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. 2003 - 2006 catch data were updated (and added).

2. Fishery catch-at-length data by gear type and sex was recompiled for all domestic fisheries since 1989

3. The EBS shelf survey 2006 biomass and length composition estimates were added. Previous abundance-at-lengths from the shelf survey were recomputed and made to be sex specific in all years.

4. New length-at-age data from 1994 and 1998 surveys were included in the model based on new published research on age and growth of Greenland turbot. This supplanted previously used age data derived from an age-estimation method that is now considered to be biased low.

5. The 2006 Aleutian Islands survey estimate was used to assess appropriate area-apportionments

6. An updated aggregated longline survey data index for the EBS and Aleutian Islands regions was included

Changes to the assessment model
The model used this year was developed under the new Stock Synthesis 2 assessment software. To the extent possible, the same assumptions were applied. Principal among these is that the slope-trawl survey is treated as an absolute index representing 75% of the Greenland turbot stock inhabiting US waters. An alternative size-based selectivity function (the so-called "double normal") was used that had fewer parameters than previous configurations and seemingly more stable behavior.

A new mortality estimate (to be published in April 2007) was adopted. The new value is 0.112 compared to 0.18 used in the past. This value seems sensible since tagging data and some age and growth research indicate that this species is longer lived than previously thought.

Diagnostics to evaluate fits to the size composition data were more extensive than in the past and this led to allowing selectivity to change over time for some of the surveys and fisheries (more than in previous models). This resolved some of the poor residual patterns.

Changes in the assessment results
The planned 2006 **EBS slope trawl survey** which covers Greenland turbot habitat was cancelled due to funding issues. The recent declines in the **BSAI longline survey** index continued in 2006. The 2006 **EBS shelf trawl survey** biomass estimate was down by about 2% from the 2005 estimate. This

compares with the average decline over the past 5 years of 3%. 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

Model results based on these surveys and data from longline and trawl fisheries result in an estimate of $B_{40\%}$ equal to 41,800 t (female spawning biomass). The current estimate of the year 2007 female spawning biomass is 60,430 t.   While improvements to the assessment modeling have been made, and there appears to be some favorable recruitment patterns in the past several years, fishing mortalities consistent with recent history are recommended for ABCs until another survey can be completed as well as more analyses to evaluate the modeling approach (see suggestions for future research). This results in a 2007 and 2008 recommended ABC for BSAI Greenland turbot of **2,440 t** for both years**.** This compares with corresponding maximum permissible levels of level of 12,680 and 13,010 t respectively under Tier 3a. The 2007 and 2008 overfishing levels, based on the adjusted $F_{35\%}$ rate are **15,600 t** and **16,030 t** corresponding to a full-selection F of 0.67.

Response to SSC comments
In the December 2005 minutes the SSC meeting the following was noted regarding the Greenland turbot assessment:

> *"Many of the length frequency plots show very large proportions of fish in the largest length class. The SSC requests that the authors consider extending the range of length bins to better mimic the dynamics of the larger fish."*

The bin-designations for lengths of Greenland turbot were re-examined and it was found to be suitable for the sizes of fish observed. The anomalous proportions noted by the SSC were determined to be a plotting error. Also, all of the length-frequency figures were reformatted for better clarity.

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). Juveniles are absent in the Aleutian Islands regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment we assume that the Greenland turbot found in the two regions represent a single management stock. NMFS initiated a tagging study in 1997 to supplement earlier international programs. Results from tag returns suggest that this species is capable of movement over large areas.

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*, we retain the common name of Greenland turbot which is also the "official" market name in the US and Canada (AFS 1991). 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. 5.1). 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 declining recruitment. For the period 1992–1997, the Council set the TAC's to 7,000 t as an added conservation measure due to concerns about apparent low levels of recruitment in the past several years. This has resulted in primarily bycatch-only fisheries. The distribution of the Greenland turbot catches has been fairly consistent in recent years (Figs. 5.2 and 5.3). In response to concerns regarding the status of the stock, the Council sharply reduced TAC's from a high for the decade of 15,000 mt in 1998 to 3,500 mt in 2004 and 2005.

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 Greenland turbot directed fishery also have contributed substantially to the discard levels (Table 5.2). Greenland turbot were 73% retained in the 2005 Bering Sea fisheries.

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

Size and age composition
No age composition information is available from the fisheries (nor from surveys). 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 and the expected values from the assessment model are presented in previous assessments. This information is used in the assessment model and adds to our ability to estimate size-specific selectivity patterns in addition to year-class variability.

Resource Surveys

Aleutian Islands
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 5.3). 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. 5.4). 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. 5.5; Table 5.4). The Aleutian Islands component of the Greenland turbot stock was excluded from the stock assessment model.

EBS slope and shelf bottom trawl survey
The older juveniles and adults on the slope were surveyed every third year from 1979-1991 (also in 1981) as part of a U.S.-Japan cooperative agreement. The slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency until 1985. In 1988, the NOAA R/V Miller Freeman was used to survey the resources on the EBS slope region. In this same year, chartered

Japanese vessels performed side-by-side experiments with the R/V Miller Freeman for calibration purposes. Due to limited vessel time, the R/V Miller Freeman sampled a smaller area and fewer stations 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 reestablished the bottom trawl survey of the upper continental slope of the eastern Bering Sea and a second survey was conducted in 2004. This survey was planned to be done every two years to improve sampling effort Greenland turbot habitat areas. The scheduled 2006 slope trawl survey was canceled due to budgetary constraints.

The trawl slope-surveys are likely to represent under-estimates the actual biomass of Greenland turbot for a number of reasons, hence, these are treated as an index representing 75% of the stock based on earlier assessment analyses (Ianelli et al. 1993). For example, the species appears to extend beyond the area of the survey and that the ability to tend bottom in the deeper waters may be compromised. 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 treated as a relative index.

Abundance estimates for juvenile Greenland turbot on the EBS shelf are provided annually by AFSC trawl surveys. For the shelf survey, the extent of Greenland turbot found in the northwestern strata (Fig. 5.6) ranges from 2%-34% (Ianelli et al. 2005). The extent that the shelf-survey estimates are affected by temperature (with smaller fractions found in the northerly zones during colder years) indicates that abundance indices may be affected.

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—the 2004 level is 57,500 t. The average shelf-survey biomass estimate during the last 14 years (1993-2006) is 31,500 t. The number of hauls and the levels of Greenland turbot sampling in the shelf surveys are presented in Table 5.5. 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 has increased then stabilized (Fig. 5.7). The shelf survey appears to be useful for detecting some recruitment patterns which are consistent with the trends in biomass (Fig. 5.8). In the last 5 years a mode of smaller fish are apparent and suggest new recruitment after a period of 9-10 years without much sign of recruitment.

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.

Survey size-at-age data was available and used for estimating growth and growth variability were previously available from 1975, 1979-1982. This year, Gregg et al. (2006) advanced the age-determination methods for Greenland turbot and 403 samples (from 1994 and 1998 surveys) were used instead of the earlier data.

Longline survey
Currently, the domestic longline survey effort extends into the Bering Sea and part of the Aleutian Islands (in alternate years). This new sampling area represents a smaller region than in past but shows 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
Bering 4		11,729		13,072		16,082		11,965		3,717	
Bering 3		6,172		6,156		5,005		3,784		1,822	
Bering 2		27,936		33,848		24,766		24,660		15,268	
Bering 1		13,491		10,068		4,788		6,206		2,297	
NE Aleutians	23,133		16,124		12,987		10,942		8,551		3030.93
SE Aleutians	2,142		1,806		1,201		1,397		936.5		565.63
Bering Sea (total)		59,328		63,144		50,641		46,616		23,103	
Aleutians (total)	25,275		17,930		14,188		12,339		9,487		3596.56
Combined	114,209	76,189	81,017	81,089	64,112	65,033	55,755	59,864	42,869	29,669	16,251

The combined time series shown above (1996-2006) was used as a relative abundance index. It was computed by taking the average RPN from 1996-2006 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 (1996-2006) 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. 5.9.

Comparisons among surveys
Among the three separate trawl surveys, the EBS slope averages about 61% of area-swept biomass levels compared to 15% for the Aleutian Islands and 24% for the EBS shelf region (Fig. 5.10). In aggregate, all of the indices show varying trends, with the longline survey showing the greatest relative decline (Fig. 5.11).

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 1998) from NMFS longline and trawl surveys (t):

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	
NMFS Bottom trawl surveys	62.5	48.4	103.0	123.6	1.8	0.6	175.1	0.2	0.5	18.5	0.6	0.7	9.0	
Cooperative Longline surveys	3	3	6	11	9	7	8	7	11	6	16	10	10	
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
NMFS Bottom trawl surveys	0.9	1.4	2.0	1.4	1.5	1.2	1.4	1.0	5.1	1.1	5.3	1.1	11.0	0.7
Domestic Longline surveys	22	23	23											

Analytic approach

Model Structure

The use of the stock synthesis program (Methot 1990) to model the eastern Bering Sea component of Greenland turbot stock has been used since 1994. The assessment model was changed when adopted within the newer stock synthesis (SS2) software. Qualitative comparisons to past versions of the model

showed that it was difficult to duplicate results precisely. However, a key assumption used in past models was retained: the slope-trawl survey is treated as an absolute index representing 75% of the Greenland turbot stock inhabiting US waters. This results in very similar recent biomass levels.

Total catch estimates used in the model were from 1960 to 2006. It was assumed that the stock was at or close to its virgin biomass level at the beginning of the catch data time series.

Model parameters were estimated by maximizing the log posterior distribution of the predicted observations given the data. Prior distributions consisted of penalties on recruitment deviations from a fixed stock-recruitment curve. This was required to stabilize estimates of recruitment early in the time series when data were limiting. The underlying parameters of the stock-recruit curve play an insignificant role in fitting the model to the data. For Greenland Turbot in the EBS the model included two fisheries, those using longline and trawl gear, and three surveys. Table 5.6 summarizes the extent of the data used in the different likelihood components. An archive of the software and model configuration can be found at http://www.afsc.noaa.gov/refm/docs/2006/BSAIGturbot.zip.

Selectivity Patterns
A dome-shaped size-based selectivity function was estimated for each survey and fishery described below. For the trawl fishery, the periods of length frequency data collections from the domestic and foreign fleet did not overlap. Consequently, the foreign and domestic fishery data were treated as from a single fishery and the selectivity patterns were allowed between 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 blocks. 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. (In Press). 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. New to this assessment, size-at-age information from the methods described by Gregg et al. (2006) were used and are summarized in Table 5.7.

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

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

$$\text{and}$$

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

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., In Press). 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 1960-2006,

- Selectivity parameters for the 2 fisheries, and 3 surveys,

- Growth parameters: 5 parameters (2 for each sex, one in common), and

- Parameter that scales the expected value of recruitment.

Model evaluation

Size composition data are not available until 1977 hence recruitment estimates information during the early period (1960s) are highly uncertain. The salient fact of having large Greenland turbot removals of 574,000 t between 1972 and 1981 (compared to 49,000 t between 1997-2006) and having the trends in abundance as observed, indicates that recruitment during the 1960s must have been reasonably high. Lacking information on the age (or sizes) of these fish results in an inability to estimate which (and how many) years recruitment had been high. In previous assessments sensitivity to these estimates was performed. However, this year evaluations of alternative model configurations were limited due to complexity related to selectivities, gear types, and general paucity of information specific to Greenland turbot. Future research topics is provided in a section below including more in-depth model configuration analyses.

Results

While this year's model has a number of differences in configuration from the previous versions, the pattern of total biomass estimates is very similar to earlier models, particularly in the recent period (Fig. 5.12). Estimates of selectivity (using the "double-normal" option in SS2) provides reasonable appearing patterns over time for the shelf survey (Fig. 5.13). The average selectivity patterns among all gear types was also reasonable (Fig. 5.14). 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. 5.15). The slope trawl survey shows that in there is variability in the proportion caught by sex. In 2002, the survey caught far more males than females but in 2004 they found more females than males (Fig. 5.16).

The model fit the new length-at-age information presented this year reasonably well, and is consistent with growth of females being significantly greater than males (Fig. 5.17). The fit to the survey indices in recent years resulted in model predictions that were above the recent longline and shelf survey observations, but below the slope survey (Fig. 5.18). 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.

Trends in Abundance
The biomass of Greenland turbot increased during the 1970s from the early 1960s level and is currently about 43% of the level expected under no fishing using average recruitment since 1977. The recent trend shows an increase of about 12% from the 2003 level bringing the 2007 total begin-year biomass (age 1 and older) estimate to about 119,000 t (Table 5.8).

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 5.8; Fig. 5.19). A comparison of this year's model result with the 2005 assessment is also presented in Table 5.8. The estimated historical numbers at age is given in Table 5.9.

Selectivity
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 our surveys do not sample intermediate size fish (35-50cm) very well. The reason for this is unclear; however, we feel that it is related to the apparent bi-modality in the size distribution observed in the trawl fishery. The age-equivalent sex-specific selectivity estimates (for 2006) from each gear type for Greenland turbot in the BSAI is given in Table 5.10. These are approximate due to the fact that selectivity processes are modeled as a function of size. Similar, approximate age-and-sex-specific weights (and maturity) are specific for each fishery (Table 5.11).

Fit to Size Composition Data
Size composition observations from the fisheries and surveys are generally poorly matched by the model predictions (Attachment 5.1). 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" 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. The nature of the inconsistencies among data types is presented below, particularly as they pertain to assessing the current stock status.

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. 5.20). 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 we selected a conservative configuration (assuming slope-survey catchability=0.75). The status of the projected

spawning biomass in year 2007 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 1978-2005 gives a long-term average female spawning biomass of about 41,800 tons. The current estimate of the year 2006 female spawning biomass is about 60,430 t, above the estimate of $B_{35\%}$ (36,580).

Specification of OFL and Maximum Permissible ABC and ABC Recommendation

The projected Greenland turbot maximum permissible ABC and OFL levels for 2007 and 2008 are shown below (catch for 2007 was set equal to the ABC recommendation):

Year	Catch	Maximum permissible ABC	Recommended ABC	OFL	Female spawning biomass
2007	**2,440** t	12,680 t	**2,440** t	**15,600** t	60,430 t
2008	**2,490** t	13,010 t	**2,490** t	**16,030** t	63,776 t

For ABC specification this year was based on maintaining the recent fishing mortality rates. Past recommendations have been similarly conservative to promote the recovery of Greenland turbot in the EBS and Aleutian Islands region. While the stock is technically not overfished and is currently above the $B_{40\%}$ level, extra caution is still warranted. Additional information from a survey in the main habitat area of Greenland turbot (e.g., the NMFS slope survey) is required to determine if increasing fishing mortality rates at this time is advisable.

The estimated overfishing level based on the adjusted $F_{35\%}$ rate is **15,600 t** corresponding to a full-selection F of 0.67. 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 not allocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

Subarea Allocation

In this assessment, we have adopted the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions. 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, we examined the length compositions from the Aleutian Islands surveys and found a lack of 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 5.12).

Since we acknowledge having limited information on the movement and recruitment processes for this species and in the interest of harvesting the "stock" evenly, we recommend that the ABC be split between regions. 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%. We therefore recommend the ABC for the Aleutian Islands be set 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:

Aleutian Islands	756
Eastern Bering Sea	1,684
Total	2,440

Standard harvest scenarios and projections

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. 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 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2007 (here assumed to be 2,500 t). In each subsequent year, the fishing mortality rate is prescribed on the basis of 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 2007, 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 Scenario 3 (5-year average F) were selected.

Scenario 3: In all future years, F is set equal to the 2002-2006 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 2 of its MSY level in 2007 and above its MSY level in 2017 under this scenario, then the stock is not overfished.)

Scenario 7: In 2007 and 2008, 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 2019 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 13 years from 2006 (Table 5.13). Fishing at the maximum permissible rate indicate that the spawning stock will gradually drop to near the $B_{40\%}$ by 2019 (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 2007 spawning biomass estimated at 60,430 t relative to ½ $B_{35\%}$ = 18,290 tons). Under the guidelines, since the year 2006 biomass estimate is above the $B_{35\%}$ level (and $B_{40\%}$) we have determined that 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 44,100 t by 2019.

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, we can only speculate on the plausibility of this scenario. 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.

A tagging study of Greenland turbot conducted by the NMFS Auke Bay Lab staff is continuing and includes release of fish with archival tags. To date, 7 fish have been recaptured with temperature, time, and depth data and are awaiting analyses.

Research and data gaps

A number of research and modeling issues need 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,

- Evaluating the extent that Greenland turbot are affected by temperature and environmental conditions relative to survey gear,

- A re-evaluation of the assumption that 75% of the stock is indexed by the slope surveys, and

- Including the Aleutian Islands survey data within the model.

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. 5.22).   The management parameters of interest derived from this assessment are presented in Table 5.14.

Acknowledgments

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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	17,200	7,000
1995	3,978	4,215	8,194	7,000	7,000
1996	1,653	4,902	6,555	10,300	7,000
1997	1,209	5,989	7,199	12,350	9,000
1998	1,830	7,319	9,149	15,000	15,000
1999	1,799	4,057	5,857	14,200	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	8,100	8,000
2003	908	2,605	3,513	5,880	4,000
2004	675	1,544	2,219	4,740	3,500
2005	729	1,831	2,560	3,930	3,500
2006	700	1,800	2,500	2,740	2,740

Table 5.2.   Estimates of discarded and retained (t) Greenland turbot based on NMFS Blend estimates by "directed" fishery, 1992-2005.

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	1,722	45	114	534	154	93	198	5	242	230	115	60	2,546	967
2004	1,207	19	78	23	219	79	72	3	193	176	99	50	1,868	351
2005	1,530	21	63	19	156	30	134	5	313	34	163	92	2,359	201

Table 5.3. Survey estimates of Greenland turbot biomass (t) for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2006. Note that the shelf-survey estimates from 1985, and 1987-2006 include the northwestern strata (8 and 9) and these were the values used in the model. The Aleutian Islands estimates prior to 1990 used different protocols and are not comparable with more recent estimates. 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

Table 5.4. 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 5.5.   Greenland turbot biological sampling levels 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	390	42	1249	11	11	292	292
1983	353	55	951				
1984	355	27	536	20		263	
1985	446	49	204				
1986	354	53	195				
1987	362	36	354				
1988	500	63	449				
1989	374	56	376				
1990	371	62	544				
1991	457	65	658				
1992	356	64	616	5		7	
1993	375	73	632	7		179	
1994	383	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		200	
1999	373	43	128	8		11	
2000	372	57	248	34		188	
2001	400	61	274	45		217	
2002	375	70	455	21		71	
2003	376	71	622	62		435	
2004	375	64	606	45		290	
2005	402	62	442	57		294	
2006	405	56	427	50		263	

Table 5.6.   Data sets used in the stock synthesis 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 and 1998
Shelf survey: size composition and biomass estimates	1979-2006
Slope survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91, 2002, 2004
Longline survey: size composition and abundance index	1996-2006
Total fishery catch data	1960-2006
Trawl fishery size composition	1977-87, 1989-91, 1993-2006
Longline fishery size composition	1977, 1979-85, 1992-2006

Table 5.7.   Summary of the length-at-age information introduced in this year's Greenland turbot assessment based on the methods presented in Gregg et al. (2006).

	1994				1998			
	Females		Males		Females		Males	
	Avg. length		Avg. length		Avg. length		Avg. length	
Age	(cm)	N	(cm)	N	(cm)	N	(cm)	N
1	13.00	1	13.00	1	13.17	3	16.00	5
2	18.17	3	19.60	8	24.44	9	22.40	5
3	28.33	9	31.50	4	25.25	8	25.56	9
4	37.82	11	38.89	9	33.50	16	32.50	8
5	44.75	12	47.17	6	35.00	2	31.50	2
6	48.00	4	54.75	4				
7	51.00	1	59.50	2	49.50	2		
8							63.00	1
9	66.00	2	74.00	1	54.00	1	68.00	1
10	60.33	6			64.50	2	67.00	1
11	65.70	10	76.00	2			77.00	2
12	65.11	9	76.50	6			75.00	2
13	67.40	15	72.00	9	73.00	1	80.00	2
14	66.53	17	80.71	7	66.00	2	75.00	2
15	70.00	9	80.54	13			76.50	4
16	64.50	10	79.65	17				
17	66.67	6	83.33	9			72.00	1
18	68.60	10	86.80	15			82.00	1
19	64.00	5	88.82	11				
20	72.67	3	85.36	11			82.00	1
21	75.00	1	82.50	4			81.00	2
22	67.00	4	82.00	2				
23	69.50	2					84.00	1
24			84.50	2				
25			89.00	2				
26			92.00	1				
27	72.00	2	88.00	2				
28			95.00	1				
29			95.00	2				
30			92.00	1				
Totals		152		152		46		50

Table 5.8.   Total harvest rate (catch / mid-year biomass), spawning and total biomass (compared with the past assessment) for BSAI Greenland turbot, 1960-2007.

Year	Total Fishing Mortality	Catch / Mid-yr Biom.	Female Spawning Biomass 2005 Assessment	Current Assessment	Total Age 1+ Biomass 2005 Assessment	Current Assessment
1960	0.09	0.105	271,162	153,756	450,078	282,090
1961	0.13	0.183	253,468	146,470	424,455	254,794
1962	0.24	0.198	225,775	133,710	385,427	212,817
1963	0.32	0.093	198,563	117,915	348,449	170,908
1964	0.23	0.075	185,884	106,884	334,072	189,455
1965	0.27	0.017	173,608	95,113	323,643	244,609
1966	0.06	0.018	174,887	92,902	336,427	351,429
1967	0.05	0.028	176,399	97,985	361,020	472,942
1968	0.05	0.036	173,889	128,788	394,016	585,992
1969	0.06	0.035	168,572	204,807	434,421	677,662
1970	0.05	0.024	171,071	306,306	483,964	749,151
1971	0.03	0.048	193,499	397,658	545,561	806,941
1972	0.06	0.088	220,539	453,514	579,284	822,646
1973	0.11	0.076	235,610	470,485	562,624	785,345
1974	0.10	0.098	254,613	472,146	543,465	747,973
1975	0.14	0.092	256,592	454,863	497,268	687,906
1976	0.13	0.092	248,079	431,913	455,667	633,900
1977	0.14	0.048	226,947	405,125	415,806	584,594
1978	0.08	0.069	218,382	389,573	411,469	568,655
1979	0.11	0.071	201,033	369,097	393,775	541,876
1980	0.12	0.095	186,806	350,478	378,708	516,026
1981	0.16	0.112	169,221	328,116	350,796	477,739
1982	0.19	0.113	151,026	303,927	314,364	431,927
1983	0.21	0.116	136,859	282,292	277,609	387,205
1984	0.23	0.063	124,408	257,350	240,202	344,323
1985	0.12	0.043	123,255	244,708	223,348	323,057
1986	0.08	0.030	123,259	235,739	212,581	307,654
1987	0.05	0.031	122,404	227,976	206,100	295,220
1988	0.06	0.024	118,112	218,525	200,163	281,545
1989	0.04	0.031	113,331	208,684	196,536	269,243
1990	0.06	0.048	107,006	196,762	190,639	254,450
1991	0.09	0.032	100,408	182,267	180,321	235,922
1992	0.05	0.016	99,506	170,463	174,120	222,479
1993	0.02	0.039	101,163	160,418	171,736	212,846
1994	0.05	0.050	97,091	147,301	164,123	199,025
1995	0.08	0.044	90,548	135,201	153,535	183,525
1996	0.07	0.038	85,526	124,937	144,083	170,228
1997	0.05	0.045	82,248	115,987	135,388	158,817
1998	0.06	0.063	77,851	106,699	125,754	147,108
1999	0.09	0.044	70,667	96,220	114,304	134,039
2000	0.06	0.057	65,244	88,363	106,085	124,590
2001	0.08	0.048	58,558	80,008	97,170	115,029
2002	0.07	0.035	53,566	73,523	90,630	108,640
2003	0.05	0.036	50,175	68,407	86,749	106,480
2004	0.05	0.023	46,996	63,851	84,590	106,915
2005	0.03	0.026	44,989	60,966	85,444	110,436
2006	0.04	0.025		59,424		114,586
2007				60,326		119,054

Table 5.9.   Estimated beginning of year numbers of Greenland turbot by age and sex (millions).

Females

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1976	37.77	16.53	24.02	18.93	10.28	6.29	5.41	4.24	2.86	2.16	1.73	1.45	1.22	76.26	0.86	0.69	0.60	0.47	0.38	0.32	3.42
1977	19.01	33.58	14.54	20.77	16.01	8.52	5.15	4.41	3.46	2.34	1.78	1.43	1.21	1.02	64.06	0.72	0.58	0.51	0.40	0.32	3.20
1978	20.27	16.95	29.75	12.76	18.02	13.73	7.26	4.38	3.75	2.94	2.00	1.52	1.23	1.04	0.88	55.42	0.63	0.51	0.44	0.35	3.08
1979	14.16	18.04	14.96	25.92	10.93	15.19	11.47	6.04	3.64	3.13	2.47	1.68	1.29	1.04	0.88	0.75	47.19	0.53	0.43	0.38	2.94
1980	9.51	12.60	15.92	13.02	22.17	9.19	12.65	9.52	5.02	3.03	2.62	2.07	1.42	1.08	0.88	0.75	0.64	40.13	0.46	0.37	2.84
1981	6.39	8.45	11.07	13.72	10.96	18.24	7.47	10.22	7.70	4.07	2.47	2.14	1.70	1.17	0.90	0.73	0.62	0.53	33.56	0.38	2.71
1982	2.41	5.67	7.39	9.47	11.41	8.86	14.51	5.90	8.08	6.11	3.25	1.99	1.73	1.38	0.96	0.74	0.60	0.51	0.44	27.76	2.57
1983	3.00	2.14	4.95	6.30	7.81	9.12	6.95	11.31	4.61	6.35	4.84	2.60	1.60	1.41	1.13	0.78	0.61	0.50	0.43	0.37	25.30
1984	1.94	2.68	1.91	4.42	5.57	6.75	7.62	5.61	8.88	3.57	4.91	3.76	2.04	1.27	1.12	0.90	0.63	0.49	0.40	0.35	21.09
1985	3.35	1.74	2.40	1.71	3.92	4.89	5.82	6.44	4.67	7.35	2.95	4.07	3.13	1.70	1.06	0.94	0.76	0.53	0.42	0.34	18.33
1986	7.12	3.00	1.55	2.14	1.52	3.47	4.27	5.02	5.50	3.97	6.24	2.51	3.47	2.68	1.46	0.91	0.81	0.66	0.46	0.36	16.22
1987	2.18	6.36	2.68	1.39	1.91	1.35	3.05	3.72	4.35	4.76	3.43	5.40	2.18	3.02	2.33	1.27	0.80	0.71	0.58	0.40	14.55
1988	2.99	1.95	5.69	2.40	1.24	1.69	1.19	2.66	3.23	3.76	4.11	2.97	4.68	1.89	2.62	2.03	1.11	0.70	0.62	0.50	13.12
1989	2.75	2.68	1.75	5.08	2.14	1.10	1.50	1.04	2.32	2.81	3.28	3.59	2.59	4.09	1.65	2.30	1.78	0.97	0.61	0.54	12.00
1990	7.08	2.46	2.39	1.56	4.53	1.90	0.97	1.31	0.90	2.01	2.44	2.84	3.11	2.25	3.56	1.44	2.00	1.55	0.85	0.53	11.00
1991	2.99	6.33	2.20	2.14	1.39	4.05	1.69	0.85	1.13	0.77	1.71	2.07	2.41	2.65	1.92	3.05	1.23	1.72	1.34	0.73	10.02
1992	1.14	2.67	5.66	1.97	1.91	1.25	3.61	1.50	0.75	0.99	0.67	1.48	1.79	2.09	2.30	1.67	2.64	1.07	1.50	1.16	9.38
1993	1.04	1.02	2.39	5.06	1.76	1.71	1.11	3.22	1.33	0.67	0.88	0.59	1.31	1.58	1.84	2.02	1.47	2.32	0.94	1.31	9.24
1994	0.90	0.93	0.91	2.14	4.52	1.57	1.53	0.99	2.87	1.18	0.59	0.77	0.52	1.14	1.36	1.58	1.73	1.26	1.98	0.80	8.99
1995	1.41	0.80	0.84	0.82	1.91	4.04	1.40	1.35	0.87	2.48	1.02	0.50	0.66	0.44	0.97	1.16	1.35	1.48	1.07	1.69	8.38
1996	3.42	1.26	0.72	0.75	0.73	1.71	3.60	1.24	1.19	0.76	2.16	0.88	0.43	0.57	0.38	0.83	1.00	1.16	1.26	0.92	8.63
1997	1.61	3.06	1.12	0.64	0.67	0.65	1.53	3.22	1.11	1.05	0.67	1.89	0.76	0.38	0.49	0.33	0.72	0.85	0.99	1.08	8.16
1998	2.00	1.44	2.74	1.00	0.57	0.60	0.58	1.36	2.86	0.98	0.93	0.58	1.64	0.66	0.32	0.42	0.28	0.61	0.73	0.84	7.82
1999	2.25	1.79	1.29	2.45	0.90	0.51	0.53	0.52	1.21	2.52	0.85	0.80	0.50	1.40	0.56	0.27	0.35	0.23	0.51	0.60	7.18
2000	7.58	2.01	1.60	1.15	2.19	0.80	0.46	0.48	0.46	1.07	2.21	0.75	0.70	0.43	1.20	0.48	0.23	0.30	0.20	0.43	6.63
2001	10.71	6.78	1.80	1.43	1.03	1.96	0.72	0.41	0.42	0.41	0.93	1.92	0.64	0.60	0.37	1.02	0.41	0.20	0.25	0.17	5.93
2002	16.33	9.58	6.06	1.61	1.28	0.92	1.75	0.64	0.36	0.37	0.36	0.81	1.66	0.55	0.51	0.32	0.87	0.35	0.17	0.22	5.21
2003	3.89	14.60	8.56	5.42	1.44	1.14	0.82	1.56	0.57	0.32	0.33	0.31	0.71	1.44	0.48	0.44	0.27	0.75	0.30	0.14	4.67
2004	2.11	3.48	13.06	7.66	4.84	1.29	1.02	0.74	1.39	0.50	0.28	0.29	0.27	0.62	1.25	0.42	0.38	0.24	0.65	0.26	4.14
2005	2.74	1.89	3.11	11.67	6.84	4.33	1.15	0.91	0.66	1.23	0.45	0.25	0.25	0.24	0.54	1.10	0.36	0.33	0.21	0.57	3.83
2006	3.99	2.45	1.69	2.78	10.44	6.12	3.87	1.03	0.81	0.58	1.09	0.39	0.22	0.22	0.21	0.47	0.95	0.32	0.29	0.18	3.81

Males

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1976	37.77	16.53	23.98	18.79	10.09	6.02	4.97	3.65	2.28	1.57	1.14	0.87	0.67	38.36	0.39	0.29	0.22	0.15	0.10	0.06	0.22
1977	19.01	33.58	14.51	20.61	15.68	8.13	4.68	3.74	2.68	1.63	1.11	0.80	0.61	0.46	26.40	0.27	0.20	0.15	0.10	0.07	0.19
1978	20.27	16.94	29.72	12.70	17.75	13.25	6.74	3.83	3.01	2.13	1.29	0.87	0.62	0.47	0.36	20.57	0.21	0.15	0.12	0.08	0.20
1979	14.16	18.04	14.94	25.78	10.76	14.66	10.66	5.30	2.94	2.28	1.60	0.96	0.64	0.46	0.35	0.26	14.98	0.15	0.11	0.08	0.20
1980	9.51	12.60	15.90	12.94	21.80	8.86	11.73	8.32	4.05	2.21	1.69	1.17	0.70	0.47	0.33	0.25	0.19	10.77	0.11	0.08	0.20
1981	6.39	8.45	11.04	13.62	10.73	17.41	6.80	8.69	5.98	2.84	1.52	1.15	0.79	0.47	0.31	0.22	0.17	0.13	7.07	0.07	0.19
1982	2.41	5.67	7.38	9.38	11.11	8.36	12.93	4.83	5.95	3.97	1.84	0.97	0.72	0.49	0.29	0.19	0.13	0.10	0.08	4.31	0.16
1983	3.00	2.14	4.94	6.23	7.58	8.52	6.08	8.94	3.20	3.81	2.48	1.13	0.59	0.44	0.29	0.17	0.11	0.08	0.06	0.05	2.64
1984	1.94	2.68	1.91	4.40	5.51	6.54	7.02	4.69	6.39	2.13	2.37	1.46	0.64	0.33	0.24	0.16	0.09	0.06	0.04	0.03	1.38
1985	3.35	1.74	2.40	1.71	3.91	4.83	5.59	5.80	3.73	4.90	1.58	1.72	1.04	0.45	0.23	0.16	0.11	0.06	0.04	0.03	0.97
1986	7.12	3.00	1.55	2.14	1.52	3.45	4.19	4.75	4.81	3.02	3.89	1.24	1.33	0.80	0.35	0.17	0.12	0.08	0.05	0.03	0.75
1987	2.18	6.36	2.68	1.39	1.91	1.35	3.03	3.62	4.03	4.02	2.49	3.18	1.00	1.08	0.65	0.28	0.14	0.10	0.07	0.04	0.63
1988	2.99	1.95	5.69	2.40	1.24	1.69	1.18	2.61	3.08	3.38	3.32	2.04	2.59	0.81	0.87	0.52	0.22	0.11	0.08	0.05	0.53
1989	2.75	2.68	1.75	5.08	2.14	1.10	1.49	1.03	2.25	2.62	2.85	2.79	1.70	2.15	0.67	0.72	0.43	0.18	0.09	0.07	0.48
1990	7.08	2.46	2.39	1.56	4.53	1.90	0.96	1.29	0.88	1.89	2.18	2.35	2.28	1.39	1.75	0.55	0.58	0.35	0.15	0.07	0.44
1991	2.99	6.33	2.20	2.14	1.39	4.05	1.69	0.85	1.12	0.74	1.55	1.74	1.84	1.76	1.06	1.32	0.41	0.44	0.26	0.11	0.38
1992	1.14	2.67	5.66	1.97	1.91	1.25	3.61	1.50	0.75	0.96	0.63	1.30	1.44	1.51	1.43	0.86	1.07	0.33	0.35	0.21	0.39
1993	1.04	1.02	2.39	5.06	1.76	1.71	1.11	3.23	1.33	0.66	0.85	0.55	1.14	1.26	1.32	1.25	0.75	0.93	0.29	0.30	0.52
1994	0.90	0.93	0.91	2.14	4.52	1.57	1.53	0.99	2.86	1.18	0.58	0.74	0.48	0.98	1.08	1.12	1.06	0.63	0.78	0.24	0.69
1995	1.41	0.80	0.84	0.82	1.91	4.04	1.40	1.35	0.87	2.45	0.99	0.48	0.60	0.38	0.78	0.85	0.88	0.82	0.49	0.60	0.71
1996	3.42	1.26	0.72	0.75	0.73	1.71	3.61	1.24	1.19	0.75	2.09	0.83	0.40	0.50	0.31	0.63	0.69	0.71	0.66	0.39	1.05
1997	1.61	3.06	1.12	0.64	0.67	0.65	1.53	3.22	1.11	1.05	0.66	1.82	0.72	0.34	0.42	0.26	0.53	0.57	0.59	0.55	1.19
1998	2.00	1.44	2.74	1.00	0.57	0.60	0.58	1.36	2.87	0.98	0.92	0.57	1.57	0.61	0.29	0.35	0.22	0.44	0.48	0.49	1.43
1999	2.25	1.79	1.29	2.45	0.90	0.51	0.53	0.52	1.21	2.52	0.85	0.79	0.49	1.31	0.51	0.24	0.29	0.18	0.36	0.38	1.52
2000	7.58	2.01	1.60	1.15	2.19	0.80	0.46	0.48	0.46	1.07	2.20	0.74	0.68	0.41	1.10	0.42	0.20	0.24	0.15	0.29	1.55
2001	10.71	6.78	1.80	1.43	1.03	1.96	0.72	0.41	0.42	0.41	0.93	1.89	0.62	0.57	0.34	0.91	0.35	0.16	0.19	0.12	1.47
2002	16.33	9.58	6.06	1.61	1.28	0.92	1.75	0.64	0.36	0.37	0.35	0.80	1.60	0.52	0.47	0.28	0.74	0.28	0.13	0.16	1.28
2003	3.89	14.60	8.56	5.42	1.44	1.14	0.82	1.56	0.57	0.32	0.33	0.31	0.69	1.38	0.45	0.40	0.24	0.63	0.24	0.11	1.19
2004	2.11	3.48	13.06	7.66	4.84	1.29	1.02	0.74	1.39	0.51	0.28	0.29	0.27	0.59	1.18	0.38	0.34	0.20	0.53	0.20	1.09
2005	2.74	1.89	3.11	11.67	6.84	4.33	1.15	0.91	0.66	1.23	0.45	0.25	0.25	0.23	0.51	1.02	0.33	0.29	0.17	0.45	1.10
2006	3.99	2.45	1.69	2.78	10.44	6.12	3.87	1.03	0.81	0.58	1.09	0.39	0.22	0.22	0.20	0.44	0.87	0.28	0.25	0.15	1.31

Table 5.10. Age-equivalent sex-specific selectivity estimates (as estimated for 2006) 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.

Age	Trawl Fishery Female	Trawl Fishery Male	Longline fishery Female	Longline fishery Male	Shelf Survey Female	Shelf Survey Male	Slope survey Female	Slope survey Male	Longline survey Female	Longline survey Male
1	0.000	0.000	0.000	0.000	0.274	0.279	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.723	0.766	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.865	0.985	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.828	1.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.801	1.000	0.003	0.004	0.000	0.000
6	0.003	0.002	0.001	0.002	0.806	1.000	0.025	0.033	0.000	0.002
7	0.028	0.017	0.006	0.008	0.821	1.000	0.099	0.128	0.000	0.013
8	0.093	0.071	0.018	0.021	0.834	1.000	0.210	0.290	0.002	0.055
9	0.176	0.177	0.045	0.046	0.847	1.000	0.303	0.472	0.011	0.140
10	0.236	0.313	0.087	0.082	0.858	1.000	0.356	0.623	0.037	0.255
11	0.259	0.448	0.143	0.127	0.868	1.000	0.380	0.726	0.085	0.375
12	0.258	0.564	0.205	0.179	0.877	1.000	0.389	0.788	0.149	0.478
13	0.245	0.653	0.267	0.232	0.886	1.000	0.392	0.821	0.217	0.555
14	0.228	0.719	0.323	0.283	0.893	1.000	0.393	0.836	0.278	0.606
15	0.211	0.765	0.370	0.332	0.899	1.000	0.390	0.840	0.328	0.636
16	0.195	0.797	0.408	0.375	0.905	1.000	0.385	0.838	0.367	0.650
17	0.180	0.820	0.439	0.414	0.910	1.000	0.377	0.833	0.395	0.654
18	0.167	0.835	0.462	0.448	0.915	1.000	0.366	0.826	0.417	0.651
19	0.156	0.845	0.480	0.477	0.919	1.000	0.353	0.820	0.432	0.644
20	0.146	0.851	0.494	0.502	0.923	1.000	0.339	0.813	0.443	0.635
21	0.138	0.856	0.504	0.523	0.926	1.000	0.324	0.807	0.452	0.626
22	0.130	0.858	0.512	0.541	0.929	1.000	0.309	0.801	0.458	0.616
23	0.124	0.860	0.518	0.556	0.932	1.000	0.296	0.795	0.463	0.607
24	0.119	0.861	0.522	0.569	0.934	1.000	0.283	0.791	0.466	0.598
25	0.114	0.861	0.526	0.580	0.936	1.000	0.271	0.786	0.469	0.590
26	0.110	0.862	0.529	0.589	0.938	1.000	0.260	0.783	0.471	0.584
27	0.107	0.862	0.531	0.597	0.940	1.000	0.250	0.780	0.473	0.578
28	0.104	0.862	0.532	0.604	0.941	1.000	0.241	0.777	0.474	0.572
29	0.101	0.861	0.533	0.610	0.942	1.000	0.234	0.774	0.475	0.568
30	0.099	0.861	0.534	0.615	0.944	1.000	0.227	0.772	0.476	0.563

Table 5.11.   Age and sex-specific mean length and weights-at-age estimates for BSAI Greenland turbot.

Age	Mid-year length (cm)		Mid-year weight (kg)	
	Females	Males	Females	Males
1	13.99	14.04	0.00	0.01
2	22.84	22.51	0.00	0.08
3	30.69	29.80	0.00	0.22
4	37.64	36.08	0.00	0.41
5	43.80	41.48	0.03	0.65
6	49.27	46.13	0.15	0.93
7	54.11	50.14	0.52	1.23
8	58.40	53.59	1.11	1.54
9	62.21	56.55	1.79	1.84
10	65.58	59.11	2.45	2.14
11	68.57	61.31	3.05	2.42
12	71.22	63.20	3.61	2.68
13	73.57	64.84	4.12	2.92
14	75.65	66.24	4.59	3.14
15	77.49	67.45	5.03	3.34
16	79.13	68.49	5.44	3.52
17	80.58	69.38	5.82	3.68
18	81.87	70.15	6.18	3.82
19	83.00	70.82	6.51	3.94
20	84.01	71.39	6.81	4.05
21	84.91	71.88	7.09	4.14
22	85.70	72.31	7.34	4.23
23	86.41	72.67	7.56	4.30
24	87.03	72.98	7.77	4.36
25	87.58	73.25	7.95	4.42
26	88.07	73.49	8.11	4.47
27	88.50	73.69	8.25	4.51
28	88.89	73.86	8.38	4.54
29	89.23	74.01	8.49	4.57
30	89.53	74.14	8.59	4.60

Table 5.12. Estimated total Greenland turbot harvest by area, 1977-2006. Values for 2006 are through Nov. 11th, 2006 and are preliminary.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1992	1,767	2,462
1978	37,423	4,766	1993	4,878	6,330
1979	34,998	6,411	1994	3,875	7,141
1980	48,856	3,697	1995	4,499	5,855
1981	52,921	4,400	1996	4,258	4,844
1982	45,805	6,317	1997	5,730	6,435
1983	43,443	4,115	1998	7,839	8,329
1984	21,317	1,803	1999	5,179	5,391
1985	14,698	33	2000	5,667	5,888
1986	7,710	2,154	2001	4,102	4,252
1987	6,519	3,066	2002	3,011	3,153
1988	6,064	1,044	2003	2,467	960
1989	4,061	4,761	2004	1,775	381
1990	7,702	2,494	2005	2,120	440
1991	3,781	4,397	2006	1,434	520

Table 5.13. Mean spawning biomass, F, and yield projections for Greenland turbot, 2005-2018. The full-selection fishing mortality rates (F's) between longline and trawl gears were assumed to be **50:50** (whereas recent averages are around 78:22). The values for $B_{40\%}$ and $B_{35\%}$ are 41,800 and 36,580 tons, respectively.

Catch	Max F_{ABC}	.75F_{ABC}	5-year avg.	$F_{75\%}$	No Fishing	Scenario 6	Scenario 7
2006	2,500	2,500	2,500	2,500	2,500	2,500	2,500
2007	12,683	2,500	2,436	2,928	0	15,601	12,683
2008	11,276	9,982	2,491	2,975	0	13,307	11,276
2009	10,982	9,782	2,670	3,173	0	12,649	13,573
2010	11,306	10,033	2,928	3,466	0	12,855	13,535
2011	11,624	10,307	3,185	3,759	0	13,056	13,559
2012	11,587	10,346	3,391	3,988	0	12,797	13,168
2013	11,193	10,128	3,535	4,140	0	12,110	12,383
2014	10,623	9,761	3,629	4,232	0	10,978	11,289
2015	9,994	9,366	3,690	4,286	0	9,810	10,011
2016	9,294	9,025	3,733	4,320	0	9,144	9,263
2017	8,860	8,732	3,769	4,346	0	8,860	8,930
2018	8,651	8,470	3,799	4,370	0	8,794	8,835
2019	8,578	8,293	3,827	4,391	0	8,824	8,848

Fishing M.	Max F_{ABC}	.75F_{ABC}	5-year avg.	$F_{75\%}$	No Fishing	Scenario 6	Scenario 7
2006	0.090	0.090	0.090	0.090	0.090	0.090	0.090
2007	0.505	0.092	0.090	0.108	0.000	0.637	0.505
2008	0.505	0.379	0.090	0.108	0.000	0.637	0.505
2009	0.505	0.379	0.090	0.108	0.000	0.637	0.637
2010	0.505	0.379	0.090	0.108	0.000	0.637	0.637
2011	0.505	0.379	0.090	0.108	0.000	0.637	0.637
2012	0.505	0.379	0.090	0.108	0.000	0.637	0.637
2013	0.505	0.379	0.090	0.108	0.000	0.637	0.637
2014	0.505	0.379	0.090	0.108	0.000	0.618	0.626
2015	0.501	0.379	0.090	0.108	0.000	0.583	0.589
2016	0.483	0.379	0.090	0.108	0.000	0.558	0.562
2017	0.468	0.376	0.090	0.108	0.000	0.542	0.545
2018	0.456	0.370	0.090	0.108	0.000	0.532	0.534
2019	0.449	0.364	0.090	0.108	0.000	0.526	0.527

Spawning biomass	Max F_{ABC}	.75F_{ABC}	5-year avg.	$F_{75\%}$	No Fishing	Scenario 6	Scenario 7
2006	59,424	59,424	59,424	59,424	59,424	59,424	59,424
2007	60,430	60,430	60,430	60,430	60,430	60,430	60,430
2008	58,203	63,776	63,811	63,547	65,111	56,564	58,203
2009	57,901	64,052	68,053	67,549	70,571	55,149	57,901
2010	57,314	63,900	71,477	70,741	75,203	53,719	55,894
2011	55,577	62,564	73,532	72,562	78,505	51,268	52,974
2012	53,054	60,414	74,597	73,392	80,849	48,145	49,472
2013	50,445	58,104	75,227	73,791	82,755	45,078	46,103
2014	48,200	56,053	75,759	74,106	84,526	42,540	43,325
2015	46,479	54,421	76,327	74,474	86,271	40,825	41,364
2016	45,294	53,200	76,949	74,914	87,998	39,943	40,308
2017	44,621	52,298	77,581	75,381	89,665	39,579	39,825
2018	44,273	51,633	78,171	75,822	91,219	39,475	39,641
2019	44,126	51,188	78,720	76,238	92,661	39,504	39,616

Table 5.14.   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 2007)	3a
Approximate age at full recruitment	10 years
$F_{35\%}$ (F_{OFL})	0.67
$F_{40\%}$	0.51
$B_{100\%}$	104,520 t
$B_{40\%}$	41,800 t
$B_{35\%}$	36,580 t
Year 2007 female spawning biomass	60,430 t
Year 2007 total (age 1+) biomass	119,340 t
$F_{ABC} = F_{40\%}$ (max permissible)	0.51
2007 Maximum permissible ABC	12,680 t
2008 Maximum permissible ABC (2007 catch = 2,500 t)	13,010 t
F_{ABC} = 5-year average F	0.09
Recommended ABC: 2007	**2,440 t**
2008	**2,490 t**
$F_{overfishing} = F_{35\%}$	0.67
2007 Greenland turbot OFL	**15,600 t**
2008 Greenland turbot OFL (2007 catch = 2,500 t)	**16,030 t**

Figures
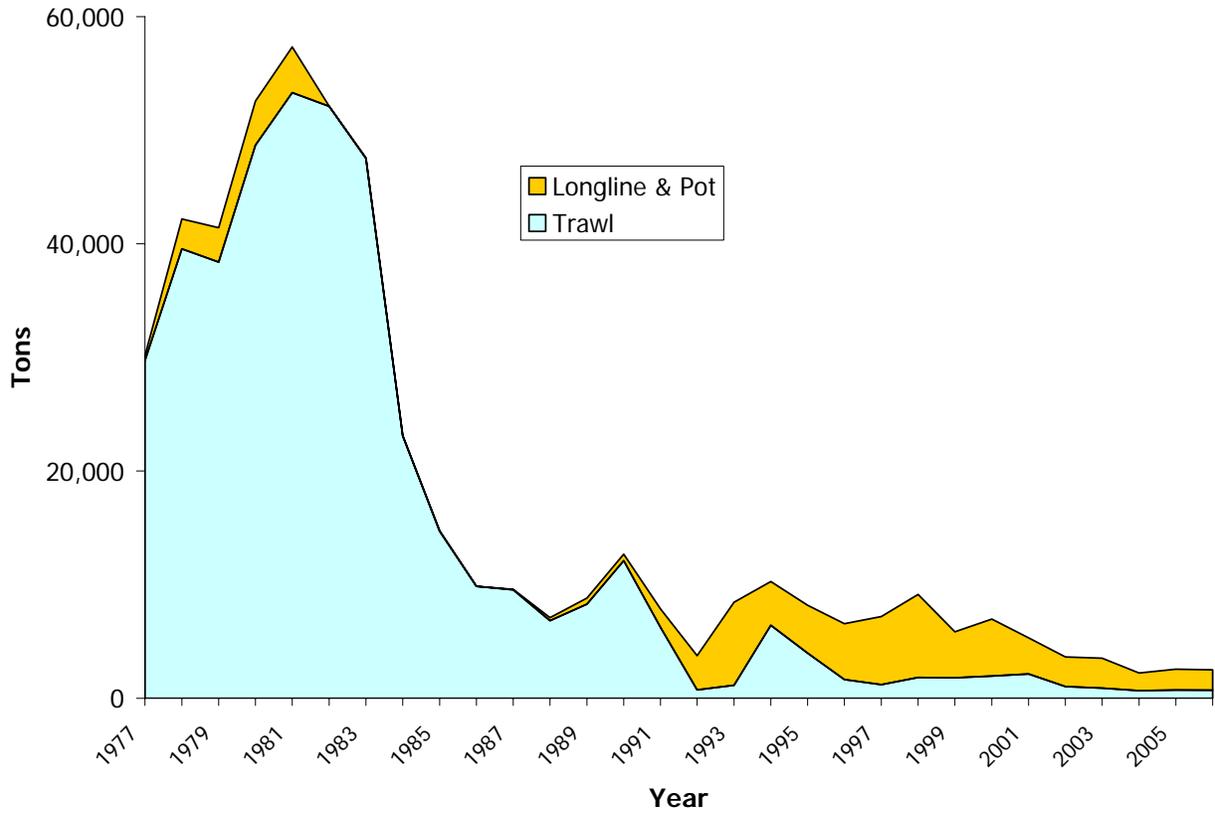
Figure 5.1.   Trawl and longline catches of Greenland turbot in the combined EBS/AI area, 1977-2006. Note: catches for 2006 are based on projections from the NMFS Regional Office.
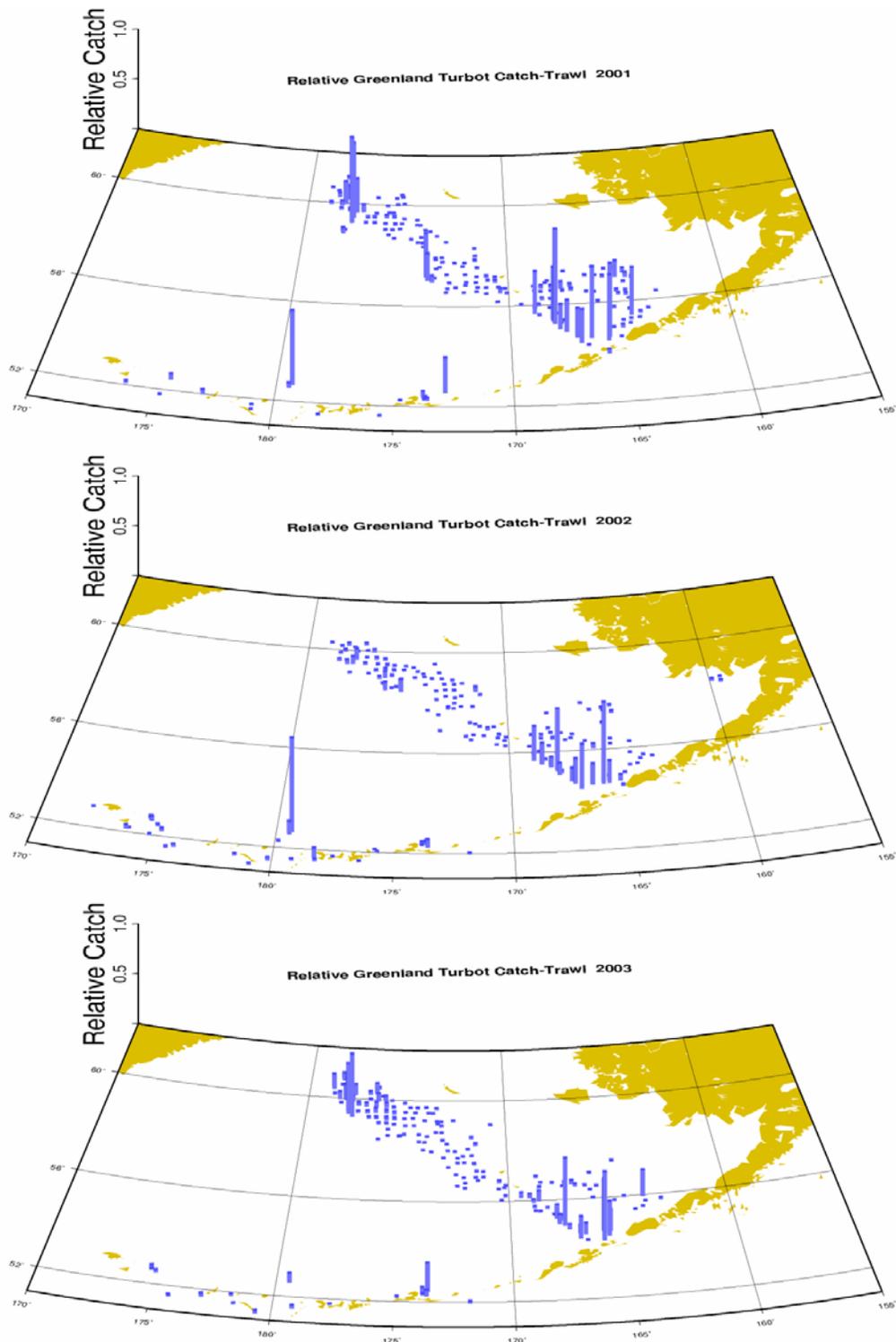
Figure 5.2. Distribution of Greenland turbot catch by trawl vessels based on aggregated NMFS observer data, 2001-2003. Vertical lines represent the relative magnitude of Greenland turbot catch for each 30' longitude by 15' latitude grids.
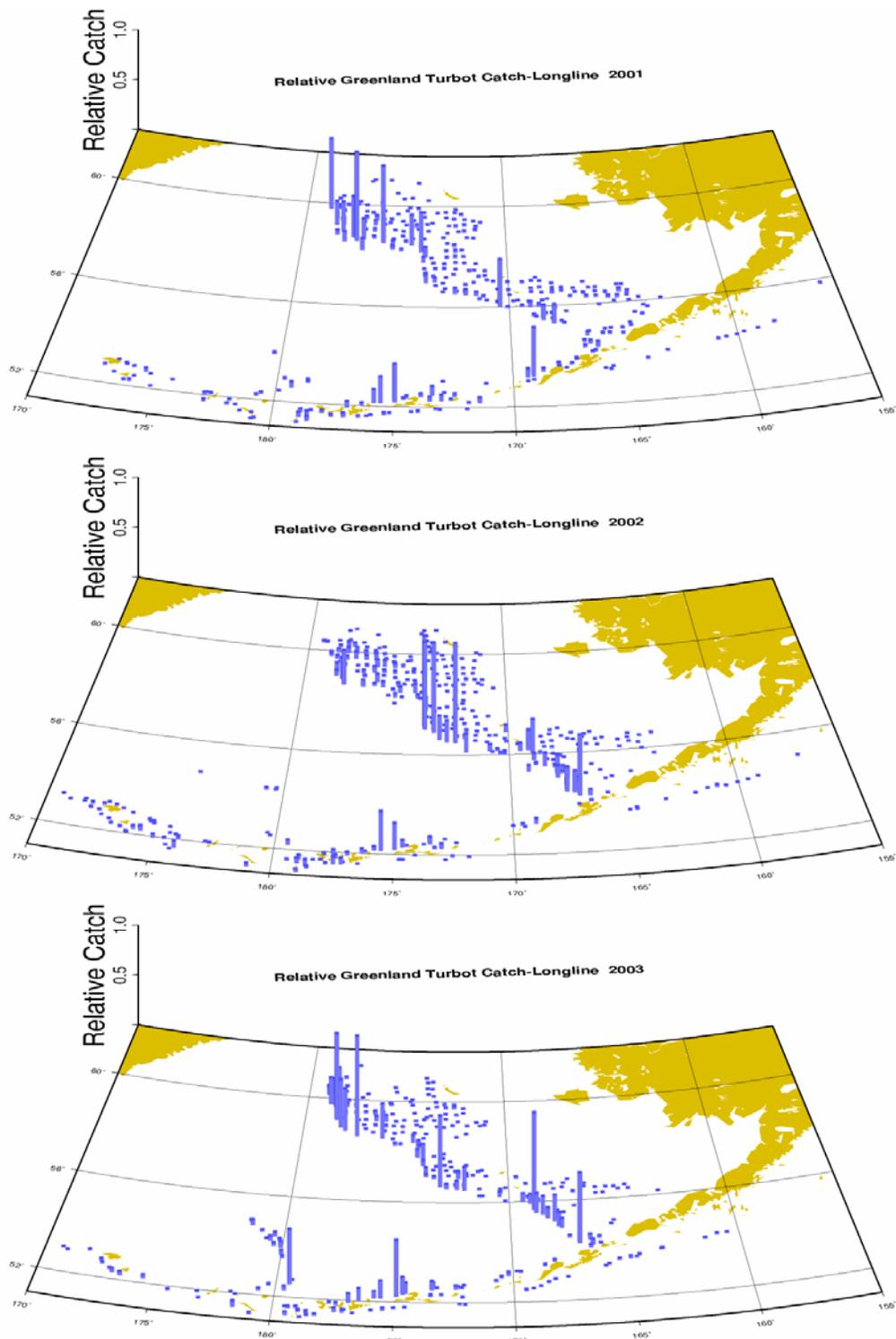
Figure 5.3.   Distribution of Greenland turbot catch by longline vessels based on aggregated NMFS observer data, 2001-2003. Vertical lines represent the relative magnitude of Greenland turbot catch for each 30' longitude by 15' latitude grids.
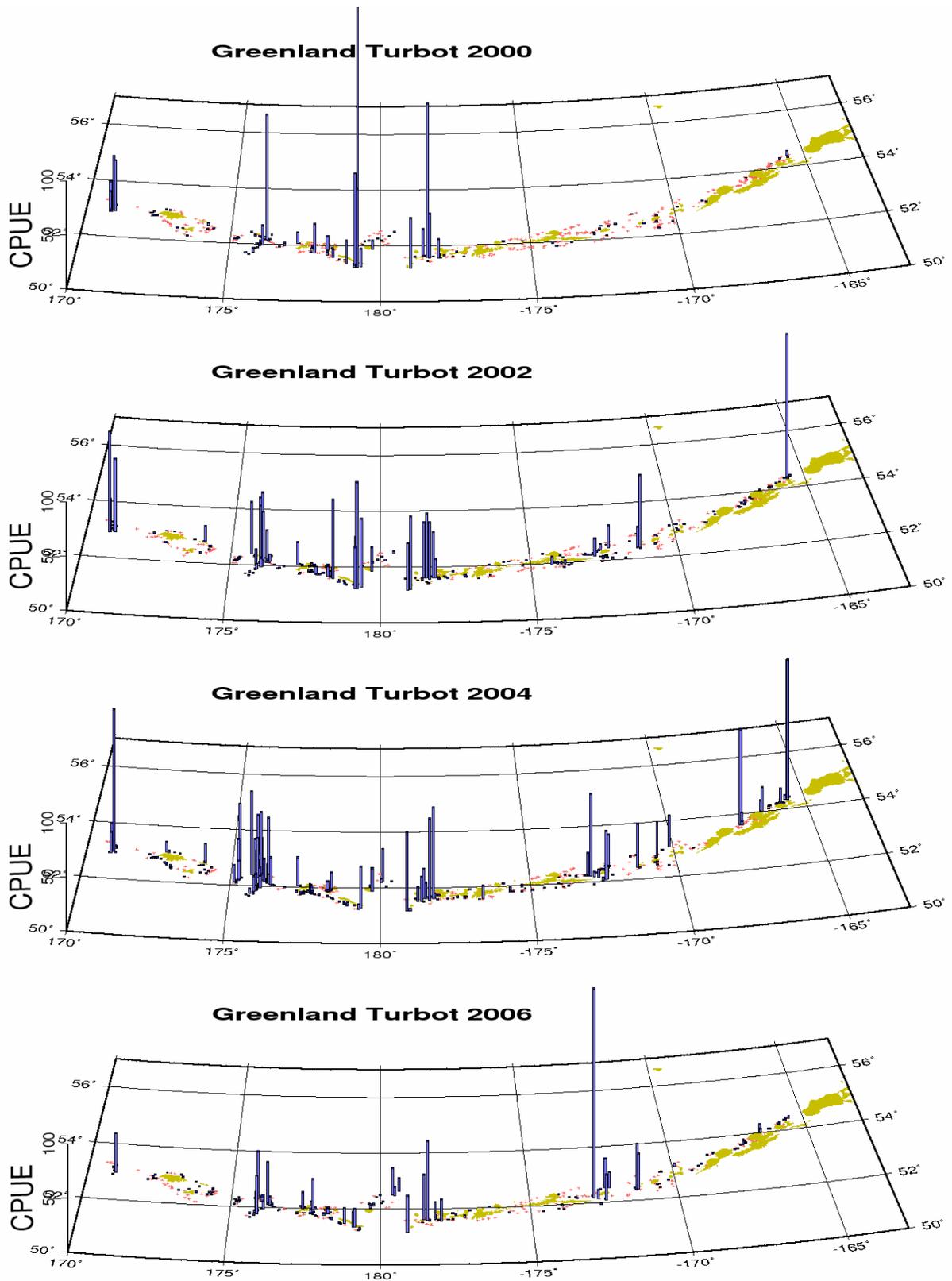
Figure 5.4. Greenland turbot catch per unit effort (relative values by weight, vertical bars) from the Aleutian Islands region bottom trawl survey, 2000-2006.
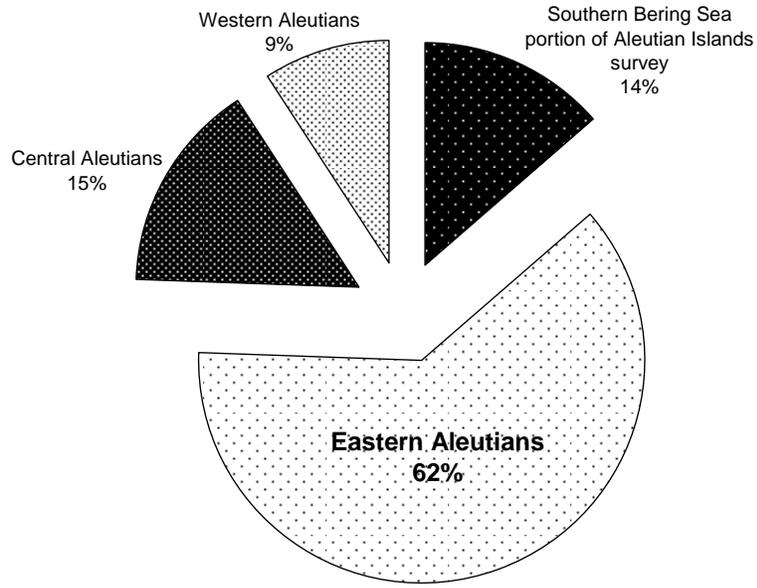
Figure 5.5.   Average Greenland turbot relative biomass from the Aleutian Islands surveys by region, 1980-2006.
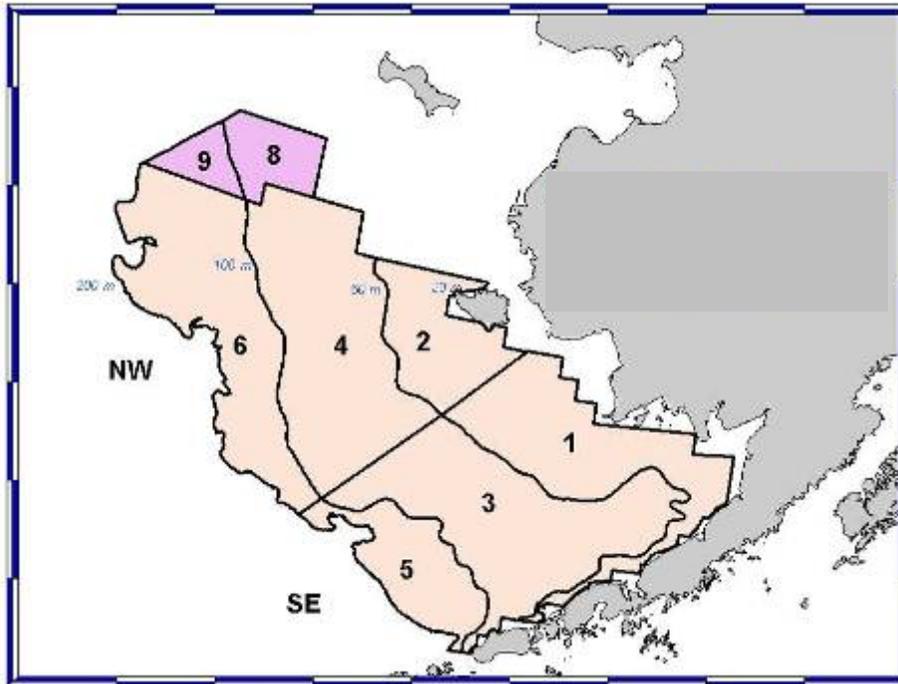
Figure 5.6.   Map showing the standard NMFS bottom-trawl survey strata (1-6) and the additional strata (8 and 9). The standard survey area (done each year since 1982) measures 463,374 km^2 and includes about 356 stations. Including the expanded area (done each year since 1987) the number of stations typically totals 376.
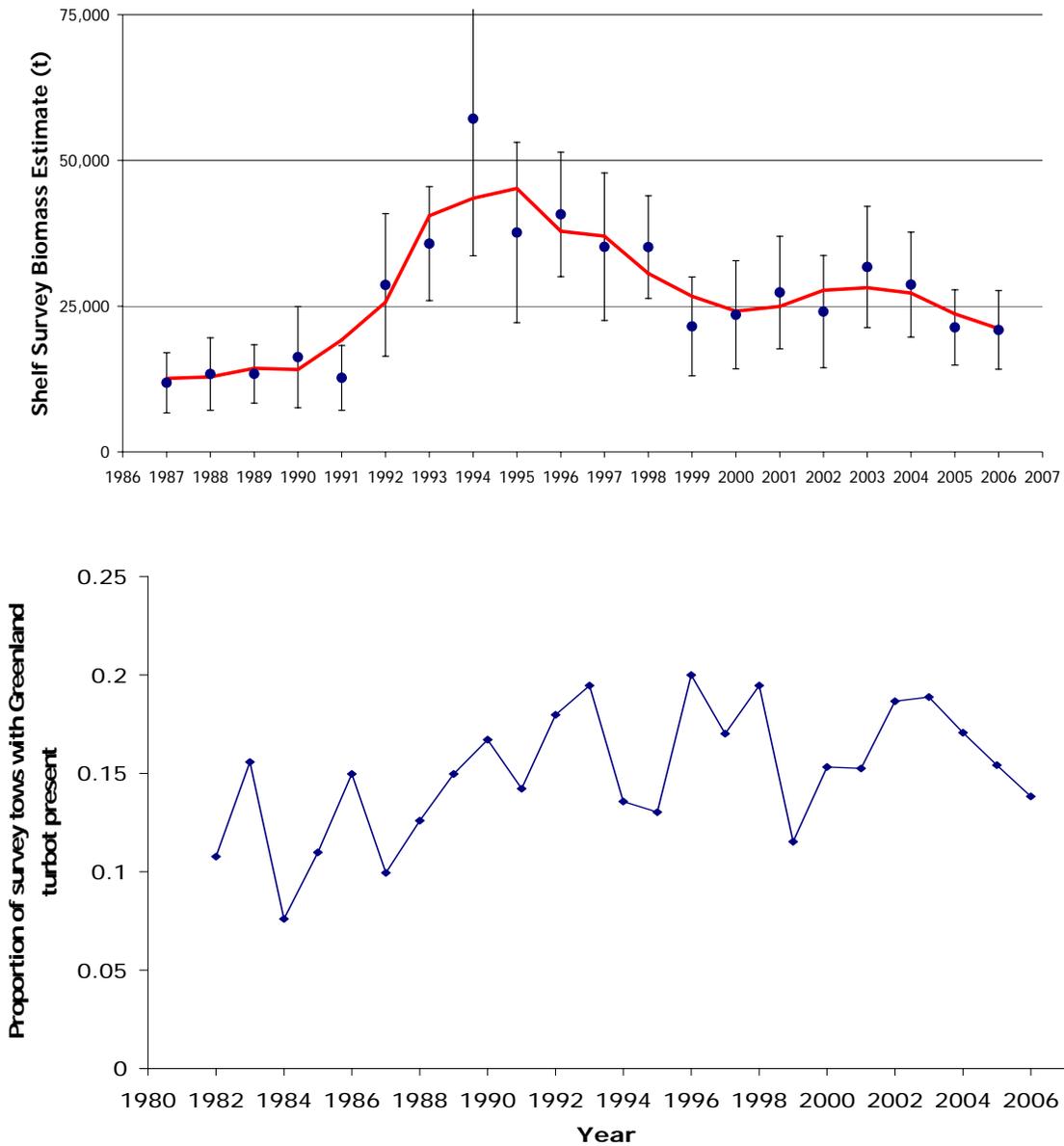
Figure 5.7.   Survey biomass estimates of Greenland turbot from the EBS shelf trawl survey (top) and the proportion of tows that caught at least one Greenland turbot (bottom), 1982-2006. The line in the top figure is a moving average value.
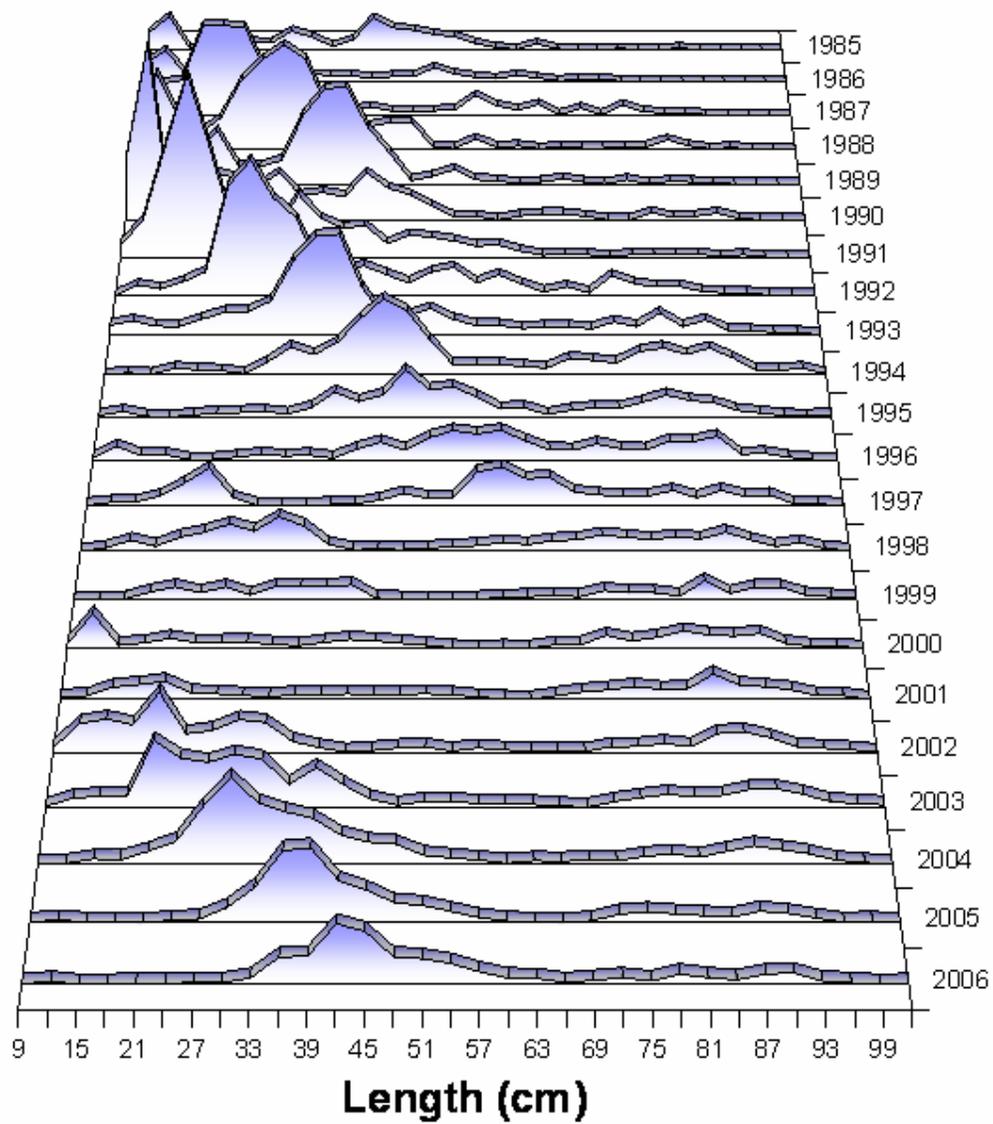
Figure 5.8.   Abundance-at-length (cm) for Greenland turbot observed from the summer NMFS shelf trawl surveys, 1985-2006 (sexes combined, all strata except for 1986 where only strata 1-6 were sampled).
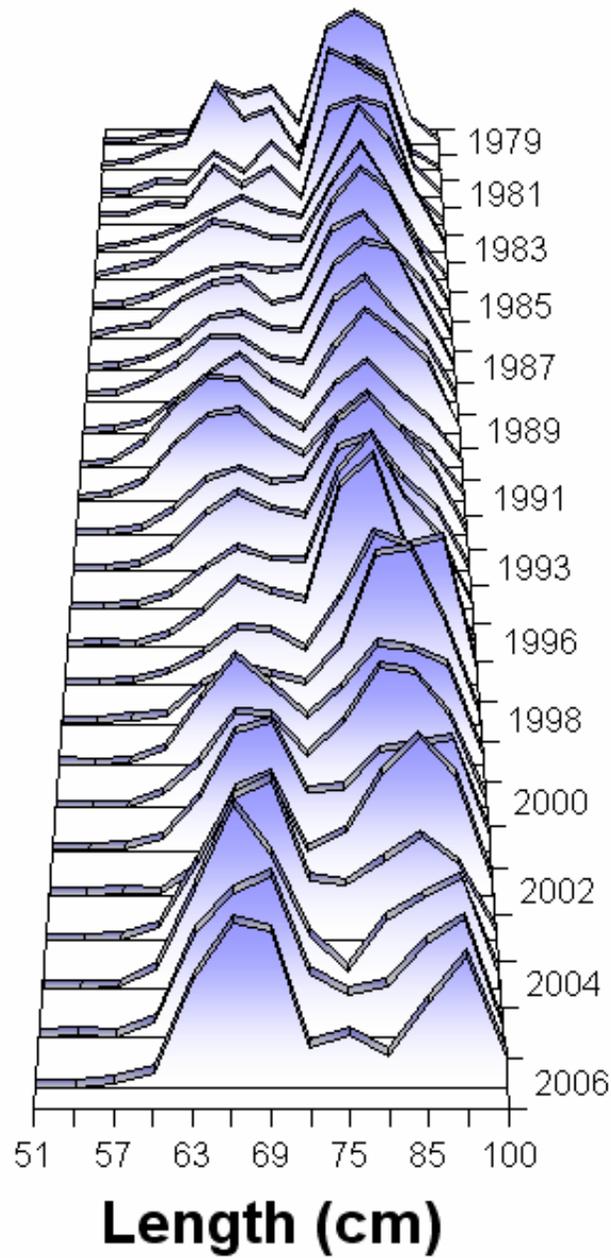
Figure 5.9.   Longline survey Greenland turbot proportions at length over time (sexes combined) as used in the model.

Average Biomass Estimates from trawl surveys (q=1)
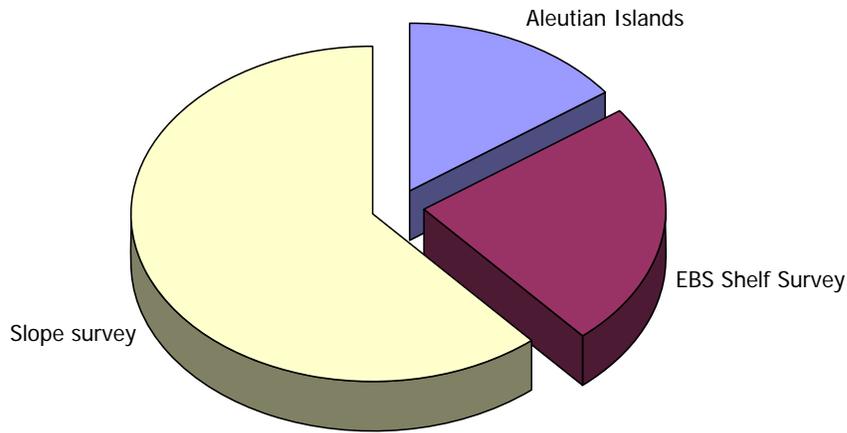
Figure 5.10.   Average Greenland turbot relative biomass from the Aleutian Islands surveys by region, 1980-2006.
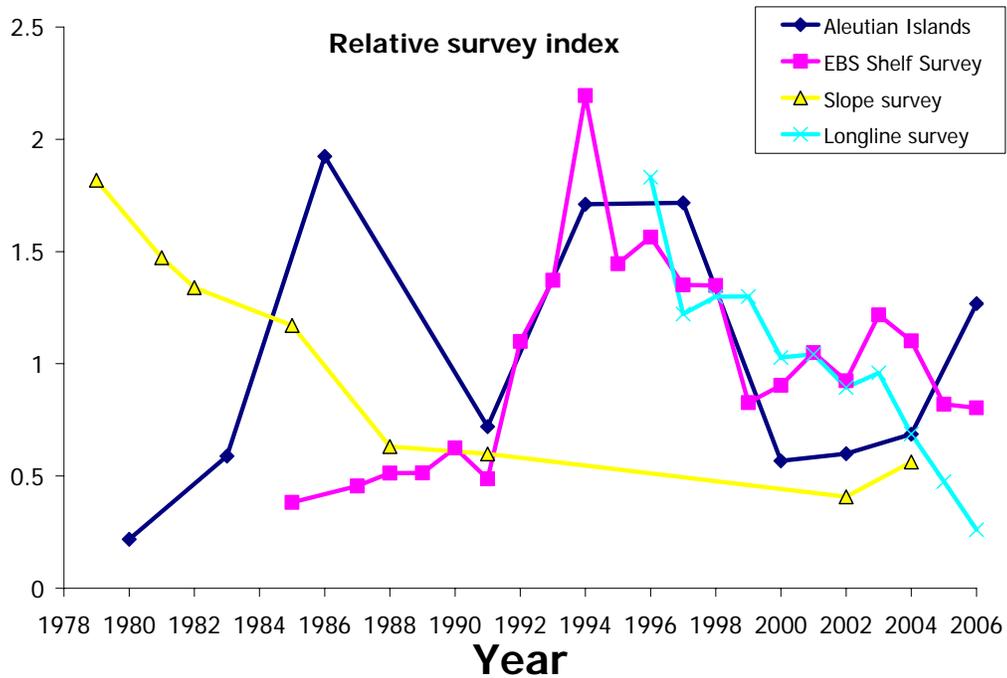
Figure 5.11.   All biomass indices available for the assessment (normalized to each have a mean value of 1.0) for Greenland turbot. Note that the Aleutian Islands survey data are not used in the model.
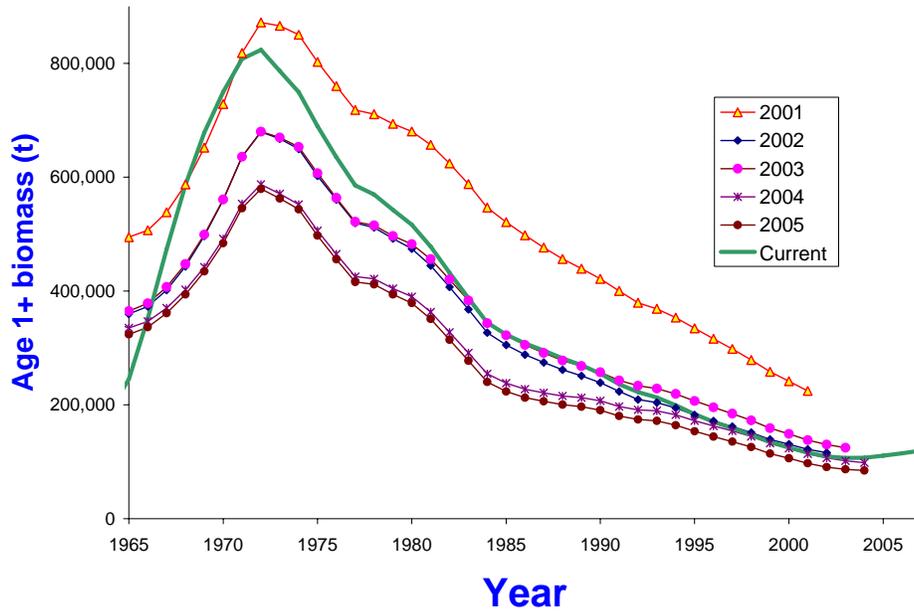
Figure 5.12   Total age 1+ biomass trend for Greenland turbot in the EBS/AI region, 1965-2007 compared to previous assessment results.
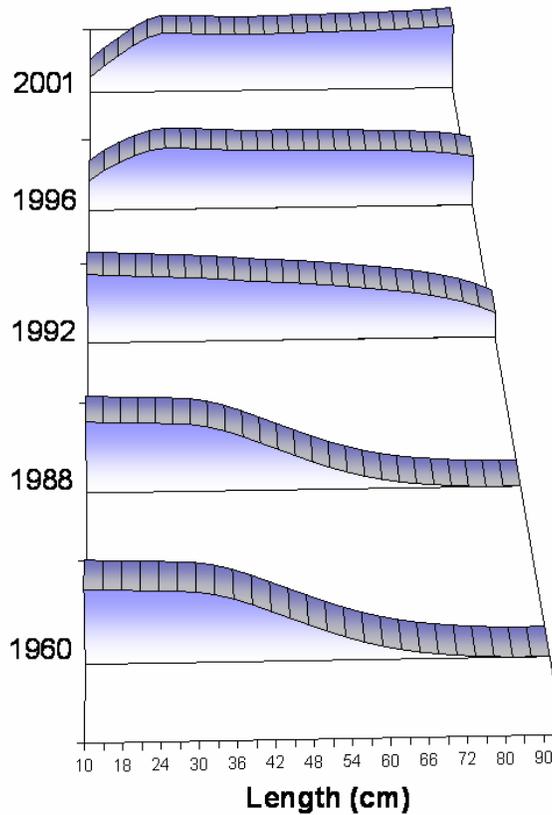
Figure 5.13.   Average size-specific selectivity patterns for EBS shelf surveys over time as estimated for female Greenland turbot. The year represents the first year in which the corresponding selectivity estimate was invoked.
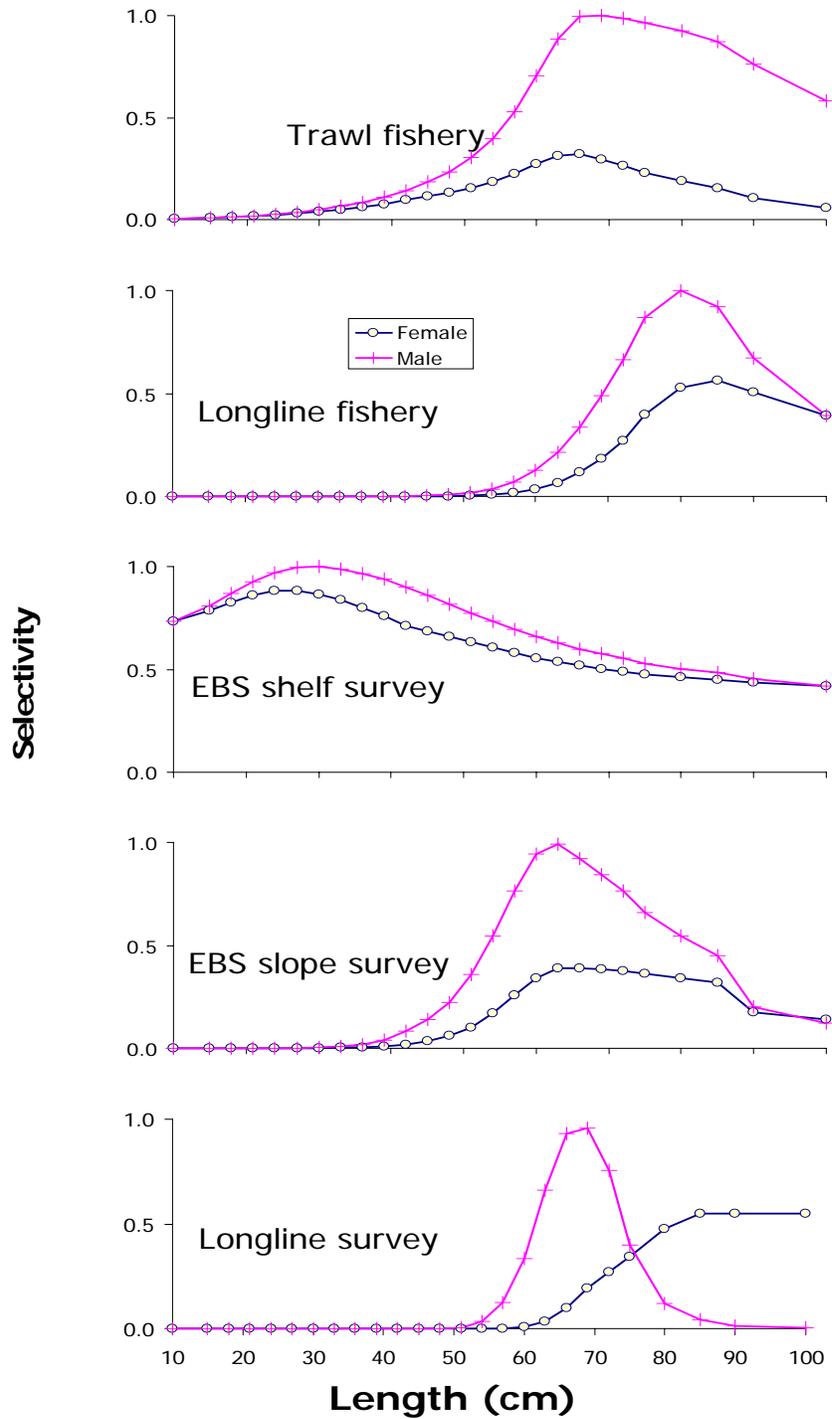
Figure 5.14.   Average (over time) size-specific selectivity patterns for all fisheries and surveys for EBS
Greenland turbot showing differences in sex-specific availability.
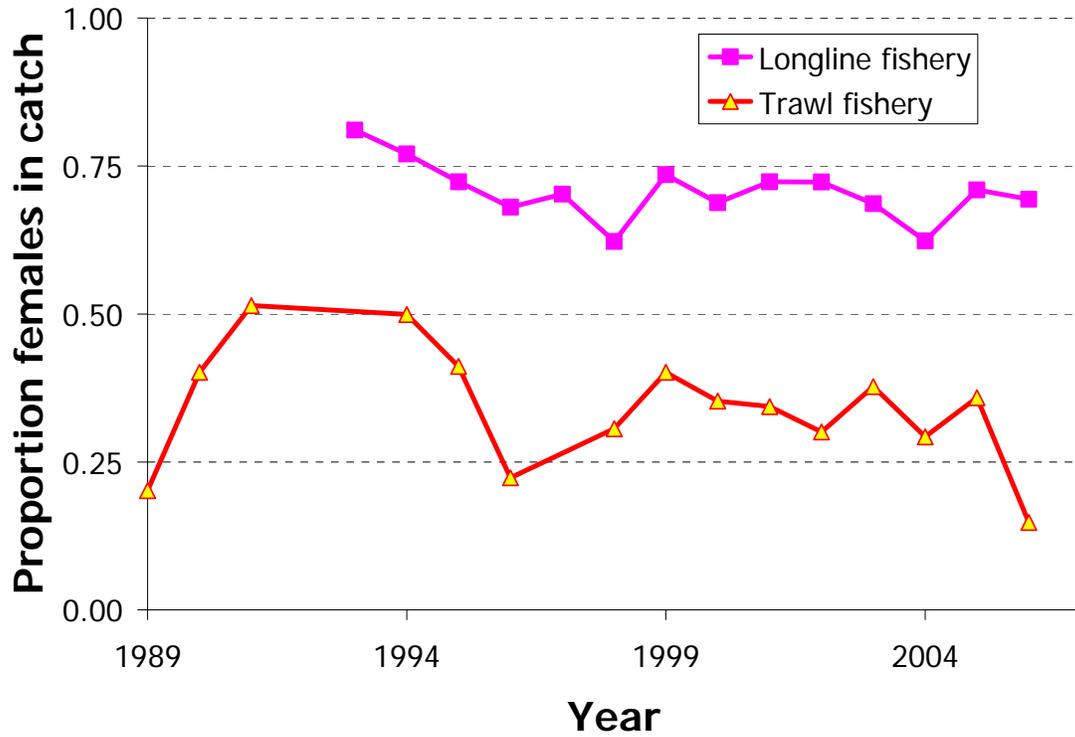
Figure 5.15.   Observed Greenland turbot sex ratio over time from trawl and longline fisheries.in the BSAI region.
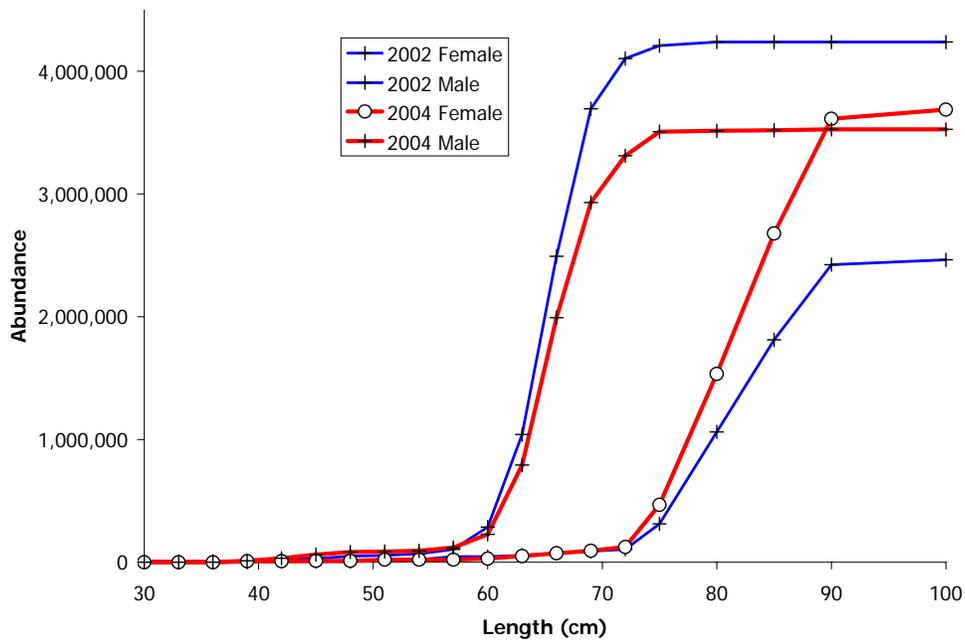
Figure 5.16.   Observed Greenland turbot sex ratio over time from trawl and longline fisheries.in the BSAI region.
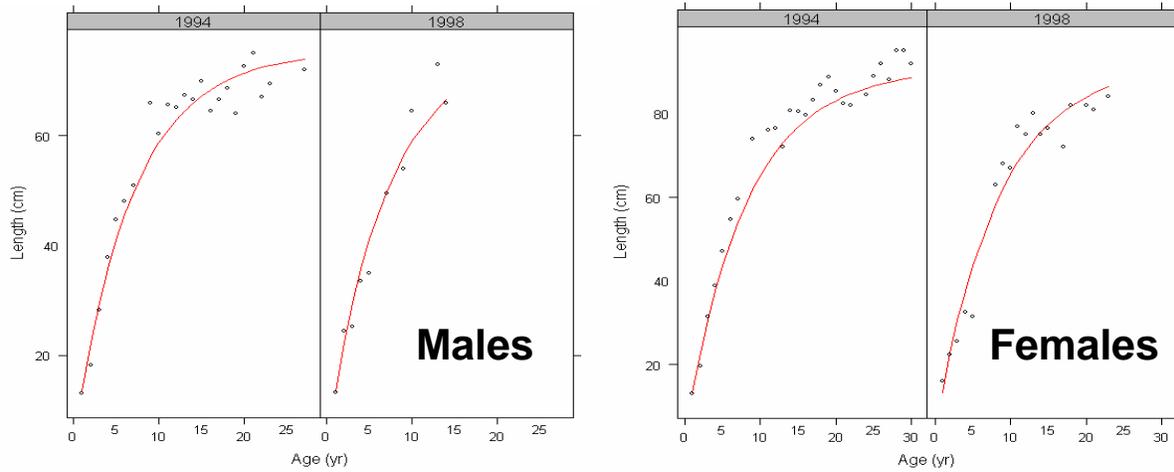
Figure 5.17.   Estimated growth (length at age) of Greenland turbot by sex in the EBS/AI region as predicted by the model and compared to the new age data using the methods of Gregg et al (2006).
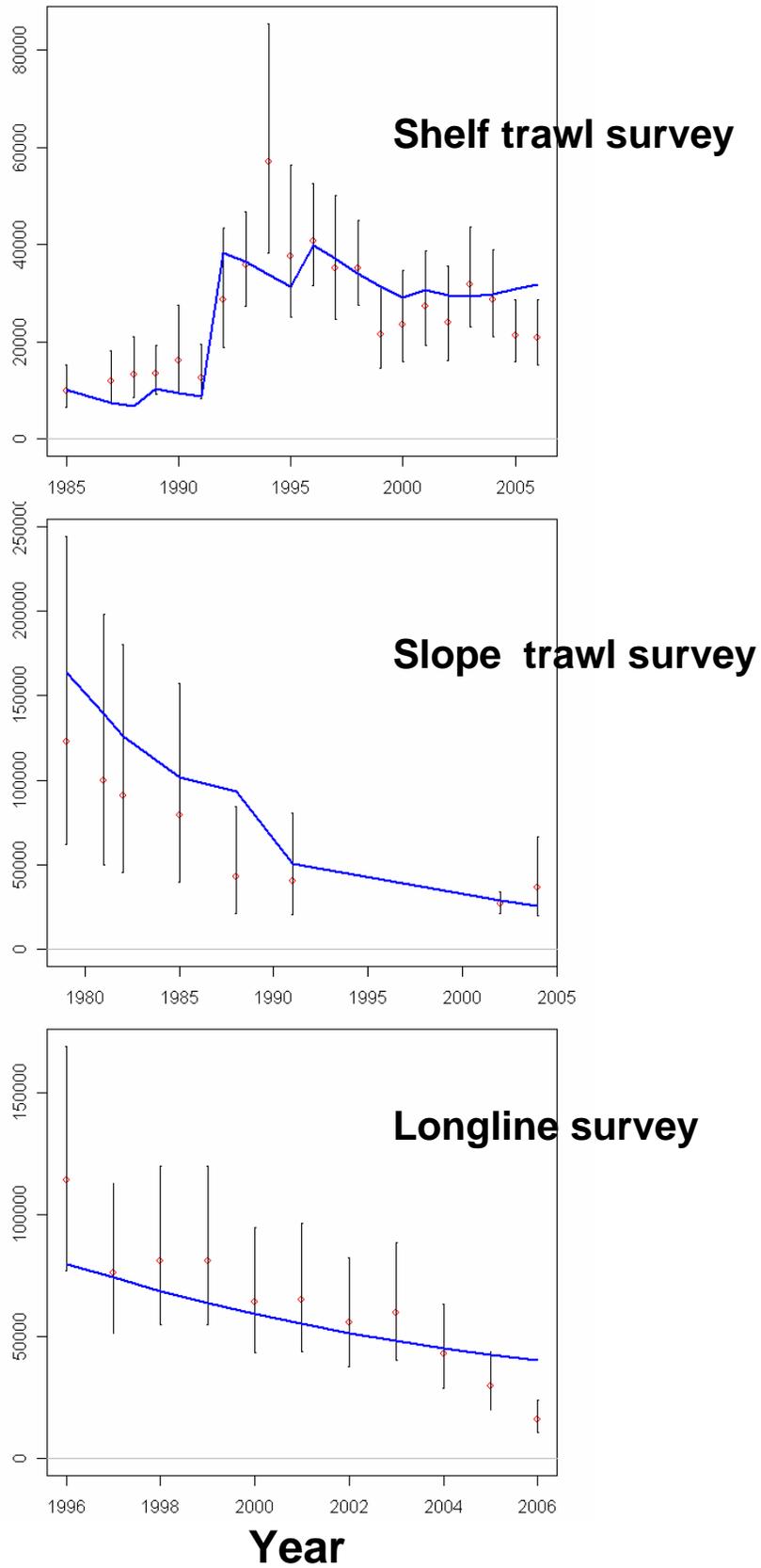
Figure 5.18.   Fits to the different survey indices for Greenland turbot in the EBS/AI region.
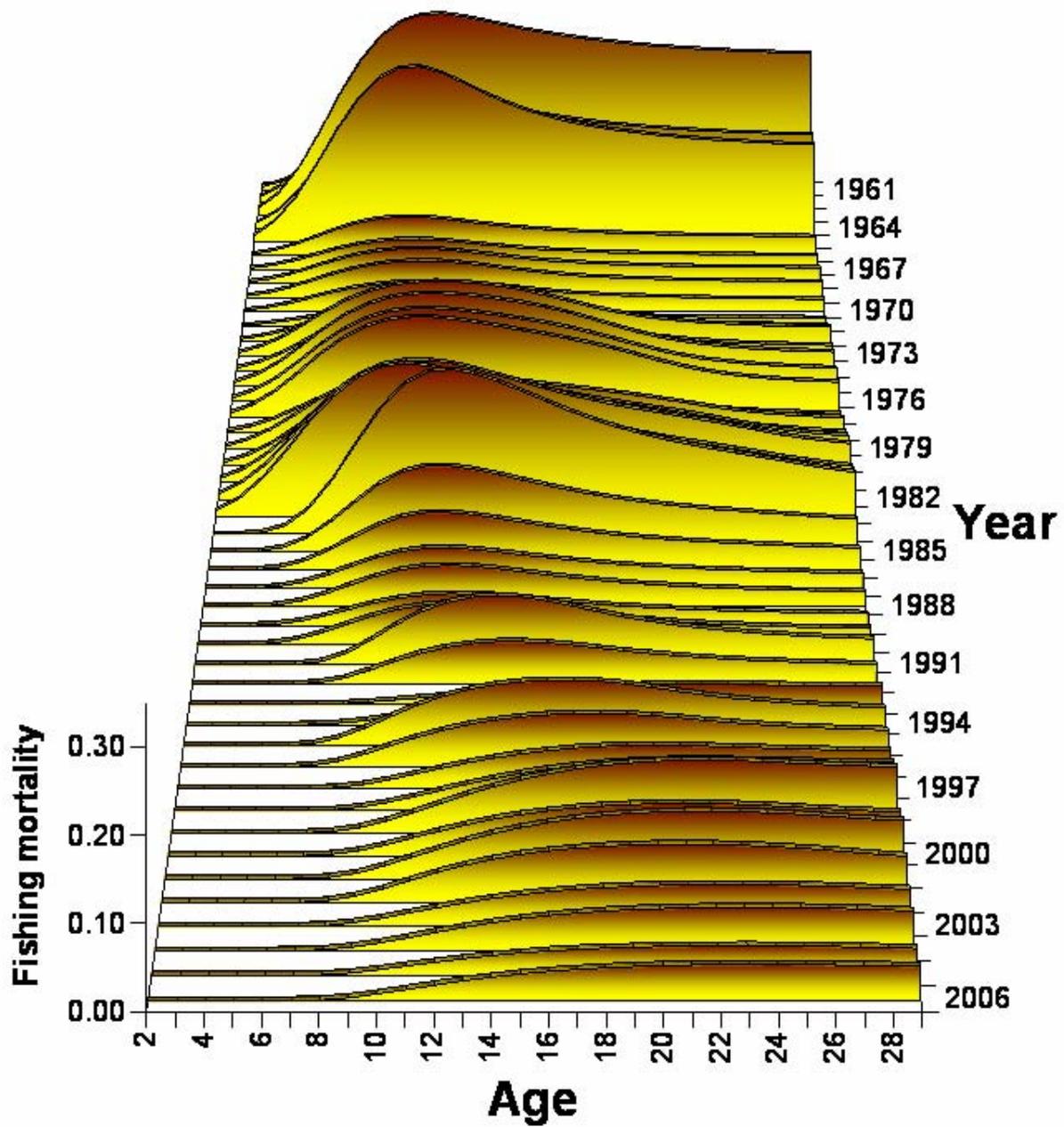
Figure 5.19.   Estimated total age-specific fishing mortality rate (gears and sexes combined) for BSAI Greenland turbot, 1960-2006.
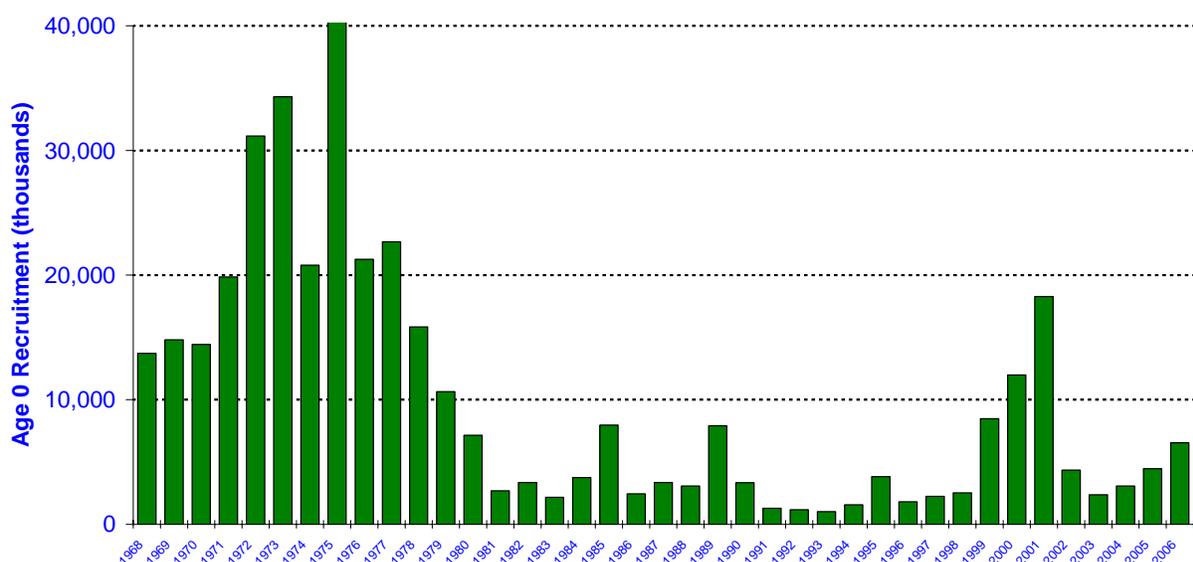
Figure 5.20.   Estimated recruitment at age 0 (thousands) for Greenland turbot in the EBS/AI region, 1968-2006.
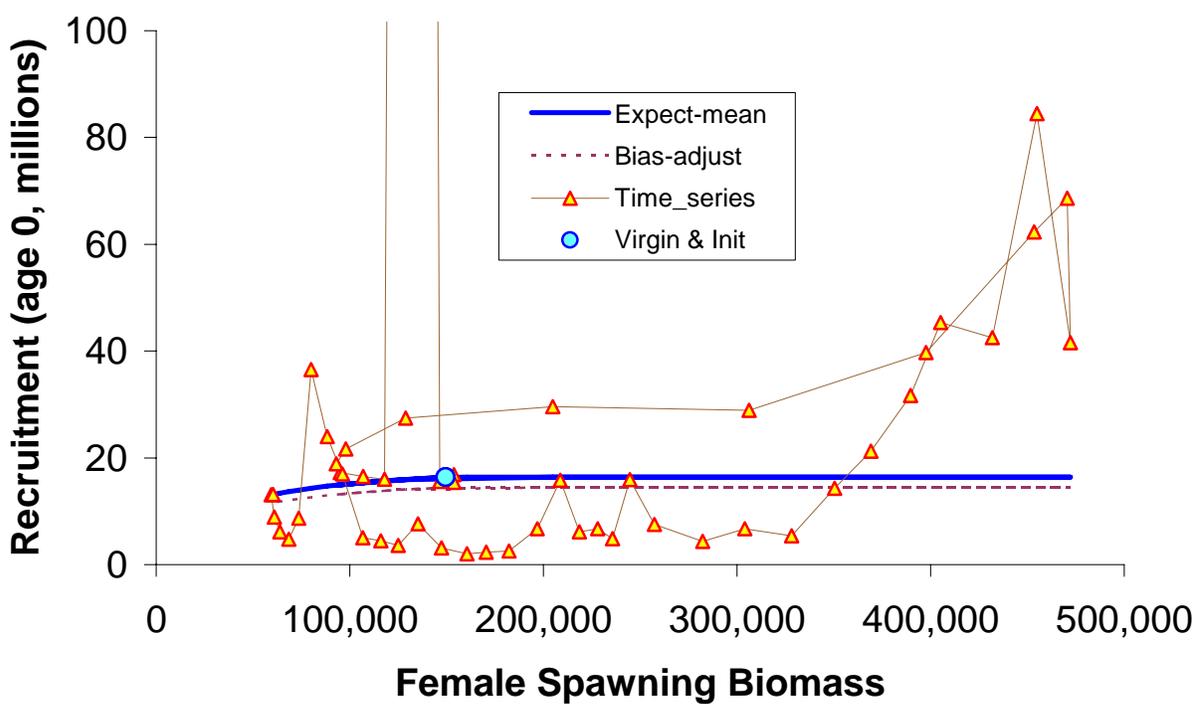
Figure 5.21.   Stock and recruitment estimates compared to fixed model shape (steepness) specified within SS2 for Greenland turbot in the BSAI region, 1960-2006.
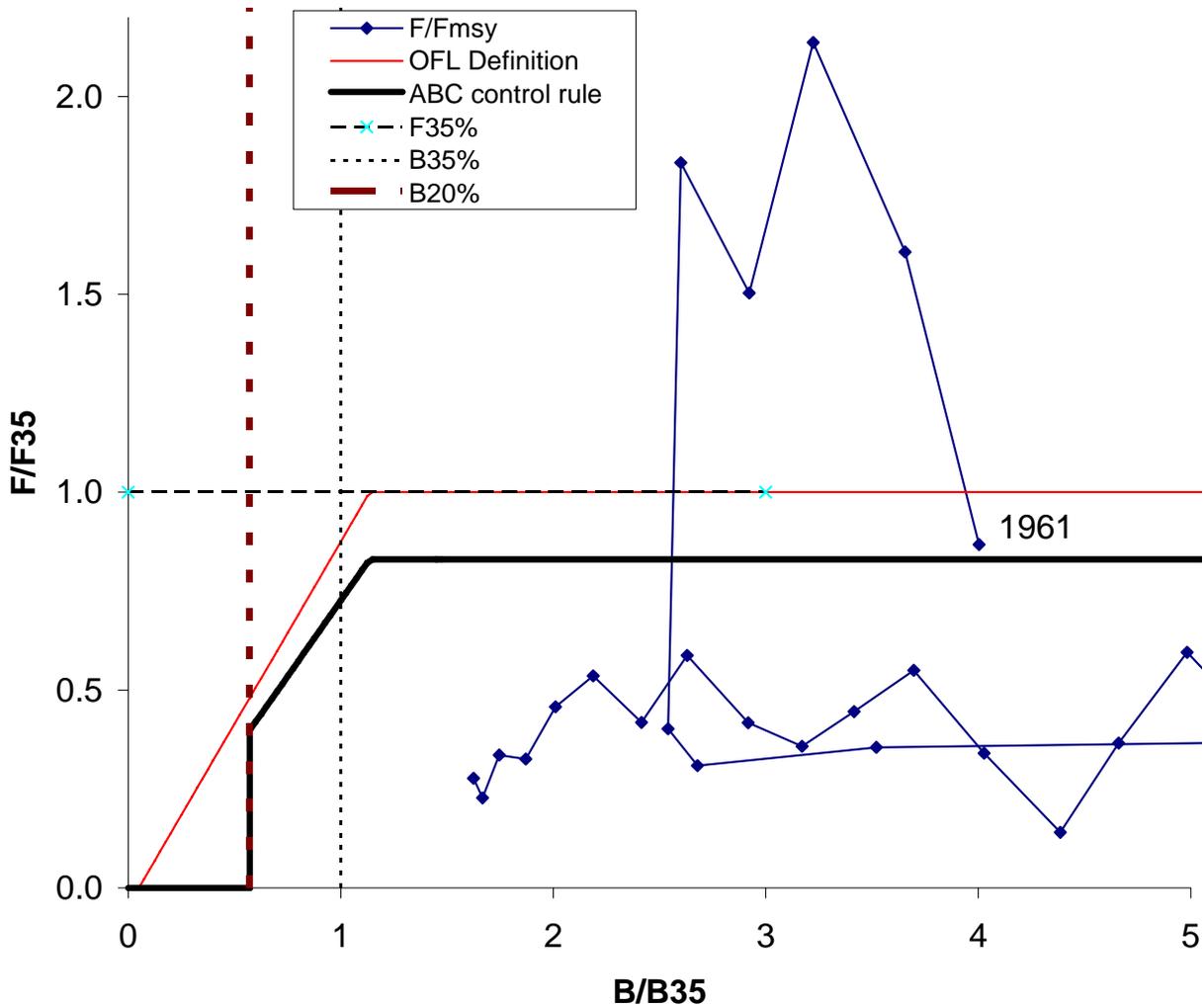
Figure 5.22. Ratio of historical F/$F_{35\%}$ versus female spawning biomass relative to $B_{35\%}$ for BSAI Greenland turbot, 1961-2006.
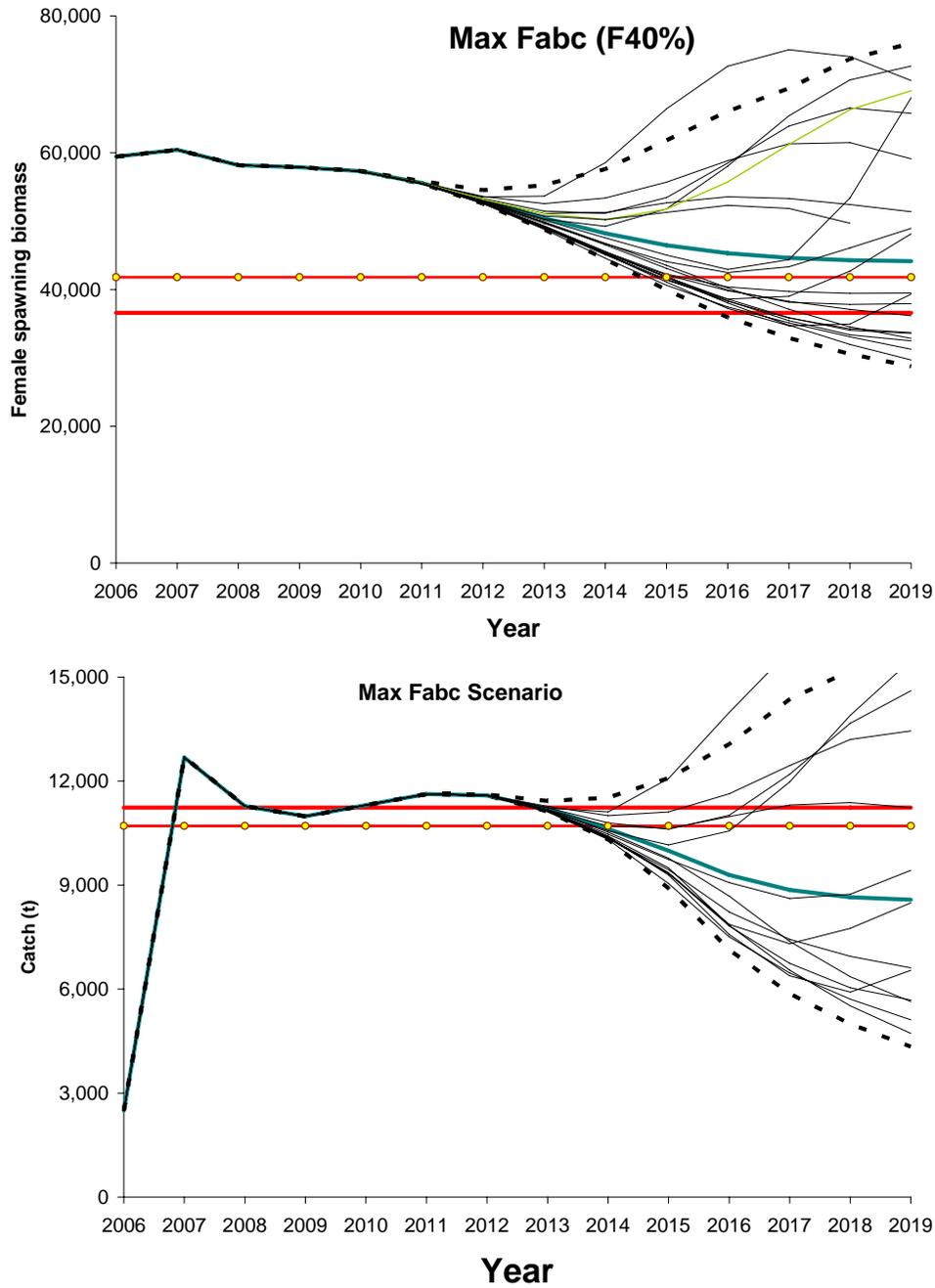
Figure 5.23. Stochastic trajectory of Greenland turbot female spawning biomass and catch for the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3 The dotted lines represent the upper and lower 90% confidence limits. Horizontal lines with marks are the values associated with $B_{40\%}$ and $F_{40\%}$ while the thick horizontal line is the expected value under constant F_{OFL} rate ($F_{35\%}$).
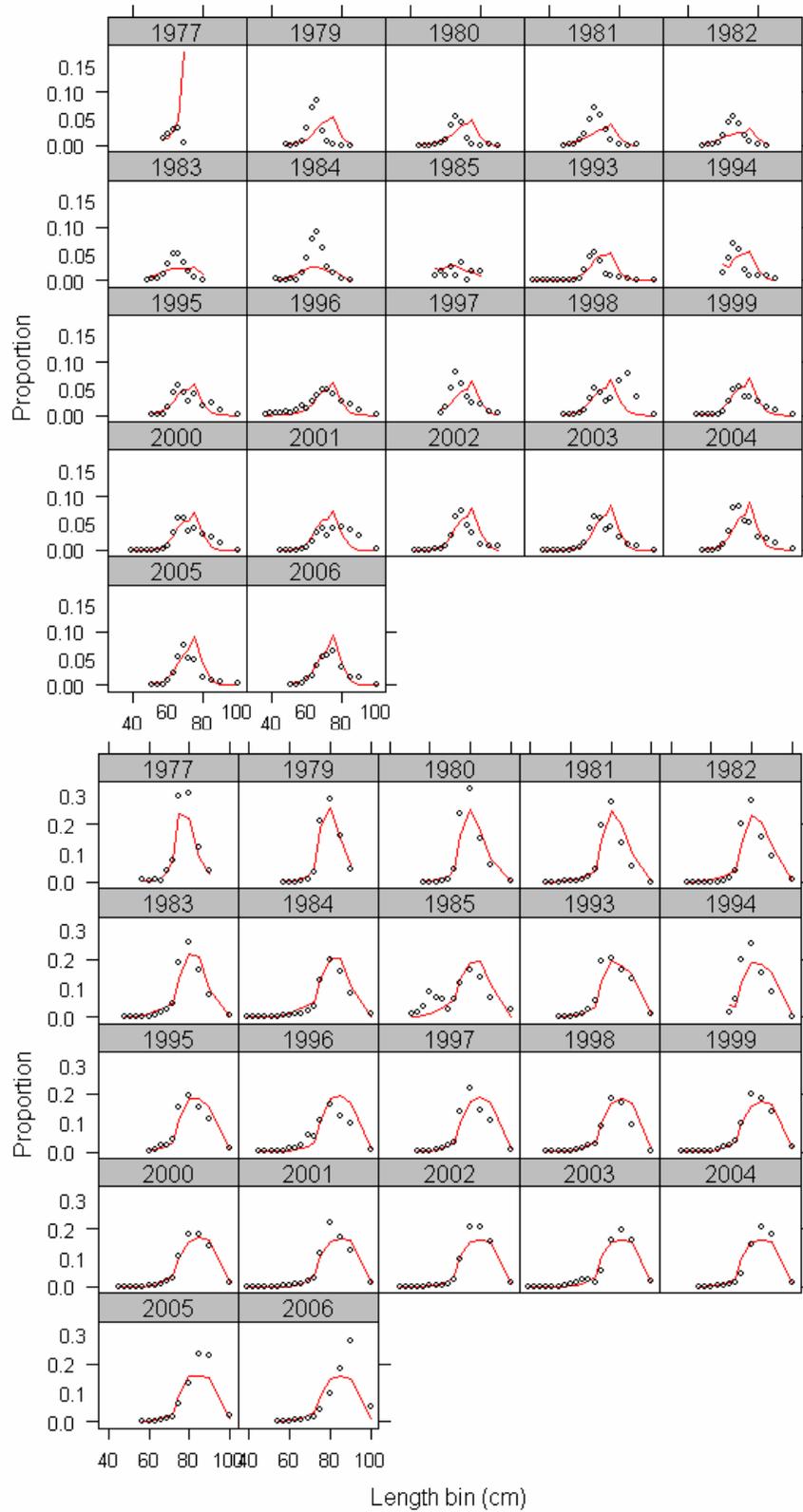
Attachment 5.1 Model fits to the size composition data
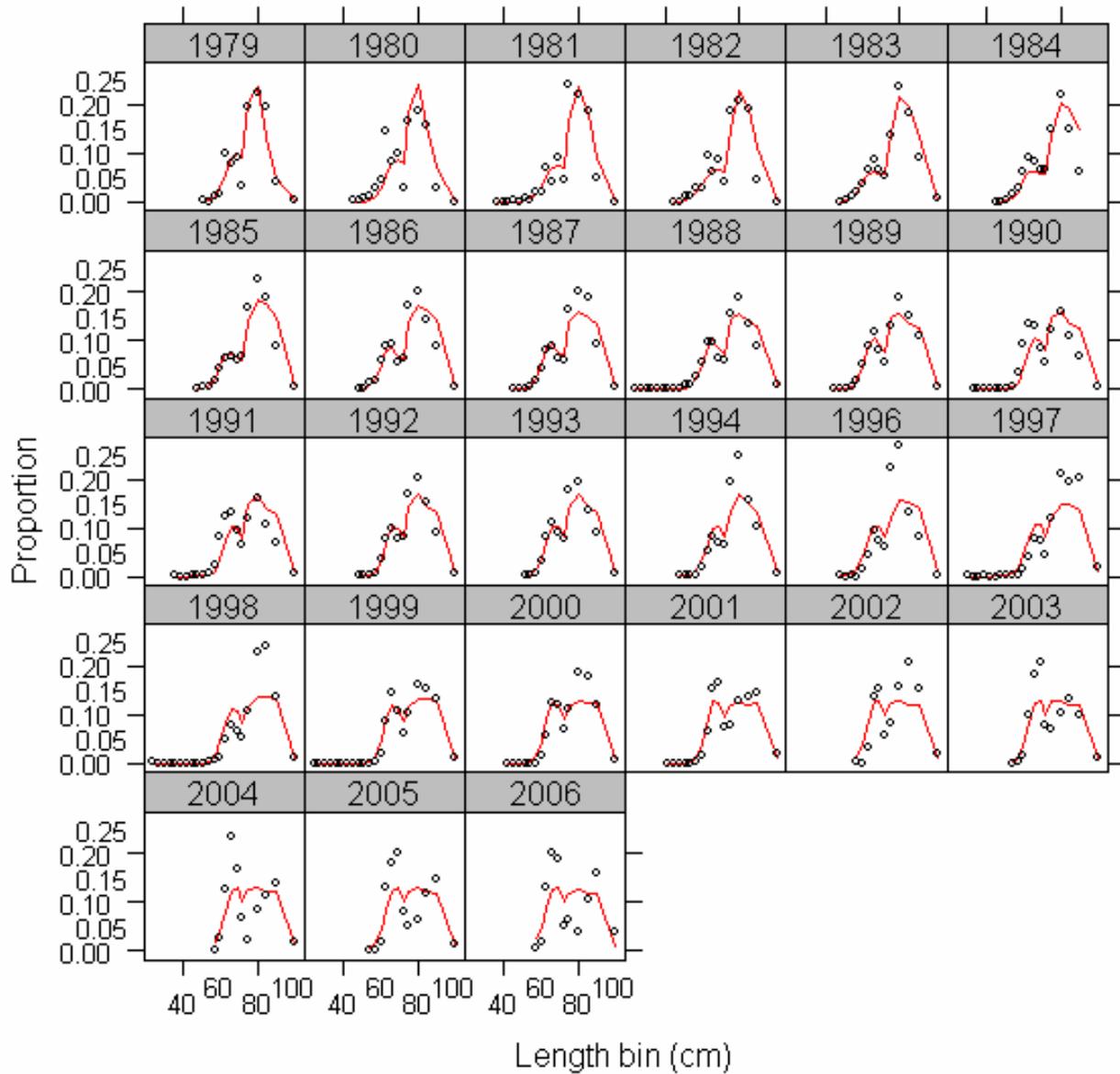
Greenland turbot model fit to longline survey length frequency data. Lines are model predictions, points are data
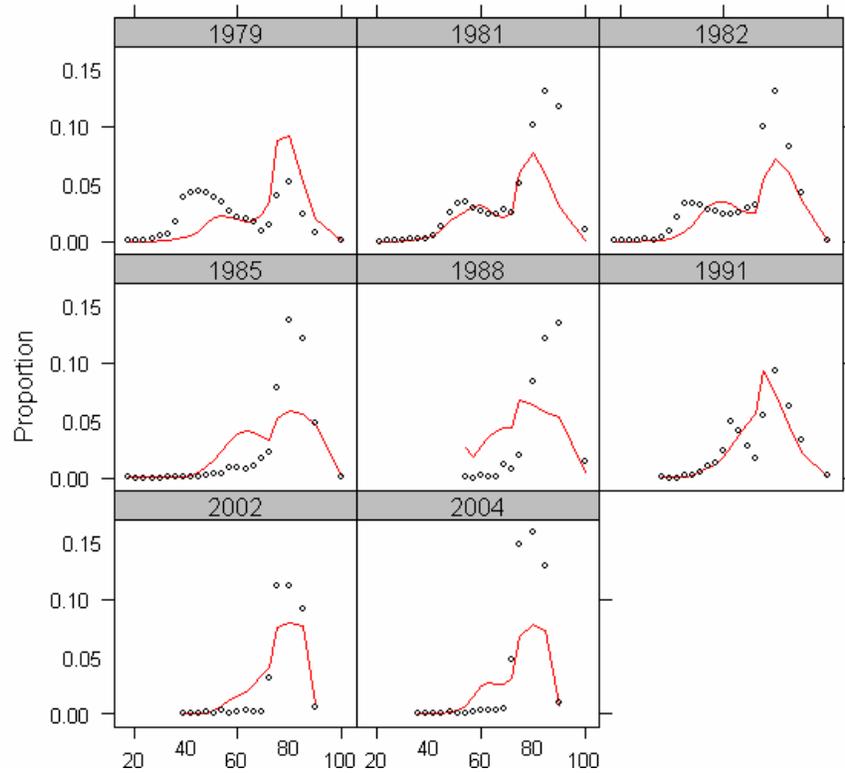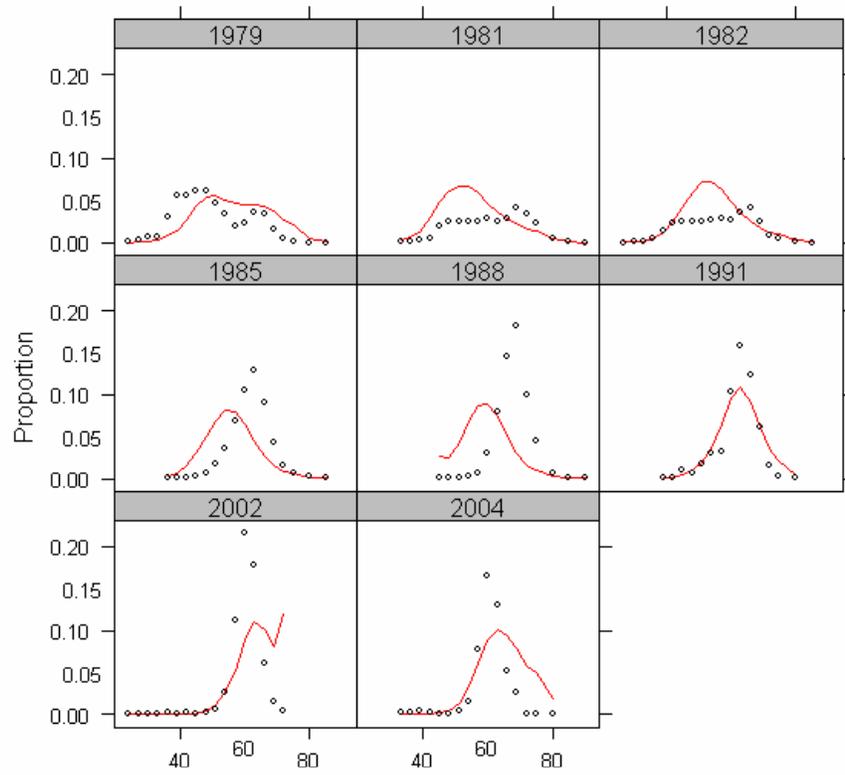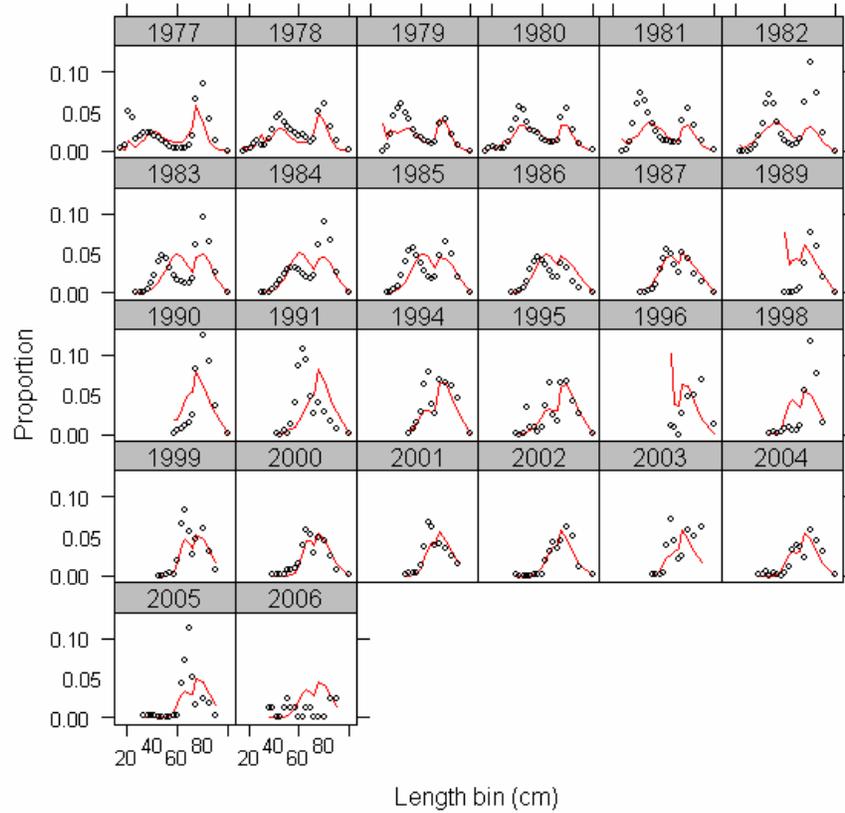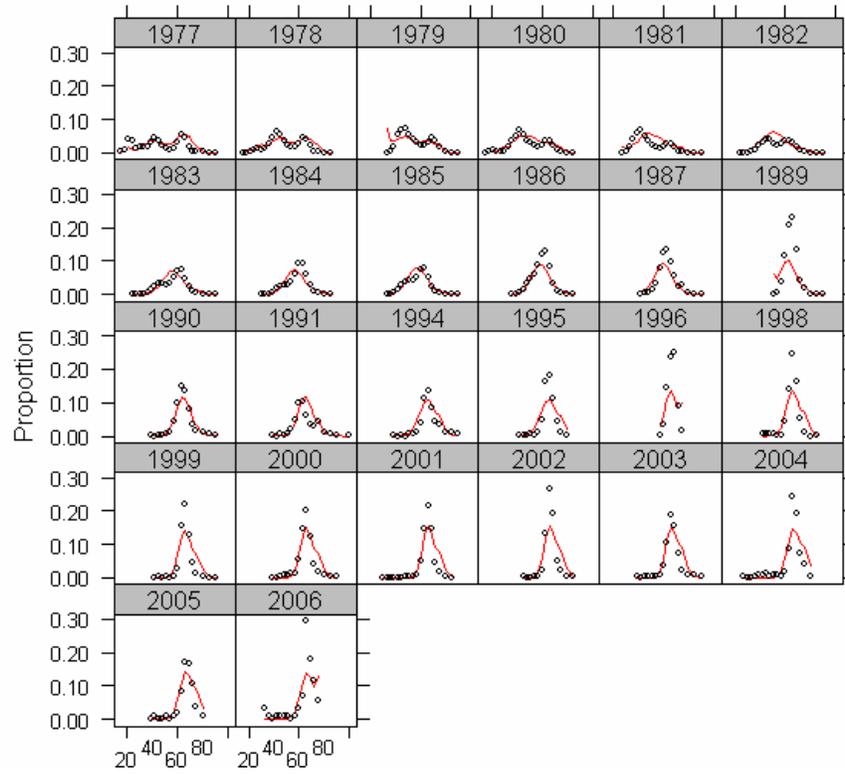
Greenland turbot model fit to EBS slope trawl survey length frequency data. Lines are model predictions, points are data
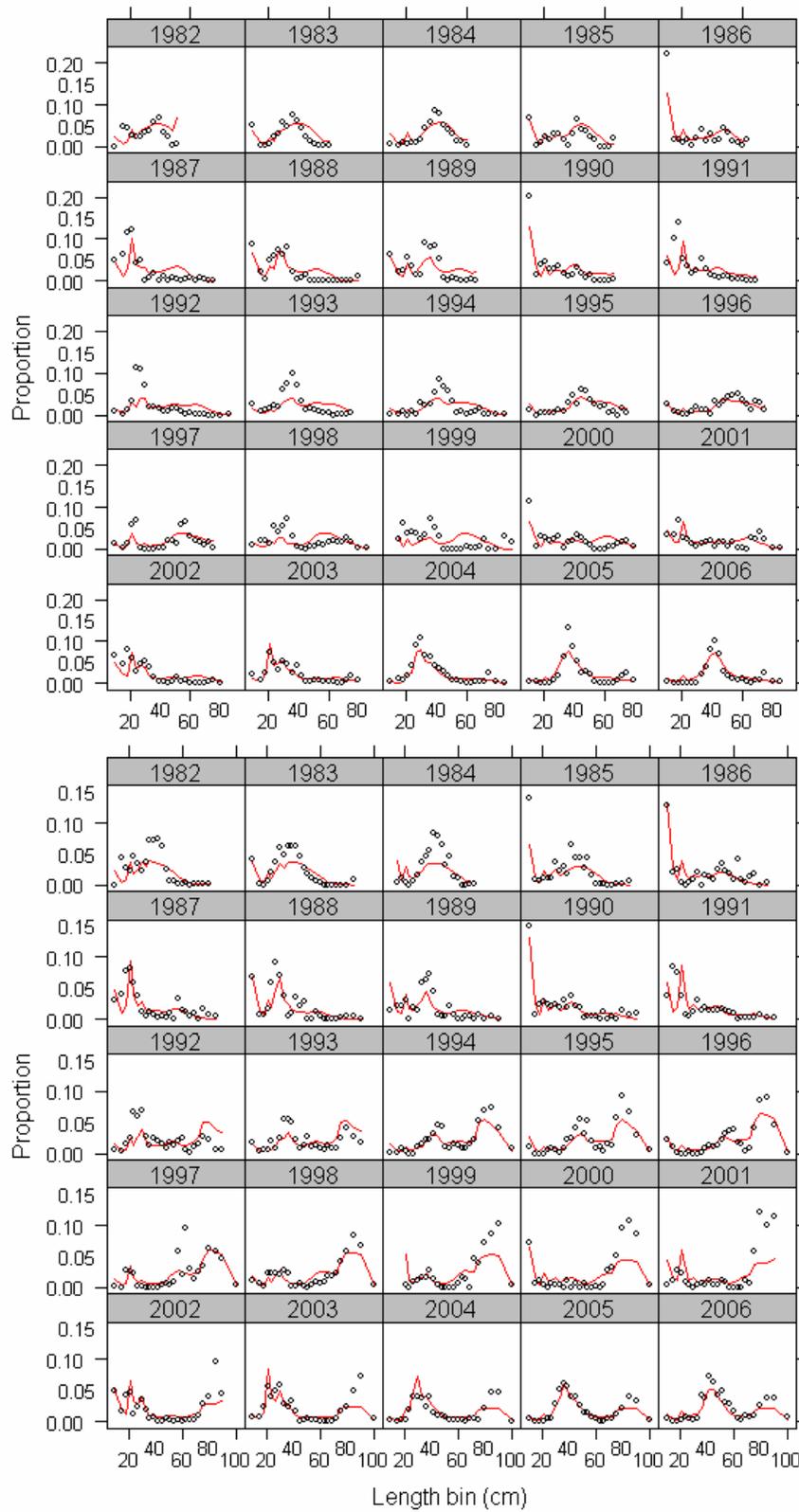
Greenland turbot model fit to EBS shelf trawl survey length frequency data. Lines are model predictions, points are data

Greenland turbot model fit to EBS longline fishery length frequency data. Lines are model predictions, points are data

Greenland turbot model fit to EBS trawl fishery length frequency data. Lines are model predictions, points are data.

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