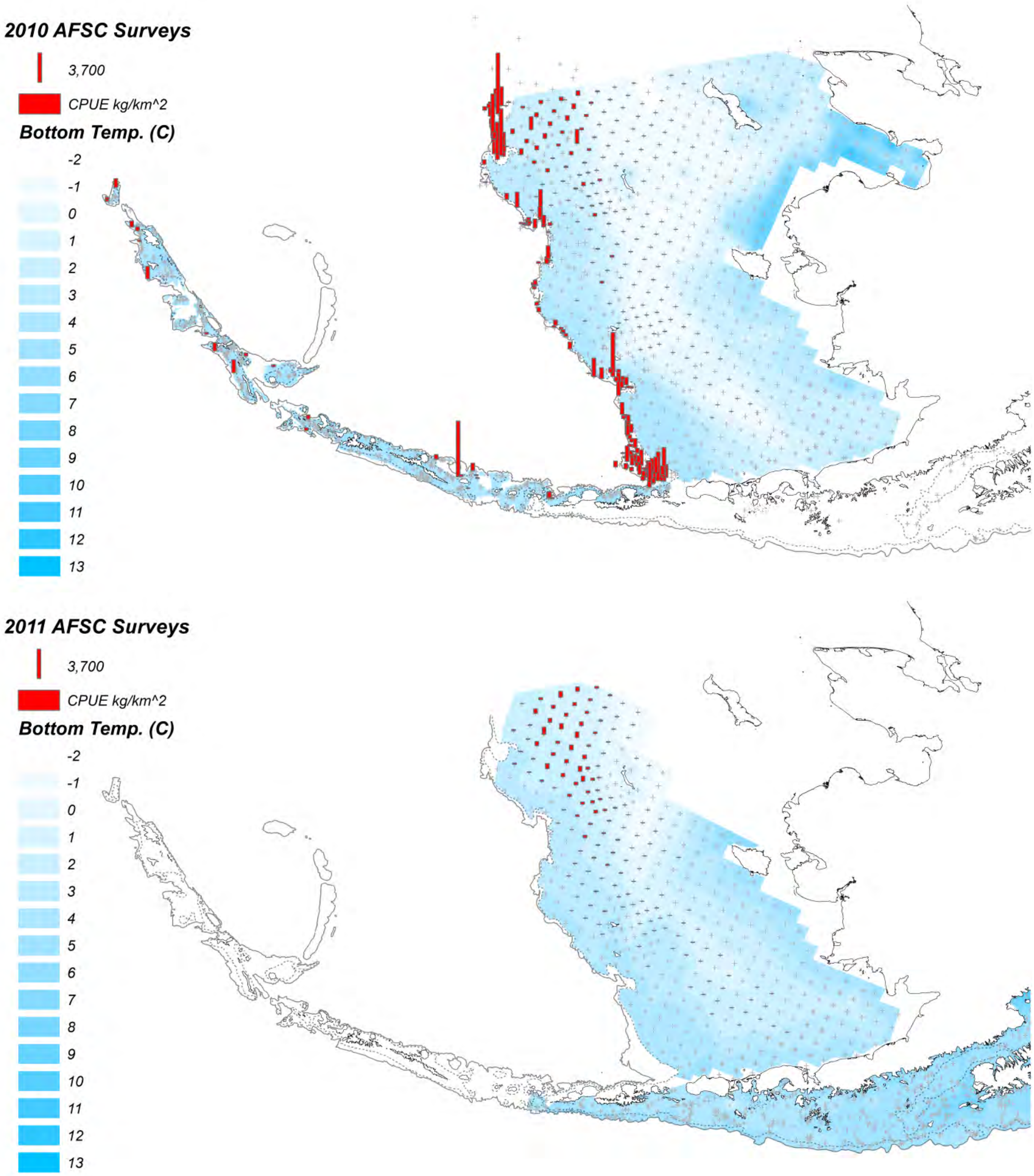


Figure 5.15.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

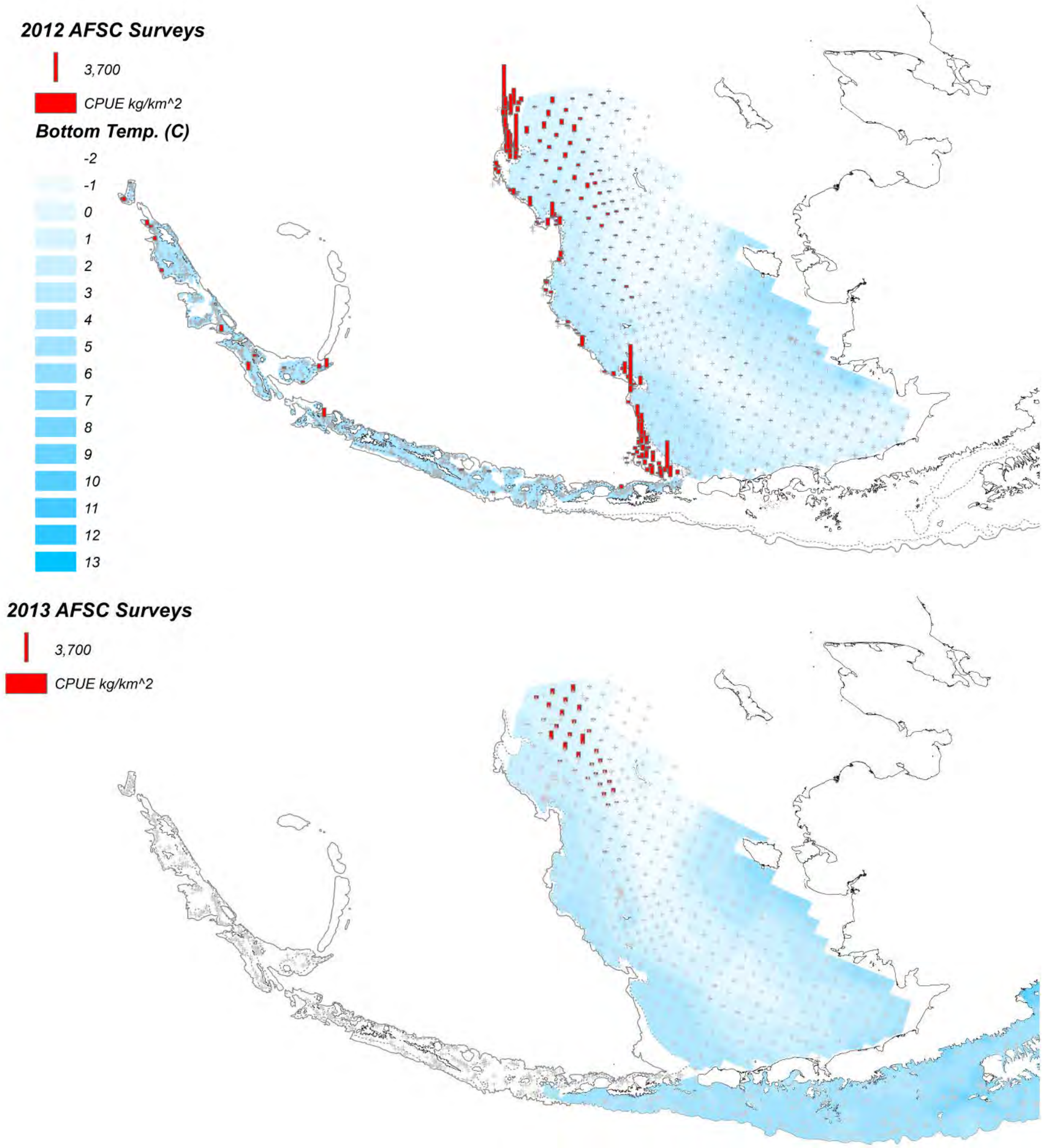
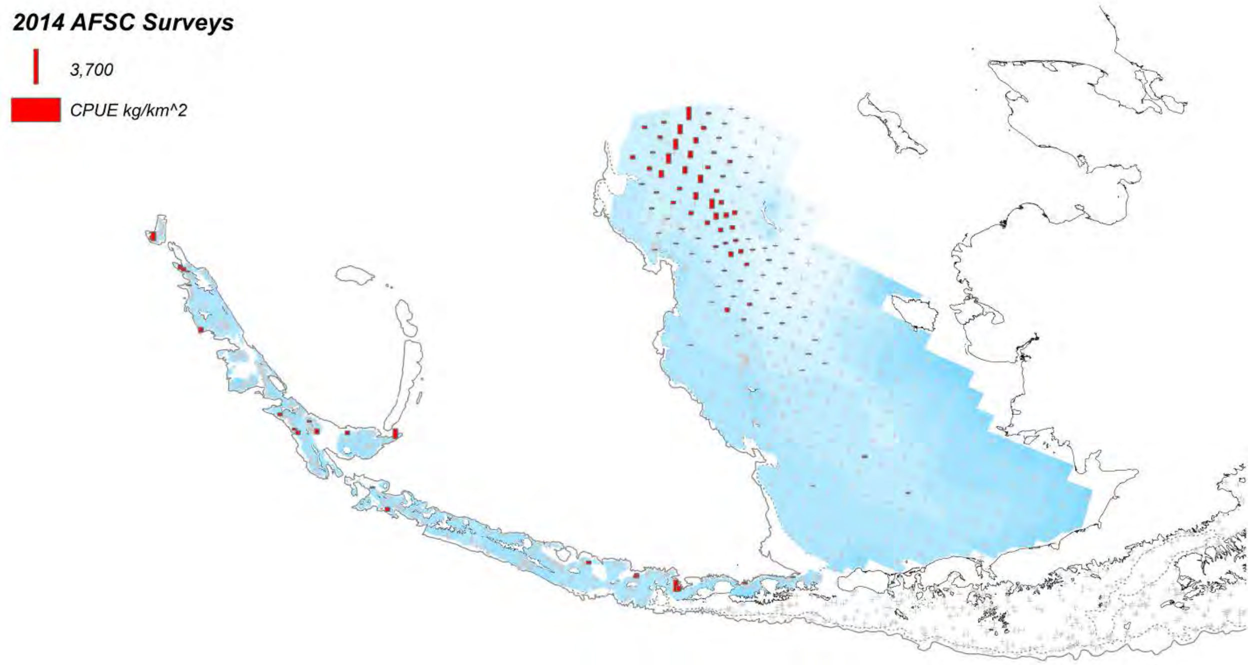


Figure 5.15.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in Celsius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.



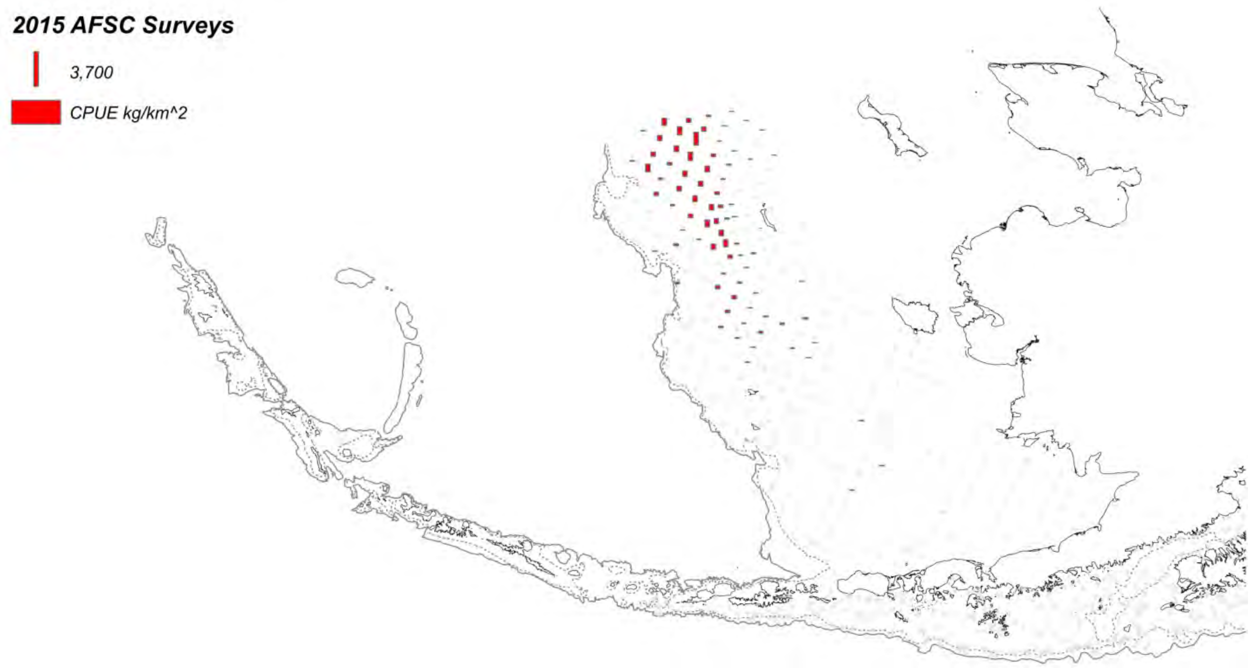


Figure 5.15.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year and 200m (dashed line) and 1000 m (solid gray line) isobaths. Bottom temperatures were not yet available for the 2015 map. Surveyed locations are marked with gray +, while areas with turbot are marked with red bars. All CPUE bars are on the same scale for all surveys.

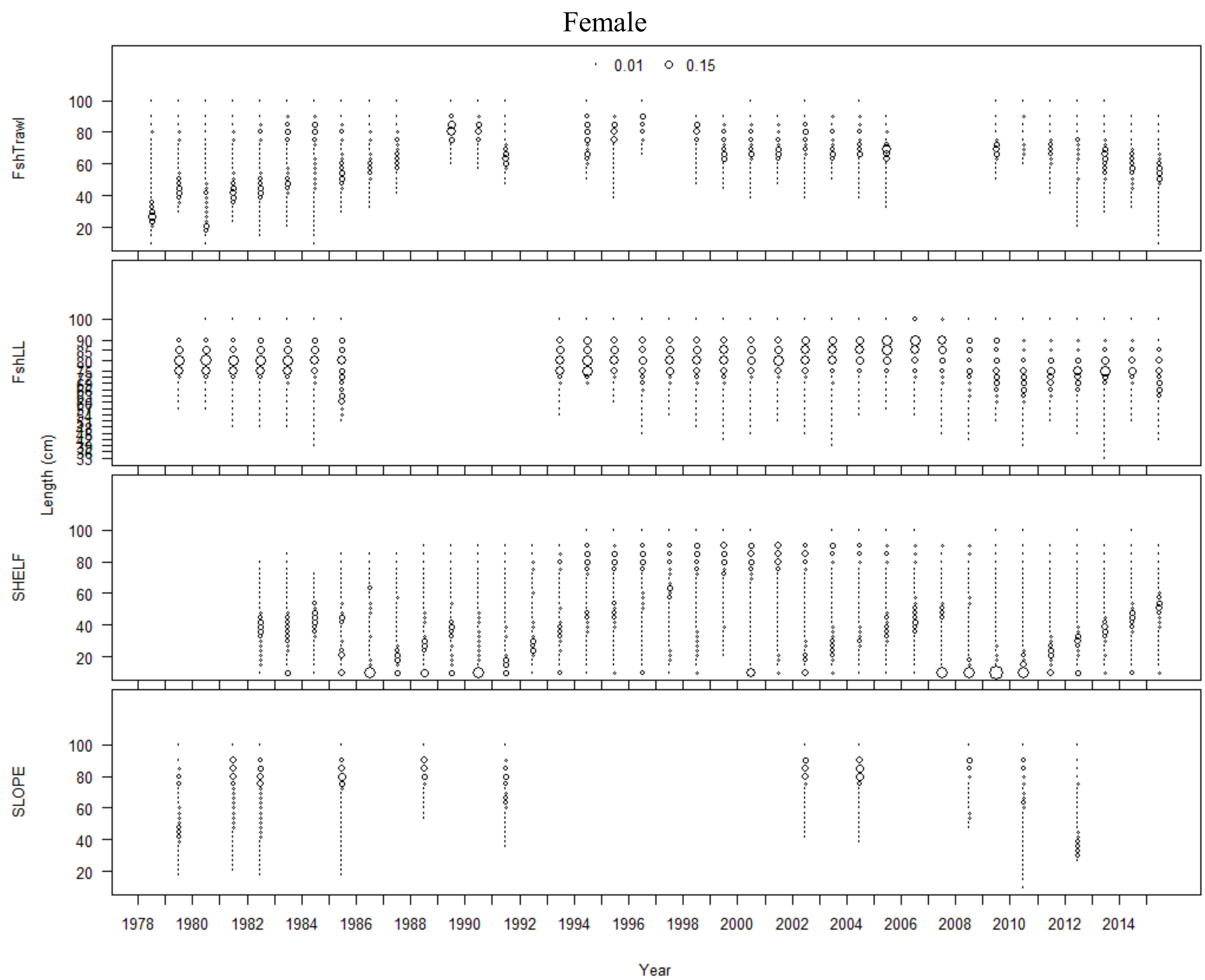


Figure 5.16. Greenland turbot size composition data for females from the Trawl fishery, longline fishery, shelf survey and slope survey.

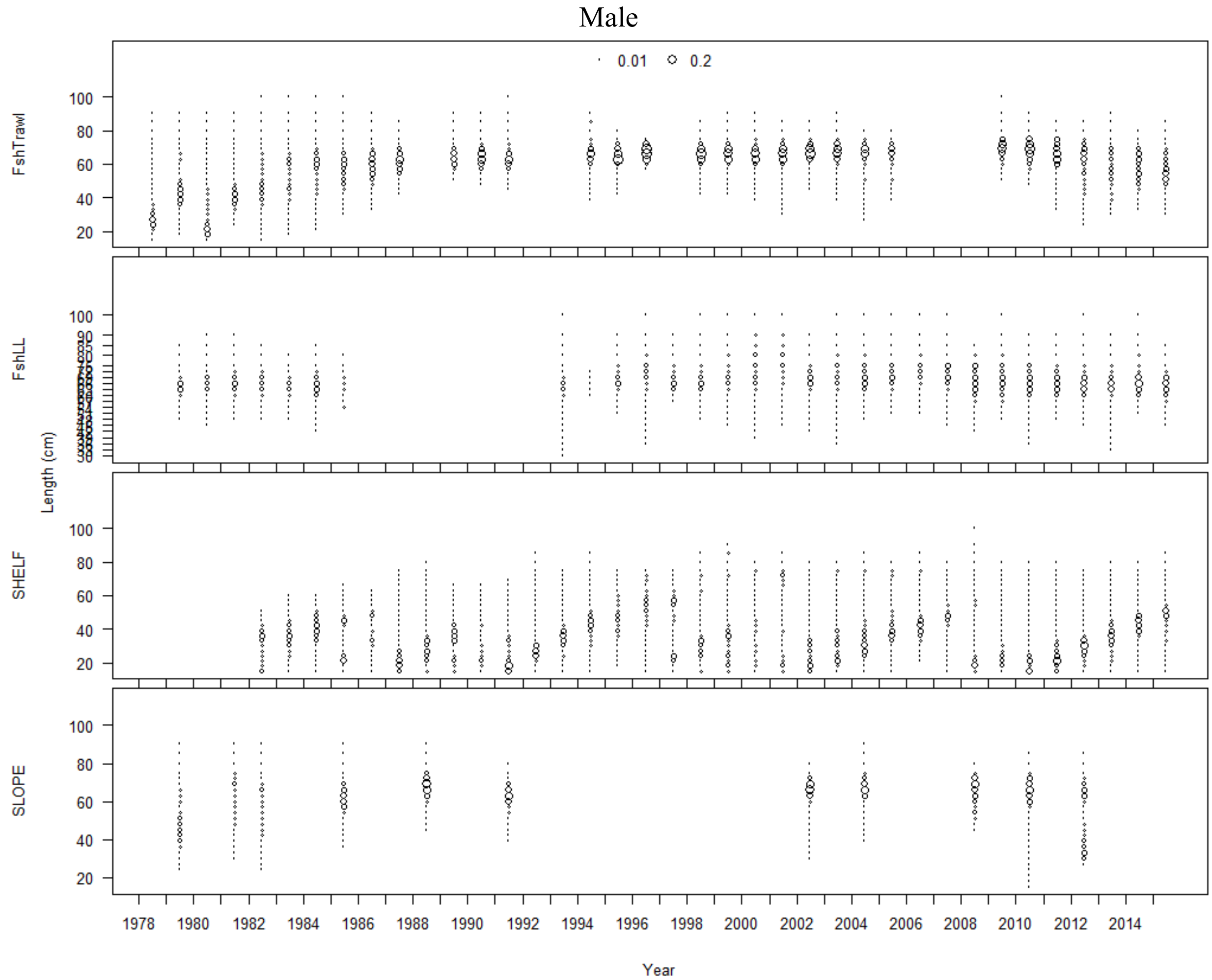


Figure 5.16. (Cont.) Greenland turbot size composition data for males from the trawl fishery, fixed-gear fishery, shelf survey and slope survey.

Combined Sexes

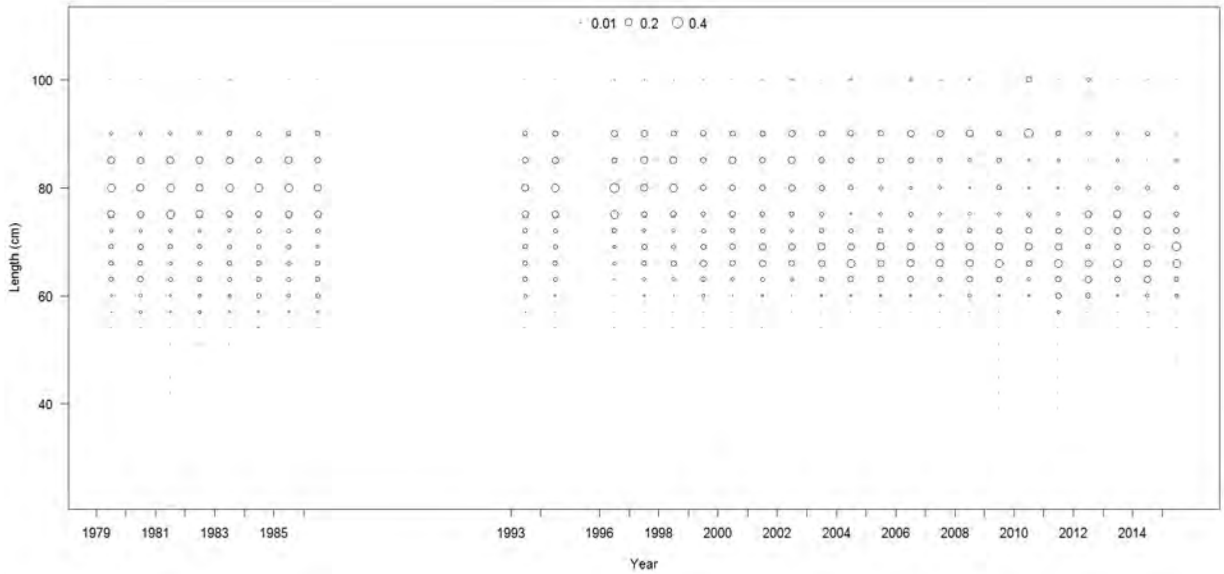


Figure 5.16. (Cont.) Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.

Figure 5.17. Age-0 recruitment (top), 2015 female spawning biomass (middle), and female spawning biomass (bottom) for the four models evaluated.

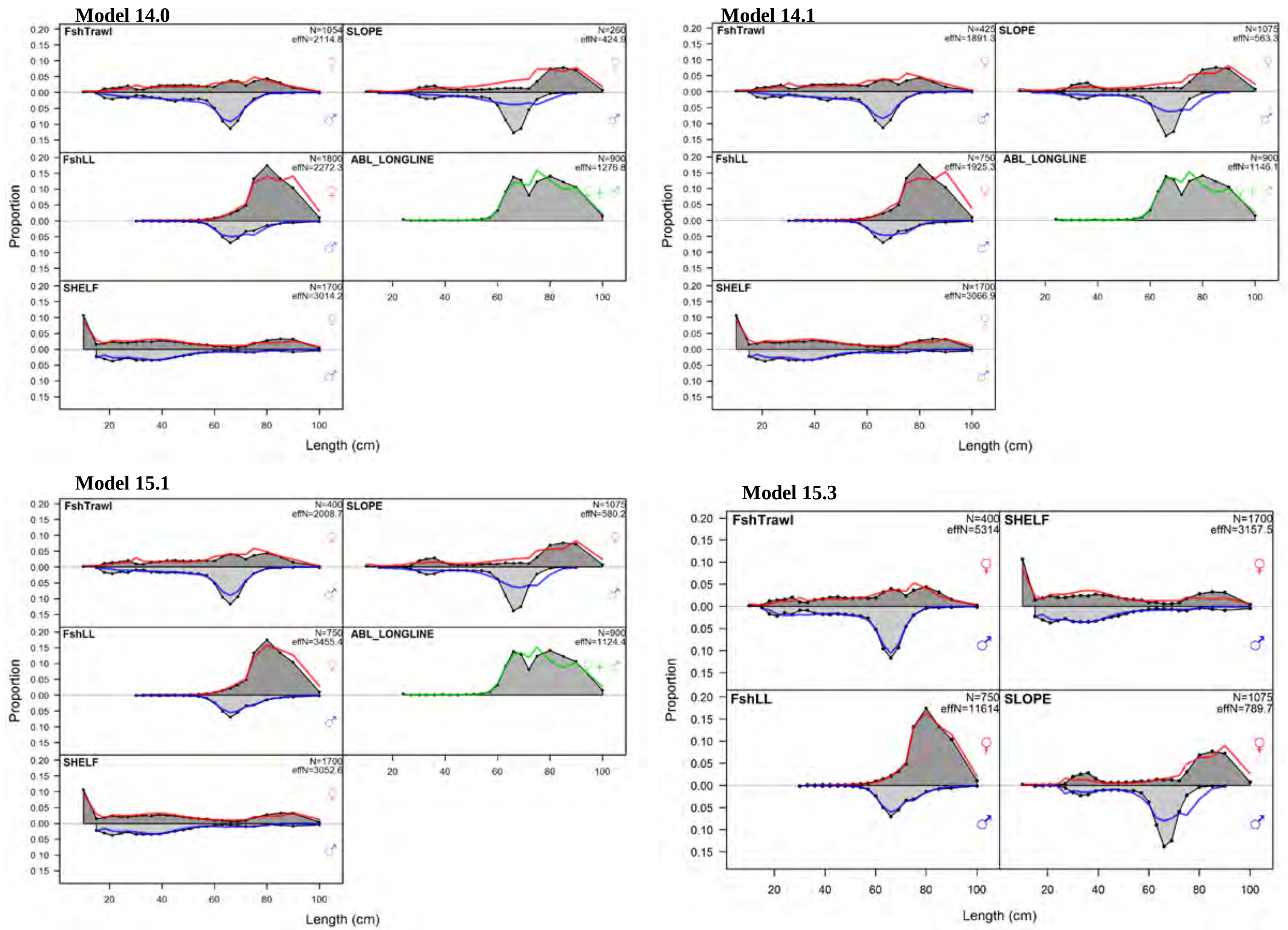
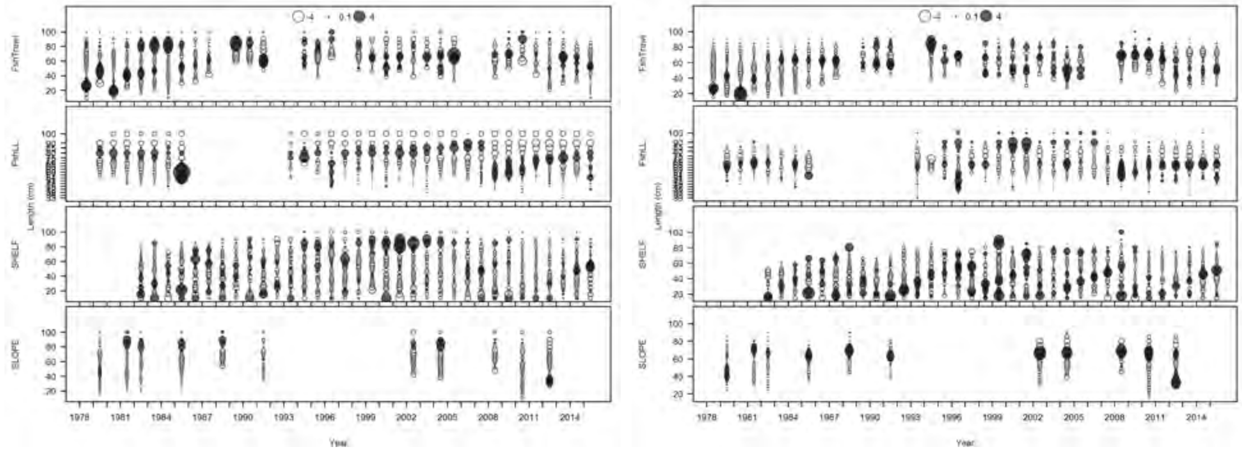
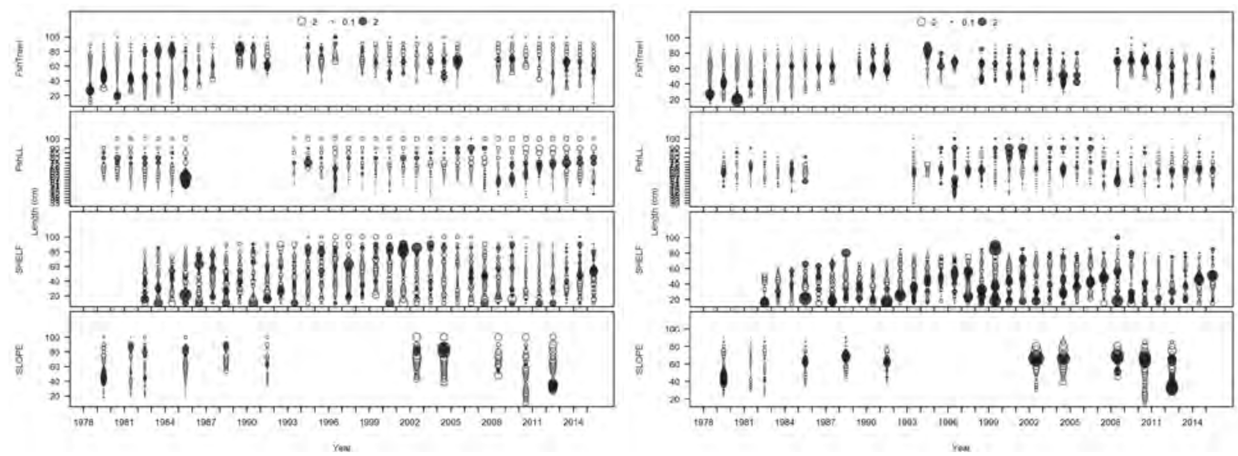


Figure 5.18. All size composition data combined across years and fits (red line female, blue line male) for fisheries and surveys.

Model 14.0



Model 15.1



Model 15.3

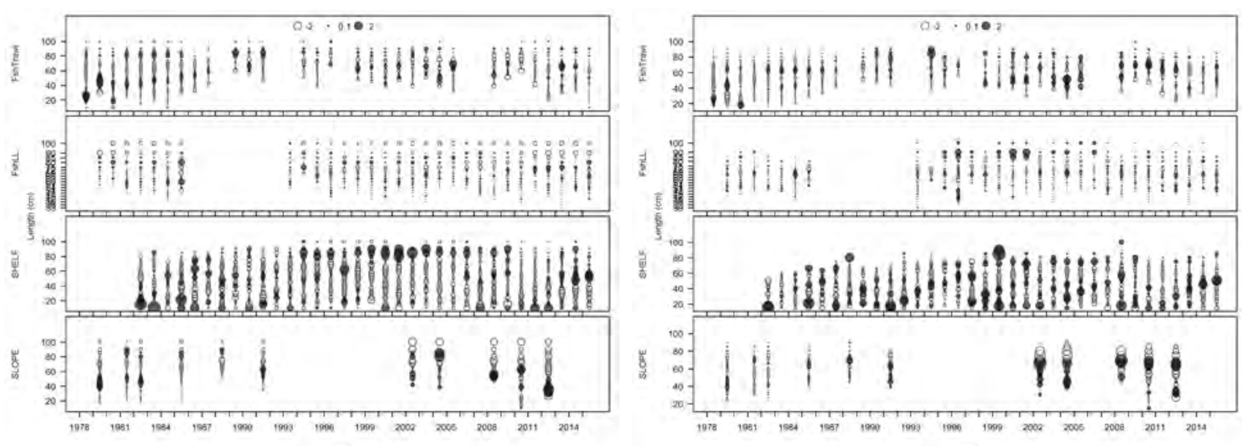


Figure 5.19. Pearson residuals for fisheries and two surveys. Closed bubbles are positive residuals and open bubbles are negative residuals. Note that the scale of the bubble graphs may differ by model.

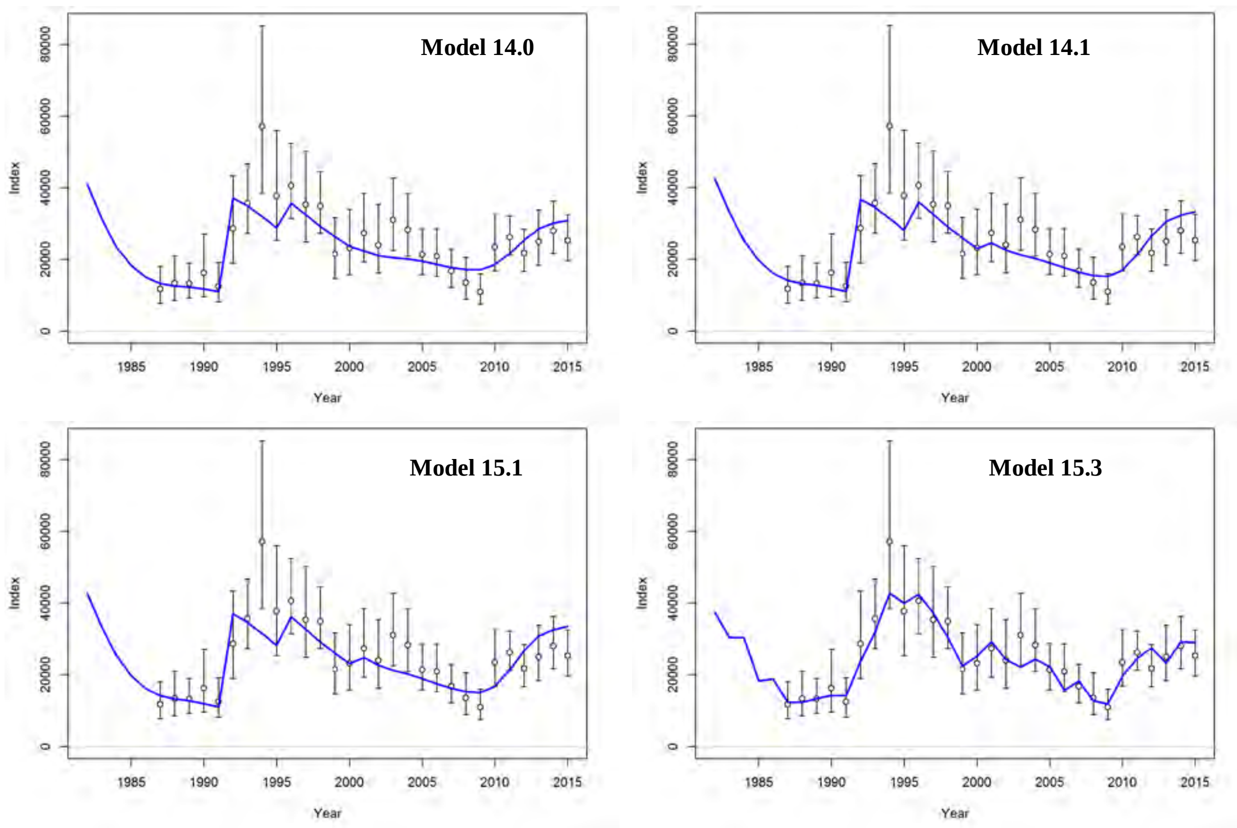
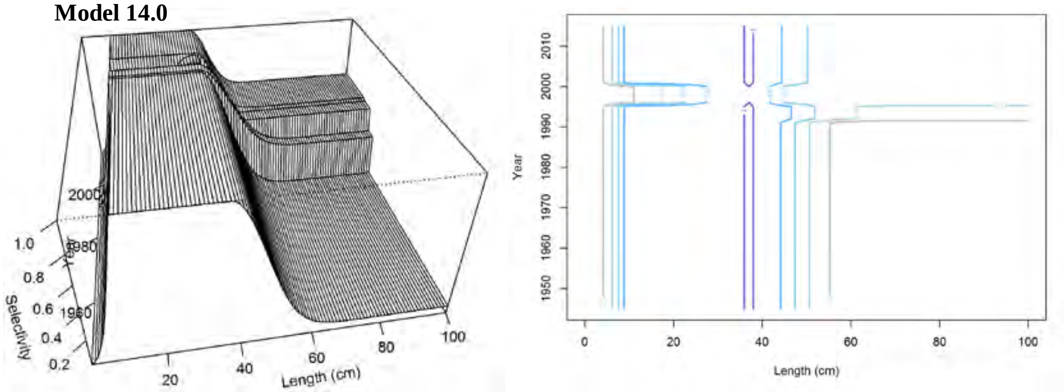
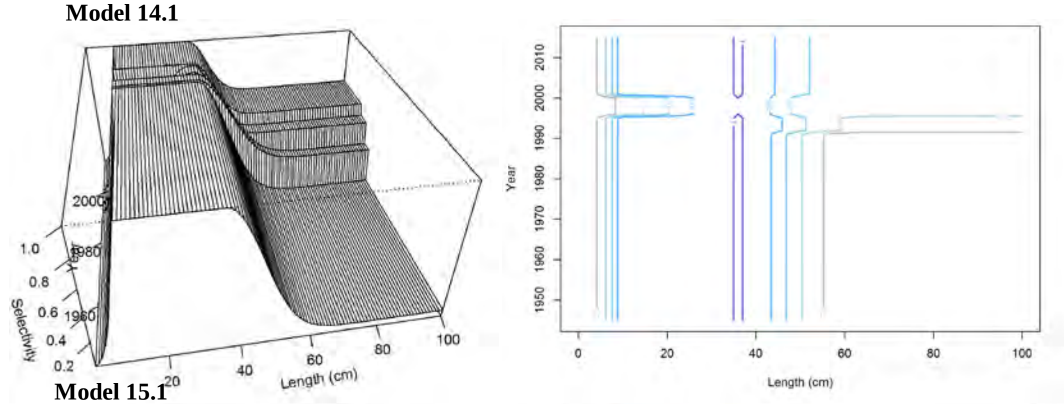


Figure 5.20. Shelf survey index (index values are the total survey biomass in tons) and model fits in blue. Error bars are 95% confidence intervals.

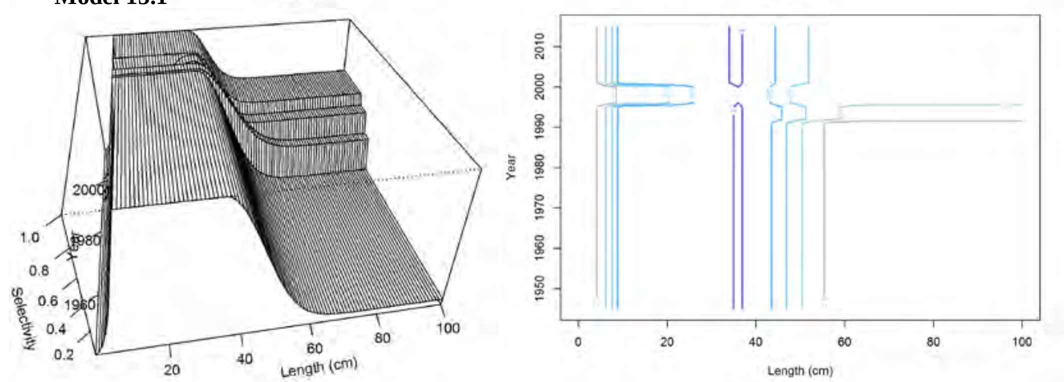
Model 14.0



Model 14.1



Model 15.1



Model 15.3

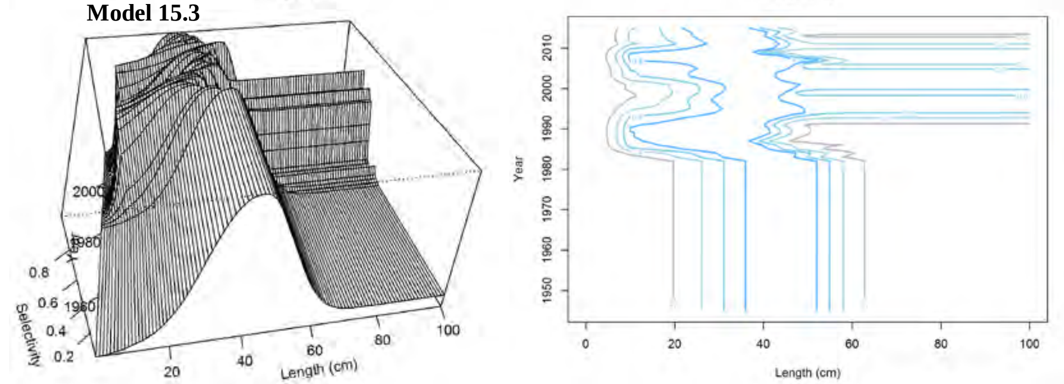


Figure 5.21. Time-varying selectivity at size for the shelf survey for females.

Model 14.0

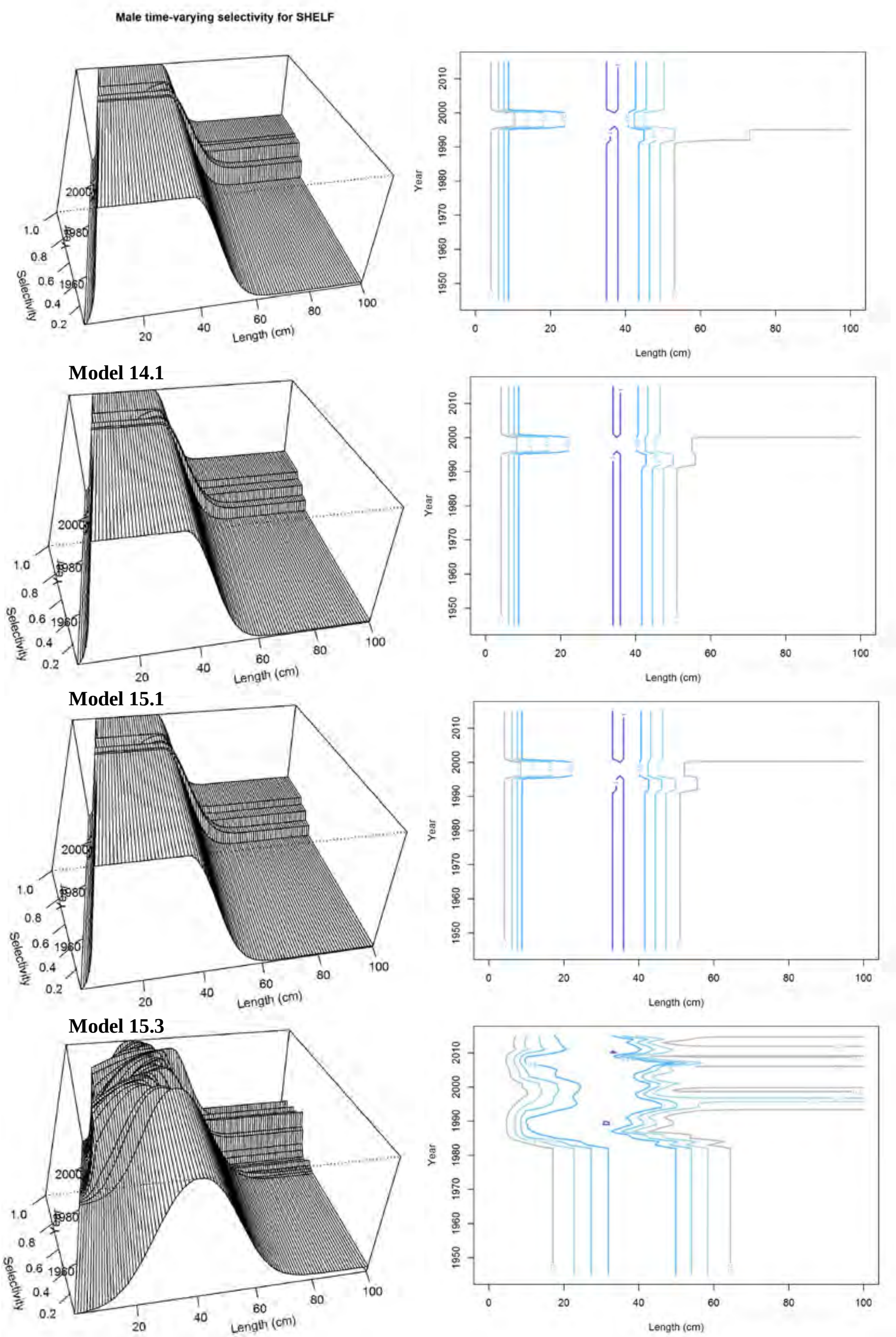


Figure 5.22. Time-varying selectivity at size for the shelf survey for males.

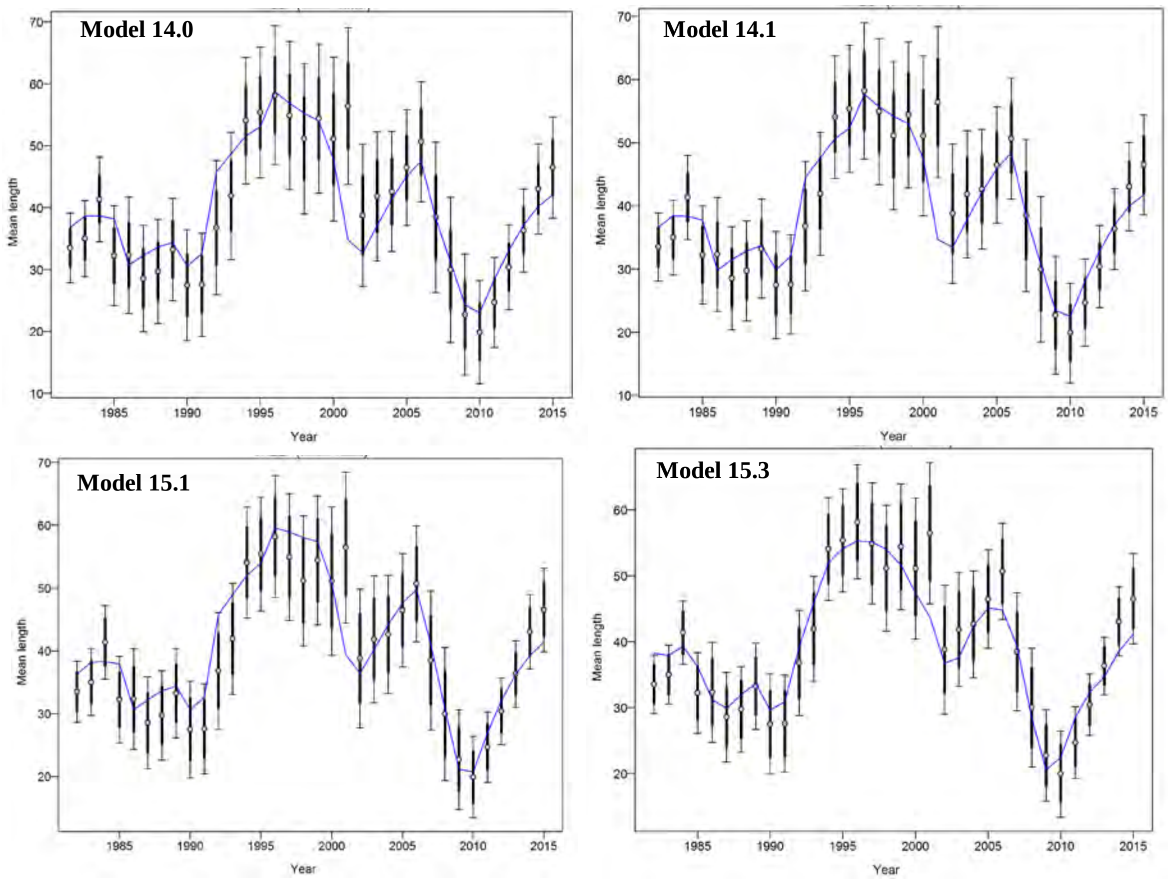


Figure 5.23. Mean length for the Sthelf survey and model fit.

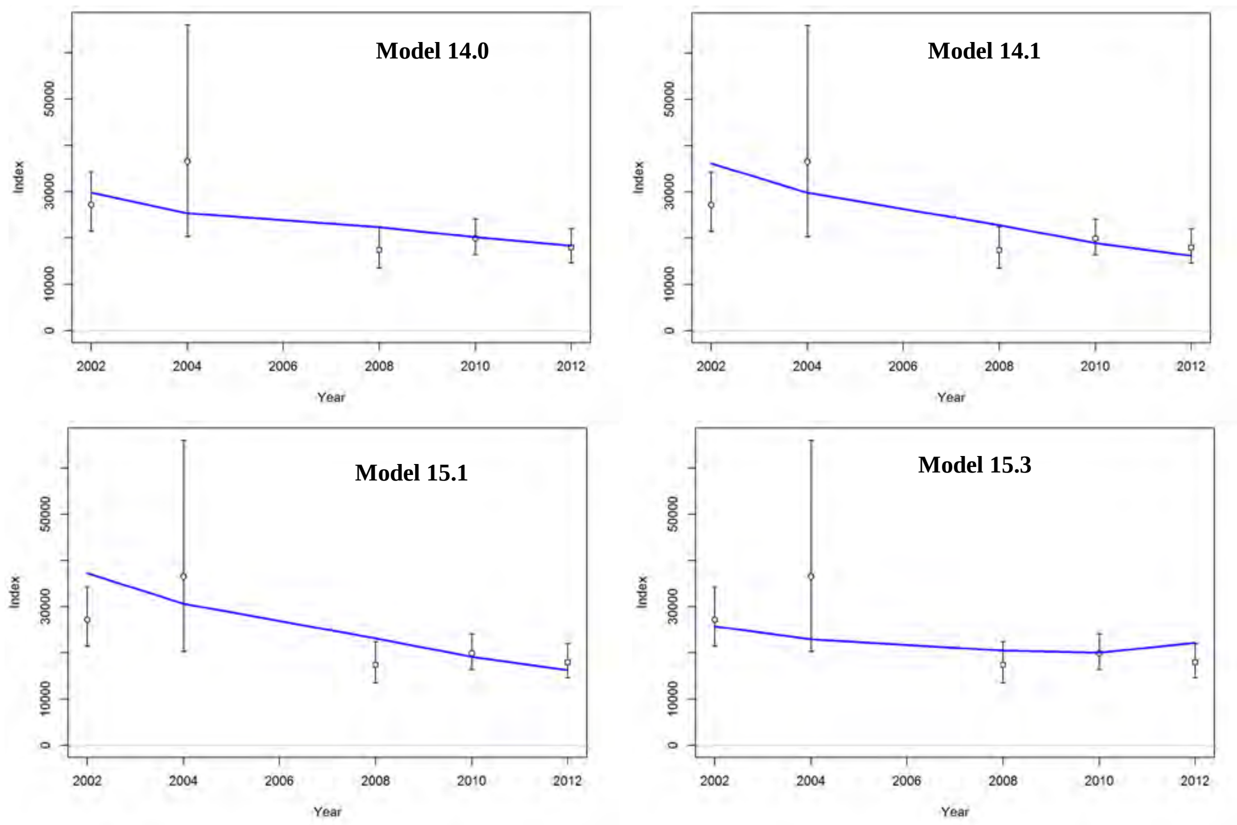


Figure 5.24. Slope survey index (index values are total survey biomass in tons) and model fits. Error bars are 95% confidence intervals.

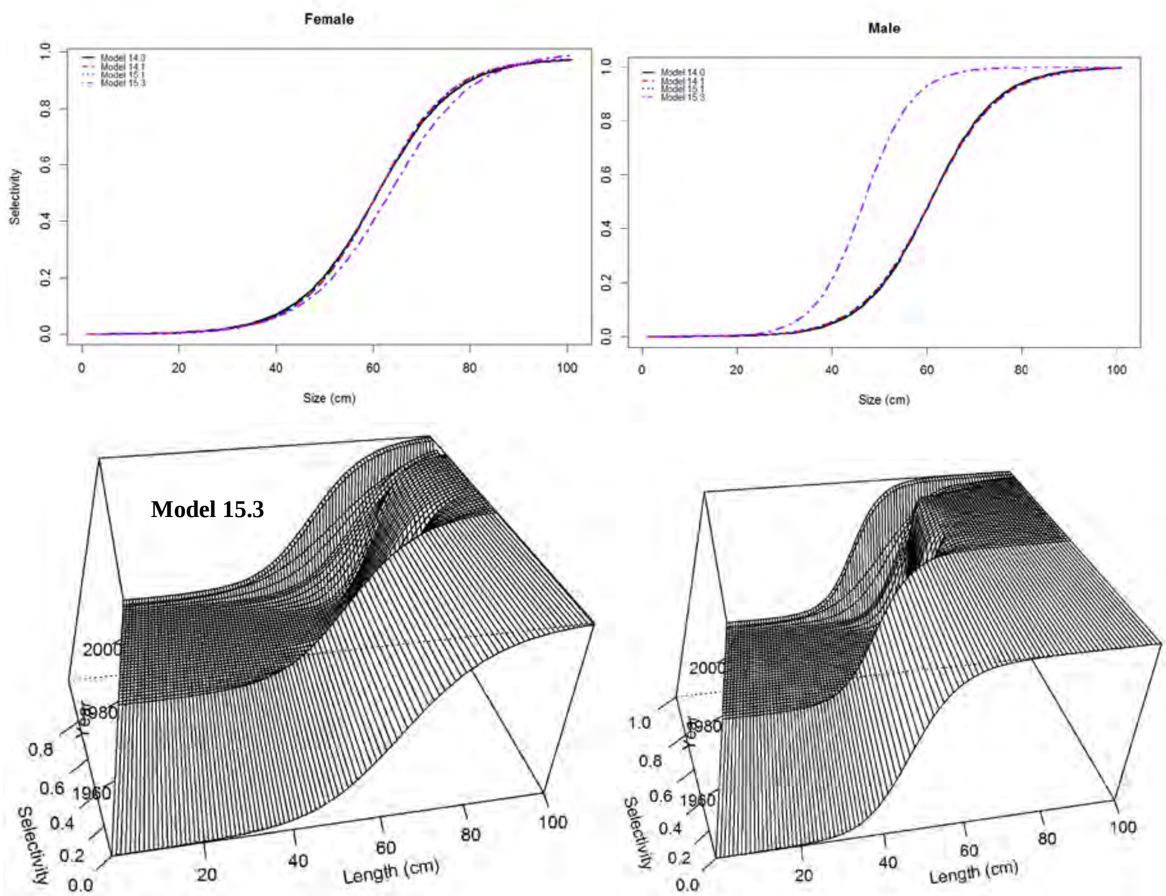


Figure 5.25. Slope survey selectivity by model and sex.

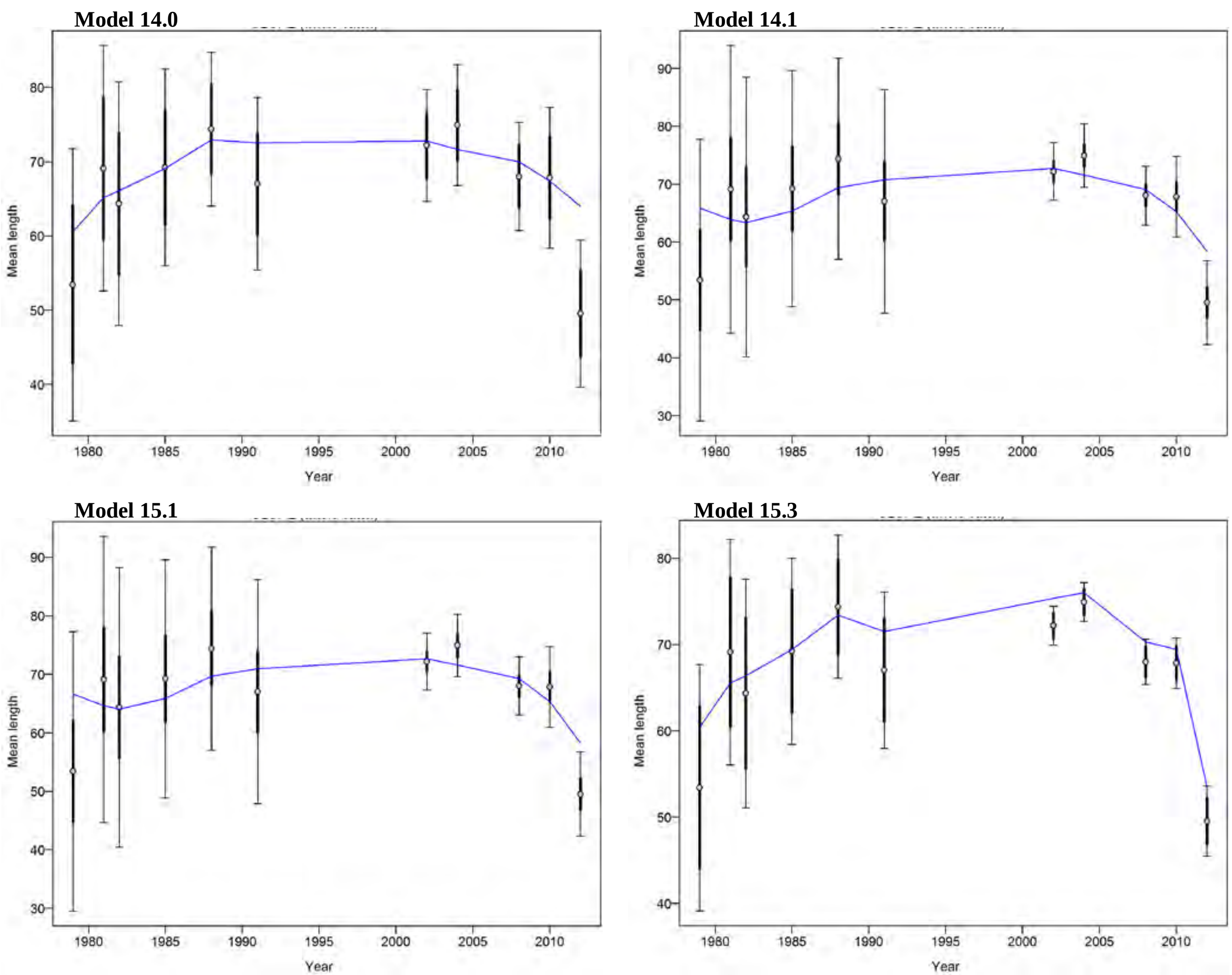


Figure 5.26. Mean size for slope survey and model fits.

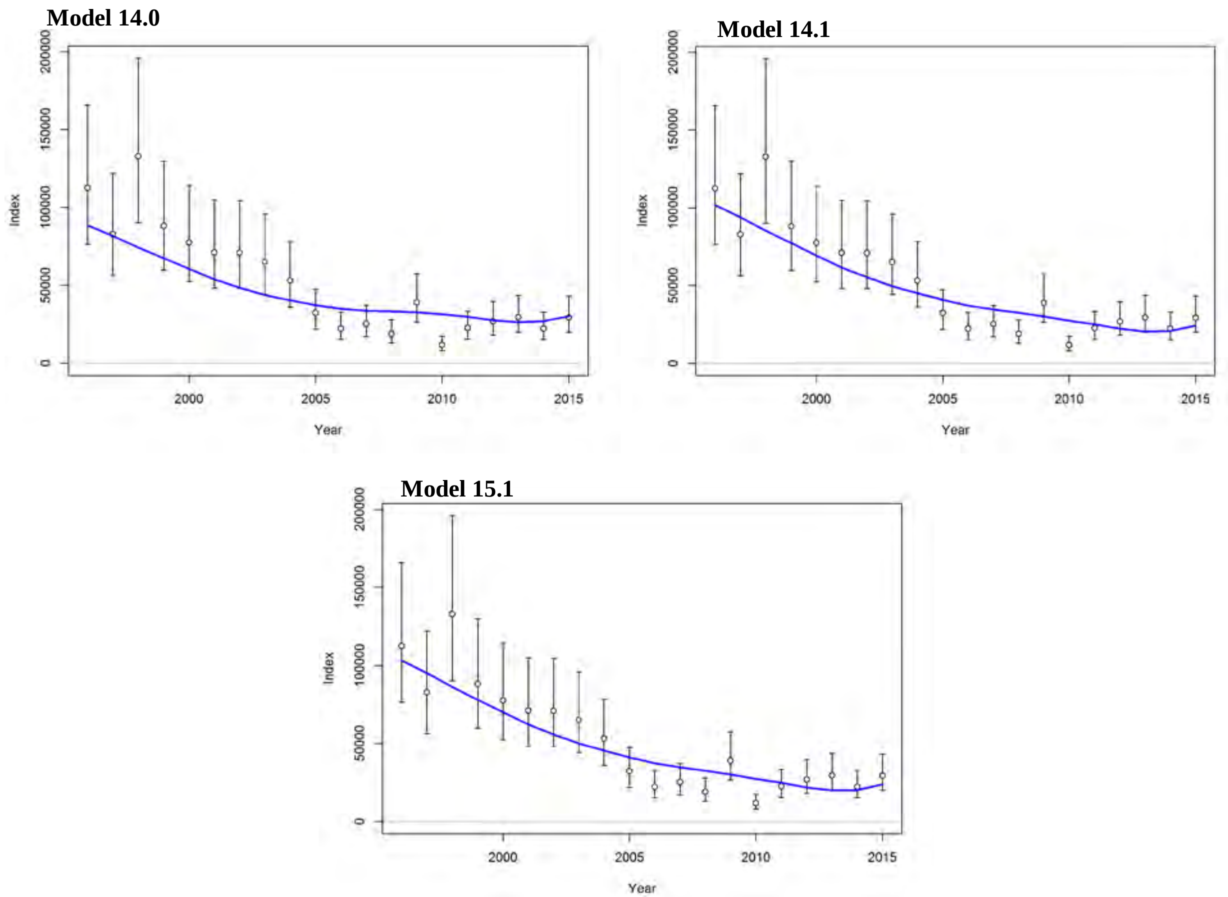


Figure 5.27. The ABL Longline survey index (index values are in relative population numbers (RPN)) and model fits. Error bars are 95% confidence intervals.

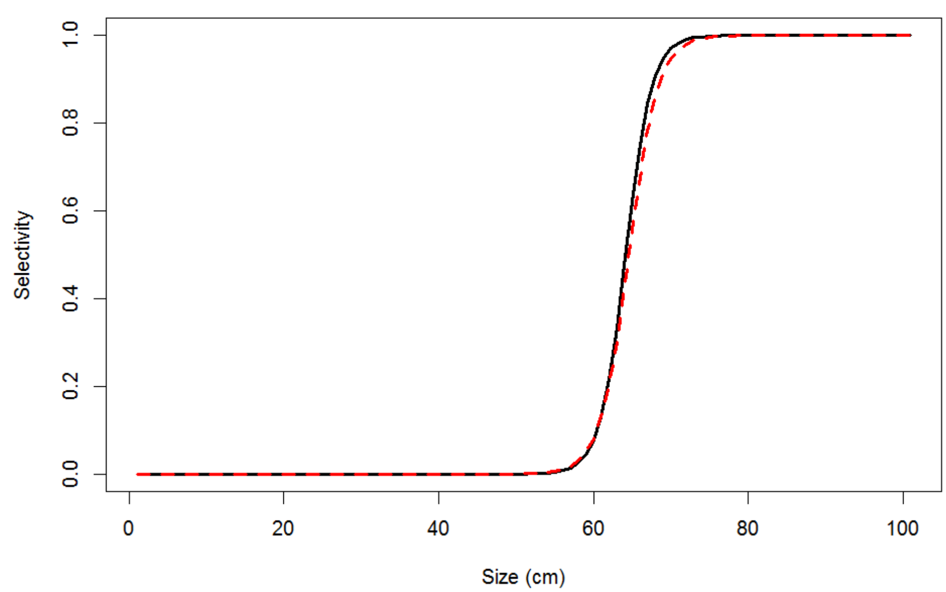


Figure 5.28. Model 15.1 ABL longline survey selectivity for Model 14.0 (black solid line) and Model 14.1 and Model 15.1 (red dashed line).

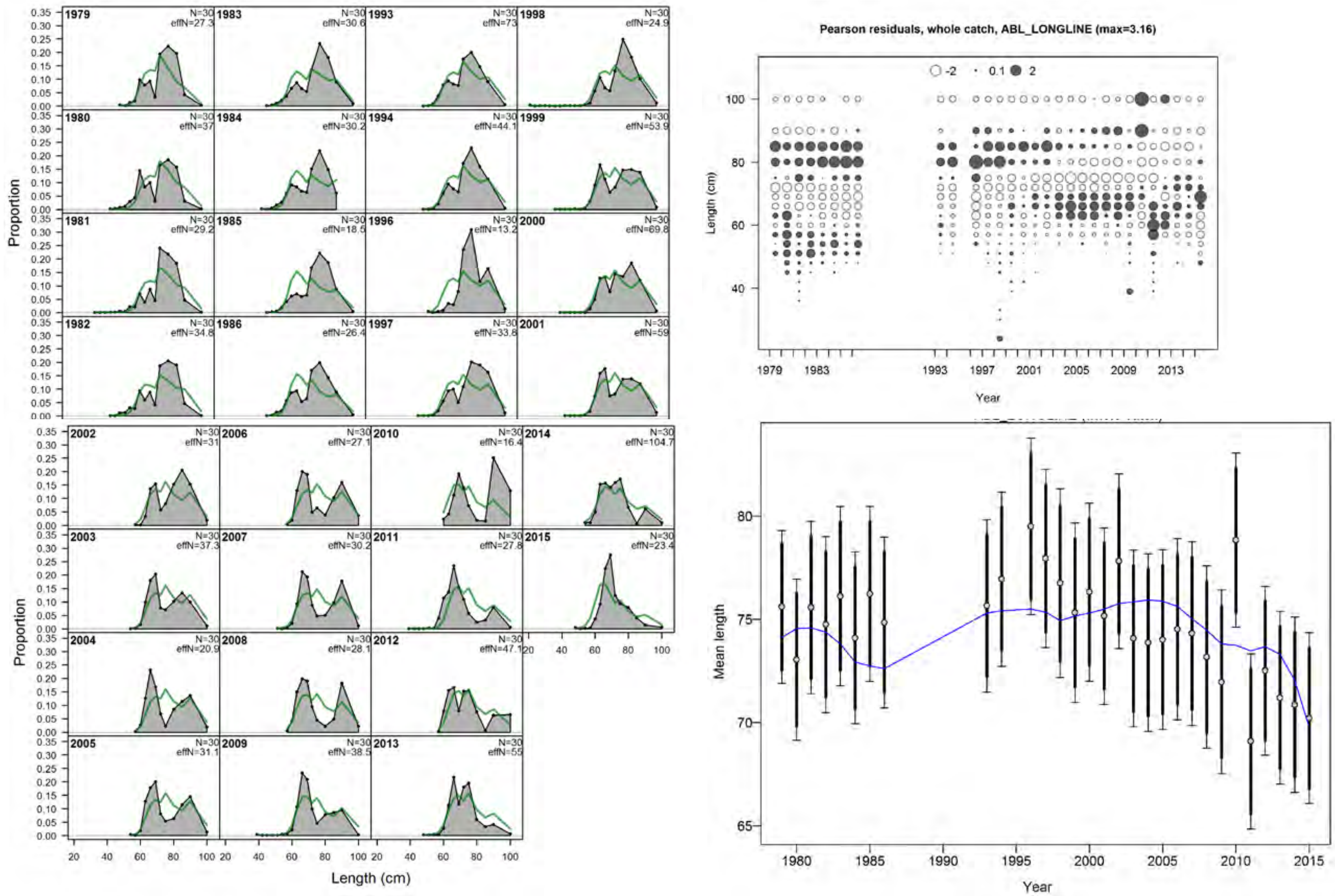


Figure 5.29. Model 15.1 Auke Bay Laboratory Longline survey (Left) size composition data and fits for combined sexes, (top right) slope survey size composition Pearson residuals, and (bottom right) mean length and model fit. **All three models with these data have similar fits.**

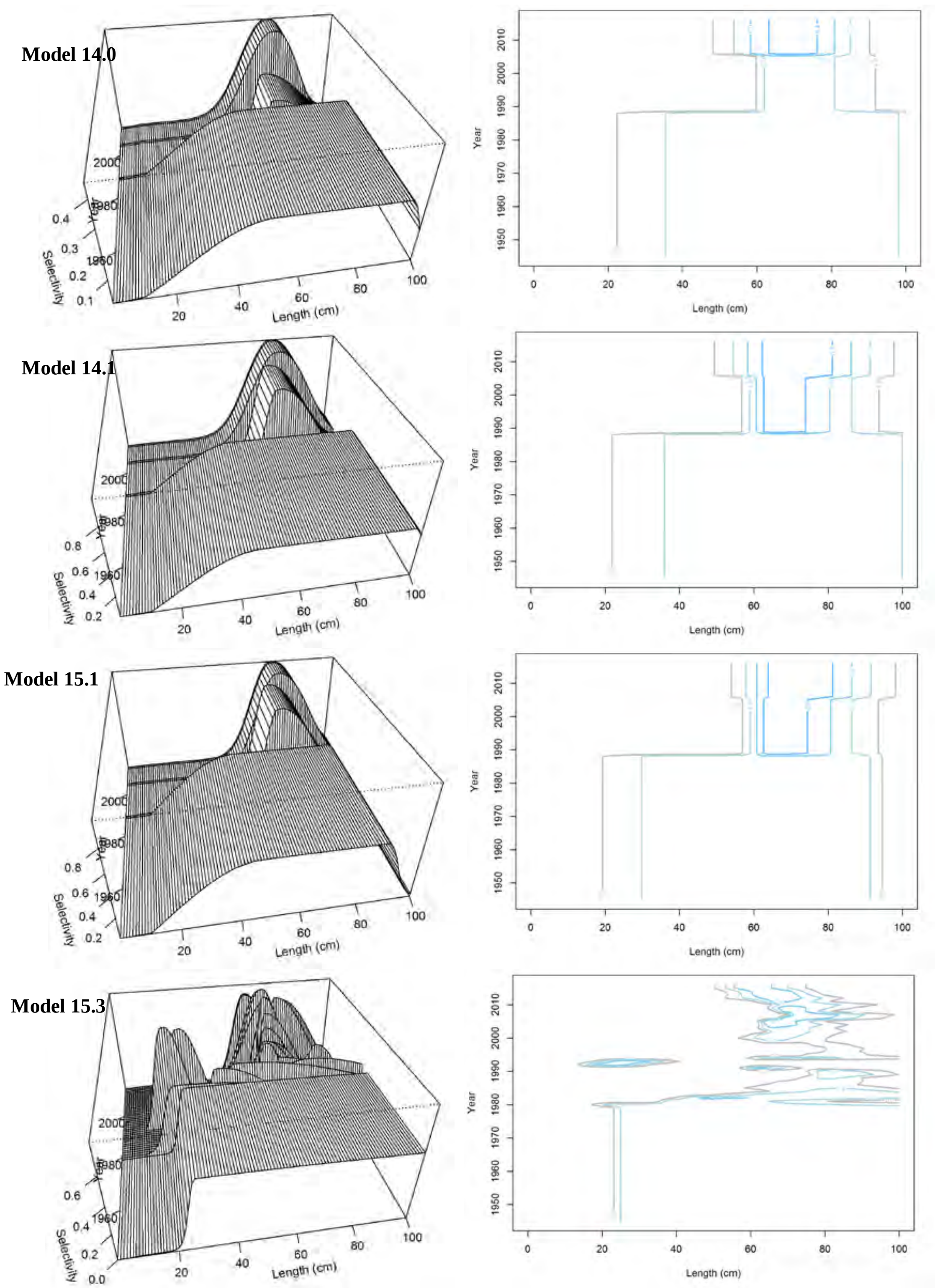


Figure 5.30. Time-varying selectivity at size for the Trawl fishery for Females.

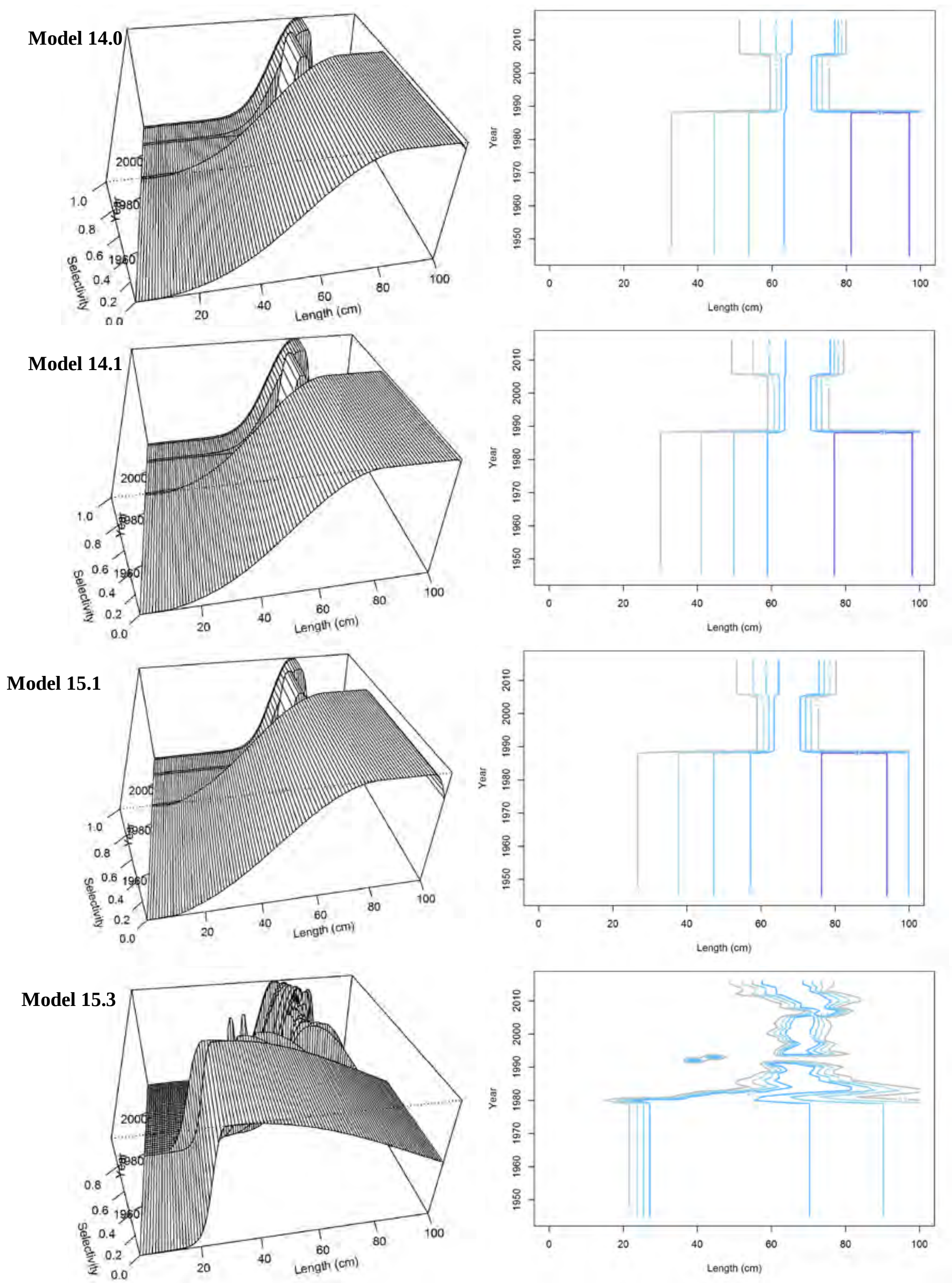


Figure 5.31. Time-varying selectivity at size for the Trawl fishery for males.

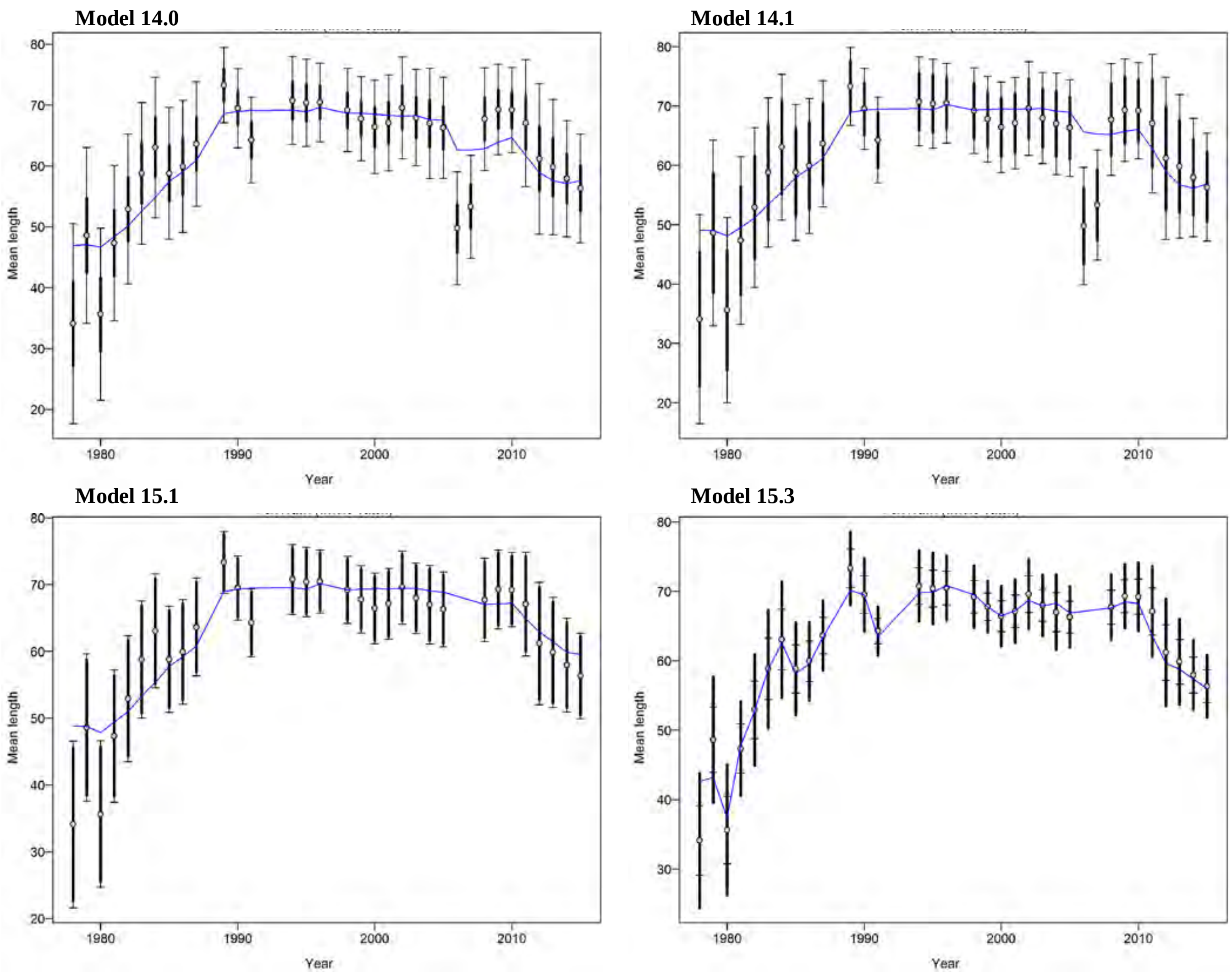


Figure 5.32. Trawl fishery mean length and model fits.

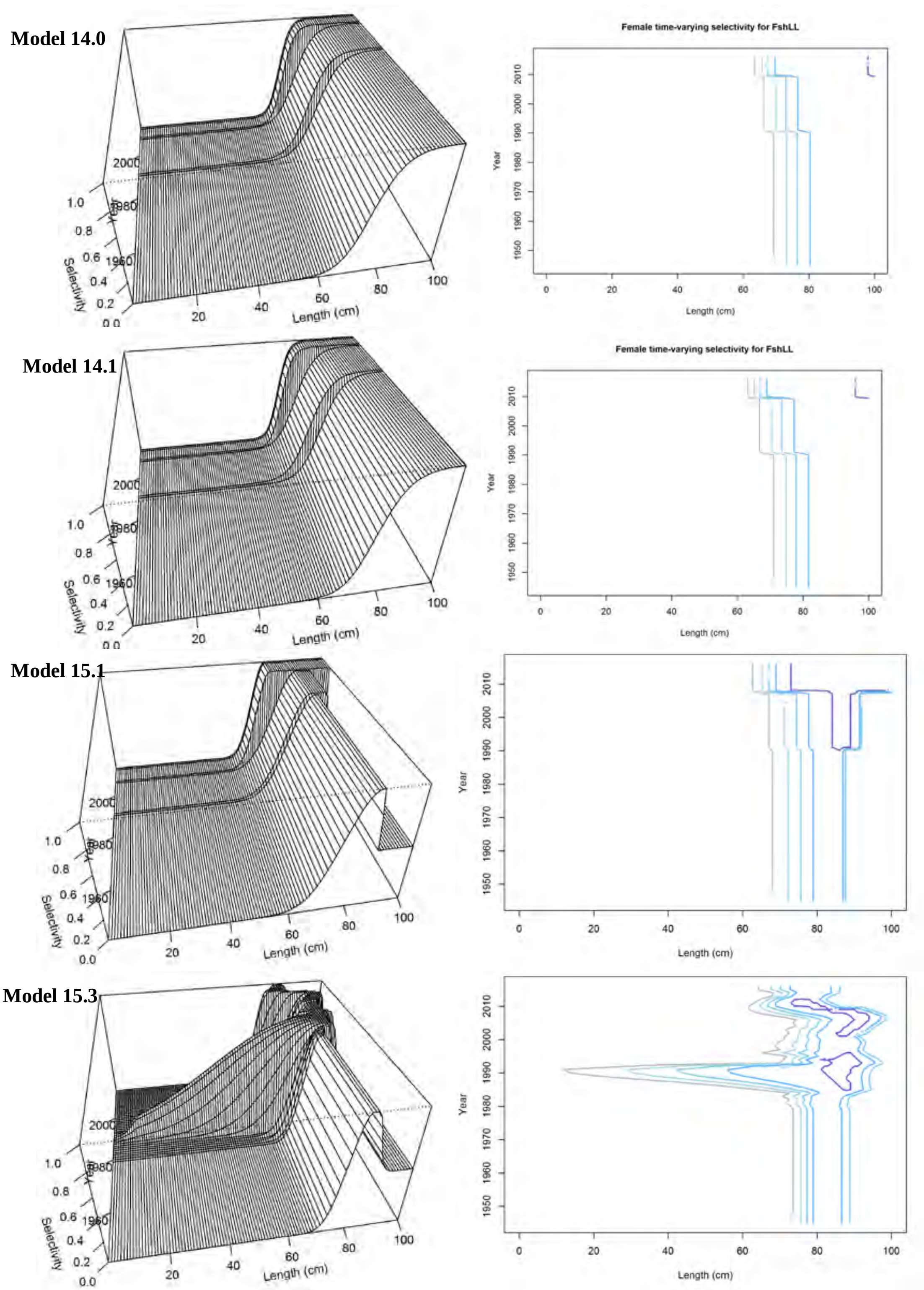


Figure 5.33. Time-varying selectivity at size for the Longline fishery for females.

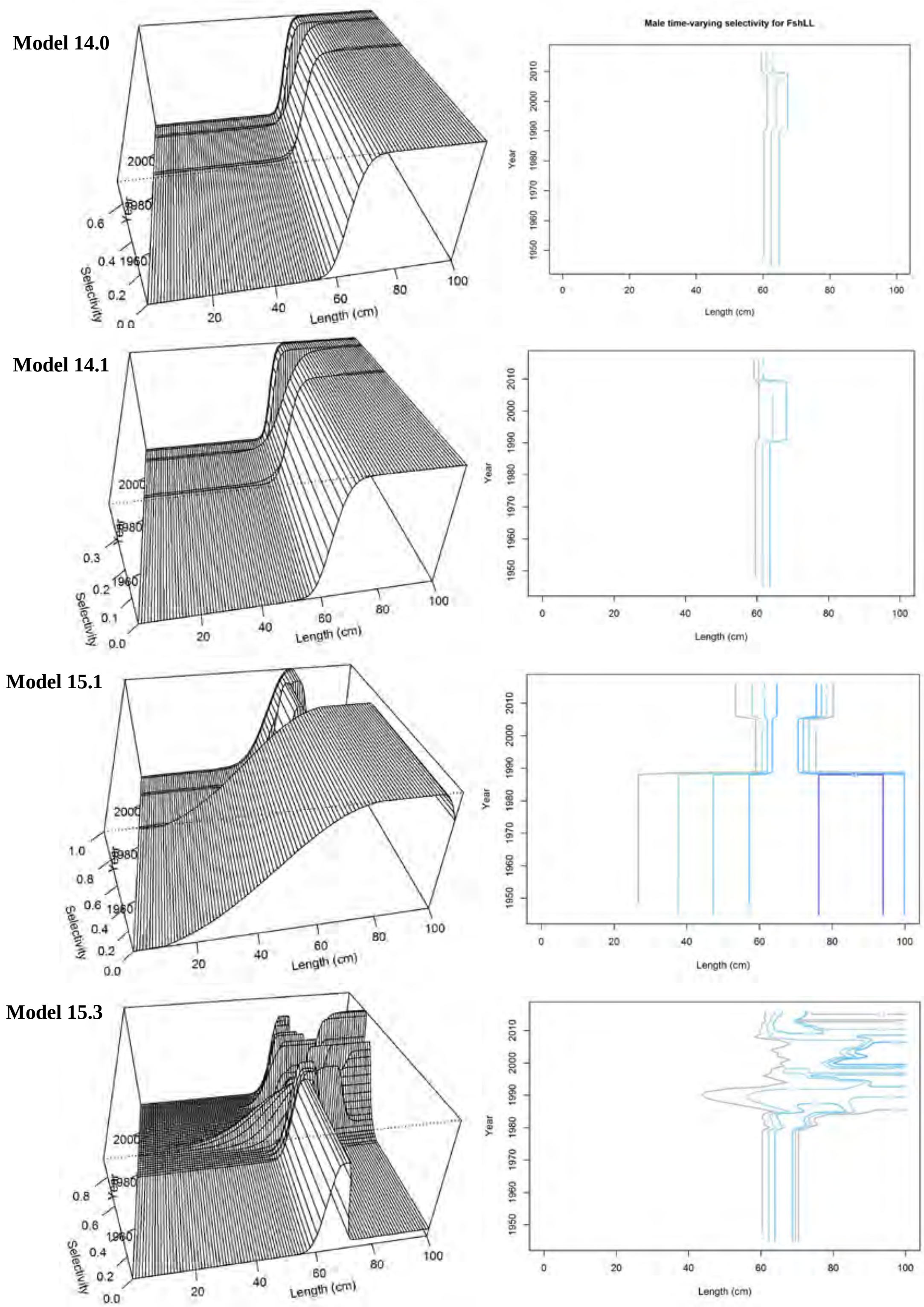


Figure 5.34. Time-varying selectivity at size for the Longline fishery for males.

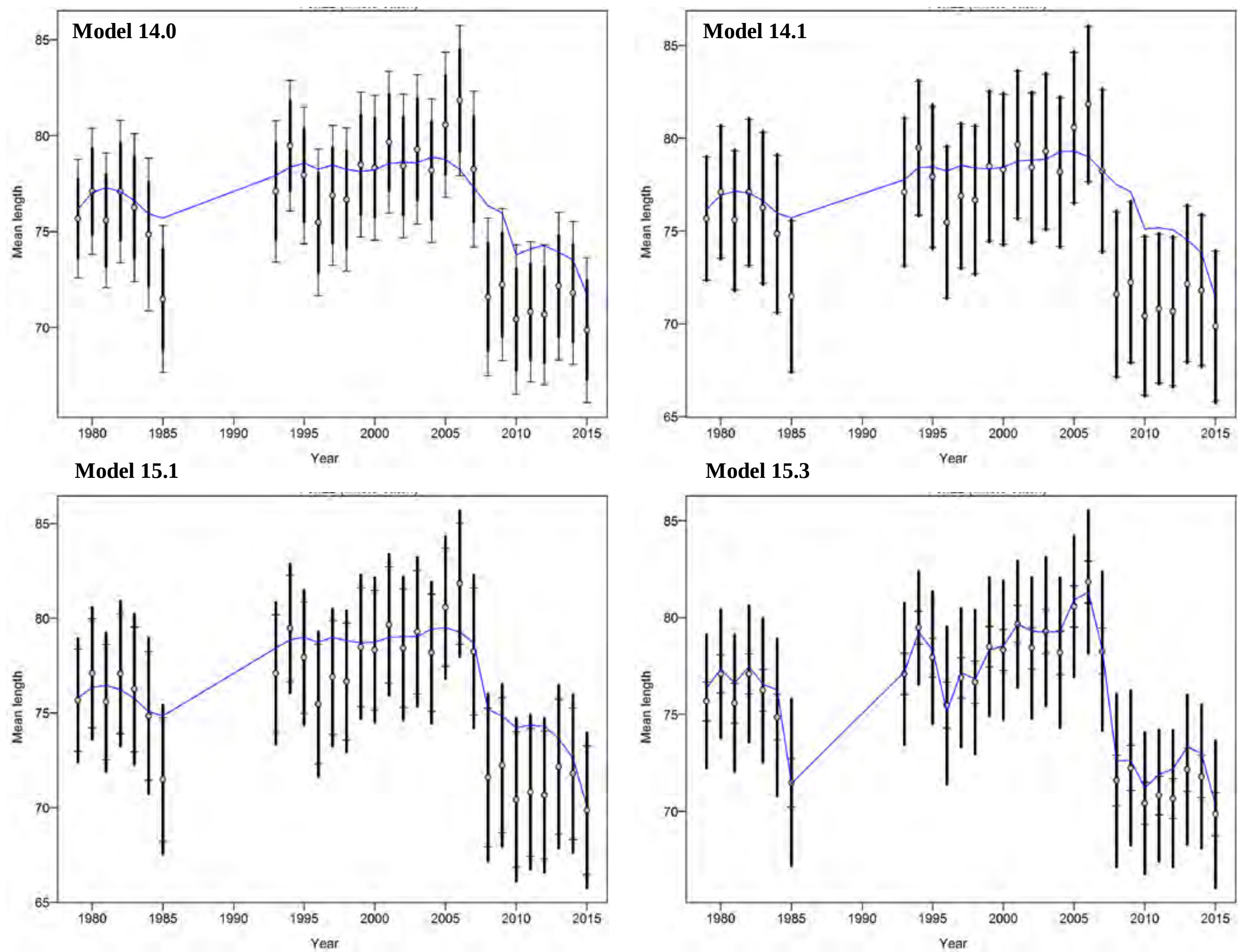


Figure 5.35. Mean length from the Longline fishery and model fits.

Figure 5.36. Age-0 recruitment for 2005-2015 for Models 14.0, 14.1, Model 14.0 with 2014 and 2015 data removed (Model14.0 Retro-2), and Model 14.0 with 2013-2015 data removed (Model 14.0 Retro-3).

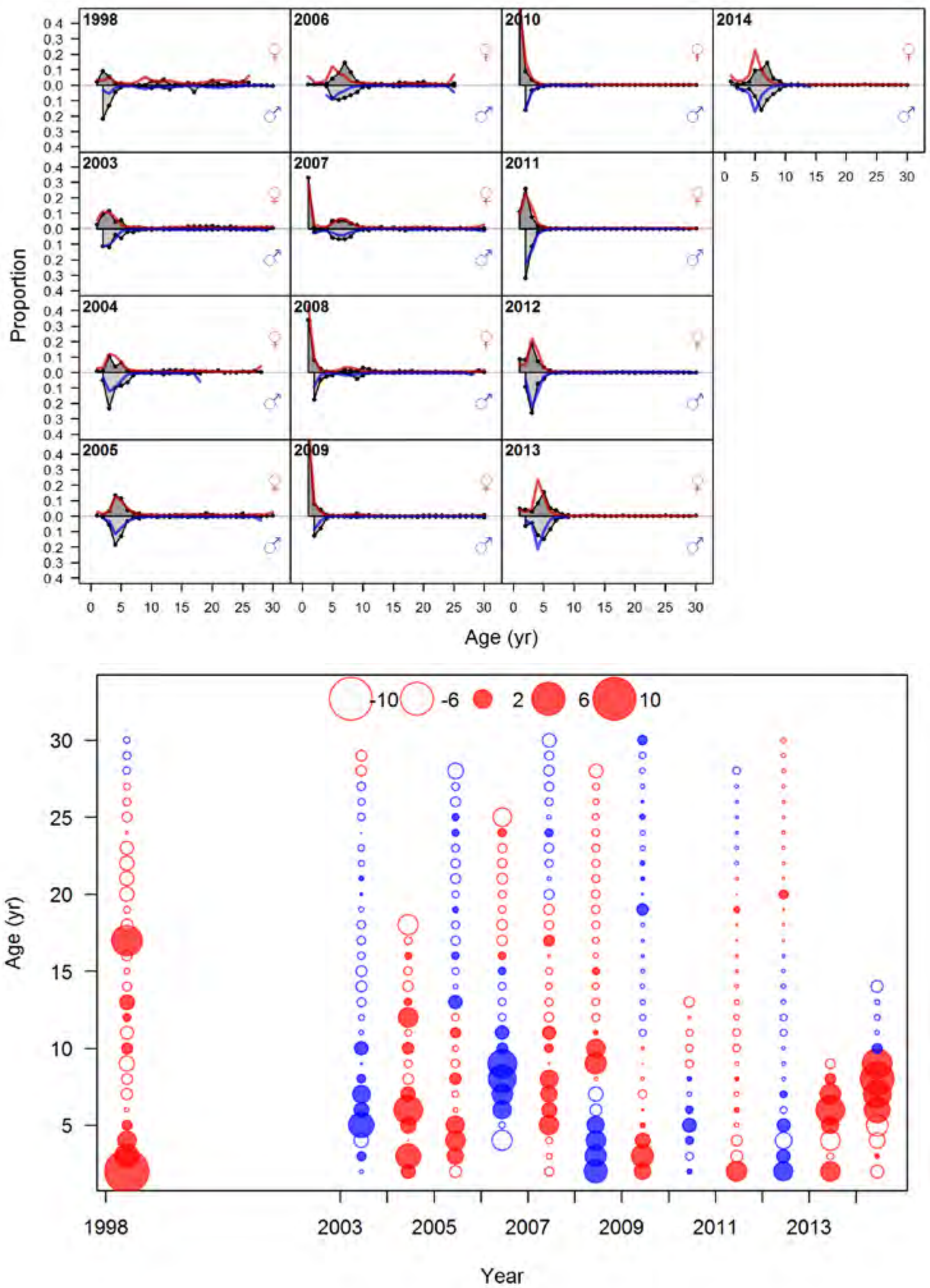


Figure 5.37. Model 15.1 (top) shelf survey age composition data and "ghost" fits (red and blue line) and (bottom) Pearson's residuals for age composition "ghost fits". Closed bubbles are positive residuals and open bubbles are negative residuals. Red bubbles are female and blue are male. "Ghost" fits are projected fits as the likelihood for the age composition data is not included in Model 15.1.

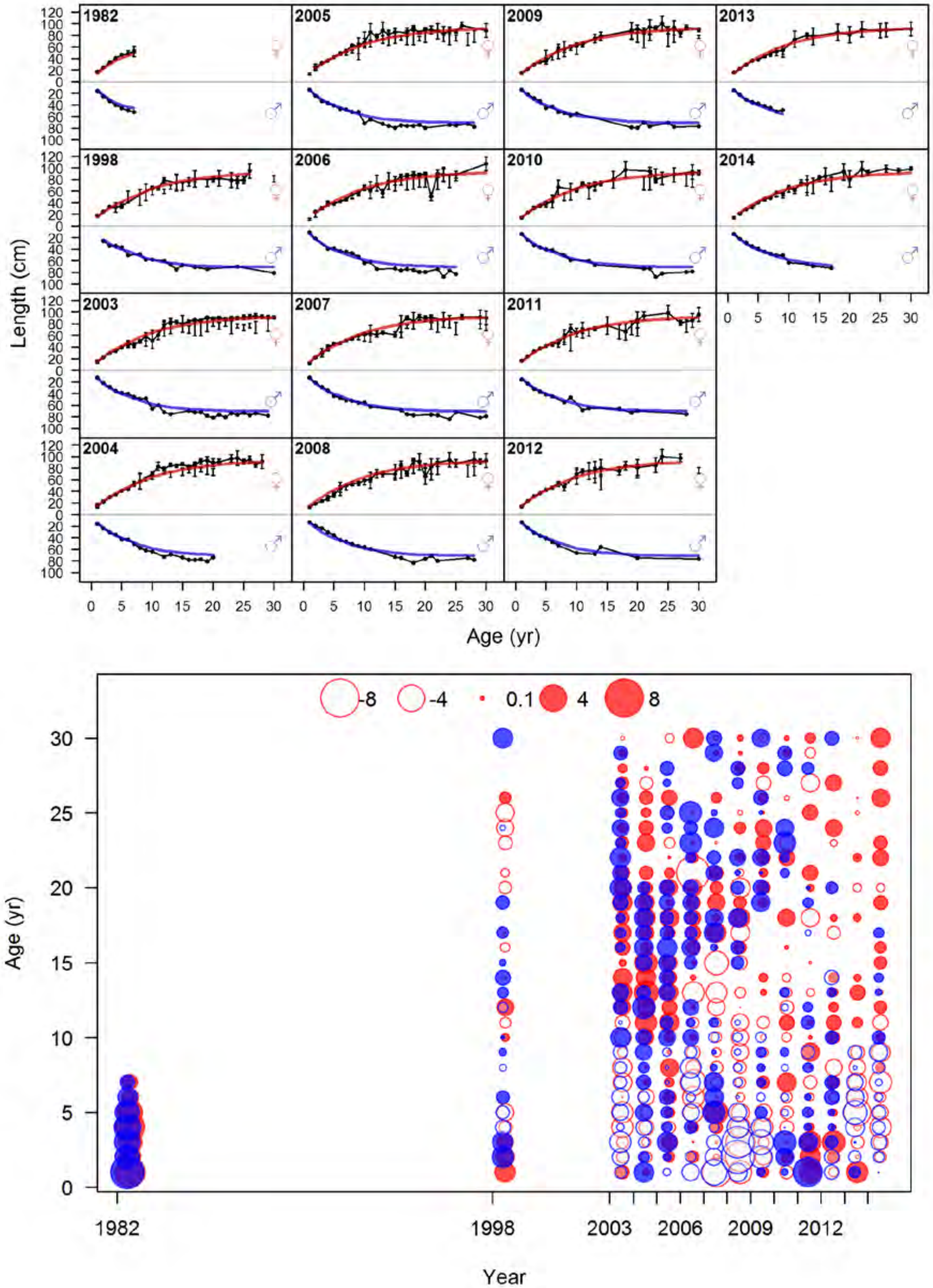


Figure 5.38. (Top) Length at age data and fits (red line). (Bottom) Pearson's residuals for length at age data. Closed bubbles are positive residuals and open bubbles are negative residuals. Red bubbles are female and blue are male.

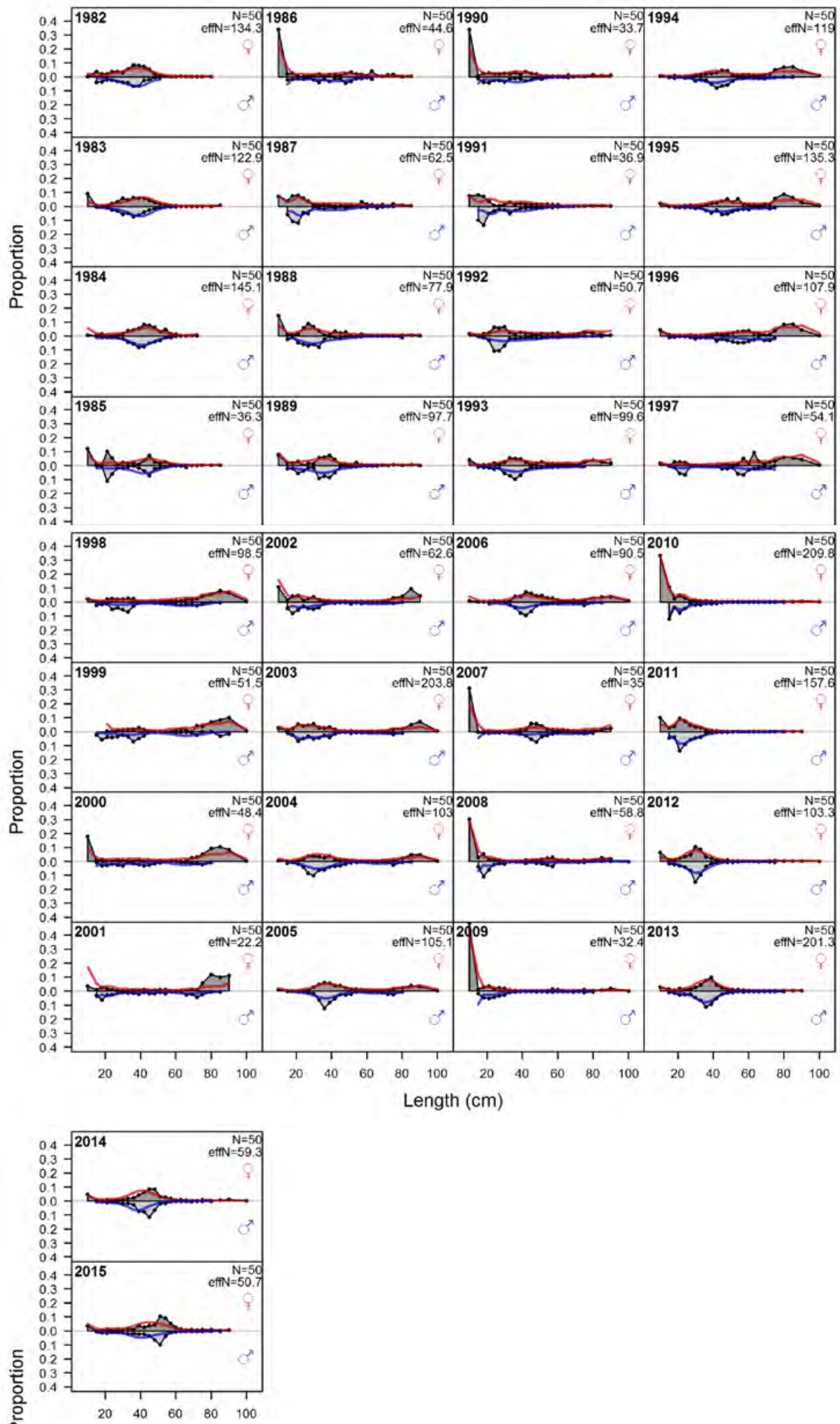


Figure 5.39. Model 15.1 shelf survey size composition data and fits (red line females, blue lines males).

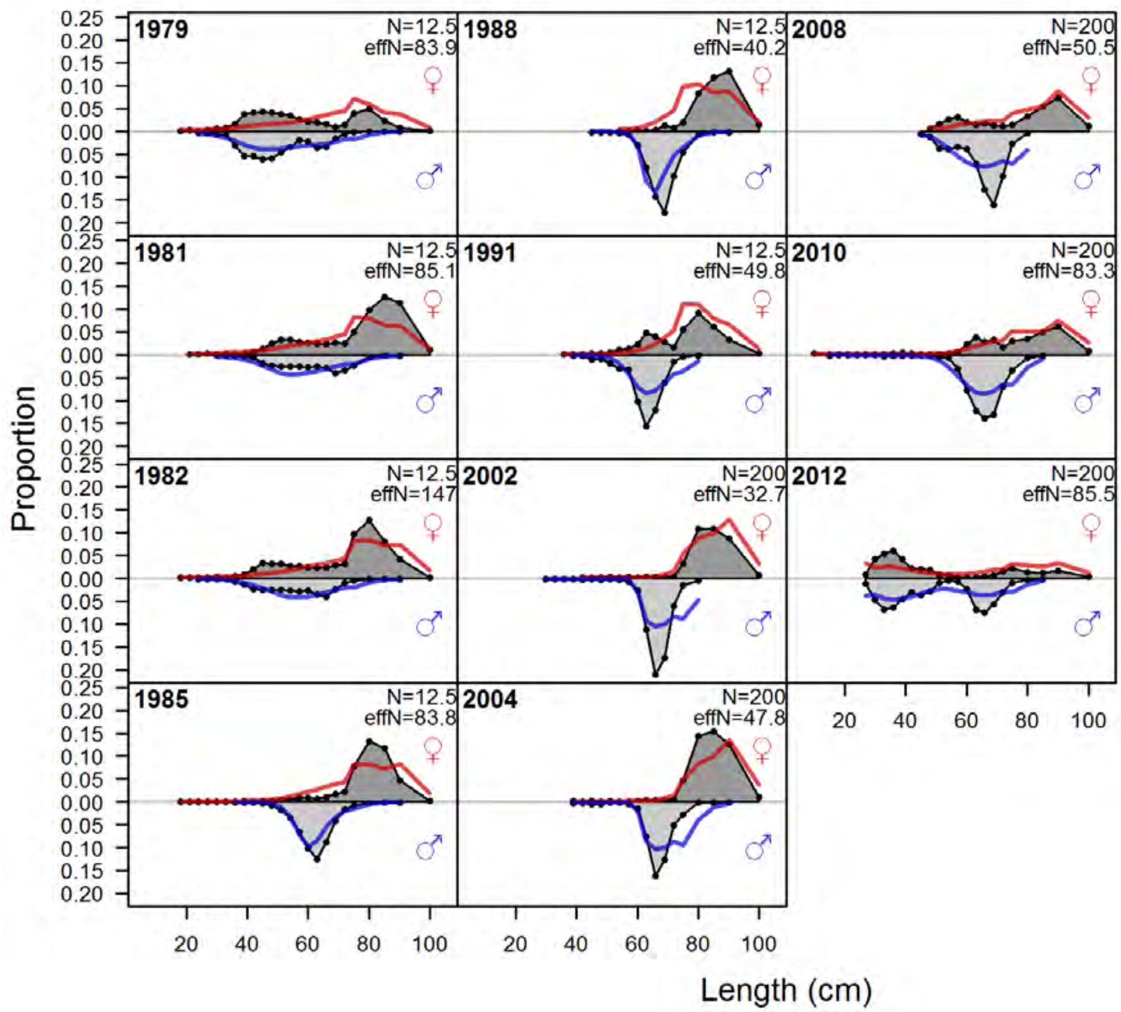


Figure 5.40. Model 15.1 slope survey size composition data and fits (red line for females and blue line for males) for all models.

Females Males

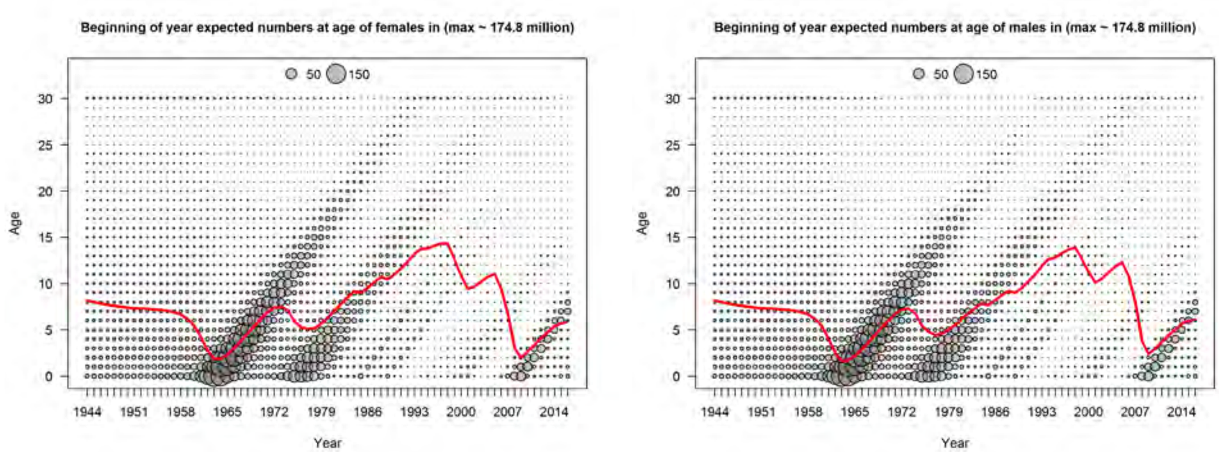


Figure 5.41. Model 15.1 BSAI Greenland turbot numbers at age and mean age by year (red line).

Females Males

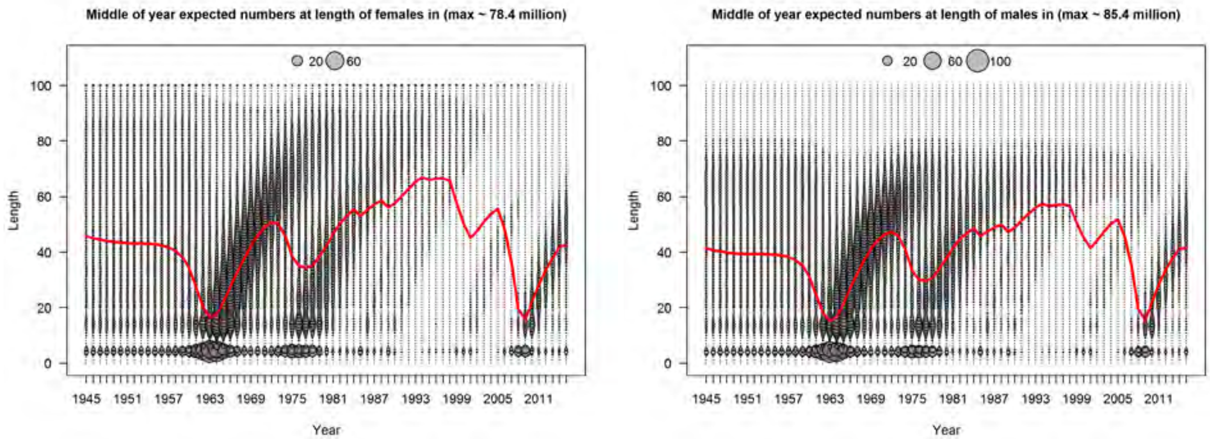


Figure 5.42. Model 15.1 BSAI Greenland turbot numbers at size and mean size by year (red line).

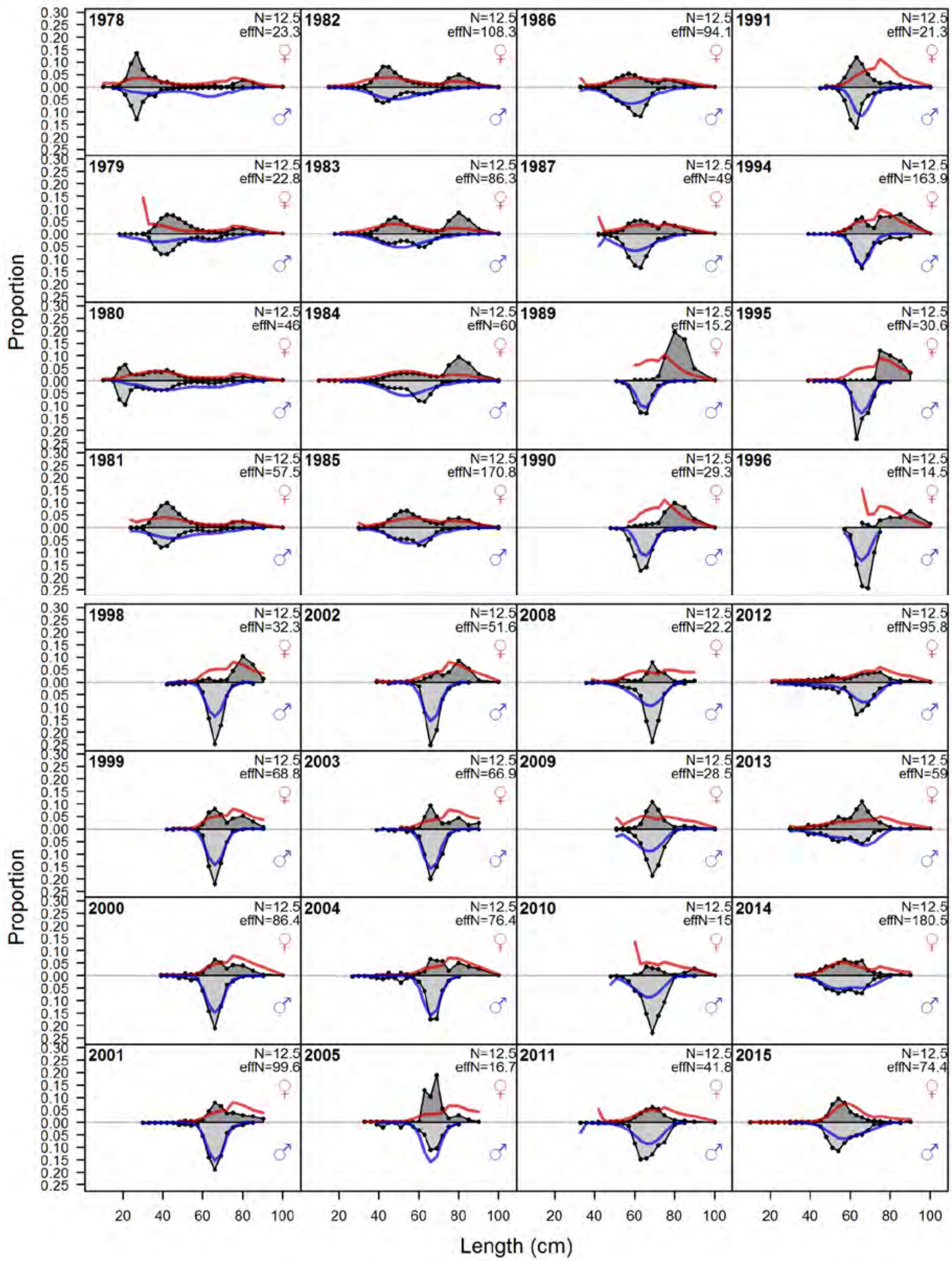


Figure 5.43. Model 15.1 Trawl fishery size composition data and fits (red lines male, blue lines female) .

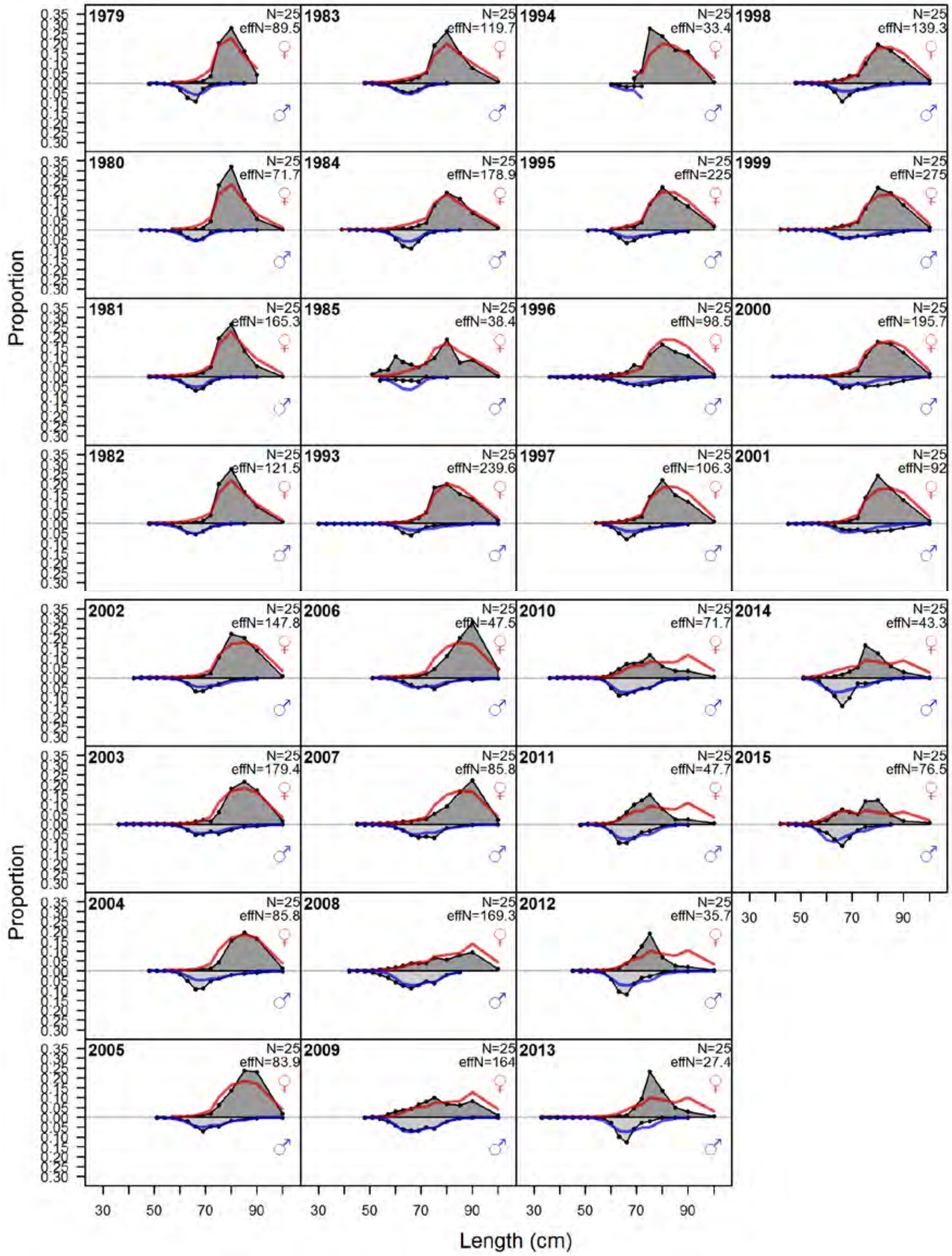


Figure 5.44. Model 15.1 Longline fishery size composition data and fits (red line) for females.

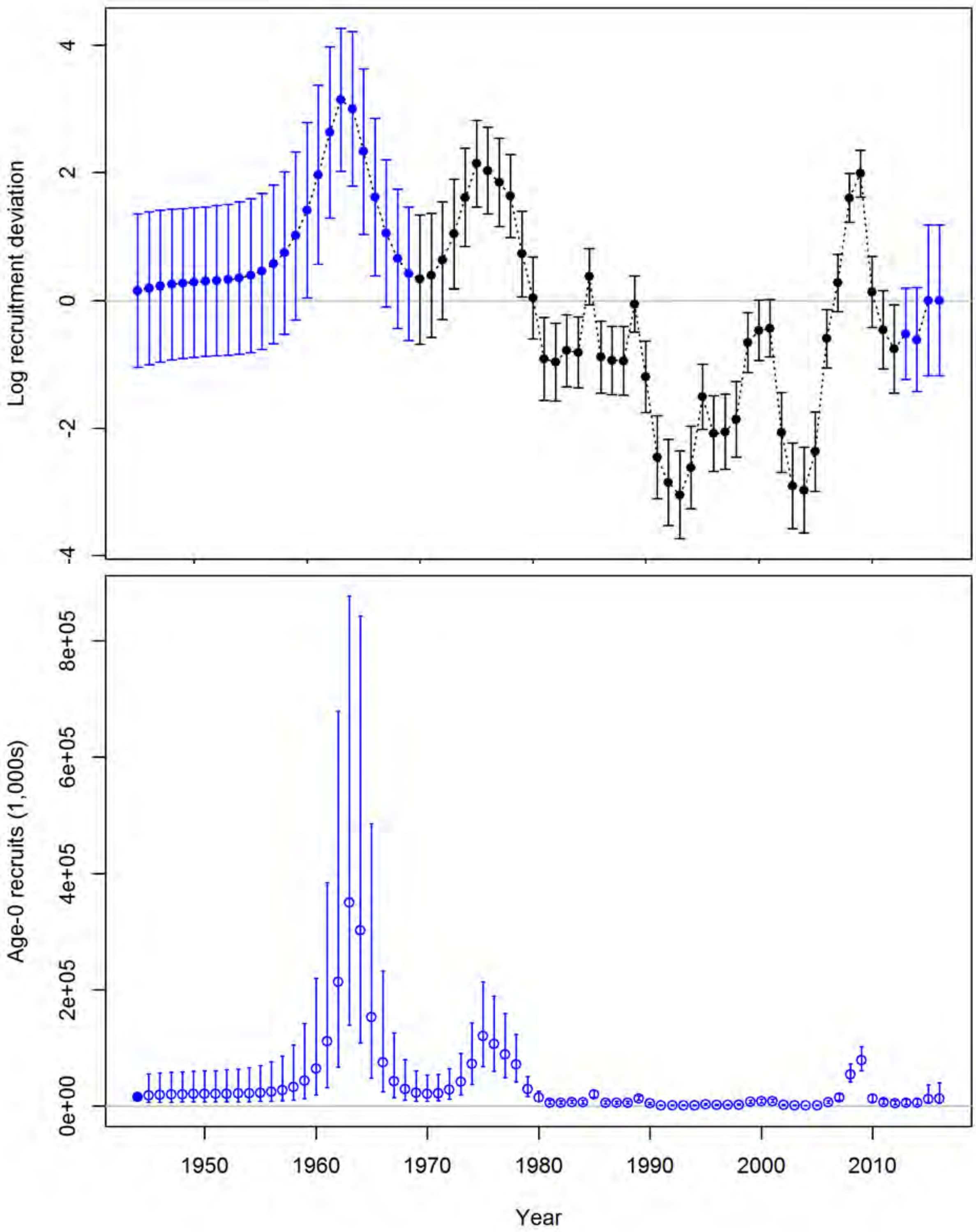


Figure 5.45. Log recruitment deviations (top) and Age-0 recruits (bottom) in thousands for Model 15.1.

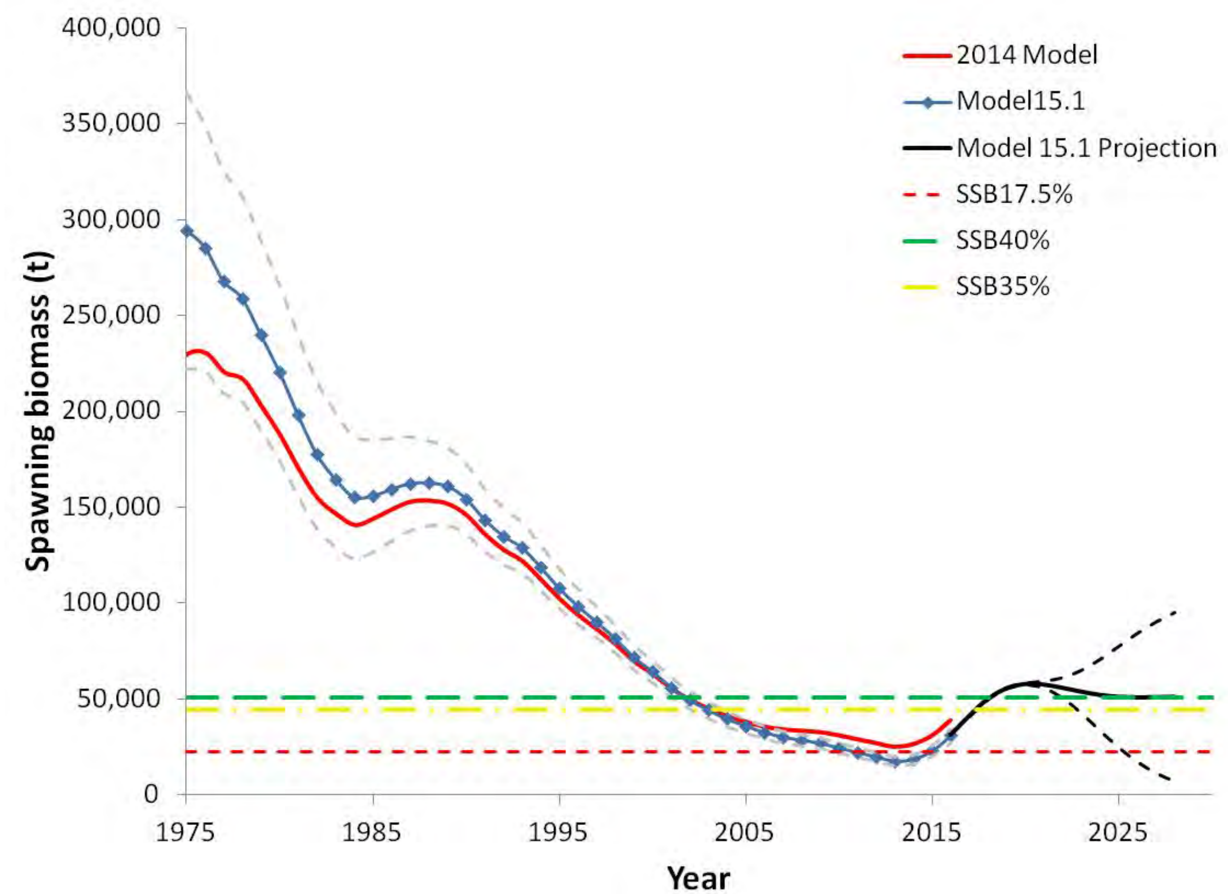


Figure 5.46. Female spawning biomass in tons for BSAI Greenland Turbot for Model 15.1 with reference levels and projection out to 2028 from Alternative 1 F_{40} fishing levels. Model error bars are 95% confidence intervals based on the inverted Hessian, projection error bars are 95% credible intervals based on 1,000 simulations. Red solid line is the spawning biomass timeseries from last year's model.

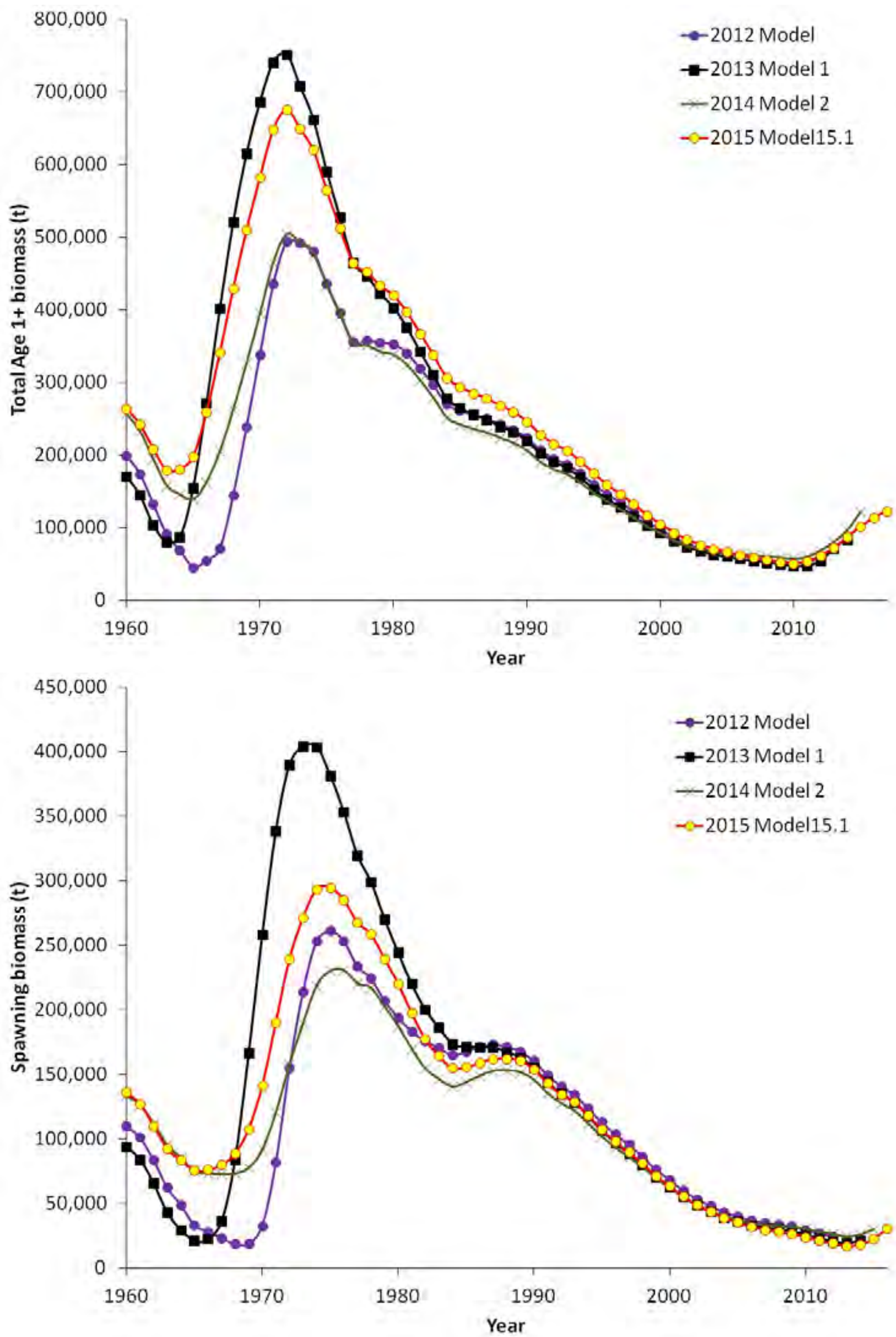


Figure 5.47. Total age +1 biomass (t) and female spawning biomass in tons for BSAI Greenland Turbot for Model 15.1 and previous years' stock assessments.

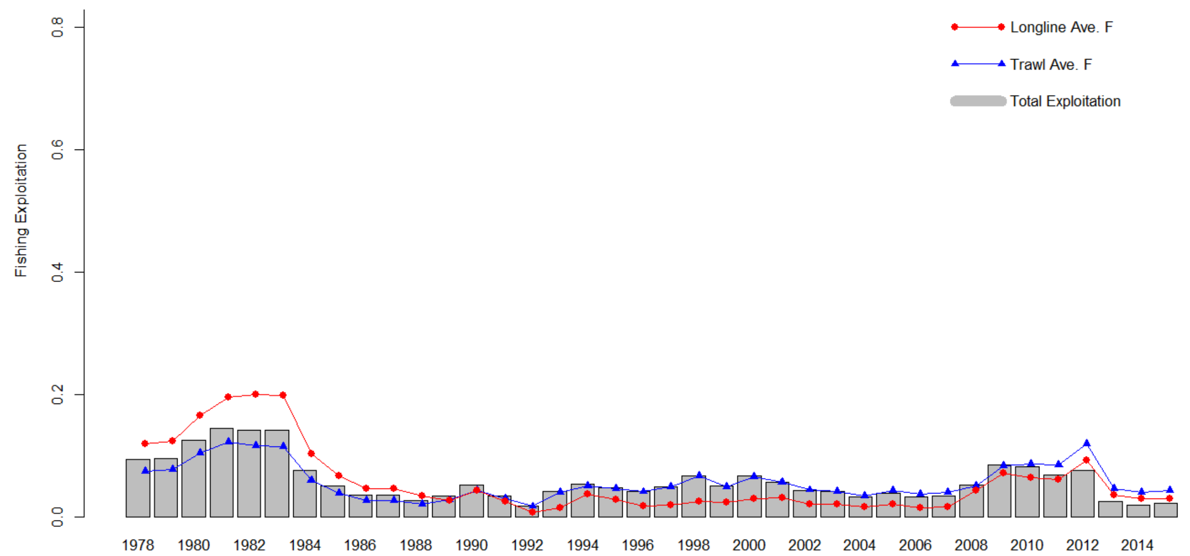


Figure 5.48. BSAI Greenland turbot total exploitation rate (bars) and average Fs for the trawl and longline fisheries for Model 15.1.

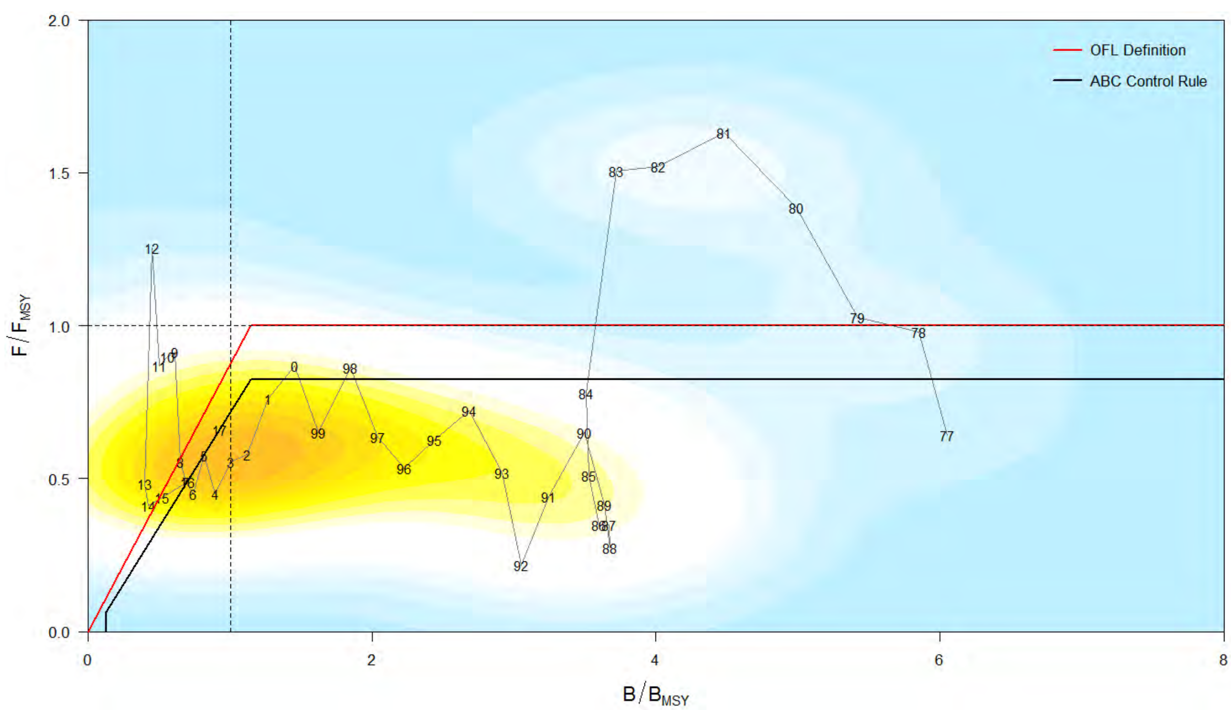


Figure 5.49. For Model 15.1 ratio of historical F/*F_{msy}* versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1977-2015. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets. The figure on the left shows the high fishing rates in the mid-1980s and the figure on the right focuses on the most recent fishing period.

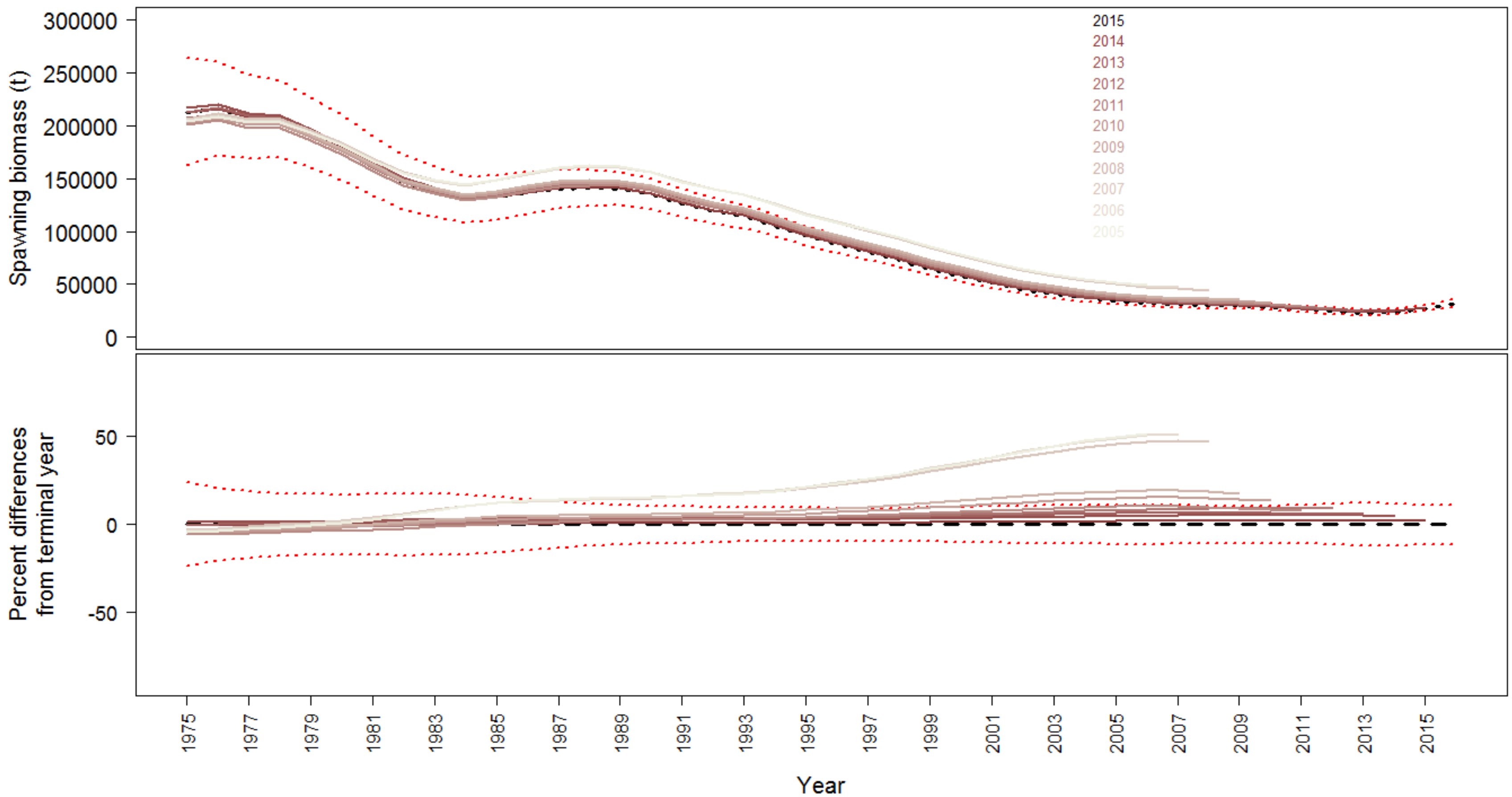


Figure 5.50. Model 14.0 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

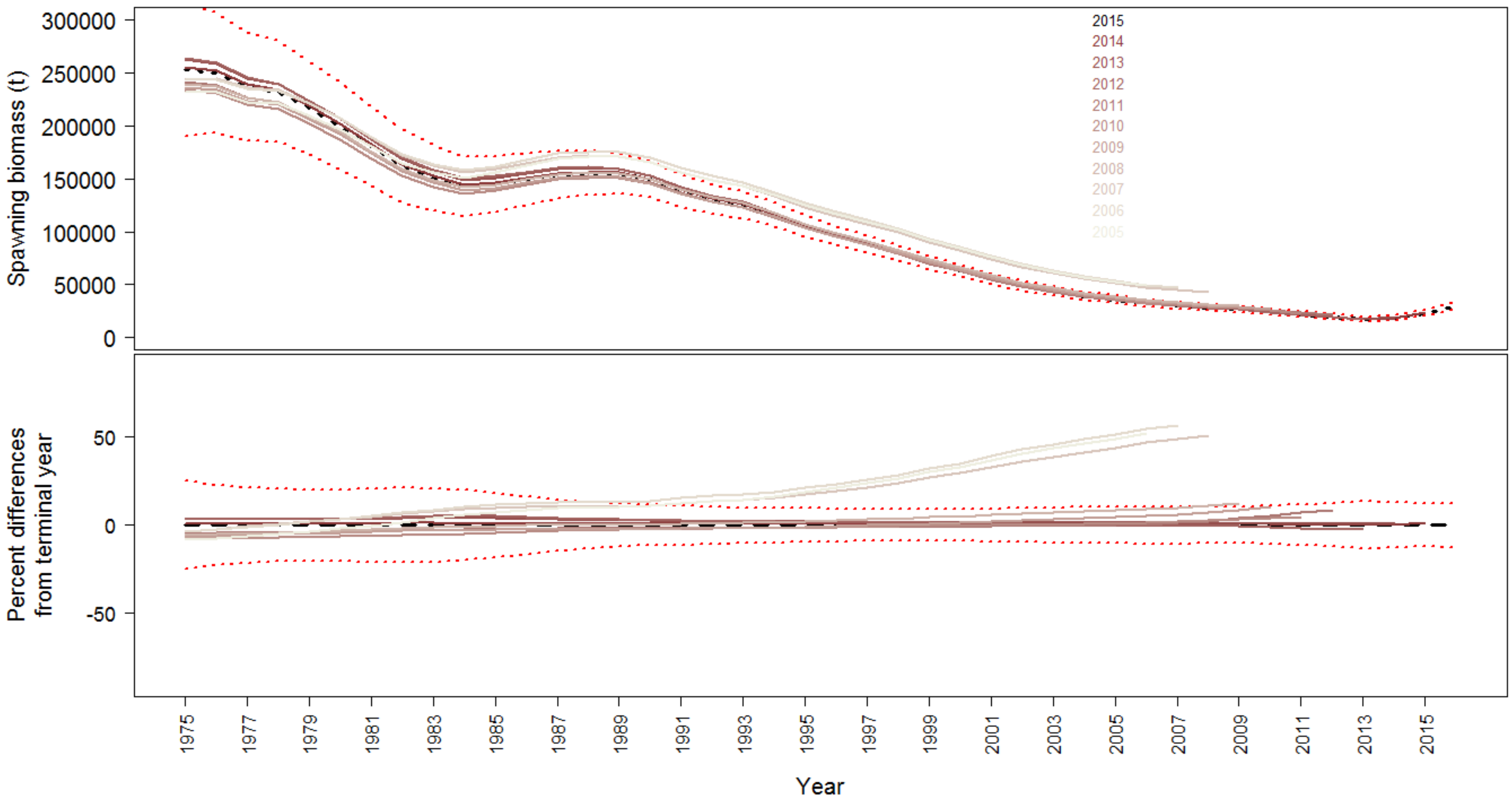


Figure 5.50 (cont.) Model 14.1 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

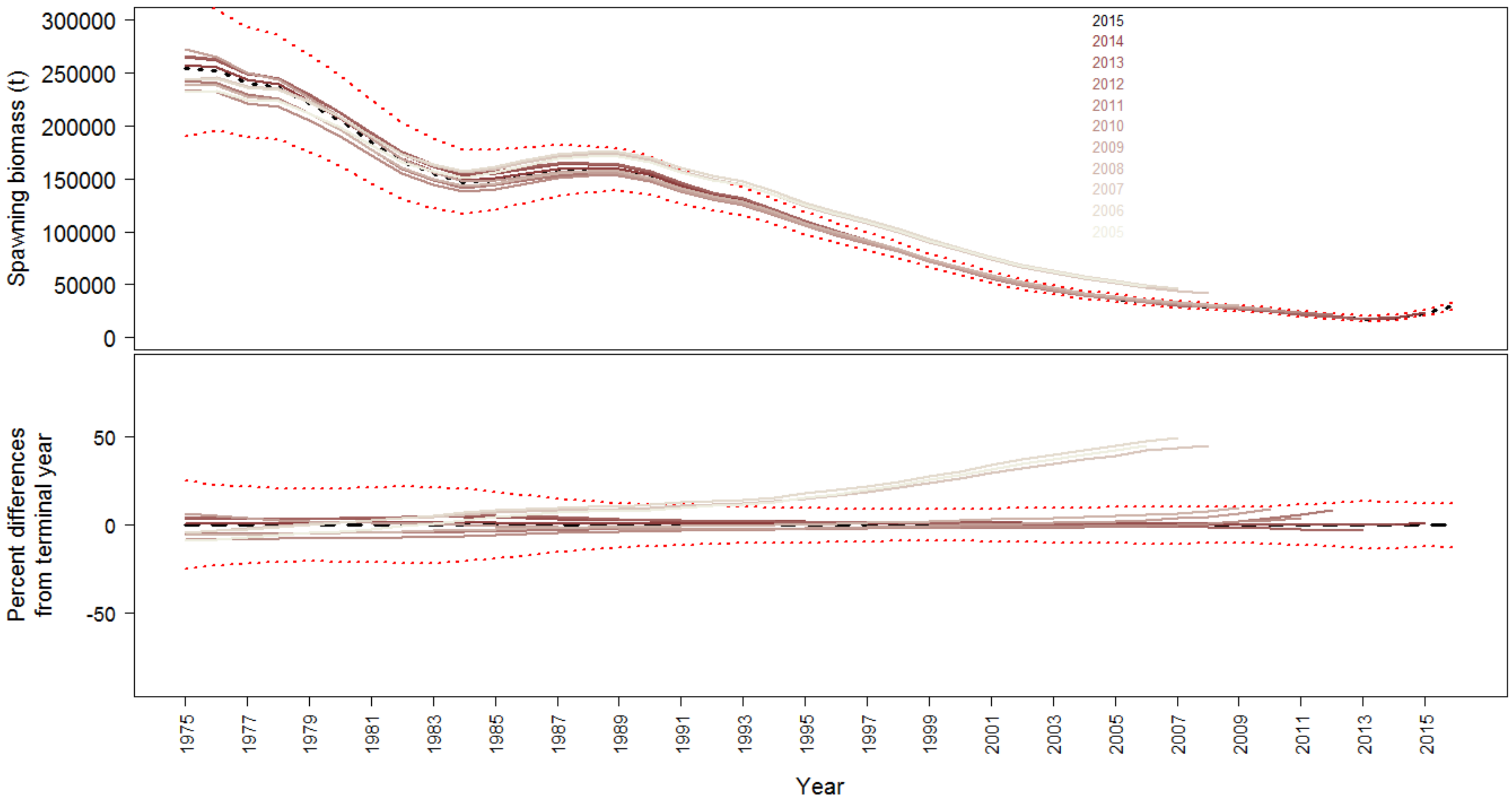


Figure 5.50 (cont.) Model 15.1 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

Figure 5.50 (cont.) Model 15.3 retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

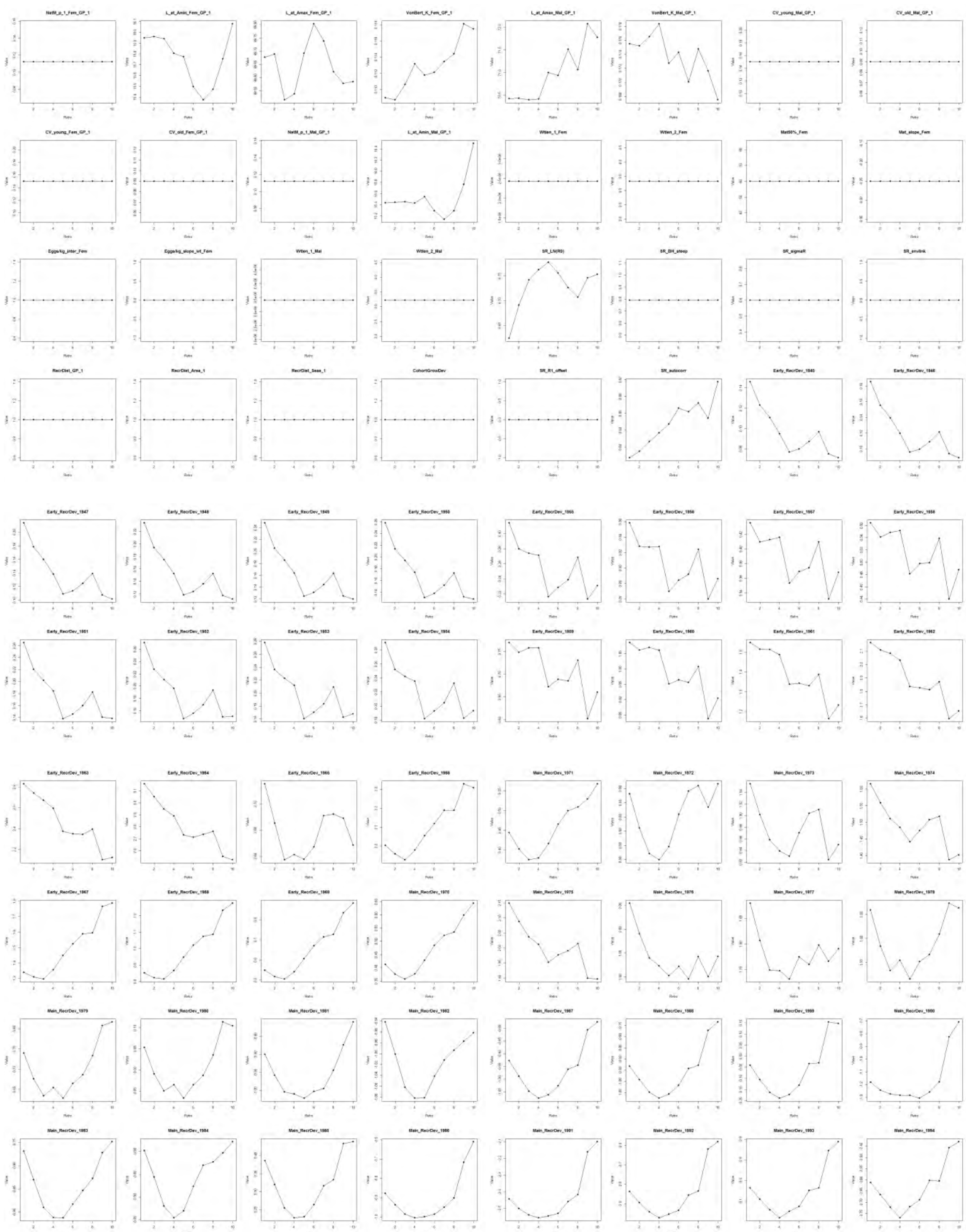


Figure 5.51. Model 15.1 retrospective analysis plots of model parameters.

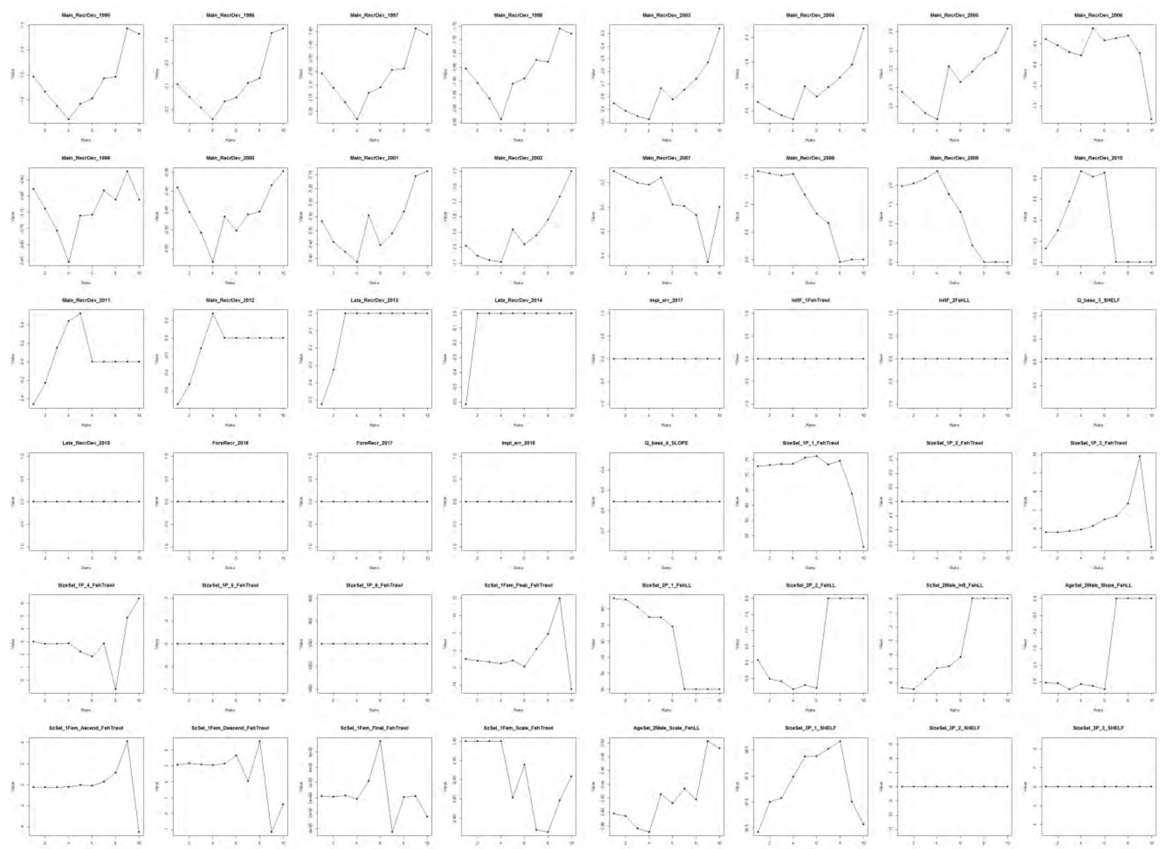


Figure 5.51 (Cont.) Model 15.1 retrospective analysis plots of model parameters.

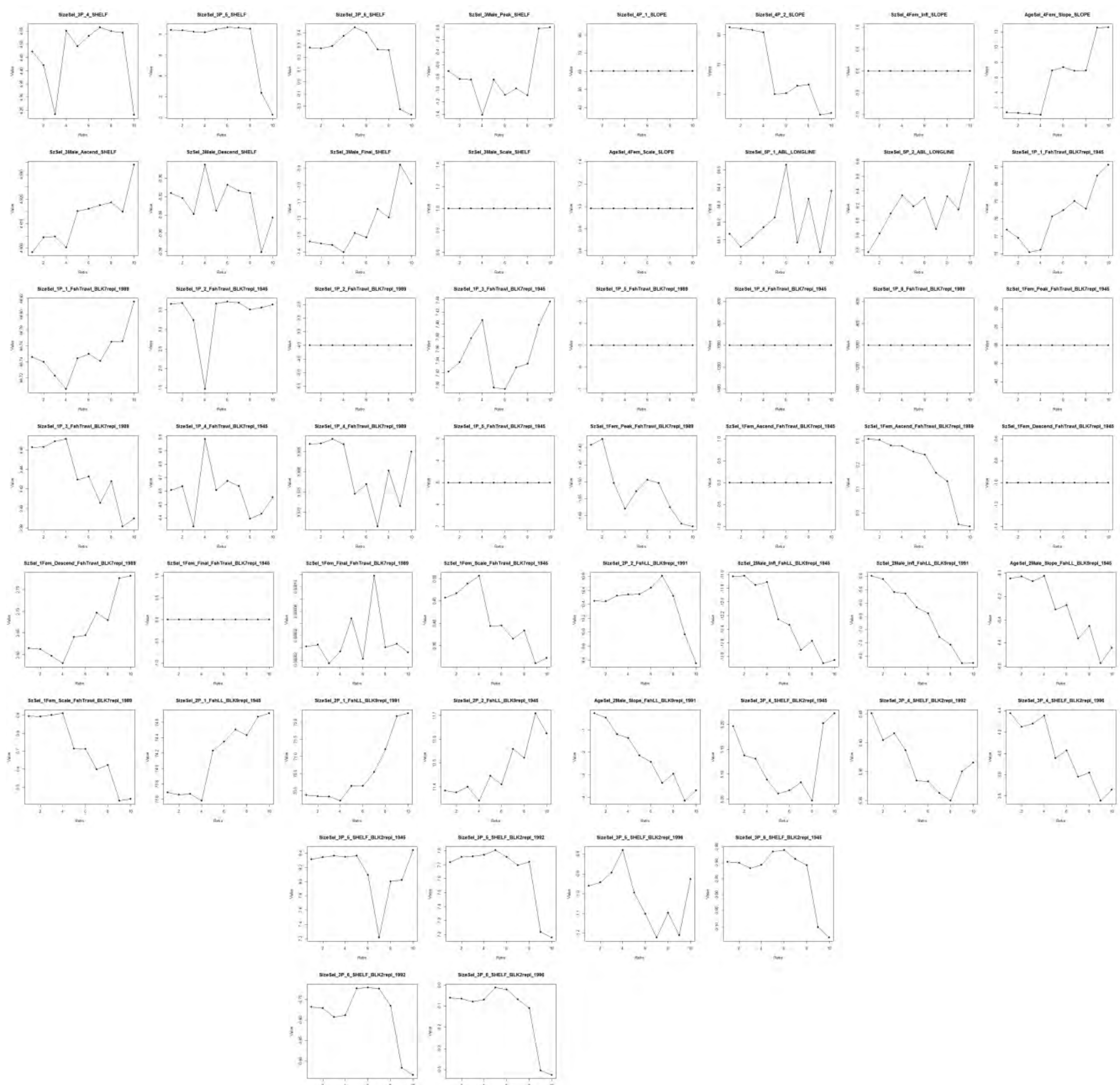


Figure 5.51 (Cont.) Model 15.1 retrospective analysis plots of model parameters.

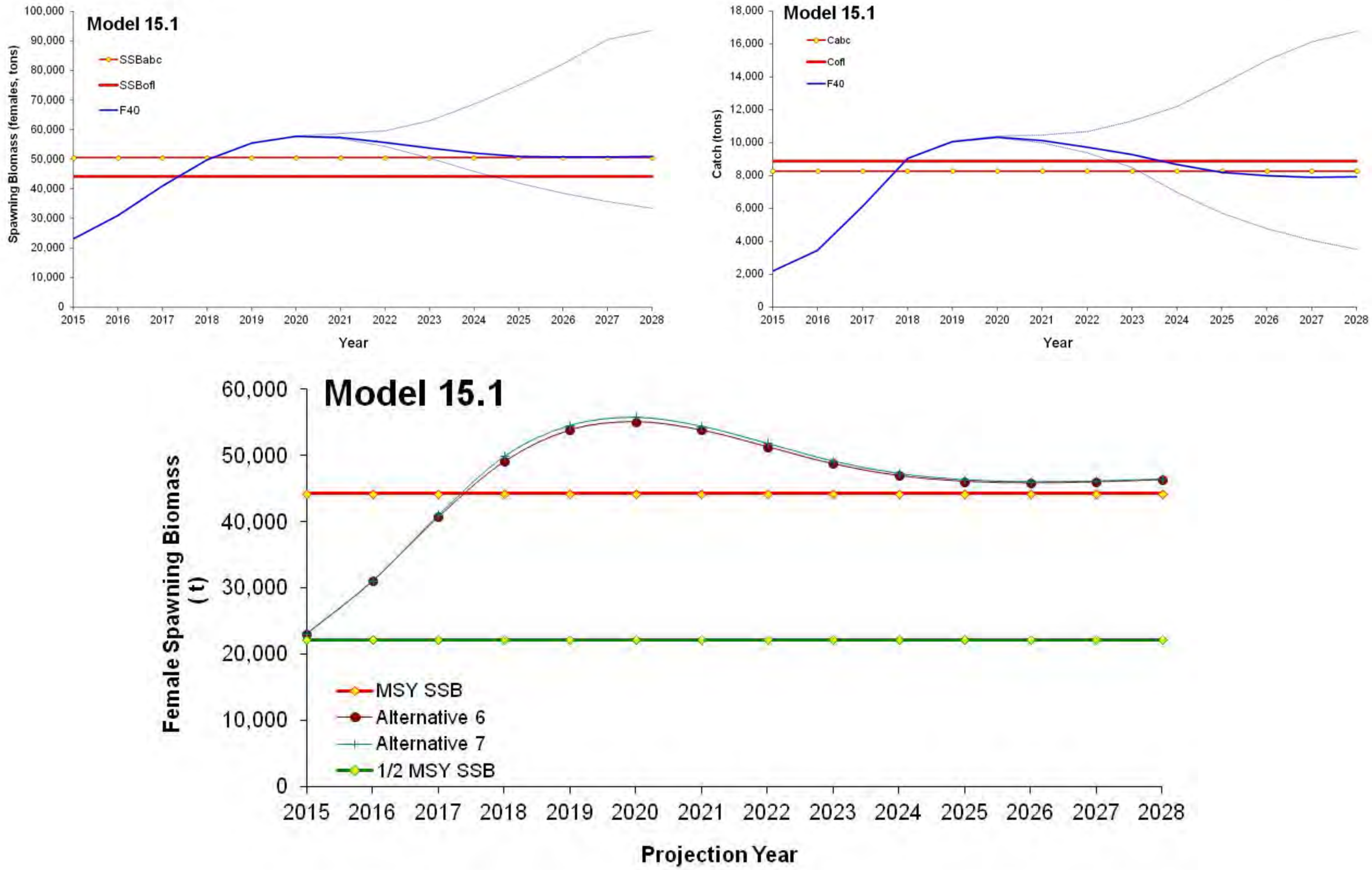


Figure 5.52. Alternative 1 projected (top left) female spawning stock biomass and (top right) catch at F_{40} fishing with long-term expected OFL and ABC reference levels, and (bottom) projected female spawning stock biomass under Alternatives 6 and 7 with SSB_{MSY} and ½ SSB_{MSY} reference levels. $SSB_{35\%}$ is our proxy for SSB_{MSY}.

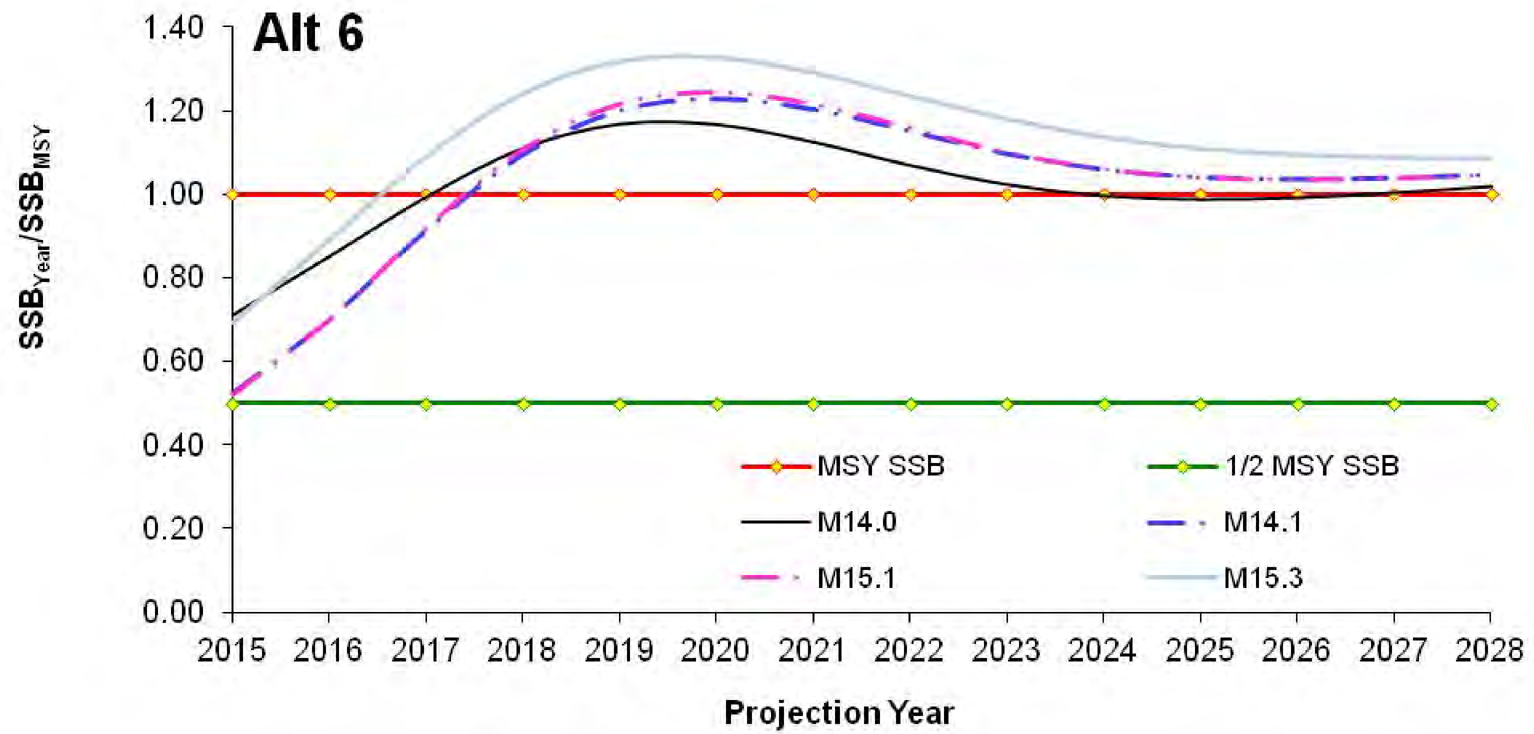


Figure 5.53. Alternative 6 projected female biomass divided by SSB_{MSY} for all models presented. Here catch is set at OFL for all years. The overfished is below ½ SSB_{MSY} (green line) in 2015 or below SSB_{MSY} (red line) in 2025.

veys.

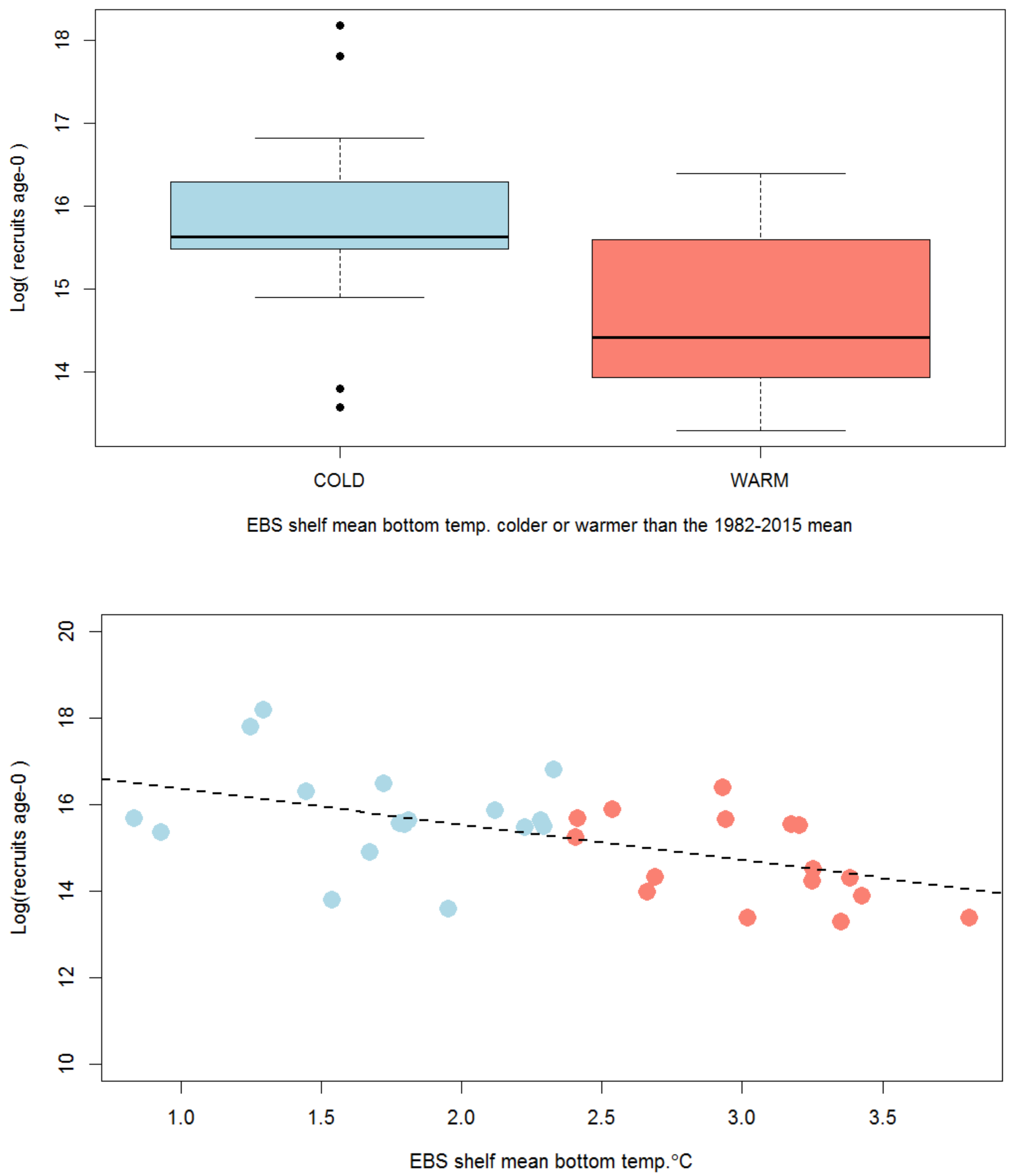


Figure 5.54. Greenland turbot Model 15.1 log recruitment at age-0 and mean bottom temperature from the EBS shelf survey (top) boxplot by above or below the mean temperature from 1982-2015 and (bottom) simple plot by EBS shelf mean bottom temperature (linear regression log(recruits age-0) ~ Temp. df = 31, R^2 = 0.289, p-value = 0.0012).

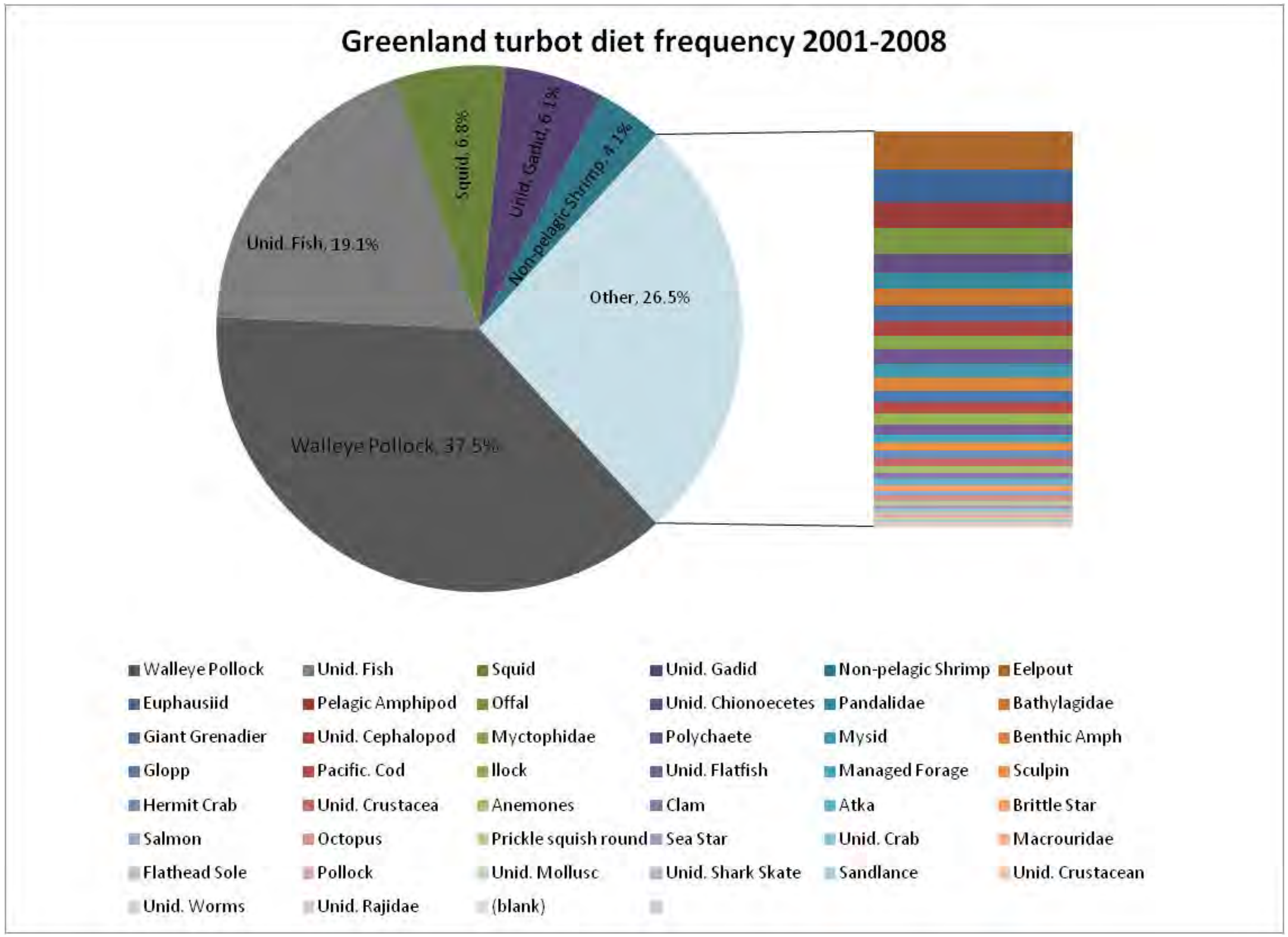


Figure 5.55. Greenland turbot prey items frequency in AFSC diet data for 2001-2008 from the Shelf and Slope bottom trawl sur