1. Assessment of the walleye 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.

Summary of major changes

Changes in the input data
The primary changes include

1) The 2009 NMFS summer bottom-trawl survey (BTS) abundance at age estimates were computed and included for this assessment.
2) The 2009 NMFS summer mid-water echo-integration trawl (EIT) survey conducted aboard the NOAA Ship Oscar Dyson were included. This was the third consecutive complete EIT survey conducted by this vessel in this region, and for the third straight year the survey extended into the Russian zone and covered part of the Navarin Basin.
3) Age composition estimates for the EIT survey derived from the population-at-length estimates using the 2009 BTS age-length key were included. To help cover ages that are less common in the BTS survey, about 100 samples from the EIT survey were included with the bottom trawl survey ages to help construct a more complete age-length key.
4) The 2008 age composition estimates were updated using EIT age data (last year the age-length key used was derived solely from the 2008 BTS age data).
5) Observer data for age and size composition and average weight-at-age and total catch (from NMFS Alaska Region) were updated and included.
6) Past approaches used to estimate mean weight-at-age in the fishery for the current and future years were re-evaluated using an age-specific biomass-weighted goodness of fit criterion. This resulted in a recommendation to modify past practices for specifying mean-weights at age for these years.

Changes in the assessment model
The modeling approach remained unchanged this year. Some refinements included enhancing the ability to do retrospective analysis (dropping recent years data in succession) and adding the capability to do one-year-ahead feedback analysis for management strategy evaluations. Developing one-year ahead feedback analysis allows consideration of how data collected in 2010 may affect assessment results in predicting biomass and stock status for 2011 under different 2010 catch scenarios. The impetus for this development was due to recent concerns that the spawning stock biomass may drop below the $B_{20\%}$ level.

Changes in the assessment results
The female spawning stock biomass is estimated to be below the B_{msy} level for 2010 but is increasing and presently projected to be above B_{msy} by 2012. Similar to last year, the application of FMP amendment 56 Tier 1b harvest control rule results in extreme sensitivity to model uncertainty. Factors affecting ABC levels were again identified. The available data indicate the spawning biomass for 2010 is projected to be lower than expected based on last year's assessment. The maximum permissible ABC based on the Tier

1b harmonic mean F_{msy} is estimated to be 813,000 t for 2010. The corresponding overfishing level (OFL) is estimated 918,000 t. The 2010 projection indicates that since the stock appears to show positive signs of recruitment (2006 and 2008 year classes) following 4-5 successively below-average year-classes, the spawning stock is anticipated to be close to the B_{msy} level by 2012.

Summary

Summary results for EBS pollock.

Reference points (female spawning biomass)	2008 assessment		This year's assessment	
$B_{40\%}$	2,427,000 t		2,351,000 t	
$B_{35\%}$	2,124,000 t		2,057,000 t	
B_0	4,980,000 t		4,934,000 t	
B_{msy}	1,919,000 t		1,863,000 t	
F_{ABC}	0.332		0.373	
F_{OFL}	0.398		0.421	
Tier 1	2009	2010	2010	2011
Female Spawning Biomass (t)	1,443,000 t	1,830,000 t	1,316,000 t	1,588,000 t
ABC (t, maximum allowable)	815,000 t	1,233,000 t	813,000 t	1,109,000 t
OFL (t)	977,000 t	1,425,000 t	918,000 t	1,220,000 t

Response to SSC and Plan Team comments

The following SSC comments were provided in its December 2008 minutes along with responses relevant to this assessment.

"*The BSAI Plan Team recommended that all authors of stocks managed in Tiers 1 through 3 should estimate the probability of the spawning stock biomass falling below $B_{20\%}$. The recommended time frame for this projection was 3-5 years. The SSC agrees with this recommendation and encourages authors to provide estimates of the probability of falling below biologically relevant thresholds such as $B_{20\%}$.*"

In this assessment we distinguished between estimation uncertainty (i.e., how well in any given year that we know the stock is above or below $B_{20\%}$) and the uncertainty in projecting forward and having the *point estimate* fall below $B_{20\%}$ (ignoring additional precautionary recommendations that may be taken by the SSC or Plan Team). This latter point is critical since it is the point estimate that would impact the fishery. To attempt to account for the process of how point estimates of stock status may change, alternative catch levels were projected forward for 2010 and 2011 given the full posterior distribution and simulated future survey and fishery data. These data were then analyzed as "new" observations for 2010 and the *actual assessment model* was run for each simulated dataset as if it were October of 2010. From each of these combinations of "assessments" and future catch levels, the point estimates of stock status relative to $B_{20\%}$ were compiled. This was intended to provide distribution of the future point estimates given new data and present levels of uncertainty.

Introduction

Walleye pollock (*Theragra chalcogramma;* hereafter referred to as pollock) are broadly distributed throughout the North Pacific with the largest concentrations found in the Eastern Bering Sea. Also marketed under the name Alaska pollock, this species continues to represent over 40% of the global whitefish production 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. They play an important in 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 (Hinckley 1987). 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 (Kotenev and Glubokov 2007). There is some indication (based on contiguous surveys) that the fish in the northern region may 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. Genetic differentiation using microsatellite methods suggest that populations from across the North Pacific Ocean and Bering Sea were similar. However, weak differences were significant on large geographical scales and conform to an isolation-by-distance pattern (O'Reilly et al. 2004; Canino et al. 2005).

Fishery

From 1954 to 1963, EBS pollock catches were low until 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 the peak catch in 1972, bilateral agreements with Japan and the USSR resulted in reductions.

Since 1977 (when the U.S. EEZ was declared) the annual average EBS pollock catch has been about 1.2 million t ranging from 0.815 million t in 2009 to nearly 1.5 million t during 2003-2006 (Fig. 1.1). United States vessels began fishing for pollock in 1980 and by 1987 they were able to take 99% of the quota. Prior to the domestication of the pollock fishery, the catch was monitored by placing observers on foreign vessels. 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 occurred beginning in 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 2000-2009 the EBS region pollock catch has averaged 1.31 million tons while during the decade preceding that the average was 1.24 million tons.

Fishery characteristics

Pre-spawning aggregations of pollock are the focus of the so-called "A-season" which opens on January 20th and extends into early-mid April. This fishery produces highly valued roe which can comprise over 4% of the catch in weight. The second season presently opens on June 10th and extends through late October. Since the closure of the Bogoslof management district (INPFC area 518) to directed pollock fishing in 1992, the A-season pollock fishery on the Eastern Bering Sea (EBS) shelf has been concentrated primarily north and west of Unimak Island (Ianelli *et al.* 2007). 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 been fairly similar during the period 2007 - 2009 (Fig. 1.2). 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. 1.3).

During the last four years (2006 through 2009) the summer fishing has concentrated more in the NW region (Fig. 1.4). Coupled with higher fuel prices, this was a concern for shore-based vessels that had much longer distances to travel to the prime fishing grounds. While the colder-than-usual bottom temperatures continue (see discussion of bottom trawl survey results below), it is unclear that these conditions are the major cause of this apparent shift in fish distribution. Ianelli et al. (2007) showed that from historical foreign-reported data that the pollock fishery often took more than half of their catch during the summer to the west of 170°W (the NW zone of the EBS). Only since 1991 had the summer pollock catches become more concentrated in the SE (east of 170°W). The 2009 monthly fishery length frequency information shows the relative catch of large fish during the winter with a shift towards smaller fish near the end of the summer season (Fig. 1.5).

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. These analyses are expected to improve our understanding on the dynamics of the pollock stock in response to fishing activities.

Fisheries Management

Due to concerns over possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions, NMFS and the NPFMC have changed management of Atka mackerel (mackerel) and pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). These changes were 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 may have had disproportionately high seasonal harvest rates within critical habitat that *could* lead to reduced sea lion prey densities. Consequently, management measures redistributed the fishery both temporally and spatially according to pollock biomass distributions. The idea was that seasonal and spatially explicit exploitation rates should be consistent with area-wide and annual exploitation rates for pollock. Three types of measures were implemented in the pollock fisheries: 1) pollock fishery exclusion zones around sea lion rookery or haulout sites; 2) phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat; and 3) 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 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. In 1998, over 22,000 t of pollock were caught in the Aleutian Island regions, with over 17,000 t caught in Aleutian Islands critical habitat region. Between 1998 and 2004 a directed fishery for pollock was prohibited. Consequently, 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. In 2000, phased-in reductions in the proportions of seasonal TAC that could be caught within the BSAI Steller sea lion Conservation Area (SCA) were implemented. Since 2005, a limited pollock fishery has been prosecuted in the Aleutian Islands but with less than 2,000 t of annual catch.

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 the year 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 when a large component of the onshore fleet also joined cooperatives. 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.

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 38% annually. During the "A-season," the average is about 49% (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. Since 2005 the annual proportion of catch within the SCA has dropped considerably with about 30% of the catch taken in this area. However, the proportion taken in the A-season reached 57% in 2007, the highest level since 1999 (Table 1.2).

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. 1.2).

The fishery continues to respond to issues related to salmon bycatch. In 2008 and 2009, bycatch levels for Chinook salmon have been well below average following record high levels in 2007. This is in part due to restrictions on areas where pollock fishing may occur and in part due to environmental conditions (and perhaps salmon abundance). Bycatch levels for chum ("other") salmon in 2005 were the highest on record but since have remained at low levels. Based on a final EIS released by NMFS in December 2009, revised salmon bycatch management measures have been developed and will become in effect by 2011. These measures were designed to have an overall Chinook salmon bycatch limit together with performance measures that will provide incentives for individual vessel operators to reduce bycatch. Salmon bycatch statistics are presented along with other bycatch estimates in the Ecosystem Considerations section below.

Catch data

From 1977-2009 the catch of EBS pollock has averaged 1.18 million t. Since 2001, the average has been above 1.33 million t. However, the average 2008 and 2009 catch has dropped to 0.903 million t due to stock declines and concomitant reductions in allowable harvest rates (Table 1.3).

Pollock catch in the Eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch for 1991-2009 are shown in Table 1.4. Since 1991, estimates of discarded pollock have ranged from a high of 9.1% of total pollock catch in 1992 to recent lows of around 1.5%. These low values reflect the implementation of the Council's Improved Utilization and Improved Retention program. Historically, discard levels were likely affected by the age-structure and relative abundance of the available population, e.g., if the most abundant year class in the population is below marketable size. With the implementation of the AFA in 1999, the vessel operators have more time to pursue optimal sizes of pollock for market since the quota is allocated to vessels (via cooperative arrangements). In addition, several vessels have made gear modifications to avoid retention of smaller pollock. In all cases, the magnitude of discards counts as part of the total catch for management (to ensure the TAC is not exceeded) and within the assessment. 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). 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).

The catch-age estimation method allows two-stage bootstrap re-sampling of the data. Observed tows were first selected with replacement, followed by re-sampling actual lengths and age-data specimens given those set of tows. This method allows an objective way to specify the "effective" sample size for fitting fishery age composition data within the assessment model. In addition, estimates of stratum-specific fishery mean weights-at-age (and variances) are provided which are useful for evaluating general patterns in growth and growth variability. For example, Ianelli et al. (2007) showed that seasonal aspects of pollock condition factor could affect estimates of mean weight-at-age. They showed that within a year, the condition factor for pollock varies by more than 15% with the "fattest" pollock caught late in the year, from October-December (although most fishing occurs during other times of the year) and the thinnest fish at length tend to occur in late winter. They also showed that spatial patterns in the fishery affect mean weights, particularly when the fishery is shifted more towards the northwest where pollock tend to be smaller at age.

The recent fishery age ranges appear to focus primarily on pollock age 4-7 with the 2000 year class making up the majority of the catch until 2006 where the relative fraction of this year class drops considerably (Fig. 1.6). The 2006 and 2007 fishery data show higher levels (proportionally) of the 2001 and 2002 year class than in previous years. The corresponding values of catch-at-age used in the model are presented in Table 1.5.

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. 6 and 1.7). The sampling effort for pollock lengths and ages by area has been shown to be relatively proportional to catches (e.g., Fig. 1.8 *in* Ianelli et al. 2004).

For total catch biomass, a constant coefficient of variation was assumed to be 3% for this stock assessment application. This value is a slightly higher than the ~1% CVs estimated by Miller (2005) for pollock in the EBS.

Resource surveys

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The annual research catches (1963 - 2009) from NMFS surveys in the Bering Sea and Aleutian Islands Region is given in Table 1.8. Since these values represent extremely small fractions of the total removals (~0.02%), their addition to the total catch values to the total removals by the fishery has negligible effect on the assessment.

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 since 1979 and since 1982 using consistent areas and gears. For pollock, this survey has been instrumental in providing an abundance index and information on the population age structure. This survey is particularly critical since it complements the EIT surveys that sample mid-water abundance levels. Between 1991 and 2008 the BTS biomass estimates ranged from 2.85 to 8.46 million t. In the mid-1980s three surveys resulted in above average biomass estimates. The stock appeared to be at lower levels during 1996-1999 then increased moderately until about 2003 and has followed a general decline since then (Table 1.9; Fig. 1.7). These surveys are multi-purpose and serve as a consistent measure of environmental conditions such as temperature characterizations which reflect the cold conditions of the past four years. Large scale zoogeographic shifts in the Eastern Bering Sea shelf due to temperature changes have been documented during a warming trend (e.g., Mueter and Litzow 2008). However, after a period of relatively warm conditions ending in 2005, the past four years have been below average and the zoogeographic response may be more complex (Fig. 1.8).

Beginning in 1987 NMFS expanded the standard survey area farther to the northwest. In earlier assessments, these extra strata (8 and 9) had been excluded for consideration within the model. The pollock biomass levels found in these non-standard regions were highly variable, ranging from 1% to 22% of the total biomass, and averaging about 6% (Table 1.10). 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). Nonetheless, since this region is contiguous with the Russian border, these strata are considered important and are included to improve coverage on the range of the exploited pollock stock. The use of the additional strata was evaluated in 2006 and accepted as appropriate by the Council’s SSC.

The 2009 biomass estimate was 2.28 million t, down from 3.0 million t in 2008 and the lowest on record since 1982 (covering the period of a consistent survey protocol). Interestingly, an even lower abundance was expected based on last year’s assessment (Ianelli et al. 2008) because of the poor year-class success from the period 2001-2005 and the fact that the bottom-trawl survey provides an index of older pollock. This survey estimate represents about 50% of the long-term 1982-2009 mean from this survey. In 2009, the distribution of pollock from the BTS was typical for the recent cold bottom conditions compared to warmer years, (e.g., 2005) with concentrations somewhat closer to the shelf break (Fig. 1.9).

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). The survey operations generally catch pollock above 40 cm in length, and in some years include many 1-year olds (with modal lengths around 10-15 cm) and rarely age 2 pollock (lengths around 15-25 cm). 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). Also, from assessment model estimates the estimated strength of the 1996 year class has apparently waned compared to survey abundance levels in some other years. Ianelli et al. (2007) reported a point estimate for the 1996 year class at around 32 billion one-year olds whereas in 2003, the estimate had been 43 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. Retrospective analyses (e.g., Parma 1993) have also highlighted these patterns as presented in Ianelli et al. (2006) and redone in this assessment (see below).

The 2009 survey age compositions were developed from age-structures collected and processed at the AFSC labs within a few weeks after the survey was completed. Since the bottom trawl survey overlaps in space and time with the EIT survey, age data from the BTS survey were applied to the length compositions for the EIT survey to provide two sources for abundances at age for 2009. However, since the EIT survey generally has a higher relative occurrence of fish age 2-4 than the BTS survey, an additional sample of 100 pollock age structures (otoliths) was included from the EIT survey and processed with the BTS data so that the smaller fish would be more adequately represented in constructing the age-length keys. The distributions of lengths-at-age between the surveys were similar (Fig. 1.11). This provides some assurance that mixing samples to better satisfy both requirements is reasonable.

The level of sampling for lengths and ages in the BTS is shown in Table 1.11. The estimated numbers-at-age from the BTS for the standard strata (1-6) and for the northern strata included are presented in Table 1.12.

As in the past few assessments, an analysis using survey data alone was conducted to evaluate mortality patterns. Cotter et al. (2004) promoted 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 early 1990s followed by recent increases (Fig. 1.12). Total mortality estimates by cohort represent lifetime averages since harvest rates (and actual natural mortality) vary from year to year. The low values estimated from some year classes (e.g., the 1990-1992 cohorts) could be because these age groups had only become available to the survey at a later age (i.e., that the availability/selectivity to the survey gear 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. The higher recent values are somewhat expected given recent population trends but also the slopes for these cohorts are relatively poorly determined since only a few abundance-at-ages have been included (e.g., 4 years for 2001 year class).

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 2009 the EIT survey resulted in a biomass estimate of 0.924 million t for the US zone, similar to the 0.997 million t value arising from the 2008 EIT survey (Honkalehto et al. 2009; Table 1.9). The abundance of 3-year old pollock (the 2006 year class) was below the expectations as projected from Ianelli et al. (2008). Above-average abundance of 1-year olds was observed this year (the 2008 year class).

For the fourth year since 2004, NMFS scientists were able to conduct an EIT survey that extended into the Russian zone. The 2004 survey estimates (from near-surface to 0.5 m off bottom) for the Navarin area was 402 thousand t (Honkalehto et al. 2005). This compares with 2007 and 2008 estimates for this Russian zone of 110 thousand t and 32 thousand t, respectively. In 2009, pollock biomass found in this region was 5,400 t. The summer of 2004 was a relative warm year compared to the other years and this may be affecting the distribution of pollock available in the survey area.

Historically, EIT abundance estimates derived from acoustic backscatter falling in the band of water above 0.5 m from the bottom to 3.0 m off bottom have been omitted from analysis by the assessment model because this layer was assessed by the bottom trawl survey. In other areas where EIT surveys of pollock are routine and concurrent BTS data are unavailable (e.g., Shelikof Strait in the Gulf of Alaska), this near-bottom layer is included. Since it is apparent that temperature conditions can affect the distribution of pollock spatially (Kotwicki et al. 2005) and within the water column (Kotwicki et al. 2004, Kotwicki et al. 2009), biomass estimates were compiled for this near-bottom layer back to 1994. The result of this work indicates that the near-bottom layer as estimated by the acoustic survey also shows declines in biomass levels in recent years. For example, the 2006-2009 mean value is about 71% of the 1994-2009 mean level for the bottom layer whereas for the mid-water layer, the recent four-year average level is about 57% of the 1994-2009 mean for the acoustic survey. Interestingly, the bottom-trawl survey 2006-2009 mean value is about 73% of the 1994-2009 mean and matches well with that component assessed by the EIT survey.

Using opportunistic acoustic data recording devices aboard the bottom-trawl survey data collection continues (e.g., as in Von Szalay et al. 2007 and Ressler et al. 2008) and is anticipated to be included for assessment consideration in 2011 (when ship time will prohibit a formal EIT survey in the EBS).

The number of trawl hauls and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.13. In 2008 the EIT survey population numbers at age estimates were computed based on age-length keys compiled from the bottom-trawl survey. These were updated using geographically split age-length keys (E and W of 170°W) from the EIT sampling (rather than the BTS age data; Fig. 1.13). For 2009 age compositions, the bottom-trawl survey collections (supplemented with 100 samples collected during the EIT survey to cover size ranges of pollock less common in the bottom-trawl survey) and subsequent age-length keys were used and applied to the EIT population-at-length estimates (Table 1.14; Fig. 1.14).

Proportions of pollock biomass estimated east vs. west of 170º W, and inside vs. outside the SCA show some patterns based on summer EIT surveys (Table 1.15). West of 170°W the proportions have averaged around 70% from 1994-2006. Since 2007 the proportions have exceeded 85%. For the SCA, the proportion was highest during 2000, 2002, and 2004 surveys (average 15%). For the period 2006-2009 the proportion has remained below 10%. The relative estimation errors for the total biomass were derived from a one-dimensional (1D) geostatistical method (Petitgas 1993, Walline 2007, Williamson and Traynor 1996). This method accounts for observed spatial structure for sampling along transects. Other sources of error (e.g., target strength, trawl sampling) were accounted for by inflating these to have a constant CV of 20% for application within the assessment model.

Comparing the geographical differences between the bottom trawl survey and the EIT suggests that in some areas the major concentrations are either nearer the bottom or in mid-water and in other areas concentrations overlap (Fig. 1.15).

Analytic approach

The assessment model

A statistical age-structured assessment model conceptually outlined in Fournier and Archibald (1982) and similar to Methot's (1990) extensions was applied over the period 1964-2009. A technical description is presented in the "Model Details" section. The analysis was first introduced in the 1996 SAFE report 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 include:

- The 2009 EBS bottom trawl survey estimate of population numbers-at-age was added.
- The 2009 EBS EIT survey estimate of population numbers-at-age were included using an age-length key from the 2009 BTS survey data.
- The 2008 EBS EIT survey estimate of population numbers-at-age were updated from last year's values by using age-length keys from the 2008 EIT survey data.
- The 2008 fishery age composition data were added.
- Length frequency data from the 2008 fishery was incorporated (and growth estimates to use in tuning the model).

A diagnostic approach to evaluate input variance specifications (via sample size under multinomial assumptions) was added in this assessment (see section titled "Model Details).

Other features added to the assessment model this year was the ability to conduct management evaluations for future years via simulations (e.g., A'mar et al. 2009). In particular, the interest in understanding the probability of the point estimate of the stock dropping below $B_{20\%}$ in future years requires projections that include the generation of new "data" and the process of conducting future "assessments." Here "data" were generated based on simulations and "assessments" refer to the model (identical to that used in this year's assessment) that analyzed the full (historical and simulated future) data set. The steps for this process were:

1) Condition the model given all currently available data (essentially the current estimate of stock size and trends)
2) Compute the posterior density of the conditioned model (using MCMC for 1,000,000 samples, and saving every 2,000th for a final sample of 500 parameter vectors)
3) For each parameter vector, project forward with pre-specified catch and simulate 2010 data including:
    a. BTS data (CV=15%)
    b. EIT data (CV=20%)
    c. 2009 fishery catch-at-age data (CV=10%)
4) Do step 3) for each of the 500 parameter sets from the posterior distribution creating 500 datasets for each level of fixed future catch (with $C_{2010} = C_{2011} = \{600, 700, \ldots, 1500\}$ kt)
5) Run the assessment model for each of these 5,000 (500 x 10 catch levels) data sets
6) Evaluate the incidence that the point estimate of spawning biomass exceeds $B_{20\%}$ in 2010 and 2011 as a function of different catch levels.

This process can also be used to provide forecasts on the distribution of estimates that might be expected from next year's surveys. Results from this analysis are presented in the section below titled "Projections with future "assessment" feedback."

Other model projections (without feedback) include near-term calculations where Tier 1 control rule is applied. Additionally, the Tier-3 approach is included for contrast.

As in the past, output values for diagnostic purposes include a "replay" of the estimated time series of spawning biomass given recruitments as estimated but omitting the fishing mortality component. This allows a more empirical evaluation of the impact of fishing.

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.

In August of 2009, AFSC staff hosted a workshop on natural mortality estimation for stock assessment purposes. This workshop was funded by NMFS Office of Science and Technology and covered a broad array of topics. One proposal dealt with the age-specific patterns of natural mortality that combined Lorenzen's (2000) observation that natural mortality is inversely proportional to length for young fish. Another adapted this with Lehodey et al.'s (2008) logistic model for older fish scaled to maturation. Combined, the following relationship was proposed for consideration:

$$M_{s,a} = M_{juv}\left(\frac{L_{mat,s}}{L_{s,a}}\right)^{\lambda} + \frac{M_{mat,s} - M_{juv}}{1+\exp\left[\beta_s\left(L_{s,a} - L_{50,s}\right)\right]}.$$

Maunder (pers. comm.) suggested that defaults of $\lambda = 1$, β_s and $L_{50,s}$ from the maturity curve, $M_{mat,s} = 1.5K_s$ from Jensen (1996) and $M_{juv} = 3W_{mat}^{-0.288}$ from Lorenzen (1996) where $L_{mat,s}$ is the length and W_{mat} the weight at which individuals first become mature, *a* = age and *s* = gender. Application of this equation to pollock life history provides a similar vector of age-specific natural mortality for the youngest and oldest ages but is significantly larger for middle-age groups compared to what is presently used (Fig. 1.16). Estimates of natural mortality are also higher when predation is explicitly considered (Livingston and Methot 1998; Hollowed et al. 2000). However, 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	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. Mature	0.000	0.008	0.290	0.642	0.842	0.902	0.948	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; subsequently Stahl and Kruse 2008a). The technicians collected 10,197 samples of maturity stage and gonad weight 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 and Kruse, 2008b). In their 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.

Ianelli et al. (2005) investigated the inter-annual variability found by Stahl (2004). 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 matched Stahl's data whereas for 2003, the model's expected values for maturity-at-length were shifted towards larger pollock. This result suggests that younger-than-currently-assumed pollock may contribute to the spawning stock.

Length and Weight at Age

Age determination methods have been validated for pollock (Kimura et al. 1992; Kastelle and Kimura 2006). Regular age-determination methods coupled with extensive length, and weight data collections 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.

Stock assessment models for groundfish in Alaska typically track numbers of individuals in the population. Management recommendations are based on allowable catch levels expressed as tons of fish. While estimates of pollock catch-at-age are based on large data sets, these are typically only available up until the most recent completed calendar year of fishing (i.e., 2008 for the assessment conducted in 2009). Consequently, estimates of weight-at-age in the current year are required to map total catch biomass (typically equal to the quota) to numbers of fish caught.

The mean weight at age in the fishery can vary due to environmental conditions in addition to spatial and temporal patterns of the fishery. For estimation errors due to sampling, bootstrap distributions of the variability (within-year) indicate that this source is relatively small compared to the between-year variability in mean weights-at-age (Table 1.16). The coefficients of variation between years is on the order of 6% to 9% (for the ages that are targeted) whereas the sampling variability is generally around 1% or 2%.

Evaluating alternative mean weight-at-age estimation performance

Alternative estimators for mean weight at age were developed based on evaluating a variety of potentially useful independent variables. Potential explanatory variables were evaluated provided that they would be available at the time of the assessment in each year (e.g., since the bottom-trawl survey is used to collect temperature information, this may be useful to predict mean weights in the fishery). The objective function used to evaluate estimator performance was simply examining how well “out-of-sample” data were predicted. For example, for a particular estimator, for the first iteration data from 1991-2000 were used to estimate the mean weights in 2001 and 2002. These estimated were then compared to the actual mean weights observed for 2001 and 2002. The second iteration repeated this process but used data from 1991-2001 to estimate 2002 and 2003 data for comparison with actual observations. This sequence was continued through to using data from 1991-2007 to estimate 2008 means (and compared with actual 2008 mean values). Since some age groups are relatively more important than others to the fishery (in terms of prediction errors), comparisons of estimates with “observed” were weighted by the relative importance of different age groups. The relative importance of estimating different age groups was computed by using the mean numbers at age estimated in the population from Ianelli et al. (2008) and accounting for the fishery selectivity and mean body mass over the recent history of the fishery. This weighting scheme is intended to favor estimators for age-groups that are most important to the fishery and is computed as

$\omega_a = \frac{\bar{N}_a s_a \bar{w}_a}{\sum \bar{N}_a s_a \bar{w}_a}$ where s_a is the mean age-*a* selectivity of the fishery, $\bar{N}_a$ is the mean number in the population at age *a* (from Ianelli et al. 2008) and $\bar{w}_a$ is the long term (1991-2008) mean weight at age in the fishery.

The estimator that performed best minimizes: $\sum_{y=2000}^{2008}\sum_{t=y}^{y+1}\sum_{a=3}^{15}\omega_a\left(w'_{t,a}-\hat{w}^k_{t,a}\right)^2$ where y is the "assessment" year, $\hat{w}^k_{t,a}$ is the kth estimator for mean weight at age a, in year y, and $w'_{t,a}$ are the actual observations in year t. The vector used for the weighting scheme (ω_a) was:

Age												
3	4	5	6	7	8	9	10	11	12	13	14	15
12%	24%	24%	19%	11%	5%	3%	1%	1.2%	0.7%	0.4%	0.2%	0.1%

Estimators evaluated included the following:

1. Modeled as a function of
    - The proportion of the catch taken W of 170°W;
    - Mean area-weighted bottom temperature from the summer bottom-trawl survey;
    - Annual abundance estimate (from Ianelli et al. 2008); and
    - Mean catch-weighted date of the fishery during the "B" season (Fig. 1.17).
    - The previous years' residual (relative to the long-term mean) for the same cohort (Fig. 1.18);
2. Recent year mean values (see Fig. 1.19 for illustrative example):
    - Equal to the most recent year of data (i.e., values for 2009 and 2010 set equal to values from 2008 data).
    - Three-year means (e.g., mean from 2006-2008 for 2009 and 2010 fishery; *this is the current convention selected by the NPFMC SSC*)
    - Most recent 5 year means
    - Most recent 7 year means
    - Most recent 10-year means

Results of the modeled mean weights at age indicated that the only explanatory variable that were significant (given the limited data set since 1991) were the residuals from the previous years. These were thus selected for contrasts relative to the recent-year mean approaches. The "out-of-sample" criteria for selecting the method that performs best indicated that the 10-year mean value minimized the error of prediction (Fig. 1.20). While it is somewhat counterintuitive that factors such as temperature, timing and location of fishing fail to perform well, it should be noted that this is a relatively short time series and confounding factors related to changes in the fishery operations since the 1999 AFA provide limited predictive power. In the future, as more data become available, such methods should improve on the ability to predict mean weight-at-age trends. Note however that the uncertainty in future mean weights-at-age has been accommodated to some degree by allowing this source of uncertainty to propagate into the pdf for F_{msy} (which affects the ABC control-rule adjustment). Based on this evaluation, the 10-year mean value for body mass-at-age was selected for use in the projection and ABC/OFL calculations.

Parameters estimated conditionally

For the selected model, 772 parameters were estimated conditioned on data and model assumptions. Initial age composition, subsequent recruitment and stock-recruitment parameters account for 69 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 1964-2009 and projected recruitment variability (using the variance of past recruitments) for five years (2010-2014). 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 in each year. The mean value of the age component is constrained to equal one and the last 5 age groups (ages 11-15) are specified to be equal. The annual components of fishing mortality result in 47 parameters and the age-time forms a 10x45 matrix of 450 parameters bringing the total fishing mortality parameters to 507.

Selectivity-at-age estimates for the bottom trawl survey are specified with age and year specific deviations in the average availability-at-age totaling 87 parameters. For the EIT survey, which began in 1979, 105 parameters are used to specify age-time specific availability. Time-varying survey selectivity is estimated to account for the changes in availability of pollock to the survey gear and is constrained by pre-specified variance terms. Four catchability coefficients were estimated: one each for the early CPUE data, the early bottom trawl survey data (where only 6 strata were surveyed), the main bottom trawl survey data, and the EIT survey data.

Based on the work of Von Szalay et al. (2007) prior distributions on the sum of the EIT and BTS catchability coefficients were introduced in Ianelli et al. (2007). This simply allows an evaluation of the extent that BTS survey covers the bottom-dwelling pollock (up to ~3 m above the bottom) and the EIT survey covers the remainder of the water column. Logically, the catchabilities from both surveys should sum to unity. Values of this sum that are less than one imply that there are spatial aspects of the pollock stock that are missed whereas values greater than one imply that there are pollock on the shelf during the summer that could be considered as “visitors” perhaps originating (and returning to) other areas such as the Russian zone. Further analytical work has been conducted to include an internally consistent manner to sum the surveys and estimate the associated variances. This is planned for consideration in next year’s assessment.

Additional fishing mortality rates used for recommending harvest levels are estimated conditionally on other outputs from the model. For example, the values corresponding to the $F_{40\%}$, $F_{35\%}$ and F_{msy} harvest rates are found by satisfying the constraint that given age specific population parameters (e.g., selectivity, maturity, mortality, weight-at-age), unique values exist that correspond to these fishing mortality rates.

The likelihood components that are used to fit the model can be categorized as:

- Total catch biomass (Log normal, σ=0.05)
- Log-normal indices of abundance (numbers of fish; bottom trawl surveys assume annual estimates of sampling error, as represented in Fig. 1.7; 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 1.17).
- Age 1 index from the EIT survey (CV set equal to 30%)
- 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

The model was evaluated as in Ianelli et al. (2007) by showing the impact of sequentially adding new data for the current year. This approach covers including or excluding new data as follows:

	Shorthand	Description
Model_1	**C**	2009 total catch only included
Model_2	**CA**	Catch and 2008 fishery age data included
Model_3	**CB**	Catch, and 2009 bottom-trawl survey data included
Model_4	**CE**	Catch, and 2009 EIT survey included
Model_5	**CAB**	Catch, age, and bottom-trawl survey
Model_6	**CAE**	Catch, age, and EIT survey
Model_7	**CBE**	Catch, bottom-trawl survey, and EIT survey
Model_8	**CABE**	Catch, age, bottom-trawl survey, and EIT survey

On October 21st 2009, approximately 900 pollock specimens from the 2009 winter fishery were processed for age determinations and made available for the assessment. These age data formed the basis of the age-length key for the winter fishery (and length compositions). For the B-season, the fishery length frequencies (and length-weight data) were processed and evaluated using age-length keys derived from the summer bottom trawl surveys. This provided the ability to conduct an alternative model run designed to evaluate if the age composition of the fishery during 2009 are likely to affect conservation concerns for the pollock stock.

Results evaluating new data introduced in 2009

Evaluating the influence of new data can reveal where consistencies with past predictions occur and where things may diverge. Similar to the 2008 assessment, results indicate that the addition of the 2009 bottom-trawl and EIT survey data had the largest impact—in opposite directions (Fig. 1.21). Adding the EIT survey data alone decreased the ABC level (compared to the model run without any new data) whereas adding the BTS data alone resulted in an increase. This is simply because the EIT survey value for 2009 was below expectations and the bottom-trawl survey data was less pessimistic (relative to expectations). This procedure highlights the sensitivity of ABC calculations when applying the Tier 1b control rule.

Closer examination of the age data that affect results show how different “data omissions” reflect the influence of the other sources of information. For example, fits for model CA (only new 2008 data include fishery catch and age compositions) to the observed 2009 survey age compositions (Fig. 1.22) were particularly poor. Similarly, if the 2008 EIT age composition data are omitted, (model CAB) the fit to the 2008 EIT age data is poor (Fig. 1.22).

Alternative non-informative prior distributions on the aggregate “catchability” of the EIT and bottom trawl survey was examined in Ianelli et al. (2007). If surveys have no overlap in sampling, then the theory is that the combined abundance levels should add to the total. Von Szalay et al.’s (2007) study examined the mechanism for such potential overlap and found that evidence of vertical herding of pollock (i.e., fish diving toward bottom and becoming vulnerable) was lacking. This indicates that a rationale for having the combined catchability be closer to unity than the current estimated value of 1.69. However, alternatives lower than this number degraded the fit to the data substantially and represents a major departure from past assessments. Highlighting this fact does provide some added level of precaution since imposing an informative prior on the combined survey catchabilities to lower values would scale population to higher levels. A likelihood profile over this quantity indicates that the value appears to be well determined and unlikely (given data and model structure assumptions) to be below a value of 1.3—which would increase the current stock-size estimated by 30% (Ianelli et al. 2007). Thus for consistency, the model presented below is the same as in previous years (where both surveys are treated as relative indices). This model was selected (CABE) as the reference case and provides a reasonable representation of stock status and associated uncertainty.

Retrospective analyses

In Ianelli et al. (2006) model evaluations entailed conducting a "retrospective analysis" (Parma 1993, Mohn 1999). This involves using the current form of the assessment model to evaluate how putative earlier assessments (using fewer years of data) would compare with the current (full-data) results. This approach provides a diagnostic to evaluate if the model tends to have systematic biases. One statistic developed by Mohn (1999) involves comparing the error rate from a "historical" assessment to the current estimates for management quantities of interest. I.e.,

$$\rho = \sum_{i=1992}^{2008} \frac{X_i^{retro} - X_i^{full}}{X_i^{full}}$$

where X_i^{retro} is an annual variable of interest (e.g., spawning biomass, exploitation rate) for the reduced model with terminal year *i* and X_i^{full} is the variable from the full time series assessment in year *i.*

This statistic will approach zero when the reduced-data series assessments exactly match the full time series assessment. Low values can also occur when differences between the reduced-data series assessments and full time series balance (equally positive and negative). Judging the significance of this statistic as a measure of bias is difficult. However, if average values are within the range of uncertainty then model specification may be reasonable (Anon. 2009). For the reference model, this statistic scored well (ranging around 3-6%) and the full time-series result was generally well within the confidence bands of the reduced data series assessments (Fig. 1.23). Note that this type of retrospective analysis differs from the comparison of this year's model results with past years assessments (as presented below).

Inclusion of the preliminary 2009 fishery age composition data

The preliminary 2009 fishery data compilation (completed in late October) provides estimates of 2009 catch-at-age totals. These data indicate that the fishery caught fewer small (age 3 and 4) pollock than expected (based on this year's model run excluding these data) and more old fish than expected (Fig. 1.24). When the preliminary 2009 fishery age composition data were formally included in the assessment model results indicate that:

- the selectivity for the older age pollock increased (consistent with the greater-than expected catch at age data);
- the probability (due to estimation error) that the 2009 spawning biomass is below $B_{20\%}$ drops from 18% to 15% (but in both runs the point estimate of B_{2010}/B_0 is about 27%);
- recruitment estimates increased slightly (~0.5%); and
- the Tier 1b maximum permissible ABC calculation increases by 25,000 t.

Since the addition of these preliminary data fail to raise conservation concerns, and due to the fact that they haven't been analyzed extensively, they are retained as a sensitivity.

Further results from reference model

Relative to last year's projection for 2009, current results indicate that the increase in spawning biomass is lower than expected (but still within statistical confidence bands (Fig. 1.25).

The estimated selectivity pattern changes over time and reflects to some degree the extent that the fishery is focused on particularly prominent year-classes (Fig. 1.26). The model fits the fishery age-composition data quite well under this form of selectivity (Fig. 1.27). The fit to the early Japanese fishery CPUE data

(Low and Ikeda, 1980) is consistent with the population trends for this period and is essentially unchanged since introduced to the assessment several years ago.

Bottom-trawl survey selectivity and fits to the numbers of age 2 and older pollock indicate that the model predicts fewer pollock than observed in the survey during 2007-2009 (Fig. 1.28). The pattern of bottom trawl survey age composition data in recent years shows the reduction in relative importance of the 2000 year class and that the 2002 and 2001 year-classes are more apparent (relatively) than they have been in previous years (Fig. 1.29).

The EIT survey selectivity estimates vary inter-annually but have generally stabilized since the early 1990s as the echo-integration and trawl methods have become more standardized (Fig. 1.30; top panel). These changes could also be due to changes in age-specific pollock distributions (and hence availability) over time. The fit to the numbers of age 2 and older pollock in the EIT survey generally falls within the confidence bounds of the survey sampling distributions (here assumed to have a CV of 20%) with a fairly reasonable pattern of residuals (Fig. 1.30; bottom panel). The model prediction for the 2009 numbers is higher than the observation (contrary to that of the bottom trawl survey). The EIT age compositions consistently track large year classes through the population and the model fits these patterns reasonably well (Fig. 1.31). The EIT age-1 index indicates a larger than expected 2008 year class but these data are generally imprecise as a pre-recruit index (Fig. 1.31; bottom panel).

The estimate of 2010 spawning stock size and corresponding estimates of B_{msy} have coefficients of variation that exceed 24% (Table 1.18). For 2010, the Tier 1 levels of yield are 813 thousand t from a fishable biomass estimated at around 3,152,000 t (Table 1.19). Estimated numbers-at-age are presented in Table 1.20 and estimated catch-at-age presented in Table 1.21. Estimated summary biomass (age 3+), female spawning biomass, and age-1 recruitment is given in Table 1.22.

The results indicate that spawning biomass will be below $B_{40\%}$ in 2010 and about 71% of the B_{msy} level. The probability that the current stock size is below 20% of B_0 (based on estimation uncertainty alone) is about 18% for 2009 but decreases for 2010 (Fig. 1.32). An alternative approach to evaluating the likelihood that future assessments will result in point estimates of being below $B_{20\%}$ is presented below under the heading "Projections with future "assessment" feedback".

Another metric on the impact of fishing suggests that the 2009 spawning stock size is about 36% of the predicted value had no fishing occurred since 1978 (Table 1.18). This compares with the 21% of $B_{100\%}$ (based on the SPR expansion from mean recruitment since 1978) and 27% of B_0 (based on the estimated stock-recruitment curve).

Abundance and exploitation trends

The current begin-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 12 million t (Table 1.23). 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. The stock is characterized by peaks in the mid 1980s and mid 1990s with a substantial decline to about 4 million t by 1991 and another low point occurring at present with the stock at the lowest levels since the late 1970s[*]. As predicted in last year's assessment, the stock has continued to decline substantially since 2003 due to apparently poor recruitment between 2000 and 2006.

The level of fishing relative to biomass estimates show that the spawning exploitation rate (SER, defined as the percent removal of spawning-aged females in any given year) has been mostly below 20% since

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

1980 until 2006-2008 when the rate has averaged more than 25% (Fig. 1.33). The estimate for 2009 is below 20% due to the reductions in TAC arising from the ABC control rules.

Compared with past year's assessments, the estimates of age 3+ pollock biomass are similar during the historical period but lower for 2009 and in projections beyond (Fig. 1.34, Table 1.23). This is due primarily to the revised estimate of the 2006 year class (last year the estimate was 38.6 billion, this year it is 24.5 billion age 1 pollock).

One way to evaluate past management and assessment performance is to plot estimated fishing mortality relative to some reference values. For EBS pollock, we computed the reference fishing mortality as from Tier 1 (unadjusted) and calculated the historical values for F_{msy} (since selectivity has changed over time). Since 1977 the current estimates of fishing mortality suggest that during the early period, harvest rates were above F_{msy} until about 1980. Since that time, the levels of fishing mortality has averaged about 35% of the F_{msy} level (Fig. 1.35).

Recruitment

The 2008 year-class strength shows mixed signals from the appearance of one-year olds in the surveys in 2009. In the EIT survey, the abundance of one-year olds was above average and the third highest since 1982 (behind 2007 and 1997) whereas in the bottom-trawl survey, one-year olds were below average (Fig. 1.36).

Data from the 2009 bottom trawl survey supports last year's results that the 2006 year class is well above average. However, the EIT survey observed fewer age three pollock than expected and this reduces the likelihood that the 2006 year class is as high as projected from last year's assessment (Fig. 1.37, top panel). Three-year olds are relatively uncommon in the bottom-trawl survey so the fact that the year-class signal in that survey is higher than expected may be due to measurement error. The stock-recruitment curve fit within the integrated model shows a fair amount of variability both in the estimated recruitments and in the uncertainty of the curve and also illustrates that the estimate of the 2009 spawning biomass is below the B_{msy} level (Fig. 1.37; bottom panel).

Previous studies linked strong Bering Sea pollock recruitment to years with warm sea temperatures and northward transport of pollock eggs and larvae (Wespestad et al. 2000; Mueter et al. 2006). As part of the "Bering-Aleutian Salmon international survey" (BASIS) project research has been also directed on the relative density and quality of young-of-year pollock. For example, Moss et al. (2009) found age-0 pollock were very abundant and widely distributed to the north and east on the Bering Sea shelf during 2004 and 2005 (warm sea temperature; high water column stratification) indicating high northern transport of pollock eggs and larvae during those years. However, recruitment success of these cohorts was low. This counter-intuitive result to the previous studies does not necessarily negate the current paradigm linking ocean conditions to successful pollock recruitment. Instead, BASIS results offer another possible explanation for the high variability in recruitment of Bering Sea pollock. When sea temperatures on the eastern Bering Sea shelf are very warm and the water column is highly stratified during summer, age-0 pollock appear to allocate more energy to growth than to lipid storage, leading to low energy density prior to winter, thus higher over-winter mortality (Swartzman et al. 2005, Winter et al. 2005).

Results from the BASIS research project also suggest that age-0 pollock abundance was low during 2006 and 2007 (cool sea temperatures; lower water column stratification; Moss et al., 2009). However, age-1 pollock (from the 2008 cohort) were evident in the BASIS survey this year which may indicate changes in spatial and vertical distribution due to environmental conditions and/or that the 2008 year class is abundant (which would be consistent with the EIT survey).

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, 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. Consistent with other groundfish stocks, the following values are based on recruitment estimates from post-1976 spawning events:

B_{msy} = 1,863 thousand t female spawning biomass

$B_{100\%}$ = 5,876 thousand t female spawning biomass*

$B_{40\%}$ = 2,351 thousand t female spawning biomass

$B_{35\%}$ = 2,057 thousand t female spawning biomass

Specification of OFL and Maximum Permissible ABC

The 2009 spawning biomass is estimated to be 1,316 kt (at the time of spawning, assuming the stock is fished at Tier 1b level). This is below the B_{msy} value of 1,863 kt. Under Amendment 56, this stock has qualified under Tier 1 and the harmonic mean value is considered a risk-averse policy since reliable estimates of F_{msy} and its pdf are available (Thompson 1996). The exploitation-rate type value that corresponds to the F_{msy} level was applied to the "fishable" biomass for computing ABC levels. For a future year, the fishable biomass is defined as the sum over ages of predicted begin-year numbers multiplied by age specific fishery selectivity and mean body mass (10-year average).

The 2010 estimate of female spawning biomass (at time of spawning assuming a 2010 Tier 1b catch level of 813 kt) is 1,316 kt. This is below the $B_{40\%}$ and B_{msy} values (2,351 and 1,863 kt, respectively). The OFL's and maximum permissible ABC values by Tier are thus:

Tier	Year	Max ABC	OFL
1b	2010	813,000 t	918,000 t
1b	2011	1,109,000 t	1,220,000 t
3b	2010	433,000 t	677,000 t
3b	2011	746,000 t	794 ,000 t

ABC Recommendation

ABC levels are affected by estimates of F_{msy} (which depends principally on the stock-recruitment relationship and demographic such as selectivity-at-age, maturity, growth), the B_{msy} level, and current stock size (both spawning and "fishable"). Last year the sensitivities of ABC calculations were highlighted under the Tier 1 control rules, especially when below the B_{msy} level. Perturbation analysis in which the point estimate of 2010 stock size (and adjustment factor if in Tier 1b) is bracketed by 5% probability on either side (put in the currency of estimation uncertainty for perspective) results in an ABC calculation from the control rule that changed by 7% (when below the target B_{msy} level). Without the

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* Note that another theoretical "unfished spawning biomass level" (based on stock-recruitment relationship, $\tilde{B}_0$) is somewhat lower (4,934 kt).

precautionary adjustment, the perturbation span affected catch levels by only 4%. Small changes (relative to the stock uncertainty) have big effects on ABC calculations.

The stock has declined from above average conditions by about 20% per year since 2003. Data and model results indicate that the biomass has stabilized in the past year and has begun to increase. Similar projections for an increase in 2009 were made last year (in Ianelli et al. 2008) that failed to materialize. During the declines from above average conditions, the spawning exploitation rate has increased by more than 15% from 2003-2007. However, based on last year's recommended ABC (and subsequent TAC) the exploitation rate on the spawning component has continued to decline. Under likely catch projections, the spawning stock biomass is expected be about 71% of B_{msy} (1,863 kt) by 2010 with future status depending on specified catch levels and recruitment (Fig. 1.38).

Given the negative survey indications, the added control rule adjustment in harvest rates seem justified to ensure that fishing mortality stays below the F_{msy} level. At the Tier 1b maximum permissible ABC level the harvest rate projection will decline further and is well below the F_{msy} level (Fig. 1.35). Projections also show that the spawning stock exploitation rates will be lower in 2010. For the $F_{40\%}$ (Tier 3) harvest rate, the exploitation rate drops more significantly (Fig, 1.39). Given the scenarios as outlined, the harvest control rule appears to sufficiently reduce the exploitation rate to justify setting the ABC to the value specified under Tier 1b, 813,000 t. Additionally, preliminary data on the 2009 fishery catch-at-age suggests that this ABC level is lower than what might be expected when the new data are formally included. For contrast, if the abundance of the 2006 year class in 2010 was set to the mean number of age 4 pollock (from 1964-2009, about 3,430 billion pollock) rather than the model estimate based on the available data (4,480 billion pollock), this would translate to an approximately 10% decrease in the ABC. Given the balance of other information, and the fact that the ABC has been reduced by 34% of the projected value from the 2008 assessment, further downward adjustments may be unnecessary.

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}. Projections based on Tier 3 are presented along with some considerations for a Tier 1 approach.

For each scenario, the projections begin with the vector of 2009 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2010 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch assumed for 2009. 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 2010 and 2011, 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 value that corresponds to some trial catch levels for 2010 and 2011 (813,000 t and 1,000,000 t). (Rationale: These catches are close to recent and historic mean levels and still would likely satisfy the constraint to be below the maximum permissible under Tier 1 levels).

Scenario 3: In all future years, *F* is set equal to the 2005-2009 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 4: In all future years, *F* is set equal to $F_{60\%}$. (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. This was requested by public comment for the DSEIS developed in 2006)

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 scenarios were designed based on the Mace et al. (1996) review of overfishing definitions and Restrepo et al. 1998 technical guidance. 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 2009 or 2) above ½ of its MSY level in 2010 and above its MSY level in 2022 under this scenario, then the stock is not overfished.)

Scenario 7: In 2010 and 2011, *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 2022 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 2009 (Table 1.24). Under Tier 3 Scenarios 1 and 2, the expected spawning biomass will decrease to below the $B_{35\%}$ then begin increasing after 2009 but not reaching $B_{40\%}$ (in expectation) until after 2012 (Fig. 1.40).

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 2009:

a) If spawning biomass for 2009 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

b) If spawning biomass for 2009 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2009 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.F). If the mean spawning biomass for 2019 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 2012 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2012 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2012 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2022. If the mean spawning biomass for 2022 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 2009, nor is it expected to be approaching an overfished condition based on Scenario 7 (the mean spawning biomass in 2012 is above the $B_{35\%}$ level; Table 1.24). For harvest recommendations, Tier 3 and a proxy for Tier 1 calculations were made that give ABC and OFL values for 2010 and 2011 (assuming catch is 813,000 t in 2010 Table 1.25).

The Tier 1 projections were approximated by substituting the B_{msy} values for $B_{40\%}$ (for the harvest control rule) and setting the F_{ABC} and F_{OFL} values to their spawning biomass-per-recruit (SPR) equivalent fishing mortalities. These SPR rates correspond to $F_{31\%}$ and $F_{27\%}$, respectively.

Projections with future "assessment" feedback

As described above, the conditioned (i.e., fitted) stock assessment model was used in simulating future datasets under 10 different levels of future catch. Each of these datasets were evaluated as if a full future assessment analysis were being conducted in order to provide insight on the likelihood of future point estimates falling below key reference points (e.g., $B_{20\%}$). This process also can also provide the distribution of estimates that might be expected from next year's survey. For example, given catch of 800,000 t the distribution of 2010 biomass "observations" (simulated) from the EIT and BTS survey are shown in Fig. 1.41.

The results from the assessments of simulated data indicate that, given the assumptions that the same modeling approach will be used next year, the point estimates for 2011 spawning biomass levels under fixed levels of catch are highly likely to be above $B_{20\%}$ (Fig. 1.42). Probabilities were based on simulations of 2010 data and running assessments for each of the 5,000 simulated datasets (500 draws from posterior distribution simulations for each of 10 different catch scenarios). The SSC requested that computations be extended to a 3-5 year horizon. Having completed the first step of doing a proper feedback simulation loop, we intend to extend this method to cover a longer period in future assessments.

Other considerations

Ecosystem considerations

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

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

For the case of pollock in the 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. Discard rates of many species have been reduced in this fishery and efforts to minimize bycatch continue.

In comparisons of the Western Bering Sea (WBS) with the Eastern Bering Sea using mass-balance food-web models based on 1980-85 summer diet data, 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 in 1980-85 were pollock and Pacific cod. 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. In a more recent study based on 1990-93 diet data (see Appendix 1 of Ecosystem Considerations chapter for methods), pollock remain in a central role in the ecosystem. The diet of pollock is similar between adults and juveniles with the exception that adults become more piscivorous (with consumption of pollock by adult pollock representing their third largest prey item). 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; Jurado-Molina et al. 2005).

Regarding specific small-scale ecosystems of the EBS, Ciannelli 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 (see Sterling and Ream 2004, Zeppelin and Ream 2006) will require careful monitoring and evaluation.

A brief summary of these two perspectives is given in Table 1.26. 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.

Ecosystem effects on the EBS pollock stock

Euphausiids, principally *Thysanoessa inermis* and *T. raschii*, are among the most important prey items for pollock in the Bering Sea (Livingston, 1991; Lang et al., 2000; Brodeur et al., 2002; Cianelli et al., 2004; Lang et al., 2005). A new analysis of MACE EIT survey backscatter data from 2004-present was used to create an index of euphausiid abundance on the Bering Sea shelf. The analysis relies on a comparison of acoustic backscatter at four frequencies (18, 38, 120, and 200 kHz) and net sampling with a Methot trawl (De Robertis et al., submitted; Ressler, P.H., manuscript in preparation). Typically, 12-24 tows are targeted at euphausiids during an EIT survey.

The 2004-2009 time series of Bering Sea summer euphausiid abundance (Fig. 1.43) shows that euphausiid backscatter has increased more than three-fold. Other data sets from the Bering Sea have also suggested an increase in large copepods since 2004 (Napp and Yamaguchi 2008). Over the same period, midwater pollock backscatter measured by the EIT survey decreased by half, and pollock age 1+ biomass estimated by the stock assessment model shows a similar decline. It is unknown if these opposing trends of euphausiid (prey) and pollock (predator) abundances are related or if they are independent responses to changes in environmental conditions. These euphausiid backscatter data are spatially explicit (Fig. 1.44), so distribution, as well as abundance, can be tracked over time. Further research on physical overlap using this index may help test hypotheses on linkages and hence help better understand temporal and spatial variability in pollock abundance.

The impact of non-cannibalistic predation may have shifted considerably in recent years. In particular, the increasing population of arrowtooth flounder in the Bering Sea is worth examining, especially considering the large predation caused by these flatfish in the Gulf of Alaska. Overall, the total noncannibal groundfish predator biomass has gone down in the Bering Sea according to current stock assessments, with the drop of Pacific cod in the 1980s exceeding the rise of arrowtooth in terms of biomass (e.g., see Fig. 4 in Boldt 2006). This may represent an increase in predation pressure on age-2 pollock, as arrowtooth are one of the few groundfish species with a measurable amount of predation on this age class. However, the dynamics of this predation interaction may be quite different than in the Gulf of Alaska. A comparison of 1990-94 natural mortality by predator for arrowtooth flounder in the Bering Sea and the Gulf of Alaska shows that they are truly a top predator in the Gulf of Alaska. However, in the Bering Sea, pollock, skates, and sharks all prey on arrowtooth flounder, giving the species a relatively high predation mortality.

The predation on small arrowtooth flounder by large pollock gives rise to a specific concern for the Bering pollock stock. Walters and Kitchell (2001) describe a predator/prey system called “cultivation/depensation” whereby a species such as pollock “cultivates” its young by preying on species that would eat its young (for example, arrowtooth flounder). If these interactions are strong, the removal of the large pollock may lead to an accelerated decline, as the control it exerts on predators of its recruits is removed—this has been cited as a cause for a decline of cod in the Baltic Sea in the presence of herring feeding on cod young (Walters and Kitchell 2001). In situations like this, it is possible that predator culling (e.g., removing arrowtooth) may not have a strong effect towards controlling predation compared to applying additional caution to pollock harvest and thus preserving this natural control.

An evaluation of the spatial dynamics of arrowtooth flounder abundance and characteristics as an important predator of pollock has revealed a number of interesting findings. First, there are 4 or 5 distinct spatial clusters (based on categorization due to time-series trends from survey CPUE data from 1982-2007). One cluster was characterized as having a fairly stable time trend, the others are variable or increasing. Generally the sizes of arrowtooth flounder are bigger in the northwest and most stomachs (84%) contained food whereas in the southeast they tend to be smaller and empty stomachs prevailed (>50%). The extent of the cold pool appears to affect arrowtooth flounder distribution with fewer fish observed on the shelf during colder years. Other investigations have shown that as arrowtooth increase in length, they prey on increasingly larger pollock prey and age-1 pollock are preyed on by a wide size range of arrowtooth (approximately 20-70 cm; Fig. 1.45). Extending this relationship further, there is evidence that when high levels of age-1 pollock are available (as indicated by surveys and the assessment), shifts in the relative size of pollock as prey are found in the arrowtooth flounder diets (Fig. 1.46). These shifts are consistent (i.e., prey becomes relatively smaller) when abundances of 1-year old pollock is high.

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 (Table 1.27). 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). Skate bycatch has more than doubled in 2008 based on preliminary data (Table 1.27). 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 1.28). 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 1.29). For example, the level of crab bycatch drops considerably 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 1.30.

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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, 1979-2008 (2008 values estimated). 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	653,569	542,077	1,195,646	98,604	293,400	316,038
1992	830,560	559,771	1,390,331	52,352	10,000	241
1993	1,094,428	232,173	1,326,601	57,132	1,957	886
1994	1,152,573	176,777	1,329,350	58,659		556
1995	1,172,304	91,941	1,264,245	64,925		334
1996	1,086,840	105,938	1,192,778	29,062		499
1997	819,888	304,543	1,124,430	25,940		163
1998	965,767	135,399	1,101,165	23,822		136
1999	783,119	206,697	989,816	1,010		29
2000	839,175	293,532	1,132,707	1,244		29
2001	961,975	425,219	1,387,194	824		258
2002	1,159,730	320,465	1,480,195	1,156		1,042
2003	933,316	557,584	1,490,900	1,653		24
2004	1,089,999	390,544	1,480,543	1,150		0
2005	802,418	680,868	1,483,286	1,621		
2006	826,980	659,455	1,486,435	1,744		
2007	728,094	626,003	1,354,097	2,519		
2008	482,542	508,023	990,566	1,060		
2009			815,000			

1979-1989 data are from Pacfin.

1990-2008 data are from NMFS Alaska Regional Office, and includes discards.

2009 EBS catch is estimated

Table 1.2. Observed total catch (rounded to nearest 1,000 t) by year and season with percentages indicating the proportion of the catch that came from within the Steller sea lion conservation area (SCA), 1998-2009. *2009 data are preliminary.*

	A season	**B-season**	**Total**
1998	385,000 t (82%)	403,000 t (38%)	788,000 t (60%)
1999	339,000 t (54%)	468,000 t (23%)	807,000 t (36%)
2000	375,000 t (36%)	572,000 t (4%)	947,000 t (16%)
2001	490,000 t (27%)	674,000 t (46%)	1,164,000 t (38%)
2002	566,000 t (54%)	690,000 t (49%)	1,256,000 t (51%)
2003	616,000 t (45%)	680,000 t (42%)	1,296,000 t (43%)
2004	531,000 t (45%)	711,000 t (34%)	1,242,000 t (38%)
2005	529,000 t (45%)	673,000 t (17%)	1,203,000 t (29%)
2006	533,000 t (51%)	764,000 t (14%)	1,298,000 t (29%)
2007	480,000 t (57%)	663,000 t (11%)	1,143,000 t (30%)
2008	342,000 t (46%)	490,000 t (12%)	832,000 t (26%)
2009	283,000 t (26%)	389,000 t (13%)	671,000 t (24%)

Table 1.3. Time series of ABC, TAC, and catch levels for EBS pollock, 1977-2008 in metric t. Source: compiled from NMFS Regional office web site and various NPFMC reports, catch for 2008 is an estimated projection.

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	859,416
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	1,195,646
1992	1,490,000	1,300,000	1,390,331
1993	1,340,000	1,300,000	1,326,601
1994	1,330,000	1,330,000	1,329,350
1995	1,250,000	1,250,000	1,264,245
1996	1,190,000	1,190,000	1,192,778
1997	1,130,000	1,130,000	1,124,430
1998	1,110,000	1,110,000	1,101,165
1999	992,000	992,000	989,816
2000	1,139,000	1,139,000	1,132,707
2001	1,842,000	1,400,000	1,387,194
2002	2,110,000	1,485,000	1,480,195
2003	2,330,000	1,491,760	1,490,900
2004	2,560,000	1,492,000	1,480,543
2005	1,960,000	1,478,500	1,483,286
2006	1,930,000	1,485,000	1,486,435
2007	1,394,000	1,394,000	1,354,097
2008	1,000,000	1,000,000	990,566
2009	815,000	815,000	815,000
1977-2009 average	1,402,364	1,201,584	1,179,535

Table 1.4. Estimates of discarded pollock (t), percent of total (in parentheses) and total catch for the Aleutians, Bogoslof, Northwest and Southeastern Bering Sea, 1991-2008. 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. 2009 data are preliminary.

	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%)	NA	2,723 (1%)	20,302 (2%)	23,783 (2%)	1,156	NA	390,414	1,089,880	1,482,373
2005	324 (20%)		2,586 (0%)	14,838 (2%)	17,747 (1%)	1,621		680,868	802,418	1,484,907
2006	310 (18%)		3,672 (1%)	11,659 (1%)	15,641 (1%)	1,744		659,455	826,980	1,488,180
2007	425 (17%)		3,560 (1%)	12,313 (2%)	16,298 (1%)	2,519		626,003	728,094	1,356,616
2008	81 (6%)		1,644 (0%)	5,952 (1%)	7,678 (1%)	1,278		508,023	482,542	991,843
2009	303 (20%)		1,810 (0%)	3,744 (1%)	5,857 (1%)	1,521		451,688	356,258	809,467

Table 1.5. Eastern Bering Sea pollock catch at age estimates based on observer data, 1979-2009. Units are in millions of fish. *NOTE: 2009 data were derived from using A-season fishery lengths and ages and B-season fishery lengths with ages from the summer surveys and are preliminary.*

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14+**	**Total**
1979	101.4	543.0	719.8	420.1	392.5	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	1.1	2,567.3
1980	9.8	462.2	822.9	443.3	252.1	210.9	83.7	37.6	21.7	23.9	25.4	15.9	7.7	3.7	2,420.8
1981	0.6	72.2	1,012.7	637.9	227.0	102.9	51.7	29.6	16.1	9.3	7.5	4.6	1.5	1.0	2,174.6
1982	4.7	25.3	161.4	1,172.2	422.3	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	1.0	2,003.8
1983	5.1	118.6	157.8	312.9	816.8	218.2	41.4	24.7	19.8	11.1	7.6	4.9	3.5	2.1	1,744.5
1984	2.1	45.8	88.6	430.4	491.4	653.6	133.7	35.5	25.1	15.6	7.1	2.5	2.9	3.7	1,938.0
1985	2.6	55.2	381.2	121.7	365.7	321.5	443.2	112.5	36.6	25.8	24.8	10.7	9.4	9.1	1,920.0
1986	3.1	86.0	92.3	748.6	214.1	378.1	221.9	214.3	59.7	15.2	3.3	2.6	0.3	1.2	2,040.5
1987	0.0	19.8	111.5	77.6	413.4	138.8	122.4	90.6	247.2	54.1	38.7	21.4	28.9	14.1	1,378.6
1988	0.0	10.7	454.0	421.6	252.1	544.3	224.8	104.9	39.2	96.8	18.2	10.2	3.8	11.7	2,192.2
1989	0.0	4.8	55.1	149.0	451.1	166.7	572.2	96.3	103.8	32.4	129.0	10.9	4.0	8.5	1,783.8
1990	1.3	33.0	57.0	219.5	200.7	477.7	129.2	368.4	65.7	101.9	9.0	60.1	8.5	13.9	1,745.9
1991	0.7	111.8	39.9	86.5	139.2	152.8	386.2	51.9	218.4	21.8	115.0	13.8	72.6	17.1	1,427.6
1992	0.0	93.5	674.9	132.8	79.5	114.2	134.3	252.2	100.1	155.1	54.3	43.1	12.5	41.8	1,888.3
1993	0.2	8.1	262.7	1,146.2	102.1	65.8	63.7	53.3	91.2	20.5	32.3	11.7	12.5	6.7	1,877.0
1994	1.6	36.0	56.8	359.6	1,066.7	175.8	54.5	20.2	13.4	20.7	8.6	9.4	7.0	3.7	1,834.0
1995	0.0	0.5	81.3	151.7	397.5	761.2	130.6	32.2	11.1	8.5	18.2	5.5	6.3	1.5	1,606.1
1996	0.0	23.2	56.2	81.8	166.4	368.5	475.1	185.6	31.4	13.4	8.8	8.6	4.8	5.3	1,429.3
1997	2.4	83.6	37.8	111.7	478.6	288.3	251.3	196.7	61.6	13.6	6.4	5.0	3.5	4.8	1,545.1
1998	0.6	51.1	89.8	72.0	156.9	686.9	199.0	128.3	108.7	29.5	6.3	5.8	2.9	3.2	1,541.2
1999	0.4	11.6	295.0	227.7	105.3	155.7	473.7	132.7	57.5	32.9	3.5	2.2	0.7	0.4	1,499.4
2000	0.0	17.4	80.2	423.2	343.0	105.4	169.1	359.5	86.0	29.6	24.4	5.7	1.6	0.8	1,645.7
2001	0.0	3.7	56.8	162.0	574.8	405.8	136.1	129.2	158.3	57.5	35.1	16.0	5.9	2.9	1,744.1
2002	0.9	56.7	111.1	214.8	284.1	602.2	267.2	99.3	87.4	95.6	34.9	14.5	12.6	2.8	1,883.9
2003	0.0	17.3	402.2	320.8	366.8	305.2	332.1	157.3	53.0	40.2	36.5	23.7	7.0	3.0	2,065.1
2004	0.0	1.1	90.0	829.6	479.7	238.2	168.7	156.9	64.0	16.9	18.9	26.1	10.6	6.6	2,107.4
2005	0.0	3.1	53.7	391.2	861.8	489.1	156.4	67.5	67.1	33.7	11.2	10.2	3.4	2.0	2,150.5
2006	0.0	12.2	84.2	290.1	622.8	592.2	279.9	108.9	49.6	38.4	16.4	9.6	9.5	5.1	2,118.9
2007	1.8	19.5	57.2	124.2	374.0	514.7	306.3	139.0	50.2	28.0	23.3	9.4	6.5	3.4	1,657.7
2008	0.0	25.9	57.1	78.9	147.3	307.7	242.0	150.3	83.9	22.4	17.8	13.7	8.6	2.7	1,158.3
2009	*0.8*	*3.4*	*151.8*	*188.8*	*73.4*	*102.0*	*126.9*	*106.9*	*85.7*	*40.7*	*26.4*	*10.5*	*9.0*	*19.7*	*946.1*
Average	4.6	68.4	223.4	345.3	374.9	328.7	211.4	119.9	69.5	36.7	25.5	13.0	8.8	6.2	1,836.3
Median	0.5	25.6	89.9	258.9	366.2	296.8	168.9	106.9	58.6	26.7	18.0	9.9	6.1	3.6	1,855.5

Table 1.6. Numbers of pollock fishery samples measured for lengths and for length-weight by sex and strata, 1977-2007, as sampled by the NMFS observer program.

Length	A Season		B Season SE		B Season NW		
Frequency	Males	Females	Males	Females	Males	Females	Total
1977	26,411	25,923	4,301	4,511	29,075	31,219	121,440
1978	25,110	31,653	9,829	9,524	46,349	46,072	168,537
1979	59,782	62,512	3,461	3,113	62,298	61,402	252,568
1980	42,726	42,577	3,380	3,464	47,030	49,037	188,214
1981	64,718	57,936	2,401	2,147	53,161	53,570	233,933
1982	74,172	70,073	16,265	14,885	181,606	163,272	520,273
1983	94,118	90,778	16,604	16,826	193,031	174,589	585,946
1984	158,329	161,876	106,654	105,234	243,877	217,362	993,332
1985	119,384	109,230	96,684	97,841	284,850	256,091	964,080
1986	186,505	189,497	135,444	123,413	164,546	131,322	930,727
1987	373,163	399,072	14,170	21,162	24,038	22,117	853,722
1991	160,491	148,236	166,117	150,261	141,085	139,852	906,042
1992	158,405	153,866	163,045	164,227	101,036	102,667	843,244
1993	143,296	133,711	148,299	140,402	27,262	28,522	621,490
1994	139,332	147,204	159,341	153,526	28,015	27,953	655,370
1995	131,287	128,389	179,312	154,520	16,170	16,356	626,032
1996	149,111	140,981	200,482	156,804	18,165	18,348	683,890
1997	124,953	104,115	116,448	107,630	60,192	53,191	566,527
1998	136,605	110,620	208,659	178,012	32,819	40,307	707,019
1999	36,258	32,630	38,840	35,695	16,282	18,339	178,044
2000	64,575	58,162	63,832	41,120	40,868	39,134	307,689
2001	79,333	75,633	54,119	51,268	44,295	45,836	350,483
2002	71,776	69,743	65,432	64,373	37,701	39,322	348,347
2003	74,995	77,612	49,469	53,053	51,799	53,463	360,390
2004	75,426	76,018	63,204	62,005	47,289	44,246	368,188
2005	76,627	69,543	43,205	33,886	68,878	63,088	355,225
2006	72,353	63,108	28,799	22,363	75,180	65,209	327,010
2007	62,827	60,522	32,945	25,518	75,128	69,116	326,054
2008	46,125	51,027	20,493	23,503	61,149	64,598	266,894
			Length – weight samples				
1977	1,222	1,338	137	166	1,461	1,664	5,988
1978	1,991	2,686	409	516	2,200	2,623	10,425
1979	2,709	3,151	152	209	1,469	1,566	9,256
1980	1,849	2,156	99	144	612	681	5,541
1981	1,821	2,045	51	52	1,623	1,810	7,402
1982	2,030	2,208	181	176	2,852	3,043	10,490
1983	1,199	1,200	144	122	3,268	3,447	9,380
1984	980	1,046	117	136	1,273	1,378	4,930
1985	520	499	46	55	426	488	2,034
1986	689	794	518	501	286	286	3,074
1987	1,351	1,466	25	33	72	63	3,010
1991	2,712	2,781	2,339	2,496	1,065	1,169	12,562
1992	1,517	1,582	1,911	1,970	588	566	8,134
1993	1,201	1,270	1,448	1,406	435	450	6,210
1994	1,552	1,630	1,569	1,577	162	171	6,661
1995	1,215	1,259	1,320	1,343	223	232	5,592
1996	2,094	2,135	1,409	1,384	1	1	7,024
1997	628	627	616	665	511	523	3,570
1998	1,852	1,946	959	923	327	350	6,357
1999	5,318	4,798	7,797	7,054	3,532	3,768	32,267
2000	12,421	11,318	12,374	7,809	7,977	7,738	59,637
2001	14,882	14,369	10,778	10,378	8,777	9,079	68,263
2002	14,004	13,541	12,883	12,942	7,202	7,648	68,220
2003	14,780	15,495	9,401	10,092	9,994	10,261	70,023
2004	7,690	7,890	6,819	6,847	4,603	4,321	38,170
2005	7,390	7,033	5,109	4,115	6,927	6,424	36,998
2006	7,324	6,989	5,085	4,068	6,842	6,356	36,664
2007	6,681	6,635	4,278	3,203	7,745	7,094	35,636
2008	4,256	4,787	2,056	2,563	5,950	6,316	25,928

Table 1.7. Numbers of pollock fishery samples used for age determination estimates by sex and strata, 1977-2007, as sampled by the NMFS observer program.

				Aged			
		A Season		B Season SE		B Season NW	
	Males	Females	Males	Females	Males	Females	Total
1977	1,229	1,344	137	166	1,415	1,613	5,904
1978	1,992	2,686	407	514	2,188	2,611	10,398
1979	2,647	3,088	152	209	1,464	1,561	9,121
1980	1,854	2,158	93	138	606	675	5,524
1981	1,819	2,042	51	52	1,620	1,807	7,391
1982	2,030	2,210	181	176	2,865	3,062	10,524
1983	1,200	1,200	144	122	3,249	3,420	9,335
1984	980	1,046	117	136	1,272	1,379	4,930
1985	520	499	46	55	426	488	2,034
1986	689	794	518	501	286	286	3,074
1987	1,351	1,466	25	33	72	63	3,010
1991	420	423	272	265	320	341	2,041
1992	392	392	371	386	178	177	1,896
1993	444	473	503	493	124	122	2,159
1994	201	202	570	573	131	141	1,818
1995	298	316	436	417	123	131	1,721
1996	468	449	442	433	1	1	1,794
1997	433	436	284	311	326	326	2,116
1998	592	659	307	307	216	232	2,313
1999	540	500	730	727	306	298	3,100
2000	666	626	843	584	253	293	3,265
2001	598	560	724	688	178	205	2,951
2002	651	670	834	886	201	247	3,489
2003	583	644	652	680	260	274	3,092
2004	560	547	599	697	244	221	2,867
2005	611	597	613	489	419	421	3,149
2006	608	599	590	457	397	398	3,048
2007	639	627	586	482	583	570	3,485
2008	492	491	313	356	541	647	2,838

Table 1.8. NMFS total pollock research catch by year in t, 1964-2009.

Year	Aleutian Is.	Bering Sea	Year	Aleutian Is.	Bering Sea
1964	0	0	1987	0	174
1965	0	18	1988	0	467
1966	0	17	1989	0	393
1967	0	21	1990	0	369
1968	0	7	1991	51	465
1969	0	14	1992	0	156
1970	0	9	1993	0	221
1971	0	16	1994	48	267
1972	0	11	1995	0	249
1973	0	69	1996	0	206
1974	0	83	1997	36	262
1975	0	197	1998	0	121
1976	0	122	1999	0	299
1977	0	35	2000	40	313
1978	0	94	2001	0	241
1979	0	458	2002	79	440
1980	193	139	2003	0	285
1981	0	466	2004	51	363
1982	40	682	2005	0	NA
1983	454	508	2006	21	251
1984	0	208	2007	0	333
1985	0	435	2008		
1986	292	163	2009		

Table 1.9. Biomass (age 1+) of Eastern Bering Sea pollock as estimated by surveys 1979-2009 (millions of tons). Note that the bottom-trawl survey data only represent biomass from the standard survey strata (1-6) areas in 1982-1984, and 1986. For all other years the estimates include strata 8-9. Also, the 1979 - 1981 bottom trawl survey data were omitted from the model since the survey gear differed.

Year	Bottom trawl Survey (t)	EIT Survey (t)	EIT Percent age 3+	Total* (t)	Near bottom biomass
1979	3.2	7.46	22%	10.660	30%
1980	1				
1981	2.3				
1982	2.856	4.9	95%	7.756	37%
1983	6.258				
1984	4.894				
1985	6.056	4.8	97%	10.856	56%
1986	4.897				
1987	5.525				
1988	7.289	4.68	97%	11.969	61%
1989	6.519				
1990	7.322				
1991	5.168	1.45	46%	6.618	78%
1992	4.583				
1993	5.636				
1994	5.027	2.89	85%	7.917	63%
1995	5.482				
1996	3.371	2.31	97%	5.681	59%
1997	3.874	2.59	70%	6.464	60%
1998	2.852				
1999	3.801	3.293	95%	7.094	54%
2000	5.265	3.05	95%	8.315	63%
2001	4.200				
2002	5.038	3.62	82%	8.658	58%
2003	8.458				
2004	3.886	3.31	99%	7.196	54%
2005	5.294				
2006	3.045	1.56		4.605	66%
2007	4.338	1.77		6.108	71%
2008	3.031	0.997		4.028	76%
2009	2.280	0.924		3.204	

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[*] 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).

Table 1.10. Survey biomass estimates (age 1+, t) of Eastern Bering Sea pollock based on area-swept expansion methods from NMFS bottom trawl surveys 1982-2009.

Year	Survey biomass estimates in strata 1-6	Survey biomass estimates in strata 8 and 9 (NW)	All area Total	NW %Total
1982	2,855,539			
1983	6,257,632			
1984	4,893,536			
1985	4,630,111	1,298,185	5,928,295	22%
1986	4,896,780			
1987	5,108,035	406,587	5,514,622	7%
1988	7,107,258	181,909	7,289,168	2%
1989	5,927,187	673,313	6,600,500	10%
1990	7,126,083	195,894	7,321,977	3%
1991	5,105,224	62,505	5,167,729	1%
1992	4,367,870	214,676	4,582,546	5%
1993	5,520,892	114,757	5,635,649	2%
1994	4,977,019	49,706	5,026,726	1%
1995	5,413,270	68,983	5,482,253	1%
1996	3,204,106	167,090	3,371,196	5%
1997	3,031,557	842,276	3,873,833	22%
1998	2,212,689	639,715	2,852,404	22%
1999	3,597,403	203,314	3,800,717	5%
2000	5,123,602	129,932	5,253,534	2%
2001	4,145,746	54,162	4,199,909	1%
2002	4,832,506	205,231	5,037,737	4%
2003	8,143,534	314,637	8,458,171	4%
2004	3,756,224	130,227	3,886,451	3%
2005	5,168,295	160,109	5,328,404	3%
2006	2,845,009	199,932	3,044,940	7%
2007	4,156,687	180,856	4,337,542	4%
2008	2,834,094	197,106	3,031,200	7%
2009	2,231,225	51,193	2,282,418	2%
Avg.	4,623,897	271,870	4,808,717	6%

Table 1.11. Sampling effort for pollock in the EBS from the NMFS bottom trawl survey 1982-2008. Years where only strata 1-6 were surveyed are shown in italics.

Year	**Number of Hauls**	**Lengths**	**Aged**	**Year**	**Number of Hauls**	**Lengths**	**Aged**
1982	*329*	*40,001*	*1,611*	1996	375	40,789	1,387
1983	*354*	*78,033*	*1,931*	1997	376	35,536	1,193
1984	*355*	*40,530*	*1,806*	1998	375	37,673	1,261
1985	434	48,642	1,913	1999	373	32,532	1,385
1986	*354*	*41,101*	*1,344*	2000	372	41,762	1,545
1987	356	40,144	1,607	2001	375	47,335	1,641
1988	373	40,408	1,173	2002	375	43,361	1,695
1989	373	38,926	1,227	2003	376	46,480	1,638
1990	371	34,814	1,257	2004	375	44,102	1,660
1991	371	43,406	1,083	2005	373	35,976	1,676
1992	356	34,024	1,263	2006	376	39,211	1,573
1993	375	43,278	1,385	2007	376	29,679	1,484
1994	375	38,901	1,141	2008	375	24,635	1,251
1995	376	25,673	1,156	2009	375		

Table 1.12. Bottom-trawl survey estimated numbers (millions) at age used for the stock assessment model, 1982-2009 based on strata 1-8. Shaded cells represent years where only strata 1-6 were surveyed. Standard errors and CVs are based on design-based sampling errors.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	StdErr	CV
1982	821	2,029	2,407	3,276	1,075	150	103	50	33	18	9	7	2	1	0	9,980	1,269	13%
1983	483	670	1,638	3,060	6,663	1,979	369	199	78	72	56	19	9	8	3	15,306	1,198	8%
1984	280	261	348	1,196	1,400	3,551	694	157	68	25	16	6	4	5	2	8,012	795	10%
1985	3,053	581	2,591	1,111	3,839	2,169	1,580	319	81	64	18	6	7	1	0	15,420	1,967	13%
1986	1,931	278	312	1,549	859	1,597	1,317	1,133	389	64	27	12	0	3	0	9,473	838	9%
1987	198	443	595	392	3,474	759	878	337	1,132	173	64	23	4	1	1	8,475	1,129	13%
1988	467	426	933	2,373	973	3,449	1,111	869	496	1,127	115	64	12	21	8	12,443	1,477	12%
1989	529	199	307	1,053	2,513	638	2,526	384	509	195	510	96	76	42	49	9,626	1,083	11%
1990	1,014	215	63	564	1,009	3,720	825	2,127	234	392	69	538	41	48	38	10,897	1,375	13%
1991	2,298	758	97	56	466	435	1,424	538	1,243	305	424	88	236	34	25	8,426	835	10%
1992	1,156	311	1,588	338	341	539	445	586	279	629	234	281	124	87	75	7,012	812	12%
1993	1,524	272	919	3,320	597	457	273	425	571	356	324	233	153	101	121	9,647	927	10%
1994	887	446	425	1,273	3,180	620	153	160	152	281	165	244	85	74	127	8,272	973	12%
1995	1,029	61	261	1,245	1,752	2,907	1,045	232	181	156	214	101	155	57	79	9,476	1,803	19%
1996	1,293	288	98	220	755	1,037	1,039	324	86	79	66	125	34	72	77	5,594	498	9%
1997	2,241	247	67	73	1,105	758	616	771	127	43	53	66	75	27	98	6,366	1,111	17%
1998	541	535	196	124	266	1,449	440	318	252	63	25	10	22	22	51	4,314	634	15%
1999	767	645	578	684	398	643	1,859	506	281	239	98	35	16	21	68	6,838	834	12%
2000	856	266	257	1,152	1,154	708	541	1,968	717	390	152	119	23	12	70	8,386	1,052	13%
2001	1,399	773	403	410	1,001	1,145	443	241	767	565	203	168	59	25	63	7,664	695	9%
2002	588	300	513	748	890	1,162	648	336	419	846	409	186	110	32	33	7,221	763	11%
2003	275	104	388	1,375	1,413	1,296	1,553	861	360	531	1,127	465	173	63	43	10,028	1,887	19%
2004	277	181	103	891	1,053	776	454	497	235	149	146	274	117	26	21	5,202	501	10%
2005	291	86	136	804	2,163	1,598	849	375	288	230	58	116	205	73	73	7,347	754	10%
2006	757	30	25	201	701	953	646	305	178	155	77	44	67	89	88	4,314	427	10%
2007	1,665	29	70	308	993	1,193	898	639	276	117	113	102	44	59	105	6,611	643	10%
2008	440	73	53	115	421	911	677	478	319	119	104	80	39	22	116	3,966	432	11%
2009	701	170	333	345	194	310	443	354	259	127	85	29	29	15	61	3,454	415	12%
Avg	991	381	561	1,009	1,452	1,318	852	553	358	268	177	126	69	37	53	8,206	969	12%

Table 1.13. Number of (age 1+) 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	3,164	2,741
	Midwater, east of St Paul	13	1,725	840	783
	Midwater, west of St Paul	31	6,689	2,324	1,958
	Bottom	4	273	0	0
1985	**Total** (Legs1 &2)	73	19,872	2,739	2,739
1988	**Total**	25	6,619	1,471	1,471
1991	**Total**	62	16,343	2,062	1,663
1994	**Total (US zone)**	76	21,506	4,966	1,770
	East of 170 W	25		1,550	612
	West of 170 W	51		3,416	1,158
	Navarin (Russia)	19		1,017	
1996	**Total**	57	16,824	1,949	1,926
	East of 170 W	15	3,551	669	815
	West of 170 W	42	13,273	1,280	1,111
1997	**Total**	86	29,536	3,635	2,285
	East of 170 W	25	6,493	966	936
	West of 170 W	61	23,043	2,669	1,349
1999	**Total**	118	42,362	4,946	2,446
	East of 170 W	41	13,841	1,945	946
	West of 170 W	77	28,521	3,001	1,500
2000	**Total**	124	43,729	3,459	2,253
	East of 170 W	29	7,721	850	850
	West of 170 W	95	36,008	2,609	1,403
2002	**Total**	126	40,234	3,307	2,200
	East of 170 W	47	14,601	1,424	1,000
	West of 170 W	79	25,633	1,883	1,200
2004	**Total (US zone)**	90	27,158	3,169	2,351
	East of 170 W	33	8,896	1,167	798
	West of 170 W	57	18,262	2,002	1,192
	Navarin (Russia)	15	5,893	461	461
2006	**Total**	83	24,265	2,693	2,692
	East of 170 W	27	4,939	822	822
	West of 170 W	56	19,326	1,871	1,870
2007	**Total (US zone)**	69	20,355	2,832	2,560
	East of 170 W	23	5,492	871	823
	West of 170 W	46	14,863	1,961	1,737
	Navarin (Russia)	4	1,407	319	315
2008	**Total (US zone)**	62	17,748	2,039	1,719
	East of 170 W	9	2,394	341	338
	West of 170 W	53	15,354	1,698	1,381
	Navarin (Russia)	6	1,754	177	176
2009	**Total (US zone)**	46	10,833	1,518	NA
	East of 170 W	13	1,576	308	NA
	West of 170 W	33	9,257	1,210	NA
	Navarin (Russia)	3	282	54	NA

Table 1.14. EIT survey estimates of EBS pollock abundance-at-age (millions), 1979-2008. *NOTE: 2009 age specific values are preliminary since they are mainly derived from the bottom-trawl age-length key.* Age 2+ totals and age-1s are modeled as separate indices.

	Age											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**Age 2+**	**Total**
1979	69,110	41,132	3,884	413	534	128	30	4	28	161	46,314	115,424
1982	108	3,401	4,108	7,637	1,790	283	141	178	90	177	17,805	17,913
1985	2,076	929	8,149	898	2,186	1,510	1,127	130	21	15	14,965	17,041
1988	11	1,112	3,586	3,864	739	1,882	403	151	130	414	12,280	12,291
1991	639	5,942	967	215	224	133	120	39	37	53	7,730	8,369
1994	453	3,906	1,127	1,670	1,908	293	69	67	30	59	9,130	9,582
1996	972	446	520	2,686	821	509	434	85	17	34	5,553	6,525
1997	12,384	2,743	385	491	1,918	384	205	143	33	18	6,319	18,703
1999	112	1,588	3,597	1,684	583	274	1,169	400	105	90	9,489	9,601
2000	258	1,272	1,185	2,480	900	244	234	725	190	141	7,372	7,630
2002	561	4,188	3,841	1,295	685	593	288	100	132	439	11,560	12,122
2004	16	275	1,189	2,929	1,444	417	202	193	68	101	6,819	6,834
2006	456	209	282	610	695	552	320	110	53	110	2,940	3,396
2007	5,589	1,026	320	430	669	589	306	166	60	52	3,618	9,207
2008	36	2,905	1,032	144	107	170	132	71	58	48	4,668	4,704
2009	*5,058*	*991*	*1,575*	*191*	*39*	*47*	*58*	*45*	*32*	*38*	*3,017*	*8,075*
Avg. 1982-2009	1,915	2,062	2,124	1,815	981	525	347	174	70	119	8,218	10,133
Median	509	1,430	1,187	1,097	717	339	220	120	56	75	7,551	9,395

Table 1.15. Mid-water pollock abundance (near surface down to 3 m from the bottom) by area as estimated from summer echo integration-trawl surveys on the U.S. EEZ portion of the of the Bering Sea shelf, 1994-2009 (as described in Honkalehto et al. 2008). Estimation errors (in millions of t) are based on a 1-dimensional geostatistical method (Petitgas 1993, Walline 2007, Williamson and Traynor 1996).

Date		**Area**	**Biomass in millions of t** (percent of total)						**Total Biomass**	**Estimation Error**
		(nmi)^2	**SCA**		**E170-SCA**		**W170**		**(millions t)**	**(for total biomass)**
1994	9 Jul-19 Aug	78,251	0.312	(11%)	0.399	(14%)	2.176	(75%)	2.886	0.136
1996	20 Jul-30 Aug	93,810	0.215	(9%)	0.269	(12%)	1.826	(79%)	2.311	0.090
1997	17 Jul-4 Sept	102,770	0.246	(10%)	0.527	(20%)	1.818	(70%)	2.591	0.096
1999	7 Jun-5 Aug	103,670	0.299	(9%)	0.579	(18%)	2.408	(73%)	3.290	0.181
2000	7 Jun-2 Aug	106,140	0.393	(13%)	0.498	(16%)	2.158	(71%)	3.049	0.098
2002	4 Jun -30 Jul	99,526	0.647	(18%)	0.797	(22%)	2.178	(60%)	3.622	0.112
2004	4 Jun -29 Jul	99,659	0.498	(15%)	0.516	(16%)	2.293	(69%)	3.307	0.122
2006	3 Jun -25 Jul	89,550	0.131	(8%)	0.254	(16%)	1.175	(75%)	1.560	0.061
2007	2 Jun -30 Jul	92,944	0.084	(5%)	0.168	(10%)	1.517	(86%)	1.769	0.080
2008	2 Jun -31 Jul	95,374	0.081	(9%)	0.027	(3%)	0.834	(89%)	0.997	0.076
2009	9 Jun -7 Aug	91,414	0.070	(8%)	0.018	(2%)	0.835	(90%)	0.924	0.081

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

Table 1.16. Mean weight-at-age estimates from the fishery (1991-2008) showing the between-year variability (middle row) and sampling error (bottom panel) based on bootstrap resampling of observer data. *NOTE: 2009 weight-at-age is treated as the ten-year average of values from 1999-2008*.

	Mean weight-at-age												
	3	4	5	6	7	8	9	10	11	12	13	14	15
1964-1990	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	0.287	0.479	0.608	0.727	0.848	0.887	1.006	1.127	1.125	1.237	1.242	1.279	1.244
1992	0.398	0.468	0.645	0.712	0.814	0.983	1.028	1.224	1.234	1.270	1.175	1.353	1.441
1993	0.495	0.613	0.656	0.772	0.930	1.043	1.196	1.230	1.407	1.548	1.650	1.688	1.635
1994	0.394	0.649	0.730	0.746	0.706	1.010	1.392	1.320	1.339	1.417	1.374	1.310	1.386
1995	0.375	0.502	0.730	0.843	0.856	0.973	1.224	1.338	1.413	1.497	1.395	1.212	1.363
1996	0.322	0.428	0.680	0.790	0.946	0.949	1.021	1.090	1.403	1.497	1.539	1.750	1.536
1997	0.323	0.466	0.554	0.742	0.888	1.071	1.088	1.240	1.410	1.473	1.724	1.458	1.423
1998	0.372	0.588	0.627	0.623	0.779	1.034	1.177	1.243	1.294	1.417	1.559	1.556	1.720
1999	0.400	0.502	0.638	0.701	0.727	0.901	1.039	1.272	1.207	1.415	1.164	1.141	1.319
2000	0.351	0.524	0.630	0.732	0.782	0.805	0.972	1.018	1.268	1.317	1.320	1.665	1.738
2001	0.324	0.497	0.669	0.787	0.963	0.995	1.062	1.137	1.327	1.451	1.585	1.466	1.665
2002	0.380	0.508	0.669	0.795	0.908	1.024	1.117	1.096	1.300	1.430	1.611	1.319	1.636
2003	0.484	0.550	0.650	0.768	0.862	0.954	1.085	1.224	1.213	1.227	1.445	1.340	1.721
2004	0.404	0.580	0.640	0.770	0.890	0.928	1.026	1.207	1.159	1.179	1.351	1.292	1.232
2005	0.353	0.507	0.639	0.739	0.880	0.948	1.063	1.094	1.267	1.312	1.313	1.164	1.419
2006	0.305	0.448	0.604	0.754	0.855	0.958	1.055	1.126	1.219	1.283	1.306	1.399	1.453
2007	0.338	0.509	0.642	0.782	0.960	1.104	1.196	1.276	1.328	1.516	1.416	1.768	1.532
2008	0.329	0.521	0.652	0.772	0.899	1.042	1.114	1.204	1.309	1.404	1.513	1.599	1.506
2009	*0.367*	*0.515*	*0.643*	*0.760*	*0.873*	*0.966*	*1.073*	*1.166*	*1.260*	*1.353*	*1.402*	*1.415*	*1.522*
Mean	0.369	0.519	0.648	0.753	0.861	0.978	1.103	1.193	1.290	1.383	1.427	1.431	1.498
Stdev	0.056	0.058	0.041	0.047	0.075	0.072	0.102	0.088	0.087	0.111	0.163	0.199	0.161
CV	15%	11%	6%	6%	9%	7%	9%	7%	7%	8%	11%	14%	11%
	Sampling error (from bootstrap)												
1991	8%	4%	3%	2%	2%	4%	2%	6%	3%	6%	4%	6%	4%
1992	2%	4%	5%	3%	3%	2%	3%	3%	4%	4%	11%	6%	6%
1993	2%	1%	3%	4%	4%	4%	3%	4%	4%	6%	7%	10%	8%
1994	8%	2%	1%	3%	8%	12%	5%	5%	4%	5%	6%	11%	6%
1995	5%	3%	2%	1%	3%	4%	6%	6%	5%	10%	6%	48%	6%
1996	7%	10%	3%	2%	1%	2%	4%	6%	13%	7%	6%	7%	9%
1997	9%	2%	1%	2%	2%	2%	3%	6%	10%	9%	14%	6%	7%
1998	5%	5%	3%	1%	3%	3%	2%	4%	8%	9%	13%	16%	14%
1999	1%	1%	2%	2%	1%	2%	3%	4%	12%	19%	42%	102%	22%
2000	4%	1%	1%	2%	2%	1%	3%	6%	5%	10%	47%	63%	48%
2001	5%	3%	1%	2%	3%	3%	2%	4%	5%	6%	8%	10%	33%
2002	4%	2%	2%	1%	1%	2%	3%	3%	5%	5%	7%	25%	22%
2003	1%	2%	1%	2%	1%	2%	3%	5%	5%	6%	10%	28%	13%
2004	4%	1%	1%	2%	2%	2%	3%	7%	6%	5%	10%	14%	9%
2005	4%	1%	1%	1%	2%	3%	3%	4%	7%	6%	20%	35%	20%
2006	4%	1%	1%	1%	1%	3%	4%	4%	7%	11%	9%	14%	7%
2007	3%	2%	1%	1%	1%	2%	3%	4%	5%	9%	9%	7%	6%
2008	3%	2%	2%	1%	1%	2%	2%	5%	5%	5%	5%	14%	6%

Table 1.17. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2009. *Note: fishery data for 2009 are preliminary.*

Year	Fishery	Year	BTS	EIT
1964-1977	10	1979	-	6
1978-1990	50			
1991	174			
1992	200	1982-2009	100	51
1993	273			(average)
1994	108			
1995	138			
1996	149			
1997	256			
1998	270			
1999	456			
2000	452			
2001	292			
2002	435			
2003	389			
2004	332			
2005	399			
2006	328			
2007	408			
2008	341			
2009	*150*			

Table 1.18. Summary model results showing the stock condition for EBS pollock. Values in parentheses are coefficients of variation (CV's) of values immediately above.

Biomass	
Year 2010 spawning biomass*	1,316,000 t
(CV)	(24%)
2009 spawning biomass	1,161,000 t
B_{msy}	1,863,000 t
(CV)	(20%)
$B_{40\%}$	2,351,000 t
(CV)	(5%)
$B_{35\%}$	2,057,000 t
B_0 (stock-recruitment curve)	4,934,000 t
2010 Percent of B_{msy} spawning biomass	71%
2010 Percent of $B_{40\%}$ spawning biomass	57%
Ratio of B_{2009} over B_{2009} under no fishing since 1978	36%
2010 Fishable biomass	3,160,000 t
Recruitment (millions of pollock at age 1)	
Steepness parameter (h)	0.67
Average recruitment (all yrs)	21,095
(CV)	63%
Average recruitment (since 1978)	22,560
(CV since 1978)	66%
2000 year class	33,990
(CV 2000 year class)	(4%)
2006 year class	24,450
(CV 2006 year class)	(16%)
Natural Mortality (age 3 and older)	**0.3**

Table 1.19. Summary results of Tier 1 yield projections for EBS pollock.

Yield projections	
Fishable biomass at *MSY*	4,839,000 t
2010 "fishable" biomass (GM)	3,152,000 t
MSYR (HM)	0.373
B_{2010}/B_{msy}	0.706
Adjustment factor	0. 691
Adjusted ABC rate	0.258
2010 MSYR yield (Tier 1 ABC)	813,000 t
MSYR (AM)	0.421
Adjusted OFL rate	0.291
2010 MSYR OFL	918,000 t

Notes: MSYR = exploitation rate relative to begin-year age fishable 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

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*Assuming 2010 catch will be 813,00 t

Table 1.20 Estimates of numbers at age for the EBS pollock stock as estimated in 2009 (millions).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**Total**
1964	3,214	3,578	2,130	495	221	310	121	48	24	141	10,282
1965	20,633	1,305	2,245	1,490	300	134	189	74	30	104	26,504
1966	12,951	8,379	819	1,560	904	185	84	119	47	86	25,133
1967	30,547	5,260	5,250	563	965	564	117	53	76	86	43,482
1968	27,740	12,398	3,242	3,307	314	541	321	67	31	94	48,054
1969	29,836	11,259	7,627	2,059	1,844	178	310	185	39	72	53,410
1970	20,826	12,112	6,928	4,749	1,200	1,082	105	183	109	63	47,358
1971	7,612	8,452	7,323	4,091	2,750	686	623	59	102	90	31,788
1972	9,472	3,088	5,032	4,140	2,207	1,429	360	324	30	87	26,169
1973	28,173	3,842	1,784	2,599	2,055	1,098	715	178	160	50	40,652
1974	20,993	11,421	2,122	817	1,129	895	480	313	78	87	38,335
1975	17,836	8,507	5,983	841	324	451	360	193	123	60	34,677
1976	13,300	7,234	4,828	2,593	369	143	200	160	84	74	28,984
1977	13,658	5,396	4,191	2,407	1,173	170	67	93	73	68	27,296
1978	26,336	5,544	3,150	2,292	1,220	577	84	33	45	67	39,350
1979	63,857	10,691	3,247	1,706	1,162	594	283	40	15	52	81,648
1980	25,589	25,928	6,453	1,849	892	551	281	135	19	31	61,727
1981	28,701	10,394	16,111	4,055	984	434	263	135	65	23	61,167
1982	15,394	11,663	6,546	11,003	2,421	526	233	142	73	47	48,047
1983	51,914	6,257	7,392	4,673	7,176	1,458	313	139	84	70	79,475
1984	12,870	21,102	3,970	5,318	3,152	4,570	891	191	85	91	52,241
1985	34,922	5,231	13,395	2,857	3,618	1,969	2,847	541	116	102	65,599
1986	13,560	14,196	3,319	9,619	1,972	2,346	1,189	1,730	327	125	48,383
1987	7,985	5,512	9,005	2,388	6,599	1,301	1,442	722	1,070	267	36,291
1988	4,932	3,246	3,501	6,535	1,684	4,507	851	936	455	836	27,483
1989	9,214	2,005	2,059	2,483	4,487	1,087	2,861	508	566	778	26,048
1990	49,951	3,746	1,272	1,472	1,683	2,922	680	1,690	303	811	64,528
1991	25,555	20,305	2,370	902	940	996	1,672	370	921	622	54,652
1992	21,387	10,388	12,848	1,694	587	562	567	868	202	807	49,909
1993	46,627	8,694	6,567	8,902	1,100	351	297	272	398	454	73,662
1994	14,328	18,955	5,525	4,664	5,629	705	204	162	149	470	50,790
1995	10,289	5,825	12,053	4,022	3,164	3,285	411	116	93	361	39,618
1996	22,730	4,183	3,704	8,829	2,859	2,005	1,775	228	66	263	46,642
1997	30,832	9,241	2,656	2,702	6,412	1,938	1,127	877	119	179	56,083
1998	14,898	12,535	5,854	1,931	1,921	4,341	1,181	610	465	156	43,892
1999	16,085	6,057	7,955	4,245	1,364	1,293	2,637	704	340	335	41,014
2000	24,740	6,539	3,850	5,664	2,954	920	828	1,560	415	403	47,872
2001	33,991	10,058	4,159	2,780	3,837	1,895	584	476	860	476	59,116
2002	21,435	13,819	6,400	3,021	1,910	2,328	1,051	325	264	757	51,308
2003	12,720	8,714	8,783	4,630	2,051	1,164	1,194	542	169	557	40,523
2004	5,536	5,171	5,540	6,189	3,133	1,204	603	592	273	396	28,638
2005	3,492	2,251	3,290	4,008	3,875	1,893	675	314	311	369	20,476
2006	8,570	1,420	1,432	2,380	2,633	2,116	995	364	173	386	20,469
2007	24,451	3,484	902	1,011	1,526	1,435	1,032	495	184	296	34,816
2008	9,617	9,940	2,213	633	642	827	651	491	245	242	25,501
2009	29,420	3,909	6,315	1,581	397	344	354	283	226	230	43,059
Median	20,730	7,806	4,509	2,650	1,764	1,039	576	278	121	149	43,270
Average	21,276	8,462	5,246	3,429	2,168	1,311	742	405	220	266	43,525

Table 1.21. Assessment model-estimated catch-at-age of EBS pollock (millions).

	1	2	3	4	5	6	7	8	9	10+	Total
1964	2.7	45.6	102.5	77.9	35.0	48.1	17.8	6.7	3.2	14.8	354.2
1965	15.2	16.9	121.0	234.1	44.4	18.6	24.7	9.2	3.5	10.1	497.8
1966	8.8	117.9	50.3	222.7	123.7	23.6	10.1	13.8	5.2	7.2	583.3
1967	34.5	141.5	681.2	122.0	204.5	114.4	23.1	10.3	14.5	10.5	1,356.4
1968	30.3	351.5	401.6	711.2	64.1	105.9	61.6	12.6	5.8	9.6	1,754.1
1969	29.8	317.7	1,056.5	381.7	333.1	31.3	54.8	32.6	6.9	11.3	2,255.7
1970	25.0	505.9	1,221.9	901.1	238.0	209.8	22.4	39.4	24.2	13.0	3,200.8
1971	11.2	452.6	1,508.3	968.2	715.5	174.9	162.0	15.5	28.4	12.3	4,049.0
1972	15.2	234.5	1,328.2	1,192.4	632.4	405.0	104.7	94.2	9.5	14.0	4,030.1
1973	54.4	416.1	595.7	940.8	741.6	393.5	255.2	63.4	61.0	14.6	3,536.2
1974	45.6	1,653.2	865.9	332.7	456.8	358.8	193.1	129.3	34.3	8.9	4,078.6
1975	29.1	756.1	2,173.8	299.8	114.4	158.0	126.0	69.6	47.5	13.3	3,787.7
1976	17.5	534.6	1,377.6	882.6	122.1	46.7	64.8	53.2	29.5	8.5	3,137.0
1977	14.2	368.1	954.8	662.5	344.4	49.1	19.2	27.9	22.8	9.8	2,472.9
1978	26.5	365.2	737.6	630.5	365.7	169.4	26.0	10.8	15.1	10.7	2,357.3
1979	56.3	460.9	653.3	437.2	365.8	187.2	88.2	13.4	5.2	10.4	2,277.9
1980	15.8	532.2	849.0	452.9	267.5	170.7	85.8	41.2	5.7	7.5	2,428.4
1981	10.3	102.6	1,089.7	683.9	238.9	104.7	63.0	32.3	15.6	3.8	2,344.8
1982	3.1	56.4	206.4	1,141.4	392.7	89.9	39.3	23.9	12.5	2.5	1,967.8
1983	7.8	25.2	183.8	361.6	872.8	222.0	47.4	21.0	13.3	5.4	1,760.3
1984	1.7	76.1	97.9	376.3	428.6	630.5	139.1	29.9	14.0	8.6	1,802.8
1985	4.3	21.4	354.5	168.5	390.9	316.8	444.3	86.7	20.0	11.2	1,818.6
1986	1.4	59.1	82.0	616.5	187.4	346.5	185.5	248.2	54.8	11.4	1,792.9
1987	0.5	16.6	159.0	100.1	445.8	131.8	155.4	93.4	141.7	10.3	1,254.6
1988	0.4	13.9	129.7	413.3	187.6	559.3	143.4	149.2	74.8	26.4	1,698.0
1989	0.7	8.6	62.3	182.3	471.1	146.9	504.3	86.1	91.8	81.3	1,635.4
1990	5.3	23.6	47.1	175.8	294.4	577.5	157.1	388.9	68.0	98.7	1,836.2
1991	2.5	125.8	71.2	95.1	157.9	200.6	436.4	85.1	240.1	113.8	1,528.4
1992	2.5	71.3	719.6	182.2	98.0	140.0	174.2	289.2	69.0	112.8	1,858.7
1993	3.3	23.3	235.4	1,130.6	128.6	65.2	68.1	62.3	91.1	79.1	1,887.0
1994	0.8	42.5	83.0	339.9	1,038.9	130.0	41.6	32.1	28.4	46.1	1,783.2
1995	0.5	12.6	115.9	140.1	396.6	773.3	90.5	24.0	18.1	51.5	1,623.1
1996	1.1	14.4	49.5	150.4	211.1	420.4	516.4	57.8	15.5	47.4	1,483.9
1997	1.6	48.3	42.7	94.1	478.3	297.7	264.7	217.0	31.3	36.4	1,512.3
1998	0.7	47.2	107.0	77.0	151.8	678.6	201.4	131.7	110.5	21.9	1,527.8
1999	0.7	14.6	267.9	222.3	106.3	152.0	462.0	124.8	59.0	14.0	1,423.5
2000	1.1	13.9	84.4	419.0	343.5	113.7	161.0	346.8	80.4	35.7	1,599.6
2001	1.6	16.9	70.1	174.7	602.7	414.8	127.1	104.2	178.0	47.6	1,737.7
2002	1.2	36.0	129.5	218.5	294.4	624.8	277.8	84.4	64.8	60.7	1,791.9
2003	0.8	20.5	370.2	347.4	369.3	304.4	344.7	151.9	43.0	92.5	2,044.6
2004	0.3	9.3	112.5	831.9	502.1	255.0	156.6	150.3	63.5	66.0	2,147.5
2005	0.2	4.3	66.4	393.2	886.8	478.7	159.7	69.9	66.0	42.9	2,168.1
2006	0.6	3.8	58.4	278.2	605.3	631.1	284.8	101.3	45.1	51.9	2,060.7
2007	1.8	10.8	40.8	124.7	356.8	486.6	322.0	143.8	52.1	56.2	1,595.7
2008	0.7	29.2	68.4	84.5	154.7	305.4	235.5	163.4	79.5	46.5	1,167.8
2009	2.7	13.5	236.1	266.2	116.9	133.7	134.7	105.1	82.1	41.3	1,132.1
Median	2.7	46.4	171.4	336.3	338.3	193.9	141.2	69.8	32.8	14.3	1,797.8
Average	10.7	179.0	435.2	418.3	349.5	269.5	166.9	92.3	48.8	32.8	2,003.1

Table 1.22. Estimated EBS pollock age 3+ biomass, female spawning biomass, and age 1 recruitment for 1964-2009. Biomass units are thousands of t, age-1 recruitment is in millions of pollock.

Year	Age 3+ biomass	Spawning biomass	Age 1 Rec.	Year	Age 3+ biomass	Spawning biomass	Age 1 Rec.
1964	1,564	437	3,214	1988	11,227	3,961	4,932
1965	2,008	551	20,633	1989	9,521	3,564	9,214
1966	1,947	635	12,951	1990	7,558	2,862	49,951
1967	3,149	784	30,547	1991	5,811	2,119	25,555
1968	3,510	963	27,740	1992	9,211	2,217	21,387
1969	5,007	1,248	29,836	1993	11,388	3,090	46,627
1970	6,159	1,618	20,826	1994	10,990	3,399	14,328
1971	6,949	1,871	7,612	1995	12,699	3,596	10,289
1972	6,444	1,832	9,472	1996	10,843	3,589	22,730
1973	4,696	1,457	28,173	1997	9,440	3,378	30,832
1974	3,196	960	20,993	1998	9,538	3,134	14,898
1975	3,384	765	17,836	1999	10,421	3,149	16,085
1976	3,431	794	13,300	2000	9,632	3,185	24,740
1977	3,457	862	13,658	2001	9,341	3,199	33,991
1978	3,340	899	26,336	2002	9,595	2,999	21,435
1979	3,212	877	63,857	2003	11,453	3,139	12,720
1980	4,124	994	25,589	2004	10,606	3,195	5,536
1981	8,031	1,670	28,701	2005	8,736	2,874	3,492
1982	9,165	2,559	15,394	2006	6,543	2,297	8,570
1983	10,168	3,155	51,914	2007	5,090	1,832	24,451
1984	9,857	3,352	12,870	2008	3,809	1,254	9,617
1985	12,027	3,603	34,922	2009	4,762	1,161	29,420
1986	11,269	3,832	13,560	2010	4,616	1,316	
1987	11,915	3,964	7,985	2011	6,223		

Table 1.23. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for the current assessment compared to estimates from the 2002-2008 assessments for EBS pollock. NOTE: see Ianelli et al. (2001) for a discussion on the interpretation of age-3+ biomass estimates.

	Current		2008		2007		2006		2005		2004		2003		2002	
	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV	Assess.	CV
1964	**1,564**	22%	1,600	22%	1,717	23%	1,810	23%	1,779	23%	1,789	23%	1,822	23%	1,784	23%
1965	**2,008**	20%	2,050	20%	2,141	21%	2,231	21%	2,222	21%	2,272	20%	2,312	20%	2,266	20%
1966	**1,947**	22%	2,007	21%	2,037	22%	2,252	21%	2,288	21%	2,326	20%	2,372	20%	2,324	20%
1967	**3,149**	17%	3,245	17%	3,206	18%	3,518	17%	3,483	17%	3,514	17%	3,575	17%	3,511	17%
1968	**3,510**	19%	3,592	18%	3,558	19%	3,881	17%	3,881	17%	3,976	17%	4,049	17%	3,976	17%
1969	**5,007**	17%	5,020	17%	5,118	17%	5,058	16%	5,323	16%	5,258	16%	5,340	16%	5,252	16%
1970	**6,159**	15%	6,005	16%	6,368	15%	5,929	16%	6,447	15%	6,211	15%	6,296	15%	6,201	15%
1971	**6,949**	13%	6,727	14%	7,164	13%	6,617	13%	7,145	13%	6,714	14%	6,797	14%	6,702	14%
1972	**6,444**	13%	6,289	14%	6,666	13%	6,265	13%	6,692	13%	6,204	13%	6,282	13%	6,194	13%
1973	**4,696**	16%	4,556	17%	4,942	16%	4,751	16%	5,055	15%	4,632	16%	4,705	16%	4,626	16%
1974	**3,196**	20%	3,064	22%	3,475	20%	3,460	19%	3,635	19%	3,288	19%	3,356	19%	3,287	19%
1975	**3,384**	13%	3,276	14%	3,604	14%	3,585	13%	3,666	14%	3,440	14%	3,489	14%	3,436	14%
1976	**3,431**	11%	3,339	11%	3,584	11%	3,577	11%	3,614	11%	3,497	11%	3,538	11%	3,492	11%
1977	**3,457**	9%	3,340	10%	3,602	10%	3,582	10%	3,548	10%	3,504	10%	3,541	10%	3,496	10%
1978	**3,340**	9%	3,202	9%	3,476	9%	3,438	10%	3,361	10%	3,385	10%	3,422	10%	3,375	10%
1979	**3,212**	9%	3,090	9%	3,363	9%	3,323	9%	3,273	10%	3,341	10%	3,380	10%	3,329	10%
1980	**4,124**	8%	4,044	7%	4,384	8%	4,320	8%	4,373	8%	4,409	8%	4,462	8%	4,385	8%
1981	**8,031**	6%	7,704	6%	8,307	6%	8,364	7%	8,289	7%	8,301	7%	8,414	7%	8,239	7%
1982	**9,165**	6%	8,783	6%	9,439	6%	9,476	6%	9,446	7%	9,472	7%	9,614	7%	9,388	7%
1983	**10,168**	5%	9,804	5%	10,493	6%	10,443	6%	10,536	7%	10,552	7%	10,728	7%	10,441	7%
1984	**9,857**	5%	9,518	5%	10,200	6%	10,088	6%	10,244	7%	10,263	7%	10,456	7%	10,143	7%
1985	**12,027**	4%	11,802	4%	12,531	5%	12,285	5%	12,435	6%	12,492	6%	12,771	6%	12,344	6%
1986	**11,269**	4%	11,075	4%	11,773	5%	11,486	5%	11,609	6%	11,677	6%	11,973	6%	11,538	6%
1987	**11,915**	4%	11,732	4%	12,401	4%	12,077	5%	12,106	5%	12,226	5%	12,596	5%	12,116	5%
1988	**11,227**	4%	11,004	4%	11,617	4%	11,330	5%	11,153	5%	11,243	5%	11,633	5%	11,317	5%
1989	**9,521**	4%	9,320	4%	9,875	4%	9,584	5%	9,384	5%	9,466	5%	9,850	5%	9,540	5%
1990	**7,558**	4%	7,345	4%	7,847	5%	7,603	5%	7,392	6%	7,454	6%	7,811	6%	7,524	6%
1991	**5,811**	5%	5,590	5%	6,097	5%	5,929	6%	5,454	6%	5,637	7%	5,977	7%	5,708	7%
1992	**9,211**	4%	8,966	4%	9,557	4%	9,270	5%	8,905	5%	9,120	5%	9,614	5%	9,227	5%
1993	**11,388**	3%	11,175	3%	11,832	4%	11,795	4%	11,669	5%	11,721	6%	12,363	6%	12,110	5%
1994	**10,990**	4%	10,782	4%	11,485	4%	11,407	5%	11,000	5%	10,998	6%	11,696	6%	11,358	6%
1995	**12,699**	3%	12,704	3%	13,615	4%	13,658	4%	13,605	6%	13,554	6%	14,474	6%	13,848	6%
1996	**10,843**	4%	10,829	4%	11,537	4%	11,480	5%	11,826	6%	11,772	7%	12,630	7%	11,988	7%
1997	**9,440**	4%	9,403	4%	10,104	5%	10,056	5%	9,966	6%	9,949	8%	10,775	8%	10,142	8%
1998	**9,538**	4%	9,467	4%	10,178	5%	9,973	5%	9,915	7%	9,943	8%	11,110	8%	10,466	9%
1999	**10,421**	3%	10,379	4%	11,081	4%	10,872	5%	10,998	6%	11,093	10%	13,339	10%	12,712	11%
2000	**9,632**	3%	9,503	4%	10,201	4%	10,052	5%	9,947	7%	10,036	12%	12,498	12%	11,807	12%
2001	**9,341**	4%	9,175	4%	9,898	5%	9,800	6%	9,566	8%	9,675	14%	12,394	14%	11,511	14%
2002	**9,595**	4%	9,554	4%	10,224	5%	10,197	7%	9,824	9%	9,899	16%	12,930	16%	11,118	17%
2003	**11,453**	3%	11,182	4%	12,865	6%	13,320	10%	13,073	13%	12,239	19%	12,688	19%		
2004	**10,606**	4%	10,274	4%	11,784	7%	12,055	12%	10,972	15%	9,894	21%	11,217	21%		
2005	**8,736**	4%	8,423	5%	9,598	8%	9,759	14%	9,277	18%	8,573					
2006	**6,543**	5%	6,340	6%	7,178	10%	7,950	17%	8,232	21%						
2007	**5,090**	6%	5,015	8%	5,363	14%	6,361	21%								
2008	**3,809**	8%	4,222	12%	4,357	20%										
2009	**4,762**	11%	6,240	20%												
2010	**4,616**	13%														

Table 1.24 Projections of catch, fishing mortality, and 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 5,876; 2,351; and 2,057 thousand t, respectively.

Catch (1,000 t)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2009	815	815	815	815	815	815	815
2010	433	813	512	334	0	537	433
2011	746	1,000	675	464	0	871	746
2012	1,120	882	873	622	0	1,258	1,365
2013	1,321	1,172	1,038	757	0	1,464	1,504
2014	1,411	1,242	1,165	871	0	1,535	1,548
2015	1,420	1,243	1,210	925	0	1,520	1,524
2016	1,417	1,248	1,230	955	0	1,504	1,506
2017	1,412	1,255	1,240	973	0	1,495	1,496
2018	1,408	1,270	1,242	983	0	1,485	1,485
2019	1,410	1,283	1,249	993	0	1,491	1,491
2020	1,435	1,283	1,266	1,008	0	1,524	1,524
2021	1,450	1,291	1,280	1,020	0	1,540	1,540
2022	1,442	1,290	1,279	1,023	0	1,524	1,524

Fishing M.	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2009	0.581	0.581	0.581	0.581	0.581	0.581	0.581
2010	0.255	0.514	0.306	0.193	0.000	0.322	0.255
2011	0.334	0.529	0.306	0.193	0.000	0.411	0.334
2012	0.404	0.364	0.306	0.193	0.000	0.490	0.508
2013	0.420	0.396	0.306	0.193	0.000	0.510	0.516
2014	0.415	0.378	0.306	0.193	0.000	0.503	0.505
2015	0.413	0.366	0.306	0.193	0.000	0.500	0.500
2016	0.412	0.360	0.306	0.193	0.000	0.497	0.497
2017	0.412	0.356	0.306	0.193	0.000	0.495	0.496
2018	0.413	0.358	0.306	0.193	0.000	0.495	0.495
2019	0.412	0.358	0.306	0.193	0.000	0.494	0.494
2020	0.414	0.355	0.306	0.193	0.000	0.497	0.497
2021	0.415	0.353	0.306	0.193	0.000	0.500	0.500
2022	0.414	0.349	0.306	0.193	0.000	0.497	0.497

Sp. Biomass (1,000 t)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2009	1,163	1,163	1,163	1,163	1,163	1,163	1,163
2010	1,360	1,314	1,351	1,371	1,408	1,348	1,360
2011	1,744	1,555	1,720	1,819	2,010	1,685	1,744
2012	2,118	1,905	2,148	2,332	2,720	2,010	2,086
2013	2,344	2,245	2,482	2,758	3,388	2,188	2,218
2014	2,406	2,392	2,647	3,010	3,897	2,211	2,222
2015	2,426	2,493	2,740	3,181	4,333	2,206	2,210
2016	2,430	2,567	2,789	3,289	4,675	2,199	2,200
2017	2,418	2,610	2,805	3,347	4,932	2,183	2,183
2018	2,417	2,649	2,821	3,393	5,147	2,181	2,181
2019	2,444	2,700	2,857	3,449	5,334	2,208	2,208
2020	2,474	2,751	2,895	3,502	5,492	2,237	2,237
2021	2,477	2,780	2,906	3,526	5,607	2,236	2,236
2022	2,459	2,785	2,896	3,525	5,673	2,216	2,216

Table 1.25 Tier 1b EBS pollock ABC and OFL projections for 2010 and for 2011.

Year	Catch	ABC	OFL
2010	813,000 t	813,000 t	918,000 t
2011	1,000,000 t	1,109,000 t	1,220,000 t

Table 1.26. 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	Data improving, indication of recent increases since 2004 (for euphasiids)	Nearly three-fold change in apparent abundance—indicates favorable conditions for recruitment (for prey)
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	Some concern, the distribution of pollock availability to different surveys may change systematically
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	Maturity study (gonad collection) underway	NA	Possible concern

Table 1.27 Bycatch estimates (t) of non-target species caught in the BSAI directed pollock fishery, 1997-2002 based on observer data, 2003-2009 based on observer data as processed through the catch accounting system (NMFS Regional Office, Juneau, Alaska).

	1997	1998	1999	2000	2001	2002
Jellyfish	6,632	6,129	6,176	9,361	3,095	1,530
Squid	1,487	1,210	474	379	1,776	1,708
Skates	348	406	376	598	628	870
Misc Fish	207	134	156	236	156	134
Sculpins	109	188	67	185	199	199
Sleeper shark	105	74	77	104	206	149
Smelts	19.5	30.2	38.7	48.7	72.5	15.3
Grenadiers	19.7	34.9	79.4	33.2	11.6	6.5
Salmon shark	6.6	15.2	24.7	19.5	22.5	27.5
Starfish	6.5	57.7	6.8	6.2	12.8	17.4
Shark	15.6	45.4	10.3	0.1	2.3	2.3
Benthic inverts.	2.5	26.3	7.4	1.7	0.6	2.1
Sponges	0.8	21	2.4	0.2	2.1	0.3
Octopus	1	4.7	0.4	0.8	4.8	8.1
Crabs	1	8.2	0.8	0.5	1.8	1.5
Anemone	2.6	1.8	0.3	5.8	0.1	0.6
Tunicate	0.1	1.5	1.5	0.4	3.7	3.8
Unident. inverts	0.2	2.9	0.1	4.4	0.1	0.2
Echinoderms	0.8	2.6	0.1	0	0.2	0.1
Seapen/whip	0.1	0.2	0.5	0.9	1.5	2.1
Other	0.8	2.9	1.1	0.8	1.2	3.7

Group	2003	2004	2005	2006	2007	2008	2009
Jellyfish	5,644	6,590	5,197	2,714	2,376	4,181	8,096
Squid	1,151	855	1,066	1,384	1,165	1,417	203
Octopus	9	3	1	2	4	4	3
Large Sculpins	43	134	138	153	164	300	288
Other Sculpins	59	17	11	23	16	16	8
Sleeper shark	74	144	128	178	180	98	22
Salmon shark,	195	25	26	36	44	42	73
Other shark	12	18	16	298	20	6	5
Eulachon	2	19	9	94	102	2	4
Other osmerids	8	2	3	6	38	2	0
Eelpouts	7	1	1	21	119	9	4
Big skate	0	71	4	3	5	4	37
Longnose skate	0	15	3	2	0	45	1
Other skates	471	755	725	1,301	1,282	2,708	3,803
Grenadier	20	10	9	9	11	4	1
Giant Grenadier	0	4	5	7	17	24	4
Lanternfish	0	0	1	10	6	2	0
Sea stars	89	7	10	11	5	18	9
Sea pens, whips	1	1	2	2	4	1	3
Misc fish	101	90	158	148	202	119	135
Other	3	2	12	8	9	10	6

Table 1.28 Bycatch estimates (t) of target species caught in the BSAI directed pollock fishery, 1997-2009 based on then NMFS Alaska Regional Office reports from observers (*2009 data are preliminary*).

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Pacific Cod	8,478	6,560	3,220	3,432	3,879	5,928	5,773	6,192	6,420	6,868	5,281	5,840	4,179
Flathead Sole	2,353	2,118	1,885	2,510	2,199	1,844	1,629	2,019	2,095	2,637	3,743	3,232	2,159
Rock Sole	1,529	779	1,058	2,688	1,673	1,885	1,345	2,301	1,041	1,189	410	1,390	1,718
Yellowfin Sole	606	1,762	350	1,466	594	768	150	671	17	148	21	129	92
Arrowtooth Flounder	1,155	1,762	273	979	529	607	550	541	551	951	2,294	1,042	935
Pacific Ocean Perch	512	692	121	22	574	545	691	321	503	426	486	216	68
Atka Mackerel	229	91	165	2	41	221	379	369	211	154	106	15	5
Rex Sole	151	68	34	10	103	169	199	322	307	397	380	223	122
Greenland Turbot	125	178	30	52	68	70	38	18	30	64	105	72	40
Alaska Plaice	1	14	3	147	14	50	7	7	4	5	2	26	51
All other	93	41	31	77	118	103	144	130	130	149	191	33	0

Table 1.29 Bycatch estimates of prohibited species caught in the BSAI directed pollock fishery, 1997-2009 based on then NMFS Alaska Regional Office reports from observers. Herring and halibut units are in t, all others represent numbers of individuals caught. Preliminary 2009 data are through October 20th, 2009.

	Herring	Red king crab	Other king crab	Bairdi crab	Opilio crab	Chinook salmon	Other salmon	Halibut
1997	1,089	0	156	6,525	88,588	43,336	61,504	127
1998	821	5,098	1,832	35,594	45,623	49,373	62,276	144
1999	785	0	2	1,078	12,778	10,187	44,585	69
2000	482	0	104	173	1,807	3,966	56,707	80
2001	224	38	5,135	86	2,179	30,107	52,835	164
2002	105	6	81	651	1,667	32,222	76,998	127
2003	913	54	9	792	762	47,015	191,892	76
2004	1,130	16	6	1,202	741	54,035	438,044	84
2005	610	0	1	651	2,213	67,351	696,865	101
2006	435	26	3	1,100	2,934	82,591	308,414	109
2007	345	8	3	946	2,936	121,452	87,177	262
2008	126	28	9.84	808	4,299	17,901	12,905	220
2009	39	35	0	812	2,973	8,130	41,531	230

Table 1.30 Bycatch rates (kg / t of catch) of target species categories caught in the BSAI directed pollock fishery by season and area for preliminary **2009** based on then NMFS Alaska Regional Office reports from observers.

kg/t of groundfish	Winter (A-season)	Summer/fall (B-season) NW	 SE	 B Total	Annual rate
Pacific cod	11.03	4.48	3.56	4.29	6.28
Flathead Sole	6.67	2.02	1.03	1.81	3.24
“Other species”	5.96	1.45	1.66	1.49	2.81
Rock Sole	8.63	0.04	0.07	0.05	2.58
Arrowtooth/Kamchatka	2.21	0.69	2.47	1.07	1.40
Other flatfish	0.24	0.01	0.70	0.16	0.18
Squid	0.32	0.00	0.52	0.11	0.17
Yellowfin sole	0.46	0.00	0.03	0.01	0.14
Pacific ocean perch	0.10	0.01	0.43	0.10	0.10
Alaska plaice	0.24	0.01	0.00	0.01	0.08
All remaining species groups	0.06	0.10	0.01	0.08	0.06
Total	35.91	8.82	10.49	9.17	17.04

Table 1.31. Summary results for EBS pollock. Units are thousands of t.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop. F. Mature	0.000	0.004	0.145	0.321	0.421	0.451	0.474	0.482	0.485	0.500	0.500	0.500	0.500	0.500	0.500
Fish. Select	0.000	0.007	0.087	0.372	0.714	1.000	0.988	0.931	0.882	0.824	0.824	0.824	0.824	0.824	0.824

Tier (2010)	1b
Age 3+ 2010 begin-year biomass	4,616,000 t
2009 Spawning biomass	1,316,000 t
B_{msy}	1,863,000 t
$B_{40\%}$	2,351,000 t
$B_{35\%}$	2,057,000 t
$B_{100\%}$	5,876,000 t
B_0	4,934,000 t

Yield Considerations		2010	2011*
ABC:	Harmonic Mean F_{msy}	813,000 t	1,109,000 t
ABC:	Yield $F_{40\%}$ (Tier 3)	433,000 t	746,000 t
OFL:	Arithmetic Mean F_{msy} Yield	918,000 t	1,220,000 t
OFL:	Yield $F_{35\%}$ (Tier 3)	677,000 t	794 ,000 t

* Assuming 2010 catches equal 813,000 t

Figures

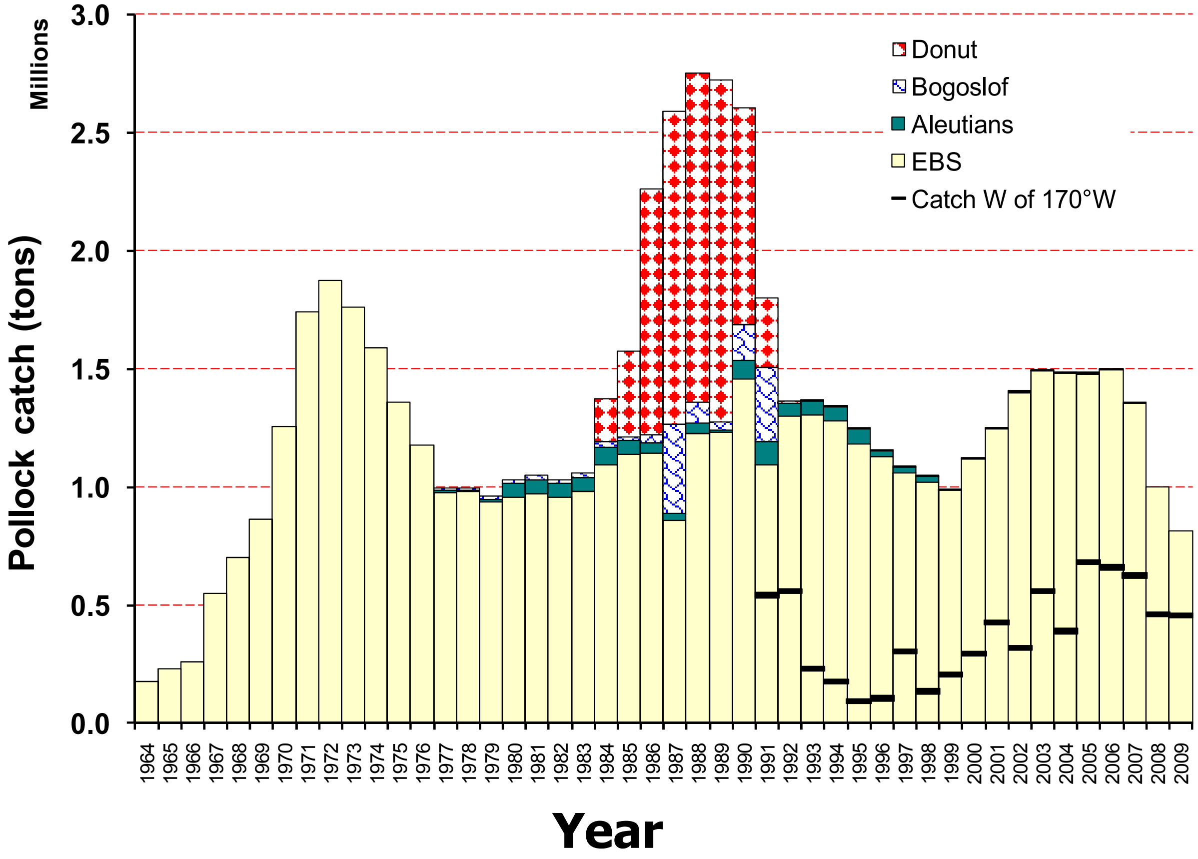


Figure 1.1. Alaska pollock catch estimates from the Eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole regions, 1964-2009. The 2009 value is based on expected totals for the year.

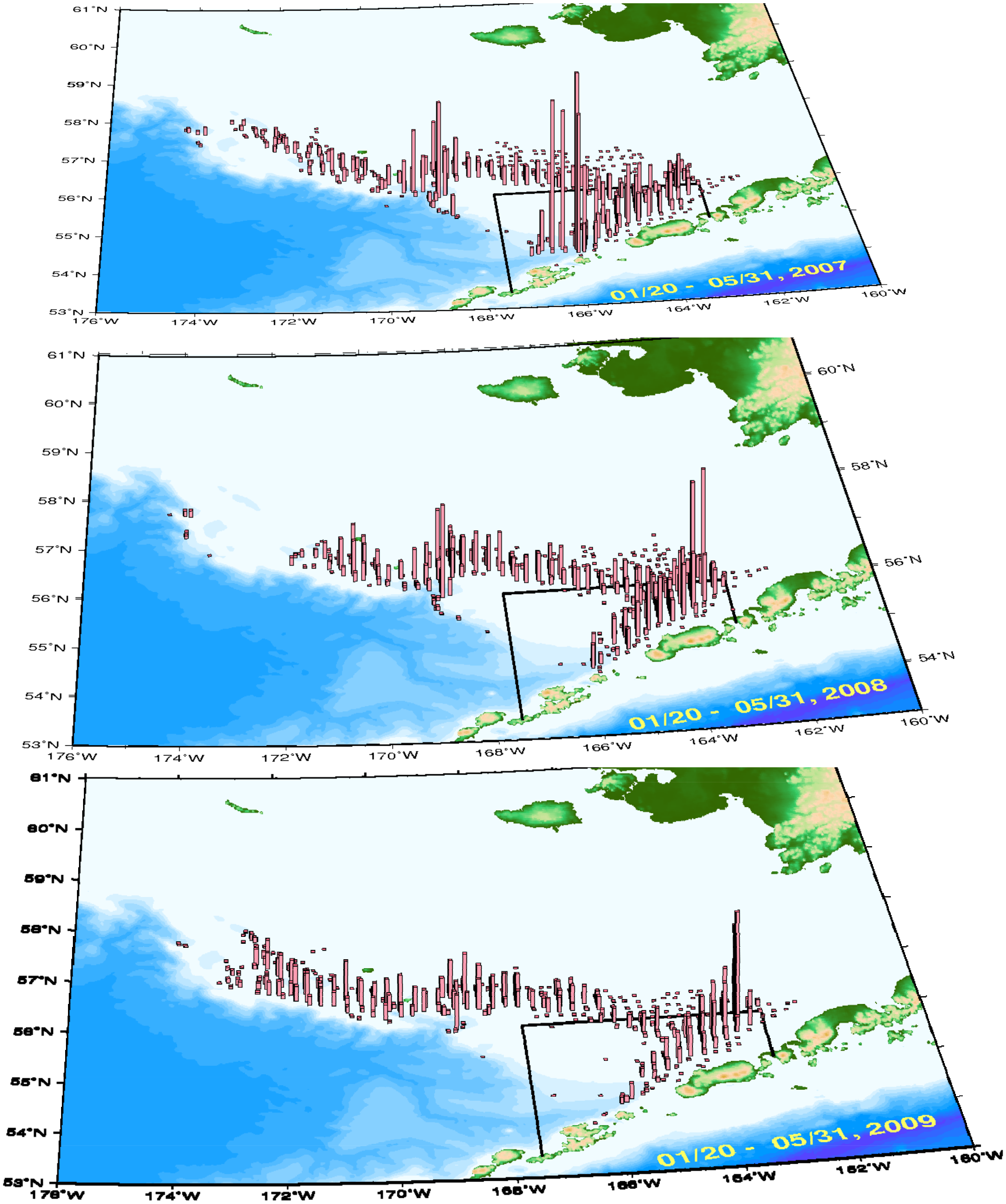


Figure 1.2. Pollock catch distribution in the fishery 2007-2009, January – May on the EBS shelf. Line delineates catcher-vessel operational area (CVOA). The column height represents relative removal on the same scale in all years.

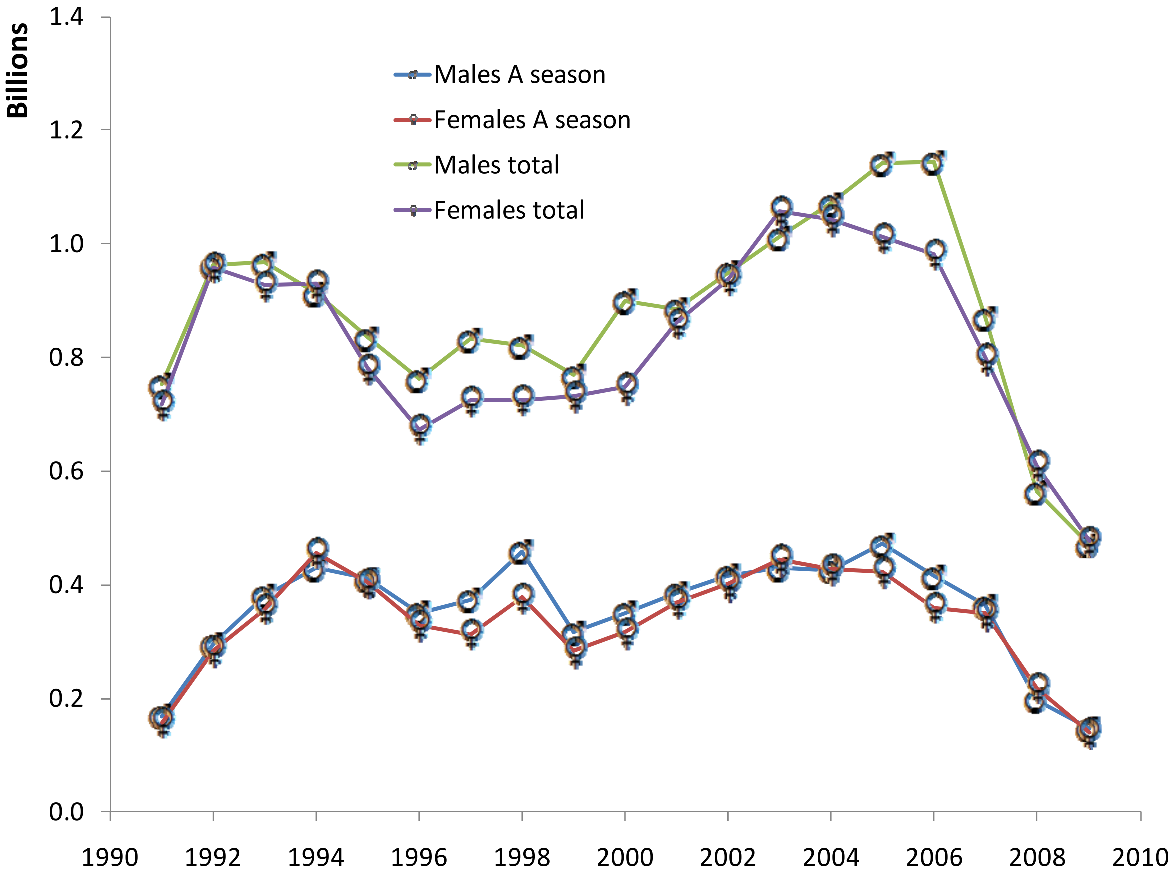


Figure 1.3. Estimate of EBS pollock catch numbers by sex for the "A season" (January-May) and for the entire annual fishery, 1991-2009. *Note values for 2009 are preliminary.*

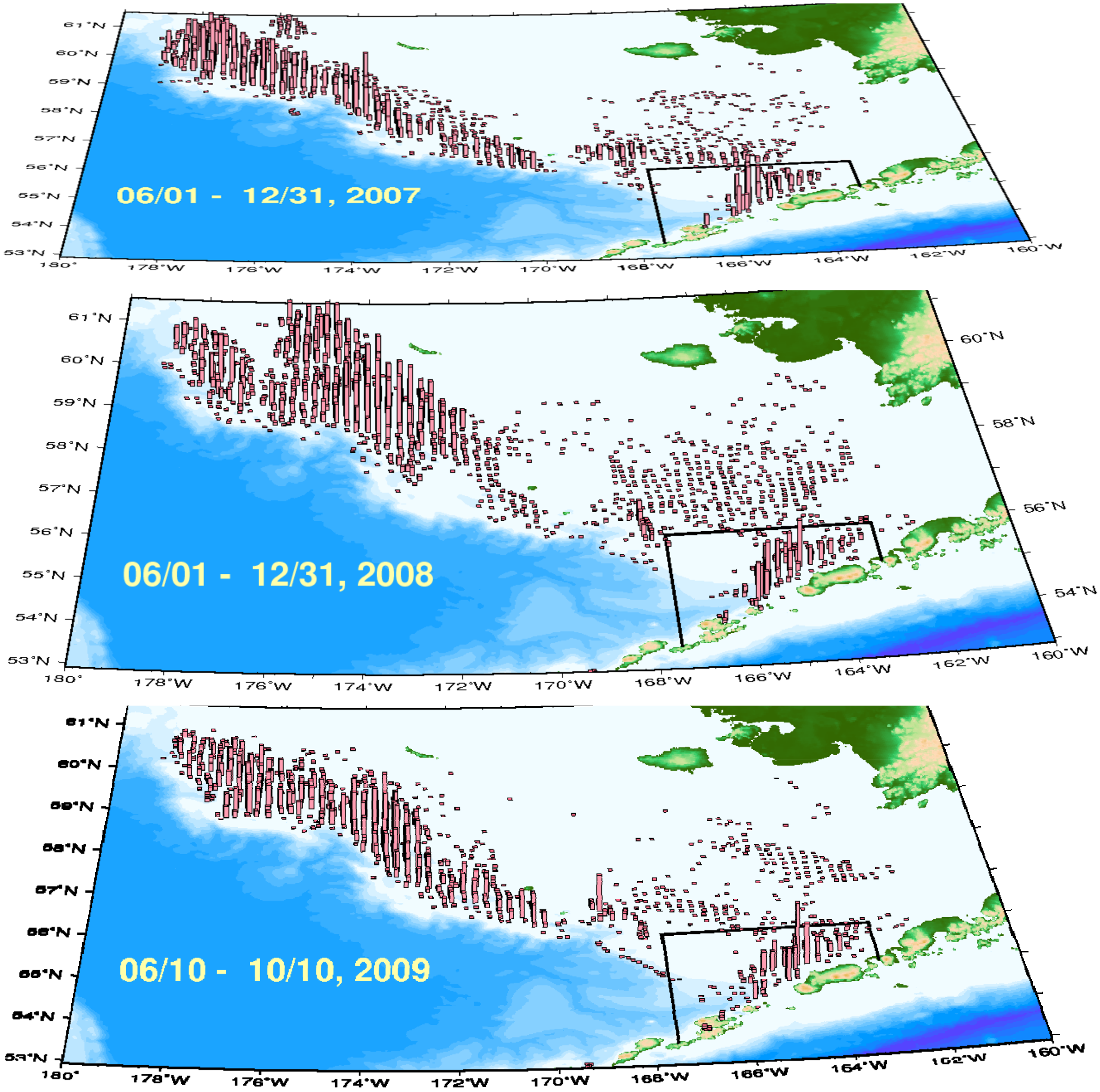


Figure 1.4. Pollock catch distribution during June – December, 2007-2009. The line delineates the catcher-vessel operational area (CVOA) and the height of the bars represents relative removal on the same scale over all years.

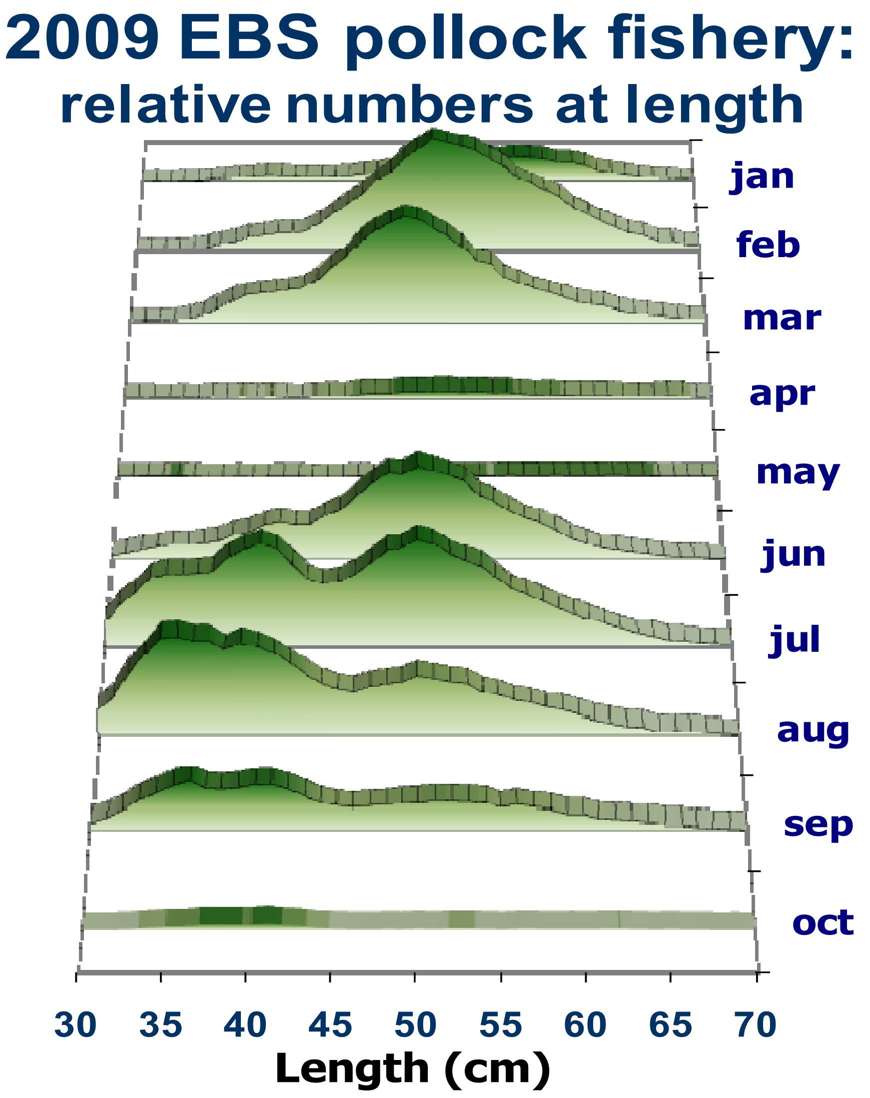


Figure 1.5. Monthly length frequency of EBS pollock as measured by NMFS observers during 2009.

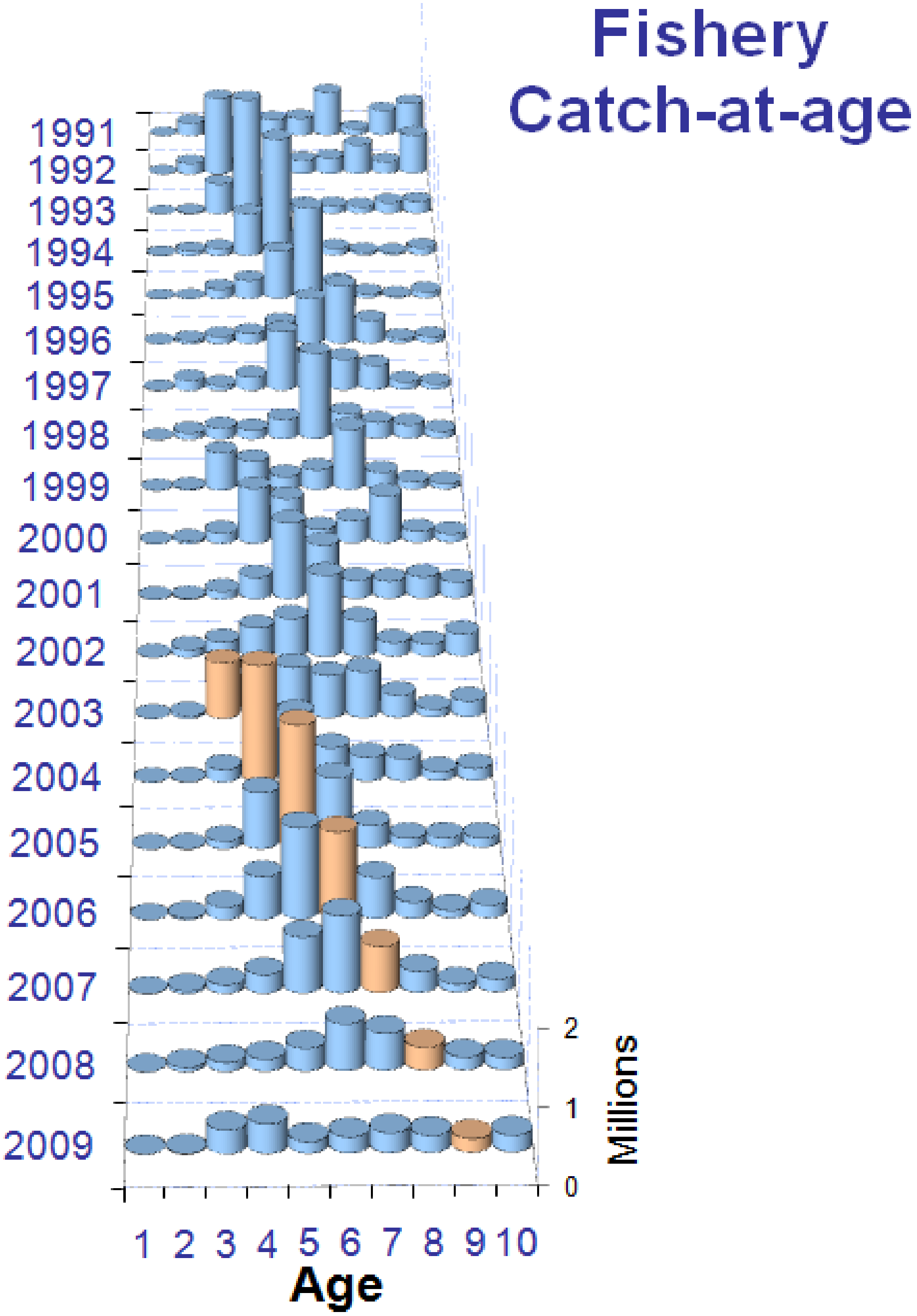


Figure 1.6. EBS pollock fishery estimated catch-at-age data (in number) for 1991-2008. Age 10 represents pollock age 10 and older. *Note: 2009 data are preliminary.*

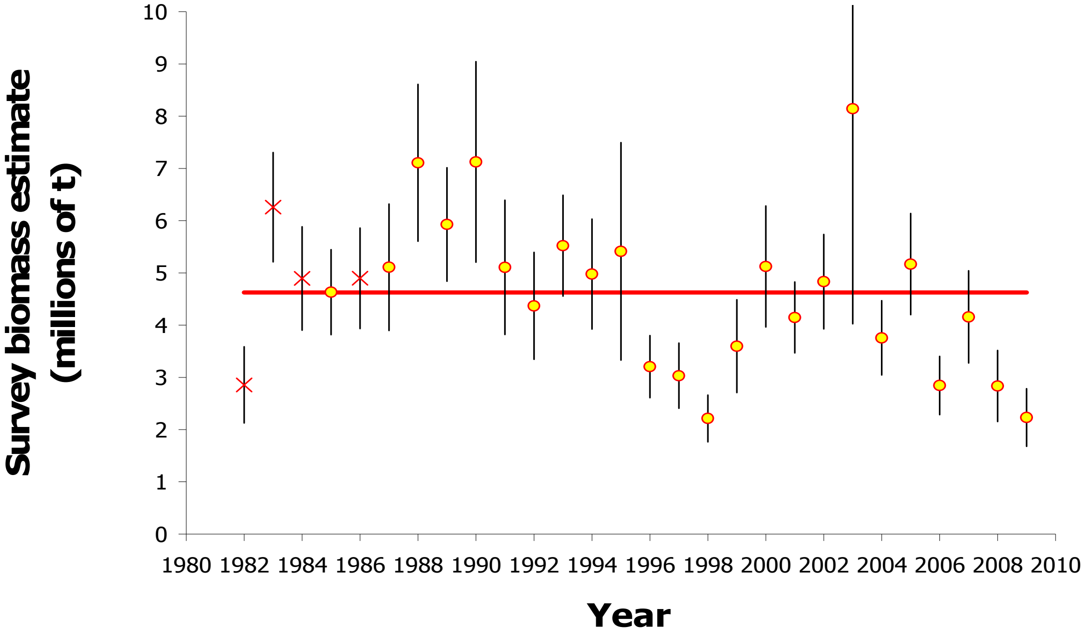


Figure 1.7. Bottom-trawl survey biomass estimates with approximate 95% confidence bounds (based on sampling error) for EBS pollock, 1982-2009. These estimates **include** the northern strata except for 1982-84, and 1986 (years indicated with crosses).

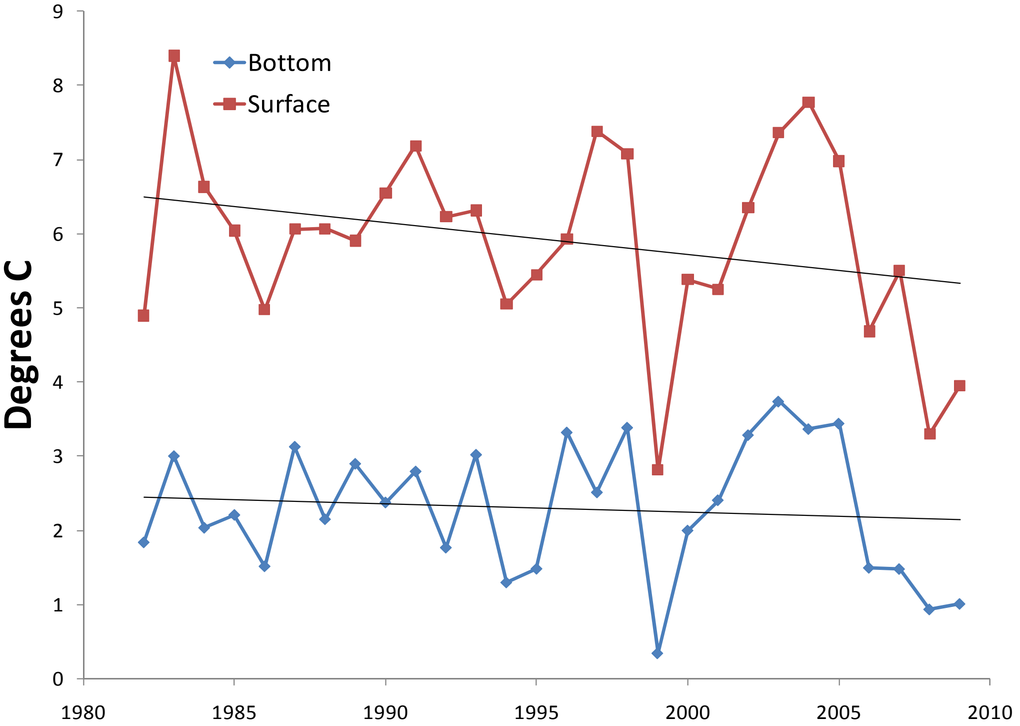


Figure 1.8. Area-weighted bottom and surface temperatures for the Bering Sea during the NMFS summer bottom-trawl surveys (1982-2009).

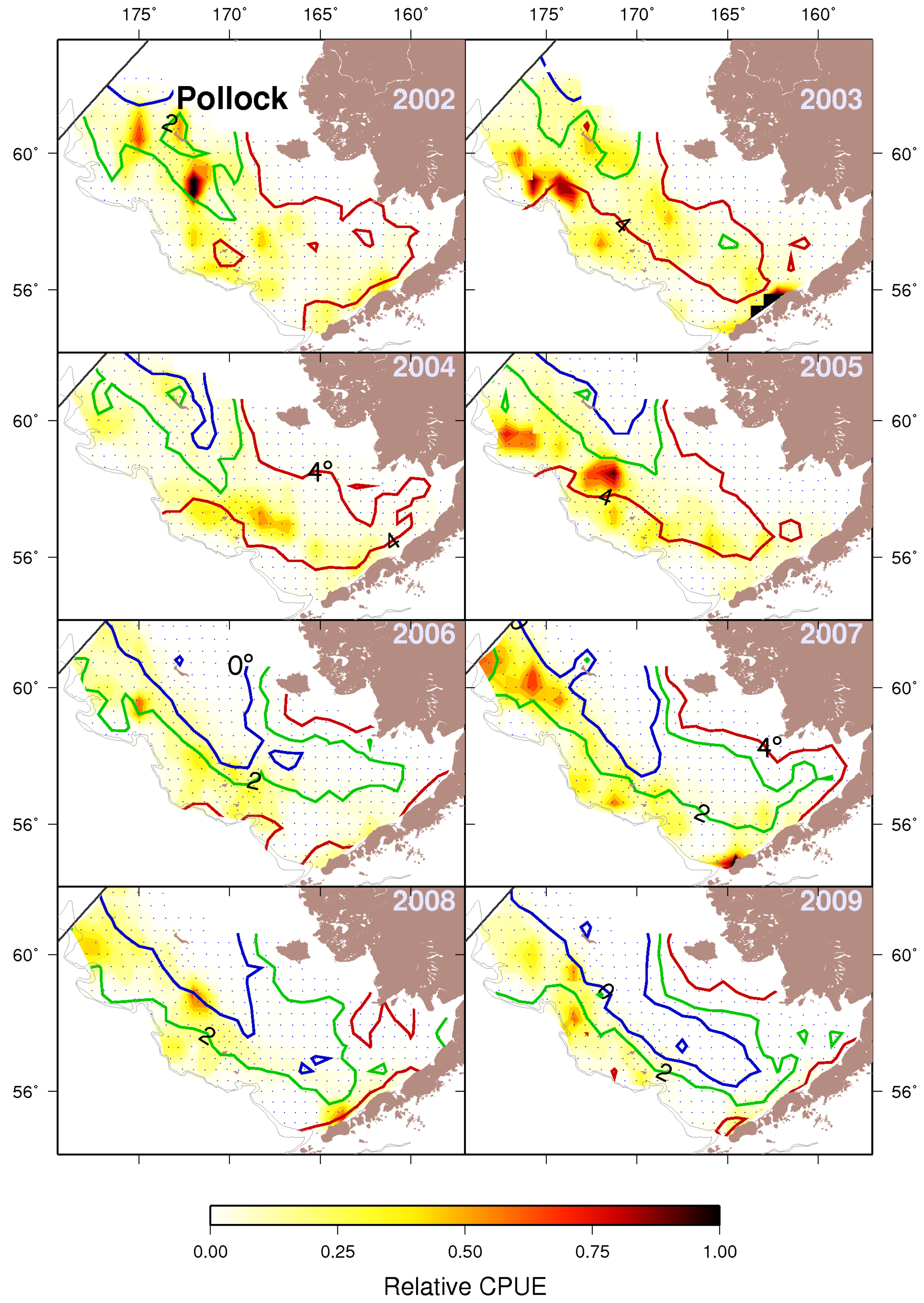


Figure 1.9. EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius from summer bottom-trawl surveys, 2002-2009.

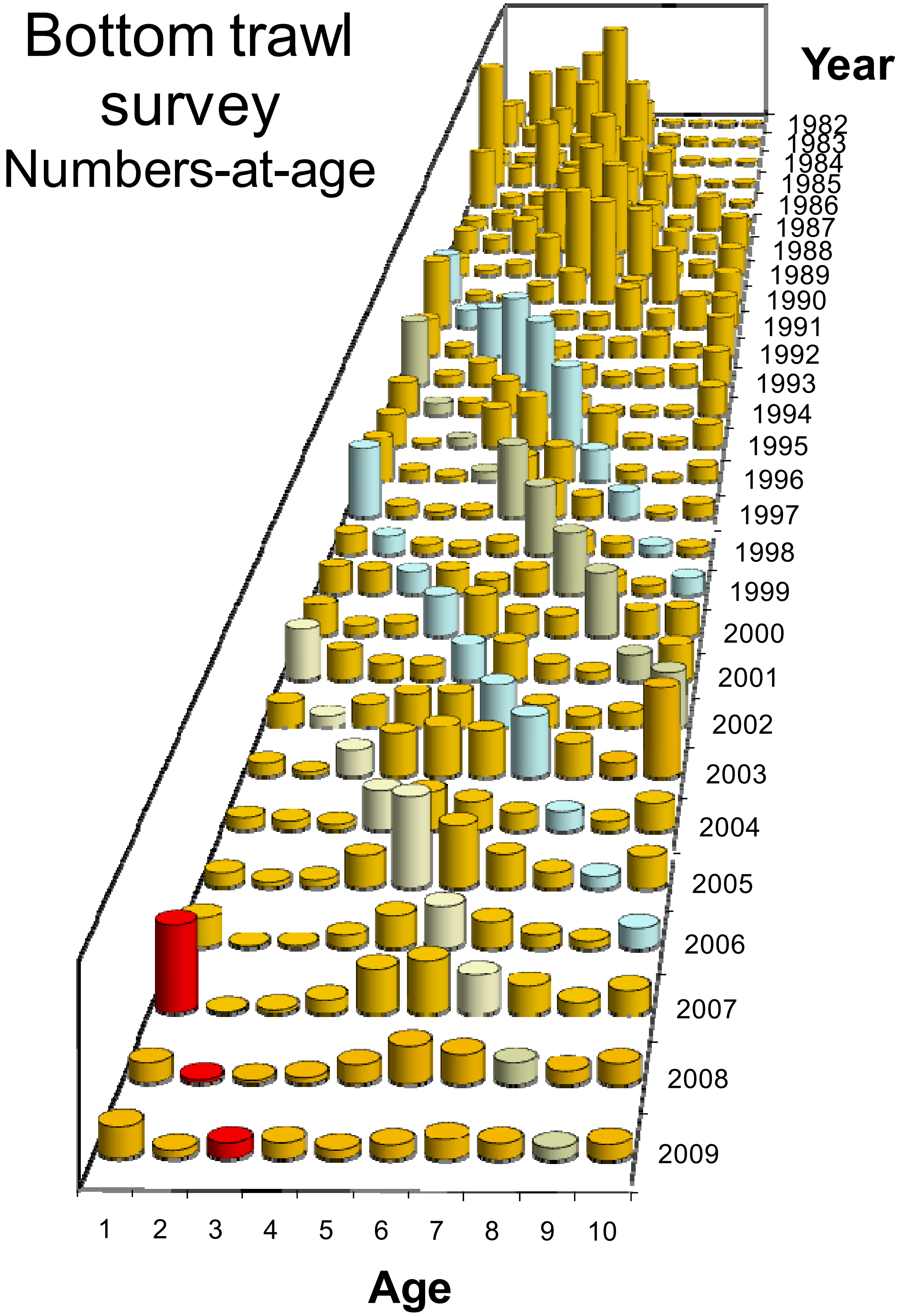


Figure 1.10. Pollock abundance levels by age and year as estimated directly from the NMFS bottom-trawl surveys (1982-2009). The lighter shaded columns represent selected cohorts through time.

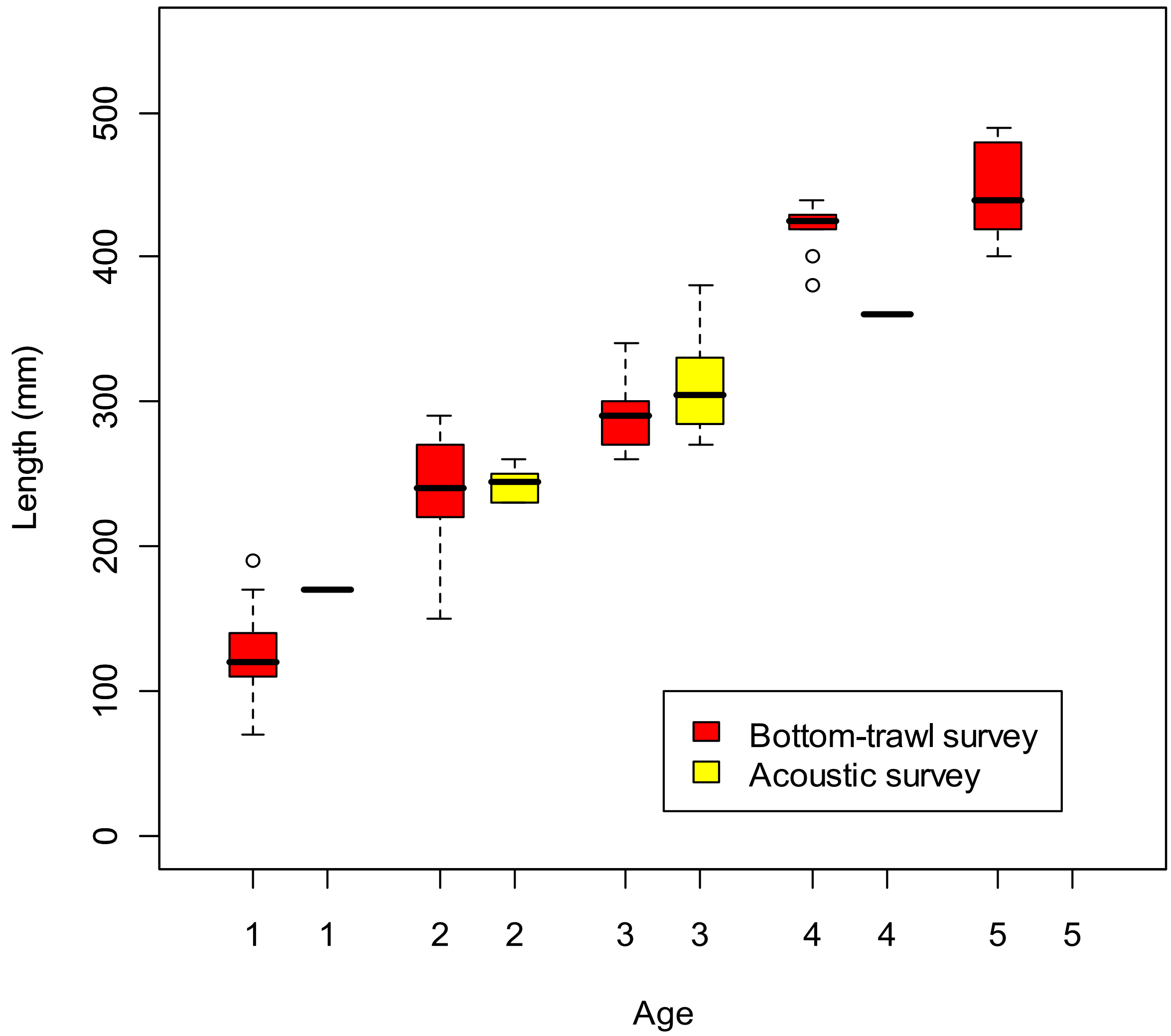


Figure 1.11. Comparisons of age samples collected from the bottom-trawl survey and Echo Integration Trawl data for 2009 EBS shelf pollock.

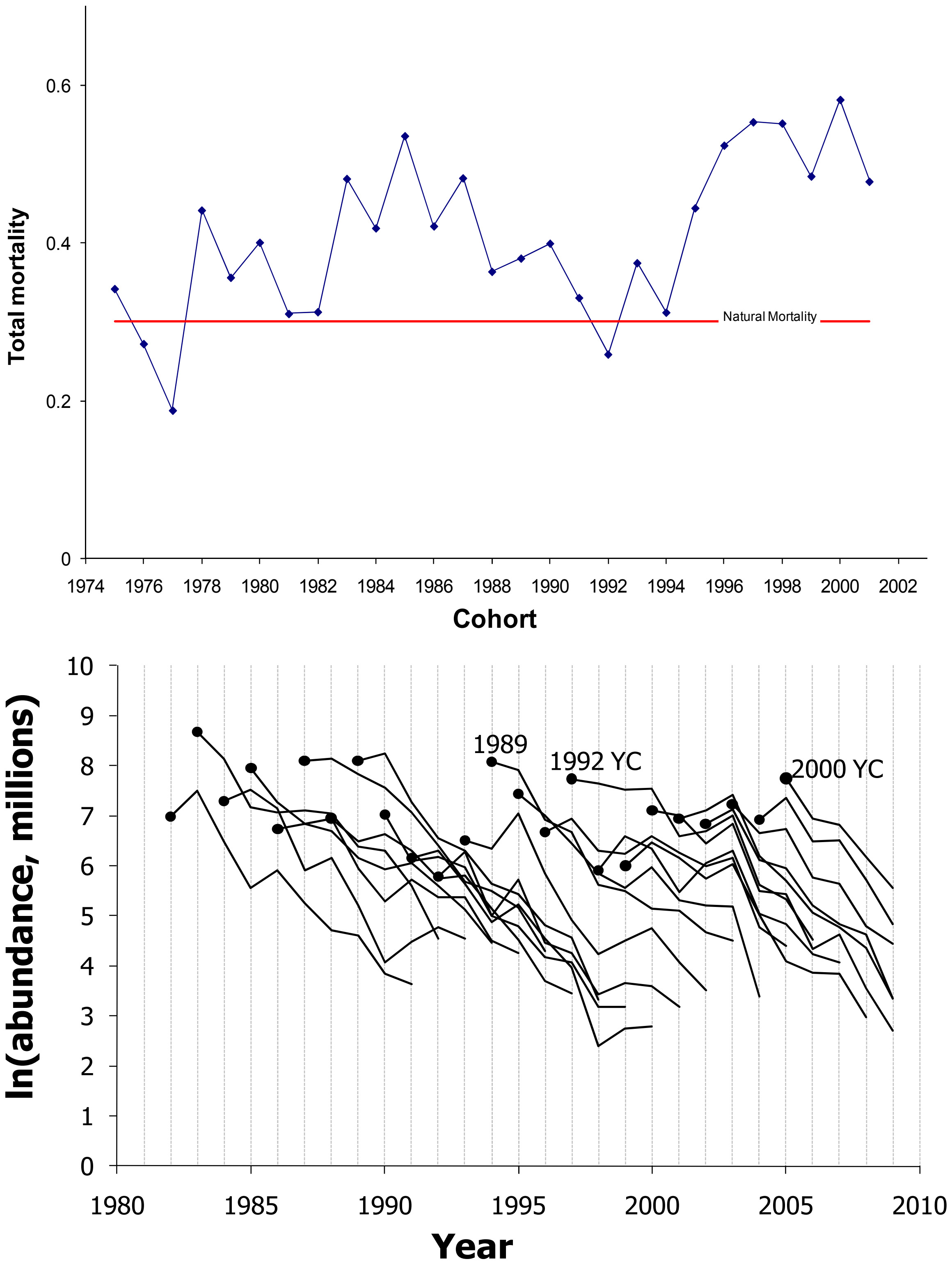


Figure 1.12. Evaluation of EBS pollock cohort abundances as observed for age 6 and older in the NMFS summer bottom trawl surveys. The bottom panel shows the raw log-abundances at age while the top panel shows the estimates of total mortality by cohort.

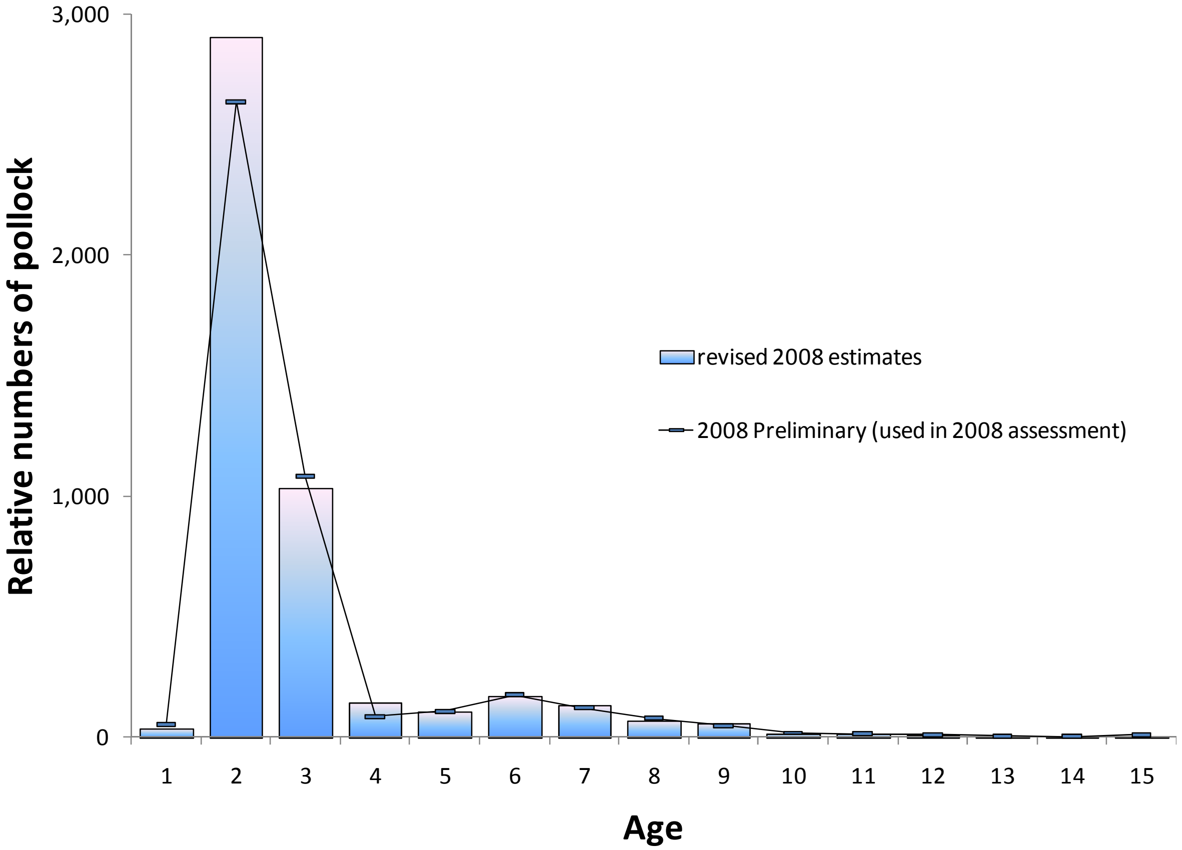


Figure 1.13. Echo-integration trawl survey 2008 age data used in the 2008 assessment (as preliminary numbers) compared to revised values used in the present assessment (columns). The revised estimates use age-samples collected only from the acoustic trawl survey whereas the preliminary data used in the 2008 assessment were derived from samples collected from the 2008 bottom-trawl survey.

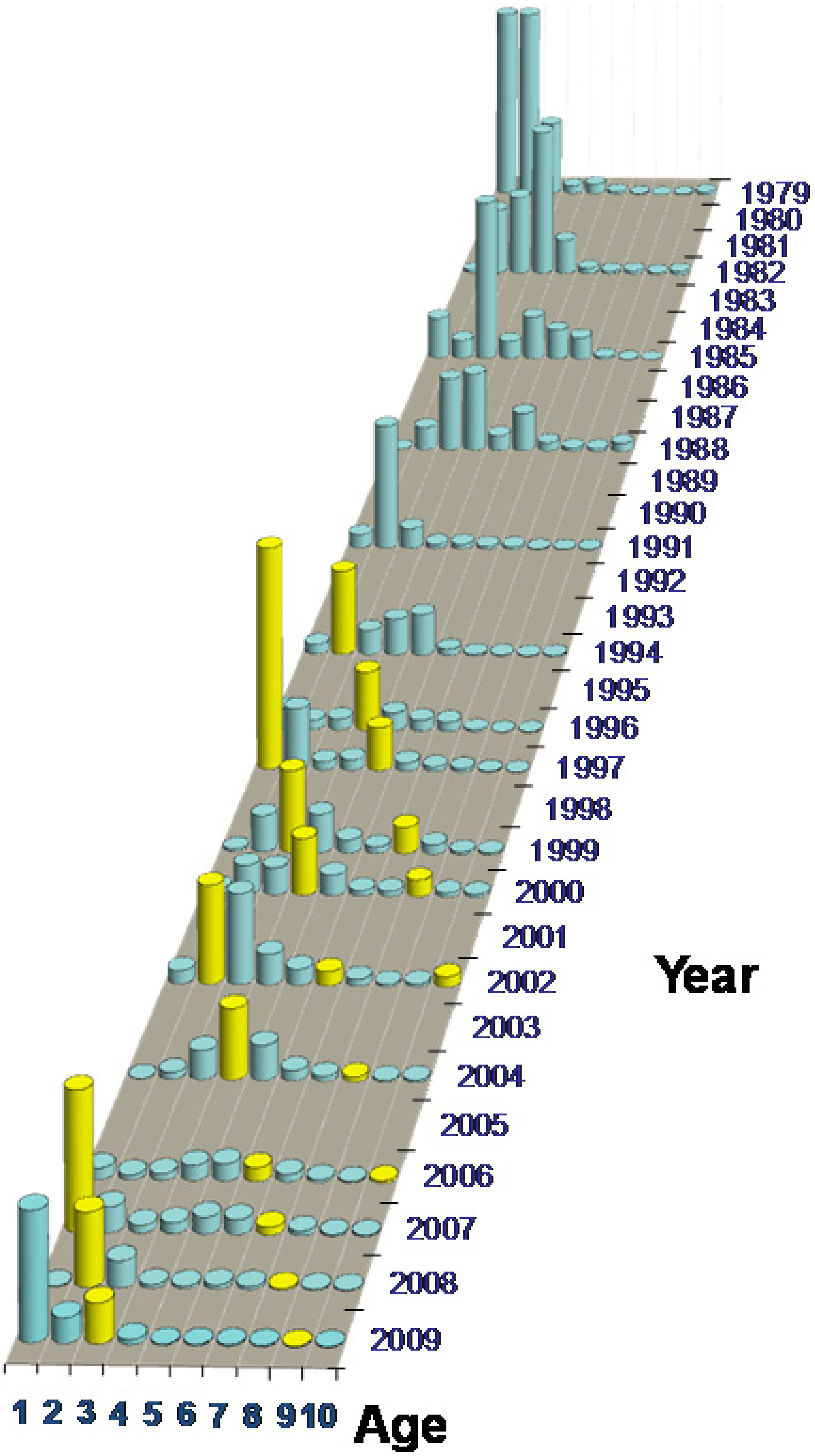


Figure 1.14. Time series of estimated abundances at age (numbers) for EBS pollock from the EIT surveys, 1979-2009. Note that the 2009 age compositions were computed using an age-length key derived from the 2009 BTS data and as such, are preliminary.

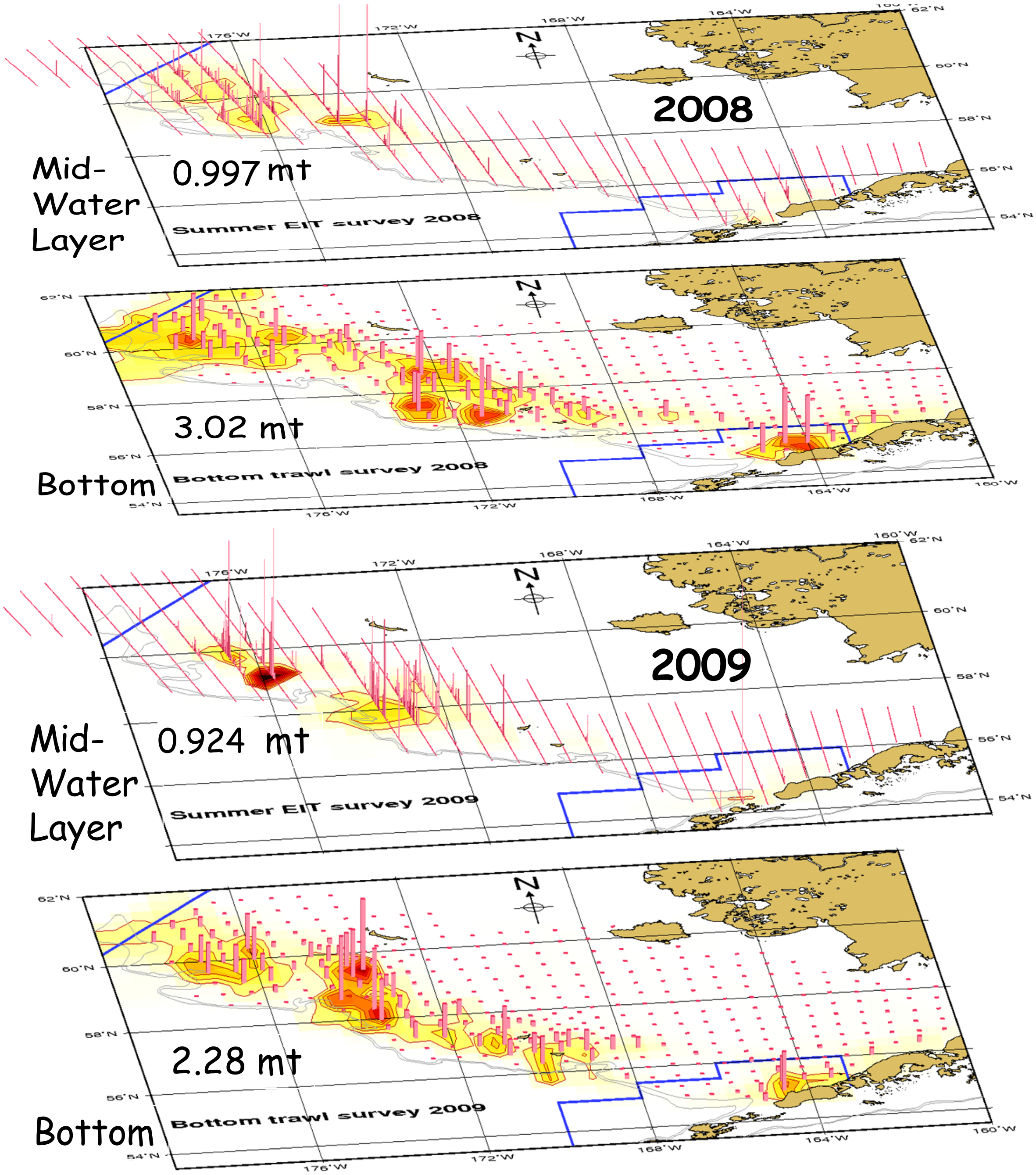


Figure 1.15. Echo-integration trawl survey results for 2008 and 2009. The lower figure is the result from the BTS data in the same years. Vertical lines represent biomass of pollock as observed in the different surveys (mt = millions of t).

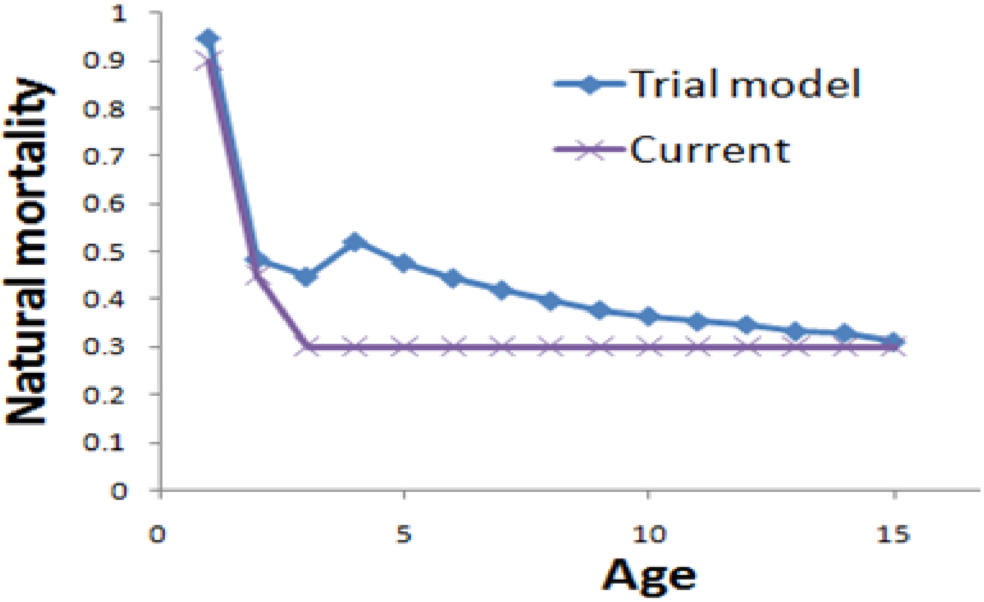


Figure 1.16. Natural mortality –at-age vectors estimated using biological model compared with the vector that has traditionally been used for the EBS pollock stock assessment.

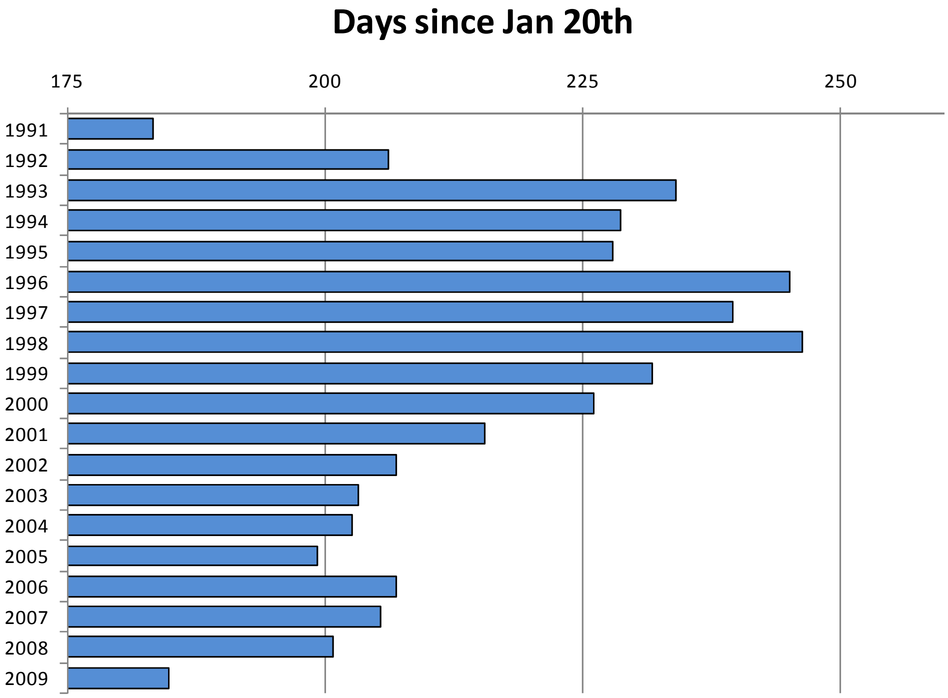


Figure 1.17. EBS pollock catch-weighted mean date of the fishery (measured as the number of days since Jan 20th in each year) based on raw observer data, 1991-2009 (2009 data preliminary as of September 28th 2009).

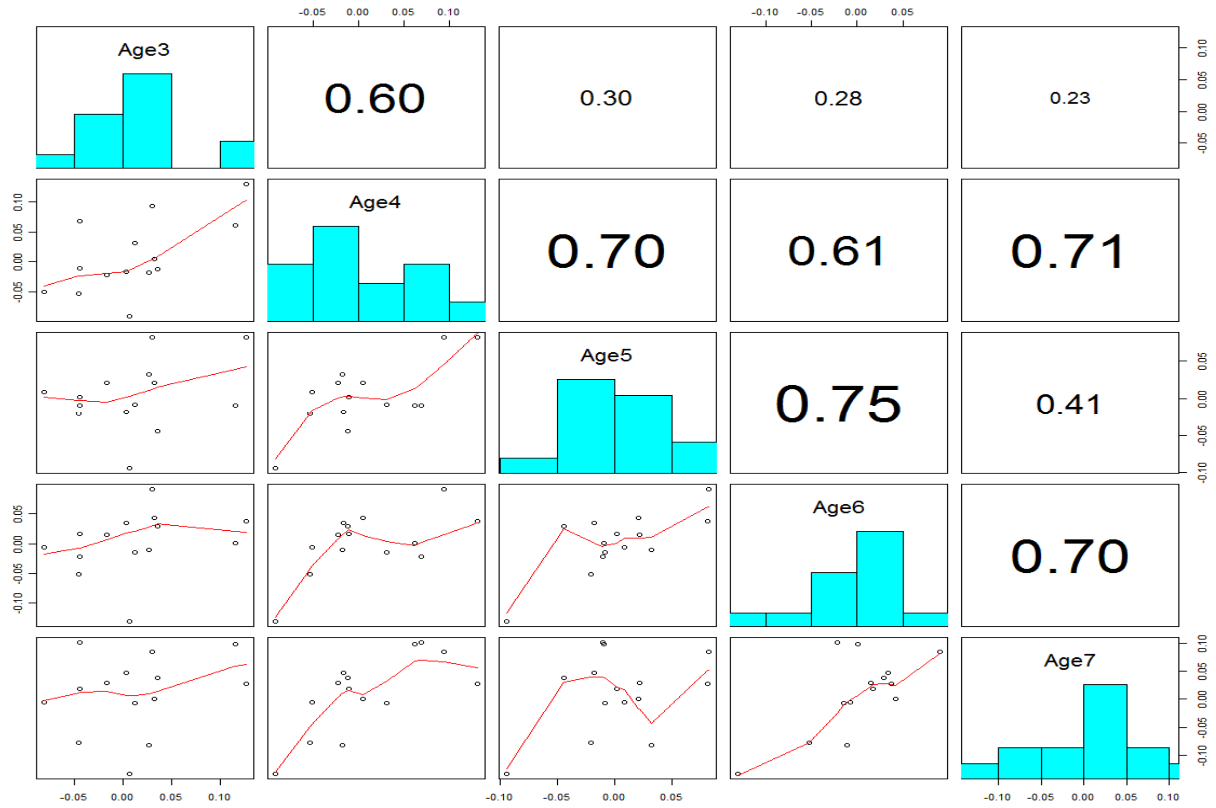


Figure 1.18. Pairwise plots of lagged residuals (relative to long-term means) for EBS pollock ages 3 through 7. Lower triangle shows points with smoothed line fit and the upper triangle shows the correlation coefficients. Residuals are lagged to track cohorts. E.g., the age 4 residual for 2003 is compared to the age 6 residual in 2005 (and the age 5 residual from 2004).

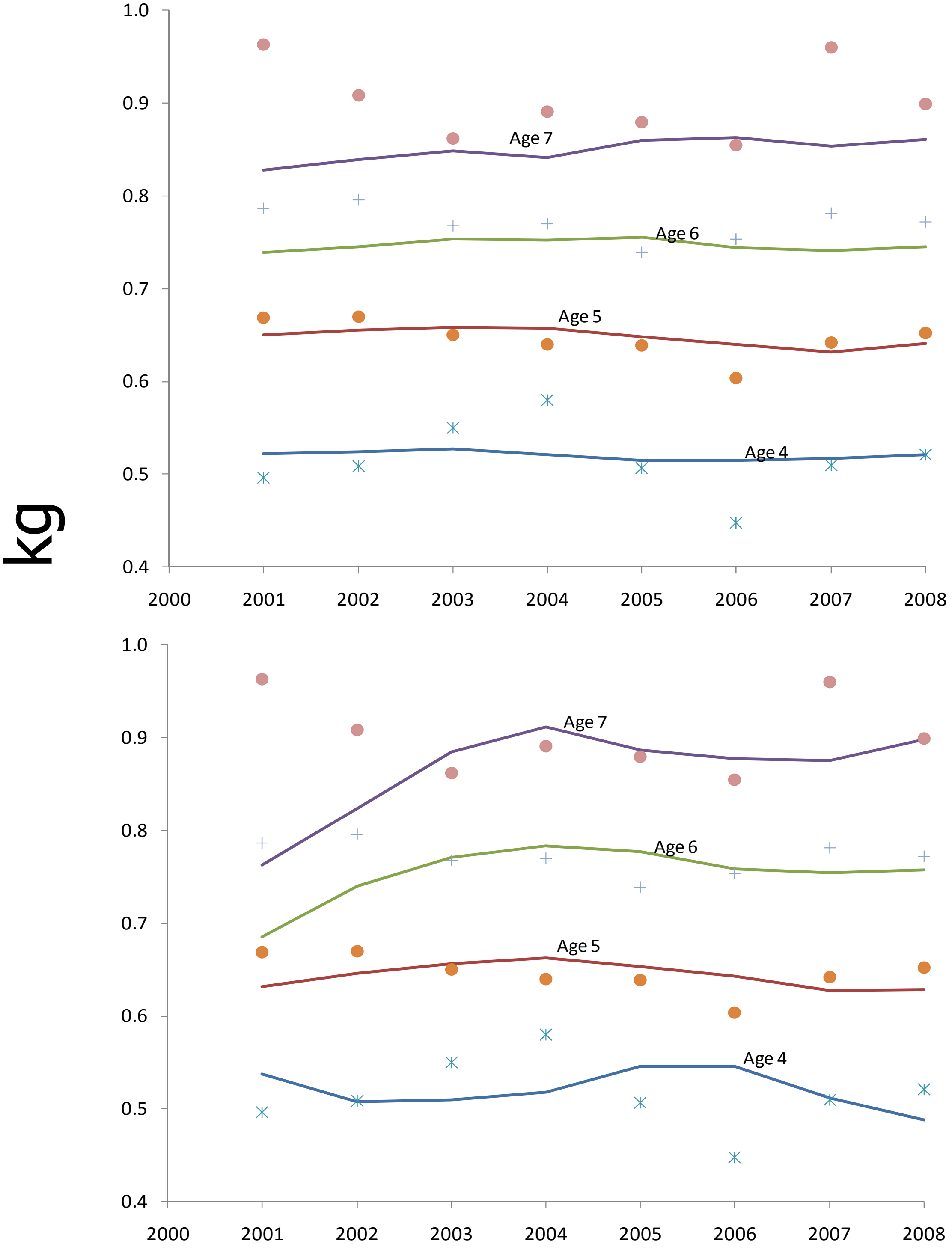


Figure 1.19. Projections of fishery mean weights-at-age (ages 4 – 7) for EBS pollock using the most recent 10-year average (i.e., data from 1991-2000 to estimate the values for 2001), top panel compared to projections using the most recent 3-year average (i.e., data from 1998-2000 to estimate values for 2001), bottom panel.

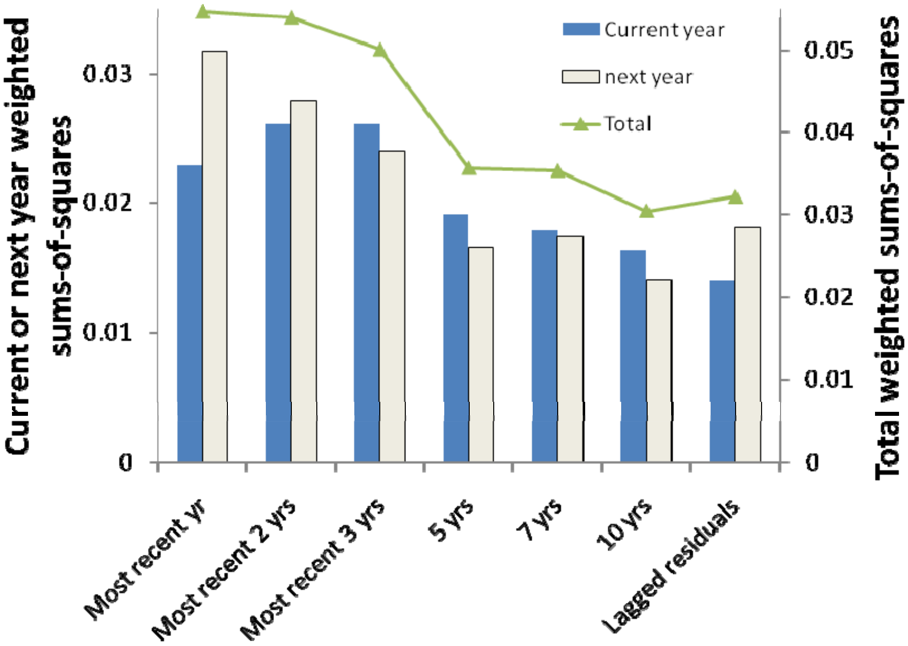


Figure 1.20. EBS pollock sums of importance-weighted squared residuals for predicting out-of-sample fishery mean weights-at-age. The approach labeled "Lagged residuals" uses prior-years' residual patterns for prediction.

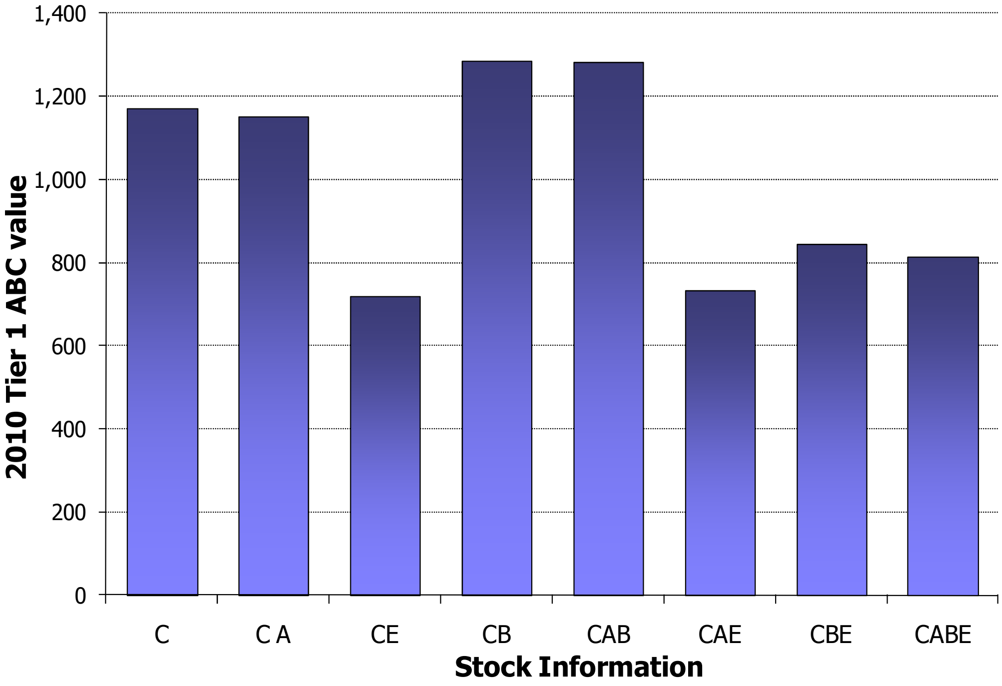


Figure 1.21. The impact of introducing new data to the assessment model on Tier 1 ABC values for 2010 (key: fishery **C**atch, fishery **A**ge, **B**ottom-trawl survey data, and **E**cho-integration trawl data.

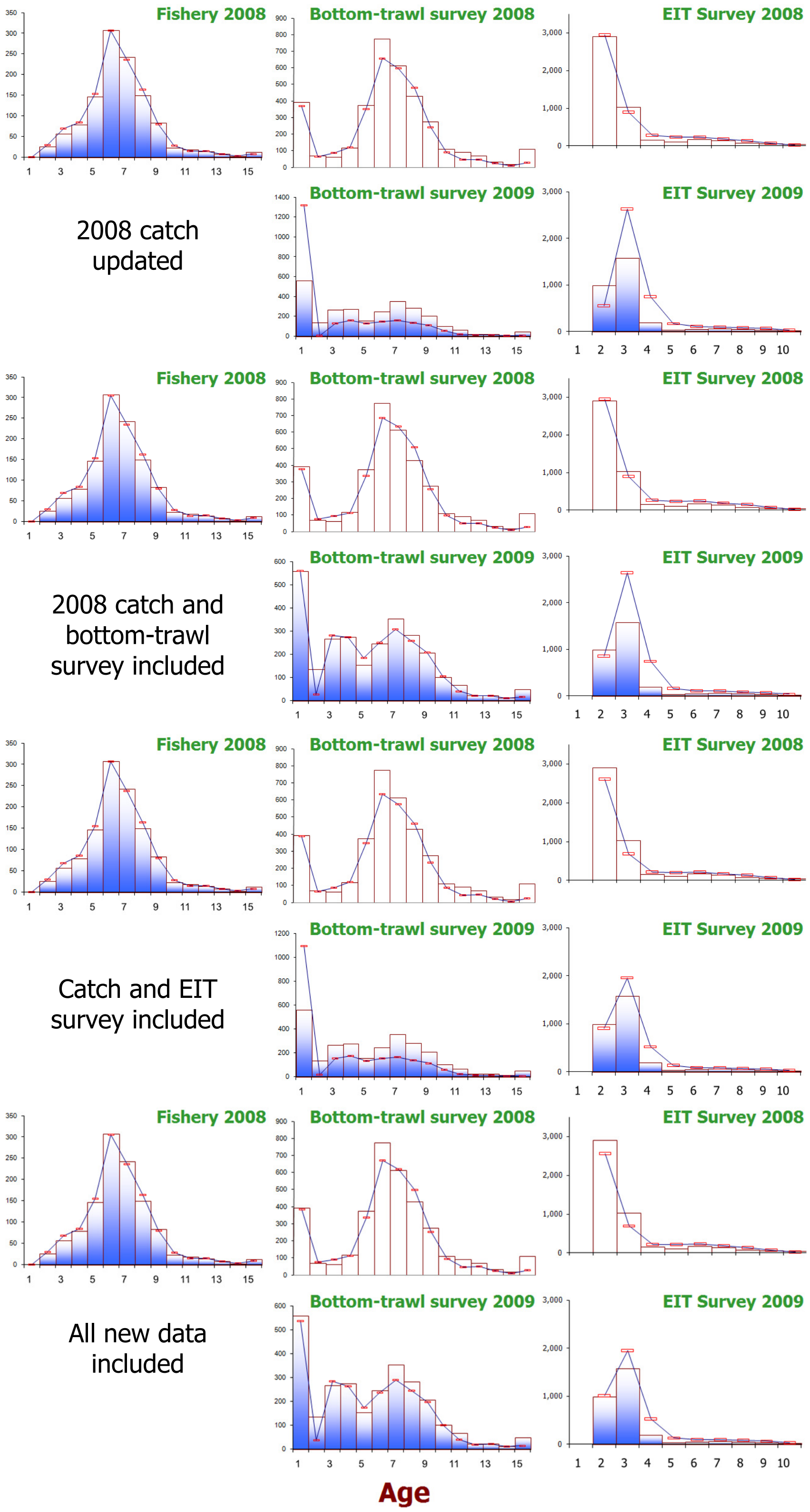


Figure 1.22. Model results of predicted EBS pollock numbers-at-age as new data were added. Columns represent the data, lines represent model predictions. Shaded columns indicate data introduced in the current assessment.

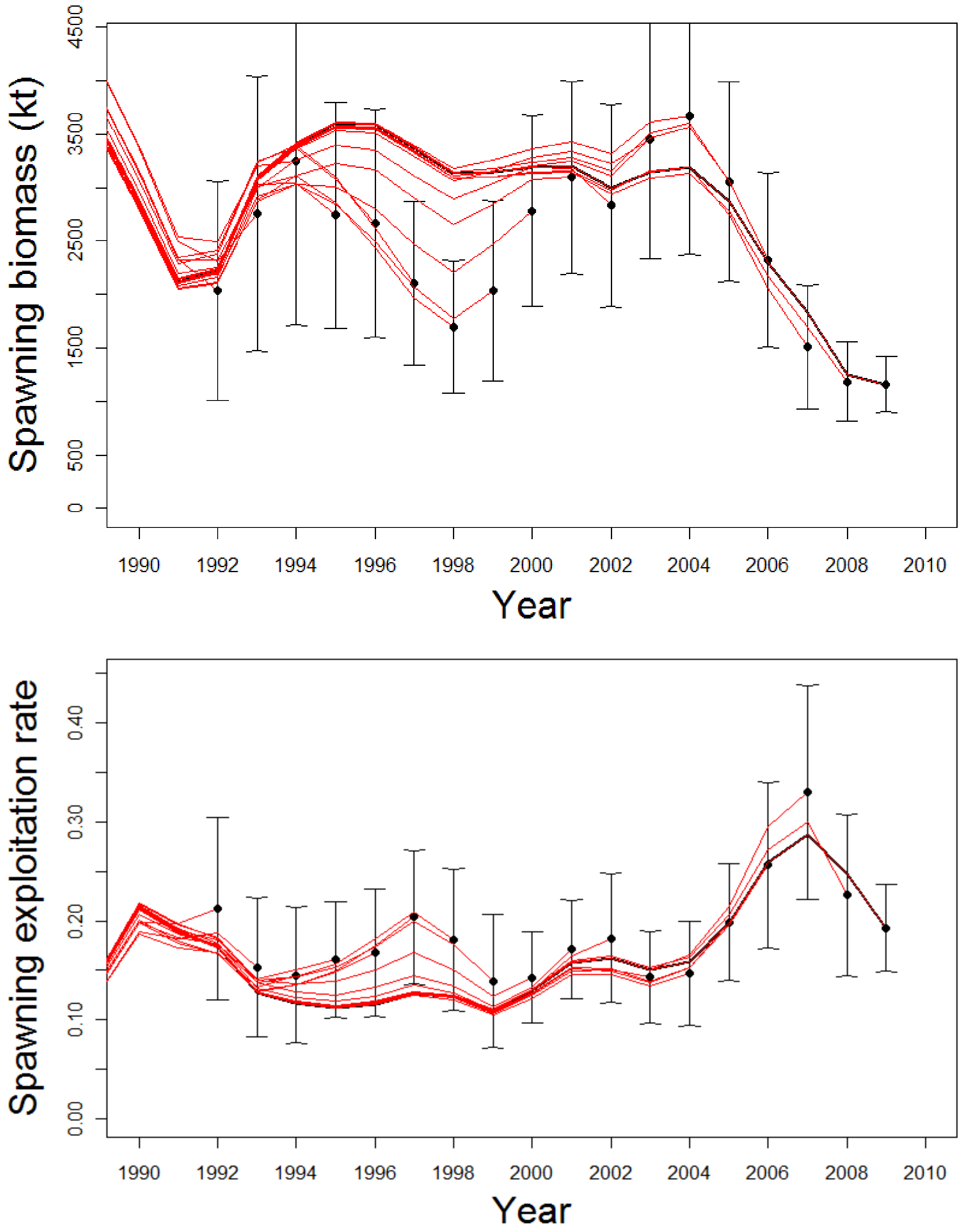


Figure 1.23. Retrospective analysis showing terminal-year error-bars (with dots) from 1992-2009 for spawning biomass (top) and spawning exploitation rate (bottom). For each of the 18 runs the same model configuration was used to re-estimate values with 1 year less data.

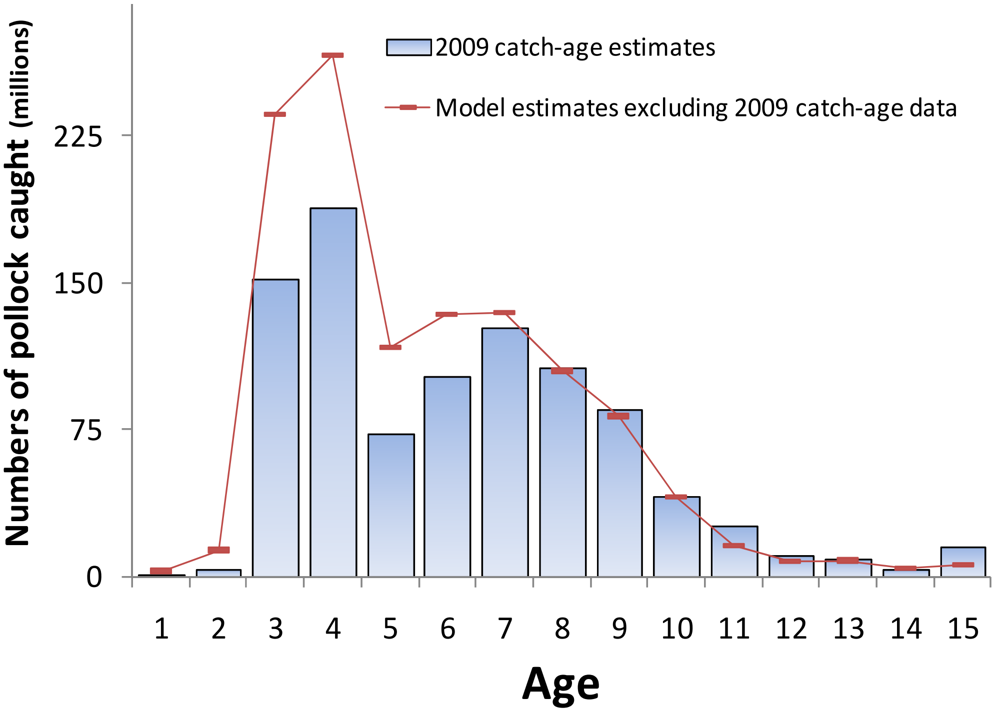


Figure 1.24. Model comparison of estimated 2009 catch-at-age with estimates of 2009 catch-at-age made using 2009 A-season fishery data and age-length keys developed using 2009 summer bottom-trawl survey age data (fishery samples collected by observers during the summer and fall were unavailable until early the following year).

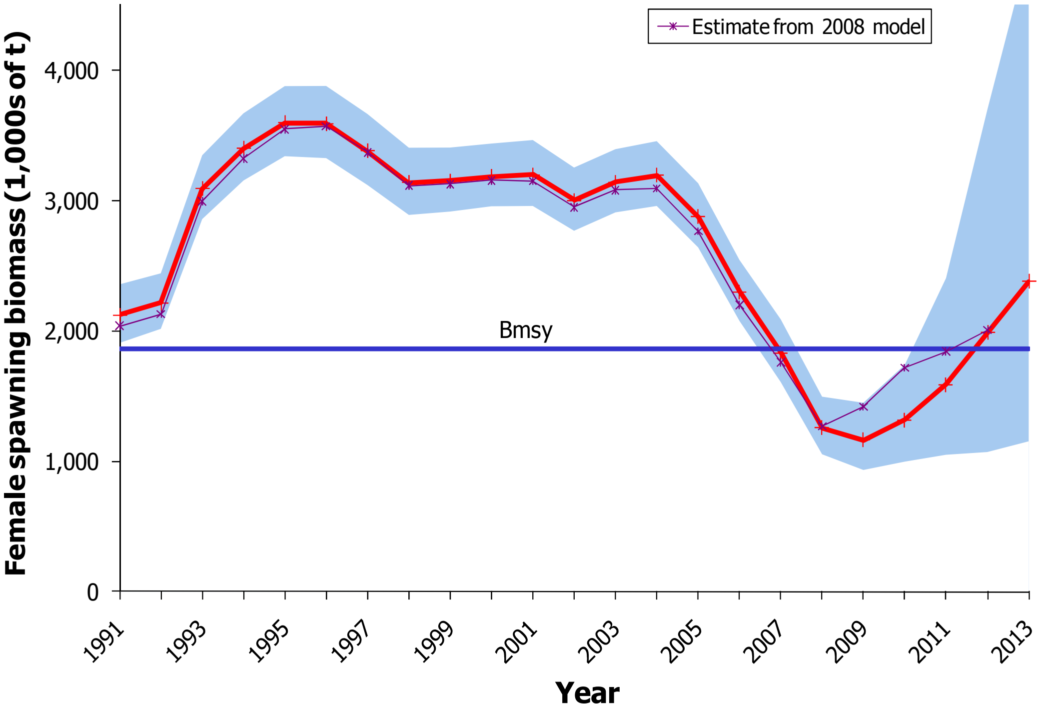


Figure 1.25. Estimated female spawning biomass and approximate 95% confidence intervals compared to estimates from the Ianelli et al. (2008) shown in the thin marked line.

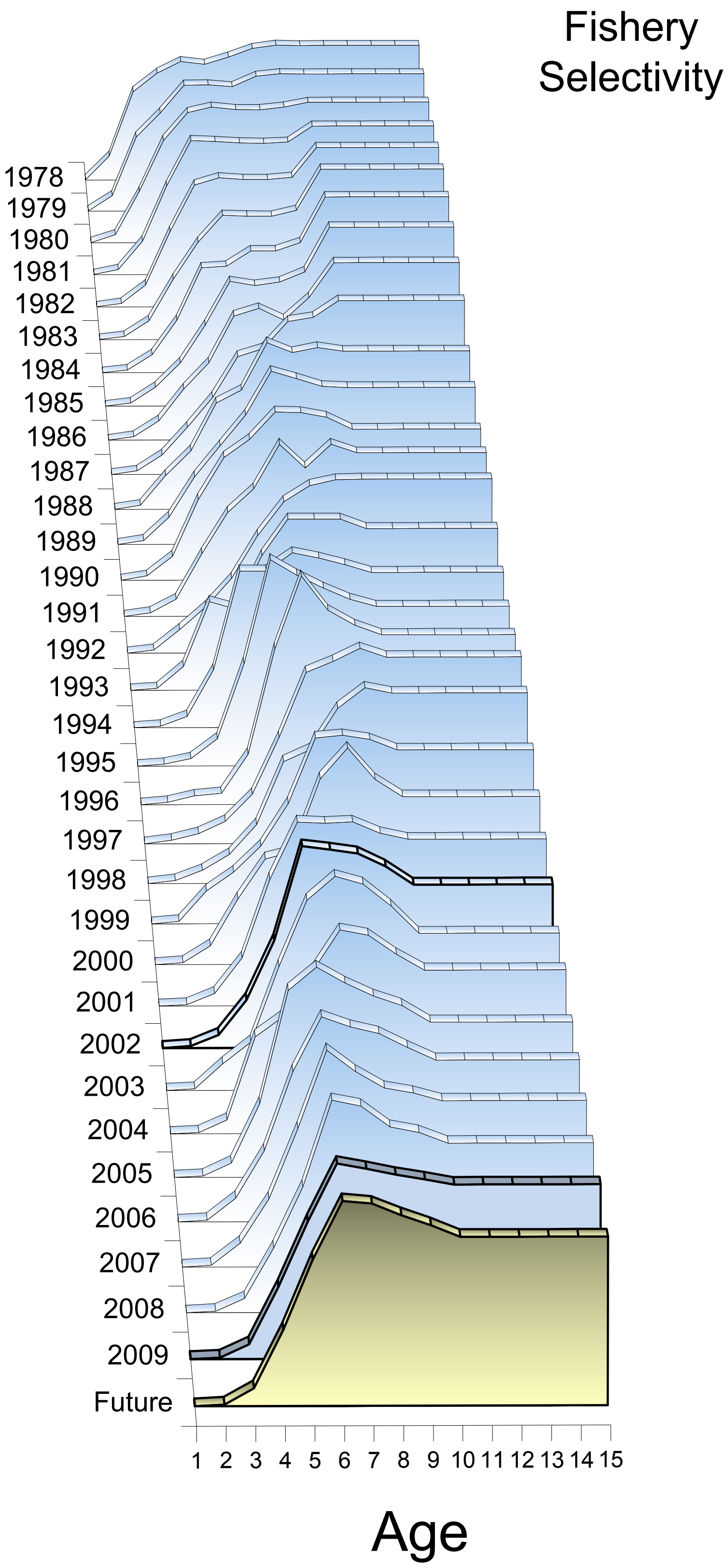


Figure 1.26. Selectivity at age estimates for the EBS pollock fishery, 1978-2009 including the estimates used for the future yield considerations.

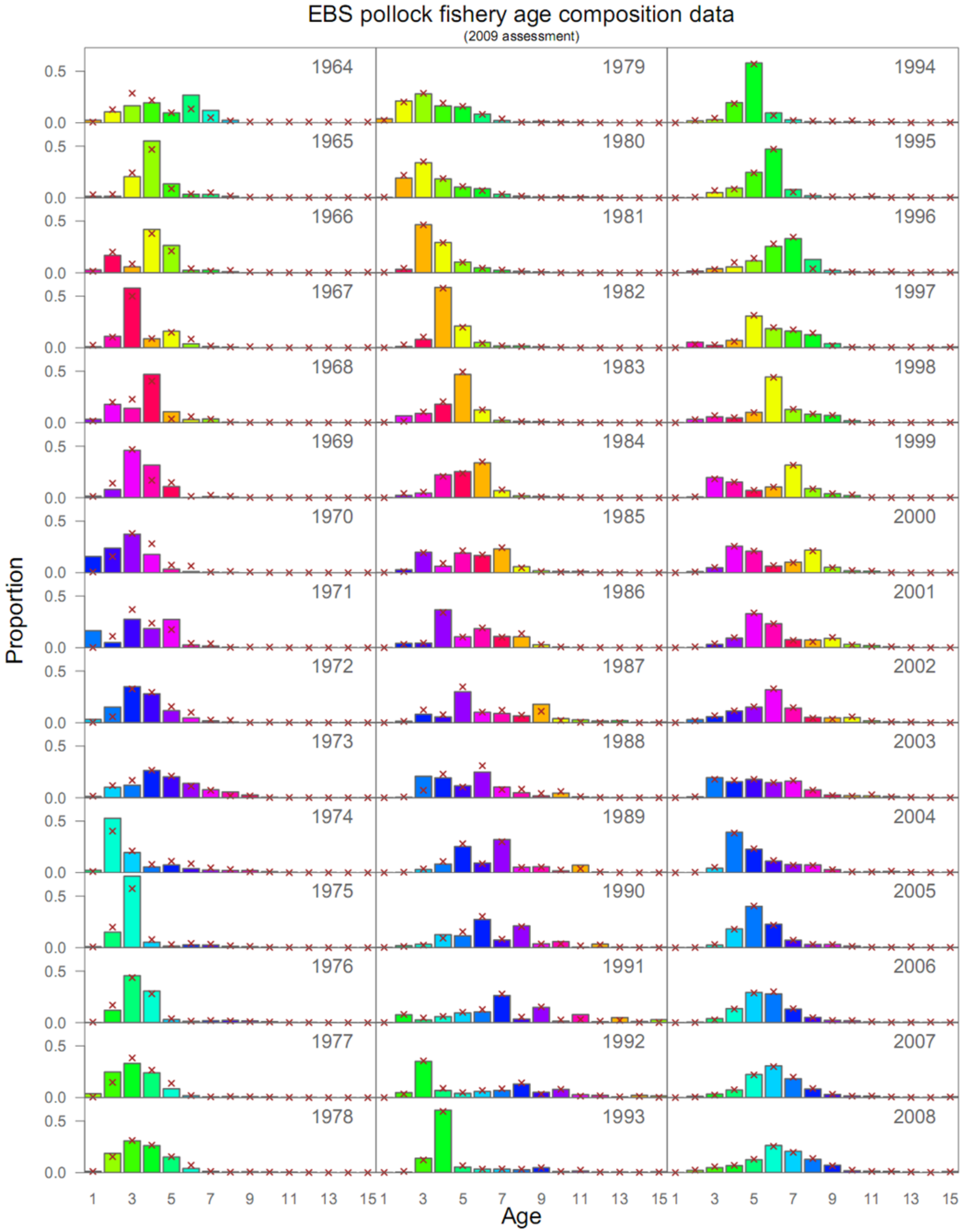


Figure 1.27. Fit to the EBS pollock fishery proportion-at-age estimates (1964-2008). Crosses represent model predictions while the vertical columns represent the data. The 2008 data are new to this year's assessment. Colors coincide with cohorts progressing through time.

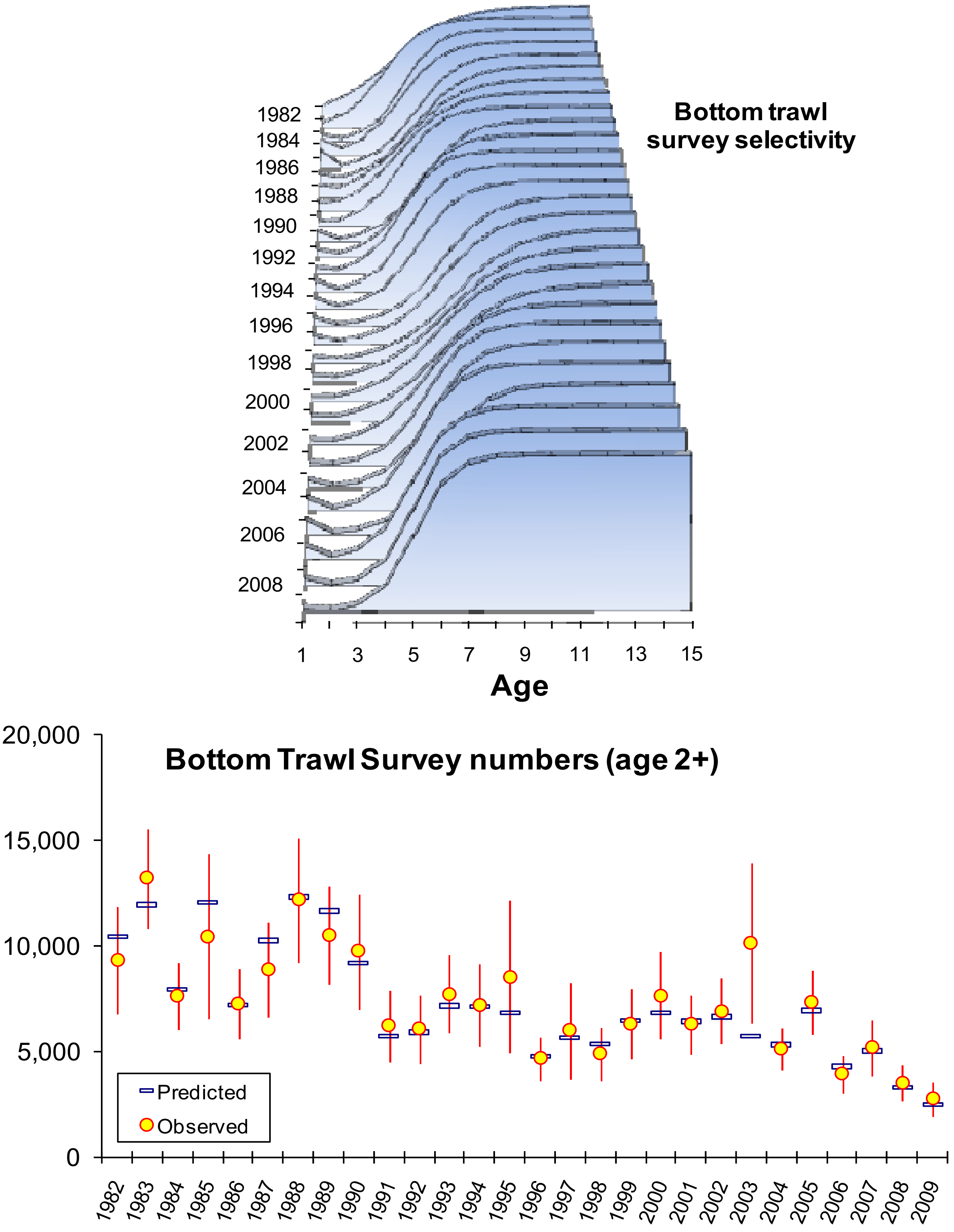


Figure 1.28. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS pollock, 1982-2009.

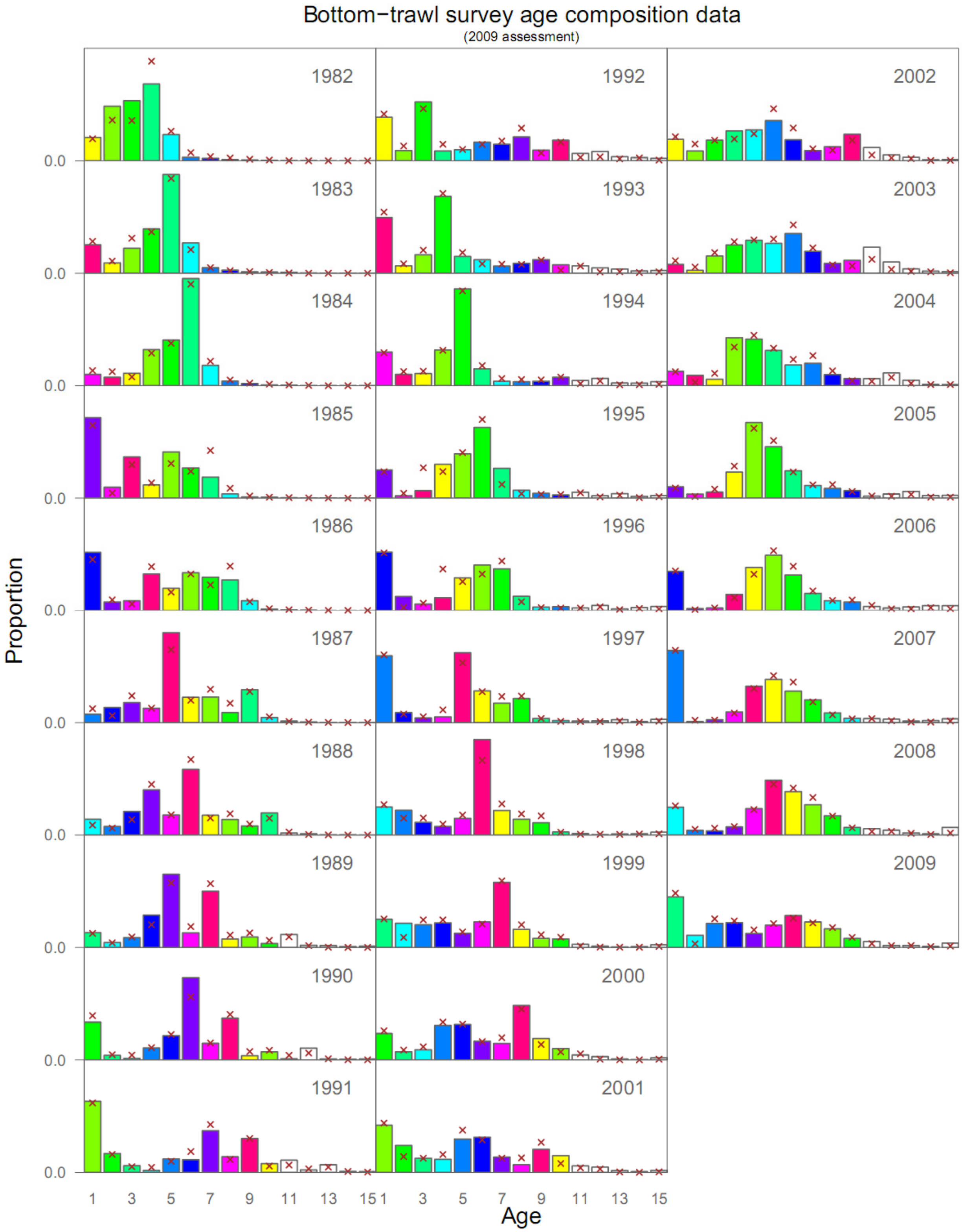


Figure 1.29. Fit to the bottom trawl survey age composition data (proportions) for EBS pollock. Crosses represent model predictions while the vertical columns represent the data (colors correspond to cohorts over time). Data new to this assessment are from 2009.

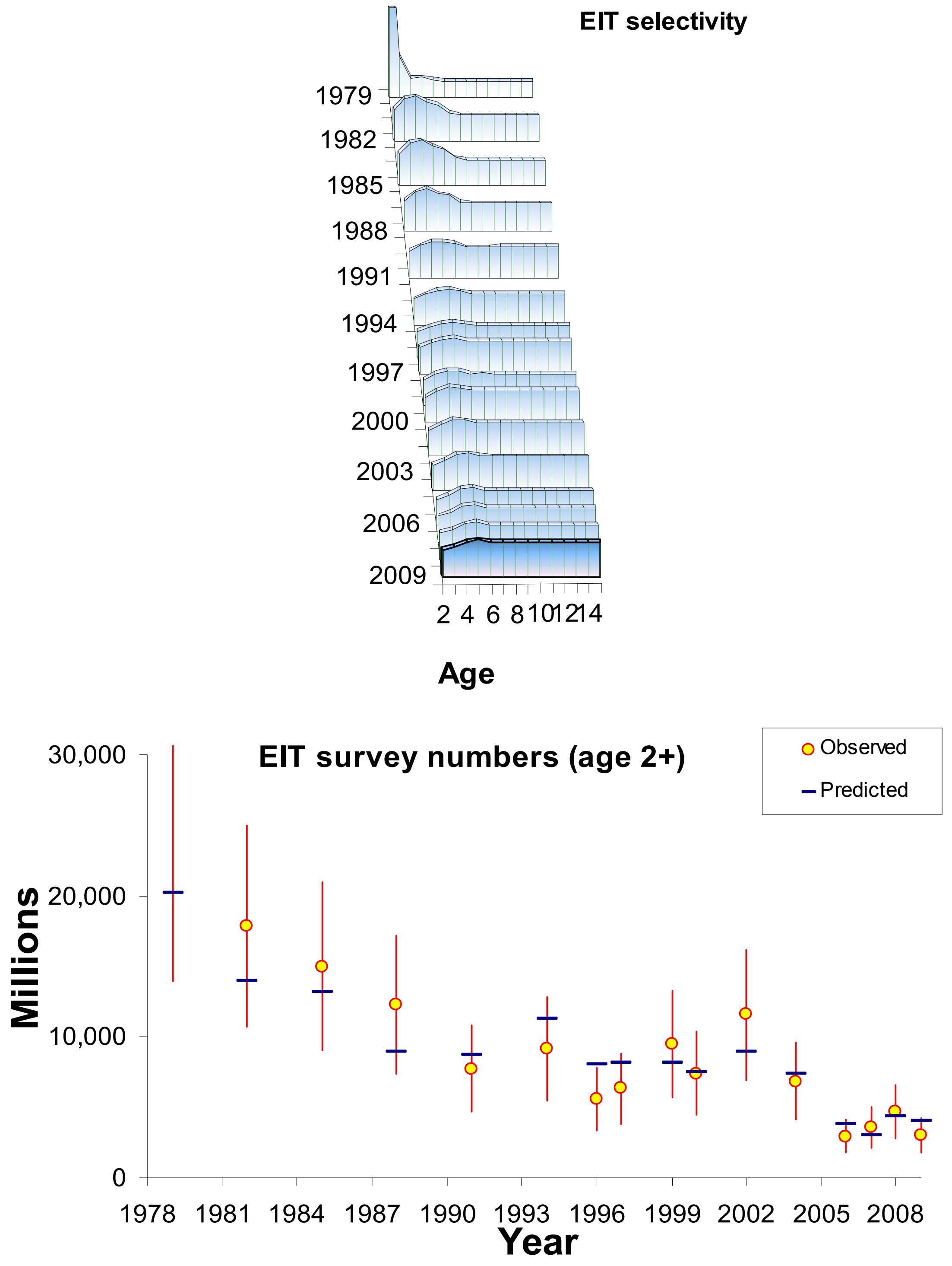


Figure 1.30. Estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS pollock age 2 and older. Note that the 1979 observed value (=46,314) is off the scale of the figure.

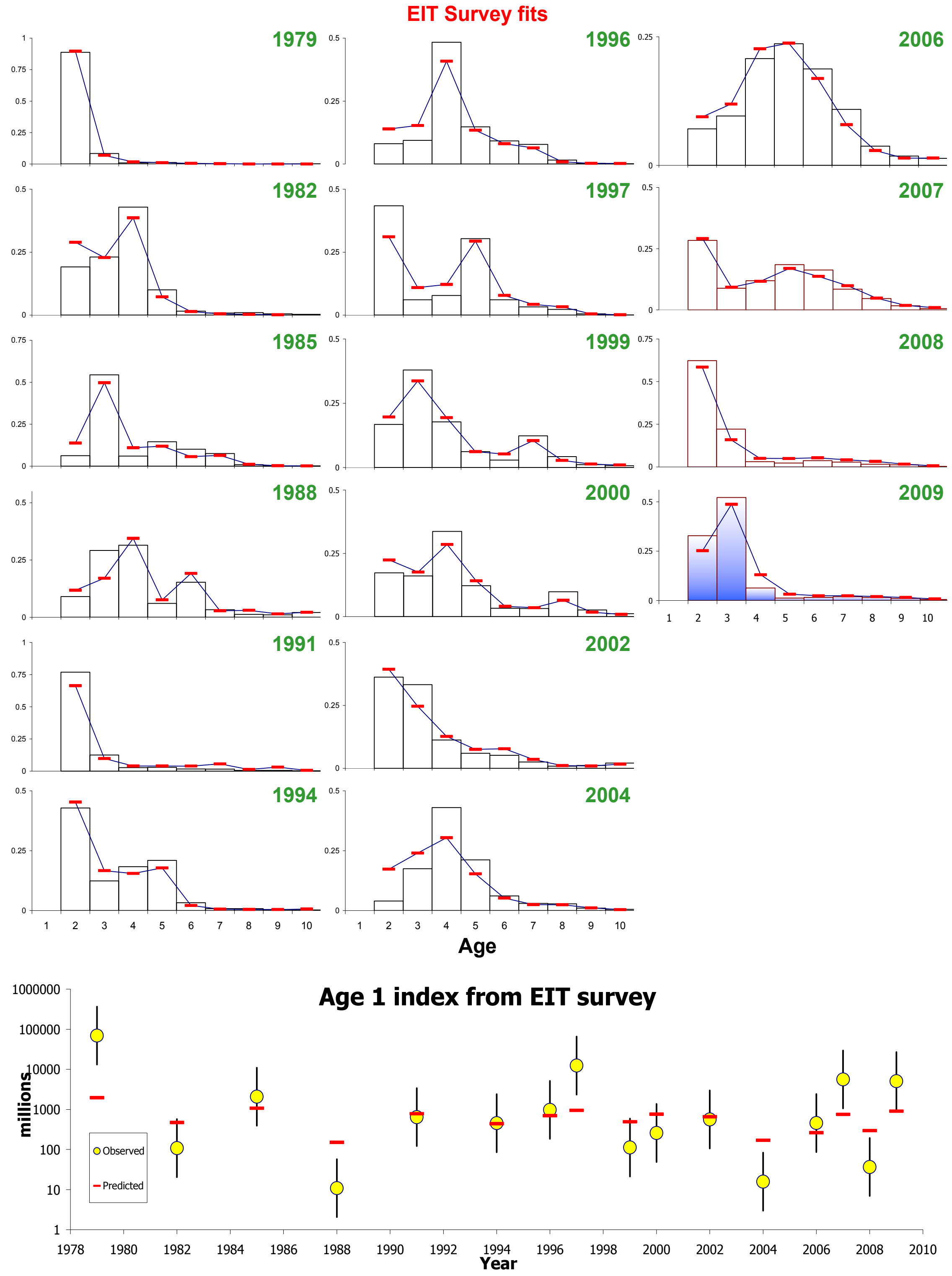


Figure 1.31. Fit to the EIT survey EBS pollock age composition data (proportions) and age 1 index (bottom panel; log-scale). Lines represent model predictions while the vertical columns and dots represent data. The 2009 age composition data are new to the assessment are shaded and the 2008 data were based on revised values using EIT age-length keys.

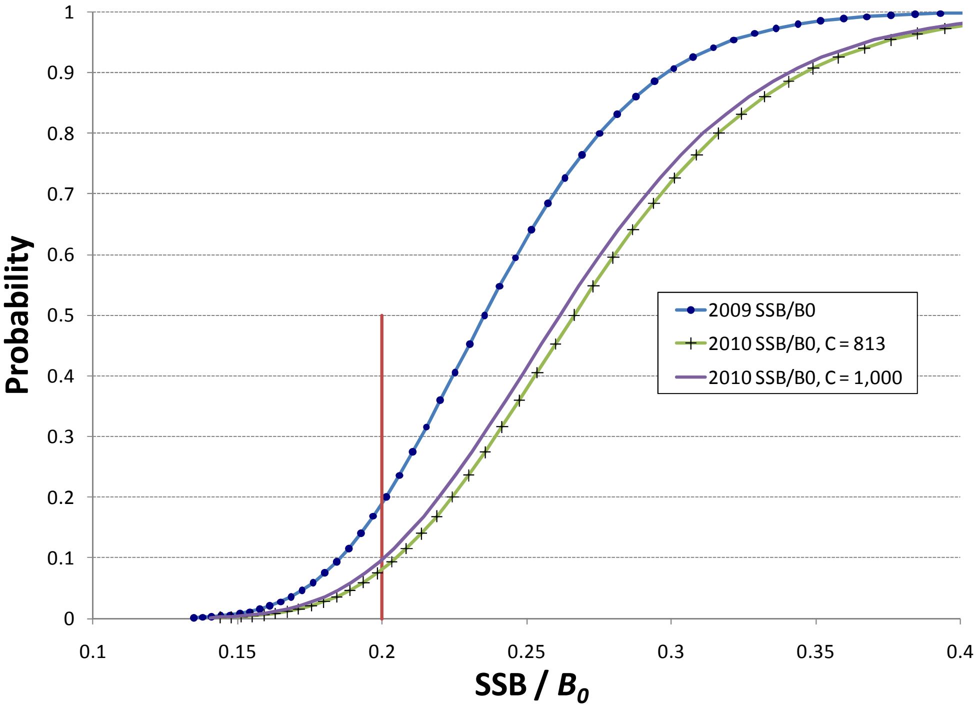


Figure 1.32. Cumulative probability estimates of 2009 and 2010 stock sizes relative to B_0 for EBS pollock under catch levels of 813 kt and 1,000 kt. Note that these reflect the estimation uncertainty of stock status (for uncertainty of future point estimates see Fig. 1.42).

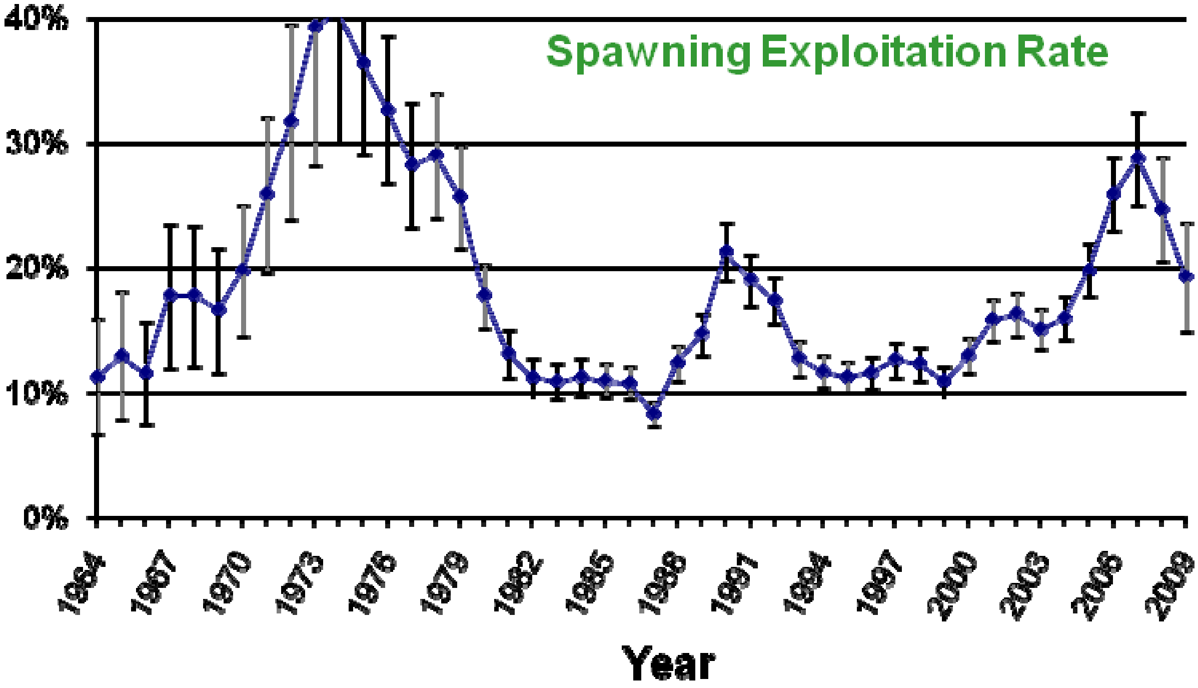


Figure 1.33. Estimated spawning exploitation rate (defined as the annual percent removals of spawning females due to the fishery) for EBS pollock, 1964-2009. Error bars represent two standard deviations from the estimates.

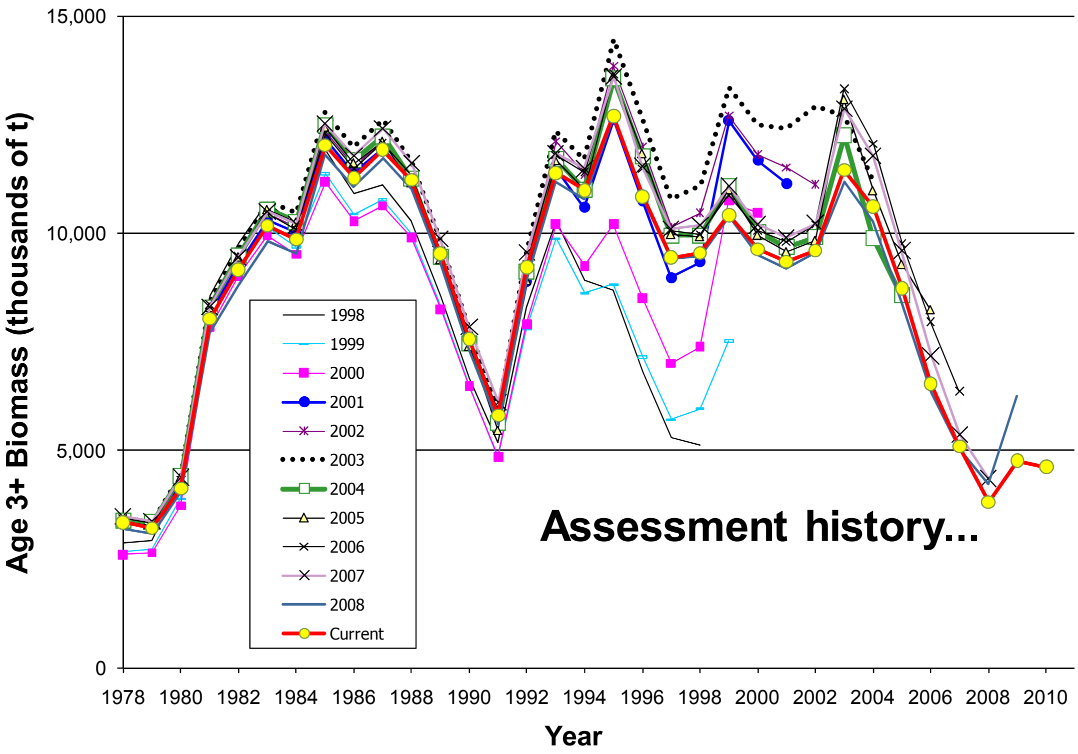


Figure 1.34. Comparison of the current assessment results with past assessments of **begin-year** EBS age-3+ pollock biomass, 1978-2010.

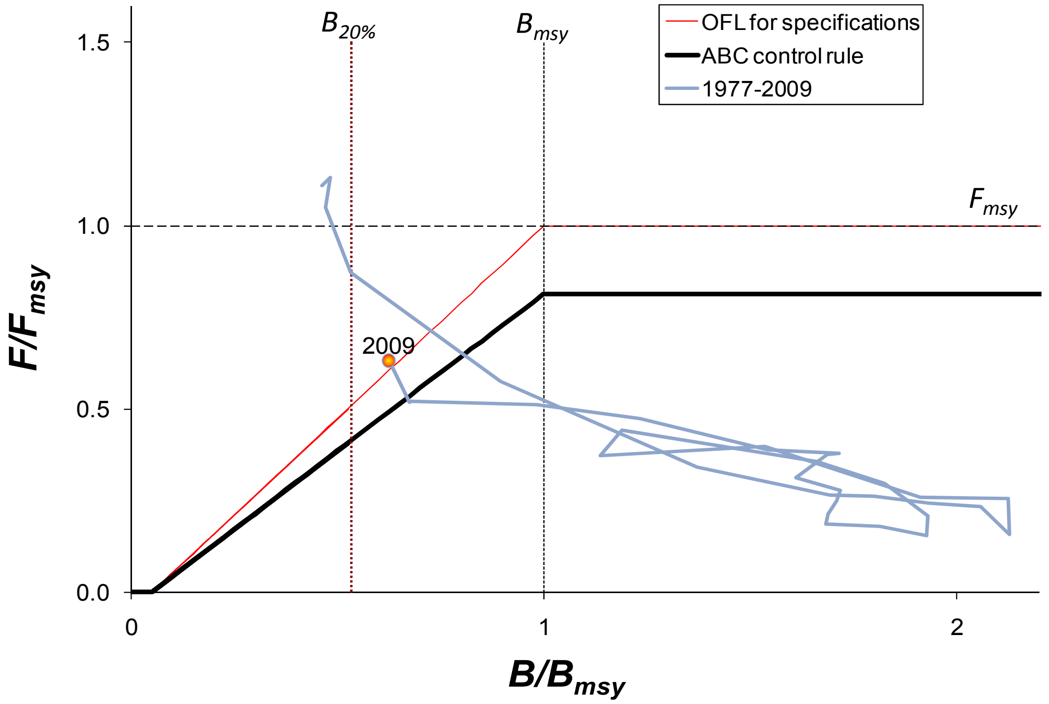


Figure 1.35. Estimated spawning biomass relative to annually estimated F_{MSY} values and fishing mortality rates for EBS pollock, 1977-2009. *Note that the control rules for OFL and ABC are designed for setting specifications in future years.*

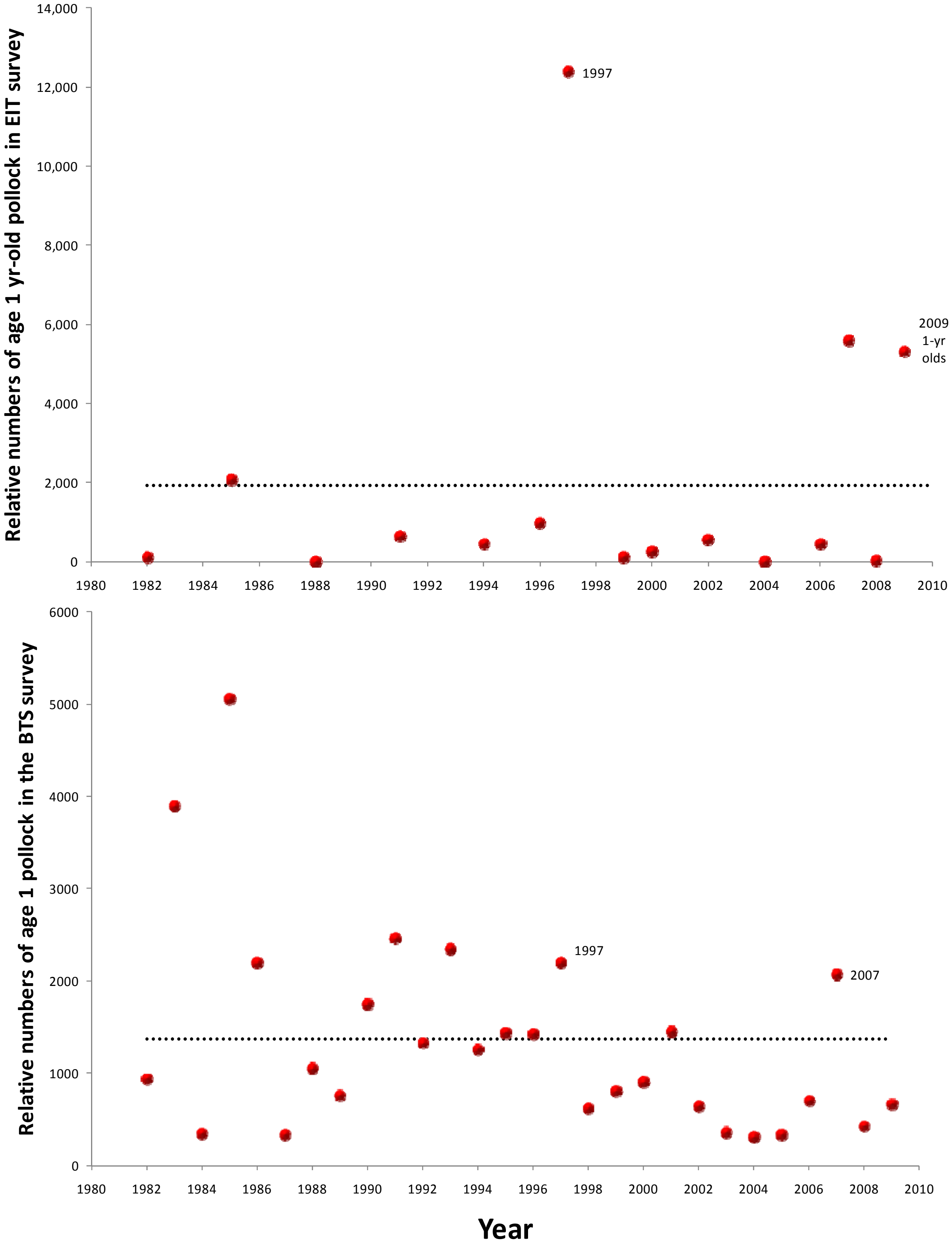


Figure 1.36. Time series of estimated age-1 abundance (relative numbers) for EBS pollock from the EIT surveys, 1982-2009 (top panel) and from the BTS surveys (bottom panel).

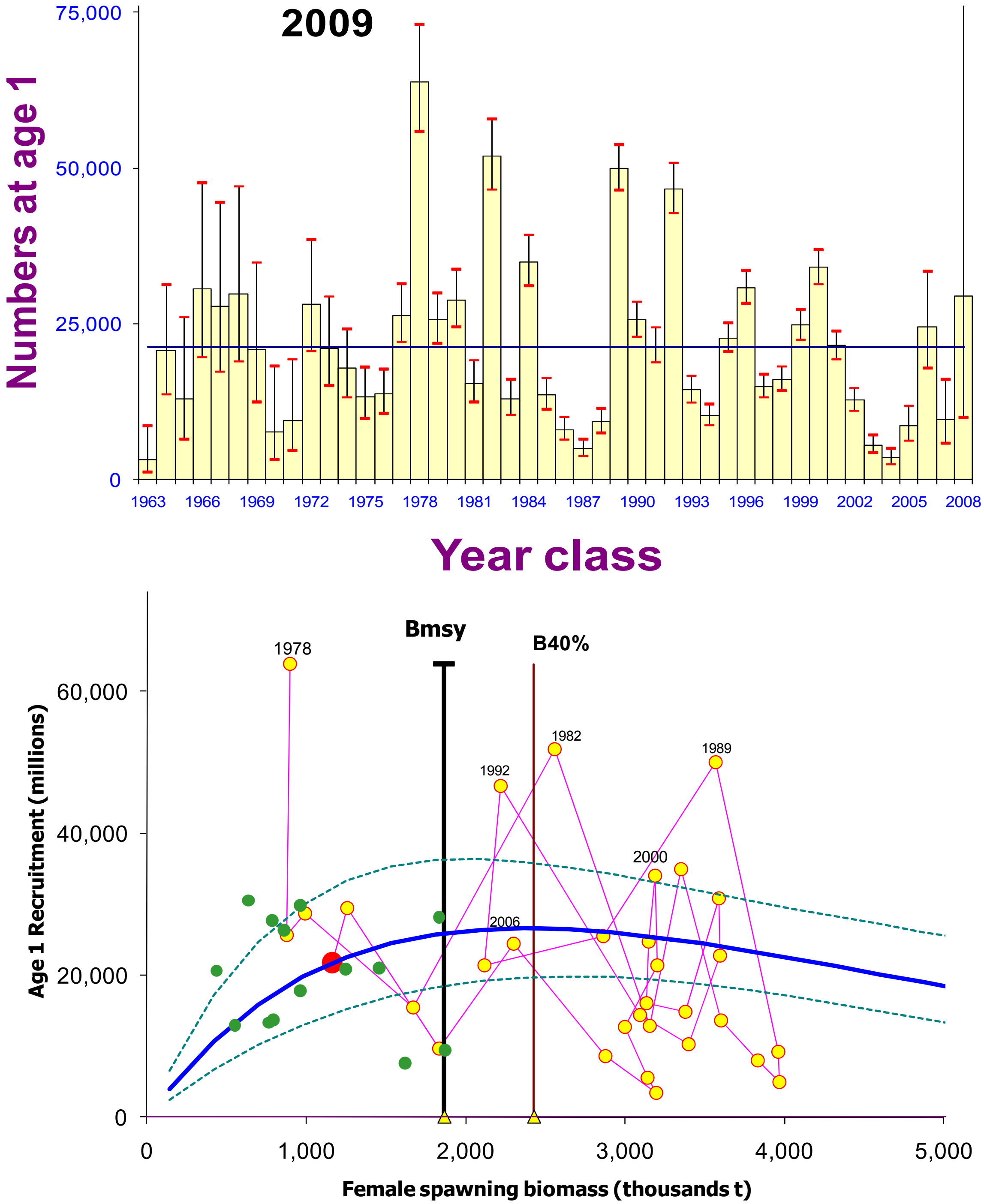


Figure 1.37. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS pollock. Labels on points correspond to year classes labels (measured as one-year olds). Solid line in upper panel represents the mean age-1 recruitment for all years since 1964 (1963-2009 year classes). Vertical lines in lower panel indicate B_{msy} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with dashed lines representing approximate lower and upper 95% confidence limits about the estimated curve.

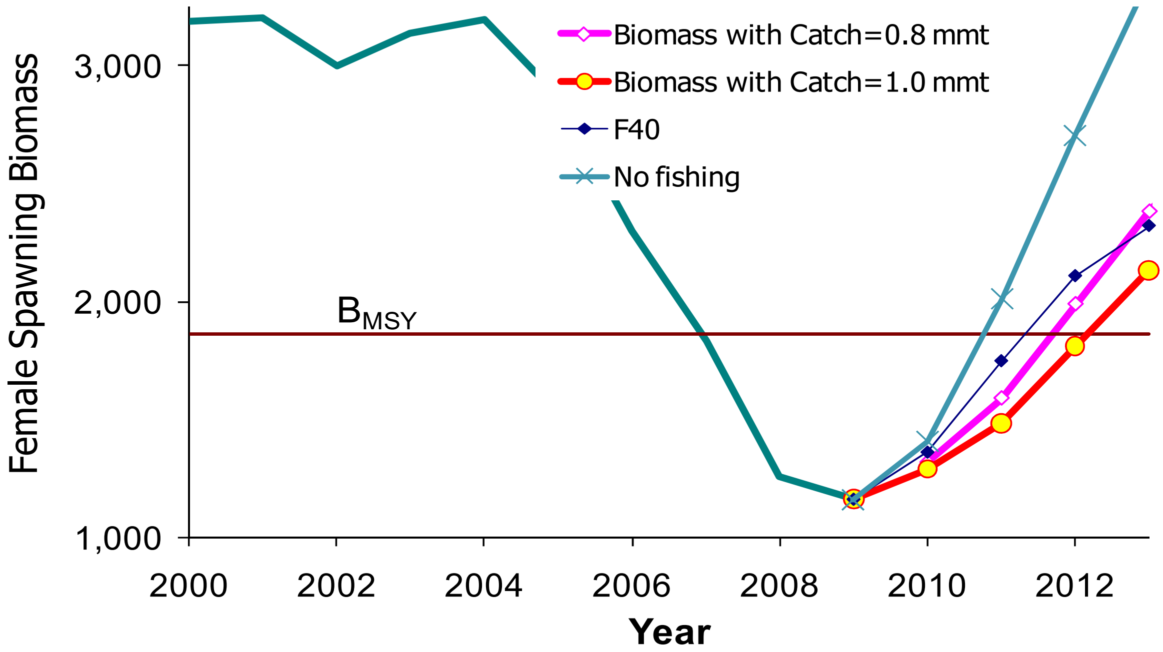


Figure 1.38. Estimated EBS pollock female spawning biomass trends, 2000-2013, under different harvest levels. The solid horizontal represents the B_{msy}, estimate. *Note vertical scale has 1 million t as lower bound.*

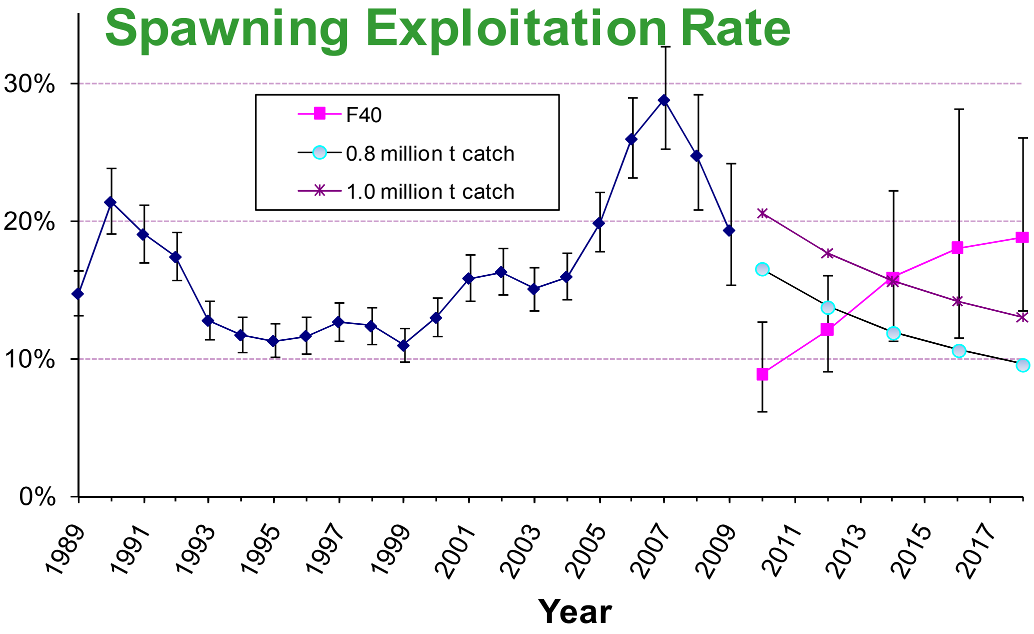
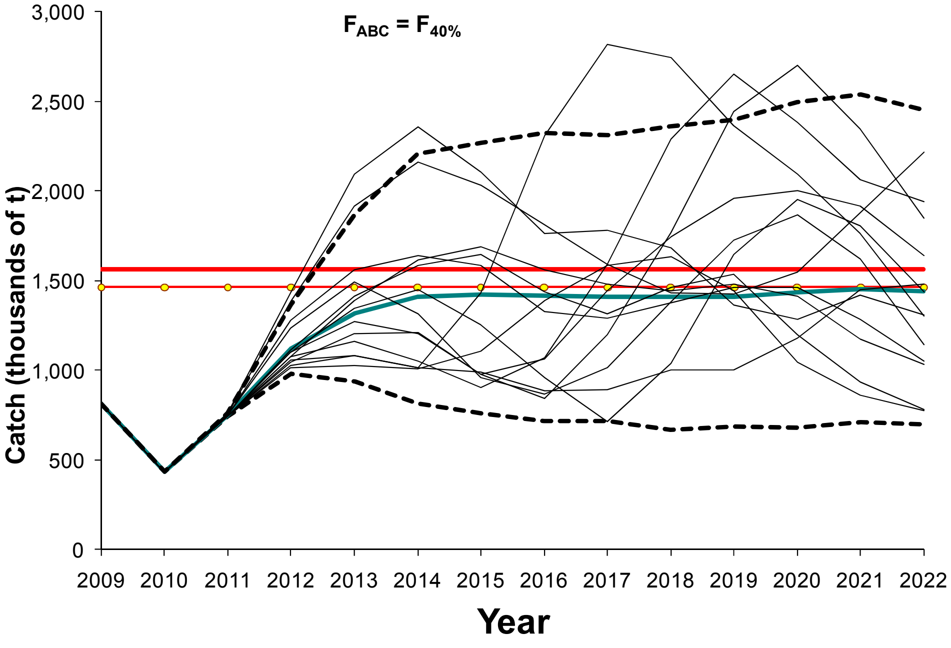


Figure 1.39. Estimated EBS pollock spawning exploitation rate (defined as the annual percent removals of spawning females due to the fishery). Error bars represent two standard deviations from the estimate and projections for 2009 show the implications of different harvest levels. Note that the $F_{40\%}$ level represents the adjusted Tier 3b value.



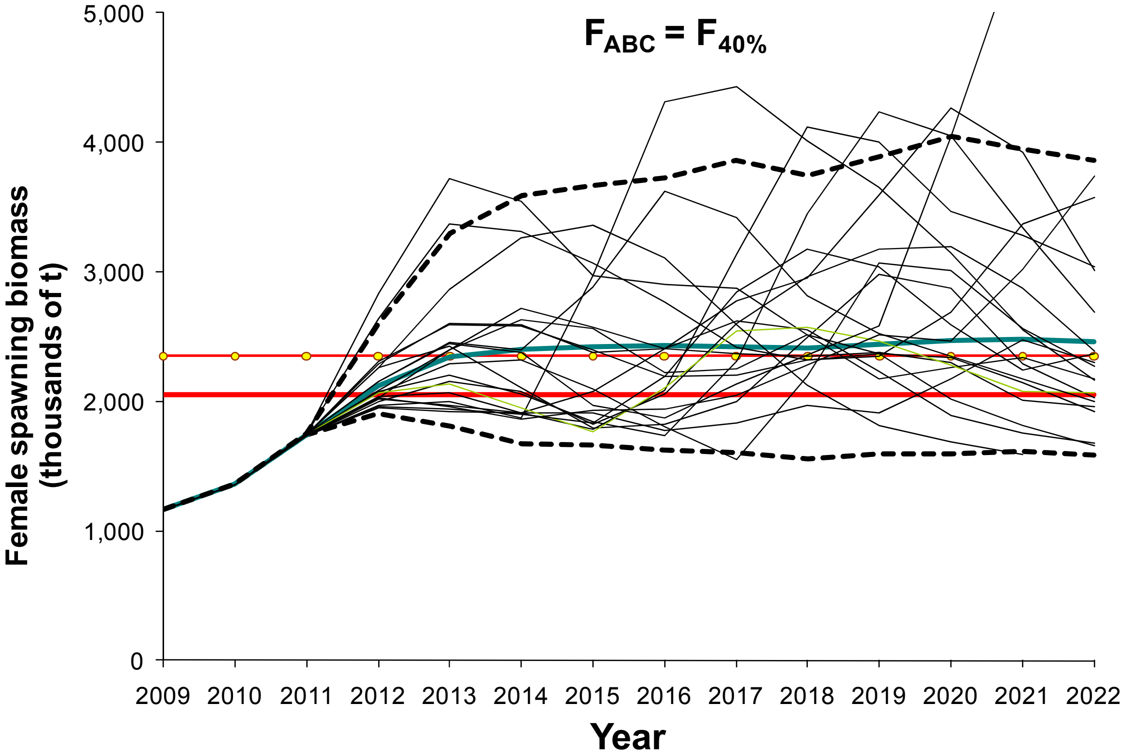


Figure 1.40. Projected EBS **Tier 3** pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines). $B_{40\%}$ is computed from average recruitment from 1978-2008. Future harvest rates follow the guidelines specified under Tier 3 Scenario 1, $F_{ABC} = F_{40\%}$. *Note that this projection method is provided only for reference purposes, the SSC has determined that a Tier 1 approach is recommended for this stock.*

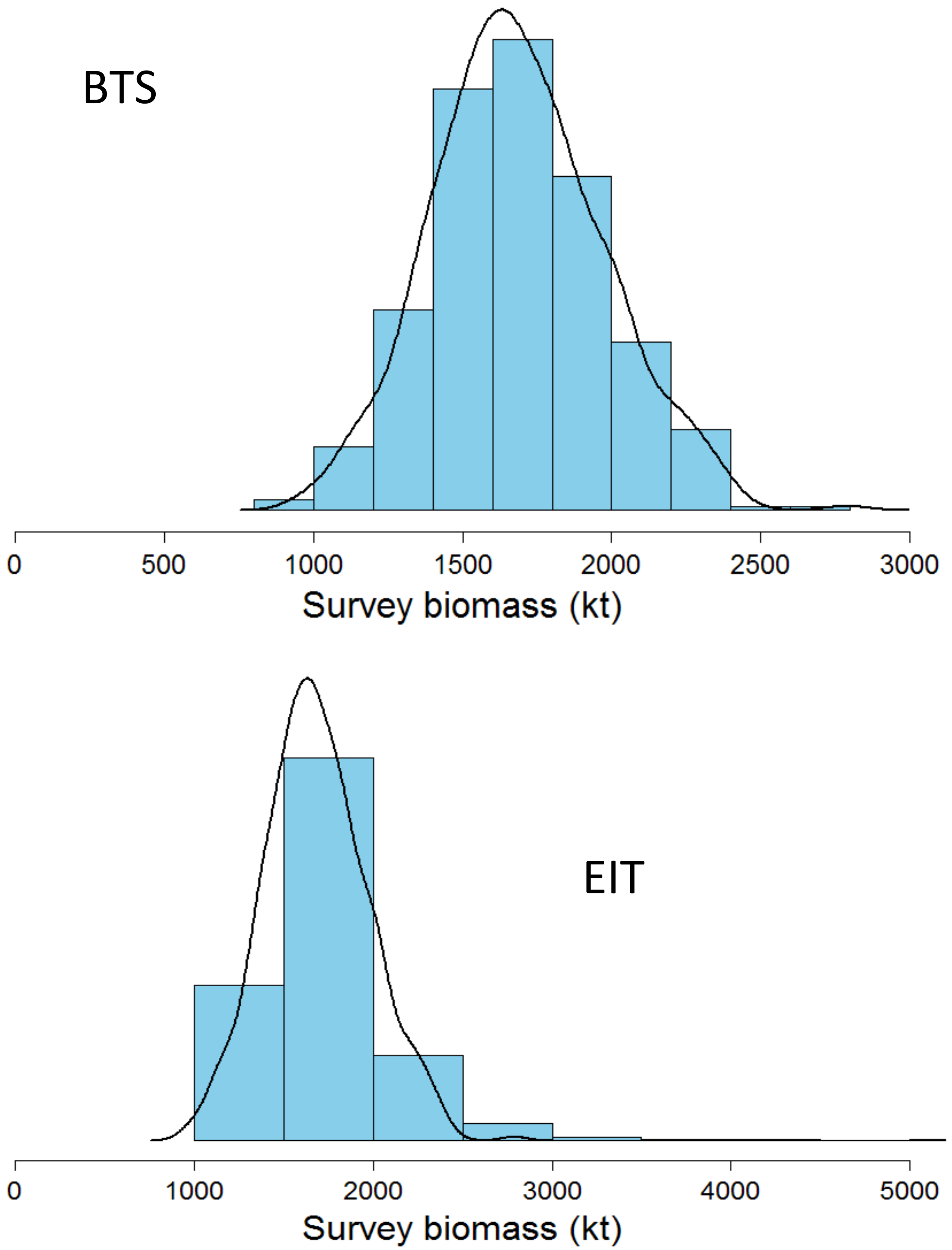


Figure 1.41. Distribution of expected 2010 survey EBS pollock biomass estimates based on model simulations (500 draws from the posterior) and 800 kt of catch in 2010 for the bottom trawl survey (BTS, top panel) and echo-integration trawl survey (EIT, bottom panel).

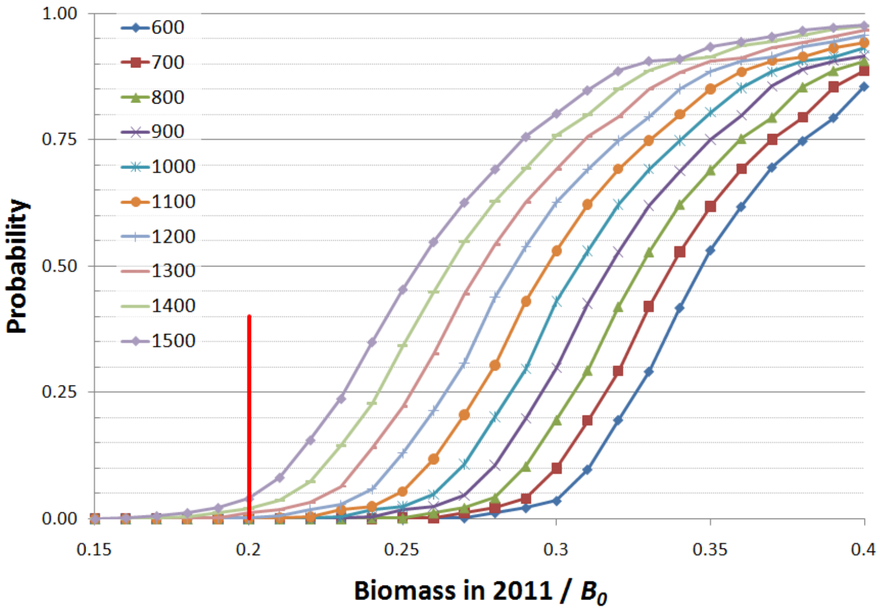


Figure 1.42. Cumulative probability estimates of 2011 stock sizes relative to B_0 for EBS pollock under a variety of 2010 and 2011 catch levels. Probabilities are based on simulations of 2010 data and running assessments for each of the 5,000 simulated datasets (500 draws from posterior distribution simulations for each of 10 different catch scenarios).

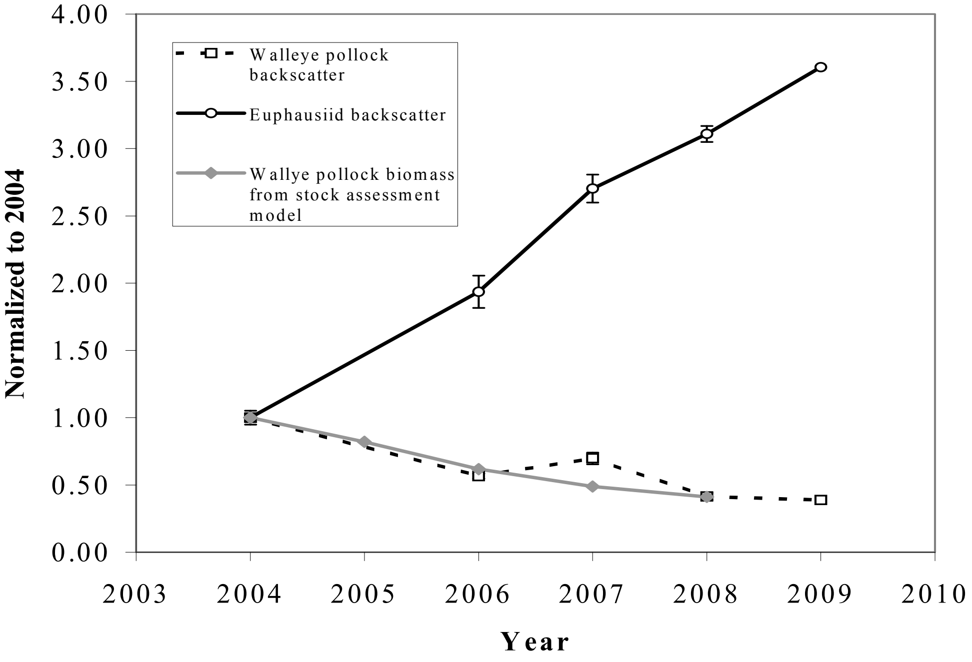


Figure 1.43. Bering Sea summer euphausiid backscatter at 120 kHz and pollock backscatter at 38 kHz from the EIT survey, and walleye pollock biomass estimated by the stock assessment model (SAFE Tables 1.9 and 1.22; Ianelli et al. 2008), 2004-2009. Each time series has been normalized to its value in 2004. The 2009 results are preliminary.

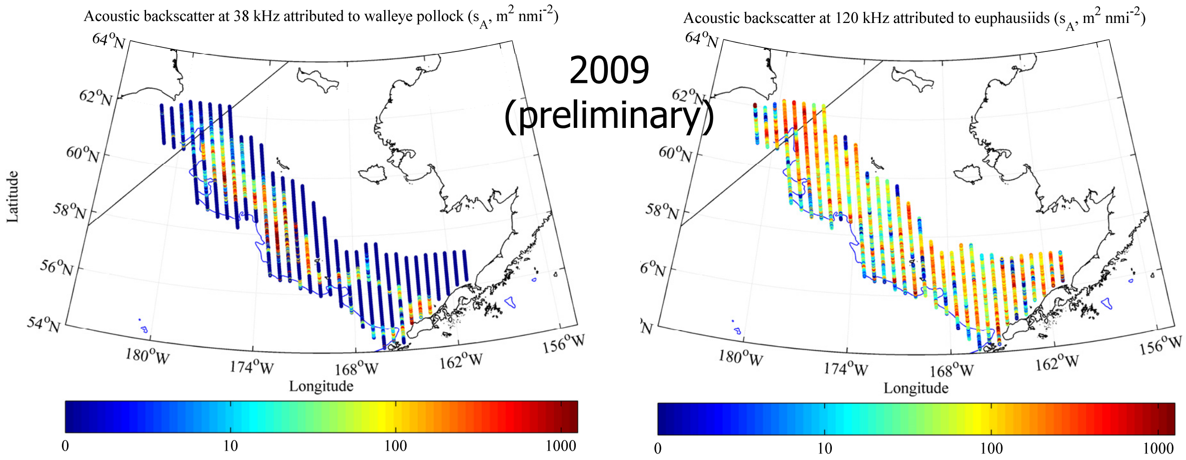


Figure 1.44. Pollock backscatter at 38 kHz (left panel) and euphausiid backscatter at 120 kHz (right panel) along tracklines from the summer 2009 EIT survey of Bering Sea pollock.

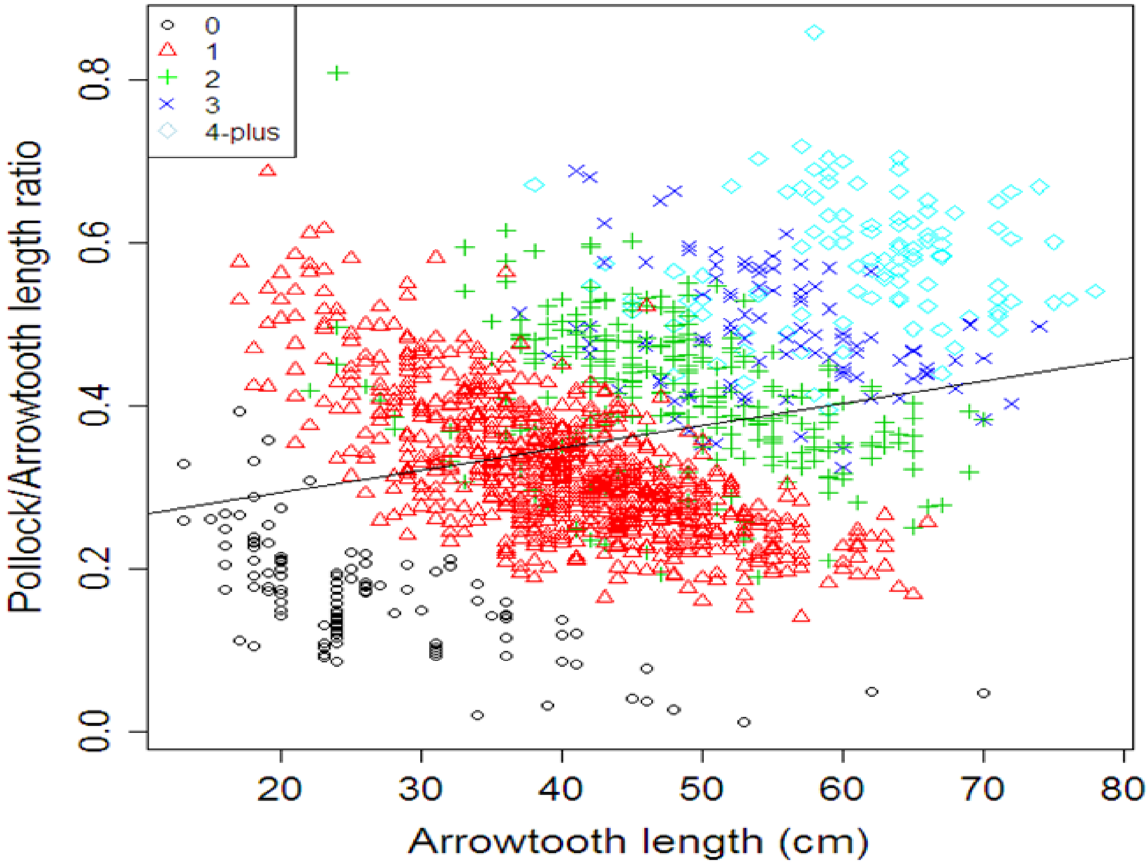


Figure 1.45. Relationship between relative EBS pollock size found in the stomachs of arrowtooth flounder (vertical axis) and arrowtooth size (based on survey stomach content data from 1983-2008).

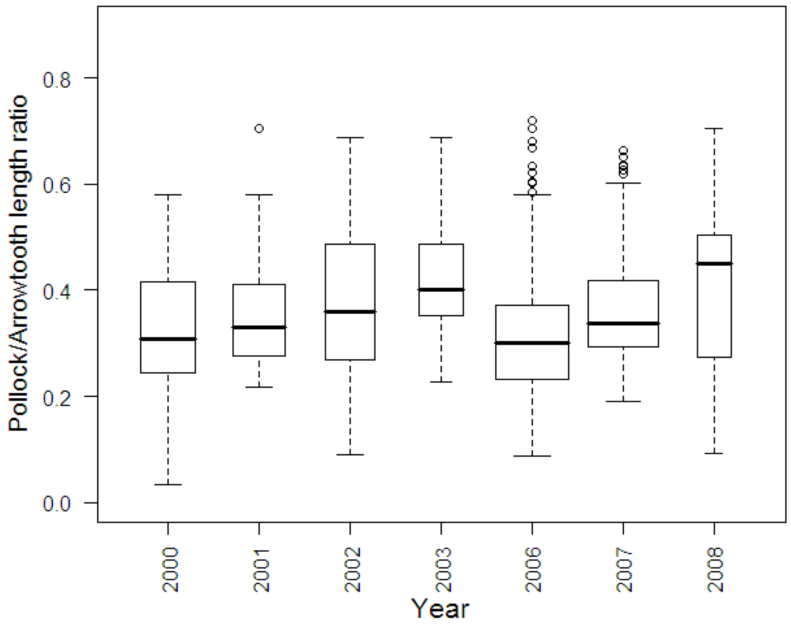


Figure 1.46. Summary of the annual distribution of relative EBS pollock size found in the stomachs of arrowtooth flounder, 2000-2008.

Model details

Below is extracted from the assessment document with equation numbers added (and some updated equations due to software changes in Microsoft word over the years).

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, McAllister and Ianelli 1997). Catch in numbers at age in year *t* ($C_{t,a}$) and total catch biomass (Y_t) were

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

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

$$F_{t,a} = s_{t,a}\mu^{f}e^{\varepsilon_t} \quad \varepsilon_t \sim N\left(0,\sigma_E^2\right) \tag{Eq. 2}$$

$$S_{t+1,a} = s_{t,a}e^{\gamma_t} \quad \gamma_t \sim N\left(0,\sigma_s^2\right) \tag{Eq. 3}$$

where $s_{t,a}$ is the selectivity for age class *a* in year *t,* and μ 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 $\gamma_{t,a}$. 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 in each year (previously selectivity was modeled in 2-year blocks were used). The basis for this model specification was to better account for the high levels of sampling and to avoid over-simplifying real changes in age-specific fishing mortality. The "mean" selectivity going forward for projections and ABC deliberations is the simple mean of the estimates from 2004-2009.

Bottom-trawl survey selectivity was set to be 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:

$$\begin{aligned} s_{t,a} &= \left[1 + e^{-\alpha_t(a-\beta_t)}\right]^{-1}, \ a > 1 \\ s_{t,a} &= \mu_s e^{\delta_t^\mu}, \qquad\qquad a = 1 \\ \alpha_t &= \bar{\alpha}e^{\delta_t^\alpha} \\ \beta_t &= \bar{\beta}e^{\delta_t^\beta} \end{aligned} \tag{Eq. 4}$$

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

$$\begin{aligned}&\delta_t^{\mu}-\delta_{t+1}^{\mu}\sim N\left(0,\sigma_{\delta^{\mu}}^2\right)\\&\delta_t^{\alpha}-\delta_{t+1}^{\alpha}\sim N\left(0,\sigma_{\delta^{\alpha}}^2\right)\\&\delta_t^{\beta}-\delta_{t+1}^{\beta}\sim N\left(0,\sigma_{\delta^{\beta}}^2\right)\end{aligned} \quad \text{(Eq. 5)}$$

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,…2009. The variance terms for these process-error parameters were specified to be 0.04.

In 2008 the EIT survey selectivity approach was modified. As an option, the age one pollock observed in this trawl can be treated as an index and are not considered part of the age composition (which then ranges from age 2-15). This was done to improve some interaction with the flexible selectivity smoother that is used for this gear and was compared. Additionally, the annual specification of input sigmas was allowed for the EIT data. This allowed better flexibility for this survey that occurs at irregular intervals and reduces the number of parameters estimated (previously, the random walk penalty occurred for every year regardless of whether a survey occurred).

A diagnostic approach to evaluate input variance specifications (via sample size under multinomial assumptions) was added in this assessment. This method uses residuals from mean ages together with the concept that the sample variance of mean age (from a given annual data set) varies inversely with input sample size. It can be shown that for a given set of input proportions at age (up to the maximum age A) $p_{a,i}$ and sample size N_i for year i, an adjustment factor f for input sample size can be computed when compared with the assessment model predicted proportions at age ($\hat{p}_{ij}$) and model predicted mean age ($\hat{\bar{a}}$):

$$\begin{aligned}&f=\operatorname{var}\left(r_i^a\sqrt{\frac{N_i}{s_i}}\right)^{-1}\\&r_i^a=\bar{a}_i-\hat{\bar{a}}_i\\&s_i=\left[\sum_j^A\bar{a}_i^2p_{ij}-\hat{\bar{a}}_i^2\right]^{0.5}\end{aligned} \quad \text{(Eq. 6)}$$

where r_i^a is the residual of mean age and

$$\hat{\bar{a}}_i=\sum_j^A j\hat{p}_{ij},\qquad \bar{a}_i=\sum_j^A jp_{ij} \quad \text{(Eq. 7)}$$

For this assessment, we use the above relationship as a diagnostic for evaluating input sample sizes by comparing model predicted mean ages with “observed” mean ages and the implied 95% confidence bands. This method provided support for modifying the frequency of allowing selectivity changes (e.g., Fig. 1.47).

Recruitment

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):

$$R_t=f\left(B_{t-1}\right)e^{\kappa_t+\tau_t},\qquad \tau_t\sim N\left(0,\sigma_R^2\right) \quad \text{(Eq. 8)}$$

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

$$B_t = \sum_{a=1}^{15} w_a \phi_a N_{at} \quad \text{(Eq. 9)}$$

and ϕ_a, the proportion of mature females at age is as shown in the sub-section titled "Natural mortality and maturity at age" under "Parameters estimated independently" above.

A reparameterized form for the stock-recruitment relationship following Francis (1992) was used. For the optional Beverton-Holt form we have:

$$R_t = f(B_{t-1}) = \frac{B_{t-1}e^{\varepsilon_t}}{\alpha + \beta B_{t-1}} \quad \text{(Eq. 10)}$$

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:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h} \qquad \beta = \frac{5h-1}{4hR_0} \quad \text{(Eq. 11)}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawning 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 prior distribution for steepness used a beta distribution as in Ianelli et al. (2001) is shown in Fig. 1.48. For this assessment and the prior on steepness used a symmetric form of the Beta distribution with alpha=beta=13.06 implying a prior mean of 0.6 and CV of 12.8% (implying that there is about 10% chance that the steepness is greater than 0.7). This conservative prior is consistent with previous years' application and serves to constrain the stock-recruitment curve from favoring unreasonably steep slopes (uninformative priors result in F_{msy} values near an F_{SPR} of about $F_{18\%}$, a value considerably higher than the default proxy of $F_{35\%}$). The residual pattern for the post-1977 recruits used in fitting the curve with a more diffuse prior resulted in all estimated recruits being below the curve for stock sizes less than B_{msy} (except for the 1978 year class). We believe this to be driven primarily by the apparent negative-slope for recruits relative to stock sizes above B_{msy} and as such, provides a potentially unrealistic estimate of productivity at low stock sizes. This prior was elicited from the rationale that residuals should be reasonably balanced throughout the range of spawning stock sizes.

The value of σ_R was fixed at 0.9. This choice was selected to be larger than the output stock-recruitment variability (~0.67) since proper estimation of this quantity would require integration over the random-effects (inter-annual recruitment variability). In addition, retaining the uncertainty at a somewhat higher level increases the uncertainty on the stock-recruitment curve estimation that in turn propagates through to the pdf of F_{msy} and hence provides a greater buffer between yield at F_{msy} (the OFL) and maximum permissible ABC.

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

$$R_t = f\left(B_{t-1}\right) = B_{t-1} e^{a\left(1 - B_{t-1}/\varphi_0 R_0\right)} / \varphi_0 \,. \qquad \text{(Eq. 12)}$$

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

$$h = \frac{e^a}{e^a + 4} \qquad \text{(Eq. 13)}$$

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.

Diagnostics
In 2006 a “replay” feature was added where the time series of recruitment estimates from a particular model is used to compute the subsequent abundance expectation had no fishing occurred. These recruitments are adjusted from the original estimates by the ratio of the expected recruitment given spawning biomass (with and without fishing) and the estimated stock-recruitment curve. I.e., the recruitment under no fishing is modified as:

$$R_t' = \hat{R}_t \frac{f\left(S_t'\right)}{f\left(\hat{S}_t\right)} \qquad \text{(Eq. 14)}$$

where $\hat{R}_t$ is the original recruitment estimate in year *t* with $f\left(S_t'\right)$ and $f\left(\hat{S}_t\right)$ representing the stock-recruitment function given spawning biomass under no fishing and under the fishing scenario, respectively.

The assessment model code allows retrospective analyses (e.g., Parma 1993, and Ianelli and Fournier 1998). This was designed to assist in specifying how spawning biomass patterns (and uncertainty) have changed due to new data. The retrospective approach simply uses the current model to evaluate how it may change over time with the addition of new data based on the evolution of data collected over the past 14 years.

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):

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

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

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

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix} , \qquad \text{(Eq. 15)}$$

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 the models presented this year, the option for including aging errors was omitted as has been recommended in past years.

Sample size values were revised and are shown in the main document. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, 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:

$$\prod_{a=1}^{A}\prod_{t=1}^{T} \frac{\left(\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\tau^2}\right\}+0.01\right)}{\sqrt{2\pi\left(\eta_{t,a}+0.1/T\right)\tau}} \qquad \text{(Eq. 16)}$$

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

$$-1/2\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left(2\pi\left(\eta_{t,a}+0.1/T\right)\right)-\sum_{a=1}^{A}T\log_e(\tau)$$
$$+\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left[\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\tau^2}\right\}+0.01\right] \qquad \text{(Eq. 17)}$$

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

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:

$$\hat{N}^s_{t,a} = e^{-0.5Z_{t,a}} N_{t,a} q^s_t s^s_{t,a} \quad \text{(Eq. 18)}$$

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 (ignoring constants) from the surveys is given by either the lognormal distribution:

$$\sum_t \left(\frac{\ln\left(A^s_t / \hat{N}^s_t\right)^2}{2\sigma^2_{s,t}} \right) \quad \text{(Eq. 19)}$$

where A^s_t is the total (numerical) abundance estimate with variance $\sigma^2_{s,t}$ from survey *s* in year *t* or optionally, the normal distribution is used:

$$\sum_t \left(\frac{\left(A^s_t - \hat{N}^s_t\right)^2}{2\sigma^2_{s,t}} \right).$$

The EIT survey is modeled using a lognormal distribution whereas for the BTS survey, a normal distribution was applied in fitting.

The contribution to the negative log-likelihood function for the observed total catches (O_t) by the fishery is given by

$$\sum_t \left(\frac{\ln\left(O_t / \hat{C}_t\right)^2}{2\sigma^2_{c,t}} \right) \quad \text{(Eq. 20)}$$

where $\sigma_{c,t}$ is pre-specified (set to 0.05) affecting the accuracy of the overall observed catch in biomass. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include $\lambda_\varepsilon \sum_t \varepsilon^2_t + \lambda_\gamma \sum_{t,a} \gamma^2_{t,a} + \lambda_\delta \sum_t \delta^2_t$ 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 facilitate estimating such a large number of parameters, 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). In 2007 this was modified to include uncertainty in weight-at-age as an explicit part of the uncertainty for F_{msy} calculations. This involved estimating a vector of parameters (w^{future}_i) on "future" mean weights for each age *i*, *i*= (1, 2,…,15), given actual observed mean and variances in weight-at-age over the period 1991-2007. The model simply computes the values of $\overline{w}_i, \sigma^2_{w_i}$ based on available data and (if this option is selected) estimates the parameters subject to the natural constraint:

$$w_i^{future} \sim N\left(\overline{w}_i, \sigma^2_{w_i}\right) \qquad \text{(Eq. 21).}$$

Note that this converges to the mean values over the time series of data (no other likelihood component within the model is affected by "future" mean weights-at-age) while retaining the natural uncertainty that can propagate through estimates of F_{msy} uncertainty. This latter point is essentially a requirement of the Tier 1 categorization.

Tier 1 projections

Tier 1 projections were calculated two ways. First, for 2010 and 2011 ABC and OFL levels, the harmonic mean F_{msy} value was computed and the analogous harvest rate ($\hat{u}_{HM}$) applied to the estimated geometric mean "fishable" biomass at B_{msy} :

$$\begin{aligned}
&ABC = B'_{GM}\,\hat{u}_{HM}\,\zeta \\
&B'_{GM} = e^{\ln\left(\hat{B}'\right) - 0.5\sigma^2_{B}} \\
&\hat{u}_{HM} = e^{\ln F_{msy} - 0.5\sigma^2_{F_{msy}}} \\
&\zeta = \frac{B_t / B_{msy} - 0.05}{1 - 0.05} \qquad B_t < B_{msy} \\
&\zeta = 1 \qquad B_t \geq B_{msy} \qquad \text{(Eq. 22)}
\end{aligned}$$

where $\hat{B}'$ is the point estimate of the "fishable biomass" defined as (for a given year)

$$\sum_{j=1}^{15} N_j s_j w_j \qquad \text{(Eq. 23)}$$

with N_j, s_j and w_j the estimated population numbers (begin year), selectivity and weights-at-age j, respectively. B_{msy} and B_t are the point estimates spawning biomass levels at equilibrium F_{msy} and in year t (at time of spawning). For these projections, catch must be specified (or solved for if in the current year when $B_t < B_{msy}$). For longer term projections a form of operating model (as has been presented for the evaluation of $B_{20\%}$) with feedback (via future catch specifications) using the control rule and assessment model would be required. Refinements to this approach are underway and are planned for the future assessments.

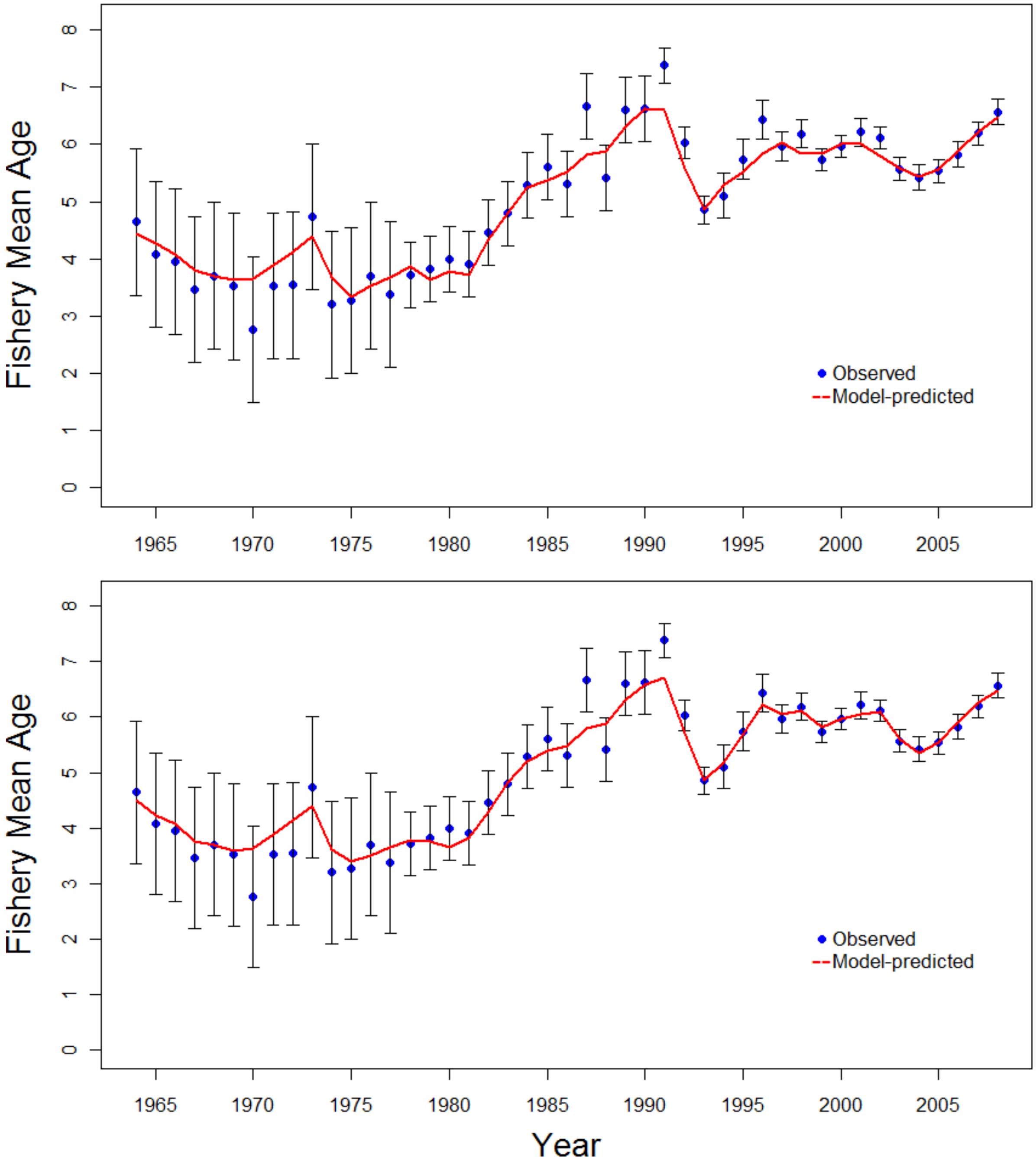


Figure 1.47. Observed and predicted fishery mean catch-at-age for the model configured with fishery selectivity changing only every two-years (top panel) compared with selectivity change in each year (bottom-panel).

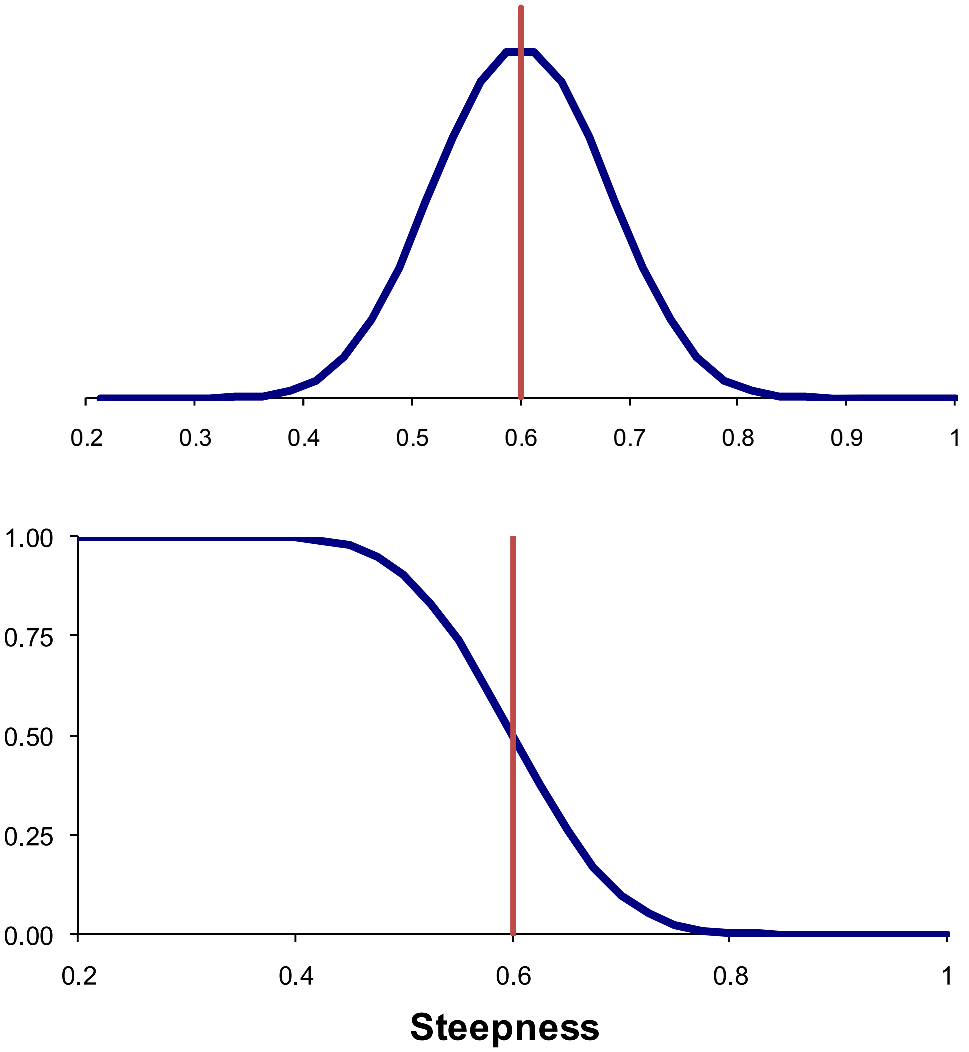


Figure 1.48. Cumulative prior probability distribution of steepness based on the beta distribution with α and β set to values which assume a mean and CV of 0.6 and 0.12, respectively. This prior distribution implies that there is about 8% chance that the value for steepness is greater than 0.7. See text for discussion.

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