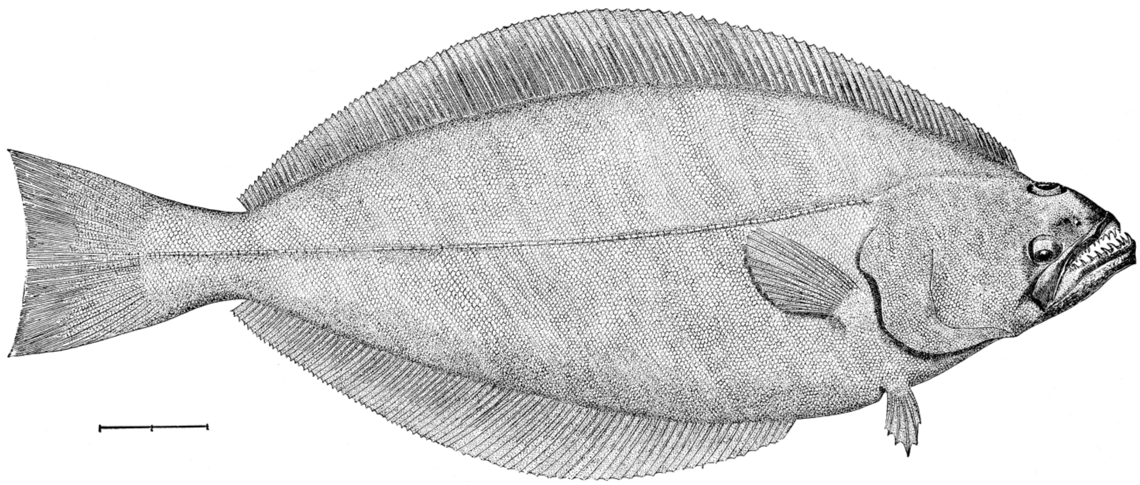
5. Assessment of Greenland Turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands



THE GREENLAND TURBOT.

Steven J. Barbeaux, James Ianelli, Dan Nichols and Jerry Hoff

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

Executive Summary

Due to time contraints created by the federal government shutdown in October, no new models were explored this year. Some figures and tables have not been updated. There were however additional data added to the two base models explored.

Summary of Changes in Assessment Inputs

<u>Addition of new fishery and survey data</u>

There were Shelf, and Auke Bay Laboratory (ABL) longline surveys conducted in 2013. The abundance estimates (or RPN for the ABL longline survey) and length data were added to this assessment. Fishery catch and length frequency data were updated to the 2013 numbers. The 2013 ABL longline survey length data have become available and added to the assessment. Also age composition and weight-at-age data from the shelf survey for 2010, 2011, and 2012 were added to the assessment.

Summary of Results

There was a major revision of the Greenland turbot stock assessment model and data in 2012, this year's assessment applies the newly available survey and fishery data to Models 2 and 3 of last year (Now Model 1 and Model 2, respectively). From the 2013 Authors' preferred reference model (Model 1) this year's estimate for $B_{100\%}$ of 99,764 t is less than last year's estimate of 119,217 t. The estimated 2013 spawning stock biomass is 20,006 t which is equivalient to $B_{20\%}$ which is slightly lower than last year's projected status for 2013 at $B_{22\%}$.of 23,485 t. Changes in stock status were mostly due to the new shelf survey biomass, new size-at-age estimates and corrections to the weight-at-age data from last year. The stock remains in Tier 3B and therefore the ABC and OFL recommendations are reduced by the decending portion in the harvest control rule. The 2014 recommended ABC (2,124) is 81% of last year's projected 2014 ABC. The projected 2014 estimated total biomass (84,546 t) is 11% lower than last year's projection for 2014 (94,752 t). Large 2008 and 2009 year classes are expected to be larger than any other recruitment event since the 1970's and will begin to have an increasing influence on spawning stock biomass starting in 2015. Estimated catch indicates that overfishing did not occur in 2013. The stock is not currently overfished, and that the stock is not approaching an overfished condition. It should be noted however, that if Model 2 was selected as the reference model, that the BSAI Greenland turbot stock would be in an overfished condition ($B_{14\%}$) in 2014. The only difference between Model 1 and Model 2 is the inclusion of autocorrelation in the recruitment deviations. Model 2 is the best fitting model and the only reason this model was not selected by the stock assessment authors is due to the fact that inclusion of autocorrelation in SS3 has not yet been thoroughly vetted and there was little time to explore this alternative this year due to the shutdown.

Quantity	As estimated or *specified last* year for: 2013	2014	As estimated or *recommended this* year for: 2014	2015
M (natural mortality rate)	0.112	0.112	0.112	0.112
Tier	3b	3b	3b	3b
Projected total (age 1+) biomass	80,989	94,752	84,546	96,298
Female spawning biomass (t)	23,485	26,537	22,010	27,624
Projected				
$B_{100\%}$	119,217	119,217	99,764	99,764
$B_{40\%}$	47,686	47,686	39,906	39,906
$B_{35\%}$	41,726	41,726	34,917	34,917
F_{OFL}	0.14	0.16	0.14	0.18
$maxF_{ABC}$	0.12	0.13	0.12	0.15
F_{ABC}	0.12	0.13	0.12	0.15
OFL (t)	2,539	3,266	2,647	3,864
maxABC (t)	2,064	2,655	2,124	3,173
ABC (t)	2,064	2,615	2,124	3,173
EBS	1,612	2,074	1,659	2,478
Aleutian Islands	452	581	465	695
Status	As determined *last* year 2011	2012	As determined *this* year 2012	2013
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Responses to SSC and Plan Team Comments on Assessments in General

Due to time contrains created by the federal government shutdown in October, no new models were explored this year.

Responses to SSC and Plan Team Comments Specific to this Assessment

No new models were explored this year (see above).

Introduction

Due to the October government shutdown model exploration this year was limited. We present the reference model from last year updated with the most recent data and one alternative model which include autocorrelation in the recruitment deviations. The stock continues to be modeled using the same software as previous assessments (Stock Synthesis 3). Our reference model this year, Model 1, has the same configuration as last year's Reference Model (2012 Model 2) and was used for all projections and specifications, Model 2 (last year's Model 3) is presented only for comparisons.

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 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 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 maximum size much smaller than females, but that mortality may not be higher than in females.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

Fishery

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Fig. 5.6). 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 correct for changes in the stock assessment model. The ABC for 2013 was set at 2,060 with a total catch as of October 12 of 1,527 t.

The majority of the catch over time has been concentrated in deeper waters (> 150 m) along the shelf edge ringing the eastern Bering Sea (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 Greeland 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 the highest amount of catch have been 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 and in the preliminary catch data for 2013, Greenland tubot catch in the Arrowtooth/Kamchatka fishery has exceeded the directed catch.

In 2008 through 2013, 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-Aug in the EBS to avoid killer whale predation. Catch information prior to 1990 included only the tonnage of Greenland turbot retained on Bering Sea fishing vessels or processed onshore (as reported by PacFIN). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (at about one half 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 9.2% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2012. The overall discard rate of Greenland turbot has dropped substantially in recent years from a high of 82% discarded in 1992 down to only 2% in 2011 and 2012. In the preliminary 2013 data if appears that Greenland turbot discards have risen steeply with a 23% discard rate so far. In the preliminary 2013 catch data 60% of the Greenland turbot discard (208 t) has come from the Arrowtooth and Kamchatka fisheries.

By gear-type and region, trawl catch was most significant in the Aleutian Islands in 2009 through 2013 (Table 5.4), whereas in the EBS there was high trawl catch in 2008, but then a switch to higher longline catches in 2009 through 2012 (Table 5.3). In the preliminary 2013 data the EBS trawl fishery has caught a larger share of EBS quota than longliners (804 t vs. 415 t), however due to the lower quota both are lower compared to previous years. 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 2008-2013 (Table 5.3).

Data

Fisheries data in this assessement were split into the Longline (including all fixed gear) and Trawl fisheries. Both the Trawl and Longline data include observations and catch from targeted catch and bycatch. There are also data from three surveys, the Shelf and Slope surveys are bottom trawl surveys conduced by the RACE Division of the Alaska Fisheries Science Center and the Auke Bay Laboratory (ABL) Longline survey has been conducted by the ABL out of Juneau, Alaska. The type of data and relevant years from each can be found in Table 5.5 and Figure 5.10.

Fishery data

<u>Catch</u>

The catch data were used as presented above for both the longline and trawl fisheries. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, the ratio of the two species for the years 1960-64 were assumed to be the same as the mean ratio caught by USSR vessels from 1965-69.

<u>Size and age composition</u>

Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 2013. The length composition data from the trawl and longline fishery 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 1989-2013 are given in Table 5.6

Catch totals from research and other sources

Annual research catches (t, 1977 - 2012) 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											1.1	3.5	n/a	n/a	0.36	n/a	n/a
Year	2013																
NMFS BT surveys	9.7																
Longline surveys	n/a																

A database for 2010 sport and research catches indicates the following 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

Recent 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 had been surveyed every third year from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. From 1979-1985, the slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency. In 1988, the NOAA ship Miller Freeman was used to survey the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side experiments with the Miller Freeman for calibration purposes. However, the Miller Freeman sampled a smaller area and fewer stations in 1988 than the previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1000 m. In 2002, the AFSC re-established the bottom trawl survey of the upper continental slope of the eastern Bering Sea and a second survey was conducted in 2004. Planned biennial slope surveys lapsed (the 2006 survey was canceled) but resumed in the summer of 2008, 2010, and 2012 (Table 5.7). Although the size composition data for 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 in which Dr. Hoff stated that the older Slope survey data were not comparable to the most recent surveys, and may have not 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 trawl slope-surveys are likely to represent under-estimates of 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, particularly given the extent of the cold pool and warm conditions in recent years (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 fit 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 (1993-2013) was 27,441 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys were presented in Table 5.8. In 2011 and 2010 the abundance estimates from the shelf surveys indicated a significant increase of Greenland turbot recruitment and an increase in the proportion of tows with Greenland turbot present (Fig. 5.11). 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, the population numbers in 2012 of 11,839,700 fish was more than double the 2010 estimate of 5,839,126 fish. The 2012 Slope survey abundance estimate was the highest population estimate since the Slope suvey was reinstated in 2002. Most of the change in population estimates is due to the changes in Greenland turbot abundance found in the two shallowest strata between 200 and 600 m depth strata (Table 5.9 and Table 5.10). In the 200-400 m strata the population was more than 8 times that of the 2010 survey estimate and the 400-600 m strata was more than double the 2010 estimate. These high numbers, but low biomass is a reflection of the large number of smaller fish moving into the slope region from the shelf due to the large 2007 through 2009 year classes as evidenced by the large number of fish between 30 cm and 50 cm observed in this survey (Fig. 5.12).

<u>Survey size composition</u>
A time series of estimated size composition of the population was available for both surveys. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the

number of fish measured in the slope surveys is greater. The shelf survey appears to be useful for detecting some recruitment patterns that are consistent with the trends in biomass. In the last 7 years signs of recruits (Greenland turbot less than about 40 cm) is clear after an absence of small fish during 2004-2006.

Survey size-at-age data was available and used for estimating growth and growth variability were previously available from 1979-1982. Gregg et al. (2006) revised age-determination methods for Greenland turbot and this year survey age composition data from 2003-2012 were included.

Aleutian Islands survey

The 2012 Aleutian Islands bottom trawl survey estimate was 2,502 t, well below the 1991-2012 average level of 12,598 t (Table 5.11) and a decline from the 2010 estimate of 6,272 t. The distribution of Greenland turbot in 2012 indicate much lower abundance in the survey compared to all previous 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. The estimated proportion of Greenland turbot in the eastern area for 2012 of 7% is far below the 1980- 2010 average of 67% of the survey abundance. Only in 2004 was the area estimate lower than the other regions. We are not certain why there was such a dramatic decline in the Greenland tubot abundance estimate in the Aleutian Islands trawl survey. Lower bottom temperatures in the shallow areas in the eastern area may have been a contributing factor (Lowe et. al. 2012). The trawl-survey area-swept data for the Aleutian Islands component of the Greenland turbot stock is not presently included in the stock assessment model.

Longline survey

The Auke Bay Laboratory Longline survey for sablefish alternates years between the Aleutian Islands and the Eastern Bering Sea slope region. In 2011 the EBS region was covered but an unusually high number of orca depredation events occurred: 10 out of 16 stations were affected. Some investigations on how to account for these events highlight the need for more detailed analysis. The 2012 survey was conducted along the Aleutian Islands and saw a more than doubling of the RPN since last AI survey in 2010. The high number on the ABL longline survey compared to the AI trawl survey makes sense in light of the the high numbers obsereved in the Slope trawl survey and expected migration of the maturing fish towards the deeper waters and the Aleutians.

The survey time series (through 2012) indicates that about 33% of the population along the combined slope regions survey is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands:

The combined time series shown above (1996-2013) was used as a relative abundance index. It was computed by taking the average RPN from 1996-2013 for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI}\frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS}\frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator function (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions (1996-2012) are given here by each area as: p^{AI} and p^{EBS} . Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years and that this approach assumes that the population proportion in these regions is constant. The time series of size composition data from the ABL longline survey extends back to the cooperative longline survey and is shown in Fig. 5.12 and Table 5. 12.

Analytic approach

Model Structure

A version of the stock synthesis program (Methot 1990) has been used to model the eastern Bering Sea component of Greenland turbot since 1994. The software and assessment model configuration has changed over time, particularly in the past five years as newer versions have become available.

Total catch estimates used in the model were from 1960 to 2013. Model parameters were estimated by maximizing the log posterior distribution of the predicted observations given the data. The model included two fisheries, those using fixed gear (longline and pots) and trawls, 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 2012 reference model and model 3. Thesecontinue to use the Beverton-Hold curve, and early recruitment series is carried back to 1945. The results from these two models were similar.

Parameters estimated independently

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

Parameter	Estimate	Source
Natural Mortality	0.112	Cooper et al. (2007)
Length at Age		
L_{min} CV	8%	Gregg et al. (2006)
L_{max} CV	7%	Gregg et al. (2006)
Maturity and Fecundity		
Length 50% mature	55	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}	1977-2010 NMFS Survey data
Beta	3.2189	1977-2010 NMFS Survey data
Female		
Alpha	2.43×10^{-6}	1977-2010 NMFS Survey data
Beta	3.325	1977-2010 NMFS Survey data
Recruitment		
Steepness	0.79	Myers et al. (1999)
Sigma R	0.6	Ianelli et al. (2011)

Natural mortality and length at age

The natural mortality of Greenland turbot was assumed to be 0.112 based on Cooper et al. (2007). This is also more consistent with re-analyses of age structures that suggest Greenland turbot live beyond 30 years (Gregg et al. 2006).

Parameters describing length-at-age are estimated within the model. Length at age 1 is assumed to be the same for both sexes and the variability in length at age 1 was assumed to have an 8% CV while at age 21 a CV of 7% was assumed. This appears to encompass the observed variability in length-at-age. As with last year, size-at-age information from the methods described by Gregg et al. (2006) were used and this information is summarized in Table 5.13.

Maturation and fecundity

Maturity and fecundity followed the same assumptions as last year's model. Recent studies on the fecundity of Greenland turbot indicate that estimates at length are 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 size from the new study suggest a larger length at 50% maturity but data were too limited to provide revised estimates. For this analysis, a logistic maturity-at-size relationship was used with 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

Weight at length relationship

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

Size composition multinomial sample size

There is always difficulty in determining the appropriate multinomial sample size for the size composition data. This year's assessment was fit following the methods employed by many of the Northwest Fisheries Science Center groundfish assessments in that the models were tuned to match the output effective sample size. For the two fisheries initial sample size for each year was determined as the $\left(100 + \left(\frac{n_i}{\sum n_i / N} / 100\right), n_i\right)$, where n_i is the number of hauls sampled in year i and N is the total number of years with samples (Table 5.14). 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 size was set at 200, the 2002 through 2010 slope survey sample size was set at 50, while those prior to 2000 were set at 25. The ABL longline sample sizes were set at 60.

Parameters estimated conditionally

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

	Model 1	Model 2
Recruitment		
Early Rec. Devs	(1945-1974) 30	(1945-1974) 30
Main Rec. Devs	(1975-2011) 37	(1975-2011) 37
Late Rec. Devs	(2012-2013) 2	(2012-2013) 2
Future Rec. Devs	(2014-2015) 2	(2014-2015) 2
R_0	1	1
R_1 offset	1	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	1
q_{Slope}	1	1
Selectivity		
Trawl Fishery	21	21
Longline Fishery	7	7
Shelf Survey	17	17
Slope Survey	2	2
ABL Longline Survey	2	2
Total Parameters	130	130

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 last year's Reference Model 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 this year's Model 2. 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 given the assumed natural mortality of 0.112. Recruitment deviations for 1945-1975 (Early Rec. Dev.s) were estimated separately from the post-1975 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 2013 this differentiation between the two periods has no effect on model results. This configuration is simply implemented to allow flexibility in exploring other model alternatives in the future.

Catchability in the Slope Survey

In our candidate models 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).

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. These blocks were the same as those used in the 2012 reference model. 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, 2005-2012
Longline Fishery	Yes	2	1945-1990, 1991-2012
Shelf Survey	Yes	4	1945-1991, 1992-1995, 1996-2000, 2001-2013
Slope Survey	Yes	1	1945-2012
ABL Longline Survey	No	1	1945-2013

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

p1 is added to the first selectivity parm (inflection)

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

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

p1 is added to the first selectivity parameter (peak)
p2 is added to the third selectivity parameter (width of ascending side)
p3 is added to the fourth selectivity parameter (width of descending side)
p4 is added to the sixth selectivity parameter (selectivity at final size bin)
p5 is the apical selectivity

This method was used for all fisheries and surveys with separate sex data. As in the 2012 reference model, the longline fishery and slope survey selectivity assumptions were simplified a single logistic curve; prior models used a different a more complicated parameterization that resulted in essentially a simple logistic shape. The longline survey size composition data are poses a challenged to model 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.

Results

Model Evaluation

Two models are presented in this year's assessment. Model 1 is the same as the 2012 reference model but includes updated data through 2013. Both candidate models were configured to have Beverton-Holt stock recruitment curve with fixed parameters noted above. Model 2 was configured as model 1, except that recruitment was modeled with an autocorrelation parameter (Rho = 0.6).

Table 5.15 includes the likelihood values for last year's reference model 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 was 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.

Selection of the 2013 reference model was based on the following considerations. Models 1 and 2 had the same error and data structure and therefore could be compared using model likelihoods. The only difference between the models was the inclusion of an autocorrelation parameter for recruitment deviations. Model 2 had a marginally better fit to all data components. The inclusion of an autocorrelation parameter made a difference in the pre-1975 recruitment deviations. To have enough Greenland turbot to support the early fishery, Model 1 created a single large positive deviation in 1962, while Model 2 created a series of lesser positive deviations between 1961 and 1967 (Fig. 5.13). Because these models rely mainly 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 at all that 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). However, to be consistent with the model selected by the Plan Team in 2012, model 1 was selected for further detailed consideration.

Model 1 diagnostics and suggestions for future improvement

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

<u>Survey indices</u>

The fit to all the surveys is about the same as the fit to last year's models. The shelf survey fails to fit the high 1994 shelf survey biomass estimate (Fig. 5.14) and also misses the decline in biomass observed between 2007 through 2009. The model estimated shelf survey biomass follow 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 staddles the US/Russian border. The rate that fish migrate between these regions is unknown. Such migration could affect the population's available to the US surveys. Additional tagging studies should be conducted to address the issue of adult Greenland turbot movement. The tagging studies should be conducted cooperatively between the US and Russian management agencies if possible.

The fit to the longline survey index of abundance mimics the 1996- 2005 index decline, but misses the apparent increase seen in the data since the low value from 2010 (Fig. 5.17). There is a trend in the residual where the earlier high values tended 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 = 0.2 (except for 2009 and 2011 due to increased whale predation where a value of 0.3 was used). 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, except for the 1998 age composition data, this disagreement was generally small. The large proportion of aged 2 and 3 fish were apparently missed for 1998 survey. The high numbers of young fish observed in the shelf survey for 2007 through 2009 were consistent with the size composition data fit well by the model.

<u>Length at age</u>

The fit of the length at age data for both males and females was good (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). There may be some change in growth occurring for the 2005-2008 males.

<u>Size composition</u>

Overall Model 1 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 fish caught in other fisheries. The directed fishery targeted the larger fish (predominantly females) on the slope, while the bycatch fishery mostly caught smaller fish (predominantly males) on the shelf resulting in very different expected selectivity patterns for the two sexes. Currently SS3 can't handle such a large difference in selectivity patterns between sexes for the same fishery. The author attempted to 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 can be rectified in future assessments. Since target was not included in the data prior to 2003, this task proved rather difficult to accomplish and was not finished by the time of the furlough.

With last years improvements the Model 1 fit to the longline 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 time blocks (Fig. 5.26) used for modeling this fishery. 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 than in previous years. Having higher selectivity for smaller males than females mimicks the migration of males to deeper waters at smaller size than females.

The Model 1 fit to the shelf survey data was the same as the fit to the 2012 Reference Model configuration. Where the model does poorly is in 1999 through 2005 when there were a higher proportion of large fish on the shelf than previously or later (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 reference model. 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. It may be useful in next year's model to explore different sample sizes for these data that are not tuned as they were this year. Although the model predicts there to have been a larger proportion of males to females (males:female ratio up to 2:1) in the population between 50 cm and 70 cm (Fig. 5.31), Model 1 may be underestimating this pool of large males as the raw Slope survey data in aggregate for all years show a male: female ratio of nearly 9:1 (Fig. 5. 32; female proportion of 0.1). Although less severe an increase in the male:female ratio at this size range was also consistently observed in both the longline and trawl fisheries size composition data.

The Auke Bay Laboratory size composition data were from combined sexes and as such very difficult to model using standard selectivity curves. Better model fits were achieved in models presented at the 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 not 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 1 and predicted time series. In all instances in this section "total biomass" refers to age 1+ biomass, spawning biomass is the female spawning biomass, and recruitment is age 0 numbers from the model unless otherwise specified.

Recruitment

The most striking feature of the Model 1 recruitment (Fig. 5.35, Table 5.18, and Table 5.19) is the extremely large 1962 year class with 1.49 billion 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. In SS3, due to how the recruitment deviations likelihood is specified, the model will always fit a single large recruitment instead of multiple events when it does not have data to inform the model. Model 2 was intended as a means to spread these recruitment events out without assuming changes in early productivity. This model configuration was rejected by the Plan Team last year because the inclusion of autocorrelation in SS3 had not been throuroughly vetted.

After 1970, Model 1 fits two large recruitment events (1975 = 285.7 million age 0 , 1978 = 107.9 million age 0). As there were no size composition data prior to 1977, the basis for these large year classes was the existence of many large fish in the early longline fishery. Because Greenland turbot appear to reach a terminal size, the exact ages were not know and therefore the exact years for these recruitment events were not known and may change in future models under different configurations. The 1978 year class was well documented and can be traced from the trawl fishery through to the longline fishery and surveys. It should be noted that for the projection model, used for determining the reference points and setting catch levels, we only use age 1 recruitment from1977 onward.

Recruitment from 1979 through to 2005 was low. The mean Age 0 recruitment for 1977 through 2013 was estimated at 11.7 million fish (rec. var. = 1.17), for the period between 1979 and 2007, the average was 5.4 million fish (rec. var.= 0.9). In 2008 recruitment of age 0 fish was estimated at 31.5 million fish and in 2009 at 80.7 million age 0 fish . These were the largest recruitment since 1978. These recent recruitment events were captured over multiple years in the Shelf survey size and age composition data, in the size composition from the last two slope surveys, and in the size composition data from the last two years in the Trawl fishery. The longline fishery should begin seeing these fish starting in 2014. The influx of new recruits in 2008 and 2009 cause a sharp drop in the predicted population mean size and mean age (Fig. 5.36 and Fig. 5.37).

Biomass and fisheries exploitation

The BSAI Greenland turbot spawning biomass in Model 1 was projected for 2014 at 22,010 t to be increasing from its lowest level of 20,006 in 2013, a drop from a peak of 404,040 t in 1973 (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 and through the 1990s drove the steepest part of the decline in spawning biomass. The mean age 0 recruitment for 1986 to 2006 was 3.7 million fish (32% of the overall 1977-2013 mean recruitment) . In 1990 the NPFMC cut ABCs to 7,000 t until through 1996 to account for low recruitment; however the ABCs were exceeded in 5 of the 7 years (Table 5.1). The stock continued to decline in the 1990s as poor recruitment continued. In 1997 the NPFMC started managing the stock as a Tier 3 stock and the ABCs were allowed to increase (Table 5.1). The mean ABC between 1997 and 2002 was 9,783 t, the mean catch however was lower and averaged about 6,355 t per year over this period. From 2003 to 2008 the ABC levels remained relatively low with a high of 4,000 t in 2003 and a low of 2,440 t in 2007. The catch dropped even lower to an average of just 2,417 t per year in this period. In 2008 with Amendment 80 an arrowtooth/ 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 for 2008 through 2012 was 3,988 t. The ABCs during this period, due to a clerical error in the projection model, went from 2,500 t in 2008 to 7,380 in 2009. From 2009 to 2012 the ABC averaged 7,325 t with a high at 9,660 t in 2012. Although the decline in spawning biomass began to slow in 2005 through 2007, the decline in spawning biomass again steepened post-2008. This decline may be correlated with increased fishing pressure during this period. Between 1986 and 2007 the mean total exploitation was estimated at 0.05 with a maximum total exploitation rate of 0.08 (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 0.09. The catch levels in 2008 through 2012 however exceeded the OFL control rule levels projected from Model 1 (Fig. 5.41). The large 2008 and 2009 year classes area still immature hence the spawning population is estimated to be declining through 2013. Projections for 2014 and onward predict an increase in spawning biomass as these year classes become mature.

The 2013 Model 1 total age 1+ biomass estimates were similar to the female spawning biomass with a steep decline from an estimated peak in 1972 of 751,827 t to its lowest point in 2010 of 47,577 t (Fig. 5.39). The difference is that the total biomass shows the impact of the 2008 and 2009 recruitments starting in 2011. Since its low point in 2010 total age +1 biomass is projected to have increased to 72,376 t in 2013 and projected to be at 84,546 t in 2014. The estimated total age-1+ biomass and female spawning biomass were both smaller than estimated in previous stock assessments. This is due to both the change in weight at age relationship from the previous assessments (Table 5.22) with the addition of the 2008 through 2012 shelf survey weight at age data.

<u>Retrospective analysis</u>

Please note: due to time constraints the retrospective analysis was not conducted for the current year, this retrospective is from last year, but from the same reference model. The restrospective analysis was conducted in SS3 by removeing data systematically by year from the model (Fig. 5.42). The largest change in the retrospective was between -4 and -5 years (from 2008 to 2009). At this point the model would no longer converge with a less contrained prior on the Shelf survey catchability. We needed to change the log(St.dev.) from 0.4 to 0.1 to achieve convergence. As we removed data, catchability for both the shelf and the slope trended lower until between -4 and -5 where the slope increased and shelf catchability continued to decreased (Fig. 5.43). At -5 and below both slope and shelf catchability trended together at between 0.49

and 0.52. This means that the data added post-2007 provided information on catchability and enabled us to loosen our assumptions on the Slope catchability. With the post-2007 dataset we see a consistent pattern of decreaseing estimated spawning biomass as we add more recent data to the model (Fig. 5.44). This retrospective analysis suggests that the model would have been biased high in previous years without the more recent data.

Harvest Recommendations

Amendment 56 Reference Points

The $B_{40\%}$ value using the mean recruitment estimated for the period 1977-2012 gives a long-term average female spawning biomass of 39,906 t. The estimated 2013 female spawning biomass is at 20,006 t or $B_{20\%}$ well below the estimate of $B_{35\%}$ (34,917 t). Because the projected spawning biomass in year 2013 is below $B_{40\%}$ Greenland turbot ABC and OFL levels will be determined at Tier 3b of Amendment 56.

Specification of OFL and Maximum Permissible ABC and ABC Recommendation

In the past several years, the ABC has been set below the maximum permissible estimates. For example, in 2008 the ABC recommendation was 21% of the maximum permissible level. The rationale for these lower values have been generally due to concerns over stock structure uncertainty, lack of apparent recruitment, and modeling issues. Last year a slope survey was conducted and while some areas show lower abundances (i.e., the Aleutian Islands) the signs of recruitment are the best ever seen for this stock. Therefore we recommend that the ABC be set to the maximum permissible.

The projected Greenland turbot maximum permissible ABC and OFL levels for 2014 and 2015 are shown below (catch for 2013 was set to 1,924 t):

Year	Catch (for projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2014	2,124 t	2,124 t	2,124 t	2,647 t	22,010 t
2015		3,173 t	3,173 t	3,864 t	27,624 t

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is 2,647 t corresponding to a full-selection F of 0.14. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) -specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is unallocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

Subarea Allocation

In this assessment, the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions was adopted. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, the length compositions from the Aleutian Islands surveys appear to have few small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 5.23).

Recent research on recruitment processes holds promise for clearer understanding (e.g., Sohn et al. (In Review) and Sohn 2009). Stock structure between regions remains uncertain and therefore the policy has been to harvest the "stock" evenly by specifying region-specific ABCs. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportions of the adult biomass in the Aleutian Islands region over the past four surveys (when both areas were covered) were 26.4%, 23.7%, 25.5%, and 12.2%. These average 21.9% which when applied to the BSAI ABC gives the following region-specific allocation:

	2014 ABC	2015 ABC
Aleutian Islands ABC	465	695
Eastern Bering Sea ABC	1,659	2,478
Total	2,124	3,173

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 2013 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2014 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2013 (here assumed to be 1,924 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 2014, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to the author's recommend level. Due to current conditions of strong recruitment and a projected increasing biomass, the recommendation is set equal to the maximum permissible ABC.

Scenario 3: In all future years, *F* is set equal to the 2008-2012 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 2013 and above its MSY level in 2023 under this scenario, then the stock is not overfished.)

Scenario 7: In 2014 and 2015, *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 2013 (Table 5.24). Fishing at the maximum permissible rate indicate that the spawning stock (Fig. 5.45) continued to decline in 2013 but will increase after 2014 with the incoming large 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 43,654 t by 2026. These projections illustrate the impact of the recent recruitment observed in the survey. For example, under all scenarios, the spawning biomass is expected to increase starting in 2014 when the recruits in recent years mature. In both Scenario 6 and 7 spawning biomass peaks in 2020 and then begins to drop again as the influence of the 2008 and 2009 year classes begins to wain and the projection relies on mean recruitment.

Under Scenarios 6 and 7 of the 2013 Reference Model, 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 in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Data Gaps and Research Priorities

Besides the assessment model improvements suggestes 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*	1,024	226	1,250	2,060	2,060

*Catch estimated as of October 2013

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2013 (the "arrowtooth/Kamchatka" fishery was combined with the Greenland turbot fishery from 2003-2009). 2013 numbers are estimates through October and are not final.

Fishery:	Greenland turbot		Sablefish		Pacific cod		Rockfish		Flatfish		Arrowtooth/Kamchatka		Others		Combined	
Year	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard	Retain	Discard
1992	62	13	196	2,121	135	557	180	103	13	3			107	261	693	3,058
1993	5,685	332	235	880	160	108	572	87	19	185			10	194	6,681	1,786
1994	6,316	368	194	2,305	149	211	316	37	27	235			38	76	7,040	3,232
1995	5,093	327	157	1,546	145	284	362	25	5	102			28	121	5,790	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63			143	140	4,733	1,822
1997	4,709	521	129	619	270	283	202	19	212	92			18	125	5,540	1,659
1998	6,905	301	125	171	278	154	42	2	628	249			123	171	8,101	1,048
1999	4,009	227	179	120	180	50	25	2	600	269			134	61	5,127	729
2000	4,798	177	192	253	130	108	39	1	838	176			186	75	6,183	790
2001	2,727	89	171	325	203	92	431	30	764	337			95	47	4,391	920
2002	1,979	73	144	207	210	139	175	18	301	217			124	49	2,933	703
2003	1,842	95	98	534	165	95	198	5	114	176			79	55	2,497	961
2004	1,244	37	78	24	221	79	72	3	154	158			99	50	1,868	352
2005	1,677	28	63	19	156	30	134	5	179	69			149	49	2,359	200
2006	1,340	33	62	52	65	31	69	8	107	19			135	46	1,778	188
2007	1,091	28	59	71	127	91	36	13	30	35			198	50	1,541	288
2008	1,537	417	42	82	17	70	142	1	96	30			203	103	2,038	703
2009	3,649	336	69	54	65	21	69	8	52	13			148	14	4,053	445
2010	1,913	17	62	27	115	19	57	2	23	72	1,662	81	8	78	3,910	228
2011	1,759	8	49	7	165	9	27	1	31	5	1,466	17	83	10	3,553	83
2012	1,893	17	36	16	116	9	17	3	47	6	2,277	12	203	17	4,656	94
2013*	367	27	47	28	12	6	44	9	38	37	635	208	39	27	1,173	348

Table 5.3. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2004-2013. Source: NMFS AK Regional Office catch accounting system. Note for 2010-2013 the Arrowtooth fishery includes the Kamchatka fishery.

	"Target" fishery	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013*
Longline and pot	Greenland turbot	1,168	1,527	1,212	1,097	573	1,192	1,813	1,763	1,908	372
	Sablefish	90	75	114	130	119	122	90	56	52	74
	Pacific cod	221	170	77	129	76	84	127	174	123	15
	Shallow-water flatfish	64	57	61	15	15	7	0	0	0	0
	Arrowtooth flounder	0	2	140	16	0	9	53	0	11	0
	Others	1	0	3	12	22	4	78	26	12	26
Trawl	Greenland turbot	61	24	0	2	205	1,349	118	4	0	2
	Pacific cod	79	15	19	89	11	2	8	0	1	3
	Arrowtooth flounder	53	154	21	3	1,176	1,435	1,689	1,483	2,277	843
	Atka mackerel	123	167	117	130	201	118	62	64	209	40
	Flathead sole	191	150	28	30	98	49	13	2	46	39
	Pollock	18	31	65	107	82	44	23	88	53	21
	Rockfish	74	139	74	47	143	73	59	28	18	50
	Other Flatfish	51	34	1	12	11	4	1	1	4	1
	Rock sole	4	1	27	8	0	2	3	1	0	3
	yellowfin sole	1	7	8	1	1	4	1	6	6	26
	Sablefish	12	7	0	0	6	0	0	0	0	1
	Others	8	0	0	0	0	0	0	0	0	0

* Through October 2012

Table 5.4. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2003-2013.

Area	Gear	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013*
Aleutian Islands	Fixed	650	218	138	346	338	111	97	213	89	57	75
	Trawl	315	196	301	179	178	712	2,164	1,653	442	1,600	227
Aleutian Islands	Total	965	414	439	525	516	824	2,261	1,866	531	1,657	302
EBS	Fixed	1,918	1,326	1,693	1,259	1,061	694	1,321	1,947	1,929	2,050	415
	Trawl	575	479	427	181	251	1,222	916	325	1,176	1,012	804
	EBS Total	2,493	1,805	2,120	1,440	1,313	1,917	2,237	2,272	3,105	3,063	1,219
Grand Total		3,458	2,220	2,559	1,965	1,829	2,741	4,497	4,138	3,636	4,720	1,521

* Estimated through Oct. 2013.

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	1960-2012
	Size composition	1977-1987, 1989-1991,1994-2013
Longline fisheries		
	Catch	1960-2012
	Size composition	1979-1985,1993-2013
Shelf Survey		
	Abundance Index	1987-2013
	Size composition	1982-2012
	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	1996-2013
	Size composition	1979-2013

Table 5.6. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2013. 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%	0	0	0	
1990	3,864	5,762	6,100	40%	0	0	0	
1991	1,851	1,752	9,295	51%	0	0	0	
1992	0	0	0		0	0	71	
1993	0	0	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	0	0	0		941	442	7,482	68%
1997	112	390	0	22%	2,393	1,014	14,833	70%
1998	307	696	822	31%	3,510	2,127	22,794	62%
1999	1,044	1,556	0	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	0	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	0	36%	4,650	1,902	43	71%
2006	15	76	0	16%	3,339	1,474	32	69%
2007	34	23	0	60%	3,833	2,130	134	64%
2008	421	1,572	1	21%	1,577	1,481	0	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	1,733	3,131	14	36%	994	652	0	60%
2013	1,176	1,113	1	51%	527	362	0	59%

Table 5.7. Survey biomass estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2008. Note that the shelf-survey estimates from 1985, and 1987-2008 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		48,700*
1981	86,800	99,600	
1982	48,600	90,600	
1983	35,100		63,800*
1984	17,900		
1985	7,700	79,200	
1986	5,600		76,500*
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	35,690		
1994	57,170		28,227
1995	37,636		
1996	40,591		
1997	35,303		28,334
1998	34,885		
1999	21,529		
2000	23,184		9,359
2001	27,280		
2002	24,000	27,589	9,891
2003	31,010		
2004	28,287	36,557	11,334
2005	21,302		
2006	20,933		20,934
2007	16,723		
2008	13,511	17,901	
2009	10,953		
2010	23,414	19,873	6,795
2011	26,156		
2012	21,792	17,984	2,600
2013	24,907		

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	401	375	28,755	11	11	292	292
1983	190	56	951				
1984	209	16	536	20		263	
1985	376	335	11,215				
1986	143	11	165				
1987	212	52	377				
1988	224	93	3,156				
1989	224	55	432				
1990	395	111	548				
1991	263	58	658			171	168
1992	187	57	616	5		7	
1993	205	63	632	7		112	
1994	238	44	536	17		196	
1995	271	47	353				
1996	192	55	450	8		100	
1997	192	45	298	11		79	
1998	371	55	445	26	21	178	127
1999	226	39	207	8		9	
2000	214	136	1,290	77		254	
2001	218	51	274	36		112	
2002	211	50	455	19		549	
2003	205	50	622	46	46	415	388
2004	240	175	2,398	134	134	758	736
2005	209	45	442	41	40	277	261
2006	236	55	427	47	47	253	232
2007	223	71	499	66	66	316	293
2008	219	158	1,713	133	130	719	668
2009	214	74	856	61	60	318	311
2010	245	206	4,684	145	65	858	319
2011	219	106	4,381	53	51	379	337
2012	237	180	4,277	114	114	839	800
2013	230	72	1,160	51		198	

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), 1980-2012.

Year	Western Aleutian	Central Aleutian	Eastern Aleutian	Southern Bering Sea	Total
1980	0	799	2,720	79	3,598
1983	525	2,357	5,747	1,094	9,722
1986	1,747	2,495	19,580	7,937	31,759
1991	2,195	3,280	4,607	1,803	11,885
1994	2,401	4,007	15,862	5,966	28,235
1997	2,137	3,130	22,708	359	28,334
2000	839	2,351	5,703	467	9,359
2002	793	1,658	6,996	444	9,891
2004	2,588	2,947	2,564	3,234	11,333
2006	1,973	1,937	15,742	1,282	20,934
2010	1,071	1,507	3,698	486	6,795
2012	1,091	1,231	181	98	2,600
Avg. since 1991	1,678	2,454	8,673	1,571	14,376

Table 5.12. Auke Bay 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
Bering 4		13,491		10,068		5,123		6,206		2,297		1,235		2,612		1,821		2,970
Bering 3		27,936		33,848		24,766		24,660		15,268		13,523		21,192		12,164		13,473
Bering 2		6,172		6,156		5,005		3,784		1,826		1,754		640		705		3,082
Bering 1		11,729		13,072		16,082		11,965		3,717		1,561		3,406		1,494		1,641
NE Aleutians	23,133				12,987		10,942		8,551		3,031		3,155		2,033		4,714	
NW Aleutians	7,212		7,208		4,049		3,411		2,666		945		984		634		1,470	
SE Aleutians	2,142		1,791		1,201		1,397		936		566		297		163		350	
SW Aleutians	6,775		5,665		3,800		4,420		2,962		1,789		939		517		1,106	
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	
Combined (/1000)	136.0	83.4	130.9	88.9	76.3	71.7	69.9	65.5	52.3	32.5	21.9	25.4	18.6	39.2	11.6	22.8	26.5	29.8

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

	1982				1991				1998			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1	16.75	20	16.61	23					17.67	3		
2	24.45	33	24.79	43					24.94	18	25.58	19
3	32.70	33	33.67	30					33.14	7	34.00	11
4	40.26	38	40.03	31					32.00	1	33.80	5
5	46.36	14	45.70	10	59.00	1			35.00	2	36.50	2
6	48.11	9	50.00	3	46.00	1	54	2			50.00	1
7	52.50	4	52.00	1	57.33	3	49	5				
8					60.50	4	56.625	8			49.00	1
9					59.00	7	59.375	16			58.00	1
10					64.90	10	63.625	8	65.80	5	58.33	3
11					65.63	8	65.71429	14	65.00	5		
12					67.36	11	68.28571	7	78.67	3	59.75	4
13					75.43	7	70.42857	7			66.75	4
14					80.67	3	72	1	75.00	1	75.00	1
15					79.57	7	71	1			67.50	2
16					80.60	15			76.00	2		
17					86.71	7			81.00	1	71.00	3
18					86.75	4						
19					86.60	5					74.00	2
20					87.33	3			80.33	3		
21					91.00	1			82.00	1		
22					88.00	1						
23									79.00	1		
24					100.00	1			79.00	2	69.50	2
25									79.00	2		
26									95.00	1		
27												
28												
29												
30											81	2

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).

	2003				2004				2005			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1	15.67	3	13.00	3	15.0	1	16.3	4			13.50	2
2	22.37	30	22.15	34	21.8	5	23.9	9	25.00	1	24.00	2
3	29.68	37	28.97	38	29.9	29	30.3	40	32.20	10	33.19	16
4	33.44	16	36.06	18	34.6	10	34.8	18	35.95	38	36.97	35
5	38.96	24	38.96	27	40.9	21	42.6	20	42.58	31	41.33	27
6	47.00	3	40.67	9	43.1	7	43.1	15	48.85	13	47.10	10
7	43.67	3	46.20	10	53.0	3	51.2	10	53.33	9	48.00	5
8	50.00	6	49.20	5	57.0	1	58.0	1	62.50	6	51.83	6
9	57.50	2	48.50	2			61.8	4	62.00	1	52.00	1
10	51.00	1	66.40	5	70.3	4	63.8	4	67.50	2	72.00	1
11	60.00	2	60.00	2	83.0	2			86.00	1	64.67	3
12	78.33	3	72.00	1	78.3	4	73.2	5	77.00	3		
13	83.67	3	76.00	1	85.6	5	68.7	3	88.00	1	72.50	2
14	83.20	5			83.8	5			81.33	3	76.00	1
15	80.00	1			87.2	6	74.0	2	85.50	2	79.00	1
16	84.20	5	70.00	2	82.0	4	78.0	2			75.50	4
17	86.43	7	72.00	1	85.2	6	78.0	1	85.00	2	76.00	1
18	85.67	6	72.00	1	91.7	3	77.0	3	92.00	3	76.00	1
19	90.67	6	78.00	1	92.5	2	81.0	1	84.60	5	74.33	3
20	89.56	9	81.50	2	89.5	2	73.5	2	90.20	5	79.00	1
21	90.00	5	76.50	2	90.7	3			89.00	2		
22	88.00	4	81.00	2					87.00	1		
23	90.17	6	74.00	1	96.5	2			82.00	1		
24	90.00	5	76.33	3	97.0	1			88.00	2	74.00	1
25	91.33	3	73.00	2	91.0	3			86.75	4	75.50	2
26	92.33	3	77.00	3	94.5	2			96.50	2		
27	93.67	3	74.00	1	85.7	3					73.00	1
28	92.00	4			91.0	1					78.00	1
29	91.75	4	78.00	1								
30	91.00	5							88.00	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).

	2006				2007				2008			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1			11.50	2	12.17	18	12.50	26	12.81	16	13.10	21
2	24.33	3	21.00	1	22.50	4	21.00	8	18.94	17	19.64	36
3	30.33	3			30.00	1	28.67	6	23.13	8	23.36	11
4	39.00	2	39.50	2	39.50	2	35.00	4	28.50	2	30.00	4
5	38.00	11	38.38	16	46.18	17	44.40	15	34.50	2	35.50	4
6	42.69	16	43.75	20	47.00	17	47.18	22	49.60	5	47.50	6
7	46.60	25	44.33	15	50.72	18	51.70	23	52.14	14	51.83	12
8	54.53	19	47.25	16	54.67	15	52.67	15	56.68	25	52.15	20
9	57.90	10	53.18	11	59.75	12	56.00	4	61.73	22	56.79	19
10	65.67	3	64.25	4	62.33	6	55.00	3	64.50	20	58.95	20
11	62.00	1	62.25	4	63.00	1	62.75	4	64.36	14	60.76	17
12	71.00	6	74.00	1	62.00	3			68.90	10	62.64	14
13	56.50	2			65.00	7			71.56	9	63.67	6
14	77.00	1							79.83	6	67.17	6
15	78.00	2	73.00	1	61.67	3			79.80	5	66.22	9
16	84.67	3	77.00	2	80.00	1	69.00	1	85.67	6	72.75	8
17	86.25	4	74.00	1	90.00	4	75.50	4	77.00	5	69.71	7
18	88.67	3	76.00	1	85.00	1	77.50	2	83.13	8	72.82	11
19	87.60	5	79.00	1	91.67	3			90.50	4	69.00	5
20	90.33	6	79.00	1	89.00	3			86.75	8	72.00	14
21	91.00	2			90.67	3	76.50	2	91.56	9	68.00	5
22	90.00	2	74.00	1			77.00	1	91.30	10	74.13	8
23	88.00	1	88.00	1	87.00	1			93.88	8	70.71	7
24			77.00	1			84.00	1	90.56	9	73.00	7
25	88.50	2	83.00	2			72.00	1	89.92	13	69.50	6
26					92.00	3			90.67	3	72.50	6
27									90.50	4	71.86	7
28									94.67	9	71.70	10
29					92.00	1	82.00	1	91.07	15	76.14	7
30	107.00	1			90.00	1	79.00	1	91.74	35	70.52	31

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).

	2009				**2010**				**2011**			
	Females		Males		Females		Males		Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N	Avg. length (cm)	N	Ave. length (cm)	N
1	15.00	6	14.25	12	14.08	38	14.06	48	16.44	9	16.10	21
2	22.05	41	21.93	73	23.22	54	23.91	57	23.74	76	23.10	90
3	29.72	29	28.60	47	30.23	22	33.30	27	32.18	33	32.09	44
4	33.30	10	33.27	11	34.57	7	36.43	14	37.06	16	36.87	15
5	35.50	2	45.00	1	38.00	2	39.75	4	41.65	17	41.78	9
6			42.50	2	42.00	1	42.00	1	46.17	6	45.33	3
7	56.00	3	52.00	1	67.00	1			46.50	2	0.00	0
8	56.00	1	53.75	4			50.50	2	57.00	1	55.50	2
9	59.56	9	58.33	3			59.00	1	72.00	2	47.00	1
10	63.75	4	54.50	2	62.25	4			65.00	2		
11	64.00	4			73.00	4			68.67	3	69.00	1
12					67.25	8	60.00	1			65.50	2
13	74.50	2			69.50	2	67.00	2	71.50	4		
14	78.00	2			73.50	4						
15									77.00	1		
16					80.00	1						
17											66.00	1
18					97.00	1			66.00	1		
19	88.00	1	78.50	2							73.00	1
20	90.50	2	79.00	1					87.00	1	70.00	1
21	87.67	3	70.00	1			73.00	1	93.50	2		
22	94.00	1	77.00	2	94.50	2	73.00	1				
23	92.50	4			80.50	2	88.00	1				
24	100.00	1					82.00	1				
25	89.00	2	71.00	1					99.00	1		
26	93.00	1	78.00	1	88.00	1						
27	83.00	2							81.67	3		
28	93.33	3					79.00	1			76.00	1
29					93.00	1	78.00	1	86.00	1		
30	89.75	4	76.75	4	92.00	3			96.00	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).

	2012			
	Females		Males	
Age	Avg. length (cm)	N	Ave. length (cm)	N
1	14.18	17	13.45	22
2	23.28	40	22.48	44
3	32.08	49	31.30	60
4	36.77	31	36.72	25
5	42.35	23	40.87	23
6	46.00	13	47.43	7
7	54.80	5	53.00	3
8	47.50	2		
9				
10	69.50	2	66.00	1
11	74.00	3		
12	75.00	1		
13	77.00	1	68.00	1
14	80.00	1	56.00	1
15				
16				
17	75.00	2		
18	84.00	2		
19				
20	81.00	1	75.00	1
21				
22				
23	85.00	1		
24	100.00	1		
25				
26				
27	97.50	2		
28				
29				
30			76.00	2

Table 5.14. Starting multinomial sample sizes for size composition data by fishery and suvey.

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Trawl	100	101	101	101	101	105	110	107	104	101	100	
Longline			100	100	100	100	100	100	94			
Shelf						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
Shelf-Age												

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Trawl	100	100	100			100	100	100		100	100	100
Longline					102	100	101	101	102	103	102	102
Shelf	200	200	200	200	200	200	200	200	200	200	200	200
Slope												
ABL Longline	60	60	60	60	60	60		60	60	60	60	60
Shelf-Age										100		

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Trawl	100	100	100	100	100	31	27	100	100	100	100	100	100
Longline	101	101	101	101	101	101	101	101	101	101	101	100	100
Shelf	200	200	200	200	200	200	200	200	200	200	200	200	200
Slope		50		50				50		50		50	
ABL Longline	60	60	60	60	60	60	60	60	60	60	60	60	60
Shelf-Age			100	100	100	100	100	100	100	100	100	100	

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 for each and differences in recruitment estimation.

		2012 Ref	Model1	Model 2
Likelihoods				
	Total	3065.2	2428.7	2364.2
	Survey	-33.1	-30.1	-30.3
	Length Composition	1807.3	1181.8	1177.0
	Age Composition	123.3	140.8	138.5
	Size at Age	1016.1	1015.2	1011.0
	Recruitment	147.3	118.7	67.1
	Parameter priors	4.4	2.2	0.7
Parameters				
	LN(R_0)	9.25	9.23	9.64
	Steepness	0.79	0.79	0.79
	Natural Mortality	0.112	0.112	0.112
	q_{Shelf}	0.65	0.61	0.67
	q_{Slope}	0.56	0.61	0.69
	Mean q_{ABLL}	0.80	0.88	1.00
	L_{max} Female	88.34	87.53	87.98
	L_{max} Male	72.49	73.32	73.45
	Von Bert K Female	0.13	0.12	0.12
	Von Bert K Male	0.18	0.16	0.16
Results				
Model				
	SSB_{1978} (t)	224,680	299,238	246,126
	SSB_{2011} (t)	27,263	23,797	19,966
Projection				
	$SSB_{100\%}$ (t)	119,217	99,464	121,114
	SSB_{2013} (t)	23,485	20,006	16,401
	$SSB_{2013\%}$	0.197	0.201	0.135
	SSB_{2014} (t)	26,537	22,010	18,620
	$SSB_{2014\%}$	0.222	0.221	0.153
2014				
	ABC (t)	2,655	2,124	1,180
	F_{ABC}	0.13	0.12	0.08
	OFL (t)	3,197	2,647	1,477
	F_{OFL}	0.16	0.14	0.10
2015				
	ABC (t)	4,281	3,173	2,042
	F_{ABC}	0.17	0.15	0.11
	OFL (t)	5,091	3,864	2,517
	F_{OFL}	0.21	0.18	0.13

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

		2012 Ref	Model 1	Model 2
Index RMSE				
	Shelf	0.238	0.224	0.224
	Slope	0.200	0.204	0.214
	ABL Longline	0.397	0.363	0.352
Size Comp				
Mean EffN	Trawl	56.9	52.3	52.1
	Longline	66.4	64.7	65.4
	Shelf	82.1	74.3	73.0
	Slope	39.2	49.5	45.8
	ABL Longline	35.9	42.2	40.9
Mean input N	Trawl	55.0	30	30
	Longline	65.4	43.5	43.5
	Shelf	90	46	46
	Slope	40	26.6	26.6
	ABL Longline	36	30	30
Age Comp				
	Mean EffN	52.0	46.1	49.1
	Mean input N	50	36	36
Rec. Var. (1975-2013)				
	Std.dev(ln(No. Age 1))	1.48	1.31	1.50

Table 5.17. Age-equivalent sex-specific selectivity estimates (as estimated for 2013) 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	0.0070	0.0072	0.0000	0.0000
3	0.0107	0.0122	0.0001	0.0000
4	0.0283	0.0338	0.0004	0.0001
5	0.0741	0.0864	0.0028	0.0016
6	0.1493	0.1724	0.0134	0.0134
7	0.2376	0.2795	0.0446	0.0470
8	0.3187	0.3901	0.1068	0.1006
9	0.3801	0.4891	0.1975	0.1617
10	0.4186	0.5681	0.3036	0.2198
11	0.4368	0.6254	0.4110	0.2698
12	0.4393	0.6633	0.5101	0.3107
13	0.4307	0.6858	0.5961	0.3433
14	0.4152	0.6974	0.6681	0.3691
15	0.3957	0.7015	0.7272	0.3894
16	0.3746	0.7011	0.7752	0.4057
17	0.3532	0.6980	0.8139	0.4187
18	0.3324	0.6936	0.8451	0.4293
19	0.3127	0.6889	0.8703	0.4380
20	0.2944	0.6844	0.8908	0.4453
21	0.2775	0.6804	0.9076	0.4514
22	0.2621	0.6771	0.9213	0.4566
23	0.2481	0.6747	0.9327	0.4611
24	0.2353	0.6731	0.9421	0.4650
25	0.2242	0.6685	0.9487	0.4674
26	0.2146	0.6612	0.9530	0.4686
27	0.2064	0.6548	0.9565	0.4696
28	0.1991	0.6492	0.9594	0.4704
29	0.1928	0.6444	0.9619	0.4711
30	0.0067	0.0067	0.0000	0.0000

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	10,714	0	23,550	1994	2,163	1,036	3,289
1961	10,582	0	23,232	1995	2,489	1,193	3,784
1962	1,488,400	1,365,869	1,610,931	1996	1,628	612	2,643
1963	10,233	0	22,624	1997	2,502	1,155	3,848
1964	9,917	0	22,051	1998	3,124	1,392	4,857
1965	9,342	0	20,902	1999	7,099	4,426	9,771
1966	9,566	0	21,560	2000	6,796	4,094	9,497
1967	10,695	0	24,390	2001	6,853	4,547	9,159
1968	12,133	0	28,162	2002	1,289	487	2,090
1969	13,163	0	31,166	2003	923	360	1,486
1970	14,372	0	35,138	2004	946	369	1,523
1971	16,582	0	43,379	2005	1,163	440	1,887
1972	21,544	0	65,752	2006	8,846	5,987	11,706
1973	21,416	0	64,185	2007	11,925	7,735	16,115
1974	13,162	0	31,769	2008	31,478	21,485	41,471
1975	285,670	221,733	349,607	2009	80,743	56,811	104,675
1976	12,881	0	30,608	2010	12,901	5,219	20,583
1977	16,630	0	42,506	2011	10,949	3,513	18,385
1978	107,930	71,141	144,719	2012	7,053	503	13,603
1979	9,024	0	18,991	2013	8,388	0	18,287
1980	19,185	8,822	29,548	**1977-2013 Average 11,766**			
1981	4,559	985	8,134				
1982	5,893	2,601	9,185				
1983	3,204	977	5,431				
1984	7,809	4,163	11,454				
1985	17,332	12,248	22,416				
1986	2,885	885	4,884				
1987	4,461	2,154	6,769				
1988	4,569	2,169	6,970				
1989	14,049	10,295	17,803				
1990	2,649	995	4,304				
1991	1,500	534	2,465				
1992	1,380	546	2,213				
1993	1,137	412	1,862				

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

Females

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	0.83	0.58	11.33	0.45	0.62	0.52	0.33	0.24	0.18	0.15	0.11	0.09	0.07	0.07	0.06	6.33	0.03	0.02	0.01	0.01	0.07
1978	5.40	0.74	0.51	9.94	0.39	0.53	0.44	0.28	0.20	0.16	0.12	0.09	0.07	0.06	0.06	0.05	5.38	0.03	0.02	0.01	0.07
1979	0.45	4.82	0.66	0.45	8.48	0.33	0.44	0.37	0.23	0.17	0.13	0.10	0.08	0.06	0.05	0.05	0.04	4.44	0.02	0.01	0.07
1980	0.96	0.40	4.29	0.57	0.38	7.12	0.27	0.37	0.31	0.19	0.14	0.11	0.08	0.06	0.05	0.04	0.04	0.03	3.64	0.02	0.07
1981	0.23	0.86	0.36	3.69	0.48	0.31	5.79	0.22	0.30	0.25	0.16	0.11	0.09	0.07	0.05	0.04	0.03	0.03	0.03	2.90	0.07
1982	0.29	0.20	0.76	0.31	3.05	0.39	0.25	4.60	0.18	0.23	0.19	0.12	0.09	0.07	0.05	0.04	0.03	0.03	0.02	0.02	2.31
1983	0.16	0.26	0.18	0.65	0.25	2.45	0.31	0.20	3.61	0.14	0.18	0.15	0.10	0.07	0.05	0.04	0.03	0.02	0.02	0.02	1.83
1984	0.39	0.14	0.23	0.15	0.53	0.20	1.94	0.24	0.15	2.83	0.11	0.14	0.12	0.08	0.05	0.04	0.03	0.02	0.02	0.02	1.46
1985	0.87	0.35	0.13	0.20	0.13	0.45	0.17	1.62	0.20	0.13	2.36	0.09	0.12	0.10	0.06	0.05	0.03	0.03	0.02	0.02	1.23
1986	0.14	0.77	0.31	0.11	0.18	0.11	0.38	0.14	1.39	0.17	0.11	2.02	0.08	0.10	0.08	0.05	0.04	0.03	0.02	0.02	1.07
1987	0.22	0.13	0.69	0.27	0.10	0.15	0.10	0.33	0.13	1.20	0.15	0.10	1.75	0.07	0.09	0.07	0.05	0.03	0.03	0.02	0.94
1988	0.23	0.20	0.12	0.61	0.24	0.09	0.13	0.09	0.29	0.11	1.04	0.13	0.08	1.52	0.06	0.08	0.06	0.04	0.03	0.02	0.83
1989	0.70	0.20	0.18	0.10	0.54	0.21	0.07	0.12	0.07	0.25	0.10	0.91	0.11	0.07	1.33	0.05	0.07	0.06	0.04	0.03	0.75
1990	0.13	0.63	0.18	0.16	0.09	0.48	0.19	0.07	0.10	0.07	0.22	0.08	0.78	0.10	0.06	1.14	0.04	0.06	0.05	0.03	0.67
1991	0.07	0.12	0.56	0.16	0.14	0.08	0.43	0.17	0.06	0.09	0.06	0.19	0.07	0.66	0.08	0.05	0.96	0.04	0.05	0.04	0.60
1992	0.07	0.07	0.11	0.50	0.15	0.13	0.07	0.38	0.15	0.05	0.08	0.05	0.16	0.06	0.56	0.07	0.04	0.82	0.03	0.04	0.56
1993	0.06	0.06	0.06	0.09	0.45	0.13	0.11	0.06	0.34	0.13	0.05	0.07	0.04	0.14	0.05	0.49	0.06	0.04	0.72	0.03	0.52
1994	0.11	0.05	0.06	0.05	0.08	0.40	0.12	0.10	0.06	0.30	0.12	0.04	0.06	0.04	0.12	0.04	0.42	0.05	0.03	0.60	0.46
1995	0.12	0.10	0.05	0.05	0.05	0.08	0.36	0.10	0.09	0.05	0.26	0.10	0.03	0.05	0.03	0.10	0.04	0.35	0.04	0.03	0.89
1996	0.08	0.11	0.09	0.04	0.04	0.04	0.07	0.32	0.09	0.08	0.04	0.22	0.08	0.03	0.04	0.03	0.08	0.03	0.29	0.04	0.77
1997	0.13	0.07	0.10	0.08	0.04	0.04	0.04	0.06	0.28	0.08	0.07	0.04	0.19	0.07	0.02	0.04	0.02	0.07	0.03	0.25	0.68
1998	0.16	0.11	0.07	0.09	0.07	0.03	0.04	0.03	0.05	0.25	0.07	0.06	0.03	0.16	0.06	0.02	0.03	0.02	0.06	0.02	0.77
1999	0.35	0.14	0.10	0.06	0.08	0.06	0.03	0.03	0.03	0.05	0.22	0.06	0.05	0.03	0.14	0.05	0.02	0.02	0.02	0.05	0.65
2000	0.34	0.32	0.12	0.09	0.05	0.07	0.06	0.03	0.03	0.03	0.04	0.19	0.05	0.04	0.02	0.12	0.04	0.01	0.02	0.01	0.58
2001	0.34	0.30	0.28	0.11	0.08	0.05	0.06	0.05	0.02	0.02	0.02	0.03	0.16	0.04	0.04	0.02	0.09	0.03	0.01	0.02	0.48
2002	0.06	0.31	0.27	0.25	0.10	0.07	0.04	0.06	0.04	0.02	0.02	0.02	0.03	0.13	0.04	0.03	0.02	0.08	0.03	0.01	0.41
2003	0.05	0.06	0.27	0.24	0.23	0.09	0.06	0.04	0.05	0.04	0.02	0.02	0.02	0.03	0.11	0.03	0.03	0.01	0.07	0.02	0.36
2004	0.05	0.04	0.05	0.24	0.22	0.20	0.08	0.06	0.03	0.04	0.03	0.02	0.02	0.01	0.02	0.10	0.03	0.02	0.01	0.06	0.32
2005	0.06	0.04	0.04	0.05	0.22	0.19	0.18	0.07	0.05	0.03	0.04	0.03	0.01	0.01	0.01	0.02	0.08	0.02	0.02	0.01	0.32
2006	0.44	0.05	0.04	0.03	0.04	0.20	0.17	0.16	0.06	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.02	0.07	0.02	0.02	0.28
2007	0.60	0.40	0.05	0.03	0.03	0.04	0.17	0.15	0.14	0.06	0.04	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.06	0.02	0.25
2008	1.57	0.53	0.35	0.04	0.03	0.03	0.03	0.16	0.14	0.13	0.05	0.03	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.05	0.23
2009	4.04	1.41	0.48	0.32	0.04	0.03	0.02	0.03	0.14	0.12	0.11	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.23
2010	0.65	3.61	1.26	0.43	0.28	0.03	0.02	0.02	0.02	0.11	0.10	0.09	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.20
2011	0.55	0.58	3.22	1.12	0.38	0.25	0.03	0.02	0.02	0.02	0.10	0.08	0.07	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.16
2012	0.35	0.49	0.52	2.88	1.00	0.34	0.22	0.03	0.02	0.02	0.02	0.08	0.07	0.06	0.02	0.02	0.01	0.01	0.01	0.00	0.13
2013	0.42	0.32	0.44	0.46	2.57	0.89	0.30	0.19	0.02	0.02	0.01	0.01	0.06	0.05	0.05	0.02	0.01	0.01	0.01	0.01	0.11

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	0.83	0.58	11.36	0.45	0.63	0.52	0.32	0.22	0.16	0.12	0.08	0.06	0.05	0.04	0.03	3.59	0.02	0.01	0.01	0.00	0.01
1978	5.40	0.74	0.51	10.00	0.39	0.53	0.44	0.27	0.18	0.13	0.10	0.07	0.05	0.04	0.03	0.03	2.85	0.01	0.01	0.00	0.01
1979	0.45	4.82	0.66	0.45	8.55	0.33	0.44	0.35	0.21	0.14	0.10	0.07	0.05	0.04	0.03	0.02	0.02	2.13	0.01	0.01	0.01
1980	0.96	0.40	4.29	0.58	0.38	7.12	0.27	0.35	0.28	0.16	0.11	0.08	0.06	0.04	0.03	0.02	0.02	0.01	1.58	0.01	0.01
1981	0.23	0.86	0.36	3.72	0.49	0.31	5.62	0.21	0.26	0.20	0.12	0.08	0.06	0.04	0.03	0.02	0.01	0.01	0.01	1.09	0.01
1982	0.29	0.20	0.76	0.31	3.09	0.39	0.24	4.20	0.15	0.19	0.14	0.08	0.05	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.73
1983	0.16	0.26	0.18	0.65	0.25	2.44	0.30	0.18	3.02	0.11	0.13	0.10	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.48
1984	0.39	0.14	0.23	0.16	0.54	0.20	1.86	0.22	0.13	2.12	0.07	0.09	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.00	0.31
1985	0.87	0.35	0.13	0.20	0.13	0.45	0.17	1.51	0.17	0.10	1.66	0.06	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.00	0.24
1986	0.14	0.77	0.31	0.11	0.18	0.11	0.38	0.14	1.25	0.14	0.08	1.35	0.05	0.05	0.04	0.02	0.01	0.01	0.01	0.00	0.19
1987	0.22	0.13	0.69	0.28	0.10	0.15	0.10	0.33	0.12	1.06	0.12	0.07	1.13	0.04	0.05	0.03	0.02	0.01	0.01	0.01	0.17
1988	0.23	0.20	0.12	0.61	0.24	0.09	0.13	0.08	0.28	0.10	0.89	0.10	0.06	0.94	0.03	0.04	0.03	0.02	0.01	0.01	0.14
1989	0.70	0.20	0.18	0.10	0.54	0.21	0.07	0.12	0.07	0.24	0.09	0.76	0.09	0.05	0.80	0.03	0.03	0.02	0.01	0.01	0.13
1990	0.13	0.63	0.18	0.16	0.09	0.48	0.19	0.07	0.10	0.06	0.21	0.07	0.64	0.07	0.04	0.67	0.02	0.03	0.02	0.01	0.11
1991	0.07	0.12	0.56	0.16	0.14	0.08	0.43	0.17	0.06	0.09	0.05	0.17	0.06	0.52	0.06	0.03	0.54	0.02	0.02	0.02	0.10
1992	0.07	0.07	0.11	0.50	0.15	0.13	0.07	0.38	0.15	0.05	0.08	0.05	0.14	0.05	0.44	0.05	0.03	0.45	0.02	0.02	0.10
1993	0.06	0.06	0.06	0.09	0.45	0.13	0.11	0.07	0.34	0.13	0.05	0.07	0.04	0.13	0.04	0.38	0.04	0.02	0.40	0.01	0.10
1994	0.11	0.05	0.06	0.05	0.08	0.40	0.12	0.10	0.06	0.30	0.12	0.04	0.06	0.03	0.11	0.04	0.33	0.04	0.02	0.34	0.10
1995	0.12	0.10	0.05	0.05	0.05	0.08	0.36	0.10	0.09	0.05	0.26	0.10	0.03	0.05	0.03	0.09	0.03	0.27	0.03	0.02	0.36
1996	0.08	0.11	0.09	0.04	0.04	0.04	0.07	0.32	0.09	0.08	0.04	0.22	0.08	0.03	0.04	0.02	0.07	0.03	0.22	0.03	0.32
1997	0.13	0.07	0.10	0.08	0.04	0.04	0.04	0.06	0.28	0.08	0.07	0.04	0.19	0.07	0.02	0.03	0.02	0.06	0.02	0.19	0.29
1998	0.16	0.11	0.07	0.09	0.07	0.03	0.04	0.03	0.05	0.25	0.07	0.06	0.03	0.16	0.06	0.02	0.03	0.02	0.05	0.02	0.41
1999	0.35	0.14	0.10	0.06	0.08	0.06	0.03	0.03	0.03	0.05	0.22	0.06	0.05	0.03	0.14	0.05	0.02	0.02	0.01	0.05	0.36
2000	0.34	0.32	0.12	0.09	0.05	0.07	0.06	0.03	0.03	0.03	0.04	0.19	0.05	0.04	0.02	0.12	0.04	0.01	0.02	0.01	0.34
2001	0.34	0.30	0.28	0.11	0.08	0.05	0.06	0.05	0.02	0.02	0.02	0.03	0.16	0.04	0.04	0.02	0.10	0.04	0.01	0.02	0.29
2002	0.06	0.31	0.27	0.25	0.10	0.07	0.04	0.06	0.04	0.02	0.02	0.02	0.03	0.13	0.04	0.03	0.02	0.08	0.03	0.01	0.26
2003	0.05	0.06	0.27	0.24	0.23	0.09	0.06	0.04	0.05	0.04	0.02	0.02	0.02	0.02	0.11	0.03	0.03	0.01	0.07	0.03	0.23
2004	0.05	0.04	0.05	0.24	0.22	0.20	0.08	0.06	0.03	0.04	0.03	0.02	0.02	0.01	0.02	0.09	0.03	0.02	0.01	0.06	0.21
2005	0.06	0.04	0.04	0.05	0.22	0.19	0.18	0.07	0.05	0.03	0.04	0.03	0.01	0.01	0.01	0.02	0.08	0.02	0.02	0.01	0.23
2006	0.44	0.05	0.04	0.03	0.04	0.20	0.17	0.16	0.06	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.02	0.07	0.02	0.02	0.21
2007	0.60	0.40	0.05	0.03	0.03	0.04	0.17	0.15	0.14	0.06	0.04	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.06	0.02	0.19
2008	1.57	0.53	0.35	0.04	0.03	0.03	0.03	0.16	0.14	0.13	0.05	0.03	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.05	0.18
2009	4.04	1.41	0.48	0.32	0.04	0.03	0.02	0.03	0.13	0.12	0.11	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.19
2010	0.65	3.61	1.26	0.43	0.28	0.03	0.02	0.02	0.02	0.11	0.09	0.09	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.00	0.15
2011	0.55	0.58	3.22	1.12	0.38	0.25	0.03	0.02	0.02	0.02	0.09	0.08	0.07	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.13
2012	0.35	0.49	0.52	2.88	1.00	0.34	0.22	0.03	0.02	0.01	0.02	0.08	0.06	0.06	0.02	0.01	0.01	0.01	0.01	0.00	0.10
2013	0.42	0.32	0.44	0.46	2.57	0.89	0.30	0.19	0.02	0.01	0.01	0.01	0.06	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.08

Table 5.20. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the 2011 assessment) for BSAI Greenland turbot, 1960-2015. 2013 through 2015 biomass estimates are from the projection Model 1.

				Female Spawning Biomass		Total Age 1+ Biomass	
	Apical Fishing	Total		2012	Current	2012	Current
Year	Mortality	Exploitation	1-SPR.	Assessment	Assessment	Assessment	Assessment
1960	0.32	0.16	0.80	110,445	94,542	199,834	171,303
1961	0.67	0.30	0.94	101,477	84,439	174,641	145,232
1962	1.12	0.42	0.98	84,028	66,012	133,674	104,428
1963	0.99	0.29	0.97	62,757	43,627	91,748	80,997
1964	0.92	0.29	0.97	49,586	30,276	69,827	87,245
1965	0.12	0.05	0.51	33,763	21,712	45,929	155,246
1966	0.08	0.04	0.37	28,992	22,831	55,366	271,766
1967	0.09	0.05	0.41	23,570	36,679	71,949	401,567
1968	0.10	0.05	0.43	19,240	84,536	145,167	520,367
1969	0.08	0.04	0.38	19,164	166,810	239,545	614,757
1970	0.05	0.03	0.27	33,366	258,212	338,440	685,939
1971	0.10	0.06	0.45	82,282	338,662	435,861	740,738
1972	0.19	0.10	0.65	155,330	389,705	493,857	751,827
1973	0.17	0.09	0.61	214,251	404,040	492,438	708,598
1974	0.23	0.12	0.70	253,256	403,455	480,773	662,466
1975	0.23	0.11	0.70	261,445	381,524	436,632	591,356
1976	0.24	0.12	0.72	253,606	353,243	396,175	527,117
1977	0.13	0.06	0.53	234,214	319,958	356,064	465,802
1978	0.20	0.09	0.66	224,680	299,238	358,135	446,800
1979	0.21	0.10	0.67	207,496	270,484	354,747	423,287
1980	0.28	0.13	0.76	194,380	244,497	352,956	403,625
1981	0.34	0.15	0.81	183,775	220,159	341,241	376,333
1982	0.34	0.15	0.81	176,013	200,503	320,126	343,016
1983	0.34	0.15	0.82	171,046	186,598	296,950	310,985
1984	0.18	0.08	0.63	165,230	173,834	270,387	278,406
1985	0.12	0.06	0.49	167,996	171,526	261,427	265,156
1986	0.08	0.04	0.38	171,438	171,281	255,657	256,367
1987	0.08	0.04	0.38	173,465	170,794	250,514	249,175
1988	0.06	0.03	0.31	171,754	167,626	242,842	240,154
1989	0.12	0.04	0.31	168,124	163,217	235,214	231,629
1990	0.19	0.06	0.43	160,849	155,369	224,057	219,865
1991	0.12	0.04	0.33	149,935	144,028	207,457	202,935
1992	0.04	0.02	0.19	141,323	135,669	195,665	191,211
1993	0.08	0.05	0.35	134,597	128,585	187,959	182,668
1994	0.18	0.06	0.45	123,962	117,791	175,370	169,462
1995	0.14	0.05	0.41	113,408	106,737	160,272	153,775
1996	0.10	0.05	0.36	104,164	97,356	146,807	140,300
1997	0.10	0.06	0.40	95,928	89,119	134,972	128,653
1998	0.14	0.08	0.47	87,007	80,376	122,644	116,596
1999	0.12	0.06	0.41	76,667	70,611	108,715	103,361
2000	0.16	0.07	0.47	68,949	63,302	98,258	93,242
2001	0.15	0.06	0.45	60,598	55,378	87,227	82,613
2002	0.11	0.05	0.37	53,933	49,071	78,548	74,315
2003	0.11	0.05	0.39	48,669	44,131	72,508	68,560
2004	0.08	0.04	0.31	43,867	39,615	67,598	63,713
2005	0.10	0.04	0.37	40,576	36,640	64,526	60,709
2006	0.07	0.03	0.32	37,634	33,872	61,263	57,441
2007	0.07	0.04	0.34	35,836	32,136	58,784	54,983
2008	0.14	0.06	0.46	34,473	30,806	56,380	52,666
2009	0.23	0.09	0.60	32,826	29,176	53,738	49,983
2010	0.21	0.09	0.59	30,121	26,531	51,507	47,577
2011	0.20	0.08	0.58	27,263	23,797	52,610	48,189
2012	0.29	0.09	0.67	25,143	21,647	68,574	54,380
2013	0.09	0.02	0.37	23,485	20,006	80,989	**72,376**
2014					**22,010**		**84,546**
2015					**27,624**		**96,298**

Table 5.21. Spawning biomass with lower (LCI) and upper (UCI) 95% confidence intervals for 1977-2014for BSAI Greenland turbot. Confidence bounds are based on 1.96×standard error. 2013 and 2014 values are from the production model.

Year	Spawning Biomass	LCI	UCI
1977	319,960	279,080	360,840
1978	299,240	260,312	338,168
1979	270,480	233,875	307,085
1980	244,500	210,451	278,549
1981	220,160	189,004	251,316
1982	200,500	172,121	228,879
1983	186,600	160,360	212,840
1984	173,830	149,230	198,430
1985	171,530	148,163	194,897
1986	171,280	149,026	193,534
1987	170,790	149,585	191,995
1988	167,630	147,456	187,804
1989	163,220	144,077	182,363
1990	155,370	137,370	173,370
1991	144,030	127,189	160,871
1992	135,670	119,825	151,515
1993	128,590	113,805	143,375
1994	117,790	104,020	131,560
1995	106,740	93,922	119,558
1996	97,356	85,384	109,328
1997	89,119	77,921	100,317
1998	80,376	69,908	90,844
1999	70,611	60,842	80,380
2000	63,302	54,191	72,413
2001	55,378	46,888	63,868
2002	49,071	41,158	56,984
2003	44,130	36,751	51,509
2004	39,615	32,724	46,506
2005	36,640	30,162	43,118
2006	33,872	27,775	39,969
2007	32,136	26,354	37,918
2008	30,806	25,292	36,320
2009	29,176	23,911	34,441
2010	26,531	21,493	31,569
2011	23,796	18,988	28,604
2012	21,647	17,033	26,261
2013	20,008	15,469	24,547
2014	22,459	17,694	27,224

Table 5.22. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot from the 2011 stock assessment (Ianelli et al. 2011) and for the 2012 Model 2.

	Mid-year length (cm)				Mid-year weight (kg)			
	2012 Reference		2013 Model 1		2012 Reference		2013 Model 1	
Age	Females	Males	Females	Males	Females	Males	Females	Males
1	13.70	13.64	14.29	14.16	0.02	0.02	0.02	0.02
2	21.94	22.34	22.06	22.21	0.08	0.08	0.08	0.08
3	30.27	30.74	29.87	30.02	0.22	0.22	0.21	0.21
4	37.61	37.75	36.82	36.67	0.45	0.43	0.42	0.40
5	44.09	43.61	42.99	42.33	0.77	0.69	0.71	0.63
6	49.80	48.51	48.48	47.15	1.15	0.97	1.05	0.89
7	54.84	52.60	53.36	51.25	1.58	1.25	1.44	1.16
8	59.29	56.02	57.71	54.74	2.04	1.53	1.87	1.43
9	63.21	58.87	61.57	57.72	2.52	1.80	2.31	1.69
10	66.67	61.26	65.00	60.25	3.00	2.04	2.76	1.93
11	69.72	63.25	68.05	62.40	3.47	2.25	3.21	2.16
12	72.41	64.92	70.77	64.23	3.92	2.44	3.66	2.37
13	74.78	66.31	73.18	65.79	4.36	2.61	4.08	2.55
14	76.88	67.48	75.33	67.12	4.76	2.75	4.49	2.72
15	78.72	68.45	77.23	68.25	5.14	2.88	4.88	2.86
16	80.35	69.26	78.93	69.22	5.48	2.98	5.24	2.99
17	81.79	69.94	80.44	70.04	5.80	3.07	5.57	3.10
18	83.06	70.50	81.78	70.73	6.08	3.15	5.87	3.20
19	84.17	70.98	82.97	71.33	6.34	3.21	6.16	3.28
20	85.16	71.37	84.03	71.83	6.57	3.26	6.41	3.35
21	86.03	71.70	84.98	72.26	6.77	3.31	6.64	3.41
22	86.80	71.98	85.82	72.63	6.95	3.34	6.85	3.46
23	87.47	72.21	86.56	72.94	7.12	3.37	7.04	3.50
24	88.07	72.40	87.22	73.21	7.26	3.39	7.21	3.53
25	88.60	72.56	87.81	73.43	7.39	3.41	7.37	3.57
26	89.06	72.70	88.34	73.63	7.51	3.44	7.51	3.60
27	89.47	72.81	88.80	73.79	7.61	3.45	7.64	3.62
28	89.83	72.91	89.22	73.93	7.70	3.47	7.75	3.65
29	90.15	72.98	89.59	74.05	7.78	3.48	7.85	3.66
30	90.74	73.10	90.31	74.23	7.92	3.50	8.05	3.69

Table 5.23. Estimated total Greenland turbot harvest by area, 1977-2013. Values for 2013 are through Oct. 18th, 2013 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	2,539	1,006
1985	14,698	33	2004	1,825	434
1986	7,710	2,154	2005	2,140	468
1987	6,519	3,066	2006	1,452	534
1988	6,064	1,044	2007	1,481	521
1989	4,061	4,761	2008	2,095	827
1990	7,702	2,494	2009	2,249	2,261
1991	4,398	3,465	2010	2,272	1,866
1992	2,462	1,290	2011	3,115	531
1993	6,331	2,137	2012	3,063	1,657
1994	7,141	3,131	2013*	1,112	300
1995	5,856	2,338			

Table 5.24. Mean spawning biomass, F, and yield projections for Greenland turbot, 2013-2026. 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**
2013	20,006	20,006	20,006	20,006	20,006	20,006	20,006
2014	22,010	22,010	22,010	22,010	22,010	22,010	22,010
2015	27,624	27,624	28,278	28,334	28,837	27,329	27,624
2016	36,120	36,120	37,769	37,884	38,923	35,492	36,120
2017	44,911	44,911	48,287	48,472	50,156	43,828	44,325
2018	51,958	51,958	57,808	58,083	60,602	50,197	50,621
2019	56,511	56,511	65,460	65,850	69,449	53,926	54,284
2020	58,616	58,616	71,202	71,732	76,659	55,112	55,410
2021	58,836	58,836	75,352	76,042	82,507	54,419	54,663
2022	57,823	57,823	78,255	79,117	87,260	52,600	52,797
2023	56,113	56,113	80,185	81,220	91,107	50,259	50,416
2024	54,083	54,083	81,344	82,548	94,176	47,796	47,919
2025	51,996	51,996	81,914	83,275	96,586	45,523	45,615
2026	50,048	50,048	82,062	83,564	98,462	43,654	43,720
F							
2013	0.11	0.11	0.11	0.11	0.11	0.11	0.11
2014	0.12	0.12	0.05	0.05	0.00	0.14	0.12
2015	0.15	0.15	0.05	0.05	0.00	0.18	0.15
2016	0.20	0.20	0.05	0.05	0.00	0.24	0.25
2017	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2018	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2019	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2020	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2021	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2022	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2023	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2024	0.22	0.22	0.05	0.05	0.00	0.27	0.27
2025	0.22	0.22	0.05	0.05	0.00	0.26	0.26
2026	0.21	0.21	0.05	0.05	0.00	0.25	0.25
Catch							
2013	1,924	1,924	1,924	1,924	1,924	1,924	1,924
2014	2,124	2,124	975	876	0	2,647	2,124
2015	3,173	3,173	1,171	1,054	0	3,864	3,173
2016	5,268	5,268	1,505	1,356	0	6,317	6,555
2017	7,351	7,351	1,951	1,760	0	8,907	9,018
2018	8,874	8,874	2,438	2,201	0	10,643	10,740
2019	10,103	10,103	2,893	2,614	0	11,963	12,047
2020	10,869	10,869	3,267	2,957	0	12,673	12,745
2021	11,182	11,182	3,549	3,217	0	12,816	12,877
2022	11,151	11,151	3,746	3,402	0	12,560	12,610
2023	10,906	10,906	3,874	3,525	0	12,085	12,126
2024	10,552	10,552	3,950	3,602	0	11,415	11,453
2025	10,129	10,129	3,989	3,643	0	10,619	10,651
2026	9,633	9,633	4,001	3,660	0	9,934	9,958

Figures

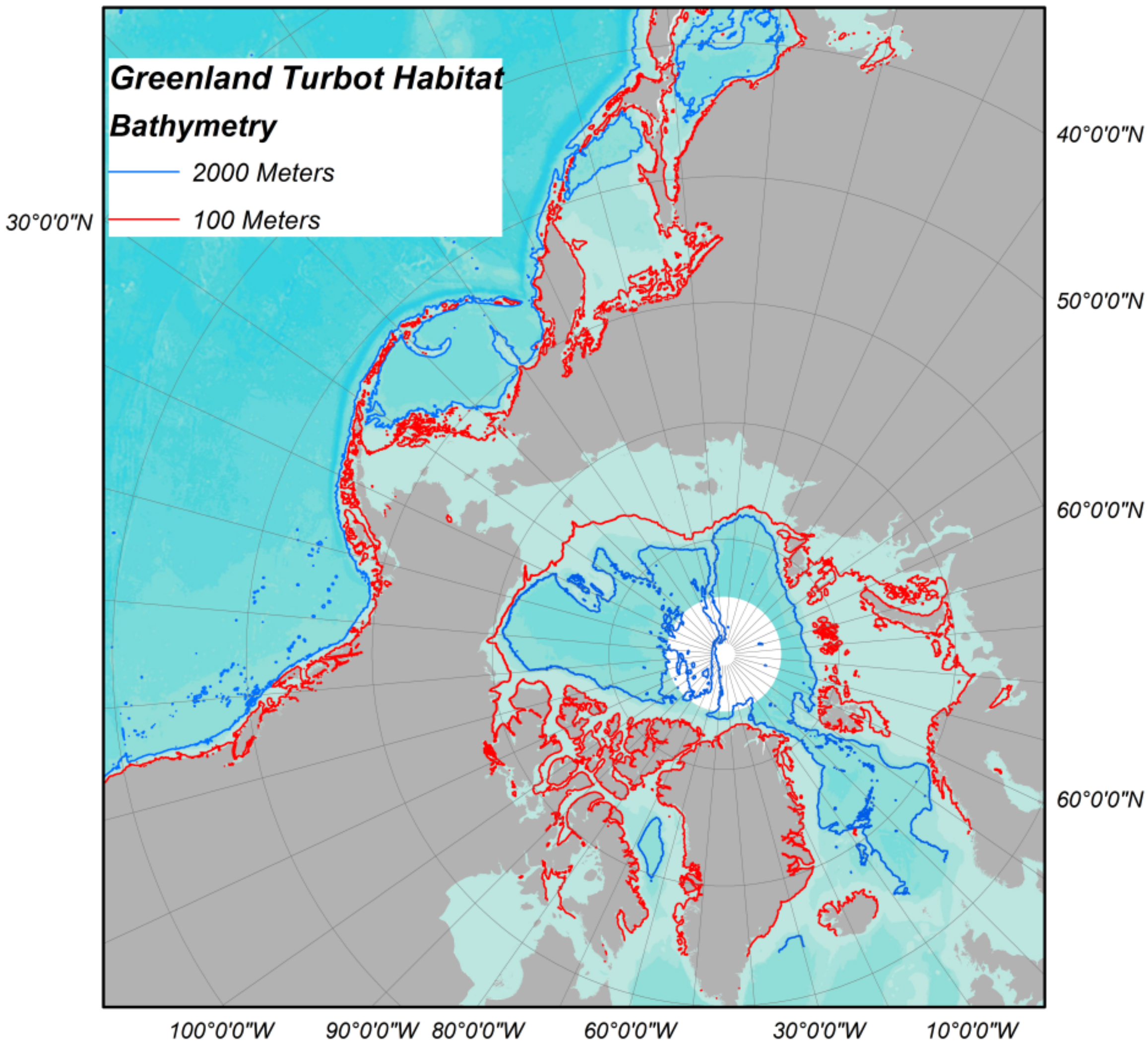
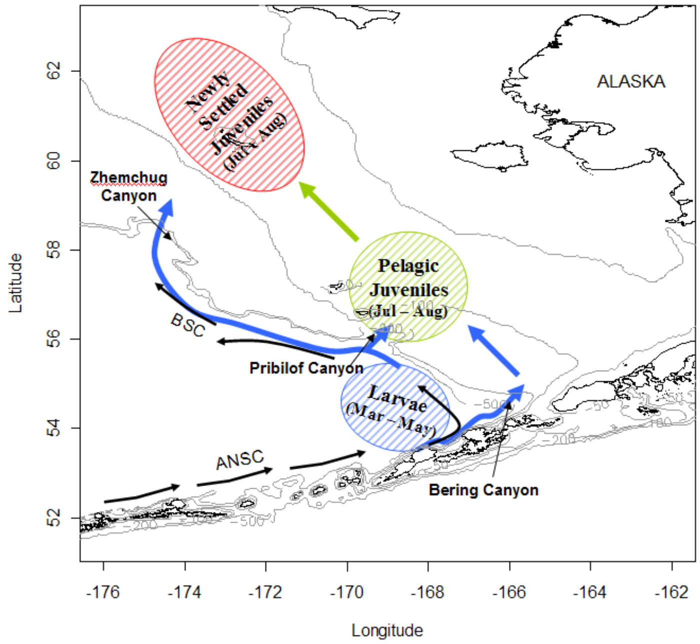


Figure 5.1. Map of the northern oceans with bathymetry at 100 meters (red) and 2000 meters (blue), possible Greenland turbot habitat.

(a)



(b)

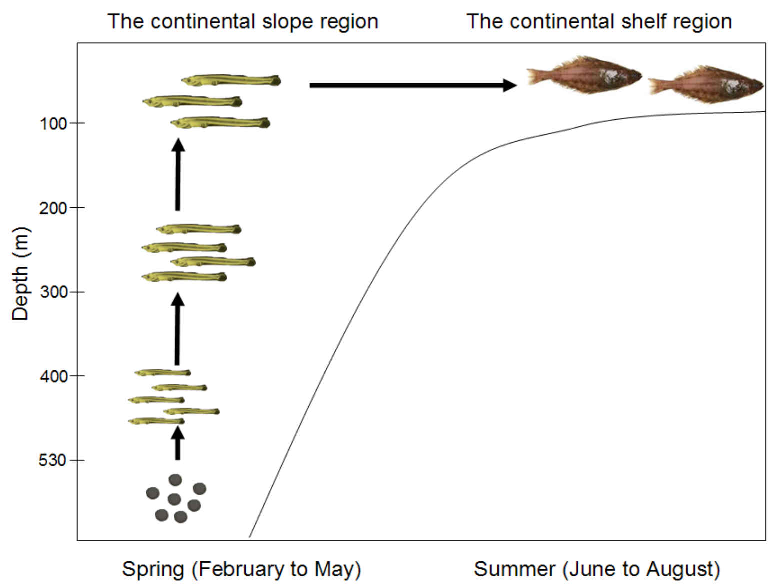


Figure 5.2. Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: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

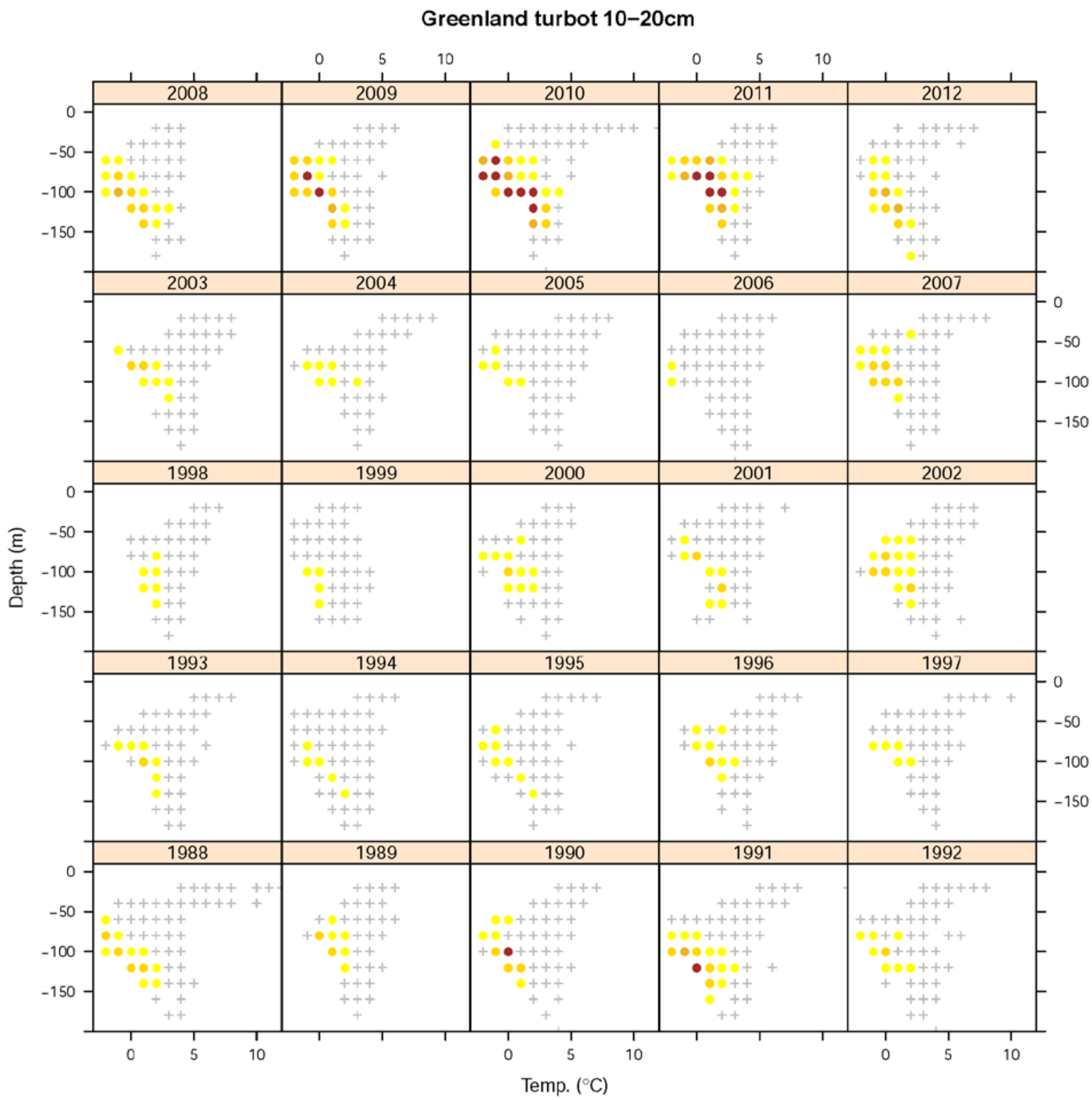


Figure 5.3. Greenland turbot (10-20 cm) density distribution by temperature and depth (left) for 1988 – 2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

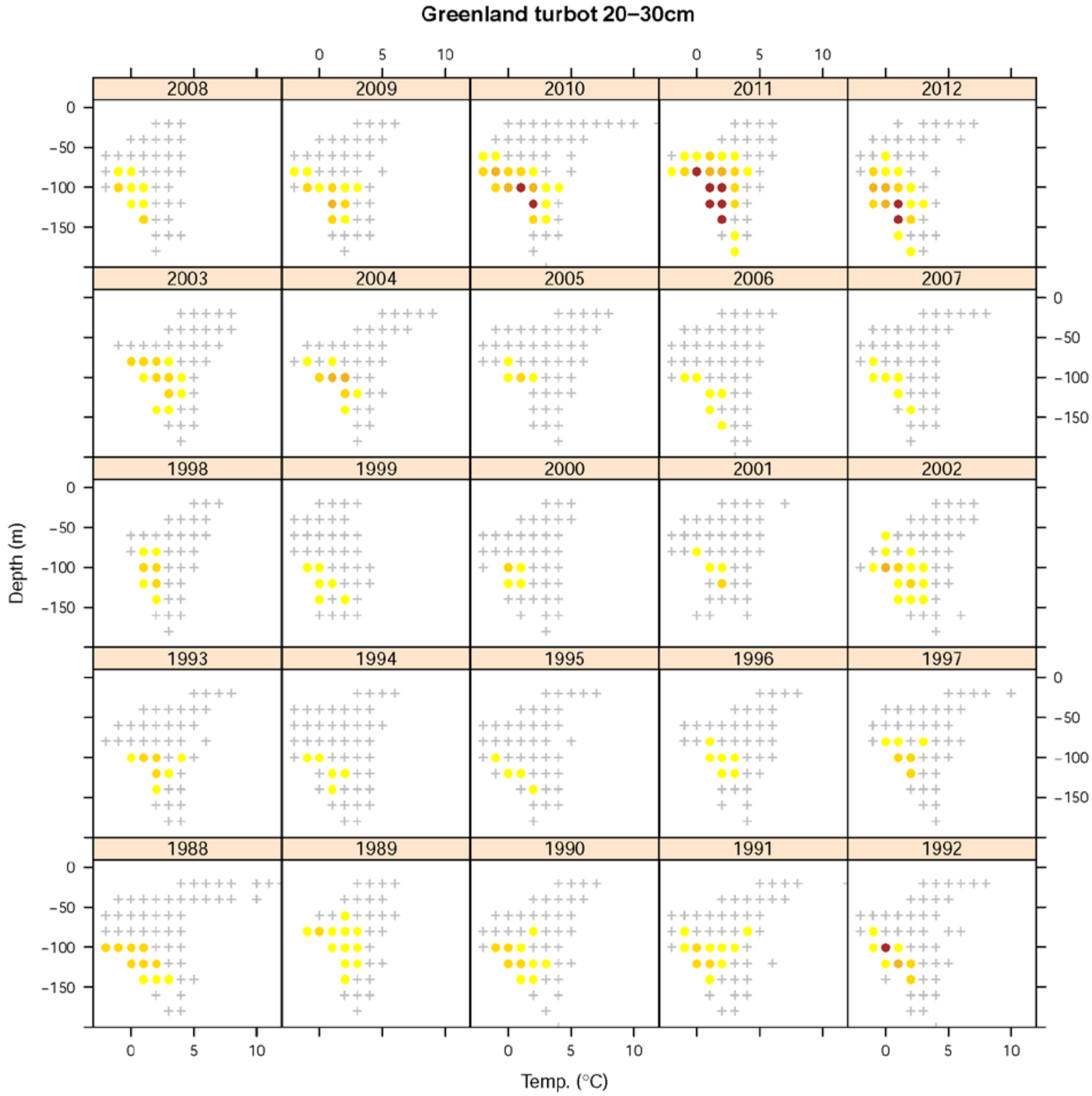


Figure 5.3.(Cont.) Greenland turbot (20-30 cm) density distribution by temperature and depth for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

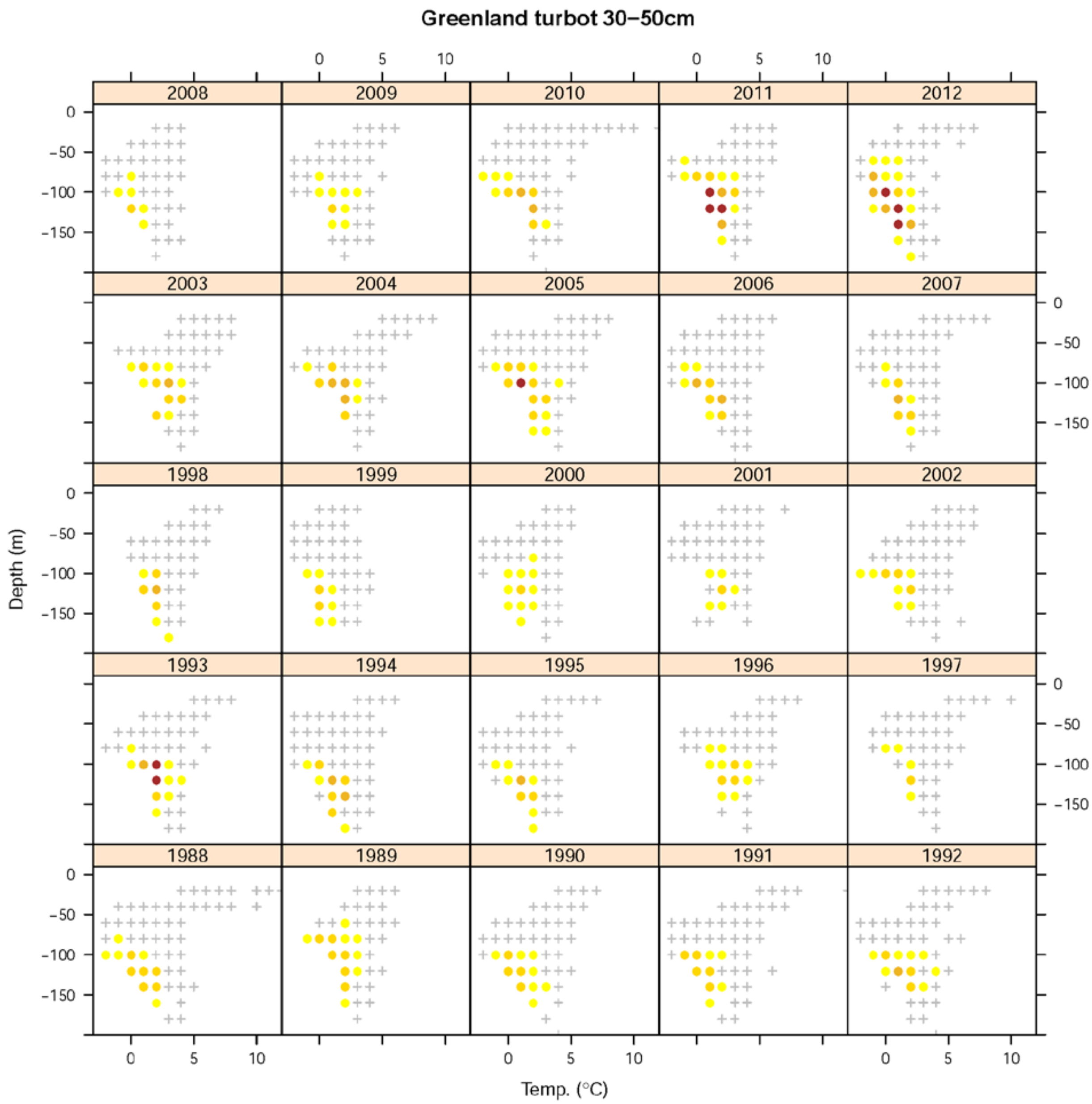


Figure 5.3.(Cont.) Greenland turbot (30-50 cm) density distribution by temperature and depth for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

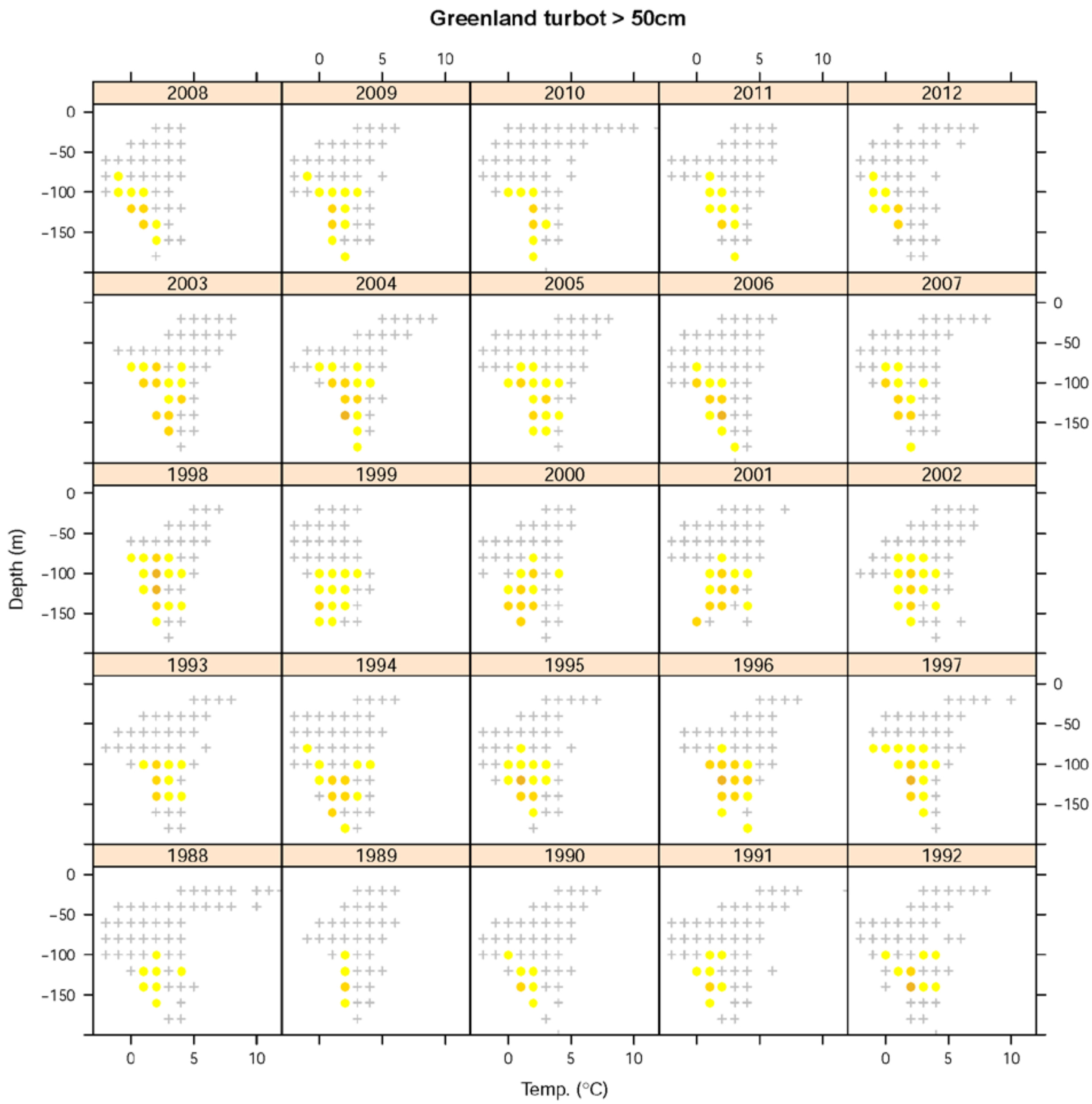


Figure 5.3.(Cont.) Greenland turbot (> 50 cm) density distribution by temperature and depth for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

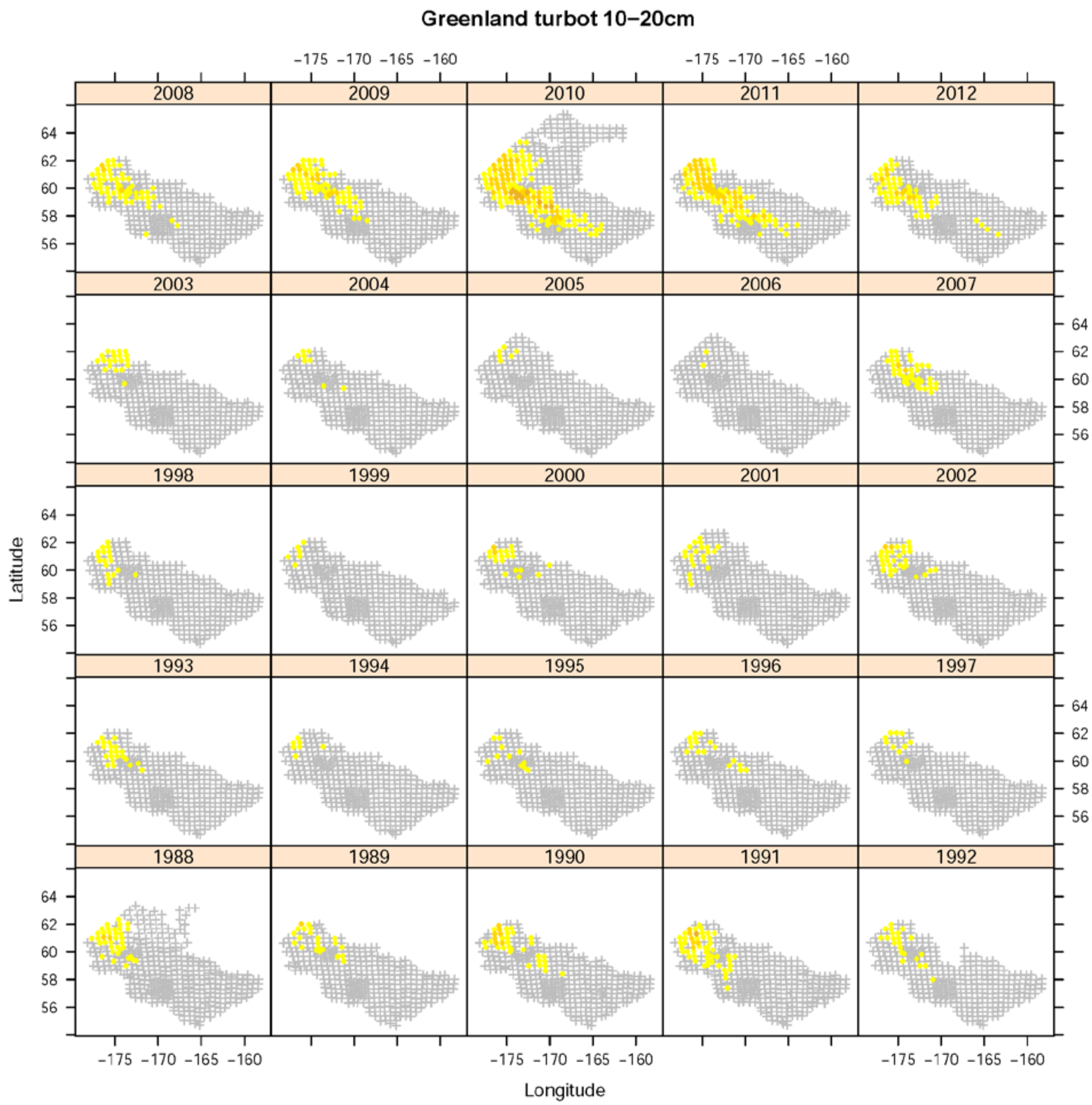


Figure 5.4. Greenland turbot (10-20 cm) density distribution by latitude and longitude for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

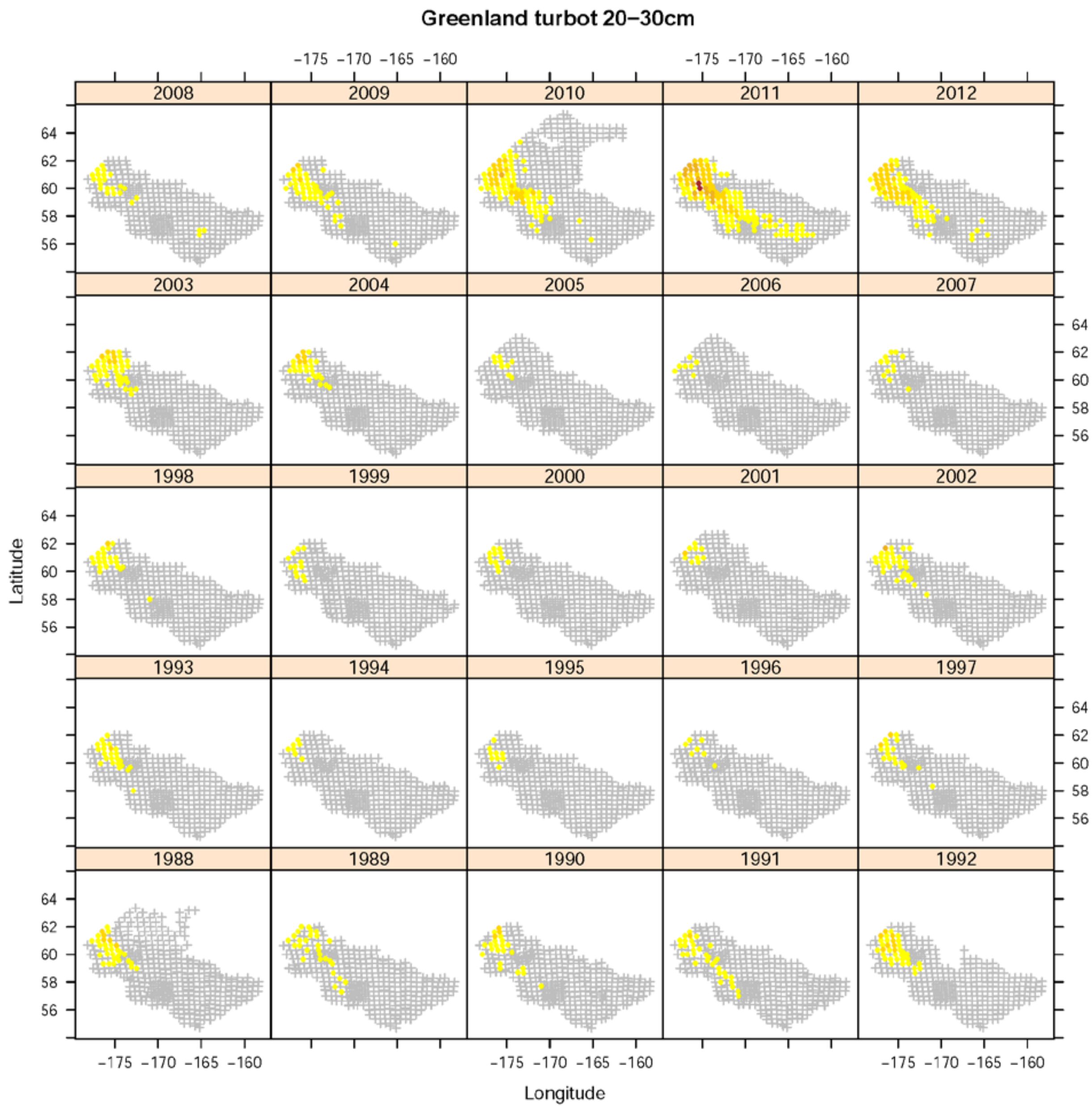


Figure 5.4.(Cont.) Greenland turbot (20-30 cm) density distribution by latitude and longitude for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

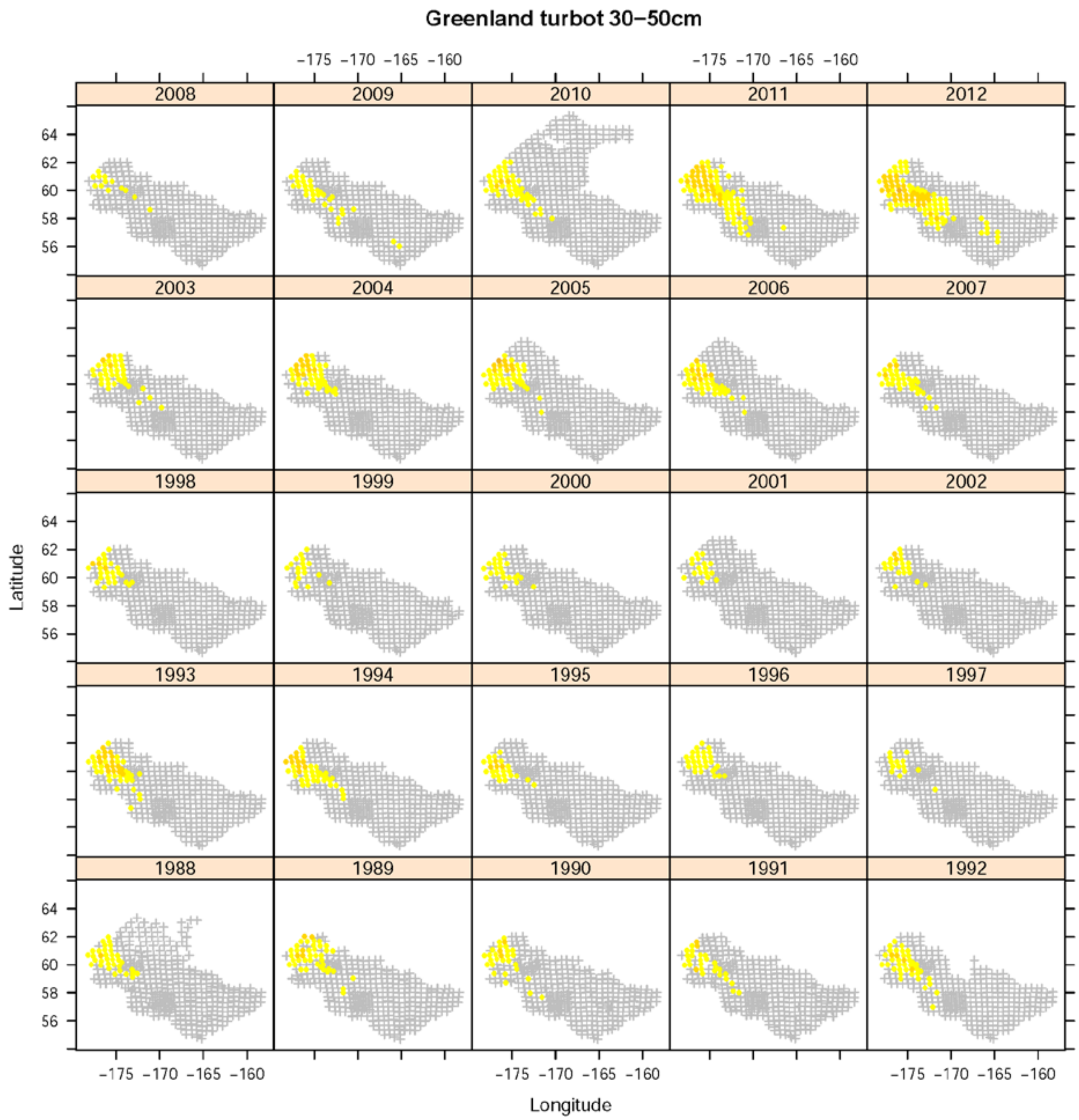


Figure 5.4.(Cont.) Greenland turbot (30-50 cm) density distribution by latitude and longitude for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

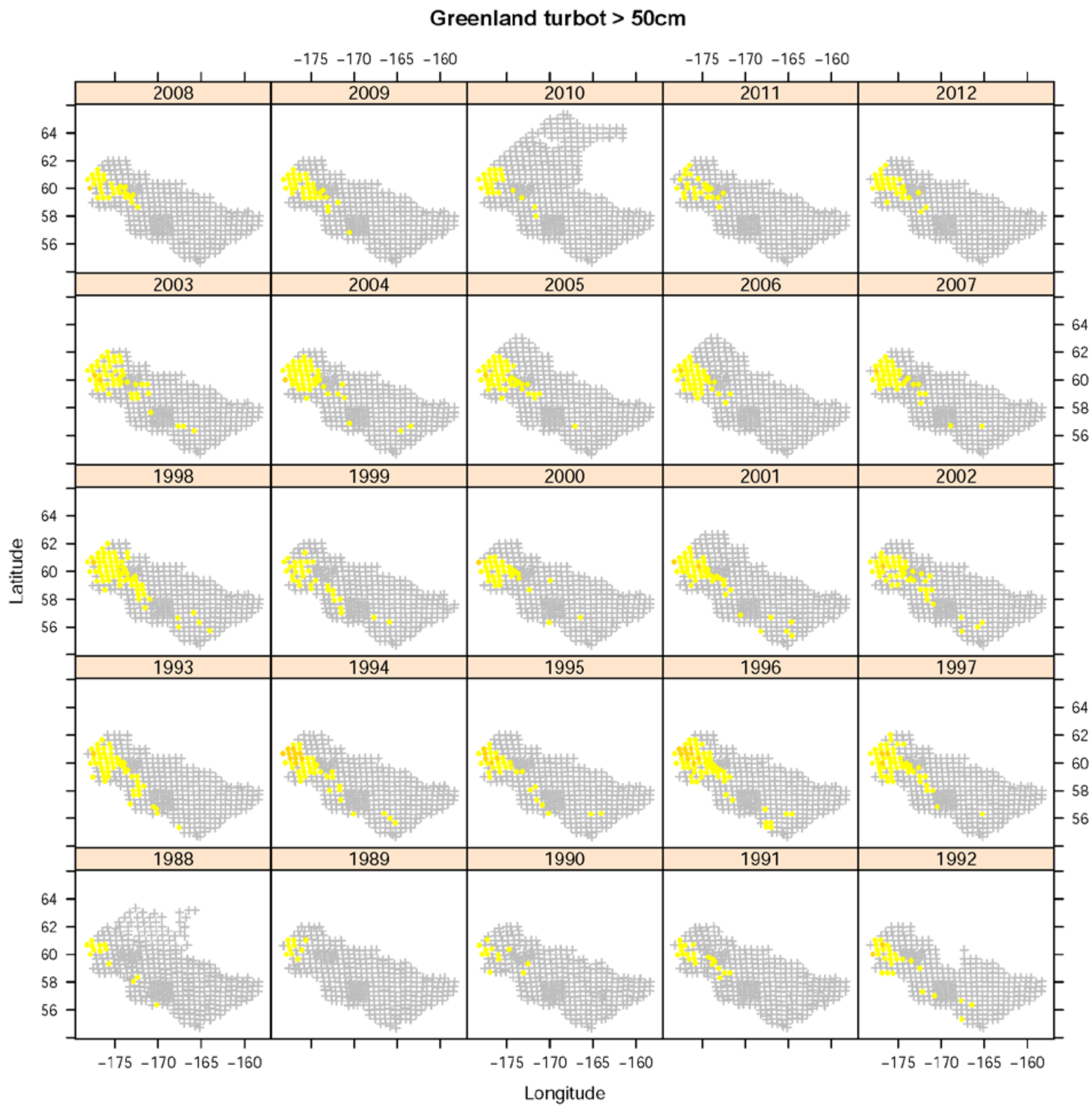


Figure 5.4.(Cont.) Greenland turbot (> 50 cm) density distribution by latitude and longitude for 1988-2012 shelf bottom trawl survey. Darker color indicates higher CPUE by number, gray are sampled locations with no catch.

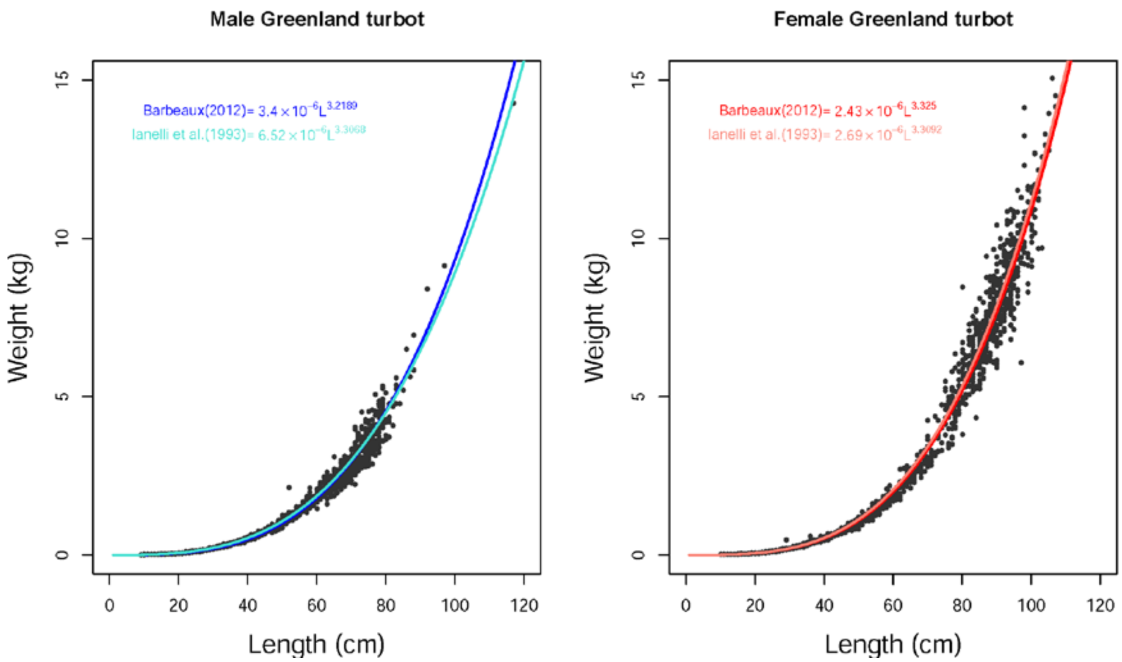


Figure 5. 5. Weight at length relationship for male and female Greenland turbot fit to all AFSC survey data from the Bering Sea and Aleutian Islands area. The weight at length relationships from Ianelli et al. (1993) are shown for comparison.

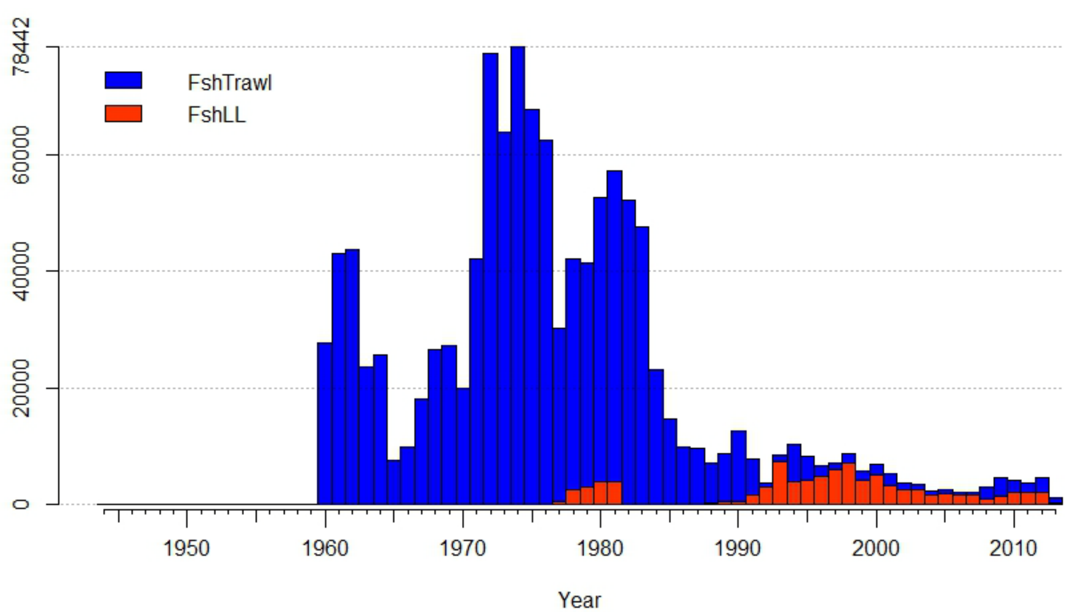
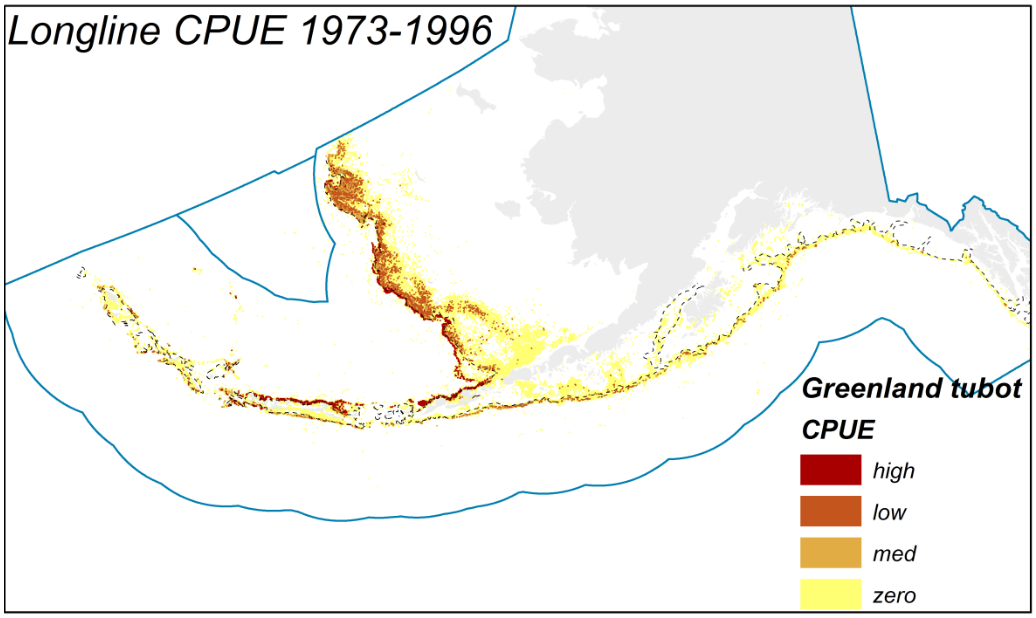


Figure 5. 6. Greenland turbot longline fishery (FshLL) and trawl (FshTrawl) catch in the Bering Sea and Aleutian Islands area from 1960 through 2011. This data includes targeted catch and bycatch.



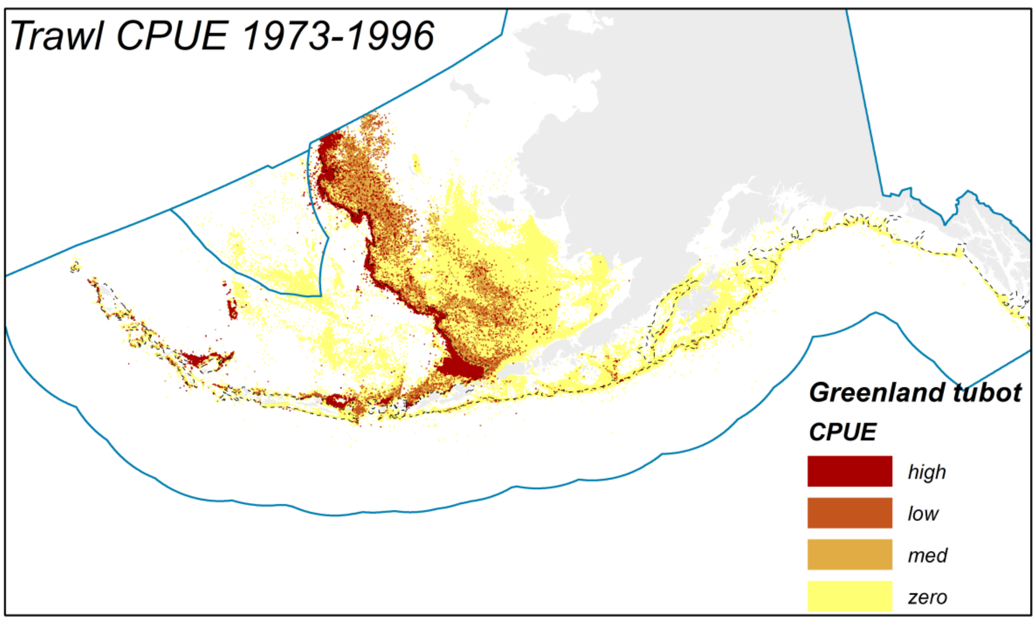


Figure 5.7. Distribution of Greenland turbot fishing CPUE 1973- 1996 from observer data (Fritz et al. 1998).

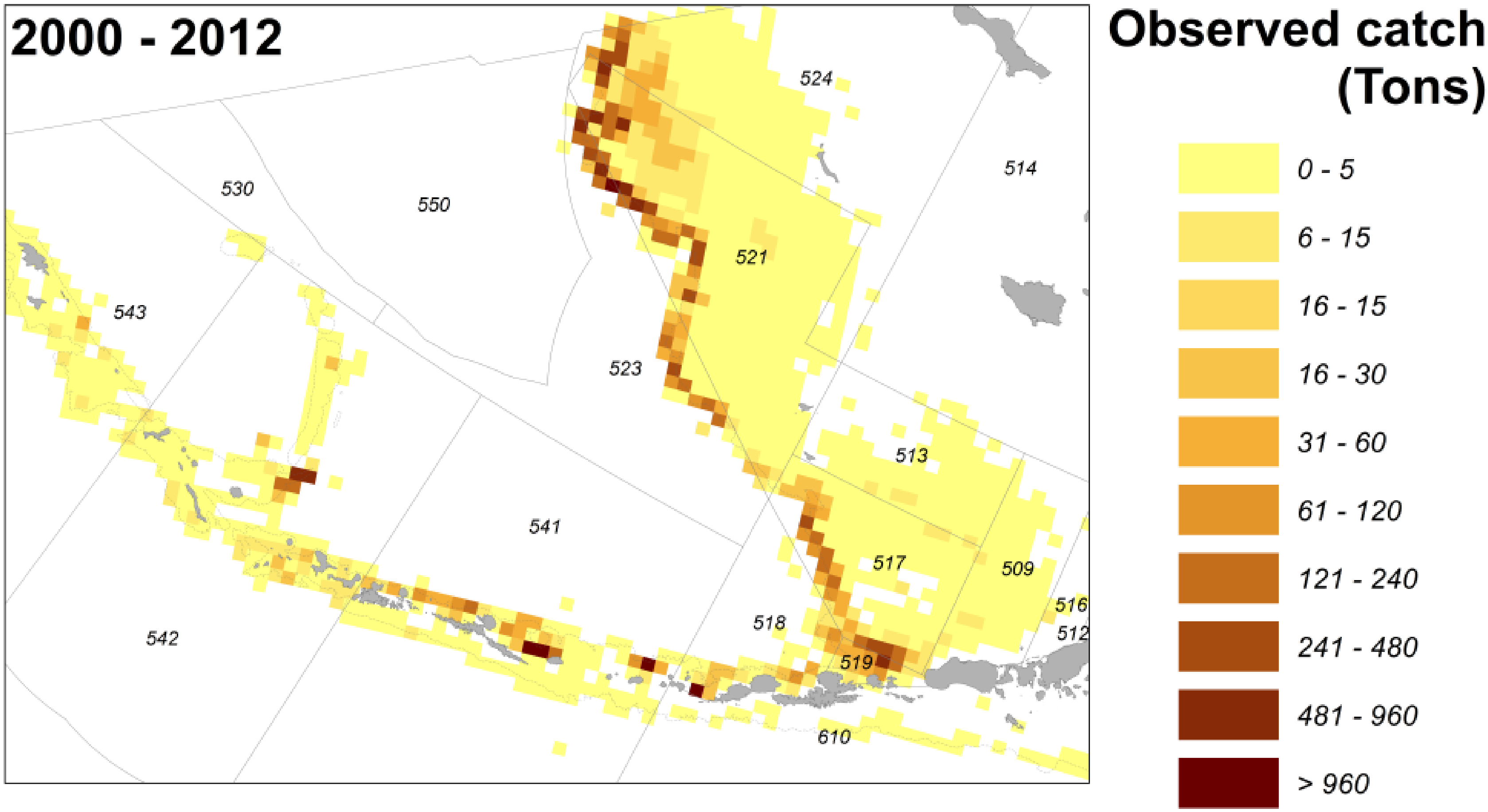


Figure 5.8 All observed catch for 2000 through 2012, data are aggregated spatially at a 400 km^2 grid.

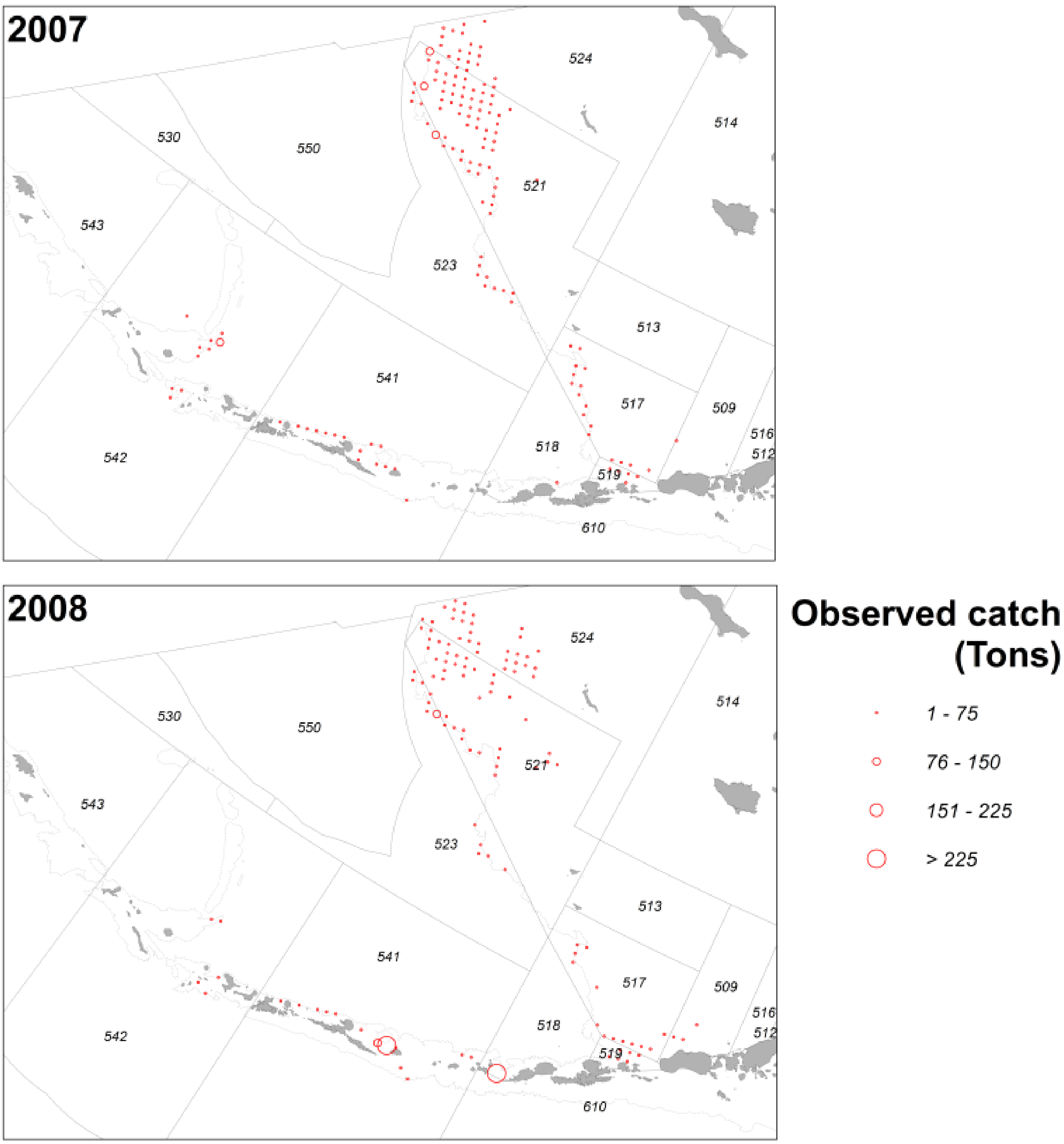


Figure 5.9. All observed Greenland turbot catch for 2007 and 2008. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

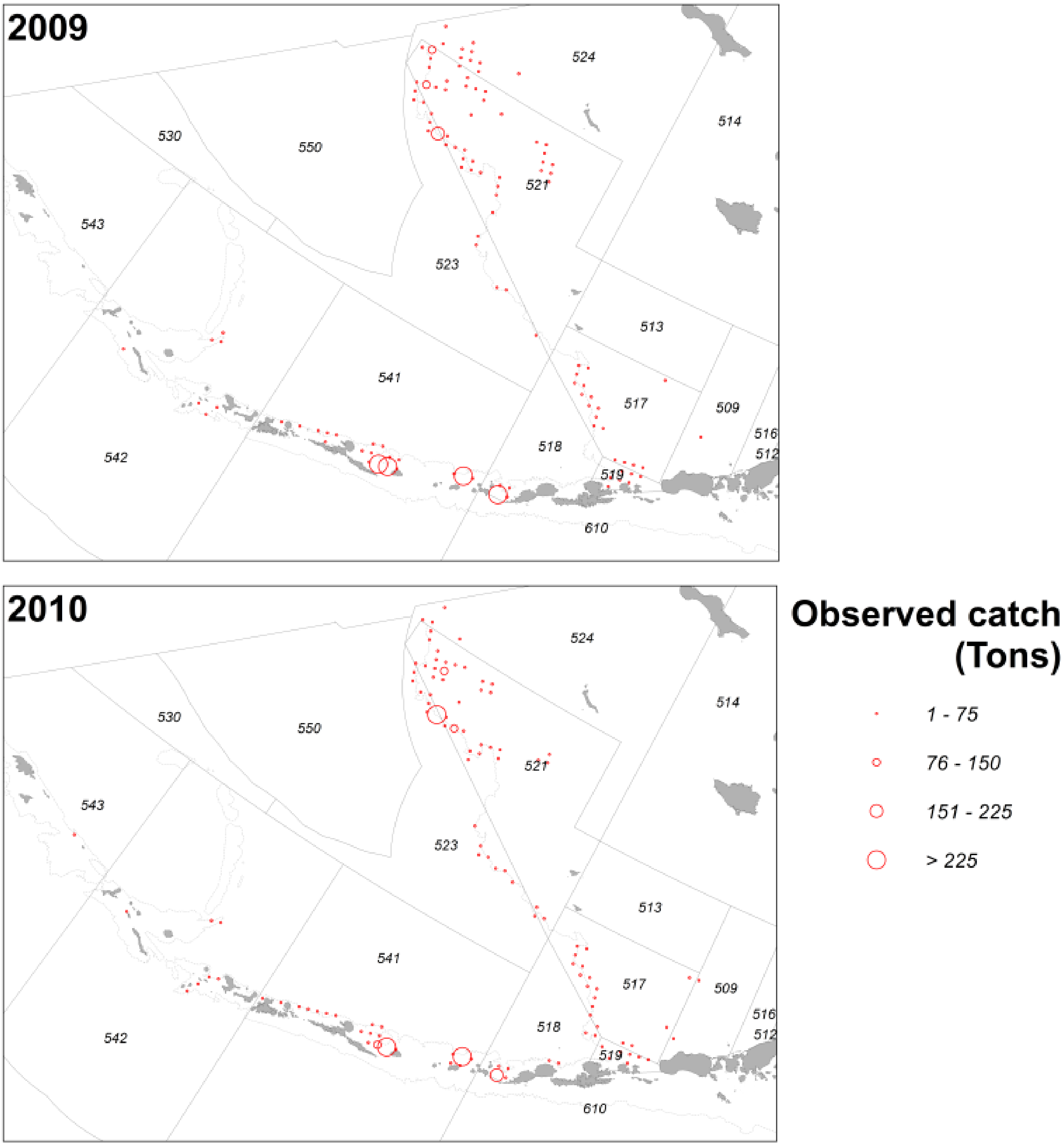


Figure 5.9.(cont.) All observed Greenland turbot catch for 2009 and 2010. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

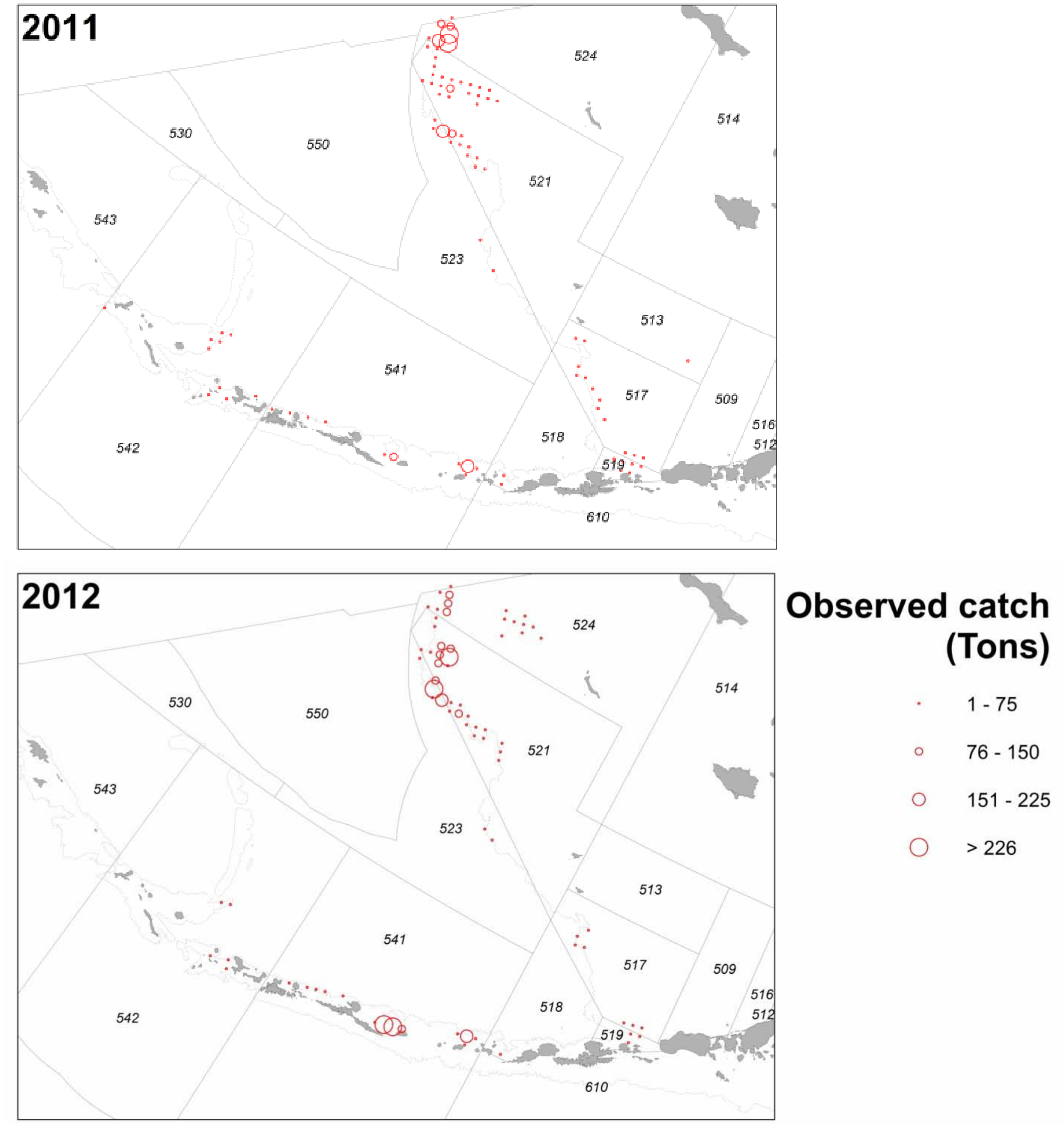


Figure 5.9.(cont.) All observed Greenland turbot catch for 2011and 2012. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

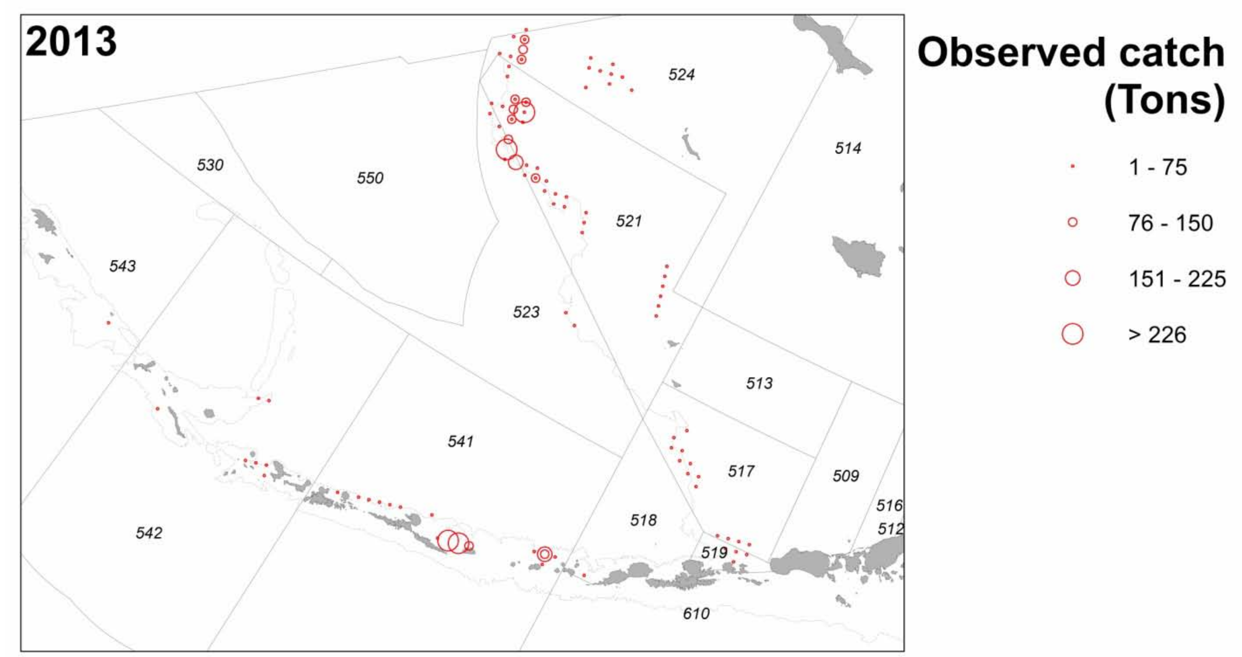


Figure 5.9.(cont.) All observed Greenland turbot catch for 2011and 2012. Data are aggregated for each year at 400 km^2. Note that areas with less than 1t are not shown.

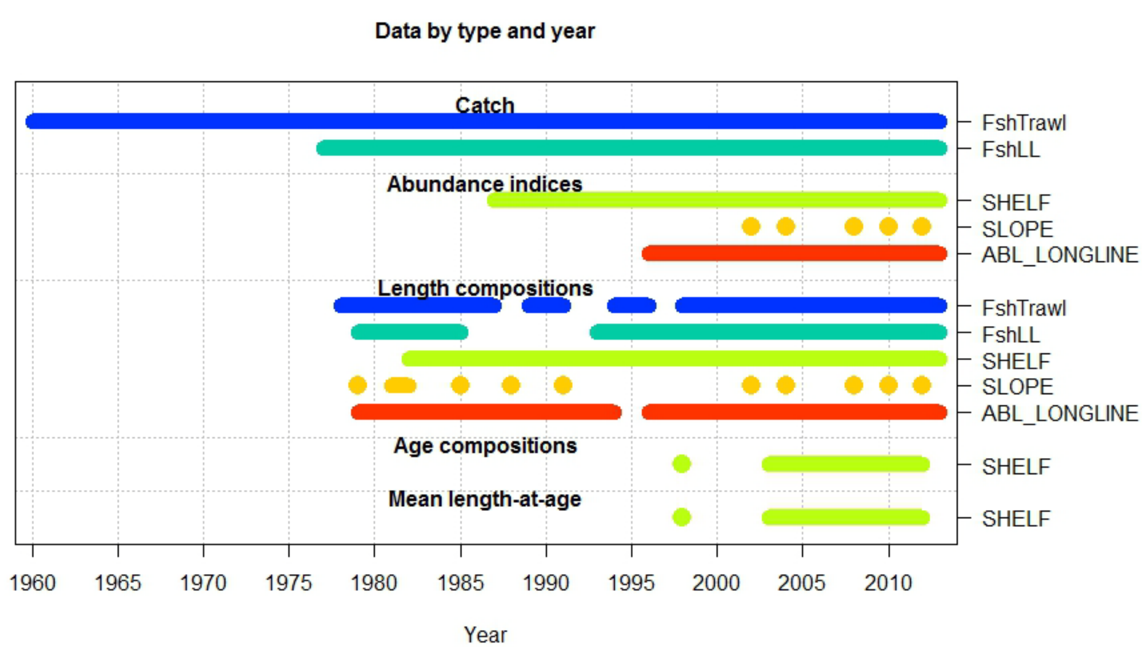


Figure 5.10. Timeline of all data included in the 2012 stock assessment models. Please note that Model 4 does not included data from prior to 1977.

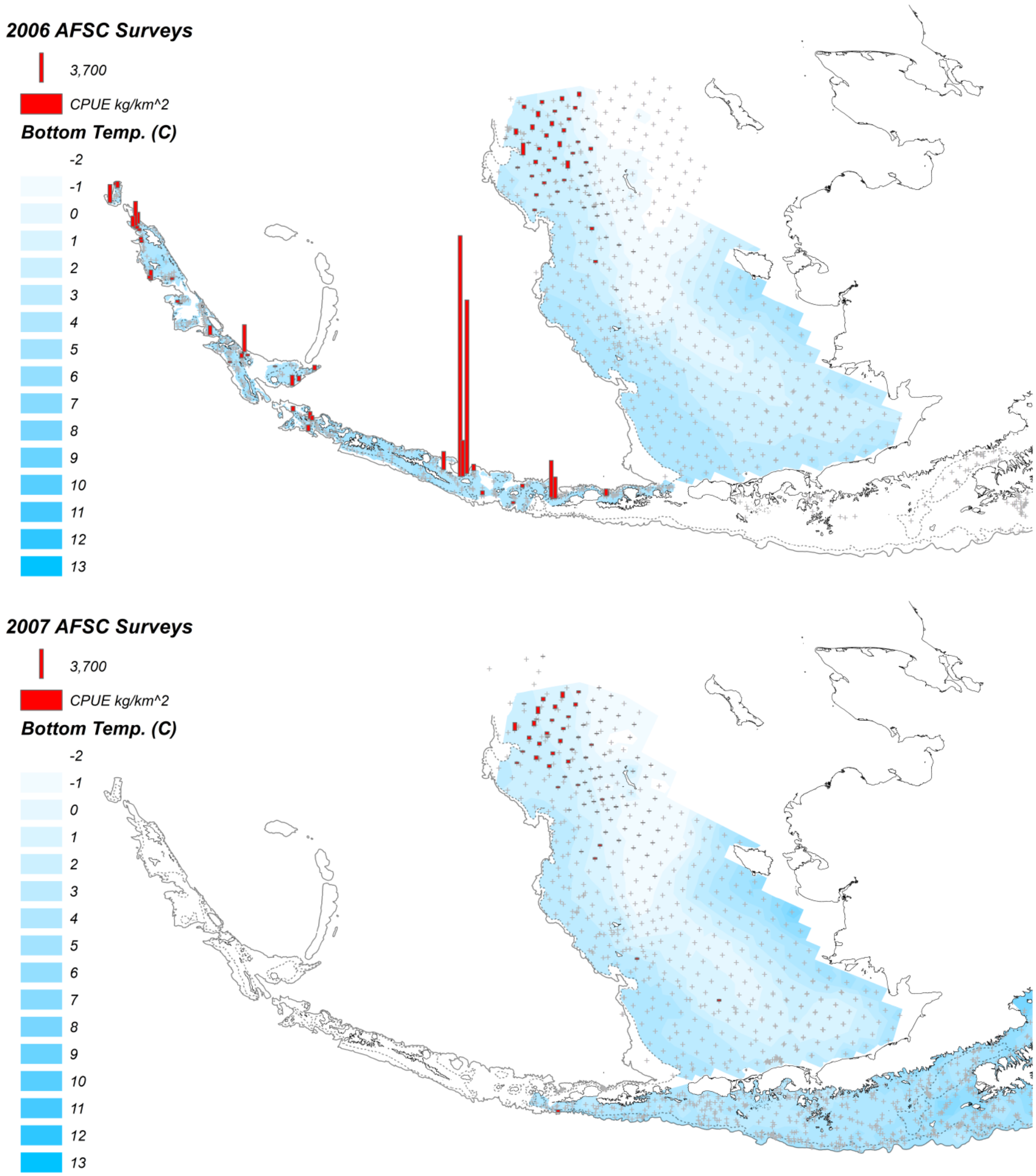
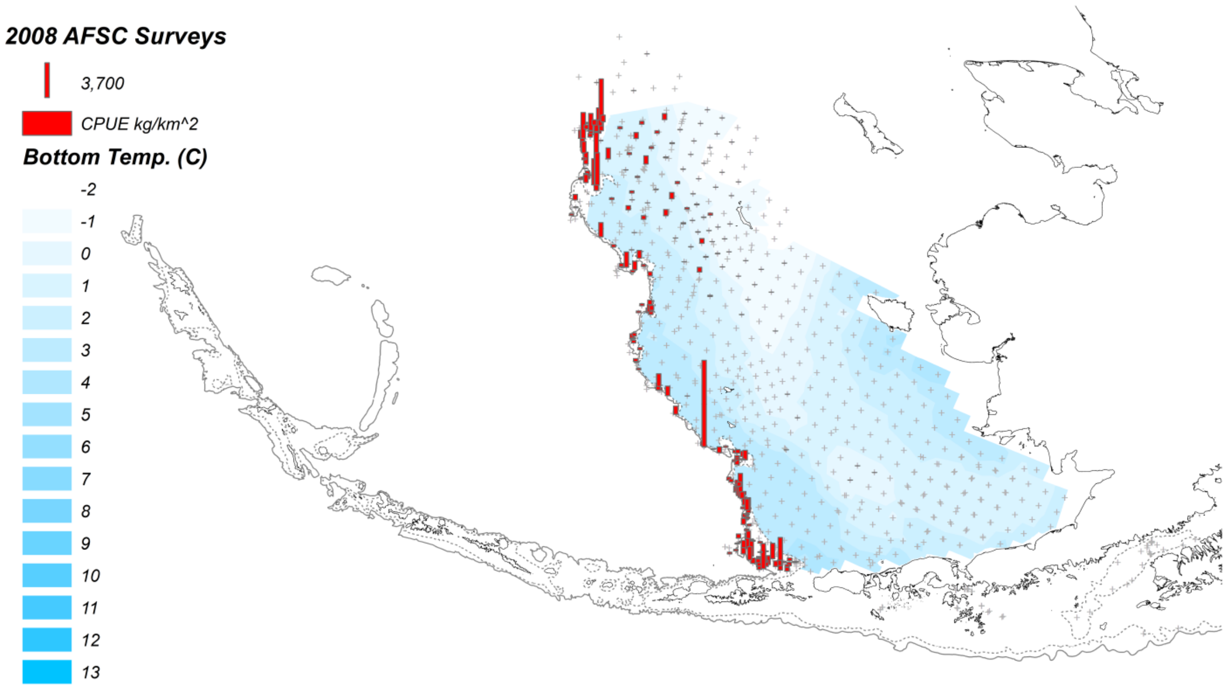


Figure 5.11. Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are maked with red bars.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



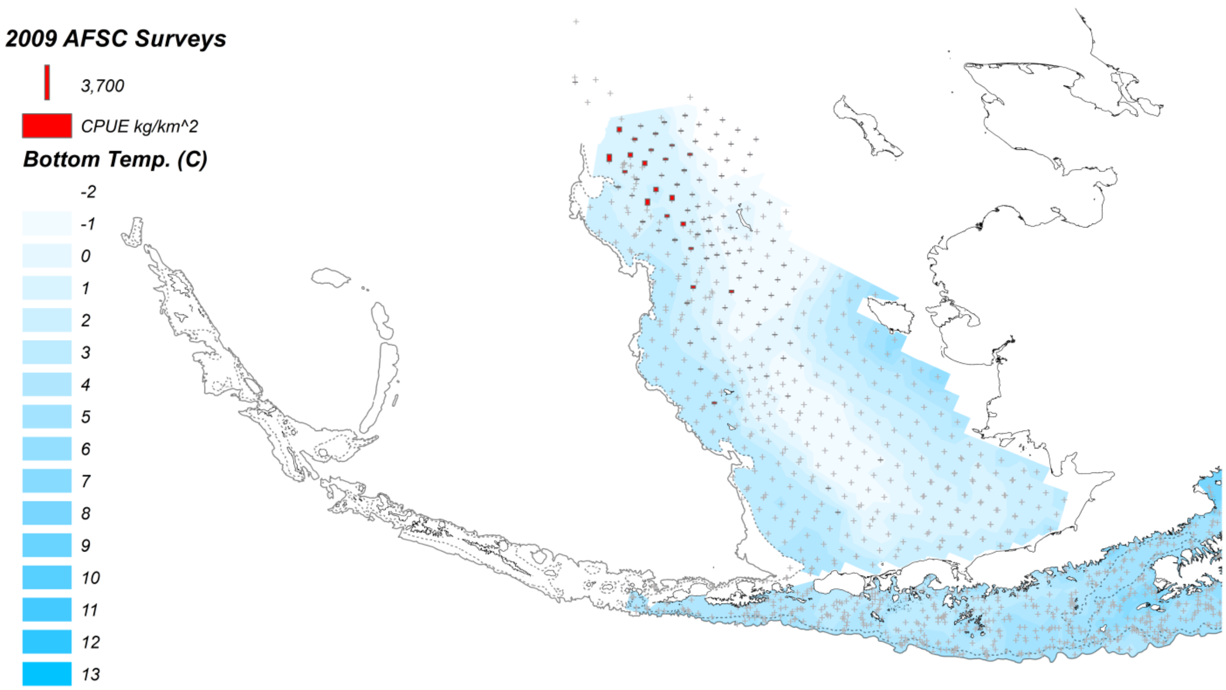


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are maked with red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

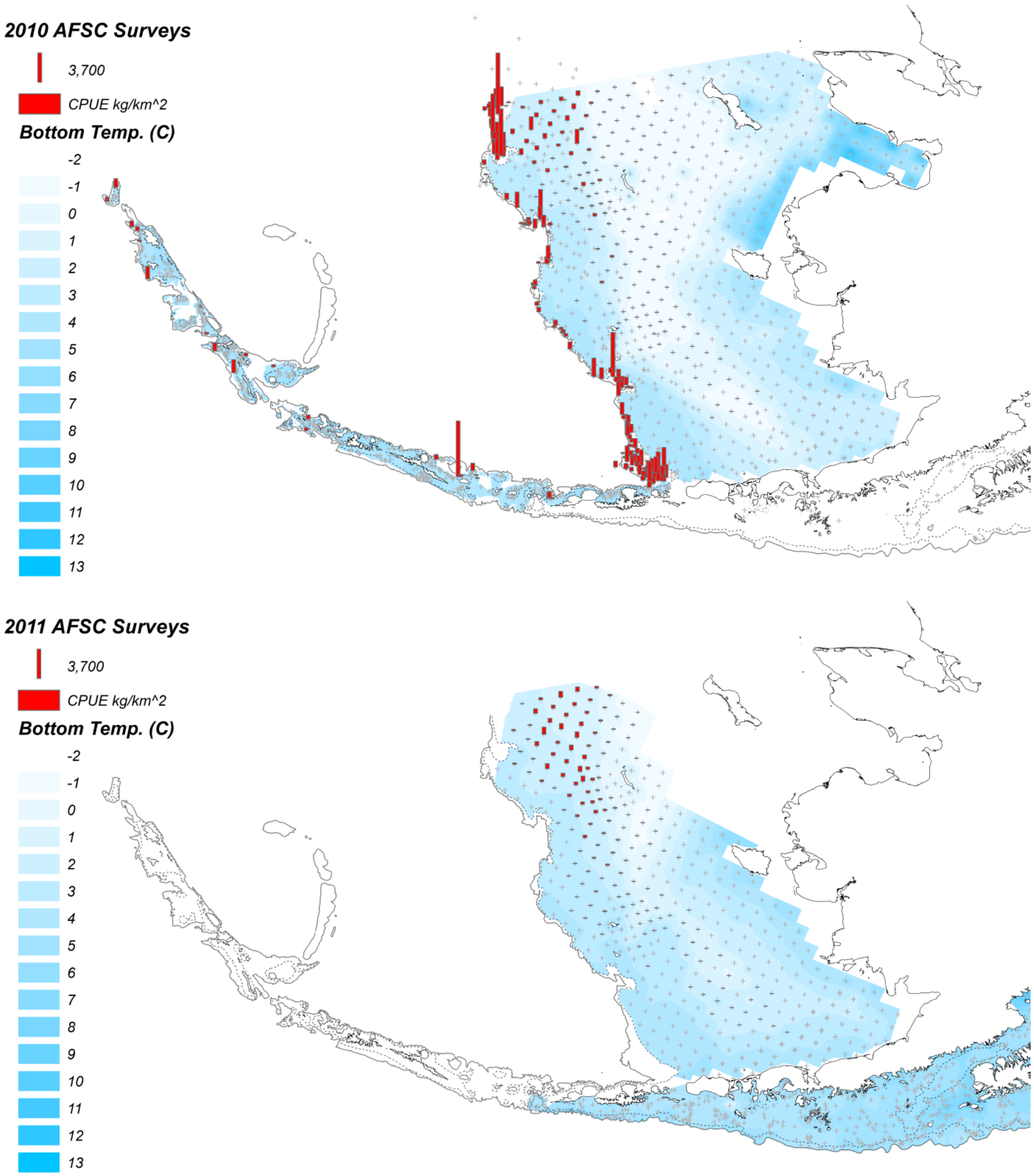
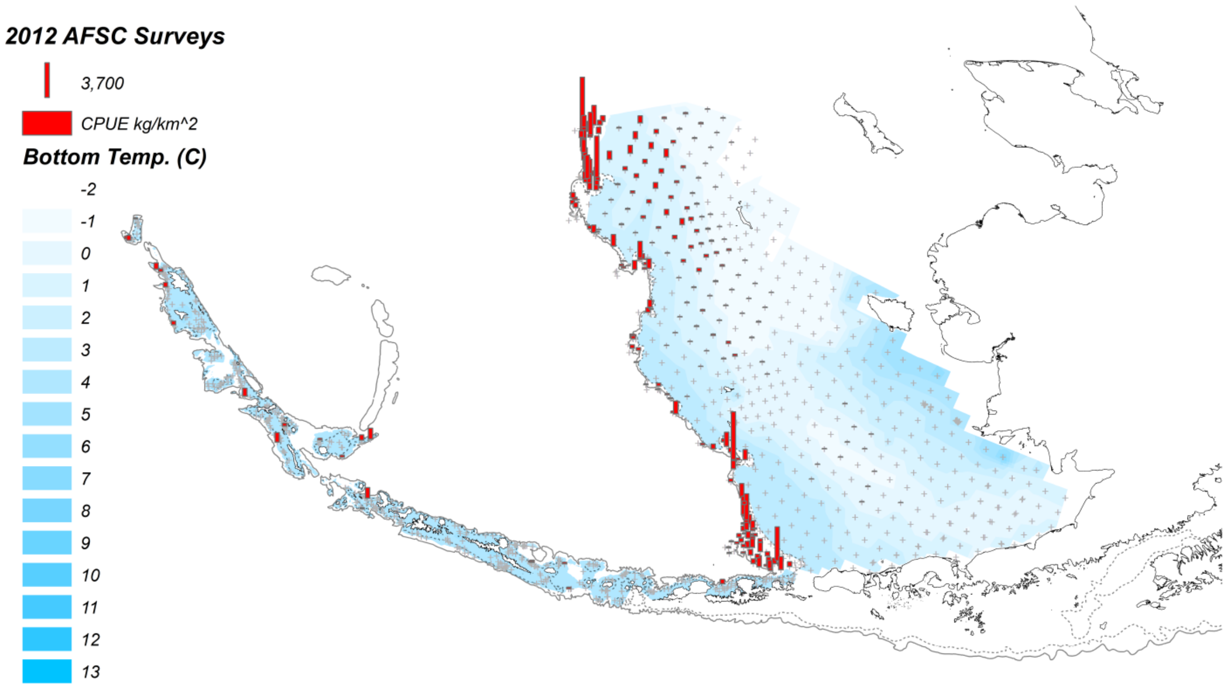


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year with bottom temperature in celcius and 200m (dashed line) and 1000 m (solid gray line) isobaths. Surveyed locations are marked with gray +, while areas with turbot are maked with red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



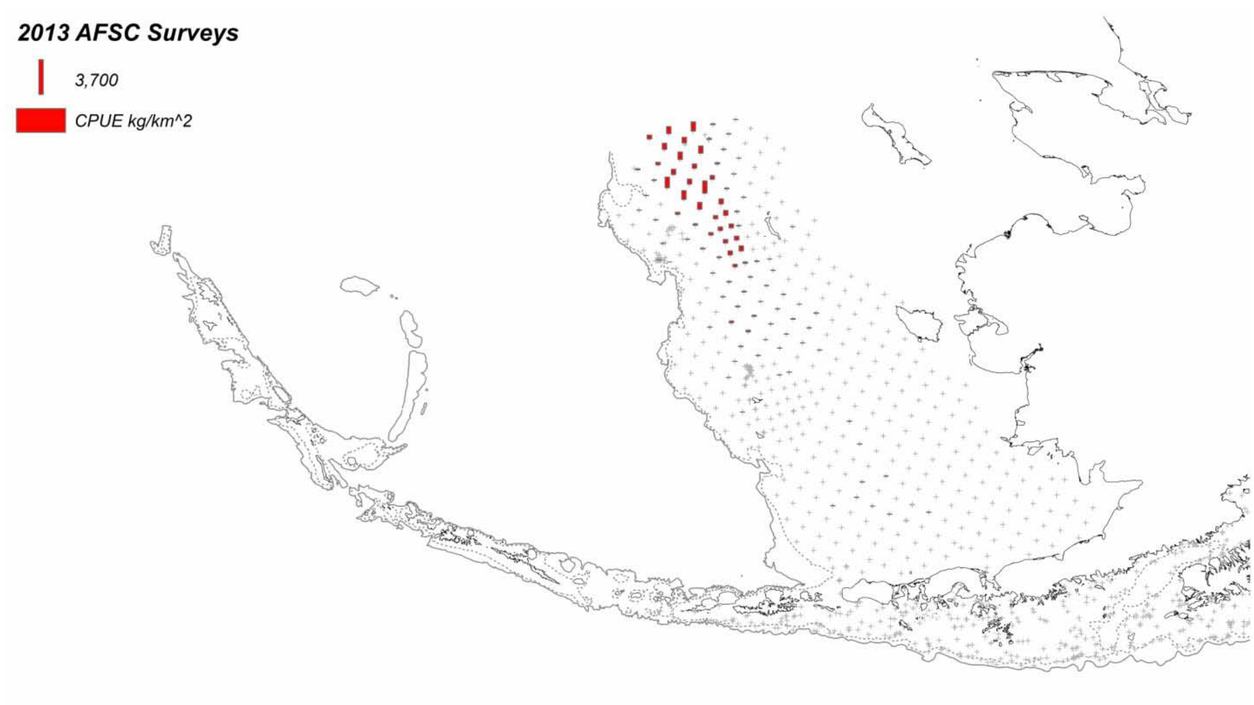


Figure 5.11.(cont.) Greenland turbot CPUE kg/km^2 for all Alaska Fisheries Science Center surveys combined for each year and 200m (dashed line) and 1000 m (solid gray line) isobaths. Bottom temperatures were not yet available for the 2013 map. Surveyed locations are marked with gray +, while areas with turbot are maked with red bars. All CPUE bars are on the same scale for all surveys.

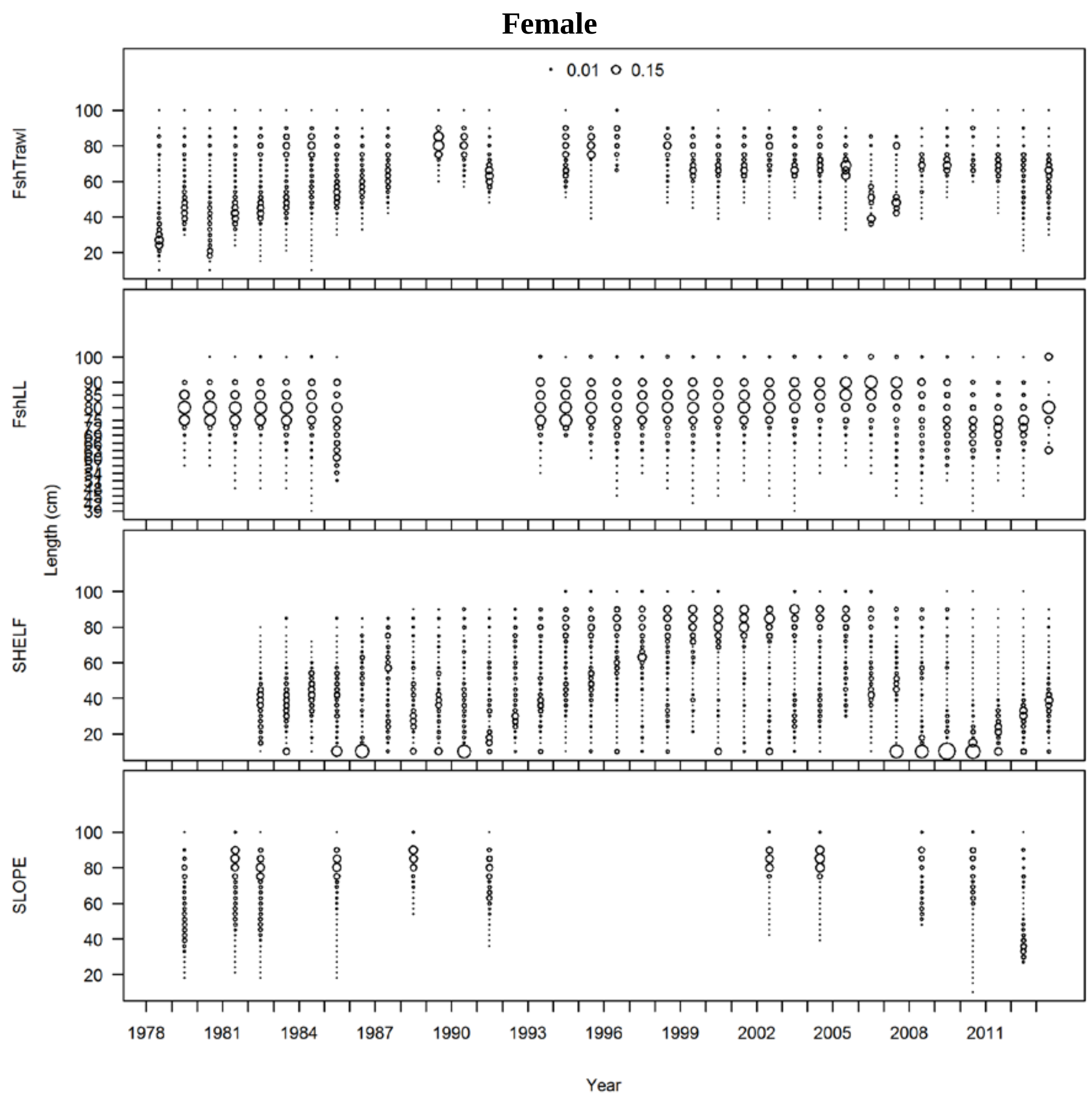


Figure 5.12. Greenland turbot size composition data for females from the Trawl fishery, longline fishery, shelf survey and slope survey.

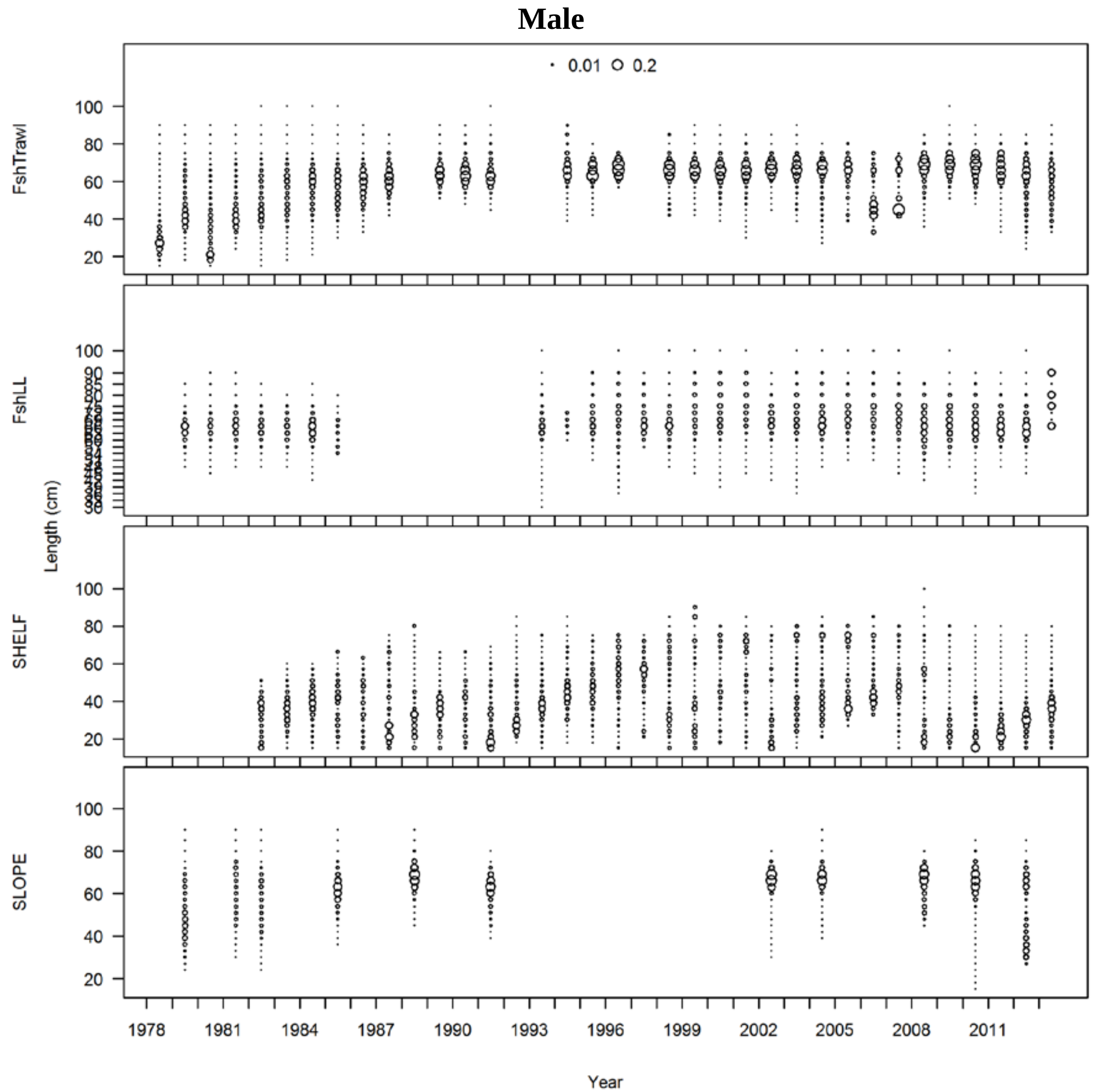


Figure 5.12. (Cont.) Greenland turbot size composition data for males from the Trawl fishery, longline fishery, shelf survey and slope survey.

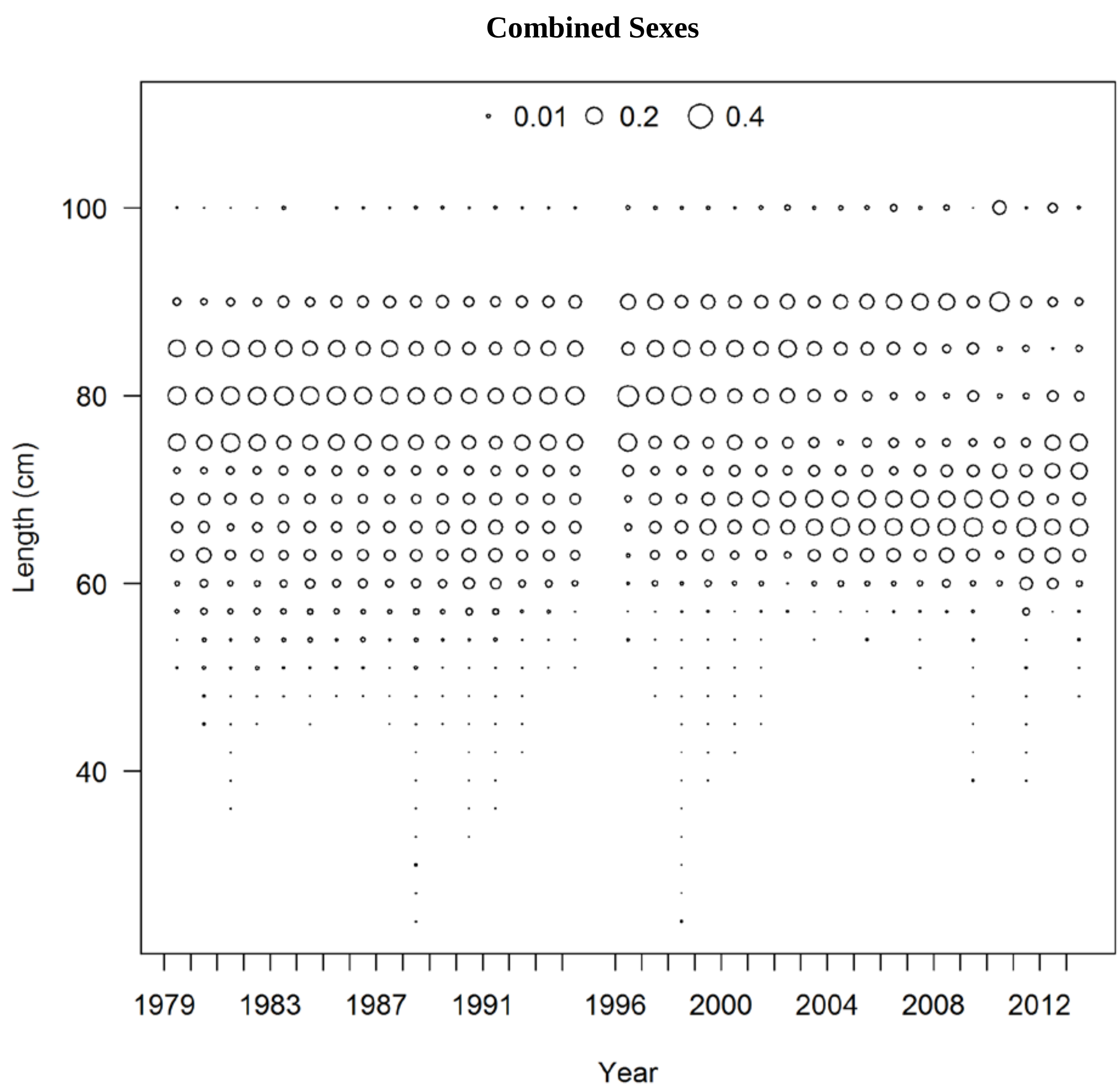
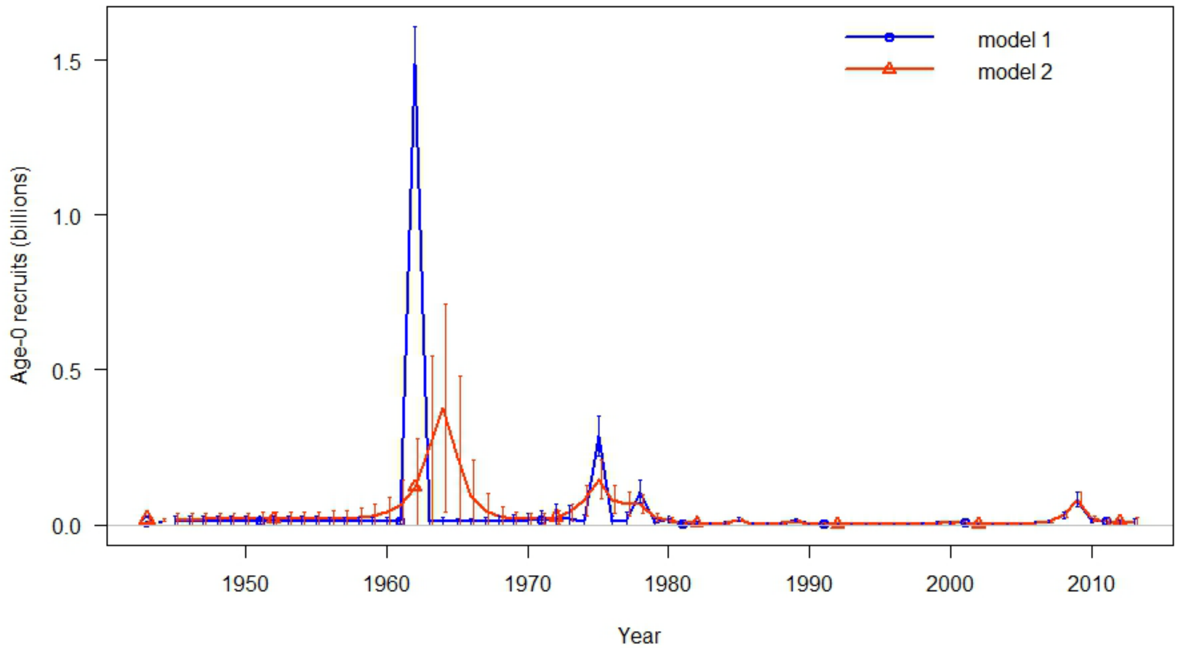


Figure 5.12. (Cont.) Greenland turbot size composition data for combined sexes from the Auke Bay Laboratory longline survey.



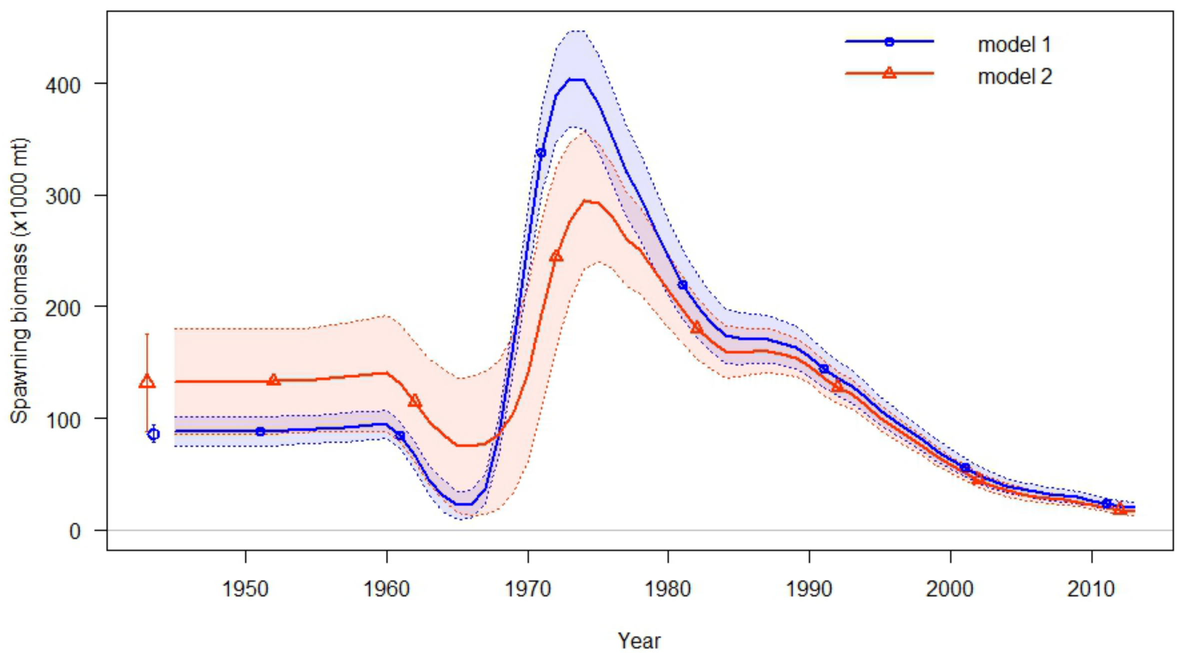


Figure 5.13. Age-0 recruitment (top) and female spawning biomass (bottom) for Model 1 and Model 2.

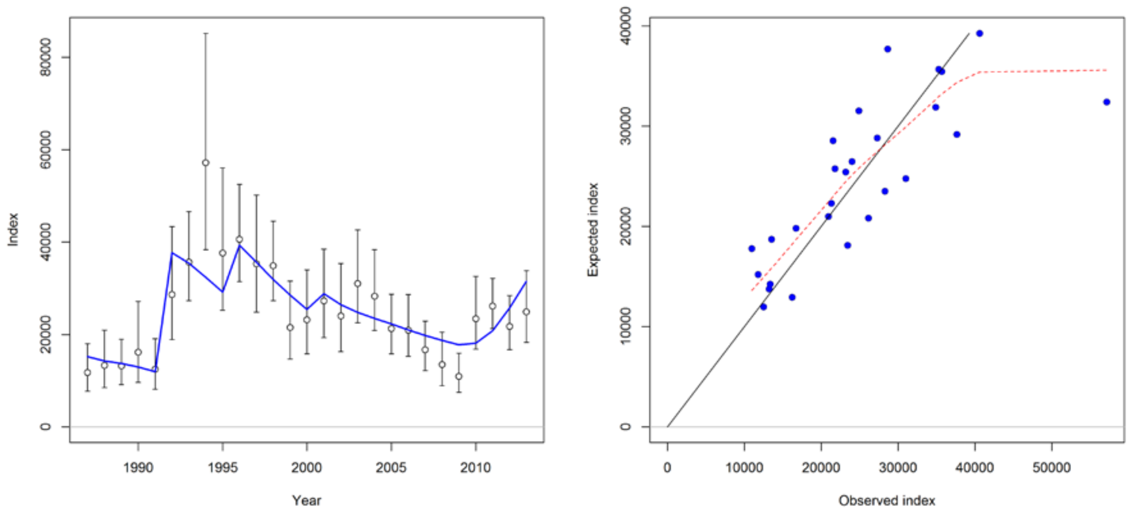


Figure 5.14. Shelf survey index (index values are total survey biomass in tons) and model fits. Error bars are 95% confidence intervals. Black line on right is 1:1 line, red line is a loess smooth.

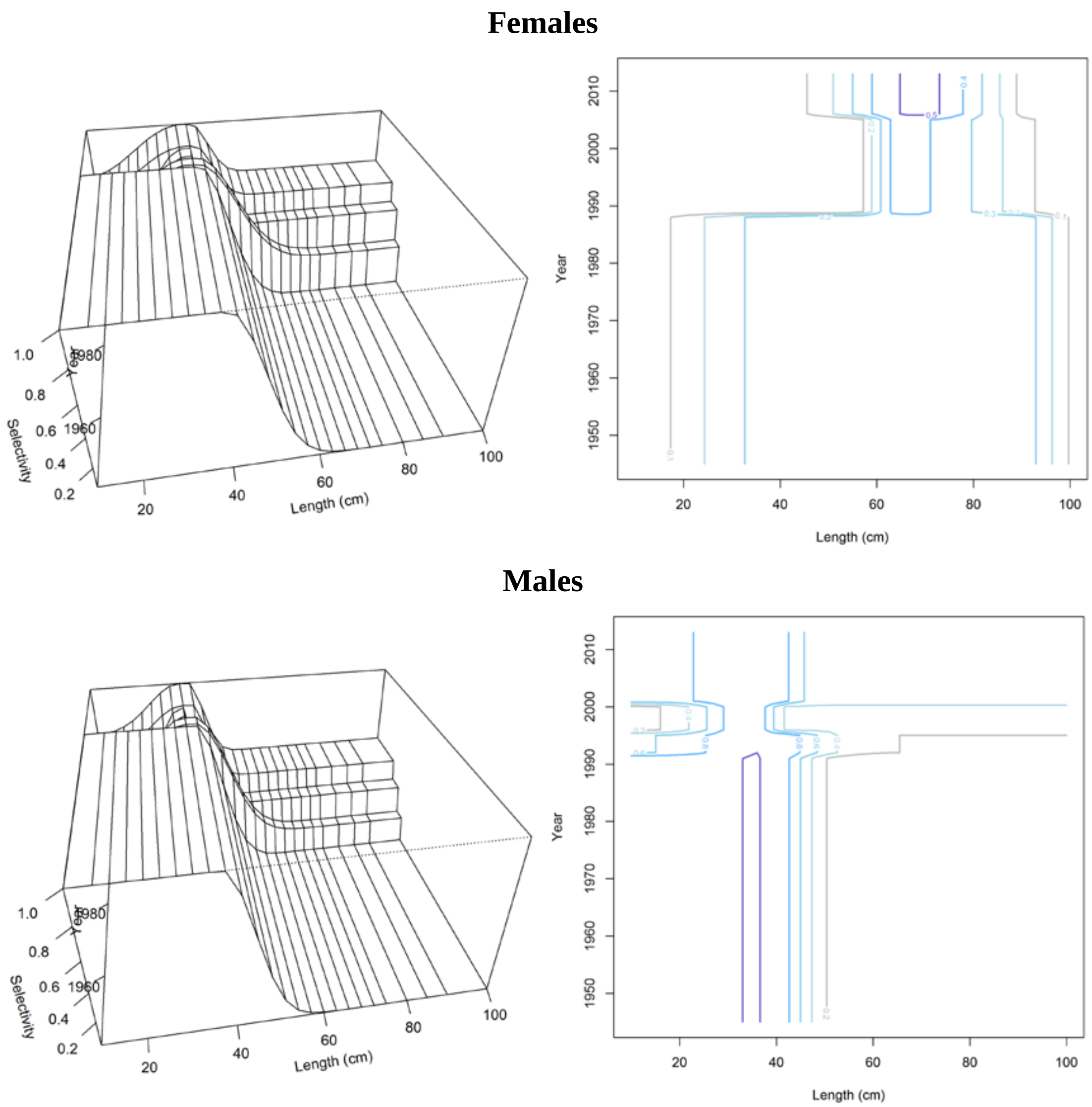


Figure 5.15. Time-varying selectivity at size for the Shelf survey for Model 2 for females (top) and males (bottom).

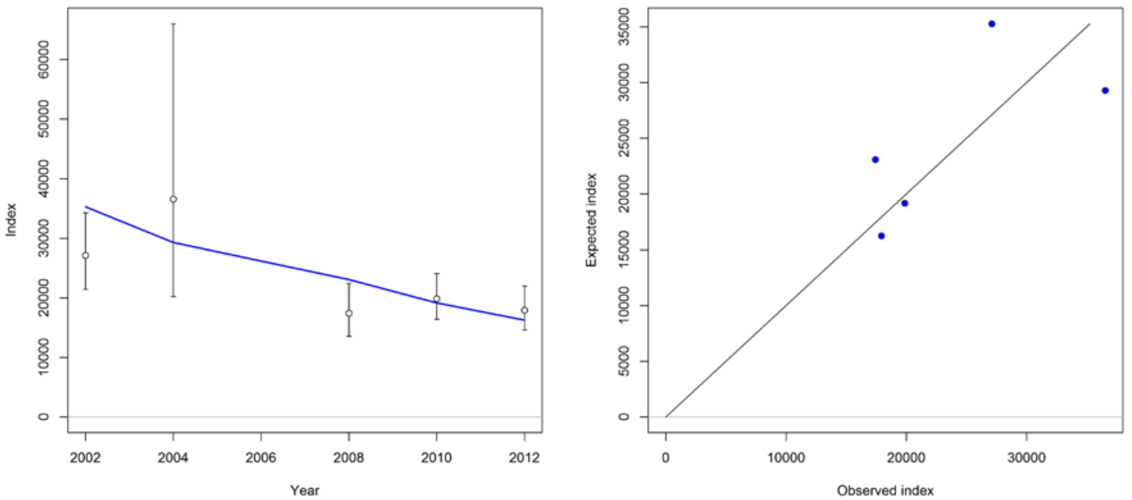


Figure 5.16. Slope survey index (index values are total survey biomass in tons) and model fits. Error bars are 95% confidence intervals. Black line on right is 1:1 line, red line is a loess smooth.

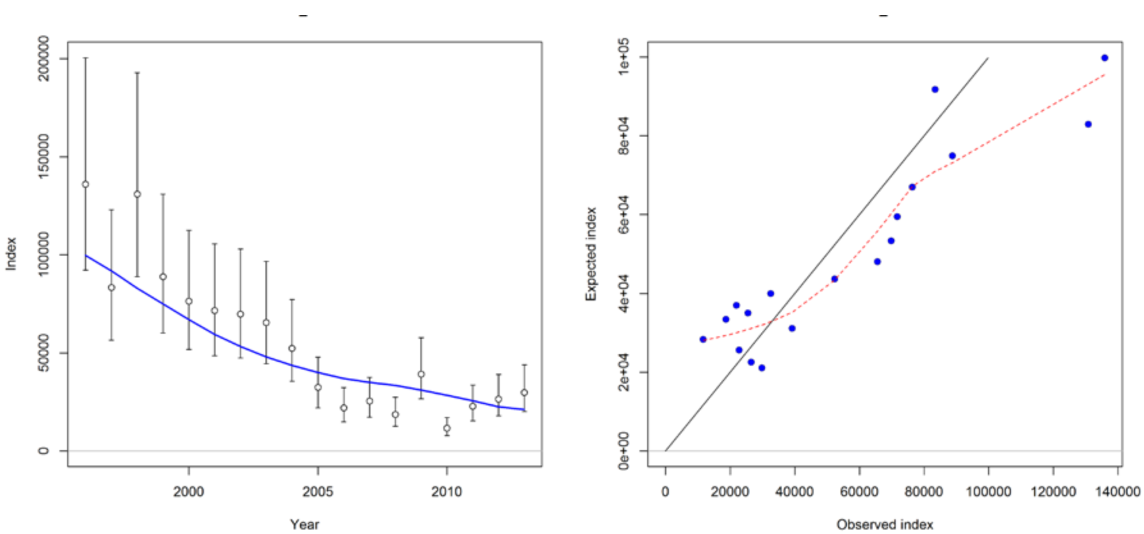


Figure 5.17. The longline survey index (index values are in relative population numbers (RPN)) and model fits. Error bars are 95% confidence intervals. Black line on right is 1:1 line, red line is a loess smooth.

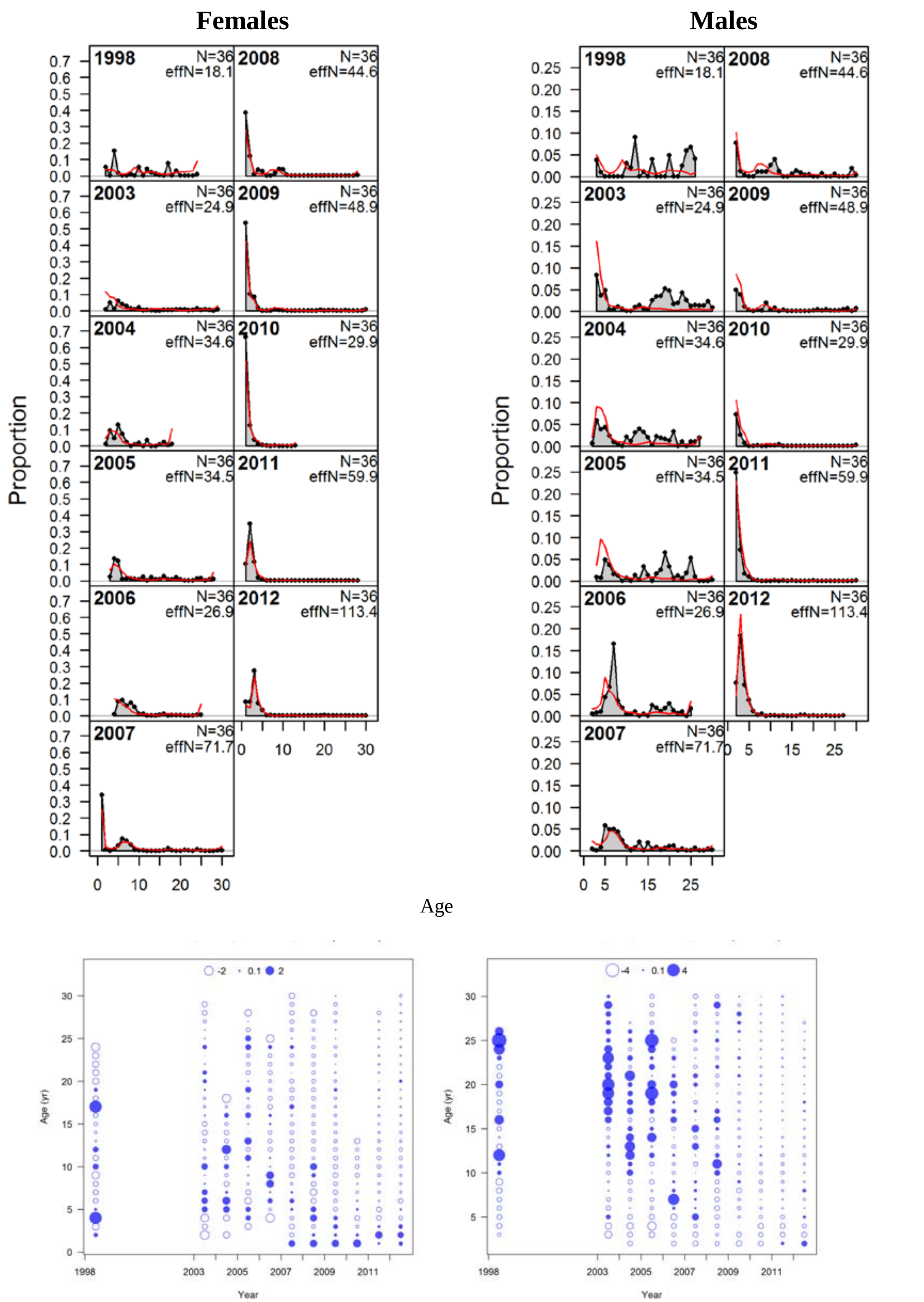


Figure 5.18. Shelf survey age composition data and fits (red line)from Model 2 (top) for Females and males. (Bottom) Shelf survey age composition Pearson residuals.

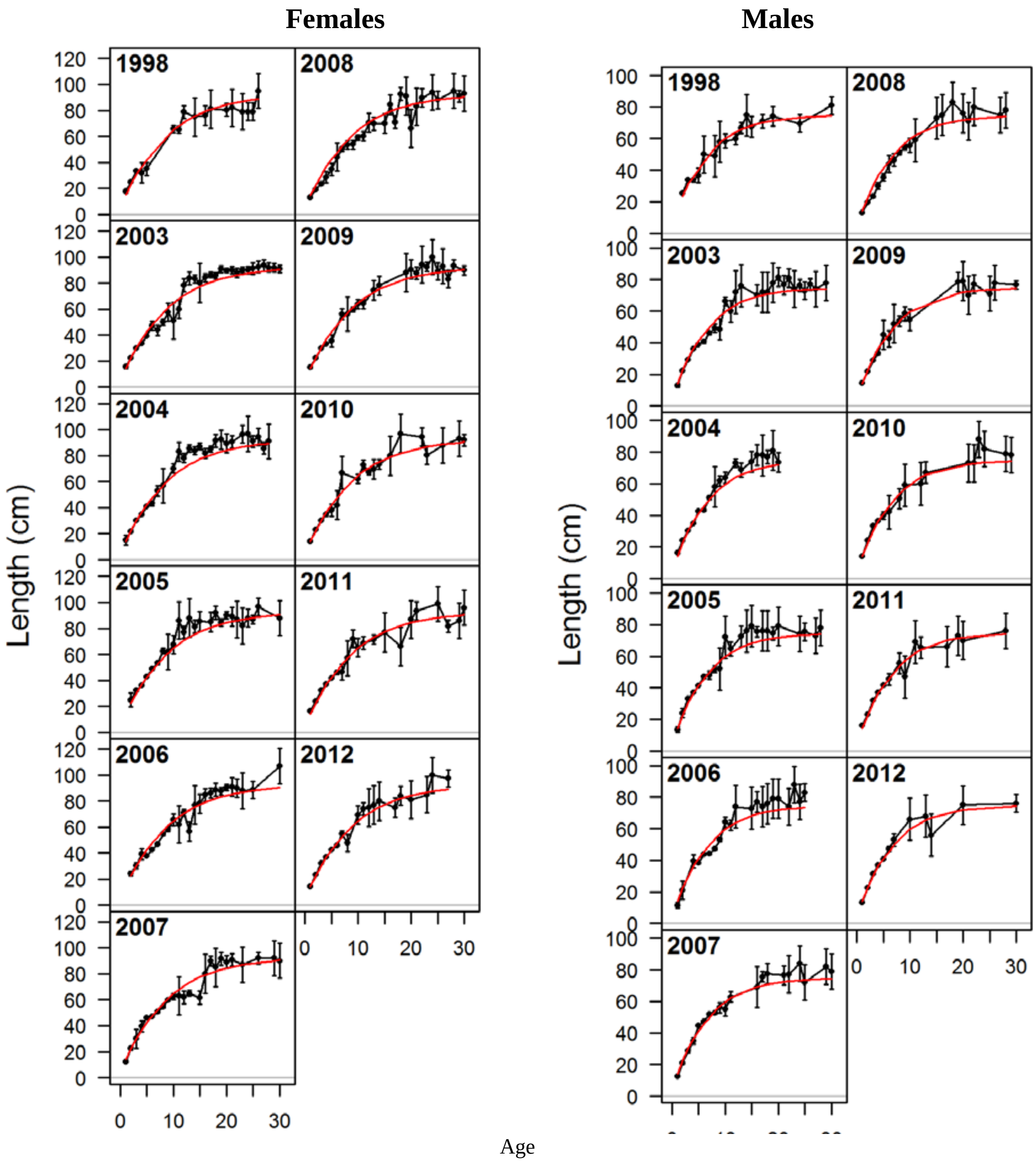


Figure 5.19. Length at age data and fits (red line) from Model 1 for females and males.

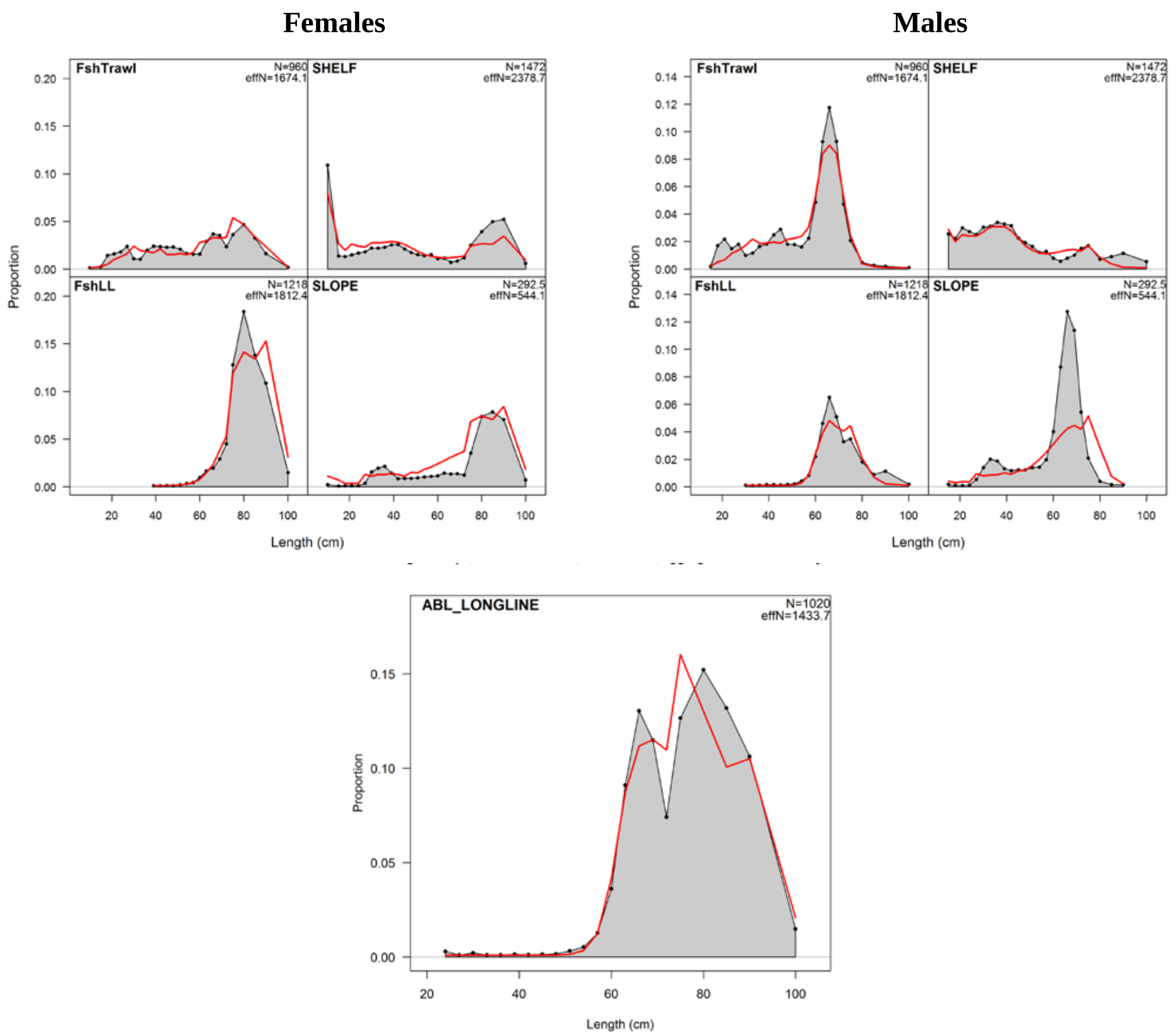


Figure 5.20. All size composition data combined across years and fits (red line) for all fisheries and survey for Model 1. ABL longline has combined males and females.

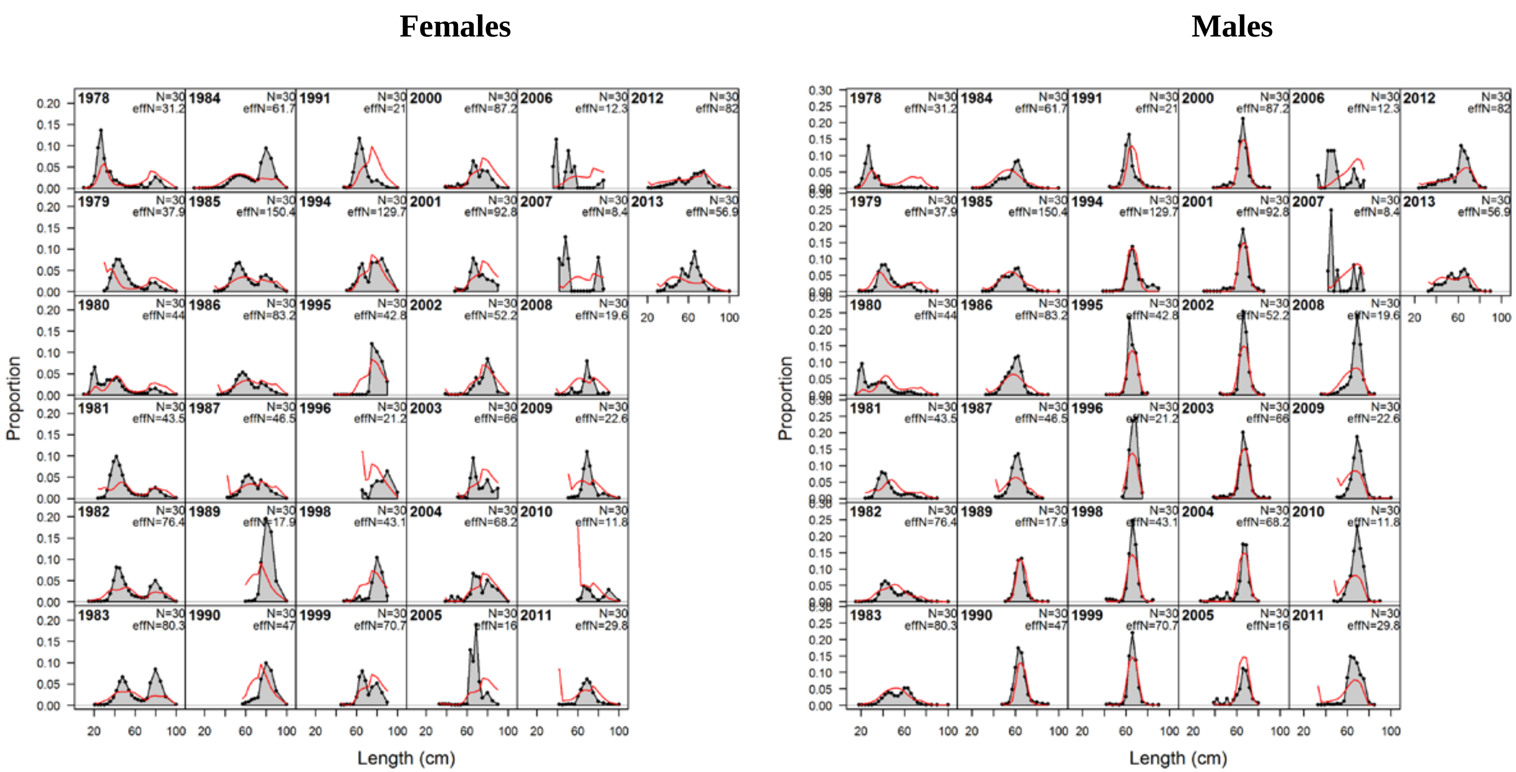


Figure 5.21. Trawl fishery size composition data and fits (red line) from Model 2 for females and males.

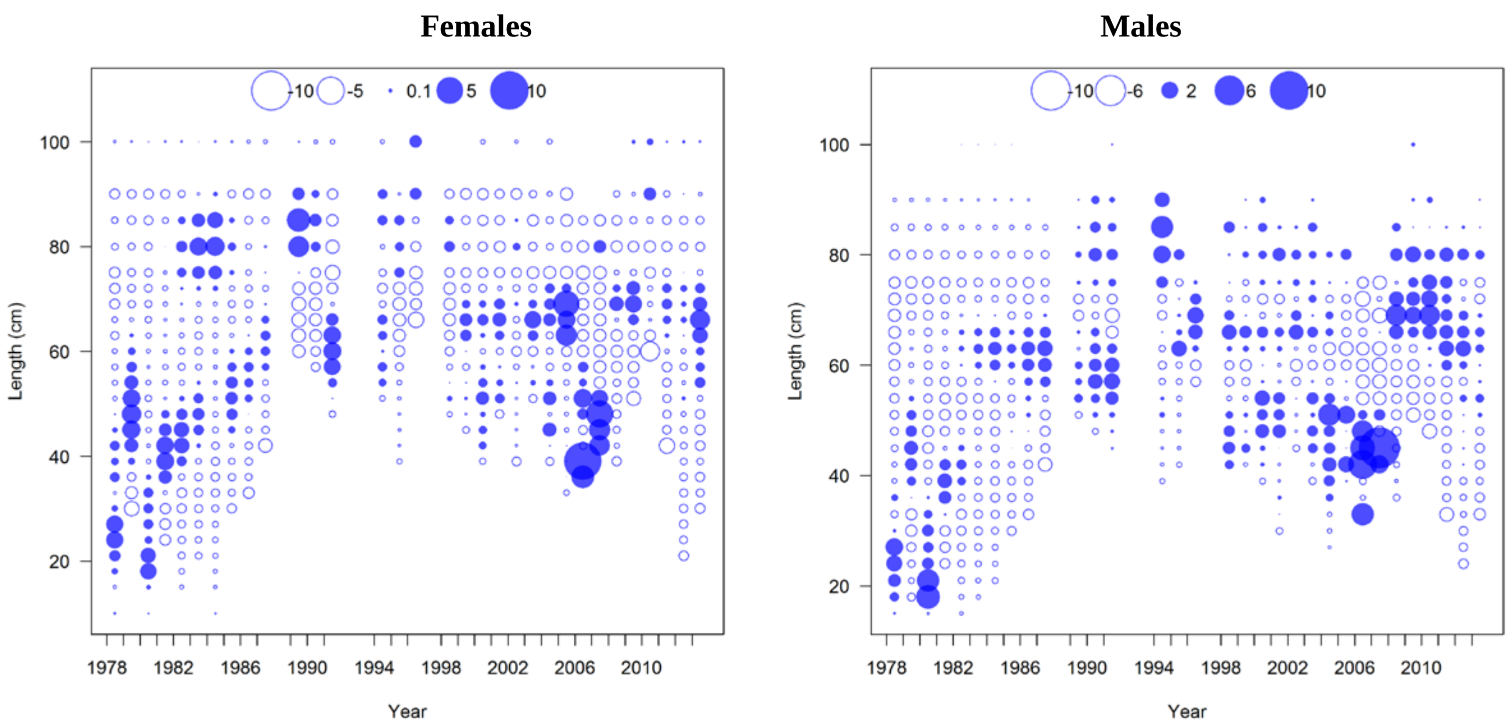


Figure 5.22. Trawl fishery size composition Pearson residuals.

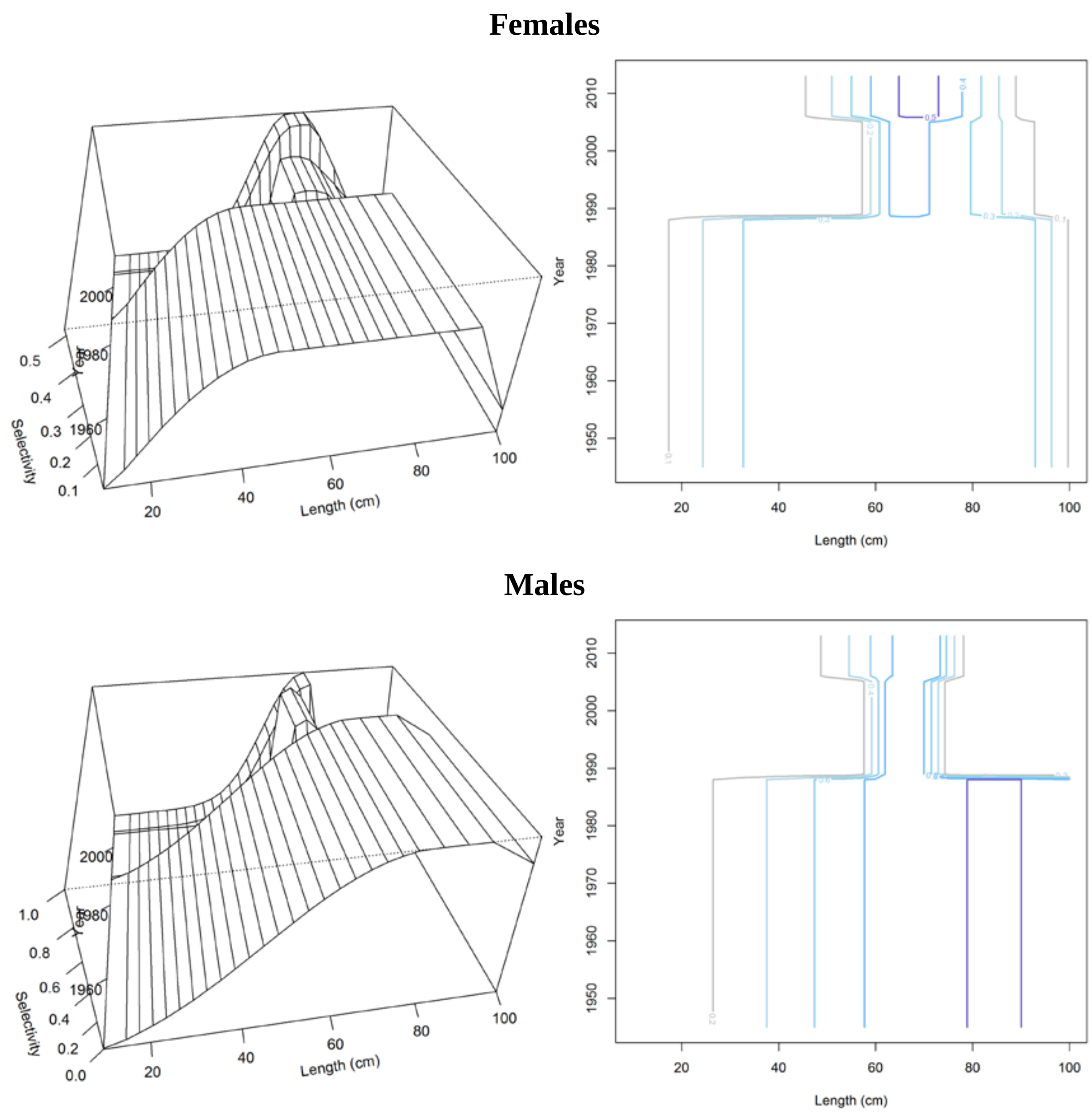


Figure 5.23. Time-varying selectivity at size for the Trawl fishery for Model 1 for Females (top) and males (bottom).

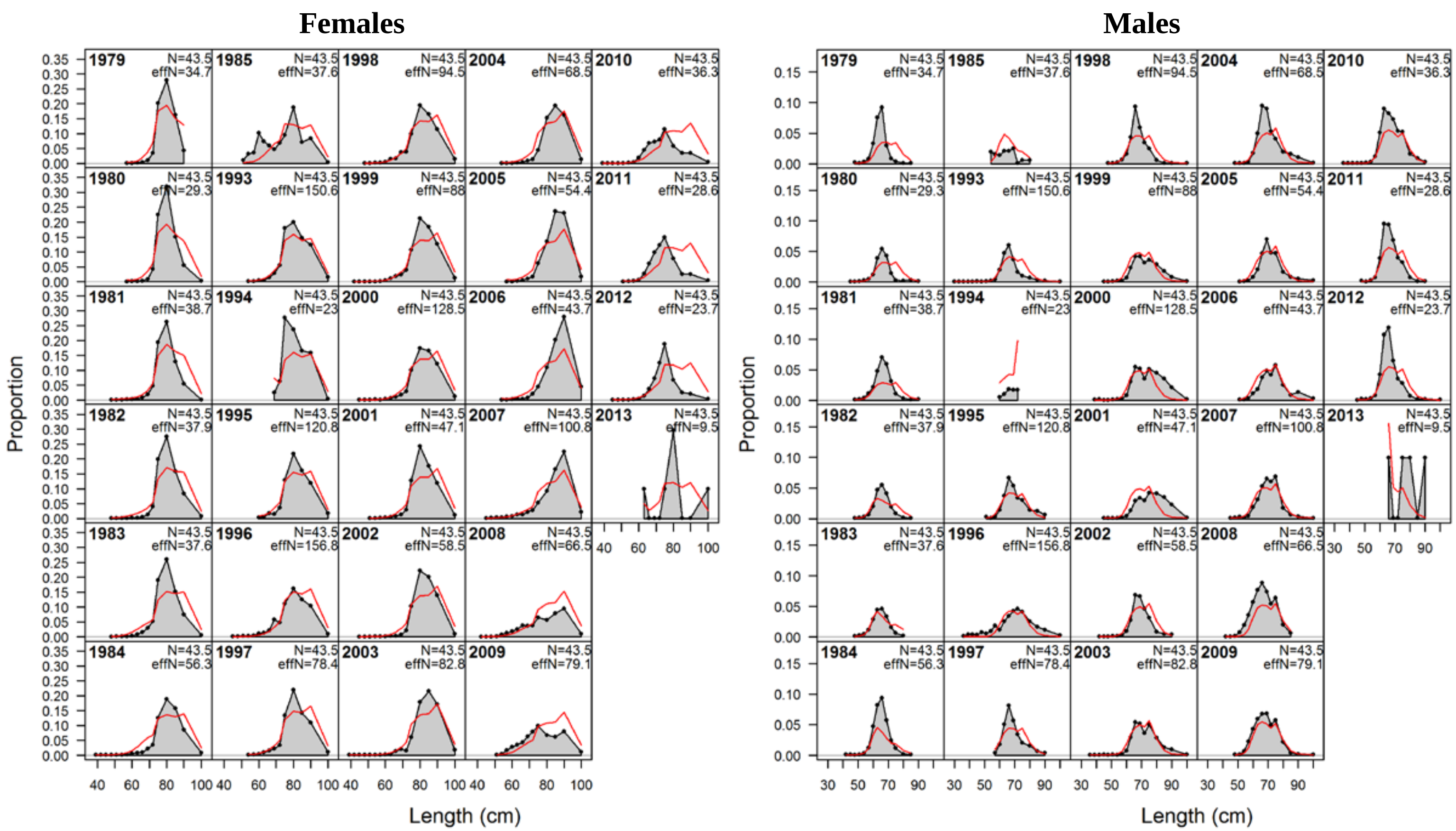


Figure 5.24. Longline fishery size composition data and fits (red line) from Model 1 for females and males.

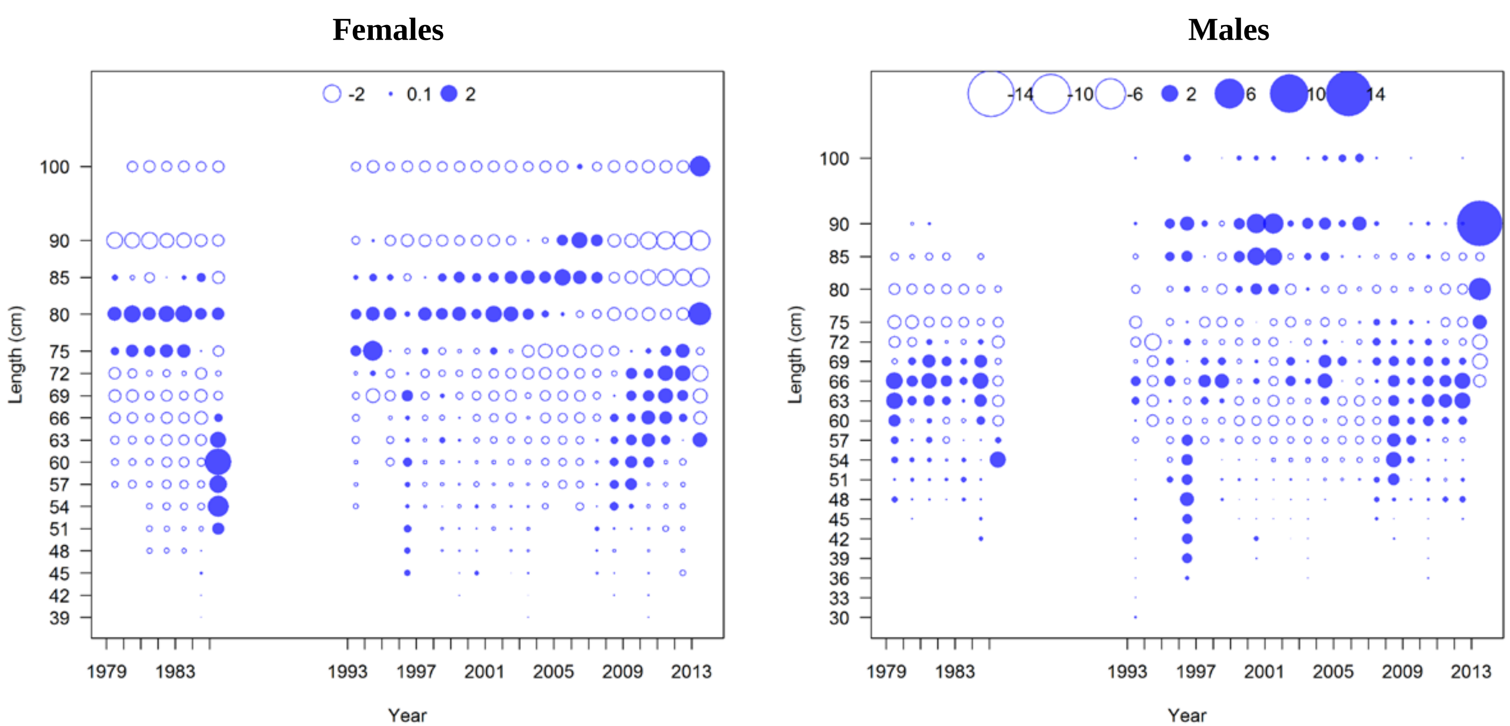


Figure 5.25. Longline fishery size composition Pearson residuals.

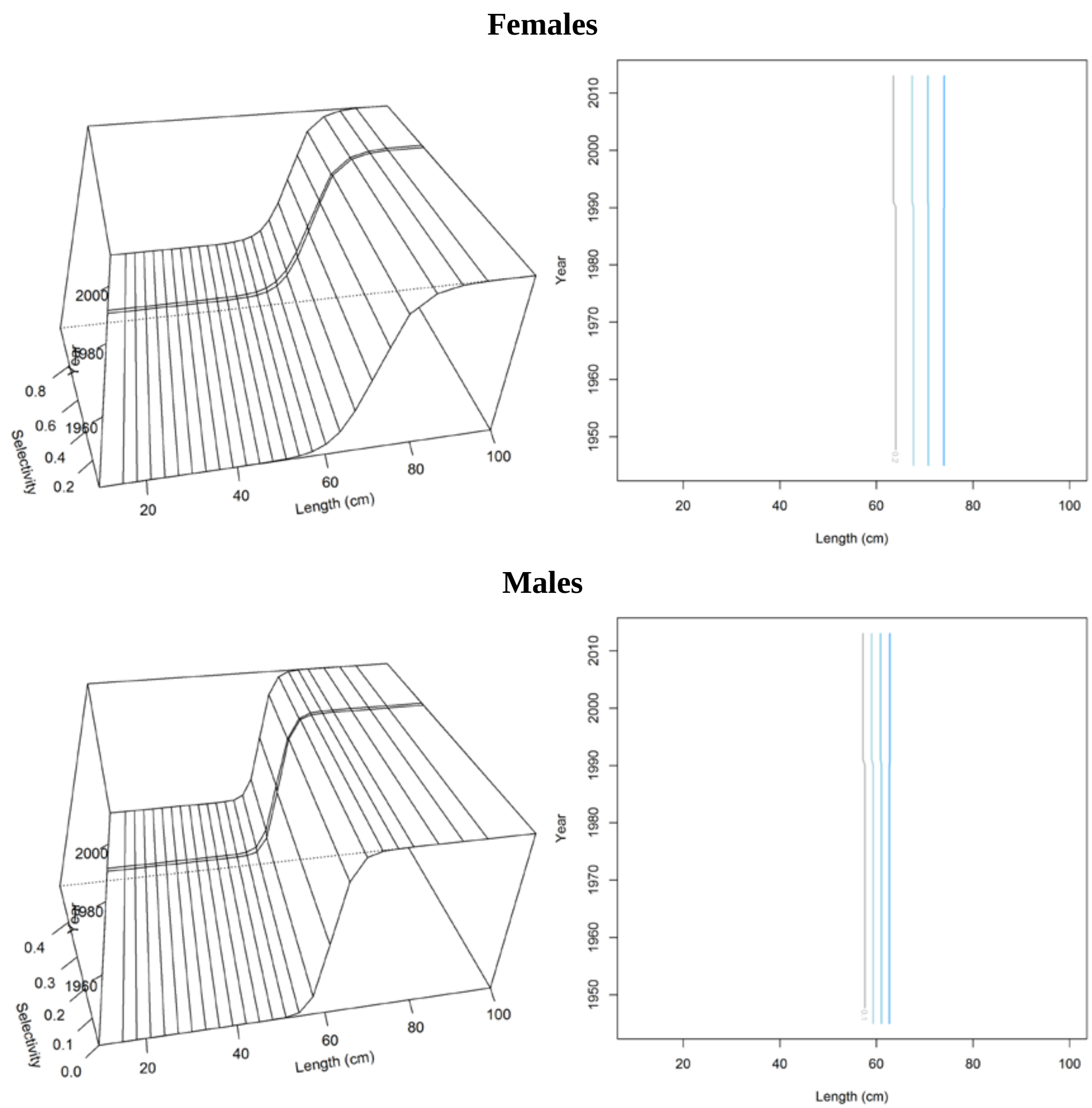


Figure 5.26. Time-varying selectivity at size for the Longline fishery for Model 1 for females (top) and males (bottom). Notice the y-axes and scales are different.

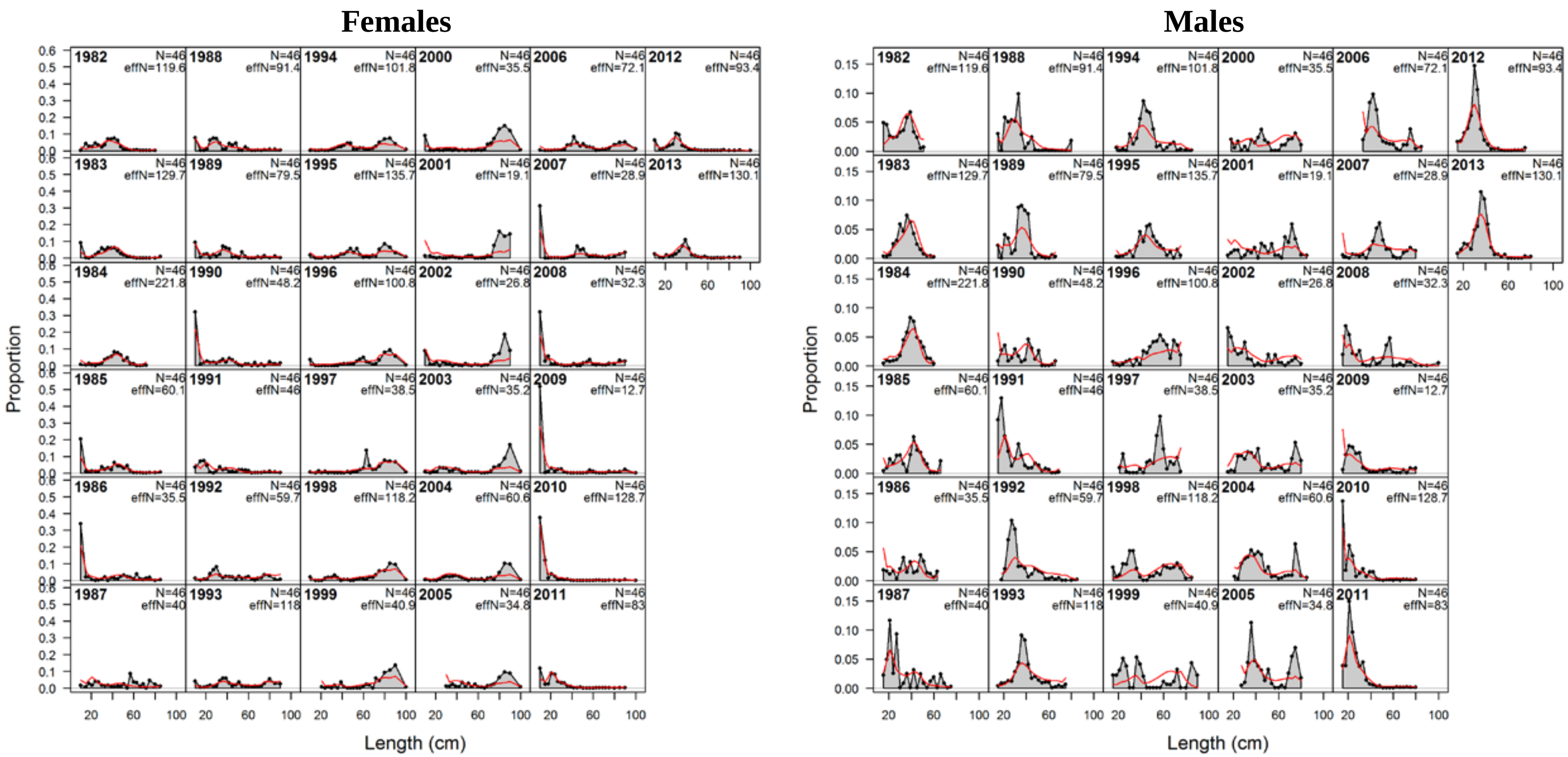


Figure 5.27. Shelf survey size composition data and fits (red line) from Model 2 for females and males.

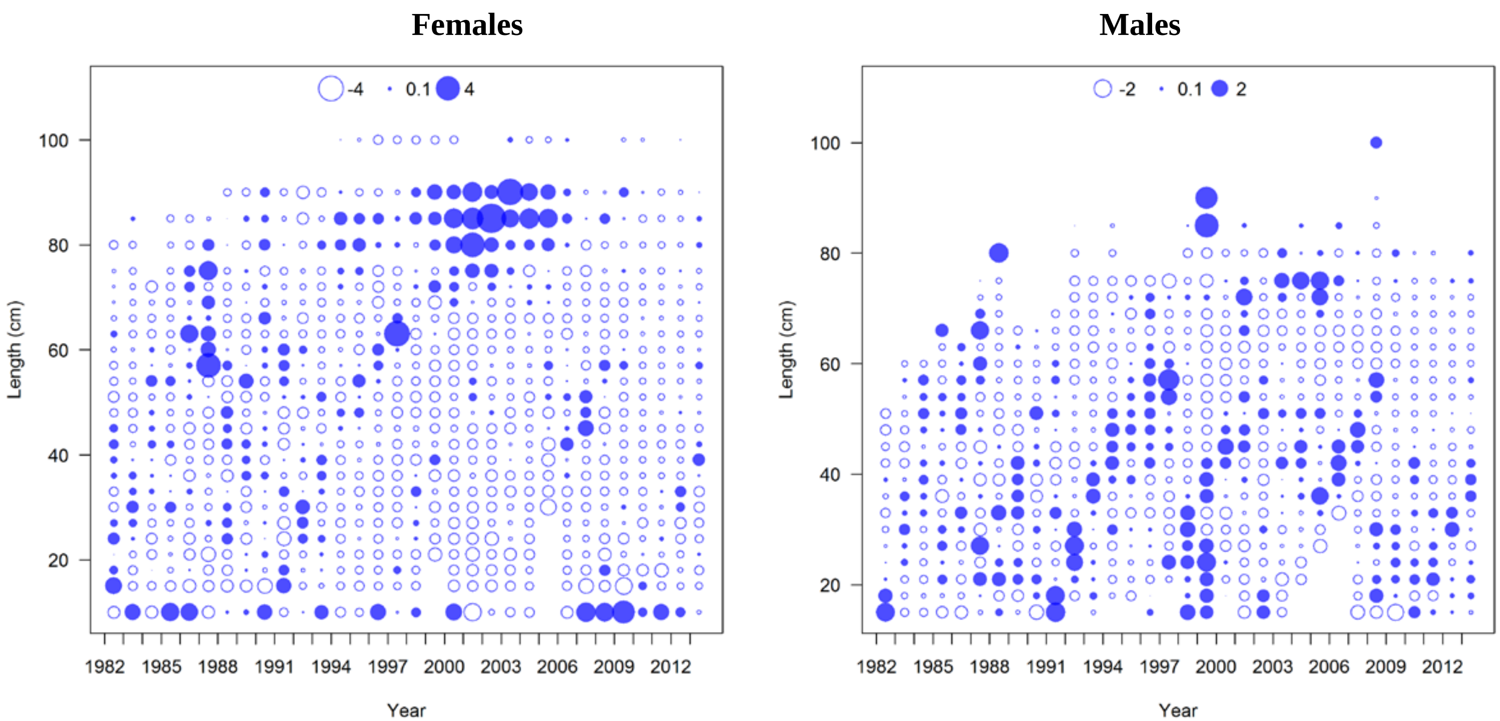


Figure 5.28. Shelf survey size composition Pearson residuals. Closed bubbles are positive residuals and open bubbles are negative residuals.

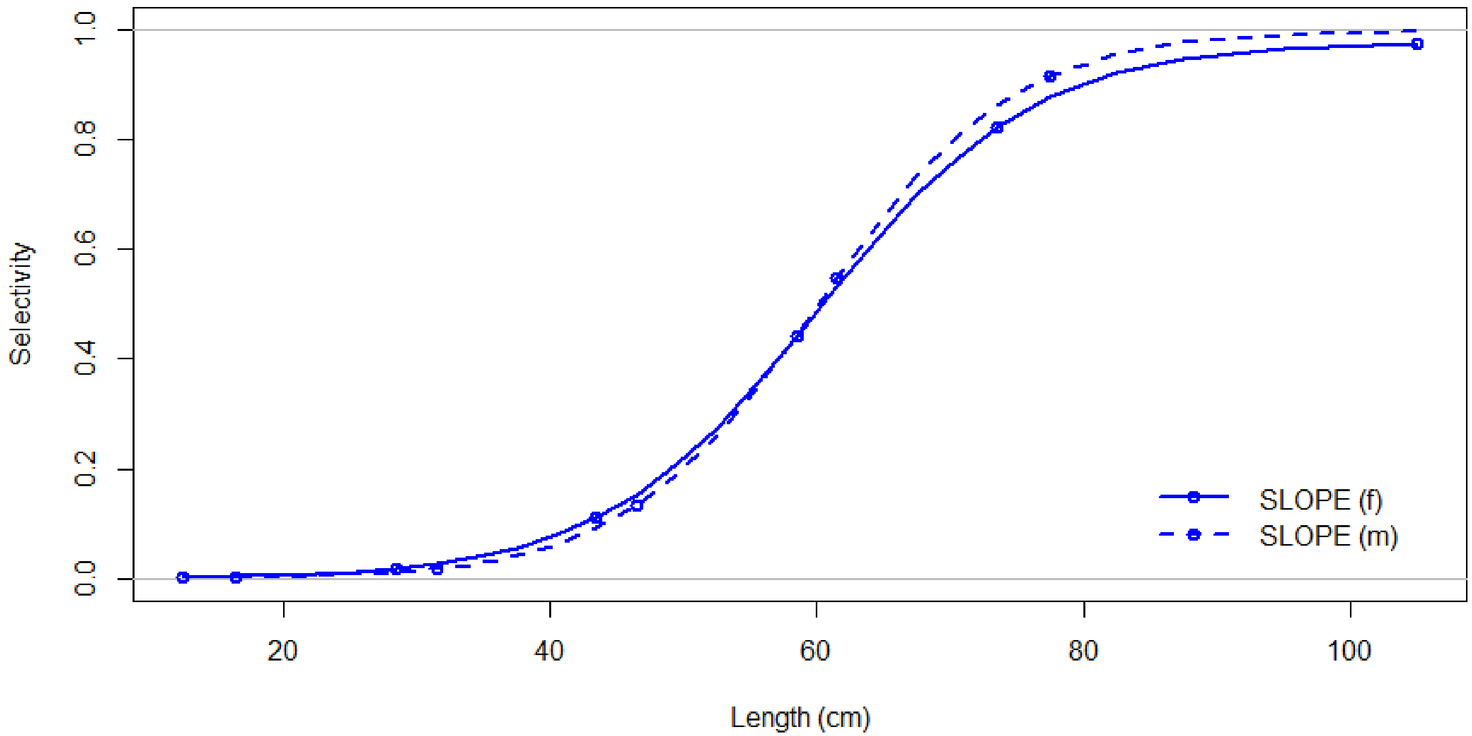


Figure 5.29. 2013 Slope survey selectivity by sex

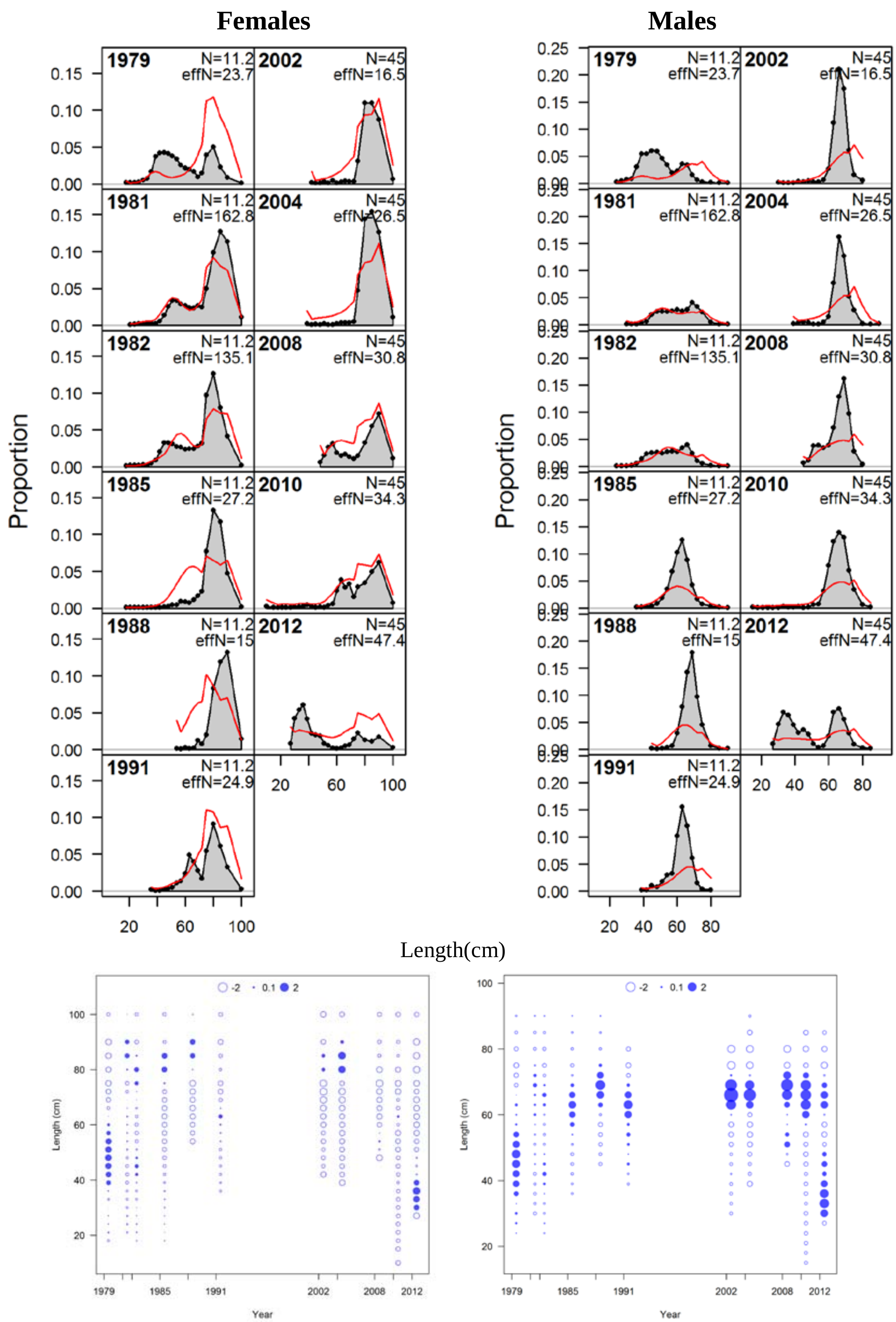


Figure 5.30. (Top) Slope survey size composition data and fits (red line)from Model 2 (top) for females and males. (Bottom) Slope survey size composition Pearson residuals.

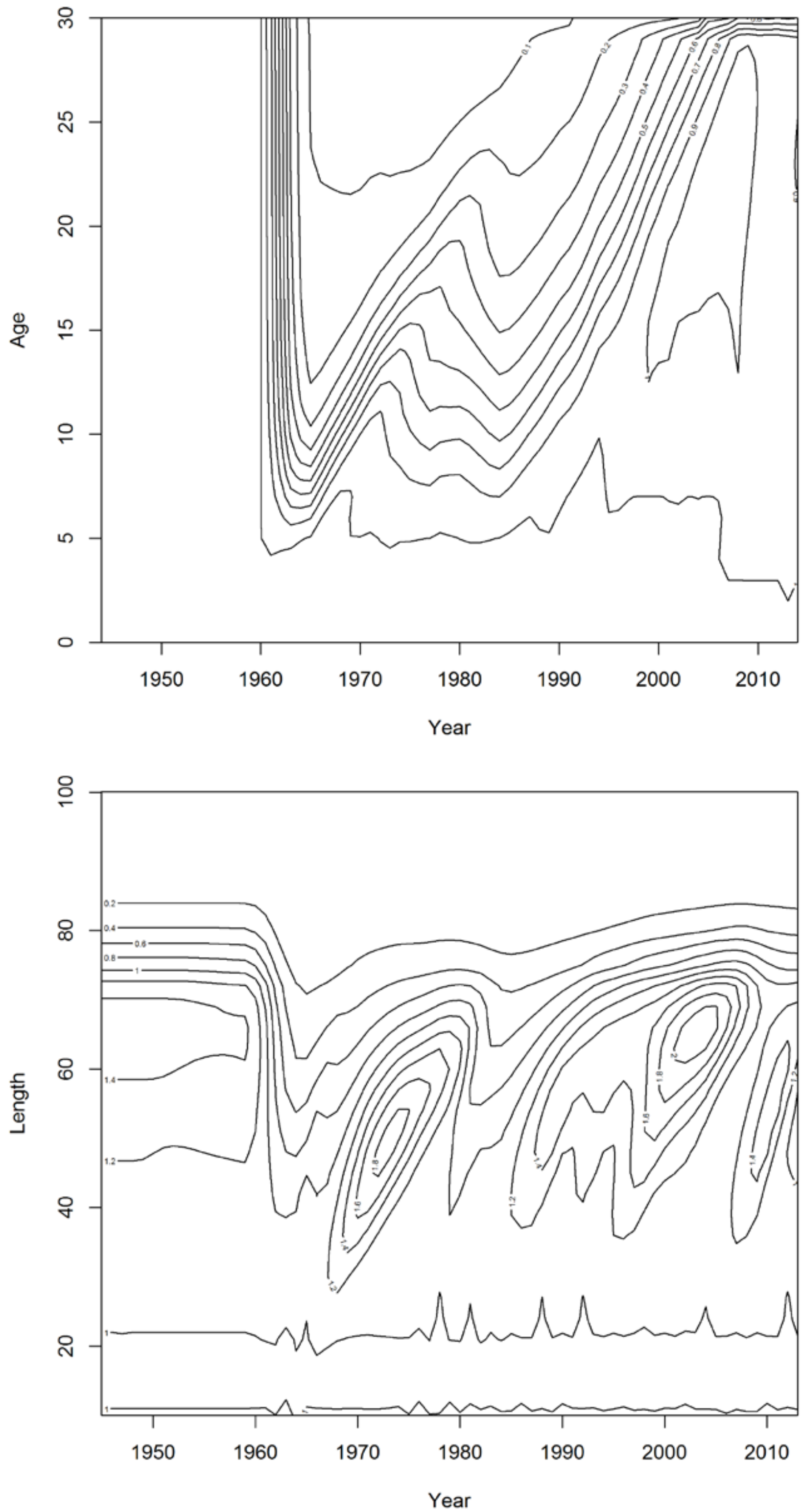


Figure 5.31. BSAI Greenland turbot sex ratio (males:females) by age (top) and size (bottom).

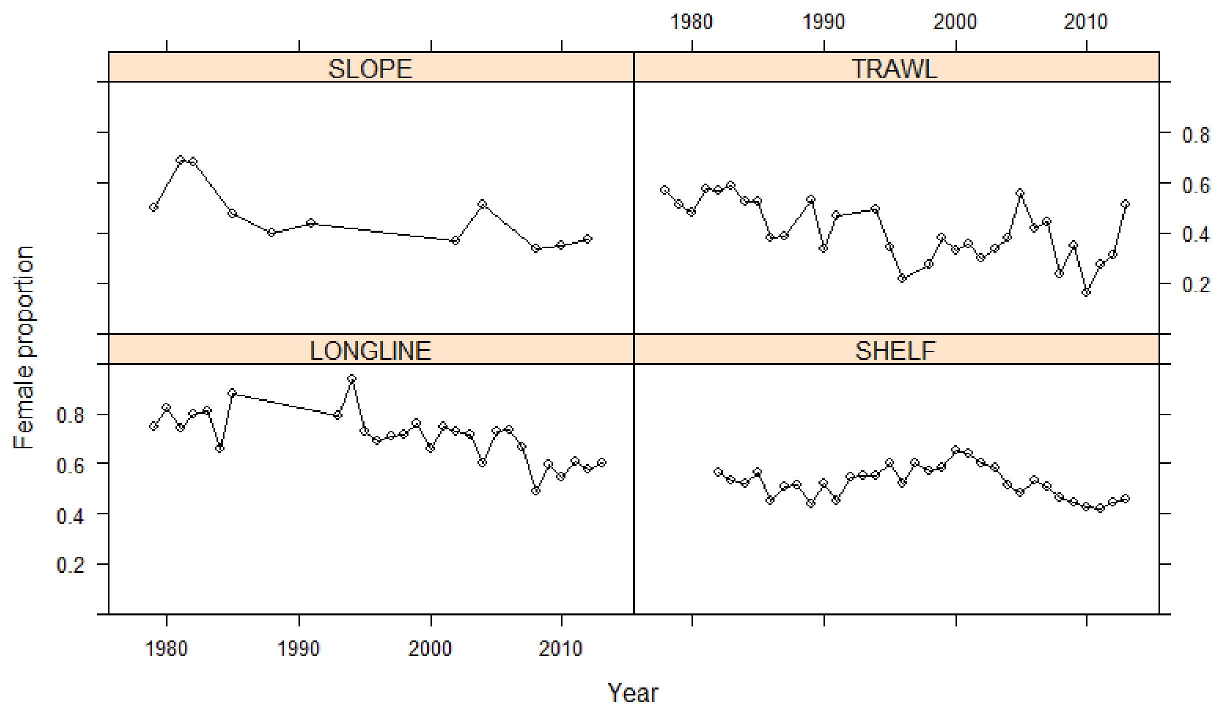


Figure 5.32. Proportion of Females in the size composition data by fishery (Trawl and Longline) or survey (Shelf and Slope) by year.

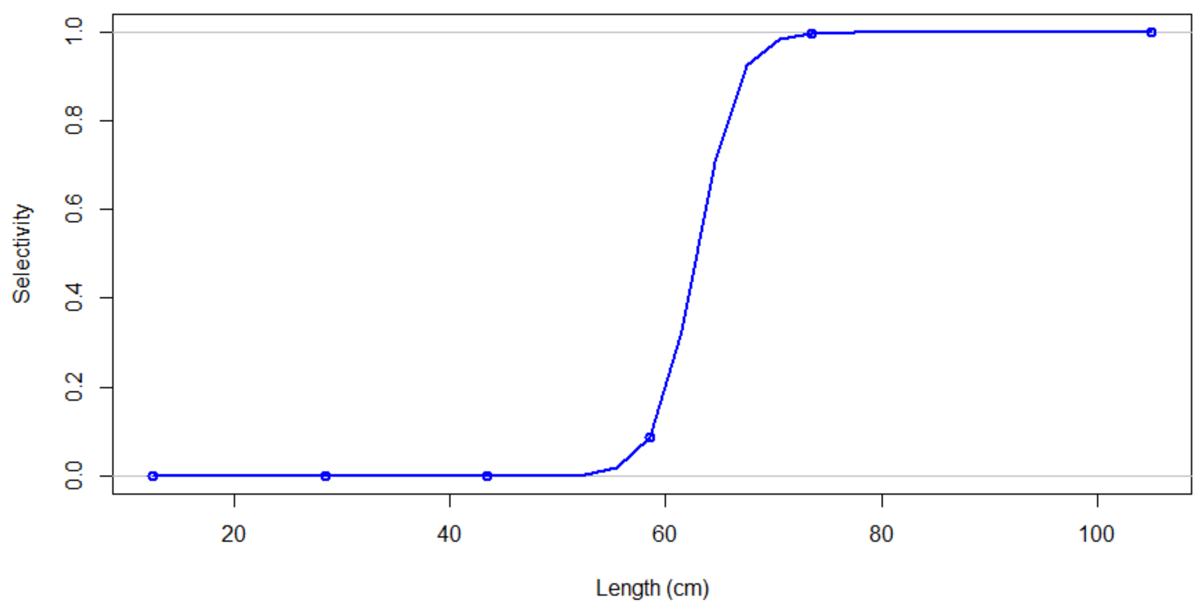


Figure 5.33. 2013 ABL longline survey selectivity by sex.

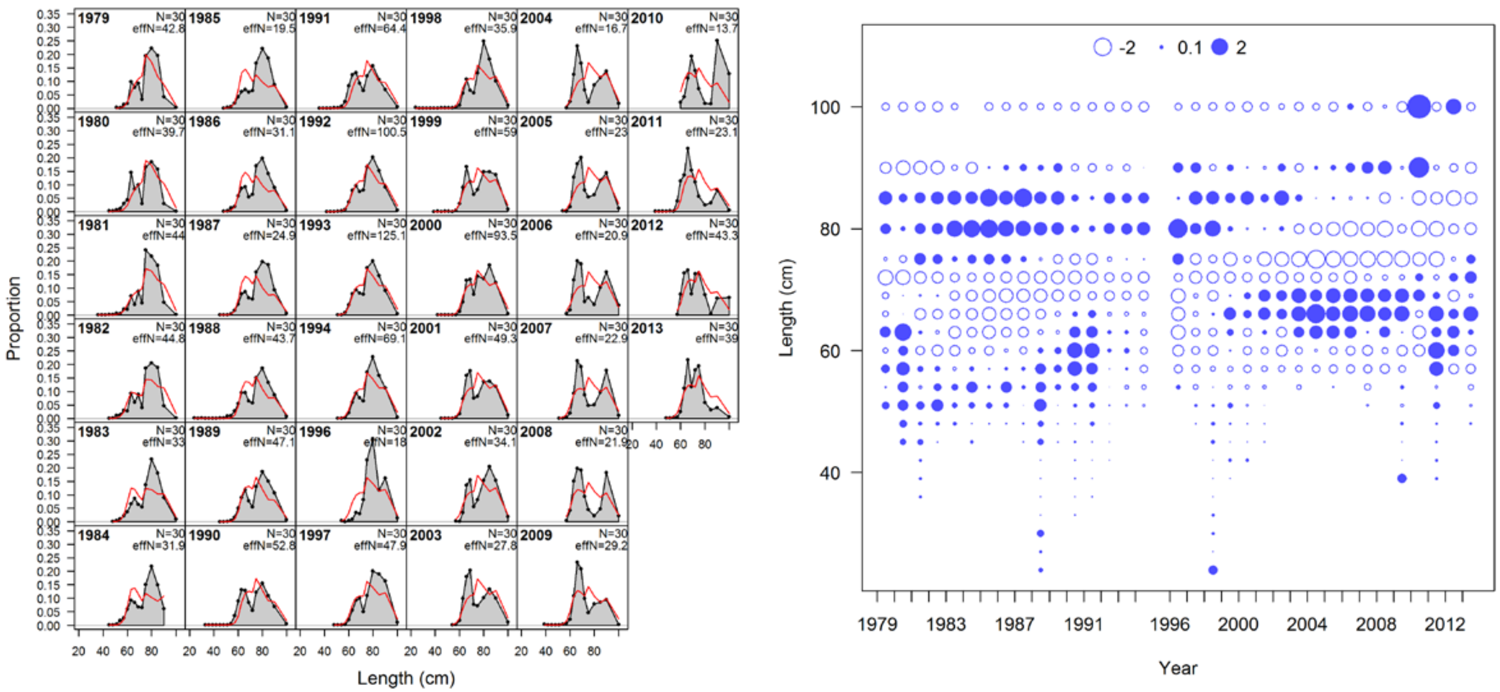


Figure 5.34. (Left) Auke Bay Laboratory Longline survey size composition data and fits (red line)from Model 1 for combined sexes. (Right) Slope survey size composition Pearson residuals.

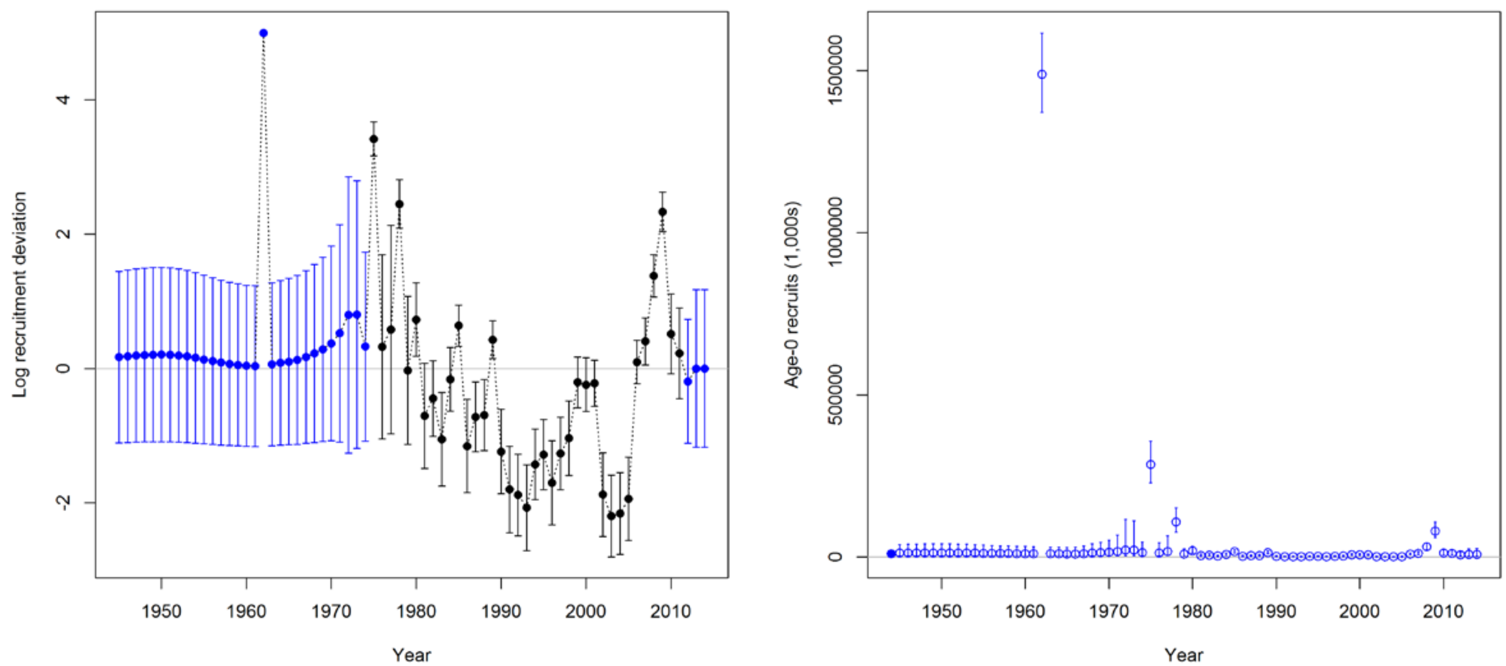


Figure 5.35. Log recruitment deviations (left) and Age-0 recruits (right) in thousands for Model 1.

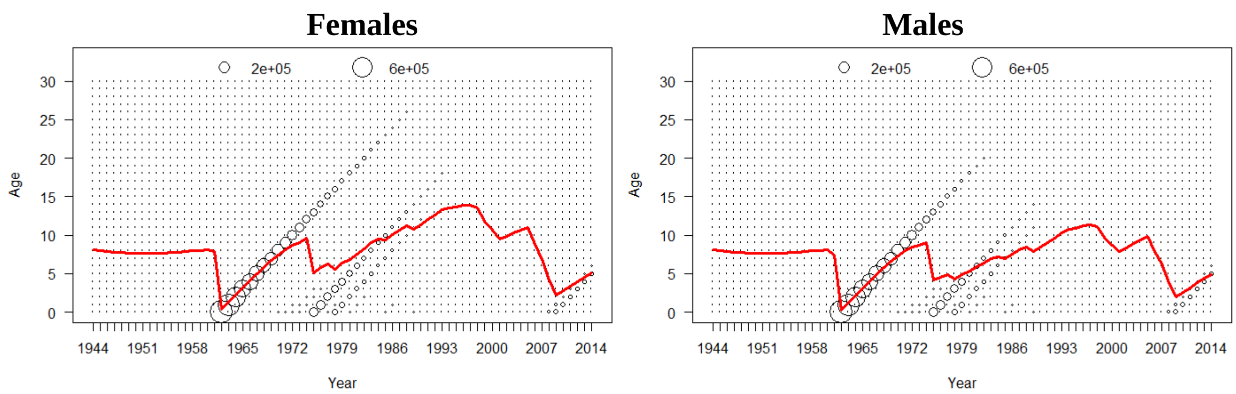


Figure 5.36. BSAI Greenland turbot numbers at age and mean age by year (red line).

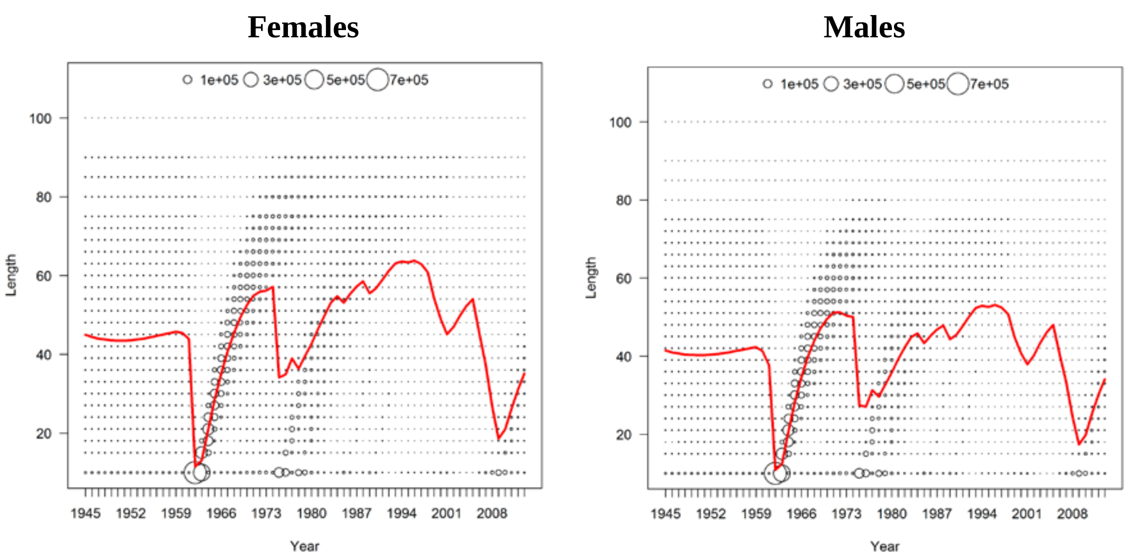


Figure 5.37. BSAI Greenland turbot numbers at size and mean size by year (red line).

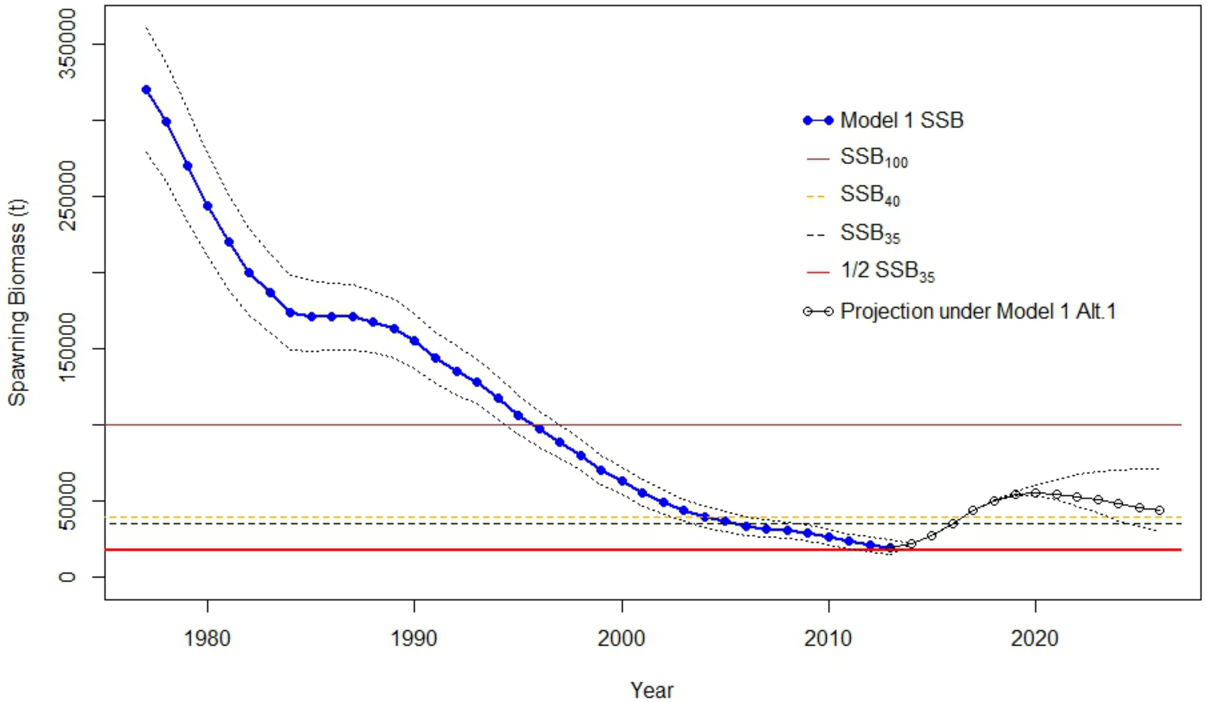


Figure 5.38. Female spawning biomass in tons for BSAI Greenland Turbot for this years reference model (Model 1) with reference levels and projection out to 2026 from Alternative 1 F_{40} fishing levels. Model error bars are 95% confidence intervals based on the inverted Hessian, projection error bars are 95% credible intervals based on 1,000 simulations.

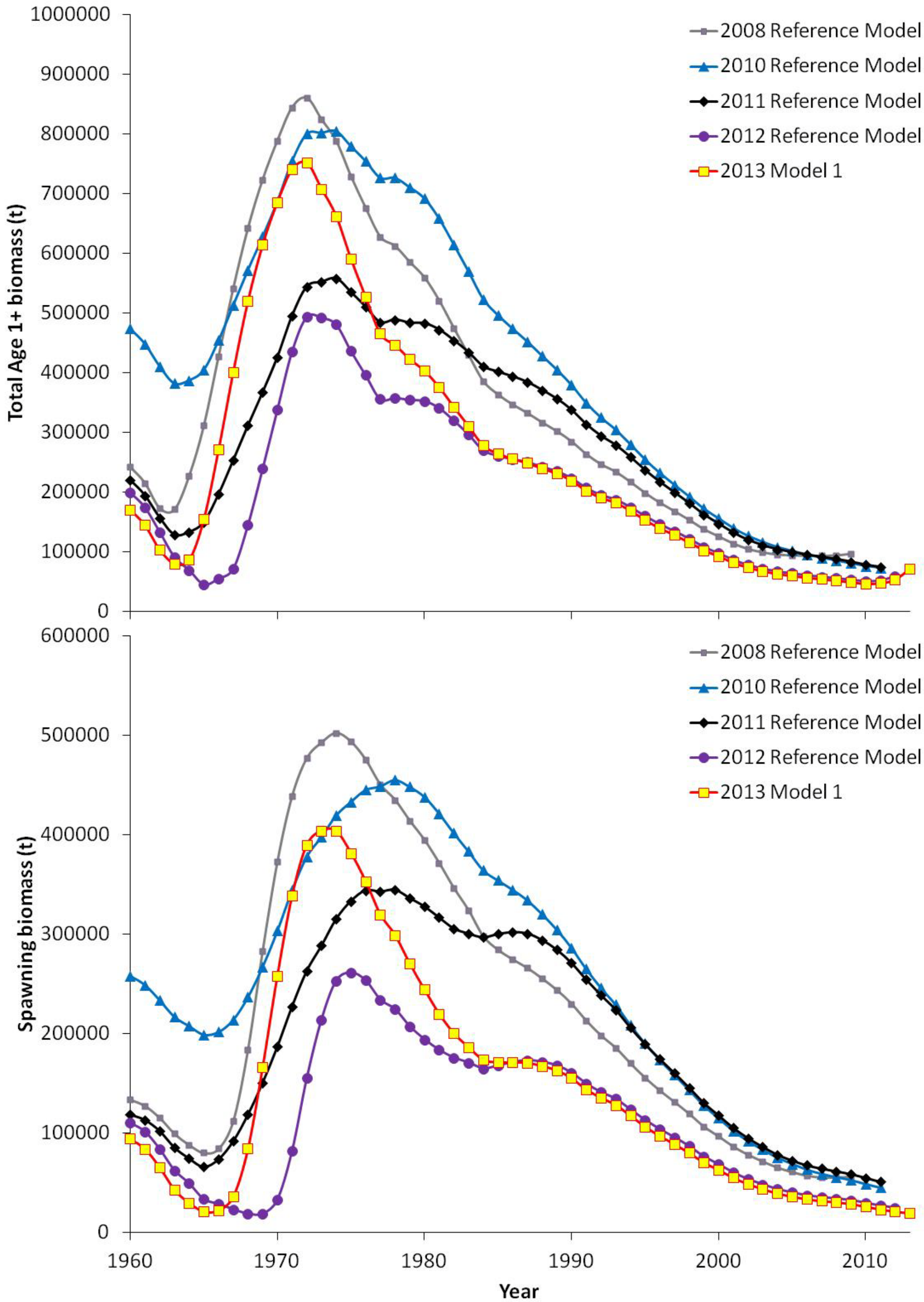


Figure 5.39. Total age +1 biomass (t) and female spawning biomass in tons for BSAI Greenland Turbot for this years reference model (Model 1) and previous years' stock assessments.

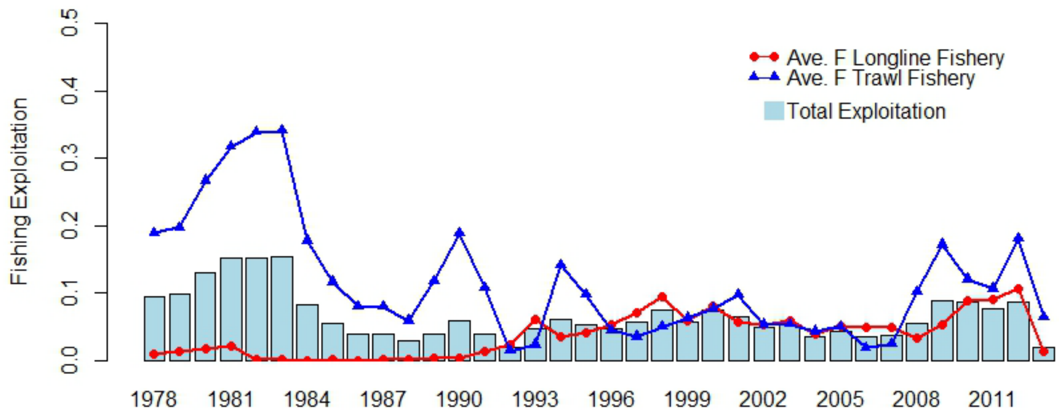


Figure 5.40. BSAI Greenland turbot total exploitation rate (bars) and average Fs for the trawl and longline fisheries.

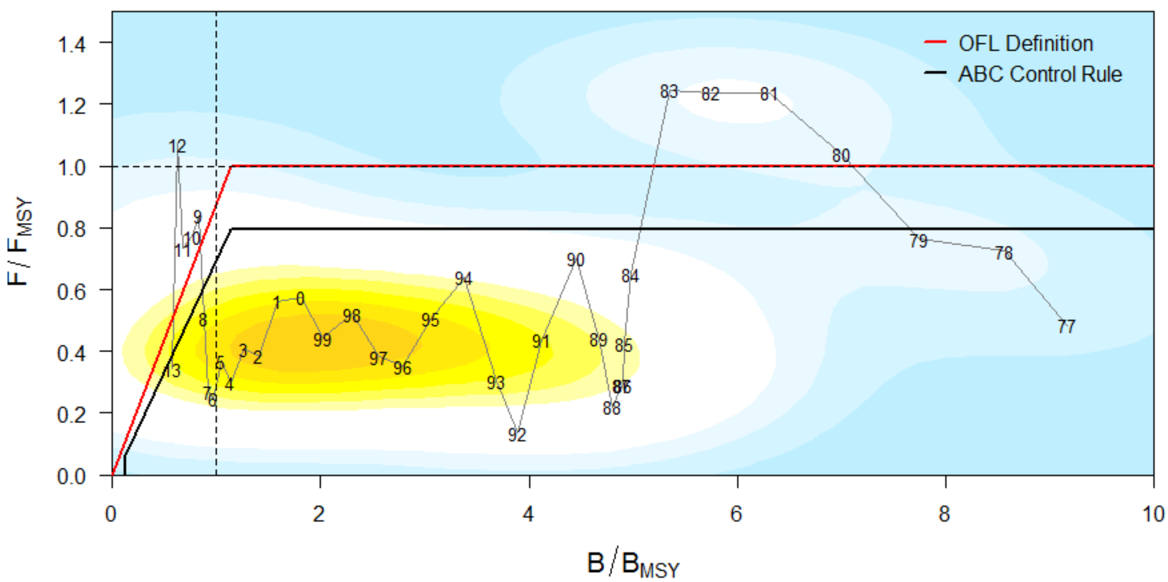


Figure 5.41. Ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1960-2011. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively. The Fs presented are the sum of the full Fs across fleets.

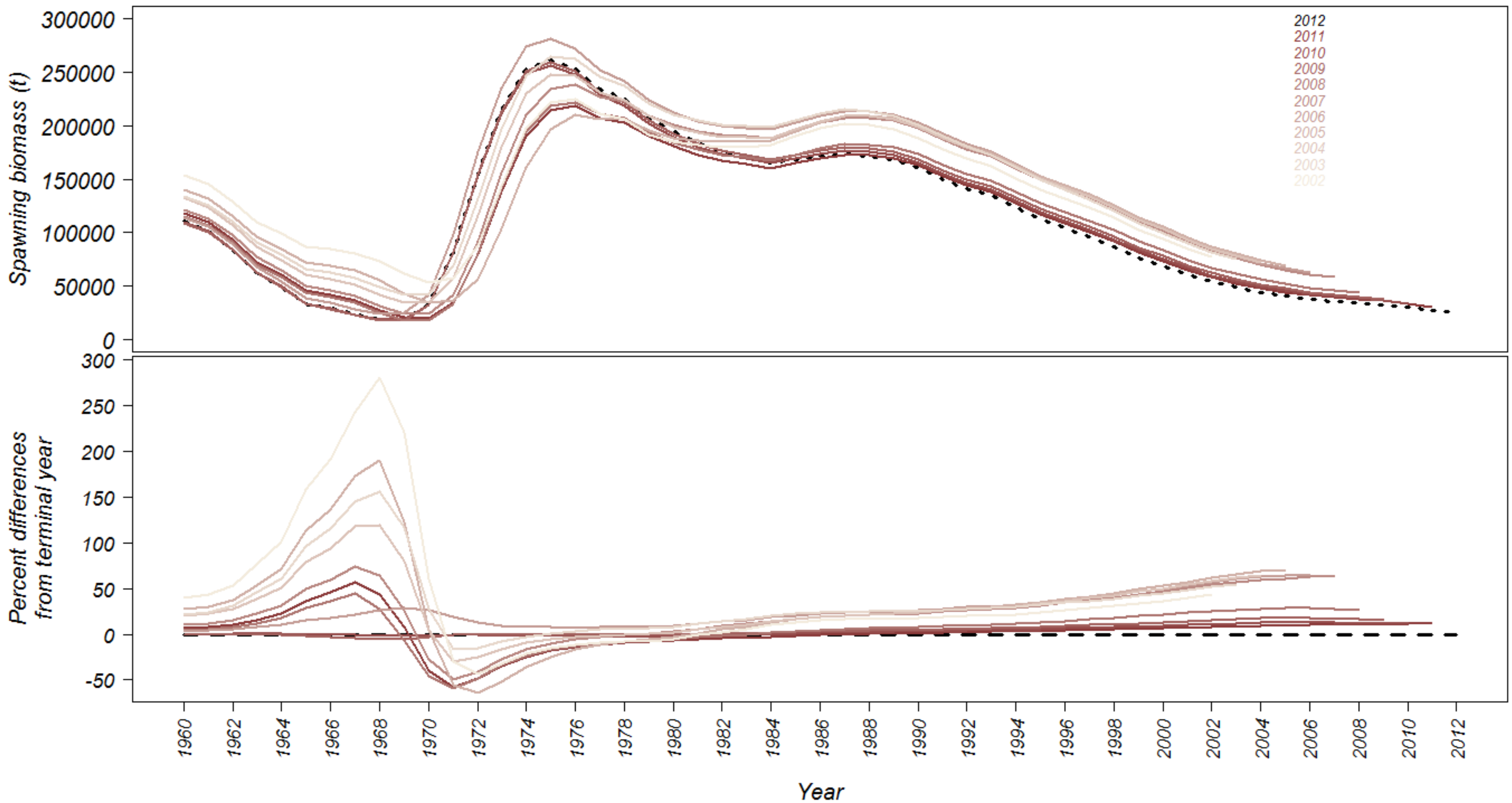


Figure 5.42. 2012 reference model retrospective analysis plot of spawning biomass (top) and change in spawning biomass per year for the retrospective runs (bottom).

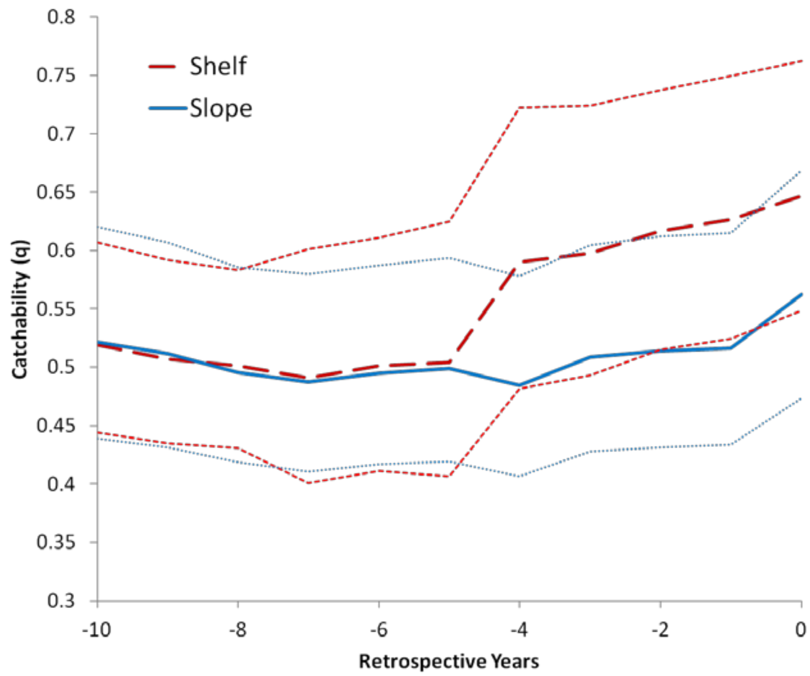


Figure 5.43. 2012 Reference model retrospective analysis plot of Shelf and Slope Survey catchability (q) estimates.

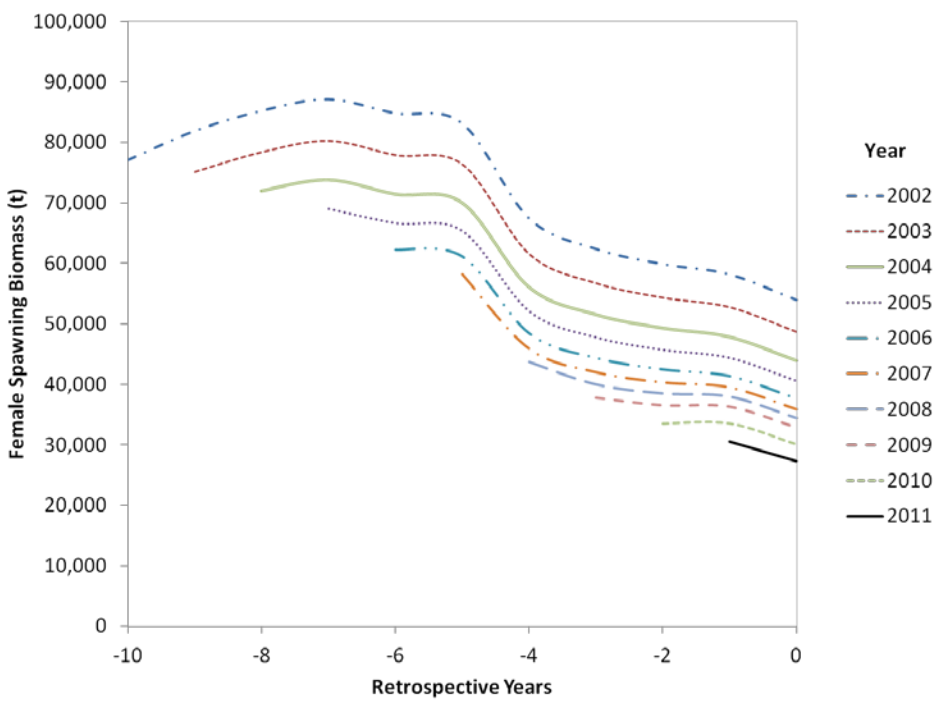


Figure 5.44. 2012 Reference model retrospective analysis plot of female spawning biomass. Each line is the female spawning biomass estimated for a specific year when data from 0 to 10 years were removed.

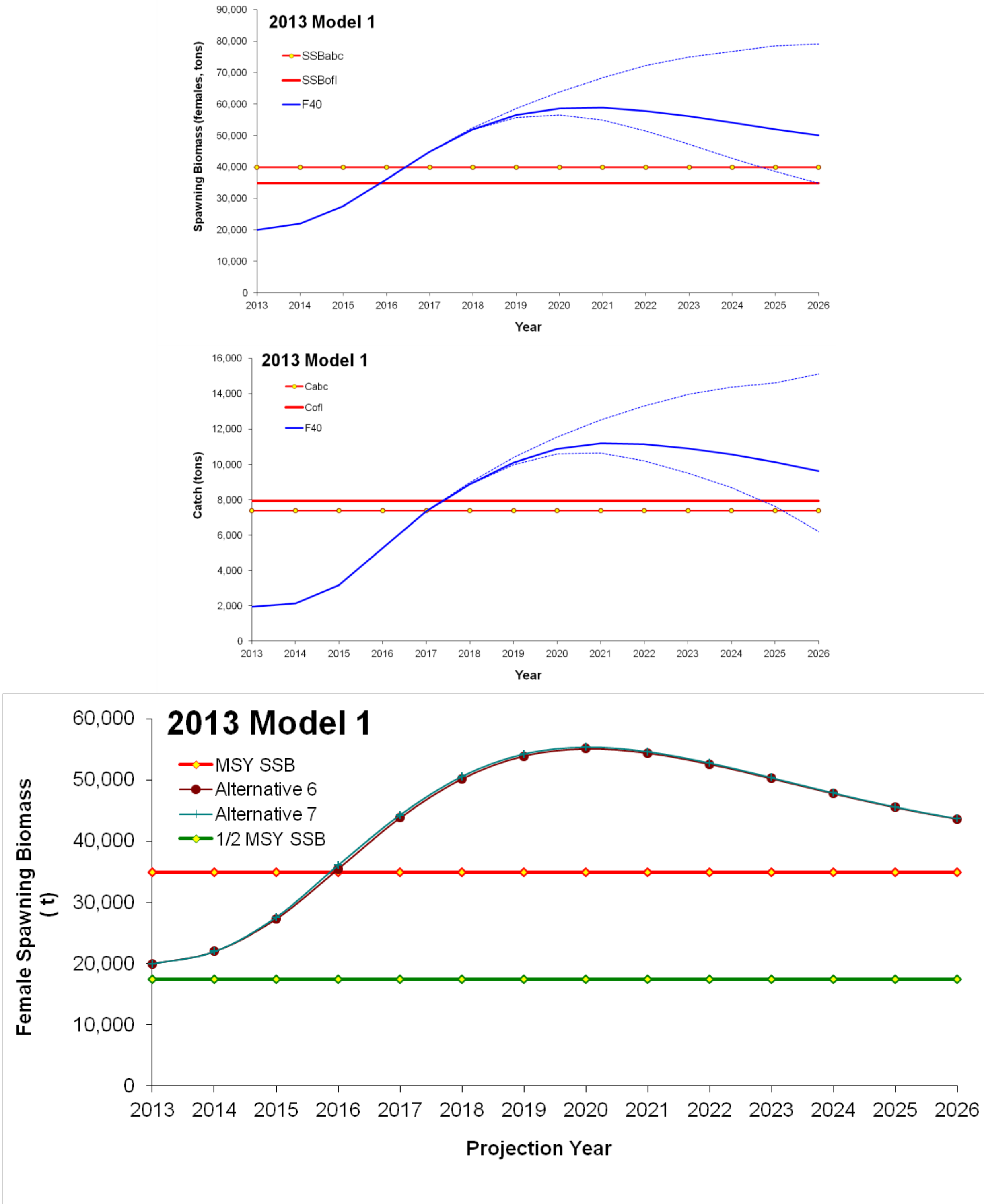


Figure 5.45. Alternative 1 projected (upper left) female spawning stock biomass and (upper right) catch at F_{40} fishing with long-term expected OFL and ABC reference levels, and (bottom) projected female spawning stock biomass under Alternatives 6 and 7 with SSB_{MSY} and ½ SSB_{MSY} reference levels. $SSB_{35\%}$ is our proxy for SSB_{MSY}.

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