Assessment of Walleye Pollock in the Gulf of Alaska

by

Martin Dorn, Steven Barbeaux, Michael Guttormsen, Bernard Megrey,
Anne Hollowed, Eric Brown, and Kally Spalinger

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: 2001 total catch and catch at age.

2. Shelikof Strait EIT survey: 2002 biomass and age composition.

3. ADF&G crab/groundfish trawl survey: 2002 biomass and length composition.

4. NMFS bottom trawl survey: 2001 age composition.

5. New maturity at age estimates using winter EIT survey specimen data, 1983-2002.

Assessment model

The age-structured assessment model developed using ADModel Builder (a C++ software language extension and automatic differentiation library) used for assessments in 1999-2001 is unchanged. Model exploration focused on approaches to modeling the survey time series, in particular the winter EIT surveys.

Assessment results

The model estimate of spawning biomass in 2003 is 177,070 t, which is 28% of unfished spawning biomass and below $B_{40\%}$ (240,000 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 in 2003 decreases to 144,490 t, or 24% of unfished spawning biomass. Lower model estimates of biomass in 2003 are primarily due to the low abundance of spawning adults in the 2002 Shelikof Strait EIT survey. In contrast, the ADFG trawl survey showed an increase in biomass in 2002. The author's 2003 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. is 49,590 t, a decrease of 35% from the last year's projected ABC for 2003, and 7% lower than last year's ABC. 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. These measures were considered warranted because current status is close to the $B_{20\%}$ level that would require a cessation of fishing under Steller sea lion protective measures implemented last year.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendation is unchanged at 6,460 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). 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 using 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.

Kodiak is the major port for pollock in the Gulf of Alaska, with 57% of the 1997-2001 landings. Sand Point and Dutch Harbor are also important ports, sharing 33% of 1997-2001 landings. Secondary ports, including Akutan, Cordova, King Cove, and Seward account for the remaining 11% of the 1997-2001 landings.

Since 1992, the Gulf of Alaska pollock TAC has been apportioned spatially and temporally to reduce impacts on Steller sea lions. Although the details of the apportionment scheme have evolved over time, 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, and ADF&G bottom trawl survey estimates of biomass and length and age composition. Binned length composition data are used in the model 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 at-sea discard estimates (Table 2). Catches include the state-managed pollock fishery in Prince William Sound. In 1996-2002, the pollock Guideline Harvest Level (GHL) for the PWS fishery was deducted from the Total Allowable Catch (TAC) recommended by North Pacific Management Council (NPFMC).

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 2001 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 2000 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	358	319	354	169
	No. lengths	2467	5889	6280	894
2nd half (C and D seasons)	No. ages	321	215	352	----
	No. lengths	6232	1324	4197	----

In the first half of 2001, the most common age class in areas 620, 630, and 640 was age-7 pollock of the 1994 year class, while in area 620 the ages 4-7 were all nearly equally common. In the second half of 2001, mean age decreased substantially in all areas with the appearance of the 1999 year class (age-2 fish) (Fig. 2).

Fishery catch at age in 1976-2001 is presented in Table 3 (See also Fig. 3). 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 750 tows, 75% 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, and 1999 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. The 2001 estimate of pollock biomass west of 140° W long is 216,761 t, a 65% decline from the 1999 survey estimate.

An adjustment was made to the survey times 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.

Bottom Trawl Age Composition

Estimates of numbers at age from the bottom trawl survey were obtained from length-stratified otolith samples and length frequency samples (Table 7). 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 2001 survey, age-1 pollock from the 2000 year class was numerically dominant in all areas, while the 1999 year class was common only in the Chirikof INPFC area (Fig. 4). In the biomass at age distribution, the 1994 year class (age-7) was the most common year class.

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 2002 are presented in an Appendix to the SAFE (Guttormsen et al. 2002). The 2002 biomass estimate for age 2+ pollock in Shelikof Strait was 229,100 t, a decrease of 38% from the 2001 biomass (Table 5). A much greater decline in >43 cm biomass was observed (Fig. 5). In contrast, the estimated abundance of age-3 fish (1.024 billion) was the third largest in the Shelikof Strait EIT time series, providing addition support for a relatively strong 1999 year class.

Additional EIT surveys in winter 2002 covered the Shumagin Islands spawning area and an area along the shelf break east of the entrance to the Shelikof sea valley, where most of the fleet was operating during winter 2002. Results from these surveys are given below.

2002 EIT survey results

		Shumagin	Shelf Break	Shelikof	Total
Total	Tons	135,600	82,100	229,100	446,900
	Percent	30%	18%	51%	
Biomass ≥43 cm	Tons	128,060	81,397	38,037	247,494
	Percent	52%	33%	15%	

During 1992-2000 the average ratio of Shelikof Strait biomass ≥43 cm (a proxy for spawning biomass) and the model estimate of total spawning biomass was 65%. In 2002, the ratio between Shelikof biomass ≥43 cm and the total *surveyed* biomass ≥43 cm was 15%, indicating the model assumption of a constant fraction of the stock spawning in Shelikof Strait may be invalid. The total surveyed biomass ≥43 cm should be considered a minimum estimate of the total spawning biomass because not all spawning areas were surveyed in winter 2002. Although Shelikof Strait EIT surveys have historically been considered a primary source of information on overall GOA pollock population trends, the results of the more extensive surveying effort in winter 2002 suggests that this assumption should be reevaluated.

Comparison of age composition for the Shelikof Strait and shelf break surveys shows a similar age composition for pollock age 6 and greater (Shelikof Strait mean age 7.0; shelf break mean age 7.2). Age and maturity data from the shelf break aggregation suggested that it consisted exclusively of pre-spawning pollock (i.e., fish that will spawn this year), rather than the mix of both immature and pre-spawning pollock that are found in Shelikof Strait (Fig. 6).

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 recent years, the biomass distributions at length have been dominated by the 1994 and 1999 year classes. In the 2002 survey, the length frequency is dominated by the age-3 fish from the 1999 year class.

Echo Integrated Trawl Survey Age Composition
Estimates of numbers at age from the Shelikof Strait EIT survey (1981 - 1991, 1994 -1998, 2000-2002 (Table 7) were obtained from length-stratified otolith samples and length frequency samples. Otoliths collected during the 1994 - 2002 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 derived from 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.

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 2002 biomass estimate for pollock for the ADF&G crab/groundfish survey was 96,237 t, an increase of 11% from the 2001 biomass estimate (Table 5). The ADF&G biomass trend does not show the same steep decline of adult fish in 2002 suggested by the 2002 Shelikof Strait EIT survey.

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. The percent of small pollock (<40 cm) increased from 4% in 2000 to 13% in 2001 and 22% in 2002.

ADF&G Survey Age Composition
Ages were determined by age readers in the AFSC age and growth unit from an initial sample of pollock otoliths collected during the 2000 ADF&G survey (N = 559). 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. The 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,

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

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 8). 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 8), 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 the1960s 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 euphausid 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 survey 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 that they could all 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.

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 9). 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.

2002 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 2002 Kodiak monthly precipitation; 2) wind mixing energy at [57N, 156W] estimated from 2002 sea-level pressure analyses; 3) advection of ocean water in the vicinity of Shelikof Strait inferred from drogued drifters deployed during the spring of 2002; 4) rough counts of pollock larvae from a survey conducted in May 2002; and 5) estimates of age-2 pollock abundance from the assessment model.

Analysis

Kodiak Precipitation: The winter started wet this year, but the spring was relatively dry. April rainfall was at a new low (0.29 inches) for the period of the recruitment time series record (1962-present). That amount of rain is just 7% of the 30-yr average (1962-1991) for April. Although precipitation increased thereafter, especially during June, that is considered too late to aid larval survival.

Kodiak precipitation for 2002

Month	% 30-yr average
Jan	172
Feb	185
Mar	85
Apr	7
May	75
June	155

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 rainfall has a score of 1.87. This is "average" on the continuum from 1 (weak) to 3 (strong).

Wind Mixing: Wind mixing followed a similar pattern established in 1997 when the PDO changed sign. Mixing is significantly below the 30-yr mean. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment.

Wind mixing at the exit of Shelikof Strait for 2002

Month	% 30-yr average
Jan	35
Feb	46
Mar	30
Apr	47
May	29
June	51

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 2.30, which equates to "average".

Advection: From an examination of drifter trajectories and wind forcing, the transport in Shelikof Strait for spring of 2002 was very weak. It is difficult at this time to quantify advection since data for the Line 8 moorings has not been analyzed, but as an early estimate, it is among the weakest on record.
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 1.0.
Relating Larval Index to Recruitment: 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/m^2) to age recruitment abundance (billions). The model estimated 6 weighting parameters.

Data used in the neural network model

Year Class	Average Larval Abundance (catch/m^2)	Age 2 Recruitment (billions)
1982	66.44347	0.19314
1985	80.4266	0.561484
1987	324.9025	0.369731
1988	255.586	1.70276
1989	537.2943	1.09101
1990	335.0086	0.432056
1991	54.2223	0.252929
1992	563.6741	0.135936
1993	45.80764	0.212
1994	124.9386	0.78524
1995	600.9925	0.329781
1996	472.0225	0.082934
1997	561.1063	0.157118
1998	73.07128	0.383759
1999	102.3862	2.47685
2000	535.4901	0.23056
2001	136.2054	
2002	167.1542	

The neural network model, which used the first 16 observation pairs were fit to the model and had a R^2 of 0.497. 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.

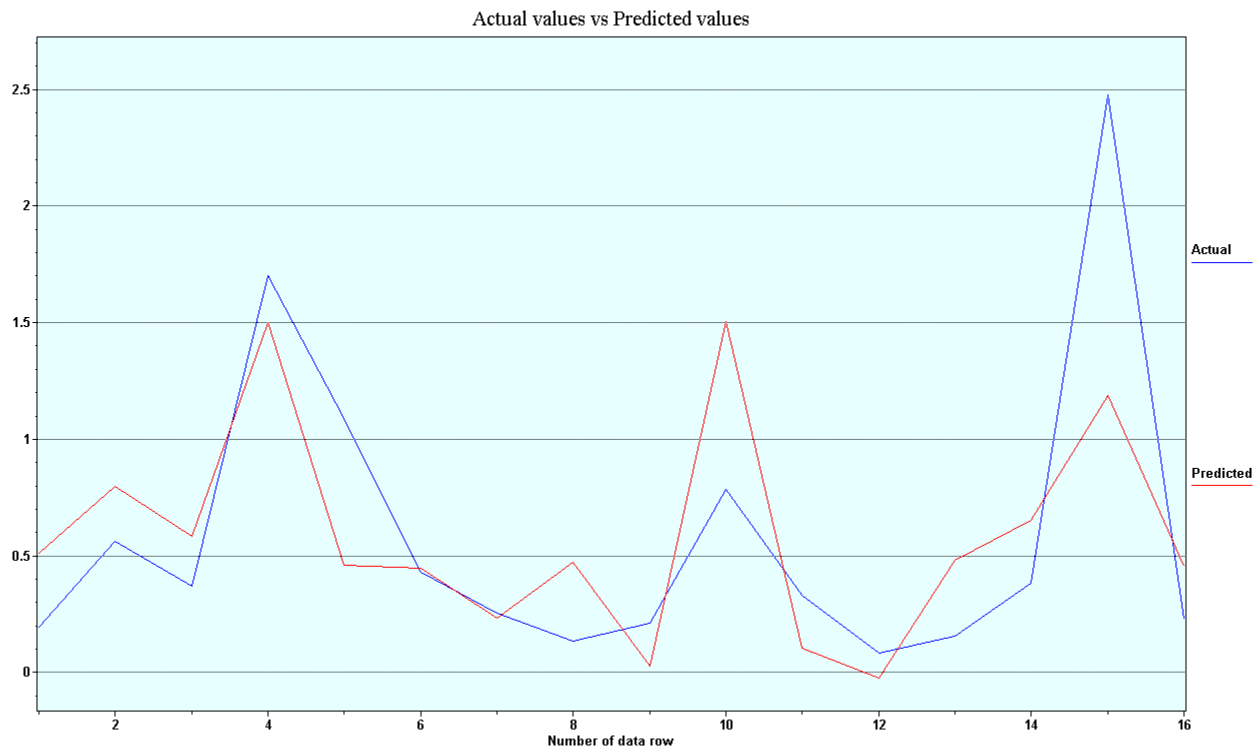

Figure. Observed and predicted recruitment values form the larval index-recruitment neural network model.

The trained network was then used to predict the recruitment for 2001 and 2002.

The predictions are

Year	Actual Recruitment	Predicted Recruitment
2001	n/a	1.626241
2002	n/a	1.840346

These values, using the 33% and 66% cutoff points given below correspond to a strong 2001 year class and a strong 2002 year class.

Note that the neural net model fit last year to these data predicted the 2000 year class to be average at 0.573 billion fish. Results of this years assessment show the predicted recruitment for the 2000 year class to be 0.231 billion.

Larval Index Counts: Plotting the data by year and binning the data into catch/m^2 categories (given below) provides another view of the data. The pattern for 2002 (based on rough counts) indicates that 2002 was a very poor year for pollock larvae, but this is somewhat misleading.

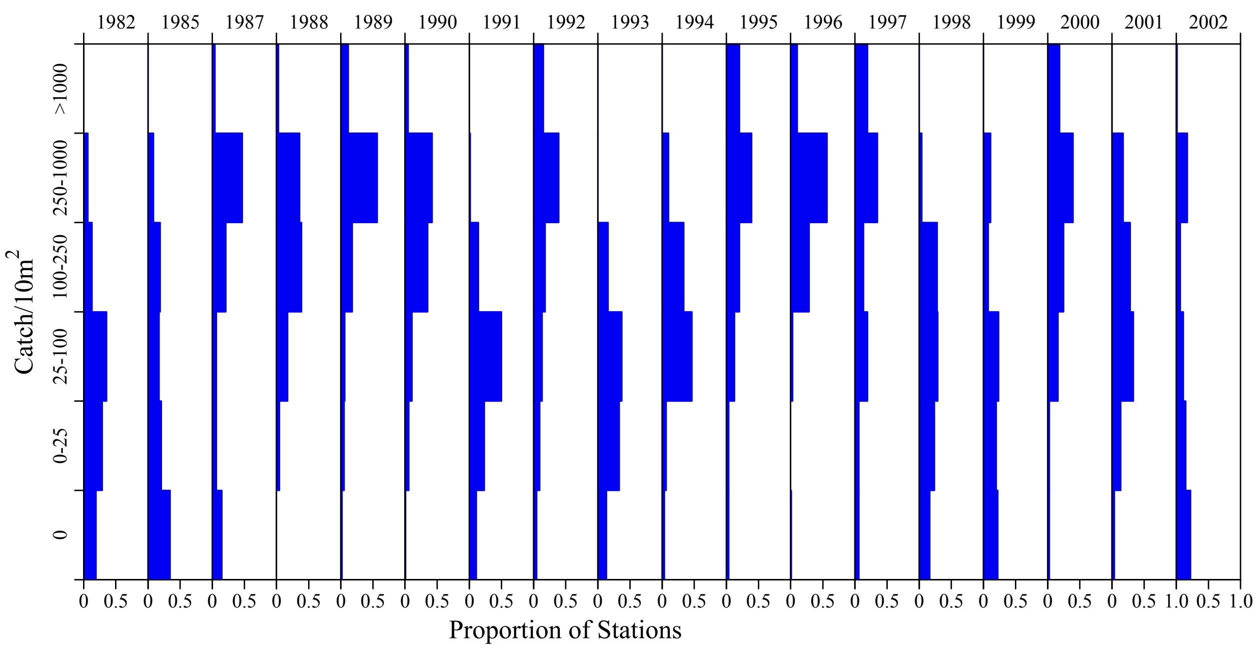

Figure. A series of histograms for larval walleye pollock densities in late May from 1982 to 2002. Data were binned into catch/m^2 categories. The data from 2000-2002 are rough counts taken at sea, and the 2002 data are from the 4MF02 cruise that was completed on June 1.

The score for larval index is set to the high end of the weak range, 1.5.

The data are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae (the area outlined in figures below). However, this year a few stations were cut due to bad weather, and these stations might have increased the proportion of stations in the 100-250 catch/10m^2 bin on the graph. Another factor is that this year's distribution of pollock appears to be more northerly in Shelikof Strait than normal. You can see in the maps that many of the southern stations of 4MF02 within the reference area didn't catch any larvae. Also, many large catches (250-1000 catch/10m^2) are northeast of our typical reference area. This might indicate that the distribution hasn't yet been advected as far southwest as they usually have been by this time – an observation supported by the observed weak advection index. We can't really conclude this, however. We rarely survey this area in late May, hence we don't know if these northeast catches are unusual. Figures below address this issue. The first figure shows some very high densities in the area north of Kodiak Island, but these densities are based on very few years (second figure) so it's unknown how consistent these high densities are from year to year. It also seems unlikely that these larvae are from the same spawning population as the larvae in our reference area.

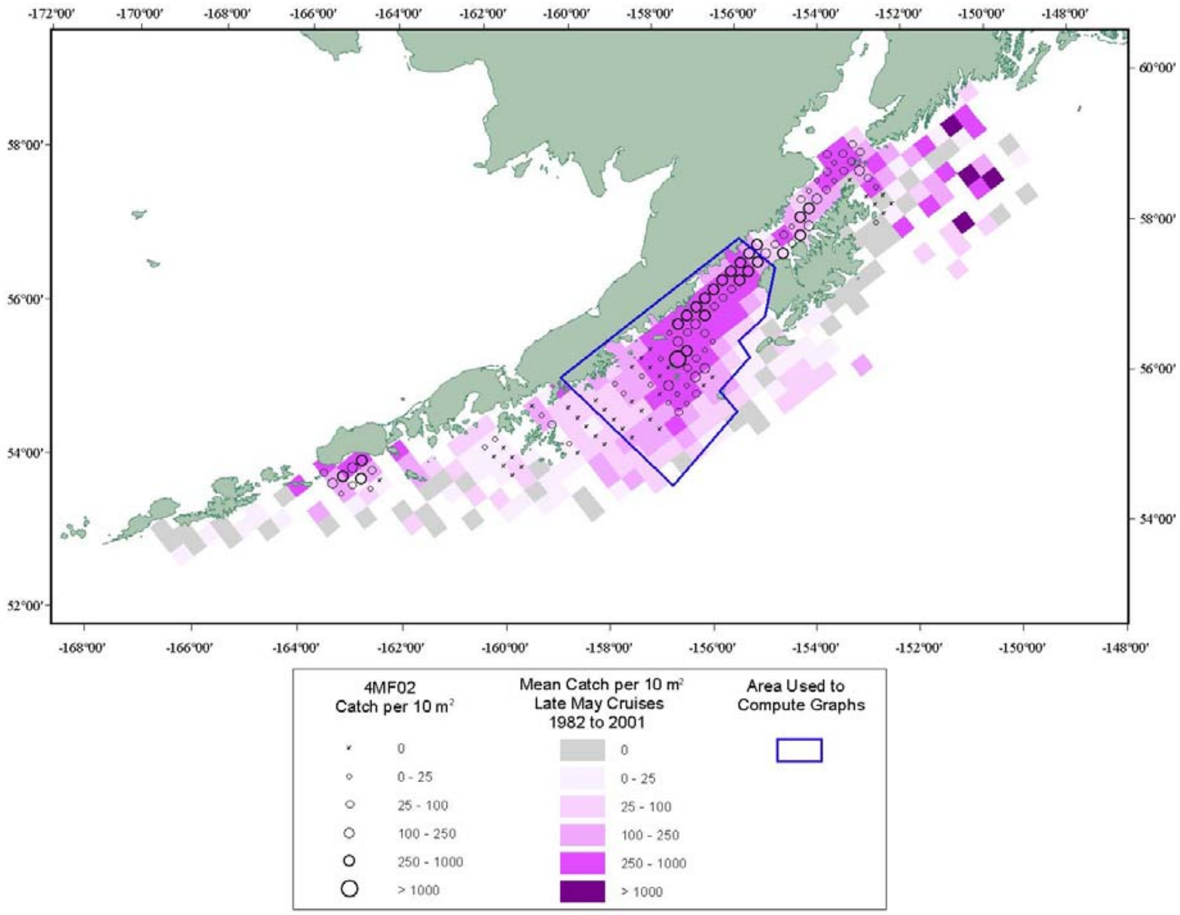

Figure. Mean catch per 10m^2 for late May cruises during 1982-2001.

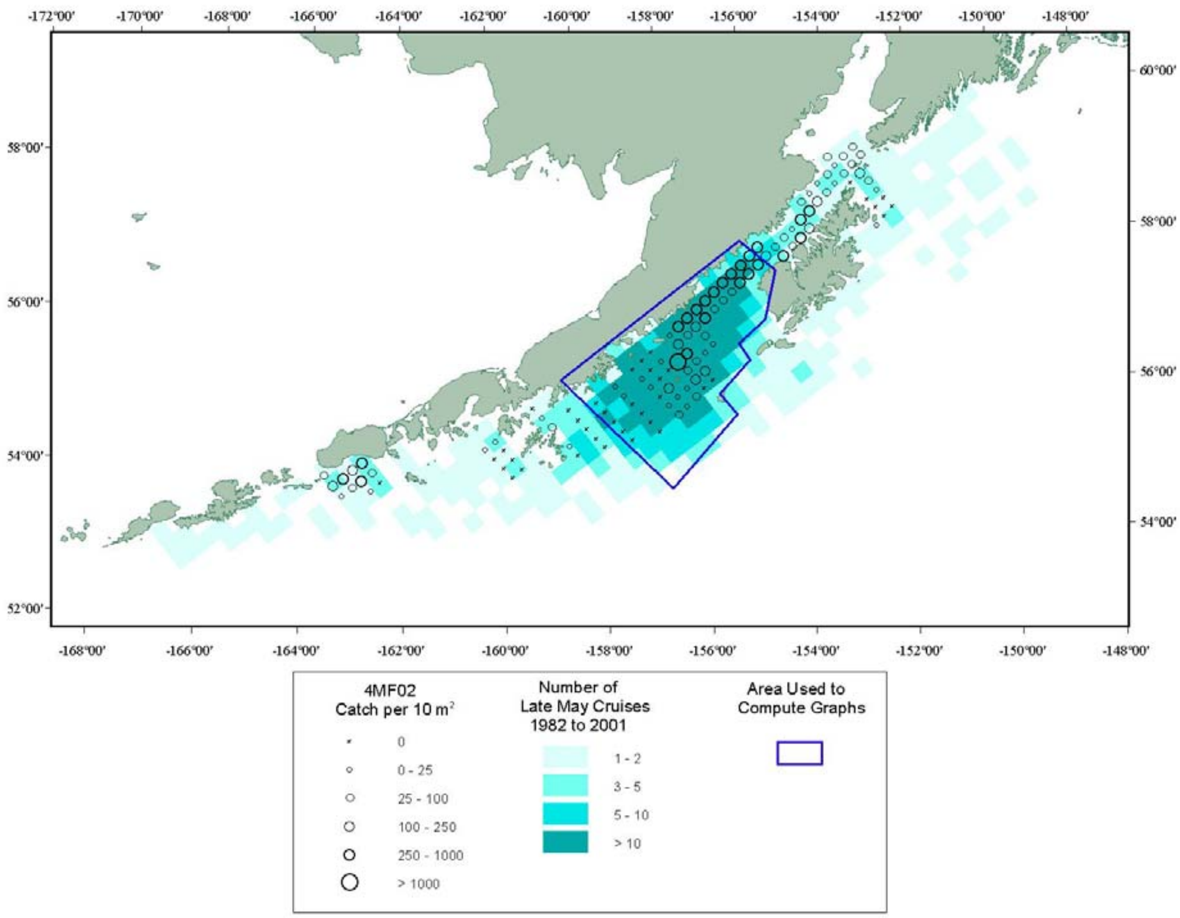

Figure. Number and location of data sampling effort, 1982-2001.

Due to the ambiguities mentioned, we will classify the larval index data as indicating a weak to average situation and give it a score at the low end of the average range, 1.67.

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 1961-2002, representing the 1959-2000 year classes (see Table 14). There were a total of 42 recruitment data points. The 33% and 66% percentile cutoff points were calculated from the full time series (33%=0.390955 billion, 66%=0.694044 billion) 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:

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 2002 year class could be predicted from the size of the 2000 year class. The 2000 year class was estimated to be 0.23096 billion and was classified as weak. The probabilities of other recruitment states following a weak year class for a lag of 2 years (n=42) are given below:

2002 Year Class		**2000 Year Class**	**Probability**	**N**
Weak	follows	Weak	0.125	5
Average	follows	Weak	0.075	3
Strong	follows	Weak	0.125	5

A weak or strong year class following a weak year class had the highest probabilities. The prediction element from this data source was also ambiguous, and we classified this data element as a compromise between the weak and strong, giving it a score of 2.0.
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 2002 year class is average.

Element	**Weights**	**Score**	**Total**
Time Sequence of R	0.2	2.0	0.4
Rain	0.2	1.87	0.374
Wind Mixing	0.2	2.3	0.46
Advection	0.2	1.00	0.2
Larval Index-abundance	0.2	1.67	0.334
Total	1.0		1.768 = Average

Analytic Approach

Model description

Age-structured models for the period 1961 to 2002 (42 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.

Likelihood component	Statistical model for error	Variance assumption
Fishery total catch (1964-2001)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-2001)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-2002)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-2002)	Multinomial	Sample size = 60
NMFS bottom trawl survey biomass (1984-2001)	Log-normal	Survey-specific CV = 0.11-0.38
NMFS bottom trawl survey age comp. (1984-2001)	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 (1989-2002)	Log-normal	CV = 0.25
ADF&G survey age comp. (2000)	Multinomial	Sample size = 10
ADF&G survey length comp. (1989-2002)	Multinomial	Sample size = 10
Fishery selectivity random walk process error	Log-normal Normal	Slope CV = 0.10 (0.001 for 1961-71) Inflection age SD = 0.40 (0.004 for 1961-71)
Recruit process error (1961-1968,2002)	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 as a 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 to provide information on relative catchability.

Ageing error
Ageing error for both survey and fishery age composition data was incorporated by use of a transition matrix (with elements associated with the probability of an observed age *j* being true age *j'*). This matrix was computed using the estimated percent-agreement levels based on standard deviations. That is, we computed the level of variance that would produce the observed level of agreement at different ages (Kimura and Lyons 1991). This took into account the probability that both readings were correct, both were off by one year in the same direction, or both were off by two years in the same direction. The probability that both agree and were off by more than two years was considered negligible.

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 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. A transition matrix was estimated using 1992-98 Shelikof Strait EIT survey data and used for survey length frequency data. The following length bins were used: 17 - 27, 28 - 35, 36 - 42, 43 - 50, 51 - 55, 56 - 70 (cm). 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). Finally, a transition matrix estimated by Hollowed et al. (1998) was used for the length-frequency data for the early period of the fishery.

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 fit using ADModel Builder, a C++ software language extension and automatic differentiation library. ADModel Builder estimates large number of parameters in a non-linear model 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 x 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:

Population process modeled	Number of parameters	Estimation details
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 1961-2002 = 42	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 1961-2002 = 42	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) = 164	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	113 ordinary parameters + 164 process error parameters + 2 fixed parameters = 279	

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

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 somewhat 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 for Gulf of Alaska pollock was estimated by Hollowed et al (1991) using maturity stage data collected during 1983-89. In response to questions at the September 2002 plan team meeting regarding pollock maturity, we examined the maturity stage data collected during winter EIT surveys in the Gulf of Alaska during 1983-2002 to evaluate whether there have been changes in maturity at age since Hollowed et al. (1991). Pollock specimen collections are a standard part of EIT surveys. In addition to collecting otoliths, each specimen is assigned a maturity code based on the appearance of the gonads. During 1983-1995, a 5-category maturity scale was used, while in 1996-2002 a more detailed 8-category scale was used. 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 that stage are assumed to be immature. We assumed that maturity stages ≥ 3 in the 1983-95 table were mature, while maturity stages ≥ 4 in the 1996-2002 table were mature (Table 10).

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 a late developing stage (i.e., stage 3 in the 1996-2002 table) may contain yolked eggs, but it was unclear whether these fish would spawn later in the year. A final concern is the difficulty of obtaining an unbiased sample of maturity stage data. Fish outside the spawning aggregations may be disproportionately sampled in comparison to fish within spawning aggregations. To estimate population length and age composition in EIT surveys, length samples are weighted by the acoustic backscatter associated with the sample; this has not been done for the maturity stage data. 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 evaluated an average of the annual proportion mature at age for all years and for subsets of years. Logistic regression was also used to estimate the age and length at 50% mature at age for each year (McCullagh and Nelder 1983).

Maturity at age is extremely variable from one year to the next (Fig. 10). It is unclear whether this represents real variability, or sampling error or even a technician effect. Between 1983 and 1988 there was a consistent decline in the percent mature for ages 2-6. Since then, the percent mature for these ages has varied, but without obvious trend. There appears to be a fairly strong autocorrelation in the maturity at age data, with periods of 3 to 4 years where pollock are consistently maturing early or late (Fig 11). Annual estimates of age at 50% maturity from logistic regression range from 3.7 years in 1984 to 6.1 years in 1991, with an average of 5.0 years. Interestingly, the age at 50% mature in 2002 is nearly identical to Hollowed et al. (1991). 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 11). There is less evidence of trends in length at 50% mature, with only the 1983 and 1984 estimates as unusually low values, and 2000 and 2001 as the only unusually high values. The average length at 50% mature for all years is approximately 43 cm.

Comparison of mean proportion mature at age for different ranges of years suggests that the long-term (1983-2002) average and the average over the past ten years (1993-2002) are consistently lower than the Hollowed et al. (1991) estimates (Fig. 12). While we are concerned about the reliability of the maturity stage data, it must be acknowledged that the Hollowed et al. (1991) estimates are based on the same data. Because there did not appear to be an objective basis for excluding data, we used the 1983-2002 average maturity at age in assessment. Clearly, obtaining reliable and unbiased estimates of maturity at age is a research priority for Gulf of Alaska pollock. We also note that apparent changes in maturity at age are in the opposite direction of what would be expected from life history theory. A decline in abundance would be expected to result in earlier age at maturity. There is no biological explanation for the apparent increase in maturity at age following the decline in pollock abundance in the 1980s.

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, $W = a\,L^b$, 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. We evaluated the effect of estimated versus fixed NMFS trawl survey catchability, and the influence of Shelikof Strait EIT survey time series, in particular the 2002 survey result. Several model configurations were also suggested by the SSC October 2002 minutes.

Model 1: Estimated NMFS trawl survey catchability. In previous assessments, catchability was fixed at one as a precautionary assumption. In the 2001 assessment (Dorn et al. 2001), a likelihood profile on trawl catchability showed that this parameter could be estimated. In most assessment models, 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 why the NMFS trawl survey should be treated differently.

Model 2: A model that conforms to last year's model assumptions: trawl catchability fixed at 1.0, and the full Shelikof Strait EIT survey time series is used in the model.

Model 3: As in Model 2, except the 2002 Shelikof Strait EIT survey is removed.

Model 4: As in Model 2, except the entire Shelikof Strait EIT survey time series is removed as suggested by the SSC.

Model 5: This model is in response to the SSC request to "alter the model in some way so that the complete hydroacoustic survey data from this year can be used." We proceeded at follows: Since biomass ≥43 cm is a reasonable proxy for total spawning biomass, we calculated a mean ratio of 65% for Shelikof Strait biomass ≥43 cm to the model estimate of total spawning biomass for the years 1992-2000. Since the total surveyed biomass ≥43 cm in 2002 was 247,494 t, 65% of that total would give a biomass ≥43 cm of 159,986 t for the Shelikof Strait survey, *if the same fraction of the total stock had migrated into Shelikof Strait in 2002 to spawn as in previous years*. This is likely a conservative estimate since the area surveyed in winter 2002 did not encompass all areas in the Gulf of Alaska where pollock spawning is know to occur. The 2002 Shelikof Strait estimate for this model run was 351,053 t = 159,986 t (Biomass ≥43 cm) + 191,067 t (Biomass < 43cm). Estimated age composition for this model was obtained by scaling up the estimated numbers at length ≥43 cm and applying the age-length key from the 2002 survey.

Model 6: This model is in response to concern expressed by NMFS Protected Resources that the recent ADFG survey estimates may show a flatter trend than the overall population due to changes in pollock distribution. This model is similar to Model 3 except that we removed the 2002 ADFG survey rather than the Shelikof Strait EIT survey.

Comparison of Model 1 (estimated trawl catchability) with Model 2 (fixed trawl catchability) indicate that despite relatively large differences in stock biomass (20% decrease for Model 2), the difference in total log likelihood is slight (1.34) (Table 12). The higher log likelihood for Model 1 is a result of better fits to the age composition data and not to the survey time series. 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. A better approach might be to estimate catchability, and then carry forward that uncertainty into the decision-making process.

Models that remove the 2002 Shelikof Strait EIT survey estimate or adjust it upwards using ancillary information behave more or less as expected. There are improvements in the model fit to other data sources, and estimated stock biomass and 2003 yields increase. The difference in total log likelihood between Model 5 and Model 2 is 5.0, with most of the difference due to improved fits to the ADF&G survey and Shelikof Strait EIT surveys. Model 4, where the entire Shelikof Strait EIT survey was removed, resulted in estimates of stock biomass that were somewhat higher in 2003, but reasonably consistent with other models in population trends. One important consequence of removing the Shelikof Strait EIT survey is that uncertainty in population and spawning biomass estimates is higher. Model 6, where the 2002 ADFG survey is removed, results in lower stock biomass and yield in 2003, and poorer fits to all surveys, including the Shelikof Strait EIT survey.

Model Evaluation

Residual plots 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 13-15 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 a juveniles, but was not nearly as strong in later fishery age composition data.

Model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 2001) (Figs. 16-18). 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 the 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 does not fit either the 2002 Shelikof Strait EIT survey or the ADF&G trawl survey biomass estimates, and instead falls in between.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.7, similar to the 2001 assessment (Fig. 19). The change in log likelihood is small (less than two) 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 13 (see also Fig. 20). Table 14 gives the estimated population numbers at age for the years 1961-2002. Table 15 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1969-2002 (see also Fig. 21). 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 2002 is estimated to be at 28% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2002 indicates the current estimated trend in spawning biomass for 1969-2002 is consistent with previous estimates (Fig. 22). All time series show a similar pattern of increasing spawning biomass to the early 1980's, an abrupt decline between 1980 and 1985, followed by a gradual decrease. Retrospective biases in the assessment are small, but based on the current assessment, there was some tendency to underestimate current year abundance from 1993 to 1998, followed by several years of overestimating current-year abundance. The estimated 2002 age composition from the current assessment shows some differences compared to the estimated age composition in the 2001 assessment, primarily lower numbers of age-2 and age-3 fish (Fig. 22). As we had anticipated last year, the estimate of the 1999 year class decreased, but remains much larger than an average year class (2.7 times mean 1979-2000 recruitment).

Stock and recruitment

Recruitment of Gulf of Alaska pollock is more variable (standard deviation of log recruitment = 1.01) than Eastern Bering Sea pollock (standard deviation of log recruitment = 0.64). Among North Pacific groundfish stocks with age-structured assessments, GOA pollock ranks second in recruitment variability after sablefish (http://www.refm.noaa.gov/stocks/specs/Data%20Tables.htm). However, unlike sablefish, 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, a typical pattern of biomass variability for Gulf of Alaska pollock will be sharp increases due to strong recruitment, followed by a period of 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. 21). Because of high recruitment variability, the mean relationship between stock size and abundance is not apparent despite good contrast in stock abundance (Fig. 23). 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. 23). 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 new year classes in the table below. Subsequent to the 1999 year class, information on the strength of recruiting year classes is mixed and highly uncertain. The 2000 year class was very abundant at age one in the 2001 NMFS trawl survey, but not particularly abundant in the Shelikof Strait EIT survey. The 2001 year class was nearly absent in the 2002 Shelikof Strait survey, but the FOCI prediction for the 2001 was average-strong due to favorable environmental conditions and good larval counts. Neither the 2000 nor the 2001 year class appears to be as strong as the 1999 year class.

Year of recruitment	2002	2003	2004
Year class	2000	2001	2002
FOCI prediction	*Average*	*Average- Strong*	*Average*
Survey information	2001 Shelikof EIT survey age-1 estimate is 272.4 million (7th in abundance out of 18 surveys) 2001 NMFS bottom trawl age-1 estimate is 412.8 million (1st in abundance out of 7 surveys)	2002 Shelikof EIT survey age-1 estimate is 6.0 million (18th in abundance out of 18 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 16). Spawning biomass reference levels were based on mean 1979-2000 recruitment (805 million). The average did not include the recruitment in 2001 and 2002 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 2000-2002 to estimate current reproductive potential. The SPR at F=0 was estimated as 0.746 kg/recruit, which is nearly equal to the estimate in the 2001 assessment. The increase in weight at age is counterbalanced by the lower maturity at age. 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. For SPR calculations, we used a selectivity pattern based on an average for 1992-2001.

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

		Equilibrium under average 1979-2000 recruitment				
F_{SPR} rate	Fishing mortality	Avg. Recr. (Million)	Total 3+ biom. (1000 t)	Female spawning biom. (1000 t)	Catch (1000 t)	Harvest rate
100.0%	0.000	805	1895	600	0	0.0%
50.0%	0.210	805	1280	300	148	11.5%
45.0%	0.248	805	1214	270	162	13.3%
40.0%	0.294	805	1146	240	176	15.4%
35.0%	0.350	805	1077	210	190	17.7%

The $B_{40\%}$ estimate of 240,000 t is about 2% lower than the estimate of 245,000 t in the 2001 assessment. The model estimate of spawning biomass in 2003 is 177,070 t, which is 28% 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 144,490 t, or 24% of unfished spawning biomass.

2003 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. Last year, 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

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

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

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

Stock status: $B / B^* \le 0.05$, *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^* (= B48%) to $0.05B^*$ (Fig. 24).

Projections for 2003 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 12. Projections are obtained using the estimated abundance of the 1999 year class (2.1 billion), and a second set of projections where the 1999 year class is assumed to be average as a precautionary assumption.

ABC recommendation

There were two major pieces of new information about abundance trends in 2002. The 2002 Shelikof Strait EIT indicated at 38% decline in total biomass, but a steeper decline (62%) in adult biomass (≥43 cm). In contrast, the 2002 ADF&G crab/groundfish survey in 2002 increased by 11%. Concern about the decline in the 2002 Shelikof Strait EIT survey is mitigated by the additional surveying effort which suggests that the decline in 2002 can be attributed to reduced utilization of Shelikof Strait for spawning (or delayed spawning) rather than a reduction in gulfwide pollock abundance. The Shelikof Strait EIT survey time series has previously showed large negative deviations from the mean fraction of the stock surveyed (See Fig. 5). Nevertheless, the cause for these apparent changes in migration to spawning areas is not known, and there is some concern that changes in spawning behavior alone could lead to rapid changes in pollock abundance in the future.

We consider Model 2 (last year's model configuration) and Model 5 (2002 Shelikof Strait EIT survey estimate derived from total survey biomass) as the two strongest candidates on which to base yield recommendations. While adjustments to survey estimates should be used sparingly (if at all), the approach we took for Model 5 has a sound rationale, and is likely to be somewhat conservative in that the total surveyed biomass during winter EIT surveys is less than the total population biomass. However, no survey used in the pollock assessment 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. On balance, Model 2 seems preferable, though we consider Model 5 as a viable alternative that others might legitimately prefer.

A second major consideration is whether to use the model estimate of the 1999 year class or whether to set it to mean recruitment for yield recommendations. Although the estimate of the 1999 year class is lower, it is considerably less uncertain than last year's estimate (Fig. 25). The model estimates of uncertainty indicate that there is negligible probability that the 1999 year class is below average. The current estimate of 1999 year class abundance is derived not only from the Shelikof Strait EIT survey results, but also from the strong appearance in the 2001 fishery age composition. More 2-year old fish were caught in 2001 than in any year since 1985. This is in contrast to the 1994 year class, whose abundance was initially estimated as very high (i.e., in the 1996 assessment), but declined to slightly larger than average in subsequent assessments. The lack of the 1994 year class in the fishery age composition data in 1996 was the first evidence that its abundance had been overestimated. Because stock size is relatively close to the B20% threshold below which fishing must be stopped, we concluded it was better to continue with the assumption of average recruitment for this year. The 2003 NMFS bottom trawl survey will be a critical piece of information for establishing the strength of this year class, and we anticipate moving to the model estimate in next year's assessment.

Based on these considerations, we used Model 2, an assumed average 1999 year class, and the adjusted $F_{40\%}$ harvest rate developed in last year's assessment for the author's recommended ABC. Compared to the projected 2003 of 76,080 t using the author's recommended adjusted $F_{40\%}$ harvest rate developed in last year's assessment, the current projection is 49,590 t, representing a decrease of 35%. This decrease is a result of the low 2002 Shelikof Strait survey biomass estimate and new maturity at age estimates. 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 the 2002 Shelikof Strait survey biomass estimate despite evidence that the fraction of the stock spawning in Shelikof Strait was lower in 2002; and 4) applying a more conservative harvest rate than the maximum permissible F_{ABC}. Collectively these risk-averse elements reduce the recommended ABC to less than 40% of the model point estimate.

In a preliminary evaluation of the probability of that the stock is below the $B_{20\%}$ threshold, we modified the assessment model to include 2003, and assumed 2003 catches will be equal to the ABC recommendation. For 2004, catch is derived from the estimate of spawning biomass in 2004 and the author's recommended fishing mortality schedule. We then sampled from the joint marginal likelihood of spawning biomass and fishing mortality in 2003 using Markov chain Monte Carlo (MCMC) (Fig. 26). 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 less than 1% in 2001, increased to 21% in 2002, and will decline to 2% in 2003, and less than 1% in 2004.

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 1979-2000 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 16. 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 2003, 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 1998-2002 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 2003 and 2004, 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 17 and 18. Table 17 contains projections using the model estimate of the 1999 year class, while Table 18 contains projections where the 1999 year class is assumed to be average. Under all harvest policies, spawning biomass is projected to increase after 2003. 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 143,200 t in 2003 for an FOFL harvest rate, which is less than $B_{35\%}$ (210,000 t), but greater than ½ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2013 is 228,960 t, 109% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2005 is 173,400 t, which is less than $B_{35\%}$, but greater than ½ of $B_{35\%}$. Projected mean spawning biomass in 2015 is 230,200 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 2002 is for the area west of 140 ^{o} 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.

Year	Foreign	Joint Venture	Domestic	Total	TAC	Research
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	48
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					53,490	32
Average (1977-2001)				117,594	137,216	164

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). 1991-2001--NMFS Alaska Regional Office.

Table 2. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska 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
1991	Retained	35,943	6,913	42,836	5,489	0	0	91,181	
	Discarded	4,838	793	3,459	207	0	10	9,308	9.3%
	Total	40,781	7,706	46,295	5,696	0	10	100,488	
1992	Retained	16,014	14,171	47,467	160	0	0	77,812	
	Discarded	3,477	3,066	6,408	73	1	20	13,045	14.4%
	Total	19,490	17,237	53,876	233	1	20	90,857	
1993	Retained	19,791	22,080	58,188	583	0	2	100,645	
	Discarded	1,413	1,708	5,065	65	8	5	8,264	7.6%
	Total	21,204	23,788	63,253	648	8	7	108,908	
1994	Retained	16,238	19,917	58,511	6,362	0	0	101,028	
	Discarded	1,028	2,321	2,453	499	2	3	6,306	5.9%
	Total	17,266	22,239	60,963	6,862	2	3	107,335	
1995	Retained	28,473	11,032	21,989	480	2,739	46	64,759	
	Discarded	1,905	2,048	3,778	53	75	1	7,859	10.8%
	Total	30,378	13,080	25,768	533	2,813	47	72,618	
1996	Retained	23,100	10,150	11,571	510	775	0	46,107	
	Discarded	1,100	2,143	1,789	103	19	3	5,156	10.1%
	Total	24,200	12,293	13,361	613	794	3	51,263	
1997	Retained	25,253	29,736	22,064	3,938	1,807	89	82,888	
	Discarded	1,009	3,179	2,998	30	19	7	7,242	8.0%
	Total	26,262	32,916	25,062	3,968	1,826	96	90,130	
1998	Retained	28,815	48,530	38,753	6,316	1,655	8	124,077	
	Discarded	370	361	262	25	2	0	1,022	0.8%
	Total	29,185	48,892	39,015	6,341	1,657	8	125,098	
1999	Retained	22,864	37,349	29,515	1,737	2,178	1	93,643	
	Discarded	521	784	578	22	39	3	1,947	2.0%
	Total	23,385	38,133	30,093	1,759	2,216	4	95,590	
2000	Retained	21,380	11,314	35,078	1,917	1,181	0	70,870	
	Discarded	694	443	854	191	22	4	2,209	3.0%
	Total	22,074	11,757	35,933	2,108	1,203	4	73,080	
2001	Retained	30,298	17,186	19,942	2,327	1,590	0	71,344	
	Discarded	173	205	330	24	0	0	732	1.0%
	Total	30,471	17,391	20,272	2,351	1,590	0	72,076	
Average (1991-2001)		25,882	22,312	37,626	2,828	1,101	18	89,768	

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

	Age															
Year	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

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

	Number aged			Number measured		
Year	Males	Females	Total	Males	Females	Total
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

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^o W lon., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

	EIT Shelikof Strait survey		NMFS bottom trawl west of 140^o W lon.	Shelikof Strait egg production	ADF&G crab/groundfish survey
Year	Biosonics	Simrad EK500			
1981	2,785,755			1,788,908	
1982					
1983	2,278,172				
1984	1,757,168		723,087		
1985	1,175,823			768,419	
1986	585,755			375,907	
1987			735,746	484,455	
1988	301,709			504,418	
1989	290,461			433,894	214,434
1990	374,731		825,535	381,475	114,451
1991	380,331			370,000	
1992	580,000	681,400		616,000	127,359
1993	295,785	408,200	754,337		132,849
1994		467,300			103,420
1995		618,300			
1996		745,400	665,699		122,477
1997		570,100			93,728
1998		489,900			81,215
1999			611,210		53,587
2000		334,900			102,871
2001		369,600	216,761		86,967
2002		229,100			96,237

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 1992-2002. 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.

		No. of tows with	Survey biomass		Number aged			Number measured	
Year	No. of tows	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
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

Table 7. 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).

Gulf of Alaska bottom trawl survey															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
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

Shelikof Strait EIT survey																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
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

Table 8. 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.

Year	Biomass (t)	FPC-adjusted biomass (t)	CV
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 9. 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.

Year class	FOCI prediction	Year of EIT survey	McKelvey index	Rank abundance of McKelvey index
1980		1981	0.078	10
1981				
1982		1983	0.001	19
1983		1984	0.062	12
1984		1985	2.092	3
1985		1986	0.579	4
1986				
1987		1988	0.017	17
1988		1989	0.399	5
1989		1990	0.049	15
1990		1991	0.022	16
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	18
2002	Average	---	---	---

Table 10. Maturity stages for female pollock used to determine pollock maturity. Female pollock ≥ stage 3 in the 1983-1995 table are considered mature, while maturity stages ≥ 4 are considered mature in the 1996-2002 table.

Maturity Stage	Condition	Description
1983-1995 table		
1	Immature	Ovaries small, transparent, tapered.
2	Developing	Ovaries tapered, two distinct lobes with well-developed red blood vessels. May be partially granular (some distinct ova).
3	Mature	Ova distinctly visible but cannot be extruded with compression. Ovaries are two large, distinct lobes. Gonads expelled through body wall incision.
4	Spawning	Ova extrude when ovaries are compressed, or ova are loose in ovaries.
5	Spent	Ovaries large but flaccid and watery. May contain remnants of disintegrated ova and associated structures.
1996-2002 table		
1	Immature	Ovary transparent, colorless to gray, eggs invisible to eye.
2	Developing I	Ovaries translucent, grayish-red, length is less than half of ventral cavity, (Single eggs can be seen with magnifying glass) (occasionally small orange ovaries).
3	Developing II	Ovaries opaque with blood capillaries, occupy about half the length of ventral cavity, eggs visible to eye as whitish, granular.
4	Pre-spawning I	Ovaries orange, reddish, occupy about 2/3 of ventral cavity, eggs clearly discernible, opaque.
5	Pre-spawning II	Ovaries fill ventral cavity, some eggs translucent (hydrated).
6	Spawning	Roe runs with slight pressure, most eggs hydrated (translucent) with few opaque eggs left in ovary.
7	Spent I	Ovaries not yet fully empty few opaque eggs left in ovary.
8	Spent II	Ovaries empty, red, a few eggs in the state of reabsorption.

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

	2		3		4		5		6		7		8		9		10+		Total
Year	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	Mat.	Tot.	SS
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	42	1	90	2	12	45	119	114	201	20	41	16	19	14	14	60	63	601
2001	0	99	1	76	16	58	20	63	58	85	113	149	37	41	18	20	23	23	614
2002	0	11	2	77	15	58	51	68	84	90	76	78	83	83	13	13	21	21	499

Proportion mature

	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	0.011	0.167	0.378	0.567	0.488	0.842	1.000	0.952
2001	0.000	0.013	0.276	0.317	0.682	0.758	0.902	0.900	1.000
2002	0.000	0.026	0.259	0.750	0.933	0.974	1.000	1.000	1.000
Average									
1983-2002	0.001	0.025	0.248	0.543	0.802	0.891	0.960	0.979	0.990
1993-2002	0.000	0.008	0.193	0.582	0.808	0.870	0.952	0.980	0.984
1998-2002	0.000	0.013	0.192	0.412	0.754	0.796	0.936	0.975	0.985
Hollowed et al. (1991)	0.034	0.116	0.325	0.639	0.867	0.960	0.989	0.997	1.000

Table 12. Results comparing model fits, stock status, and 2003 yield for different model configurations.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Model fits						
Total -log(Likelihood)	787.947	789.297	781.379	555.247	784.329	786.851
NMFS trawl q	0.70	1.00	1.00	1.00	1.00	1.00
Age composition data						
Fishery effective N	243	241	244	226	244	241
NMFS bottom trawl effective N	46	45	46	58	46	44
Shelikof Strait EIT effective N	39	38	33	---	35	38
Length composition data						
ADF&G trawl effective N	36	35	37	34	36	34
Historical trawl survey effective N	19	20	20	16	20	20
Survey abundance						
NMFS bottom trawl RMSE	0.443	0.442	0.442	0.348	0.439	0.449
Shelikof Strait EIT RMSE	0.388	0.375	0.352	---	0.373	0.377
ADF&G trawl RMSE	0.258	0.258	0.228	0.272	0.236	0.260
Historical trawl survey RMSE	1.524	1.522	1.523	1.594	1.521	1.522
Egg production survey RMSE	0.510	0.481	0.475	0.491	0.476	0.484
Stock status						
Estimated 1999 YC						
2003 Spawning biomass	217,630	177,070	207,910	166,050	196,470	166,010
(CV)	(19%)	(14%)	(15%)	(21%)	(14%)	(15%)
2003 3+ biomass	1,293,200	1,137,600	1,425,700	894,220	1,268,000	1,071,400
(CV)	(19%)	(17%)	(20%)	(27%)	(16%)	(18%)
Depletion (B2003/B0)	29%	28%	32%	27%	30%	26%
$B_{40\%}$	303,029	257,500	263,461	247,539	260,671	255,438
1999 YC reduced to average						
2003 Spawning biomass	184,290	144,490	165,970	155,430	158,280	136,040
(CV)	(19%)	(13%)	(13%)	(18%)	(13%)	(14%)
2003 3+ biomass	809,950	670,410	820,820	741,840	718,280	642,710
(CV)	(16%)	(11%)	(18%)	(20%)	(11%)	(11%)
Depletion (B2003/B0)	26%	24%	28%	26%	26%	23%
$B_{40\%}$	285,155	240,186	241,154	241,821	240,363	239,527
2003 yield (000 t)						
Estimated 1999 YC						
F_{OFL}	147.68	120.09	165.64	92.64	146.23	106.65
MaxFABC	126.47	102.46	141.43	79.14	124.83	90.95
Author's F	106.69	86.02	119.02	66.51	104.97	76.26
1999 YC reduced to average						
F_{OFL}	90.58	69.41	93.70	75.94	83.11	62.04
MaxFABC	77.55	59.21	80.01	64.87	70.94	52.89
Author's F	65.30	49.59	67.19	54.48	59.53	44.23

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 2002
Model 4--Remove entire Shelikof Strait survey
Model 5--Use total 2002 EIT survey biomass
Model 6--Remove ADF&G 2002

Table 13. 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 domestic (1985-91)	Recent domestic (1992-2001)	EIT survey	Bottom trawl survey	ADF&G bottom trawl	400-mesh eastern trawl 1961-82
2	0.001	0.039	0.041	0.032	1.000	0.150	0.053	0.119
3	0.019	0.265	0.156	0.129	1.000	0.255	0.112	0.389
4	0.425	0.761	0.421	0.401	0.998	0.423	0.221	0.750
5	1.000	1.000	0.733	0.752	0.992	0.661	0.391	0.934
6	0.948	0.928	0.943	0.934	0.971	0.906	0.596	0.985
7	0.712	0.685	1.000	0.988	0.900	1.000	0.777	0.997
8	0.366	0.341	0.849	1.000	0.703	0.866	0.899	0.999
9	0.129	0.121	0.464	0.976	0.385	0.629	0.966	1.000
10	0.038	0.037	0.154	0.387	0.142	0.418	1.000	1.000

Table 14. Total estimated abundance at age (numbers in 000,000s) of Gulf of Alaska pollock from the age-structured assessment model.

	Age								
	2	3	4	5	6	7	8	9	10
1961	377	192	119	74	54	38	28	21	16
1962	411	279	142	88	55	40	28	21	27
1963	441	304	207	105	65	40	30	21	36
1964	100	326	226	153	78	48	30	22	42
1965	248	74	242	167	113	57	36	22	47
1966	139	184	55	178	122	83	42	26	51
1967	329	103	136	40	127	87	59	31	57
1968	407	243	76	99	29	90	63	43	65
1969	693	302	180	56	70	20	65	46	80
1970	309	513	223	126	36	45	14	46	92
1971	716	229	380	161	87	25	32	10	102
1972	1,339	531	170	276	114	62	18	23	82
1973	986	992	392	120	185	77	43	13	78
1974	3,388	730	734	279	80	124	53	31	67
1975	652	2,509	540	518	180	52	84	38	72
1976	418	482	1,836	378	359	125	37	61	81
1977	1,960	309	348	1,273	261	250	89	27	104
1978	2,668	1,449	224	239	867	179	176	64	97
1979	2,455	1,970	1,039	154	164	599	126	127	118
1980	3,485	1,814	1,424	716	105	113	422	91	180
1981	1,778	2,573	1,314	996	495	73	79	303	200
1982	421	1,314	1,871	915	682	339	51	57	369
1983	497	309	936	1,296	631	472	239	37	315
1984	193	365	219	631	860	421	324	172	260
1985	486	140	251	137	377	514	264	226	318
1986	1,637	354	97	152	75	201	282	167	397
1987	559	1,196	249	63	95	46	126	194	417
1988	154	411	862	172	42	62	30	83	446
1989	368	113	298	604	115	27	40	20	387
1990	1,688	272	83	213	410	75	17	25	296
1991	1,080	1,248	200	60	146	263	46	11	235
1992	431	799	916	144	41	96	170	30	161
1993	252	318	581	640	95	27	62	109	136
1994	140	186	231	407	427	62	17	39	168
1995	219	103	135	163	276	282	40	11	143
1996	829	162	76	97	113	188	192	27	109
1997	364	613	119	55	68	78	129	132	96
1998	99	269	447	84	36	44	49	81	147
1999	183	72	187	285	50	21	25	28	143
2000	400	135	51	123	172	29	12	15	110
2001	2,141	295	98	35	77	103	17	7	84
2002	195	1,577	213	66	22	45	60	10	63

Table 15. 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 biomass (1,000 t)	3+ total biomass (1,000 t)	Female spawn. biom. (1,000	Age 2 recruits (million)	Catch (t)	Harvest rate	2001 Assessment results: 3+ total biomass	2001 Assessment results: Female spawn. biom.	2001 Assessment results: Age 2 recruits	2001 Assessment results: Harvest rate
1969	695	593	141	693	17,553	3%	607	156	708	3%
1970	755	709	138	309	9,343	1%	726	157	316	1%
1971	846	740	153	716	9,458	1%	758	174	732	1%
1972	1,049	852	171	1,339	34,081	4%	871	197	1,370	4%
1973	1,278	1,133	188	986	36,836	3%	1,160	221	1,006	3%
1974	1,837	1,339	221	3,388	61,880	5%	1,371	264	3,447	5%
1975	2,256	2,160	275	652	59,512	3%	2,206	337	659	3%
1976	2,353	2,291	381	418	86,527	4%	2,339	446	421	4%
1977	2,379	2,091	481	1,960	118,356	6%	2,134	552	1,952	6%
1978	2,640	2,247	524	2,668	96,935	4%	2,281	593	2,646	4%
1979	3,089	2,728	531	2,455	105,748	4%	2,749	609	2,438	4%
1980	3,695	3,183	584	3,485	114,622	4%	3,192	667	3,470	4%
1981	4,094	3,833	474	1,778	147,744	4%	3,833	550	1,772	4%
1982	4,025	3,964	542	421	168,740	4%	3,959	612	419	4%
1983	3,419	3,344	707	497	215,608	6%	3,337	780	496	6%
1984	2,733	2,704	749	193	307,401	11%	2,697	805	193	11%
1985	2,065	1,992	642	486	284,826	14%	1,986	678	492	14%
1986	1,868	1,602	588	1,637	87,809	5%	1,597	612	1,650	5%
1987	1,770	1,679	487	559	69,751	4%	1,679	512	564	4%
1988	1,619	1,594	392	154	65,739	4%	1,597	412	155	4%
1989	1,509	1,447	355	368	78,392	5%	1,451	379	371	5%
1990	1,518	1,234	384	1,688	90,744	7%	1,239	408	1,702	7%
1991	1,552	1,370	347	1,080	100,488	7%	1,378	375	1,095	7%
1992	1,794	1,723	291	431	90,857	5%	1,738	321	441	5%
1993	1,618	1,577	329	252	108,908	7%	1,595	368	264	7%
1994	1,353	1,331	385	140	107,335	8%	1,350	425	144	8%
1995	1,144	1,123	356	219	72,618	6%	1,141	389	235	6%
1996	1,009	929	326	829	51,263	6%	949	352	911	5%
1997	969	934	282	364	90,130	10%	972	306	410	9%
1998	851	836	214	99	125,098	15%	889	236	57	14%
1999	676	650	191	183	95,590	15%	690	218	195	14%
2000	616	566	173	400	73,080	13%	540	200	519	14%
2001	814	589	164	2,141	72,076	12%	537	194	3,282	13%
2002	1,151	1,130	142	195		---				
Average										
1969-2002	1,795	1,654	362	976	98,638	6%	1,683	409	1,046	6%
1979-2000				805						

Table 16. 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 1996-2001. Proportion mature females is the average for 1983-2002 from winter EIT survey specimen data. Spawning weight at age is the average for the Shelikof Strait EIT survey in 2000-2002.

			Weight at age (kg)			
Age	Natural mortality	Fishery selectivity (Avg. 1992-2002)	Spawning (March 15)	Population (June-Aug.)	Fishery (Avg. 1999-2001)	Proportion mature females
2	0.3	0.032	0.070	0.115	0.321	0.001
3	0.3	0.129	0.190	0.358	0.490	0.025
4	0.3	0.401	0.406	0.653	0.733	0.248
5	0.3	0.752	0.693	0.857	0.921	0.543
6	0.3	0.934	0.911	0.956	1.043	0.802
7	0.3	0.988	1.080	1.056	1.189	0.891
8	0.3	1.000	1.266	1.236	1.318	0.960
9	0.3	0.976	1.415	1.276	1.442	0.979
10+	0.3	0.387	1.649	1.418	1.587	0.990

Table 17. Projections of Gulf of Alaska pollock expected spawning biomass, full recruitment fishing mortality, and catch for 2003-2015 under different harvest policies. All projections begin with estimated age composition in 2003 using Model 2. Coefficients of variation are given in parentheses, and reflect only variability in recruitment in 2004-2015. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 643,800, 257,500, and 225,300 t, respectively. These estimates are based on 1979-2001 mean recruitment (i.e., including the 1999 year class).

Spawning biomass	*F_{OFL}*		*Max F_{ABC}*		*Author's recommended F*		*50% of max FABC*		*Average F*		*F = 0*	
2003	175,698	(0.00)	176,550	(0.00)	177,333	(0.00)	178,897	(0.00)	175,846	(0.00)	181,280	(0.00)
2004	233,289	(0.00)	239,426	(0.00)	245,233	(0.00)	257,576	(0.00)	237,250	(0.00)	277,932	(0.00)
2005	243,508	(0.01)	256,395	(0.01)	269,084	(0.01)	300,219	(0.01)	263,853	(0.01)	356,307	(0.01)
2006	228,300	(0.11)	244,081	(0.11)	260,013	(0.10)	307,974	(0.09)	261,485	(0.11)	398,398	(0.07)
2007	232,162	(0.27)	249,802	(0.27)	266,584	(0.25)	327,850	(0.23)	272,472	(0.27)	453,316	(0.19)
2008	233,618	(0.36)	252,698	(0.36)	268,187	(0.34)	338,995	(0.34)	277,838	(0.37)	492,596	(0.28)
2009	238,434	(0.37)	259,267	(0.38)	273,629	(0.35)	353,413	(0.37)	286,048	(0.40)	533,394	(0.31)
2010	239,972	(0.38)	261,815	(0.39)	274,677	(0.36)	359,291	(0.39)	289,442	(0.42)	550,546	(0.35)
2011	241,750	(0.38)	264,512	(0.39)	276,519	(0.37)	365,996	(0.39)	293,027	(0.42)	570,416	(0.36)
2012	244,143	(0.39)	267,566	(0.40)	279,012	(0.37)	372,392	(0.40)	296,931	(0.43)	587,317	(0.37)
2013	246,544	(0.40)	270,412	(0.41)	281,612	(0.38)	377,905	(0.40)	300,543	(0.44)	600,930	(0.37)
2014	247,377	(0.40)	271,776	(0.41)	282,734	(0.38)	381,695	(0.41)	302,722	(0.44)	611,620	(0.37)
2015	247,322	(0.40)	272,029	(0.41)	282,807	(0.38)	383,582	(0.41)	303,543	(0.44)	618,716	(0.38)
Fishing mortality	*F_{OFL}*		*Max F_{ABC}*		*Author's recommended F*		*50% of max FABC*		*Average F*		*F = 0*	
2003	0.23	(0.00)	0.20	(0.00)	0.16	(0.00)	0.10	(0.00)	0.23	(0.00)	0	---
2004	0.32	(0.00)	0.27	(0.00)	0.23	(0.00)	0.14	(0.00)	0.23	(0.00)	0	---
2005	0.33	(0.01)	0.29	(0.00)	0.26	(0.01)	0.15	(0.00)	0.23	(0.00)	0	---
2006	0.30	(0.07)	0.27	(0.05)	0.25	(0.07)	0.15	(0.00)	0.23	(0.00)	0	---
2007	0.29	(0.13)	0.26	(0.10)	0.24	(0.13)	0.15	(0.00)	0.23	(0.00)	0	---
2008	0.29	(0.18)	0.25	(0.15)	0.24	(0.18)	0.14	(0.04)	0.23	(0.00)	0	---
2009	0.29	(0.20)	0.25	(0.17)	0.24	(0.20)	0.14	(0.06)	0.23	(0.00)	0	---
2010	0.29	(0.21)	0.25	(0.18)	0.24	(0.21)	0.14	(0.08)	0.23	(0.00)	0	---
2011	0.29	(0.21)	0.25	(0.18)	0.24	(0.22)	0.14	(0.09)	0.23	(0.00)	0	---
2012	0.29	(0.20)	0.26	(0.18)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2013	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2014	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2015	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
Catch	*F_{OFL}*		*Max F_{ABC}*		*Author's recommended F*		*50% of max FABC*		*Average F*		*F = 0*	
2003	120,087	(0.00)	102,460	(0.00)	86,021	(0.00)	52,603	(0.00)	117,050	(0.00)	0	---
2004	196,179	(0.02)	174,784	(0.02)	153,429	(0.01)	100,786	(0.01)	145,611	(0.02)	0	---
2005	195,630	(0.08)	182,446	(0.07)	167,976	(0.08)	108,209	(0.06)	147,081	(0.07)	0	---
2006	181,838	(0.31)	171,886	(0.28)	164,583	(0.30)	114,205	(0.20)	151,923	(0.22)	0	---
2007	183,716	(0.50)	172,412	(0.46)	169,294	(0.49)	119,114	(0.34)	156,667	(0.37)	0	---
2008	183,327	(0.57)	171,544	(0.53)	168,876	(0.56)	120,376	(0.41)	159,178	(0.43)	0	---
2009	180,738	(0.59)	168,064	(0.56)	164,777	(0.59)	114,715	(0.47)	153,922	(0.47)	0	---
2010	186,370	(0.58)	173,939	(0.55)	169,874	(0.59)	119,306	(0.47)	159,428	(0.46)	0	---
2011	187,998	(0.59)	175,800	(0.56)	171,400	(0.59)	120,680	(0.48)	160,927	(0.47)	0	---
2012	189,918	(0.60)	178,078	(0.56)	172,815	(0.60)	122,043	(0.48)	162,367	(0.47)	0	---
2013	192,475	(0.60)	180,008	(0.57)	175,273	(0.60)	123,498	(0.49)	163,820	(0.48)	0	---
2014	192,219	(0.60)	180,016	(0.57)	175,228	(0.60)	123,932	(0.48)	164,015	(0.48)	0	---
2015	192,512	(0.59)	180,559	(0.57)	175,521	(0.60)	124,517	(0.49)	164,526	(0.48)	0	---

Table 18. Projections of Gulf of Alaska pollock expected spawning biomass, full recruitment fishing mortality, and catch for 2003-2015 under different harvest policies. All projections begin with estimated age composition in 2003 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 2004-2015. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 600,000, 240,000, and 210,000 t, respectively.

Spawning biomass	F_{OFL}		*Max* F_{ABC}		*Author's recommended F*		*50% of max FABC*		*Average F*		*F = 0*	
2003	143,190	(0.00)	143,840	(0.00)	144,450	(0.00)	145,640	(0.00)	142,660	(0.00)	147,460	(0.00)
2004	157,350	(0.00)	161,130	(0.00)	164,750	(0.00)	172,170	(0.00)	154,820	(0.00)	184,380	(0.00)
2005	166,670	(0.01)	173,370	(0.01)	180,000	(0.01)	194,640	(0.01)	164,490	(0.01)	221,440	(0.01)
2006	181,410	(0.13)	190,330	(0.13)	199,370	(0.12)	221,000	(0.11)	181,700	(0.14)	265,230	(0.10)
2007	202,340	(0.28)	213,930	(0.28)	225,260	(0.27)	256,300	(0.26)	208,740	(0.31)	324,300	(0.23)
2008	213,020	(0.36)	227,490	(0.36)	239,670	(0.34)	282,490	(0.36)	228,820	(0.41)	376,540	(0.33)
2009	219,890	(0.36)	237,060	(0.37)	249,250	(0.35)	304,400	(0.38)	244,770	(0.42)	424,740	(0.36)
2010	222,220	(0.37)	241,290	(0.38)	252,860	(0.36)	318,070	(0.39)	254,630	(0.43)	459,710	(0.37)
2011	224,300	(0.37)	244,760	(0.38)	255,920	(0.36)	329,750	(0.39)	262,540	(0.43)	492,110	(0.37)
2012	226,660	(0.38)	248,010	(0.39)	258,780	(0.36)	339,050	(0.39)	269,240	(0.43)	517,560	(0.38)
2013	228,960	(0.39)	250,880	(0.39)	261,450	(0.37)	346,420	(0.39)	274,720	(0.43)	537,480	(0.37)
2014	229,970	(0.39)	252,470	(0.39)	262,820	(0.37)	351,660	(0.40)	278,420	(0.43)	553,020	(0.37)
2015	230,200	(0.39)	253,040	(0.39)	263,220	(0.37)	354,770	(0.40)	280,490	(0.43)	564,020	(0.37)
Fishing mortality	F_{OFL}		*Max* F_{ABC}		*Author's recommended F*		*50% of max FABC*		*Average F*		*F = 0*	
2003	0.20	(0.00)	0.17	(0.00)	0.14	(0.00)	0.08	(0.00)	0.23	(0.00)	0	---
2004	0.22	(0.00)	0.19	(0.00)	0.16	(0.00)	0.10	(0.00)	0.23	(0.00)	0	---
2005	0.24	(0.01)	0.21	(0.01)	0.18	(0.01)	0.12	(0.01)	0.23	(0.00)	0	---
2006	0.26	(0.10)	0.23	(0.09)	0.20	(0.11)	0.13	(0.06)	0.23	(0.00)	0	---
2007	0.28	(0.16)	0.24	(0.14)	0.22	(0.17)	0.14	(0.07)	0.23	(0.00)	0	---
2008	0.28	(0.19)	0.25	(0.17)	0.23	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2009	0.29	(0.20)	0.25	(0.18)	0.23	(0.21)	0.14	(0.10)	0.23	(0.00)	0	---
2010	0.29	(0.21)	0.25	(0.18)	0.24	(0.22)	0.14	(0.10)	0.23	(0.00)	0	---
2011	0.29	(0.20)	0.25	(0.18)	0.24	(0.22)	0.14	(0.10)	0.23	(0.00)	0	---
2012	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2013	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2014	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.09)	0.23	(0.00)	0	---
2015	0.29	(0.20)	0.26	(0.17)	0.24	(0.21)	0.14	(0.08)	0.23	(0.00)	0	---
Catch	F_{OFL}		*Max* F_{ABC}		*Author's recommended F*		*50% of max FABC*		*Average F*		*F = 0*	
2003	69,410	(0.00)	59,210	(0.00)	49,590	(0.00)	30,390	(0.00)	77,590	(0.00)	0	---
2004	84,640	(0.02)	74,910	(0.02)	65,100	(0.02)	42,580	(0.02)	84,870	(0.02)	0	---
2005	99,340	(0.11)	90,310	(0.11)	80,710	(0.10)	55,870	(0.10)	94,160	(0.10)	0	---
2006	129,150	(0.41)	118,580	(0.38)	108,540	(0.41)	76,340	(0.31)	111,940	(0.27)	0	---
2007	156,040	(0.55)	143,320	(0.52)	136,420	(0.56)	92,520	(0.42)	126,640	(0.41)	0	---
2008	166,190	(0.57)	153,240	(0.55)	148,720	(0.58)	100,140	(0.47)	136,070	(0.45)	0	---
2009	170,180	(0.57)	157,500	(0.55)	153,760	(0.58)	104,050	(0.48)	140,600	(0.46)	0	---
2010	174,450	(0.57)	162,580	(0.54)	158,570	(0.58)	109,290	(0.47)	146,310	(0.46)	0	---
2011	175,020	(0.58)	163,580	(0.55)	159,410	(0.58)	110,850	(0.47)	147,990	(0.46)	0	---
2012	176,610	(0.58)	165,550	(0.55)	160,700	(0.58)	112,640	(0.47)	149,820	(0.46)	0	---
2013	179,040	(0.58)	167,420	(0.55)	163,010	(0.59)	114,290	(0.47)	151,560	(0.47)	0	---
2014	179,060	(0.58)	167,690	(0.55)	163,190	(0.58)	115,020	(0.47)	152,160	(0.47)	0	---
2015	179,440	(0.58)	168,320	(0.55)	163,610	(0.58)	115,780	(0.47)	152,920	(0.47)	0	---

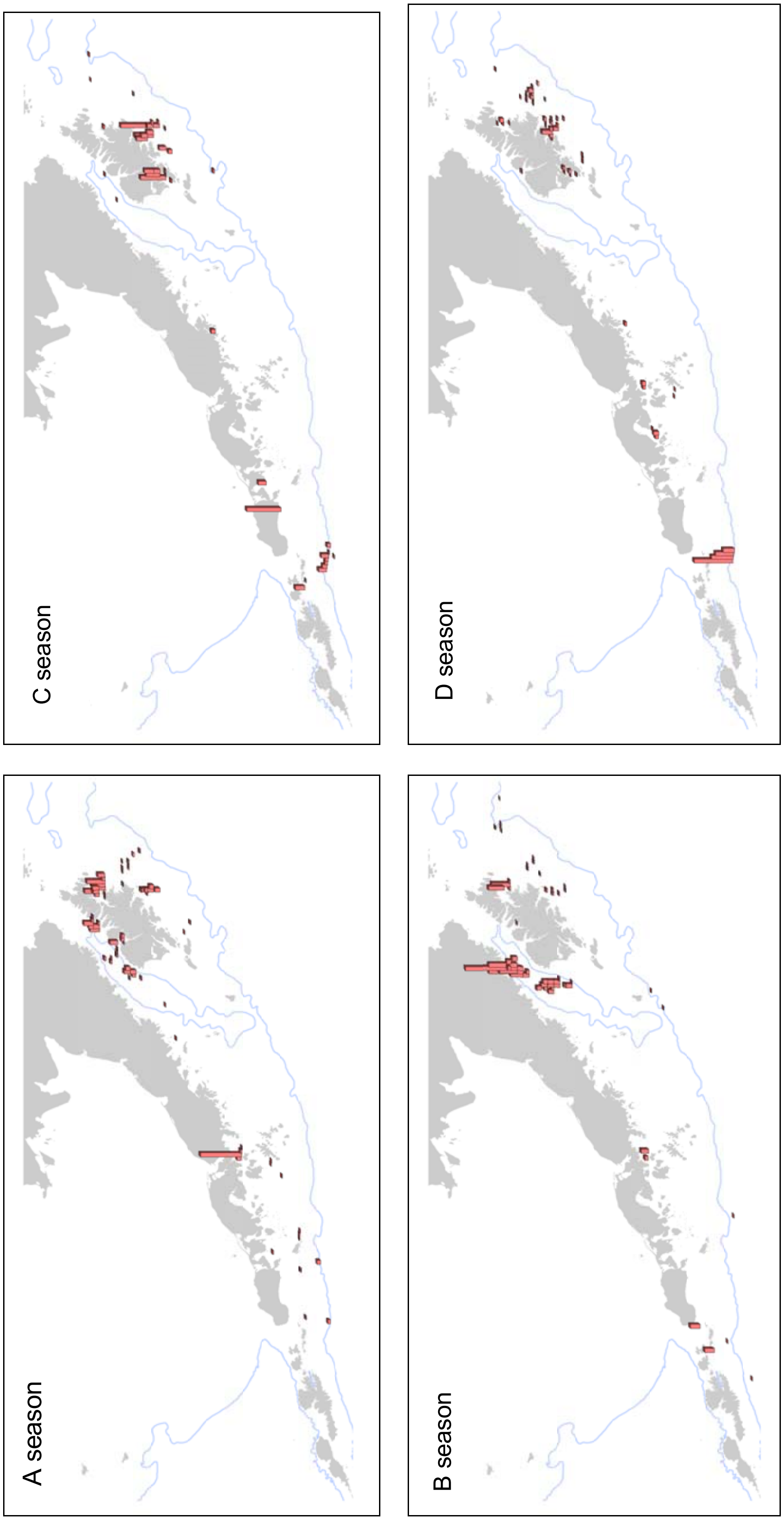


Figure 1. Pollock catch in 2001 by 10 sq. nmi. blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations, representing approximately 18% of the total GOA pollock catch. Blocks with less than 1.0 t of pollock catch are not shown. The height of the bar is proportional to the catch.

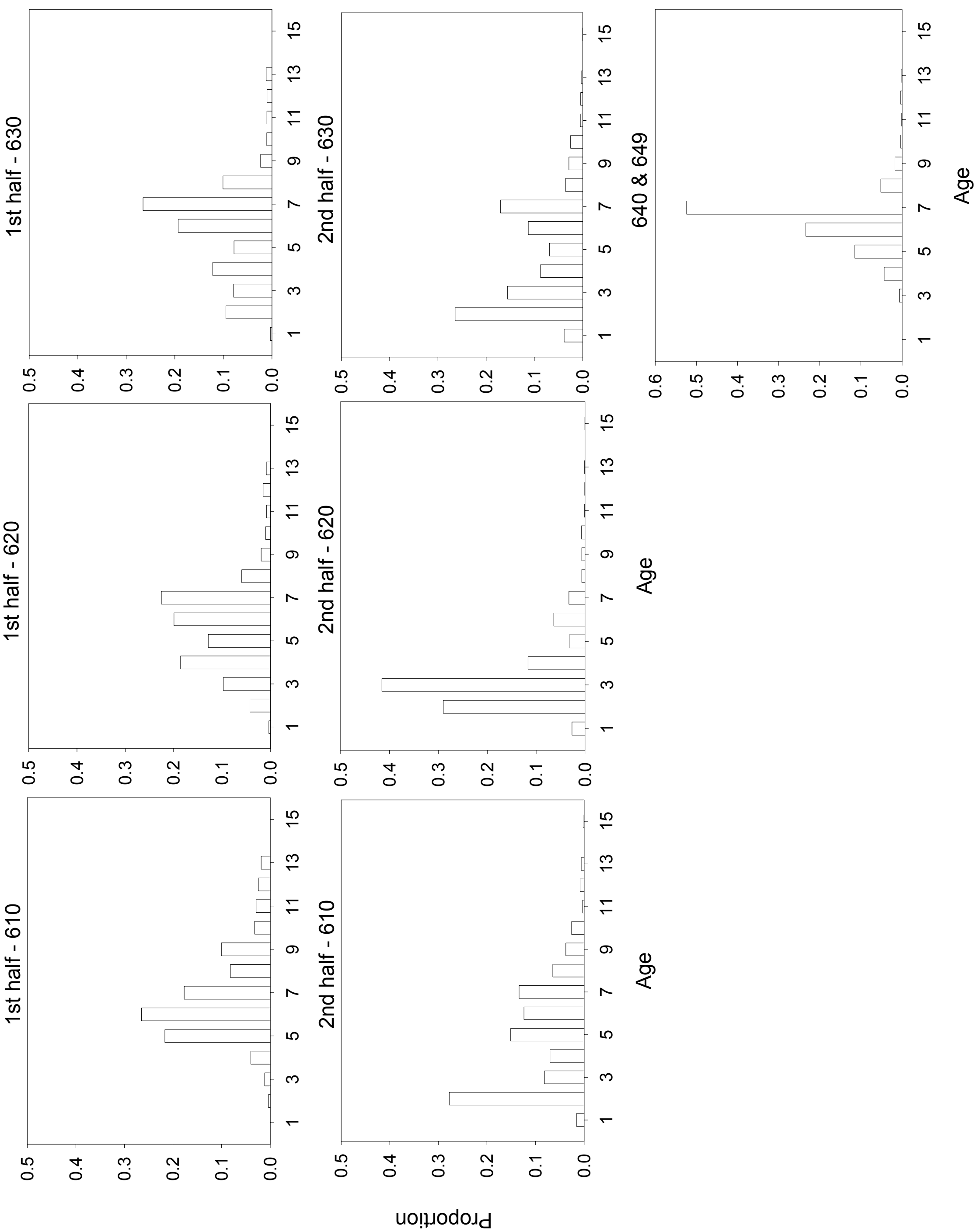


Figure 2. Gulf of Alaska pollock catch proportions at age by half year and statistical area in 2001.

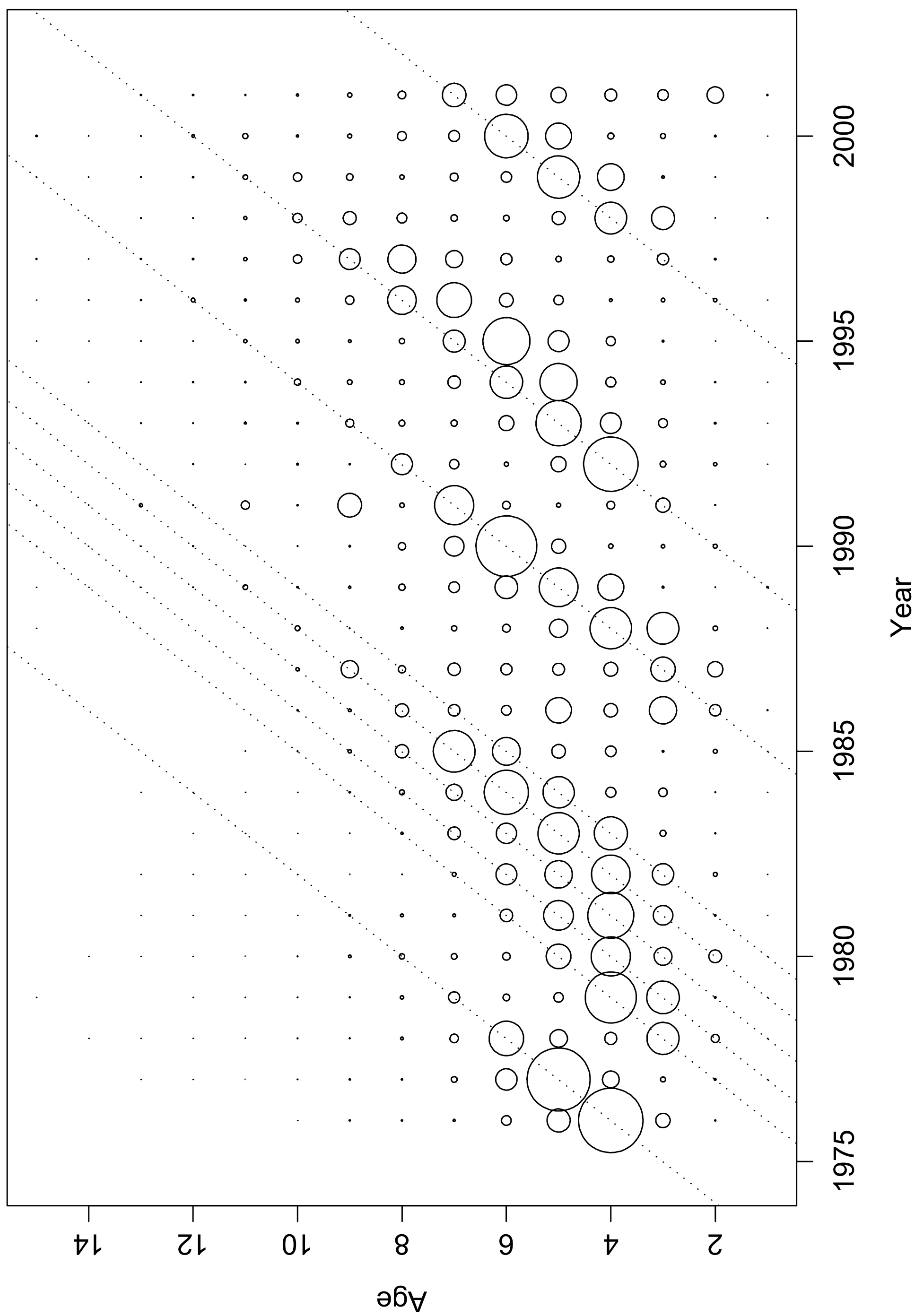


Figure 3. Gulf of Alaska pollock catch proportions at age (1976-2001). The diameter of the circle is proportional to the catch. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

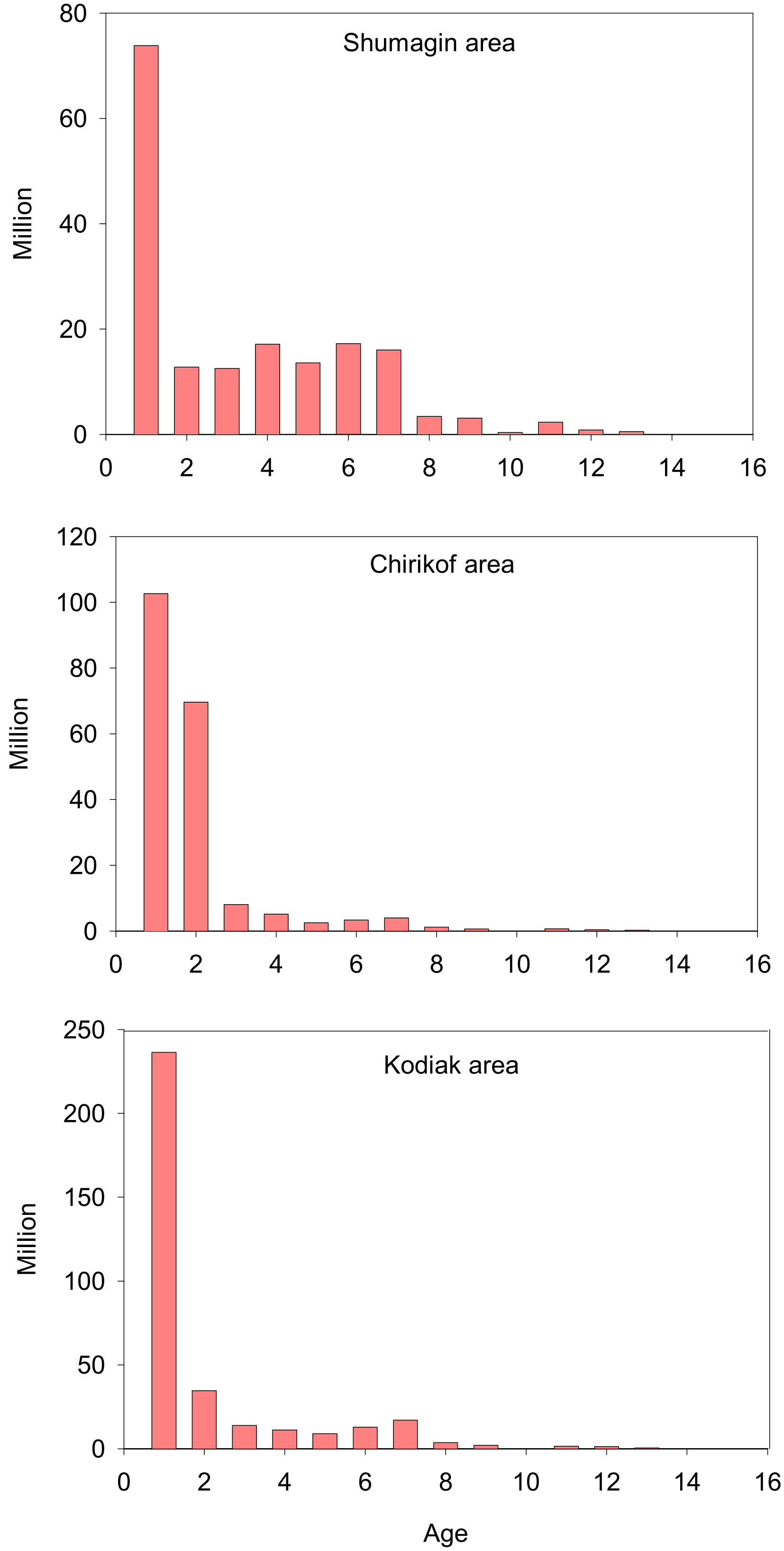


Figure 4. Pollock age distribution by INPFC area for the 2001 NMFS bottom trawl survey

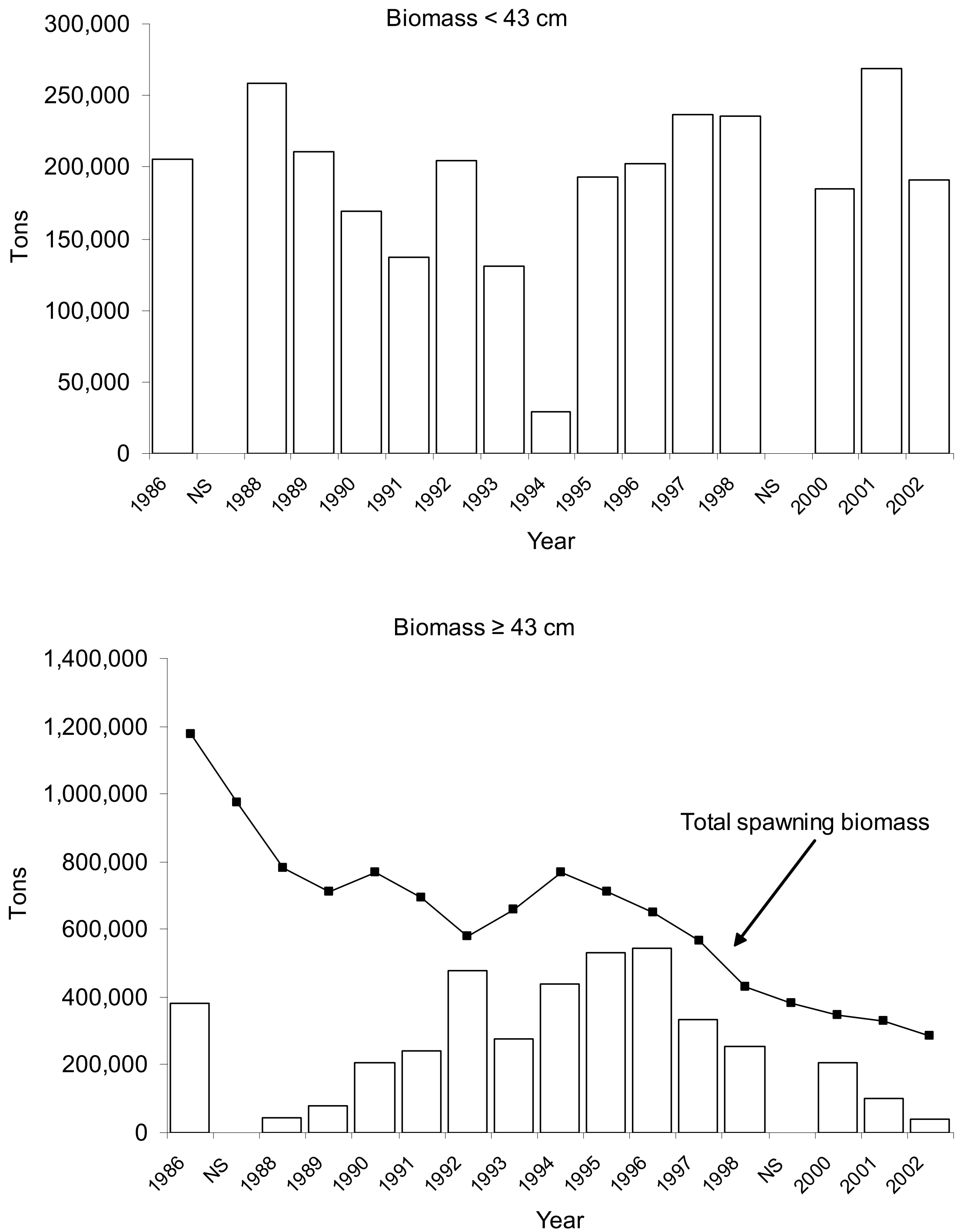


Figure 5. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2002 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

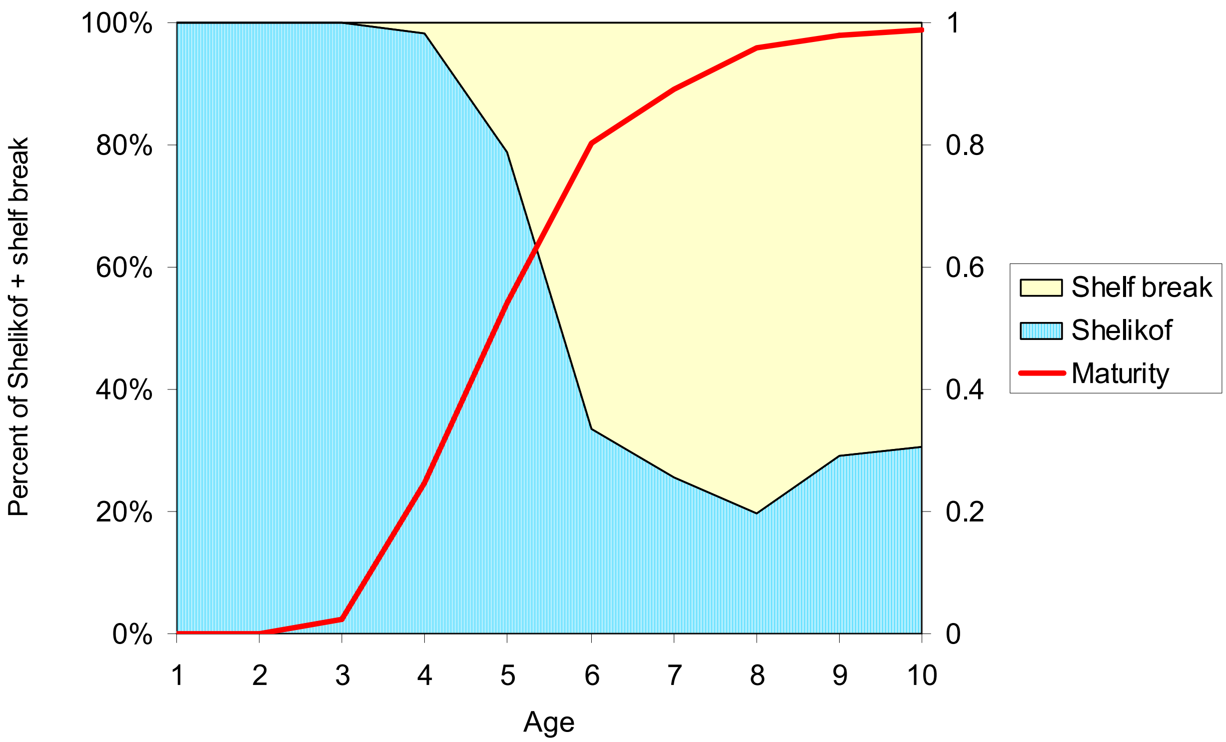


Figure 6. Percent composition of pollock by age for the combined 2002 Shelikof Strait and shelf break EIT surveys numbers at age. Female maturity at age is also shown.

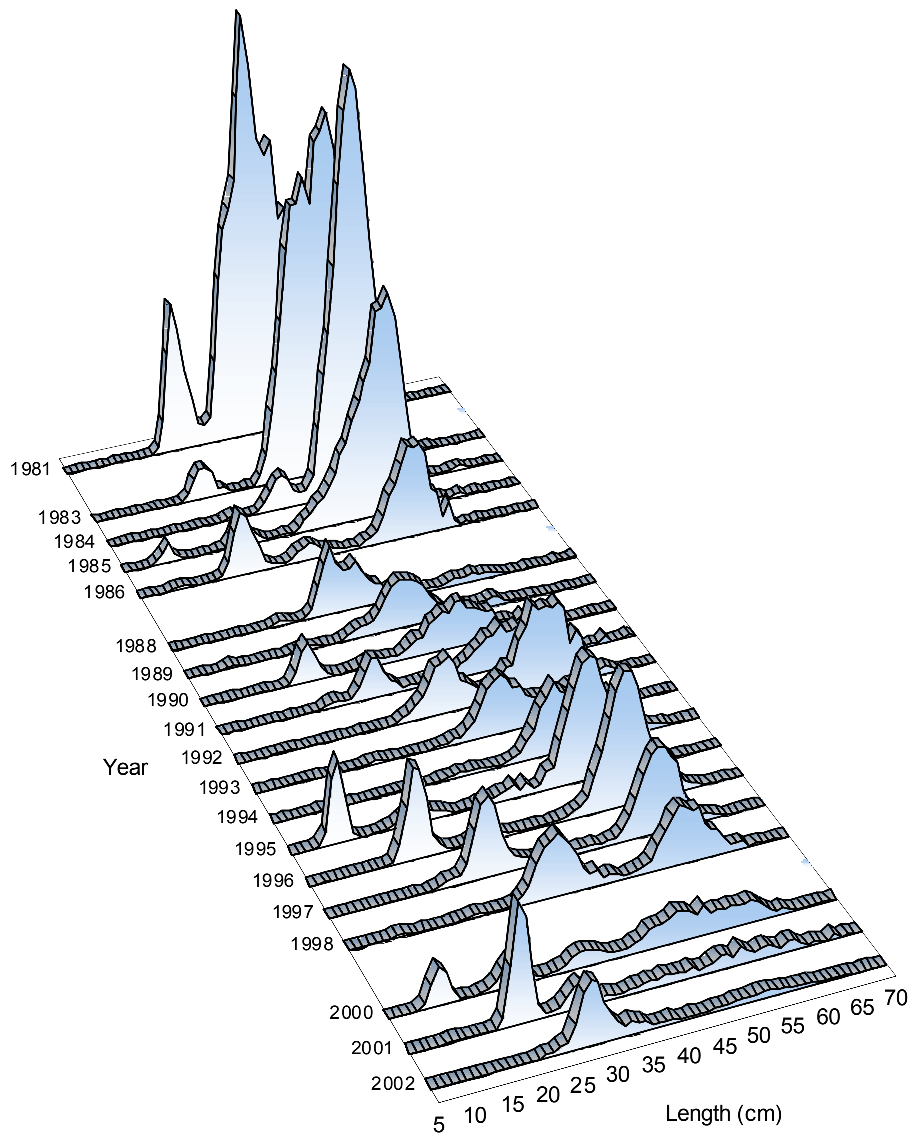


Figure 7. Biomass distribution by length of pollock in the Shelikof Strait EIT survey (1981-2002, except 1982,1987 and 1999).

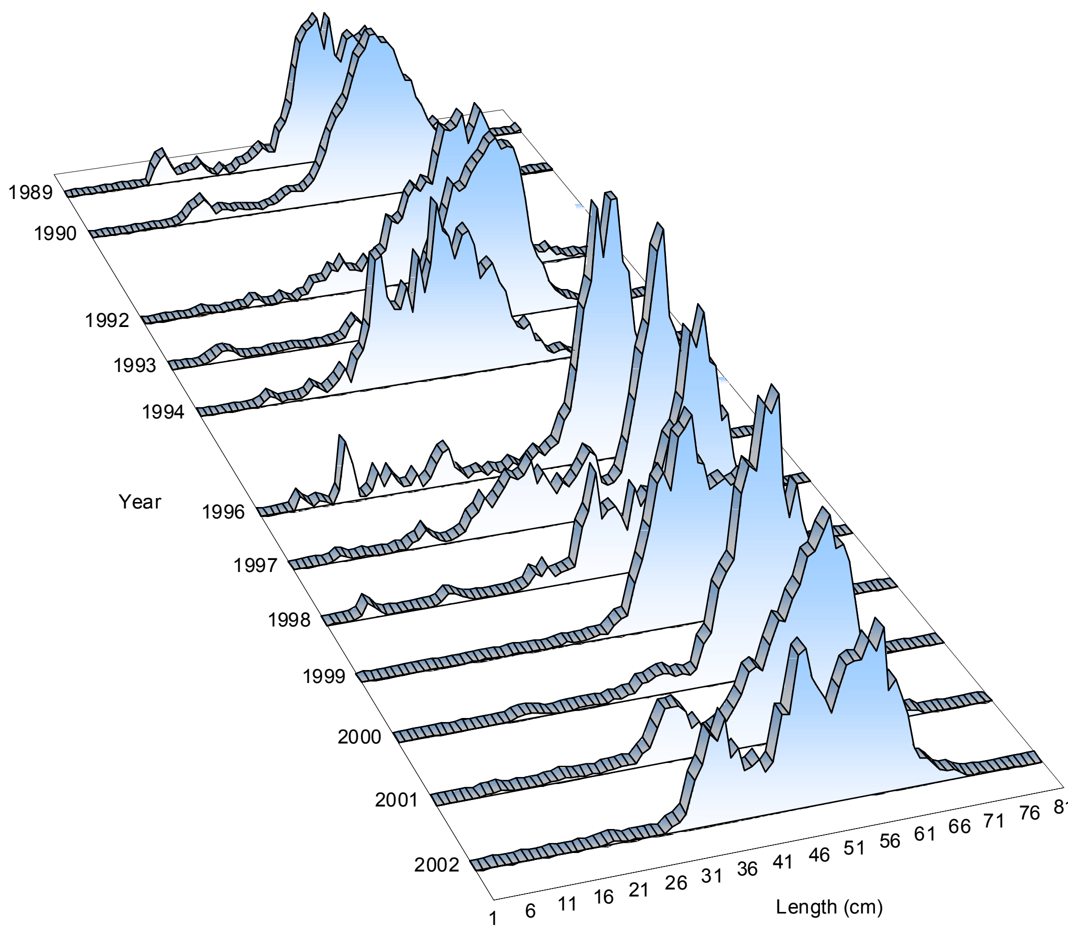


Figure 8. Length frequency of pollock in the ADF&G bottom trawl survey (1989-2002, except 1991 and 1995).

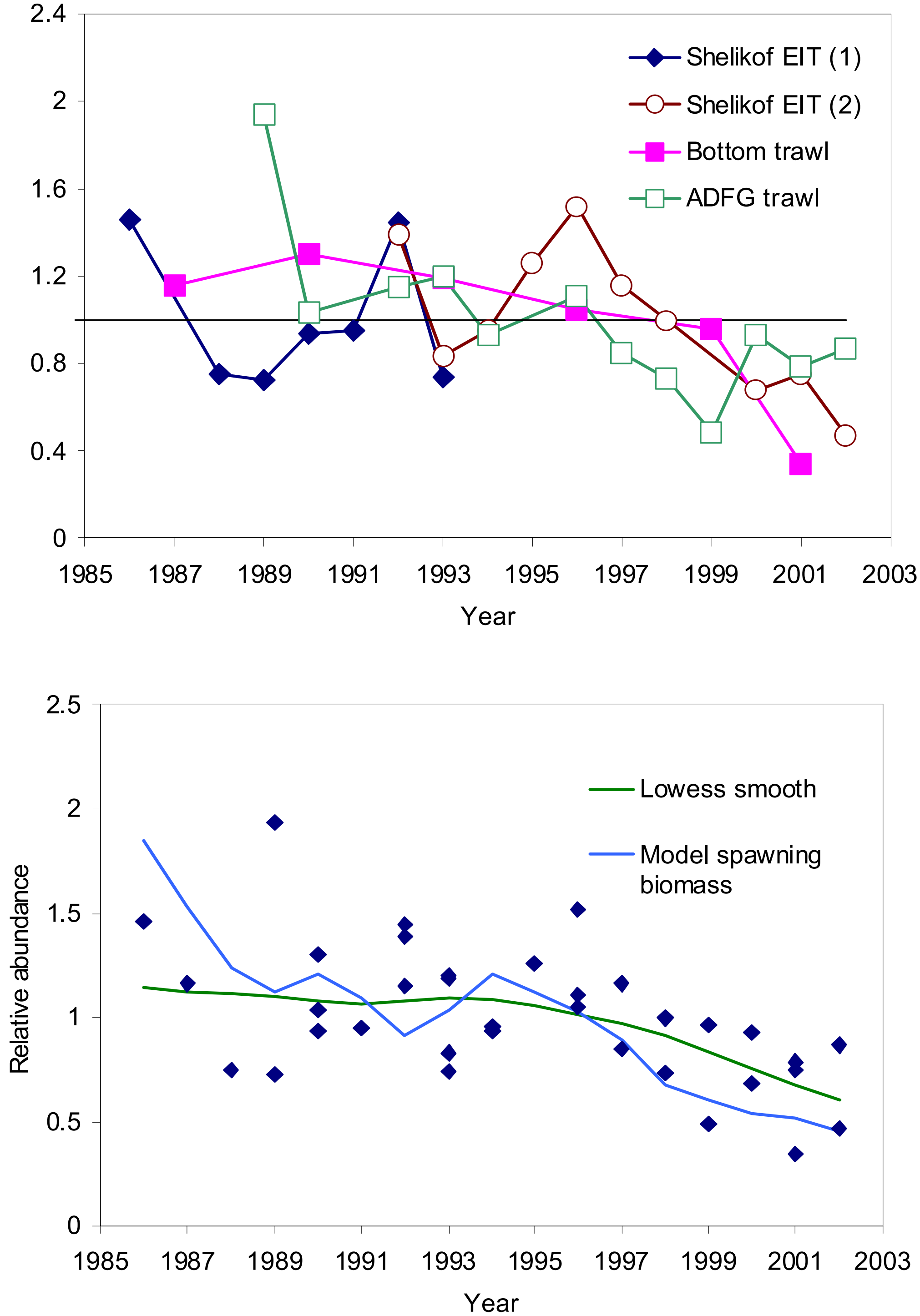


Figure 9. Trends in Gulf pollock biomass since 1986 for the Shelikof Strait EIT survey, the triennial bottom trawl survey, and the ADF&G coastal trawl survey. Each survey biomass estimate is standardized to the survey average since 1986. The Shelikof Strait EIT survey is split into separate time series 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.

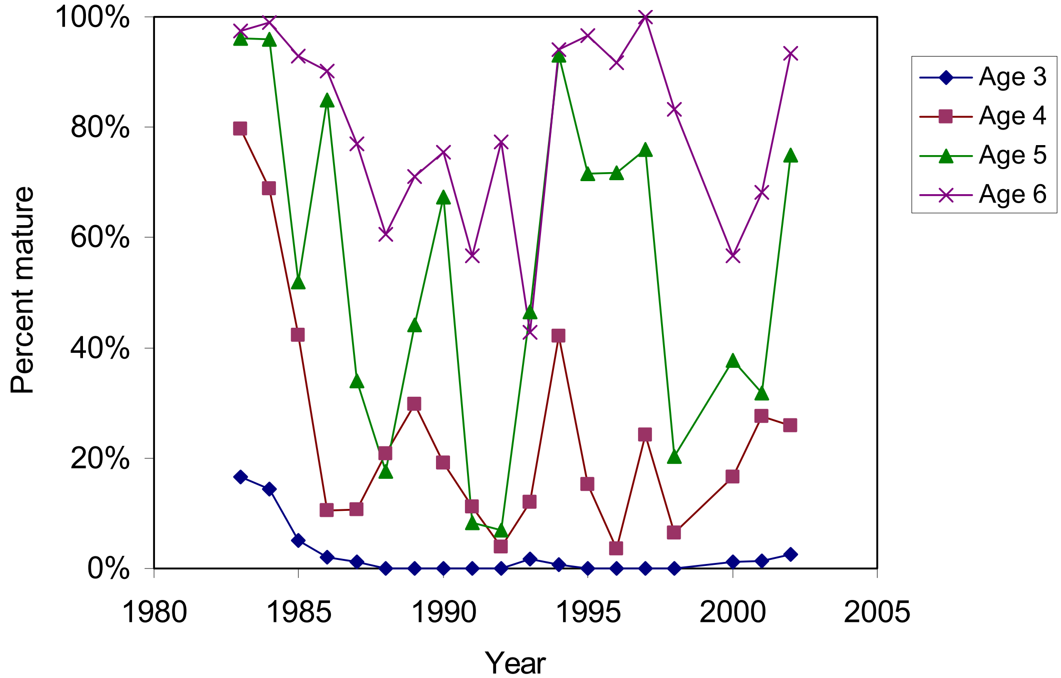


Figure 10. Percent mature female pollock ages 3-6 from winter EIT survey data in the Gulf of Alaska, 1983-2002.

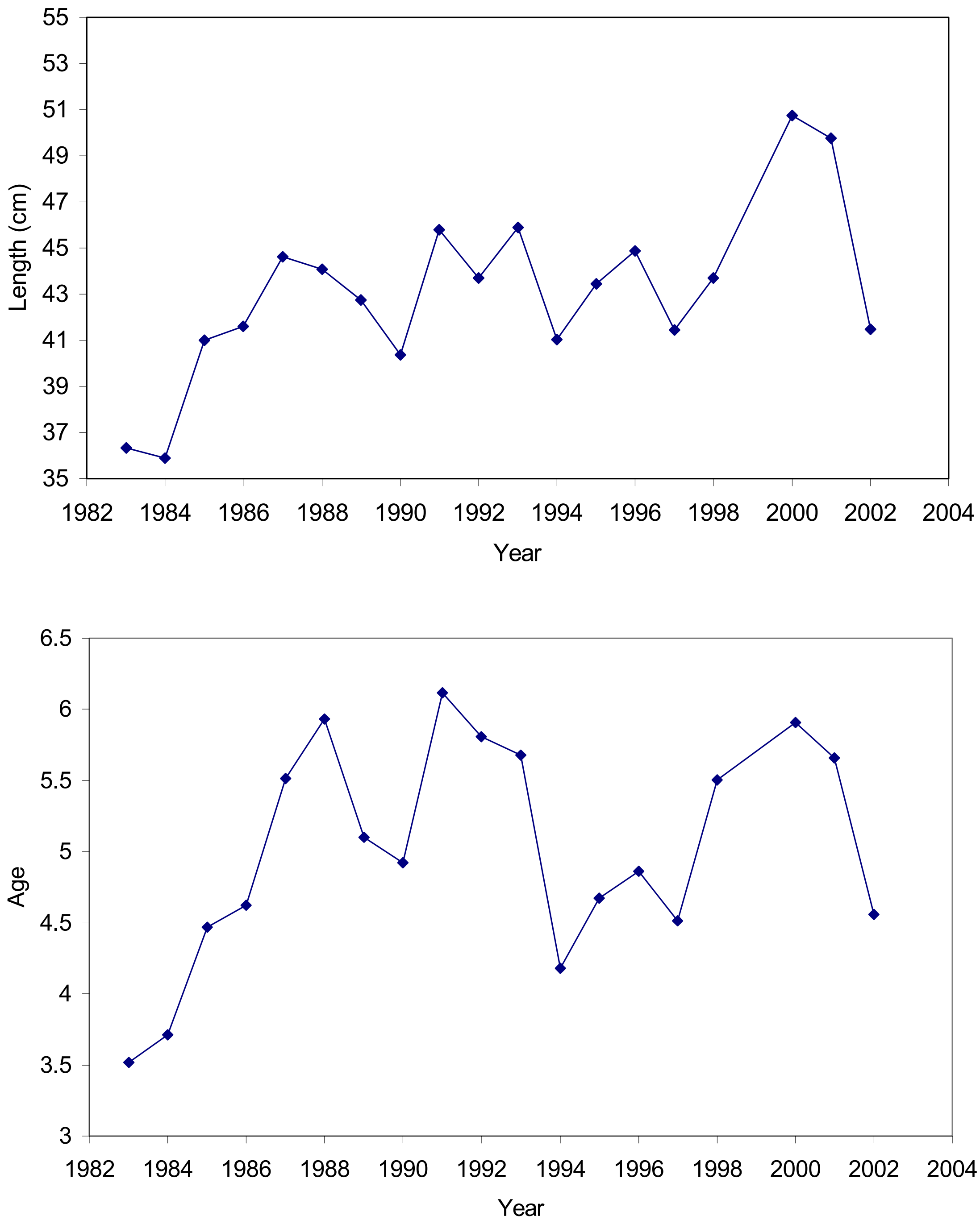


Figure 11. Age and length at 50% mature from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2002.

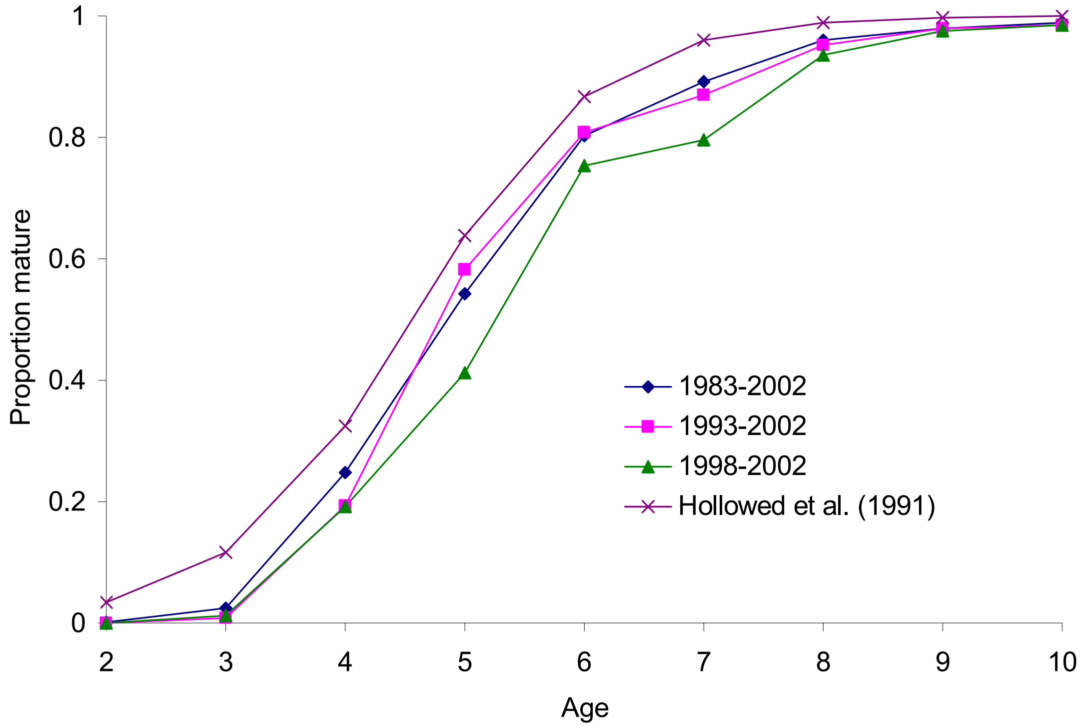
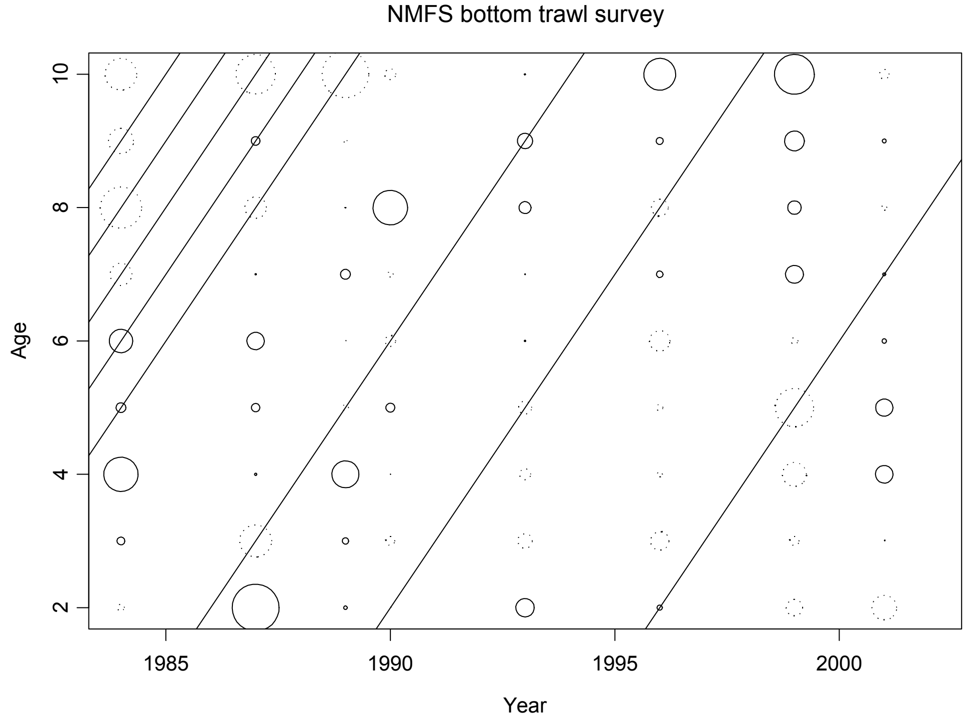


Figure 12. Maturity at age for Gulf of Alaska female pollock obtained by averaging the annual proportion mature at age for different ranges of years. The estimated maturity at age for Hollowed et al. (1991) is also shown.

Figure 13. Residuals from Model 2 for fishery age composition (1972-2001). 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, and 1994).



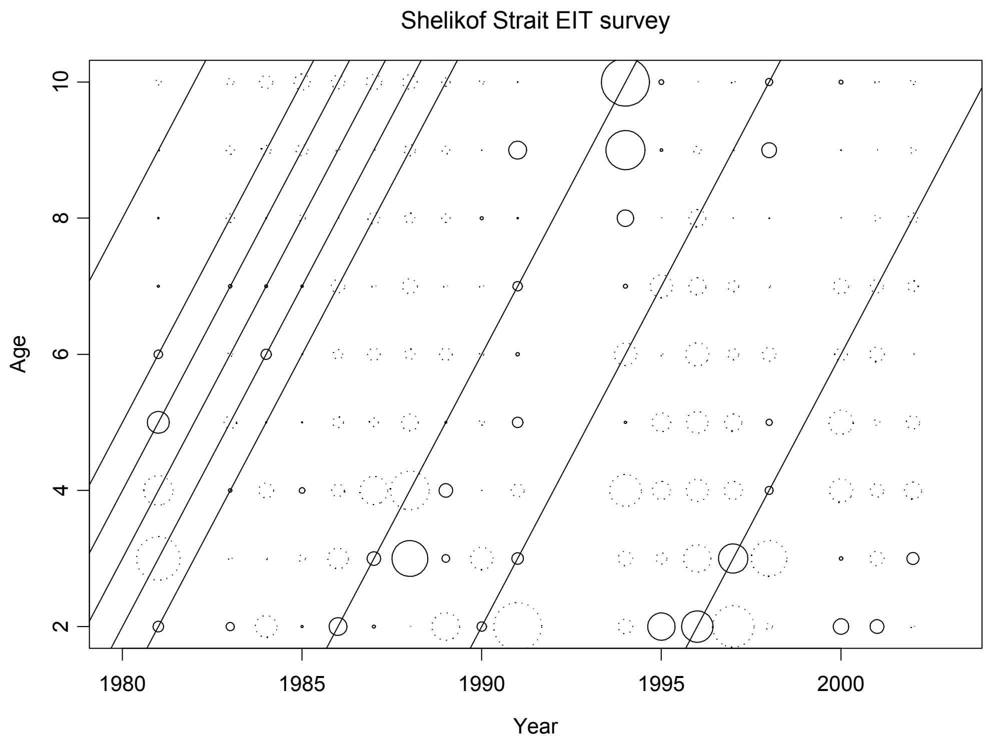


Figure 14. Residuals from Model 2 for the Shelikof Strait EIT survey age composition (top) and NMFS bottom trawl age composition (bottom). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

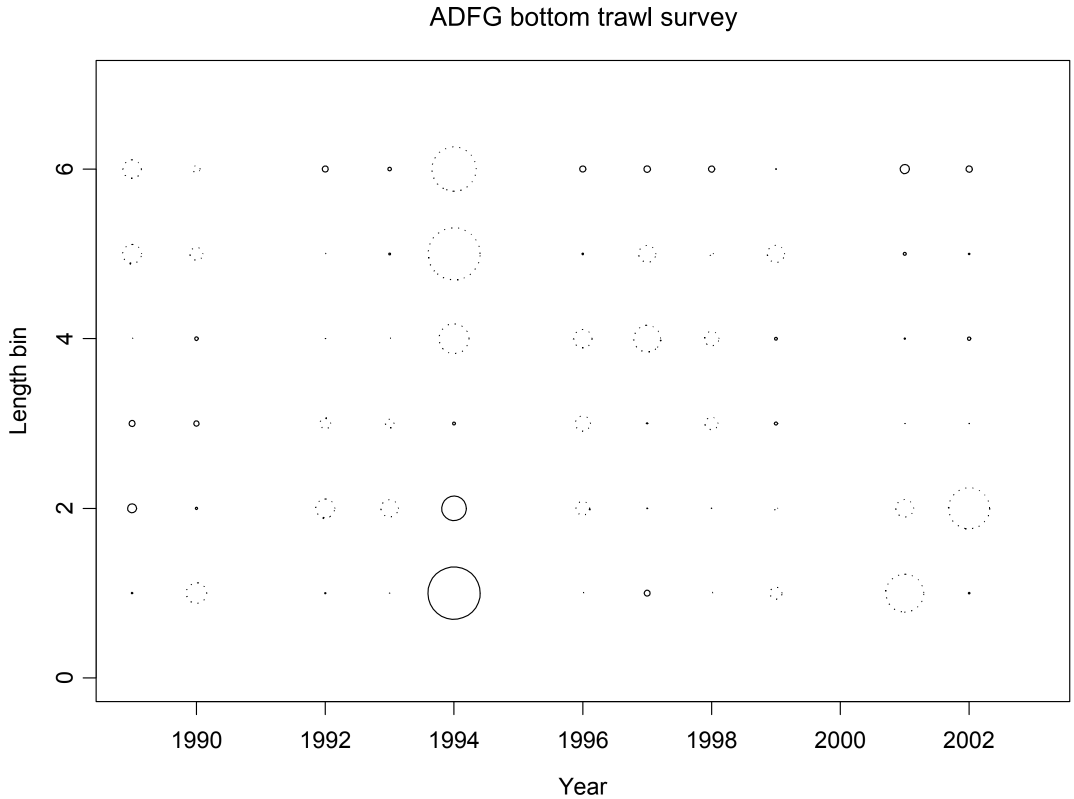


Figure 15. Residuals from Model 2 for the ADF&G survey length composition.

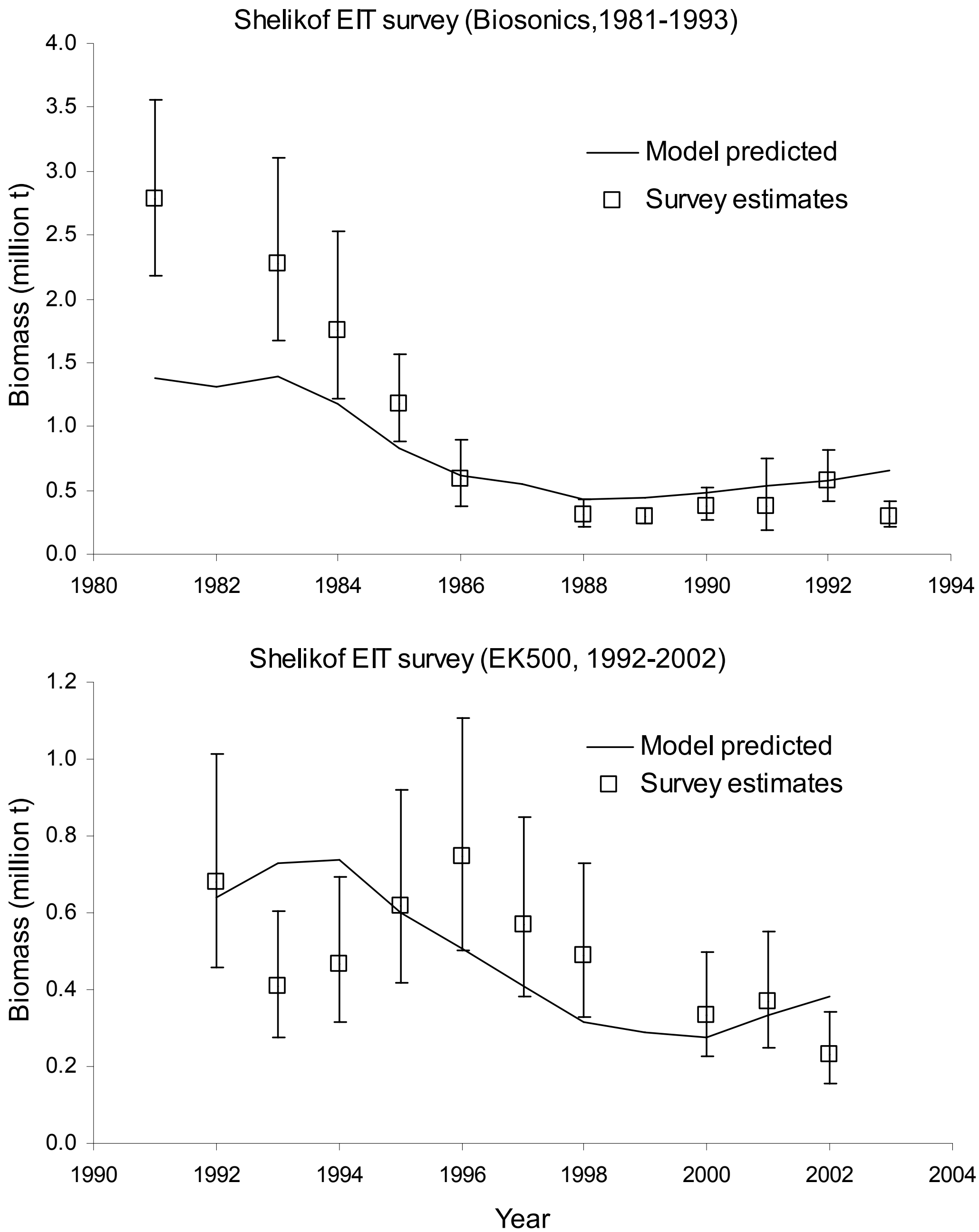


Figure 16. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with two catchability periods corresponding to the two acoustic systems used for the survey. Error bars indicate plus and minus two standard deviations for the survey biomass estimate. Since variance estimates are unavailable for EK500 biomass estimates, an assumed CV of 0.2 is used in the assessment model.

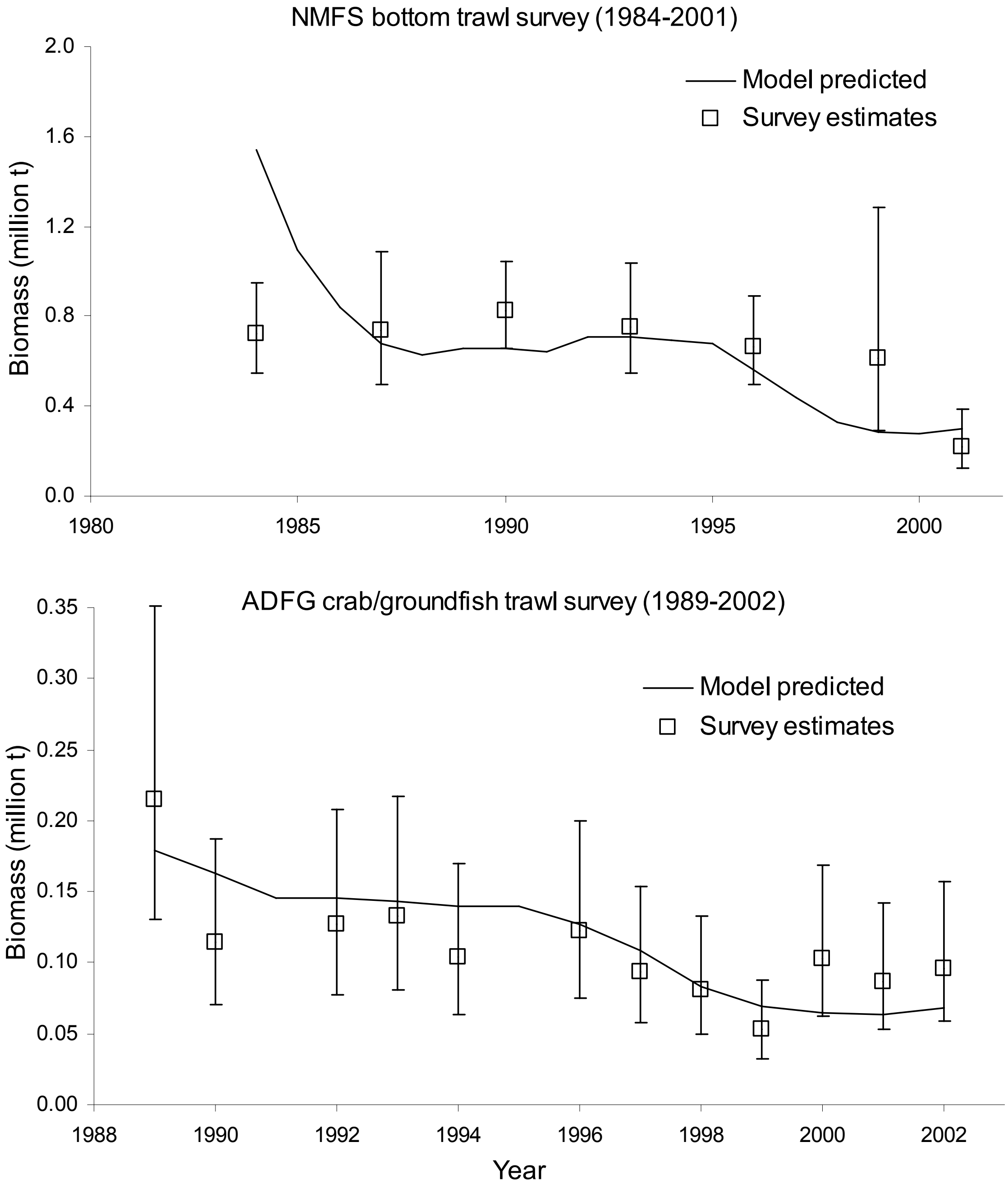


Figure 17. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top panel), and the ADFG crab/groundfish survey (bottom panel). Error bars indicate plus and minus two standard deviations for the survey biomass estimate. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.

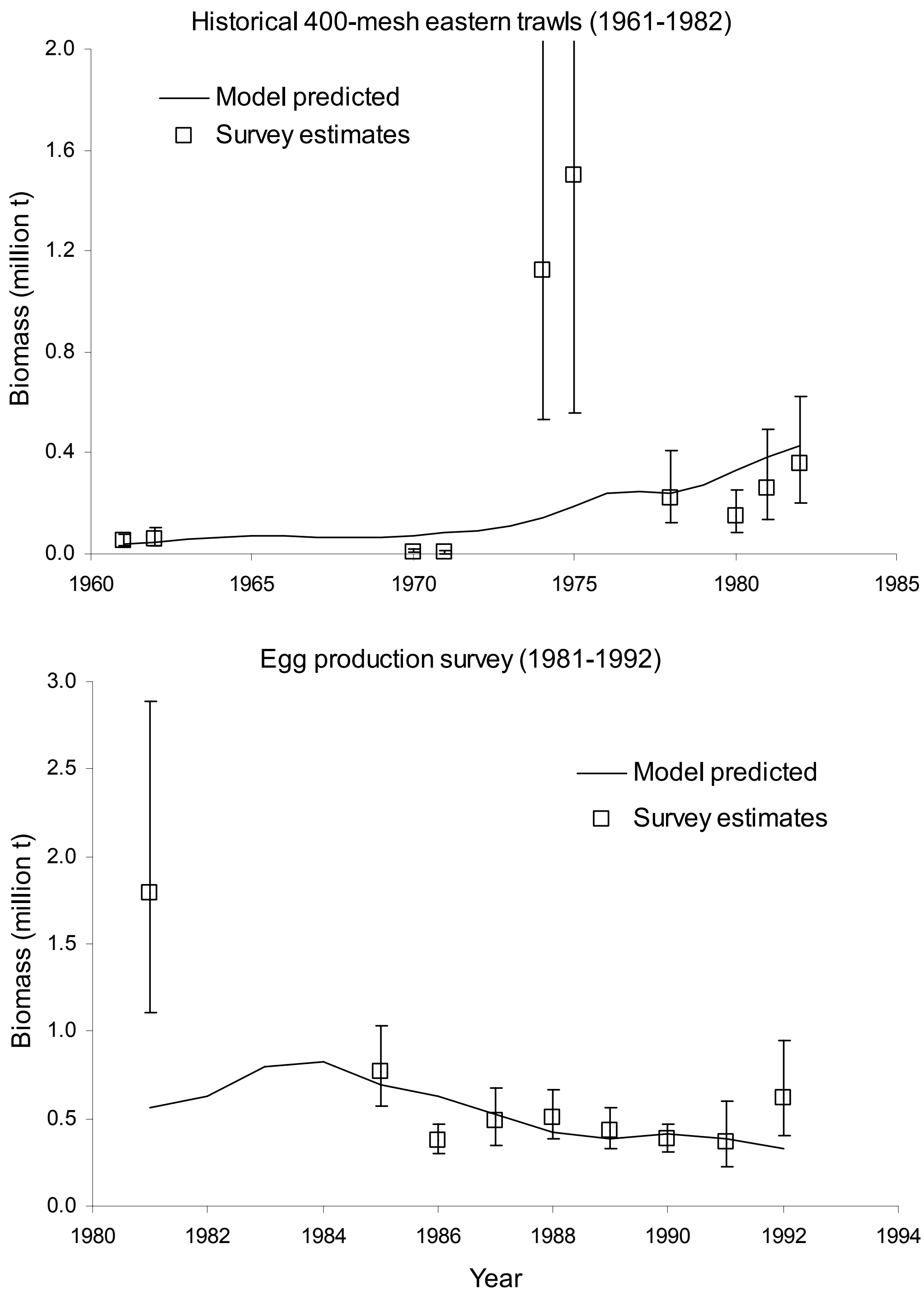


Figure 18. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top panel), and the egg production survey. Error bars indicate plus and minus two standard deviations for the survey biomass estimate.

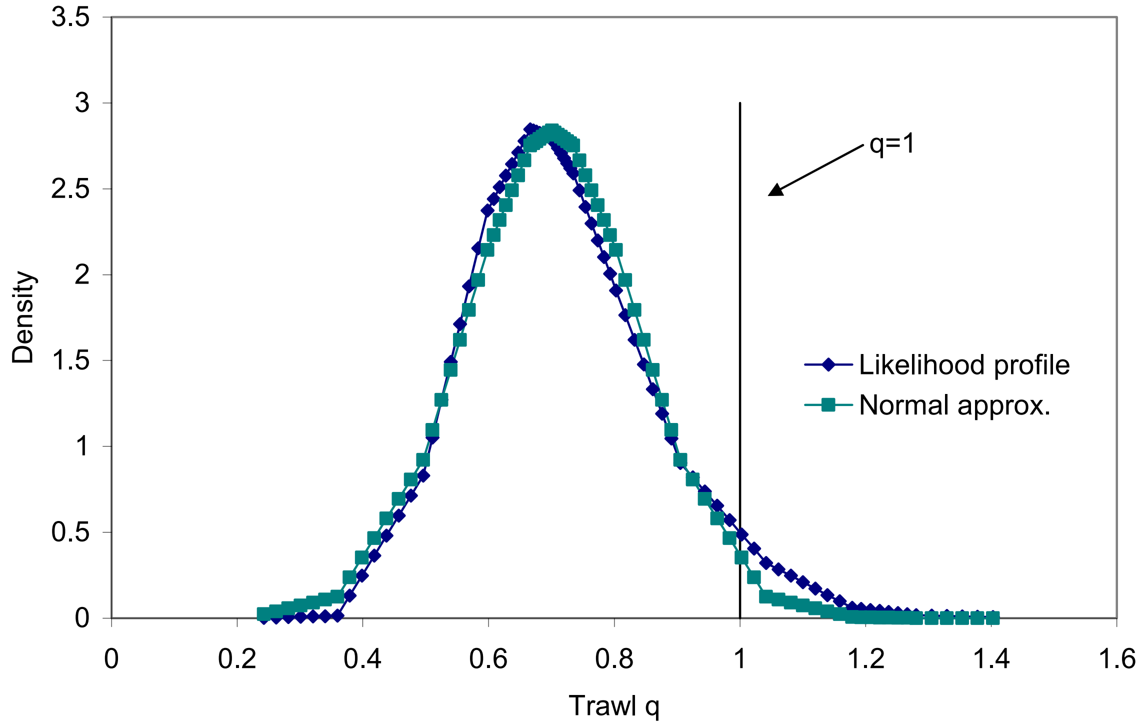


Figure 19. Uncertainty in the catchability coefficient for the NMFS trawl survey derived from likelihood profiling for Model 1.

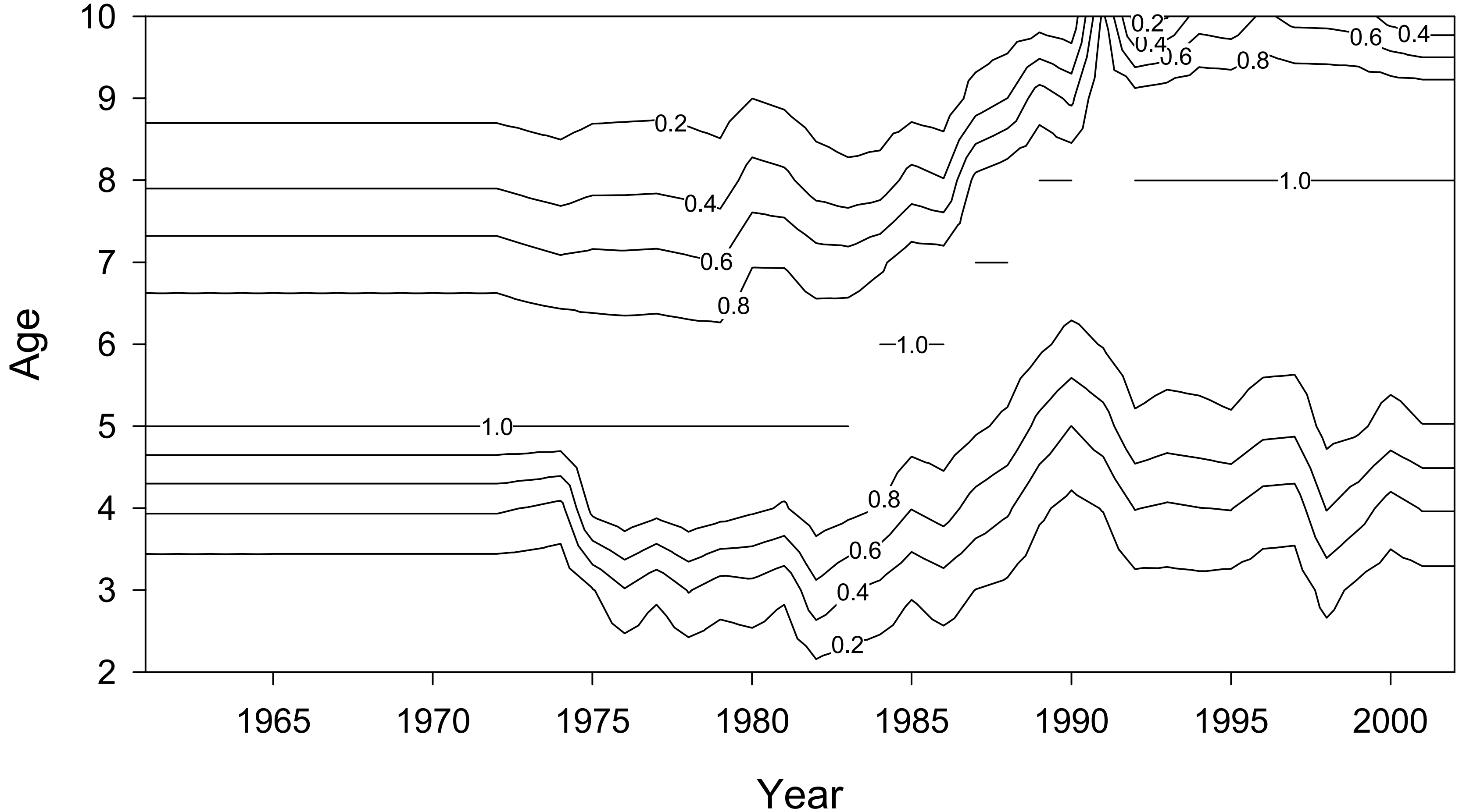
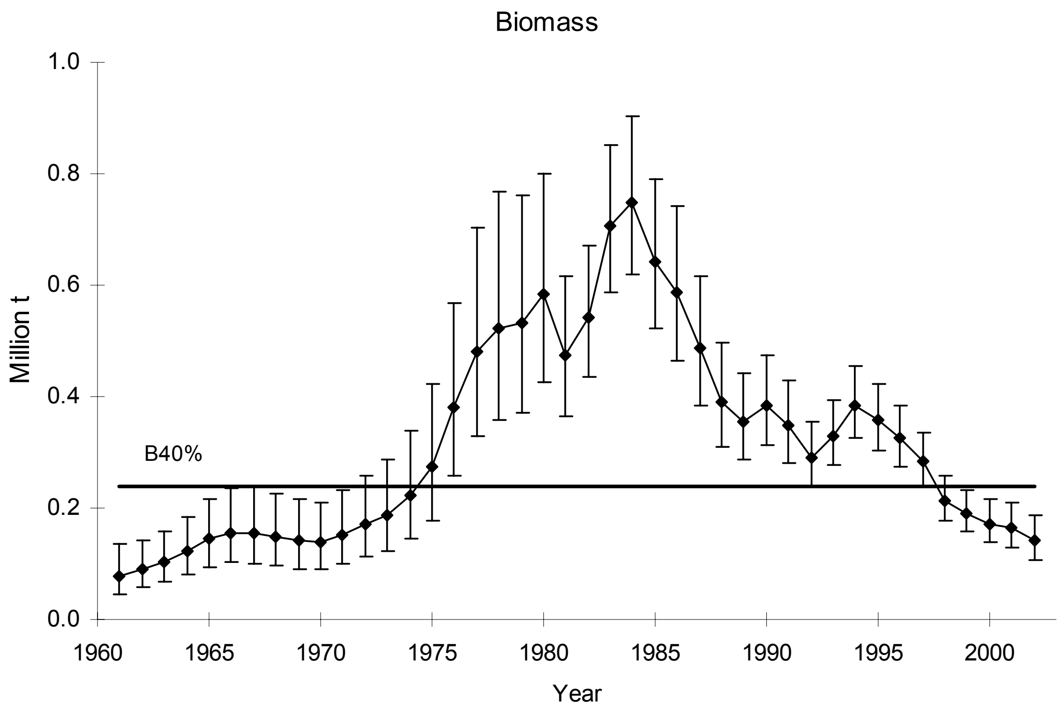


Figure 20. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock.



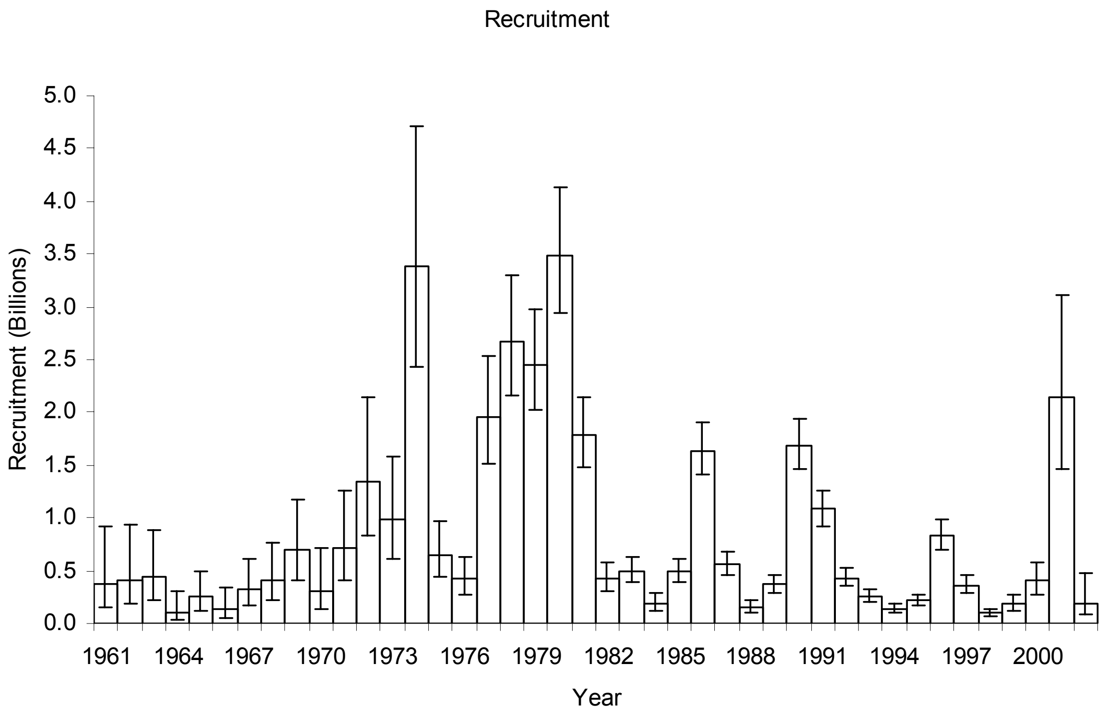
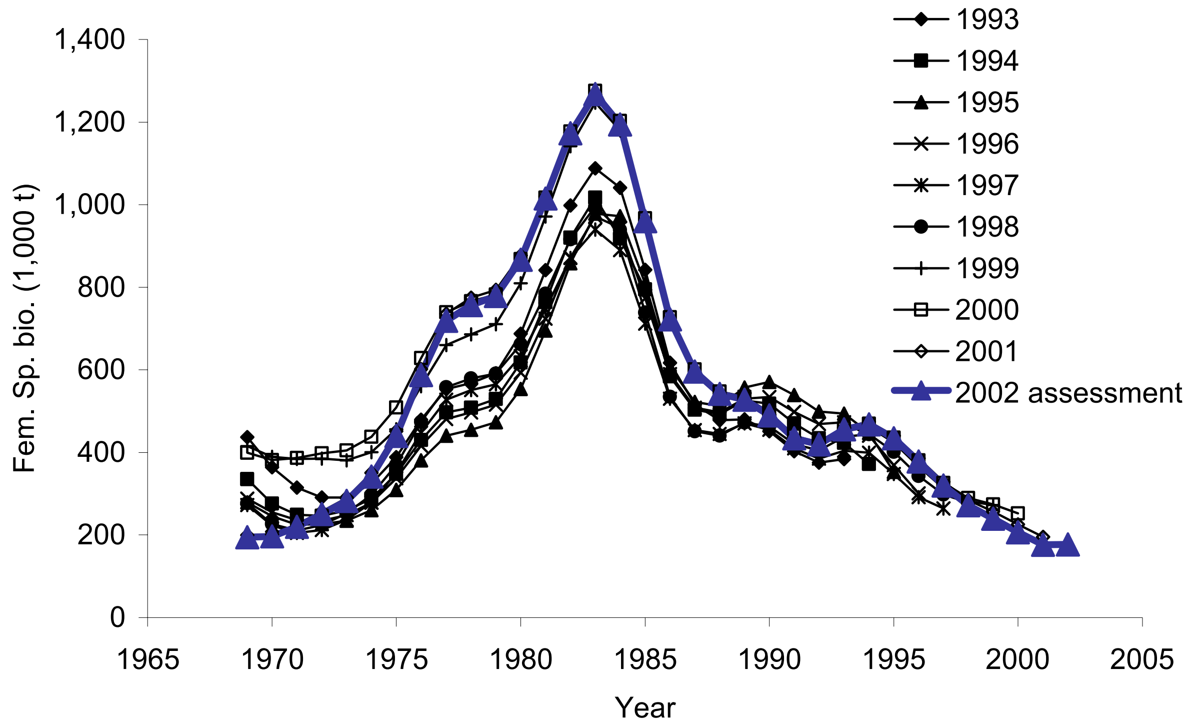


Figure 21. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top panel) and age-2 recruitment (billions of fish, bottom panel) from 1961 to 2002. Vertical bars represent two standard deviations. The B40% line represents the current estimate of this benchmark.



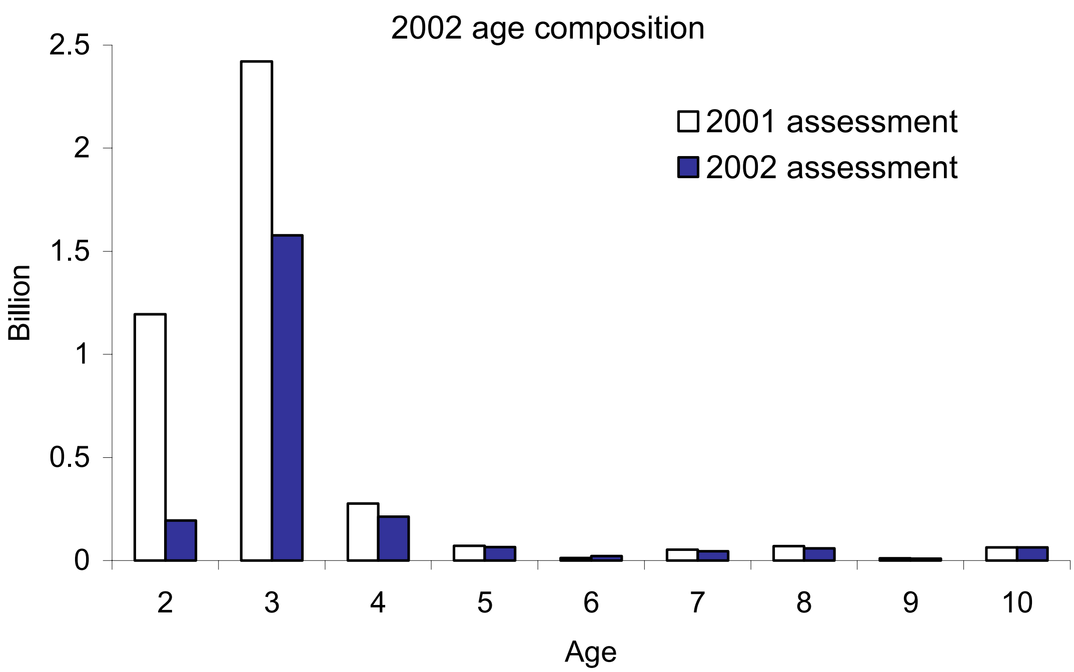


Figure 22. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1993-2002 (top panel). For this figure, the time series of female spawning biomass for the 2002 assessment was calculated using the weight at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2002 from the 2001 and 2002 assessments.

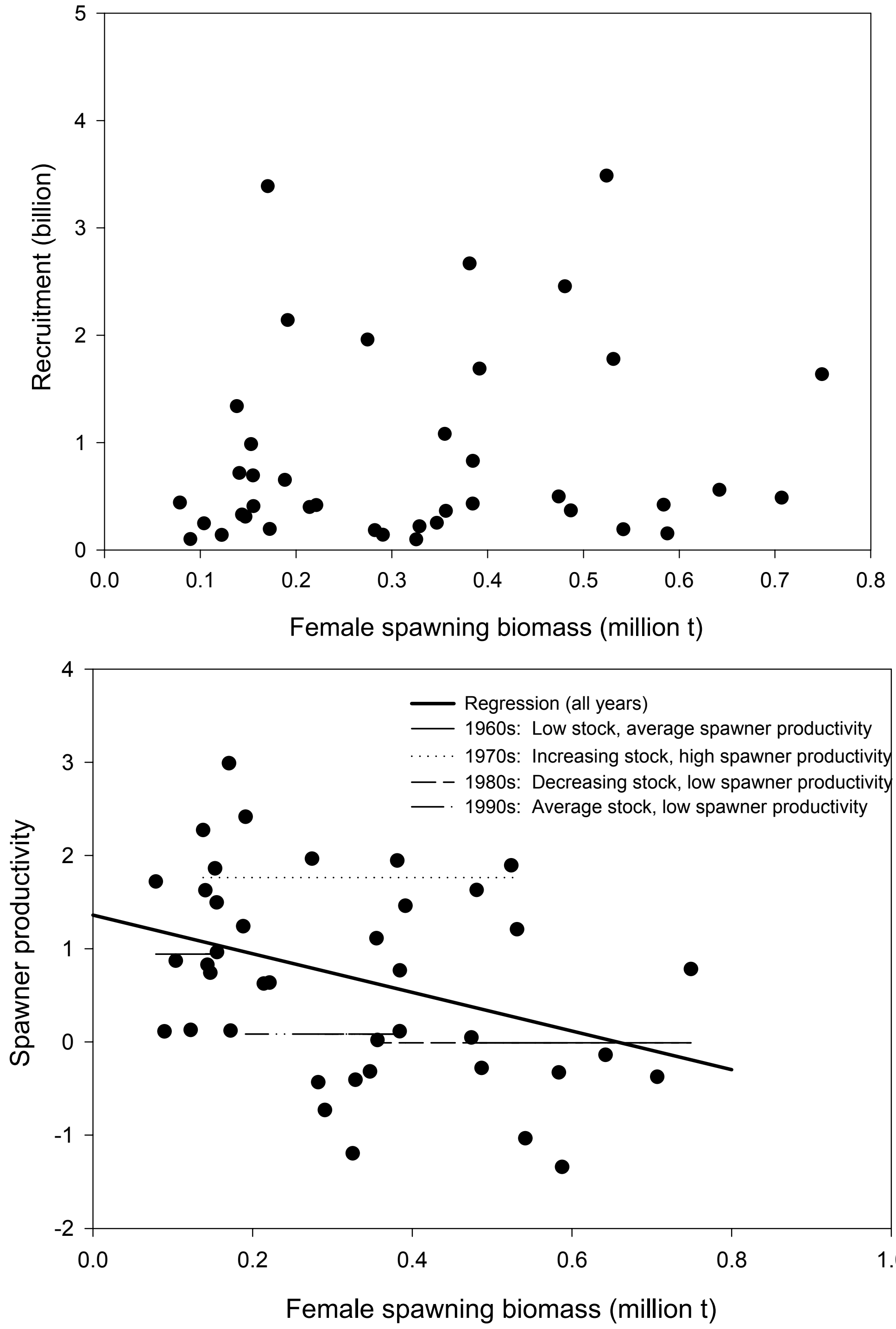


Figure 23. Gulf of Alaska pollock recruitment as a function of female spawning biomass (top). Spawner productivity $\log(R / S)$ in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.

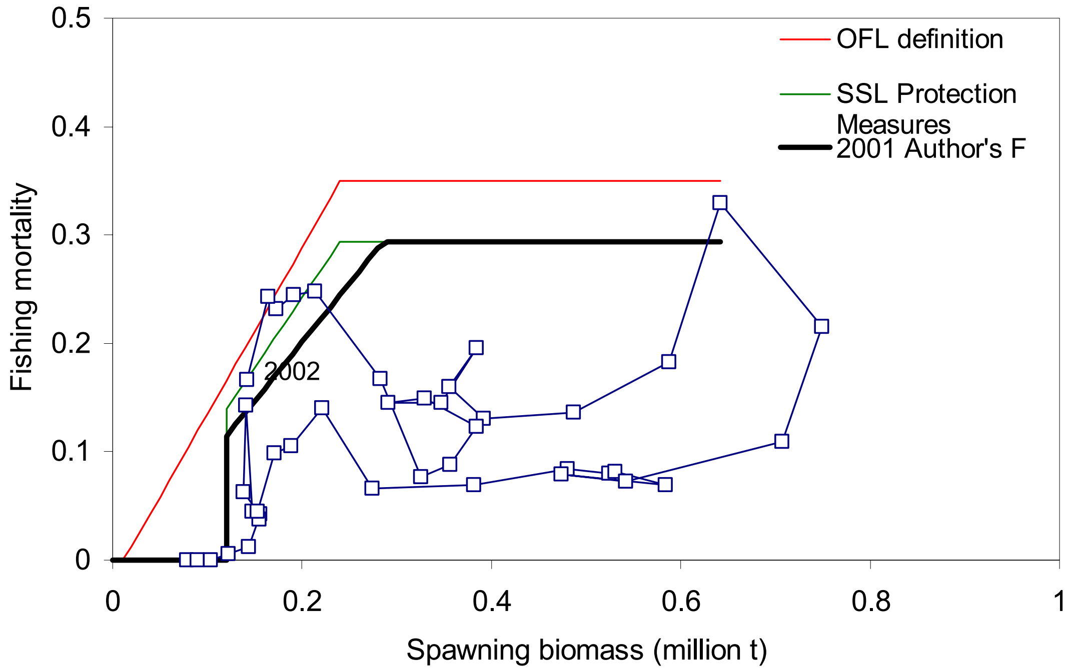


Figure 24. Estimates of Gulf of Alaska pollock spawning biomass and fishing mortality (1961-2002). The OFL definition and maximum permissible ABC are based on current estimates of fishery selectivity, maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure cannot be used to evaluate management performance relative to reference levels (F_{ABC}, F_{OFL} and $B_{40\%}$).

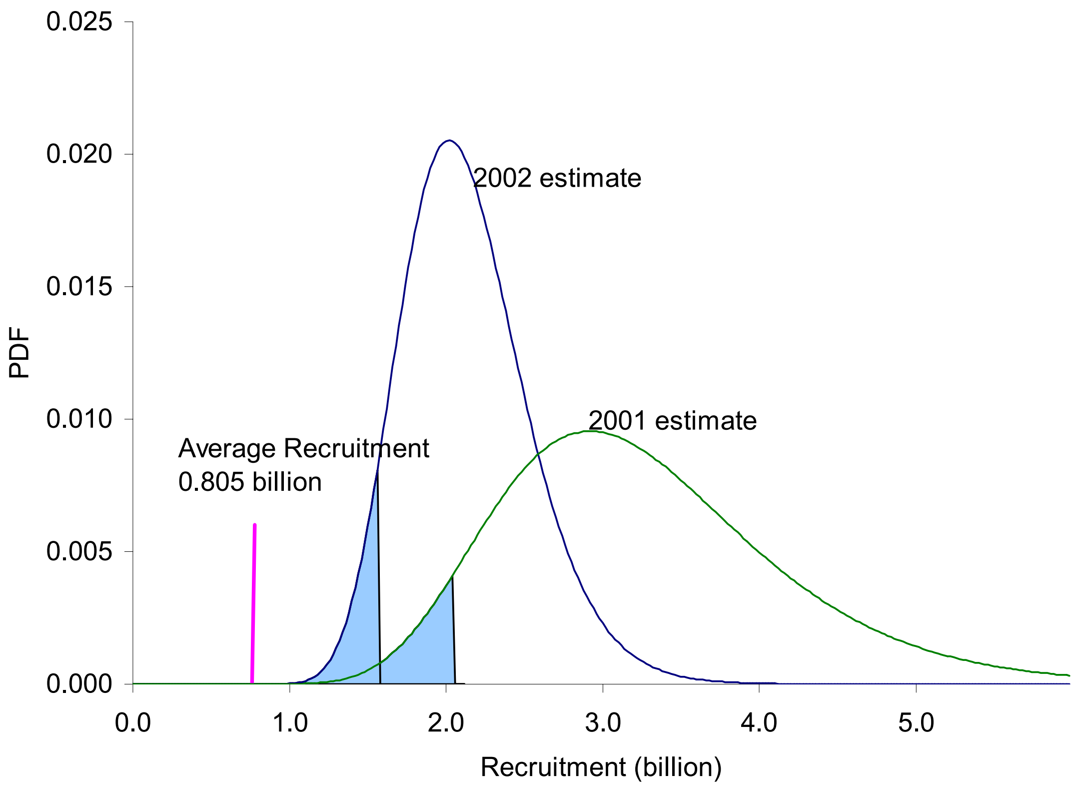


Figure 25. Uncertainty in the estimate of age-2 abundance of the 1999 year class in 2001 and 2002.

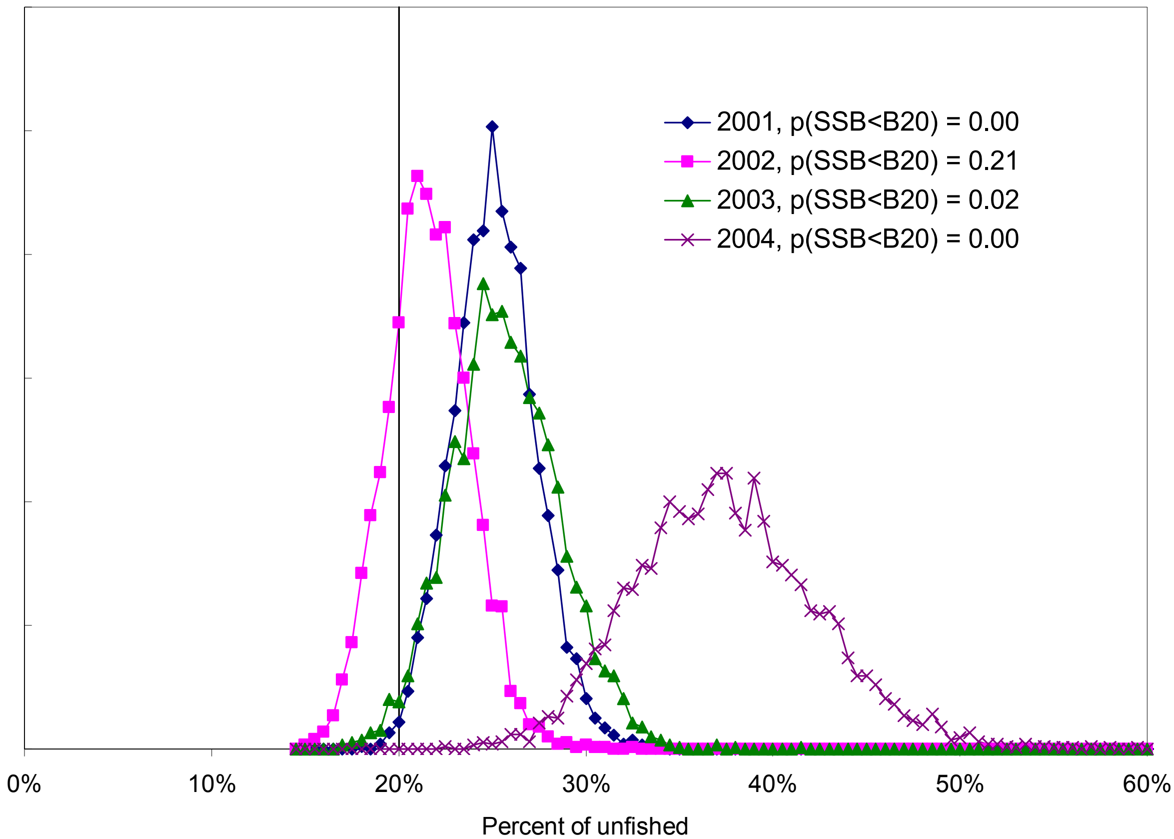


Figure 26. Uncertainty in spawning biomass in 2001-2004 based on a thinned MCMC chain from the joint marginal likelihood for Model 2 where catch in 2003 is fixed at the author's recommended ABC. In 2004, catch is derived from the MCMC estimate of spawning biomass in 2004 and the author's recommended 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 and 1999 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 1993, 1996 and 1999 surveys was dominated by smaller fish (<40 cm) (Martin 1997). 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 1991-2000, pollock catch the Southeast and East Yakutat statistical areas averaged 20 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. The 1996 and 1999 surveys had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Fig. 27). 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 >30 cm (a proxy for exploitable biomass) for the 1999 survey. Because the NMFS trawl survey in 2001 did not extend to southeast Alaska, no new survey information will be available until 2003. 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 **2002 ABC of 6,460 t** (28,709 t * 0.75 M), and a **2002 OFL of 8,613 t** (28,709 t * M).

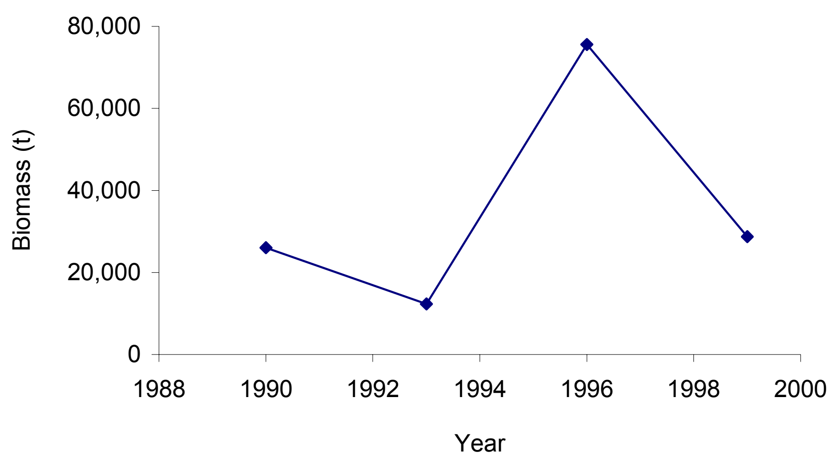


Figure 27. Pollock biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-1999.

Appendix B: 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), thus reducing the overall intensity of any averse 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 have adverse impacts, both on 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 surveying during winter has focused on the Shelikof Strait spawning grounds, with limited surveying of the Shumagin Islands spawning grounds in the middle to late 1990s, and additional exploratory surveying along the shelf break in the early 1990s. It is important to make the best use of limited information on biomass distribution from surveys when apportioning the TAC. Here we summarize available information on 1) the timing of pollock migration to and from spawning areas, 2) the winter distribution of pollock in the Gulf of Alaska, and 3) the summer distribution of pollock.

Timing of pollock movement to and from spawning areas

There is limited information concerning the timing of pollock movement to and from spawning areas in the Gulf of Alaska. Replicated surveys of pollock in the 1980s show a gradual buildup of biomass in Shelikof Strait, followed by a rapid decline after the peak of spawning between 15 March and 1 April (Fig. 28). Pollock distribution in the Gulf of Alaska trawl survey, which begins in June, shows that pollock have migrated to their summer feeding habitat, with relatively low biomass in areas where spawning occurred earlier in the year, such as upper Shelikof Strait. Since approximately 65% of GOA pollock spawn in Shelikof Strait, there would have to be significant migration of adult fish both to the east side of Kodiak Island and to the southwest after spawning to produce the pollock distribution in summer surveys.

Since the earliest survey in Shelikof Strait began on February 21, no survey information exists on pollock distribution between January 20, when the current A season fishery opens, and late February. Beginning in 2000, there have been two fishery openings (A and B seasons) prior to peak spawning. The distribution of fishing around Kodiak Island in these two openings has been very different, suggesting that the pollock have not attained their typical spawning distribution by January 20 (Figs. 29-31). During the A-season in 2000 and 2001, catches were on Kodiak Island side of the strait near the northern end. In the B-season, fishing was concentrated further down the strait along the Alaska Peninsula side. This suggests that, at least in some years, pre-spawning pollock may migrate around the north end of Kodiak Island to Shelikof Strait. In 2002, a very different pattern was observed, with no pollock catches in the northern part of Shelikof Strait, and large catches along the shelf break outside of Shelikof Strait during in the B season. In the Shumagin area, fishing patterns were similar in the A and the B seasons, which is consistent with survey results indicating earlier spawning in this area.

Previous recommendations for apportioning the A-season TAC between management areas were based on the assumption that the pollock stock on January 20 has the same spatial distribution as the mean distribution on the spawning grounds in mid-March. The experience of the fishing fleet since 2000 suggests that this assumption should be reconsidered, at least for areas 620 and 630. We present three options for apportioning the TAC between 620 and 630 for the A season fishery (Fig. 32). The first option assumes that the migration has not started by the A season opening, and apportions the TAC between areas 620 and 630 by assuming the summer percentage in 630 and obtaining 620 percent by subtraction. This results in a percent apportionment of 24.73%, 45.23% and 30.05% in areas 610, 620, and 630 respectively. The second option is based on the estimated winter distribution, giving 24.73%, 66.46% and 8.81%, while the last option takes the midpoint of these two assumptions, giving 24.73%, 55.84% and 19.43% for areas 610, 620, and 630 respectively. Note that the proportion in 610 remains the same in each option, reflecting the assumption that pollock targeted by the 610 fishery in A season are fish that will spawn in area 610.

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. No acoustic survey has been comprehensive, covering all areas where pollock could potentially occur. Therefore a "composite" approach was developed to use data from several different surveys. We used data from 1) Shelikof Strait surveys in 1992-2002, 2) surveys of the Shumagin Island area in 1995, 2001, and 2002 (Wilson et al. 1995, Guttormsen et al. 2001, 2002), 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 1992-2002.

Results indicate that an average of 63% of the pollock biomass was in Shelikof Strait in winter (Appendix table 1). For the Shumagin surveys in 1995, 2001, and 2002, 25% 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 echo sounder/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 24.73%, 66.46%, and 8.81% in areas 610, 620, and 630.

Summer distribution

The NMFS bottom trawls 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 2001 survey results resulting in an average biomass distribution of 45.95%, 22.44%, 29.37%, and 2.25% in areas 610, 620, 630, and 640 (Fig. 33).

TAC Rollovers

In 2002, the low abundance of pre-spawning pollock in Shelikof Strait resulted in significant unharvested TAC in area 620 at the end of the A and B seasons. An underage or overage of TAC for a seasonal opening can be added to or subtracted from subsequent allowances provided the seasonal allowances do not exceed 30% of the total TAC. Historically, adjustments in the seasonal TACs have been made only within management areas. For example, this year, the underage in area 620 was rolled over into the TACs for C and D seasons in area 620, where summer bottom trawl surveys indicate that the abundance of adult pollock is much lower than in winter. To achieve the goal of the Steller Sea Lion Protection Measures to equalize the exploitation rates spatially and temporally, a better approach would be to accumulate the gulf-wide overage or underage at the end of the winter fisheries (i.e., the end of the B season), then apportion the tonnage between areas 610, 620, and 630 according to the summer biomass distribution.

Specific recommendations for plan team consideration

1. Consider alternative apportionment schemes for the A season fishery in areas 620 and 630

Option A. Summer survey biomass distribution in areas 620 and 630: 610, 24.73%; 620, 45.23%; and 630, 30.05%.

Option B. Winter survey biomass distribution in areas 620 and 630: 610, 24.73%; 620, 66.46%; and 630, 8.81%.

Option C. Midpoint between summer and winter distributions in areas 620 and 630: 610, 24.73%; 620, 55.84%; and 630, 19.43%.

2. Recommend that overage or underages at the end of the winter fisheries be accumulated for all areas and be redistributed to management areas according to the summer distribution of biomass.

Example calculation of 2003 Seasonal and Area TAC Allowances

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

1) Since no information is available on the seasonal distribution of pollock in area 640, use summer biomass distribution:

640 0.0225 x Total TAC = 2,250 t

2) 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.

A season 0.25 x (Total TAC – 2,250) = 24,437
B season 0.25 x (Total TAC – 2,250) = 24,437 t

C season 0.25 x (Total TAC – 2,250) = 24,437 t
D season 0.25 x (Total TAC – 2,250) = 24,437 t

3) For the A season, the allocation of TAC to areas 610, 620 and 630 is based on either the "composite" estimate of winter biomass distribution, or 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. In the example below, we use Option C which assumes that the migration is half completed.

610 0.2473 * 24,437 t = 6,043 t
620 0.5584 * 24,437 t = 13,646 t
630 0.1943 * 24,437 t = 4,748 t

4) 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 0.2473 * 24,437 t = 6,043 t
620 0.6646 * 24,437 t = 16,241 t
630 0.0881 * 24,437 t = 2,153 t

5) 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 0.4595 / (1 – 0.0225) x 24,437 = 11,487 t
620 0.2244 / (1 – 0.0225) x 24,437 = 5,610 t
630 0.2937 / (1 – 0.0225) x 24,437 = 7,342 t

610 0.4595 / (1 – 0.0225) x 24,437 = 11,487 t
620 0.2244 / (1 – 0.0225) x 24,437 = 5,610 t
630 0.2937 / (1 – 0.0225) x 24,437 = 7,342 t

Appendix Table 1. Estimates of percent pollock in management areas 610-630 during winter EIT surveys in the Gulf of Alaska.

Survey	Year				Percent of biomass by management area			Percent of total biomass		
		Model estimates of total 2+ biomass at spawning	Survey biomass estimate[1]	Percent	Area 610	Area 620	Area 630	Area 610	Area 620	Area 630
Shelikof Strait	1992	1,018,880	681,400	66.9%						
Shelikof Strait	1993	1,128,430	408,200	36.2%						
Shelikof Strait	1994	1,127,330	467,300	41.5%						
Shelikof Strait	1995	935,423	618,300	66.1%						
Shelikof Strait	1996	831,504	745,400	89.6%						
Shelikof Strait	1997	750,855	570,100	75.9%	0.0%	98.8%	1.2%			
Shelikof Strait	1998	617,717	489,900	79.3%	0.0%	97.5%	2.5%			
Shelikof Strait	2000	488,167	334,900	68.6%	0.0%	97.8%	2.2%			
Shelikof Strait	2001	543,573	369,600	68.0%	0.0%	98.3%	1.7%			
Shelikof Strait	2002	588,229	229,104	38.9%	0.0%	97.7%	2.3%			
Shelikof Strait	Average			63.1%	0.0%	98.0%	2.0%	0.0%	61.9%	1.2%
Shumagin	1995	935,423	290,100	31.0%	90.0%	10.0%	0.0%			
Shumagin	2001	543,573	108,791	20.0%	84.8%	15.2%	0.0%			
Shumagin	2002	588,229	135,644	23.1%	100.0%	0.0%	0.0%			
Shumagin	Average			24.7%	91.6%	8.4%	0.0%	22.6%	2.1%	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				97.06%				24.00%	64.51%	8.55%
Rescaled total				100.00%				24.73%	66.46%	8.81%

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

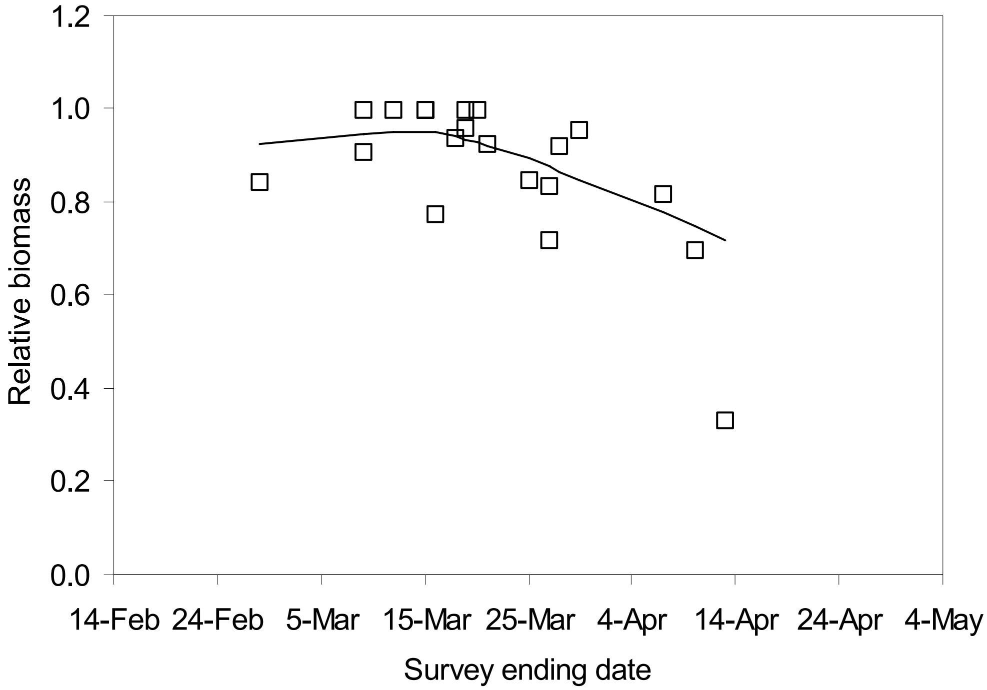


Figure 28. Relative biomass of pollock in Shelikof Strait as a function of survey ending date from replicated acoustic surveys in 1981-88. Relative biomass is the survey biomass divided by the maximum survey biomass for the year. A lowess smooth is also shown.

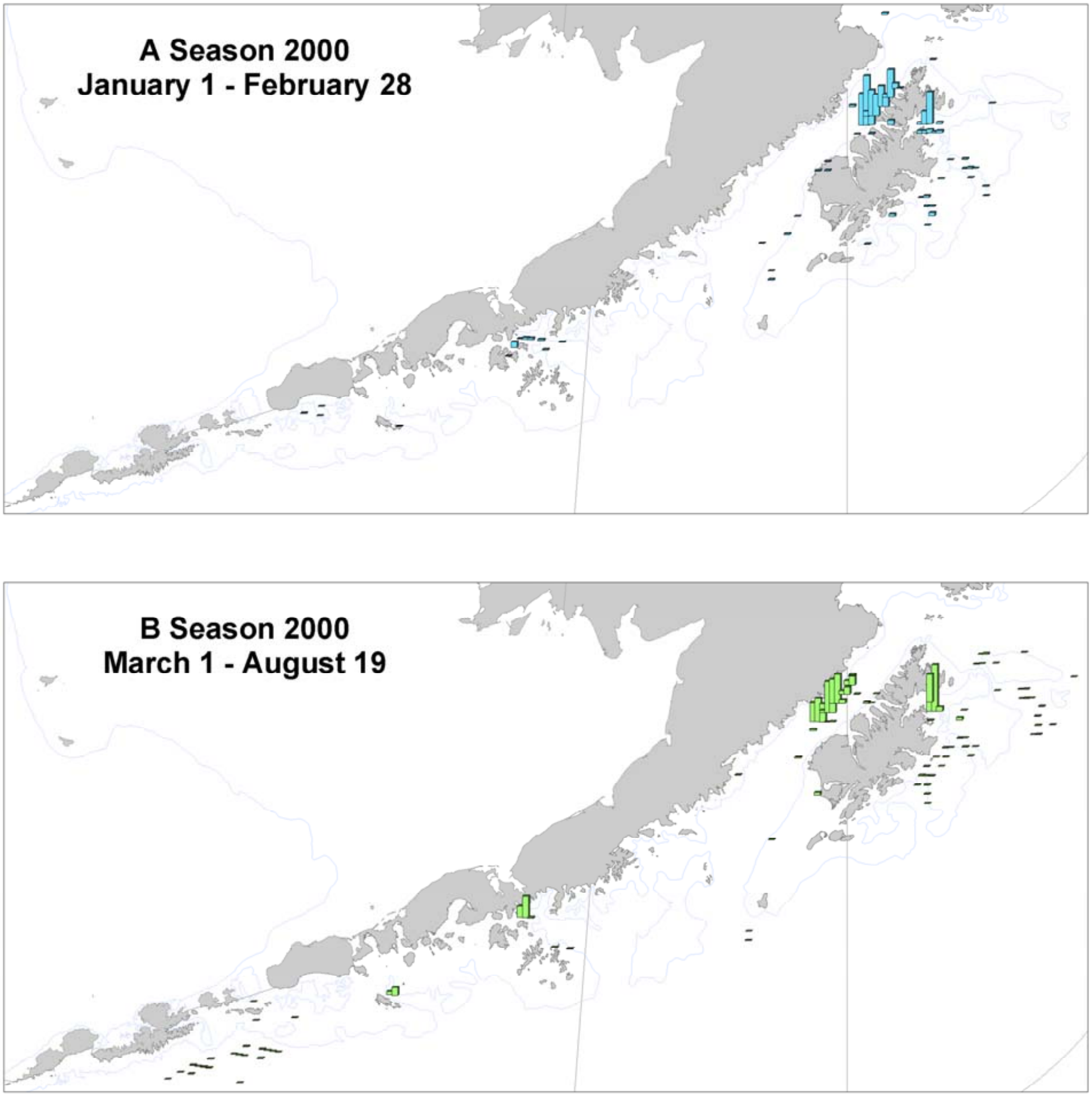
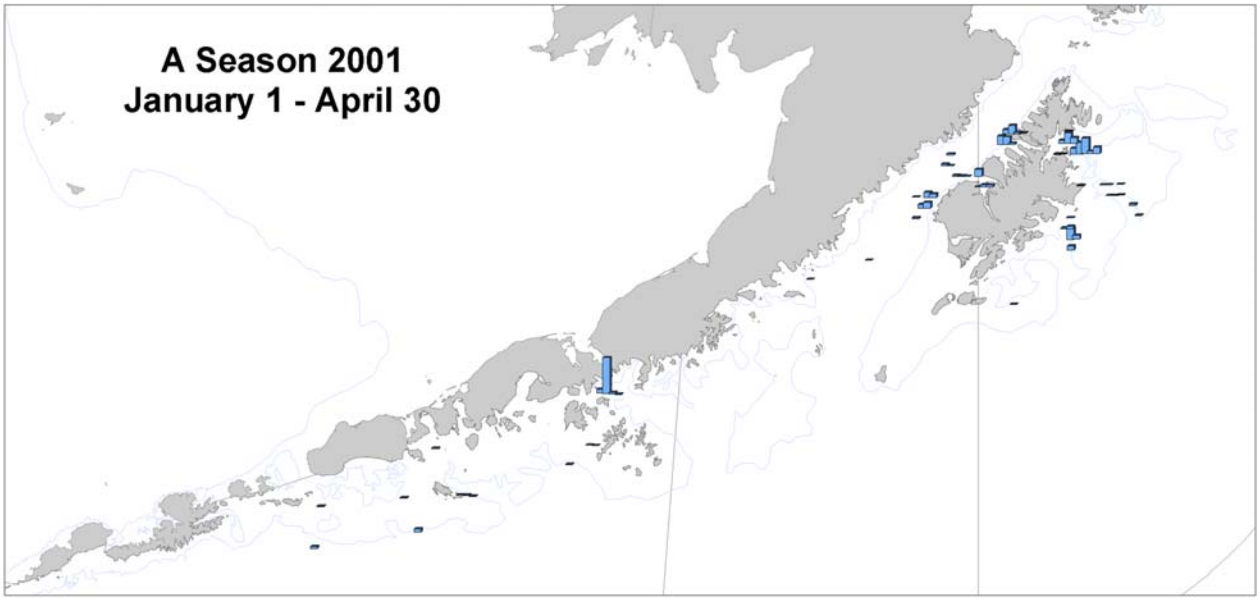


Figure 29. Comparison of observer-recorded catches of Gulf of Alaska pollock during the A and B seasons of 2000.



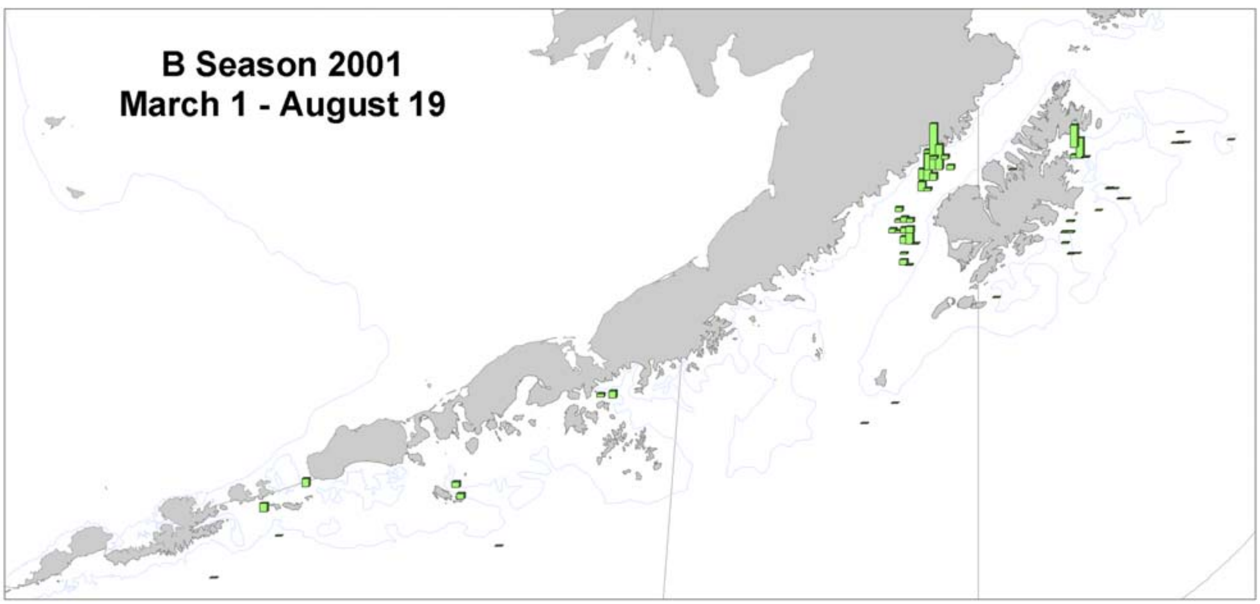


Figure 30. Comparison of observer-recorded catches of Gulf of Alaska pollock during the A and B seasons of 2001.

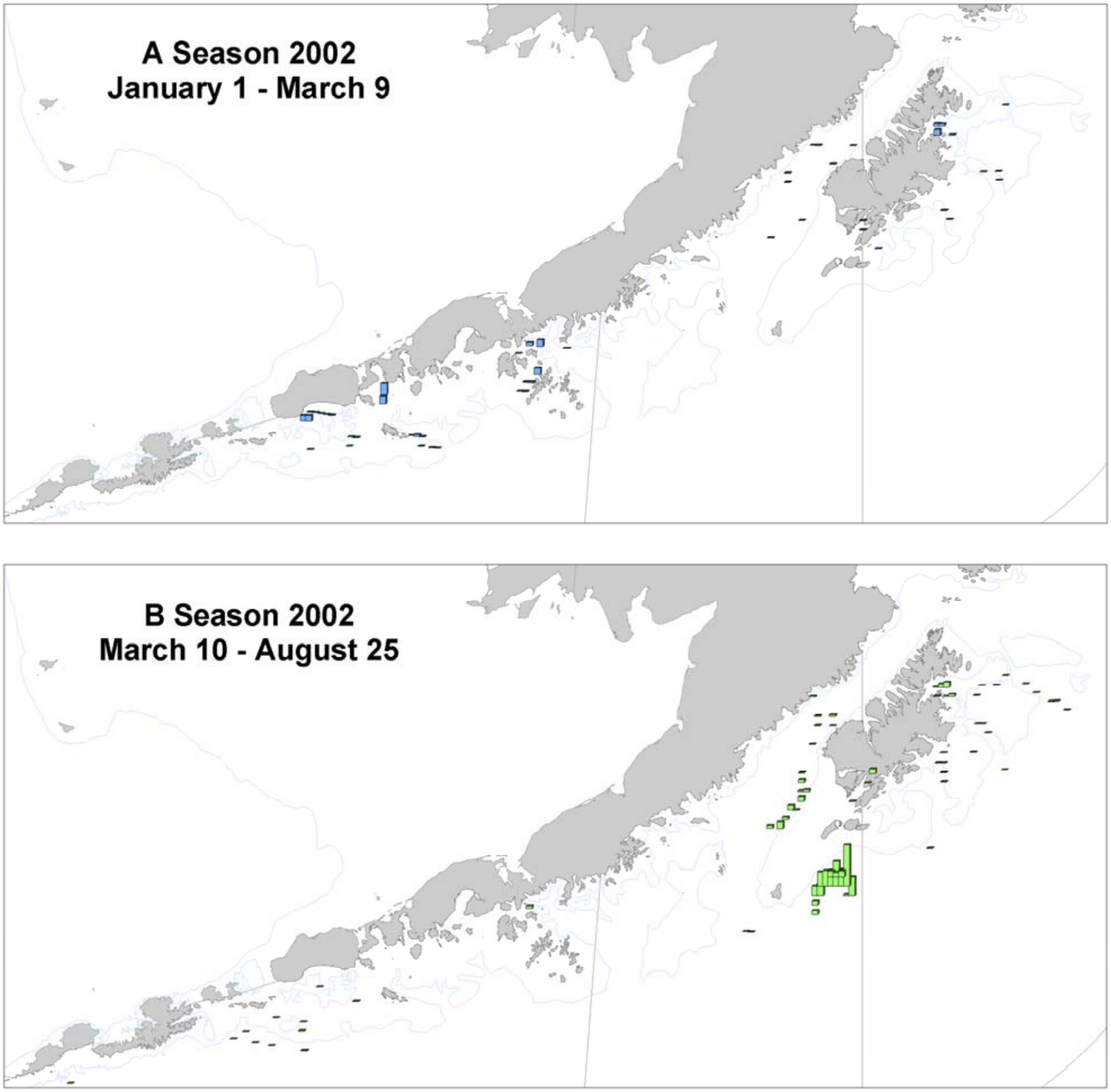


Figure 31. Comparison of observer-recorded catches of Gulf of Alaska pollock during the A and B seasons of 2002.

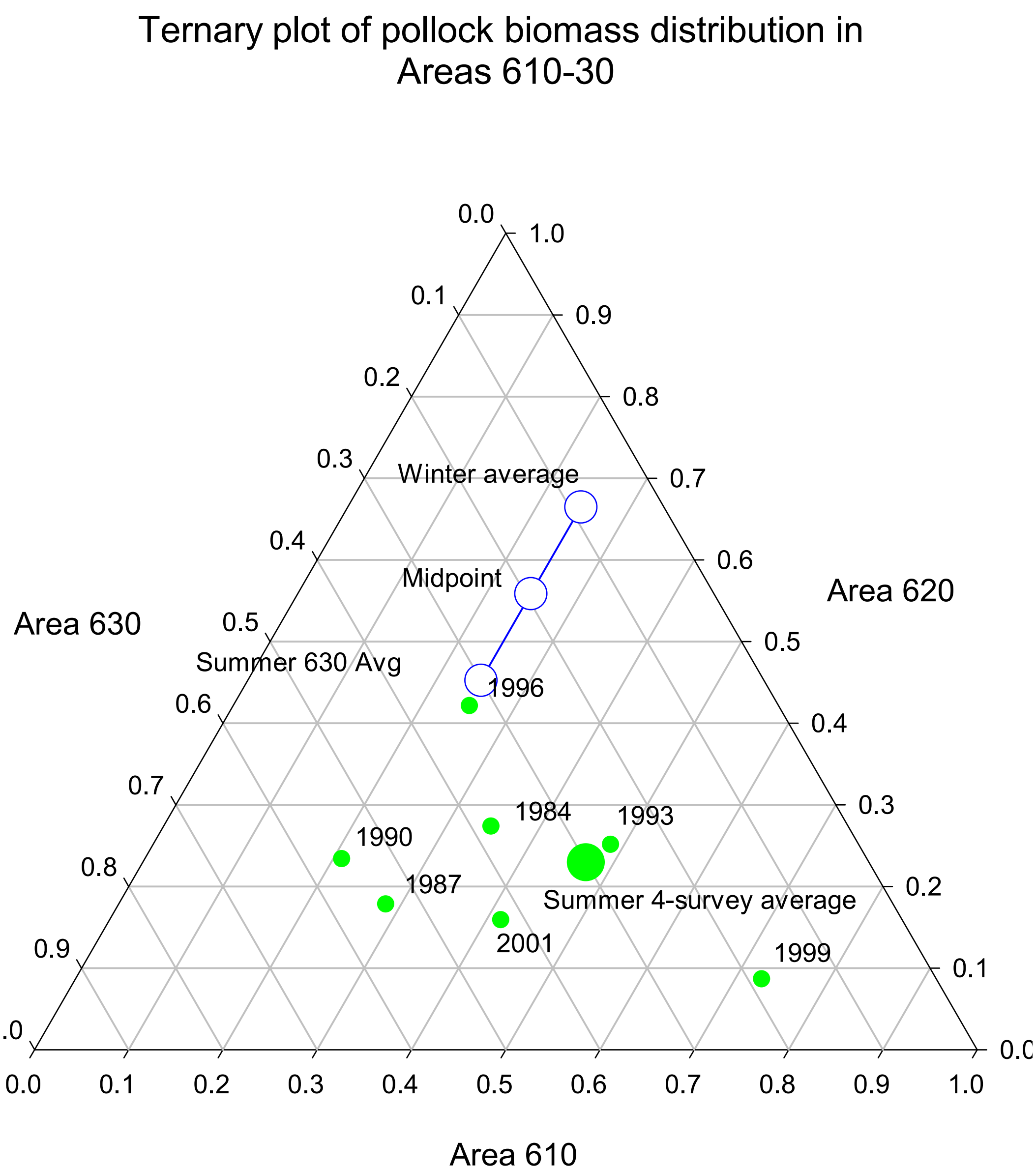
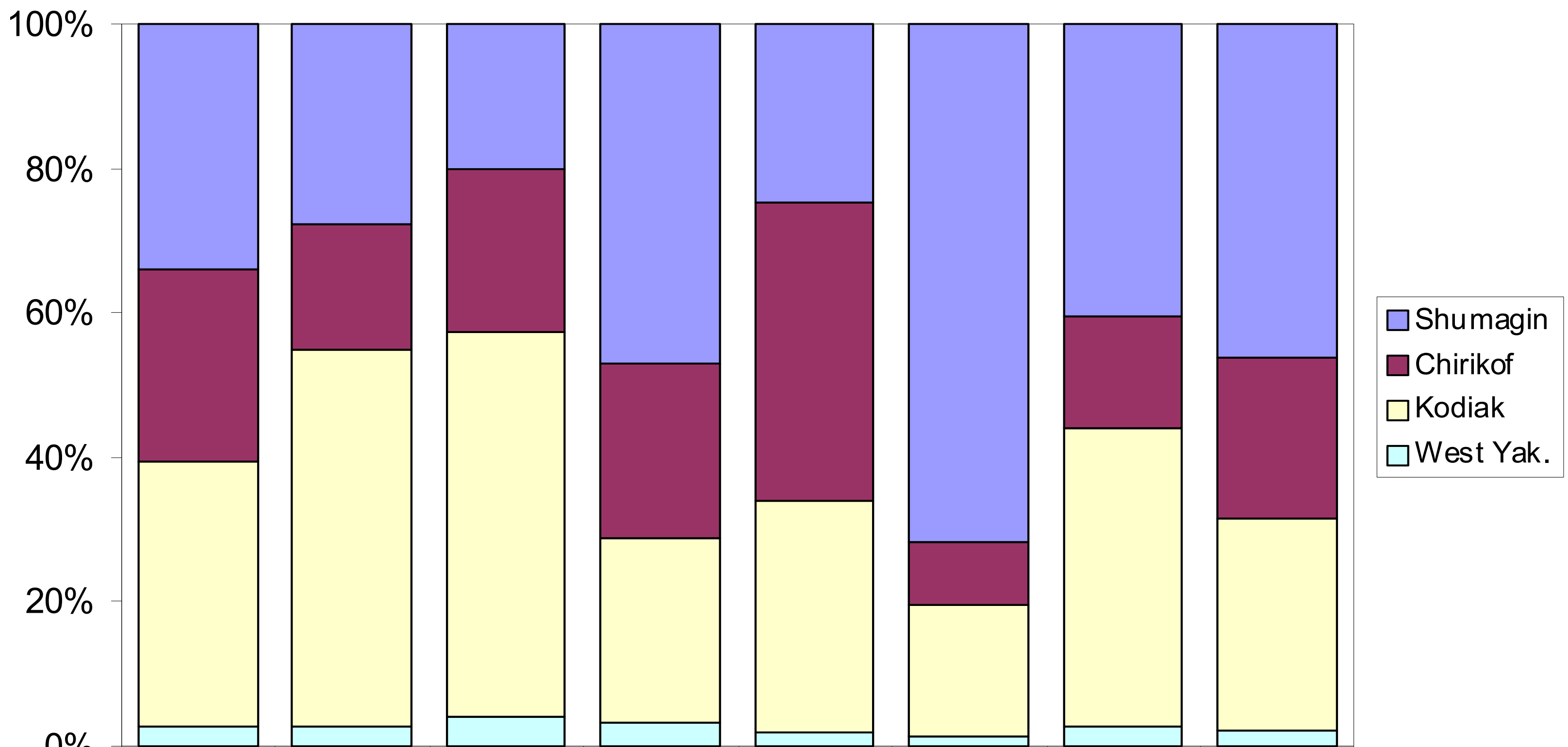


Figure 32. Ternary plot of the seasonal biomass distribution of walleye pollock in the Gulf of Alaska.



	1984	1987	1990	1993	1996	1999	2001	4 survey avg (1993-2001)
Shumagin	33.82%	27.59%	20.03%	46.98%	24.60%	71.81%	40.40%	45.95%
Chirikof	26.66%	17.38%	22.41%	24.32%	41.37%	8.57%	15.49%	22.44%
Kodiak	36.90%	52.41%	53.43%	25.49%	32.20%	18.30%	41.49%	29.37%
West Yak.	2.62%	2.62%	4.13%	3.21%	1.83%	1.32%	2.62%	2.25%

Figure 33. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2001. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.

Appendix C: 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 1964 to 1999 (36 yrs). The Baranov (1918) catch equations are assumed, so that

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

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

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

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 = age-specific selectivity, and f_i = 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 (~ 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 (~ 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 a 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,

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