Eastern Bering Sea
Walleye Pollock Stock Assessment

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Summary

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 88 and 91, respectively.

The 2000 NMFS bottom-trawl survey estimates of population numbers-at-age were available for analysis in this assessment. In terms of biomass, the bottom-trawl survey estimate for 2000 is 5.14 million tons, up 44% from the 1999 estimate of 3.57 million. In addition, for the second consecutive year, the EBS region was surveyed using the Echo-Integration trawl (EIT) gear. The biomass estimate from the 2000 EIT survey was 3.05 million tons, down slightly (7%) from 3.29 estimated in 1999. These differences in trend indications are somewhat expected given the current age-structure estimates of the population. As in the previous two assessments, the 1996 year-class is apparently well above average abundance. In addition, this year class is becoming more available to the bottom trawl survey gear and somewhat less available to the summer EIT survey gear.

The NMFS observer samples of pollock age and size composition were evaluated for the 1999 fishery and these data were included in the analyses. This represents the first year under the new observer sampling protocol for measuring fish and taking otoliths. The new method appears to provide more precise estimates of catch numbers at age. The geographic range of sampling was expanded over a greater number of hauls while the actual number of fish aged has stayed about the same. The estimates of weight-at-age from the fishery were also revised. The total catch estimate was updated and for 2000, we assumed that the catch is equal to the 2000 TAC

(1,139,000 t). We also examined observer data for different fishing patterns with the implementation of new management measures and the American Fisheries Act (AFA). Results show that vessels spent more time searching over broader regions in 2000 compared with previous years. Under the AFA, the "race-for-fish" has been largely eliminated and hence, vessels can operate more efficiently.

In January 2000, an external reviewer reviewed the EBS pollock assessment methodology prepared a report (Appendix 3). Several suggestions for improving this assessment were provided and we attempt to address them in this chapter along with the SSC concerns.

Minor changes to the assessment model were made relative to that used in Ianelli et al. (1999). These include the addition of Japanese CPUE data during the period 1965-1976 as recommended by the SSC and by the reviewer (Appendix 3). Other changes include a reformulation of the prior distribution used for the stock-recruitment steepness parameter to increase flexibility between the Beverton-Holt form and Ricker forms (a Beta distribution was assumed).

Computations leading to the year 2001 ABC alternatives based on the $F_{40\%}$ and F_{msy} are 1,842 and 2,125 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value). The 2001 overfishing level (OFL) alternatives for the reference model are 2,350 and 3,536 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 continuing declines in Steller sea lion populations in adjacent areas continues to cause concern since pollock are an important prey item.

In the summer of 2000, NMFS conducted a bottom-trawl survey throughout the Aleutian Islands region. The estimate of on-bottom pollock in the Aleutians from this survey is 132,145 t. This gives **ABC** and **OFL values are 23,750 t** and **31,666 t,** respectively.

For the Bogoslof region, we followed the SSC recommendations and compute maximum permissible ABC and OFL based on Tier 5. This results in **45,150 t** and **60,200 t** for ABC and OFL, respectively. Further to the December 1999 SSC meeting minutes; we reduced the ABC relative to the target stock size (2 million tons). This gives a recommended 2001 ABC of **8,470 t** for the Bogoslof Island region.

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 foreign 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 pattern of the fishery from 1995 to 1999 had been to have an “A-season” opening on January 20th with the season lasting about 1 month, depending on the catch rate. Historically, a second “B-season” opening has occurred on September 1st (though 1995 opened on Aug 15th). This has changed considerably over the past few years and management has focused on minimizing the possibility that the pollock fishery inhibits the recovery of the Steller sea lion population or adversely modifies their habitat. We discuss this in detail in the next section.

Since the closure of the Bogoslof management district (518) to directed pollock fishing in 1992, the “A-season” (January – March) 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 gradually changed during the period 1998 - 2000 (Figs. 1.2). 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. 1.3). 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. 1.4).

After 1992, the “B-season” (typically September – October) 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 shift was due to the implementation of the CVOA (Catcher Vessel Operational Area) in 1992 and also the geographic distribution of pollock by size. The pattern in the past few years shows an increase in this trend (towards catching pollock west of 170°W) and decreasing amounts with the Sea lion conservation area (SCA; Fig. 1.5). The length frequency information from the fishery reveals a marked progression of the large 1989 year-class growing over time and the appearance of the 1992 year-class in 1996-97 and subsequent 1996 year class in 1998-99 (Fig. 1.6).

Fishery Management: Steller sea lion RFRPAs and the AFA

In 1999 and 2000, the NMFS and the NPFMC made changes to the Atka mackerel (mackerel) and pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) to reduce the intensity of competitive interactions with endangered Steller sea lions. The evidence for competitive interactions suggested it was possibly occurring, but in different ways for the two fisheries. For the pollock fisheries, comparisons of seasonal fishery catch and pollock biomass distributions (from surveys) by area in the eastern Bering Sea (EBS) led to the conclusion that the pollock fishery had disproportionately high seasonal harvest rates within critical habitat which could lead to reduced sea lion prey densities. In the pollock case, the measure of "fishery effect" was somewhat equivocal. Nonetheless, the goal of the management measures was to redistribute the fishery both temporally and spatially according to pollock biomass distributions. The underlying assumption in this approach was that the independently derived area-wide and annual exploitation rate for pollock would not reduce local prey densities for sea lions. We examine the temporal and spatial dispersion of the fishery to evaluate the effectiveness of the measures.

NMFS' strategy to reduce the possibility of competitive interactions of both fisheries with sea lions involved both temporal and spatial dispersion of catch to reduce the local and acute effects of the fishery on prey densities within critical habitat. In both cases, independently derived acceptable biological catch (ABC) and total allowable catch (TAC) levels were not affected. Three types of measures were implemented in both fisheries:

- Additional pollock fishery exclusion zones around sea lion rookery or haulout sites,
- Phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat, and
- Additional seasonal TAC releases to disperse the fishery in time.

Prior to the RFRPAs, the pollock fishery occurred in each of the three major fishery management regions of the north Pacific ocean managed by the NPFMC: the Aleutian Islands

(1,001,780 km^2 inside the EEZ), the eastern Bering Sea (968,600 km^2), and the Gulf of Alaska (1,156,100 km^2). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 km^2 of ocean surface, or 12% of the fishery management regions.

Prior to 1999, a total of 84,100 km^2, or 22% of critical habitat, was closed to the pollock fishery. Most of this closure consisted of the 10 and 20 nm radius all-trawl fishery exclusion zones around sea lion rookeries (48,920 km^2 or 13% of critical habitat). The remainder was largely management area 518 (35,180 km^2, or 9% of critical habitat) which was closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock.

As a result of the RFRPAs, an additional 83,080 km^2 (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 km^2 (11%) around sea lion haulouts in the GOA and eastern Bering Sea. Consequently, after the RFRPAs were implemented, a total of 210,350 km^2 (54%) of critical habitat was closed to the pollock fishery. The portion of critical habitat that remained open to the pollock fishery consisted primarily of the area between 10 and 20 nm from rookeries and haulouts in the GOA and parts of the eastern Bering Sea foraging area.

The Bering Sea/Aleutian Islands pollock fishery was also subject to changes in total catch and catch distribution. Disentangling the specific changes in the temporal and spatial dispersion of the EBS pollock fishery resulting from the sea lion management measures from those resulting from implementation of the American Fisheries Act (AFA) is difficult. The AFA reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector by 2000. Both of these changes would be expected to reduce the rate at which the catcher processor sector (allocated 36% of the EBS pollock TAC) caught pollock beginning in 1999, and the fleet as a whole in 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation that otherwise could have been more disruptive to the industry.

Reductions in pollock catches from BSAI sea lion critical habitat were realized by closing the entire Aleutian Islands region to pollock fishing and by phased-in reductions in the proportions of seasonal TAC that could be caught from the Sea Lion Conservation Area, an area which overlaps considerably with sea lion critical habitat. In 1998, over 22,000 mt of pollock was caught in the Aleutian Island regions, with over 17,000 mt caught in AI critical habitat; pollock fishery removals of pollock from the Aleutian Islands in 1999 and 2000 to date have been 0.

On the eastern Bering Sea shelf, both the catches of pollock and the proportion of the total catch caught in critical habitat have been reduced significantly since 1998 as a result of the RFRPAs:

	Year		
Months	1998	1999	2000
January-March	441,000 (88%)	222,300 (57%)	156,800 (39%)
January-December	642,100 (60%)	372,800 (39%)	

Reductions in total pollock removals from critical habitat was one of the primary goals of the RFRPAs. Another similar goal was to spatially disperse the fishery throughout more of the pollock range on the eastern Bering Sea shelf. To measure changes in spatial dispersion of the fishery, the total pollock catch by season within 10 km x 10 km (100 km^2) cells was estimated for 1998-2000. An increase in spatial dispersion was achieved, as evidenced by the increase in the number of cells with catch and the decrease in average catch per cell (Fig. 1.7).

Seasonal TAC releases were intended to disperse the fishery throughout more of the year. Prior to the RFRPAs (1998), the fishery was concentrated in 2 seasons, each approximately 6 weeks in length in January-February, and September-October; 94% of the pollock fishery occurred during these four months, with 45% in January-February and 49% in September-October. In 1999, the RFRPAs dispersed the early fishery into March (which reduced the percentage taken in February) and the later fishery into August, but very little into the April-July period. Therefore, the 1999 post-RFRPA EBS pollock fishery was dispersed only slightly more than the pre-RFRPA fishery. In 2000, the proportion taken in March has increased relative to 1999, and there are provisions for the fishery to start as early as June 10, which could disperse the fishery temporally more than in 1999.

Another measure of the temporal dispersion of the pollock fishery is daily catch rates. For this analysis, daily pollock catches were estimated for January-March 1998-2000. Prior to the implementation of the RFRPAs in 1998, daily catches averaged over 8,100 mt/day, and peaked at over 21,300 mt/day. In 1999 and 2000, average daily catch rates for January-March declined about 22% to 6,200 and 6,400 mt/day, respectively; daily maximums were 15,400 and 12,500 mt/day, reductions of 38% and 41%, respectively. Of all the measures of temporal and spatial dispersion evidenced in 1999 and 2000, the daily catch rate is the one that the cooperative provisions of the AFA were likely to affect independent of the RFRPAs. Absent the cooperative authority granted the fishery and the reduction in catcher/processor capacity granted by the AFA, it is unlikely that daily catch rates would have been reduced as a result of the RFRPAs alone.

Yet another way to examine changes in fishery behavior in the past few years is by examining the distance vessels travel during the season. For example, the top 7 pollock-producing vessels in the Eastern Bering Sea during 1997-2000 substantially increased the distance traveled during the "A-season" fishery (Fig. 1.8). NMFS is currently investigating methods to take advantage of this extra "surveying time" by commercial vessels. We envisage a cooperative investigations using calibrated hydro-acoustic gear on selected vessels so that a more synoptic distribution of pollock can be obtained throughout the area and over the course of a fishing season. We feel that this holds good potential to gain a better understanding of the dynamic structure of pollock aggregations prior to spawning and while fishing is occurring. This may lead to information useful for evaluating the finer-scale abundance of pollock that may be available within Steller sea lion critical habitat.

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, 1990-1999 are shown in Table 1.2. Since 1990 estimates of discarded pollock have ranged from a high of 11% of total pollock catch in 1991 to a low of 1.5% in 1998 (the 1999 value was 3%). These recent low values reflect the implementation of the Council's Improved Utilization and Improved Retention program. Variability in discard rates may also be due to the age-structure and relative abundance of the available population. For example, if the most abundant year-class in the population is below marketable size, these smaller fish may be caught incidentally. With the implementation of the AFA, the fleets 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. In all cases, the magnitude of discards is accounted for within the population assessment and for management (to ensure the TAC is not exceeded).

We estimate the catch-at-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; 2) INPFC area 51 from July -December; 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 catch proportions-at-age suggests that in 1999 a broad range of age groups were harvested (Fig. 1.9). We present these values (as used in the age-structured model) from 1964-1999 in Table 1.3. The new 1999 estimates of pollock catch-at-age data were collected using a new survey sampling strategy. Under the new scheme, more observers collect otoliths from a greater number of hauls (but far fewer specimens per haul). The objective of the new system was to improve geographic coverage while at the same time lowering the total number of otoliths collected (since a large number were not subsequently aged and arguably would not contribute further to the precision of catch-at-age estimates). The geographic coverage was significantly improved (Fig. 1.10) as was the precision when compared with earlier years (Fig. 1.11). The sampling effort for lengths was significantly decreased in 1999, but the number of otoliths processed for age-determinations increased (Table 1.4). As part of a study to evaluate the effectiveness of the new sampling protocol, observers in 1999 also collected data using the "old" method. These samples have not been processed to date but should allow a more direct comparison between the old and new methods. This research is ongoing.

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	1988
Bering Sea	15	94	458	139	466	682	508	208	435	163	174	467
Aleutian Islands				193		40	454			292		

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bering Sea	393	369	465	156	221	267	249	206	262	121	162	NA

Aleutian Islands	51	48	36	NA

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 2000 the bottom trawl survey biomass estimate has ranged from 3.2 to 5.5 million t. The estimate for 2000 is 5.14 million tons, up 44% from the 1999 estimate of 3.57 million. Overall, a general increase in stock size has become apparent in the past few years (Fig. 1.12).

The pollock distribution in 1999 had somewhat higher catch rates around St. Matthew Is. than usual and an absence of pollock extending into Bristol Bay and on the upper shelf. This pattern is typical of cold years (the average bottom temperature in 1999 was lower than any other observed by NMFS summer surveys in the EBS). The 2000 survey was more typical in the geographical abundance pattern relative to past years and probably reflects a return to temperature conditions near the long term means (Fig. 1.13). The level of sampling for lengths and ages in the bottom-trawl survey is shown in Table 1.6.

Research on applying NMFS survey data to gain insights on the movement and distribution of pollock around the Bering sea continues. Recently, survey catch rates have been compiled on an age-specific basis. This facilitates comparing catch rates by age over space and time. One application of such analyses are to examine the relative abundance inside and outside of management areas. For example, catch rates inside of the Sea lion critical area shows the tendency for few young fish and relatively high old-fish catch rates compared to pollock outside of the SCA (Fig. 1.14). This gives some indication of how selectivity/availability of the age-structured population may change under different geographical management practices.

Since we now have accumulated several years of data from our bottom trawl surveys, we conducted some analyses on the mortality of the 1982-1991 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. 1.15). 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). However, during the last decade 6 EIT summer surveys have been conducted in 1991, 1994, 1996, 1997, 1999 and 2000.

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). For the 2000 EIT survey the estimate was 3.05 million tons, down slightly (7%) from 1999. These differences in trend are somewhat expected given the current age-structure estimates of the population.

The details and preliminary research results from the 2000 EIT survey are presented in the Appendix 2. In brief, from June 7 to August 2, 2000 the NMFS/AFSC/MACE program conducted an EIT survey of walleye pollock on the eastern Bering Sea shelf from Port Moller, Alaska to the U.S./Russia convention line. As in past years, the NOAA ship *Miller Freeman* was used. The principal objective was to collect echo integration data and trawl data necessary to determine the distribution, biomass, and biological composition of walleye pollock on the eastern Bering Sea shelf and slope. Pollock were observed on all transects throughout the eastern Bering Sea shelf area surveyed, except for the second transect, northwest of Port Moller entrance (Fig. 1.16). East of the Pribilof Islands, highest pollock concentrations were encountered on two transects north of central Unimak Island. Pollock densities were lower between Unimak and the Pribilofs. West of the Pribilofs, pollock increased and peaked in density on two transects southwest of St. Matthew Island. In the far west, pollock were heavily concentrated in a few spots along the U.S./Russia border. Walleye pollock dominated midwater trawl catches, accounting for 94% of the catch by weight. Numbers and biomass of pollock were estimated for the entire geographic area covered by the survey. Estimated pollock abundance in midwater (14 m below the surface to 3 m off bottom) was 3.05 million tons for the total survey area. Numbers of pollock were estimated to be 7.63 billion. Proportions of pollock biomass estimated east vs. west of 170° W, and inside vs. outside the sea lion conservation area (SCA), are about the same for summer EIT surveys conducted from 1994 to 2000 (Table 1.7). In summer 2000, mean lengths estimated for the population differed between areas. Inside the

SCA, mean length was 47 cm. East of 170° W excluding the SCA, average length was 45 cm, and west of 170° W, average length was 34 cm. For the whole Bering Sea shelf population, mean length was 36 cm. The time series of estimated EIT survey proportions-at-age is presented in Fig. 1.17. The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.8.

At the time of this writing, the ageing of otolith collections from the 2000 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 keys derived from the NMFS 2000 bottom trawl survey. This was also done in 1999 (Ianelli *et al.* 1999). The 1999 EIT age compositions have subsequently been updated using the 1999 EIT survey age-length keys. The effect of using the new 1999 EIT age composition estimates relative to those used last year (as computed using the BTS age-length key) gave slightly higher estimates of 1999 age 3+ biomass (7.5 million tons compare to 7.99 million tons; a 6% difference). We expect these differences to be on the order of normal sampling error levels and that seems to be the case here. However, for model sensitivity, we include a run (Model 0, below) which ignores these preliminary age compositions (as presented in Fig. 1.17).

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:

- Fishery CPUE data (Low and Ikeda 1980) from Japanese vessels during 1965-1976 were incorporated.
- The 2000 EBS bottom trawl survey estimate of population numbers-at-age was included.
- The 2000 EBS EIT survey estimate of population numbers-at-age was included (preliminary values based on bottom trawl survey age-length keys).

The technical aspects of this model are presented in Section 1.14 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 1.9 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, 698 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 1964-2000. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (2001-2005). 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, 60 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 37 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 37x15 or 555 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 200 parameters for these data. Similarly, for the EIT survey, which began in 1979, these parameters number 233. 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. 1.12) 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 with effective sample sizes presented in Table 1.10). 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. An external review of our stock assessment methods (Appendix 3) had a number of recommendations for research and presentation. These included

1. Doing a model run where all data prior to 1980 were ignored or at least the 1979 EIT survey point downweighted;

2. Using early Japanese CPUE data where there are concerns about the low levels of estimated stock sizes;
3. Further downweight early (1960's) catch-age data
4. Illicit any prior distributions from a broad panel of experts (or using data from other areas)
5. Improve documentation and clearly specify alternative model conditions.

We attempt to respond to these and other concerns in this assessment.

A list of the models presented includes:

Model 0 Same as Model 1, but excludes the estimated age-composition data from the 2000 EIT survey (these data were derived from an age-length key based on the bottom-trawl survey).

Model 1 **Reference model,** 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 and 1999.

Model 2 same as reference model but with survey selectivities constant over time.

Model 3 same as reference model but data from 1980 onwards only.

Model 4a same as reference model but with 17% lower assumed variability in stock-recruitment process error.

Model 4b same as reference model but with 33% lower assumed variability in stock-recruitment process error.

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, with Beverton-Holt stock-recruitment curve.

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

Model 8 prior distribution on stock-recruitment steepness parameter uniform.

These models can be summarized as follows:

Model Number	Description
0	Ignore 2000 EIT age composition data
1	Reference model
2	Constant survey selectivities (EIT and BTS)
3	Model from 1980 onwards only (no early data)
4a	Moderate assumption of process in stock-recruitment curve
4b	Low assumption of process in stock-recruitment curve
5	Full time series for estimate stock-recruitment curve
6	Use Beverton-Holt stock-recruitment curve
7	Constant stock-recruitment (but stochastic) relationship
8	Non-informative prior distribution on stock-recruitment steepness

We selected Model 1 as our main reference model. This is most similar to Model 2 from Ianelli *et al.* (1999). The difference from last year's model is that the selectivity estimates are based only on estimates from 1999 since the establishment of cooperatives and new regulations may be best reflected in the most recent year of fishery data. In addition, this year's model runs all include the fishery CPUE data from 1965-1976. As with last year, the stock-recruitment curve fitting for the Reference model (Model 1) is using only the period from 1978-2000.

Model 0 ignores the information on the preliminary age-composition as estimated for the 2000 EIT survey data. These data will be revised in the coming year since the age structures used to derive the age composition estimates were from a different gear type (though in the same year and general area). Model 2 here represents a configuration where survey selectivity is not allowed to vary over time. While we feel this model greatly underestimates stock condition uncertainty, we include it since the SSC and reviewers were concerned with issues of parsimony and over-parameterization. Model 3 is in response to the reviewer's comments on using only the recent data. Models 4a and 4b are sensitivities to the lower levels of process error allowed in recruitment variability about the stock-recruitment curve (preliminary model runs suggested that there was some sensitivity to this value). Model 5 represents a run tuning the stock-recruitment curve to the entire time series 1964-2000. Model 6 implements a Beverton-Holt stock-recruitment curve instead of a Ricker. Model 7 assumes no stock-recruitment curve relationship within the model (and hence is not useful for evaluating recruitment overfishing). Model 8 removes the effect of the prior distribution on the reference model.

An evaluation of the goodness of fit for the different models is presented in Table 1.11. These indicate that the reference model fits considerably better than Model 2

(CV's as presented in parentheses in Table 1.12). 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 1 may best represent the underlying processes that affect observations (e.g., availability of different age-classes can change over time to different gear types).

(Table 1.13). 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 considerably between Models 1 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 1 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.

In the past few years we've included an analyses using an ocean current circulation model to aid in the estimation of year-class strengths for forecasting. We failed to update this analysis this year but have found that its implementation had relative little impact on values critical for harvest management regulations. The environmental effect 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 1.12 & 1.13. The difference in the current and projected age structure for Model 1 relative to the last two year's assessments (1998 and 1997) is shown in Fig. 1.18. This figure shows that the absolute numbers at age are estimated to be somewhat higher in the current assessment compared to the last two years. The increases may be attributed to the increase in the 1999 and 2000 survey abundance estimates (the bottom trawl survey in these two years increased by 61% and then 44%). The 1992 year-class again is estimated to be slightly higher than in the past two years of assessments, presumably due to the predominance of that year-class in the recent EBS bottom-trawl surveys and in the fishery (e.g., Fig. 1.23 below).

The estimated Model 1 selectivity pattern for the fishery shows how estimates of selectivity change over time (Fig. 1.19). An example of how well the model fit the fishery age-composition data is given in Fig. 1.20. The addition of Japanese fishery CPUE data (Loh and Ikeda, 1980) did not provide much new insight on the early abundance trends other than that these data are consistent with the estimates from last year's pattern for this period (Fig. 1.21).

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. 1.22). The model fits to the age composition estimates are shown in Fig. 1.23.

The Model 1 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. 1.24). This is further illustrated in the model fit to the EIT survey age composition data (Fig. 1.25). 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 1 are presented in Table 1.14 and estimated catch-at-age presented in Table 1.15.

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 substantially in 1999 and 2000. 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. 1.22 and 1.23).

Current exploitable biomass estimates (ages 3 and older) derived from the statistical catch-age model 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. Since then, the stock has apparently increased, declined slightly then increased again and is currently estimated to be over 10 million tons.

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

1.16, Fig. 1.26). 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 1.16). 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 1 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. 1.27). This compares to an overall average SER of 22.5% (1964 – 2000). 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 1 (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. 1.28). 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 7 direct observations of this year class from survey data: the EIT survey conducted in 1997, 1999, and 2000 and the bottom trawl surveys in 1997, 1998, 1999, and 2000 (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 1 results computed based on recruitment from post-1976 spawning events:

$B_{40\%}$ = **2,426** t female spawning biomass

$B_{35\%}$ = **2,170** t female spawning biomass

B_{msy} = **1,779** t female spawning biomass

1.7.2. Specification of OFL and Maximum Permissible ABC

For Model 1, the year 2000 spawning biomass is estimated to be **3,066** thousand tons (at the time of spawning, assuming the stock is fished at F_{msy}). This is well above the B_{msy} value of **1,779**. 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 **2,761** thousand tons for year 2001 spawning values (under $F_{40\%}$ policy). This is well above the $B_{40\%}$ value of **2,426**. The OFL's and maximum permissible ABC values by both methods are thus:

	OFL	Max ABC
Tier 1a	**3,536 thousand t**	**2,125 thousand t**
Tier 3a	**2,350 thousand t**	**1,842 thousand t**

1.7.3. ABC Recommendation

Currently, the biomass of eastern Bering Sea pollock appears to be increasing and estimated at about 10.5 million t (total age-3+). The estimated female spawning biomass projected to the time of spawning in the year 2000 is about **2,761** thousand tons, well above of the $B_{40\%}$ level of **2,426** thousand tons and well above the $B_{35\%}$ and the value estimated for B_{msy} (**2,170** and **1,779** respectively; Fig. 1.29).

For the year 2000, maximum permissible ABC alternatives based on the $F_{40\%}$ and F_{msy} are 1,842 and 2,125 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value) as shown in Table 1.13 for Model 1. However, recruitment since the 1996-year class is below average. Hence, short term projections (shown below) predict that the spawning stock is likely to drop below the $B_{40\%}$ and B_{msy} levels. While we feel there is nothing intrinsically wrong with having the population drop below it's optimal level (since under perfect management, it is expected to be below the target exactly half of the time) choosing a harvest level that reduces this likelihood might 1) provide stability to the fishery; 2) provide added conservation given the current Steller sea lion population declines; and 3) provide added conservation due to unknown stock removals in Russian waters.

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 Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2000 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2001 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2000. 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 2001, 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 2001 recommended in the assessment to the *max* F_{ABC} for 2001. (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 1996-2000 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 2001 and above its MSY level in 2011 under this scenario, then the stock is not overfished.)

Scenario 7: In 2001 and 2002, 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 2013 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 2000 (Table 1.17). Under Scenario 1, the expected spawning biomass will decrease to slightly below $B_{35\%}$ then increase to above $B_{40\%}$ by the year 2006 (Fig. 1.30). Under this scenario, the yields are expected to vary between 1 – 1.8 million tons. If the highly conservative harvest rates (estimated from the last 5 years) are to continue, then the stock is not projected to drop below $B_{40\%}$ at any time in the future (Fig. 1.31).

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 2001:
>
> a) If spawning biomass for 2001 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
>
> b) If spawning biomass for 2001 is estimated to be above $B_{35\%}$, the stock is above its MSST.
>
> c) If spawning biomass for 2001 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 1.17). If the mean spawning biomass for 2011 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 2003 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2003 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2003 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2013. If the mean spawning biomass for 2013 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 2001, nor is it expected to be approaching an overfished condition based on Scenario 7.

1.8. Other considerations

1.8.1. Ecosystem concerns

Pollock in the eastern Bering Sea represent a principle component of the ecosystem. The current condition of the stock is excellent—there are a number of different age-classes in the population and the abundance is well above the expected long-term average under moderate fishing conditions (Fig. 1.32).

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch (via multi-species analyses of technical interactions);
- Controlling the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock in the EBS, the NPFMC and NMFS continues to manage the fishery on the basis of these issues in addition to the single-species harvest approach. The prevention of overfishing is clearly set out as a main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to use pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the NMFS observer program and managed on that basis. Discarding rates have been greatly reduced in this fishery and multi-species interactions is an ongoing research project within NMFS with extensive food-habit studies and simulation analyses to evaluate a number "what if" scenarios with multi-species interactions.

1.8.2. 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 RPA's and the American Fisheries Act (AFA). These have reduced the "race for fish" that was common in years before 1999. The impact of the AFA reduces bycatch and improves recovery percentages. In addition, the ability to avoid small fish will be enhanced since the fishery occurs over longer periods with lower daily harvest rates.

On August 8th 2000, NMFS implemented the US District Court's grant of an injunction that closed all trawling within Critical Habitat. The impact of this injunction on management advice is unknown. Since there is evidence of age-specific differences in abundance inside and outside of

Critical Habitat based on survey data, it is reasonable to assume that the age-specific availability of the pollock population has changed under the injunction. Based on bottom-trawl survey data, it is likely that the injunction has increased harvests on a younger segment of the population. The magnitude of this shift is probably relatively small, but could affect different fishery sectors disproportionately. For example, smaller vessels that traditionally have focused on producing products from larger fish found relatively close to coastal areas may be displaced or in required to shift methods of operation.

1.8.3. 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, most of the juvenile fish in this area are believed to recruit to the eastern Bering Sea spawning stock as adults. This was evident with the 1989 year-class, which occurred in relatively low abundance in the US EEZ, but was very abundant in the Russian EEZ early in life. The 1989 year-class subsequently was 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%
1999	708						
2000	586						
Avg.	498	62%	2%	9%	15%	24%	50%

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

1.8.4. Steller sea lions and the pollock fishery

As exemplified by the management measures taken to avoid competition with the pollock fisheries, NMFS applied several conservation principles in an additive approach, all of which were intended to promote Steller sea lion protection. NMFS began with a model that served as the basis for determining fisheries effects. The model assumed that the current level of fishing (i.e., as determined by the TAC-setting process) and the overall harvest rate were safe for the pollock stocks, whereas concentration of removals in time and space were inconsistent with efforts to promote Steller sea lion recovery. The revised RPAs thus called for a) protection of key areas and time periods to prevent competition around rookeries and haulouts, and b) constraints on fishing outside these areas to minimize the potential for localized depletion and adverse modification of critical habitat. Overall, the status quo is consistent with the underlying goal of providing protection from the effects of localized depletion. This conclusion is based on the following information summarizing the justifications for implementing the status quo management actions for Steller sea lions.

Evaluation of the adequacy of the revised RPAs in achieving the desired conservation goals was constrained by available data, but the harvest rate was considered the best available measure. That is, the criterion for measuring the success of the management regime was whether future pollock harvest rates, by season and area, were likely to be consistent with (i.e., sufficiently low) those discussed the preceding biological opinions and the revised RPA document. Four individual criteria were developed and evaluated, as detailed in the following excerpt from the revised final RPAs (October 1999).

A. The target harvest rate should be 0% around rookeries and haulouts, and during the period from November 1 to January 20.

This target harvest rate will be achieved by the appropriate prohibitions on pollock fishing in these areas and during this period. The principles, guidelines, and management measures will establish the necessary constraints on fishing to ensure that competition does not occur between the pollock fisheries and Steller sea lions in these key areas and during this important period.

B. Seasonally-specific harvest rates should not exceed a target rate determined by the product of the overall harvest rate and the portion of the annual TAC taken per season.

If a safe level of harvesting is established by the TAC-setting process, then the seasonal harvest rate should be determined as the product of the overall harvest rate and the portion of the annual TAC to be taken in that season. For example, if the overall harvest rate is 20% and the portion of the TAC taken per season is 25%, then the target harvest rate would be 0.20*0.25 = 0.05, or 5%. These target harvest rates have been achieved through guidelines and management measures setting a seasonal cap of 30% of the annual TAC. In addition, the first two seasons will be limited to a combined total of 40% of the annual TAC to provide additional protection for the winter/spring period.

C. The target harvest rate should be observed in each of the management areas used in a given season.

In the Bering Sea, the target harvest rate should be observed inside and outside of the SCA (Sea Lion Conservation Area). Without better information, the distribution of the pollock stock in the Bering Sea in the A and B seasons is assumed to be 50% inside the SCA and 50% outside the SCA. Therefore, harvest rates and catches inside and outside the SCA should be equivalent to achieve the target harvest rate. In 1998 (Fig. 8), 88% of the (single) A season harvest was taken from the SCA, and the harvest rate inside the SCA was estimated to be 17%. In 1999, 73% of the A season harvest was taken from the SCA (exceeding the 62.5% limit), and 32% of the B season harvest was taken from the SCA. The estimated harvest rate inside the SCA dropped to 5.1% for the A season and 1.2% for the B season. For 2000, the A and B season catches should each be split with no more than 50% from inside the SCA and at least 50% outside the SCA. As a result of the seasonal caps and the dispersal of the catch inside and outside of the SCA, harvest rates should remain equally low in these two areas.

For the 1999 C and D seasons in the Bering Sea, the portions of the harvests taken inside the SCA were lowered to 25% and 35%, respectively, as an incremental step toward the target rates of 15% and 25% in 2000. The dispersal of catch will match the distribution of the stock, and will therefore keep the harvest rates inside and outside of the SCA low and approximately equivalent.

D. <u>The seasons must be dispersed throughout the fished part of the year if harvest rates per individual season are to have meaning relevant to temporal dispersion</u>.

To achieve temporal dispersion, the harvest rate within seasons must be held to their respective caps and the seasons must be dispersed. In 1999, when four seasons were required, the first two seasons in the Bering Sea occurred within a period of about two months (or about 20% of the fished part of the year). The portion of the annual TAC taken from these combined seasons was reduced to 40% (from 45% in 1998), but the first two seasons effectively constituted one season where 27.5% of the TAC was taken, followed by a five-day pause, and then 12.5% of the TAC was taken. Similarly, the C and D seasons were separated in time only because the catch was taken more quickly than expected in the C season and a defacto stand-down was imposed until the D season started. In the Gulf of Alaska, the D season was set to start only 5 days after the closure of the C season or October 5, whichever came first. In both regions, the seasons were poorly dispersed throughout the fished portion of the year, negating the value of the 4-season approach.

> For 2000 and beyond, the dispersion of seasons will prevent the aggregation of seasons in the Gulf of Alaska and the SCA of the Bering Sea. In both cases, the seasons divide the fished portion of the year (January 20 to November 1) into four equal seasons. By allowing two seasons outside the SCA in the Bering Sea, the RFRPAs will allow flexibility to the different sectors of the fleet to determine how and where they will fish. Stand-downs are not required in either region, and the fleets are able to exert considerable control over their pattern of fishing within a season. The expectation is that fishing with each season will be slowed through both management measures required by the RPAs and through cooperative efforts of the various fishing sectors (i.e., through cooperatives).

Based on the above, NMFS believes that the RFRPAs, taken together, 1) provide the necessary protection for prey resources around rookeries and major haulouts, and for the winter period, and 2) disperse the fisheries over the remaining time and areas in a manner sufficient to maintain local harvest rates commensurate with the overall annual harvest rate. NMFS believes that such dispersal significantly reduces the probability of localized depletion of pollock for Steller sea lions. Therefore, NMFS also believes that the RFRPAs are sufficient to avoid jeopardizing the continued existence of the western population of Steller sea lions and destroying or adversely modifying its designated critical habitat.

1.9. Summary

Summary results are given in Table 1.18.

1.10. Acknowledgements

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1.11. References

Bailey, K.M., T.J. Quinn, P. Bentzen, and W.S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theregra chalcogramma*. Advances in Mar. Biol. 37:179-255.

Stepanenko, M.A. 1997. Variations from year to year in the spatial differentiation of the walleye pollock, *Theragra chalcogramma*, and the cod, *Gadus macrocephalus*, in the Bering Sea. Journ. of Ichthyol. 37:14-20.

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

Deriso, R. B., T. J. Quinn II, and P. R. Neal. 1985. Catch-age analysis with auxiliary information. Can J. Fish. Aquat. Sci. 42:815-824.

Dorn, M.W. 1992. Detecting environmental covariates of Pacific whiting *Merluccius productus* growth using a growth-increment regression model. Fish. Bull. 90:260-275.

Fair, L.F. 1994. Eastern Bering Sea walleye pollock: revised estimates of population parameters, relation of recruitment to biological and environmental variables, and forecasting. M.S. Thesis, University of Alaska Fairbanks, Fairbanks AK. 131 p.

Fair, L.F. and T.J. Quinn II, (In prep.). Eastern Bering Sea walleye pollock: a comparison of forecasting methods. Draft MS. Juneau Center, School of Fish. And Ocean Sci. Univ. Alaska Fairbanks. 32 p.

Fournier, D. 1998. An Introduction to AD model builder for use in nonlinear modeling and statistics. Otter Research Ltd. PO Box 2040, Sidney BC V8L3S3, Canada, 53p.

Fournier, D.A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49: 922-930.

Greiwank, A., and G.F. Corliss (eds.) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Harrison, R. C. 1993. Data Report: 1991 bottom trawl survey of the Aleutian Islands area. Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., NOAA Tech. Memo. NMFS-AFSC-12.

Ianelli, J.N. 1996. An alternative stock assessment model of the Eastern Bering Sea pollock fishery. *In*: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, Appendix Section 1:1-73.Ianelli, J.N. 1997. An alternative stock assessment analysis for Gulf of Maine cod. SARC-24 Working Paper A2. 29p.

Ianelli, J.N. and D.A. Fournier. 1998. Alternative age-structured analyses of the NRC simulated stock assessment data. *In* Restrepo, V.R. [ed.]. Analyses of simulated data sets in support of the NRC study on stock assessment methods. NOAA Tech. Memo. NMFS-F/SPO-30. 96 p.

Ianelli, J.N., L. Fritz, T. Honkalehto, N. Williamson and G. Walters 1998. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 1999. *In*: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:1-79.

Kimura, D.K. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. *In* R.J. Beamish and G.A. McFarlane (eds.), Effects on ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aq. Sci. 108:57-66.

Kimura, D.K., J.J. Lyons, S.E. MacLellan, and B.J. Goetz. 1992. Effects of year-class strength on age determination. Aust. J. Mar. Freshwater Res. 43:1221-8.

Loh, L.L., and Ikeda. 1980. Average density index of walleye pollock in the Bering Sea. NOAA Tech. Memo. SFRF743.

Mace, P., L. Botsford, J. Collie, W. Gabriel, P. Goodyear J. Powers, V. Restrepo, A. Rosenberg, M. Sissenwine, G. Thompson, J. Witzig. 1996. Scientific review of definitions of overfishing in U.S. Fishery Management Plans. NOAA Tech. Memo. NMFS-F/SPO-21. 20 p.

McAllister, M.K. and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54:284-300.

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

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Res. Bull. Int. Commn. NW Atlant. Fish. 9: 65-74.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, B.P. Flannery. 1992. Numerical Recipes in C. Second Ed. Cambridge University Press. 994 p.

Quinn, T.J. and R.B. Deriso 1999. Quantitative Fish Dynamics. Oxford University Press, New York. 542 p.

Quinn II, T. J. and J. S. Collie. 1990. Alternative population models for eastern Bering Sea pollock. INPFC Symposium on application of stock assessment techniques to gadids. Int. North Pac. Fish. Comm. Bull. 50:243-258.

Restrepo, V.R., G.G. Thompson, P.M Mace, W.L Gabriel, L.L. Low, A.D. MacCall, R.D. Methot, J.E. Powers, B.L. Taylor, P.R. Wade, and J.F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31. 54 p.

Ronholt, L. L., K. Teshima, and D. W. Kessler. 1994. The groundfish resources of the Aleutian Islands region and southern Bering Sea, 1980, 1983, and 1986. Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., NOAA Tech. Memo. NMFS-AFSC-31.

Schnute, J.T. 1994. A general framework for developing sequential fisheries models. Can. J. Fish. Aquat. Sci. 51:1676-1688.

Schnute, J.T. and Richards, L.J. 1995. The influence of error on population estimates from catch-age models. Can. J. Fish. Aquat. Sci. 52:2063-2077.

Shuntov, V. P., A. F. Volkov, O. S. Temnykh, and E. P. Dulepova. 1993. Pollock in the ecosystems of the Far East Seas. TINRO, Vladivostok.

Thompson, G.G. 1996. Spawning exploitation rate: a useful and general measure of relative fishing mortality. Alaska Fisheries Science Center contribution. Unpubl. Manuscr., 7 p.

Thompson, G.G. 1996. Risk-averse optimal harvesting in a biomass dynamic model. Unpubl. Manuscr., 54 p. Alaska Fisheries Science Center, 7600 Sand Pt. Way NE, Seattle WA, 98115. Distributed as Appendix B to the Environmental Analysis Regulatory Impact Review of Ammendments 44/44 to the Fishery Management Plans for the Groundfish Fisheries of the Bering Sea and Aleutian Islands Area and the Gulf of Alaska.

Traynor J. J. and M. O. Nelson. 1985. Results of the U.S. hydroacoustic survey of pollock on the continental shelf and slope. *In*: R.G. Bakkala and K. Wakabayashi (eds.), Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May-August 1979. Int. North Pac. Fish. Comm. Bull. 44: 192-199.

Walters, C. J. 1969. A generalized computer simulation model for fish population studies. Trans. Am. Fish. Soc. 98:505 -512.

Wespestad, V. G. 1990. Walleye pollock. Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1989. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., NOAA Tech. Memo. NMFS F/AKC.

Wespestad, V. G. and J. M. Terry. 1984. Biological and economic yields for eastern Bering Sea walleye pollock under differing fishing regimes. N. Amer. J. Fish. Manage., 4:204-215.

Wespestad, V. G. and J. Traynor. 1989. Walleye pollock. In: L-L. Low and R. Narita (editors), Condition of groundfish resources in the Bering Sea-Aleutian Islands region as assessed in 1988. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., NOAA Tech. Memo. NMFS F/AKC-178.

Wespestad, V. G., J. Ianelli, L. Fritz, T. Honkalehto, G. Walters. 1996. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 1997. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:1-73.

Wespestad, V.G., L.W. Fritz, W.J. Ingraham, and B.A. Megrey. 1997. On Relationships between Cannibalism, climate variability, physical transport and recruitment success of Bering Sea Walleye Pollock, *Theragra chalcogramma.* ICES Internatinal Symposium, Recruitment Dynamics of exploited marine populations: physical-biological interactions. Baltimore, MD, Sept 22-24.

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	988,674	965	trace	29
2000	NA	NA	1,138,000	1,165	NA	28

1979-1989 data are from Pacfin.

1990-1999 data are from NMFS Alaska Regional Office, includes discards.

2000 catch assuming full TAC will be taken (1,117,000 reported as of Oct 31, 2000).

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
Southeast (51)		582,660	57,851	640,511	
Northwest (52)		764,369	50,313	814,682	
Aleutians		69,682	9,343	79,025	
Total	**1990**	1,416,711	117,507	1,534,218	7.7%
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	**1991**	1,318,966	163,095	1,482,061	11.0%
Southeast (51)		600,861	62,596	663,457	
Northwest (52)		445,811	55,172	500,983	
Aleutians		45,246	3,498	48,745	
Total	**1992**	1,091,919	121,266	1,213,185	10.0%
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	**1993**	1,271,914	111819	1,383,732	8.1%
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	**1994**	1,312,892	109,202	1,422,094	7.7%
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	**1995**	1,228,654	98,542	1,339,728	7.4%
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	**1996**	1,145,133	77,206	1,222,339	6.3%
Southeast (51)		749,007	71,043	820,050	
Northwest (52)		281,986	22,557	304,543	
Aleutians		25,323	617	25,940	
Total	**1997**	1,056,316	94,217	1,150,533	8.2%
Southeast (51)		950,631	15,135	965,767	
Northwest (52)		133,818	1,581	135,399	
Aleutians		23,657	164	23,822	
Total	**1998**	1,108,106	16,881	1,124,987	1.5%
Southeast (51)		756,047	27,100	783,148	
Northwest (52)		204,785	1,912	206,697	
Aleutians		529	480	1,010	
Total	**1999**	961,362	29,492	990,855	3.0%

Table 1.3. Eastern Bering Sea walleye pollock catch by age in numbers (millions), 1979-1999.

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	2,567.3
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	2,420.7
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	2,174.6
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	2,003.7
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	1,744.5
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	1,938.0
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	1,919.9
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	2,040.4
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	1,378.5
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	2,192.2
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	1,783.8
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	1,746.2
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	1,438.8
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	2,079.0
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	1,905.2
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	1,917.5
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	1,606.9
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	1,326.1
1997	0.1	65.4	33.2	107.1	470.6	290.8	255.9	198.9	62.9	14.2	6.5	5.1	3.1	14.8	1,528.8
1998	0.0	36.3	86.7	72.3	160.8	704.0	203.6	128.6	107.6	29.1	5.7	6.3	3.0	7.4	1,551.5
1999	0.1	7.5	296.5	219.5	105.0	154.8	475.9	131.4	57.3	33.1	3.9	2.1	0.4	2.5	1,490.0

Table 1.4. Numbers of samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-1999.

	Strata	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Measured males	Aleutians	34,023	33,585	33,052	28,465	21,993	12,336	10,477	6,906	75
	Northwest	126,023	110,487	38,524	28,169	17,909	22,290	58,307	32,185	16,629
	Southeast A Season	198,835	150,554	122,436	138,338	127,876	148,706	123,385	134,743	35,702
	Southeast B Season	102,225	134,371	143,420	153,336	175,524	193,832	114,826	205,309	38,208
Total		461,106	428,997	337,432	348,308	343,302	377,164	306,995	351,326	92,613
Measured females	Aleutians	14,620	19,079	21,055	16,125	16,475	8,792	9,056	5,368	60
	Northwest	124,934	114,778	39,985	28,185	19,282	22,144	51,358	39,576	19,019
	Southeast A Season	184,351	142,016	112,602	146,918	124,000	140,868	102,530	108,645	31,791
	Southeast B Season	90,056	136,626	135,661	146,540	150,632	149,583	105,999	174,729	35,019
Total		413,961	412,499	309,303	337,768	310,389	321,387	268,943	295,104	85,889
Aged males	Aleutians	22	110	81	157	73	86	15	142	0
	Northwest	320	179	147	132	123	0	326	216	312
	Southeast A Season	373	454	451	200	297	470	431	588	533
	Southeast B Season	248	317	475	571	415	442	284	307	728
Total		963	1,060	1,154	1,060	908	998	1,056	1,098	1,573
Aged females	Aleutians	23	121	82	151	105	77	15	166	0
	Northwest	340	178	153	142	131	0	326	236	312
	Southeast A Season	385	458	478	201	313	451	434	652	485
	Southeast B Season	233	332	458	574	392	434	312	308	725
Total		981	1,089	1,171	1,068	941	962	1,087	1,192	1,522

Table 1.5. Biomass (age 1+) of eastern Bering Sea walleye pollock as estimated by surveys 1979-2000(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]	(95%)	6.86	52%
2000	5.14	3.05		8.19	63%

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[1] Although the two survey estimates are added in this table, the stock assessment model treats them as separate, independent 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
2000	352	41,762	1,545

Table 1.7. Distribution of pollock between areas from summer echo integration-trawl surveys on the Bering Sea shelf, 1994-2000. Data are estimated pollock biomass between the surface and 3 m off bottom. Error bounds only quantify acoustic sampling variability. Other sources of error (trawl sampling, error associated with target strength or ageing error, etc.) are not included.

			Biomass (million mt) (percent)				
	Dates	**Area** $(\text{nmi})^2$	**SCA**	**E170-SCA**	**W170**	**Total Biomass (million mt)**	**95% Confidence Bounds**
1994	Jul 9-Aug 19	78,251	0.312 (11%)	0.399 (14%)	2.18 (75%)	2.89	NA
1996	Jul 20-Aug 30	93,810	0.215 (9%)	0.269 (12%)	1.83 (79%)	2.31	2.15-2.48
1997	Jul 17-Sept 4	102,770	0.246 (10%)	0.527 (20%)	1.82 (70%)	2.59	2.42-2.76
1999	Jun 7-Aug 5*	103,670	0.299 (9%)	0.579 (18%)	2.41 (73%)	3.29	2.95-3.62
2000	Jun 7- Aug 2*	106,140	0.393 (13%)	0.498 (16%)	2.16 (71%)	3.05	2.88-3.22

* Note four weeks earlier than previous years' surveys

SCA = Sea lion Conservation Area
E170 - SCA = East of 170 W minus SCA
W170 = West of 170 W

Table 1.8. 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**	122	42,364	4,946	2,446
	East of 170 W	45	13,842	1,945	946
	West of 170 W	77	28,522	3,001	1,500
2000	**Total**	128	43,729	3,459	2,253
	East of 170 W	32	7,721	850	850
	West of 170 W	96	36,008	2,609	1,403

Table 1.9. Average weights-at-age (kg) by year as used in the model for the fishery and for computing biomass levels for EBS pollock. NOTE: 2000 weight-at-age is treated as the three-year average of values from 1997-1999.

	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	0.325	0.468	0.554	0.745	0.890	1.071	1.084	1.236	1.332	1.421	1.570	1.451	1.418
1998	0.007	0.170	0.362	0.574	0.629	0.636	0.778	1.046	1.173	1.242	1.236	1.337	1.443	1.487	1.709
1999	0.007	0.170	0.412	0.492	0.655	0.697	0.750	0.960	1.081	1.347	1.275	1.389	1.488	1.531	1.514
2000	0.007	0.170	0.366	0.511	0.613	0.693	0.806	1.026	1.113	1.275	1.281	1.387	1.504	1.492	1.552

Table 1.10. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2000.

Year	**Fishery**	**Year**	**Fishery**	**BTS**	**EIT**
1964	10	1979	50	NA	8
1965	10	1980	50	NA	NA
1966	10	1981	50	NA	NA
1967	10	1982	50	75	25
1968	10	1983	50	75	NA
1969	10	1984	50	75	NA
1970	10	1985	50	75	25
1971	10	1986	50	75	NA
1972	10	1987	50	75	NA
1973	10	1988	50	75	25
1974	10	1989	50	75	NA
1975	10	1990	50	75	NA
1976	10	1991	100	75	25
1977	10	1992	100	75	NA
1978	50	1993	100	75	NA
		1994	100	75	25
		1995	100	75	NA
		1996	100	75	25
		1997	100	75	25
		1998	100	75	NA
		1999	100	75	50
		2000	NA	75	25

Table 1.11. Results comparing fits Models 0-8. Note that the total negative-log likelihood values are not directly comparable between Models 0 & 3 and all the others since different amounts of data were involved. 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 4a**	**Model 4b**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Total –ln(likelihood)	-1,246	-1,265	-1,206	-877	-1,271	-1,277	-1,265	-1,270	-1,277	-1,279
Age Composition data										
Effective N Fishery	133	133	126	216	133	132	135	134	134	133
Effective N Bottom trawl survey	220	223	86	222	224	225	223	223	223	222
Effective N Hydro acoustic survey	46	46	42	71	45	45	46	46	46	46
Survey abundance estimates, RMSE*										
Trawl Survey	0.17	0.17	0.22	0.17	0.17	0.17	0.17	0.17	0.17	0.17
EIT survey	0.27	0.27	0.65	0.21	0.27	0.27	0.27	0.26	0.26	0.26
Recruitment Residuals										
Due to Stock	0.24	0.24	0.24	0.43	0.24	0.24	0.24	0.24	0.24	0.24
Residual RMSE	0.40	0.40	0.42	0.24	0.40	0.39	0.39	0.40	0.40	0.40
Total	0.65	0.64	0.65	0.68	0.64	0.63	0.63	0.64	0.64	0.64

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

Table 1.12. Results reflecting the stock condition for Models 0-8. 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 4a	Model 4b	Model 5	Model 6	Model 7	Model 8
Biomass										
Year 2001 spawning biomass[3]	2,663	2,761	1,066	2,552	2,603	2,394	2,280	2,820	1,484	1,227
Year 2001 spawning biomass[4]	2,949	3,066	1,887	3,296	3,086	3,108	3,143	3,091	3,092	3,167
(CV)	(20%)	(19%)	(14%)	(19%)	(18%)	(17%)	(19%)	(20%)	(19%)	(17%)
2000 spawning biomass	3,087	3,197	2,153	3,445	3,211	3,224	3,269	3,218	3,219	3,289
B_{msy}	1,776	1,779	1,091	1,484	1,479	1,284	1,400	1,894	428	1,032
(CV)	(28%)	(28%)	(18%)	(24%)	(19%)	(13%)	(16%)	(39%)	(15%)	(18%)
$B_{40\%}$ %	2,411	2,426	2,241	2,264	2,430	2,435	2,207	2,432	2,434	2,444
(CV)	(18%)	(18%)	(18%)	(19%)	(18%)	(18%)	(18%)	(18%)	(18%)	(18%)
Percent of B_{msy} % spawners	150%	155%	98%	172%	176%	186%	163%	149%	347%	119%
Percent of $B_{40\%}$ spawners	122%	126%	84%	146%	127%	128%	142%	127%	127%	130%
2000 Age 3+ Biomass	10,169	10,490	6,917	11,190	10,541	10,591	10,725	10,561	10,567	10,802
Ratio B_{2000}/B_{1999} (3+ biomass)	97%	97%	90%	97%	98%	98%	98%	98%	98%	98%
Recruitment										
Steepness parameter (*h*)	0.69	0.69	0.88	0.77	0.73	0.78	0.80	0.81	0.60	0.91
Avg Recruitment (since 1978)	20,926	21,016	19,898	21,639	21,043	21,071	21,094	21,044	21,044	21,105
(CV since 1978)	65%	65%	69%	66%	65%	64%	65%	65%	65%	65%
Avg. Recruitment (all yrs)	23,037	23,182	21,414	21,639	23,224	23,270	23,351	23,240	23,257	23,358
(CV process error)	70%	69%	76%	66%	69%	68%	69%	69%	69%	69%
1996 year-class	48,065	48,537	29,053	51,263	48,614	48,521	49,678	48,837	48,888	50,152
(CV 1996 year-class)	(21%)	(21%)	(16%)	(20%)	(20%)	(19%)	(20%)	(21%)	(21%)	(19%)

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

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

Table 1.13. Results relating to yield for Models 0-8. See text for model descriptions.

	Model 0	**Model 1**	**Model 2**	**Model 3**	**Model 4a**	**Model 4b**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
2001 Har. Mean F_{msy} yield	1,975	2,125	3,722	3,600	3,101	4,267	4,950	2,166	6,789	7,304
2001 F_{msy} yield	3,360	3,536	4,308	5,539	4,335	5,211	5,730	3,388	7,472	8,142
(CV)	(50%)	(49%)	(25%)	(44%)	(39%)	(29%)	(25%)	(45%)	(20%)	(21%)
Year 2001 $F_{40\%}$ Yield	1,757	1,842	1,152	2,008	1,852	1,862	1,889	1,857	1,857	1,902
Year 2001 $F_{35\%}$ Yield	2,246	2,350	1,436	2,549	2,364	2,378	2,411	2,370	2,371	2,429
MSY (long-term expectation)	1,820	1,839	3,434	2,348	1,885	2,058	2,533	1,864	1,454	4,444
Average F *(over ages 1-15)*										
F_{msy}	1.14	1.18	3.58	1.92	1.64	2.30	2.71	1.10	6.19	8.29
(CV)	(145%)	(146%)	(130%)	(168%)	(130%)	(111%)	(95%)	(134%)	(53%)	(135%)
$F_{40\%}$	0.477	0.490	0.393	0.429	0.492	0.494	0.488	0.493	0.493	0.495
Full-selection equivalent F's										
F_{msy}	1.788	1.808	5.321	3.137	2.509	3.536	4.167	1.683	9.482	12.673
$F_{40\%}$	0.751	0.751	0.583	0.700	0.754	0.759	0.752	0.755	0.755	0.756
$F_{35\%}$	1.020	1.020	0.763	0.942	1.025	1.031	1.021	1.026	1.025	1.028

Table 1.14 Estimates of numbers at age for the EBS pollock stock under Model 1 (millions).

Year	1	2	3	4	5	6	7	8	9	10+
1964	3,592	2,140	1,437	209	49	154	50	7	4	25
1965	16,304	1,453	1,328	927	88	17	59	22	3	17
1966	11,975	6,601	905	875	427	35	7	28	11	12
1967	23,873	4,847	4,094	586	441	201	18	4	15	13
1968	19,959	9,634	2,951	2,421	228	153	78	7	2	14
1969	23,420	8,064	5,908	1,807	1,043	89	65	36	4	9
1970	20,500	9,384	4,848	3,517	917	463	39	29	16	5
1971	13,101	8,192	5,582	2,773	1,667	371	185	16	11	8
1972	9,902	5,205	4,760	2,927	1,131	550	121	59	5	6
1973	36,097	3,973	2,920	2,170	968	345	168	37	18	4
1974	21,524	14,393	2,101	1,064	495	196	70	34	7	4
1975	16,763	8,510	7,017	562	145	57	23	8	4	1
1976	12,792	6,737	4,729	2,572	129	27	11	4	2	1
1977	14,623	5,160	3,912	2,171	858	38	8	3	1	1
1978	27,461	5,911	3,069	2,031	889	319	14	3	1	1
1979	66,013	11,123	3,550	1,656	881	313	88	4	1	1
1980	25,592	26,749	6,724	1,983	762	337	96	26	1	0
1981	27,432	10,380	16,426	4,081	1,049	354	134	37	10	1
1982	13,590	11,137	6,517	11,247	2,409	538	161	59	16	4
1983	45,325	5,521	7,040	4,621	7,344	1,454	303	89	32	10
1984	11,160	18,417	3,498	5,049	3,117	4,673	880	182	52	24
1985	30,661	4,535	11,686	2,512	3,411	1,980	2,874	535	111	42
1986	12,129	12,460	2,877	8,390	1,696	2,164	1,216	1,743	326	85
1987	6,715	4,929	7,907	2,069	5,685	1,083	1,339	744	1,071	232
1988	4,968	2,730	3,136	5,763	1,450	3,836	708	840	469	800
1989	9,279	2,019	1,735	2,270	3,945	940	2,379	414	494	708
1990	48,229	3,771	1,283	1,254	1,547	2,541	578	1,373	241	650
1991	22,478	19,602	2,394	916	831	918	1,374	289	693	438
1992	15,917	9,135	12,434	1,698	595	474	469	640	136	520
1993	34,313	6,468	5,787	8,720	1,066	317	220	193	268	269
1994	9,923	13,946	4,109	4,153	5,577	586	146	95	84	247
1995	9,537	4,033	8,866	2,965	2,726	3,229	294	70	46	166
1996	22,843	3,876	2,565	6,432	1,994	1,658	1,753	153	36	116
1997	48,537	9,285	2,464	1,870	4,527	1,309	911	847	75	71
1998	18,225	19,728	5,901	1,795	1,314	2,958	712	434	408	66
1999	10,845	7,408	12,540	4,302	1,263	862	1,623	343	212	213
2000	12,003	4,408	4,709	9,075	3,000	834	504	821	169	212
Median	16,763	6,737	4,109	2,270	1,066	474	168	59	18	17
Average	21,016	8,429	5,127	3,228	1,775	983	532	276	137	135

Table 1.15. Estimated catch-at-age of EBS pollock for Model 1.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1964	11	47	161	78	22	65	18	2	1	5
1965	44	27	127	307	36	7	19	6	1	3
1966	35	146	99	244	136	10	2	6	2	2
1967	117	176	717	244	206	84	7	1	5	4
1968	83	297	444	888	95	57	26	2	0	3
1969	224	372	1,008	496	366	32	24	13	1	3
1970	232	509	960	1,107	365	187	16	12	6	2
1971	197	587	1,420	1,093	814	184	93	8	6	4
1972	87	506	1,601	1,428	588	286	62	31	3	3
1973	460	549	1,305	1,335	628	223	108	24	12	2
1974	392	2,755	1,189	780	377	149	53	26	6	3
1975	127	885	3,116	345	97	38	15	5	3	1
1976	66	486	1,572	1,246	69	15	6	2	1	1
1977	56	280	1,021	852	376	17	4	1	1	0
1978	68	277	726	736	410	177	8	2	1	0
1979	146	466	760	549	374	162	46	2	0	0
1980	40	797	1,055	494	248	137	40	11	0	0
1981	26	129	1,077	720	282	120	47	14	4	0
1982	7	77	241	1,156	388	111	35	14	4	1
1983	18	28	194	358	899	231	51	16	6	2
1984	3	72	93	385	385	689	138	28	10	6
1985	10	18	312	193	425	294	452	82	22	12
1986	4	47	74	620	203	309	184	258	63	22
1987	1	9	110	96	438	110	178	96	156	38
1988	1	7	62	379	157	542	130	150	94	178
1989	2	6	36	157	447	139	457	77	104	180
1990	11	13	40	114	268	598	164	381	68	193
1991	6	81	88	97	167	248	445	92	224	152
1992	5	48	574	225	146	155	182	244	53	204
1993	8	19	156	1,033	240	104	80	69	93	85
1994	2	34	92	411	1,059	165	46	29	25	68
1995	2	8	159	237	423	752	76	18	11	37
1996	4	10	35	278	197	373	531	46	13	37
1997	10	24	35	83	462	303	284	259	27	23
1998	3	49	82	78	131	669	217	130	142	21
1999	2	19	251	218	119	158	448	101	61	60
2000	3	12	104	507	311	167	152	262	53	65

Table 1.16. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for Model 1 (current assessment) compared to estimates from the 1999 (columns 4 & 5), 1998 (columns 6 & 7) and 1997 (columns 8 & 9) assessments for EBS pollock.

Age 3+ Biomass	**Current Assessment**	**CV**	**1999 Assessment**	**CV**	**1998 Assessment**	**CV**	**1997 Assessment**	**CV**
1964	751	35%	917	41%	1,037	30%		
1965	976	36%	976	32%	1,227	26%		
1966	1,001	39%	919	31%	1,096	28%		
1967	1,957	34%	1,858	24%	2,095	22%		
1968	2,312	36%	2,312	27%	2,510	23%		
1969	3,379	29%	3,579	22%	3,810	19%		
1970	3,998	25%	4,479	19%	5,083	15%		
1971	4,372	21%	5,161	16%	5,813	12%		
1972	3,984	19%	4,896	15%	5,648	11%		
1973	2,873	26%	3,357	20%	3,922	14%		
1974	1,648	41%	1,952	28%	2,342	19%		
1975	2,536	23%	2,683	18%	3,014	13%		
1976	2,694	17%	2,748	16%	3,008	13%		
1977	2,701	13%	2,716	14%	2,894	13%		
1978	2,608	14%	2,668	15%	2,867	13%	3,244	19%
1979	2,640	16%	2,720	16%	2,933	15%	3,183	21%
1980	3,723	15%	3,888	16%	4,294	14%	4,618	19%
1981	7,834	12%	8,064	13%	8,569	12%	9,190	16%
1982	9,021	13%	9,229	13%	9,778	12%	10,524	17%
1983	9,958	12%	10,153	12%	10,705	12%	11,555	16%
1984	9,518	13%	9,685	12%	10,179	12%	11,028	17%
1985	11,182	10%	11,370	10%	11,919	11%	12,853	15%
1986	10,277	10%	10,440	10%	10,913	11%	11,796	16%
1987	10,636	9%	10,769	9%	11,116	10%	11,952	15%
1988	9,910	8%	9,991	9%	10,274	10%	11,020	15%
1989	8,251	9%	8,305	9%	8,546	10%	9,210	16%
1990	6,473	10%	6,497	10%	6,659	12%	7,240	18%
1991	4,859	11%	4,842	11%	5,180	13%	5,690	20%
1992	7,920	9%	7,800	10%	8,294	13%	9,465	21%
1993	10,233	10%	9,873	10%	10,279	16%	12,086	25%
1994	9,285	10%	8,622	12%	8,917	18%	10,626	29%
1995	10,267	12%	8,817	15%	8,680	22%	9,998	32%
1996	8,556	14%	7,147	17%	6,811	26%	8,142	36%
1997	7,057	17%	5,710	22%	5,307	31%	6,631	42%
1998	7,448	22%	5,961	28%	5,133	39%	5,133	39%
1999	10,772	30%	7,513	36%				
2000	10,490	34%						

Table 1.17 Projections of Model 1 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. The values for $B_{40\%}$ and $B_{35\%}$ are **2,426** and **2,170** respectively.

Sp.Biomass	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2000	3,197	3,197	3,197	3,197	3,197	3,197	3,197
2001	3,066	3,066	3,187	3,161	3,314	2,984	3,066
2002	2,432	2,432	2,869	2,767	3,447	2,204	2,432
2003	2,079	2,079	2,664	2,504	3,691	1,852	2,026
2004	2,143	2,143	2,731	2,530	4,145	1,938	1,987
2005	2,331	2,331	2,896	2,677	4,537	2,137	2,148
2006	2,494	2,494	3,070	2,842	4,883	2,282	2,284
2007	2,563	2,563	3,177	2,944	5,115	2,326	2,326
2008	2,576	2,576	3,241	2,998	5,353	2,319	2,318
2009	2,578	2,578	3,280	3,030	5,557	2,314	2,314
2010	2,591	2,591	3,316	3,061	5,734	2,326	2,326
2011	2,610	2,610	3,345	3,089	5,873	2,344	2,344
2012	2,613	2,613	3,355	3,097	5,972	2,344	2,344
2013	2,596	2,596	3,344	3,085	6,037	2,326	2,326

F	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2000	0.295	0.295	0.295	0.295	0.295	0.295	0.295
2001	0.490	0.490	0.245	0.296	0.000	0.665	0.490
2002	0.480	0.480	0.245	0.296	0.000	0.587	0.480
2003	0.403	0.403	0.239	0.296	0.000	0.486	0.533
2004	0.400	0.400	0.231	0.296	0.000	0.495	0.507
2005	0.414	0.414	0.230	0.296	0.000	0.527	0.529
2006	0.429	0.429	0.233	0.296	0.000	0.552	0.552
2007	0.436	0.436	0.234	0.296	0.000	0.561	0.561
2008	0.439	0.439	0.236	0.296	0.000	0.563	0.563
2009	0.440	0.440	0.236	0.296	0.000	0.563	0.562
2010	0.441	0.441	0.237	0.296	0.000	0.563	0.563
2011	0.441	0.441	0.238	0.296	0.000	0.564	0.564
2012	0.441	0.441	0.237	0.296	0.000	0.563	0.563
2013	0.440	0.440	0.237	0.296	0.000	0.563	0.563

Yield	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2000	1,138	1,138	1,138	1,138	1,138	1,138	1,138
2001	1,842	1,842	1,010	1,197	0	2,351	1,842
2002	1,725	1,725	1,140	1,302	0	1,824	1,725
2003	1,313	1,313	1,139	1,279	0	1,315	1,635
2004	1,157	1,157	1,021	1,140	0	1,190	1,277
2005	1,153	1,153	956	1,052	0	1,244	1,268
2006	1,283	1,283	1,006	1,098	0	1,410	1,414
2007	1,399	1,399	1,089	1,188	0	1,519	1,519
2008	1,453	1,453	1,155	1,253	0	1,550	1,550
2009	1,463	1,463	1,187	1,281	0	1,545	1,545
2010	1,460	1,460	1,202	1,292	0	1,539	1,539
2011	1,463	1,463	1,209	1,299	0	1,548	1,548
2012	1,471	1,471	1,216	1,307	0	1,554	1,554

Table 1.18. Summary results for Model 1, 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	0.001	0.012	0.088	0.226	0.431	0.884	1.426	1.534	1.489	1.464	1.489	1.489	1.489	1.489	1.489

	Model 1
2001 Spawning biomass	**3,066** t
B_{msy}	**1,779** t
$B_{40\%}$	**2,426** t
$B_{35\%}$	**2,170** t

Yield Considerations	
Year 2000 Harmonic Mean F_{msy} Yield	**2,125** t
Year 2001 Yield F40% (adjusted)	**1,842** t
Full Selection F's	
F_{msy}	**1.808**
$F_{40\%}$	**0.751**
$F_{35\%}$	**1.020**

1.13. Figures

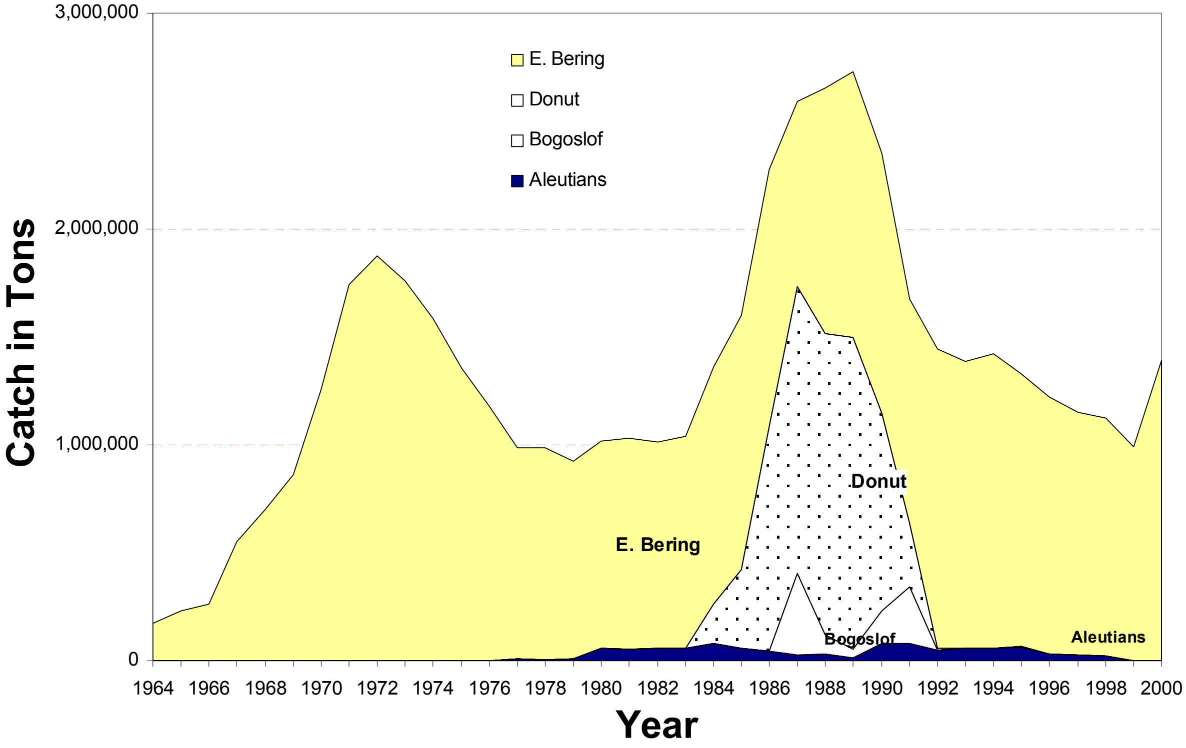


Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-2000.

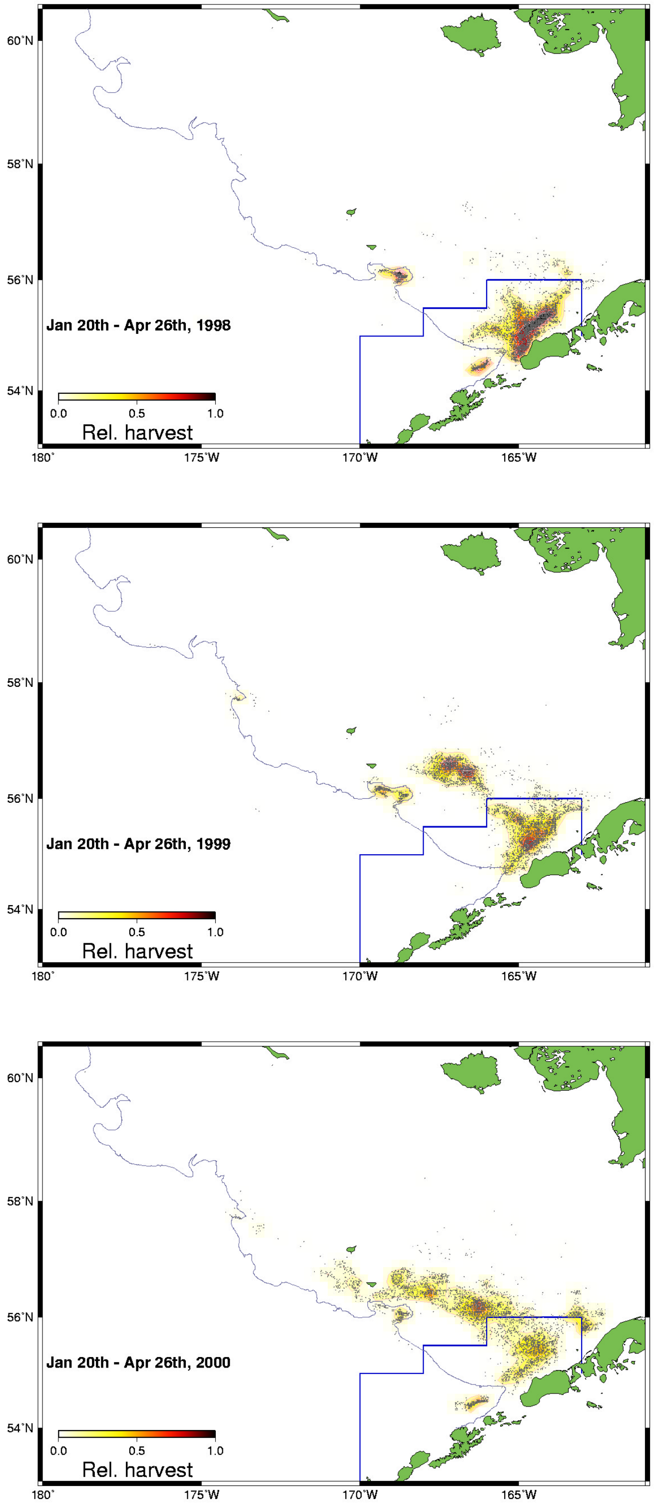


Figure 1.2. Concentrations of the pollock fishery 1998-2000, January - June on the EBS shelf. Line delineates SCA (sea lion conservation area). The density represents relative removal on the same scale over all years.

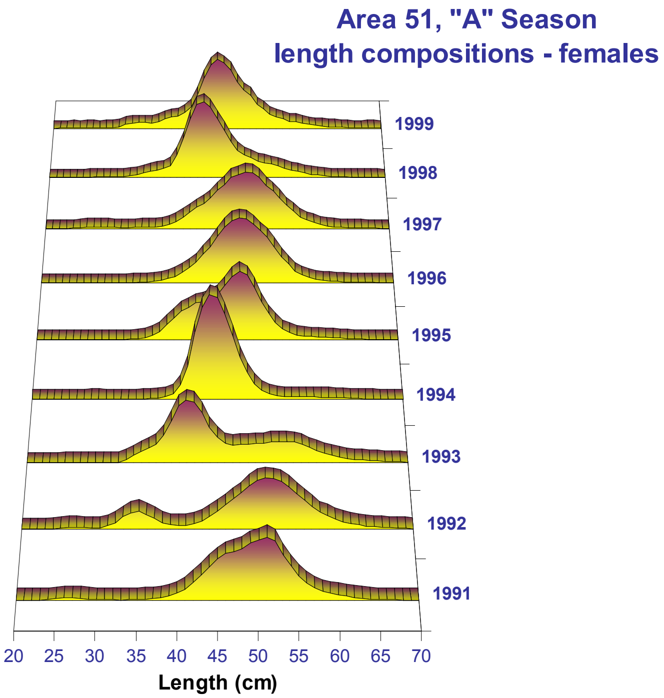


Figure 1.3. Fishery length frequency for the “A season” EBS pollock, 1991-1999.

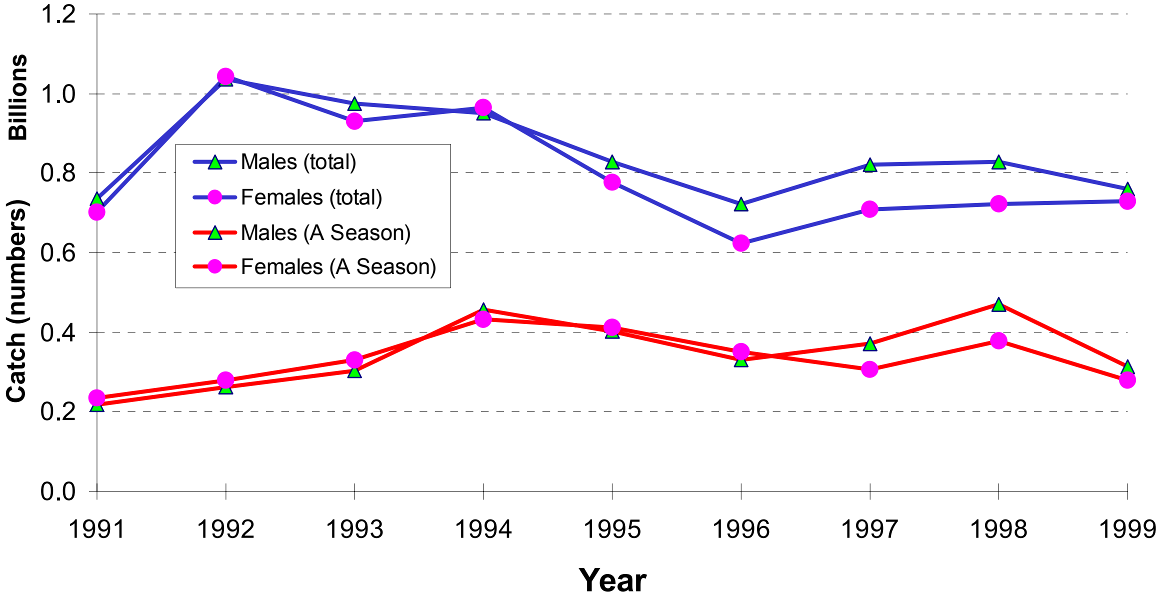


Figure 1.4. Estimate of EBS pollock catch numbers by sex for the “A season” and for the entire fishery, 1991-1999.

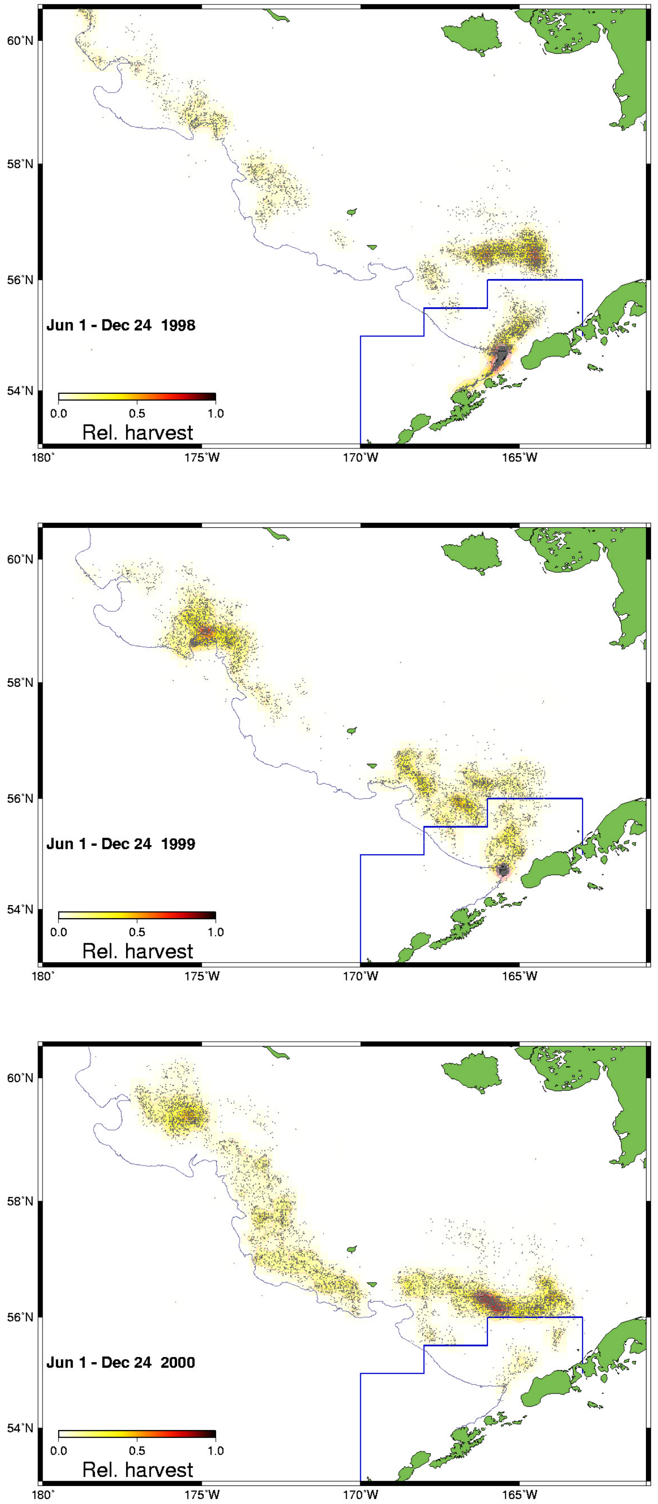


Figure 1.5. Concentrations of the pollock fishery 1998-2000, July – December on the EBS shelf. Line delineates SCA (sea lion conservation area). The density represents relative removal on the same scale over all years.

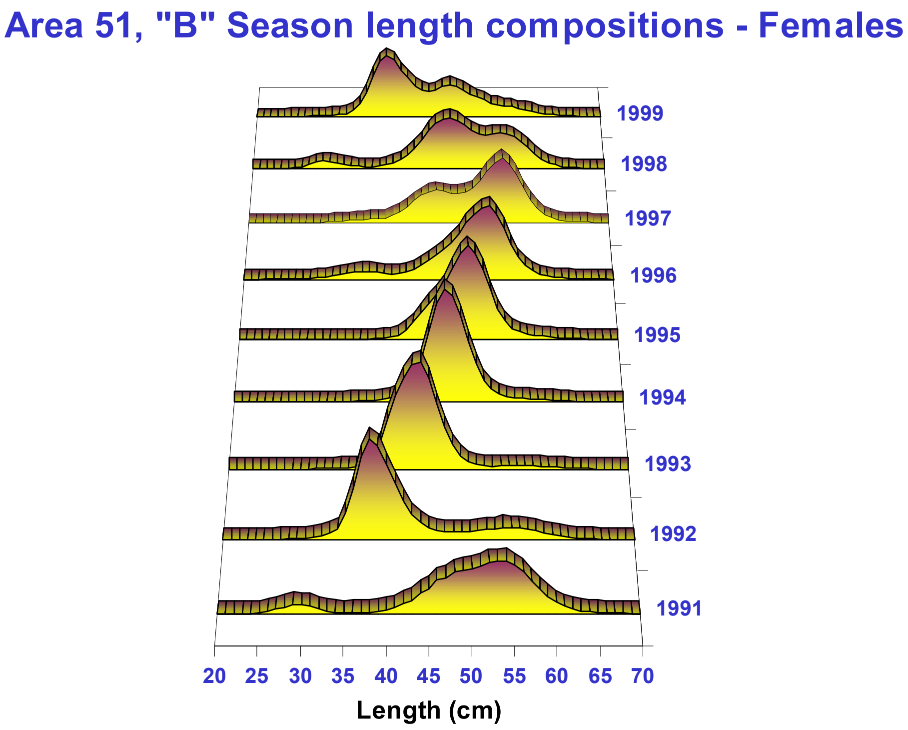
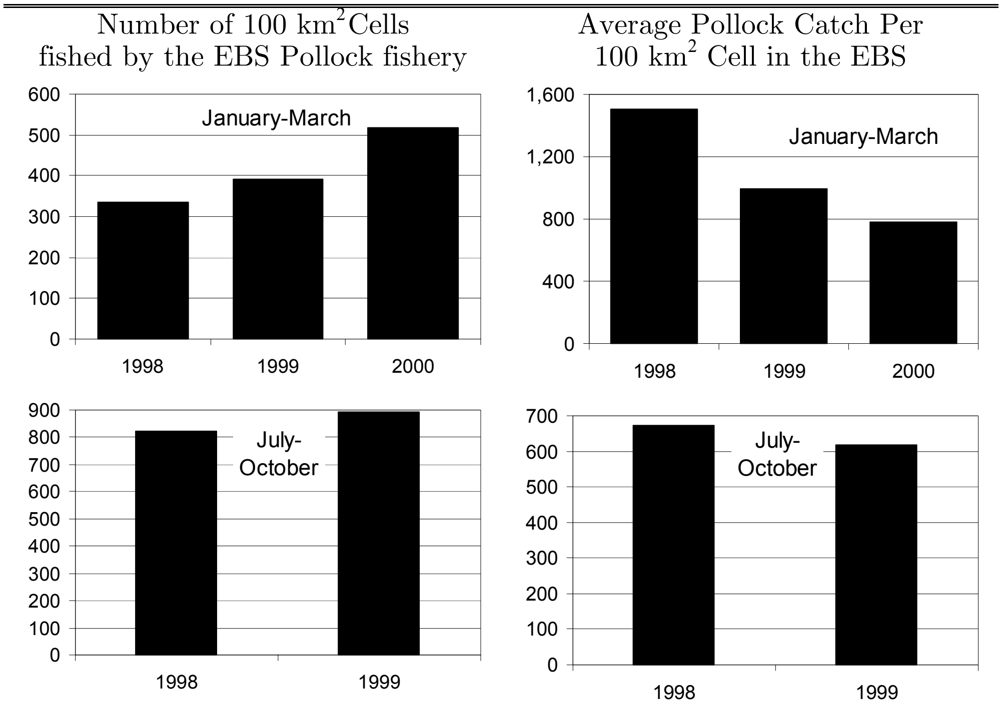

Area 51, "B" Season length compositions - Females

Figure 1.6. Length frequency of EBS pollock observed in the "B season" (June-December) for 1991-1999.


Number of 100 km^2 Cells fished by the EBS Pollock fishery

Average Pollock Catch Per 100 km^2 Cell in the EBS

Figure 1.7. Spatial dispersion of the EBS pollock fisheries in January-March and July-October 1998-2000 as measured by number of 100 km^2 cells where fishing occurred and the average pollock catch in each cell.

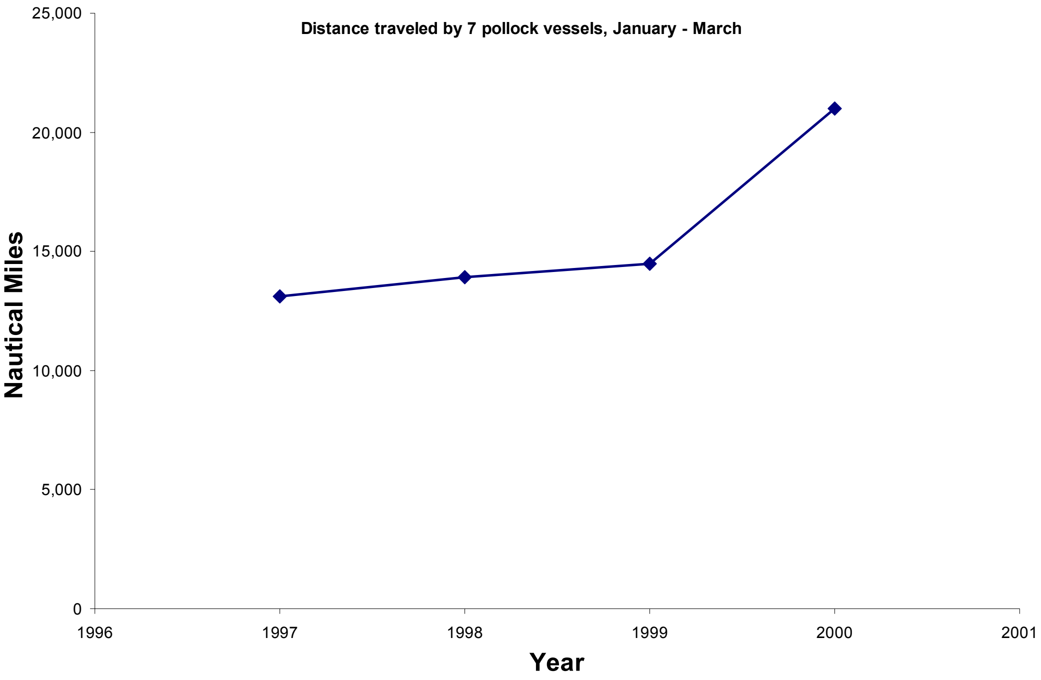


Figure 1.8. Total estimated distance traveled for the top 7 pollock-producing vessels in the Eastern Bering Sea, January-March, 1997-2000.

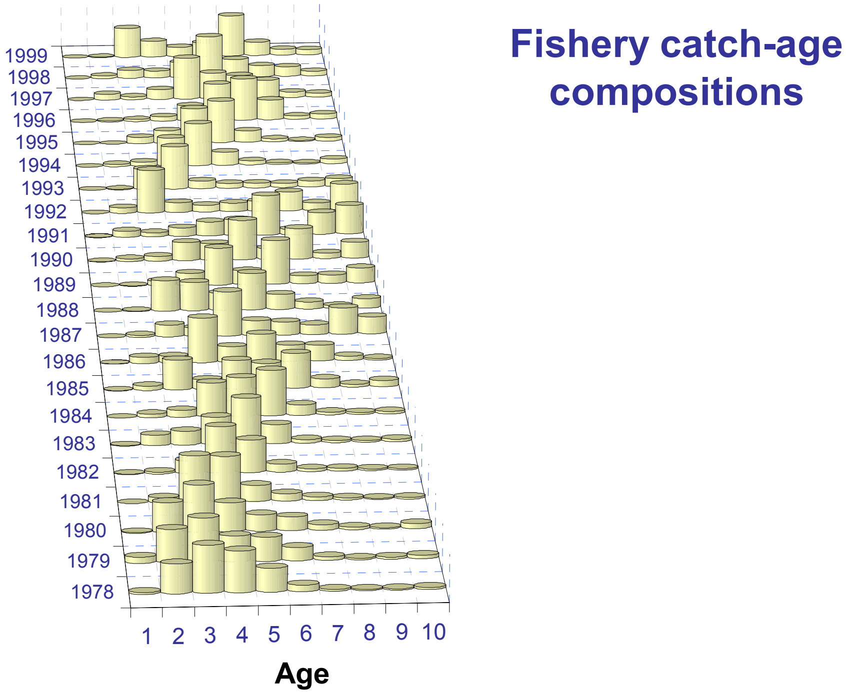


Figure 1.9. EBS walleye pollock fishery catch-at-age data (proportions).

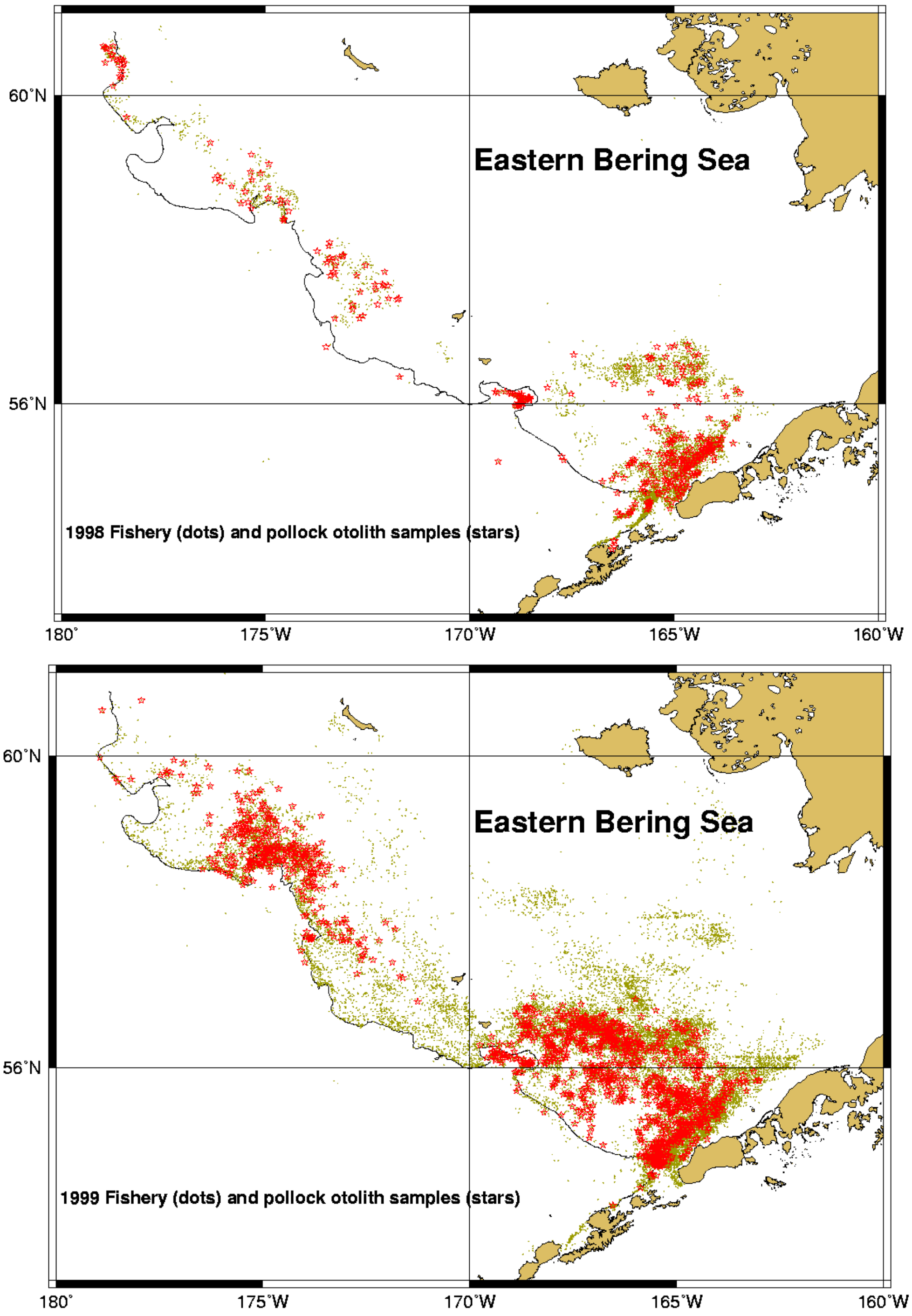


Figure 1.10. EBS walleye pollock fishery sampling locations under the old sampling protocol (1998, top) and under the new protocol (1999, bottom). Points represent haul locations and stars represent hauls were otolith samples were collected.

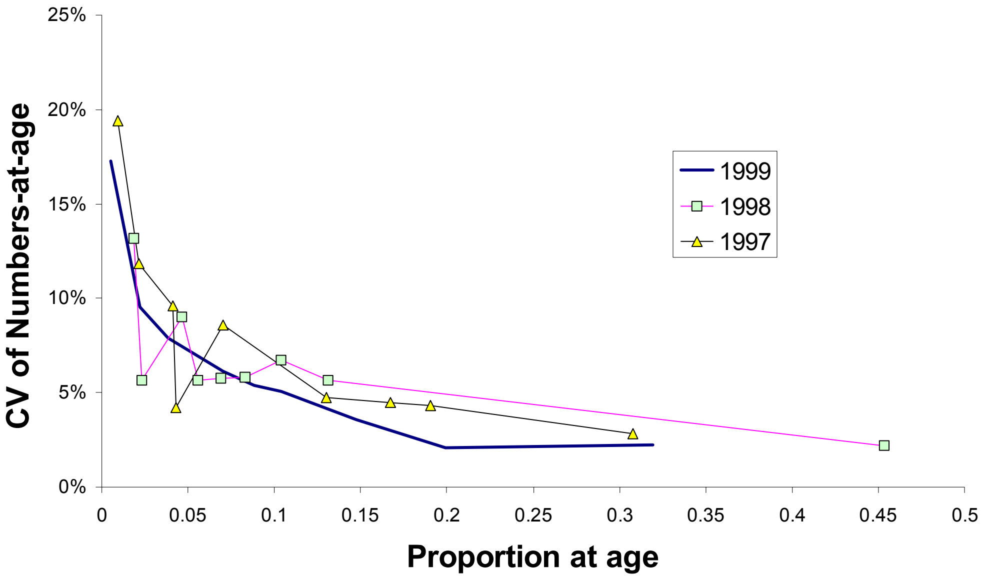


Figure 1.11. Estimated coefficients of variation in catch numbers-at-age from the EBS walleye pollock fishery relative to the proportion of catch numbers-at-age. In 1999 the new observer sampling methods compare with the old sampling protocol of 1997 and 1998.

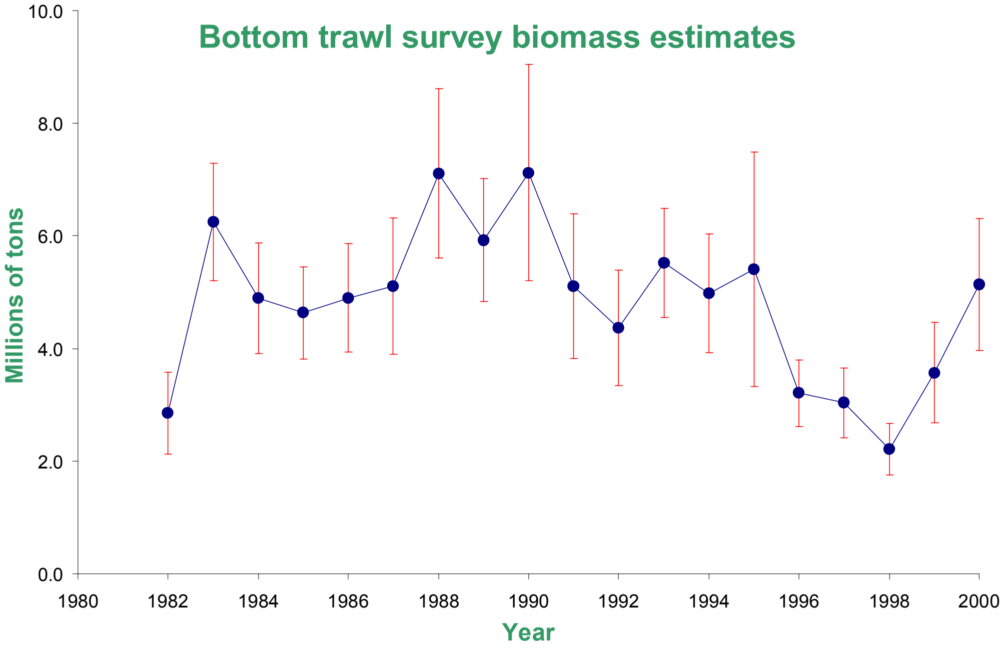


Figure 1.12. Bottom-trawl survey biomass estimates with 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1979-1999 (note that the 1979-1981 estimates were not used in the current analyses since the survey sampling gear changed).

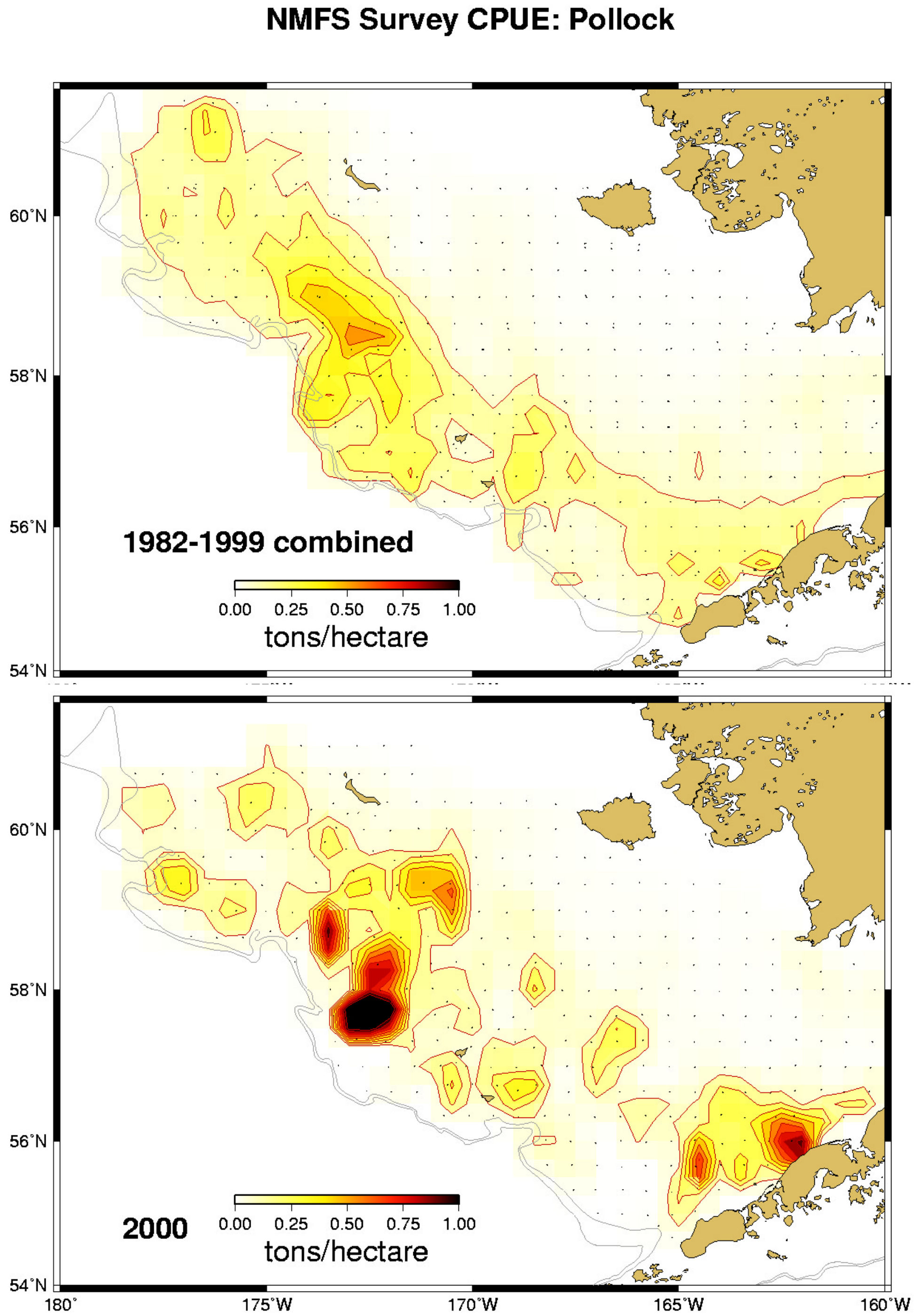


Figure 1.13. Maps showing the average walleye pollock catch-per-unit effort (1982-1999) compared to that observed during the 2000 NMFS EBS shelf bottom-trawl survey (bottom). Note that the average distribution plot contains CPUE values from the northwest portion that is not part of the "standard" survey area.

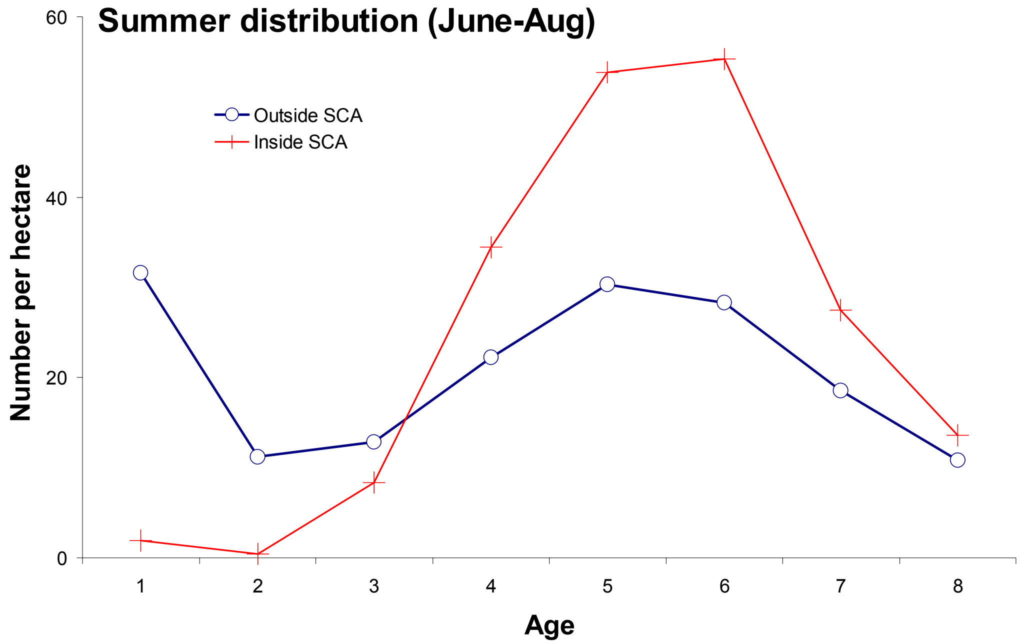


Figure 1.14. EBS pollock age mean number per hectare by age based on tow-by-tow age-specific CPUE analyses of the NMFS bottom-trawl survey, 1982-1999. Source: Troy Buckley, (AFSC) pers. comm.

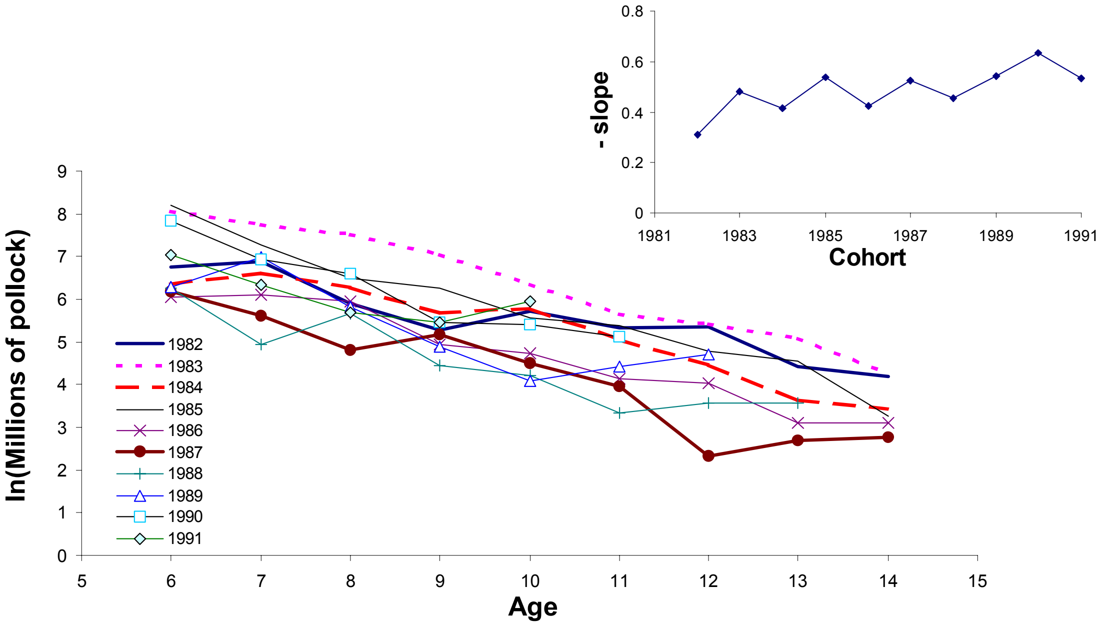


Figure 1.15. Log-abundance levels of individual cohorts (year-classes) as estimated directly from the NMFS bottom-trawl surveys (lower left). Negative slopes (as a proxy for total instantaneous mortality, Z) for each cohort are shown in the top right side.

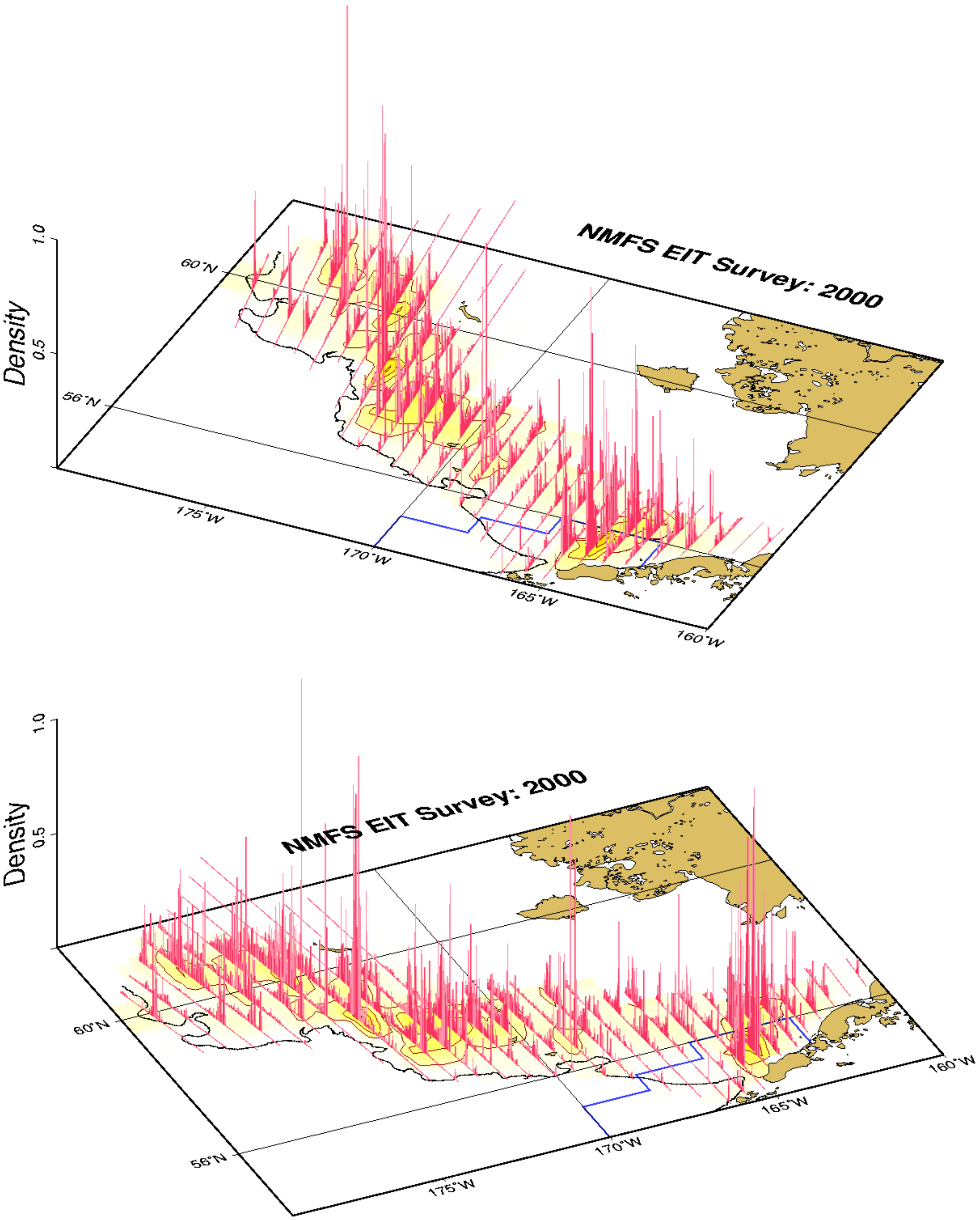


Figure 1.16. Acoustic return assigned to pollock from the NMFS EIT summer 2000 survey. The two images are from different viewpoints of the same data.

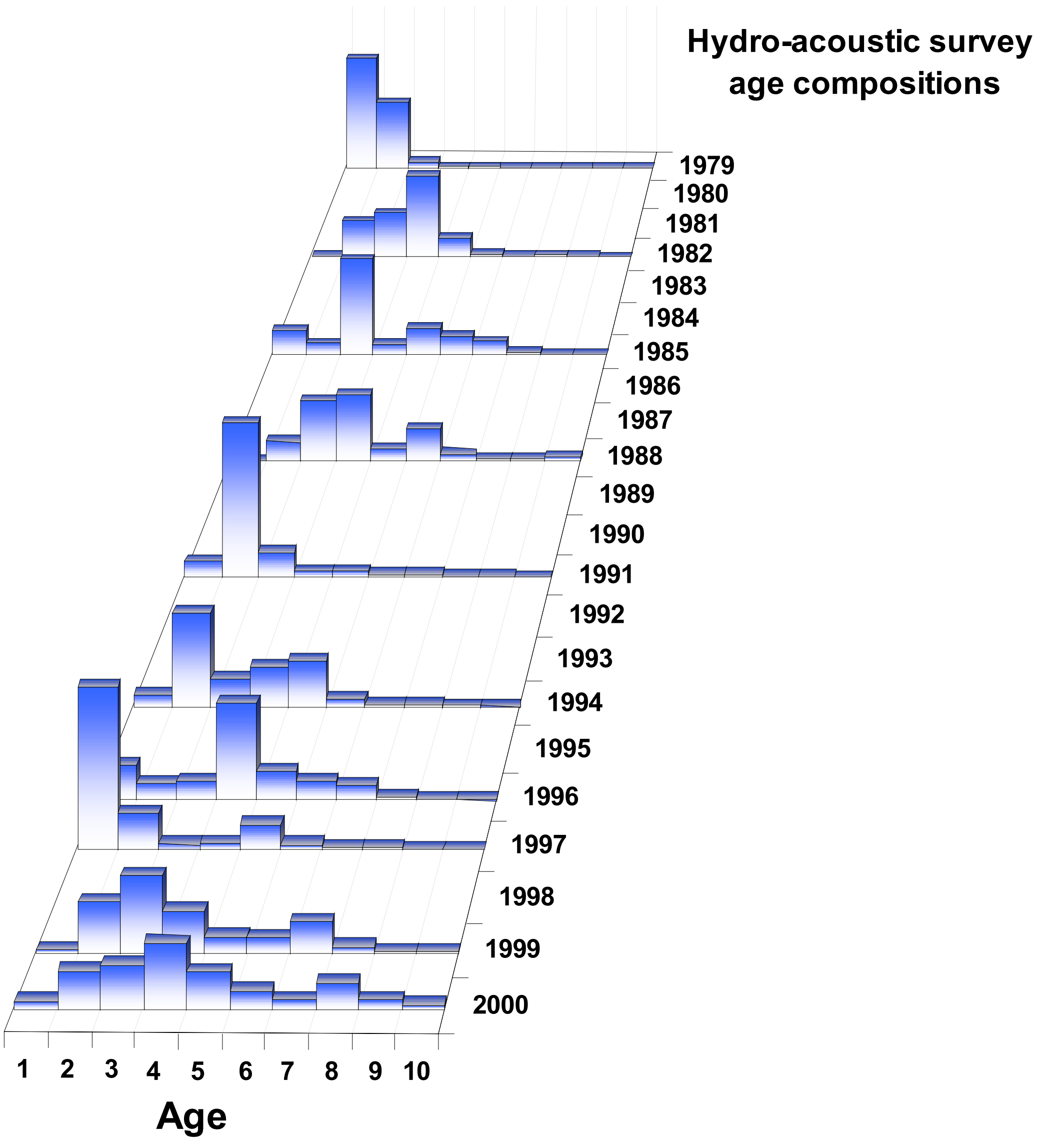


Figure 1.17. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-2000. NOTE: the 2000 estimate of age composition is preliminary (age-length keys from the BTS were used).

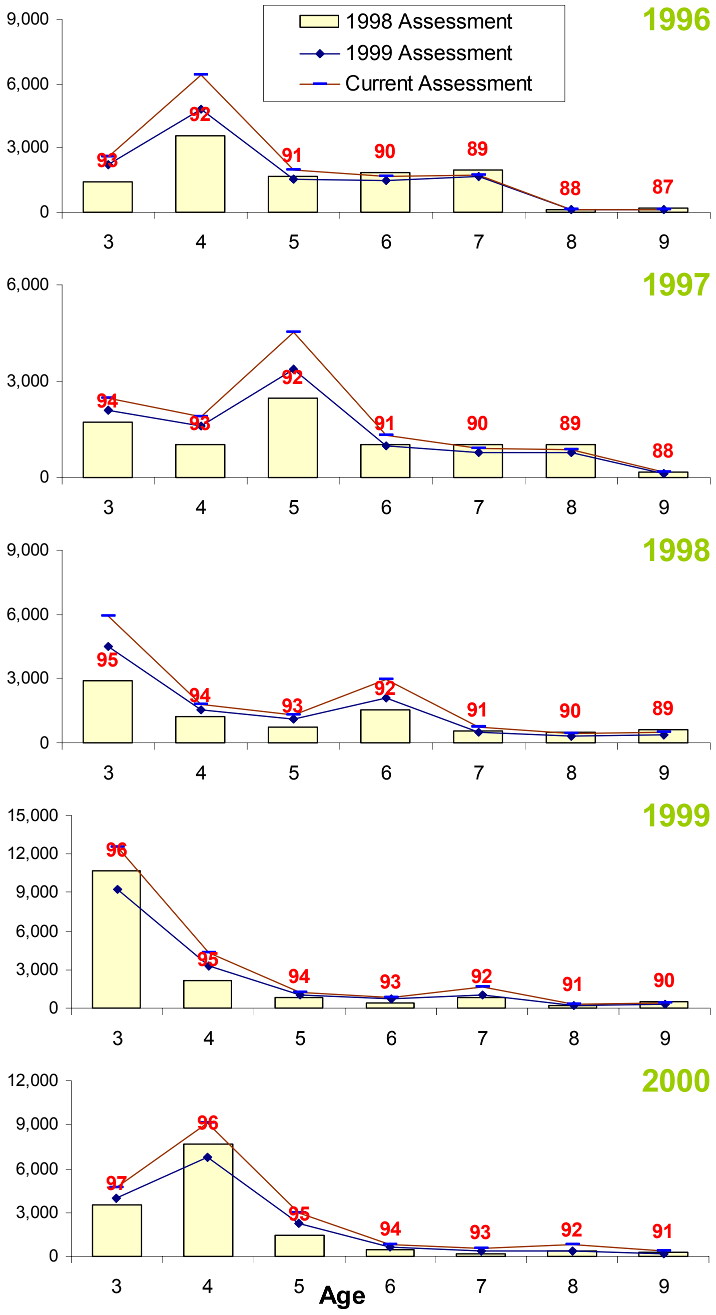


Figure 1.18. Projected EBS walleye pollock Model 1 population numbers at age compared with those presented in the last two assessments (Model 2 from Ianelli *et al.*1998 & 1999). Note that the "age 9" category represents all pollock age 9 and older. Projections assume adjusted $F_{40\%}$ harvest levels.

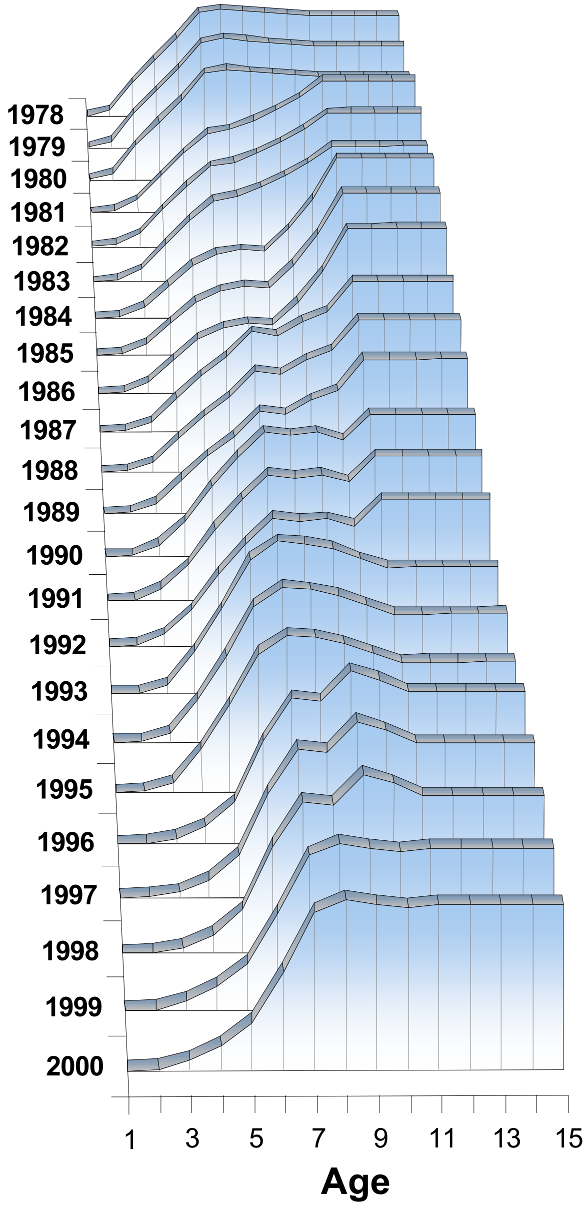


Figure 1.19. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-2000 estimated for Model 1.

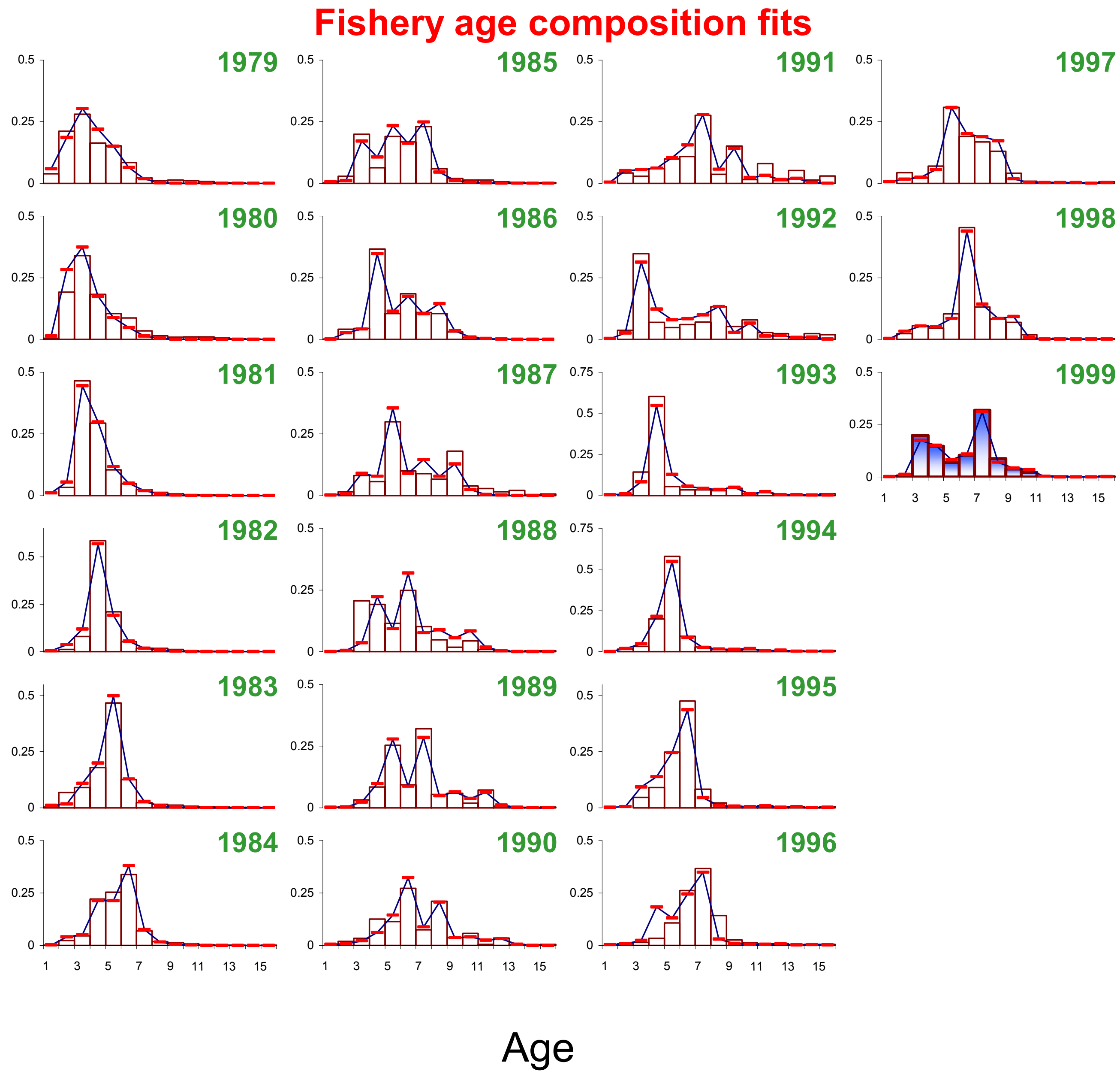


Figure 1.20. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1978-1997). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

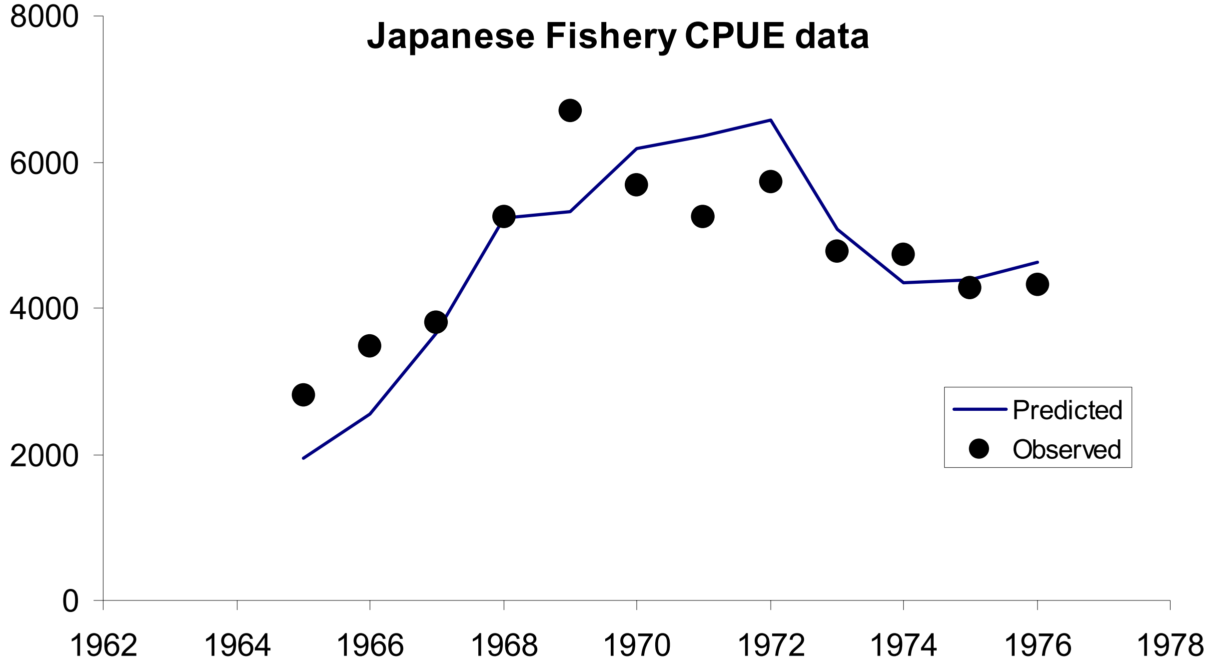


Figure 1.21. Model 1 fit to the EBS walleye pollock fishery CPUE data from Loh and Ikeda (1980).

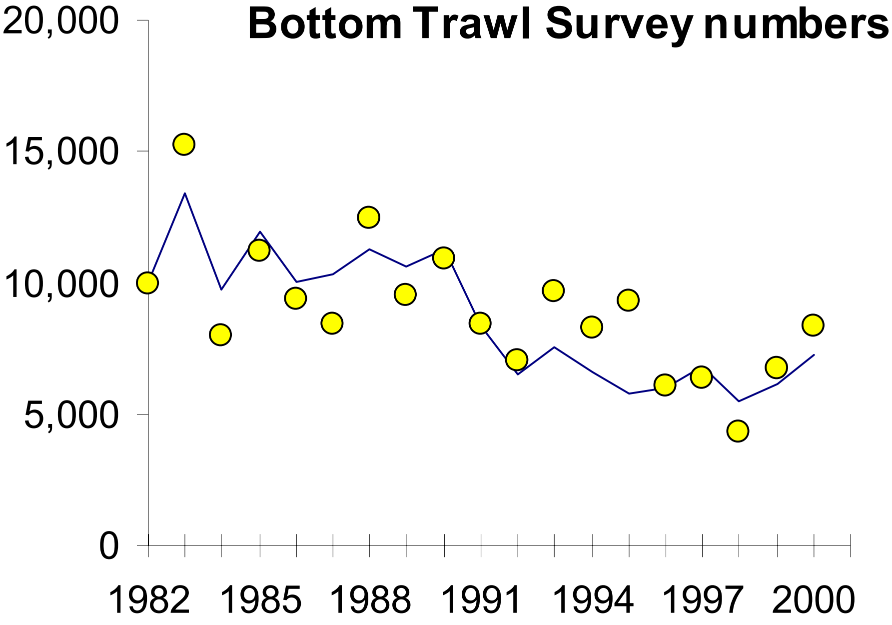


Figure 1.22. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock, Model 1.

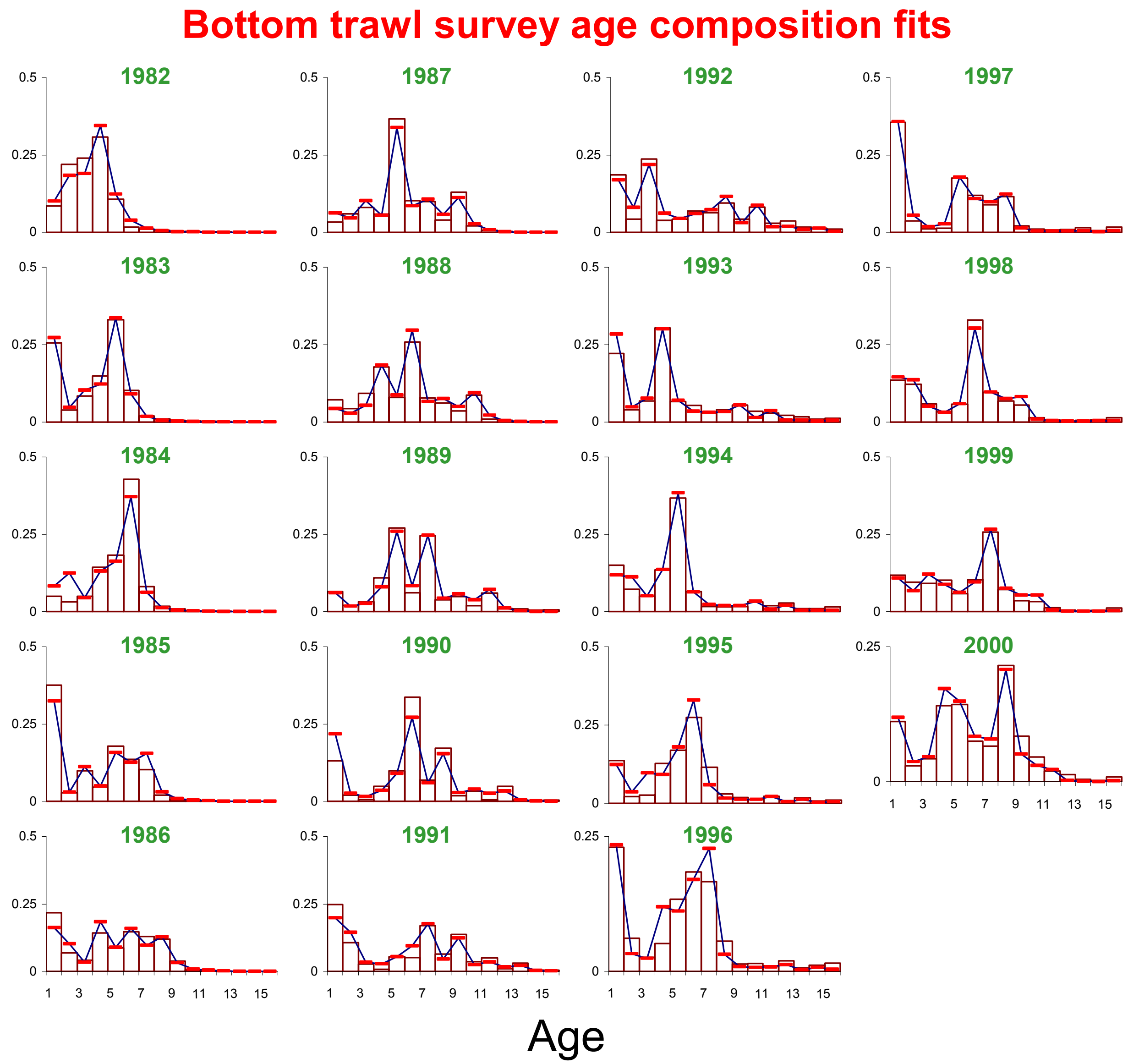


Figure 1.23. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data.

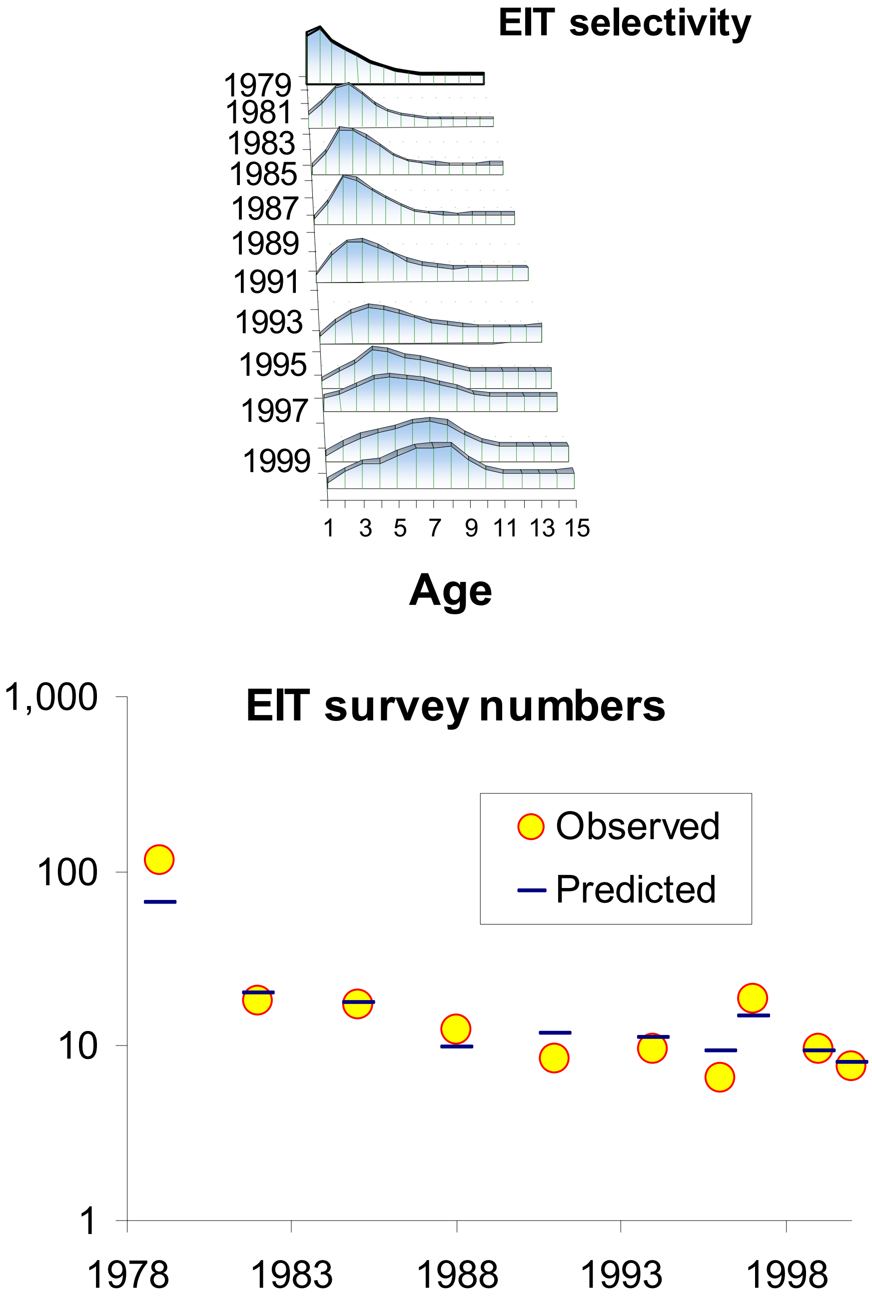


Figure 1.24. Model 1 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock.

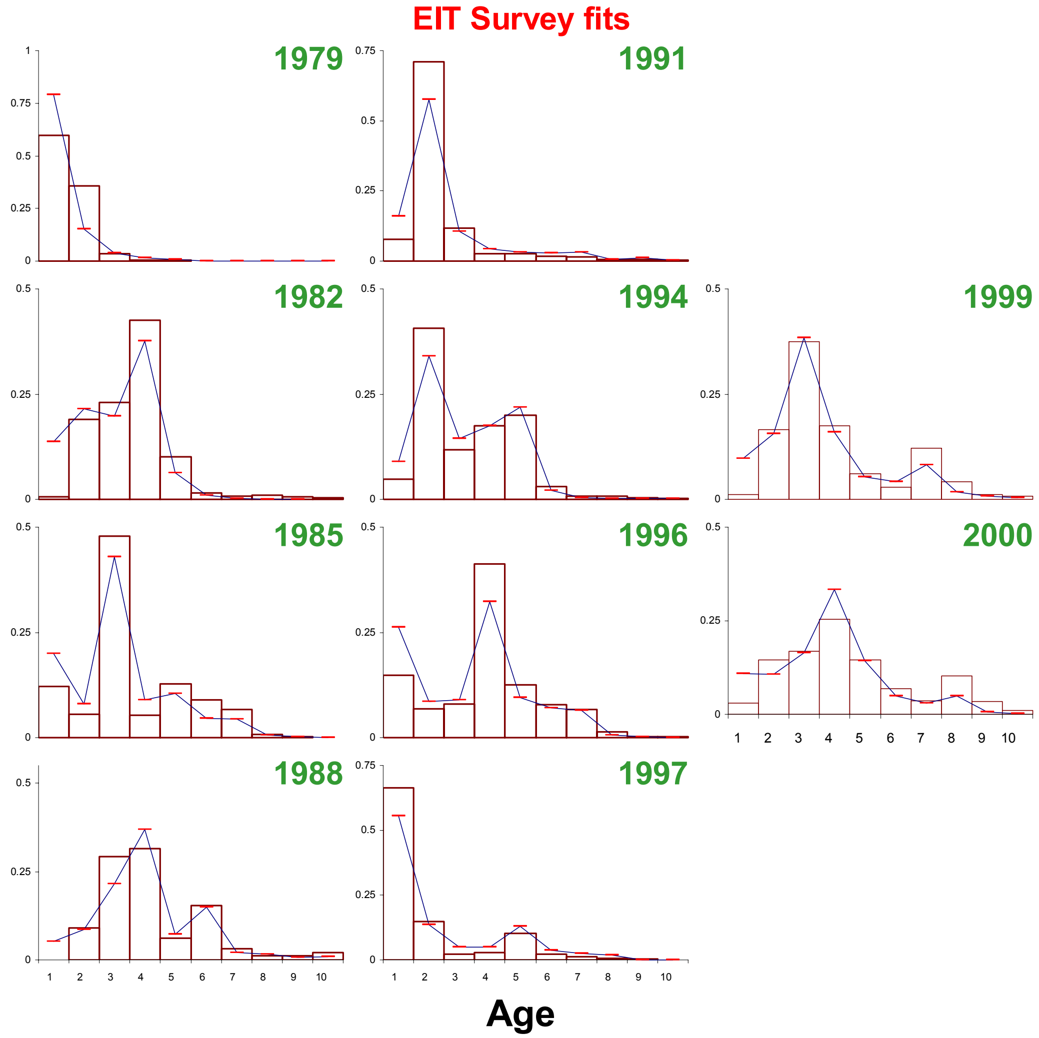


Figure 1.25. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

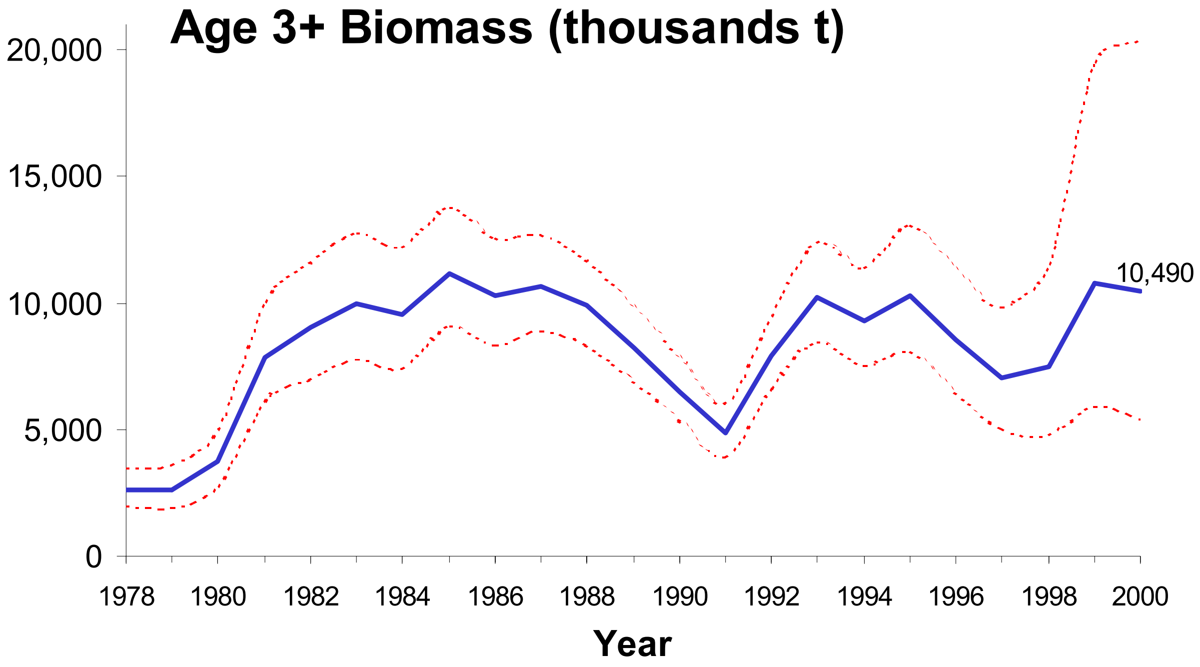


Figure 1.26. Estimated age 3+ EBS walleye pollock biomass under Model 1, 1978-2000. Approximate upper and lower 95% confidence limits are shown by dashed lines.

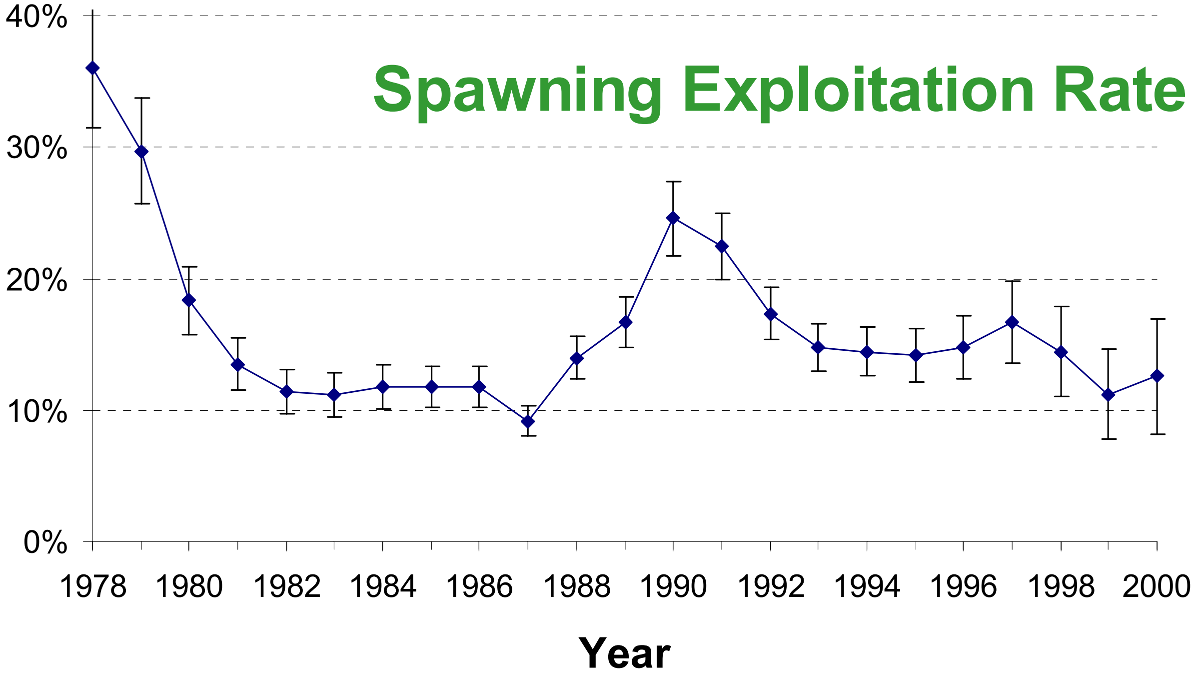


Figure 1.27. Estimated spawning exploitation rate (computed as the percent removals of spawning females each year) for EBS walleye pollock, Model 1. Error bars represent two standard deviations of the estimate.

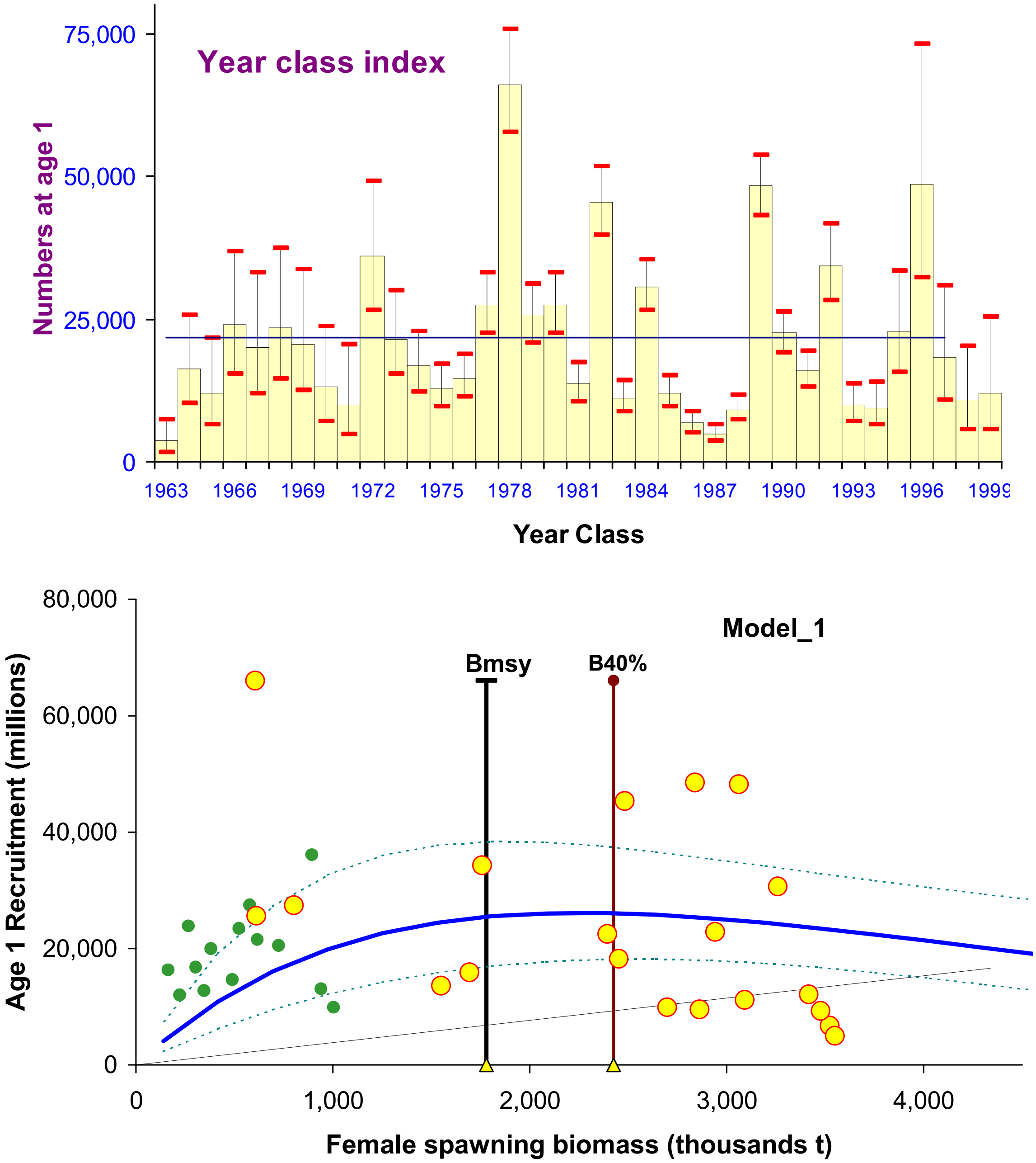


Figure 1.28. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate B_{msy} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with diagonal representing the replacement lines with no fishing. Dashed lines represent lower and upper 95% confidence limits about the curve.

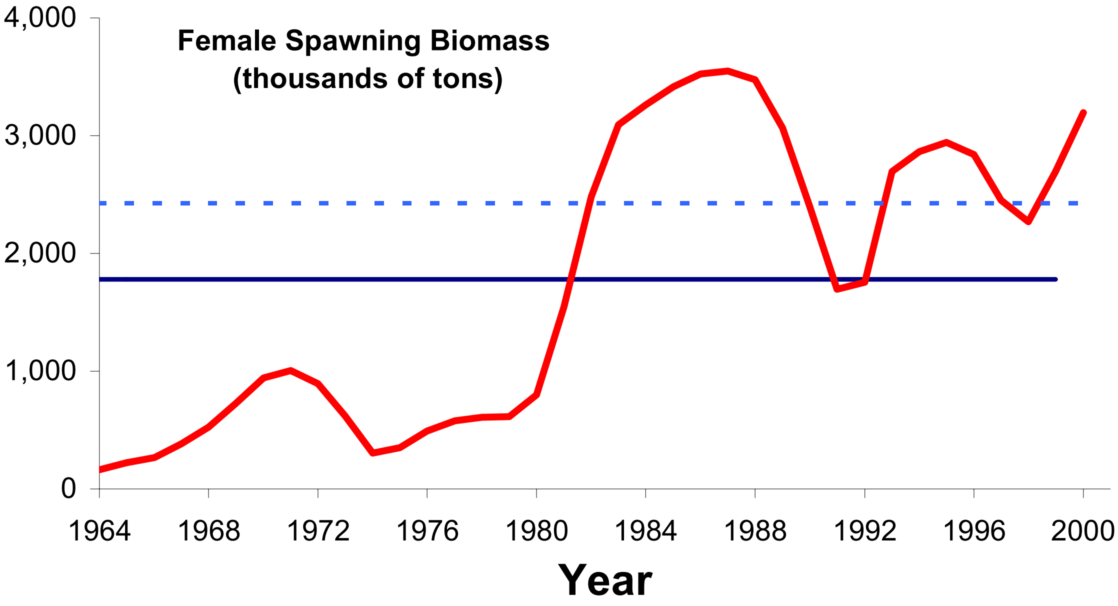


Figure 1.29. EBS walleye pollock female spawning biomass abundance trends, 1979-2001 as estimated by Model 1. Horizontal solid and dashed lines represent the B_{msy}, and $B_{40\%}$ levels, respectively.

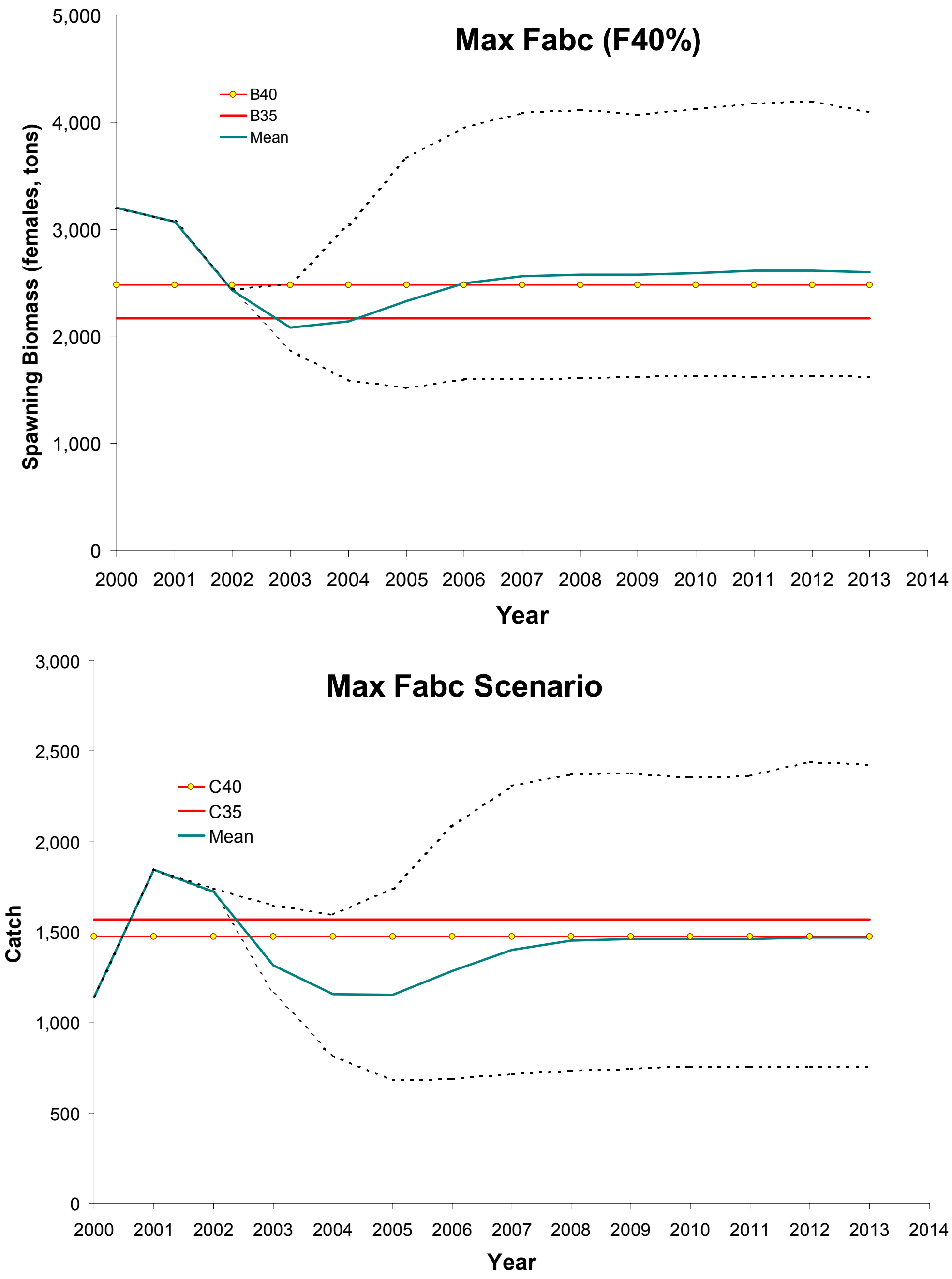
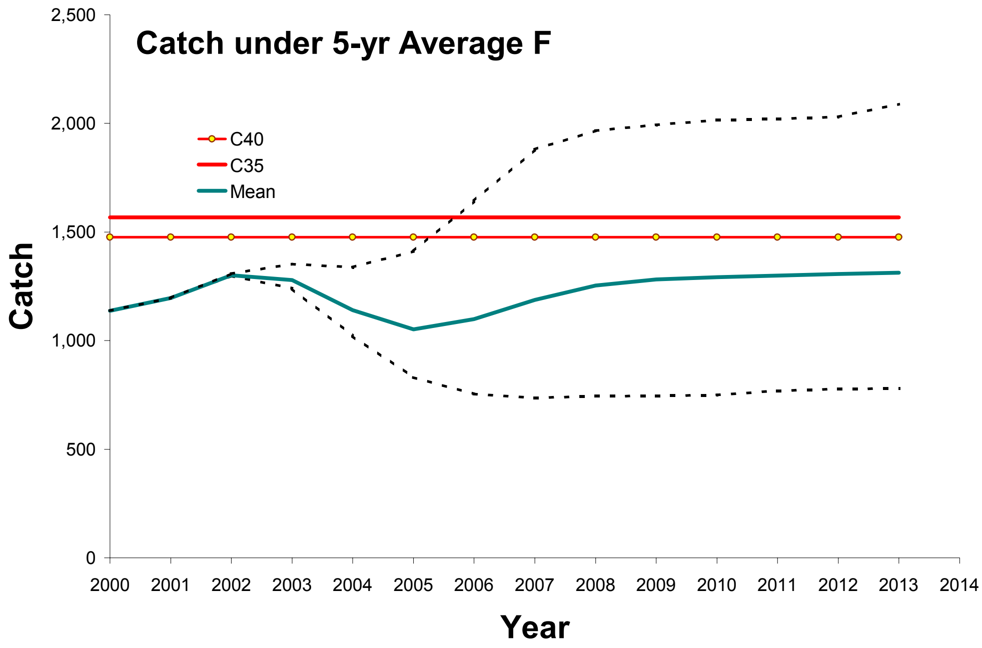


Figure 1.30. Projected EBS walleye pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2000. Future harvest rates follow the guidelines specified under Scenario 1, max F_{ABC} assuming $F_{ABC} = F_{40\%}$.



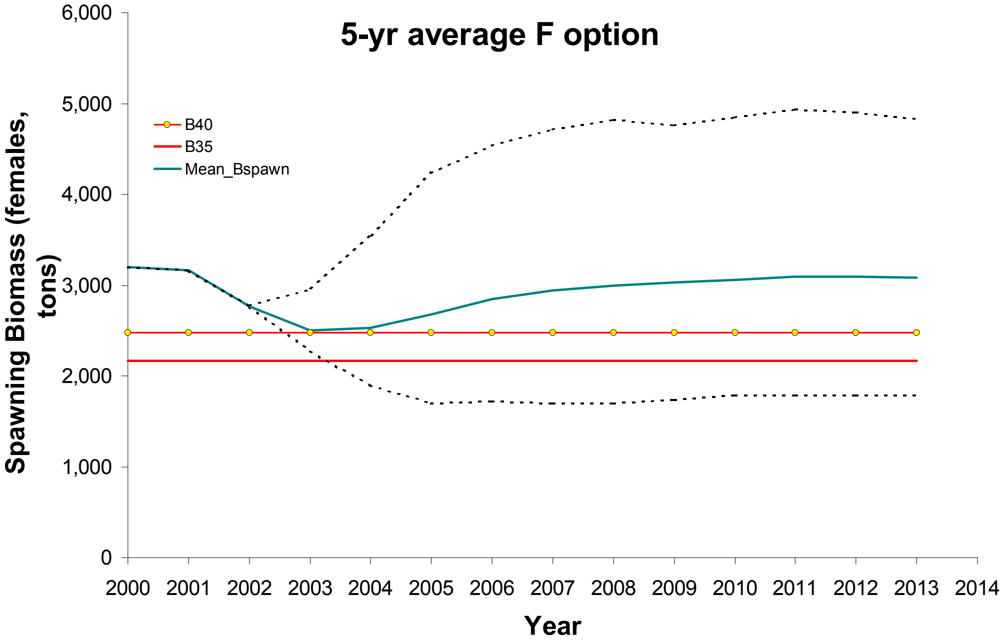


Figure 1.31. Projected EBS walleye pollock yield (top) and spawning biomass (bottom) under Fequal to the mean value from 1996-2000 relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1.

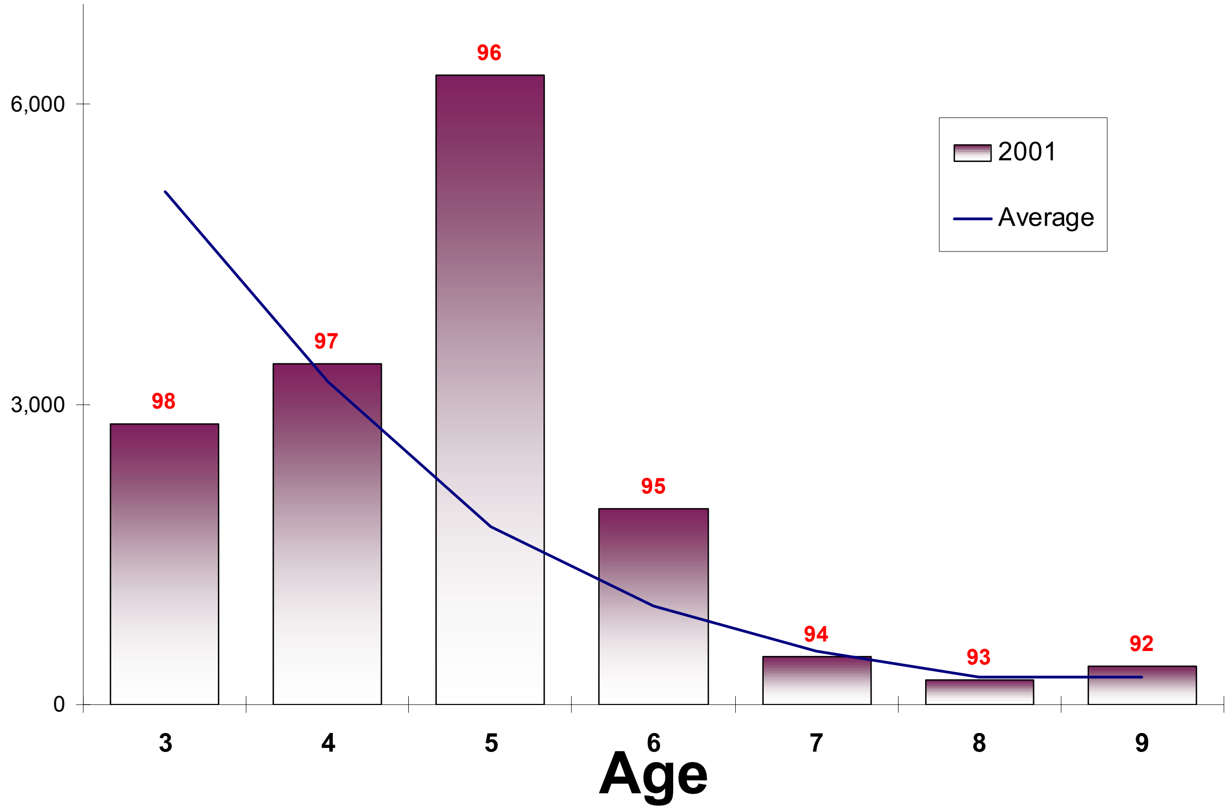


Figure 1.32. Projected begin-year 2001 age composition of the EBS pollock population (bars) relative to the average abundance 1964-2000 (line). Numbers on top of bars represent year-class. Age 9 represents all of age 9 and older pollock.

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 $(C_{a,t})$ 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

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

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 modeled as a stochastic function of spawning stock biomass. A further modification made in Ianelli et al. (1998) was to have an environmental component to account for the differential survival attributed to larval drift (e.g., Wespestad et al. 2000). (κ_t):

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

with mature spawning biomass during year t was defined as:

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

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

The environmental component is based on hypotheses about the relationship between surface advection during the post-spawning period (pollock egg and larval stages) and pollock survival. Wespestad et al. (2000) 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 et al. 1998) 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 (**Ψ**) 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.

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:

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1} e^{\varepsilon_t}}{\alpha + \beta B_{t-1}}$$

where

R_t is recruitment at age 1 in year t,

B_t is the biomass of mature spawning females in year t,

ε_t is the "recruitment anomaly" for year t,

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. Steepness of 0.7 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988).

In Ianelli et al. (1999) we assumed the expected value of steepness was 0.7 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 (see section 1.14.2 below). In the year 2000, one aspect of the review (Appendix 3) pointed out:

> *"Priors need to be described, explained and justified—and ideally need to be supplied by a range of "experts" rather than a single analyst."*

In response to this, we selected a compromise situation whereby we examined results on slope-at-the-origin values obtained for other gadids around the world and pooled them to illicit a more reasonably defensible prior distribution. This work is continuing and has not been fully implemented in this assessment (a new functional form for the prior distribution is used, the beta distribution, but set up to be similar to the prior distribution in the last assessment). In the models presented here, we also conducted sensitivity to the effect of using completely uninformative prior distributions as an alternative (Model 8).

To have the critical value for the stock-recruitment function (steepness, h) on the same scale for the Ricker model, we begin with the parameterization of Kimura (1990):

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1} e^{a\left(1-\frac{B_{t-1}}{\varphi_0 R_0}\right)}}{\varphi_0}.$$

It can be shown that the Ricker parameter a maps to steepness as:

$$h = \frac{e^a}{e^a + 4}$$

so that the prior used on h can be implemented in both the Ricker and Beverton-Holt stock-recruitment forms. Here the term φ_0 represents the equilibrium unfished spawning biomass per-recruit.

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 100 for the fishery data, 50 for the bottom trawl survey, and 25 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."

We assumed that the survey was completed at the beginning of the year (prior to the fishery). Survey numbers account for removals that occurred during the first part of the year (since surveys occur 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:

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

where the superscript s indexes the type of survey (EIT or BTS). For these analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the EIT and bottom trawl surveys). The contribution to the negative log-likelihood function from the surveys is given by

$$\sum_{t^s} \left(\frac{\ln\left(A^s_{t\cdot} / \hat{N}^s_{t\cdot} \right)^2}{2\sigma^2_{t^s}} \right)$$

where $A^s_{t\cdot}$ is the total (numerical) abundance estimate with variance $\sigma^2_{t^s}$ from survey s in year t.

The contribution to the negative log-likelihood function for the observed total catches ($O_{t\cdot}$) by the fishery 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 698 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.

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

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

Note that the survival rate, s, and proportion mature females, f, 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 $\frac{f'(F)}{f''(F)}$
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

$f'(F) = \frac{f(F+d) - f(F-d)}{2d}$ and $f''(F) = \frac{f(F+d) - 2f(F) + f(F-d)}{d^2}$ 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 2000 Aleutian Island bottom trawl survey estimated biomass at 132.2 thousand t, an increase over the 1997 survey estimates of 105.1 thousand t (Table 1.19). Surveys from this region indicate that the biomass peaked in 1983 and declined to the 1994 level. The 1994 survey indicated a strong mode of either age 1 or 2 pollock—the 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 in recent years.

Table 1.19. Pollock biomass estimates from the Aleutian Islands Triennial Groundfish Survey, 1980-2000. Note estimates since 1991 have been revised this year due to discrepancies found in the strata definitions.

	Aleutian Islands and Unalaska-Umnak area (~165W-170W)		Aleutian Region (170E-170W)	
Year	Old estimates	New estimates	Old estimates	New estimates
1980	308,745		252,013	
1983	778,666		495,982	
1986	550,517		448,138	
1991	183,303	**218,783**	179,653	**167,140**
1994	151,444	**117,198**	86,374	**77,503**
1997	205,766	**158,912**	105,600	**93,512**
2000	180,456	**133,366**	132,145	**105,554**

Catch-age data are relatively scarce for pollock caught in the Aleutian Islands region; the data that are available come primarily from the eastern area (INPFC area 541). 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 (Fig. 1.33). The stock definition for "Aleutian Islands pollock" is therefore confounded with Bering Sea abundance levels and abundance in the Aleutian Basin. We therefore consider pollock in the Aleutian Island region as an operational “stock” for from management with biomass levels on the order of 100 - 200 thousand tons (for age 3 and older). In the past two years, harvest levels in this region have only been about 1,000 tons with no directed pollock fishing allowed.

It seems unlikely that pollock in the eastern Aleutian Islands represent 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 a number of age-structured model runs were done on this stock in the past, the results showed a large degree 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 (2000 survey biomass $\times M \times 0.75$) of **23,750 t** at a biomass of 105,554 t (with $M = 0.3$). The OFL based on Tier 5 (2000 survey biomass $\times M$) gives **31,666 t**.

	1997	**1998**	**1999**	**2000**	**2001**	**F**
F_{ABC}	17,413 – 28,000 t	23,760 t	23,760 t	23,760 t	**23,750** t	0.225 = 0.75 M
$\mathrm{F}_{\mathrm{OFL}}$	24,000 – 38,000 t	31,680 t	31,680 t	31,680 t	**31,666** t	0.3 = M

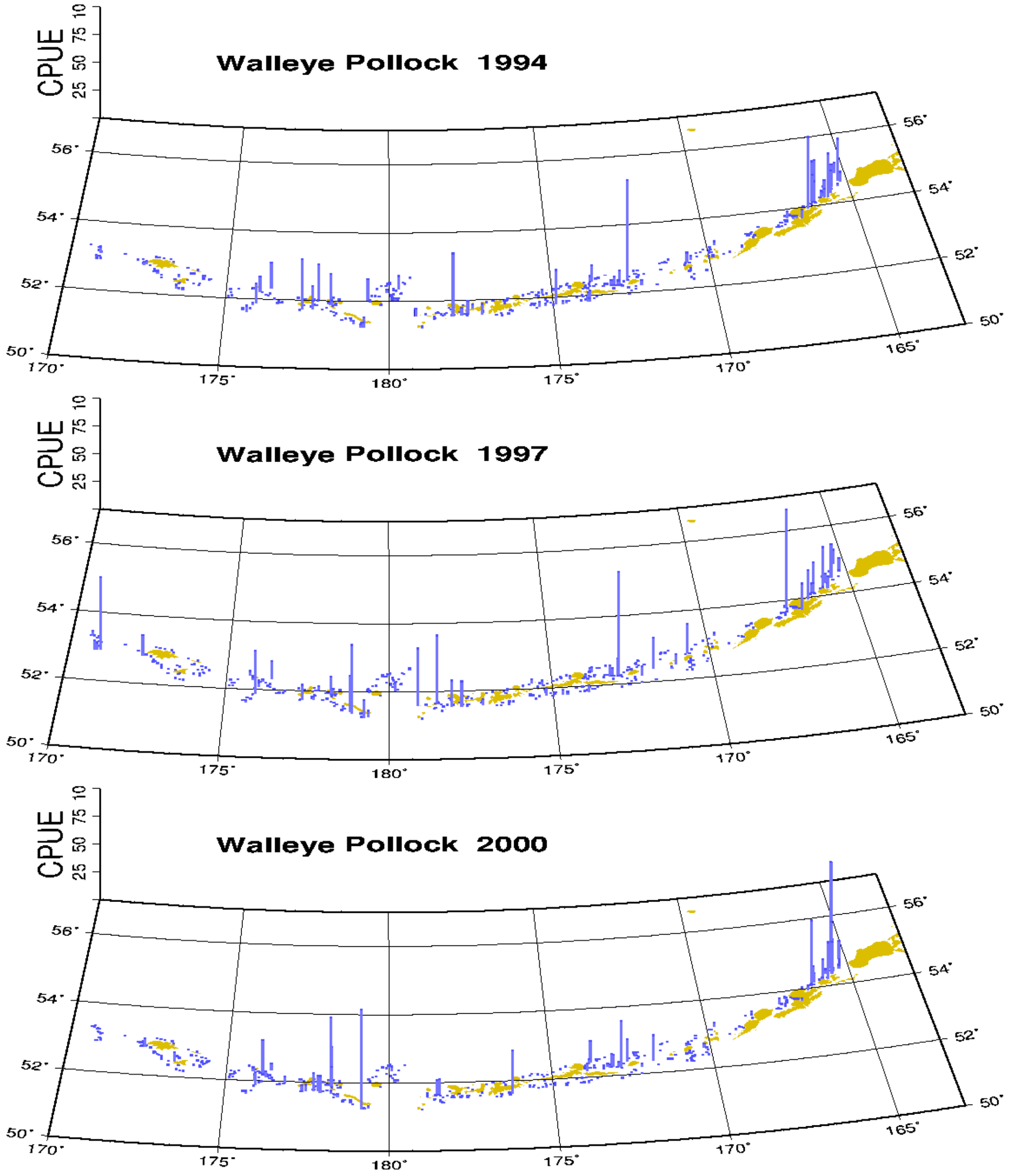


Figure 1.33. NMFS survey distributions of pollock in the Aleutian Islands region, 1994, 1997, and 2000. The height of the vertical bars is proportional to survey station pollock catch rate.

1.16. Aleutian Basin-Bogoslof Island Area

In 1999 the Plan Team requested that we present 3 alternative methods for computing ABC values for the Bogoslof region. They included:

1. The same method as in past years (with 2,000,000 ton estimate for $B_{40\%}$)
2. A simplified age-structured model based on recent Bogoslof population trends (not updated since Ianelli et al. (1999)
3. The same method as is currently used for the Aleutian Islands region (i.e., Tier 5, F_{ABC} =0.75*M)

The Council SSC considered the age-structured model to be inappropriate since it covers only part of the stock and concurred with the Plan Team on placing Bogoslof pollock in Tier 5. They also recommend reducing the ABC value further based on the historical target for biomass in this region (2 million tons). This year we these two calculations for ABC values for NPFMC consideration.

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.

1.16.1. ABC estimates 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) 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	2000
2.4	2.1	--	1.3	0.9	0.6	0.49	1.1	0.68	0.39	0.49	0.48	0.30

The survey estimated abundance of pollock in the Bogoslof area (Area 518) decreased in 2000 (Appendix 2).

Tier 5 computations use the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC (2000 survey biomass $\times M \times 0.75$) of **45,150 t** at a biomass of 301,000 t (with $M = 0.2$). The OFL is **60,200 t**.

Given the survey estimate of exploitable biomass of 0.301 million t and M = 0.2 and based on the SSC discussions for further reductions in ABC based on considerations of a target stock size of 2 million tons, the F_{ABC} recommendation is computed as:

$$F_{abc} \leq F_{40\%} \times \left(\frac{B_{2000}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.27 \times \left(\frac{301,000}{2,000,000} - 0.05 \right) \Big/ (1 - 0.05) = 0.0282$$

Using a fishing mortality rate of 0.021 translates to an exploitation rate of 0.021 which when multiplied by 301,000 t, gives a **2001 ABC of 8,470 t for the Bogoslof region.**