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. 2008 and 2009 catch data were updated (and added).
2. The Eastern Bering Sea (EBS) shelf survey 2009 biomass and length composition estimates were added.
3. About 300 age samples were included from the 2007 shelf survey to provide more information on sex-specific growth patterns of Greenland turbot (previously only data from 1994 and 1998 were used)

Changes to the assessment model

The model used this year was modified from SS2 to SS3 version of Stock Synthesis software. To the extent possible, the configurations are similar.

Changes in the assessment results

The 2009 **EBS shelf trawl survey** biomass estimate was down by about 19% from the 2008 estimate and estimates from the last three years average about 58% of the long-term mean value from this survey. In terms of numbers, the survey was up 47% from the 2008 value and was 7% above the long-term mean for population numbers. The increase in population numbers is due to above average abundances of young Greenland turbot.

The slope-trawl survey was assumed to index 75% of the Greenland turbot stock inhabiting U.S. waters. Model results based on these surveys and data from longline and trawl fisheries result in an estimate of $B_{40\%}$ equal to 24,255t (female spawning biomass). The current estimate of the year 2009 female spawning biomass is 44,871t. There appears to be a favorable recruitment pattern in recent years after a period of relatively few small fish occurring on the shelf in surveys. Recommended ABCs are adjusted from the maximum permissible given uncertainties highlighted by the different abundance indices in this region and the lack of evidence of substantive stock increases in the adult population. Under this calculation, the 2010 and 2011 ABC levels for BSAI Greenland turbot of 3,761 and 3,456 t respectively. The corresponding maximum permissible ABC levels under Tier 3a are 6,124 and 5,372 t, respectively. The 2010 and 2011 overfishing levels, based on the $F_{35\%}$ rate are 7,464 t and 6,856 t corresponding to a full-selection F of 0.315.

Response to SSC comments

The following excerpt is from the December 2008 SSC minutes:

The SSC also reiterates two comments to the assessment authors from the December 2007 minutes:

- *The SSC notes several lack-of-fit issues such as the poor fit to size data, and residual patterns in survey abundances. We encourage the authors to explore differences in availability to the surveys* *over time, for example, by examining the spatial distribution of different size classes to the extent data are available.*

- *The SSC requests that the author evaluate the importance of the slope survey data to the current model.*

The latter request is particularly relevant given budgetary constraints that could affect the slope survey in 2010.

In this year's assessment the newest version of stock synthesis software was used (previous assessments used versions that dated to 2007). This software has a new form of size-based selectivity that was used and attempts were made to provide better fits to all of the available data. However, shifts in Greenland turbot sex-ratios (within surveys) and between fisheries highlight the difficulties in accommodating the available observations.

The importance of the slope survey to the Greenland turbot assessment is critical because it covers the habitat range of Greenland turbot and is unaffected by depredation by killer whales (as is the case with the longline survey). It is likely that without a regular slope trawl-survey, future ABCs will be reduced due to greater levels of uncertainty. Additionally, conducting regular surveys in the Aleutian Islands region would allow for better monitoring capabilities since a significant component of the population is common in this area.

The Plan Team commented on the 2008 Greenland turbot assessment regarding ABC and OFL recommendations:

> *"…because of differences noted in biomass estimates, coupled with continuing uncertainties in stock trends, the Team recommended a stair-step procedure for increasing the ABC up to the maximum permissible ABC, assuming that there is a 2010 survey. If no survey occurs in 2010 the team recommends maintaining the 2009 ABC for 2010. The step for 2009 would yield an ABC that is 60% of the maximum permissible ABC, or 7,380 t, which corresponds to a full selection fishing mortality rate of 0.27. The OFL fishing mortality rate is computed under Tier 3a, FOFL = F35% = 0.57, and translates into a 2009 OFL of 14,900 t."*

This request was included in the assessment in 2008 and is carried forward again this year as the recommendation because the concerns remain.

The Team also recommended that the author explore *1) the scale of biomass estimated by the model and 2) the proposed ABC effect of recent recruitment indicated by the 2009 fishery.* The scale of the biomass was re-evaluated and the effect of recent recruitment was investigated for near and medium term time frames in the section titled "Projections and harvest alternatives."

Summary

Status and catch specifications (t) of Greenland turbot in recent years. Biomass for each year corresponds to the projection given in the SAFE report issued in the preceding year. The OFL and ABC for 2010 and 2011 are recommendations made in this assessment. Catch data are current through 10/31/09.

Year	Area	Age 1+ Bio.	OFL	ABC	TAC	Catch
2008	BSAI	104,100	15,600	2,540	2,540	2,541
	EBS			1,750	1,750	1,949
	AI			787	787	592
2009	BSAI	104,583	14,800	7,380	7,380	4,200
	EBS			5,090	5,090	2,025
	AI			2,290	2,290	2,175
2010	BSAI	61,100	7,464	3,761		
	EBS			2,595		
	AI			1,166		
2011	BSAI		6,856	3,456		
	EBS			2,385		
	AI			1,071		

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).

In 2008 and 2009, trawl-caught Greenland turbot has exceeded the level of catch by longline vessels (Table 5.1). This shift in the proportion of catch by sector is 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 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 11% of all Greenland turbot caught in groundfish fisheries were discarded (on average) during 2004-2008.

By gear-type and region, trawl catch was most significant in the Aleutian Islands in 2009 compared to relatively high levels of trawl catch in the EBS in 2008 (Table 5.3). By target fishery, the gain in trawl-fishery has occurred primarily in the Greenland turbot and "arrowtooth flounder" fisheries in 2008 and 2009 (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 sample sizes for the period of the domestic fishery from 1989 – 2009 are given in Table 5.5.

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. Planned biennial slope surveys lapsed (the 2006 survey was canceled) but resumed in the summer of 2008 (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). 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. The shelf survey biomass estimates are therefore treated as a relative abundance index.

The combined estimates from the shelf and slope indicate a decline in EBS abundance for the 4 years of observations that were available when US-Japanese slope surveys were conducted in 1979, 1981, 1982, and 1985. After 1985, the 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 17 years (1993-2009) is 24,700 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys are presented in Table 5.7. The biomass trends track somewhat differently than the proportion of tows with Greenland turbot, suggesting that the extent of the spatial distribution has remained relatively constant (or increased slightly) while the density within stations increased but recently declined (Fig. 5.3).

The 2008 EBS slope trawl survey biomass estimate was 17,900 t (first presented in the 2008 assessment) which compared to the next most recent (2004) estimate of 36,600 t. Most of this difference was attributed to the lack of Greenland turbot found in the 400-600 m depth strata compared to the other years (Table 5.8).

Survey size 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. 5.4). In the last 7-8 years an advancing mode of smaller fish are apparent and suggest new recruitment after a period of 9-10 years without much sign of recruitment. Also apparent is recruitment in the past year based on the mode of Greenland turbot at about 10cm.

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 403 samples (from 1994, 1998, and 2007 surveys) were used instead of the earlier data. Research on Greenland turbot age-validation methods continues at the AFSC.

Aleutian Islands survey

In 2006 NMFS scientists surveyed the Aleutian Islands region with bottom trawls and longline gear and the shelf region of the EBS were surveyed with trawl gear. The 2006 Aleutian Islands bottom trawl survey estimate was 20,900 t, an increase of 85% from the 2004 survey estimate and is above the 1991-2006 average level of 17,100 t (Table 5.6). The distribution of Greenland turbot in 2006 indicate fewer survey stations with moderate catches of Greenland turbot but somewhat higher variability compared to data from other recent surveys (Fig. 5.5). The breakdown of area specific survey biomass for the Aleutian Islands region shows that the eastern region has the highest densities and contains about 62% of the biomass, on average (Fig. 5.6; Table 5.9). The trawl-survey area-swept data for the Aleutian Islands component of the Greenland turbot stock was excluded from the stock assessment model but is used for the Tier 5 calculations.

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. As a result, the 2009 index information was unavailable for this assessment (though research recommendations coming from a review of the sablefish assessment will require formal analysis to provide a continuous index (with associated uncertainty) that includes the effect of whale depredation on survey stations).

The survey time series (through 2008) indicates that about 25% 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
Bering 4		11,729		13,072		16,082		11,965		3,717		1,561	
Bering 3		6,172		6,156		5,005		3,784		1,822		1,754	
Bering 2		27,936		33,848		24,766		24,660		15,268		13,523	
Bering 1		13,491		10,068		4,788		6,206		2,297		1,235	
NE Aleutians	23,133		16,124		12,987		10,942		8,551		3,031		3,155
SE Aleutians	2,142		1,806		1,201		1,397		937		566		297
Bering Sea (total)		59,328		63,144		50,641		46,616		23,103		18,074	
Aleutians (total)	25,275		17,930		14,188		12,339		9,487		3,597		3,452
Combined	114,457	76,142	81,193	81,039	64,251	64,993	55,875	59,827	42,962	29,651	16,287	23,196	15,632

The combined time series shown above (1996-2008) was used as a relative abundance index. It was computed by taking the average RPN from 1996-2008 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 (1996-2008) 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. A coefficient of variation of 20% for this index was assumed. The time series of length frequency data from the longline survey extends back to the cooperative longline survey and is shown in Fig. 5.7.

Annual research catches (1977 - 2009) from NMFS longline and trawl surveys (t) 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
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
Longline surveys												1.1	3.5		

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. 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.

Total catch estimates used in the model were from 1960 to 2009. 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 (longlines 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/2009/BSAIGturbot.zip.

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 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 5.11.

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

$$w = 2.69 \times 10^{-6} L^{3.3092} \quad \text{for females}$$

and

$$w = 6.52 \times 10^{-6} L^{3.068} \quad \text{for males}$$

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

Maturation and fecundity
Recent studies on the fecundity of Greenland turbot indicate that estimates 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 recruitment estimates from 1960-2009 (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).

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 52,800 t between 1997-2008) 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.

In response to the SSC request to fit the available data better, the input variances for the indices were re-evaluated. In past assessments, fitting to the EBS slope survey time series was given higher priority and this was used to scale the population (i.e., by specifying that the availability/catchability coefficient was 0.75 and that the CV for the index averaged 12%). This constraint tends to result in poorer fits to the other trend data (the longline survey and shelf bottom-trawl data). To resolve this, the input variances for the slope surveys were set at their sampling error estimates (averaging about 20% CV). This resulted in better fits to the other indices while degrading the fit to the slope survey (Fig. 5.8):

	Emphasis on fitting slope survey R^2	Balanced emphasis R^2
Shelf bottom-trawl survey	0.442	0.555
Slope bottom-trawl survey	0.827	0.518
Sablefish longline survey	0.700	0.767

The selected model for this year was based on the balanced treatment of the different survey indices.

Results

This year's model configuration put less weight on fitting the slope survey data. The residual pattern of the model fit to survey indices is improved over previous years (Fig. 5.8). However, there are still periods where predictions are below and above observations. This is particularly notable for the longline sablefish survey and the EBS shelf trawl survey. The fit to the slope survey (considered to best cover the habitat for Greenland turbot) fits well and the residual patterns are reasonable. The shifts in selectivity were intended to reflect inter-annual habitat changes (e.g., extent of the cold pool or some other environmental factor) and random changes in spatial distribution (Fig. 5.9). A consequence of fitting the trend data better in the current assessment results in considerably higher abundances during the mid 1970s compared to previous years (Fig. 5.10).

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 an increase of about 4% from the 2004 level bringing the 2010 total begin-year biomass (age 1 and older) estimate to about 61,100 t (Table 5.12).

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 5.12; Fig. 5.11). A comparison of this year's model result with the 2008 assessment is also presented in Table 5.12. The estimated historical numbers at age is given in Table 5.13.

Selectivity

Estimates of selectivity (using recommended option #24 in SS3) provide patterns that appear reasonable over time for the shelf survey (Fig. 5.9). The average selectivity patterns among all gear types was also reasonable (Fig. 5.12). 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 comprises about 70% females (Fig. 5.13). The slope trawl survey also shows that in there is variability in the proportion female. In 2002 and 2008 the survey resulted in far more males than females—opposite of what was estimated for 2004 (more females than males; Fig. 5.14). This highlights the sex and size specific variability within the same region between years. Females in all years tended to be larger (as expected) and in 2008 the slope survey indicated some smaller than usual Greenland turbot.

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. 5.12). 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 age-equivalent sex-specific selectivity estimates (for 2009) from each gear type for Greenland turbot in the BSAI is given in Table 5.14. These are approximate because selectivity processes are modeled as a function of size. Similar, approximate age-and-sex-specific weights are available (Table 5.15).

Fit to age and size composition data

The model fit the available length-at-age data well and indicates that females grow larger than male Greenland turbot (Fig. 5.15). The conversion of maturity at size (input to the model) combined with growth and weight-length relationship resulted in a slightly smaller weight-at-age for females (and analogously reproductive output) compared to Ianelli et al. (2008; Fig. 5.16). Size composition observations from the fisheries and surveys are matched by the model predictions reasonably well (see Attachment 5.1, Figs. 5.21-5.26). 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, there has been evidence of positive recruitment for Greenland turbot (Fig. 5.17). Analyses on fitting the stock-recruitment relationship indicated that the residuals were highly auto-correlated. Therefore, the assumptions required to pursue stock-recruitment analyses are difficult to justify.

Maximum Sustainable Yield
Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship, which for Greenland turbot may be impractical as the extent the stock structure is likely to be beyond the area surveyed and fished. As with many other groundfish, 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, for the basis for recommendations were based on a conservative model configuration (assuming slope-survey catchability=0.75). The status of the projected spawning biomass in year 2009 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 1978-2007 gives a long-term average female spawning biomass of 24,255 t. The current estimate of the year 2009 female spawning biomass is about 44,871 t, above the estimate of $B_{35\%}$ (21,223 t).

Specification of OFL and Maximum Permissible ABC and ABC Recommendation

The choice for recommending an ABC in recent years has been much lower than the maximum permissible estimates (in 2008 the ABC recommendation was 21% of the maximum permissible level). The rationale for this low value has been partly due to the lack of recent surveys on the slope region and partly because of concerns over stock structure uncertainty, data and modeling issues. This year a slope survey was prosecuted and there are positive signs of recruitment. Hence, the rationale for keeping the ABC recommendation so far below the maximum permissible is less defensible. As an alternative, we recommend that the ABC be set to 60% of the maximum permissible as one of an intermediate stair-step towards converting to the maximum permissible ABC level. Based on discussions with the Plan Team, this step was proposed to remain constant (i.e., 60% of maximum permissible) for 2010 as well. This rate is designed to acknowledge the issues identified in past assessments. Reducing ABC below the maximum permissible level also seems prudent because of concerns about uncertainties in the stock trends. Two surveys (the longline and the shelf bottom trawl survey) indicate somewhat steeper declines than predicted by the model (Fig. 5.8).

The projected Greenland turbot maximum permissible ABC and OFL levels for 2010 and 2011 are shown below (catch for 2010 was set equal to the ABC recommendation):

Year	Catch (for 2011 projection)	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2010	3,761 t	6,124 t	3,761 t	7,464 t	44,871 t
2011		5,372 t	3,456 t	6,856 t	39,953 t

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is 7,464 t corresponding to a full-selection F of 0.315. 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. 5.18).

Tier 5 ABC/OFL estimates
As an alternative, Tier 5 ABC and OFL estimates are 5,107 t and 6,850 t respectively. These estimates were based on the mean biomass estimate of 60,800 t (computed as the sum of mean biomass estimates since 2004 for the Aleutian Islands, EBS slope, and EBS shelf surveys) and a natural mortality rate of 0.112.

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 5.16).

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 proportion of the adult biomass in the Aleutian Islands region has ranged from 24% to 49%. The ABC for the Aleutian Islands is 31% of the total ABC, with 69% allocated to the eastern Bering Sea. These rates are based on mean values observed from biomass estimates and give the following region-specific allocation:

	60% of maximum permissible ABC	Maximum permissible ABC
Aleutian Islands ABC	1,166	1,904
Eastern Bering Sea ABC	2,595	4,216
Total	3,761	6,120

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 2009 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2010 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2009 (here assumed to be 4,200 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 2010, 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. Here values equal to 60% of the maximum permissible F_{ABC} as requested by the Plan Teams and SSC in 2008

Scenario 3: In all future years, F is set equal to the 2005-2009 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 2009 and above its MSY level in 2022 under this scenario, then the stock is not overfished.)

Scenario 7: In 2010 and 2011, 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 2022 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2009 (Table 5.17). Fishing at the maximum permissible rate indicate that the spawning stock will gradually drop to near the $B_{40\%}$ by 2021 (Fig. 5.19).

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 2009 spawning biomass estimated at 44,871t relative to $0.5B_{35\%}$ =0.0 t). Under the guidelines, since the 2009 biomass estimate is above the $B_{35\%}$ level (and $B_{40\%}$) and the stock is not overfished.

Projections of fishable biomass 13 years into the future under alternative fishing mortality rates were examined. The same natural mortality and growth parameters that were used in the previous stock synthesis runs were employed for the projections. Projections with fishing at the maximum permissible level result in an expected value of spawning biomass of 24,200 t by 2022. These projections illustrate the impact of the recent recruitment observed in the survey. For example, under most scenarios, 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.

Currently, the ecosystem group within the REFM Division is actively evaluating the pattern of mortality between different species in the EBS. One aspect of this work involves developing a multi-species model. Results from this work indicate that Greenland turbot has been an important predator.

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. 5.18). Management parameters of interest derived from this assessment are presented in Table 5.18.

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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
1997	1,209	5,989	7,199		9,000
1998	1,830	7,319	9,149		15,000
1999	1,799	4,057	5,857		9,000
2000	1,946	5,027	6,973		9,300
2001	2,149	3,163	5,312		8,400
2002	1,033	2,605	3,638		8,000
2003	908	2,605	3,513		4,000
2004	675	1,544	2,220		3,500
2005	729	1,831	2,559		3,500
2006	360	1,605	1,965		2,740
2007	429	1,400	1,829		2,440
2008	1,935	806	2,741		2,540
2009	2,932	1,264	4,196*		7,380

*Catch estimated as of October 2009.

Table 5.2. Estimates of discarded and retained (t) Greenland turbot based on NMFS estimates by "target" fishery, 1992-2009 (the "arrowtooth" fishery was combined with the Greenland turbot fishery from 2003-2009).

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	1,677	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	3,436	334	64	50	34	18	64	5	51	12	115	14	3,764	432

Table 5.3. Estimates of Greenland turbot catch by gear and area based on NMFS Regional Office estimates, 2003-2009.

Area	Gear	2003	2004	2005	2006	2007	2008	2009
Aleutian Islands	Fixed	650	218	138	346	338	111	90
	Trawl	315	196	301	179	178	712	2,083
	Aleutian Islands Total	965	414	439	525	516	824	2,173
EBS	Fixed	1,918	1,326	1,693	1,259	1,061	694	1,175
	Trawl	575	479	427	181	251	1,222	849
	EBS Total	2,493	1,805	2,120	1,440	1,313	1,917	2,024
Grand Total		3,458	2,220	2,559	1,965	1,829	2,741	4,196

Table 5.4. Estimates of Greenland turbot catch (t) by gear and "target" fishery, 2004-2009. Source: NMFS AK Regional Office catch accounting system.

	"Target" fishery	2004	2005	2006	2007	2008	2009
Longline and pot	Greenland turbot	1,168	1,527	1,212	1,097	573	1,083
	Sablefish	90	75	114	130	119	114
	Pacific cod	221	170	77	129	76	49
	Shallow-water flatfish	64	57	61	15	15	6
	Arrowtooth flounder	0	2	140	16	0	9
	Others	1	0	3	12	22	4
Trawl	Greenland turbot	61	24	0	2	205	1,349
	Pacific cod	79	15	19	89	11	2
	Arrowtooth flounder	53	154	21	3	1,176	1,329
	Atka mackerel	123	167	117	130	201	85
	Flathead sole	191	150	28	30	98	49
	Pollock	18	31	65	107	82	44
	Rockfish	74	139	74	47	143	65
	Other Flatfish	51	34	1	12	11	4
	Rock sole	4	1	27	8	0	2
	yellowfin sole	1	7	8	1	1	3
	Sablefish	12	7	0	0	6	0
	Others	8	0	0	0	0	0

Table 5.5. Greenland turbot BSAI fishery length sample sizes by gear type and sex, 1989-2009.

	Fixed			**Trawl**		
Year	Female	Male	% Female	Female	Male	% Female
1989	0	0		1,405	5,568	20%
1990	0	0		3,864	5,762	40%
1991	0	0		1,924	1,818	51%
1993	3,921	915	81%	0	0	--
1994	503	150	77%	1,024	1,027	50%
1995	1,870	715	72%	255	365	41%
1996	941	442	68%	112	390	22%
1997	2,393	1,014	70%	0	0	--
1998	3,510	2,127	62%	307	696	31%
1999	8,053	2,900	74%	1,044	1,556	40%
2000	6,604	2,992	69%	724	1,328	35%
2001	4,054	1,550	72%	467	892	34%
2002	4,725	1,811	72%	186	433	30%
2003	4,624	2,113	69%	197	325	38%
2004	4,348	2,625	62%	179	433	29%
2005	4,650	1,902	71%	118	211	36%
2006	3,339	1,474	69%	15	76	16%
2007	3,816	2,127	64%	34	23	60%
2008	1,577	1,481	52%	421	1,572	21%
2009	3,217	2,586	55%	1,134	2,583	31%

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		

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	290		
2005	373	61	441	56	293		
2006	376	56	427	49	262		
2007	376	83	499	68	334	334	303
2008	375	78	406	59	245		
2009	375	104					

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

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

Table 5.9. Time series of Aleutian Islands survey sub-regions estimates of Greenland turbot biomass (t), 1980-2006.

	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

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, 2007
Shelf survey: size composition and biomass estimates	1979-2009
Slope survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91, 2002, 2004, 2008
Longline survey: size composition and abundance index	1996-2008
Total fishery catch data	1960-2008
Trawl fishery size composition	1977-87, 1989-91, 1993-2009
Longline fishery size composition	1977, 1979-85, 1992-2009

Table 5.11. Summary of the length-at-age information used for this BSAI Greenland turbot assessment (see Gregg et al. 2006 for methods).

	1994				1998				2007			
	Males		Females		Males		Females		Males		Females	
Age	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N	Avg. length (cm)	N
1	13.00	1	13.00	1	13.17	3	16.00	5	11.79	24	12.18	17
2	18.17	3	19.60	8	24.44	9	22.40	5	20.86	7	22.50	4
3	28.33	9	31.50	4	25.25	8	25.56	9	25.17	6	30.00	1
4	37.82	11	38.89	9	33.50	16	32.50	8	35.00	4	39.50	2
5	44.75	12	47.17	6	35.00	2	31.50	2	44.40	15	46.18	17
6	48.00	4	54.75	4					47.18	22	47.00	17
7	51.00	1	59.50	2	49.50	2			51.70	23	50.72	18
8							63.00	1	52.67	15	54.67	15
9	66.00	2	74.00	1	54.00	1	68.00	1	59.00	3	60.45	11
10	60.33	6			64.50	2	67.00	1	55.00	3	64.80	5
11	65.70	10	76.00	2			77.00	2	58.80	5	63.0a0	1
12	65.11	9	76.50	6			75.00	2			62.00	3
13	67.40	15	72.00	9	73.00	1	80.00	2			65.00	7
14	66.53	17	80.71	7	66.00	2	75.00	2				
15	70.00	9	80.54	13			76.50	4			61.67	3
16	64.50	10	79.65	17					69.00	1	80.00	1
17	66.67	6	83.33	9			72.00	1	77.00	3	90.00	4
18	68.60	10	86.80	15			82.00	1	77.50	2	85.00	1
19	64.00	5	88.82	11							91.67	3
20	72.67	3	85.36	11			82.00	1			87.00	2
21	75.00	1	82.50	4			81.00	2	76.50	2	90.67	3
22	67.00	4	82.00	2							87.00	1
23	69.50	2					84.00	1				
24			84.50	2					84.00	1		
25			89.00	2					72.00	1		
26			92.00	1							92.00	3
27	72.00	2	88.00	2								
28			95.00	1								
29			95.00	2					82.00	1	92.00	1
30			92.00	1								
31									79.00	1		
Totals		152		152		46		50		139		140

Table 5.12. Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the past assessment) for BSAI Greenland turbot, 1960-2010.

			Female Spawning Biomass		Total Age 1+ Biomass	
Year	Total Fishing Mortality	Catch / Mid-yr Biom.	2008 Assessment	Current Assessment	2008 Assessment	Current Assessment
1960	0.31	0.174	134,017	86,526	242,758	159,007
1961	0.70	0.329	127,543	77,017	215,567	130,671
1962	1.45	0.503	115,725	58,796	173,759	86,835
1963	1.68	0.342	99,810	33,728	171,413	67,210
1964	1.18	0.304	88,473	17,655	227,498	84,507
1965	0.08	0.036	80,369	11,180	311,971	207,105
1966	0.04	0.024	84,501	11,928	427,509	409,938
1967	0.03	0.028	112,275	25,661	541,343	644,659
1968	0.03	0.031	184,121	93,163	642,446	870,624
1969	0.03	0.026	283,351	251,044	723,430	1,061,860
1970	0.02	0.016	372,973	451,483	788,654	1,212,170
1971	0.03	0.032	438,738	624,403	843,964	1,325,390
1972	0.07	0.056	476,783	733,176	859,695	1,373,200
1973	0.06	0.048	492,555	777,673	823,749	1,346,170
1974	0.09	0.060	502,063	790,785	787,665	1,303,330
1975	0.09	0.055	493,459	773,590	728,755	1,226,270
1976	0.10	0.054	475,391	743,668	675,772	1,150,460
1977	0.05	0.028	450,462	705,527	627,372	1,075,180
1978	0.08	0.041	434,977	675,777	611,963	1,033,470
1979	0.08	0.042	414,063	640,629	585,338	979,274
1980	0.11	0.057	394,753	607,404	559,354	926,391
1981	0.12	0.067	371,601	571,103	520,810	861,587
1982	0.13	0.066	346,501	533,826	474,692	790,147
1983	0.13	0.066	324,080	499,279	429,593	720,218
1984	0.07	0.035	297,955	465,122	385,997	651,756
1985	0.05	0.024	284,423	440,307	363,701	605,446
1986	0.04	0.017	274,730	417,420	346,891	565,330
1987	0.04	0.018	266,136	394,745	332,679	528,410
1988	0.03	0.014	255,520	370,313	316,939	491,030
1989	0.04	0.019	244,070	345,701	302,343	456,068
1990	0.07	0.030	230,149	319,663	285,093	419,857
1991	0.04	0.021	213,275	292,061	263,947	380,677
1992	0.01	0.011	198,387	267,690	247,035	348,577
1993	0.03	0.026	186,004	244,739	234,450	320,810
1994	0.06	0.035	170,405	219,607	217,482	290,332
1995	0.05	0.032	155,864	196,888	198,975	259,798
1996	0.04	0.028	143,062	176,949	182,755	233,317
1997	0.04	0.034	131,539	159,326	168,445	210,204
1998	0.06	0.049	119,730	142,169	153,976	188,108
1999	0.05	0.035	106,890	124,707	138,281	165,711
2000	0.06	0.047	97,046	111,015	126,439	148,104
2001	0.06	0.041	86,786	97,444	114,453	130,799
2002	0.04	0.031	78,609	86,446	105,382	116,644
2003	0.04	0.033	71,867	77,244	99,811	105,632
2004	0.03	0.023	65,737	68,919	96,076	96,247
2005	0.04	0.029	61,245	62,331	94,884	89,189
2006	0.03	0.024	57,623	56,383	94,014	82,524
2007	0.03	0.024	55,902	51,778	93,914	77,000
2008	0.07	0.038	55,876	48,156	94,795	71,996
2009	0.12	0.063	56,499	44,871	97,524	66,776
2010				39,953		61,149

Table 5.13. 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+
1978	13.6	23.4	16.2	30.9	15.6	19.5	15.6	9.1	2.8	1.8	1.2	0.8	0.5	0.4	0.5	0.5	120.5	0.3	0.2	0.1	0.4
1979	8.8	12.2	20.8	14.4	27.1	13.5	16.7	13.2	7.7	2.4	1.5	1.1	0.7	0.4	0.4	0.4	0.5	105.0	0.3	0.1	0.4
1980	5.2	7.8	10.8	18.4	12.6	23.4	11.5	14.1	11.1	6.4	2.0	1.3	0.9	0.6	0.4	0.3	0.4	0.4	91.5	0.2	0.4
1981	1.1	4.6	7.0	9.6	16.1	10.8	19.7	9.5	11.6	9.2	5.3	1.7	1.1	0.8	0.5	0.3	0.3	0.3	0.4	79.1	0.6
1982	1.6	1.0	4.1	6.1	8.3	13.6	8.9	16.1	7.8	9.5	7.5	4.4	1.4	0.9	0.7	0.4	0.3	0.2	0.3	0.3	68.4
1983	0.7	1.4	0.9	3.6	5.3	7.0	11.3	7.3	13.1	6.3	7.7	6.2	3.7	1.2	0.8	0.6	0.4	0.2	0.2	0.2	59.3
1984	1.9	0.6	1.3	0.8	3.2	4.5	5.8	9.2	5.9	10.6	5.1	6.4	5.2	3.1	1.0	0.7	0.5	0.3	0.2	0.2	51.4
1985	4.6	1.7	0.6	1.1	0.7	2.7	3.9	5.0	7.8	5.0	9.0	4.4	5.5	4.5	2.7	0.9	0.6	0.4	0.3	0.2	45.2
1986	1.3	4.1	1.5	0.5	1.0	0.6	2.4	3.3	4.3	6.7	4.3	7.8	3.8	4.8	3.9	2.4	0.8	0.5	0.4	0.2	40.1
1987	2.0	1.2	3.7	1.3	0.5	0.9	0.5	2.1	2.9	3.7	5.9	3.8	6.8	3.4	4.2	3.5	2.1	0.7	0.5	0.3	35.7
1988	1.7	1.8	1.1	3.3	1.2	0.4	0.8	0.5	1.8	2.5	3.2	5.1	3.3	6.0	3.0	3.7	3.1	1.9	0.6	0.4	31.9
1989	5.4	1.5	1.6	1.0	2.9	1.0	0.4	0.7	0.4	1.6	2.2	2.8	4.5	2.9	5.3	2.6	3.3	2.7	1.7	0.5	28.6
1990	1.6	4.9	1.4	1.4	0.8	2.5	0.9	0.3	0.6	0.4	1.4	1.9	2.5	4.0	2.6	4.7	2.3	2.9	2.4	1.5	25.8
1991	0.6	1.5	4.3	1.2	1.2	0.7	2.2	0.8	0.3	0.5	0.3	1.2	1.7	2.2	3.4	2.2	4.1	2.0	2.6	2.1	23.9
1992	0.5	0.5	1.3	3.9	1.1	1.1	0.6	1.9	0.7	0.2	0.4	0.3	1.0	1.5	1.9	3.0	2.0	3.6	1.8	2.3	22.9
1993	0.4	0.4	0.4	1.2	3.5	0.9	1.0	0.6	1.7	0.6	0.2	0.4	0.2	0.9	1.3	1.7	2.7	1.8	3.2	1.6	22.2
1994	0.8	0.3	0.4	0.4	1.1	3.1	0.8	0.9	0.5	1.5	0.5	0.2	0.3	0.2	0.8	1.1	1.5	2.3	1.5	2.8	20.7
1995	1.9	0.7	0.3	0.4	0.4	0.9	2.8	0.8	0.8	0.4	1.3	0.4	0.1	0.3	0.2	0.7	1.0	1.3	2.0	1.3	20.4
1996	0.7	1.7	0.6	0.3	0.3	0.3	0.8	2.5	0.7	0.7	0.4	1.1	0.4	0.1	0.2	0.1	0.6	0.8	1.1	1.7	18.8
1997	0.9	0.6	1.5	0.5	0.2	0.3	0.3	0.7	2.2	0.6	0.6	0.3	0.9	0.3	0.1	0.2	0.1	0.5	0.7	0.9	17.9
1998	0.8	0.8	0.5	1.3	0.5	0.2	0.3	0.3	0.7	1.9	0.5	0.5	0.3	0.8	0.3	0.1	0.2	0.1	0.4	0.6	16.2
1999	2.6	0.7	0.7	0.5	1.2	0.4	0.2	0.2	0.2	0.6	1.7	0.4	0.4	0.2	0.7	0.2	0.1	0.2	0.1	0.4	14.3
2000	2.9	2.3	0.6	0.6	0.4	1.1	0.4	0.2	0.2	0.2	0.5	1.4	0.4	0.4	0.2	0.6	0.2	0.1	0.1	0.1	12.6
2001	3.7	2.6	2.1	0.6	0.6	0.4	0.9	0.4	0.1	0.2	0.2	0.4	1.2	0.3	0.3	0.2	0.5	0.2	0.1	0.1	10.8
2002	0.6	3.3	2.3	1.9	0.5	0.5	0.3	0.8	0.3	0.1	0.2	0.1	0.4	1.0	0.3	0.3	0.1	0.4	0.1	0.0	9.4
2003	0.3	0.6	3.0	2.1	1.7	0.4	0.4	0.3	0.8	0.3	0.1	0.1	0.1	0.3	0.9	0.2	0.2	0.1	0.4	0.1	8.2
2004	0.3	0.3	0.5	2.7	1.8	1.5	0.4	0.4	0.3	0.7	0.2	0.1	0.1	0.1	0.3	0.8	0.2	0.2	0.1	0.3	7.2
2005	0.5	0.3	0.2	0.5	2.4	1.7	1.3	0.4	0.4	0.2	0.6	0.2	0.1	0.1	0.1	0.2	0.7	0.2	0.2	0.1	6.6
2006	3.2	0.4	0.2	0.2	0.4	2.1	1.5	1.2	0.3	0.3	0.2	0.5	0.2	0.1	0.1	0.1	0.2	0.6	0.2	0.1	5.8
2007	4.2	2.9	0.4	0.2	0.2	0.4	1.9	1.3	1.1	0.3	0.3	0.2	0.4	0.2	0.1	0.1	0.1	0.2	0.5	0.1	5.1
2008	9.5	3.7	2.6	0.3	0.2	0.2	0.3	1.7	1.2	0.9	0.2	0.2	0.2	0.4	0.1	0.1	0.1	0.1	0.2	0.4	4.6
2009	3.6	8.5	3.3	2.3	0.3	0.2	0.2	0.3	1.5	1.0	0.8	0.2	0.2	0.1	0.3	0.1	0.0	0.1	0.1	0.1	4.4

Table 5.13 (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+
1978	13.6	23.4	16.2	30.9	15.6	19.4	15.3	8.8	2.6	1.6	1.1	0.6	0.4	0.3	0.3	0.4	76.0	0.2	0.1	0.0	0.0
1979	8.8	12.2	20.8	14.4	27.1	13.4	16.4	12.8	7.2	2.2	1.3	0.9	0.5	0.3	0.3	0.3	0.3	62.5	0.1	0.1	0.0
1980	5.2	7.8	10.8	18.5	12.6	23.3	11.3	13.7	10.4	5.8	1.7	1.1	0.7	0.4	0.3	0.2	0.2	0.2	51.3	0.1	0.1
1981	1.1	4.6	7.0	9.6	16.0	10.7	19.3	9.2	10.8	8.2	4.5	1.3	0.8	0.5	0.3	0.2	0.2	0.2	0.2	41.1	0.2
1982	1.6	1.0	4.1	6.1	8.3	13.5	8.7	15.4	7.1	8.3	6.2	3.4	1.0	0.6	0.4	0.3	0.2	0.1	0.1	0.2	32.6
1983	0.7	1.4	0.9	3.6	5.3	6.9	11.0	6.9	11.9	5.4	6.2	4.6	2.6	0.8	0.5	0.3	0.2	0.1	0.1	0.1	25.7
1984	1.9	0.6	1.3	0.8	3.1	4.4	5.6	8.7	5.3	9.0	4.1	4.6	3.4	1.9	0.6	0.4	0.2	0.1	0.1	0.1	20.3
1985	4.6	1.7	0.6	1.1	0.7	2.7	3.8	4.7	7.2	4.3	7.3	3.3	3.8	2.8	1.6	0.5	0.3	0.2	0.1	0.1	17.0
1986	1.3	4.1	1.5	0.5	1.0	0.6	2.3	3.2	4.0	6.0	3.6	6.1	2.7	3.1	2.4	1.3	0.4	0.2	0.2	0.1	14.6
1987	2.0	1.2	3.7	1.3	0.5	0.9	0.5	2.0	2.8	3.4	5.1	3.1	5.2	2.3	2.7	2.0	1.1	0.3	0.2	0.1	12.7
1988	1.7	1.8	1.1	3.3	1.2	0.4	0.8	0.5	1.7	2.4	2.9	4.3	2.6	4.4	2.0	2.3	1.7	1.0	0.3	0.2	11.1
1989	5.4	1.5	1.6	1.0	2.9	1.0	0.3	0.7	0.4	1.5	2.0	2.5	3.7	2.3	3.8	1.7	2.0	1.5	0.8	0.3	9.8
1990	1.6	4.9	1.4	1.4	0.8	2.5	0.9	0.3	0.6	0.3	1.3	1.7	2.1	3.2	1.9	3.2	1.5	1.7	1.3	0.7	8.7
1991	0.6	1.5	4.3	1.2	1.2	0.7	2.2	0.8	0.2	0.5	0.3	1.0	1.4	1.7	2.6	1.6	2.7	1.2	1.4	1.1	7.9
1992	0.5	0.5	1.3	3.9	1.1	1.1	0.6	1.9	0.6	0.2	0.4	0.2	0.9	1.2	1.5	2.2	1.3	2.3	1.0	1.2	7.7
1993	0.4	0.4	0.4	1.2	3.5	0.9	1.0	0.6	1.7	0.6	0.2	0.3	0.2	0.8	1.0	1.3	1.9	1.2	2.0	0.9	7.9
1994	0.8	0.3	0.4	0.4	1.1	3.1	0.8	0.9	0.5	1.5	0.5	0.2	0.3	0.2	0.7	0.9	1.1	1.7	1.0	1.8	7.7
1995	1.9	0.7	0.3	0.4	0.4	0.9	2.8	0.8	0.8	0.4	1.3	0.4	0.1	0.3	0.1	0.6	0.7	0.9	1.4	0.9	7.9
1996	0.7	1.7	0.6	0.3	0.3	0.3	0.8	2.5	0.7	0.7	0.4	1.1	0.4	0.1	0.2	0.1	0.5	0.6	0.8	1.2	7.4
1997	0.9	0.6	1.5	0.5	0.2	0.3	0.3	0.7	2.2	0.6	0.6	0.3	1.0	0.3	0.1	0.2	0.1	0.4	0.5	0.7	7.3
1998	0.8	0.8	0.5	1.3	0.5	0.2	0.3	0.3	0.7	2.0	0.5	0.5	0.3	0.8	0.3	0.1	0.2	0.1	0.3	0.5	6.9
1999	2.6	0.7	0.7	0.5	1.2	0.4	0.2	0.2	0.2	0.6	1.7	0.5	0.5	0.3	0.7	0.2	0.1	0.1	0.1	0.3	6.2
2000	2.9	2.3	0.6	0.6	0.4	1.1	0.4	0.2	0.2	0.2	0.5	1.5	0.4	0.4	0.2	0.6	0.2	0.1	0.1	0.1	5.5
2001	3.7	2.6	2.1	0.6	0.6	0.4	0.9	0.4	0.1	0.2	0.2	0.5	1.3	0.3	0.3	0.2	0.5	0.2	0.1	0.1	4.6
2002	0.6	3.3	2.3	1.9	0.5	0.5	0.3	0.8	0.3	0.1	0.2	0.2	0.4	1.1	0.3	0.3	0.2	0.4	0.1	0.0	3.9
2003	0.3	0.6	3.0	2.1	1.7	0.4	0.4	0.3	0.8	0.3	0.1	0.1	0.1	0.3	1.0	0.2	0.2	0.1	0.4	0.1	3.4
2004	0.3	0.3	0.5	2.7	1.8	1.5	0.4	0.4	0.3	0.7	0.2	0.1	0.1	0.1	0.3	0.8	0.2	0.2	0.1	0.3	3.0
2005	0.5	0.3	0.2	0.5	2.4	1.7	1.3	0.4	0.4	0.2	0.6	0.2	0.1	0.1	0.1	0.3	0.7	0.2	0.2	0.1	2.8
2006	3.2	0.4	0.2	0.2	0.4	2.1	1.5	1.2	0.3	0.3	0.2	0.5	0.2	0.1	0.1	0.1	0.2	0.6	0.2	0.2	2.5
2007	4.2	2.9	0.4	0.2	0.2	0.4	1.9	1.3	1.1	0.3	0.3	0.2	0.5	0.2	0.1	0.1	0.1	0.2	0.5	0.1	2.3
2008	9.5	3.7	2.6	0.3	0.2	0.2	0.3	1.7	1.2	0.9	0.3	0.2	0.2	0.4	0.1	0.1	0.1	0.1	0.2	0.5	2.1
2009	3.6	8.5	3.3	2.3	0.3	0.2	0.2	0.3	1.5	1.0	0.8	0.2	0.2	0.1	0.3	0.1	0.0	0.1	0.1	0.1	2.1

Table 5.14. Age-equivalent sex-specific selectivity estimates (as estimated for 2009) 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	0.01	0.01	0.01	0.01
2	0.01	0.01	0.01	0.00
3	0.01	0.01	0.01	0.00
4	0.01	0.01	0.01	0.00
5	0.00	0.01	0.01	0.00
6	0.01	0.01	0.01	0.00
7	0.03	0.01	0.05	0.01
8	0.10	0.04	0.17	0.02
9	0.20	0.12	0.37	0.05
10	0.27	0.24	0.57	0.10
11	0.28	0.36	0.72	0.16
12	0.25	0.47	0.81	0.22
13	0.21	0.55	0.86	0.28
14	0.17	0.60	0.88	0.33
15	0.14	0.63	0.90	0.37
16	0.12	0.64	0.90	0.40
17	0.11	0.64	0.91	0.42
18	0.10	0.63	0.91	0.44
19	0.09	0.63	0.91	0.46
20	0.08	0.61	0.91	0.47
21	0.08	0.60	0.91	0.49
22	0.08	0.59	0.91	0.49
23	0.07	0.59	0.91	0.50
24	0.07	0.58	0.91	0.51
25	0.07	0.57	0.91	0.51
26	0.07	0.56	0.91	0.52
27	0.07	0.56	0.91	0.52
28	0.07	0.55	0.91	0.52
29	0.07	0.55	0.91	0.53
30	0.07	0.54	0.91	0.53

Table 5.15. 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	13.57	13.57	0.015	0.008
2	21.89	21.60	0.077	0.015
3	30.25	29.42	0.226	0.073
4	37.57	36.06	0.467	0.206
5	43.99	41.69	0.791	0.407
6	49.60	46.46	1.182	0.661
7	54.52	50.51	1.621	0.949
8	58.83	53.94	2.090	1.255
9	62.60	56.85	2.572	1.564
10	65.90	59.32	3.054	1.864
11	68.79	61.41	3.525	2.148
12	71.32	63.19	3.978	2.412
13	73.54	64.69	4.406	2.652
14	75.48	65.97	4.806	2.869
15	77.18	67.05	5.177	3.062
16	78.67	67.97	5.517	3.232
17	79.97	68.74	5.827	3.382
18	81.11	69.40	6.109	3.512
19	82.11	69.96	6.363	3.626
20	82.99	70.44	6.590	3.723
21	83.75	70.84	6.794	3.808
22	84.43	71.18	6.975	3.880
23	85.01	71.47	7.136	3.942
24	85.53	71.72	7.279	3.995
25	85.98	71.92	7.406	4.040
26	86.37	72.10	7.519	4.079
27	86.72	72.25	7.618	4.112
28	87.02	72.38	7.706	4.141
29	87.29	72.48	7.783	4.165
30	87.52	72.58	7.850	4.186

Table 5.16. Estimated total Greenland turbot harvest by area, 1977-2009. Values for 2009 are through Nov. 4th, 2009 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	2,467	960
1987	6,519	3,066	2004	1,805	414
1988	6,064	1,044	2005	2,120	439
1989	4,061	4,761	2006	1,440	525
1990	7,702	2,494	2007	1,313	516
1991	3,781	4,397	2008	1,917	824
1992	1,767	2,462	2009	2,024	2,173
1993	4,878	6,330			

Table 5.17. Mean spawning biomass, F, and yield projections for Greenland turbot, 2009-2022. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed to be **50:50** (whereas recent averages are around 80:20). The values for $B_{40\%}$ and $B_{35\%}$ are 24,255 and 21,223 tons, respectively.

Catch	Max F_{ABC}	0.6 x F_{ABC}	5-year avg.	F75%	No Fishing	Scenario 6	Scenario 7
2009	4,200	4,200	4,200	4,200	4,200	4,200	4,200
2010	6,124	3,761	1,471	1,484	0	7,464	6,124
2011	5,372	3,456	1,411	1,423	0	6,372	5,372
2012	4,656	3,134	1,335	1,346	0	5,378	5,673
2013	4,011	2,821	1,252	1,263	0	4,291	4,751
2014	3,354	2,582	1,189	1,198	0	3,418	3,693
2015	3,195	2,495	1,176	1,185	0	3,283	3,469
2016	3,460	2,611	1,238	1,248	0	3,653	3,783
2017	3,873	2,868	1,356	1,366	0	4,198	4,282
2018	4,199	3,130	1,480	1,491	0	4,587	4,642
2019	4,334	3,309	1,576	1,588	0	4,722	4,757
2020	4,320	3,394	1,638	1,651	0	4,673	4,697
2021	4,240	3,405	1,673	1,686	0	4,540	4,555
2022	4,152	3,378	1,694	1,707	0	4,405	4,415
Fishing M.	**Max F_{ABC}**	**0.6 x F_{ABC}**	**5-year avg.**	**F75%**	**No Fishing**	**Scenario 6**	**Scenario 7**
2009	0.158	0.158	0.158	0.158	0.158	0.158	0.158
2010	0.255	0.153	0.059	0.059	0.000	0.315	0.255
2011	0.255	0.153	0.059	0.059	0.000	0.315	0.255
2012	0.255	0.153	0.059	0.059	0.000	0.315	0.315
2013	0.255	0.153	0.059	0.059	0.000	0.298	0.315
2014	0.241	0.153	0.059	0.059	0.000	0.271	0.283
2015	0.241	0.153	0.059	0.059	0.000	0.273	0.281
2016	0.249	0.153	0.059	0.059	0.000	0.287	0.292
2017	0.251	0.153	0.059	0.059	0.000	0.294	0.297
2018	0.248	0.153	0.059	0.059	0.000	0.292	0.294
2019	0.242	0.153	0.059	0.059	0.000	0.284	0.285
2020	0.235	0.153	0.059	0.059	0.000	0.275	0.276
2021	0.230	0.152	0.059	0.059	0.000	0.268	0.268
2022	0.227	0.151	0.059	0.059	0.000	0.262	0.262
Spawning biomass	**Max F_{ABC}**	**0.6 x F_{ABC}**	**5-year avg.**	**F75%**	**No Fishing**	**Scenario 6**	**Scenario 7**
2009	44,871	44,871	44,871	44,871	44,871	44,871	44,871
2010	39,953	39,953	39,953	39,953	39,953	39,953	39,953
2011	33,822	35,468	37,067	37,057	38,095	32,890	33,822
2012	28,679	31,526	34,424	34,407	36,358	27,130	28,679
2013	24,928	28,592	32,505	32,481	35,215	23,012	24,244
2014	22,993	27,163	31,832	31,803	35,188	21,046	21,876
2015	23,020	27,360	32,587	32,553	36,478	21,190	21,769
2016	24,083	28,523	34,198	34,161	38,562	22,350	22,756
2017	25,112	29,745	35,870	35,829	40,709	23,399	23,680
2018	25,576	30,516	37,175	37,131	42,544	23,788	23,982
2019	25,472	30,766	38,039	37,990	44,000	23,559	23,691
2020	25,063	30,667	38,575	38,521	45,159	23,030	23,121
2021	24,609	30,432	38,940	38,882	46,142	22,488	22,549
2022	24,238	30,196	39,232	39,169	47,021	22,071	22,112

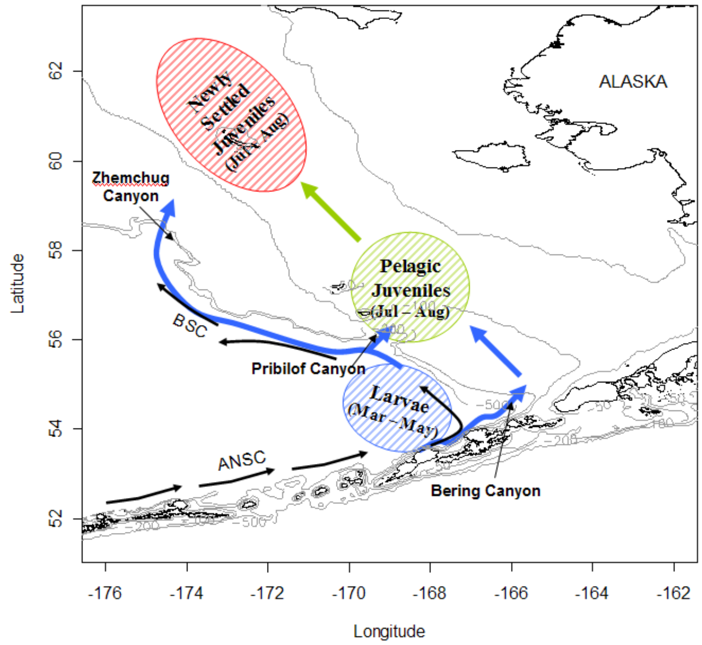
Table 5.18. Summary management values based on this assessment. Note that the fishing mortality rates assume 50:50 contribution from longline gear and trawl gear.

Management Parameter	Value
M (natural mortality)	0.112 yr^{-1}
Amendment 56 Tier (in 2010)	3a
Approximate age at full recruitment	10 years
$F_{35\%}$ (F_{OFL})	0.315
$F_{40\%}$	0.255
$B_{100\%}$	60,637 t
$B_{40\%}$	24,255 t
$B_{35\%}$	21,223 t
Year 2009 female spawning biomass	44,871 t
Year 2010 female spawning biomass	39,953 t
Year 2009 total (age 1+) biomass	67,501 t
$F_{ABC} = F_{40\%}$ (max permissible)	0.255
2010 Maximum permissible ABC	6,124 t
2011 Maximum permissible ABC	5,372 t
F_{ABC} = *60% of Max Permissible*	0.153
Recommended ABC: 2010	3,761 t
2011	3,456 t
$F_{overfishing} = F_{35\%}$	0.315
2010 **Greenland turbot OFL**	7,464 t
2011 **Greenland turbot OFL**	6,856 t*

* assuming 2010 catch = 3,761 t

Figures

(a)



(b)

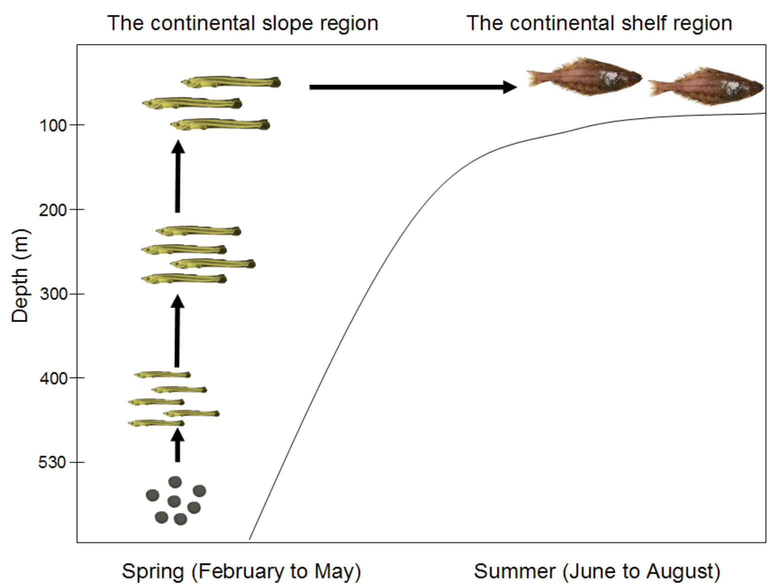


Figure 5.1. Schematic representation of Greenland halibut distribution and connectivity from larvae to settled juveniles. (a) Horizontally changed distribution through different life history stages (Blue circle: slope spawning ground, Green circle: shelf nursery ground of pelagic juveniles, Red circle: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

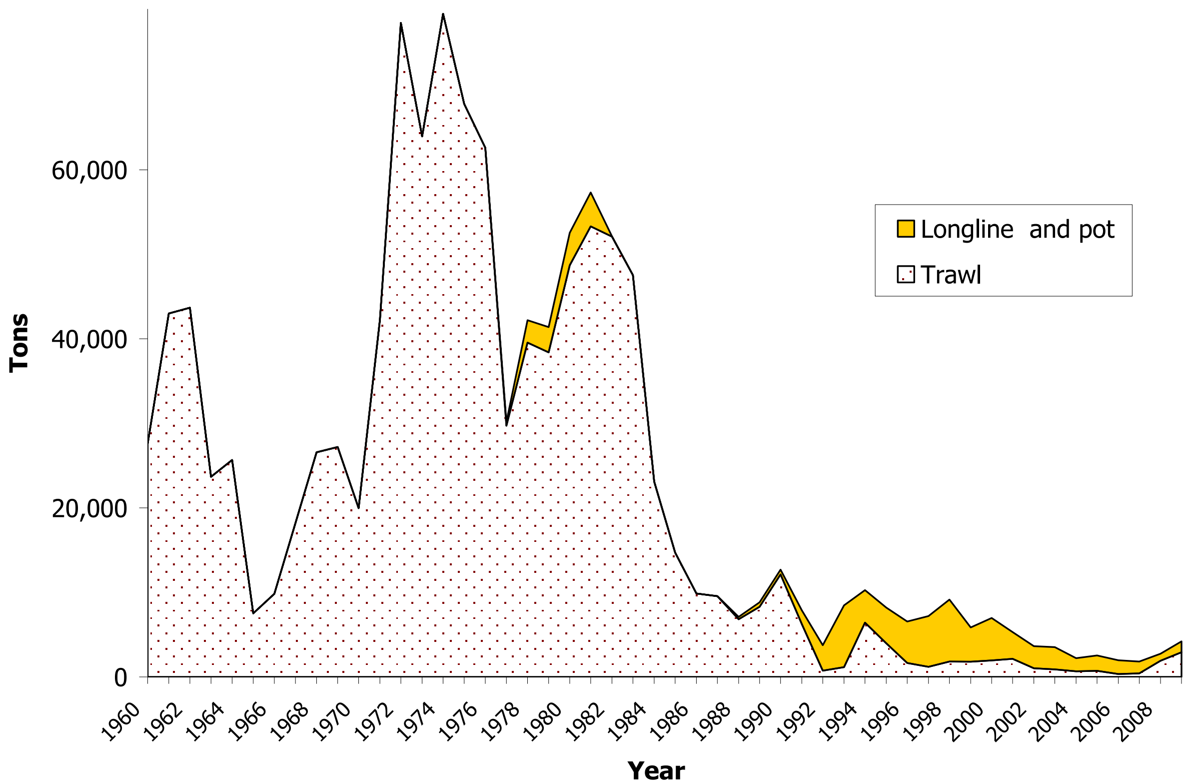
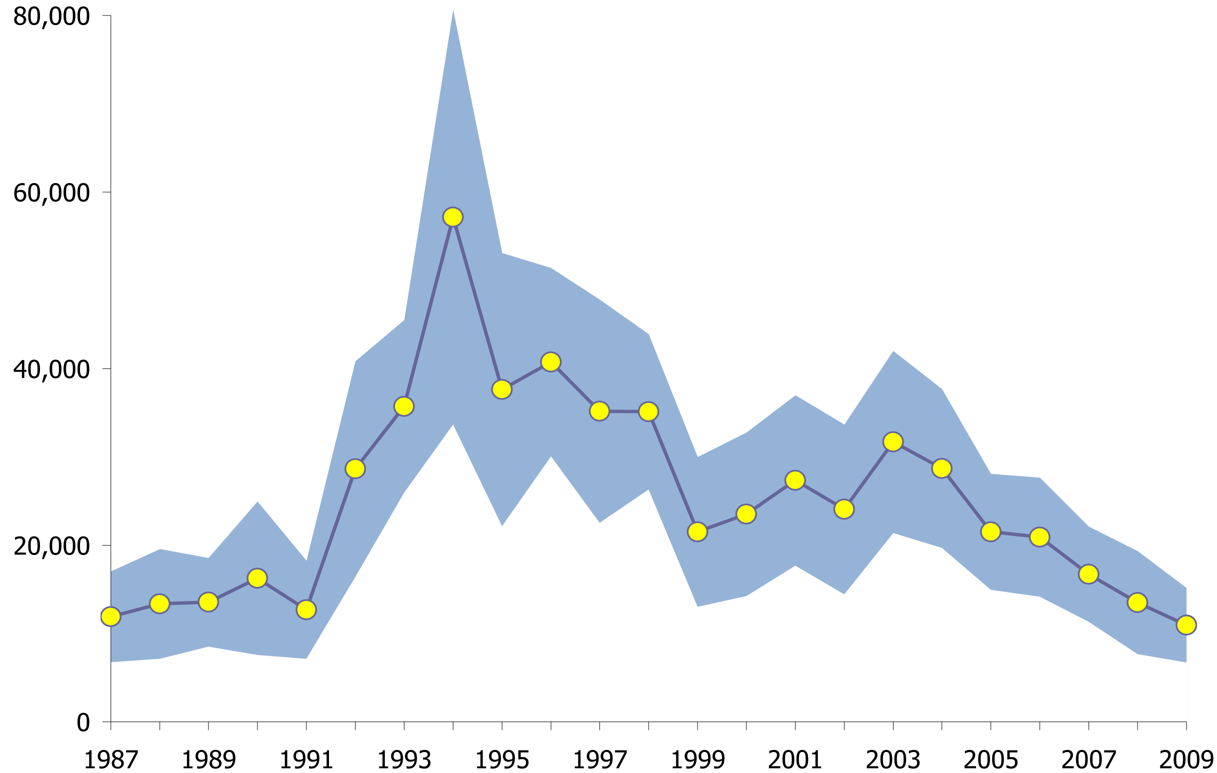


Figure 5.2. Trawl and longline catches of Greenland turbot in the combined EBS/AI area, 1960-2009.



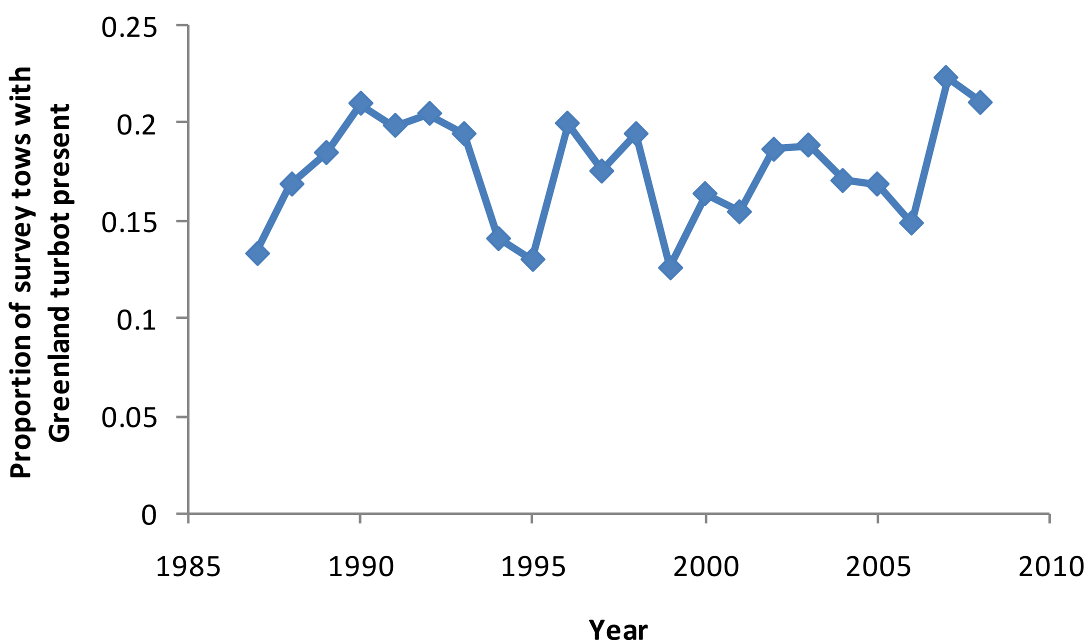


Figure 5.3. Survey biomass estimates of Greenland turbot from the EBS shelf trawl survey (top) and the proportion of tows that caught at least one Greenland turbot (bottom), 1982-2009.

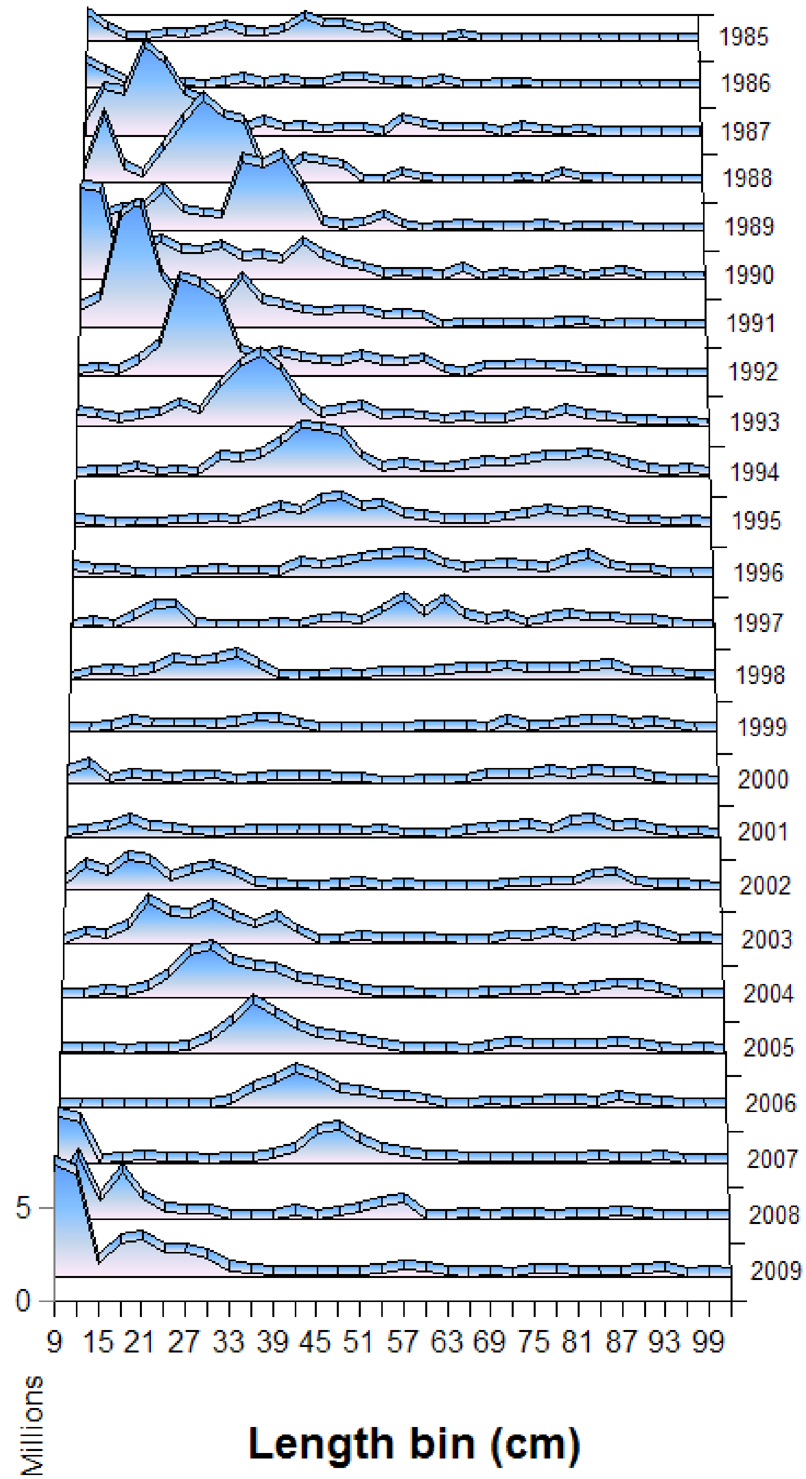


Figure 5.4. Abundance-at-length (cm) for Greenland turbot observed from the summer NMFS shelf trawl surveys, 1985-2009 (sexes combined, all strata except for 1986 where only strata 1-6 were sampled).

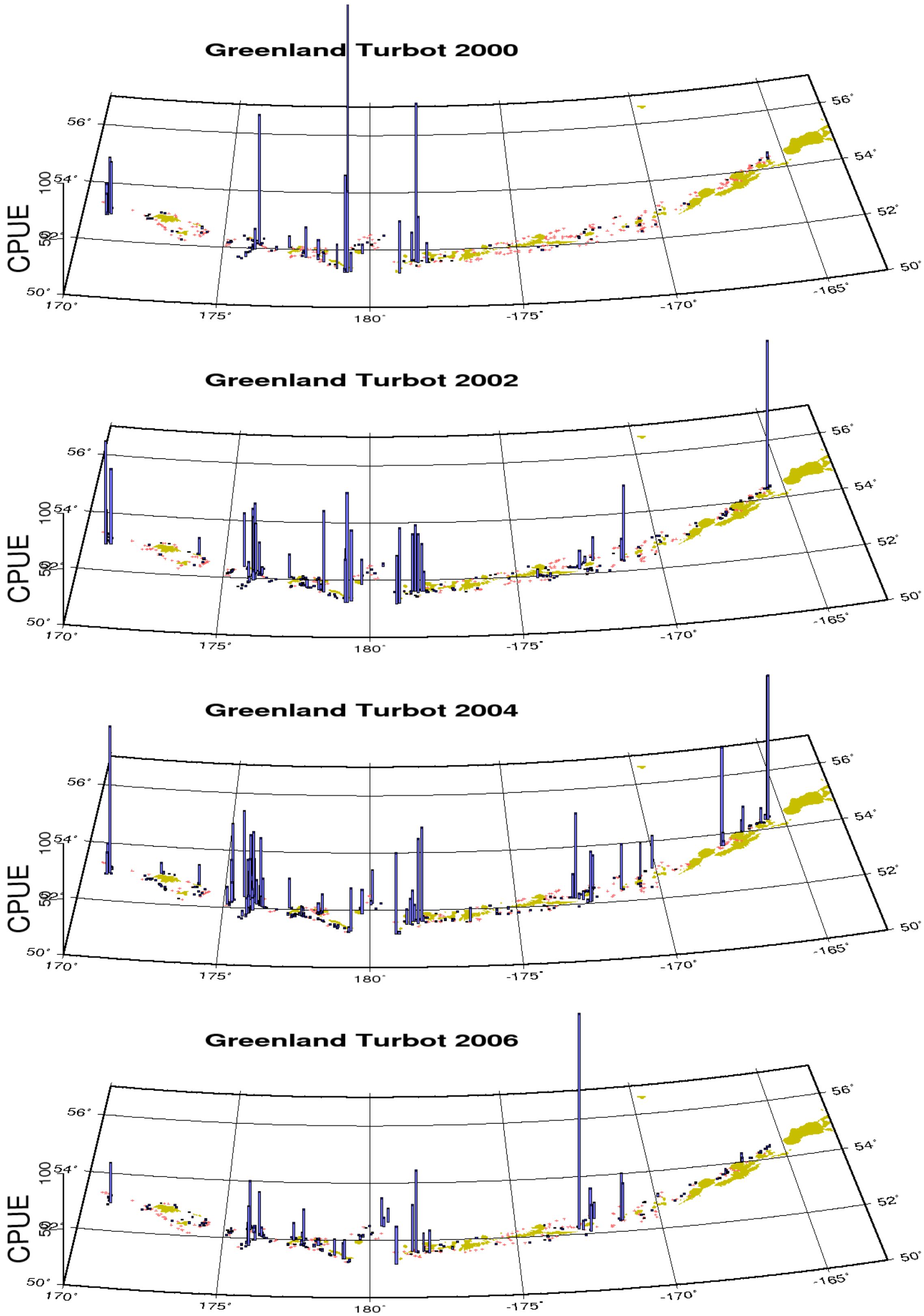


Figure 5.5. Greenland turbot catch per unit effort (relative values by weight, vertical bars) from the Aleutian Islands region bottom trawl survey, 2000-2006.

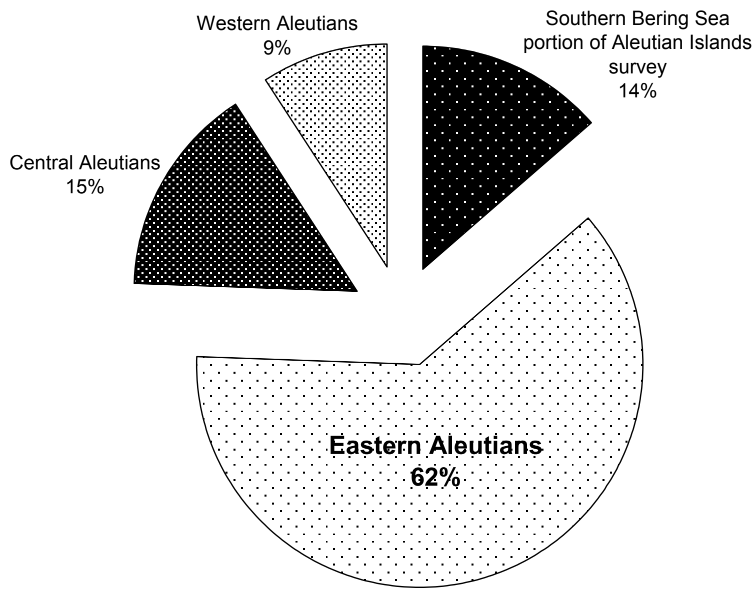


Figure 5.6. Average Greenland turbot relative biomass from the Aleutian Islands surveys by region, 1980-2006.

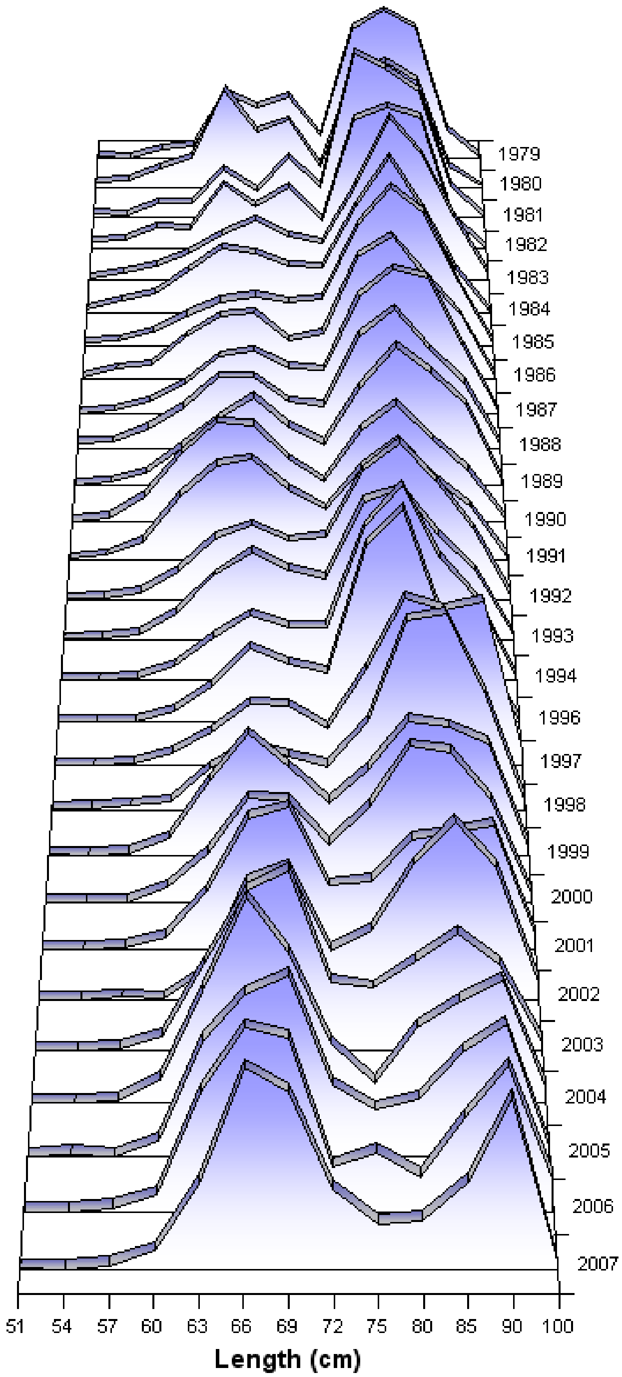


Figure 5.7. Longline survey Greenland turbot proportions at length over time (sexes combined) as used in the model.

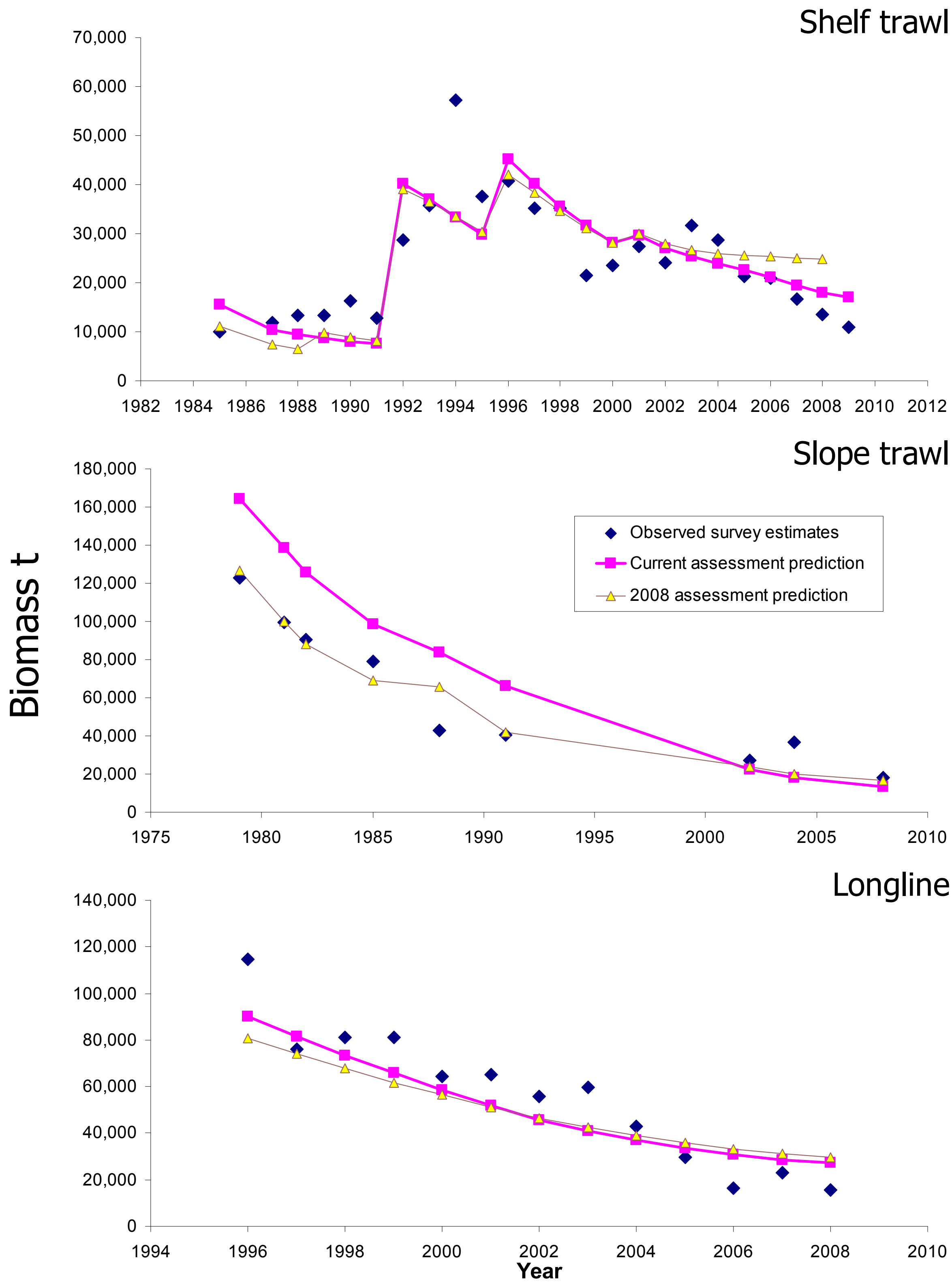


Figure 5.8. Fits to the EBS shelf trawl survey (top), the EBS slope survey (middle) and longline survey (bottom) indices for Greenland turbot in the EBS/AI region comparing last year's assessment with the current assessment.

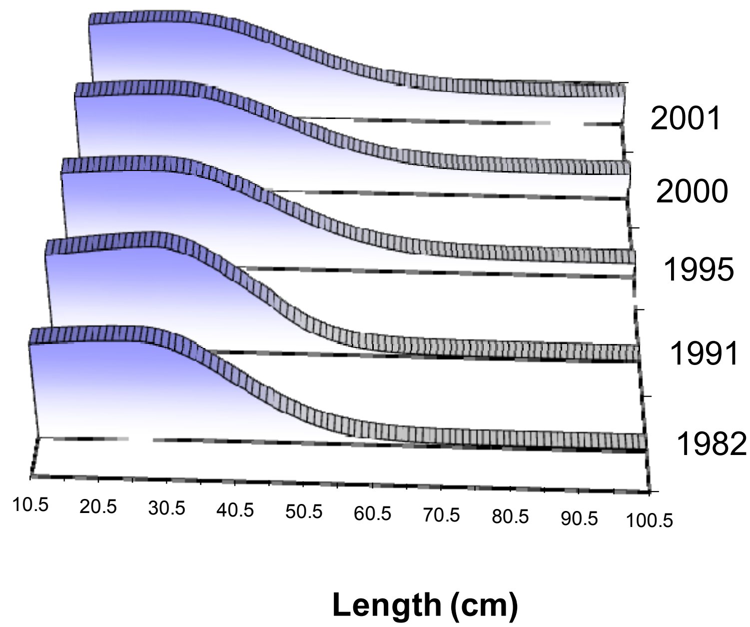


Figure 5.9. Average size-specific selectivity patterns for EBS shelf surveys over time as estimated for female Greenland turbot. The year represents the first year in which the corresponding selectivity estimate was invoked.

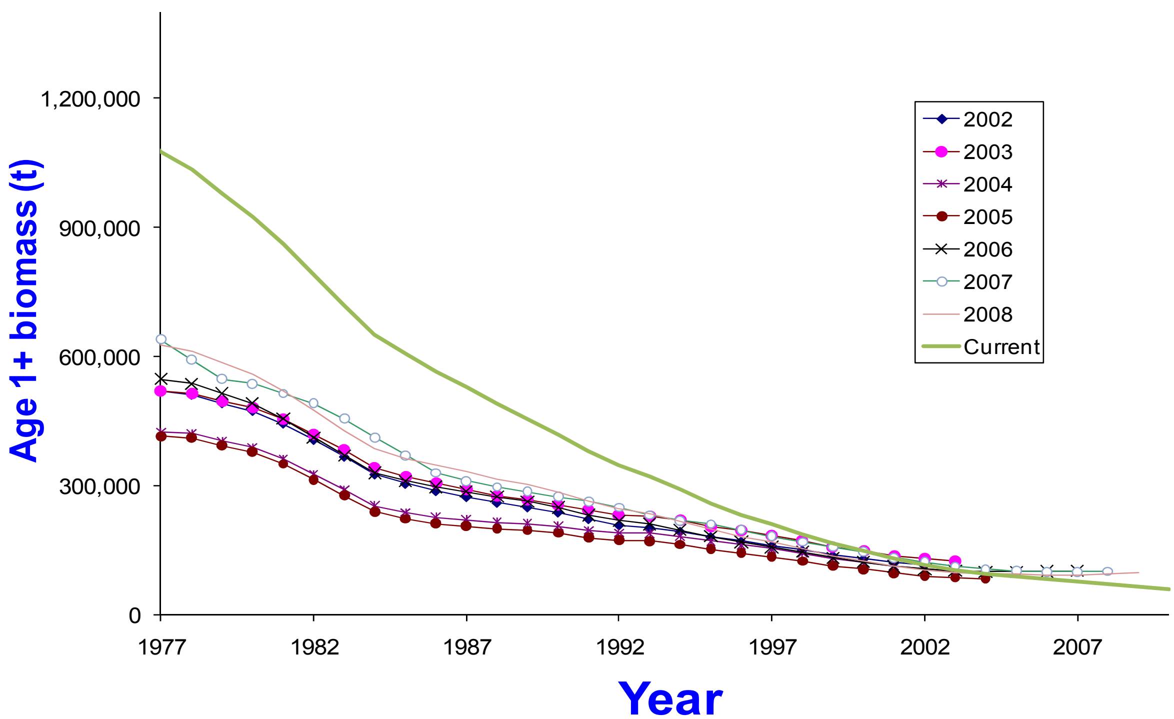


Figure 5.10 Current assessment estimates of total age 1+ biomass for Greenland turbot in the BSAI region, 1965-2009 compared to previous assessments.

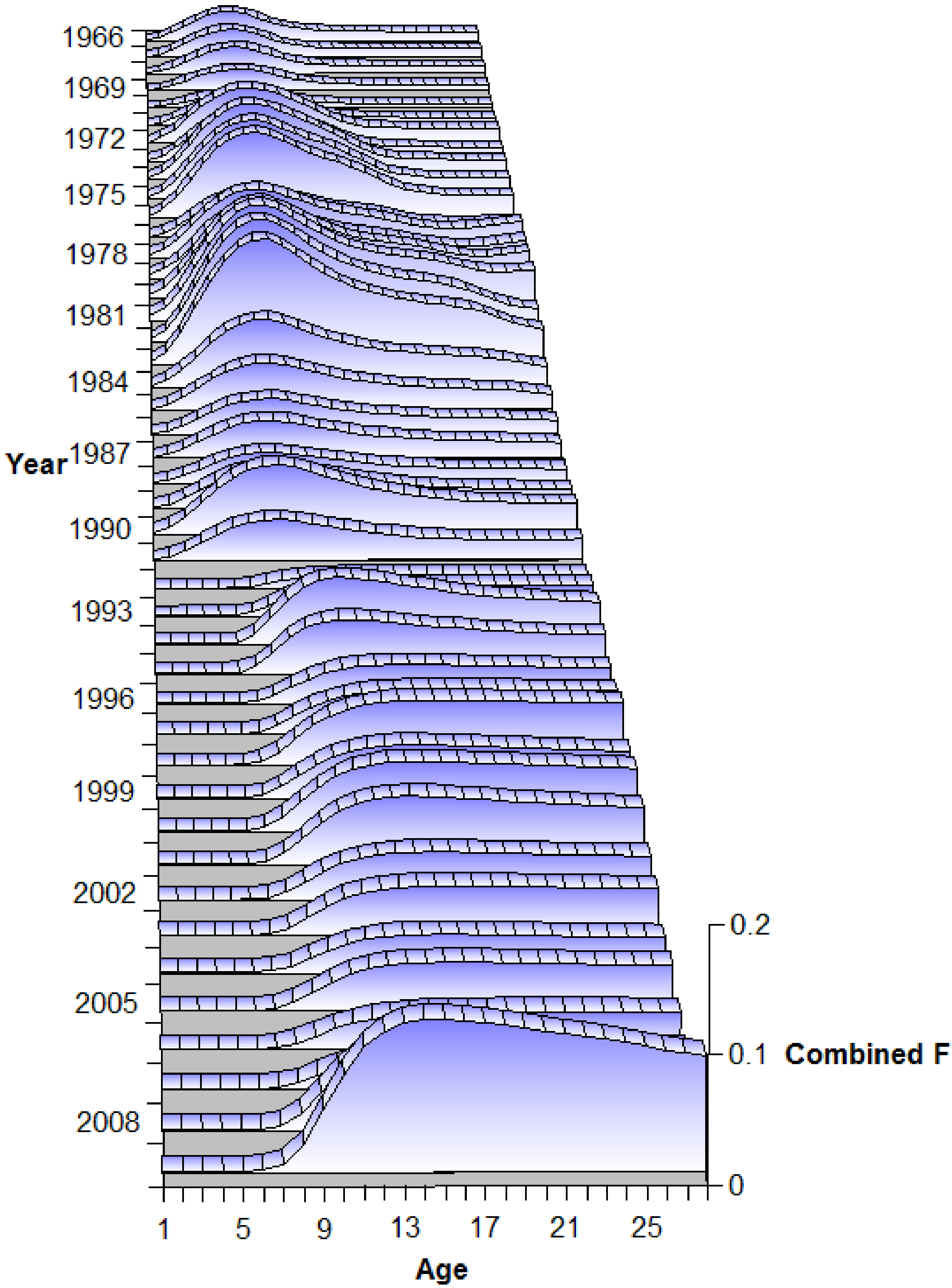


Figure 5.11. Estimated total age-specific fishing mortality rate (gears and sexes combined) for BSAI Greenland turbot, 1970-2009.

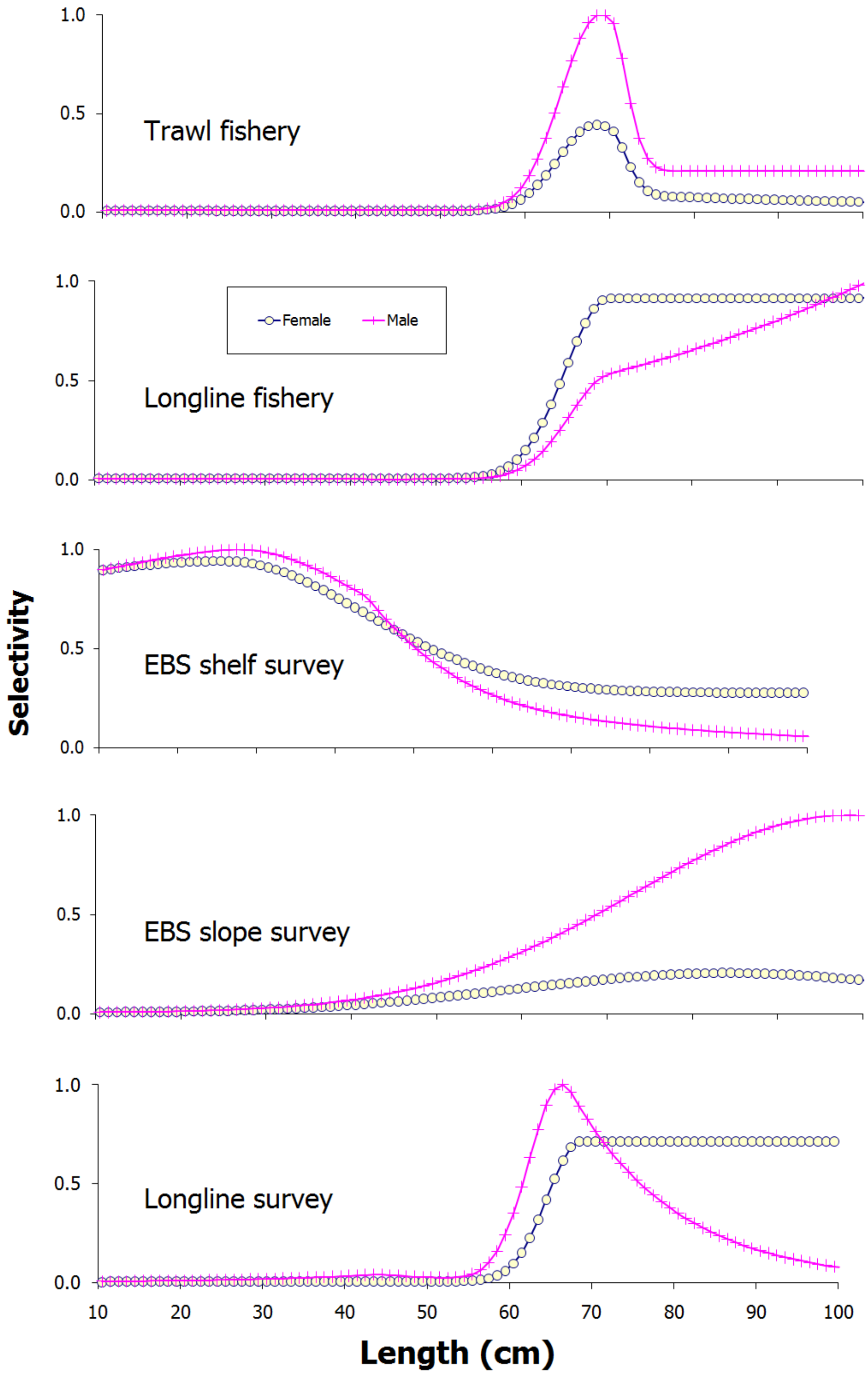


Figure 5.12. Size-specific estimates of selectivity patterns for all fisheries and surveys for EBS Greenland turbot showing differences in sex-specific availability in the current year (some earlier years had different selectivity estimates).

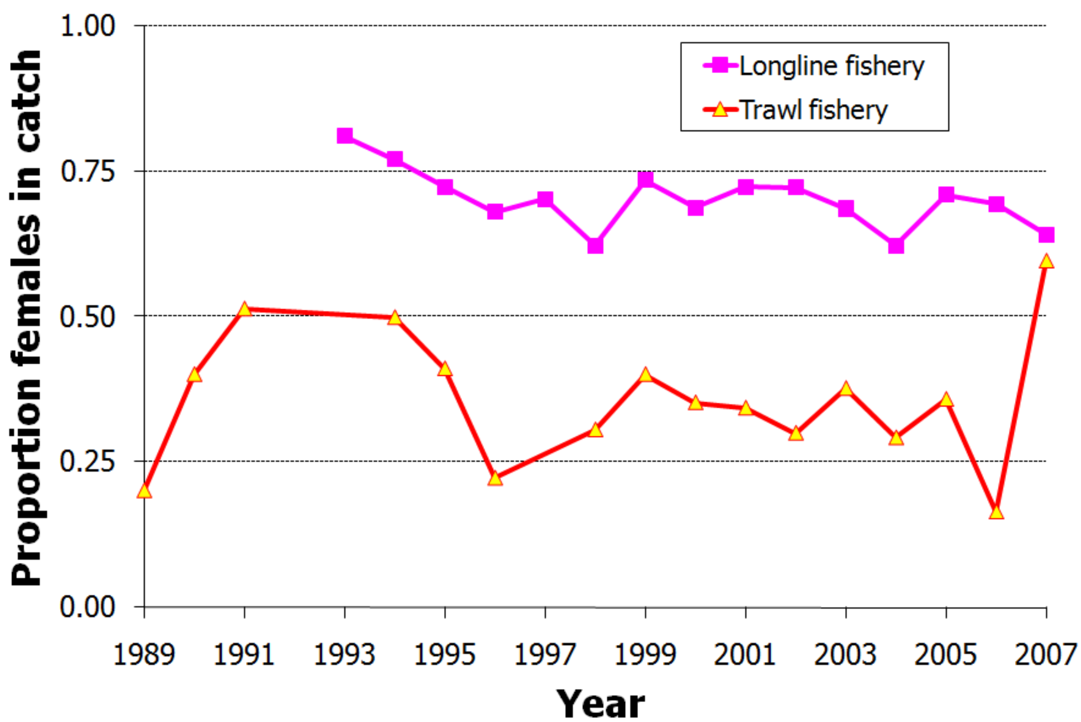


Figure 5.13. Observed Greenland turbot sex ratio over time from the BSAI region trawl and longline fisheries.

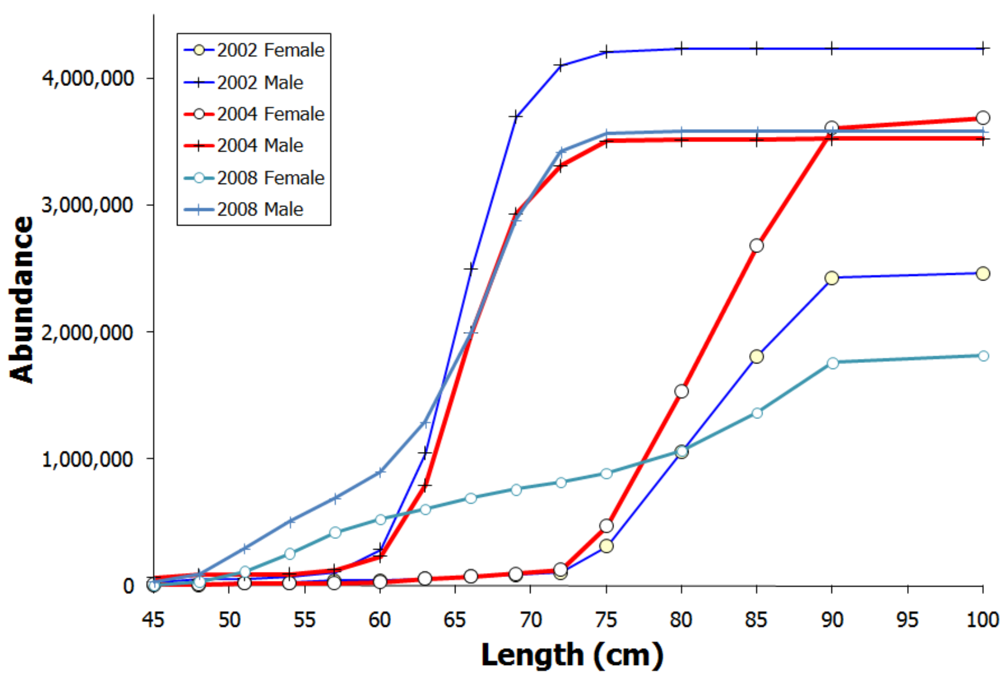


Figure 5.14. EBS slope trawl survey estimates of Greenland turbot cumulative abundance-at-length by sex for 2002, 2004, and 2008.

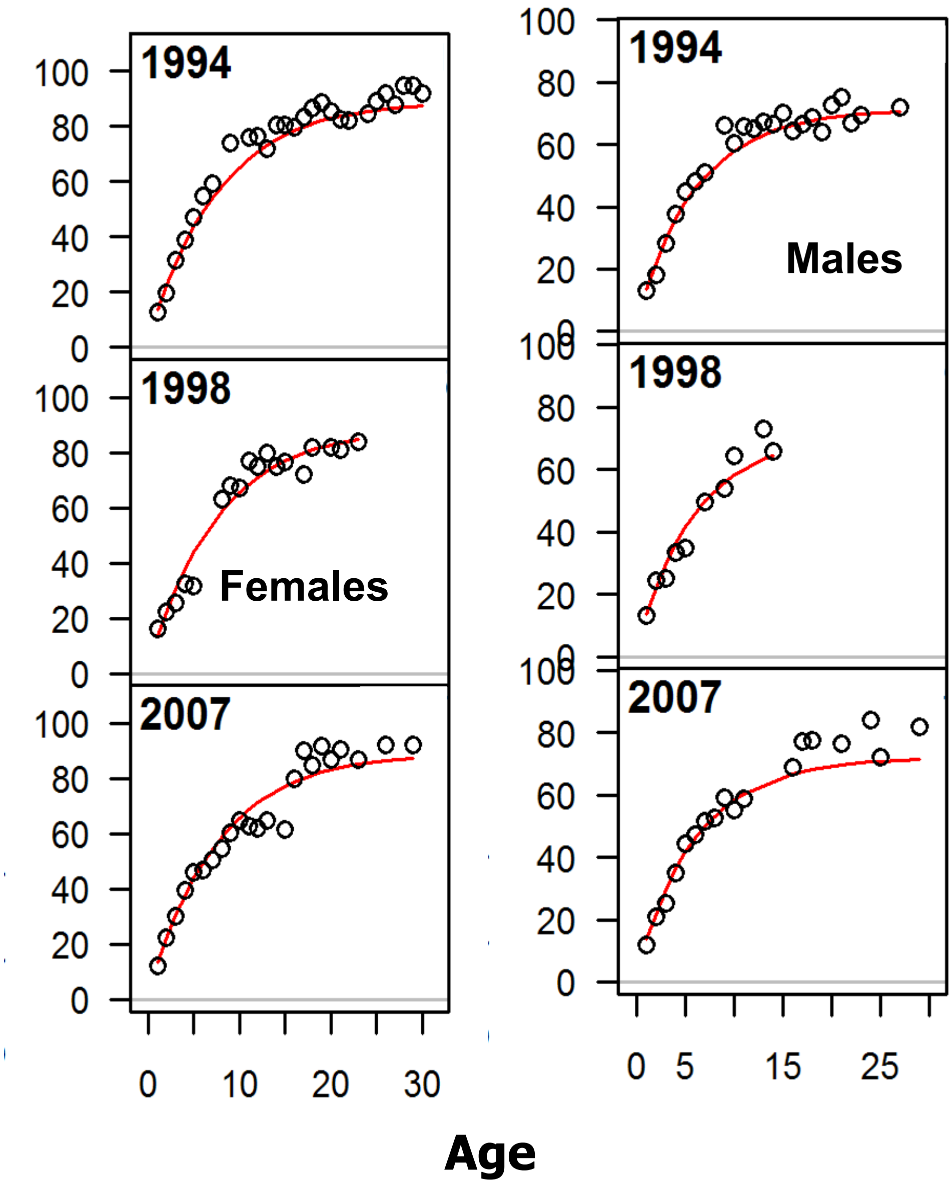


Figure 5.15. Estimated growth (length at age) of Greenland turbot by sex (female on left, males on right) in the EBS/AI region as predicted by the model and compared to the available age data using the methods of Gregg et al (2006).

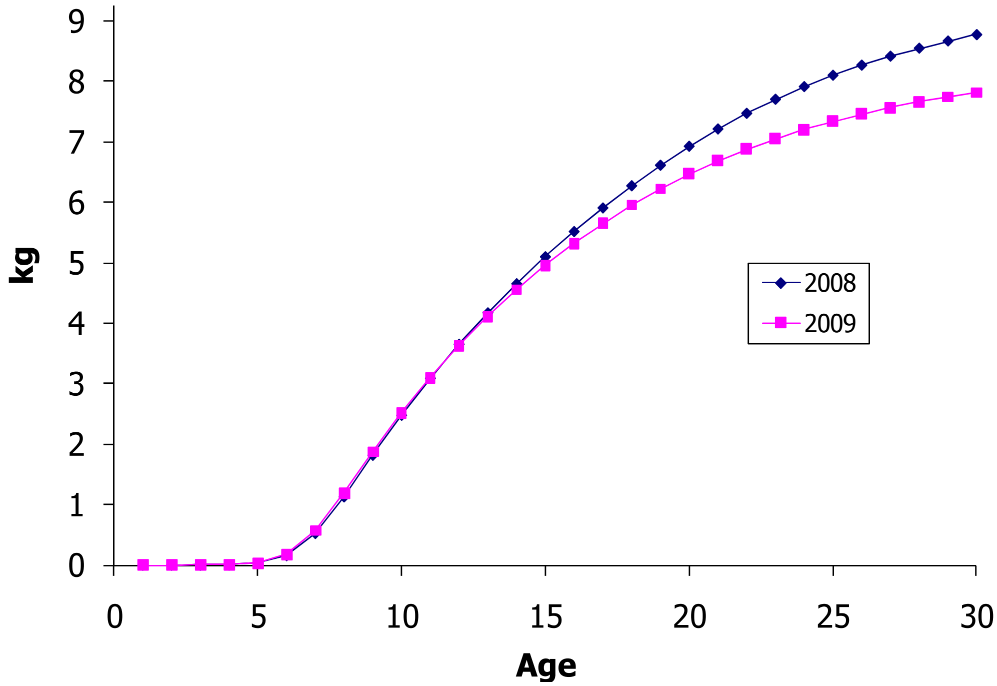


Figure 5.16. Comparison of the weight at age (adjusted for proportion mature) of female Greenland turbot as estimated by the model this year compared to Ianelli et al. (2008).

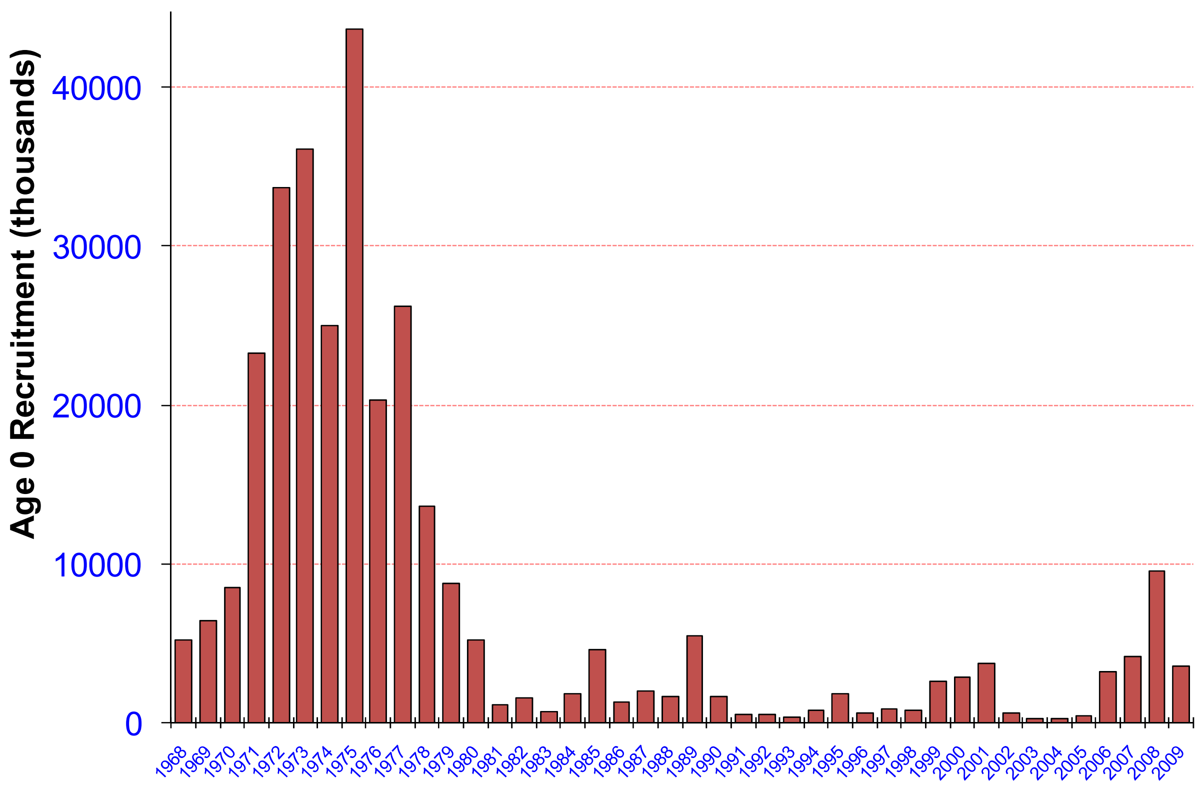


Figure 5.17. Estimated recruitment at age 0 (thousands) for Greenland turbot in the EBS/AI region, 1968-2009.

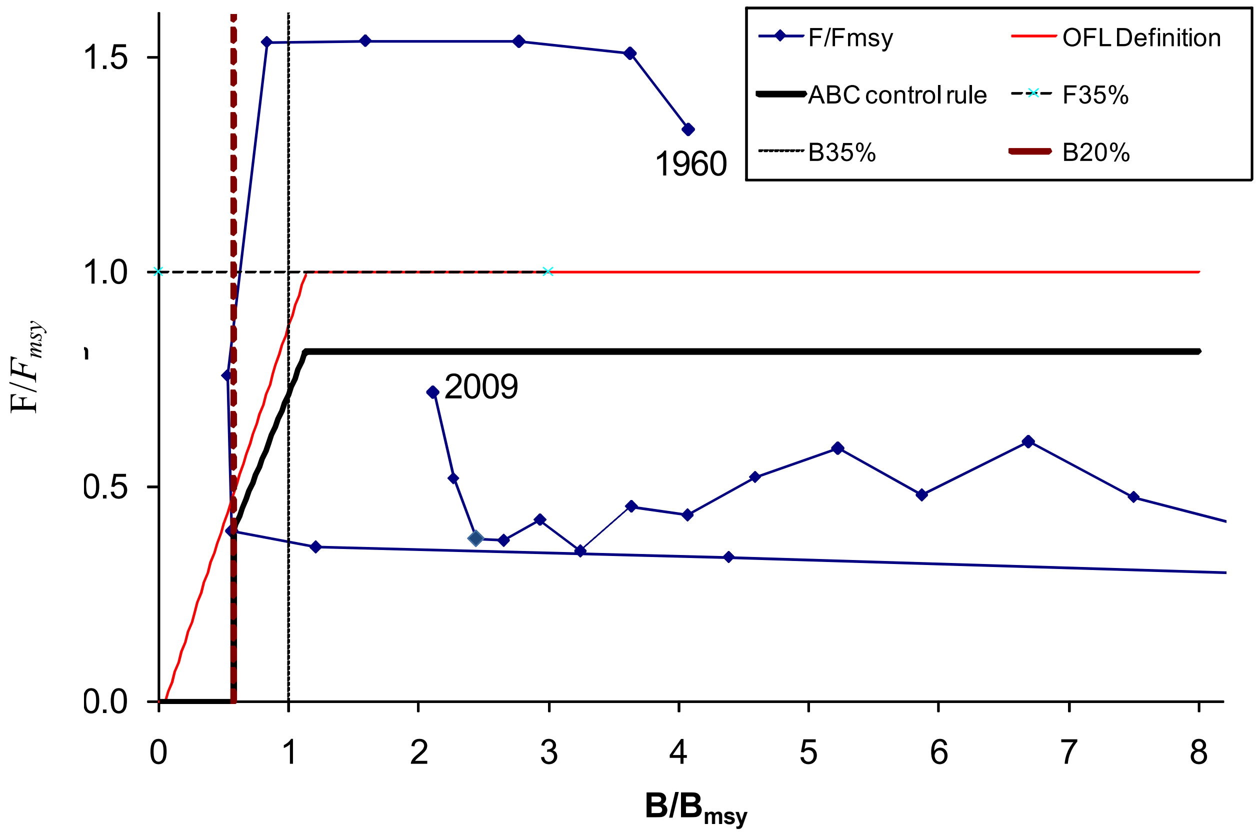
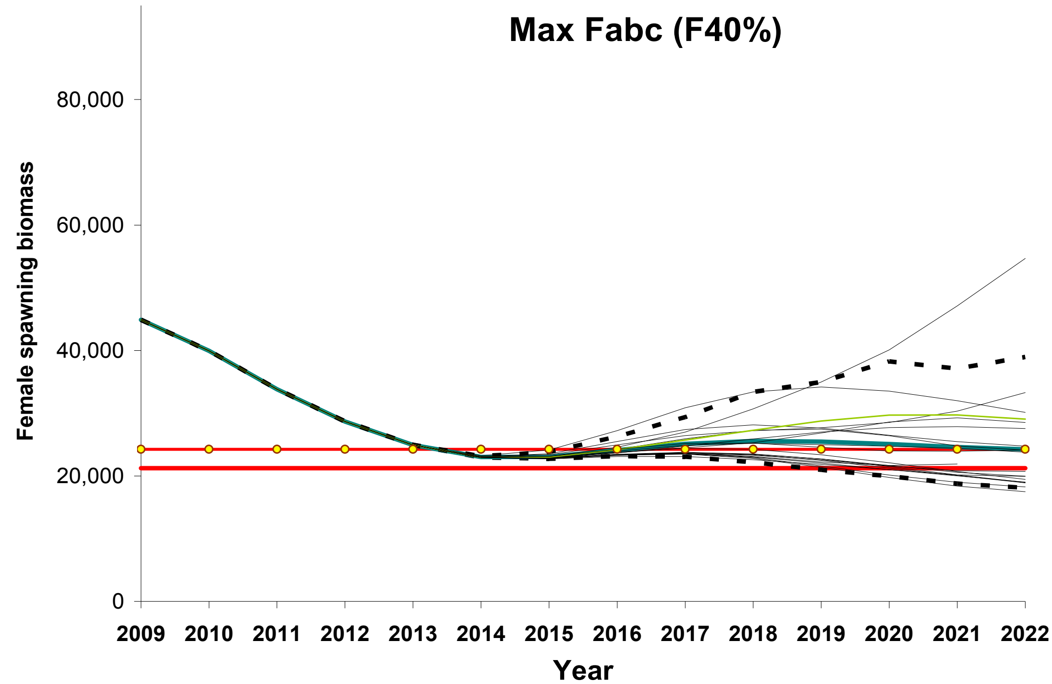


Figure 5.18. Ratio of historical F/F_{msy} versus female spawning biomass relative to B_{msy} for BSAI Greenland turbot, 1960-2008. Note that the proxies for F_{msy} and B_{msy} are $F_{35\%}$ and $B_{35\%}$, respectively.



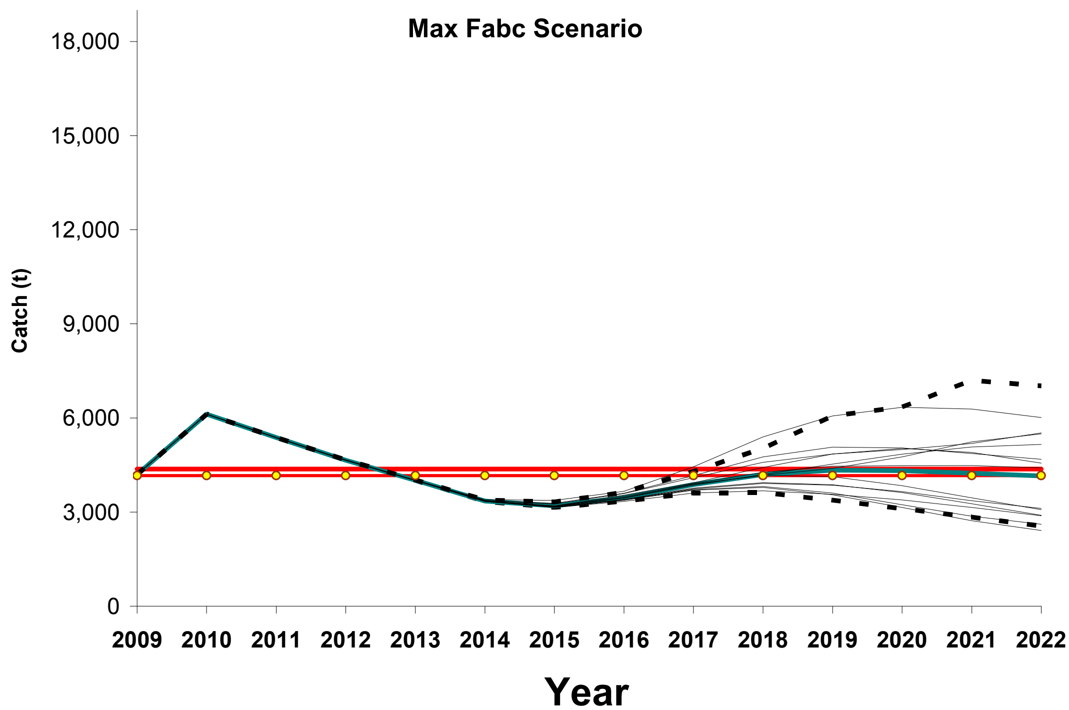


Figure 5.19. Stochastic trajectory of Greenland turbot female spawning biomass and catch for the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3. The dotted lines represent the upper and lower 90% confidence limits. Horizontal lines with marks are the values associated with $B_{40\%}$ and $F_{40\%}$ while the thick horizontal line is the expected value under constant F_{OFL} rate ($F_{35\%}$).

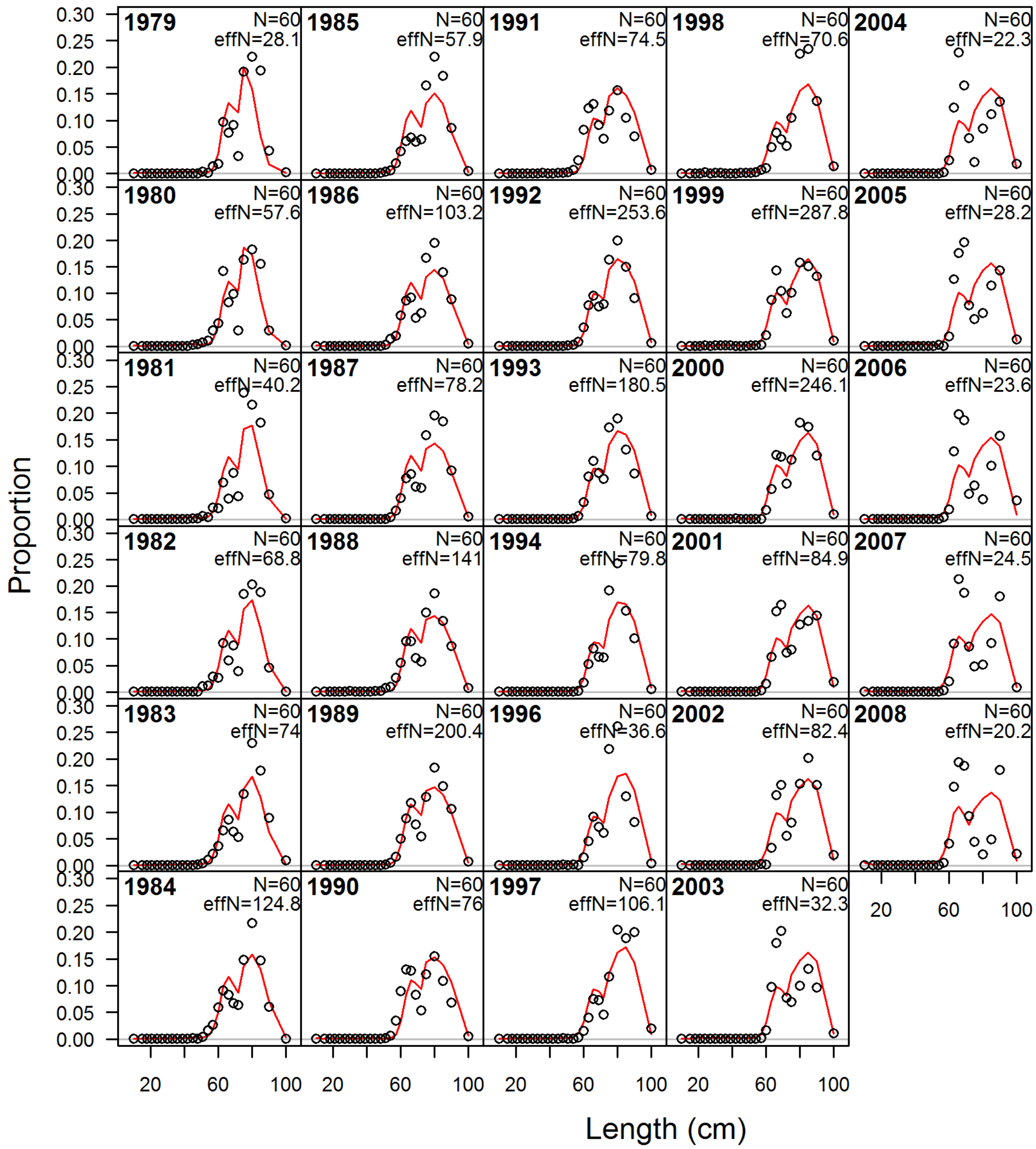


Figure 5.20. Greenland turbot model fit to longline survey length frequency data (sexes combined). Lines are model predictions, points are data.

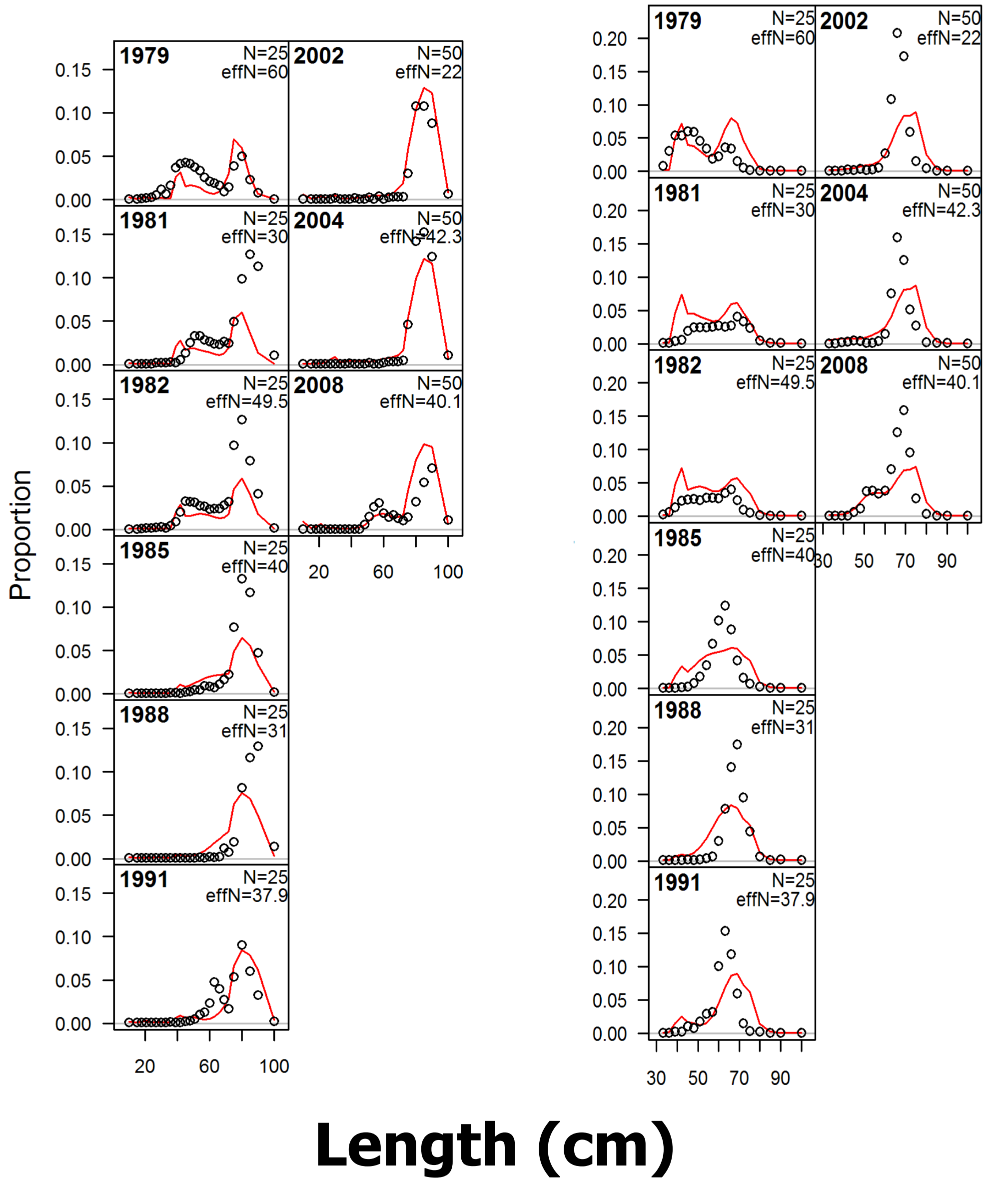


Figure 5.21. Greenland turbot model fit to EBS slope trawl survey length frequency data. The left set are females, while the right set are males. Lines are model predictions, points are data; females on left and males on right.

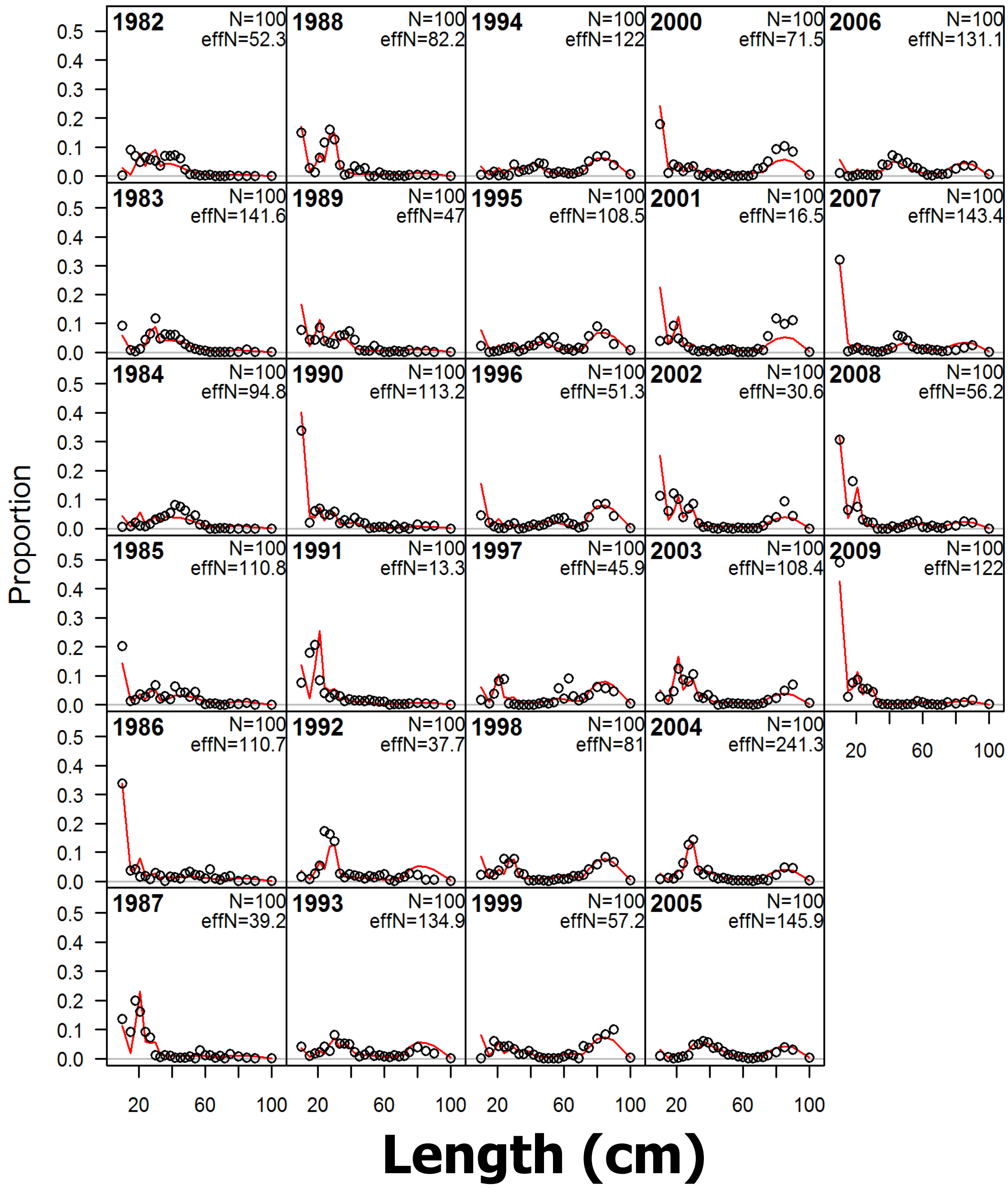


Figure 5.22. Greenland turbot model fit to EBS shelf trawl survey **female** length frequency data. Lines are model predictions, points are data.

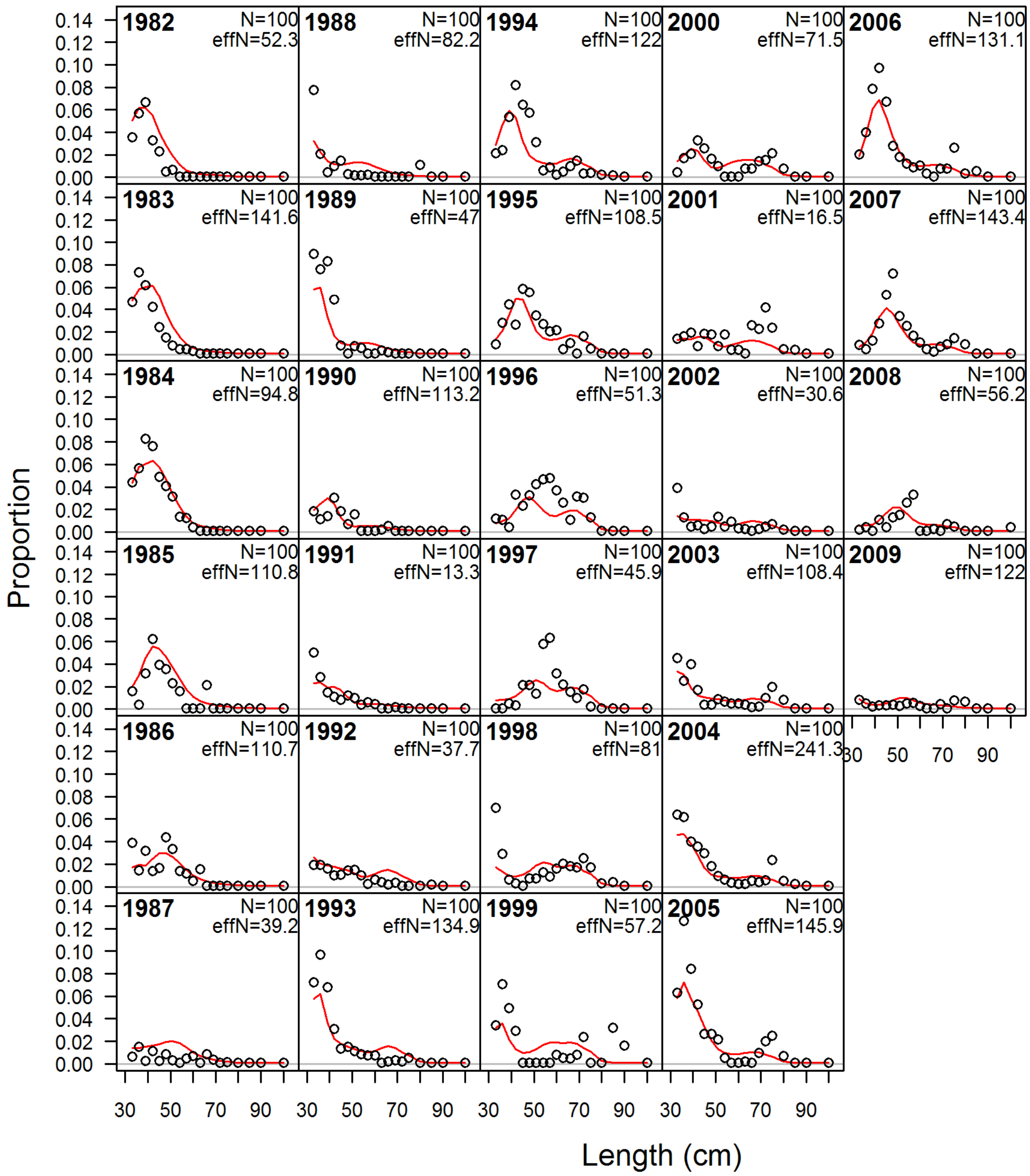


Figure 5.23. Greenland turbot model fit to EBS shelf trawl survey **male** length frequency data. Lines are model predictions, points are data

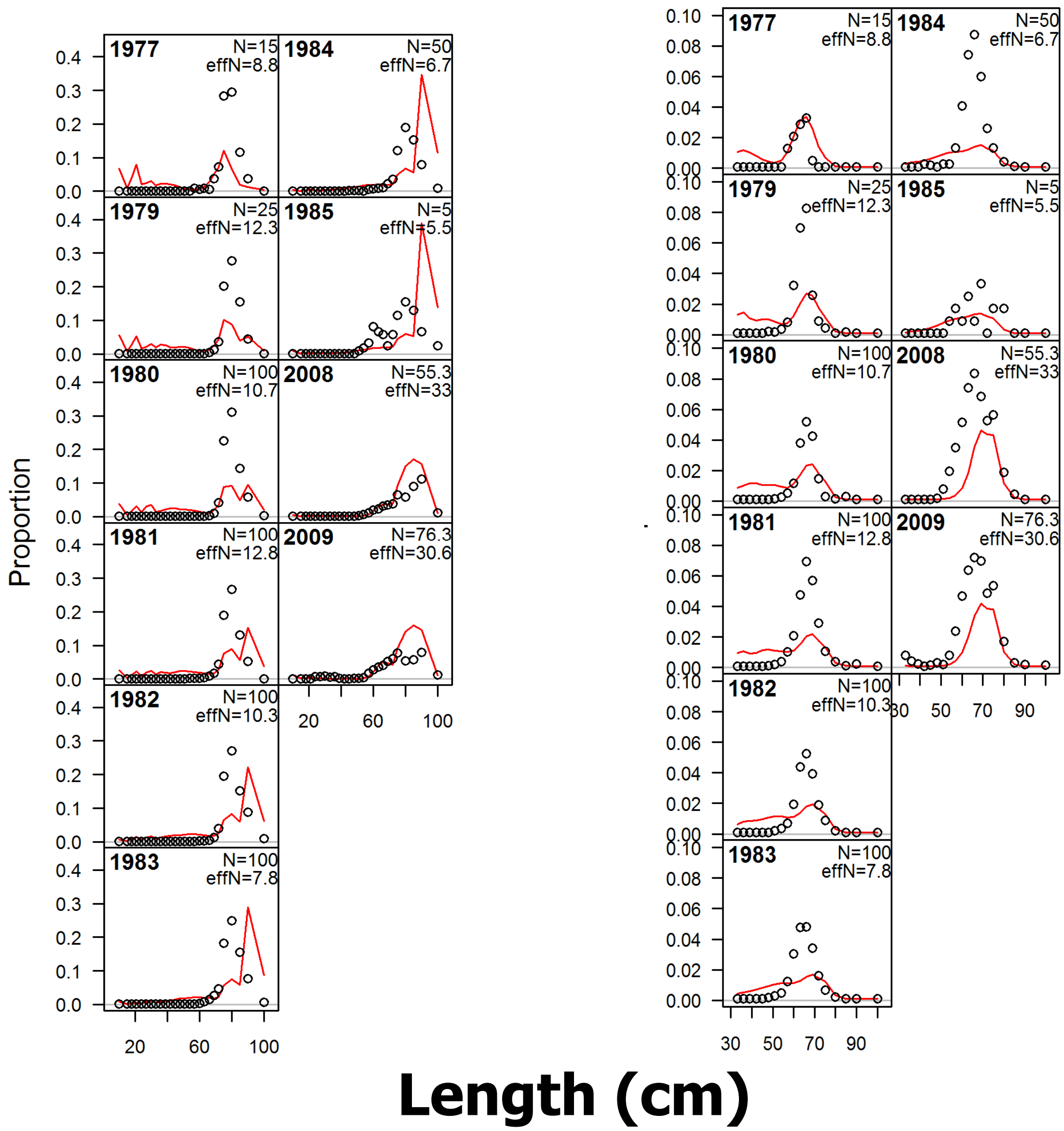


Figure 5.24. Greenland turbot model fit to EBS longline fishery length frequency data (combined sexes). Lines are model predictions, points are data; females on left and males on right.

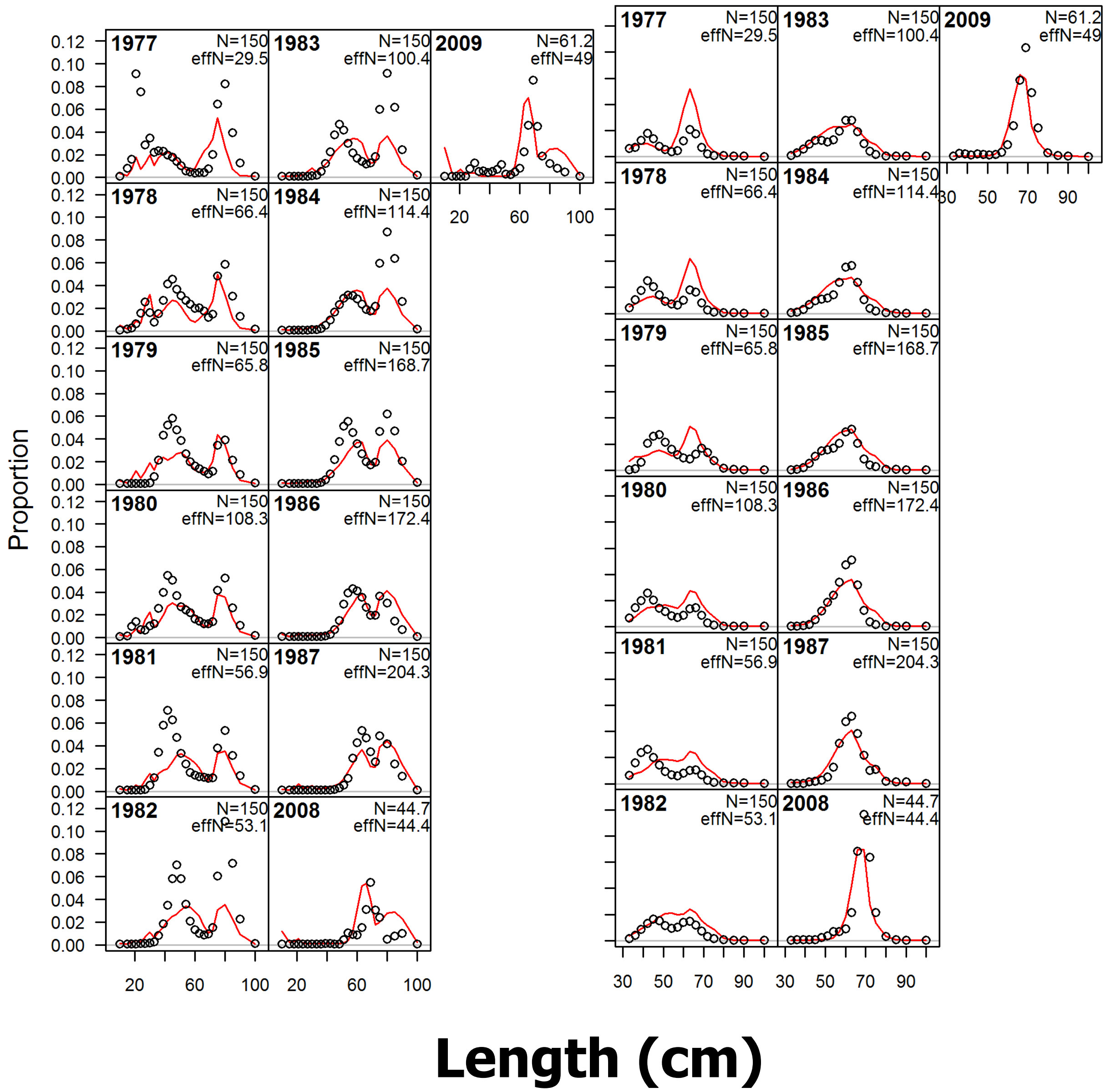


Figure 5.25. Greenland turbot model fit to EBS trawl fishery length frequency data. The left set are females, while the right set are males. Lines are model predictions, points are data; females on left and males on right.