ASSESSMENT OF GREENLAND TURBOT STOCK IN THE EASTERN BERING SEA AND ALEUTIAN ISLANDS

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Executive Summary

Changes to this year's assessment in the past year include:

1. New summary estimates of retained and discarded Greenland turbot by different target fisheries,
2. Update the estimated catch levels by gear type in recent years,
3. Incorporation of an aggregated longline survey data index from recent efforts in the EBS and AI, and
4. New length frequency and biomass data from the 2000 and 2001 NMFS eastern Bering Sea shelf survey.

Conditions do not appear to have changed substantively over the past several years. For example, the abundance of Greenland turbot from the eastern Bering Sea (EBS) shelf-trawl survey has found only spotty quantities with very few small fish that were common in the late 1970s and early 1980s. Annual catches have averaged less than 8,000 tons over the last 15 years. The assessment model developed this year used the same data as in the past, but aggregated over both sexes. The target stock size ($B_{40\%}$, female spawning biomass) is estimated at about 80,000 tons while the projected year 2002 total is about 132,000 tons. The adjusted yield projection from $F_{40\%}$ computations is estimated at 30,160 t for 2002. Given the continued downward abundance trend and no sign of recruitment to the EBS shelf, extra caution is warranted. We therefore recommend that the ABC be set to 25% of the maximum F_{ABC} value giving **8,100** tons. This low level is recommended until further information on the source of Greenland turbot production is found. Namely, whether or not recruitment to the adult slope population is still occurring even though the bottom trawl estimates of small Greenland turbot on the shelf has been at low levels since the early 1980s. In 2000 a pilot survey of the slope region was conducted. Analyses of this work has been completed and a new survey will commence in the summer of 2002.

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.

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).

4.1. 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. 4.1). 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 4.1). 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 longline fishery (in 2000) was mainly concentrated along the slope regions while the trawl fishery catch was patchier and had highest catch rates in the southeastern area (Fig. 4.2).

Table 4.1. Catches of Greenland turbot by gear type (including discards) since implementation of the MFCMA.

Year	Trawl	Longline & Pot	Total
1977	29,722	439	30,161
1978	39,560	2,629	42,189
1979	38,401	3,008	41,409
1980	48,689	3,863	52,552
1981	53,298	4,023	57,321
1982	52,090	32	52,122
1983	47,529	29	47,558
1984	23,107	13	23,120
1985	14,690	41	14,731
1986	9,864	0	9,864
1987	9,551	34	9,585
1988	6,827	281	7,108
1989	8,293	529	8,822
1990	10,869	577	11,446
1991	9,289	814	10,103
1992	1,559	1,130	2,689
1993	1,142	7,306	8,448
1994	6,427	3,843	10,272
1995	3,978	4,214	8,193
1996	1,653	4,900	6,553
1997	1,209	6,327	7,536
1998	1,829	7,295	9,124
1999	1,710	3,917	5,627
2000	1,905	4,736	6,641
2001*	2,116	3,127	5,243

* Estimate as of 10/14/01, source: NMFS Regional Office, Juneau, AK

Catch information prior to 1990 included only the tonnage of Greenland turbot retained onboard Bering Sea fishing vessels or processed onshore (as reported by PacFIN). However, Greenland turbot are also discarded overboard in other trawl target fisheries. The following estimates of discards from 1990-98 were estimated from a combination of discard rates observed from vessels with 100% observer sampling and NMFS regional office weekly processor reports.

Year	**Trawl**	**Longline**	**Total**
1990	na	Na	1,250 t
1991	na	Na	3,427 t
1992	na	Na	1,013 t
1993	na	Na	1,333 t
1994	854 t	1,858 t	2,711 t
1995	535 t	2,087 t	2,622 t
1996	354 t	1,042 t	1,396 t
1997	289 t	1,533 t	1,822 t
1998	140 t	661 t	801 t

Additional information on 1999-2001 retained and discarded catch of Greenland turbot indicates that a large fraction of discards occurred due to the sablefish fishery (Table 4.2). The proportion of discards attributed to the sablefish fishery increased from 17% in 1999 to about 40% in 2001.

Table 4.2. Estimates of discarded and retained Greenland turbot based on NMFS Blend estimates by fishery, 1999-2001 (Note: 2001 estimates as of October, 2001).

	1999			2000			2001		
Fishery	Discarded	Retained	Total	Discarded	Retained	Total	Discarded	Retained	Total
G.Turbot	227	4,009	4,236	177	4,798	4,975	89	2,724	2,813
Flathead sole	56	363	420	67	510	577	138	514	652
Sablefish	120	179	300	253	192	446	373	167	540
ATF	76	131	207	93	262	355	182	201	383
P. Cod	50	180	230	108	130	238	63	185	247
Rockfish	2	25	27	1	39	39	30	431	461
A. Mackerel	42	112	154	43	161	204	21	50	72
Others	156	127	283	48	92	139	43	92	135
Total	729	5,128	5,857	790	6,183	6,973	940	4,364	5,304

Catch and catch per unit effort (CPUE)

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.

A CPUE index derived in Alton et al. (1988) for the years 1978-84 for the trawl fishery was used as an index of abundance in the stock synthesis model:

Year	1978	1979	1980	1981	1982	1983	1984
CPUE Index	291	316	449	409	235	195	335

Ianelli et al. (1999) presented a preliminary examination of recent catch rate data based on the NMFS NORPAC observer database. Due to the short seasons for the directed fishery in recent years we concluded that these data are not reliable as an index of abundance.

Size and age composition

No age composition information is available from the fisheries or surveys. Survey size-at-age data were available from 1975, 1979-1982. These data are used to establish the length-age (and variability in length-at-age) within the stock assessment model. 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 a later section titled “Model evaluation” (Fig. 4.8). 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.

4.2. Resource Surveys

Abundance estimates for juvenile Greenland turbot on the EBS shelf are provided annually by AFSC trawl surveys. The older juveniles and adults on the slope were assessed every third year from 1979-1991 (also in 1981) during U.S.-Japan cooperative surveys. 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 surveyed the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side trawl experiments with the Miller Freeman for calibration purposes. Due to limited vessel time, the area and number of stations sampled by the Miller Freeman was less than sampled by the Japanese trawlers in most 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 200-1,000 m (Table 4.3).

We believe that the U.S. and Japanese trawl slope-surveys under-estimate the actual biomass of Greenland turbot when swept-area expansions are made. Thus, we treat these as indices of relative abundance. That is, 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.

The AFSC will institute a bottom trawl survey of the upper continental slope of the eastern Bering Sea in 2002. This survey will be conducted biennially. The benthic resources of the eastern Bering Sea continental slope have been explored with bottom trawls in prior years (1979-1991). The 2002 survey will initiate a time series of trawl survey results that will provide information on abundance trends and trends in the biological condition of the groundfish and invertebrate resources in that habitat.

A pilot survey was conducted during the summer of 2000 to gain familiarity with the survey area and any challenges that the continental slope might pose. For the pilot survey we used one vessel for 35 days to make two trial tows at each station with Poly Noreastern trawls rigged with two different trawl footropes—a mudsweep footrope used successfully on the Washington-California continental slope and a rough-bottom rockhopper footrope designed to enable trawling over much rougher bottom. Because of the short duration of the field work and the need to fish each station twice, the number of stations that were sampled is approximately 25% of the total expected sample when the survey is fully implemented. For this reason, 2000 survey estimates are not considered reliable for stock assessment abundance estimation.

The combined estimates from the shelf and slope indicate a decline in EBS abundance for the 4 years of observations that were available during 1979-1985. After 1985, the slope biomass estimates (and the 1991 Aleutian Islands estimate) are not comparable to previous years due to differences in depths sampled. The interpretation of the CPUE data from these surveys, however, suggests a moderate decline in abundance between 1985 and 1991. The average shelf-survey biomass estimate during the last 9 years (1993-2001) is 29,968 tons with a declining trend during this period.

The following table summarizes the sampling that has occurred for the EBS bottom trawl survey data since 1982:

Year	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
No. hauls	329	354	355	353	354	342	353	353	352	351
No. Lengths	969	951	536	196	195	82	200	183	232	360
Year	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
No. hauls	336	355	355	356	355	356	355	353	352	355
No. Lengths	440	400	398	313	297	197	93	207	248	274

Biomass estimates from U.S.-Japan cooperative surveys in the Aleutian Islands region suggest an increasing trend from 48,700 t in 1980 to 76,560 t in 1986 (the 1991 estimate is not directly comparable). Relative to the trend in the EBS, the apparent increased abundance in the Aleutian Island Region may be due to migration of older fish from the EBS. In 1997 NMFS AFSC conducted a triennial bottom-trawl survey of the Aleutian Islands region using methods described in Harrison (1993). The preliminary area-swept estimate of biomass from this survey is 32,027 tons. This compares with a value of 29,106 tons estimated from the 1994 survey. Examining the distribution of where the survey found Greenland turbot in the Aleutian Islands reveals similar patterns between the 1994 and 1997 surveys.

Previously, the eastern Bering Sea Cooperative longline survey was incorporated for use as a relative abundance index. This survey covered a larger portion of the slope and shelf area than the present longline survey. A bootstrap resampling scheme was used to provide confidence bounds on the annual relative abundance estimates. We used the median values of the bootstrap estimates as our relative population index. This index represents numerical abundance whereas the shelf and slope surveys represent biomass indices. We continue to work on methods of incorporating recent domestic longline surveys which, beginning in 1996, have been extended 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 slope regions is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands compared to the abundances along the slope of the EBS:

Relative Population No. (RPN)	**Year**					
Area	1996	1997	1998	1999	2000	2001
Bering 4		11,729		13,072		16,082
Bering 3		6,172		6,156		5,005
Bering 2		27,936		33,848		24,766
Bering 1		13,491		10,068		4,788
NE Aleutians	23,133		17,120		12,987	
SE Aleutians	2,142		1,806		1,201	
Bering Sea		59,328		63,144		50,641
Aleutians	25,275		17,930		14,188	
Combined	101,512	78,997	72,010	84,078	56,984	67,430

The combined time series shown above (1996-2001) was used this year as a relative abundance index (Fig. 4.3). It was computed by taking the average RPN from 1996-2001 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 are given here by each area as: p^{AI} and p^{EBS} .

Table 4.3. Survey estimates of Greenland turbot biomass for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2001.

	Eastern Bering Sea			Aleutians
Year	**Shelf**	**Slope**	**Shelf and Slope Combined**	
1975	126,700	---	---	---
1979	225,600	123,000	348,600	---
1980	172,200	---	---	48,700
1981	86,800	99,600	186,400	---
1982	48,600	90,600	139,200	---
1983	35,100	---	---	63,800
1984	17,900	---	---	---
1985	7,700	79,200	86,900	---
1986	5,600	---	---	76,500
1987	10,600	---	---	---
1988	14,800	42,700*	57,500*	---
1989	8,900	---	---	---
1990	14,300	---	---	---
1991	13,000	40,500	53,900*	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	37,271***	---	9,452**
2001	25,311	---	---	---

* The 1988 and 1991 estimate are from 200-800 m whereas earlier (and 2000) slope estimates are from 200-1,000 m.
** The 1980, 1983, and 1986 surveys sampled 1-900 m whereas the 1991, 1994, 1997, 2000 surveys sampled only 1-500 m.
*** Based on a preparatory survey using mudsweep footrope. These data were not used in the assessment model. See text for further details.

A time series of estimated size composition of the population was available for the shelf and slope trawl surveys and for the longline survey. These are presented in the form of estimated length frequencies of the population vulnerable to the survey sampling gear. 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 time series of length frequencies from the longline survey was presented in Ianelli et al. (1994). The Greenland turbot size composition from the 2001 shelf trawl survey is given in Fig. 4.4. For data from other years refer to Fig. 4.8 (showing data and model fits).

This year, 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 (in tons):

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
NMFS Bottom trawl surveys	62.48	48.36	103.01	123.6	15.14	0.73	175.22	72.84	0.56	18.48
Domestic Longline surveys	NA									
Cooperative Longline surveys	3	3	6	11	9	7	8	7	11	6
Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
NMFS Bottom trawl surveys	0.64	0.85	11.37	0.88	1.43	8.51	1.44	1.47	4.64	1.38
Domestic Longline surveys										
Cooperative Longline surveys	16	10	10	22	23	23				

4.3. Model Structure

The use of the stock synthesis program (Methot 1990) to model the eastern Bering Sea component of Greenland turbot stock was presented in previous assessments (Ianelli et al. 1994, 1995). Before 1994, stock assessments of Greenland turbot in the eastern Bering Sea and Aleutian Islands have relied in part on stock reduction analysis (SRA) to provide historical trends in the fishery (Wilderbuer and Sample 1992). This year efforts were begun to simplify the model used for Greenland turbot. A functional, two-fishery combined-sexes model is complete and appears to have the same general patterns of recruitment and abundances when fit to the same length and survey indices. However, further model specification issues need to be addressed before it can be used extensively. For example, inconsistencies with the data seem to become more obvious. Thus, we feel that more consideration of how the data are used is needed before an appropriate model can be developed. As with past years, the length-version of the stock synthesis program (Methot 1990) was used for this assessment. Catch data used in the stock synthesis model were from 1960 to 2001. The last eight years were adjusted to include discards. 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 are estimated by maximizing the log likelihood (L) of the predicted observations given the data. Data are classified into different components. For example, age composition from a survey and catch per unit effort (CPUE) from a fishery are different components. The total L is a sum of the likelihoods for each component. The total L may also include a component for a stock-recruitment relationship and penalty functions to help stabilize parameter estimates. The likelihood components may be weighted by an emphasis factor. For Greenland Turbot in the EBS the model included two fisheries, those using longline and trawl gear, and three surveys. Table 4.4 summarizes the extent of the data used in the different likelihood components.

Table 4.4. 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	1975, 1979-82
Shelf Survey: size composition and biomass estimates	1979-2001
Slope Survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91
Longline Survey: size composition and abundance index	1996-2001
Total Fishery Catch Data	1960-2001
Trawl CPUE Index	1978-1984
Trawl Catch Size Composition	1977-87, 1989-91, 1993-2001
Longline Catch Size Composition	1977, 1979-85, 1992-2001

The stock synthesis model allows for several forms of underlying stock-recruitment relationships. We chose the Beverton-Holt (1957) form as parameterized by Kimura (1988). Because annual recruitments are estimated as parameters in the model, they can be thought of as “anomalies” from the underlying stock-recruitment curve. These recruitment anomalies can be due to process and observation errors. Process errors refer to the real differences from the mean stock-recruitment curve caused by natural variation in recruitment success. Observation errors refer to our ability to estimate the true recruitment levels due to sampling problems. In this application, observation error is considered negligible compared to the magnitude of recruitment variability (process error). Consequently, the underlying parameters of the stock-recruit curve play an insignificant role in fitting the model to the data. A series of stochastic recruitment were used for the projections (described below). For further details on the model specifications of the length-version of the stock synthesis program, see Thompson *et al.* (Pacific cod chapter, this volume).

Selectivity Patterns

A dome-shaped size-based selectivity function (Methot 1990) 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, we treated the foreign and domestic trawl data as from a single fishery and simply let the selectivity pattern be different between the respective periods. Because larger fish have been observed in the recent EBS shelf region trawl surveys, selectivity was also was estimated separately for two periods: 1994-present and 1982-1993.

4.3.1. Parameters estimated independently

Natural mortality, length at age, length-weight relationship

The natural mortality of Greenland turbot was assumed to be 0.18. This estimate was used because it is slightly less than that of other flatfish species with a slightly lower maximum age. Greenland turbot taken by the commercial fishery have been aged as old as 21 years.

Parameters describing length-at-age are estimated within the model. We do assume that the length at age 1 is the same for both sexes and that the variability in length at age 1 has a 8% CV and that the variability in length at age 21 has a CV of 7%. This appears to encompass the observed variability in length-at-age.

As in the previous assessments, size-at-age information from surveys conducted between 1976-82 were used in the model to help estimate the relationship between age and length. The length-weight relationship for Greenland turbot estimated by Ianelli et al. (1993) was:

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

and

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

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

Maturation and fecundity

Maturation and fecundity by size or age is poorly understood for Greenland turbot. Alton *et al.* (1988) present the results from studies of Greenland turbot in different areas in addition to the EBS region. For this analysis, we have chose a logistic size-maturity relationship which has 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.

4.3.2. Parameters estimated conditionally

The key parameters estimated within the model include:

- Annual recruitment estimates from 1960-1996 (1965-1969 aggregated to have a single mean value),
- Selectivity parameters for the 2 fisheries, and 3 surveys,
- Growth parameters: 5 parameters (2 for each sex, one in common),
- Parameter that scales the expected value of recruitment, and
- Effective effort-fishing mortality rates (solved by matching predicted catch biomass to the observed catch biomass exactly), 1960-2001.

4.4. Model evaluation

Size composition data are not available until 1977 hence we are unable to resolve recruitment strength information during the early period (1960s) with the model. Initially, we set the individual recruitment estimates from 1960-69 equal to that predicted by an equilibrium stock-recruitment relationship. This yielded a poor fit to the size composition data and estimated a virgin recruitment level that gave the mean unfished biomass more than 1.8 million metric tons. When all recruitment deviations were estimated (the full model), a single large deviation resulted in the early part of the time series. This indicated a year class more than an order of magnitude greater than the mean estimated recruitment since 1970. Both the full model and the equilibrium recruitment models were therefore unsatisfactory. To compensate, we pooled recruitment deviation estimates from 1965-69 as in Ianelli et al. (1993).

Initial model configurations with the shelf survey biomass estimates treated as an absolute abundance index and the slope survey as a relative index gave unreasonable biomass levels. The best fit occurred when the slope abundance index represented only about 5% of the biomass available to the slope survey. That means that a slope survey biomass estimate of 50,000 tons would expand to 1,000,000 tons of actual biomass available. This value of "Q" or catchability for the slope survey is unreasonably low compared to values of Q common for other flatfish species. Consequently, we investigated the effect of different fixed values of slope survey Q on the fit to individual data components. Results from this exercise indicate that the majority of the likelihood components were consistent with a low Q value for the slope survey, but that the likelihood surface was relatively flat with respect to Q (Ianelli et al. 1993). For this year's assessment, we selected the conservative model (where slope-survey catchability is fixed at 0.75).

Trends in Abundance

The fits to the abundance indices are given in Fig. 4.5. The assessment model predictions for shelf survey biomass are far below the observed estimates during the early years and subsequently track the survey estimates well. These data are consistent with the conclusion of Alton et al. (1988) that recruitment of juveniles in the EBS has been low since the early 1980s. The reason that the model fits the early period of the shelf trawl survey index poorly is because such high levels of recruitment are inconsistent with observations of numbers of older fish later in the time series. The overall trend for the slope survey estimates is mimicked by the assessment model, but indicates biases based on the fixed Q values used in each model for the slope survey. The general trend of the longline survey index shows increasing numbers while the model predicts declines. The failure to fit the apparent increasing trend from the longline survey data with the model reflects the relatively large standard errors associated with this index. If we increase the model emphasis on the survey longline trend, the fits to the other surveys degrades considerably (Ianelli et al. 1995). The effect of high emphasis on the longline survey (increasing biomass trend) would indicate a much higher level of current spawning biomass.

The biomass of Greenland turbot has roughly doubled during the 1970s from the early 1960s level and is currently about half of the unfished level. The 2001 total beginning of the year biomass (age 1 and older) estimate is about 250,000 (with slope survey Q set to 0.75; Fig. 4.6). In past years, extra caution has been exercised in setting harvest levels of Greenland turbot because of the lack of recruitment success in recent years. For this reason, we selected the conservative assumption to have Q for the slope survey set equal to 0.75 for our ABC recommendations. It should be noted that the slope survey biomass estimates do not include the biomass estimates from the Aleutian Islands, which averages about one fourth to one third of the total population biomass. It is therefore very likely that the biomass estimates from this model configuration are biased towards low values. The historical fishing mortality rates (combined gears) increased over time and was highest in 1981 through 1983 (Table 4.5). The effect of different models on historical biomass levels is also presented in Table 4.5. The estimated historical numbers at age is given in Table 4.6.

Table 4.5. Historical fishing mortality rates (combined gear types), female spawning biomass, and beginning of year age 1+ biomass values by year and relative to the 1999 assessment.

		Female Spawner Biomass		Total Age 1+ Biomass	
Year	**F**	**1999 Asssessment**	**Current Assessment**	**1999 Assessment**	**Current Assessment**
1960	0.05	393,726	376,576	668,857	636,220
1961	0.07	377,211	360,014	642,265	609,750
1962	0.08	351,093	333,852	600,587	568,388
1963	0.05	324,941	307,656	559,110	527,496
1964	0.05	311,960	294,639	539,019	508,106
1965	0.02	298,353	281,087	524,369	494,427
1966	0.02	296,168	279,171	535,561	506,738
1967	0.04	292,675	276,226	565,363	538,387
1968	0.05	284,976	269,239	611,553	587,300
1969	0.05	275,990	261,222	672,634	651,819
1970	0.03	278,320	265,126	745,236	728,270
1971	0.06	307,085	296,360	830,988	818,110
1972	0.10	348,784	341,276	880,834	871,805
1973	0.08	384,858	380,662	871,818	866,018
1974	0.10	425,171	423,668	853,547	850,275
1975	0.09	443,339	443,667	803,731	802,467
1976	0.09	440,404	441,703	759,823	759,819
1977	0.05	415,908	417,932	717,545	717,987
1978	0.07	400,167	402,968	710,584	710,554
1979	0.08	377,036	380,534	695,056	693,598
1980	0.10	359,641	363,365	684,123	680,332
1981	0.11	339,460	342,704	663,671	656,746
1982	0.09	321,370	323,492	634,440	624,016
1983	0.09	312,112	312,400	601,853	587,991
1984	0.04	307,708	305,446	563,453	546,597
1985	0.03	315,708	310,280	540,659	520,995
1986	0.02	321,805	313,386	519,288	497,772
1987	0.02	321,183	310,352	499,111	476,375
1988	0.02	310,905	298,471	478,893	456,093
1989	0.03	295,308	282,007	460,823	439,271
1990	0.04	275,503	262,167	439,908	421,238
1991	0.04	256,405	243,318	415,120	400,042
1992	0.02	242,662	230,692	390,594	379,389
1993	0.05	236,989	227,038	375,985	368,772
1994	0.05	225,450	217,945	356,723	353,228
1995	0.04	210,977	206,376	334,398	334,453
1996	0.04	198,826	196,967	313,608	316,248
1997	0.05	189,395	190,269	293,655	298,201
1998	0.07	178,911	181,876	272,951	278,744
1999	0.07	165,378	169,750	251,486	258,040
2000			158,493		241,255
2001			143,845		224,324

Table 4.6. 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+
1973	31.98	15.62	10.23	12.76	36.74	28.92	23.17	18.51	14.74	3.20	2.46	1.91	1.50	1.20	1.07	0.83	0.66	0.54	0.45	0.38	1.89
1974	42.46	26.63	13.00	8.42	10.07	28.46	22.34	17.89	14.29	11.38	2.47	1.90	1.48	1.16	0.93	0.83	0.64	0.51	0.42	0.35	1.75
1975	23.07	35.32	22.15	10.65	6.54	7.64	21.52	16.88	13.52	10.80	8.60	1.87	1.44	1.12	0.88	0.70	0.62	0.49	0.39	0.32	1.59
1976	41.66	19.20	29.38	18.17	8.31	5.00	5.82	16.38	12.85	10.29	8.22	6.54	1.42	1.09	0.85	0.67	0.53	0.47	0.37	0.29	1.45
1977	38.25	34.67	15.97	24.11	14.20	6.36	3.81	4.43	12.48	9.79	7.84	6.26	4.99	1.08	0.83	0.65	0.51	0.41	0.36	0.28	1.33
1978	42.96	31.90	28.90	13.22	19.49	11.35	5.08	3.04	3.54	9.96	7.81	6.25	4.99	3.98	0.86	0.66	0.52	0.41	0.32	0.29	1.28
1979	35.90	35.79	26.57	23.86	10.56	15.34	8.92	3.98	2.38	2.77	7.79	6.10	4.88	3.89	3.10	0.67	0.52	0.40	0.32	0.25	1.22
1980	20.78	29.91	29.81	21.93	19.05	8.31	12.05	7.00	3.13	1.87	2.17	6.09	4.76	3.80	3.03	2.41	0.52	0.40	0.31	0.24	1.14
1981	13.66	17.30	24.90	24.52	17.28	14.73	6.41	9.28	5.39	2.40	1.43	1.66	4.65	3.63	2.90	2.31	1.83	0.40	0.31	0.24	1.05
1982	7.00	11.37	14.39	20.43	19.17	13.23	11.24	4.89	7.07	4.09	1.82	1.08	1.25	3.50	2.73	2.18	1.73	1.37	0.30	0.23	0.97
1983	4.68	5.82	9.46	11.81	15.97	14.67	10.09	8.57	3.72	5.39	3.12	1.39	0.83	0.96	2.67	2.08	1.66	1.32	1.05	0.23	0.91
1984	6.95	3.89	4.85	7.77	9.26	12.26	11.23	7.72	6.56	2.85	4.12	2.39	1.06	0.63	0.73	2.04	1.59	1.27	1.01	0.80	0.87
1985	14.24	5.80	3.25	4.01	6.28	7.41	9.79	8.97	6.16	5.24	2.28	3.29	1.91	0.85	0.50	0.58	1.63	1.27	1.01	0.81	1.34
1986	21.74	11.88	4.84	2.70	3.28	5.10	6.00	7.94	7.27	5.00	4.24	1.84	2.67	1.54	0.69	0.41	0.47	1.32	1.03	0.82	1.74
1987	13.54	18.14	9.91	4.02	2.22	2.69	4.17	4.91	6.49	5.95	4.09	3.47	1.51	2.18	1.26	0.56	0.33	0.39	1.08	0.84	2.09
1988	8.87	11.30	15.14	8.24	3.31	1.81	2.20	3.41	4.01	5.31	4.86	3.34	2.84	1.23	1.78	1.03	0.46	0.27	0.32	0.88	2.40
1989	7.95	7.41	9.43	12.61	6.81	2.72	1.49	1.80	2.80	3.30	4.36	3.99	2.74	2.33	1.01	1.46	0.85	0.38	0.22	0.26	2.69
1990	10.76	6.64	6.19	7.88	10.53	5.68	2.26	1.23	1.48	2.29	2.69	3.55	3.25	2.23	1.90	0.82	1.19	0.69	0.31	0.18	2.40
1991	16.07	8.99	5.54	5.17	6.58	8.78	4.70	1.85	0.99	1.19	1.84	2.16	2.85	2.61	1.79	1.52	0.66	0.95	0.55	0.25	2.07
1992	6.06	13.42	7.51	4.63	4.32	5.49	7.27	3.84	1.49	0.80	0.95	1.47	1.73	2.28	2.09	1.43	1.22	0.53	0.76	0.44	1.85
1993	4.54	5.06	11.21	6.27	3.87	3.60	4.57	6.04	3.18	1.23	0.66	0.79	1.22	1.43	1.88	1.72	1.18	1.00	0.44	0.63	1.89
1994	3.97	3.79	4.23	9.36	5.24	3.23	3.00	3.80	5.00	2.62	1.01	0.54	0.64	0.98	1.15	1.51	1.38	0.94	0.80	0.35	2.00
1995	3.87	3.32	3.17	3.53	7.82	4.37	2.68	2.47	3.11	4.07	2.12	0.82	0.43	0.51	0.79	0.92	1.21	1.10	0.75	0.64	1.87
1996	5.61	3.24	2.77	2.64	2.95	6.53	3.64	2.22	2.03	2.54	3.31	1.72	0.66	0.35	0.41	0.63	0.74	0.97	0.88	0.60	2.00
1997	5.14	4.68	2.70	2.31	2.21	2.46	5.44	3.02	1.83	1.68	2.09	2.71	1.40	0.54	0.28	0.33	0.51	0.59	0.78	0.71	2.09
1998	5.11	4.30	3.91	2.26	1.93	1.84	2.05	4.52	2.50	1.51	1.37	1.70	2.19	1.13	0.43	0.23	0.27	0.41	0.47	0.62	2.22
1999	4.81	4.26	3.59	3.27	1.89	1.61	1.54	1.70	3.73	2.05	1.23	1.11	1.36	1.75	0.90	0.34	0.18	0.21	0.32	0.37	2.22
2000	4.81	4.02	3.56	3.00	2.73	1.57	1.34	1.28	1.41	3.07	1.68	1.00	0.90	1.11	1.42	0.73	0.28	0.14	0.17	0.26	2.08
2001	4.81	4.02	3.36	2.98	2.50	2.28	1.31	1.11	1.05	1.15	2.51	1.36	0.81	0.73	0.89	1.13	0.58	0.22	0.12	0.13	1.86

Males

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1973	31.98	15.62	10.23	12.79	37.06	29.18	23.33	18.64	14.85	3.23	2.47	1.92	1.51	1.21	1.08	0.84	0.67	0.55	0.46	0.38	1.92
1974	42.46	26.63	13.00	8.43	10.15	28.80	22.57	18.02	14.40	11.47	2.49	1.91	1.49	1.17	0.94	0.84	0.65	0.52	0.43	0.35	1.79
1975	23.07	35.32	22.15	10.67	6.60	7.73	21.80	17.06	13.62	10.88	8.67	1.88	1.44	1.12	0.88	0.71	0.63	0.50	0.39	0.32	1.62
1976	41.66	19.20	29.38	18.20	8.39	5.06	5.89	16.60	12.98	10.36	8.28	6.60	1.43	1.10	0.86	0.67	0.54	0.48	0.38	0.30	1.49
1977	38.25	34.67	15.97	24.15	14.33	6.44	3.86	4.49	12.65	9.89	7.90	6.31	5.03	1.09	0.84	0.65	0.52	0.41	0.37	0.29	1.37
1978	42.96	31.90	28.90	13.24	19.59	11.48	5.15	3.08	3.59	10.10	7.90	6.30	5.04	4.02	0.87	0.67	0.52	0.41	0.33	0.30	1.32
1979	35.90	35.79	26.57	23.89	10.62	15.46	9.02	4.04	2.42	2.82	7.92	6.19	4.94	3.95	3.15	0.68	0.53	0.41	0.32	0.26	1.27
1980	20.78	29.91	29.81	21.96	19.17	8.38	12.16	7.09	3.17	1.90	2.21	6.21	4.86	3.88	3.10	2.47	0.54	0.41	0.32	0.25	1.20
1981	13.66	17.30	24.90	24.56	17.41	14.87	6.47	9.37	5.46	2.44	1.46	1.70	4.78	3.74	2.98	2.38	1.90	0.41	0.32	0.25	1.12
1982	7.00	11.37	14.39	20.47	19.34	13.38	11.36	4.94	7.15	4.16	1.86	1.11	1.29	3.64	2.84	2.27	1.81	1.44	0.31	0.24	1.04
1983	4.68	5.82	9.46	11.83	16.11	14.85	10.21	8.66	3.76	5.45	3.17	1.42	0.85	0.99	2.78	2.17	1.73	1.39	1.10	0.24	0.98
1984	6.95	3.89	4.85	7.78	9.34	12.42	11.38	7.82	6.63	2.88	4.17	2.43	1.09	0.65	0.76	2.13	1.66	1.33	1.06	0.85	0.94
1985	14.24	5.80	3.25	4.02	6.31	7.48	9.92	9.09	6.24	5.29	2.30	3.33	1.94	0.87	0.52	0.60	1.70	1.33	1.06	0.85	1.43
1986	21.74	11.88	4.84	2.70	3.29	5.13	6.07	8.05	7.37	5.06	4.29	1.86	2.70	1.57	0.70	0.42	0.49	1.38	1.08	0.86	1.85
1987	13.54	18.14	9.91	4.03	2.22	2.70	4.20	4.97	6.58	6.03	4.14	3.51	1.52	2.21	1.29	0.58	0.35	0.40	1.13	0.88	2.22
1988	8.87	11.30	15.14	8.25	3.32	1.82	2.20	3.43	4.06	5.38	4.93	3.38	2.87	1.25	1.80	1.05	0.47	0.28	0.33	0.92	2.54
1989	7.95	7.41	9.43	12.61	6.82	2.73	1.50	1.81	2.82	3.34	4.42	4.05	2.78	2.36	1.02	1.48	0.86	0.39	0.23	0.27	2.84
1990	10.76	6.64	6.19	7.88	10.53	5.69	2.27	1.24	1.50	2.32	2.73	3.62	3.31	2.27	1.92	0.84	1.21	0.71	0.32	0.19	2.54
1991	16.07	8.99	5.54	5.17	6.58	8.79	4.74	1.88	1.02	1.22	1.88	2.21	2.92	2.67	1.83	1.55	0.67	0.97	0.57	0.25	2.20
1992	6.06	13.42	7.51	4.63	4.32	5.49	7.32	3.92	1.54	0.83	0.99	1.52	1.78	2.35	2.15	1.47	1.25	0.54	0.78	0.46	1.97
1993	4.54	5.06	11.21	6.27	3.87	3.60	4.58	6.10	3.26	1.28	0.69	0.82	1.26	1.47	1.94	1.77	1.22	1.03	0.45	0.65	2.01
1994	3.97	3.79	4.23	9.36	5.24	3.23	3.01	3.82	5.08	2.71	1.06	0.57	0.68	1.04	1.21	1.60	1.46	1.00	0.85	0.37	2.17
1995	3.87	3.32	3.17	3.53	7.82	4.37	2.69	2.50	3.16	4.17	2.22	0.87	0.46	0.55	0.84	0.99	1.30	1.18	0.81	0.69	2.06
1996	5.61	3.24	2.77	2.64	2.95	6.53	3.65	2.24	2.07	2.60	3.43	1.82	0.71	0.38	0.45	0.69	0.81	1.06	0.97	0.66	2.24
1997	5.14	4.68	2.70	2.31	2.21	2.46	5.45	3.04	1.86	1.72	2.16	2.84	1.50	0.59	0.31	0.37	0.57	0.66	0.87	0.79	2.37
1998	5.11	4.30	3.91	2.26	1.93	1.84	2.06	4.54	2.53	1.55	1.42	1.78	2.35	1.24	0.48	0.26	0.30	0.47	0.54	0.71	2.59
1999	4.81	4.26	3.59	3.27	1.89	1.61	1.54	1.71	3.77	2.09	1.28	1.17	1.47	1.92	1.02	0.40	0.21	0.25	0.38	0.44	2.69
2000	4.81	4.02	3.56	3.00	2.73	1.57	1.35	1.28	1.42	3.13	1.73	1.06	0.97	1.21	1.58	0.84	0.32	0.17	0.20	0.31	2.56
2001	4.81	4.02	3.36	2.98	2.50	2.28	1.31	1.12	1.06	1.18	2.58	1.43	0.87	0.79	0.99	1.30	0.68	0.27	0.14	0.17	2.35

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 (Fig. 4.7). 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 not clear; however, we feel that it is related to the apparent bi-modality in the size distribution observed in the trawl fishery (see Fig. 4.8).

Fit to Size Composition Data

Size composition observations from the fisheries and surveys are generally poorly matched by the model predictions (Fig. 4.8). These figures display an "effective *N*" value for each year and gear type. This is a rough measure of how well the model fits the data. Higher values for effective *N* imply better fits to the data. This lack of fit can be attributed to several reasons. First, the influence of size composition data on the total likelihood for a given gear type and year depends on the number of Greenland turbot measured. 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 has been poor since the early 1980s as indicated by trawl surveys on the EBS shelf. There is evidence from slope surveys that this poor recruitment has reduced abundance of the exploitable stock. Consequently, we expect continued reduction of the exploitable stock into the next millennium. As presented in previous assessments, there were several strong year-classes through the 1970s, which were followed by a series of poor recruitment of Greenland turbot since the early 1980s (Fig. 4.9). Preliminary analyses on fitting the stock-recruitment relationship indicated that the residuals were highly auto-correlated. At this time, the authors feel that the environmental conditions are likely to dominate any relationship between spawning biomass and recruitment in explaining recruitment variability. Therefore, analyses of stock-recruitment relationship to calculate an MSY value were not pursued.

4.5. Projections and harvest alternatives

Maximum Sustainable Yield

Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship, which for Greenland turbot may be impractical as many functional forms can fit the data equally well. As presented above, the harvest strategy relative to reductions in spawning biomass per recruit (e.g., $F_{40\%}$) was selected in the absence of information on the stock-recruitment productivity relationship required for calculating MSY levels.

ABC and Overfishing levels

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 the most conservative configuration (assuming slope-survey catchability=0.75). The status of the projected spawning biomass in year 2002 relative to $B_{40\%}$ would place Greenland turbot in Tier 3a of Amendment 56.

We computed $B_{40\%}$ value by using the mean recruitment estimated for the period 1978-1998. The results indicate that the long-term average female spawning biomass is around 80,000 tons. The current estimate of the year 2002 female spawning biomass is about 132,000 t.

To enhance the rebuilding potential of Greenland turbot in the EBS and Aleutian Islands region and given the considerable uncertainty in the stock dynamics, we feel that extra caution is warranted. As new survey information from the slope region (to begin in 2002) becomes available these issues should be resolved. **We therefore recommend an ABC of 8,100 tons.** This is based 25% of the max F_{ABC} ($F_{40\%}$). We feel that this is justified based on the projections for the anticipated further declines and lack of apparent recruitment.

Our recommendation for overfishing, based on the adjusted $F_{35\%}$ rate is **36,500 t** corresponding to an full-selection F of 0.32. 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).

4.5.1. 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 2001 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2002 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2001 (here assumed to be 6,000 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 1000 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 2002, 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 a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2002 recommended in the assessment to the *max* F_{ABC} for 2002. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1997-2001 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 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.)

Scenarios 1 through 5 were projected 13 years from 2001 (Table 4.7).

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 ½ of its MSY level in 2002 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

Scenario 7: In 2002 and 2003, 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 2014 under this scenario, then the stock is not approaching an overfished condition.)

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 2002 spawning biomass estimated at 132,000 t relative to ½ $B_{35\%}$ = 35,000 tons). Under the guidelines, since the year 2002 biomass estimate is well 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. The results suggest a continued decline until about 2007 (Fig. 4.10). For this scenario, annual yield drops as low as 8,700 t and biomass falls to about 67% of the $B_{40\%}$ level. The yield fishing at the 25% of the $F_{40\%}$ harvest rate (Scenario 2), with equal trawl and longline F levels) eases the expected decline considerably (Fig. 4.11). Under Scenarios 6 and 7, the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Table 4.7. Mean spawning biomass, F, and yield projections for Greenland turbot, 2001-2014. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed **equal**. The values for $B_{40\%}$ and $B_{35\%}$ are 80,040 and 70,040 tons, respectively.

Sp.Biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2001	143,845	143,845	143,845	143,845	143,845	143,845	143,845
2002	132,130	132,130	132,130	132,130	132,130	132,130	132,130
2003	103,430	119,943	114,144	120,894	126,058	98,755	103,430
2004	82,574	109,575	99,616	111,258	120,642	75,685	82,574
2005	67,560	100,797	87,966	103,029	115,799	60,682	64,649
2006	58,665	93,497	78,786	96,127	111,563	52,700	54,934
2007	54,301	88,262	72,578	91,160	108,590	49,148	50,449
2008	54,631	86,815	71,157	89,885	108,783	50,115	50,869
2009	58,513	89,205	73,790	92,401	112,479	54,392	54,804
2010	63,778	94,070	78,627	97,378	118,588	59,740	59,941
2011	68,903	100,106	84,217	103,543	125,979	64,644	64,723
2012	73,125	106,215	89,589	109,799	133,475	68,431	68,446
2013	76,317	112,049	94,409	115,813	140,855	71,064	71,052
2014	78,577	117,378	98,541	121,351	147,881	72,745	72,725
Fishing	Mortality						
2001	0.044	0.044	0.044	0.044	0.044	0.044	0.044
2002	0.259	0.065	0.130	0.054	0.000	0.320	0.259
2003	0.259	0.065	0.130	0.054	0.000	0.320	0.259
2004	0.259	0.065	0.130	0.054	0.000	0.302	0.320
2005	0.216	0.065	0.130	0.054	0.000	0.239	0.255
2006	0.186	0.065	0.127	0.054	0.000	0.205	0.214
2007	0.171	0.065	0.117	0.054	0.000	0.190	0.196
2008	0.172	0.065	0.114	0.054	0.000	0.194	0.197
2009	0.185	0.064	0.116	0.054	0.000	0.212	0.213
2010	0.200	0.064	0.119	0.054	0.000	0.232	0.233
2011	0.214	0.064	0.122	0.054	0.000	0.250	0.250
2012	0.223	0.064	0.125	0.054	0.000	0.262	0.263
2013	0.230	0.065	0.126	0.054	0.000	0.271	0.271
2014	0.235	0.065	0.127	0.054	0.000	0.276	0.276
Yield							
2001	6,000	6,000	6,000	6,000	6,000	6,000	6,000
2002	30,160	8,092	15,804	6,831	0	36,474	30,160
2003	23,933	7,390	13,767	6,286	0	27,712	23,933
2004	19,296	6,771	12,074	5,800	0	20,402	23,350
2005	13,477	6,234	10,689	5,375	0	13,314	15,047
2006	10,194	5,785	9,438	5,016	0	10,067	10,929
2007	8,769	5,475	8,038	4,768	0	8,789	9,265
2008	8,925	5,381	7,713	4,697	0	9,198	9,483
2009	10,166	5,457	8,079	4,781	0	10,784	10,952
2010	11,827	5,668	8,745	4,972	0	12,791	12,881
2011	13,448	5,972	9,478	5,231	0	14,686	14,727
2012	14,764	6,301	10,178	5,510	0	16,168	16,181
2013	15,795	6,636	10,805	5,796	0	17,254	17,254
2014	16,553	6,960	11,363	6,074	0	17,975	17,970

4.6. Other Considerations

4.6.1. 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 4.8).

Table 4.8. Estimated total Greenland turbot harvest by area, 1977-2001.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1991	4,075	3,636
1978	37,423	4,766	1992	951	725
1979	34,998	6,411	1993	5,125	3,323
1980	48,856	3,697	1994	6,902	3,032
1981	52,921	4,400	1995	5,713	2,086
1982	45,805	6,317	1996	4,386	1,578
1983	43,443	4,115	1997	6,594	943
1984	21,317	1,803	1998	8,303	821
1985	14,698	33	1999	5,204	423
1986	7,710	2,154	2000	5,624	1,017
1987	6,519	3,066	2001	4,197	1,046
1988	6,064	1,044			
1989	4,061	4,761			
1990	7,702	2,494			

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 33% of the total ABC, with 67% allocated to the eastern Bering Sea. These rates represent the mid-point of the values observed from biomass estimates and give the following allocation:

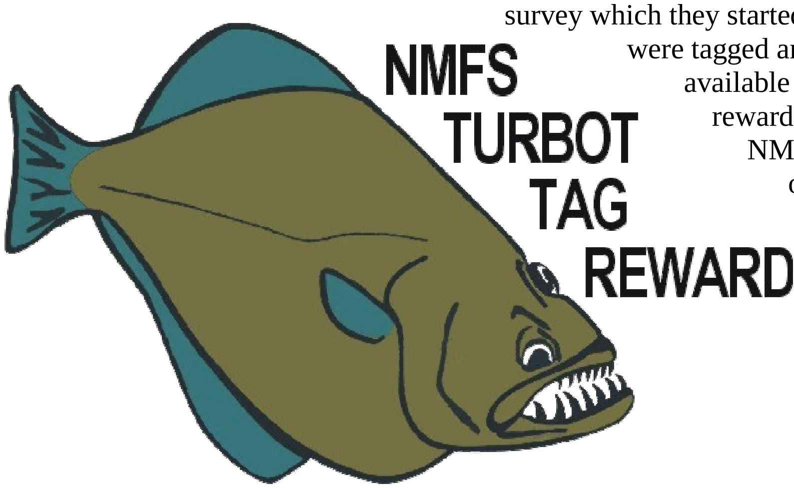
Aleutian Islands	2,700 t
Eastern Bering Sea	5,400 t
Total	8,100 t

4.6.2. 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 is an important predator.

The NMFS Auke Bay Lab staff continued to conduct a tagging study of Greenland turbot from the longline survey which they started in 1997. This year 128 Greenland turbot were tagged and released. Artwork (featured at left) is now available on hats given as tagged-fish recapture rewards. Earlier tagging studies were undertaken by NMFS from trawl vessels in the early 1980s. To our knowledge, only five recaptured tagged Greenland turbot were reported from this work. The total number of releases by year were: 1985—262 fish; 1986—320 fish, 1987—241 fish. This low number of recaptures may be due to poor survival of trawl-caught Greenland turbot, under-reporting, and/or poor tag-retention properties.



4.7. Summary

The management parameters of interest derived from this assessment are presented in Table 4.9. Please note, however, that management actions should be based on a more complete evaluation of the alternatives presented above rather than the single values given here.

Table 4.9. Summary management values based on this assessment. Note that the fishing mortality rates assume 50% contribution from longline gear and 50% from trawl.

Management Parameter	Value
M	0.18 yr-1
Approximate age at full recruitment	10 years
$F_{35\%}$	0.32
$F_{40\%}$	0.26
$B_{40\%}$	80,040 t
Year 2000 female spawning biomass	132,000 t
$F_{ABC} = F_{40\%} \times 25\%$	0.065
Recommended ABC	**8,100**
$F_{overfishing} = F_{35\%}$	0.32
Overfishing level	**36,500 t**

4.8. Acknowledgments

Mike Sigler and Chris Lunsford provided the summaries for the 1996-2001 longline survey data.

4.9. References

AFS Publication, 1991. Common and Scientific Names of Fishes from the United States and Canada. American Fisheries Society Special Publication 20. C. Richard Robins, Chairman. 183 p. American Fisheries Society, 5410 Grosvenor Lane, Suite 110, Bethesda, MD 20814-2199.

Alton, M.S., R.G. Bakkala, G.E. Walters, and P.T. Munro. 1988. Greenland turbot *Reinhardtius hippoglossoides* of the eastern Bering Sea and Aleutian Islands region. NOAA Tech. Rep., NMFS 71, 31 p.

Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., Lond., Ser. 2, 19.

D'yakov, Yu. P. 1982. The fecundity of the Greenland turbot, *Reinhardtius hippoglossoides*, (Pleuronectidae), from the Bering Sea. J. Ichthyol. [Engl. Transl. Vopr. Ikhtiol] 22(5):59-64.

Harrison, R.C. 1993. Data Report: 1991 Bottom trawl survey of the Aleutian Islands Area. NOAA Tech. Memo. NMFS-AFSC-12. 144p.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1993. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1994. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1994. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1995. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Ianelli, J.N. and T. K. Wilderbuer. 1995. Greenland Turbot (*Reinhardtius hippoglossoides)* stock assessment and management in the Eastern Bering Sea. *In:* Proceedings of the International Symposium on North Pacific Flatfish. Alaska Sea Grant. AK-SG-95-04:407-441.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1999. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2000. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Kimura, D.K. 1988. Analyzing relative abundance indices with log-linear models. N. Am. Journ. Fish. Manage. 8:175-180.

Methot, R.D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. *In* Proceedings of the symposium on applications of stock assessment techniques to Gadids. L. Low [ed.]. Int. North Pac. Fish. Comm. Bull. 50: 259-277.

Wilderbuer, T.K. and T.M. Sample. 1992. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1993. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Zenger, H.H. and M.F. Sigler. 1992. Relative abundance of Gulf of Alaska sablefish and other groundfish based on NMFS longline surveys, 1988-90. U.S. Dept. of Comm. NOAA Tech. Memo. NMFS F/NWC-216.

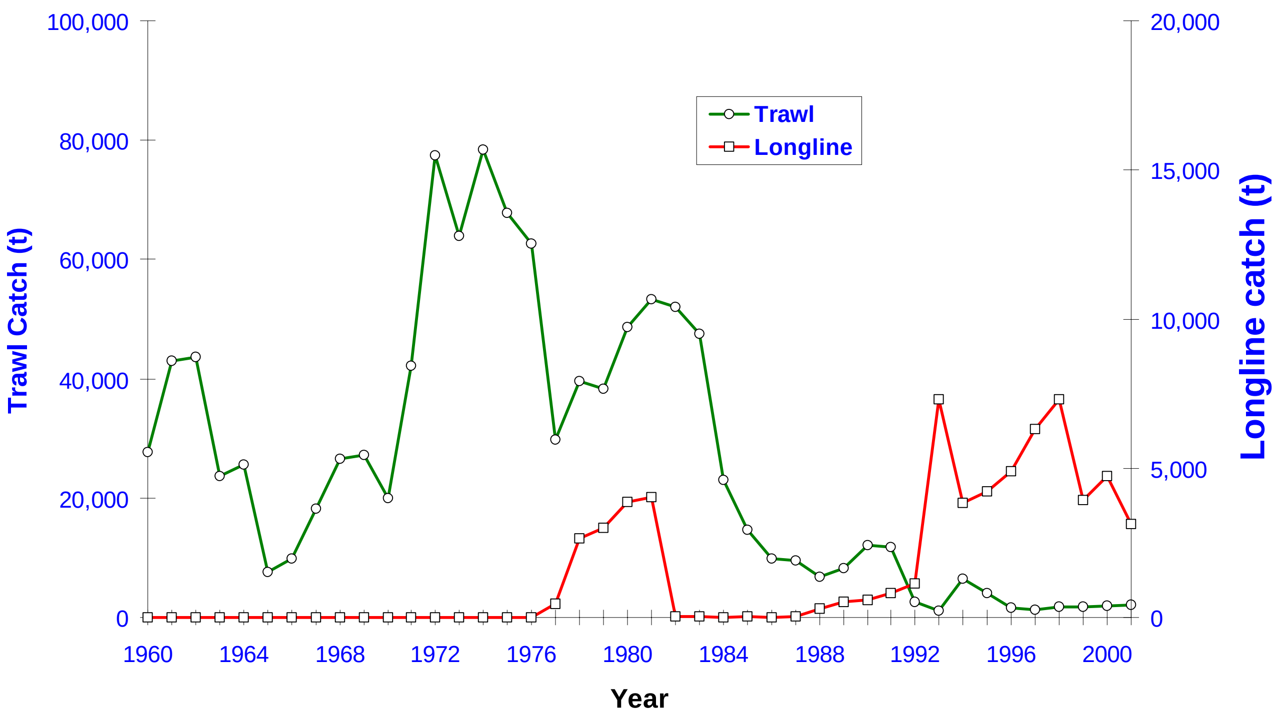


Figure 4.1. Comparison of trawl (1960-2001) and longline (1977-2001) catches of Greenland turbot in the combined EBS/AI area.

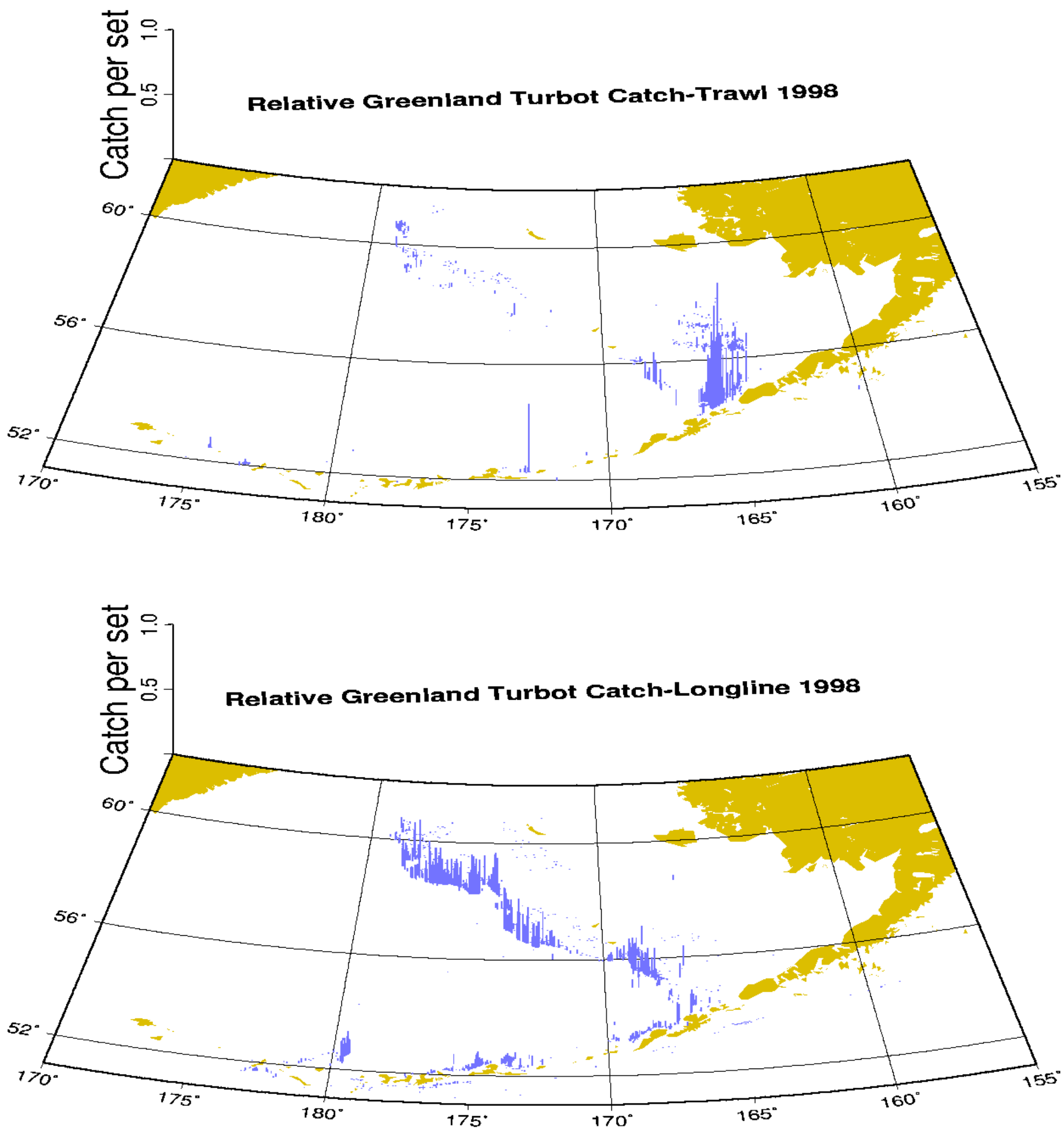


Figure 4.2. 1998 longline and trawl locations of successful Greenland turbot fishing operations based on NMFS observer data. Vertical lines represent the relative magnitude of Greenland turbot catch for each observed haul.

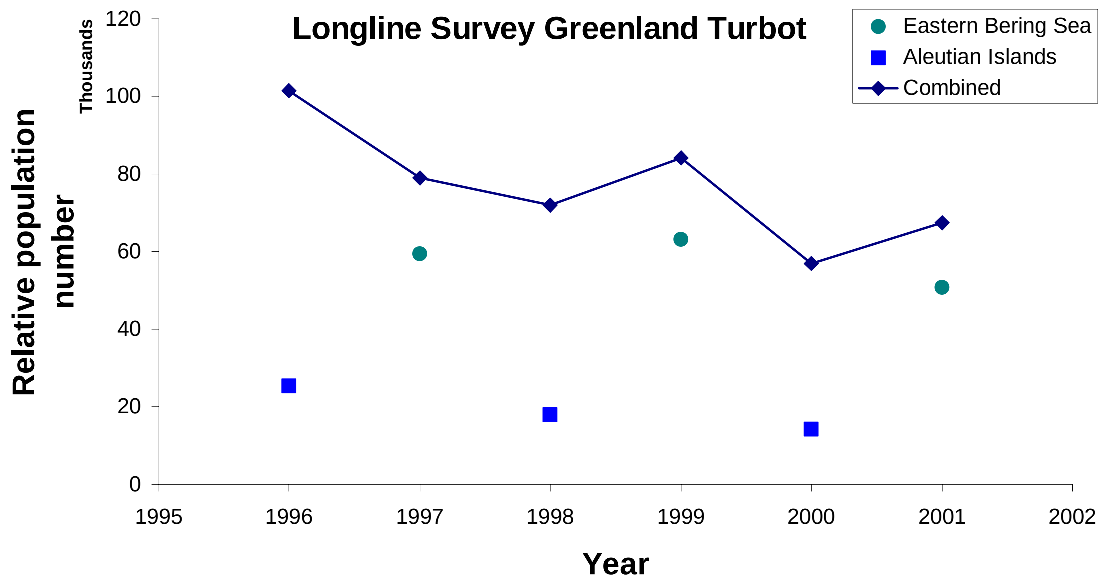


Figure 4.3. Greenland turbot longline survey abundance trends for the 2 regions and as combined and used within the assessment model.

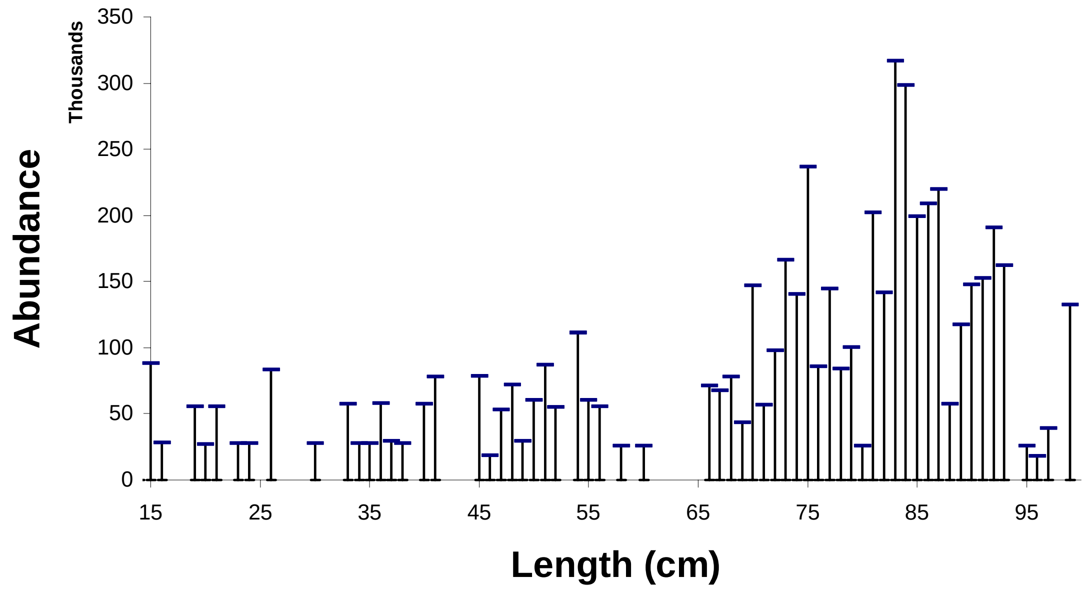


Figure 4.4. Length frequency of Greenland turbot observed from the summer 2001 NMFS bottom trawl survey. This year 274 Greenland turbot were measured.

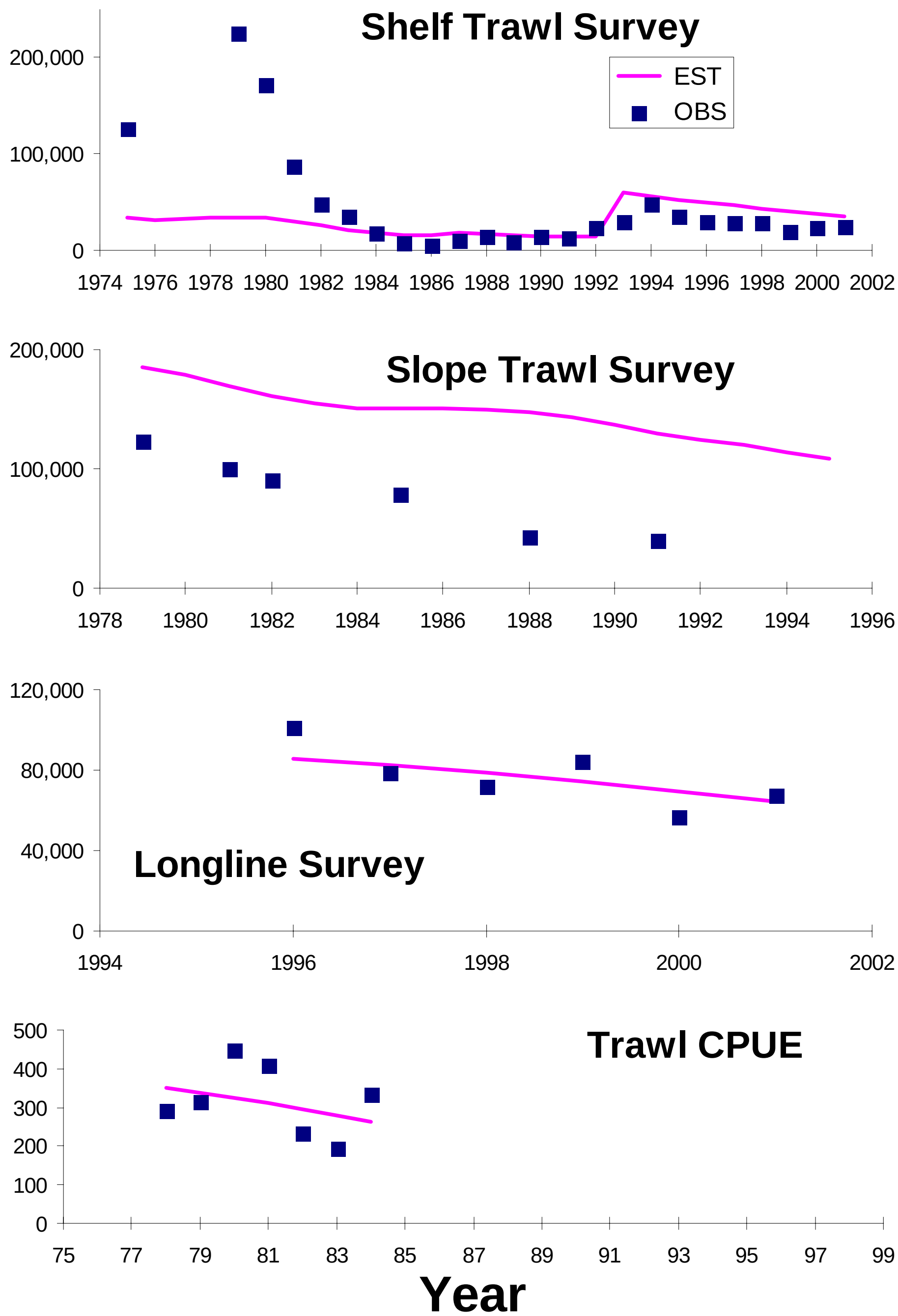


Figure 4.5. Fits to the different survey and fishery indices for Greenland turbot in the EBS/AI region. Note that the poor fit to the slope survey is due to the conservative assumption about survey Q=0.75.

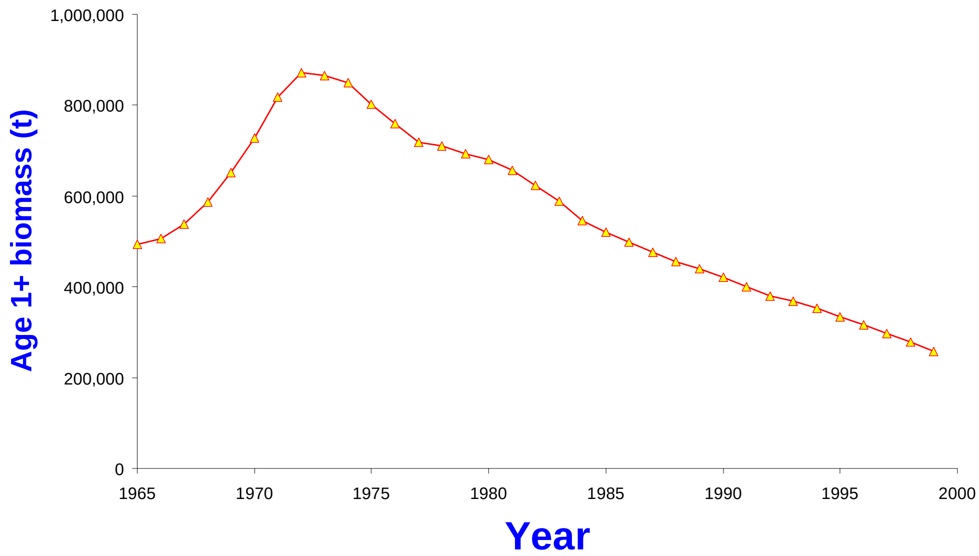


Figure 4.6 Total age 1+ biomass trend for the individual models of Greenland turbot in the EBS/AI region, 1965-2001.

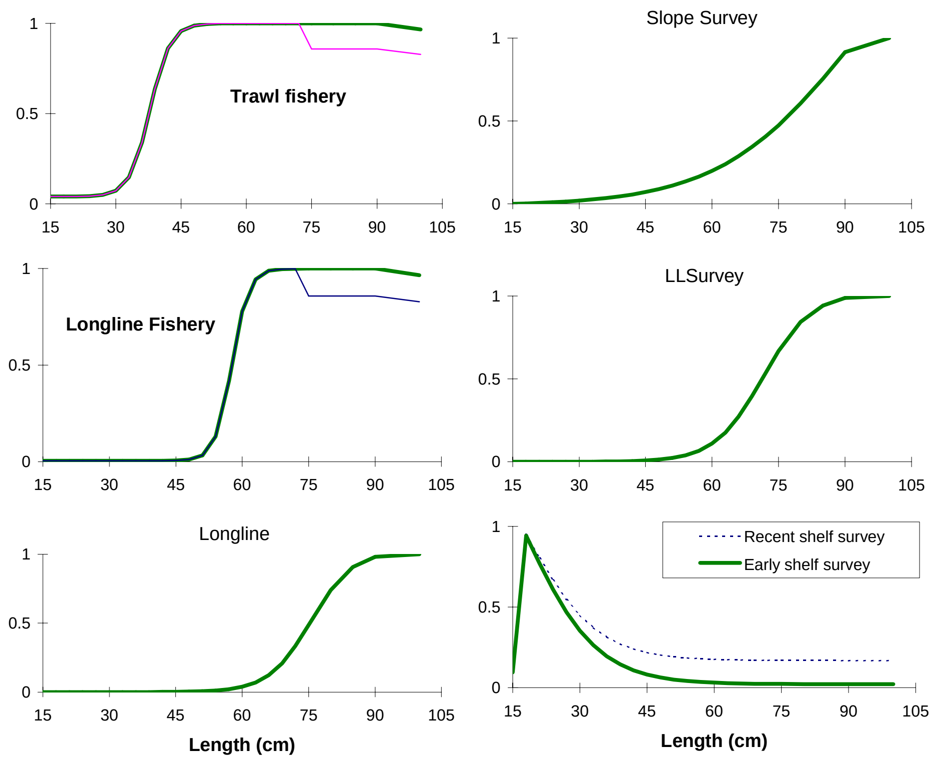


Figure 4.7. Size-specific selectivity patterns for surveys and fisheries of Greenland turbot in the EBS/AI region.

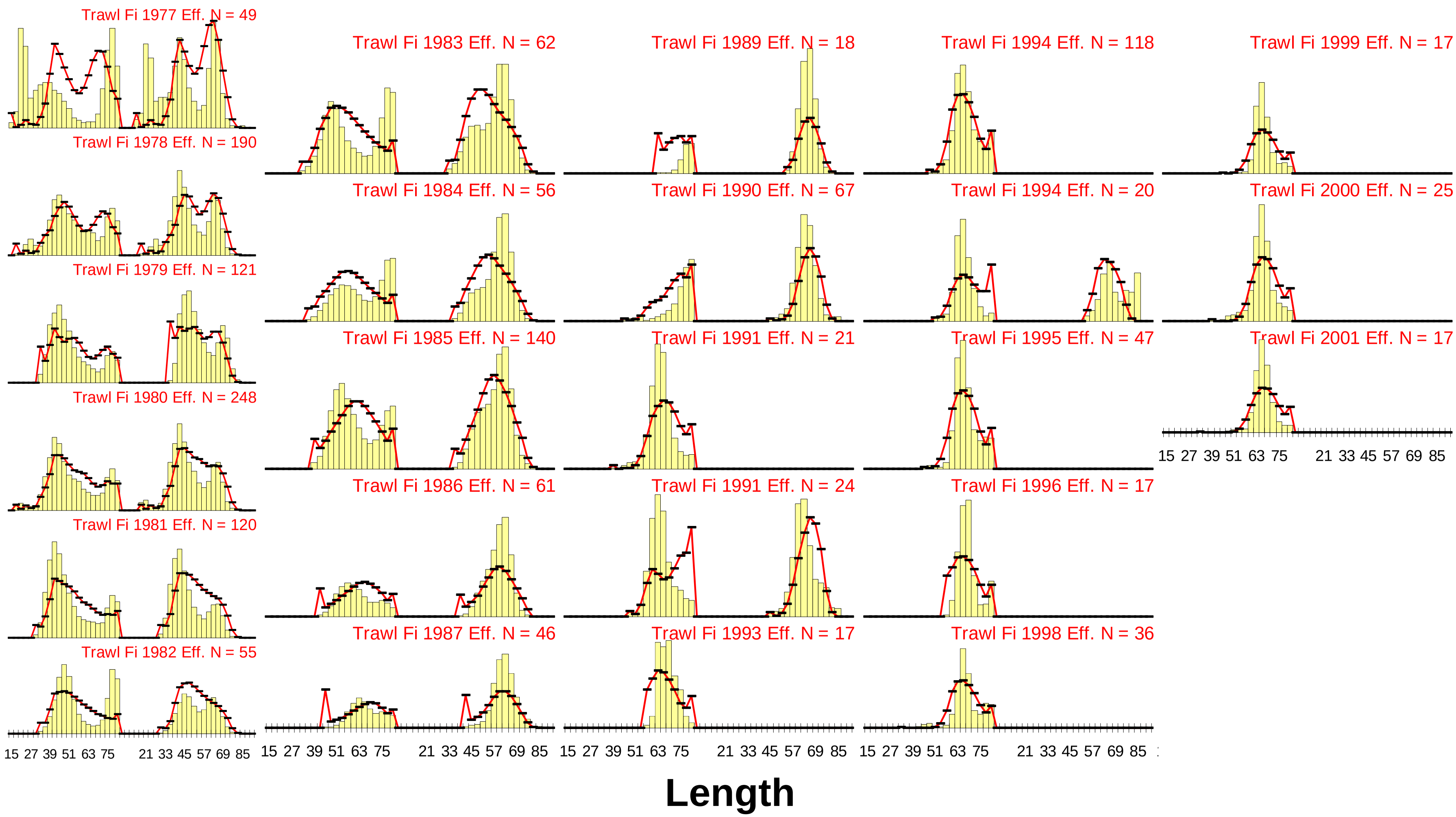


Figure 4.8. Fit to Greenland Turbot **trawl fishery** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

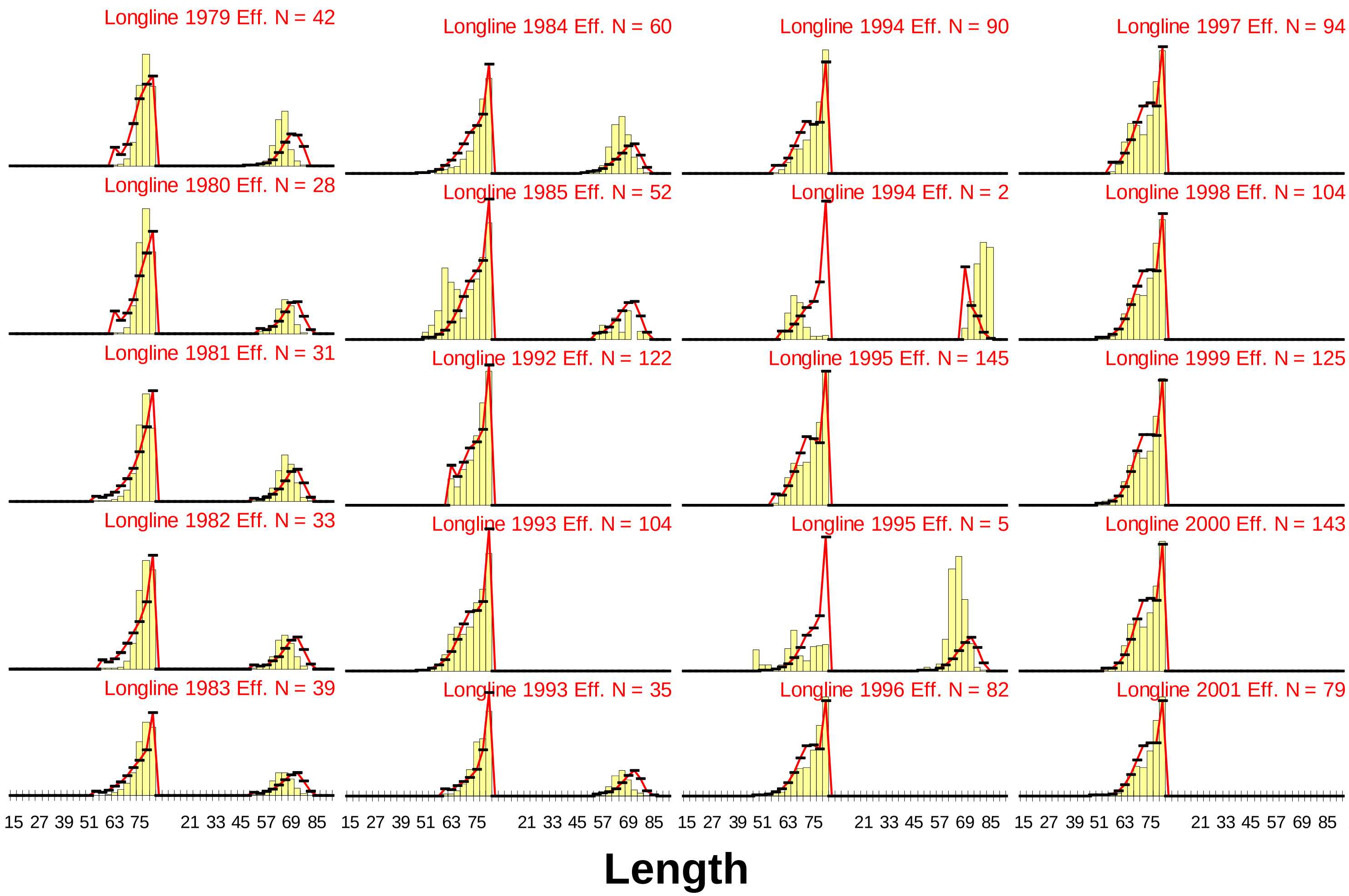


Figure 4.8. (cont'd) Fit to Greenland Turbot **longline fishery** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

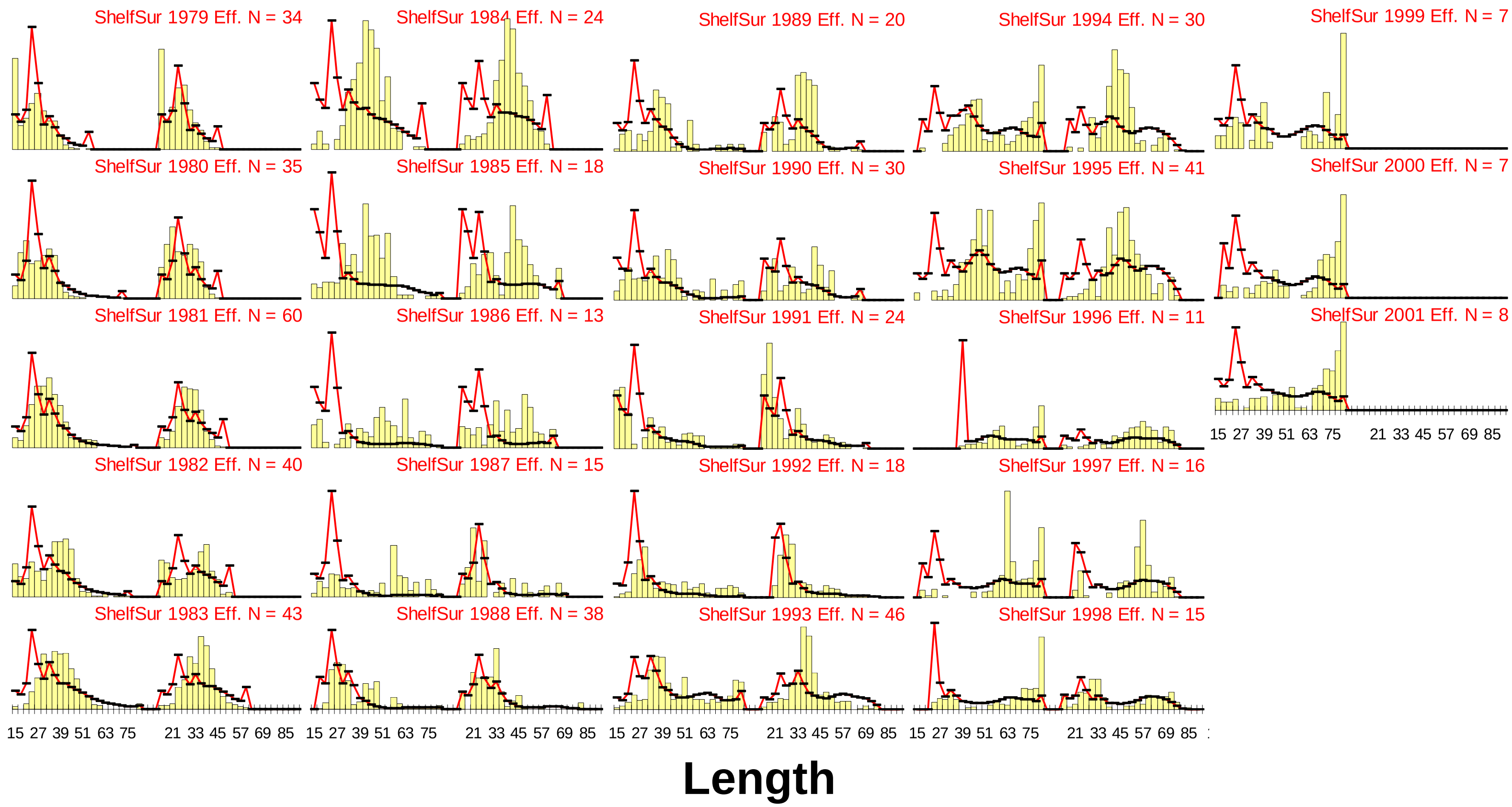


Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS shelf survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

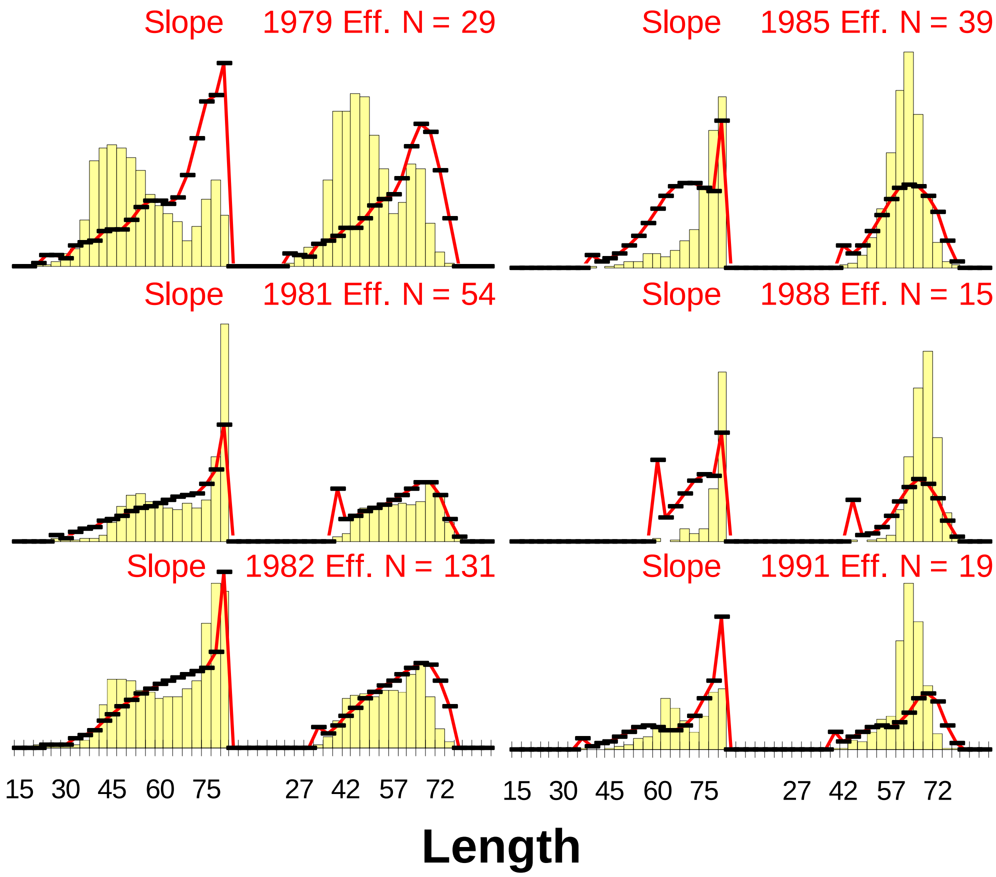


Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS slope trawl survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

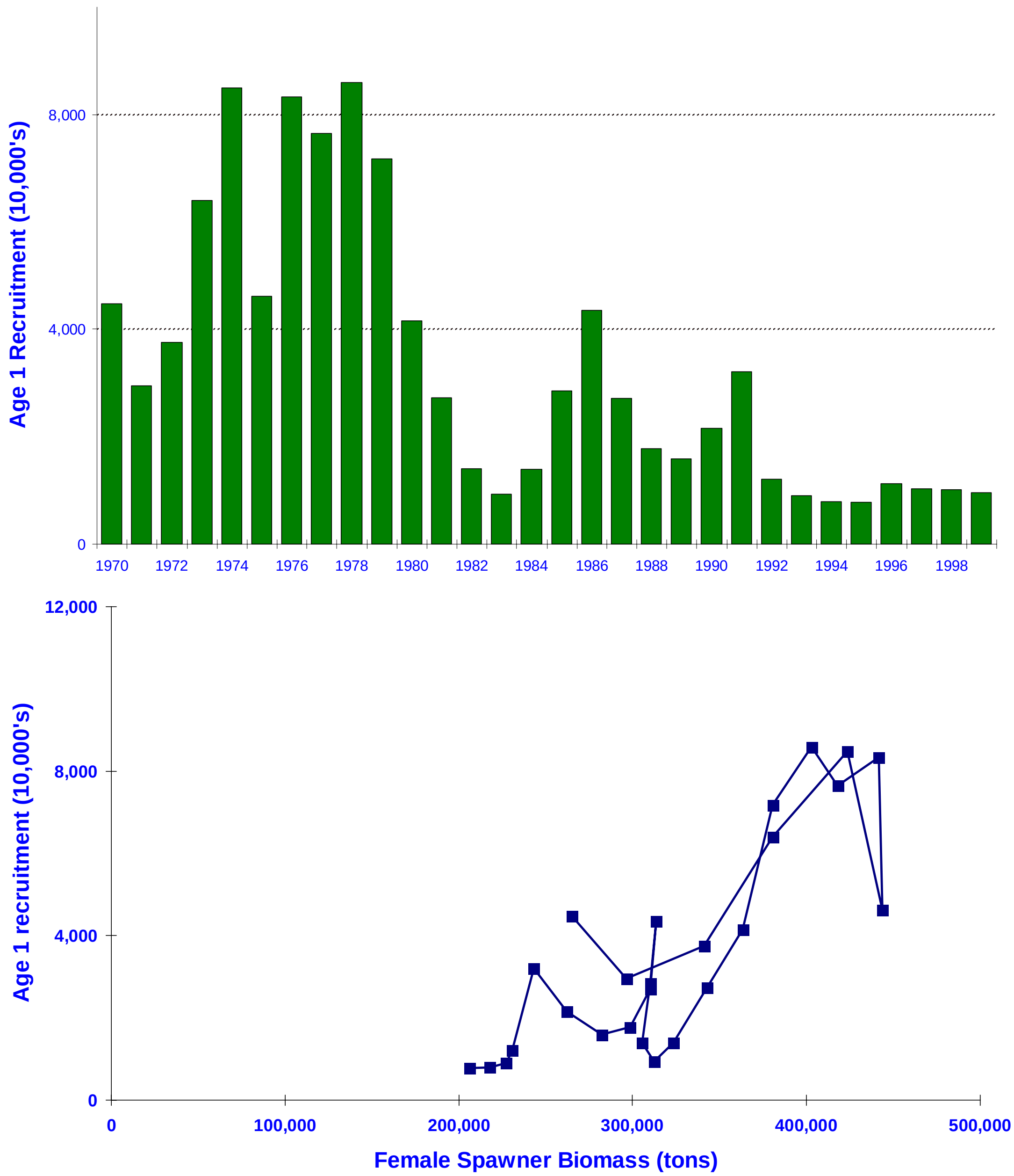


Figure 4.9. Estimated recruitment to age 1 (upper panel) and the observed stock-recruitment pattern (lower panel) of Greenland turbot in the EBS/AI region, 1970-1999.

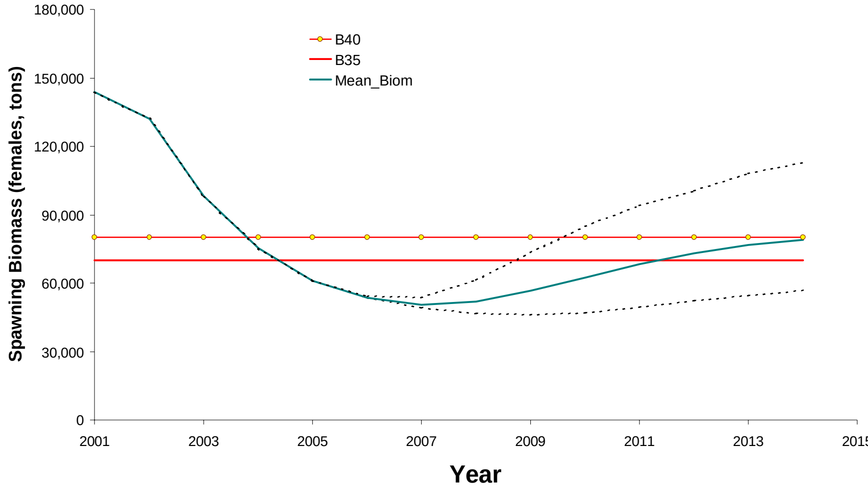


Figure 4.10. Stochastic trajectory of female spawning biomass and projected levels for maximum allowable fishing mortality rate under Amendment 56/56, Tier 3. These runs are assume relative fishing mortality rates between longline and trawl fishing gear is the same as the estimated 2001 value. The dashed lines represent the upper and lower 90% confidence limits.

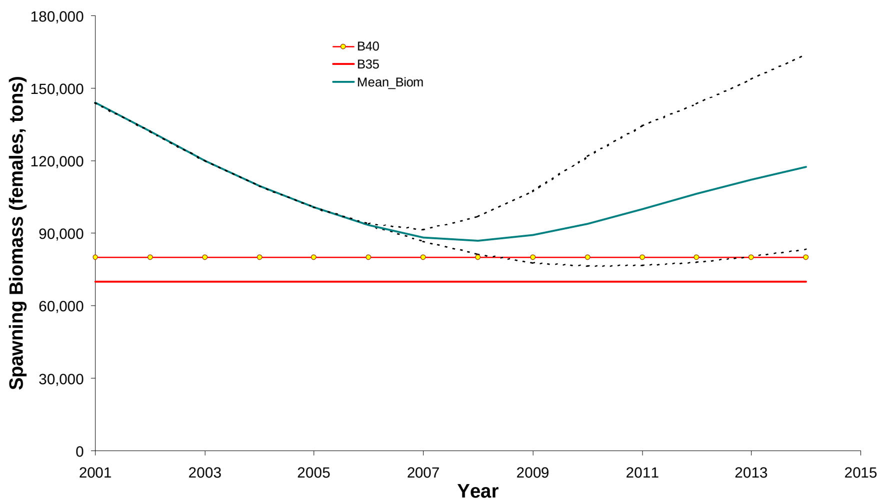


Figure 4.11. Stochastic trajectory of female spawning biomass and projected levels for 25% of the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3. These runs assume relative fishing mortality rates between longline and trawl fishing gear are equal. The dashed lines represent the upper and lower 90% confidence limits.