

Assessment of Walleye Pollock in the Gulf of Alaska

by

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Summary of major changes

Relative to last year's assessment, the following changes have been made in the current assessment.

New Input data:

1. Fishery: 2002 total catch and catch at age.
2. Shelikof Strait EIT survey: 2003 biomass and age composition.
3. ADF&G crab/groundfish trawl survey: 2003 biomass and length composition, 2002 age composition.
4. NMFS bottom trawl survey: 2003 biomass and age composition.
5. New ageing error transition matrix using percent agreement between age readers and testers, 1987-2002.

Assessment model

The age-structured assessment model developed using ADModel Builder (a C++ software language extension and automatic differentiation library) and used for assessments in 1999-2002 is fundamentally unchanged. Model exploration focused on evaluating the contribution of each survey time series to the assessment. An appendix (Appendix C) evaluates the appropriateness of fishing mortality and stock biomass reference points used to manage Gulf of Alaska pollock and presents results from a preliminary model with time-varying juvenile mortality.

Assessment results

The model estimate of spawning biomass in 2004 is 195,350 t, which is 31% of unfished spawning biomass and below $B_{40\%}$ (248,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. Estimates of spawning stock depend strongly on the strength of the 1999 year class. If it is assumed that the 1999 year class is only average in abundance, a risk averse assumption compared to the model estimate, spawning stock decreases to 165,580 t, or 27% of unfished spawning biomass. Estimates of a modest improvement in stock status in 2004 are due to increases in biomass estimates from the 2003 NMFS bottom trawl survey and the 2003 Shelikof Strait EIT survey. In contrast, the ADFG trawl survey showed a decline of 30%. The author's 2004 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 65,660 t, nearly equal to last year's projected ABC for 2004 with similar model assumptions. This recommendation is based on a more conservative alternative to the maximum permissible F_{ABC} introduced in the 2002 SAFE, and a conservative assumption for the strength of the 1999 year class.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendation in Appendix A is 6,520 t and the OFL is 8,694 t.

Introduction

Walleye pollock (*Theragra chalcogramma*) is a semi-pelagic schooling fish widely distributed in the North Pacific Ocean. Pollock in the Gulf of Alaska are managed as a single stock independently of pollock in the Bering Sea and Aleutian Islands. The separation of pollock in Alaskan waters into eastern Bering Sea and Gulf of Alaska stocks is supported by analysis of larval drift patterns from spawning locations (Bailey et al. 1997), genetic studies of allozyme frequencies (Grant and Utter 1980), mtDNA variability (Mulligan et al. 1992), and microsatellite allele variability (Bailey et al. 1997).

The results of studies of stock structure in the Gulf of Alaska are equivocal. There is evidence from allozyme frequency and mtDNA that spawning populations in the northern part of the Gulf of Alaska (Prince William Sound and Middleton Island) may be genetically distinct from the Shelikof Strait spawning population (Olsen et al. 2002). However significant variation in allozyme frequency was found between Prince William Sound samples in 1997 and 1998, indicating a lack of stability in genetic structure for this spawning population. Olsen et al. (2002) suggest that interannual genetic variation may be due to variable reproductive success, adult philopatry, source-sink population structure, or utilization of the same spawning areas by genetically distinct stocks with different spawning timing. Peak spawning at the two major spawning areas in the Gulf of Alaska occurs at different times. In the Shumagin Island area, peak spawning occurs between February 15- March 1, while in Shelikof Strait peak spawning occurs between March 15 and April 1. It is unclear whether the difference in timing is genetic or caused by differing environmental conditions in the two areas.

Fishery

The commercial fishery for walleye pollock in the Gulf of Alaska started as a foreign fishery in the early 1970s (Megrey 1989). Catches increased rapidly during the late 1970s and early 1980s (Table 1). Large spawning aggregations were discovered in Shelikof Strait in 1981, and a fishery developed for which pollock roe was an important product. The domestic fishery for pollock developed rapidly in the Gulf of Alaska with only a short period of joint venture operations in the mid-1980s. The fishery was fully domestic by 1988.

The fishery for pollock in the Gulf of Alaska is entirely shore-based with approximately 90% of the catch taken with pelagic trawls. During winter, fishing effort usually targeted primarily on pre-spawning aggregations in Shelikof Strait and near the Shumagin Islands (Fig. 1). Fishing areas in summer are less predictable, but typically fishing occurs on the east side of Kodiak Island and in nearshore waters along the Alaska Peninsula.

Incidental catch in the Gulf of Alaska pollock fishery is low. For tows classified as pollock targets in the Gulf of Alaska, more than 95% of the catch by weight consists of pollock (Fig. 2). Arrowtooth flounder and Pacific cod account for approximately 60% of the incidental catch, with the remainder consisting of a variety of species, including flatfish, jellyfish, smelts, sharks, and skates.

Kodiak is the major port for pollock in the Gulf of Alaska, with 56% of the 1998-2002 landings. Sand Point and Dutch Harbor are also important ports, sharing 33% of 1998-2002 landings. Secondary ports, including Cordova, Port Moller, King Cove, Akutan, and Kenai, account for the remaining 11% of the 1998-2002 landings.

Since 1992, the Gulf of Alaska pollock TAC has been apportioned spatially and temporally to reduce impacts on Steller sea lions. The details of the apportionment scheme have evolved over time, but the general objective is to allocate the TAC to management areas based on the distribution of surveyed

biomass, and to establish three or four seasons between mid-January and autumn during which some fraction of the TAC can be taken. The Steller Sea Lion Protection Measures implemented in 2001 establish four seasons in the Central and Western GOA beginning January 20, March 10, August 25, and October 1, with 25% of the total TAC allocated to each season. Allocations to management areas 610, 620 and 630 are based on the seasonal biomass distribution as estimated by groundfish surveys. In addition, a new harvest control rule was implemented that requires a cessation of fishing when spawning biomass declines below 20% of unfished stock biomass.

Data Used in the Assessment

The data used in the assessment model consist of estimates of annual catch in tons, fishery age composition, NMFS summer bottom trawl survey estimates of biomass and age composition, echo integration trawl (EIT) survey estimates of biomass and age composition in Shelikof Strait, egg production estimates of spawning biomass in Shelikof Strait, ADF&G bottom trawl survey estimates of biomass and length and age composition, and historical estimates of biomass and length and age composition from surveys conducted prior to 1984 using a 400-mesh eastern trawl. Binned length composition data are used in the model only when age composition estimates are unavailable, such as the fishery in the early part of the modeled time period.

Total Catch

Estimated catch was derived by the NMFS Regional Office from a blend of weekly processor reports and observer discard estimates (Table 2). Catches include the state-managed pollock fishery in Prince William Sound. In 1996-2003, the pollock Guideline Harvest Level (GHL) for the PWS fishery was deducted from the Acceptable Biological Catch (ABC) by Gulf of Alaska plan team.

Fishery Age Composition

Estimates of fishery age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). Pollock otoliths collected during the 2002 fishery were aged using the revised criteria described in Hollowed et al. (1995). Catch age composition was estimated using methods described by Kimura and Chikuni (1989). Age samples were used to construct age-length keys by sex and stratum. These keys were applied to length frequency data to obtain stratum-specific age composition estimates, which were then weighted by the catch in numbers in each stratum to obtain an overall age composition. Age and length samples from the 2002 fishery were stratified by half year and statistical area as follows:

| Time strata | | Shumagin-610 | Chirikof-620 | Kodiak-630 | W. Yakutat and PWS-640 and 649 |
|----------------------------|-------------|--------------|--------------|------------|--------------------------------|
| 1st half (A and B seasons) | No. ages | 235 | 331 | 208 | 252 |
| | No. lengths | 1661 | 3592 | 1091 | 1447 |
| 2nd half (C and D seasons) | No. ages | 344 | 343 | 353 | ---- |
| | No. lengths | 3455 | 5199 | 3332 | ---- |

In the first half of 2002, ages 6-8 were relatively common in areas 610, 620, and 640, while in area 630 a broader range was nearly equally common (ages 3-8). The relatively strong 1994 year class was still noticeable as a mode of age-8 fish, but this year class is no longer a dominant component of the catch. In

the second half of 2002, mean age decreased substantially in all areas and catches were dominated by age-2 and age-3 fish (2000 and 1999 year classes) (Fig. 3).

Fishery catch at age in 1976-2002 is presented in Table 3 (See also Fig. 4). Sample sizes for ages and lengths are given in Table 4.

Gulf of Alaska Bottom Trawl Survey

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) every three years (beginning in 1984) to assess the abundance of groundfish in the Gulf of Alaska (Table 5). Starting in 2001, the survey frequency was increased to every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and management area (Martin 1997). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized poly-Nor' eastern high opening bottom trawls rigged with roller gear. Surveying effort averages 800 tows, 70% of which contain pollock (Table 6).

The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140° W lon., obtained by adding the biomass estimates for the Shumagin, Chirikof, Kodiak INPFC areas, and the western portion of Yakutat INPFC area. Biomass estimates for 1990, 1993, 1996, 1999, and 2003 for the west Yakutat region were obtained by splitting strata and survey CPUE data at 140° W lon. (M. Martin, AFSC, Seattle, WA, pers. comm. 1998). For surveys in 1984 and 1987, the average percent in West Yakutat in the 1990-99 surveys was used (2.7% increase). The average was also used in 2001, when West Yakutat was not surveyed.

An adjustment was made to the survey time series to account for unsurveyed pollock in Prince William Sound. This adjustment was derived from an area-swept biomass estimate for PWS from a trawl survey conducted by ADF&G in 1999, using a standard ADF&G 400 mesh eastern trawl. The 1999 biomass estimate for PWS was 6,304 t ± 2,812 t (95% CI) (W. Bechtol, ADF&G, 1999, pers. comm.). The PWS biomass estimate should be considered a minimum estimate because ADF&G survey gear is less effective at catching pollock compared to the triennial survey gear (von Szalay and Brown 2001). For 1999, the biomass estimates for the NMFS bottom trawl survey and the PWS survey were simply added to obtain a total biomass estimate. The adjustment factor for the 1999 survey, (PWS + NMFS)/NMFS, was applied to other triennial surveys, and increased biomass by 1.05%. We consider this an interim approach to assessing PWS pollock, and anticipate improvements from increased surveying effort in PWS and additional comparative work.

The Alaska Fisheries Science Center's (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted the eighth comprehensive triennial bottom trawl survey during the summer of 2003. The spatial distribution of pollock was similar to earlier surveys, with higher CPUEs around Kodiak Island, nearshore along the Alaska Peninsula, and just north of Dixon Entrance in Southeast Alaska (Fig. 11). The 2003 gulfwide biomass estimate of pollock was 424,519 t (Table 7). For the area surveyed in 2001, the estimated pollock biomass increased by 86% between 2001 and 2003. Unlike surveys in 1999 and 2001, which had CVs of 38% and 30% respectively, the 2003 biomass estimate is relatively precise (CV = 12%). The uncertainty in the 2003 estimate is similar to gulfwide surveys prior to 1999 (Table 6). The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140° W long, obtained by adding the biomass estimates for the Shumagin, Chirikof, Kodiak INPFC areas, and the western portion of Yakutat INPFC area. The biomass estimate for this portion of the Gulf of Alaska is 399,690 t.

Bottom Trawl Age Composition

Estimates of numbers at age from the bottom trawl survey were obtained from random otolith samples and length frequency samples (Table 6). Numbers at age were estimated for three strata: Western GOA (Shumagin INPFC area), Central GOA (Chirikof and Kodiak INPFC areas), Eastern GOA (Yakutat and Southeastern INPFC areas) using age-length keys and CPUE-weighted length frequency data. The combined Western and Central age composition was used in the assessment model.

In the estimated age composition for the 2003 survey, age-3 and age-4 pollock from the 2000 and 1999 year class were common in all areas. Age-1 pollock from the 2002 year class numerically the most common age group in Chirikof and Kodiak INPFC areas, but were relatively uncommon in the Shumagin INPFC area (Fig. 5).

Shelikof Strait Echo Integration Trawl Survey

Echo integration trawl surveys to assess the biomass of pollock in the Shelikof Strait area have been conducted annually since 1981 (except 1982 and 1999). Survey methods and results for 2003 are presented in an Appendix to the SAFE (Guttormsen et al. 2003). The 2003 biomass estimate for age 2+ pollock in Shelikof Strait is 270,200 t, an increase of 18% from the 2002 biomass (Table 5). Despite the increase in total biomass, the biomass >43 cm biomass (a proxy for spawning biomass) continued to decline in Shelikof Strait (Fig. 6). The estimated abundance of age-4 fish (0.705 billion) (1999 year class) was the largest since the early 1980s in the Shelikof Strait EIT time series. The age-4 fish were small, with a mean weight approximately 70% of the long term average, suggesting density-dependent growth (Fig. 12).

Additional EIT surveys in winter 2003 covered the Shumagin Islands spawning area, Sanak Gully, and an area along the shelf break east of the entrance to the Shelikof sea valley, and a spawning grounds near Middleton Island. Results from these surveys are given below.

2003 EIT survey results

| | | <i>Shumagin</i> | <i>Sanak</i> | <i>Shelikof</i> | <i>Shelf break</i> | <i>Middleton</i> | <i>Total</i> |
|-------------------|---------|-----------------|--------------|-----------------|--------------------|------------------|--------------|
| Total | Tons | 67,200 | 81,400 | 270,200 | 30,900 | 6,900 | 456,600 |
| | Percent | 15% | 18% | 59% | 7% | 2% | |
| Biomass ≥43 cm | Tons | 46,400 | 77,900 | 24,500 | 29,000 | 6,000 | 183,700 |
| | Percent | 25% | 42% | 13% | 16% | 3% | |

These survey results provide a mixed picture concerning the status of the pollock stock in the Gulf of Alaska. The total biomass from all winter surveys combined is slightly higher than the combined biomass estimated in 2002, but several new areas were surveyed in 2003. Estimates of pollock biomass declined in the Shumagin area (50% decrease) and along the shelf break (62% decrease) compared to 2002 estimates. Survey results continue to raise questions about the appropriateness of the Shelikof Strait survey time series as an index of overall stock abundance. Only 13% of the combined survey biomass ≥43 cm (a proxy for spawning biomass) was found in Shelikof Strait, and greater than 40% of the combined survey biomass ≥43 cm was in Sanak Gully, an area where biomass was estimated for the first time in 2003 (the 2002 survey of Sanak Gully was not quantitative). Nevertheless, the large numbers of the age-4 fish in both the Shumagin and Shelikof Strait areas suggests that spawning biomass will increase in these areas in the future as these fish become mature.

Since the assessment model only includes individuals age 2 and older, the biomass of age-1 fish in the 1995 and 2000 surveys was subtracted from the total biomass for those years (reducing the biomass by 15% and 14% respectively (Table 5). In all other years, the biomass of age-1 fish was less than 2% of the total EIT biomass estimate.

Echo Integrated Trawl Survey Length Frequency

Annual biomass distributions by length from the Shelikof Strait EIT survey show the progression of strong year classes through the population (Fig. 7). In the 2003 survey, the length frequency is dominated by the age-4 fish from the 1999 year class. Length frequency data are not used in the assessment model because estimates of age composition are available for all surveys.

Echo Integrated Trawl Survey Age Composition

Estimates of numbers at age from the Shelikof Strait EIT survey (1981 - 1991, 1994 -1998, 2000-2003 (Table 8) were obtained from random otolith samples and length frequency samples. Otoliths collected during the 1994 - 2003 EIT surveys were aged using the revised criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 6.

Egg Production Estimates of Spawning Biomass

Estimates of spawning biomass in Shelikof Strait based on egg production methods were included in the assessment model. A complete description of the estimation process is given in Picquelle and Megrey (1993). The estimates of spawning biomass in Shelikof Strait show a pattern similar to the acoustic survey (Table 5). The annual egg production spawning biomass estimate for 1981 is questionable because of sampling deficiencies during the egg surveys for that year (Kendall and Picquelle 1990). Coefficients of variation (CV) associated with these estimates were included in the assessment model. Egg production estimates were discontinued because the Shelikof Strait EIT survey provided similar information.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

The Alaska Department of Fish and Game (ADF&G) has conducted bottom trawl surveys of nearshore areas of the Gulf of Alaska since 1987. Although these surveys are designed to monitor population trends of Tanner crab and red king crab, walleye pollock and other fish are also sampled. Standardized survey methods using a 400-mesh eastern trawl were employed from 1987 to the present. The survey is designed to sample a fixed number of stations from mostly nearshore areas from Kodiak Island to Unimak Pass, and does not cover the entire shelf area. The average number of tows completed during the survey is 360. Details of the ADF&G trawl gear and sampling procedures are in Blackburn and Pengilly (1994).

The 2003 biomass estimate for pollock for the ADF&G crab/groundfish survey was 66,989 t, a decrease of 30% from the 2002 biomass estimate (Table 5).

ADF&G Survey Length Frequency

Pollock length-frequency for the ADF&G survey in 1989-2002 (excluding 1991 and 1995) typically show a primary mode at lengths greater than 45 cm (Fig. 8). The predominance of large fish in the ADF&G survey may result from the selectivity of the gear, or because of greater abundance of large pollock in the areas surveyed.

ADF&G Survey Age Composition

Ages were determined by age readers in the AFSC age and growth unit from samples of pollock otoliths collected during the 2000 and 2002 ADF&G surveys (N = 559 & 538). Comparison with fishery age composition shows that older fish (> age-8) are more common in the ADF&G crab/groundfish survey. This is consistent with the assessment model, which estimates a domed-shaped selectivity pattern for the

fishery, but an asymptotic selectivity pattern for the ADF&G survey.

Pre-1984 bottom trawl surveys

Considerable survey work was carried out in the Gulf of Alaska prior to the start of the NMFS triennial bottom trawl surveys in 1984. Between 1961 and the mid-1980s, the most common bottom trawl used for surveying was the 400-mesh eastern trawl. This trawl (or minor variants thereof) was used by IPHC for juvenile halibut surveys in the 1960s, 1970s, and early 1980s, and by NMFS for groundfish surveys in the 1970s.

Comparative work using the ADF&G 400-mesh eastern trawl and the NMFS poly-Nor' eastern trawl produced estimates of relative catchability (von Szalay and Brown 2001), making it possible to evaluate trends in pollock abundance from these earlier surveys in the pollock assessment. Von Szalay and Brown (2001) estimated a fishing power correction (FPC) for the ADFG 400-mesh eastern trawl of 3.84 (SE = 1.26), indicating that 400-mesh eastern trawl CPUE for pollock would need to be multiplied by this factor to be comparable to the NMFS poly-Nor' eastern trawl.

In most cases, earlier surveys in the Gulf of Alaska were not designed to be comprehensive, with the general strategy being to cover the Gulf of Alaska west of Cape Spencer over a period of years, or to survey a large area to obtain an index for group of groundfish, i.e., flatfish or rockfish. For example, Ronholt et al. (1978) combined surveys for several years to obtain gulfwide estimates of pollock biomass for 1973-6. There are several difficulties with such an approach, including the possibility of double-counting or missing a portion of the stock that happened to migrate between surveyed areas.

We obtained an annual gulfwide index of pollock abundance using generalized linear models (GLM). Based on examination of historical survey trawl locations, we identified four index sites (one per INPFC area) that were surveyed relatively consistently during the period 1961-1983, and during the triennial survey time series (1984-99). The index sites were designed to include a range of bottom depths from nearshore to the continental slope. We fit a generalized linear model (GLM) to pollock CPUE data with year, site, depth strata (0-100 m, 100-200 m, 200-300 m, >300 m), and a site-depth interaction as factors. Both the pre-1984 400-mesh eastern trawl data and post-1984 triennial trawl survey data were used. For the earlier period, analysis was limited to sites where at least 20 trawls were made during the summer (May 1-Sept 15).

Pollock CPUE data consist of observations with zero catch and positive values otherwise, so we used a GLM model with Poisson error and a logarithmic link (Hastie and Tibshirani 1990). This form of GLM has been used in other marine ecology applications to analyze trawl survey data (Smith 1990, Swartzman et al. 1992). The fitted model was used to predict mean CPUE by site and depth for each year with survey data. Predicted CPUEs (kg km^{-2}) were multiplied by the area within a depth strata by INPFC area (km^2) and summed to obtain proxy biomass estimates by INPFC area. Since each INPFC area contained only a single non-randomly selected index site, these proxy biomass estimates are potentially biased and would not incorporate the variability in relationship between the mean CPUE at an index site and the mean CPUE for the entire INPFC area. We used a comparison between these proxy biomass estimates by INPFC area and the actual NMFS triennial survey estimates by INPFC area for 1984-99 to obtain correction factors and variance estimates. Correction factors had the form of a ratio estimate (Cochran 1977), in which the sum of the NMFS survey biomass estimates for an INPFC area for 1984-99 is divided by the sum of the proxy biomass estimates for the same period.

Variances were obtained by bootstrapping data within site-depth strata and repeating the biomass estimation algorithm. A parametric bootstrap assuming a lognormal distribution was used for the INPFC area correction factors. Variance estimates do not reflect the uncertainty in the FPC estimate. In the

assessment model, we do not apply the FPC to the biomass estimates, but instead include the information about FPC estimate (mean and variance) as a likelihood component for relative survey catchability,

$$\log L = \frac{(q_1/q_2 - \hat{FPC})^2}{2\sigma_{FPC}^2},$$

where q_1 is the catchability of the NMFS bottom trawl survey, q_2 is the catchability of historical 400-mesh eastern trawl surveys, \hat{FPC} is the estimated fishing power correction (= 3.84), and σ_{FPC} is the standard error of the FPC estimate (= 1.26).

Estimates of pollock biomass are very low (<300,000 t) between 1961 and 1971, increase by at least a factor of ten in 1974 and 1975, and then decline to approximately 900,000 t in 1978 (Table 9). No trend in pollock abundance is noticeable since 1978, and biomass estimates during 1978-1982 are in the same range as the post-1984 triennial survey biomass estimates. The coefficients of variation (CV) for GLM-based biomass estimates range between 0.24 and 0.64, and, as should be anticipated, are larger than the triennial survey biomass estimates, which range between 0.12 and 0.38.

Results were generally consistent with the multi-year combined survey estimates published previously (Table 9), and indicate a large increase in pollock biomass in the Gulf of Alaska occurred between the early 1960s (~200,000 t) and the mid 1970s (>2,000,000 t). Increases in pollock biomass between the 1960s and 1970s were also noted by Alton et al. (1987). In the 1961 survey, pollock were a relatively minor component of the groundfish community with a mean CPUE of 16 kg/hr (Ronholt et al. 1978). Arrowtooth flounder was the most common groundfish with a mean CPUE of 91 kg/hr. In the 1973-76 surveys, the CPUE of arrowtooth flounder was similar to the 1961 survey (83 kg/hr), but pollock CPUE had increased 20-fold to 321 kg/hr, and was by far the dominant groundfish species in the Gulf of Alaska. Meuter and Norcross (2002) also found that pollock was low in the relative abundance in 1960s, became the dominant species in Gulf of Alaska groundfish community in the 1970s, and subsequently declined in relative abundance.

Questions concerning the comparability of pollock CPUE data from historical trawl surveys with later surveys probably can never be fully resolved. However, because of the large magnitude of the change in CPUE between the surveys in the 1960s and the early 1970s using similar trawling gear, the conclusion that there was a large increase pollock biomass seems robust. Model results suggest that population biomass in 1961, prior to large-scale commercial exploitation of the stock, may have been the lowest observed. Early speculation about the rise of pollock in the Gulf of Alaska in the early 1970s implicated the large biomass removals of Pacific Ocean perch, a potential competitor for euphausiid prey (Somerton et al. 1979, Alton et al. 1987). More recent work has focused on role of climate change (Anderson and Piatt 1999, Bailey 2000). The occurrence of large fluctuations in pollock abundance without large changes in direct fishing impacts suggests a need for conservative management. If pollock abundance is controlled primarily by the environment, or through indirect ecosystem effects, it may be difficult to reverse population declines, or to achieve rebuilding targets should the stock become depleted. Reliance on sustained pollock harvests in the Gulf of Alaska, whether by individual fishermen, processing companies, or fishing communities, may simply not be possible over the long-term.

Qualitative trends

To qualitatively assess recent trends in abundance, we standardized each survey time series by dividing the annual estimate by the average since 1986 so all could be plotted on the same scale. The Shelikof Strait EIT survey was split into separate time series corresponding to the two acoustic systems used for the survey. Although there is considerable variability in each survey time series, a fairly clear downward

trend is evident (Fig. 9). A lowess scatterplot smoother (SPLUS 1993) fit to the relative abundance data in aggregate shows a similar, but more gradual, decline than the estimated biomass trend from the assessment model.

We also evaluated indices derived from fisheries catch data for trends in biological characteristics (Fig. 10). The percent of females in the catch shows no obvious trend that would indicate differential mortality on the more valuable roe-bearing females. The mean age shows interannual variability due to strong year classes passing through the population, but no downward trends that would suggest excessive mortality rates. The percent of old fish in the catch (nominally defined as age 8 and older) is also highly variable due to variability in year class strength, but has apparently increased over time, opposite to the typical pattern in an exploited population. This pattern may be partly attributable to changes in fishery selectivity or to changes in ageing criteria, but is consistent with assessment results showing low fishing mortality rates. We computed an index of catch at age diversity using the Shannon-Wiener information index,

$$- \sum p_a \ln p_a ,$$

where p_a is the proportion at age. Increases in fishing mortality would tend to reduce age diversity, but year class variability would also influence age diversity. The index of age diversity is relatively stable during 1976-2002 (Fig. 10).

McKelvey Index

McKelvey (1996) found a significant correlation between the abundance of age-1 pollock in the Shelikof Strait EIT survey and subsequent estimates of year-class strength. The McKelvey index is defined as the estimated abundance of 9-16 cm fish in the Shelikof Strait EIT survey, and is an index of recruitment at age 2 in the following year (Table 10). The relationship between the abundance of age-1 pollock in the Shelikof Strait EIT survey and year-class strength provides a recruitment forecast for the year following the most recent Shelikof Strait EIT survey.

2003 FOCI Year Class Prediction

Data

This forecast is based on five data sources: three physical properties and two biological data sets. The sources are: 1) observed 2003 Kodiak monthly precipitation, 2) wind mixing energy at [57N, 156W] estimated from 2003 sea-level pressure analyses, 3) advection of ocean water in the vicinity of Shelikof Strait inferred from drogued drifters deployed during the spring of 2003, 4) rough counts of pollock larvae from a survey conducted in May 2003, and 5) estimates of age 2 pollock abundance from this year's assessment.

Analysis

Kodiak Precipitation: Monthly precipitation totals (inches) are prepared by the Kodiak, Alaska, National Weather Service Office from hourly observations. Data were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.

The winter started wet this year. Spring started with near normal precipitation, but May, a crucial period in the early life history of pollock, was relatively dry. June saw a return to above average rainfall.

Kodiak precipitation for 2003

| <i>Month</i> | <i>% 30-yr average</i> |
|--------------|------------------------|
| Jan | 236 |
| Feb | 120 |
| Mar | 131 |
| Apr | 94 |
| May | 31 |
| June | 122 |

FOCI believes that Kodiak precipitation is a valid proxy for fresh-water runoff that contributes to the density contrast between coastal and Alaska Coastal Current water in Shelikof Strait. The greater the contrast, the more likely that eddies and other instabilities will form. Such secondary circulations have attributes that make them beneficial to survival of larval pollock. Based on this information, the forecast element for Kodiak 2003 rainfall has a score of 2.24. This is "average to strong" on the continuum from 1 (weak) to 3 (strong).

Wind Mixing: For the first time since 1997, monthly mean mixing exceeded the 30-yr mean. This happened during March, the period when pollock are spawning and substantially before the first feeding larvae of the 2003 year class. Mixing during other months was near or below average.

Wind mixing at the exit of Shelikof Strait for 2003

| <i>Month</i> | <i>% 30-yr average</i> |
|--------------|------------------------|
| Jan | 87 |
| Feb | 30 |
| Mar | 158 |
| Apr | 80 |
| May | 97 |
| June | 55 |

Strong mixing in winter helps transport nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak spring mixing is thought to better enable first feeding pollock larvae to locate and capture food. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment. This year's scenario produces a wind mixing score of 2.15, which equates to "average".

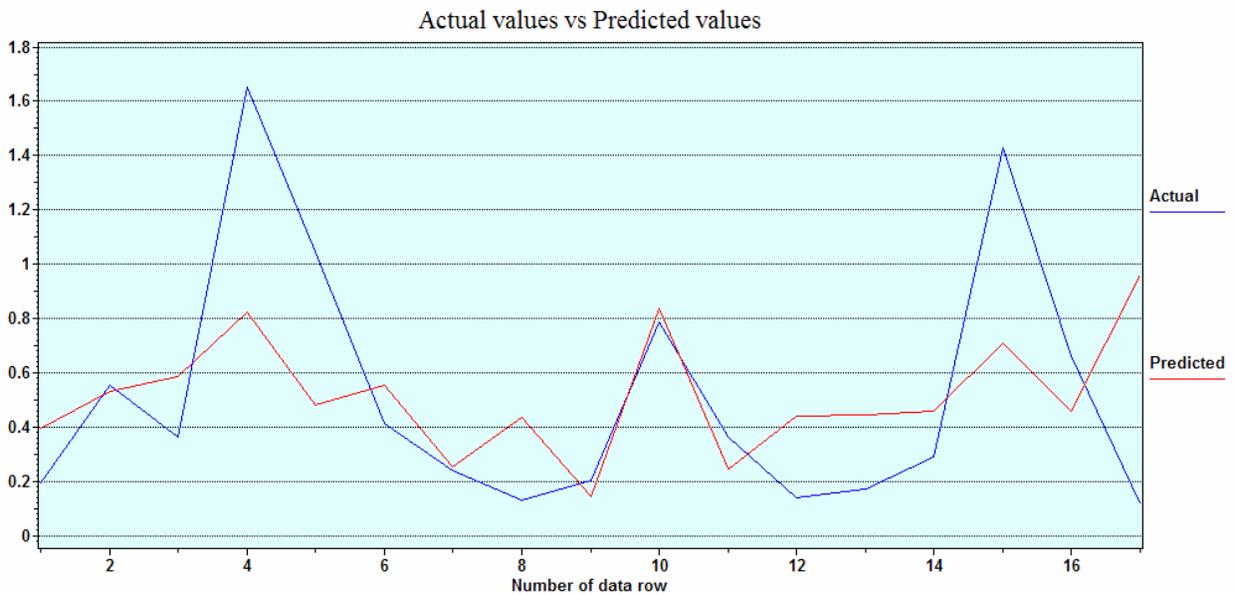
Advection: From an examination of drifter trajectories and wind forcing, the transport in Shelikof Strait for spring of 2003 was average. We have hypothesized that very strong transport is bad for pollock survival, and that moderate transport is best and that very weak transport is, while not as disastrous as strong transport, still detrimental to larval survival. Advection was given a score of 2.0.

Relating Larval Index to Recruitment: As in last year's analysis, a nonlinear neural network model with one input neuron (larval abundance), 3 hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (catch/m²) to age-2 recruitment abundance (billions). The model estimated 6 weighting parameters.

Data used in the neural network model.

| <i>Year Class</i> | <i>Average Larval Abundance (catch/m²)</i> | <i>Age 2 Recruitment (billions)</i> |
|-------------------|---|-------------------------------------|
| 1982 | 66.44347 | 0.192071 |
| 1985 | 80.4266 | 0.551805 |
| 1987 | 324.9025 | 0.361285 |
| 1988 | 256.9029 | 1.65348 |
| 1989 | 537.2943 | 1.04816 |
| 1990 | 335.0086 | 0.41271 |
| 1991 | 54.2223 | 0.238671 |
| 1992 | 563.6741 | 0.132253 |
| 1993 | 45.80764 | 0.202603 |
| 1994 | 124.9386 | 0.787051 |
| 1995 | 600.9925 | 0.360514 |
| 1996 | 472.0225 | 0.138638 |
| 1997 | 561.1063 | 0.16983 |
| 1998 | 72.81539 | 0.289686 |
| 1999 | 102.3862 | 1.43102 |
| 2000 | 486.1835 | 0.66197 |
| 2001 | 174.624 | 0.115187 |
| 2002 | 276.6972 | |
| 2003 | 90.40014 | |

The neural network model, which used the first 17 observation pairs were fit to the model and had a R^2 of 0.219. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) are given below where row number corresponds to the rows of the data matrix given above.



Observed and predicted recruitment values from the larval index-recruitment neural network model

The trained network was then used to predict the recruitment for 2002 and 2003.

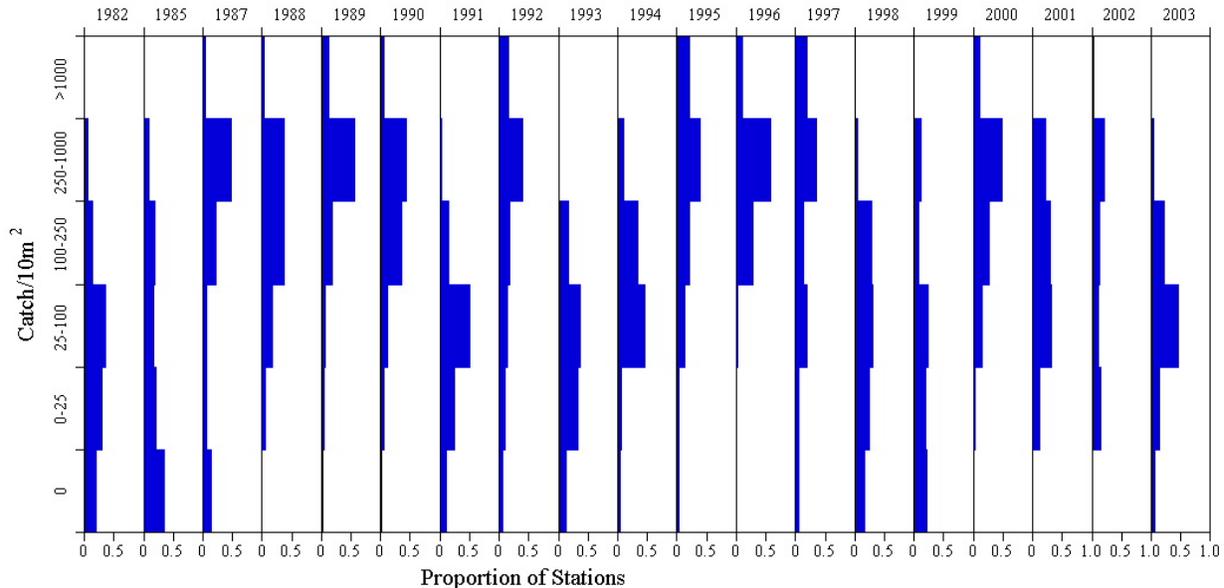
The predictions are

| <i>Year</i> | <i>Actual Recruitment</i> | <i>Predicted Recruitment</i> |
|-------------|---------------------------|------------------------------|
| 2002 | n/a | 0.755 |
| 2003 | n/a | 0.619 |

These values, using the 33% (0.355) and 66% (0.675) cutoff points given below correspond to a strong 2002 year class and an average 2003 year class.

Note that the neural net model fit last year to these data predicted the 2002 year class to be strong at 1.84 billion fish.

Larval Index Counts: Plotting the data by year and binning the data into catch/10 m² categories (given below) provides another view of the data. The pattern for 2003 (based on rough counts) seems very similar to 1994 in that the two strongest modes fall into the 25-100 and 100-250 catch/10 m² bins.



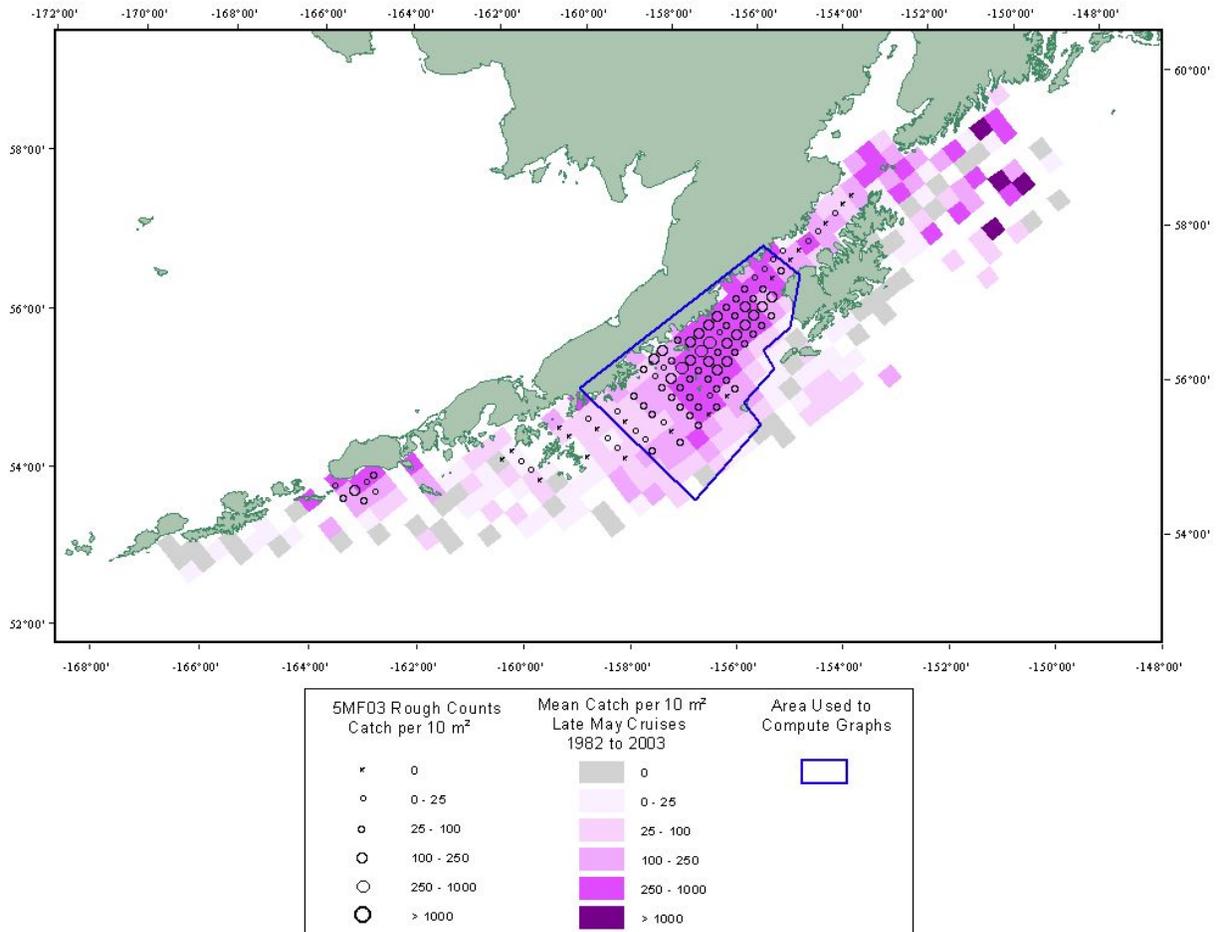
Histograms of larval walleye pollock densities in late May from 1982 to 2003. Data were binned into catch/10 m² categories. The data from 2000-2003 are rough counts taken at sea, and the 2003 data are from the 5MF03 cruise that was completed on June 1.

The data for the figure below are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae (the area outlined in blue in the figure). This year's distribution of pollock appears to be centered in the typical reference area. Also the larval abundance figures in the middle of the reference area are somewhat above average.

Given these two pieces of information, the score for larval index is set to the high end of the average, 2.33.

Spawner/Recruit Time Series: The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition. The data set consisted of estimates of age 2 abundance from

1961-2003, representing the 1959-2001 year classes. There were a total of 43 recruitment data points. The 33% (0.355 billion) and 66% (0.675 billion) percentile cutoff points were calculated from the full time series and used to define the three recruitment states of weak, average and strong. The lower third of the data points were called weak, the middle third average and the upper third strong. Using these definitions, nine transition probabilities were then calculated:



Mean catch per 10 m² for late May cruises during 1982-2003

1. Probability of a weak year class following a weak
2. Probability of a weak year class following an average
3. Probability of a weak year class following a strong
4. Probability of an average year class following a weak
5. Probability of an average year class following an average
6. Probability of an average year class following a strong
7. Probability of a strong year class following a weak
8. Probability of a strong year class following an average
9. Probability of a strong year class following a strong

The probabilities were calculated with a time lag of two years so that the 2003 year class could be predicted from the size of the 2001 year class. The 2001 year class was estimated to be 0.115187 billion and was classified as weak. The probabilities of other recruitment states following a weak year class for a lag of 2 years (n=43) are given below:

| 2003 Year Class | | 2001 Year Class | Probability | N |
|-----------------|---------|-----------------|-------------|---|
| Weak | follows | Weak | 0.097 | 4 |
| Average | follows | Weak | 0.073 | 3 |
| Strong | follows | Weak | 0.146 | 6 |

The probability of a strong year class following a weak year class had the highest probability. We classified this data element as a strong, giving it a score at the low end of strong 2.34. Each of the data elements was weighted equally.

Conclusion

Based on these five elements and the weights assigned in the table below, the FOCI forecast of the 2003 year class is average.

| <i>Element</i> | <i>Weights</i> | <i>Score</i> | <i>Total</i> |
|------------------------|----------------|--------------|----------------|
| Time Sequence of R | 0.2 | 2.34 | 0.468 |
| Rain | 0.2 | 2.24 | 0.448 |
| Wind Mixing | 0.2 | 2.15 | 0.43 |
| Advection | 0.2 | 2.00 | 0.4 |
| Larval Index-abundance | 0.2 | 2.33 | 0.466 |
| Total | 1.0 | | 2.21 = Average |

Analytic Approach

Model description

Age-structured models for the period 1961 to 2003 (43 yrs) were used to assess Gulf of Alaska pollock. Population dynamics were modeled using standard formulations for mortality and fishery catch (e.g. Fournier and Archibald 1982, Deriso et al. 1985, Hilborn and Walters 1992). Year- and age-specific fishing mortality was modeled as a product of a year effect, representing the full-recruitment fishing mortality, and an age effect, representing the selectivity of that age group to the fishery. The age effect was modeled using a double-logistic function with time-varying parameters (Dorn and Methot 1990, Sullivan et al. 1997). The model was fit to time series of catch biomass, survey indices of abundance, and estimates of age and length composition from the fishery and surveys. Details of the population dynamics and estimation equations are presented in an appendix.

Model parameters were estimated by maximizing the log likelihood of the data, viewed as a function of the parameters. Lognormal likelihoods were used for survey biomass and total catch estimates, and multinomial likelihoods were used for age and length composition data.

| <i>Likelihood component</i> | <i>Statistical model for error</i> | <i>Variance assumption</i> |
|--|------------------------------------|--|
| Fishery total catch (1964-2002) | Log-normal | CV = 0.05 |
| POP fishery length comp. (1964-71) | Multinomial | Sample size = 60 |
| Fishery age comp. (1972-2003) | Multinomial | Year-specific sample size = 60-400 |
| Shelikof EIT survey biomass (1981-2003) | Log-normal | Survey-specific CV = 0.10-0.35 |
| Shelikof EIT survey age comp. (1981-2003) | Multinomial | Sample size = 60 |
| NMFS bottom trawl survey biomass (1984-2003) | Log-normal | Survey-specific CV = 0.11-0.38 |
| NMFS bottom trawl survey age comp. (1984-2003) | Multinomial | Survey-specific sample size = 38-74 |
| Egg production biomass (1981-92) | Log-normal | Survey specific CV = 0.10-0.25 |
| ADF&G trawl survey biomass (1989-2003) | Log-normal | CV = 0.25 |
| ADF&G survey age comp. (2000,2002) | Multinomial | Sample size = 10 |
| ADF&G survey length comp. (1989-2003) | Multinomial | Sample size = 10 |
| Fishery selectivity random walk process error | Log-normal | Slope CV = 0.10 (0.001 for 1961-71) |
| | Normal | Inflection age SD = 0.40 (0.004 for 1961-71) |
| Recruit process error (1961-1968,2003) | Log-normal | CV = 1.0 |

Recruitment

In most years, year-class abundance at age 2 was estimated as a free parameter. Constraints were imposed on recruitment at the start of the modeled time period to improve parameter estimability. Instead of estimating the abundance of each age of the initial age composition independently, we parameterized the initial age composition with mean log recruitment plus a log deviation from an equilibrium age structure based on that mean initial recruitment. A penalty was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period. We also used the same penalty for log deviations in recruitment for 1961-68. These relatively weak constraints were sufficient to obtain fully converged parameter estimates.

Modeling fishery data

A four-parameter double logistic equation was used to model fisheries selectivity. Instead of grouping years with similar selectivity patterns as in previous assessments (Hollowed et al., 1994, 1995, 1998), we allowed the parameters of the double logistic function to vary according to a random walk process (Sullivan et al. 1999). This approach allows selectivity to vary from one year to the next, but restricts the amount of variation that can occur. The resulting selectivity patterns are similar to those obtained by grouping years, but transitions between selectivity patterns occur gradually rather than abruptly. Constraining the selectivity pattern for a group of years to be similar can be done simply by reducing the year-specific standard deviation of the process error term. Since limited data are available from the Pacific Ocean perch fishery years (1964-71), the process error standard deviation for those years was assumed to be very small, so that annual changes in selectivity are not allowed during that period.

Modeling survey data

Survey abundance was assumed to be proportional to total abundance as modified by the estimated survey selectivity pattern. Expected population numbers at age for the survey were based on the mid-date of the survey, assuming constant fishing and natural mortality throughout the year. Standard deviations in the log-normal likelihood were set equal to the sampling error CV (coefficient of variation) associated with each survey estimate of abundance (Kimura 1991).

Survey catchability coefficients can be fixed or freely estimated. In previous assessments, the NMFS bottom trawl survey catchability was fixed at one as a precautionary constraint on the total biomass estimated by the model. In the 2001 assessment (Dorn et al. 2001), a likelihood profile on trawl catchability showed that the maximum likelihood estimate of trawl catchability was approximately 0.7. This result is reasonable because pollock are known to form pelagic aggregations and occur in nearshore areas not intensively sampled by the NMFS bottom trawl survey. In this assessment we carry forward a model with estimated trawl catchability as an alternative for consideration. Catchability coefficients for other surveys were estimated as free parameters. Egg production estimates of spawning stock biomass were included in the model by setting the age-specific selectivity equal to the estimated percent mature at age (Hollowed et al. 1991).

The EK500 acoustic system has been used to estimate biomass since 1992. Earlier surveys (1981-91) were obtained with an older Biosonics acoustic system (Table 5). Biomass estimates similar to the Biosonics acoustic system can be obtained using the EK500 when a volume backscattering (S_v) threshold of -58.5 dB is used (Hollowed et al. 1992). Because of the newer system's lower noise level, abundance estimates since 1992 have been based on a S_v threshold of -69 dB. We split the Shelikof Strait EIT survey time series into two periods corresponding to the two acoustic systems, and estimated separate survey catchability coefficients for each period. For the 1992 and 1993 surveys, biomass estimates using both noise thresholds were used to provide information on relative catchability.

Ageing error

An ageing error transition matrix is used in the assessment model to convert population numbers at age to expected fishery and survey catch at age. This matrix was computed using the estimated percent-agreement levels. We evaluated trends in age reader agreement using data from tests between age readers during 1987-2003 (Table 12). Mean percent agreement is close to 100% at age 1 and declines to 40% at age 10 (Fig. 16). Annual estimates of percent agreement are variable, but show no obvious trend (Fig. 15), from which we concluded that using a single transition matrix for all years in the assessment model was appropriate.

An ageing error model was fit to the observed percent agreement at ages 2 and 9. The model is based on a linear increase in the standard deviation of ageing error and the assumption that ageing error is normally distributed (Table 13). The model predicts percent agreement by taking into account the probability that both readers are correct, both readers are off by one year in the same direction, and both readers are off by two years in the same direction (Methot 2000). The probability that both agree and were off by more than two years was considered negligible. The agreement between model predictions of percent agreement and the data is good (Fig. 16).

Length frequency data

The assessment model was fit to length frequency data from various sources by converting predicted age distributions (as modified by age-specific selectivity) to predicted length distributions using an age-length transition matrix. Because seasonal differences in pollock length at age are large, several transition matrices were used. For each matrix, unbiased length distributions at age were estimated for several years using age-length keys, then averaged across years. A transition matrix estimated by Hollowed et al. (1998) was used for length-frequency data from the early period of the fishery. A transition matrix was estimated using 1992-98 Shelikof Strait EIT survey data and used for winter survey length frequency data. The following length bins were used: 17 - 27, 28 - 35, 36 - 42, 43 - 50, 51 - 55, 56 - 70 (cm). Finally, a transition matrix was estimated using second and third trimester fishery age and length data during the years (1989-98) and was used for the ADF&G survey length frequency data. The following length bins were used: 25 - 34, 35 - 41, 42 - 45, 46 - 50, 51 - 55, 56 - 70 (cm), so that the first three bins would capture most of the summer length distribution of the age-2, age-3 and age-4 fish, respectively. Bin definitions were different for the summer and the winter transition matrices to account for the

seasonal growth of the younger fish (ages 2-4).

Parameter estimation

A large number of parameters are estimated when using this modeling approach. More than half of these parameters are year-specific deviations in fishery selectivity coefficients. Parameters were estimated using ADModel Builder, a C++ software language extension and automatic differentiation library. Parameters in nonlinear models are estimated in ADModel Builder using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. The optimizer in ADModel builder is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-4}). ADModel builder includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest.

A list of model parameters is shown below:

| <i>Population process modeled</i> | <i>Number of parameters</i> | <i>Estimation details</i> |
|---------------------------------------|--|---|
| Initial age structure | Ages 3-10 = 8 | Estimated as log deviances from the log mean; constrained by random deviation process error from an equilibrium unfished age structure |
| Recruitment | Years 1961-2003 = 43 | Estimated as log deviances from the log mean; recruitment in 1961-68 constrained by random deviation process error. |
| Natural mortality | Age- and year-invariant = 1 | Not estimated in the model |
| Fishing mortality | Years 1961-2003 = 43 | Estimated as log deviances from the log mean |
| Mean fishery selectivity | 4 | Slope parameters estimated on a log scale |
| Annual changes in fishery selectivity | 4 * (No. years -1) = 168 | Estimated as deviations from mean selectivity and constrained by random walk process error |
| Survey catchability | No. of surveys + 1 = 7 | AFSC bottom trawl survey catchability not estimated, other catchabilities estimated on a log scale. Two catchability periods were estimated for the EIT survey. |
| Survey selectivity | 10 (EIT survey: 2, BT survey: 4, ADF&G survey: 2, Historical 400-mesh eastern trawls: 2) | Slope parameters estimated on a log scale. The egg production survey uses a fixed selectivity pattern equal to maturity at age. |
| Total | 114 basic parameters + 168 process error parameters + 2 fixed parameters = 284 | |

Parameters Estimated Independently

Pollock life history characteristics, including natural mortality, growth, and maturity, were estimated independently. These parameters are used in the model to estimate spawning and population biomass, and obtain predictions of fishery and survey biomass. Pollock life history parameters include:

- Natural mortality (M)
- Proportion mature at age.

- Weight at age and year by fishery and by survey

Natural mortality

Hollowed and Megrey (1990) estimated natural mortality using a variety of methods including estimates based on: a) growth parameters (Alverson and Carney 1975, and Pauly 1980), b) GSI (Gunderson and Dygert, 1988), c) monitoring cohort abundance, and d) estimation in the stock synthesis model (Methot 1993). These methods produced estimates of natural mortality that ranged from 0.24 to 0.30. The maximum age observed was 22 years. For the assessment modeling, natural mortality was assumed to be 0.3 for all ages.

Hollowed et al. (2000) developed a model for Gulf of Alaska pollock that accounted for predation mortality. The model suggested that natural mortality declines from 0.8 at age 2 to 0.4 at age 5, and then remains relatively stable with increasing age. In addition, stock size was higher when predation mortality was included. A theoretical analysis of a simple age-structured model by Clark (1999) evaluated the effect of an erroneous M on both estimated abundance and target harvest rates. He found that “errors in estimated abundance and target harvest rate were always in the same direction, with the result that, in the short term, extremely high exploitation rates can be recommended (unintentionally) in cases where the natural mortality rate is overestimated and historical exploitation rates in the catch-at-age data are low.” He proposed that this error could be avoided by using a conservative (low) estimate of natural mortality. This suggests that the current approach of using a potentially low but still credible estimate of M for assessment modeling is consistent with the precautionary approach. However, it should be emphasized that the role of pollock as prey in the Gulf of Alaska ecosystem cannot be fully evaluated using a single species assessment model (Hollowed et al. 2000).

Maturity at age

In the 2002 assessment, maturity at age for Gulf of Alaska pollock was estimated using maturity stage data collected during winter EIT surveys in the Gulf of Alaska during 1983-2002. These new estimates replaced a maturity at age vector estimated by Hollowed et al. (1991) using maturity stage data collected during 1983-89. Maturity stages for female pollock describe a continuous process of ovarian development between immature and post-spawning. For the purposes of estimating a maturity vector (the proportion of an age group that has been or will be reproductively active during the year) for stock assessment, all fish greater than or equal to a particular maturity stage are assumed to be mature, while those less than that stage are assumed to be immature. We assumed that maturity stages in which ovarian development had progressed to the point where ova were distinctly visible were mature. Maturity stage data should not be considered the most reliable data to estimate maturity at age. The stages are qualitative rather than quantitative, so there is subjectivity in assigning stages, and a potential for different technicians to apply criteria differently. Because the link between pre-spawning maturity stages and eventual reproductive activity later in the season is not well established, the division between mature and immature stages is problematic. Changes in the timing of spawning could also affect maturity at age estimates. Merati (1993) compared visual maturity stages with ovary histology and a blood assay for vitellogenin and found general consistency between the different approaches. Merati (1993) noted that ovaries classified as late developing stage (i.e. immature) may contain yolked eggs, but it was unclear whether these fish would spawn later in the year. The average sample size of female pollock maturity stage data per year from winter EIT surveys in the Gulf of Alaska is 850 (Table 11).

We updated the 2002 estimates of maturity at age (based on an average of the annual 1983-2002 proportion mature at age) with the results from the 2003 survey (only the Shelikof Strait survey samples have been aged). Estimates for 2000 and 2001 have also changed since last year because it was discovered that those estimates mistakenly included data from summer EIT surveys on the east side of Kodiak Island. Based on a relatively few samples, estimates of maturity at age in 2003 were low, but

within the range observed in recent years (Fig. 13). The proportion of mature age-4 fish was 19% compared to 25% for the long-term average. Because there did not appear to be an objective basis for excluding data, we used the 1983-2002 average maturity at age in assessment.

Logistic regression (McCullagh and Nelder 1983) was also used to estimate the age and length at 50% mature at age for each year. Annual estimates of age at 50% maturity are highly variable and range from 3.7 years in 1984 to 6.1 years in 1991, with an average of 5.0 years. Length at 50% mature is less variable than the age at 50% mature, suggesting that at least some of the variability in the age at maturity can be attributed to changes in length at age (Fig 14). There is less evidence of trends in the length at 50% mature, with only the 1983 and 1984 estimates as unusually low values. The average length at 50% mature for all years is approximately 43 cm.

Weight at age

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = aL^b$, were also estimated. Weights at age was estimated by multiplying length at age by the predicted weight based on the length-weight regressions.

Model selection and evaluation

Model Selection

A range of different model configurations were used to assess the sensitivity of the results to model assumptions and different data sources. As in last year's assessment, we compared models with estimated and fixed NMFS trawl survey catchability. We also evaluated the effect of each survey time series by sequentially dropping each from the model, as suggested by the independent review of the pollock assessment by Center for Independent Experts (CIE).

Model 1: Estimated NMFS trawl survey catchability. In previous assessments, catchability was fixed at one as a precautionary assumption. In the previous assessments, a likelihood profile on trawl catchability showed that this parameter could be estimated. In most assessment models in the North Pacific, survey catchability is estimated as a free parameter when possible to do so, e.g., assessments for eastern Bering Sea pollock, sablefish, and Gulf of Alaska Pacific Ocean perch. Since catchability is estimated for all other surveys in the pollock assessment, there is no *a priori* reason from a technical perspective for treating the NMFS trawl survey differently.

Model 2: A model that conforms to last year's model assumptions: trawl catchability fixed at 1.0, and all other catchabilities freely estimated.

Model 3: As in Model 2, except the entire Shelikof Strait EIT survey time series is removed.

Model 4: As in Model 2, except the entire NMFS bottom trawl time series is removed.

Model 5: As in Model 2, except the entire ADF&G survey time series is removed.

Model 6: Model 6. As in Model 2, except the entire historical 400-mesh Eastern trawl survey time series is removed.

Comparison of Model 1 (estimated trawl catchability) with Model 2 (fixed trawl catchability) indicate that despite relatively large differences in stock biomass (21% decrease for Model 2), the difference in total log likelihood is very slight (0.47) (Table 14). When a similar analysis was performed last year, the estimate of catchability was 0.70, rather than 0.85 in the current assessment. Although Model 1 would be preferred by maximum likelihood criterion, the difference in model fit is not significant. Until a more precise estimate of catchability is possible, we consider that the historical convention of fixing catchability to be warranted. It should be noted that this represents a “hidden” element of conservatism in the assessment, since estimates of stock biomass and yield are lower when catchability is fixed. Not surprisingly, the uncertainty in biomass estimates are higher (and more realistic) for Model 1, since the assumption of known catchability in Model 2 artificially reduces uncertainty in the assessment.

Comparison of models that remove each survey times series sequentially are broadly consistent with the base model that includes all surveys (Fig. 17). All show a similar pattern of increase and decline, suggesting that no survey has a dominant influence on the estimated trend in abundance. For the full time period, removing the Shelikof Strait time series results in a much low peak abundance in the mid-1980s, while removing the historical 400-mesh Eastern trawl time series results in higher abundance before 1975. For the period since 1990, removing the Shelikof Strait EIT survey results in higher biomass, while removing either of the bottom trawl surveys results in lower biomass. This suggests some lack of consistency between spawning survey in Shelikof Strait, and summer bottom trawl surveys. One predictable result of removing surveys is that CVs of the biomass estimates increase.

Model Evaluation

Residual plots for model 2 (provisionally identified as the base model) were prepared to examine the goodness of fit of the base-run model to the age composition data. The Pearson residuals for a multinomial distribution are

$$r_i = \frac{p_i - \hat{p}_i}{\sqrt{(\hat{p}_i(1 - \hat{p}_i)/m)}}$$

where p_i is the observed proportion at age, \hat{p}_i is the expected proportion at age, and m is the sample size (McCullagh and Nelder 1983). Figures 18-20 show residuals for the fit to the fishery, the Shelikof Strait EIT survey and the NMFS trawl survey age compositions, and the ADFG trawl survey length composition. Although there are large residuals for some ages and years, no severe pattern of residuals is evident in the fishery age composition. Two moderate patterns were apparent in the fishery data. The first is a tendency for strong year classes to gain strength from adjacent weaker year classes as they become older, producing a pattern of negative residuals for the adjacent year classes. This pattern is most apparent for the strong 1984 year class beginning in 1990 at age 6. In addition, there is a tendency for strong year classes to shift a year as they become older. This pattern is most obvious for the 1988 year class, which began to change into a 1989 year class in 1995.

In the Shelikof Strait EIT survey age composition, the most extreme residuals tend to be for juvenile fish of ages two and three. Since the Shelikof Strait survey covers only a portion of winter habitat of juvenile fish, this pattern could be explained by differences in spatial distribution of different year classes. For example, the 1995 year class was uncommon in the Shelikof Strait EIT survey at age two and age three, but first appeared as large numbers in the fishery age composition data as three-year-old fish in the Shumagin area in 1998. In contrast, the 1994 year class was very abundant in the Shelikof Strait EIT survey as juveniles, but was not nearly as strong in later fishery age composition data. A similar pattern seems to be developing for the 1999 year class.

Model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 2001) (Figs. 21-23). General trends in survey time series are fit reasonably well. For example, both the model and all surveys show a declining trend in the 1990s. But since each survey time series shows a different pattern of decline, the model is unable to fit all surveys simultaneously. The ADF&G survey matches the model trend better than any other survey, despite receiving less weight in model fitting. The discrepancy between the NMFS trawl survey and the Shelikof Strait EIT survey biomass estimates in the 1980s accounts for the poor model fit to both time series during in those years. More recently, the model fits extremely well the 2003 biomass estimates from the NMFS bottom trawl survey and the ADF&G trawl survey, but shows a poorer fit to the 2003 Shelikof Strait EIT survey biomass estimate.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.85 (Fig. 24). The change in log likelihood is very small (less than one) between models with fixed and estimated catchability, indicating that despite the large change in biomass, there is little objective basis for choosing one model over the other.

Assessment Model Results

Parameter estimates and model output for Model 2 are presented in a series of tables and figures. Estimated selectivity for different periods in the fishery and for surveys is given in Table 15. Table 16 gives the estimated population numbers at age for the years 1961-2003. Table 17 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1969-2003 (see also Fig. 26). Stock size peaked in the early 1980s at approximately twice unfished stock size. In 1998, the stock dropped below the $B_{40\%}$ for the first time since the 1970s, and in 2003 is estimated to be at 23% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2003 indicates the current estimated trend in spawning biomass for 1969-2003 is consistent with previous estimates (Fig. 27). All time series show a similar pattern of decreasing spawning biomass in the 1990s. Retrospective biases in the assessment are small, but based on the current assessment, there was some tendency to underestimate ending year abundance from 1993 to 1997, followed by several years of overestimating ending year abundance. The estimated 2003 age composition from the current assessment shows some differences compared to the estimated age composition in the 2002 assessment (Fig. 27). The number of age-4 pollock (1999 year class) is lower than the model estimate last year, but higher than the average year scenario that was used to recommend the ABC. The estimated number of age-3 fish from the 2000 year class is much larger than estimated last year, based on a relatively strong appearance in 2002 fishery and 2003 bottom survey age composition data.

Stock and recruitment

Recruitment of Gulf of Alaska pollock is more variable ($CV = 1.05$) than Eastern Bering Sea pollock (0.61). Among North Pacific groundfish stocks with age-structured assessments, GOA pollock ranks third in recruitment variability after sablefish and Pacific Ocean perch (<http://www.refm.noaa.gov/stocks/specs/Data%20Tables.htm>). However, unlike sablefish and Pacific Ocean perch, pollock have a short generation time (5 yrs), so that large year classes do not persist in the population long enough to have a buffering effect on population variability. Because of these intrinsic population characteristics, the typical pattern of biomass variability for Gulf of Alaska pollock will be sharp increases due to strong recruitment, followed by periods of gradual decline until the next strong year class recruits to the population. Gulf of Alaska pollock is more likely to show this pattern than any other groundfish stock in the North Pacific due to the combination of a short generation time and high

recruitment variability.

Since 1980, strong year classes have occurred every four to six years (Fig. 26). Because of high recruitment variability, the mean relationship between stock size and recruitment abundance is not apparent despite good contrast in stock abundance (Fig. 28). Strong and weak year classes have been produced both at high spawning biomass and low spawning biomass. The 1972 year class (one of the largest on record) was produced by an estimated spawning biomass close to current levels, suggesting that the stock has the potential to produce strong year classes. Spawner productivity is higher at low spawning biomass compared to high spawning biomass, indicating that survival of eggs to recruitment is density-dependent (Fig. 28). However, this pattern of density-dependent survival emerges from strong decadal trends in spawner productivity. These decadal trends in spawner productivity have produced the pattern of increase and decline in the GOA pollock population. The last two decades have been a period of relatively low spawner productivity.

We summarize information on recent year classes in the table below. Subsequent to the 2000 year class, which appears to be at least moderate in abundance, information becomes extremely sketchy. Both the 2001 and the 2002 year class were nearly absent in the Shelikof Strait surveys, but the FOCI prediction for the 2001 was average-strong due to favorable environmental conditions and good larval counts. Neither the 2001 nor the 2002 year class appears to be as strong as the 1999 year class. If the pattern of relatively strong pollock recruitment every 4-6 years continues, then the next episode of strong recruitment would be expected occur in 2005-07.

| | | | |
|---------------------|--|---|----------------|
| Year of recruitment | 2003 | 2004 | 2005 |
| Year class | 2001 | 2002 | 2003 |
| FOCI prediction | <i>Average-Strong</i> | <i>Average</i> | <i>Average</i> |
| Survey information | 2002 Shelikof EIT survey age-1 estimate is 6.0 million (19th in abundance out of 19 surveys) | 2003 Shelikof EIT survey age-1 estimate is 45.1 million (16th in abundance out of 19 surveys) 2003 NMFS bottom trawl age-1 estimate is 75.5 million (6th in abundance out of 9 surveys) | |

Projections and Harvest Alternatives

Reference fishing mortality rates and spawning biomass levels

Since 1997, Gulf pollock have been managed under Tier 3 of NPFMC harvest guidelines. In Tier 3, reference mortality rates are based on the spawning biomass per recruit (SPR), while biomass reference levels are estimated by multiplying the SPR by average recruitment. Estimates of the FSPR harvest rates were obtained using the life history characteristics of Gulf of Alaska pollock (Table 18). Spawning biomass reference levels were based on mean 1979-2002 recruitment (816 million). The average did not include the recruitment in 2003 due to uncertainty in the estimates of year class strength. Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using mean weight at age for the Shelikof Strait EIT surveys in 2001-2003 to estimate current reproductive potential. The SPR at $F=0$ was estimated as 0.760 kg/recruit, which is slightly higher than the estimate in the 2002 assessment. F_{SPR} rates depend the selectivity pattern of the fishery. Selectivity in the Gulf of Alaska pollock fishery changed as the fishery evolved from a foreign fishery occurring along the shelf break to a domestic

fishery on spawning aggregations and in nearshore waters (Fig. 1). Since 1992, Gulf of Alaska pollock have been managed with time and area restrictions, and selectivity has been fairly stable (Fig. 25). For SPR calculations, we used a selectivity pattern based on an average for 1992-2003.

Gulf of Alaska pollock F_{SPR} harvest rates are given below:

| F_{SPR} rate | Fishing mortality | Equilibrium under average 1979-2002 recruitment | | | | |
|----------------|-------------------|---|----------------------------|-----------------------------------|-------------------|-----------------|
| | | Avg. Recr. (Million) | Total 3+ biom. (1000 t) | Female spawning biom. (1000 t) | Catch (1000 t) | Harvest rate |
| 100.0% | 0.000 | 816 | 1939 | 620 | 0 | 0.0% |
| 50.0% | 0.210 | 816 | 1325 | 310 | 148 | 11.2% |
| 45.0% | 0.249 | 816 | 1259 | 279 | 163 | 12.9% |
| 40.0% | 0.294 | 816 | 1192 | 248 | 177 | 14.8% |
| 35.0% | 0.349 | 816 | 1122 | 217 | 191 | 17.0% |

The $B_{40\%}$ estimate of 248,000 t is about 3% higher than the estimate of 240,000 t in the 2002 assessment. The model estimate of spawning biomass in 2004 is 195,350 t, which is 31% of unfished spawning biomass and below $B_{40\%}$ (240,000 t), thereby placing Gulf of Alaska pollock in sub-tier “b” of Tier 3. In sub-tier “b” the OFL and maximum permissible ABC fishing mortality rates are adjusted downwards as described by the harvest guidelines (see SAFE Summary Chapter). Estimates of spawning stock depend strongly on the strength of the 1999 year class. If it is assumed that the 1999 year class is only average in abundance (a risk averse assumption compared to the model estimate), spawning stock decreases to 165,580 t, or 27% of unfished spawning biomass.

2004 acceptable biological catch

The definitions of OFL and maximum permissible F_{ABC} under Amendment 56 provide a buffer between the overfishing level and the intended harvest rate, as required by NMFS national standard guidelines. Since estimates of stock biomass from assessment models are uncertain, the buffer between OFL and ABC provides a margin of safety so that assessment error will not result in the OFL being inadvertently exceeded. For Gulf of Alaska pollock, the maximum permissible F_{ABC} harvest rate is 83.5% of the OFL harvest rate. In the 2001 assessment, based on an analysis that showed that the buffer between the maximum permissible F_{ABC} and OFL decreased when the stock is below approximately $B_{50\%}$, we developed a more conservative alternative that maintains a constant buffer between ABC and F_{ABC} at all stock levels. While there is always some probability of exceeding F_{OFL} due to imprecise stock assessments, it did not seem reasonable to reduce safety margin as the stock declines.

This alternative is given by the following

$$\text{Define } B^* = B_{40\%} \frac{F_{35\%}}{F_{40\%}}$$

Stock status: $B / B^* > 1$, then $F = F_{40\%}$

Stock status: $0.05 < B / B^* \leq 1$, then $F = F_{40\%} \times (B / B^* - 0.05) / (1 - 0.05)$

Stock status: $B / B^* \leq 0.05$, then $F = 0$

This alternative has the same functional form as the maximum permissible F_{ABC} ; the only difference is that it declines linearly from B^* ($= B_{47\%}$) to $0.05B^*$ (Fig. 29).

Projections for 2004 for F_{OFL} , the maximum permissible F_{ABC} , and an adjusted $F_{40\%}$ harvest rate with a constant buffer between F_{ABC} and F_{OFL} are given for Models 1-6 in Table 14. Projections are obtained using the estimated abundance of the 1999 year class (1.4 billion), and a second set of projections where the 1999 year class is assumed to be average as a precautionary assumption.

ABC recommendation

There are three major sources of new information about abundance trends in 2003. The 2003 NMFS bottom trawl survey biomass increased 86% over a comparable area in 2001, supporting our conclusion that the 2001 biomass estimate was anomalously low. The 2003 Shelikof Strait EIT survey indicated a 18% increase in total biomass since 2002, but a continued decline (-36%) in adult biomass (≥ 43 cm). In addition, the 2003 ADF&G crab/groundfish survey biomass decreased by 30%. Although a summer EIT survey was conducted in 2003, final results are not available for this assessment. Preliminary results suggest consistency with the NMFS trawl survey in total biomass and spatial pattern. The overall picture both from surveys and assessment results suggests a modest increase in pollock abundance since last year—not as large as was projected, but greater than the precautionary scenario that was used to set the 2003 ABC.

Major concerns about Gulf of Alaska pollock include 1) the further decline of spawning activity in Shelikof Strait, and 2) a continued reduction in the estimated size of the 1999 year class (the current estimate is 65% of the 2002 estimate). The decline in spawning activity in Shelikof Strait is somewhat mitigated by the additional winter surveying effort, which found significant aggregations of spawning pollock elsewhere in the Gulf of Alaska. Nevertheless, the cause of these apparent changes in utilization of spawning habitat is unknown, and there is concern that changes in spawning behavior alone could impact pollock abundance in the future.

We consider Model 2 the strongest candidate on which to base yield recommendations. The change in the estimate of NMFS trawl catchability for Model 1 between this year and last year suggests that basing an assessment on an estimated trawl catchability could increase interannual variability in ABC recommendations. Models which omit an entire survey time series are useful for sensitivity analyses, but because of the increase in uncertainty when surveys are omitted, we are reluctant to take out surveys unless there is good evidence to think a survey is biased. For example, although the Shelikof Strait EIT survey and the NMFS bottom trawl survey show highly contradictory trends in the 1980s, both are used in the assessment model. No survey covers the entire spatial distribution of pollock (or distance above bottom). Bottoms trawls do not adequately survey the pelagic component of the stock, while the Shelikof Strait EIT survey covers only part of potential spawning habitat. If the different components of the population sampled by each survey show different trends than the population as a whole, it may be advisable to use each survey time series as is, despite some lack of model fit, to obtain the most robust estimates of overall population trends.

A second consideration is whether to use the model estimate of the 1999 year class or whether to set it to

mean recruitment for yield recommendations. Setting a year class at age 5 equal to mean instead of using the model estimate is an exceptional measure that requires good justification. Although the estimate of the 1999 year class is lower, it is considerably less uncertain than last year's estimate (Fig. 30). The model estimates of uncertainty indicate that there is negligible probability that the 1999 year class is less than or equal to the mean.

Arguments for setting the 1999 year class to the mean are the following. First, the estimate of 1994 year class in 1998 is nearly equal to the current estimate of the 1999 year class at age 4. In the current assessment, the 1994 year class (at age 9) is estimated to be average in strength, so it is still possible that subsequent estimates of the 1999 year class could be lower. Second, because stock size is relatively close to the $B_{20\%}$ threshold below which fishing must be stopped, erring on the side of caution would allow the stock to increase, moving the stock closer to B_{MSY} . Finally, it is unclear whether the downward trend in recent estimates of strong year classes is attributable to estimation error, or whether it represents an increase in juvenile mortality not accounted for in the assessment. Evidence of an increase in predation on juvenile pollock (principally by arrowtooth flounder, Pacific cod, and Pacific halibut) has been reported by other studies (Bailey 2000, Hollowed et al. 2000), but these studies rely on the same information used in the stock assessment. NPFMC harvest guidelines do not deal with the appropriate response to an increase in juvenile mortality. One approach would be recalculate $F_{40\%}$ for this new higher level of ecosystem consumption, resulting in higher fishing mortality rates. Alternatively, fishing mortality rates could be adjusted downwards to compensate for the increase in predation, thereby preserving the same quantity of spawning biomass per recruit as occurred prior to the increase in predation. Clearly additional research is needed both to further evaluate potential changes in juvenile pollock mortality and to develop an appropriate management response. The potential increase in juvenile pollock mortality adds additional uncertainty to the assessment, which led us to base the author's recommended 2004 ABC on mean recruitment for the 1999 year class.

Based on these considerations, we used Model 2, an assumed an average 1999 year class, and the adjusted $F_{40\%}$ harvest rate used in last year's assessment for the author's recommended ABC. The projected 2004 ABC is 65,660 t, nearly equal to the projected 2004 ABC of 65,100 t in last year's assessment with the same assumptions. The elements of risk-aversion in this recommendation relative to using the point estimate of the model and the maximum permissible F_{ABC} are the following: 1) fixing trawl catchability at 1.0; 2) assuming an average 1999 year class instead of the model estimate; 3) not adjusting or removing the 2003 Shelikof Strait survey biomass estimate despite good evidence that the fraction of the stock spawning in Shelikof Strait was lower in 2003; and 4) applying a more conservative harvest rate than the maximum permissible F_{ABC} . Collectively these risk-averse elements reduce the recommended ABC to approximately 50% of the model point estimate.

To evaluate the probability of that the stock is below the $B_{20\%}$ threshold, we modified the assessment model to include 2004, and assumed 2004 catches will be equal to the ABC recommendation. For 2005 and subsequent years, catch is derived from the estimate of spawning biomass in that year and the author's recommended fishing mortality schedule. We then sampled from the joint marginal likelihood of spawning biomass and fishing mortality in 2004 using Markov chain Monte Carlo (MCMC) (Fig. 31). A chain of 1,000,000 samples was thinned by selecting every 200th sample. Analysis of the thinned MCMC chain indicates that probability of the stock being below $B_{20\%}$ was approximately 8% in 2002, 7% in 2003, and will be less than 1% in 2004 and subsequent years.

Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and

Management Act (MSFCMA). For each scenario, the projections begin with the 2003 numbers at age as projected by the assessment model. In each year, the fishing mortality rate is determined by the spawning biomass in that year and the respective harvest scenario. Recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments during 1979-2002 as estimated by the assessment model. Spawning biomass is computed in each year based on the time of peak spawning (March 15) using the maturity and weight schedules in Table 18. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follows (“ $max F_{ABC}$ ” 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 the F_{ABC} recommended in the assessment.

Scenario 3: In all future years, F is set equal to 50% of $max F_{ABC}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1999-2003 average F . (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC} .)

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

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

Scenario 6: In all future years, F is set equal to F_{OFL} . (Rationale: This scenario determines whether a stock is overfished.)

Scenario 7: In 2004 and 2005, F is set equal to $max F_{ABC}$, and in all subsequent years, F is set equal to F_{OFL} . (Rationale: This scenario determines whether a stock is approaching an overfished condition.)

Results from scenarios 1-5 are presented in Tables 19 and 20. Table 19 contains projections using the model estimate of the 1999 year class, while Table 20 contains projections where the 1999 year class is assumed to be average. Under all harvest policies, spawning biomass is projected to increase after 2004. The magnitude of the increase depends on the harvest policy, but depends to greater extent on the strength of incoming year classes

Scenarios 6 and 7 are used to make the MSFCMA’s required status determination as follows:

Spawning biomass is projected to be 193,211 t in 2004 for an FOFL harvest rate, which is less than $B_{35\%}$ (217,000 t), but greater than $\frac{1}{2}$ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2014

is 236,500 t, 109% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2006 is 216,100 t, which is less than $B_{35\%}$, but greater than $\frac{1}{2}$ of $B_{35\%}$. Projected mean spawning biomass in 2016 is 238,400 t, 110% of $B_{35\%}$. Therefore, Gulf of Alaska pollock is not approaching an overfished condition.

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Table 1. Walleye pollock catch (t) in the Gulf of Alaska. The TAC for 2003 is for the area west of 140° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound (1,700 t). Research catches are also reported.

| <i>Year</i> | <i>Foreign</i> | <i>Joint Venture</i> | <i>Domestic</i> | <i>Total</i> | <i>TAC</i> | <i>Research</i> |
|----------------------------|----------------|----------------------|-----------------|--------------|------------|-----------------|
| 1964 | 1,126 | | | 1,126 | --- | |
| 1965 | 2,749 | | | 2,749 | --- | |
| 1966 | 8,932 | | | 8,932 | --- | |
| 1967 | 6,276 | | | 6,276 | --- | |
| 1968 | 6,164 | | | 6,164 | --- | |
| 1969 | 17,553 | | | 17,553 | --- | |
| 1970 | 9,343 | | | 9,343 | --- | |
| 1971 | 9,458 | | | 9,458 | --- | |
| 1972 | 34,081 | | | 34,081 | --- | |
| 1973 | 36,836 | | | 36,836 | --- | |
| 1974 | 61,880 | | | 61,880 | --- | |
| 1975 | 59,512 | | | 59,512 | --- | |
| 1976 | 86,527 | | | 86,527 | --- | |
| 1977 | 117,834 | | 522 | 118,356 | 150,000 | 89 |
| 1978 | 96,392 | 34 | 509 | 96,935 | 168,800 | 100 |
| 1979 | 103,187 | 566 | 1,995 | 105,748 | 168,800 | 52 |
| 1980 | 112,997 | 1,136 | 489 | 114,622 | 168,800 | 229 |
| 1981 | 130,324 | 16,857 | 563 | 147,744 | 168,800 | 433 |
| 1982 | 92,612 | 73,917 | 2,211 | 168,740 | 168,800 | 110 |
| 1983 | 81,358 | 134,131 | 119 | 215,608 | 256,600 | 213 |
| 1984 | 99,260 | 207,104 | 1,037 | 307,401 | 416,600 | 311 |
| 1985 | 31,587 | 237,860 | 15,379 | 284,826 | 305,000 | 167 |
| 1986 | 114 | 62,591 | 25,103 | 87,809 | 116,000 | 1202 |
| 1987 | | 22,823 | 46,928 | 69,751 | 84,000 | 227 |
| 1988 | | 152 | 65,587 | 65,739 | 93,000 | 19 |
| 1989 | | | 78,392 | 78,392 | 72,200 | 73 |
| 1990 | | | 90,744 | 90,744 | 73,400 | 158 |
| 1991 | | | 100,488 | 100,488 | 103,400 | 16 |
| 1992 | | | 90,857 | 90,857 | 87,400 | 40 |
| 1993 | | | 108,908 | 108,908 | 114,400 | 116 |
| 1994 | | | 107,335 | 107,335 | 109,300 | 70 |
| 1995 | | | 72,618 | 72,618 | 65,360 | 44 |
| 1996 | | | 51,263 | 51,263 | 54,810 | 147 |
| 1997 | | | 90,130 | 90,130 | 79,980 | 56 |
| 1998 | | | 125,098 | 125,098 | 124,730 | 64 |
| 1999 | | | 95,590 | 95,590 | 94,580 | 35 |
| 2000 | | | 73,080 | 73,080 | 94,960 | 56 |
| 2001 | | | 72,076 | 72,076 | 90,690 | 77 |
| 2002 | | | 51,937 | 51,937 | 53,490 | 78 |
| 2003 | | | | | 49,590 | 38 |
| Average (1977-2002) | | | | 115,069 | 130,870 | 161 |

Sources: 1964-85--Megrey (1988); 1986-90--Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission. Domestic catches in 1986-90 were adjusted for discard as described in Hollowed et al. (1991). 1991-2002--NMFS Alaska Regional Office.

Table 2. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 1991-2002 compiled from blend estimates by the Alaska Regional Office.

| Year | Utilization | Shumagin 610 | Chirikof 620 | Kodiak 630 | West Yakutat 640 | Prince William Sound 649 (state waters) | | Southeast and East Yakutat 650 & 659 | Total | Percent discard |
|----------------------------|-------------|--------------|--------------|------------|------------------|---|--------------------------------------|--------------------------------------|---------|-----------------|
| | | | | | | Sound 649 (state waters) | Southeast and East Yakutat 650 & 659 | | | |
| 1991 | Retained | 35,943 | 6,913 | 42,836 | 5,489 | 0 | 0 | 0 | 91,181 | |
| | Discarded | 4,838 | 793 | 3,459 | 207 | 0 | 0 | 10 | 9,308 | 9.3% |
| | Total | 40,781 | 7,706 | 46,295 | 5,696 | 0 | 0 | 10 | 100,488 | |
| 1992 | Retained | 16,014 | 14,171 | 47,467 | 160 | 0 | 0 | 0 | 77,812 | |
| | Discarded | 3,477 | 3,066 | 6,408 | 73 | 1 | 1 | 20 | 13,045 | 14.4% |
| | Total | 19,490 | 17,237 | 53,876 | 233 | 1 | 1 | 20 | 90,857 | |
| 1993 | Retained | 19,791 | 22,080 | 58,188 | 583 | 0 | 0 | 2 | 100,645 | |
| | Discarded | 1,413 | 1,708 | 5,065 | 65 | 8 | 8 | 5 | 8,264 | 7.6% |
| | Total | 21,204 | 23,788 | 63,253 | 648 | 8 | 8 | 7 | 108,908 | |
| 1994 | Retained | 16,238 | 19,917 | 58,511 | 6,362 | 0 | 0 | 0 | 101,028 | |
| | Discarded | 1,028 | 2,321 | 2,453 | 499 | 2 | 2 | 3 | 6,306 | 5.9% |
| | Total | 17,266 | 22,239 | 60,963 | 6,862 | 2 | 2 | 3 | 107,335 | |
| 1995 | Retained | 28,473 | 11,032 | 21,989 | 480 | 2,739 | 46 | 46 | 64,759 | |
| | Discarded | 1,905 | 2,048 | 3,778 | 53 | 75 | 1 | 1 | 7,859 | 10.8% |
| | Total | 30,378 | 13,080 | 25,768 | 533 | 2,813 | 47 | 47 | 72,618 | |
| 1996 | Retained | 23,100 | 10,150 | 11,571 | 510 | 775 | 0 | 0 | 46,107 | |
| | Discarded | 1,100 | 2,143 | 1,789 | 103 | 19 | 3 | 3 | 5,156 | 10.1% |
| | Total | 24,200 | 12,293 | 13,361 | 613 | 794 | 3 | 3 | 51,263 | |
| 1997 | Retained | 25,253 | 29,736 | 22,064 | 3,938 | 1,807 | 89 | 89 | 82,888 | |
| | Discarded | 1,009 | 3,179 | 2,998 | 30 | 19 | 7 | 7 | 7,242 | 8.0% |
| | Total | 26,262 | 32,916 | 25,062 | 3,968 | 1,826 | 96 | 96 | 90,130 | |
| 1998 | Retained | 28,815 | 48,530 | 38,753 | 6,316 | 1,655 | 8 | 8 | 124,077 | |
| | Discarded | 370 | 361 | 262 | 25 | 2 | 0 | 0 | 1,022 | 0.8% |
| | Total | 29,185 | 48,892 | 39,015 | 6,341 | 1,657 | 8 | 8 | 125,098 | |
| 1999 | Retained | 22,864 | 37,349 | 29,515 | 1,737 | 2,178 | 1 | 1 | 93,643 | |
| | Discarded | 521 | 784 | 578 | 22 | 39 | 3 | 3 | 1,947 | 2.0% |
| | Total | 23,385 | 38,133 | 30,093 | 1,759 | 2,216 | 4 | 4 | 95,590 | |
| 2000 | Retained | 21,380 | 11,314 | 35,078 | 1,917 | 1,181 | 0 | 0 | 70,870 | |
| | Discarded | 694 | 443 | 854 | 191 | 22 | 4 | 4 | 2,209 | 3.0% |
| | Total | 22,074 | 11,757 | 35,933 | 2,108 | 1,203 | 4 | 4 | 73,080 | |
| 2001 | Retained | 30,298 | 17,186 | 19,942 | 2,327 | 1,590 | 0 | 0 | 71,344 | |
| | Discarded | 173 | 205 | 330 | 24 | 0 | 0 | 0 | 732 | 1.0% |
| | Total | 30,471 | 17,391 | 20,272 | 2,351 | 1,590 | 0 | 0 | 72,076 | |
| 2002 | Retained | 17,046 | 20,106 | 10,615 | 1,808 | 1,216 | 0 | 0 | 50,791 | |
| | Discarded | 416 | 425 | 287 | 10 | 6 | 2 | 2 | 1,146 | 2.2% |
| | Total | 17,462 | 20,531 | 10,902 | 1,818 | 1,222 | 2 | 2 | 51,937 | |
| Average (1991-2002) | | 25,180 | 22,164 | 35,399 | 2,744 | 1,111 | 17 | 17 | 86,615 | |

Table 3. Catch at age (000,000s) of walleye pollock in the Gulf of Alaska.

| Year | Age | | | | | | | | | | | | | | | |
|------|------|-------|-------|--------|--------|--------|--------|-------|-------|-------|------|------|------|------|------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total |
| 1976 | 0.00 | 1.91 | 24.21 | 108.69 | 39.08 | 16.37 | 3.52 | 2.25 | 1.91 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 198.25 |
| 1977 | 0.01 | 2.76 | 7.06 | 23.83 | 89.68 | 30.35 | 8.33 | 2.13 | 1.79 | 0.67 | 0.44 | 0.10 | 0.02 | 0.00 | 0.00 | 167.17 |
| 1978 | 0.08 | 12.11 | 48.32 | 18.26 | 26.39 | 51.86 | 12.83 | 4.18 | 1.36 | 1.04 | 0.32 | 0.04 | 0.01 | 0.00 | 0.00 | 176.80 |
| 1979 | 0.00 | 2.53 | 48.83 | 76.37 | 14.15 | 10.13 | 16.70 | 5.02 | 1.27 | 0.60 | 0.16 | 0.04 | 0.00 | 0.00 | 0.00 | 175.81 |
| 1980 | 0.25 | 19.01 | 26.50 | 58.31 | 36.63 | 11.31 | 8.61 | 8.00 | 3.89 | 1.11 | 0.50 | 0.21 | 0.08 | 0.03 | 0.00 | 174.42 |
| 1981 | 0.14 | 2.59 | 31.55 | 73.91 | 47.97 | 20.29 | 4.87 | 4.83 | 2.73 | 0.26 | 0.03 | 0.02 | 0.00 | 0.00 | 0.00 | 189.19 |
| 1982 | 0.01 | 10.67 | 55.55 | 100.77 | 71.73 | 54.25 | 10.46 | 1.33 | 0.93 | 0.55 | 0.03 | 0.02 | 0.02 | 0.00 | 0.00 | 306.31 |
| 1983 | 0.00 | 3.64 | 20.64 | 110.03 | 137.31 | 67.41 | 42.01 | 7.38 | 1.24 | 0.06 | 0.28 | 0.07 | 0.00 | 0.00 | 0.00 | 390.07 |
| 1984 | 0.34 | 2.37 | 33.00 | 38.80 | 120.80 | 170.72 | 62.55 | 19.31 | 5.42 | 0.10 | 0.07 | 0.03 | 0.03 | 0.00 | 0.00 | 453.54 |
| 1985 | 0.04 | 12.74 | 5.53 | 33.22 | 42.22 | 86.02 | 128.95 | 41.19 | 10.84 | 2.20 | 0.70 | 0.00 | 0.00 | 0.00 | 0.00 | 363.64 |
| 1986 | 0.66 | 8.63 | 20.34 | 10.12 | 19.13 | 7.32 | 8.70 | 9.78 | 2.13 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 87.59 |
| 1987 | 0.00 | 8.83 | 14.03 | 8.00 | 6.89 | 6.44 | 7.18 | 4.19 | 9.95 | 1.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 67.44 |
| 1988 | 0.17 | 3.05 | 20.80 | 26.95 | 11.94 | 5.10 | 3.45 | 1.62 | 0.34 | 3.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 76.62 |
| 1989 | 1.08 | 0.27 | 1.47 | 19.39 | 28.89 | 16.96 | 8.09 | 4.76 | 1.69 | 1.10 | 3.62 | 0.43 | 0.01 | 0.00 | 0.00 | 87.77 |
| 1990 | 0.00 | 2.77 | 2.40 | 2.99 | 9.49 | 40.39 | 13.06 | 4.90 | 1.08 | 0.41 | 0.01 | 0.56 | 0.01 | 0.07 | 0.06 | 78.20 |
| 1991 | 0.00 | 0.59 | 9.68 | 5.45 | 2.85 | 5.33 | 26.67 | 3.12 | 16.10 | 0.87 | 5.65 | 0.42 | 2.19 | 0.21 | 0.77 | 79.90 |
| 1992 | 0.05 | 3.25 | 5.57 | 50.61 | 14.13 | 4.02 | 8.77 | 19.55 | 1.02 | 1.49 | 0.20 | 0.73 | 0.00 | 0.00 | 0.00 | 109.41 |
| 1993 | 0.02 | 1.97 | 9.43 | 21.83 | 47.46 | 15.72 | 6.55 | 6.29 | 8.52 | 1.81 | 2.07 | 0.49 | 0.72 | 0.13 | 0.24 | 123.25 |
| 1994 | 0.06 | 1.26 | 4.49 | 9.63 | 35.92 | 31.32 | 12.20 | 4.84 | 4.60 | 6.15 | 1.44 | 1.02 | 0.29 | 0.09 | 0.08 | 113.37 |
| 1995 | 0.00 | 0.06 | 1.01 | 5.11 | 11.52 | 25.83 | 12.09 | 2.99 | 1.52 | 2.00 | 1.82 | 0.19 | 0.28 | 0.03 | 0.15 | 64.61 |
| 1996 | 0.00 | 1.27 | 1.37 | 1.12 | 3.50 | 5.11 | 12.87 | 10.60 | 3.14 | 1.53 | 0.80 | 1.43 | 0.35 | 0.23 | 0.16 | 43.48 |
| 1997 | 0.00 | 1.07 | 6.72 | 3.77 | 3.28 | 6.60 | 10.09 | 16.52 | 12.24 | 5.06 | 2.06 | 0.79 | 0.54 | 0.17 | 0.02 | 68.92 |
| 1998 | 0.31 | 0.27 | 26.44 | 36.44 | 15.06 | 6.65 | 7.50 | 11.36 | 14.96 | 10.76 | 3.75 | 0.75 | 0.38 | 0.21 | 0.11 | 134.95 |
| 1999 | 0.00 | 0.42 | 2.21 | 22.74 | 36.10 | 8.99 | 6.89 | 3.72 | 5.71 | 7.27 | 4.01 | 1.07 | 0.56 | 0.12 | 0.10 | 99.92 |
| 2000 | 0.08 | 0.98 | 2.84 | 3.47 | 14.65 | 24.63 | 6.24 | 5.05 | 2.30 | 1.24 | 3.00 | 1.52 | 0.30 | 0.14 | 0.04 | 66.48 |
| 2001 | 0.74 | 10.13 | 6.59 | 7.34 | 9.42 | 12.59 | 14.44 | 4.73 | 2.70 | 1.35 | 0.65 | 0.83 | 0.61 | 0.00 | 0.04 | 72.14 |
| 2002 | 0.16 | 12.31 | 20.72 | 6.76 | 4.47 | 8.75 | 5.37 | 6.06 | 1.33 | 0.82 | 0.43 | 0.30 | 0.33 | 0.22 | 0.13 | 68.16 |

Table 4. Number of aged and measured fish in the Gulf of Alaska domestic pollock fishery used to estimate fishery age composition.

| <i>Year</i> | <i>Number aged</i> | | | <i>Number measured</i> | | |
|-------------|--------------------|----------------|--------------|------------------------|----------------|--------------|
| | <i>Males</i> | <i>Females</i> | <i>Total</i> | <i>Males</i> | <i>Females</i> | <i>Total</i> |
| 1989 | 882 | 892 | 1,774 | 6,454 | 6,456 | 12,910 |
| 1990 | 453 | 689 | 1,142 | 17,814 | 24,662 | 42,476 |
| 1991 | 1,146 | 1,322 | 2,468 | 23,946 | 39,467 | 63,413 |
| 1992 | 1,726 | 1,755 | 3,481 | 31,608 | 47,226 | 78,834 |
| 1993 | 926 | 949 | 1,875 | 28,035 | 31,306 | 59,341 |
| 1994 | 136 | 129 | 265 | 24,321 | 25,861 | 50,182 |
| 1995 | 499 | 544 | 1,043 | 10,591 | 10,869 | 21,460 |
| 1996 | 381 | 378 | 759 | 8,581 | 8,682 | 17,263 |
| 1997 | 496 | 486 | 982 | 8,750 | 8,808 | 17,558 |
| 1998 | 924 | 989 | 1,913 | 78,955 | 83,160 | 162,115 |
| 1999 | 980 | 1,115 | 2,095 | 16,304 | 17,964 | 34,268 |
| 2000 | 1,108 | 972 | 2,080 | 13,167 | 11,794 | 24,961 |
| 2001 | 1,063 | 1,025 | 2,088 | 13,731 | 13,552 | 27,283 |
| 2002 | 1,036 | 1,025 | 2,066 | 9,924 | 9,851 | 19,775 |

Table 5. Biomass estimates (t) of walleye pollock from NMFS echo integration trawl surveys in Shelikof Strait, NMFS bottom trawl surveys (west of 140 W. long.), egg production surveys in Shelikof Strait, and ADF&G crab/groundfish trawl surveys. The biomass of age-1 fish is not included in Shelikof Strait EIT survey estimates in 1995 and 2000 (106,900 and 54,400 t respectively). An adjustment of +1.05% was made to the AFSC bottom trawl biomass time series to account for unsurveyed biomass in Prince William Sound. In 2001, when the NMFS bottom trawl survey did not extend east of 147° W lon., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

| <i>Year</i> | <i>EIT Shelikof Strait survey</i> | | <i>NMFS bottom trawl west of 140° W lon.</i> | | <i>ADF&G Shelikof Strait egg production crab/groundfish survey</i> | |
|-------------|-----------------------------------|---------------------|--|--|--|---------|
| | <i>Biosonics</i> | <i>Simrad EK500</i> | | | | |
| 1981 | 2,785,755 | | | | 1,788,908 | |
| 1982 | | | | | | |
| 1983 | 2,278,172 | | | | | |
| 1984 | 1,757,168 | | 719,937 | | | |
| 1985 | 1,175,823 | | | | 768,419 | |
| 1986 | 585,755 | | | | 375,907 | |
| 1987 | | | 732,541 | | 484,455 | |
| 1988 | 301,709 | | | | 504,418 | |
| 1989 | 290,461 | | | | 433,894 | 214,434 |
| 1990 | 374,731 | | 825,592 | | 381,475 | 114,451 |
| 1991 | 380,331 | | | | 370,000 | |
| 1992 | 580,000 | 681,400 | | | 616,000 | 127,359 |
| 1993 | 295,785 | 408,200 | 754,390 | | | 132,849 |
| 1994 | | 467,300 | | | | 103,420 |
| 1995 | | 618,300 | | | | |
| 1996 | | 745,400 | 665,745 | | | 122,477 |
| 1997 | | 570,100 | | | | 93,728 |
| 1998 | | 489,900 | | | | 81,215 |
| 1999 | | | 607,147 | | | 53,587 |
| 2000 | | 334,900 | | | | 102,871 |
| 2001 | | 369,600 | 216,777 | | | 86,967 |
| 2002 | | 229,100 | | | | 96,237 |
| 2003 | | 270,200 | 399,690 | | | 66,989 |

Table 6. Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Gulf of Alaska bottom trawl survey and the Shelikof Strait EIT survey. For the Shelikof Strait EIT survey, CVs are reported for 1981-91, while relative estimation error using a geostatistical method are reported for 1992-2003. For the Gulf of Alaska bottom trawl survey, the number of measured pollock is approximate due to subsample expansions in the database, and the total number measured includes both sexed and unsexed fish.

| Year | No. of tows | | Survey biomass | | Number aged | | Number measured | | |
|-----------------------------------|----------------------|--------------------------|----------------|-------|-------------|-------|-----------------|---------|--------|
| | No. of tows | No. of tows with pollock | CV | Males | Females | Total | Males | Females | Total |
| Bottom trawl survey | | | | | | | | | |
| 1984 | 929 | 536 | 0.14 | 1,119 | 1,394 | 2,513 | 8,979 | 13,286 | 24,064 |
| 1987 | 783 | 533 | 0.20 | 672 | 675 | 1,347 | 8,101 | 15,654 | 24,608 |
| 1990 | 708 | 549 | 0.12 | 503 | 560 | 1,063 | 13,955 | 18,967 | 35,355 |
| 1993 | 775 | 628 | 0.16 | 879 | 1,013 | 1,892 | 14,496 | 18,692 | 34,921 |
| 1996 | 807 | 668 | 0.15 | 509 | 560 | 1,069 | 14,653 | 15,961 | 34,526 |
| 1999 | 764 | 567 | 0.38 | 560 | 613 | 1,173 | 10,808 | 11,314 | 24,080 |
| 2001 | 489 | 302 | 0.30 | 395 | 519 | 914 | NA | NA | NA |
| 2003 | 807 | 508 | 0.12 | 514 | 589 | 1,103 | NA | NA | NA |
| Shelikof Strait EIT survey | | | | | | | | | |
| | No. of midwater tows | No. of bottom trawl tows | | | | | | | |
| 1981 | 36 | 18 | 0.12 | 1,921 | 1,815 | 3,736 | NA | NA | NA |
| 1983 | 47 | 1 | 0.16 | 1,642 | 1,103 | 2,745 | NA | NA | NA |
| 1984 | 42 | 0 | 0.18 | 1,739 | 1,622 | 3,361 | NA | NA | NA |
| 1985 | 57 | 0 | 0.14 | 1,055 | 1,187 | 2,242 | NA | NA | NA |
| 1986 | 38 | 1 | 0.22 | 642 | 618 | 1,260 | NA | NA | NA |
| 1987 | 27 | 0 | --- | 557 | 643 | 1,200 | NA | NA | NA |
| 1988 | 26 | 0 | 0.17 | 537 | 464 | 1,001 | NA | NA | NA |
| 1989 | 21 | 0 | 0.10 | 757 | 796 | 1,553 | NA | NA | NA |
| 1990 | 25 | 16 | 0.17 | 988 | 1,117 | 2,105 | NA | NA | NA |
| 1991 | 16 | 2 | 0.35 | 478 | 628 | 1,106 | NA | NA | NA |
| 1992 | 17 | 8 | 0.04 | 784 | 765 | 1,549 | NA | NA | NA |
| 1993 | 22 | 2 | 0.05 | 583 | 624 | 1,207 | NA | NA | NA |
| 1994 | 42 | 12 | 0.05 | 554 | 633 | 1,187 | NA | NA | NA |
| 1995 | 22 | 3 | 0.05 | 599 | 575 | 1,174 | NA | NA | NA |
| 1996 | 30 | 8 | 0.04 | 724 | 775 | 1,499 | NA | NA | NA |
| 1997 | 16 | 14 | 0.04 | 682 | 853 | 1,535 | NA | NA | NA |
| 1998 | 22 | 9 | 0.04 | 863 | 784 | 1,647 | NA | NA | NA |
| 2000 | 31 | 0 | 0.05 | 430 | 370 | 800 | NA | NA | NA |
| 2001 | 15 | 9 | 0.05 | 314 | 378 | 692 | NA | NA | NA |
| 2002 | 18 | 1 | 0.07 | 278 | 326 | 604 | NA | NA | NA |
| 2003 | 17 | 2 | 0.05 | 294 | 322 | 616 | NA | NA | NA |

Table 7. Number of survey hauls, number of hauls with walleye pollock, mean CPUE, biomass, coefficient of variation and mean weight based on the 2003 Gulf of Alaska NMFS bottom trawl survey, by INPFC area and depth intervals.

| <i>INPFC area</i> | <i>Depth (m)</i> | <i>Number of Trawl hauls</i> | <i>Hauls with catch</i> | <i>CPUE (kg/km²)</i> | <i>Biomass (t)</i> | <i>CV</i> | <i>Mean weight (kg)</i> |
|-------------------|------------------|----------------------------------|-----------------------------|---------------------------------|--------------------|-----------|-----------------------------|
| Shumigan | 1 - 100 | 161 | 100 | 4,638 | 191,512 | 0.22 | 0.670 |
| | 101 - 200 | 46 | 36 | 1,409 | 20,674 | 0.36 | 0.810 |
| | 201 - 300 | 10 | 7 | 355 | 989 | 0.51 | 1.174 |
| | 301 - 500 | 9 | 5 | 46 | 118 | 0.37 | 0.920 |
| | 501 - 700 | 4 | 0 | 0 | 0 | --- | --- |
| | All depths | 230 | 148 | 3,370 | 213,291 | 0.20 | 0.683 |
| Chirkof | 1 - 100 | 75 | 31 | 1,584 | 41,251 | 0.46 | 0.626 |
| | 101 - 200 | 64 | 38 | 849 | 20,240 | 0.48 | 0.865 |
| | 201 - 300 | 25 | 25 | 863 | 9,965 | 0.24 | 0.483 |
| | 301 - 500 | 5 | 2 | 50 | 80 | 0.65 | 0.956 |
| | 501 - 700 | 3 | 0 | 0 | 0 | --- | --- |
| | All depths | 172 | 96 | 1,101 | 71,536 | 0.30 | 0.650 |
| Kodiak | 1 - 100 | 104 | 48 | 1,470 | 56,612 | 0.24 | 0.570 |
| | 101 - 200 | 106 | 67 | 854 | 37,019 | 0.35 | 0.848 |
| | 201 - 300 | 25 | 23 | 747 | 8,579 | 0.21 | 0.664 |
| | 301 - 500 | 9 | 1 | 2 | 7 | 1.00 | 0.566 |
| | 501 - 700 | 2 | 0 | 0 | 0 | --- | --- |
| | All depths | 246 | 139 | 1,043 | 102,217 | 0.18 | 0.655 |
| Yakutat | 1 - 100 | 16 | 14 | 499 | 8,307 | 0.51 | 0.203 |
| | 101 - 200 | 37 | 31 | 246 | 7,219 | 0.23 | 0.137 |
| | 201 - 300 | 17 | 15 | 312 | 1,611 | 0.18 | 0.531 |
| | 301 - 500 | 6 | 3 | 33 | 87 | 0.57 | 0.843 |
| | 501 - 700 | 3 | 1 | 9 | 14 | 1.00 | 0.710 |
| | All depths | 79 | 64 | 312 | 17,237 | 0.27 | 0.178 |
| Southeastern | 1 - 100 | 13 | 10 | 899 | 5,882 | 0.57 | 0.137 |
| | 101 - 200 | 28 | 25 | 916 | 10,154 | 0.21 | 0.175 |
| | 201 - 300 | 26 | 25 | 748 | 3,781 | 0.34 | 0.685 |
| | 301 - 500 | 10 | 1 | 135 | 420 | 1.00 | 0.763 |
| | 501 - 700 | 3 | 0 | 0 | 0 | --- | --- |
| | All depths | 80 | 61 | 754 | 20,238 | 0.21 | 0.189 |
| Total | All Depths | 807 | 508 | 1,376 | 424,519 | 0.12 | 0.543 |

Table 8. Estimated number at age (000,000s) from the echo integration-trawl survey in Shelikof Strait, and from the NMFS bottom trawl survey. For the acoustic survey in 1987, the percent at age is given. Bottom trawl survey estimates are for the Western and Central Gulf of Alaska only (Management areas 610-630).

| <i>Gulf of Alaska bottom trawl survey</i> | | | | | | | | | | | | | | | | |
|---|-----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|--------------|
| <i>Year</i> | <i>1</i> | <i>2</i> | <i>3</i> | <i>4</i> | <i>5</i> | <i>6</i> | <i>7</i> | <i>8</i> | <i>9</i> | <i>10</i> | <i>11</i> | <i>12</i> | <i>13</i> | <i>14</i> | <i>15</i> | <i>Total</i> |
| 1984 | 0.93 | 10.02 | 67.81 | 155.78 | 261.17 | 474.57 | 145.10 | 24.80 | 16.59 | 1.66 | 0.21 | 1.32 | 0.00 | 0.00 | 0.00 | 1159.96 |
| 1987 | 25.45 | 363.02 | 172.99 | 138.97 | 91.13 | 168.27 | 78.14 | 43.99 | 175.39 | 22.41 | 7.81 | 3.51 | 1.82 | 0.00 | 0.00 | 1292.88 |
| 1989 | 208.88 | 63.49 | 47.56 | 243.15 | 301.09 | 104.43 | 54.47 | 28.39 | 26.14 | 5.98 | 10.66 | 0.00 | 0.00 | 0.00 | 0.00 | 1094.23 |
| 1990 | 64.04 | 251.21 | 48.34 | 46.68 | 209.77 | 240.82 | 74.41 | 110.41 | 26.13 | 34.23 | 5.03 | 27.73 | 5.70 | 1.07 | 1.63 | 1147.19 |
| 1993 | 139.31 | 71.15 | 50.94 | 182.96 | 267.12 | 91.51 | 33.12 | 68.98 | 76.62 | 26.36 | 11.85 | 6.29 | 3.82 | 1.82 | 4.41 | 1036.25 |
| 1996 | 194.23 | 128.79 | 17.30 | 26.13 | 50.04 | 63.18 | 174.41 | 87.62 | 52.37 | 27.73 | 12.10 | 18.46 | 7.16 | 9.68 | 19.70 | 888.90 |
| 1999 | 109.73 | 19.17 | 20.94 | 66.76 | 118.94 | 56.80 | 59.04 | 47.71 | 56.40 | 81.97 | 65.18 | 9.67 | 8.28 | 2.50 | 0.76 | 723.85 |
| 2001 | 412.83 | 117.03 | 34.42 | 33.39 | 25.05 | 33.45 | 37.01 | 8.20 | 5.74 | 0.59 | 4.48 | 2.52 | 1.28 | 0.00 | 0.18 | 716.19 |
| 2003 | 75.46 | 18.40 | 128.41 | 140.74 | 73.27 | 44.72 | 36.10 | 25.27 | 14.51 | 8.61 | 3.23 | 1.79 | 1.26 | 0.00 | 0.00 | 571.77 |
| <i>Shelikof Strait EIT survey</i> | | | | | | | | | | | | | | | | |
| <i>Year</i> | <i>1</i> | <i>2</i> | <i>3</i> | <i>4</i> | <i>5</i> | <i>6</i> | <i>7</i> | <i>8</i> | <i>9</i> | <i>10</i> | <i>11</i> | <i>12</i> | <i>13</i> | <i>14</i> | <i>15</i> | <i>Total</i> |
| 1981 | 77.65 | 3,481.18 | 1,510.77 | 769.16 | 2,785.91 | 1,051.92 | 209.93 | 128.52 | 79.43 | 25.19 | 1.73 | 0.00 | 0.00 | 0.00 | 0.00 | 10,121.37 |
| 1983 | 1.21 | 901.77 | 380.19 | 1,296.79 | 1,170.81 | 698.13 | 598.78 | 131.54 | 14.48 | 11.61 | 3.92 | 1.71 | 0.00 | 0.00 | 0.00 | 5,210.93 |
| 1984 | 61.65 | 58.25 | 324.49 | 141.66 | 635.04 | 988.21 | 449.62 | 224.35 | 41.03 | 2.74 | 0.00 | 1.02 | 0.00 | 0.00 | 0.00 | 2,928.07 |
| 1985 | 2,091.74 | 544.44 | 122.69 | 314.77 | 180.53 | 347.17 | 439.31 | 166.68 | 42.72 | 5.56 | 1.77 | 1.29 | 0.00 | 0.00 | 0.00 | 4,258.67 |
| 1986 | 575.36 | 2,114.83 | 183.62 | 45.63 | 75.36 | 49.34 | 86.15 | 149.36 | 60.22 | 10.62 | 1.29 | 0.00 | 0.00 | 0.00 | 0.00 | 3,351.78 |
| 1987 | 7.5% | 25.5% | 55.8% | 2.9% | 1.7% | 1.2% | 1.6% | 1.2% | 2.1% | 0.4% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| 1988 | 17.44 | 109.93 | 694.32 | 322.11 | 77.57 | 16.99 | 5.70 | 5.60 | 3.98 | 8.96 | 1.78 | 1.84 | 0.20 | 0.00 | 0.00 | 1,266.41 |
| 1989 | 399.48 | 89.52 | 90.01 | 222.05 | 248.69 | 39.41 | 11.75 | 3.83 | 1.89 | 0.55 | 10.66 | 1.42 | 0.00 | 0.00 | 0.00 | 1,119.25 |
| 1990 | 49.14 | 1,210.17 | 71.69 | 63.37 | 115.92 | 180.06 | 46.33 | 22.44 | 8.20 | 8.21 | 0.93 | 3.08 | 1.51 | 0.79 | 0.24 | 1,782.08 |
| 1991 | 21.98 | 173.65 | 549.90 | 48.11 | 64.87 | 69.60 | 116.32 | 23.65 | 29.43 | 2.23 | 4.29 | 0.92 | 4.38 | 0.00 | 0.00 | 1,109.32 |
| 1994 | 155.71 | 30.33 | 42.97 | 29.31 | 146.27 | 79.07 | 40.47 | 25.98 | 42.66 | 46.46 | 14.22 | 6.40 | 1.08 | 2.25 | 0.55 | 663.72 |
| 1995 | 10,000.00 | 467.55 | 71.97 | 71.72 | 98.51 | 235.25 | 116.74 | 51.36 | 15.96 | 10.30 | 13.98 | 5.57 | 2.04 | 0.42 | 0.00 | 11,161.37 |
| 1996 | 51.50 | 3,193.33 | 110.73 | 23.75 | 51.72 | 68.32 | 193.46 | 114.14 | 38.40 | 12.53 | 10.93 | 5.13 | 2.42 | 0.02 | 0.37 | 3,876.75 |
| 1997 | 66.42 | 179.05 | 1,230.48 | 77.54 | 17.69 | 42.98 | 50.48 | 95.27 | 51.52 | 13.96 | 2.34 | 2.97 | 0.91 | 0.45 | 0.00 | 1,832.04 |
| 1998 | 390.12 | 85.49 | 123.98 | 467.34 | 133.52 | 13.64 | 30.44 | 34.55 | 70.48 | 24.64 | 13.63 | 6.56 | 0.26 | 0.54 | 0.54 | 1,395.74 |
| 2000 | 4,275.17 | 621.45 | 180.36 | 13.61 | 58.41 | 114.11 | 14.63 | 10.95 | 8.53 | 6.79 | 12.05 | 5.99 | 1.67 | 0.92 | 0.00 | 5,324.66 |
| 2001 | 272.48 | 3,591.22 | 296.13 | 51.47 | 34.83 | 18.99 | 28.53 | 10.81 | 5.10 | 2.20 | 1.00 | 1.55 | 0.57 | 0.41 | 0.20 | 4,315.50 |
| 2002 | 6.01 | 137.88 | 1,023.82 | 86.05 | 13.21 | 12.98 | 6.15 | 5.41 | 1.16 | 0.51 | 0.28 | 0.27 | 0.12 | 0.10 | 0.00 | 1,293.95 |
| 2003 | 45.19 | 64.26 | 187.48 | 705.94 | 46.12 | 5.43 | 2.92 | 1.01 | 1.31 | 0.57 | 0.19 | 0.00 | 0.12 | 0.00 | 0.00 | 1,060.54 |

Table 9. Estimates of pollock biomass obtained from GLM model predictions of pollock CPUE and INPFC area expansions. Biomass estimates were multiplied by the von Szalay and Brown (2001) FPC of 3.84 for comparison to the NMFS triennial trawl survey biomass estimates. Coefficients of variation do not reflect the variance of the FPC estimate.

| <i>Year</i> | <i>Biomass (t)</i> | <i>FPC-adjusted biomass (t)</i> | <i>CV</i> |
|-------------|--------------------|-------------------------------------|-----------|
| 1961 | 50,356 | 193,369 | 0.24 |
| 1962 | 57,496 | 220,783 | 0.30 |
| 1970 | 7,979 | 30,640 | 0.42 |
| 1971 | 4,257 | 16,348 | 0.64 |
| 1974 | 1,123,447 | 4,314,035 | 0.38 |
| 1975 | 1,501,142 | 5,764,384 | 0.52 |
| 1978 | 223,277 | 857,383 | 0.31 |
| 1980 | 146,559 | 562,787 | 0.27 |
| 1981 | 257,219 | 987,719 | 0.33 |
| 1982 | 356,433 | 1,368,703 | 0.29 |

Other estimates of pollock biomass from surveys using 400-mesh eastern trawls.

| | | | |
|---------|-----------|-----------|----------------------------|
| 1961 | 57,449 | 220,604 | Ronholt et al. 1978 |
| 1961-62 | 91,075 | 349,728 | Ronholt et al. 1978 |
| 1973-75 | 1,055,000 | 4,051,200 | Alton et al. 1977 |
| 1973-76 | 739,293 | 2,838,885 | Ronholt et al. 1978 |
| 1973-75 | 610,413 | 2,343,986 | Hughes and Hirschhorn 1979 |

Table 10. Predictions of Gulf of Alaska pollock year-class strength. The FOCI prediction is the prediction of year-class strength made in the natal year of the year class, and was derived from environmental indices, larval surveys, and the time series characteristics of pollock recruitment. The McKelvey index is the estimated abundance of 9-16 cm pollock from the Shelikof Strait EIT survey.

| <i>Year class</i> | <i>FOCI prediction</i> | <i>Year of EIT survey</i> | <i>McKelvey index</i> | <i>Rank abundance of McKelvey index</i> |
|-------------------|------------------------|---------------------------|-----------------------|---|
| 1980 | | 1981 | 0.078 | 10 |
| 1981 | | | | |
| 1982 | | 1983 | 0.001 | 20 |
| 1983 | | 1984 | 0.062 | 12 |
| 1984 | | 1985 | 2.092 | 3 |
| 1985 | | 1986 | 0.579 | 4 |
| 1986 | | | | |
| 1987 | | 1988 | 0.017 | 18 |
| 1988 | | 1989 | 0.399 | 5 |
| 1989 | | 1990 | 0.049 | 15 |
| 1990 | | 1991 | 0.022 | 17 |
| 1991 | | 1992 | 0.153 | 9 |
| 1992 | Strong | 1993 | 0.054 | 14 |
| 1993 | Average | 1994 | 0.156 | 8 |
| 1994 | Average | 1995 | 10.004 | 1 |
| 1995 | Average-Strong | 1996 | 0.056 | 13 |
| 1996 | Average | 1997 | 0.066 | 11 |
| 1997 | Average | 1998 | 0.390 | 6 |
| 1998 | Average | | | |
| 1999 | Average | 2000 | 4.275 | 2 |
| 2000 | Average | 2001 | 0.274 | 7 |
| 2001 | Average-Strong | 2002 | 0.006 | 19 |
| 2002 | Average | 2003 | 0.045 | 16 |
| 2003 | Average | | --- | --- |

Table 11. Maturity at age of female pollock derived from maturity stage data collected during winter EIT surveys in the Gulf of Alaska.

| Year | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10+ | | Total SS |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|-------------|
| | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | |
| 1983 | 0 | 145 | 19 | 115 | 284 | 356 | 291 | 303 | 189 | 194 | 171 | 174 | 33 | 35 | 7 | 7 | 4 | 4 | 1333 |
| 1984 | 0 | 39 | 25 | 173 | 97 | 141 | 349 | 364 | 507 | 512 | 237 | 237 | 132 | 133 | 21 | 21 | 1 | 1 | 1621 |
| 1985 | 3 | 204 | 4 | 79 | 75 | 177 | 53 | 102 | 182 | 196 | 261 | 263 | 122 | 123 | 30 | 30 | 9 | 9 | 1183 |
| 1986 | 0 | 93 | 1 | 48 | 6 | 57 | 62 | 73 | 46 | 51 | 71 | 74 | 151 | 151 | 57 | 57 | 14 | 14 | 618 |
| 1987 | 0 | 39 | 2 | 171 | 5 | 47 | 18 | 53 | 30 | 39 | 69 | 78 | 57 | 60 | 116 | 117 | 34 | 34 | 638 |
| 1988 | 0 | 49 | 0 | 136 | 24 | 115 | 12 | 68 | 20 | 33 | 10 | 15 | 13 | 13 | 6 | 7 | 27 | 28 | 464 |
| 1989 | 0 | 35 | 0 | 50 | 52 | 175 | 122 | 276 | 71 | 100 | 57 | 62 | 16 | 16 | 12 | 12 | 70 | 70 | 796 |
| 1990 | 0 | 86 | 0 | 109 | 19 | 99 | 182 | 270 | 468 | 620 | 202 | 222 | 103 | 109 | 58 | 60 | 268 | 269 | 1844 |
| 1991 | 0 | 47 | 0 | 159 | 3 | 27 | 7 | 85 | 34 | 60 | 89 | 111 | 19 | 22 | 45 | 46 | 71 | 71 | 628 |
| 1992 | 0 | 12 | 0 | 43 | 5 | 126 | 20 | 291 | 41 | 53 | 53 | 54 | 104 | 105 | 23 | 23 | 57 | 58 | 765 |
| 1993 | 0 | 38 | 1 | 62 | 6 | 50 | 59 | 127 | 48 | 112 | 37 | 46 | 61 | 63 | 58 | 58 | 67 | 68 | 624 |
| 1994 | 0 | 43 | 1 | 144 | 27 | 64 | 230 | 247 | 64 | 68 | 41 | 46 | 38 | 39 | 84 | 84 | 137 | 137 | 872 |
| 1995 | 0 | 147 | 0 | 61 | 13 | 85 | 63 | 88 | 231 | 239 | 90 | 92 | 35 | 38 | 11 | 12 | 42 | 43 | 805 |
| 1996 | 0 | 61 | 0 | 89 | 1 | 28 | 43 | 60 | 78 | 85 | 198 | 203 | 131 | 136 | 55 | 55 | 44 | 46 | 763 |
| 1997 | 0 | 11 | 0 | 111 | 7 | 29 | 19 | 25 | 123 | 123 | 135 | 135 | 234 | 235 | 125 | 125 | 49 | 49 | 843 |
| 1998 | 0 | 69 | 0 | 72 | 14 | 215 | 13 | 64 | 15 | 18 | 53 | 55 | 65 | 65 | 112 | 112 | 86 | 87 | 757 |
| 2000 | 0 | 29 | 1 | 81 | 1 | 8 | 36 | 57 | 78 | 100 | 11 | 19 | 11 | 13 | 10 | 10 | 36 | 39 | 356 |
| 2001 | 0 | 44 | 0 | 57 | 13 | 45 | 16 | 52 | 33 | 40 | 69 | 73 | 29 | 30 | 13 | 14 | 19 | 19 | 374 |
| 2002 | 0 | 11 | 2 | 77 | 15 | 58 | 51 | 68 | 84 | 90 | 76 | 78 | 83 | 83 | 13 | 13 | 21 | 21 | 499 |
| 2003 | 0 | 40 | 1 | 34 | 29 | 151 | 12 | 31 | 9 | 17 | 10 | 11 | 3 | 4 | 8 | 8 | 5 | 5 | 301 |
| <i>Proportion mature</i> | | | | | | | | | | | | | | | | | | | |
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ | | | | | | | | | | |
| 1983 | 0.000 | 0.165 | 0.798 | 0.960 | 0.974 | 0.983 | 0.943 | 1.000 | 1.000 | | | | | | | | | | |
| 1984 | 0.000 | 0.145 | 0.688 | 0.959 | 0.990 | 1.000 | 0.992 | 1.000 | 1.000 | | | | | | | | | | |
| 1985 | 0.015 | 0.051 | 0.424 | 0.520 | 0.929 | 0.992 | 0.992 | 1.000 | 1.000 | | | | | | | | | | |
| 1986 | 0.000 | 0.021 | 0.105 | 0.849 | 0.902 | 0.959 | 1.000 | 1.000 | 1.000 | | | | | | | | | | |
| 1987 | 0.000 | 0.012 | 0.106 | 0.340 | 0.769 | 0.885 | 0.950 | 0.991 | 1.000 | | | | | | | | | | |
| 1988 | 0.000 | 0.000 | 0.209 | 0.176 | 0.606 | 0.667 | 1.000 | 0.857 | 0.964 | | | | | | | | | | |
| 1989 | 0.000 | 0.000 | 0.297 | 0.442 | 0.710 | 0.919 | 1.000 | 1.000 | 1.000 | | | | | | | | | | |
| 1990 | 0.000 | 0.000 | 0.192 | 0.674 | 0.755 | 0.910 | 0.945 | 0.967 | 0.996 | | | | | | | | | | |
| 1991 | 0.000 | 0.000 | 0.111 | 0.082 | 0.567 | 0.802 | 0.864 | 0.978 | 1.000 | | | | | | | | | | |
| 1992 | 0.000 | 0.000 | 0.040 | 0.069 | 0.774 | 0.981 | 0.990 | 1.000 | 0.983 | | | | | | | | | | |
| 1993 | 0.000 | 0.016 | 0.120 | 0.465 | 0.429 | 0.804 | 0.968 | 1.000 | 0.985 | | | | | | | | | | |
| 1994 | 0.000 | 0.007 | 0.422 | 0.931 | 0.941 | 0.891 | 0.974 | 1.000 | 1.000 | | | | | | | | | | |
| 1995 | 0.000 | 0.000 | 0.153 | 0.716 | 0.967 | 0.978 | 0.921 | 0.917 | 0.977 | | | | | | | | | | |
| 1996 | 0.000 | 0.000 | 0.036 | 0.717 | 0.918 | 0.975 | 0.963 | 1.000 | 0.957 | | | | | | | | | | |
| 1997 | 0.000 | 0.000 | 0.241 | 0.760 | 1.000 | 1.000 | 0.996 | 1.000 | 1.000 | | | | | | | | | | |
| 1998 | 0.000 | 0.000 | 0.065 | 0.203 | 0.833 | 0.964 | 1.000 | 1.000 | 0.989 | | | | | | | | | | |
| 2000 | 0.000 | 0.012 | 0.125 | 0.632 | 0.780 | 0.579 | 0.846 | 1.000 | 0.923 | | | | | | | | | | |
| 2001 | 0.000 | 0.000 | 0.289 | 0.308 | 0.825 | 0.945 | 0.967 | 0.929 | 1.000 | | | | | | | | | | |
| 2002 | 0.000 | 0.026 | 0.259 | 0.750 | 0.933 | 0.974 | 1.000 | 1.000 | 1.000 | | | | | | | | | | |
| 2003 | 0.000 | 0.029 | 0.192 | 0.387 | 0.529 | 0.909 | 0.750 | 1.000 | 1.000 | | | | | | | | | | |
| <i>Averages</i> | | | | | | | | | | | | | | | | | | | |
| All years | 0.001 | 0.024 | 0.244 | 0.547 | 0.807 | 0.906 | 0.953 | 0.982 | 0.989 | | | | | | | | | | |
| 1994-2003 | 0.000 | 0.008 | 0.198 | 0.600 | 0.858 | 0.913 | 0.935 | 0.983 | 0.983 | | | | | | | | | | |
| 1999-2003 | 0.000 | 0.017 | 0.216 | 0.519 | 0.767 | 0.852 | 0.891 | 0.982 | 0.981 | | | | | | | | | | |

Table 13. Ageing error transition matrix used in the Gulf of Alaska pollock assessment model.

| <i>True Age</i> | <i>St. dev.</i> | <i>Observed Age</i> | | | | | | | | | | |
|-----------------|-----------------|---------------------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|--------|
| | | <i>1</i> | <i>2</i> | <i>3</i> | <i>4</i> | <i>5</i> | <i>6</i> | <i>7</i> | <i>8</i> | <i>9</i> | <i>10</i> | |
| 1 | 0.18 | 0.9970 | 0.0030 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.23 | 0.0138 | 0.9724 | 0.0138 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.27 | 0.0000 | 0.0329 | 0.9342 | 0.0329 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.32 | 0.0000 | 0.0000 | 0.0571 | 0.8858 | 0.0571 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 5 | 0.36 | 0.0000 | 0.0000 | 0.0000 | 0.0832 | 0.8335 | 0.0832 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6 | 0.41 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.1090 | 0.7817 | 0.1090 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 7 | 0.45 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.1333 | 0.7325 | 0.1333 | 0.0004 | 0.0000 | 0.0000 |
| 8 | 0.50 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0012 | 0.1554 | 0.6868 | 0.1554 | 0.0012 | 0.0000 |
| 9 | 0.54 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0028 | 0.1747 | 0.6450 | 0.1775 | 0.0000 |
| 10 | 0.59 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0052 | 0.1913 | 0.8035 | 0.0000 |

Table 14. Results comparing model fits, stock status, and 2004 yield for different model configurations.

| | <i>Model 1</i> | <i>Model 2</i> | <i>Model 3</i> | <i>Model 4</i> | <i>Model 5</i> | <i>Model 6</i> |
|-------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Model fits | | | | | | |
| Total -log(Likelihood) | 846.57 | 847.04 | 580.94 | 741.18 | 818.51 | 761.23 |
| NMFS trawl q | 0.85 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Age composition data | | | | | | |
| Fishery effective N | 243 | 242 | 166 | 254 | 242 | 231 |
| NMFS bottom trawl effective N | 78 | 78 | 61 | --- | 62 | 78 |
| Shelikof Strait EIT effective N | 34 | 34 | --- | 29 | 34 | 34 |
| Length composition data | | | | | | |
| ADF&G trawl effective N | 33 | 33 | 30 | 31 | --- | 33 |
| Historical trawl survey effective N | 20 | 20 | 20 | 20 | 20 | --- |
| Survey abundance | | | | | | |
| NMFS bottom trawl RMSE | 0.420 | 0.420 | 0.314 | --- | 0.442 | 0.424 |
| Shelikof Strait EIT RMSE | 0.377 | 0.373 | --- | 0.326 | 0.378 | 0.375 |
| ADF&G trawl RMSE | 0.253 | 0.258 | 0.247 | 0.281 | --- | 0.259 |
| Historical trawl survey RMSE | 1.526 | 1.526 | 1.597 | 1.515 | 1.524 | --- |
| Egg production survey RMSE | 0.500 | 0.488 | 0.573 | 0.491 | 0.492 | 0.511 |
| Stock status | | | | | | |
| Estimated 1999 YC | | | | | | |
| 2004 Spawning biomass | 248,260 | 195,350 | 187,370 | 177,720 | 176,140 | 198,860 |
| (CV) | (17%) | (11%) | (12%) | (17%) | (12%) | (11%) |
| 2004 3+ biomass | 1,047,500 | 910,260 | 945,270 | 840,360 | 850,940 | 921,110 |
| (CV) | (15%) | (12%) | (15%) | (17%) | (13%) | (12%) |
| Depletion (B2004/B0) | 37% | 31% | 32% | 29% | 29% | 31% |
| B _{40%} | 268,257 | 248,126 | 236,264 | 241,042 | 246,491 | 255,088 |
| 1999 YC reduced to average | | | | | | |
| 2004 Spawning biomass | 186,910 | 165,580 | 172,480 | 149,000 | 148,990 | 169,870 |
| (CV) | (16%) | (10%) | (11%) | (17%) | (11%) | (10%) |
| 2004 3+ biomass | 812,300 | 740,440 | 860,200 | 677,630 | 696,930 | 755,540 |
| (CV) | (14%) | (10%) | (13%) | (14%) | (10%) | (10%) |
| Depletion (B2004/B0) | 28% | 27% | 29% | 25% | 24% | 27% |
| B _{40%} | 268,257 | 248,126 | 236,264 | 241,042 | 246,491 | 255,088 |
| 2004 yield (000 t) | | | | | | |
| Estimated 1999 YC | | | | | | |
| F_{OFL} | 153.96 | 136.813 | 132.59 | 118.03 | 115.63 | 137.26 |
| MaxFABC | 132.46 | 117.47 | 113.68 | 100.96 | 99.15 | 117.88 |
| Author's F | 112.40 | 99.42 | 96.08 | 85.04 | 83.71 | 99.79 |
| 1999 YC reduced to average | | | | | | |
| F_{OFL} | 104.70 | 91.06 | 108.47 | 77.32 | 77.02 | 92.90 |
| MaxFABC | 89.83 | 77.96 | 92.86 | 65.95 | 65.87 | 79.56 |
| Author's F | 75.88 | 65.66 | 78.29 | 55.26 | 55.32 | 67.03 |

Comments:

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

Model descriptions (see text for model details):

- Model 1--Estimated NMFS trawl survey catchability
- Model 2--Last year's model configuration
- Model 3--Remove Shelikof Strait survey
- Model 4--Remove NMFS bottom trawl survey
- Model 5--Remove ADF&G survey
- Model 6--Remove historical 400-mesh eastern trawl surveys

Table 15. Estimated selectivity at age for Gulf of Alaska pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions, with random walk process error for the fishery logistic parameters. Fishery selectivity at age reported below is the average of the annual selectivity for the indicated time period, rescaled so that the maximum is one.

| Age | POP fishery (1961-71) | Foreign (1972- 84) | Early | | Recent | | Bottom trawl survey | ADF&G bottom trawl | 400-mesh eastern trawl 1961-82 | |
|-----|--------------------------|-----------------------|-----------------------|-------------------------|------------|-------|------------------------|-----------------------|--------------------------------------|--|
| | | | domestic (1985-91) | domestic (1992-2003) | EIT survey | | | | | |
| 2 | 0.001 | 0.041 | 0.043 | 0.040 | 1.000 | 0.167 | 0.056 | 0.120 | | |
| 3 | 0.021 | 0.260 | 0.158 | 0.133 | 0.997 | 0.272 | 0.123 | 0.392 | | |
| 4 | 0.415 | 0.753 | 0.424 | 0.364 | 0.989 | 0.434 | 0.249 | 0.753 | | |
| 5 | 1.000 | 1.000 | 0.739 | 0.683 | 0.967 | 0.657 | 0.440 | 0.935 | | |
| 6 | 0.947 | 0.923 | 0.952 | 0.893 | 0.912 | 0.892 | 0.653 | 0.986 | | |
| 7 | 0.702 | 0.677 | 1.000 | 0.975 | 0.790 | 1.000 | 0.823 | 0.997 | | |
| 8 | 0.363 | 0.344 | 0.834 | 1.000 | 0.581 | 0.890 | 0.925 | 0.999 | | |
| 9 | 0.132 | 0.127 | 0.435 | 0.949 | 0.338 | 0.658 | 0.976 | 1.000 | | |
| 10 | 0.040 | 0.041 | 0.152 | 0.398 | 0.159 | 0.438 | 1.000 | 1.000 | | |

Table 16. Total estimated abundance at age (numbers in 000,000s) of Gulf of Alaska pollock from the age-structured assessment model.

| | <i>Age</i> | | | | | | | | |
|---------|------------|-------|-------|-------|-----|-----|-----|-----|-----|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1961 | 370 | 192 | 118 | 73 | 54 | 38 | 28 | 21 | 16 |
| 1962 | 409 | 274 | 142 | 87 | 54 | 40 | 28 | 20 | 27 |
| 1963 | 438 | 303 | 203 | 105 | 65 | 40 | 30 | 21 | 35 |
| 1964 | 98 | 324 | 224 | 151 | 78 | 48 | 30 | 22 | 42 |
| 1965 | 254 | 73 | 240 | 166 | 111 | 57 | 35 | 22 | 47 |
| 1966 | 135 | 188 | 54 | 177 | 121 | 81 | 42 | 26 | 51 |
| 1967 | 335 | 100 | 139 | 39 | 126 | 86 | 58 | 31 | 57 |
| 1968 | 395 | 248 | 74 | 101 | 28 | 90 | 62 | 43 | 65 |
| 1969 | 686 | 293 | 184 | 54 | 72 | 20 | 64 | 45 | 79 |
| 1970 | 322 | 508 | 216 | 128 | 34 | 46 | 13 | 45 | 91 |
| 1971 | 694 | 238 | 376 | 156 | 89 | 24 | 33 | 10 | 101 |
| 1972 | 1,298 | 514 | 176 | 273 | 110 | 63 | 17 | 24 | 82 |
| 1973 | 991 | 962 | 380 | 125 | 183 | 74 | 44 | 12 | 78 |
| 1974 | 3,244 | 734 | 711 | 270 | 83 | 123 | 51 | 31 | 66 |
| 1975 | 661 | 2,403 | 543 | 502 | 174 | 54 | 83 | 36 | 72 |
| 1976 | 418 | 489 | 1,758 | 379 | 347 | 121 | 38 | 60 | 80 |
| 1977 | 1,938 | 309 | 353 | 1,216 | 262 | 242 | 86 | 28 | 103 |
| 1978 | 2,671 | 1,434 | 224 | 242 | 826 | 179 | 169 | 62 | 96 |
| 1979 | 2,482 | 1,972 | 1,028 | 154 | 165 | 569 | 126 | 122 | 116 |
| 1980 | 3,505 | 1,835 | 1,426 | 707 | 105 | 114 | 401 | 91 | 175 |
| 1981 | 1,788 | 2,588 | 1,330 | 997 | 488 | 73 | 80 | 287 | 196 |
| 1982 | 437 | 1,322 | 1,882 | 927 | 683 | 335 | 51 | 57 | 354 |
| 1983 | 493 | 320 | 941 | 1,304 | 639 | 473 | 236 | 37 | 304 |
| 1984 | 207 | 362 | 227 | 635 | 867 | 427 | 325 | 170 | 252 |
| 1985 | 474 | 151 | 249 | 142 | 380 | 519 | 269 | 226 | 310 |
| 1986 | 1,601 | 345 | 104 | 152 | 78 | 203 | 287 | 171 | 391 |
| 1987 | 540 | 1,169 | 243 | 68 | 95 | 48 | 128 | 198 | 414 |
| 1988 | 157 | 397 | 843 | 167 | 45 | 62 | 31 | 85 | 447 |
| 1989 | 362 | 115 | 288 | 590 | 112 | 30 | 40 | 21 | 389 |
| 1990 | 1,603 | 268 | 84 | 205 | 400 | 73 | 19 | 25 | 299 |
| 1991 | 1,039 | 1,185 | 197 | 61 | 140 | 255 | 45 | 11 | 237 |
| 1992 | 416 | 768 | 870 | 141 | 42 | 92 | 164 | 28 | 163 |
| 1993 | 237 | 307 | 558 | 606 | 93 | 27 | 59 | 105 | 137 |
| 1994 | 139 | 175 | 223 | 390 | 402 | 60 | 17 | 37 | 166 |
| 1995 | 208 | 103 | 127 | 157 | 263 | 265 | 39 | 11 | 140 |
| 1996 | 806 | 154 | 75 | 91 | 108 | 178 | 179 | 26 | 107 |
| 1997 | 383 | 596 | 113 | 54 | 64 | 75 | 122 | 122 | 93 |
| 1998 | 153 | 283 | 435 | 80 | 36 | 40 | 47 | 76 | 138 |
| 1999 | 185 | 112 | 197 | 278 | 47 | 21 | 23 | 26 | 131 |
| 2000 | 308 | 136 | 80 | 131 | 168 | 27 | 12 | 13 | 99 |
| 2001 | 1,385 | 227 | 99 | 56 | 84 | 99 | 15 | 7 | 75 |
| 2002 | 682 | 1,016 | 163 | 68 | 35 | 50 | 58 | 9 | 56 |
| 2003 | 118 | 499 | 731 | 114 | 45 | 23 | 32 | 36 | 45 |
| Average | 816 | 604 | 433 | 291 | 195 | 129 | 86 | 59 | 149 |

Table 17. Estimates of population biomass, recruitment, and harvest of Gulf of Alaska pollock from the age-structured assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

| Year | 2+ total | | Female | | Age 2 | | 2002 Assessment results | | | | |
|------------------|----------------------|----------------------------------|-----------------|-----------------------|-----------|-----------------|-------------------------|------------------------|-------------------|-----------------|--|
| | biomass (1,000 t) | 3+ total biomass (1,000 t) | spawn. biom. | recruits (million) | Catch (t) | Harvest rate | 3+ total biomass | Female spawn. biom. | Age 2 recruits | Harvest rate | |
| 1969 | 690 | 589 | 140 | 686 | 17,553 | 3% | 593 | 141 | 693 | 3% | |
| 1970 | 751 | 704 | 138 | 322 | 9,343 | 1% | 709 | 138 | 309 | 1% | |
| 1971 | 840 | 738 | 152 | 694 | 9,458 | 1% | 740 | 153 | 716 | 1% | |
| 1972 | 1,035 | 844 | 170 | 1,298 | 34,081 | 4% | 852 | 171 | 1,339 | 4% | |
| 1973 | 1,259 | 1,114 | 187 | 991 | 36,836 | 3% | 1,133 | 188 | 986 | 3% | |
| 1974 | 1,797 | 1,320 | 219 | 3,244 | 61,880 | 5% | 1,339 | 221 | 3,388 | 5% | |
| 1975 | 2,199 | 2,102 | 270 | 661 | 59,512 | 3% | 2,160 | 275 | 652 | 3% | |
| 1976 | 2,293 | 2,231 | 373 | 418 | 86,527 | 4% | 2,291 | 381 | 418 | 4% | |
| 1977 | 2,322 | 2,037 | 470 | 1,938 | 118,356 | 6% | 2,091 | 481 | 1,960 | 6% | |
| 1978 | 2,589 | 2,196 | 511 | 2,671 | 96,935 | 4% | 2,247 | 524 | 2,668 | 4% | |
| 1979 | 3,049 | 2,684 | 519 | 2,482 | 105,748 | 4% | 2,728 | 531 | 2,455 | 4% | |
| 1980 | 3,670 | 3,154 | 569 | 3,505 | 114,622 | 4% | 3,183 | 584 | 3,485 | 4% | |
| 1981 | 4,082 | 3,819 | 467 | 1,788 | 147,744 | 4% | 3,833 | 474 | 1,778 | 4% | |
| 1982 | 4,023 | 3,959 | 538 | 437 | 168,740 | 4% | 3,964 | 542 | 421 | 4% | |
| 1983 | 3,425 | 3,351 | 708 | 493 | 215,608 | 6% | 3,344 | 707 | 497 | 6% | |
| 1984 | 2,741 | 2,710 | 753 | 207 | 307,401 | 11% | 2,704 | 749 | 193 | 11% | |
| 1985 | 2,074 | 2,003 | 646 | 474 | 284,826 | 14% | 1,992 | 642 | 486 | 14% | |
| 1986 | 1,869 | 1,608 | 590 | 1,601 | 87,809 | 5% | 1,602 | 588 | 1,637 | 5% | |
| 1987 | 1,763 | 1,675 | 489 | 540 | 69,751 | 4% | 1,679 | 487 | 559 | 4% | |
| 1988 | 1,609 | 1,583 | 393 | 157 | 65,739 | 4% | 1,594 | 392 | 154 | 4% | |
| 1989 | 1,496 | 1,435 | 355 | 362 | 78,392 | 5% | 1,447 | 355 | 368 | 5% | |
| 1990 | 1,491 | 1,222 | 383 | 1,603 | 90,744 | 7% | 1,234 | 384 | 1,688 | 7% | |
| 1991 | 1,514 | 1,339 | 345 | 1,039 | 100,488 | 8% | 1,370 | 347 | 1,080 | 7% | |
| 1992 | 1,734 | 1,666 | 284 | 416 | 90,857 | 5% | 1,723 | 291 | 431 | 5% | |
| 1993 | 1,559 | 1,520 | 319 | 237 | 108,908 | 7% | 1,577 | 329 | 252 | 7% | |
| 1994 | 1,298 | 1,275 | 371 | 139 | 107,335 | 8% | 1,331 | 385 | 140 | 8% | |
| 1995 | 1,092 | 1,072 | 343 | 208 | 72,618 | 7% | 1,123 | 356 | 219 | 6% | |
| 1996 | 962 | 885 | 310 | 806 | 51,263 | 6% | 929 | 326 | 829 | 6% | |
| 1997 | 928 | 891 | 267 | 383 | 90,130 | 10% | 934 | 282 | 364 | 10% | |
| 1998 | 828 | 806 | 201 | 153 | 125,098 | 16% | 836 | 214 | 99 | 15% | |
| 1999 | 668 | 642 | 180 | 185 | 95,590 | 15% | 650 | 191 | 183 | 15% | |
| 2000 | 606 | 568 | 165 | 308 | 73,080 | 13% | 566 | 173 | 400 | 13% | |
| 2001 | 713 | 567 | 160 | 1,385 | 72,076 | 13% | 589 | 164 | 2,141 | 12% | |
| 2002 | 995 | 891 | 139 | 682 | 51,937 | 6% | 1,130 | 142 | 195 | 5% | |
| 2003 | 1,017 | 993 | 140 | 118 | --- | --- | --- | --- | --- | --- | |
| Average | | | | | | | | | | | |
| 1969-2003 | 1,742 | 1,606 | 350 | 932 | 97,264 | 7% | 1,654 | 362 | 976 | 6% | |
| 1979-2002 | | | | 816 | | | | | | | |

Table 18. Gulf of Alaska pollock life history and fishery vectors used to estimate spawning biomass per recruit (F_{SPR}) harvest rates. Population weight at age is the average for the bottom trawl survey in 1999-2003. Proportion mature females is the average for 1983-2003 from winter EIT survey specimen data. Spawning weight at age is the average for the Shelikof Strait EIT survey in 2001-2003.

| Age | Natural mortality | Fishery selectivity (Avg. 1992-2003) | Weight at age (kg) | | | Proportion mature females |
|-----|-------------------|---|------------------------|---------------------------|-----------------------------|---------------------------|
| | | | Spawning (March 15) | Population (June-Aug.) | Fishery (Avg. 2000-2002) | |
| 2 | 0.3 | 0.040 | 0.075 | 0.150 | 0.307 | 0.001 |
| 3 | 0.3 | 0.133 | 0.175 | 0.421 | 0.452 | 0.024 |
| 4 | 0.3 | 0.364 | 0.322 | 0.630 | 0.696 | 0.244 |
| 5 | 0.3 | 0.683 | 0.575 | 0.800 | 0.964 | 0.547 |
| 6 | 0.3 | 0.893 | 0.951 | 0.943 | 1.085 | 0.807 |
| 7 | 0.3 | 0.975 | 1.162 | 1.078 | 1.211 | 0.906 |
| 8 | 0.3 | 1.000 | 1.262 | 1.221 | 1.335 | 0.953 |
| 9 | 0.3 | 0.949 | 1.497 | 1.312 | 1.453 | 0.982 |
| 10+ | 0.3 | 0.398 | 1.733 | 1.445 | 1.636 | 0.989 |

Table 19. Projections of Gulf of Alaska pollock expected spawning biomass, full recruitment fishing mortality, and catch for 2004-2016 under different harvest policies. All projections begin with estimated age composition in 2004 using Model 2. Coefficients of variation are given in parentheses, and reflect only variability in recruitment in 2005-2016. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 620,000, 248,000, and 217,000 t, respectively.

| <i>Spawning biomass</i> | F_{OFL} | | $Max F_{ABC}$ | | <i>Author's recommended F</i> | | <i>50% of max FABC</i> | | <i>Average F</i> | | $F = 0$ | |
|--------------------------|-----------|--------|---------------|--------|-------------------------------|--------|------------------------|--------|------------------|--------|---------|--------|
| 2004 | 193,211 | (0.00) | 194,333 | (0.00) | 195,361 | (0.00) | 197,502 | (0.00) | 194,570 | (0.00) | 200,727 | (0.00) |
| 2005 | 220,559 | (0.00) | 227,823 | (0.00) | 234,724 | (0.00) | 250,082 | (0.00) | 230,965 | (0.00) | 275,646 | (0.00) |
| 2006 | 204,374 | (0.01) | 216,063 | (0.01) | 227,733 | (0.01) | 256,548 | (0.01) | 226,469 | (0.01) | 312,588 | (0.01) |
| 2007 | 191,609 | (0.10) | 204,225 | (0.10) | 217,317 | (0.09) | 252,714 | (0.08) | 216,966 | (0.10) | 332,918 | (0.07) |
| 2008 | 209,388 | (0.25) | 223,269 | (0.24) | 237,478 | (0.23) | 280,159 | (0.22) | 237,395 | (0.25) | 386,535 | (0.18) |
| 2009 | 224,449 | (0.35) | 240,628 | (0.36) | 255,154 | (0.34) | 308,783 | (0.35) | 259,145 | (0.38) | 441,828 | (0.29) |
| 2010 | 229,112 | (0.36) | 247,311 | (0.37) | 260,758 | (0.35) | 324,051 | (0.38) | 270,067 | (0.41) | 474,243 | (0.34) |
| 2011 | 231,152 | (0.35) | 251,070 | (0.36) | 263,526 | (0.34) | 335,566 | (0.38) | 277,381 | (0.40) | 501,926 | (0.35) |
| 2012 | 232,343 | (0.35) | 253,627 | (0.36) | 265,403 | (0.33) | 345,448 | (0.37) | 283,146 | (0.40) | 529,048 | (0.35) |
| 2013 | 234,331 | (0.35) | 256,488 | (0.36) | 267,766 | (0.33) | 353,835 | (0.37) | 288,597 | (0.39) | 550,636 | (0.35) |
| 2014 | 236,498 | (0.35) | 259,194 | (0.36) | 270,202 | (0.34) | 360,610 | (0.36) | 293,270 | (0.39) | 567,448 | (0.34) |
| 2015 | 238,341 | (0.35) | 261,586 | (0.36) | 272,376 | (0.34) | 366,388 | (0.36) | 297,391 | (0.39) | 581,470 | (0.34) |
| 2016 | 238,340 | (0.35) | 261,991 | (0.36) | 272,583 | (0.34) | 369,408 | (0.36) | 299,186 | (0.39) | 591,212 | (0.34) |
| <i>Fishing mortality</i> | F_{OFL} | | $Max F_{ABC}$ | | <i>Author's recommended F</i> | | <i>50% of max FABC</i> | | <i>Average F</i> | | $F = 0$ | |
| 2004 | 0.27 | (0.00) | 0.23 | (0.00) | 0.19 | (0.00) | 0.11 | (0.00) | 0.22 | (0.00) | 0 | --- |
| 2005 | 0.31 | (0.00) | 0.27 | (0.00) | 0.23 | (0.00) | 0.14 | (0.00) | 0.22 | (0.00) | 0 | --- |
| 2006 | 0.28 | (0.01) | 0.25 | (0.01) | 0.22 | (0.01) | 0.15 | (0.00) | 0.22 | (0.00) | 0 | --- |
| 2007 | 0.26 | (0.08) | 0.24 | (0.07) | 0.21 | (0.08) | 0.14 | (0.02) | 0.22 | (0.00) | 0 | --- |
| 2008 | 0.28 | (0.13) | 0.25 | (0.11) | 0.23 | (0.14) | 0.14 | (0.03) | 0.22 | (0.00) | 0 | --- |
| 2009 | 0.29 | (0.17) | 0.25 | (0.15) | 0.24 | (0.18) | 0.14 | (0.05) | 0.22 | (0.00) | 0 | --- |
| 2010 | 0.29 | (0.19) | 0.25 | (0.17) | 0.24 | (0.20) | 0.14 | (0.08) | 0.22 | (0.00) | 0 | --- |
| 2011 | 0.29 | (0.20) | 0.26 | (0.17) | 0.24 | (0.21) | 0.14 | (0.09) | 0.22 | (0.00) | 0 | --- |
| 2012 | 0.29 | (0.19) | 0.26 | (0.17) | 0.24 | (0.20) | 0.14 | (0.09) | 0.22 | (0.00) | 0 | --- |
| 2013 | 0.29 | (0.19) | 0.26 | (0.16) | 0.24 | (0.20) | 0.14 | (0.08) | 0.22 | (0.00) | 0 | --- |
| 2014 | 0.29 | (0.18) | 0.26 | (0.16) | 0.24 | (0.19) | 0.14 | (0.07) | 0.22 | (0.00) | 0 | --- |
| 2015 | 0.29 | (0.19) | 0.26 | (0.16) | 0.24 | (0.20) | 0.14 | (0.07) | 0.22 | (0.00) | 0 | --- |
| 2016 | 0.29 | (0.18) | 0.26 | (0.16) | 0.24 | (0.19) | 0.14 | (0.07) | 0.22 | (0.00) | 0 | --- |
| <i>Catch</i> | F_{OFL} | | $Max F_{ABC}$ | | <i>Author's recommended F</i> | | <i>50% of max FABC</i> | | <i>Average F</i> | | $F = 0$ | |
| 2004 | 136,813 | (0.00) | 117,466 | (0.00) | 99,421 | (0.00) | 60,831 | (0.00) | 113,343 | (0.00) | 0 | --- |
| 2005 | 155,534 | (0.02) | 140,691 | (0.02) | 125,282 | (0.02) | 84,358 | (0.02) | 116,923 | (0.02) | 0 | --- |
| 2006 | 134,763 | (0.10) | 126,791 | (0.09) | 117,385 | (0.09) | 86,419 | (0.07) | 114,121 | (0.08) | 0 | --- |
| 2007 | 135,844 | (0.35) | 128,422 | (0.32) | 120,806 | (0.34) | 91,176 | (0.22) | 122,268 | (0.23) | 0 | --- |
| 2008 | 158,948 | (0.52) | 148,148 | (0.49) | 142,347 | (0.52) | 99,954 | (0.37) | 131,685 | (0.38) | 0 | --- |
| 2009 | 166,885 | (0.56) | 154,161 | (0.53) | 150,486 | (0.56) | 101,545 | (0.44) | 134,979 | (0.44) | 0 | --- |
| 2010 | 171,744 | (0.55) | 159,074 | (0.53) | 155,600 | (0.56) | 105,692 | (0.46) | 140,414 | (0.44) | 0 | --- |
| 2011 | 176,403 | (0.53) | 164,441 | (0.50) | 160,673 | (0.54) | 110,916 | (0.44) | 145,751 | (0.42) | 0 | --- |
| 2012 | 177,035 | (0.53) | 165,554 | (0.50) | 161,415 | (0.53) | 112,195 | (0.44) | 146,792 | (0.42) | 0 | --- |
| 2013 | 177,989 | (0.53) | 166,950 | (0.50) | 162,176 | (0.53) | 113,462 | (0.43) | 147,978 | (0.42) | 0 | --- |
| 2014 | 180,800 | (0.53) | 169,309 | (0.50) | 164,743 | (0.53) | 115,301 | (0.43) | 149,768 | (0.42) | 0 | --- |
| 2015 | 181,438 | (0.53) | 169,992 | (0.50) | 165,593 | (0.53) | 116,126 | (0.42) | 150,433 | (0.42) | 0 | --- |
| 2016 | 180,994 | (0.53) | 169,885 | (0.50) | 165,334 | (0.53) | 116,620 | (0.43) | 150,789 | (0.42) | 0 | --- |

Table 20. Projections of Gulf of Alaska pollock expected spawning biomass, full recruitment fishing mortality, and catch for 2004-2016 under different harvest policies. All projections begin with estimated age composition in 2004 using Model 2, except that the 1999 year class has been assumed to be average. Coefficients of variation are given in parentheses, and reflect only variability in recruitment in 2005-2016. The values for B100%, B40%, and B35% are 620,000, 248,000, and 217,000 t, respectively.

| <i>Spawning biomass</i> | F_{OFL} | $Max F_{ABC}$ | <i>Author's recommended F</i> | 50% of max F_{ABC} | <i>Average F</i> | $F = 0$ |
|-------------------------|----------------|----------------|-------------------------------|-------------------------|------------------|----------------|
| 2004 | 164,027 (0.00) | 164,830 (0.00) | 165,572 (0.00) | 167,077 (0.00) | 164,168 (0.00) | 169,359 (0.00) |
| 2005 | 182,475 (0.00) | 187,442 (0.00) | 192,179 (0.00) | 202,328 (0.00) | 184,132 (0.00) | 219,020 (0.00) |
| 2006 | 181,640 (0.01) | 190,136 (0.01) | 198,571 (0.01) | 218,250 (0.01) | 187,411 (0.01) | 254,986 (0.01) |
| 2007 | 181,680 (0.11) | 191,801 (0.10) | 202,191 (0.10) | 228,390 (0.09) | 190,291 (0.11) | 284,190 (0.08) |
| 2008 | 205,007 (0.25) | 217,076 (0.25) | 229,302 (0.24) | 263,370 (0.23) | 217,933 (0.27) | 342,413 (0.20) |
| 2009 | 222,786 (0.36) | 237,778 (0.36) | 251,131 (0.34) | 297,119 (0.36) | 245,138 (0.40) | 403,740 (0.32) |
| 2010 | 228,560 (0.36) | 246,121 (0.37) | 259,029 (0.35) | 316,735 (0.39) | 260,554 (0.42) | 446,027 (0.36) |
| 2011 | 230,998 (0.35) | 250,587 (0.36) | 262,820 (0.34) | 330,923 (0.38) | 270,921 (0.41) | 481,023 (0.36) |
| 2012 | 232,324 (0.35) | 253,448 (0.36) | 265,153 (0.33) | 342,490 (0.37) | 278,758 (0.40) | 513,562 (0.36) |
| 2013 | 234,340 (0.35) | 256,421 (0.36) | 267,685 (0.33) | 351,902 (0.37) | 285,618 (0.40) | 539,164 (0.36) |
| 2014 | 236,509 (0.35) | 259,169 (0.36) | 270,182 (0.34) | 359,331 (0.37) | 291,246 (0.39) | 558,949 (0.35) |
| 2015 | 238,349 (0.35) | 261,576 (0.36) | 272,374 (0.34) | 365,533 (0.37) | 296,017 (0.39) | 575,174 (0.35) |
| 2016 | 238,344 (0.35) | 261,987 (0.36) | 272,585 (0.34) | 368,833 (0.36) | 298,253 (0.39) | 586,547 (0.34) |

| <i>Fishing mortality</i> | F_{OFL} | $Max F_{ABC}$ | <i>Author's recommended F</i> | 50% of max F_{ABC} | <i>Average F</i> | $F = 0$ |
|--------------------------|-------------|---------------|-------------------------------|-------------------------|------------------|---------|
| 2004 | 0.22 (0.00) | 0.19 (0.00) | 0.16 (0.00) | 0.10 (0.00) | 0.22 (0.00) | 0 --- |
| 2005 | 0.25 (0.00) | 0.22 (0.00) | 0.19 (0.00) | 0.12 (0.00) | 0.22 (0.00) | 0 --- |
| 2006 | 0.25 (0.01) | 0.22 (0.01) | 0.19 (0.01) | 0.13 (0.01) | 0.22 (0.00) | 0 --- |
| 2007 | 0.25 (0.09) | 0.22 (0.08) | 0.20 (0.09) | 0.13 (0.05) | 0.22 (0.00) | 0 --- |
| 2008 | 0.28 (0.14) | 0.24 (0.12) | 0.22 (0.15) | 0.14 (0.06) | 0.22 (0.00) | 0 --- |
| 2009 | 0.28 (0.18) | 0.25 (0.15) | 0.23 (0.19) | 0.14 (0.07) | 0.22 (0.00) | 0 --- |
| 2010 | 0.29 (0.20) | 0.25 (0.17) | 0.23 (0.21) | 0.14 (0.09) | 0.22 (0.00) | 0 --- |
| 2011 | 0.29 (0.20) | 0.25 (0.17) | 0.24 (0.21) | 0.14 (0.09) | 0.22 (0.00) | 0 --- |
| 2012 | 0.29 (0.19) | 0.26 (0.17) | 0.24 (0.20) | 0.14 (0.09) | 0.22 (0.00) | 0 --- |
| 2013 | 0.29 (0.19) | 0.26 (0.16) | 0.24 (0.20) | 0.14 (0.08) | 0.22 (0.00) | 0 --- |
| 2014 | 0.29 (0.18) | 0.26 (0.16) | 0.24 (0.19) | 0.14 (0.08) | 0.22 (0.00) | 0 --- |
| 2015 | 0.29 (0.19) | 0.26 (0.16) | 0.24 (0.20) | 0.14 (0.07) | 0.22 (0.00) | 0 --- |
| 2016 | 0.29 (0.18) | 0.26 (0.16) | 0.24 (0.19) | 0.14 (0.07) | 0.22 (0.00) | 0 --- |

| <i>Catch</i> | F_{OFL} | $Max F_{ABC}$ | <i>Author's recommended F</i> | 50% of max F_{ABC} | <i>Average F</i> | $F = 0$ |
|--------------|----------------|----------------|-------------------------------|-------------------------|------------------|---------|
| 2004 | 91,060 (0.00) | 77,959 (0.00) | 65,655 (0.00) | 40,139 (0.00) | 88,779 (0.00) | 0 --- |
| 2005 | 107,169 (0.03) | 95,755 (0.03) | 84,126 (0.03) | 55,553 (0.02) | 94,322 (0.03) | 0 --- |
| 2006 | 108,399 (0.11) | 100,012 (0.11) | 90,756 (0.10) | 64,498 (0.09) | 97,456 (0.09) | 0 --- |
| 2007 | 124,173 (0.38) | 115,465 (0.36) | 106,553 (0.38) | 77,608 (0.28) | 111,018 (0.25) | 0 --- |
| 2008 | 154,627 (0.54) | 142,811 (0.51) | 135,471 (0.55) | 93,673 (0.41) | 124,731 (0.41) | 0 --- |
| 2009 | 167,540 (0.56) | 154,269 (0.53) | 149,885 (0.57) | 100,177 (0.46) | 132,887 (0.45) | 0 --- |
| 2010 | 172,333 (0.55) | 159,414 (0.53) | 155,693 (0.56) | 104,867 (0.46) | 138,992 (0.44) | 0 --- |
| 2011 | 176,878 (0.53) | 164,812 (0.50) | 160,986 (0.54) | 110,490 (0.44) | 144,786 (0.42) | 0 --- |
| 2012 | 177,245 (0.53) | 165,725 (0.50) | 161,599 (0.53) | 111,890 (0.44) | 146,136 (0.42) | 0 --- |
| 2013 | 178,078 (0.53) | 167,024 (0.50) | 162,275 (0.53) | 113,261 (0.43) | 147,533 (0.42) | 0 --- |
| 2014 | 180,834 (0.53) | 169,338 (0.50) | 164,791 (0.53) | 115,163 (0.43) | 149,466 (0.42) | 0 --- |
| 2015 | 181,450 (0.53) | 170,003 (0.50) | 165,614 (0.53) | 116,031 (0.42) | 150,228 (0.42) | 0 --- |
| 2016 | 180,998 (0.53) | 169,888 (0.50) | 165,343 (0.53) | 116,556 (0.43) | 150,649 (0.42) | 0 --- |

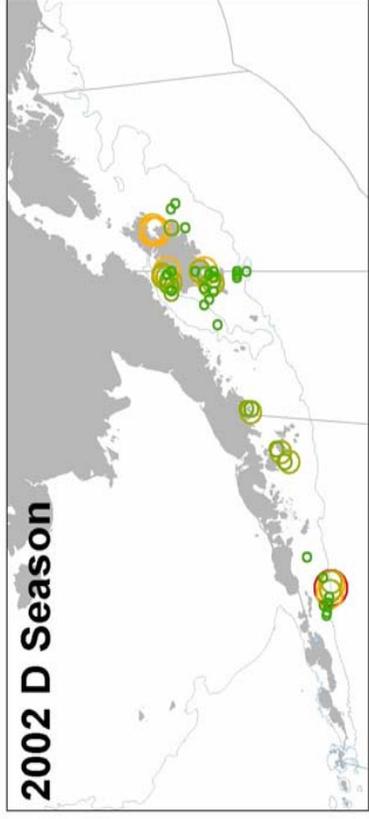
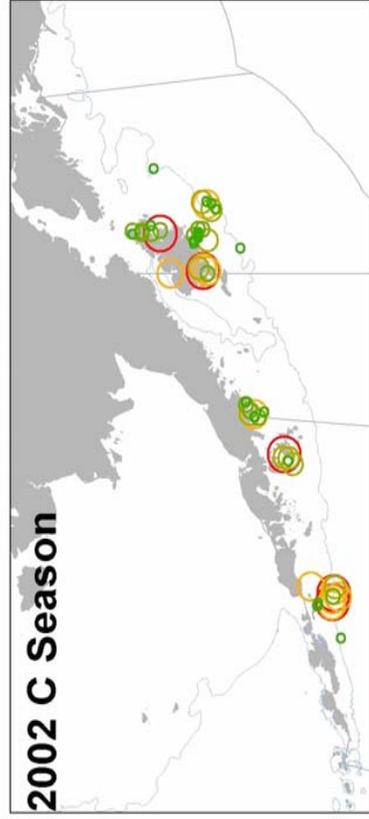
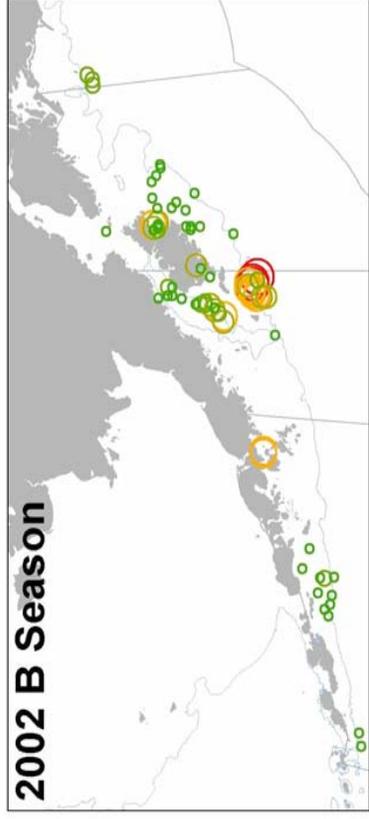
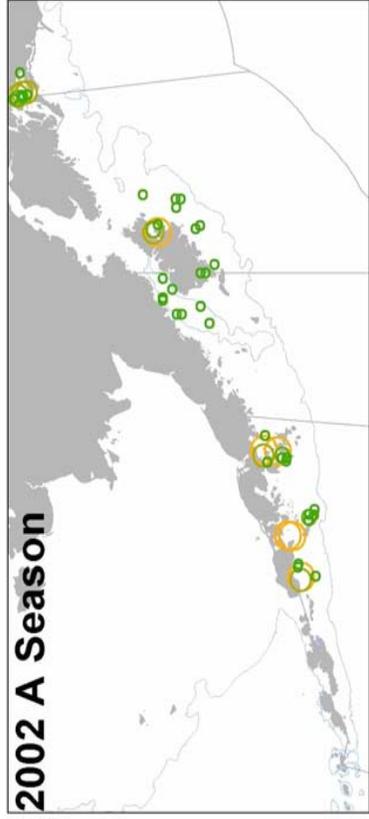


Figure 1. Pollock catch in 2002 by 10 sq. nmi. blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

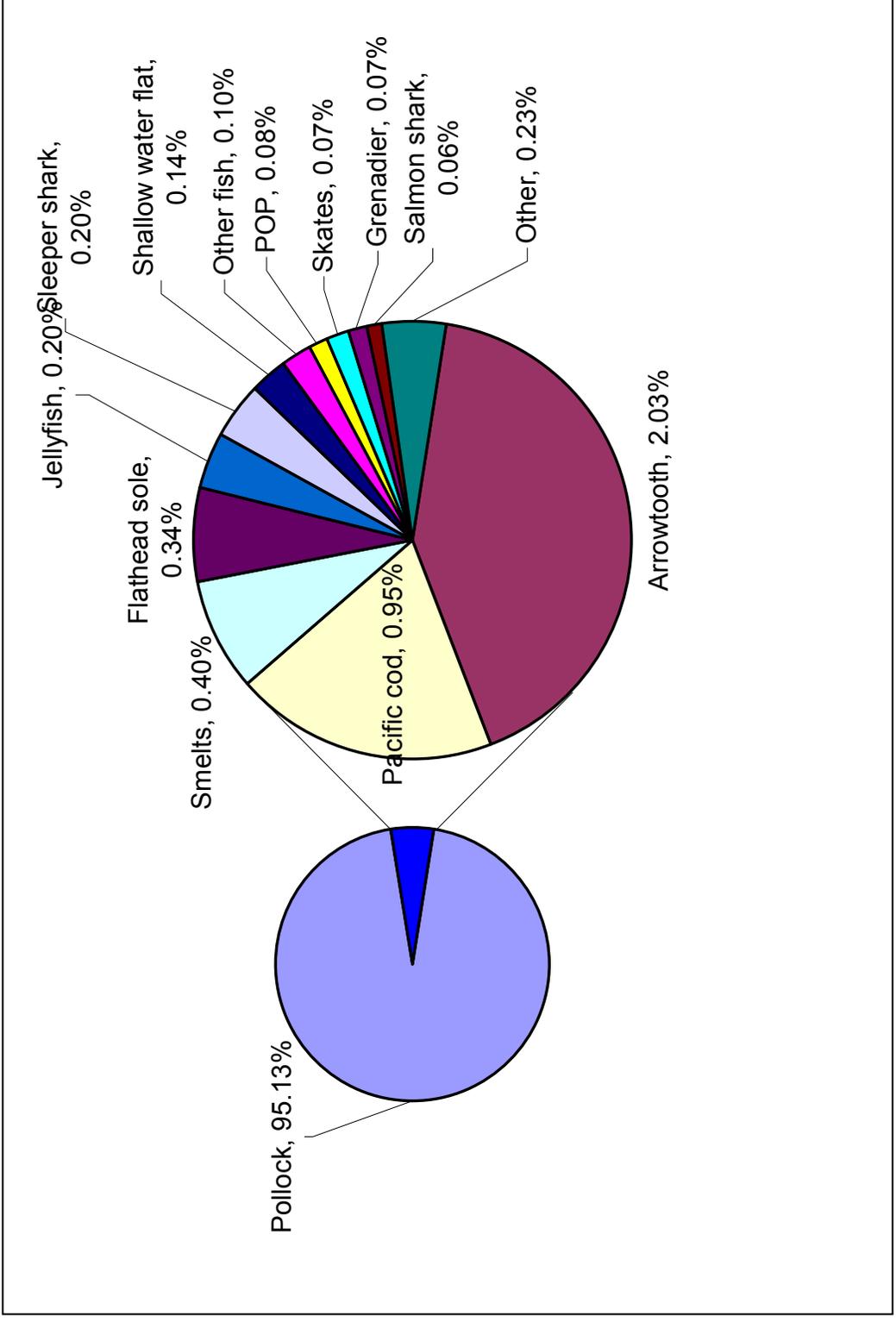


Figure 2. Incidental catch (including both retained and discarded species) in tows classified as pollock targets in the Gulf of Alaska (1997-2002).

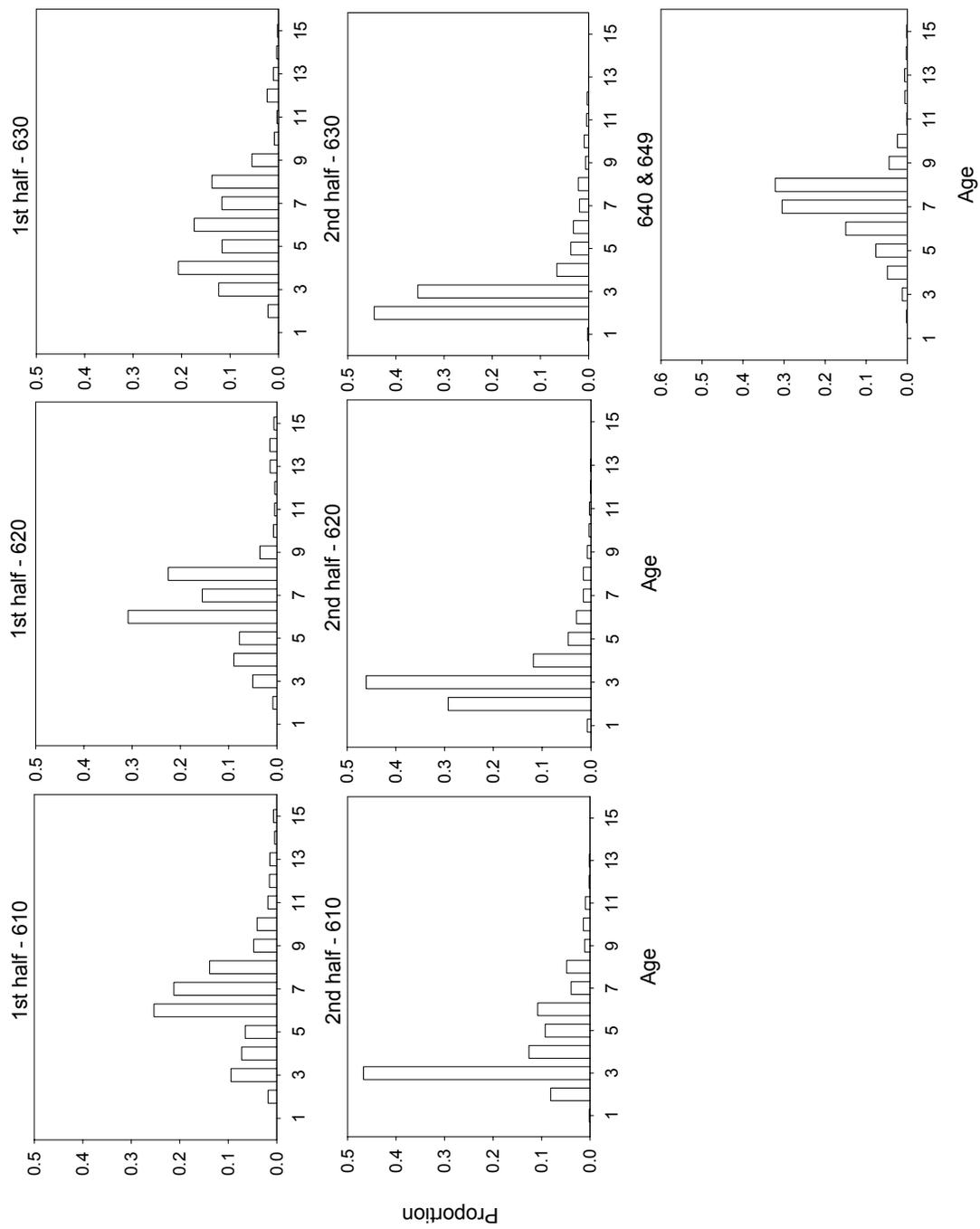


Figure 3. 2002 catch age composition by half year and statistical area.

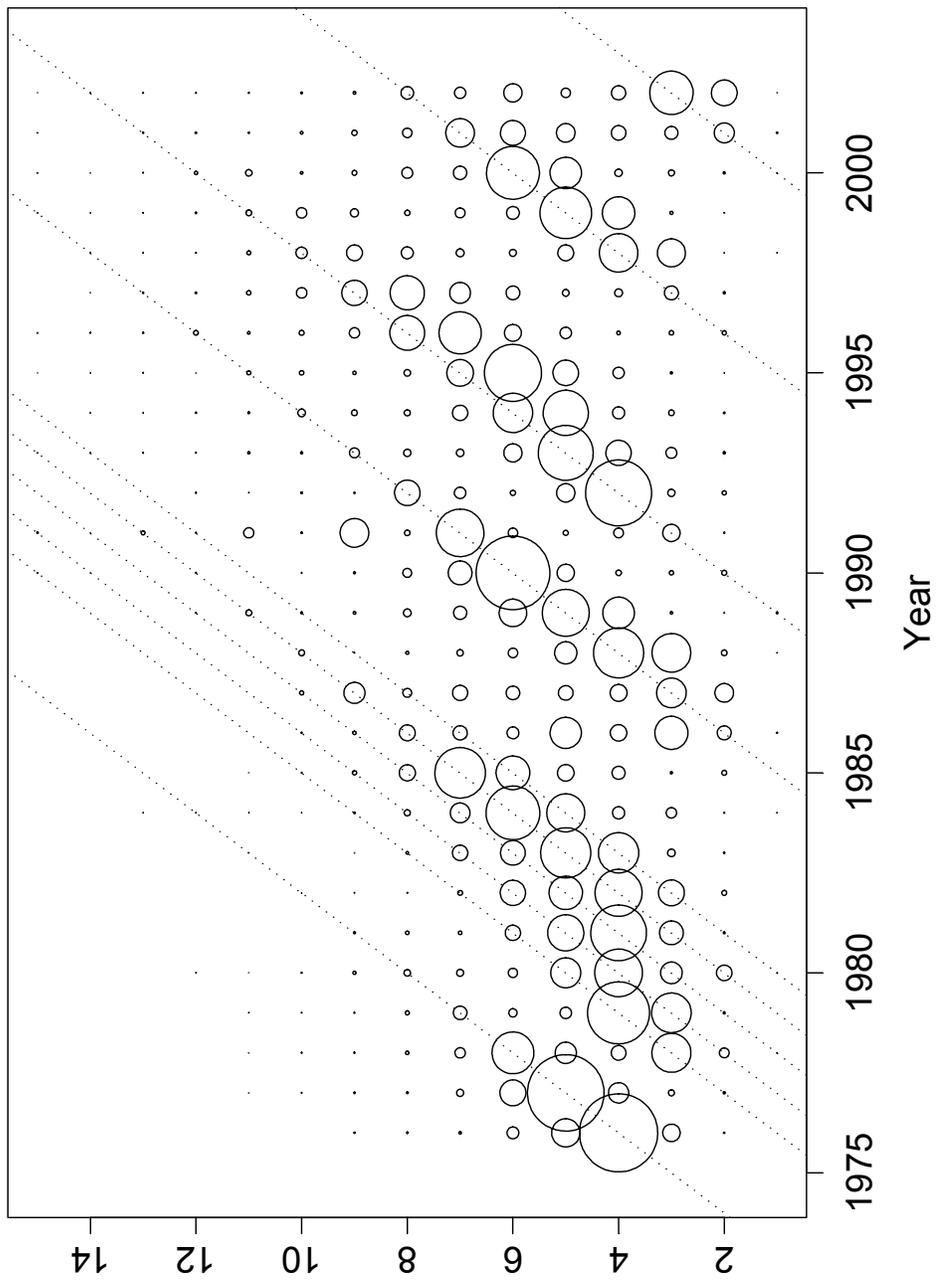


Figure 4. Gulf of Alaska pollock catch age composition (1976-2002). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1984, 1988, 1994, and 1999).

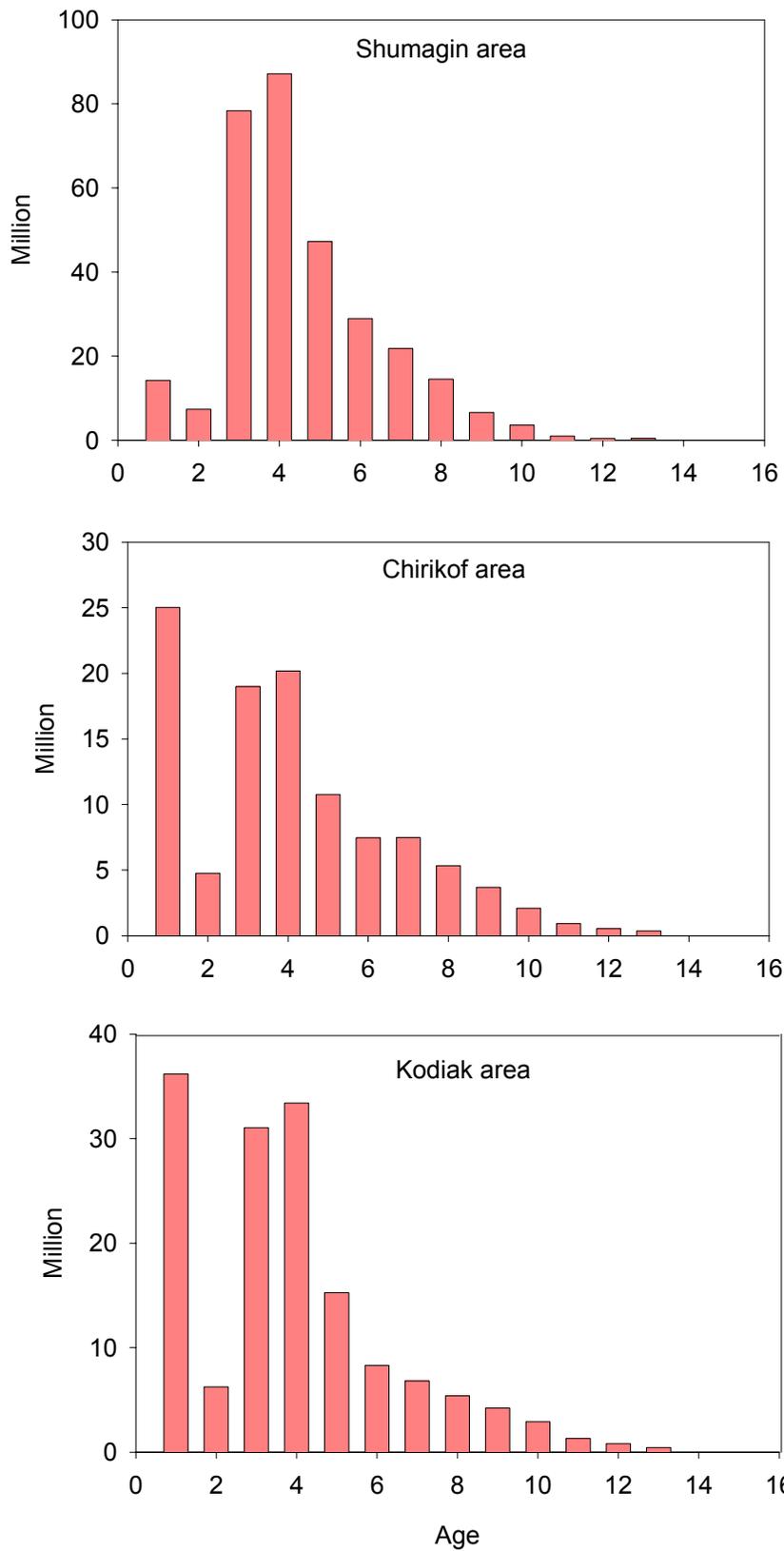


Figure 5. Pollock age composition by INPFC area for the 2003 NMFS bottom trawl survey

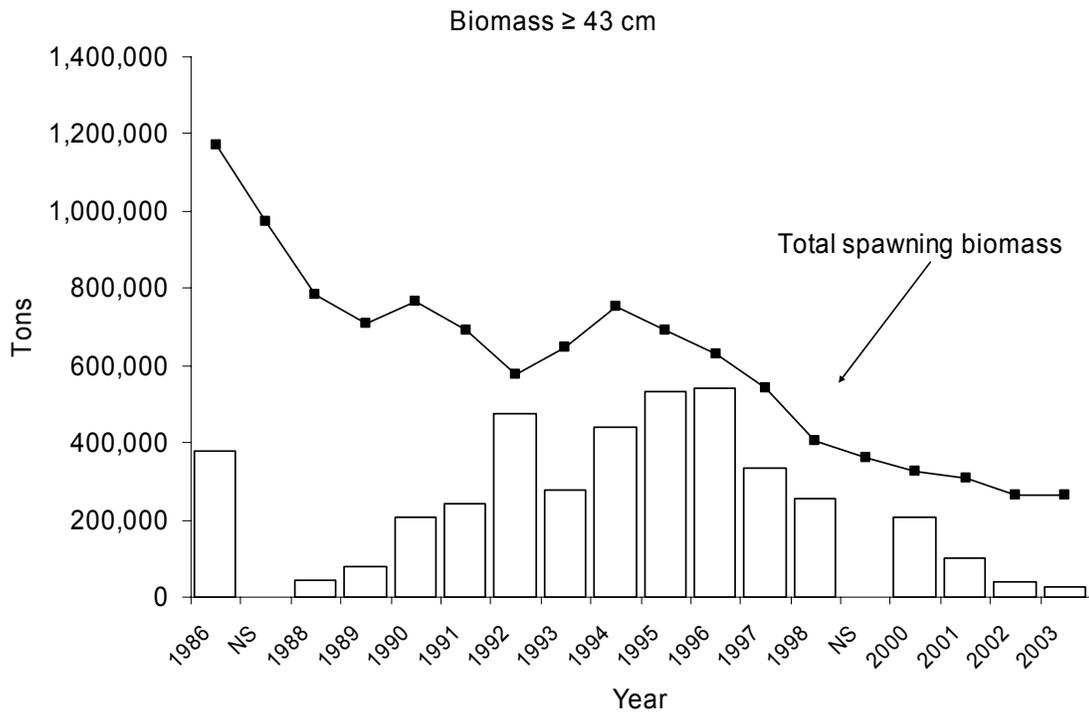
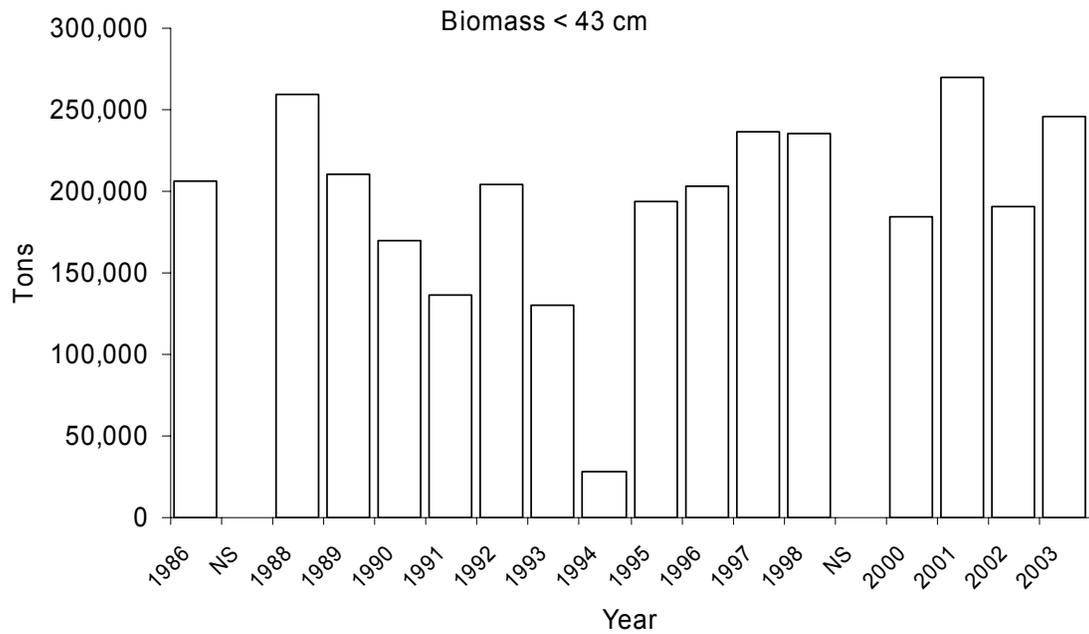


Figure 6. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2003 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

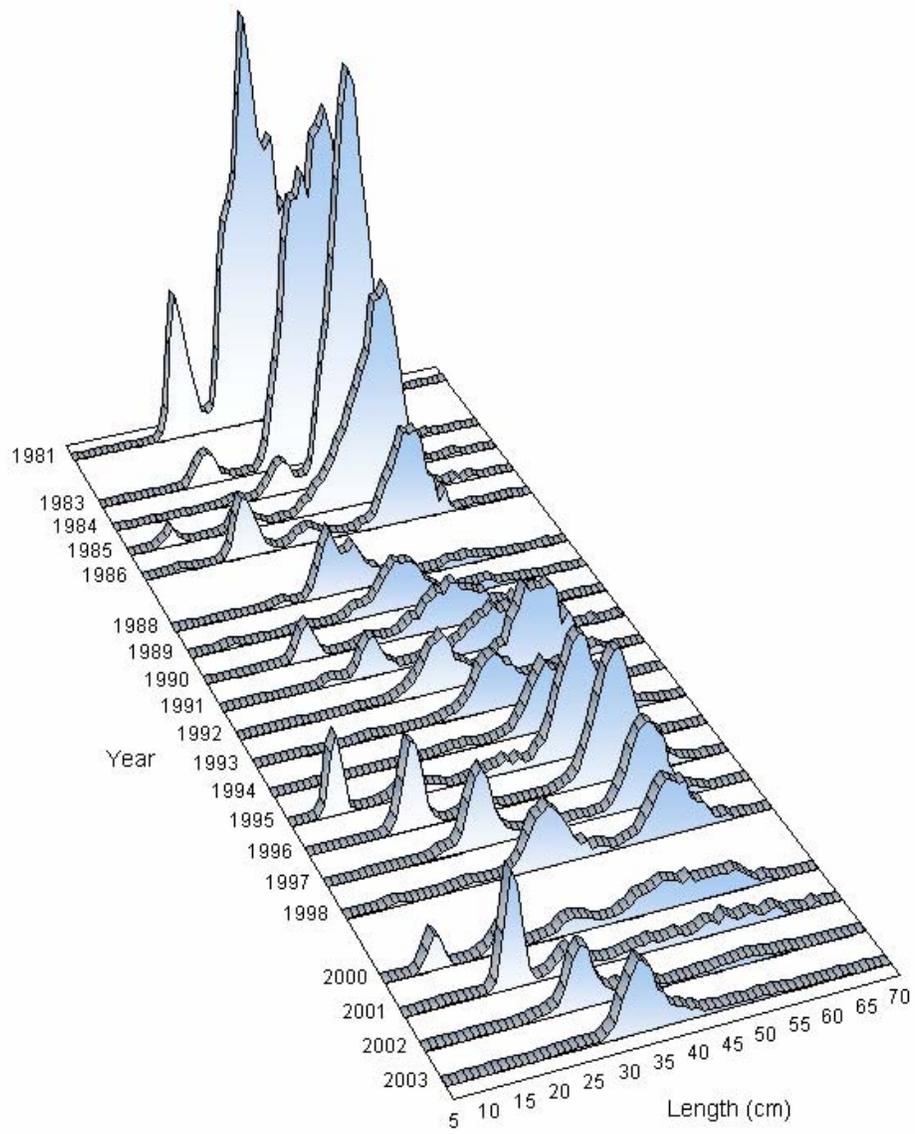


Figure 7. Biomass by length for pollock in the Shelikof Strait EIT survey (1981-2003, except 1982,1987 and 1999).

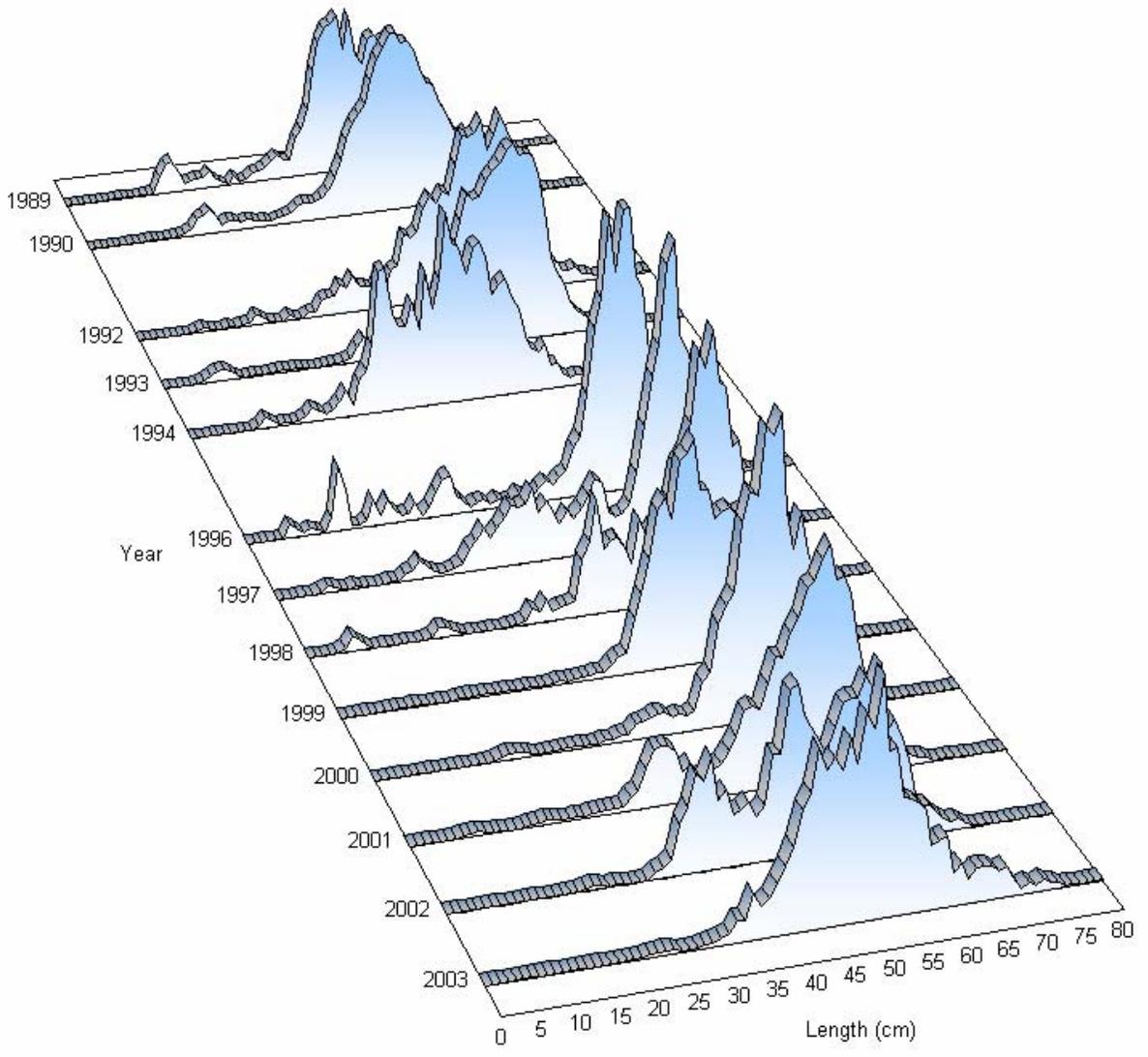


Figure 8. Length frequency of pollock in the ADF&G crab/groundfish trawl survey (1989-2003, except 1991 and 1995).

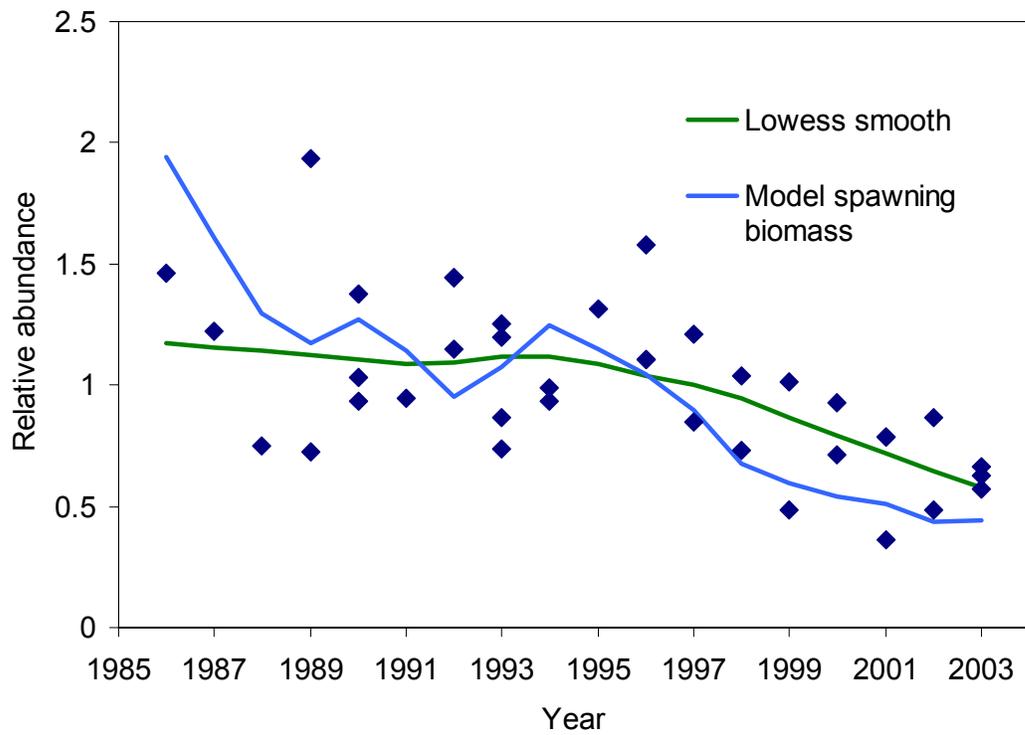
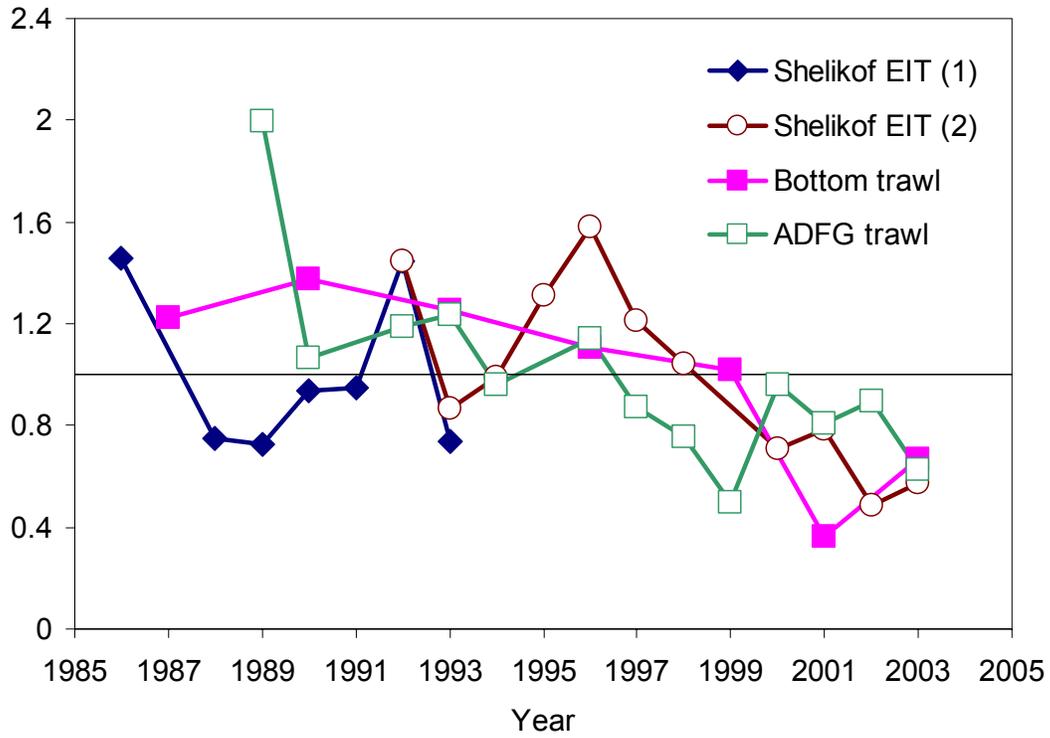


Figure 9. Trends in pollock biomass since 1986 for the Shelikof Strait EIT survey, the triennial bottom trawl survey, and the ADF&G crab/groundfish survey (top). Each survey biomass estimate is standardized to the survey average since 1986. The Shelikof Strait EIT survey is split into separate time series corresponding to the two acoustic systems used for the survey. In the bottom panel, a lowess smooth (SPLUS 1993) of the same data is compared to the estimated biomass trend from the assessment model.

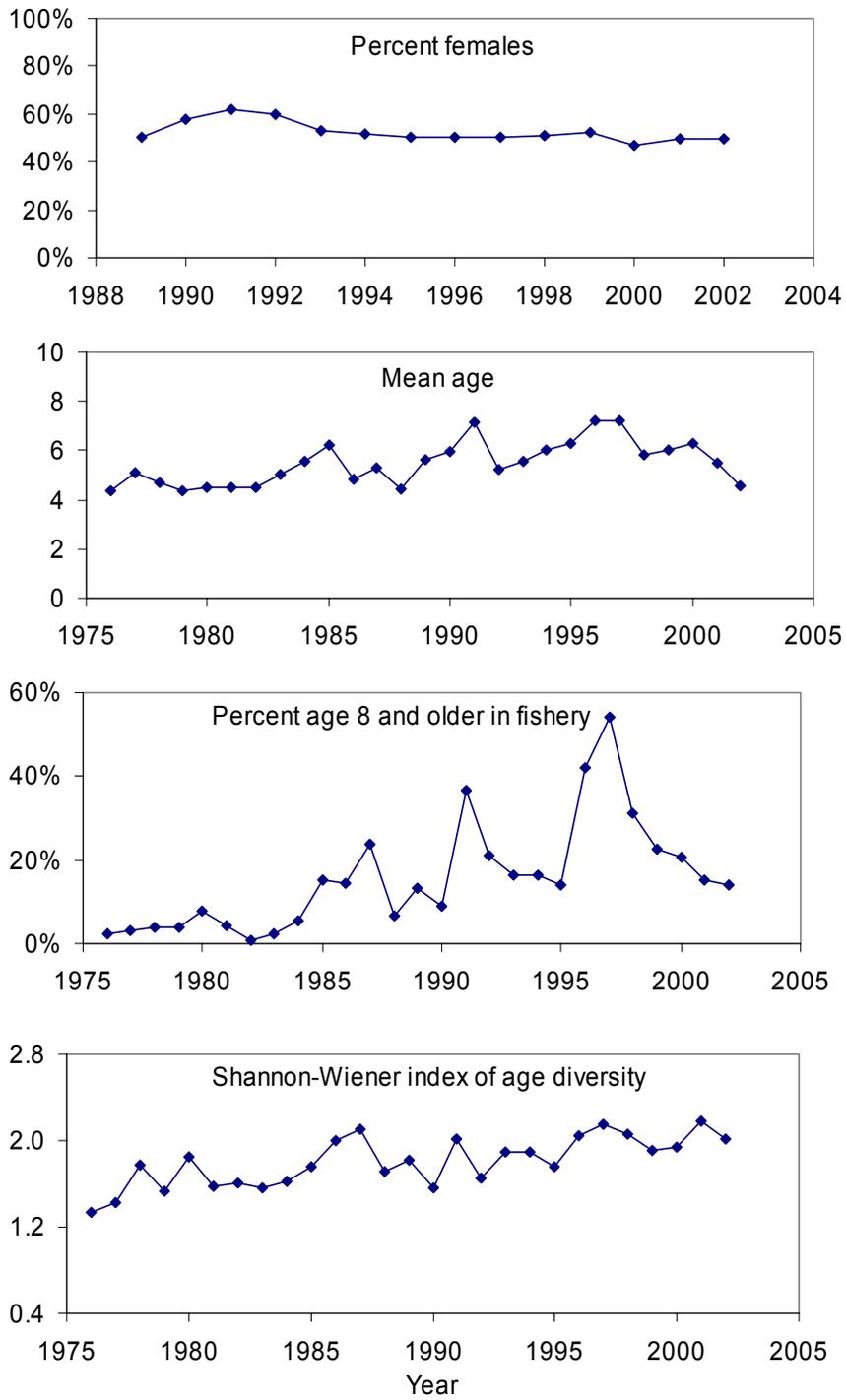


Figure 10. Gulf of Alaska pollock catch characteristics.

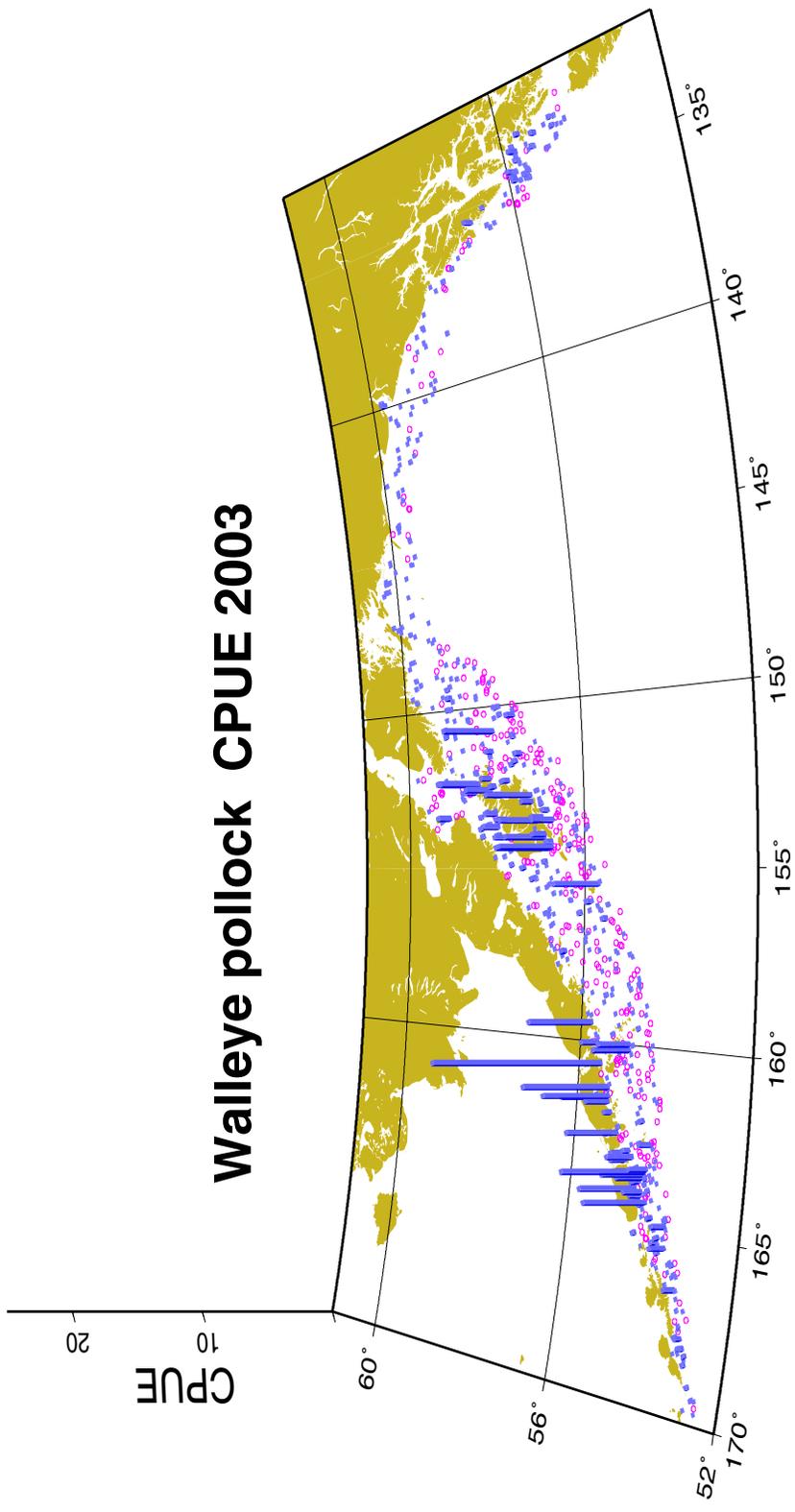


Figure 11. Walleye pollock CPUE in the 2003 NMFS bottom trawl survey in the Gulf of Alaska.

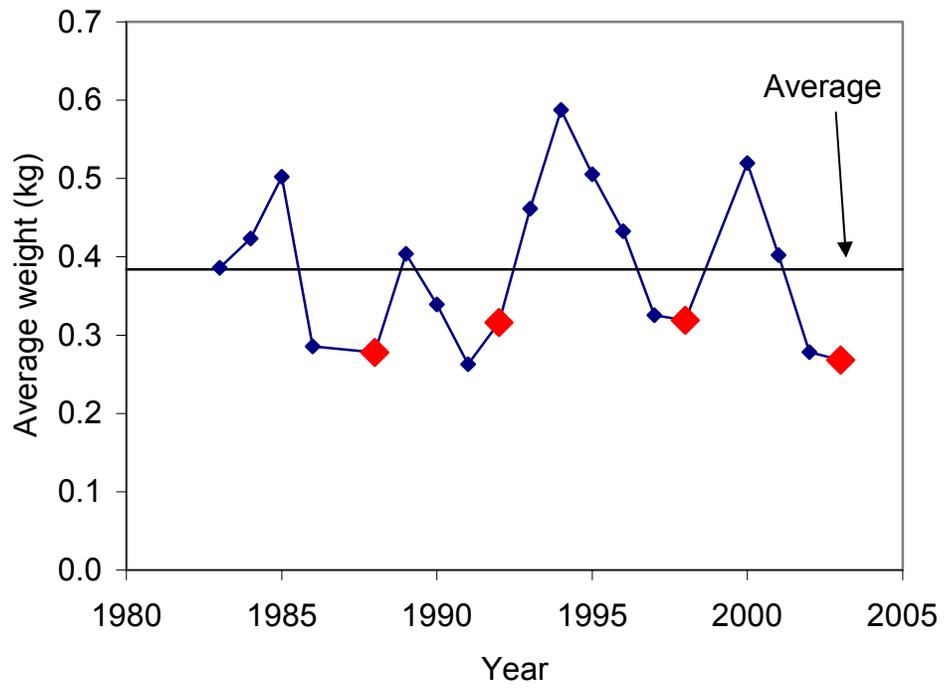


Figure 12. Mean weight of age-4 pollock in the Shelikof Strait EIT survey. Strong year classes are indicated by the large red symbols.

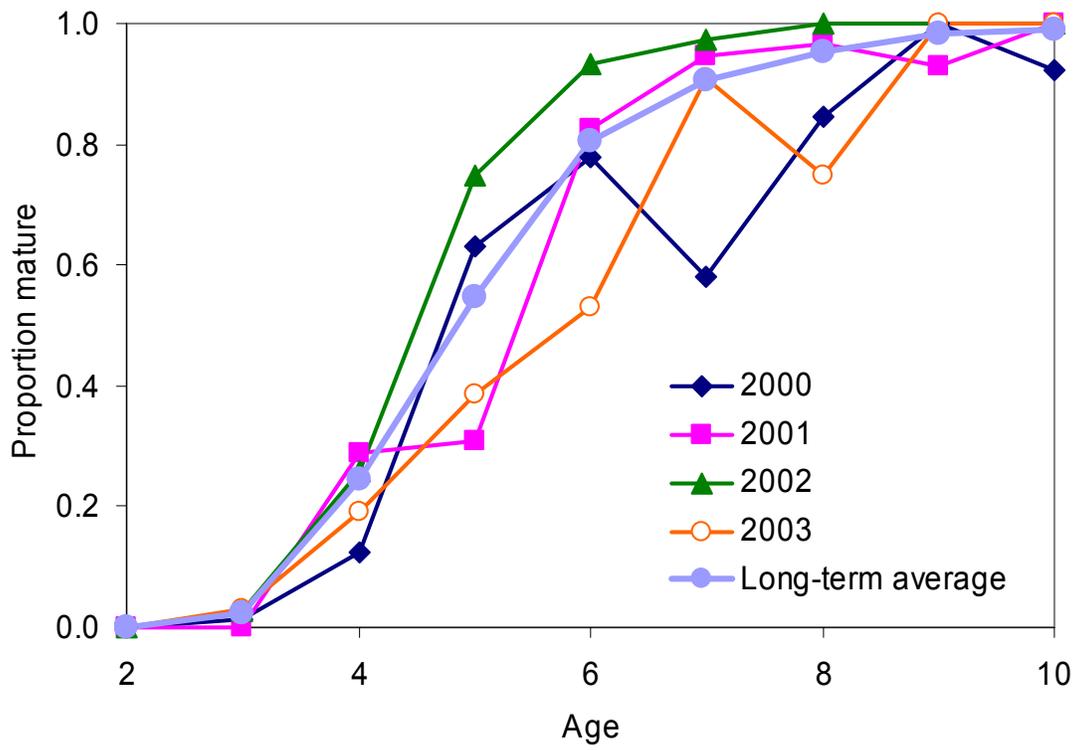


Figure 13. Estimates of the proportion mature at age from visual maturity data collected during 2000-2003 winter EIT surveys in the Gulf of Alaska.

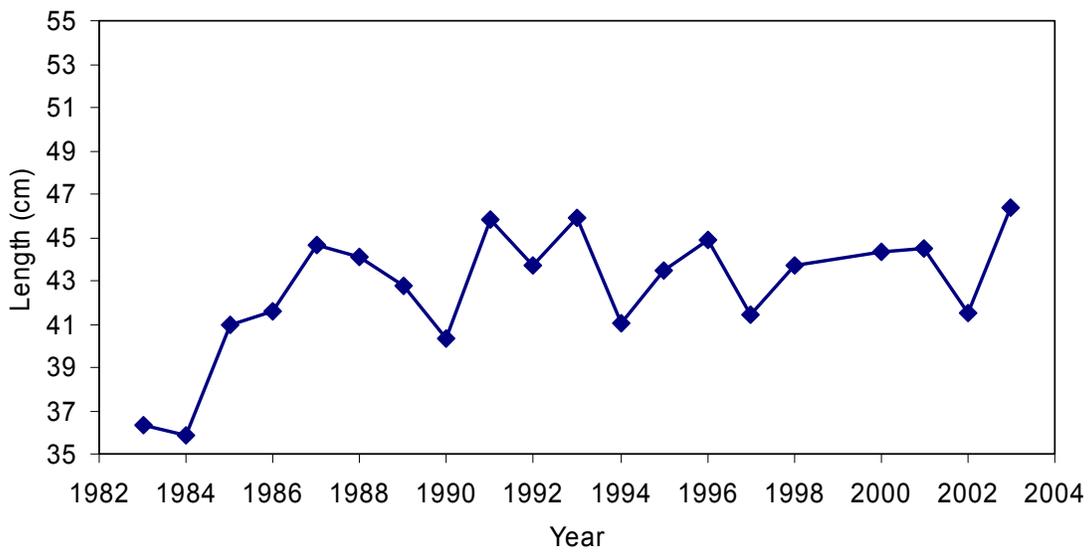
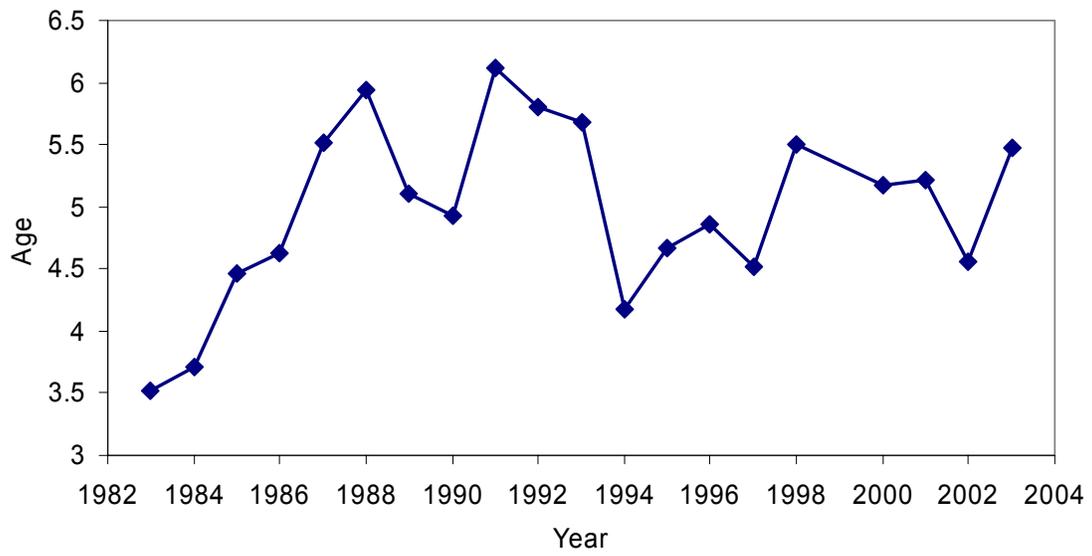


Figure 14. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2003.

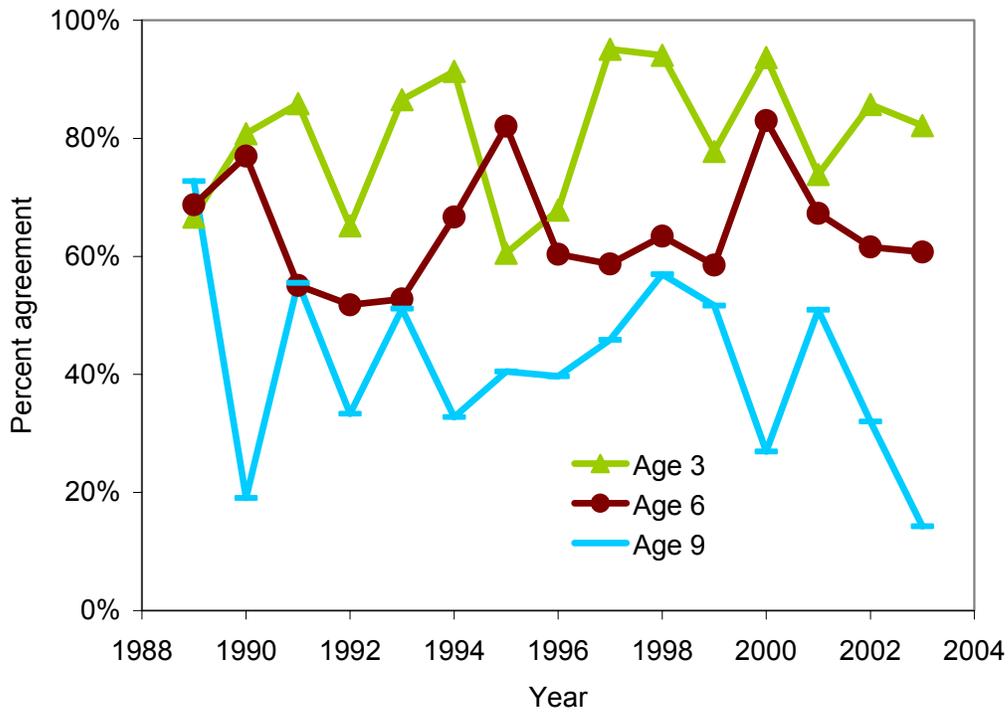


Figure 15. Trends in percent agreement in reader-tester evaluations for pollock age readers (total sample size = 16,870).

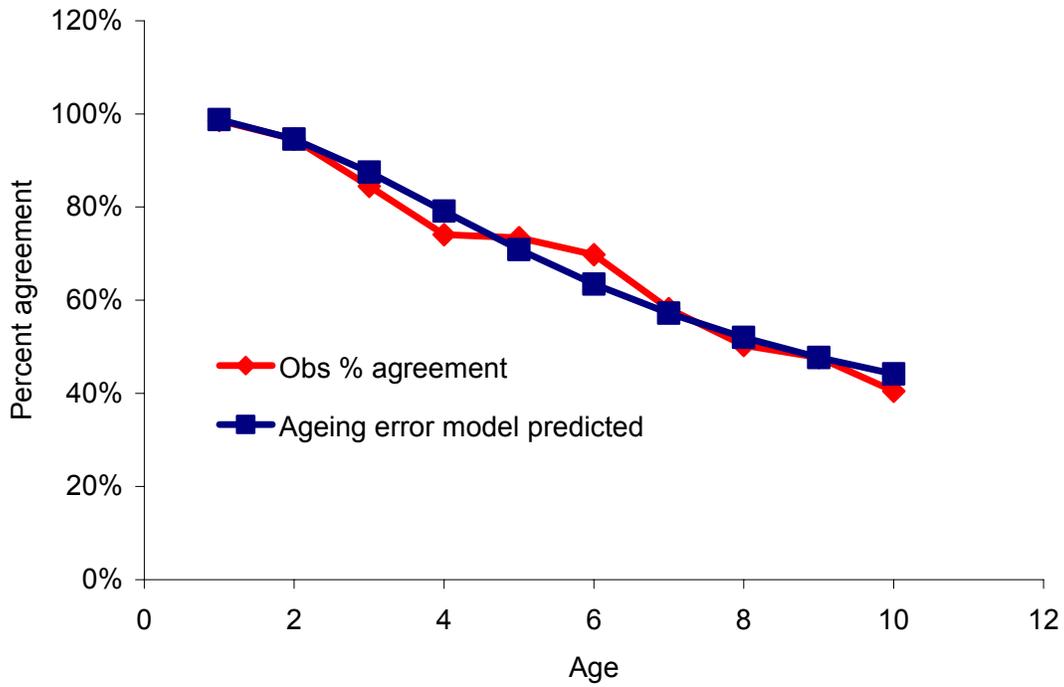


Figure 16. Average percent agreement by age during 1987-2003 in reader-tester evaluations for pollock age readers and predictions of percent agreement for an ageing error model.

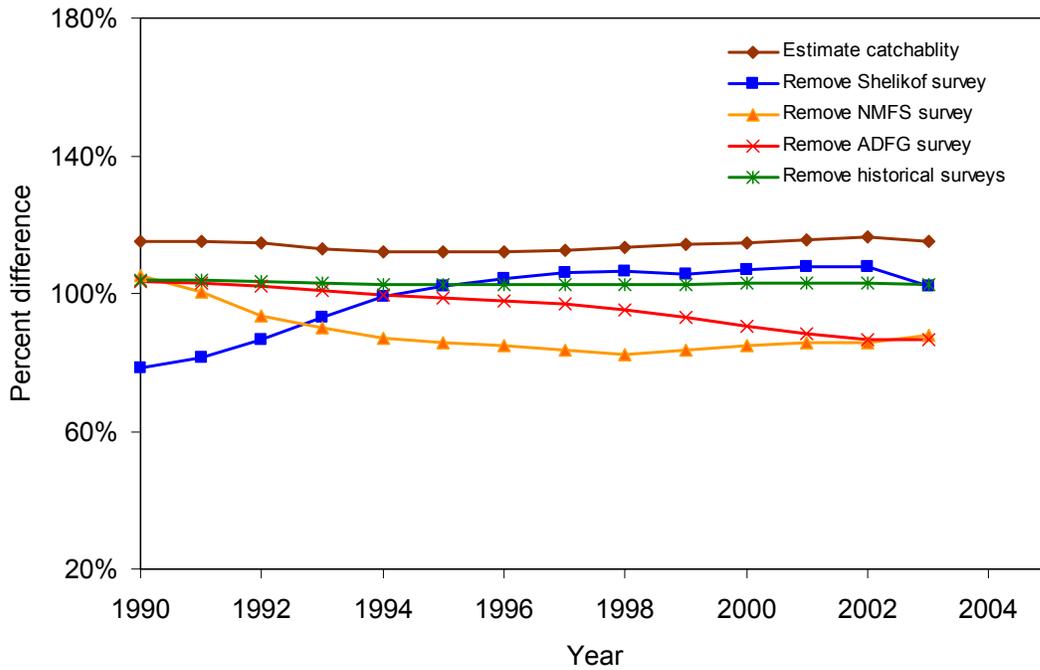
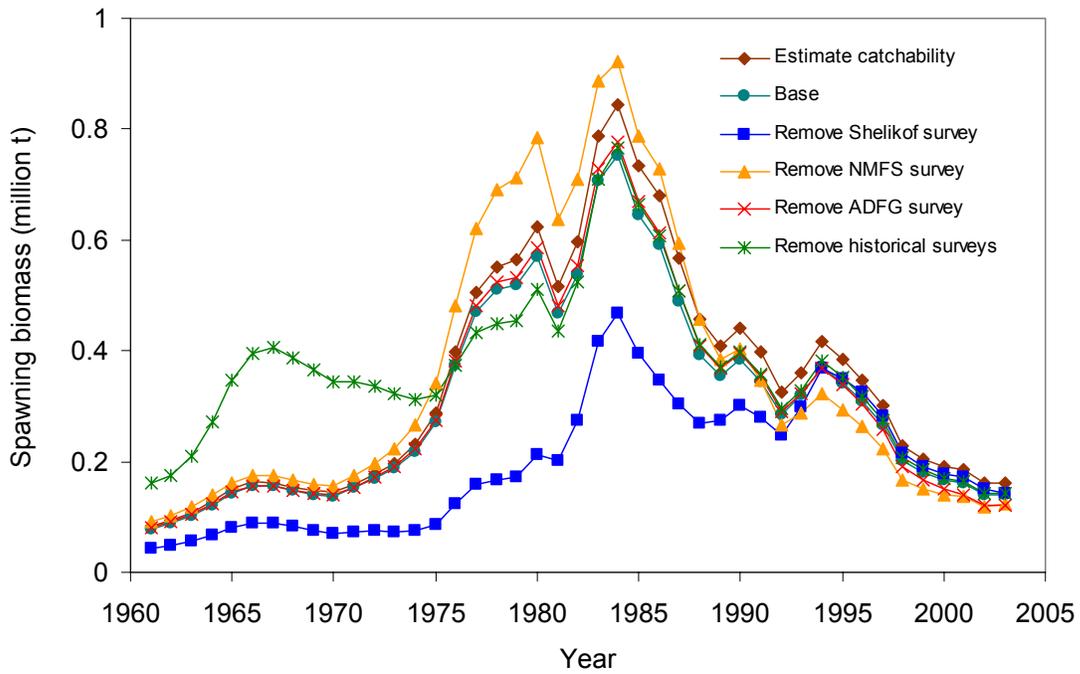


Figure 17. Comparison of estimated female spawning biomass for models that remove each survey time series. The top panel shows the entire modeled period, while the bottom panel shows the percent difference relative to the base model (all surveys included, fixed NMFS survey catchability) since 1990.

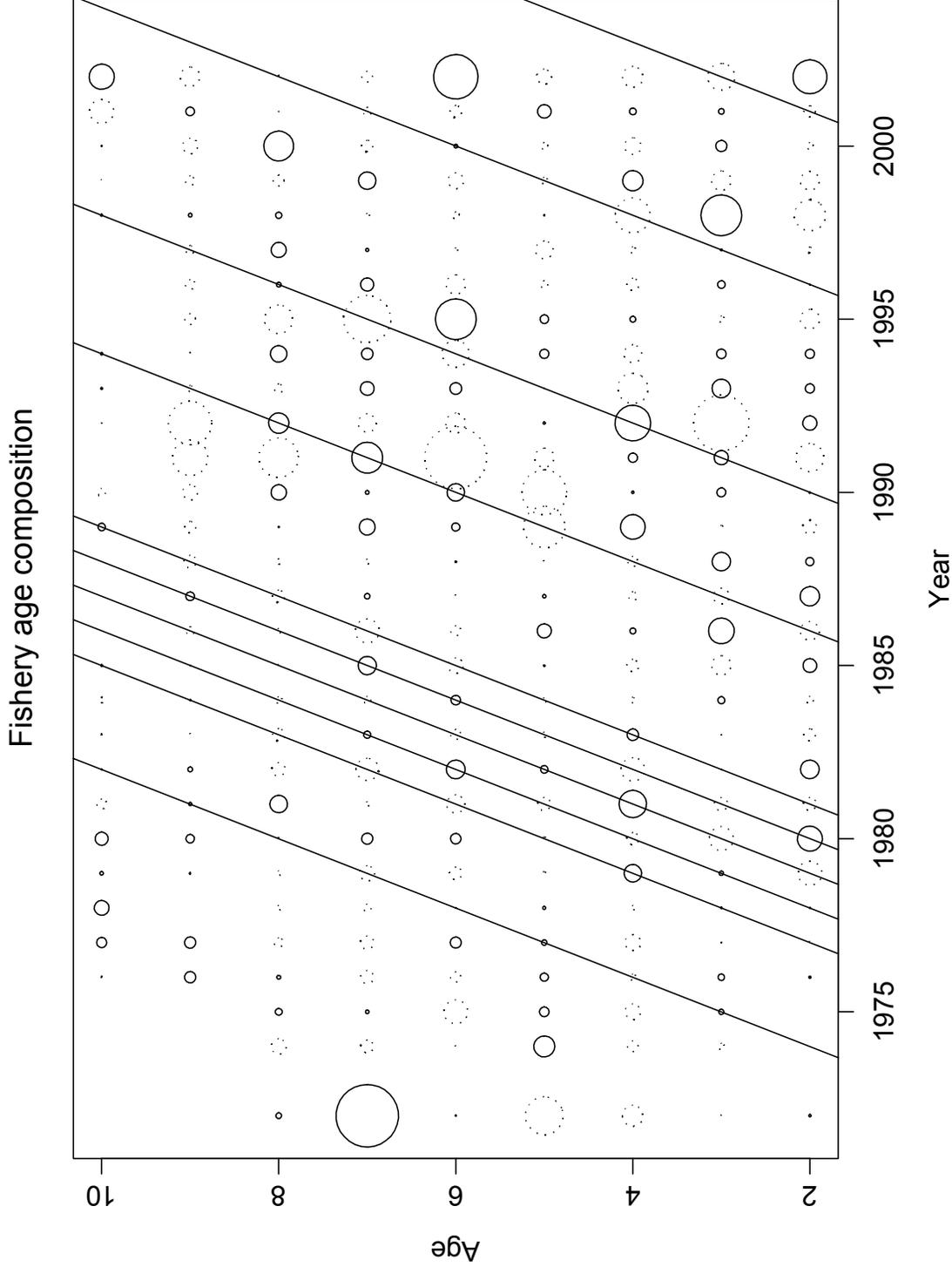


Figure 18. Residuals from Model 2 for fishery age composition (1972-2002). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, and 1999).

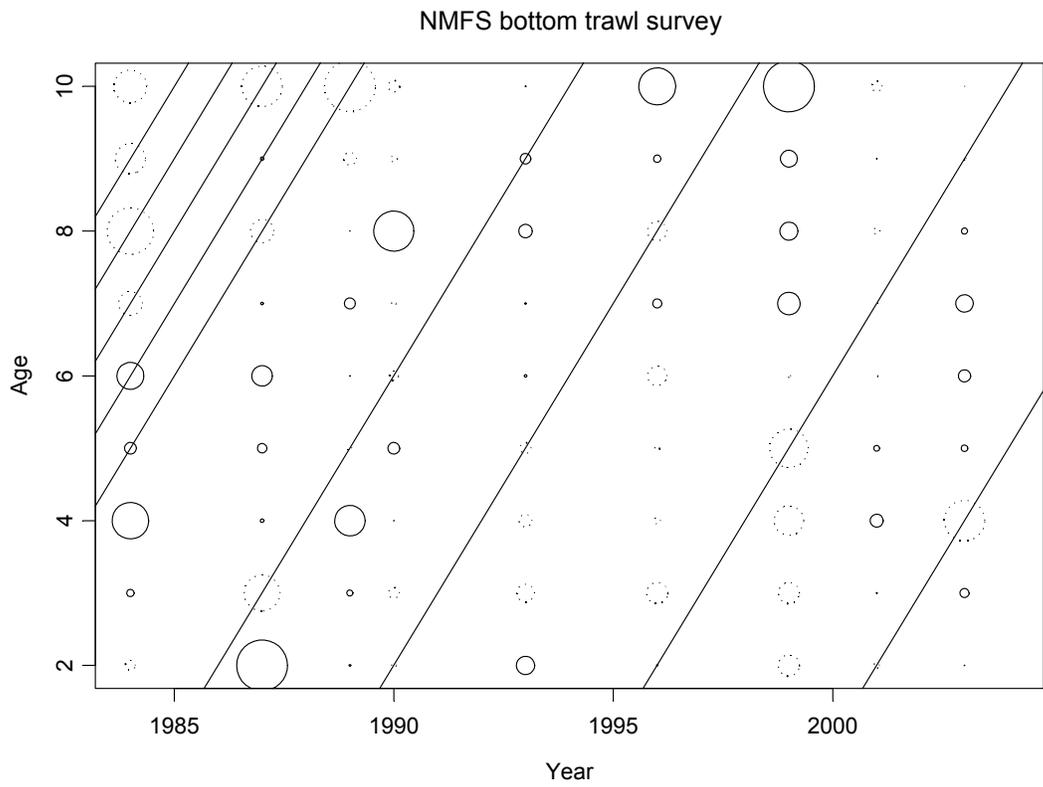
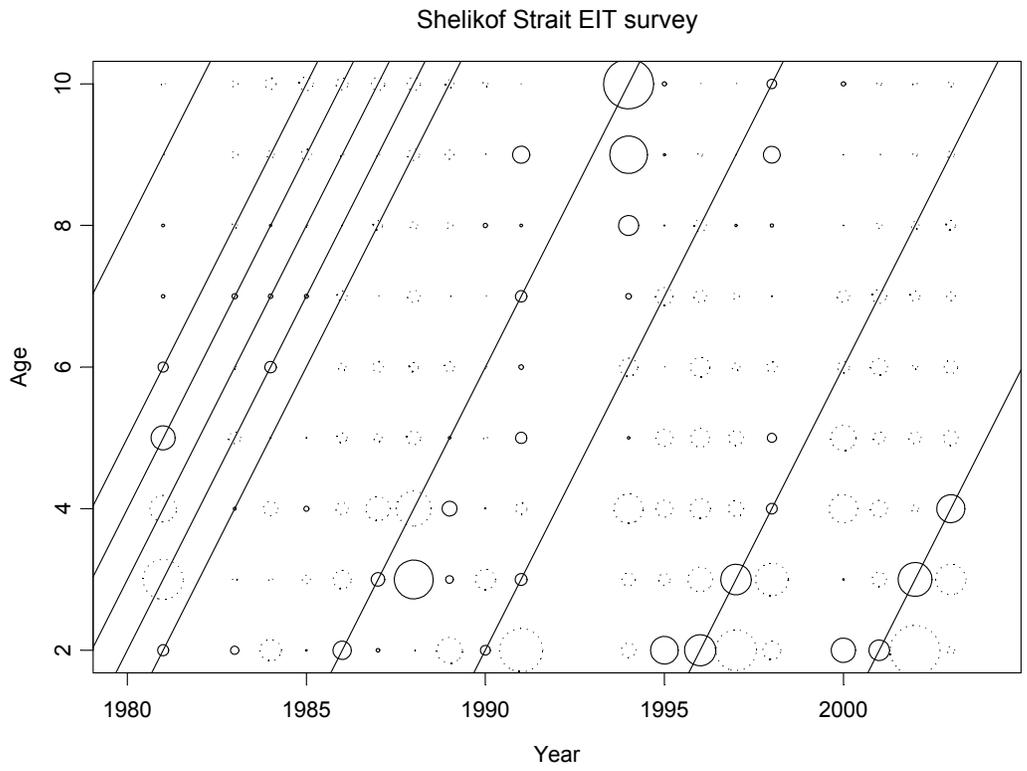


Figure 19. Residuals from Model 2 for the Shelikof Strait EIT survey age composition (top) and NMFS bottom trawl age composition (bottom). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, and 1999).

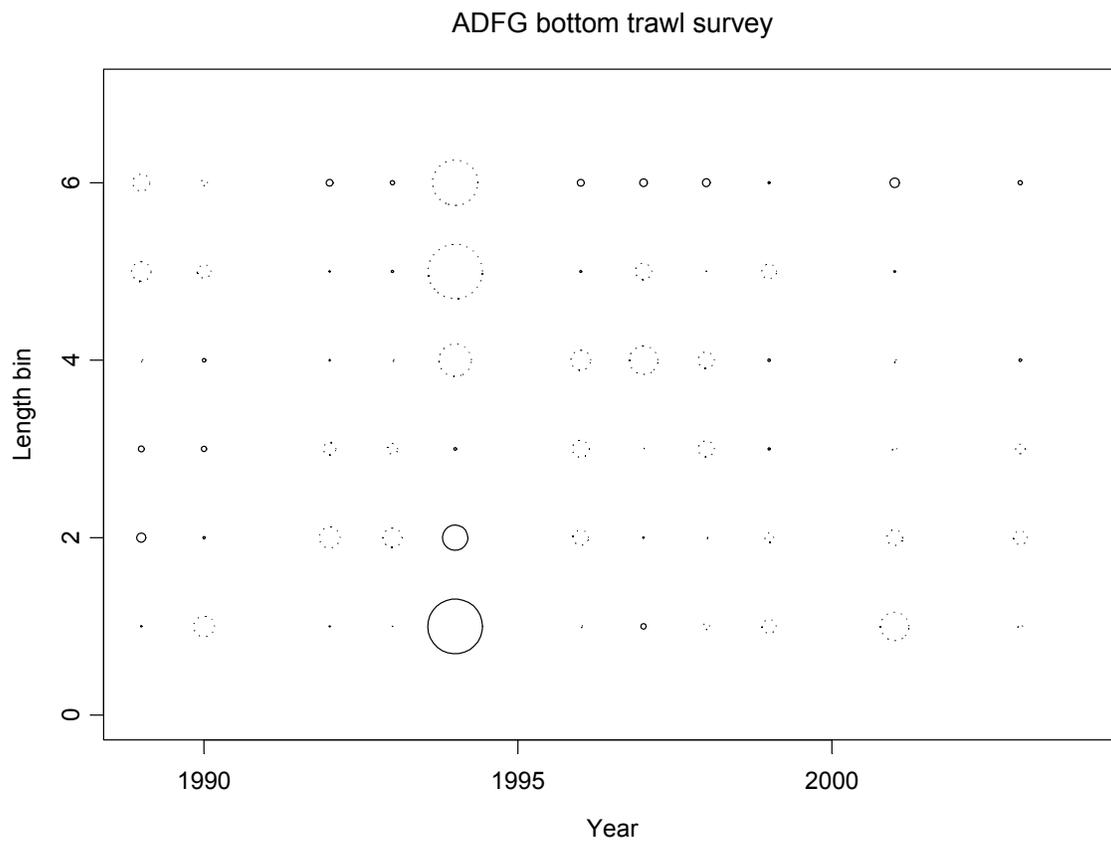


Figure 20. Residuals from Model 2 for the ADF&G survey length composition.

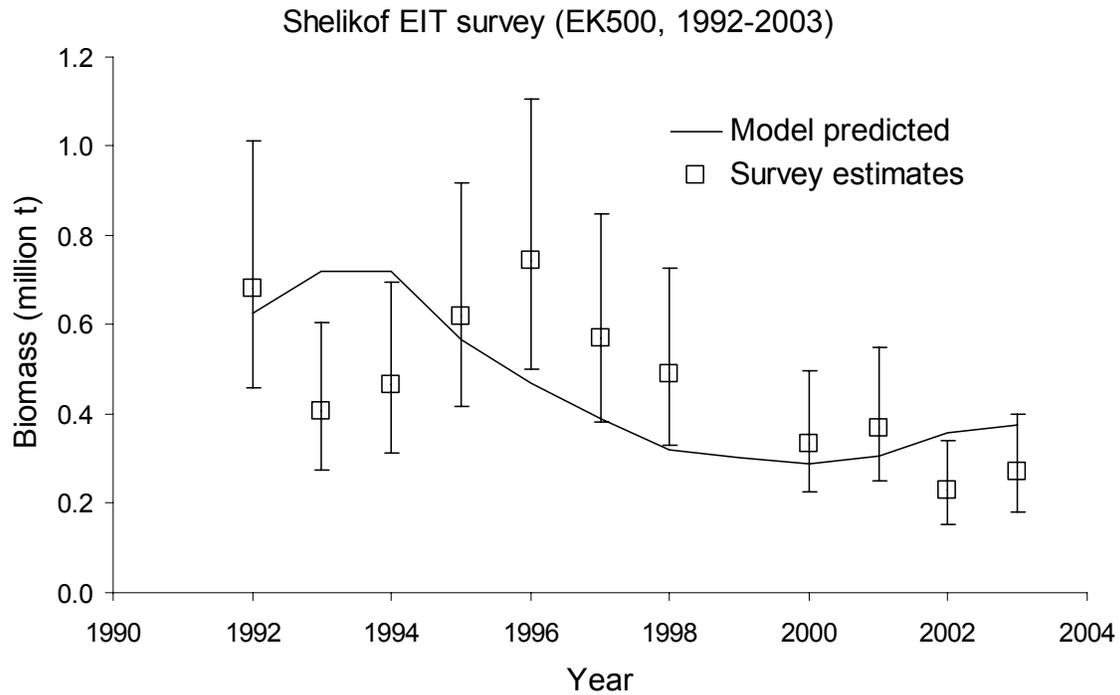
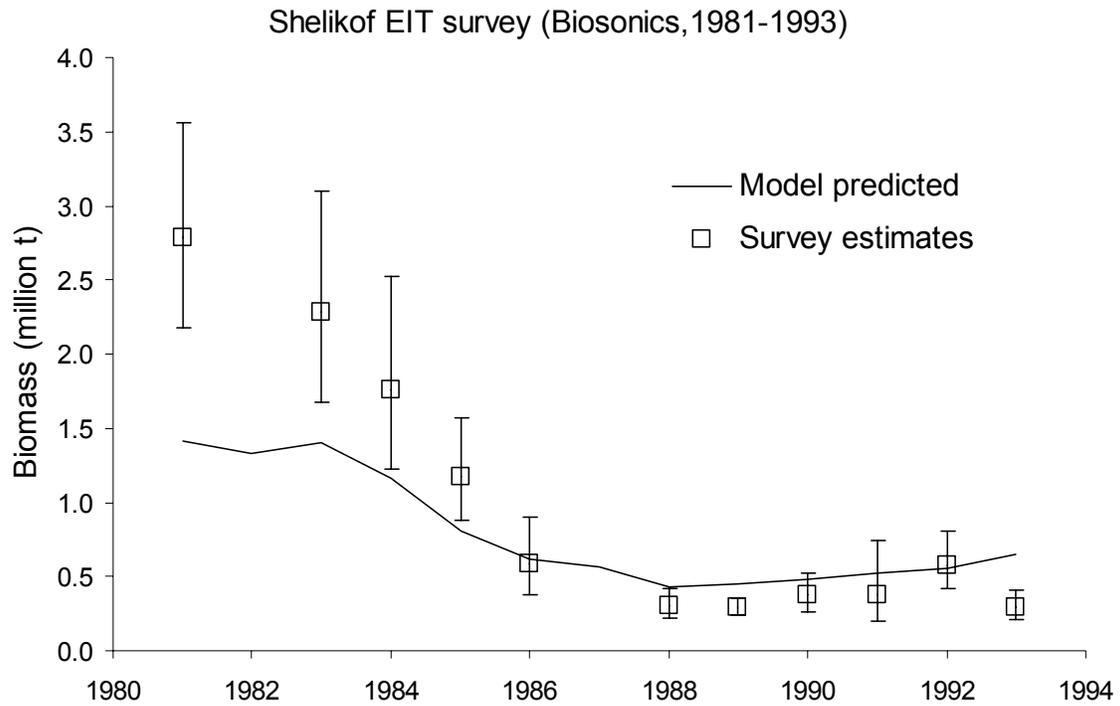


Figure 21. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with two catchability periods corresponding to the two acoustic systems used for the survey. Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for EK500 biomass estimates, an assumed CV of 0.2 is used in the assessment model.

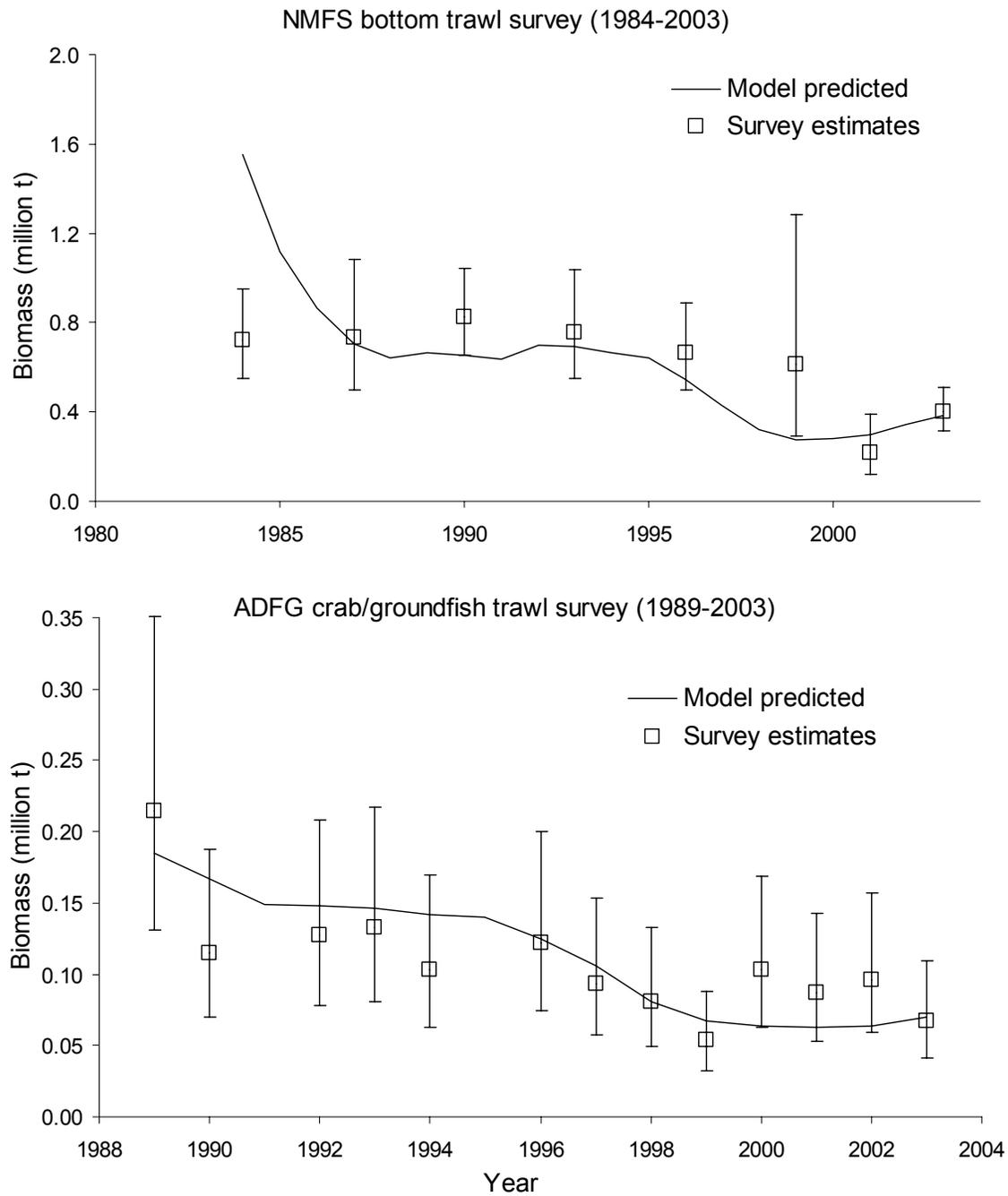


Figure 22. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.

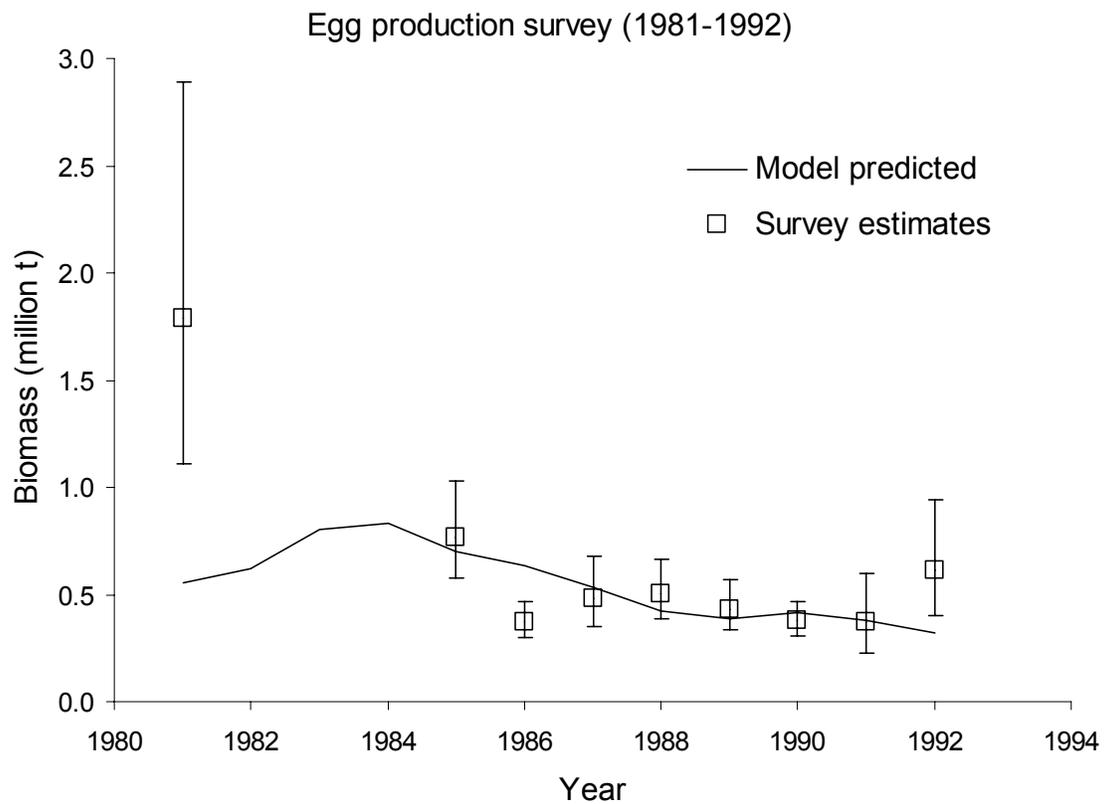
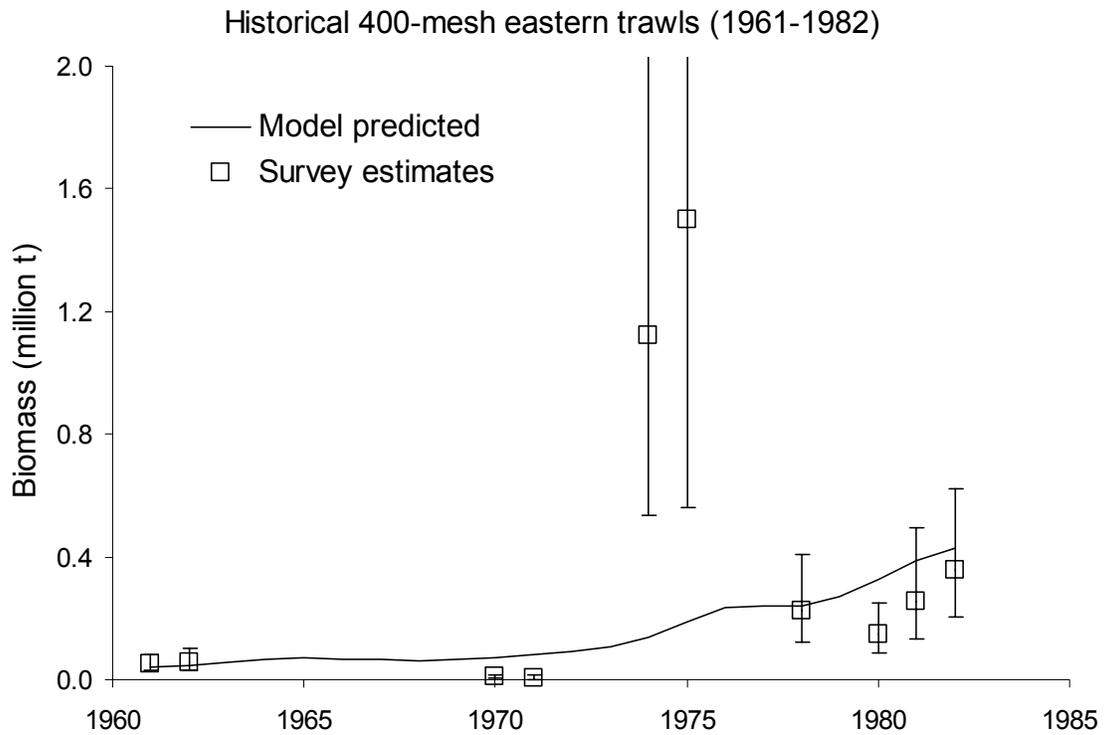


Figure 23. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top), and the egg production survey (bottom). Error bars indicate plus and minus two standard deviations.

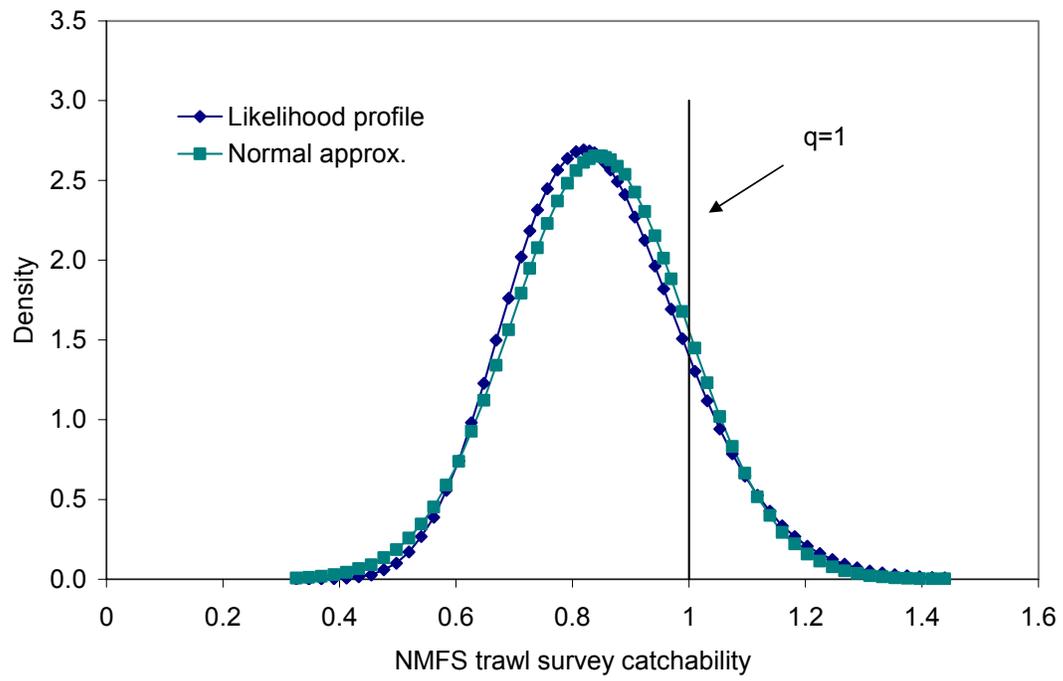


Figure 24. Uncertainty in the catchability coefficient for the NMFS trawl survey from a likelihood profile for Model 1.

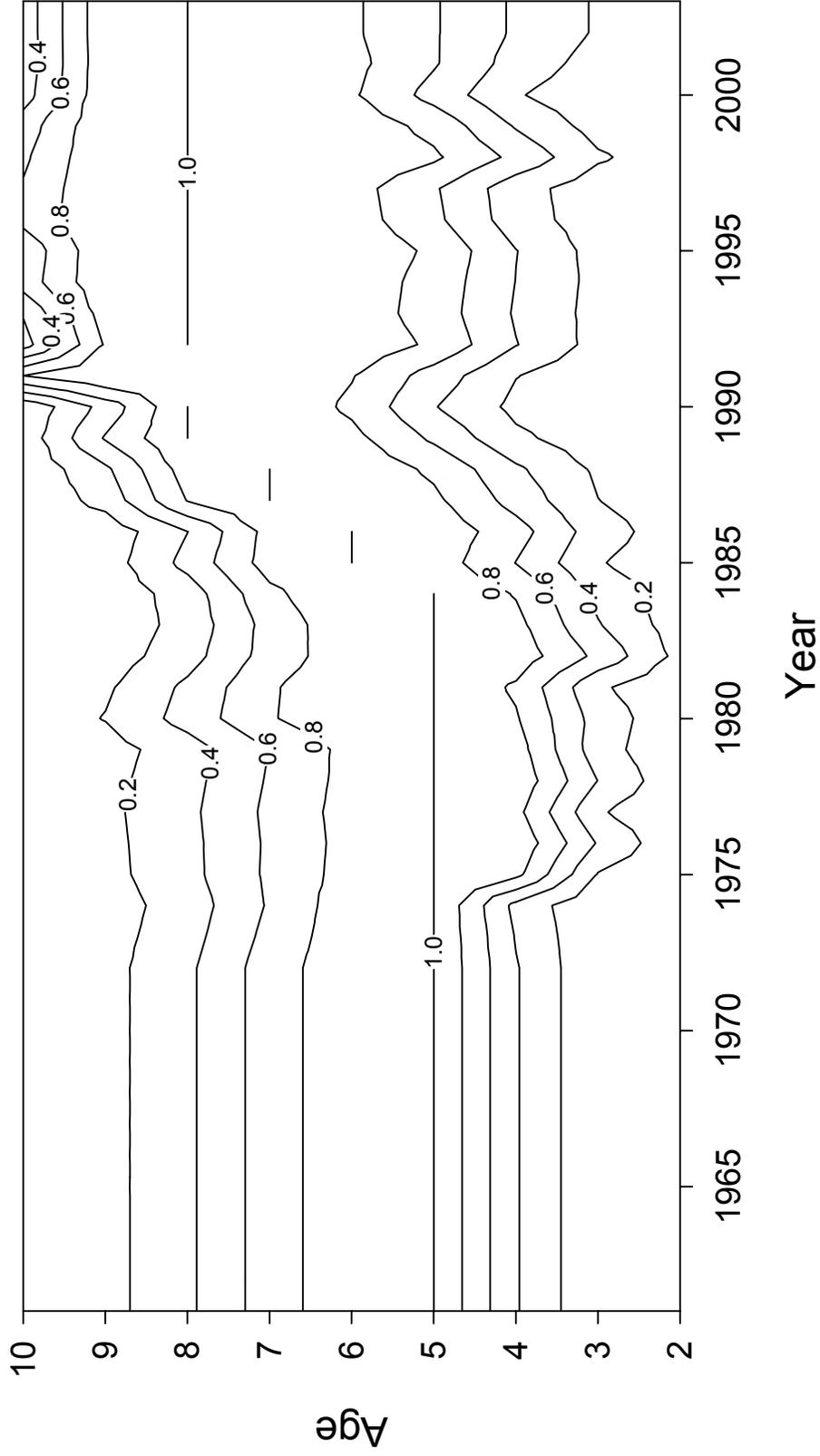


Figure 25. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock.

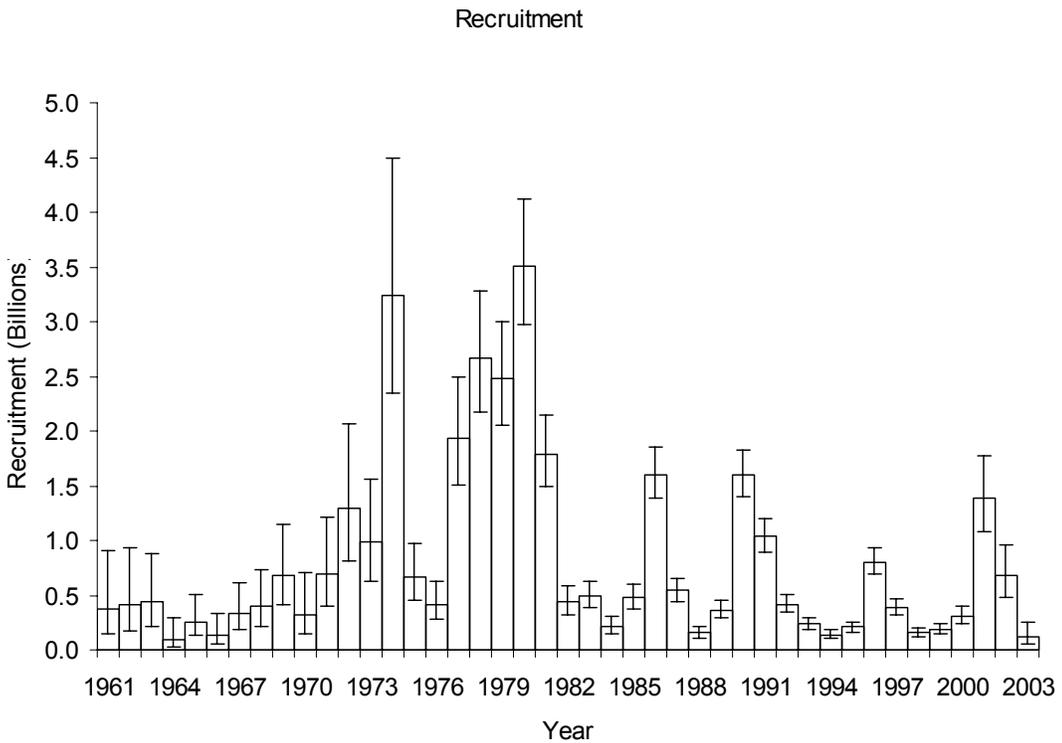
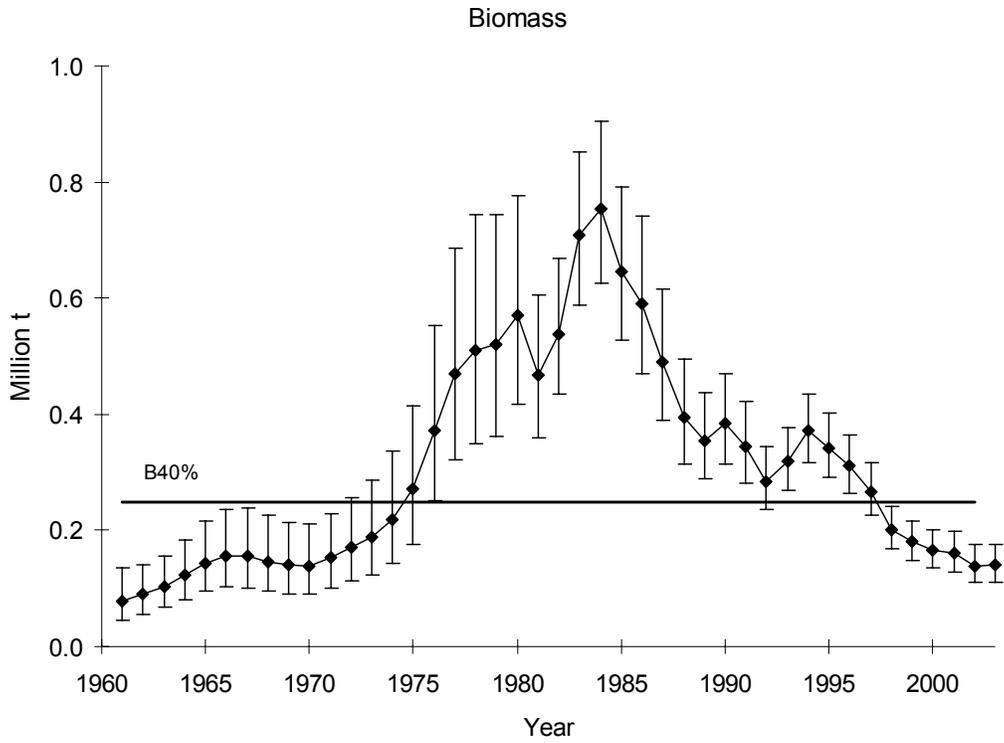


Figure 26. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-2 recruitment (billions of fish, bottom) from 1961 to 2003. Vertical bars represent two standard deviations. The B40% line represents the current estimate of this benchmark.

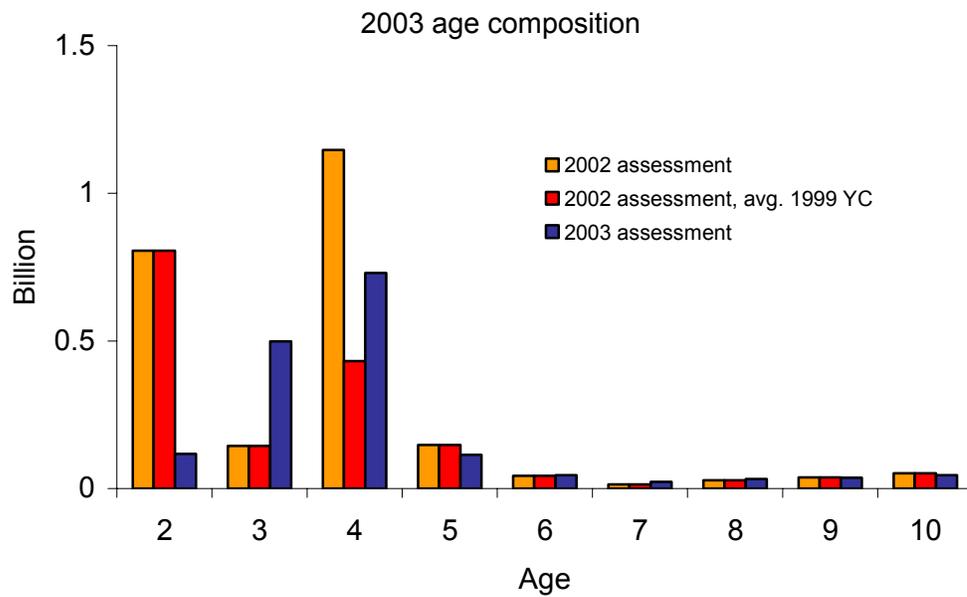
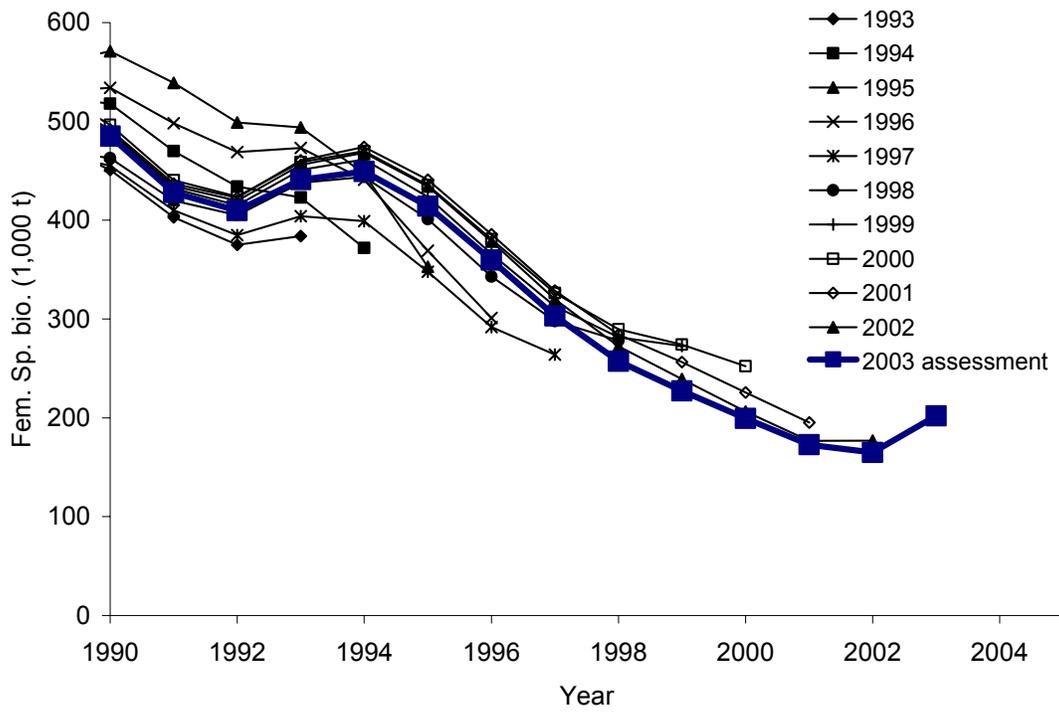


Figure 27. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1993-2003 (top). For this figure, the time series of female spawning biomass for the 2003 assessment was calculated using the weight and maturity at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2003 from the 2002 and 2003 assessments.

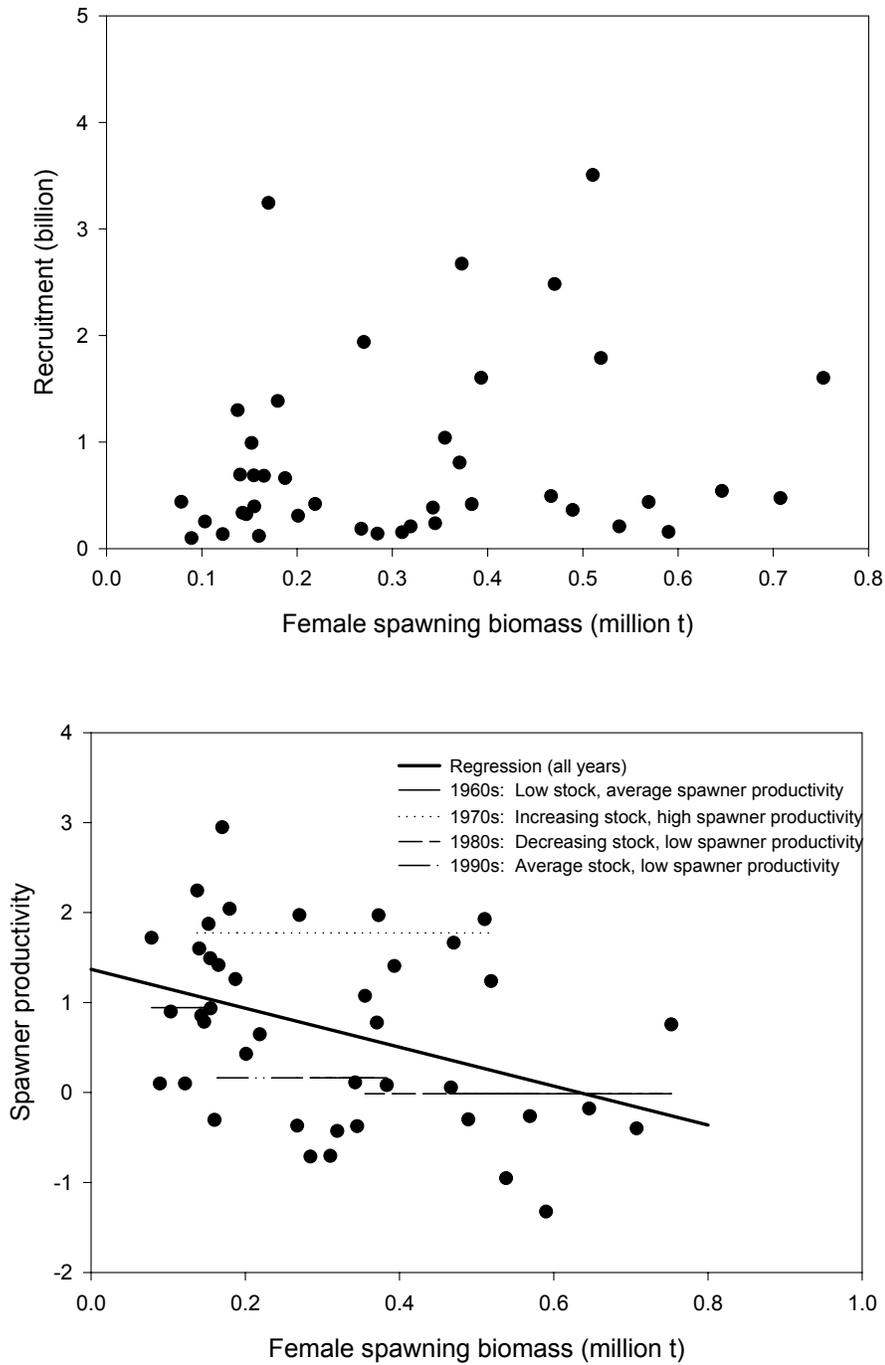


Figure 28. Gulf of Alaska pollock recruitment as a function of female spawning biomass (top). Spawner productivity $\log(R/S)$ in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.

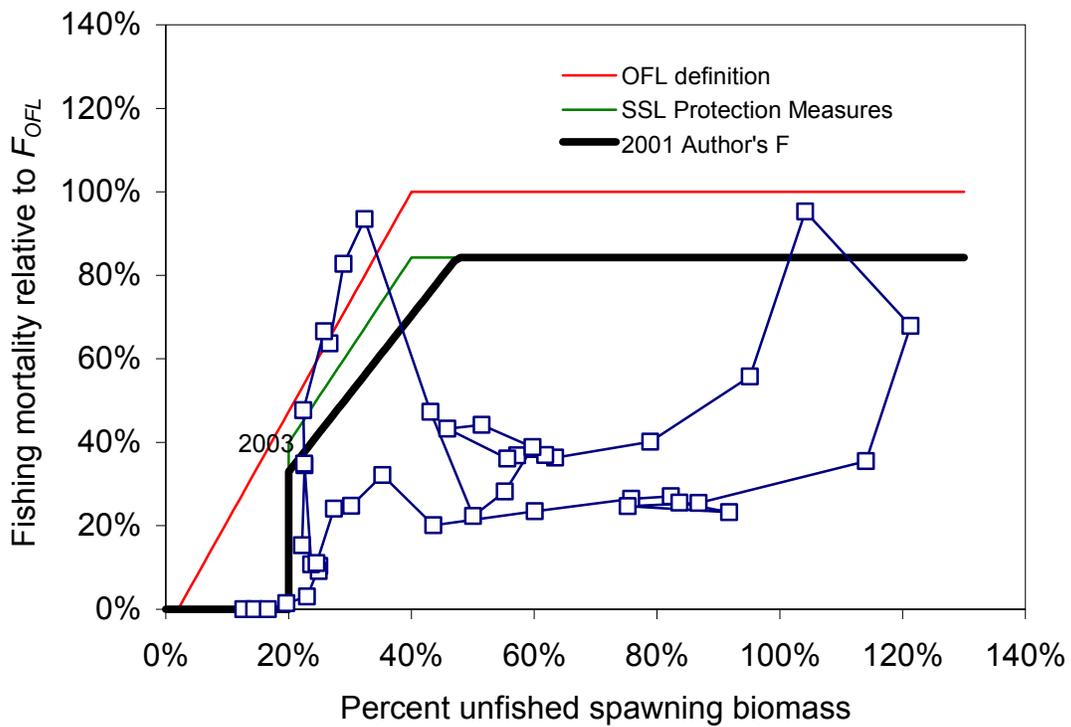


Figure 29. Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} (1961-2003). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of unfished spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure cannot be used to evaluate management performance relative to biomass reference levels.

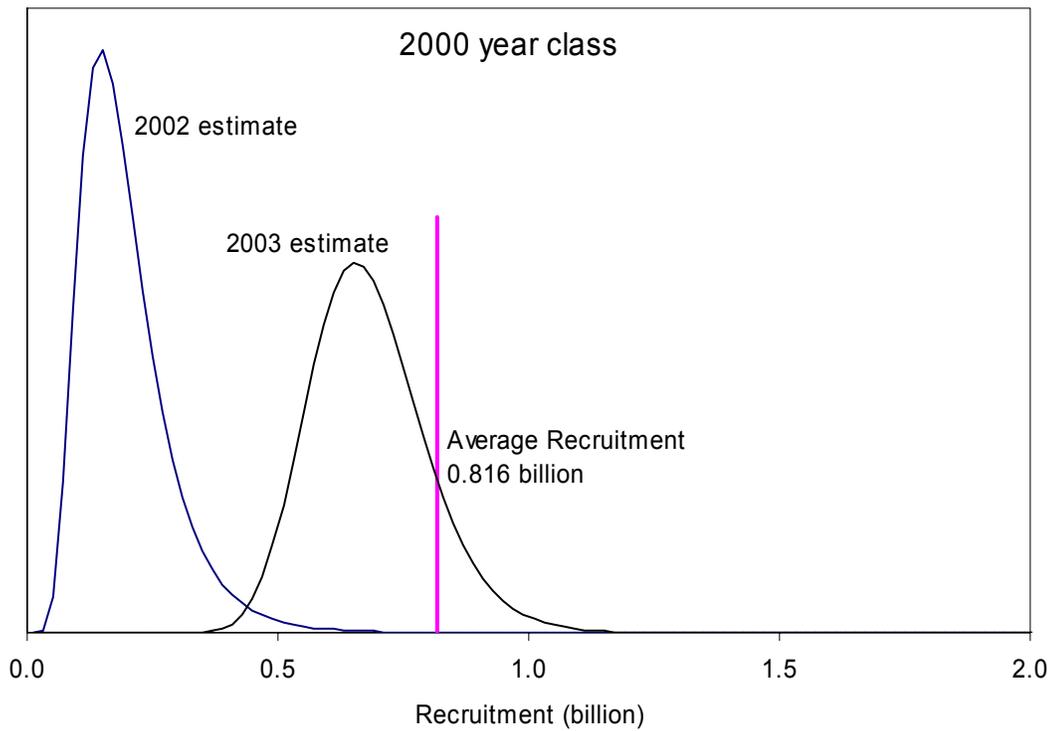
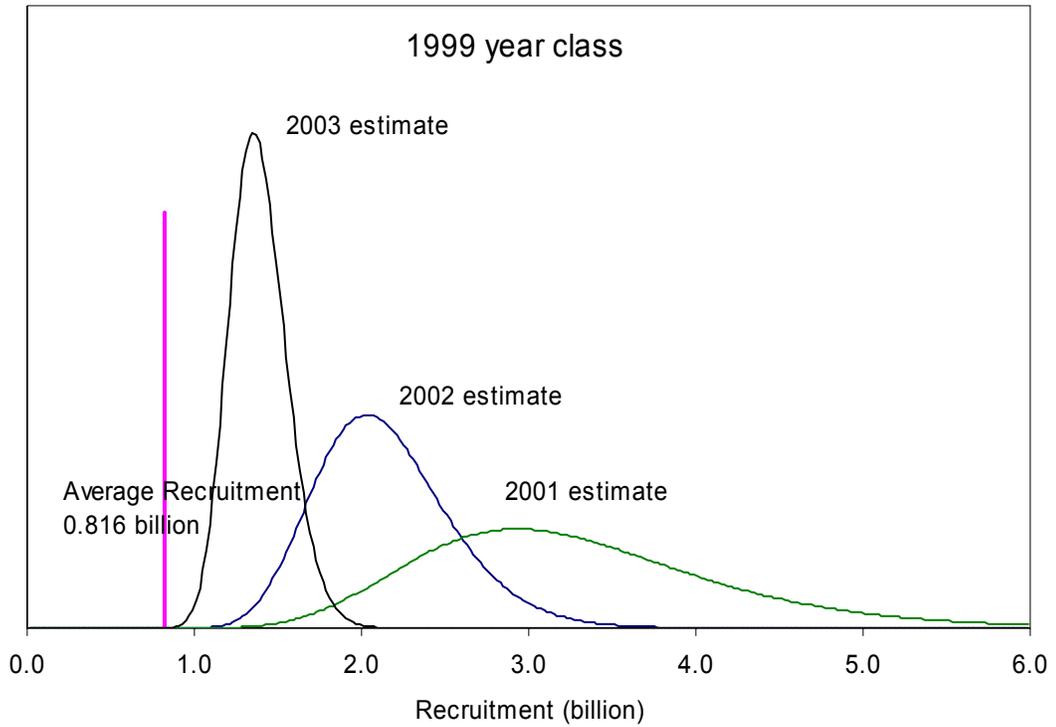


Figure 30. Uncertainty in the estimate of recruitment abundance of the 1999 year class in 2001, 2002, and 2003 stock assessments (top) and the 2000 year class in 2002 and 2003 assessments (bottom).

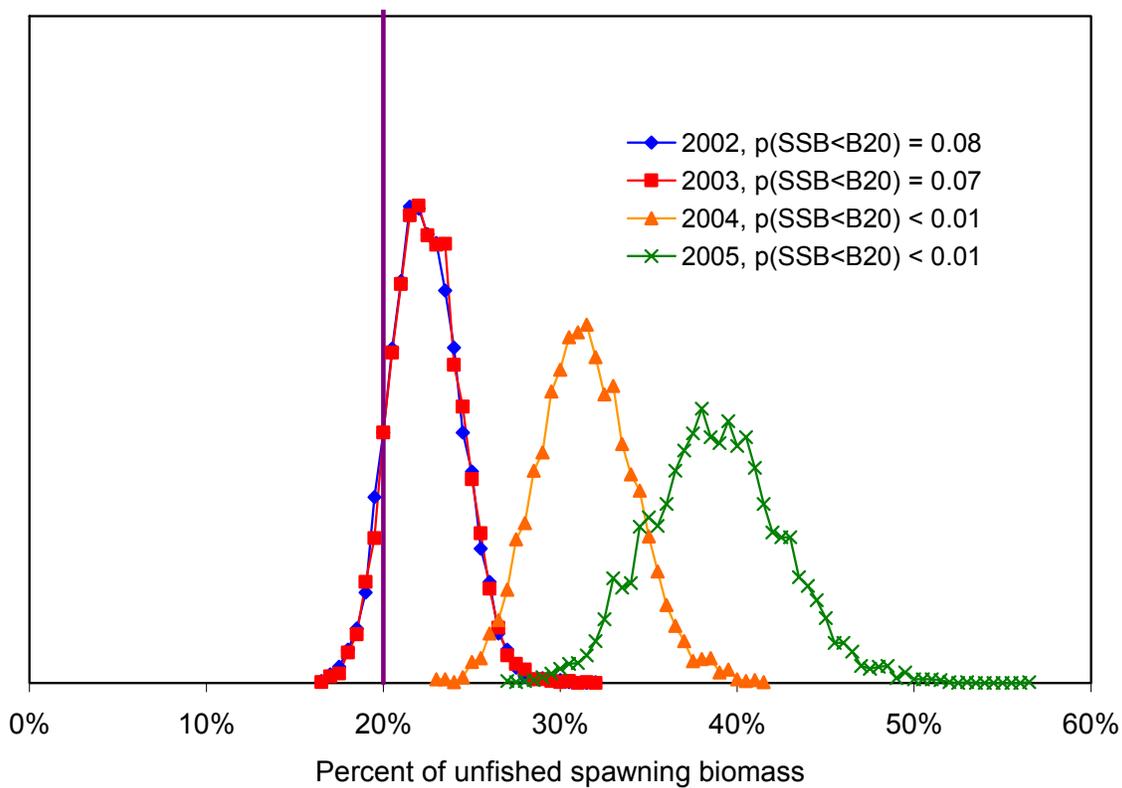


Figure 31. Uncertainty in spawning biomass in 2002-2005 based on a thinned MCMC chain from the joint marginal likelihood for Model 2 where catch in 2004 is set to the author's recommended ABC. In 2005, catch is derived from spawning biomass in 2005 and the author's recommended fishing mortality schedule.

Appendix A: Southeast Alaska pollock

Bottom trawl surveys indicate a substantial reduction in pollock abundance east of 140° W. lon. Stock structure in this area is poorly understood. Bailey et al. (1999) suggest that pollock metapopulation structure in southeast Alaska is characterized by numerous fiord populations. In the 1996, 1999 and 2003 bottom trawl surveys, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Pollock size composition in the 1996, 1999 and 2003 surveys was dominated by smaller fish (<40 cm). These juveniles are unlikely to influence the population dynamics of pollock in the central and western Gulf of Alaska. Ocean currents are generally northward in this area, suggesting that juvenile settlement is a result of spawning further south. Spawning aggregations of pollock have been reported from the northern part of Dixon Entrance (Saunders et al. 1988).

Historically, there has been little directed fishing for pollock in southeast Alaska (Fritz 1993). During 1991-2002, pollock catch the Southeast and East Yakutat statistical areas averaged 17 t (Table 2). The current ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska.

Pollock biomass estimates from the bottom trawl survey are highly variable, in part due to year-to-year differences in survey coverage. Surveys in 1996, 1999, and 2003 had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Fig. 32). We recommend placing southeast Alaska pollock in Tier 5 of NPFMC harvest policy, and basing the ABC and OFL on natural mortality (0.3) and the biomass for the 2003 survey. Biomass in southeast Alaska was estimated by splitting survey strata and CPUE data in the Yakutat INPFC area at 140° W. lon. and combining the strata east of the line with comparable strata in the Southeastern INPFC area. This gives a **2004 ABC of 6,520 t** ($28,979 \text{ t} * 0.75 \text{ M}$), and a **2004 OFL of 8,694 t** ($28,979 \text{ t} * \text{M}$).

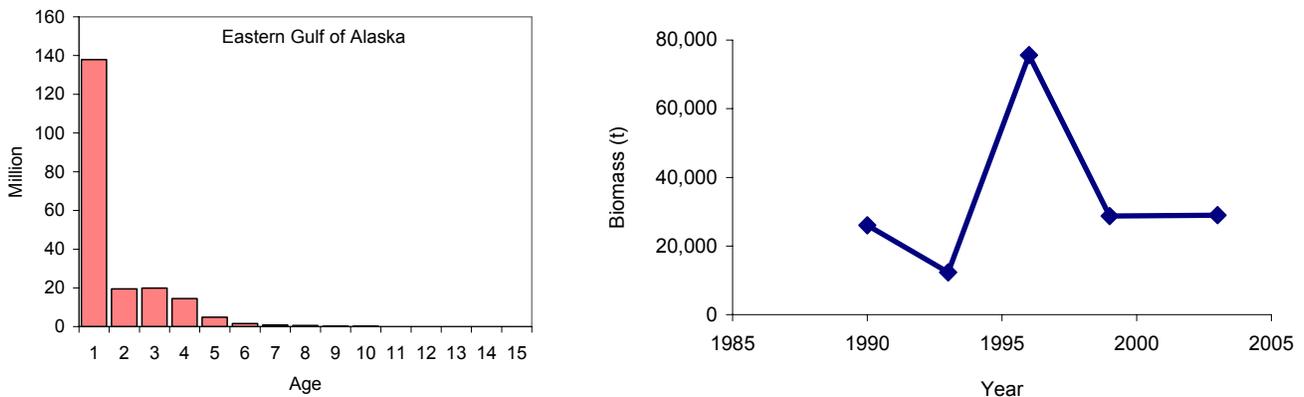


Figure 32. Pollock age composition in 2003 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2003 (right).

Appendix B: Gulf pollock stock assessment model

Population dynamics

The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 10, with age 10 defined as a “plus” group, i.e., all individuals age 10 and older. The model extends from 1961 to 2003 (43 yrs). The Baranov (1918) catch equations are assumed, so that

$$c_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}} [1 - \exp(-Z_{ij})]$$

$$N_{i+1,j+1} = N_{ij} \exp(-Z_{ij})$$

$$Z_{ij} = \sum_k F_{ik} + M$$

except for the plus group, where

$$N_{i+1,10} = N_{i,9} \exp(-Z_{i,9}) + N_{i,10} \exp(-Z_{i,10})$$

where N_{ij} is the population abundance at the start of year i for age j fish, F_{ij} = fishing mortality rate in year i for age j fish, and c_{ij} = catch in year i for age j fish. A constant natural mortality rate, M , irrespective of year and age, is assumed.

Fishing mortality is modeled as a product of year-specific and age-specific factors (Doubleday 1976)

$$F_{ij} = s_j f_i$$

where s_j is age-specific selectivity, and f_i is the annual fishing mortality rate. To ensure that the selectivities are well determined, we require that $\max(s_j) = 1$. Following previous assessments, a scaled double-logistic function (Dorn and Methot 1990) was used to model age-specific selectivity,

$$s'_j = \left(\frac{1}{1 + \exp[-\beta_1(j - \alpha_1)]} \right) \left(1 - \frac{1}{1 + \exp[-\beta_2(j - \alpha_2)]} \right)$$

$$s_j = s'_j / \max(s'_j)$$

where α_1 = inflection age, β_1 = slope at the inflection age for the ascending logistic part of the equation, and α_2 , β_2 = the inflection age and slope for the descending logistic part.

Measurement error

Model parameters were estimated by maximum likelihood (Fournier and Archibald 1982, Kimura 1989, 1990, 1991). Fishery observations consist of the total annual catch in tons, C_i , and the proportions at age in the catch, p_{ij} . Predicted values from the model are obtained from

$$\hat{C}_i = \sum_j w_{ij} c_{ij}$$

$$\hat{p}_{ij} = c_{ij} / \sum_j c_{ij}$$

where w_{ij} is the weight at age j in year i . Year-specific weights at age are used when available.

Log-normal measurement error in total catch and multinomial sampling error in the proportions at age give a log-likelihood of

$$\log L_k = \sum_i [\log(C_i) - \log(\hat{C}_i)]^2 / 2 \sigma_i^2 + \sum_i m_i \sum_j p_{ij} \log(\hat{p}_{ij} / p_{ij})$$

where σ_i is standard deviation of the logarithm of total catch ($\sim CV$ of total catch) and m_i is the size of the age sample. In the multinomial part of the likelihood, the expected proportions at age have been divided by the observed proportion at age, so that a perfect fit to the data for a year gives a log likelihood value of zero (Fournier and Archibald 1982). This formulation of the likelihood allows considerable flexibility to give different weights (i.e. emphasis) to each estimate of annual catch and age composition. Expressing these weights explicitly as CVs (for the total catch estimates), and sample sizes (for the proportions at age) assists in making reasonable assumptions about appropriate weights for estimates whose variances are not routinely calculated.

Survey observations consist of a total biomass estimate, B_i , and survey proportions at age π_{ij} .

Predicted values from the model are obtained from

$$\hat{B}_i = q \sum_j w_{ij} s_j N_{ij} \exp [\phi_i Z_{ij}]$$

where q = survey catchability, w_{ij} is the survey weight at age j in year i (if available), s_j = selectivity at age for the survey, and ϕ_i = fraction of the year to the mid-point of the survey. Although there are multiple surveys for Gulf pollock, a subscript to index a particular survey has been suppressed in the above and subsequent equations in the interest of clarity. Survey selectivity was modeled using a either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the i th year are given by

$$\hat{\pi}_{ij} = s_j N_{ij} \exp[\phi_i Z_{ij}] / \sum_j s_j N_{ij} \exp[\phi_i Z_{ij}]$$

Log-normal errors in total biomass and multinomial sampling error in the proportions at age give a log-likelihood for survey k of

$$\log L_k = \sum_i [\log(B_i) - \log(\hat{B}_i)]^2 / 2 \sigma_i^2 + \sum_i m_i \sum_j \pi_{ij} \log(\hat{\pi}_{ij} / \pi_{ij})$$

where σ_i is the standard deviation of the logarithm of total biomass (\sim CV of the total biomass) and m_i is the size of the age sample from the survey.

Process error

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the pollock model, these annual recruitment and fishing mortality parameters are generally estimated as free parameters, with no additional error constraints. We use process error to describe changes in fisheries selectivity over time. To model temporal variation in a parameter γ , the year-specific value of the parameter is given by

$$\gamma_i = \bar{\gamma} + \delta_i$$

where $\bar{\gamma}$ is the mean value (on either a log scale or linear scale), and δ_i is an annual deviation subject to the constraint $\sum \delta_i = 0$. For a random walk where annual *changes* are normally distributed, the log-likelihood is

$$\log L_{Proc.Err.} = \sum \frac{(\delta_i - \delta_{i+1})^2}{2 \sigma_i^2}$$

where σ_i is the standard deviation of the annual change in the parameter. We use a process error model for all four parameters of the fishery double-logistic curve.

The total log likelihood is the sum of the likelihood components for each fishery and survey, plus a term for process error,

$$\text{Log } L = \sum_k \text{Log } L_k + \sum_p \text{Log } L_{Proc.Err.}$$

Appendix C. Evaluation of Gulf of Alaska pollock management parameters using Bayesian stock-recruit analysis, stock depletion estimators, and models with annually-varying juvenile mortality

A recent review of North Pacific harvest policy (Goodman et al. 2002) recommended a “closer look” at the suitability of $F_{35\%}$ as a proxy for F_{MSY} for Gulf of Alaska pollock. This recommendation was based on the observation that there has been a long-term decline in pollock abundance despite harvest rates being consistently lower than $F_{35\%}$. In this section, we carry out a “closer look” with three analyses. First, we conduct a Bayesian stock-recruit analysis using methods adapted from Dorn (2002). A second analysis applies a novel approach to estimating stock depletion that more effectively separates the effect of fishing from long-term environmental effects on stock abundance than conventional estimates of stock depletion. A final analysis develops a preliminary assessment model with annually-varying juvenile mortality, and uses model results to explore several potential management responses to an apparent increase in juvenile pollock mortality caused by ecosystem changes.

Bayesian stock-recruit model

The Beverton-Holt curve was re-parameterized using R_0 , the expected recruitment for an unfished stock size of S_0 , and a parameter that measures the resiliency of the stock, h , defined as the proportion of R_0 that recruits when the stock is reduced to 20% of unfished biomass (i.e., the “steepness” parameter of Mace and Doonan (1988)). The Beverton-Holt curve with these new parameters is given by

$$R = \frac{0.8 R_0 h S}{0.2 \varphi_0 R_0 (1 - h) + (h - 0.2) S},$$

where $S_0 = \varphi_0 R_0$, and φ_0 is spawning biomass per recruit for an unfished stock, which is estimated independently using conventional spawning biomass per recruit equations. Steepness ranges between 0.2 (recruits related linearly to spawning biomass) to 1.0 (recruits independent of spawning biomass).

Variability around the stock-recruit relationship was assumed lognormal. The assumption of lognormal errors in S-R models is based on both theoretical considerations (Hilborn and Walters 1992) and empirical studies (Peterman 1981, Myers et al. 1995). A lognormal probability density for recruitment is

$$p(R/\hat{R}(S, R_0, h), \sigma^2) = \frac{1}{R \sqrt{2\pi} \sigma} \exp \left[-\frac{1}{2\sigma^2} \left(\log R - \log \hat{R} + \frac{\sigma^2}{2} \right)^2 \right],$$

where $\hat{R}(S, R_0, h)$ is the expected recruitment as a function of the S-R parameters and spawning biomass, and σ^2 is a shape parameter. Note that the mean of the lognormal variate is used here rather than the usual parameterization with the median, $m = \hat{R} \exp(-\sigma^2/2)$.

There are three parameters for which priors need to be developed, R_0 , h , and σ^2 . The prior for steepness was modeled by assuming the logit of h was normally distributed (after rescaling h into the interval (0,1), $(h_k - 0.2) / 0.8$, and simplifying),

$$\beta = \log\left(\frac{h - 0.2}{1 - h}\right), \beta \sim N(\mu, \xi^2).$$

For h in the interval (0.2,1.0), the logit β ranges from $-\infty$ to $+\infty$. The use of the logit transformation makes it straightforward to specify a prior mean and variance.

A normal prior was used for R_0 ,

$$R_0 \sim N(\bar{R}_0, \omega^2),$$

where \bar{R}_0 is prior mean, and ω^2 is the prior variance. For σ^2 , a locally uniform prior for σ on a log scale was used. The negative log-likelihood is proportional to

$$-\log L_1 = \sum_i \frac{(\log R_i - \log \hat{R}_i(S_i, R_0, h) + \sigma^2 / 2)^2}{2\sigma^2} + n \log \sigma.$$

Note that we assume no correlation in recruitment and no error in estimates of spawning biomass, i.e., the usual simplifying assumptions in analyses of S-R data.

The negative log-prior is proportional to

$$-\log L_2 = \frac{1}{2\xi^2}(\beta - \mu)^2 + \frac{1}{2\omega^2}(R_0 - \bar{R}_0)^2.$$

The log joint posterior distribution is the sum of the log-likelihood and the log prior,

$$L = \log L_1 + \log L_2.$$

The mode of the joint posterior distribution was obtained using the AD Model Builder nonlinear optimization software (Otter Research 1996).

Obtaining posterior distributions using the Markov Chain Monte Carlo algorithm

To estimate F_{MSY} , the marginal posterior distribution of the stock-recruit parameters is needed, obtained by integrating joint posterior distribution with respect to the other parameters. Rather than attempting to evaluate this integral analytically, we used a MCMC algorithm to obtain random samples from the joint distribution. From these samples it is an easy matter to obtain empirical histograms that approximate the marginal distribution of any parameter of interest. The MCMC algorithm generates a Markov chain of random samples (i.e., each sample is conditionally dependent on the preceding sample) whose stationary distribution is the joint posterior distribution. Gelman (1995) provides a good introduction to MCMC

methods, including the Hastings-Metropolis algorithm provided in the AD Model Builder software (see 30 January 1998 <http://otter-rsch.com/cc/cctoc.html> for additional details). Marginal posterior distributions were obtained by subsampling every 200th sample from a chain of length 1,000,000 of the MCMC algorithm after discarding the first 50,000 cycles.

Estimates of F_{MSY}

Let $h_{(C)}$, $R_{0(C)}$ be a sample of the stock-recruit parameters from the joint posterior distribution generated by the MCMC algorithm. For each sample, the equilibrium recruitment $R^{EQ}(p)$ is obtained for a sequence of harvest rates where SPR is reduced to a fraction p of unfished SPR ($p = 1.00, 0.99, 0.98, \dots, 0.10$),

$$R^{EQ}(p) = \max \left(0, R_{0(C)} \frac{0.8 h_{(C)} p - 0.2 (1 - h_{(C)})}{p (h_{(C)} - 0.2)} \right).$$

Some combinations of SPR rate and sampled stock-recruit parameters result in negative equilibrium recruitment, indicating that the SPR rate is not sustainable--hence the use of the *max* function in the above equation.

Equilibrium yield, $Y^{EQ}(p)$, and equilibrium spawning biomass, $S^{EQ}(p)$, at SPR rate p are

$$Y^{EQ}(p) = \eta_p R^{EQ}(p), \text{ and}$$

$$S^{EQ}(p) = p \varphi_0 R^{EQ}(p),$$

where η_p is the yield per recruit when SPR is reduced to a fraction p of unfished SPR.

F_{MSY} can be regarded as the fishing mortality rate at which expected yield is maximized,

$$SPR_{F_{MSY}} = \max_p E(Y^{EQ}(p)).$$

The expected yield at a particular SPR rate is obtained by averaging the equilibrium yield for each of the MCMC samples drawn from the joint posterior distribution. Of course, the relationship of the SPR rate to yield is also of interest, in addition to the point estimates.

Extension to the Ricker stock-recruit curve

Kimura (1988) re-parameterized the Ricker curve in relation to R_0 , the expected recruitment for an unfished stock size of S_0 , and a curvature parameter, α . The Ricker curve with parameters R_0 and α is

$$R = \frac{S}{\varphi_0} \exp \left[\alpha \left(1 - \frac{S}{R_0 \varphi_0} \right) \right].$$

Note that e^α is the potential increase in reproductive success relative to an unfished stock, so that additive changes in α imply multiplicative changes in reproductive success at low stock size. Steepness is not a useful parameter for the dome-shaped Ricker model because recruitment at 20% of unfished biomass can be greater than unfished recruitment (steepness >1). We modeled the similarity of stocks in their response to harvesting by assuming that the curvature parameter for the k th stock was normally distributed,

$$\alpha_k \sim N(\mu, \tau^2).$$

Priors for μ and τ^2 were the same as those developed for the Beverton-Holt curve.

Equilibrium recruitment for the Ricker curve is given by

$$R^{EQ}(p) = \frac{R_0}{p} \left(1 + \frac{\log p}{\alpha} \right).$$

Specification of prior means and variances

Our goal was to integrate the Bayesian approach into the NPFMC tier system, in which proxies for management parameters are for used data-limited stocks, but ideally are replaced by actual estimates as information accumulates. The tier system views this accumulation of information as step process whereby the SSC determines whether the analyses and data are sufficient to elevate the stock to tier 1 management. A Bayesian analysis is a formal process for combining prior knowledge with data, with the data dominating posterior distribution when they are highly informative. We developed priors for β and R_0 that are consistent with proxies used to manage tier 3 stocks, and then obtained posterior distributions to evaluate whether available stock-recruit data support these proxies, or whether other management parameters would be more appropriate for Gulf of Alaska pollock.

Prior for β

The derivation of F35% as a proxy for FMSY is from a theoretical analysis by Clark (1991). Clark initially considered S-R curves the Beverton-Holt and Ricker models that differed by the potential increase in reproductive success (R/S at the origin) relative to an unfished stock (R_0/S_0). Potential increases in reproductive success by factors of 4, 8, and 16 (steepness = 0.50, 0.67, and 0.80, respectively) were considered plausible, while factors of 2 and 32 (steepness = 0.33, and 0.89, respectively) were considered implausible. A prior distribution was generated from these considerations by using a potential increase in reproductive success of 8 ($\beta = 0.34$) as the midpoint of the distribution, and setting the prior variance so that factors 4 and 16 were located at the 10th and 90th percentiles of the distribution (Appendix Table 1).

An alternate prior was based on a meta-analysis of stock-recruit data for many stocks by Myers et al. (1999). For gadids, Myers et al. (1999) obtained a median steepness of 0.79, with upper and lower 90% quantiles of 0.67 and 0.87 respectively using stock-recruit data from 49 stocks.

Prior for R_0

To be consistent with the B40% proxy and the Steller sea lion protection measures biomass threshold of B20%, the prior mean for R_0 was set to average age-2 recruitment for the period 1979-2000 (0.805 billion). Identifying a prior variance is difficult. The variance of mean 1979-2000 recruitment from the assessment model (CV = 0.055) could be considered a lower bound on the uncertainty. For most analyses, we used a prior variance that quadrupled the estimation error (CV = 0.220), but also evaluated prior variances that were larger and smaller. This prior variance implies an uncertainty of plus or minus approximately 40%. We note that because this prior was generated from data (the recruitment estimates), there is some bending of Bayesian principles in this approach. Nevertheless, this approach is in accord with the tier system philosophy of progressing from proxies to estimates of management parameters as additional information becomes available.

Bayesian Model Averaging

Since both Beverton-Holt and Ricker stock-recruit curves were used in this analysis, it would be useful to combine the results from the separate analyses for an overall result. Bayesian model averaging (Hoeting et al. 1999) allows uncertainty in the choice of the appropriate model to be included formally in posterior distributions of management parameters. This is particularly important when the results differ depending on which model is used. For some parameter of interest Δ , the posterior distribution given the data D is

$$pr(\Delta | D) = \sum_{k=1}^K pr(\Delta | M_k, D) pr(M_k | D)$$

where M_1, \dots, M_K are the models under consideration. This is simply a weighted average of the posterior distributions, with the weights given by the posterior model probability,

$$pr(M_k | D) = \frac{pr(D | M_k) pr(M_k)}{\sum_{l=1}^K pr(D | M_l) pr(M_l)}$$

where

$$pr(D | M_k) = \int pr(D | \theta_k, M_k) pr(\theta_k | M_k) d\theta_k$$

is the posterior model probability, or integrated likelihood. Equal prior probabilities for the Beverton-Holt and the Ricker models were assumed, $pr(\text{Beverton-Holt}) = pr(\text{Ricker}) = 0.5$. Posterior model probabilities were obtained by averaging a sample of likelihood values from the posterior generated with MCMC. Because a large number of samples are usually needed to obtain a good estimate, we ran the MCMC chain out to 10,000,000 for this exercise. However, nearly identical results were obtained using the Laplace approximation of the mode of the posterior density.

Results

Fits of the Beverton-Holt and Ricker models to the stock-recruit estimates were similar (Fig. 33). The Ricker curve is slightly dome-shaped, and has a slightly lower slope at the origin than the Beverton-Holt curve. Estimates of R_0 were within 5% for the two models (Appendix Table 2).

Posterior distributions of β for the Beverton-Holt curve and α for the Ricker curve are only marginally narrower than the priors, indicating that the S-R estimates for Gulf of Alaska pollock are not very informative about the shape of the S-R curve (Fig. 34). For the Beverton-Holt curve, the distribution of steepness parameter β is shifted upwards slightly, indicating higher resilience than the prior, while for the Ricker curve, the distribution of slope parameter α is shifted downwards slightly, implying lower resilience.

Posterior distributions of R_0 for both the Beverton-Holt and the Ricker model are shifted upwards from the prior mean (Fig. 35). Sensitivity analyses indicate that the results are strongly dependent on the priors used, as would be expected with uninformative data. For the Myers et al. (1999) prior for steepness, the posterior mean of steepness increases from 0.70 for the base model to 0.78. For R_0 , increasing the variance of the prior allows R_0 to increase, whereas, predictably, the posterior mean is closer to the prior mean when the prior variance is reduced (Appendix Table 2).

Posterior model probabilities were 0.47 and 0.53 for the Beverton-Holt and the Ricker models, respectively, indicating that the data nearly equally consistent with the Beverton-Holt and the Ricker models, with a slight preference for the Ricker model. For marine species, cannibalism is often invoked as a rationale for a dome-shaped S-R relationship. Cannibalism appears to be less important in pollock population dynamics in the Gulf of Alaska, as opposed to the Eastern Bering Sea. However, diet data are not available during the years of peak pollock abundance in the 1980s, so cannibalism could play a stronger role than currently recognized.

For the base model, expected yield was maximized at F35% for both the Beverton-Holt curves and Ricker curves. Expected yield is extremely flat in the range of F25%-F50%, suggesting at least 80% of the expected maximum yield could be obtained by fishing mortality rates in this range (Fig. 36). For the prior derived from the Myers et al. (1999) meta-analysis for gadid stocks, expected yield was maximized at F29%, which is a fishing mortality rate approximately 25% higher than F35%. This suggests that the F_{MSY} proxy of F35% used in the North Pacific is a relatively low harvest rate to achieve MSY for gadids in general.

Although the Beverton-Holt and Ricker curves are similar, there are significant differences between the two models in the population response to harvesting. The Ricker model produces estimates of expected yield that are higher, and maximum occurs at a higher stock size in comparison to the Beverton-Holt curve (Fig. 37). The two models also produce different estimates of equilibrium stock size when fishing at F40% (Fig. 38). For the Beverton-Holt model, equilibrium stock size is approximately 32% of unfished abundance, while for the Ricker model, equilibrium stock size is 46% of unfished abundance. For the Bayesian model average, equilibrium stock size is 39% of unfished stock size. However, the distribution of equilibrium stock is bi-modal, and the average of the distribution is located in valley between the two modes.

Some Tentative Conclusions

Based on the Bayesian stock recruit analysis, F35% appears to be an appropriate proxy for FMSY for Gulf of Alaska pollock. Stock recruit data are relatively uninformative, but do not suggest that that this stock has a low steepness that would make F35% too aggressive. If pollock is typical of gadids elsewhere, FMSY could be at a considerably higher fishing mortality rate.

The use of average biomass when fishing at F40%, B40%, also appears to be appropriate as an inflection point in the harvest control rule, as long as it is understood that the B40% is not intended to be an estimate of 40% of unfished stock size. For posterior means using the Beverton-Holt model, B40% occurs at approximately 30% of unfished stock size, while for the Ricker model, B40% occurs at

approximately 46% of unfished stock size. Since both the Ricker and Beverton-Holt models are empirical models, it should not be surprising if nature does not correspond to either model. Nevertheless, as the stock comes into equilibrium with the North Pacific harvest policy, some drift in the estimates of B40% should be anticipated.

The other important management parameter in the pollock harvest control rule is B20% (which unlike B40% is explicitly intended to be an estimate of 20% of unfished stock size). For the short time that this feature of the pollock harvest control rule has been in place, the same approach has been used estimate B20% as has been used for B40%. The posterior mean estimate of unfished stock size (and B20%) is approximately 13% higher than estimate currently used, but these results are highly dependent on the prior. If the Bayes posterior mean is used to estimate B20%, the current estimate of B20% would be actually be B17.7%. The expected ratio of equilibrium recruitment when fishing at F40% to unfished recruitment is 80% for the Beverton-Holt model, 116% percent for the Ricker model, and 99% for the posterior model average. This suggests that current empirical method of estimating B20% should converge over time to a value between the true B16% and B23%.

Estimates of unfished stock size based on recruitment estimates (both the empirical approach and the Bayesian analysis) are strongly influenced by the pollock outburst in the 1970s, when six strong year classes recruited to the population. It is unclear whether these events are likely to occur once in fifty years, or once in two hundred years. Another approach to estimating unexploited stock size is to use abundance prior to exploitation, as is usually done in marine mammal assessments. Mean spawning stock in the first decade of the stock assessment (1961-70), when exploitation was low, is estimated to be approximately 90% of 2003 stock size. While this estimate is perhaps unrealistic, it does demonstrate the advantage of using the current empirical method, which is simple to calculate, unlikely to be too badly biased in the long-term, and has built-in convergence properties as the full range of environmental variability is sampled.

Estimates of stock depletion

In the North Pacific, unfished stock size is usually estimated by multiplying mean recruitment since 1977 by the spawning biomass per recruit in the absence of fishing. The break at 1977 recognizes the shift in the PDO (Pacific decadal oscillation) that occurred in 1977. Some researchers have identified subsequent regime shifts, i.e., in 1989 and 1998 (Hare and Mantua 2000), but there is no general agreement about these regime shifts. The use of post-1977 mean recruitment is problematic for GOA pollock because they do not appear to respond to PDO-scale variation (Hollowed et al. 2001). Although the 1970s was a decade of strong recruitment for GOA pollock, four out the seven strong year classes (> 1.0 billion age-2 recruit) in the 1970s occurred prior to 1977. Recruitment success ($\log(R/S)$) for pollock in the Gulf of Alaska was average in 1960s, high in 1970s, and low in the 1980s and 1990s (Dorn et al. 2001).

Pollock was estimated to be 23% of unfished stock size in 2003 when using an estimate of unfished stock size based on post-1977 mean. An important question is why stock abundance is at this level if pollock have been consistently harvested at less than FMSY. We address this question by exploring an alternative estimate of unfished stock size obtained by “replaying” the population dynamics without fishing. The simplest approach is to replay the population dynamics with the same recruitment time series. For example, mean virtual unfished spawning biomass since 1977 for GOA pollock is nearly equivalent to B_{zero} obtained by multiplying mean recruitment during that time period by the spawning biomass per recruit without fishing (Appendix Table 3). A depletion estimate can then be obtained by taking the ratio of the model estimate of current biomass to virtual unfished biomass (Fig. 39). This estimate, unlike the conventional estimate, implicitly takes into account environmental trends that affect stock productivity. Both the conventional estimate of depletion and this estimator do not take into account the potential impact of fishing on recruitment due to changes in stock biomass (potentially fewer recruits at low stock

size, or more cannibalism at high stock size).

To evaluate these potential impacts, we also replayed the stock dynamics with a rescaled recruitment time series based on a stock-recruit relationship,

$$R^* = R_{Est} \left[\frac{E(R|S_{unfished})}{E(R|S_{fished})} \right]$$

where R^* is the recruitment used to replay the stock dynamics, R_{Est} is the recruitment estimate from the stock assessment, and $E(R/S_{unfished})$ is the expected recruitment based the stock recruit curves estimated in the previous section. With this estimator, the increase in spawning biomass without fishing produces changes in year-class strength, but the same pattern of recruitment variability is retained (Fig. 40).

Estimates of stock depletion range in 2002 from 43.5% when the original recruitment estimates are used to 40.1% when the Beverton-Holt curve is used with posterior mean parameter values, and to 46.4% when the Ricker curve used (Fig. 41). All of these estimates are substantially higher than the current proxy for BMSY of B35%. It is clear that significant decline of pollock abundance from the peak in the 1980 would have occurred without fishing. One advantage of this approach is that it is possible to explicitly compare alternative hypotheses for the current level of stock abundance. For example, for the stock to be below 35% of unfished stock size, steepness would have to be 0.47, i.e., lower than the lowest value considered plausible by Clark (1991). These analyses suggest that environmental variability is the most likely explanation for current low level of stock abundance. While it is possible that Gulf of Alaska pollock may have a stock-recruit relationship with extremely low steepness, the stock-recruit data for Gulf of Alaska pollock suggest that this has relatively low probability ($p(\text{steepness} < 0.47) = 0.02$ for the Bayes model average).

Models with changing juvenile mortality

For this analysis, the assessment model was modified to include age-1 pollock, and estimates of survey numbers at age one and fishery catch at age one were included in the model. Independent selectivity coefficients were estimated for the age one fish for the Shelikof Strait EIT survey and the NMFS bottom trawl survey instead of the double-logistic curves used to model selectivity for the older ages. We modeled age-specific natural mortality m_a as

$$m_a = m + (m_1 - m)e^{(-\lambda(a-1))}$$

where m_1 is the natural mortality of age-1 pollock and λ controls the speed at which m_1 approaches m (Fig. 42). All analyses were based on a fixed value of $m = 0.3$, consistent with the standard assessment model. We developed priors for m_1 and λ based on the mortality schedule used in the Eastern Bering Sea pollock assessment model, where $m_1 = 0.9$, $m_2 = 0.45$, and $m_{3+} = 0.3$, but made our priors sufficiently broad to reflect the uncertainty in the EBS values and their questionable applicability to Gulf of Alaska pollock (Fig. 43). Annual changes in juvenile mortality were included by modeling m_1 with random walk process error. The year-specific value of $\log(m_1)$ is given by

$$\log(m_{1i}) = \gamma + \delta_i$$

where γ is the log mean, and δ_i is an annual deviation in year i subject to the constraint $\sum \delta_i = 0$. For a random walk where annual *changes* are normally distributed, the log-likelihood is

$$\log L = \sum \frac{(\delta_i - \delta_{i+1})^2}{2\sigma_i^2}$$

where σ_i is the standard deviation of the annual change in the parameter. Setting the σ_i to different values controls how much m_1 can change from one year to the next. We fixed σ_i to a low value (0.0005) prior to the start of NMFS bottom trawl surveys in 1984, and evaluated different values of σ_i for the post-1984 period ($\sigma_i = 0.015, 0.030, 0.060$).

This model for juvenile mortality has a number of advantages. Anchoring the upper end of the mortality curve to a fixed value of m gives the model the stability enjoyed by conventional fixed- M assessment models. Adult pollock have greater ability to avoid predation than juveniles, so it seems reasonable that their natural mortality would be relatively stable over time. Diet data indicate the dominant piscivores in the Gulf of Alaska (principally Arrowtooth flounder) consume mostly juvenile pollock (Fig. 44). The goal of this simple approach is to model the impact of ecosystem changes, primarily changes in predator abundance, without delving into complexities of splitting out individual predatory populations, or modeling the details of age-specific predation.

Estimates of mean age-specific mortality are similar to the Eastern Bering Sea pollock assessment at age one, but show a more gradual decline towards 0.3 (Fig. 45). Estimated mean age-specific mortalities are broadly consistent with those estimated by Hollowed et al. (2000) in a model for Gulf of Alaska pollock including predators, but the natural mortality of older fish is higher (~ 0.4) in Hollowed et al. (2000). Comparison of models with different assumptions for the post-1984 standard deviation for random walk process error, σ_i , all show a slight dip in the late 1980s followed by sharp increase in the 1990s (Fig. 46). The magnitude of the increase is strongly dependent on how large σ_i is assumed to be.

Compared to the base model, including age-1 fish in the model and modeling annual changes in juvenile mortality have relatively minor effects on estimates of female spawning biomass (Fig 47). Spawning biomass is approximately 10% higher until the mid-1990s, after which the spawning biomass is nearly identical. Estimates of year class abundance are much higher. Recruitment at age one is approximately 3.5 times higher than at age two for the base model for most of the modeled period, then increases to 4 times higher beginning in the 1990s (Fig. 47).

To assess the potential management implications of an increase in juvenile mortality, we contrasted two simple extensions to spawning biomass per recruit theory, which assumes a constant natural mortality rate over time. When natural mortality varies from one year to the next, an F40% harvest rate can be based on either on the current estimate of natural mortality, or on the long-term average. Calculating F40% using the current estimate of natural mortality is straightforward, but is unlikely to change ABC recommendations because an increase in juvenile mortality does not influence the tradeoff between the harvest of adults and their reproductive output. If long-term average is considered appropriate, a change in juvenile mortality means that an average recruit will no longer produce 40% of unfished spawning output as it would under average conditions. Increases in juvenile mortality would require the harvest rate to be shifted downwards, while a decrease in juvenile mortality could allow an increase in the harvest rate.

A comparison of these two approaches is given in Figure 48. As expected, the annual estimates of F40%

using the year-specific mortality curves are nearly identical to F40% calculated on the basis of the mean mortality rate, even though the actual amount of spawning output produced per recruit changes substantially. In contrast, the alternative of keeping the spawning output per recruit constant at 40% the unfished rate results in a decline in the fishing mortality rate as juvenile mortality increases in 1990s, with the magnitude of the decrease depending of how much juvenile mortality has increased. For a $\sigma_i = 0.030$, the F40% harvest rate is reduced by 29%, while for $\sigma_i = 0.015$ and $\sigma_i = 0.060$ the F40% harvest is reduced by 8% and 60% respectively.

Although we have not brought trends in the abundance of predatory species into the analysis, other research that included these trends also suggests an increase in juvenile pollock mortality (Hollowed et al. 2000, Bailey 2000). The model developed here is based only on survey and fishery data and arrives at a similar result. We consider the model at a preliminary stage of development, and anticipate further development of this approach in future stock assessments. The merits of maintaining constant spawning output per recruit in a changing ecosystem (i.e., the second approach developed above) have not been fully explored, however this approach may offer additional protection to a population subject to increased risk from other components of the ecosystem.

Appendix Table 1. Prior values used in a Bayesian analysis of Gulf of Alaska stock-recruit data.

| S-R model | Prior | β or α mean | β or α st. dev. | R_0 mean | R_0 CV |
|------------------------|--|--------------------------|------------------------------|------------|----------|
| Beverton-Holt | Base | 0.34 | 0.63 | 0.805 | 0.220 |
| Beverton-Holt | Low R_0 variance | 0.34 | 0.63 | 0.805 | 0.110 |
| Beverton-Holt | High R_0 variance | 0.34 | 0.63 | 0.805 | 0.440 |
| Beverton-Holt | Myers et al. (1999) prior for Gadids | 1.00 | 0.76 | 0.805 | 0.220 |
| Ricker | Base | 2.079 | 0.54 | 0.805 | 0.220 |
| Bayes model average | Base assumptions for Beverton-Holt and Ricker models | | | | |

Appendix Table 2. Posterior means of S-R and management parameters for a Bayesian analysis of Gulf of Alaska pollock stock-recruit data. For the Ricker model, the reported steepness is given by $h = \exp(\alpha)/(\exp(\alpha) + 4)$, which is the steepness of a B-H curve with the same slope at the origin as the Ricker curve. F_{MSY} is defined as the fishing mortality rate at which expected yield is maximized, considering uncertainty in the S-R relationship.

| S-R model | Prior | Steepness | R_0 (billion) | Percent SPR at FMSY | Unfished stock size (million t) | Percent unfished stock size at FMSY | Percent unfished stock size at F40% |
|---------------------|--------------------------------------|-----------|-----------------|---------------------|---------------------------------|-------------------------------------|-------------------------------------|
| Beverton-Holt | Prior | 0.67 | 0.805 | 38% | 0.601 | 27.3% | 29.6% |
| Beverton-Holt | Base | 0.70 | 0.932 | 35% | 0.695 | 26.1% | 31.8% |
| Beverton-Holt | Low R_0 variance | 0.70 | 0.853 | 34% | 0.636 | 25.5% | 32.3% |
| Beverton-Holt | High R_0 variance | 0.68 | 1.062 | 37% | 0.792 | 27.6% | 31.0% |
| Beverton-Holt | Myers et al. (1999) prior for Gadids | 0.78 | 0.916 | 29% | 0.683 | 22.7% | 34.7% |
| Ricker | Prior | 0.67 | 0.805 | 26% | 0.601 | 32.4% | 52.7% |
| Ricker | Base | 0.59 | 0.890 | 35% | 0.664 | 38.3% | 46.1% |
| Bayes model average | Prior | 0.67 | 0.805 | 30% | 0.601 | 28.5% | 41.1% |
| Bayes model average | Base | 0.64 | 0.911 | 35% | 0.680 | 32.6% | 39.3% |

Appendix Table 3. Gulf of Alaska pollock age 3+ (000,000 tons) and female spawning biomass (000,000 tons) from the 2002 stock assessment (model estimates) and virtual biomass obtained by “replaying” the population dynamics with the same recruitment estimates but without fishing. The ratio is an estimate of stock depletion (model estimate/virtual biomass without fishing).

| Year | 3+ biomass | | | Female spawning biomass | | | Catch (tons) |
|---------------------|-----------------|----------------------------|-------|-------------------------|----------------------------|-------|--------------|
| | Model estimates | Zero catch virtual biomass | Ratio | Model estimates | Zero catch virtual biomass | Ratio | |
| 1961 | 0.371 | 0.371 | 100% | 0.079 | 0.079 | 100% | |
| 1962 | 0.448 | 0.448 | 100% | 0.090 | 0.090 | 100% | |
| 1963 | 0.534 | 0.534 | 100% | 0.104 | 0.104 | 100% | |
| 1964 | 0.621 | 0.621 | 100% | 0.123 | 0.123 | 100% | 1,126 |
| 1965 | 0.599 | 0.600 | 100% | 0.144 | 0.144 | 100% | 2,749 |
| 1966 | 0.586 | 0.591 | 99% | 0.156 | 0.158 | 98% | 8,932 |
| 1967 | 0.538 | 0.554 | 97% | 0.155 | 0.162 | 96% | 6,276 |
| 1968 | 0.547 | 0.569 | 96% | 0.147 | 0.156 | 94% | 6,164 |
| 1969 | 0.593 | 0.619 | 96% | 0.141 | 0.152 | 92% | 17,553 |
| 1970 | 0.709 | 0.754 | 94% | 0.138 | 0.155 | 89% | 9,343 |
| 1971 | 0.740 | 0.790 | 94% | 0.153 | 0.172 | 89% | 9,458 |
| 1972 | 0.852 | 0.904 | 94% | 0.171 | 0.192 | 89% | 34,081 |
| 1973 | 1.133 | 1.210 | 94% | 0.188 | 0.218 | 86% | 36,836 |
| 1974 | 1.339 | 1.438 | 93% | 0.221 | 0.260 | 85% | 61,880 |
| 1975 | 2.160 | 2.304 | 94% | 0.275 | 0.327 | 84% | 59,512 |
| 1976 | 2.291 | 2.473 | 93% | 0.381 | 0.446 | 85% | 86,527 |
| 1977 | 2.091 | 2.354 | 89% | 0.481 | 0.570 | 84% | 118,356 |
| 1978 | 2.247 | 2.577 | 87% | 0.524 | 0.645 | 81% | 96,935 |
| 1979 | 2.728 | 3.098 | 88% | 0.531 | 0.668 | 80% | 105,748 |
| 1980 | 3.183 | 3.598 | 88% | 0.584 | 0.732 | 80% | 114,622 |
| 1981 | 3.833 | 4.294 | 89% | 0.474 | 0.589 | 80% | 147,744 |
| 1982 | 3.964 | 4.500 | 88% | 0.542 | 0.669 | 81% | 168,740 |
| 1983 | 3.344 | 3.908 | 86% | 0.707 | 0.876 | 81% | 215,608 |
| 1984 | 2.704 | 3.357 | 81% | 0.749 | 0.988 | 76% | 307,401 |
| 1985 | 1.992 | 2.796 | 71% | 0.642 | 0.962 | 67% | 284,826 |
| 1986 | 1.602 | 2.594 | 62% | 0.588 | 0.999 | 59% | 87,809 |
| 1987 | 1.679 | 2.563 | 66% | 0.487 | 0.860 | 57% | 69,751 |
| 1988 | 1.594 | 2.371 | 67% | 0.392 | 0.711 | 55% | 65,739 |
| 1989 | 1.447 | 2.172 | 67% | 0.355 | 0.611 | 58% | 78,392 |
| 1990 | 1.234 | 1.862 | 66% | 0.384 | 0.657 | 58% | 90,744 |
| 1991 | 1.370 | 1.935 | 71% | 0.347 | 0.605 | 57% | 100,488 |
| 1992 | 1.723 | 2.243 | 77% | 0.291 | 0.500 | 58% | 90,857 |
| 1993 | 1.577 | 2.070 | 76% | 0.329 | 0.528 | 62% | 108,908 |
| 1994 | 1.331 | 1.813 | 73% | 0.385 | 0.589 | 65% | 107,335 |
| 1995 | 1.123 | 1.605 | 70% | 0.356 | 0.555 | 64% | 72,618 |
| 1996 | 0.929 | 1.362 | 68% | 0.326 | 0.511 | 64% | 51,263 |
| 1997 | 0.934 | 1.313 | 71% | 0.282 | 0.459 | 61% | 90,130 |
| 1998 | 0.836 | 1.179 | 71% | 0.214 | 0.382 | 56% | 125,098 |
| 1999 | 0.650 | 1.021 | 64% | 0.191 | 0.366 | 52% | 95,590 |
| 2000 | 0.566 | 0.967 | 59% | 0.173 | 0.351 | 49% | 73,080 |
| 2001 | 0.589 | 0.997 | 59% | 0.164 | 0.359 | 46% | 72,076 |
| 2002 | 1.130 | 1.517 | 75% | 0.142 | 0.325 | 44% | 51,936 |
| Bzero (mean recr.) | | 1.895 | | | 0.600 | | |
| Average (1979-2002) | | 2.297 | | | 0.619 | | |

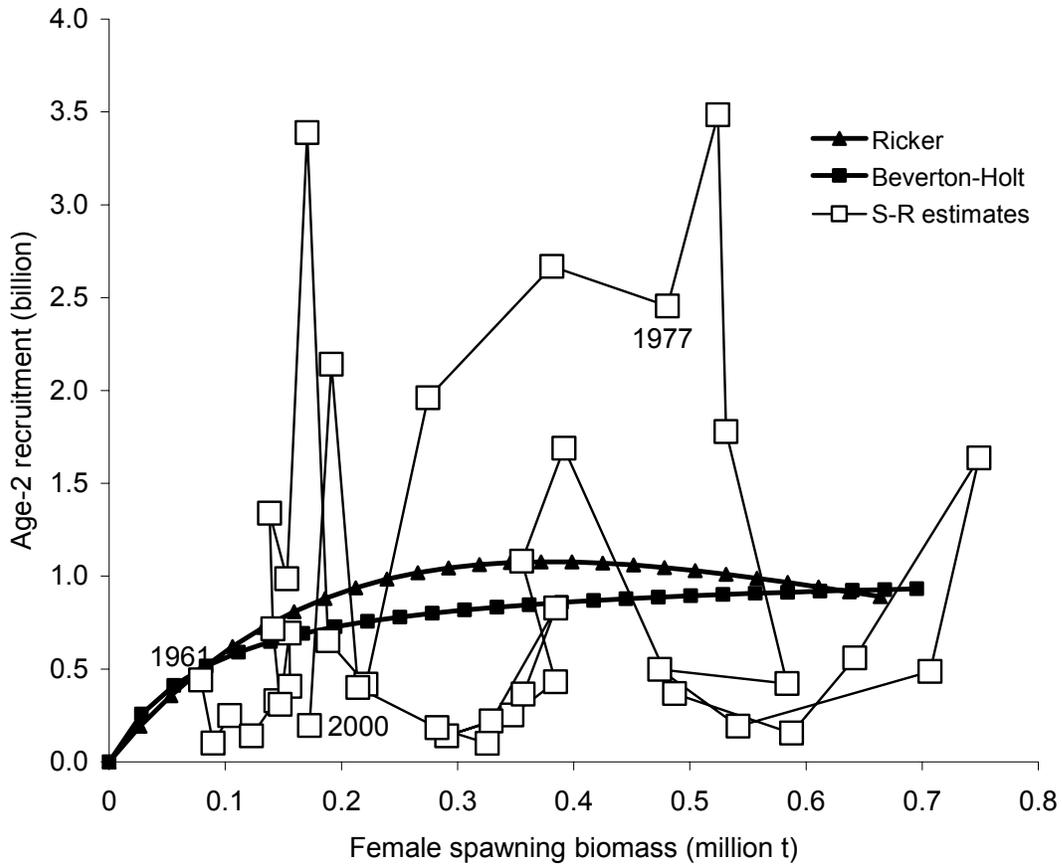
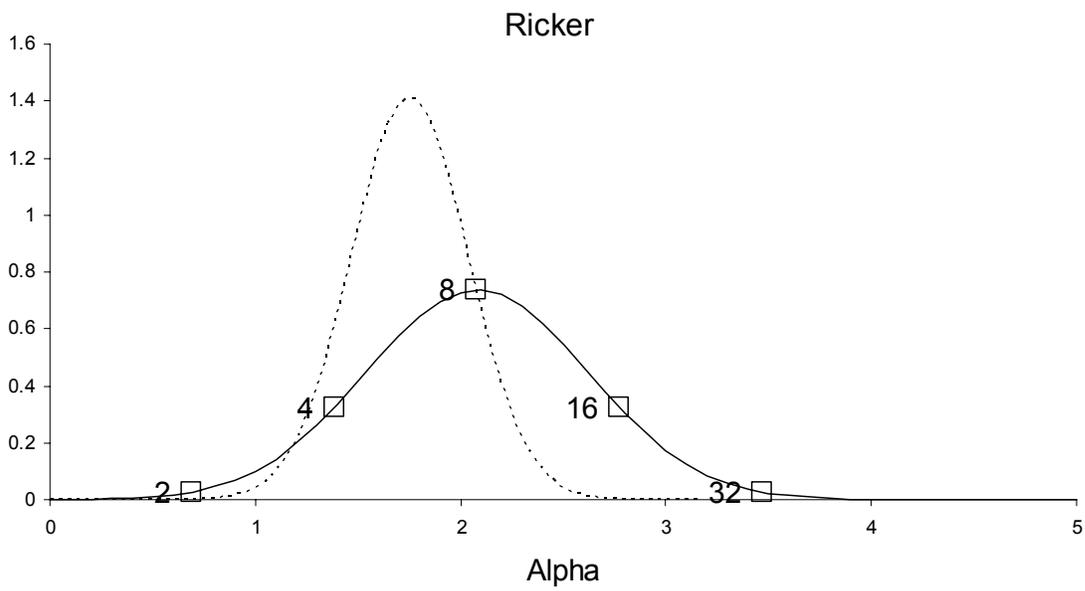
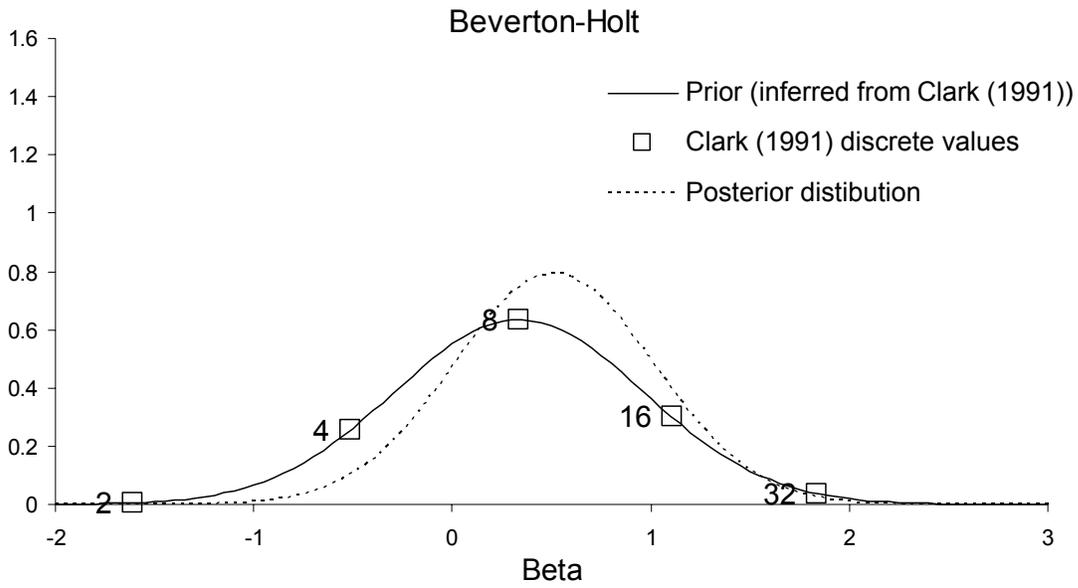


Figure 33. Gulf of Alaska pollock stock-recruit estimates, and mean stock-recruit curves based on posterior parameter means for Beverton-Holt and Ricker models.



Figure

34. Prior and posterior distributions of β (logit-transformed steepness) for the Beverton-Holt curve (top) and α for the Ricker curve (bottom).

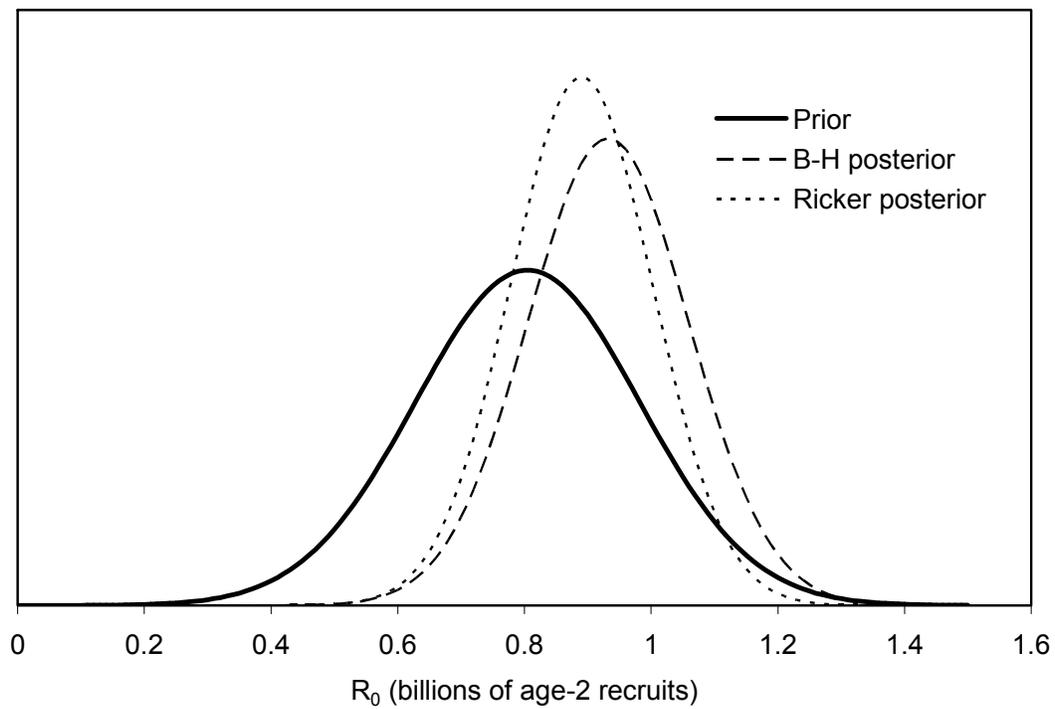


Figure 35. Prior and posterior distributions of R_0 for the Beverton-Holt and Ricker curves.

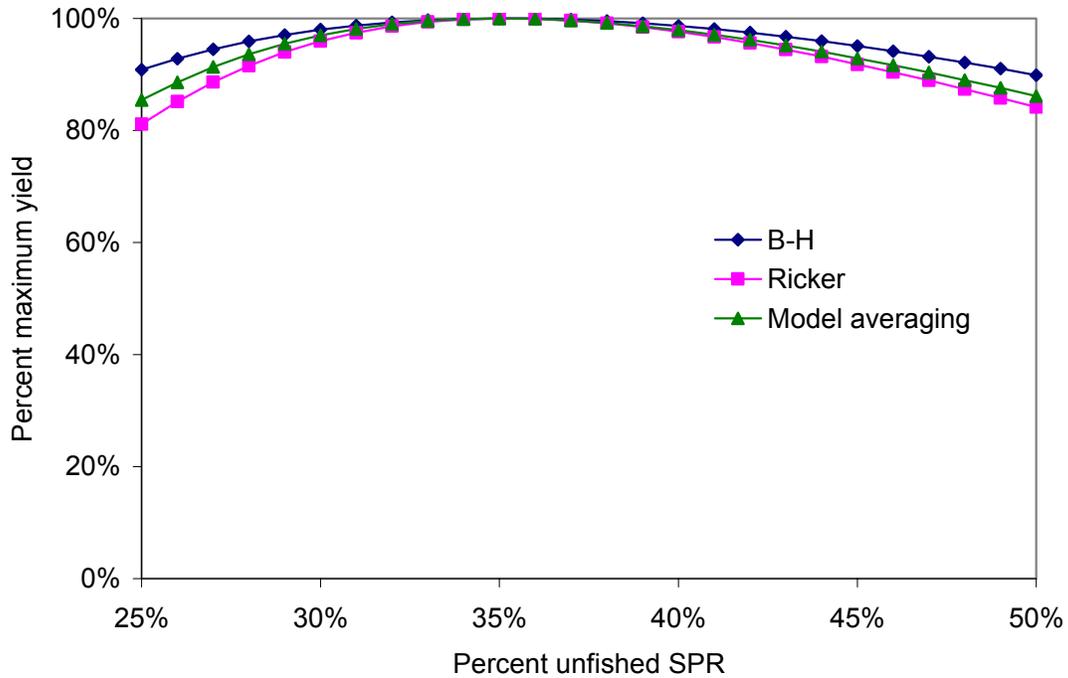


Figure 36. Percent of expected maximum yield as a function of F_{SPR} harvest rates between F25% and F50% based on MCMC samples from the posterior distribution.

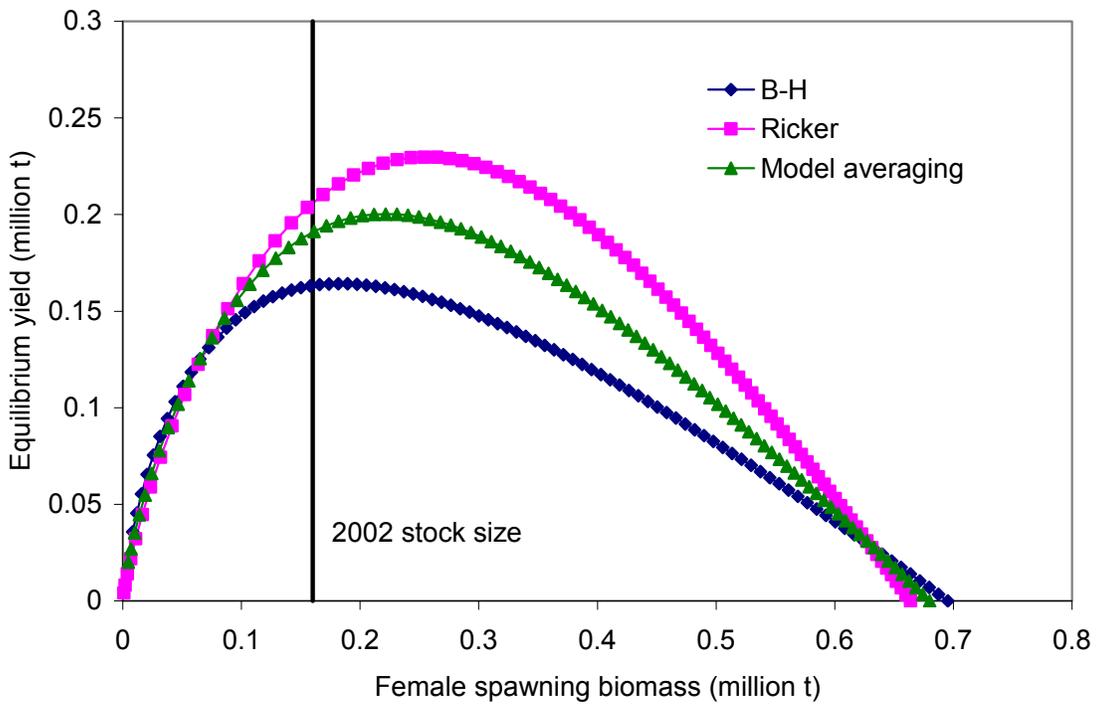


Figure 37. Equilibrium yield as a function of equilibrium spawning biomass based on MCMC samples from the posterior distribution.

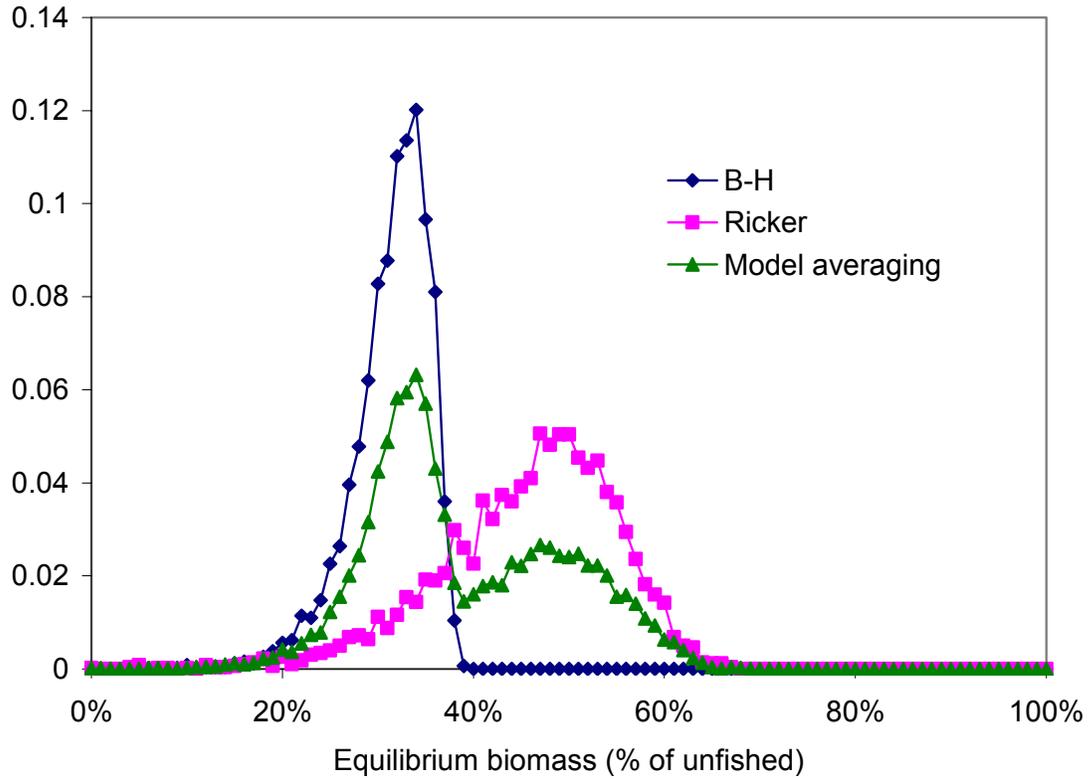


Figure 38. Posterior distribution of equilibrium biomass when fishing at F40% for Beverton-Holt and Ricker curves based on MCMC sampling from the posterior distribution.

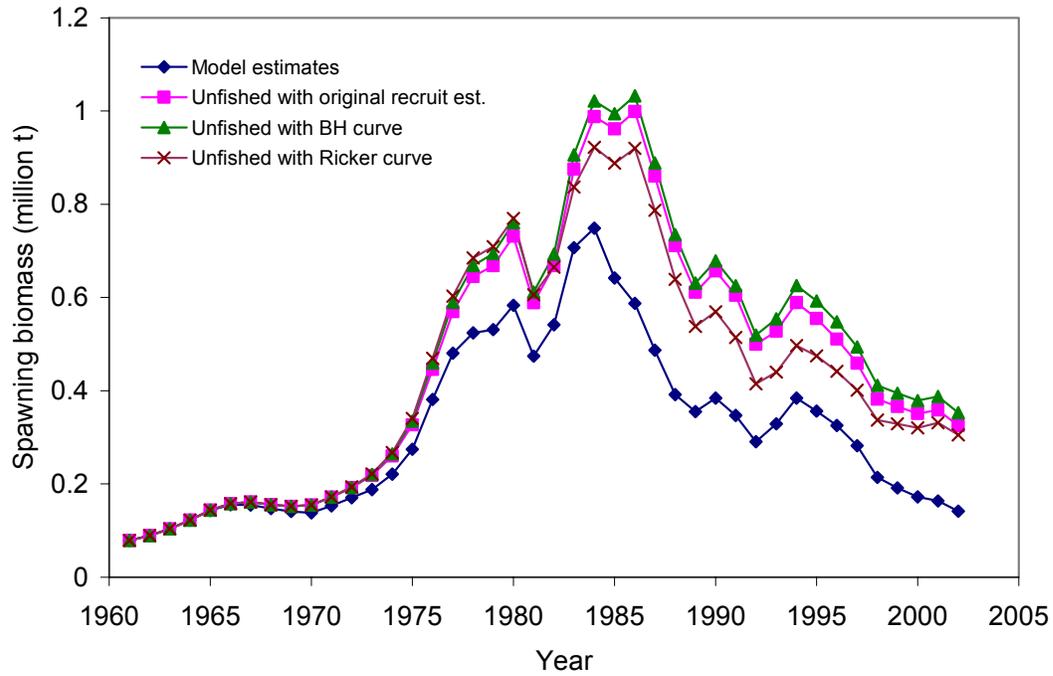


Figure 39. Female spawning biomass trajectories for simulated unfished populations of Gulf of Alaska pollock.

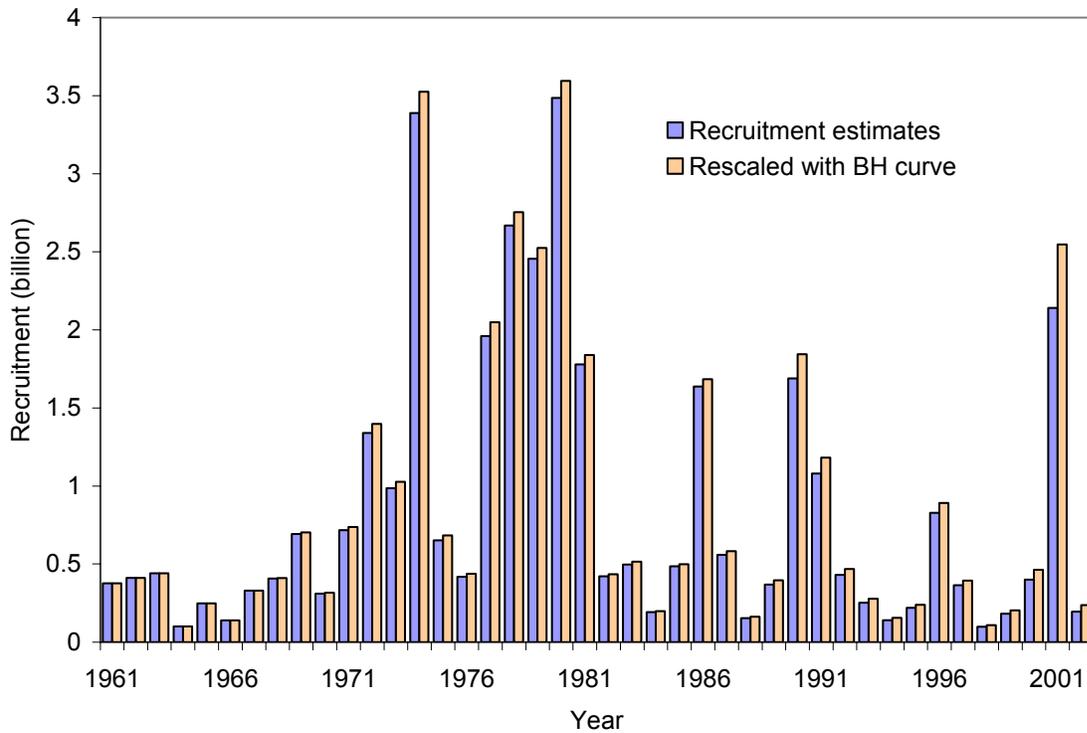


Figure 40. Comparison of original recruitment estimates and rescaled recruitments for a Beverton-Holt curve used to simulate an unfished stock.

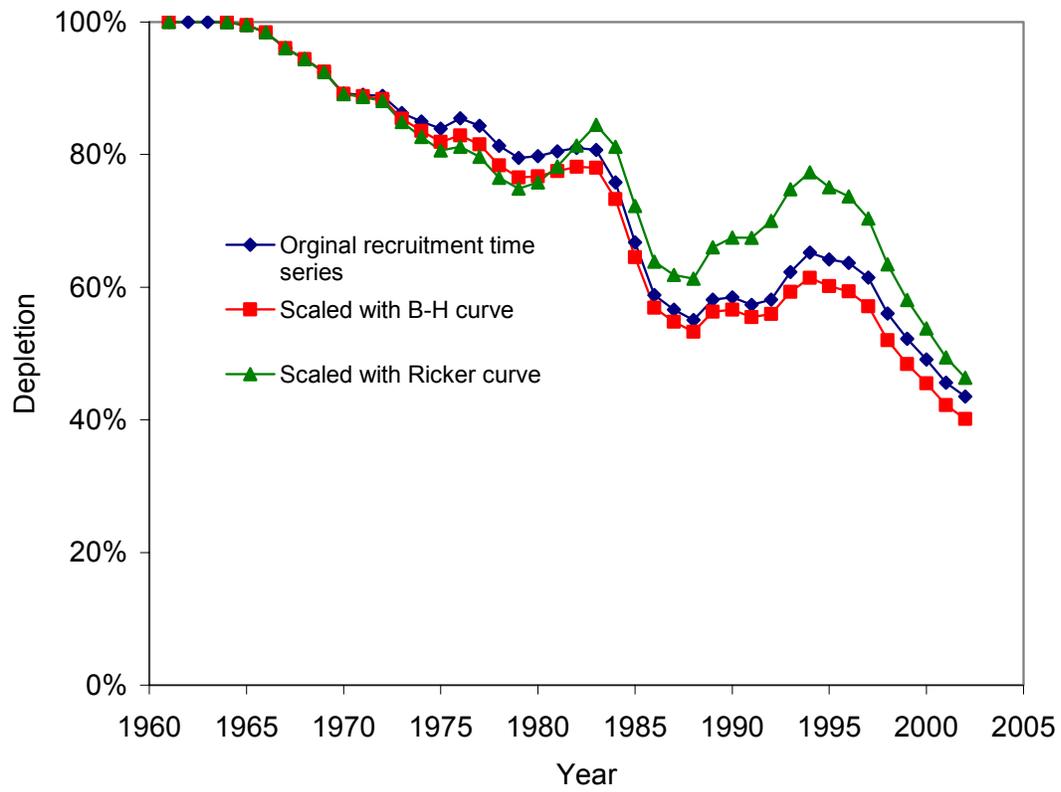


Figure 41. Gulf of Alaska pollock spawning biomass depletion ($B_{\text{current}}/\text{virtual unfished biomass}$) estimated by replaying stock dynamics without fishing.

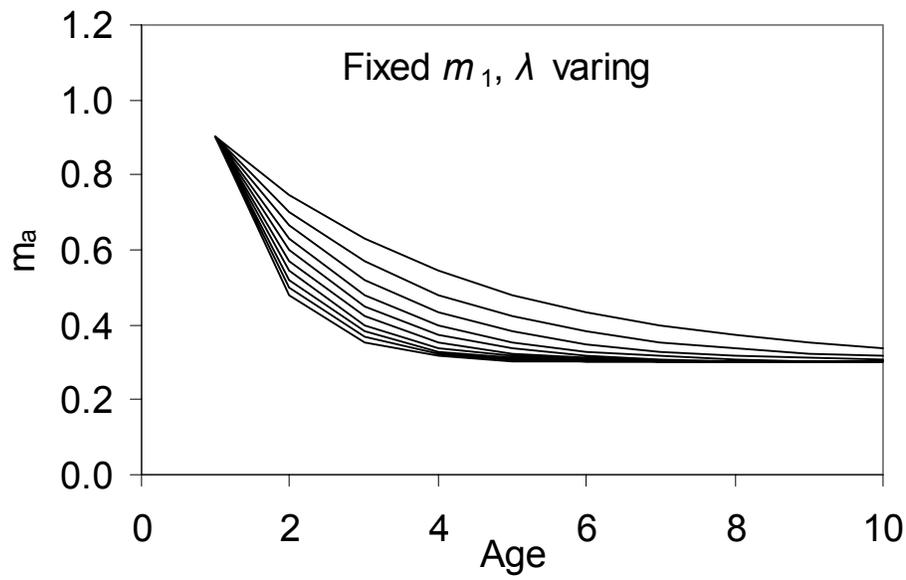
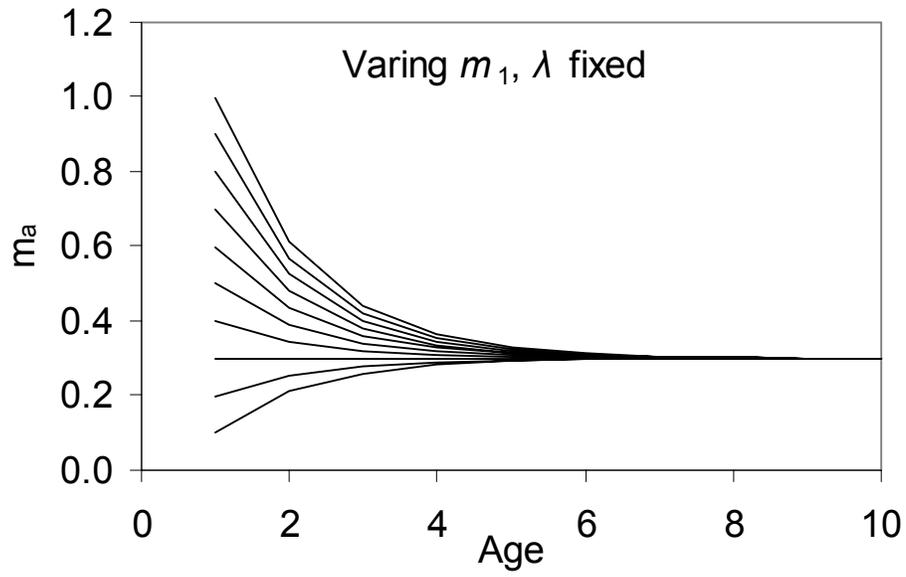


Figure 42. Families of curves obtained by varying the parameters of the juvenile mortality model.

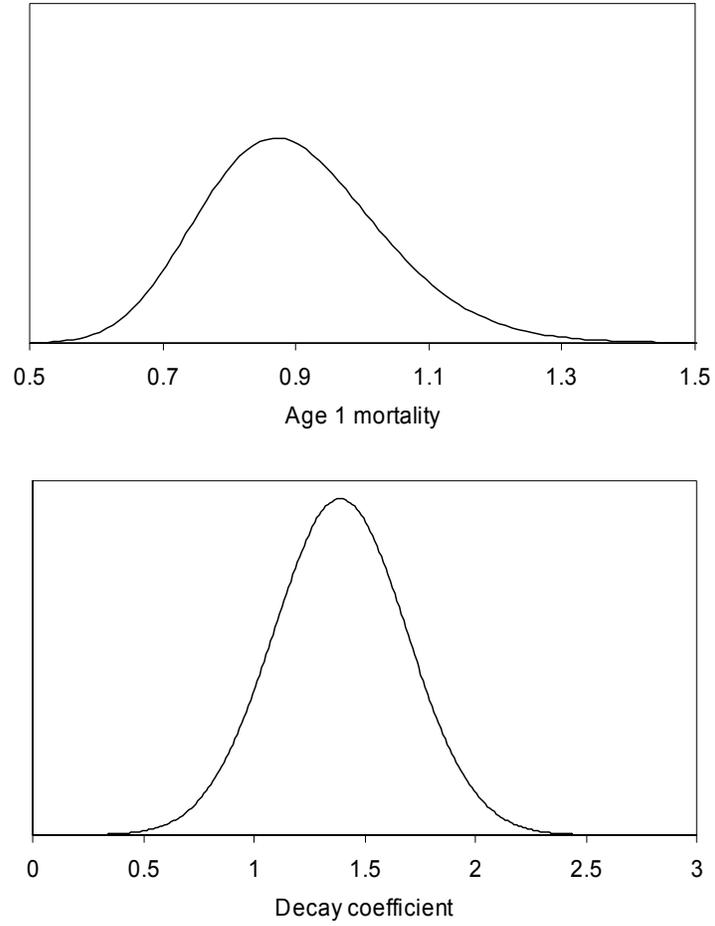


Figure 43. Priors for age-1 mortality m_1 (top) and the coefficient controlling the speed at which m_1 approaches m (λ) for the juvenile mortality model (bottom).

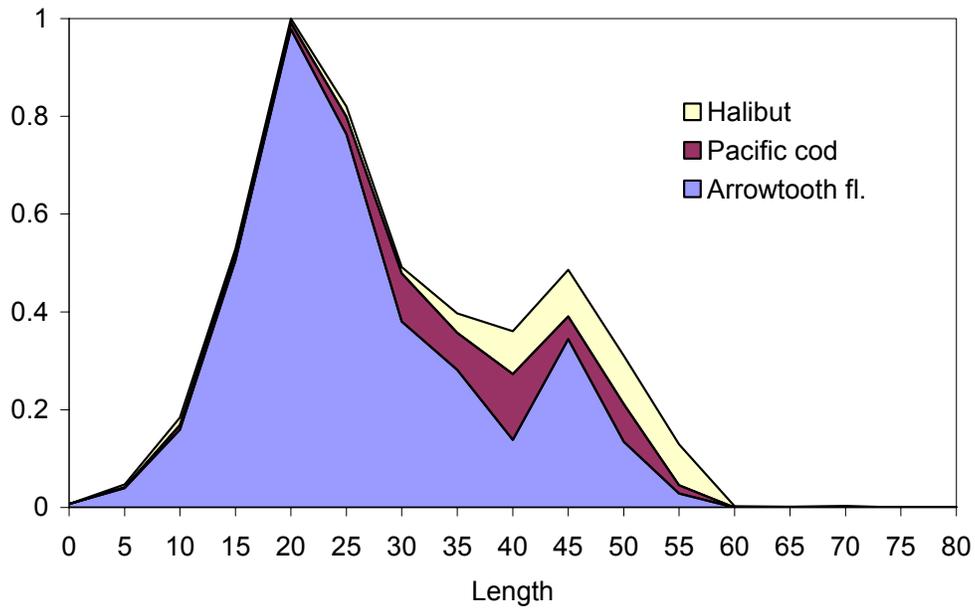


Figure 44. Relative consumption of pollock by 5 cm length class by dominant piscivores in the Gulf of Alaska. Estimates are based on stomach content data and survey biomass estimates for NMFS bottom trawl surveys in 1996 and 2001.

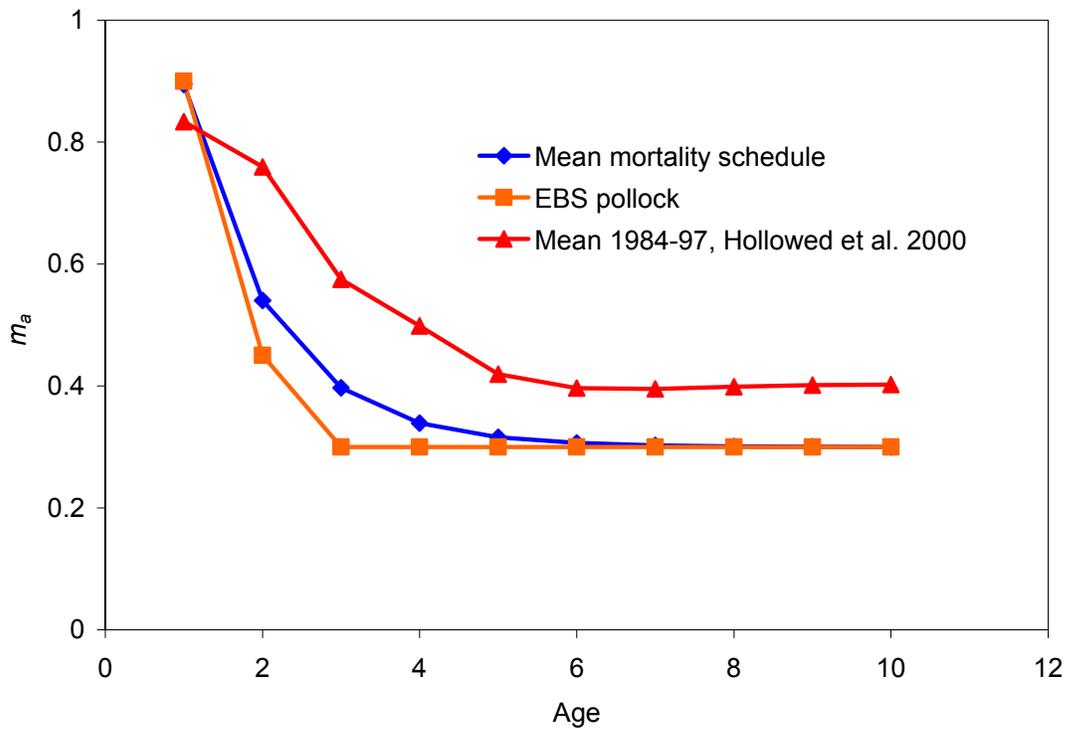


Figure 45. Mean age-specific natural mortality for a model with varying juvenile mortality compared to the mortality vector for EBS pollock and the 1984-97 average from the Hollowed et al. (2000) predation model.

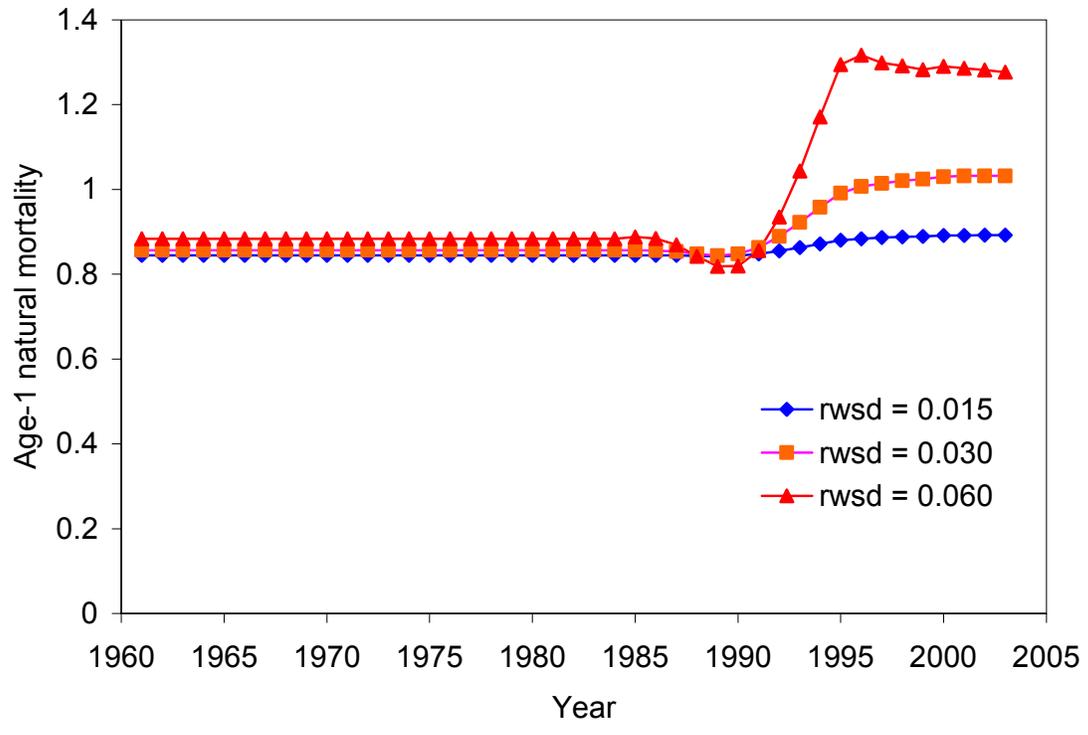


Figure 46. Annual estimates of age-1 natural mortality for models with different assumptions for post-1984 random walk standard deviation.

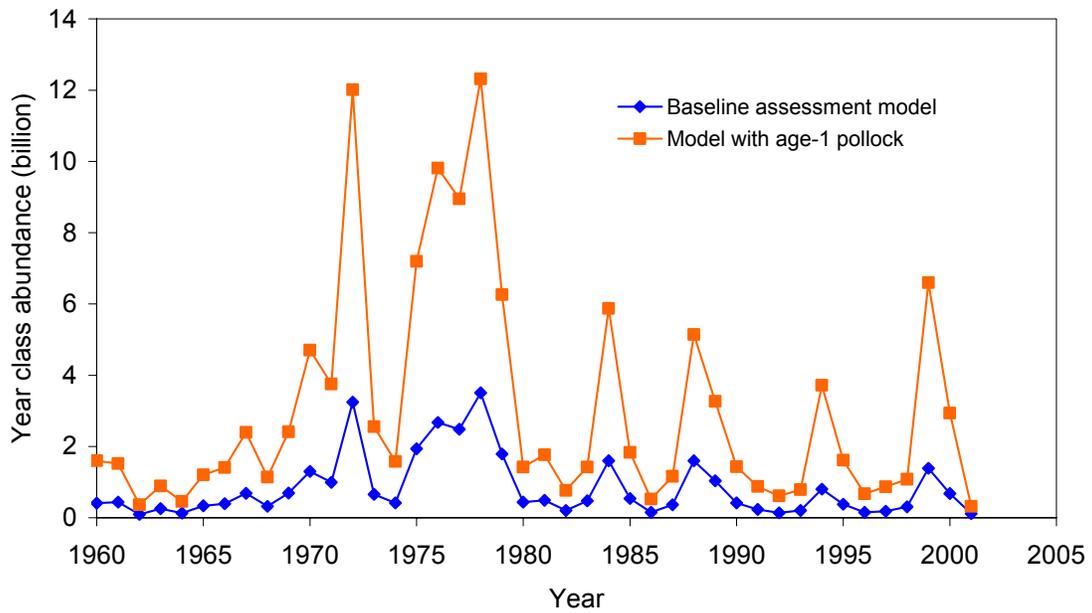
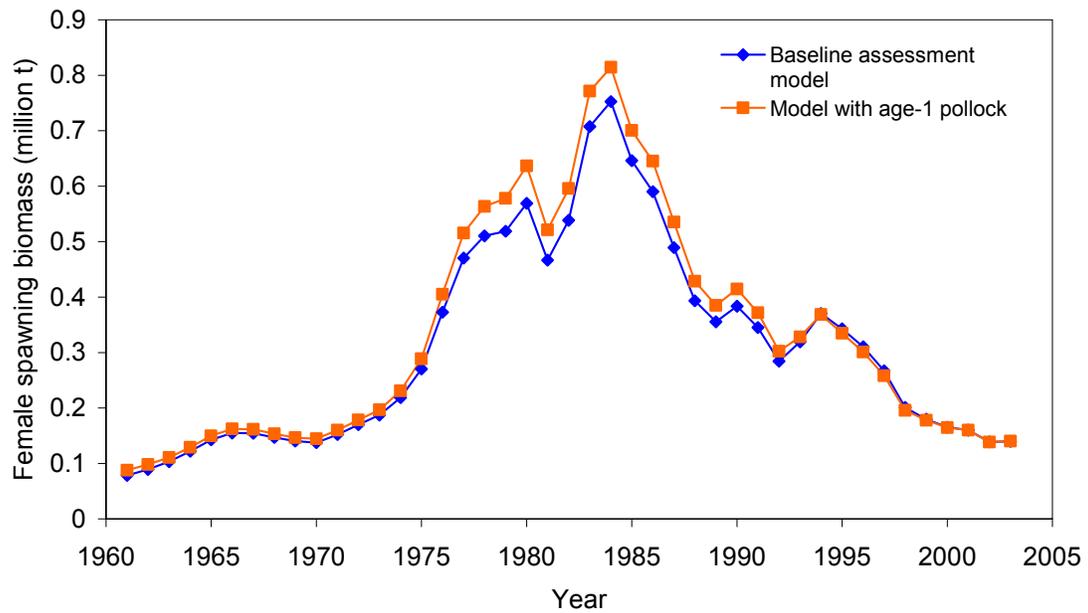


Figure 47. Comparison of spawning biomass (top) and year class abundance (bottom) between the baseline assessment model and a model including age-1 pollock and annual variation in juvenile mortality.

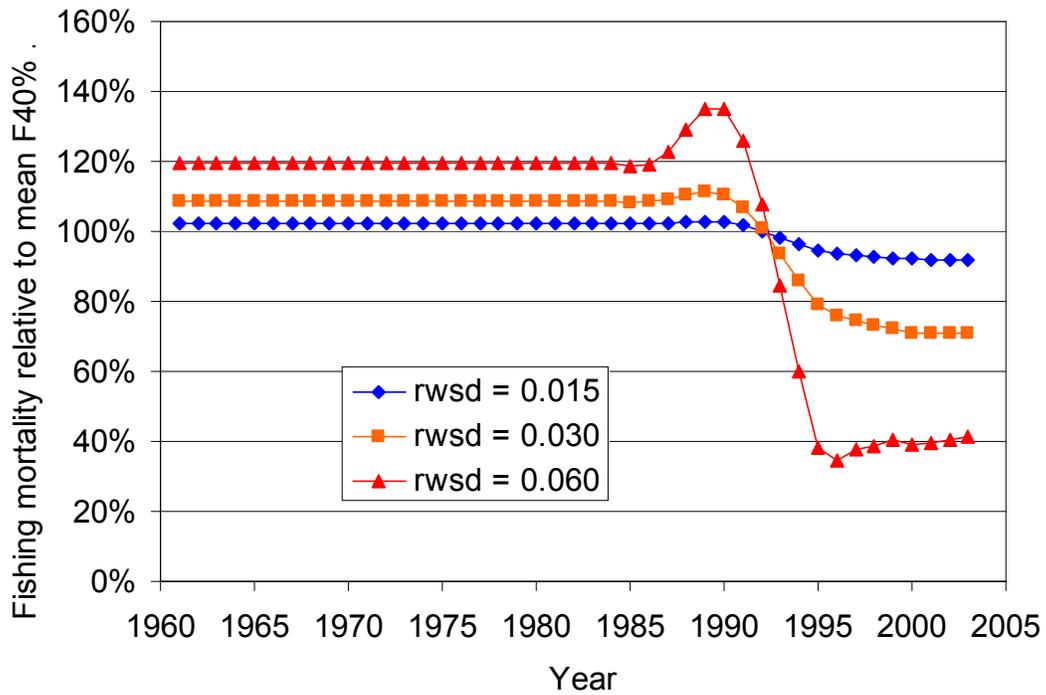
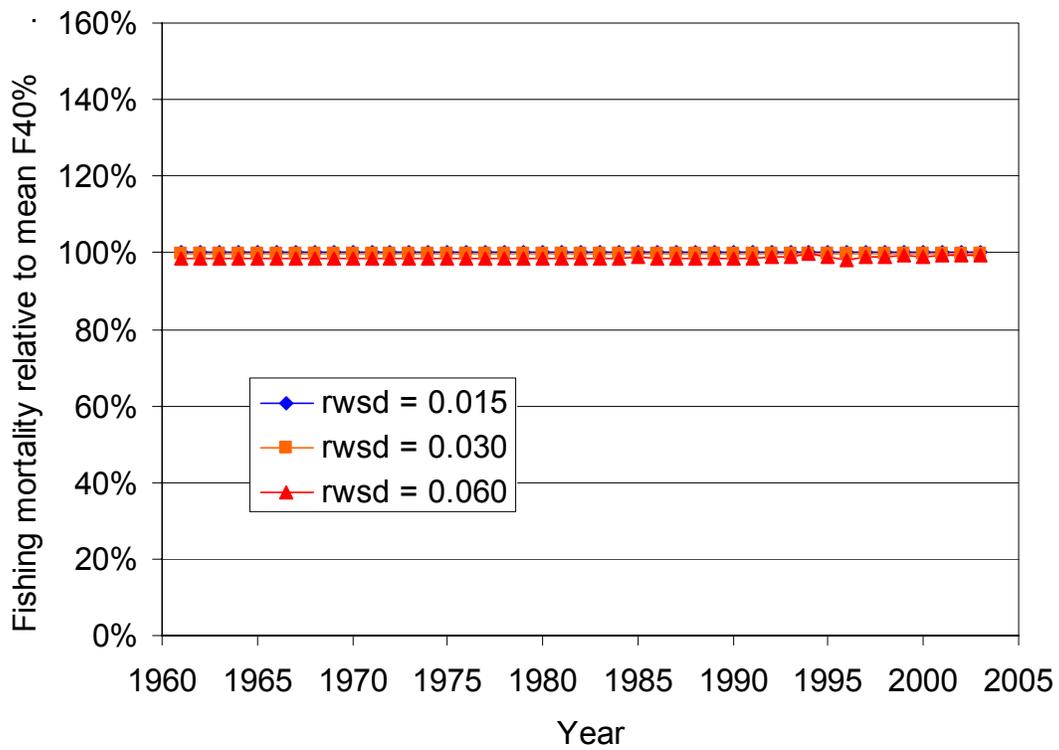


Figure 48. Annual fishing mortality rate relative to F40% calculated using the mean natural mortality rate for the entire time period for a model with annual variation in juvenile mortality. The top panel shows the relative change in the F40% harvest rate when FSPR is calculated using the year-specific natural mortality rate, while the bottom panel shows the relative change in the F40% harvest rate required to maintain the spawning output per recruit at 40% of unfished SPR for the mean natural mortality rate.

Appendix D: Seasonal distribution and apportionment of walleye pollock among management areas in the Gulf of Alaska

Since 1992, the Gulf of Alaska pollock TAC has been apportioned between management areas based on the distribution of biomass in groundfish surveys. Both single species and ecosystem considerations provide the rationale for TAC apportioning. From an ecosystem perspective, apportioning the TAC will spatially distribute the effects of fishing on other pollock consumers (i.e., Steller sea lions), potentially reducing the overall intensity of any adverse effects. From the perspective of the pollock population, apportioning the TAC ensures that no smaller component of the stock experiences higher mortality than any other. Although no sub-stock units of pollock have yet been identified in the Gulf of Alaska, it would be precautionary to manage the fishery so that if these sub-units do exist they would not be subject to high fishing mortality. Protection of sub-stock units would be most important during spawning season, when they are spatially separated. The Steller Sea Lion Protection Measures implemented in 2001 require apportionment of pollock TAC based on the seasonal distribution of biomass. Although spatial apportionment is intended to reduce the potential impact of fishing on endangered Steller Sea Lions, it is important to recognize that apportioning the TAC based on an inaccurate or inappropriate estimate of biomass distribution could be detrimental, both to pollock population itself, and on species that depend on pollock.

Walleye pollock in the Gulf of Alaska undergo an annual migration between summer foraging habitats and winter spawning grounds. Since surveying effort has been concentrated during the summer months and prior to spawning in late winter, the dynamics and timing of this migration are not well understood. Regional biomass estimates are highly variable, indicating either large sampling variability, large interannual changes in distribution, or, more likely, both. There is a comprehensive survey of the Gulf of Alaska in summer, but historically surveying during winter has focused on the Shelikof Strait spawning grounds. Recently there has been expanded EIT surveying effort outside of Shelikof Strait in winter, but no acoustic survey has been comprehensive, covering all areas where pollock could potentially occur.

Winter distribution

In winter, an annual acoustic survey in Shelikof Strait has been conducted since 1981. A significant portion of the remaining shelf and upper slope waters in the Gulf of Alaska west of Cape Suckling has been surveyed at least once during winter by exploratory surveys and surveys with shorter time series. Therefore a “composite” approach was developed to use data from several different surveys. We used data from 1) Shelikof Strait surveys in 1992-2003, 2) surveys of the Shumagin Island area in 1995, and 2001-03 (Wilson et al. 1995, Guttormsen et al. 2001, 2002, 2003), and 3) an exploratory survey along the shelf break in 1990 (Karp 1990). Each of these surveys covered a non-overlapping portion of the Gulf of Alaska shelf and upper slope west of Cape Suckling. Surveys of the Shumagin Island area in 1994 and 1996 were not used in this analysis because most fish were in post-spawning condition, and replicated surveys of spawning pollock in Shelikof Strait indicate a rapid decline in abundance after peak spawning (Wilson 1994, Wilson et al. 1996).

The “composite” approach was to estimate the percent of the total stock surveyed during a particular survey by dividing the survey biomass by the estimated total biomass of pollock at spawning from the assessment model. The percent for each non-overlapping survey was added together to form a composite biomass distribution, which, with some luck, ought to be close to 100%. Model estimates of biomass at spawning took into account the total mortality between the start of the year and spawning, and used mean weight at age from Shelikof Strait surveys in 1992-2003.

Results indicate that an average of 65% of the pollock biomass was in Shelikof Strait in winter (Appendix table 4). For the Shumagin surveys in 1995, 2001, and 2002, 24% of the total stock biomass was surveyed on average. The sum of the percent biomass for all surveys was 97%, which may reflect sampling variability, interannual variation in spawning location, or differences in echosounder/integration systems, but also suggests reasonable consistency between the aggregate biomass of pollock surveyed acoustically in winter and the assessment model estimates of abundance. After rescaling, the resulting average biomass distribution was 23.62%, 67.47%, and 8.90% in areas 610, 620, and 630. These estimates are within 1% of last year's estimates. We have not used recent survey results along the shelf break in areas 620 and 630, nor the 2003 estimates of biomass in Sanak Gully in area 610 because the relationship between these newly surveyed aggregations and those in Shelikof Strait and the Shumagin Islands is unclear.

A-season apportionment between areas 620 and 630

Last year, based on evaluation of fishing patterns which suggested that the migration to spawning areas was not complete by January 20, the plan team recommended an alternative apportionment scheme for areas 620 and 630 based on the midpoint of the summer and winter distributions in area 630. This approach was not used for area 610 because A season fishing patterns suggested that most of the fish captured in area 610 would eventually spawn in area 610. The resulting A season apportionment updated with 2003 survey data is: 610, 23.62%; 620, 56.90%; 630, 19.48%.

Middleton Island winter EIT survey results

The apportionment for area 640, which is not managed by season, has previously been based on the summer distribution of the biomass. Fishing, however, takes place primarily in winter or early spring on a spawning aggregation near Middleton Island. During 28-29 March 2003, this area was surveyed by the NOAA ship *Miller Freeman* for the first time and biomass estimate of 6900 t was obtained. Although maturity stage data suggested the timing of the survey was appropriate, discussions with fishing vessels contacted during the survey raised some questions about survey timing relative to peak biomass. Notwithstanding, a tier 5 calculation based on this spawning biomass gives an ABC of 1,550 t (6,901 t * 0.75 M), compared to 1,300 t for the author's 2004 ABC recommendation and an apportionment based on the summer biomass distribution. This suggests that the current approach of basing the area 640 apportionment on the gulfwide ABC and the summer biomass distribution is at least consistent with the biomass present near Middleton Island in the winter. We recommend continuing this approach until sufficient survey information during winter has accumulated to evaluate interannual variation in the biomass present in this area.

Summer distribution

The NMFS bottom trawl is summer survey (typically extending from mid-May to mid-August). Because of large shifts in the distribution of pollock between management areas one survey to the next, and the high variance of biomass estimates by management area, Dorn et al. (1999) recommended that the apportionment of pollock TAC be based upon the four most recent NMFS summer surveys. The four-survey average was updated with 2003 survey results in an average biomass distribution of 47.68%, 20.88%, 29.46%, and 1.98% in areas 610, 620, 630, and 640 (Fig. 33).

Example calculation of 2004 Seasonal and Area TAC Allowances for W/C/WYK

Warning: This example is based on hypothetical ABC of 100,000 t.

1) Deduct the Prince William Sound Guideline Harvest Level.

2) Use summer biomass distribution for the 640 allowance:

$$640 \quad 0.0198 \times \text{Total TAC} = 1,980 \text{ t}$$

3) Calculate seasonal apportionments of TAC for the A, B, C, and D seasons at 25 %, 25%, 25%, and 25 % of the remaining annual TAC west of 140° W lon.

$$\text{A season} \quad 0.25 \times (\text{Total TAC} - 1,980) = 24,505 \text{ t}$$

$$\text{B season} \quad 0.25 \times (\text{Total TAC} - 1,980) = 24,505 \text{ t}$$

$$\text{C season} \quad 0.25 \times (\text{Total TAC} - 1,980) = 24,505 \text{ t}$$

$$\text{D season} \quad 0.25 \times (\text{Total TAC} - 1,980) = 24,505 \text{ t}$$

4) For the A season, the allocation of TAC to areas 610, 620 and 630 is based on a blending of winter and summer distributions to reflect that pollock may not have completed their migration to spawning areas by Jan. 20, when the A season opens.

$$610 \quad 0.2363 * 24,505 \text{ t} = 5,788 \text{ t}$$

$$620 \quad 0.5690 * 24,505 \text{ t} = 13,943 \text{ t}$$

$$630 \quad 0.1948 * 24,505 \text{ t} = 4,774 \text{ t}$$

5) For the B season, the allocation of TAC to areas 610, 620 and 630 is based on the composite estimate of winter biomass distribution

$$610 \quad 0.2363 * 24,505 \text{ t} = 5,790 \text{ t}$$

$$620 \quad 0.6747 * 24,505 \text{ t} = 16,534 \text{ t}$$

$$630 \quad 0.0890 * 24,505 \text{ t} = 2,181 \text{ t}$$

6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the average biomass distribution in areas 610, 620 and 630 in the most recent four NMFS bottom trawl surveys.

$$610 \quad 0.4768 / (1 - 0.0198) \times 24,505 = 11,920 \text{ t}$$

$$620 \quad 0.2088 / (1 - 0.0198) \times 24,505 = 5,220 \text{ t}$$

$$630 \quad 0.2946 / (1 - 0.0198) \times 24,505 = 7,365 \text{ t}$$

$$610 \quad 0.4768 / (1 - 0.0198) \times 24,505 = 11,920 \text{ t}$$

$$621 \quad 0.2088 / (1 - 0.0198) \times 24,505 = 5,220 \text{ t}$$

$$630 \quad 0.2946 / (1 - 0.0198) \times 24,505 = 7,365 \text{ t}$$

Appendix Table 4. Estimates of winter pollock biomass distribution in management areas 610-630 from EIT surveys in the Gulf of Alaska.

| Survey | Year | Model estimates of total 2+ biomass at spawning | Survey biomass estimate ¹ | Percent | Percent of biomass by management area | | | Percent of total biomass | | |
|---------------------------------|---------|--|--|---------|--|----------|-------------|-----------------------------|----------|----------|
| | | | | | Area 610 | Area 620 | Area 630 | Area 610 | Area 620 | Area 630 |
| Shelikof Strait | 1992 | 988,803 | 681,400 | 68.9% | | | | | | |
| Shelikof Strait | 1993 | 1,087,800 | 408,200 | 37.5% | | | | | | |
| Shelikof Strait | 1994 | 1,080,730 | 467,300 | 43.2% | | | | | | |
| Shelikof Strait | 1995 | 893,155 | 618,300 | 69.2% | | | | | | |
| Shelikof Strait | 1996 | 791,619 | 745,400 | 94.2% | | | | | | |
| Shelikof Strait | 1997 | 715,836 | 570,100 | 79.6% | 0.0% | 98.8% | 1.2% | | | |
| Shelikof Strait | 1998 | 594,972 | 489,900 | 82.3% | 0.0% | 97.5% | 2.5% | | | |
| Shelikof Strait | 2000 | 479,067 | 334,900 | 69.9% | 0.0% | 97.8% | 2.2% | | | |
| Shelikof Strait | 2001 | 492,865 | 369,600 | 75.0% | 0.0% | 98.3% | 1.7% | | | |
| Shelikof Strait | 2002 | 538,089 | 229,100 | 42.6% | 0.0% | 97.7% | 2.3% | | | |
| Shelikof Strait | 2003 | 551,884 | 270,200 | 49.0% | 0.0% | 97.6% | 2.4% | | | |
| Shelikof Strait | Average | | | 64.7% | 0.0% | 98.0% | 2.0% | 0.0% | 63.4% | 1.3% |
| Shumagin | 1995 | 893,155 | 290,100 | 32.5% | 90.0% | 10.0% | 0.0% | | | |
| Shumagin | 2001 | 492,865 | 108,791 | 22.1% | 84.8% | 15.2% | 0.0% | | | |
| Shumagin | 2002 | 538,089 | 135,644 | 25.2% | 100.0% | 0.0% | 0.0% | | | |
| Shumagin | 2003 | 551,884 | 67,160 | 12.2% | 99.7% | 0.3% | 0.0% | | | |
| Shumagin | Average | | | 23.0% | 93.6% | 6.4% | 0.0% | 21.5% | 1.5% | 0.0% |
| Shelf break/east side Kodiak | 1990 | 1,042,640 | 96,610 | 9.3% | 14.9% | 6.2% | 78.9% | 1.4% | 0.6% | 7.3% |
| Total | | | | 96.93% | | | | 22.90% | 65.40% | 8.63% |
| Rescaled total | | | | 100.00% | | | | 23.63% | 67.47% | 8.90% |

¹The biomass of age-1 pollock was not included in Shelikof Strait survey biomass in 1995 and 2000.

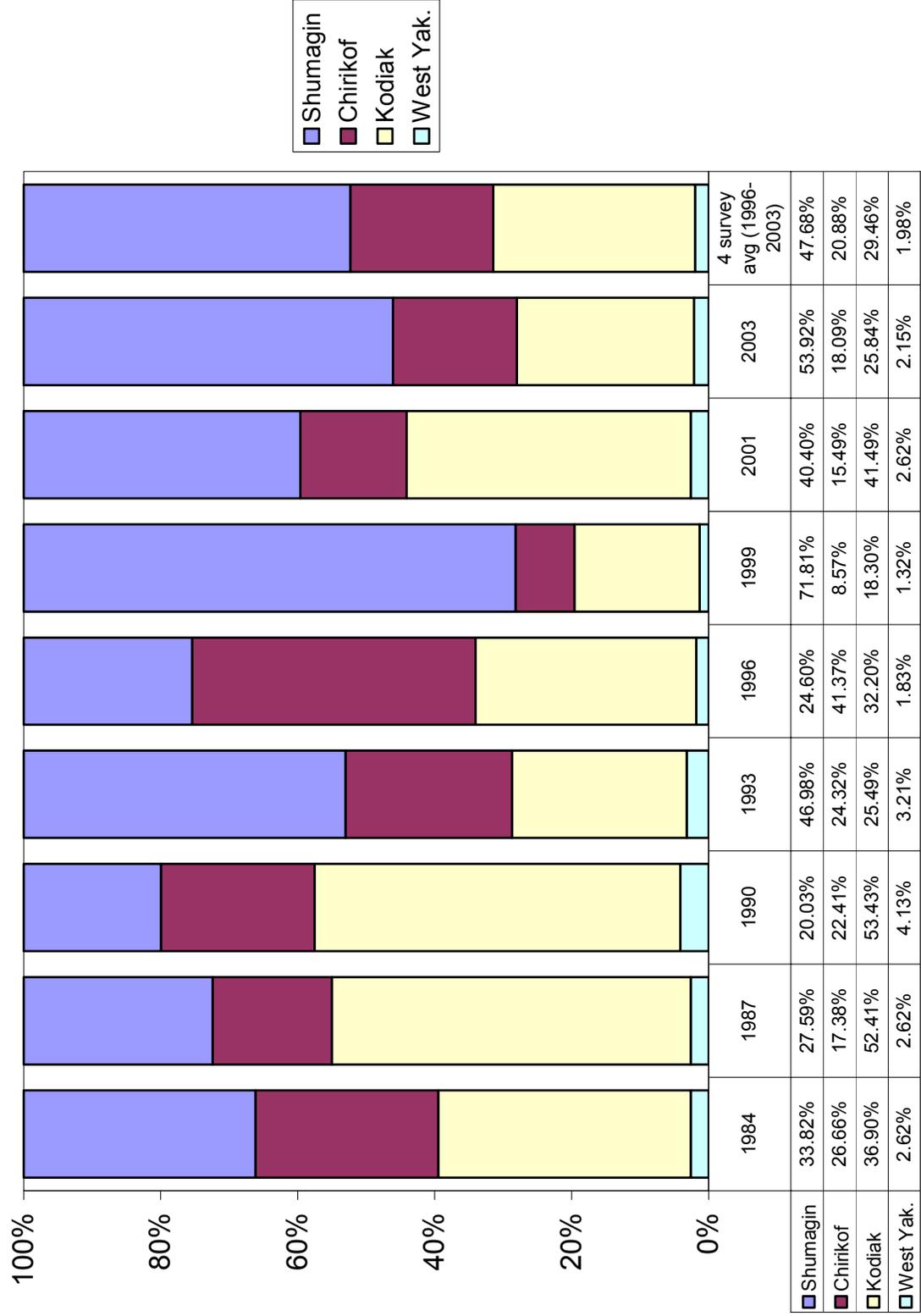


Figure 49. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2003. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.