# 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 Bogoslof Island area analysis is presented in separate section below. A new age-structured Aleutian Islands assessment for pollock is presented in section 1A.

*Changes in the input data*
The 2003 NMFS bottom-trawl survey estimates of population numbers-at-age were available for analysis in this assessment. The biomass estimate for 2003 is 8.51 million tons, an increase of 77% from the 2002 estimate of 4.82 million tons. The echo-integration trawl (EIT) 2002 survey age compositions were updated. Previously, these ages were approximated using the age-samples collected and analyzed from the 2002 bottom-trawl survey.

The NMFS observer samples of pollock age and size composition were evaluated for the 2002 fishery and these data were included in the analyses. The estimates of average weight-at-age from the fishery were also revised. The time-series of total pollock catch estimates from 1991-2002 was updated from the 2003 version of NMFS official catch statistics (i.e., the blend data). For some years the amounts have changed slightly compared to values used in last year's assessment. For 2003, we assumed that the catch is equal to the 2003 TAC (1,492,000 t).

*Changes in the assessment model*
No major changes to the assessment model were made this year. As in past years, an array of model alternatives were performed and evaluated for contrast. New alternatives presented this year include a re-evaluation of the ageing-error matrix (Model 2) and an examination of including Russian catches from the Navarin area (the northwestern extension of the EBS shelf region) as presented in Model 3.

Tier 1 calculations were done two ways this year. Previously, the harmonic mean of the next year's yield as computed within the model was used as a risk-averse approximation to that specified in Amendment 56. However, Amendment 56 calculation was done by computing the harmonic mean of the $F_{msy}$ value, then applying this directly to the projected geometric mean biomass level. To implement this type of calculation, we computed the harvest fraction relative to the age 3+ biomass that corresponds to the $F_{msy}$ level. We call this rate the "MSYR" to distinguish it from the continuous form of fishing mortality specified in the model. Therefore, the harmonic mean MSYR value applied to the geometric mean age 3+ biomass provides a simple, straightforward way to compute yield levels.

*Changes in the assessment results*
The 2004 maximum ABC alternatives based on the $F_{40\%}$ and $F_{msy}$ are 2,527 and 2,562 thousand tons, respectively for the reference model ($F_{msy}$ harvests based on the harmonic mean value). As with last year, a lower value for the $F_{msy}$ value reflects the level of uncertainty about stock size. The 2004 overfishing level (OFL) alternatives for the reference model are 3,115 and 2,738 thousand tons corresponding to $F_{35\%}$ and $F_{msy}$ (arithmetic mean). Stock levels appear to be relatively high for EBS pollock, but a large degree of uncertainty in the estimates remains.

In the summer of 2002, the estimate of on-bottom pollock in the Aleutians from the NMFS survey was 175,283 t. By Tier 5 calculations, this gives ABC and OFL values of 39,438 t and 52,585 t, respectively. Alternative ABC and OFL's are provided for section 1A attached to this document.

For the Bogoslof region, we followed the SSC recommendations and compute maximum permissible ABC and OFL based on Tier 5. This results in **29,700 t** and **39,600 t** for ABC and OFL, respectively. Following SSC recommendations reduced the ABC relative to the target stock size (2 million tons). This gives a 2003 ABC of **2,570 t** for the Bogoslof Island region.

## Introduction

### Stock structure

In the U.S. portion of the Bering Sea three stocks of pollock are identified for management purposes. These are: eastern Bering Sea which consists of pollock occurring on the eastern Bering Sea shelf from Unimak Pass and to the U.S.-Russia Convention line; the Aleutian Islands Region encompassing the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and the Central Bering Sea—Bogoslof Island pollock. These three management stocks undoubtedly have some degree of exchange. The Bogoslof stock is a group that forms a distinct spawning aggregation that has some connection with the deep water region of the Aleutian Basin. 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. Bailey et al. (1999) present a thorough review of population structure of pollock throughout the north Pacific region. Recent genetic studies using mitochondrial DNA methods have found the largest differences to be between pollock from the east and western sides of the north Pacific.

## 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 t in 1987 to nearly 1.5 million t (including the Bogoslof Islands area catch; Fig. 1.1). Stock biomass has apparently ranged from a low of 4-5 million t to highs of 10-12 million t. United States vessels began fishing for pollock in 1980 and by 1987 they were able to take 99% of the quota. Since 1988, only U.S. vessels have been operating in this fishery. By 1991, the current NMFS observer program for north Pacific groundfish-fisheries was in place.

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 modern fishery (since the early 1990s) has been to focus on a winter, spawning-aggregation fishery (the "A-season) with an opening on January 20th. This first season typically lasts about 4-6 weeks, depending on the catch rates. A second season opening has occurred on September 1st (though 1995 opened on Aug 15th). This has changed considerably since 1998. Currently, the first season generally extends into the middle of March and the summer season begins in mid-late June.

Since the closure of the Bogoslof management district (INPFC area 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 (and deeper) between Unimak Island and the Pribilof Islands. This pattern has varied somewhat during the period 2001 - 2003 (Fig. 1.2). In particular, the 2003 winter fishery was distributed further north than in previous years. This may be due to the warm conditions and anecdotal reports that roe developed earlier than usual. 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 females 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 consistent concentrations of catch around the Unimak Island area and along the 100 m depth contour to the northwest of the Pribilof Islands. (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 1998-2001 (Fig. 1.6). The preliminary data for the 2003 fishery (based on about one third of the usual length data that will be available) shows an unusually high mode of fish at around 40cm. This may be an indication of the strength of the 1999 year class but also may be due to the unusually warm conditions seen in the Bering Sea this year.

## Fisheries Management

In response to continuing concerns over the possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions, NMFS and the NPFMC have made changes to the Atka mackerel (mackerel) and pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). These have been designed to reduce the possibility of competitive interactions with Steller sea lions. 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 that *could* lead to reduced sea lion prey densities. Consequently, the management measures were designed 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. Here we examine the temporal and spatial dispersion of the fishery to evaluate the potential effectiveness of the measures.

Three types of measures were implemented in the pollock 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 management measures, 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.

In 1999, 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, 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.

In 2000, further reductions in seasonal 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 t of pollock were caught in the Aleutian Island regions, with over 17,000 t caught in AI critical habitat. Since 1998 directed fishery removals of pollock have been prohibited.

On the eastern Bering Sea shelf, an estimate (based on observer at-sea data) of the proportion of pollock caught in Steller sea lion critical habitat (SCA) has averaged about 44% annually. During the "A-season," this figure increases to about 53% (since pollock are more concentrated in this area during this period). The proportion of pollock caught within the SCA varies considerably, presumably due to temperature regimes and population age structure. The pattern of catch since 1998 is shown below:

| Year | Months | Catch Outside SCA | Total Catch | Percent Inside SCA |
|---|---|---|---|---|
| 1998 | Jan-Jun | 71 | 385 | 82% |
| | Jul-Dec | 248 | 403 | 39% |
| | Jan-Dec | 318 | 788 | 60% |
| 1999 | Jan-Jun | 155 | 339 | 54% |
| | Jul-Dec | 360 | 468 | 23% |
| | Jan-Dec | 515 | 807 | 36% |
| 2000 | Jan-Jun | 241 | 375 | 36% |
| | Jul-Dec | 550 | 572 | 4% |
| | Jan-Dec | 791 | 947 | 16% |
| 2001 | Jan-Jun | 357 | 490 | 73% |
| | Jul-Dec | 367 | 674 | 54% |
| | Jan-Dec | 724 | 1,164 | 62% |
| 2002 | Jan-Jun | 263 | 566 | 47% |
| | Jul-Dec | 350 | 690 | 51% |
| | Jan-Dec | 613 | 1,256 | 49% |
| 2003 | Jan-Jun | 336 | 616 | 55% |
| | Jul-Dec | 397 | 680 | 58% |
| | Jan-Dec | 733 | 1,296 | 57% |

*Note: Pollock catches (thousands of tons) are as reported by at-sea observers only, 2003 data are preliminary.*

An additional goal for minimizing the potential for impacting the sea lion population is to disperse the fishery throughout more of the pollock range on the eastern Bering Sea shelf. While the distribution of fishing during the A season is limited due to ice and weather conditions, there appears to be some dispersion to the northwest area (Fig. 1.2).

Seasonal TAC releases were intended to disperse the fishery throughout more of the year. Prior to the increased sea lion conservation measures, 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.

## 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, 1991-2002 are shown in Table 1.2. Since 1991, estimates of discarded pollock have ranged from a high of 9.1% of total pollock catch in 1992 to a low of 1.3% in 2001. These recent low values reflect the implementation of the Council's Improved Utilization and Improved Retention program. Discard rates are likely affected by 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: *i*) INPFC area 51 from January - June; *ii*) INPFC area 51 (east of 170°W) from July -December; and *iii*) INPFC area 52 (west of 170°W) from January - December. This method was used to derive the age compositions from 1991-2002 (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).

The time series of the catch proportions-at-age suggests that during 1999-2002 a broad range of age groups were harvested with a continued strong showing of the 1992, 1995, and 1996 year classes (Fig. 1.7). We present these values (as used in the age-structured model) from 1979-2002 in Table 1.3. Since 1999 the observer program adopted a new sampling strategy for lengths and age-determination studies. Under this scheme, more observers collect otoliths from a greater number of hauls (but far fewer specimens per haul). This has improved the geographic coverage but lowered the total number of otoliths collected. Previously, large numbers were collected but most were not aged. The sampling effort for lengths has decreased since 1999 but the number of otoliths processed for age-determinations increased (Table 1.4). Also, we qualitatively evaluated the proportional allocation of sampling effort for pollock catch, length, and age samples (Fig. 1.8). This shows that there doesn't appear to be much discrepancy between allocation percentages for length measurements and otolith collections relative to catch locations. A study to evaluate the effectiveness of the new sampling protocol has been completed and the report is currently in review.

## Resource surveys

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 - 2003) 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 | 1989 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bering Sea | 15 | 94 | 458 | 139 | 466 | 682 | 508 | 208 | 435 | 163 | 174 | 467 | 393 |
| Aleutian Is. | | | | 193 | | 40 | 454 | | | 292 | | | |

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bering Sea | 369 | 465 | 156 | 221 | 267 | 249 | 206 | 262 | 121 | 162 | 164 | 149 | 179 | 236 |
| Aleutian Is. | | 51 | | | 48 | | | 36 | | | 40 | | 79 | |

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.

### 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. Bottom trawl surveys are considered to assess pollock from the bottom to 3 m off bottom. Until 1975 the survey only covered a small portion of the pollock range. In 1975 and since 1979, the survey was expanded to encompass more of the EBS shelf occupied by pollock. The level of sampling for lengths and ages in the bottom-trawl survey is shown in Table 1.5.

Since 1983 the biomass estimates have been relatively high and showed an increasing trend through 1990 (Table 1.6). Between 1991 and 2003 the bottom trawl survey biomass estimate has ranged from 2.2 to

8.51 million t. The estimate for 2003 is 8.51 million tons, up 77% from the 2002 estimate and 19% higher than the next highest point estimate (in 1990). This high survey estimate was partly due to a large catch of pollock in a survey tow near Amak Island (northeast of Unimak Island) in the southeastern part of the survey area. The surrounding area was opportunistically observed with a recording echo-sounding device and confirmed that large quantities of pollock were around this region. Omitting the largest tow from the survey calculations nonetheless still resulted in a large biomass estimate (at around 6.5 million tons). The time-series of survey estimates suggest an increasing trend since about 1997 but with the 2003 estimate having an extremely large variance (Fig. 1.9). This high variance tempers somewhat the optimistic survey estimate (compounded with issues related to the warm bottom temperature presented below). In general, the interannual variability of survey estimates is due to the effect of year class variability. Survey abundance-at-age estimates reflect the impact of this variability (Fig. 1.10). Other sources of variance may be due to unaccounted for variability in natural mortality and movement. For example, some strong year classes appear in the surveys over several ages (e.g., the 1989 year class) while others appear at older ages (e.g., the 1992 year class). This suggests that the age-specific spatial distribution of pollock available to bottom-trawl gear is variable.

In 2002 and 2003, pollock survey catch-rates were higher than normal north of St. Matthew Island and more pollock were found in the middle region of the shelf than usual (Fig. 1.11). This reflects the warmer than average temperatures observed on the shelf this year. Compared with the “average” density of pollock found in the EBS shelf, 2003 had very high concentrations in the middle shelf region and moderate concentrations of pollock at the shelf break.

The survey age composition information provides insights on temporal patterns in length-at-age. In particular, when converted to weights-at-age it appears that in recent years the average size (ages 4-8) is about 90% of the average since 1982 (Fig. 1.12). Since 1982, the pattern in size at age shows a regular periodic trend about every 10 years. This pattern seems to be inversely related (approximately) to pollock abundance and suggests that density dependent processes may be involved.

As in the past few assessments, we conducted an analysis on the total mortality of the 1974-1996 cohorts based solely on NMFS survey data. This simple approach involves regressing the log-abundance of age 6 and older pollock against age by cohort. We selected age 6 because younger pollock are still recruiting to the bottom trawl survey gear. A key assumption of this analysis is that all ages are equally available to the gear. The estimates of total mortality by cohort are difficult to interpret—here we take them as some form of average mortality over the life of the cohort (since we know that harvest rates varied from year to year). The values used in the regression are shown in Fig. 1.13. The estimates of mortality shows somewhat of an increasing trend for these cohorts with a mean total instantaneous value around 0.45 (except for the 1990-1992 cohorts; Fig. 1.14). The low values estimated from some year classes, namely the 1990-1992 cohorts, could be due to the fact that there are fewer age-groups (6, 5, and 4, respectively) in the regressions or that these age groups have only recently become available to the survey (i.e., that the availability/selectivity to the survey gear has changed for these cohorts). Alternatively, it may suggest some net immigration into the survey area or a period of lower natural mortality. In general, 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).

### *Effect of temperature*

For the past two years we have evaluated the effect of bottom temperature on pollock habitat relative to the standard survey area. Conceptually, the idea is that if the survey area is constant yet the preferred habitat for pollock varies within that area, then some index that causes this variability should improve the reliability of the survey to index the population. Previously, temperature was shown to affect the proportion of the stock that is within or outside of the standard survey area. These patterns were further examined by comparing pollock density with selected on-bottom isotherms (Fig. 1.15). For 2003 the general warm pattern seen over the past few years has continued. In particular, the area around Saint Matthew Island shows a much higher pollock abundance than usual. This is likely due to the fact that warm bottom temperatures extend across the mid-shelf region. In cold years (e.g., 1999) the formation of the "cold pool" in the middle shelf seems to restrict the distribution of pollock over this region.

### 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 (Honkalehto et al. 2002a). The most recent EIT summer survey was conducted in 2002. The details and research results from these EIT surveys have been presented in detail in previous assessments (e.g., Ianelli et al. 2002).

Proportions of pollock biomass estimated east vs. west of 170º W, and inside vs. outside the sea lion conservation area (SCA), are about the same for summer EIT surveys conducted from 1994 to 2002 (Table 1.7). The time series of estimated EIT survey proportions-at-age is presented in Fig. 1.16. The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.8. In 2001 and 2002, NMFS has conducted winter EIT surveys on the EBS shelf region in addition to the Bogoslof Island region (Honkalehto et al. 2002b). These added areas cover most of the SCA. One purpose of these studies was to assess the variability of pollock concentrated within this zone by season and over different years. Preliminary analyses piecing these data together with the main assessment model have provided some indication that the population tends to aggregate within the SCA in the winter. Unfortunately, the estimated "available" segment of the population (based on age compositions from 1991, 1995, 2000 - 2002 winter surveys) suggests that a broad range of ages are either within the survey area but not fully vulnerable to the trawl or echo sign (e.g., the fish could be on the bottom and hence not counted in the echo-integration procedure); or outside of the area. Unfortunately, the relative degree of vulnerability/availability is difficult to quantify. Presumably, younger fish tended to be outside of this region during the winter (since they are commonly found/caught during summer EIT surveys) while older bigger fish may be in the area but close to the bottom (as indicated from bottom trawl surveys).

## Analytic approach

### 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). Changes from last year's analyses include:

- The 2003 EBS bottom trawl survey estimate of population numbers-at-age was included.
- Estimates of the 2002 EBS EIT survey population numbers-at-age were revised using age-length keys derived from the EIT survey (previously, the keys used for the 2002 estimates were based on the bottom-trawl survey.

The technical aspects of this model are presented in the attached section titled "Model Details" 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 a number of similarities to Methot's extension (1990). We implemented the model using automatic differentiation software developed as a set of libraries under the C++ language.

## 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 (Livingston and Method 1998, Hollowed et al. 2000, Bailey 2001). 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 relationship can curve downwards where at higher stock sizes lower average recruitment levels are expected.

Livingston and Methot (1998) and Hollowed et al. (2000) investigated sources of natural mortality for pollock. Their results concluded that when pollock consumption by predators (e.g., Steller sea lions, Pacific cod) are accounted for, “natural mortality” was considerably higher than the values used here. Specifying a conservative (lower) natural mortality rate is more precautionary (Clark 1999).

Maturity at age was assumed the same as that given in Wespestad (1995) which dates back to Smith (1981). This was shown to be consistent with maturity observed in winter surveys in recent years. Pollock reproductive studies are continuing and will be an active study area with sample collections planned for future winter surveys and fishing operations. Values currently in use 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 |

Currently, there are several research projects being undertaken to better understand the reproductive ecology of pollock. These include industry-cooperative research to obtain fine-scale spatial and temporal patterns during the late winter and early spring season. In 2002 and 2003 a total of 10,197 samples were taken for maturity stage and gonad weight from 16 different vessels. Additionally, 173 histological samples are being processed to evaluate the utility of maturity state and gonad weight relative to body weight. This research is being undertaken by a graduate student at the University of Alaska Fairbanks and should be completed by the third quarter of 2004. Preliminary indications on the maturity-at-length samples suggest that the currently used schedule are reasonable (i.e., the currently used maturity-at-age schedule appears to be sufficiently conservative).

### *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.

### Parameters estimated conditionally

For the reference model presented here, 608 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 1964-2003. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (2004-2008). 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, 63 parameters comprise initial age composition, subsequent recruitment values and stock-recruitment parameters.

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 it's mean value will be equal to one, this means that it will not be confounded with the time component (see attached section titled "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 41 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 an 11x14 matrix of 154 parameters. This brings the total fishing mortality parameters to 195. 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 39x15 or 585 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 69 parameters for these data (for the logistic time-varying selectivity curves). For the EIT survey, which began in 1979, there are 275 parameters describing age-time specific availability. 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.

As last year, we evaluate the effect of temperature ($T_t$) on the survey catchability in year *t* as:

$$q_t = \mu_q + \beta_q T_t$$

where $\mu_q$ is the mean catchability and $\beta_q$ represents the slope parameter. The time series of temperature (Fig. 1.17) is used in Model 4 (which, for the model was normalized to have a mean value of zero).

For all other models, the catchability coefficient for the bottom-trawl survey is estimated in the same manner as is done for the other two indices (early CPUE data and the EIT survey).

Finally, 2 additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$ and $F_{35\%}$ (and the $F_{30\%}$) 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, $\sigma$=0.05)

- Bottom trawl survey variances (annual estimates of standard error, as represented in Fig. 1.9) and an assumed variance for the EIT survey abundance index, (i.e., Log normal, $\sigma$=0.2)
- Fishery and survey proportions-at-age estimates (Robust quasi-multinomial with effective sample sizes presented in Table 1.10).
- Selectivity constraints (penalties on age-age variability, time changes, and decreasing (with age) patterns)
- Stock-recruitment penalties (penalties involved with fitting a stochastic stock-recruitment relationship within the integrated model).

## Model evaluation

To examine model assumptions and data sensitivities, we evaluated several dozen different model configurations. For clarity, we present a limited number of these results. Some of these are in response to specific requests by the NPFMC family and others are intended to illustrate some properties of model behavior relative to the extensive surveys and fishery observations conducted by the AFSC for walleye pollock.

A list of the models presented includes:

**Model 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 last year's assessment.

**Model 2** As reference model but with ageing error included.

**Model 3** As reference model but with Russian catch included

**Model 4** As reference model but with bottom-trawl survey catchability including an environmental covariate (bottom temperature).

**Model 5** As reference model, but with bottom-trawl survey catchability fixed at 1.0.

**Model 6** As Model 5 but estimating natural mortality.

**Model 7** As Reference Model, but disregarding the survey information.

These models can be summarized as follows:

| Model | Description |
|---|---|
| 1 | Reference model |
| 2 | Employ re-estimated age-error matrix |
| 3 | Add in estimates of Russian catch in Navarin area |
| 4 | Bottom temperature a covariate with survey catchability |
| 5 | Bottom-trawl survey catchability fixed at 1.0. |
| 6 | Estimate natural mortality |
| 7 | Disregard survey data |

Our reference model can be characterized as one that includes a moderate number of stochastic processes. These are principally changes in age-specific availability over time for survey and fishery gears and recruitment variability. As specified, these processes involve a large number of parameters but capture a reasonable amount of the overall uncertainty.

As with last year, the stock-recruitment curve fitting for the Reference model (Model 1) is using only the period from 1978-2003. Previous analyses using alternative stock-recruitment forms and periods gave consistently more optimistic scenarios than the Reference Model presented here. We selected the current stock-recruitment relationship and period for estimation because we believe it results in more conservative estimates of stock productivity while retaining reasonable properties (i.e., relatively good fits to the observed data).

In Model 2 we include an updated ageing error estimate. We evaluated the trend in reader agreement over time and found that the ageing imprecision has been fairly consistent (Fig. 1.18). Overall, 25,887 pollock samples have been tested (i.e., read by different age-determination experts) enabling age-specific estimates of the standard deviation of ageing errors (assuming unbiased age-determinations; Fig. 1.19). Results from this model gives an worse goodness of fit (i.e., a higher –ln(likelihood) function; Table 1.11). As expected, the recruitment variability increased (from 61% CV to 72%) with the ageing error included. The estimated stock size was slightly lower with this model compared with Model 1 but the reference fishing mortality rates were similar (Table 1.12).

One concern that frequently arises in the EBS pollock stock assessment is the effect of Russian catches adjacent to the US-Russia convention line (maritime boundary). To evaluate this effect, the catches from the Navarin area were treated added to the US EBS shelf region catches and submitted to the stock-assessment model for analysis. Since both the EIT and BTS indices are treated as a relative index (except for Model 5) the hypothesis is simply that there is a single shared stock between the US shelf region and the Navarin basin in the Russian zone. These time-series of catches used in Model 3 are shown (compared to the baseline catches) in the following table (thousands of tons):

| Area | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EBS | 175 | 231 | 262 | 550 | 702 | 863 | 1,257 | 1,744 | 1,875 | 1,759 | 1,588 | 1,357 | 1,178 | 978 | 979 | 936 | 958 | 974 | 956 | 981 |
| EBS & Navarin | 294 | 389 | 441 | 926 | 1,179 | 1,444 | 2,097 | 2,907 | 3,173 | 3,003 | 2,717 | 2,287 | 1,955 | 1,608 | 1,591 | 1,527 | 1,578 | 1,874 | 1,760 | 1,703 |

| Area | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EBS | 1,092 | 1,140 | 1,142 | 1,019 | 1,229 | 1,230 | 1,455 | 1,196 | 1,390 | 1,327 | 1,329 | 1,264 | 1,193 | 1,124 | 1,101 | 990 | 1,133 | 1,387 | 1,480 | 1,492 |
| EBS & Navarin | 1,595 | 1,628 | 1,712 | 1,482 | 2,081 | 1,914 | 1,687 | 1,374 | 1,705 | 1,716 | 1,507 | 1,584 | 1,894 | 1,804 | 1,745 | 1,623 | 1,511 | 1,913 | 1,850 | 1,917 |

Source: Report from the Russian Delegation to the 2003 meeting on the Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea. For years prior to 1980 we assumed a 5-year moving average ratio of US zone- Russian zone catches.

Since we have shown that the pollock distribution appears to be affected by ambient temperature, we continue to evaluate the effect of bottom temperature on survey catchability (Model 4). In the 2002 assessment, results suggested that there is a slight negative relationship between bottom temperatures and survey catchability (slope -0.103, with standard error 0.125). This year, given the warm temperature and high biomass estimate, the slope parameter changed to have a positive sign ($\beta$=0.046 and standard error 0.125). As before, the significance of this fit is low given this standard error, and the overall fit is only slightly better (the -lnL improves by 0.06 units compared to Model 1; Table 1.11). It now appears that survey catchability tends to be slightly lower at colder temperatures and slightly higher at warmer temperatures (Fig. 1.20).

Bottom temperature alone does not provide a strong indicator for changes in survey availability. Presumably factors affecting this covariate are complicated by the current age-structure of the population (younger pollock may be more or less sensitive than older pollock) and perhaps the vertical distribution of pollock. For contrast, in Model 5 we constrained survey catchability to be exactly equal to one. This resulted in a worse fit to the data and a much higher biomass estimate.

Obtaining model estimates of survey catchability that are greater than 1.0 may seem counterintuitive, given that we expect the bottom-trawl gear to be missing pollock that are up in the water column and outside of the survey area. We note that there is a significant age-component to this catchability and that the estimates are likely an artifact of model mis-specification rather than due to the effects of "herding" or other survey mechanism. For example, factoring the age-effect (selectivity) of the survey gear and considering the average biomass of pollock age 5 and older, the survey catchability is slightly less than 1.0. Considering age 3 and older pollock biomass, the average catchability by the survey is about 0.7.

This effect is because younger pollock appear to be less available to bottom-trawl survey gear.

In Model 6 we evaluated the ability of our model to estimate natural mortality (with survey catchability fixed at a value of 1.0). The parameterization was specified for age-3 and older as $Me^{\rho}$ where the estimate was (from *M=0.3*): $\hat{\rho}$ =-0.009 with a standard error of 0.088 (and $Me^{\rho}$ =0.297). In the past two years, this estimate has continued to decline. This may reflect the fact that some year-classes (e.g., the 1992 year-class) have persisted above expectations. This is also evident in the catch-curve analysis presented above where the total cohort mortality is considerably lower for the 1992 year class.

Finally, in Model 7 we examined the influence of our survey data on assessment model results. Disregarding both survey indices and age composition data sets (the data were still physically included in the model, but were downweighted in the –ln(likelihood) function to 1/100th of their original emphasis. This model yielded estimates similar to Model 1, but with higher variance.

Based on the examinations of the alternative models presented here (and also over those that were run but not presented) we feel that our Model 1 is appropriate and encompasses a wide range of uncertainties about the stock status. Adding in the effect of ageing error (Model 2) degraded the fit to the data and did not appreciably affect the model results. Including Russian catches explicitly into the assessment (Model 3) inflated the biomass considerably but had little effect on resource resiliency estimates. Selection of this model would imply some ability to foretell future catch levels in the Russian zone. The affect of bottom temperature (Model 4) had little effect and resulted in a slope with a sign opposite from that estimated last year (not too surprisingly since the standard errors for the slope was high and continues to be so). Model 5 (bottom-trawl survey catchability fixed at 1) has precedence from other assessments but provides a somewhat more optimistic view of the stock condition compared to Model 1. Allowing natural mortality to be estimated freely in Model 6 confirms somewhat the catch-curve analysis presented above and compared with past years, suggests that natural mortality is decreasing slightly. Model 7 was presented primarily as a sensitivity analysis. The survey data provide important information regarding age groups that are not fully selected by the fishery. Additionally, the most recent fishery age composition data is 2002 while for the survey, 2003 age composition data were available.

Biomass estimates from different surveys often differ substantially from those based on model results. For example, the "total age-3+ biomass" estimates for 2001 are over 11 million tons compared to the bottom-trawl survey biomass estimate of slightly more than 4.1 million tons. Such a difference can be attributed to three main factors: **weight** (averaged by age), **time** (within a year), and **selectivity/availability**. The effects of these factors were presented in detail in previous assessments (Ianelli et al. 2001). The same interpretation issues apply in the current study—namely that "biomass estimates" depend on the ages considered (and the catchability implications from surveys), the time of year, and the average weight estimates.

## 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 year's assessment (2002) is shown in Fig. 1.21. This figure shows that the absolute numbers at age are estimated to be somewhat higher in the current assessment. The 1992 year class is estimated to be slightly higher than in the past, presumably due to the predominance of that year class in the recent EBS bottom-trawl surveys and in the fishery (e.g., Fig. 1.26 below). The 1996 year class is still estimated to be quite strong and is about the same as last year's estimate. The recent year class estimates (1998-2000) have grown slightly compared with last year.

The estimated Model 1 selectivity pattern changes over time to become slightly more dome-shaped during the 1990s (Fig. 1.22). This may have coincided with the move to pelagic-only trawl gear as larger (older) fish tend to be more bottom-oriented. Model 1 fits the fishery age-composition data quite well and strong year classes are clearly evident (Fig. 1.23). The fit to the early Japanese fishery CPUE data (Low and Ikeda, 1980) is consistent with the populations trends for this period (Fig. 1.24).

We specified that selectivity could 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. 1.25). The bottom trawl survey age composition data are somewhat inconsistent in 2000-2003. The abundance of the 1995 year class has apparently increased while the proportion of the 1996 year class in these years was lower than expected (Fig. 1.26). This trend has continued with the addition of this year's data. Since the 1996 year class is so important to the fishery in the near-term, this development requires close attention (even though the 1996 year class has consistently appeared strong in the EIT survey (see below) and the fishery). We also point out that the 1992 year class was not well observed by the bottom trawl survey as age 3, 4, and to some extent, as 5-year old pollock.

The Model 1 fit and estimated selectivity for the EIT survey data show a dramatic change in selectivity pattern over time (Fig. 1.27). This may be due in part to changes in pollock distribution (as the overall densities changed and also to the fact that large numbers of 1 and 2-year old fish were apparent in the survey during the early surveys. Also, the number of hauls sampled has generally increased over time—presumably this trend affects the overall estimate of the age composition of pollock available to the survey. These patterns are also illustrated in the model fit to the EIT survey age composition data (Fig. 1.28). 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. Estimated summary biomass (age 3+), female spawning biomass, and age 1 recruitment for Model 1 is given in Table 1.16.

Uncertainty computations are a central part of the analyses presented in this assessment. In the past year, development of Bayesian integration methods has continued. Often with highly non-linear models, the multidimensional shape of the posterior distribution can be highly curved and present problems when expressing approximations to marginal distributions (e.g., as we do here via the Delta-method propagation-of-errors to obtain variance estimates for management quantities of interest). To explore this property, we computed the joint distribution based on 1 million Monte-Carlo Markov Chain simulations drawn from the posterior distribution. The chain was thinned to reduce potential serial correlation to 5,000 parameter "draws" from the posterior distribution. Selected model parameters (Model 1) are plotted pair-wise to provide some indication of the shape of the posterior distribution. In general, the model given the available data appears to be quite well behaved (clusters of parameters do not appear to follow strange curved or skewed tear-drop shapes). In terms of policy evaluation, we projected the model forward (for each "sample" from the posterior) with a fixed catch of 1.3 and 1.5 million tons. The probability that the current stock size is below the (uncertain) $B_{35\%}$ level is quite low. However, by 2004, the expectation is that the stock size will be well above the $B_{35\%}$ stock size level (with about 40% probability), then increase (with considerable uncertainty) to well above this level by 2008 (Fig. 1.29).

The NPFMC Groundfish Plan Team suggested that additional graphs showing the effect of future catches projected on the basis of one or more of the standard harvest scenarios, rather than constant catch scenarios only. Also, the Plan Team asked that the assessment authors consider presenting confidence intervals around the recommended ABC. These are presented in Figure 1.30.

## 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 - 2003. 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. 1.25 and 1.26).

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 10.5 to 12.5 million t. Peak biomass occurred in 1985 and declined to about 6 million t by 1991. Since then, the age 3 and older biomass has increased, and recently been variable around 12 million tons[1].

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 1.17, Fig. 1.31). 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 and peaked around 1995. A decrease in abundance is expected in future years as the 1992 and 1996 year classes age.

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 1.17). This may be attributed to the increasing trends from both the EIT and bottom trawl survey estimates for the 1999 year class. Overall, compared with seven past assessments, the retrospective pattern shows a steady increase in estimates of stock size during the late 1990s (Fig. 1.32).

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 11% in the past 10 years (Fig. 1.33). This compares to an overall average SER of 17% (1964 – 2003). 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%).

One way to evaluate past management and assessment performance is to plot estimated fishing mortality relative to the (current) maximum permissible values. For EBS pollock, we computed the reference fishing mortality as from Tier 3 (unadjusted) and calculated the historical values for $F_{40\%}$ (since selectivity has changed over time; Fig. 1.34, top panel). Since 1977 the current estimates of fishing mortality suggest that during the early period, harvest rates were above $F_{40\%}$ until about 1981. Since that time, the levels of fishing mortality have averaged about 51% of $F_{40\%}$ (Fig. 1.34, bottom panel).

## Recruitment

Recruitment of pollock is highly variable and difficult to predict. It is becoming clear that there is a great deal of interannual 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. In earlier assessments (prior to 1998), 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.

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[1] Please refer to Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

The coefficient of variation or "CV" (reflecting uncertainty) on the strength of the 1996 year class is about 15% for Model 1. Currently, the 1999 & 2000 year classes appear to be slightly above average (with wide confidence margins; Fig. 1.35). As more survey observations on these year classes occur, the precision of these estimates is expected to increase.

## Projections and harvest alternatives

### 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:

$B_{100\%}$ = 7,232 thousand t female spawning biomass[2]

$B_{40\%}$ = **2,835** thousand t female spawning biomass

$B_{35\%}$ = **2,481** thousand t female spawning biomass

$B_{msy}$ = **2,468** thousand t female spawning biomass

### Specification of OFL and Maximum Permissible ABC

For Model 1, the year 2004 spawning biomass is estimated to be 3,525 thousand tons (at the time of spawning, assuming the stock is fished at $F_{msy}$). This is well above the $B_{msy}$ value of 2,468. 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. In the past, the calculations for the harmonic mean value for $F_{msy}$ computations is somewhat different from the procedure outlined in Tier 1 of Amendment 56. Previously, the harmonic mean was computed from the estimated pdf for the year 2004 *yield* under $F_{msy}$ rather than first finding the harmonic mean of $F_{msy}$ and applying its value to the geometric mean of the 2004 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 (and the condition that the correlation between stock size and $F_{msy}$ is > $-0.5\ln\left(\sigma_B / \sigma_{F_{msy}}\right)$.

To provide the NPFMC with an alternative, this year we included an exploitation-rate type value that corresponds to the $F_{msy}$ levels as applied to the age 3+ biomass.

Corresponding values under Tier 3 are 3,741 thousand tons for year 2004 spawning values (under $F_{40\%}$ policy). This is well above the $B_{35\%}$ value of 2,481 . The OFL's and maximum permissible ABC values by both methods are thus:

| | OFL | Max ABC |
|---|---|---|

[2] Note that another theoretical "unfished spawning biomass level" (based on stock-recruitment relationship $\tilde{B}_0$) is somewhat lower (6,256t).

| | | |
|---|---|---|
| **Tier 1a** | **2,738 thousand t** | **2,562 thousand t** |
| **Tier 3a** | **3,115 thousand t** | **2,527 thousand t** |

## ABC Recommendation

Currently, the biomass of eastern Bering Sea pollock appears to be quite high and decreasing. The total begin-year age-3+ biomass in 2004 is projected to be about 11,217 thousand t. The estimated female spawning biomass projected to the time of spawning in the year 2004 is about **3,741** thousand tons, well above of the $B_{40\%}$ level of **2,610** thousand tons and well above the $B_{35\%}$ and the value estimated for $B_{msy}$ (**2,481** and **2,468** respectively; Fig. 1.36).

For 2004, maximum permissible ABC alternatives based on the $F_{40\%}$ and harmonic-mean $F_{msy}$ are 2,527 and 2,562 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. Current estimates of recruitment (e.g., the 1999 and 2000 year classes) are expected to be slightly above average but are highly uncertain. Hence, short-term projections predict that the spawning stock is likely to drop below the $B_{35\%}$ and $B_{msy}$ levels. There is nothing intrinsically wrong with having the population drop below the optimal level (since under perfect management, it is expected to be below the target exactly half of the time). However, choosing a harvest level that reduces this likelihood could 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. Therefore it seems prudent to recommend a harvest level lower than the maximum permissible values. As an example, under constant catch scenarios of 1.5 and 1.3 million tons, the stock is expected to remain well above the $B_{35\%}$ level (Fig. 1.37).

## 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 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. 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 2004, 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 2004 recommended in the assessment to the *max* $F_{ABC}$ for 2004. (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 1999-2003 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 FOFL. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2004 or 2) above ½ of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

*Scenario 7*: In 2004 and 2005, $F$ 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 2016 under this scenario, then the stock is not approaching an overfished condition.)

## 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 2003 (Table 1.18). Under Scenario 1, the expected spawning biomass will decrease to slightly below $B_{35\%}$ then increase to above $B_{40\%}$ by the year 2007 (Fig. 1.36). Under this scenario, the yields are expected to vary between 1.0 – 1.8 million tons. If the highly conservative catch levels (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. 1.38).

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 2003:

a) If spawning biomass for 2004 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

b) If spawning biomass for 2004 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2004 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 1.18). If the mean spawning biomass for 2014 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 2006 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2006 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2006 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2016. If the mean spawning biomass for 2015 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 2004, nor is it expected to be approaching an overfished condition based on Scenario 7.

## Other considerations

### Ecosystem considerations

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 continue 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 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.

In general, the climatic conditions that may affect the Bering Sea ecosystem have apparently undergone a change since the late 1990s. After spending most of the 1990s in positive mode the Pacific Decadal Oscillation (PDO) shifted to negative in 1998/99. This coincides with cooler-than-average northeastern Pacific surface temperatures and warmer-than-average central Pacific surface temperatures. This negative PDO has continued into 2001 and 2002. The implications are that the eastern Bering Sea is getting warmer and could probably stay warmer for a while. Coincidentally, the OSCURS model runs have shown a tendency for April-May-June surface currents in the eastern Bering Sea to resume stronger on-shelf drift in 3 of the last 5 years (1998, 1999, 2002) after a hiatus since 1991 (Jim Ingraham, pers. comm.). This may indicate favorable conditions for pollock survival during these years.

A recent analysis comparing the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models was published this year (Aydin et al., 2002). This study shows that the production in these two systems is quite different. On a per-unit-area measure, the western Bering Sea has higher productivity than the EBS. Also, the pathways of this productivity are different with much of the energy flowing through epifaunal species (e.g., sea urchins and brittlestars) in the WBS whereas for the EBS, crab and flatfish species play a similar role. In both regions, the keystone species are pollock and Pacific cod. Based on the evaluation of the food web using a mass-balance equation, Aydin et al. (2002) found that the EBS ecosystem was relatively mature due to the large number of interconnections.

Another way of evaluating ecosystem considerations is to look at how the **ecosystem affects the EBS pollock stock** and at how the **EBS pollock fishery affects the ecosystem.** A brief summary of these two perspectives is given in Table 1.19. Unlike the food-web models discussed above, examining predators and prey in isolation may overly simplify relationships. This table serves to highlight the main connections and the status of our understanding or lack thereof. The fishery bycatch estimates of target and non-target species is given in Tables 1.20 & 1.21, respectively.

### 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.

## Summary

Summary results are given in Table 1.22.

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# Tables

Table 1.1 Catch from the eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979-2003. (2003 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 | 9,446 | | |
| 1980 | 437,253 | 521,027 | 958,280 | 58,157 | | |
| 1981 | 714,584 | 258,918 | 973,502 | 55,517 | | |
| 1982 | 713,912 | 242,052 | 955,964 | 57,753 | | |
| 1983 | 687,504 | 293,946 | 981,450 | 59,021 | | |
| 1984 | 442,733 | 649,322 | 1,092,055 | 77,595 | 181,200 | |
| 1985 | 604,465 | 535,211 | 1,139,676 | 58,147 | 363,400 | |
| 1986 | 594,997 | 546,996 | 1,141,993 | 45,439 | 1,039,800 | |
| 1987 | 529,461 | 329,955 | 859,416 | 28,471 | 1,326,300 | 377,436 |
| 1988 | 931,812 | 296,909 | 1,228,721 | 41,203 | 1,395,900 | 87,813 |
| 1989 | 904,201 | 325,399 | 1,229,600 | 10,569 | 1,447,600 | 36,073 |
| 1990 | 640,511 | 814,682 | 1,455,193 | 79,025 | 917,400 | 151,672 |
| 1991 | 542,056 | 653,589 | 1,195,646 | 98,604 | 293,400 | 264,760 |
| 1992 | 559,771 | 830,560 | 1,390,331 | 52,352 | 10,000 | 160 |
| 1993 | 232,173 | 1,094,431 | 1,326,604 | 57,132 | 1,957 | 886 |
| 1994 | 176,777 | 1,152,573 | 1,329,350 | 58,659 | NA | 566 |
| 1995 | 91,941 | 1,172,304 | 1,264,245 | 64,925 | trace | 264 |
| 1996 | 105,938 | 1,086,840 | 1,192,778 | 29,062 | trace | 387 |
| 1997 | 304,543 | 819,888 | 1,124,430 | 25,940 | trace | 168 |
| 1998 | 135,399 | 965,767 | 1,101,165 | 23,822 | trace | 136 |
| 1999 | 206,697 | 783,119 | 989,816 | 1,010 | trace | 29 |
| 2000 | 293,532 | 839,175 | 1,132,707 | 1,244 | trace | 28 |
| 2001 | 425,219 | 961,975 | 1,387,194 | 824 | trace | 258 |
| 2002 | 320,463 | 1,159,732 | 1,480,195 | 1,156 | trace | NA |
| 2003 | NA | NA | 1,491,760 | 1,615 | trace | NA |

1979-1989 data are from Pacfin.
1990-2003 data are from NMFS Alaska Regional Office, includes discards.
2003 EBS catch assuming full TAC will be taken; for Aleutians catch data as of Oct 4, 2003

Table 1.2. Estimated retained, discarded, and percent discarded of total catch in the Aleutians, Northwest and Southeastern Bering Sea, 1991-2002. Units are in tons, SE represents the EBS east of 170° W, NW is the EBS west of 170° W, source: NMFS Blend database.

| Area | Year | Discard | Retained | Total | Percent Discard |
|---|---|---|---|---|---|
| Aleutian Islands | | 5,231 | 93,373 | 98,604 | 5.3% |
| Bogoslof | | 20,327 | 295,711 | 316,038 | 6.4% |
| NW | **1991** | 48,205 | 493,852 | 542,056 | 8.9% |
| SE | | 66,789 | 586,763 | 653,552 | 10.2% |
| 1991 Total | | 140,572 | 1,469,716 | 1,610,288 | 8.7% |
| Aleutian Islands | | 2,982 | 49,369 | 52,352 | 5.7% |
| Bogoslof | | 240 | 1 | 241 | 99.6% |
| NW | **1992** | 57,609 | 502,162 | 559,771 | 10.3% |
| SE | | 71,195 | 759,364 | 830,560 | 8.6% |
| 1992 Total | | 132,027 | 1,310,897 | 1,442,924 | 9.1% |
| Aleutian Islands | | 1,733 | 55,399 | 57,132 | 3.0% |
| Bogoslof | | 308 | 578 | 886 | 34.8% |
| NW | **1993** | 26,100 | 206,073 | 232,173 | 11.2% |
| SE | | 83,989 | 1,010,443 | 1,094,431 | 7.7% |
| 1993 Total | | 112,130 | 1,272,491 | 1,384,622 | 8.1% |
| Aleutian Islands | | 1,373 | 57,286 | 58,659 | 2.3% |
| Bogoslof | | 11 | 545 | 556 | 2.0% |
| NW | **1994** | 16,083 | 160,693 | 176,777 | 9.1% |
| SE | | 88,098 | 1,064,476 | 1,152,573 | 7.6% |
| 1994 Total | | 105,565 | 1,283,000 | 1,388,565 | 7.6% |
| Aleutian Islands | | 1,380 | 63,545 | 64,925 | 2.1% |
| Bogoslof | | 267 | 66 | 334 | 80.1% |
| NW | **1995** | 9,715 | 82,226 | 91,941 | 10.6% |
| SE | | 87,491 | 1,084,812 | 1,172,304 | 7.5% |
| 1995 Total | | 98,854 | 1,230,650 | 1,329,503 | 7.4% |
| Aleutian Islands | | 994 | 28,067 | 29,062 | 3.4% |
| Bogoslof | | 7 | 492 | 499 | 1.4% |
| NW | **1996** | 4,838 | 101,100 | 105,938 | 4.6% |
| SE | | 71,367 | 1,015,473 | 1,086,840 | 6.6% |
| 1996 Total | | 77,206 | 1,145,133 | 1,222,339 | 6.3% |
| Aleutian Islands | | 617 | 25,323 | 25,940 | 2.4% |
| Bogoslof | | 13 | 150 | 163 | 7.7% |
| NW | **1997** | 22,557 | 281,986 | 304,543 | 7.4% |
| SE | | 71,031 | 748,857 | 819,888 | 8.7% |
| 1997 Total | | 94,217 | 1,056,316 | 1,150,533 | 8.2% |
| Aleutian Islands | | 164 | 23,657 | 23,822 | 0.7% |
| Bogoslof | | 3 | 133 | 136 | 1.9% |
| NW | **1998** | 1,581 | 133,818 | 135,399 | 1.2% |
| SE | | 15,135 | 950,631 | 965,767 | 1.6% |
| 1998 Total | | 16,883 | 1,108,239 | 1,125,123 | 1.5% |
| Aleutian Islands | | 480 | 529 | 1,010 | 47.6% |
| Bogoslof | | 11 | 18 | 29 | 38.7% |
| NW | **1999** | 1,912 | 204,785 | 206,697 | 0.9% |
| SE | | 27,089 | 756,030 | 783,119 | 3.5% |
| 1999 Total | | 29,492 | 961,362 | 990,855 | 3.0% |
| Aleutian Islands | | 790 | 455 | 1,244 | 63.4% |
| Bogoslof | | 20 | 10 | 29 | 66.6% |
| NW | **2000** | 1,941 | 291,590 | 293,532 | 0.7% |
| SE | | 19,678 | 819,497 | 839,175 | 2.3% |
| 2000 Total | | 22,428 | 1,111,552 | 1,133,981 | 2.0% |
| Aleutian Islands | | 380 | 445 | 824 | 46.1% |
| Bogoslof | | 28 | 231 | 258 | 10.8% |
| NW | **2001** | 2,450 | 422,769 | 425,219 | 0.6% |
| SE | | 14,873 | 947,015 | 961,889 | 1.5% |
| 2001 Total | | 17,731 | 1,370,459 | 1,388,190 | 1.3% |
| Aleutian Islands | | 758 | 398 | 1,156 | 65.6% |
| Bogoslof | | 12 | 1,031 | 1,042 | 1.1% |
| NW | **2002** | 1,439 | 319,025 | 320,463 | 0.4% |
| SE | | 19,226 | 1,140,504 | 1,159,730 | 1.7% |
| 2002 Total | | 21,434 | 1,460,959 | 1,482,393 | 1.4% |

Table 1.3. Eastern Bering Sea walleye pollock catch at age estimates based on observer data, 1979-2002. Units are in millions of fish.

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1979 | 101.4 | 543.2 | 720 | 420.2 | 392.6 | 215.5 | 56.3 | 25.7 | 35.9 | 27.5 | 17.6 | 7.9 | 3 | 0.5 | 2,567.30 |
| 1980 | 9.8 | 462.4 | 823.3 | 443.5 | 252.2 | 211 | 83.7 | 37.6 | 21.8 | 23.9 | 25.5 | 15.9 | 7.7 | 2.5 | 2,420.70 |
| 1981 | 0.6 | 72.2 | 1012.9 | 638 | 227 | 102.9 | 51.7 | 29.6 | 16.1 | 9.4 | 7.5 | 4.6 | 1.5 | 0.6 | 2,174.60 |
| 1982 | 4.8 | 25.3 | 161.4 | 1172.4 | 422.4 | 103.7 | 36 | 36 | 21.5 | 9.1 | 5.4 | 3.2 | 1.9 | 0.7 | 2,003.70 |
| 1983 | 5.1 | 118.6 | 157.8 | 313 | 817 | 218.3 | 41.4 | 24.7 | 19.8 | 11.1 | 7.6 | 4.9 | 3.5 | 1.7 | 1,744.50 |
| 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 | 1,938.00 |
| 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 | 1,919.90 |
| 1986 | 3.1 | 86 | 92.3 | 748.5 | 214.1 | 378.1 | 221.9 | 214.2 | 59.7 | 15.2 | 3.3 | 2.6 | 0.3 | 1.2 | 2,040.40 |
| 1987 | 0 | 19.9 | 112.2 | 78 | 415.8 | 139.6 | 123.2 | 91.2 | 248.6 | 54.4 | 38.9 | 21.6 | 29.1 | 6.1 | 1,3.50 |
| 1988 | 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 | 2,192.20 |
| 1989 | 0 | 4.8 | 55.3 | 149.5 | 452.6 | 167.3 | 574.1 | 96.6 | 104.1 | 32.5 | 129.5 | 10.9 | 4 | 2.6 | 1,783.80 |
| 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 | 1,746.20 |
| 1991 | 1 | 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 | 1,438.80 |
| 1992 | 0 | 79 | 721.7 | 143.5 | 98.1 | 125 | 145.4 | 276.8 | 109.3 | 165.4 | 59.4 | 50.2 | 14.2 | 91 | 2,079.00 |
| 1993 | 0.1 | 9.2 | 275 | 1144.5 | 103 | 64.3 | 62.2 | 53.5 | 84.9 | 21.8 | 34.5 | 12.6 | 13.1 | 26.5 | 1,905.20 |
| 1994 | 0.3 | 31.5 | 59.8 | 383.4 | 1109.5 | 180.5 | 54.9 | 21 | 13.5 | 20.1 | 9.1 | 10.7 | 7.6 | 15.7 | 1,917.50 |
| 1995 | 0 | 0.3 | 75.3 | 146.6 | 398.4 | 764.7 | 131.8 | 34.9 | 10.9 | 6 | 15.3 | 4.4 | 7.1 | 11.3 | 1,606.90 |
| 1996 | 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 | 1,326.10 |
| 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 | 1,528.80 |
| 1998 | 0 | 36.3 | 86.7 | 72.3 | 160.8 | 704 | 203.6 | 128.6 | 107.6 | 29.1 | 5.7 | 6.3 | 3 | 7.4 | 1,551.50 |
| 1999 | 0.1 | 7.5 | 296.5 | 219.5 | 105 | 154.8 | 475.9 | 131.4 | 57.3 | 33.1 | 3.9 | 2.1 | 0.4 | 2.5 | 1,490.00 |
| 2000 | 0 | 15.7 | 82.1 | 427.2 | 345.8 | 106.2 | 168.5 | 353.3 | 86.8 | 29.1 | 22.8 | 5.7 | 1.5 | 1.5 | 1,646.30 |
| 2001 | 0 | 2.6 | 46.1 | 149.3 | 592.6 | 409.8 | 142.3 | 129.8 | 154.7 | 55.2 | 33.6 | 15.8 | 5.6 | 3.1 | 1,742.30 |
| 2002 | 0.64 | 46.93 | 106.11 | 211.23 | 283.46 | 609.80 | 270.75 | 101.19 | 81.84 | 91.01 | 33.81 | 14.41 | 11.89 | 4.35 | 1,867.41 |
| Average | 5.55 | 76.76 | 248.39 | 345.56 | 352.52 | 310.70 | 204.82 | 118.79 | 71.43 | 38.59 | 26.79 | 12.78 | 9.23 | 11.76 | 1,833.73 |
| Median | 0.20 | 34.75 | 99.21 | 220.10 | 314.63 | 216.90 | 143.85 | 98.89 | 58.50 | 24.90 | 16.45 | 9.50 | 4.05 | 4.17 | 1,825.60 |

Table 1.4. Numbers of fishery samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-2002, of pollock as sampled by the NMFS observer program.

| | **Strata** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measured | Aleutians | 34,023 | 33,585 | 33,052 | 28,465 | 21,993 | 12,336 | 10,477 | 6,906 | 75 | 70 | 51 | 46 |
| males | Northwest | 126,023 | 110,487 | 38,524 | 28,169 | 17,909 | 22,290 | 58,307 | 32,185 | 16,629 | 43,897 | 58,561 | 42,424 |
| | SE A Season | 198,835 | 150,554 | 122,436 | 138,338 | 127,876 | 148,706 | 123,385 | 134,743 | 35,702 | 62,300 | 52,948 | 68,346 |
| | SE B Season | 102,225 | 134,371 | 143,420 | 153,336 | 175,524 | 193,832 | 114,826 | 205,309 | 38,208 | 62,855 | 65,921 | 63,702 |
| Total | | 461,106 | 428,997 | 337,432 | 348,308 | 343,302 | 377,164 | 306,995 | 351,326 | 92,613 | 169,122 | 177,481 | 174,518 |
| Measured | Aleutians | 14,620 | 19,079 | 21,055 | 16,125 | 16,475 | 8,792 | 9,056 | 5,368 | 60 | 114 | 102 | 61 |
| Females | Northwest | 124,934 | 114,778 | 39,985 | 28,185 | 19,282 | 22,144 | 51,358 | 39,576 | 19,019 | 42,162 | 63,414 | 44,798 |
| | SE A Season | 184,351 | 142,016 | 112,602 | 146,918 | 124,000 | 140,868 | 102,530 | 108,645 | 31,791 | 55,800 | 50,552 | 66,129 |
| | SE B Season | 90,056 | 136,626 | 135,661 | 146,540 | 150,632 | 149,583 | 105,999 | 174,729 | 35,019 | 40,233 | 58,447 | 62,075 |
| Total | | 413,961 | 412,499 | 309,303 | 337,768 | 310,389 | 321,387 | 268,943 | 295,104 | 85,889 | 138,309 | 172,515 | 173,063 |
| Aged | Aleutians | 22 | 110 | 81 | 157 | 73 | 86 | 15 | 142 | 0 | 0 | 0 | 0 |
| males | Northwest | 320 | 179 | 147 | 132 | 123 | 0 | 326 | 216 | 312 | 269 | 257 | 237 |
| | SE A Season | 373 | 454 | 451 | 200 | 297 | 470 | 431 | 588 | 533 | 660 | 695 | 646 |
| | SE B Season | 248 | 317 | 475 | 571 | 415 | 442 | 284 | 307 | 728 | 833 | 544 | 797 |
| Total | | 963 | 1,060 | 1,154 | 1,060 | 908 | 998 | 1,056 | 1,098 | 1,573 | 1,762 | 1,496 | 1,680 |
| Aged | Aleutians | 23 | 121 | 82 | 151 | 105 | 77 | 15 | 166 | 0 | 0 | 1 | 0 |
| females | Northwest | 340 | 178 | 153 | 142 | 131 | 0 | 326 | 236 | 312 | 313 | 306 | 281 |
| | SE A Season | 385 | 458 | 478 | 201 | 313 | 451 | 434 | 652 | 485 | 616 | 678 | 677 |
| | SE B Season | 233 | 332 | 458 | 574 | 392 | 434 | 312 | 308 | 725 | 574 | 465 | 839 |
| Total | | 981 | 1,089 | 1,171 | 1,068 | 941 | 962 | 1,087 | 1,192 | 1,522 | 1,504 | 1,450 | 1,797 |

Table 1.5. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-2003.

| Year | Number of Hauls | Lengths | Aged | Year | Number of Hauls | Lengths | Aged |
|---|---|---|---|---|---|---|---|
| 1982 | 329 | 40,001 | 1,611 | 1993 | 355 | 43,278 | 1,385 |
| 1983 | 354 | 78,033 | 1,931 | 1994 | 355 | 38,901 | 1,141 |
| 1984 | 355 | 40,530 | 1,806 | 1995 | 356 | 25,673 | 1,156 |
| 1985 | 353 | 48,642 | 1,913 | 1996 | 355 | 40,789 | 1,387 |
| 1986 | 354 | 41,101 | 1,344 | 1997 | 356 | 35,536 | 1,193 |
| 1987 | 342 | 40,144 | 1,607 | 1998 | 355 | 37,673 | 1,261 |
| 1988 | 353 | 40,408 | 1,173 | 1999 | 353 | 32,532 | 1,385 |
| 1989 | 353 | 38,926 | 1,227 | 2000 | 352 | 41,762 | 1,545 |
| 1990 | 352 | 34,814 | 1,257 | 2001 | 355 | 47,335 | 1,641 |
| 1991 | 351 | 43,406 | 1,083 | 2002 | 355 | 43,361 | 1,695 |
| 1992 | 336 | 34,024 | 1,263 | 2003 | 356 | 46,480 | 1,638 |

Table 1.6. Biomass (age 1+) of eastern Bering Sea walleye pollock as estimated by surveys 1979-2003 (millions of tons).

| Year | Bottom trawl Survey (t) | EIT Survey (t) | EIT Percent age 3+ | Total[3] (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[4] | (95%) | 6.86 | 52% |
| 2000 | 5.14 | 3.05 | (95%) | 8.19 | 63% |
| 2001 | 4.14 | | | | |
| 2002 | 4.82 | 3.60 | (84%) | 8.42 | 57% |
| 2003 | 8.51 | | | | |

[3] 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).

[4] 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 1.7. Distribution of pollock between areas from summer echo integration-trawl surveys on the Bering Sea shelf, 1994-2002. Data are estimated pollock biomass from 14 m below the surface down to 3 m off bottom.

| | Dates | Area (nmi)$^2$ | SCA | Biomass (million mt) (percent) E170-SCA | W170 | Total Biomass (million mt) |
|---|---|---|---|---|---|---|
| **1994** | Jul 9-Aug 19 | 78,251 | 0.312 | 0.399 | 2.18 | 2.89 |
| | | | (11%) | (14%) | (75%) | |
| **1996** | Jul 20-Aug 30 | 93,810 | 0.215 | 0.269 | 1.83 | 2.31 |
| | | | (9%) | (12%) | (79%) | |
| **1997** | Jul 17-Sept 4 | 102,770 | 0.246 | 0.527 | 1.82 | 2.59 |
| | | | (10%) | (20%) | (70%) | |
| **1999** | Jun 7-Aug 5 | 103,670 | 0.299 | 0.579 | 2.41 | 3.29 |
| | | | (9%) | (18%) | (73%) | |
| **2000** | Jun 7- Aug 2 | 106,140 | 0.393 | 0.498 | 2.16 | 3.05 |
| | | | (13%) | (16%) | (71%) | |
| **2002** | Jun 4 – Jul 30 | 99,526 | 0.647 | 0.797 | 2.178 | 3.622 |
| | | | (18%) | (22%) | (60%) | |

Key: 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 |
| 2002 | **Total** | 126 | 40,234 | 3,233 | 2,200 |
| | East of 170 W | 48 | 14,601 | 1,424 | 1,000 |
| | West of 170 W | 78 | 25,633 | 1,809 | 1,200 |

Table 1.9. Fishery annual average weights-at-age (kg) as estimated from NMFS observer data. These values are used in the model for computing the predicted fishery catch (in weight) and for computing biomass levels for EBS pollock. NOTE: 2003 weight-at-age is treated as the three-year average of values from 2000-2002.

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964-1990 | 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 | 0.17 | 0.28 | 0.47 | 0.60 | 0.72 | 0.84 | 0.88 | 1.00 | 1.11 | 1.13 | 1.19 | 1.21 | 1.26 | 1.24 |
| 1992 | 0.007 | 0.17 | 0.39 | 0.45 | 0.61 | 0.66 | 0.74 | 0.90 | 0.96 | 1.15 | 1.17 | 1.20 | 1.13 | 1.18 | 1.30 |
| 1993 | 0.007 | 0.17 | 0.49 | 0.61 | 0.66 | 0.77 | 0.93 | 1.08 | 1.19 | 1.24 | 1.39 | 1.51 | 1.63 | 1.59 | 1.46 |
| 1994 | 0.007 | 0.17 | 0.40 | 0.63 | 0.72 | 0.73 | 0.71 | 0.99 | 1.29 | 1.23 | 1.20 | 1.33 | 1.31 | 1.28 | 1.28 |
| 1995 | 0.007 | 0.17 | 0.39 | 0.50 | 0.73 | 0.84 | 0.85 | 1.00 | 1.24 | 1.31 | 1.37 | 1.49 | 1.40 | 1.34 | 1.49 |
| 1996 | 0.007 | 0.17 | 0.33 | 0.45 | 0.72 | 0.82 | 0.96 | 0.97 | 1.06 | 1.14 | 1.37 | 1.45 | 1.49 | 1.68 | 1.46 |
| 1997 | 0.007 | 0.17 | 0.32 | 0.47 | 0.55 | 0.74 | 0.89 | 1.07 | 1.08 | 1.24 | 1.33 | 1.42 | 1.57 | 1.45 | 1.42 |
| 1998 | 0.007 | 0.17 | 0.36 | 0.57 | 0.63 | 0.64 | 0.78 | 1.05 | 1.17 | 1.24 | 1.24 | 1.34 | 1.44 | 1.49 | 1.71 |
| 1999 | 0.007 | 0.17 | 0.41 | 0.49 | 0.66 | 0.70 | 0.75 | 0.96 | 1.08 | 1.35 | 1.27 | 1.52 | 2.40 | 1.12 | 1.10 |
| 2000 | 0.007 | 0.17 | 0.38 | 0.50 | 0.63 | 0.78 | 0.77 | 0.82 | 1.02 | 1.05 | 1.31 | 1.29 | 1.38 | 1.92 | 1.41 |
| 2001 | 0.007 | 0.17 | 0.27 | 0.51 | 0.68 | 0.82 | 0.99 | 1.05 | 1.07 | 1.20 | 1.28 | 1.47 | 1.59 | 1.44 | 1.62 |
| 2002 | 0.007 | 0.17 | 0.39 | 0.46 | 0.67 | 0.83 | 0.94 | 1.09 | 1.11 | 1.14 | 1.31 | 1.48 | 1.71 | 1.36 | 1.80 |
| 2003 | 0.007 | 0.17 | 0.35 | 0.49 | 0.66 | 0.81 | 0.90 | 0.99 | 1.07 | 1.13 | 1.30 | 1.41 | 1.56 | 1.57 | 1.61 |

Table 1.10. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2003.

| **Year** | **Fishery** | **Year** | **Fishery** | **BTS** | **EIT** |
|---|---|---|---|---|---|
| 1964 | 10 | 1979 | 50 | | 25 |
| 1965 | 10 | 1980 | 50 | | |
| 1966 | 10 | 1981 | 50 | | |
| 1967 | 10 | 1982 | 50 | 100 | 48 |
| 1968 | 10 | 1983 | 50 | 100 | |
| 1969 | 10 | 1984 | 50 | 100 | |
| 1970 | 10 | 1985 | 50 | 100 | 73 |
| 1971 | 10 | 1986 | 50 | 100 | |
| 1972 | 10 | 1987 | 50 | 100 | |
| 1973 | 10 | 1988 | 50 | 100 | 25 |
| 1974 | 10 | 1989 | 50 | 100 | |
| 1975 | 10 | 1990 | 50 | 100 | |
| 1976 | 10 | 1991 | 200 | 100 | 62 |
| 1977 | 10 | 1992 | 200 | 100 | |
| 1978 | 50 | 1993 | 200 | 100 | |
| | | 1994 | 200 | 100 | 77 |
| | | 1995 | 200 | 100 | |
| | | 1996 | 200 | 100 | 57 |
| | | 1997 | 200 | 100 | 86 |
| | | 1998 | 200 | 100 | |
| | | 1999 | 200 | 100 | 122 |
| | | 2000 | 200 | 100 | 128 |
| | | 2001 | 200 | 100 | |
| | | 2002 | 200 | 100 | 126 |
| | | 2003 | 200 | 100 | |

Table 1.11. Results comparing fits Models 1-7. See text for additional model descriptions.

| **Fits to data sources** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** |
|---|---|---|---|---|---|---|---|
| ***Total –ln(likelihood)*** | **-1288.7** | **-1284.5** | **-1289.1** | **-1288.7** | **-1284.8** | **-1284.9** | **-1133.6** |
| Number of parameters | 608 | 608 | 608 | 609 | 607 | 608 | 608 |
| ***Age Composition data*** | | | | | | | |
| Effective N Fishery | 185 | 210 | 185 | 185 | 180 | 180 | 218 |
| Effective N Bottom trawl survey | 228 | 194 | 227 | 227 | 236 | 236 | 91 |
| Effective N Hydro acoustic survey | 134 | 177 | 134 | 134 | 135 | 135 | 17 |

| ***Survey abundance estimates, RMSE**** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** |
|---|---|---|---|---|---|---|---|
| Trawl Survey | 0.21 | 0.21 | 0.19 | 0.21 | 0.22 | 0.22 | 0.28 |
| EIT survey | 0.33 | 0.31 | 0.32 | 0.33 | 0.34 | 0.34 | 0.57 |

| ***Recruitment Residuals*** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** |
|---|---|---|---|---|---|---|---|
| Due to Stock | 0.25 | 0.22 | 0.24 | 0.25 | 0.24 | 0.24 | 0.24 |
| Residual RMSE | 0.38 | 0.51 | 0.39 | 0.38 | 0.39 | 0.39 | 0.42 |
| Total | 0.63 | 0.72 | 0.63 | 0.63 | 0.63 | 0.63 | 0.66 |

Notes: Model 7 total –ln(likelihood) value is not comparable with others (since survey data are disregarded in the model fitting).
Effective N (sample size) computations are as presented in McAllister and Ianelli (1997).
RMSE = $\sqrt{\frac{\sum \ln\left(obs/pred\right)^2}{n}}$

Table 1.12. Results reflecting the stock condition for Models 1-7. Values in parentheses are coefficients of variation (CV's) of values immediately above. See text for model descriptions.

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
|---|---|---|---|---|---|---|---|
| ***Biomass*** | | | | | | | |
| Year 2004 spawning biomass[5] | 3,525 | 3,298 | 5,104 | 3,516 | 4,000 | 3,991 | 2,720 |
| Year 2004 spawning biomass[6] | 3,741 | 3,486 | 5,399 | 3,732 | 4,208 | 4,196 | 2,837 |
| (CV) | (21%) | (21%) | (21%) | (21%) | (19%) | (20%) | (28%) |
| 2003 spawning biomass | 4,079 | 3,822 | 5,843 | 4,070 | 4,583 | 4,561 | 3,306 |
| $B_{msy}$ | 2,468 | 2,257 | 3,499 | 2,466 | 2,684 | 2,679 | 2,435 |
| (CV) | (27%) | (25%) | (29%) | (27%) | (27%) | (27%) | (31%) |
| $B_{40\%}$ | 2,835 | 2,779 | 4,019 | 2,832 | 3,022 | 3,025 | 2,659 |
| (CV) | (19%) | (19%) | (19%) | (19%) | (18%) | (18%) | (19%) |
| $B_{35\%}$ | 2,481 | 2,384 | 3,517 | 2,478 | 2,644 | 2,647 | 2,327 |
| $B_0$ (stock-recruitment curve) | 6,256 | 5,676 | 8,832 | 6,249 | 6,783 | 6,774 | 6,011 |
| Percent of $B_{msy}$ spawning biomass | 143% | 146% | 146% | 143% | 149% | 149% | 112% |
| Percent of $B_{40\%}$ spawning biomass | 132% | 125% | 134% | 132% | 139% | 139% | 107% |
| 2004 Age 3+ Biomass | 11,093 | 10,315 | 15,977 | 11,065 | 12,373 | 12,302 | 8,930 |
| Ratio $B_{2003}/B_{2002}$ (3+ biomass) | 87% | 86% | 88% | 87% | 88% | 88% | 89% |
| ***Recruitment*** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
| Steepness parameter (*h*) | 0.641 | 0.639 | 0.635 | 0.641 | 0.633 | 0.634 | 0.609 |
| Avg Recruitment (all yrs) | 23,635 | 23,211 | 35,056 | 23,617 | 24,933 | 24,633 | 22,945 |
| (CV) | 61% | 72% | 59% | 61% | 62% | 62% | 63% |
| Avg. ecruitment (since 1978) | 26,384 | 25,865 | 37,404 | 26,357 | 28,124 | 27,740 | 24,744 |
| (CV since 1978) | 62% | 76% | 64% | 62% | 63% | 63% | 69% |
| 1996 year class | 42,981 | 44,129 | 60,359 | 42,878 | 46,121 | 45,532 | 53,477 |
| (CV 1996 year class) | (15%) | (14%) | (15%) | (15%) | (14%) | (19%) | (20%) |
| ***Natural Mortality*** | | | | | | | |
| *(age 3 and older)* | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 | 0.297 | 0.300 |

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

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

Table 1.13. Results relating to yield for Models 1-7. See text for model descriptions.

| | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** |
|---|---|---|---|---|---|---|---|
| *Yield projections* | | | | | | | |
| $B_{msy}$ (age 3+) | 9,277 | 8,472 | 13,056 | 9,267 | 9,988 | 9,927 | 8,746 |
| 2004 Age 3+ biomass (GM) | 10,972 | 10,200 | 15,814 | 10,944 | 12,278 | 12,189 | 8,710 |
| MSYR (HM) | 0.233 | 0.233 | 0.229 | 0.233 | 0.228 | 0.227 | 0.208 |
| 2004 MSYR yield (Tier 1 ABC) | **2,562** | 2,376 | 3,622 | 2,555 | 2,800 | 2,772 | 1,814 |
| MSYR (AM) | 0.250 | 0.249 | 0.245 | 0.250 | 0.244 | 0.244 | 0.227 |
| 2004 MSYR OFL | **2,738** | 2,537 | 3,882 | 2,731 | 3,000 | 2,971 | 1,978 |
| 2004 $F_{msy}$ yield (HM) | 2,506 | 2,283 | 3,580 | 2,498 | 2,688 | 2,561 | 1,726 |
| 2004 Yield $F_{msy}$ (AM) | 3,800 | 3,429 | 5,431 | 3,792 | 4,042 | 3,988 | 2,884 |
| | (44%) | (43%) | (44%) | (44%) | (43%) | (45%) | (49%) |
| MSY (long-term expectation) | 2,240 | 2,039 | 3,096 | 2,237 | 2,357 | 2,337 | 1,902 |
| *Average F's* | | | | | | | |
| $F_{msy}$ | 0.550 | 0.512 | 0.553 | 0.550 | 0.481 | 0.473 | 0.666 |
| | (109%) | (106%) | (111%) | (109%) | (105%) | (110%) | (124%) |
| $F_{40\%}$ (average F) | 0.325 | 0.308 | 0.338 | 0.325 | 0.301 | 0.295 | 0.474 |
| $F_{35\%}$ 2004 Yield | 3,115 | 2,825 | 4,572 | 3,109 | 3,429 | 3,370 | 2,739 |
| 2004 yield F40% | 2,527 | 2,297 | 3,706 | 2,521 | 2,792 | 2,745 | 2,243 |
| *Full Selection F's* | | | | | | | |
| $F_{msy}$ (AM) | 0.962 | 0.872 | 0.960 | 0.963 | 0.853 | 0.839 | 1.123 |
| $F_{msy}$ (HM) | 0.474 | 0.445 | 0.475 | 0.474 | 0.419 | 0.407 | 0.550 |
| F40% | 0.569 | 0.525 | 0.586 | 0.570 | 0.534 | 0.524 | 0.799 |
| $F_{35\%}$ | 0.738 | 0.677 | 0.763 | 0.740 | 0.688 | 0.674 | 1.044 |
| *Spawning biomass levels* | | | | | | | |
| $B_{40\%}$ | 2,835 | 2,779 | 4,019 | 2,832 | 3,022 | 3,025 | 2,659 |
| $B_{35\%}$ | 2,481 | 2,432 | 3,517 | 2,478 | 2,644 | 2,647 | 2,327 |
| $B_0$ (stock-recruitment curve) | 6,256 | 5,728 | 8,832 | 6,249 | 6,783 | 6,774 | 6,011 |

Notes: MSYR = exploitation rate relative to begin-year age 3+ biomass corresponding to $F_{msy}$.
$F_{msy}$ yields calculated within the model (i.e., including uncertainty in both the estimate of $F_{msy}$ and in projected stock size).
HM = Harmonic mean
GM = Geometric mean
AM = Arithmetic mean

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

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10+** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1964** | 5,091 | 3,989 | 2,280 | 551 | 237 | 368 | 150 | 63 | 34 | 213 | 12,976 |
| **1965** | 20,965 | 2,066 | 2,512 | 1,597 | 340 | 145 | 230 | 96 | 41 | 167 | 28,159 |
| **1966** | 14,845 | 8,508 | 1,302 | 1,762 | 992 | 209 | 91 | 148 | 63 | 141 | 28,061 |
| **1967** | 28,345 | 6,024 | 5,338 | 897 | 1,118 | 634 | 137 | 60 | 99 | 138 | 42,789 |
| **1968** | 26,058 | 11,483 | 3,732 | 3,479 | 504 | 637 | 375 | 83 | 37 | 148 | 46,535 |
| **1969** | 26,859 | 10,558 | 7,120 | 2,439 | 1,967 | 289 | 379 | 228 | 51 | 116 | 50,006 |
| **1970** | 21,356 | 10,863 | 6,482 | 4,476 | 1,450 | 1,177 | 176 | 231 | 139 | 99 | 46,450 |
| **1971** | 9,969 | 8,626 | 6,608 | 3,912 | 2,519 | 823 | 685 | 103 | 134 | 136 | 33,515 |
| **1972** | 11,373 | 4,018 | 5,162 | 3,716 | 2,003 | 1,304 | 441 | 367 | 55 | 141 | 28,580 |
| **1973** | 27,504 | 4,584 | 2,299 | 2,671 | 1,769 | 973 | 651 | 223 | 188 | 102 | 40,963 |
| **1974** | 21,193 | 11,058 | 2,540 | 1,070 | 1,116 | 759 | 433 | 295 | 103 | 135 | 38,703 |
| **1975** | 17,702 | 8,501 | 5,950 | 1,073 | 397 | 427 | 303 | 177 | 123 | 101 | 34,754 |
| **1976** | 13,443 | 7,144 | 4,937 | 2,683 | 421 | 162 | 183 | 133 | 79 | 102 | 29,288 |
| **1977** | 14,704 | 5,433 | 4,226 | 2,454 | 1,193 | 193 | 77 | 89 | 66 | 91 | 28,526 |
| **1978** | 28,483 | 5,950 | 3,262 | 2,274 | 1,208 | 602 | 100 | 41 | 48 | 85 | 42,054 |
| **1979** | 64,859 | 11,548 | 3,623 | 1,857 | 1,123 | 564 | 287 | 49 | 20 | 66 | 83,994 |
| **1980** | 26,705 | 26,300 | 7,052 | 2,097 | 941 | 540 | 276 | 142 | 24 | 44 | 64,122 |
| **1981** | 30,504 | 10,836 | 16,228 | 4,331 | 1,164 | 502 | 292 | 151 | 78 | 38 | 64,124 |
| **1982** | 16,378 | 12,390 | 6,840 | 11,238 | 2,622 | 628 | 262 | 155 | 81 | 62 | 50,656 |
| **1983** | 54,361 | 6,655 | 7,853 | 4,867 | 7,382 | 1,607 | 377 | 159 | 95 | 88 | 83,444 |
| **1984** | 12,983 | 22,092 | 4,224 | 5,638 | 3,284 | 4,720 | 1,012 | 239 | 101 | 117 | 54,409 |
| **1985** | 35,624 | 5,276 | 14,027 | 3,042 | 3,864 | 2,123 | 2,927 | 620 | 150 | 134 | 67,788 |
| **1986** | 13,192 | 14,477 | 3,350 | 10,107 | 2,087 | 2,503 | 1,320 | 1,798 | 388 | 175 | 49,398 |
| **1987** | 7,766 | 5,361 | 9,194 | 2,417 | 6,956 | 1,360 | 1,567 | 817 | 1,134 | 351 | 36,924 |
| **1988** | 4,644 | 3,157 | 3,408 | 6,661 | 1,684 | 4,678 | 885 | 982 | 514 | 940 | 27,554 |
| **1989** | 9,773 | 1,888 | 2,005 | 2,458 | 4,585 | 1,111 | 2,966 | 536 | 598 | 894 | 26,812 |
| **1990** | 55,934 | 3,972 | 1,199 | 1,444 | 1,684 | 3,002 | 698 | 1,775 | 322 | 906 | 70,935 |
| **1991** | 27,110 | 22,734 | 2,522 | 857 | 975 | 1,022 | 1,734 | 375 | 980 | 684 | 58,992 |
| **1992** | 21,687 | 11,019 | 14,429 | 1,797 | 574 | 581 | 577 | 907 | 202 | 893 | 52,666 |
| **1993** | 54,804 | 8,813 | 6,978 | 10,088 | 1,147 | 308 | 289 | 256 | 418 | 514 | 83,615 |
| **1994** | 14,917 | 22,277 | 5,607 | 5,083 | 6,587 | 634 | 142 | 144 | 136 | 531 | 56,057 |
| **1995** | 11,638 | 6,064 | 14,181 | 4,103 | 3,438 | 3,954 | 334 | 79 | 84 | 411 | 44,287 |
| **1996** | 27,303 | 4,731 | 3,862 | 10,409 | 2,837 | 2,171 | 2,259 | 199 | 49 | 319 | 54,139 |
| **1997** | 42,981 | 11,099 | 3,010 | 2,826 | 7,405 | 1,935 | 1,313 | 1,241 | 113 | 219 | 72,142 |
| **1998** | 19,189 | 17,472 | 7,062 | 2,204 | 2,015 | 5,071 | 1,182 | 732 | 711 | 197 | 55,836 |
| **1999** | 20,498 | 7,801 | 11,120 | 5,178 | 1,577 | 1,390 | 3,157 | 678 | 430 | 541 | 52,370 |
| **2000** | 28,727 | 8,333 | 4,967 | 8,137 | 3,647 | 1,056 | 886 | 1,920 | 410 | 618 | 58,700 |
| **2001** | 31,032 | 11,677 | 5,305 | 3,628 | 5,688 | 2,403 | 657 | 523 | 1,127 | 641 | 62,681 |
| **2002** | 11,904 | 12,615 | 7,433 | 3,869 | 2,520 | 3,700 | 1,469 | 379 | 299 | 1,074 | 45,262 |
| **2003** | 12,988 | 4,839 | 8,022 | 5,414 | 2,687 | 1,625 | 2,206 | 840 | 214 | 832 | 39,667 |
| **Median** | 21,079 | 8,504 | 5,234 | 2,934 | 1,726 | 997 | 437 | 229 | 118 | 157 | 47,966 |
| **Average** | 23,635 | 9,556 | 5,931 | 3,870 | 2,393 | 1,447 | 837 | 451 | 248 | 330 | 48,698 |

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

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1964** | 6 | 39 | 108 | 79 | 36 | 50 | 18 | 6 | 3 | 16 | 362 |
| **1965** | 26 | 20 | 115 | 224 | 50 | 19 | 26 | 9 | 4 | 12 | 506 |
| **1966** | 19 | 109 | 78 | 219 | 118 | 21 | 9 | 13 | 5 | 11 | 603 |
| **1967** | 66 | 137 | 557 | 189 | 225 | 111 | 22 | 9 | 14 | 18 | 1,347 |
| **1968** | 60 | 256 | 381 | 716 | 99 | 109 | 59 | 12 | 5 | 19 | 1,715 |
| **1969** | 92 | 316 | 935 | 419 | 329 | 44 | 58 | 35 | 8 | 21 | 2,257 |
| **1970** | 91 | 404 | 1,043 | 935 | 295 | 219 | 33 | 43 | 26 | 22 | 3,111 |
| **1971** | 57 | 428 | 1,384 | 1,054 | 661 | 198 | 166 | 25 | 33 | 37 | 4,043 |
| **1972** | 65 | 334 | 1,357 | 1,161 | 602 | 371 | 122 | 99 | 15 | 36 | 4,160 |
| **1973** | 202 | 486 | 746 | 1,020 | 652 | 340 | 221 | 74 | 61 | 32 | 3,834 |
| **1974** | 188 | 1,398 | 956 | 470 | 474 | 307 | 170 | 113 | 39 | 50 | 4,166 |
| **1975** | 86 | 613 | 2,036 | 443 | 156 | 158 | 108 | 61 | 42 | 33 | 3,736 |
| **1976** | 53 | 417 | 1,417 | 939 | 140 | 50 | 55 | 39 | 23 | 28 | 3,162 |
| **1977** | 46 | 256 | 1,006 | 719 | 332 | 50 | 19 | 22 | 16 | 21 | 2,486 |
| **1978** | 53 | 216 | 657 | 662 | 390 | 188 | 31 | 12 | 14 | 24 | 2,248 |
| **1979** | 113 | 393 | 688 | 512 | 344 | 166 | 83 | 14 | 6 | 18 | 2,336 |
| **1980** | 35 | 684 | 1,047 | 458 | 230 | 127 | 63 | 32 | 5 | 9 | 2,691 |
| **1981** | 20 | 88 | 916 | 687 | 276 | 130 | 72 | 36 | 18 | 9 | 2,252 |
| **1982** | 6 | 60 | 233 | 1,104 | 393 | 103 | 41 | 24 | 12 | 9 | 1,985 |
| **1983** | 16 | 25 | 209 | 377 | 876 | 210 | 47 | 19 | 11 | 10 | 1,801 |
| **1984** | 4 | 75 | 101 | 365 | 362 | 667 | 152 | 33 | 14 | 18 | 1,791 |
| **1985** | 11 | 18 | 332 | 195 | 421 | 297 | 433 | 83 | 21 | 20 | 1,830 |
| **1986** | 4 | 47 | 76 | 620 | 218 | 336 | 188 | 232 | 52 | 26 | 1,798 |
| **1987** | 2 | 14 | 175 | 124 | 556 | 143 | 209 | 107 | 144 | 43 | 1,516 |
| **1988** | 1 | 10 | 78 | 409 | 160 | 585 | 140 | 152 | 77 | 138 | 1,750 |
| **1989** | 2 | 6 | 49 | 160 | 462 | 147 | 495 | 88 | 95 | 138 | 1,641 |
| **1990** | 11 | 14 | 37 | 110 | 265 | 574 | 166 | 394 | 74 | 192 | 1,837 |
| **1991** | 6 | 84 | 84 | 71 | 166 | 211 | 444 | 90 | 242 | 156 | 1,553 |
| **1992** | 7 | 60 | 703 | 215 | 138 | 167 | 203 | 299 | 69 | 282 | 2,143 |
| **1993** | 8 | 16 | 101 | 1,037 | 253 | 102 | 82 | 62 | 91 | 97 | 1,850 |
| **1994** | 2 | 29 | 59 | 382 | 1,085 | 160 | 31 | 26 | 22 | 75 | 1,871 |
| **1995** | 1 | 6 | 113 | 237 | 441 | 786 | 57 | 11 | 11 | 45 | 1,708 |
| **1996** | 3 | 8 | 40 | 357 | 195 | 346 | 508 | 41 | 10 | 54 | 1,562 |
| **1997** | 5 | 18 | 30 | 92 | 485 | 295 | 283 | 245 | 22 | 35 | 1,509 |
| **1998** | 2 | 26 | 63 | 65 | 119 | 702 | 232 | 132 | 125 | 29 | 1,496 |
| **1999** | 2 | 8 | 117 | 221 | 132 | 169 | 490 | 108 | 57 | 62 | 1,366 |
| **2000** | 3 | 10 | 60 | 398 | 349 | 146 | 156 | 347 | 61 | 80 | 1,612 |
| **2001** | 4 | 16 | 71 | 196 | 600 | 365 | 127 | 104 | 185 | 91 | 1,759 |
| **2002** | 2 | 27 | 108 | 209 | 284 | 627 | 292 | 78 | 55 | 162 | 1,844 |
| **2003** | 3 | 11 | 127 | 318 | 327 | 297 | 473 | 186 | 42 | 133 | 1,917 |
| **Median** | 9 | 53 | 151 | 379 | 311 | 178 | 124 | 52 | 22 | 33 | 1,834 |
| **Average** | 35 | 180 | 460 | 454 | 342 | 252 | 165 | 88 | 46 | 58 | 2,079 |

Table 1.16. Estimated EBS pollock Model 1 age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964-2004.

| Year | Age 3+ | Spawning | Age 1 Rec. | Year | Age 3+ | Spawning | Age 1 Rec. |
|---|---|---|---|---|---|---|---|
| 1964 | 1,822 | 534 | 5,091 | 1984 | 10,456 | 3,568 | 12,983 |
| 1965 | 2,312 | 655 | 20,965 | 1985 | 12,771 | 3,854 | 35,624 |
| 1966 | 2,372 | 764 | 14,845 | 1986 | 11,973 | 4,106 | 13,192 |
| 1967 | 3,575 | 937 | 28,345 | 1987 | 12,596 | 4,217 | 7,766 |
| 1968 | 4,049 | 1,136 | 26,058 | 1988 | 11,633 | 4,141 | 4,644 |
| 1969 | 5,340 | 1,411 | 26,859 | 1989 | 9,850 | 3,716 | 9,773 |
| 1970 | 6,296 | 1,723 | 21,356 | 1990 | 7,811 | 2,983 | 55,934 |
| 1971 | 6,797 | 1,885 | 9,969 | 1991 | 5,977 | 2,194 | 27,110 |
| 1972 | 6,282 | 1,789 | 11,373 | 1992 | 9,614 | 2,249 | 21,687 |
| 1973 | 4,705 | 1,430 | 27,504 | 1993 | 12,363 | 3,348 | 54,804 |
| 1974 | 3,356 | 979 | 21,193 | 1994 | 11,696 | 3,639 | 14,917 |
| 1975 | 3,489 | 793 | 17,702 | 1995 | 14,474 | 4,048 | 11,638 |
| 1976 | 3,538 | 823 | 13,443 | 1996 | 12,630 | 4,221 | 27,303 |
| 1977 | 3,541 | 893 | 14,704 | 1997 | 10,775 | 3,896 | 42,981 |
| 1978 | 3,422 | 921 | 28,483 | 1998 | 11,110 | 3,682 | 19,189 |
| 1979 | 3,380 | 910 | 64,859 | 1999 | 13,339 | 3,941 | 20,498 |
| 1980 | 4,462 | 1,082 | 26,705 | 2000 | 12,498 | 4,109 | 28,727 |
| 1981 | 8,414 | 1,799 | 30,504 | 2001 | 12,394 | 4,377 | 31,032 |
| 1982 | 9,614 | 2,709 | 16,378 | 2002 | 12,930 | 4,256 | 11,904 |
| 1983 | 10,728 | 3,341 | 54,361 | 2003 | 12,688 | 4,079 | 12,988 |
| | | | | 2004 | 11,217 | 3,891 | |

Table 1.17. 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 2003-1997 assessments for EBS pollock. NOTE: see Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

| | Current Assess. | CV | 2002 Assess. | CV | 2001 Assess. | CV | 2000 Assess. | CV | 1999 Assess. | CV | 1998 Assess. | CV | 1997 Assess. | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | 1,822 | 46% | 1,784 | 46% | 1,726 | 46% | 751 | 35% | 917 | 41% | 1,037 | 30% | | |
| 1965 | 2,312 | 40% | 2,266 | 40% | 2,196 | 40% | 976 | 36% | 976 | 32% | 1,227 | 26% | | |
| 1966 | 2,372 | 40% | 2,324 | 40% | 2,251 | 41% | 1,001 | 39% | 919 | 31% | 1,096 | 28% | | |
| 1967 | 3,575 | 33% | 3,511 | 33% | 3,420 | 33% | 1,957 | 34% | 1,858 | 24% | 2,095 | 22% | | |
| 1968 | 4,049 | 34% | 3,976 | 34% | 3,876 | 34% | 2,312 | 36% | 2,312 | 27% | 2,510 | 23% | | |
| 1969 | 5,340 | 31% | 5,252 | 32% | 5,137 | 32% | 3,379 | 29% | 3,579 | 22% | 3,810 | 19% | | |
| 1970 | 6,296 | 30% | 6,201 | 30% | 6,079 | 30% | 3,998 | 25% | 4,479 | 19% | 5,083 | 15% | | |
| 1971 | 6,797 | 27% | 6,702 | 27% | 6,580 | 28% | 4,372 | 21% | 5,161 | 16% | 5,813 | 12% | | |
| 1972 | 6,282 | 26% | 6,194 | 26% | 6,078 | 27% | 3,984 | 19% | 4,896 | 15% | 5,648 | 11% | | |
| 1973 | 4,705 | 31% | 4,626 | 31% | 4,520 | 32% | 2,873 | 26% | 3,357 | 20% | 3,922 | 14% | | |
| 1974 | 3,356 | 38% | 3,287 | 38% | 3,193 | 39% | 1,648 | 41% | 1,952 | 28% | 2,342 | 19% | | |
| 1975 | 3,489 | 27% | 3,436 | 27% | 3,366 | 26% | 2,536 | 23% | 2,683 | 18% | 3,014 | 13% | | |
| 1976 | 3,538 | 22% | 3,492 | 22% | 3,434 | 22% | 2,694 | 17% | 2,748 | 16% | 3,008 | 13% | | |
| 1977 | 3,541 | 20% | 3,496 | 20% | 3,444 | 20% | 2,701 | 13% | 2,716 | 14% | 2,894 | 13% | | |
| 1978 | 3,422 | 20% | 3,375 | 20% | 3,327 | 19% | 2,608 | 14% | 2,668 | 15% | 2,867 | 13% | 3,244 | 19% |
| 1979 | 3,380 | 19% | 3,329 | 19% | 3,280 | 19% | 2,640 | 16% | 2,720 | 16% | 2,933 | 15% | 3,183 | 21% |
| 1980 | 4,462 | 16% | 4,385 | 16% | 4,322 | 16% | 3,723 | 15% | 3,888 | 16% | 4,294 | 14% | 4,618 | 19% |
| 1981 | 8,414 | 14% | 8,239 | 14% | 8,127 | 14% | 7,834 | 12% | 8,064 | 13% | 8,569 | 12% | 9,190 | 16% |
| 1982 | 9,614 | 13% | 9,388 | 13% | 9,261 | 13% | 9,021 | 13% | 9,229 | 13% | 9,778 | 12% | 10,524 | 17% |
| 1983 | 10,728 | 13% | 10,441 | 13% | 10,298 | 13% | 9,958 | 12% | 10,153 | 12% | 10,705 | 12% | 11,555 | 16% |
| 1984 | 10,456 | 13% | 10,143 | 13% | 10,000 | 13% | 9,518 | 13% | 9,685 | 12% | 10,179 | 12% | 11,028 | 17% |
| 1985 | 12,771 | 11% | 12,344 | 11% | 12,181 | 11% | 11,182 | 10% | 11,370 | 10% | 11,919 | 11% | 12,853 | 15% |
| 1986 | 11,973 | 11% | 11,538 | 11% | 11,381 | 11% | 10,277 | 10% | 10,440 | 10% | 10,913 | 11% | 11,796 | 16% |
| 1987 | 12,596 | 10% | 12,116 | 10% | 11,951 | 10% | 10,636 | 9% | 10,769 | 9% | 11,116 | 10% | 11,952 | 15% |
| 1988 | 11,633 | 10% | 11,317 | 10% | 11,159 | 10% | 9,910 | 8% | 9,991 | 9% | 10,274 | 10% | 11,020 | 15% |
| 1989 | 9,850 | 10% | 9,540 | 10% | 9,394 | 10% | 8,251 | 9% | 8,305 | 9% | 8,546 | 10% | 9,210 | 16% |
| 1990 | 7,811 | 11% | 7,524 | 11% | 7,393 | 11% | 6,473 | 10% | 6,497 | 10% | 6,659 | 12% | 7,240 | 18% |
| 1991 | 5,977 | 13% | 5,708 | 13% | 5,582 | 12% | 4,859 | 11% | 4,842 | 11% | 5,180 | 13% | 5,690 | 20% |
| 1992 | 9,614 | 10% | 9,227 | 10% | 8,898 | 10% | 7,920 | 9% | 7,800 | 10% | 8,294 | 13% | 9,465 | 21% |
| 1993 | 12,363 | 11% | 12,110 | 10% | 11,503 | 10% | 10,233 | 10% | 9,873 | 10% | 10,279 | 16% | 12,086 | 25% |
| 1994 | 11,696 | 11% | 11,358 | 11% | 10,590 | 11% | 9,285 | 10% | 8,622 | 12% | 8,917 | 18% | 10,626 | 29% |
| 1995 | 14,474 | 12% | 13,848 | 12% | 12,617 | 13% | 10,267 | 12% | 8,817 | 15% | 8,680 | 22% | 9,998 | 32% |
| 1996 | 12,630 | 13% | 11,988 | 13% | 10,752 | 14% | 8,556 | 14% | 7,147 | 17% | 6,811 | 26% | 8,142 | 36% |
| 1997 | 10,775 | 15% | 10,142 | 15% | 8,984 | 16% | 7,057 | 17% | 5,710 | 22% | 5,307 | 31% | 6,631 | 42% |
| 1998 | 11,110 | 16% | 10,466 | 17% | 9,335 | 20% | 7,448 | 22% | 5,961 | 28% | 5,133 | 39% | 5,133 | 39% |
| 1999 | 13,339 | 20% | 12,712 | 21% | 12,593 | 28% | 10,772 | 30% | 7,513 | 36% | | | | |
| 2000 | 12,498 | 23% | 11,807 | 24% | 11,680 | 33% | 10,490 | 34% | | | | | | |
| 2001 | 12,394 | 27% | 11,511 | 27% | 11,145 | 39% | | | | | | | | |
| 2002 | 12,930 | 32% | 11,118 | 33% | | | | | | | | | | |
| 2003 | 12,688 | 37% | | | | | | | | | | | | |
| 2004 | 11,217 | 42% | | | | | | | | | | | | |

Table 1.18 Projections of Model 1 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 7,232; 2,835; and 2,481 t, respectively.

| *Sp.Biomass* | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
|---|---|---|---|---|---|---|---|
| 2003 | 4,091 | 4,091 | 4,091 | 4,091 | 4,091 | 4,091 | 4,091 |
| 2004 | 3,774 | 3,774 | 3,943 | 3,964 | 4,121 | 3,678 | 3,774 |
| 2005 | 2,968 | 2,968 | 3,565 | 3,648 | 4,330 | 2,697 | 2,968 |
| 2006 | 2,496 | 2,496 | 3,257 | 3,378 | 4,478 | 2,231 | 2,447 |
| 2007 | 2,515 | 2,515 | 3,253 | 3,388 | 4,790 | 2,288 | 2,361 |
| 2008 | 2,737 | 2,737 | 3,462 | 3,593 | 5,213 | 2,516 | 2,540 |
| 2009 | 2,925 | 2,925 | 3,691 | 3,825 | 5,640 | 2,680 | 2,687 |
| 2010 | 3,005 | 3,005 | 3,841 | 3,984 | 5,999 | 2,730 | 2,732 |
| 2011 | 3,009 | 3,009 | 3,910 | 4,064 | 6,277 | 2,715 | 2,716 |
| 2012 | 3,002 | 3,002 | 3,942 | 4,105 | 6,484 | 2,702 | 2,703 |
| 2013 | 3,011 | 3,011 | 3,973 | 4,144 | 6,655 | 2,712 | 2,712 |
| 2014 | 3,036 | 3,036 | 4,013 | 4,191 | 6,812 | 2,736 | 2,736 |
| 2015 | 3,048 | 3,048 | 4,040 | 4,222 | 6,940 | 2,745 | 2,745 |
| 2016 | 3,039 | 3,039 | 4,044 | 4,231 | 7,034 | 2,733 | 2,733 |
| *F* | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2003 | 0.157 | 0.157 | 0.157 | 0.157 | 0.157 | 0.157 | 0.157 |
| 2004 | 0.325 | 0.325 | 0.163 | 0.143 | 0.000 | 0.422 | 0.325 |
| 2005 | 0.325 | 0.325 | 0.163 | 0.143 | 0.000 | 0.392 | 0.325 |
| 2006 | 0.276 | 0.276 | 0.162 | 0.143 | 0.000 | 0.319 | 0.352 |
| 2007 | 0.269 | 0.269 | 0.157 | 0.143 | 0.000 | 0.321 | 0.330 |
| 2008 | 0.279 | 0.279 | 0.156 | 0.143 | 0.000 | 0.341 | 0.344 |
| 2009 | 0.289 | 0.289 | 0.157 | 0.143 | 0.000 | 0.356 | 0.357 |
| 2010 | 0.293 | 0.293 | 0.158 | 0.143 | 0.000 | 0.361 | 0.361 |
| 2011 | 0.295 | 0.295 | 0.159 | 0.143 | 0.000 | 0.362 | 0.362 |
| 2012 | 0.295 | 0.295 | 0.159 | 0.143 | 0.000 | 0.361 | 0.361 |
| 2013 | 0.295 | 0.295 | 0.159 | 0.143 | 0.000 | 0.361 | 0.361 |
| 2014 | 0.295 | 0.295 | 0.160 | 0.143 | 0.000 | 0.362 | 0.362 |
| 2015 | 0.296 | 0.296 | 0.160 | 0.143 | 0.000 | 0.362 | 0.362 |
| 2016 | 0.296 | 0.296 | 0.159 | 0.143 | 0.000 | 0.362 | 0.362 |
| *Catch* | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2003 | 1,400 | 1,400 | 1,400 | 1,400 | 1,400 | 1,400 | 1,400 |
| 2004 | 2,555 | 2,555 | 1,398 | 1,242 | 0 | 3,149 | 2,555 |
| 2005 | 2,063 | 2,063 | 1,324 | 1,201 | 0 | 2,192 | 2,063 |
| 2006 | 1,452 | 1,452 | 1,209 | 1,116 | 0 | 1,445 | 1,773 |
| 2007 | 1,308 | 1,308 | 1,087 | 1,044 | 0 | 1,358 | 1,459 |
| 2008 | 1,424 | 1,424 | 1,097 | 1,050 | 0 | 1,542 | 1,573 |
| 2009 | 1,605 | 1,605 | 1,188 | 1,122 | 0 | 1,751 | 1,758 |
| 2010 | 1,722 | 1,722 | 1,283 | 1,205 | 0 | 1,856 | 1,858 |
| 2011 | 1,761 | 1,761 | 1,343 | 1,262 | 0 | 1,874 | 1,874 |
| 2012 | 1,757 | 1,757 | 1,362 | 1,283 | 0 | 1,855 | 1,855 |
| 2013 | 1,752 | 1,752 | 1,369 | 1,289 | 0 | 1,849 | 1,849 |
| 2014 | 1,762 | 1,762 | 1,379 | 1,298 | 0 | 1,866 | 1,866 |
| 2015 | 1,776 | 1,776 | 1,390 | 1,310 | 0 | 1,880 | 1,880 |
| 2016 | 1,780 | 1,780 | 1,397 | 1,318 | 0 | 1,882 | 1,882 |

Table 1.19. Analysis of ecosystem considerations for BSAI pollock and the pollock fishery.

| Indicator | Observation | Interpretation | Evaluation |
|---|---|---|---|
| **Ecosystem effects on EBS pollock** | | | |
| *Prey availability or abundance trends* | | | |
| Zooplankton | Stomach contents, ichthyoplankton surveys, changes mean wt-at-age | Stable, data limited | Probably no concern |
| *Predator population trends* | | | |
| Marine mammals | Fur seals declining, Steller sea lions increasing slightly | Possibly lower mortality on pollock | Probably no concern |
| Birds | Stable, some increasing some decreasing | Affects young-of-year mortality | Probably no concern |
| Fish (Pollock, Pacific cod, halibut) | Stable to increasing | Possible increases to pollock mortality | |
| *Changes in habitat quality* | | | |
| Temperature regime | Cold years pollock distribution towards NW on average | Likely to affect surveyed stock | No concern (dealt with in model) |
| Winter-spring environmental conditions | Affects pre-recruit survival | Probably a number of factors | Causes natural variability |
| Production | Fairly stable nutrient flow from upwelled BS Basin | Inter-annual variability low | No concern |
| **Fishery effects on ecosystem** | | | |
| *Fishery contribution to bycatch* | | | |
| Prohibited species | Stable, heavily monitored | Likely to be safe | No concern |
| Forage (including herring, Atka mackerel, cod, and pollock) | Stable, heavily monitored | Likely to be safe | No concern |
| HAPC biota | Likely minor impact | Likely to be safe | No concern |
| Marine mammals and birds | Very minor direct-take | Safe | No concern |
| Sensitive non-target species | Likely minor impact | Data limited, likely to be safe | No concern |
| *Fishery concentration in space and time* | Generally more diffuse | Mixed potential impact (fur seals vs Steller sea lions) | Possible concern |
| *Fishery effects on amount of large size target fish* | Depends on highly variable year-class strength | Natural fluctuation | Probably no concern |
| *Fishery contribution to discards and offal production* | Decreasing | Improving, but data limited | Possible concern |
| *Fishery effects on age-at-maturity and fecundity* | New study initiated in 2002 | NA | Possible concern |

Table 1.20 Bycatch estimates (mt) of target species caught in the BSAI directed pollock fishery, 1997-2002 based on then NMFS Blend data.

| | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|
| Pacific Cod | 8,478 | 6,560 | 3,220 | 3,432 | 3,879 | 5,928 |
| Flathead Sole | 2,353 | 2,118 | 1,885 | 2,510 | 2,199 | 1,844 |
| Rock Sole | 1,529 | 779 | 1,058 | 2,688 | 1,673 | 1,885 |
| Yellowfin Sole | 606 | 1,762 | 350 | 1,466 | 594 | 768 |
| Arrowtooth Flounder | 1,155 | 1,762 | 273 | 979 | 529 | 607 |
| Pacific Ocean Perch | 512 | 692 | 121 | 22 | 574 | 545 |
| Atka Mackerel | 229 | 91 | 165 | 2 | 41 | 221 |
| Rex Sole | 151 | 68 | 34 | 10 | 103 | 169 |
| Greenland Turbot | 125 | 178 | 30 | 52 | 68 | 70 |
| Alaska Plaice | 1 | 14 | 3 | 147 | 14 | 50 |
| All other | 93 | 41 | 31 | 77 | 118 | 103 |

Table 1.21 Bycatch estimates (mt) of non-target species caught in the BSAI directed pollock fishery, 1997-2002 based on observer data.

| Data | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|
| Jellyfish | 6,632 | 6,129 | 6,176 | 9,361 | 3,095 | 1,530 |
| Squid | 1,538 | 1,236 | 475 | 379 | 1,776 | 1,708 |
| Skates | 350 | 406 | 376 | 598 | 628 | 870 |
| Otherfish (non specified) | 222 | 139 | 156 | 236 | 156 | 134 |
| Sculpins | 109 | 188 | 67 | 185 | 199 | 199 |
| Sleeper shark | 105 | 74 | 77 | 104 | 206 | 149 |
| Smelts | 20 | 30 | 39 | 49 | 72 | 15 |
| Grenadiers | 36 | 41 | 79 | 33 | 12 | 6 |
| Salmon shark | 7 | 16 | 25 | 20 | 22 | 27 |
| Starfish | 7 | 58 | 7 | 6 | 13 | 17 |
| Shark | 16 | 45 | 10 | 0 | 2 | 2 |
| Benthic invertebrates | 3 | 26 | 7 | 2 | 1 | 2 |
| Sponges | 1 | 21 | 2 | 0 | 2 | 0 |
| Octopus | 1 | 5 | 0 | 1 | 5 | 8 |
| Crabs | 1 | 8 | 1 | 1 | 2 | 1 |
| Anemone | 3 | 2 | 0 | 6 | 0 | 1 |
| Tunicate | 0 | 2 | 1 | 0 | 4 | 4 |
| Unidentified invertebrates | 0 | 3 | 0 | 4 | 0 | 0 |
| Seapen/whip | 0 | 0 | 0 | 1 | 1 | 2 |
| Lanternfish | 0 | 0 | 0 | 0 | 0 | 3 |
| Birds | 0 | 2 | 1 | 0 | 0 | 0 |
| Echinoderms | 1 | 3 | 0 | 0 | 0 | 0 |
| Sandfish | 0 | 0 | 0 | 0 | 0 | 0 |
| Shrimp | 0 | 0 | 0 | 0 | 0 | 0 |
| Sticheidae | 0 | 0 | 0 | 0 | 0 | 0 |
| Coral | 0 | 0 | 0 | 0 | 0 | 0 |
| Dogfish | | 0 | 0 | 0 | 0 | 0 |
| Sandlance | 0 | | | 0 | | 0 |

Table 1.22. Summary results for Model 1, EBS pollock. Tonnage units are thousands of metric tons.

| 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 | 0.002 | 0.015 | 0.109 | 0.426 | 0.896 | 1.375 | 1.694 | 1.750 | 1.500 | 1.258 | 1.195 | 1.195 | 1.195 | 1.195 | 1.195 |

| Base model | **Model 1** |
|---|---|
| Tier (2003) | 1 |
| Age 3+ 2004 begin-year biomass | **11,217** t |
| 2003 Spawning biomass | **4,079** t |
| $B_{msy}$ | **2,468** t |
| $B_{40\%}$ | **2,835** t |
| $B_{35\%}$ | **2,481** t |
| $B_{100\%}$ | **7,232** t |
| $B_0$ | **6,256** t |
| **Yield Considerations** | |
| Year 2003 Harmonic Mean $F_{msy}$ Yield | **2,562** t |
| Year 2003 Yield $F_{40\%}$ (adjusted) | **2,527** t |
| Full Selection F's | |
| $F_{msy}$ | **0.962** |
| $F_{40\%}$ | **0.569** |
| $F_{35\%}$ | **0.738** |

## Figures

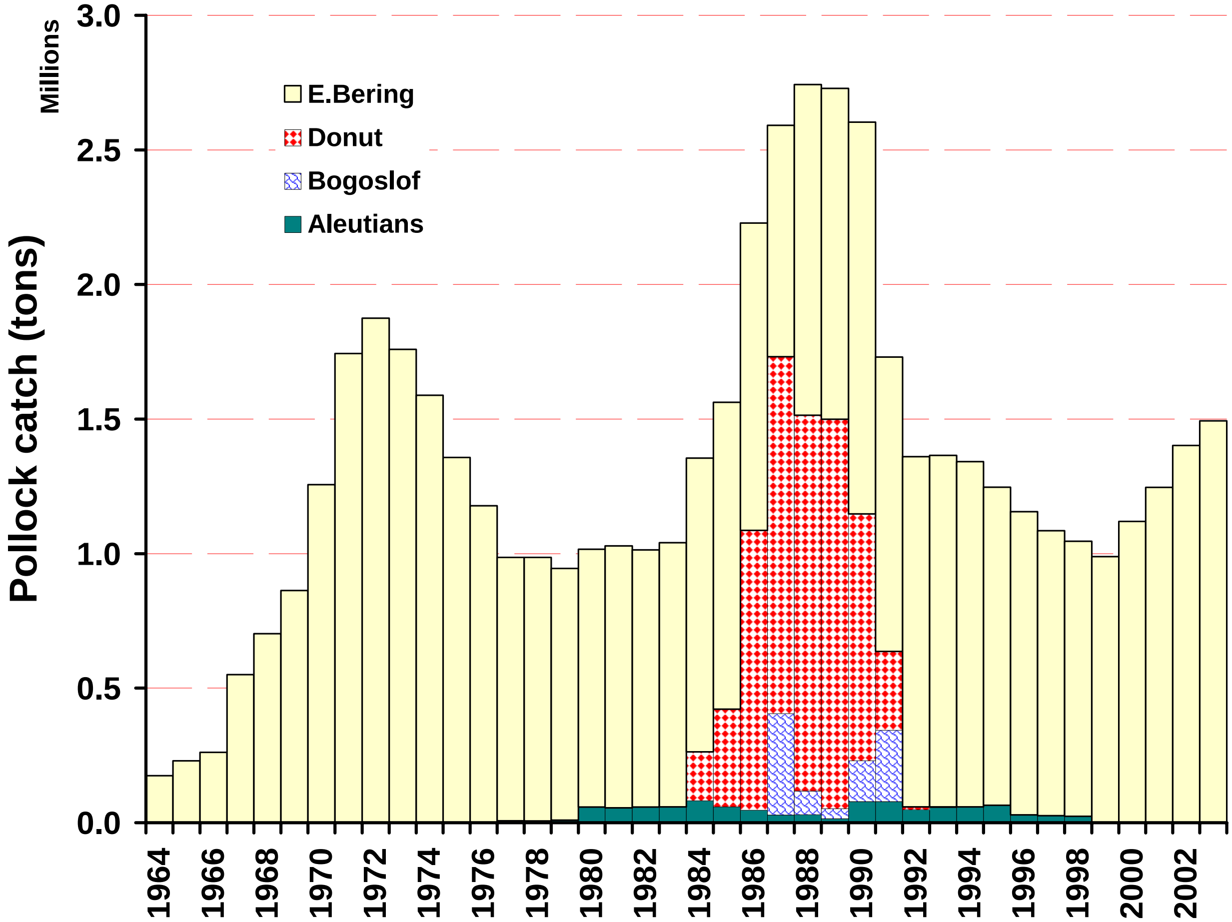



Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-2003.

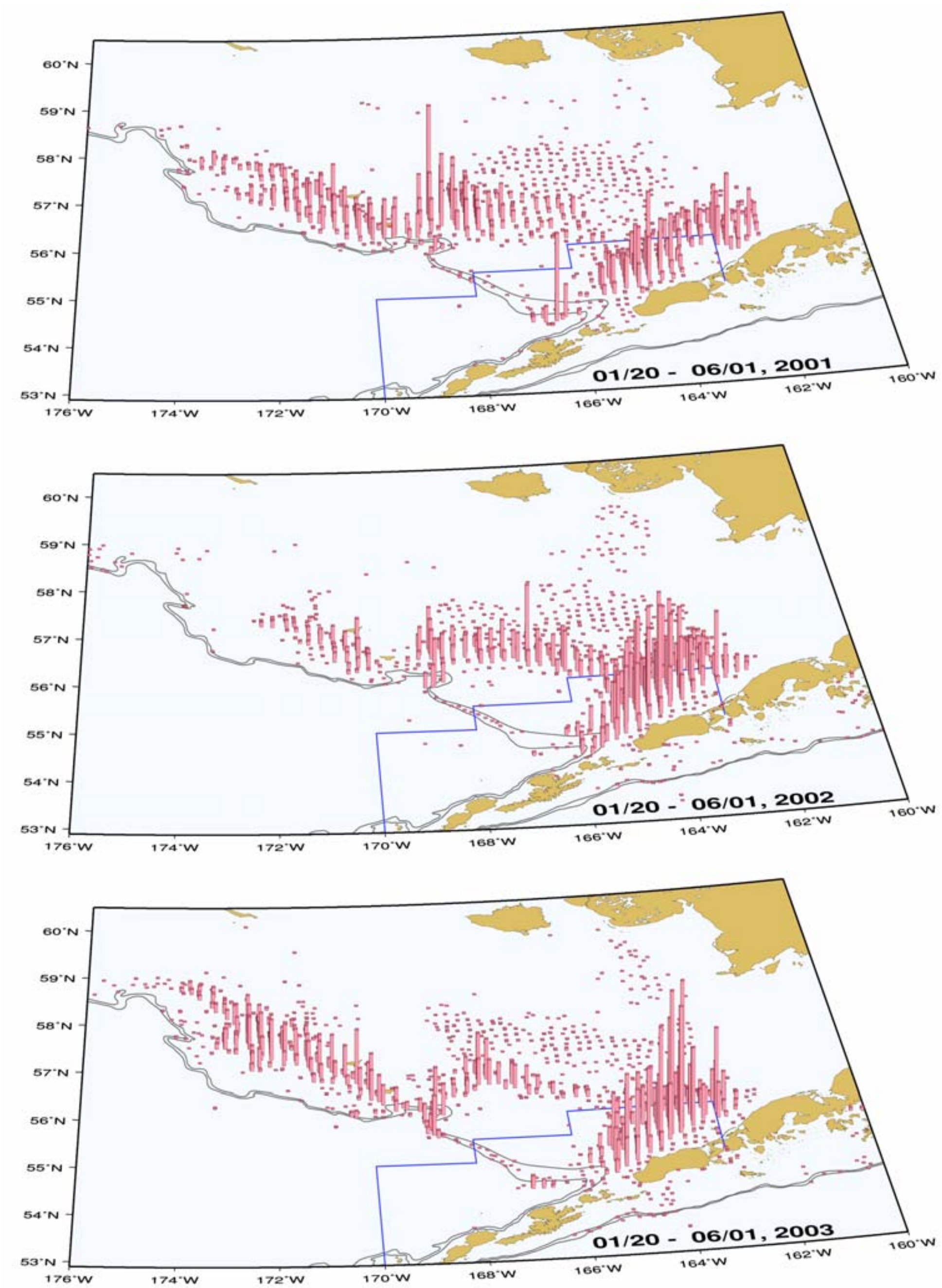



Figure 1.2. Concentrations of the pollock fishery 2001-2003, January - June on the EBS shelf. Line delineates SCA (sea lion conservation area). The column height represents relative removal on the same scale in all years.

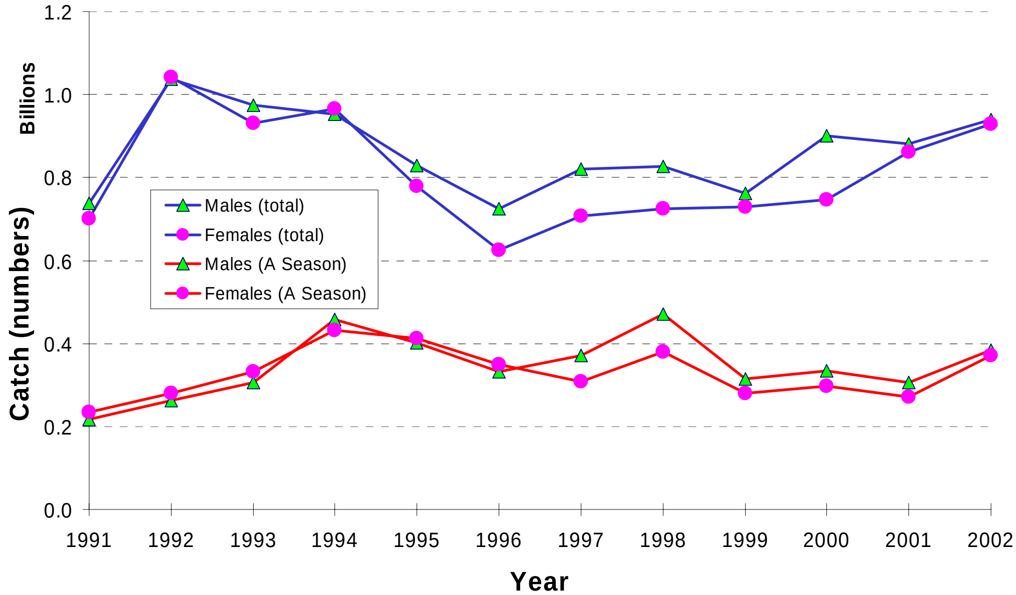



Figure 1.3. Estimate of EBS pollock catch numbers by sex for the "A season" (January-June) and for the entire annual fishery, 1991-2002.

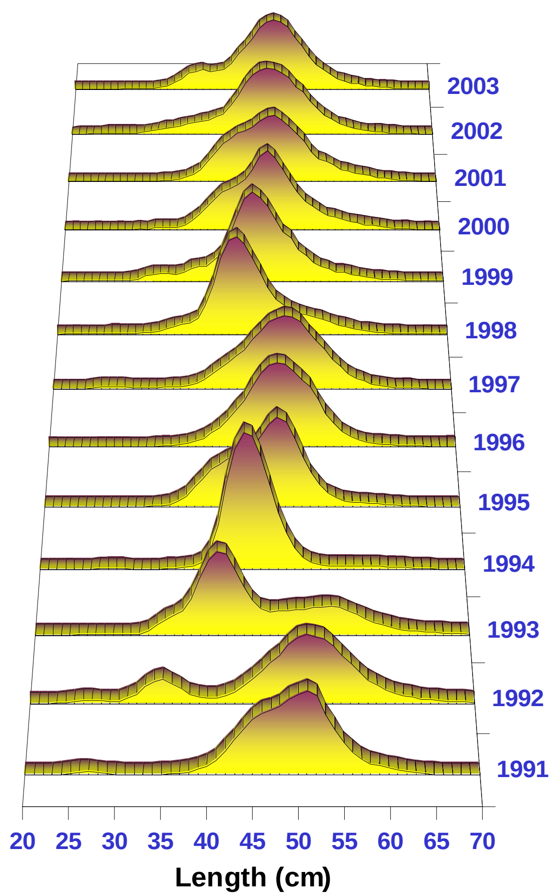



Figure 1.4. Fishery length frequency for the "A season" (January-June) EBS pollock, 1991-2003. Data for 2003 are preliminary.

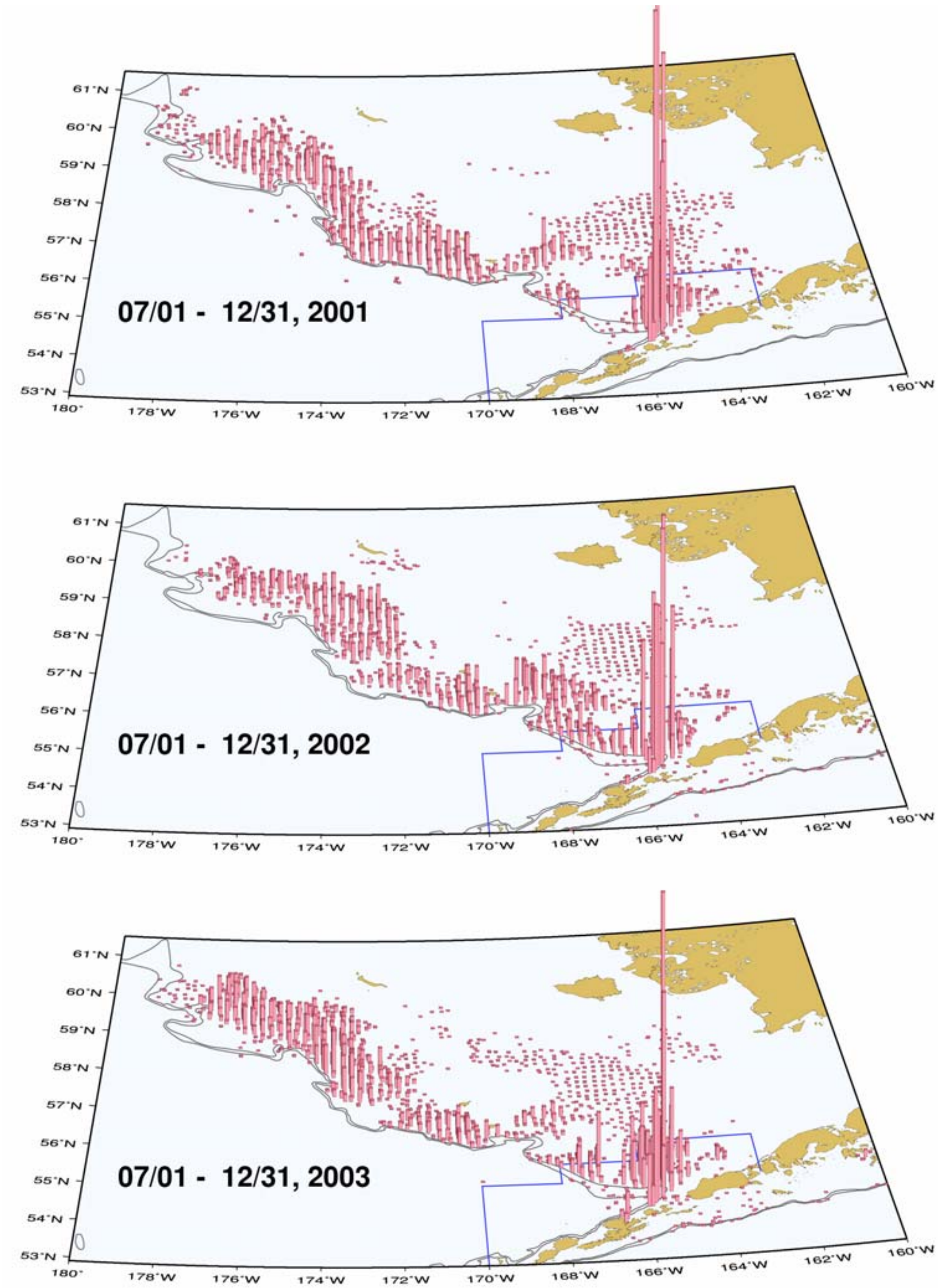



Figure 1.5. Concentrations of the pollock fishery 2001-2003, July – December on the EBS shelf. Line delineates SCA (sea lion conservation area). The density represents relative removal on the same scale over all years.

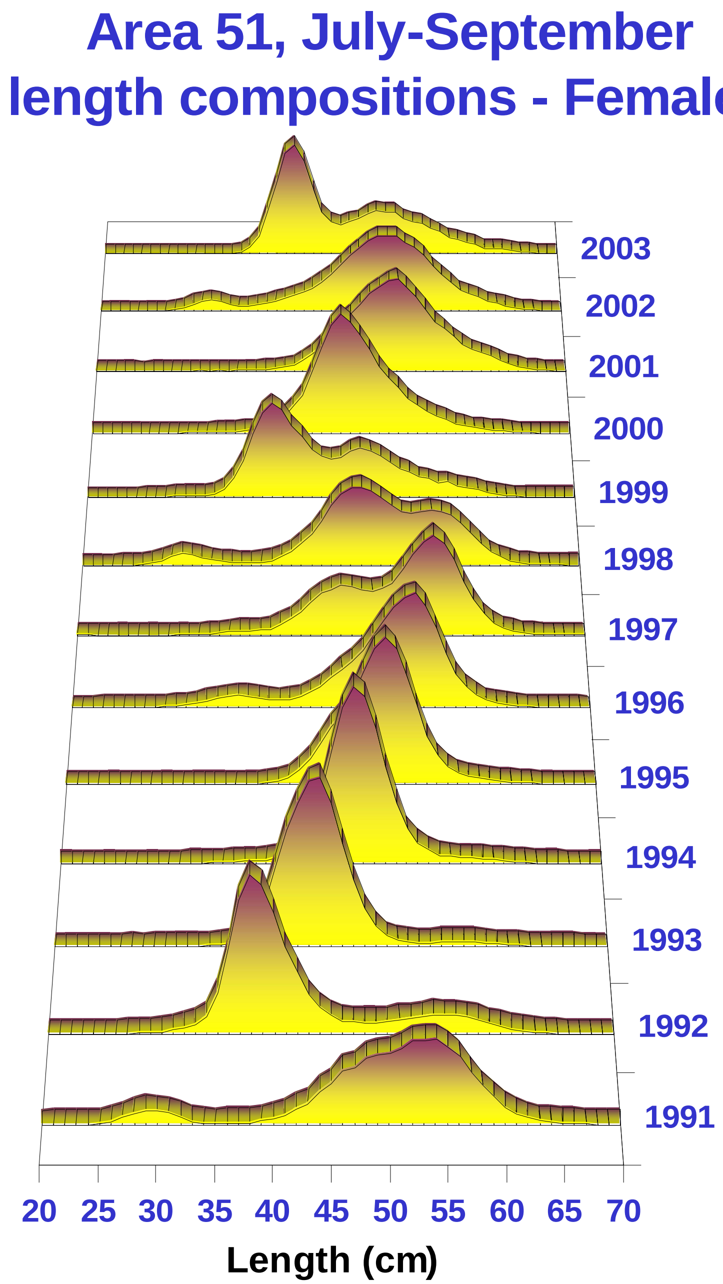



Figure 1.6. Length frequency of EBS pollock observed in period July-December for 1991-2003. Data for 2003 are preliminary.

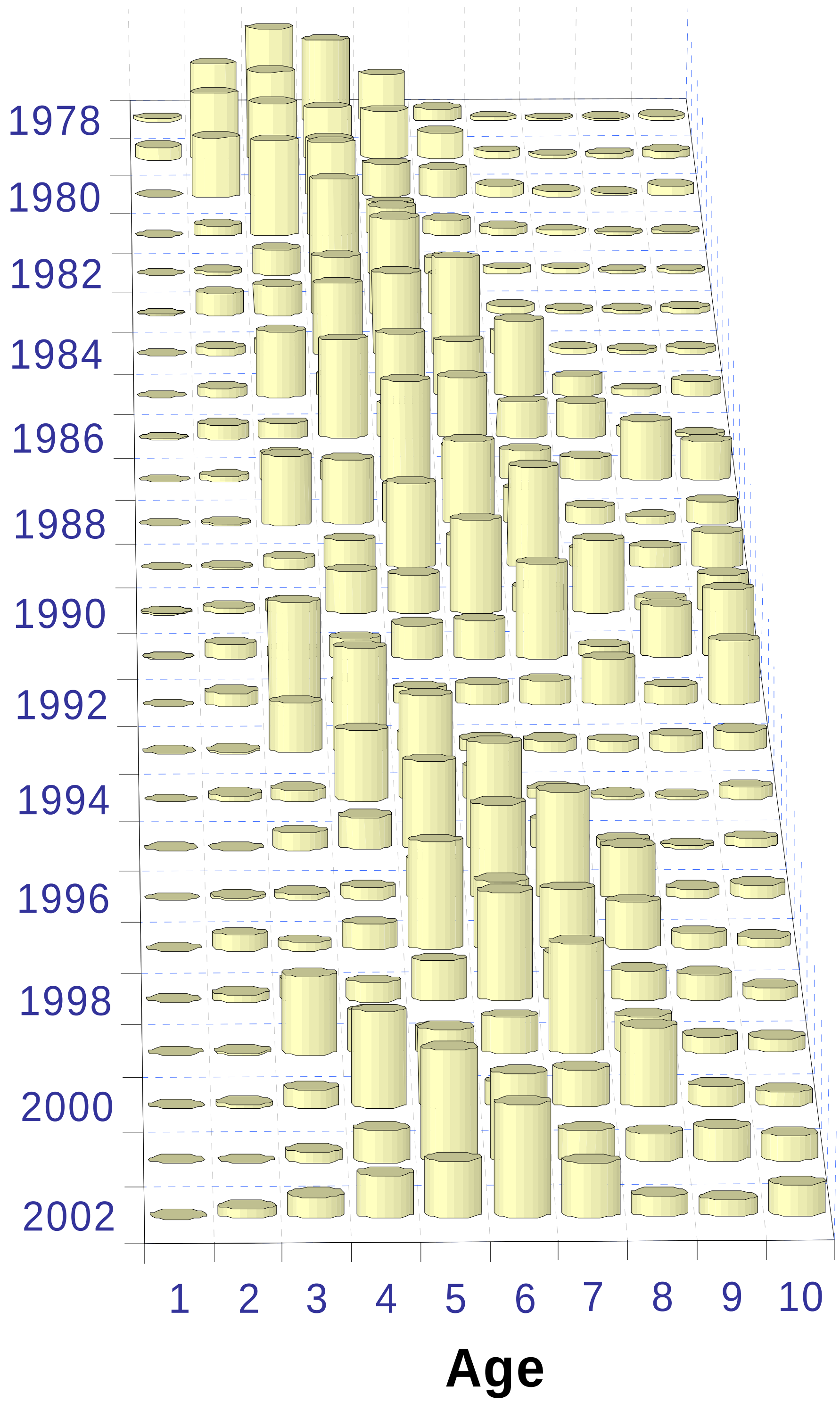



Figure 1.7. EBS walleye pollock fishery estimated catch-at-age data (proportions) for 1978-2002. Age 10 represents pollock age 10 and older.

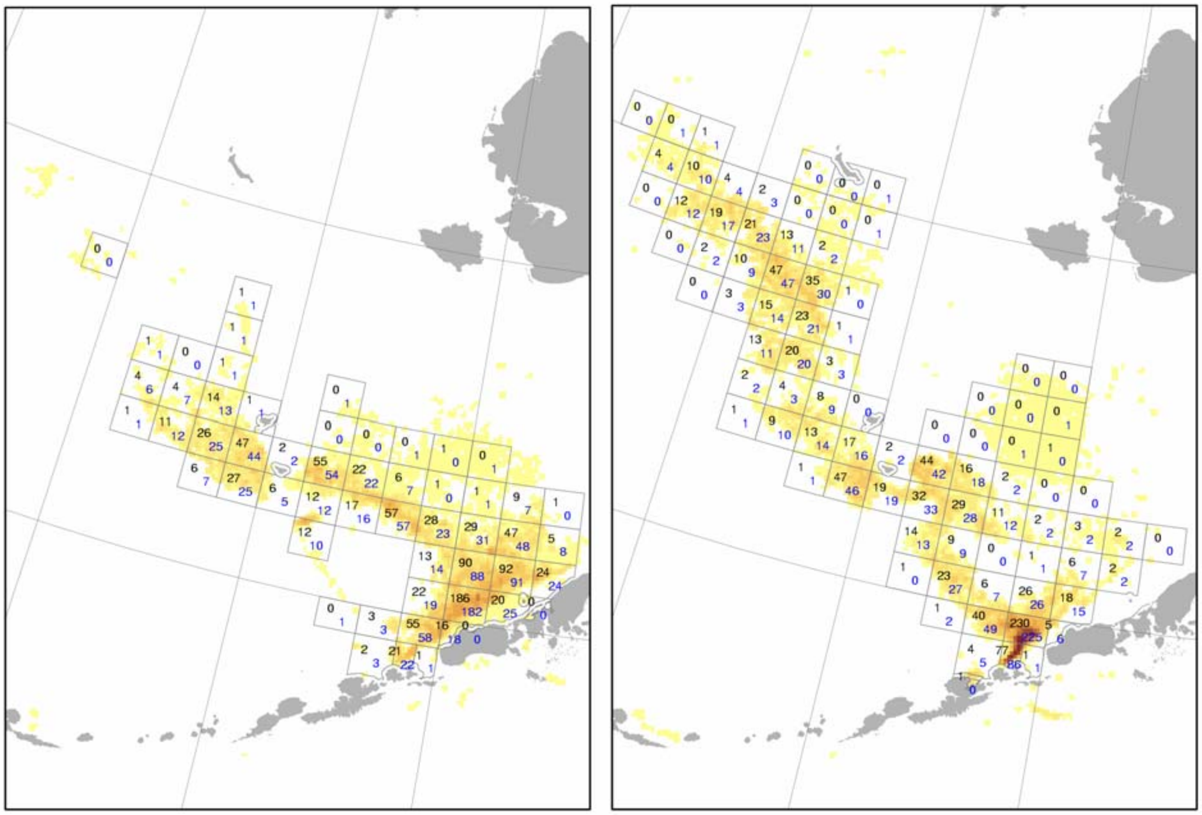


Figure 1.8. Sampling effort for lengths (upper left corner of grids) and otoliths (lower right corner of grids) of pollock in the EBS during 2002. Values represent the number-per-thousand of samples within each cell divided by the total number of samples for Jan-June (left panel) and July-Dec (right panel).

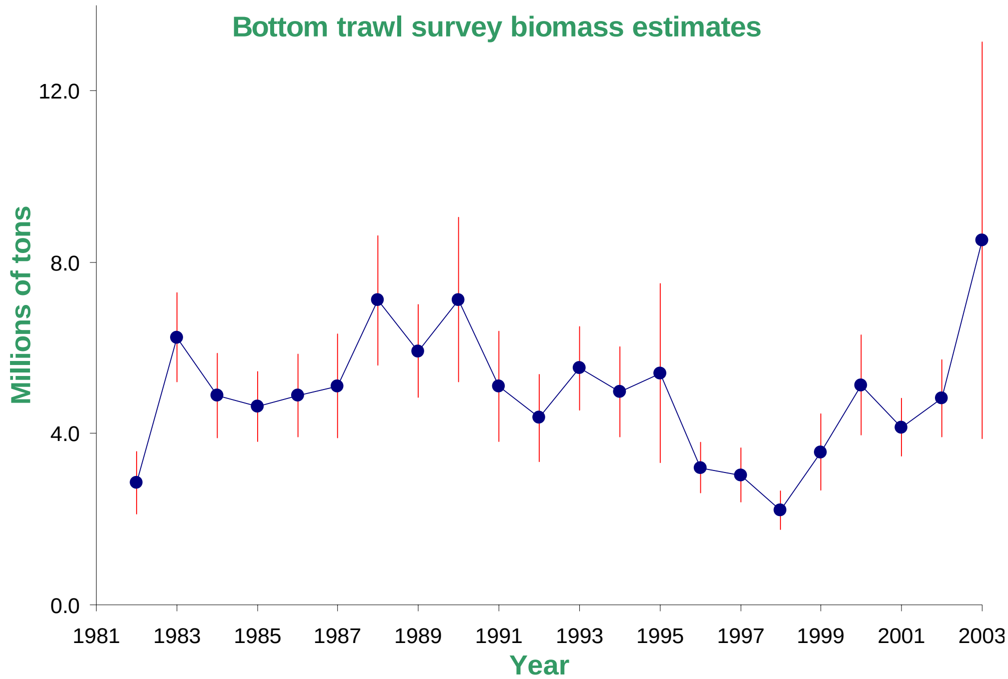



Figure 1.9. Bottom-trawl survey biomass estimates with approximate 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1982-2003.

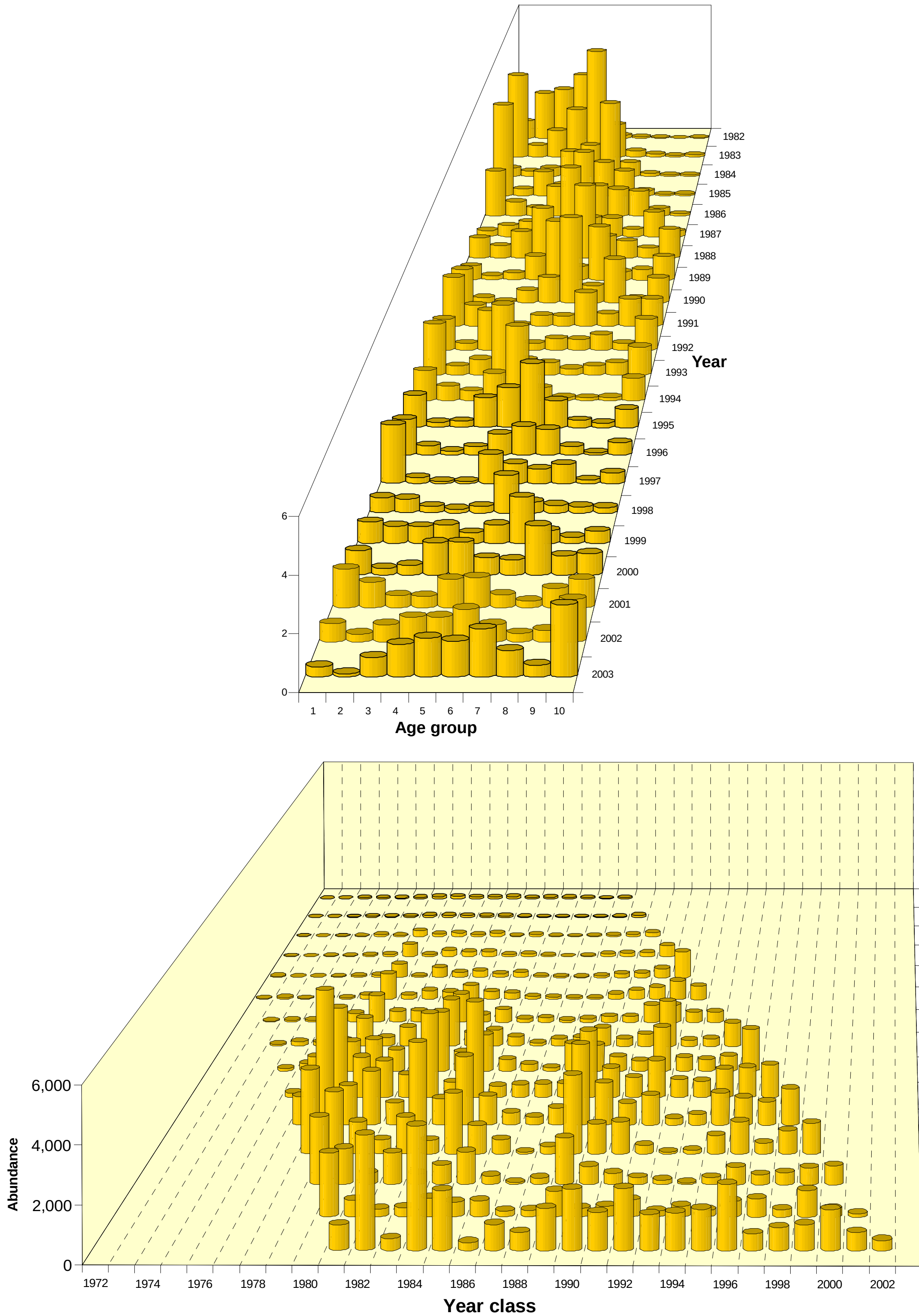



Figure 1.10. Pollock abundance levels by age and year plotted over time (top) and by individual cohorts (year classes) as estimated directly from the NMFS bottom-trawl surveys.

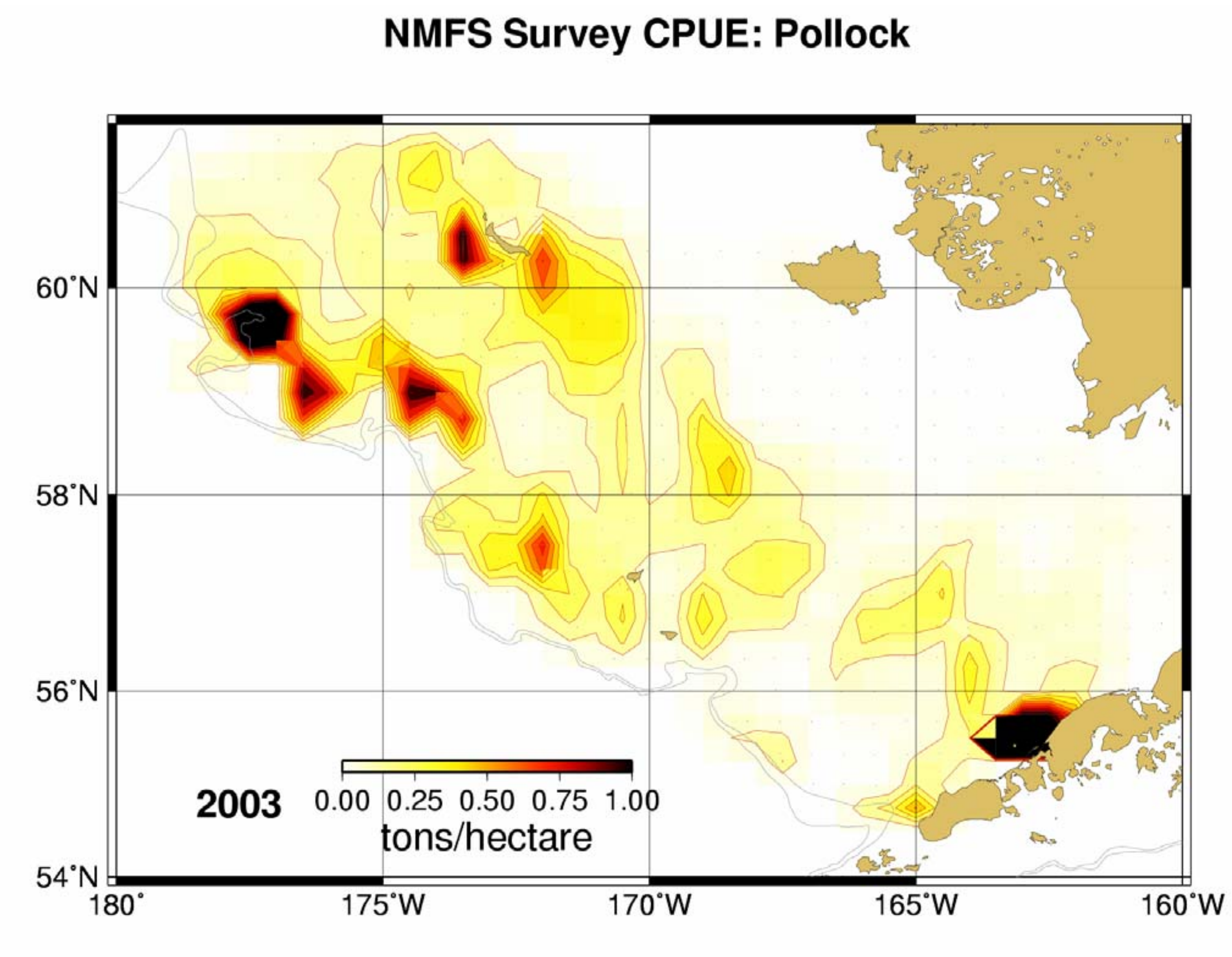



Figure 1.11. Maps showing the walleye pollock catch-per-unit effort observed during the 2003 NMFS EBS shelf bottom-trawl survey (bottom).

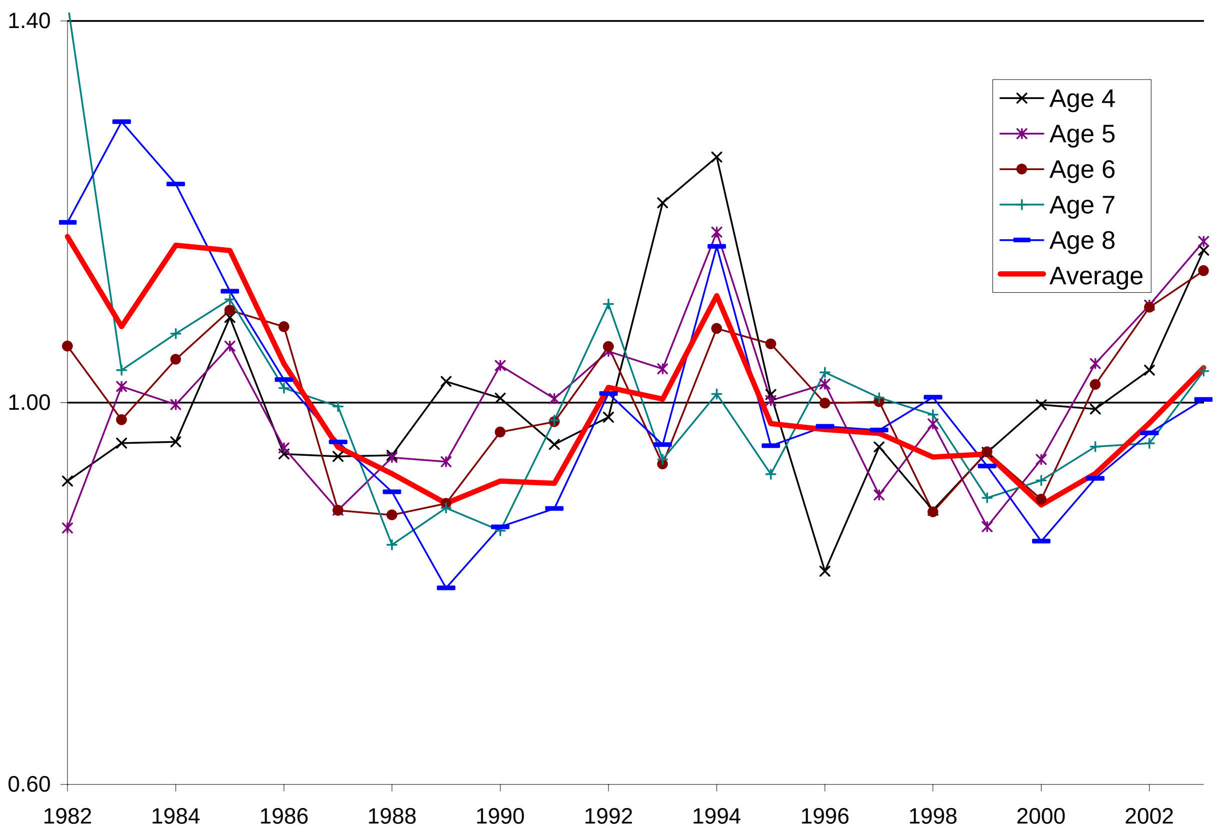



Figure 1.12. Trends in pollock average weights-at-age based on NMFS bottom trawl survey estimates, 1982-2003. Values are shown relative to their mean within each age or age group. Note that the length-weight relationship used here is constant; hence, the differences are how average lengths-at-age vary over time in terms of weight.

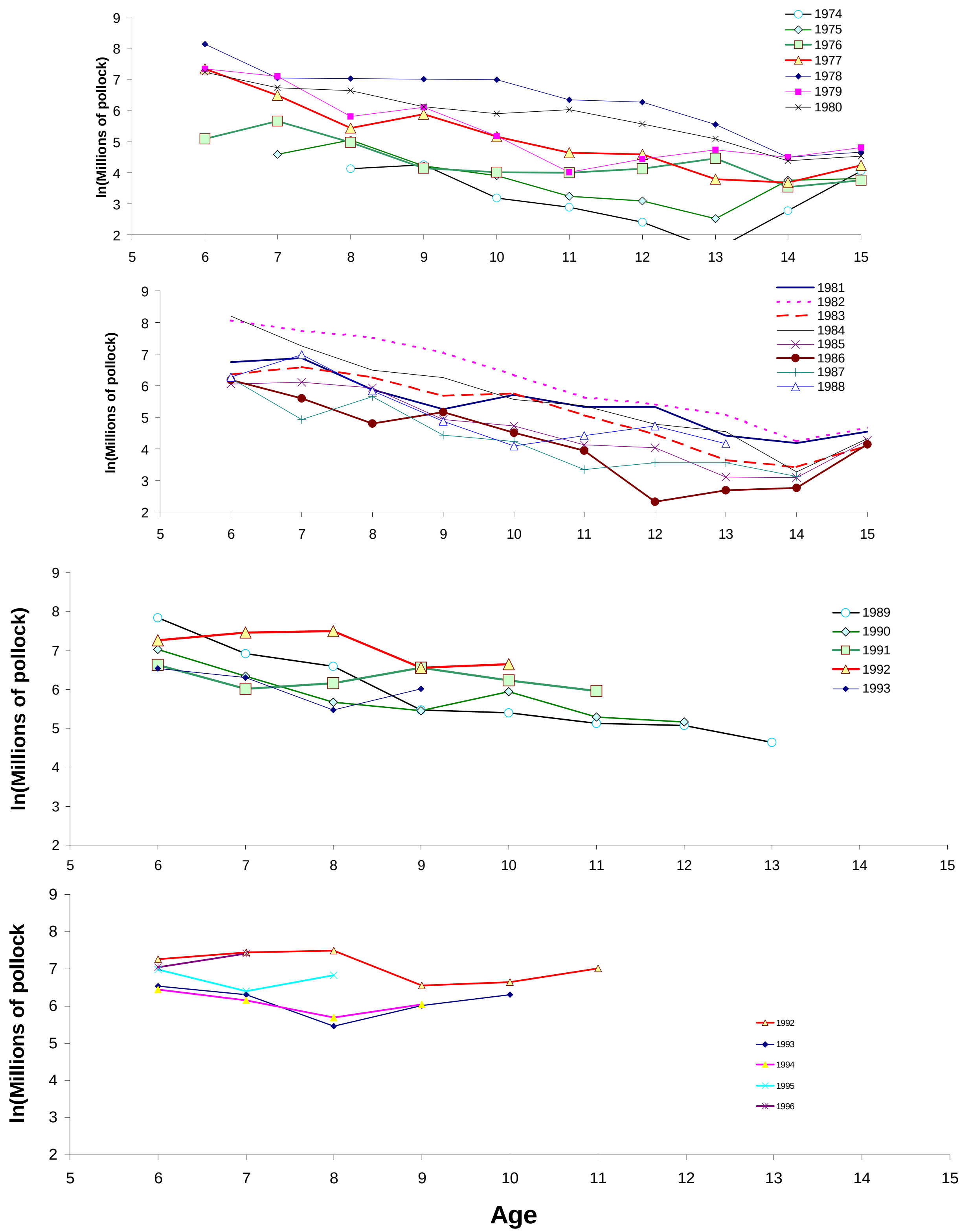



Figure 1.13. Log-abundance levels of individual EBS pollock cohorts (year classes) as estimated directly from the NMFS bottom-trawl surveys. Estimates at age 15 were omitted since they represent age 15 and older pollock.

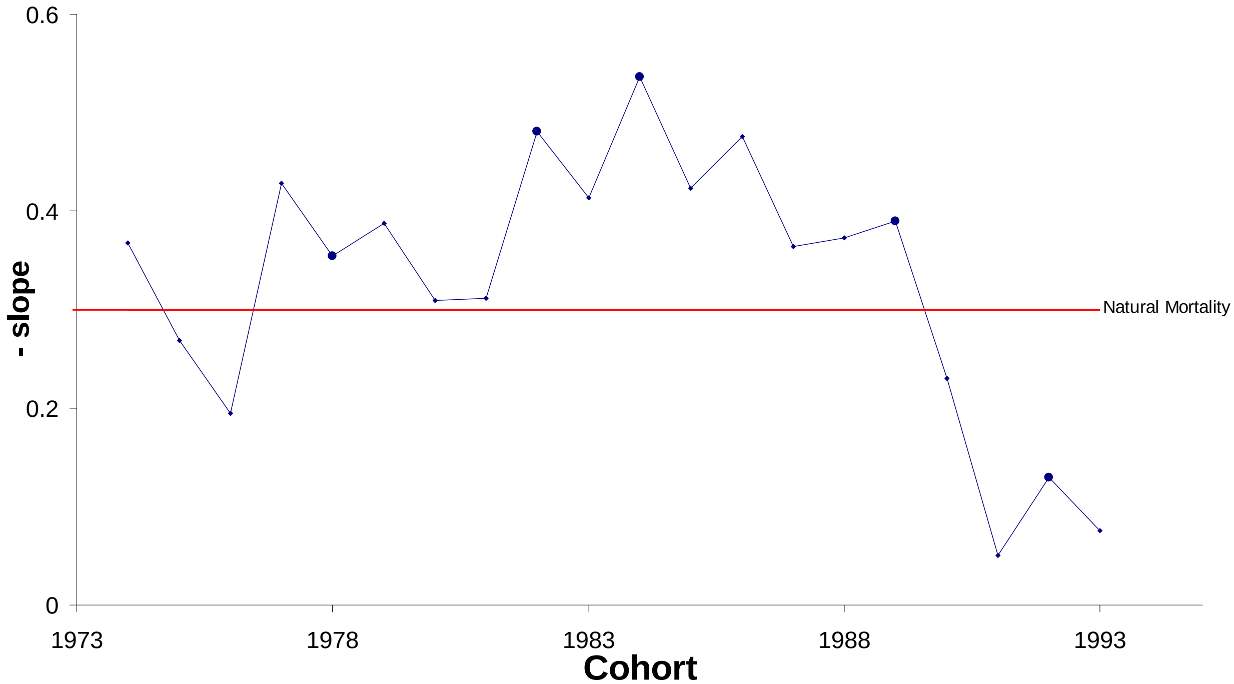



Figure 1.14. Negative slope estimates (as a proxy for total instantaneous mortality, Z) for 1974-1993 EBS pollock cohorts based on log-abundance levels as estimated directly from the NMFS bottom-trawl surveys. The assumed natural mortality rate for ages 3+ is shown as the single horizontal line. Year classes greater than average are indicated by the larger filled circles.

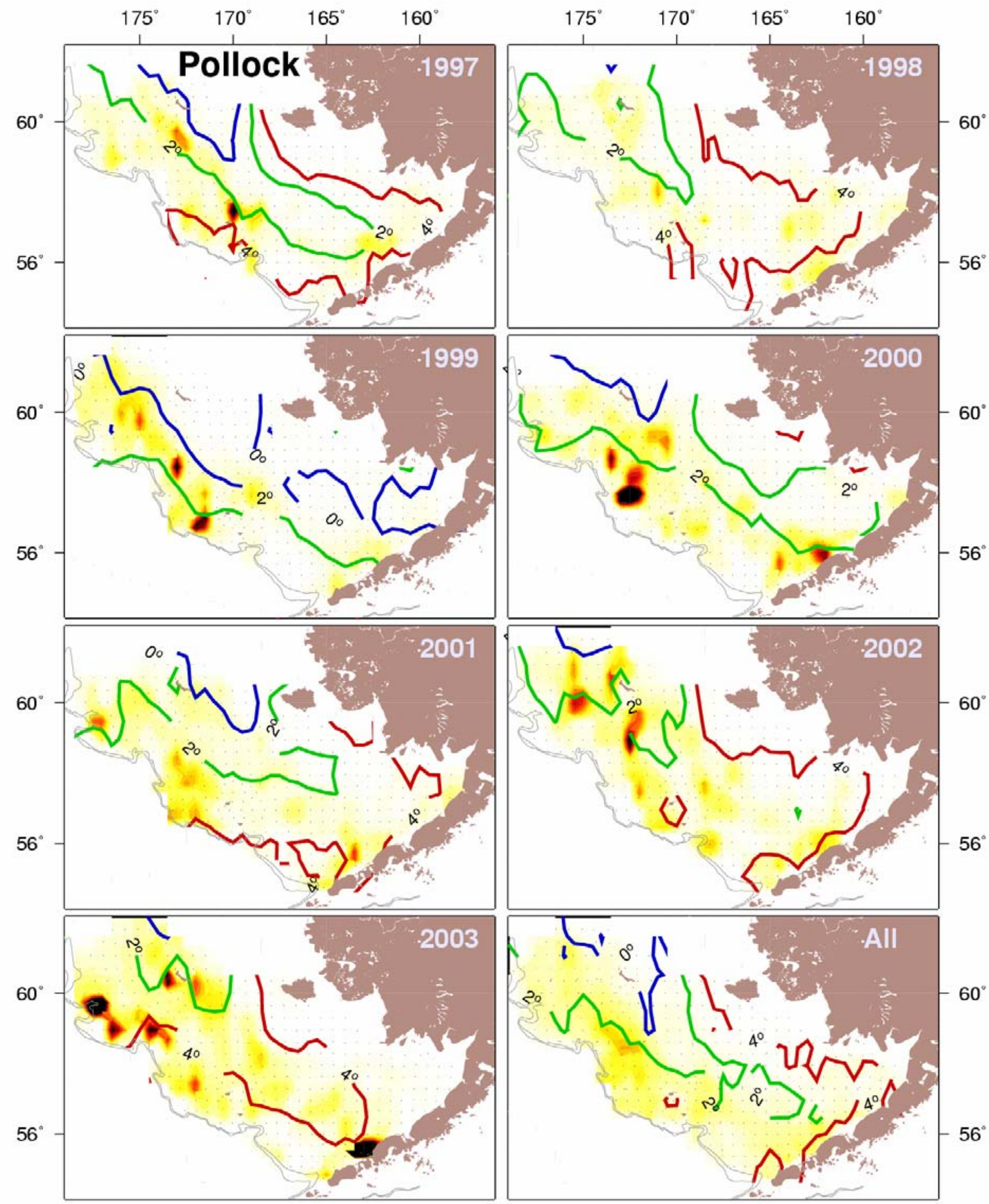



Figure 1.15. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius for 1997-2003. The average temperature and pollock density from 1982-2003 is shown in the lowest right panel.

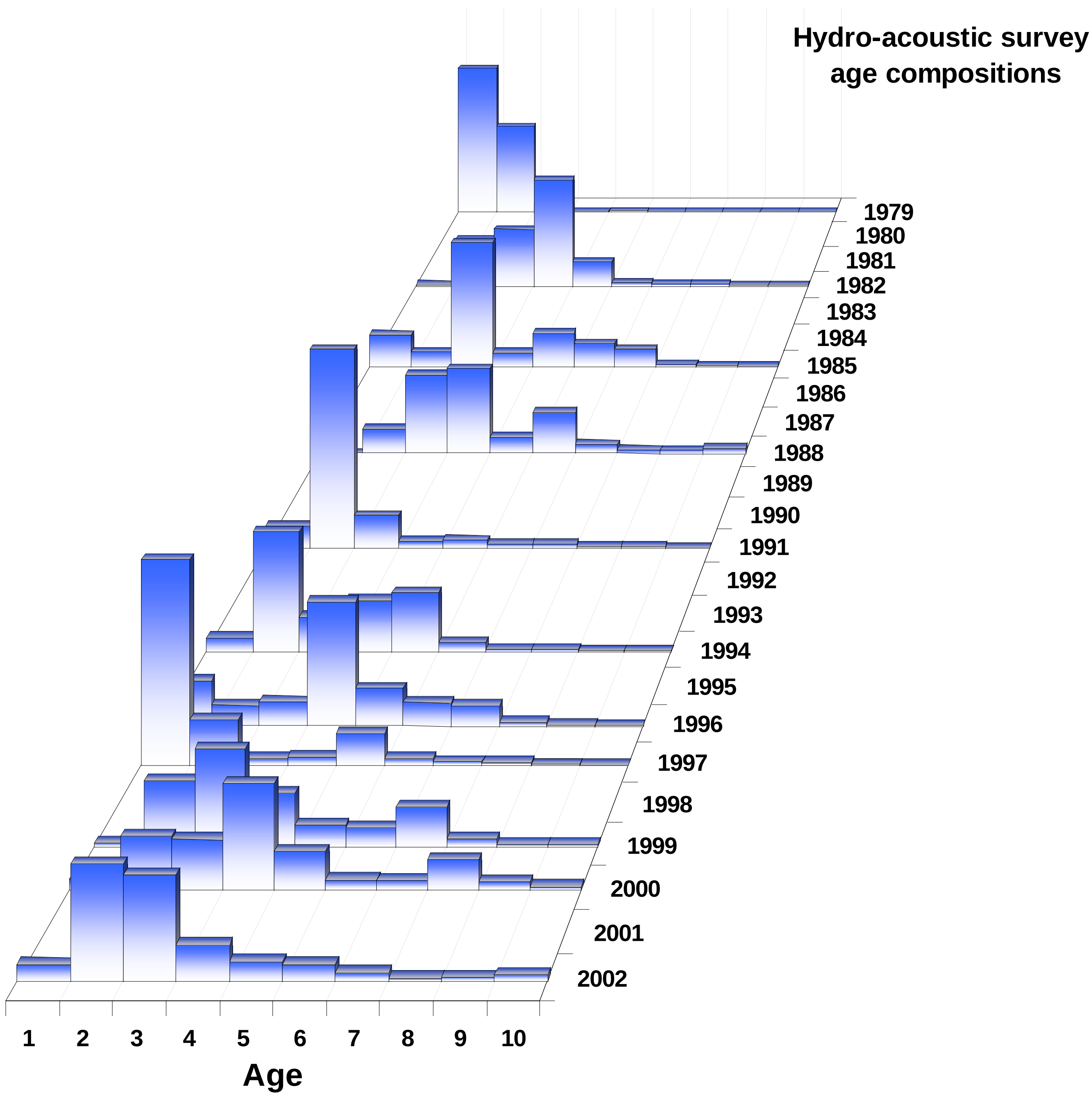



Figure 1.16. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-2002. Note: 2002 estimates represent revised age compositions based on age-length keys derived from the EIT age data.

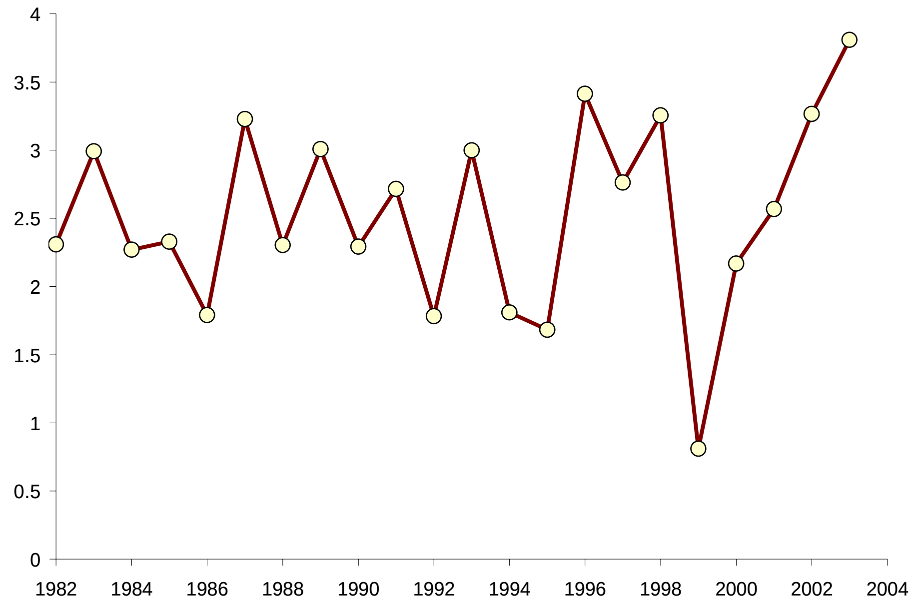



Figure 1.17. Mean summer bottom temperatures used to model bottom trawl survey pollock catchability, 1982-2003. (Note: these were normalized to have mean zero for use in the model).

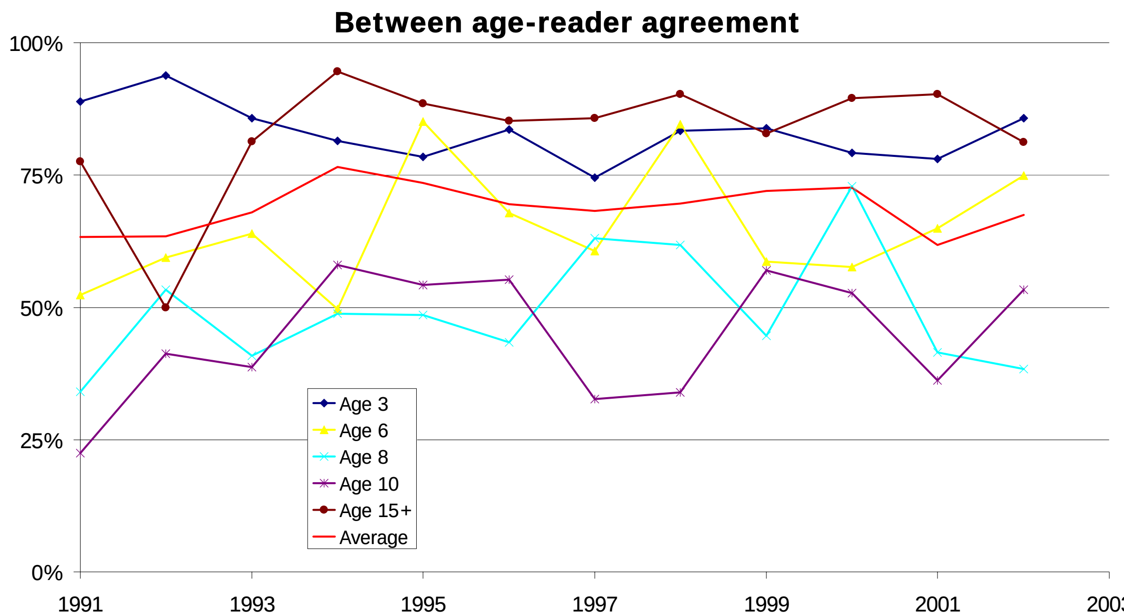



Figure 1.18. Trend in between age-reader agreement by age for EBS pollock based on observer and NMFS survey collections. The "Average" is the percent agreement over all age groups. The "Age 15+" represents the between-reader agreement that pollock specimens are age 15 or older (and hence have a higher agreement rate than say for age 10).

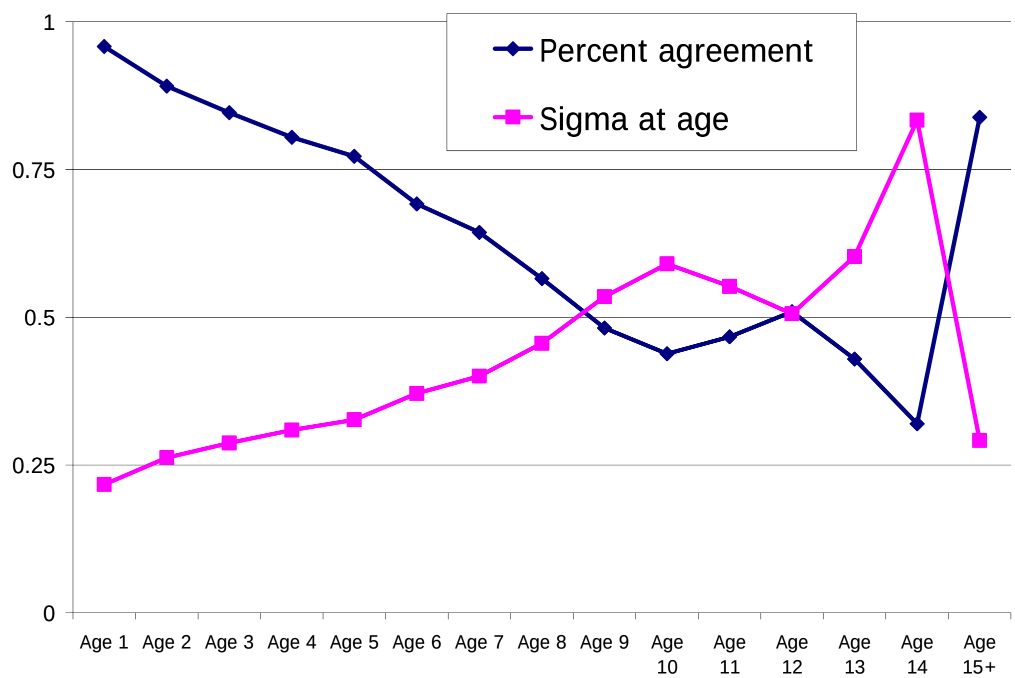



Figure 1.19. Average between-reader agreement and estimated standard deviations (Sigma at age) used to construct the ageing-error matrix. The "Age 15+" represents the between-reader agreement that pollock specimens are age 15 or older (and hence have a higher agreement rate than say for age 10).

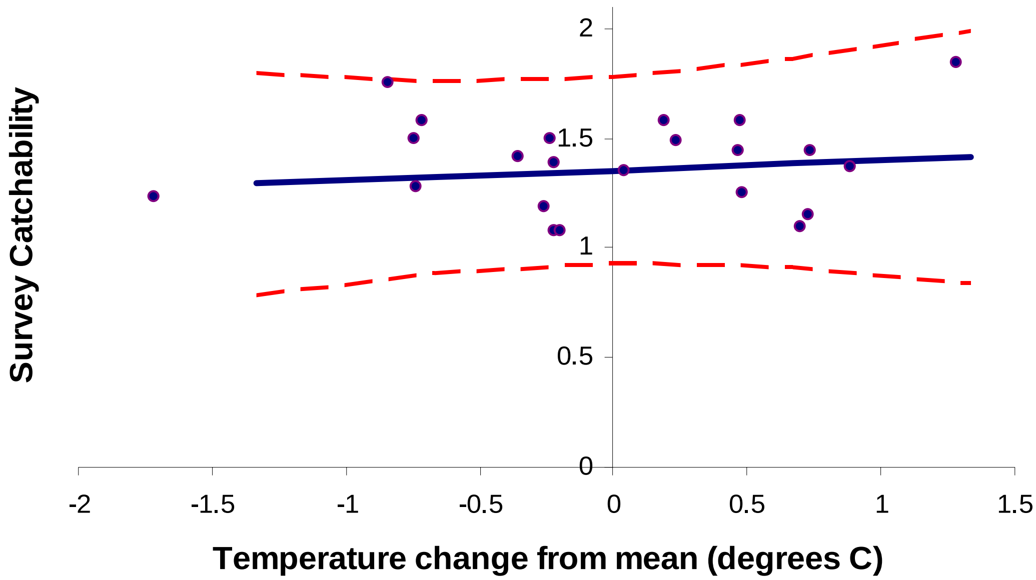



Figure 1.20. Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0) as under Model 4. Points represent residuals relative to survey estimates (i.e., $\hat{q}_t + \ln\left(\hat{I}_t / I_t\right)$ where $\hat{I}_t$ and $I_t$ represent the predicted and observed survey indices respectively and $\hat{q}_t$ is the expected catchability given the temperature anomaly in year *t*.

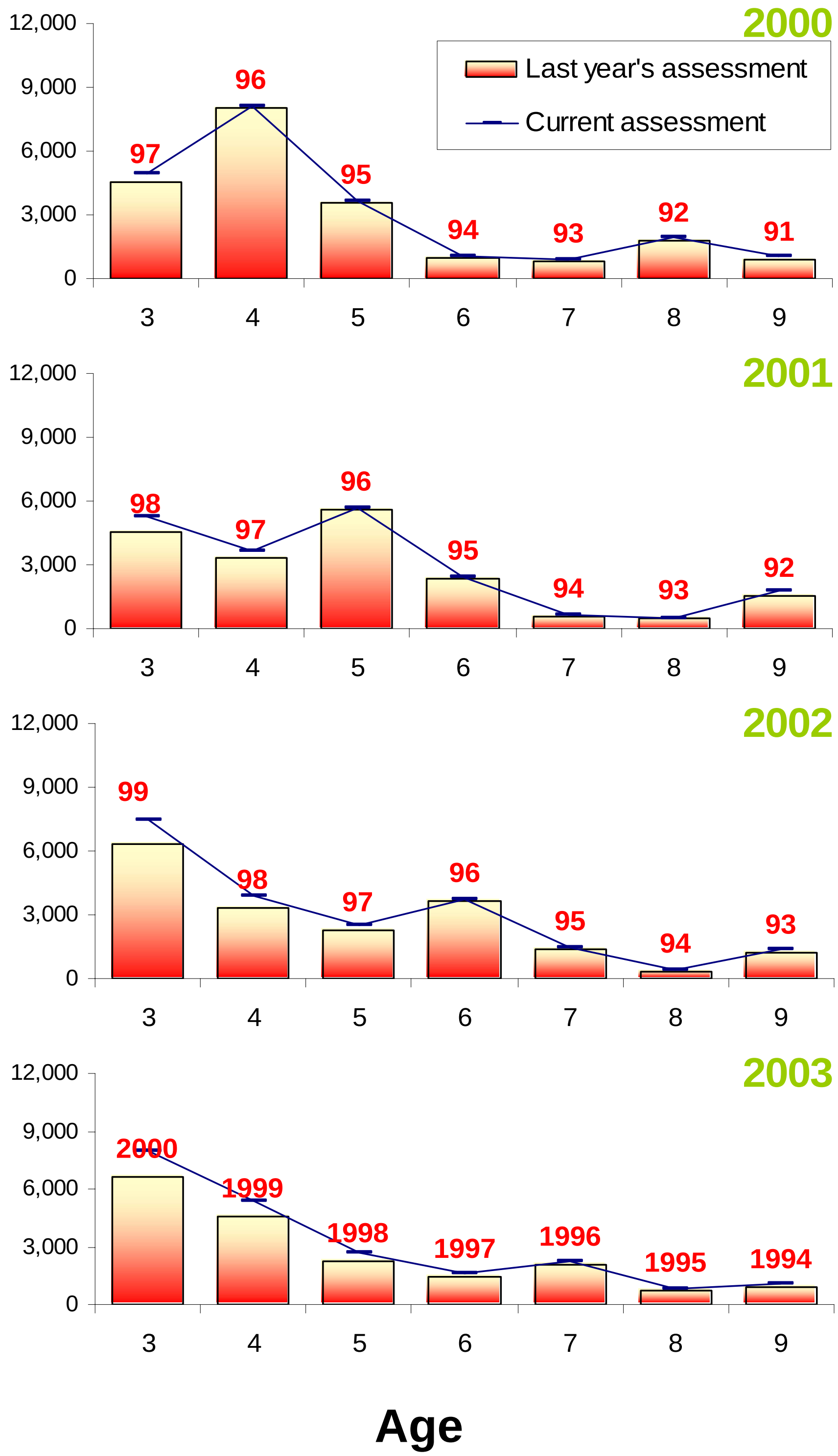



Figure 1.21. Projected EBS walleye pollock Model 1 population numbers at age compared with those presented in the last assessment (Model 1 from Ianelli *et al.*2001). Note that the "age 9" category represents all pollock age 9 and older.

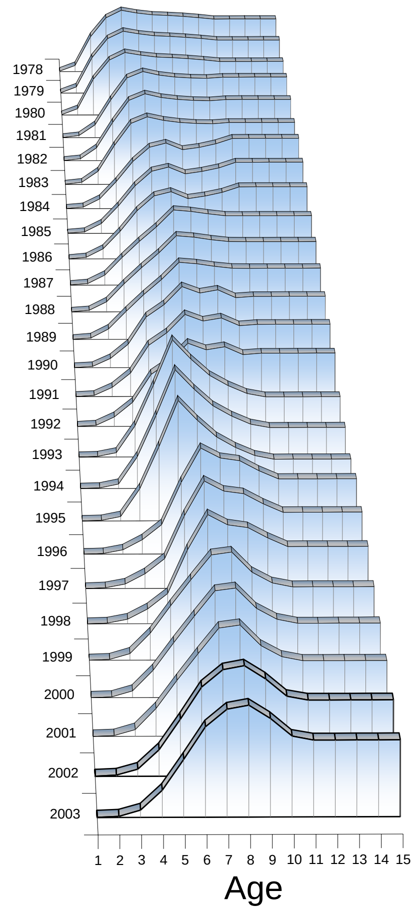



Figure 1.22. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-2003 estimated for Model 1.

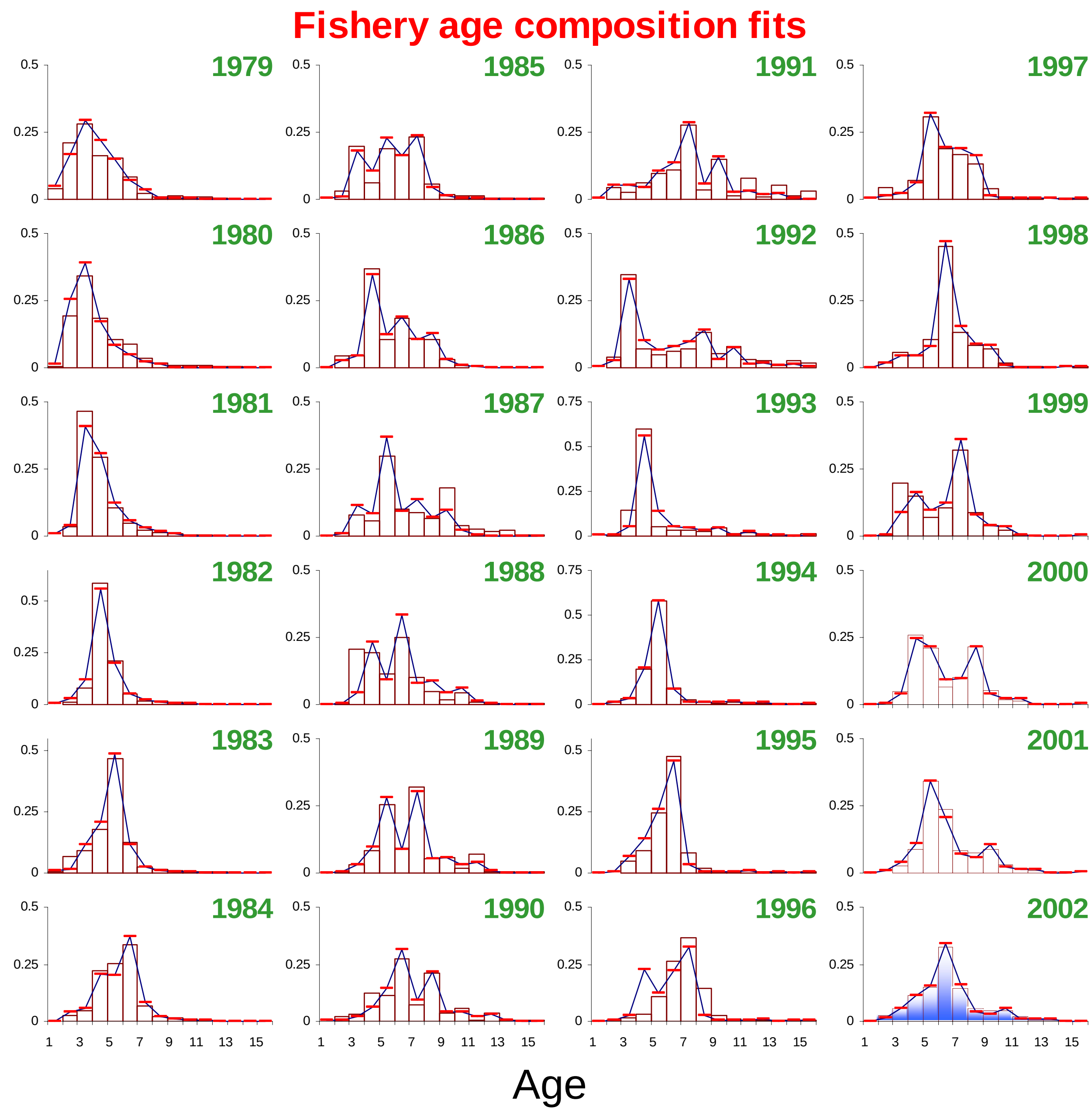



Figure 1.23. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1979-2002). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

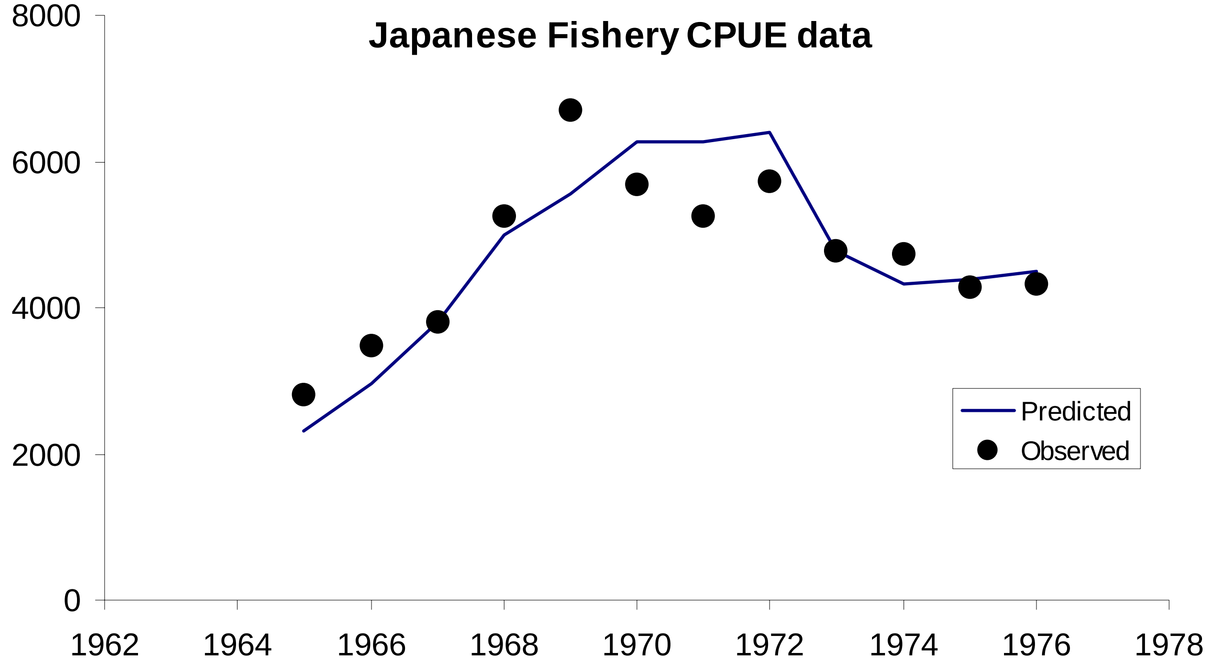
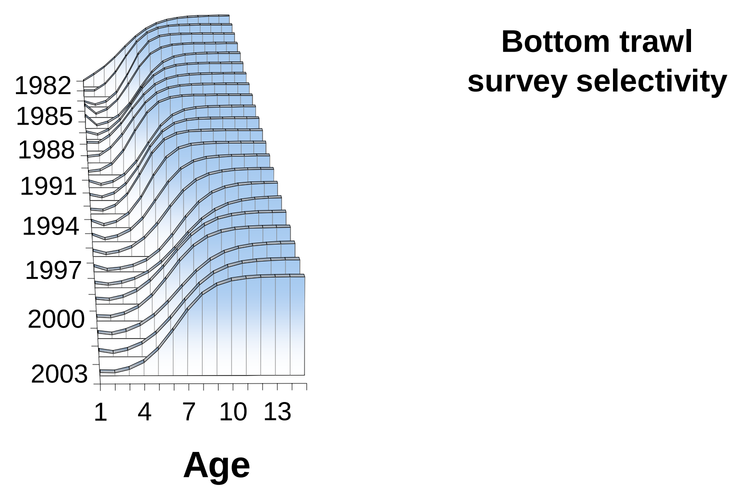



Figure 1.24. Model 1 fit to the EBS walleye pollock fishery CPUE data from Low and Ikeda (1980).



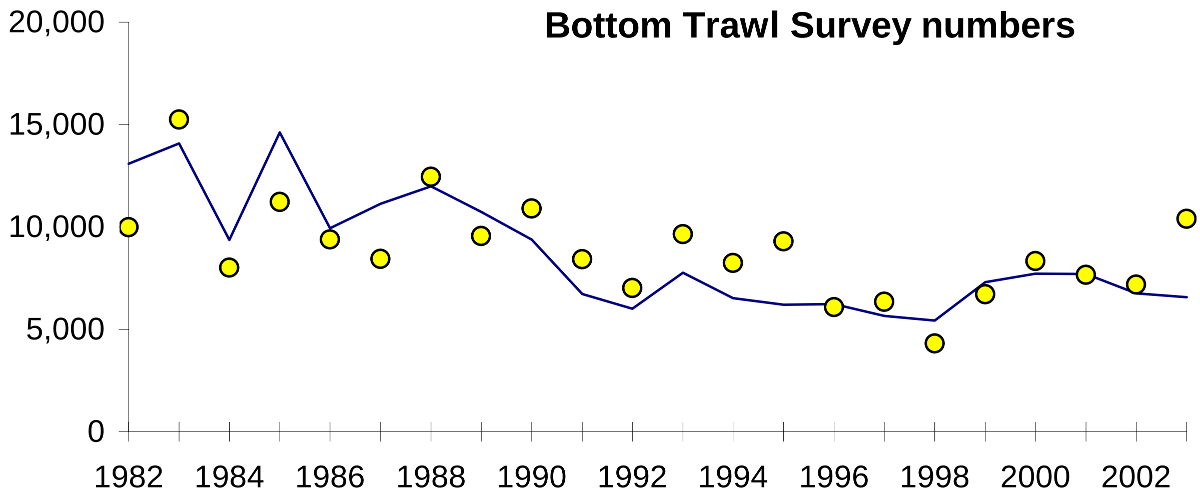




Figure 1.25. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS walleye pollock, Model 1.

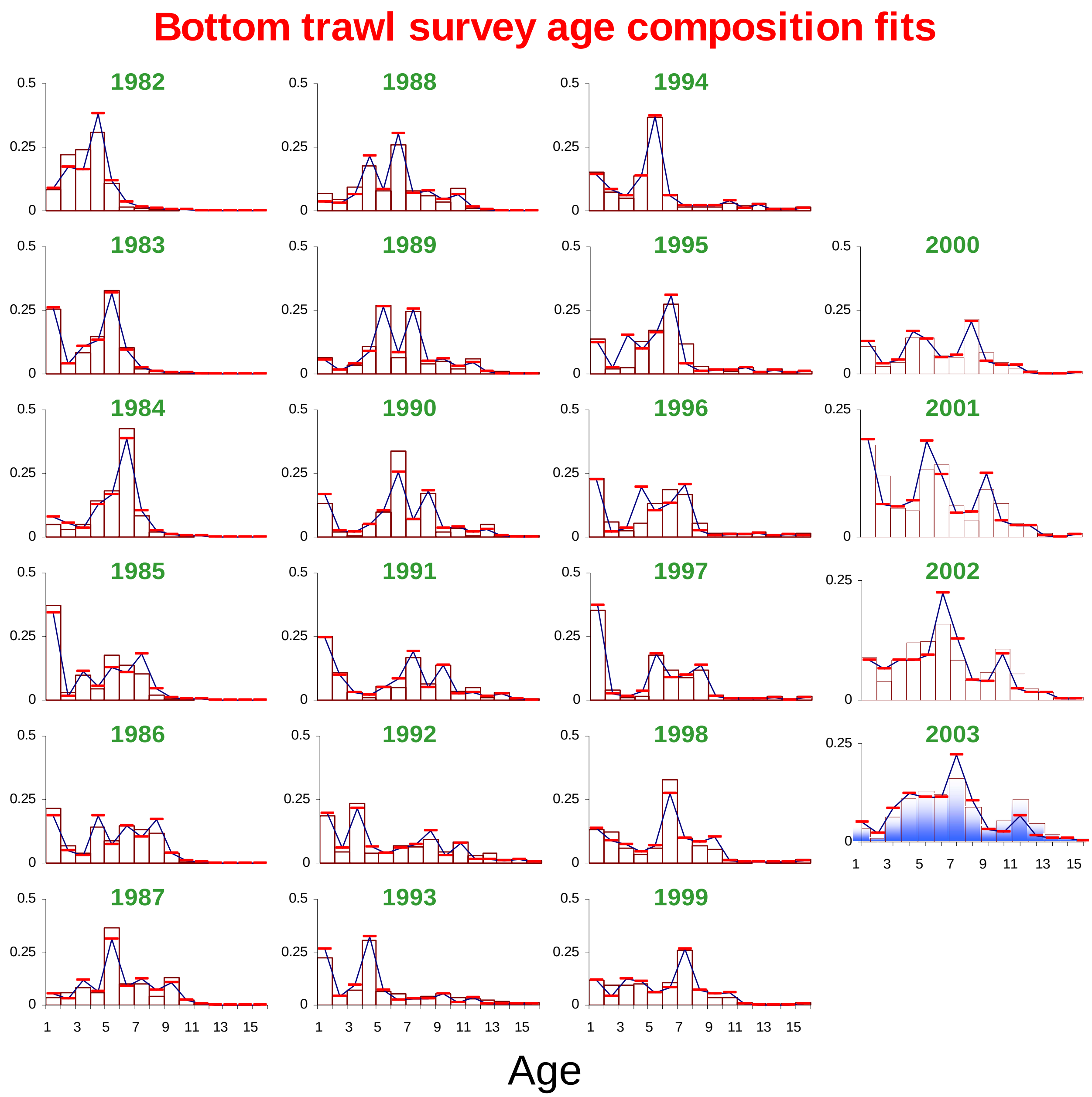
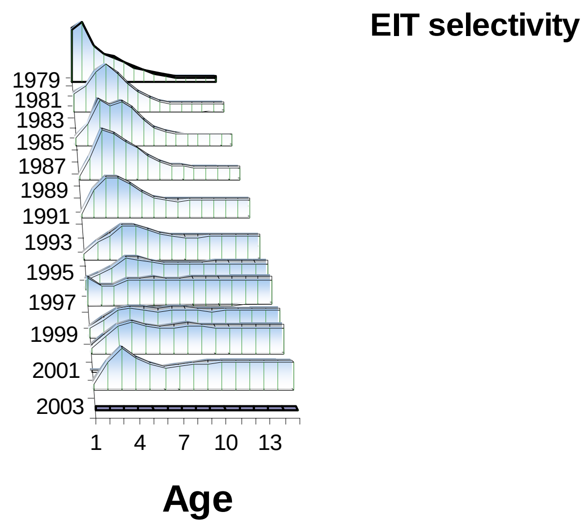



Figure 1.26. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded (2003).



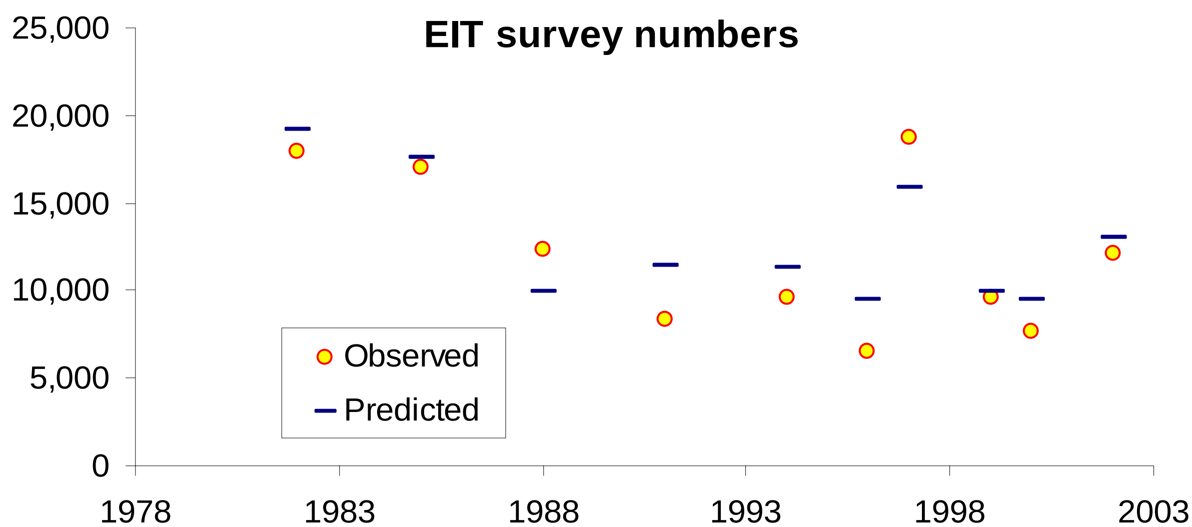




Figure 1.27. Model 1 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock. Note that the 1979 value (observed=115,424; predicted=47,127) are not plotted.

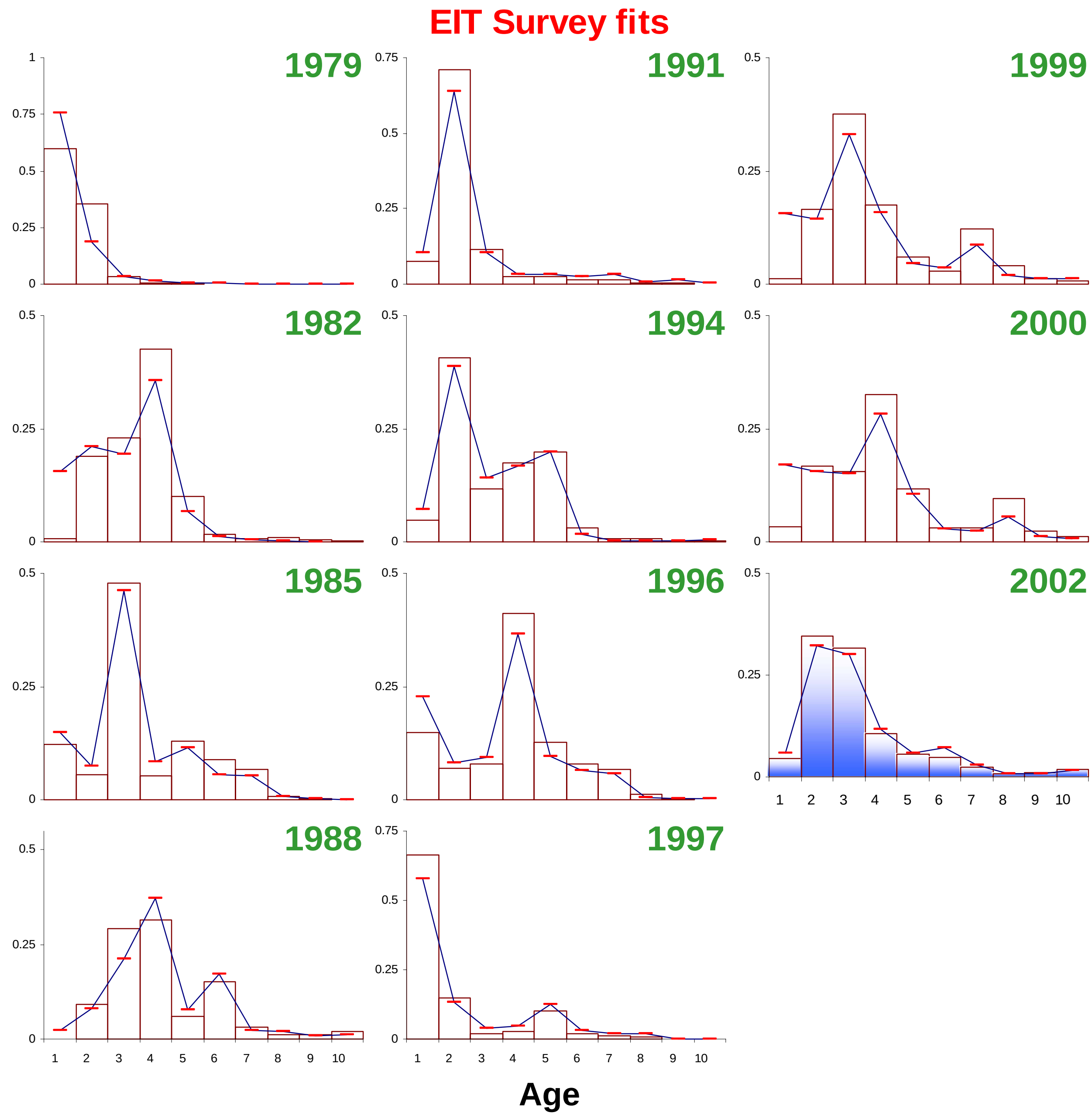



Figure 1.28. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data. Data new to the assessment are shaded.

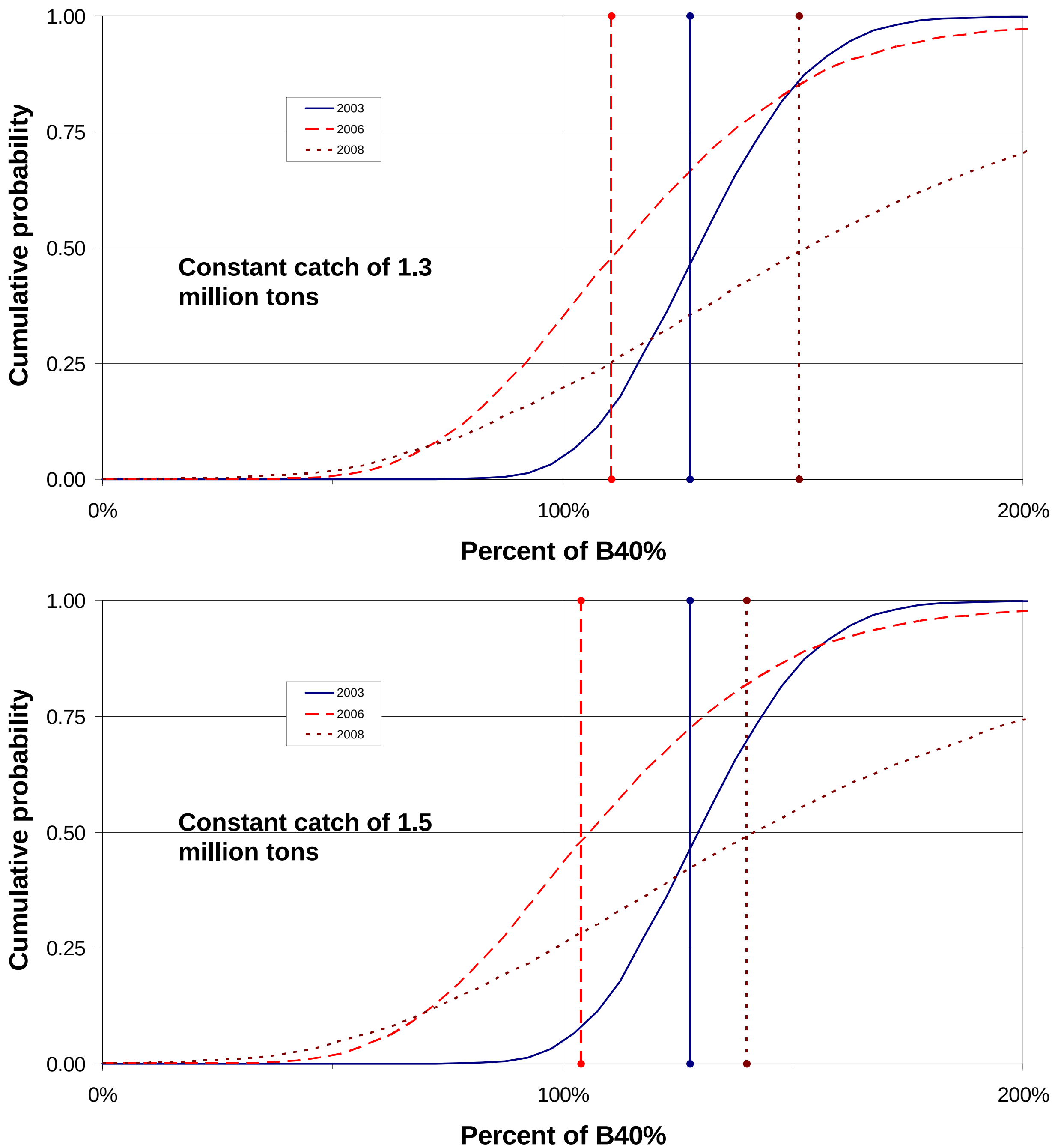



Figure 1.29. Cumulative probability that projected female spawning biomass levels will drop below $B_{40\%}$ based on a fixed constant catch levels of 1.3 (top) and 1.5 (bottom) million tons. Marginal distributions the full joint posterior distribution based on a thinned MCMC chain used for integration. Corresponding expected values (means) are shown by the vertical lines terminated with closed circles.

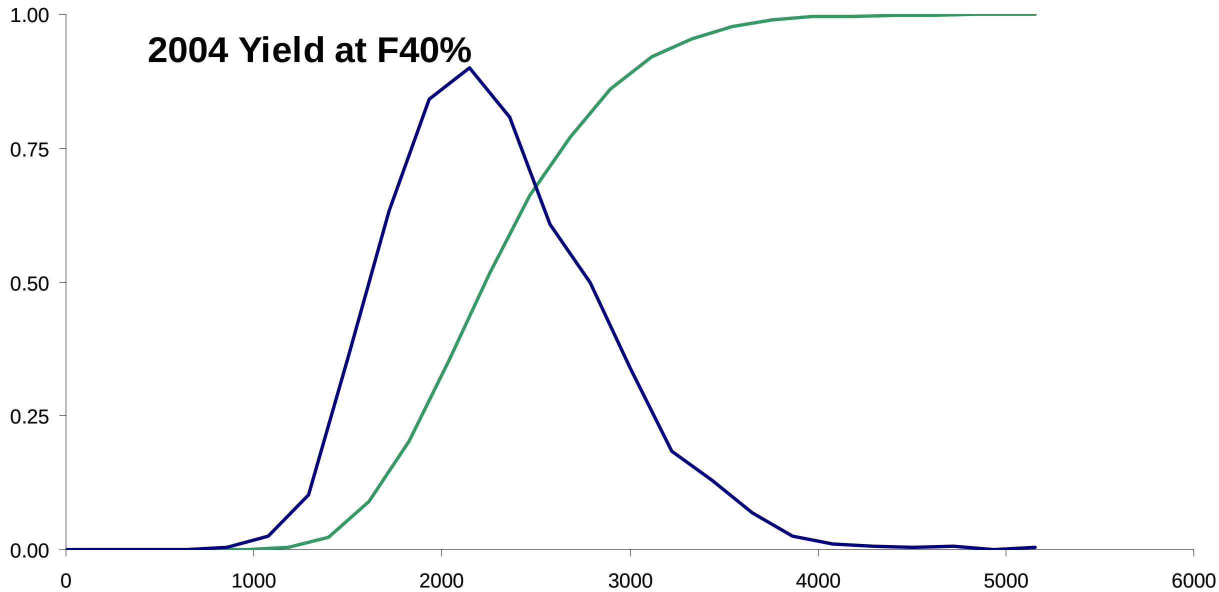



Figure 1.30. Marginal distribution of 2004 yield (thousands of tons) at $F_{40\%}$ for EBS pollock. The distribution (shown as a cumulative and probability distribution) represents the full joint posterior based on an MCMC chain of length 1,000,000 using every 200th value for integration.

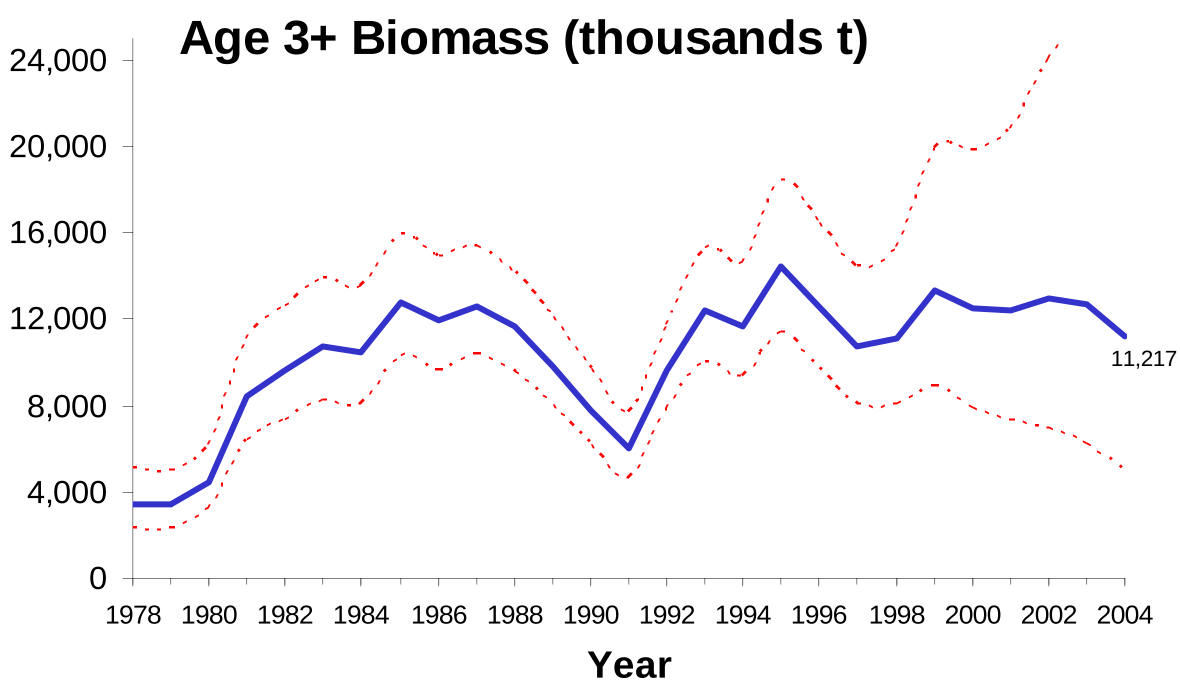



Figure 1.31. Estimated age 3+ EBS mid-year walleye pollock biomass under Model 1, 1978-2004. Approximate upper and lower 95% confidence limits are shown by dashed lines.

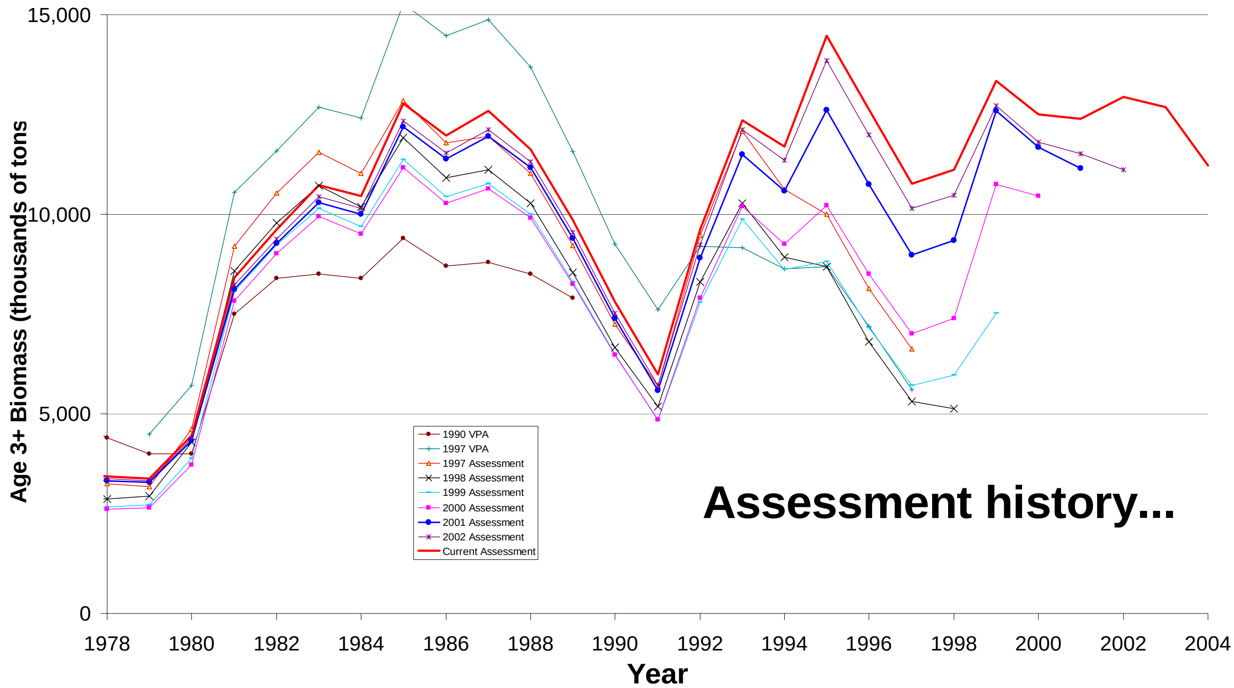



Figure 1.32. Comparison of the current assessment results with past assessments of begin-year EBS age-3+ pollock biomass, 1978-2003.

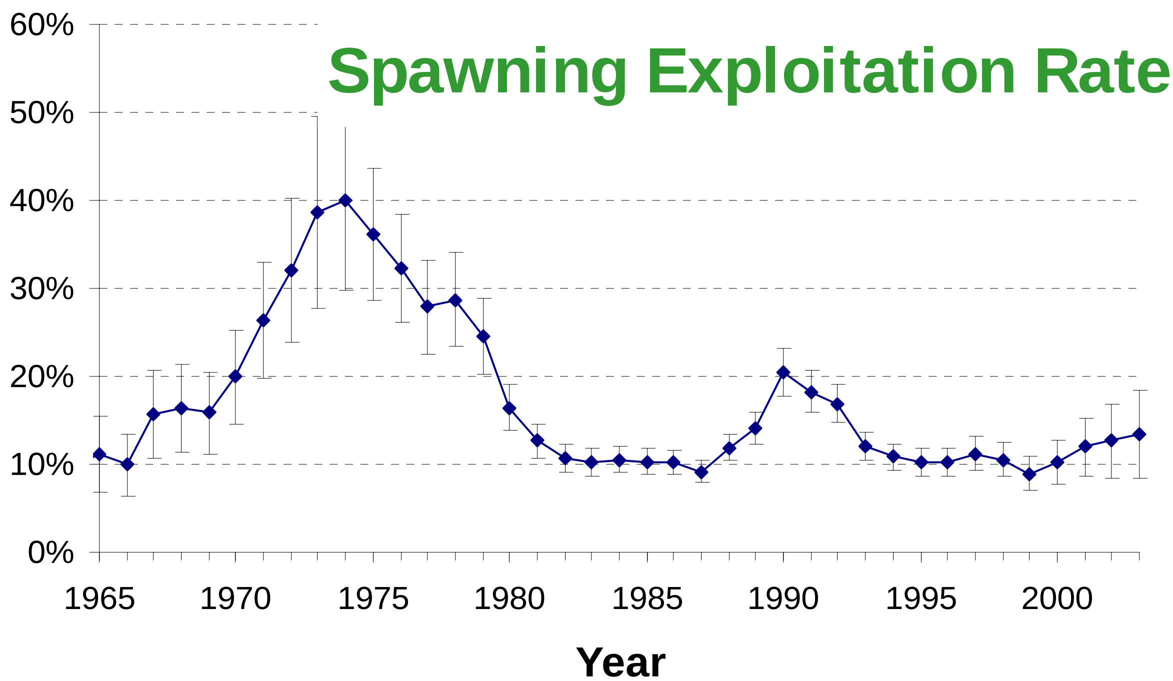
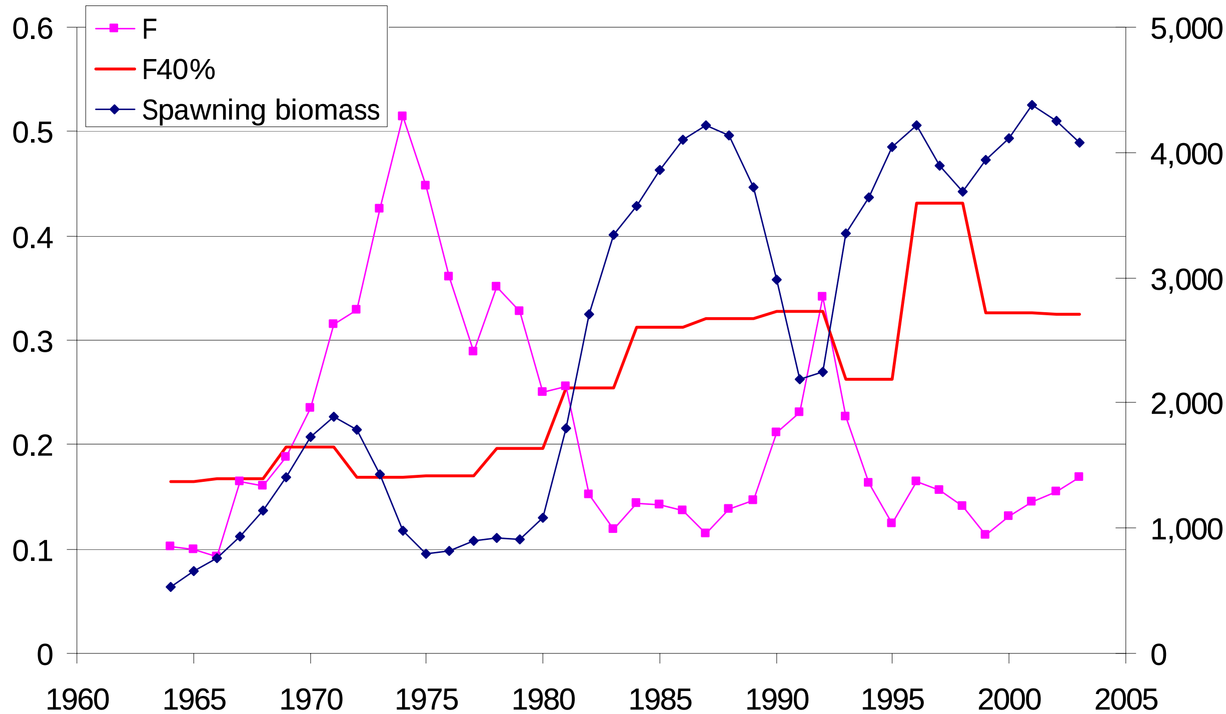



Figure 1.33. Estimated spawning exploitation rate (defined as the annual percent removals by fishing of spawning females) for EBS walleye pollock, Model 1. Error bars represent two standard deviations from the estimate.



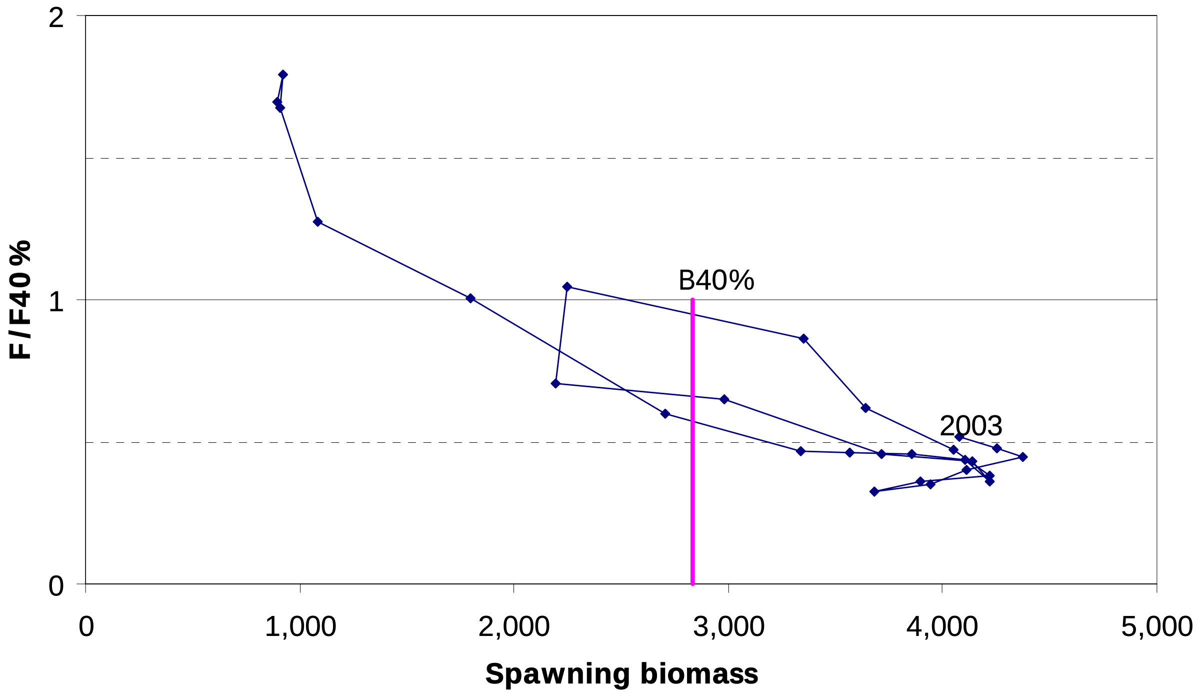




Figure 1.34. Spawning biomass relative to annually computed $F_{40\%}$ values and fishing mortality rates for EBS pollock, 1977-2003. Fishing mortality rates are based on the average over ages 1-15.

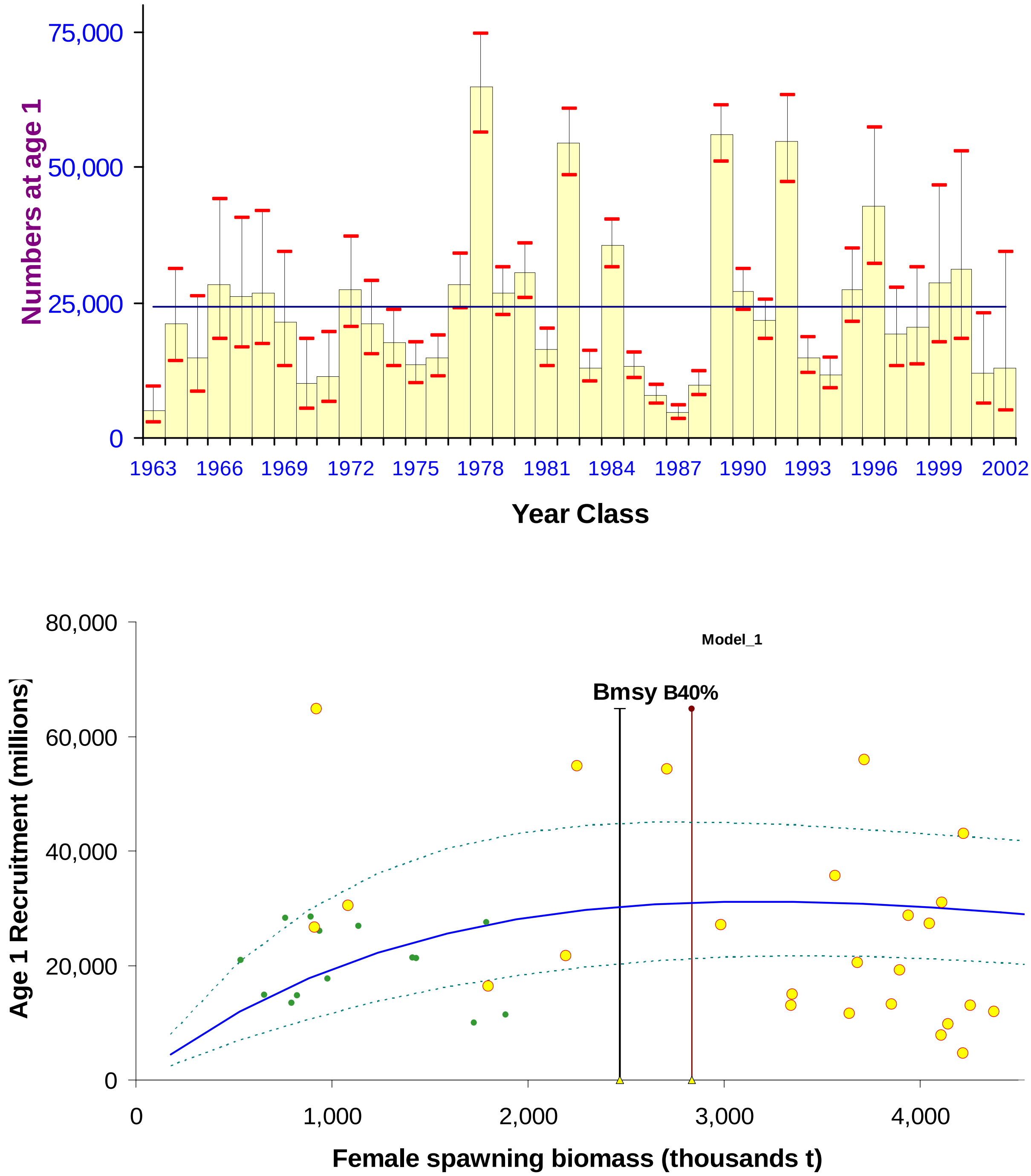
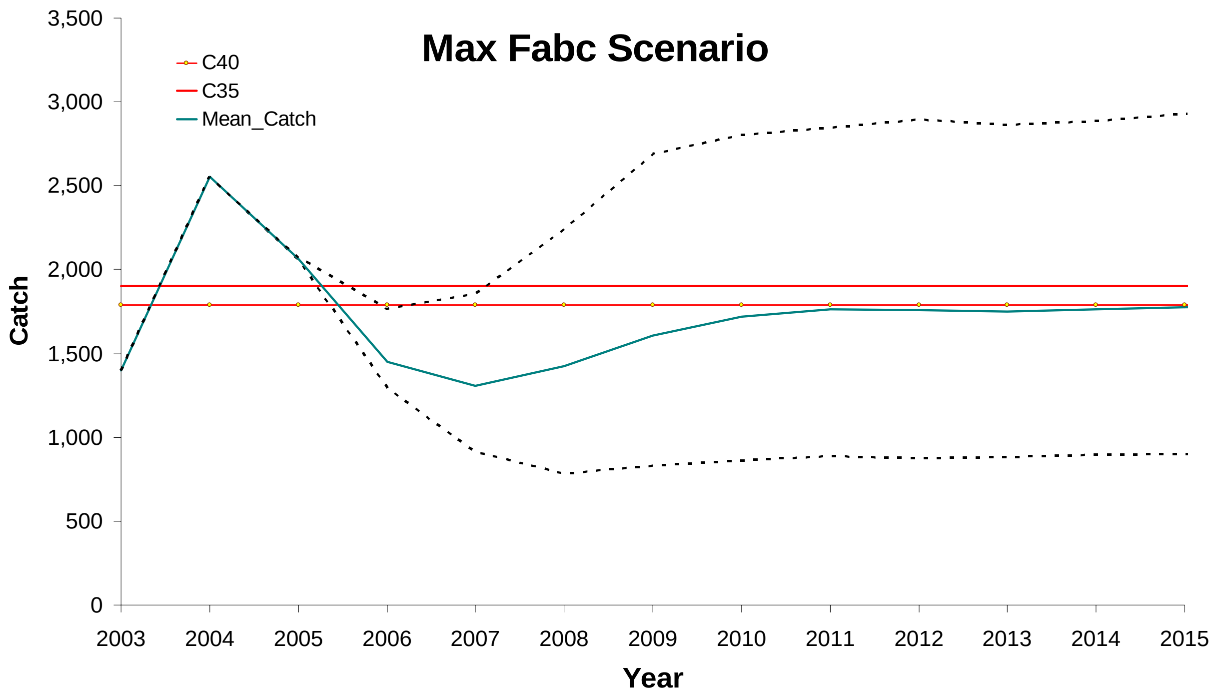



Figure 1.35. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate $B_{msy}$ 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.



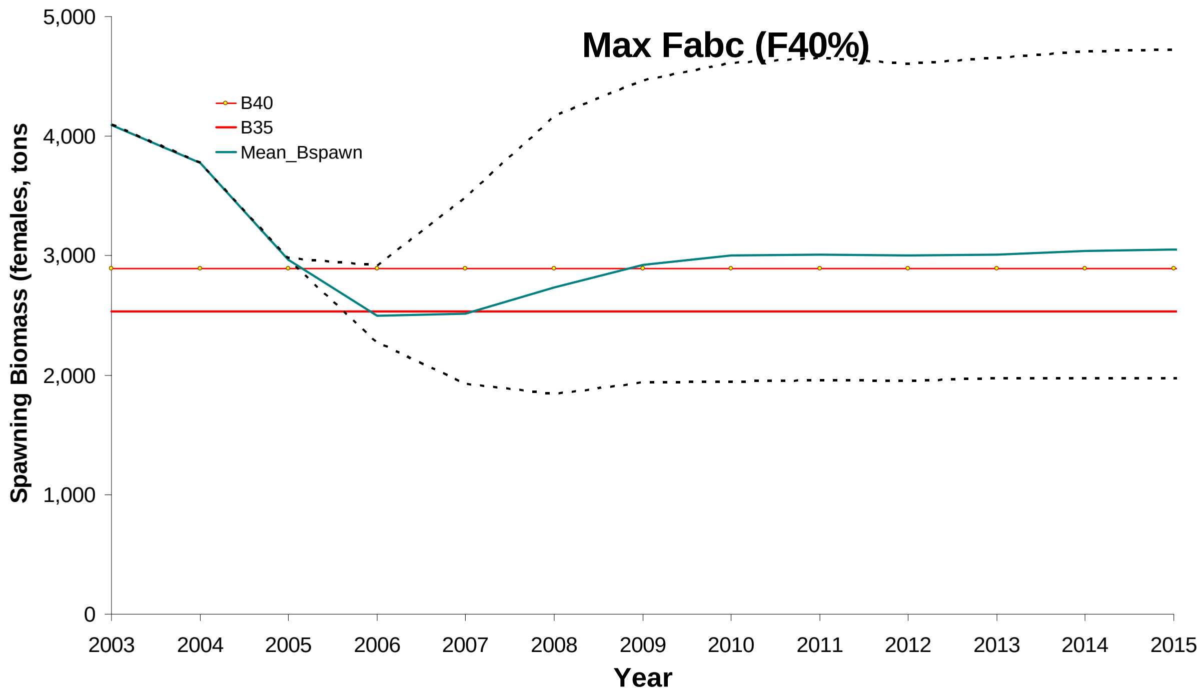




Figure 1.36. Projected EBS walleye pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2003. Future harvest rates follow the guidelines specified under Scenario 1, max $F_{ABC}$ assuming $F_{ABC} = F_{40\%}$.

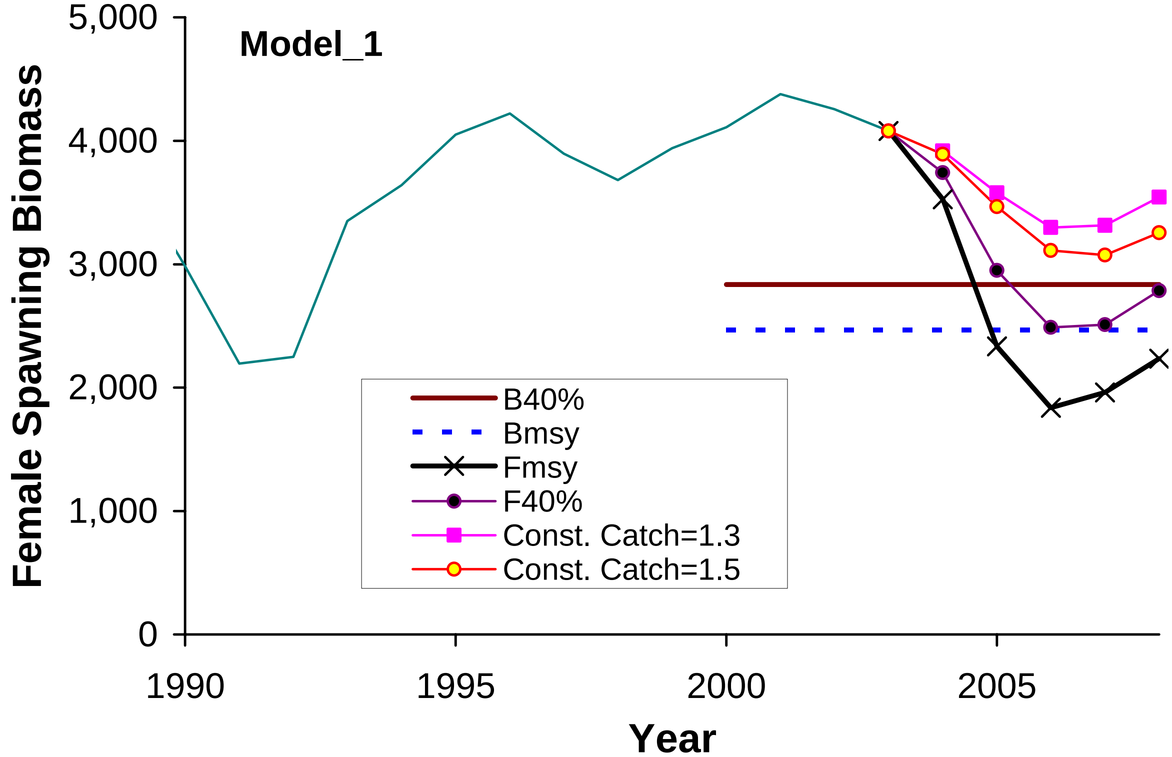



Figure 1.37. EBS walleye pollock female spawning biomass abundance trends, 1990-2008 as estimated by Model 1 and projections to 2008 at different catch strategies. Note that the $F_{msy}$ catch levels are unadjusted. Horizontal solid and dashed lines represent the $B_{msy}$, and $B_{40\%}$ levels, respectively.

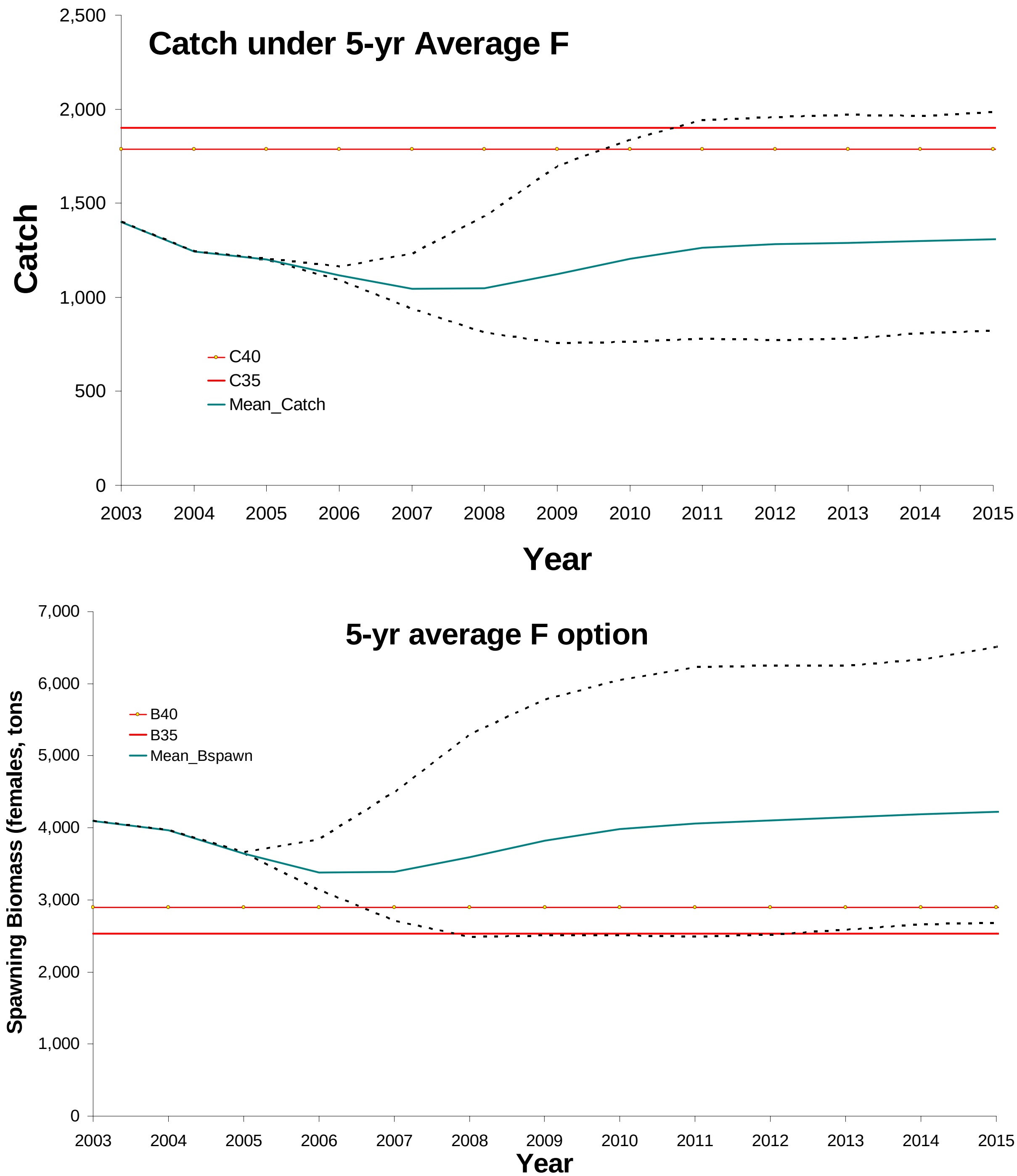



Figure 1.38. Projected EBS walleye pollock yield (top) and spawning biomass (bottom) under *F* equal to the mean value from 1999-2003 relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1.

# Model details

## 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 instantaneous fishing mortality for age class $a$, in year $t$, |
| $M_{ta}$ | is the instantaneous natural mortality in year $t$ for age class $a$, and |
| $Z_{ta}$ | is the instantaneous 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

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

where

| | |
|---|---|
| $s_{t,a}$ | is the selectivity for age class $a$ in year $t$, and |
| $\mu^F$ | 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 ($\sigma_s^2$) 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., $\sigma_E^2$) 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.

One form used to model bottom-trawl survey selectivity (used in Models 1, 3-7) is to have an asymptotic yet retain the properties desired for the characteristics of this gear. Namely, that the function should allow for flexibility in selecting age 1 pollock. Additionally, time-varying shifts should be allowed. The new functional form of this selectivity is:

$$
\begin{aligned}
s_{t,a} &= \left[1 + e^{-\alpha_t(a-\beta_t)}\right]^{-1}, \; a > 1 \\
s_{t,a} &= \mu_s e^{\delta_t^\mu}, \qquad\qquad a = 1 \\
\alpha_t &= \overline{\alpha} e^{\delta_t^\alpha} \\
\beta_t &= \overline{\beta} e^{\delta_t^\beta}
\end{aligned}
$$

where the parameters of the selectivity function follow a random walk process as in Dorn et al. (2000):

$$
\begin{aligned}
\delta_t^\mu - \delta_{t+1}^\mu &\sim N\left(0, \sigma_{\delta^\mu}^2\right) \\
\delta_t^\alpha - \delta_{t+1}^\alpha &\sim N\left(0, \sigma_{\delta^\alpha}^2\right). \\
\delta_t^\beta - \delta_{t+1}^\beta &\sim N\left(0, \sigma_{\delta^\beta}^2\right)
\end{aligned}
$$

The parameters to be estimated in this part of the model are thus the $\overline{\alpha}, \overline{\beta}, \delta_t^\mu, \delta_t^\alpha, \text{and } \delta_t^\beta$ for $t$=1982, 1983,…2003. The variance terms for these parameters were specified to be 0.04.

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). ($\kappa_t$):

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

with mature spawning biomass during year $t$ was defined as:

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

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

### *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:

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

where

$R_t$ is recruitment at age 1 in year *t*,

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

$\varepsilon_t$ 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 spawning biomass (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). The same prior distribution for steepness based on a beta distribution as in Ianelli et al. (2001) and is shown in Fig. 1.39.

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):

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

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 $\varphi_0$ 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 2 presented above, we implemented a revised ageing matrix. Sample size values were fixed at values shown in Table 1.10. 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."

Within the model, predicted survey abundance accounted for within-year mortality since surveys occur during the middle of the year. 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 $\lambda_c$ 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 $\lambda$'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. The approach we use to solve for $F_{msy}$ and related quantities (e.g., $B_{msy}$, MSY) within a general integrated model context was shown in Ianelli et al. (2001).

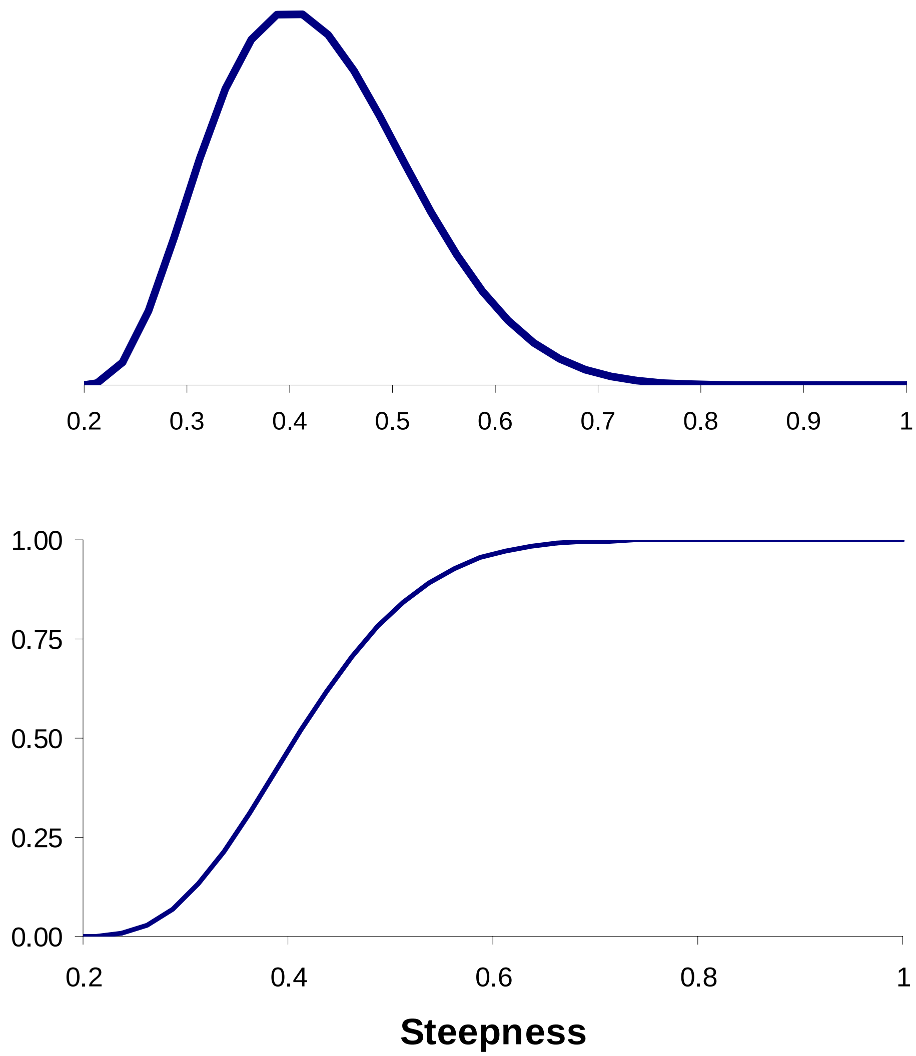



Figure 1.39. Cumulative prior probability distribution of steepness based on the beta distribution ($\alpha$=4, $\beta$=10) assumed for the main model.

## Aleutian Basin-Bogoslof Island Area

Since 1999 we have presented 2 alternative methods for computing ABC values for the Bogoslof region. They include:

1. The same method as in past years (with 2,000,000 ton estimate as a target stock size)
2. The Tier 5 method ($F_{ABC}$ =0.75*M)

In 1999 we proposed a third method: a simplified age-structured model based on recent Bogoslof population trends. The Council SSC considered the age-structured model to be inappropriate since it covered only part of the stock and concurred with the Plan Team on placing Bogoslof pollock in Tier 5. In this year's assessment for the EBS region, catch from the Navarin region (in the Russian zone) were included as part of the EBS stock in Model 3. This resulted in a larger overall biomass to the EBS region and the overall change in fishing mortality was relatively minor. A similar approach taken with the Bogoslof Island region catches would presumably yield similar results.

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish belong to the same "stock". The pollock found in our surveys are generally older than age 5 and are considered 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 were also strong on the shelf, 1972, 1978, 1982, 1984, 1989, 1992, and 1996. There has been some indication that there are strong year classes appearing on the shelf that have not been coincidentally as strong (in a relative sense) in the Bogoslof region (Ianelli, et al 2001). The conditions leading to strong year classes of pollock in the Basin appears to be density related and may be functionally related to abundance on the shelf.

Differences in spawning time and fecundity have been documented between eastern Bering Sea pollock and Aleutian Basin pollock. 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). 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.

### ABC estimates for Bogoslof area

The National Marine Fisheries Service has conducted echo-integration-trawl (EIT) surveys for Aleutian Basin pollock spawning in the Bogoslof Island area annually since 1988, with two exceptions: a Bogoslof Island area EIT survey was not conducted in 1990 and the 1999 Bogoslof Island area EIT survey was conducted by the Fisheries Agency of Japan. The annual Bogoslof Island area EIT survey results (Fig 1.40) show that population decline occurred between 1988 and 1994, and then has been stable with some increases (e.g., in 1995). The movement of pollock from the 1989 year class to the Bogoslof Island area was partly responsible for the 1995 increase (Fig. 1.41), 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. A small increase in estimated biomass in 1998 was followed by a continued decline in the 1999, 2000, 2001, and 2002 surveys. 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. The 1989 year class remains the predominant year class in the Bogoslof area. The 2003 Bogoslof Island EIT survey results have been published as an AFSC Processed Report (McKelvey and Williamson 2003). The summary Bogoslof Island area EIT survey biomass estimates, 1988-2003, are as follows:

| Biomass (millions of t) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
| 2.4 | 2.1 | - | 1.3 | 0.9 | 0.6 | 0.49 | 1.1 | 0.68 | 0.39 | 0.49 | 0.48 | 0.30 | 0.23 | 0.23 | 0.20 |

Tier 5 computations use the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC (2003 survey biomass × $M$ × 0.75) of **29,700 t** at a biomass of 198,000 t (with $M = 0.2$). The OFL is **39,600 t**.

Given the survey estimate of exploitable biomass of 0.198 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:

$$F_{abc} \leq F_{40\%} \bullet \left( \frac{B_{2003}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.27 \bullet \left( \frac{198{,}403}{2{,}000{,}000} - 0.05 \right) \Big/ (1 - 0.05) = 0.014$$

Using a fishing mortality rate of 0.014 translates to an exploitation rate of 0.013 which when multiplied by 198,000 t, gives a **2004 ABC of 2,570 t for the Bogoslof region.**

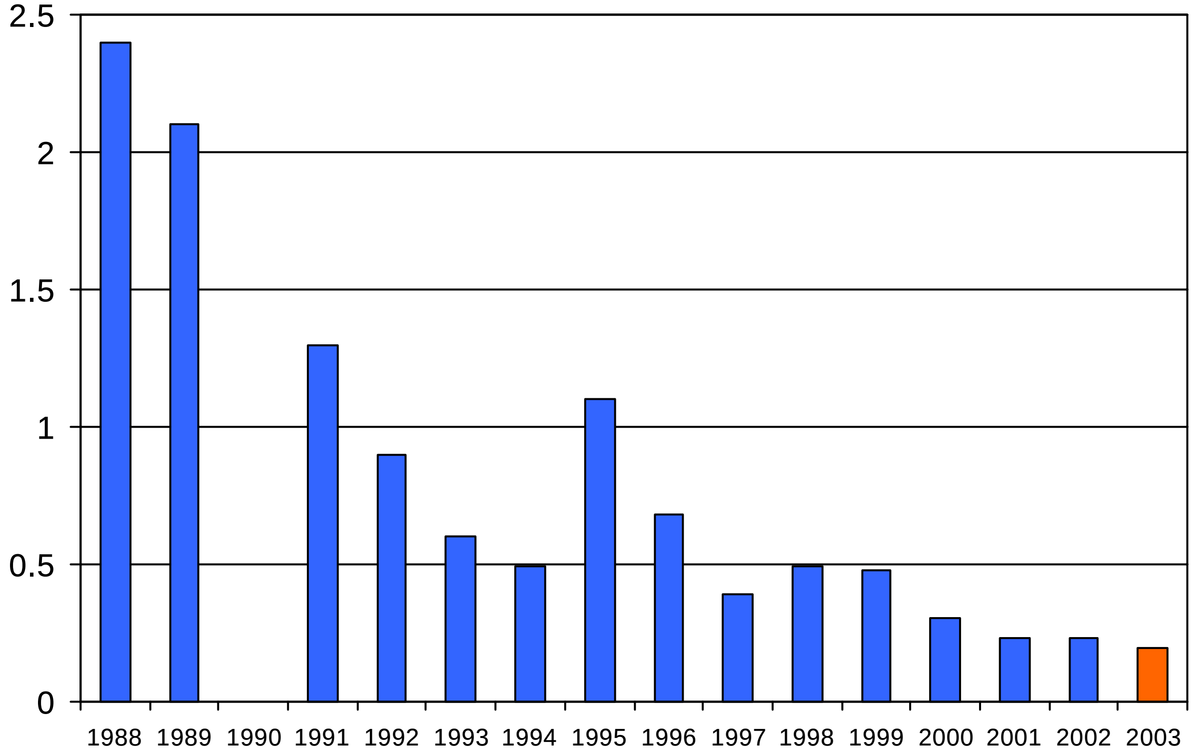



Figure 1.40. Pollock biomass estimates from the 1988-2003 Bogoslof Area EIT surveys in millions of tons. There was no survey in 1990.

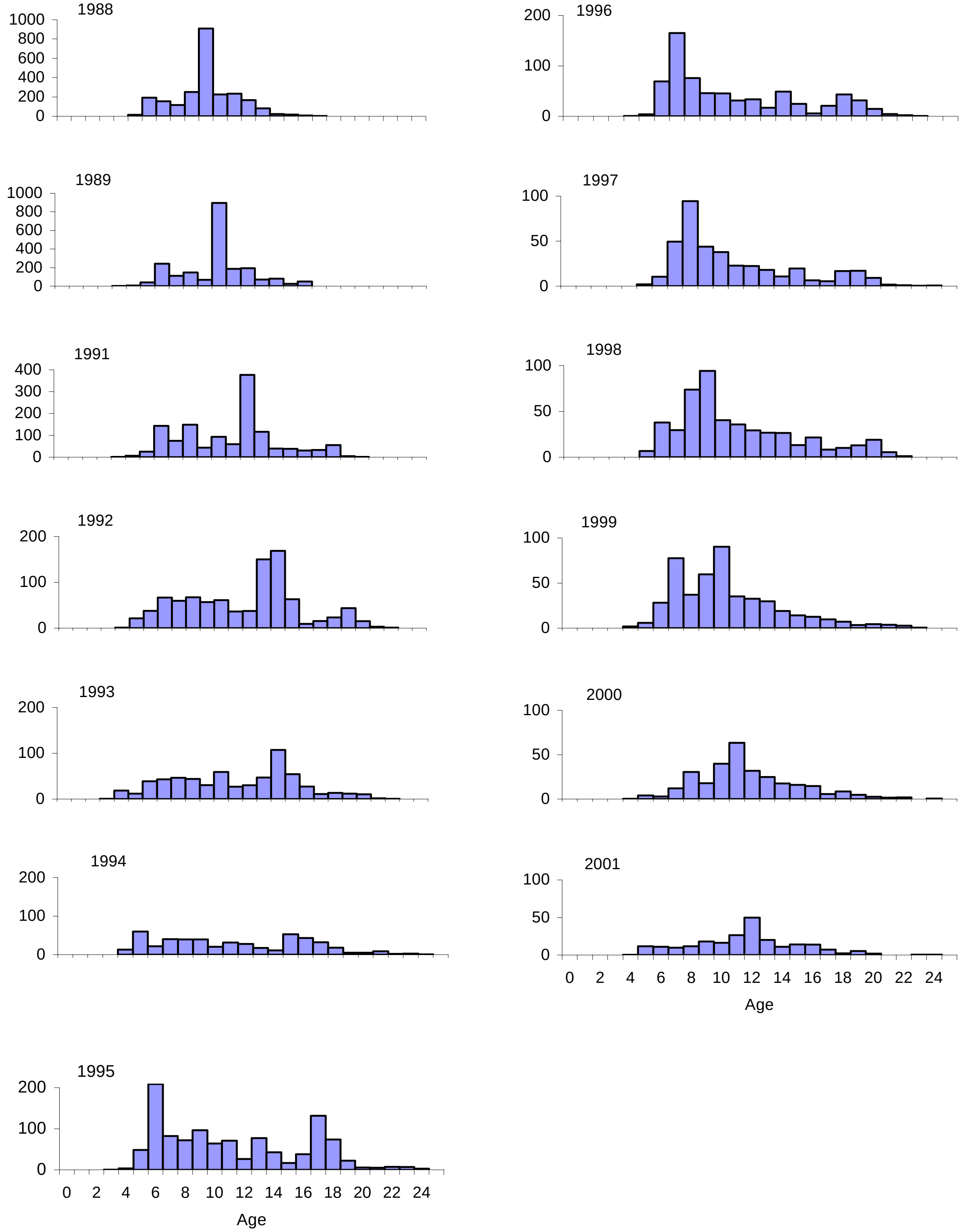



Figure 1.41. Pollock biomass-at-age estimates from the 1988-2001 Bogoslof Area EIT surveys (thousands of mt). There was no survey in 1990. Please note that the y-axis scales differ.

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