1. Assessment of Alaska Pollock Stock in the Eastern Bering Sea

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Executive Summary

The focus of this chapter is on the Eastern Bering Sea (EBS) region. The Aleutian Islands region (Chapter 1A) and the Bogoslof Island area (Chapter 1B) are presented as separate sections.

Changes in the input data
The 2005 NMFS summer bottom-trawl (BTS) survey biomass and age composition estimates were added. The biomass estimate from the BTS was 5.134 million tons, up 37% from the 2004 estimate of 3.756 million t. The 2004 echo-integration trawl (EIT) survey numbers-at-age estimates were revised using EIT samples for the age-length key (previously the 2004 BTS age-length key was used).

Observer data for age and size composition and average weight-at-age were evaluated for the 2004 fishery and were included in the analyses. Total pollock catch for 2004 was estimated from the NMFS Alaska Region data. The 2005 catch was projected to be 1,478,500 t.

Changes in the assessment model
No major changes were made to the assessment model this year.

Changes in the assessment results
The 2006 maximum ABC alternatives based on the $F_{40\%}$ and F_{msy} are 1,876 and 1,931 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value). These values are nearly identical to the alternatives from last year (the 2005 values were 1,897 and 1,962 for $F_{40\%}$ and F_{msy}). The 2006 overfishing level (OFL) alternatives for the reference model are 2,282 and 2,085 thousand tons corresponding to $F_{35\%}$ and F_{msy} (arithmetic mean). The 2007 $F_{40\%}$ (Tier 3 harvest levels) harvest level is projected to be about 1.4 million t (compared to last year's projection of 2007 dropping to 1.1 million t). These revisions are due mainly to the fact that the estimated biomass of the 2000 year class (5-yr olds in 2005) has increased by 14% compared to last year's estimate of this year class (as 5-yr olds in 2005). The 2000 year class is projected to be about 27% of the total biomass in 2006 and about 42% of the "exploitable biomass" (which takes selectivity estimates into consideration).

Response to SSC and Plan Team comments
General comments
The SSC requested that SAFE chapter sections be consistent so that relevant sections can be easily found. To this end, the AFSC developed a checklist for SAFE chapters which this assessment follows.

Specific comments
An inconsistency between the text description of the model and the equations specifying selectivity changes was corrected. The model selected in the past (and also recommended this year) allows for fishery selectivity to change every three years. The sequence of these changes was adjusted so that the estimated selectivity for 2005 (where fishery age data are yet unavailable) was specified to be the same as in 2004 and 2003 (consistent with the assumption used last year).

The SSC provided a number of useful references on approaches to model selection and encouraged further developments on model selection methods. Some of these approaches were investigated but in general apply to non-Bayesian models. These methods have a number of advantages. However, most models that have been presented were done for sensitivity considerations rather than development of alternative models. A list of all models presented for EBS pollock since 1999 was compiled and summarized for illustration. Further discussion on model selection approaches is presented in the section below titled "Model Evaluation." In particular, judging model performance in the context of fisheries management and the possible role of ongoing management strategy evaluations (MSEs) are presented.

Introduction

Walleye pollock (*Theragra chalcogramma*) are broadly distributed throughout the North Pacific with largest concentrations found in the Eastern Bering Sea. Also marketed under the name Alaska pollock, this species represented over 40% of the global whitefish production in 2004 with the market disposition split fairly evenly between fillets, whole (head and gutted), and surimi. An important component of the commercial production is the sale of roe from pre-spawning pollock. Pollock are considered a relatively fast growing and short-lived species and currently represents a major biological component of the Bering Sea ecosystem.

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 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 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.

Fishery

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 they 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-1980s. 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. During 2002-2005 the EBS region pollock catch has averaged 1.463 million tons while for the period 1982-2000, the average was 1.15 million tons. The effect of this level of fishing continues to be closely monitored by resource assessment surveys and an extensive fishery observer program.

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 (Fig. 1.2).

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 2002 - 2005 (Fig. 1.3). In particular, the 2003 winter fishery was distributed farther north than in previous years. This may be due to the warm conditions and anecdotal reports that roe developed earlier than usual. The catch estimates by sex for the A-season compared to estimates for the entire season indicate that over time, the number of males and females has been fairly equal (Fig. 1.4). The length frequency information from the fishery shows that the size of pollock caught are generally larger than 40 cm with some smaller fish caught during years when a strong year class appeared (Fig. 1.5).

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 show consistent concentrations of catch around the Unimak Island area and along the 100 m depth contour to the northwest of the Pribilof Islands. (Fig. 1.6). 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, the 1996 year class in 1998-2001, and subsequently the 2000 year class (Fig. 1.7). The 2003 fishery data show an unusually high mode of fish at around 40cm that advanced to 45 cm by 2004 and reached about 48 cm in 2005 (preliminary data). This is consistent with an indication of a strong 2000 year class (with some possible confounding of the 1999 year class).

Barbeaux et al. (2005b) presented some results on the development of small-scale spatial patterns of pollock aggregations. This involved a subset of some 32,000 km (~17,300 nm) of tracked acoustic backscatter collected opportunistically aboard commercial vessels. They found that during the daytime pollock tend to form patchy, dense aggregations while at night they disperse to a few uniform low-density aggregations. Changes in trawl tow duration and search patterns coincide with these changes in pollock distributions. Qualitative results suggest that rapid changes in distributions and local densities of Alaska pollock aggregations occur in areas of high fishing pressure. Analyses of this type will continue to improve understanding on the dynamics of the pollock fishery and biological responses.

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 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. Work continues on evaluating the effectiveness of these measures and the potential for adverse fishery and Steller sea lion (or other marine mammal) interactions. These are presented in the ecosystem considerations section below.

Three types of measures were implemented in the pollock fisheries:

- 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 after the onshore fleet. 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 Steller sea lion Conservation Area (SCA) 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 SCA, 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 the 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. In 2005 the proportion of catch within the SCA has dropped considerably with less than 30% taken in this area. The pattern of catch since 1998 is shown below:

Year	Months	Catch outside SCA	Catch Total	Percent catch inside SCA
1998	Jan-Jun	71	385	82%
	Jul-Dec	248	403	38%
	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	27%
	Jul-Dec	367	674	46%
	Jan-Dec	724	1,164	38%
2002	Jan-Jun	263	566	54%
	Jul-Dec	350	690	49%
	Jan-Dec	613	1,256	51%
2003	Jan-Jun	336	616	45%
	Jul-Dec	397	680	42%
	Jan-Dec	733	1,296	43%
2004	Jan-Jun	293	531	45%
	Jul-Dec	472	711	34%
	Jan-Dec	765	1,242	38%
2005	Jan-Jun	293	529	45%
	Jul-Dec	558	673	17%
	Jan-Dec	851	1,203	29%

Note: Pollock catches (thousands of tons) are as reported by at-sea observers only, 2005 data are preliminary.

An additional goal to minimize potential adverse effects on sea lion populations 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. 1.3).

The fishery in recent years has undertaken measures to reduce bycatch of salmon. Recent bycatch levels for chinook and chum salmon have been very high due in part to large runs of salmon and in part to restrictions on areas where pollock fishing may occur. The Council acted and developed an extensive analysis leading to amendment 84 of the FMP. The new regulations from this amendment will be implemented by August 2006.

Catch data

Since 2001, the total allowable catch (TAC) for EBS pollock has been at record levels over 1.4 million t. This is roughly 22% above the average levels of catch from 1977-2004 (1.15 million t; Table 1.2).

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 discards 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 for 1991-2004 are shown in Table 1.3. 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). Presentation of bycatch of other non-target, target and prohibited species is presented in the section titled "Ecosystem Considerations" below.

The catch-at-age composition was estimated 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*) January–June (all areas, but mainly east of 170°W); *ii*) INPFC area 51 (east of 170°W) from July–December; and *iii*) INPFC area 52 (west of 170°W) from July–December . This method was used to derive the age compositions from 1991-2004 (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). Presently, all age-composition estimates are being re-evaluated. In part, this reevaluation is a research project in collaboration with a student at University of Alaska, Juneau. The goal is to develop an area-specific catch-age model for pollock around the Bering Sea. Another evaluation involves implementing statistical sampling theory estimators developed by Miller (2005). These estimators are developed for virtually all quantities required from fishery data for stock assessment purposes. Since they also provide covariance estimates, the potential to improve on the statistical rigor for the treatment of stock assessment data should be excellent. It is hoped that these methods can be routinely implemented. For the EBS pollock, the estimated variance of the total catch is consistent with the assumption used here with excellent agreement between the NMFS official catch statistics and that of Miller. The assumed coefficient of variation of total catch estimation uncertainty of 3% is a bit higher than the ~1% CVs estimated by Miller (2005) for pollock in the EBS.

The time series of the catch proportions-at-age suggests that during 1999-2004 a broad range of age groups were harvested. In 2004 (new data presented in this assessment) the age ranges narrowed somewhat and the fishery appeared be concentrated on four and five-year old pollock (Fig. 1.8). The values used in the age-structured model are presented in Table 1.4. Since 1999 the observer program adopted a new sampling strategy for lengths and age-determination studies (Barbeaux et al. 2005a). 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 (Tables 1. 5 and 1.6). The sampling effort for pollock catch, length, and age samples by area has been shown to be relatively proportional (e.g., Fig. 1.8 *in* Ianelli et al. 2004).

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 - 2005) 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	1990
Bering Sea	15	94	458	139	466	682	508	208	435	163	174	467	393	369
Aleutian Is.				193		40	454			292				

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Bering Sea	465	156	221	267	249	206	262	121	162	164	149	179	236		NA
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 BTS is shown in Table 1.7.

Between 1983 and 1990 the BTS biomass estimates were relatively high and showed a slightly increasing trend (Table 1.8; Fig. 1.9). Between 1991 and 2005 the BTS biomass estimates ranged from 2.21 to 8.14 million t. The 2005 estimate is 5.13 million tons, up by more than 30% of the 2004 estimate (which was well below the 2003 estimate). The estimates also suggest an increasing trend since about 1997. However, the optimistic 2003 estimate has an extremely large variance. This may have been 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 variability may be due to unaccounted-for variability in natural mortality and migration. 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). More recently, the estimate of the strength of the 1996 year class has waned compared to previous assessments. In 2003 the point estimate for this year class was 43 billion one-year olds whereas for the current assessment, the estimate is about 31 billion. This could be due in part to emigration of this year-class outside of our main fishery and survey zones. Alternatively, this may reflect the effect of variable natural mortality rates.

In 2004 the highest pollock concentrations from the BTS were to the west of the Pribolof Islands and in the northwest portion of the survey area whereas in 2005 pollock were more wide-spread (Fig. 1.11). These years differed from the pattern observed in 2003 in which high concentrations were apparent in the middle shelf region and more moderate pollock densities occurred near the shelf break (the western edge of the survey region).

Beginning in 1987 NMFS expanded the standard survey area farther to the northwest (Fig. 1.12). For consistency, these extra strata (8 and 9) have been excluded for consideration within the model. The pollock biomass levels found in these non-standard regions were highly variable, ranged from 1% to 22% of the total biomass, and averaged about 5% (Table 1.9). Closer examination of the years where significant concentrations of pollock were found (1997 and 1998) revealed some stations with high catches of pollock. The variance estimates for these northwest strata were quite high in those years (CVs of 95% and 65% for 1997 and 1998 respectively). Variable catch rates and periodic high abundances in this northwest area suggest pollock movement in and out of the standard survey area supporting the hypothesis of emigration as one cause for interannual variability in survey estimates.

The survey age composition information provides insights on temporal patterns in length-at-age. In particular, when converted to weight-at-age it appears that in recent years the average size (ages 4-8) has recovered to about average compared with the below-average sizes observed from 1995-2002 (Fig. 1.13). 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, an analysis using survey data alone was conducted to evaluate mortality patterns. Cotter et al. (2004) promote this type of analysis as having a simple and intuitive appeal which is independent of population scale. In this approach, log-abundance of age 6 and older pollock is regressed against age by cohort. The negative values estimated for the slope are estimates of total annual mortality. Age-6 was selected 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. Total mortality by cohort seems to be variable (unlike the example in Cotter et al., 2004) with lower mortality overall for cohorts during the 1990s followed by some recent increases (Fig. 1.14). Total mortality estimates by cohort are difficult to interpret—here we take them as average mortality over the life of the cohort (since we know that harvest rates varied from year to year). The low values estimated from some year classes, (1990-1992 cohorts, could be because there are fewer age-groups (6, 5, and 4, respectively) in the regressions or because 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 (although the model values tend to be somewhat higher, averaging about 0.5 for these cohorts).

Effect of temperature

For the past several years the effect of bottom temperature on pollock habitat relative to the standard survey area has been evaluated. Modeling survey availability as a function of temperature helps account for the observation that environmental conditions affect the distribution of pollock. Previously, temperature was shown to affect the proportion of the stock that lies within or outside of the standard survey area. The recent temperature pattern continues to be relatively warm, especially compared to the 1999 values (Fig. 1.15). These patterns were further examined by comparing pollock density with selected on-bottom isotherms (Fig. 1.16). The 2005 average bottom temperature was nearer the average.

Using an innovative approach to link temperature with pollock density patterns, Kotwicki et al. (2005) were able to develop hypotheses about seasonal movement. They suggest that younger pollock respond to temperature and tend to be distributed farther north than the larger age-3 and older pollock. This may be related to changes in diet as pollock age and get larger (becoming less planktivorous and more piscivorous) since zooplankton tend to be more abundant in the northwestern region of the Eastern Bering Sea.

Echo-integration trawl (EIT) surveys

The EIT surveys are conducted biennially and are designed to estimate the off-bottom component of the pollock stock (compared to the BTS which are conducted annually and provide an abundance index of the near-bottom pollock). In summer 2004 NMFS conducted an EIT survey that extended into the Russian zone (Honkalehto et al. 2005). The biomass estimate from this survey was 3.31 million t, down from 3.62 million t estimated in 2002 but close to the average estimated by this survey since 1982 (3.36 million t; Table 1.8). The EIT survey estimates included population numbers at age (revised this year using an age-length key based on 2004 EIT data) which revealed a relatively abundant 2000 year-class (Fig. 1.17). The number of trawl hauls and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.10.

Proportions of pollock biomass estimated east vs. west of 170º W, and inside vs. outside the SCA, are about the same for summer EIT surveys conducted from 1994 to 2004 (Table 1.11). Compared to 2002, the relative abundance of pollock in 2004 was much greater in the northwest region of the survey area with concentrations of pollock extending to the convention line (US-Russia boundary) and beyond (Fig. 1.18).

In the 2004 assessment, the age-length key compiled from the AFSC bottom trawl survey (for 2004) was used to convert the EIT survey abundance-at-length estimates into abundance-at-age. Since then, the age-determinations for the 2004 EIT survey have been completed and age-length keys specific to the EIT survey now are available. On examining the patterns of these length-at-age data, a distinct feature was recognized in the eastern area (E of 170°W). For the area east of about 167.5°W there was a marked shift in the relative abundance of four and five year-old fish with more four-year old pollock in the eastern area and more five-year old pollock in the western side (between about 167.5° and 170°W) although the length distributions for these groups were very similar. Analyses involving repeat age-determinations by different scientists and scrutiny of fishery data over a similar period confirmed this pattern (Fig. 1.19; Table 1.12). However, further evaluations and possibly additional age-determinations will be pursued to determine if a more fine-scale stratification is required. For the purposes of this assessment, the standard approach of having two age-length keys, one W of 170°W and one E of 170°W, for estimating the age compositions was used. However, further evaluations and possibly additional age-determinations will be pursued to determine if a more fine-scale stratification is required.

The effect of the new estimates (using the 2004 EIT age-length keys) on last year's assessment model was determined by comparing results from last year's 2004 EIT age composition estimates (where the 2004 NMFS bottom-trawl survey age-length key was used) with results using the new estimates of 2004 EIT age composition estimates. The revised data showed that fewer age 2 pollock were present and more were estimated to be age 3 and age 5. The large numbers of age 4 pollock were similar (top panel, Fig. 1.20). The impact of the revised data was visible based on model fits but overall had a relatively small effect on the main results (i.e., current stock size, stock productivity, etc).

Analytic approach

Model structure

A statistical age-structured assessment model conceptually outlined in Fournier and Archibald (1982) and similar to Methot's (1990) extensions was used. A technical description is presented in the "Model Details" section. The analysis was first introduced in the 1996 SAFE report (Ianelli 1996) and compared to the cohort-analyses that had been used previously. The current model also was documented in the Academy of Sciences National Research Council (Ianelli and Fournier 1998). The model was implemented using automatic differentiation software developed as a set of libraries under the C++ language (AD Model Builder).

The main changes from last year's analyses are:

- the 2005 EBS bottom trawl survey estimate of population numbers-at-age was added;
- the 2004 EBS EIT survey estimate of population numbers-at-age was re-estimated using age-length keys from the 004 EIT survey data; and
- the 2004 fishery age composition data were added.

Parameters estimated independently

Natural mortality and maturity at age

For the reference model fixed natural mortality-at-age were assumed (M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively; Wespestad and Terry 1984). These values have been applied to catch-age models and forecasts since 1982 and appear reasonable for pollock. Estimates of natural mortality are higher when predation (e.g., when consumption by Steller sea lions and Pacific cod) are explicitly considered (Livingston and Methot 1998; Hollowed et al. 2000). The reference model values were selected because Clark (1999) found that specifying a conservative (lower) natural mortality rate is typically more precautionary when natural mortality rates are uncertain.

Pollock maturity-at-age (Smith 1981) values (tabulated with reference model values for natural mortality-at-age) are:

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

These maturity-at-age values were reevaluated based on the studies of Stahl (2004). A total of 10,197 samples of maturity stage and gonad weight were collected during late winter and early spring of 2002 and 2003 from 16 different vessels. In addition, 173 samples were collected for histological determination of maturity state (Stahl 2004). In her study, maturity-at-length converted to maturity-at-age via a fishery-derived age-length key from the same seasons and areas suggest similar results to the maturity-at-age schedule used in this assessment but with some inter-annual variability.

For the purposes of this assessment, the inter-annual variability found by Stahl (2004) was evaluated by converting the modeled population estimates at-age in 2002 and 2003 to expected maturity-at-length and comparing these results with those of Stahl. This involved using the fixed maturity-at-age levels presented above (for the reference model) to get estimates of total mature and immature numbers at age and then converting those to values at length using female mean-lengths at age (with an assumed natural variability about these means). Expected proportion mature-at-length for 2002 matches Stahl's data whereas for 2003, the expected values are shifted towards larger pollock (Fig. 1.21). This result suggests younger pollock (than currently assumed) may contribute to the spawning stock. For the purpose of this assessment, we continue to use the maturity schedule presented above.

Length and Weight at Age

Extensive length, weight, and age data have been collected and show that growth may differ by sex, area, and year class. Pollock in the northwest area typically are smaller at age than pollock in the southeast area. The differences in average weight-at-age are taken into account by stratifying estimates of catch-at-age by year, area, season and weighting estimates proportional to catch (Table 1.13).

Parameters estimated conditionally

A total of 640 parameters were estimated were estimated for the reference model. Initial age composition, subsequent recruitment values and stock-recruitment parameters account for 66 parameters. This includes vectors describing mean recruitment and variability for the first year (as ages 2-15 in 1964, projected forward from 1949) and the recruitment mean and deviations (at age 1) from 1964-2005 and projected recruitment variability (using the variance of past recruitments) for five years (2006-2010). 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.

Fishing mortality is parameterized to be semi-separable with year and age (selectivity) components. The age component is allowed to vary over time; changes are allowed every three years with the three most recent years (2003-2005) forming the last "group" of estimates. The mean value of the age component is constrained to equal one the last 4 age groups (ages 12-15) are specified to be equal. The year component of fishing mortality result in 43 parameters and the age-time forms an 11x14 matrix of 154 parameters bringing the total fishing mortality parameters to 197. This compares 39x15 or 585 implied fishing mortality parameters in cohort analysis (e.g., Pope 1972) which assumes no errors in total catch-at-age estimates.

Selectivity-at-age estimates for the bottom trawl survey are specified with age and year specific deviations in the average availability-at-age and a catchability coefficient totaling 75 parameters. For the EIT survey, which began in 1979, 297 parameters are used to specify age-time specific availability. Estimates for changes in EIT selectivity sometimes occur for years when the survey was not conducted increasing the number of parameters estimated, but avoiding problems associated with irregularly spaced surveys over time. Time-varying survey selectivity is estimated to account for the uncertain availability of pollock to the survey gear.

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 μ_q is the mean catchability and β_q represents the slope parameter. The bottom temperature time series (Fig. 1.15) is used in Model 3 (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). These three catchability coefficients (one for each index) are estimated as free parameters.

Finally, three additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$, $F_{35\%}$ 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 these fishing mortality rates.

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

- Total catch biomass (Log normal, σ=0.05)
- Log-normal indices of abundance (bottom trawl surveys assume annual estimates sampling error, as represented in Fig. 1.9; for the EIT and CPUE indices values of σ=0.2 were assumed)
- Fishery and survey proportions-at-age estimates (robust quasi-multinomial with effective sample sizes presented in Table 1.14).
- Selectivity constraints: penalties/priors on age-age variability, time changes, and decreasing (with age) patterns
- Stock-recruitment: penalties/priors involved with fitting a stochastic stock-recruitment relationship within the integrated model.

Model evaluation

At the December 2004 meeting, the SSC encouraged further developments on model selection approaches including some computationally less-intensive approaches (e.g., Zhang, 1993). These approaches are intuitively appealing since distributional assumptions about the data are avoided and most importantly, they are insensitive to mis-specifications of the likelihood function (e.g., incorrect variance terms) since they involve direct model performance measures. However, in a stock assessment context, there are a number of issues that affect objective model selection processes.

The models presented over the years primarily have been structured to test sensitivity to assumptions and data. A total of 45 models have been presented since 1999 (Table 1.15). Each model was selected from a larger set designed to evaluate sensitivity to data or model assumptions. A number of the models were requested by the SSC or Plan Team or simply to illustrate model behavior. Still others only affected projected ABC and catch recommendations (e.g., different options for specifying future selectivity).

Rather than having an objective selection where all models are considered equally plausible apriori, our approach has been to balance likely levels of process errors (e.g., recruitment variability, survey age-specific availability) with observation errors (e.g., the estimates of age composition derived from expanding samples from surveys and fisheries). Conservation concerns may also affect model selection. For example, some models may fit the data equally well, but are rejected for ABC recommendations due to conservation concerns. If alternative models indicate ABC levels substantially lower than the reference model, then given the precautionary approach and evidence of a conservation concern, an alternative model might be selected in favor of the reference model.

In model selection, perhaps model performance should be judged for setting ABC when other factors (e.g., migration, growth changes, productivity shifts) are ignored. Essentially, this leads to a computationally intensive approach known as management strategy evaluations (MSEs). In an MSE, an "assessment model" is evaluated based on "known" simulation tests where alternative hypotheses about the stock dynamics (typically much more complex) are run through a feedback scenario.

This year, a limited set of sensitivity models is presented. These are presented to exhibit behavior and responses to data and assumptions. However, for management purposes the reference model (Model 1) is recommended since it seems to characterize the key aspects of uncertain processes and observations and, compared to all but one alternative, is more precautionary.

The models presented are:

Model 1 **Reference model,** future selectivity based on most recent (3-year) estimate (short-term selectivity estimate). This has been the model configuration selected by the Council for ABC over a number of years.

Model 2 As reference model but with ageing error included.

Model 3 As reference model but with bottom-trawl survey catchability including an environmental covariate (average summer bottom temperature in the EBS).

Model 4 As reference model, but with bottom-trawl survey catchability fixed at 1.0.

Model 5 As Model 4 but estimating natural mortality.

Model 6 As reference model but includes Russian catches.

These models can be summarized as follows:

Model	Description
1	Reference model
2	Employ re-estimated age-error matrix
3	Bottom temperature a covariate with survey catchability
4	Bottom-trawl survey catchability fixed at 1.0.
5	Estimate natural mortality
6	Include Russian catches

The reference model (Model 1) is recommended for management purposes since it seems to characterize the key aspect of uncertain processes and observations and, compared to all but one alternative, is more precautionary.

In Model 2 the estimated errors in age-determination process (Ianelli et al., 2003) were included. Results from this model provided a slightly worse fit (i.e., a higher –ln(likelihood) function; Table 1.16). As expected, the recruitment variability increased (from 62% CV to 73%) when ageing error was included. The estimated stock size was slightly lower with this model compared with Model 1 but the reference fishing mortality rates were similar (Table 1.17).

In Model 3, the effect of bottom temperature on survey catchability was evaluated. Mean bottom temperature is slightly positively correlated with survey availability (β=0.039 and standard error 0.121). As before, the significance of this fit is low given this standard error, and the overall fit is virtually identical compared to Model 1 (Table 1.16; Fig. 1.22). Mean bottom temperature alone fails to provide a strong indicator for changes in survey availability. Presumably availability also is affected 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.

In Model 4 survey catchability was specified to equal to one. The fit of the data was degraded and biomass estimates were much higher.

In Model 5 estimation of natural mortality was evaluated (with survey catchability fixed at a value of 1.0). The parameterization was specified for age-3 and older as Me^{ρ} where the estimate was (from $M=0.3$): $\hat{\rho}$=0.056 with a standard error of 0.079 (and Me^{ρ}=0.317). Estimated natural mortality resulted in values similar to the reference model assumption.

In Model 6, Russian catches in the northern Bering Sea are included. To evaluate this effect, the catches from the Navarin area were 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. The time-series of catches used in Model 6 is shown compared to the baseline catches in the following table (thousands of t):

Area	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
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	1,092
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	1,595

Area	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
EBS	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	1,480	1,478
EBS & Navarin	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	2,000	2,000

Source: Report from the Russian Delegation to the 2005 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 and for 2004-2005 years we assumed removals near 520 thousand tons.

Model 1 appears to be a reasonable representation of 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. In addition, including aging error can inflate the recruitment variability and that this further inflates estimates of stock productivity. For this reason, Model 1 is preferred. Adding bottom temperature information (Model 3) had little effect and resulted in a slope with a sign opposite from that estimated last year (not too surprisingly since the standard error for the slope was high and continues to be so). Model 4 (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 5 suggests that natural mortality might be higher than assumed. Model 6 was presented primarily as a sensitivity analysis to Russian catches. Including Russian catches explicitly into the assessment 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. Given these results, the reference model was selected for subsequent presentations in the following sections.

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 are summarized in Tables 1.17 & 1.18. Comparing the current and projected age structure for Model 1 relative to the last year's assessment (2004; Fig. 1.23) shows that the absolute biomass-at-age estimates of the 1999, 2000, and 2003 year-class are higher in the current assessment. However, compared to the recent average biomass-at-age levels, the 2006 levels are significantly below average for 6 out of 15 age groups (e.g., Fig. 1.28 bottom panel). The 2000 year class is projected to be the mainstay of the fishery for 2006.

The estimated Model 1 selectivity pattern changes over time to become slightly more dome-shaped since 2000 (Fig. 1.24). This may be due in part to older fish becoming more bottom-oriented and dispersed and thus less available to the fishery. Model 1 fits the fishery age-composition data quite well and strong year classes are clearly evident (Fig. 1.25). The fit to the early Japanese fishery CPUE data (Low and Ikeda, 1980) is consistent with the population trends for this period (Fig. 1.26).

As in previous assessments, the selectivity was specified so that it could vary slightly over time for both survey types (EIT and BTS). 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. 1.27). The bottom trawl survey age composition data indicate the 2000 year class as being substantial and that the 1996 year class estimate is now more in line with this survey observation than in previous assessments (Fig. 1.28). Another notable characteristic of the BTS age composition data is that the 1992 year class is still showing as age 13 year olds.

The EIT survey selectivity dramatically changed over time (Fig. 1.29) possibly due in part to changes in pollock distribution as the overall densities changed and the large numbers of 1 and 2-year old fish that were observed 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. 1.30). 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 1.19 and estimated catch-at-age presented in Table 1.20. Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment for Model 1 is given in Table 1.21.

To explore the multidimensional parameter uncertainty, the posterior distribution was integrated using Monte-Carlo Markov Chain methods. This involved generating 1 million simulations drawn from the posterior distribution. This chain was then "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 (no curved or skewed tear-drop shapes; Fig. 1.31). The population was projected assuming fixed catches of 1.3 and 1.5 million tons. The probability that the 2005 stock size is below $B_{40\%}$ level is quite low. However, by 2008, the expectation is that the stock size will drop below the $B_{40\%}$ stock size level (with about 75% probability), and then increase (with considerable uncertainty) to similar levels by 2010 (Fig. 1.32). The NPFMC Groundfish Plan Team requested a figure depicting future catches (using one or more of the standard harvest scenarios) rather than just constant catch scenarios. Also, the Plan Team asked that the assessment authors consider presenting confidence intervals around the recommended ABC. These are presented in Figure 1.33.

Abundance and exploitation trends

The current mid-year 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 8 to 10 million t (Table 1.22, Fig. 1.34). 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. Peak biomass occurred in 1985 and then the population declined to about 4 million t by 1991 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. This was followed by the 1996 and 2000 year classes that have kept the stock at relatively high levels. Since 1992, the age 3 and older biomass has increased, and recently been variable around 8 million tons[1]. Assuming subsequent year classes are only average will mean that the stock will decline over the next few years.

Retrospectively, compared with last year's assessment the estimates of age 3+ pollock biomass are somewhat higher in the current assessment for recent years and nearly identical before 2002 (Table 1.22). Overall, compared with the seven past assessments, the retrospective pattern appears to be relatively balanced between over and under estimates, especially since 1998 when the same statistical model has been used (Fig. 1.35).

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 13% in the past 10 years and for 2005 is estimated at nearly 18% (Fig. 1.36). This compares to an overall average SER of 17% (1964 – 2005). 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. 1.37, 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. 1.37, bottom panel).

Recruitment

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 and 2000 year classes appear to be slightly above average (with wide confidence margins; Fig. 1.38). As more survey observations on these year classes occur, the precision of these estimates is expected to increase.

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

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:

$B_{100\%}$ = 6,563 thousand t female spawning biomass[2]

$B_{40\%}$ = **2,625** thousand t female spawning biomass

$B_{35\%}$ = **2,297** thousand t female spawning biomass

B_{msy} = **2,122** thousand t female spawning biomass

Specification of OFL and Maximum Permissible ABC

For Model 1, the year 2006 spawning biomass is estimated to be 2,503 thousand tons (at the time of spawning, assuming the stock is fished at F_{msy}). This is above the B_{msy} value of 2,122. 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. A simplified exploitation-rate type value that corresponds to the F_{msy} levels as applied to the age 3+ biomass was used for computing ABC levels under Tier 1 (Ianelli et al. 2004).

The 2006 estimate (assuming Tier 3 catch levels) is 2,677 thousand t. This is above the $B_{35\%}$ value of 2,297 . The OFL's and maximum permissible ABC values by both methods are thus:

Year		OFL	Max ABC
2006	Tier 1a	2,085 thousand t	1,931 thousand t
2006	Tier 3a	2,282 thousand t	1,876 thousand t
2007	Tier 1a	1,928 thousand t	1,786 thousand t
2007	Tier 3a	1,703 thousand t	1,417 thousand t

ABC Recommendation

As with last year, the biomass of Eastern Bering Sea pollock appears to be high but decreasing. The total begin-year age-3+ biomass in 2006 is projected to be about 8,232 thousand t. The estimated female spawning biomass projected to the time of spawning in the year 2006 is about **2,677** thousand tons, slightly above of the $B_{40\%}$ level of **2,610** thousand tons and well above the $B_{35\%}$ and the value estimated for B_{msy} (**2,297** and **2,122** respectively; Fig. 1.39).

Thompson and Dorn (2004) presented an approach where an "uncertainty" adjustment consistent with the risk-averse objectives specified in Alternative 3b from the Programmatic Supplemental Environmental Impact Statement (PSEIS; with assumptions). This involved maximizing the difference between average yield and half of the average squared first-differences (ASFD) in yield. In other words, this specifies a trade off between maximizing yield while minimizing between-year variability in yield. The standard projection model was modified so that for each simulated trajectory the ASFD could be computed along

[2] Note that another theoretical "unfished spawning biomass level" (based on stock-recruitment relationship $\tilde{B}_0$) is somewhat lower (5,541t).

with mean yield. This was profiled over a range of "F_{ABC} adjustments" and initial evaluations found that the results were sensitive to recruitment assumptions. More importantly, the value of the adjustment factor was sensitive to acknowledging the fact that the actual TAC is unlikely to ever exceed 1.5 million tons of pollock. When this constraint was added to the projection (i.e., that there was a cap of 1.5 million t) the objective function was maximized when there was no adjustment to the F_{ABC} value.

For 2006, the maximum permissible ABC alternatives based on the $F_{40\%}$ and harmonic-mean F_{msy} are 1,876 and 1,931 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value) as shown in Table 1.18 for Model 1. The 2000 year class is well above average and represents the mainstay of the population (about 27% of the total biomass in 2006, or 42% of the "exploitable" biomass—that adjusted by selectivity). Projections based on the current age-composition estimates indicate that the spawning stock is likely to drop below the $B_{35\%}$ level by 2007 and may drop below B_{msy} by 2008. 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 harvest levels below the maximum permissible values (e.g., constant catch scenarios of 1.5 and 1.3 million t; Fig. 1.40). For ABC considerations, the 2006 value that follows the Tier 3 harvest control rule is recommended since it is more precautionary than that of Tier 1.

Standard Harvest Scenarios and Projection Methodology

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). While EBS pollock is generally considered to fall within Tier 1, the standard projection model requires knowledge of future uncertainty in F_{msy}. Due to this and other complications, an option to have projections based on Tier 1 has been delayed. For this section, we thus treat this stock as if it were managed under Tier 3 for projections, but provide a proxy ABC and OFL value under Tier 1 rules (by using the same harmonic and arithmetic mean values for MSYR as applied to the age 3+ biomass).

For each scenario, the projections begin with the vector of 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch assumed for 2005. 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 1,000 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 2006 and 2007, are as follows (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 2006 and 2007 recommended in the assessment to the $max\ F_{ABC}$ for 2006. (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 2001-2005 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2006 or 2) above ½ of its MSY level in 2006 and above its MSY level in 2018 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, 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 2018 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 2005 (Table 1.23). Under Scenario 2, the expected spawning biomass will decrease to slightly below $B_{35\%}$ then increase to above $B_{40\%}$ by the year 2009 (Fig. 1.39). 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 projected to stay above $B_{40\%}$ (Fig. 1.41).

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 2006 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
b) If spawning biomass for 2006 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c) If spawning biomass for 2006 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 1.23). If the mean spawning biomass for 2016 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 2008 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2008 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2008 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2018. If the mean spawning biomass for 2018 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 2006, nor is it expected to be approaching an overfished condition based on Scenario 7 (the mean spawning biomass in 2008 is above the $B_{35\%}$ level; Table 1.23). For harvest recommendations, Tier 3 and a proxy for Tier 1 calculations were made that give ABC and OFL values for 2006 and 2007 (assuming catch is 1,492,000 t in 2006; Table 1.24).

Other considerations

Localized depletion estimators

A number of studies have been undertaken to evaluate on evaluating pollock exploitation patterns in the Eastern Bering Sea. Battaile (2004) used a DeLury model to investigate potential localized depletion by the fishery. The estimator used the slope of log-CPUE versus cumulative effort, for data from 1995-1999 stratified by small areas, short seasons and years. He found that of 237 depletion estimators, 172 had negative slopes while 65 had positive slopes. Each group had subsets that were statistically significant (more than expected based on chance alone). Depletion was most easily detected in areas of low abundance and consequently lower catch and effort. Overall, his estimates of depletion were smaller than the overall depletion expected from the estimates of exploitation rates. As noted in Barbeaux et al. (Chapter 1a) for the Aleutian Islands, estimators involving CPUE data from a pollock fishery are likely to be problematic due to hyperstability. Nonetheless, there is evidence that pollock can repopulate areas rapidly (Barbeaux and Dorn 2003). Subsequent studies involve evaluating opportunistic acoustic back-scatter data collected from commercial echo-sounders (Barbeaux et al. 2005). This may provide more reliable CPUE measures since the back-scatter from pollock in the water column is a fairly passive way to estimate fish density.

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 Eastern Bering Sea, 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 the 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 comparisons of the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models Aydin et al. (2002) found 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 (Fig. 1.42). This study showed that the food web estimated for the EBS ecosystem appears to be relatively mature due to the large number of interconnections among species. The diet of pollock is similar between adults and juveniles with the exception that adults become more pisciverous (with consumption of pollock by adult pollock representing their third largest prey item; Figs. 1.43). In terms of magnitude, pollock cannibalism may account for 2.5 million t to nearly 5 million t of pollock consumed (based on uncertainties in diet percentage and total consumption rate; Fig. 1.44).

Regarding specific small-scale ecosystems of the EBS, Cianelli et al. (2004) presented an application of an ecosystem model scaled to data available around the Pribilof Islands region. They applied bioenergetics and foraging theory to characterize the spatial extent of this ecosystem. They compared energy balance, from a food web model relevant to the foraging range of northern fur seals and found that a range of 100 nautical mile radius encloses the area of highest energy balance representing about 50% of the observed foraging range for lactating fur seals. This suggests that fur seals depend on areas outside the energetic balance region. This study develops a method for evaluating the shape and extent of a key ecosystem in the EBS (i.e., the Pribilof Islands). Furthermore, the extent that the pollock fishery extends into northern fur seal foraging habitat (e.g. Robson et al. 2004) will require careful monitoring and evaluation.

Ecosystem effects on the EBS pollock stock

A brief summary of these two perspectives is given in Table 1.25. 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.

EBS pollock fishery effects on the ecosystem.

Since the pollock fishery is primarily pelagic in nature, the bycatch of non-target species is small relative to the magnitude of the fishery (Tables 1.26). Jellyfish represent the largest component of the bycatch of non-target species and has been stable at around 5-6 thousand tons per year (except for 2000 when over 9,000 t were caught). The data on non-target species shows a high degree of inter-annual variability which reflects the spatial variability of the fishery and high observation error. This variability may mask any significant trends in bycatch.

The catch of other target species in the pollock fishery represent less than 1% of the total pollock catch. Nonetheless incidental catch of Pacific cod has increased since 1999 but is below the 1997 levels (Table 1.27). The incidental catch of flatfish was variable over time and has increased slightly. Proportionately, the incidental catch has decreased since the overall levels of pollock catch have increased. The catch of prohibited species was also variable but showed noticeable trends (Table 1.28). For example, the level of crab bycatch drops considerable after 1998 when all BSAI pollock fishing was restricted to using only pelagic trawls. Recent levels of salmon bycatch have increased dramatically and current restrictions are under revision to help minimize this problem.

Summary

Summary results are given in Table 1.29.

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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, 1979-2005. (2005 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	653,589	542,056	1,195,645	98,604	293,400	264,760
1992	830,560	559,771	1,390,331	52,352	10,000	160
1993	1,094,431	232,173	1,326,604	57,132	1,957	886
1994	1,152,573	176,777	1,329,350	58,659	NA	566
1995	1,172,304	91,941	1,264,245	64,925	trace	264
1996	1,086,840	105,938	1,192,778	29,062	trace	387
1997	819,888	304,543	1,124,431	25,940	trace	168
1998	965,767	135,399	1,101,166	23,822	trace	136
1999	783,119	206,697	989,816	1,010	trace	29
2000	839,175	293,532	1,132,707	1,244	trace	28
2001	961,975	425,219	1,387,194	824	trace	258
2002	1,159,732	320,463	1,480,195	1,156	trace	NA
2003	933,459	557,552	1,491,012	1,653	trace	NA
2004	1,089,880	390,414	1,480,294	1,150	Trace	923
2005			1,478,500			

1979-1989 data are from Pacfin.

1990-2004 data are from NMFS Alaska Regional Office, includes discards.
2005 EBS catch assuming full TAC will be taken

Table 1.2. Time series of ABC, TAC, and catch levels for EBS pollock, 1977-2004. Source: compiled from NMFS Regional office web site and various NPFMC reports.

Year	ABC	TAC	Catch
1977	950,000	950,000	978,370
1978	950,000	950,000	979,431
1979	1,100,000	950,000	935,714
1980	1,300,000	1,000,000	958,280
1981	1,300,000	1,000,000	973,502
1982	1,300,000	1,000,000	955,964
1983	1,300,000	1,000,000	981,450
1984	1,300,000	1,200,000	1,092,055
1985	1,300,000	1,200,000	1,139,676
1986	1,300,000	1,200,000	1,141,993
1987	1,300,000	1,200,000	1,018,946
1988	1,500,000	1,300,000	1,228,721
1989	1,340,000	1,340,000	1,229,600
1990	1,450,000	1,280,000	1,455,193
1991	1,676,000	1,300,000	1,093,670
1992	1,490,000	1,300,000	1,301,137
1993	1,340,000	1,300,000	1,306,263
1994	1,330,000	1,330,000	1,282,379
1995	1,250,000	1,250,000	1,182,388
1996	1,190,000	1,190,000	1,126,049
1997	1,130,000	1,130,000	1,059,061
1998	1,110,000	1,110,000	1,021,775
1999	992,000	992,000	987,492
2000	1,139,000	1,139,000	1,117,672
2001	1,842,000	1,400,000	1,244,956
2002	2,110,000	1,485,000	1,400,603
2003	2,330,000	1,491,760	1,491,760
2004	2,560,000	1,492,000	1,480,830
1977-2004 average	1,399,250	1,195,706	1,149,146

Table 1.3. Estimates of discarded pollock (t), percent of total (in parentheses) and total catch for the Aleutians, Bogoslof, Northwest and Southeastern Bering Sea, 1991-2004. Units are in tons, SE represents the EBS east of 170° W, NW is the EBS west of 170° W, source: NMFS Blend and catch-accounting system database.

	Discarded pollock					**Total (retained plus discard)**				
	Aleutian Is.	Bogoslof	NW	SE	Total	Aleutian Is.	Bogoslof	NW	SE	Total
1991	5,231 (5%)	20,327 (6%)	48,205 (9%)	66,789 (10%)	140,552 (9%)	98,604	316,038	542,056	653,552	1,610,288
1992	2,982 (6%)	240 (100%)	57,609 (10%)	71,195 (9%)	132,026 (9%)	52,352	241	559,771	830,560	1,442,924
1993	1,733 (3%)	308 (35%)	26,100 (11%)	83,989 (8%)	112,130 (8%)	57,132	886	232,173	1,094,431	1,384,622
1994	1,373 (2%)	11 (2%)	16,083 (9%)	88,098 (8%)	105,565 (8%)	58,659	556	176,777	1,152,573	1,388,565
1995	1,380 (2%)	267 (80%)	9,715 (11%)	87,491 (7%)	98,853 (7%)	64,925	334	91,941	1,172,304	1,329,503
1996	994 (3%)	7 (1%)	4,838 (5%)	71,367 (7%)	77,206 (6%)	29,062	499	105,938	1,086,840	1,222,339
1997	617 (2%)	13 (8%)	22,557 (7%)	71,031 (9%)	94,218 (8%)	25,940	163	304,543	819,888	1,150,533
1998	164 (1%)	3 (2%)	1,581 (1%)	15,135 (2%)	16,883 (2%)	23,822	136	135,399	965,767	1,125,123
1999	480 (48%)	11 (38%)	1,912 (1%)	27,089 (3%)	29,492 (3%)	1,010	29	206,697	783,119	990,855
2000	790 (64%)	20 (69%)	1,941 (1%)	19,678 (2%)	22,429 (2%)	1,244	29	293,532	839,175	1,133,981
2001	380 (46%)	28 (11%)	2,450 (1%)	14,873 (2%)	17,731 (1%)	824	258	425,219	961,889	1,388,190
2002	758 (66%)	12 (1%)	1,439 (0%)	19,226 (2%)	21,435 (1%)	1,156	1,042	320,463	1,159,730	1,482,391
2003	468 (28%)	NA	2,980 (1%)	14,063 (2%)	17,512 (1%)	1,653	NA	557,552	933,459	1,492,664
2004	758 (66%)	(0%)	2,723 (1%)	20,302 (2%)	23,783 (2%)	1,156	923	390,414	1,089,880	1,482,373

Table 1.4. Eastern Bering Sea walleye pollock catch at age estimates based on observer data, 1979-2004. 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	720.0	420.2	392.6	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	0.5	2,567.3
1980	9.8	462.4	823.3	443.5	252.2	211.0	83.7	37.6	21.8	23.9	25.5	15.9	7.7	2.5	2,420.8
1981	0.6	72.2	1,012.9	638.0	227.0	102.9	51.7	29.6	16.1	9.4	7.5	4.6	1.5	0.6	2,174.6
1982	4.8	25.3	161.4	1,172.4	422.4	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	0.7	2,003.8
1983	5.1	118.6	157.8	313.0	817.0	218.3	41.4	24.7	19.8	11.1	7.6	4.9	3.5	1.7	1,744.5
1984	2.1	45.8	88.6	430.8	491.9	654.3	133.9	35.6	25.1	15.7	7.1	2.5	2.9	1.7	1,938.0
1985	2.7	55.3	382.2	122.1	366.7	322.3	444.3	112.8	36.7	25.9	24.9	10.7	9.4	4.0	1,920.0
1986	3.1	86.0	92.3	748.5	214.1	378.1	221.9	214.2	59.7	15.2	3.3	2.6	0.3	1.2	2,040.5
1987	0.0	19.9	112.2	78.0	415.8	139.6	123.2	91.2	248.6	54.4	38.9	21.6	29.1	6.1	1,378.6
1988	0.0	10.7	455.2	422.8	252.8	545.9	225.4	105.2	39.3	97.1	18.3	10.2	3.8	5.5	2,192.2
1989	0.0	4.8	55.3	149.5	452.6	167.3	574.1	96.6	104.1	32.5	129.5	10.9	4.0	2.6	1,783.8
1990	1.0	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	1,745.9
1991	1.0	60.9	40.7	85.4	141.5	156.9	396.4	51.6	217.1	22.1	114.7	15.2	74.4	60.9	1,438.8
1992	0.0	79.0	721.7	143.5	98.1	125.0	145.4	276.8	109.3	165.4	59.4	50.2	14.2	91.0	2,079.0
1993	0.1	9.2	275.0	1,144.5	103.0	64.3	62.2	53.5	84.9	21.8	34.5	12.6	13.1	26.5	1,905.2
1994	0.3	31.5	59.8	383.4	1,109.5	180.5	54.9	21.0	13.5	20.1	9.1	10.7	7.6	15.7	1,917.5
1995	0.0	0.3	75.3	146.6	398.4	764.7	131.8	34.9	10.9	6.0	15.3	4.4	7.1	11.3	1,606.9
1996	0.0	9.5	19.8	44.0	145.9	353.3	493.7	192.9	35.3	16.3	10.1	9.7	4.4	14.3	1,349.4
1997	0.1	65.4	33.2	107.1	470.6	290.8	255.9	198.9	62.9	14.2	6.5	5.1	3.1	14.8	1,528.8
1998	0.0	36.3	86.7	72.3	160.8	704.0	203.6	128.6	107.6	29.1	5.7	6.3	3.0	7.4	1,551.5
1999	0.1	7.5	296.5	219.5	105.0	154.8	475.9	131.4	57.3	33.1	3.9	2.1	0.4	2.5	1,490.0
2000	0.0	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	1,646.3
2001	0.0	2.6	46.1	149.3	592.6	409.8	142.3	129.8	154.7	55.2	33.6	15.8	5.6	4.9	1,742.3
2002	0.6	46.9	106.1	211.2	283.5	609.8	270.7	101.2	81.8	91.0	33.8	14.4	11.9	4.3	1,867.4
2003	0.0	18.0	425.5	317.9	360.5	302.1	329.3	156.0	53.3	37.4	36.7	22.3	7.5	7.2	2,073.6
2004	0.0	1.5	122.4	914.9	498.9	233.9	160.1	152.0	59.9	15.0	16.2	23.8	9.8	10.7	2,219.2
Average	5.1	71.6	250.4	366.4	358.5	307.5	208.2	121.6	70.4	37.7	26.8	13.6	9.2	11.7	1,858.7
Median	0.1	32.3	109.2	266.9	353.1	226.1	152.8	103.2	58.5	24.9	16.9	10.5	5.0	4.8	1,886.3

Table 1.5. Numbers of pollock fishery samples measured for lengths and for length-weight by sex and strata, 1977-2004, as sampled by the NMFS observer program.

Lengths

	A Season		B Season SE		B Season NW	
	Males	Females	Males	Females	Males	Females
1977	26,411	25,923	4,301	4,511	29,075	31,219
1978	25,110	31,653	9,829	9,524	46,349	46,072
1979	59,782	62,512	3,461	3,113	62,298	61,402
1980	42,726	42,577	3,380	3,464	47,030	49,037
1981	64,718	57,936	2,401	2,147	53,161	53,570
1982	74,172	70,073	16,265	14,885	181,606	163,272
1983	94,118	90,778	16,604	16,826	193,031	174,589
1984	158,329	161,876	106,654	105,234	243,877	217,362
1985	119,384	109,230	96,684	97,841	284,850	256,091
1986	186,505	189,497	135,444	123,413	164,546	131,322
1987	373,163	399,072	14,170	21,162	24,038	22,117
1991	297,933	261,545	104,733	102,343	103,438	90,905
1992	254,752	236,342	58,497	58,420	143,256	145,574
1993	174,321	153,797	28,041	28,954	149,983	141,382
1994	165,794	162,393	28,580	28,467	161,015	154,016
1995	153,669	145,385	16,170	16,356	178,931	154,007
1996	162,093	150,841	18,165	18,348	199,588	155,606
1997	135,832	113,502	60,192	53,191	116,448	107,630
1998	143,511	115,988	32,819	40,307	208,659	178,012
1999	36,343	32,755	16,282	18,339	38,831	35,631
2000	65,658	59,319	40,729	38,882	62,958	40,329
2001	82,380	78,312	42,371	43,873	53,047	50,654
2002	78,130	78,891	33,006	32,410	63,823	62,202
2003	85,923	90,489	45,110	45,589	45,441	48,384
2004	87,826	88,864	43,877	40,076	54,369	53,540

L-wt samples

	A Season		B Season SE		B Season NW	
	Males	Females	Males	Females	Males	Females
1977	1,222	1,338	137	166	1,461	1,664
1978	1,991	2,686	409	516	2,200	2,623
1979	2,709	3,151	152	209	1,469	1,566
1980	1,849	2,156	99	144	612	681
1981	1,821	2,045	51	52	1,623	1,810
1982	2,030	2,208	181	176	2,852	3,043
1983	1,199	1,200	144	122	3,268	3,447
1984	980	1,046	117	136	1,273	1,378
1985	520	499	46	55	426	488
1986	689	794	518	501	286	286
1987	1,351	1,466	25	33	72	63
1991	3,901	4,032	820	890	1,538	1,662
1992	2,119	2,180	389	388	1,687	1,736
1993	1,285	1,354	444	462	1,463	1,418
1994	1,873	1,948	174	177	1,517	1,537
1995	1,410	1,493	223	232	1,320	1,343
1996	2,208	2,236	1	1	1,409	1,384
1997	664	661	511	523	616	665
1998	1,996	2,113	327	350	959	923
1999	5,318	4,798	3,532	3,768	7,797	7,054
2000	12,631	11,520	7,946	7,688	12,198	7,674
2001	15,438	14,867	8,431	8,696	10,580	10,270
2002	15,144	15,290	6,368	6,303	12,578	12,539
2003	16,853	17,870	8,731	8,793	8,624	9,215
2004	8,989	9,193	4,232	3,902	5,895	5,978

Table 1.6. Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977-2004, as sampled by the NMFS observer program.

	Aged					
	A Season		B Season SE		B Season NW	
	Males	Females	Males	Females	Males	Females
1977	1,229	1,344	137	166	1,415	1,613
1978	1,992	2,686	407	514	2,188	2,611
1979	2,647	3,088	152	209	1,464	1,561
1980	1,854	2,158	93	138	606	675
1981	1,819	2,042	51	52	1,620	1,807
1982	2,030	2,210	181	176	2,865	3,062
1983	1,200	1,200	144	122	3,249	3,420
1984	980	1,046	117	136	1,272	1,379
1985	520	499	46	55	426	488
1986	689	794	518	501	286	286
1987	1,351	1,466	25	33	72	63
1991	592	600	195	212	244	237
1992	597	584	137	161	313	327
1993	516	545	133	134	503	491
1994	332	328	141	147	586	592
1995	370	421	123	131	436	417
1996	553	522	1	1	442	433
1997	448	451	326	326	284	311
1998	734	825	216	232	307	307
1999	540	500	306	298	730	727
2000	677	639	252	291	833	574
2001	635	577	168	197	697	680
2002	711	761	178	203	798	840
2003	674	735	225	238	597	625
2004	661	675	230	194	512	596

Table 1.7. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-2005. Total haul numbers including those beyond the standard 1-6 strata are shown in parentheses.

Year	Number of Hauls	Lengths	Aged	Year	Number of Hauls	Lengths	Aged
1982	329	40,001	1,611	1993	355 (375)	43,278	1,385
1983	354	78,033	1,931	1994	355 (375)	38,901	1,141
1984	355	40,530	1,806	1995	356 (376)	25,673	1,156
1985	430 (434)	48,642	1,913	1996	355 (375)	40,789	1,387
1986	354	41,101	1,344	1997	356 (376)	35,536	1,193
1987	342 (356)	40,144	1,607	1998	355 (375)	37,673	1,261
1988	353 (373)	40,408	1,173	1999	353 (373)	32,532	1,385
1989	353 (373)	38,926	1,227	2000	352 (372)	41,762	1,545
1990	351 (371)	34,814	1,257	2001	355 (375)	47,335	1,641
1991	351 (371)	43,406	1,083	2002	355 (375)	43,361	1,695
1992	336 (356)	34,024	1,263	2003	356 (376)	46,480	1,638
				2004	355 (375)	44,102	1,660
				2005	353 (373)	35,976 (33,842)	1,676

Table 1.8. Biomass (age 1+) of Eastern Bering Sea walleye pollock as estimated by surveys 1979-2005 (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	4.77	3.62	(84%)	8.39	57%
2003	8.14				
2004	3.75	3.31		7.06	53
2005	5.13				

[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 1.9. Biomass (age 1+, t) of Eastern Bering Sea walleye pollock as estimated by NMFS bottom trawl surveys 1982-2005.

Year	Standard survey area	NW segment of survey area	Total	NW %Total
1982	2,855,540		2,855,539	
1983	6,257,632		6,257,632	
1984	4,893,536		4,893,536	
1985	4,630,111		4,630,111	
1986	4,896,779		4,896,780	
1987	5,108,035	416,558	5,524,593	8%
1988	7,107,260	181,909	7,289,168	2%
1989	5,927,187	591,623	6,518,809	9%
1990	7,126,084	195,894	7,321,977	3%
1991	5,105,225	62,523	5,167,748	1%
1992	4,367,870	214,676	4,582,546	5%
1993	5,520,892	114,757	5,635,649	2%
1994	4,977,020	49,721	5,026,740	1%
1995	5,413,271	68,983	5,482,253	1%
1996	3,204,105	167,090	3,371,196	5%
1997	3,031,557	842,276	3,873,833	22%
1998	2,212,688	639,715	2,852,404	22%
1999	3,597,404	203,314	3,800,717	5%
2000	5,134,616	129,932	5,264,548	2%
2001	4,145,746	54,163	4,199,909	1%
2002	4,832,507	205,231	5,037,737	4%
2003	8,140,574	317,089	8,457,662	4%
2004	3,756,228	130,227	3,886,455	3%
2005	5,133,606	160,109	5,293,715	3%

Table 1.10. 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
2004	**Total (US zone)**	139	29,934	3,251	2,351
	East of 170 W	45	8,881	1,152	798
	West of 170 W	94	21,053	2,099	1,192
	Russian zone	15	5,893	461	461

Table 1.11. Distribution of pollock between areas from summer echo integration-trawl surveys on the Bering Sea shelf, 1994-2004. 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%)	
2004	Jun 4 – Jul 29	99,659	0.498	0.516	2.293	3.307
			(15 %)	(16%)	(69%)	

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

Table 1.12. Fishery mean lengths at age, standard deviations, and sample sizes by area W of 170°W (NW) and E of 170°W (SE) for ages 4 and 5 from the July-Dec 2004 EBS pollock fishery.

	NW			SE		
Age	**Average**	**Std. Dev**	**N**	**Average**	**Std. Dev**	**N**
4	40.44	2.13	194	45.3	2.66	162
5	43.93	3.02	89	46.71	2.69	83

Table 1.13. 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: 2005 weight-at-age is treated as the three-year average of values from 2002-2004.

	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	0.170	0.277	0.471	0.603	0.722	0.837	0.877	0.996	1.109	1.127	1.194	1.207	1.256	1.244
1992	0.007	0.170	0.387	0.454	0.615	0.660	0.745	0.898	0.960	1.151	1.174	1.203	1.132	1.184	1.304
1993	0.007	0.170	0.492	0.611	0.657	0.770	0.934	1.078	1.187	1.238	1.385	1.512	1.632	1.587	1.465
1994	0.007	0.170	0.398	0.628	0.716	0.731	0.709	0.995	1.287	1.228	1.197	1.329	1.308	1.282	1.282
1995	0.007	0.170	0.389	0.505	0.733	0.841	0.854	1.000	1.235	1.314	1.375	1.488	1.402	1.336	1.491
1996	0.007	0.170	0.332	0.448	0.717	0.817	0.964	0.966	1.059	1.142	1.371	1.452	1.487	1.679	1.460
1997	0.007	0.170	0.325	0.468	0.554	0.745	0.890	1.071	1.084	1.236	1.332	1.421	1.570	1.451	1.418
1998	0.007	0.170	0.362	0.574	0.629	0.636	0.778	1.046	1.173	1.242	1.236	1.337	1.443	1.487	1.709
1999	0.007	0.170	0.412	0.492	0.655	0.697	0.750	0.960	1.081	1.347	1.275	1.516	2.399	1.118	1.104
2000	0.007	0.170	0.380	0.501	0.626	0.779	0.773	0.822	1.020	1.046	1.311	1.387	1.504	1.492	1.552
2001	0.007	0.170	0.275	0.512	0.678	0.818	0.990	1.055	1.073	1.195	1.279	1.376	1.482	1.506	1.597
2002	0.007	0.170	0.389	0.462	0.673	0.829	0.944	1.089	1.111	1.137	1.312	1.389	1.495	1.512	1.559
2003	0.007	0.274	0.484	0.551	0.654	0.771	0.866	0.956	1.082	1.224	1.236	1.225	1.468	1.339	1.772
2004	0.007	0.133	0.384	0.548	0.628	0.761	0.884	0.910	1.019	1.195	1.162	1.172	1.419	1.345	1.267
2005	0.007	0.192	0.419	0.520	0.652	0.787	0.898	0.985	1.071	1.185	1.237	1.262	1.461	1.399	1.533

Table 1.14. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2004. Note that for the 2004 assessment, the 2004 EIT sample size was half of the value (139) specified here since the BTS age-length key was used.

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	
			2004	200	100	139
			2005		100	

Table 1.15. List of alternative models presented in past assessments (since 1999) for EBS pollock.

Model description	Assessment years
Reference model	1999-2004
Bottom temperature a covariate with survey catchability	2001-2004
Bottom-trawl survey catchability fixed at 1.0.	2001-2004
Estimate natural mortality	2001-2004
Employ re-estimated age-error matrix	2003-2004
Fit fishery catch-age precisely (VPA-like assumption)	2004
Add in estimates of Russian catch in Navarin area	2003
Disregard survey data	2001-2003
Fishery selectivity allowed to vary more frequently	2001-2002
BTS selectivity parameterization sensitivity	2001
Dome-shaped survey selectivity allowed	2002
Full time series for estimate stock-recruitment curve	2000
Low assumption of process in stock-recruitment curve	2000
Model from 1980 onwards only (no early data)	2000
Moderate assumption of process in stock-recruitment curve	2000
Non-informative prior distribution on stock-recruitment steepness	2000
Use Beverton-Holt stock-recruitment curve	2000
Constant survey selectivities (EIT and BTS)	1999, 2000
Constant stock-recruitment (but stochastic) relationship	1999, 2000
Exclude current year EIT age composition data	1999, 2000
Use entire time series for estimating the stock-recruitment relationship within model	1999
Future selectivity based on most recent 10-year average.	1999
Future selectivity equals average selectivity since 1964	1999
Use OSCURS current model to affect improve recruitment prediction	1999

Table 1.16. Results comparing fits Models 1-6. See text for additional model descriptions.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
-ln(Likelihoods)						
Priors	9.16	9.19	9.15	9.02	8.93	9.10
CPUE	1.95	2.04	1.95	1.96	1.93	1.90
Bottom Trawl Survey	9.92	9.83	9.95	11.34	10.99	9.36
EIT Survey	-5.45	-5.19	-5.47	-4.95	-5.13	-6.05
Fishery Age Comp	-862.30	-864.09	-862.25	-863.05	-862.96	-862.69
Bottom Trawl Age Comp	-384.05	-383.56	-384.34	-383.98	-383.65	-384.14
EIT Age Comp	-255.88	-258.26	-259.01	-259.00	-259.06	-253.23
Stock-recruitment curve	2.73	5.56	2.72	2.78	2.69	3.12
Recruitment deviations	18.96	24.20	18.93	19.05	19.27	19.61
Catch	0.00	0.00	0.00	0.00	0.00	0.00
Fishery selectivity penalty/prior	22.59	24.40	22.64	23.85	23.65	22.47
BTS penalty/prior	13.73	13.75	14.00	13.49	13.69	14.44
EIT penalty/prior	29.21	28.56	32.21	32.25	32.22	24.86
Total –ln(likelihood)	-1399.43	-1393.57	-1399.51	-1397.23	-1397.42	-1401.24
Number of parameters	640	640	641	639	640	640
Age Composition data						
Effective N Fishery	194	244	194	194	194	194
Effective N Bottom trawl survey	134	140	139	156	146	129
Effective N Hydro acoustic survey	204	306	240	241	242	162

Survey abundance estimates, RMSE*	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Trawl Survey	0.237	0.241	0.239	0.255	0.250	0.227
EIT survey	0.341	0.345	0.341	0.349	0.346	0.332

Recruitment Residuals	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Due to Stock	0.24	0.21	0.24	0.24	0.24	0.24
Residual RMSE	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.39	0.52	0.39	0.39	0.40	0.40

Notes: 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 1.17. Results reflecting the stock condition for Models 1-5. 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
Biomass						
Year 2006 spawning biomass[5]	2,503	2,364	2,519	3,123	3,145	3,560
Year 2006 spawning biomass[6]	2,677	2,534	2,698	3,313	3,350	3,801
(CV)	(20%)	21%	21%	17%	17%	21%
2005 spawning biomass	3,221	3,100	3,230	3,934	4,036	4,546
B_{msy}	2,122	1,929	2,125	2,345	2,377	3,028
(CV)	(26%)	24%	27%	26%	24%	27%
$B_{40\%}$	2,625	2,546	2,596	2,806	2,799	3,737
(CV)	(5%)	5%	5%	4%	4%	5%
$B_{35\%}$	2,297	2,228	2,272	2,455	2,449	3,270
B0 (stock-recruitment curve)	5,541	5,048	5,544	6,103	6,180	7,885
Percent of Bmsy spawning biomass	118%	123%	119%	133%	132%	118%
Percent of B40% spawning biomass	103%	100%	104%	118%	120%	102%
2005 Age 3+ Biomass	8,232	7,746	8,335	10,014	10,343	11,713
Ratio B2003/B2002 (3+ biomass)	89%	87%	89%	90%	90%	90%
Recruitment						
Steepness parameter (*h*)	0.649	0.651	0.649	0.642	0.637	0.646
Avg Recruitment (all yrs)	22,365	21,954	22,370	23,837	25,747	33,559
(CV)	62%	73%	62%	63%	64%	62%
Avg. recruitment (since 1978)	24,223	23,766	24,233	26,190	28,559	34,880
(CV since 1978)	66%	79%	66%	66%	66%	68%
2000 year class	45,485	46,947	45,993	51,956	55,590	63,683
(CV 2000 year class)	18%	18%	18%	17%	20%	18%
Natural Mortality						
(age 3 and older)	0.300	0.300	0.300	0.300	0.317	0.300

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

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

Table 1.18. Results relating to yield for Models 1-6. See text for model descriptions.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Yield projections						
B_{msy} (age 3+)	8,313	7,610	8,327	9,112	9,504	11,805
2006 Age 3+ biomass (GM)	8,059	7,581	8,152	9,853	10,161	11,464
MSYR (HM)	0.240	0.241	0.239	0.235	0.239	0.237
2006 MSYR yield (Tier 1 ABC)	**1,931**	1,829	1,952	2,312	2,428	2,719
MSYR (AM)	0.259	0.260	0.258	0.254	0.258	0.257
2006 MSYR OFL	**2,085**	1,970	2,107	2,499	2,627	2,941
MSY (long-term expectation)	2,104	1,930	2,106	2,257	2,399	2,962
Average F's						
F_{msy}	0.483	0.490	0.487	0.429	0.473	0.484
	(109%)	(108%)	(110%)	(105%)	(112%)	(111%)
$F_{40\%}$ (average F)	0.275	0.276	0.276	0.256	0.285	0.279
$F_{35\%}$ 2006 Yield	2,282	2,163	2,322	2,782	3,060	3,270
2006 yield F40%	1,876	1,779	1,907	2,297	2,522	2,687
Full Selection F's						
F_{msy} (AM)	0.918	0.938	0.933	0.822	0.900	0.914
F_{msy} (HM)	0.416	0.423	0.419	0.373	0.404	0.416
F40%	0.522	0.528	0.528	0.491	0.542	0.528
$F_{35\%}$	0.665	0.672	0.674	0.621	0.692	0.673
Spawning biomass levels						
B_0 (stock-recruitment curve)	5,541	5,048	5,544	6,103	6,180	7,885
$B_{100\%}$	6,563	6,365	6,490	7,014	6,998	9,342
$B_{40\%}$	2,625	2,546	2,596	2,806	2,799	3,737
$B_{35\%}$	2,297	2,228	2,272	2,455	2,449	3,270

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 1.19 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	5,215	3,762	2,178	518	241	366	149	63	35	215	12,740
1965	20,741	2,117	2,367	1,519	315	147	230	96	42	169	27,740
1966	13,842	8,419	1,332	1,654	929	194	93	148	63	142	26,817
1967	30,273	5,620	5,305	935	1,028	580	124	61	99	140	44,165
1968	27,852	12,284	3,477	3,364	530	600	349	75	37	149	48,717
1969	29,130	11,302	7,600	2,204	1,904	309	361	213	46	116	53,184
1970	22,147	11,821	6,997	4,835	1,255	1,116	187	221	131	101	48,810
1971	9,446	8,986	7,140	4,145	2,812	730	661	109	130	132	34,292
1972	11,045	3,830	5,336	3,944	2,235	1,518	404	360	60	138	28,872
1973	26,552	4,476	2,240	2,766	1,986	1,127	788	206	184	95	40,419
1974	20,343	10,763	2,479	984	1,249	914	530	373	98	132	37,865
1975	17,183	8,242	5,818	995	408	529	397	232	164	101	34,067
1976	12,797	6,966	4,589	2,604	457	191	253	191	112	127	28,285
1977	14,502	5,193	4,016	2,338	1,195	213	93	124	94	119	27,886
1978	28,561	5,887	3,047	2,183	1,166	604	111	49	66	114	41,787
1979	63,871	11,593	3,441	1,633	1,069	579	310	58	25	95	82,675
1980	26,360	25,936	7,142	2,094	810	474	262	146	27	57	63,308
1981	30,157	10,706	16,083	4,513	1,120	396	235	134	75	44	63,463
1982	15,902	12,253	6,713	10,825	2,748	646	230	140	79	71	49,607
1983	52,580	6,463	7,770	4,808	7,114	1,668	383	137	83	89	81,096
1984	12,445	21,373	4,104	5,610	3,250	4,524	1,041	240	86	108	52,780
1985	33,598	5,059	13,570	2,962	3,789	2,064	2,821	652	150	121	64,786
1986	12,947	13,658	3,208	9,753	2,035	2,496	1,256	1,722	401	162	47,637
1987	7,542	5,263	8,663	2,309	6,730	1,350	1,537	776	1,072	341	35,583
1988	4,710	3,066	3,341	6,260	1,608	4,528	851	971	494	880	26,710
1989	7,644	1,915	1,947	2,350	4,245	1,035	2,869	508	595	864	23,973
1990	52,692	3,108	1,216	1,367	1,587	2,714	651	1,693	308	912	66,246
1991	26,895	21,419	1,969	827	875	933	1,554	337	918	695	56,422
1992	20,657	10,934	13,608	1,399	535	546	534	809	182	872	50,075
1993	51,670	8,397	6,934	9,479	848	307	276	235	376	498	79,022
1994	13,167	21,005	5,334	4,922	6,110	526	175	143	126	470	51,979
1995	9,676	5,353	13,363	3,902	3,376	3,683	257	70	73	348	40,101
1996	22,175	3,934	3,408	9,817	2,747	2,182	2,073	127	41	267	46,771
1997	30,605	9,015	2,505	2,508	6,993	1,832	1,308	1,124	78	202	56,172
1998	14,439	12,442	5,732	1,819	1,750	4,741	1,125	767	648	170	43,634
1999	16,144	5,870	7,913	4,169	1,276	1,195	2,956	672	452	497	41,145
2000	22,844	6,563	3,733	5,756	2,924	871	745	1,767	396	582	46,182
2001	45,485	9,287	4,178	2,720	3,959	1,851	507	425	1,017	609	70,038
2002	15,840	18,492	5,911	3,041	1,863	2,483	1,062	285	241	994	50,212
2003	8,409	6,439	11,765	4,286	2,048	1,128	1,350	562	153	738	36,879
2004	14,603	3,419	4,096	8,364	2,818	1,209	621	692	296	530	36,647
2005	16,631	5,937	2,174	2,913	5,507	1,668	668	320	365	486	36,668
Median	18,763	7,604	4,383	2,840	1,807	984	519	234	128	165	45,173
Average	22,365	9,013	5,565	3,700	2,320	1,352	771	429	241	326	46,082

Table 1.20. Estimated catch-at-age of EBS pollock for Model 1 (millions).

Year	1	2	3	4	5	6	7	8	9	10+	Total
1964	5.6	39.8	110.5	80.3	36.5	48.5	16.9	6.2	3.0	16.0	363.4
1965	21.8	21.8	116.7	229.3	46.5	19.0	25.5	9.2	3.5	12.1	505.4
1966	13.3	79.3	60.3	230.4	126.7	23.0	9.5	13.1	4.9	9.5	570.0
1967	38.6	134.4	663.0	191.8	190.3	94.4	19.1	8.9	13.8	19.1	1,373.5
1968	35.5	294.2	435.1	690.7	98.2	97.7	54.0	11.1	5.2	20.3	1,742.0
1969	36.4	264.8	931.6	443.8	345.9	49.3	54.6	30.6	6.4	15.5	2,178.8
1970	30.3	503.0	1,217.4	902.9	233.6	193.4	33.8	39.8	23.6	24.0	3,202.0
1971	17.0	498.1	1,579.8	982.1	664.1	161.1	152.3	25.1	29.6	35.6	4,144.7
1972	24.2	256.5	1,396.3	1,102.8	623.1	396.0	109.9	97.5	16.1	44.8	4,067.1
1973	52.2	475.4	797.5	944.9	657.5	359.8	248.3	64.6	57.7	30.3	3,688.1
1974	46.9	1,328.1	997.2	380.4	468.7	331.0	189.5	132.9	34.8	47.5	3,957.1
1975	32.6	846.5	2,014.4	330.2	131.2	164.1	121.4	70.7	49.9	31.1	3,792.0
1976	15.8	539.8	1,249.7	866.5	147.9	57.5	74.5	55.6	32.3	36.0	3,075.6
1977	14.8	335.2	930.4	666.7	331.2	54.8	23.3	30.8	23.2	28.6	2,439.0
1978	30.4	396.5	733.2	645.7	335.1	161.3	29.0	12.6	16.8	28.4	2,389.0
1979	51.9	316.0	532.8	471.5	375.4	197.7	99.3	18.4	8.1	29.5	2,100.5
1980	17.4	574.5	911.6	506.7	240.3	136.7	70.4	39.0	7.2	14.9	2,518.8
1981	12.0	143.6	1,273.8	697.6	215.7	73.9	40.8	23.1	12.8	7.3	2,500.6
1982	3.2	53.9	192.7	1,059.3	431.2	112.5	39.3	23.6	13.4	12.4	1,941.7
1983	8.1	21.8	171.4	364.9	873.1	227.6	51.2	18.2	11.0	12.5	1,759.7
1984	1.9	72.5	91.2	428.8	401.7	621.7	140.3	32.0	11.5	15.3	1,816.8
1985	3.9	22.4	350.8	186.0	363.6	319.9	430.4	95.6	24.9	20.6	1,818.1
1986	1.4	57.0	78.2	577.9	184.5	366.2	181.5	239.1	62.9	26.0	1,774.8
1987	0.7	19.1	184.1	119.6	534.7	174.3	195.3	94.7	148.1	47.7	1,518.5
1988	0.4	9.6	145.5	458.7	182.8	568.7	144.1	145.5	68.9	110.9	1,835.1
1989	0.6	6.3	88.9	180.4	504.7	136.0	507.4	79.5	86.9	111.4	1,702.0
1990	6.6	16.0	85.9	160.6	284.9	536.0	170.4	395.1	67.3	177.5	1,900.2
1991	2.2	62.2	69.6	91.1	120.4	183.9	402.5	79.7	222.7	157.5	1,391.7
1992	2.5	46.8	702.8	220.7	104.6	150.3	189.7	263.8	60.9	272.1	2,014.0
1993	4.3	25.0	250.7	1,067.5	119.2	61.9	73.1	56.7	93.0	115.4	1,866.7
1994	0.8	37.9	58.1	316.1	988.7	156.4	70.4	38.3	26.8	83.5	1,777.1
1995	0.4	6.4	96.5	167.6	372.9	770.2	74.9	13.2	10.7	41.9	1,554.6
1996	0.7	3.6	18.9	326.3	236.9	361.4	483.9	18.8	4.7	25.1	1,480.4
1997	1.3	20.6	42.8	126.2	513.7	272.7	237.2	216.2	13.7	30.0	1,474.4
1998	0.6	26.1	89.8	84.1	118.2	651.4	188.5	136.6	105.0	23.4	1,423.7
1999	0.6	12.3	124.0	192.7	86.2	164.2	495.5	119.7	73.2	68.9	1,337.3
2000	0.9	8.9	53.2	355.8	368.7	162.1	149.2	343.0	61.0	74.2	1,577.1
2001	1.9	13.4	63.1	177.8	526.7	362.5	106.8	86.8	165.0	81.6	1,585.5
2002	0.8	32.3	108.1	239.2	295.8	575.6	264.3	68.8	46.5	160.6	1,792.0
2003	0.5	12.7	411.3	417.6	361.6	251.9	363.1	142.3	33.7	118.4	2,113.1
2004	0.9	6.7	141.5	805.7	492.4	267.3	165.4	173.2	64.6	83.7	2,201.2
2005	0.9	11.2	72.5	271.2	931.3	357.4	172.6	77.6	77.3	29.1	2,001.1
Median	4.1	43.3	177.7	360.3	333.1	179.1	130.8	60.6	28.2	30.1	1,826.6
Average	12.9	182.2	467.7	446.7	349.2	248.4	158.8	86.8	45.3	56.0	2,053.9

Table 1.21. Estimated EBS pollock Model 1 age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964-2005. Biomass units are thousands of t, age-1 recruitment is in millions of pollock.

Year	Age 3+	Spawning	Age 1 Rec.	Year	Age 3+	Spawning	Age 1 Rec.
1964	1,779	527	5,215	1985	12,435	3,757	33,598
1965	2,222	634	20,741	1986	11,609	3,981	12,947
1966	2,288	732	13,842	1987	12,106	4,064	7,542
1967	3,483	903	30,273	1988	11,153	3,967	4,710
1968	3,881	1,096	27,852	1989	9,384	3,536	7,644
1969	5,323	1,375	29,130	1990	7,392	2,810	52,692
1970	6,447	1,733	22,147	1991	5,454	2,030	26,895
1971	7,145	1,975	9,446	1992	8,905	2,073	20,657
1972	6,692	1,928	11,045	1993	11,669	3,119	51,670
1973	5,055	1,576	26,552	1994	11,000	3,400	13,167
1974	3,635	1,107	20,343	1995	13,605	3,791	9,676
1975	3,666	893	17,183	1996	11,826	3,960	22,175
1976	3,614	891	12,797	1997	9,966	3,633	30,605
1977	3,548	922	14,502	1998	9,915	3,355	14,439
1978	3,361	929	28,561	1999	10,998	3,395	16,144
1979	3,273	888	63,871	2000	9,947	3,323	22,844
1980	4,373	1,033	26,360	2001	9,566	3,373	45,485
1981	8,289	1,761	30,157	2002	9,824	3,175	15,840
1982	9,446	2,666	15,902	2003	13,073	3,447	8,409
1983	10,536	3,273	52,580	2004	10,972	3,434	14,603
1984	10,244	3,492	12,445	2005	9,277	3,221	16,631

Table 1.22. 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 2004-1999 assessments for EBS pollock. NOTE: see Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

	Current		2004		2003		2002		2001		2000		1999	
	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV
1964	1,779	46%	1,789	46%	1,822	46%	1,784	46%	1,726	46%	751	35%	917	41%
1965	2,222	41%	2,272	40%	2,312	40%	2,266	40%	2,196	40%	976	36%	976	32%
1966	2,288	41%	2,326	40%	2,372	40%	2,324	40%	2,251	41%	1,001	39%	919	31%
1967	3,483	33%	3,514	33%	3,575	33%	3,511	33%	3,420	33%	1,957	34%	1,858	24%
1968	3,881	34%	3,976	34%	4,049	34%	3,976	34%	3,876	34%	2,312	36%	2,312	27%
1969	5,323	32%	5,258	31%	5,340	31%	5,252	32%	5,137	32%	3,379	29%	3,579	22%
1970	6,447	29%	6,211	30%	6,296	30%	6,201	30%	6,079	30%	3,998	25%	4,479	19%
1971	7,145	25%	6,714	27%	6,797	27%	6,702	27%	6,580	28%	4,372	21%	5,161	16%
1972	6,692	25%	6,204	26%	6,282	26%	6,194	26%	6,078	27%	3,984	19%	4,896	15%
1973	5,055	30%	4,632	31%	4,705	31%	4,626	31%	4,520	32%	2,873	26%	3,357	20%
1974	3,635	37%	3,288	38%	3,356	38%	3,287	38%	3,193	39%	1,648	41%	1,952	28%
1975	3,666	28%	3,440	27%	3,489	27%	3,436	27%	3,366	26%	2,536	23%	2,683	18%
1976	3,614	22%	3,497	22%	3,538	22%	3,492	22%	3,434	22%	2,694	17%	2,748	16%
1977	3,548	20%	3,504	20%	3,541	20%	3,496	20%	3,444	20%	2,701	13%	2,716	14%
1978	3,361	20%	3,385	20%	3,422	20%	3,375	20%	3,327	19%	2,608	14%	2,668	15%
1979	3,273	20%	3,341	19%	3,380	19%	3,329	19%	3,280	19%	2,640	16%	2,720	16%
1980	4,373	16%	4,409	16%	4,462	16%	4,385	16%	4,322	16%	3,723	15%	3,888	16%
1981	8,289	13%	8,301	14%	8,414	14%	8,239	14%	8,127	14%	7,834	12%	8,064	13%
1982	9,446	13%	9,472	13%	9,614	13%	9,388	13%	9,261	13%	9,021	13%	9,229	13%
1983	10,536	13%	10,552	13%	10,728	13%	10,441	13%	10,298	13%	9,958	12%	10,153	12%
1984	10,244	13%	10,263	13%	10,456	13%	10,143	13%	10,000	13%	9,518	13%	9,685	12%
1985	12,435	11%	12,492	11%	12,771	11%	12,344	11%	12,181	11%	11,182	10%	11,370	10%
1986	11,609	11%	11,677	11%	11,973	11%	11,538	11%	11,381	11%	10,277	10%	10,440	10%
1987	12,106	10%	12,226	10%	12,596	10%	12,116	10%	11,951	10%	10,636	9%	10,769	9%
1988	11,153	9%	11,243	10%	11,633	10%	11,317	10%	11,159	10%	9,910	8%	9,991	9%
1989	9,384	10%	9,466	10%	9,850	10%	9,540	10%	9,394	10%	8,251	9%	8,305	9%
1990	7,392	11%	7,454	11%	7,811	11%	7,524	11%	7,393	11%	6,473	10%	6,497	10%
1991	5,454	12%	5,637	13%	5,977	13%	5,708	13%	5,582	12%	4,859	11%	4,842	11%
1992	8,905	9%	9,120	10%	9,614	10%	9,227	10%	8,898	10%	7,920	9%	7,800	10%
1993	11,669	10%	11,721	11%	12,363	11%	12,110	10%	11,503	10%	10,233	10%	9,873	10%
1994	11,000	10%	10,998	11%	11,696	11%	11,358	11%	10,590	11%	9,285	10%	8,622	12%
1995	13,605	11%	13,554	12%	14,474	12%	13,848	12%	12,617	13%	10,267	12%	8,817	15%
1996	11,826	11%	11,772	13%	12,630	13%	11,988	13%	10,752	14%	8,556	14%	7,147	17%
1997	9,966	12%	9,949	15%	10,775	15%	10,142	15%	8,984	16%	7,057	17%	5,710	22%
1998	9,915	13%	9,943	16%	11,110	16%	10,466	17%	9,335	20%	7,448	22%	5,961	28%
1999	10,998	12%	11,093	20%	13,339	20%	12,712	21%	12,593	28%	10,772	30%	7,513	36%
2000	9,947	13%	10,036	23%	12,498	23%	11,807	24%	11,680	33%	10,490	34%		
2001	9,566	15%	9,675	27%	12,394	27%	11,511	27%	11,145	39%				
2002	9,824	17%	9,899	32%	12,930	32%	11,118	33%						
2003	13,073	25%	12,239	37%	12,688	37%								
2004	10,972	30%	9,894	42%	11,217	42%								
2005	9,277	35%	8,573											
2006	8,232	41%												

Table 1.23 Projections of Model 1 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. Note that the values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 6,563; 2,625; and 2,297 t, respectively.

Catch	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2005	1,492	1,492	1,492	1,492	1,492	1,492	1,492
2006	1,872	1,492	1,021	1,308	0	2,266	1,872
2007	1,247	1,417	892	1,146	0	1,310	1,247
2008	1,098	1,160	833	1,034	0	1,154	1,336
2009	1,203	1,225	869	1,053	0	1,305	1,370
2010	1,392	1,399	978	1,167	0	1,529	1,549
2011	1,534	1,537	1,085	1,279	0	1,672	1,677
2012	1,608	1,609	1,167	1,363	0	1,728	1,729
2013	1,624	1,625	1,209	1,399	0	1,728	1,729
2014	1,622	1,622	1,225	1,411	0	1,716	1,716
2015	1,623	1,623	1,236	1,418	0	1,718	1,718
2016	1,635	1,635	1,246	1,429	0	1,736	1,736
2017	1,643	1,643	1,254	1,437	0	1,741	1,742
2018	1,641	1,641	1,258	1,441	0	1,737	1,737

F	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2005	0.187	0.187	0.187	0.187	0.187	0.187	0.187
2006	0.275	0.210	0.137	0.181	0.000	0.348	0.275
2007	0.226	0.241	0.129	0.181	0.000	0.264	0.226
2008	0.220	0.226	0.129	0.181	0.000	0.258	0.276
2009	0.231	0.233	0.130	0.181	0.000	0.275	0.281
2010	0.240	0.241	0.132	0.181	0.000	0.290	0.292
2011	0.246	0.247	0.133	0.181	0.000	0.298	0.299
2012	0.248	0.248	0.134	0.181	0.000	0.300	0.301
2013	0.249	0.249	0.134	0.181	0.000	0.301	0.301
2014	0.249	0.249	0.134	0.181	0.000	0.300	0.300
2015	0.250	0.250	0.135	0.181	0.000	0.300	0.300
2016	0.250	0.250	0.135	0.181	0.000	0.301	0.301
2017	0.250	0.250	0.135	0.181	0.000	0.301	0.301
2018	0.250	0.250	0.135	0.181	0.000	0.301	0.301

Sp.Biomass	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***	***Scenario 7***
2005	3,219	3,219	3,219	3,219	3,219	3,219	3,219
2006	2,672	2,728	2,793	2,754	2,922	2,609	2,672
2007	2,183	2,316	2,585	2,431	3,126	2,012	2,183
2008	2,146	2,202	2,624	2,392	3,459	1,978	2,114
2009	2,337	2,360	2,856	2,578	3,919	2,167	2,220
2010	2,556	2,566	3,149	2,834	4,436	2,364	2,384
2011	2,689	2,694	3,373	3,026	4,881	2,466	2,474
2012	2,732	2,735	3,505	3,129	5,240	2,484	2,487
2013	2,730	2,731	3,575	3,173	5,543	2,467	2,469
2014	2,729	2,730	3,617	3,200	5,769	2,462	2,463
2015	2,742	2,743	3,660	3,231	5,973	2,474	2,475
2016	2,767	2,767	3,705	3,268	6,146	2,497	2,498
2017	2,770	2,770	3,724	3,282	6,266	2,497	2,498
2018	2,756	2,756	3,725	3,277	6,354	2,482	2,482

Table 1.24 Scenario 1 (maximum permissible F_{ABC} under Tier 3 which equals a proxy for Author's recommended) EBS pollock projections of Model 1 showing assumed catches and respective ABCs and OFLs given those catch levels. Also shown are Tier 1 levels for 2006 and approximate values for 2007 (using project age-3+ biomass levels and the HM F_{msy} value).
Units are thousands of tons.

	Catch	Tier 3 ABC	Tier 3 OFL	Tier 1 ABC	Tier 1 OFL
2006	1,492	1,872	2,266	1,931	2,085
2007	1,417	1,417	1,703	1,786	1,928

Table 1.25. 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 1.26 Bycatch estimates (mt) of non-target species caught in the BSAI directed pollock fishery, 1997-2002 based on observer data, 2003-2005 based on observer data as processed through the catch accounting system (NMFS Regional Office, Juneau, Alaska).

	1997	1998	1999	2000	2001	2002		2003	2004	2005
Jellyfish	6,632	6,129	6,176	9,361	3,095	1,530	Jellyfish	5,644	6,040	5,183
Squid	1,487	1,210	474	379	1,776	1,708	Squid	1,151	855	1,041
Skates	348	406	376	598	628	870	Skate	452	673	718
Misc Fish	207	134	156	236	156	134	Misc fish	101	77	154
Sculpins	109	188	67	185	199	199	Large Sculpins	42.6	116	137
Sleeper shark	105	74	77	104	206	149	Shark	81.8	107	84
Smelts	19.5	30.2	38.7	48.7	72.5	15.3	Sea star	89.4	6.77	9.22
Grenadiers	19.7	34.9	79.4	33.2	11.6	6.5	Other Sculpins	59.2	15.5	10.8
Salmon shark	6.6	15.2	24.7	19.5	22.5	27.5	Grenadier	20.4	9.40	8.99
Starfish	6.5	57.7	6.8	6.2	12.8	17.4	Eulachon	2.49	18.8	8.98
Shark	15.6	45.4	10.3	0.1	2.3	2.3	Other osmerids	7.51	1.97	3.38
Benthic inverts.	2.5	26.3	7.4	1.7	0.6	2.1	Snails	1.26	0.94	6.91
Sponges	0.8	21.0	2.4	0.2	2.1	0.3	Eelpouts	7.03	0.61	1.33
Octopus	1.0	4.7	0.4	0.8	4.8	8.1	Giant Grenad.	0.31	3.50	5.02
Crabs	1.0	8.2	0.8	0.5	1.8	1.5	Octopus	1.10	2.58	1.16
Anemone	2.6	1.8	0.3	5.8	0.1	0.6	Sea pens/whips	0.58	0.95	1.65
Tunicate	0.1	1.5	1.5	0.4	3.7	3.8	Birds	0.13	0.11	2.42
Unident. inverts	0.2	2.9	0.1	4.4	0.1	0.2	Anemone	0.40	0.41	0.29
Echinoderms	0.8	2.6	0.1	0.0	0.2	0.1	Misc crabs	0.75	0.03	0.26
Seapen/whip	0.1	0.2	0.5	0.9	1.5	2.1	Lanternfish	0.29	0.07	0.63
Birds	0.2	2.1	0.7	0.2	0.3	0.3	Capelin	0.01	0.32	0.35
Lanternfish	0.4	0.2	0.0	0.1	0.3	2.7	Urochordate	0.00	0.01	0.49
Coral	0.0	0.2	0.0	0.1	0.0	0.0	Pandal. shrimp	0.01	0.01	0.43
Dogfish	0.0	0.1	0.0	0.0	0.1	0.0	Corals Bryozo.	0.01	0.04	0.35
Sandfish	0.0	0.0	0.1	0.4	0.1	0.3	Brittle star	0.26	0.01	0.02
Sandlance	0.0	0.0	0.0	0.0	0.0	0.2	Invertebrate	0.04	0.12	0.09
Shrimp	0.1	0.3	0.3	0.0	0.1	0.2	Stichaeidae	0.08	0.07	0.04
Sticheidae	0.1	0.0	0.0	0.0	0.3	0.0	Sponge	0.10	0.05	0.03
							Other	0.09	0.08	0.07

Table 1.27 Bycatch estimates (mt) of target species caught in the BSAI directed pollock fishery, 1997-2004 based on then NMFS Alaska Regional Office reports from observers.

	1997	1998	1999	2000	2001	2002	2003	2004
Pacific Cod	8,478	6,560	3,220	3,432	3,879	5,928	5,773	6,192
Flathead Sole	2,353	2,118	1,885	2,510	2,199	1,844	1,629	2,019
Rock Sole	1,529	779	1,058	2,688	1,673	1,885	1,345	2,301
Yellowfin Sole	606	1,762	350	1,466	594	768	150	671
Arrowtooth Flounder	1,155	1,762	273	979	529	607	550	541
Pacific Ocean Perch	512	692	121	22	574	545	691	321
Atka Mackerel	229	91	165	2	41	221	379	369
Rex Sole	151	68	34	10	103	169		
Greenland Turbot	125	178	30	52	68	70	38	18
Alaska Plaice	1	14	3	147	14	50	7	7
Other flatfish							199	322
All other	93	41	31	77	118	103	144	130

Table 1.28 Bycatch estimates (mt) of prohibited species caught in the BSAI directed pollock fishery, 1997-2004 based on then NMFS Alaska Regional Office reports from observers, (n=numbers, t=metric tons).

	1997	1998	1999	2000	2001	2002	2003	2004
Herring (t)	1,089	821	785	482	224	105	895	963
Red king crab (n)	0	5,098	0	0	38	6	53	10
Other king crab (n)	156	1,832	2	104	5,135	81	9	6
Bairdi crab (n)	6,525	35,594	1,078	173	86	651	784	1,200
Other tanner crab (n)	88,588	45,623	12,778	1,807	2,179	1,667	761	740
Chinook salmon (n)	43,336	49,373	10,187	3,966	30,107	32,222	46,044	53,343
Other salmon (n)	61,504	62,276	44,585	56,707	52,835	76,998	190,146	436,176
Halibut (t)	127	144	69	80	164	127	97	92

Table 1.29. 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 Fish.	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
Selectivity	0.000	0.013	0.213	0.614	1.170	1.528	1.900	1.767	1.507	1.236	1.010	1.010	1.010	1.010	1.010

Base model	**Model 1**
Tier (2005)	**1**
Age 3+ 2006 begin-year biomass	**8,232** t
2005 Spawning biomass	**3,221** t
B_{msy}	**2,122** t
$B_{40\%}$	**2,625** t
$B_{35\%}$	**2,297** t
$B_{100\%}$	**6,563** t
B_0	**5,541** t

Yield Considerations		**2006**	**2007**
ABC:	Harmonic Mean F_{msy}	**1,931** t	**1,786** t
ABC:	Yield $F_{40\%}$ (Tier 3)	**1,876** t	**1,417** t
OFL:	Arithimetic Mean F_{msy} Yield	**2,085** t	**1,928** t
OFL:	Yield $F_{40\%}$ (Tier 3)	**2,282** t	**1,703** t

Full Selection F's	
F_{msy}	**0.918**
$F_{40\%}$	**0.522**
$F_{35\%}$	**0.665**

Figures

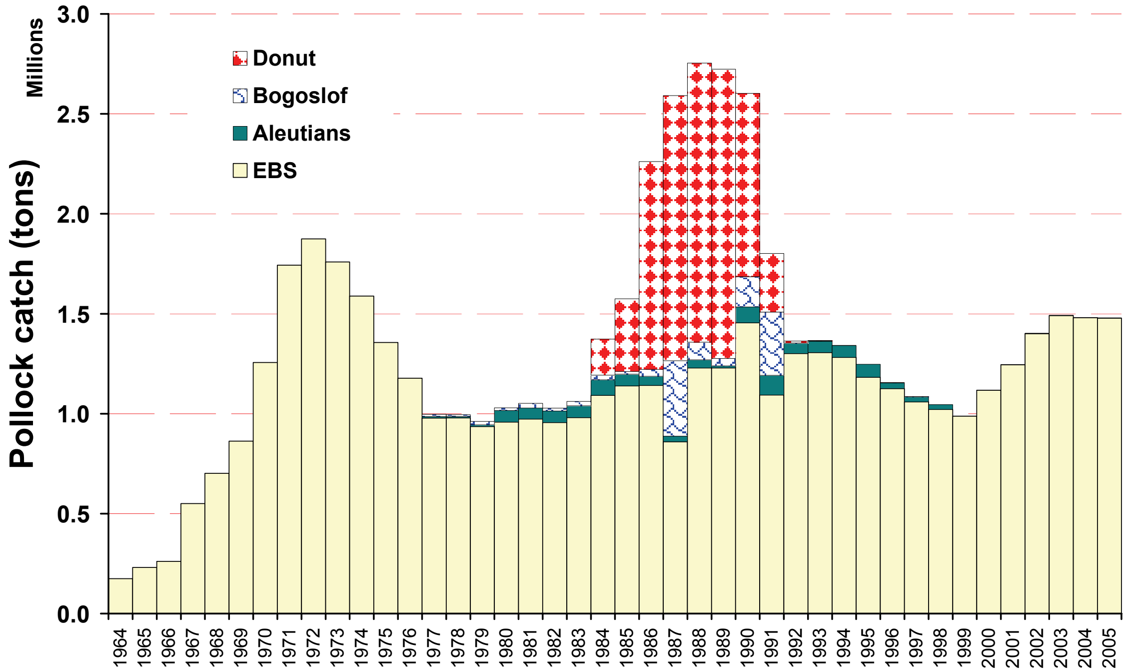


Figure 1.1. Walleye pollock catch in the Eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-2005

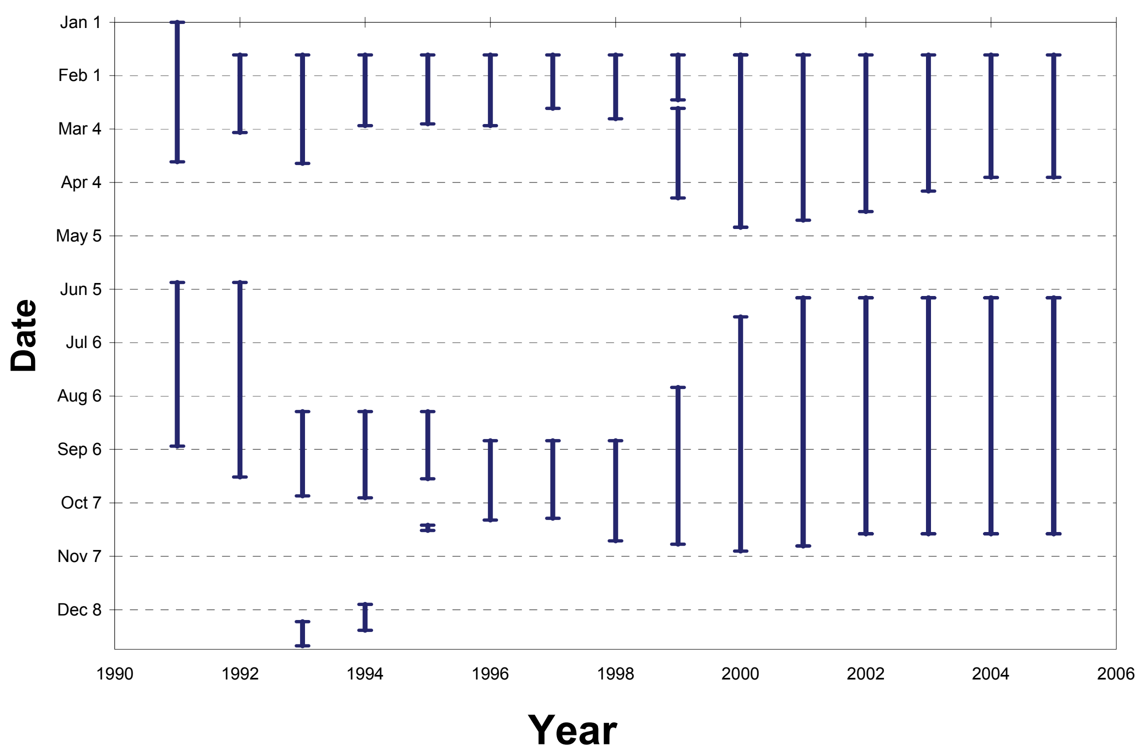


Figure 1.2. Period length and timing of the main EBS pollock fishing seasons 1991-2005 (some fishery sectors had variable openings).

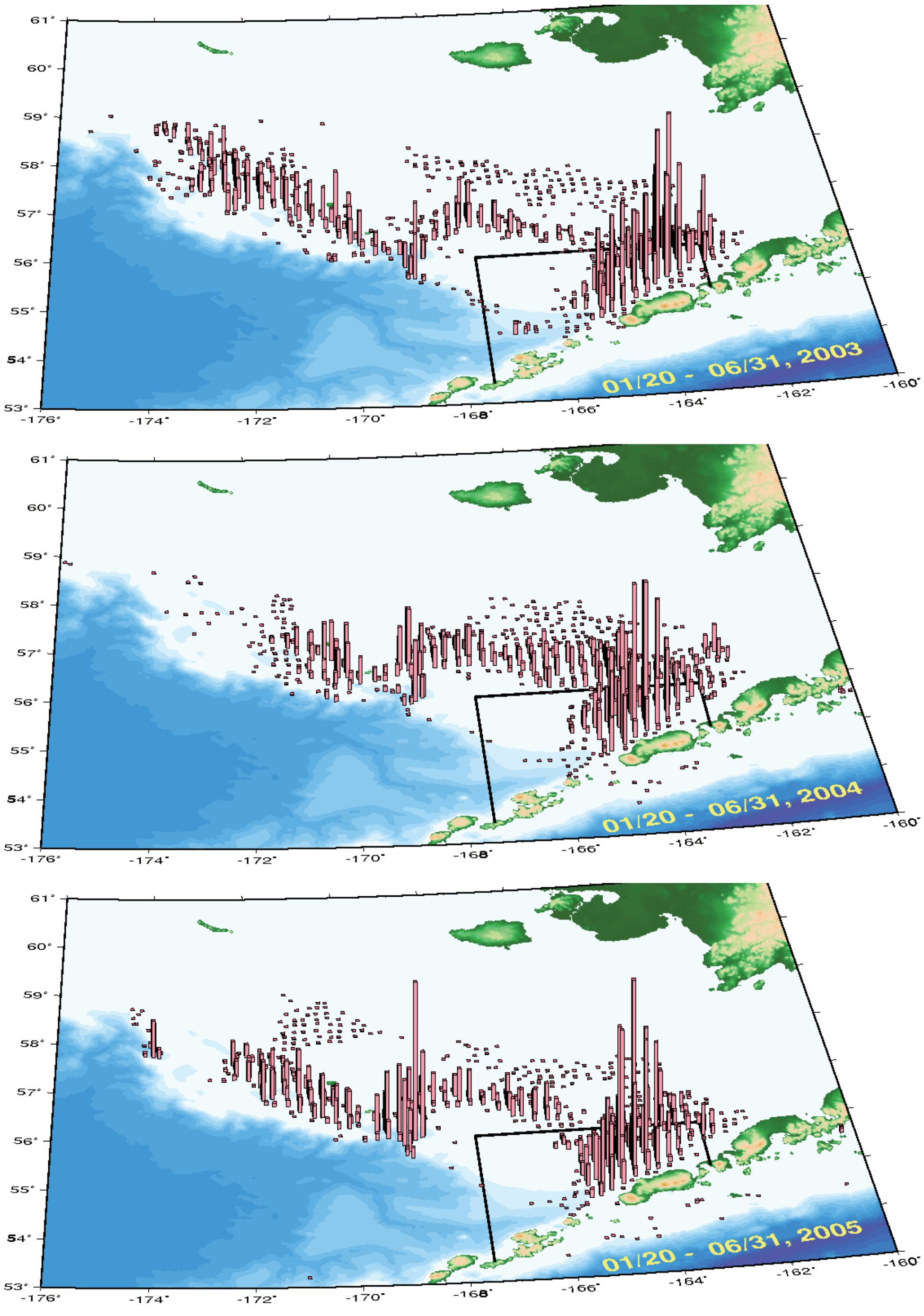


Figure 1.3. Concentrations of the pollock fishery 2003-2005, January - June on the EBS shelf. Line delineates catcher-vessel operational area (CVOA). The column height represents relative removal on the same scale in all years.

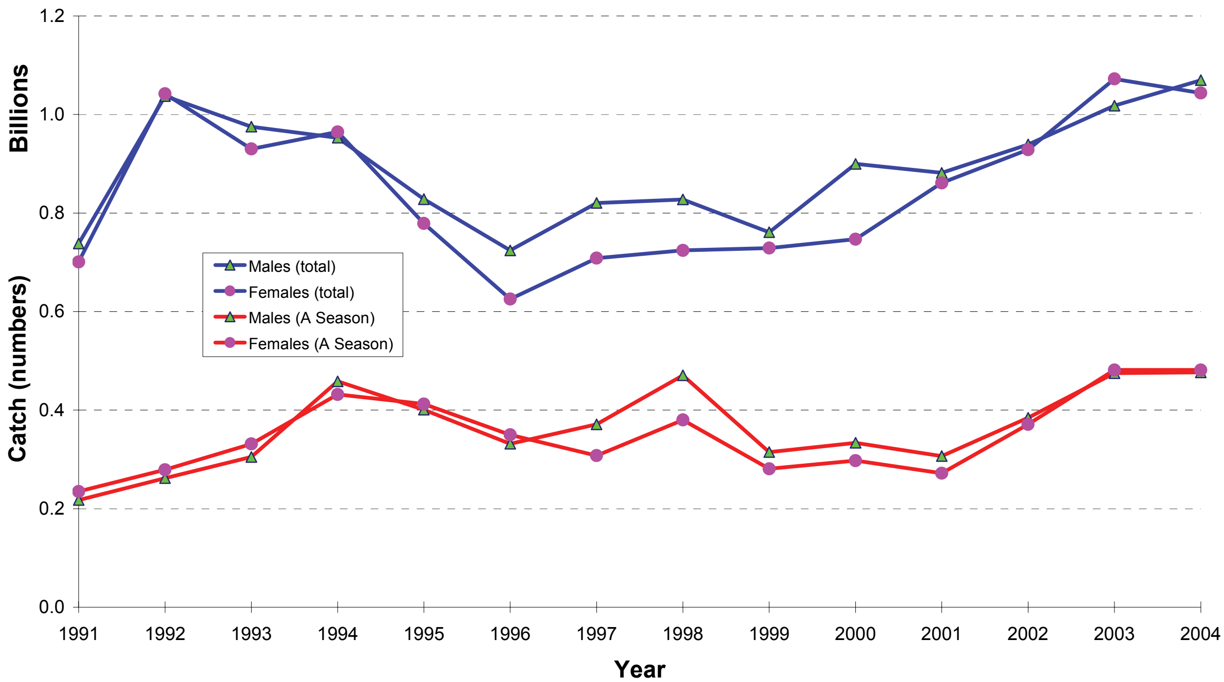


Figure 1.4. Estimate of EBS pollock catch numbers by sex for the "A season" (January-June) and for the entire annual fishery, 1991-2004.

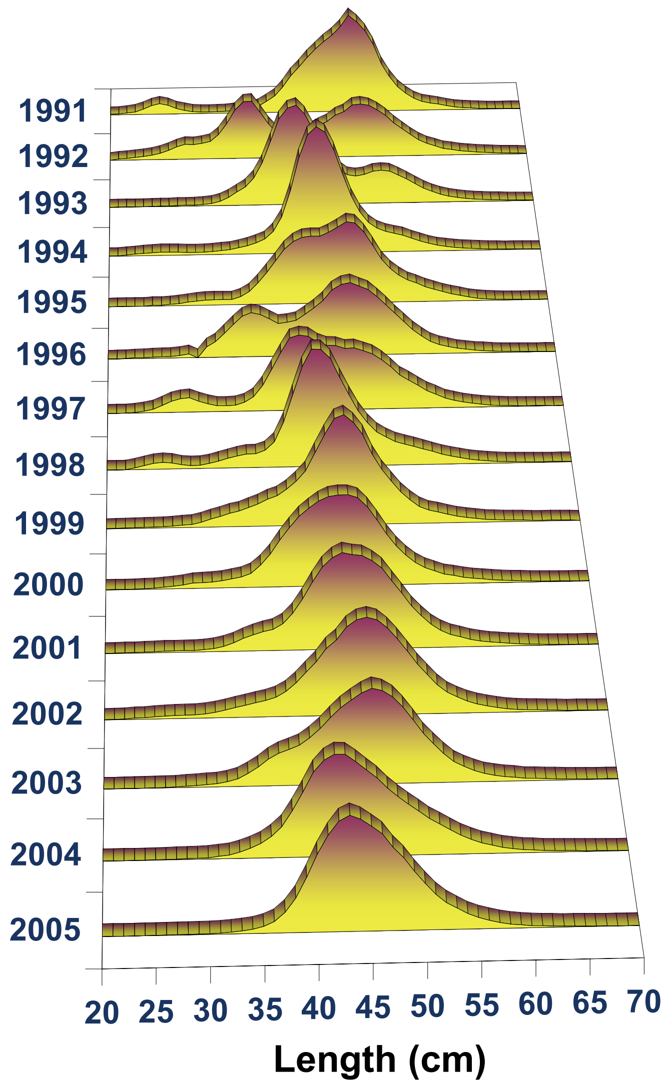


Figure 1.5. Fishery length frequency for the "A season" (January-June) female EBS pollock, 1991-2005. Data for 2005 are preliminary.

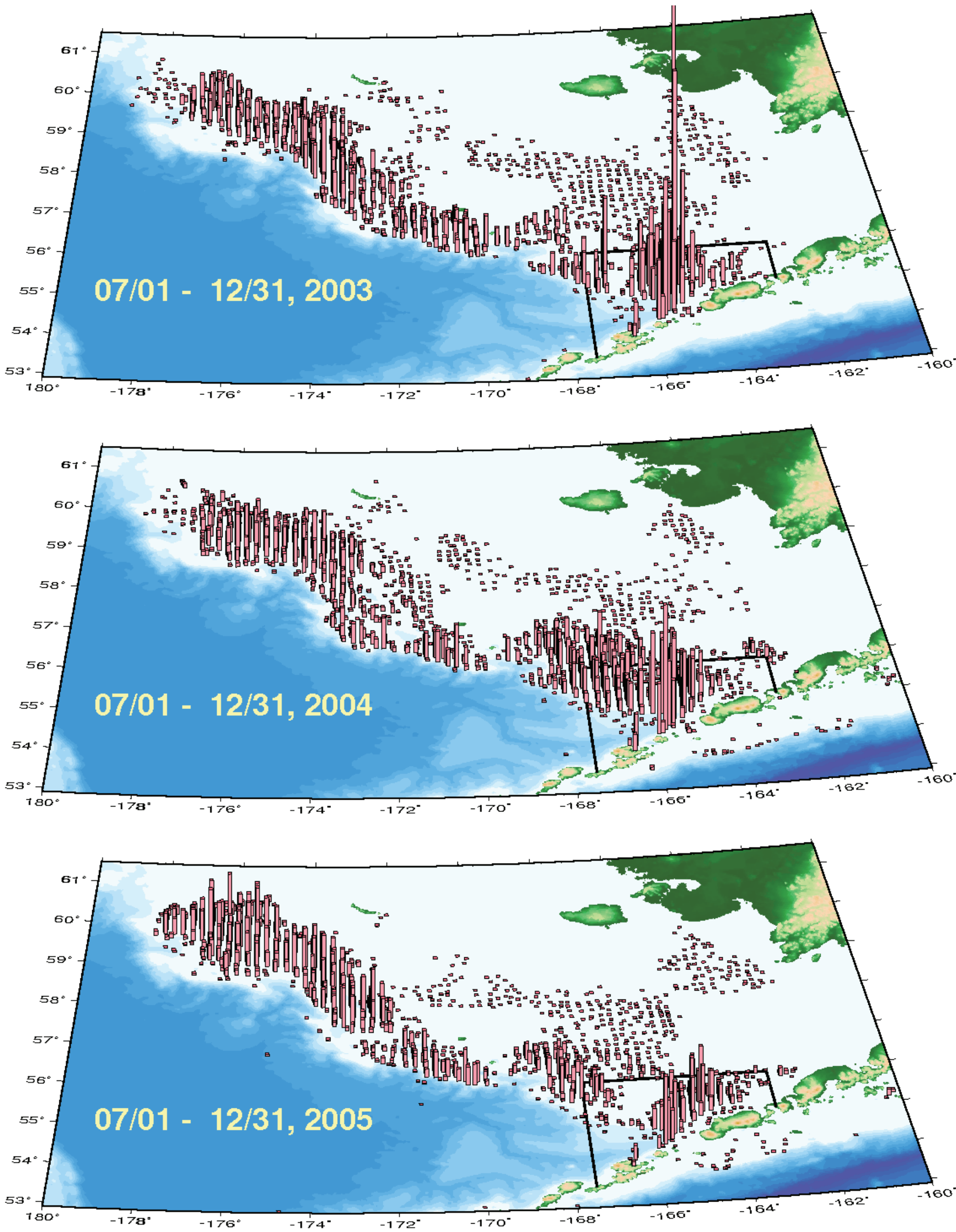


Figure 1.6. Concentrations of the pollock fishery 2003-2005, July – December on the EBS shelf. Line delineates the catcher-vessel operational area (CVOA). The height of the bars represents relative removal on the same scale over all years.

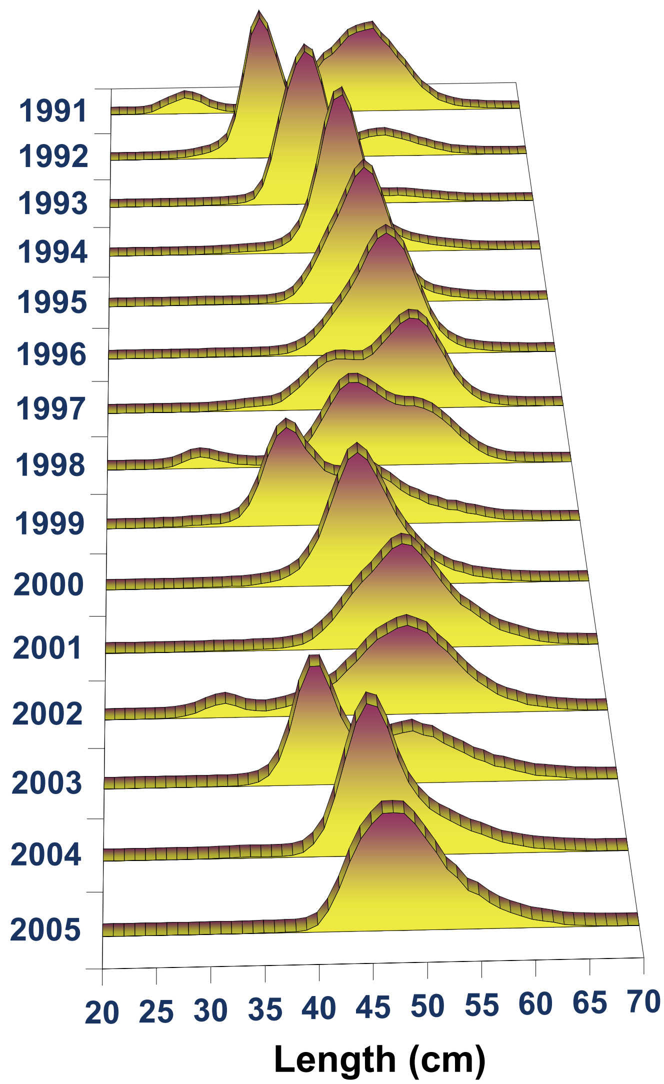


Figure 1.7. Length frequency of EBS pollock observed in period July-December for 1991-2005. Data for 2005 are preliminary.

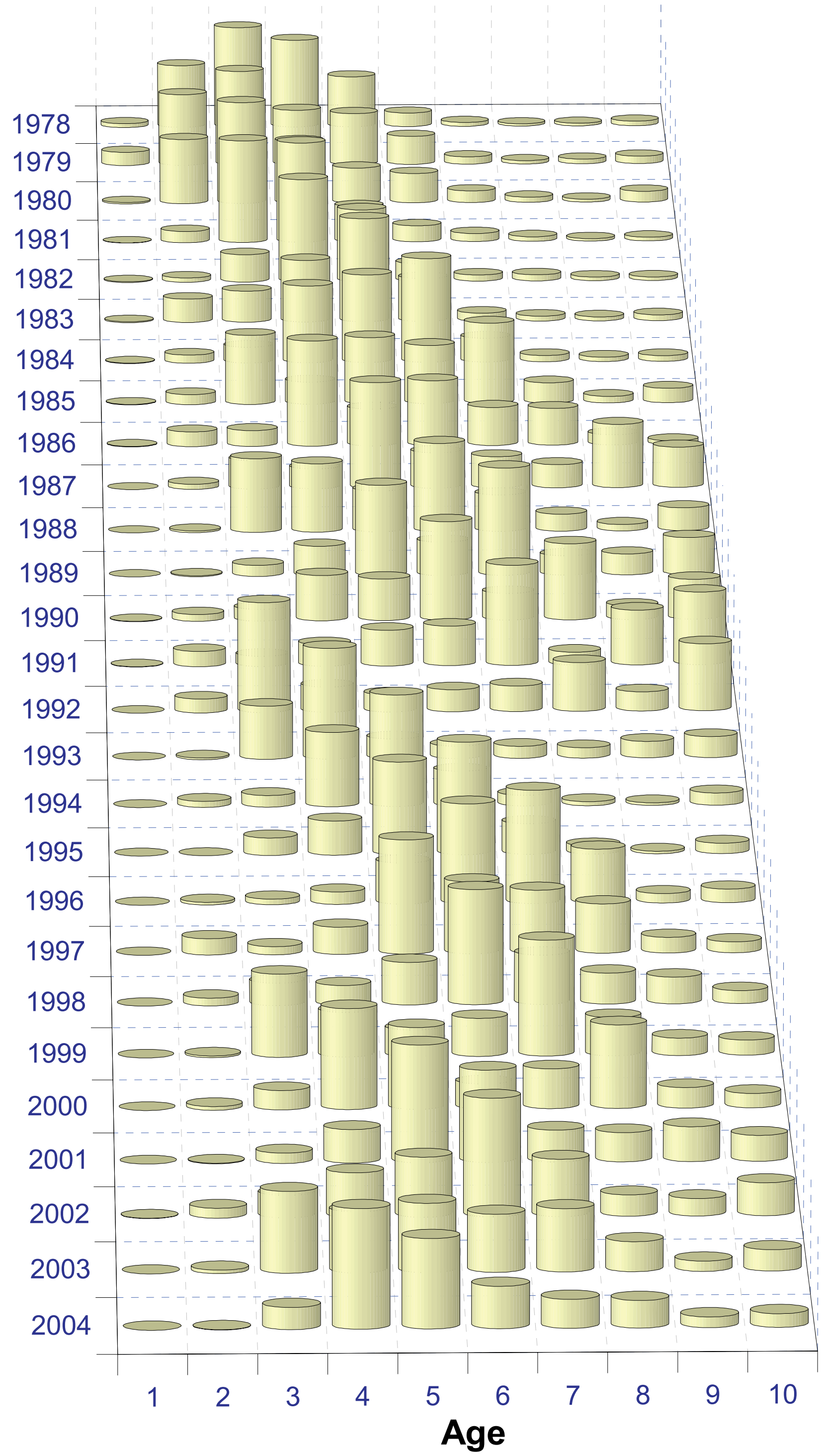


Figure 1.8. EBS walleye pollock fishery estimated catch-at-age data (proportions) for 1978-2004. Age 10 represents pollock age 10 and older.

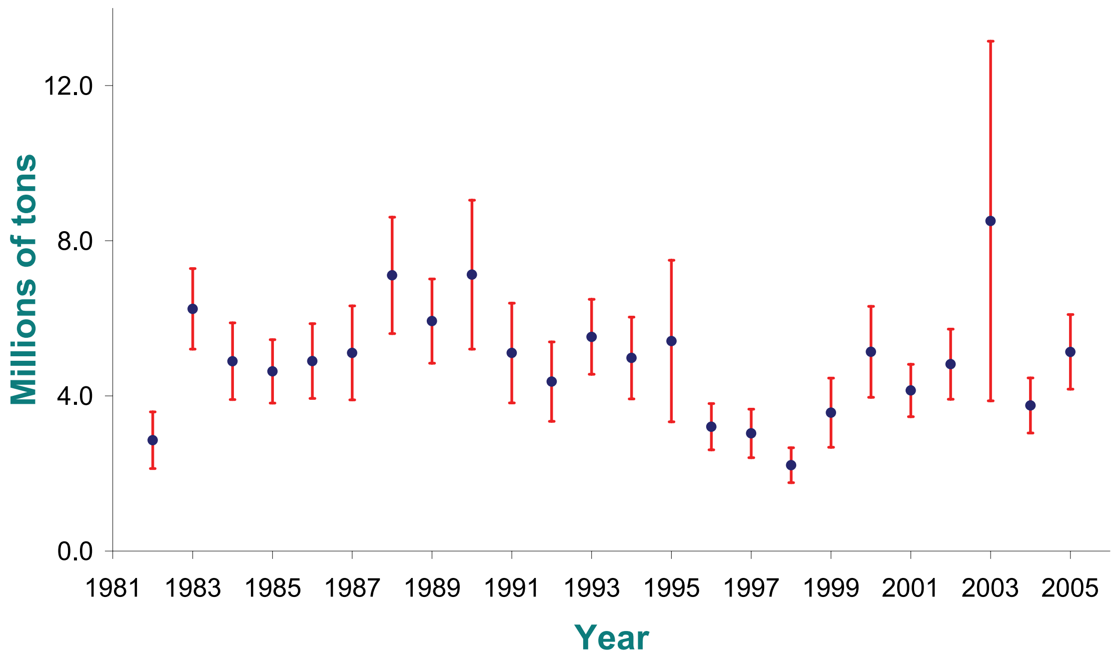


Figure 1.9. Bottom-trawl survey biomass estimates with approximate 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1982-2005.

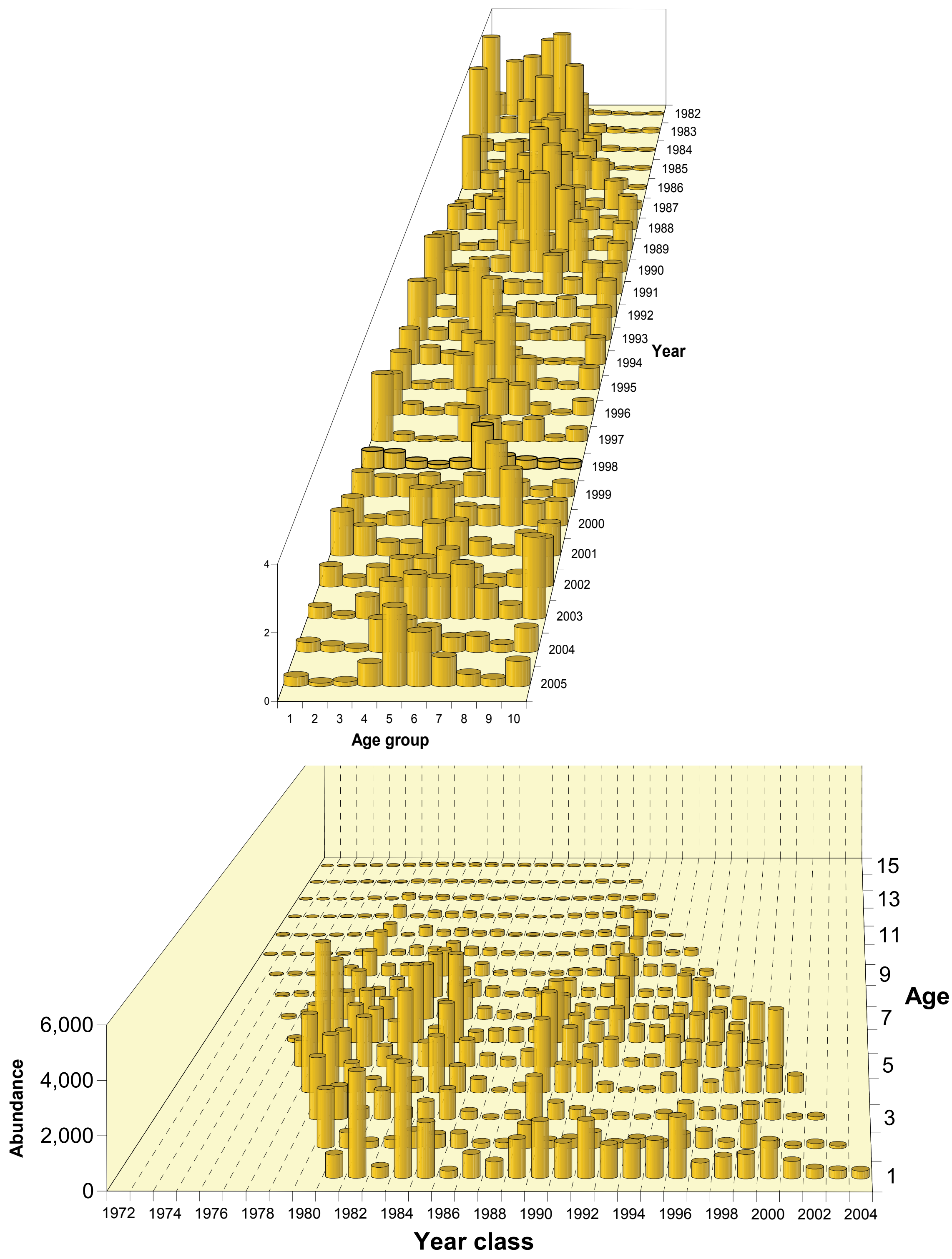


Figure 1.10. Pollock abundance levels by age and year plotted over time (top) and by individual cohorts (year classes) as estimated directly from the NMFS bottom-trawl surveys (1982-2005).

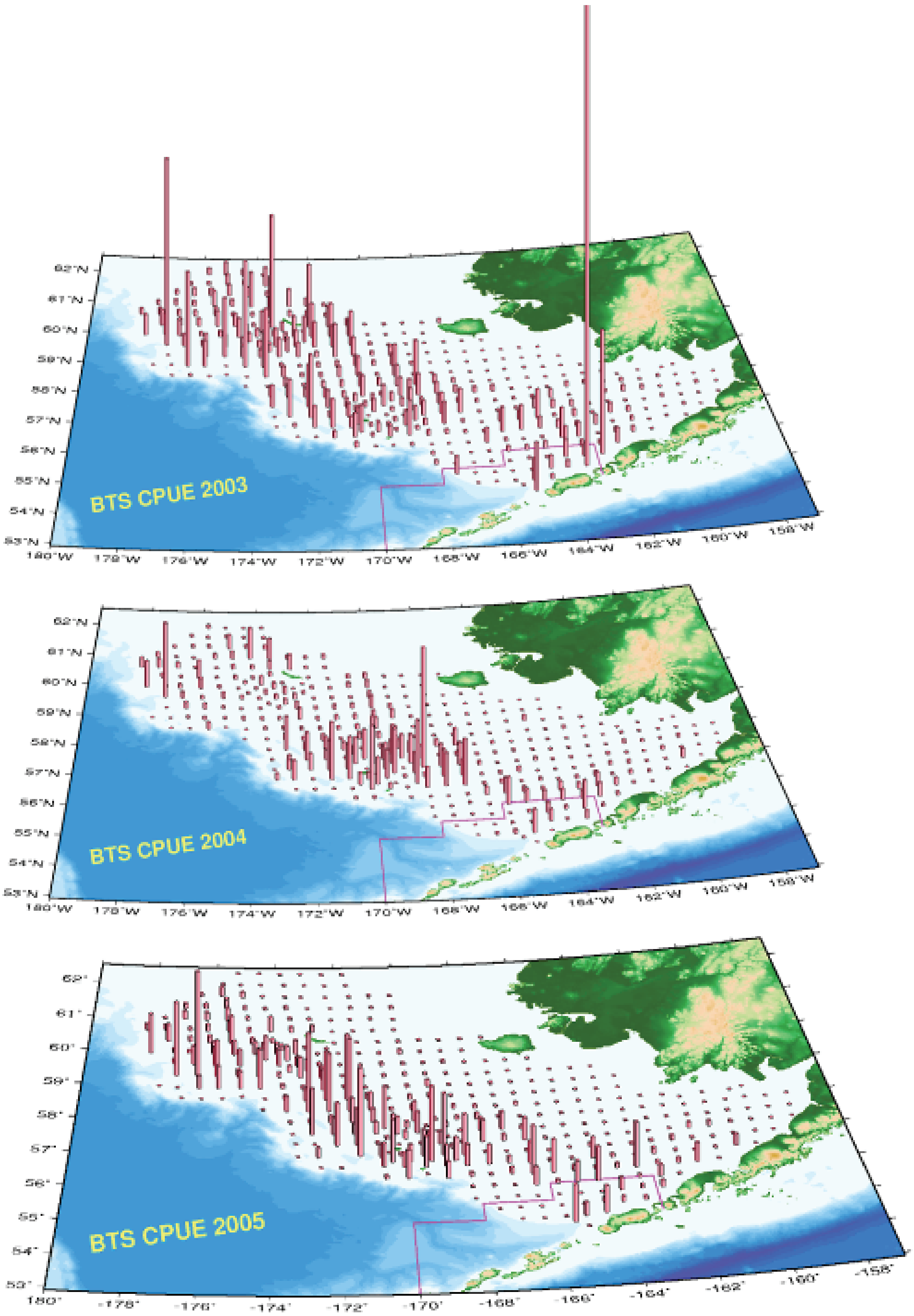


Figure 1.11. Maps showing the walleye catch-per-unit effort observed from the 2003 - 2005 NMFS EBS shelf bottom-trawl surveys.

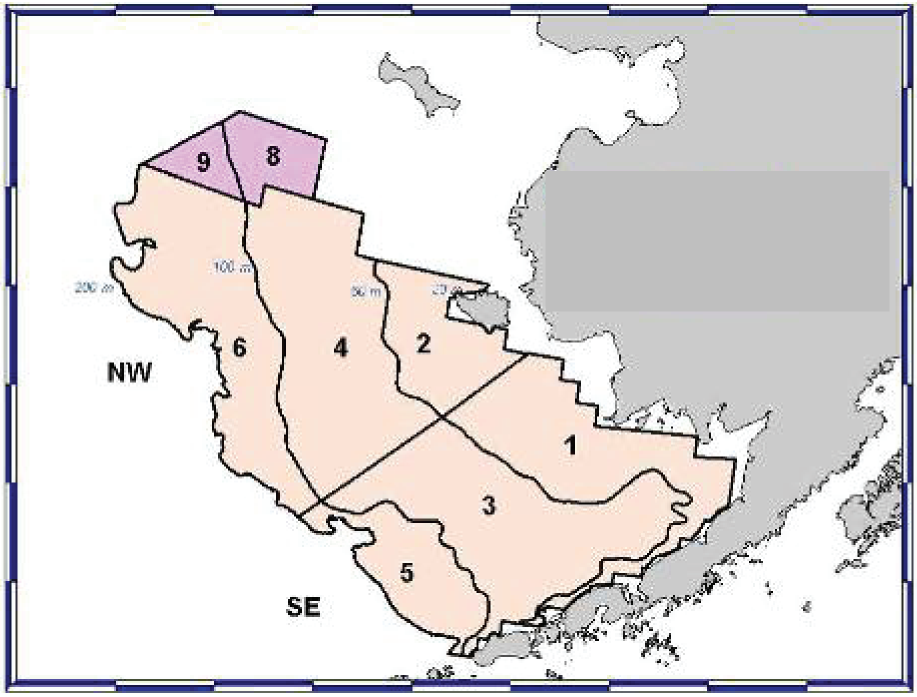


Figure 1.12. Map showing the standard NMFS bottom-trawl survey strata (1-6) and the additional strata (8 and 9). The standard survey area (done each year since 1982) measures 463,374 km^2 and includes about 356 stations. Including the expanded area (done each year since 1987) the number of stations typically totals 376.

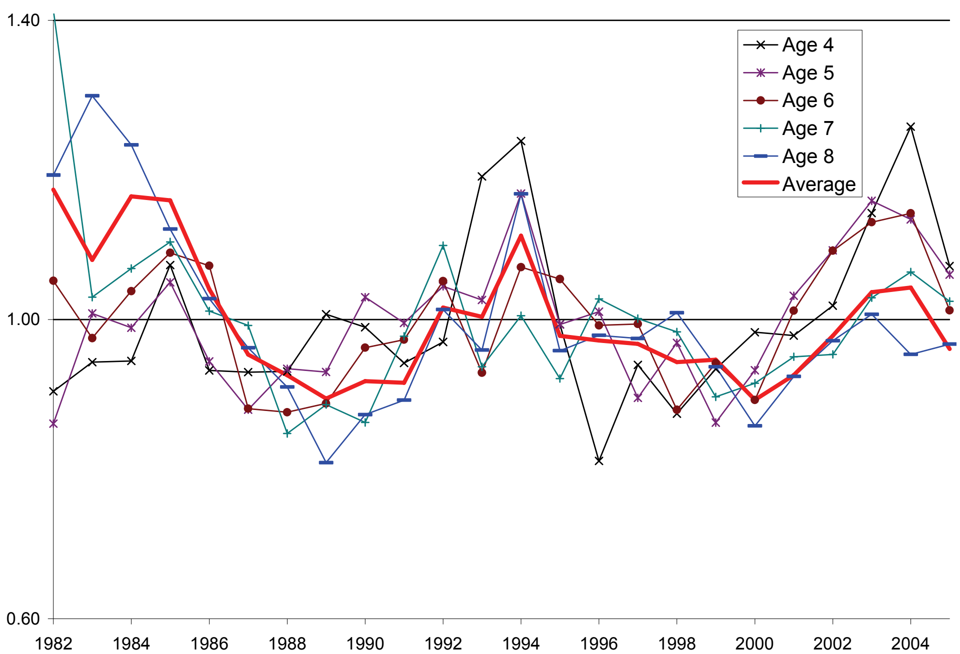


Figure 1.13. Trends in pollock average weights-at-age based on NMFS bottom trawl survey estimates, 1982-2005. Values are shown relative to their mean within each age or age group. Note that the length-weight relationship used here is constant; hence, the differences are how average lengths-at-age vary over time in terms of weight.

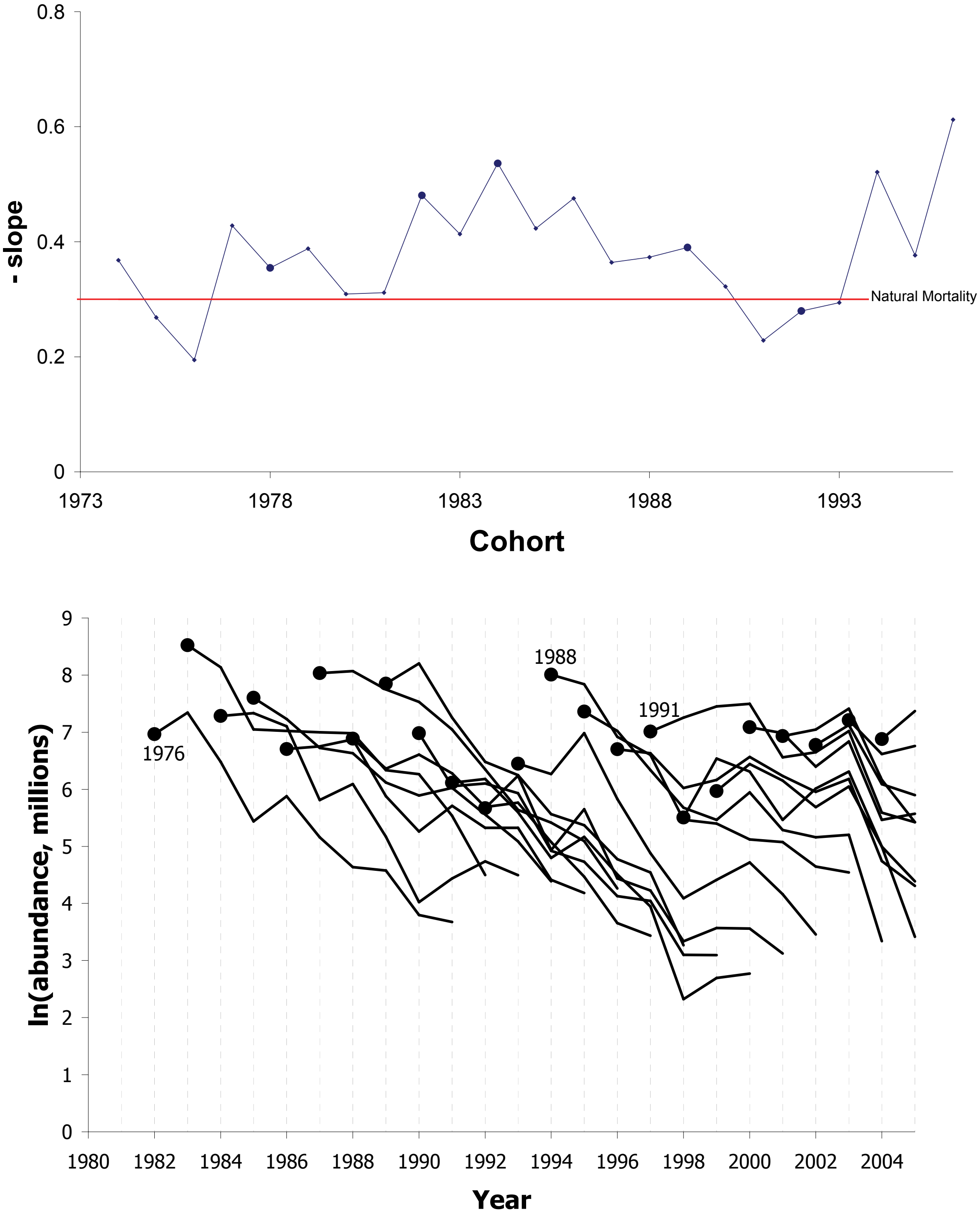


Figure 1.14. Evaluation of cohort abundances as observed for age 6 and older in the NMFS summer bottom trawl surveys. The bottom panel shows the raw log-abundances at age while the top panel shows the estimates of total mortality by cohort.

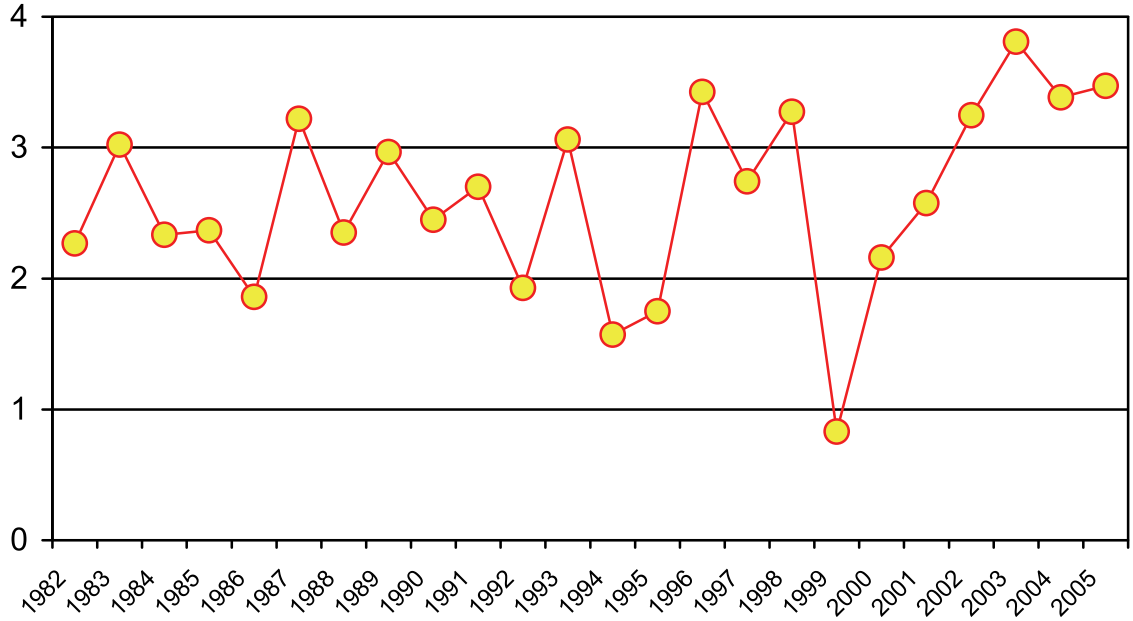


Figure 1.15. Mean summer bottom temperatures used to model bottom trawl survey pollock catchability, 1982-2004. (Note: these were normalized to have mean zero for use in the model).

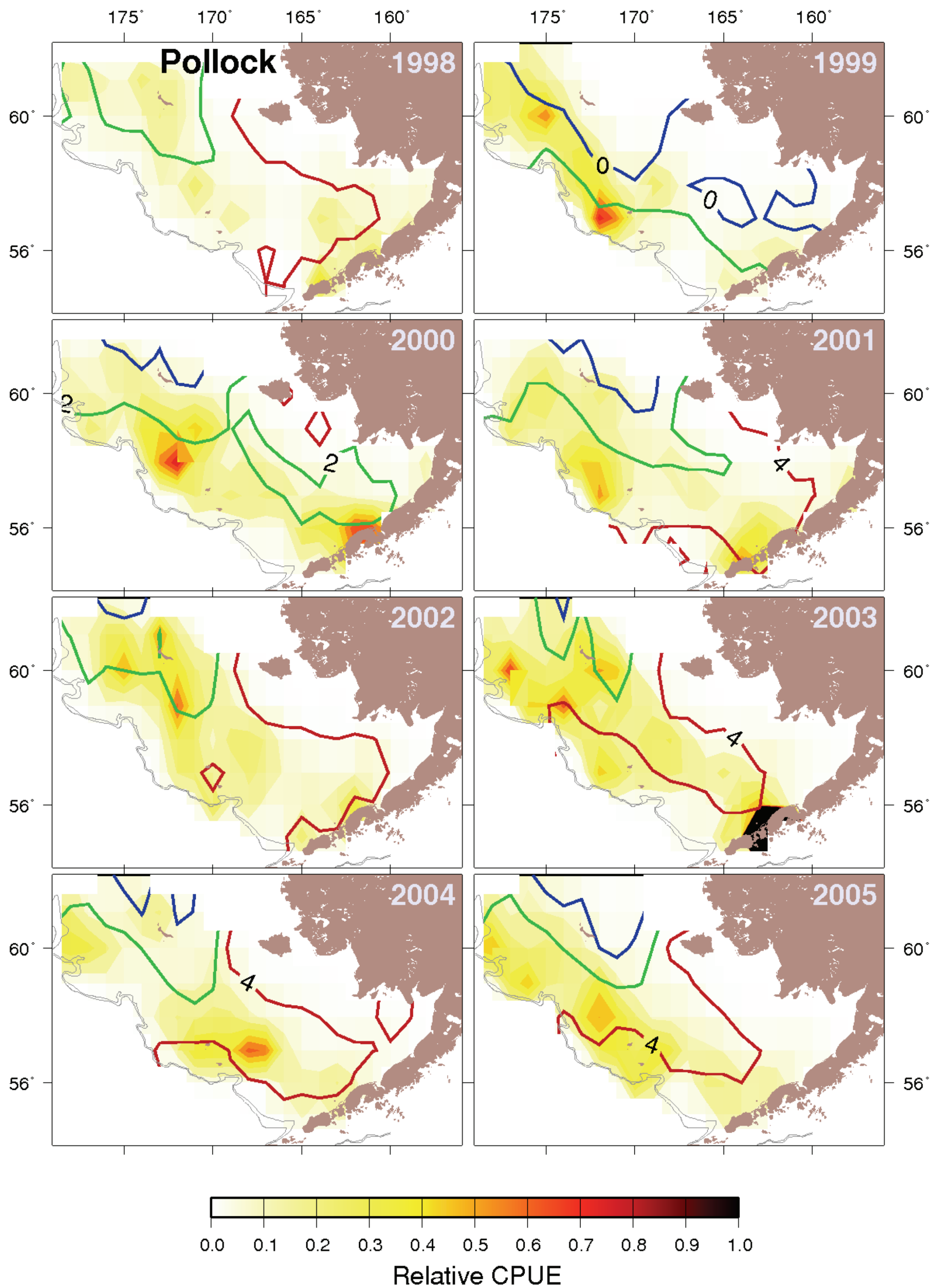


Figure 1.16. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius from summer bottom-trawl surveys,1998-2005.

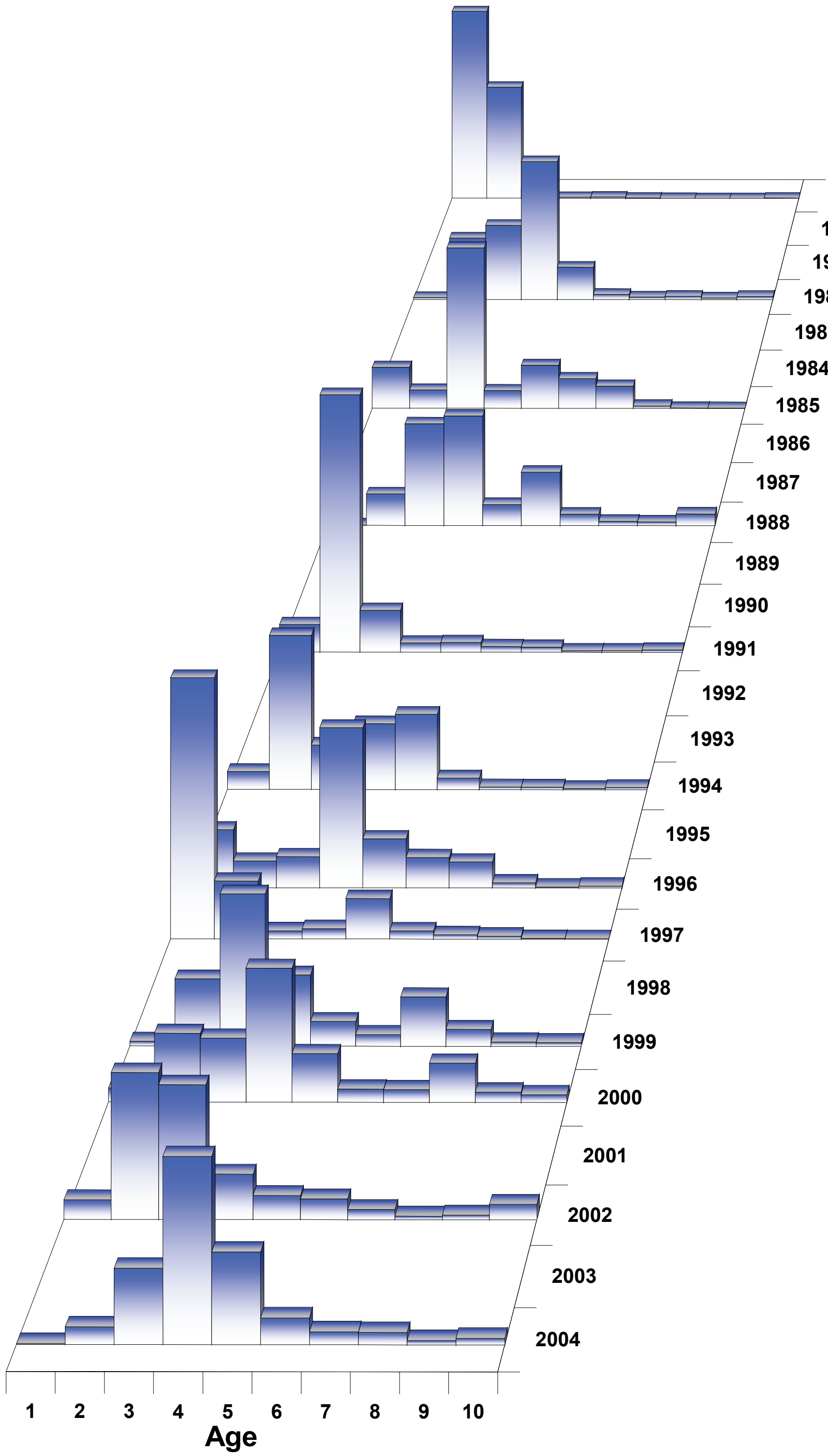


Figure 1.17. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-2004. Note that the 2004 age compositions were re-estimated this year using age data from the EIT survey (these data were previously unavailable).

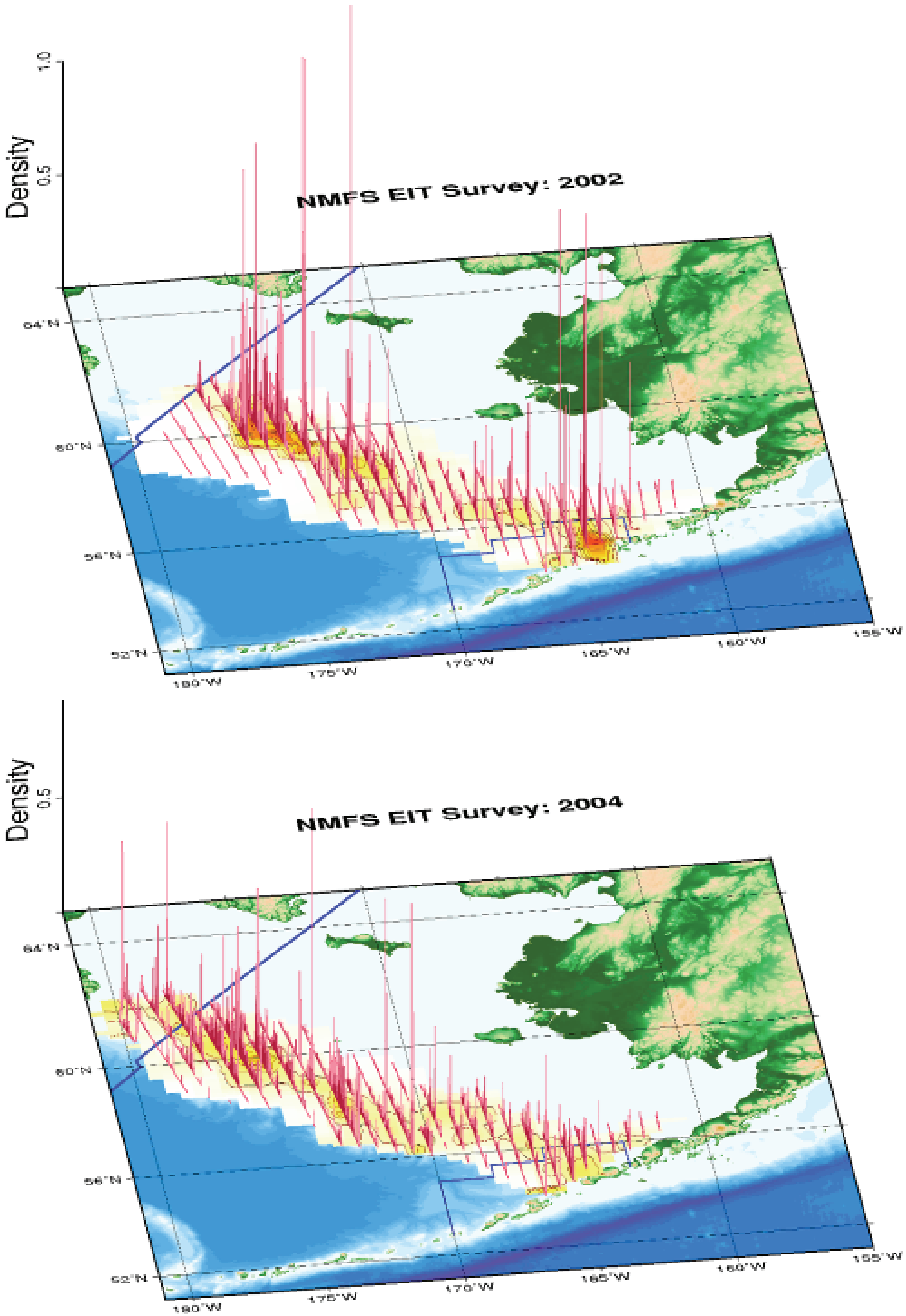


Figure 1.18. Echo-integration trawl survey results for 2002 and 2004. Vertical lines represent biomass of pollock as observed using acoustic methods.

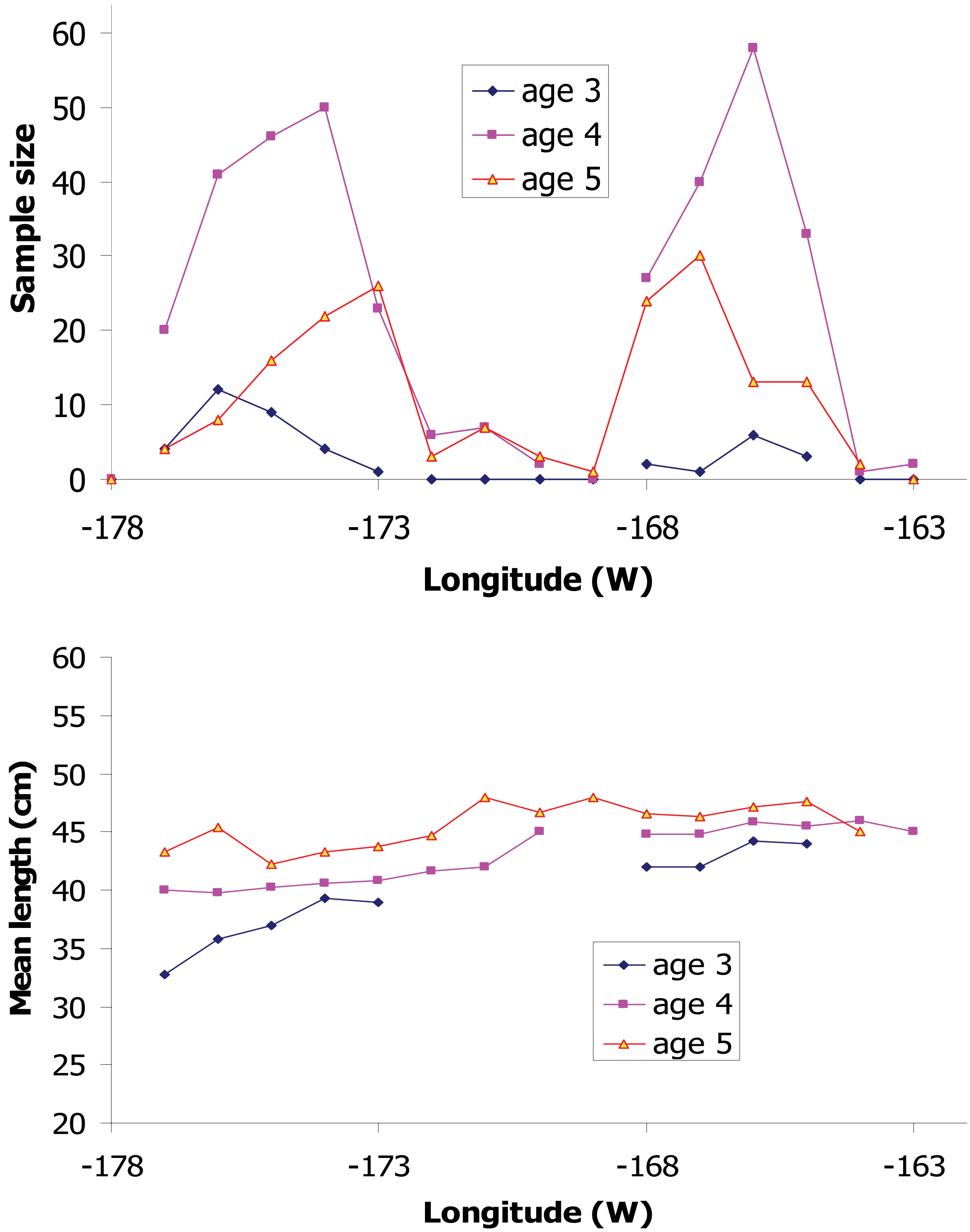


Figure 1.19. EBS pollock sample size by longitude and age group (top panel) and mean length at age by longitude (bottom panel) for the July – October 2004 fishery.

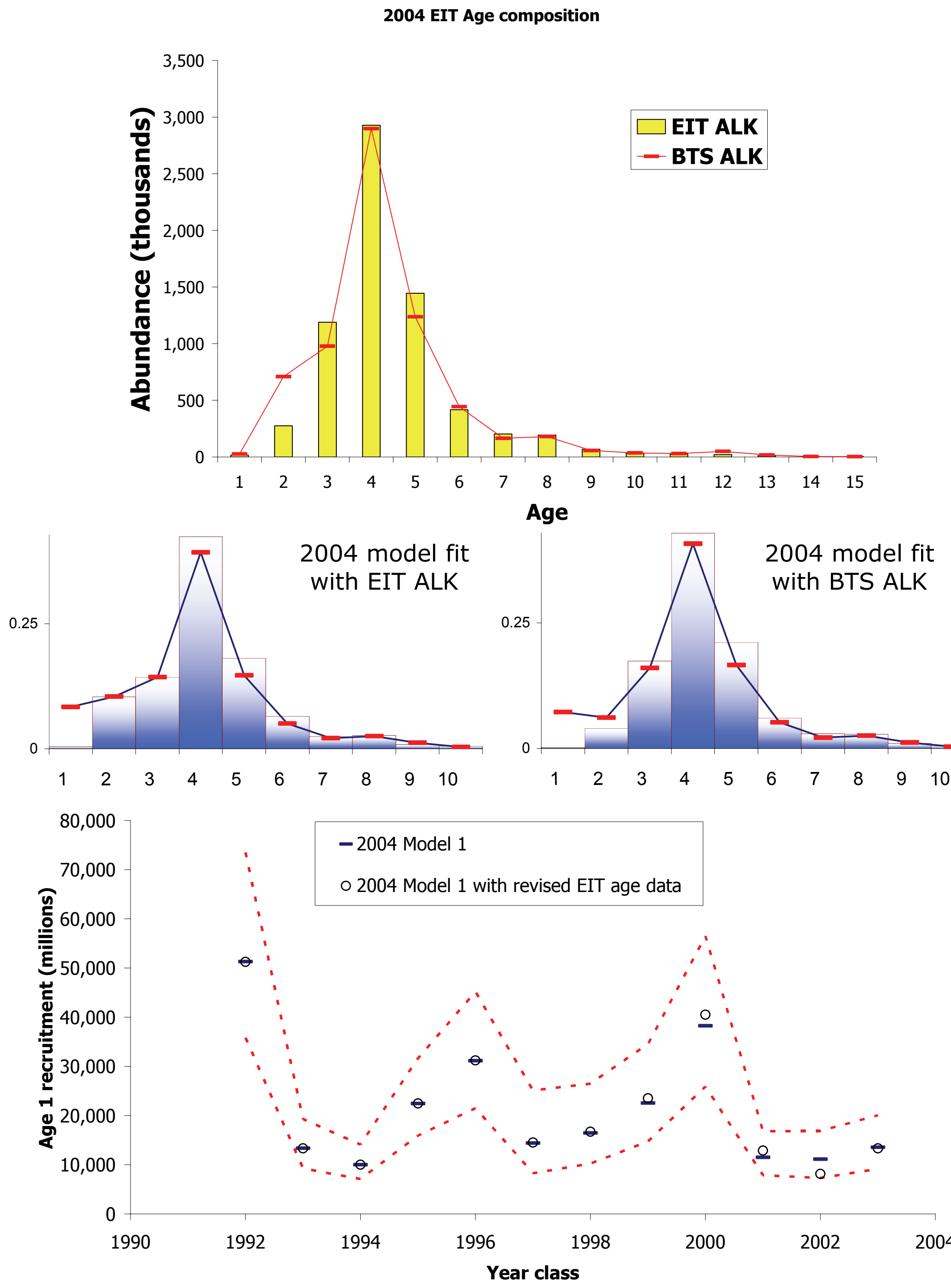


Figure 1.20. Revised 2004 echo-integration trawl survey age composition compared to that used in the previous assessment (top panel) and subsequent fit and recruitment estimate results based on the 2004 version of the model (middle two figures). The bottom panel shows last year's fit with the EIT data compiled using the BTS age-length-key (ALK) compared to last year's Model 1 with the revised EIT ALK that was also used in this year's assessment.

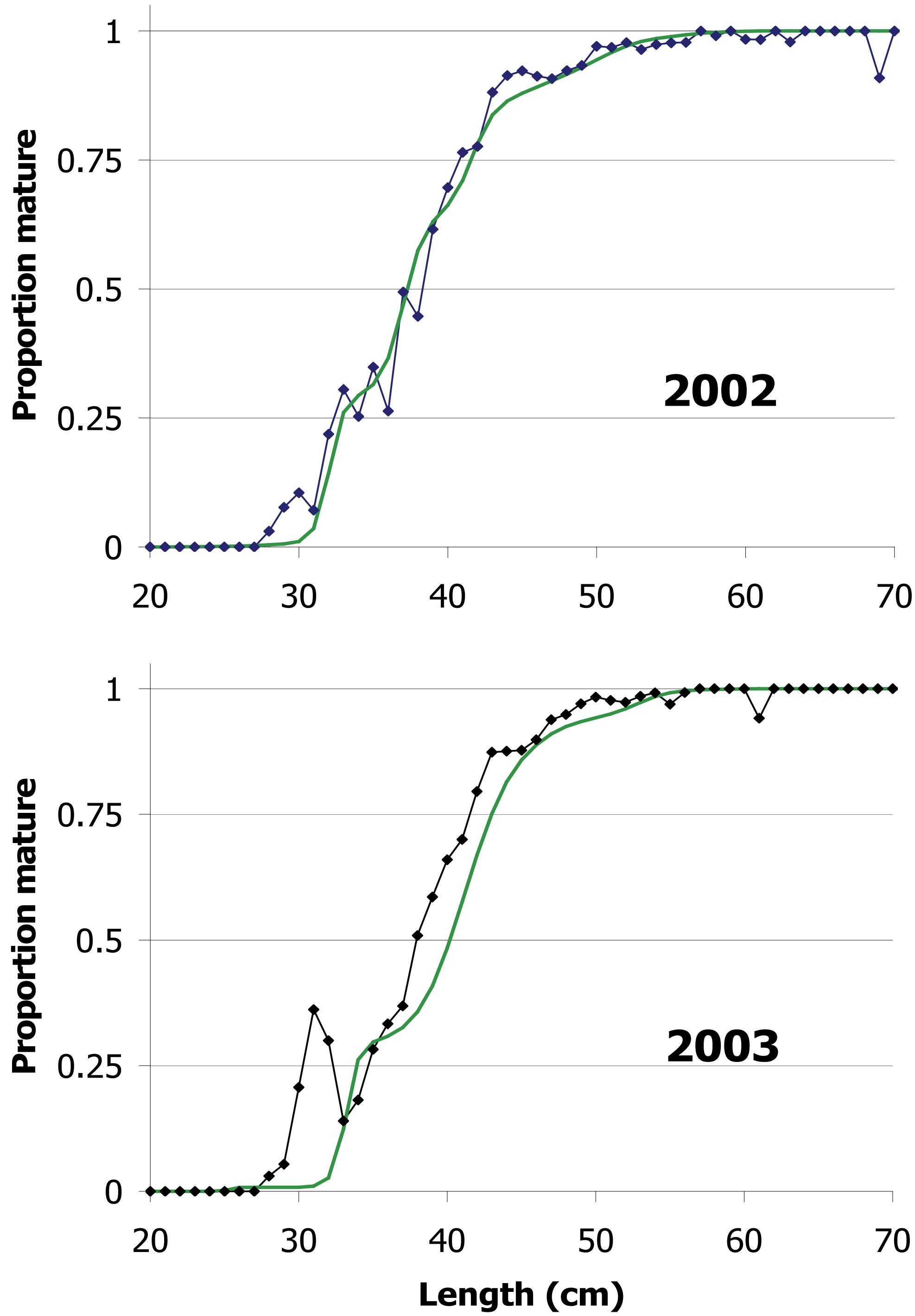


Figure 1.21. Expected female pollock proportion mature at length given the current maturation schedule and estimates of numbers at age (solid lines) compared to the observed proportions mature from Stahl (2004; as indicated by lines with diamonds).

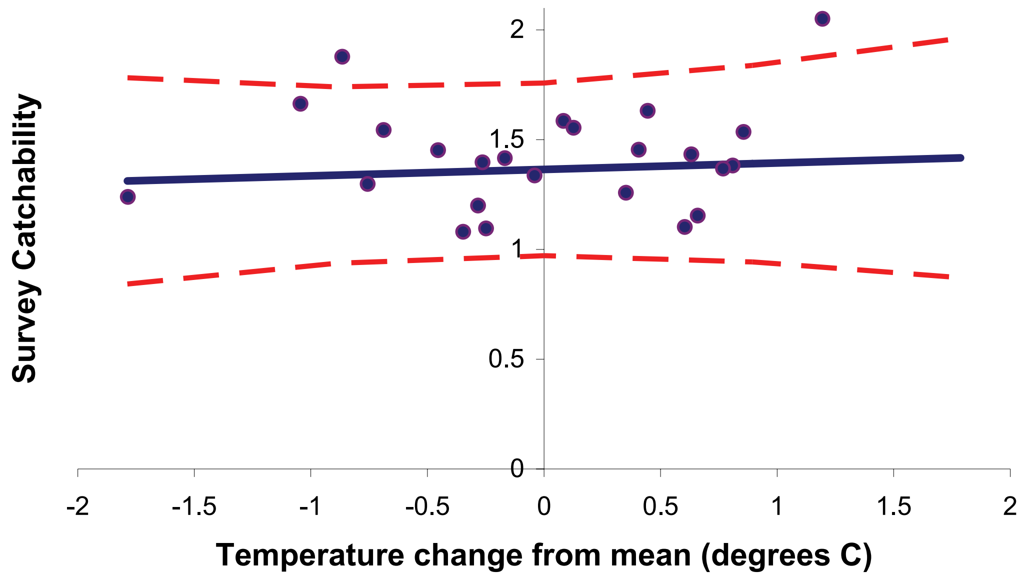


Figure 1.22. Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0) as under Model 3. Points represent residuals relative to survey estimates (i.e., $\hat{q}_t + \ln\left(\hat{I}_t / I_t\right)$ where $\hat{I}_t$ and I_t represent the predicted and observed survey indices respectively and $\hat{q}_t$ is the expected catchability given the temperature anomaly in year *t*.

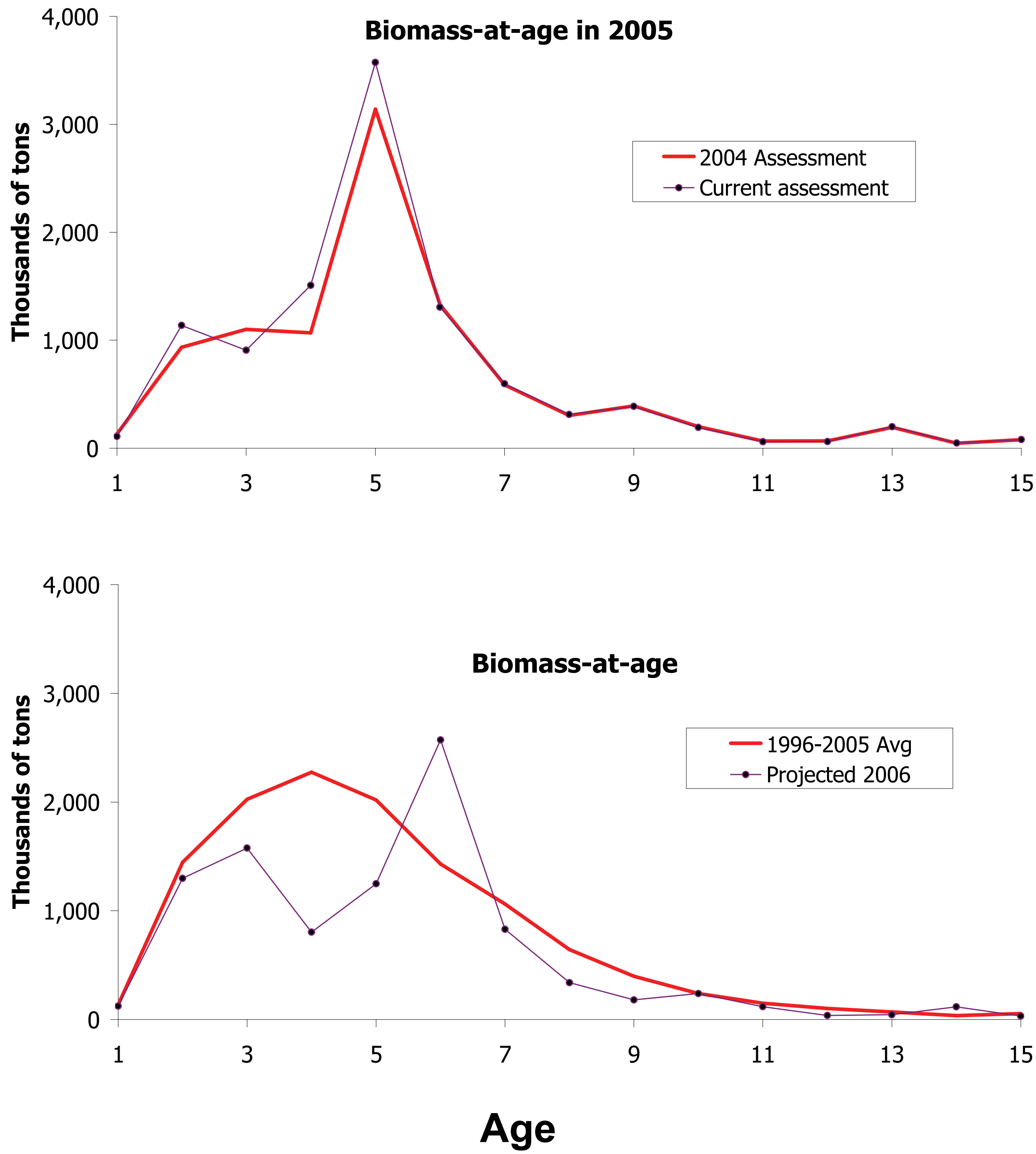


Figure 1.23. Estimates of 2005 population begin-year biomass-at-age from the 2004 assessment compared to the current assessment (top panel) for EBS walleye pollock Model 1 and the projection for 2006 (from the current assessment) compared to the average population biomass-at-age from 1996-2005 (lower panel).

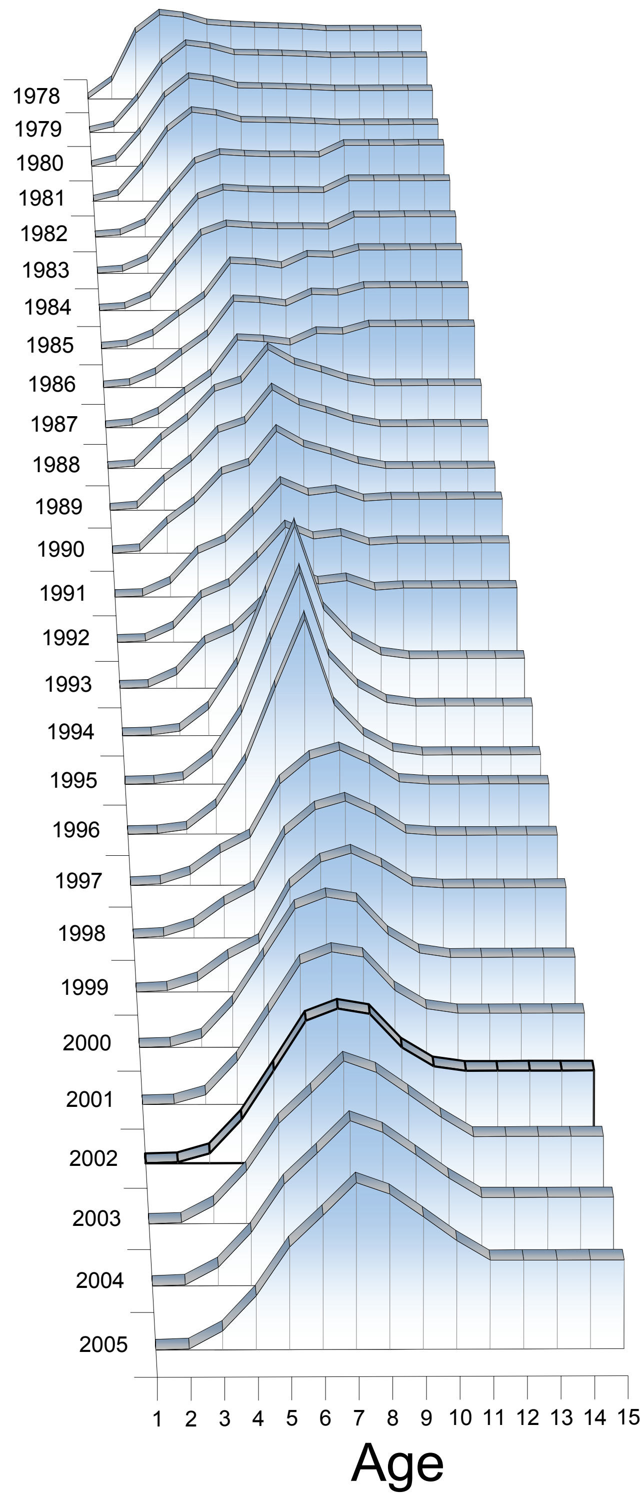


Figure 1.24. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-2005 estimated for Model 1.

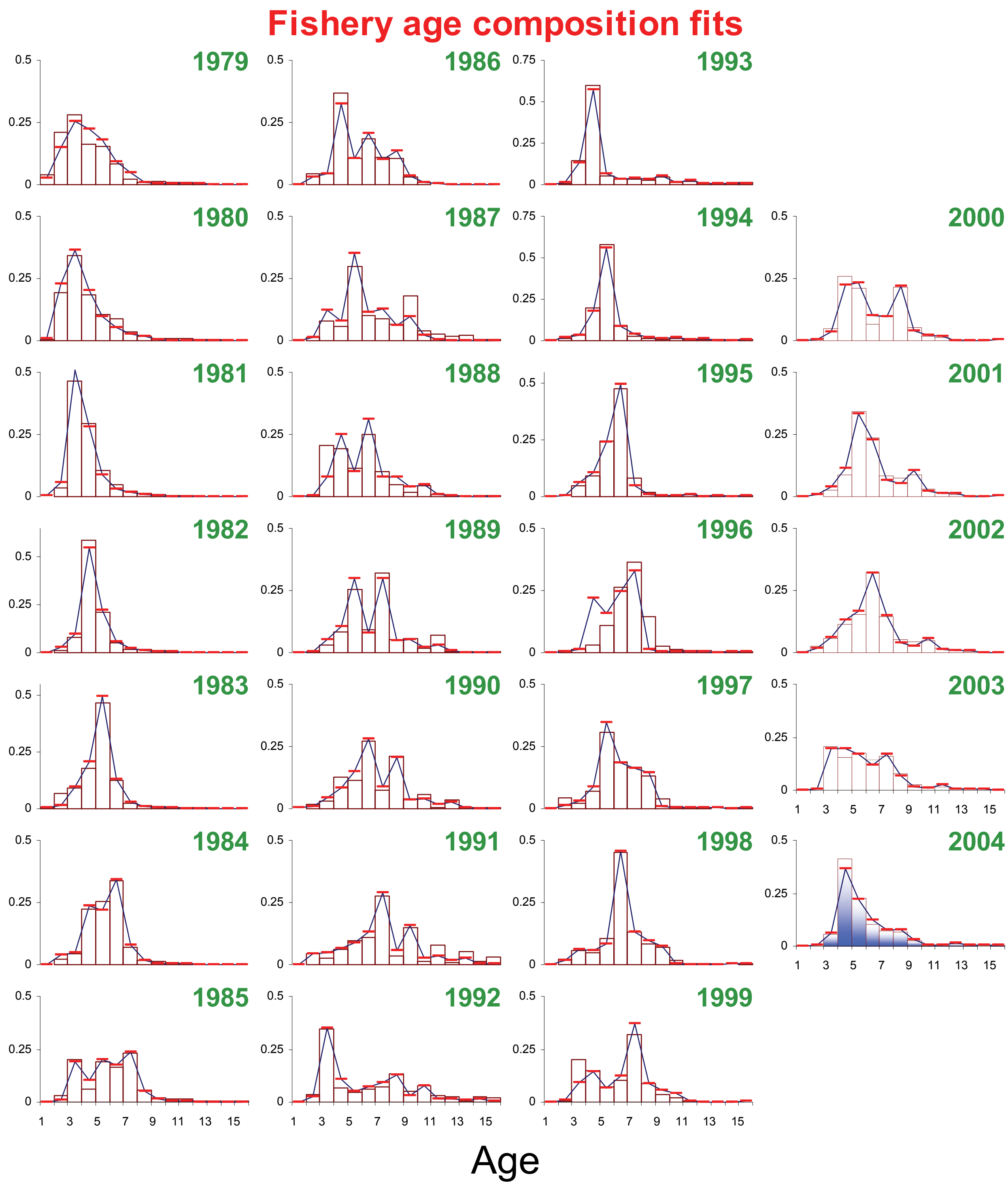


Figure 1.25. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1979-2004). Lines represent model predictions while the vertical columns represent the data. Data new to this year's assessment are shaded.

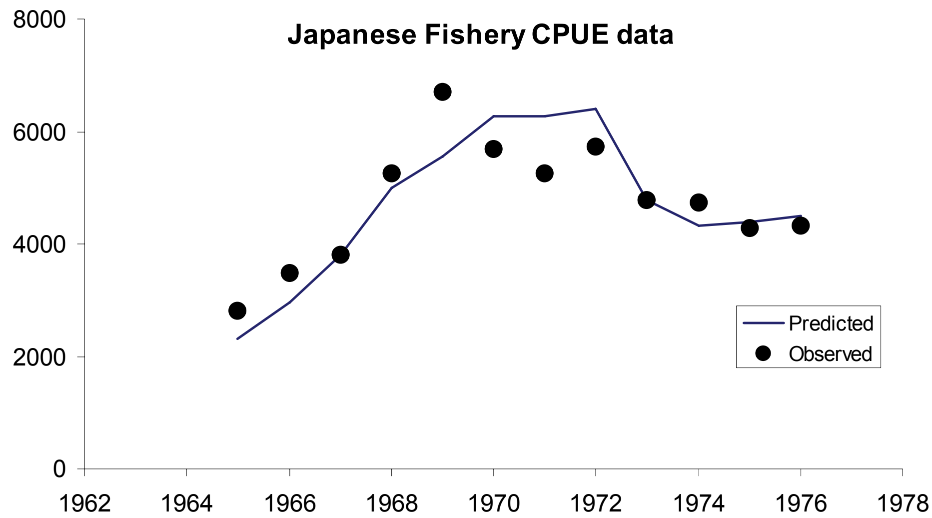


Figure 1.26. Model 1 fit to the EBS walleye pollock fishery CPUE data from Low and Ikeda (1980).

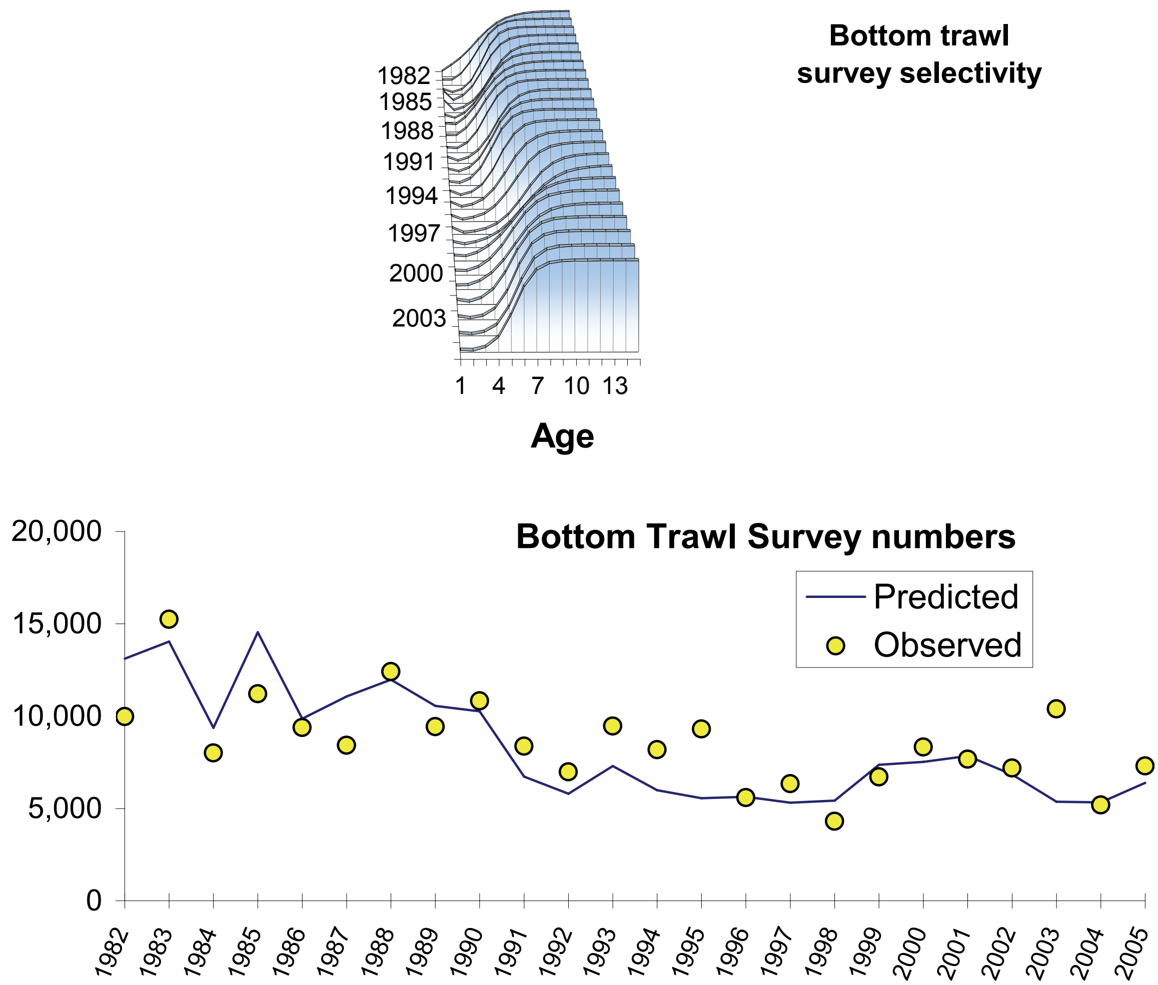


Figure 1.27. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS walleye pollock, 1982-2005, Model 1.

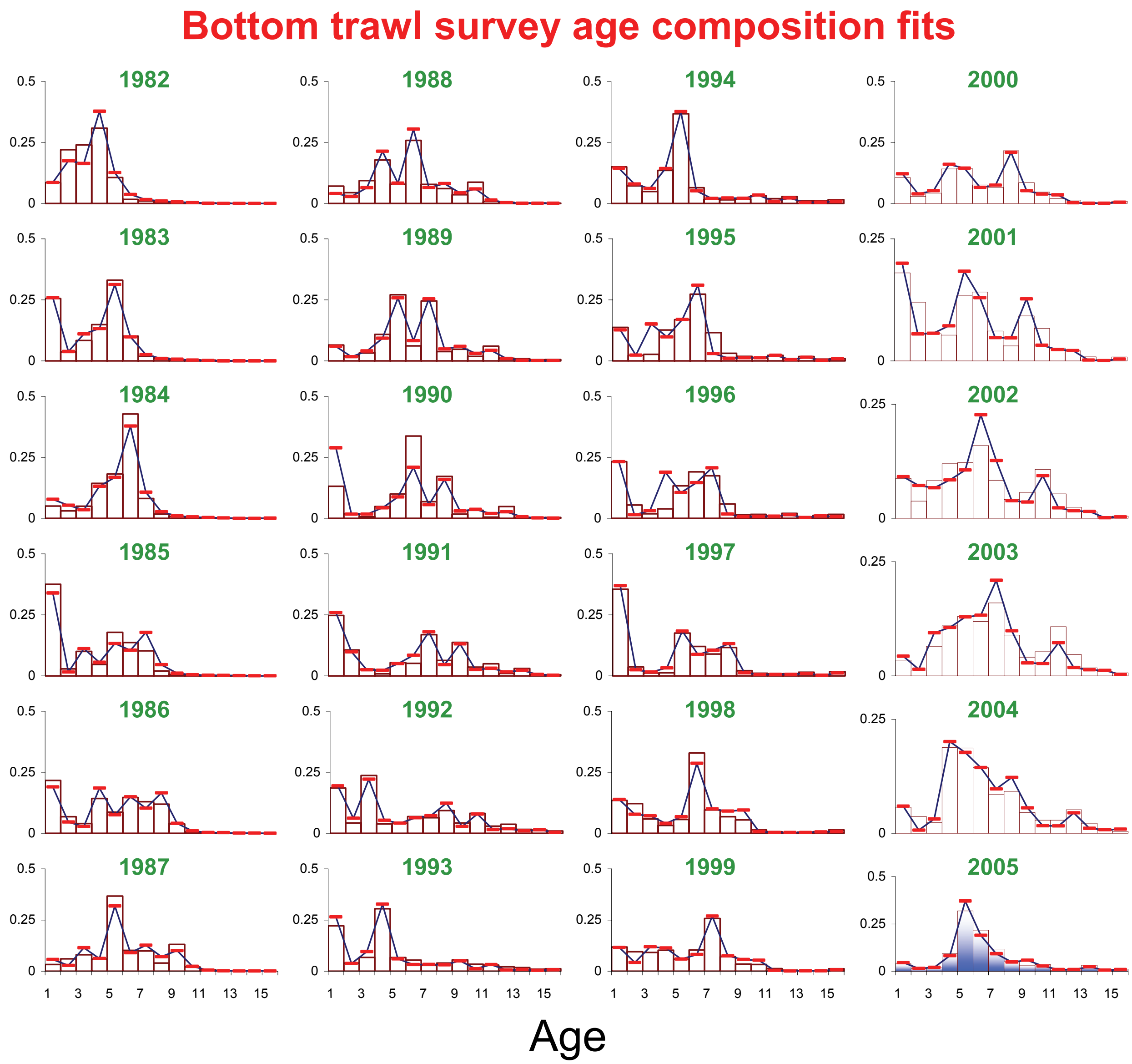
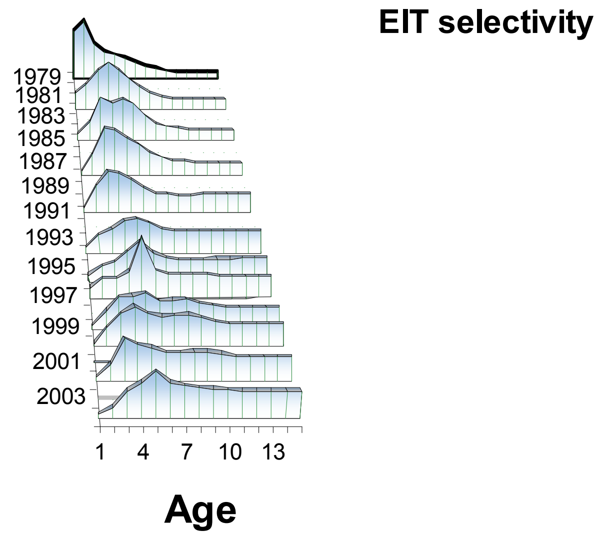


Figure 1.28. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded (2005).



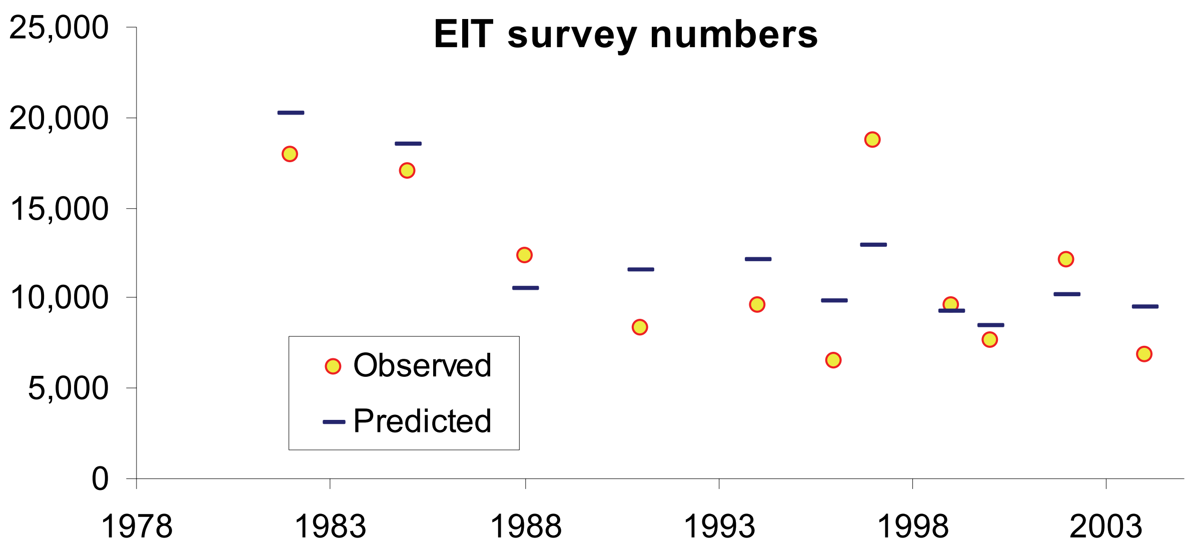


Figure 1.29. Model 1 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock. Note that the 1979 value (observed=115,424; predicted=47,127) are not plotted.

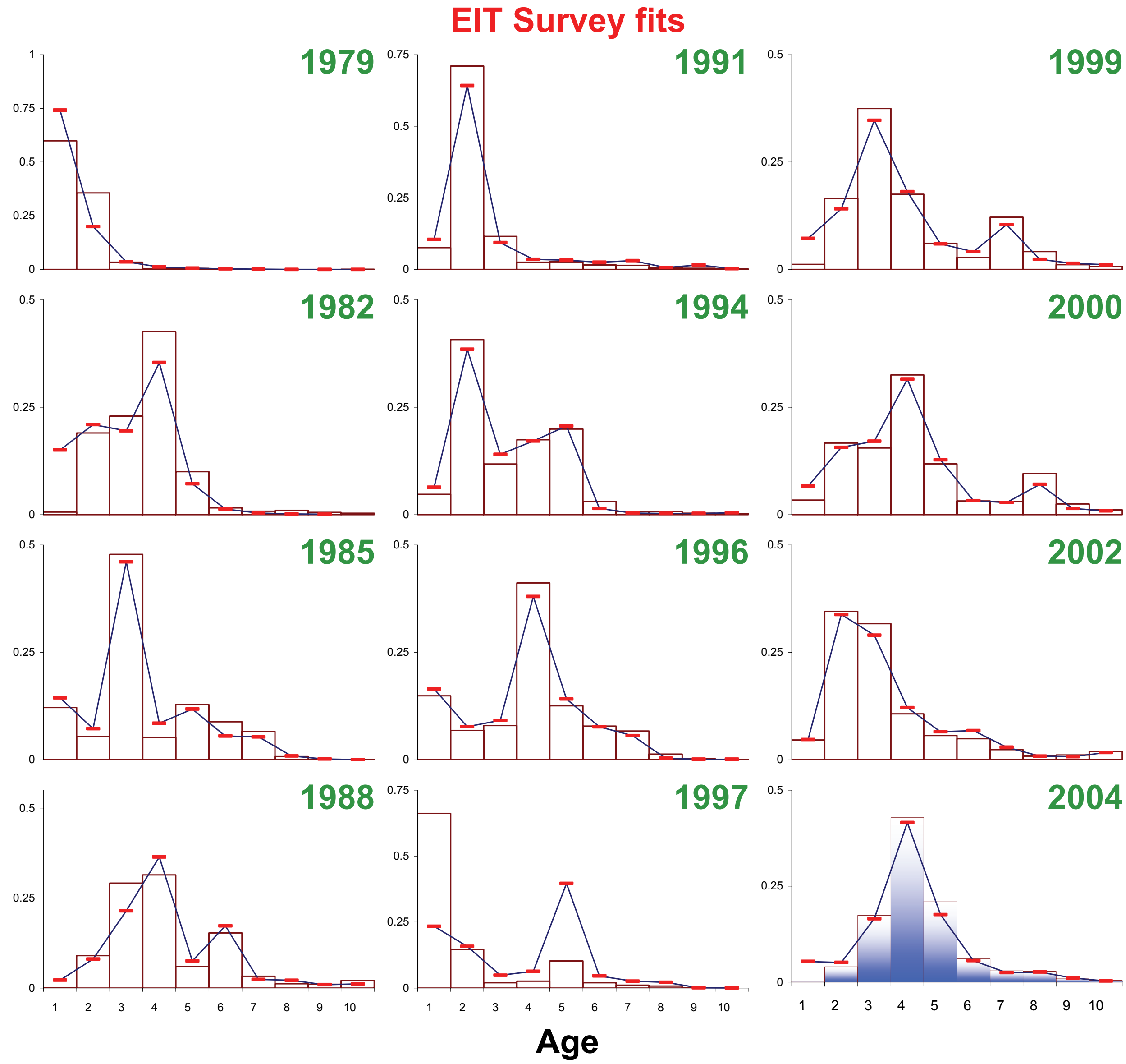


Figure 1.30. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data. Data new to the assessment are shaded.

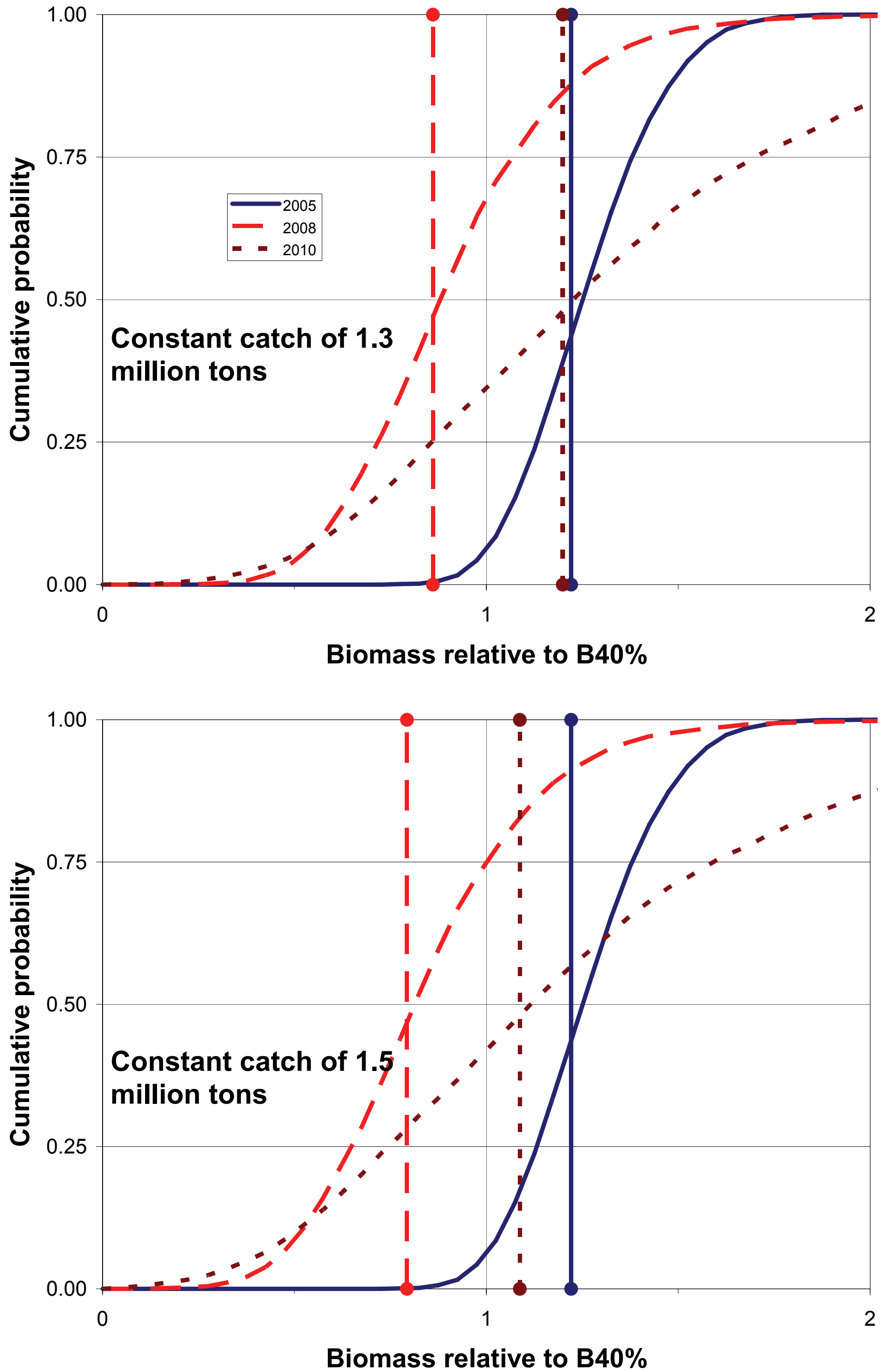


Figure 1.31. Cumulative probability that projected female spawning biomass levels will drop below $B_{40\%}$ based on a fixed constant catch levels of 1.3 (top) and 1.5 (bottom) million tons. Marginal distributions of the full joint posterior distribution based on a thinned MCMC chain used for integration. Corresponding expected values (means) are shown by the vertical lines terminated with closed circles.

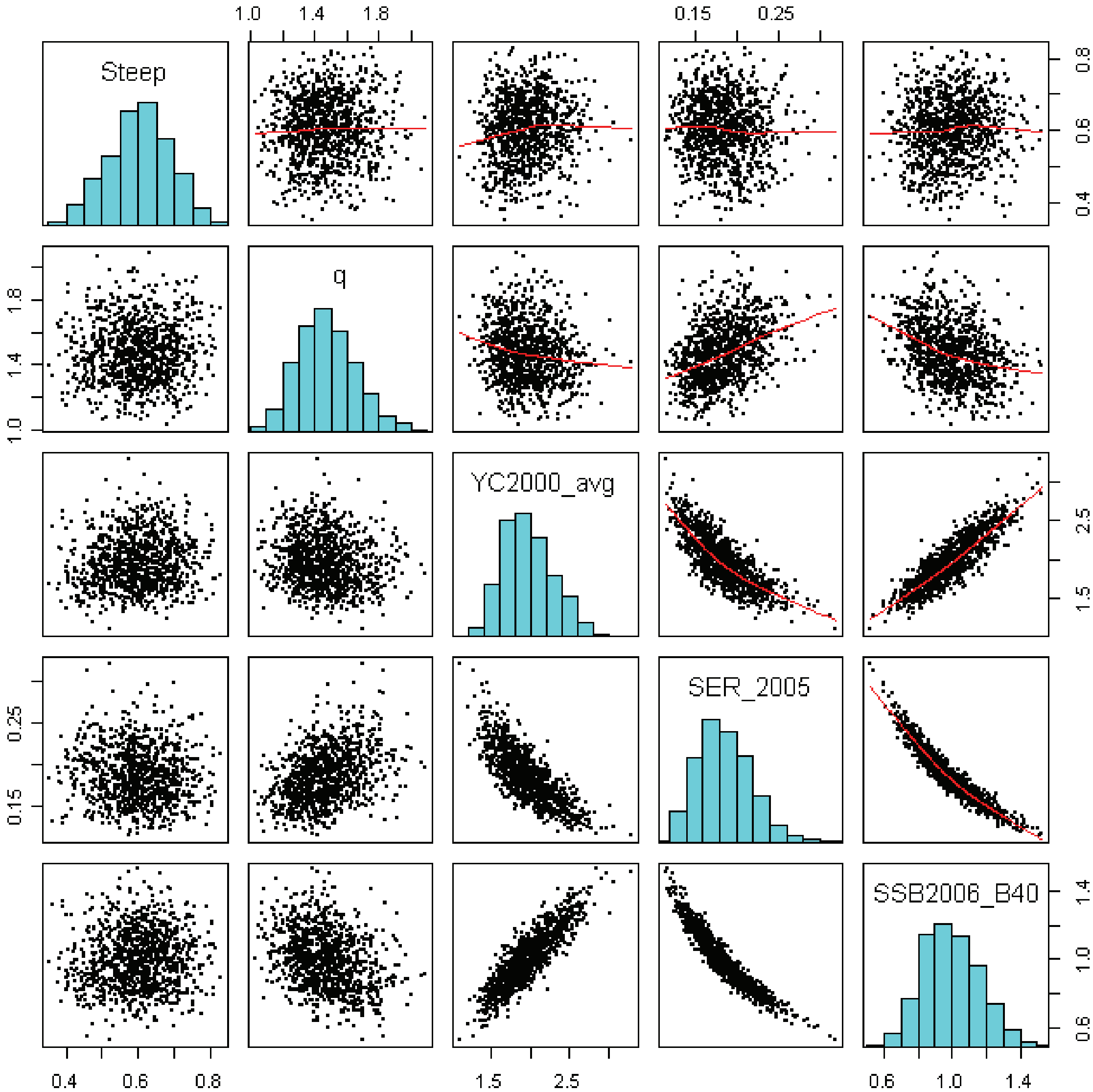


Figure 1.32. Bivariate and marginal distributions of key parameters integrated over an MCMC chain for Model 1 (length one million with every 200th sample selected and a burn-in of 4,000).

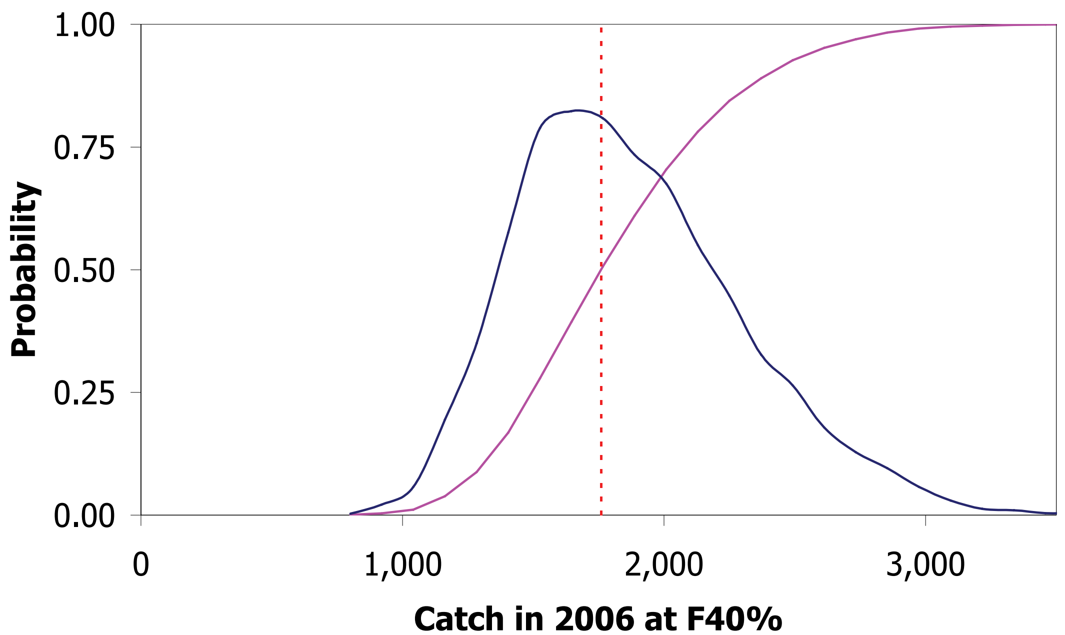


Figure 1.33. Marginal distribution of the 2006 yield (thousands of tons) at $F_{40\%}$ for EBS pollock based on the MCMC integration of the posterior distribution.

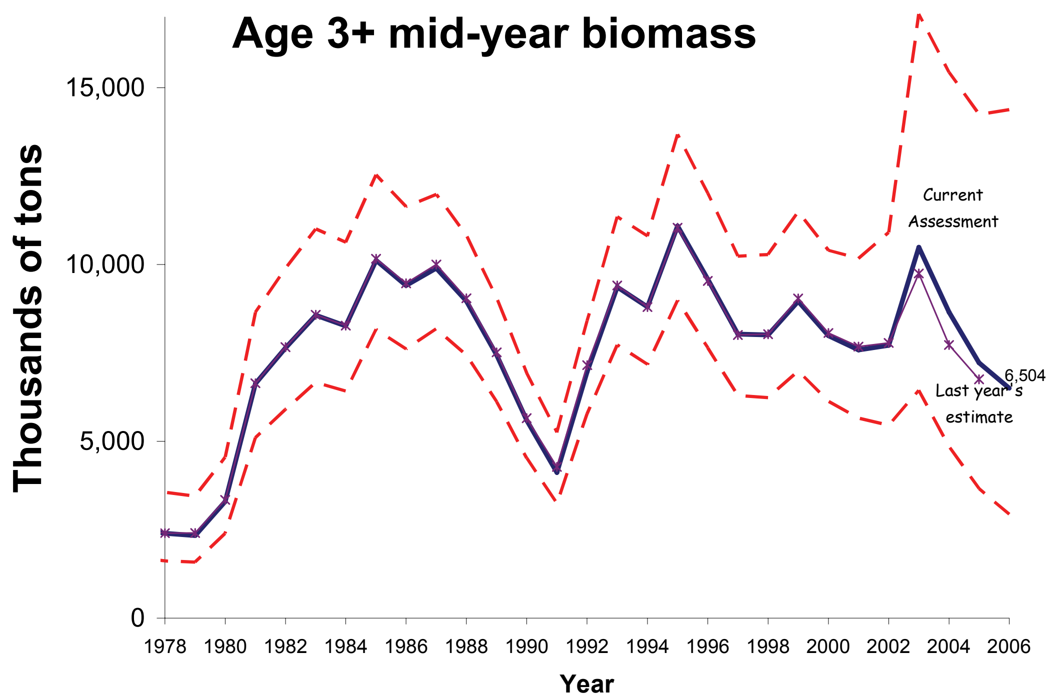


Figure 1.34. Estimated age 3+ EBS mid-year walleye pollock biomass under Model 1, 1978-2004. Approximate upper and lower 95% confidence limits are shown by dashed lines. Superimposed is the estimate of mid-year age 3+ biomass from last year's assessment

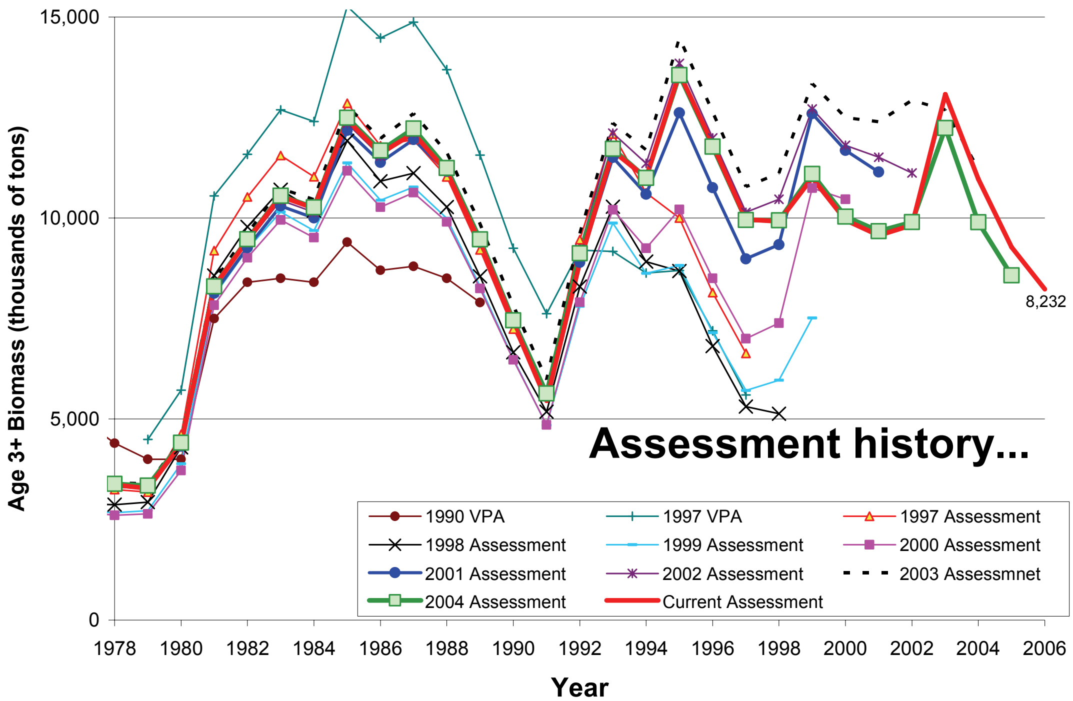


Figure 1.35. Comparison of the current assessment results with past assessments of **begin-year** EBS age-3+ pollock biomass, 1978-2006.

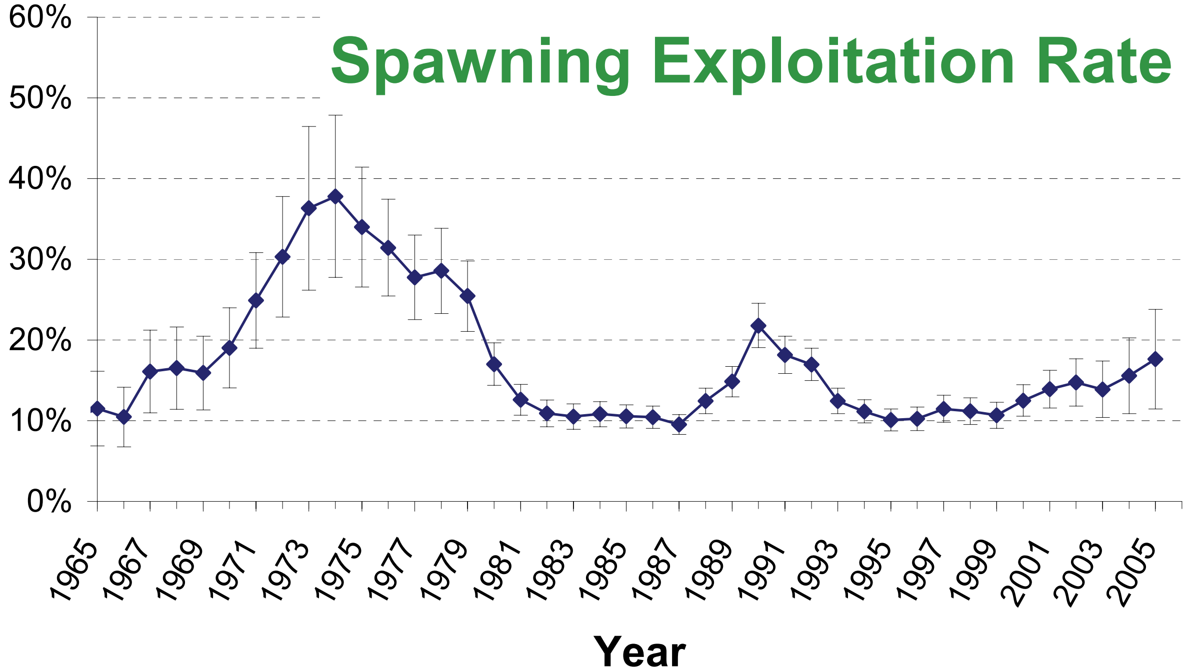


Figure 1.36. Estimated spawning exploitation rate (defined as the annual percent removals by fishing of spawning females) for EBS walleye pollock, Model 1. Error bars represent two standard deviations from the estimate.

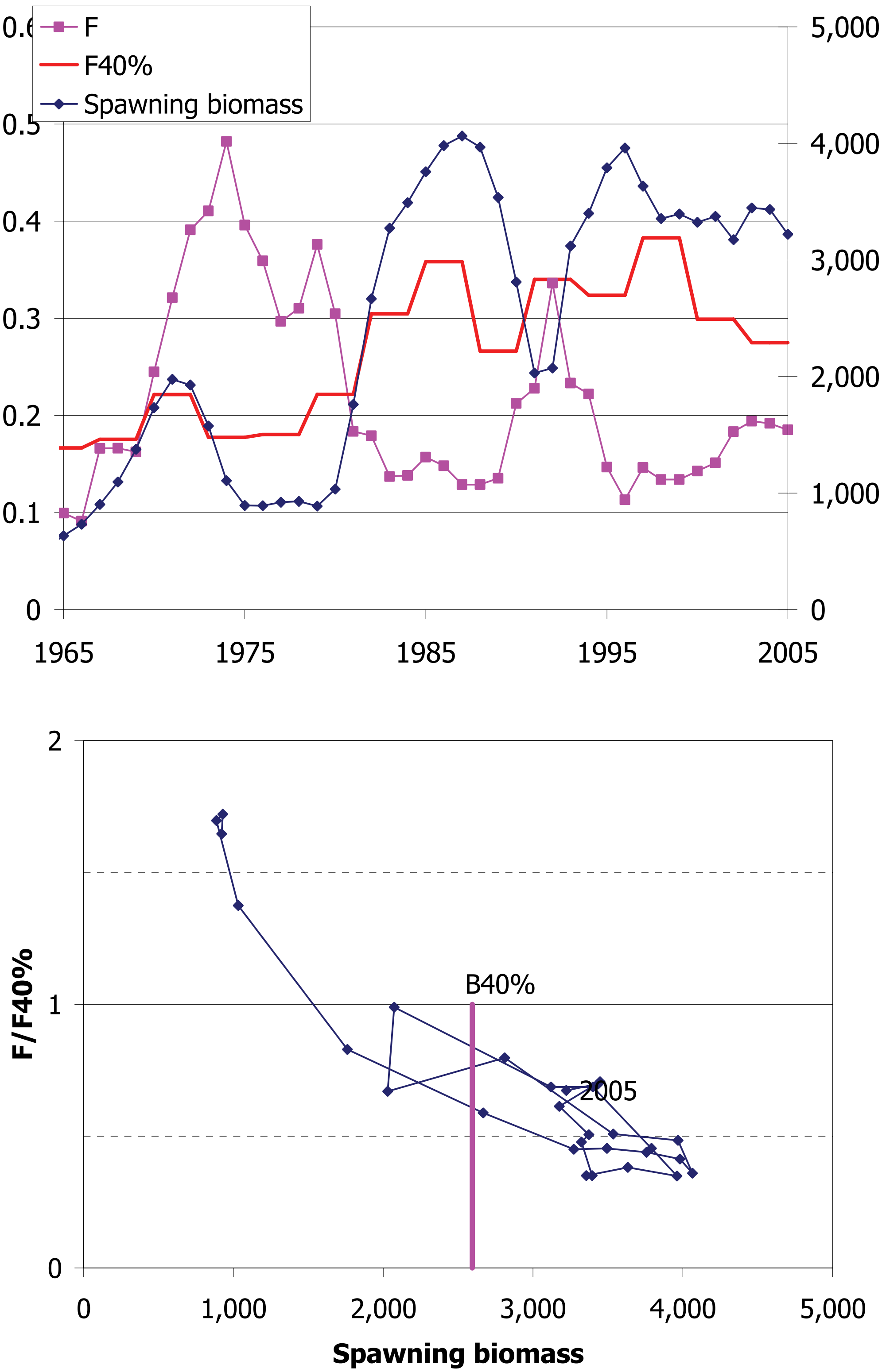


Figure 1.37. Spawning biomass relative to annually computed $F_{40\%}$ values and fishing mortality rates for Model 1, EBS pollock, 1977-2005 over time (top) and plotted jointly (bottom). Fishing mortality rates are based on the average over ages 1-15.

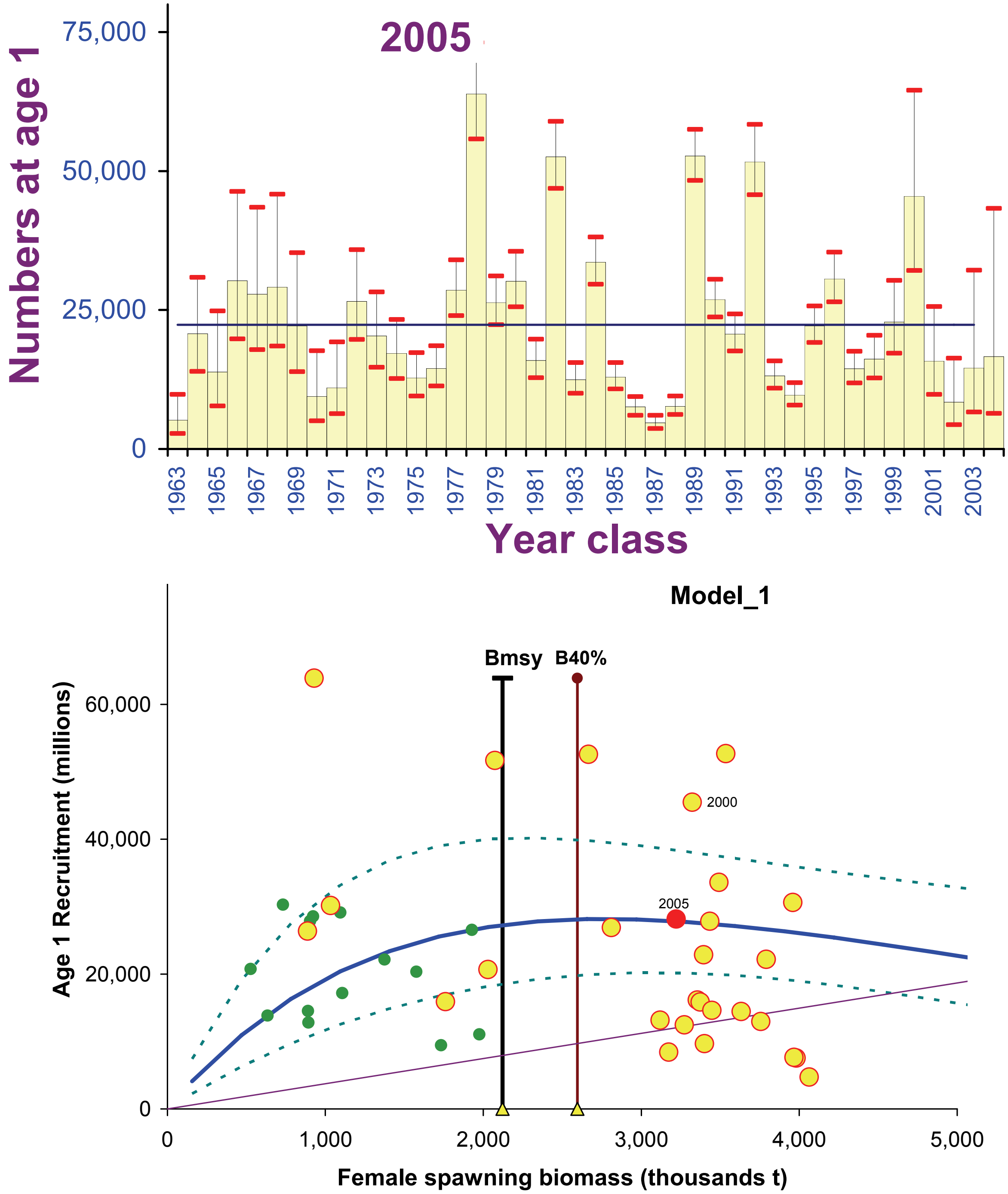
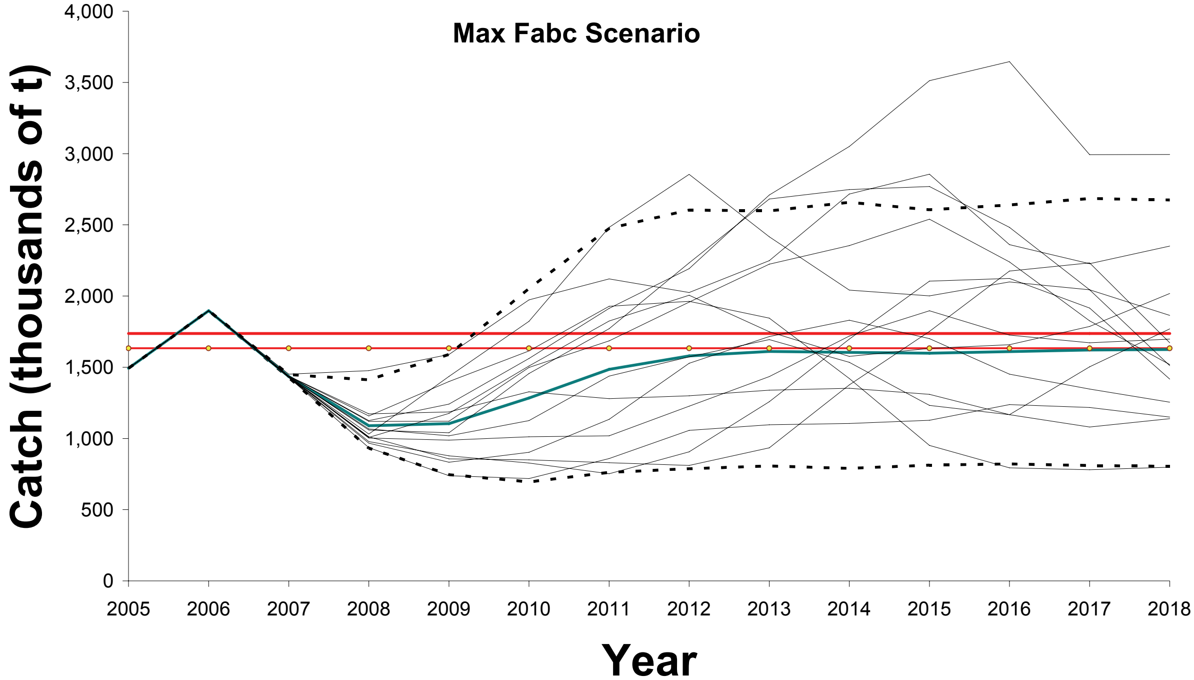


Figure 1.38. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate 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.



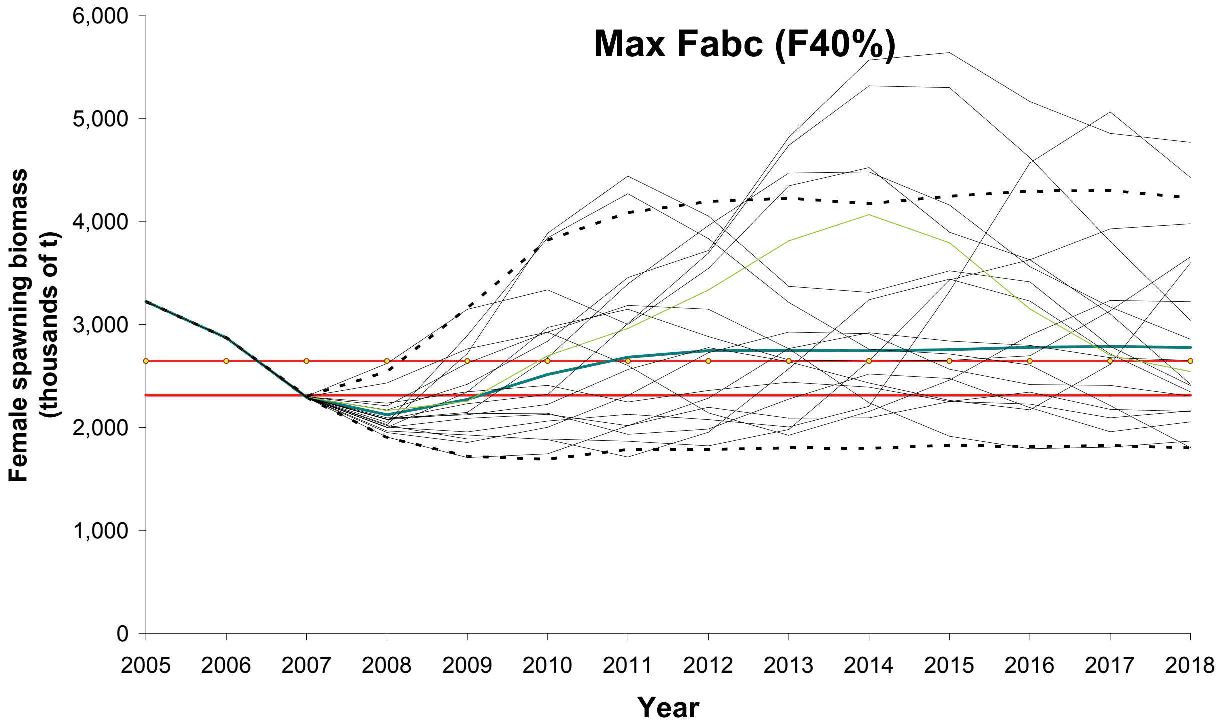


Figure 1.39. Projected EBS walleye pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2005. Future harvest rates follow the guidelines specified under Scenario 1, max F_{ABC} assuming $F_{ABC} = F_{40\%}$.

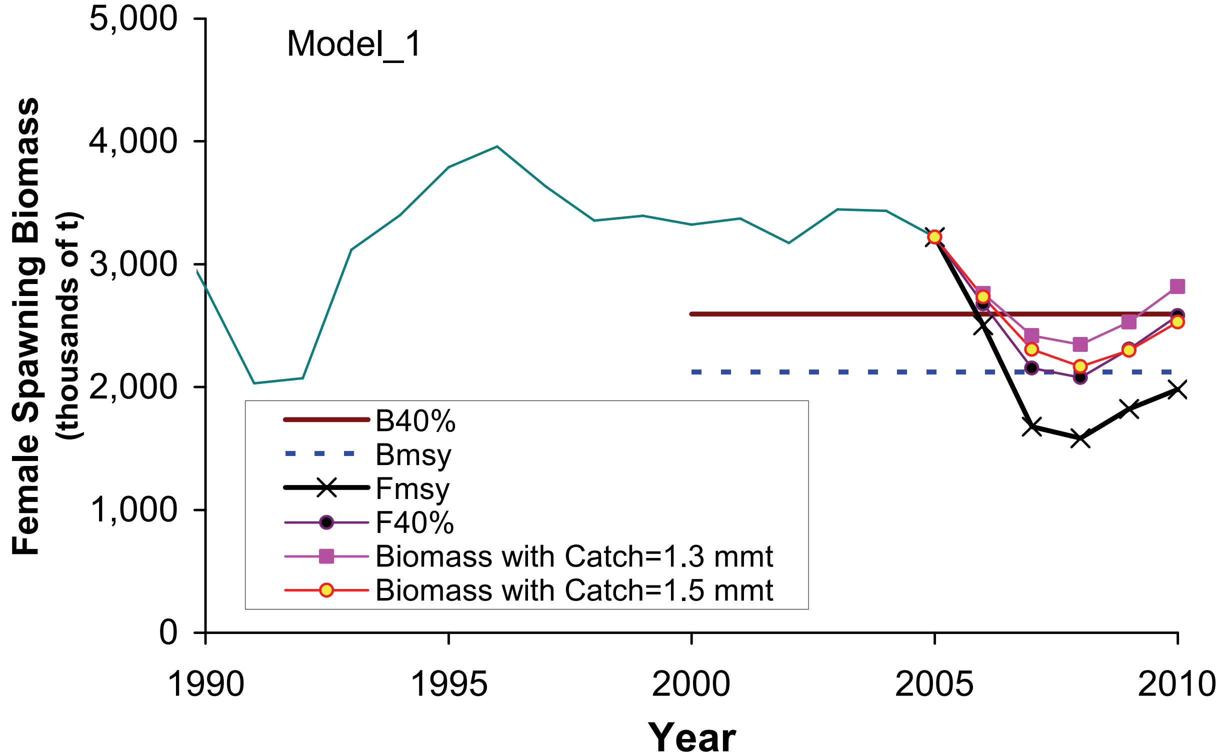


Figure 1.40. EBS walleye pollock female spawning biomass trends, 1990-2009 as estimated by Model 1 under different 2006-2010 harvest levels. Note that the F_{msy} and $F_{40\%}$ catch levels are unadjusted arithmetic mean fishing mortality rates. Horizontal solid and dashed lines represent the B_{msy}, and $B_{40\%}$ levels, respectively.

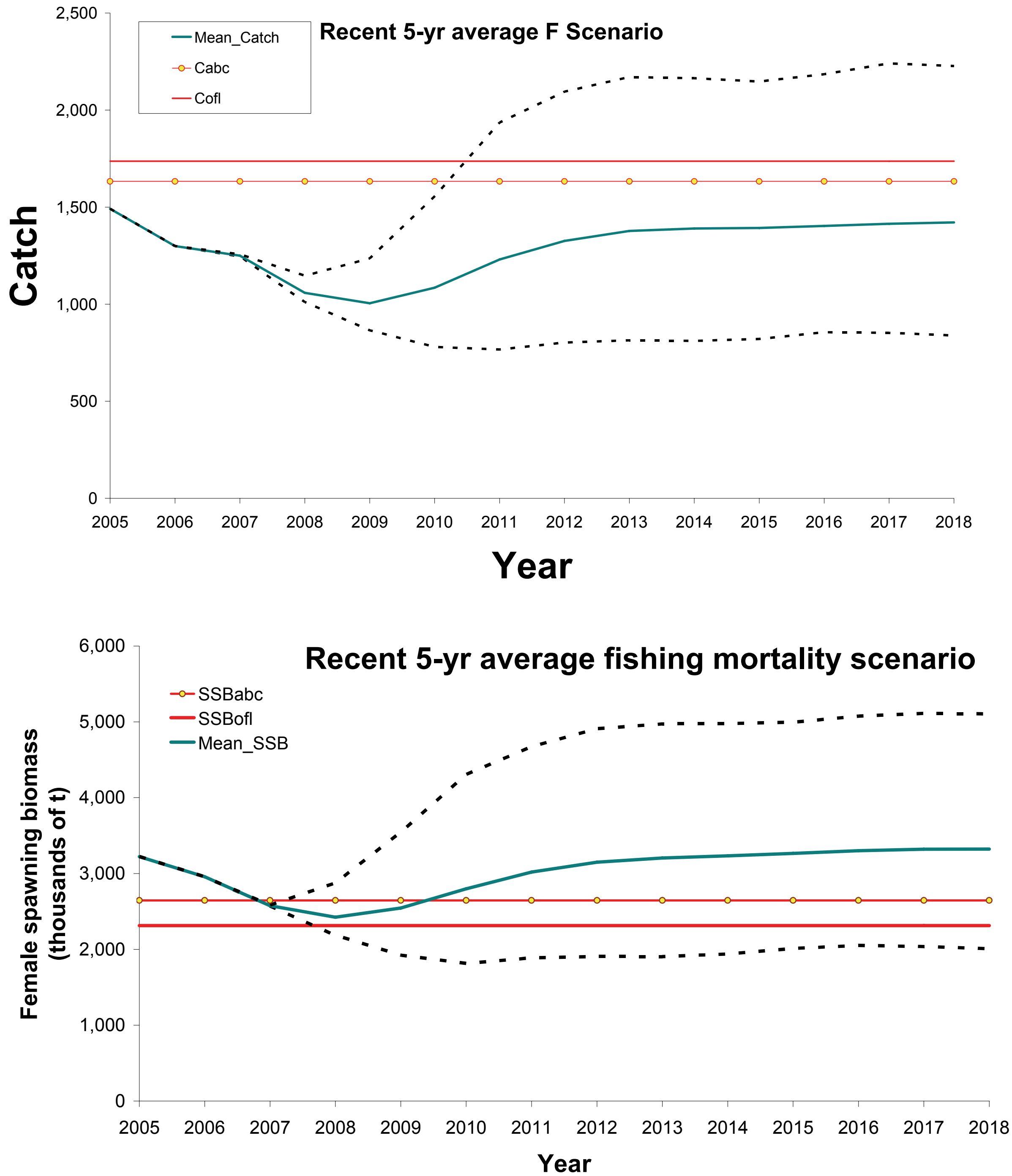


Figure 1.41. Projected EBS walleye pollock yield (top) and spawning biomass (bottom) in thousands of tons under F equal to the mean value from 2001-2005 relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1.

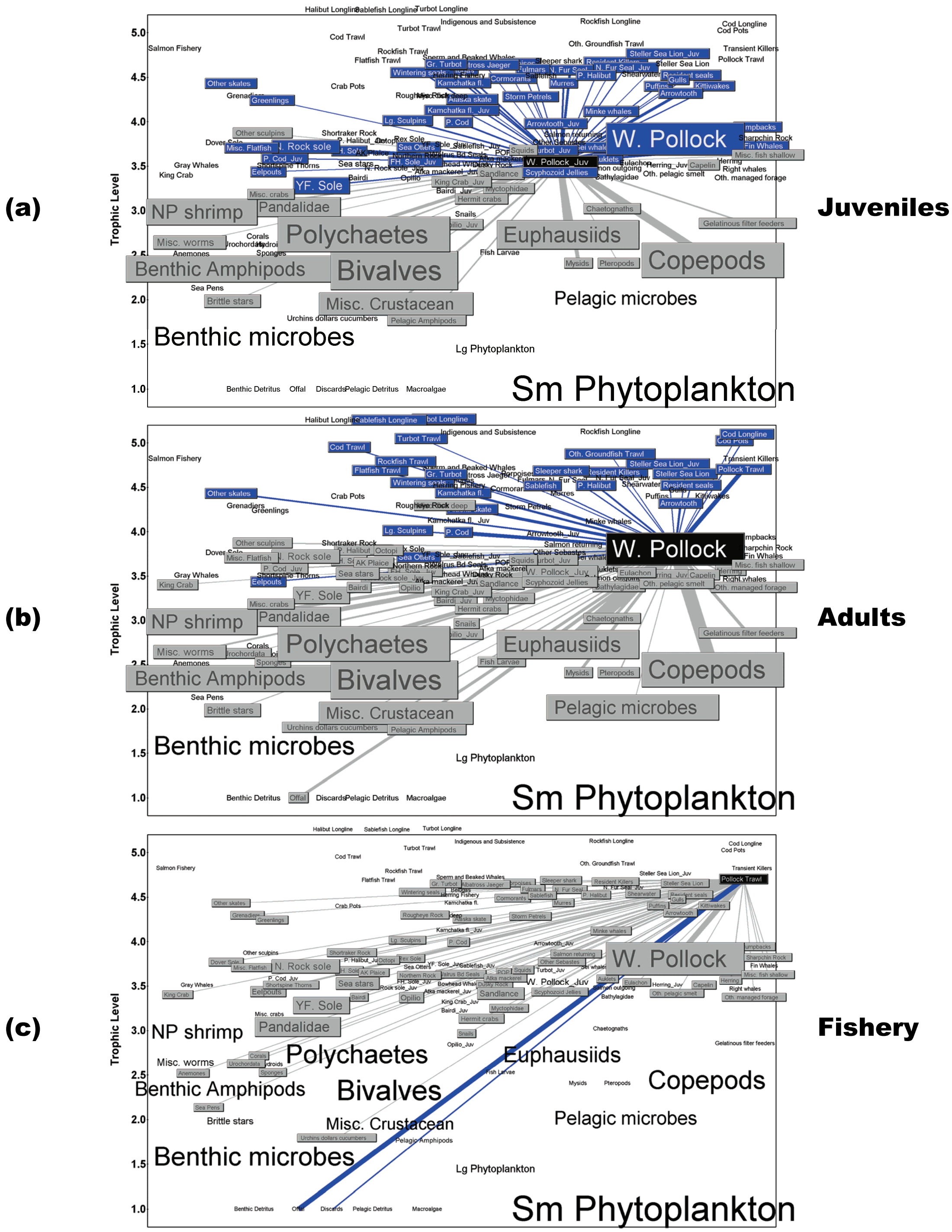


Figure 1.42. Food web pathways for the EBS region based on data from 1990-1994 emphasizing the position of EBS pollock juveniles (a), adults (b) and the pollock fishery (c). Outlined species and fisheries represent predators of pollock (dark box with light text) and prey of pollock (light boxes with dark text). Box and text size is proportional to each species' standing stock biomass, while the widths are proportional to the consumption between boxes (tons/year).

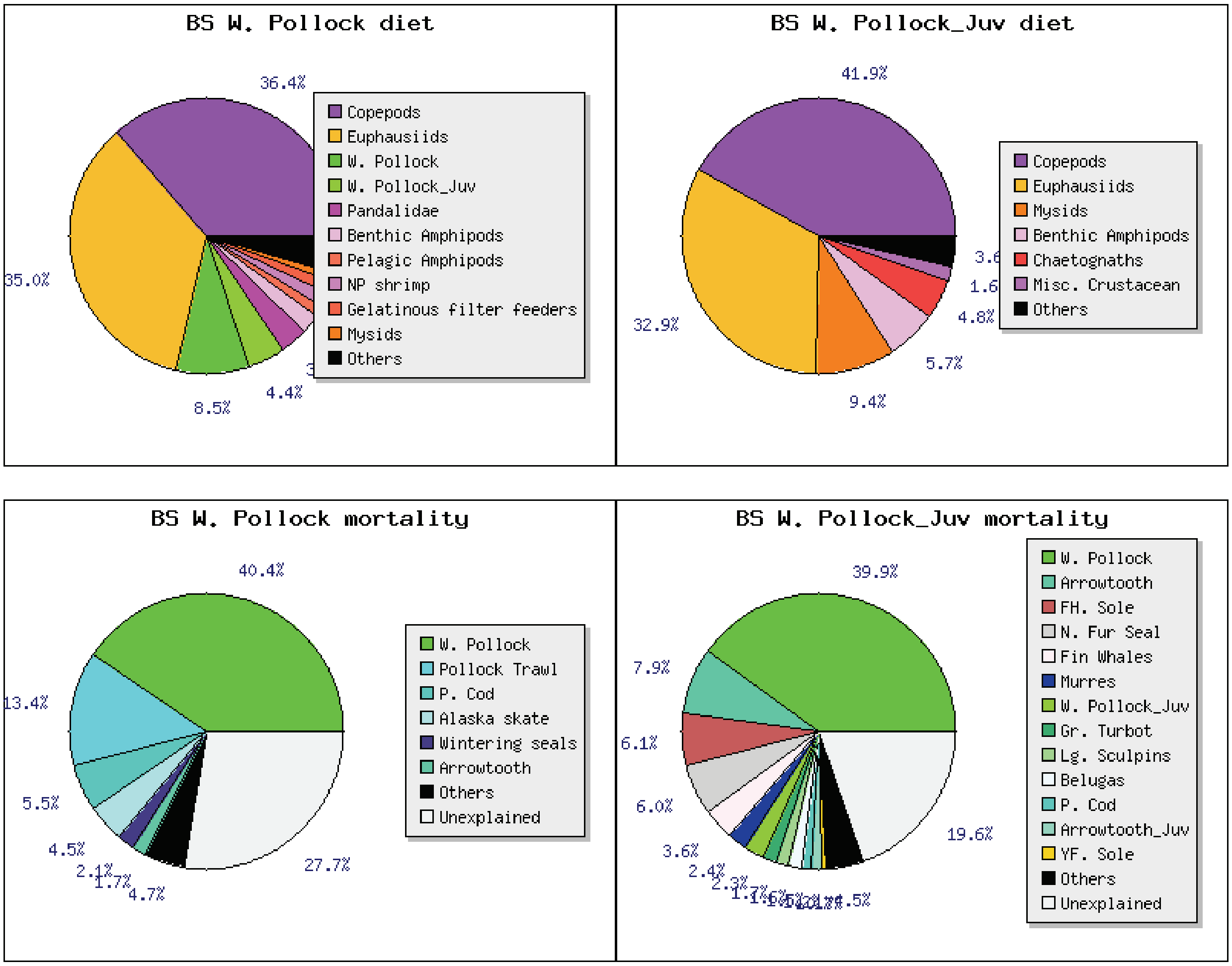


Figure 1.43. Diet (top) and mortality sources (bottom) for EBS pollock adults (left) and juveniles (right) based on data from 1990-1994. yield (top). “Unexplained” mortality is the difference between the stock assessment total exploitation rate averaged for 1990-1994, and the predation and fishing mortality, which are calculated independently of the assessment, using predator diets, consumption rates, and fisheries catch.

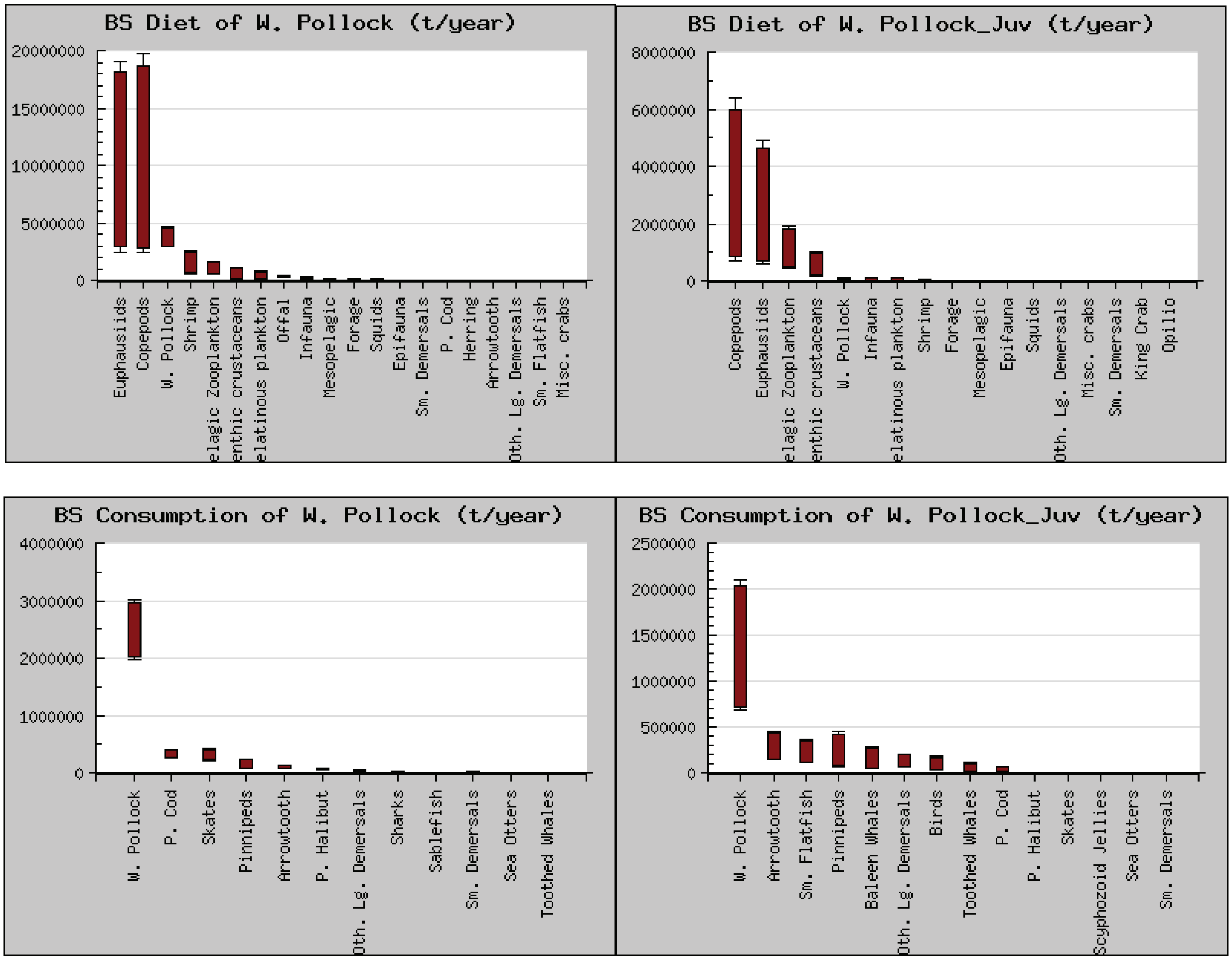


Figure 1.44. Diet (top) and mortality sources (bottom) for EBS pollock adults (left) and juveniles (right) based on data from 1990-1994. Error bars represent uncertainty of propagated consumption rates and population variance.

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

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

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 ($F_{t,a}$) following Butterworth et al. (2003) 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
μ^f	is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term (σ_s^2) to allow selectivity to change slowly over time–thus improving our ability to estimate the $\gamma_{t,a}$. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., σ_E^2) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model "selectivity" of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise, e.g., Lauth et al. 2004). The magnitude of these changes is determined by the prior variances as presented above. For the application here selectivity is allowed to change every three years to reduce the number of parameters but retain some variability attributed to the process of selectivity variability. Specifically, the last three years of the model (in this case 2003-2005) is configured to have the same selectivity and changes are allowed in each 3-year period prior (e.g., the next most recent selectivity change would occur between the years 1999 and 2000.

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 flexibility in selecting age 1 pollock over time. The functional form of this selectivity is:

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

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 $\bar{\alpha}, \bar{\beta}, \delta_t^\mu, \delta_t^\alpha, \text{and } \delta_t^\beta$ for *t*=1982, 1983,…2005. The variance terms for these parameters were specified to be 0.04.

In these analyses, recruitment (R_t) represents numbers of age-1 individuals modeled as a stochastic function of spawning stock biomass. A further modification made in Ianelli et al. (1998) was to have an environmental component to account for the differential survival attributed to larval drift (e.g., Wespestad et al. 2000). (κ_t):

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

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

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

and ϕ_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,*

ε_t is the "recruitment anomaly" for year *t*,

α, β are stock-recruitment function parameters.

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

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

where

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

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of 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. 1.45.

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 φ_0 represents the equilibrium unfished spawning biomass per-recruit.

Parameter estimation

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

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

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

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

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

where *A,* and *T,* represent the number of age classes and years, respectively, *n* is the sample size, and $O_{at}, \hat{C}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For Model 2 presented above, we implemented a revised ageing matrix. Sample size values were fixed at values shown in Table 1.14. 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 λ_c represents prior assumptions about the accuracy of the observed catch data. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include $\lambda_\varepsilon \sum_t \varepsilon_t{}^2 + \lambda_\gamma \sum_{ta} \gamma_{t,a}{}^2 + \lambda_\delta \sum_t \delta_t{}^2$ where the size of the λ*'s* represent prior assumptions about the variances of these random variables. 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).

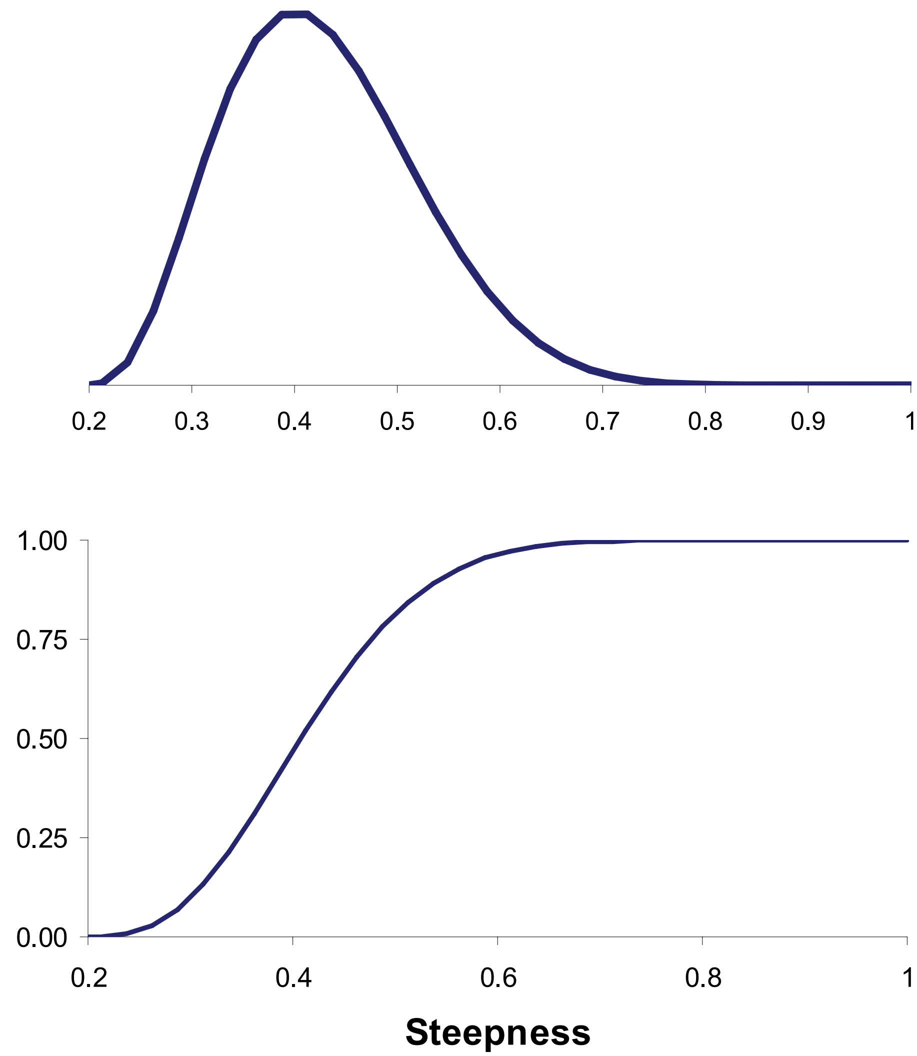


Figure 1.45. Cumulative prior probability distribution of steepness based on the beta distribution (α=4, β=10) assumed for the main model.