Eastern Bering Sea
Walleye Pollock Stock Assessment

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Summary

As in the 1998 SAFE, the primary focus of this chapter is on the eastern Bering Sea region. The Aleutian Islands Region and Bogoslof Island area are treated separately in Sections 1.15 and 1.16 on pages 80 and 83, respectively.

The 1999 NMFS bottom-trawl survey estimates of population numbers at age were included for this assessment. In terms of biomass, the bottom-trawl survey estimate for 1999 is 3.57 million tons, up 61% from the 1998 estimate of 2.21 million. In addition, the EBS region was surveyed using the Echo-Integration trawl (EIT) methods. The biomass estimate from the 1999 EIT survey was 3.29 million tons, up 27% from the 1997 estimate (the last year that an EIT survey was conducted in this region). As expected, the most abundant age group in this survey was the 1996 year-class. While both survey methods showed promising increases in abundance, the water temperatures during the survey periods (summer of 1999) were the coldest ever experienced in all the years that NMFS has been surveying this region during summer months. These temperature anomalies may have affected the availability of pollock to the survey gear and consequently, may affect the biomass estimates.

The NMFS observer samples of pollock age and size composition were evaluated for the 1998 fishery and these data were included in the analyses. The estimates of weight-at-age from the fishery were also revised for 1998. The total catch estimate was updated for 1998, and for 1999 we assumed that the catch is equal to the 1999 TAC (992,000 t).

No substantive changes to the assessment model were made compared to the 1998 SAFE chapter. We made some minor modifications to the model configuration. First, we now use the annual estimates of bottom trawl survey variances (previously we used the average variance over

all years). Second, we added control over the time period used to fit the stock-recruitment parameters within the model. This was done so that the parameters reflected the fit to the current "regime" (since 1977). Previously we simply used the entire time-series since 1964.

Computations leading to the year 2000 ABC alternatives based on the $F_{40\%}$ and F_{msy} are **1,102** and **1,197** thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value). The year 2000 overfishing level (OFL) alternatives for the reference model are **1,471** and **1,678** thousand tons corresponding to $F_{35\%}$ and F_{msy} (arithmetic mean). These harvest level determinations fail to account for uncertainty in potential changes in harvest rates on the EBS stock outside of the US EEZ (particularly for pre-recruit age groups). Also, apparent declines in Steller sea lion populations in adjacent areas continues to cause concern since pollock are considered an important prey item. However, we believe a significant degree of uncertainty in future environmental conditions (due to recent observations of environmental change) has been factored into this assessment. We feel that appropriate precautionary measures accounting for stock assessment uncertainty have been implemented.

Recommended harvest levels for the Aleutian Islands region were computed in the same way as last year. The **ABC** and **OFL values are 23,760 t and 31,680 t,** respectively. For the Bogoslof region, we constructed three methods for harvest level determination: 1) the same method that has been used in the past; 2) from a simple age-structured analyses tuned to the Bogoslof Island winter survey age-compositions; and 3) the same method that is current used for the Aleutian Islands region (i.e., Tier 5). These methods gave results for the year 2000 ABC ranging from 14,200 t (old method) to 110,000 t (age structured method). The difference in these values is due to differences in the estimate of $B_{40\%}$ value. The old method assumed about 1 million tons (female spawning biomass) while the age structured method estimates a value of about 100,000 t.

At the December 1998 Council meeting, the SSC encouraged increased efforts on stock structure studies of pollock in the Bering Sea and adjacent areas. In September 1999 the Parties to the Central Bering Sea Convention held an international workshop on stock identification methods. This workshop addressed the current state-of-the-art techniques. A sampling protocol and exchange program between the countries was established. Problems were highlighted and efforts were made to keep management applications of stock-structure studies a high priority.

1.1. Introduction

The stock structure of Bering Sea pollock (*Theragra chalcogramma*) is not well defined. In the U.S. portion of the Bering Sea pollock are considered to form three stocks for management purposes. These are: eastern Bering Sea which consists of pollock occurring on the eastern Bering Sea shelf from Unimak Pass to the U.S.-Russia Convention line; Aleutian Islands Region which encompasses the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and Central Bering Sea -Bogoslof Island pollock, which are thought be a mixture of pollock that migrate from the U.S. and Russian shelves to the Aleutian Basin around the time of maturity. In the Russian EEZ, pollock are considered to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line. The northern stock is believed to be a mixture of eastern and western Bering Sea pollock with the former predominant. Currently, scientists at the AFSC are collaborating on a genetics study that will help clarify issues surrounding stock structure. In September 1999, scientists from countries belonging to the Central Bering Sea Convention convened a stock identification workshop in Yokohama, Japan, where they presented results of current research on pollock stock identification. This workshop addressed the current state-of-the-art techniques. A sampling protocol and exchange program between the countries was established. Problems were highlighted and efforts were made to keep management applications of stock-structure studies a high priority.

1.2. Catch history and fishery data

From 1954 to 1963, pollock were harvested at low levels in the Eastern Bering Sea and directed fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970-75 when catches ranged from 1.3 to 1.9 million t annually (Fig. 1.1). Following a peak catch of 1.9 million t in 1972, catches were reduced through bilateral agreements with Japan and the USSR.

Since the advent of the U.S. EEZ in 1977 the annual average eastern Bering Sea pollock catch has been 1.2 million t and has ranged from 0.9 million in 1987 to nearly 1.5 million t in 1990 while stock biomass has ranged from a low of 4-5 million to highs of 10-12 million t. Since implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977, catch quotas have ranged from 0.95 to 1.3 million t (Fig. 1.1). In 1980 United States vessels began harvesting pollock and by 1987 they were able to take 99% of the quota. Since 1988 the harvest has been taken exclusively by U.S. vessels.

Foreign vessels began fishing in the mid-1980s in the international zone of the Bering Sea (commonly referred to as the “Donut Hole”). The Donut Hole is entirely contained in the deep water of the Aleutian Basin and is distinct from the customary areas of pollock fisheries, namely the continental shelves and slopes. Japanese scientists began reporting the presence of large quantities of pollock in the Aleutian Basin in the mid-to-late 1970's, but large scale fisheries did not occur until the mid-1980's. In 1984, the Donut Hole catch was only 181 thousand t (Fig. 1.1, Table 1.1). The catch grew rapidly and by 1987 the high seas catch exceeded the pollock catch within the U.S. Bering Sea EEZ. The extra-EEZ catch peaked in 1989 at 1.45 million t and has declined sharply since then. By 1991 the donut hole catch was 80% less than the peak catch, and data for 1992 and 1993 indicate very low catches (Table 1.1). A fishing moratorium was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin by resource assessment fisheries.

Fishery characteristics

The general pattern of the fishery since 1995 has been to have an “A-season” opening on January 20th with the season lasting about 1 month, depending on the catch rate. A second “B-season” opening occurs on September 1st (though 1995 opened on Aug 15th).

A-Season: Since the closure of the Bogoslof management district (518) to directed pollock fishing in 1992, the A-season pollock fishery on the eastern Bering Sea (EBS) shelf has been concentrated primarily north and west of Unimak Island (Ianelli *et al.* 1998). Depending on ice conditions and fish distribution, there has also been effort along the 100 m contour between Unimak Island and the Pribilof Islands. This pattern has continued for the A-seasons of 1998 and 1999 (Figs. 1.2 and 1.3). The total catch estimates by sex for the A-season compared to the fishery as a whole indicates that over time, the number of males and female has been fairly equal with a slight tendency to harvesting males more than females in recent years (Fig. 1.4). The length frequency information from the fishery shows that the size of pollock is generally larger than 40 cm but with some smaller fish caught during years when a strong year-class appeared (Fig. 1.5).

B-Season: After 1992, the B-season fishery has been conducted to a much greater extent west of 170°W than it had been prior to 1992 (Ianelli *et al.* 1998). This is a reflection of the implementation of the CVOA in 1992, the distribution of pollock by size on the eastern Bering Sea shelf, and the desire of the fleet to catch pollock larger than 35 cm. The length frequency information from this fishery reveals the marked progression of the large 1989 year-class growing over time and the incursion of the 1992 year-class in 1996 and 1997 (Fig. 1.6).

1999 Fishery

The management and prosecution of the 1999 EBS/AI pollock fishery were significantly different from previous years. The American Fisheries Act was passed and measures to avoid jeopardy or adverse modification of habitat for the Steller sea lion population recovery were implemented. The latter measures were presented as reasonable and prudent alternatives (RPAs). Based on the RPAs presented to the Council in December 1998, a series of measures for the 1999 BSAI A-season were adopted by NMFS:

1) The Aleutian Islands were closed to direct pollock fishing.

2) The maximum percentage of A-season TAC that can be taken from the CH/CVOA was set at 62.5%, to be further reduced to 50% in 2000.

3) The A-season was divided into an A1 season (27.5% of the TAC) from January 20-February 15, and an A2 season (12.5% of the TAC) starting February 20 for the catcher-processor and onshore sectors; motherships had a single season starting February 1 and the CDQ sector could take it's A-season TAC at any time from January 20-April 15.

4) In the eastern Bering sea and eastern Aleutian Islands from 164°W-170°W (which includes portions of the western GOA), 20 nm pollock trawl exclusion zones were placed around 8 Steller sea lion haulouts year-round, around 7 haulouts during the summer (May 1-October 31), and 2 haulouts during the winter (November 1-April 30). A 10 nm year-round pollock trawl exclusion zone was also placed around Cape Sarichef in 1999, to be increased to 20 nm in 2000. These haulout pollock trawl exclusion zones are in addition to the seasonal 20 and year-round 10 nm all-trawl exclusion zones around eight rookeries.

The "B" season was also restructured. In 1999 the "B" season started August 1 with 30% of the TAC and a "C" seasons starting September 15 with 30% of the TAC was established for the eastern Bering Sea.

Spatial allocations were also established by the Council and NMFS to satisfy the RPA guidelines. These include a 2-year phase-in to reduce the percentage of pollock harvested within CH/CVOA:

Max. Seasonal TAC % from the CH/CVOA	1999	2000
B-Season	25%	15%
C-Season	35%	25%

NOTE: For the year 2000, the "B-season" will be called the "C-season" and the currently referenced "C-season" will be known as the "D-season".

1.2.1. Fisheries catch Data

Significant quantities of pollock are discarded and must be taken into account in estimation of population size and forecasts of yield. Observer length frequency observations indicated that discarded pollock include both large and small pollock. Since observers usually sample the catch prior to discarding, the size distribution of pollock sampled closely reflects that of the actual *total* catch. Discard data as compiled by the NMFS Alaska Regional Office have been included in estimates of total catch since 1990.

Pollock catch in the eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch, 1990-1998 are shown in Table 1.2. Discarded pollock since 1990 has ranged from a high of 11% of total pollock catch in 1991 to a low of 1.5% in 1998. This low value reflects the implementation of the Council's Improved Utilization and Improved Retention program. Discard rates may also be due to the age-structure of the available population. E.g., if the most abundant year-class in the population is below marketable size, smaller fish may be caught incidentally. With the implementation of the AFA, the fleets will have more time to pursue the sizes of fish they desire since they are guaranteed a fraction of the quota. In addition, several vessels have made gear modifications to avoid retention of smaller pollock. The magnitude of these discards is accounted for within the population assessment since these total harvest estimates are available by seasonal and spatial strata.

We estimate catch age composition using the methods described by Kimura (1989) and modified by Dorn (1992). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: 1) INPFC area 51 from January - June (the "A" season); 2) INPFC area 51 from July -December (the "B" season); and 3) INPFC area 52 from January - December. This method was used to derive the age compositions from 1991-1998 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch - age composition estimates as presented in Wespestad *et al.* (1996). Recently, we examined stratifying the fisheries catch data by month and NMFS survey areas as opposed to the normal fishery seasons and INPFC areas. The results from this work are preliminary but compared favorably with the current estimates of catch-at-age.

The time series of the proportion estimated at each age is presented in Fig. 1.7. Data values used in the age-structured model for catch-at-age for 1964-1998 are given in Table 1.3. while the sampling effort for the lengths and processed otoliths are shown in Table 1.4.

1.3. Resource surveys

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 surveys in the Bering Sea and Aleutian Islands Region (tons):

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Bering Sea	15	94	458	139	466	682	508	208	435	163	174
Aleutian Islands				193		40	454			292	

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Bering Sea	467	393	369	465	156	221	267	249	206	262	121	162
Aleutian Islands				51			48			36		

Since these values represent extremely small fractions of the total removals (~0.02%), they are not explicitly added to the total removals by the fishery.

1.3.1. Bottom trawl surveys

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea. Until 1975 the survey only covered a portion of the pollock range. In 1975 and since 1979, the survey was expanded to encompass most of the range of pollock. Since 1984 the biomass estimates have been relatively high and showed an increasing trend through 1990 (Table 1.5). Between 1991 and 1996 the bottom trawl survey biomass estimate has ranged from 3.2 to 5.5 million t. The biomass estimate from the 1999 EIT survey was 3.29 million tons, up 27% from the 1997 estimate (the last year that an EIT survey was conducted in this region). Overall, a general decline in stock size has become apparent in the past few years relative to the first half of the 1990's (Fig. 1.8).

The general distribution of walleye pollock in 1999 was unusual compared to the average distribution observed since 1982 (Fig. 1.9). Specific anomalies in pollock distribution include somewhat higher catch rates around St. Matthew Is. than usual, and the absence of pollock extending into Bristol Bay and on the upper shelf. This pattern is typical of cold years. In fact, the average bottom temperature in 1999 was lower than any other observed by NMFS summer surveys in the EBS. The mean bottom temperature was 0.81°C compared to 3.26°C last year (a very warm year) and 2.54°C for the average of the entire 1982-1998 time series. This may have affected the distribution of pollock observed in the survey. Several other species exhibited significant changes in distribution—primarily with fewer fish observed on the inner shelf regions. The vast majority of the pollock abundance was on the outer shelf in 1999 (100-200m; Fig. 1.9).

The age composition from the 1999 survey showed increases over the 1998 estimate, particularly for the fish aged 6 years and younger (Fig. 1.10). This is expected due to the increasing availability to the bottom trawl survey gear with age, but may also be related to the large difference in the thermal structure in the Bering Sea in 1999 (cold, somewhat stratified) compared to 1998 (warm, well mixed). The level of sampling for lengths and ages in the bottom-trawl survey is shown in Table 1.6.

Since we now have accumulated several years of data from our bottom trawl surveys, we conducted some analyses on the mortality of the 1982-1990 cohorts based only on survey data. This involved simply regressing the log-abundance *as measured by the trawl survey alone* of age 6 and older pollock against age for each of these cohorts. This provides some measure of the total mortality for these cohorts independent of the stock assessment model and fishery data. The total mortality shows somewhat of an increasing trend for these cohorts with a mean total instantaneous value around 0.45 (Fig. 1.11). These values are consistent with the types of values obtained from within the assessment models for total mortality (though the model values tend to be somewhat higher, averaging about 0.5 for these cohorts).

1.3.2. Echo-integration trawl (EIT) surveys

Whereas bottom trawl surveys are conducted annually and assess pollock from the bottom to 3 m off bottom, EIT surveys have been conducted approximately triennially since 1979 to estimate pollock in midwater (Traynor and Nelson 1985). During the 1990s, EIT summer surveys have been conducted in 1991, 1994, 1996, 1997, and 1999.

The details and preliminary research results from the 1999 EIT survey are summarized in the Appendix. Briefly, the 1999 survey operated from 12 June – 29 July westward from Port Moller, Alaska to the U.S./Russia Convention Line. Biomass of pollock in midwater (from 14m below the surface to 3 m from the bottom) was estimated at 3.29 million tons with 2.41 million tons (72%) west of 170° W longitude. The EIT survey estimated that 11% of the biomass was within the CH/CVOA (360,000 tons). The time series of estimated EIT survey proportions at age is presented in Fig. 1.12. The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.7. At the time of this writing, the ageing of otolith collections from the 1999 EIT survey has not been completed. Since we feel this information is critical to our estimates of future stock outlook, we derived preliminary age-composition estimates by applying the age-length key derived from the NMFS 1999 bottom trawl survey. While there may be differences, we expect these to be on the order of normal sampling error levels. For model sensitivity, we include a run (Model 0, below) which ignores these preliminary age compositions (as presented in Fig. 1.12).

We examined the spatial abundances of pollock observed from the EIT survey and found patterns similar to the bottom trawl survey. That is, the abundance of pollock was lower than normal on the inner portions of the shelf and did not extend very far into the Bristol Bay region. We also examined pollock fishing locations (as observed by NMFS observers) in 1999 relative to the densities observed by the EIT survey (Fig. 1.13). This showed that for July, where both the (CDQ) fishery and survey overlapped, the operations were close to the areas of high density. In August, the fishery shifted to areas where the pollock densities were observed to be lower by the EIT survey one month earlier. This may reflect pollock movements and may also be due to different age-groups being targeted by the fishery compared to what the EIT survey observes (generally smaller fish).

1.4. Analytic approach

1.4.1. Model structure

The SAM analysis was first introduced in the 1996 SAFE (Ianelli 1996) and was compared with the cohort-analysis method that has been used extensively for pollock in past years. Since the cohort-analyses methods can be thought of as special cases of the SAM analysis (e.g., as shown in Ianelli 1997), we have not continued the use of VPA/cohort algorithms due to their limitations in dealing with many aspects of data in a statistical sense. The statistical age-structured approach has also been documented from analyses performed on simulated data for the Academy of Sciences National Research Council (Ianelli and Fournier 1998). Other changes from last year's analyses include:

- The 1999 EBS bottom trawl survey estimate of population numbers-at-age was included.
- The 1999 EBS EIT survey estimate of population numbers-at-age was included (preliminary values).

The technical aspects of this model are presented in Appendix 1 and have been presented previously (Ianelli 1996, and Ianelli and Fournier 1998). Briefly, the model structure is developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++.

1.4.2. Parameters estimated independently

Natural Mortality and maturity at age

We assumed fixed natural mortality-at-age values based on studies of Wespestad and Terry (1984). These provide estimates of M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively. These values have been used since 1982 in catch-age models and forecasts and appear to approximate the true rate of natural mortality for pollock. Recent studies on Gulf of Alaska pollock indicate that natural mortality may be considerably higher when predators are taken explicitly into account. This may also hold for the EBS region, however, the abundance of pollock is proportionately much higher than all other fish species compared to the Gulf of Alaska. This may explain why cannibalism is much more common in the EBS than in the Gulf. Note that to some degree, the role of cannibalism is modeled through the implementation of a Ricker (1975) stock-recruitment curve. This curve can take the form where having higher stock sizes may result in lower average recruitment levels.

Maturity at age was assumed the same as that given in Wespestad (1995). These values are given here together with the baseline assumption of natural mortality-at-age:

Age	1	2	3	4	5	6	7	
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	
Prop. Mature	0.000	0.008	0.290	0.642	0.842	0.902	0.948	
Age	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
M	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop. Mature	0.964	0.970	1.000	1.000	1.000	1.000	1.000	1.000

Length and Weight at Age

Length, weight, and age data have been collected extensively for pollock. Samples of length-age and weight-length data within each stratum indicate growth differences by sex, area, and year-class. General patterns have been that pollock in the northwest area are slightly smaller at age than in the southeast. Since our estimates of harvests-at-age are stratified by area (and season), these differences are taken into account before analyses within the model. For the fishery, we use year (when available) and age-specific estimates of average weights at age as computed from the fishery age and length sampling programs. These values are shown in Table 1.8 and are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight). Since we do not assume a fishery catch-effort relationship explicitly, the fishing mortality rates depend largely on the total annual harvests by weight. For the bottom-trawl and EIT surveys, we tune the model to estimates of total numbers of fish.

1.4.3. Parameters estimated conditionally

For the reference model presented here, 637 parameters were estimated. These include vectors describing recruitment variability in the first year (as ages 2-15 in 1964) and the recruitment deviations (at age 1) from 1964-1999. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (2000-2004). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1964 (that comprises the initial age composition in that year) to have a mean value different from subsequent years. Thus, 58 parameters comprise initial age composition and subsequent recruitment values.

Fishing mortality is parameterized to be semi-separable. That is, there is a year component and an age (selectivity) component. The age component is allowed to vary over time with changes allowed every three years. The age component is constrained such that its mean value will be equal to one, this means that it will not be confounded with the time component (see Section 1.14, Model details). In addition, we assume that the age-component parameters are constant for the last 4 age groups (ages 12-15). Therefore, the time component of fishing mortality numbers 36 parameters (estimable since we place low variance on the likelihood component on the total catch biomass) and the added age-time component of variability results in a matrix 12x11 matrix of 132 parameters. This brings the total fishing mortality parameters to 168. Please note however, that in standard cohort analyses such as that of Pope (1972) the number of parameters for a similarly dimensioned problem would be 36x15 or 540 fishing mortality parameters. Of course in a VPA, these parameters are not estimated statistically, rather implicitly using an algorithm that assumes no errors in the total catch-at-age.

For the bottom trawl survey, a similar parameterization for the selectivity-at-age estimates includes an overall catchability coefficient, age and year specific deviations in the average availability-at-age which totals 188 parameters for these data. Similarly, for the EIT survey, which began in 1979, these parameters number 221. Estimates for changes in EIT selectivity sometimes occur for years when the survey was not conducted. This increases the number of parameters we estimate, but avoids problems associated with surveys occurring on irregularly spaced intervals. The idea of estimating these changes is to allow some continuity in unaccounted-for variability of fish available to our survey gear. That is, we expect things to change in this regard but our null hypothesis is that the survey operation is constant with respect to relative changes in age class availability.

Finally, 2 additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$ and $F_{35\%}$ harvest rates. These rates satisfy the constraint that given selectivity-at-age vector (we used the mean selectivities based on model configuration), proportion-mature-at-age, natural mortality rate, and weight at age, there are unique values that correspond to the fishing mortality rates.

The likelihood components can thus be partitioned into the following groups:

- Total catch biomass (Log normal, σ=0.05)
- Bottom trawl survey variances (annual estimates of standard error, as represented in Fig. 1.8) and an assumed variance for the EIT survey abundance index, (i.e., Log normal, σ=0.2)
- Fishery and survey proportions-at-age estimates (Robust quasi-multinomial (effective sample size of 200 for fishery, 30 for surveys). These values were selected based on comparisons of catch-at-age variance estimates obtained from the fishery stratified sampling scheme (Kimura 1989) with values obtained in earlier fits to the stock assessment model (Ianelli 1996, Table A1, Annex B).
- Selectivity constraints (penalties on age-age variability, time changes, and non-decreasing (with age) patterns

1.5. Model evaluation

To examine model assumptions and data sensitivities, we present results from an array of different model configurations. Some of these are in response to specific requests by the NPFMC family and others are intended to illustrate some properties of model behavior relative to the extensive surveys and fishery observations conducted by the AFSC for walleye pollock. A list of the models presented includes:

Model 0 Same as Model 2, but excludes the estimated age-composition data from the 1999 EIT survey (these data were derived from an age-length key based on the bottom-trawl survey).

Model 1 Future selectivity based on most recent 10-year average (medium-term selectivity estimate).

Model 2 **Reference model,** same as Model 1 but with future selectivity based on most recent (3-year) estimate (short-term selectivity estimate). This was the model configuration selected by the Council for ABC recommendations in 1998.

Model 3 same as reference model but with selectivity for future years based on average selectivity since 1964 (long-term selectivity estimate).

Model 4 same as reference model but with survey selectivities constant over time.

Model 5 same as reference model but the entire time series for estimating the stock-recruitment relationship internal to the model

Model 6 same as reference model but with the OSCURS effect on recruitment added.

Model 7 expected recruitment constant with respect to stock size (though annual recruitment is still stochastic).

These models are summarized as follows:

Model Number	1999 EIT Age comp. included?	Selectivity	Age 1 Recruitment Period	Larval Drift Effect Included?	Mean Recruitment
0	No	3 yrs	1978 -	No	Ricker
1	Yes	10 yrs	1978 -	No	Ricker
2	Yes	3 yrs	1978 -	No	Ricker
3	Yes	36 yrs	1978 -	No	Ricker
4	Yes	3 yrs	1978 -	No	Ricker
5	Yes	3 yrs	1964 -	No	Ricker
6	Yes	3 yrs	1964 -	Yes	Ricker
7	Yes	3 yrs	NA	No	Average

Model 0 ignores the information on the preliminary age-composition as estimated for the 1999 EIT survey data. Models 1 and 3 were carried out to determine the effect of alternative assumptions about future selectivity estimates and affect only quantities related to F_{msy} determinations and future projections.

In Model 4 we evaluate the effect of not allowing survey selectivity to vary over time. In Model 5 we examine the influence of using the full time-series in the estimation of the stock-recruitment relationship within the model. Since the stock-recruitment curve affects estimates of F_{msy} and B_{msy}, we considered inferences about the fitted curve to be important. In Model 6, we added the effect of the environment as presented in last-year's assessment using output from the surface-driven model of Bering Sea currents (OSCURS, Wespestad *et al.* 1997). Finally, in Model 7 we assumed that recruitment has no relationship with spawning stock size and that for all levels of biomass, the expected recruitment was the same. This renders MSY-type computations valid only in the sense of yield-per-recruit analyses.

An evaluation of the goodness of fit for the models is presented in Table 1.9. Predictably, results from Model 4 fit the data extremely poorly compared to the other models. The variance about current stock size was higher for Model 2 compared to Model 4 based on the coefficients of variation (CV's as presented in parentheses in Table 1.10). This reflects the fact that with more parameters involved, fewer assumptions are required at a *cost* of higher variance. It can be argued that most modern stock assessment models tend to under-estimate the level of uncertainty (e.g., NRC 1997). Model 2 may best represent the underlying processes that affect observations (e.g., availability of different age-classes can change over time to different gear types). Therefore, the results presented in subsequent sections are based on Model 2. This differs from last year's recommendation (where Model 1 was selected) but follows the Council's Plan Team and SSC 1998 recommendations.

Results from Model 7 (average recruitment independent of stock size) are similar to Model 2 in many respects. For example, the year 2000 begin-year female spawning biomass levels are quite similar, as are the indications on the fits to the data. Since Model 7 does not have an integrated stock-recruitment relationship, analyses on MSY-related quantities are equivalent to yield-per-recruit analyses. That is, Model 7 configuration is inappropriate to evaluate recruitment-overfishing. For this reason, the level of B_{msy} is quite low and the F_{msy} is considerably higher than for the other models. This outcome suggests that, given the assumed natural mortality rate and estimated fishery selectivity pattern, the maximum yield-per-recruit occurs at a much higher fishing mortality rate than has been recently observed.

Model 5 had a slightly higher value for F_{msy} and the overall stock levels were higher (Table 1.11). Using the full time series to fit the stock-recruitment model (Model 5) gave slightly different fits to the data. The impact of changing the time frame for the stock-recruitment model part appears to be relatively high, with B_{msy} increasing by about 30% between Models 2 and 5. This highlights some of the key criticisms of using stock-recruitment estimates and problems with reliably estimating productivity relationships in general (Quinn and Deriso 1999). Namely, the issue of contrast in estimating the stock-recruitment relationship is much lower for Model 2 than Model 5, and there are few data points. The assumed stationarity in the stock-recruitment relationship may also be violated, especially considering the different components of the ecosystem that were present during the 1960s compared with the 1980s and 1990s.

Model 6 is best contrasted with Model 5 since we include the environmental effect parts to the whole time-series (1964-1999). In fact, the addition of the OSCURS model of egg and larval drift to help explain survival of pre-recruit pollock did not affect values critical for harvest management regulations. The environmental effect, as implemented here, did not appear to shift or influence the underlying stock-recruitment relationship that was estimated (although it did help explain part of the inter-annual variability).

1.6. Results

Several key results have been summarized in Tables 1.10 & 1.11. The difference in the current and projected age structure for Model 2 relative to the last two year's assessments (1998 and 1997) is shown in Fig. 1.14. This figure shows very similar predictions in absolute numbers at age for the near term, despite different assumed future catch levels. The slight increase in estimated numbers at age may be attributed to the increase in the 1999 survey abundance estimates (the current survey is 61% higher (in biomass) than the 1998 estimate). In addition, the 1992 year-class is estimated to be slightly higher than last year, presumably due to the predominance of that year-class in the recent EBS bottom-trawl surveys and in the fishery (e.g., Fig. 1.18 below).

The estimated Model 2 selectivity pattern for the fishery shows how estimates of selectivity change over time (Fig. 1.15). An example of how well the model fit the fishery age-composition data is given in Fig. 1.16. Selectivity was allowed to vary slightly over time for both surveys. This was done to account for potential changes in fish distribution. For example, it seems reasonable to assume that the presence of 1-year-olds available to the bottom-trawl gear on the shelf might be variable, even when the abundance is the same (Fig. 1.17). The model fits to the age composition estimates are shown in Fig. 1.18.

The Model 2 fit and estimated selectivity for the EIT survey data shows a failure to estimate the 1979 total age 1+ numbers very well. This is due to the large number of 1 and 2-year old fish apparent in the survey that year (Fig. 1.19). This is further illustrated in the model fit to the EIT survey age composition data (Fig. 1.20). The proportions at age observed in the survey are generally consistent with what appeared later in the bottom-trawl survey and fishery. Estimated numbers-at-age for Model 2 are presented in Table 1.12 and estimated catch-at-age presented in Table 1.13.

1.6.1. Abundance and exploitation trends

The eastern Bering Sea bottom trawl survey estimates exhibited an increasing trend during the 1980s, were relatively stable from 1991 to 1995, and decreased sharply in 1996 but rose slightly in 1997 and then 1999. This may be due, in part, to age-related distribution changes within the pollock population. Results from combined bottom trawl and EIT surveys, which more fully sample the population, have shown that older pollock are more vulnerable to bottom trawls than younger pollock (e.g., Figs. 1.17 and 1.18).

Current exploitable biomass estimates (ages 3 and older) derived from catch-age models and survey abundance estimates suggest that the abundance of eastern Bering Sea pollock remained at a fairly high level from 1982-88, with estimates ranging from 10 to 11.5 million t. Peak biomass occurred in 1985 and declined to about 5 million t in 1991, then increased to over 9.8 million t by 1993. Results from the model indicate that the biomass for ages three years and older is about 7.51 million t in the beginning of 1999.

Historically, biomass levels have increased from 1979 to the mid-1980's due to the strong 1978 and relatively strong 1982 and 1984 year-classes recruiting to the fishable population (Table 1.14, Fig. 1.21). From 1985-86 to 1991 the fishable stock declined as these above average year-classes decreased in abundance with age and were replaced by weaker year-classes. In 1992 an upturn in abundance began with the recruitment of a strong 1989 year-class, but biomass has been decreasing since 1993, the year-classes entering the fishery in recent years have been weak except for the 1992 year-class. An increase in abundance is expected in future years as apparently above average 1996 year-class recruits to the exploitable population. Retrospectively, compared with last year's assessment the recent estimates of age 3+ pollock biomass are somewhat lower in the current assessment during the 1980s and higher in recent years (Table 1.14). Again, this may be attributed to the increasing trends from both the EIT and bottom trawl survey estimates for 1999.

The abundance and exploitation pattern estimated from Model 2 shows that the spawning exploitation rate (SER, defined as the percent removal of spawning-aged females in any given year) has averaged about 18% in the past 10 years (Fig. 1.22). This compares to an overall average SER of 22.5% (1964 – 1999). The observed variation in pollock abundance is primarily due to natural variation in the survival of individual year-classes. These values of SER are relatively low compared to the estimates at the MSY level (~30%).

1.6.2. Recruitment

Recruitment of pollock is highly variable and difficult to predict. It is becoming clear that there is a great deal of variation in the distribution of pre-recruit pollock, both in depth and geographic area. To some extent, our approach takes this into account since age 1 fish are included in our model and data from both the EIT and bottom trawl survey are used. Previously, the primary measure of pollock recruitment has been the relative abundance of age 1 pollock (or pollock smaller than 20 cm when age data are unavailable) in the annual eastern Bering Sea bottom-trawl survey. Also, bottom-trawl survey estimates of age 1 recruitment, when regressed against age 3 pollock estimates from catch-age models, indicate a linear relationship. This had been used to project age 3 numbers in population forecasts. Our method does not require external regressions since the necessary accounting is done explicitly, within a standard age-structured model. The key advantage in our approach is that the observation and process errors are maintained and their effect can be evaluated.

It appears that the annual bottom trawl survey does not fully cover the distribution of age 1 pollock. This is especially evident for the 1989 year-class that the survey found to be slightly below average, but upon recruitment to the fishery, was a very strong year-class. It appears that a significant amount of this year-class was distributed in the Russian EEZ—beyond the standard survey area—or unavailable to bottom trawl gear (perhaps in mid-water). In 1996, Russian scientists reported the 1995 year-class to be strong, but it appeared to be below average in the U. S. survey. However, in the 1997 EIT survey the 1995 year-class was abundant adjacent to the Russian EEZ.

The coefficient of variation or "CV" (reflecting uncertainty) on the strength of the 1996 year-class is about 25% for Model 2 (down from 39% last year). The 1996 year-class appears to be moderately strong. However, the 95% confidence bounds for the 1996 year-class are only slightly above mean recruitment for all years since 1964 (Fig. 1.23). Adding the effect of the surface currents on recruitment success appears to be a plausible mechanism but it does not reduce the degree of uncertainty in the magnitude of the 1996 year-class. This is due to the fact that we now have 5 direct observations of this year class from survey data: the EIT survey conducted in 1997 and 1999, and the bottom trawl surveys in 1997, 1998, and 1999 (though 2- and 3-year olds are uncommonly available to bottom-trawl survey gear).

1.7. Projections and harvest alternatives

1.7.1. Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available. However, the extent of their reliability is questionable. We therefore present both reference points for pollock in the BSAI to retain the option for classification in either Tier 1 or Tier 3 of Amendment 56. These Tiers require reference point estimates for biomass level determinations. For our analyses, we selected the following values from Model 2 results computed based on recruitment from post-1976 spawning events:

$B_{40\%}$ = 2,340 t female spawning biomass

$B_{35\%}$ = 2,047 t female spawning biomass

B_{msy} = 1,793 t female spawning biomass

1.7.2. Specification of OFL and Maximum Permissible ABC

For Model 2, the year 2000 spawning biomass is estimated to be 2,159 thousand tons. This is well above the B_{msy} value of 1,793. Under Amendment 56, Tier 1a, the harmonic mean value is considered a risk-averse policy provided reliable estimates of F_{msy} and its pdf are available. The harmonic mean value for F_{msy} computations is somewhat different from the procedure outlined in Tier 1 of Amendment 56. Here the harmonic mean is computed from the estimated pdf for the year 2000 yield under F_{msy} rather than first finding the harmonic mean of F_{msy} and applying its value to the maximum likelihood estimate for the year 2000 stock size. The method we use results in somewhat lower ABC values since uncertainty in both the F_{msy} value and future stock size are both considered.

Corresponding values under Tier 3 are 2,247 thousand tons for year 2000 spawning values (under $F_{40\%}$ policy). This is slightly below the $B_{40\%}$ value of 2,340. The OFL's and maximum permissible ABC values by both methods are thus:

	OFL	**Max ABC**
Tier 1a	**1,678 thousand t**	**1,197 thousand t**
Tier 3b	**1,471 thousand t**	**1,102 thousand t**

1.7.3. ABC Recommendation

Currently, the biomass of eastern Bering Sea pollock appears to be increasing and estimated at about 7.5 million t (total age-3+). The estimated female spawning biomass projected to the time of spawning in the year 2000 is about 2,247 thousand tons, just shy of the $B_{40\%}$ level of 2,340 thousand tons and well above the $B_{35\%}$ and the value estimated for B_{msy} (2,047 and 1,793, respectively; Fig. 1.24). The current estimates gives very similar values for MSY (1.47 million tons for Model 2). This is down from the estimate presented last year (1.9 million tons) due to the different time-frame for which the stock-recruitment was estimated within the model (1978-1999 this year compared with 1964-1998 last year).

For the year 2000, ABC alternatives based on the $F_{40\%}$ and F_{msy} are **1,102** and **1,197** thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value) as shown in Table 1.11 for Model 2.

1.7.4. Standard Harvest Scenarios and Projection Methodology

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 (A "*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.)

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 follow (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 one-half 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.)

1.7.5. Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the max F_{ABC} value and use $F_{35\%}$ as a proxy for F_{msy}. Scenarios 1 through 7 were projected 14 years from 1999 (Table 1.15). Under Scenario 1, the expected spawning biomass will increase to slightly below $B_{40\%}$ then fluctuate between $B_{40\%}$ and $B_{35\%}$ for a few years then increases to above

$B_{40\%}$ by the year 2006 (Fig. 1.25). Under this scenario, the yields are expected to increase to a value slightly less than 1.5 million tons (Fig. 1.26).

Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2000:

a) If spawning biomass for 2000 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

b) If spawning biomass for 2000 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2000 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Table 1.15). If the mean spawning biomass for 2010 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

a) If the mean spawning biomass for 2002 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2002 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2002 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2012. If the mean spawning biomass for 2012 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2000, nor is it expected to be approaching an overfished condition based on Scenario 7.

1.8. Other considerations

1.8.1. Fishing fleet dynamics

It has become common knowledge that several (most) vessels fishing for pollock have made gear modifications designed to reduce the take of under-sized fish. This may change the effective selectivity of the gear in a predictable way. While our approach allows for changes in selectivity, further analyses on this effect may be warranted.

Other substantial changes are occurring with the implementation of the new revised final RPA's (RFRPA) and the American Fisheries Act. These will likely reduce the "race for fish" that was common in past years. The impact is likely to continue to reduce bycatch and improve recovery percentages. In addition, the ability to avoid small fish will be enhanced since the fishery will occur over longer periods (and harvests at lower daily rates).

1.8.2. Stock structure

Recent information obtained from U.S. and Russian EIT surveys in the Bering Sea indicate that the eastern Bering Sea pollock stock has a distribution that is continuous into the Russian EEZ. The 1994 Miller Freeman EIT survey found a biologically-similar distribution of pollock inhabiting the region from the Pribilofs to Cape Navarin. In 1996 and 1997, each country surveyed their own EEZ and again results show the distribution of pollock in the northwest portion of the U.S. EEZ continuing across the Convention Line into the Cape Navarin region. Historical Russian data also suggest that pollock in the Russian EEZ east of 176 E are predominantly of eastern Bering Sea origin (Shuntov et al 1993). However, current Russian opinion is that an oceanographic regime shift has recently occurred in the northern Bering Sea resulting in a far smaller fraction (5%) of EBS pollock in the Navarin region.

Further, it is thought that most of the juvenile fish in this area will recruit to the eastern Bering Sea spawning stock as adults. This was evident with the 1989 year-class, which was found in relatively low abundance in the US EEZ, but was found to be very abundant in the Russian EEZ early in life. The 1989 year-class subsequently was found to be the one of the largest year-classes produced within the eastern Bering Sea.

The problem of a straddling pollock stock is that the western Bering Sea pollock stock is currently at a low level of abundance. With the decease in western Bering Sea pollock abundance Russian and joint-venture fishing effort have increased in the Russian EEZ northern area. If significant harvests of juvenile pollock that will recruit to the eastern Bering Sea exploitable population occur in the Russian EEZ, then there may be a reduction in the exploitable biomass and yield in the US EEZ. The following table contains the reported catch for the Navarin area (176E to the Convention Line) received from TINRO, the catch as a percentage of the total western Bering Sea catch, and the age composition of the catch for ages 1,2,3, and 4 and older:

Year	Navarin Catch 1,000's tons	Percent Russian Bering Sea catch	Catch at age 0	1	2	3	4+
1976	467	85%	0%	0%	5%	78%	18%
1977	180	68%	0%	0%	3%	13%	84%
1978	254	61%	0%	3%	6%	21%	91%
1979	285	52%	14%	23%	55%	6%	3%
1980	620	49%	0%	1%	15%	78%	7%
1981	900	75%	0%	0%	6%	39%	55%
1982	804	64%	0%	1%	10%	23%	67%
1983	722	65%	8%	30%	3%	21%	39%
1984	503	50%	0%	6%	0%	2%	95%
1985	488	58%	0%	44%	31%	14%	11%
1986	570	69%	0%	8%	45%	14%	33%
1987	463	63%	0%	0%	6%	28%	67%
1988	852	76%	0%	1%	7%	22%	70%
1989	684	70%					
1990	232	53%					
1991	178	39%					
1992	316	53%					
1993	389	46%	0%	2%	7%	11%	80%
1994	178	43%	0%	0%	11%	17%	70%
1995	320	98%	0%	0%	16%	22%	62%
1996	753	95%					
1997	680	93%					
1998	627	NA	4%	37%	34%	6%	6%
Avg.	498	62%	2%	9%	15%	24%	50%

Currently, NMFS is collaborating with scientists at the University of Washington in using micro-satellite DNA methods for evaluating the genetic composition of pollock from diverse regions. These methods are powerful and provide promise for a clearer understanding of stock structure issues, particularly as they are tested over multi-year collections.

1.8.3. Steller sea lions and the pollock fishery

Temporal patterns

To assess the means of slowing the fishery down temporally, a measure was constructed along the following lines. First, we conceptualized an "ideal slow" fishery as one that catches the same quantities each day from the beginning of the year until the end (e.g., Fig. 1.27). To summarize annual differences and reflect changes in management, we computed the sums-of-squared differences between the idealized "slow" fishery and the observed fishery. For the EBS, the 1999 value was well below the average and the 1998 value (Fig. 1.28).

Spatial dispersion

The catches in 1998 and 1999 were compared by constructing A1 and A2 seasons that matched the same times of the actual 1999 A1 and A2 seasons (since in 1998 the "A" season was undivided). The catch percentage from all areas for the A1 season was 69% in 1998 and 62% in 1999. Broken out by area, the A-season CH/CVOA harvests dropped from 87% to 55% of the catch between 1998 and 1999 (Table 1.16). Similar declines occurred between years for the different seasons. Spatially, these values are illustrated in Figures 1.29-1.32 for both 1998 and the A1 and A2 "seasons".

During the early 1980s the harvest during Jan-Mar in the CH/CVOA was relatively low since most foreign fishing occurred during the summer. As the joint-venture fleet grew in the later part of that decade, the value of the roe fishery was recognized and the harvest levels during this period and area increased (Fig. 1.33).

Comparing harvest rates (defined as catch biomass divided by the begin-period age 3+ stock biomass) for 1999 within CH/CVOA was done by reconstructing catch-estimates within this area by season for all foreign and domestic observer data. For the A-season, we computed the estimated stock size within the CH/CVOA as 26%, 38% and 50% of the total age 3+ population based on the most recent assessment (Ianelli *et al.* 1998). The two lower percentages were derived from the environmental assessment analyses (NMFS 1999) while the 50% was selected as an alternative default value. The default 50% value was in response to unsubstantiated claims that nearly all (100%) of the EBS pollock stock become concentrated in this region during the spawning season.

These results provide some perspective on the relative magnitude of harvest rates within the CH/CVOA and insight on how the 1999 season has progressed under the RPA's as implemented. The highest estimated harvest rate within the CH/CVOA (Jan-Mar) occurred in 1991 with 44% of the available population estimated as having been harvested (Case 1 with 26% EBS stock inside CH/CVOA; Table 1.17). Since that time, the level has fluctuated between 11% and 33%.

In 1999, the harvest rate within the CH/CVOA dropped by more than 33% of the 1998 level, indicating that there has been a large decrease on the fishing pressure within this region. Also, note that pollock surplus production is about 30% per year, accounting for levels of natural mortality (as might occur due to predators such as sea lions).

In 1999 the estimated exploitation rate was possibly as high as 11% for the entire A season (note that this value is likely to be much lower since it is probable that more than 26% of the stock was inside CH/CVOA). If the target annual exploitation rate is about 20%, it may seem that the (approximately) correct 3-month exploitation rate should be about 5%. Breaking the A season into two periods, the A1 and A2 seasons, the exploitation rate over this period (not counting for natural mortality) decreases to 24% for the 1998 A1 and 13% for 1998 A2 seasons (Table 1.18). For 1999, the split-season (A1 and A2) exploitation rates are 8% and 3% respectively. This is close to the notion of an approximate 5% target over four seasons.

Another way to examine the change from 1998 harvests during the A-season is to evaluate the estimated difference in total tonnage of pollock removed within CH/CVOA. If one applies the 1998 harvest rate (33%) to the 1999 CH/CVOA Jan-Mar biomass estimate, the harvest within this area would have been about 410 thousand tons. This is 212 thousand tons more than the actual amount caught in 1999. The 1999 harvest rate inside the CH/CVOA Jan-Mar was less than half the 1998 value.

Comparing trends in the fishery by seasons, the observer data indicate that the fishery has become more concentrated in the beginning (Jan-Mar) period and the latter (Sep-Dec) periods since 1991 (Table 1.19). The spatial pattern of fishing since 1991 regarding the proportions harvested within the CH/CVOA has averaged about 75% during Jan-Mar season and about 47% during the Sep-Dec season (Table 1.20). In recent years, approximately 35% of the harvests during the Sep-Dec period were taken within the CH/CVOA area. On average, 58% of the total annual harvests have been taken from within the CH/CVOA area. The projection for 1999 is to be substantially lower than average assuming that much smaller proportions are taken during the latter half of the year from this area (as in the past).

1.9. Summary

Summary results are given in Table 1.21.

1.10. Acknowledgements

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1.12. Tables

Table 1.1 Catch from the eastern Bering Sea by area, the Aleutian Islands and the Bogoslof Island area, 1979-99. (1999 values set equal to TAC). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W.

	Eastern Bering Sea			Aleutians	Donut Hole	Bogoslof I.
Year	**Southeast**	**Northwest**	**Total**			
1979	368,848	566,866	935,714	9,504		
1980	437,253	521,027	958,280	58,156		
1981	714,584	258,918	973,502	55,516		
1982	713,912	242,052	955,964	57,978		
1983	687,504	293,946	981,450	59,026		
1984	442,733	649,322	1,092,055	81,834	181,200	
1985	604,465	535,211	1,139,676	58,730	363,400	
1986	594,997	546,996	1,141,993	46,641	1,039,800	
1987	529,461	329,955	859,416	28,720	1,326,300	377,436
1988	931,812	296,909	1,228,721	30,000	1,395,900	87,813
1989	904,201	325,399	1,229,600	15,531	1,447,600	36,073
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	712,206	505,095	1,217,301	78,649	293,400	264,760
1992	663,457	500,983	1,164,440	48,745	10,000	160
1993	1,095,314	231,287	1,326,601	57,132	1,957	886
1994	1,183,360	180,098	1,363,458	58,637	NA	566
1995	1,170,828	91,939	1,262,766	64,429	trace	264
1996	1,086,840	105,938	1,192,778	29,062	trace	387
1997	820,050	304,543	1,124,593	25,940	trace	168
1998	965,766	135,399	1,101,165	23,822	trace	136
1999	814,622	177,378	992,000	1,001	trace	111

1979-1989 data are from Pacfin.

1990-1999 data are from NMFS Alaska Regional Office, includes discards; 1999 prorated from October 31 estimate by area.

Table 1.2. Estimated retained, discarded, and percent discarded of total catch in the Aleutians, Northwest and Southeastern Bering Sea, 1990-1999. Source: NMFS Blend database.

Area	Year	Catch Retained	Discard	Total	Discard Percentage
	1990				
Southeast (51)		582,660	57,851	640,511	
Northwest (52)		764,369	50,313	814,682	
Aleutians		69,682	9,343	79,025	
Total		1,416,711	117,507	1,534,218	7.7%
	1991				
Southeast (51)		614,889	97,317	712,206	
Northwest (52)		458,610	46,485	505,095	
Aleutians		73,608	5,041	78,649	
Bogoslof		245,467	19,293	264,760	
Total		1,318,966	163,095	1,482,061	11.0%
	1992				
Southeast (51)		600,861	62,596	663,457	
Northwest (52)		445,811	55,172	500,983	
Aleutians		45,246	3,498	48,745	
Total		1,091,919	121,266	1,213,185	10.0%
	1993				
Southeast (51)		1,011,020	84,294	1,095,314	
Northwest (52)		205,495	25,792	231,287	
Aleutians		55,399	1,733	57,132	
Total		1,271,914	111819	1,383,732	8.1%
	1994				
Southeast (51)		1,091,547	91,813	1,183,360	
Northwest (52)		164,020	16,078	180,098	
Aleutians		57,325	1,311	58,637	
Total		1,312,892	109,202	1,422,094	7.7%
	1995				
Southeast (51)		1,083,381	87,447	1,183,360	
Northwest (52)		82,226	9,713	91,939	
Aleutians		63,047	1,382	64,429	
Total		1,228,654	98,542	1,339,728	7.4%
	1996				
Southeast (51)		1,015,473	71,367	1,086,840	
Northwest (52)		101,100	4,838	105,938	
Aleutians		28,067	994	29,062	
Total		1,145,133	77,206	1,222,339	6.3%
	1997				
Southeast (51)		749,007	71,043	820,050	
Northwest (52)		281,986	22,557	304,543	
Aleutians		25,323	617	25,940	
Total		1,056,316	94,217	1,150,533	8.2%
	1998				
Southeast (51)		950,631	15,135	965,767	
Northwest (52)		133,818	1,581	135,399	
Aleutians		23,657	164	23,822	
Total		1,108,106	16,881	1,124,987	1.5%

Table 1.3. Eastern Bering Sea walleye pollock catch by age in numbers (millions), 1979-1998.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543.2	720.0	420.2	392.6	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	0.5	2567.3
1980	9.8	462.4	823.3	443.5	252.2	211.0	83.7	37.6	21.8	23.9	25.5	15.9	7.7	2.5	2420.7
1981	0.6	72.2	1012.9	638.0	227.0	102.9	51.7	29.6	16.1	9.4	7.5	4.6	1.5	0.6	2174.6
1982	4.8	25.3	161.4	1172.4	422.4	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	0.7	2003.7
1983	5.1	118.6	157.8	313.0	817.0	218.3	41.4	24.7	19.8	11.1	7.6	4.9	3.5	1.7	1744.5
1984	2.1	45.8	88.6	430.8	491.9	654.3	133.9	35.6	25.1	15.7	7.1	2.5	2.9	1.7	1938.0
1985	2.7	55.3	382.2	122.1	366.7	322.3	444.3	112.8	36.7	25.9	24.9	10.7	9.4	4.0	1919.9
1986	3.1	86.0	92.3	748.5	214.1	378.1	221.9	214.2	59.7	15.2	3.3	2.6	0.3	1.2	2040.4
1987	0.0	19.9	112.2	78.0	415.8	139.6	123.2	91.2	248.6	54.4	38.9	21.6	29.1	6.1	1378.5
1988	0.0	10.7	455.2	422.8	252.8	545.9	225.4	105.2	39.3	97.1	18.3	10.2	3.8	5.5	2192.2
1989	0.0	4.8	55.3	149.5	452.6	167.3	574.1	96.6	104.1	32.5	129.5	10.9	4.0	2.6	1783.8
1990	1.3	33.2	57.3	220.7	201.8	480.3	129.9	370.4	66.1	102.5	9.1	60.4	8.5	4.7	1746.2
1991	1.0	60.9	40.7	85.4	141.5	156.9	396.4	51.6	217.1	22.1	114.7	15.2	74.4	60.9	1438.8
1992	0.0	79.0	721.7	143.5	98.1	125.0	145.4	276.8	109.3	165.4	59.4	50.2	14.2	91.0	2079.0
1993	0.1	9.2	275.0	1144.5	103.0	64.3	62.2	53.5	84.9	21.8	34.5	12.6	13.1	26.5	1905.2
1994	0.3	31.5	59.8	383.4	1109.5	180.5	54.9	21.0	13.5	20.1	9.1	10.7	7.6	15.7	1917.5
1995	0.0	0.3	75.3	146.6	398.4	764.7	131.8	34.9	10.9	6.0	15.3	4.4	7.1	11.3	1606.9
1996	0.0	9.5	19.7	43.8	144.9	350.7	486.3	190.4	32.9	14.8	8.9	8.8	4.1	11.3	1326.1
1997	0.1	65.4	32.6	109.7	472.8	289.1	254.6	198.5	62.8	14.2	6.5	5.1	3.1	14.8	1529.3
1998	0.0	31.2	90.2	79.2	170.4	682.3	197.5	124.3	107.2	29.3	5.3	6.3	3.1	7.7	1534.1

Table 1.4. Numbers of samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-1998. The bottom section illustrates the proportions of catch (in weight) and length and age samples by area for the 1998 fishery).

	Strata	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Measured males	Aleutians	34,023	33,585	33,052	28,465	21,993	12,336	10,477	6,906
	Northwest	126,023	110,487	38,524	28,169	17,909	22,290	58,307	4,368
	Southeast A Season	198,835	150,554	122,436	138,338	127,876	148,706	123,385	134,743
	Southeast B Season	102,225	134,371	143,420	153,336	175,524	193,832	114,826	205,309
Total		461,106	428,997	337,432	348,308	343,302	377,164	306,995	351,326
Measured females	Aleutians	14,620	19,079	21,055	16,125	16,475	8,792	9,056	5,368
	Northwest	124,934	114,778	39,985	28,185	19,282	22,144	51,358	6,362
	Southeast A Season	184,351	142,016	112,602	146,918	124,000	140,868	102,530	108,645
	Southeast B Season	90,056	136,626	135,661	146,540	150,632	149,583	105,999	174,729
Total		413,961	412,499	309,303	337,768	310,389	321,387	268,943	295,104
Aged males	Aleutians	22	110	81	157	73	86	15	142
	Northwest	320	179	147	132	123	0	326	61
	Southeast A Season	373	454	451	200	297	470	431	588
	Southeast B Season	248	317	475	571	415	442	284	307
Total		963	1,060	1,154	1,060	908	998	1,056	1,098
Aged females	Aleutians	23	121	82	151	105	77	15	166
	Northwest	340	178	153	142	131	0	326	66
	Southeast A Season	385	458	478	201	313	451	434	652
	Southeast B Season	233	332	458	574	392	434	312	308
Total		981	1,089	1,171	1,068	941	962	1,087	1,192

Area	Total 1998 Catch	Proportion Catch	Proportion Length samples	Proportion Age Samples
SouthEast	965,767	86%	96%	81%
Northwest	135,399	12%	2%	6%
Aleutians	23,822	2%	2%	13%
Total	1,124,987			

Table 1.5. Biomass (age 1+) of eastern Bering Sea walleye pollock as estimated by surveys 1979-1999 (millions of tons).

Year	Bottom trawl survey (t)	EIT Survey (t)	EIT Percent age 3+	Total[1] (t)	Near bottom biomass
1979	3.20	7.46	(22%)	10.66	30%
1980	1.00				
1981	2.30				
1982	2.86	4.90	(95%)	7.76	46%
1983	6.24				
1984	4.89				
1985	4.63	4.80	(97%)	9.43	54%
1986	4.90				
1987	5.11				
1988	7.11	4.68	(97%)	11.79	63%
1989	5.93				
1990	7.13				
1991	5.11	1.45	N/A	6.56	79%
1992	4.37				
1993	5.52				
1994	4.98	2.89	(85%)	7.87	64%
1995	5.41				
1996	3.20	2.31	(97%)	5.51	60%
1997	3.03	2.59	(70%)	5.62	54%
1998	2.21				
1999	3.57	3.29[2]		6.86	52%

[1] Although the two survey estimates are added in this table, the stock assessment model treats them as separate indices (survey "q's" are estimated).

[2] This figure excludes the zone near the "horseshoe" area of the EBS (southeast) not usually surveyed, the value including this area was 3.35 million tons.

Table 1.6. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-1999.

Year	Number of Hauls	Lengths	Aged
1982	329	40,001	1,611
1983	354	78,033	1,931
1984	355	40,530	1,806
1985	353	48,642	1,913
1986	354	41,101	1,344
1987	342	40,144	1,607
1988	353	40,408	1,173
1989	353	38,926	1,227
1990	352	34,814	1,257
1991	351	43,406	1,083
1992	336	34,024	1,263
1993	355	43,278	1,385
1994	355	38,901	1,141
1995	356	25,673	1,156
1996	355	40,789	1,387
1997	356	35,536	1,193
1998	355	37,673	1,261
1999	353	32,532	1,385

Table 1.7. Number of hauls and sample sizes for EBS pollock collected by the EIT surveys.

Year	Stratum	No. Hauls	No. lengths	No. otoliths collected	No. aged
1979	**Total**	25	7,722	NA	2,610
1982	**Total**	48	8,687	NA	2,741
	Midwater, east of St Paul	13	1,725		783
	Midwater, west of St Paul	31	6,689		1,958
	Bottom	4	273		0
1985	**Total** (Legs1 &2)	73	19,872	NA	2,739
1988	**Total**	25	6,619	1,519	1,471
1991	**Total**	62	16,343	2,065	1,663
1994	**Total**	77	21,506	4,973	1,770
	East of 170 W				612
	West of 170 W				1,158
1996	**Total**	57	16,910	1,950	1,926
	East of 170 W				815
	West of 170 W				1,111
1997	**Total**	86	30,535	3,635	2,285
	East of 170 W				936
	West of 170 W				1,349
1999	**Total**	116	39,798	4,946	NA
	East of 170 W				NA
	West of 170 W				NA

Table 1.8. Average weights-at-age (kg) by year as used in the model for the fishery and for computing biomass levels for EBS pollock. NOTE: 1999 weight-at-age is treated as the three-year average of values from 1996-1998.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1964-90	0.007	0.170	0.303	0.447	0.589	0.722	0.840	0.942	1.029	1.102	1.163	1.212	1.253	1.286	1.312
1991	0.007	0.170	0.277	0.471	0.603	0.722	0.837	0.877	0.996	1.109	1.127	1.194	1.207	1.256	1.244
1992	0.007	0.170	0.387	0.454	0.615	0.660	0.745	0.898	0.960	1.151	1.174	1.203	1.132	1.184	1.304
1993	0.007	0.170	0.492	0.611	0.657	0.770	0.934	1.078	1.187	1.238	1.385	1.512	1.632	1.587	1.465
1994	0.007	0.170	0.398	0.628	0.716	0.731	0.709	0.995	1.287	1.228	1.197	1.329	1.308	1.282	1.282
1995	0.007	0.170	0.389	0.505	0.733	0.841	0.854	1.000	1.235	1.314	1.375	1.488	1.402	1.336	1.491
1996	0.007	0.170	0.332	0.448	0.717	0.817	0.964	0.966	1.059	1.142	1.371	1.452	1.487	1.679	1.460
1997	0.007	0.170	0.326	0.466	0.554	0.747	0.892	1.071	1.085	1.235	1.333	1.422	1.571	1.451	1.419
1998	0.007	0.170	0.388	0.631	0.633	0.645	0.774	1.044	1.191	1.261	1.317	1.350	1.496	1.517	1.630
1999	0.007	0.170	0.349	0.515	0.635	0.736	0.877	1.027	1.112	1.213	1.341	1.408	1.518	1.549	1.503

Table 1.9. Results comparing fits Models 0-7. Effective N (sample size) computations are as presented in McAllister and Ianelli (1997). See text for model descriptions.

Fits to data sources	**Model 0**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Age Composition data								
Effective N Fishery	155	156	156	156	142	156	156	156
Effective N Bottom trawl survey	173	176	176	176	79	177	177	177
Effective N Hydro acoustic survey	51	44	44	44	35	42	42	44
Survey abundance estimates, RMSE*								
Trawl Survey	0.18	0.18	0.18	0.18	0.22	0.18	0.18	0.18
EIT survey	0.31	0.31	0.31	0.31	0.64	0.31	0.31	0.31
Recruitment Residuals								
Due to Stock	0.24	0.23	0.23	0.23	0.23	0.25	0.34	0.24
RMSE Env	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000
Residual RMSE	0.43	0.43	0.43	0.43	0.47	0.36	0.26	0.43
Total	0.66	0.67	0.67	0.67	0.69	0.61	0.61	0.66

$$*\mathrm{RMSE} = \sqrt{\frac{\sum \ln\left(obs/pred\right)^2}{n}}$$

Table 1.10. Results reflecting the stock condition for Models 0-7. Values in parentheses are coefficients of variation (CV's) of values immediately above. See text for model descriptions.

	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Biomass								
Year 2000 spawning biomass [3]	1,865	2,175	2,159	2,192	1,585	1,998	2,009	1,479
Year 2000 spawning biomass [4]	1,935	2,250	2,247	2,254	1,629	2,537	2,546	2,313
(CV)	(22%)	(21%)	(21%)	(21%)	(15%)	(17%)	(18%)	(20%)
1999 spawning biomass	1,654	1,910	1,910	1,910	1,502	2,149	2,149	1,957
B_{msy}	1,766	1,782	1,793	1,784	1,810	1,271	1,272	581
(CV)	(22%)	(22%)	(22%)	(22%)	(22%)	(9%)	(9%)	(11%)
$B_{40\%}$	2,291	2,340	2,340	2,340	2,229	2,213	2,214	2,358
(CV)	(18%)	(18%)	(18%)	(18%)	(18%)	(18%)	(18%)	(18%)
Percent of B_{msy} % spawners	106%	122%	120%	123%	88%	157%	158%	254%
Percent of $B_{40\%}$ spawners	84%	96%	96%	96%	73%	115%	115%	98%
1999 Age 3+ Biomass	6,610	7,513	7,513	7,513	5,806	8,318	8,343	7,697
Ratio B_{1999}/B_{1998} (3+ biomass)	123%	126%	126%	126%	115%	127%	128%	127%
Recruitment								
Avg Recruitment (since 1978)	21,502	21,958	21,958	21,958	20,919	22,646	22,675	22,129
(CV since 1978)	73%	72%	72%	72%	79%	69%	69%	72%
Avg. Recruitment (all yrs)	20,044	20,322	20,322	20,322	19,675	20,764	20,777	20,393
(CV process error)	67%	66%	66%	66%	70%	63%	63%	66%
1996 year-class	31,863	35,935	35,935	35,935	26,353	39,056	39,500	36,903
(CV 1996 year-class)	(26%)	(24%)	(24%)	(24%)	(16%)	(22%)	(22%)	(24%)

[3] At time of spawning, fishing at F_{msy}

[4] At time of spawning, fishing at $F_{40\%}$

Table 1.11. Results relating to yield for Models 0-7. See text for model descriptions.

	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Year 2000 Harmonic Mean F_{msy} yield	966	1,279	1,197	1,315	881	3,410	3,404	4,213
Point estimate of year 2000 F_{msy} yield	1,392	1,717	1,678	1,704	1,145	3,837	3,842	4,699
(CV)	(41%)	(36%)	(39%)	(34%)	(34%)	(22%)	(22%)	(21%)
Year 2000 $F_{40\%}$ Yield	947	1,201	1,139	1,232	860	1,311	1,311	1,172
Year 2000 $F_{35\%}$ Yield	1,223	1,513	1,471	1,521	1,097	1,693	1,692	1,515
MSY (long-term expectation)	1,446	1,465	1,473	1,444	1,386	1,957	1,959	1,359
Average F (over ages 1-15)								
F_{msy}	0.74	0.62	0.80	0.54	0.62	2.49	2.48	4.91
(CV)	(90%)	(72%)	(92%)	(62%)	(83%)	(73%)	(73%)	(31%)
$F_{40\%}$	0.456	0.399	0.483	0.369	0.436	0.481	0.480	0.487
Full-selection equivalent F's								
F_{msy}	1.210	0.898	1.240	0.812	0.993	3.917	3.897	7.625
$F_{40\%}$	0.741	0.582	0.752	0.555	0.694	0.757	0.755	0.756
$F_{35\%}$	1.021	0.767	1.039	0.709	0.940	1.049	1.046	1.045

Table 1.12 Estimates of numbers at age for the EBS pollock stock under Model 2 (millions).

Year	1	2	3	4	5	6	7	8	9	10+
1964	3,057	1,634	999	177	70	143	71	35	32	216
1965	16,216	1,240	1,026	679	88	27	57	33	18	155
1966	13,125	6,577	776	684	306	29	9	24	16	104
1967	26,130	5,320	4,094	502	328	119	12	4	12	69
1968	23,315	10,570	3,257	2,410	178	82	35	4	2	39
1969	27,181	9,442	6,529	2,016	1,005	57	30	14	2	21
1970	22,256	10,938	5,701	3,874	1,054	471	27	14	7	12
1971	8,397	8,946	6,564	3,299	1,947	469	216	13	7	9
1972	8,838	3,366	5,289	3,574	1,506	763	191	89	5	7
1973	34,455	3,556	1,879	2,474	1,452	615	314	79	37	5
1974	20,440	13,795	1,866	710	761	450	193	100	25	14
1975	16,562	8,140	6,761	557	160	174	104	46	23	9
1976	13,618	6,665	4,519	2,581	161	46	51	31	14	10
1977	14,913	5,494	3,828	2,029	940	58	17	19	11	9
1978	28,623	6,026	3,225	1,909	857	396	25	7	8	9
1979	66,846	11,593	3,623	1,760	842	312	117	7	2	5
1980	25,370	27,086	7,014	2,043	821	331	102	38	2	3
1981	27,531	10,290	16,648	4,292	1,094	390	138	43	16	2
1982	13,524	11,177	6,462	11,426	2,559	573	184	64	19	8
1983	45,923	5,494	7,066	4,585	7,488	1,559	329	104	35	14
1984	11,104	18,660	3,480	5,067	3,097	4,787	953	200	62	29
1985	30,589	4,512	11,840	2,500	3,427	1,972	2,961	585	123	51
1986	11,787	12,430	2,863	8,501	1,688	2,176	1,216	1,811	360	98
1987	6,674	4,790	7,888	2,058	5,760	1,078	1,351	749	1,122	263
1988	4,817	2,713	3,047	5,749	1,443	3,891	706	850	475	858
1989	8,908	1,958	1,724	2,205	3,937	937	2,415	414	504	753
1990	47,289	3,620	1,244	1,246	1,504	2,537	576	1,400	243	685
1991	20,760	19,219	2,298	888	824	893	1,383	290	713	453
1992	12,675	8,436	12,188	1,629	575	471	461	650	138	534
1993	25,867	5,150	5,342	8,536	1,018	306	220	192	275	273
1994	8,474	10,512	3,270	3,819	5,426	560	144	96	85	253
1995	8,068	3,444	6,679	2,350	2,480	3,114	281	68	46	167
1996	17,320	3,279	2,189	4,822	1,558	1,482	1,660	142	35	113
1997	35,936	7,039	2,084	1,596	3,386	993	765	760	67	70
1998	15,464	14,604	4,472	1,516	1,112	2,113	487	328	338	60
1999	9,535	6,284	9,274	3,246	1,050	683	1,000	199	139	164
Median	16,389	6,621	3,961	2,278	1,074	516	204	84	34	56
Average	20,322	8,167	4,917	2,981	1,720	974	522	264	139	154

Table 1.13. Estimated catch-at-age of EBS pollock for Model 2.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1964	4	20	72	52	29	58	24	9	6	28
1965	25	18	89	232	43	12	22	10	4	24
1966	26	126	86	211	127	11	3	7	4	20
1967	88	171	731	230	193	64	6	2	4	21
1968	61	267	465	923	90	37	14	1	1	9
1969	183	404	1,128	517	323	17	9	4	1	6
1970	167	519	1,085	1,087	369	157	9	5	2	3
1971	78	526	1,515	1,107	805	185	84	5	2	3
1972	61	339	1,704	1,415	593	297	73	35	2	3
1973	346	511	809	1,277	746	313	158	41	18	3
1974	277	2,595	984	439	468	275	117	61	15	8
1975	111	852	2,877	300	87	93	55	24	12	5
1976	69	535	1,557	1,154	72	20	22	14	6	4
1977	60	352	1,091	764	355	22	6	7	4	3
1978	72	277	740	676	383	210	13	4	4	4
1979	149	478	753	570	347	154	58	4	1	2
1980	40	788	1,060	493	257	127	39	14	1	1
1981	26	126	1,060	728	279	124	45	15	6	1
1982	7	77	236	1,142	394	112	37	14	5	2
1983	18	29	195	350	890	236	52	18	7	3
1984	4	74	91	382	378	685	142	29	11	7
1985	10	18	316	192	425	287	448	86	23	13
1986	4	48	73	628	202	306	178	257	65	25
1987	1	9	110	95	440	109	176	94	156	41
1988	1	7	61	376	155	547	127	148	91	184
1989	2	6	36	152	444	138	457	76	101	188
1990	12	13	40	116	259	584	161	381	68	208
1991	6	84	86	96	164	236	441	90	228	161
1992	5	47	576	221	141	152	177	245	53	213
1993	7	17	162	1,051	228	98	79	68	94	87
1994	2	30	85	408	1,062	158	46	30	26	72
1995	2	8	147	214	417	761	78	18	12	41
1996	4	9	31	217	189	391	554	45	11	35
1997	11	21	33	82	463	292	283	266	25	24
1998	5	48	77	84	165	667	192	123	133	22
1999	3	21	165	186	159	221	402	76	56	64

Table 1.14. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for Model 2 (current assessment) compared to estimates from the 1998 (columns 4 & 5) and 1997 (columns 6 & 7) assessments for EBS pollock.

Age 3+ Biomass	Current Assessment	CV	1998 Assessment	CV	1997 Assessment	CV
1964	917	41%	1,037	30%		
1965	976	32%	1,227	26%		
1966	919	31%	1,096	28%		
1967	1,858	24%	2,095	22%		
1968	2,312	27%	2,510	23%		
1969	3,579	22%	3,810	19%		
1970	4,479	19%	5,083	15%		
1971	5,161	16%	5,813	12%		
1972	4,896	15%	5,648	11%		
1973	3,357	20%	3,922	14%		
1974	1,952	28%	2,342	19%		
1975	2,683	18%	3,014	13%		
1976	2,748	16%	3,008	13%		
1977	2,716	14%	2,894	13%		
1978	2,668	15%	2,867	13%	3,244	19%
1979	2,720	16%	2,933	15%	3,183	21%
1980	3,888	16%	4,294	14%	4,618	19%
1981	8,064	13%	8,569	12%	9,190	16%
1982	9,229	13%	9,778	12%	10,524	17%
1983	10,153	12%	10,705	12%	11,555	16%
1984	9,685	12%	10,179	12%	11,028	17%
1985	11,370	10%	11,919	11%	12,853	15%
1986	10,440	10%	10,913	11%	11,796	16%
1987	10,769	9%	11,116	10%	11,952	15%
1988	9,991	9%	10,274	10%	11,020	15%
1989	8,305	9%	8,546	10%	9,210	16%
1990	6,497	10%	6,659	12%	7,240	18%
1991	4,842	11%	5,180	13%	5,690	20%
1992	7,800	10%	8,294	13%	9,465	21%
1993	9,873	10%	10,279	16%	12,086	25%
1994	8,622	12%	8,917	18%	10,626	29%
1995	8,817	15%	8,680	22%	9,998	32%
1996	7,147	17%	6,811	26%	8,142	36%
1997	5,710	22%	5,307	31%	6,631	42%
1998	5,961	28%	5,133	39%	5,133	39%
1999	7,513	36%				

Table 1.15 Projections of Model 2 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. The values for $B_{40\%}$ and $B_{35\%}$ are 2,340 and 2,047 respectively.

Sp.Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
1999	1,910	1,910	1,910	1,910	1,910	1,910	1,910
2000	2,252	2,252	2,322	2,290	2,396	2,205	2,252
2001	2,225	2,225	2,495	2,365	2,855	2,076	2,225
2002	2,032	2,032	2,446	2,230	3,150	1,840	1,976
2003	2,038	2,038	2,522	2,233	3,579	1,842	1,878
2004	2,179	2,179	2,681	2,357	4,008	1,986	1,995
2005	2,305	2,305	2,826	2,490	4,345	2,102	2,103
2006	2,381	2,381	2,946	2,592	4,668	2,156	2,156
2007	2,412	2,412	3,022	2,651	4,942	2,173	2,173
2008	2,414	2,414	3,054	2,671	5,139	2,167	2,167
2009	2,415	2,415	3,074	2,683	5,308	2,165	2,165
2010	2,417	2,417	3,087	2,691	5,438	2,167	2,167
2011	2,419	2,419	3,093	2,696	5,531	2,170	2,170
2012	2,427	2,427	3,103	2,705	5,616	2,177	2,177
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
1999	0.394	0.394	0.394	0.394	0.394	0.394	0.394
2000	0.464	0.464	0.232	0.338	0.000	0.627	0.464
2001	0.458	0.458	0.241	0.338	0.000	0.588	0.458
2002	0.413	0.413	0.233	0.338	0.000	0.516	0.556
2003	0.400	0.400	0.227	0.338	0.000	0.504	0.514
2004	0.411	0.411	0.227	0.338	0.000	0.529	0.531
2005	0.421	0.421	0.229	0.338	0.000	0.548	0.549
2006	0.428	0.428	0.231	0.338	0.000	0.556	0.556
2007	0.431	0.431	0.232	0.338	0.000	0.560	0.560
2008	0.432	0.432	0.233	0.338	0.000	0.560	0.560
2009	0.434	0.434	0.234	0.338	0.000	0.562	0.562
2010	0.434	0.434	0.234	0.338	0.000	0.561	0.561
2011	0.433	0.433	0.234	0.338	0.000	0.560	0.560
2012	0.432	0.432	0.234	0.338	0.000	0.560	0.560
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2000	1,102	1,102	604	843	0	1,402	1,102
2001	1,261	1,261	824	1,042	0	1,426	1,261
2002	1,283	1,283	980	1,217	0	1,358	1,616
2003	1,152	1,152	957	1,142	0	1,193	1,261
2004	1,111	1,111	910	1,051	0	1,188	1,204
2005	1,242	1,242	979	1,129	0	1,354	1,358
2006	1,345	1,345	1,062	1,219	0	1,447	1,447
2007	1,384	1,384	1,110	1,265	0	1,478	1,478
2008	1,402	1,402	1,141	1,293	0	1,483	1,483
2009	1,407	1,407	1,159	1,305	0	1,483	1,483
2010	1,402	1,402	1,165	1,307	0	1,476	1,476
2011	1,400	1,400	1,166	1,309	0	1,477	1,477
2012	1,405	1,405	1,170	1,314	0	1,485	1,485

Table 1.16 Percent of catch taken within CH/CVOA by season (NOTE: A1 and A2 seasons were not implemented in 1998 but for presentation purposes, the same periods in both years were used. I.e., A1 = Jan 20th – Feb 15th, A2 = Feb 16th – Mar 31st.)

Catch w/in CH/CVOA	1998	1999
A1	91%	72%
A2	77%	33%
All A - Season	87%	55%

Table 1.17. Estimated harvest levels inside the CH/CVOA during the months Jan-Mar, 1985-1999. The early period was based on harvest levels from NMFS observer data from foreign and joint venture fishing operations (1980-1989). Biomass (thousands of tons) was computed based on model estimates of 3+ biomass (Ianelli *et al.* 1998), assuming 26% (Case 1), 38% (Case 2), and 50% (Case 3) of the population was available w/in the CH/CVOA during these months. Note that 1991 was the last year that the Bogoslof area was open to fishing.

Year	Jan-Mar Catch in CH/CVOA	Case 1 CH/CVOA Biomass[5]	Case 1 CH/CVOA Harvest Rate	Case 2 CH/CVOA Harvest Rate	Case 3 CH/CVOA Harvest Rate
1985	29	3,099	0.9%	0.6%	0.5%
1986	120	2,837	4.2%	2.9%	2.2%
1987	405	2,890	14.0%	9.6%	7.3%
1988	271	2,671	10.1%	6.9%	5.3%
1989	54	2,222	2.4%	1.7%	1.3%
1990	na	Na	na	na	Na
1991	594	1,347	44.1%	30.2%	22.9%
1992	282	2,156	13.1%	8.9%	6.8%
1993	290	2,673	10.9%	7.4%	5.7%
1994	538	2,318	23.2%	15.9%	12.1%
1995	557	2,257	24.7%	16.9%	12.8%
1996	327	1,771	18.5%	12.6%	9.6%
1997	410	1,380	29.7%	20.3%	15.5%
1998	443	1,335	33.2%	22.7%	17.3%
1999	198	1,829	10.8%	7.4%	5.6%

[5] The biomass estimates (thousands of tons) in the CH/CVOA are only from the EBS stock; the Bogoslof Island/Aleutian Basin stock was (known to be present in CH/CVOA during the winter spawning season) was not included.

Table 1.18. Estimated harvest rate (catch/estimated biomass) inside the CH/CVOA assuming 26% of the age 3+ biomass is in this area at the beginning of the year.

Year	**A1**	**A2**
1998	**24%**	**13%**
1999	**8%**	**3%**

Table 1.19. Percentage of total annual EBS harvest by season as estimated from NMFS domestic observer data, 1991-1998.

Year	**Jan-Mar**	**Apr-Aug**	**Sep-Dec**
1991	39%	58%	3%
1992	38%	46%	17%
1993	42%	22%	36%
1994	42%	26%	32%
1995	46%	24%	30%
1996	45%	5%	50%
1997	46%	6%	47%
1998	47%	4%	48%
Average	43%	24%	33%

Table 1.20. Estimate of proportion of harvest taken within CH/CVOA by season and over the whole year, 1991-1999. Estimates based on observed tows from NMFS domestic observer data. The average level is based on the total tonnages summed over years. Note that 1991 was the last year that the Bogoslof area was open to fishing.

Year	**Jan-Mar**	**Apr-Aug**	**Sep-Dec**	**All year**
1991	99%	23%	24%	52%
1992	52%	32%	89%	49%
1993	53%	41%	56%	51%
1994	94%	51%	43%	66%
1995	95%	48%	52%	71%
1996	61%	74%	52%	57%
1997	75%	78%	35%	57%
1998	87%	78%	35%	61%
1999	55%			54%
Average	75%	39%	47%	58%

Table 1.21. Summary results for Model 2, EBS pollock.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop.F. Mature	0.000	0.004	0.145	0.321	0.421	0.451	0.474	0.482	0.485	0.500	0.500	0.500	0.500	0.500	0.500
Fish. Selectivity	0.00	0.01	0.05	0.17	0.49	1.17	1.56	1.45	1.55	1.50	1.41	1.41	1.41	1.41	1.41

	Model 2
Y2K Spawning biomass	2,247 t
B_{msy}	1,793 t
$B_{40\%}$	2,340 t
$B_{35\%}$	2,047 t

Yield Considerations	
Year 2000 Harmonic Mean F_{msy} Yield	1,197 t
Year 2000 Yield F40% (adjusted)	1,102 t
Full Selection F's	
Fmsy	1.240
$F_{40\%}$	0.752
$F_{35\%}$	1.039

1.13. Figures

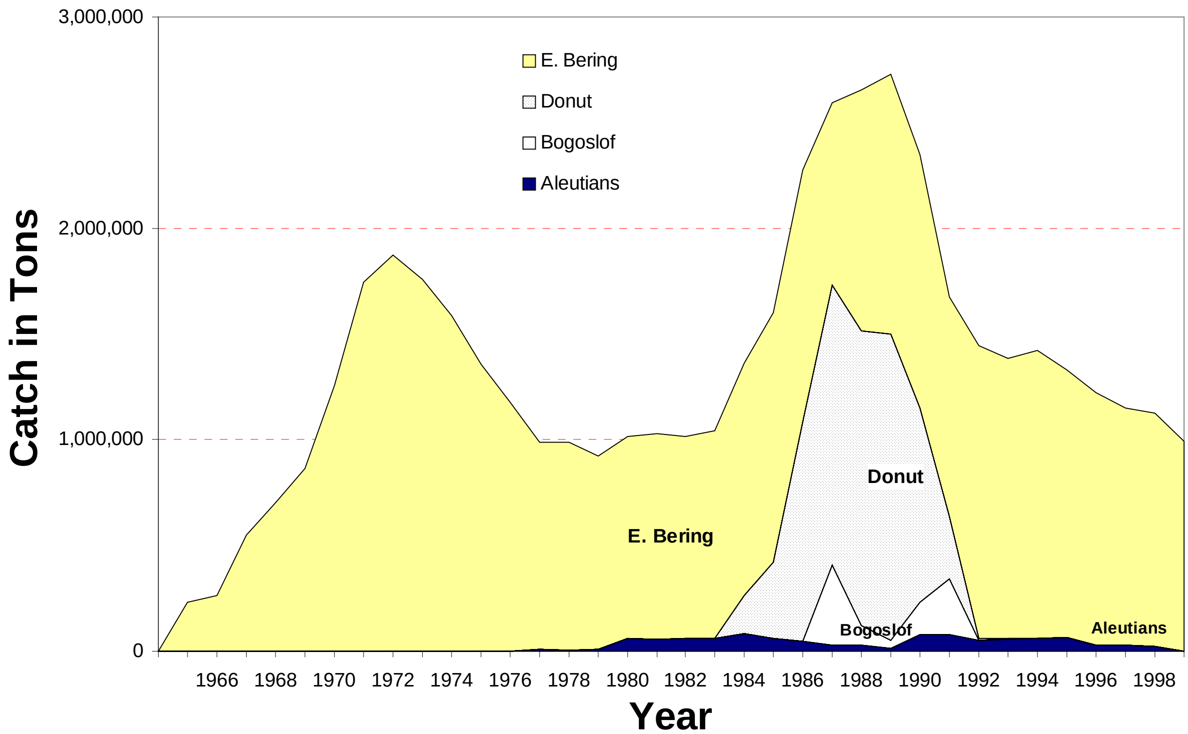

Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-1999.

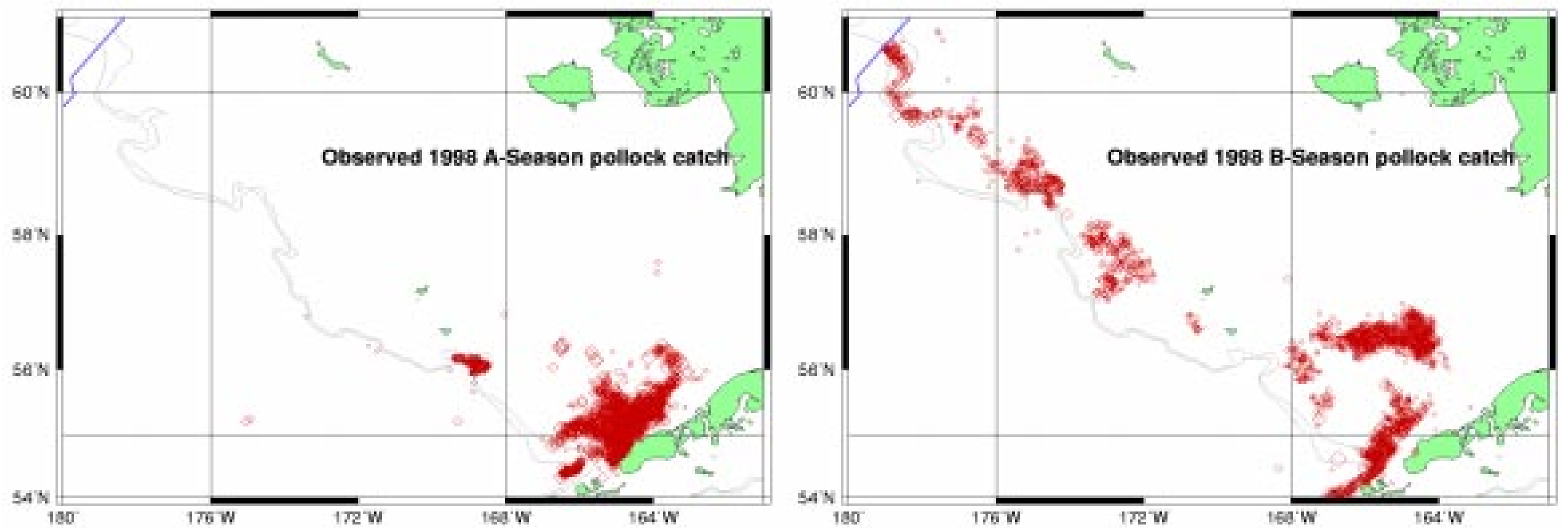

Figure 1.2. Observed locations of the 1998 pollock fishery in the A-(left) and B-(right) seasons on the EBS shelf. The size of the circles approximates nominal catch rates.

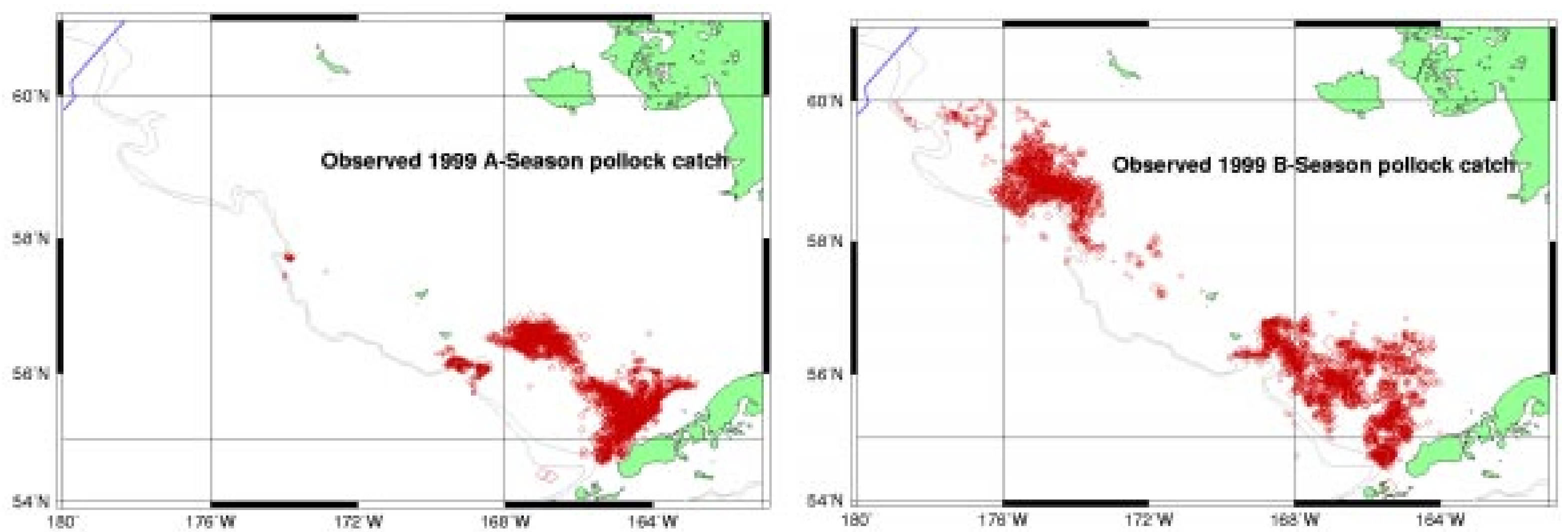

Figure 1.3. Observed locations of the 1999 pollock fishery in the A-(left) and B-(right) seasons on the EBS shelf. The size of the circles approximates nominal catch rates. NOTE: These data are preliminary.

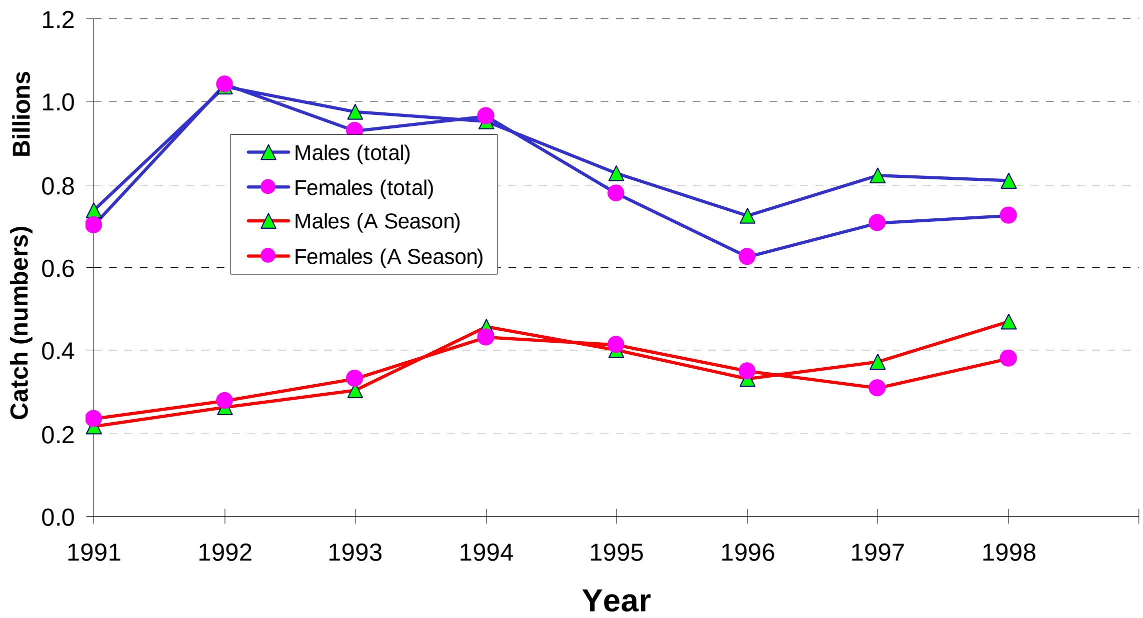

Figure 1.4. Estimate of EBS pollock catch numbers by sex for the "A season" and for the entire fishery, 1991-1998.

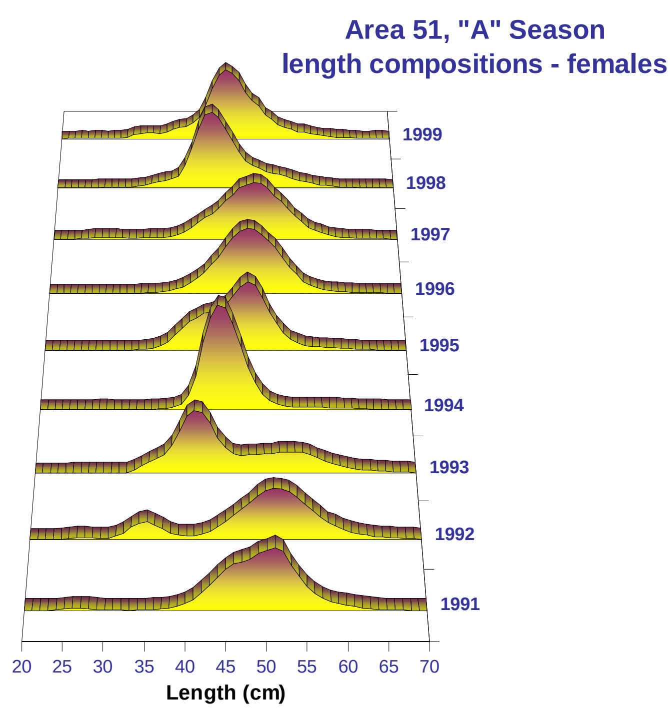

Figure 1.5. Fishery length frequency for the "A season" EBS pollock, 1991-1999.

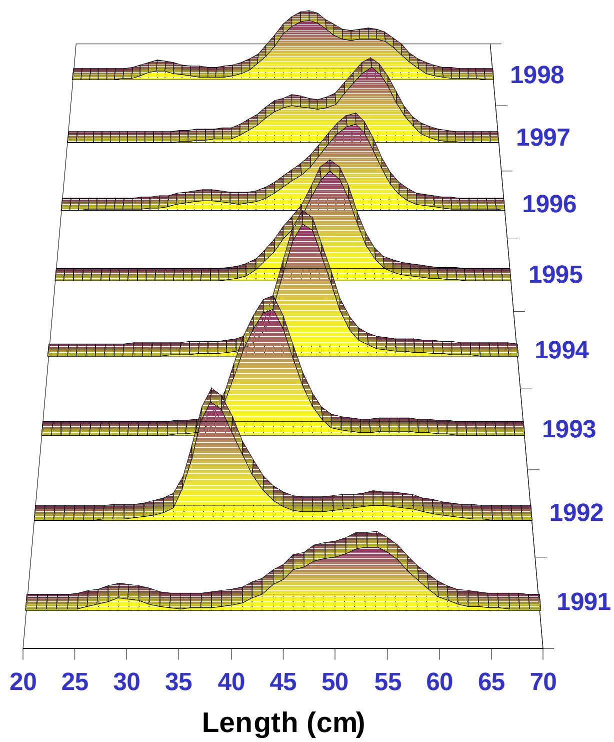

Figure 1.6. Length frequency of EBS pollock observed in the “B season” for 1991-1998.

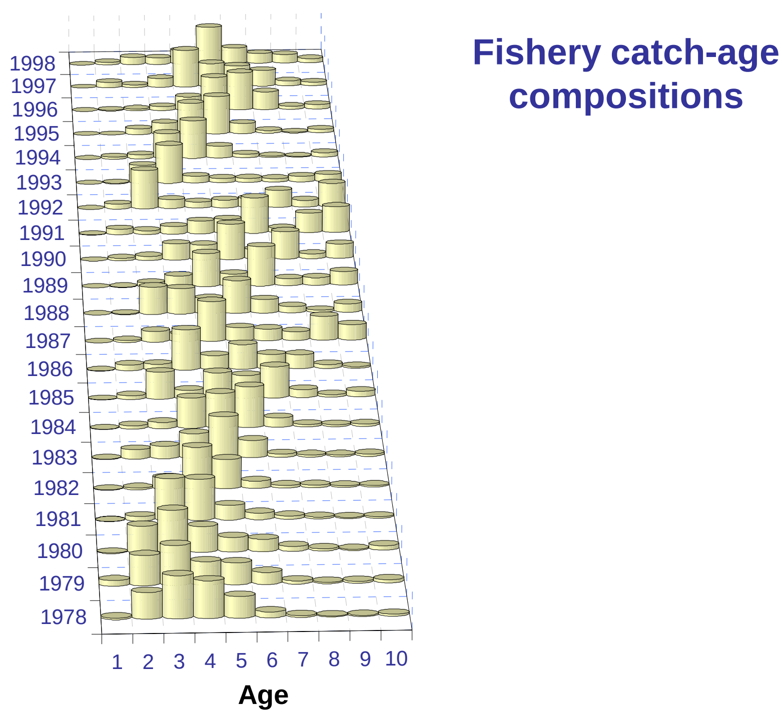

Figure 1.7. EBS walleye pollock fishery catch-at-age data (proportions).

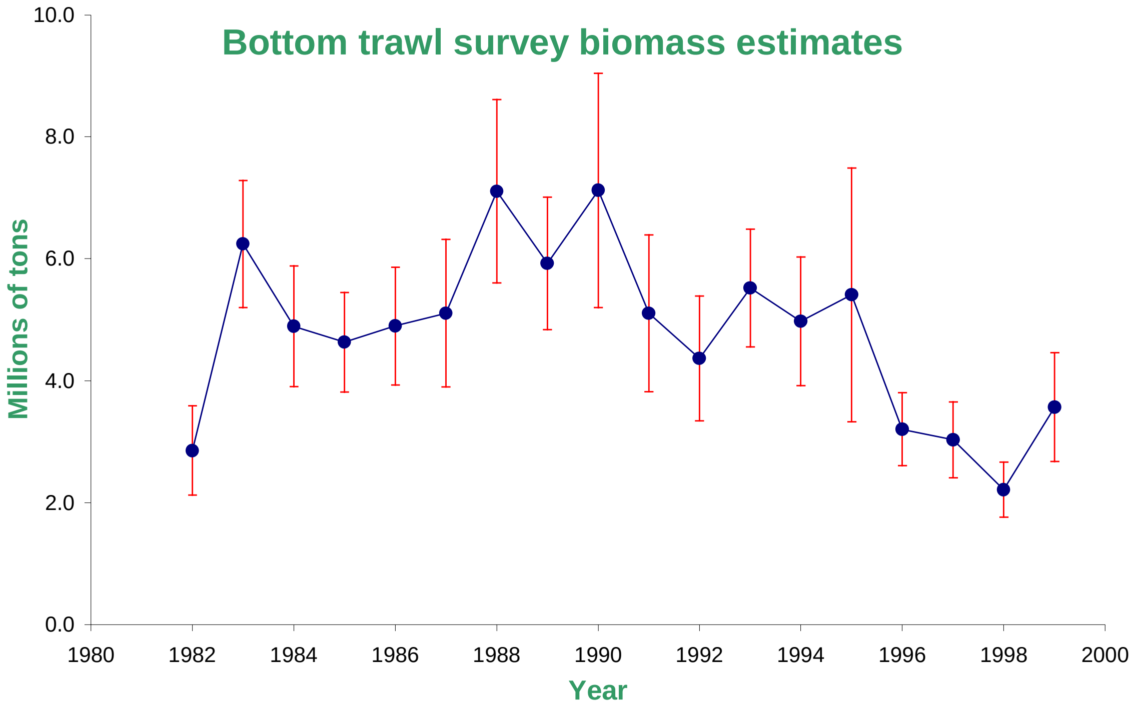

Figure 1.8. Bottom-trawl survey biomass estimates with 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1979-1999 (note that the 1979-1981 estimates were not used in the current analyses since the survey sampling gear changed).

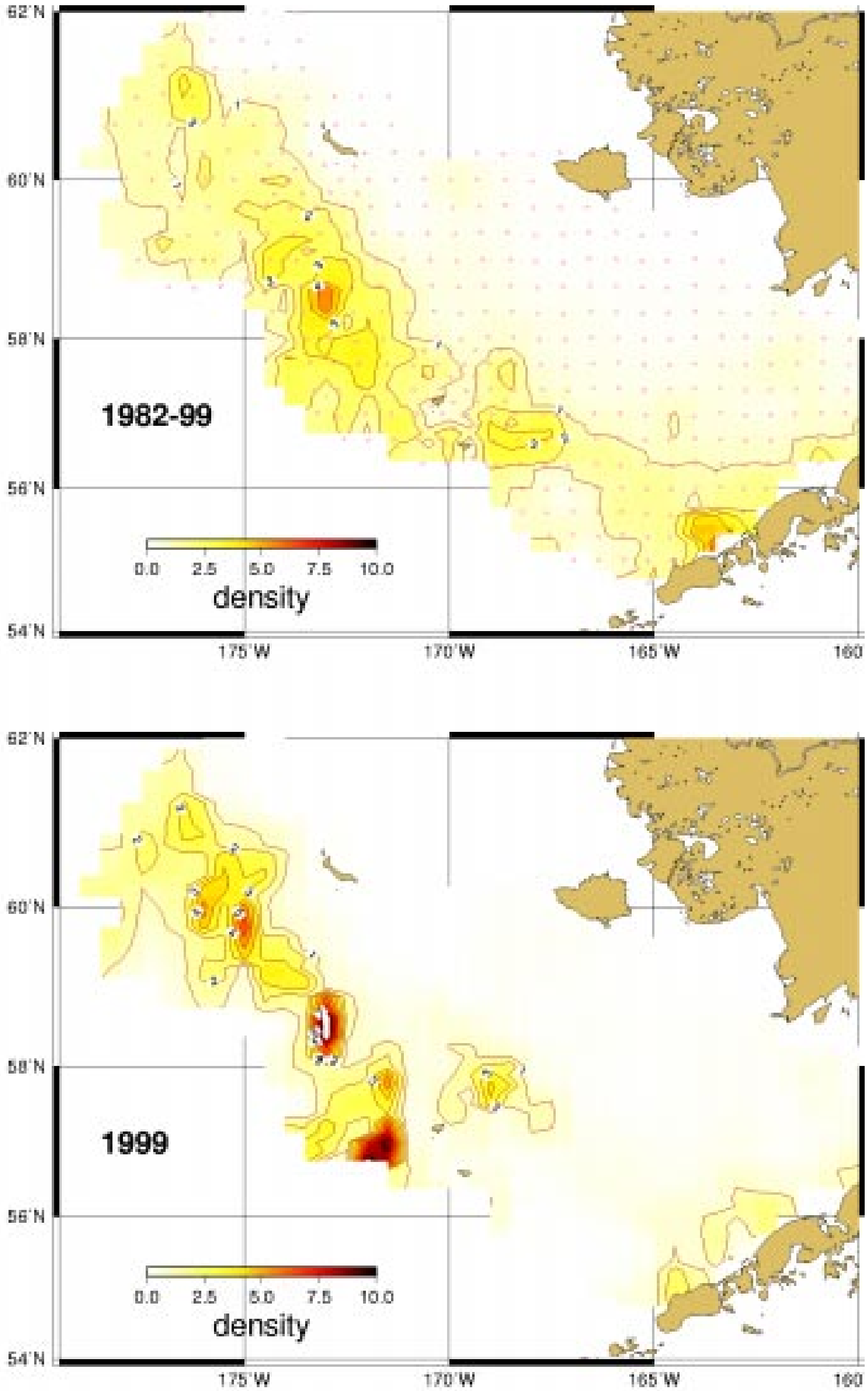

Figure 1.9. Map showing the average walleye pollock catch-per-unit effort (1982-1999) compared to that observed during the 1999 NMFS EBS shelf bottom-trawl survey (bottom).

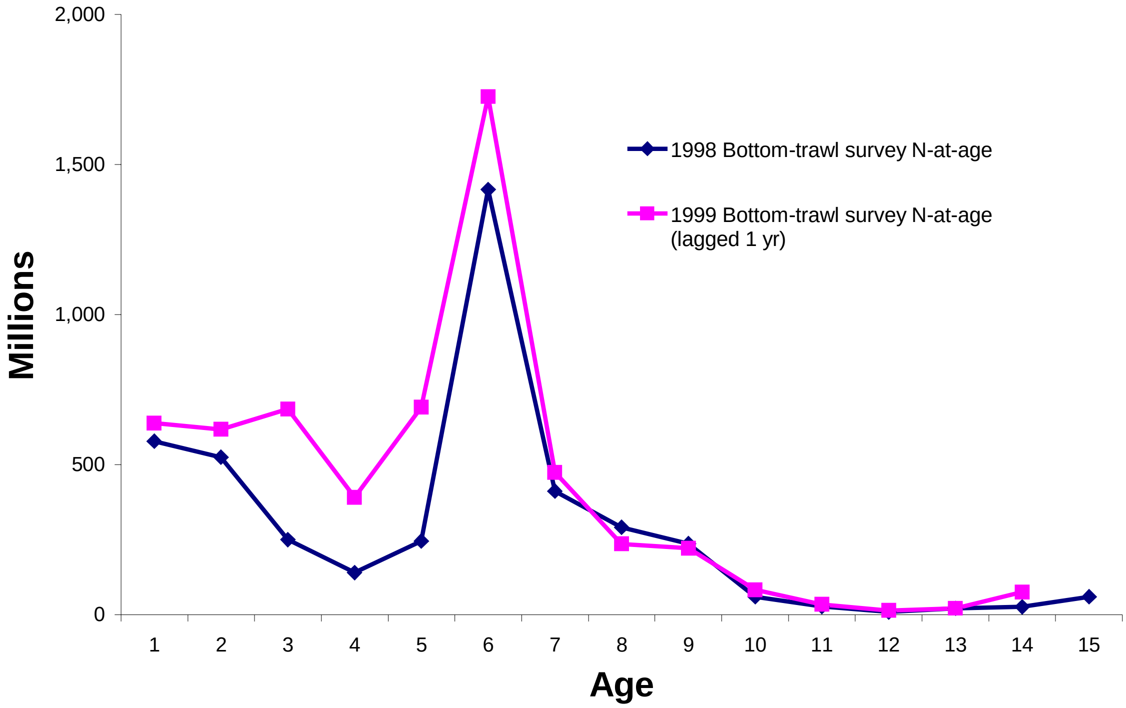

Figure 1.10. EBS pollock age distribution observed during the 1998 and 1999 (lagged) NMFS bottom-trawl survey. Note that age 6 represents the 1992 year-class. In addition, estimates of all ages younger than age 8 are higher than expected (given constant availability/selectivity).

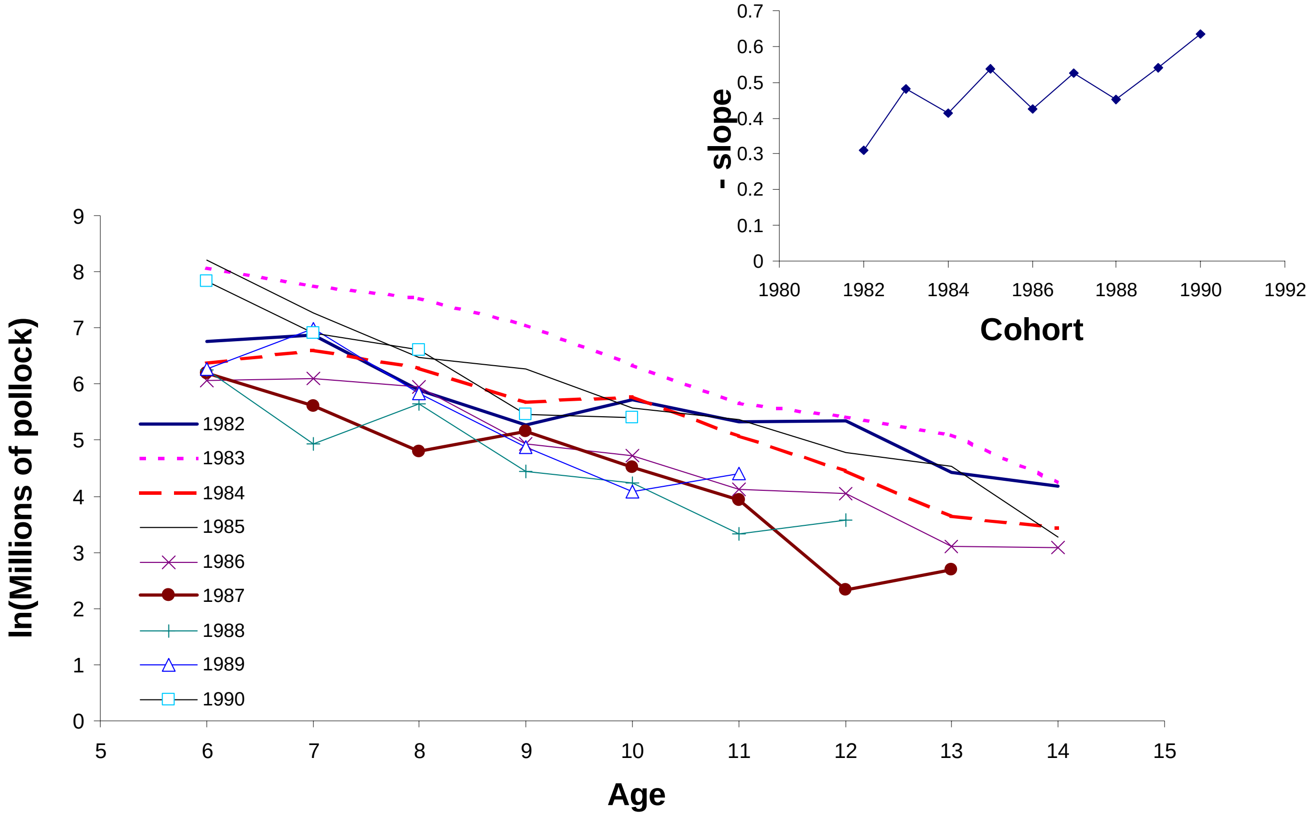

Figure 1.11. Log-abundance levels of individual cohorts (year-classes) as estimated directly from the NMFS bottom-trawl surveys (lower left). Negative slopes (as a proxy for total instantaneous mortality, Z) for each cohort are shown in the top right side.

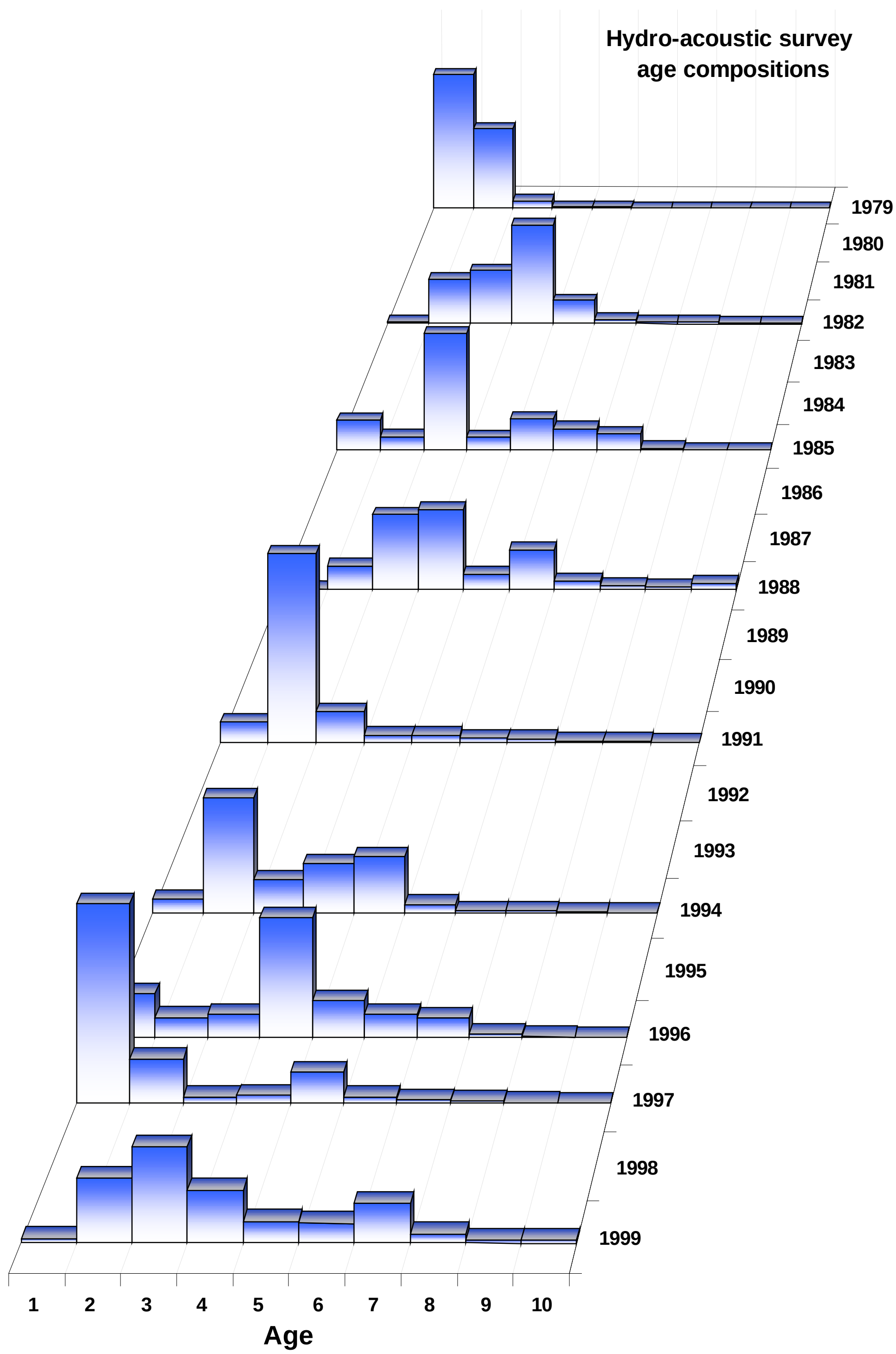

Figure 1.12. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-1999. NOTE: the 1999 estimate of age composition is preliminary.

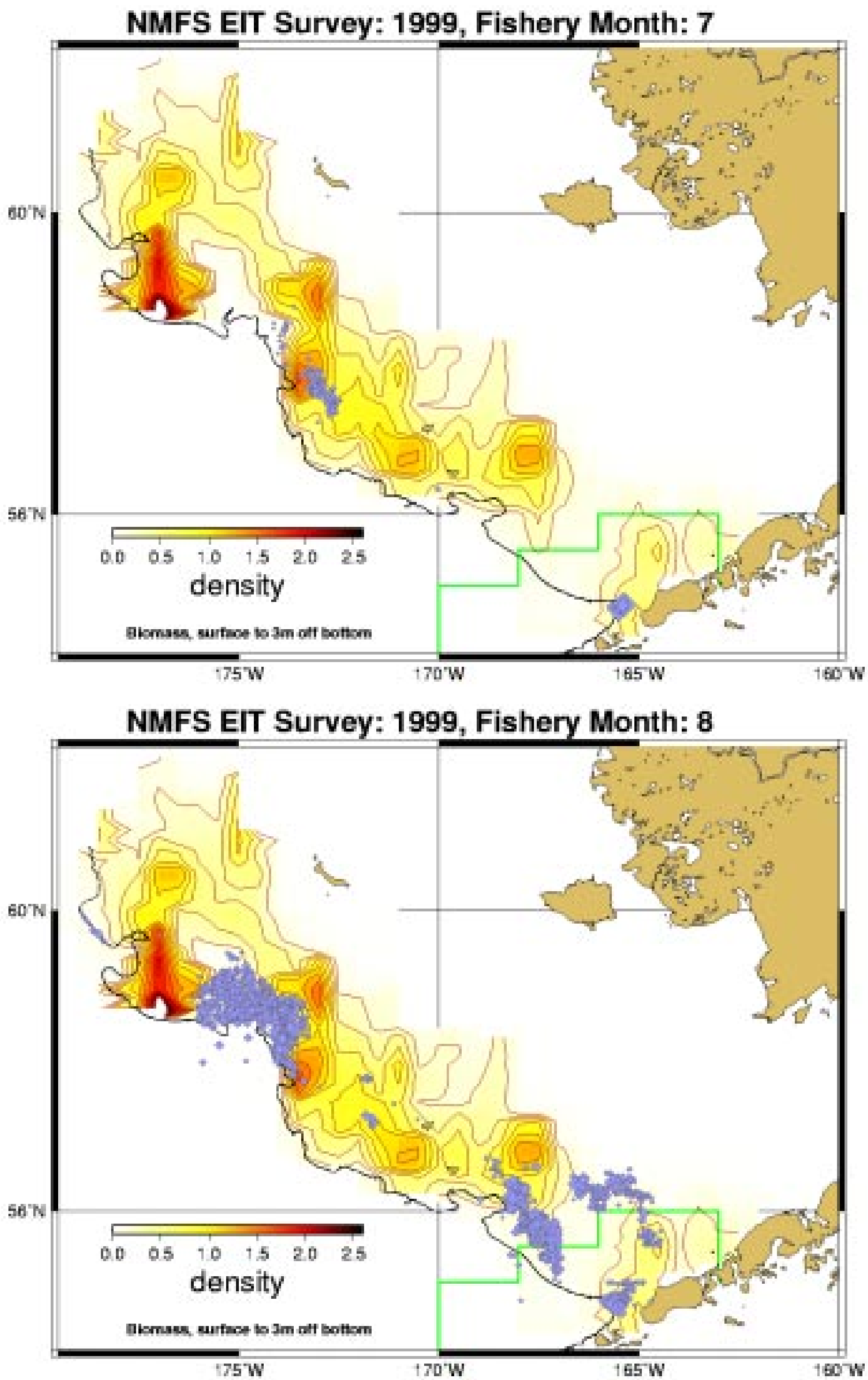

Figure 1.13. Contours of EIT survey density compared with pollock fishery locations (diamonds) in July (top) and August (bottom), 1999. The NMFS EIT Survey was completed by the end of July, 1999 (in the northwestern area).

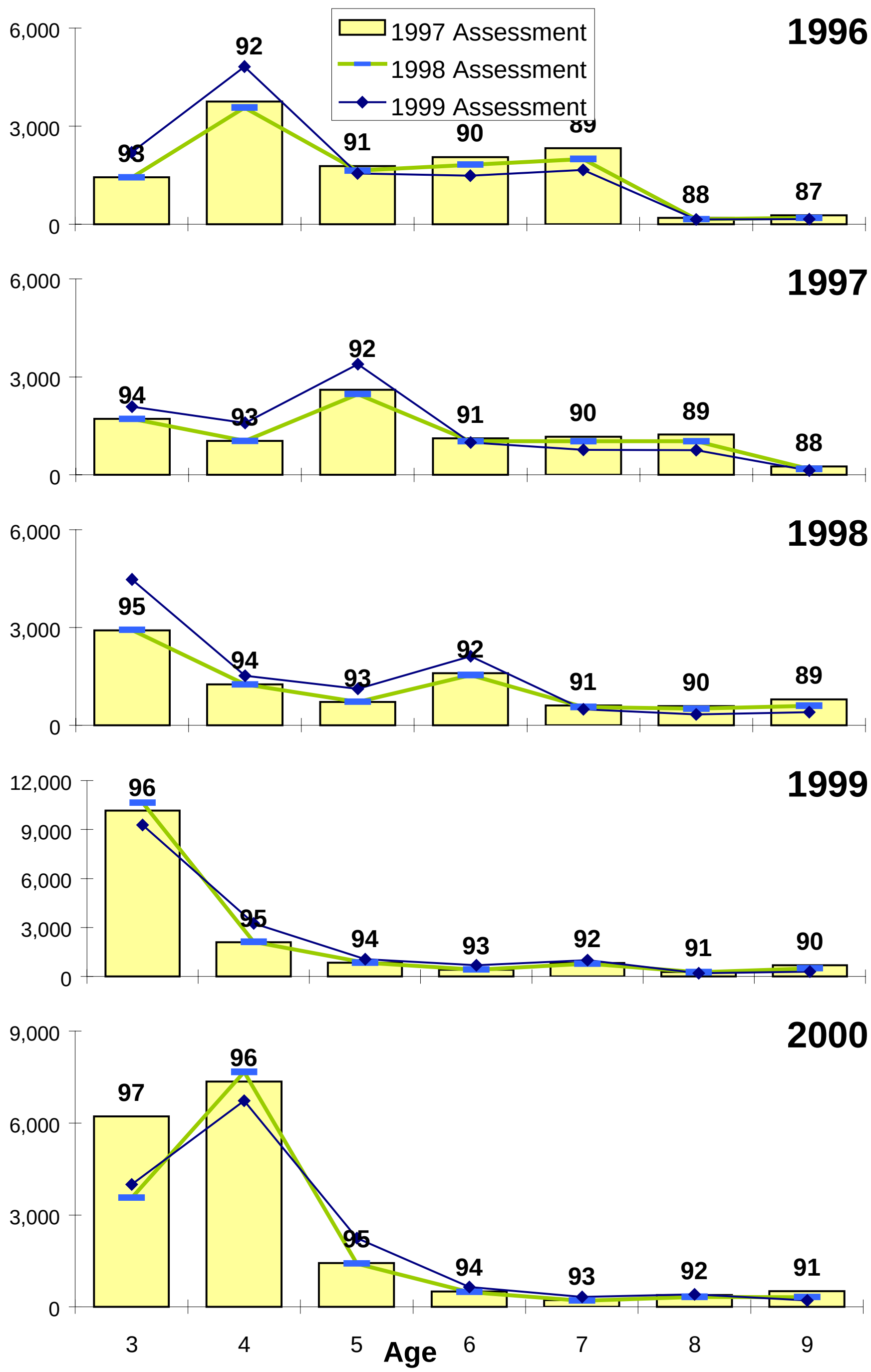

Figure 1.14. Projected EBS walleye pollock Model 2 population numbers at age compared with those presented in the last two assessments (Model 4 from Wespestad et al. 1997, Model 2 from Ianelli *et al.*1998). Note that the "age 9" category represents all pollock age 9 and older. Projections assume adjusted $F_{40\%}$ harvest levels.

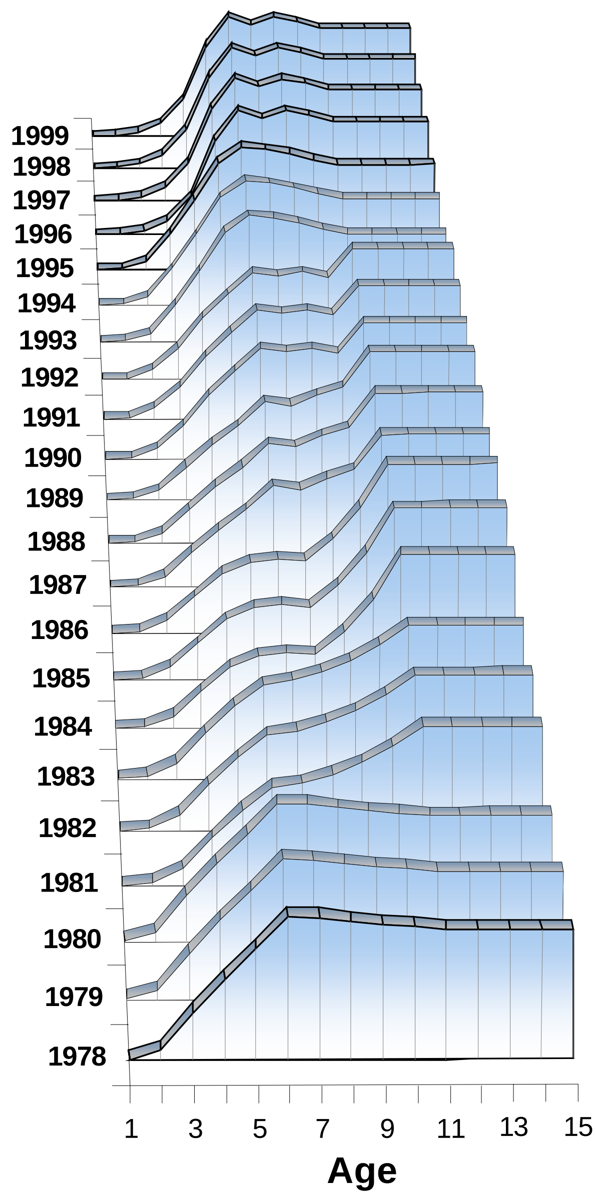

Figure 1.15. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-1999 estimated for Model 2.

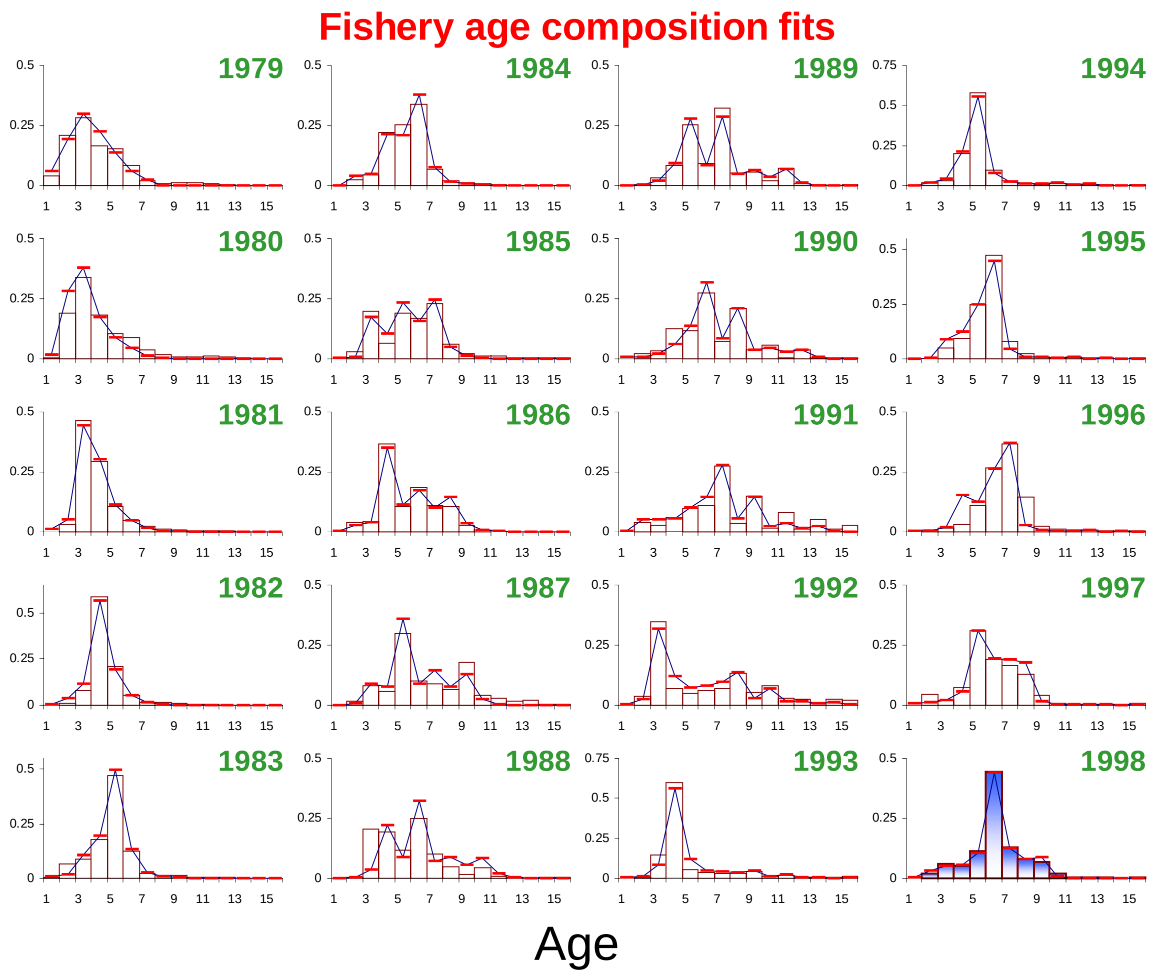

Figure 1.16. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1978-1997). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

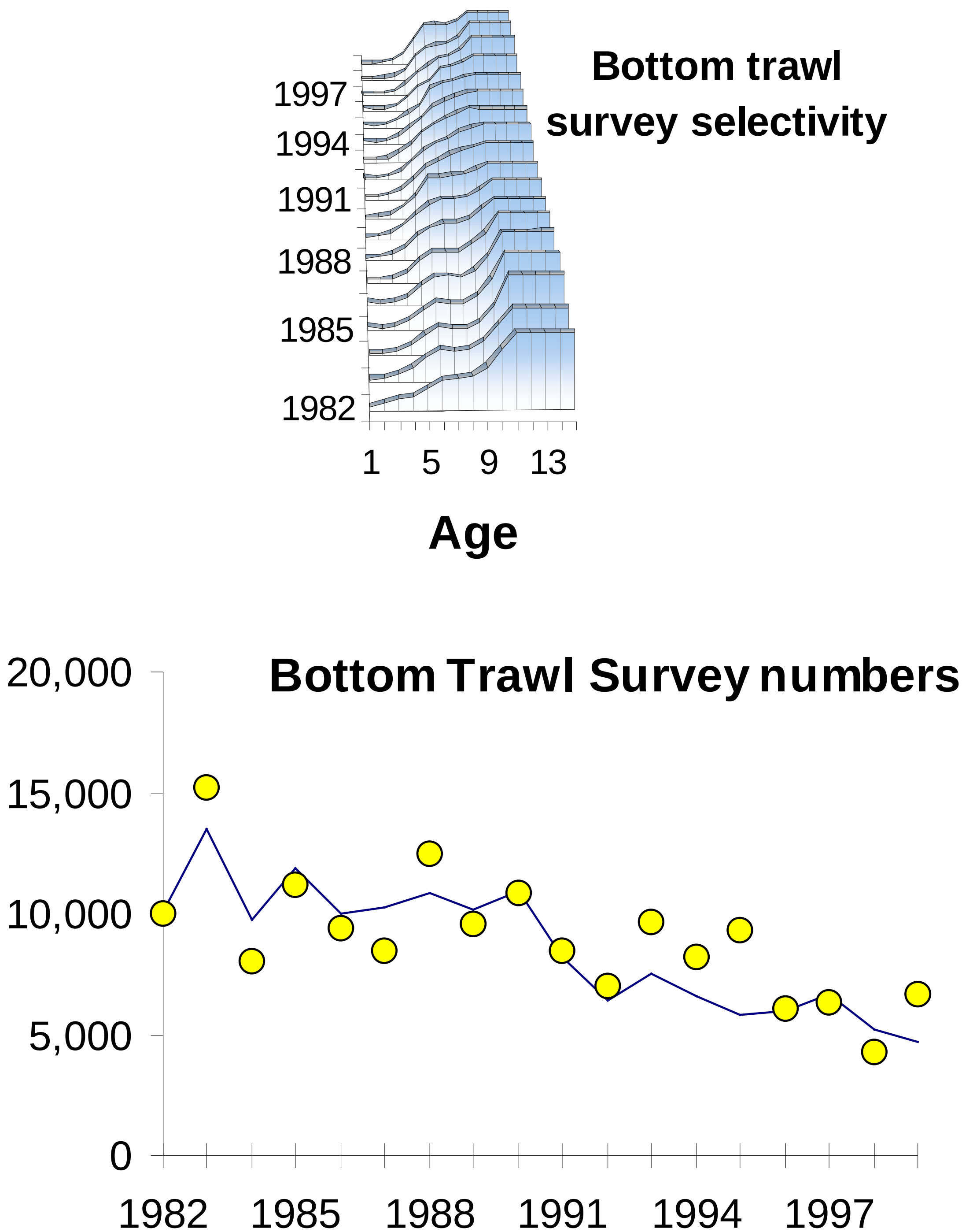

Figure 1.17. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock, Model 2.

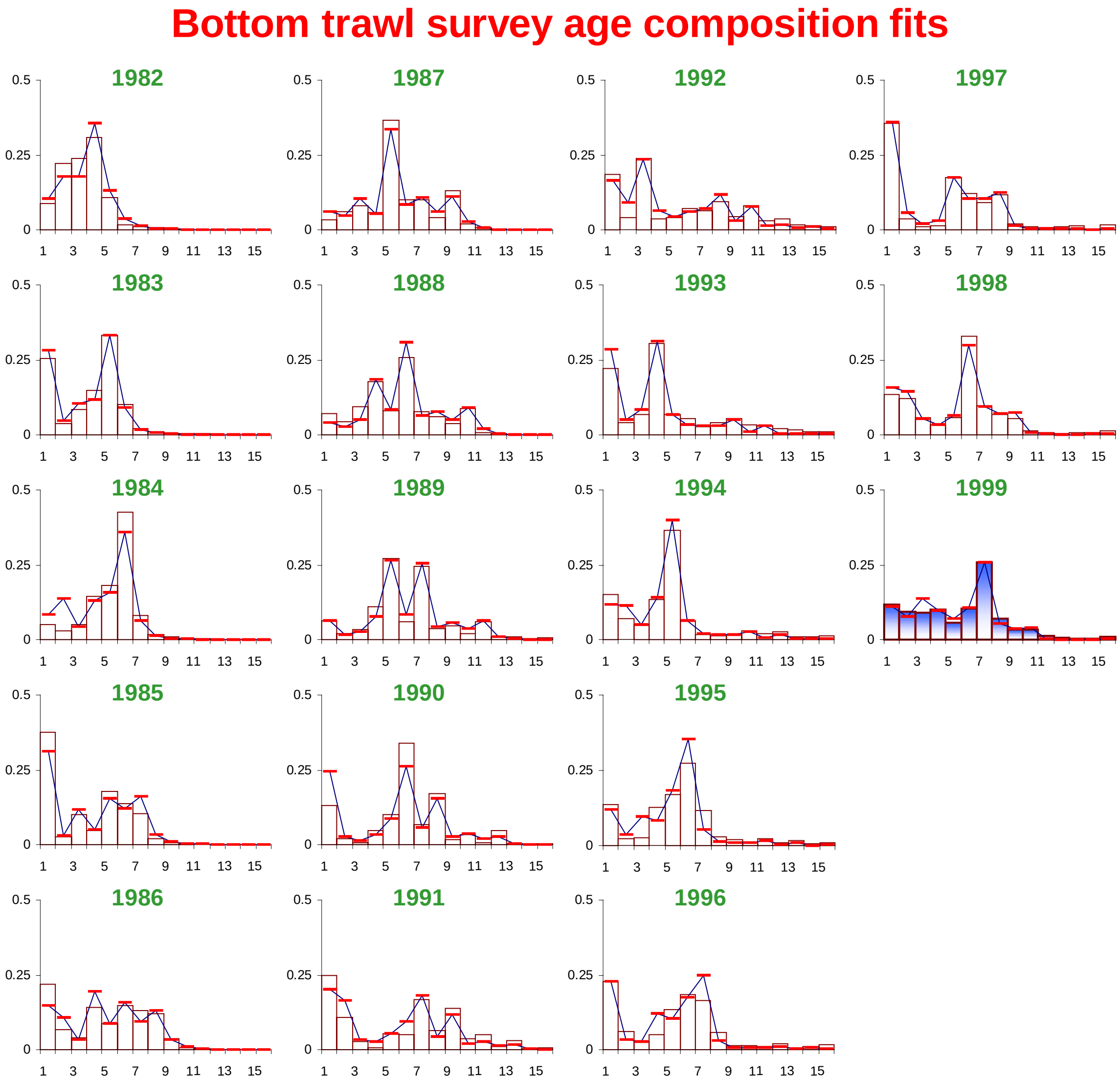

Figure 1.18. Model 2 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

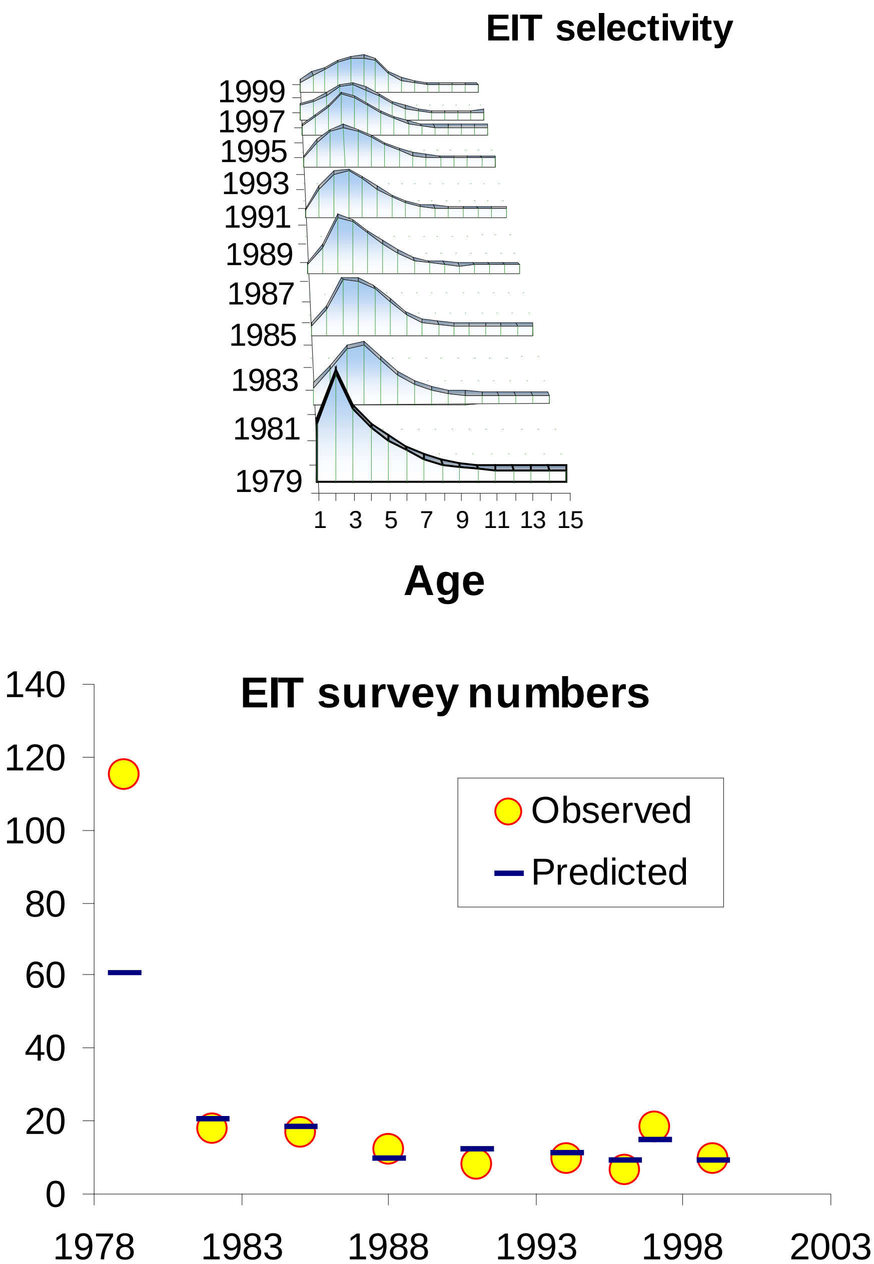

Figure 1.19. Model 2 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock.

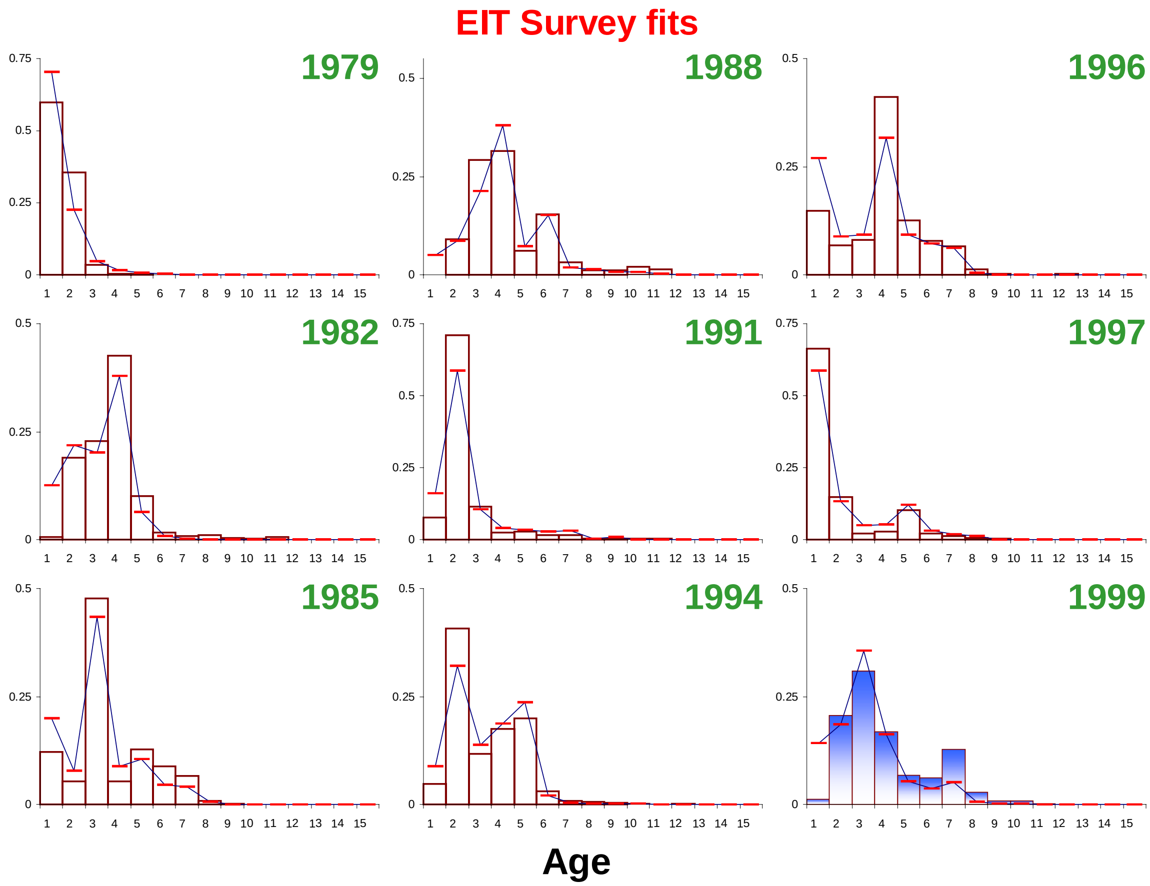

Figure 1.20. Model 2 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

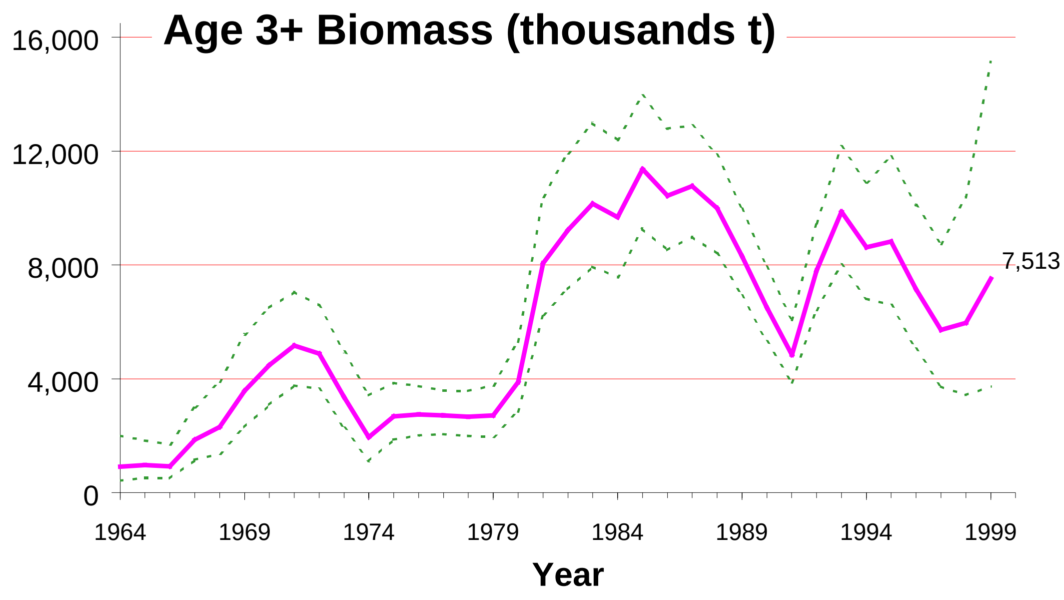

Figure 1.21. Estimated age 3+ EBS walleye pollock biomass under Model 2. Approximate upper and lower 95% confidence limits are shown by dashed lines.

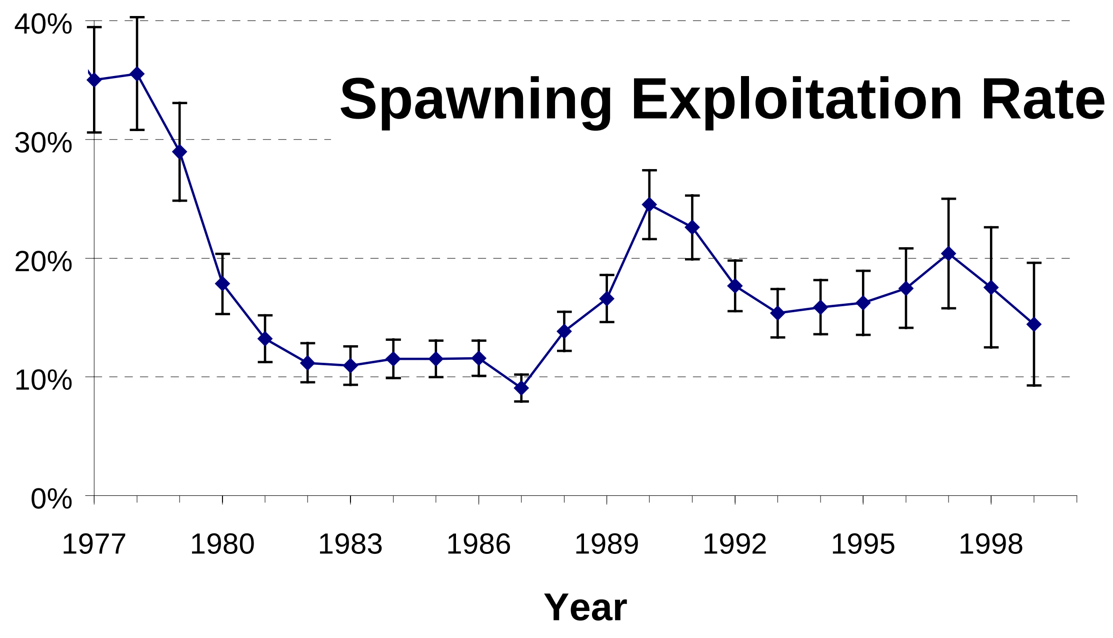

Figure 1.22. Estimated spawning exploitation rate (computed as the percent removals of spawning females each year) for EBS walleye pollock, Model 2. Error bars represent two standard deviations of the estimate.

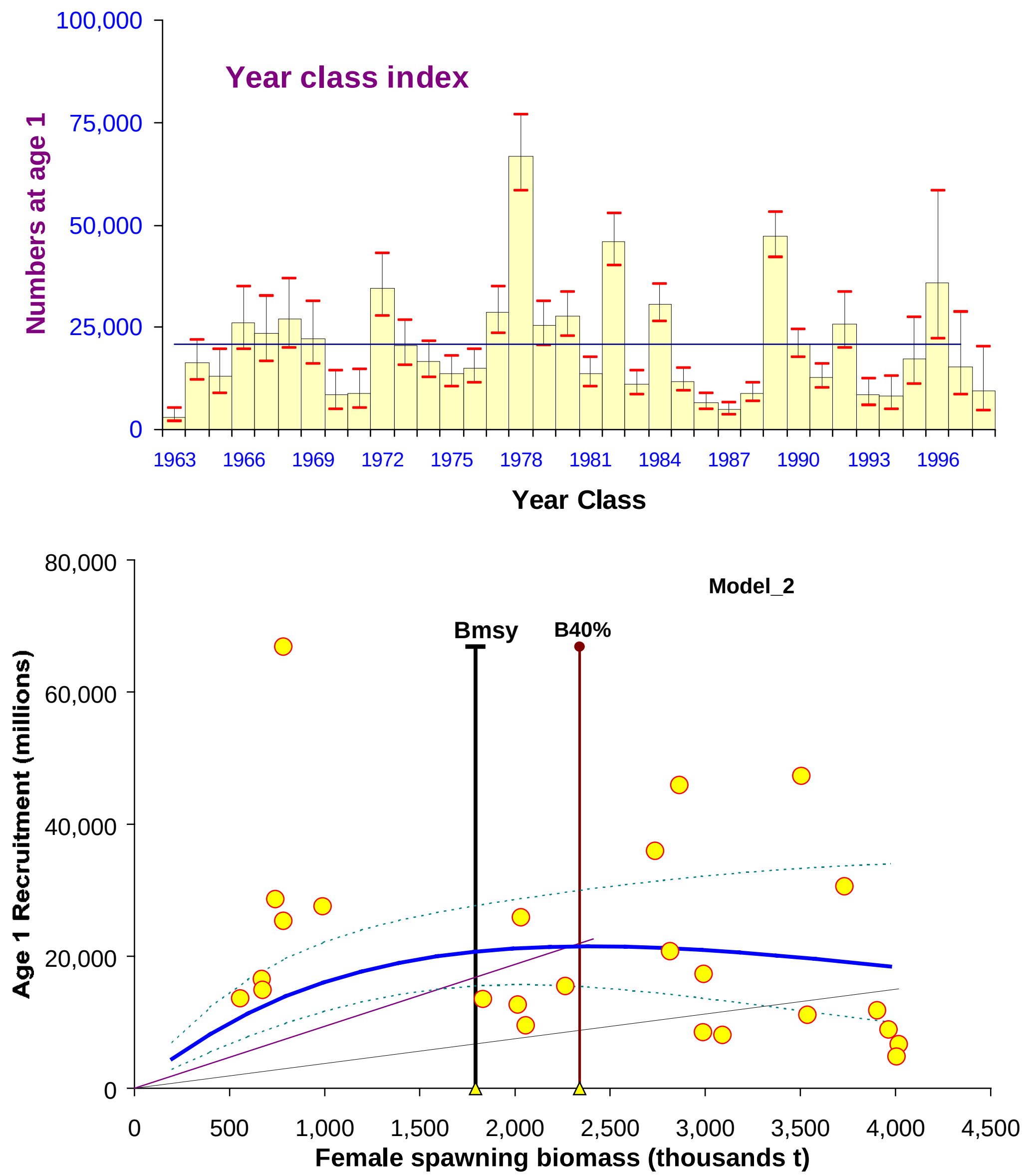

Figure 1.23. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 2. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate B_{msy} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with diagonals representing the replacement lines with no fishing (lower line) and with fishing at the $F_{40\%}$ rate. Dashed lines represent lower and upper 95% confidence limits about the curve.

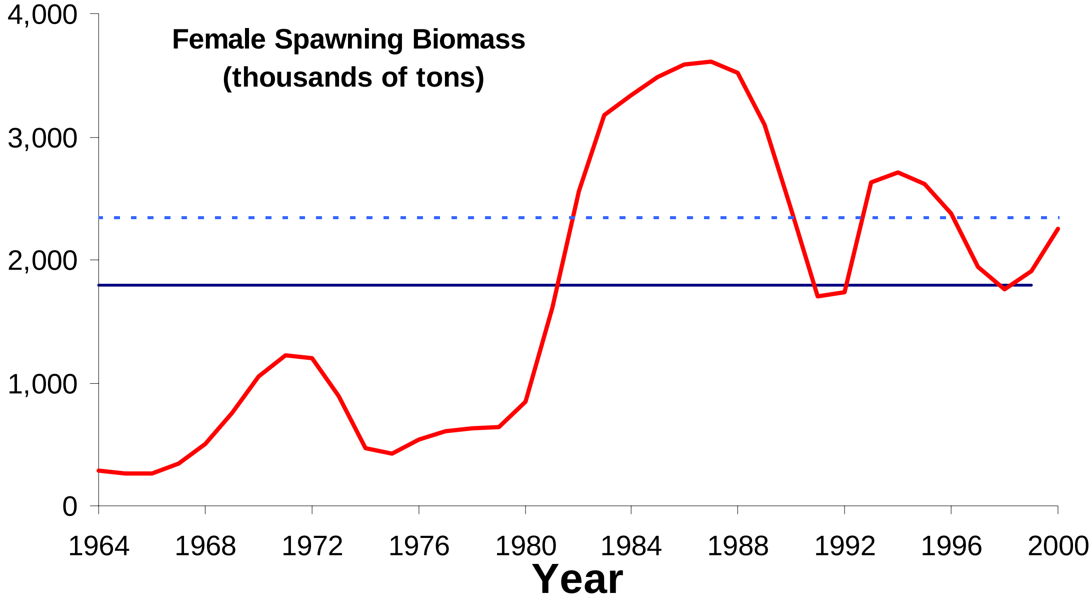

Figure 1.24. EBS walleye pollock female spawning biomass abundance trends, 1979-2000 as estimated by Model 2. Horizontal solid and dashed lines represent the B_{msy}, and $B_{40\%}$ levels, respectively.

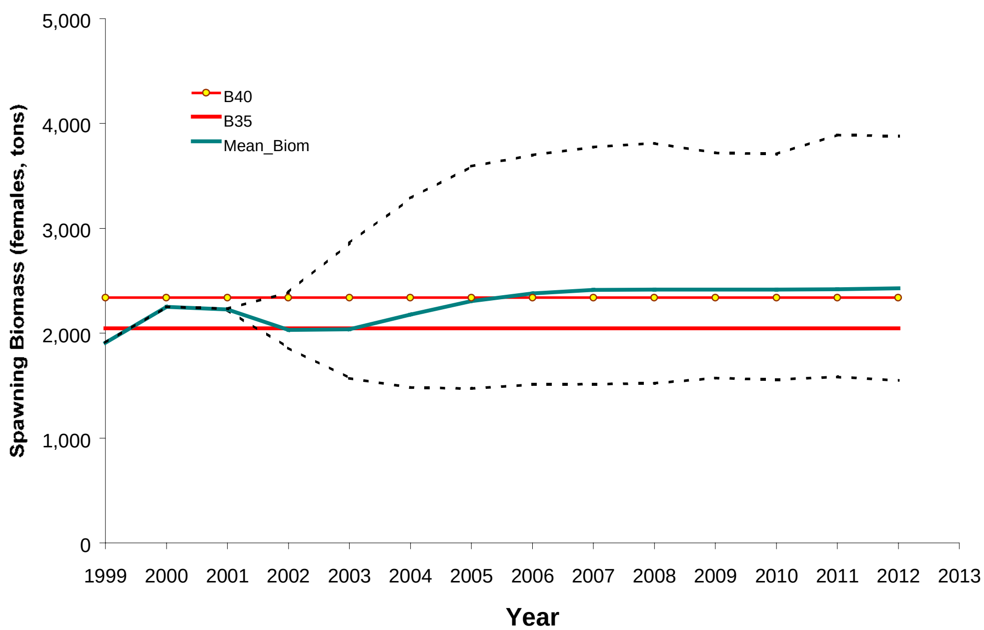

Figure 1.25. Projected **Female spawning biomass** relative to the $B_{40\%}$ and $B_{35\%}$ levels (for EBS walleye pollock, Model 2). $B_{40\%}$ is computed from average recruitment from 1978-1999. Future harvest rates follow the guidelines specified under Scenario 1, max F_{ABC} assuming $F_{ABC} = F_{40\%}$.

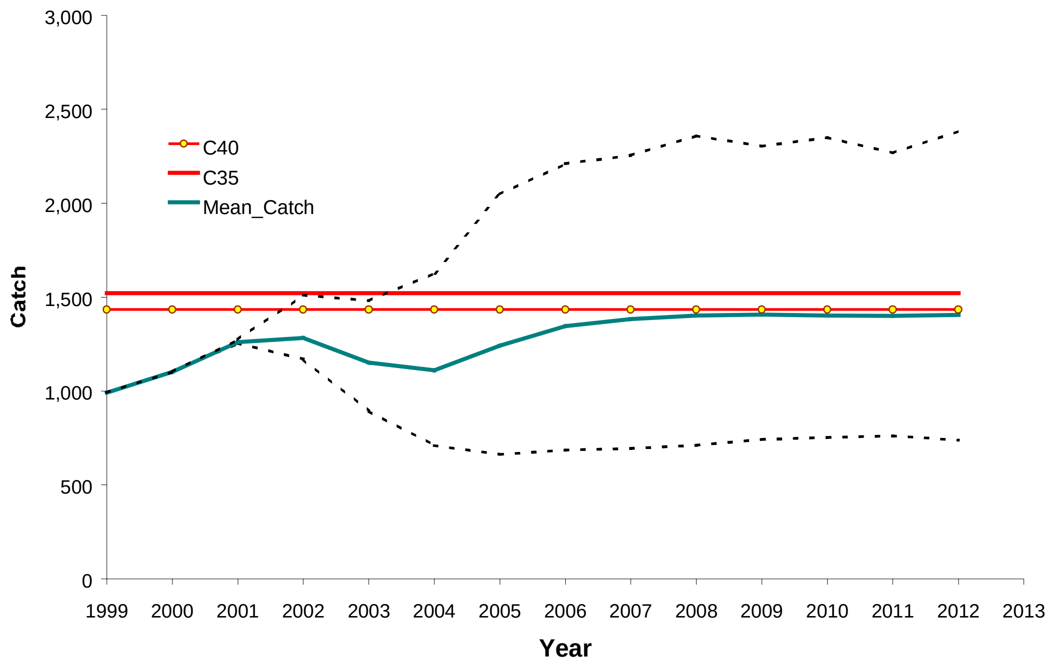

Figure 1.26. Projected EBS walleye pollock **yield** under $F_{ABC} = F_{40\%}$ relative to the long-term expected values for yield under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 2.

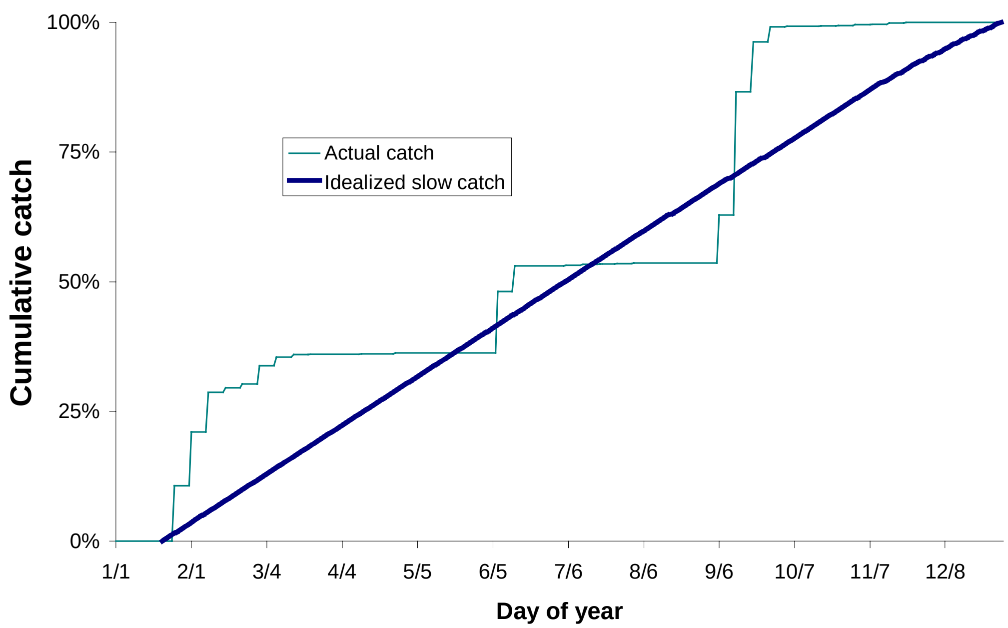

Figure 1.27. Schematic showing an “ideal slow” fishery versus an actual catch (normalized to sum to one).

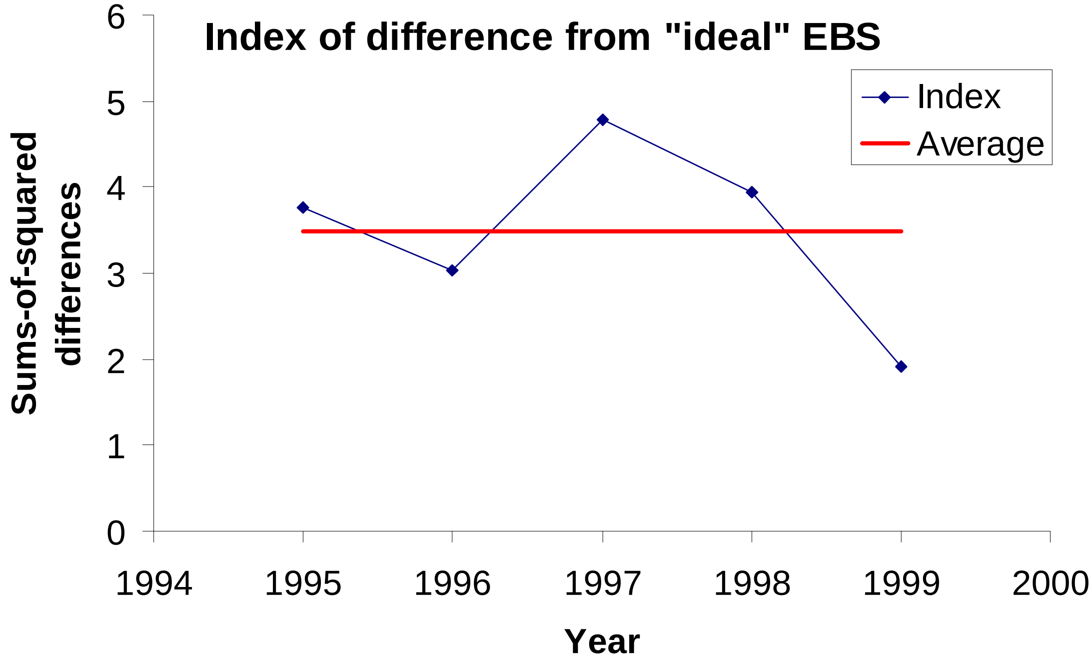

Figure 1.28. Index of difference between an "ideal slow" fishery by year for the Eastern Bering Sea, January 20th - March 1st.

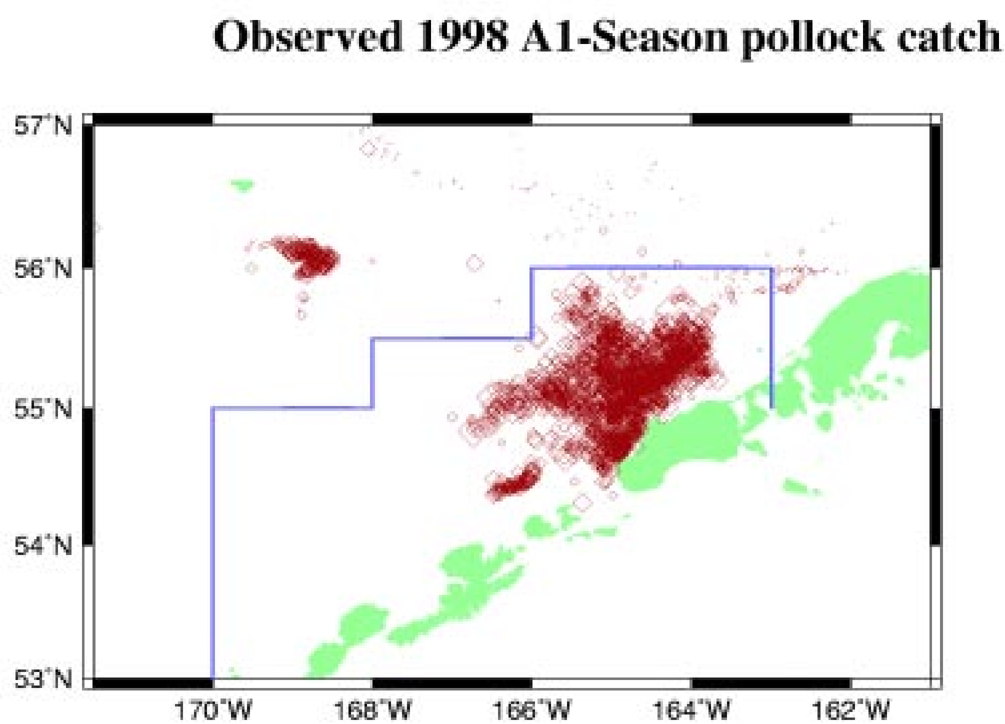

Figure 1.29. Pattern of harvest inside the CH/CVOA for A-1 season in 1998. NOTE: fishery data for 1998 were split as if the A season had been split based on the 1999 dates. In 1998 the season was managed as a single period.

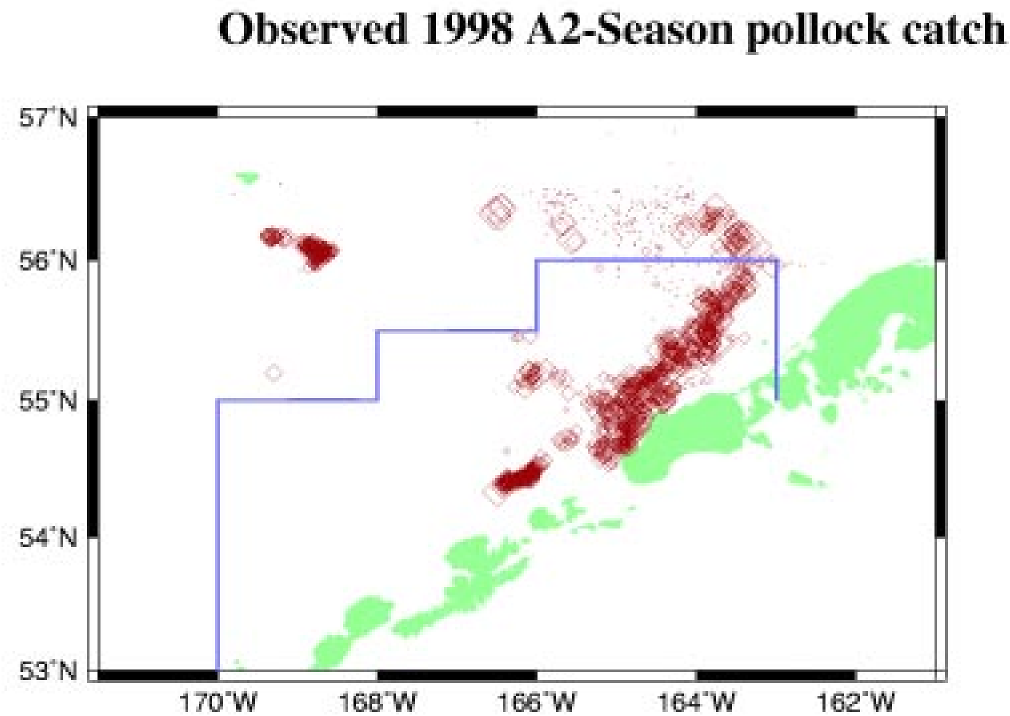

Figure 1.30. Pattern of harvest inside the CH/CVOA for A-2 season in 1998. NOTE: fishery data for 1998 were split as if the A season had been split based on the 1999 dates. In 1998 the season was managed as a single period.

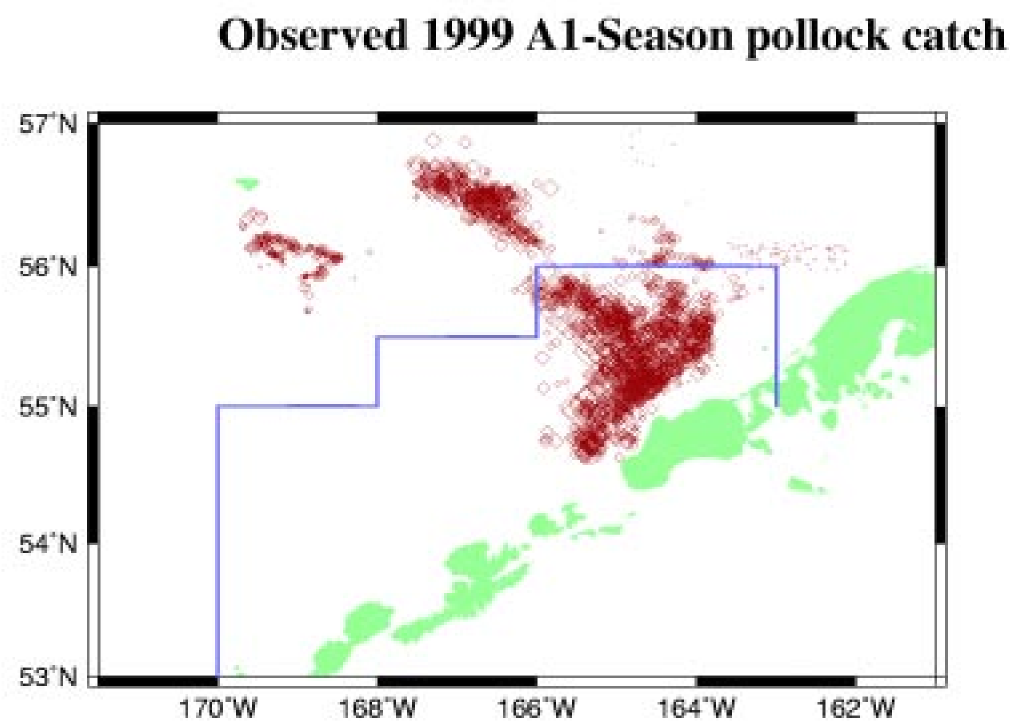

Figure 1.31. Pattern of harvest inside the CH/CVOA for A-1 season in 1999.

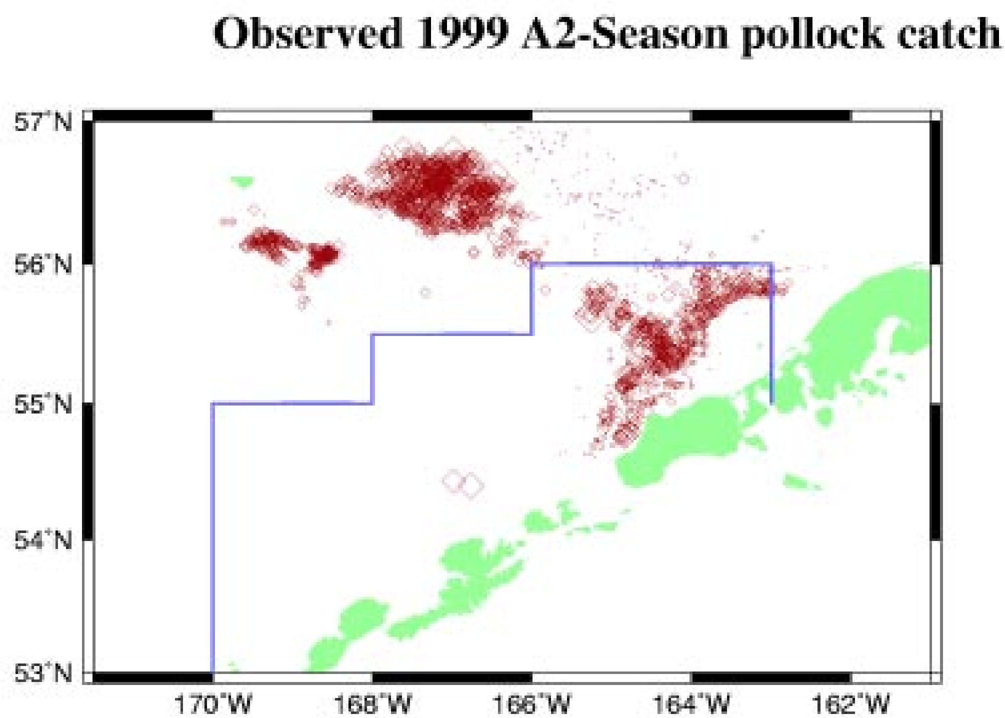

Figure 1.32. Pattern of harvest inside the CH/CVOA for A-2 season in 1999.

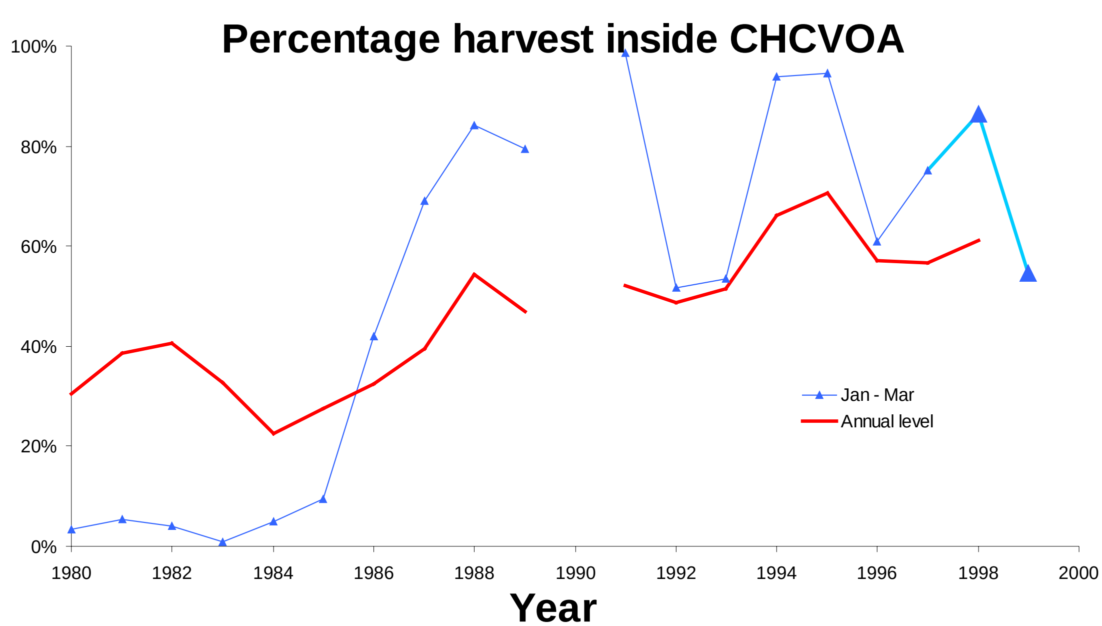

Figure 1.33. Pattern of harvest inside the CH/CVOA for A-season and overall in the EBS, 1980 – 1999.

1.14. Model details

1.14.1. Model structure

We used an explicit age-structured model with the standard catch equation as the operational population dynamics model (e.g., Fournier and Archibald 1982, Hilborn and Walters 1992, Schnute and Richards 1995). Catch in numbers at age in year t ($C_{t\cdot}$) and total catch biomass (Y_{t}) were

$$
\begin{aligned}
C_{t,a} &= \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-Z_{a,t}}\right)N_{t,a}, && 1 \le t \le T \quad 1 \le a \le A \\
N_{t+1,a+1} &= N_{t,a}e^{-Z_{t,a}} && 1 \le t \le T \quad 1 \le a < A \\
N_{t+1,A} &= N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}} && 1 \le t \le T \\
Z_{t,a} &= F_{t,a} + M_{t,a} \\
C_{t\cdot} &= \sum_{a=1}^{A} C_{t,a} \\
p_{t,a} &= C_{t,a}/C_{t\cdot} \\
Y_{t} &= \sum_{a=1}^{A} w_a C_{t,a} \text{ , and}
\end{aligned}
$$

where

T	is the number of years,
A	is the number of age classes in the population,
$N_{t,a}$	is the number of fish age a in year t,
$C_{t,a}$	is the catch of age class a in year t,
$p_{t,a}$	is the proportion of the total catch in year t, that is in age class a,
$C_{t\cdot}$	is the total catch in year t,
w_a	is the mean body weight (kg) of fish in age class a,
$Y_{t\cdot}$	is the total yield biomass in year t,
$F_{t,a}$	is the instantantaneous fishing mortality for age class a, in year t,
M_{ta}	is the instantantaneous natural mortality in year t for age class a, and
Z_{ta}	is the instantantaneous total mortality for age class a, in year t.

We reduced the freedom of the parameters listed above by restricting the variation in the fishing mortality rates ($F_{t,a}$) by assuming that

$$F_{t,a} = s_{t,a}\mu^f \exp(\varepsilon_t) \qquad \varepsilon_t \sim N(0,\sigma_E^2)$$
$$s_{t+1,a} = s_{t,a} \exp(\gamma_{t,a}), \qquad \gamma_{t,a} \sim N(0,\sigma_s^2)$$

where

$s_{t,a}$ is the selectivity for age class a in year t, , and

μ^F is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term (σ_s^2) to allow selectivity to change slowly over time–thus improving our ability to estimate the $\gamma_{t,a}$. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., σ_E^2) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model "selectivity" of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise). The magnitude of these changes is determined by the prior variances as presented above. Last year we investigated the sensitivity of model results with different prior variances for comparison.

In the SAM analyses, recruitment (R_t) represents numbers of age-1 individuals. Last year our model treated recruitment simply as a stochastic process about a (geometric) mean value (R_0):

$$N_{t,1} = R_t = R_0 e^{\tau_t}, \qquad \tau_t \sim \mathrm{N}(0,\sigma_R^2) \quad .$$

This year we added a stochastic Ricker function of spawning stock biomass:

$$R_t = B_{t-1} e^{\alpha - B_{t-1}\beta + \tau_t}, \qquad \tau_t \sim \mathrm{N}(0,\sigma_R^2) \quad ,$$

and also a stochastic Ricker function with an environmental component (κ_t) :

$$R_t = B_{t-1} e^{\alpha - B_{t-1}\beta + \kappa_t + \tau_t}, \qquad \tau_t \sim \mathrm{N}(0,\sigma_R^2) \quad .$$

Mature spawning biomass during year t was defined as:

$$B_t = \sum_{a=1}^{15} w_a \phi_a N_{at}$$

where ϕ_a , the proportion of mature females at age, was the same as that presented in Wespestad (1995).

The environmental component discussed above is derived from Wespestad et al. (1997) study on factors that appear to be critical for EBS pollock recruitment. They presented hypotheses about the relationship between surface advection during the post-spawning period and pollock survival. They found that during years when the surface currents tended north-north westward along the shelf that year class strength was improved compared to years when currents were more easterly. They used the OSCURS model to simulate drift. In a subsequent analyses (Ianelli and Fournier, In Prep.) their analysis was extended to apply within a stock assessment model context. The procedure is briefly outlined as follows:

1) run the OSCURS model for 90 days in each year starting at 165W and 55.5N storing the daily locations;

2) compute the average location of the simulated drifter over the 90 day period within each year using the GMT program (Wessel and Smith 1991) ***fitcircle***.

3) plot these points and create a geographic grid (**A**) centered such that it covers all mean values over all years,

4) create an indicator matrix ($\mathbf{\Psi}$) dimensioned such that the rows correspond to the number of years needed for the model (here 1964 – 1997) and the columns represent either the row or column index of the geographic grid. For example, say the average location of a drifter in 1980 fell within the bounds of the geographic grid cell represented by the 2nd column and 4th row, then the indicator matrix would have 2 and 4 as entries for the row corresponding to 1980.

Submit the indicator matrix as data to be read in to the model so that the values of the geographic grid matrix can be estimated where:

$$\kappa_t = A\left(\Psi_{t,1}, \Psi_{t,2}\right), \qquad \kappa_t \sim \mathrm{N}\left(0, \sigma_\kappa^2\right) \ .$$

The idea is simply that there are “good” circulation patterns and “bad” circulation patterns within the first few months after spawning.

The computation for predicting survey proportions at age and total numbers changed from the previous analyses (e.g., Wespestad *et al.* 1996, 1997). Previously we assumed that the survey was completed at the beginning of the year (prior to the fishery). This year we adjusted survey numbers to account for removals that occurred during the first part of the year allowed the effects of total mortality so that survey abundance predicted by the model for the middle of the year instead of the beginning of the year. This is more reasonable since the surveys for the EBS have always occurred during the summer months. As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant). Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$N^s_{t,a} = e^{-0.5Z_{t,a}} N_{t,a} q^s_t s^s_{t,a}$$

where the superscript s denotes quantities pertaining to the survey processes. For these preliminary analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the EIT and bottom trawl surveys).

Reparameterization of the stock-recruitment function

This year we implemented a reparameterized form for the stock-recruitment relationship as by Francis (1992). For the Beverton-Holt form we have:

$$R_i = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1}}$$

where

R_i	is recruitment at age 1 in year i,
S_i	is the biomass of female spawners in year i,
ε_i	is the "recruitment anomaly" for year i,
α, β	are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$
$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawner biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawners (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of $h = 0.9$ implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level recruitment. Steepness of 0.9 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). Here we assume the expected value of steepness is 0.9 with a 20% coefficient of variation. The prior distribution was assumed to be lognormal within the range 0.2-1.0. Clearly, alternative values could be applied, particularly in the sense of taking the experience among other fish stocks (e.g., Lierman and Hilborn (1997)). Since we include a stock-recruitment curve as an integrated part of the assessment, assumptions about prior parameter values are critical, particularly if the data are non-informative. This feature also allows for computation of F_{msy} values and related quantities such as MSY, B_{msy} etc. The method we develop for this is described in section 1.14.2 below.

Parameter estimation

The objective function was simply the product of the negative log-likelihood function and prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log-likelihood function for the survey and fishery catch at age data (in numbers):

$$f = n \cdot \sum_{a,t} p_{at} \ln\left(\hat{p}_{at}\right),$$

$$p_{at} = \frac{O_{at}}{\sum_a O_{at}}, \qquad \hat{p}_{at} = \frac{\hat{C}_{at}}{\sum_a \hat{C}_{at}}$$

$$\hat{C} = C \cdot E_{ageing}$$

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix},$$

where A, and T, represent the number of age classes and years, respectively, n is the sample size, and O_{at}, $\hat{C}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For model runs presented above, we assumed that ageing error was insignificant. Sample size values were fixed at 200 for the fishery data, 100 for the bottom trawl survey, and 50 for the EIT survey. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, it is well known that the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A}\prod_{t=1}^{T} \frac{\left(\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\tau^2}\right\}+0.01\right)}{\sqrt{2\pi\left(\eta_{t,a}+0.1/T\right)\tau}}$$

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$-1/2\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left(2\pi\left(\eta_{t,a}+0.1/T\right)\right)-\sum_{a=1}^{A} T\log_e(\tau)$$
$$+\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left[\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\tau^2}\right\}+0.01\right]$$

where $\eta_{t,a} = \hat{p}_{t,a}\left(1-\hat{p}_{t,a}\right)$

and $\tau^2 = 1/n$

gives the variance for $p_{t,a}$

$$\left(\eta_{t,a}+0.1/T\right)\tau^2.$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered "outliers."

The contribution to the log-likelihood function for the observed total catches is given by

$$\lambda_c \sum_t \left(\log\left(O_{t\cdot} / \hat{C}_{t\cdot} \right)^2 \right)$$

where λ_c represents prior assumptions about the accuracy of the observed catch data. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include

$\lambda_\varepsilon \sum_t \varepsilon_t^2 + \lambda_\gamma \sum_{ta} \gamma_{t,a}^2 + \lambda_\delta \sum_t \delta_t^2$ where the size of the λ*'s* represent prior assumptions about the variances of these random variables. For the model presented below, over 540 parameters were estimated. Most of these parameters are associated with year-to-year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in-variables, the reader is referred to Schnute (1994). To easily estimate such a large number of parameters in such a non-linear model, automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest. For key quantities of interest, e.g., current stock size, the software also produces likelihood profiles which avoids the assumption that the likelihood shape is quadratic (implied when the inverse Hessian estimates are used).

1.14.2. Solving for F_{msy} in an integrated model context

Recruitment in year i is given by the Beverton-Holt model

$$R_i = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1}} \quad ,$$

and for the Ricker model as

$$R_i = S_{i-1} e^{\alpha - \beta S_{i-1} + \varepsilon_i}$$

where

R_i is recruitment at age 3 in year *i,*

S_i is the biomass of females spawning in year i,

ε_i is the "recruitment anomaly" for year i,

α, β are stock-recruitment function parameters.

Since ϕ (see below) is the expected female spawning biomass produced by a single recruit, then at equilibrium we have for the Beverton-Holt Model:

$R_{eq} = \dfrac{R_{eq}\phi}{\alpha + \beta R_{eq}\phi}$. Solving for R_{eq} gives

$$R_{eq} = \frac{(\phi\text{-}\alpha)}{\beta\phi},$$

similarly, for the Ricker model one obtains

$$R_{eq} = \frac{\ln(\phi) + \alpha}{\beta\phi}$$

with

$$\phi = \sum_{j=1}^{15+} W_j N_j s_j f_j$$
$$N_j = 1 \qquad j = 1$$
$$N_j = N_{j-1} s_{j-1} \qquad 1 < j \leq 25$$

Note that the survival rate, s_j, and proportion mature females, f_j, are age specific. Equilibrium yield (Y) is computed for a given exploitation rate (F), giving $Y = F \cdot \overline{B}$ where $\overline{B}$ is the average equilibrium exploitable biomass. Solving for the MSY simply involves determining the exploitation rate where yield is maximized. Analytical methods are commonly used to find this value by taking the first derivative with respect to *F*, setting the result equal to zero, and solving for *F*. Unfortunately, such analytical methods are not readily available for common forms of stock-recruitment functions used in fisheries with non-trivial age-specific selectivities. Here we implement a numerical method which solves for MSY and can be applied to a broad family of models. The method implements the Newton-Raphson technique for finding the root of an equation (here, the first derivative of yield). The steps are outlined as:

1) pick a trial F and evaluate the equilibrium yield, $f(F)$;

2) compute the first and second derivatives of yield wrt F;

3) update original trial F from 1) by subtracting the ratio $\dfrac{f'(F)}{f''(F)}$

4) repeat steps 1) – 3) a fixed number of times so that the final adjustment in step 3) is very small. Note, convergence is usually implemented through the use of some sort of tolerance level. However, in our case we wish maintain differentiability, therefore we use a fixed number of iterations.

In practice, finite difference approximations for the derivatives given above appear to work satisfactorily which further improves one's ability to implement this type of algorithm. That is, let

$f'(F) = \dfrac{f(F+d) - f(F-d)}{2d}$ and $f''(F) = \dfrac{f(F+d) - 2f(F) + f(F-d)}{d^2}$ where d is some small value, say $1\text{x}10^{-7}$.

1.15. Aleutian Island Region Pollock

In 1997 we presented an updated analysis of the age-structured information available for the Aleutian Islands Region. Geographically, there are questions as to the appropriateness of defining pollock caught in the "Aleutian Islands" region as being from a separate stock. From this early analysis, it was clear that removals from this area are potentially from the EBS stock. Therefore, interpretations of the results raised many important questions.

The 1997 Aleutian Island bottom trawl survey estimated biomass at 105.6 thousand t, an increase over the 1994 survey estimates of 86.4 thousand t (Table 1.22). Survey biomass in this region peaked in 1983 and declining to the 1994 level. The 1994 survey indicated a strong mode of either age 1 or 2 pollock; 1992 or 1993 year-class. These fish appeared to have entered the fishable population in 1996 and have stabilized or increased pollock biomass in the Aleutian Islands.

Table 1.22. Pollock biomass estimates from the Aleutian Islands Triennial Groundfish Survey, 1980-1997.

Year	Aleutian Islands and Unalaska-Umnak area (~165W-170W)	Aleutian Region(170E-170W)
1980	308,745	252,013
1983	778,666	495,982
1986	550,517	448,138
1991	183,303	179,653
1994	151,444	86,374
1997	205,766	105,600

In the Aleutian Islands region the status and dynamics of pollock are not well understood. Catch-age data are limited, and most data are from the eastern Aleutians. Trawl survey data show that most of the biomass is located in the eastern Aleutian Islands and along the north side of Unalaska-Umnak islands in the eastern Bering Sea region. Analysis is also confounded by the question of stock definition. The available data suggest that the operational "stock" for this region is currently on the order of 100 - 200 thousand tons (for age 3) and harvests in the most recent year have been on the order of 30 thousand tons. Continued harvests at around that level represent about a 20% harvest rate. This has been shown to be an appropriate level for pollock in other areas. Since the selectivity seems to be on older individuals, this rate would also be conservative on a per-recruit basis. Recent harvest patterns by area show that many fewer fish are being removed from the eastern area compared to recent history (Fig. 1.34).

It is likely that pollock in the eastern Aleutian Islands is not a discrete stock, since pollock are continuously distributed from the eastern Bering Sea. In prior assessments it was assumed that stock dynamics in the Aleutian Islands are similar to that of eastern Bering Sea pollock and the biomass trend the same. Analyses on MSY values for Aleutian Islands pollock were not pursued given, among other things, potential problems with stock definition and paucity of data for this region.

Although limited number of age-structured model runs were done on this stock in the past, the results showed a fair amount of ambiguity. Consequently, until the issues of stock definition and survey interpretation are resolved, we recommend continuing the use of the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC based on Tier 5 (1997 survey biomass $\times M \times 0.75$) of **23,760 t** at a biomass of 105,600 t (with $M = 0.3$). The OFL based on Tier 5 (1997 survey biomass $\times M$) gives **31,680 t** at a biomass of 105,600 t.

	1997	**1998**	**1999**	**Year 2000**	**F**
F_{ABC}	17,413 – 28,000 t	23,760 t	23,760 t	23,760 t	0.225 = 0.75 M
$F_{overfishing}$	24,000 – 38,000 t	31,680 t	31,680 t	31,680 t	0.3 = M

Figure 1.34. NMFS blend data estimates of pollock harvest by area within the Aleutian Islands Regions.

1.16. Aleutian Basin-Bogoslof Island Area

This year, the Plan Team requested that 3 alternative methods be presenting ABC values for the Bogoslof region be presented. They include:

- The same method as in past years (with 2,000,000 ton estimate for $B_{40\%}$)
- A simplified age-structured model based on recent Bogoslof population trends
- The same method as is currently used for the Aleutian Islands region (i.e., Tier 5, F_{ABC} =0.75*M)

These three methods are presented in subsequent sections.

1.16.1. Historical Method for computing ABC for Bogoslof area

Aleutian Basin pollock spawning in the Bogoslof Island area have been surveyed annually since 1988. Pollock harvested in the Bogoslof Island fishery (Area 518) have noticeably different age compositions than those taken on the eastern Bering Sea shelf (Wespestad and Traynor 1989). The following survey results show that population decline occurred between 1988 and 1994, and then increased in 1995. The movement of pollock from the 1989 year-class to the Bogoslof Island area was partly responsible for the 1995 increase, but the abundance of all ages increased between 1994 and 1995. The decrease between 1995 and 1996 was followed by a continued decline in 1997. This suggests that the 1995 estimate may have been over-estimated, or that conditions in that year affected the apparent abundance of pollock. The current population levels on the eastern Bering Sea shelf, and the absence of extremely large year-classes, suggests that pollock abundance will not increase significantly in the Bogoslof area in the coming years. A summary report of the 1999 survey is attached (Appendix 1.A) with summary Bogoslof Island EIT survey biomass estimates, 1988-1999, as follows:

Biomass (million t)											
1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
2.4	2.1	--	1.3	0.9	0.6	0.49	1.1	0.68	0.39	0.49	0.48

The survey estimated abundance of pollock in the Bogoslof area (Area 518) increased in 1998 (Appendix 1.B). Based on the 1999 survey estimate of exploitable biomass of 0.475 million t and M = 0.2 the estimated year 2000 biomass is projected to be about 0.389 million t. In 1997 the SSC determined that the estimates for $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ were reliable for this stock with values of 2,000,000 t, 0.27, and 0.37 respectively. This places Bogoslof pollock under Tier 3 of

Amendment 44. As in previous years, decaying the current year biomass estimate with a natural mortality rate of $M = 0.2$ gives a projected stock size of 389,000 t for 2000. The maximum allowable F_{ABC} allowed under Tier 3b is computed as:

$$F_{abc} \le F_{40\%} \times \left(\frac{B_{2000}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.27 \times \left(\frac{389{,}153}{2{,}000{,}000} - 0.05 \right) \Big/ (1 - 0.05) = 0.041$$

Using a fishing mortality rate of 0.041 translates to an exploitation rate of 0.037 which when multiplied by 389,000 t, gives a **2000 ABC of 14,200 t for the Bogoslof region.**

The OFL fishing mortality rate is computed under Tier 3b as follows:

$$F_{OFL} = F_{30\%} \times \left(\frac{B_{2000}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.37 \times \left(\frac{389{,}000}{2{,}000{,}000} - 0.05 \right) \Big/ (1 - 0.05) = 0.056$$

A fishing mortality of 0.056 translates to an exploitation rate of 0.050 which, when multiplied by a projected biomass of 389,000 t gives a **2000 OFL of 19,300 t**.

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish belong to the same "stock", which as 4-5+ old adults, are distinct from eastern Bering Sea pollock. Data on the age structure of Bogoslof-Basin pollock show that a majority of pollock in the Basin originated from year-classes that are strong on the shelf, 1972, 1978, 1982, 1984, and 1989. The mechanism causing pollock to move from the shelf to the Basin appears to be density related, with the abundance in the Basin proportional to year-class size.

Differences in spawning time and fecundity have been documented between eastern Bering Sea pollock and Aleutian Basin pollock. In addition, Aleutian Basin pollock are smaller at a given age than pollock on the eastern Bering Sea shelf. Pollock in the northern shelf have a similar size at age as Aleutian Basin pollock although a very different age composition. However, Aleutian Basin pollock may not be an independent stock. Very few pollock younger than 5 years old have ever been found in the Aleutian Basin including the Russian portion. Recruits to the basin are coming from another area, most likely the surrounding shelves either in the US or Russian EEZ.

1.16.2. Tier 3 age-structured model

Aleutian Basin pollock spawning in the Bogoslof Island area are currently managed under Tier 3b. Since last year's SAFE, the overfishing definition has changed. In past years, an age-structured model has not been developed or applied to this stock for evaluating the appropriate $B_{40\%}$ and other target harvest rates. If this area is to be managed under Tier 3, then the requirement is that an age-structured model is needed. We constructed such a model but with several simplifying assumptions. These are:

- The age composition estimates for ages 6-15+ from the annual Bogoslof surveys represent the best available information on variability in year-class strengths
- We assume a fixed natural mortality rate of 0.2 (as assumed for this region in past SAFE reports)
- The fishing mortality during this period (1992-1999) is negligible since catches have averaged about 0.05% of the total biomass.
- Fishery selectivity is knife-edged at age 6
- Age 6 recruitment estimates from 1992-1998 (the 1986-1993 year classes) adequately reflect the magnitude and variability of the period since 1983 (spawned in 1977) onwards.
- The average weight- and maturity-at-age is the same as used for the EBS pollock (needed for computing SPR rates)
- The age composition samples follow a multinomial distribution with sample size set to 50
- The total population estimates (age 6 and older) from each year of survey follow a log-normal distribution with standard deviation set to 0.25

The observed and predicted numbers at age from fitting the simplified model are shown in Table 1.23 and the fit to these data are illustrated in Fig. 1.35.

The projection results are shown in Table 1.24. This gives an ABC of **110,000 t** at spawning biomass of 257,000 t. The OFL under $F_{35\%}$ gives **132,000 t**.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2000, nor is it expected to be approaching an overfished condition based on Scenario 7.

Table 1.23. Observed and predicted numbers at age from the Bogoslof winter spawning surveys (thousands).

Observed N	6	7	8	9	10	11	12	13	14	15+
1992	53,983	96,780	74,243	71,337	54,815	56,551	33,112	34,363	142,108	328,643
1993	43,770	46,418	48,295	42,223	28,314	51,052	25,050	26,790	42,113	208,461
1994	25,798	37,729	36,454	36,088	16,910	26,805	23,070	12,837	8,502	146,066
1995	278,316	104,698	67,673	80,136	53,388	54,107	19,143	58,843	31,591	248,996
1996	96,065	187,278	85,336	40,169	36,975	24,052	24,274	12,374	36,444	117,113
1997	15,758	55,462	87,529	38,245	27,670	16,210	15,840	12,607	7,228	56,036
1998	60,731	34,001	69,518	77,021	32,054	24,517	20,733	18,563	18,495	67,379

Predicted	6	7	8	9	10	11	12	13	14	15
1992	38,921	69,778	51,319	37,582	50,734	29,109	21,049	31,093	73,293	169,498
1993	65,252	53,423	43,739	42,016	30,769	41,538	23,832	17,234	25,457	198,780
1994	60,848	49,818	40,787	35,811	34,400	25,192	34,008	19,512	14,110	183,590
1995	108,878	89,142	72,983	33,394	29,319	28,164	20,625	27,844	15,975	161,863
1996	127,809	104,641	85,673	59,754	27,341	24,005	23,059	16,887	22,796	145,601
1997	109,308	89,494	73,271	70,143	48,922	22,385	19,653	18,879	13,825	137,873
1998	76,222	62,405	51,093	59,989	57,428	40,054	18,327	16,091	15,457	124,200
1999	78,242	64,059	52,447	41,831	49,115	47,018	32,793	15,005	13,174	114,341

Table 1.24 Projections of mean spawning biomass, fishing mortality, and yield for Bogoslof pollock for the seven scenarios. The values for $B_{40\%}$ and $B_{35\%}$ are 96,810 t and 84,709 t, respectively.

Sp. Biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
1999	278,500	278,500	278,500	278,500	278,500	278,500	278,500
2000	256,532	256,532	264,114	270,563	271,919	253,171	256,532
2001	204,455	204,455	233,366	260,646	266,716	192,661	204,455
2002	168,515	168,515	209,481	252,086	262,078	153,060	166,307
2003	143,974	143,974	191,059	244,613	257,802	127,436	136,036
2004	127,680	127,680	177,413	238,755	254,556	111,313	116,809
2005	116,635	116,635	167,062	233,887	251,813	101,141	104,523
2006	109,313	109,313	159,294	229,835	249,457	95,195	97,106
2007	105,265	105,265	154,219	227,235	248,205	92,603	93,609
2008	102,093	102,093	149,803	224,424	246,454	90,652	91,154
2009	100,969	100,969	147,373	222,954	245,802	90,428	90,662
2010	100,366	100,366	145,637	221,805	245,297	90,381	90,485
2011	99,868	99,868	144,233	220,764	244,769	90,220	90,262
2012	99,670	99,670	143,312	220,029	244,438	90,238	90,254
F							
1999	0.002	0.002	0.002	0.002	0.002	0.002	0.002
2000	0.233	0.233	0.117	0.020	0.000	0.286	0.233
2001	0.233	0.233	0.117	0.020	0.000	0.286	0.233
2002	0.233	0.233	0.117	0.020	0.000	0.286	0.286
2003	0.233	0.233	0.117	0.020	0.000	0.286	0.286
2004	0.233	0.233	0.117	0.020	0.000	0.284	0.285
2005	0.232	0.232	0.117	0.020	0.000	0.276	0.280
2006	0.231	0.231	0.117	0.020	0.000	0.268	0.271
2007	0.229	0.229	0.117	0.020	0.000	0.263	0.265
2008	0.226	0.226	0.117	0.020	0.000	0.259	0.260
2009	0.225	0.225	0.117	0.020	0.000	0.259	0.259
2010	0.224	0.224	0.117	0.020	0.000	0.259	0.259
2011	0.224	0.224	0.117	0.020	0.000	0.259	0.259
2012	0.224	0.224	0.117	0.020	0.000	0.259	0.259
Yield							
1999	1,000	1,000	1,000	1,000	1,000	1,000	1,000
2000	110,474	110,474	58,338	10,487	0	132,224	110,474
2001	88,302	88,302	51,637	10,112	0	100,966	88,302
2002	73,062	73,062	46,451	9,788	0	80,596	87,446
2003	62,689	62,689	42,461	9,506	0	67,458	71,885
2004	55,822	55,822	39,513	9,284	0	58,973	61,968
2005	51,054	51,054	37,269	9,098	0	52,591	54,832
2006	47,679	47,679	35,584	8,943	0	48,368	49,785
2007	45,684	45,684	34,500	8,847	0	46,360	47,135
2008	43,943	43,943	33,531	8,738	0	44,840	45,236
2009	43,318	43,318	33,021	8,685	0	44,727	44,907
2010	42,982	42,982	32,652	8,642	0	44,709	44,790
2011	42,750	42,750	32,345	8,602	0	44,624	44,658
2012	42,629	42,629	32,150	8,575	0	44,593	44,605

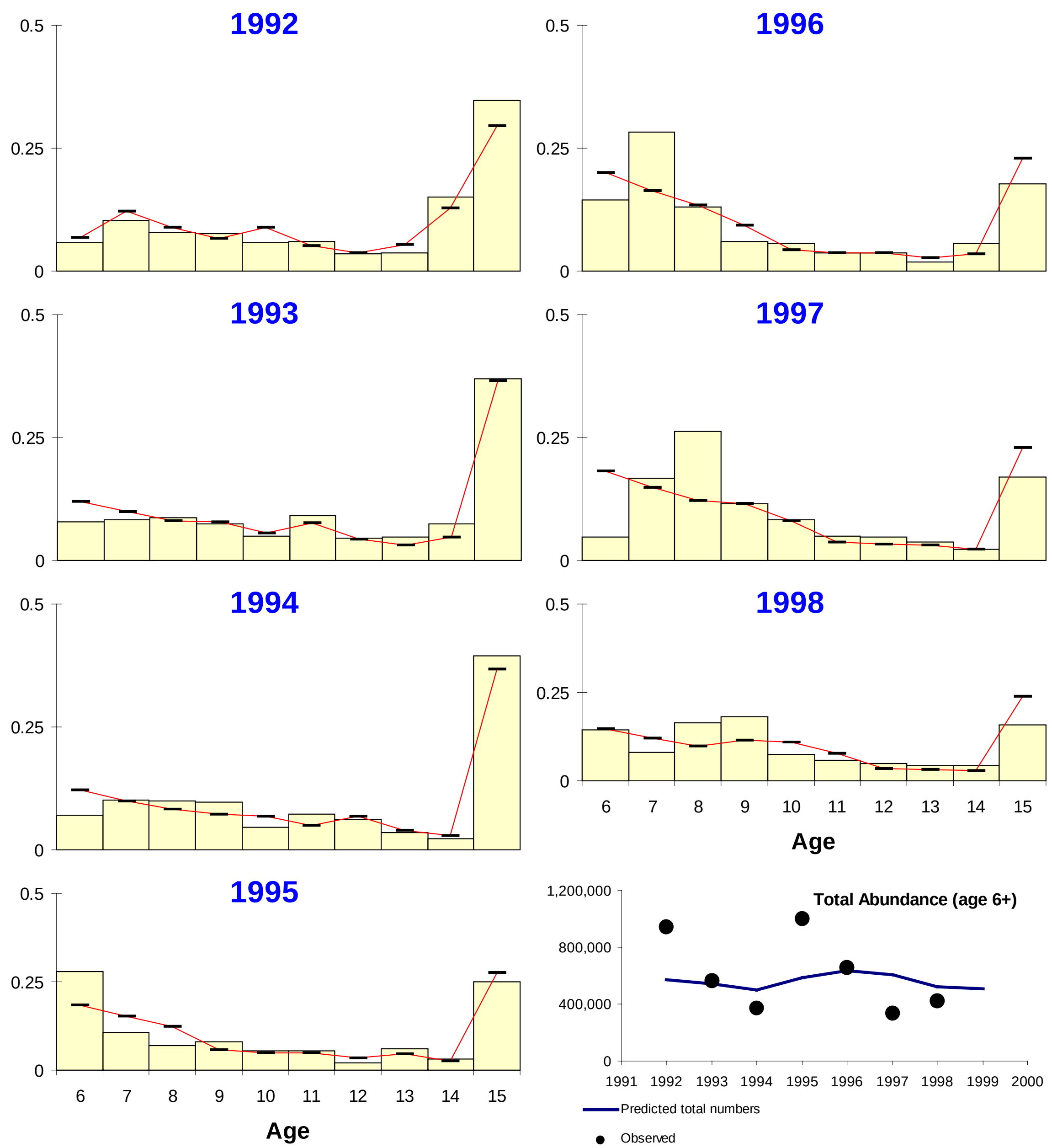

Figure 1.35. Age composition fit to Bogoslof pollock survey data and total numbers (lower right panel), 1991-1998.

1.16.3. Tier 5 ABC computation

Tier 5 computations use the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC (1999 survey biomass $\times M \times 0.75$) of **71,300 t** at a biomass of 475,000 t (with $M = 0.2$). The OFL gives **95,000 t**.