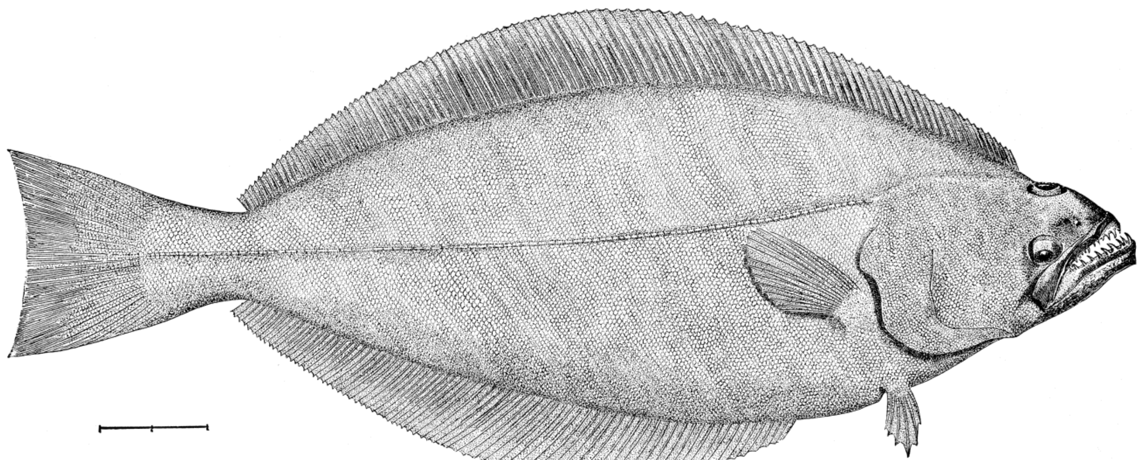
5. Assessment of the Greenland Turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

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Executive Summary

Two models are presented this year. Model 1 is the same as last year's (2013) Model 1 with updated and corrected data. Model 2 is based on Model 2 from last year (2013) with some minor improvements on selectivity and catchability as well as updated and corrected data. For the previous two years the authors have put forward Model 2 as an alternative model configuration which includes an autocorrelation parameter for recruitment deviations. The primary reason this model was not chosen is because the authors and the Plan Team concluded that the approach had not yet been thoroughly vetted. Thorson et al . (2014) show not only that this approach can be useful, but also provides a prior distribution for the autocorrelation parameter for Pleuronectidae species. We recommend the autocorrelated model (Model 2) be used for managing this species as it provides an improvement in overall fit to the data and better addresses recruitment in the 1960s when catches were high, but there were no composition or fishery independent data.

Summary of Changes in Assessment Inputs

Changes in the model

The length of females at 50% mature was discovered to be incorrect in the model and has been changed from 55 cm to 60 cm as per D'yakov's (1982). A comparison between Model 1 resulting spawning stock biomass and reference points at different length of females at 50% mature has been provided.

Other than updating the female length at 50% mature, Model 1 has the same configuration as Model 1 from 2013.

Model 2 has been adjusted from Model 2 for 2013. A prior of 0.437 (sd = 0.265) was used for the recruitment autocorrelation parameter instead of fixed at 0.6 as parameterized last year. Catchability (*q*) for both the shelf and slope surveys were fixed at 0.62 and 0.57 instead of like last year's Model 2 being fit with informative priors. An additional selectivity bin (2010-2014) was added to the longline fishery length composition data for Model 2.

Addition of new fishery and survey data

There was a new shelf bottom trawl survey and Auke Bay Laboratory (ABL) longline survey in 2014. The index values for the shelf bottom trawl survey used in 2013last year included estimates from the expanded northern strata, but the length composition was only from the standard survey region. This has been corrected for this assessment. The shelf composition data were changed to include all length and age data for the expanded survey into the northern strata for 1987 onward. The abundance estimate (or RPN for the ABL longline survey) and length data were added to this assessment

Fishery catch data for this year's model were updated to the 2014 numbers. There was a 433 t decline in the 2003 catch estimtate from last year. For all other years the change was minor (less than 12t). For Model 2 the 2006 and 2007 trawl fishery length composition data were removed as the sample sizes were deemed too small.

Summary of Results

This assessment applies the newly available survey and fishery data to Model 1 and alters Model 2 to provide the best fit to the new data. The 2007-2009 year classes still prove to be very large and are contributing to the steep increase in abundance in the BSAI. This after a 37-year decline in the stock where recruitment had not kept up with natural and fishing mortality. Both Models presented this year show an increase in both total biomass and spawning biomass as the strong 2007-2009 year classes mature. This year's estimate of $B_{100\%}$ for Model 1 (90,578 t) and Model 2 (130,123 t) bracket last year's estimate of 99,764 t. The estimated 2014 spawning stock biomass for Model 1 is 20,825t and Model 2 is 26,341t, which are equivalient to $B_{23\%}$ or $B_{20\%}$ which for Model 1 is the same as last year's projected status for 2014 at $B_{23\%}$. The projected 2015 estimated total biomass for Model 1 is 79,020 t and for Model 2 is 122,298 t, again bracketing last year's projectied total biomass estimate for 2015 of 96,298 t. The stock remains in Tier 3B and therefore the ABC and OFL recommendations are reduced by the descending portion in the harvest control rule. The long-term Fabc and Fofl for Model 1 are 0.203 and 0.252 and for Model 2 are 0.176 and 0.218. The 2015 recommended ABC from Model 1 is 2,923 t and 3,173 t for Model 2. Model 1 is at 92 % and Model 2 is at 100% of last year's projected 2015 ABC. Estimated catch indicates that overfishing did not occur in 2014. Neither model presented this year show the stock as currently overfished, and the stock is not approaching an overfished condition.

	As estimated or *specified last* year for:		As estimated or *recommended this* year* for:	
Quantity	2014	2015	2015	2016
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass	84,546	96,298	122,298	132,666
Female spawning biomass (t)	22,010	27,624	30,853	38,848
Projected				
$B_{100\%}$	99,764	99,764	130,123	130,123
$B_{40\%}$	39,906	39,906	52,049	52,049
$B_{35\%}$	34,917	34,917	45,543	45,543
F_{OFL}	0.14	0.18	0.12	0.18
$maxF_{ABC}$	0.12	0.15	0.10	0.15
F_{ABC}	0.12	0.15	0.10	0.15
OFL (t)	2,647	3,864	3,903	6,453
maxABC (t)	2,124	3,173	3,172	5,248
ABC (t)	2,124	3,173	3,172	5,248
EBS	1,659	2,478	2,448	4,050
Aleutian Islands	465	695	724	1,198
	As determined *last* year		As determined *this* year	
Status	2012	2013	2013	2014
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 2

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 2013: The SSC looks forward to the authors' responses to SSC comments from last year's (2012) assessment, as well as a more thorough evaluation of Model 2 (model with autocorrelation) in next year's assessment. Research into potential mechanisms behind such an autocorrelation is a high priority for this depressed stock.

Authors' Response: We continued to evaluate autocorrelation in recruitment for this stock and have determined that Model 2, with autocorrelation specifically modeled is the better choice for management as it provides the better model fit and diffuses the large pre-1970 recruitment seen in previous uncorrelated models. Thorson et al. (2014) analysis of autocorrelation in stock recruitment have provided substantial documentation on including autocorrelation in recruitement and a prior for use in Pleuronectidae species assessments such as Greenland turbot.

Introduction

Two models are presented for consideration. Model 1 is the model configuration that has been accepted by the SSC for the previous 2 years updated with the most recent data. An error was discovered in the female length at 50% mature used last year and has been corrected in both models presented this year. Model 2 is similar to the models presented for the past 2 years with a parameter for autocorrelation in recruitment. Model 2 differs from last year's autocorrelated model in that an additional time block (2010-2014) for the longline fishery selectivity was added to improve the residual pattern, and catchability was fixed for shelf and survey indices. The stock continues to be modeled using the same software as previous assessments (Stock Synthesis 3).

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*, common name of 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 Chuchki seas. 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, straddling the border between US and Russian exclusive economic zones. 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 (< 100m) and colder shelf waters (< 0°C). The larger specimens were in higher concentrations in deeper (> 100 m), warmer waters (> 0°C) (Fig. 5.3 and Fig. 5.4).

Juveniles are absent in the Aleutian Islands (AI) 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. For this assessment, data from the AFSC slope and shelf surveys from 2003 - 2011 were pooled to obtain growth curves for both male and female Greenland Turbot (Fig. 5.5). This sexual 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 much smaller maximum size 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. 5.6). 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 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 and as of October 27 catch in 2014 was at 1,645 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. 7 and Fig. 5. 8), 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. Since 2008, however, at a 400km^2 resolution, the cells with highest amounts of catch have been observed in the Eastern Aleutian Islands (Fig. 5.9), 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 higest catch of Greenland turbot outside of the directed fishery. For 2008, 2012, 2013 and in the preliminary catch data for 2014, Greenland tubot catch in the Arrowtooth/Kamchatka fishery has exceeded the directed catch.

Within the domestic fishery from 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). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (approximately 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 10.3% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2014. The overall discard rate of Greenland turbot has dropped substantially in recent years from a high of 84% discarded in 1992 down to only 2% in 2011 and 2012. Because of the drop in the ABC for 2013 and 2014 the overall discard rate has increased to 20% in 2013 and 15% so far in 2014. In the preliminary 2014 catch data 60% of the Greenland turbot discard (208 t) has come from the Arrowtooth and Kamchatka fisheries.

Greenland turbot catch in the Aleutian Islands through 2007 was split nearly even between trawl and longline fisheries In 2008 the trawl fishery started catching the majority of Greenland turbot (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 2014 data the EBS trawl fishery has caught a larger share of EBS quota than longliners(813 t and 656 t, respectively). 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 - 2014 (Table 5.3).

Data

Fisheries data used within this assessement were split into the longline (including all fixed gear) and trawl fisheries. Both the trawl and longline fishery data include observations and catch from targeted catch and bycatch. There are also data from three surveys: the shelf and slope bottom trawl surveys conduced by the RACE Division of the AFSC and the ABL longline survey. The type of data and relevant years from each can be found in Table 5.5 and Figure 5.10.

Fishery data

Catch

The catch data were used as presented above for both the longline and trawl fisheries (Table 5.1). The early catches included Greenland turbot and arrowtooth flounder combined. In order to separate the catch of Greenland turbot from the combined catch, 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 2013. The length composition data from the trawl and longline fisheries are presented in the Appendix 5.1 (along with the expected values from the assessment model) and absolute sample sizes for the period of the domestic fishery by sex and fishery from 1989-2014 are given in Table 5.6

Catch totals from research and other sources

Annual research catches (t, 1977 - 2014) 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	*
Year	2013	2014															
NMFS BT surveys	1.0	1.3															
Longline surveys	*	*															

* Not yet available from AKFIN

2010 sport and research catches for Greenland turbot:

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

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).

EBS slope and shelf bottom trawl survey

The older juveniles and adults on the slope have been surveyed triennially from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. From 1979-1985, the slope trawl surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency. In 1988, the NOAA ship R/V 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 R/V Miller Freeman for calibration purposes,however, the R/V Miller Freeman sampled a smaller area and fewer stations in 1988 than the previous years. The R/V Miller Freeman sampled 133 stations over a depth interval of 200-800 m as opposed to earlier slope surveys where 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 EBS upper continental slope 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). Although the size composition data for trawl surveys prior to 2002 were used in this assessment, the abundance estimates were not (Table 5.8). This was decided after discussions with Dr. Jerry Hoff, the current Slope survey Chief Scientist. Dr. Hoff stated that the older slope survey data were not comparable to the most recent surveys, and may not have been conducted consistently enough in the early years to be considered a time series. The surveys differed in vessel power, in gear used, and in the ability of the surveyors to determine whether the gear was in contact with the bottom.

The slope trawl surveys are likely to under estimate the BSAI-wide biomass of Greenland turbot since fish are found consistently in other regions. A similar issue likely affects the distribution of Greenland turbot on the shelf region(Ianelli et al. 2011). The shelf and recent slope survey biomass estimates are therefore treated as a relative abundance index and a separate catchability parameter were set for each.

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 (1994-2014) was 27,077 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys are presented in Table 5.8. In 2010 and 2011 there was an increase in the proportion of tows with Greenland turbot present and the abundance estimates from the shelf surveys indicated a significant increase of Greenland turbot recruitment (Fig. 5.11). 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.

Although the 2012 EBS slope biomass estimate of 17,984 t was down from 2010 estimate of 19,873 t (Table 5.9), the population numbers in 2012 of 11,839,700 fish was more than double the 2010 estimate of 5,839,126 fish (Table 5.10). The 2012 Slope survey abundance estimate was the highest population estimate since the Slope survey 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 (Tables 5.9 and 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 abundance is a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007, 2008, and 2009 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Fig. 5.12).

Survey size composition

A time series of estimated size composition of the population is available for both shelf and slope trawl surveys. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the number of fish measured in the slope survey is greater. The shelf survey is useful for detecting recruitment patterns that are consistent with the trends in biomass. Increase in recruitment has been visible over the last 7 years (Greenland turbot less than about 40 cm) following an absence of small fish during 2004-2006.

Survey size-at-age data 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 survey age composition data from 2003-2012 were included.

Aleutian Islands survey

The 2014 AI 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 of the AI 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 AI 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. 2012), but that did not hold true for 2014 where we saw an increase in bottom temperatures. The trawl-survey area-swept data for the AI component of the Greenland turbot stock is not presently included in the stock assessment model.

Longline survey
The ABL longline survey for groundfish alternates years between the AI and the EBS slope region. The combined time series is used as a relative abundance index (Table 5. 12). It is computed by taking the average RPN from 1996-2014 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 functions (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions (1996-2014) 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 U.S.-Japanese cooperative longline survey in 1979 and is shown in Fig. 5.12.

Analytic Approach

Model Structure

A version of the stock synthesis program (Methot 1990) has been used to model the EBS 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 are from 1960 to 2014. Model parameters are estimated by maximizing the log posterior distribution of the predicted observations given the data. The model includes data from two fisheries (fixed gear (longline and pots) and trawl), together with three surveys covering various years (Table 5.5). No new modeling approaches were examined in this year’s assessment. The models presented are based on 2013 Model1 and Model 2. These continue to use the Beverton-Holt curve, and early recruitment series is carried back to 1945. The results from these two models were similar.

Parameters Estimated Outside the Assessment Model

All independently estimated parameters were the same for both models presented. These parameters are listed in the following table.

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 is 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).

Maturation and fecundity

Maturity and fecundity followed the same assumptions as last year's models except the female length at 50% mature was corrected from 55cm to 60cm as per D'yakov (1982). Recent studies on the fecundity of Greenland turbot indicate that maturity 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 the ABL longline and both bottom trawl surveys conducted by the AFSC in the BSAI. 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, separate weight at length relationships were calucated for each sex in 2012 that continue to be used ($w = 2.43 \times 10^{-6} L^{3.325}$ 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

Determining the appropriate multinomial sample size for the size composition data is always problematic. This year’s assessment model was fit following the methods employed by many of the Northwest Fisheries Science Center groundfish. Initial values were selected and then the models were tuned to match the output effective sample size by having the effective N/ adjusted input values close to 1. Initial sample sizes for the two fisheries for each year were set to 50 (Table 5.13). The initial annual size composition sample sizes for the surveys were set at the same values as those used in previous assessments. The shelf trawl survey sample sizes were set to 200, the 2002 through 2012 slope survey sample sizes were set to 50, while those prior to 2000 were set to 25. The ABL longline sample sizes were set to 60.

Parameters Estimated Inside the Assessment Model

The following are the key parameters estimated and the corresponding number of parameters within the two candidate models.:

Parameter	# of Parameters Model 1	# of Parameters Model 2
Recruitment		
Early Rec. Devs	(1945-1970) 25	(1945-1970) 25
Main Rec. Devs	(1970-2012) 43	(1970-2012) 43
Late Rec. Devs	(2013-2014) 3	(2013-2014) 3
Future Rec. Devs	(2015-2016) 2	(2015-2016) 2
R_0	1	1
Rho	0	1
Growth		
L_{min} (M and F)	2	2
L_{max} (M and F)	2	2
Von Bert K (M and F)	2	2
Catchability		
q_{Shelf}	1	0
q_{Slope}	1	0
Selectivity		
Trawl Fishery	21	21
Longline Fishery	7	13
Shelf Survey	17	17
Slope Survey	2	2
ABL Longline Survey	2	2
Total Parameters	130	135

Recruitment and generating 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 2012 and 2013 assessment models and both of 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). For Model 2 an autocorrelation parameter was investigated 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. Although different ρ -values were explored last year, ρ was fixed at 0.6 for the 2013 Model 2. For this year's Model 2 we used the prior of 0.473 (SD=0.265) estimated by Thorson et al. (2014) for Pleuronectidae species. For both Model 1 and 2 the starting year was pushed back to 1945 which allowed more flexibility for 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). Both sets of Rec.Dev.s are deviations from R_0 and sum to 0.0 seperately. Seperating 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 for 2014 this differentiation between the two periods had 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

In Model 1 the shelf survey was fit with a lognormal prior (log(q) = -0.6938, q = 0.5) log SD = 0.4) and an informative lognormal prior on the slope survey (log(q) = -0.28768, q = 0.75) log SD = 0.1). With the change in data the fit for q with these priors started to become unreasonably high. To counteract this for the Model 2 presented this year we selected catchabilities for the shelf and slope from a model fit without the 2007 through 2014 data. This was meant to eliminate the effects of the 2007 through 2009 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. The different time blocks for the fisheries and surveys are shown in the table below. For Model 1these blocks were the same as those used in the 2013 models. For Model 2 we added a time block for 2010-2014 for the longline fishery. Data from the longline survey are combined hence a sex aggregated size-based selectivity function was used.

	Sex specific?	Number of blocks	Block years
Trawl Fishery	Yes	3	1945-1988, 1989-2005, 2005-2014
Longline Fishery			
Model 1	Yes	Model1(2)	1945-1990, 1991-2014
Model2	Yes	Model2(3)	1945-1990,1991-2009, 2010-2014
Shelf Survey	Yes	4	1945-1991, 1992-1995, 1996-2000, 2001-2014
Slope Survey	Yes	1	1945-2014
ABL Longline Survey	No	1	1945-2014

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 parameter (inflection)

p2 is added to the second selectivity parameter (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

This method was used for all fisheries and surveys with separate sex data. As in the 2013 models, the longline fishery and slope survey selectivity assume a single logistic curve. The longline survey size composition data poses a challenge to modeling since sexes are aggregated and the data are often bimodal which presumably represents males and females. Although a simple logistic model can be fit to the data, the residual pattern is often undesirable.

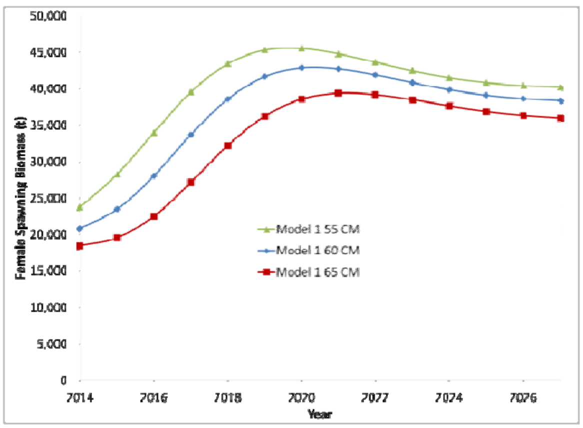
Length-at-age

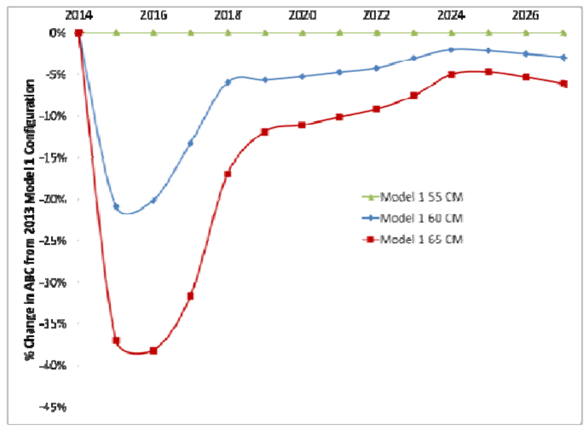
Parameters describing length-at-age are estimated within the model. Length at age 1 is assumed to be the same for both sexes and the variability in length at age 1 is assumed to have an 8% CV while at age 21 a CV of 7% is assumed. This appears to encompass the observed variability in length-at-age. As 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 5.14.

Results

Female length at 50% mature

As describe previously the female length at 50% mature was incorrectly parameterized in previous models, back to 2002. The value used previously was 55 cm but was changed to 60 cm for models considered in this year's assessment. We ran last year's configuration, Model 1, with values at 55 cm, 60 cm, and 65 cm to show the effects of changing this value. A length of 65 cm is near the value suggested by Cooper et al. (2007). This change does not effect the status of the stock or the model fit. It did however change the reference points and current estimates of spawning biomass (Fig. 5.13 and below) and therefore the ABC and OFL values.





Model Evaluation

Two models are presented in this year's assessment. Model 1 is the same as the 2013 Model 1 with updated data through 2014. Model 2 was configured as Model 1, except that recruitment was modeled with an informative prior on an autocorrelation parameter with a mean of 0.473 and standard deviation of 0.265, catchability was fixed, and an additional selectivity time block was instituted for the more recent (2010-2014) longline fishery length compositon data. Both candidate models were configured to have Beverton-Holt stock recruitment curve with fixed parameters noted above.

Table 5.15 includes the likelihood values for last year's authors' preferred and both of 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 5.16 provides measures of model fit to the individual component of all three models including survey index RMSE, mean effective N for the age and size composition data and the recruitement variability for the candidate models. The fits to the data are very similar between the the two models presented.

Selection of the 2014 Author's selected model was based on the following considerations. Models 1 and 2 have different error and data structures and therefore can not be compared using model likelihoods. Model 2 has a marginally worse fit to the survey indices due to fixed catchability, but has a marginally better fit to the length and age components for the fishery data and shelf survey, and slightly worse fit for the slope and ABL longline survey length composition data.

The inclusion of an autocorrelation parameter made a difference in the pre-1970 recruitment deviations. To have enough Greenland turbot to support the early fishery, Model 1 created a single large positive deviation in 1964, while Model 2 created a series of lesser positive deviations between 1961 and 1968 (Fig.5.13). Because these models rely primarily on size composition data, especially in the early part of the catch time series, the estimates of population age structure prior to 1970 is uncertain. Importantly, the autocorrelation parameter reflects characteristics of many groundfish stocks which undergo periods of low recruitment and periods of above average recruitment. Such a pattern might be more plausible, particularly absent any information suggesting a single strong year class occurred in 1962 (other than the fact that the population as modeled required more fish to account for the large catches).

In addition the retrospective pattern for the two models are substantially different and Model 2 shows a substantial improvement over Model 1 (Model 1 Rho = 0.62 vs. Model 2 Rho = 0.32). The majority of this improvement was simply due to fixing the shelf and slope survey catchability and therefore may not actually show an improvement in the model.

In the end there is little quantifiable difference between the two models that can be used to decide between the two models. In the Authors' opinion Model 2 is the preferred model due to how it handles the pre-1970 recruitment deviations, providing a more diverse age structure in the "pre-historic" model. In addition the large late-1970's and late 2000's high recruitment are evidenced in the data and shown to cover a number of years suggesting there is autocorrelation in recruitment for this species.

Model 2 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 fit to all the surveys is approximately the same as the fit in last year's models. The shelf survey fails to fit the high 1994 shelf survey biomass estimate (Fig. 5.14). In addition the model does not fit the 2003 and 2004 increase in abundance but provides a simple slope from the high in 1995 through the low 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. Larger Greenland turbot are thought to migrate off the shelf and this probably varies depending on environmental conditions. This type of variability (due to irregular ontongenetic movement) may indicate the need for time-varying selectivity curves (Fig. 5.15).

The slope survey index used in this year's assessment comprises only 5 points yet fits reasonably well (Fig. 5.16). 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 available to the US surveys. Additional tagging studies should be conducted to address the issue of adult Greenland turbot movement. Ideally, tagging studies should be conducted cooperatively between the US and Russian management agencies.Although not implemented this year, the authors are exploring a split area model that would allow ontogenetic movement between the slope and shelf.

The fit to the ABL longline survey index of abundance mimics the 1996 - 2010 index decline (Fig. 5.17). 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. A trend is present in the residuals in which the earlier high values tend to be underestimated and the later low values overestimated. The RPN index values are highly variable between years in the later period. 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 2010 values were low compared to the earlier surveys, the uncertaintly around these points was also lower. The point estimates for this period are likely less precise then what was assumed. A geostastical based estimate of variability should be explored for this index which could provide a better starting point for the uncertainty used in our assessment.

<u>Age composition</u>
The shelf survey age composition predictions matched the data well for both males and females (Fig. 5.18). The model consistently underestimated the peak proportion at age for the younger fish and overestimated the proportion at age for older fish. The difference was more inflated in the females then the males. However, with the exception of the 1998 age composition data, this disagreement was generally small. The large proportion of age 2 and 3 fish were not fit well in the 1998 shelf survey data. The high numbers of young fish observed in the shelf survey for 2007 through 2009 were consistent with the size composition data and were fit well by the model.

<u>Length at age</u>
The model fit the length at age data for both males and females well (Fig. 5.19). 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).

<u>Size composition</u>

Overall Model 2 did a reasonable job of capturing the large trends observed in the size composition data (Fig. 5.20). The trawl fishery size composition data (Fig. 5.21 and Fig. 5.22) is not fit well and and fitting these data remain problematic. There was a large shift in the trawl fishery selectivity between the foreign and domestic fisheries (Fig. 5.23 and Table 5.17) 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 varying selectivity, there remains patterns in the residuals for females that are problematic in the early years of the size data (1979-1989; Fig. 5.23). The trawl fishery size composition data are pooled from the directed fishery and from bycatch 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 seperate 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 could 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 2 fit to the longline fishery data (Fig. 5.24. Fig. 5.25, and Table 5.16) appeared reasonable. There was only a small shift in selectivity to smaller fish between the two early time blocks and a larger shift in the later 2010-2014 time block (Fig. 5.26). 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 mimicks the migration of males to deeper waters at a smaller size than females.

Model 2 fit to the shelf survey data is similar to the fit to the 2013 Model 1 configuration. The model performs poorly in 1999 through 2005 when there are a higher proportion of large fish on the shelf than in earlier and later years (Fig. 5.27 and Fig. 5.28). In this case the model appears to consistently underestimate the proportion of larger fish, particularly for larger females.

The slope survey size composition selectivity was modeled as a logistic model (Fig. 5.29) with no time blocks, but separate selectivity for males and females. The model fits (Fig. 5.30) were about the same as last year's Model 1. The fits were rather poor and generally underestimated the peak of the highest abundance size bins, particularly for males (Fig. 5.30). This may therefore underestimate the large males in the population. No other survey or fishery encounters these large males. Although 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 50 cm and 70 cm (Fig. 5.31), the raw survey data show no trend in male to female ratio for all sizes in aggregate (Fig. 5.32).

The ABL longline survey 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 at last year's September plan team 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. We fit the model using a single logistic curve(Fig. 5.33), but these data were bimodal and the model tends to fit a single mode to these data resulting (Fig. 5.34) in overfitting between the male and female peaks and underfitting the two peaks for all years.

Splitting the selectivity for males and females and increasing the weight to the slope survey 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.

Time Series Results

In this section we will present the results from Model 2 and predicted time series. In all instances in this section “total biomass” refers to age 1+ biomass, spawning biomass is the female spawning biomass, and recruitment is age 0 numbers from the model unless otherwise specified.

Recruitment

Model 2 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 0.601 with a standard deviation of 0.04. The most striking feature of the Model 2 recruitment (Fig. 5.35, Table 5.18, and Table 5.19)are the extremely large 1962- 1967 year classes with between 75 and 292 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. Unlike Model 1 used in 2013, Model 2 fits autocorrelation in the recruitment forcing the model to create several large year classes throughout the 60s. Due to how the recruitment deviations likelihood is specified using SS3, 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. Model 2 was intended as a means to spread these recruitment events out without assuming changes in early productivity. The Model 2 configuration was rejected by the Plan Team in 2012 because the inclusion of autocorrelation in SS3 had not been throuroughly vetted. A recent study by Thorson et al (2014) has shown improved model performance with the assumption of autcorrelated recruitment deviations and in this case we see an improvement in recruitment and how these early years are handled by the model.

After 1970, Model 2 fits another large recruitment event during 1974-1978 with an average recruitment of 95 million fish during these five years reaching a maximum of 149 million age-0 fish in 1975. As there were no size composition data prior to 1977, the basis for these large year classes was the existence of many large fish in the early longline fishery. Because Greenland turbot appear to reach a terminal size, the exact ages were not known and therefore the exact years for these recruitment events were not known and may change in future models under different configurations. The 1978 year class was well documented and can be traced from the trawl fishery through 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 5.4 million age-0 fish (rec.var=0.92). The mean age-0 recruitment from 1977 through 2014 was estimated at 13.8

million fish (rec. var. = 1.24). Recruitment of age-0 fish was estimated in 2007 at 16.1 million, 2008 at 43.4 million, 2009 at 84.6 million and 2010 at 17.1 million age-0 fish. 2009 saw the largest recruitment since 1976. 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. Although the 2014 longline fishery data are not complete for 2014 as a significant portion of the fishery occurs in October and November, we do see these large year classes beginning to enter the size composition data. The influx of new recruits from 2007 through 2010 result in a sharp drop in the predicted population mean size and mean age (Fig. 5.36 and Fig. 5.37).

<u>Biomass and fisheries exploitation</u>

The BSAI Greenland turbot spawning biomass in Model 2 was projected for 2015 at 30,853 t to be increasing from its lowest level of 24,931 t ($B_{19\%}$) in 2013, a drop from a peak of 230,809 t in 1977 ($B_{177\%}$; Table 5.20, Table 5.21, Fig.5.38 and Fig. 5.39). The large early 1980s fishery combined with a lack of good recruitment in the mid- to late-1980s through the 1990s drove the steepest part of the decline in spawning biomass. The mean age-0 recruitment from 1986 to 2006 was 4.6 million fish (33% of the overall 1977-2014 mean recruitment). In 1990 the NPFMC cut ABCs to 7,000 t until 1996 to account for low recruitment; however the ABCs were exceeded in 5 of the 7 years (Table 5.1). The stock continued to decline in the 1990s as poor recruitment continued. In 1997 the NPFMC started managing the stock as a Tier 3 stock and the ABCs were allowed to increase (Table 5.1). The mean ABC between 1997 and 2002 was 9,783 t, the mean catch however was lower and averaged about 6,355 t per year over this period. From 2003 to 2008 the ABC levels remained relatively low with a high of 4,000 t in 2003 and a low of 2,440 t in 2007. The catch dropped even lower to an average of just 2,417 t per year in this period. In 2008 with Amendment 80 an arrowtooth/ Kamchatcka 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 from 2008 through 2012 was 3,988 t. The ABCs during this period, due to a clerical error in the projection model, increased from 2,500 t in 2008 to 7,380 in 2009. From 2009 to 2012 the ABC averaged 7,325 t with a high of 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 0.13 with a maximum total exploitation rate of 0.25 (Table 5.17 and Fig. 5.40). The increased fishing explotation rate in 2009 and 2010, that may have steepened the most recent decline, was only 0.21 and 0.17, respectively. The catch levels in 2008 through 2012 however exceeded the OFL control rule levels projected from Model 2 (Fig. 5.41). 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 2015 and onward predict an increase in spawning biomass as these year classes grow and mature.

The 2014 Model 2 total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 of 503,964 t to its lowest point in 2010 of 58,390 t (Fig. 5.39). 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 97,442 in 2014 and projected to be at 122,298 t in 2015. The increase in total age 1+ and female spawning biomass over last year's model is partly due to a change the size at age relationship from last year (Table 5.22) with the addition of data from the northern portion of the shelf survey.

<u>Retrospective analysis</u>

The restrospective analysis was conducted in SS3 by removing data systematically by year from both Model 1 and Model 2 for 10 years (Figs. 5.42, 5.43, 5.44, and 5.45). The largest changes in the retrospectives for both models were between -7 and -6 years (from 2007 to 2008). In Model 1 as we removed data, catchability for both the shelf and the slope surveys trended lower until between -7 and -6, at which point it stabilized somewhat (Fig. 5.44). This is likely the effect of the large 2007-2010 year classes entering the shelf survey, but not yet fully recruited as adults to the slope in the 2012 slope survey. The Model 1 provides a better fit with an increasing q with the newer shelf survey index because it doesn't show a large increase in biomass. 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 survey composition data and none of the more recent indices show a large increase in biomass that would be expected if the fish had remained in the area. This highlights the problem resulting from the lack of 2014 slope survey. Greenland turbot are a migratory stock and should be evident in this region. Using the alternating ABL longline survey as an index without the balancing slope survey is also problematic as the 2014 longline survey occurred in the Aleutian Islands and the recent large recruitments observed on the shelf have not yet been observed in the Aleutian Islands.

In general, Model 2 with the fixed catchability provides a better retrospective pattern (Model 1 Rho = 0.62 vs. Model 2 Rho = 0.32). This is not unexpected because Model 2 is constrained by the fixed catchabilities. In both models R_0 is affected by the large year classes. Even with a fixed catchability for Model 2, an increasing trend is evident as data are removed. However, the change in R_0 is a bit steeper between -7 and -6 in Model 1, where q is allowed to change. Other parameter changes with recruitment of the large incoming year classes including shelf and slope survey selectivity parameters, main recruitment deviations, and growth parameters (Fig. 5.45). The shift in both slope survey selectivity parameters is dramatic with the exclusion of the 2012 composition data between year -2 and -3 in both models. The main recruitment deviations post-1984 show an increasing trend as data are removed. Von Bertalanffy 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 beween years -7 and -6.

MCMC

This year we are presenting Bayesian posterior distributions of our parameter estimates simply as an informative exercise (Fig. 5.46). We used a Markov chain approach to investigate the behaviors of our parameter estimates. This approach was not used to determine any of our final model estimates where the asymptotic likelihoos estimates were used. In short, a random walk through the parameter space was simulated using a Markov chain. The Markov chain converges to a stationary distribution approximating a posterior distribution. For this exercise we removed the first 10,000 iterations out of 2,000,000 for burn-in and "thinned" the sample to every 2,000th iteration, leaving 995 iterations. Most parameters in Model 2 behaved as expected, The maximum likelihood estimates (MLE) for recruitment and spawning stock biomass fit within the posterior distribution and median well (Fig. 5.47 and Fig. 5.48). The recruitment deviations were well behaved in this model (Fig. 5.49). There is general agreement between the MLE and the MCMC posterior median for most parameters. There was a difference between the MLE and the posterior median for the recruitment autocorrelation parameter (0.60 vs. 0.53), but the difference was not enough to greatly influence recruitment estimates (Fig. 5.47). In addition selectivity parameters for the trawl fishery and shelf survey appear to have differences, but again appear to have little effect on the ending model estimates. In some cases it appears there is little information in the size composition data to inform the individual parameter selection, here the posterior distributions appear flat and both the posterior median and asymptotic fit remain at the initial value. This is translated into increased uncertaintly in the estimates. For several of the selectivity parameters for the trawl fishery and shelf survey it appears that the maximum likelihood estimates are likely limited by parameter boundaries. This raises a question of whether the selectivities presented are appropriate and further likelihood profiles and sensitivity analyses will be conducted to determine the effects of these parameter selections on model performance and final estimates.

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean recruitment estimated for the period 1977-2014 gives a long-term average female spawning biomass of 52,049 t. The estimated 2014 female spawning biomass is at 26,341 t or $B_{20\%}$,well below the estimate of $B_{35\%}$ (45,543 t). Because the projected spawning biomass in year 2014 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.; e.g.,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 2013 a slope survey was conducted and while some areas show lower abundances (i.e., the Aleutian Islands) the signs of recruitment are the best 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 2015 and 2016 are shown below (catch for 2014 was set to 1,805 t):

Year	Catch (for projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2015	3,172 t	3,172 t	3,172 t	3,903 t	30,853 t
2016		5,248 t	5,248 t	6,453 t	38,848 t

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is 3,903 t corresponding to a full-selection F of 0.12. 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 EBS and AI 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 AI and the EBS. In support of this hypothesis, the length compositions from the AI 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 AI and EBS has varied (Table 5.23).

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 EBS slope survey estimates and AI surveys, the proportions of the adult biomass in the AI 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:

	2015 ABC	2016 ABC
Aleutian Islands ABC	724	1,198
Eastern Bering Sea ABC	2,448	4,050
Total	3,172	5,248

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 2014 (here assumed to be 1,805 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 2015, are as follows ("*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 2008-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

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

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA′s requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above half of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, 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 expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2014 (Table 5.24). Fishing at the maximum permissible rate indicate that the spawning stock (Fig. 5.50) 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 2013 spawning biomass estimated at 19,865 t relative to $0.5B_{35\%}$ = 17,459 t) and will be above its MSY value (34,918 t) in 2023 at 50,259 t.

Projections with fishing at the maximum permissible level result in an expected value of spawning biomass of 57,526 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 wain and the projection relies on mean recruitment.

Under Scenarios 6 and 7 of the 2014 Model 2 the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Ecosystem Considerations

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 on 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.

Data Gaps and Research Priorities

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

- An evaluation of possible differential natural mortality between males and females,
- Spatial distribution and migration needs to be better explored through tagging experiments,
- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear.
- Although we understand that a portion of this stock extends into Russian waters, Russian catch is not considered in this assessment. How to take into account this unknown mortality should be explored further.

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Tables

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

Year	Trawl	Longline & Pot	Total	ABC	TAC
1977	29,722	439	30,161	40,000	
1978	39,560	2,629	42,189	40,000	
1979	38,401	3,008	41,409	90,000	
1980	48,689	3,863	52,552	76,000	
1981	53,298	4,023	57,321	59,800	
1982	52,090	32	52,122	60,000	
1983	47,529	29	47,558	65,000	
1984	23,107	13	23,120	47,500	
1985	14,690	41	14,731	44,200	
1986	9,864	0.4	9,864	35,000	33,000
1987	9,551	34	9,585	20,000	20,000
1988	6,827	281	7,108	14,100	11,200
1989	8,293	529	8,822	20,300	6,800
1990	12,119	577	12,696	7,000	7,000
1991	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*	946	700	1,646	2,124	2,124

*Catch estimated as of October 23, 2014

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2014. 2014 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	0	0	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	0	30	203	7	4,624	96
2013	579	13	27	38	12	5	49	10	38	42	635	208	0	13	38	2	1,394	351
2014*	624	16	11	44	12	5	40	1	28	49	598	129	1	27	44	0	1,391	255

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2005-2014. Source: NMFS AK Regional Office catch accounting system.

	"Target" fishery	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Longline and pot	Greenland turbot	1,531	1,212	1,232	743	1,191	1,833	1,773	1,914	589	626
	Sablefish	76	132	137	124	149	100	57	52	63	55
	Pacific cod	166	77	129	76	84	111	174	123	15	15
	Kam/Arrow flounder	0	140	16	0	9	49	0	4	0	0
	Halibut	104	63	19	12	0	74	30	13	28	3
	Others	2	5	11	22	1	0	0	1	4	0
Trawl	Greenland turbot	24	0	2	205	1,349	118	4	0	3	14
	Pacific cod	15	21	90	9	2	5	0	1	2	2
	Kam/Arrow flounder	154	21	3	1,176	1,434	1,690	1,483	2,277	843	727
	Atka mackerel	167	117	130	201	118	62	64	209	40	45
	Flathead sole	150	28	58	99	49	13	2	46	39	19
	Pollock	31	65	107	86	44	26	29	53	21	41
	Rockfish	139	74	47	142	73	59	28	18	54	41
	Other Flatfish	34	1	12	11	4	1	0	1	4	0
	Rock sole	1	27	8	0	2	3	1	0	3	5
	yellowfin sole	7	8	1	1	4	1	6	6	35	52
	Sablefish	7	0	0	5	1	0	0	0	1	0
	Others	0	0	0	0	0	0	0	0	0	0

* Through October 2014

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2003-2014.

Area	Gear	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Aleutian Islands	Fixed	360	238	167	358	345	110	99	220	90	58	66	44
	Trawl	340	196	301	179	178	712	2,164	1,653	442	1,600	231	133
AI Total		700	434	468	537	523	822	2,263	1,872	532	1,658	296	177
EBS	Fixed	1,821	1,346	1,713	1,270	1,201	867	1,336	1,948	1,944	2,050	634	656
	Trawl	591	479	427	183	280	1,222	916	325	1,176	1,012	815	813
EBS Total		2,412	1,825	2,140	1,453	1,481	2,089	2,252	2,273	3,120	3,062	1,449	1,469
Grand Total		3,111	2,259	2,608	1,989	2,004	2,911	4,515	4,145	3,652	4,720	1,745	1,646

* Estimated through Oct. 2014.

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, 2008-2014
Longline fisheries		
	Catch	1960-2014
	Size composition	1979-1985,1993-2014
Shelf Survey		
	Abundance Index	1987-2014
	Size composition	1982-2014
	Age composition	1998,2003-2012
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 abundance index	1996-2014
	Size composition	1979-2014

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2014. 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	1,009	1,304		44%	382	463		45%

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, 1975-2014. Note that the shelf survey estimates from 1985, and 1987-2014 include the northwestern strata (8 and 9) and these were the values used in the model. The Aleutian Islands surveys prior to 1990 used different operational protocols and may not compare well with subsequent surveys. The 1988 and 1991 slope estimates are from 200-800 m whereas the other slope estimates are from 200 - 1,000m.

	Eastern Bering Sea		Aleutian Islands
Year	Shelf	Slope	Survey
1975	126,700		
1979	225,600	123,000	
1980	172,200		3,598*
1981	86,800	99,600	
1982	48,600	90,600	
1983	35,100		9,684*
1984	17,900		
1985	7,700	79,200	
1986	5,600		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

Table 5.8. Levels of Greenland turbot biological sampling 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	150	1,567	11	11	292	292
1983	442	120	951				
1984	460	65	536	20		263	
1985	417	94	685				
1986	388	59	195				
1987	393	53	377				
1988	441	63	414				
1989	444	75	432				
1990	404	78	544				
1991	406	74	658				
1992	361	73	616	5		7	
1993	396	73	632	7		179	
1994	436	57	536	17		196	
1995	537	51	353				
1996	382	75	450	8		100	
1997	382	66	298	11		79	
1998	616	73	445	25	21	200	127
1999	426	51	207	8		11	
2000	423	61	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	64	442	57	56	294	278
2006	457	56	427	49	48	262	239
2007	443	84	499	68	68	334	311
2008	432	79	406	59	59	245	235
2009	422	104	856	72	71	351	344
2010	415	145	3,199	70	69	362	358
2011	422	156	4,381	61	59	427	381
2012	451	110	2,133	62	62	418	408
2013	455	96	1,160	63		382	
2014	428	96	1,567	59		359	

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 Laboratory longline survey RPNs for Greenland turbot biomass by year and region.

Relative Population No. (RPN)									**Year**										
Area	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bering 4		11,729		13,072		16,082		11,965		3,717		1,561		3,406		1,494		1,641	
Bering 3		6,172		6,156		5,005		3,784		1,826		1,754		640		705		3,082	
Bering 2		27,936		33,848		24,766		24,660		15,268		13,523		21,192		12,164		13,473	
Bering 1		13,491		10,068		5,123		6,206		2,297		1,235		2,612		1,821		2,970	
NE Aleutians	23,133		23,121		12,987		10,942		8,551		3,031		3,155		2,033		4,714		4,240
NW Aleutians	7,212		7,208		4,049		3,411		2,666		945		984		634		1,470		1,322
SE Aleutians	2,142		1,791		1,201		1,397		936		566		297		163		350		181
SW Aleutians	6,775		5,665		3,800		4,420		2,962		1,789		939		517		1,106		573
Bering Sea (total)		59,328		63,144		50,975		46,616		23,107		18,074		27,850		16,184		21,166	
Aleutians (total)	39,262		37,784		22,037		20,170		15,115		6,331		5,374		3,347		7,639		6,315
Combined (/1000)	142.53	81.88	137.17	87.15	80.00	70.36	73.22	64.34	54.87	31.89	22.98	24.95	19.51	38.44	12.15	22.34	27.73	29.21	22.93

Table 5.13. Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	1998				**2003**				**2004**			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	17.67	3			15.67	3	13.00	3	15.0	1	16.3	4
2	24.94	18	25.58	19	22.37	30	22.15	34	21.8	5	23.9	9
3	33.14	7	34.00	11	29.68	37	28.97	38	29.9	29	30.3	40
4	32.00	1	33.80	5	33.44	16	36.06	18	34.6	10	34.8	18
5	35.00	2	36.50	2	38.96	24	38.96	27	40.9	21	42.6	20
6			50.00	1	47.00	3	40.67	9	43.1	7	43.1	15
7					43.67	3	46.20	10	53.0	3	51.2	10
8			49.00	1	50.00	6	49.20	5	57.0	1	58.0	1
9			58.00	1	57.50	2	48.50	2			61.8	4
10	65.80	5	58.33	3	51.00	1	66.40	5	70.3	4	63.8	4
11	65.00	5			60.00	2	60.00	2	83.0	2		
12	78.67	3	59.75	4	78.33	3	72.00	1	78.3	4	73.2	5
13			66.75	4	83.67	3	76.00	1	85.6	5	68.7	3
14	75.00	1	75.00	1	83.20	5			83.8	5		
15			67.50	2	80.00	1			87.2	6	74.0	2
16	76.00	2			84.20	5	70.00	2	82.0	4	78.0	2
17	81.00	1	71.00	3	86.43	7	72.00	1	85.2	6	78.0	1
18					85.67	6	72.00	1	91.7	3	77.0	3
19			74.00	2	90.67	6	78.00	1	92.5	2	81.0	1
20	80.33	3			89.56	9	81.50	2	89.5	2	73.5	2
21	82.00	1			90.00	5	76.50	2	90.7	3		
22					88.00	4	81.00	2				
23	79.00	1			90.17	6	74.00	1	96.5	2		
24	79.00	2	69.50	2	90.00	5	76.33	3	97.0	1		
25	79.00	2			91.33	3	73.00	2	91.0	3		
26	95.00	1			92.33	3	77.00	3	94.5	2		
27					93.67	3	74.00	1	85.7	3		
28					92.00	4			91.0	1		
29					91.75	4	78.00	1				
30			81	2	91.00	5						

Table 5.13(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2005				2006				2007			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1			13.50	2			11.50	2	12.17	18	12.50	26
2	25.00	1	24.00	2	24.33	3	21.00	1	22.50	4	21.00	8
3	32.20	10	33.19	16	30.33	3			30.00	1	28.67	6
4	35.95	38	36.97	35	39.00	2	39.50	2	39.50	2	35.00	4
5	42.58	31	41.33	27	38.00	11	38.38	16	46.18	17	44.40	15
6	48.85	13	47.10	10	42.69	16	43.75	20	47.00	17	47.18	22
7	53.33	9	48.00	5	46.60	25	44.33	15	50.72	18	51.70	23
8	62.50	6	51.83	6	54.53	19	47.25	16	54.67	15	52.67	15
9	62.00	1	52.00	1	57.90	10	53.18	11	59.75	12	56.00	4
10	67.50	2	72.00	1	65.67	3	64.25	4	62.33	6	55.00	3
11	86.00	1	64.67	3	62.00	1	62.25	4	63.00	1	62.75	4
12	77.00	3			71.00	6	74.00	1	62.00	3		
13	88.00	1	72.50	2	56.50	2			65.00	7		
14	81.33	3	76.00	1	77.00	1						
15	85.50	2	79.00	1	78.00	2	73.00	1	61.67	3		
16			75.50	4	84.67	3	77.00	2	80.00	1	69.00	1
17	85.00	2	76.00	1	86.25	4	74.00	1	90.00	4	75.50	4
18	92.00	3	76.00	1	88.67	3	76.00	1	85.00	1	77.50	2
19	84.60	5	74.33	3	87.60	5	79.00	1	91.67	3		
20	90.20	5	79.00	1	90.33	6	79.00	1	89.00	3		
21	89.00	2			91.00	2			90.67	3	76.50	2
22	87.00	1			90.00	2	74.00	1			77.00	1
23	82.00	1			88.00	1	88.00	1	87.00	1		
24	88.00	2	74.00	1			77.00	1			84.00	1
25	86.75	4	75.50	2	88.50	2	83.00	2			72.00	1
26	96.50	2							92.00	3		
27			73.00	1								
28			78.00	1								
29									92.00	1	82.00	1
30	88.00	1			107.00	1			90.00	1	79.00	1

Table 5.13(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2008				**2009**				**2010**			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	12.81	16	13.10	21	15.00	6	14.25	12	14.08	38	14.06	48
2	18.94	17	19.64	36	22.05	41	21.93	73	23.22	54	23.91	57
3	23.13	8	23.36	11	29.72	29	28.60	47	30.23	22	33.30	27
4	28.50	2	30.00	4	33.30	10	33.27	11	34.57	7	36.43	14
5	34.50	2	35.50	4	35.50	2	45.00	1	38.00	2	39.75	4
6	49.60	5	47.50	6			42.50	2	42.00	1	42.00	1
7	52.14	14	51.83	12	56.00	3	52.00	1	67.00	1		
8	56.68	25	52.15	20	56.00	1	53.75	4			50.50	2
9	61.73	22	56.79	19	59.56	9	58.33	3			59.00	1
10	64.50	20	58.95	20	63.75	4	54.50	2	62.25	4		
11	64.36	14	60.76	17	64.00	4			73.00	4		
12	68.90	10	62.64	14					67.25	8	60.00	1
13	71.56	9	63.67	6	74.50	2			69.50	2	67.00	2
14	79.83	6	67.17	6	78.00	2			73.50	4		
15	79.80	5	66.22	9								
16	85.67	6	72.75	8					80.00	1		
17	77.00	5	69.71	7								
18	83.13	8	72.82	11					97.00	1		
19	90.50	4	69.00	5	88.00	1	78.50	2				
20	86.75	8	72.00	14	90.50	2	79.00	1				
21	91.56	9	68.00	5	87.67	3	70.00	1			73.00	1
22	91.30	10	74.13	8	94.00	1	77.00	2	94.50	2	73.00	1
23	93.88	8	70.71	7	92.50	4			80.50	2	88.00	1
24	90.56	9	73.00	7	100.00	1					82.00	1
25	89.92	13	69.50	6	89.00	2	71.00	1				
26	90.67	3	72.50	6	93.00	1	78.00	1	88.00	1		
27	90.50	4	71.86	7	83.00	2						
28	94.67	9	71.70	10	93.33	3					79.00	1
29	91.07	15	76.14	7					93.00	1	78.00	1
30	91.74	35	70.52	31	89.75	4	76.75	4	92.00	3		

Table 5.13(Cont.) Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	2011				2012			
	Females		Males		Females		Males	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	16.44	9	16.10	21	14.18	17	13.45	22
2	23.74	76	23.10	90	23.28	40	22.48	44
3	32.18	33	32.09	44	32.08	49	31.30	60
4	37.06	16	36.87	15	36.77	31	36.72	25
5	41.65	17	41.78	9	42.35	23	40.87	23
6	46.17	6	45.33	3	46.00	13	47.43	7
7	46.50	2	0.00	0	54.80	5	53.00	3
8	57.00	1	55.50	2	47.50	2		
9	72.00	2	47.00	1				
10	65.00	2			69.50	2	66.00	1
11	68.67	3	69.00	1	74.00	3		
12			65.50	2	75.00	1		
13	71.50	4			77.00	1	68.00	1
14					80.00	1	56.00	1
15	77.00	1						
16								
17			66.00	1	75.00	2		
18	66.00	1			84.00	2		
19			73.00	1				
20	87.00	1	70.00	1	81.00	1	75.00	1
21	93.50	2						
22								
23					85.00	1		
24					100.00	1		
25	99.00	1						
26								
27	81.67	3			97.50	2		
28			76.00	1				
29	86.00	1						
30	96.00	1					76.00	2

Table 5.14. Starting multinomial sample sizes for size composition data by fishery and survey: Trawl = trawl fishery, Longline = longline fishery, Shelf = AFSC bottom trawl slope survey, Slope = AFSC bottom trawl slope survey, ABL Longline = ABL longline survey.

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

Table 5.15. 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 and differences in recruitment estimation.

	2013	**Model 1**	**Model 2**
Likelihoods			
Total	2428.7	2156.78	2015.07
Survey	-30.1	-44.52	-36.87
Length Composition	1181.8	993.60	887.18
Age Composition	140.8	72.85	71.08
Size at Age	1015.2	1016.82	1023.58
Recruitment	118.7	115.40	66.00
Parameter priors	2.2	2.45	3.96
Parameters			
$LN(R_0)$	9.23	9.19	9.67
Steepness	0.79	0.79	0.79
Natural Mortality	0.112	0.11	0.11
q_{Shelf}	0.61	0.95	0.62
q_{Slope}	0.61	0.65	0.57
Mean q_{ABLL}	0.88	0.97	0.82
L_{max} Female	87.53	88.07	88.14
L_{max} Male	73.32	73.49	73.29
Von Bert K Female	0.12	0.12	0.12
Von Bert K Male	0.16	0.17	0.17
Results			
Model			
SSB_{1978} (t)	299,238	244,962	247,240
SSB_{2011} (t)	23,797	23,599	25,258
Projection			
$SSB_{100\%}$ (t)	99,464	90,578	130,123
SSB_{2014} (t)		20,825	26,341
$SSB_{2014\%}$		23%	20%
SSB_{2015} (t)		23,437	30,853
$SSB_{2015\%}$		26%	24%
2015			
ABC (t)		2,924	3,172
F_{ABC}		0.13	0.10
OFL (t)		3,611	3,903
F_{OFL}		0.16	0.12
2016			
ABC (t)		4,179	5,248
F_{ABC}		0.15	0.13
OFL (t)		5,158	6,453
F_{OFL}		0.19	0.16

Table 5.16. Model index RMSE, tuning diagnostics, and recruitment variability for candidate models.

			2013	Model 1	Model 2
Retrospective					
		Rho	NA	0.62	0.32
Index RMSE					
		Shelf	0.24	0.22	0.25
		Slope	0.20	0.20	0.23
		ABL Longline	0.40	0.37	0.39
Size Comp					
	Mean EffN	Trawl	56.9	60.1	64.3
		Longline	66.4	66.9	68.7
		Shelf	82.1	97.2	98.4
		Slope	39.2	44.0	41.4
		ABL Longline	35.9	43.3	41.9
	Mean input N	Trawl	55.0	30.0	30.0
		Longline	65.4	43.5	43.5
		Shelf	90	46.0	46.0
		Slope	40	26.6	26.6
		ABL Longline	36	30.0	30.0
Age Comp					
		Mean EffN	52.0	74.8	84.8
		Mean input N	50.0	30.0	30.0
Rec. Var. (1975-2014)					
		Std.dev(ln(No. Age 1))	1.48	1.48	1.41

Table 5.17. Age-equivalent sex-specific selectivity estimates (as estimated for 2014) from each gear type for Greenland turbot in the BSAI. Note that selectivity processes are modeled as a function of size and that some 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	0.0067	0.0067	0.0000	0.0000
3	0.0068	0.0069	0.0000	0.0000
4	0.0091	0.0103	0.0000	0.0000
5	0.0262	0.0302	0.0005	0.0015
6	0.0782	0.0845	0.0089	0.0189
7	0.1653	0.1748	0.0528	0.0722
8	0.2622	0.2842	0.1538	0.1543
9	0.3422	0.3916	0.2961	0.2426
10	0.3928	0.4831	0.4463	0.3215
11	0.4145	0.5535	0.5803	0.3857
12	0.4139	0.6039	0.6886	0.4358
13	0.3986	0.6380	0.7714	0.4742
14	0.3750	0.6601	0.8328	0.5036
15	0.3477	0.6738	0.8777	0.5262
16	0.3196	0.6819	0.9104	0.5439
17	0.2924	0.6867	0.9341	0.5578
18	0.2669	0.6894	0.9514	0.5689
19	0.2436	0.6912	0.9641	0.5780
20	0.2226	0.6927	0.9734	0.5854
21	0.2037	0.6942	0.9803	0.5917
22	0.1868	0.6961	0.9854	0.5969
23	0.1718	0.6985	0.9892	0.6014
24	0.1583	0.7015	0.9920	0.6052
25	0.1473	0.7004	0.9937	0.6075
26	0.1388	0.6952	0.9944	0.6083
27	0.1315	0.6908	0.9951	0.6091
28	0.1252	0.6869	0.9956	0.6097
29	0.1198	0.6836	0.9959	0.6101
30	0.1099	0.6784	0.9966	0.6109

Table 5.18. Time series of age-0 recruits (number in 1,000s) with lower (LCI) and upper (UCI) 95% confidence intervals for 1960-2013.

Year	Age-0 Recruits	LCI	UCI	Year	Age-0 Recruits	LCI	UCI
1960	32,702	0	73,133	1994	1,387	575	2,200
1961	46,216	0	105,037	1995	4,421	2,787	6,054
1962	75,901	0	174,744	1996	3,145	1,791	4,499
1963	144,350	0	326,279	1997	2,493	1,275	3,710
1964	270,369	0	549,846	1998	3,528	1,860	5,197
1965	292,952	0	593,575	1999	9,220	6,310	12,130
1966	157,988	0	348,680	2000	9,834	6,858	12,809
1967	74,489	0	162,219	2001	10,224	7,524	12,924
1968	40,951	0	86,176	2002	1,871	933	2,810
1969	27,641	0	56,433	2003	765	308	1,221
1970	22,663	286	45,040	2004	744	292	1,196
1971	22,221	1,578	42,864	2005	1,439	660	2,218
1972	26,072	3,824	48,320	2006	9,624	6,577	12,672
1973	37,953	9,374	66,532	2007	16,093	10,854	21,332
1974	71,149	25,779	116,519	2008	43,422	30,894	55,950
1975	148,799	83,338	214,262	2009	84,588	61,615	107,561
1976	95,454	43,118	147,790	2010	17,084	8,757	25,411
1977	84,864	37,314	132,414	2011	9,993	4,060	15,926
1978	75,799	35,970	115,628	2012	7,094	1,861	12,327
1979	19,166	5,492	32,840	2013	8,937	1,276	16,598
1980	9,265	1,938	16,591	2014	12,629	0	27,802
1981	5,900	1,184	10,617				
1982	4,568	1,054	8,081	**1977-2013 Average 13,853**			
1983	4,510	1,334	7,686				
1984	6,804	2,675	10,933				
1985	17,979	12,277	23,681				
1986	4,972	2,562	7,382				
1987	5,214	2,944	7,483				
1988	5,334	2,969	7,698				
1989	14,471	10,494	18,448				
1990	4,458	2,263	6,653				
1991	1,454	556	2,352				
1992	1,035	373	1,697				
1993	874	307	1,441				

Table 5.19. Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex.

Females

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	4.24	4.27	5.89	2.43	1.07	0.59	0.38	0.29	0.26	0.28	0.37	0.57	0.76	0.51	0.20	0.07	0.03	0.01	0.01	0.00	0.01
1978	3.79	3.79	3.79	5.16	2.08	0.90	0.48	0.31	0.23	0.20	0.21	0.28	0.43	0.57	0.38	0.15	0.05	0.02	0.01	0.01	0.01
1979	0.96	3.39	3.37	3.30	4.36	1.70	0.71	0.37	0.23	0.17	0.14	0.15	0.20	0.29	0.39	0.26	0.10	0.04	0.02	0.01	0.01
1980	0.46	0.86	3.01	2.93	2.79	3.56	1.34	0.54	0.27	0.17	0.12	0.10	0.10	0.13	0.20	0.26	0.17	0.07	0.02	0.01	0.01
1981	0.30	0.41	0.76	2.59	2.43	2.21	2.70	0.98	0.38	0.19	0.11	0.08	0.06	0.07	0.08	0.12	0.16	0.11	0.04	0.01	0.01
1982	0.23	0.26	0.37	0.65	2.13	1.89	1.64	1.91	0.66	0.25	0.12	0.07	0.05	0.04	0.04	0.05	0.07	0.09	0.06	0.02	0.02
1983	0.23	0.20	0.23	0.31	0.53	1.65	1.39	1.15	1.28	0.43	0.16	0.07	0.04	0.03	0.02	0.02	0.03	0.04	0.05	0.04	0.02
1984	0.34	0.20	0.18	0.20	0.26	0.41	1.22	0.98	0.77	0.84	0.27	0.10	0.04	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.03
1985	0.90	0.30	0.18	0.16	0.17	0.21	0.33	0.96	0.76	0.59	0.63	0.20	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.05
1986	0.25	0.80	0.27	0.16	0.14	0.15	0.18	0.28	0.78	0.61	0.47	0.50	0.16	0.06	0.03	0.01	0.01	0.01	0.01	0.01	0.05
1987	0.26	0.22	0.72	0.24	0.14	0.12	0.12	0.15	0.23	0.65	0.50	0.39	0.41	0.13	0.05	0.02	0.01	0.01	0.01	0.01	0.05
1988	0.27	0.23	0.20	0.63	0.21	0.12	0.10	0.11	0.13	0.19	0.54	0.42	0.32	0.33	0.11	0.04	0.02	0.01	0.01	0.00	0.04
1989	0.72	0.24	0.21	0.18	0.56	0.18	0.10	0.09	0.09	0.11	0.16	0.45	0.35	0.27	0.28	0.09	0.03	0.01	0.01	0.01	0.04
1990	0.22	0.65	0.21	0.19	0.16	0.50	0.16	0.09	0.08	0.08	0.09	0.14	0.38	0.29	0.22	0.23	0.07	0.03	0.01	0.01	0.04
1991	0.07	0.20	0.58	0.19	0.17	0.14	0.45	0.15	0.08	0.07	0.06	0.07	0.11	0.30	0.23	0.17	0.18	0.06	0.02	0.01	0.04
1992	0.05	0.06	0.18	0.52	0.17	0.15	0.13	0.40	0.13	0.07	0.06	0.05	0.06	0.09	0.25	0.19	0.14	0.15	0.05	0.02	0.04
1993	0.04	0.05	0.06	0.16	0.46	0.15	0.13	0.11	0.35	0.11	0.06	0.05	0.05	0.06	0.08	0.22	0.17	0.13	0.13	0.04	0.05
1994	0.07	0.04	0.04	0.05	0.14	0.41	0.14	0.12	0.10	0.31	0.10	0.05	0.04	0.04	0.05	0.07	0.19	0.14	0.11	0.11	0.08
1995	0.22	0.06	0.03	0.04	0.05	0.13	0.37	0.12	0.10	0.09	0.26	0.08	0.04	0.03	0.03	0.04	0.06	0.15	0.11	0.09	0.15
1996	0.16	0.20	0.06	0.03	0.03	0.04	0.11	0.33	0.11	0.09	0.07	0.22	0.07	0.04	0.03	0.03	0.03	0.05	0.12	0.09	0.20
1997	0.12	0.14	0.18	0.05	0.03	0.03	0.04	0.10	0.29	0.09	0.08	0.06	0.19	0.06	0.03	0.02	0.02	0.03	0.04	0.10	0.25
1998	0.18	0.11	0.13	0.16	0.04	0.02	0.03	0.03	0.09	0.26	0.08	0.07	0.05	0.16	0.05	0.03	0.02	0.02	0.02	0.03	0.30
1999	0.46	0.16	0.10	0.11	0.14	0.04	0.02	0.02	0.03	0.08	0.22	0.07	0.06	0.05	0.14	0.04	0.02	0.02	0.02	0.02	0.27
2000	0.49	0.41	0.14	0.09	0.10	0.13	0.04	0.02	0.02	0.03	0.07	0.19	0.06	0.05	0.04	0.11	0.04	0.02	0.01	0.01	0.24
2001	0.51	0.44	0.37	0.13	0.08	0.09	0.11	0.03	0.02	0.02	0.02	0.06	0.16	0.05	0.04	0.03	0.09	0.03	0.02	0.01	0.21
2002	0.09	0.46	0.39	0.33	0.11	0.07	0.08	0.10	0.03	0.02	0.02	0.02	0.05	0.13	0.04	0.03	0.03	0.08	0.02	0.01	0.18
2003	0.04	0.08	0.41	0.35	0.29	0.10	0.06	0.07	0.09	0.02	0.01	0.01	0.02	0.04	0.11	0.03	0.03	0.02	0.07	0.02	0.16
2004	0.04	0.03	0.07	0.37	0.31	0.26	0.09	0.06	0.06	0.08	0.02	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.02	0.06	0.16
2005	0.07	0.03	0.03	0.07	0.33	0.28	0.23	0.08	0.05	0.06	0.07	0.02	0.01	0.01	0.01	0.03	0.08	0.03	0.02	0.02	0.18
2006	0.48	0.06	0.03	0.03	0.06	0.29	0.25	0.21	0.07	0.04	0.05	0.06	0.02	0.01	0.01	0.01	0.03	0.07	0.02	0.02	0.17
2007	0.80	0.43	0.06	0.03	0.02	0.05	0.26	0.22	0.19	0.06	0.04	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.02	0.16
2008	2.17	0.72	0.38	0.05	0.02	0.02	0.05	0.23	0.20	0.16	0.06	0.03	0.04	0.04	0.01	0.01	0.01	0.01	0.02	0.05	0.15
2009	4.23	1.94	0.64	0.34	0.05	0.02	0.02	0.04	0.20	0.17	0.14	0.05	0.03	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.17
2010	0.85	3.78	1.73	0.57	0.31	0.04	0.02	0.02	0.04	0.17	0.14	0.12	0.04	0.02	0.02	0.03	0.01	0.00	0.00	0.00	0.14
2011	0.50	0.76	3.38	1.55	0.51	0.27	0.04	0.02	0.01	0.03	0.15	0.12	0.09	0.03	0.02	0.02	0.02	0.01	0.00	0.00	0.12
2012	0.35	0.45	0.68	3.02	1.38	0.46	0.24	0.03	0.01	0.01	0.03	0.12	0.10	0.08	0.03	0.02	0.02	0.02	0.01	0.00	0.10
2013	0.45	0.32	0.40	0.61	2.70	1.24	0.41	0.22	0.03	0.01	0.01	0.02	0.10	0.08	0.06	0.02	0.01	0.01	0.01	0.00	0.08
2014	0.63	0.40	0.28	0.36	0.54	2.41	1.10	0.36	0.19	0.02	0.01	0.01	0.02	0.08	0.07	0.05	0.02	0.01	0.01	0.01	0.07

Table 5.19 (cont.) Estimated beginning of year numbers (1×10^7) of Greenland turbot by age and sex.

Males

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	4.24	4.27	5.85	2.38	1.05	0.59	0.41	0.33	0.34	0.41	0.63	1.12	1.73	1.34	0.60	0.26	0.12	0.07	0.04	0.03	0.21
1978	3.79	3.79	3.78	5.09	2.04	0.89	0.49	0.34	0.28	0.28	0.35	0.53	0.94	1.45	1.12	0.50	0.21	0.10	0.06	0.04	0.20
1979	0.96	3.39	3.35	3.26	4.29	1.69	0.73	0.40	0.28	0.23	0.23	0.28	0.43	0.76	1.17	0.91	0.40	0.17	0.08	0.05	0.19
1980	0.46	0.86	2.99	2.89	2.74	3.55	1.39	0.60	0.33	0.23	0.19	0.19	0.23	0.35	0.61	0.95	0.73	0.33	0.14	0.07	0.20
1981	0.30	0.41	0.75	2.55	2.39	2.22	2.84	1.10	0.47	0.26	0.18	0.15	0.15	0.18	0.27	0.48	0.74	0.57	0.25	0.11	0.21
1982	0.23	0.26	0.36	0.64	2.08	1.90	1.74	2.21	0.86	0.37	0.20	0.14	0.11	0.11	0.14	0.21	0.37	0.57	0.44	0.20	0.25
1983	0.23	0.20	0.23	0.31	0.52	1.65	1.48	1.35	1.71	0.66	0.28	0.16	0.11	0.09	0.09	0.11	0.16	0.28	0.44	0.34	0.35
1984	0.34	0.20	0.18	0.20	0.25	0.41	1.29	1.15	1.05	1.33	0.51	0.22	0.12	0.08	0.07	0.07	0.08	0.13	0.22	0.35	0.55
1985	0.90	0.30	0.18	0.16	0.17	0.21	0.34	1.08	0.96	0.87	1.10	0.43	0.18	0.10	0.07	0.06	0.06	0.07	0.10	0.19	0.75
1986	0.25	0.80	0.27	0.16	0.13	0.14	0.18	0.29	0.92	0.82	0.74	0.94	0.36	0.16	0.09	0.06	0.05	0.05	0.06	0.09	0.80
1987	0.26	0.22	0.72	0.24	0.14	0.12	0.12	0.16	0.25	0.79	0.71	0.64	0.81	0.31	0.13	0.07	0.05	0.04	0.04	0.05	0.77
1988	0.27	0.23	0.20	0.63	0.21	0.12	0.10	0.11	0.14	0.22	0.69	0.61	0.56	0.70	0.27	0.12	0.06	0.04	0.04	0.04	0.72
1989	0.72	0.24	0.21	0.18	0.56	0.18	0.10	0.09	0.09	0.12	0.19	0.60	0.53	0.49	0.61	0.24	0.10	0.06	0.04	0.03	0.66
1990	0.22	0.65	0.21	0.19	0.16	0.50	0.16	0.09	0.08	0.08	0.10	0.17	0.52	0.46	0.42	0.53	0.20	0.09	0.05	0.03	0.60
1991	0.07	0.20	0.58	0.19	0.17	0.14	0.44	0.15	0.08	0.07	0.07	0.09	0.14	0.43	0.38	0.35	0.44	0.17	0.07	0.04	0.54
1992	0.05	0.06	0.18	0.52	0.17	0.15	0.12	0.40	0.13	0.07	0.06	0.06	0.07	0.12	0.37	0.33	0.30	0.38	0.15	0.06	0.50
1993	0.04	0.05	0.06	0.16	0.46	0.15	0.13	0.11	0.35	0.11	0.06	0.05	0.05	0.07	0.10	0.32	0.29	0.26	0.33	0.13	0.49
1994	0.07	0.04	0.04	0.05	0.14	0.41	0.14	0.12	0.10	0.31	0.10	0.06	0.05	0.05	0.06	0.09	0.27	0.24	0.22	0.28	0.52
1995	0.22	0.06	0.03	0.04	0.05	0.13	0.37	0.12	0.10	0.09	0.27	0.09	0.05	0.04	0.04	0.05	0.07	0.23	0.20	0.18	0.67
1996	0.16	0.20	0.06	0.03	0.03	0.04	0.11	0.33	0.11	0.09	0.07	0.23	0.07	0.04	0.03	0.03	0.04	0.06	0.19	0.17	0.72
1997	0.12	0.14	0.18	0.05	0.03	0.03	0.04	0.10	0.29	0.09	0.08	0.07	0.20	0.06	0.03	0.03	0.03	0.03	0.05	0.16	0.75
1998	0.18	0.11	0.13	0.16	0.04	0.02	0.03	0.03	0.09	0.26	0.08	0.07	0.06	0.17	0.05	0.03	0.02	0.02	0.03	0.04	0.76
1999	0.46	0.16	0.10	0.11	0.14	0.04	0.02	0.02	0.03	0.08	0.22	0.07	0.06	0.05	0.14	0.04	0.02	0.02	0.02	0.02	0.65
2000	0.49	0.41	0.14	0.09	0.10	0.13	0.04	0.02	0.02	0.03	0.07	0.19	0.06	0.05	0.04	0.12	0.04	0.02	0.02	0.02	0.56
2001	0.51	0.44	0.37	0.13	0.08	0.09	0.11	0.03	0.02	0.02	0.02	0.06	0.16	0.05	0.04	0.03	0.10	0.03	0.02	0.01	0.47
2002	0.09	0.46	0.39	0.33	0.11	0.07	0.08	0.10	0.03	0.02	0.02	0.02	0.05	0.14	0.04	0.03	0.03	0.08	0.03	0.01	0.40
2003	0.04	0.08	0.41	0.35	0.29	0.10	0.06	0.07	0.09	0.02	0.01	0.01	0.02	0.04	0.12	0.04	0.03	0.02	0.07	0.02	0.35
2004	0.04	0.03	0.07	0.37	0.31	0.26	0.09	0.06	0.06	0.08	0.02	0.01	0.01	0.01	0.04	0.10	0.03	0.03	0.02	0.06	0.32
2005	0.07	0.03	0.03	0.07	0.33	0.28	0.23	0.08	0.05	0.06	0.07	0.02	0.01	0.01	0.01	0.03	0.09	0.03	0.02	0.02	0.32
2006	0.48	0.06	0.03	0.03	0.06	0.29	0.25	0.21	0.07	0.04	0.05	0.06	0.02	0.01	0.01	0.01	0.03	0.07	0.02	0.02	0.29
2007	0.80	0.43	0.06	0.03	0.02	0.05	0.26	0.22	0.19	0.06	0.04	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.02	0.26
2008	2.17	0.72	0.38	0.05	0.02	0.02	0.05	0.23	0.20	0.16	0.06	0.03	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.05	0.24
2009	4.23	1.94	0.64	0.34	0.05	0.02	0.02	0.04	0.20	0.17	0.14	0.05	0.03	0.03	0.04	0.01	0.01	0.01	0.01	0.02	0.25
2010	0.85	3.78	1.73	0.57	0.31	0.04	0.02	0.02	0.04	0.17	0.14	0.12	0.04	0.02	0.03	0.03	0.01	0.00	0.00	0.01	0.22
2011	0.50	0.76	3.38	1.55	0.51	0.27	0.04	0.02	0.02	0.03	0.15	0.12	0.10	0.03	0.02	0.02	0.03	0.01	0.00	0.00	0.19
2012	0.35	0.45	0.68	3.02	1.38	0.46	0.24	0.03	0.01	0.01	0.03	0.12	0.10	0.08	0.03	0.02	0.02	0.02	0.01	0.00	0.16
2013	0.45	0.32	0.40	0.61	2.70	1.24	0.41	0.22	0.03	0.01	0.01	0.02	0.10	0.08	0.06	0.02	0.01	0.01	0.02	0.00	0.13
2014	0.63	0.40	0.28	0.36	0.54	2.41	1.10	0.36	0.19	0.02	0.01	0.01	0.02	0.08	0.07	0.05	0.02	0.01	0.01	0.01	0.12

Table 5.20. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the 2013 assessment) for BSAI Greenland turbot, 1960-2015. 2015 through 2016 biomass estimates are from the projection Model 2.

				Female Spawning Biomass		Total Age 1+ Biomass	
Year	Apical Fishing Mortality	Total Exploitation	1-SPR.	2013 Assessment	Current Assessment	2013 Assessment	Current Assessment
1960	0.24	0.11	0.65	94,542	134,275	171,303	257,656
1961	0.46	0.18	0.84	84,439	126,605	145,232	233,366
1962	0.62	0.22	0.90	66,012	112,539	104,428	195,418
1963	0.42	0.15	0.82	43,627	95,852	80,997	159,072
1964	0.53	0.18	0.87	30,276	86,168	87,245	146,472
1965	0.16	0.05	0.51	21,712	75,566	155,246	139,513
1966	0.17	0.06	0.54	22,831	73,863	271,766	163,601
1967	0.25	0.09	0.66	36,679	73,211	401,567	205,919
1968	0.27	0.10	0.69	84,536	73,594	520,367	263,098
1969	0.21	0.08	0.60	166,810	78,183	614,757	327,237
1970	0.12	0.05	0.42	258,212	92,317	685,939	394,907
1971	0.21	0.09	0.60	338,662	120,946	740,738	465,396
1972	0.36	0.15	0.77	389,705	157,786	751,827	503,964
1973	0.30	0.13	0.72	404,040	190,005	708,598	492,326
1974	0.39	0.16	0.80	403,455	218,715	662,466	476,651
1975	0.38	0.16	0.79	381,524	230,249	591,356	433,886
1976	0.41	0.16	0.81	353,243	230,809	527,117	393,101
1977	0.22	0.09	0.62	319,958	220,707	465,802	354,323
1978	0.32	0.12	0.74	299,238	216,994	446,800	351,340
1979	0.33	0.12	0.74	270,484	202,766	423,287	342,498
1980	0.43	0.16	0.82	244,497	187,714	403,625	338,430
1981	0.50	0.18	0.85	220,159	170,056	376,333	324,898
1982	0.48	0.17	0.85	200,503	154,920	343,016	303,115
1983	0.47	0.17	0.85	186,598	146,680	310,985	279,206
1984	0.24	0.09	0.65	173,834	140,905	278,406	252,111
1985	0.16	0.06	0.51	171,526	144,250	265,156	242,469
1986	0.11	0.04	0.39	171,281	149,145	256,367	236,353
1987	0.11	0.04	0.39	170,794	153,092	249,175	231,233
1988	0.08	0.03	0.32	167,626	153,590	240,154	223,876
1989	0.15	0.04	0.32	163,217	151,975	231,629	216,911
1990	0.25	0.06	0.45	155,369	146,043	219,865	206,711
1991	0.15	0.04	0.35	144,028	135,926	202,935	191,342
1992	0.04	0.02	0.20	135,669	127,908	191,211	180,666
1993	0.09	0.05	0.37	128,585	122,021	182,668	174,067
1994	0.22	0.06	0.46	117,791	112,379	169,462	162,668
1995	0.17	0.06	0.42	106,737	102,350	153,775	148,580
1996	0.11	0.05	0.37	97,356	93,809	140,300	136,386
1997	0.11	0.06	0.41	89,119	86,418	128,653	125,728
1998	0.15	0.08	0.48	80,376	78,581	116,596	114,551
1999	0.13	0.06	0.41	70,611	69,676	103,361	102,184
2000	0.17	0.08	0.48	63,302	62,993	93,242	92,879
2001	0.17	0.06	0.45	55,378	55,516	82,613	83,051
2002	0.11	0.05	0.37	49,071	49,540	74,315	75,638
2003	0.11	0.04	0.36	44,131	44,875	68,560	70,934
2004	0.09	0.03	0.31	39,615	40,923	63,713	67,760
2005	0.10	0.04	0.35	36,640	38,006	60,709	66,010
2006	0.07	0.03	0.31	33,872	35,446	57,441	64,081
2007	0.07	0.03	0.32	32,136	34,051	54,983	62,749
2008	0.13	0.05	0.42	30,806	33,315	52,666	61,342
2009	0.21	0.08	0.55	29,176	32,612	49,983	59,651
2010	0.17	0.07	0.54	26,531	30,921	47,577	58,390
2011	0.16	0.06	0.52	23,797	28,835	48,189	60,747
2012	0.23	0.07	0.62	21,647	26,865	54,380	69,331
2013	0.09	0.02	0.35	20,006	24,931	72,376	80,929
2014	0.08	0.02	0.33	22,010	26,342	84,546	97,442
2015				27,624	**30,853**	96,298	**122,298**
2016					**38,848**		**132,666**

Table 5.21. Spawning biomass with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2015 for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. 2015 values are from the production model.

Year	Spawning Biomass	LCI	UCI
1977	220,710	177,974	263,446
1978	216,990	177,884	256,096
1979	202,770	166,822	238,718
1980	187,710	154,537	220,883
1981	170,060	139,541	200,579
1982	154,920	126,745	183,095
1983	146,680	120,371	172,989
1984	140,910	116,136	165,684
1985	144,250	120,559	167,941
1986	149,150	126,547	171,753
1987	153,090	131,624	174,556
1988	153,590	133,326	173,854
1989	151,970	132,904	171,036
1990	146,040	128,280	163,800
1991	135,930	119,510	152,350
1992	127,910	112,723	143,097
1993	122,020	107,986	136,054
1994	112,380	99,479	125,281
1995	102,350	90,550	114,150
1996	93,809	82,983	104,635
1997	86,418	76,454	96,382
1998	78,581	69,398	87,764
1999	69,676	61,209	78,143
2000	62,993	55,165	70,821
2001	55,516	48,274	62,758
2002	49,540	42,822	56,258
2003	44,875	38,630	51,120
2004	40,923	35,104	46,742
2005	38,006	32,556	43,456
2006	35,446	30,307	40,585
2007	34,051	29,153	38,949
2008	33,315	28,598	38,032
2009	32,612	28,035	37,189
2010	30,921	26,456	35,386
2011	28,835	24,489	33,181
2012	26,865	22,634	31,096
2013	24,931	20,756	29,106
2014	26,342	22,097	30,587
2015	30,853	26,111	35,595

Table 5.22. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot from the 2013 stock assessment (Barbeaux et al. 2013) and for the 2014 Model 2.

	Mid-year length (cm)				Mid-year weight (kg)			
	2013 Reference		2014 Model 2		2013 Reference		2014 Model 2	
Age	Females	Males	Females	Males	Females	Males	Females	Males
1	14.29	14.16	14.19	13.84	0.02	0.02	0.02	0.02
2	22.06	22.21	22.13	22.27	0.08	0.08	0.08	0.08
3	29.87	30.02	30.11	30.44	0.21	0.21	0.22	0.22
4	36.82	36.67	37.20	37.33	0.42	0.40	0.44	0.42
5	42.99	42.33	43.48	43.15	0.71	0.63	0.73	0.67
6	48.48	47.15	49.06	48.06	1.05	0.89	1.09	0.94
7	53.36	51.25	54.00	52.21	1.44	1.16	1.50	1.23
8	57.71	54.74	58.39	55.71	1.87	1.43	1.94	1.51
9	61.57	57.72	62.28	58.66	2.31	1.69	2.40	1.77
10	65.00	60.25	65.74	61.16	2.76	1.93	2.86	2.02
11	68.05	62.40	68.80	63.26	3.21	2.16	3.32	2.25
12	70.77	64.23	71.51	65.04	3.66	2.37	3.77	2.46
13	73.18	65.79	73.92	66.53	4.08	2.55	4.19	2.64
14	75.33	67.12	76.06	67.80	4.49	2.72	4.60	2.80
15	77.23	68.25	77.96	68.87	4.88	2.86	4.98	2.94
16	78.93	69.22	79.64	69.77	5.24	2.99	5.33	3.06
17	80.44	70.04	81.13	70.53	5.57	3.10	5.65	3.16
18	81.78	70.73	82.45	71.17	5.87	3.20	5.94	3.24
19	82.97	71.33	83.63	71.71	6.16	3.28	6.21	3.32
20	84.03	71.83	84.67	72.17	6.41	3.35	6.45	3.38
21	84.98	72.26	85.59	72.56	6.64	3.41	6.66	3.43
22	85.82	72.63	86.41	72.88	6.85	3.46	6.86	3.48
23	86.56	72.94	87.14	73.16	7.04	3.50	7.03	3.51
24	87.22	73.21	87.78	73.39	7.21	3.53	7.19	3.54
25	87.81	73.43	88.35	73.59	7.37	3.57	7.33	3.57
26	88.34	73.63	88.86	73.75	7.51	3.60	7.46	3.60
27	88.80	73.79	89.31	73.89	7.64	3.62	7.57	3.62
28	89.22	73.93	89.71	74.01	7.75	3.65	7.67	3.64
29	89.59	74.05	90.06	74.11	7.85	3.66	7.76	3.65
30	90.31	74.23	90.74	74.26	8.05	3.69	7.92	3.68

Table 5.23. Estimated total Greenland turbot harvest by area, 1977-2014. *Values for 2014 are through Oct. 23[th], 2014 and are preliminary.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1996	4,844	1,712
1978	37,423	4,766	1997	6,435	764
1979	34,998	6,411	1998	8,075	682
1980	48,856	3,697	1999	5,386	467
1981	52,921	4,400	2000	5,888	1,086
1982	45,805	6,317	2001	4,253	1,060
1983	43,443	4,115	2002	3,151	485
1984	21,317	1,803	2003	2,412	700
1985	14,698	33	2004	1,825	434
1986	7,710	2,154	2005	2,140	468
1987	6,519	3,066	2006	1,453	537
1988	6,064	1,044	2007	1,481	523
1989	4,061	4,761	2008	2,089	822
1990	7,702	2,494	2009	2,252	2,263
1991	4,398	3,465	2010	2,273	1,872
1992	2,462	1,290	2011	3,120	532
1993	6,332	2,137	2012	3,062	1,658
1994	7,143	3,131	2013	1,449	296
1995	5,856	2,338	2014*	1,469	177

Table 5.24. Mean spawning biomass (t), F, and yield projections (t) for Greenland turbot, 2014-2027. 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
2014	26,341	26,341	26,341	26,341	26,341	26,341	26,341
2015	30,853	30,853	30,853	30,853	30,853	30,853	30,853
2016	38,848	38,848	39,894	39,798	40,450	38,484	38,848
2017	48,759	48,759	51,460	51,255	52,667	47,934	48,759
2018	57,448	57,448	63,012	62,665	65,079	55,956	56,628
2019	63,131	63,131	72,723	72,187	75,947	60,660	61,247
2020	65,600	65,600	80,020	79,246	84,701	62,026	62,528
2021	65,630	65,630	85,248	84,205	91,615	60,976	61,397
2022	64,327	64,327	89,019	87,693	97,190	58,751	59,098
2023	62,568	62,568	91,848	90,244	101,844	56,298	56,580
2024	60,845	60,845	94,062	92,195	105,828	54,189	54,402
2025	59,361	59,361	95,823	93,715	109,264	52,740	52,895
2026	58,266	58,266	97,233	94,908	112,231	51,817	51,930
2027	57,526	57,526	98,385	95,866	114,818	51,269	51,350
F							
2014	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2015	0.10	0.10	0.03	0.04	0.00	0.12	0.10
2016	0.13	0.13	0.03	0.04	0.00	0.16	0.13
2017	0.16	0.16	0.03	0.04	0.00	0.20	0.20
2018	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2019	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2020	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2021	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2022	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2023	0.18	0.18	0.03	0.04	0.00	0.22	0.22
2024	0.18	0.18	0.03	0.04	0.00	0.20	0.21
2025	0.17	0.17	0.03	0.04	0.00	0.20	0.20
2026	0.16	0.16	0.03	0.04	0.00	0.19	0.19
2027	0.16	0.16	0.03	0.04	0.00	0.18	0.18
Catch							
2014	1,805	1,805	1,805	1,805	1,805	1,805	1,805
2015	3,172	3,172	1,096	1,284	0	3,903	3,172
2016	5,248	5,248	1,453	1,699	0	6,335	5,248
2017	8,639	8,639	1,938	2,263	0	10,267	10,610
2018	11,192	11,192	2,439	2,844	0	13,403	13,549
2019	12,495	12,495	2,860	3,329	0	14,756	14,886
2020	13,053	13,053	3,164	3,673	0	15,168	15,281
2021	13,045	13,045	3,362	3,894	0	14,901	14,997
2022	12,741	12,741	3,489	4,030	0	14,318	14,397
2023	12,352	12,352	3,574	4,118	0	13,548	13,637
2024	11,947	11,947	3,637	4,182	0	12,535	12,609
2025	11,402	11,402	3,687	4,230	0	11,823	11,876
2026	10,961	10,961	3,727	4,269	0	11,382	11,419
2027	10,655	10,655	3,760	4,301	0	11,128	11,154

Figures

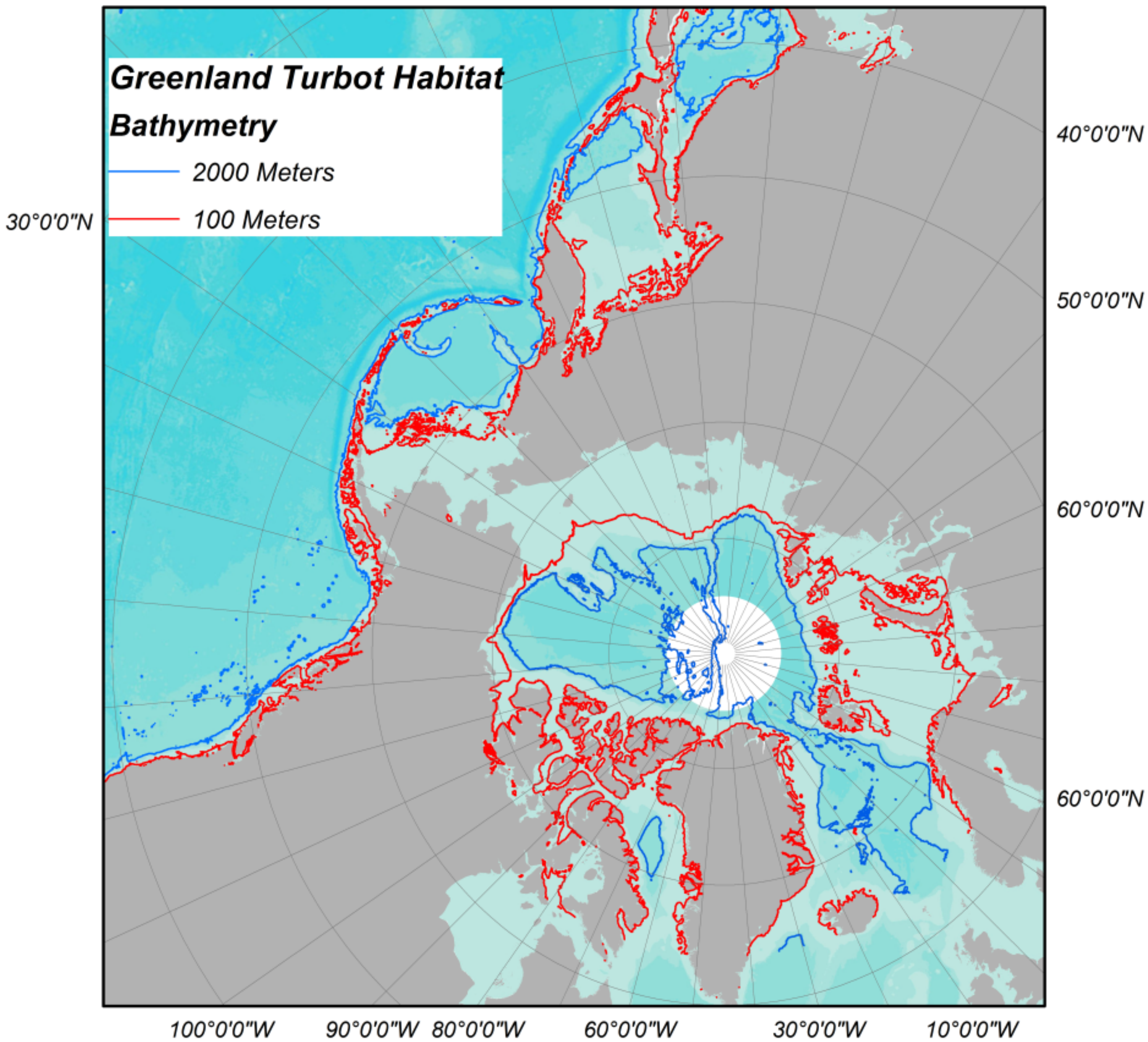
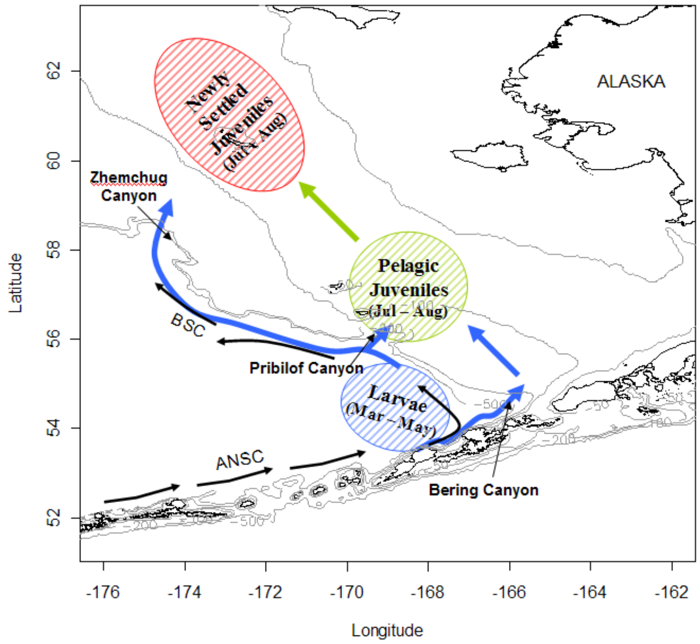


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), between which is possible Greenland turbot habitat.

(a)



(b)

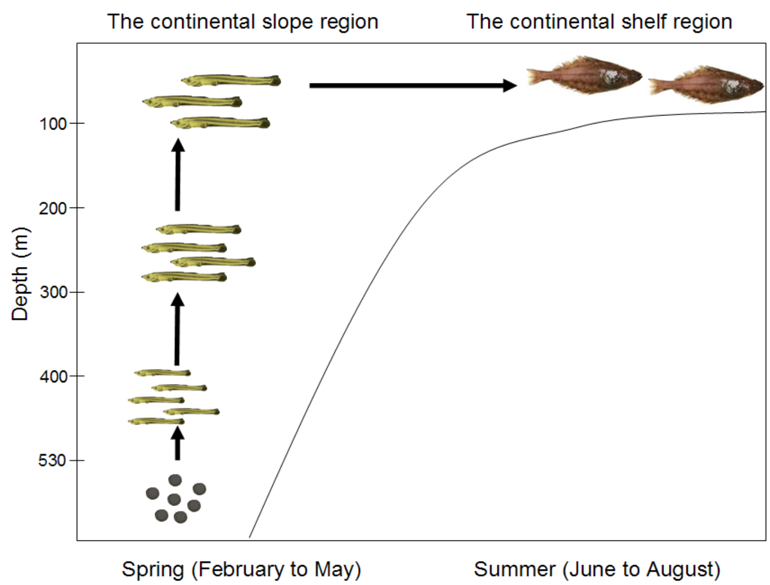


Figure 5.2. Schematic representation of Greenland turbot distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: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

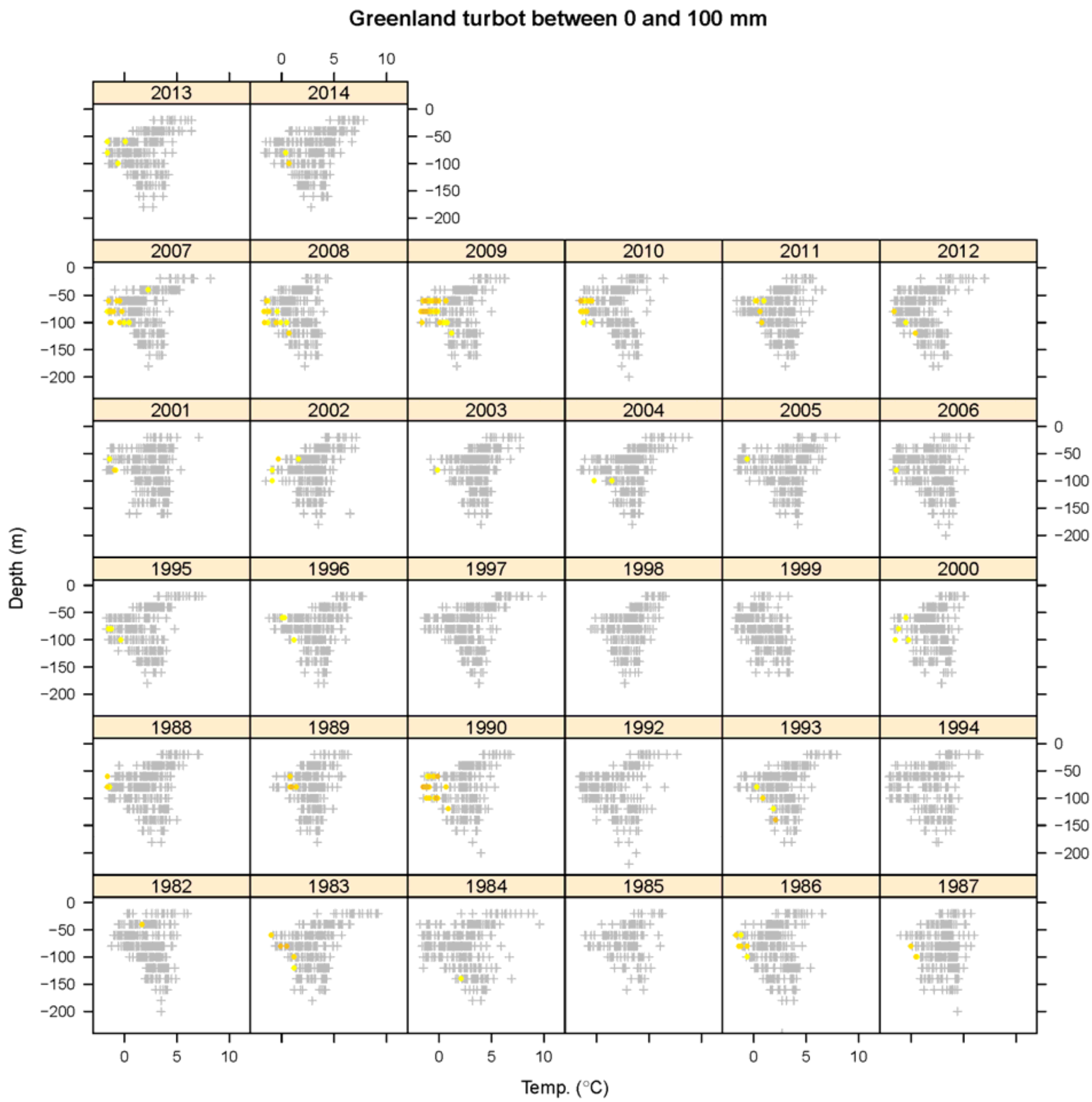


Figure 5.3. Greenland turbot (0-100 mm) density distribution by temperature and depth (left) for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

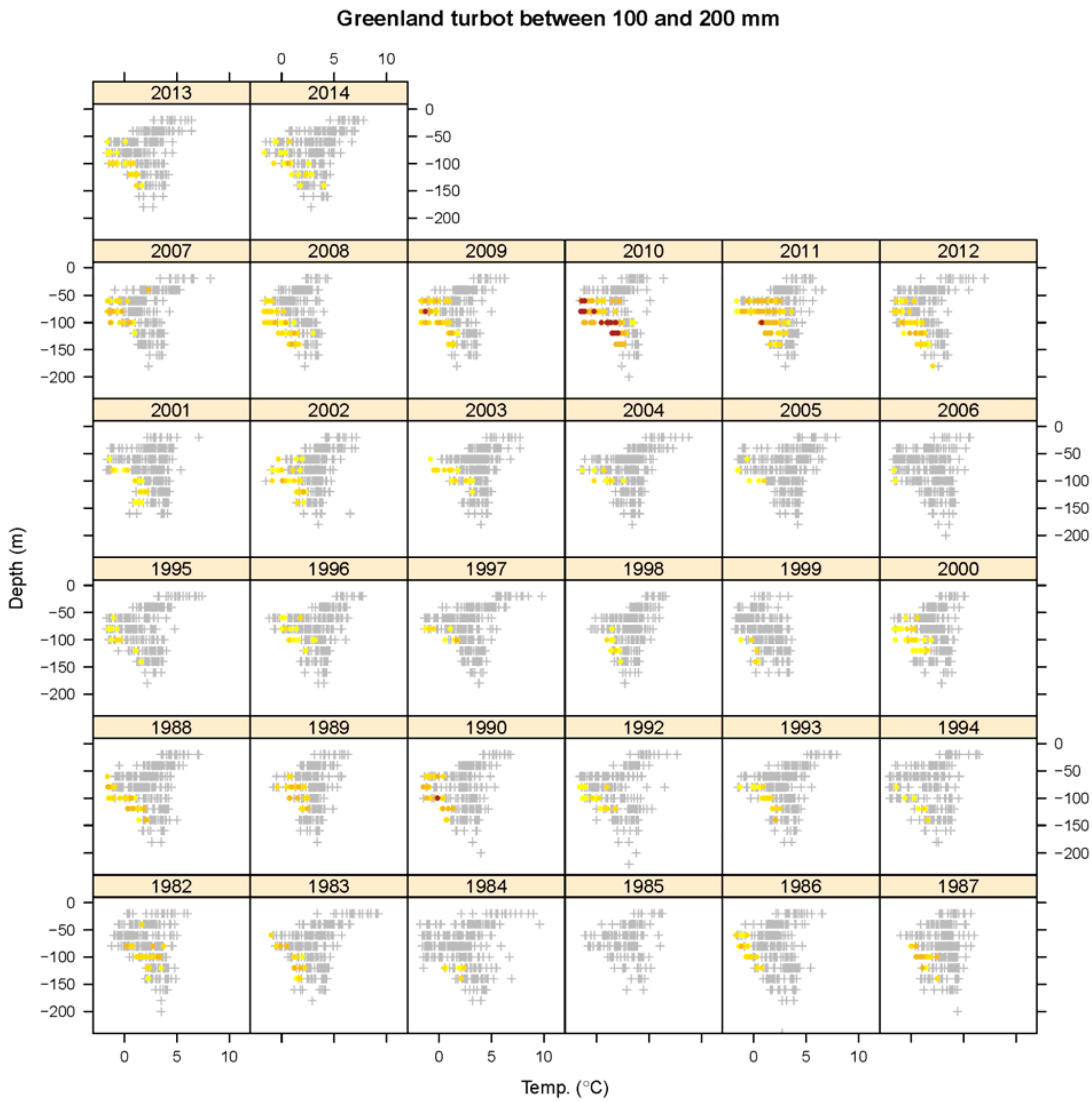


Figure 5.3.(Cont.) Greenland turbot (100-200 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

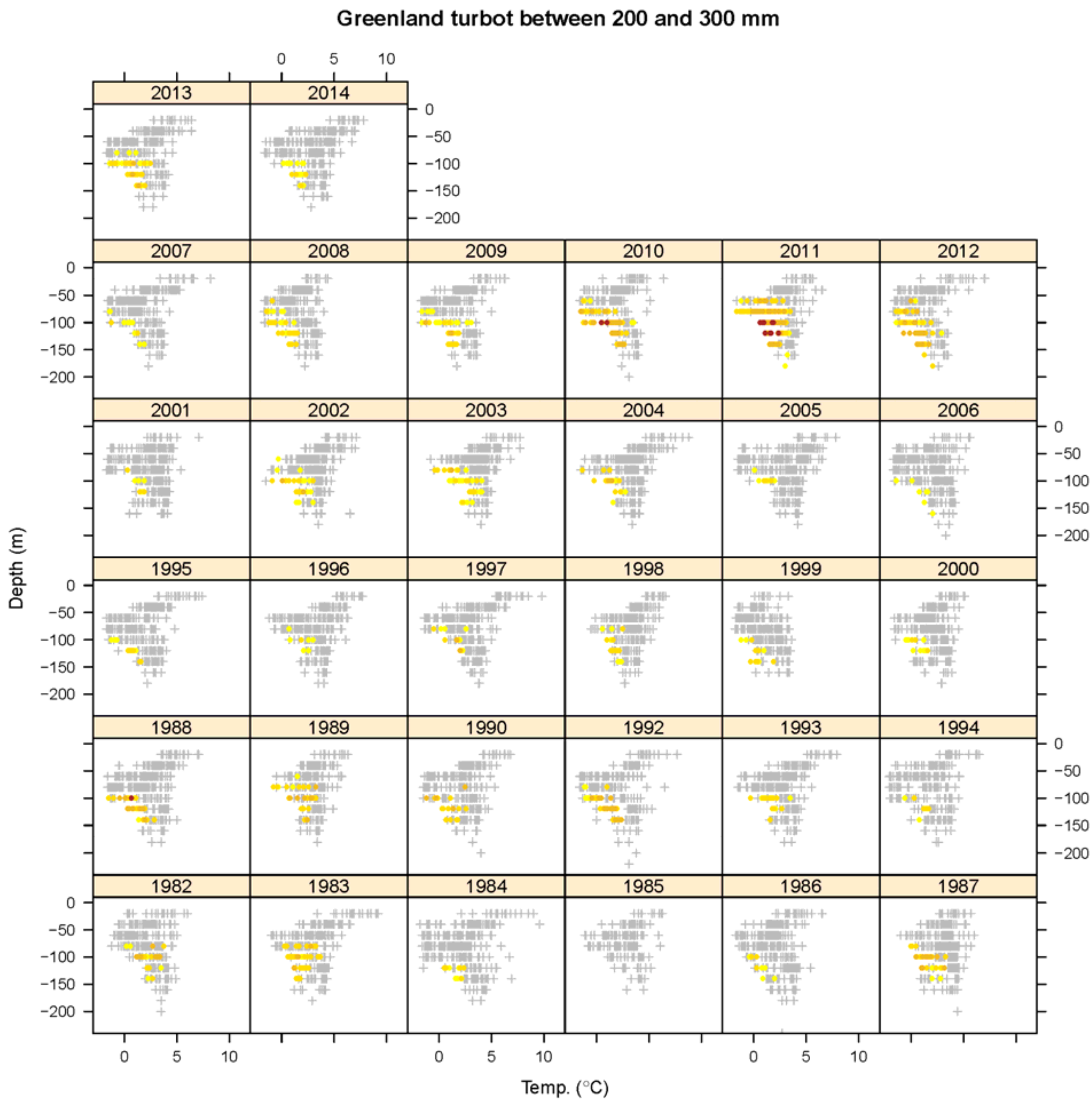


Figure 5.3.(Cont.) Greenland turbot (200-300 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

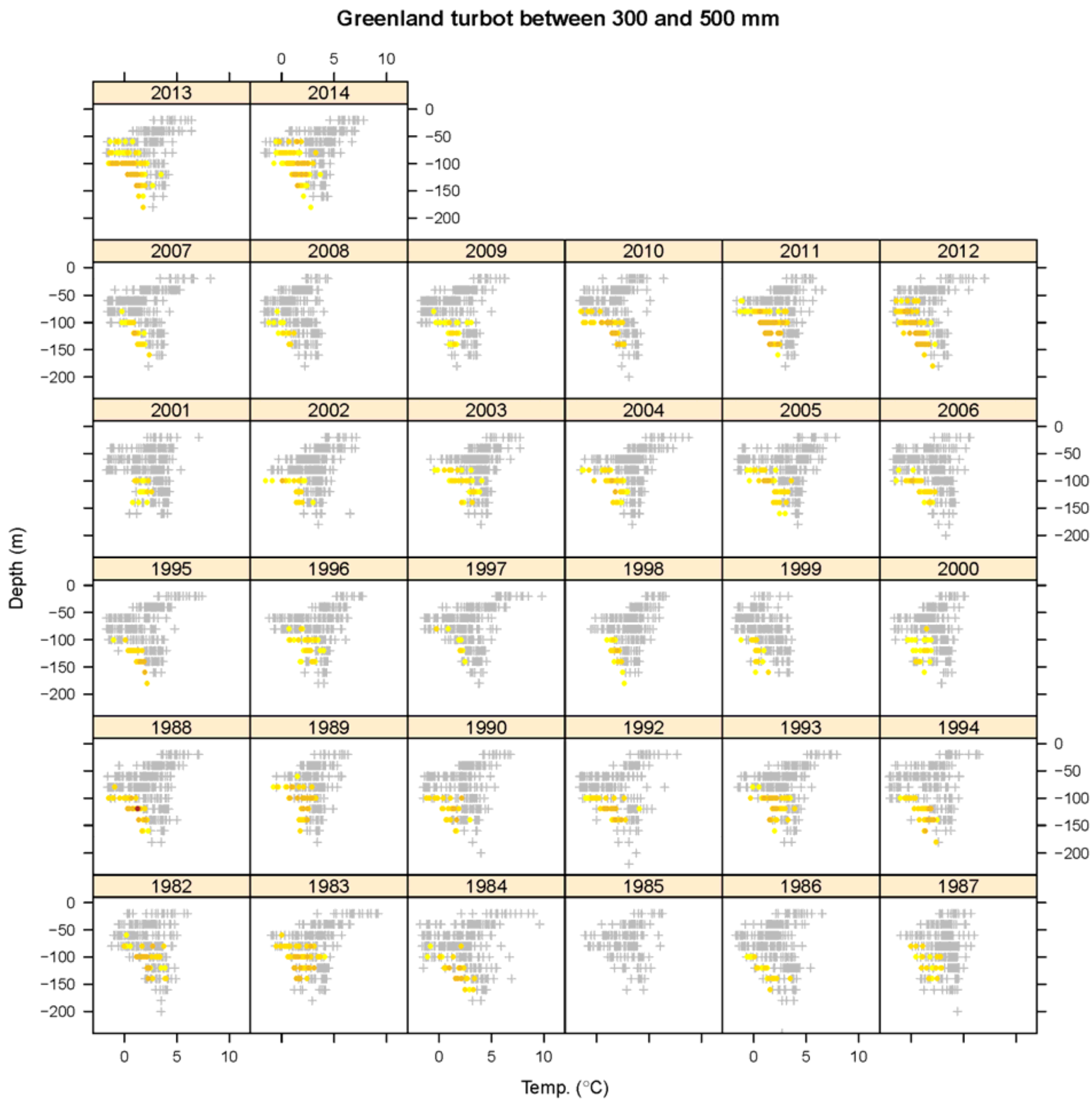


Figure 5.3.(Cont.) Greenland turbot (300-500 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

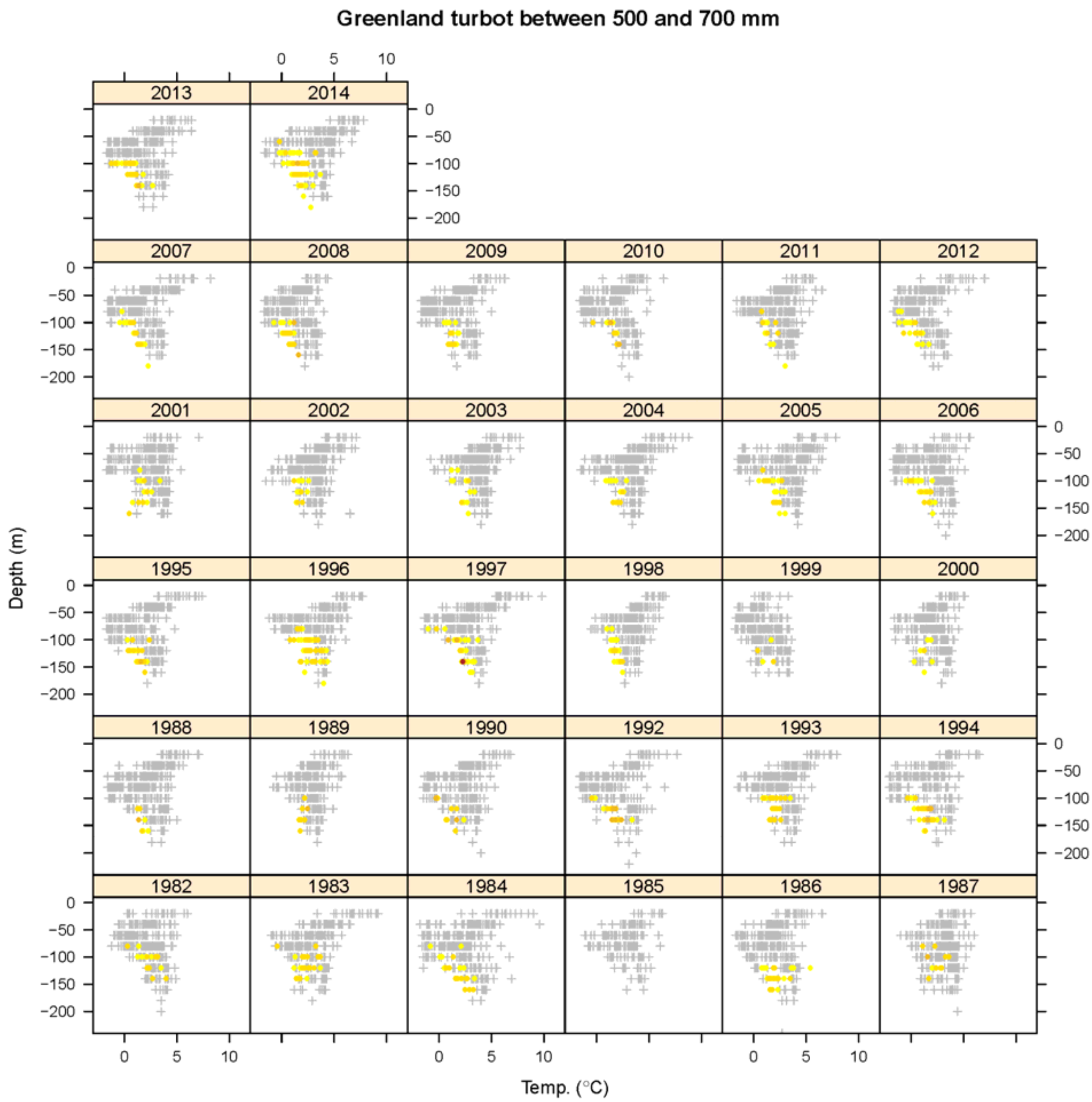


Figure 5.3.(Cont.) Greenland turbot (500-700 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

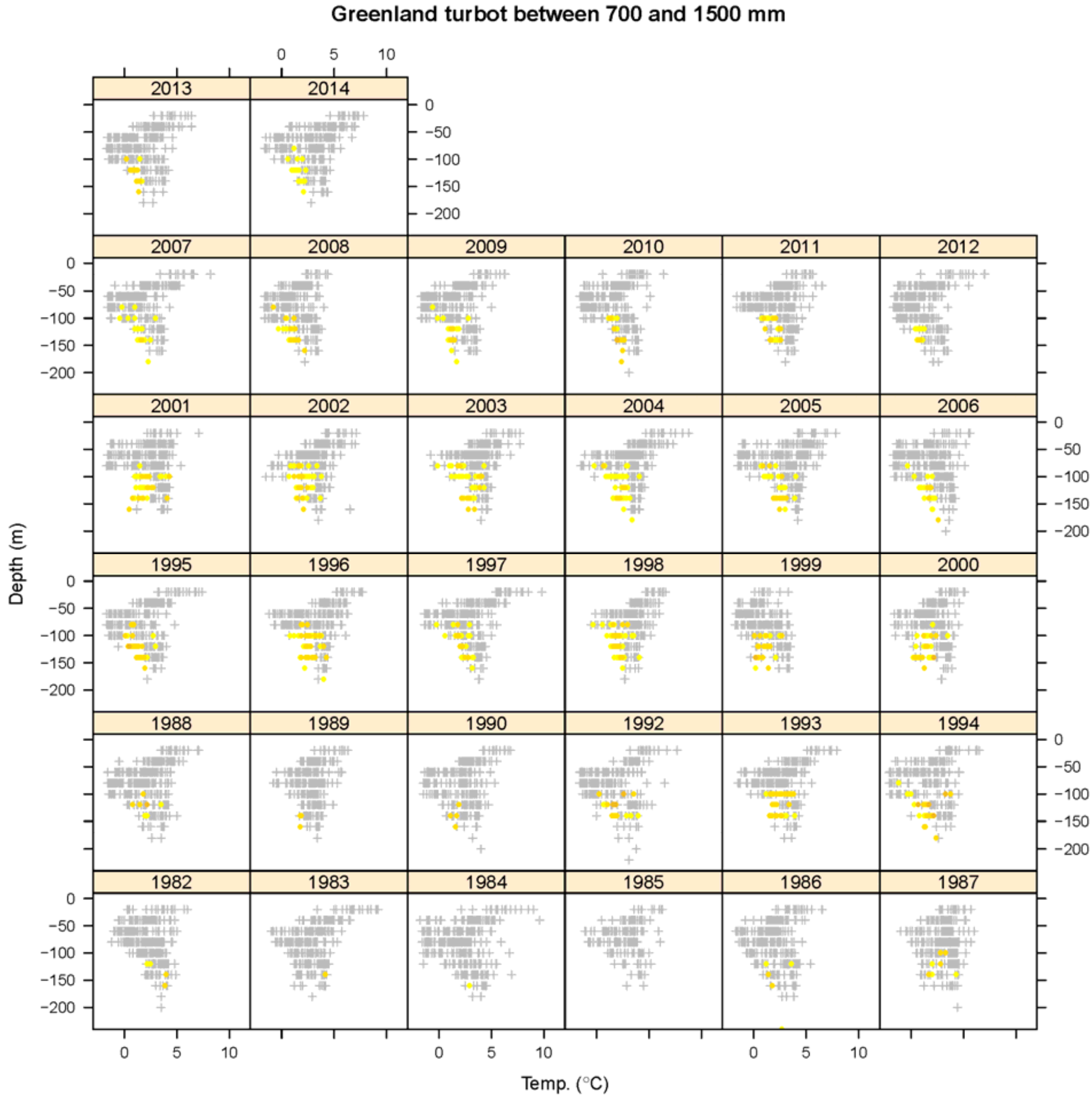


Figure 5.3.(Cont.) Greenland turbot (700-1500 mm) density distribution by temperature and depth for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

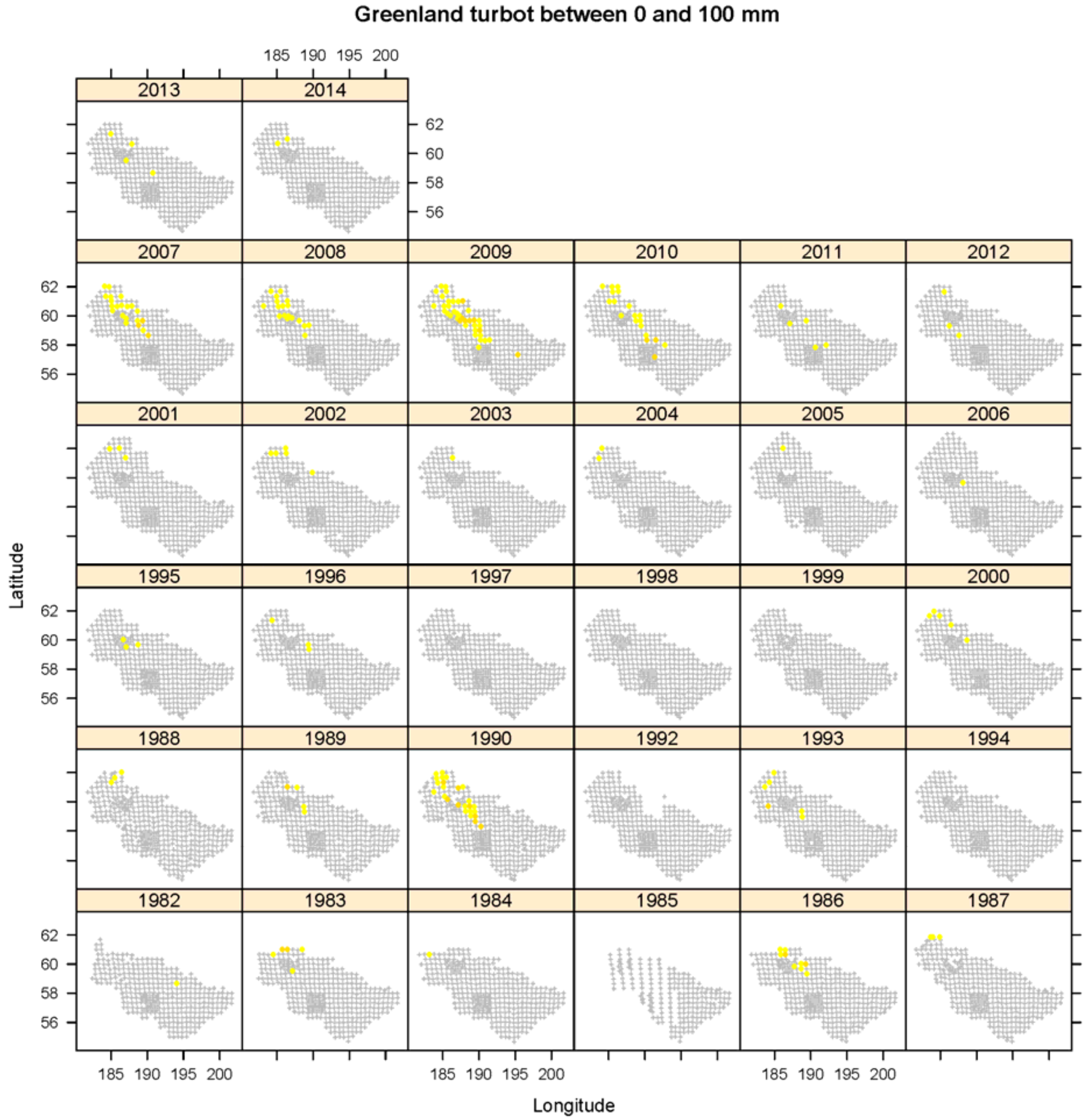


Figure 5.4. Greenland turbot (0-100 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

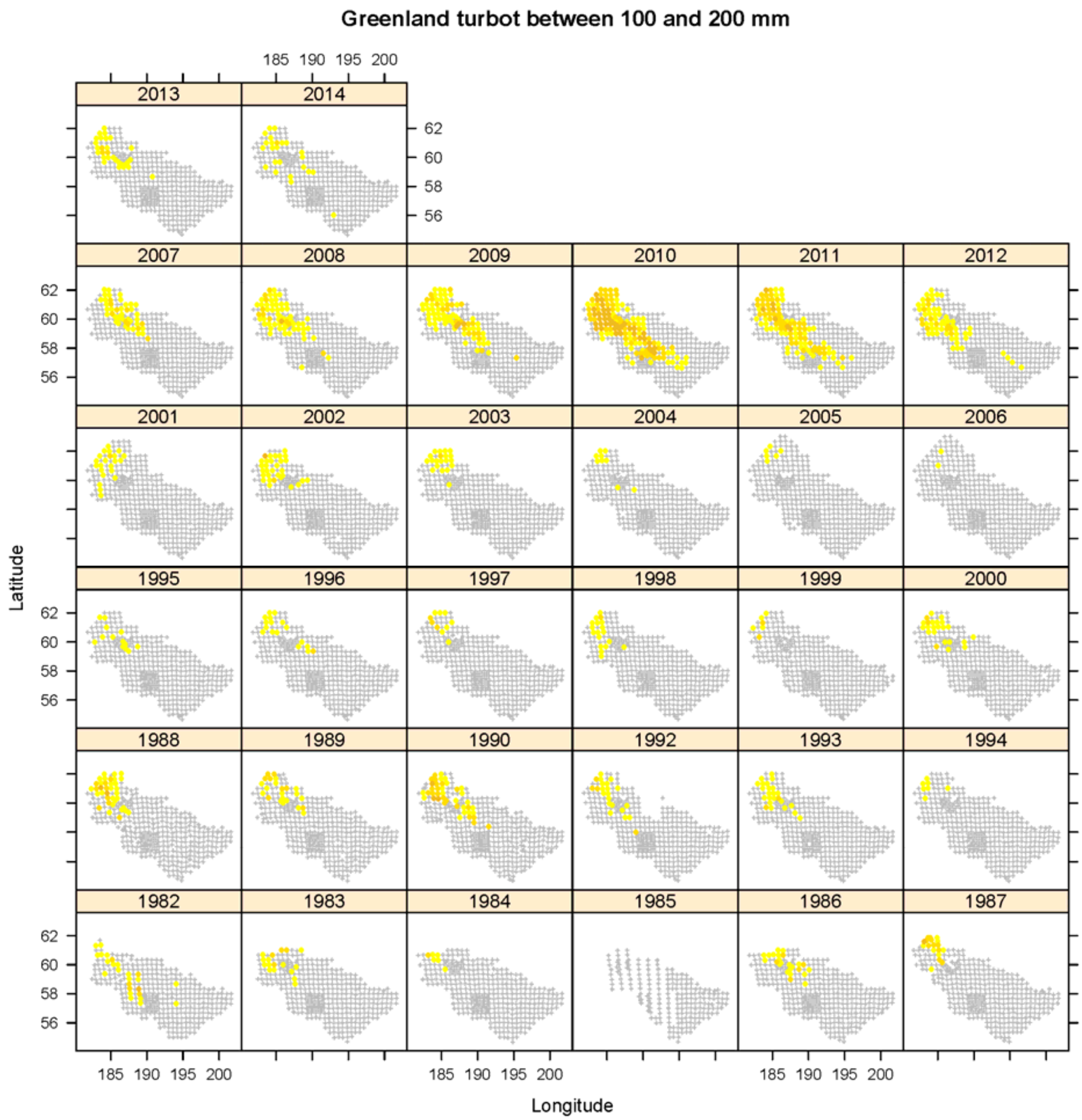


Figure 5.4.(Cont.) Greenland turbot (100-200 cm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

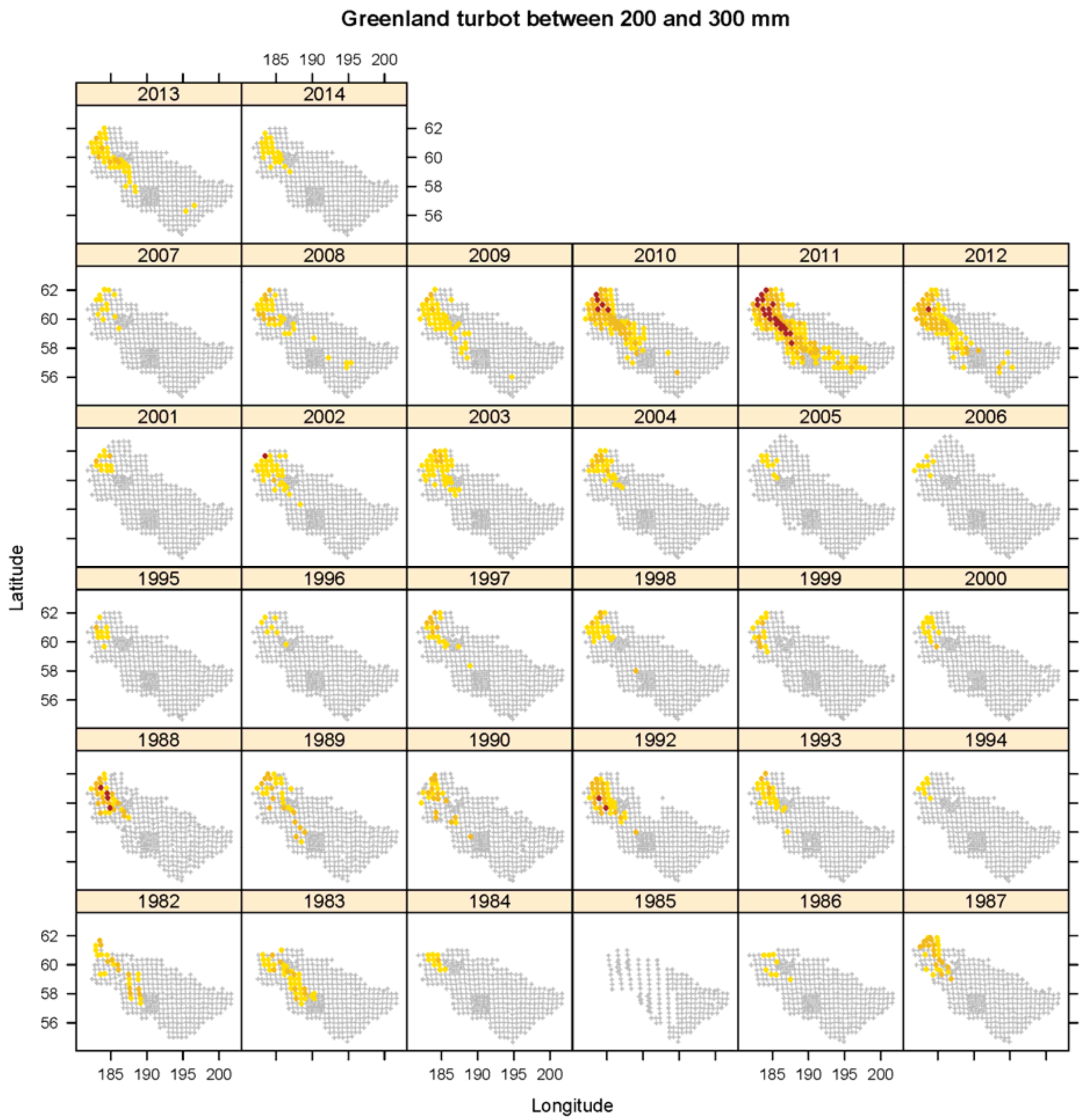


Figure 5.4.(Cont.) Greenland turbot (200-300 cm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

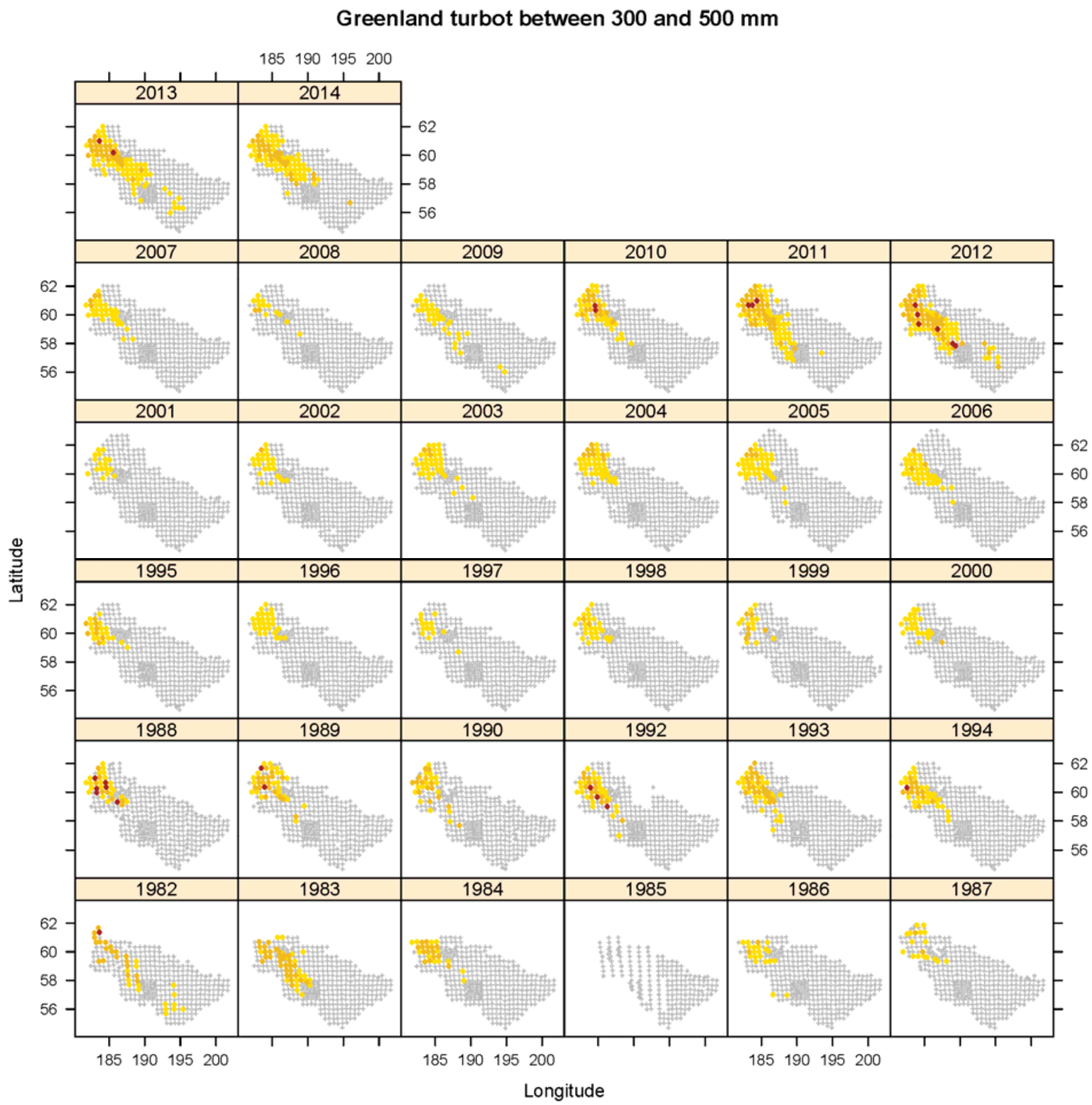


Figure 5.4.(Cont.) Greenland turbot (300- 500 mm) density distribution by latitude and longitude for 1988 – 2012 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

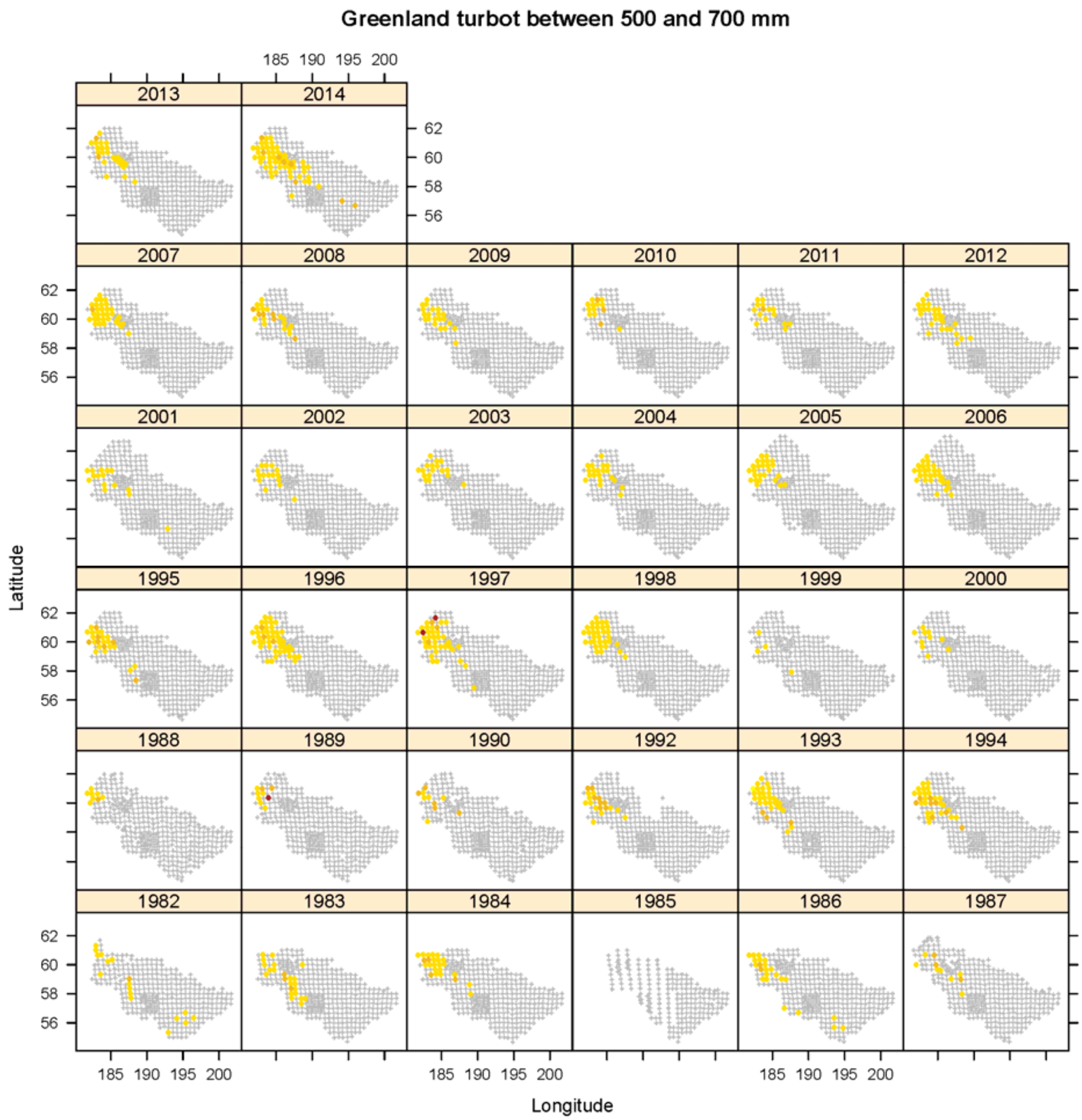


Figure 5.4.(Cont.) Greenland turbot (500- 700 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

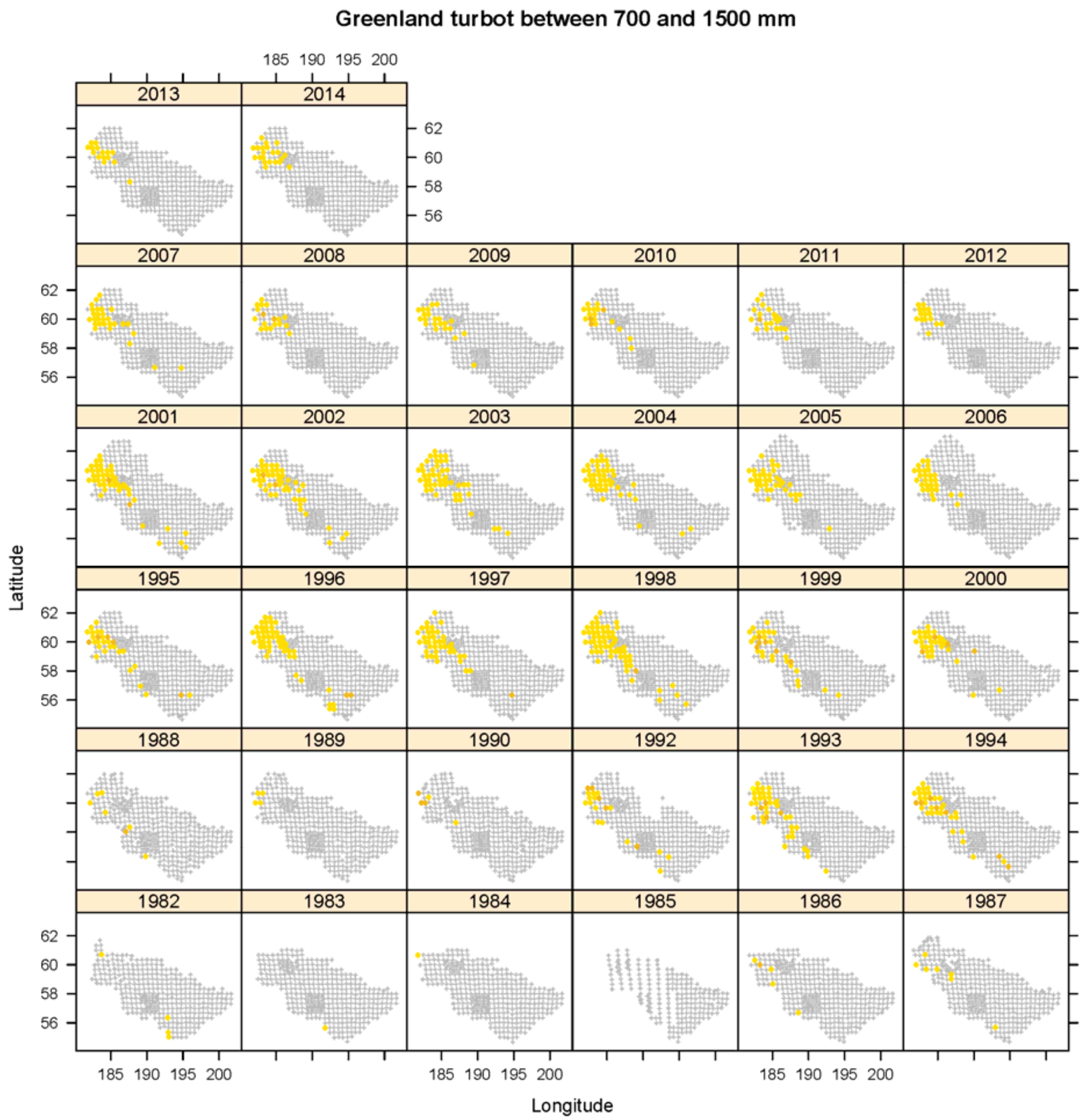


Figure 5.4.(Cont.) Greenland turbot (700- 1500 mm) density distribution by latitude and longitude for 1982 – 2014 shelf bottom trawl surveys. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

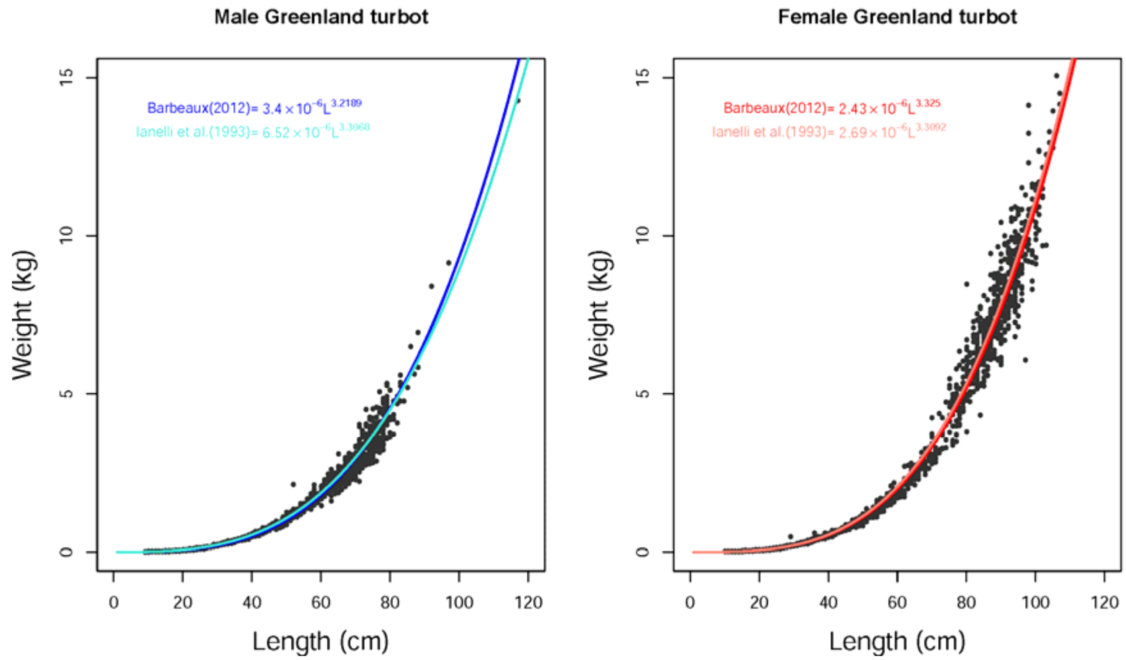


Figure 5. 5. Weight at length relationship for male (left panel) and female (right panel) Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area, years 2003-2011. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

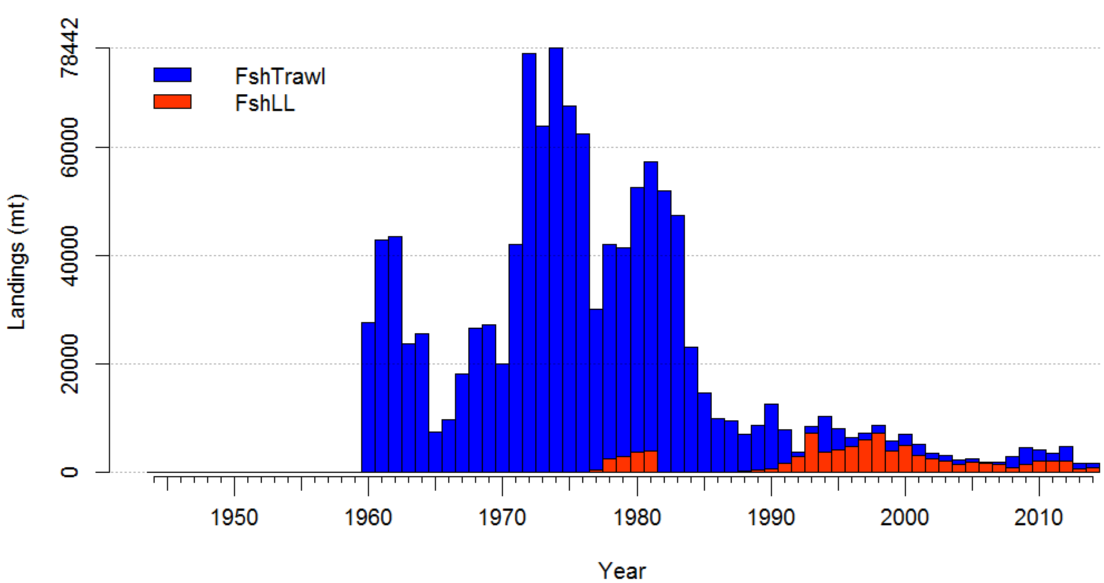


Figure 5. 6. Greenland turbot longline (FshLL, red bars) and trawl (FshTrawl, blue bars) catch in the Bering Sea and Aleutian Islands area from 1960 through 2014. This data includes targeted catch and bycatch.

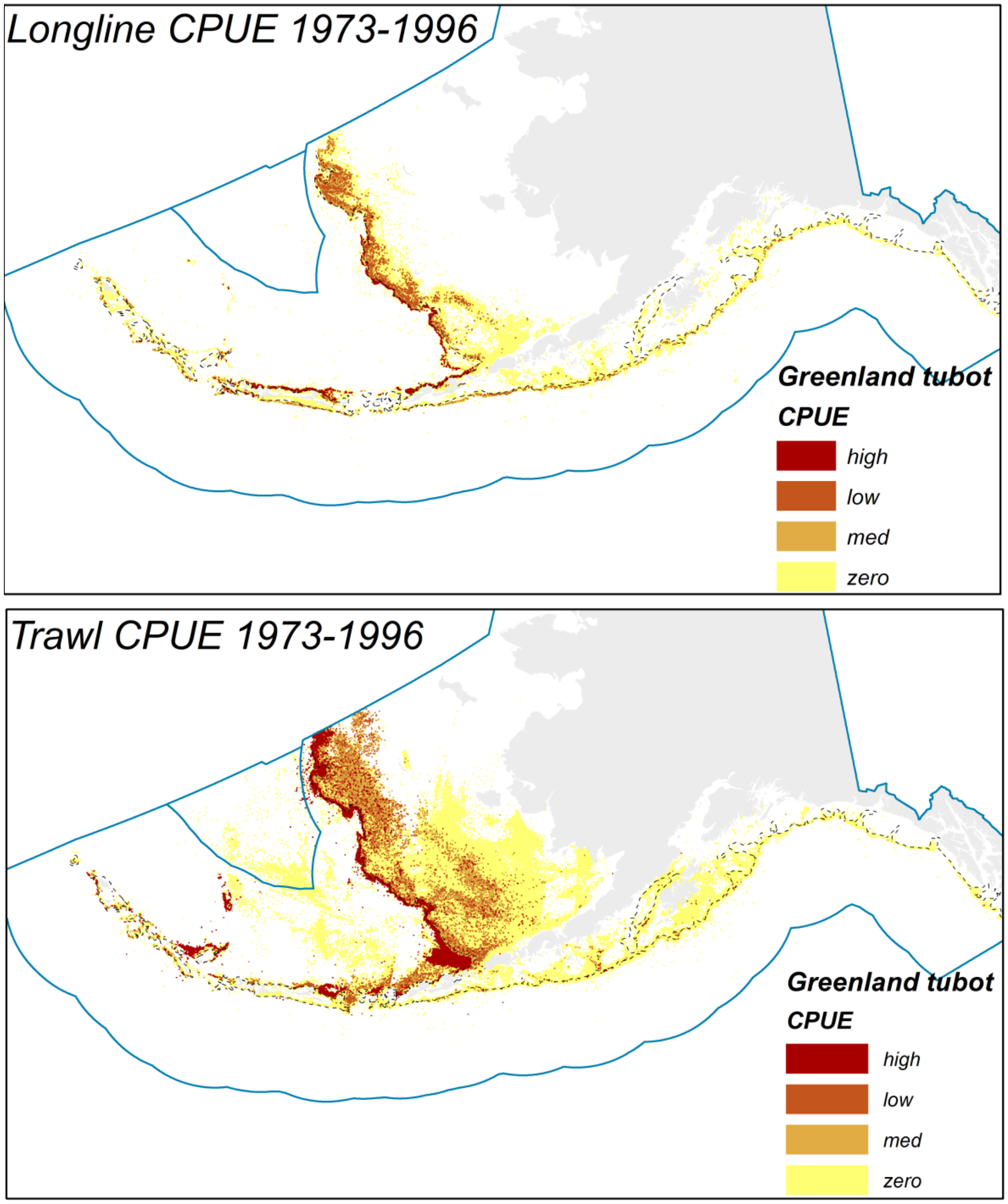


Figure 5.7. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data within the longline (top panel) and trawl (bottom panel) fisheries (Fritz et al 1998).

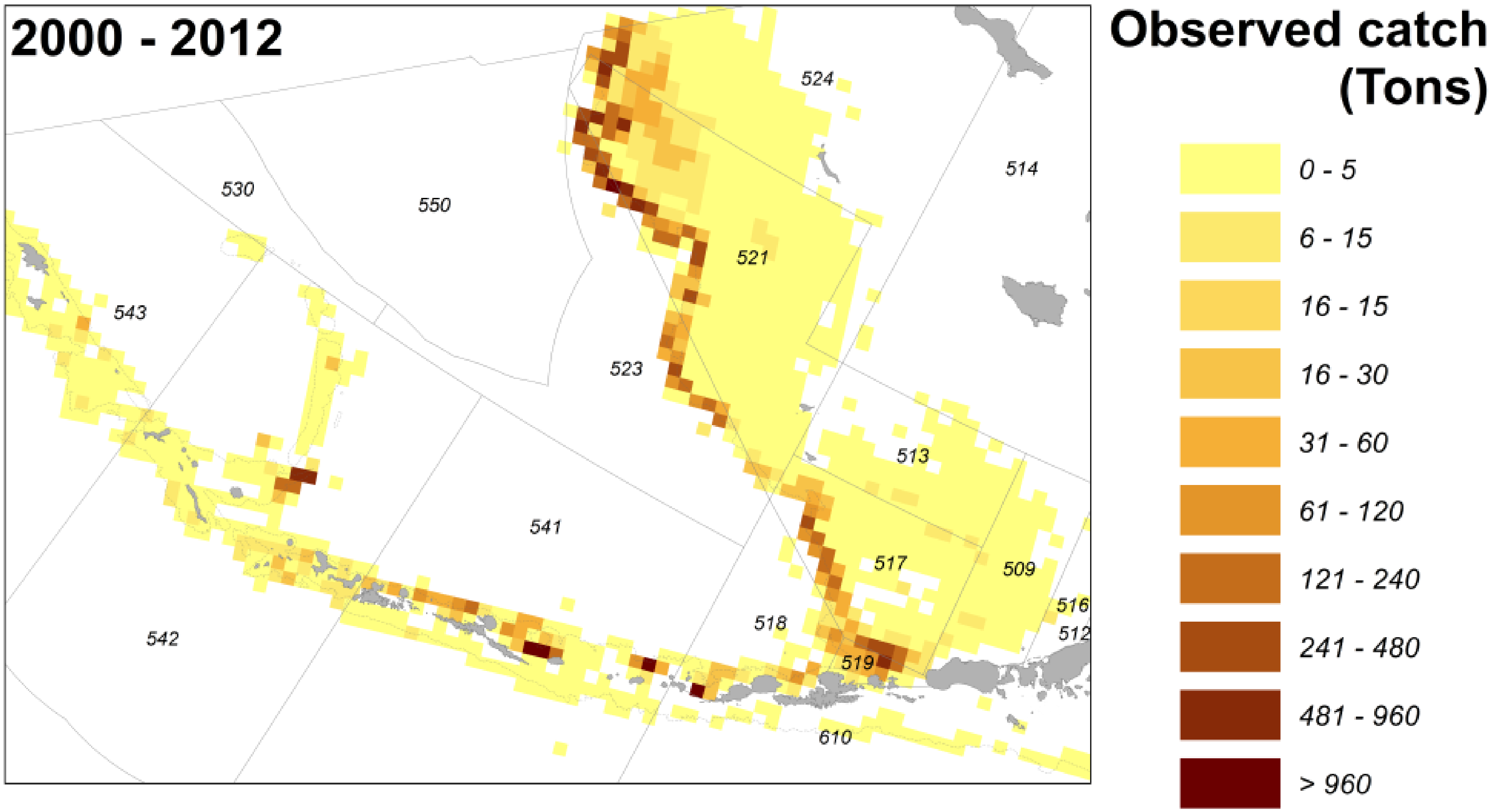


Figure 5.8 All observed Greenland turbot catch in the BSAI for 2000 through 2012, data are aggregated spatially at a 400 km^2 grid.

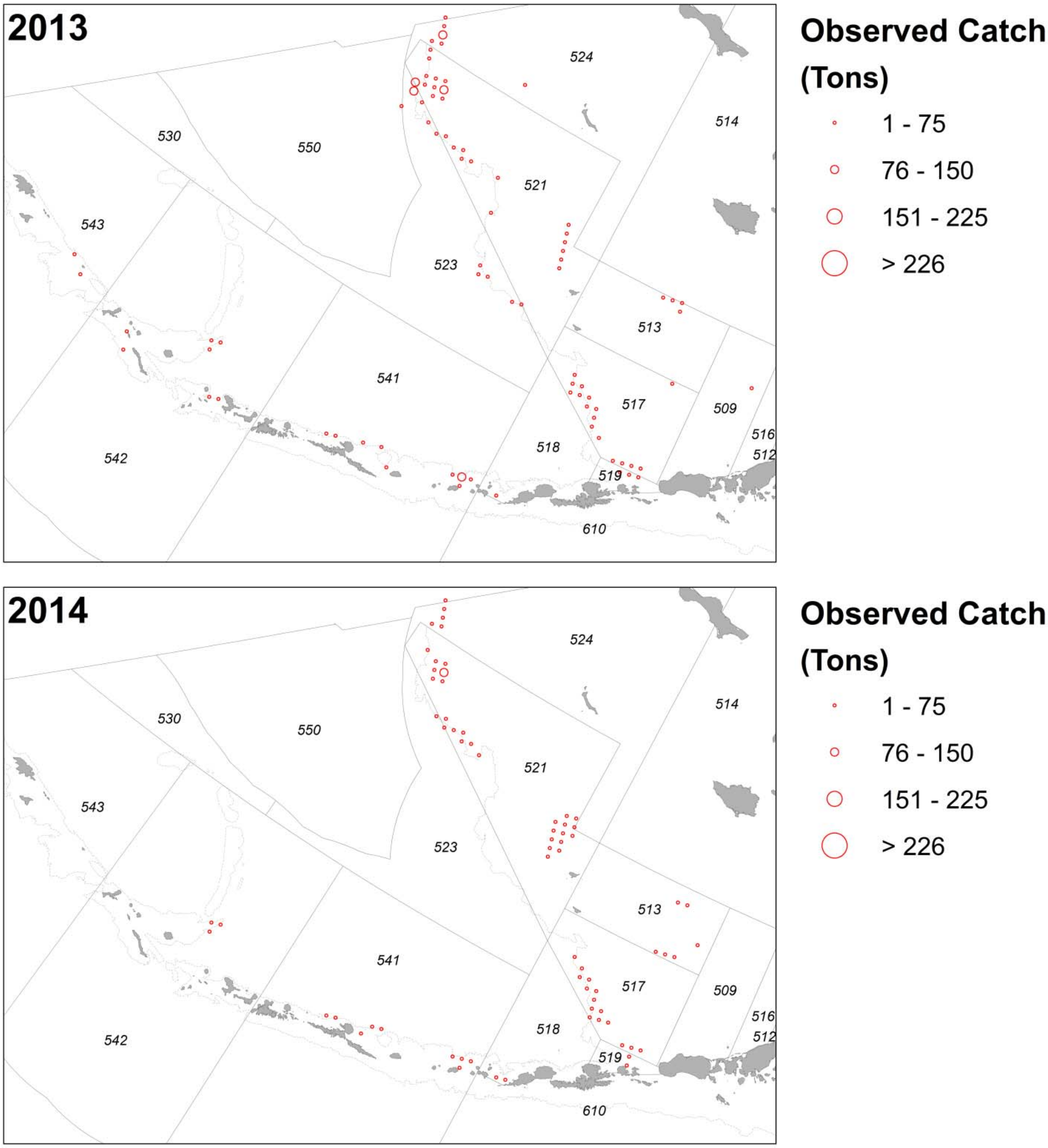


Figure 5.9.All observed Greenland turbot catch for 2013 and 2014. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

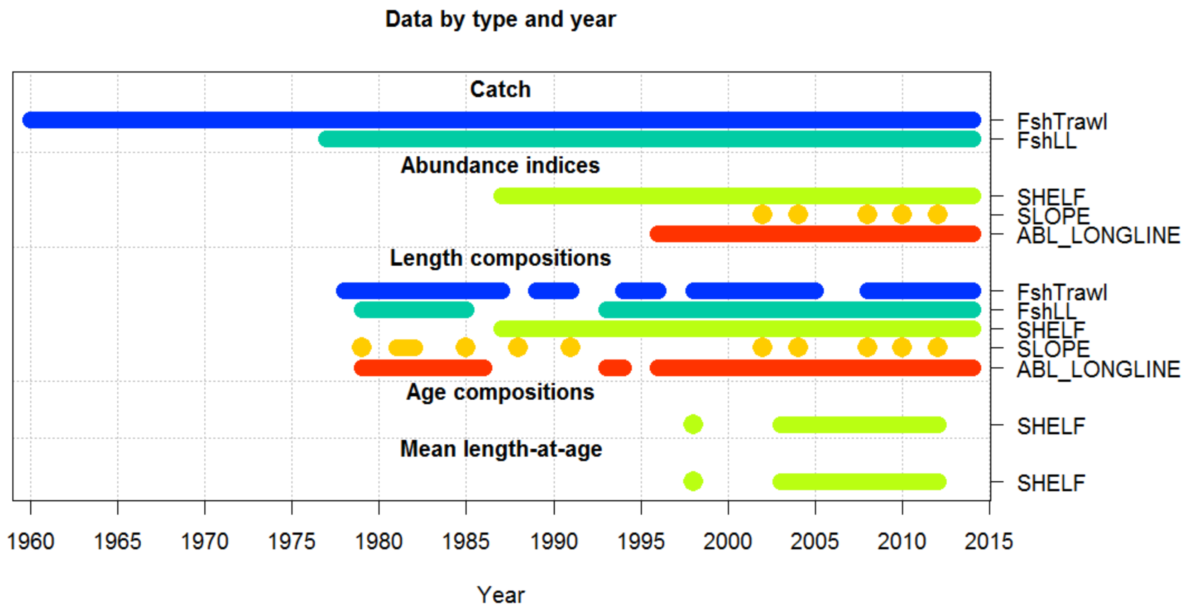
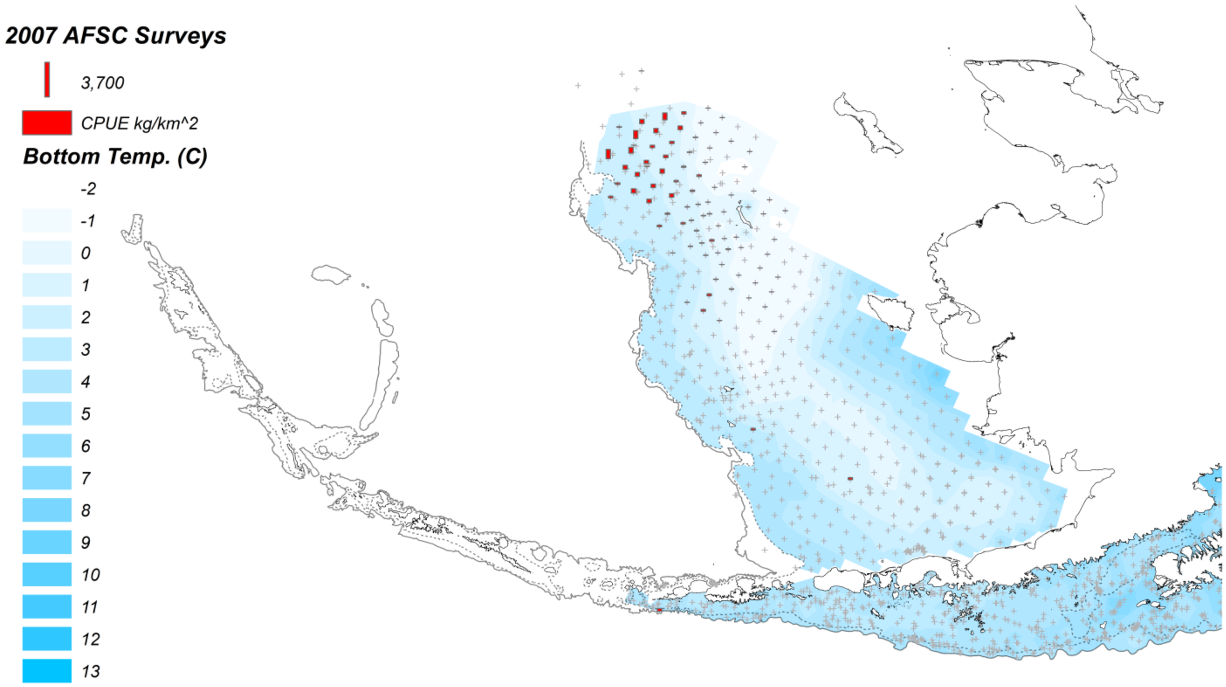


Figure 5.10. Timeline of all data included in the 2014 stock assessment models. FshTrawl = trawl fishery, FshLL = longline fishery, SHELF = Bering Sea trawl shelf survey, SLOPE = Bering Sea trawl slope survey, ABL_LONGLINE = Auke Bay Laboratory longline survey.



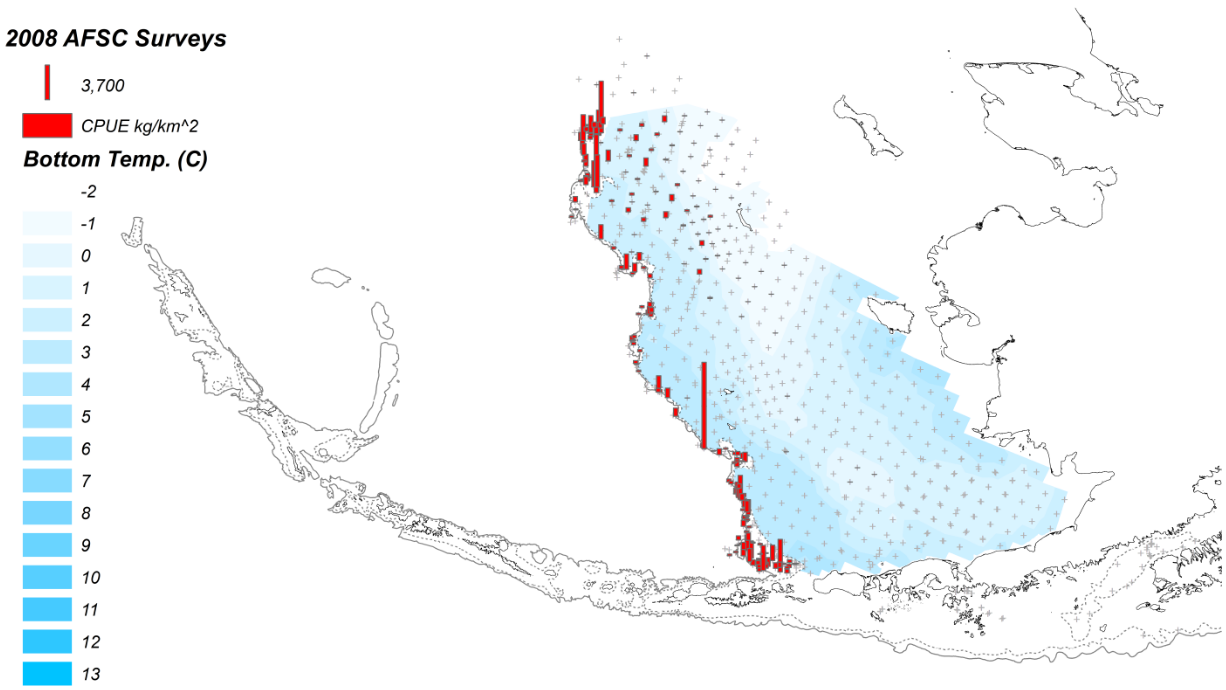


Figure 5.11. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

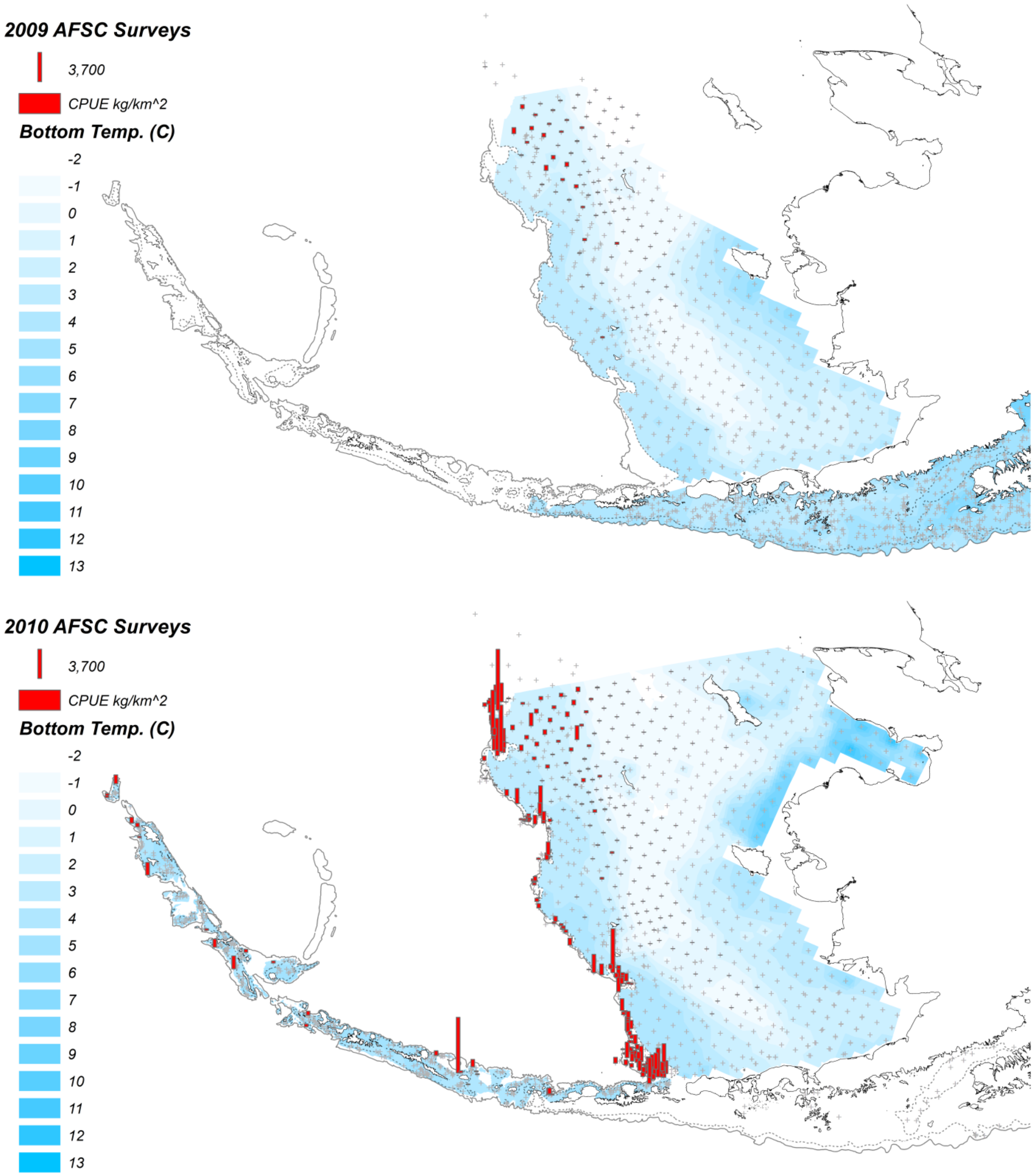


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

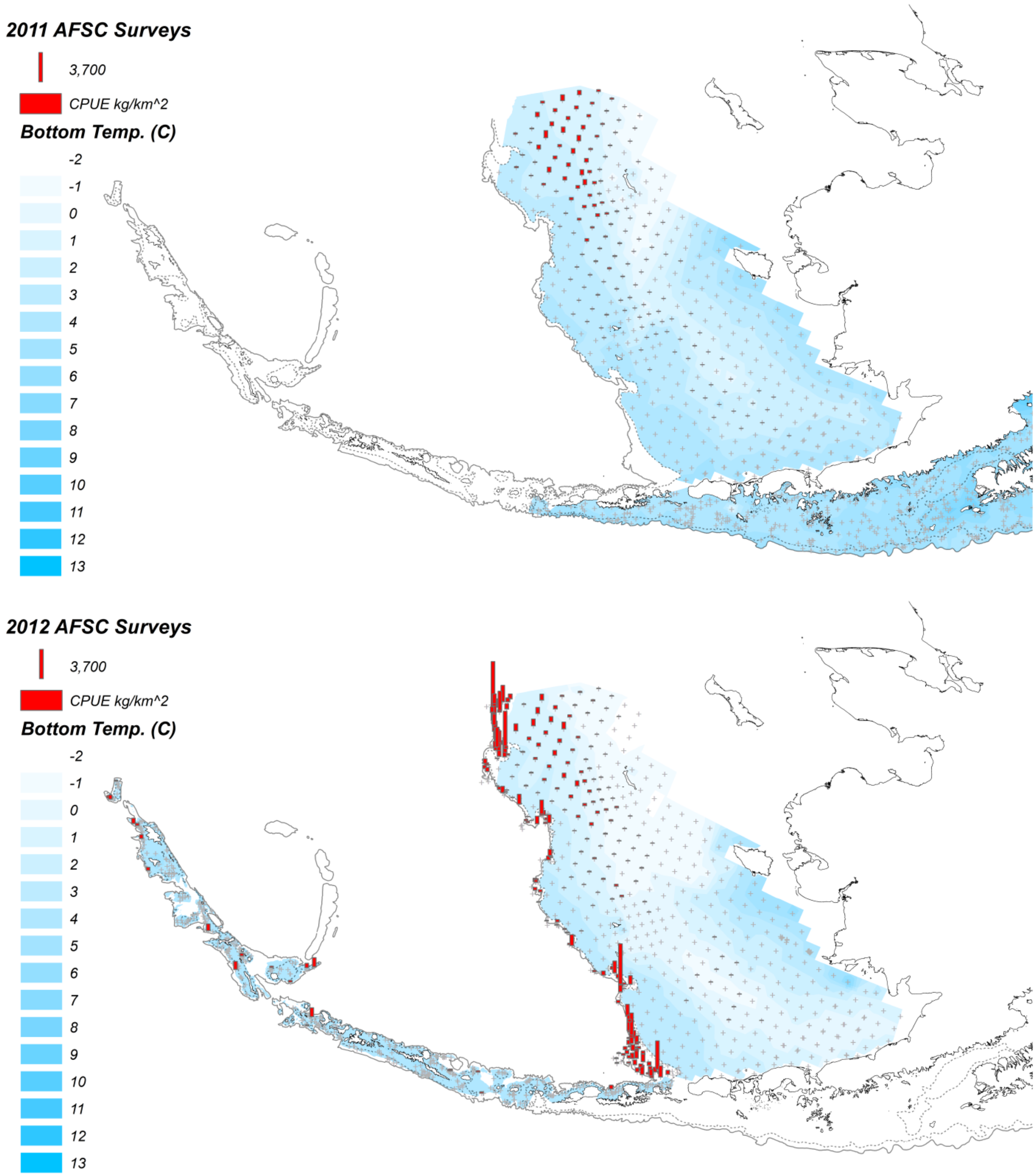
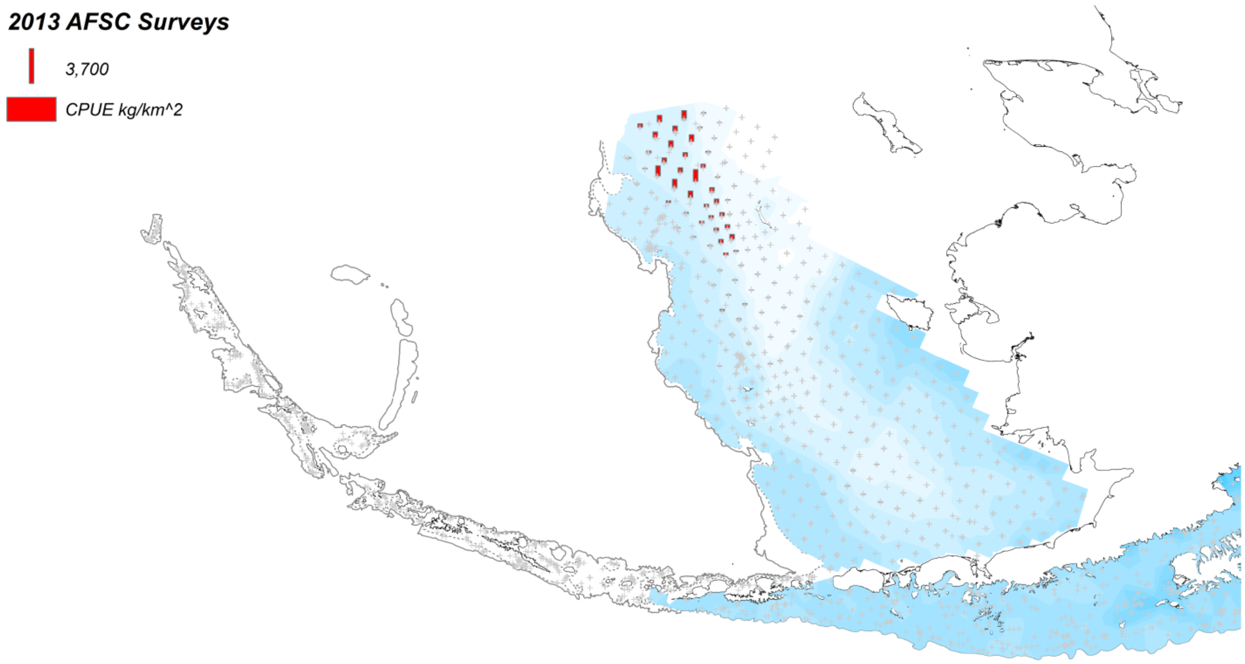


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.



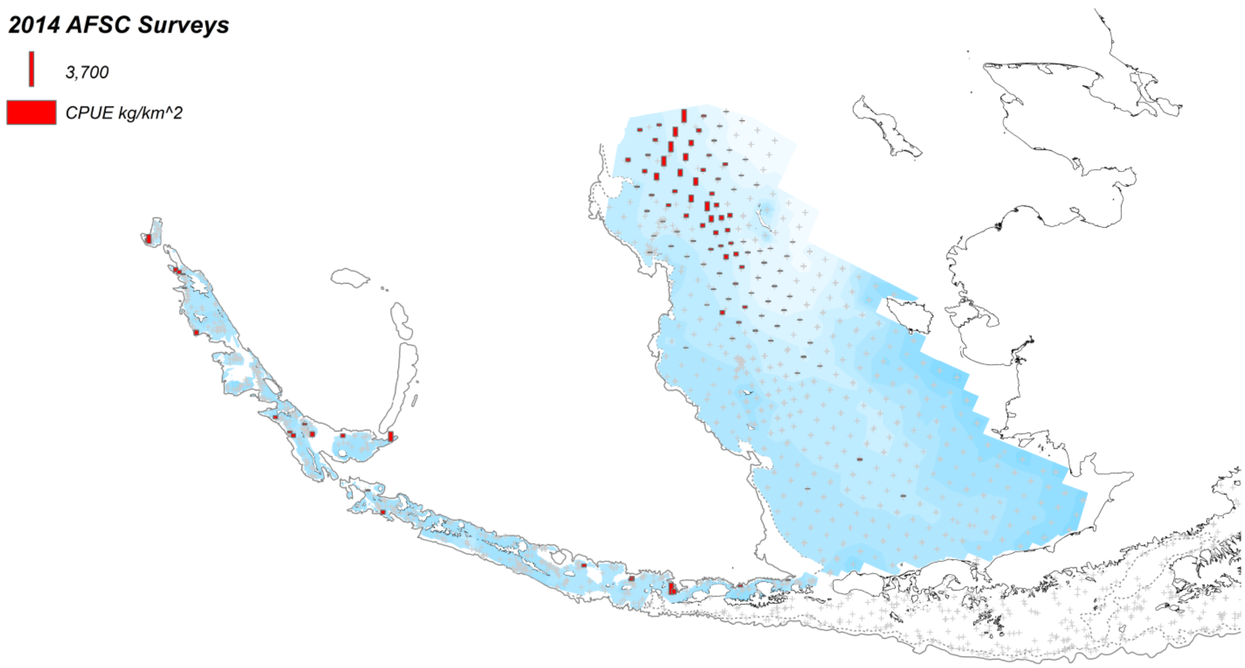


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot catch are marked with red bars. All CPUE bars are on the same scale for all surveys.

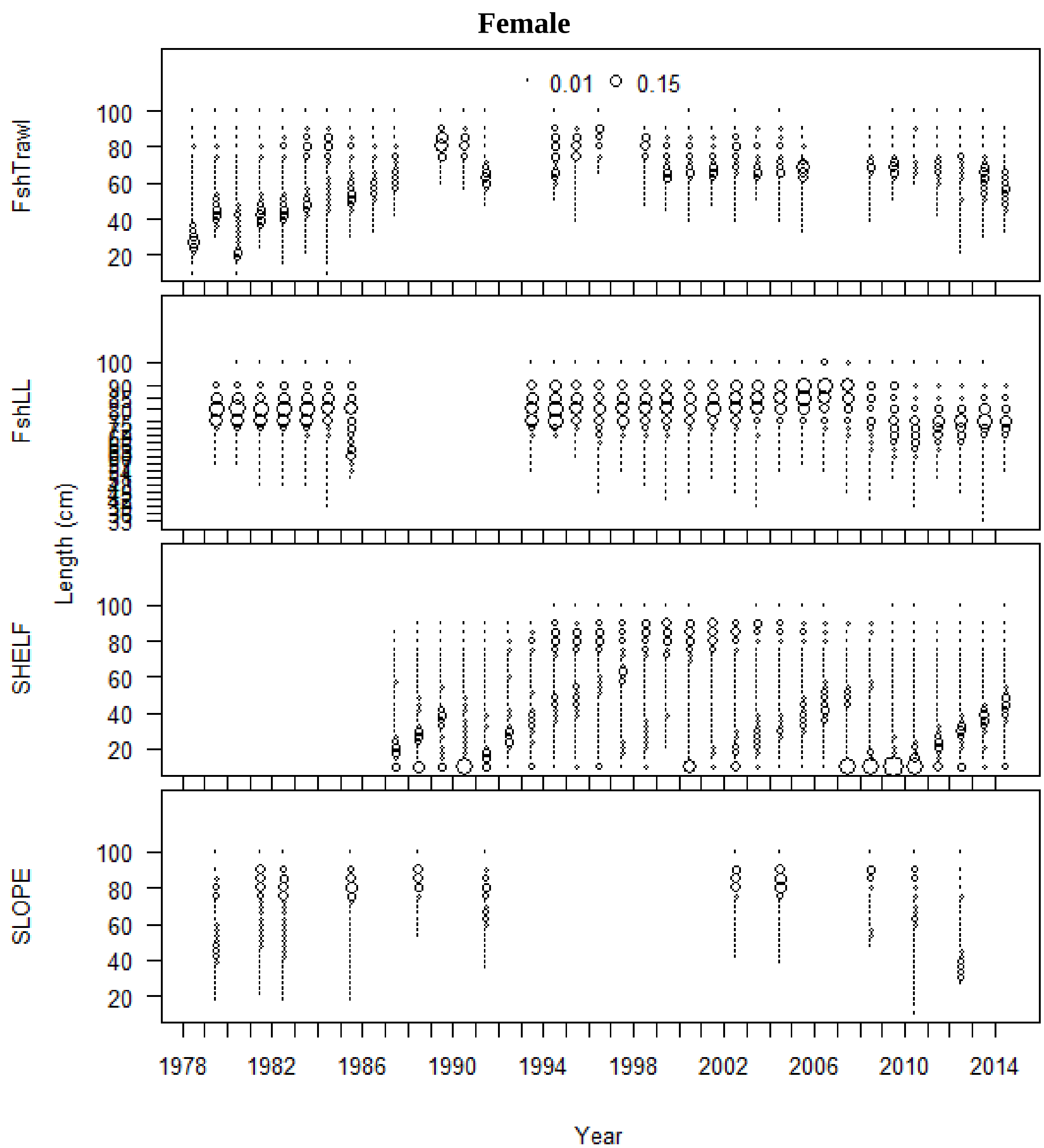


Figure 5.12. Greenland turbot size composition data for females from the trawl fishery (FshTrawl), longline fishery (FshLL), shelf survey (SHELF)and slope survey (SLOPE).

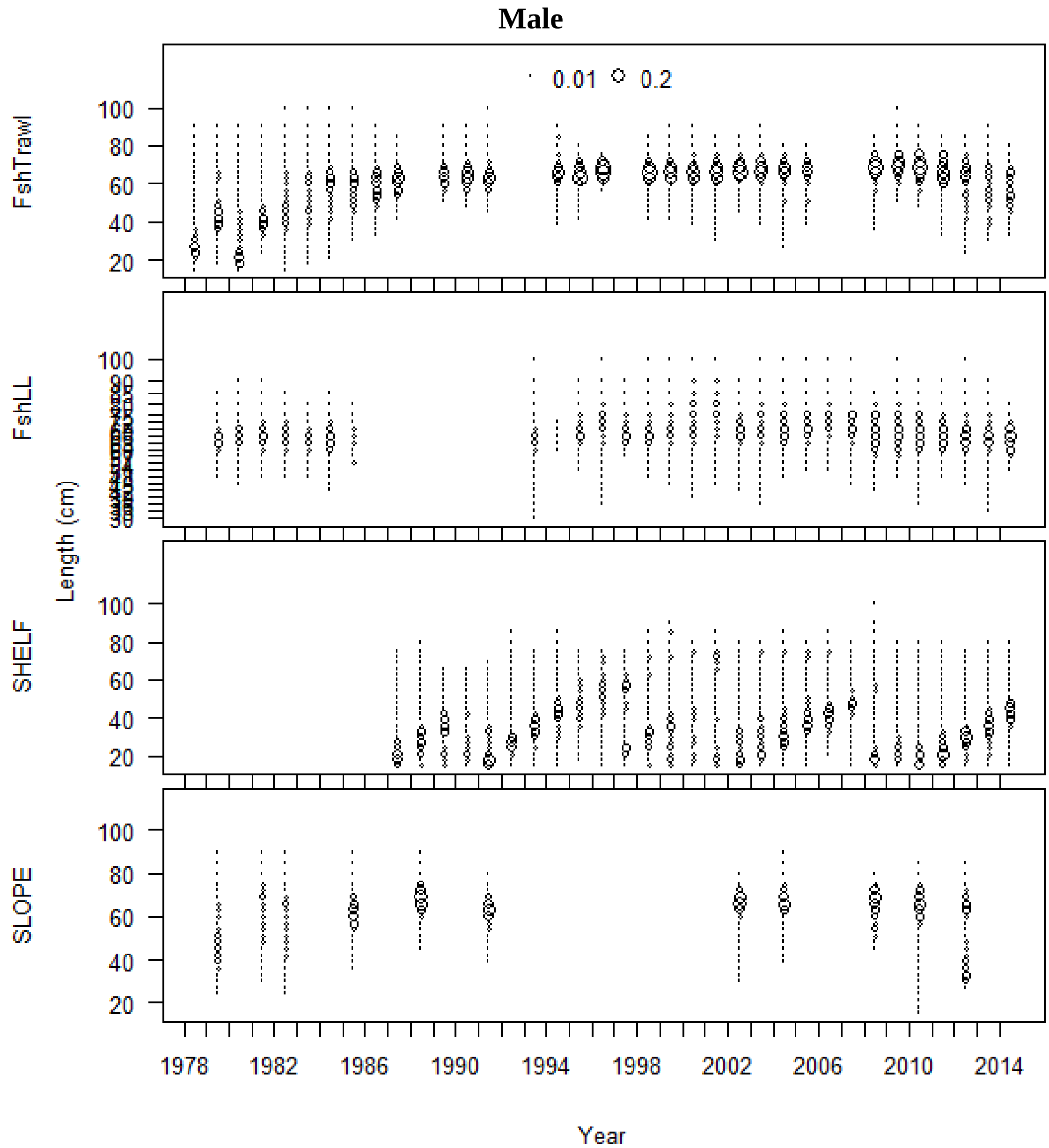


Figure 5.12. (Cont.) Greenland turbot size composition data for males from the trawl fishery (FshTrawl), longline fishery (FshLL), shelf survey (SHELF) and slope survey (SLOPE).

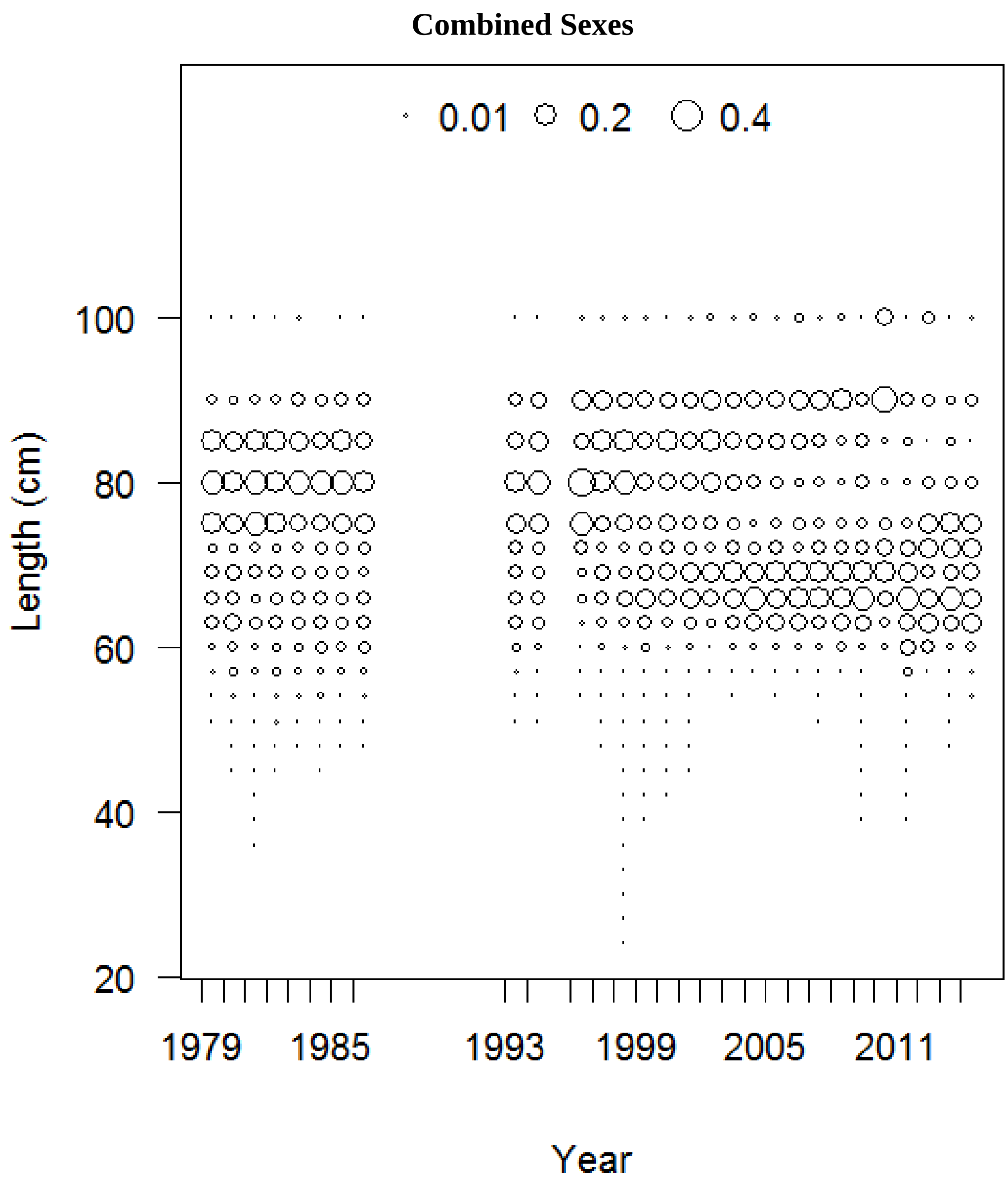


Figure 5.12. (Cont.) Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.

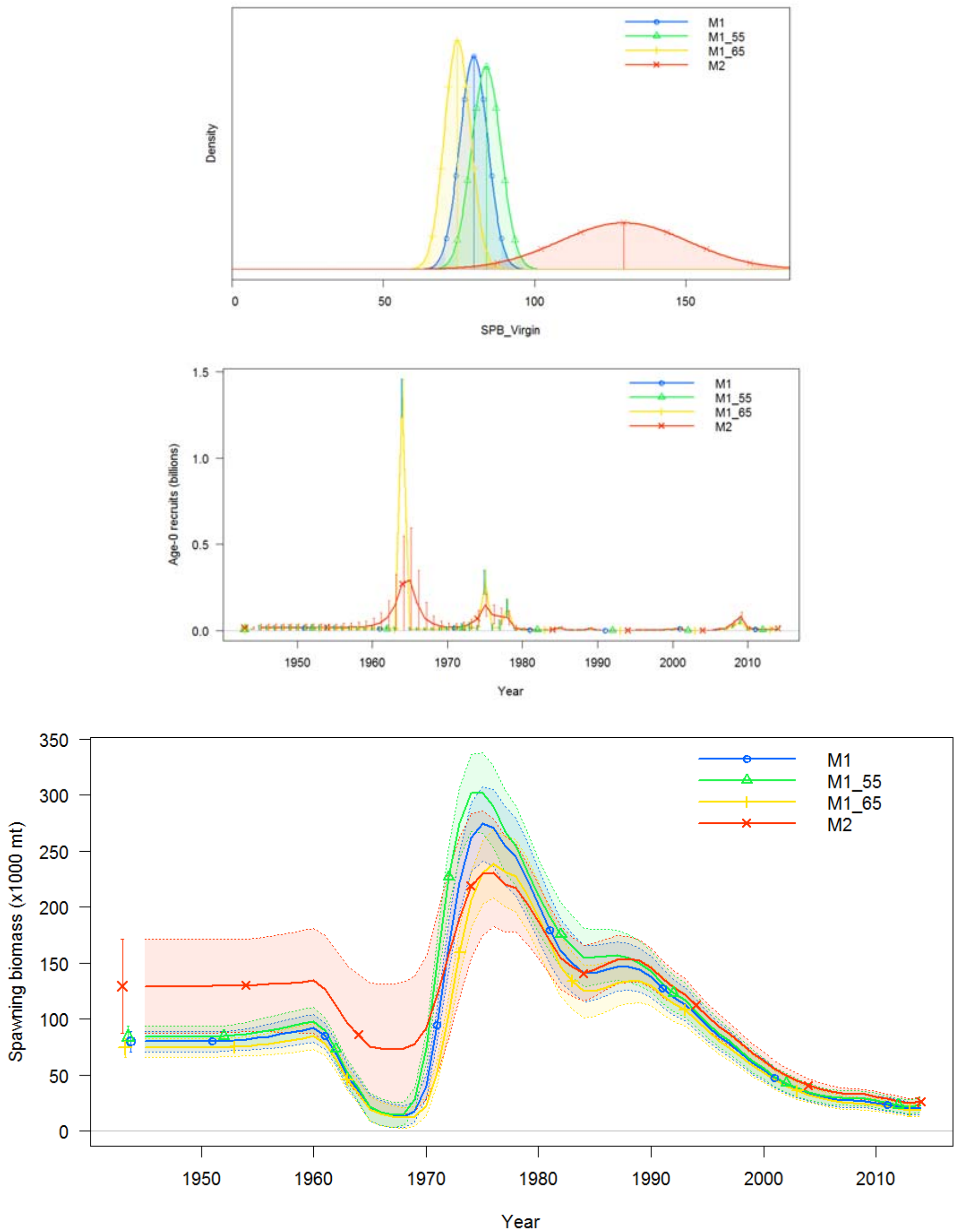


Figure 5.13. Virgin spawning biomass (top panel), age-0 recruitment (middle panel), and female spawning biomass (bottom panel) for Model 1 (M1) and Model 2 (M2). M1_55 and M1_65 are Model 1 with female length at 50% mature at 55cm and 65cm respectively.

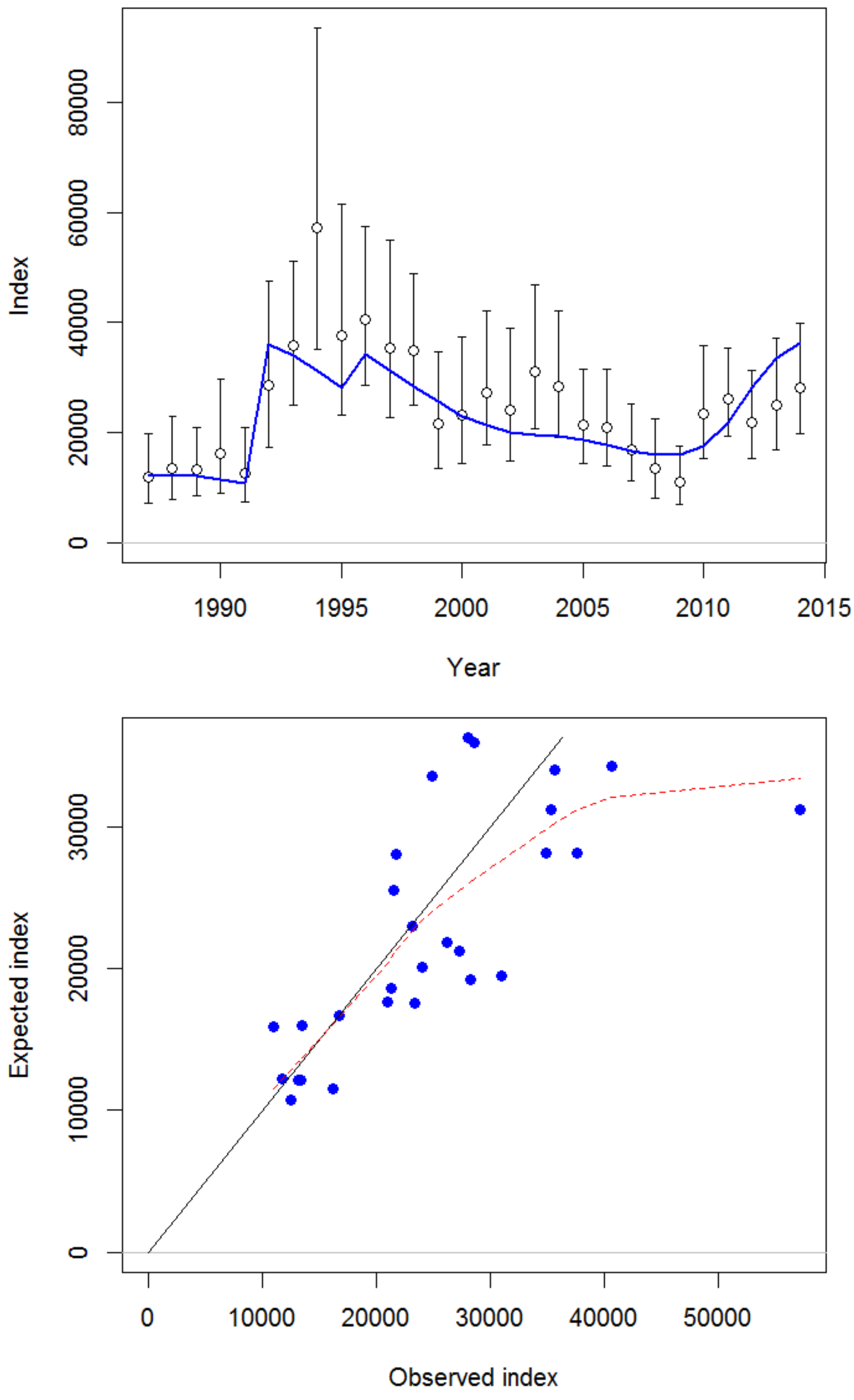


Figure 5.14. (Top Panel) Shelf survey index (index values are total survey biomass in tons), error bars as 95% confidence intervals, Model 2 fit (blue line). (Bottom panel) Model 2 expected index values plotted by observed index values with 1:1 line (black line) and loess smooth (red line).

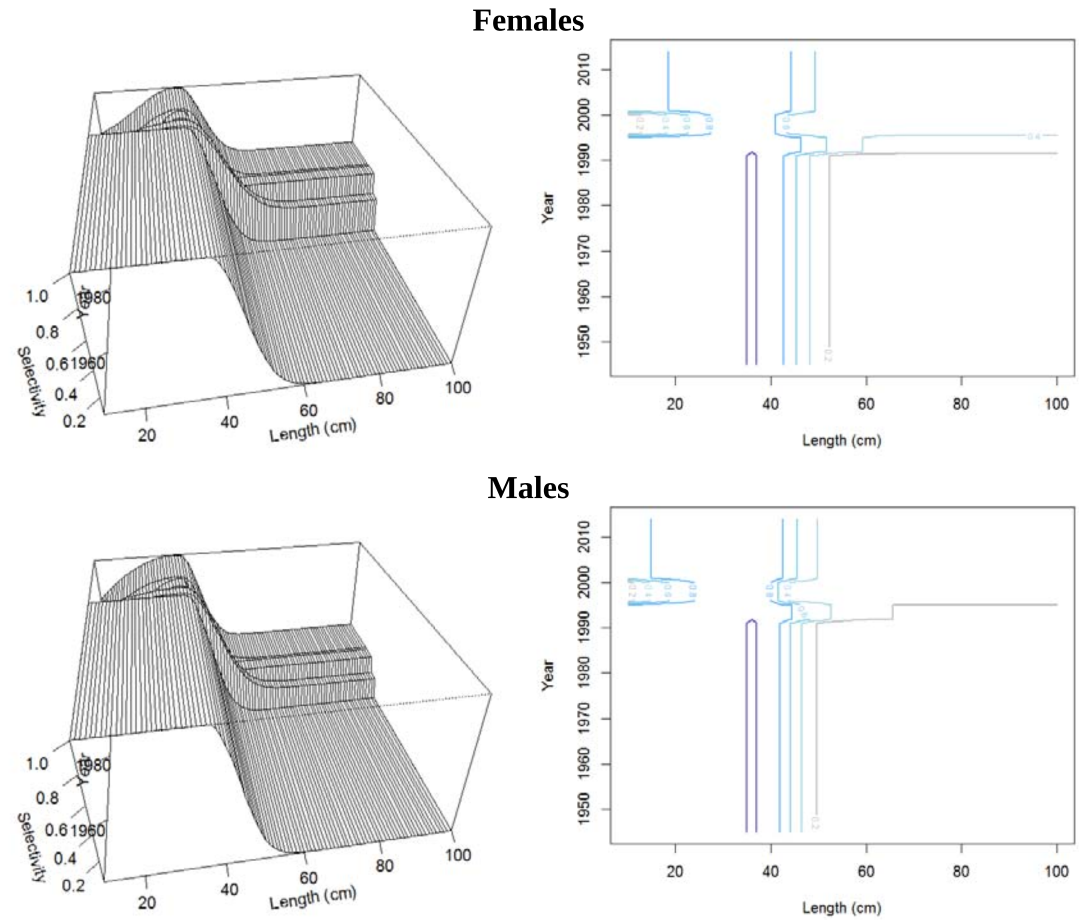


Figure 5.15. Time-varying selectivity at size for the shelf survey for Model 2 for females (top) and males (bottom).

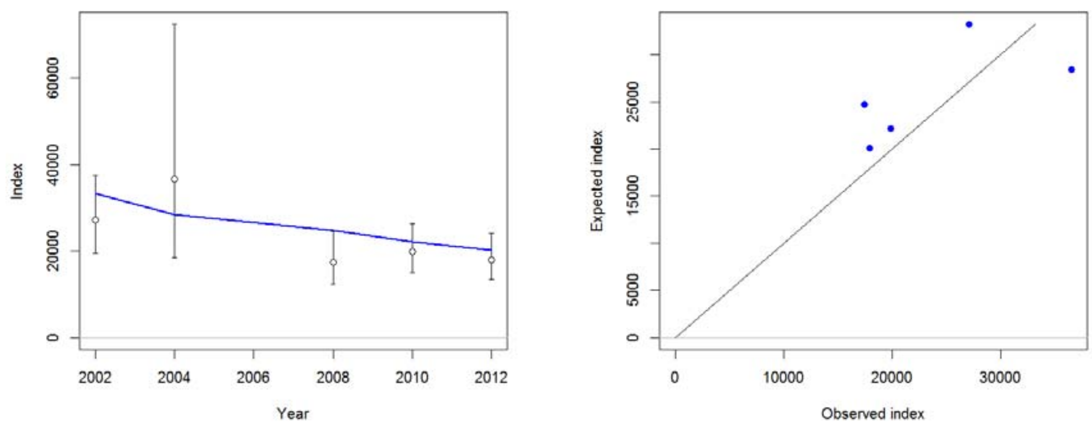


Figure 5.16. (Left Panel) Slope survey index (index values are total survey biomass in tons), error bars as 95% confidence intervals, and Model 2 fit (blue line). (Right panel) Model 2 expected index values plotted by observed index values with 1:1 line (black line) and loess smooth (red line).

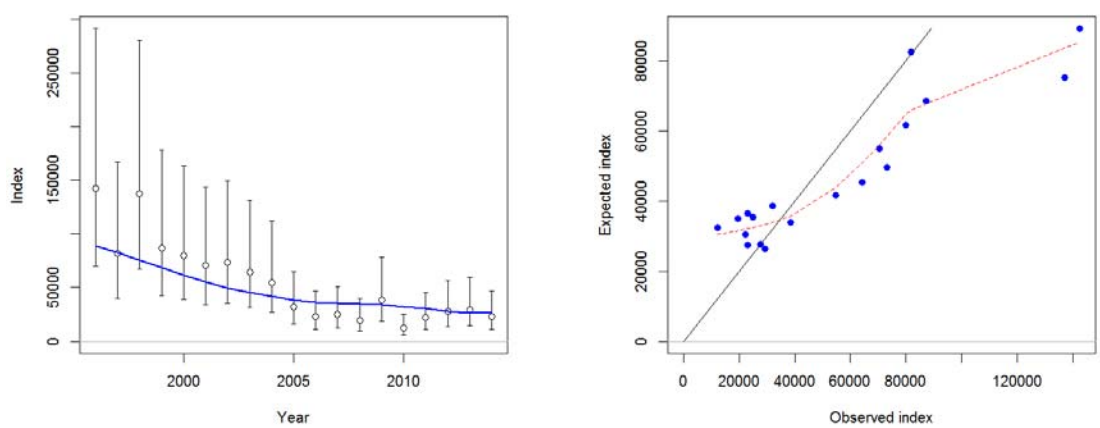


Figure 5.17. (Left Panel)The longline survey index (index values are in relative population numbers (RPN)), error bars as 95% confidence intervals, and Model 2 fit (blue line). (Bottom panel) Model 2 expected index values plotted by observed index values with 1:1 line (black line) and loess smooth (red line).

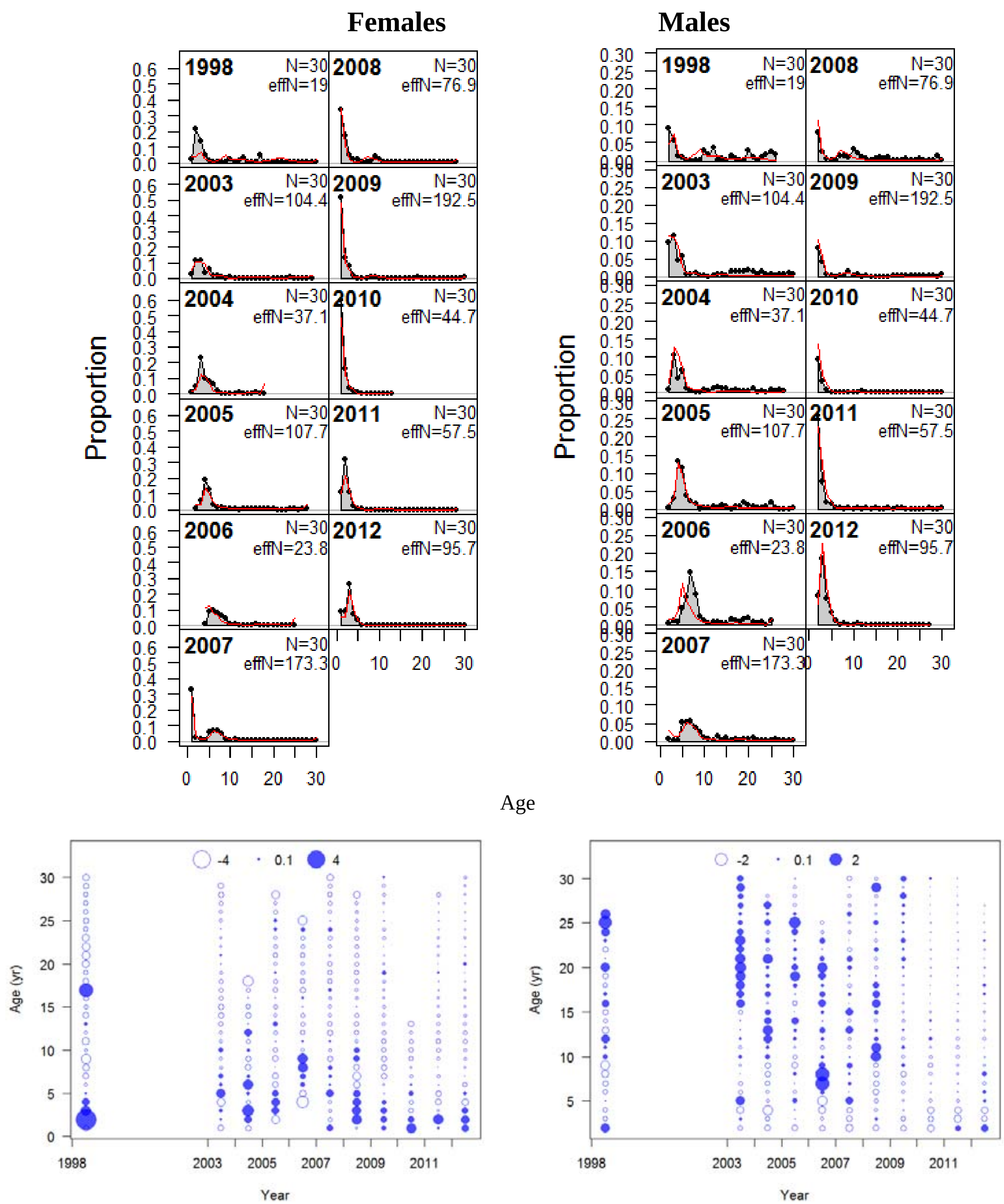


Figure 5.18. Shelf survey age composition data and Model 2 fits (red line) by year for females (top left panel) and males (top right panel). Shelf survey age composition Pearson residuals for females (bottom left panel) and males (bottom right panel).

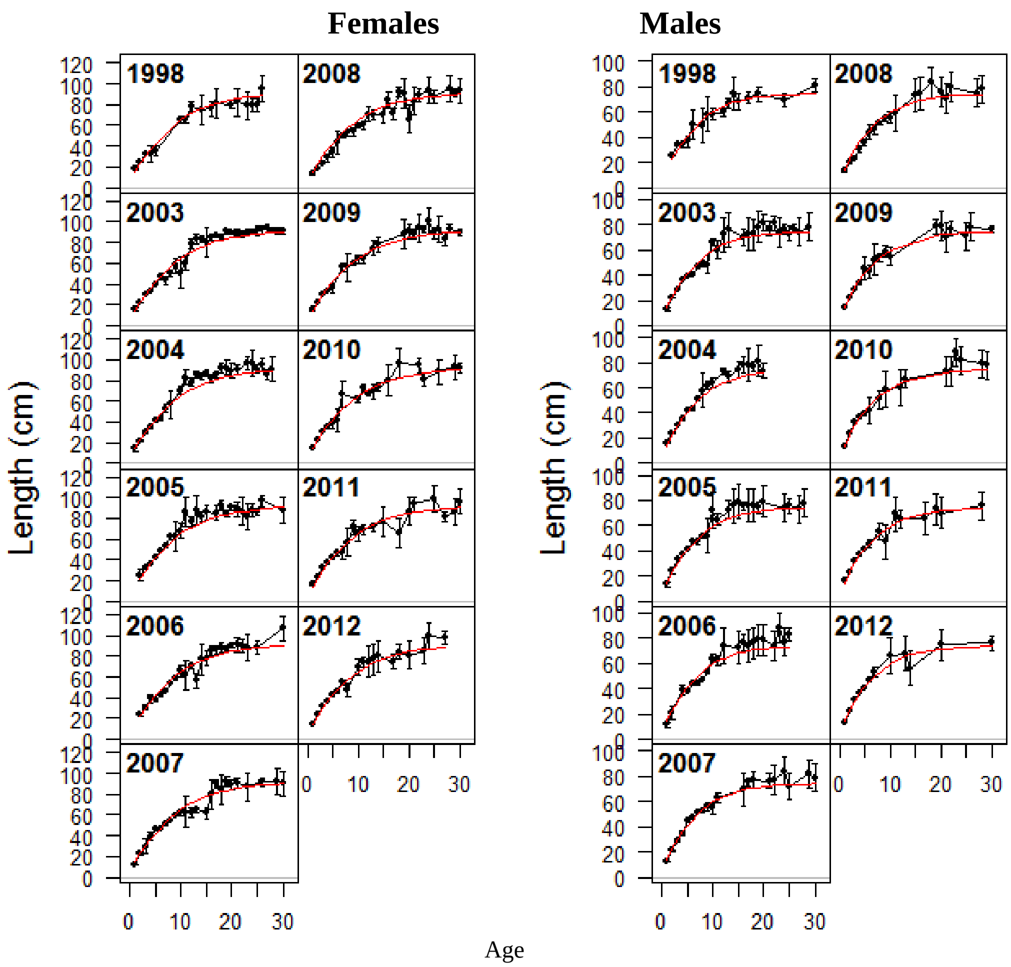


Figure 5.19. Length at age data and Model 2 fits (red line) by year for females (left panel) and males (right panel).

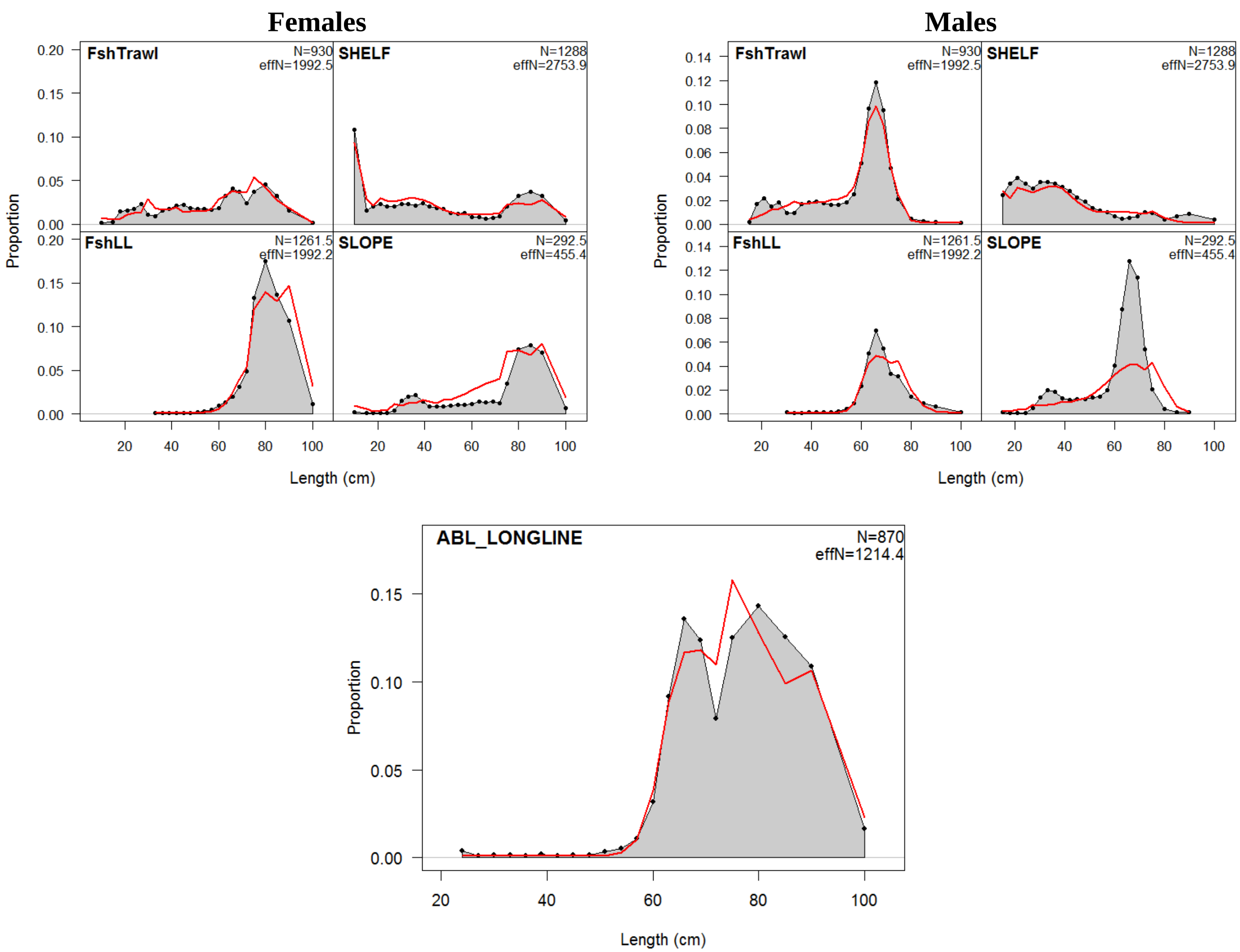


Figure 5.20. Greenland turbot size composition data combined across years and separated by sex (females in top left panel, males in top right panel) with Model 2 fits (red line) from the Trawl fishery (FshTrawl), longline fishery (FshLL), shelf survey (SHELF) and slope survey (SLOPE). ABL longline (bottom panel) size composition data are combined across years and sex.

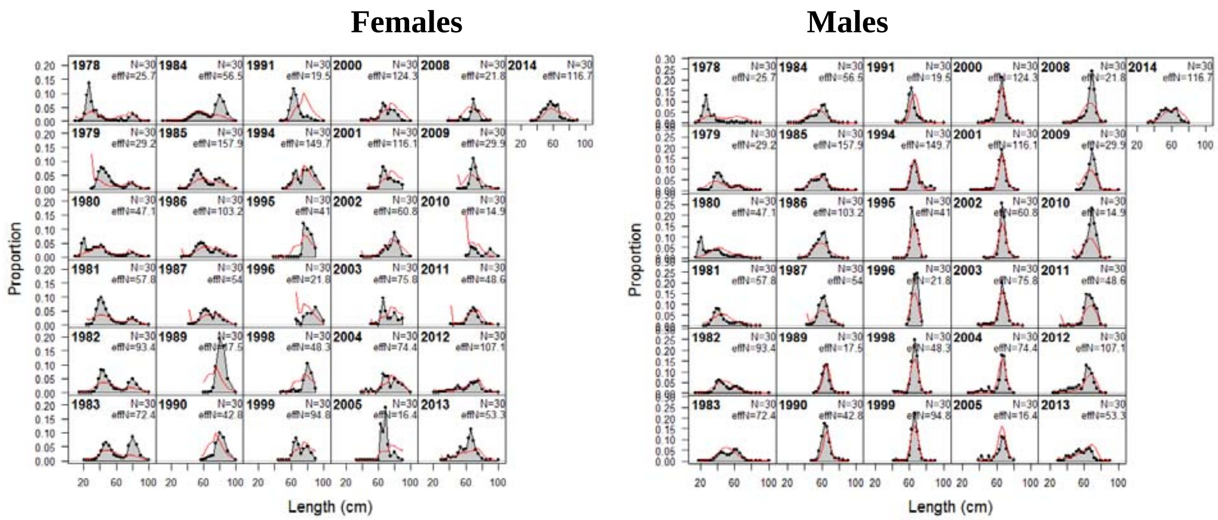


Figure 5.21. Trawl fishery size composition data and Model 2 fits (red line) by year for females (left panel) and males (right panel).

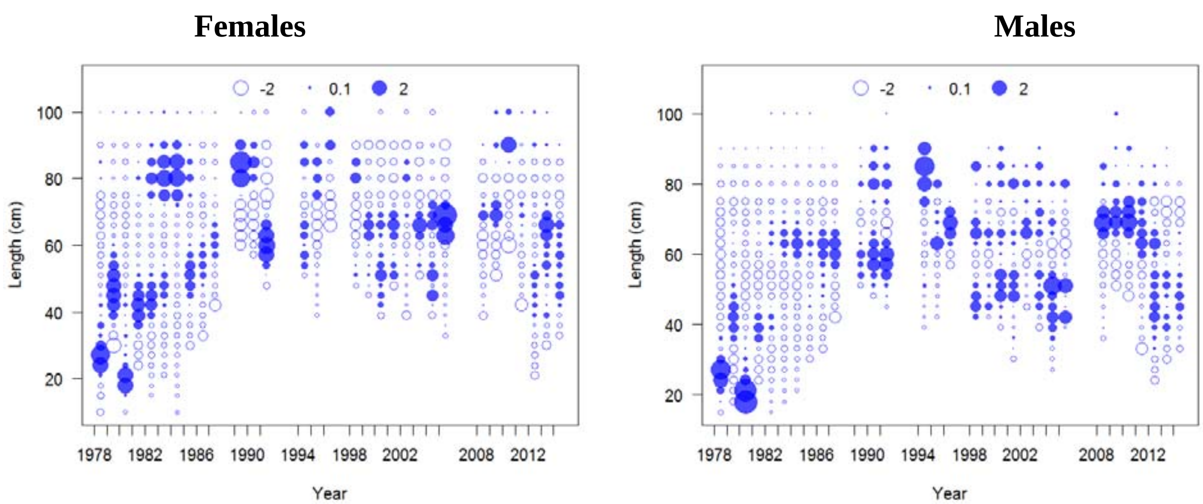


Figure 5.22. Trawl fishery size composition Pearson residuals for females (left panel) and males (right panel) .

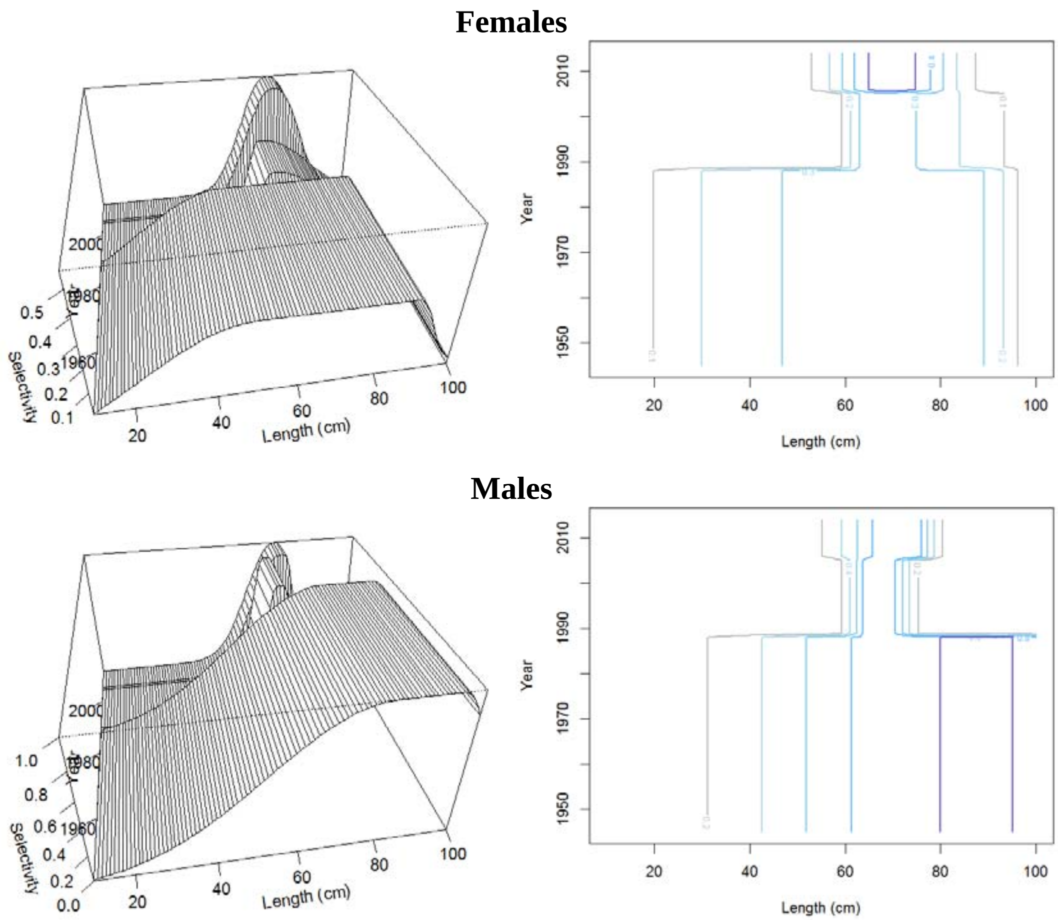


Figure 5.23. Time-varying selectivity at size for the trawl fishery for Model 2 for females (top) and males (bottom).

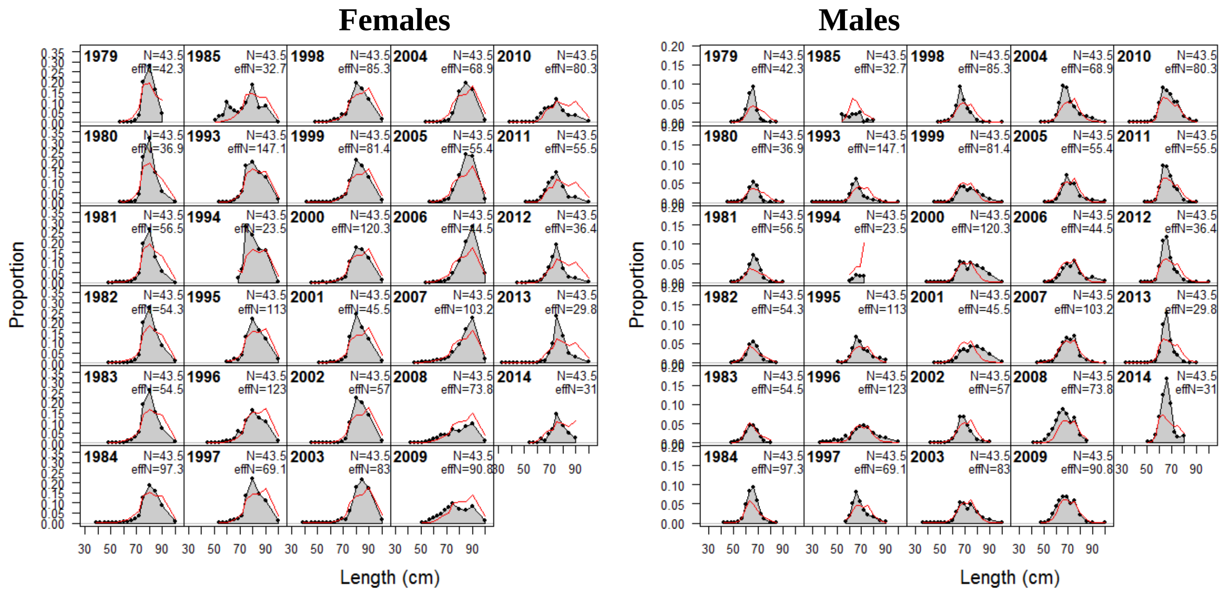


Figure 5.24. Longline fishery size composition data and Model 2 fits (red line) by year for females (left panel) and males (right panel).

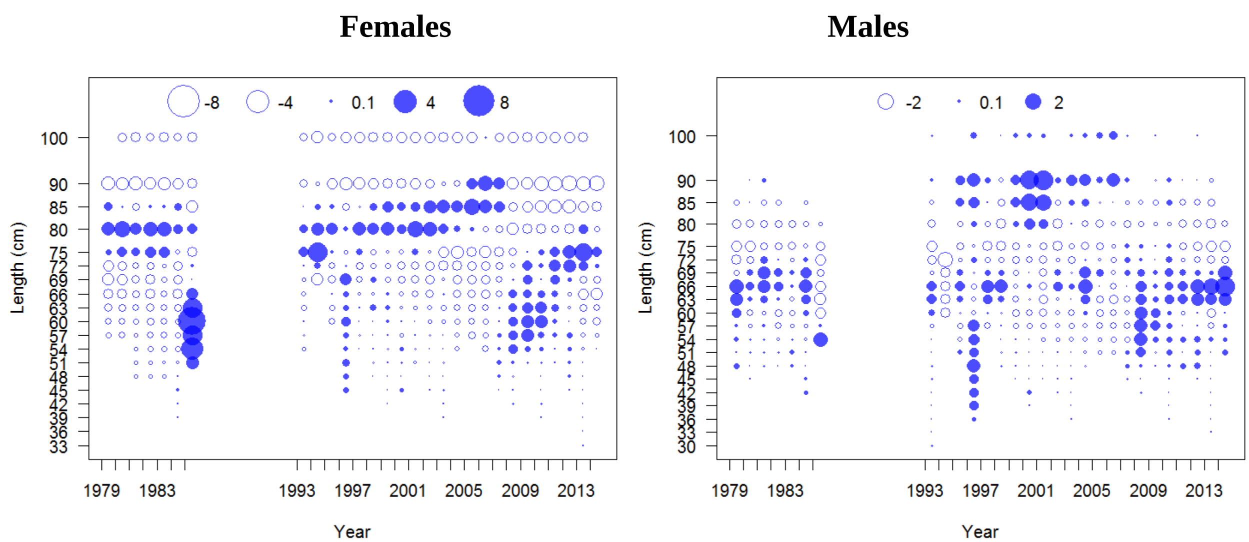


Figure 5.25. Longline fishery size composition Pearson residuals for females (left panel) and males (right panel).

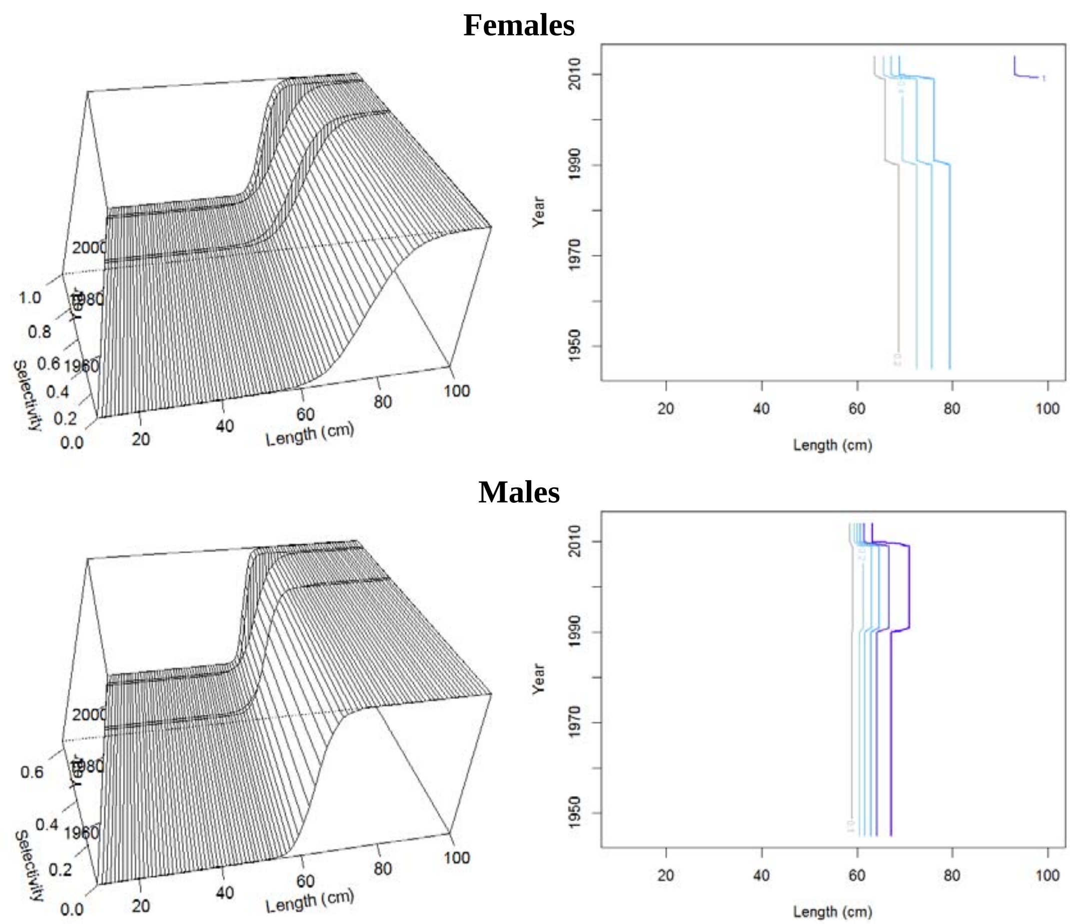


Figure 5.26. Time-varying selectivity at size for the longline fishery for Model 2 for females (top) and males (bottom). Notice the y-axes and scales are different.

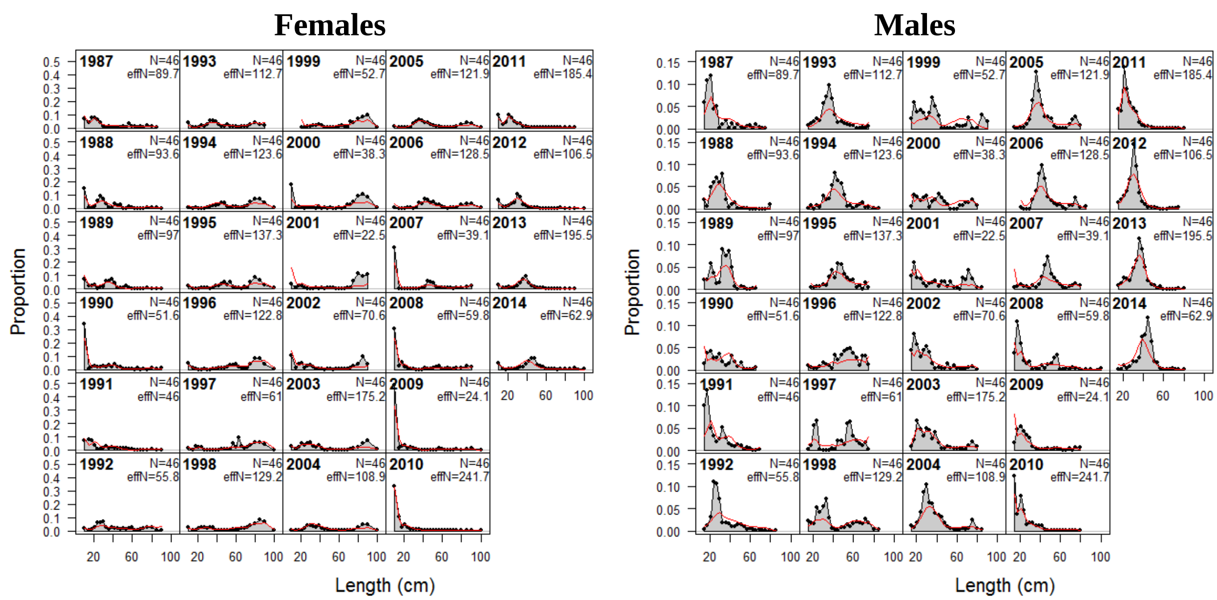


Figure 5.27. Shelf survey size composition data and Model 2 fits (red line) by yearfor females (left panel) and males (right panel).

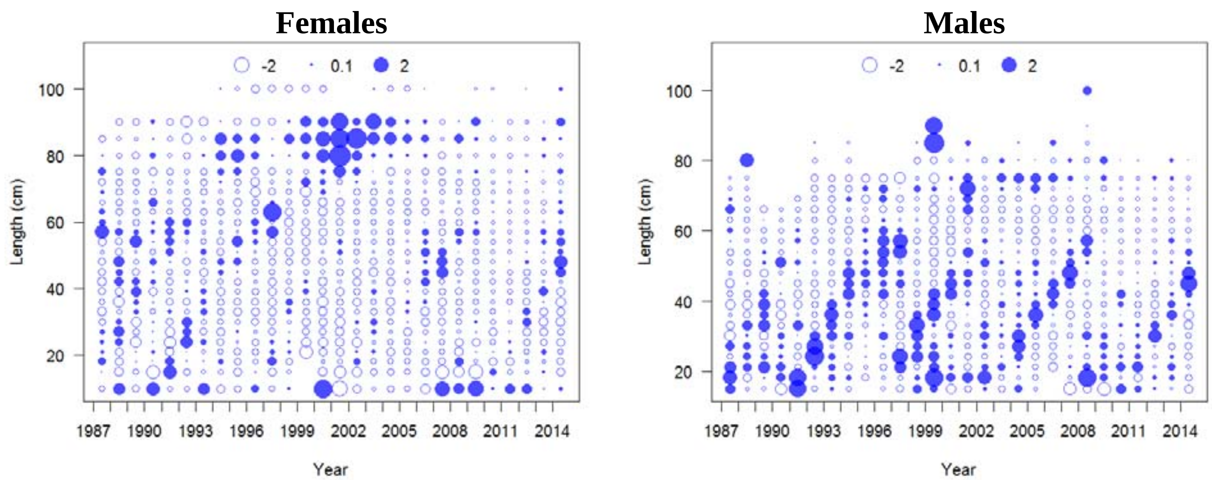


Figure 5.28. Shelf survey size composition Pearson residuals for females (left panel) and males (right panel) . Closed bubbles are positive residuals and open bubbles are negative residuals.

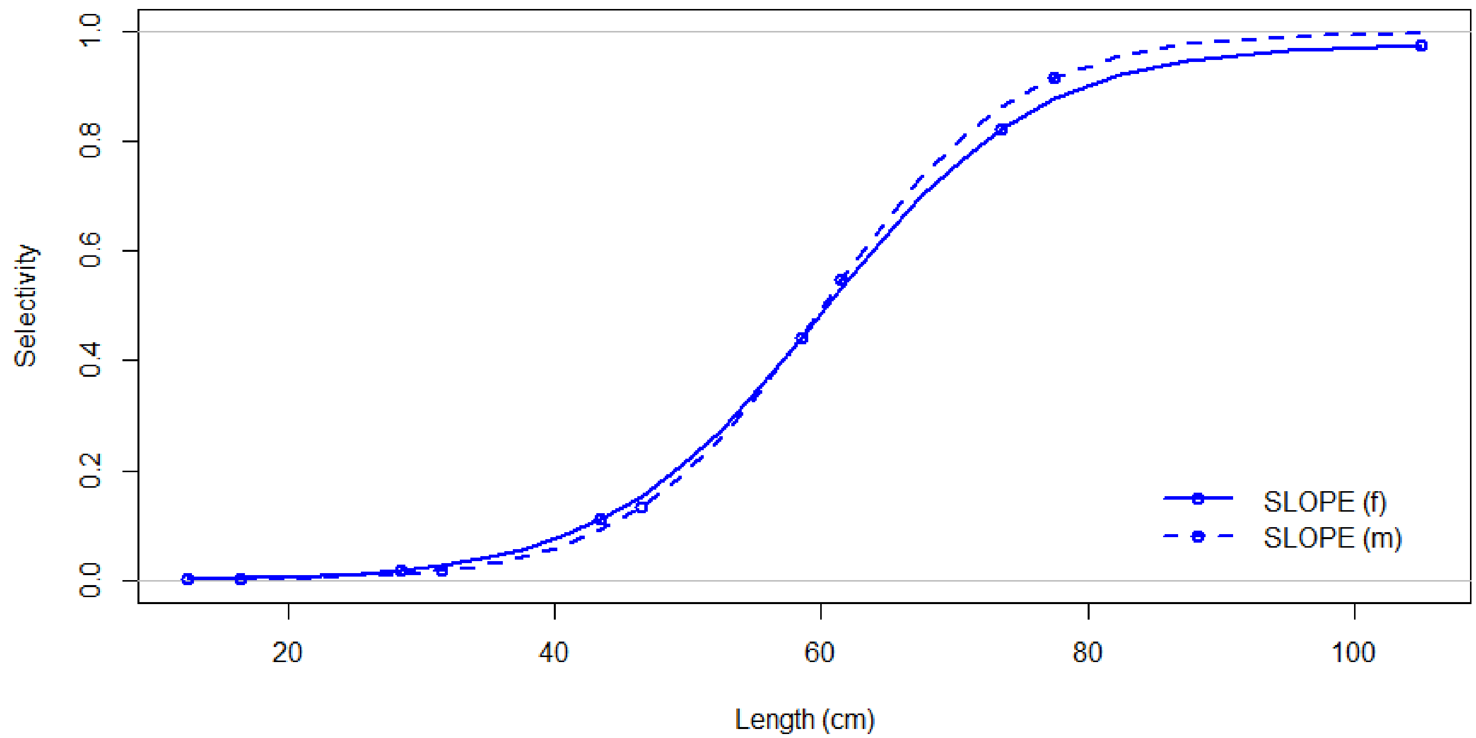


Figure 5.29. The slope survey size selectivity by sex (solid line = females, dashed line = males) for all years combined for Model 2.

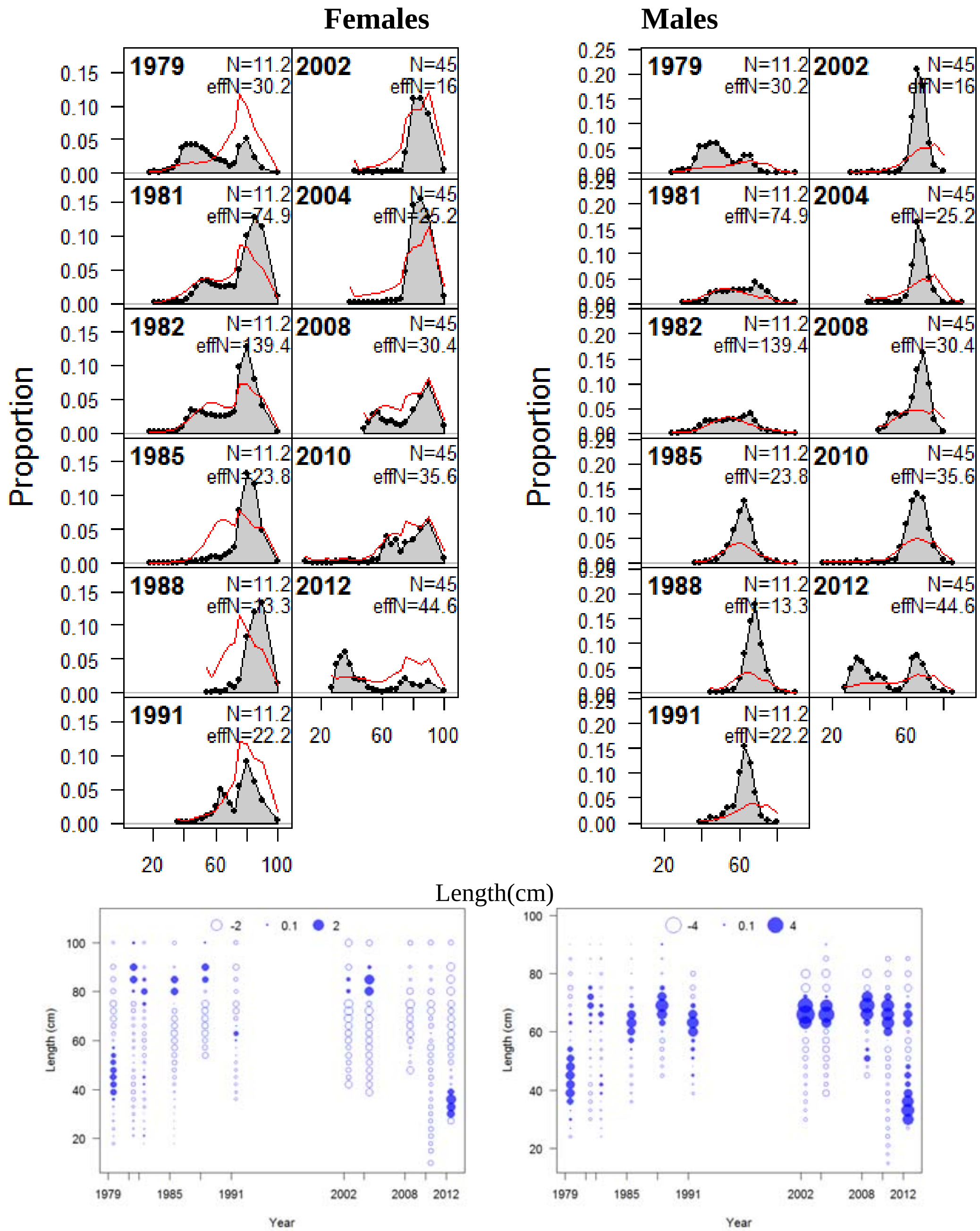


Figure 5.30. Slope survey size composition data and Model 2 fits (red line) by year for females (top left panel) and males (top right panel). Slope survey size composition Pearson residuals for females (bottom left panel) and males (bottom right panel).

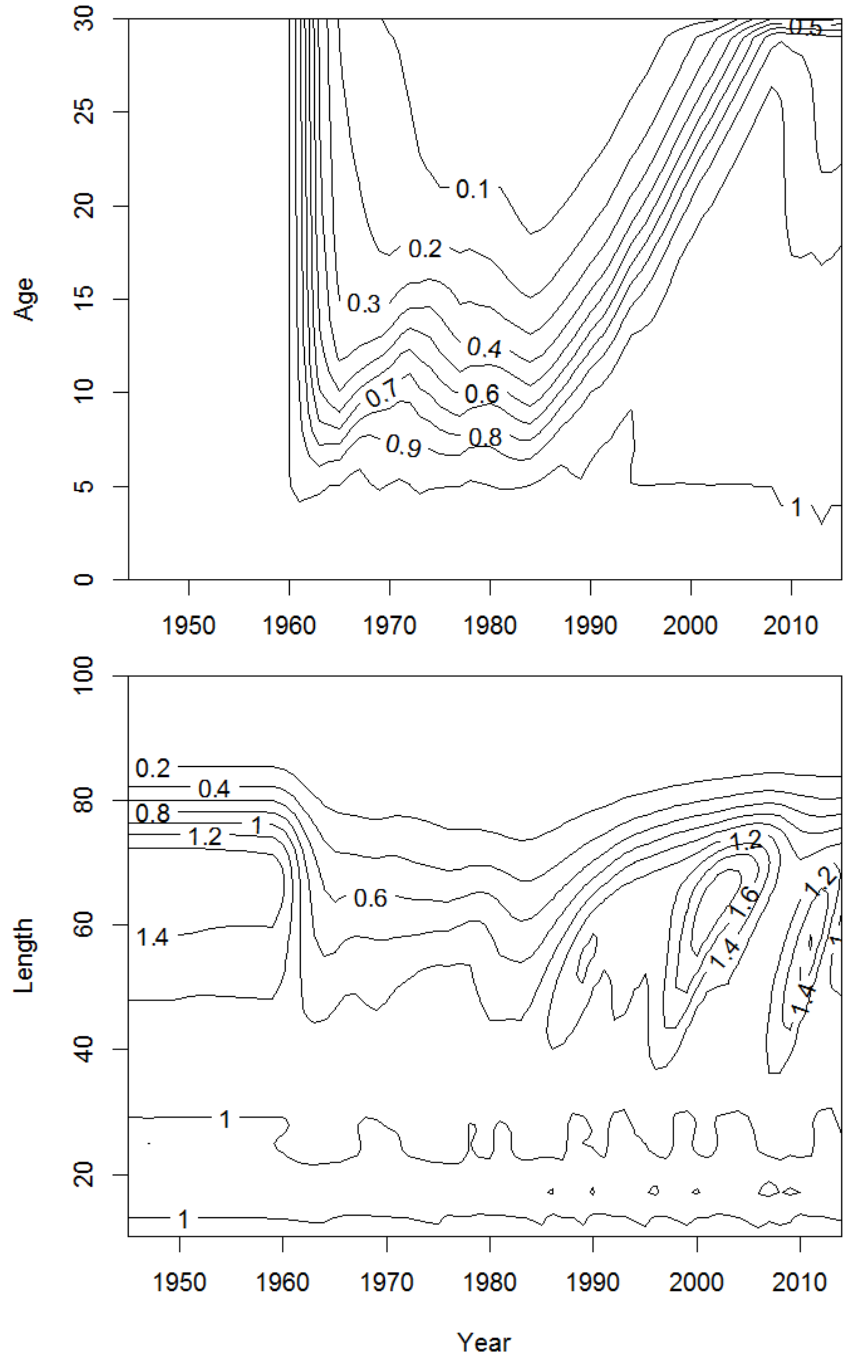


Figure 5.31. BSAI Greenland turbot sex ratio (males:females) by age (top panel) and size (bottom panel).

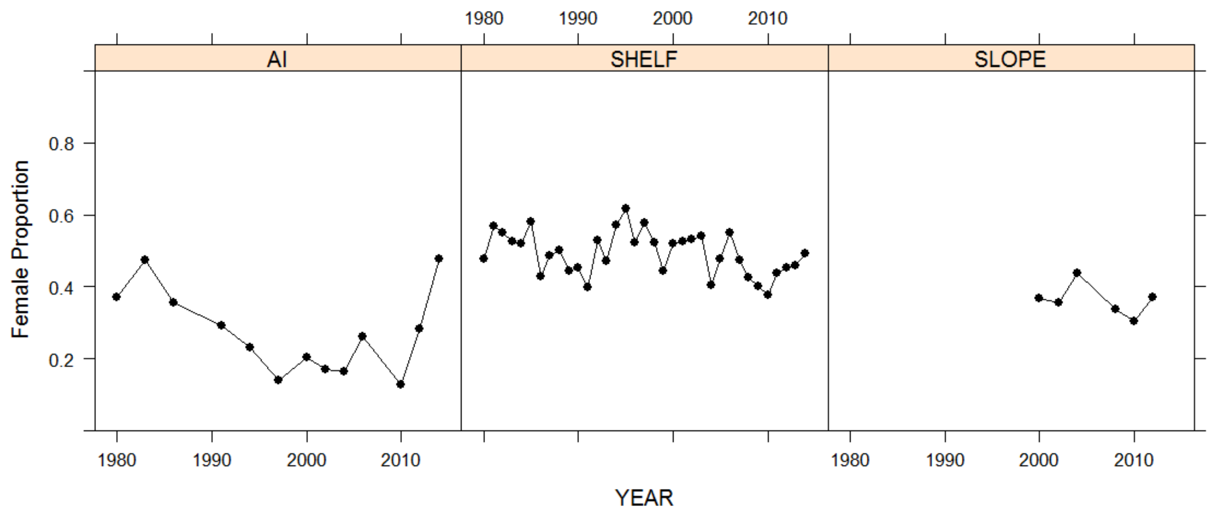


Figure 5.32. Proportion of females in the size composition data by survey and year. AI = Aleutian Islands trawl survey, Shelf = EBS shelf trawl survey, and Slope = EBS slope trawl survey.

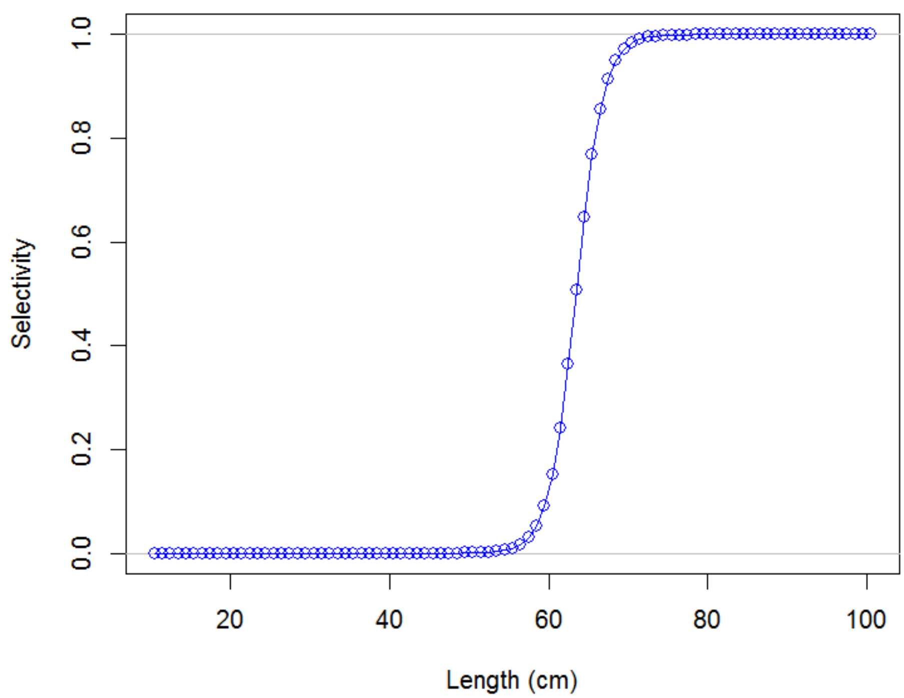


Figure 5.33. TheABL longline survey size selectivity for both sexes and all years combined for Model 2.

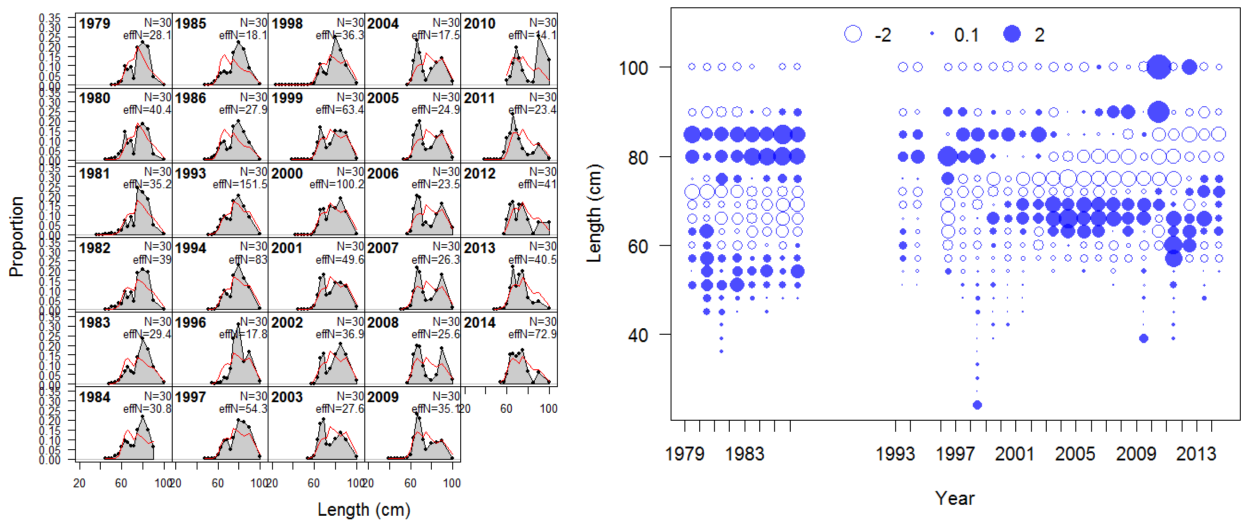


Figure 5.34. Auke Bay Laboratory longline survey size composition data and Model 2 fits (red line) by year for combined sexes (left panel). Auke Bay Laboratory longline survey size composition Pearson residuals (right panel).

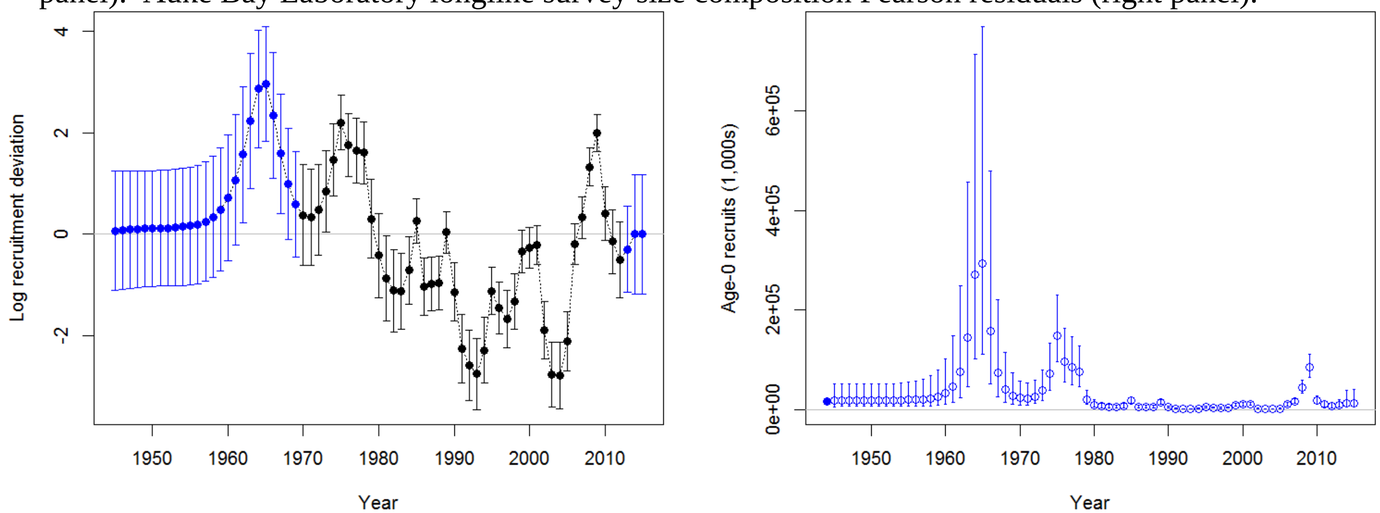


Figure 5.35. Log recruitment deviations (left panel) and age-0 recruits (right panel) in thousands for Model 2.

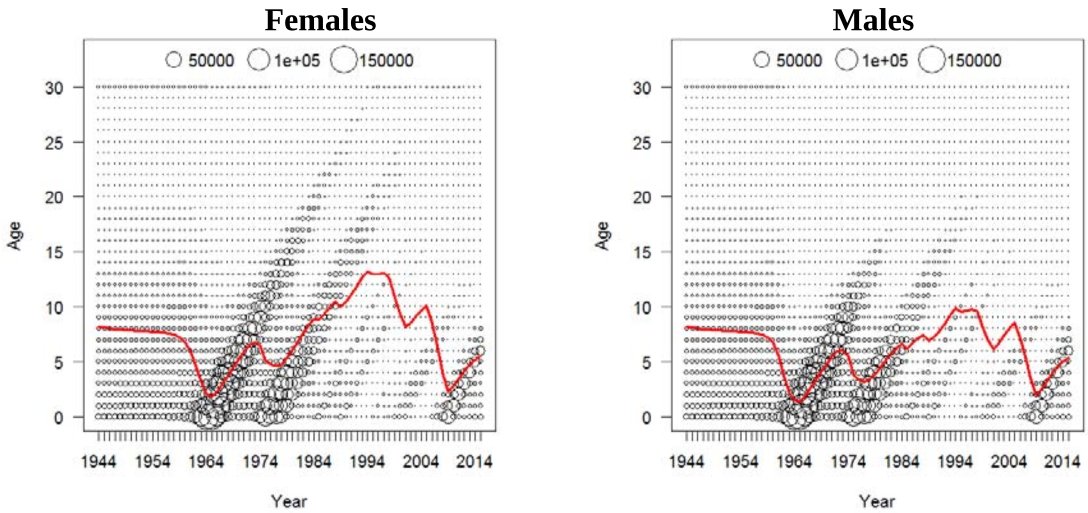


Figure 5.36. Model 2 BSAI Greenland turbot numbers at age and mean age by year (red line) for females (left panel) and males (right panel).

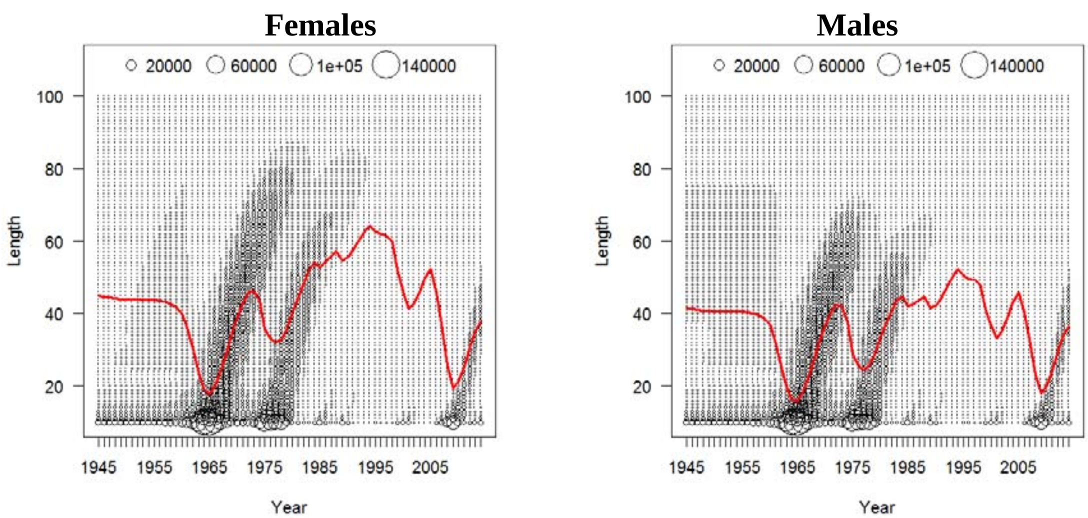


Figure 5.37. Model 2 BSAI Greenland turbot numbers at size and mean size by year (red line) for females (left panel) and males (right panel).

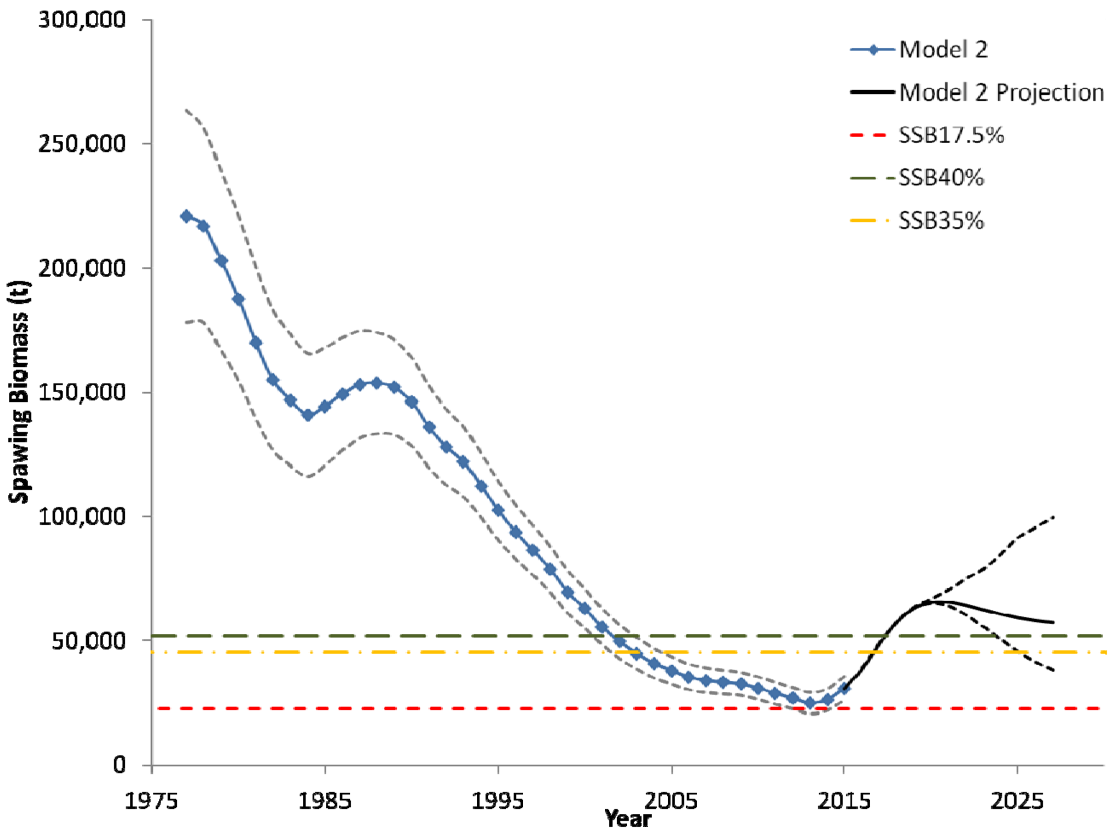


Figure 5.38. Female spawning biomass in tons for BSAI Greenland turbot for Model 2 with reference levels and projection to 2027 from Alternative 1 $F_{40\%}$ fishing levels. Model error bars (gray dashed lines) are 95% confidence intervals based on the inverted Hessian, projection error bars are 95% credible intervals based on 1,000 simulations (black dashed lines).

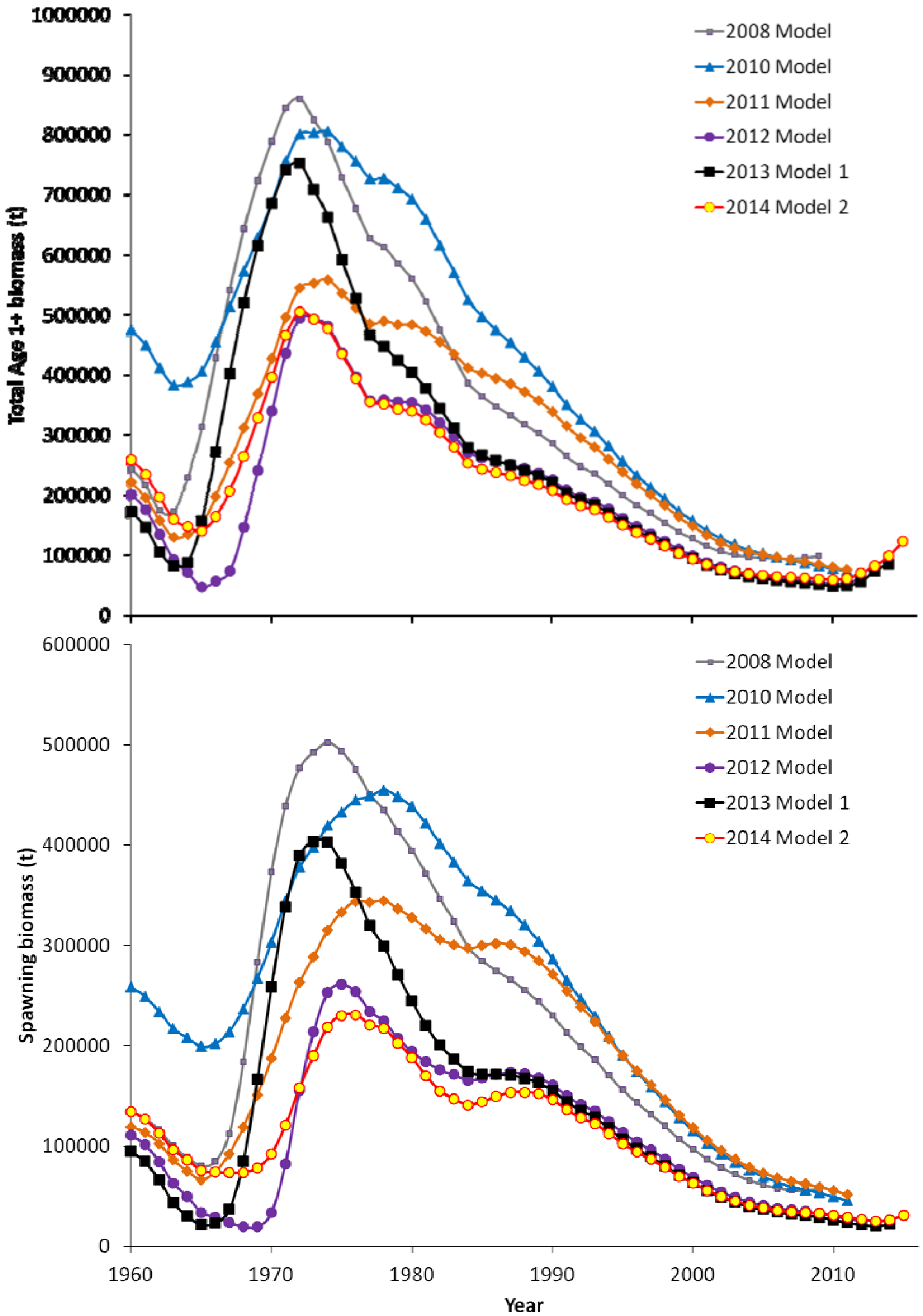


Figure 5.39. Total age +1 biomass (t; top panel) and female spawning biomass in tons (bottom panel) for BSAI Greenland turbot for this year's Model 2 and previous years' stock assessment models.

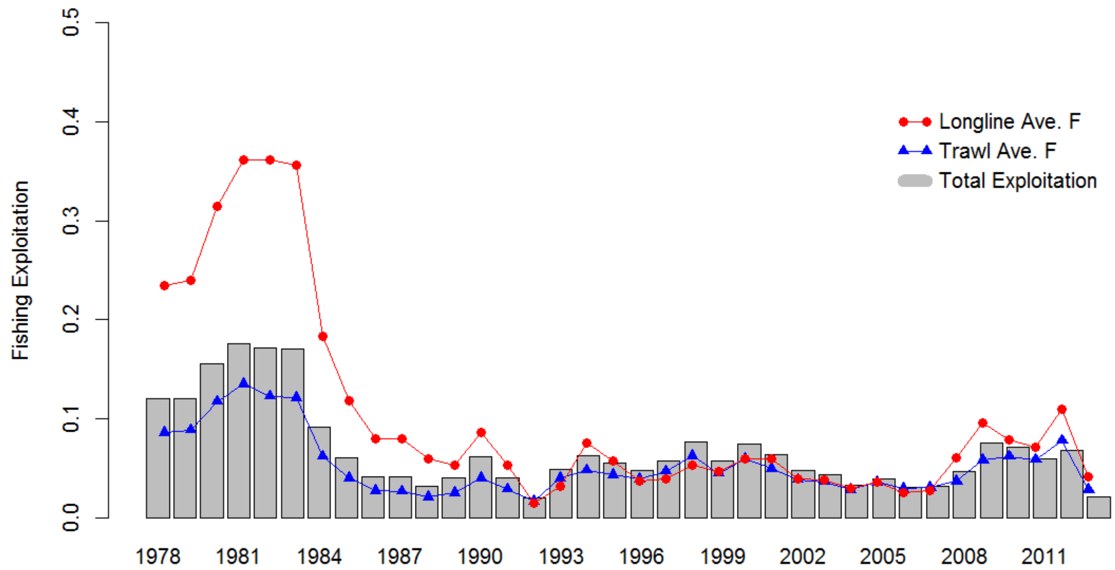


Figure 5.40. BSAI Greenland turbot total exploitation rate (bars) and average Fs for the trawl (blue line with triangles) and longline (red line with circles) fisheries.

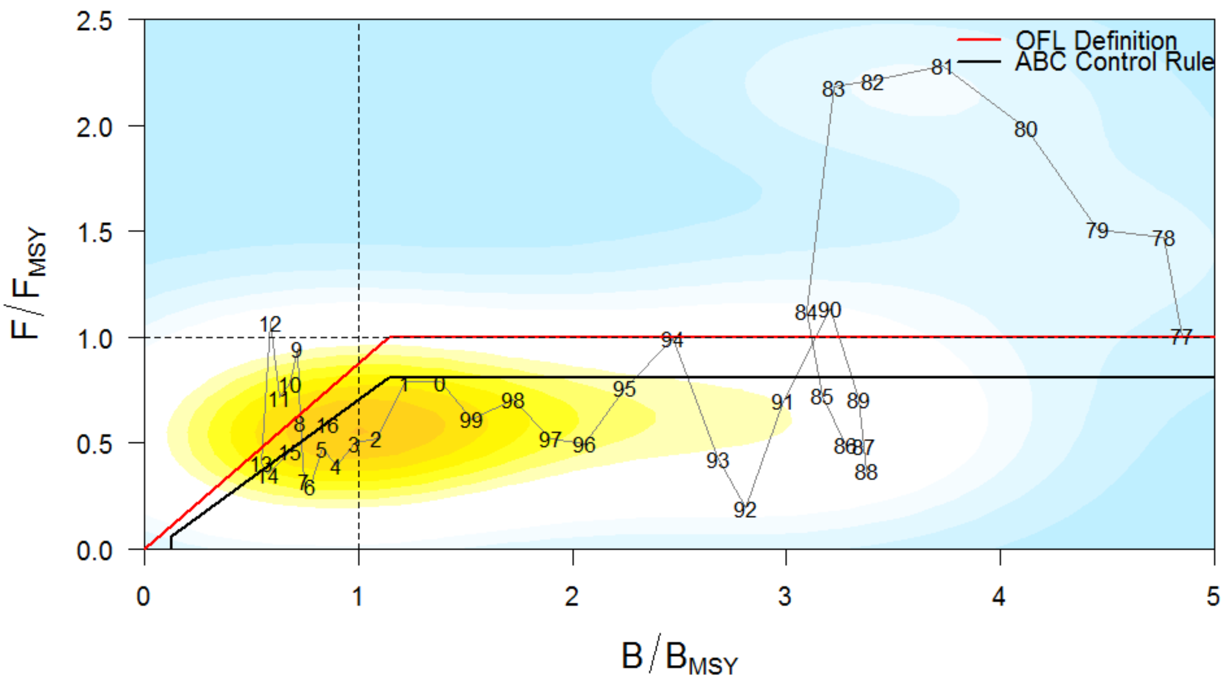


Figure 5.41. Ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1977-2016. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.

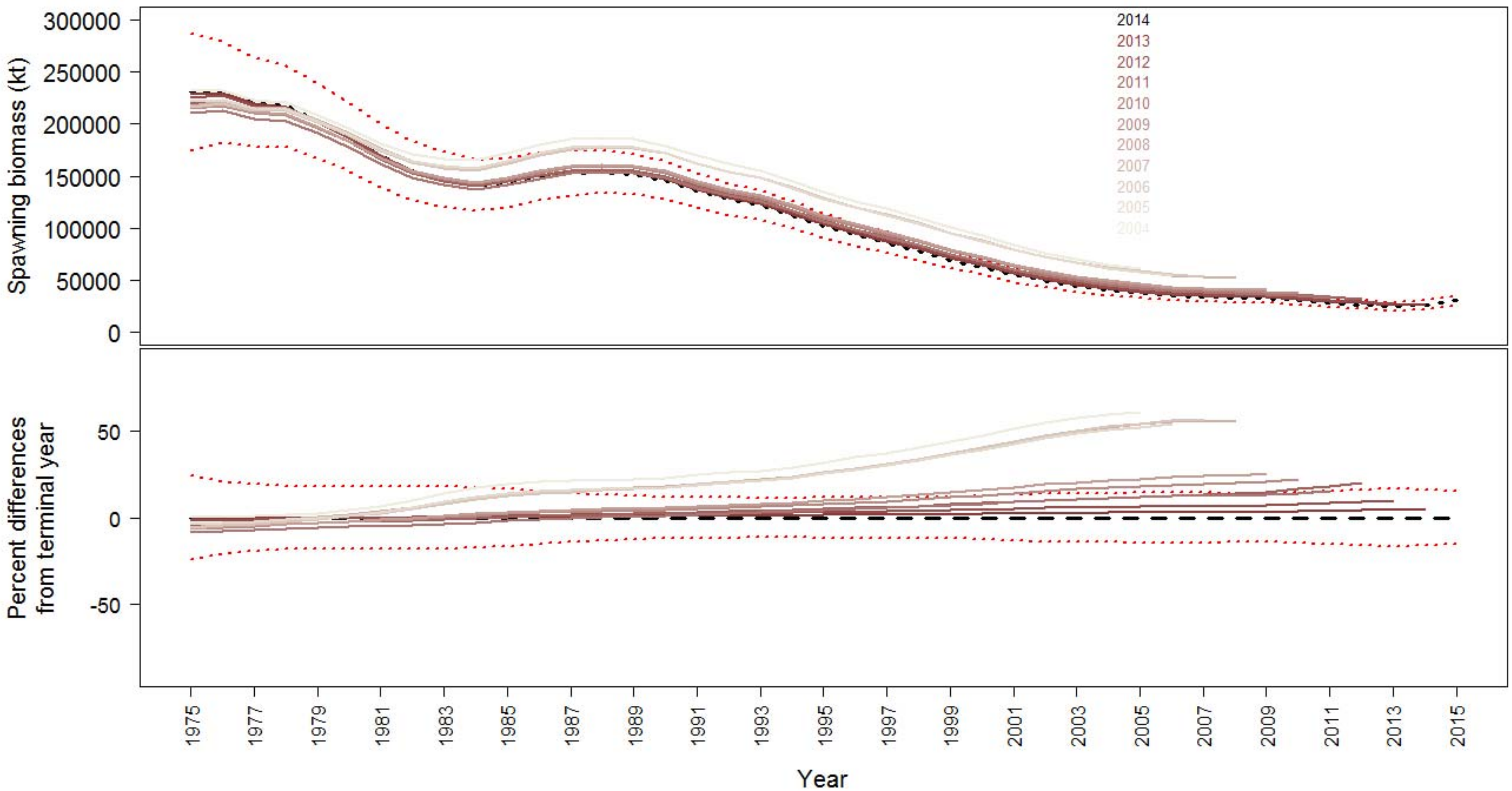


Figure 5.42. Model 2 retrospective analysis plot of spawning biomass (top panel) and change in spawning biomass per year for the retrospective runs (bottom panel).

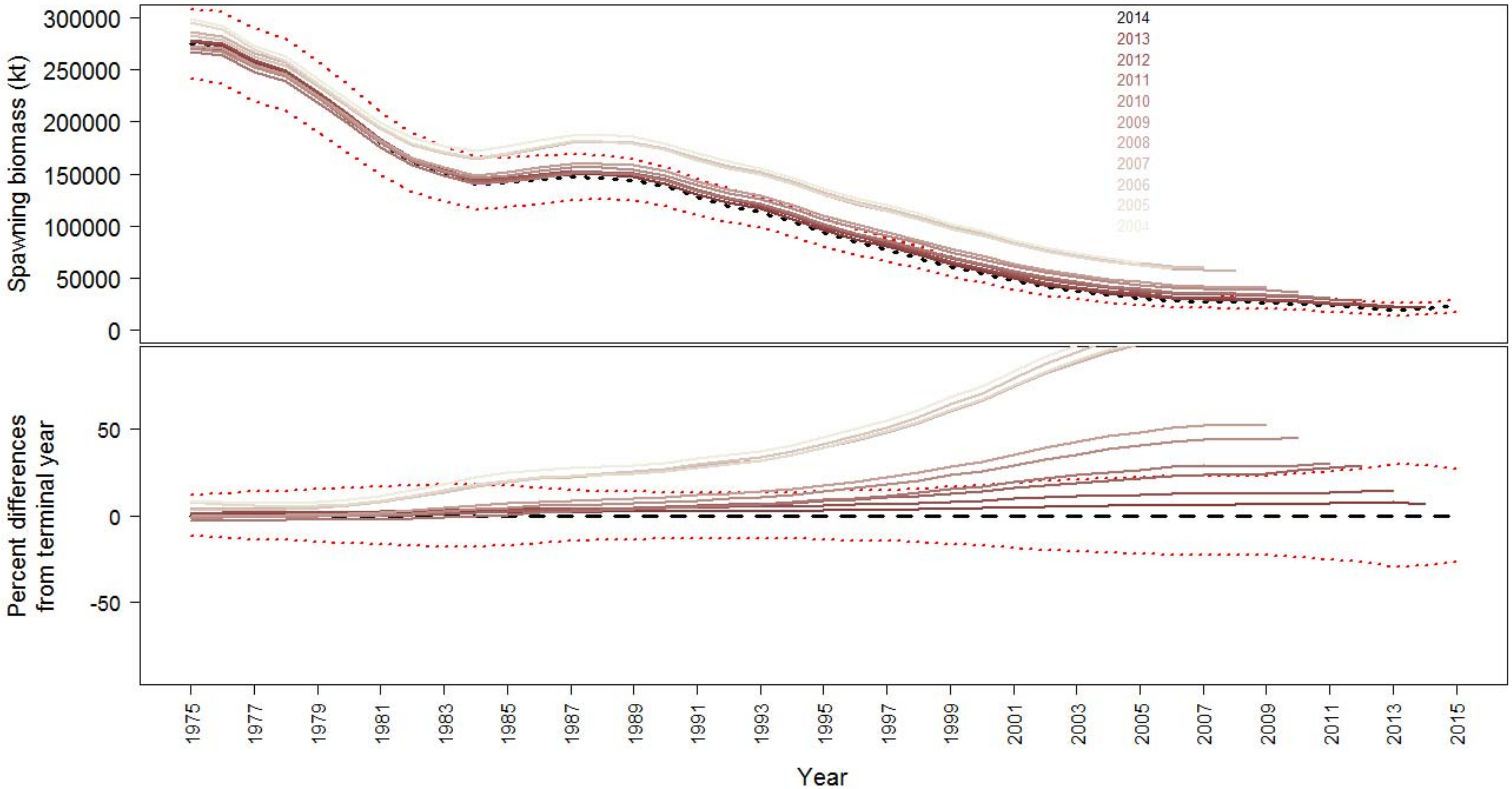


Figure 5.43. Model 1 retrospective analysis plot of spawning biomass (top panel) and change in spawning biomass per year for the retrospective runs (bottom panel).

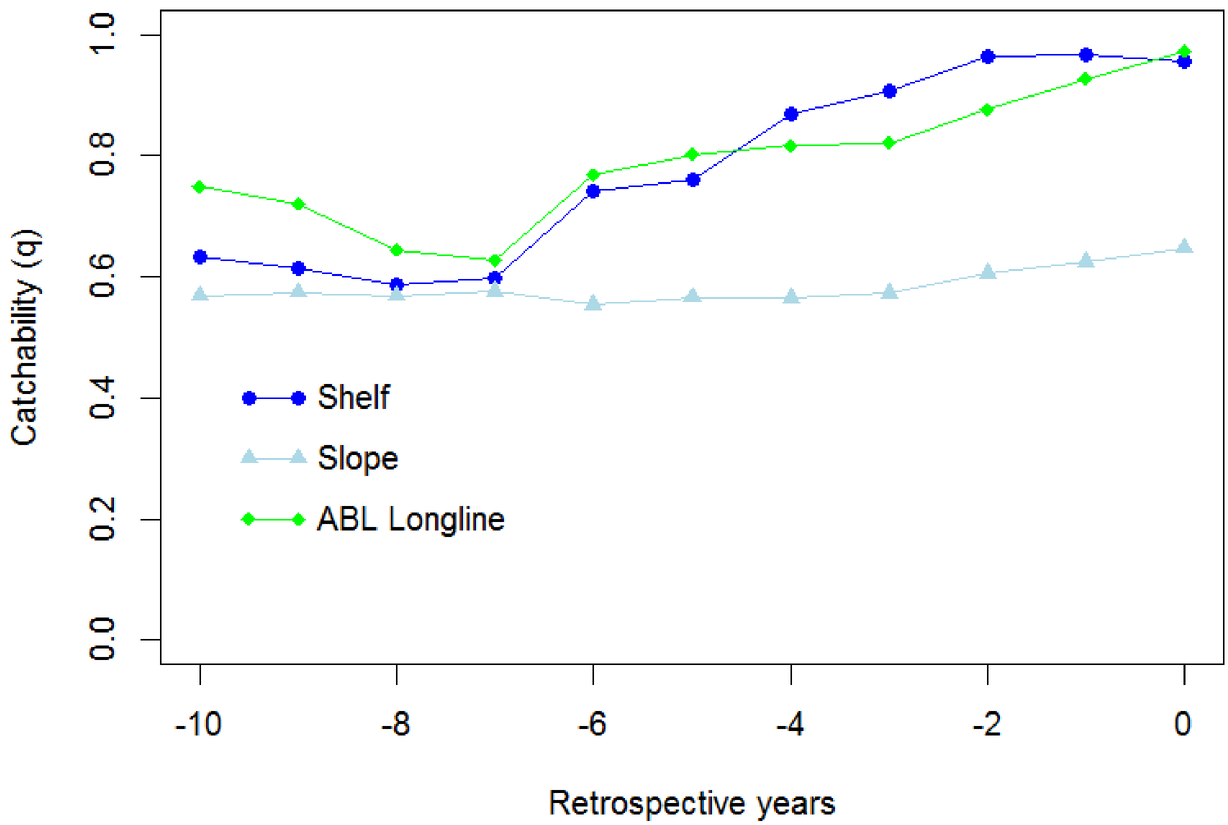


Figure 5.44. Model 1 retrospective analysis plot of catchability (q) for shelf, slope, and ABL longline surveys.

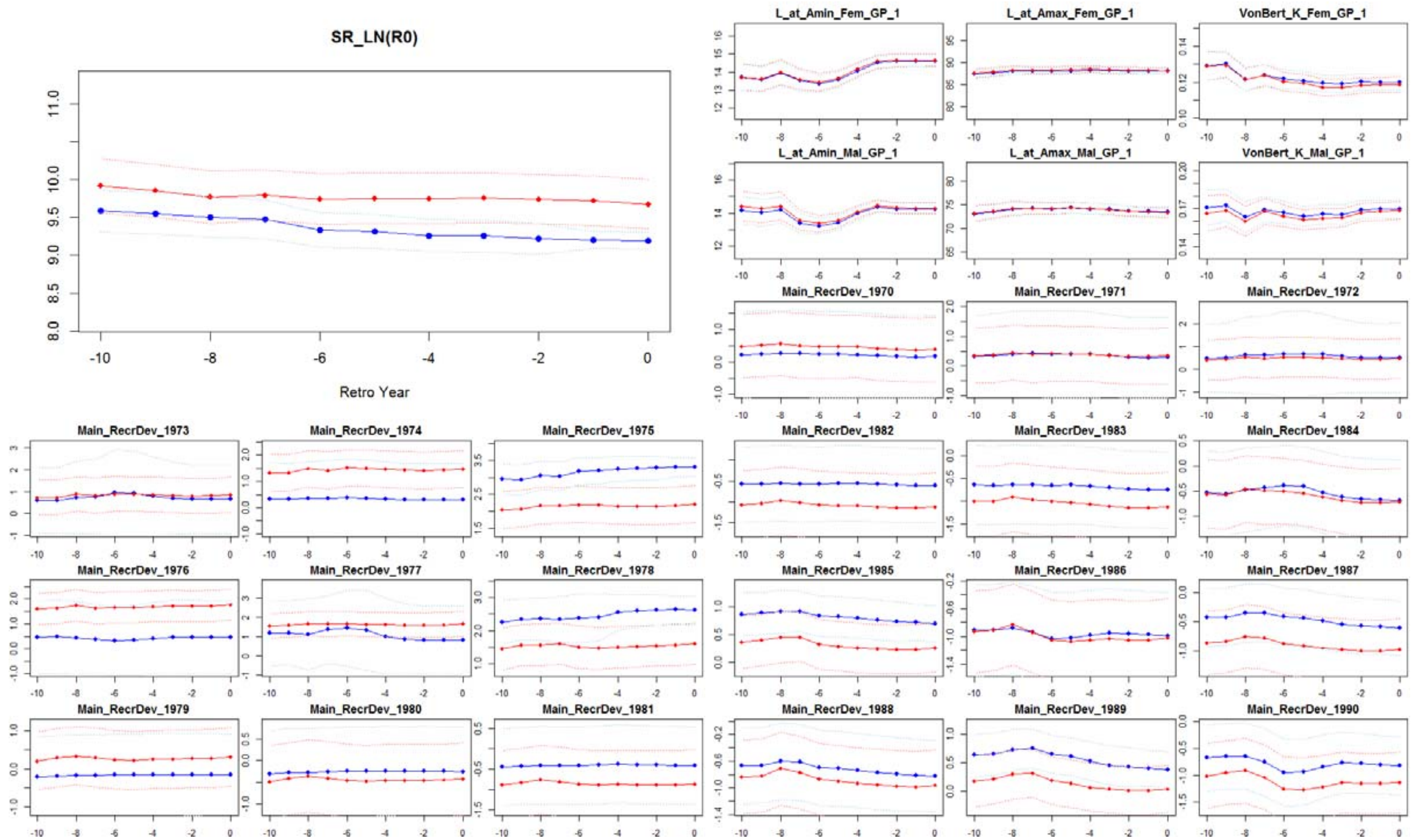


Figure 5.45. Model parameters with 10-year retrospective for Model 1 (blue) and Model 2 (red).

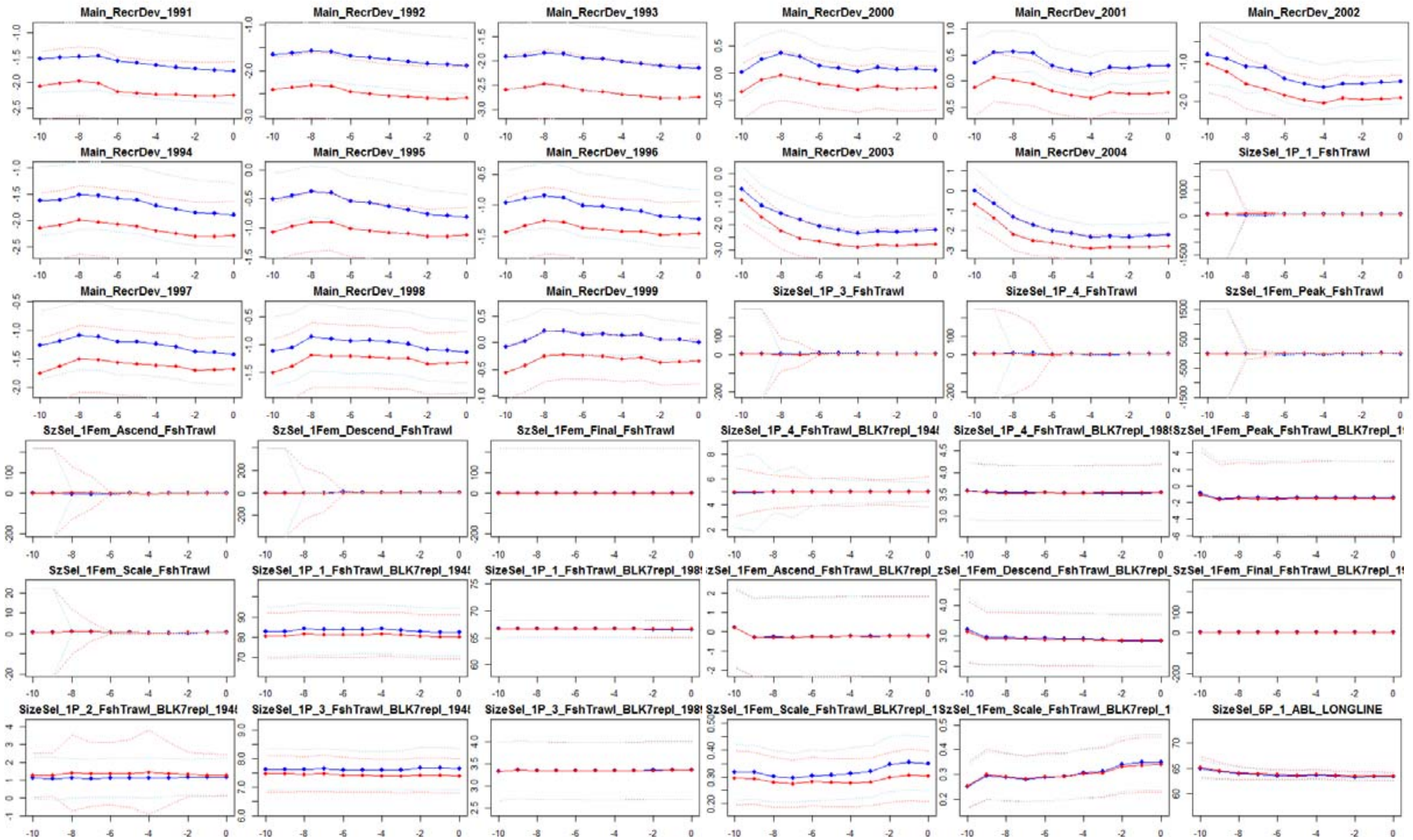


Figure 5.45 cont. Model parameters with retrospective for Model 1 (blue) and Model 2 (red).

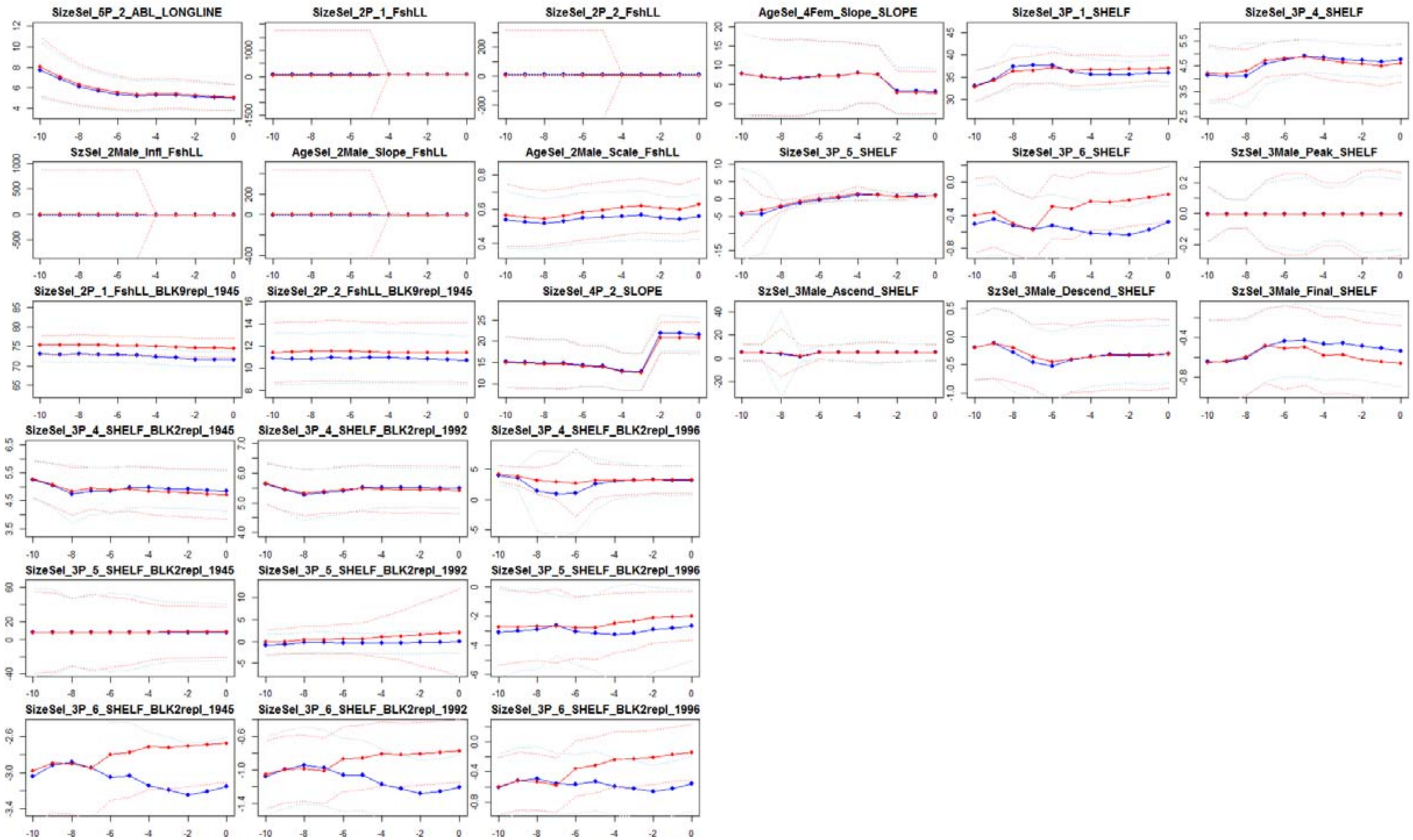


Figure 5.45 cont. Model parameters with retrospective for Model 1 (blue) and Model 2 (red).

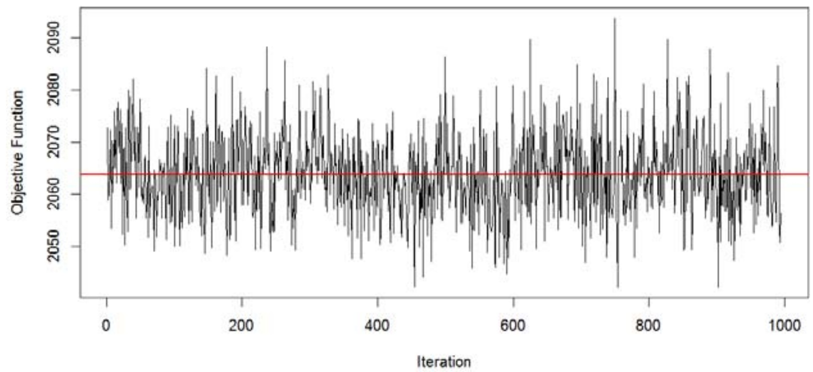


Figure 5.46. MCMC trace of Model 2 objective function for 2,000,000 runs with a 10,000 burn in and thinned to every 2000th iteration. Red line is the median objective function.

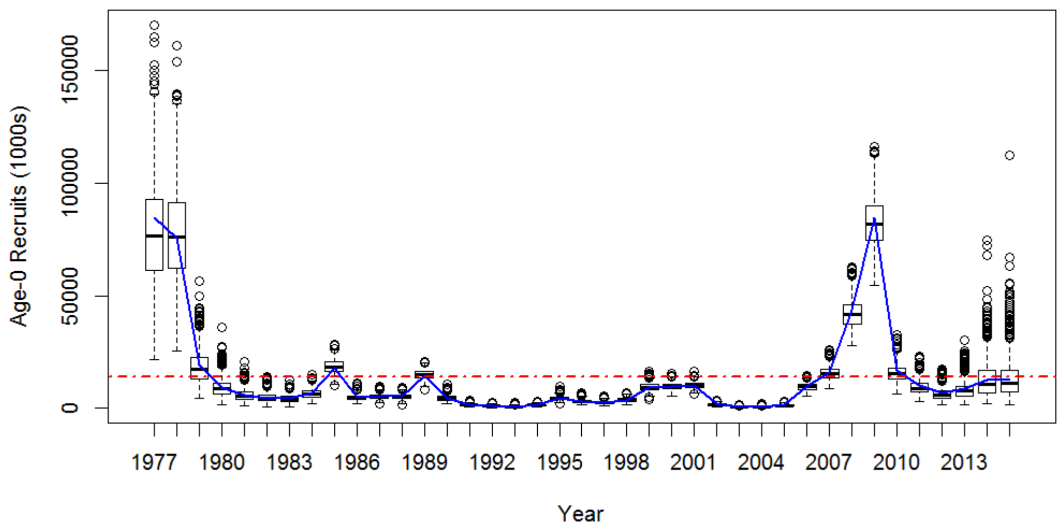


Figure 5.47. Boxplot of posterior distribution of age-0 recruits (1,000s), MLEs (blue line) and MLE mean recruitment for 1977-2013 (red dot-dash line).

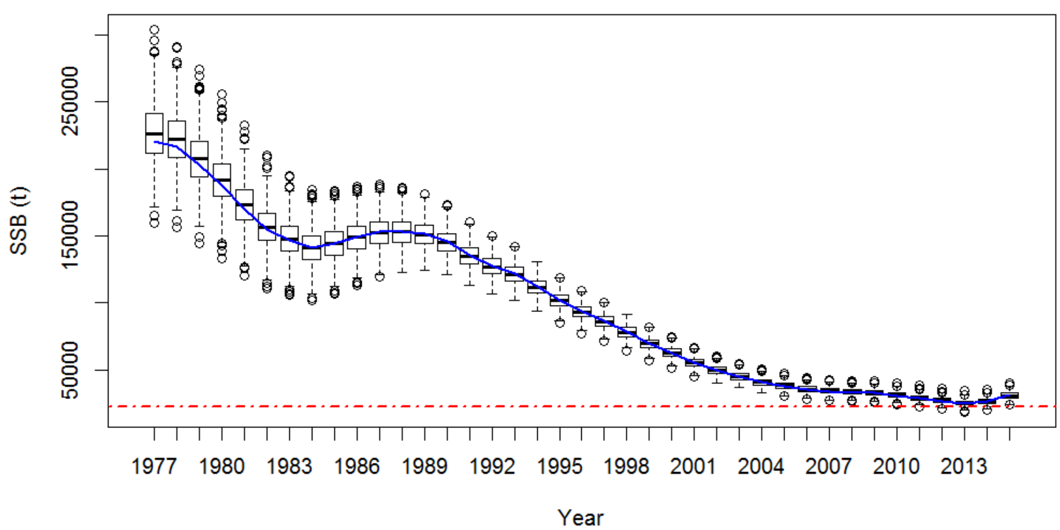


Figure 5.48. Boxplot of posterior distribution of female spawning biomass, MLEs (blue line), and MLE projected $SSB_{17.5\%}$ (red dot-dash line).

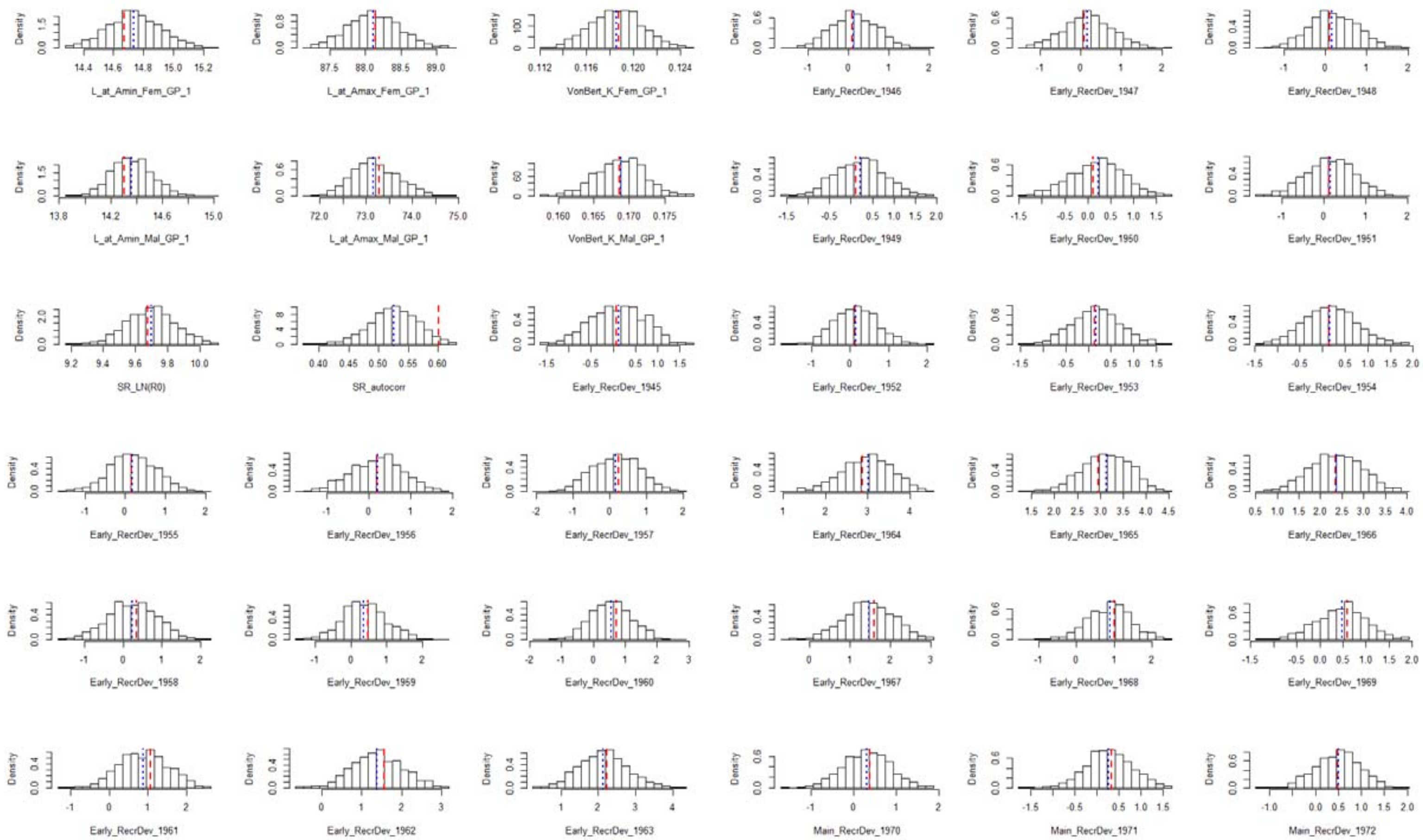


Figure 5.49. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

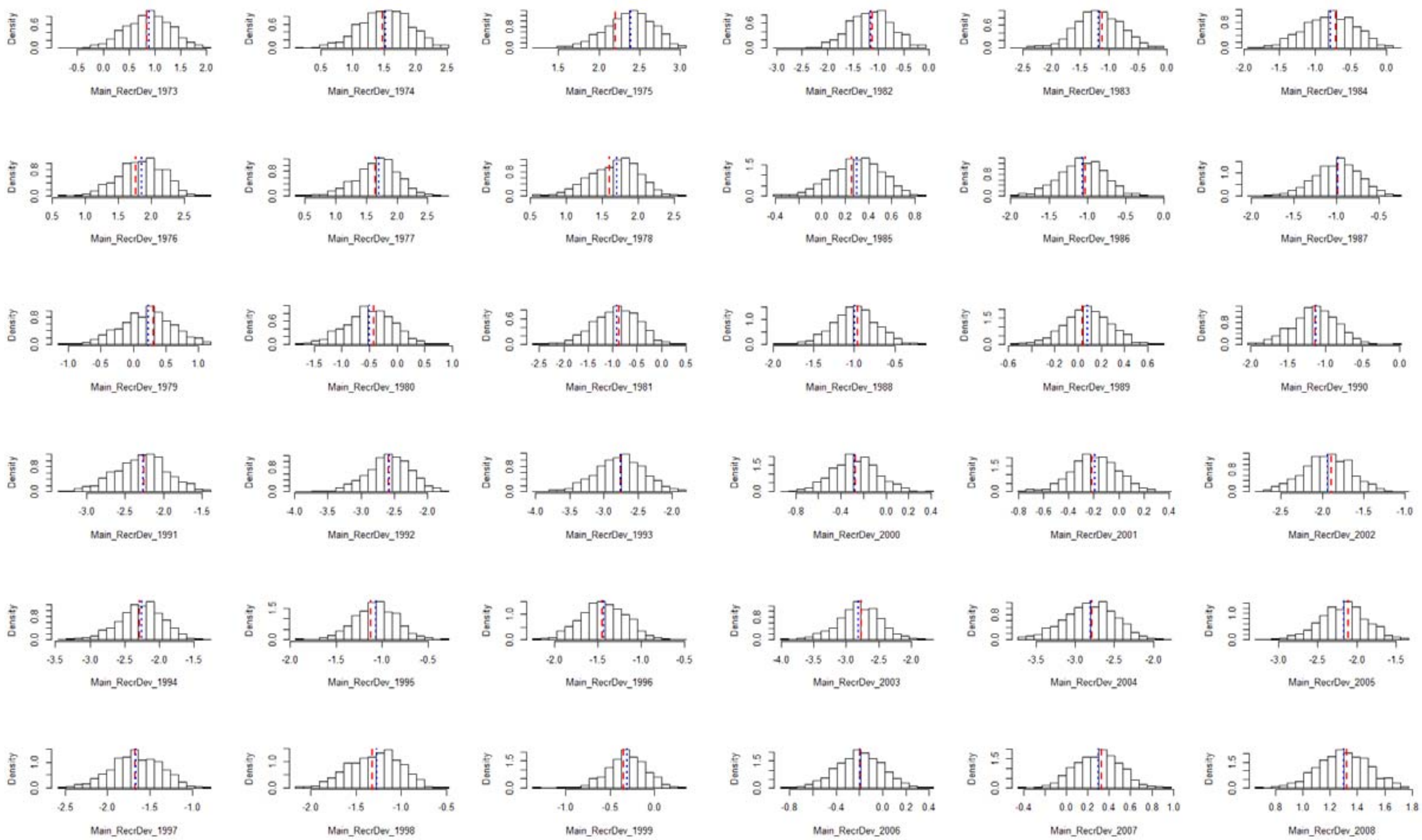


Figure 5.49 cont. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

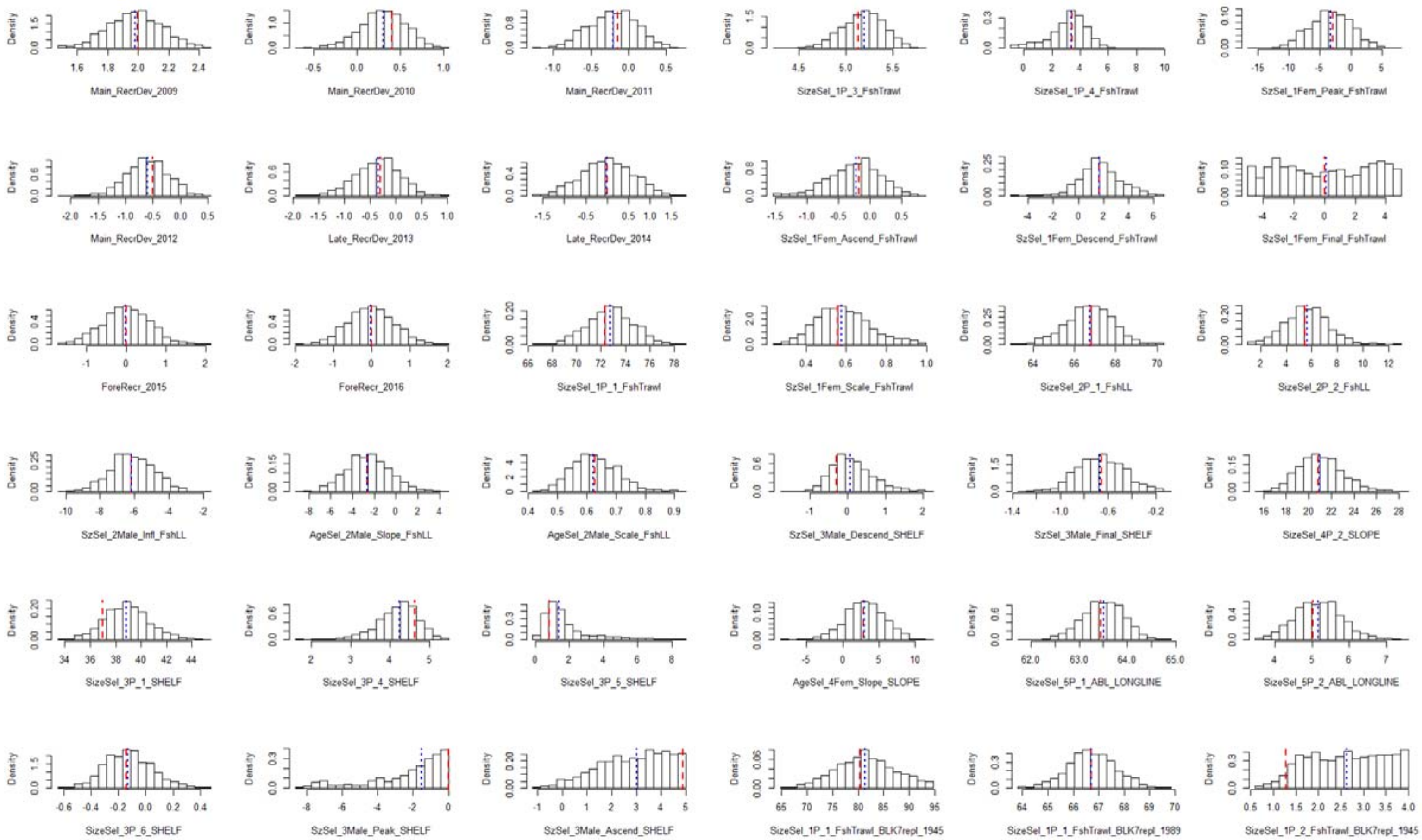


Figure 5.49 cont. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

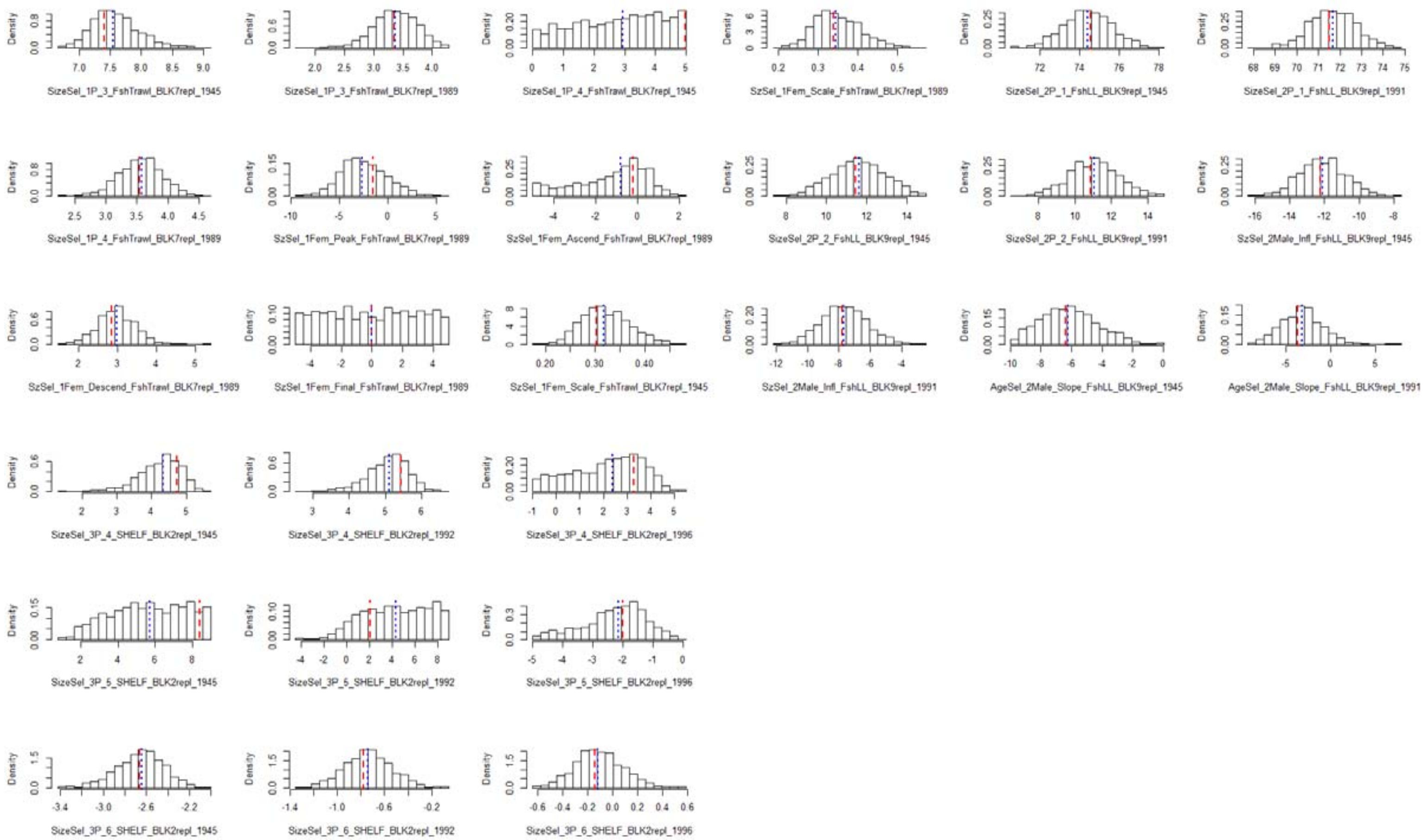


Figure 5.49 cont. Posterior densities for Model 2 parameters, red dashed line is the maximum likelihood estimate, blue dotted line is the posterior median.

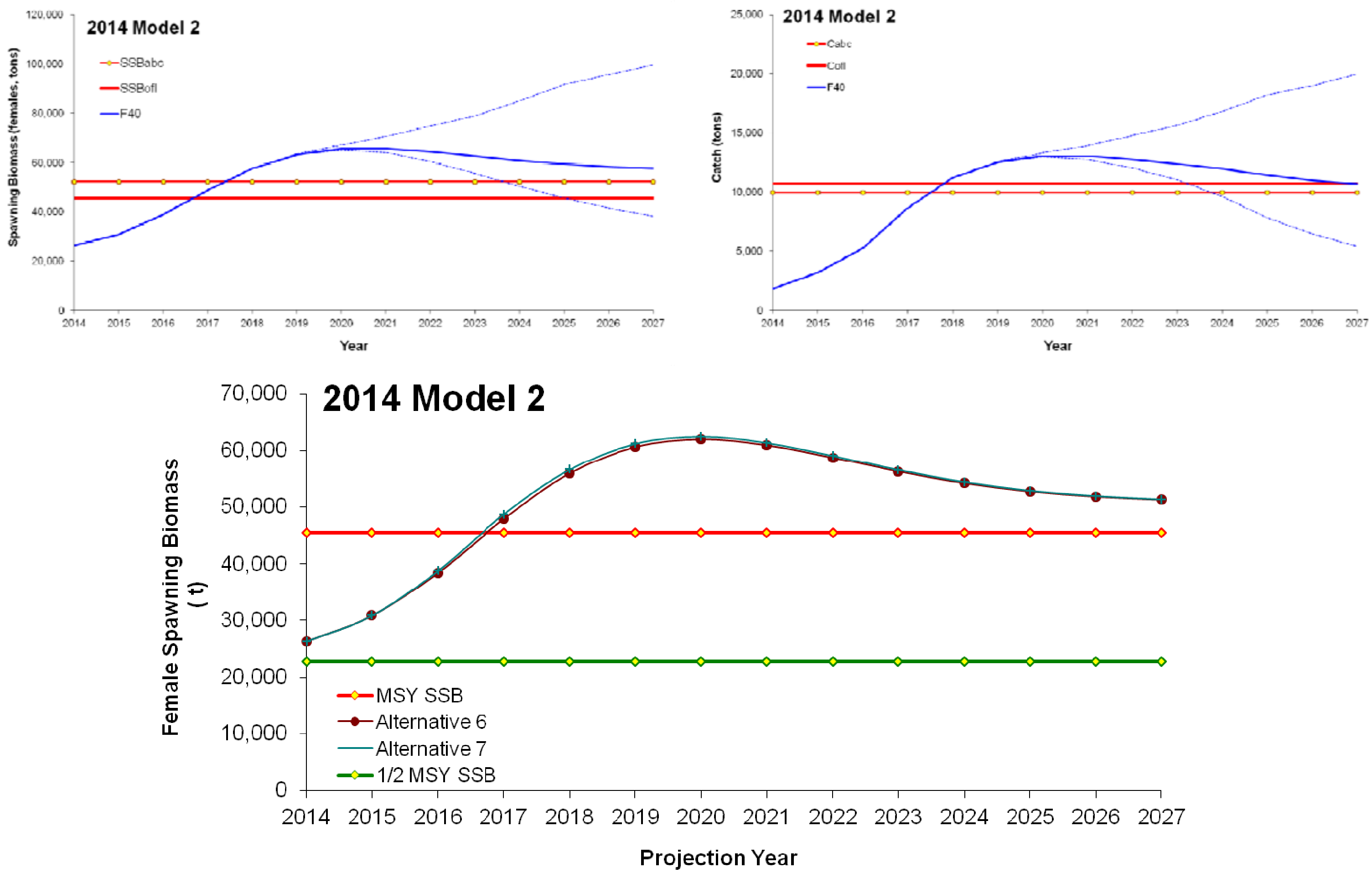


Figure 5.50. Alternative 1 projected female spawning stock biomass (upper left panel) and catch (upper right panel) at $F_{40\%}$ fishing with long-term expected OFL and ABC reference levels, and projected female spawning stock biomass under Alternatives 6 and 7 with SSB_{MSY} and ½ SSB_{MSY} reference levels (bottom panel). $SSB_{35\%}$ is our proxy for SSB_{MSY}.

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