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

James N. Ianelli, Thomas K. Wilderbuer,
and Terrance M. Sample

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA 98115-0070

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, and
3. New length frequency and biomass data from the 1999 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. The majority of the catch has shifted to longline gear in recent years. The assessment model analysis was similar to last year but with a slightly higher estimated overall abundance. We attribute this to a slightly improved fit to the longline survey data trend. The target stock size ($B_{40\%}$, female spawning biomass) is estimated at about 81,200 tons while the projected year 2000 spawning biomass is about 150,800 tons. The adjusted yield projection from $F_{40\%}$ computations is estimated at 34,700 tons for 2000 (233,000 tons total age 1+ biomass). 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 which gives 9,300 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 continued to decline since the early 1980s. Survey plans for the year 2000 are to include the slope region of the EBS. This should help assess the prime area where Greenland turbot are found. As additional survey information become available and signs of recruitment (perhaps from areas other than the shelf) are apparent, then we believe that the full ABC or increases in harvest may be appropriate for this species.

4.1. 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 1998) 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	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*	2,722	6,278	9,000

* Prorated from 10/16/99 estimates, source: NMFS Regional Office, Juneau, AK

Catch information print 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. These values were used in the assessment model.

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 1997 and 1998 retained and discarded catch of Greenland turbot indicates that a large fraction of discards occurred due to the sablefish fishery (Fig. 4.3). The proportion of discards attributed to the sablefish fishery decreased from 38% in 1997 to 16% in 1998.

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	78	79	80	81	82	83	84
CPUE Index	291	316	449	409	235	195	335

In last year's SAFE report, we 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 4.2).

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 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 7 years (1993-1999) is 31,634 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	1992	1993	1994	1995	1996	1997	1998	1999
No. hauls	329	354	355	353	354	342	353	353	352	351	336	355	355	356	355	356	355	353
No. Lengths	969	951	536	196	195	82	200	183	232	360	440	400	398	313	297	197	93	207

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.

Table 4.2. Survey estimates of Greenland turbot biomass for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-1999.

	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*	12,100**
1992	24,000	---	---	---
1993	30,400	---	---	---
1994	48,800	---	---	29,106 **
1995	34,800	---	---	---
1996	30,300	---	---	---
1997	29,218	---	---	32,027**
1998	28,126	---	---	---
1999	19,797	---	---	---

* The 1988 and 1991 estimate are from 200-800 m whereas the earlier slope estimates are from 200-1,000 m.

** The 1980, 1983, and 1986 surveys sampled 1-900 m whereas the 1991, 1994 and 1997 survey sampled only 1-500 m.

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 27% 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 Popln. Number	**Year**			
Area	**1996**	**1997**	**1998**	**1999**
Bering 4		11,729		13,072
Bering 3		6,172		6,156
Bering 2		27,936		33,848
Bering 1		13,491		10,068
NE Aleutians	23,133		17,120	
SE Aleutians	2,142		1,806	

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 1999 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 1999. 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 4.3 summarizes the extent of the data used in the different likelihood components.

Table 4.3. 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	1979-1999
Slope Survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91
Longline Survey: size composition and abundance index	1984-1993
Total Fishery Catch Data	1960-1999
Trawl CPUE Index	1978-1984
Trawl Catch Size Composition	1977-87, 1989-91, 1993-98
Longline Catch Size Composition	1977, 1979-85, 1992-98

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 levels 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 time 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:

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

and

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

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

Maturation and fecundity

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), 1960-1999.

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). As in previous years, we found a pattern of poorer fits as the slope-survey value of Q was increased:

	Description		Total Log Likelihood
Model 1	Slope Q fixed at 0.25	(high biomass)	-3327.11
Model 2	Slope Q fixed at 0.50	(mod. Biomass)	-3338.74
Model 3	Slope Q fixed at 0.75	(low biomass)	-3351.95

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 1999 total beginning of the year biomass (age 1 and older) ranges from about 250,000 to 330,000 tons with slope survey Q set to 0.75 and 0.25, respectively (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 of Model 3, with 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 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 4.4). The effect of different models on historical biomass levels is also presented in Table

4.4. The estimated historical numbers at age based on Model 3 show the change in the age structure over time (Table 4.5).

Table 4.4. Historical fishing mortality rates (Model 3, combined gear types), female spawning biomass, and beginning of year age 1+ biomass values by year and model configuration.

		Female Spawner Biomass			Total Age 1+ Biomass		
Year	F	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
1960	0.05	459,042	417,256	393,726	783,247	711,607	668,857
1961	0.07	459,042	400,823	377,211	756,692	685,096	642,265
1962	0.08	442,651	374,825	351,093	715,102	643,592	600,587
1963	0.05	416,705	348,775	324,941	673,936	602,542	559,110
1964	0.05	390,685	335,837	311,960	654,462	583,137	539,019
1965	0.02	377,737	322,341	298,353	641,561	583,137	524,369
1966	0.02	364,201	320,364	296,168	655,864	582,742	535,561
1967	0.04	362,122	317,302	292,675	691,639	615,421	565,363
1968	0.05	358,912	310,280	284,976	746,905	665,492	611,553
1969	0.05	351,852	302,286	275,990	819,730	731,248	672,634
1970	0.03	344,232	306,072	278,320	905,063	808,645	745,236
1971	0.06	349,572	337,047	307,085	1,003,708	899,051	830,988
1972	0.10	384,235	381,641	348,784	1,063,466	952,195	880,834
1973	0.08	434,246	421,046	384,858	1,060,462	944,923	871,818
1974	0.10	479,911	464,846	425,171	1,044,616	927,056	853,547
1975	0.09	530,188	485,886	443,339	994,491	876,584	803,731
1976	0.09	556,437	484,342	440,404	949,687	831,897	759,823
1977	0.05	557,401	459,566	415,908	905,684	788,469	717,545
1978	0.07	532,370	442,529	400,167	897,790	780,687	710,584
1979	0.08	513,651	417,907	377,036	882,419	764,756	695,056
1980	0.10	487,274	399,321	359,641	872,858	753,933	684,123
1981	0.11	467,521	378,227	339,460	854,449	733,843	663,671
1982	0.09	445,790	359,791	321,370	826,600	704,743	634,440
1983	0.09	427,643	350,901	312,112	793,627	671,660	601,853
1984	0.04	420,038	347,360	307,708	752,361	631,914	563,453
1985	0.03	418,452	356,290	315,708	724,313	606,971	540,659
1986	0.02	429,383	362,645	321,805	695,640	582,762	519,288
1987	0.02	436,501	361,305	321,183	666,892	559,316	499,111
1988	0.02	434,121	349,376	310,905	638,046	535,799	478,893
1989	0.03	419,366	331,467	295,308	611,494	514,497	460,823
1990	0.04	397,364	308,996	275,503	581,951	490,312	439,908
1991	0.04	370,272	287,414	256,405	548,790	462,380	415,120
1992	0.02	344,614	271,644	242,662	516,135	434,839	390,594
1993	0.05	325,681	264,296	236,989	494,080	417,465	375,985
1994	0.05	315,623	251,155	225,450	467,659	395,566	356,723
1995	0.04	299,657	234,999	210,977	438,093	370,592	334,398
1996	0.04	280,471	221,311	198,826	410,235	347,268	313,608
1997	0.05	264,048	210,461	189,395	383,200	324,802	293,655
1998	0.07	250,775	198,608	178,911	355,545	301,661	272,951
1999	0.07	236,496	183,644	165,378	327,310	277,828	251,486

Table 4.5. Estimated beginning of year numbers of Greenland turbot by age and sex (millions) estimated for Model 3.

Females

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1971	14.20	18.28	56.61	46.99	38.34	30.78	24.56	5.67	4.30	3.37	2.60	2.10	1.93	1.51	1.20	0.99	0.82	0.68	0.57	0.47	2.37
1972	18.27	11.84	15.23	46.80	37.76	30.37	24.32	19.40	4.48	3.39	2.66	2.06	1.66	1.52	1.19	0.95	0.78	0.65	0.54	0.45	2.24
1973	31.69	15.21	9.85	12.50	36.61	28.83	23.08	18.46	14.73	3.40	2.58	2.02	1.56	1.26	1.16	0.90	0.72	0.59	0.49	0.41	2.04
1974	43.32	26.39	12.66	8.11	9.90	28.41	22.28	17.83	14.26	11.38	2.63	1.99	1.56	1.21	0.97	0.89	0.70	0.56	0.46	0.38	1.90
1975	23.61	36.05	21.95	10.38	6.32	7.52	21.48	16.84	13.47	10.78	8.60	1.99	1.50	1.18	0.91	0.73	0.68	0.53	0.42	0.35	1.72
1976	42.99	19.66	30.00	18.03	8.14	4.84	5.73	16.35	12.81	10.25	8.20	6.54	1.51	1.14	0.90	0.69	0.56	0.51	0.40	0.32	1.57
1977	40.25	35.79	16.35	24.63	14.13	6.23	3.69	4.36	12.45	9.76	7.81	6.25	4.98	1.15	0.87	0.68	0.53	0.43	0.39	0.31	1.44
1978	45.69	33.57	29.83	13.55	19.94	11.31	4.97	2.94	3.48	9.94	7.78	6.23	4.98	3.97	0.92	0.70	0.55	0.42	0.34	0.31	1.39
1979	38.60	38.08	27.96	24.64	10.84	15.71	8.88	3.90	2.31	2.73	7.77	6.08	4.86	3.88	3.09	0.71	0.54	0.42	0.33	0.26	1.32
1980	22.68	32.17	31.72	23.09	19.72	8.54	12.34	6.97	3.06	1.81	2.13	6.07	4.74	3.78	3.02	2.40	0.56	0.42	0.33	0.25	1.23
1981	15.02	18.89	26.78	26.11	18.25	15.27	6.59	9.50	5.36	2.35	1.39	1.63	4.63	3.62	2.88	2.30	1.83	0.42	0.32	0.25	1.13
1982	7.56	12.51	15.72	22.00	20.50	14.00	11.66	5.02	7.24	4.08	1.78	1.05	1.23	3.49	2.72	2.17	1.73	1.37	0.32	0.24	1.03
1983	5.10	6.29	10.41	12.91	17.27	15.72	10.69	8.90	3.83	5.52	3.11	1.36	0.80	0.94	2.67	2.08	1.65	1.32	1.05	0.24	0.97
1984	7.96	4.25	5.24	8.56	10.17	13.30	12.06	8.19	6.82	2.94	4.23	2.38	1.04	0.61	0.72	2.04	1.59	1.27	1.01	0.80	0.93
1985	16.08	6.64	3.54	4.34	6.94	8.15	10.64	9.64	6.55	5.45	2.35	3.38	1.91	0.83	0.49	0.58	1.63	1.27	1.01	0.81	1.38
1986	20.41	13.42	5.54	2.94	3.55	5.64	6.62	8.63	7.82	5.32	4.42	1.91	2.75	1.55	0.68	0.40	0.47	1.33	1.03	0.82	1.78
1987	11.85	17.04	11.20	4.61	2.43	2.91	4.62	5.42	7.07	6.40	4.35	3.62	1.56	2.25	1.27	0.55	0.33	0.38	1.09	0.85	2.13
1988	7.72	9.89	14.22	9.32	3.80	1.99	2.38	3.78	4.43	5.78	5.24	3.56	2.96	1.28	1.84	1.04	0.45	0.27	0.31	0.89	2.43
1989	6.99	6.45	8.25	11.84	7.70	3.12	1.63	1.96	3.11	3.64	4.75	4.31	2.93	2.43	1.05	1.51	0.85	0.37	0.22	0.26	2.73
1990	9.57	5.84	5.38	6.89	9.89	6.43	2.60	1.35	1.61	2.54	2.97	3.88	3.51	2.39	1.98	0.85	1.23	0.69	0.30	0.18	2.43
1991	14.36	7.99	4.88	4.50	5.76	8.25	5.33	2.12	1.09	1.30	2.04	2.39	3.12	2.82	1.92	1.60	0.69	0.99	0.56	0.24	2.10
1992	5.65	11.99	6.67	4.07	3.75	4.80	6.83	4.35	1.72	0.88	1.04	1.64	1.92	2.50	2.27	1.54	1.28	0.55	0.79	0.45	1.87
1993	4.33	4.72	10.02	5.57	3.40	3.14	4.00	5.68	3.61	1.42	0.73	0.86	1.36	1.59	2.06	1.87	1.27	1.05	0.45	0.65	1.91
1994	3.93	3.62	3.94	8.37	4.66	2.84	2.61	3.33	4.71	2.98	1.17	0.59	0.70	1.10	1.28	1.66	1.50	1.02	0.84	0.36	2.05
1995	3.94	3.28	3.02	3.29	6.99	3.89	2.36	2.15	2.72	3.83	2.41	0.94	0.48	0.56	0.88	1.03	1.33	1.20	0.81	0.67	1.92
1996	5.51	3.29	2.74	2.52	2.75	5.83	3.23	1.95	1.77	2.23	3.12	1.96	0.76	0.39	0.45	0.71	0.82	1.07	0.96	0.65	2.08
1997	5.45	4.61	2.75	2.29	2.11	2.30	4.86	2.69	1.62	1.46	1.83	2.55	1.60	0.62	0.31	0.37	0.57	0.66	0.86	0.77	2.20
1998	4.81	4.55	3.85	2.30	1.91	1.76	1.92	4.04	2.22	1.33	1.20	1.49	2.07	1.29	0.50	0.25	0.29	0.46	0.53	0.69	2.36
1999	4.81	4.02	3.80	3.21	1.92	1.60	1.47	1.59	3.33	1.82	1.08	0.97	1.20	1.65	1.03	0.40	0.20	0.23	0.36	0.42	2.39

Males

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1971	14.20	18.28	56.61	47.01	38.46	30.97	24.75	5.71	4.32	3.39	2.62	2.12	1.95	1.53	1.21	0.99	0.82	0.69	0.57	0.48	2.41
1972	18.27	11.84	15.23	46.85	37.95	30.56	24.49	19.55	4.51	3.41	2.68	2.07	1.67	1.54	1.21	0.96	0.79	0.65	0.54	0.45	2.29
1973	31.69	15.21	9.85	12.53	36.93	29.11	23.26	18.61	14.85	3.43	2.59	2.03	1.57	1.27	1.17	0.92	0.73	0.60	0.50	0.41	2.09
1974	43.32	26.39	12.66	8.12	9.98	28.76	22.53	17.97	14.37	11.47	2.65	2.00	1.57	1.22	0.98	0.91	0.71	0.57	0.46	0.39	1.94
1975	23.61	36.05	21.95	10.40	6.38	7.62	21.79	17.03	13.58	10.86	8.67	2.00	1.51	1.19	0.92	0.74	0.69	0.54	0.43	0.35	1.77
1976	42.99	19.66	30.00	18.06	8.21	4.91	5.81	16.59	12.97	10.34	8.27	6.60	1.52	1.15	0.91	0.70	0.57	0.53	0.41	0.33	1.62
1977	40.25	35.79	16.35	24.68	14.26	6.32	3.75	4.43	12.64	9.88	7.87	6.30	5.03	1.16	0.88	0.69	0.54	0.43	0.40	0.32	1.49
1978	45.69	33.57	29.83	13.56	20.05	11.44	5.05	2.99	3.54	10.09	7.88	6.28	5.03	4.01	0.93	0.70	0.55	0.43	0.35	0.32	1.45
1979	38.60	38.08	27.96	24.67	10.91	15.84	8.99	3.96	2.35	2.77	7.91	6.18	4.93	3.94	3.15	0.73	0.55	0.43	0.34	0.27	1.39
1980	22.68	32.17	31.72	23.12	19.84	8.62	12.46	7.06	3.11	1.84	2.18	6.20	4.84	3.86	3.09	2.47	0.57	0.43	0.34	0.26	1.30
1981	15.02	18.89	26.78	26.15	18.39	15.42	6.65	9.60	5.44	2.39	1.42	1.67	4.77	3.72	2.97	2.37	1.90	0.44	0.33	0.26	1.20
1982	7.56	12.51	15.72	22.04	20.68	14.17	11.80	5.08	7.33	4.15	1.82	1.08	1.27	3.63	2.84	2.26	1.81	1.44	0.33	0.25	1.11
1983	5.10	6.29	10.41	12.93	17.42	15.93	10.84	9.00	3.88	5.59	3.16	1.39	0.82	0.97	2.77	2.17	1.73	1.38	1.11	0.26	1.05
1984	7.96	4.25	5.24	8.57	10.25	13.47	12.23	8.31	6.90	2.97	4.28	2.43	1.07	0.63	0.75	2.13	1.67	1.33	1.06	0.85	1.00
1985	16.08	6.64	3.54	4.34	6.97	8.24	10.79	9.78	6.65	5.52	2.38	3.43	1.94	0.85	0.51	0.60	1.71	1.33	1.06	0.85	1.49
1986	20.41	13.42	5.54	2.95	3.56	5.68	6.69	8.76	7.94	5.39	4.48	1.93	2.78	1.58	0.69	0.41	0.49	1.39	1.08	0.86	1.90
1987	11.85	17.04	11.20	4.61	2.43	2.92	4.65	5.48	7.17	6.50	4.41	3.67	1.58	2.28	1.29	0.57	0.34	0.40	1.14	0.89	2.26
1988	7.72	9.89	14.22	9.32	3.80	1.99	2.39	3.80	4.48	5.86	5.32	3.61	3.00	1.29	1.86	1.06	0.47	0.28	0.33	0.93	2.58
1989	6.99	6.45	8.25	11.85	7.71	3.13	1.64	1.97	3.13	3.69	4.82	4.37	2.97	2.47	1.06	1.53	0.87	0.38	0.23	0.27	2.89
1990	9.57	5.84	5.38	6.89	9.89	6.44	2.61	1.36	1.63	2.57	3.02	3.95	3.58	2.43	2.02	0.87	1.25	0.71	0.31	0.19	2.58
1991	14.36	7.99	4.88	4.50	5.76	8.26	5.36	2.16	1.12	1.33	2.09	2.45	3.19	2.89	1.96	1.63	0.70	1.01	0.57	0.25	2.23
1992	5.65	11.99	6.67	4.07	3.75	4.81	6.88	4.44	1.77	0.91	1.08	1.69	1.98	2.57	2.33	1.58	1.31	0.56	0.81	0.46	2.00
1993	4.33	4.72	10.02	5.57	3.40	3.14	4.01	5.73	3.69	1.47	0.76	0.89	1.40	1.64	2.13	1.93	1.31	1.08	0.47	0.67	2.03
1994	3.93	3.62	3.94	8.37	4.66	2.84	2.62	3.35	4.77	3.07	1.22	0.63	0.74	1.15	1.35	1.75	1.58	1.07	0.89	0.38	2.22
1995	3.94	3.28	3.02	3.29	6.99	3.89	2.37	2.17	2.76	3.92	2.51	1.00	0.51	0.60	0.94	1.10	1.42	1.29	0.87	0.72	2.11
1996	5.51	3.29	2.74	2.52	2.75	5.83	3.24	1.97	1.80	2.28	3.23	2.06	0.82	0.42	0.49	0.77	0.90	1.16	1.05	0.71	2.31
1997	5.45	4.61	2.75	2.29	2.11	2.30	4.87	2.70	1.64	1.49	1.89	2.67	1.70	0.68	0.34	0.40	0.63	0.74	0.96	0.86	2.48
1998	4.81	4.55	3.85	2.30	1.91	1.76	1.92	4.06	2.25	1.36	1.24	1.56	2.20	1.40	0.56	0.28	0.33	0.52	0.60	0.78	2.73
1999	4.81	4.02	3.80	3.21	1.92	1.60	1.47	1.60	3.37	1.86	1.12	1.02	1.28	1.81	1.15	0.45	0.23	0.27	0.42	0.49	2.85

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 (Table 4.6). Since there are several areas of uncertainty surrounding this assessment, we select Model 3 for the basis for recommendations since it is the most conservative. The status of the projected spawning biomass in year 2000 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 81,300 tons. The current estimate of the year 2000 female spawning biomass is about 165,000 t.

To enhance the rebuilding potential of Greenland turbot in the EBS and Aleutian Islands region and given the continued downward abundance trend and no sign of recruitment to the EBS shelf, extra caution is warranted further developing this fishery. **We therefore recommend an ABC of 9,300 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. As additional survey information become available and signs of recruitment (perhaps from areas other than the shelf) are apparent, then we believe that the full ABC may be appropriate for this species. Also, the last area-swept quantitative survey in the adult habitat was conducted in 1991. NMFS plans to survey the slope region of the EBS again in the year 2000. This may provide improved insights on the status of the Greenland turbot stock.

Our recommendation for overfishing, based on the adjusted $F_{35\%}$ rate under Model 3, is **42,000 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 (Table 4.6).

Table 4.6. Yield estimates for the year 2000 (Y2K) based on different fishing mortality rates and model assumptions. The values in bold face were selected for ABC recommendations.

	Model 1	**Model 2**	**Model 3**
F	**Q=.25**	**Q=.50**	**Q=.75**
$F_{40\%}$	0.258	0.259	**0.259**
Y2K Yield 25% $F_{40\%}$	12,300	10,400	**9,300**
Y2K Spawn. Bio.	200,000	167,600	**165,000**
$B_{40\%}$	97,700	86,700	**81,300**

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 1999 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2000 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 1999. 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 2000, 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 2000 recommended in the assessment to the *max* F_{ABC} for 2000. (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 1994-1998 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 1999 (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 2000 and above its MSY level in 2010 under this scenario, then the stock is not overfished.)

Scenario 7: In 2000 and 2001, *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 2012 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 2000 spawning biomass estimated at 150,800 tons relative to ½ $B_{35\%}$ = 35,500 tons). Under the guidelines, since the year 2000 biomass estimate is well above the $B_{35\%}$ level (and $B_{40\%}$) we have determined that the stock is not overfished.

Table 4.7. Mean spawning biomass, F, and yield projections based on Model 3 for Greenland turbot, 1999-2012. 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 81,200 and 71,100 tons, respectively.

Sp.Biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
1999	165,366	165,366	165,366	165,366	165,366	165,366	165,366
2000	150,827	150,827	150,827	150,827	150,827	150,827	150,827
2001	117,174	135,910	129,333	136,965	142,844	111,868	117,174
2002	92,232	122,746	111,496	124,604	135,241	84,447	92,232
2003	74,421	111,703	97,311	114,150	128,526	65,833	71,182
2004	62,931	102,603	86,222	105,465	122,724	55,829	58,737
2005	57,261	96,118	78,582	99,265	118,707	51,316	52,990
2006	56,853	93,702	75,826	97,031	118,094	51,769	52,738
2007	60,227	95,133	77,445	98,579	120,850	55,705	56,237
2008	65,133	99,091	81,516	102,638	125,968	60,819	61,079
2009	70,013	104,313	86,536	107,970	132,385	65,564	65,668
2010	74,177	109,979	91,651	113,770	139,388	69,335	69,359
2011	77,398	115,544	96,361	119,501	146,475	72,022	72,011
2012	79,683	120,544	100,371	124,680	153,015	73,746	73,724
F							
1999	0.057	0.057	0.057	0.057	0.057	0.057	0.057
2000	0.258	0.064	0.129	0.054	0.000	0.319	0.258
2001	0.258	0.064	0.129	0.054	0.000	0.319	0.258
2002	0.258	0.064	0.129	0.054	0.000	0.319	0.319
2003	0.235	0.064	0.129	0.054	0.000	0.255	0.277
2004	0.197	0.064	0.129	0.054	0.000	0.214	0.226
2005	0.178	0.064	0.124	0.054	0.000	0.195	0.202
2006	0.176	0.064	0.119	0.054	0.000	0.197	0.201
2007	0.187	0.064	0.118	0.054	0.000	0.213	0.215
2008	0.200	0.064	0.120	0.054	0.000	0.232	0.233
2009	0.213	0.064	0.122	0.054	0.000	0.248	0.249
2010	0.222	0.064	0.124	0.054	0.000	0.260	0.261
2011	0.228	0.064	0.125	0.054	0.000	0.269	0.269
2012	0.233	0.064	0.126	0.054	0.000	0.274	0.274
Yield							
1999	9,000	9,000	9,000	9,000	9,000	9,000	9,000
2000	34,717	9,310	18,185	7,891	0	41,986	34,717
2001	27,355	8,445	15,734	7,212	0	31,670	27,355
2002	21,830	7,675	13,680	6,600	0	24,307	26,412
2003	16,333	7,004	11,994	6,062	0	15,673	18,201
2004	11,739	6,435	10,640	5,601	0	11,314	12,501
2005	9,750	6,037	9,398	5,278	0	9,581	10,219
2006	9,646	5,874	8,687	5,149	0	9,793	10,170
2007	10,717	5,897	8,777	5,175	0	11,257	11,477
2008	12,242	6,046	9,242	5,311	0	13,164	13,282
2009	13,756	6,284	9,847	5,521	0	14,973	15,027
2010	15,044	6,576	10,490	5,774	0	16,439	16,458
2011	16,073	6,888	11,090	6,043	0	17,536	17,539
2012	16,827	7,186	11,624	6,300	0	18,261	18,256

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 2006 (Fig. 4.10). The yield (fishing at the unadjusted $F_{40\%}$ harvest rate, with equal trawl and longline F levels) gives a broad range values and of future spawning stock sizes (Fig. 4.11). This yield drops as low as 10,000 t per year at less than half the current stock size and averages about 28,000 tons at the $B_{40\%}$ level. The shorter-term projection with a constant $F_{40\%}$ (unadjusted) results in a drop of yield to 11,000 t by the year 2004 based on Model 3 (Table 4.8). Under Scenarios 6 and 7, the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Table 4.8. Biomass and yield projections based on Model 3 levels for Greenland turbot, 1999-2012. Average recruitment levels were assumed and the full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed **equal**.

Year	**Spawning Biomass**	**Total Yield**	***F*** ($F_{40\%}$)
1999	165,366	9,000	0.057
2000	150,827	34,717	0.258
2001	117,174	27,355	0.258
2002	92,232	21,830	0.258
2003	74,421	16,333	0.235
2004	62,931	11,739	0.197
2005	57,261	9,750	0.178
2006	56,853	9,646	0.176
2007	60,227	10,717	0.187
2008	65,133	12,242	0.200
2009	70,013	13,756	0.213
2010	74,177	15,044	0.222
2011	77,398	16,073	0.228
2012	79,683	16,827	0.233

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 4.9).

Table 4.9. Estimated total Greenland turbot harvest by area, 1977-1998.

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

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. For Model 3 (slope survey Q=.75), the allocation would thus be:

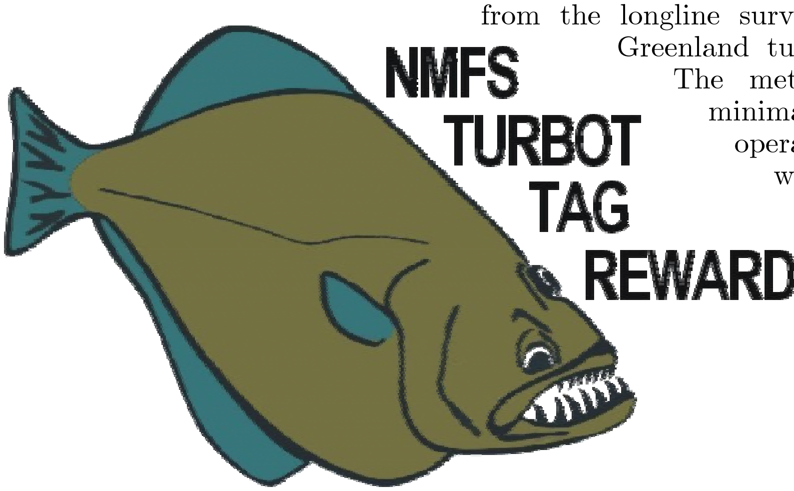
Aleutian Islands	3,100 t
Eastern Bering Sea	6,200 t
Total	9,300 t

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 multispecies model. Preliminary results from this effort indicate that Greenland turbot is an important predator.

Since the slope region of the Bering Sea has not been surveyed by trawl gear since 1991 and the cooperative longline survey in the Bering Sea region has been terminated, the sources of information needed for stock assessment continue to decline. The Eastern Bering Sea shelf survey gives some indication of recruitment, however, the extent to which Greenland turbot depend on this region as a "nursery" area is unclear. In 1996 the NMFS longline survey was extended to the Eastern Bering Sea and Aleutian Islands region (in alternate years). While this survey is designed for assessment of sablefish, the depth ranges covered also can provide a reasonable index for Greenland turbot (Ianelli and Wilderbuer 1995).



The NMFS Auke Bay Lab staff continued to conduct a feasibility study on tagging Greenland turbot from the longline survey in 1997 and have continued to tag Greenland turbot on an opportunistic basis in 1999. The methods seem to be working well with minimal interference with normal survey operations. This year 188 Greenland turbot were tagged and released bringing the total releases of this species in the last three years up to 549. We have developed some artwork (featured at left) for placement on a cap which will be issued for recapture rewards. The locations of the four known recaptured Greenland turbot from this effort are shown in Figure 12. 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 4.10. 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 4.10. 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
$B_{40\%}$	81,300 t
Year 2000 female spawning biomass	165,000 t
$F_{ABC} = F_{40\%} \times 25\%$	0.064
Recommended ABC	**9,300**
$F_{overfishing} = F_{35\%}$	0.32
Overfishing level	**42,000 t**

4.8. Acknowledgments

Mike Sigler compiled the summaries for the 1996-1999 longline survey data.

4.9. References

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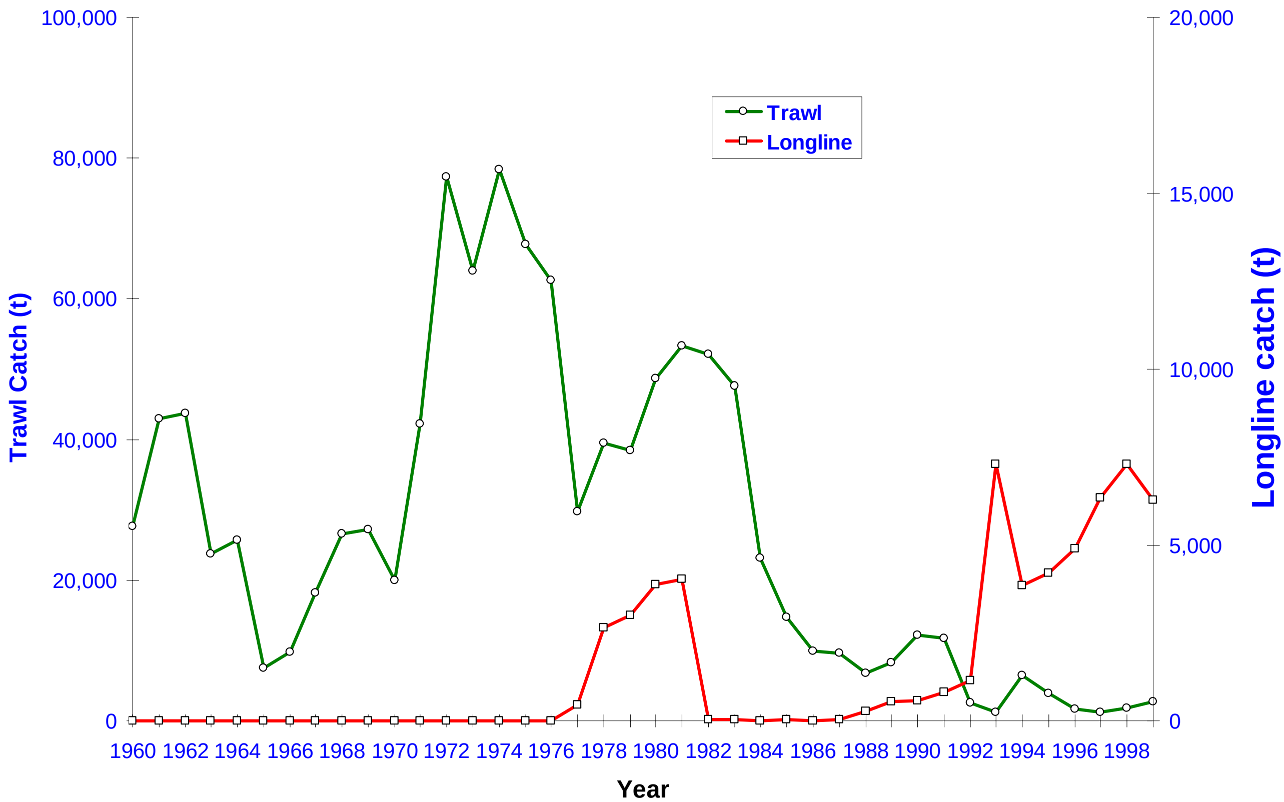

Figure 4.1. Comparison of trawl (1960-99) and longline (1977-99) catches of Greenland turbot in the combined EBS/AI area.

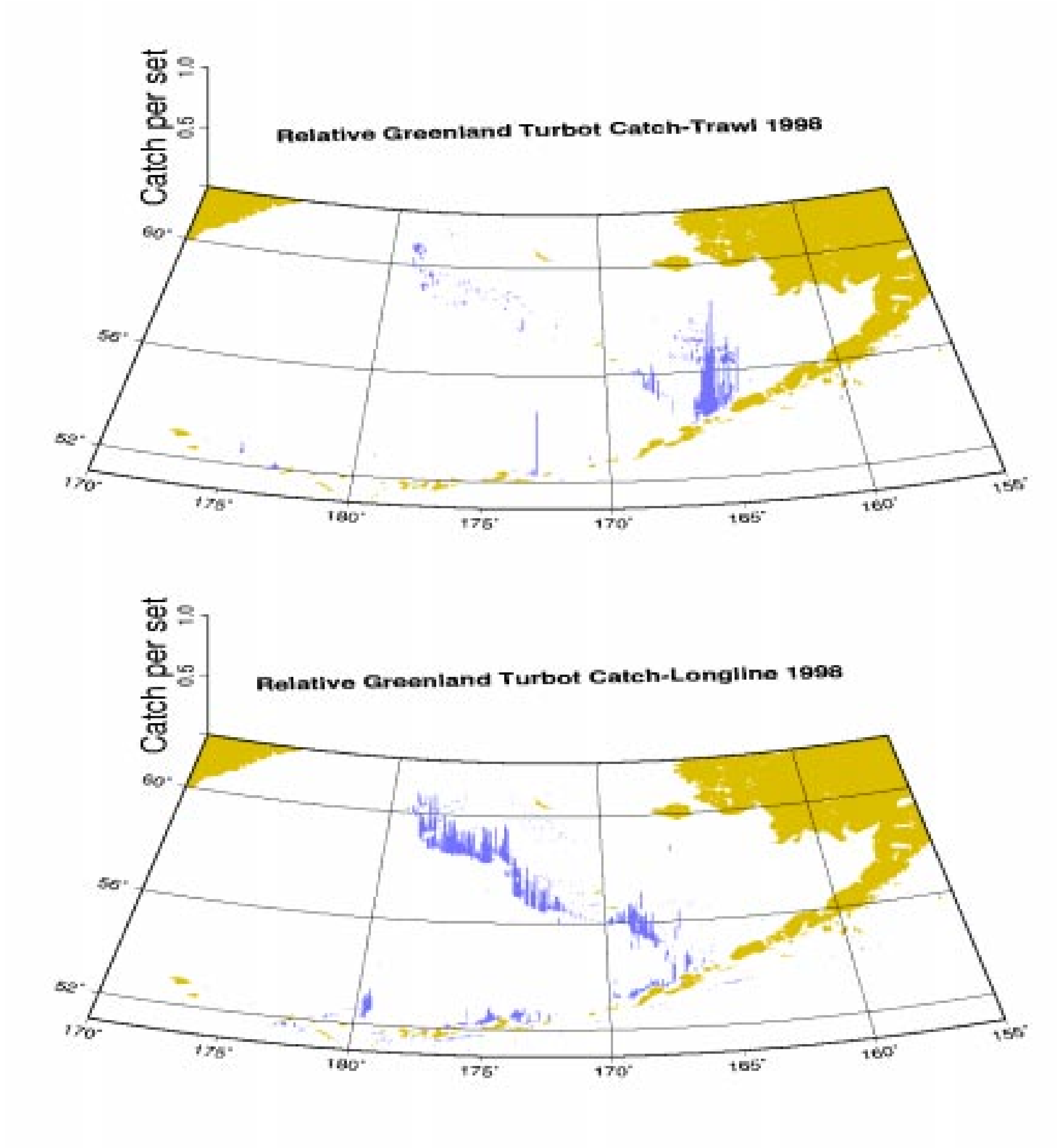

Figure 4.2. 1998 longline and trawl locations of successful Greenland turbot fishing operations based on NMFS observer data. Vertical lines represent the relative magnitude of Greenland turbot catch for each observed haul.

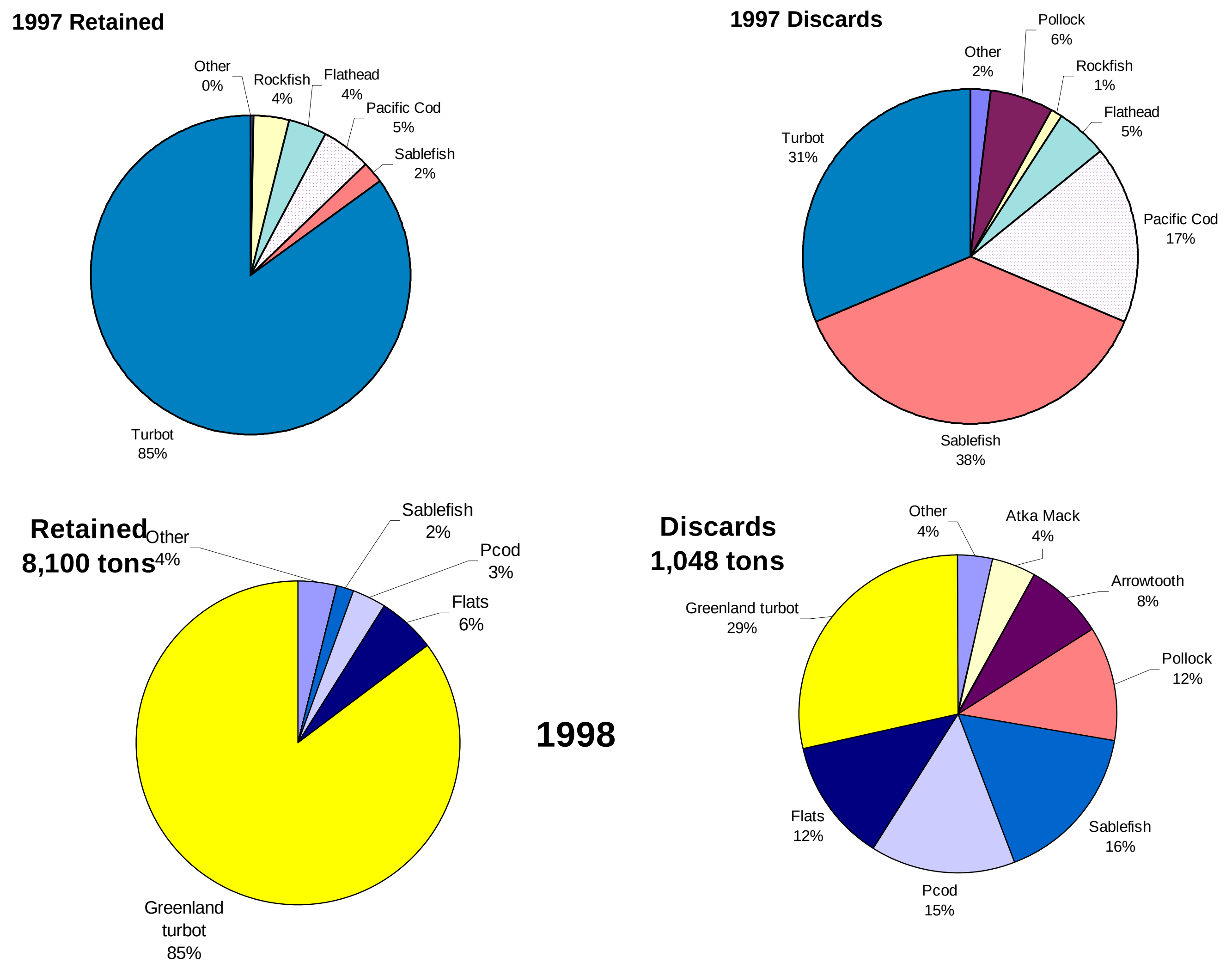

Figure 4.3. 1997 and 1998 retained and discarded Greenland turbot by directed fishery. (Source: AFSC blend database, NOTE: these totals differ slightly from those presented in the text due to differences between catch estimation done "in-season" and that done by analysis of observer *and* weekly processor reports)

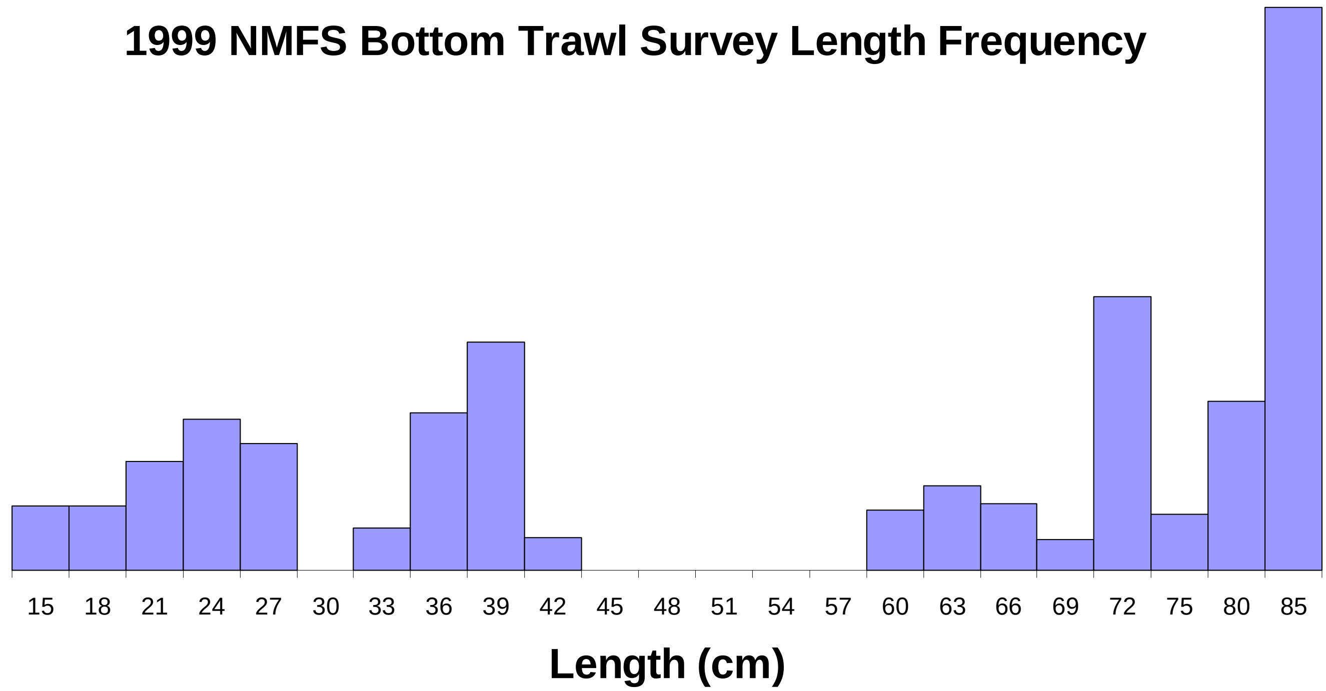

Figure 4.4. Length frequency of Greenland turbot observed from the summer 1999 NMFS bottom trawl survey. This year a total of 207 Greenland turbot were measured.

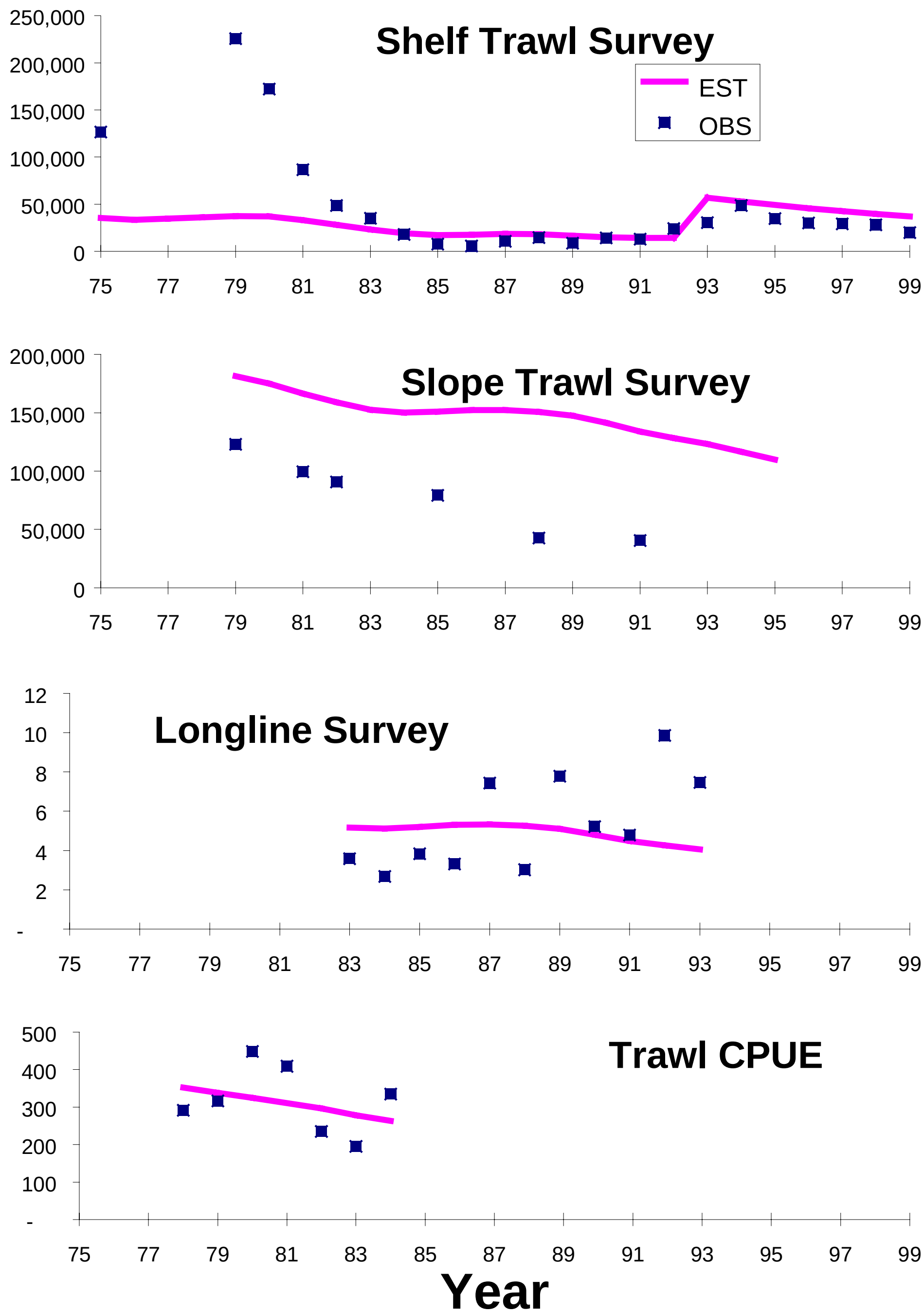

Figure 4.5. Model 3 fits to the different survey and fishery indices for Greenland turbot in the EBS/AI region. Note that the poor fit to the slope survey is due to the conservative assumption about survey Q=0.75.

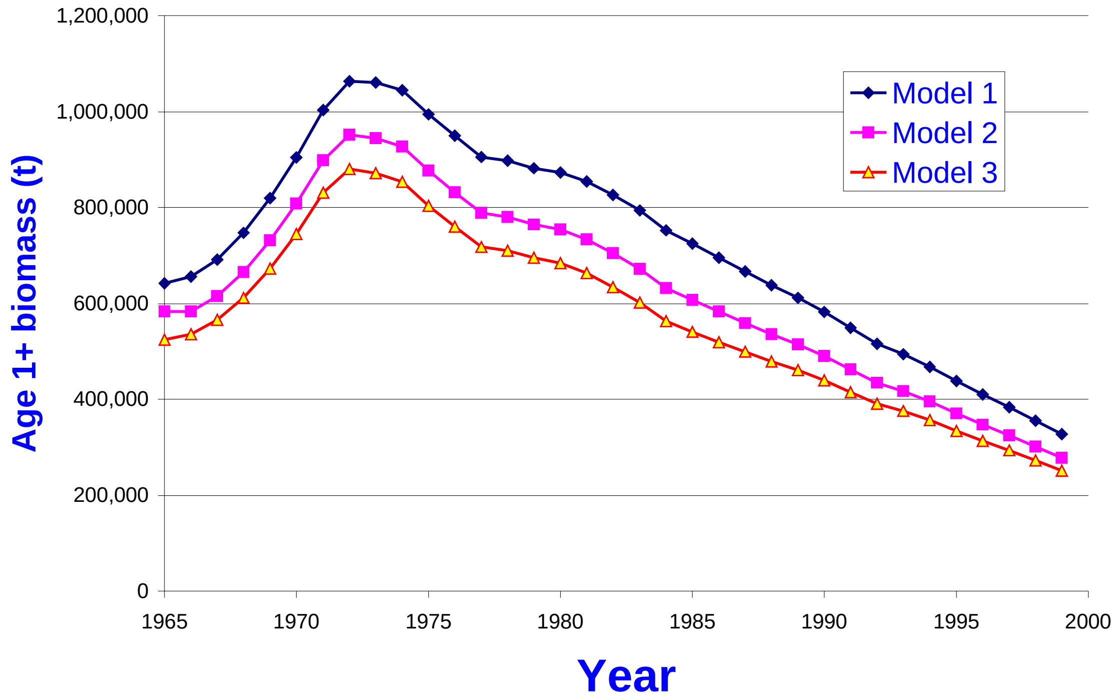

Figure 4.6 Total age 1+ biomass trend for the individual models of Greenland turbot in the EBS/AI region, 1965-1999.

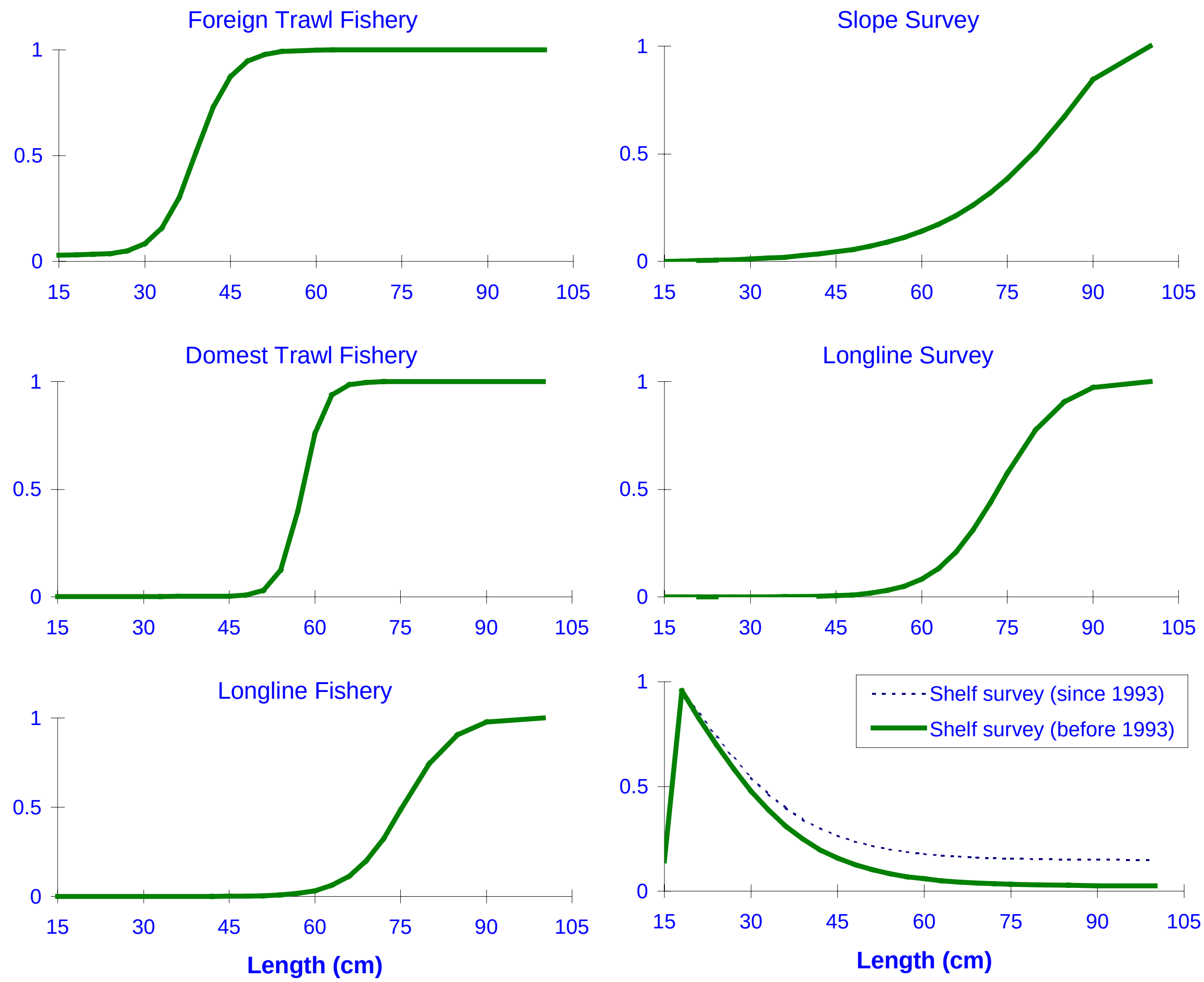

Figure 4.7. Size-specific selectivity patterns for surveys and fisheries of Greenland turbot in the EBS/AI region.

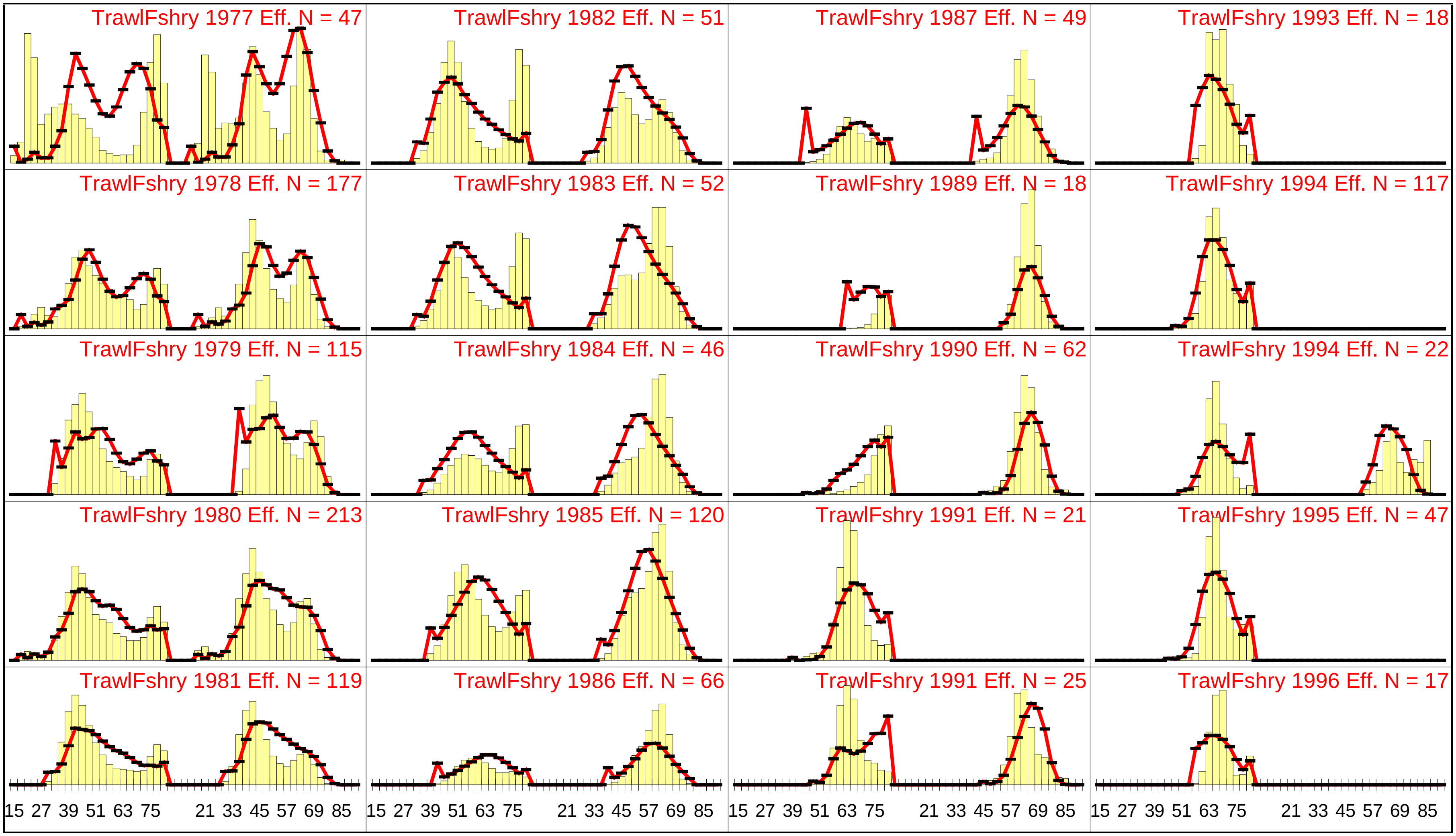

Figure 4.8. Fit to Greenland Turbot **trawl fishery** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes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

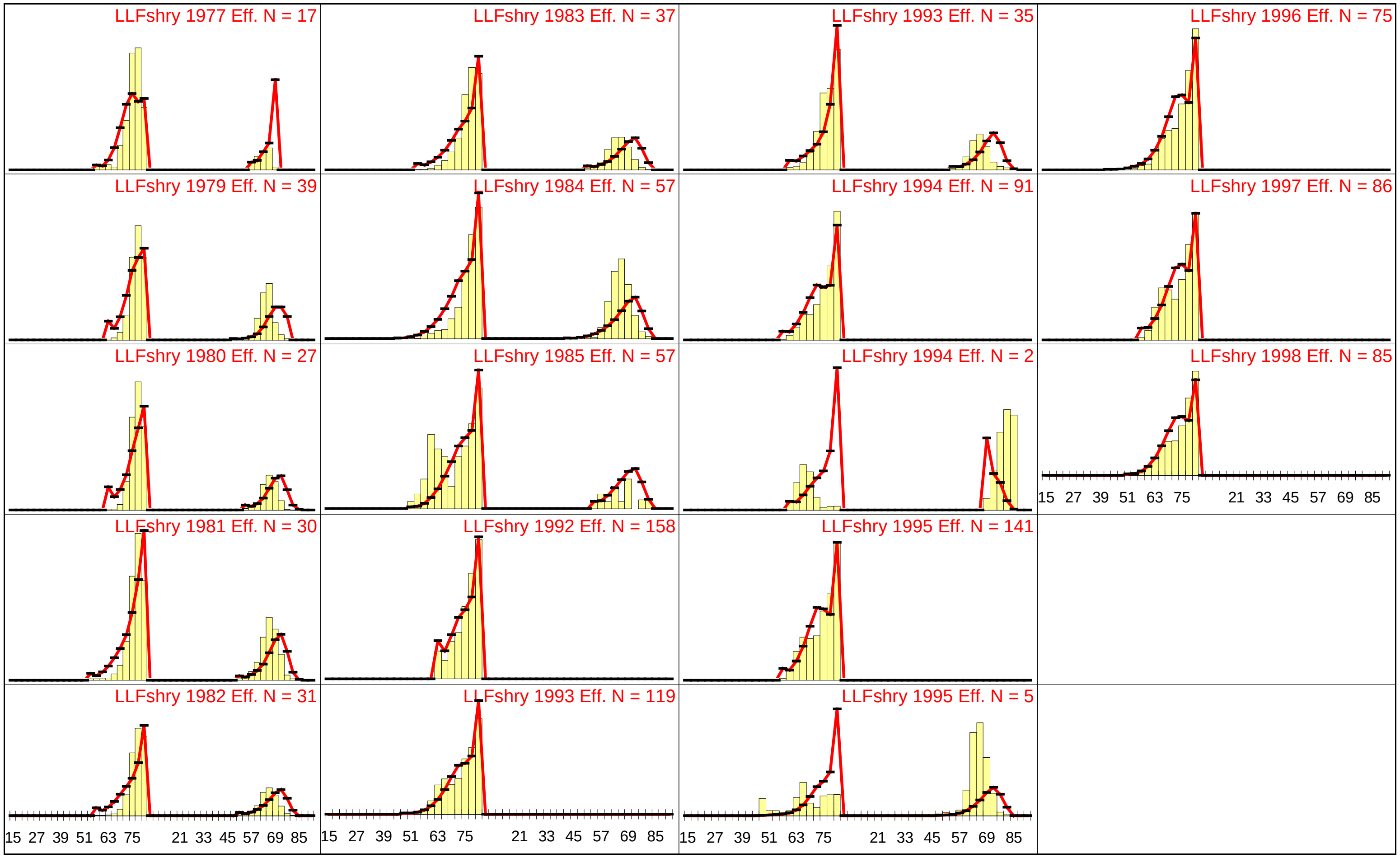

Figure 4.8. (cont'd) Fit to Greenland Turbot **longline fishery** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for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

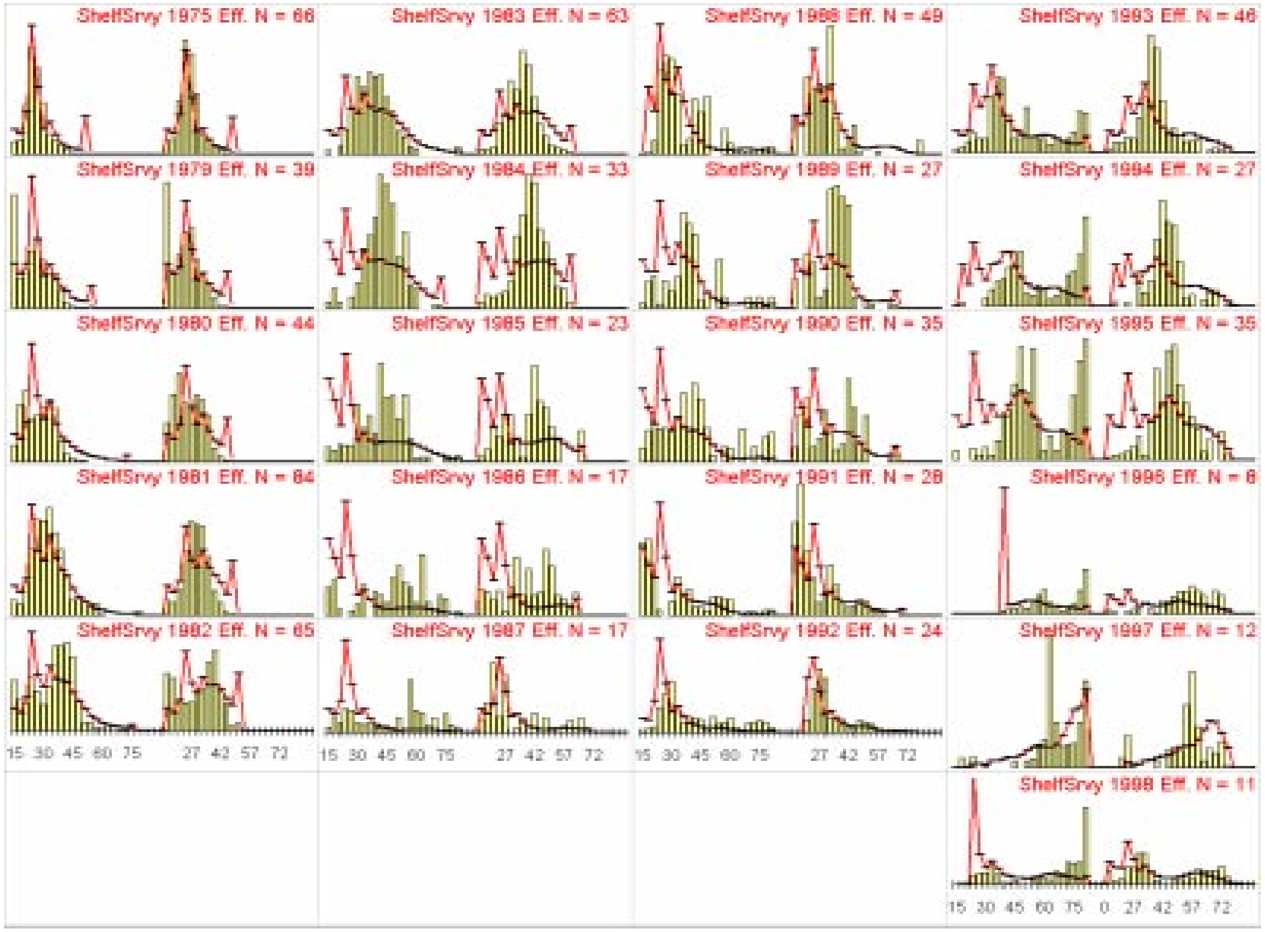

Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS shelf survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for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

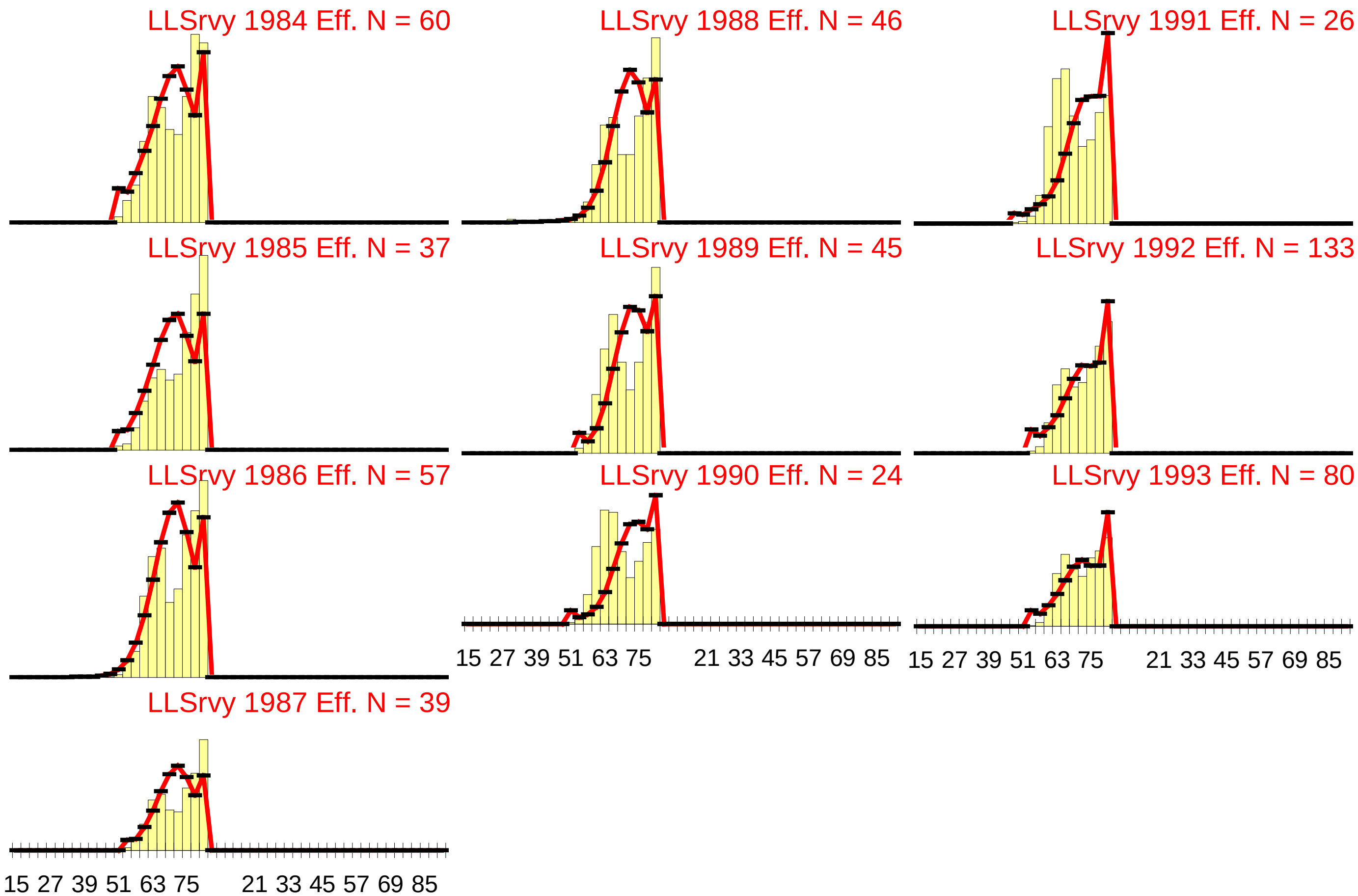

Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS longline survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are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

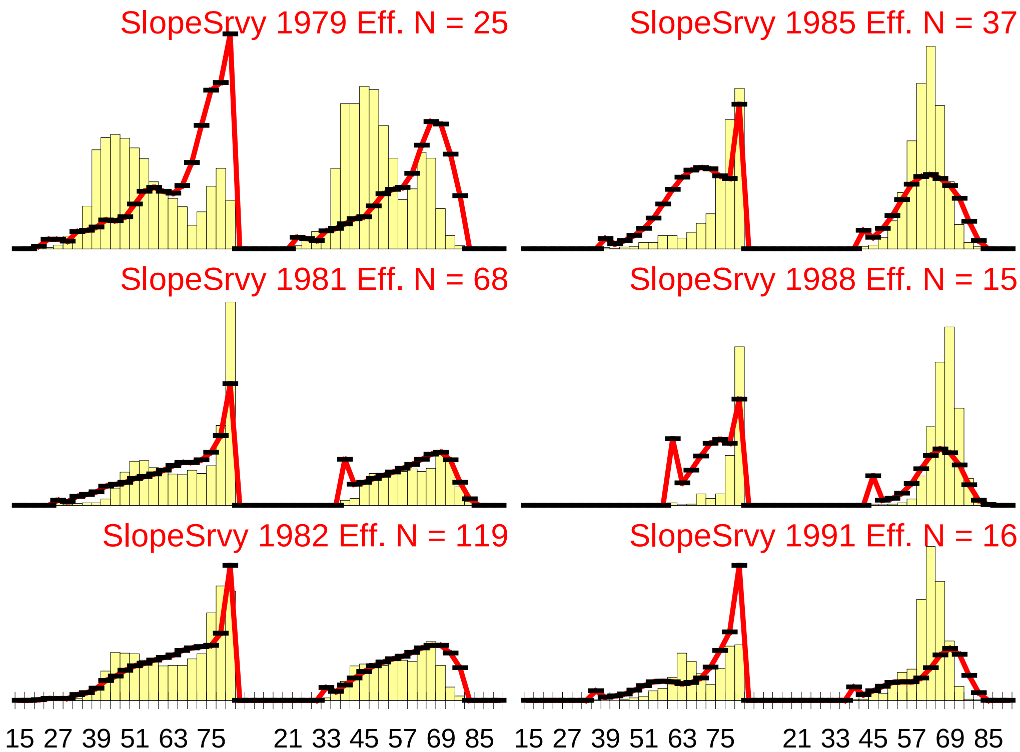

Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS slope trawl survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side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

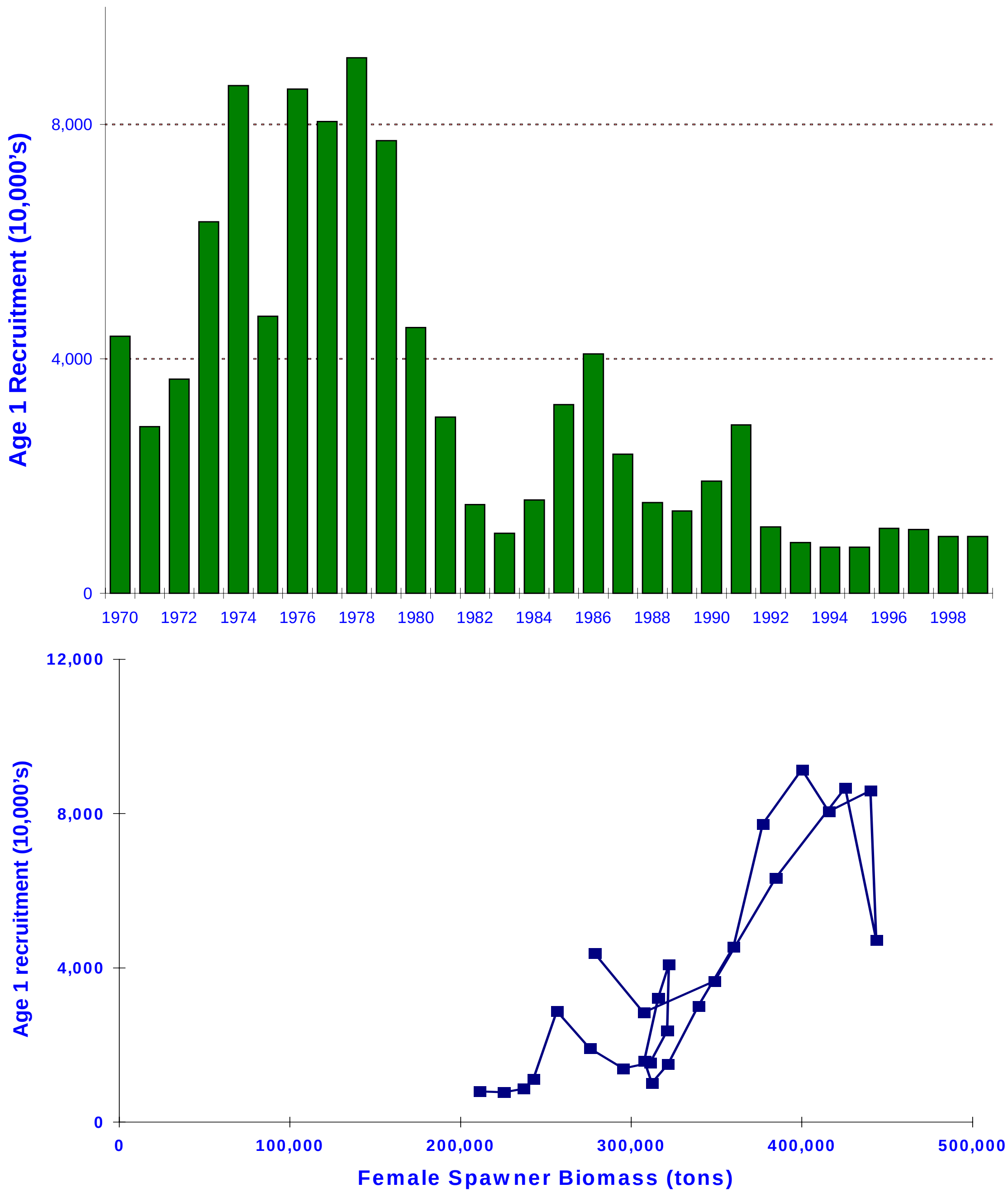

Figure 4.9. Model 3 estimated recruitment to age 1 (upper panel) and the observed stock-recruitment pattern (lower panel) of Greenland turbot in the EBS/AI region, 1970-1999.

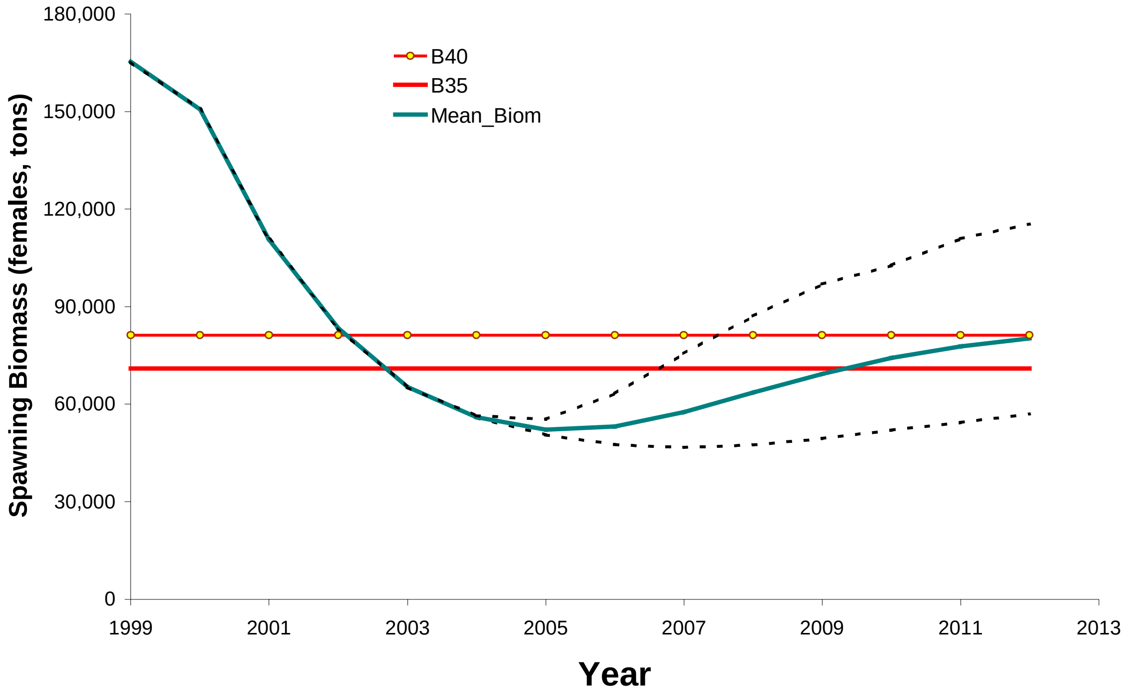

Figure 4.10. Stochastic trajectory of female spawning biomass and projected levels for maximum allowable fishing mortality rate under Amendment 56/56, Tier 3. These runs are based on Model 3 and assume relative fishing mortality rates between longline and trawl fishing gear is the same as the estimated 1999 value. The dashed lines represent the upper and lower 90% confidence limits.

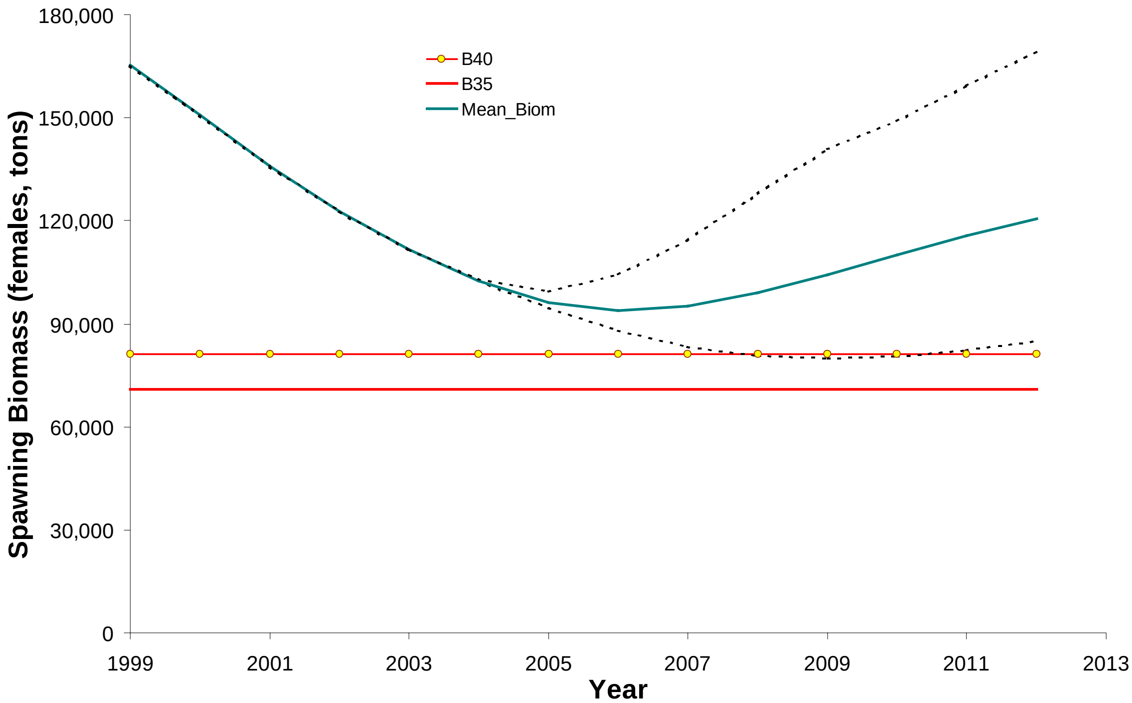

Figure 4.11. Stochastic trajectory of female spawning biomass and projected levels for 25% of the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3. These runs are based on Model 3 and assume relative fishing mortality rates between longline and trawl fishing gear is the same as the estimated 1999 value. The dashed lines represent the upper and lower 90% confidence limits.

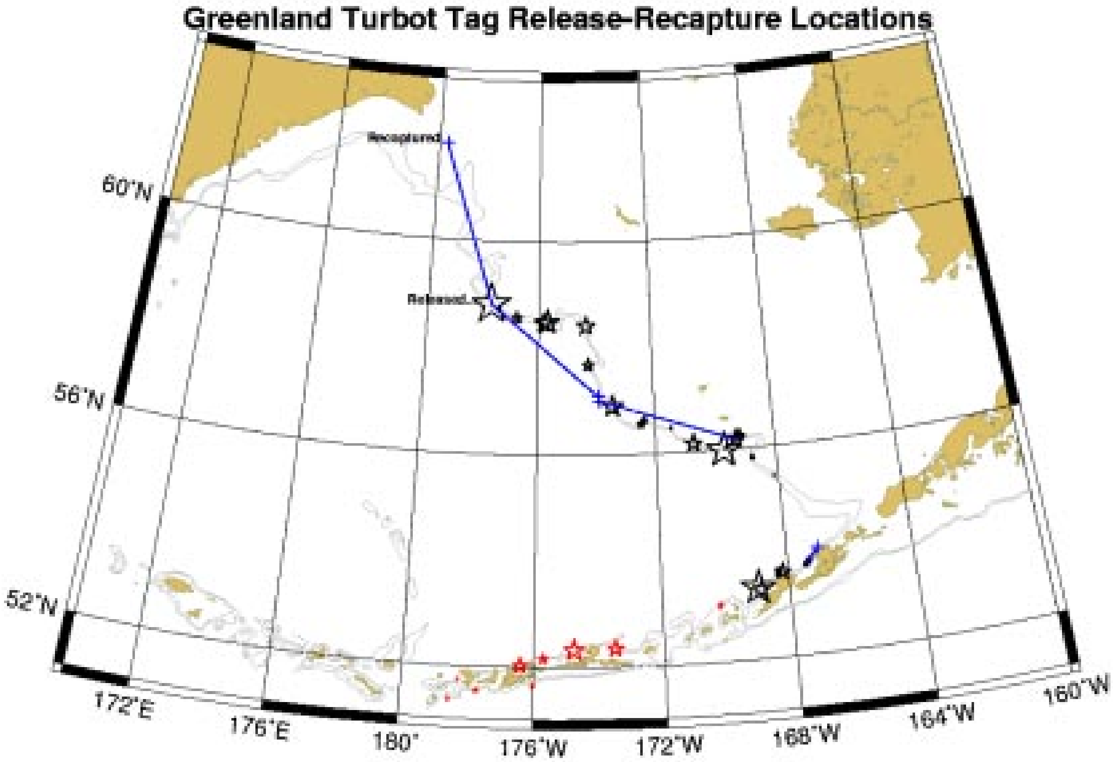

Figure 4.12. Release and recapture points (cross) of Greenland turbot in the EBS region. Size of stars represent relative number of released Greenland turbot, lines terminating with “+” signs represent recaptures.