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

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Executive summary

Relative to last year's assessment, the following changes have been made in the current assessment.

Changes to the input data

1. 2010 and 2011 catch data were updated (and added).
2. The Eastern Bering Sea (EBS) shelf survey 2011 biomass and length composition estimates were added.
3. Several additional years of NMFS bottom-trawl shelf-survey age data were completed and are included.
4. Fishery catch-at-length data were updated for longline and trawl gear from 2004-2011.

Changes to the assessment model

The software used was Stock Synthesis (SS3) version 3.21d (windows 64-bit). Changes from previous years included refinements to estimating selectivities (additional parameters estimated), an alternative model in which male natural mortality is estimated (with female mortality fixed), and some adjustments to the length bin structure.

Changes in the assessment results

The 2011 EBS shelf trawl survey biomass increased by 11% from the 2010 estimate to 26,200 t and is more than double the 2009 estimate. It is also the largest biomass estimate since 1998 and ranks 7th highest from the survey since 1987 (25 years). In terms of population numbers, the estimate for 2011 was the highest ever recorded with 2010 estimate coming in second (since the standard survey began in 1982). The total 2011 population estimate (in numbers, all ages) from the EBS survey was over five times the average for Greenland turbot. The high numbers were almost entirely due to an increase in Greenland turbot less than about 30 cm. Results from the longline survey (which provides an index of the adult population) indicate a low but steady population trend.

Model results based on these surveys and data from longline and trawl fisheries result in an estimate of $B_{40\%}$ equal to 21,560 t (female spawning biomass). The current estimate of the 2011 female spawning biomass is 51,300 t. There appears to be a favorable recruitment pattern in recent years and the 2010 survey saw the largest abundance of 1-yr old Greenland turbot on record. Recommended ABCs are set to the maximum permissible there are indications of strong recruitment. The corresponding maximum permissible ABC levels for Greenland turbot under Tier 3a are 9,660 and 8,029 t, for 2012 and 2013 espectively. The 2012 and 2013 overfishing levels, based on the $F_{35\%}$ rate are 11,658 t and 9,697 t corresponding to a full-selection F of 0.453.

Response to SSC comments

There were no comments specific to Greenland turbot assessment this year. Under general SAFE report comments they requested that if alternative models are available, they be arrayed so that ABC and OFL and status determinations can be selected. They also requested that authors incorporate their best estimate of total landings that will occur for the entire year.

Two model alternatives for ABC recommendations are provided in entirety. Catch for 2011 was based on the best available total-year estimate.

Summary

Quantity	As estimated or *specified last* year for: 2011	2012	As estimated or *recommended this* year for: 2012	2013
M (natural mortality rate)	0.112	0.112		
Tier	3a	3a		
Projected total (age 1+) biomass (t)	74,000	69,700	76,850	73,910
Female spawning biomass (t)				
Projected	45,504	40,407	47,687	41,441
$B_{100\%}$	71,048	71,048	53,900	53,900
$B_{40\%}$	28,419	28,419	21,560	21,560
$B_{35\%}$	24,867	24,867	18,870	18,870
F_{OFL}	0.293	0.293	0.453	0.453
$maxF_{ABC}$	0.247	0.247	0.367	0.367
F_{ABC}	0.247	0.247	0.367	0.367
OFL (t)	7,217	6,764	11,658	9,697
maxABC (t)	6,137	5,750	9,660	8,029
ABC (t; BSAI)	6,137	5,750	9,660	8,029
EBS	4,590	4,301	7,226	6,006
Aleutian Islands	1,547	1,449	2,434	2,023
Status	As determined *last* year for: 2009	2010	As determined *this* year for: 2010	2011
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) within the US 200-mile exclusive economic zone are mainly distributed in the eastern Bering Sea (EBS) and Aleutian Islands region. 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. 5.1). 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.

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).

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. For further background on this assessment and the methods used refer to Ianelli and Wilderbuer (1995).

Catch history and fishery data

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. 5.2). 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. Since 1996 the ABC levels have varied but averaged 7,660 t (with catch for that period averaging 4,550 t). The size frequency of the catch from the fisheries over time shows the how there are usually two modes present representing males at the smaller mode and females at the larger (Fig. 5.3).

Recently the trawl-caught Greenland turbot has exceeded the level of catch by longline vessels since about 2008 (Table 5.1). The shift in the proportion of catch by sector was due 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 by Bering Sea fishing vessels or processed onshore (as reported by PacFIN). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (at about one half of all sources of Greenland turbot discards during 1992-2002) while

Pacific cod fisheries and the "flatfish" fisheries also have contributed substantially to the discard levels (Table 5.2). About 12.6% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2010.

By gear-type and region, trawl catch was most significant in the Aleutian Islands in 2009 and 2010 whereas in the EBS there was high trawl catch in 2008 but then a switch to higher longline catches in 2009 -2011 (Table 5.3). By target fishery, the gain in trawl-fishery has occurred primarily in the Greenland turbot and "arrowtooth flounder" (and for 2011, the Kamchatka flounder) fisheries in 2008 - 2011 (Table 5.4).

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

Size and age composition

Fishery age composition data are becoming available for Greenland turbot. Age-determination methods have improved in the last few years and new age data are used this year. Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 1991. The length composition data from the trawl and longline fishery are presented in the appendix (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 – 2010 are given in Table 5.5.

Catch totals from research and other sources

Annual research catches (t, 1977 - 2011) 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	
NMFS Bottom trawl survey	62.5	48.4	103	124	2	1	175	0.2	0.5	19	0.6	0.7	9.0	0.9	1.4	2.0	
Longline surveys	3	3	6	11	9	7	8	7	11	6	16	10	10	22	23	23	
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NMFS Bottom trawl survey	1.4	1.5	1.2	1.4	1.0	5.1	1.1	5.3	1.1	11.0	0.7	0.76	0.59	0.49	0.42	0.816	0.950
Longline surveys												1.1	3.5	n/a	n/a	.364	

An updated 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	5.21
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).

Resource Surveys

EBS slope and shelf bottom trawl survey
The older juveniles and adults on the slope have 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. There was a gap in the planned biennial slope surveys when the 2006 survey was canceled but the surveys resumed in the summer of 2008 and in 2010 (Table 5.6).

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. Hence, the slope survey is treated as an index representing 75% of the stock based on earlier assessment analyses (Ianelli et al. 1993). The logic was based on average area-swept biomass estimates relative to the total compared to EBS on-shelf biomass and estimates of biomass from the Aleutian Islands (which are omitted from the model). 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 (Figs. 5.4 and 5.5). The shelf survey biomass estimates are therefore treated as a relative abundance index.

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) have averaged 55,000 t, with a 2004 level of 57,500 t. The average shelf-survey biomass estimate during the last 18 years (1993-2011) is 24,680 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys are presented in Table 5.7. In 2011 and 2010 the abundance estimates from the shelf surveys indicate a significant increase of Greenland turbot recruitment but also the proportion of tows with Greenland turbot present has increased (Fig. 5.6). 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.

As reported in Ianelli et al (2010) the 2010 EBS slope trawl survey biomass estimate was up by 11% from the next most recent slope survey (in 2008). Most of the change in estimated biomass was due to Greenland turbot abundances observed in the 400-600 m depth strata (Table 5.8).

Survey size and age composition
A time series of estimated size composition of the population was available for the shelf and slope trawl surveys and for the longline survey. 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 (Fig. 5.7). In the last 5 years signs of recruits (Greenland turbot less than about 40cm) is clear after a dearth 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 1975, 1979-1982. Gregg et al. (2006) revised age-determination methods for Greenland turbot and this year survey age composition data from 2003-2009 were included (previously only data from 1994, 1998, and 2007 surveys were available).

Aleutian Islands survey

As reported in Ianelli et al (2010) the 2010 Aleutian Islands bottom trawl survey estimate was 6,800 t, well below the 1991-2010 average level of 15,800 t (Table 5.6). The distribution of Greenland turbot in 2010 indicate lower abundances and variability of Greenland turbot in the survey compared to other recent surveys (Fig. 5.8). The breakdown of area specific survey biomass for the Aleutian Islands region shows that the eastern region has the highest densities and contains about 61% of the biomass, on based on average biomass from survey data from 1991-2010 (Fig. 5.9; Table 5.9). 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 sablefish longline survey alternates years between the Aleutian Islands and the Eastern Bering Sea slope region. This year 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. For this year's assessment, the 2008 and 2010 data were assigned CVs of 0.3 whereas a CV of 0.2 was used for the earlier period.

The survey time series (through 2011) 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:

Relative Population No. (RPN)									Year							
Area	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Bering 1		13,491		10,068		5,123		6,206		2,297		1,235		2,612		1,821
Bering 2		27,936		33,848		24,766		24,660		15,268		13,523		21,192		12,164
Bering 3		6,172		6,156		5,005		3,784		1,826		1,754		640		705
Bering 4		11,729		13,072		16,082		11,965		3,717		1,561		3,406		1,494
NE Aleutians	23,133		23,121		12,987		10,942		8,551		3,031		3,155		2,033	
NW Aleutians	7,212		7,208		4,049		3,411		2,666		945		984		634	
SE Aleutians	2,142		1,791		1,201		1,397		936		566		297		163	
SW Aleutians	6,775		5,665		3,800		4,420		2,962		1,789		939		517	
Bering Sea		59,328		63,144		50,975		46,616		23,107		18,074		27,850		16,184
Aleutians (total)	39,262		37,784		22,037		20,170		15,115		6,331		5,374		3,347	
Combined index	119.5	88.4	115.0	94.0	67.1	75.9	61.4	69.4	46.0	34.4	19.3	26.9	16.4	41.5	10.2	24.1

The combined time series shown above (1996-2011) was used as a relative abundance index. It was computed by taking the average RPN from 1996-2011 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 (1996-2011) are given here by each area as: p^{AI} (~33%) and p^{EBS} (~67%). 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 length frequency data from the longline survey extends back to the cooperative longline survey and is shown in Fig. 5.10.

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 four years as newer versions have become available.

Total catch estimates used in the model were from 1960 to 2011. Model parameters were estimated by maximizing the log posterior distribution of the predicted observations given the data. Prior distributions consisting of very small penalties on recruitment deviations from a mean value were assumed. This was required to stabilize estimates of recruitment early in the time series when data were limiting. The model included two fisheries, those using fixed gear (longline and pots) and trawls, together with three surveys covering various years (Table 5.10). An archive of the software and model configuration for the final model can be found at http://www.afsc.noaa.gov/refm/docs/2011/BSAIGturbot.zip.

Some key assumptions from past models were retained—most importantly that the slope-trawl survey is treated as an absolute index representing 75% of the Greenland turbot stock inhabiting US waters. In 2011 the NMFS survey extended into waters well north of the normal survey area but relatively minor amounts of Greenland turbot were found (Ianelli et al. 2010).

Selectivity Patterns

Gender-specific size-based selectivity functions were estimated for each survey and fishery described below. For the trawl fishery, foreign operations occurred prior to the domestic fishery hence could be treated as a single fishery with an allowance for different size-based selectivity patterns estimated for the respective periods. Because the EBS shelf trawl surveys appear to cover only part of the range of this stock, selectivity was allowed to vary over time at roughly 5-year periods. This increased the overall model uncertainty but reflected the uncertain nature of Greenland turbot occurrence on the EBS shelf region.

Parameters estimated independently

Natural mortality, length at age, length-weight relationship

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

Parameters describing length-at-age are estimated within the model. Length at age 1 is assumed to be the same for both sexes and the variability in length at age 1 was assumed to have a 9% CV while at age 25 the CV was freely estimated. 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 5.11.

The length-weight relationship for Greenland turbot estimated by Ianelli et al. (1993) was:

$$w = 2.69\times10^{-6} L^{3.3092} \quad \text{for females}$$

and

$$w = 6.52\times10^{-6} L^{3.068} \quad \text{for males}$$

where L = length in mm, and w = weight in grams.

Maturation and fecundity

Recent studies on the fecundity of Greenland turbot indicate that estimates of fecundity 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.

Parameters estimated conditionally

The key parameters estimated within the model include:

- Annual age-0 recruitment estimates from 1960-2010 (parameterized as deviations scaled to the estimated mean recruitment)
- Selectivity for the 2 fisheries, and 3 surveys over different time frames, and
- Growth: 5 parameters (2 for each sex, one in common).
- Natural mortality of males (relative to females which were fixed at 0.112;—model 2 in this year's assessment)

Model evaluation

Size composition data are unavailable until 1977 hence recruitment estimates information during the early period (1960s) are highly uncertain. The removal of 574,000 tons of Greenland turbot between 1972 and 1981 (compared to a total 64,300 t from 1997-2011) and the observed trends in abundance indicate that recruitment during the 1960s must have been high. Lacking information on the age (or sizes) of these fish impedes estimation of which (or how many) year classes were high. In previous assessments sensitivity to these estimates was performed. Evaluations of alternative model configurations were limited due to complexity related to selectivities, gear types, and general paucity of information specific to Greenland turbot.

Since gender-specific natural mortality rates are considered important for a number of flatfish species (e.g., Ralston 2006, Wilderbuer and Turnock 2009), we evaluated the ability to estimate male natural mortality relative to females (which remained fixed at 0.112).

Results

Comparing the model with and without assuming male mortality was the same as females (at 0.112) resulted in better overall fits (~10 ln-likelihood units) when male mortality was freely estimated. Strictly speaking, the addition of a single parameter to improve model fit would be justified. However, the improvements come largely from the stock recruitment likelihood component (Table 5.12). While model 2 might justifiably be considered the best choice for proceeding with ABC recommendations, we feel that it would be premature—principally because the stock recruitment function in a model like this is essentially a prior on how recruitment may vary relative to spawning biomass and may be inappropriate to include as a model selection criterion. However, we provide the summary tables and projection results for Model 2 as an attachment should the Plan Teams or SSC wish to use those results. Results for model fits and other tables will all refer to Model 1 option (male and female natural mortality fixed at 0.112).

The model fit to the index data shows residual patterns that are autocorrelated but fall generally well within the confidence bands assumed for the data (Fig. 5.11). Such autocorrelation might be expected for species such as Greenland turbot in the BSAI region since they appear to be affected by periods of warm and cold bottom temperatures rather than real changes in abundance. The fit to the slope survey (considered to best cover the habitat for Greenland turbot and be less susceptible to temperature changes) fits well.

Trends in Abundance

The biomass of Greenland turbot increased during the 1970s from the early 1960s level and is currently about 61% of the level expected under no fishing using average recruitment since 1977. The recent trend shows a gradual decline over the past 3 decades with the 2012 total begin-year biomass (age 1 and older) estimate to about 76,800 t (Table 5.13).

The historical fishing mortality rates (combined gears) began at high levels (but highly uncertain), decreased then peaked in recent decades in 1980 through 1983 (Table 5.13; Fig. 5.12). A comparison of this year's model result with the 2010 assessment shows Table 5.13. The current assessment results in similar abundances during the mid 1970s compared to assessments prior to 2009 (Fig. 5.13). The estimated historical numbers at age is given in Table 5.14.

Selectivity

Estimates of selectivity (using recommended option #24 in SS3—a "double normal" parameterization which describes the ascending and descending limbs of the curve with defined initial and final selectivity levels as parameters) provide patterns that appear reasonable over time for the shelf survey and other gear types (Figs. 5.14 and 5.15). Since the male selectivity estimates were different for these gear types, the proportions at sex between gear types over time was examined. This showed that the trawl fishery tends to catch slightly less than 50% females whereas the longline fishery catch has comprised about 70% females with a distinct trend towards 50:50 in recent years (Fig. 5.16). The slope trawl survey also shows that there is variability in the proportions female over time. In 2002, 2008, and 2010 the survey resulted in far more males than females—opposite of what was estimated for 2004 (more females than males; Fig. 5.17). This highlights the variability within the same region between years regarding observed sex ratios and also the difficulty in fitting the data—especially when sex ratio differences appear to occur at relatively small sizes (e.g., <30cm).

Selectivity of Greenland turbot varied considerably between all of the surveys and fisheries. The shelf survey selected only small fish whereas the slope survey caught much larger fish. A similar pattern was observed between the trawl and longline fisheries with the longline fishery consistently catching larger Greenland turbot (e.g., Fig. 5.14). Note that the average selectivity estimates for the slope and shelf surveys indicate that the surveys sample intermediate size fish (35-50cm) poorly. The reason for this is unclear; however, it could be related to the apparent bi-modality in the size distribution observed in the trawl fishery. The approximate age and sex-specific selectivity estimates (for 2010) from each gear type for Greenland turbot in the BSAI is given in Table 5.15. These are approximate because selectivity processes are modeled as a function of size. Similarly, approximate age-and-sex-specific weights are available and these are used in the projection model (Table 5.16).

Fit to age and size composition data

The model fit the available length-at-age data reasonably well and indicates that females grow larger than male Greenland turbot (Fig. 5.18). Size composition observations from the fisheries and surveys are matched by the model predictions reasonably well (see Attachment 5.A, Figs. 5.22 -5.27). The discrepancies observed may be attributed to three issues. First, in some years, relatively few fish were measured so adjustments of the model to those data would depend on the trade-off in fitting other data, which may have had more extensive sampling. Second, unaccounted fish movement and hence changing availability affects fits to size composition data when an "average" (as opposed to annually varying) gear selectivity is used. Finally, natural mortality rate is undoubtedly variable among cohorts and years, the extent of which would affect our ability to model the age structure of the population accurately.

Recruitment

Recruitment of young juvenile Greenland turbot appeared to have been poor for about 15 years since the early 1980s after several strong year-classes during the 1970s. Recently, and especially in 2010, there has been evidence of big increases in recruitment for Greenland turbot (Fig. 5.19).

Maximum Sustainable Yield

Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship including that the spawning stock range is covered. For Greenland turbot is is likely that the stock extends beyond the range of the area surveyed and fished. For this reason, a harvest strategy using spawning biomass per recruit as proxies for F_{msy} (e.g., $F_{35\%}$) was selected in the absence of information on the stock-recruitment productivity relationship required for calculating MSY levels.

Projections and harvest alternatives

Amendment 56 Reference Points

The recommended harvest levels vary considerably among models depending on the assumptions made about the catchability coefficients from the slope-trawl survey (Ianelli et al. 1999). Since there are several areas of uncertainty surrounding this assessment, recommendations were based on a conservative model configuration.(assuming slope-survey catchability=0.75). The status of the projected spawning biomass in year 2012 relative to $B_{40\%}$ would place Greenland turbot in Tier 3a of Amendment 56.

The $B_{40\%}$ value using the mean recruitment estimated for the period 1978-2009 gives a long-term average female spawning biomass of 21,560 t. The estimated 2012 female spawning biomass is about 47,700 t, above the estimate of $B_{35\%}$ (18,870 t).

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. This 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. Hence, the arguments for keeping the ABC recommendation below the maximum permissible are less compelling. Therefore we recommend that the ABC be set to the maximum permissible.

The projected Greenland turbot maximum permissible ABC and OFL levels for 2012 and 2013 are shown below (catch for 2012 was set equal to the ABC recommendation):

Year	Catch (for 2013projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2012	9,660 t	9,660 t	9,660 t	11,658 t	47,687 t
2013		8,029 t	8,029 t	9,697 t	41,441 t

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is 11,658 t corresponding to a full-selection F of 0.453. 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). The history of stock size relative to the reference level (based on recruitments since 1977) shows that the fishing mortality has been well below the $F_{40\%}$ level but is beginning to increase (Fig. 5.20).

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 5.17).

Recent research on recruitment processes holds promise for clearer understanding (e.g., Sohn et al. (2010) 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 three surveys (when both areas were covered) were 26.4%, 23.7%, and 25.5%. These average 25.2% which when applied to the BSAI ABC gives the following region-specific allocation:

	ABC
Aleutian Islands ABC	2,434
Eastern Bering Sea ABC	7,226
Total	9,660

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 2011 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2012 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2011 (here assumed to be 2,858 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 2012, 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 2007-2011 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 2011 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2012 and 2013, 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 2024 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2011 (Table 5.18). Fishing at the maximum permissible rate indicate that the spawning stock will gradually drop to near the $B_{40\%}$ by 2021 (Fig. 5.21).

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 2011 spawning biomass estimated at 51,278 t relative to $0.5B_{35\%}$ = 12,433 t). Under the guidelines, since the 2011 biomass estimate is above the $B_{35\%}$ level (and $B_{40\%}$) and the stock is not overfished.

Projections with fishing at the maximum permissible level result in an expected value of spawning biomass of 40,291 t by 2024. These projections illustrate the impact of the recent recruitment observed in the survey. For example, under all scenarios except the no-fishing alternative, the spawning biomass is expected to decline until 2015 when the recruits in recent years mature.

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

Other Considerations

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.

Research and data gaps

A number of research and modeling issues continue to require further consideration. These include:

- An evaluation of possible differential natural mortality between males and females,

- Development of statistically based "effective sample size" values for size composition data (e.g., through boot-strapping original survey and observer data),
- Including more length-at-age information using the new methods, investigating age-specific natural mortality, and
- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear.

Summary

The pattern of total fishing mortality relative to spawning biomass suggests that the EBS Greenland turbot stock is approaching the $B_{40\%}$ level, but that historically the fishing mortality was below the $F_{40\%}$ level (Fig. 5.20). Management parameters of interest derived from this assessment are presented in Table 5.19.

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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	31.8	52,122	60,000	
1983	47,529	28.8	47,558	65,000	
1984	23,107	12.6	23,120	47,500	
1985	14,690	40.6	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	6,245	1,617	7,863	7,000	7,000
1992	749	3,003	3,752	7,000	7,000
1993	1,145	7,323	8,467	7,000	7,000
1994	6,426	3,845	10,272	7,000	7,000
1995	3,978	4,215	8,194	7,000	7,000
1996	1,653	4,902	6,555	7,000	7,000
1997	1,209	5,989	7,199	9,000	9,000
1998	1,830	7,319	9,149	15,000	15,000
1999	1,799	4,057	5,857	9,000	9,000
2000	1,946	5,027	6,973	9,300	9,300
2001	2,149	3,163	5,312	8,400	8,400
2002	1,033	2,605	3,638	8,000	8,000
2003	908	2,605	3,513	4,000	4,000
2004	675	1,544	2,220	3,500	3,500
2005	729	1,831	2,559	3,500	3,500
2006	360	1,605	1,965	2,740	2,740
2007	429	1,400	1,829	2,440	2,440
2008	1,935	806	2,741	2,540	2,540
2009	3,080	1,417	4,497	7,380	7,380
2010	2,070	1,975	4,046	6,120	6,120
2011	1,340	1,518	2,858*	6,140	5,050

*Catch estimated as of October 2011

Table 5.2. Estimates of BSAI discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2011 (the "arrowtooth" fishery was combined with the Greenland turbot fishery from 2003-2011).

Fishery:	Greenland turbot		Sablefish		Pacific cod		Rockfish		Flatfish		Others		Combined	
Year	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	1,676	28	63	19	156	30	136	5	179	69	149	49	2,359	200
2006	1,340	33	62	52	65	32	71	8	105	23	135	46	1,778	194
2007	1,225	28	59	71	128	91	36	13	59	39	198	50	1,704	292
2008	1,706	417	42	82	16	69	142	1	96	37	206	104	2,207	710
2009	3,649	336	69	54	65	21	69	8	52	13	148	14	4,053	445
2010	3,580	98	62	27	109	19	57	2	23	73	78	8	3,910	227
2011	2,330	14	41	7	142	7	20	1	577	39	64	10	3,174	78

Table 5.3. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2003-2011.

Area	Gear	2003	2004	2005	2006	2007	2008	2009	2010	2011
Aleutian	Fixed	650	218	167	355	343	115	97	213	82
Islands	Trawl	315	196	301	179	178	712	2,164	1,653	412
Aleutian Islands	Total	965	414	439	468	534	521	827	2,261	1,866
	Fixed	1,918	1,326	1,713	1,270	1,200	873	1,333	1,947	1,589
EBS	Trawl	575	479	427	183	280	1,223	916	322	1,170
	EBS Total	2,493	1,805	2,120	2,140	1,452	1,481	2,095	2,249	2,272
BSAI Total		3,458	2,220	2,608	1,986	2,002	2,922	4,510	4,138	3,252

Table 5.4. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2004-2011. Source: NMFS AK Regional Office catch accounting system. *Note, 2011 data are preliminary.*

	"Target" fishery	2004	2005	2006	2007	2008	2009	2010	2011
	Greenland turbot	1,168	1,527	1,212	1,097	573	1,192	1,818	1,371
	Sablefish	90	75	114	130	119	122	77	41
Longline and pot	Pacific cod	221	170	77	129	76	84	121	152
	Shallow-water flatfish	64	57	61	15	15	7	77	26
	Arrowtooth flounder	0	2	140	16	0	9	53	0
	Others	1	0	3	12	22	4	0	
	Greenland turbot	61	24	0	2	205	1,349	118	4
	Pacific cod	79	15	19	89	11	2	7	0
	Arrowtooth flounder	53	154	21	3	1,176	1,435	1,689	892
	Kamchatka flounder								582
	Atka mackerel	123	167	117	130	201	118	62	45
	Flathead sole	191	150	28	30	98	49	12	2
Trawl	Pollock	18	31	65	107	82	44	1	4
	Rockfish	74	139	74	47	143	73	59	22
	Other Flatfish	51	34	1	12	11	4	1	0
	Rock sole	4	1	27	8	0	2	3	1
	yellowfin sole	1	7	8	1	1	4	1	4
	Sablefish	12	7	0	0	6	0	12	6
	Others	8	0	0	0	0	0	0	0

Table 5.5. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2011 (Source: NMFS observer program data) and assumptions on multinomial sample sizes by gear type (columns headed SS N).

	Trawl fishery				Longline fishery			
Year	Female	Male	% Female	SS N	Female	Male	% Female	SS N
1989	1,335	5,002	21%	141	0	0		Na
1990	3,864	5,762	40%	386	0	0		Na
1991	1,851	1,752	51%	192	0	0		Na
1992					0	0		Na
1993				0	3,921	915	81%	392
1994	1,122	1,027	52%	102	503	150	77%	50
1995	217	355	38%	26	1,870	715	72%	187
1996	112	390	22%	11	941	442	68%	94
1997	0	0		0	2,393	1,014	70%	239
1998	307	696	31%	31	3,510	2,127	62%	351
1999	1,044	1,556	40%	104	7,961	2,835	74%	500
2000	724	1,328	35%	72	6,550	2,962	69%	500
2001	467	892	34%	47	4,054	1,550	72%	405
2002	186	433	30%	19	4,725	1,811	72%	473
2003	197	325	38%	20	4,608	2,113	69%	462
2004	179	433	29%	39	4,286	2,564	63%	435
2005	118	211	36%	21	4,639	1,902	71%	415
2006	15	76	16%	6	3,338	1,473	69%	305
2007	34	23	60%	4	3,816	2,127	64%	377
2008	421	1,572	21%	127	1,577	1,481	52%	194
2009	1,017	2,993	25%	255	3,486	2,704	56%	393
2010	289	3,560	8%	244	3,290	2,859	54%	390
2011	262	536	33%	51	1,043	641	62%	107

Table 5.6. Survey 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	10,600		
1988	14,800	42,700	
1989	8,900		
1990	14,300		
1991	13,000	40,500	11,925
1992	24,000		
1993	30,400		
1994	48,800		28,227
1995	34,800		
1996	30,300		
1997	29,218		28,334
1998	28,126		
1999	19,797		
2000	22,957		9,359
2001	25,347		
2002	21,450	27,589	9,891
2003	23,685		
2004	20,910	36,557	11,334
2005	21,359		
2006	20,933		20,934
2007	16,726		
2008	13,514	17,901	NA
2009	10,956		
2010	23,415	19,873	6,795
2011	26,156		

* U.S. - Japanese cooperative surveys

Table 5.7. 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	334	41	1,228	11	11	292	292
1983	353	55	951				
1984	355	27	536	20		263	
1985	358	46	200				
1986	354	53	195				
1987	360	36	354				
1988	373	58	414				
1989	373	56	376				
1990	371	62	544				
1991	372	65	658				
1992	356	64	616	5		7	
1993	375	73	632	7		179	
1994	376	52	530	17		196	
1995	376	49	343				
1996	375	75	450	8		100	
1997	376	64	298	11		79	
1998	375	73	445	25	21	200	127
1999	373	43	128	8		11	
2000	372	57	248	34		188	
2001	375	58	270	43		215	
2002	375	70	455	21		71	
2003	376	71	622	62	26	435	192
2004	375	64	606	45	45	290	280
2005	373	61	441	56	55	293	277
2006	376	56	427	49	48	262	239
2007	376	83	499	68	68	334	311
2008	375	78	406	59	59	245	235
2009	376	103	856	72	32	351	344
2010	376	144	3,199	70		362	
2011	376	155	4,381	61		427	

Table 5.8. Eastern Bering Sea slope survey estimates of Greenland turbot biomass (t), 2002, 2004, 2008, and 2010 by depth category.

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

Table 5.9. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot biomass (t), 1980-2010.

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	1,070	1,544	3,698	482	6,795
Avg. since 1991	1,749	2,607	9,735	1,755	15,846

Table 5.10. Data sets used in the stock synthesis (SS3) model for Greenland Turbot in the EBS. All size and age data are specified by sex.

Data Component	**Years of data**
Survey size at age data	1994, 1998, 2003-2009
Shelf survey: size composition and biomass estimates	1979-2011
Shelf survey age composition data	1998, 2003-2009
Slope survey: size composition and biomass estimates	1979, 1981, 1982, 1985, 1988, 1991, 2002, 2004, 2008, 2010
Longline survey: size composition and abundance index	1996-2011
Total fishery catch data	1960-2011
Trawl fishery size composition	1977-87, 1989-91, 1993-2011
Longline fishery size composition	1977, 1979-85, 1992-2011

Table 5.11. Summary of the shelf-survey length-at-age information used for this BSAI Greenland turbot assessment and sample size by age and by year.

	Mean length (cm)		Sample size	
Age	Female	Male	Female	Male
1	14.28	13.26	19	19
2	22.70	22.90	33	34
3	30.65	29.85	29	35
4	34.22	35.15	31	36
5	38.95	40.08	30	33
6	44.31	43.91	23	29
7	49.46	46.49	28	26
8	52.55	48.54	25	27
9	56.45	54.12	19	28
10	64.36	58.04	23	20
11	69.85	59.82	22	12
12	76.30	69.88	20	11
13	75.05	67.21	23	10
14	81.84	75.50	19	4
15	77.41	73.41	17	12
16	82.15	73.30	18	10
17	83.62	74.51	24	12
18	88.93	75.50	21	8
19	88.27	76.41	23	10
20	86.41	79.00	28	9
21	88.36	73.66	26	4
22	90.22	77.00	12	6
23	87.77		20	
24	87.95	75.85	15	13
25	86.99	75.15	21	9
26	93.49	77.51	16	5
27	87.11	73.50	11	4
28	91.21	78.00	12	4
29	90.99	79.60	10	5
30	89.08	78.50	25	10

	Sample size	
Year	Female	Male
1998	75	53
2003	107	60
2004	105	52
2005	78	67
2006	68	51
2007	72	63
2008	69	46
2009	69	53

Table 5.12. Negative log likelihood components of the Greenland turbot comparing models 1 (M fixed) and model 2 (male mortality freely estimated). Right-most two columns represent the difference from the "best fitting" for that component—shading indicates a worse fit)

-ln likelihood component	M Fixed Model 1	M Est Model 2	M Fixed Model 1	M Est Model 2
Age composition	210.1	208.6	1.5	0.0
Length composition	2,175.8	2,179.3	0.0	3.4
Recruitment	113.0	102.7	10.3	0.0
Size at age	833.5	826.9	6.6	0.0
Survey indices	-26.4	-21.4	0.0	5.0
Total	3,306.0	3,296.0	10.0	0.0

Table 5.13. Fishing mortality rate (maximum F over ages, combined sex and fisheries), harvest rate (measured as 1-SPR), spawning and total biomass (compared with the 2010 assessment) for BSAI Greenland turbot, 1960-2011.

Year	Total Fishing Mortality	1-SPR	Female Spawning Biomass 2010 Assessment	Female Spawning Biomass Current Assessment	Total Age 1+ Biomass 2010 Assessment	Total Age 1+ Biomass Current Assessment
1960	0.17	0.485	258,392	118,843	474,088	220,366
1961	0.31	0.725	249,139	113,381	448,382	194,345
1962	0.43	0.859	233,857	102,327	410,807	157,311
1963	0.31	0.817	217,227	85,826	382,489	129,006
1964	0.33	0.846	207,912	74,723	387,637	133,337
1965	0.07	0.404	199,234	66,321	405,268	150,022
1966	0.07	0.352	201,923	74,009	454,564	196,743
1967	0.09	0.415	214,194	92,187	513,301	253,541
1968	0.10	0.441	236,920	118,828	572,267	311,592
1969	0.09	0.384	267,433	150,934	628,292	367,441
1970	0.06	0.261	303,476	187,110	687,282	426,328
1971	0.10	0.413	344,265	227,388	754,980	495,239
1972	0.18	0.586	378,122	263,160	800,335	544,065
1973	0.14	0.526	398,008	288,527	802,344	551,959
1974	0.18	0.599	419,604	315,374	804,777	557,812
1975	0.16	0.577	433,239	333,284	779,701	535,080
1976	0.16	0.587	445,162	344,128	755,006	510,665
1977	0.09	0.392	448,813	342,858	726,749	484,585
1978	0.12	0.507	455,179	344,621	726,596	489,050
1979	0.13	0.516	448,328	336,226	710,828	483,658
1980	0.17	0.601	438,277	327,888	692,314	482,781
1981	0.19	0.639	421,551	316,764	658,565	472,334
1982	0.18	0.615	401,701	305,743	614,943	454,325
1983	0.16	0.596	383,432	300,647	569,952	434,625
1984	0.08	0.381	364,461	296,896	523,769	410,716
1985	0.05	0.268	354,272	300,123	496,953	401,782
1986	0.04	0.191	344,867	302,051	474,170	393,764
1987	0.04	0.189	334,294	300,666	452,610	384,540
1988	0.03	0.151	320,364	294,188	428,782	371,096
1989	0.04	0.192	304,839	284,481	405,651	356,651
1990	0.07	0.278	286,540	271,102	379,923	338,026
1991	0.04	0.203	265,271	254,463	349,900	314,078
1992	0.01	0.109	246,392	238,886	325,430	294,602
1993	0.03	0.229	229,402	224,266	305,148	279,179
1994	0.07	0.268	209,171	206,306	280,792	259,257
1995	0.05	0.246	190,557	189,773	255,222	237,313
1996	0.04	0.222	173,884	174,729	232,722	217,654
1997	0.05	0.256	158,867	160,564	212,765	199,870
1998	0.07	0.322	143,845	145,984	193,194	181,958
1999	0.05	0.246	128,066	130,564	172,775	162,914
2000	0.07	0.302	115,466	118,109	156,575	147,730
2001	0.07	0.273	102,728	105,568	140,403	132,537
2002	0.05	0.227	92,402	95,251	127,252	120,324
2003	0.05	0.236	83,723	86,466	117,110	111,554
2004	0.03	0.176	75,762	78,554	108,454	104,569
2005	0.04	0.211	69,472	72,690	102,061	99,974
2006	0.03	0.182	63,755	67,853	95,884	95,501
2007	0.03	0.172	59,422	64,537	90,773	91,825
2008	0.06	0.199	56,110	61,791	86,111	88,135
2009	0.10	0.301	53,151	59,031	81,298	83,822
2010	0.08	0.309	49,176	55,288	76,979	78,586
2011	0.08	0.254		51,278		75,026

Table 5.14. Estimated beginning of year numbers of Greenland turbot by age and sex (millions).

Females

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	87.8	6.1	61.3	17.0	32.0	2.4	1.6	4.0	23.0	18.6	15.0	12.2	10.3	9.1	8.1	7.3	6.4	5.4	0.5	0.4	3.2
1978	26.8	78.5	5.5	54.6	15.1	28.2	2.1	1.4	3.5	19.9	16.0	12.9	10.5	8.9	7.9	7.1	6.3	5.5	4.7	0.5	3.2
1979	12.2	23.9	70.0	4.9	48.3	13.2	24.4	1.8	1.2	3.0	16.8	13.6	11.0	9.0	7.5	6.7	6.0	5.4	4.7	4.0	3.2
1980	15.3	10.9	21.4	62.3	4.3	42.3	11.5	20.9	1.5	1.0	2.5	14.3	11.5	9.3	7.6	6.4	5.7	5.2	4.6	4.1	6.1
1981	1.4	13.7	9.7	19.0	55.0	3.8	36.2	9.7	17.5	1.3	0.8	2.1	11.9	9.6	7.8	6.4	5.4	4.8	4.3	3.9	8.6
1982	2.8	1.3	12.2	8.6	16.7	47.7	3.2	30.5	8.1	14.5	1.1	0.7	1.7	9.8	8.0	6.5	5.3	4.5	4.1	3.6	10.6
1983	1.2	2.5	1.1	10.8	7.6	14.5	40.7	2.7	25.4	6.7	12.0	0.9	0.6	1.4	8.3	6.7	5.5	4.5	3.8	3.4	12.1
1984	3.2	1.1	2.3	1.0	9.5	6.6	12.4	34.4	2.3	21.3	5.6	10.1	0.7	0.5	1.2	7.0	5.7	4.6	3.8	3.3	13.3
1985	11.1	2.9	1.0	2.0	0.9	8.4	5.8	10.8	29.8	2.0	18.4	4.9	8.7	0.6	0.4	1.1	6.1	5.0	4.0	3.3	14.5
1986	2.5	10.0	2.6	0.9	1.8	0.8	7.4	5.1	9.5	26.2	1.7	16.1	4.3	7.7	0.6	0.4	0.9	5.4	4.4	3.6	15.7
1987	3.6	2.2	8.9	2.3	0.8	1.6	0.7	6.6	4.5	8.4	23.1	1.5	14.3	3.8	6.8	0.5	0.3	0.8	4.7	3.9	17.1
1988	2.8	3.2	2.0	8.0	2.0	0.7	1.4	0.6	5.8	4.0	7.4	20.4	1.3	12.6	3.3	6.0	0.4	0.3	0.7	4.2	18.5
1989	12.7	2.5	2.9	1.8	7.1	1.8	0.6	1.3	0.5	5.1	3.5	6.5	18.0	1.2	11.2	2.9	5.3	0.4	0.3	0.6	20.2
1990	2.5	11.3	2.2	2.6	1.6	6.3	1.6	0.5	1.1	0.5	4.5	3.1	5.8	15.9	1.0	9.9	2.6	4.7	0.3	0.2	18.5
1991	0.9	2.2	10.1	2.0	2.3	1.4	5.6	1.4	0.5	1.0	0.4	4.0	2.7	5.1	14.0	0.9	8.7	2.3	4.1	0.3	16.5
1992	0.8	0.8	2.0	9.1	1.8	2.1	1.3	4.9	1.2	0.4	0.9	0.4	3.5	2.4	4.5	12.3	0.8	7.7	2.0	3.7	14.8
1993	0.5	0.7	0.7	1.8	8.1	1.6	1.8	1.1	4.4	1.1	0.4	0.8	0.3	3.1	2.1	4.0	10.9	0.7	6.8	1.8	16.4
1994	0.7	0.5	0.6	0.7	1.6	7.2	1.4	1.6	1.0	3.9	1.0	0.3	0.7	0.3	2.7	1.9	3.5	9.6	0.6	5.9	15.9
1995	3.0	0.6	0.4	0.6	0.6	1.4	6.5	1.3	1.4	0.9	3.4	0.9	0.3	0.6	0.3	2.4	1.6	3.0	8.4	0.6	19.2
1996	2.2	2.7	0.6	0.4	0.5	0.5	1.3	5.8	1.1	1.3	0.8	3.0	0.8	0.3	0.5	0.2	2.1	1.4	2.7	7.4	17.3
1997	1.3	2.0	2.4	0.5	0.3	0.5	0.5	1.1	5.1	1.0	1.1	0.7	2.7	0.7	0.2	0.5	0.2	1.8	1.3	2.3	21.6
1998	2.1	1.2	1.8	2.2	0.5	0.3	0.4	0.4	1.0	4.5	0.9	1.0	0.6	2.3	0.6	0.2	0.4	0.2	1.6	1.1	20.9
1999	7.6	1.8	1.0	1.6	1.9	0.4	0.3	0.4	0.4	0.9	4.0	0.8	0.9	0.5	2.0	0.5	0.2	0.3	0.1	1.4	19.1
2000	6.8	6.8	1.7	0.9	1.4	1.7	0.4	0.2	0.3	0.3	0.8	3.5	0.7	0.8	0.5	1.8	0.4	0.1	0.3	0.1	17.9
2001	7.8	6.1	6.1	1.5	0.8	1.3	1.5	0.3	0.2	0.3	0.3	0.7	3.1	0.6	0.7	0.4	1.5	0.4	0.1	0.3	15.7
2002	1.0	7.0	5.4	5.4	1.3	0.7	1.1	1.4	0.3	0.2	0.2	0.3	0.6	2.7	0.5	0.6	0.3	1.3	0.3	0.1	14.0
2003	0.4	0.9	6.3	4.9	4.8	1.2	0.7	1.0	1.2	0.3	0.2	0.2	0.2	0.5	2.4	0.5	0.5	0.3	1.2	0.3	12.4
2004	0.4	0.3	0.8	5.6	4.3	4.3	1.1	0.6	0.9	1.1	0.2	0.1	0.2	0.2	0.5	2.1	0.4	0.4	0.3	1.0	11.2
2005	0.6	0.3	0.3	0.7	5.0	3.9	3.9	0.9	0.5	0.8	1.0	0.2	0.1	0.2	0.2	0.4	1.8	0.4	0.4	0.2	10.8
2006	4.8	0.5	0.3	0.3	0.6	4.5	3.5	3.4	0.8	0.5	0.7	0.8	0.2	0.1	0.1	0.2	0.4	1.6	0.3	0.3	9.7
2007	5.7	4.3	0.5	0.3	0.2	0.6	4.0	3.1	3.1	0.7	0.4	0.6	0.7	0.2	0.1	0.1	0.1	0.3	1.4	0.3	8.9
2008	8.0	5.1	3.8	0.4	0.2	0.2	0.5	3.6	2.8	2.7	0.7	0.4	0.5	0.7	0.1	0.1	0.1	0.1	0.3	1.3	8.1
2009	8.7	7.2	4.5	3.4	0.4	0.2	0.2	0.5	3.2	2.4	2.4	0.6	0.3	0.5	0.6	0.1	0.1	0.1	0.1	0.2	8.3
2010	41.6	7.8	6.4	4.0	3.0	0.3	0.2	0.2	0.4	2.8	2.1	2.1	0.5	0.3	0.4	0.5	0.1	0.1	0.1	0.1	0.2
2011	6.8	37.2	7.0	5.7	3.6	2.7	0.3	0.2	0.1	0.4	2.4	1.9	1.8	0.4	0.2	0.4	0.4	0.1	0.1	0.1	0.1

Table 5.14 (cont'd). Estimated beginning of year numbers of Greenland turbot by age and sex (millions).

Males

Yr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1977	87.8	6.0	58.1	15.7	28.2	2.0	1.2	2.6	12.0	7.6	4.7	2.9	1.9	1.3	0.9	0.6	0.4	0.2	0.0	0.0	0.0
1978	26.8	76.5	5.2	50.4	13.5	23.7	1.6	0.9	2.0	9.0	5.6	3.4	2.1	1.3	0.9	0.6	0.4	0.3	0.2	0.0	0.0
1979	12.2	23.3	66.4	4.5	43.0	11.1	18.9	1.2	0.7	1.4	6.1	3.7	2.2	1.3	0.8	0.6	0.4	0.3	0.2	0.1	0.0
1980	15.3	10.6	20.3	57.5	3.8	35.6	8.9	14.3	0.9	0.5	0.9	4.0	2.4	1.4	0.8	0.5	0.3	0.2	0.2	0.1	0.1
1981	1.4	13.3	9.2	17.5	48.7	3.1	27.5	6.4	9.8	0.6	0.3	0.6	2.4	1.4	0.8	0.5	0.3	0.2	0.1	0.1	0.1
1982	2.8	1.2	11.6	7.9	14.8	39.3	2.4	19.5	4.3	6.2	0.4	0.2	0.3	1.3	0.8	0.4	0.3	0.2	0.1	0.1	0.1
1983	1.2	2.5	1.1	10.0	6.7	12.0	30.0	1.7	13.1	2.7	3.8	0.2	0.1	0.2	0.7	0.4	0.2	0.1	0.1	0.1	0.1
1984	3.2	1.1	2.1	0.9	8.4	5.5	9.2	21.8	1.2	8.6	1.7	2.3	0.1	0.1	0.1	0.4	0.2	0.1	0.1	0.0	0.1
1985	11.1	2.8	0.9	1.9	0.8	7.1	4.5	7.4	17.0	0.9	6.4	1.3	1.7	0.1	0.0	0.1	0.3	0.2	0.1	0.1	0.1
1986	2.5	9.7	2.4	0.8	1.6	0.7	6.0	3.7	6.0	13.6	0.7	5.0	1.0	1.3	0.1	0.0	0.1	0.2	0.1	0.1	0.1
1987	3.6	2.2	8.5	2.1	0.7	1.4	0.6	5.0	3.1	4.9	11.1	0.6	4.1	0.8	1.0	0.1	0.0	0.0	0.2	0.1	0.1
1988	2.8	3.2	1.9	7.4	1.8	0.6	1.2	0.5	4.2	2.5	4.0	9.0	0.5	3.3	0.6	0.8	0.0	0.0	0.0	0.1	0.2
1989	12.7	2.4	2.8	1.7	6.4	1.6	0.5	1.0	0.4	3.5	2.1	3.3	7.4	0.4	2.7	0.5	0.7	0.0	0.0	0.0	0.3
1990	2.5	11.1	2.1	2.4	1.4	5.5	1.3	0.4	0.8	0.3	2.9	1.7	2.7	6.0	0.3	2.2	0.4	0.6	0.0	0.0	0.2
1991	0.9	2.2	9.6	1.9	2.1	1.2	4.6	1.1	0.4	0.7	0.3	2.2	1.3	2.1	4.6	0.2	1.7	0.3	0.4	0.0	0.2
1992	0.8	0.8	1.9	8.4	1.6	1.8	1.0	3.9	0.9	0.3	0.5	0.2	1.8	1.1	1.7	3.7	0.2	1.3	0.3	0.3	0.2
1993	0.5	0.7	0.7	1.7	7.3	1.4	1.6	0.9	3.4	0.8	0.3	0.5	0.2	1.6	0.9	1.4	3.2	0.2	1.1	0.2	0.4
1994	0.7	0.5	0.6	0.6	1.4	6.3	1.2	1.3	0.8	2.9	0.7	0.2	0.4	0.2	1.3	0.8	1.2	2.6	0.1	0.9	0.5
1995	3.0	0.6	0.4	0.5	0.5	1.3	5.5	1.1	1.1	0.7	2.4	0.5	0.2	0.3	0.1	1.0	0.6	0.9	2.0	0.1	1.1
1996	2.2	2.6	0.5	0.3	0.5	0.5	1.1	4.8	0.9	1.0	0.5	1.9	0.4	0.1	0.2	0.1	0.8	0.5	0.7	1.6	1.0
1997	1.3	1.9	2.3	0.5	0.3	0.4	0.4	0.9	4.1	0.8	0.8	0.5	1.6	0.4	0.1	0.2	0.1	0.7	0.4	0.6	2.1
1998	2.1	1.1	1.7	2.0	0.4	0.3	0.3	0.3	0.8	3.5	0.7	0.7	0.4	1.3	0.3	0.1	0.2	0.1	0.5	0.3	2.2
1999	7.6	1.8	1.0	1.4	1.7	0.4	0.2	0.3	0.3	0.7	3.0	0.5	0.6	0.3	1.1	0.2	0.1	0.1	0.1	0.4	1.9
2000	6.8	6.6	1.6	0.9	1.3	1.5	0.3	0.2	0.3	0.3	0.6	2.5	0.4	0.5	0.2	0.9	0.2	0.1	0.1	0.0	1.9
2001	7.8	5.9	5.7	1.4	0.7	1.1	1.3	0.3	0.2	0.2	0.2	0.5	2.0	0.4	0.4	0.2	0.7	0.2	0.0	0.1	1.5
2002	1.0	6.8	5.2	5.0	1.2	0.6	1.0	1.1	0.2	0.1	0.2	0.2	0.4	1.6	0.3	0.3	0.2	0.5	0.1	0.0	1.2
2003	0.4	0.9	5.9	4.5	4.4	1.0	0.6	0.8	1.0	0.2	0.1	0.2	0.1	0.3	1.3	0.2	0.2	0.1	0.4	0.1	1.0
2004	0.4	0.3	0.8	5.2	3.9	3.8	0.9	0.5	0.7	0.8	0.2	0.1	0.1	0.1	0.3	1.1	0.2	0.2	0.1	0.4	0.9
2005	0.6	0.3	0.3	0.7	4.5	3.4	3.3	0.8	0.4	0.6	0.7	0.1	0.1	0.1	0.1	0.2	0.9	0.2	0.2	0.1	1.0
2006	4.8	0.5	0.3	0.2	0.6	3.9	3.0	2.9	0.7	0.4	0.5	0.6	0.1	0.1	0.1	0.1	0.2	0.7	0.1	0.1	0.9
2007	5.7	4.2	0.5	0.2	0.2	0.5	3.4	2.6	2.5	0.6	0.3	0.4	0.5	0.1	0.1	0.1	0.1	0.1	0.6	0.1	0.9
2008	8.0	4.9	3.6	0.4	0.2	0.2	0.4	3.0	2.2	2.1	0.5	0.3	0.4	0.4	0.1	0.0	0.1	0.1	0.1	0.5	0.8
2009	8.7	7.0	4.3	3.1	0.3	0.2	0.2	0.4	2.6	1.9	1.8	0.4	0.2	0.3	0.3	0.1	0.0	0.0	0.0	0.1	1.0
2010	41.6	7.6	6.1	3.7	2.7	0.3	0.2	0.1	0.3	2.1	1.5	1.4	0.3	0.2	0.2	0.3	0.0	0.0	0.0	0.0	0.8
2011	6.8	36.3	6.6	5.3	3.3	2.4	0.3	0.1	0.1	0.3	1.8	1.2	1.1	0.2	0.1	0.2	0.2	0.0	0.0	0.0	0.7

Table 5.15. Age-equivalent sex-specific selectivity estimates (as estimated for 2011) 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	0.009	0.012	0.004	0.005
2	0.008	0.012	0.004	0.006
3	0.006	0.012	0.004	0.007
4	0.005	0.012	0.004	0.008
5	0.006	0.016	0.009	0.012
6	0.021	0.046	0.040	0.038
7	0.058	0.140	0.119	0.110
8	0.105	0.293	0.225	0.220
9	0.140	0.462	0.330	0.345
10	0.158	0.613	0.415	0.463
11	0.162	0.731	0.480	0.565
12	0.156	0.816	0.526	0.648
13	0.146	0.875	0.558	0.716
14	0.135	0.914	0.581	0.769
15	0.123	0.939	0.597	0.812
16	0.113	0.956	0.608	0.847
17	0.103	0.967	0.616	0.876
18	0.094	0.975	0.622	0.899
19	0.087	0.980	0.626	0.919
20	0.080	0.984	0.629	0.936
21	0.075	0.988	0.631	0.951
22	0.070	0.992	0.633	0.964
23	0.065	0.996	0.634	0.975
24	0.061	1.000	0.635	0.986
25	0.059	0.998	0.636	0.992
26	0.057	0.990	0.636	0.994
27	0.056	0.983	0.636	0.996
28	0.055	0.977	0.636	0.997
29	0.054	0.972	0.636	0.998
30	0.052	0.964	0.636	1.000

Table 5.16. Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot.

	Mid-year length (cm)		Mid-year weight (kg)	
Age	Females	Males	Females	Males
1	12.36	12.36	0.012	0.012
2	22.06	21.98	0.084	0.083
3	30.84	30.41	0.257	0.245
4	38.50	37.51	0.539	0.494
5	45.17	43.50	0.916	0.808
6	50.98	48.54	1.369	1.162
7	56.04	52.78	1.874	1.534
8	60.45	56.36	2.407	1.904
9	64.29	59.37	2.949	2.259
10	67.63	61.90	3.485	2.591
11	70.55	64.04	4.001	2.895
12	73.09	65.84	4.490	3.167
13	75.30	67.35	4.945	3.408
14	77.23	68.63	5.364	3.619
15	78.91	69.71	5.743	3.802
16	80.37	70.61	6.085	3.960
17	81.65	71.38	6.391	4.094
18	82.76	72.02	6.664	4.208
19	83.72	72.56	6.905	4.305
20	84.57	73.02	7.118	4.386
21	85.30	73.40	7.306	4.453
22	85.94	73.72	7.472	4.509
23	86.50	74.00	7.618	4.555
24	86.98	74.22	7.746	4.593
25	87.41	74.42	7.861	4.628
26	87.77	74.58	7.964	4.662
27	88.10	74.72	8.053	4.691
28	88.38	74.83	8.131	4.715
29	88.62	74.93	8.199	4.736
30	89.04	75.08	8.317	4.767

Table 5.17. Estimated total Greenland turbot harvest by area, 1977-2011. Values for 2011 are through Nov. 2nd, 2011 and are preliminary.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1994	3,875	7,141
1978	37,423	4,766	1995	4,499	5,855
1979	34,998	6,411	1996	4,258	4,844
1980	48,856	3,697	1997	5,730	6,435
1981	52,921	4,400	1998	7,839	8,329
1982	45,805	6,317	1999	5,179	5,391
1983	43,443	4,115	2000	5,667	5,888
1984	21,317	1,803	2001	4,102	4,252
1985	14,698	33	2002	3,011	3,153
1986	7,710	2,154	2003	2,493	965
1987	6,519	3,066	2004	1,805	414
1988	6,064	1,044	2005	2,140	468
1989	4,061	4,761	2006	1,452	534
1990	7,702	2,494	2007	1,481	521
1991	3,781	4,397	2008	2,095	827
1992	1,767	2,462	2009	2,249	2,261
1993	4,878	6,330	2010	2,272	1,866
			2011	2,759	493

Table 5.18. Mean spawning biomass, F, and yield projections for Greenland turbot, 2011-2024. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be **50:50** (whereas the catch from 2008-2011 has been around 40:60). The values for $B_{40\%}$ and $B_{35\%}$ are 21,560 and 18,870 tons, respectively.

Catch	*Max F_{ABC}*	*F_{ABC}*	*5-year avg.*	*$F_{75\%}$*	*No Fishing*	*Scenario 6*	*Scenario 7*
2011	3,252	3,252	3,252	3,252	3,252	3,252	3,252
2012	9,660	9,660	1,624	2,409	0	11,658	9,660
2013	8,029	8,029	1,570	2,296	0	9,316	8,029
2014	7,086	7,086	1,564	2,259	0	7,993	8,571
2015	6,887	6,887	1,635	2,342	0	7,676	8,092
2016	7,721	7,721	1,853	2,644	0	8,648	8,950
2017	9,706	9,706	2,263	3,232	0	11,001	11,224
2018	11,933	11,933	2,757	3,939	0	13,556	13,724
2019	13,288	13,288	3,181	4,528	0	14,933	15,060
2020	13,434	13,434	3,458	4,890	0	14,793	14,890
2021	12,690	12,690	3,592	5,033	0	13,635	13,708
2022	11,527	11,527	3,615	5,012	0	12,092	12,147
2023	10,297	10,297	3,564	4,888	0	10,590	10,632
2024	9,195	9,195	3,470	4,709	0	9,329	9,360
Fishing M.	*Max FABC*	*FABC*	*5-year avg.*	*F75%*	*No Fishing*	*Scenario 6*	*Scenario 7*
2011	0.108	0.108	0.108	0.108	0.108	0.108	0.108
2012	0.367	0.367	0.057	0.085	0.000	0.453	0.367
2013	0.367	0.367	0.057	0.085	0.000	0.453	0.367
2014	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2015	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2016	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2017	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2018	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2019	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2020	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2021	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2022	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2023	0.367	0.367	0.057	0.085	0.000	0.453	0.453
2024	0.367	0.367	0.057	0.085	0.000	0.453	0.453
Spawning biomass	*Max FABC*	*FABC*	*5-year avg.*	*F75%*	*No Fishing*	*Scenario 6*	*Scenario 7*
2011	51,278	51,278	51,278	51,278	51,278	51,278	51,278
2012	47,687	47,687	47,687	47,687	47,687	47,687	47,687
2013	41,441	41,441	45,790	45,375	46,642	40,325	41,441
2014	37,478	37,478	45,168	44,399	46,769	35,634	37,478
2015	36,528	36,528	46,800	45,727	49,067	34,221	35,699
2016	39,314	39,314	51,693	50,347	54,573	36,698	37,879
2017	44,229	44,229	58,571	56,959	62,061	41,347	42,290
2018	48,552	48,552	65,139	63,229	69,311	45,330	46,083
2019	50,761	50,761	70,172	67,902	75,166	47,060	47,659
2020	50,729	50,729	73,428	70,739	79,376	46,470	46,945
2021	49,039	49,039	75,125	71,987	82,110	44,256	44,630
2022	46,389	46,389	75,590	72,008	83,623	41,205	41,499
2023	43,346	43,346	75,150	71,156	84,183	37,924	38,154
2024	40,291	40,291	74,080	69,725	84,021	34,787	34,966

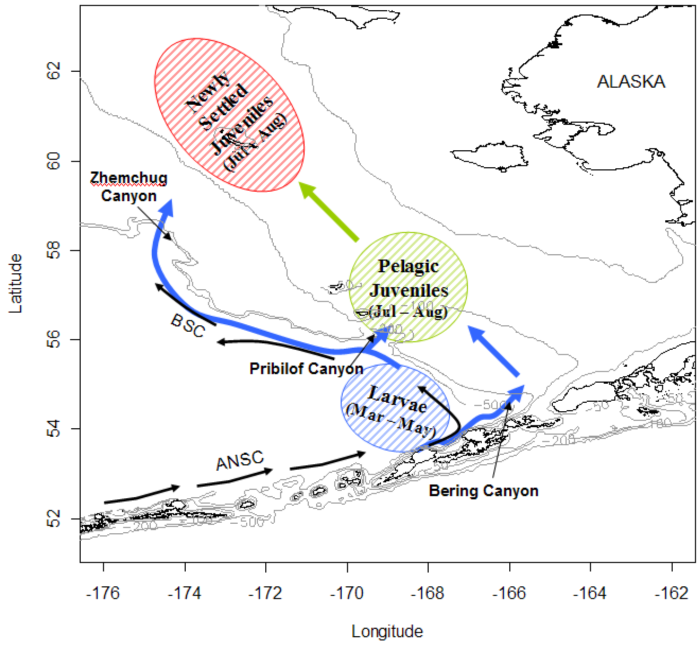
Table 5.19. Summary management values based on this assessment. Note that the fishing mortality rates assume 50:50 contribution from longline gear and trawl gear.

Management parameter	Value
M (natural mortality)	0.112 yr^{-1}
Amendment 56 Tier (in **2012**)	3a
Approximate age at full recruitment	10 years
$F_{35\%}$ (F_{OFL})	0.453
$F_{40\%}$	0.367
$B_{100\%}$	53,900 t
$B_{40\%}$	21,560 t
$B_{35\%}$	18,870 t
2011 female spawning biomass	51,278 t
2012 female spawning biomass	47,687 t
2013 female spawning biomass	41,441 t
2011 total (age 1+) biomass	75,026 t
2012 total (age 1+) biomass	76,845 t
2013 total (age 1+) biomass	73,913 t
$F_{ABC} = F_{40\%}$ (max permissible)	0.367
2012 Maximum permissible ABC	9,660 t
2013 Maximum permissible ABC	8,029 t
$F_{ABC} = F_{40\%}$	0.367
Recommended ABC: 2012	9,660 t
2013	8,029 t
$F_{overfishing} = F_{35\%}$	0.453
2012 Greenland turbot OFL	11,658 t
2013 Greenland turbot OFL	9,697 t*

* assuming catch **2012** = 9,660t

Figures

(a)



(b)

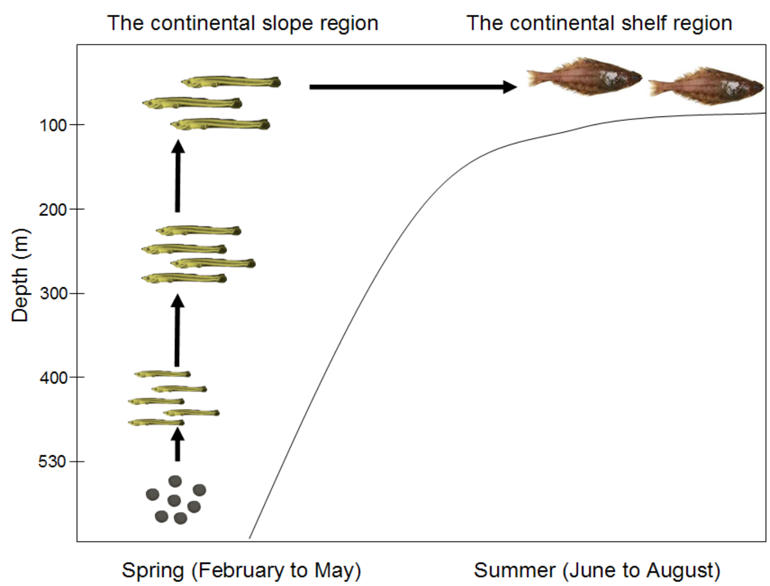


Figure 5.1. Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: settlement ground). Blue arrows: possible larval transport routes from slope to shelf. (b) Vertically changed distribution as they develop. ***Source: Sohn (2009).***

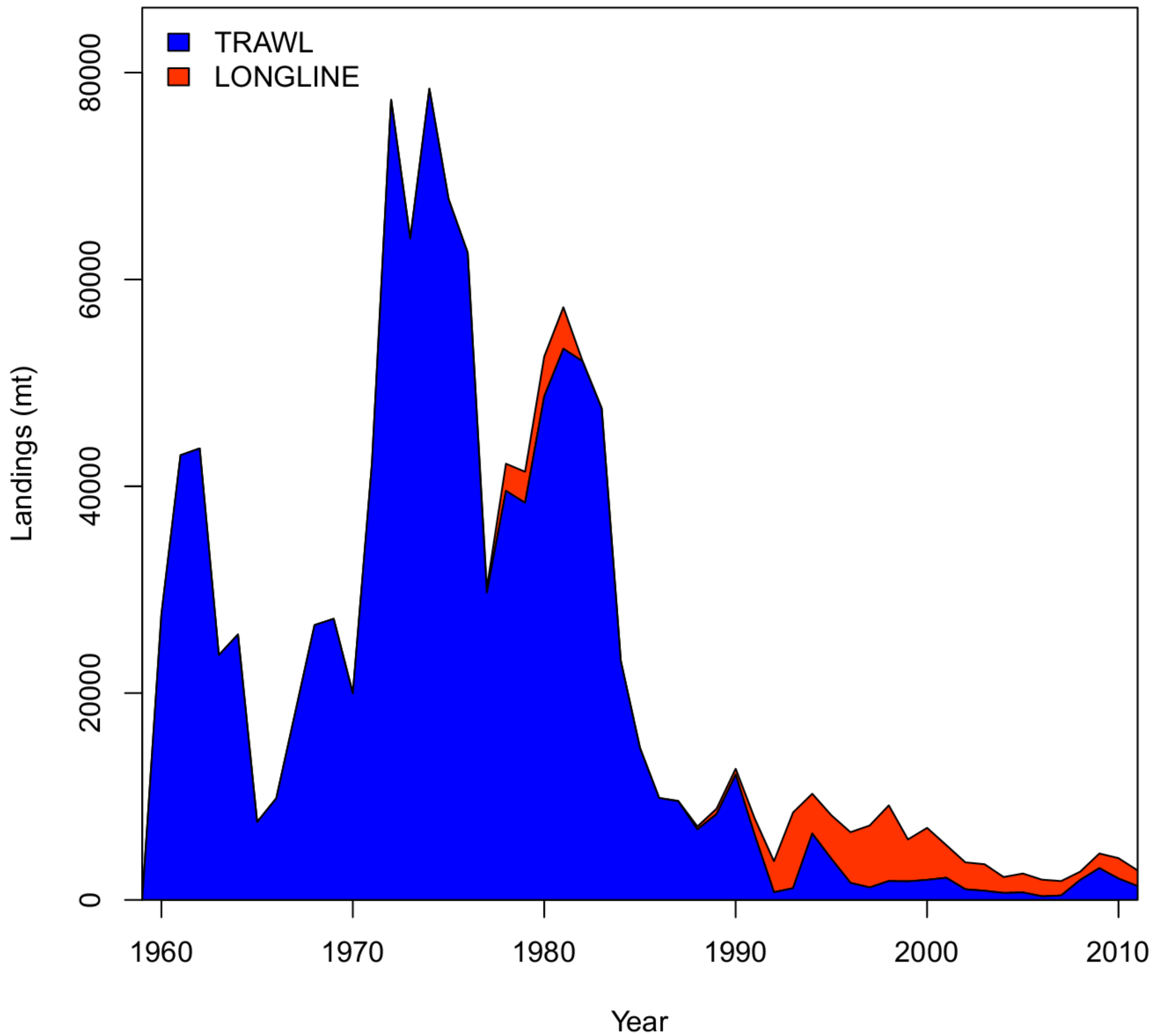


Figure 5.2. Trawl and longline catches of Greenland turbot in the combined EBS/AI area, 1960-2011.

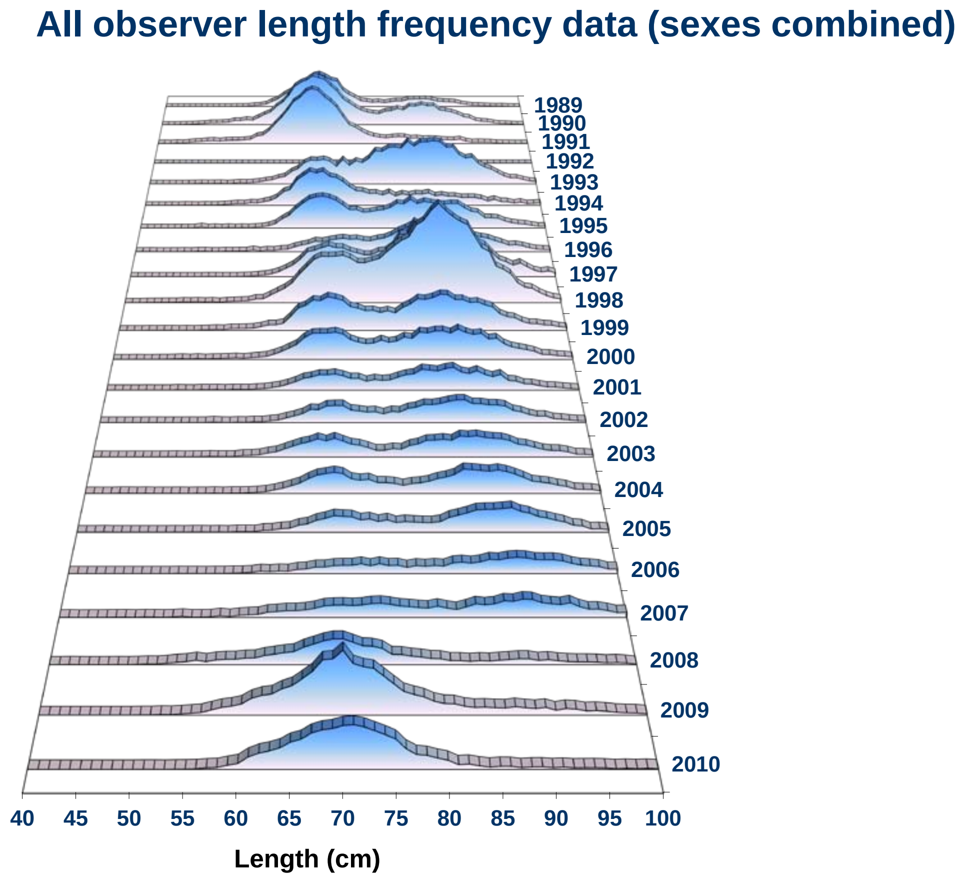


Figure 5.3. Combined fishery catch length frequency of Greenland turbot in the BSAI area, 1989-2010 based on NMFS observer program data, sexes combined (based on raw observations)..

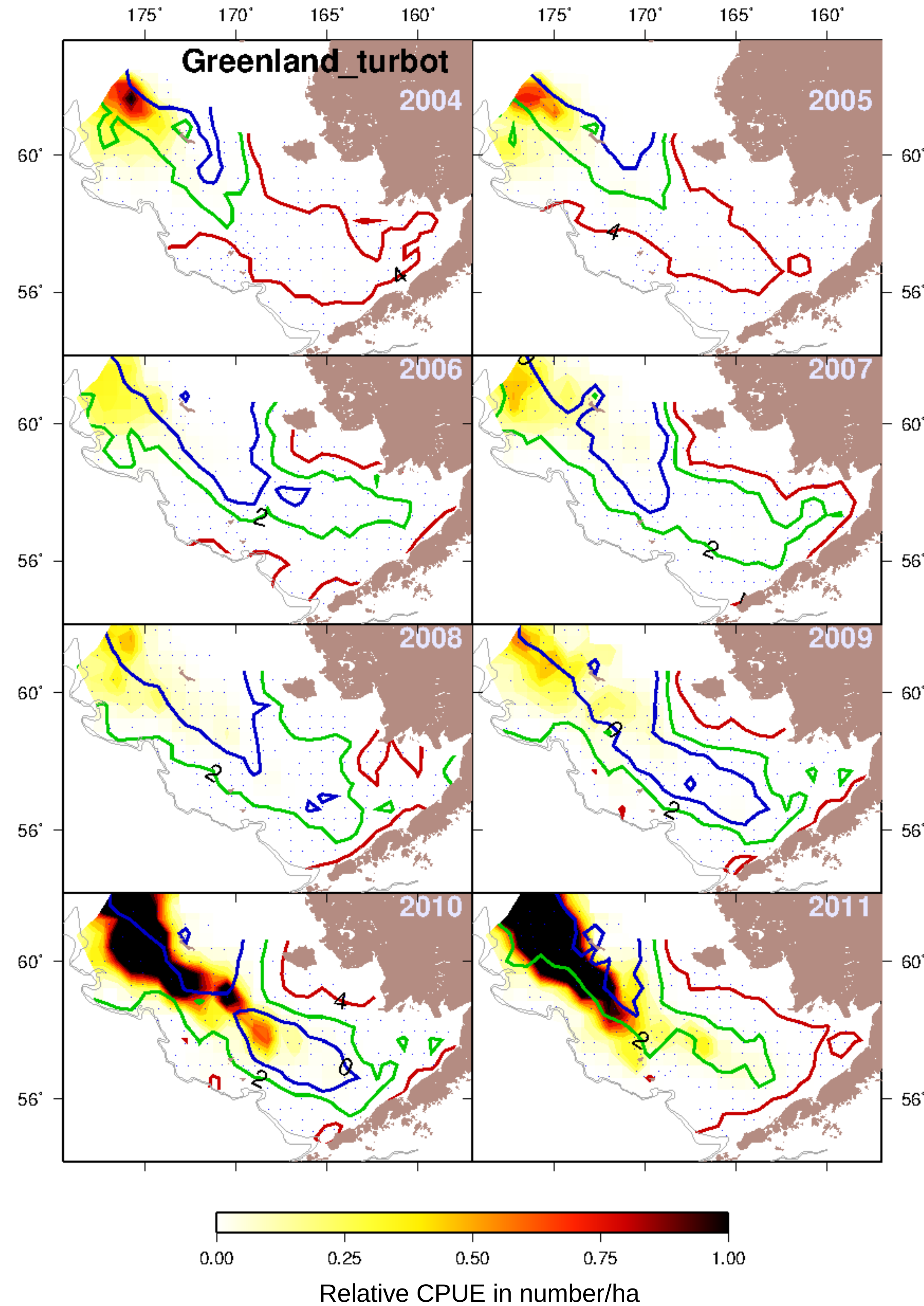


Figure 5.4. Greenland turbot relative CPUE by **number** based on NMFS EBS bottom trawl surveys, 2004-2011. Also shown are bottom temperature contours.

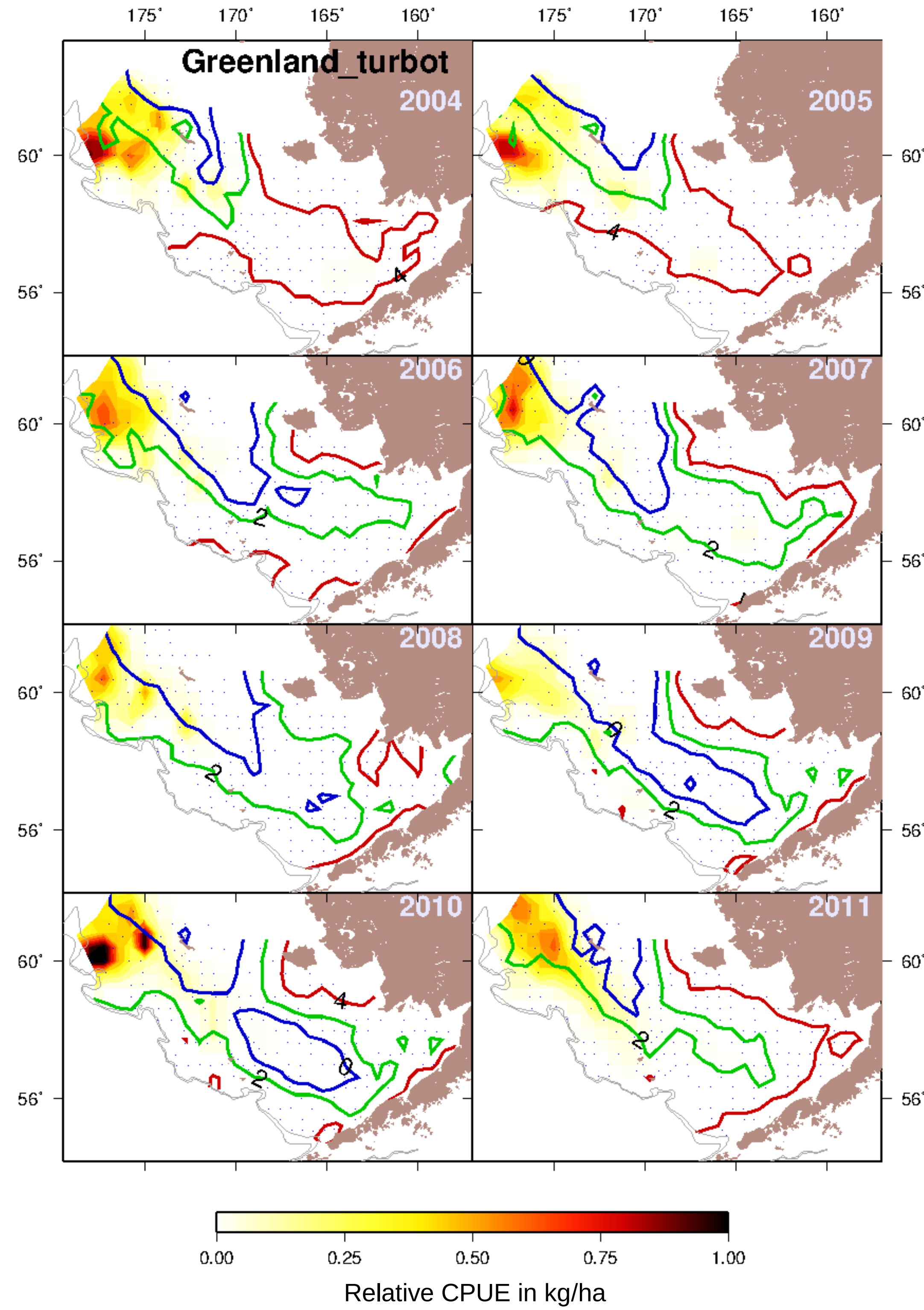


Figure 5.5. Greenland turbot relative CPUE by **weight** based on NMFS EBS bottom trawl surveys, 2004-2011. Also shown are bottom temperature contours.

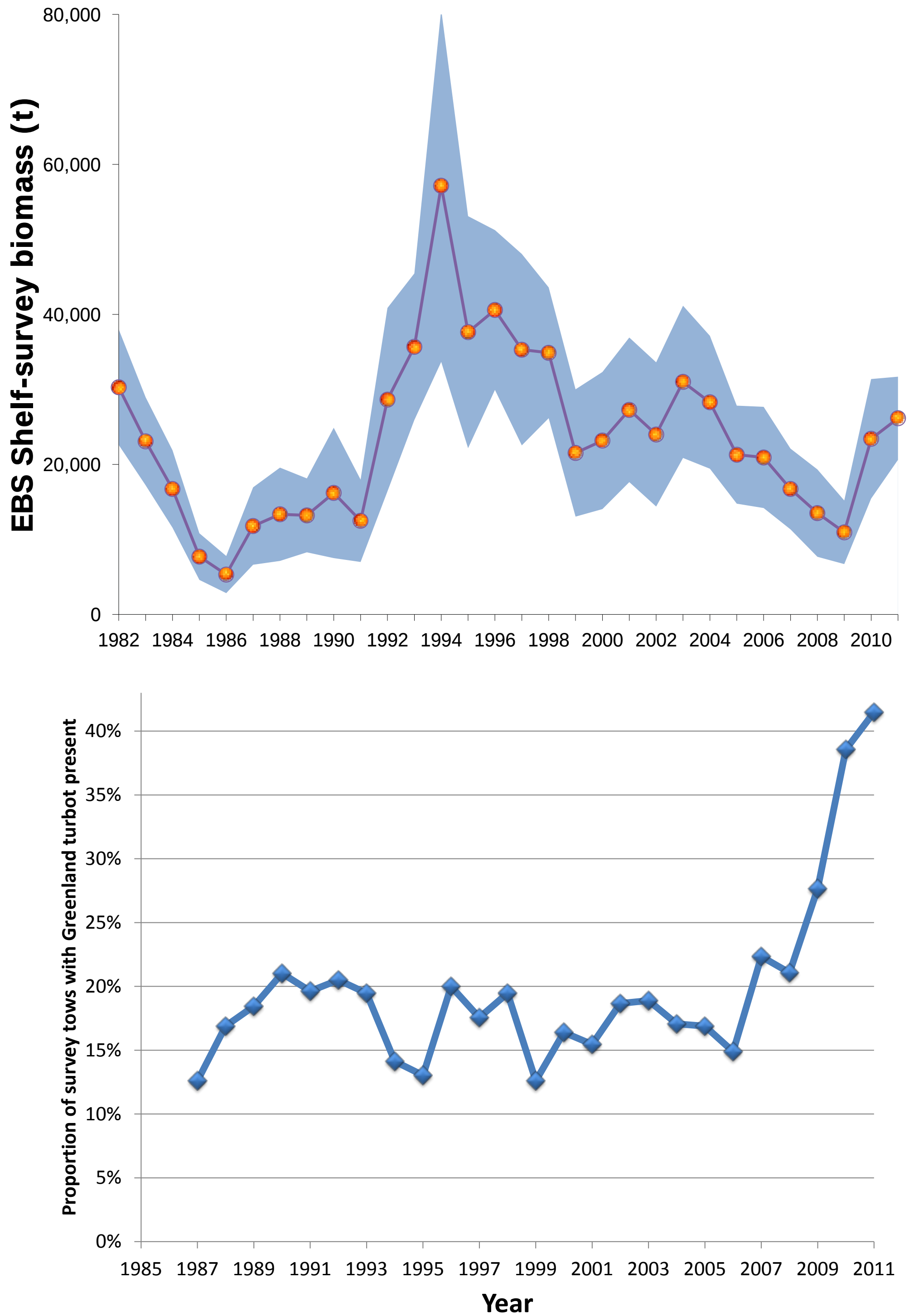


Figure 5.6. Survey biomass estimates of Greenland turbot from the EBS shelf trawl survey (top; 1982-2011) and the proportion of tows that caught at least one Greenland turbot (bottom; 1987-2011).

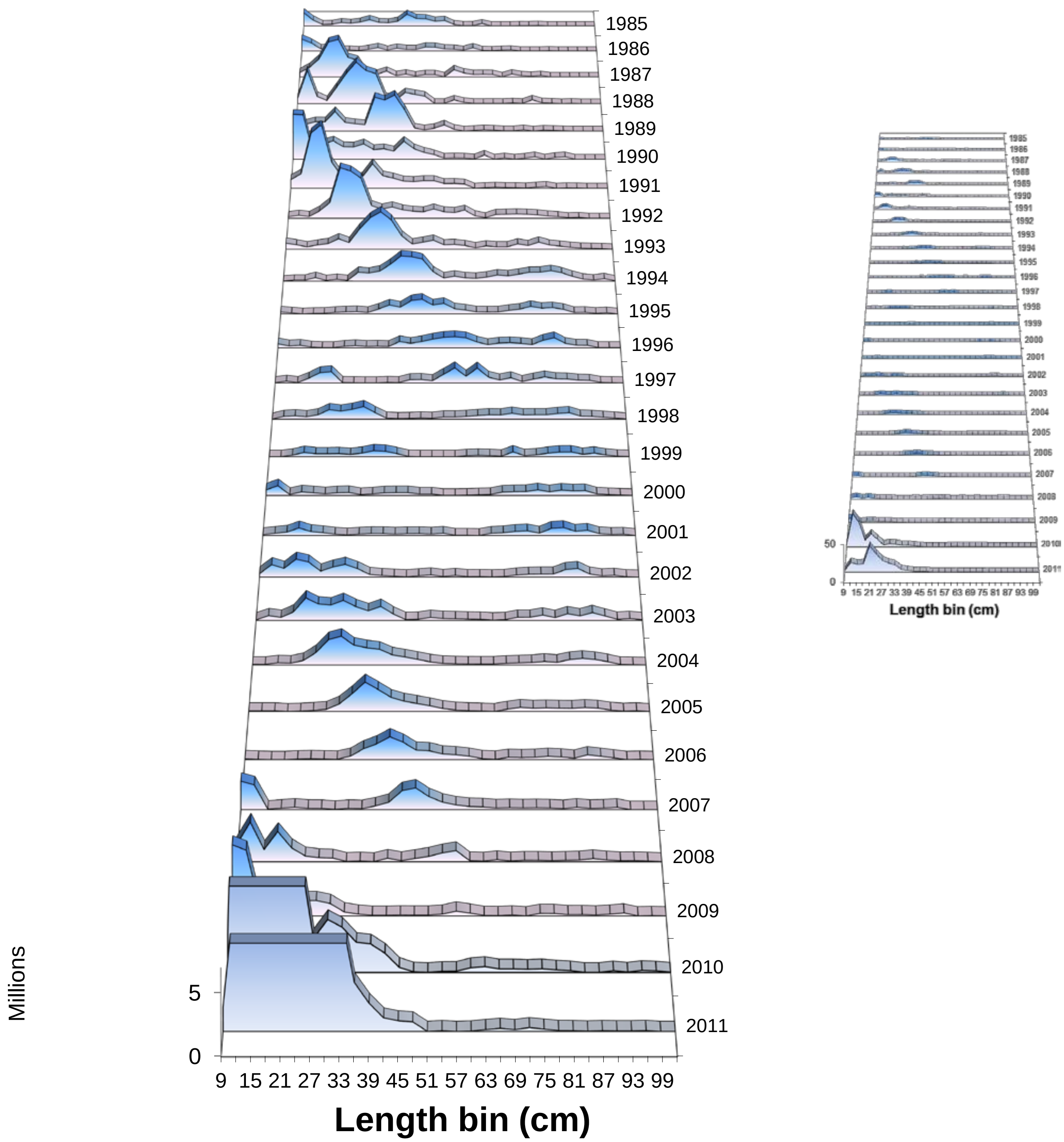


Figure 5.7. Abundance-at-length (cm) for Greenland turbot observed from the summer NMFS shelf trawl surveys, 1985-2011 (sexes combined, all strata except for 1986 where only strata 1-6 were sampled). Note that the 2010 and 2011 are truncated in the main figure—the inset shows the same figure with the vertical scale magnified by an order of magnitude.

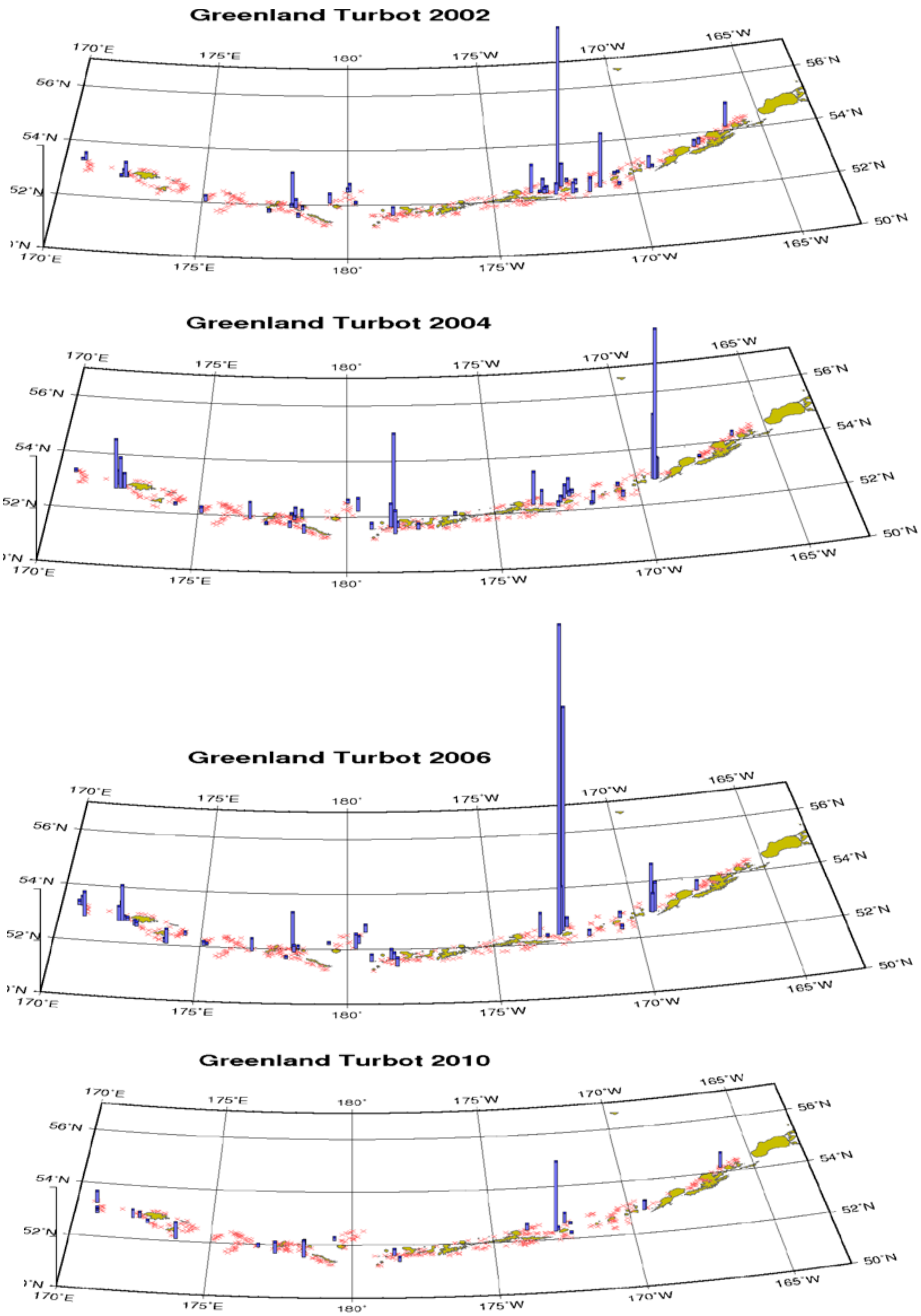


Figure 5.8. Greenland turbot catch per unit effort (relative values by weight, vertical bars) from the Aleutian Islands region bottom trawl survey, 2002-2010.

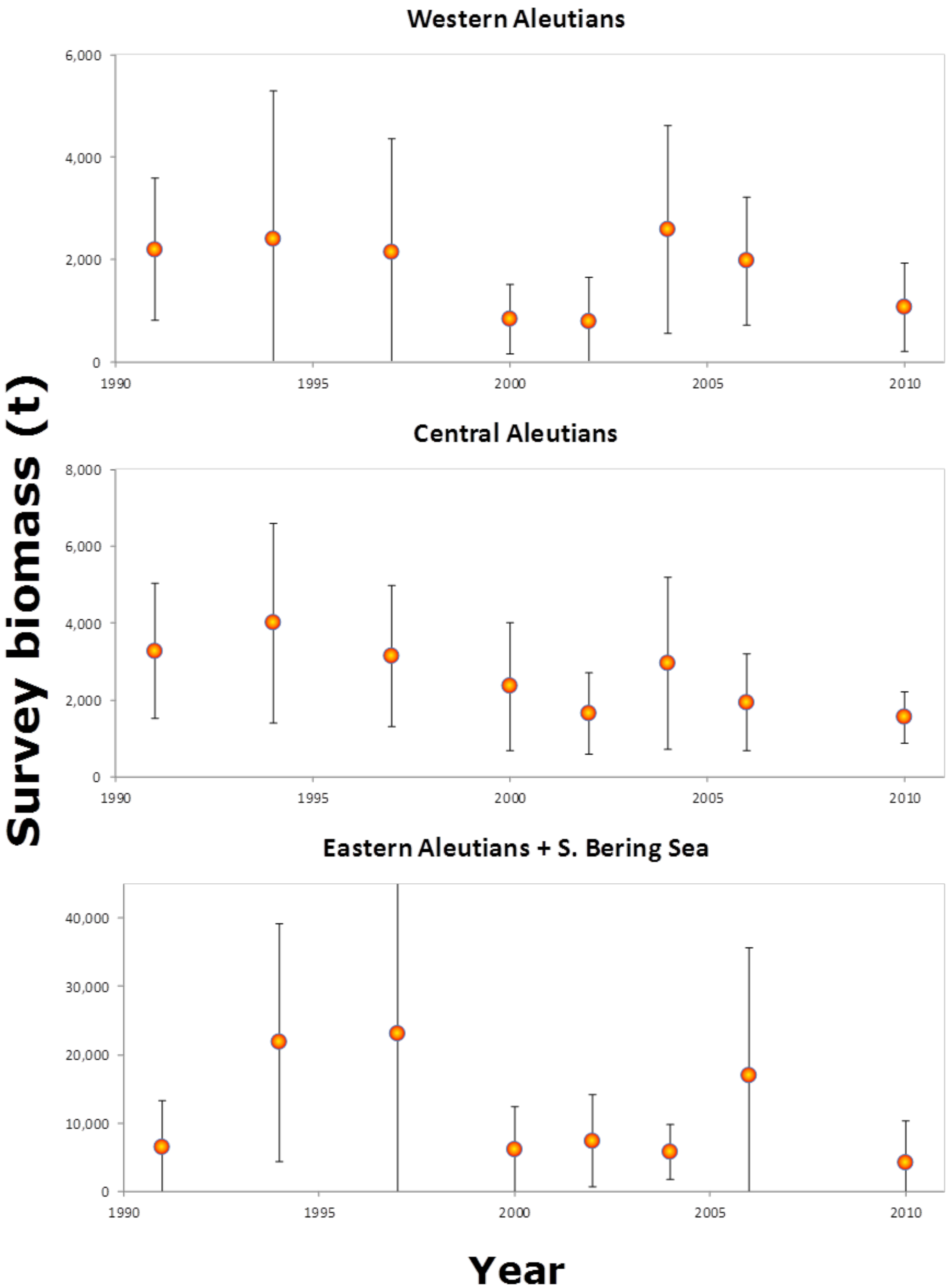


Figure 5.9. Greenland turbot relative biomass from the Aleutian Islands surveys by region, 1991-2010.

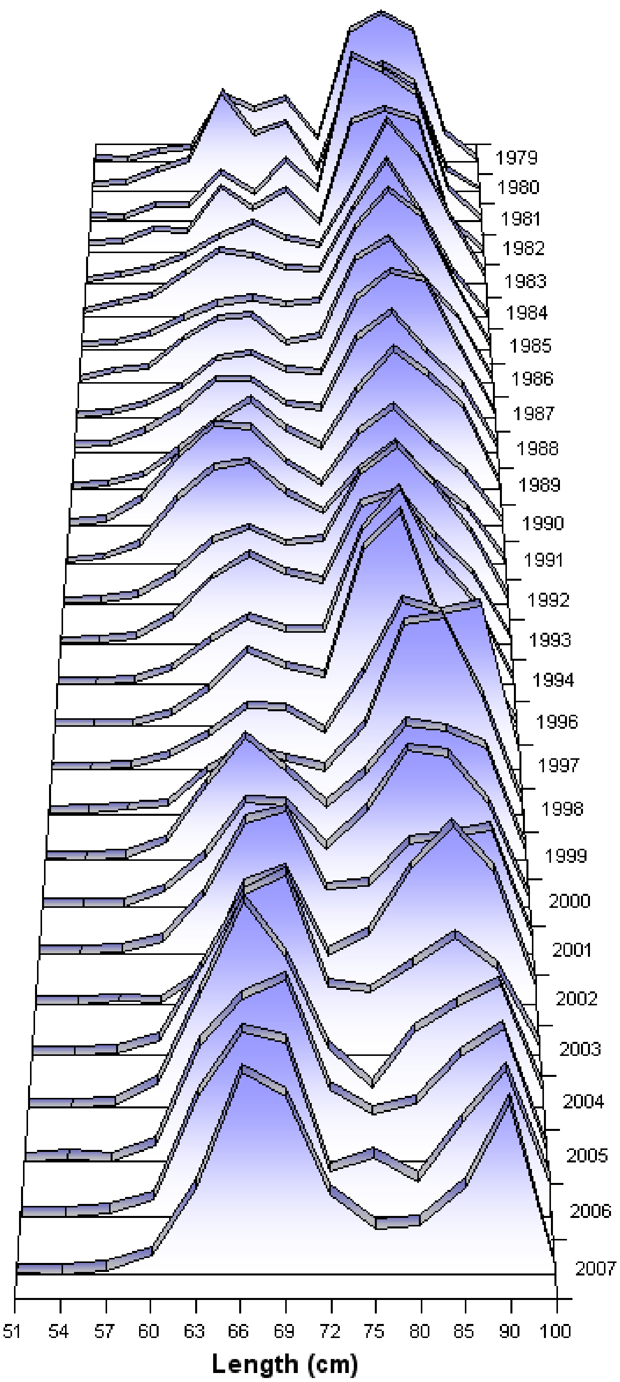


Figure 5.10. Longline survey Greenland turbot proportions at length over time (sexes combined) as used in the model.

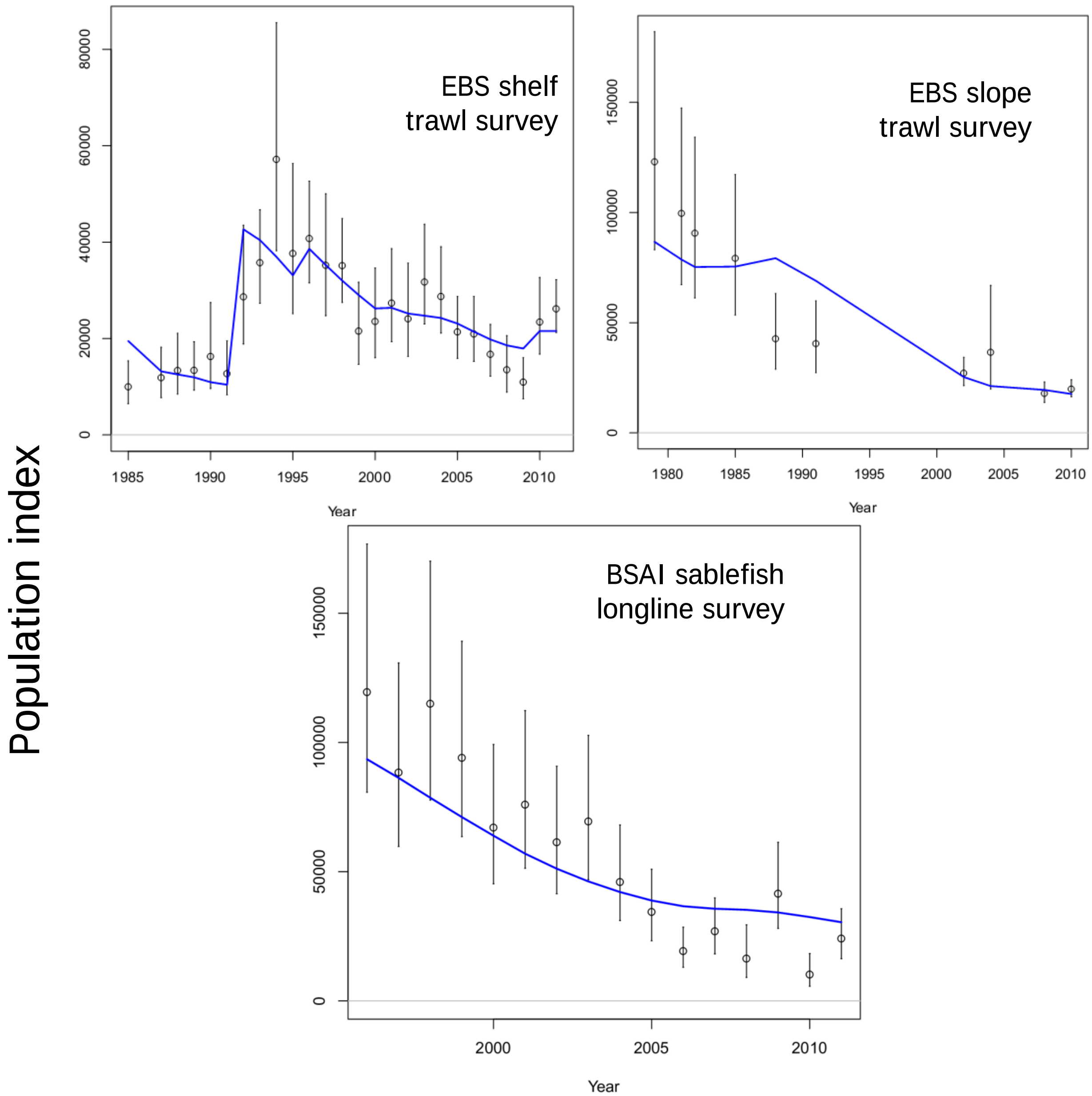


Figure 5.11. Model fits to the EBS shelf trawl survey (top left), the EBS slope trawl survey (top right) and longline survey (bottom) indices for Greenland turbot in the EBS/AI region.

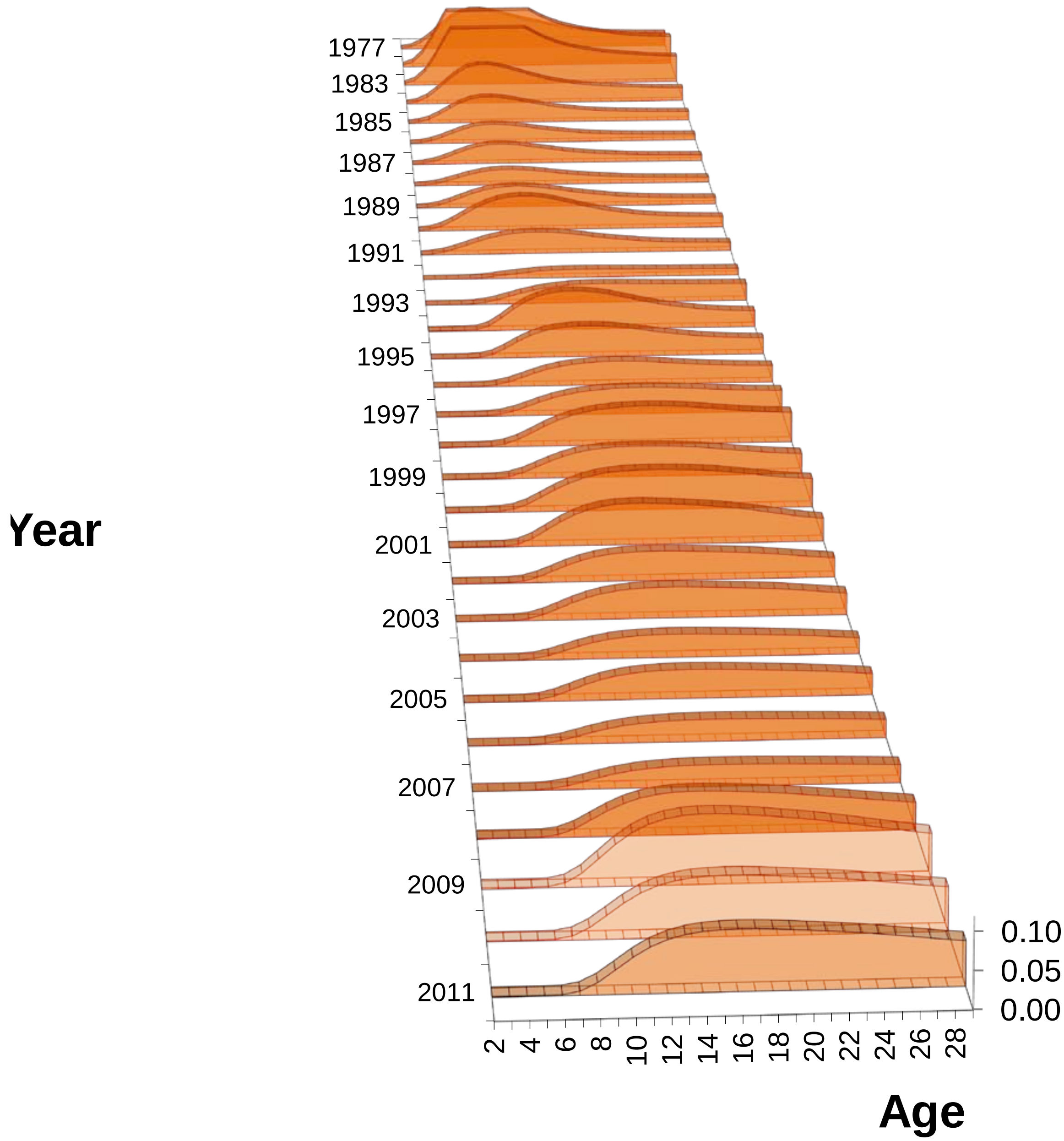


Figure 5.12. Estimated total age-specific fishing mortality rate (gears and sexes combined) for BSAI Greenland turbot, 1977-2011.

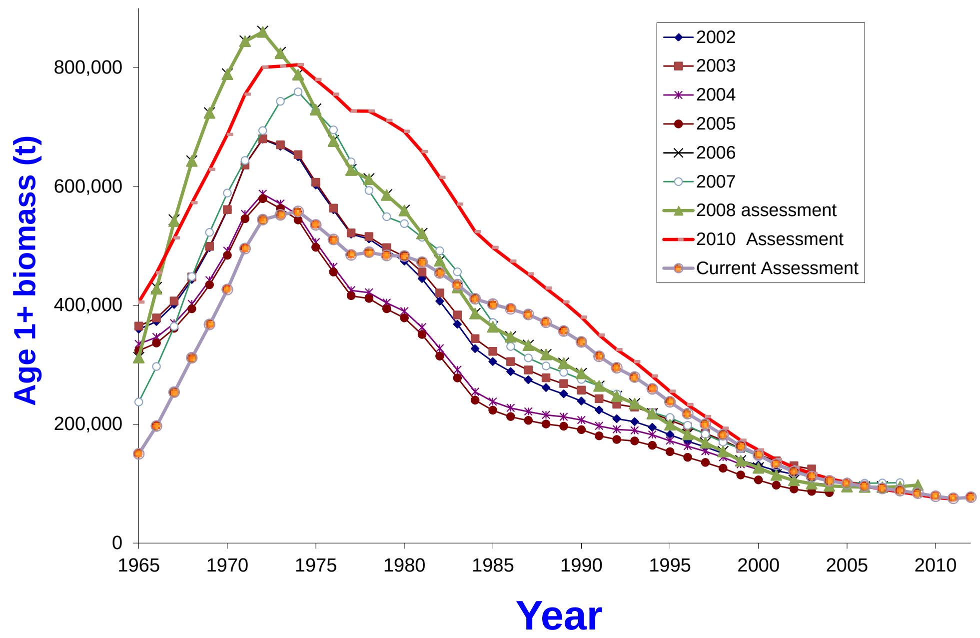


Figure 5.13 Current assessment estimates of total age 1+ biomass for Greenland turbot in the BSAI region, 1965-2012 compared to previous assessments.

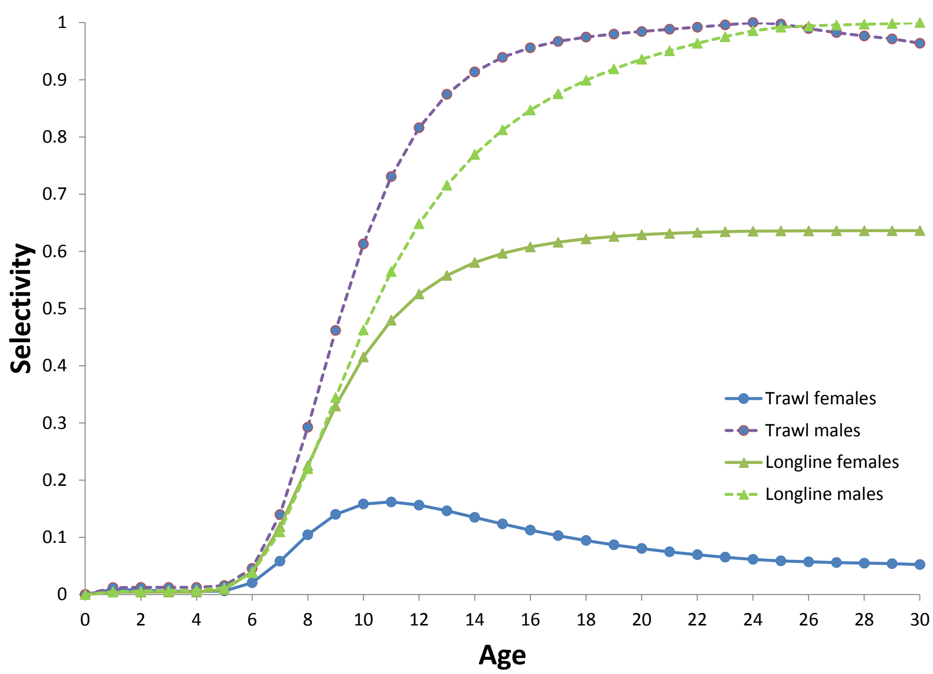


Figure 5.14. Estimated selectivity-at-age patterns for EBS Greenland turbot fisheries showing differences in sex-specific availability in the current year (some earlier years had different selectivity estimates).

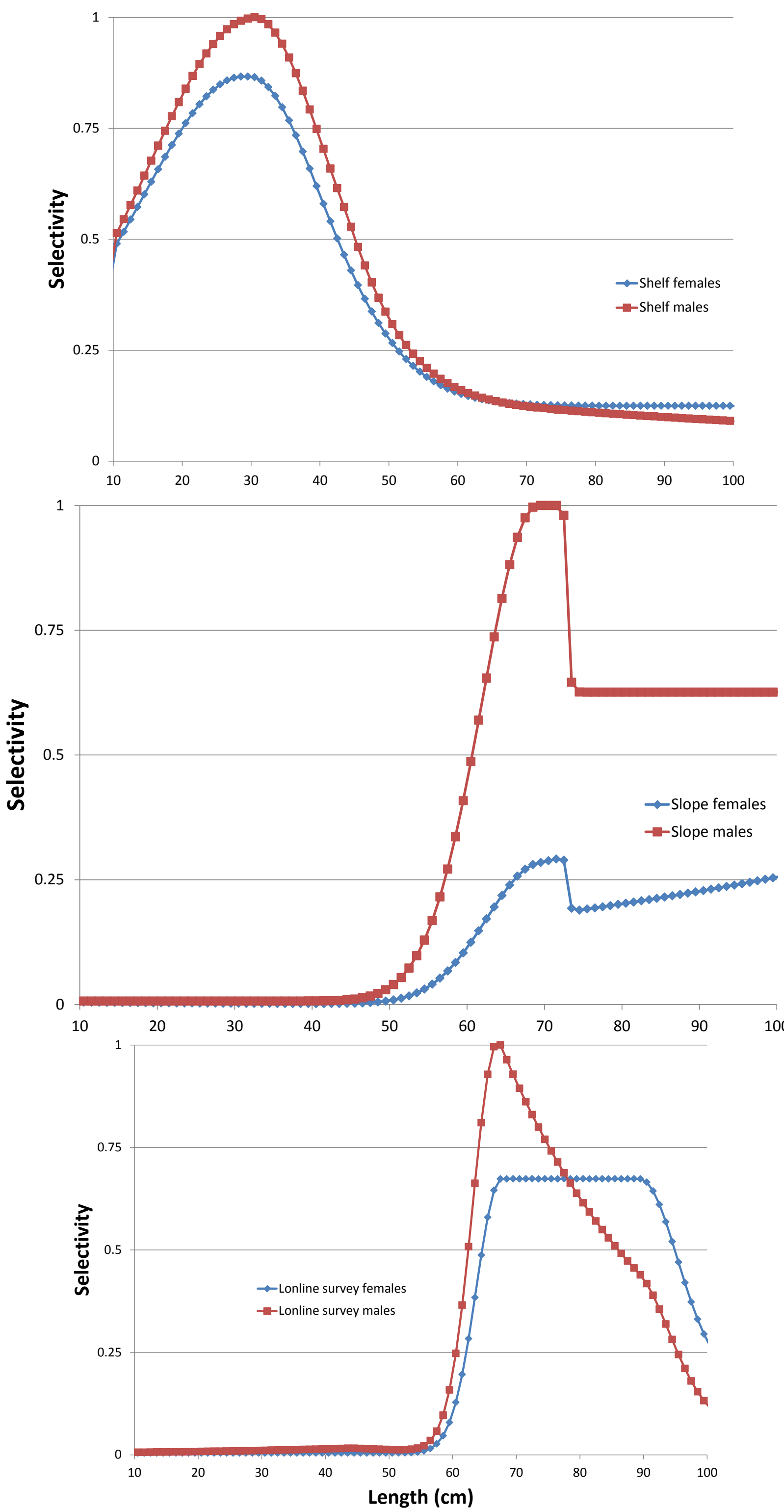


Figure 5.15. Average size-specific estimates of selectivity patterns for EBS Greenland turbot surveys showing differences in sex-specific availability in the current year (some earlier years had different selectivity estimates).

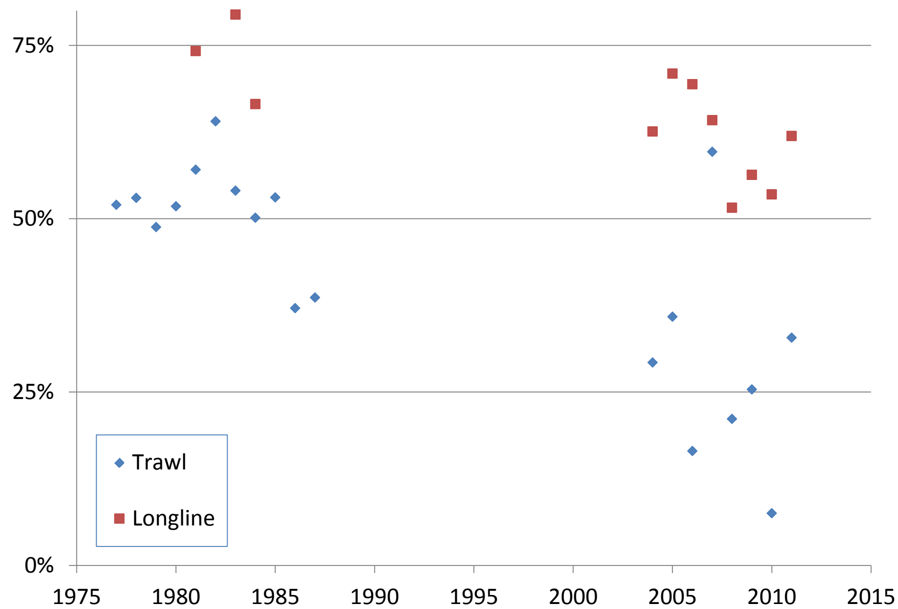


Figure 5.16. Observed Greenland turbot sex ratio over time from the BSAI region trawl and longline fisheries.

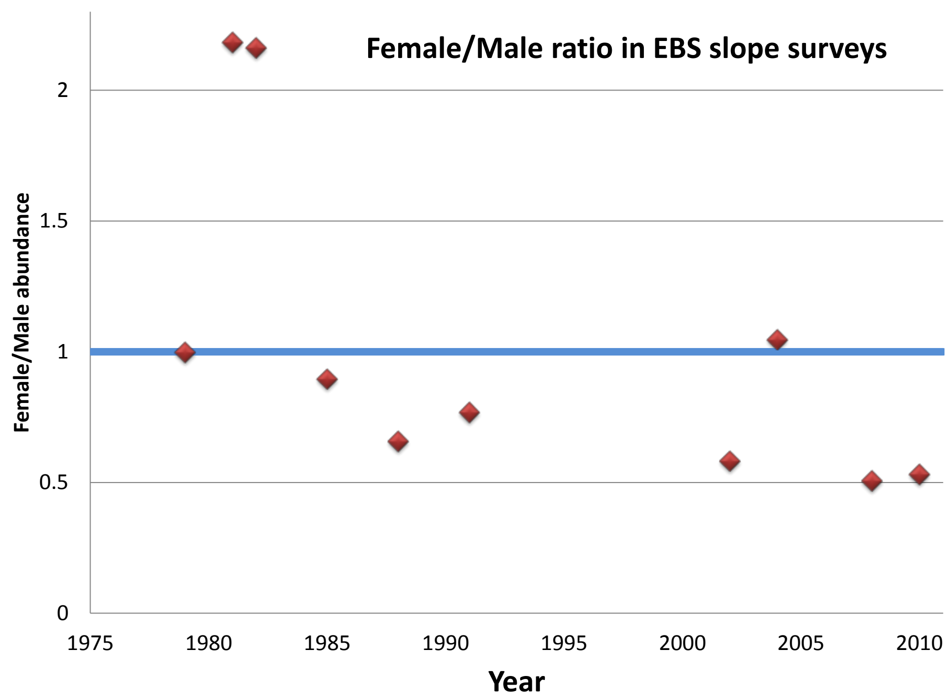


Figure 5.17. EBS slope trawl survey estimates of Greenland turbot sex ratio.

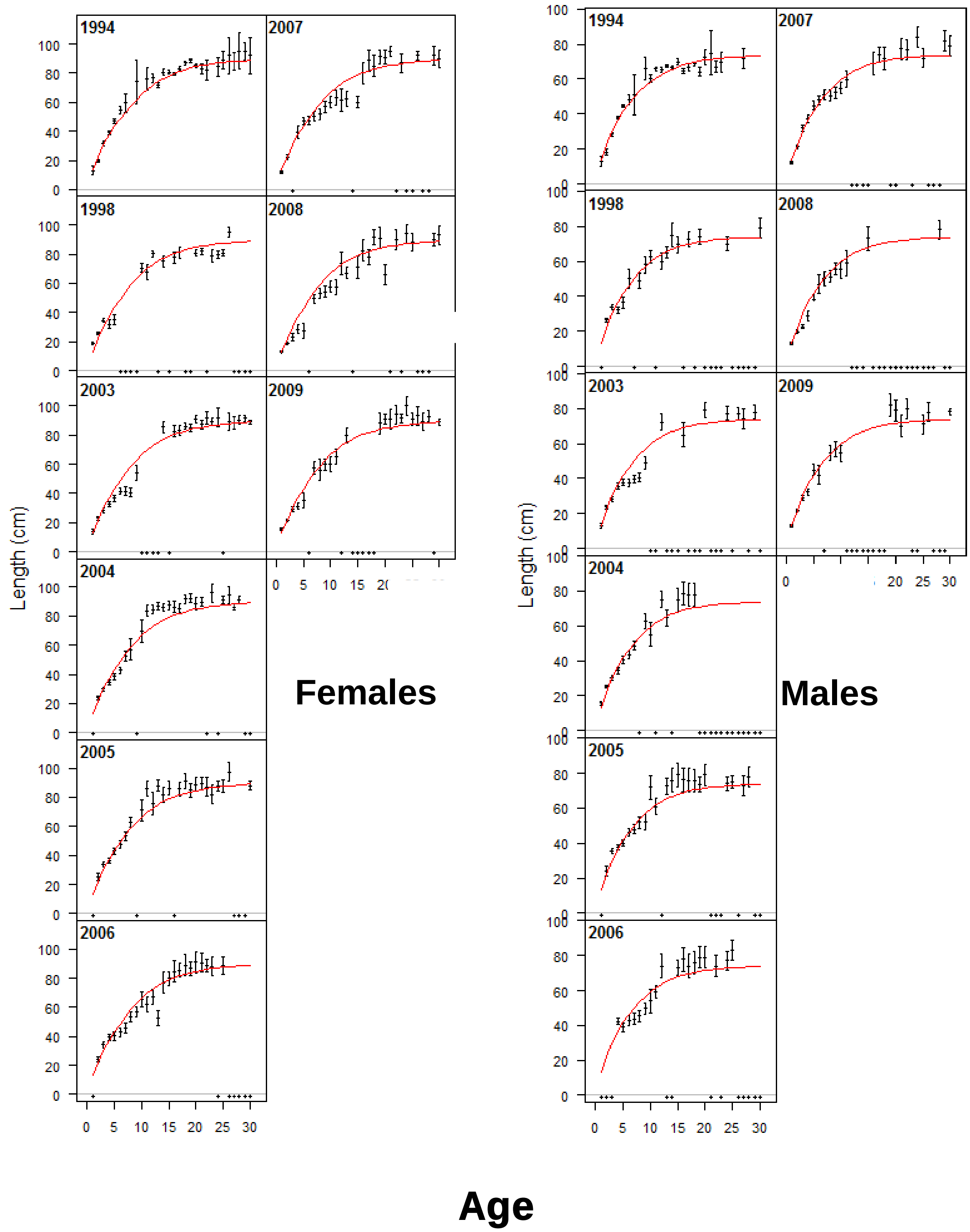


Figure 5.18. Estimated growth (length at age) of Greenland turbot by sex (female on left, males on right) in the EBS/AI region as predicted by the model and compared to the available age data using the methods of Gregg et al (2006).

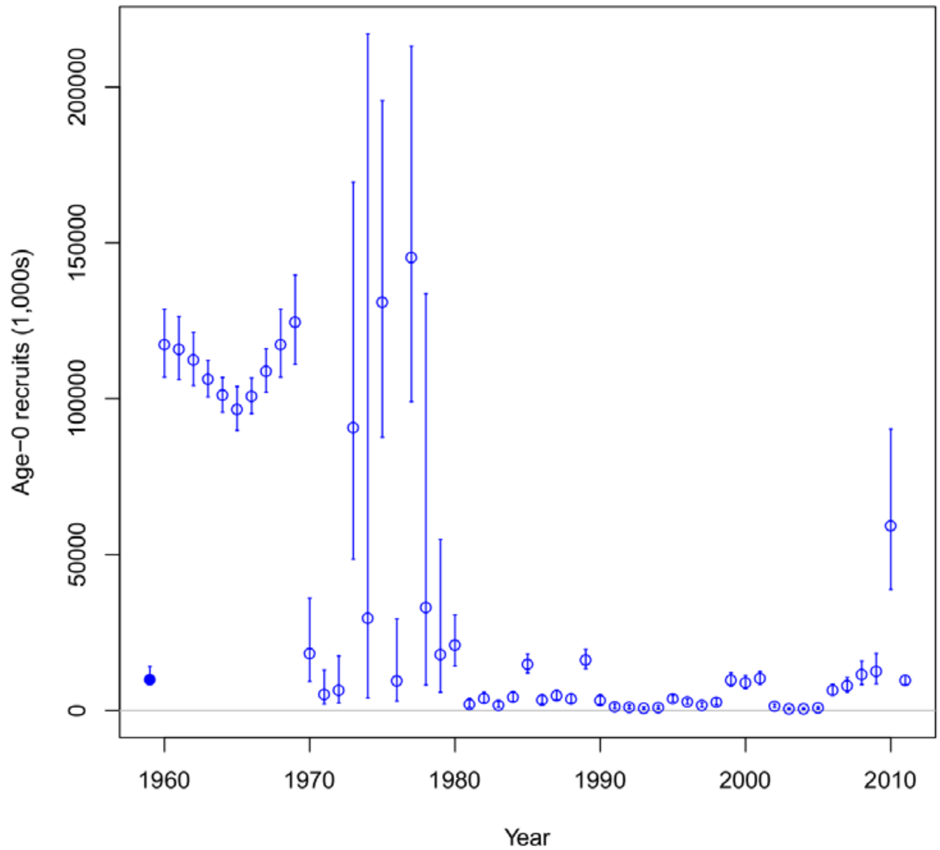


Figure 5.19. Estimated recruitment at age 0 (thousands) for Greenland turbot in the EBS/AI region, 1977-2011.

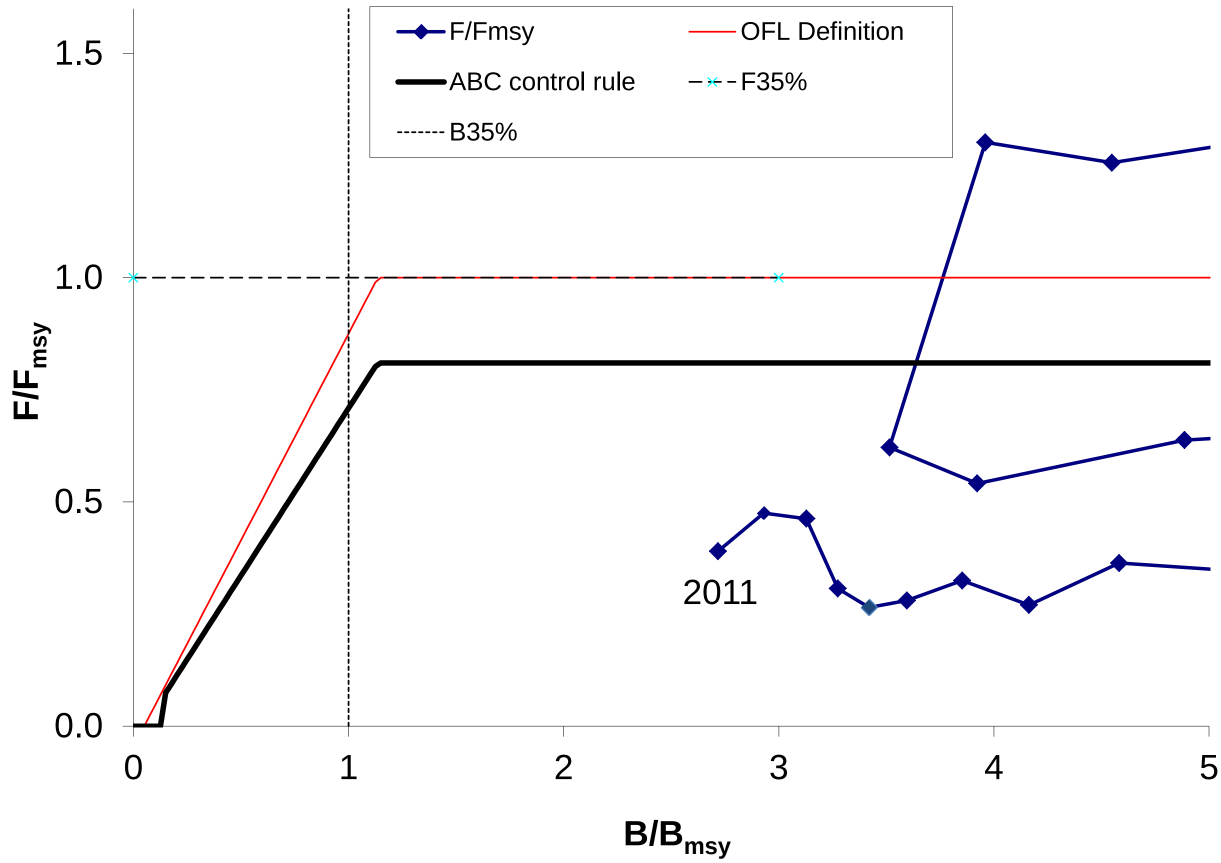


Figure 5.20. Ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1960-2011. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively.

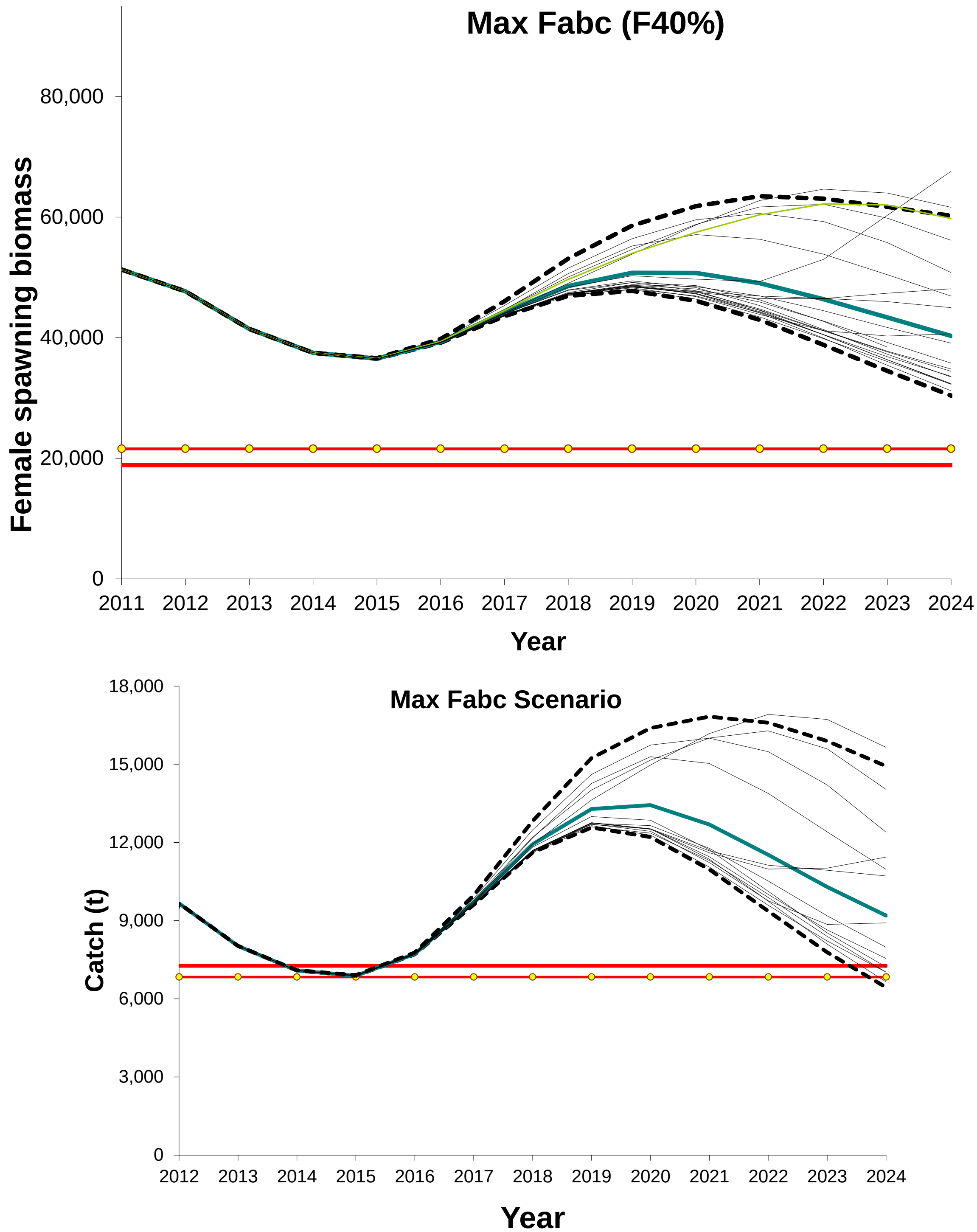


Figure 5.21. Stochastic trajectory of Greenland turbot female spawning biomass (top) and catch (bottom) for the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3. The dotted lines represent the 90% confidence limits. Horizontal lines with marks are the values associated with $B_{40\%}$ and $F_{40\%}$ while the thick horizontal line is the expected value under constant F_{OFL} rate ($F_{35\%}$).

Attachment 5.A Fits to composition data

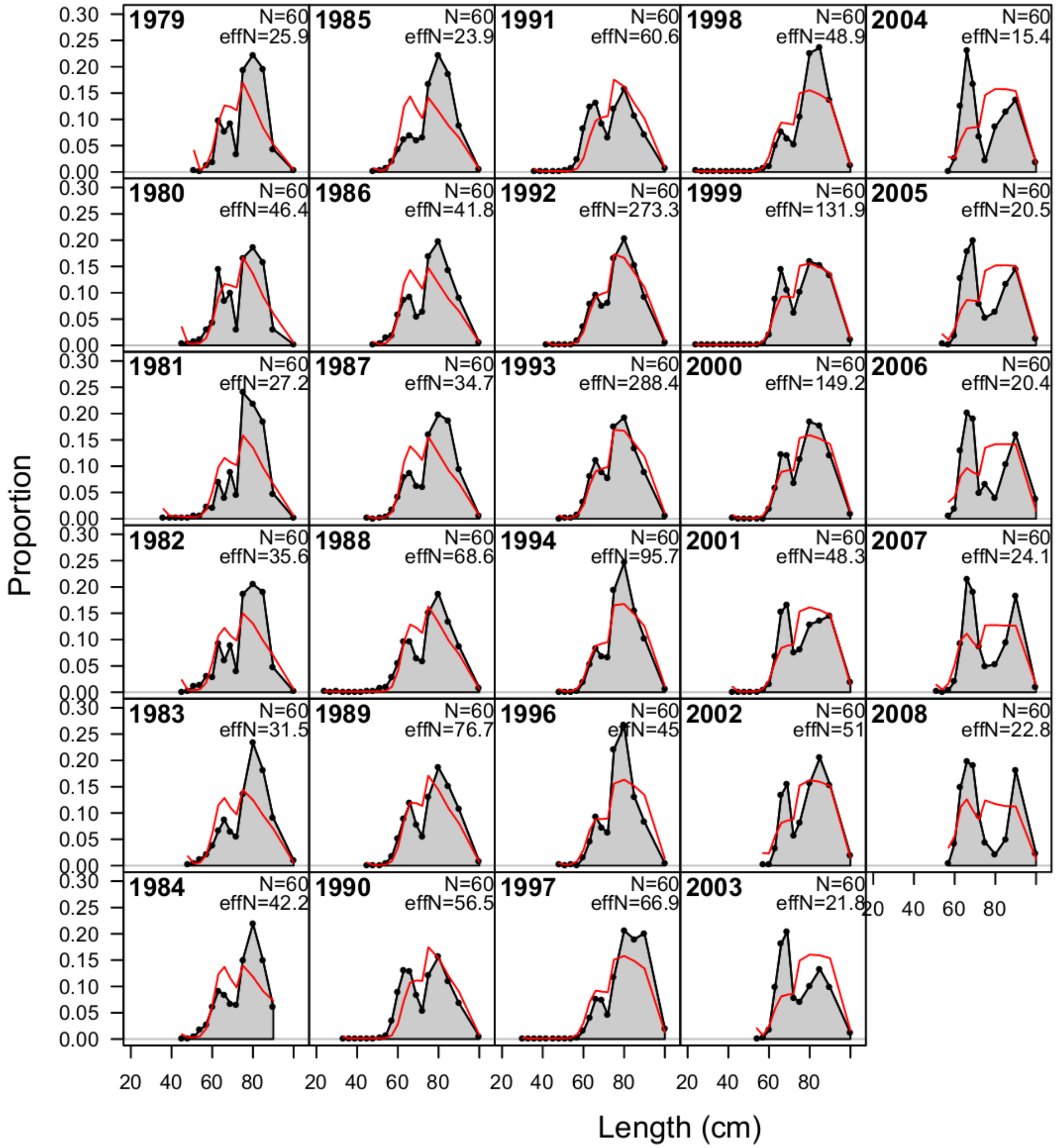


Figure 5.22. Greenland turbot model fit to longline survey length frequency data (sexes combined). Lines are model predictions, points are data.

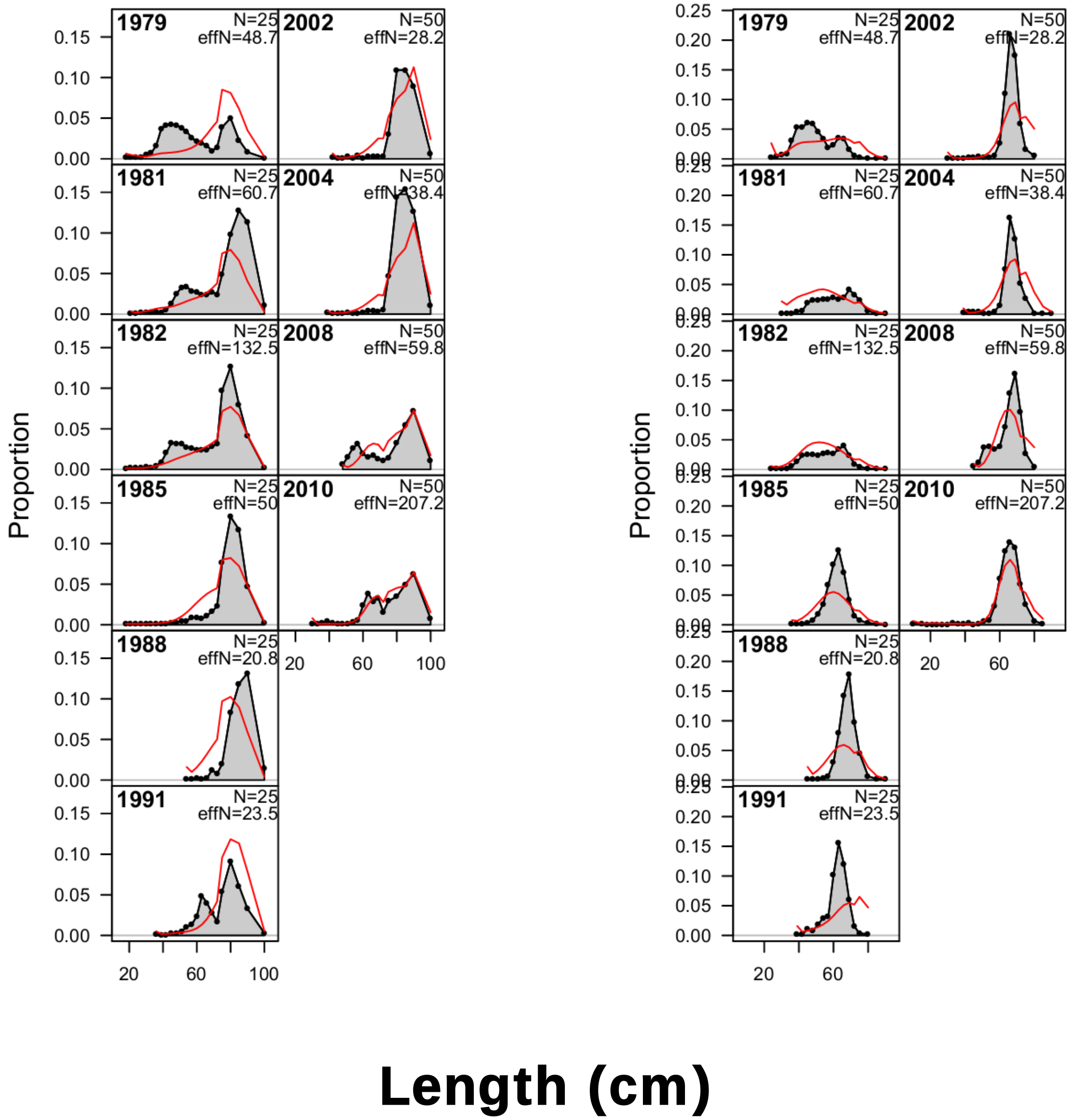


Figure 5.23. Greenland turbot model fit to EBS slope trawl survey length frequency data. The left set are females, while the right set are males. Lines are model predictions, points are data; females on left and males on right.

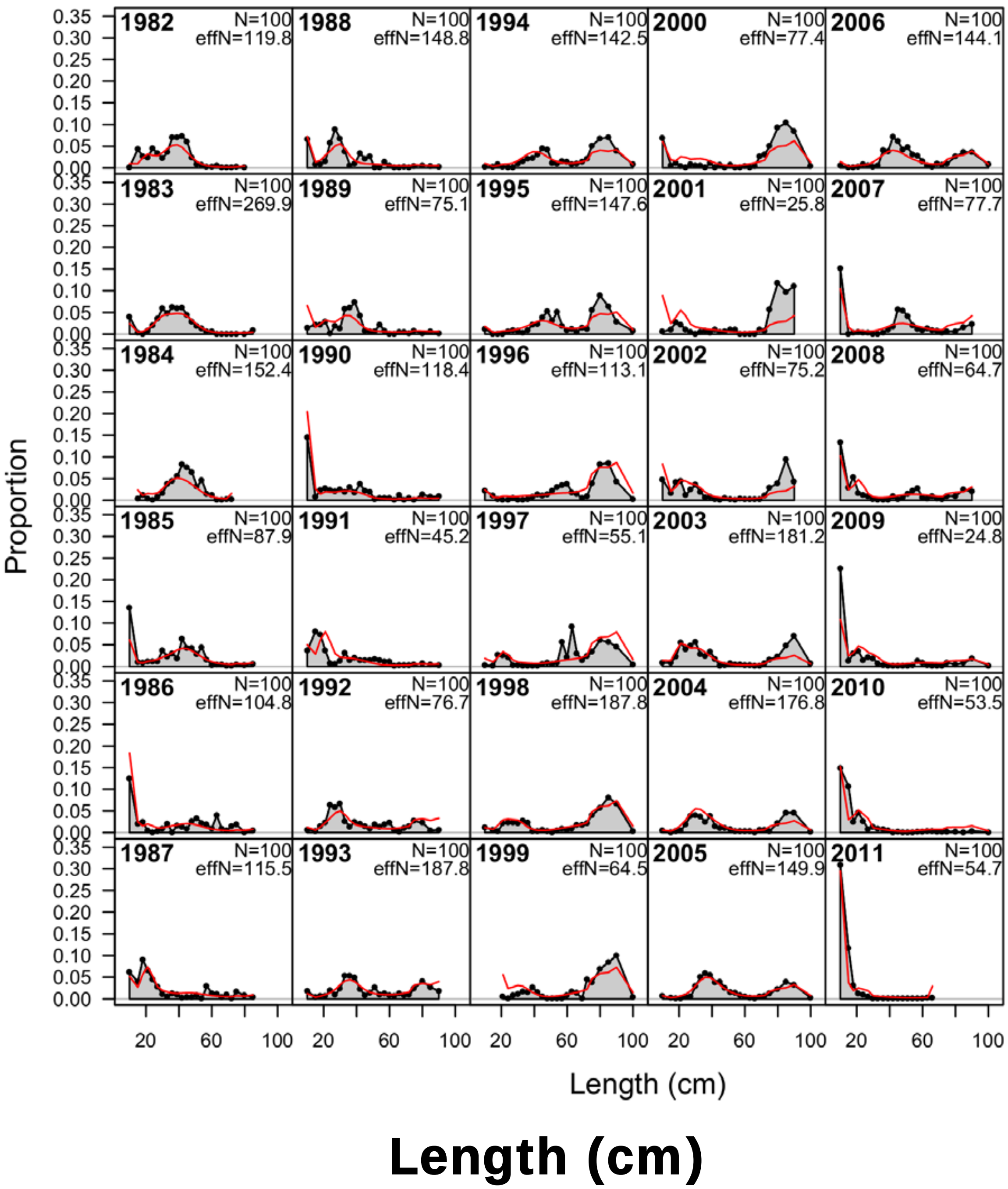
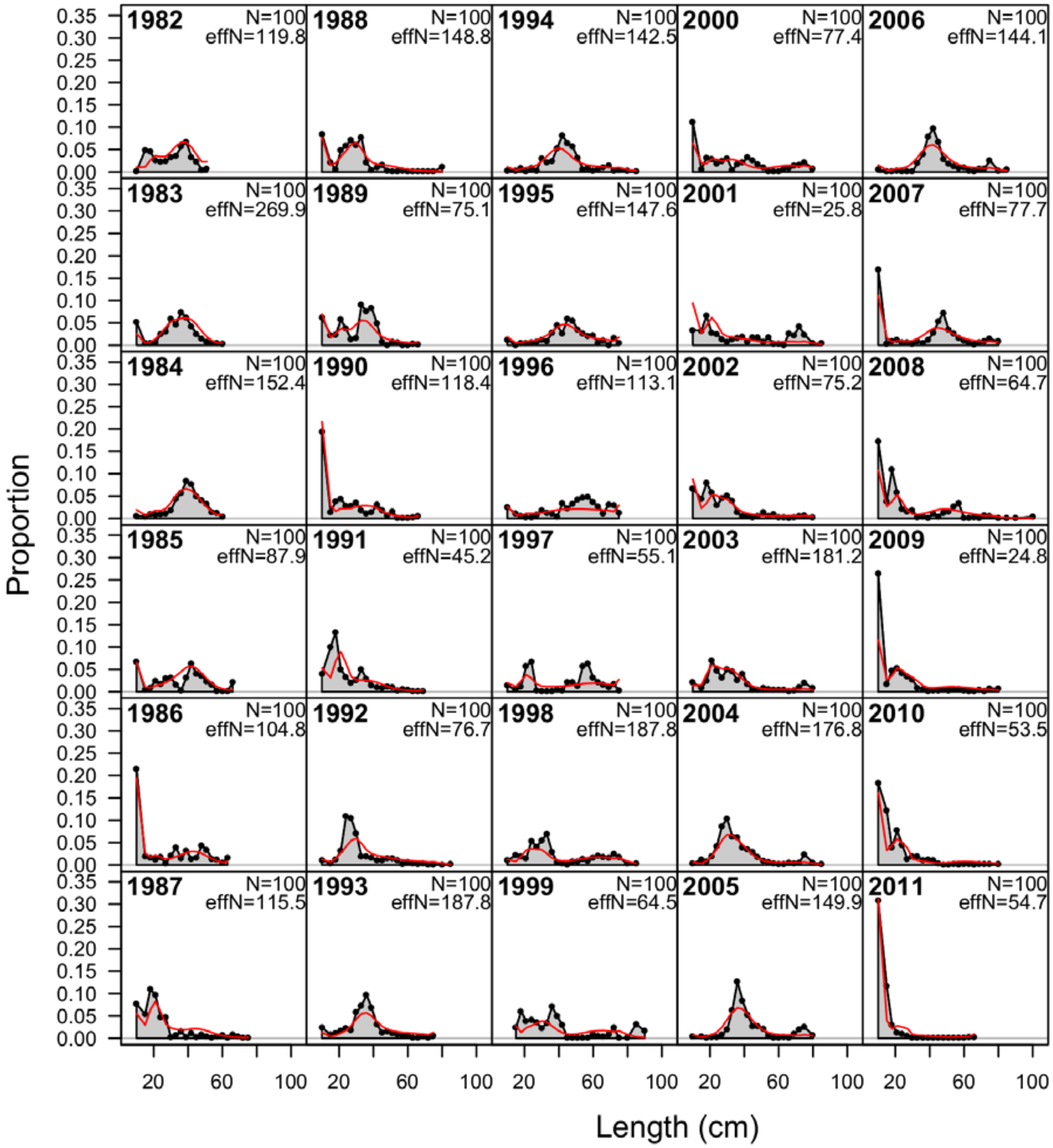


Figure 5.24. Greenland turbot model fit to EBS shelf trawl survey **female** length frequency data. Lines are model predictions, points are data.



Length (cm)

Figure 5.25. Greenland turbot model fit to EBS shelf trawl survey **male** length frequency data. Lines are model predictions, points are data

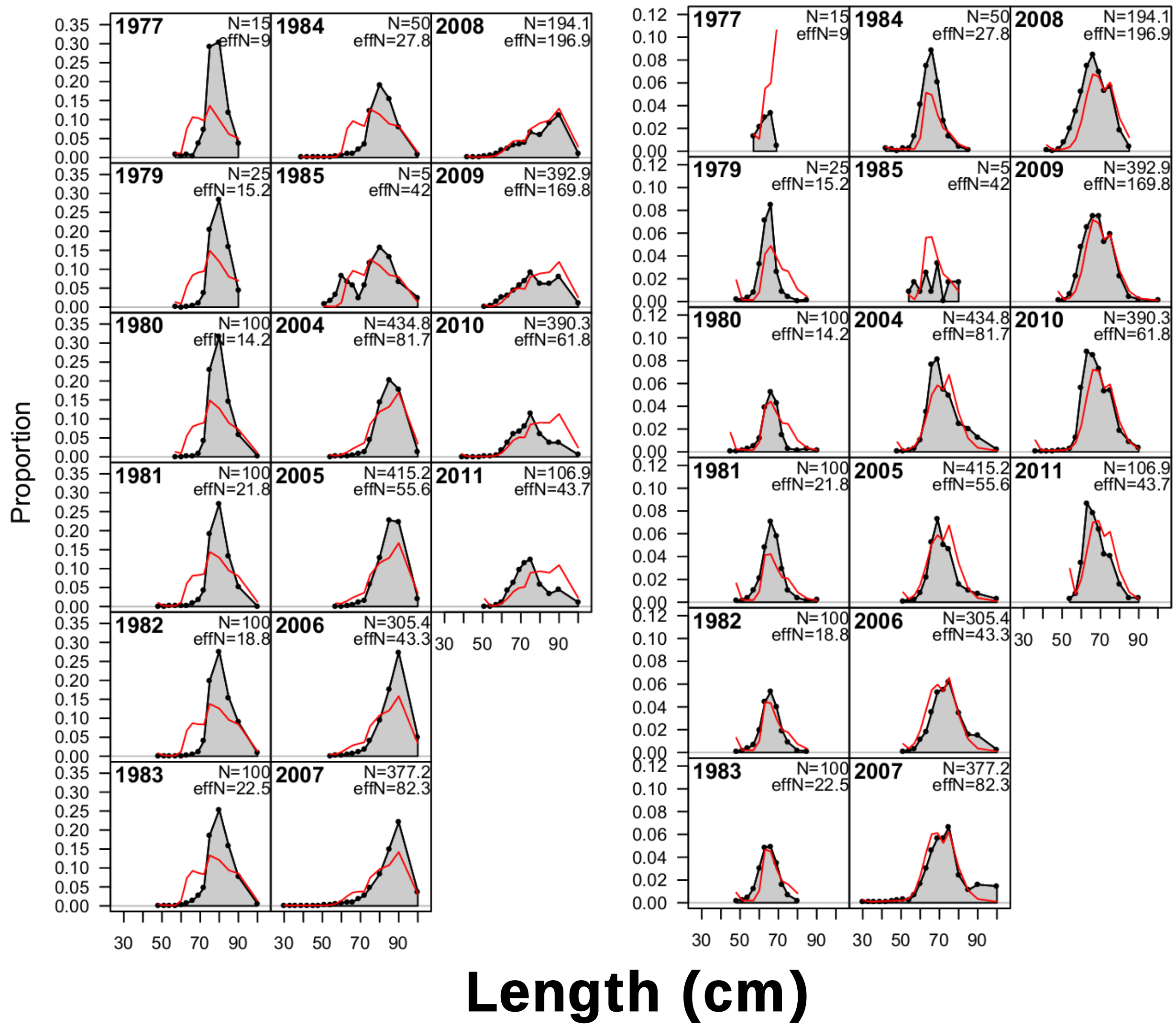
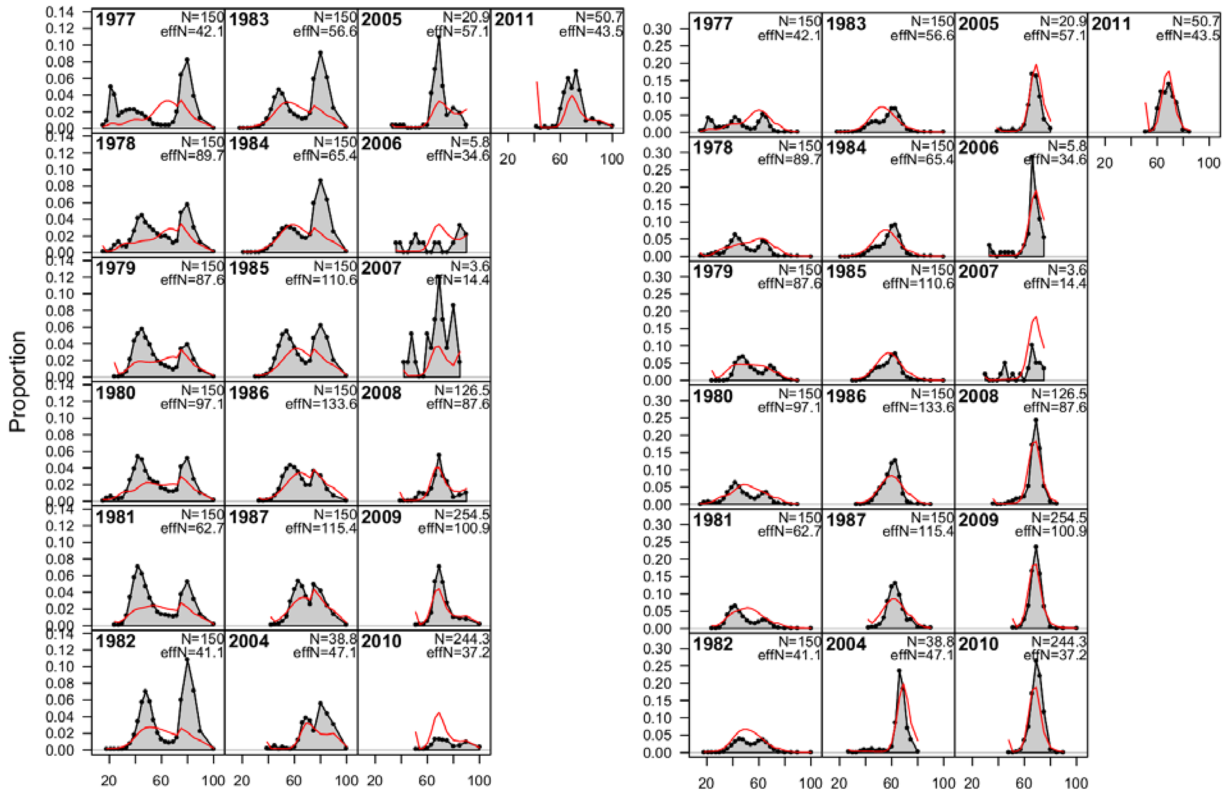


Figure 5.26. Greenland turbot model fit to EBS longline fishery length frequency data (combined sexes). Lines are model predictions, points are data; females on left and males on right.



Length (cm)

Figure 5.27. Greenland turbot model fit to EBS trawl fishery length frequency data. The left set are females, while the right set are males. Lines are model predictions, points are data; females on left and males on right.

Attachment 5.B Table for Model 2 (estimate differential male natural mortality)

The following tables are provided to allow alternative evaluation for ABC/OFL and status determinations should Model 2 be selected.

Model 2 (Alternative) summary table

Quantity	As estimated or *specified last* year for: 2011	2012	As estimated or *recommended this* year for: 2012	2013
M (natural mortality rate)	0.112	0.112	0.112 (0.208)	0.112 (0.208)
Tier	3a	3a	3a	3a
Projected total (age 1+) biomass (t)	74,000	69,700	112,961	102,406
Female spawning biomass (t)				
Projected	49,198	45,504	85,796	80,298
$B_{100\%}$	71,048	71,048	74,873	74,873
$B_{40\%}$	28,419	28,419	29,949	29,949
$B_{35\%}$	24,867	24,867	26,205	26,205
F_{OFL}	0.293	0.293	0.688	0.688
$maxF_{ABC}$	0.293	0.293	0.554	0.554
F_{ABC}	0.247	0.247	NA	NA
OFL (t)	7,217	7,217	17,960	14,486
maxABC (t)	6,137	6,137	14,772	11,905
ABC (t; BSAI)	6,137	6,137	14,772	11,905
EBS portion	4,590	4,590	11,050	8,905
C AI portion	4,301	4,301	3,722	3,000
Status	As determined *last* year for: 2009	2010	As determined *this* year for: 2010	2011
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Table 5B.1. Mean spawning biomass, F, and yield projections for Greenland turbot, 2011-2024 **for model 2 (optionally available)** under the harvest scenarios. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be **50:50**

Catch	Max FABC	FABC	5-year avg.	F75%	No Fishing	Scenario 6	Scenario 7
2011	3,252	3,252	3,252	3,252	3,252	3,252	3,252
2012	14,772	14,772	1,650	3,559	0	17,960	14,772
2013	11,905	11,905	1,553	3,278	0	13,910	11,905
2014	10,065	10,065	1,493	3,091	0	11,414	12,266
2015	9,199	9,199	1,486	3,033	0	10,268	10,870
2016	9,497	9,497	1,575	3,192	0	10,610	11,043
2017	10,951	10,951	1,781	3,609	0	12,366	12,682
2018	12,633	12,633	2,030	4,114	0	14,332	14,567
2019	13,570	13,570	2,233	4,508	0	15,288	15,464
2020	13,509	13,509	2,351	4,710	0	14,984	15,117
2021	12,737	12,737	2,390	4,739	0	13,854	13,954
2022	11,641	11,641	2,371	4,644	0	12,419	12,494
2023	10,504	10,504	2,315	4,478	0	11,023	11,080
2024	9,479	9,479	2,239	4,279	0	9,827	9,869
Fishing M.	Max FABC	FABC	5-year avg.	F75%	No Fishing	Scenario 6	Scenario 7
2011	0.105	0.105	0.105	0.105	0.105	0.105	0.105
2012	0.554	0.554	0.057	0.125	0.000	0.688	0.554
2013	0.554	0.554	0.057	0.125	0.000	0.688	0.554
2014	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2015	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2016	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2017	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2018	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2019	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2020	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2021	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2022	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2023	0.554	0.554	0.057	0.125	0.000	0.688	0.688
2024	0.554	0.554	0.057	0.125	0.000	0.688	0.688
Spawning biomass	Max FABC	FABC	5-year avg.	F75%	No Fishing	Scenario 6	Scenario 7
2011	85,796	85,796	85,796	85,796	85,796	85,796	85,796
2012	80,298	80,298	80,298	80,298	80,298	80,298	80,298
2013	68,528	68,528	76,942	75,738	77,977	66,433	68,528
2014	60,599	60,599	75,377	73,152	77,319	57,199	60,599
2015	57,433	57,433	76,999	73,907	79,738	53,268	55,933
2016	59,954	59,954	83,230	79,385	86,686	55,348	57,431
2017	65,825	65,825	92,298	87,754	96,435	60,905	62,528
2018	71,177	71,177	101,023	95,747	105,877	65,875	67,138
2019	73,806	73,806	107,716	101,600	113,388	67,937	68,917
2020	73,413	73,413	112,009	104,945	118,604	66,850	67,607
2021	70,715	70,715	114,186	106,109	121,776	63,480	64,063
2022	66,649	66,649	114,675	105,589	123,273	58,895	59,342
2023	62,016	62,016	113,904	103,873	123,473	53,961	54,303
2024	57,369	57,369	112,239	101,369	122,701	49,236	49,497

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