Assessment of Walleye Pollock in the Gulf of Alaska

by

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Summary of major changes

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

New Input data:

1. Fishery: 2004 total catch and catch at age.

2. Shelikof Strait EIT survey: 2005 biomass and age composition.

3. NMFS bottom trawl survey: 2005 biomass and size composition

3. ADF&G crab/groundfish trawl survey: 2005 biomass and length composition, 2004 age composition.

Assessment model

The age-structured assessment model developed using ADModel Builder (a C++ software language extension and automatic differentiation library) and used for assessments in 1999-2004 is fundamentally unchanged. Model exploration focused on evaluating the contribution of each survey time series to the assessment.

Assessment results

The model estimate of spawning biomass in 2006 is 193,092 t, which is 35% of unfished spawning biomass and below $B_{40\%}$ (224,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. Estimates of stock status in 2006 are similar to 2005, and are consistent with survey trend estimates (2% increase in the Shelikof Strait EIT survey, 11% decline in the NMFS bottom trawl survey, and 20% decline in the ADFG trawl survey). The leveling off of the recent increase in spawning biomass is due to the aging of the relatively strong 1999 and 2000 year classes and the lack of significant recruitment in subsequent years. Spawning biomass is projected to decline after 2006 at least until 2008. There is some evidence that the 2004 year class may be relatively strong, but uncertainty concerning its magnitude is high. The author's 2006 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 81,300 t, a decrease of 6% from the 2005 ABC. This recommendation is based on a more conservative alternative to the maximum permissible F_{ABC} introduced in the 2001 SAFE. The OFL in 2006 is 110,100 t. In 2007, the ABC and OFL are 65,060 t and 89,500 t, respectively.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendations for 2006 and 2007 in Appendix A is 6,157 t and the OFL is 8,209 t (the same for both years).

Responses to Comments of the Scientific and Statistical Committee (SSC)

From the December, 2003 minutes:

"*The SSC recommends that the assessment authors consider the role of arrowtooth flounder predation within the assessment model, for example by using arrowtooth biomass (or estimates of predation) as a covariate in estimates of natural mortality for younger age classes.*"
Hollowed et al. (2000) developed stock assessment model for Gulf of Alaska pollock that included predation mortality. This work demonstrated that including predation in the assessment model was technically feasible, but required assumptions in addition to the usual ones in an assessment model, such as an assumption of residual natural mortality and a model for predator satiation. Diet data for arrowtooth flounder and other pollock predators in the Gulf of Alaska is limited. It is only since 1990 that comprehensive samples have been collected, and samples are collected every other year in the summer during NMFS bottom trawl surveys.

A more general problem is how to use assessment results that include predation mortality to provide ABC recommendations. Gulf of Alaska pollock are managed under Tier 3, where reference fishing mortality rates are based on spawning biomass per recruit (SPR), while biomass reference levels are estimated by multiplying the SPR by average recruitment. Hollowed et al. (2000) estimated higher total natural mortality when arrowtooth flounder predation was included in the model, which would have resulted in an increased harvest rate when fishing at $F_{40\%}$. This seemed an inappropriate management response to a population that may be at higher risk due to ecosystem changes, and the assessment model with predation was not carried forward. Collie and Gislason (2001) argue that "it would be risky and inappropriate to use the formula for calculating *F*40% to adjust the BRP (biological reference points) of a given species in response to changes in growth or mortality rates. Particularly for prey species, it can also be risky to maintain the *F*40% for average conditions when the demographic parameters change. Hence, alternatives to *Fx*% need to be found for forage fish species." We have begun work on a management strategy evaluation (MSE) for Gulf of Alaska pollock to evaluate current harvest polices and potential alternatives when natural mortality is not constant, and SSC input as this work progresses will be needed.

"p. 45, 1st paragraph: Based on cut-offs, values in the table suggest an average year class in 2003, not a weak year class."

In this year's assessment, the neural network element of the FOCI forecast predicts a weak 2004 year class and an average 2005 year class based on the cut-off values. The initial assessment model estimate of the 2003 year class is 276 million, which would be considered a weak year class, i.e., below the 33rd percentile.

"The aging-error transition matrix should include a probability that both readers are off by one year in opposite directions for consistency (a maximum difference of 2 years)."

The method of using percent agreement to estimate the standard deviation of ageing error was first implemented in the stock synthesis model (Methot 2000) and is widely applied in North Pacific stock assessments. It is based on the assumption that ageing error is normally distributed around the true age, and age readers are always off in the same direction. Since errors in age reading occur when deciding whether an ambiguous check in an ageing structure represents an annulus or not, errors in same direction may be more common than errors in opposite directions. Data presented in Heifetz et al. (1999) for known age fish suggest that reader errors in opposite directions are much less frequent than errors in the same direction, at least for sablefish.

“Table 1.12 should include a break-down of the different likelihood components in addition to the total log-likelihood for a full evaluation of differences among models.”

Table 1.12 now includes a listing of different likelihood components.

“ p. 53: Residual plots in Fig 1.14 – 1.16 appear to correspond to model 2a. Figure legends say model 3.”

This error has been remedied.

“Fig 1.21 is very difficult to read. It would be preferable to use the same style that was used for Fig 1.6 and 1.7.”

Figure 1.21 has been modified as suggested.

Introduction

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

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

Fishery

The commercial fishery for walleye pollock in the Gulf of Alaska started as a foreign fishery in the early 1970s (Megrey 1989). Catches increased rapidly during the late 1970s and early 1980s (Table 1.1). A large spawning aggregation was discovered in Shelikof Strait in 1981, and a fishery developed for which pollock roe was an important product. The domestic fishery for pollock developed rapidly in the Gulf of Alaska with only a short period of joint venture operations in the mid-1980s. The fishery was fully domestic by 1988.

The fishery for pollock in the Gulf of Alaska is entirely shore-based with approximately 90% of the catch taken with pelagic trawls. During winter, fishing effort targets pre-spawning aggregations in Shelikof Strait and near the Shumagin Islands (Fig. 1.1). Fishing in summer is less predictable, but typically occurs on the east side of Kodiak Island and in nearshore waters along the Alaska Peninsula.

Incidental catch in the Gulf of Alaska directed pollock fishery is low. For tows classified as pollock targets in the Gulf of Alaska, more than 95% of the catch by weight consists of pollock (Table 1.2). The most common managed species in the incidental catch are arrowtooth flounder, Pacific cod, flathead sole, Pacific Ocean perch and the shortraker/rougheye rockfish complex. The most common non-target species are eulachon, capelin, squid, grenadiers, and various shark species.

Kodiak is the major port for pollock in the Gulf of Alaska, with 61% of the 2000-2004 landings. Sand Point and Dutch Harbor are also important ports, sharing 27% of 2000-2004 landings. Secondary ports, including Cordova, Port Moller, King Cove, Akutan, Seward and Kenai, account for the remaining 12% of the 2000-2004 landings.

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

biomass, and to establish three or four seasons between mid-January and autumn during which some fraction of the TAC can be taken. The Steller Sea Lion Protection Measures implemented in 2001 established 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 levels.

Data Used in the Assessment

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

Total Catch

Estimated catch was derived by the NMFS Regional Office from shoreside electronic logbooks and observer estimates of at-sea discards (Table 1.3). Catches include the state-managed pollock fishery in Prince William Sound. In 1996-2005, the pollock Guideline Harvest Level (GHL) for the PWS fishery was deducted from the Acceptable Biological Catch (ABC) by the NPFMC Gulf of Alaska Plan Team.

Fishery Age Composition

Estimates of fishery age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). Pollock otoliths collected during the 2004 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 2004 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	174	400	393	71
	No. lengths	623	1423	1190	188
	Catch (t)	7,850	18,450	6,970	1340
2nd half (C and D seasons)	No. ages	402	387	392	----
	No. lengths	2187	962	1521	----
	Catch (t)	15,610	6,220	7,480	8

In the first half of 2004, the age-4 and age-5 fish (2000 and 1999 year classes respectively) were dominant in all areas. In the second half of 2004, the age-4 fish were dominant in areas 610 and 630, while in area 620, the age-2 and age-3 fish were more common in the catch than older fish (Fig. 1.2).

Fishery catch at age in 1976-2004 is presented in Table 1.4 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.5.

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 1.6). 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. In a typical survey, 800 tows are completed. On average, 70% of these tows contain pollock (Table 1.7).

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

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

The Alaska Fisheries Science Center's (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted the ninth comprehensive bottom trawl survey since 1984 during the summer of 2005. The spatial distribution of pollock was similar to earlier surveys, with higher CPUEs around Kodiak Island, nearshore along the Alaska Peninsula, and just north of Dixon Entrance in Southeast Alaska (Fig. 1.4). The 2005 gulfwide biomass estimate of pollock was 381,258 t (Table 1.8), representing a decrease 10% of from the 2003 gulfwide estimate. The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140º W long, obtained by adding the biomass estimates for the Shumagin, Chirikof, Kodiak INPFC areas, and the western portion of Yakutat INPFC area. The biomass estimate for this portion of the Gulf of Alaska is 354,912 t.

Bottom Trawl Age and length Composition

Estimates of numbers at age from the bottom trawl survey were obtained from random otolith samples and length frequency samples (Table 1.9). 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. Since age composition estimates are not yet available for the 2005 survey, size composition estimates were used in the assessment model. Size composition by statistical area showed a bimodal distribution, with a mode of juvenile pollock likely representing the one-year-old fish, and a mode of adult fish consisting from multiple year classes (Fig. 1.5). In the Shumagin area, there was a secondary mode at 28 cm, likely representing age-2 fish. In other statistical areas, there was a strong mode of age-1 fish that became progressively larger from the Chirikof area to the Southeast area, most likely due to seasonal growth during the course of the survey.

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 2005 are presented in a NMFS processed report (Guttormsen et al. 2005). Biomass estimates from 1992 onwards were re-estimated to take into account recently published work of eulachon acoustic target strength (Gauthier and Horne 2004). Previously, acoustic backscatter was attributed to eulachon based on the percent composition of eulachon in trawls, and it was assumed that eulachon had the same target strength as pollock. Since Gauthier and Horne (2004) determined that the target strength of eulachon was much lower than pollock, the acoustic backscatter could be attributed entirely to pollock even when eulachon were known to be present. Since eulachon abundance has increased since 2000, the more recent surveys increased by a greater percentage than the pre-2000 surveys, though not enough to significantly alter the overall pattern in the time series. The 2005 biomass estimate for age 2+ pollock in Shelikof Strait is 338,038 t, an increase of 2% from the 2004 biomass (Table 1.6). Biomass ≥43 cm biomass (a proxy for spawning biomass) increased by 78% from the 2004 estimate primarily due to the maturation of the relatively strong 1999 and 2000 year classes (Fig. 1.6). For the first time since 2000, significant quantities of age-1 fish were found in Shelikof Strait (1.6 billion), suggesting that 2004 year class may be above average.

Additional EIT surveys in winter 2005 covered the Shumagin Islands spawning area, Sanak Gully, and an area along the shelf break east of the entrance to the Shelikof sea valley. Results from these surveys are given below.

2005 EIT survey results

		Shumagin	*Sanak*	*Shelikof*	*Chirikof shelf break*	*Total*
Total	Tons	51,970	65,548	356,117	77,037	550,671
	Percent	9%	12%	65%	14%	
Biomass ≥43 cm	Tons	49,028	63,372	252,608	72,290	437,298
	Percent	11%	14%	58%	17%	

In comparison to 2003, when these areas were last surveyed, biomass estimates are higher near Kodiak Island (Shelikof Strait 30% increase, shelf break 2 ½ times higher), and lower in the western Gulf of Alaska (Shumagin 23% lower, and Sanak gully 17% lower). The total biomass >43 cm, a proxy for spawning biomass, is similar to the assessment models estimate of male + female spawning biomass of 416,000 t. Since none of the surveys outside of Shelikof Strait are used in the model, these estimates provide independent support for the assessment results. They also suggest that pollock are not spawning in significant quantities outside these areas in the Gulf of Alaska.

Since the assessment model only includes individuals age 2 and older, the biomass of age-1 fish in the 1995, 2000, and 2005 surveys was subtracted from the total biomass for those years, reducing the biomass by 15%, 13%, and 5% respectively (Table 1.6). 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. 1.7). In the 2005 survey, the age-1 fish from the 2005 year class were numerically dominant, but appear as a secondary mode in the biomass distribution by length. Length frequency data are not used in the assessment model because estimates of age composition are available for all surveys.

Echo Integrated Trawl Survey Age Composition
Estimates of numbers at age from the Shelikof Strait EIT survey (1981 - 1991, 1993 -1998, 2000-2005 (Table 1.9 were obtained from random otolith samples and length frequency samples. Otoliths collected during the 1994 - 2005 EIT surveys were aged using the revised criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.7.

Egg Production Estimates of Spawning Biomass

Estimates of spawning biomass in Shelikof Strait based on egg production methods were included in the assessment model. A complete description of the estimation process is given in Picquelle and Megrey (1993). The estimates of spawning biomass in Shelikof Strait show a pattern similar to the acoustic survey (Table 1.6). The annual egg production spawning biomass estimate for 1981 is questionable because of sampling deficiencies during the egg surveys for that year (Kendall and Picquelle 1990). Coefficients of variation (CV) associated with these estimates were included in the assessment model. Egg production estimates were discontinued because the Shelikof Strait EIT survey provided similar information.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

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

The 2005 biomass estimate for pollock for the ADF&G crab/groundfish survey was 79,089 t, a decrease of 20% from the 2004 biomass estimate (Table 1.6).

ADF&G Survey Length Frequency
Pollock length-frequencies for the ADF&G survey in 1989-2002 (excluding 1991 and 1995) typically show a primary mode at lengths greater than 45 cm (Fig. 1.8). The predominance of large fish in the ADF&G survey may result from the selectivity of the gear, or because of greater abundance of large pollock in the areas surveyed.

ADF&G Survey Age Composition
Ages were determined by age readers in the AFSC age and growth unit from samples of pollock otoliths collected during the 2000, 2002, and 2004 ADF&G surveys (N = 559, 538 & 591). 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 the depth strata (km^2) and summed to obtain proxy biomass estimates by INPFC area. Since each INPFC area contained only a single non-randomly selected index site, these proxy biomass estimates are potentially biased and would not incorporate the variability in relationship between the mean CPUE at an index site and the mean CPUE for the entire INPFC area. We used a comparison between these proxy biomass estimates by INPFC area and the actual NMFS triennial survey estimates by INPFC area for 1984-99 to obtain correction factors and variance estimates. Correction factors had the form of a ratio estimate (Cochran 1977), in which the sum of the NMFS survey biomass estimates for an INPFC area for 1984-99 is divided by the sum of the proxy biomass estimates for the same period.

Variances were obtained by bootstrapping data within site-depth strata and repeating the biomass estimation algorithm. A parametric bootstrap assuming a lognormal distribution was used for the INPFC

area correction factors. Variance estimates do not reflect the uncertainty in the FPC estimate. In the assessment model, we do not apply the FPC to the biomass estimates, but instead include the information about FPC estimate (mean and variance) as a likelihood component for relative survey catchability,

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

where q_1 is the catchability of the NMFS bottom trawl survey, q_2 is the catchability of historical 400-mesh eastern trawl surveys, $\hat{F}PC$ 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 were very low (<300,000 t) between 1961 and 1971, increased by at least a factor of ten in 1974 and 1975, and then declined to approximately 900,000 t in 1978 (Table 1.10). 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 1.10), 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 lower than at any time since then. 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 precautionary 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 be difficult over the long-term.

Qualitative trends

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

the survey. Although there is considerable variability in each survey time series, a fairly clear downward trend is evident to 2000, followed by a stable, though variable, trend (Fig. 1.9).

We also evaluated indices derived from fisheries catch data for trends in biological characteristics (Fig. 1.10). The percent of females in the catch is close to 50-50, but shows a slight, though non-significant, downward trend, which may be related to changes in the seasonal distribution of the catch. The mean age shows interannual variability due to strong year classes passing through the population, but no downward trends that would suggest excessive mortality rates. The percent of old fish in the catch (nominally defined as age 8 and older) is also highly variable due to variability in year class strength, but increased to a peak in 1997, and has since declined due to weaker recruitment in the 1990s. Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch is approximately 11%. We computed an index of catch at age diversity using the Shannon-Wiener information index,

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

where p_a is the proportion at age. Increases in fishing mortality would tend to reduce age diversity, but year class variability would also influence age diversity. The index of age diversity is relatively stable during 1976-2004 (Fig. 1.10).

McKelvey Index

McKelvey (1996) found a significant correlation between the abundance of age-1 pollock in the Shelikof Strait EIT survey and subsequent estimates of year-class strength. The McKelvey index is defined as the estimated abundance of 9-16 cm fish in the Shelikof Strait EIT survey, and is an index of recruitment at age 2 in the following year (Table 1.11). 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. The 2005 Shelikof EIT survey age-1 estimate is 1.6 billion (4th in abundance out of 22 surveys), a relatively large value indicative of stronger than average recruitment for the 2004 year class.

2005 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 2005 Kodiak monthly precipitation. The Kodiak Weather Service Office (http://padq.arh.noaa.gov/) prepares monthly precipitation totals (inches) from hourly observations. Data for 2005 were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.

2. Wind mixing energy at [57°N, 156°W] estimated from 2005 sea-level pressure analyses. Monthly estimates of wind mixing energy (W m^{-2}) were computed for a location near the southwestern end of Shelikof Strait. To make the estimates, twice-daily gradient winds were computed for that location using the METLIB utility (Macklin et al., 1984). Gradient winds were converted to surface winds using an empirical formula based on Macklin et al. (1993). Estimates of wind mixing energy were computed using constant air density (1.293 kg m^{-3}) and the drag coefficient formulation of Large and Pond (1982).

3. Advection of ocean water near Shelikof Strait inferred from drogued drifters deployed during the spring of 2005.

4. Rough counts of pollock larvae from a survey conducted in late May–early June 2005.

5. Estimates of age-2 pollock abundance and spawner biomass from the 2005 assessment.

Analysis
Kodiak Precipitation: Kodiak precipitation is a 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. The season began with typical precipitation during January. For all contributing winter and spring months, precipitation was near or above normal, with February being the wettest (at 153% of the 30-yr February average.

Kodiak precipitation for 2005

Month	*% 30-yr average*
Jan	104
Feb	153
Mar	111
Apr	103
May	139
June	104

Based on this information, the forecast element for Kodiak 2005 rainfall has a score of 2.21. This is "average to strong" on the continuum from 1 (weak) to 3 (strong).

Wind Mixing: Following the decadal trend established in the late 1990s, wind mixing at the southern end of Shelikof Strait was again below the long-term average for all winter and spring months of 2005, except March.

Wind mixing at the exit of Shelikof Strait for 2005

Month	*% 30-yr average*
Jan	46
Feb	48
Mar	114
Apr	74
May	39
June	39

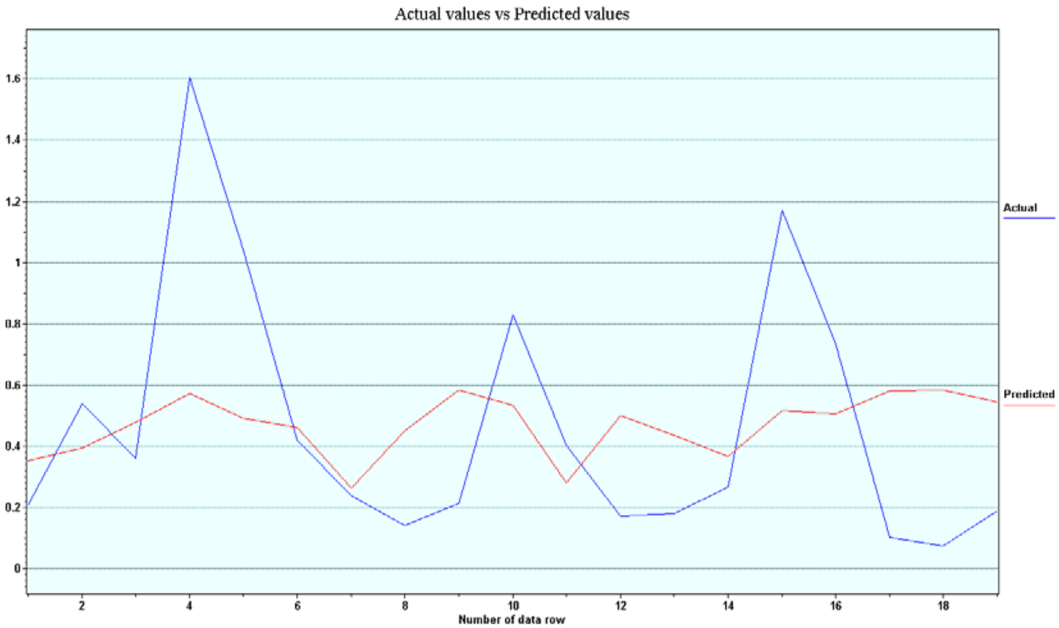
Strong mixing in winter helps transport nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak spring mixing is thought to better enable first feeding pollock larvae to locate and capture food. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment. This year's scenario produces a wind mixing score of 2.29, which equates to "average-to-strong".

Advection: From an examination of drifter trajectories and wind forcing, the transport in Shelikof Strait for spring of 2005 was strong until mid April and then weak, which would support a prediction of an average to strong year class. We have hypothesized that very strong transport is bad for pollock survival, that moderate transport is best, and that very weak transport, while not as disastrous as strong transport, still is detrimental to larval survival. Advection was given a score of 2.29.

Relating the Larval Index to Recruitment: As in last year's analysis, a nonlinear neural network model with one input neuron (larval abundance), three hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (CPUA, average catch, m^{-2}) to age-2 recruitment abundance (billions). The model estimated six weighting parameters. The neural network model, which used the 19 observation pairs in the table below to fit the model, had a very low R^2 of 0.054. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) are given in figure below, where row number corresponds to the rows of the data matrix given in the table.

Data used in the neural network model

Year Class	*Mean CPUA*	*Recruit*
1982	71.14483	0.206506
1985	80.42379	0.539391
1987	329.7428	0.361222
1988	217.9464	1.60372
1989	537.2899	1.04255
1990	373.8137	0.418636
1991	54.21859	0.239326
1992	562.7872	0.141279
1993	185.3388	0.212236
1994	126.5823	0.828361
1995	605.2316	0.402497
1996	477.6918	0.172455
1997	568.421	0.179436
1998	74.29526	0.266972
1999	119.071	1.17074
2000	492.0364	0.734729
2001	171.3022	0.103318
2002	175.6366	0.074741
2003	133.4611	0.188679



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

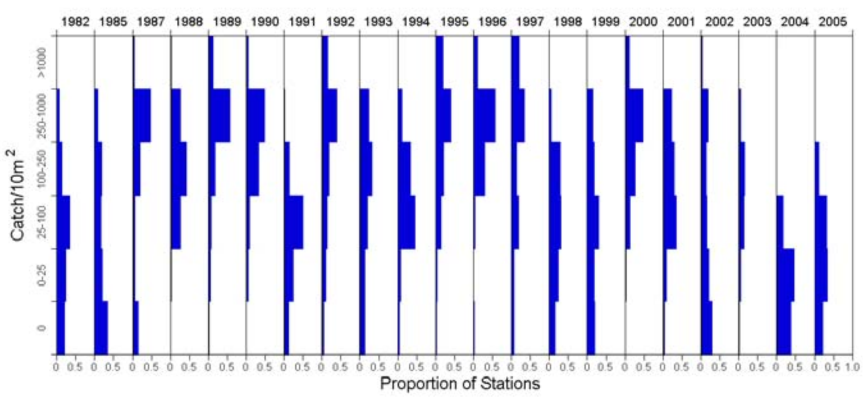
The trained network was then used to predict the recruitment for 2004 and 2005. The predictions are given in the table below.

Neural network model predictions for 2004 and 2005

Year	*Actual Recruitment*	*Predicted Recruitment*
2004	n/a	0.248
2005	n/a	0.339

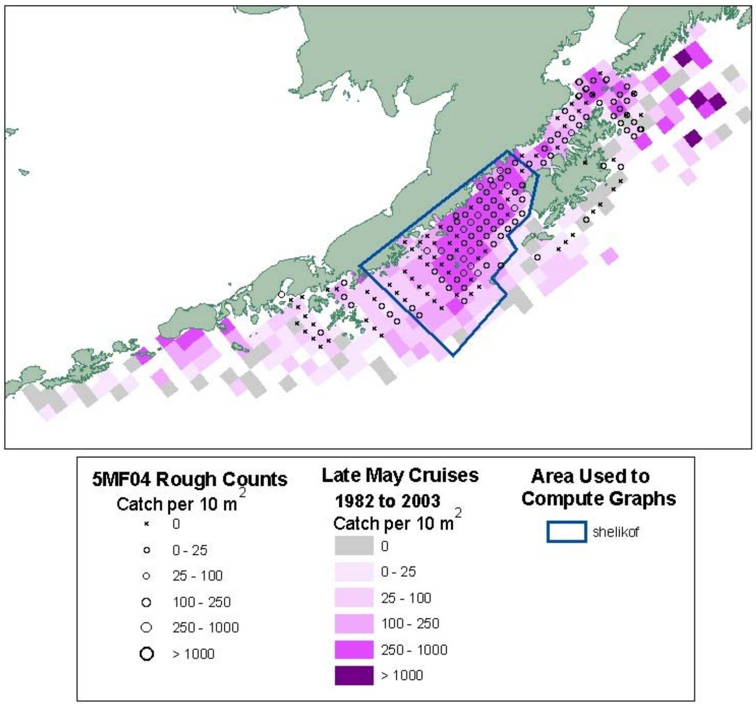
These values, using the 33% (0.335 billion) and 66% (0.701 billion) cutoff points given below, correspond to a weak 2004 year class and an average 2005 year class.

Larval Index Counts: Plotting the data by year and binning the data into catch/10 m^2 categories (given below) provides another view of the data. The pattern for 2005 (based on rough counts) show patterns similar to last year in that most of the data fall into the three lowest binning categories, but there were some data observation occupying the higher density bins. These patterns indicate that the 2005-year class may be below average.

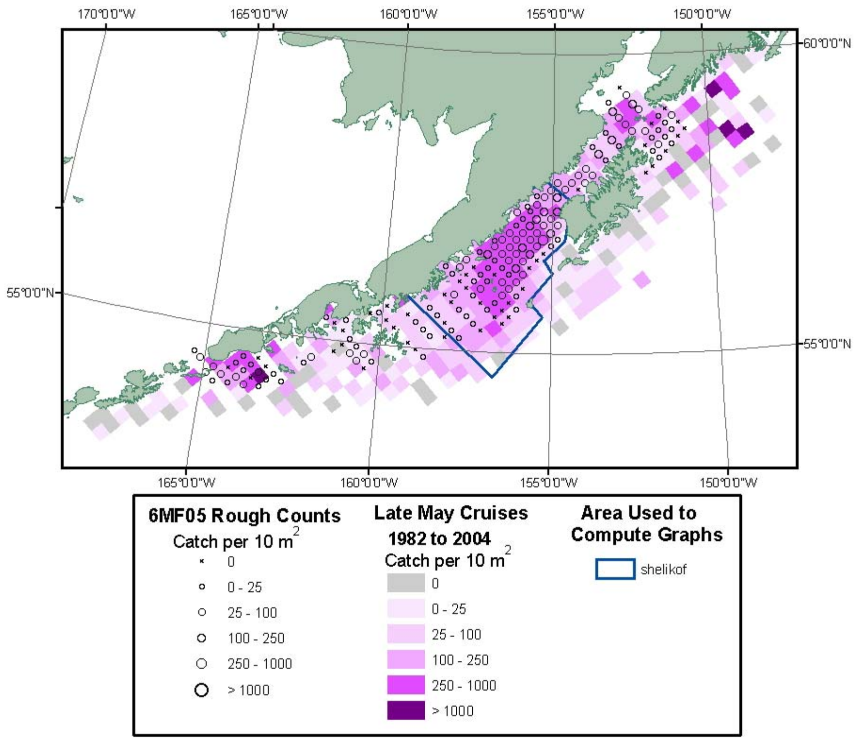


A series of histograms for larval walleye pollock densities in late May from 1982 to 2005.

Data were binned into catch/10 m^2 categories. The data from 2000-2005 are rough counts taken at sea, and the 2005 data are from the 6MF05 cruise that was completed on June 3. The data for above figure were taken from a reference area that is routinely sampled and that usually contains the majority of the larvae. This year's distribution of pollock appears to be centered in the typical reference area, and the larval abundance figures in the middle of the reference area seem to be average. Also, the distribution of larvae in 2005 are further to the west compared to 2004 suggesting that some of the Shelikof larvae might be in their nursery area at the time of the survey. Comparing the two maps shows that the 2005 rough counts seem to be higher compared to 2004. Given these two pieces of information, the score for larval index is set to average or 2.0.



Rough counts in 2004 (catch per 10 m^2) compared to the mean for late May cruises during 1982-2003.



Rough counts in 2005 (catch per 10 m^2) compared to the mean for late May cruises during 1982-2004.

Recruitment Time Series: The time series of recruitment from this year's assessment was analyzed using transition probabilities over time. The data set consisted of age 2 abundance estimates from 1961-2005, representing the 1959-2003 year classes. There were a total of 45 recruitment data points. The 33% (0.335 billion) and 66% (0.701 billion) percentile cutoff points were calculated from the full time series and used to define the three recruitment states of weak, average and strong. The lower third of the data points were called weak, the middle third average and the upper third strong. Using these definitions, nine transition probabilities were then calculated:

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

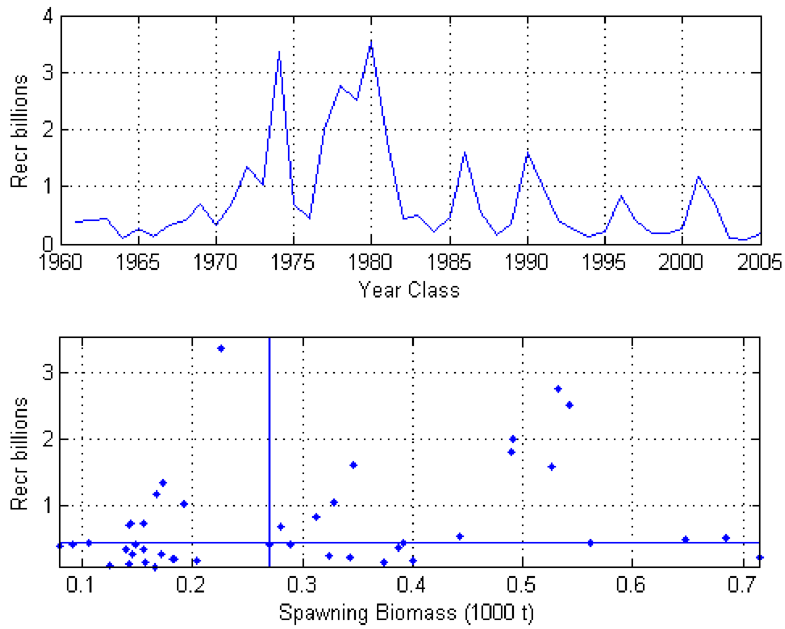
The probabilities were calculated with a time lag of two years so that the 2005 year class could be predicted from the size of the 2003 year class. The 2003 year class was estimated to be 0.188679 billion and was classified as weak. The probabilities of other recruitment states following a weak year class for a lag of 2 years (n=45) are given below:

Probability of the 2005 year class being weak, average and strong following a weak 2003 year class

2005 Year Class		*2003 Year Class*	*Probability*	*N*
Weak	follows	Weak	0.093	4
Average	follows	Weak	0.070	3
Strong	follows	Weak	0.139	6

The probability of a strong year class following a weak year class two years later had the highest probability. We classified this data element as a strong, giving it a score at the low end of strong 2.34.

Spawner/Recruit Time Series: The data from the previous analysis only looked at the time sequence of the recruitment data points. This section looks at both the recruitment (R) and the spawning biomass (SB) in the context of transition probabilities after Rothschild and Mullin (1985). The benefit is that it is non-parametric and it provides a way to predict recruitment without applying a presumed functional spawner-recruit relationship. It involves partitioning the spawning stock into N-tiles and the recruitment into N-tiles, classifying the stock into NxN states. We used the 50% percentile of the data to calculate the median spawning biomass (0.269 million tons) and recruitment (0.435 billion). These values were used to partition the spawner-recruit space into 2x2 classification matrix, state 1:low SB-low R, state 2:low SB-high R, state 3:high SB-low R, and state 4:high SB-high R. The classification matrix can then be used to evaluate transition probabilities between the cells. The time series of recruitment data and the 2x2 spawning biomass-recruitment plot are shown in the figure below.



Time series of recruitment and the 2x2 classification of the spawning biomass and recruitment data

Transition matrix calculated from data in above figure

Transition Probability matrix	To state1	To state 2	To state 3	To state 4
From state 1	0.692	0.308	0.000	0.000
From state 2	0.375	0.500	0.000	0.125
From state 3	0.125	0.000	0.500	0.375
From state 4	0.000	0.000	0.267	0.733

To calculate the score takes two steps. First, we determine which state is the current state by taking the estimate of spawning biomass in 2005 (0.1827 million tons) and note that it falls below the median value of 0.269. We can see that in 2005 we are in either state 1 or state 2. The probabilities of transitioning from state 1 or state 2 to other states are given in the first two rows of the above table.
If we are in state 1, then recruitment can either be below (a recruitment score of 1) or above the median (a recruitment score of 3). Note the probability for transitioning from state 1 to state 3 or 4 is 0.0 and from state 2 to state 3 is 0.0. If we start in state 1, then the combined recruitment score would be the weighted average of the recruitment scores for each possible transition, where the weighting factors are the probabilities. So, the calculations for the second step proceed as described below.

The weighted recruitment score (given we start in state 1) is the recruitment score for staying in state 1 (recruitment below the median, score=1) times the weight (the probability of transitioning from state 1 back to state 1) plus the recruitment score for transitioning from state 1 to state 2 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 1 to state 2), all divided by the sum of the weights.

$$= \frac{(1*0.692)+(3*0.308)}{(0.692+0.308)} = 1.61$$

Similarly, the weighted recruitment score (given we start in state 2)

$$= \frac{(1*0.375)+(3*0.5)+(3*0.125)}{(0.375+0.5+0.125)} = 2.25$$

We average over these two weighted scores because stating from either state 1 or state 2 is equally likely if the starting spawning biomass in 2005 is below the median, giving a final score of 1.97, or the middle range of average.

Conclusion
A low weighting score of 0.1 was assigned to the larval index data element because the recruitment variability explained by larval abundance was very low. Each of the remaining data elements were weighted equally. Based on these six elements and the weights assigned in the table below, the FOCI forecast of the 2005 year class is average.

Final 2005 pollock recruitment forecast

Element	Weights	Score	Total
Time Sequence of R	0.18	2.34	0.4212
Rain	0.18	2.21	0.3978
Wind Mixing	0.18	2.29	0.4122
Advection	0.18	2.29	0.4122
Larval Index-abundance	0.10	2.00	0.2000
Spawner-Recruit Data	0.18	1.68	0.3024
Total	1.00		2.1458= Average

Analytic Approach

Model description

Age-structured models for the period 1961 to 2005 (45 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 (1964-2005)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-2004)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-2005)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-2005)	Multinomial	Sample size = 60
NMFS bottom trawl survey biomass (1984-2005)	Log-normal	Survey-specific CV = 0.11-0.38
NMFS bottom trawl survey age comp. (1984-2003)	Multinomial	Survey-specific sample size = 38-74
NMFS bottom trawl survey size comp. (2005)	Multinomial	Survey-specific sample size = 60
Egg production biomass (1981-92)	Log-normal	Survey specific CV = 0.10-0.25
ADF&G trawl survey biomass (1989-2005)	Log-normal	CV = 0.25
ADF&G survey age comp. (2000,2002,2004)	Multinomial	Sample size = 10
ADF&G survey length comp. (1989-2005)	Multinomial	Sample size = 10
Historical trawl survey biomass (1961-1982)	Log-normal	Survey-specific CV = 0.24-0.64
Historical trawl survey age comp. (1973)	Multinomial	Sample size = 60
Historical trawl survey length comp. (1961-1982)	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 (1961-1968,2005)	Log-normal	CV =1.0

Recruitment
In most years, year-class abundance at age 2 was estimated as a free parameter. Constraints were imposed on recruitment at the start of the modeled time period to improve parameter estimability. Instead of estimating the abundance of each age of the initial age composition independently, we parameterized

the initial age composition with mean log recruitment plus a log deviation from an equilibrium age structure based on that mean initial recruitment. A penalty was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period. We also used the same penalty for log deviations in recruitment for 1961-68, and in 2005. Log deviations were estimated as free parameters in other years. 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 fishery selectivity. To accommodate changes in selectivity during the development of the fishery, we allowed the parameters of the double logistic function to vary according to a random walk process (Sullivan et al. 1997). 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) and in 2005, the process error standard deviation for those years was assumed to be very small, so that annual changes in selectivity are highly restricted during these years.

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 0.8. This result is reasonable because pollock are known to form pelagic aggregations and occur in nearshore areas not well 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 1.6). 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
An ageing error transition matrix is used in the assessment model to convert population numbers at age to expected fishery and survey catch at age (Table 1.12). Dorn et al. (2003) estimated this matrix using an ageing error model fit to the observed percent agreement at ages 2 and 9. Mean percent agreement is close to 100% at age 1 and declines to 40% at age 10. Annual estimates of percent agreement are

variable, but show no obvious trend, from which it was concluded that using a single transition matrix for all years in the assessment model was appropriate. The model is based on a linear increase in the standard deviation of ageing error and the assumption that ageing error is normally distributed. The model predicts percent agreement by taking into account the probability that both readers are correct, both readers are off by one year in the same direction, and both readers are off by two years in the same direction (Methot 2000). The probability that both agree and were off by more than two years was considered negligible. A cooperative project between AFSC and ADF&G is in progress to validate pollock ageing criteria using radiometric methods (D. Kimura, pers. comm.)

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

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

A list of model parameters is shown below:

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 1961-2005 = 45	Estimated as log deviances from the log mean; recruitment in 1961-68, and 2005 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated in the model
Fishing mortality	Years 1961-2005 = 45	Estimated as log deviances from the log mean
Mean fishery selectivity	4	Slope parameters estimated on a log scale, intercept parameters on an arithmetic scale
Annual changes in fishery selectivity	4 * (No. years -1) = 176	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	118 primary parameters + 176 process error parameters + 2 fixed parameters = 296	

Parameters Estimated Independently

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

- Natural mortality (M)
- Proportion mature at age
- Weight at age and year by fishery and by survey

Natural mortality

Hollowed and Megrey (1990) estimated natural mortality using a variety of methods including estimates based on: a) growth parameters (Alverson and Carney 1975, and Pauly 1980), b) GSI (Gunderson and Dygert, 1988), c) monitoring cohort abundance, and d) estimation in the assessment model. 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. In theoretical study, Clark (1999) evaluated by the effect of an erroneous M on both estimated abundance and target harvest rates for a simple age-structured model. He found that "errors in estimated abundance and target harvest rate were always in the same direction, with the result that, in the short term, extremely high exploitation rates can be recommended (unintentionally) in cases where the natural mortality rate is overestimated and historical exploitation rates in the catch-at-age data are low." He proposed that this error could be avoided by using a conservative (low) estimate of natural mortality. This suggests that the current approach of using a potentially low but still credible estimate of M for assessment modeling is consistent with the precautionary approach. However, it should be emphasized that the role of pollock as prey in the Gulf of Alaska ecosystem cannot be fully evaluated using a single species assessment model (Hollowed et al. 2000).

Maturity at age

In the 2002 assessment, maturity at age for Gulf of Alaska pollock was estimated using maturity stage data collected during winter EIT surveys in the Gulf of Alaska during 1983-2002. These new estimates replaced a maturity at age vector estimated by Hollowed et al. (1991) using maturity stage data collected during 1983-89. Maturity stages for female pollock describe a continuous process of ovarian development between immature and post-spawning. For the purposes of estimating a maturity vector (the proportion of an age group that has been or will be reproductively active during the year) for stock assessment, all fish greater than or equal to a particular maturity stage are assumed to be mature, while those less than that stage are assumed to be immature. We assumed that maturity stages in which ovarian development had progressed to the point where ova were distinctly visible were mature. Maturity stage data should not be considered the most reliable data to estimate maturity at age. The stages are qualitative rather than quantitative, so there is subjectivity in assigning stages, and a potential for different technicians to apply criteria differently. Because the link between pre-spawning maturity stages and eventual reproductive activity later in the season is not well established, the division between mature and immature stages is problematic. Changes in the timing of spawning could also affect maturity at age estimates. Merati (1993) compared visual maturity stages with ovary histology and a blood assay for vitellogenin and found general consistency between the different approaches. Merati (1993) noted that ovaries classified as late developing stage (i.e., immature) may contain yolked eggs, but it was unclear whether these fish would spawn later in the year. The average sample size of female pollock maturity stage data per year from winter EIT surveys in the Gulf of Alaska is 850 (Table 1.13).

Estimates of maturity at age in 2005 from winter EIT surveys were above the long-term average for all ages (Fig. 1.11). For example, the proportion of mature age-5 fish was 88% compared to 57% for the long-term average. Because there did not appear to be an objective basis for excluding data, we used the 1983-2004 average maturity at age in the assessment.

Logistic regression (McCullagh and Nelder 1983) was also used to estimate the age and length at 50% mature at age for each year. Annual estimates of age at 50% maturity are highly variable and range from 3.7 years in 1984 to 6.1 years in 1991, with an average of 4.9 years. Length at 50% mature is less variable than the age at 50% mature, suggesting that at least some of the variability in the age at maturity can be attributed to changes in length at age (Fig 1.12). There is less evidence of trends in the length at 50% mature, with only the 1983 and 1984 estimates as unusually low values. The average length at 50% mature for all years is approximately 42 cm.

Weight at age

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific

age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a\,L^b$, were also estimated. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions.

Model selection and evaluation

Model Selection

A range of different model configurations were used to assess the sensitivity of the results to model assumptions and different data sources. As in last year's assessment, we compared models with estimated and fixed NMFS trawl survey catchability. We also evaluated the effect of the ADF&G survey and the Shelikof Strait EIT survey on estimated stock status by reducing the weights used in fitting data from these surveys.

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

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

Model 3: As in model 2, except that weights used to fit the model to ADF&G survey time series were reduced (higher assumed CVs for biomass index, and lower nominal samples for length and age composition).

Model 4: As in model 2, except that weights used to fit the model to Shelikof Strait EIT survey time series were reduced (higher assumed CVs for biomass index, and lower nominal samples for length and age composition).

Comparison of Model 1 (estimated trawl catchability) with Model 2 (fixed trawl catchability) indicate that a despite consistent difference in stock biomass (13% decrease for Model 2), the difference in total log likelihood is small (1.2) (Table 1.14). When a similar analysis was performed in previous assessments, the estimate of catchability ranged from 0.70 to 0.85, rather than 0.77 in the current assessment, suggesting some tendency for the estimate to jump around. Although Model 1 would be preferred by maximum likelihood criterion, the difference in model fit probably 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 built into the assessment, since estimates of stock biomass and yield are lower when catchability is fixed. Not surprisingly, the uncertainty in biomass estimates are higher (and more realistic) for Model 1, since the assumption of known catchability in Model 2 artificially reduces uncertainty in the assessment.

Comparison of models that down weight either the ADFG trawl survey or the Shelikof Strait EIT survey (models 3 and 4) indicate the estimated biomass trends are broadly consistent with the base model (Fig. 1.13). All show a similar pattern of increase and decline, suggesting that no survey has a dominant influence on the estimated trend in abundance. For the full time period, down-weighting the Shelikof Strait EIT time series results in much lower peak abundance in the mid-1980s. For the period since 1990, down weighting the Shelikof Strait EIT survey results in higher biomass, while down weighting the

ADFG trawl survey results in lower biomass. This suggests some lack of consistency between the EIT survey in Shelikof Strait and the ADFG trawl survey.

Model Evaluation

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

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

where p_i is the observed proportion at age, $\hat{p}_i$ is the expected proportion at age, and m is the sample size (McCullagh and Nelder 1983). Figure 1.14 is a comparison of observed and predicted fisheries age composition, and Figures 1.15-1.17 show residuals for the fit to the fishery, the Shelikof Strait EIT survey and the NMFS trawl survey age compositions, and the ADFG trawl survey length composition. Although there are large residuals for some ages and years, no severe pattern of residuals is evident in the fishery age composition. Two moderate patterns were apparent in the fishery data. The first is a tendency for strong year classes to gain strength from adjacent weaker year classes as they become older, producing a pattern of negative residuals for the adjacent year classes. This pattern is most apparent for the strong 1984 year class beginning in 1990 at age 6. In addition, there is a tendency for strong year classes to shift a year as they become older. This pattern is most obvious for the 1988 year class, which began to change into a 1989 year class in 1995.

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

Model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 2003) (Figs. 1.18-1.20). General trends in survey time series are fit reasonably well. For example, both the model and all surveys show a declining trend in the 1990s. But since each survey time series shows a different pattern of decline, the model is unable to fit all surveys simultaneously. The ADF&G survey matches the model trend better than any other survey, despite receiving less weight in model fitting. The discrepancy between the NMFS trawl survey and the Shelikof Strait EIT survey biomass estimates in the 1980s accounts for the poor model fit to both time series during in those years. More recently, the model fits extremely well both the biomass estimates from the both the NMFS bottom trawl survey and the ADF&G trawl survey in 2005, but shows a poorer fit to recent Shelikof Strait EIT survey biomass estimates.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.80 (Fig. 1.21). The change in log likelihood is very small (less than one) between models with fixed and estimated catchability, indicating that despite the large change in biomass, there is little objective basis for choosing one model over the other.

Assessment Model Results

Parameter estimates and model output for Model 2 are presented in a series of tables and figures. Estimated selectivity for different periods in the fishery and for surveys is given in Table 1.15 (see also Figure 1.22). Table 1.16 gives the estimated population numbers at age for the years 1961-2005. Table 1.17 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1969-2005 (see also Fig. 1.23). 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, reached a minimum in 2003 of 26% of unfished stock size, and by 2005 had increased to 37% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1995-2004 indicates the current estimated trend in spawning biomass for 1990-2005 is consistent with previous estimates (Fig. 1.24). All time series show a similar pattern of decreasing spawning biomass in the 1990s. Retrospective biases in the assessment are small, but based on the current assessment there was some tendency to underestimate ending year abundance from 1993 to 1997, followed by several years of overestimating ending year abundance. Assessment results from since 2002 are very consistent. The estimated 2005 age composition from the current assessment is very similar to the estimated age composition in the 2003 assessment (Fig. 1.24). Estimates of the relatively strong 1999 and 2000 year classes in this assessment are similar to estimates in last year's assessment, though the 1999 year class is still trending downwards (13% lower) (Fig. 1.25).

Stock and recruitment

Recruitment of Gulf of Alaska pollock is more variable (CV = 1.06) than Eastern Bering Sea pollock (CV = 0.61). Among North Pacific groundfish stocks with age-structured assessments, GOA pollock ranks third in recruitment variability after sablefish and Pacific Ocean perch (http://www.afsc.noaa.gov/refm/stocks/estimates.htm). However, unlike sablefish and Pacific Ocean perch, pollock have a short generation time (<10 yrs), so that large year classes do not persist in the population long enough to have a buffering effect on population variability. Because of these intrinsic population characteristics, the typical pattern of biomass variability for Gulf of Alaska pollock will be sharp increases due to strong recruitment, followed by periods of gradual decline until the next strong year class recruits to the population. Gulf of Alaska pollock is more likely to show this pattern than any other groundfish stock in the North Pacific due to the combination of a short generation time and high recruitment variability.

Since 1980, strong year classes have occurred every four to six years (Fig. 1.23). Because of high recruitment variability, the mean relationship between stock size and recruitment abundance is not apparent despite good contrast in stock abundance. 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. 1.26). However, this pattern of density-dependent survival emerges from strong decadal trends in spawner productivity. These decadal trends in spawner productivity have produced the pattern of increase and decline in the GOA pollock population. The last two decades have been a period of relatively low spawner productivity.

We summarize information on recent year classes in the table below. Subsequent to the 2000 year class, which appears to be moderate in abundance, information is sketchy. The 2001, 2002, and the 2003 year

classes have not been common in the Shelikof Strait EIT surveys or fishery sampling, and apparently are weak in comparison to the 1999 and 2000 year classes. If the pattern of relatively strong pollock recruitment every 4-6 years continues, then the next episode of strong recruitment would be expected occur in 2005-07. There is relatively good evidence that the 2004 year is at least above average, based on the comparative abundance of age-1 fish in the 2005 Shelikof Strait EIT survey and the 2005 NMFS bottom trawl survey. The summer EIT survey results on the *R/V Oscar Dyson* also lend support to the winter EIT survey result, though apparently the geographic distribution of the age-1 fish in summer was restricted to a relatively small area in Shelikof Strait.

Year of recruitment	2005	2006	2007
Year class	2003	2004	2005
FOCI prediction	*Average*	*Average*	*Average*
Survey information	2004 Shelikof EIT survey age-1 estimate is 8.3 million (20th in abundance out of 22 surveys)	2005 Shelikof EIT survey age-1 estimate is 1.6 billion (4th in abundance out of 22 surveys) 2005 summer EIT survey age-1 estimate is 1.2 billion 2005 NMFS bottom trawl estimate is 155 million (4th in abundance out of 10 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 F_{SPR} harvest rates were obtained using the life history characteristics of Gulf of Alaska pollock (Table 1.18). Spawning biomass reference levels were based on mean 1979-2004 recruitment (755 million), which is 4% lower than the post-1979 mean in the 2004 assessment due to the inclusion of the weak 2002 year class in the average. The average did not include the recruitment in 2005 (2003 year class) due to uncertainty in the estimates of year class strength. Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using mean weight at age for the Shelikof Strait EIT surveys in 2001-2005 to estimate current reproductive potential. The SPR at F=0 was estimated as 0.729 kg/recruit, which is nearly the same as the estimate in last year's assessment (2% higher). This 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. 1.1). Since 1992, Gulf of Alaska pollock have been managed with time and area restrictions, and selectivity has been fairly stable (Fig. 1.22). For SPR calculations, we used a selectivity pattern based on an average for 1992-2004.

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

F_{SPR} rate	Fishing mortality	Equilibrium under average 1979-2002 recruitment				
		Avg. Recr. (Million)	Total 3+ biom. (1000 t)	Female spawning biom. (1000 t)	Catch (1000 t)	Harvest rate
100.0%	0.000	755	1793	559	0	0.0%
50.0%	0.198	755	1205	280	132	11.0%
45.0%	0.234	755	1141	252	145	12.7%
40.0%	0.276	755	1076	224	157	14.6%
35.0%	0.326	755	1009	196	169	16.8%

The $B_{40\%}$ estimate of 224,000 t is 2% lower than the $B_{40\%}$ estimate of 229,000 t in the 2004 assessment due to the lower post-1977 mean recruitment. The model estimate of spawning biomass in 2006 is 193,092 t, which just below 35% of unfished spawning biomass and below $B_{40\%}$ (224,000 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).

2006 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 84.3% of the OFL harvest rate. In the 2001 assessment, based on an analysis that showed that the buffer between the maximum permissible F_{ABC} and OFL decreased when the stock is below approximately $B_{50\%}$, we developed a more conservative alternative that maintains a constant buffer between ABC and F_{ABC} at all stock levels (Table 1.19). 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 $B^{*} = B_{40\%} \frac{F_{35\%}}{F_{40\%}}$

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

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

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

This alternative has the same functional form as the maximum permissible F_{ABC}; the only difference is that it declines linearly from B^* (= $B_{47\%}$) to 0.05B^* (Fig. 1.27).

Projections for 2006 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 in Table 1.20.

ABC recommendation

There are three major sources of new information about abundance trends in 2005. The 2005 Shelikof Strait EIT survey indicated a 2% increase in total biomass since 2004, but a stronger increase (78%) increase in adult biomass (≥43 cm) due to maturation of the 1999 and 2000 year classes. For the first time since 2000, significant quantities of age-1 fish were found in Shelikof Strait (1.6 billion), suggesting that 2004 year class may be above average. The 2005 NMFS bottom trawl survey indicated an 11% decline since 2003. The 2005 ADF&G crab/groundfish survey biomass decreased by 20% from the 2004 estimate, but is 18% higher than the 2003 estimate, suggesting that these differences are mostly sampling variability. Model estimates of stock status in 2006 are similar to 2005, and are generally consistent with survey trends. The model adequately fits the new survey information. The overall picture both from surveys and assessment results suggest a leveling off in the recent increase in pollock abundance and a reasonable consistency with model projections in previous assessments.

The primary concerns about Gulf of Alaska pollock for the short-term are 1) weak recruitment to the population after the 2000 year class, 2) lower than expected spawning biomass estimates for Shelikof Strait. Since the early 1980s, there has been a pattern of relatively strong pollock recruitment every 4-6 years. If this pattern continues, the next episode of strong recruitment would be expected occur in 2005-07. There is evidence from several sources that the 2004 year class (recruiting in 2006) will be above average in abundance, but uncertainty concerning its magnitude is large. The concern over the decline in spawning activity in Shelikof Strait is mitigated by the additional winter surveying efforts in 2005, which in aggregate resulted in an estimate of spawning biomass close to the model estimate. Nevertheless, the cause of these changes in utilization of spawning habitat is unknown, and there is concern that changes in spawning behavior alone could impact pollock abundance in the future.

We consider Model 2 as the strongest candidate on which to base yield recommendations. Changes in the estimate of NMFS trawl catchability with an additional data suggest that basing an assessment on an estimated trawl catchability could increase interannual variability in ABC recommendations. Model comparisons suggest that the assumption that NMFS trawl catchability equals 1.0 is a reasonable precautionary assumption. Models which down weight an entire survey time series are useful for sensitivity analyses, but we are reluctant to de-emphasize a survey unless there is good evidence to think it is biased. No survey covers the entire spatial distribution of pollock (or distance above bottom). 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.

Based on these considerations, we used Model 2 with an adjusted $F_{40\%}$ harvest rate for the author's recommended 2005 ABC of 81,300 t. 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) applying a more conservative harvest rate than the maximum permissible F_{ABC}. Collectively these risk-averse elements reduce the recommended ABC to approximately 63% of the model point estimate.

In 2007, the ABC based an adjusted $F_{40\%}$ harvest rate is 65,060 t (Table 1.20). The OFL in 2006 is 110,100 t, and the OFL in 2007 if the recommended ABC is taken in 2006 is 89,500 t.

To evaluate the probability that the stock will drop below the $B_{20\%}$ threshold, we projected the stock forward for five years and removed catches based on the spawning biomass in each year and the author's recommended fishing mortality schedule. This projection incorporates uncertainty in stock status, uncertainty in the estimate of $B_{20\%}$, and variability in future recruitment. We then sampled from the likelihood of future spawning biomass using Markov chain Monte Carlo (MCMC) (Fig. 1.28). 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 dropping below $B_{20\%}$ will be less than 1% in all years.

Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the 2005 numbers at age as estimated by the assessment model and remove the 2005 TAC from the population. 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 1979-2004 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 1.18. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2006, 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 2001-2005 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

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

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

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

Scenario 7: In 2006 and 2007, F is set equal to $max\ F_{ABC}$, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.20. Under all harvest policies except the F=0 policy, mean spawning biomass is projected to decrease from 2006 to 2008 due to the lack of recent recruitment, then increase gradually (Fig. 1.29). Plots of individual projection runs are highly variable (Fig. 1.30), and may provide a more realistic view of potential pollock abundance in the future.

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

Spawning biomass is projected to be 190,536 t in 2006 for an F_{OFL} harvest rate, which is less than $B_{35\%}$ (196,000 t), but greater than ½ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2016 is 219,280 t, 112% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2008 is 151,482 t, which is less than $B_{35\%}$, but greater than ½ of $B_{35\%}$. Projected mean spawning biomass in 2018 is 218,623 t, 112% of $B_{35\%}$. Therefore, Gulf of Alaska pollock is not approaching an overfished condition.

Ecosystem considerations

Prey of pollock

An ECOPATH model was assembled to characterize food web structure in Gulf of Alaska using diet data and population estimates during 1990-93. We use ECOPATH here simply as a tool to integrate diet data and stock abundance estimates in a consistent way to evaluate ecosystem interactions. We focus primarily on first-order trophic interactions: prey of pollock and the predators of pollock.

Pollock trophic interactions occur primarily in the pelagic pathway in the food web, which leads from phytoplankton through various categories of zooplankton to planktivorous fish species such as capelin and sandlance (Fig. 1.31); the primary prey of pollock are euphausiids. Pollock also consume shrimp, which are more associated with the benthic pathway, and make up approximately 18% of age 2+ pollock diet. All ages of GOA pollock are primarily zooplanktivorous during the summer growing season (>80% by weight zooplankton in diets for juveniles and adults; Fig 1.32). While there is an ontogenetic shift in diet from copepods to larger zooplankton (primarily euphausiids) and fish (Fig. 1.32), cannibalism is not as prevalent in the Gulf of Alaska as in the Eastern Bering Sea, and fish consumption is low even for large pollock (Yang and Nelson 2000).

There are no extended time series of zooplankton abundance for the shelf waters of the Gulf of the Alaska. Brodeur and Ware (1995) provide evidence that biomass of zooplankton in the center of the Alaska Gyre was twice as high in the 1980s than in the 1950s and 1960s, consistent with a shift to positive values of the PDO since 1977. The percentage of zooplankton in diets of pollock is relatively constant throughout the 1990s (Fig. 1.32). While indices of stomach fullness exist for these survey years, a more detailed bioenergetic modeling approach would be required to examine if feeding and growth conditions have changed over time, especially given the fluctuations in GOA water temperature in recent years (Fig. 15, Ecosystem Considerations Appendix), as water temperature has a considerable effect on digestion and other energetic rates.

Predators of pollock

Initial ECOPATH model results show that the top five predators on pollock >20 cm by relative importance are arrowtooth flounder, Pacific halibut, Pacific cod, Steller sea lion (SSL), and the directed pollock fishery (Fig. 1.33). For pollock less than 20cm, arrowtooth flounder represent close to 50% of total mortality. All major predators show some diet specialization, and none depend on pollock for more than 50% of their total consumption (Fig. 1.34). Pacific halibut is most dependent on pollock (48%), followed by SSL (39%), then arrowtooth flounder (24% for juvenile and adult pollock combined), and lastly Pacific cod (18%). It is important to note that although arrowtooth flounder is the largest single source of mortality for both juvenile and adult pollock (Fig 1.33), arrowtooth depend less on pollock in their diets then do the other predators.

Arrowtooth consume a greater number of smaller pollock than do Pacific cod or Pacific halibut, which consume primarily adult fish. However, by weight, larger pollock are important to all three predators (Fig. 1.35). Length frequencies of pollock consumed by the western stock of Steller sea lions tend towards larger fish, and generally match the size frequencies of cod and halibut (Zeppelin et al. 2004). The diet of Pacific cod and Pacific halibut are similar in that the majority of their diet besides pollock is from the benthic pathway of the food web. Alternate prey for Steller sea lions and arrowtooth flounder are similar, and come primarily from the pelagic pathway.

Predation mortality, as estimated by ECOPATH, is extremely high for GOA pollock >20cm. Estimates for the 1990-1993 time period indicate that known sources of predation sum to 90%-120% of the total production of walleye pollock calculated from 2004 stock assessment growth and mortality rates; estimates greater than 100% may indicate a declining stock (as shown by the stock assessment trend in the early 1990s; Fig 1.36, top), or the use of mortality rates which are too low. Conversely, as >20cm pollock include a substantial number of 2-year olds, it may be that mortality rate estimates for this age range is low. In either case, predation mortality for pollock in the GOA is much greater a proportion of pollock production than as estimated by the same methods for the Bering Sea, where predation mortality (primarily pollock cannibalism) was up to 50% of total production.

Aside from long-recognized decline in Steller sea lion abundance, the major predators of pollock in the Gulf of Alaska are stable to increasing, in some cases notably so since the 1980s (Fig. 1.36, top). This high level of predation is of concern in light of the declining trend of pollock with respect to predator increases. To assess this concern, it is important to determine if natural mortality may have changed over time (e.g. the shifting control hypothesis; Bailey 2000). To examine predator interactions more closely than in the initial model, diet data of major predators in trawl surveys were examined in all survey years since 1990.

Trends in total consumption of walleye pollock were calculated by the following formula:

$$Consumption = \sum B_{pred,size,subregion} \cdot DC_{pred,size,subregion} \cdot WLF_{pred,size,GOA} \cdot Ration_{pred,size}$$

where B(pred, size, subregion) is the biomass of a predator size class in the summer groundfish surveys in a particular survey subregion; DC is the percentage by weight of pollock in that predator group as measured from stomach samples, WLF is the weight frequency of pollock in the stomachs of that predator group pooled across the GOA region, calculated from length frequencies in stomachs and length-weight relationships from the surveys. Finally, ration is an applied yearly ration for that predator group calculated by fitting weight-at-age to the generalized von Bertalanffy growth equations as described in Essington et al. (2001). Ration is assumed fixed over time for a given size class of predator.

Fig. 1.36 (bottom) shows annual total estimates of consumption of pollock (all age classes) in survey years by the four major fish predators. Other predators, shown as constant, are taken from ECOPATH

modeling results and displayed for comparison. Catch is shown as reported in Table 1.1. In contrast, the line in the figure shows the historical total production (tons/year) plus yearly change in biomass (positive or negative) from the stock assessment results. In a complete accounting of pollock mortality, the height of the bars should match the height of the line. As shown, estimates of consumption greatly surpass estimates of production; fishing mortality is a relatively small proportion of total consumption. Overestimates in consumption rates could arise through seasonal differences in diets; while ration is seasonally adjusted, diet proportions are based on summer data. Also, better energetic estimates of consumption would improve these estimates. In terms of the stock assessment, underestimates of production could result from underestimating natural mortality, especially at ages 2-3, underestimating the rate of decline which occurred between 1990-present, or underestimates of the total biomass of pollock; this analysis should be revisited using higher mortality at younger ages than assumed in the current stock assessment.

To better judge natural mortality, consumption was calculated for two size groups of pollock, divided at 30cm fork length. This size break, which differs from the break in the ECOPATH analysis, is based on finding minima between modes of pollock in predator diets (Fig. 1.35). This break is different from the transition matrices used in the stock assessment; perhaps due to differences in size selection between predators and surveys. For this analysis, it is assumed that pollock<30cm are ages 0-2 while pollock ≥30cm are age 3+ fish.

Consumption of age 0-2 pollock per unit predator biomass (using survey biomass) varied considerably through survey years, although within a year all predators had similar consumption levels (Fig. 1.37, top). Correlation coefficients of consumption rates were 0.98 between arrowtooth and halibut, and 0.90 for both of these species with pollock. Correlation coefficients of these three species with cod were ~0.55 for arrowtooth and halibut and ~0.20 with pollock. The majority of this predation by weight occurred on age 2 pollock.

Plotted against age 2 pollock numbers calculated from the stock assessment, consumption/biomass and total consumption by predators shows a distinct pattern (Fig. 1.37, lower two graphs). In "low" recruitment years consumption is consistently low, while in high recruitment years consumption is high, but does not increase linearly, rather consumptions seems to level out at high numbers of juvenile pollock, resembling a classic "Type II" functional response. This suggests the existence bottom-up control of juvenile consumption, in which strong year classes of pollock "overwhelm" feeding rates of predators, resulting in potentially lower juvenile mortality in good recruitment years which may amplify the recruitment. However, this result should be examined iteratively within the stock assessment, as the back-calculated numbers at age 2 assume a constant natural mortality rate. Assuming a lower mortality rate due to predator satiation would lead to lower estimates of age 2 numbers, which would make the response appear more linear.

Consumption of pollock ≥30cm shows a different pattern over time. A decline of consumption per unit biomass is evident for halibut and cod (Fig. 1.38, top). Arrowtooth shows a nonsignificant decline; it is possible that the noise in the arrowtooth trend, mirroring the consumption of <30cm fish, is due to the choice of 30cm as an age cutoff. As a function of age 3+ assessment biomass, consumption per unit biomass and total consumption remained constant as the stock declined, and then fell off rapidly at low biomass levels in recent years (Fig. 1.38, middle and bottom). Again, this result should be approached iteratively, but it suggests increasing predation mortality on age 3+ pollock between 1990-2005, possibly requiring increased foraging effort from predators.

There has been a marked decline in Pacific halibut weight at age since the 1970s that Clark et al. (1999) attributed to the 1977 regime shift without being able to determine the specific biological mechanisms that produced the change. Possibilities suggested by Clark et al. (1999) include the physiological effect of

an increase in temperature, intra- and interspecific competition for prey, or a change in prey quality. The two species most dependent on pollock in the early 1990s (Pacific halibut and Steller sea lion) have both shown an exceptional biological response during the post-1977 period consistent with a reduction in carrying capacity (growth for Pacific halibut, survival for Steller sea lions). In contrast, the dominant predator on pollock in the Gulf of Alaska (arrowtooth flounder) has increased steadily in abundance over the same period and shows no evidence of decline in size at age. Given that arrowtooth flounder has a range of potential prey types to select from during periods of low pollock abundance (Fig. 1.34), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.37 and 1.38 suggest that recruitment remains bottom-up controlled even under the current estimates of high predation mortality, and may lead to strong year classes. However, top-down control seems to have increased on age 3+ pollock in recent years, perhaps as predators have attempted to maintain constant pollock consumption during a period of declining abundance. It is possible that natural mortality on adult pollock will remain high in the ecosystem in spite of decreasing pollock abundance.

Ecosystem modeling

To examine the relative role of pollock natural versus fishing mortality within the GOA ecosystem, a set of simulations were run using the ECOPATH model shown in Fig. 1.31. Following the method outlined in Aydin et al. (2005), 20,000 model ecosystems were drawn from distributions of input parameters; these parameter sets were subjected to a selection/rejection criteria of species persistence resulting in approximately 500 ecosystems with nondegenerate paramters. These models, which did not begin in an equilibrium state, were projected forward using ECOSIM algorithms until equilibrium conditions were reached. For each group within the model, a perturbation experiment was run in all acceptable ecosystems by reducing the species survival (increasing mortality) by 10%, or by reducing gear effort by 10%, and reporting the percent change in equilibrium of all other species or fisheries catches. The resulting changes are reported as ranges across the generated ecosystems, with 50% and 95% confidence intervals representing the distribution of percent change in equilibrium states for each perturbation.

Fig. 1.39 shows the changes in other species when simulating a 10% decline in adult pollock survival (top graph), a 10% decline in juvenile pollock survival (middle graph), and a 10% decline in pollock trawl effort. Fisheries in these simulations are governed by constant fishing mortality rates rather than harvest control rules. Only the top 20 effects are shown in each graph; note the difference in scales between each graph.

The model results indicate that the largest effects of declining adult pollock survival would be declines in halibut and Steller sea lion biomass. Declines in juvenile survival would have a range of effects, including halibut and Steller sea lions, but also releasing a range of competitors for zooplankton including rockfish and shrimp. The pollock trawl itself has a lesser effect throughout the ecosystem (recall that fishing mortality is small in proportion to predation mortality for pollock); the strongest modeled effects are not on competitors for prey but on incidentally caught species (Table 1.2), with the strongest effects being on sharks.

The results presented above are taken from Gulfwide weighted averages of consumption; Steller sea lions and the fishing fleet are central place foragers, making foraging trips from specific locations (ports in the case of the fishing fleet, and rookeries or haulouts for Steller sea lions). Foraging bouts (or trawl sets) begin at the surface, and foragers attack their prey from the top down. For such species, directed and local changes in fishing may have a disproportionate effect compared to the results shown here.

In contrast, predation by groundfish is not as constrained geographically, and captures are likely to occur when the predator swims upwards from the bottom. Changes in the vertical distribution of pollock may tend to favor one mode of foraging over another. For example, if pollock move deeper in the water column due to surface warming, foraging groundfish might obtain an advantage over surface foragers. Alternatively, pollock may respond adaptively to predation risks from groundfish or surface foragers by changing its position in the water column.

Of species affecting pollock (Fig. 1.40), arrowtooth have the largest impact on adult pollock, while bottom-up processes (phytoplankton and zooplankton) have the largest impact on juvenile pollock. It is interesting to note that the link between juvenile and adult pollock is extremely uncertain (wide error bars) within these models.

Finally, of the four major predators of pollock (Fig 1.41), all are affected by bottom-up forcing; Steller sea lions, Pacific cod, and Pacific halibut are all affected by pollock perturbations, while pollock effects on arrowtooth are much more minor.

Pair-wise correlations in predator trends were examined for consistent patterns (Fig. 1.42). For each pair-wise comparison, we used the maximum number of years available. Time series for Steller sea lions and Pacific cod begin in mid 1970s, while other time series extend back to the early 1960s. We make no attempt to evaluate statistical significance (biomass trends are highly autocorrelated), and emphasize that correlation does not imply causation. If two populations are strongly correlated in time, there are many possible explanations: both populations are responding to similar forcing, one or other is causative agent, etc.

Pollock abundance, fishery catches, and Steller sea lions are positively correlated (Fig. 1.42). Since the harvest policy for pollock is modified fixed harvest rate strategy, a positive correlation between catch and abundance would be expected. The Steller sea lion trend is more strongly correlated with pollock abundance than pollock catches, but this correlation is based on data since 1976, and does not include earlier years of low pollock abundance. The only strong inverse correlation is between arrowtooth flounder and Steller sea lions. A strong positive correlation exists between Pacific cod and Pacific halibut, and, from the 1960s to the present, between Pacific halibut and arrowtooth flounder.

Several patterns are apparent in abundance trends and the diet data. First, the two predators with alternate prey in the benthic pathway, Pacific cod and Pacific halibut, covary and have been relatively stable in the post-1977 period. Second, the long term increases in both Pacific halibut and arrowtooth flounder (with quite different diets apart from pollock) may be linked to similarities in their reproductive behavior. Both spawn offshore in late winter, and conditions that enhance onshore advection, such as El Niños, may play an important role in recruitment to nursery areas for these species (Bailey and Picquelle 2002).

Finally, it is apparent that the potential for competition between Steller sea lions and arrowtooth flounder is underappreciated, perhaps because arrowtooth flounder seem poorly designed to compete as forager in the pelagic zone. However, arrowtooth flounder consume both the primary prey of Steller sea lions (pollock), and alternate pelagic prey also utilized by Steller sea lions (capelin, herring, sandlance, salmon). Arrowtooth predation on pollock occurs at a smaller size than pollock targeted by Steller sea lions. The arrowtooth flounder population is nearly unexploited, is increasing in abundance, may be increasing its per unit consumption of pollock, and shows no evidence of density-dependent growth. And lastly, since 1976 there has been a strong inverse correlation between arrowtooth flounder and Steller sea lion abundance that is at least consistent with competition between these species.

Summary

Natural mortality = 0.3
Tier: 3b

2006 harvests

Maximum permissible ABC:	$F_{40\%\ (adjusted)} = 0.23$	Yield = 95,200 t
Recommended ABC:	$F_{40\%\ (adjusted)} = 0.20$	Yield = 81,300 t
Overfishing (OFL):	$F_{35\%\ (adjusted)} = 0.27$	Yield = 110,100 t

2007 harvest

Maximum permissible ABC:	$F_{40\%\ (adjusted)} = 0.20$	Yield = 73,200 t
Recommended ABC:	$F_{40\%\ (adjusted)} = 0.17$	Yield = 65,060 t
Overfishing (OFL):	$F_{35\%\ (adjusted)} = 0.22$	Yield = 89,500 t

Equilibrium female spawning biomass

$B_{100\%}$ = 559,000 t
$B_{40\%}$ = 224,000 t
$B_{35\%}$ = 196,000 t

Projected 2006 biomass

Age 3+ biomass = 608,370 t
Female spawning biomass = 193,092 t

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Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The TAC for 2005 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 (910 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	76
1998			125,098	125,098	124,730	64
1999			95,590	95,590	94,580	35
2000			73,080	73,080	94,960	56
2001			72,076	72,076	90,690	77
2002			51,937	51,937	53,490	78
2003			50,666	50,666	49,590	128
2004			63,913	63,913	65,660	16
2005					86,100	
Average (1977-2004)				110,942	128,541	160

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). 1991-2004--NMFS Alaska Regional Office.

Table 1.2. Incidental catch (t) of FMP species (upper table) and non-target species (bottom table) in the walleye pollock directed fishery in the Gulf of Alaska in 2003 and 2004. Incidental catch estimates include both retained and discarded catch. The "other" FMP species group in the upper table is broken down by species (or less inclusive species groupings) in the lower table.

Managed species/species group	*2003*	*2004*
Pollock	49346.0	62712.2
Arrowtooth flounder	667.6	1033.7
Pacific cod	275.7	499.7
Other (sharks, skates, squid, sculpin, octopus, but excluding skates in 2004)	201.4	292.2
Flathead sole	141.0	268.3
Shortraker and rougheye rockfish	118.8	38.5
Pacific Ocean perch	93.4	60.0
Rex sole	15.5	35.4
Miscellaneous flatfish	25.5	18.2
Atka mackerel	0.0	17.9
Sablefish	3.5	2.3
Dover sole and Greenland turbot	2.0	1.7
Pelagic shelf rockfish complex	2.1	1.5
Unidentified skate	NA	1.8
Big and longnose skate	NA	1.4
Northern rockfish	0.3	0.5
Other rockfish complex	0.5	0.1
Thornyheads	0.5	0.0
Percent non-pollock	*3.0%*	*3.5%*

Non target species/species group	*2003*	*2004*
Other osmerids	350.239	66.034
Squid	53.474	131.351
Eulachon	16.050	168.266
Capelin	6.220	67.986
Scyphozoan jellyfish	43.630	22.370
Grenadier	53.927	7.636
Miscellaneous fish	42.190	15.237
Other sharks	4.681	11.126
Spiny dogfish	3.860	4.979
Other skates	3.107	NA
Pandalid shrimp	0.544	1.455
Pacific sleeper shark	0.481	0.801
Salmon shark	0.005	1.008
Other Sculpins	0.884	0.000
Surf smelt	0.000	0.442
Sea star	0.194	0.000
Sea anemone unidentified	0.000	0.110
Misc crabs	0.074	0.000
Murres	0.000	0.011
Octopus	0.000	0.001

Table 1.3. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 1992-2004 compiled 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*
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	
2002	Retained	17,046	20,106	10,615	1,808	1,216	0	50,791	
	Discarded	416	425	287	10	6	2	1,146	2.2%
	Total	17,462	20,531	10,902	1,818	1,222	2	51,937	
2003	Retained	16,347	18,972	12,225	940	1,118	0	49,603	
	Discarded	161	658	210	2	31	0	1,063	2.1%
	Total	16,508	19,630	12,435	943	1,149	0	50,666	
2004	Retained	23,226	24,221	14,023	215	1,100	0	62,785	
	Discarded	229	440	421	11	26	0	1,127	1.8%
	Total	23,455	24,661	14,444	226	1,127	0	63,913	
Average (1993-2004)		23,488	23,776	29,292	2,347	1,301	14	80,218	

Table 1.4. 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
2002	0.16	12.31	20.72	6.76	4.47	8.75	5.37	6.06	1.33	0.82	0.43	0.30	0.33	0.22	0.13	68.16
2003	0.14	2.69	21.47	22.95	5.33	3.25	4.66	3.76	2.58	0.54	0.19	0.04	0.09	0.04	0.05	67.79
2004	0.85	6.28	11.91	31.84	25.09	5.98	2.43	2.63	0.77	0.22	0.25	0.00	0.00	0.00	0.00	88.24

Table 1.5. 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
2002	1,036	1,025	2,061	9,924	9,851	19,775
2003	1,091	1,119	2,210	8,375	8,220	16,595
2004	1,217	996	2,213	4,446	3,622	8,068

Table 1.6. 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, 2000 and 2005 (114,200, 57,300 and 18,100 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		719,937		
1985	1,175,823			768,419	
1986	585,755			375,907	
1987			732,541	484,455	
1988	301,709			504,418	
1989	290,461			433,894	214,434
1990	374,731		825,592	381,475	114,451
1991	380,331			370,000	
1992	580,000	713,429		616,000	127,359
1993	295,785	435,753	754,390		132,849
1994		492,593			103,420
1995		649,401			
1996		777,172	665,745		122,477
1997		583,017			93,728
1998		504,774			81,215
1999			607,147		53,587
2000		391,327			102,871
2001		432,749	216,777		86,967
2002		256,743			96,237
2003		317,269	399,690		66,989
2004		330,753			99,358
2005		338,038	354,912		79,089

Table 1.7. Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Gulf of Alaska bottom trawl survey and the Shelikof Strait EIT survey. For the Shelikof Strait EIT survey, CVs are reported for 1981-91, while relative estimation error using a geostatistical method are reported for 1992-2003. For the Gulf of Alaska bottom trawl survey, the number of measured pollock is approximate due to subsample expansions in the database, and the total number measured includes both sexed and unsexed fish.

		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
2003	807	508	0.12	514	589	1,103	NA	NA	NA
2005	839	516	0.15	NA	NA	NA	NA	NA	NA
Shelikof Strait EIT survey									
	No. of midwater tows	No. of bottom trawl tows							
1981	36	18	0.12	1,921	1,815	3,736	NA	NA	NA
1983	47	1	0.16	1,642	1,103	2,745	NA	NA	NA
1984	42	0	0.18	1,739	1,622	3,361	NA	NA	NA
1985	57	0	0.14	1,055	1,187	2,242	NA	NA	NA
1986	38	1	0.22	642	618	1,260	NA	NA	NA
1987	27	0	---	557	643	1,200	NA	NA	NA
1988	26	0	0.17	537	464	1,001	NA	NA	NA
1989	21	0	0.10	757	796	1,553	NA	NA	NA
1990	25	16	0.17	988	1,117	2,105	NA	NA	NA
1991	16	2	0.35	478	628	1,106	NA	NA	NA
1992	17	8	0.04	784	765	1,549	NA	NA	NA
1993	22	2	0.05	583	624	1,207	NA	NA	NA
1994	42	12	0.05	554	633	1,187	NA	NA	NA
1995	22	3	0.05	599	575	1,174	NA	NA	NA
1996	30	8	0.04	724	775	1,499	NA	NA	NA
1997	16	14	0.04	682	853	1,535	NA	NA	NA
1998	22	9	0.04	863	784	1,647	NA	NA	NA
2000	31	0	0.05	430	370	800	NA	NA	NA
2001	15	9	0.05	314	378	692	NA	NA	NA
2002	18	1	0.07	278	326	604	NA	NA	NA
2003	17	2	0.05	294	322	616	NA	NA	NA
2004	13	2	0.09	422	315	737	NA	NA	NA
2005	22	1	0.04	543	335	878	NA	NA	NA

Table 1.8. Number of survey hauls, number of hauls with walleye pollock, mean CPUE, biomass, coefficient of variation and mean weight based on the 2005 Gulf of Alaska NMFS bottom trawl survey, by INPFC area and depth intervals.

INPFC area	*Depth (m)*	*Number of Trawl hauls*	*Hauls with catch*	*CPUE (kg/km^2)*	*Biomass (t)*	*CV*	*Mean weight (kg)*
Shumigan	1 - 100	117	56	2,296	94,811	0.45	0.760
	101 - 200	36	30	2,973	43,636	0.41	0.865
	201 - 300	12	12	353	983	0.40	0.779
	301 - 500	9	2	32	81	0.84	0.790
	501 - 700	4	0	0	0	---	---
	701-1000	2	0	0	0	---	---
	All depths	180	100	2,139	139,511	0.33	0.790
Chirkof	1 - 100	71	28	1,735	45,159	0.54	1.413
	101 - 200	62	38	264	6,304	0.30	0.723
	201 - 300	25	23	768	8,871	0.18	0.247
	301 - 500	10	4	16	25	0.51	0.667
	501 - 700	6	1	21	42	1.00	1.01
	701-1000	3	0	0	0	---	---
	All depths	177	94	888	60,401	0.41	0.788
Kodiak	1 - 100	109	58	2,069	79,693	0.25	0.610
	101 - 200	139	89	1,062	46,040	0.28	0.381
	201 - 300	29	28	1,136	13,050	0.37	0.738
	301 - 500	8	3	838	2,440	0.99	0.874
	501 - 700	5	0	0	0	---	---
	701-1000	3	0	0	0	---	---
	All depths	293	178	1,392	141,223	0.17	0.519
Yakutat	1 - 100	15	12	111	1,842	0.47	0.136
	101 - 200	42	38	270	7,925	0.22	0.252
	201 - 300	21	21	555	2,872	0.24	0.585
	301 - 500	8	5	384	1,010	0.49	0.777
	501 - 700	4	0	0	0	---	---
	701-1000	2	0	0	0	---	---
	All depths	92	76	239	13,648	0.16	0.267
Southeastern	1 - 100	9	4	80	525	0.97	0.101
	101 - 200	37	32	1,221	13,537	0.23	0.250
	201 - 300	32	31	1,831	9,250	0.29	0.614
	301 - 500	13	1	3	9	1.00	1.083
	501 - 700	4	0	0	0	---	---
	701-1000	2	0	0	0	---	---
	All depths	97	68	832	23,321	0.18	0.313
Total	All Depths	839	516	1,191	381,258	0.15	0.488

Table 1.9. 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, when total abundance could not be estimated, 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
2003	75.46	18.40	128.41	140.74	73.27	44.72	36.10	25.27	14.51	8.61	3.23	1.79	1.26	0.00	0.00	571.77
							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
1992	228.03	33.69	73.54	188.10	367.99	84.11	84.99	171.18	32.70	56.35	2.30	14.67	0.90	0.30	0.00	1,338.85
1993	63.29	76.08	37.05	72.39	232.79	126.19	26.77	35.63	38.72	16.12	7.77	2.60	2.19	0.49	1.51	739.61
1994	185.98	35.77	49.30	31.75	155.03	83.58	42.48	27.23	44.45	48.46	14.79	6.65	1.12	2.34	0.57	729.49
1995	10,689.87	510.37	79.37	77.70	103.33	245.23	121.72	53.57	16.63	10.72	14.57	5.81	2.12	0.44	0.00	11,931.45
1996	56.14	3,307.21	118.94	25.12	53.99	71.03	201.05	118.52	39.80	13.01	11.32	5.32	2.52	0.03	0.38	4,024.36
1997	70.37	183.14	1,246.55	80.06	18.42	44.04	51.73	97.55	52.73	14.29	2.40	3.05	0.93	0.46	0.00	1,865.72
1998	395.47	88.54	125.57	474.36	136.12	14.22	31.93	36.30	74.08	25.90	14.30	6.88	0.27	0.56	0.56	1,425.05
2000	4,484.41	755.03	216.52	15.83	67.19	131.64	16.82	12.61	9.87	7.84	13.87	6.88	1.88	1.06	0.00	5,741.46
2001	288.93	4,103.95	351.74	61.02	41.55	22.99	34.63	13.07	6.20	2.67	1.20	1.91	0.69	0.50	0.24	4,931.27
2002	8.11	162.61	1,107.17	96.58	16.25	16.14	7.70	6.79	1.46	0.66	0.35	0.34	0.15	0.13	0.00	1,424.45
2003	51.19	89.58	207.69	802.46	56.58	7.69	4.14	1.58	1.46	0.85	0.28	0.00	0.10	0.00	0.00	1,223.60
2004	52.58	93.94	57.58	159.62	356.33	48.78	2.67	3.42	3.32	0.52	0.42	0.00	0.66	0.00	0.00	779.84
2005	1,626.13	157.49	55.54	34.63	172.74	162.40	36.02	3.61	2.39	0.00	0.76	0.00	0.00	0.00	0.00	2,251.71

Table 1.10. 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 published estimates of pollock biomass from surveys using 400-mesh eastern trawls

Year	*Biomass (t)*	*Source*
1961	57,449	*Ronholt et al. 1978*
1961-62	91,075	*Ronholt et al. 1978*
1973-75	1,055,000	*Alton et al. 1977*
1973-76	739,293	*Ronholt et al. 1978*
1973-75	610,413	*Hughes and Hirschhorn 1979*

Table 1.11. 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	11
1981				
1982		1983	0.001	22
1983		1984	0.062	13
1984		1985	2.092	3
1985		1986	0.579	5
1986				
1987		1988	0.017	19
1988		1989	0.399	6
1989		1990	0.049	16
1990		1991	0.022	18
1991		1992	0.153	10
1992	Strong	1993	0.054	15
1993	Average	1994	0.156	9
1994	Average	1995	10.004	1
1995	Average-Strong	1996	0.056	14
1996	Average	1997	0.066	12
1997	Average	1998	0.390	7
1998	Average			
1999	Average	2000	4.275	2
2000	Average	2001	0.274	8
2001	Average-Strong	2002	0.006	21
2002	Average	2003	0.045	17
2003	Average	2004	0.008	20
2004	Average	2005	1.626	4
2005	Average	2006	---	---

Table 1.12. Ageing error transition matrix used in the Gulf of Alaska pollock assessment model.

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

Table 1.13. Maturity at age of female pollock derived from maturity stage data collected during winter EIT surveys in the Gulf of Alaska (1983-2005).

	2		*3*		*4*		*5*		*6*		*7*		*8*		*9*		*10+*		
Year	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Mat.*	*Tot.*	*Total*
1983	0	145	19	115	284	356	291	303	189	194	171	174	33	35	7	7	4	4	1333
1984	0	39	25	173	97	141	349	364	507	512	237	237	132	133	21	21	1	1	1621
1985	3	204	4	79	75	177	53	102	182	196	261	263	122	123	30	30	9	9	1183
1986	0	93	1	48	6	57	62	73	46	51	71	74	151	151	57	57	14	14	618
1987	0	39	2	171	5	47	18	53	30	39	69	78	57	60	116	117	34	34	638
1988	0	49	0	136	24	115	12	68	20	33	10	15	13	13	6	7	27	28	464
1989	0	35	0	50	52	175	122	276	71	100	57	62	16	16	12	12	70	70	796
1990	0	86	0	109	19	99	182	270	468	620	202	222	103	109	58	60	268	269	1844
1991	0	47	0	159	3	27	7	85	34	60	89	111	19	22	45	46	71	71	628
1992	0	12	0	43	5	126	20	291	41	53	53	54	104	105	23	23	57	58	765
1993	0	38	1	62	6	50	59	127	48	112	37	46	61	63	58	58	67	68	624
1994	0	43	1	144	27	64	230	247	64	68	41	46	38	39	84	84	137	137	872
1995	0	147	0	61	13	85	63	88	231	239	90	92	35	38	11	12	42	43	805
1996	0	61	0	89	1	28	43	60	78	85	198	203	131	136	55	55	44	46	763
1997	0	11	0	111	7	29	19	25	123	123	135	135	234	235	125	125	49	49	843
1998	0	69	0	72	14	215	13	64	15	18	53	55	65	65	112	112	86	87	757
2000	0	29	1	81	1	8	36	57	78	100	11	19	11	13	10	10	36	39	356
2001	0	44	0	57	13	45	16	52	33	40	69	73	29	30	13	14	19	19	374
2002	0	11	2	77	15	58	51	68	84	90	76	78	83	83	13	13	21	21	499
2003	0	40	1	34	29	151	12	31	9	17	10	11	3	4	8	8	5	5	301
2004	0	30	0	24	58	104	149	219	35	47	2	3	7	7	6	6	4	4	444
2005	0	46	0	27	12	17	90	102	89	102	16	17	5	5	2	2	3	3	321

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	0.012	0.125	0.632	0.780	0.579	0.846	1.000	0.923
2001	0.000	0.000	0.289	0.308	0.825	0.945	0.967	0.929	1.000
2002	0.000	0.026	0.259	0.750	0.933	0.974	1.000	1.000	1.000
2003	0.000	0.029	0.192	0.387	0.529	0.909	0.750	1.000	1.000
2004	0.000	0.000	0.558	0.680	0.745	0.667	1.000	1.000	1.000
2005	0.000	0.000	0.706	0.882	0.873	0.941	1.000	1.000	1.000
Average									
All years	0.001	0.022	0.279	0.568	0.807	0.897	0.957	0.984	0.990
1994-2004	0.000	0.007	0.262	0.603	0.840	0.893	0.944	0.985	0.984
1999-2004	0.000	0.011	0.401	0.602	0.781	0.887	0.943	0.986	1.000

Table 1.14. Results comparing model fits, stock status, and 2006 yield for different model configurations.

	Model 1	Model 2	Model 3	Model 4
Model fits				
Total log(Likelihood)	-900.85	-902.05	-886.94	-746.50
Catch	-0.33	-0.49	-0.46	-0.10
Catch age and length comp	-340.97	-342.05	-342.29	-335.77
EIT survey biomass	-66.67	-65.85	-65.56	-13.91
EIT survey age and length comp	-213.75	-215.08	-213.81	-138.21
Bottom trawl survey biomass	-21.60	-22.03	-22.90	-13.93
Bottom trawl survey age and length comp	-70.25	-71.44	-70.96	-62.69
Egg production biomass	-23.44	-21.87	-22.08	-20.60
ADFG trawl survey biomass	-6.61	-6.99	-3.13	-6.82
ADFG trawl survey age and length comp	-21.19	-21.24	-10.77	-21.00
EIT survey age-1 recruitment index	-0.34	-0.34	-0.34	-0.36
Historical 400-mesh trawl survey biomass	-54.13	-53.26	-53.30	-52.03
Historical trawl survey age and length comp	-24.77	-24.81	-24.79	-26.01
Penalties	-56.80	-56.60	-56.54	-55.08
NMFS trawl q	0.77	1.00	1.00	1.00
Age composition data				
Fishery effective N	288	283	281	281
NMFS bottom trawl effective N	68	67	70	70
Shelikof Strait EIT effective N	31	29	30	27
Length composition data				
ADF&G trawl effective N	37	37	38	38
Historical trawl survey effective N	20	20	20	20
Survey abundance				
NMFS bottom trawl RMSE	0.389	0.391	0.397	0.344
Shelikof Strait EIT RMSE	0.348	0.343	0.344	0.402
ADF&G trawl RMSE	0.235	0.241	0.258	0.238
Historical trawl survey RMSE	1.523	1.522	1.521	1.524
Egg production survey RMSE	0.458	0.439	0.441	0.442
Stock status (t)				
2006 Spawning biomass	233,380	194,410	186,060	214,630
(CV)	(16%)	(10%)	(11%)	(11%)
2006 3+ biomass	720,200	608,370	585,200	695,070
(CV)	(17%)	(12%)	(12%)	(13%)
Depletion (B2005/B0)	37%	35%	33%	38%
$B_{40\%}$	253,118	223,736	223,657	224,898
2006 yield (000 t)				
MaxABC	130.03	95.23	87.86	117.56
Author's recommended ABC	115.18	81.30	74.86	100.62

Comments:

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

Model descriptions (see text for details):

Model 1--Estimated NMFS trawl survey catchability
Model 2--Last year's model configuration
Model 3--Reduced emphasis on ADF&G survey
Model 4--Reduced emphasis on Shelikof EIT survey

Table 1.15. Estimated selectivity at age for Gulf of Alaska pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions with random walk process error for the fishery logistic parameters. Fishery selectivity at age reported below is the average of the annual selectivity for the indicated time period, rescaled so that the maximum is one.

Age	*POP fishery (1961-71)*	*Foreign (1972-84)*	*Early domestic (1985-91)*	*Recent domestic (1992-2004)*	*EIT survey*	*Bottom trawl survey*	*ADF&G bottom trawl*	*400-mesh eastern trawl 1961-82*
2	0.001	0.041	0.041	0.083	1.000	0.185	0.058	0.120
3	0.021	0.265	0.153	0.203	1.000	0.290	0.128	0.389
4	0.413	0.757	0.414	0.441	0.999	0.448	0.260	0.749
5	1.000	1.000	0.730	0.735	0.995	0.662	0.459	0.933
6	0.945	0.917	0.948	0.917	0.978	0.888	0.674	0.985
7	0.698	0.664	1.000	0.983	0.918	1.000	0.838	0.997
8	0.362	0.334	0.832	1.000	0.734	0.897	0.933	0.999
9	0.133	0.124	0.434	0.931	0.405	0.662	0.979	1.000
10	0.041	0.040	0.152	0.369	0.144	0.435	1.000	1.000

Table 1.16. 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	378	198	121	74	55	39	28	21	16
1962	419	280	146	90	55	41	29	21	28
1963	449	310	207	109	66	41	30	21	36
1964	101	332	230	154	80	49	30	22	43
1965	261	74	246	170	113	59	36	22	48
1966	139	193	55	181	124	83	43	27	52
1967	346	103	143	40	129	89	60	32	58
1968	409	256	76	104	29	92	64	44	67
1969	713	303	190	55	74	20	66	47	81
1970	337	528	224	133	36	48	14	47	94
1971	730	250	391	162	92	25	34	10	104
1972	1,374	540	185	284	114	66	18	25	84
1973	1,049	1,018	400	132	191	77	45	13	80
1974	3,434	777	752	285	88	129	54	33	68
1975	697	2,544	574	532	184	58	88	38	74
1976	439	516	1,862	403	370	129	41	64	83
1977	2,003	324	373	1,293	279	258	92	30	108
1978	2,724	1,481	236	257	883	192	182	66	101
1979	2,480	2,011	1,063	162	176	611	136	131	123
1980	3,479	1,833	1,455	734	111	122	432	98	187
1981	1,768	2,568	1,328	1,019	508	77	86	310	210
1982	429	1,306	1,867	926	699	349	54	62	382
1983	489	315	930	1,294	639	484	247	39	328
1984	206	359	223	626	859	427	334	178	271
1985	478	150	247	139	373	512	270	233	331
1986	1,622	348	104	150	76	197	282	172	411
1987	555	1,184	245	68	93	47	124	194	430
1988	161	408	854	169	45	60	30	82	455
1989	377	118	296	599	113	29	39	20	394
1990	1,609	278	87	211	406	73	18	25	301
1991	1,002	1,189	205	62	145	260	45	11	238
1992	400	741	873	147	43	95	168	29	164
1993	239	295	538	609	97	28	61	107	138
1994	145	176	214	375	404	63	18	39	168
1995	220	107	128	150	253	266	41	12	143
1996	862	163	78	91	104	171	179	28	109
1997	416	637	120	57	64	71	117	122	96
1998	181	307	466	85	38	41	44	72	140
1999	177	132	215	301	50	22	23	25	130
2000	252	130	95	145	185	29	12	13	98
2001	1,040	186	94	66	94	112	17	7	74
2002	729	761	133	64	42	58	68	10	55
2003	164	531	543	91	43	28	37	44	46
2004	146	119	376	374	62	29	18	25	63
2005	276	103	82	252	248	41	19	12	64
Average	810	600	436	299	197	131	88	61	153

Table 1.17. Estimates of population biomass, recruitment, and harvest of Gulf of Alaska pollock from the age-structured assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

							2004 Assessment results			
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*	*3+ total biomass*	*Female spawn. biom.*	*Age 2 recruits*	*Harvest rate*
1969	712	607	146	713	17,553	3%	598	143	700	3%
1970	777	727	144	337	9,343	1%	715	140	330	1%
1971	872	765	161	730	9,458	1%	752	156	715	1%
1972	1,081	879	179	1,374	34,081	4%	863	174	1,343	4%
1973	1,322	1,168	198	1,049	36,836	3%	1,144	192	1,026	3%
1974	1,895	1,390	236	3,434	61,880	4%	1,360	226	3,363	5%
1975	2,326	2,223	291	697	59,512	3%	2,174	280	685	3%
1976	2,428	2,364	409	439	86,527	4%	2,311	391	433	4%
1977	2,458	2,163	509	2,003	118,356	5%	2,115	490	2,000	6%
1978	2,723	2,323	548	2,724	96,935	4%	2,281	531	2,741	4%
1979	3,176	2,812	560	2,480	105,748	4%	2,781	541	2,507	4%
1980	3,778	3,266	617	3,479	114,622	4%	3,251	598	3,523	4%
1981	4,164	3,904	500	1,768	147,744	4%	3,908	488	1,790	4%
1982	4,082	4,019	570	429	168,740	4%	4,035	559	435	4%
1983	3,459	3,386	688	489	215,608	6%	3,407	681	493	6%
1984	2,764	2,733	712	206	307,401	11%	2,753	712	206	11%
1985	2,091	2,020	641	478	284,826	14%	2,037	644	473	14%
1986	1,887	1,623	519	1,622	87,809	5%	1,638	523	1,594	5%
1987	1,781	1,691	436	555	69,751	4%	1,696	440	539	4%
1988	1,626	1,600	397	161	65,739	4%	1,597	398	156	4%
1989	1,515	1,452	386	377	78,392	5%	1,446	385	361	5%
1990	1,510	1,240	347	1,609	90,744	7%	1,229	345	1,602	7%
1991	1,526	1,358	329	1,002	100,488	7%	1,344	326	1,041	7%
1992	1,737	1,671	294	400	90,857	5%	1,669	287	418	5%
1993	1,555	1,516	331	239	108,908	7%	1,523	323	239	7%
1994	1,294	1,270	377	145	107,335	8%	1,278	372	141	8%
1995	1,088	1,067	343	220	72,618	7%	1,076	343	213	7%
1996	967	884	309	862	51,263	6%	889	311	830	6%
1997	945	906	267	416	90,130	10%	901	268	404	10%
1998	860	834	204	181	125,098	15%	823	203	174	15%
1999	703	677	187	177	95,590	14%	664	184	182	14%
2000	635	604	176	252	73,080	12%	591	171	272	12%
2001	694	585	173	1,040	72,076	12%	579	167	1,196	12%
2002	894	783	149	729	51,937	7%	832	144	746	6%
2003	936	903	146	164	50,666	6%	959	143	107	5%
2004	838	809	165	146	63,913	8%	841	168	127	8%
2005	765	709	208	276	---	---	---	---	---	---
Average										
1969-2005	1,726	1,593	347	903	95,043	6%	1,613	346	920	6%
1979-2004				755						

Table 1.18. Gulf of Alaska pollock life history and fishery vectors used to estimate spawning biomass per recruit (F_{SPR}) harvest rates. Population weight at age is the average for the bottom trawl survey in 1999-2003. Proportion mature females is the average for 1983-2005 from winter EIT survey specimen data. Spawning weight at age is the average for the Shelikof Strait EIT survey in 2001-2005.

			Weight at age (kg)			
Age	*Natural mortality*	*Fishery selectivity (Avg. 1992-2004)*	*Spawning (March 15)*	*Population (June-Aug.)*	*Fishery (Avg. 1999-2003)*	*Proportion mature females*
2	0.3	0.083	0.077	0.150	0.310	0.001
3	0.3	0.203	0.211	0.421	0.482	0.022
4	0.3	0.441	0.390	0.630	0.663	0.279
5	0.3	0.735	0.592	0.800	0.857	0.568
6	0.3	0.917	0.849	0.943	1.040	0.807
7	0.3	0.983	1.118	1.078	1.200	0.897
8	0.3	1.000	1.264	1.221	1.340	0.957
9	0.3	0.931	1.423	1.312	1.441	0.984
10+	0.3	0.369	1.666	1.445	1.671	0.990

Table 1.19. Methods used to assess Gulf of Alaska pollock, 1977-2004. The basis for catch recommendation in 1977-1989 is the presumptive method by which the TAC was determined (based on the assessment and SSC minutes). The basis for catch recommendation given in 1990-2004 is the method used by the Plan Team to derive the ABC recommendation given in the SAFE summary chapter.

Year	*Assessment method*	*Basis for catch recommendation in following year*	*B40% (t)*
1977	Survey biomass, CPUE trends, M=0.4	MSY = 0.4 * M * Bzero	---
1978	Survey biomass, CPUE trends	MSY = 0.4 * M * Bzero	---
1979	Survey biomass, CPUE trends	MSY = 0.4 * M * Bzero	---
1980	Survey biomass, CPUE trends	MSY = 0.4 * M * Bzero	---
1981	Survey biomass, CPUE trends	MSY = 0.4 * M * Bzero	---
1982	CAGEAN	MSY = 0.4 * M * Bzero	---
1983	CAGEAN	Mean annual surplus production	---
1984	Projection of survey numbers at age	Stabilize biomass trend	---
1985	CAGEAN, projection of survey numbers at age, CPUE trends	Stabilize biomass trend	---
1986	CAGEAN, projection of survey numbers at age	Stabilize biomass trend	---
1987	CAGEAN, projection of survey numbers at age	Stabilize biomass trend	---
1988	CAGEAN, projection of survey numbers at age	10% of exploitable biomass	---
1989	Stock synthesis	10% of exploitable biomass	---
1990	Stock synthesis, reduce *M* to 0.3	10% of exploitable biomass	---
1991	Stock synthesis, assume trawl survey catchability = 1	FMSY from an assumed SR curve	---
1992	Stock synthesis	Max[-Pr(SB<Threshold)+Yld]	---
1993	Stock synthesis	Pr(SB>B20)=0.95	---
1994	Stock synthesis	Pr(SB>B20)=0.95	---
1995	Stock synthesis	Max[-Pr(SB<Threshold)+Yld]	---
1996	Stock synthesis	Amendment 44 Tier 3 guidelines	289,689
1997	Stock synthesis	Amendment 44 Tier 3 guidelines	267,600
1998	Stock synthesis	Amendment 44 Tier 3 guidelines	240,000
1999	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	247,000
2000	AD model builder	Amendment 56 Tier 3 guidelines	250,000
2001	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	245,000
2002	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	240,000
2003	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000
2004	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC}, and stairstep approach for projected ABC increase)	229,000

Table 1.20. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2005-2018 under different harvest policies. All projections begin with estimated age composition in 2005 using base run model. Coefficients of variation are given in parentheses, and reflect only variability in recruitment in 2006-2017. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 559,000, 224,000, and 196,000 t, respectively.

Spawning biomass (t)	*Max F_{ABC}*	*Author's recommended F*	*50% of max FABC*	*Average F*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2005	204,912	204,912	204,912	204,912	204,912	204,912	204,912
2006	191,870	193,092	195,765	194,721	199,747	190,536	191,870
2007	161,414	166,903	179,645	174,044	200,863	155,671	161,414
2008	152,259	159,463	177,347	167,438	211,591	145,055	151,482
2009	167,427	175,770	198,209	184,743	245,176	159,083	163,215
2010	192,407	201,667	231,185	215,561	293,465	182,113	184,576
2011	213,242	222,929	262,708	245,948	344,250	200,147	201,434
2012	225,703	235,516	287,001	269,658	391,139	209,766	210,358
2013	231,421	241,248	303,830	286,350	431,382	213,248	213,497
2014	234,900	244,653	316,625	299,349	465,958	215,138	215,239
2015	237,728	247,298	326,237	309,462	492,296	217,001	217,040
2016	240,672	250,111	334,420	318,215	513,863	219,280	219,294
2017	241,481	250,787	339,261	323,602	529,292	219,589	219,594
2018	240,796	249,967	341,284	326,103	539,353	218,621	218,623

Fishing mortality	*Max F_{ABC}*	*Author's recommended F*	*50% of max FABC*	*Average F*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2005	0.19	0.19	0.19	0.19	0	0.19	0.19
2006	0.23	0.20	0.12	0.15	0	0.27	0.23
2007	0.19	0.17	0.11	0.15	0	0.22	0.19
2008	0.18	0.16	0.11	0.15	0	0.20	0.21
2009	0.20	0.17	0.11	0.15	0	0.22	0.23
2010	0.21	0.19	0.12	0.15	0	0.24	0.25
2011	0.23	0.21	0.12	0.15	0	0.26	0.26
2012	0.23	0.22	0.13	0.15	0	0.27	0.27
2013	0.24	0.22	0.13	0.15	0	0.27	0.27
2014	0.24	0.23	0.13	0.15	0	0.27	0.27
2015	0.24	0.23	0.13	0.15	0	0.28	0.28
2016	0.25	0.23	0.13	0.15	0	0.28	0.28
2017	0.24	0.23	0.13	0.15	0	0.28	0.28
2018	0.24	0.23	0.13	0.15	0	0.28	0.28

Catch (t)	*Max F_{ABC}*	*Author's recommended F*	*50% of max FABC*	*Average F*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2005	86,100	86,100	86,100	86,100	86,100	86,100	86,100
2006	95,235	81,296	49,763	62,254	0	110,103	95,235
2007	72,729	65,056	44,548	59,488	0	79,820	72,729
2008	74,681	68,218	48,357	63,258	0	80,916	86,964
2009	94,197	87,993	59,721	71,245	0	102,979	106,383
2010	117,562	112,682	73,826	83,051	0	129,499	131,092
2011	136,602	132,562	86,955	94,810	0	149,476	150,082
2012	147,510	143,659	96,081	103,008	0	159,336	159,466
2013	151,981	148,159	101,077	107,433	0	162,930	162,886
2014	153,350	149,743	102,697	108,841	0	163,893	163,825
2015	154,548	150,726	104,234	110,279	0	164,782	164,738
2016	155,419	151,622	105,249	111,223	0	165,622	165,600
2017	154,417	150,553	105,399	111,432	0	164,280	164,270
2018	152,884	149,235	105,104	111,101	0	162,641	162,637

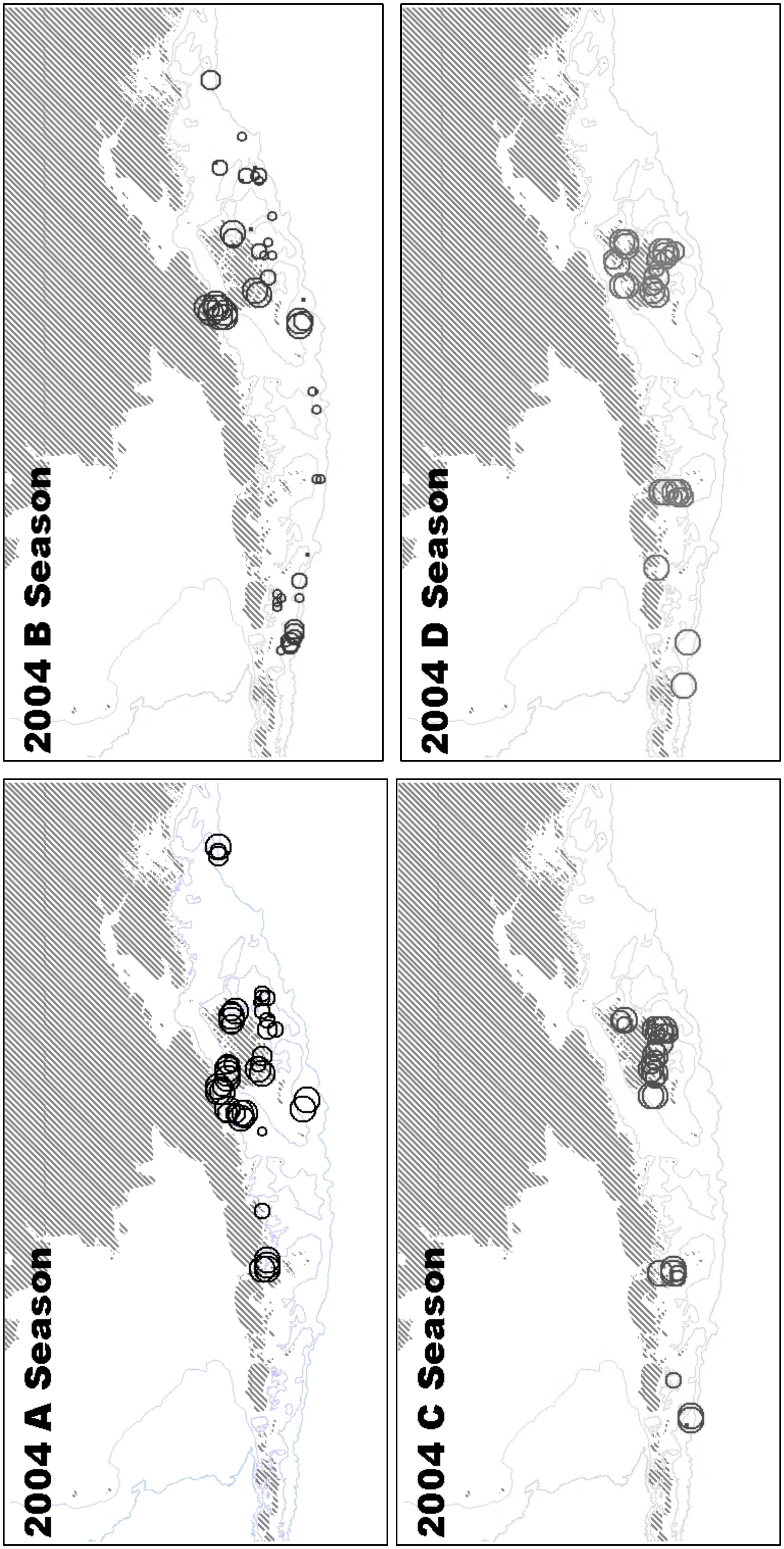


Figure 1.1 Pollock catch in 2004 by 10 sq. nmi. blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

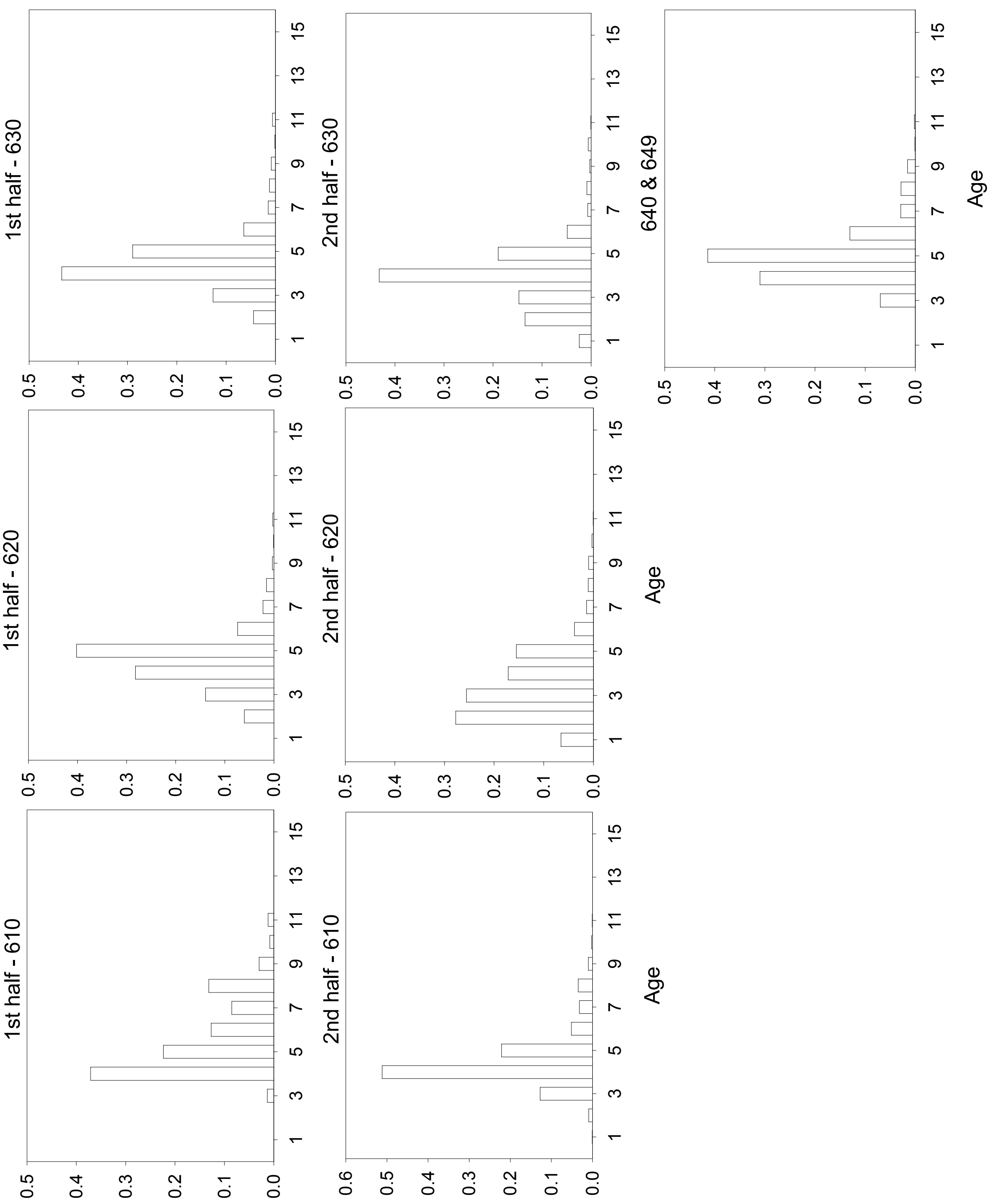


Figure 1.2. 2004 catch age composition by half year and statistical area.

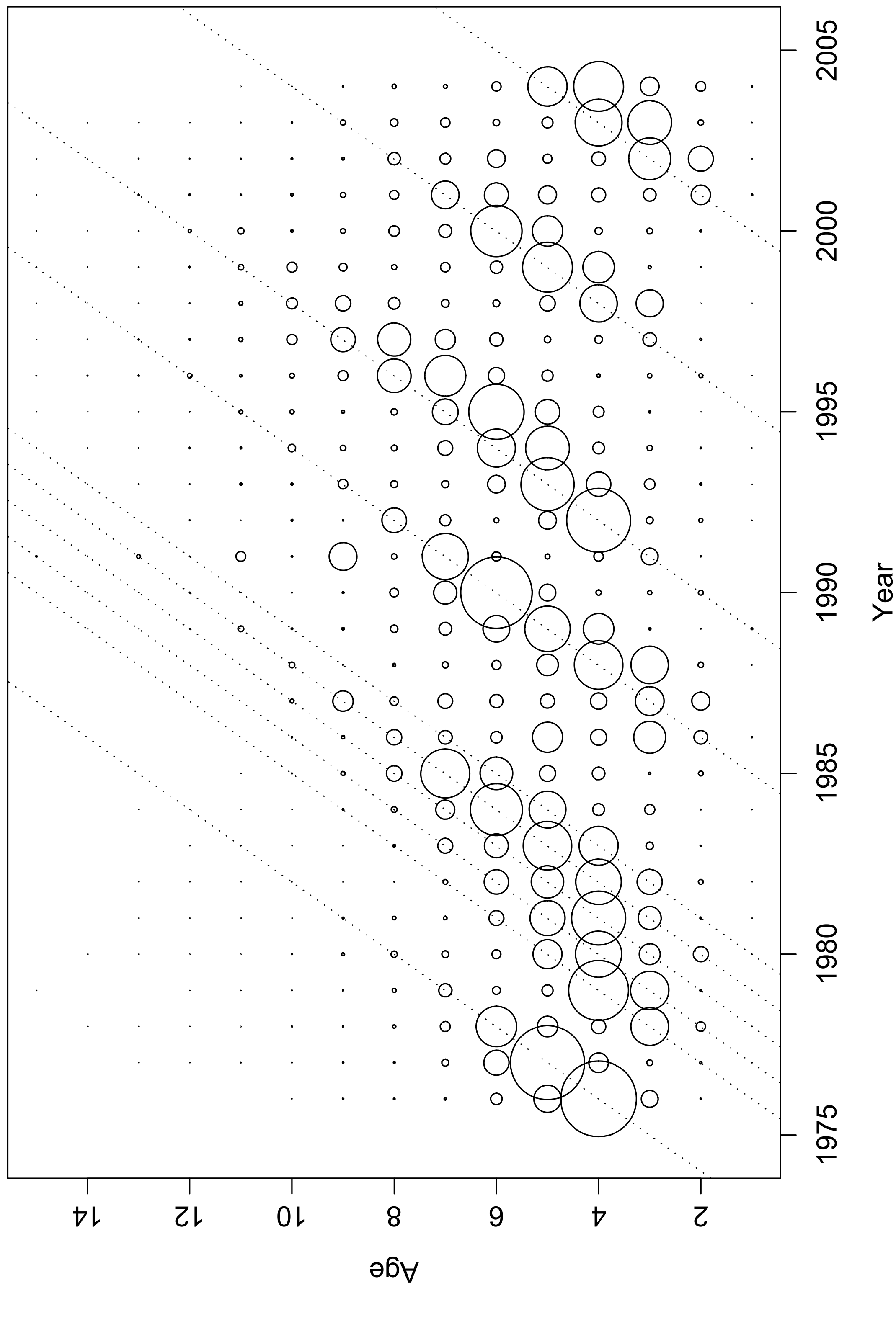


Figure 1.3. Gulf of Alaska pollock catch age composition (1976-2004). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, and 1999).

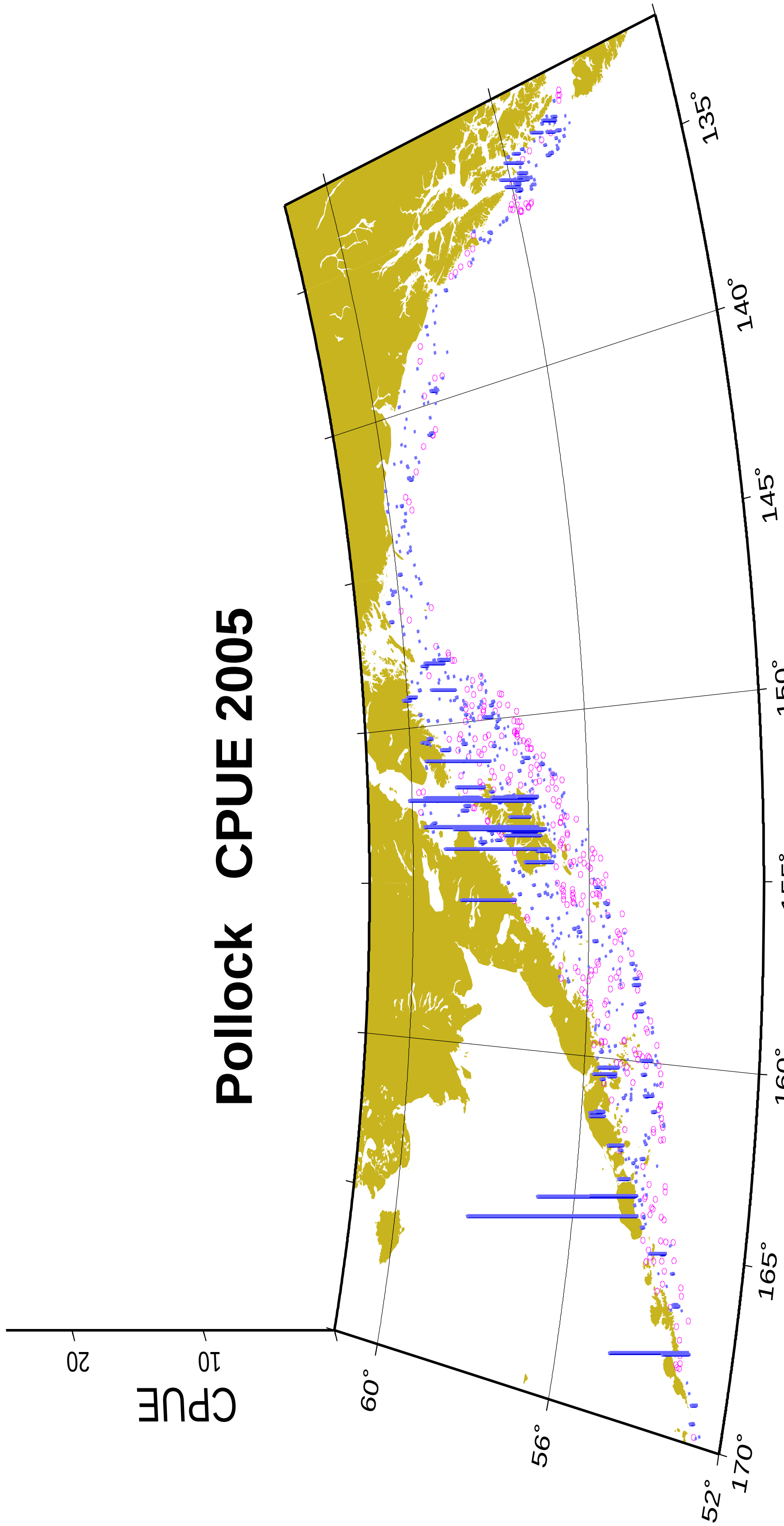


Figure 1.4. Pollock CPUE for the 2005 NMFS bottom trawl survey.

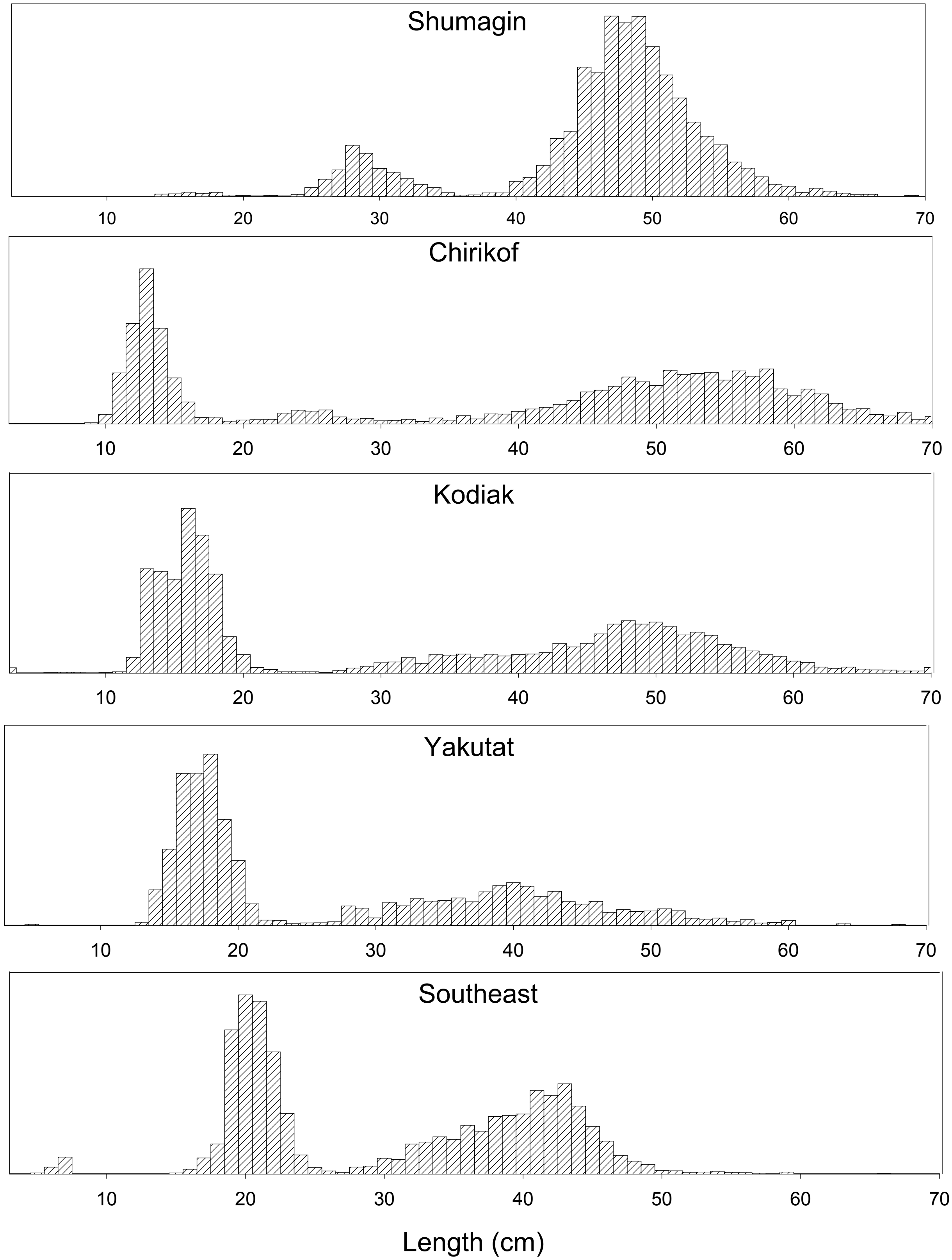
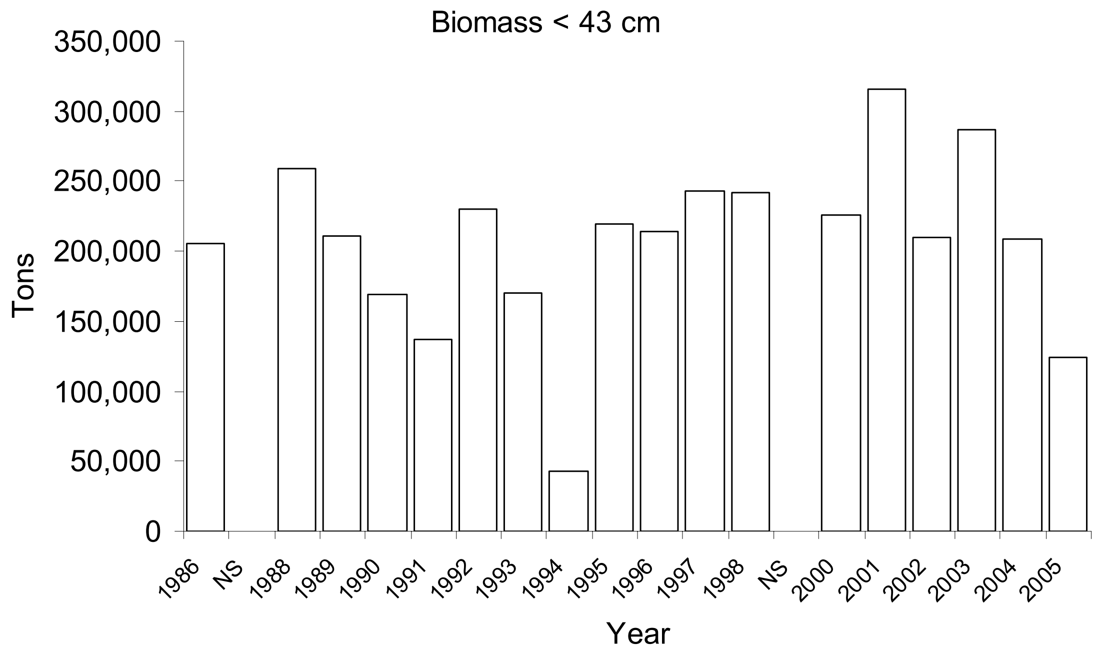


Figure 1.5. Size composition of pollock by statistical area for the 2005 NMFS bottom trawl survey.



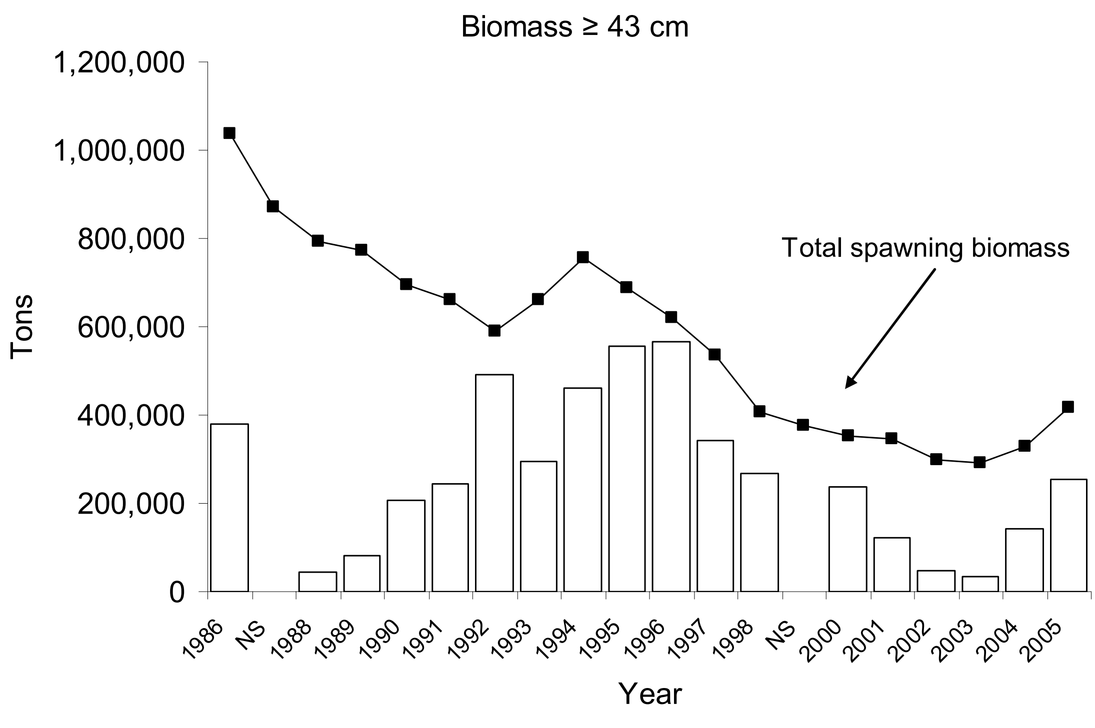


Figure 1.6. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2005 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

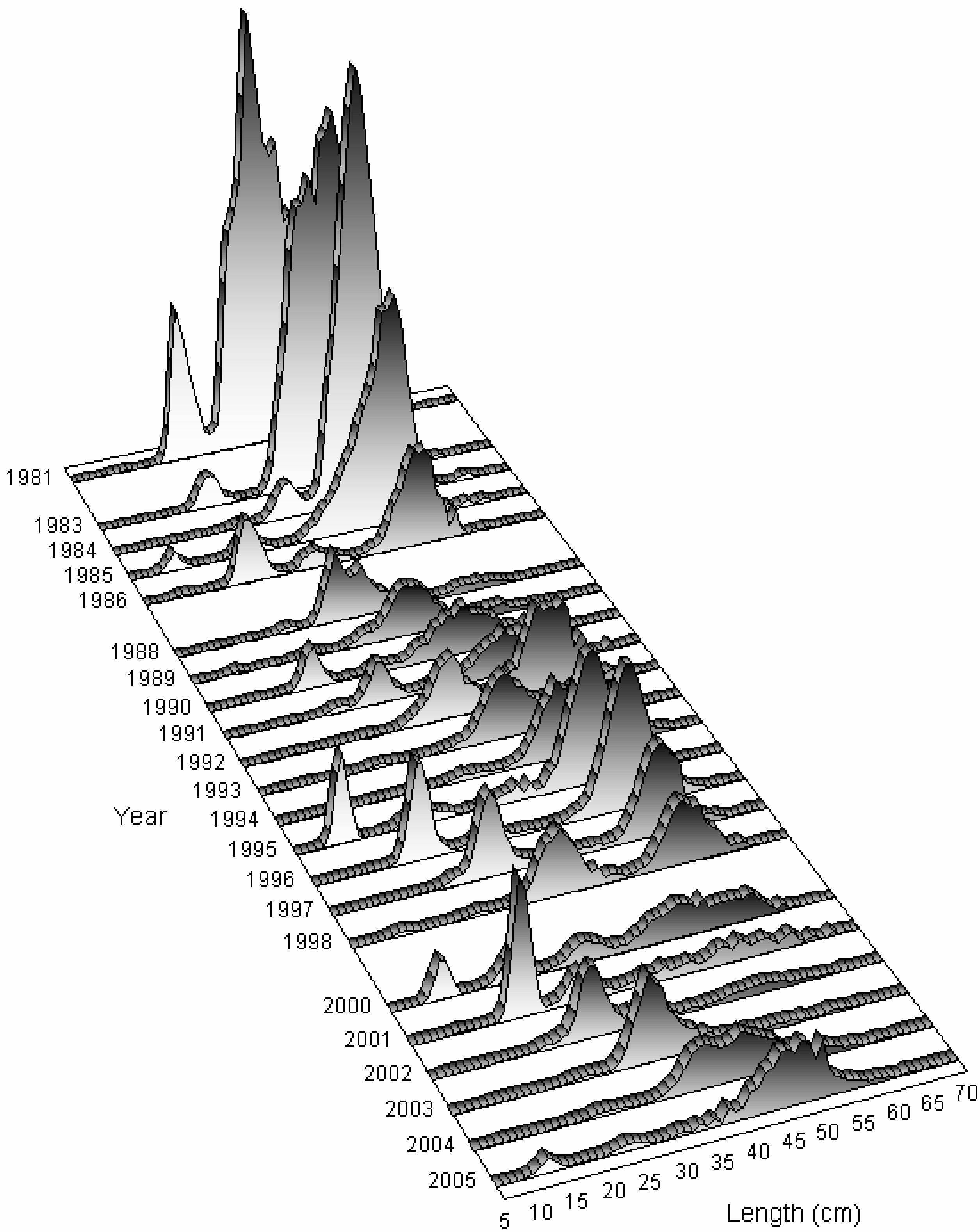


Figure 1.7. Biomass by length for pollock in the Shelikof Strait EIT survey (1981-2005, except 1982,1987 and 1999).

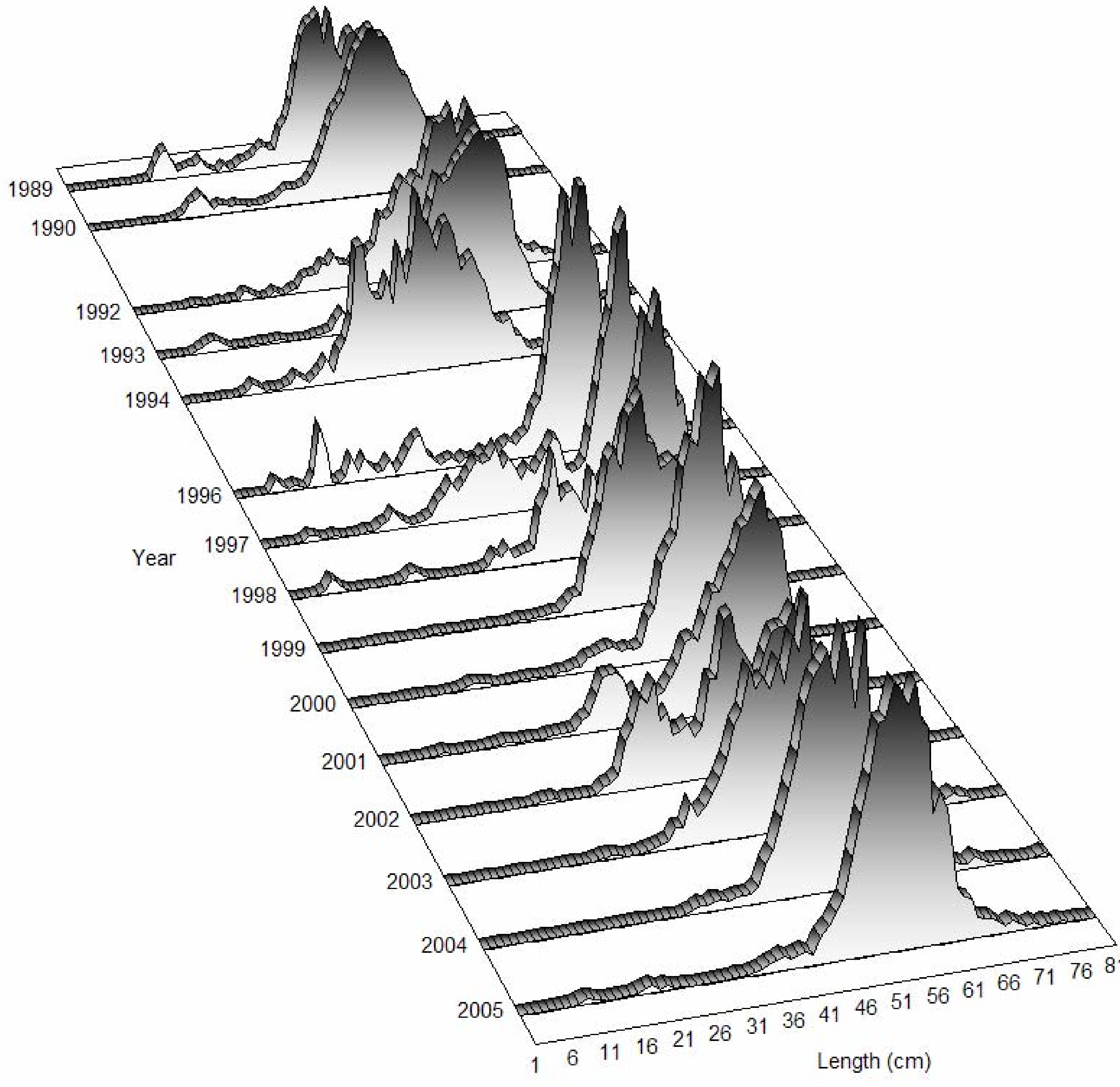


Figure 1.8. Length frequency of pollock in the ADF&G crab/groundfish trawl survey (1989-2005, except 1991 and 1995).

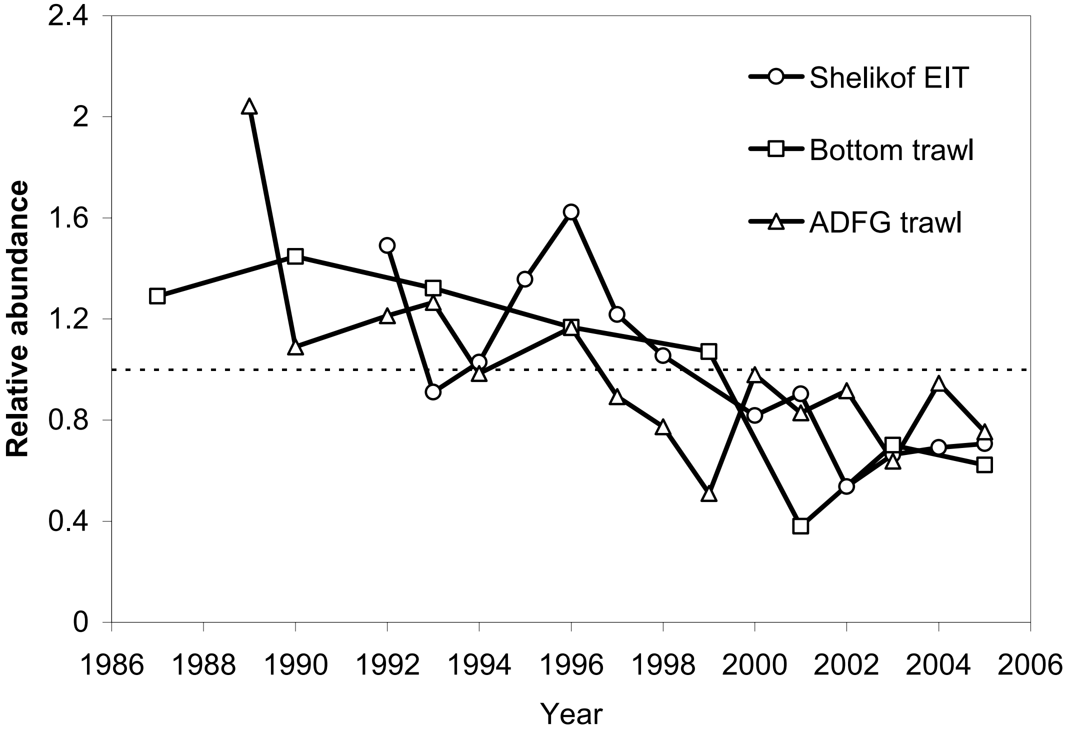


Figure 1.9. Relative trends in pollock biomass since 1987 for the Shelikof Strait EIT survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the survey average since 1986.

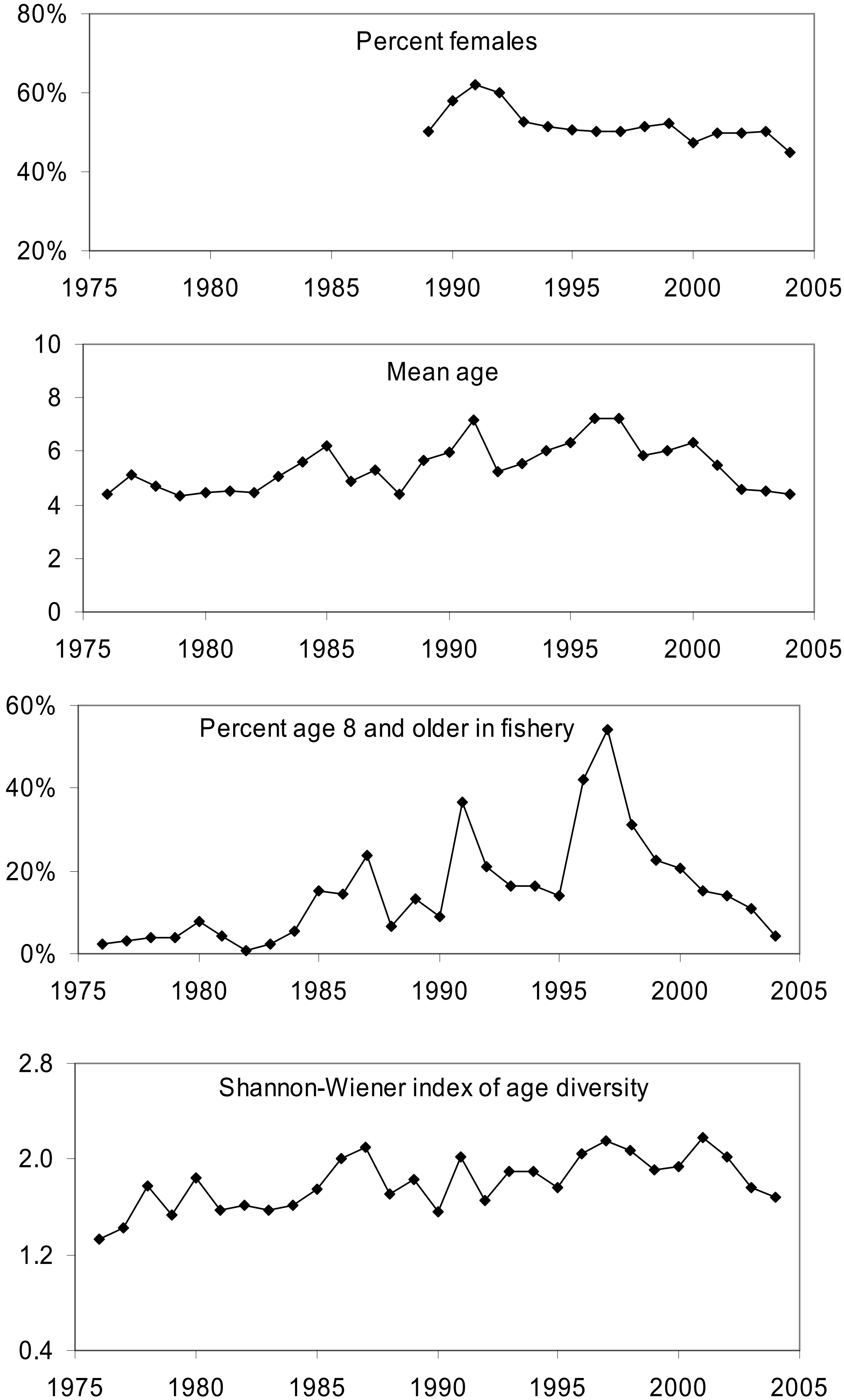


Figure 1.10. Gulf of Alaska pollock catch characteristics.

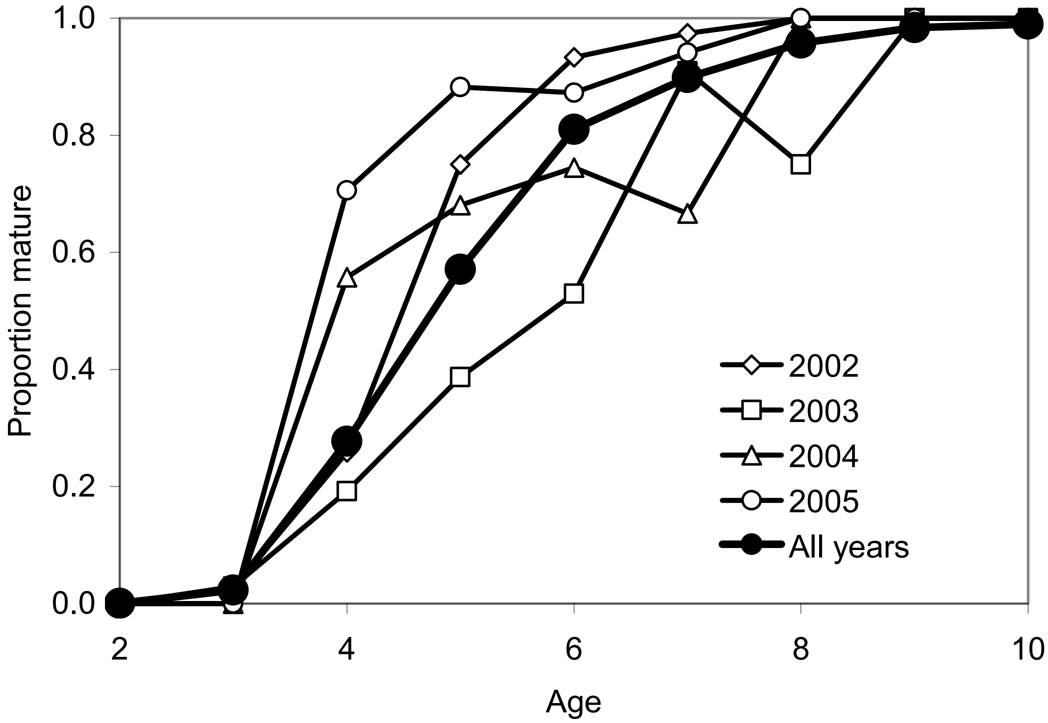
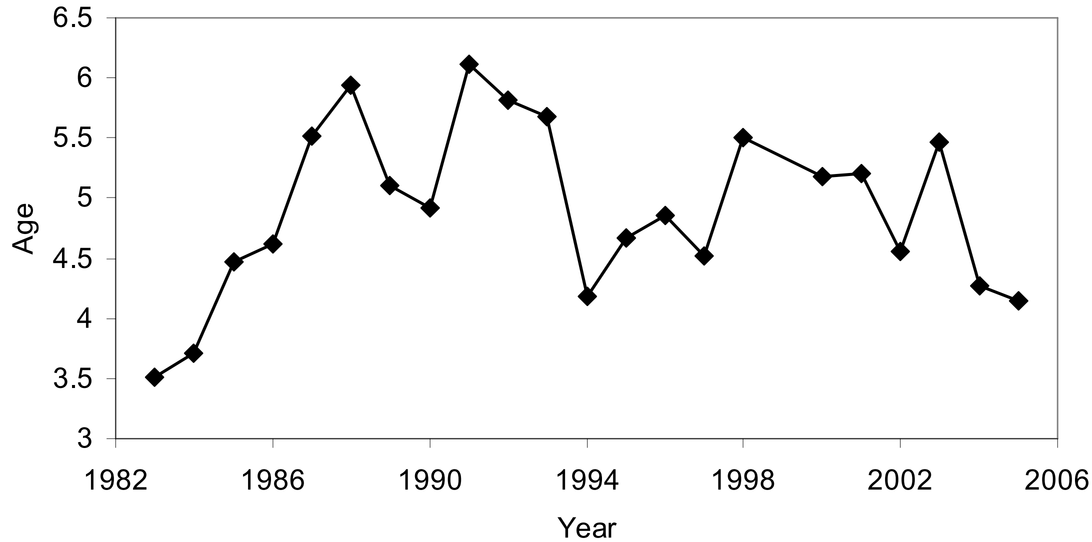


Figure 1.11. Estimates of the proportion mature at age from visual maturity data collected during 2002-2005 winter EIT surveys in the Gulf of Alaska.



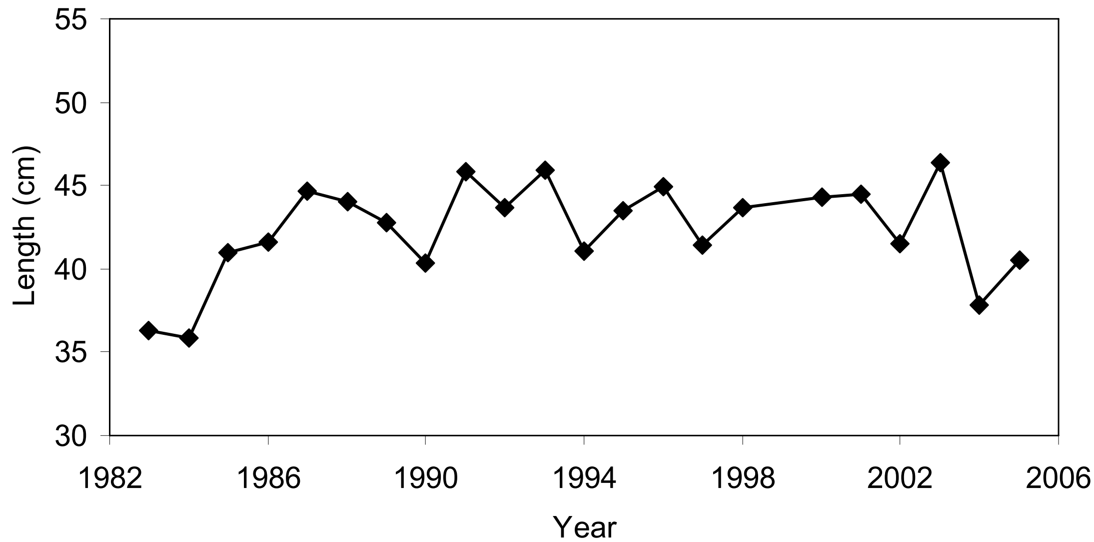


Figure 1.12. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2004.

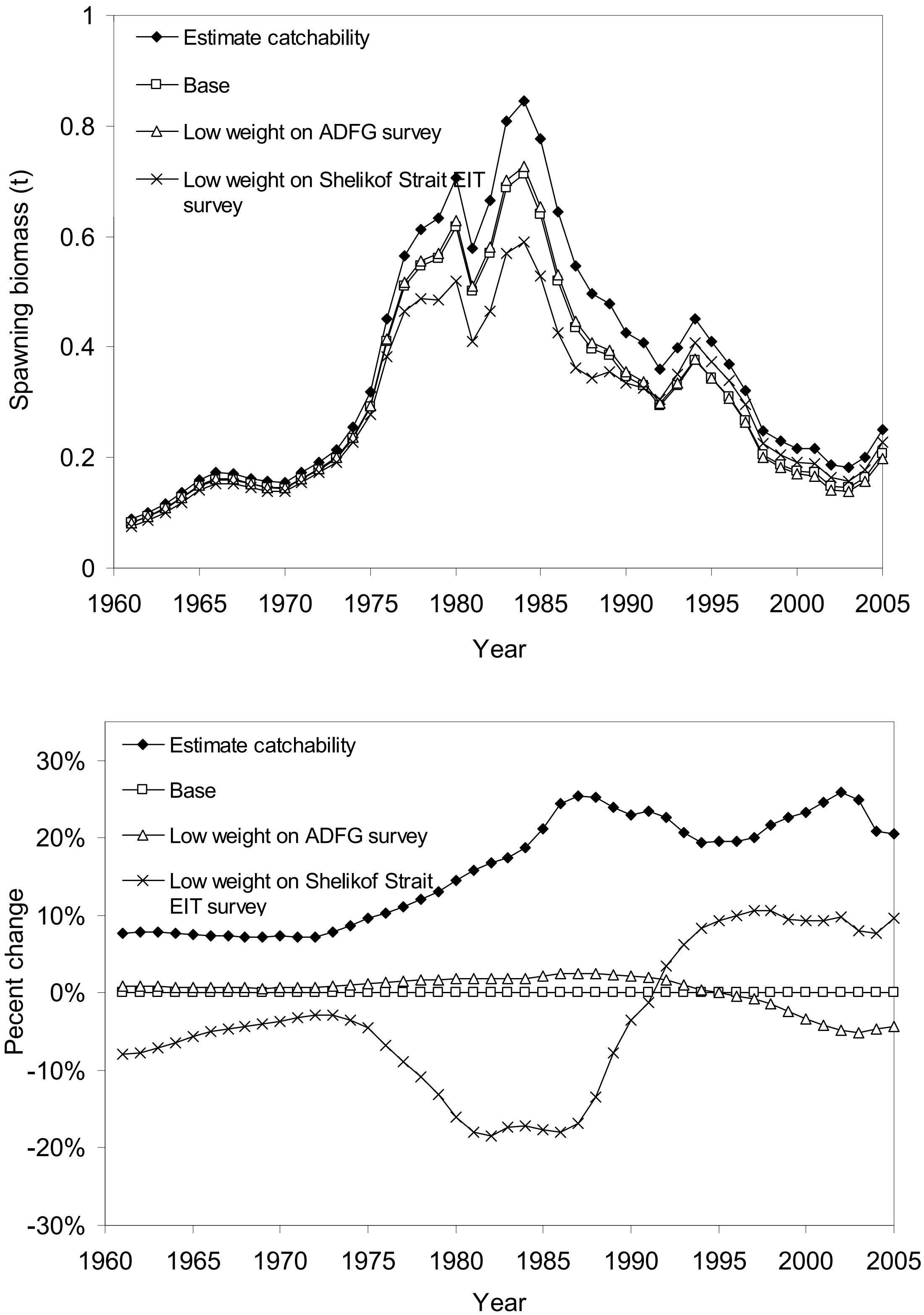


Figure 1.13. Comparison of estimated female spawning biomass for alternative models. The top panel shows the entire modeled period, while the bottom panel shows the percent difference relative to the base model (fixed NMFS survey catchability) since 1990.

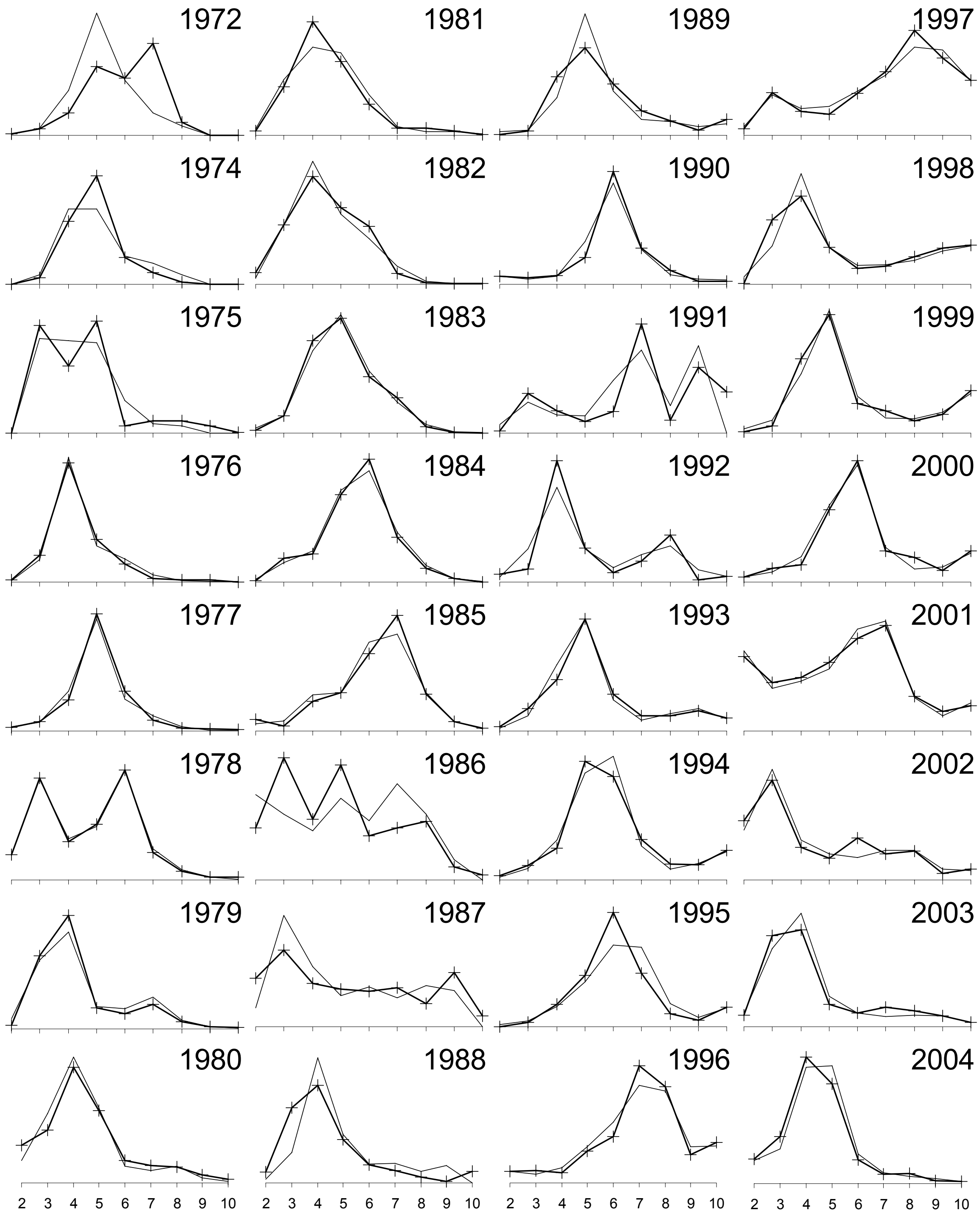
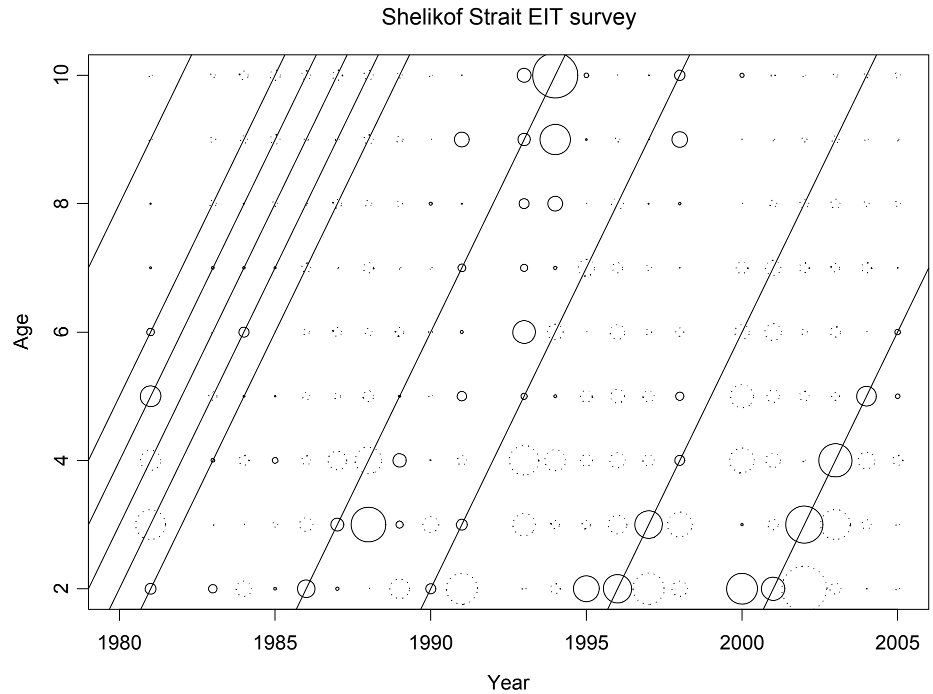


Figure 1.14. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

Figure 1.15. Residuals from base model for fishery age composition (1972-2004). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, and 1999).



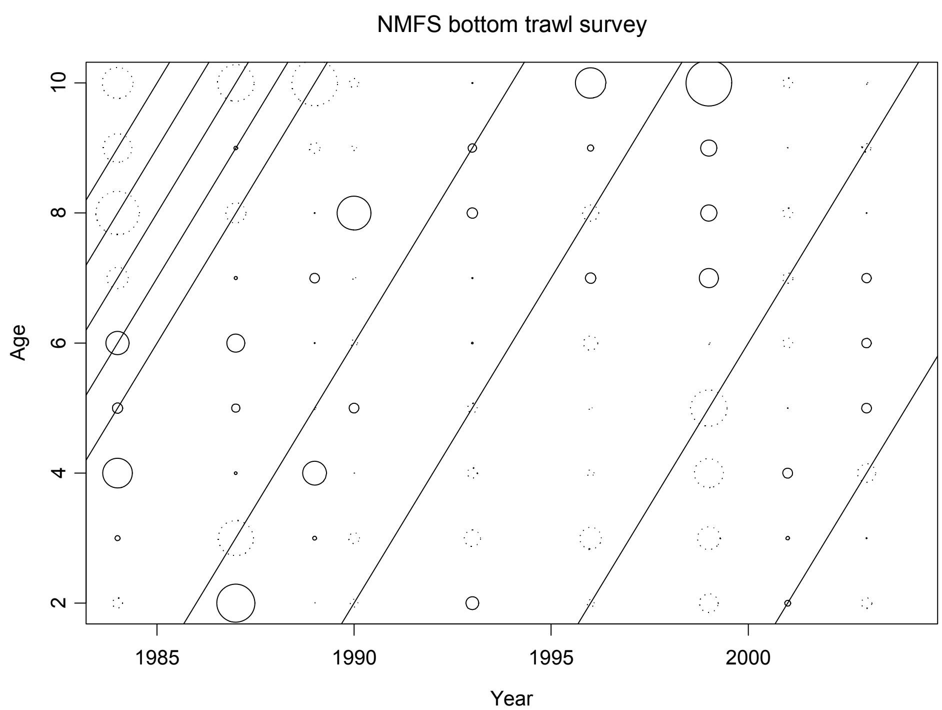


Figure 1.16. Residuals from base model for the Shelikof Strait EIT survey age composition (top) and NMFS bottom trawl age composition (bottom). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, and 1999).

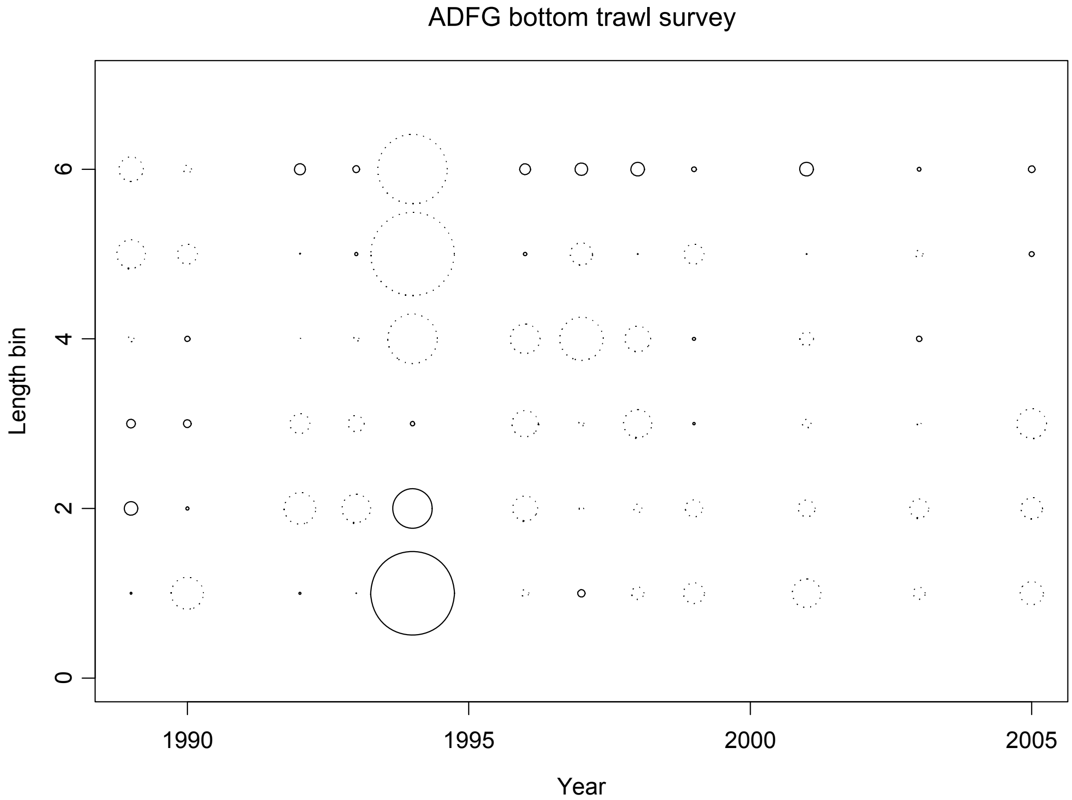


Figure 1.17. Residuals from base model for the ADF&G survey length composition.

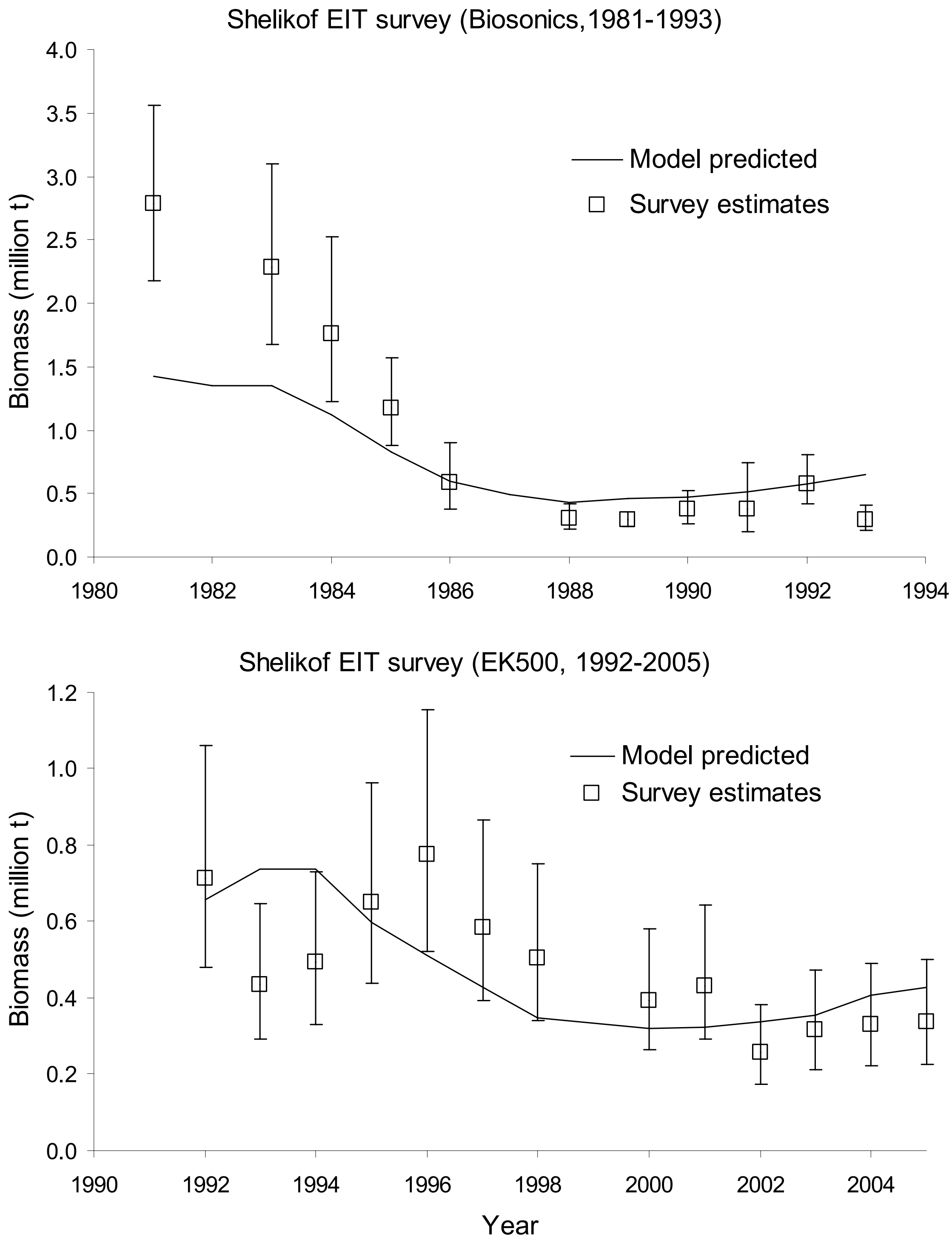


Figure 1.18. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with two catchability periods corresponding to the two acoustic systems used for the survey. Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for EK500 biomass estimates, an assumed CV of 0.2 is used in the assessment model.

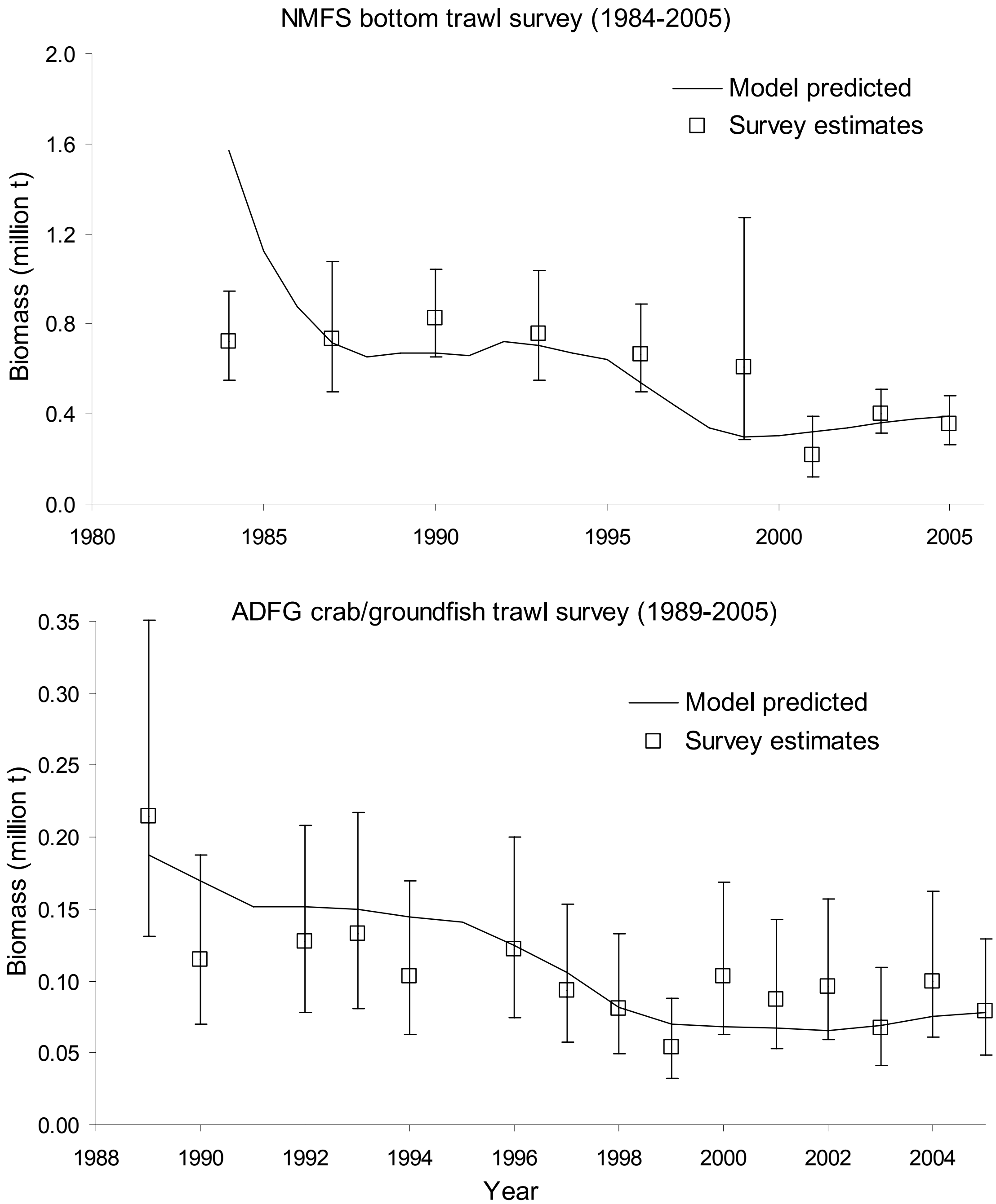


Figure 1.19. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.

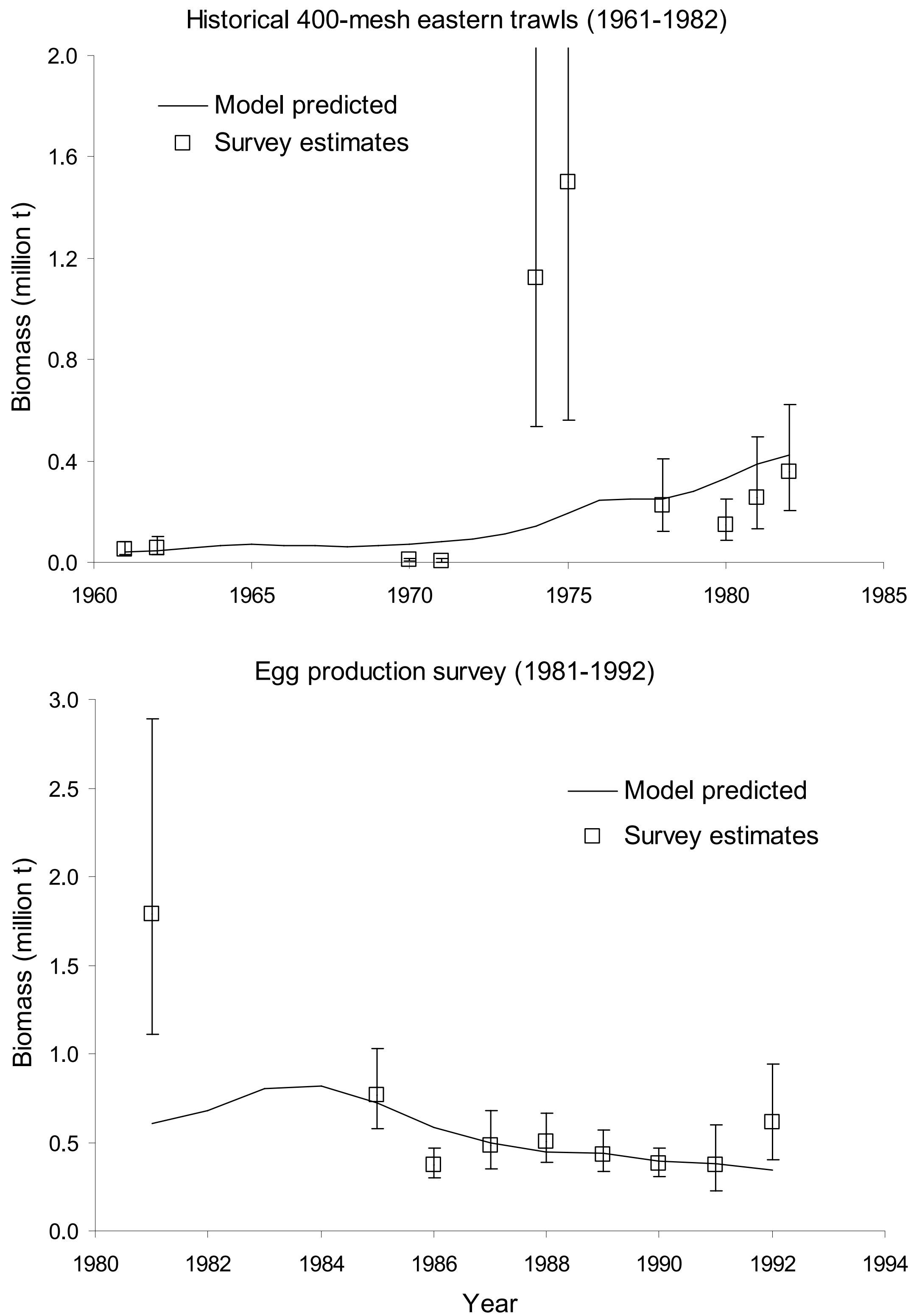


Figure 1.20. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top), and the egg production survey (bottom). Error bars indicate plus and minus two standard deviations.

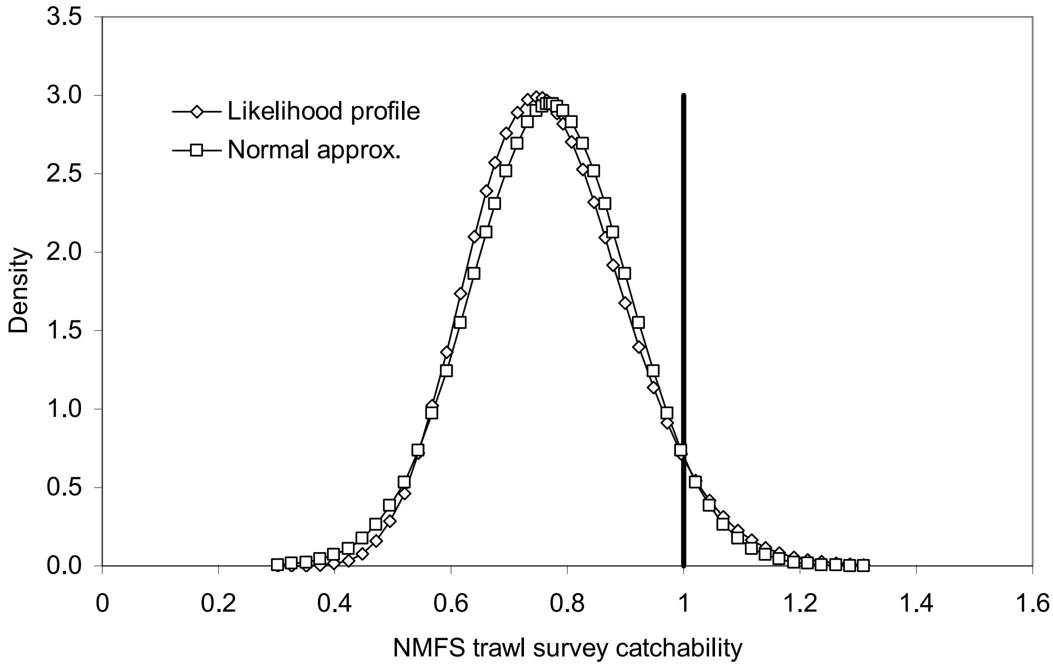


Figure 1.21. Uncertainty in the catchability coefficient for the NMFS trawl survey from a likelihood profile for Model 1.

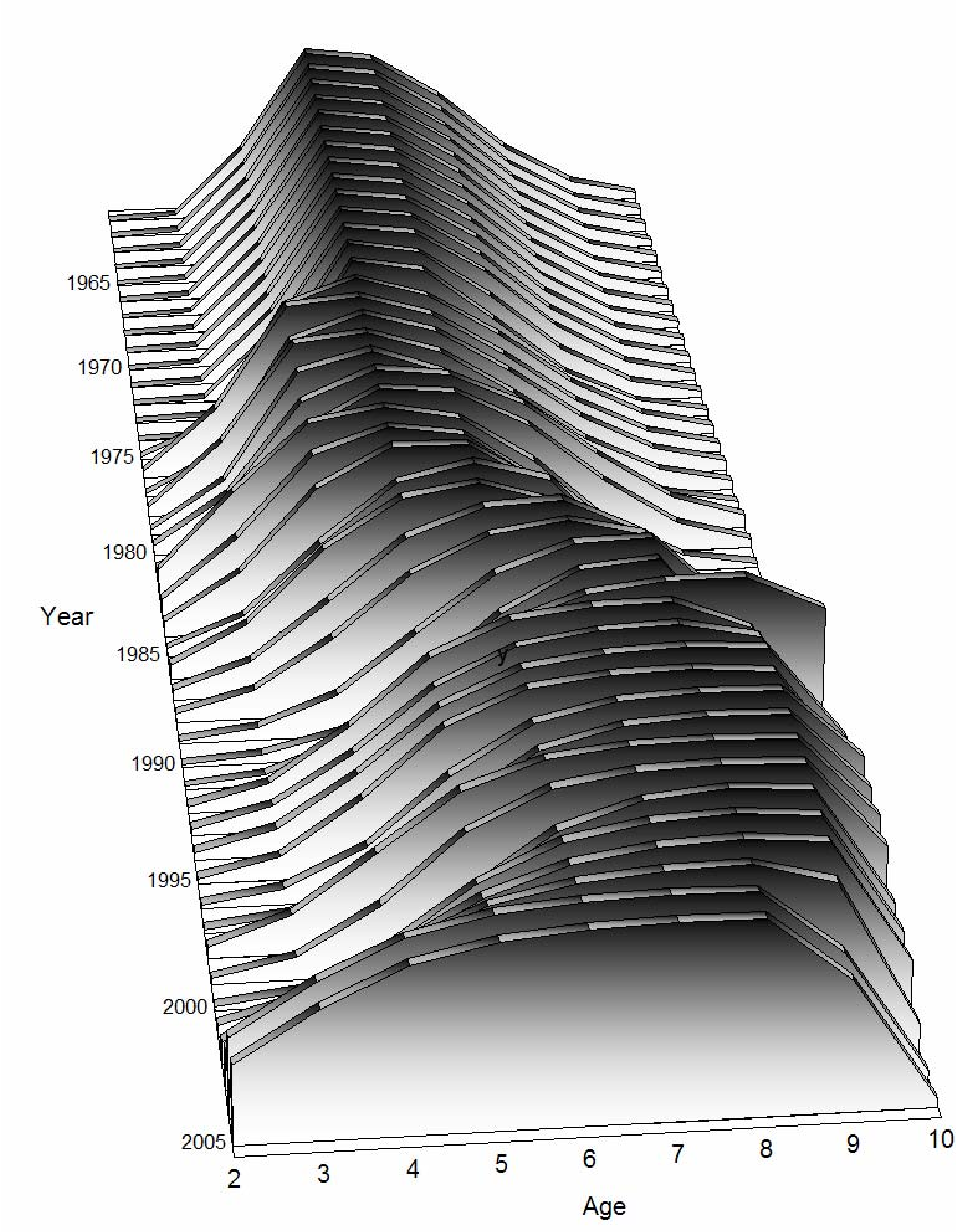
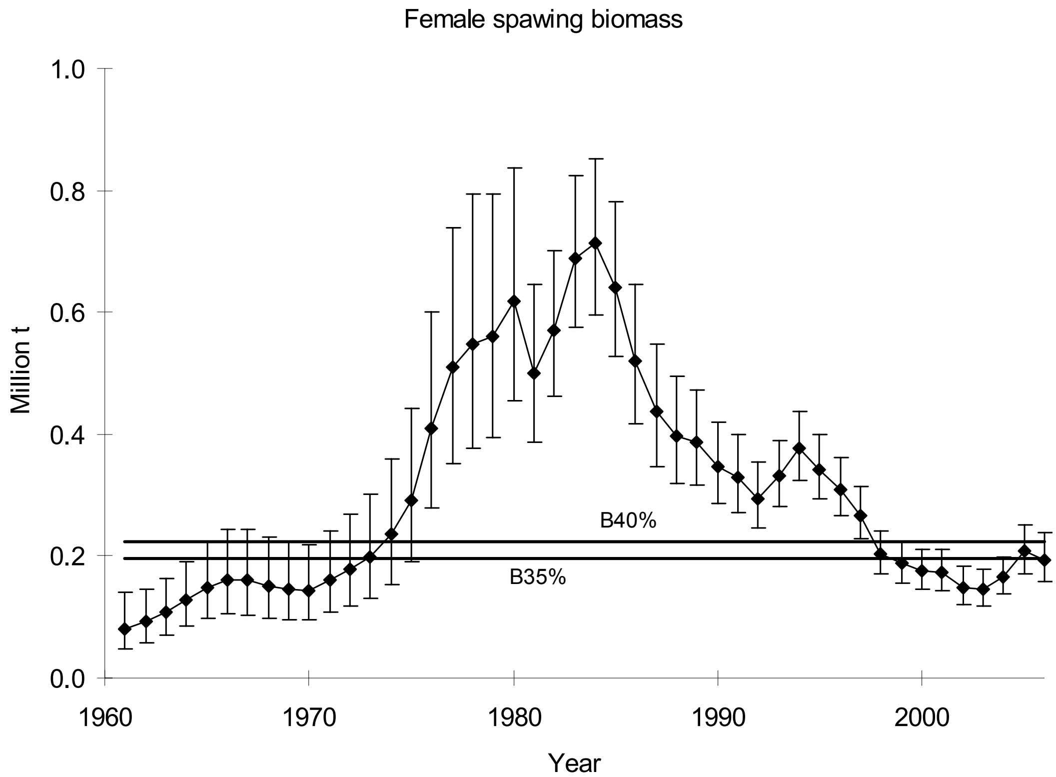


Figure 1.22. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock. The maximum selectivity in each year is 1.0.



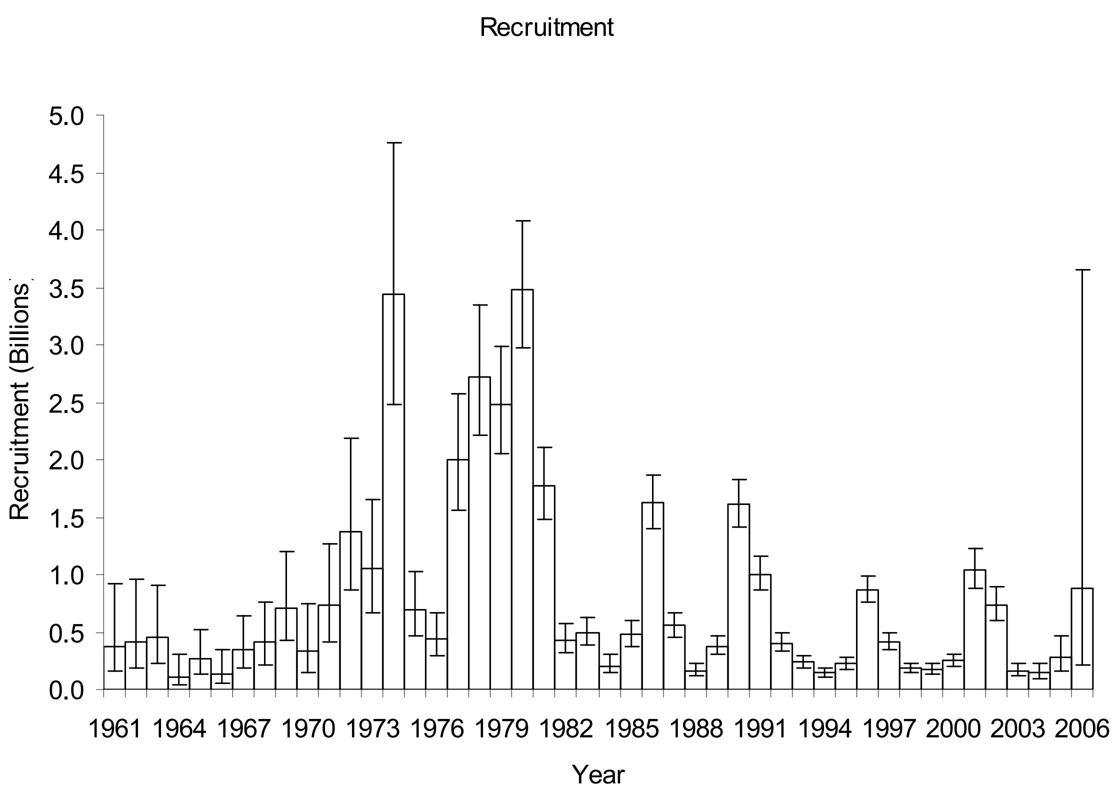
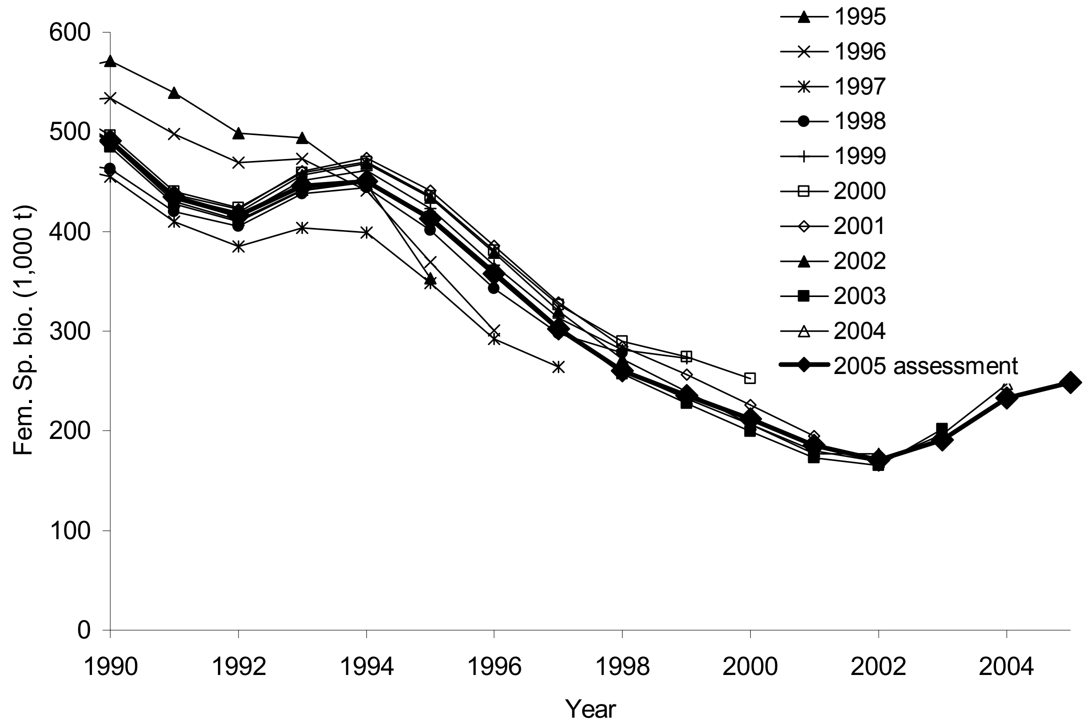


Figure 1.23. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-2 recruitment (billions of fish, bottom) from 1961 to 2006. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



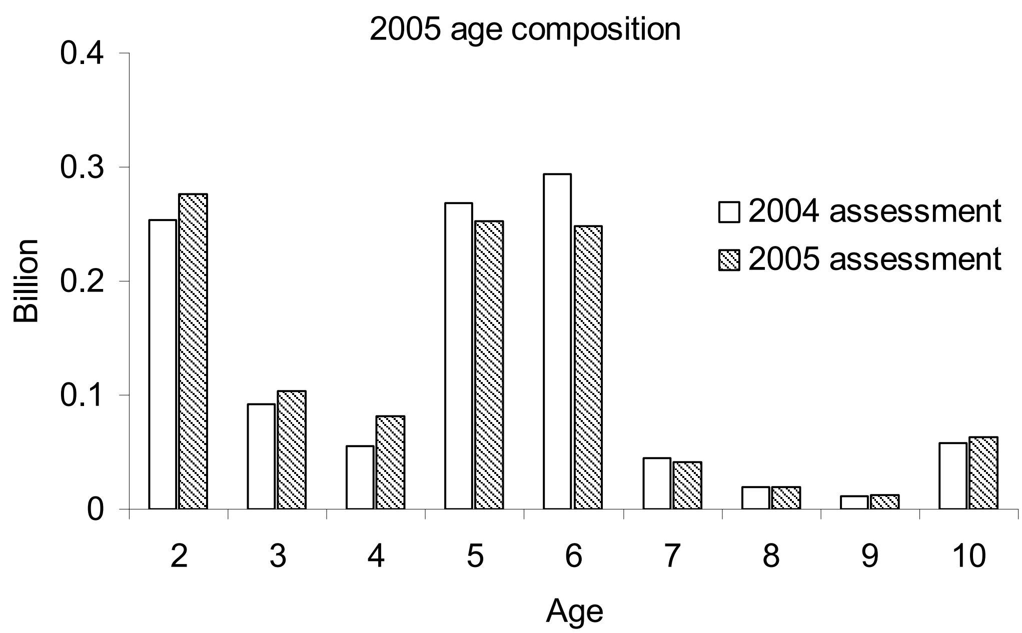


Figure 1.24. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1994-2005 (top). For this figure, the time series of female spawning biomass for the 2005 assessment was calculated using the weight and maturity at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2005 from the 2004 and 2005 assessments.

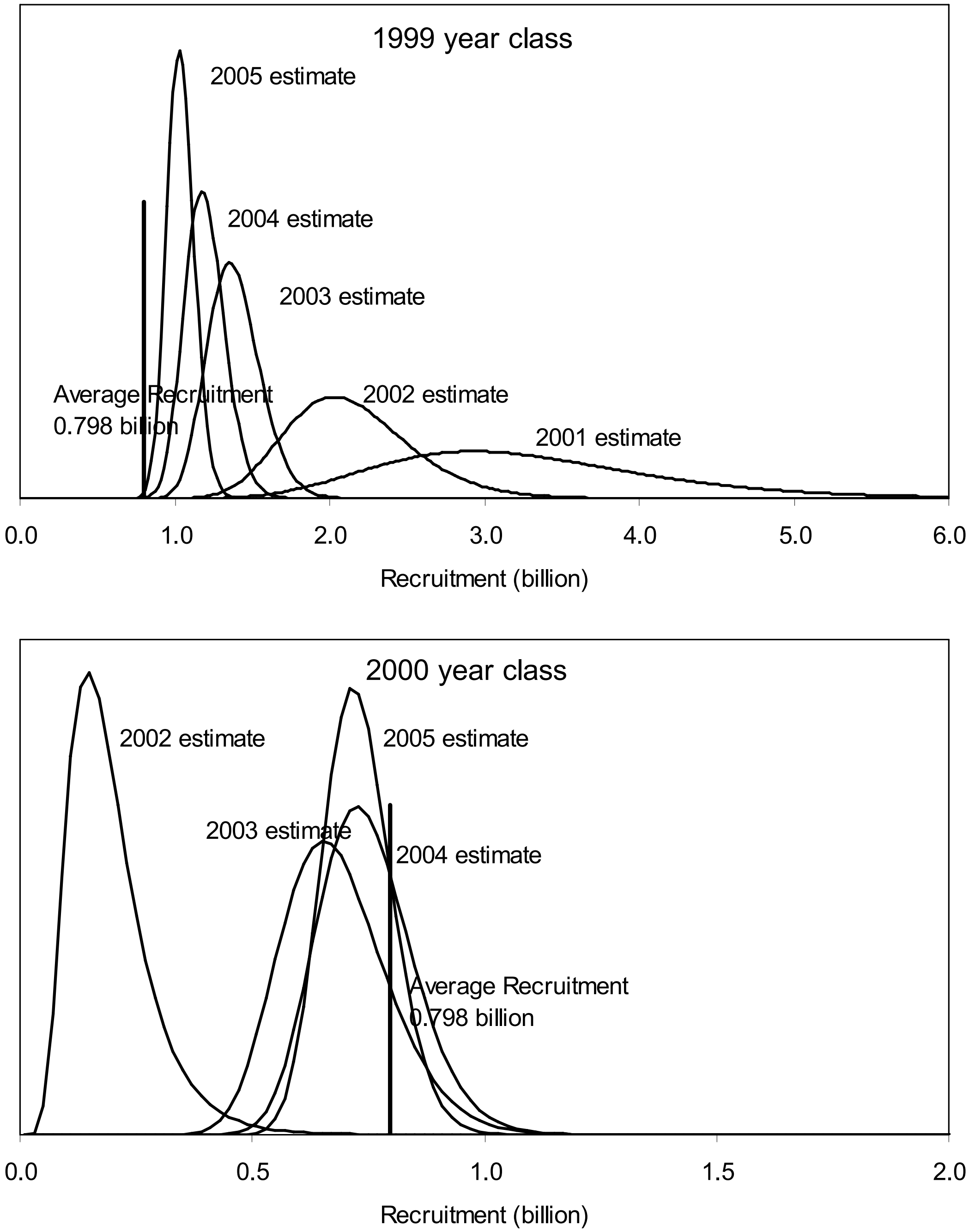
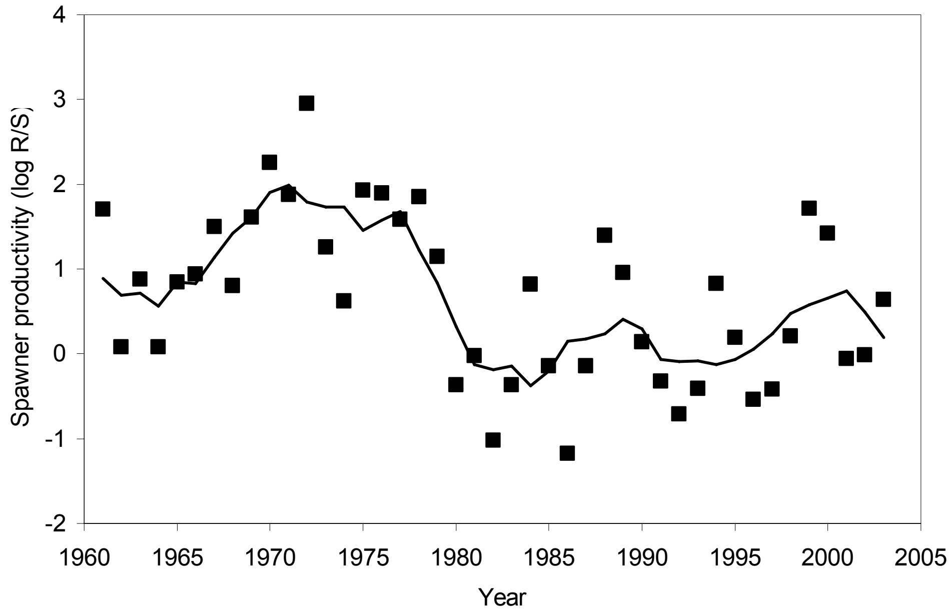


Figure 1.25. Uncertainty in the estimate of recruitment abundance of the 1999 year class in 2001, 2002, 2003, 2004, and 2005 stock assessments (top) and the 2000 year class in 2002, 2003, 2004, and 2005 assessments (bottom).



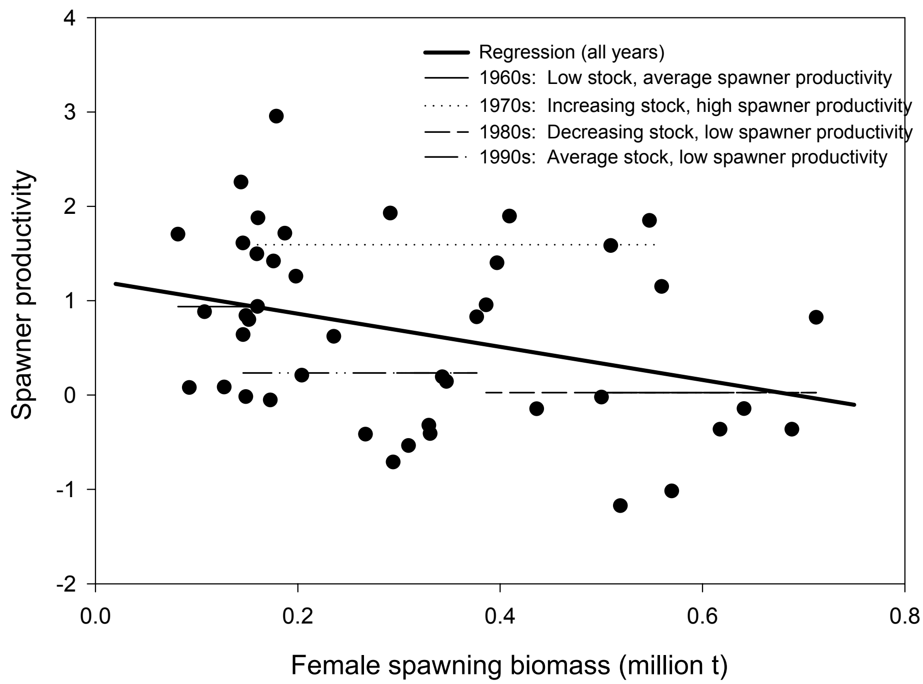
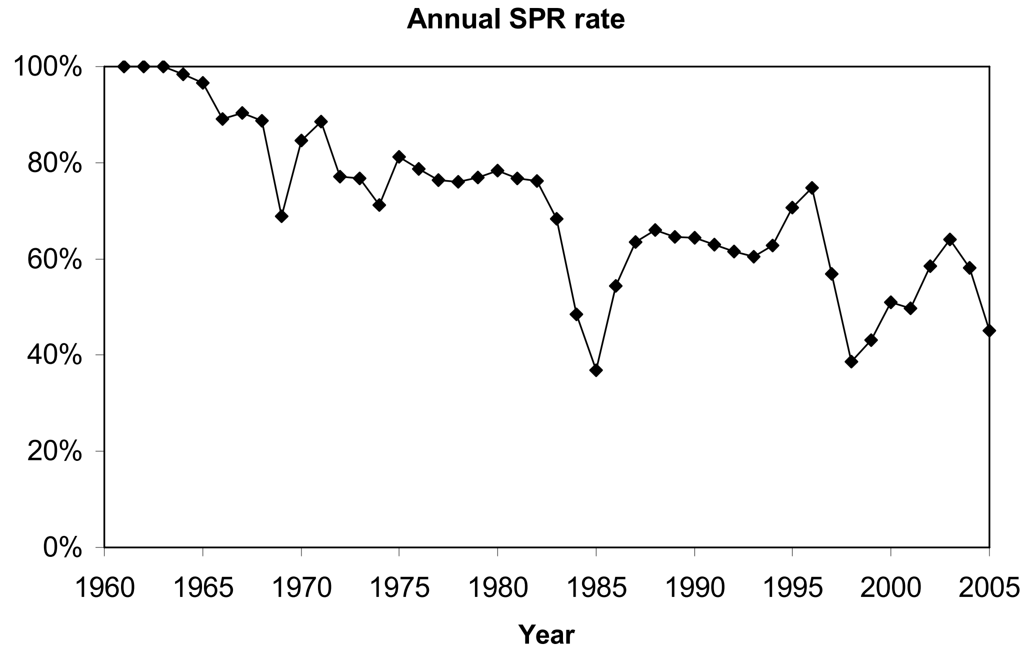


Figure 1.26. Gulf of Alaska pollock spawner productivity *log(R/S)* in 1961-2003 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.



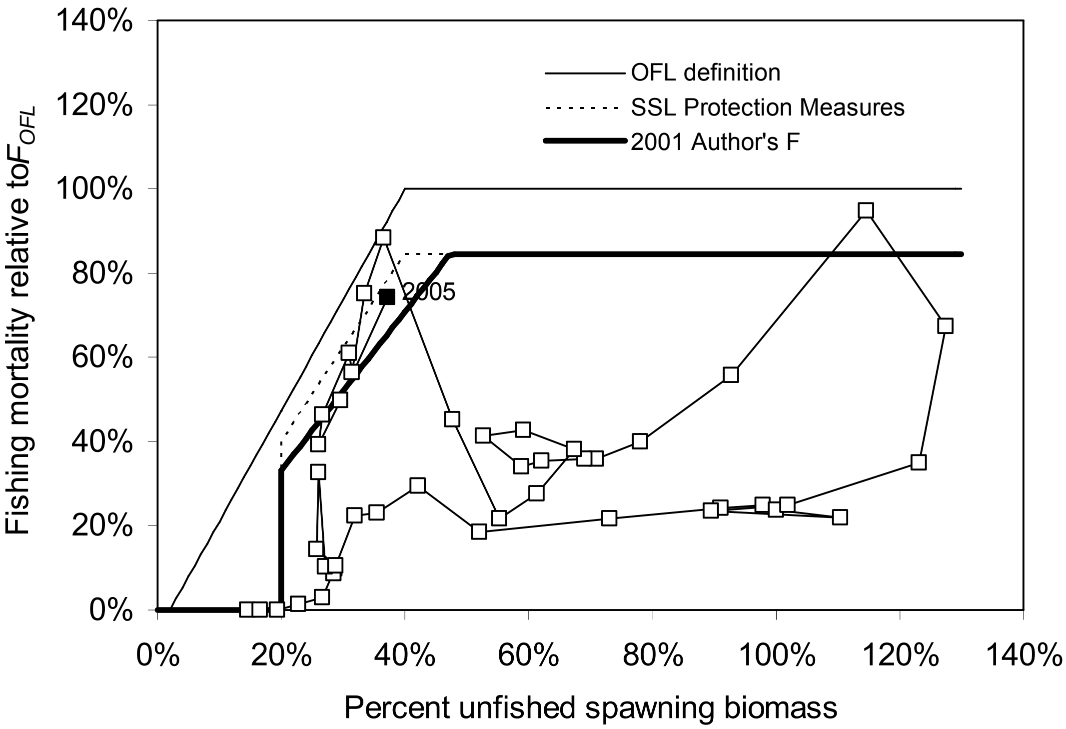


Figure 1.27. Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} (1961-2005). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of unfished spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

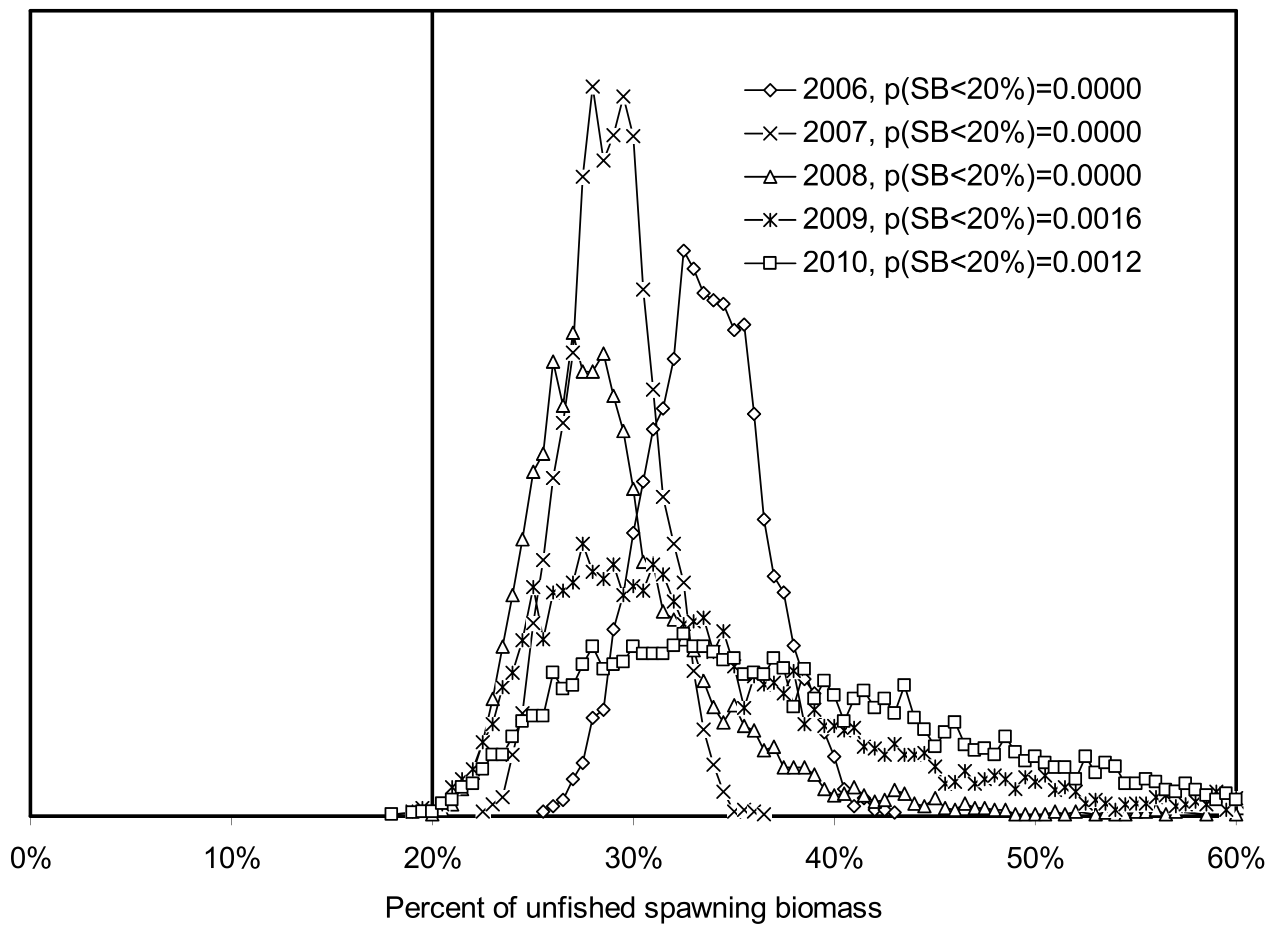


Figure 1.28. Uncertainty in spawning biomass in 2006-2010 based on a thinned MCMC chain from the joint marginal likelihood for Model 2 where catch is set to the author's recommended ABC.

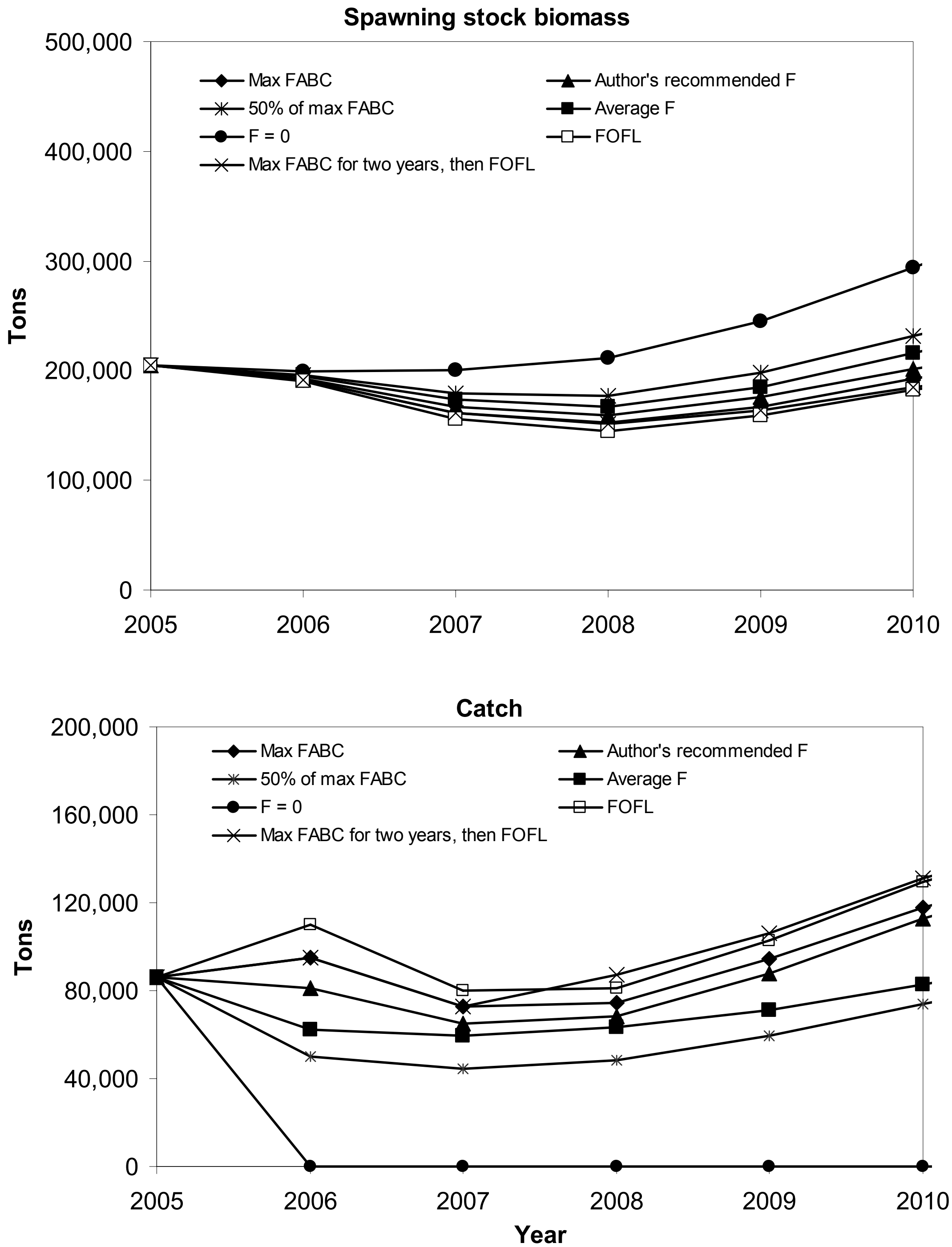


Figure 1.29. Projected spawning biomass and catches in 2005-10 under different harvest strategies.

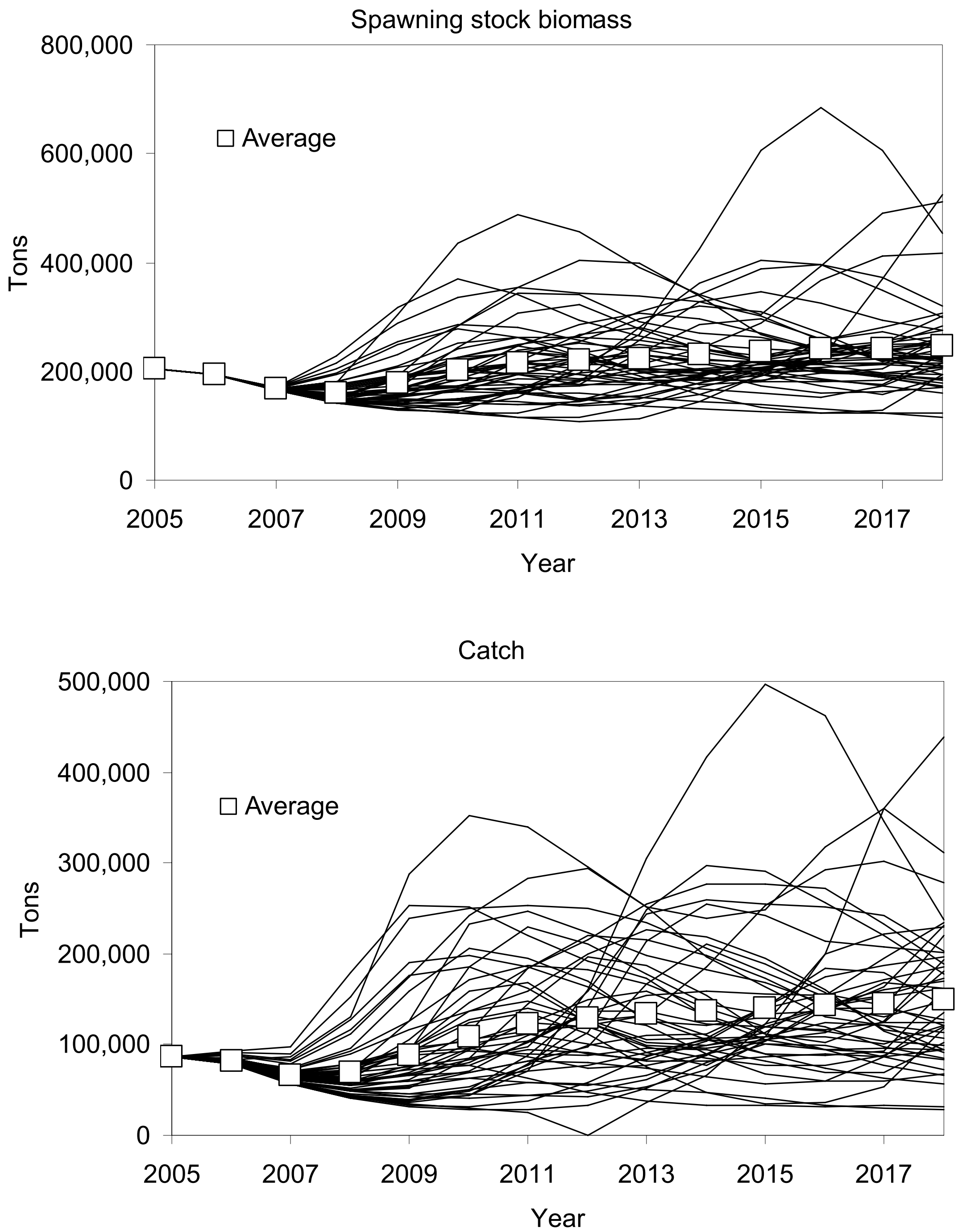


Figure 1.30. Variability in projected spawning biomass and catch in 2005-18 under the recommended FABC.

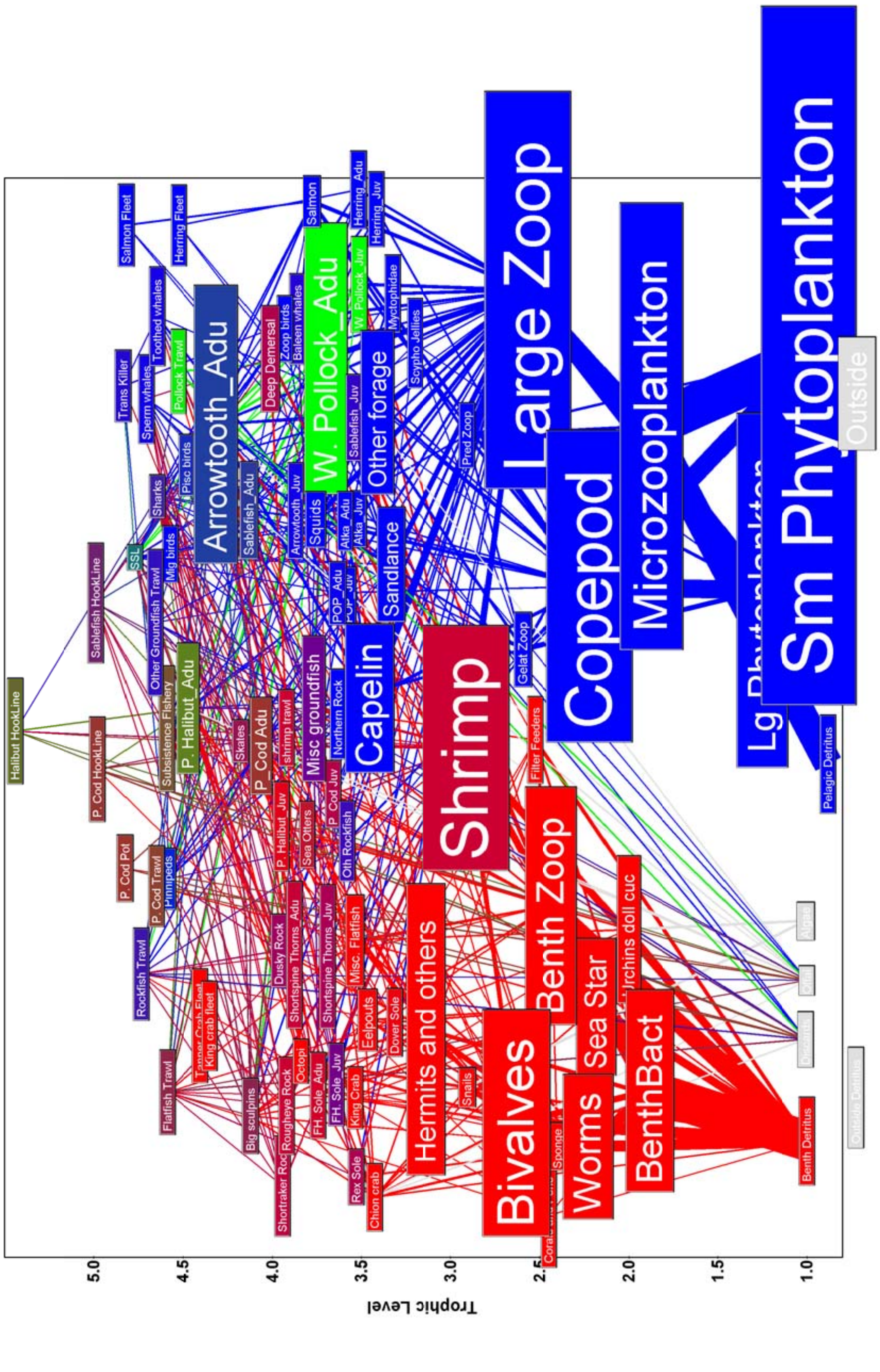
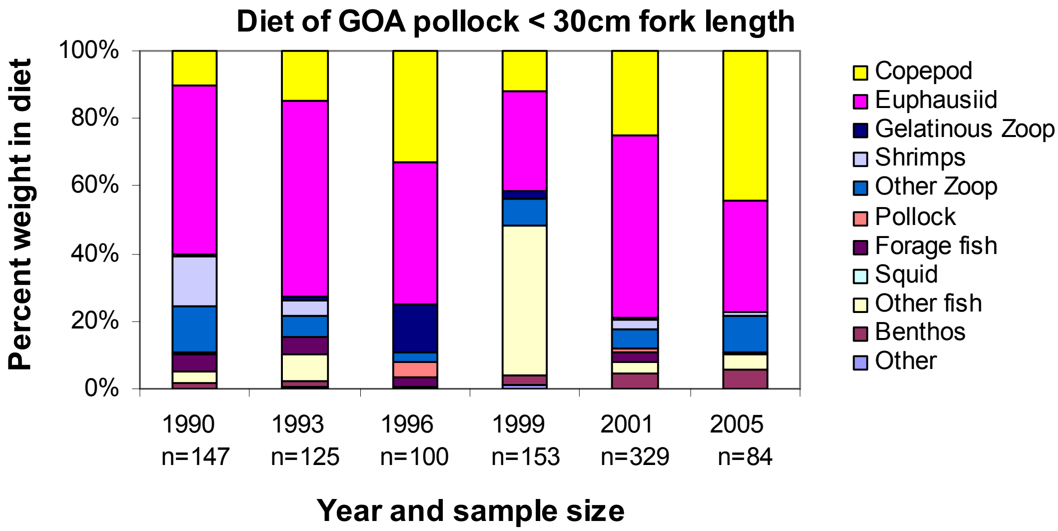


Figure 1.31. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



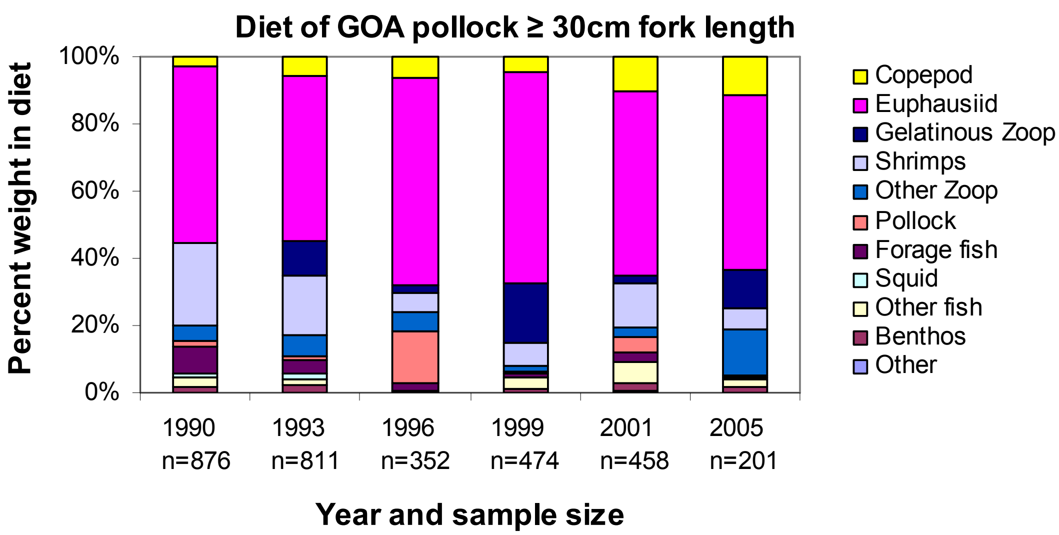
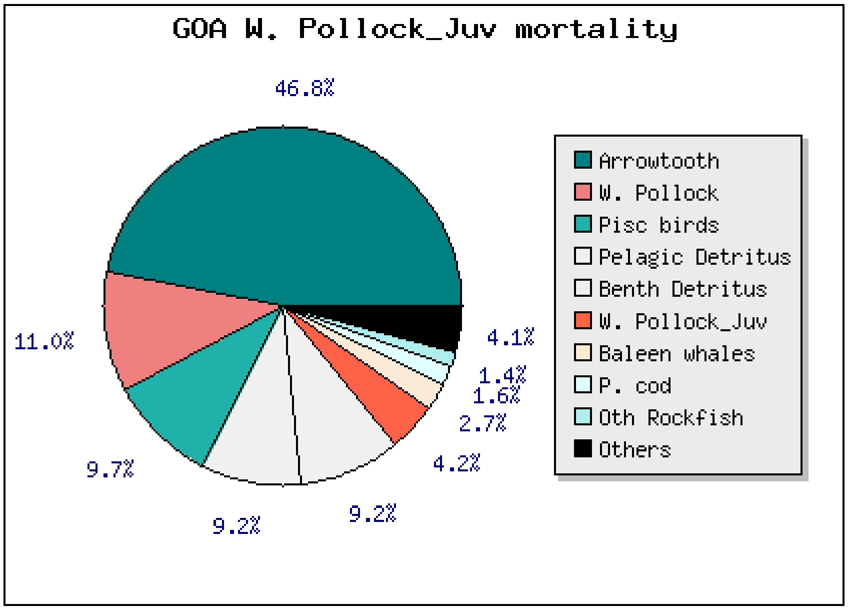


Figure 1.32. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



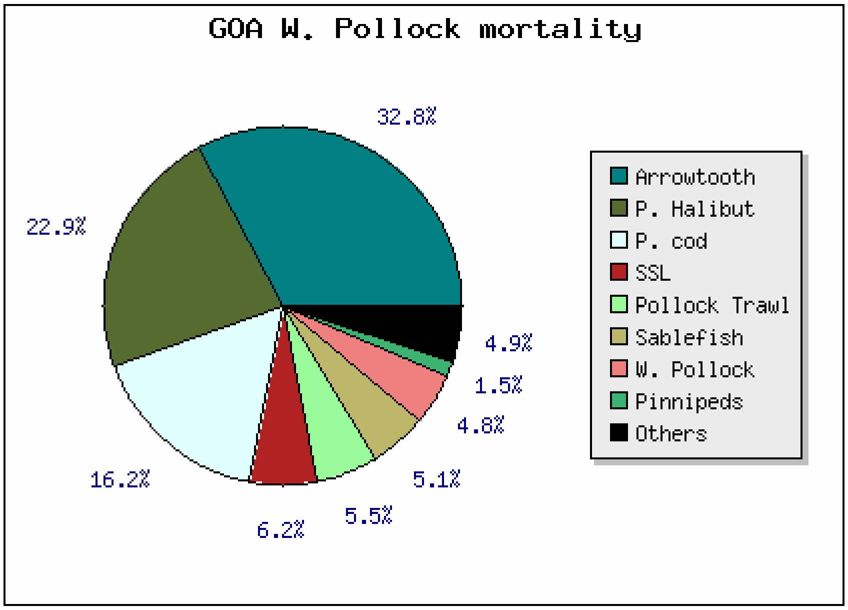


Figure 1.33. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

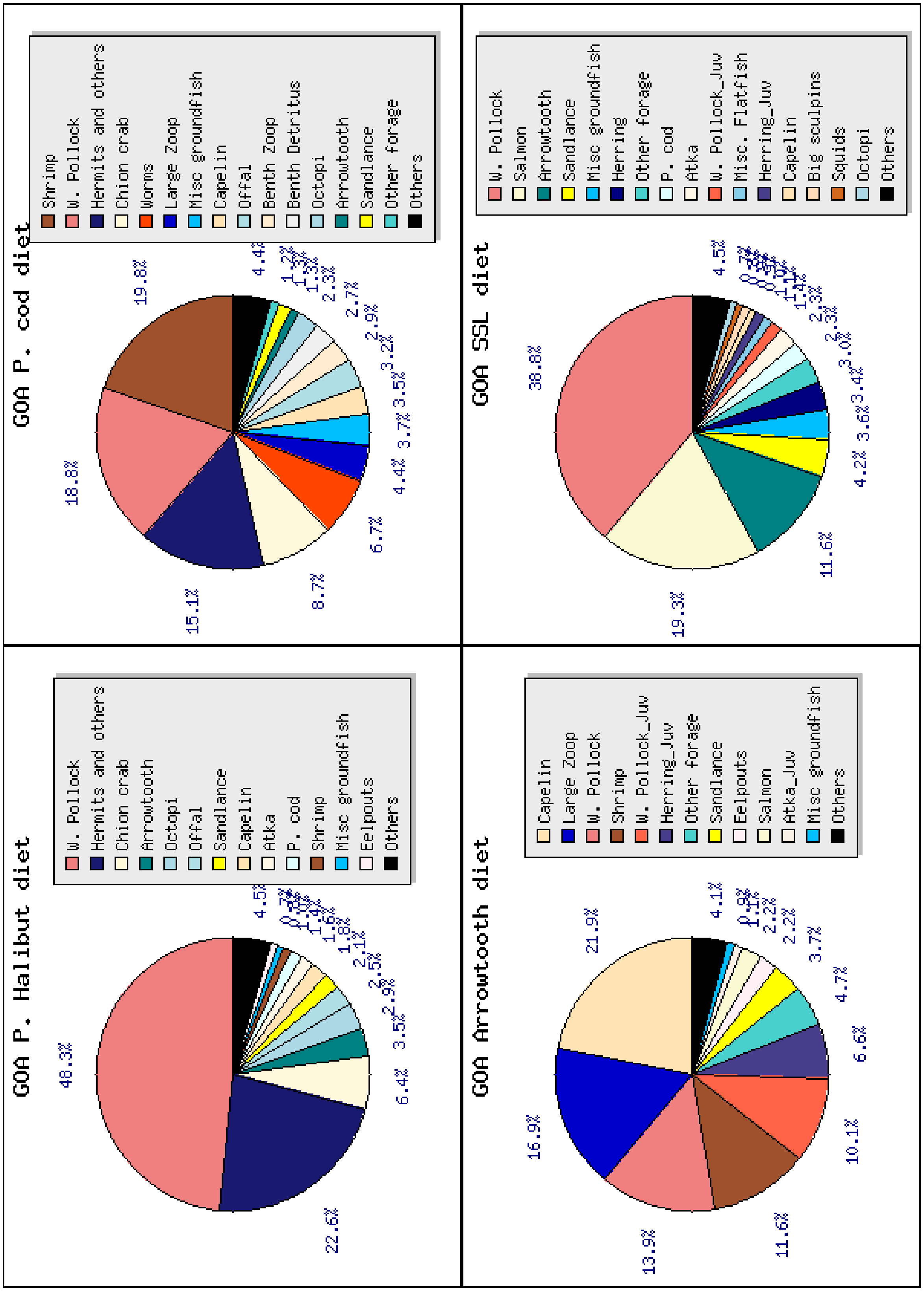


Figure 1.34. Diet diversity of major predators of walleye pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

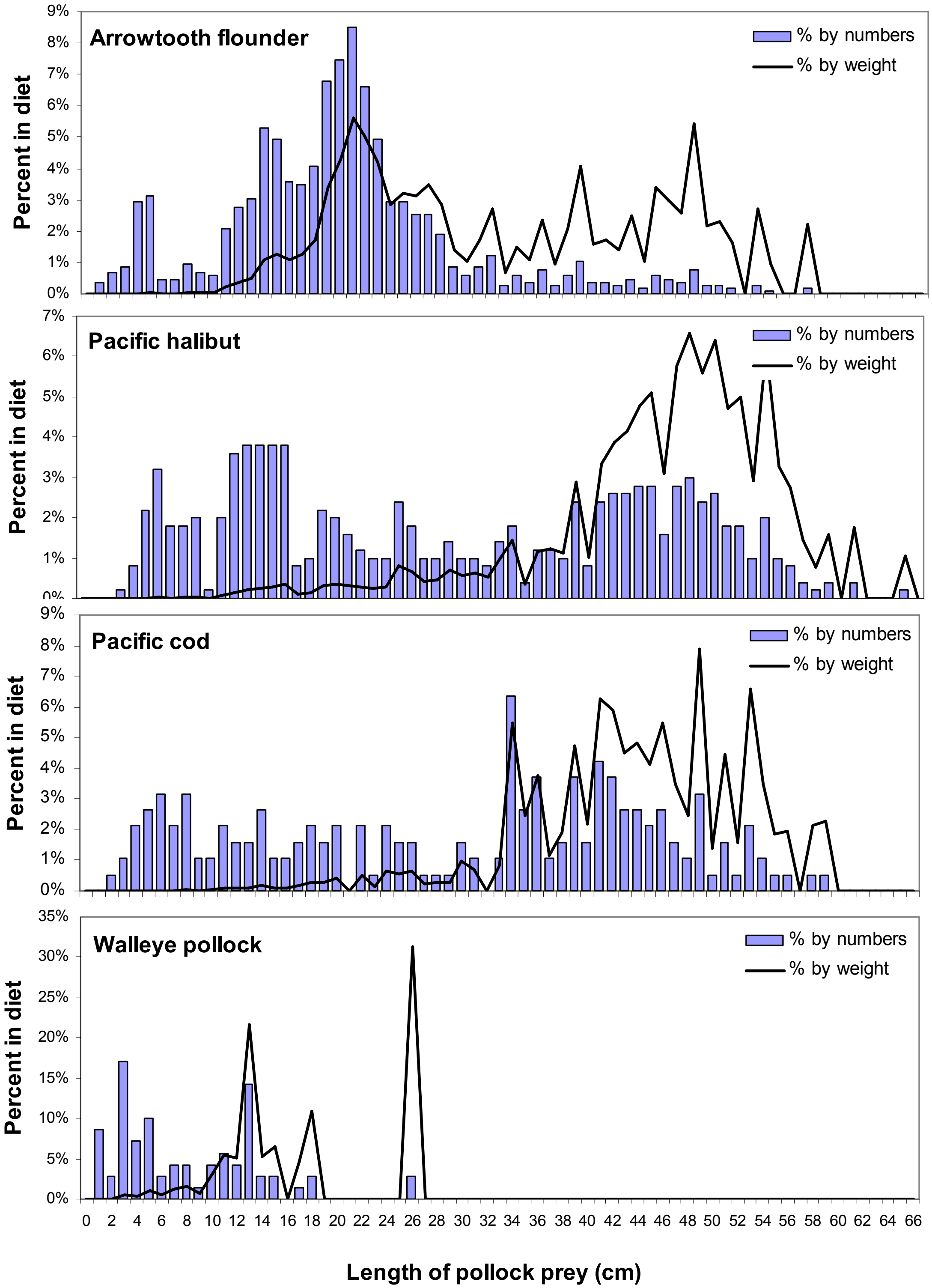
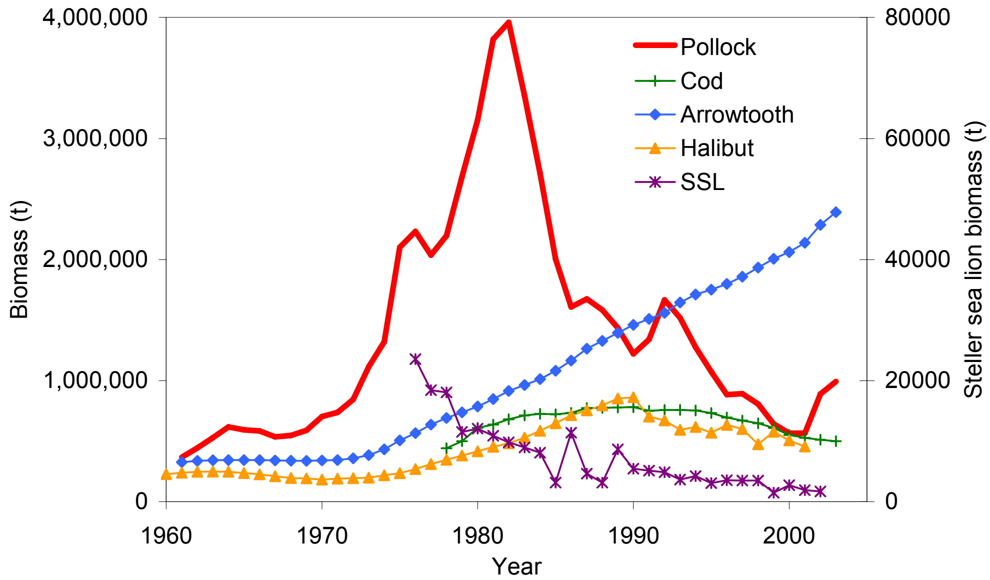


Figure 1.35. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



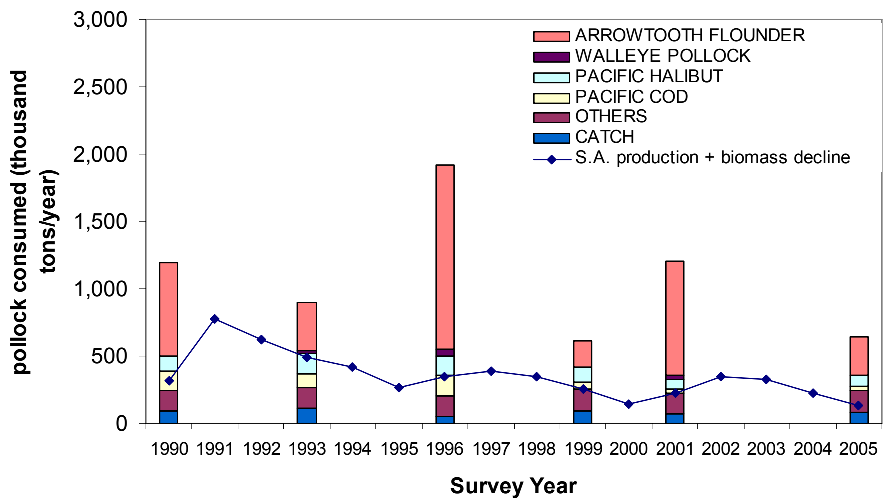


Figure 1.36. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock asessement data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line). See text for calculation methods.

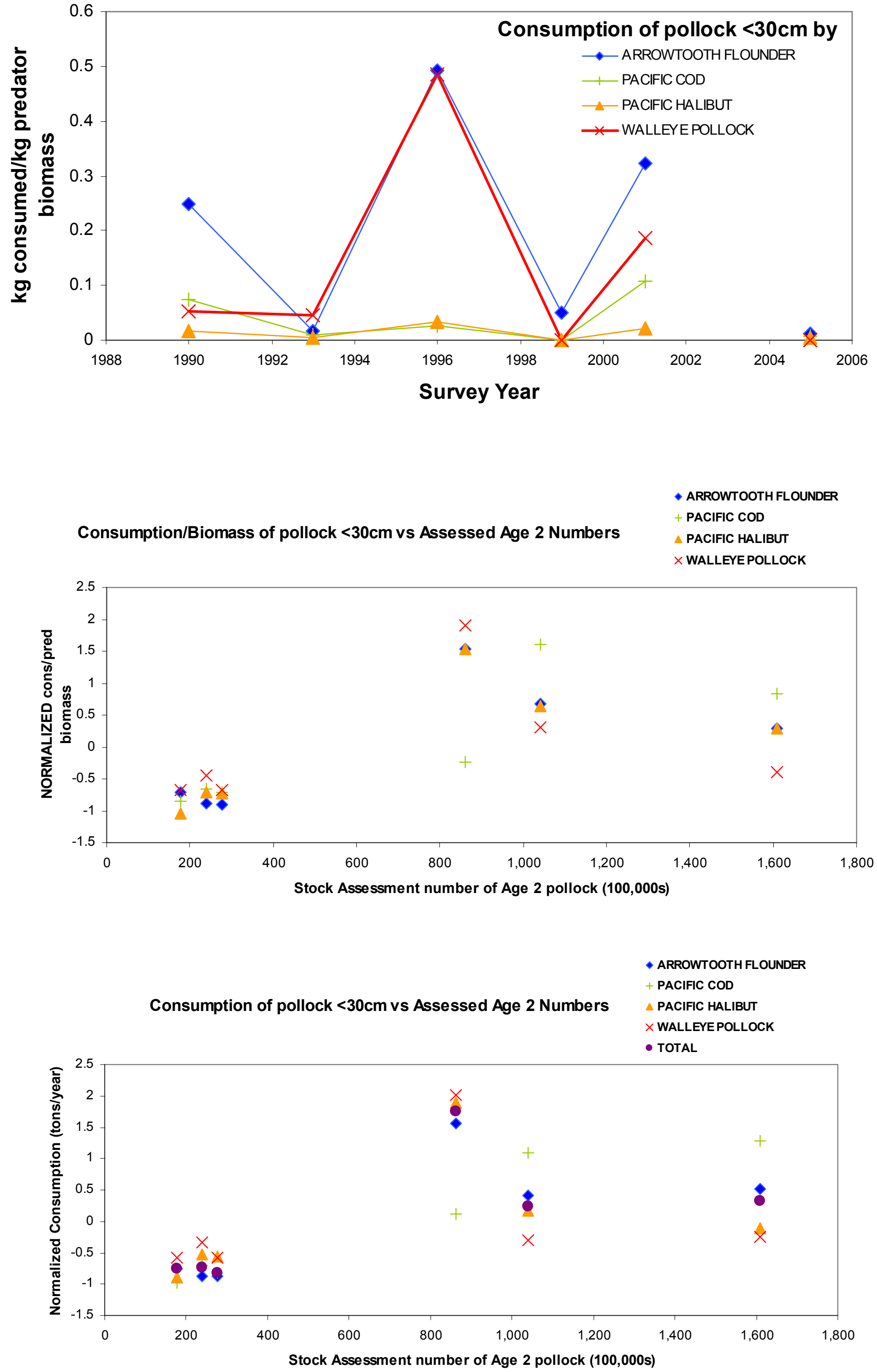
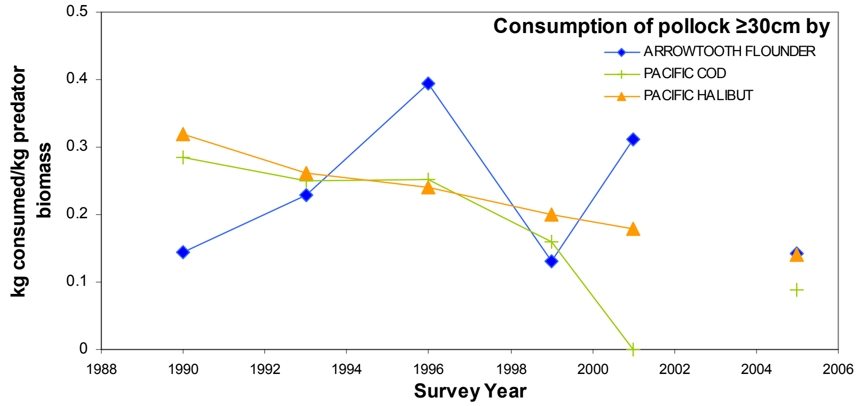
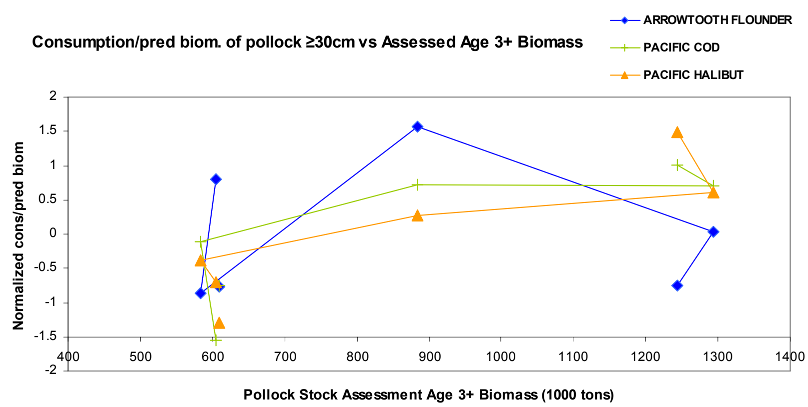


Figure 1.37. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers reported in Table 1.16.





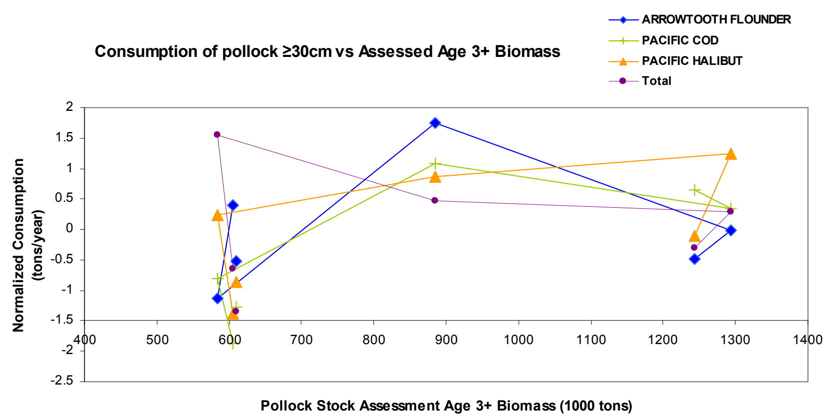


Figure 1.38. (Top) Consumption per unit predator survey biomass of GOA walleye pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass reported in Table 1.17.

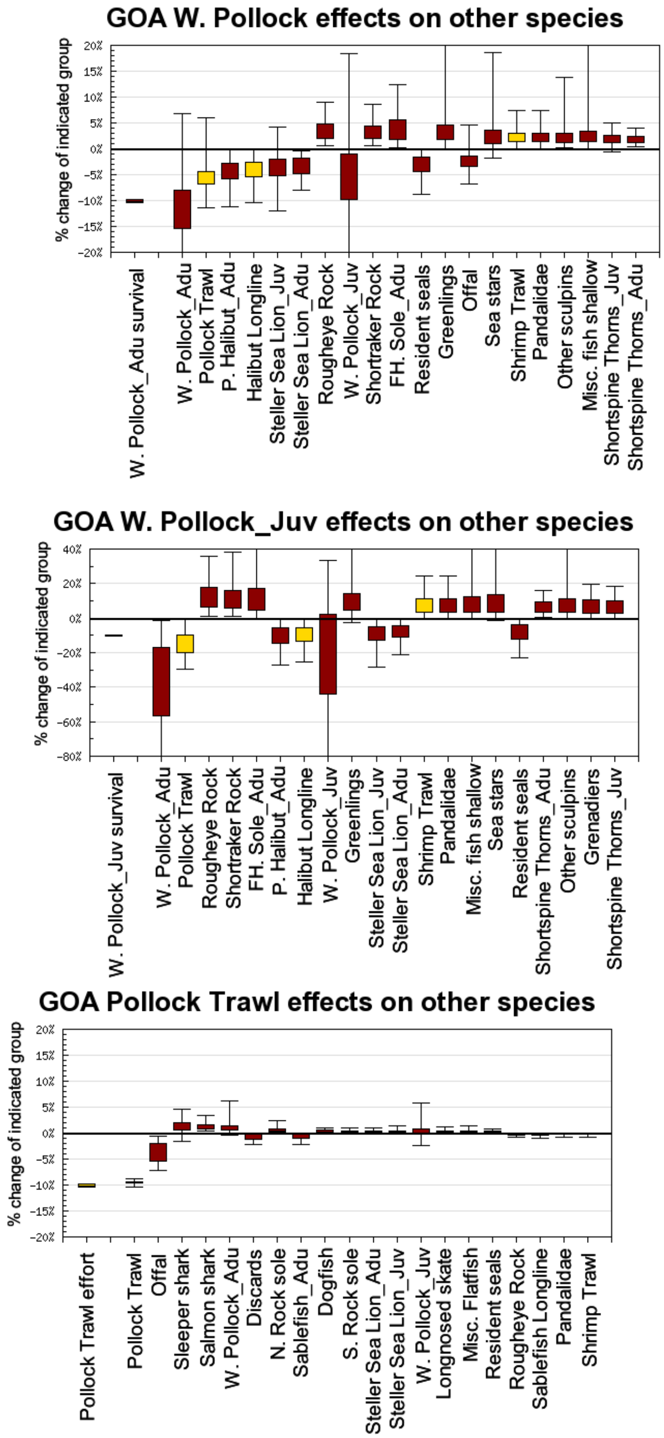
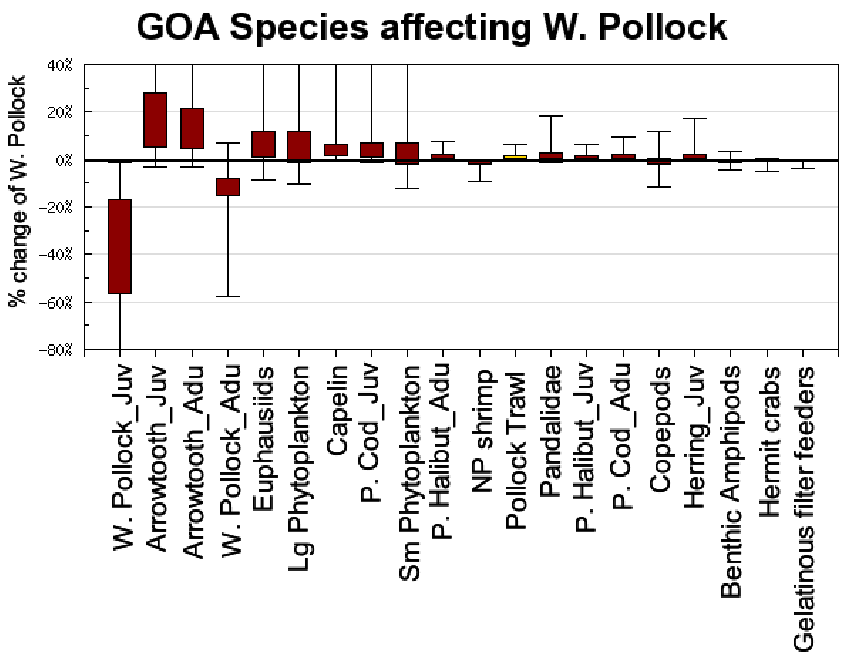


Figure 1.39. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled species, while light bars indicate changes in fisheries catch (landings+discards) assuming a constant fishing rate within the indicated fishery. Graphs show 50% and 95% confidence intervals (bars and lines respectively) summarized over 20,000 ecosystems drawn from error ranges of input parameters (see Aydin et al. 2005 for methodology). Only the top 20 effects, sorted by median, are shown for each perturbation.



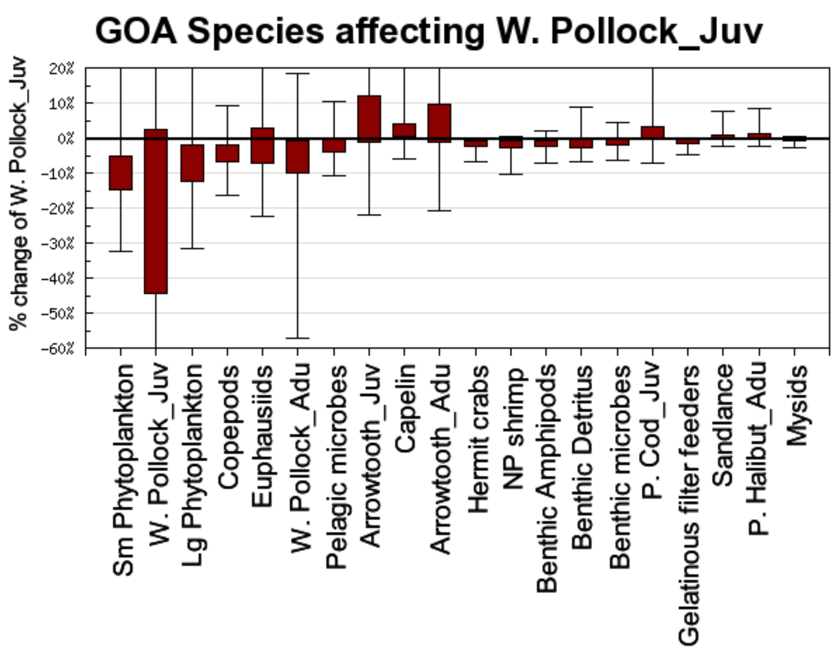


Figure 1.40. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50% and 95% confidence intervals (bars and lines respectively) summarized over 20,000 ecosystems drawn from error ranges of input parameters (see Aydin et al. 2005 for methodology). Only the top 20 effects, sorted by median, are shown for each perturbation.

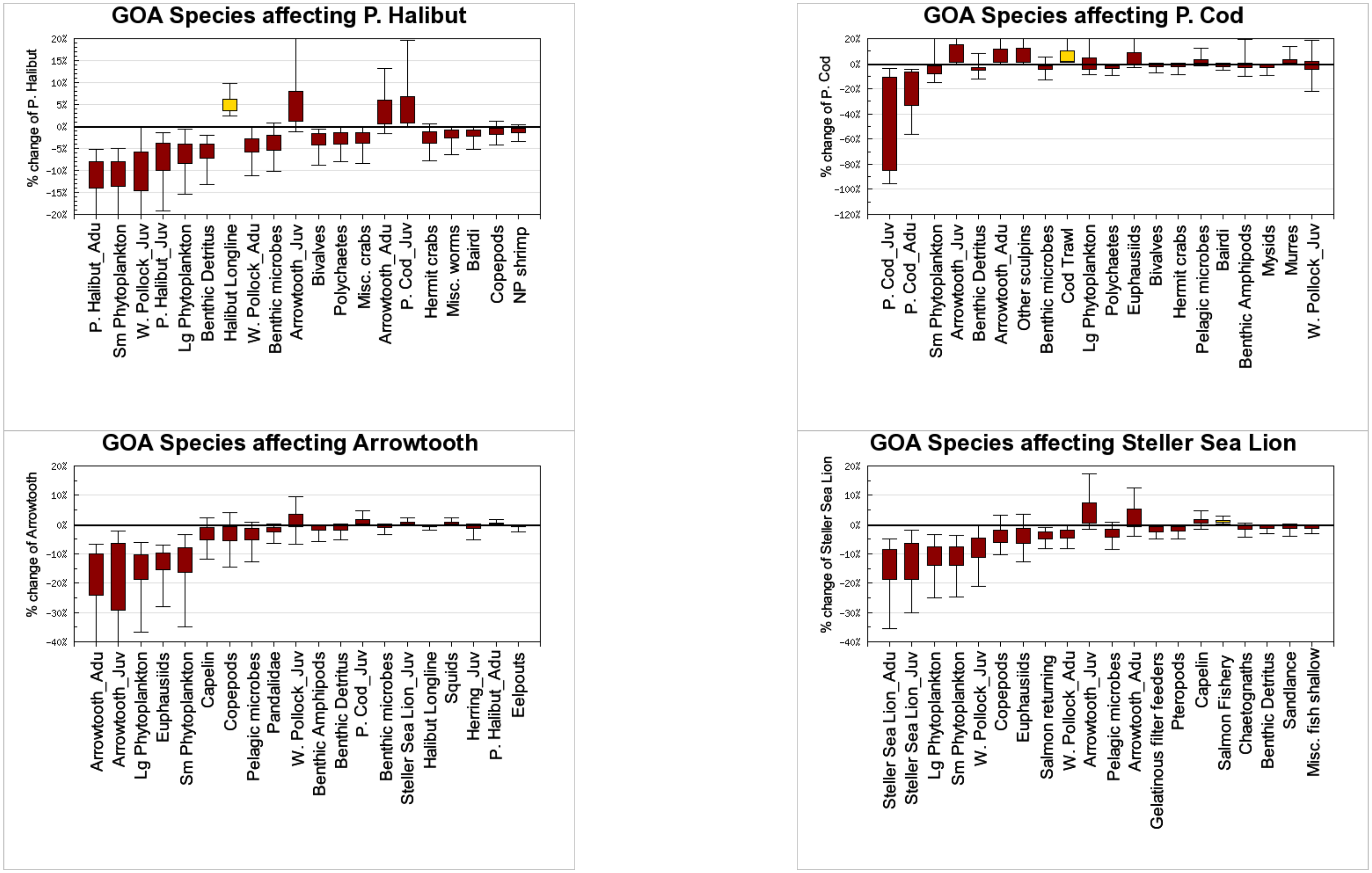


Figure 1.41. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50% and 95% confidence intervals (bars and lines respectively) summarized over 20,000 ecosystems drawn from error ranges of input parameters (see Aydin et al. 2005 for methodology). Only the top 20 effects, sorted by median, are shown for each perturbation.

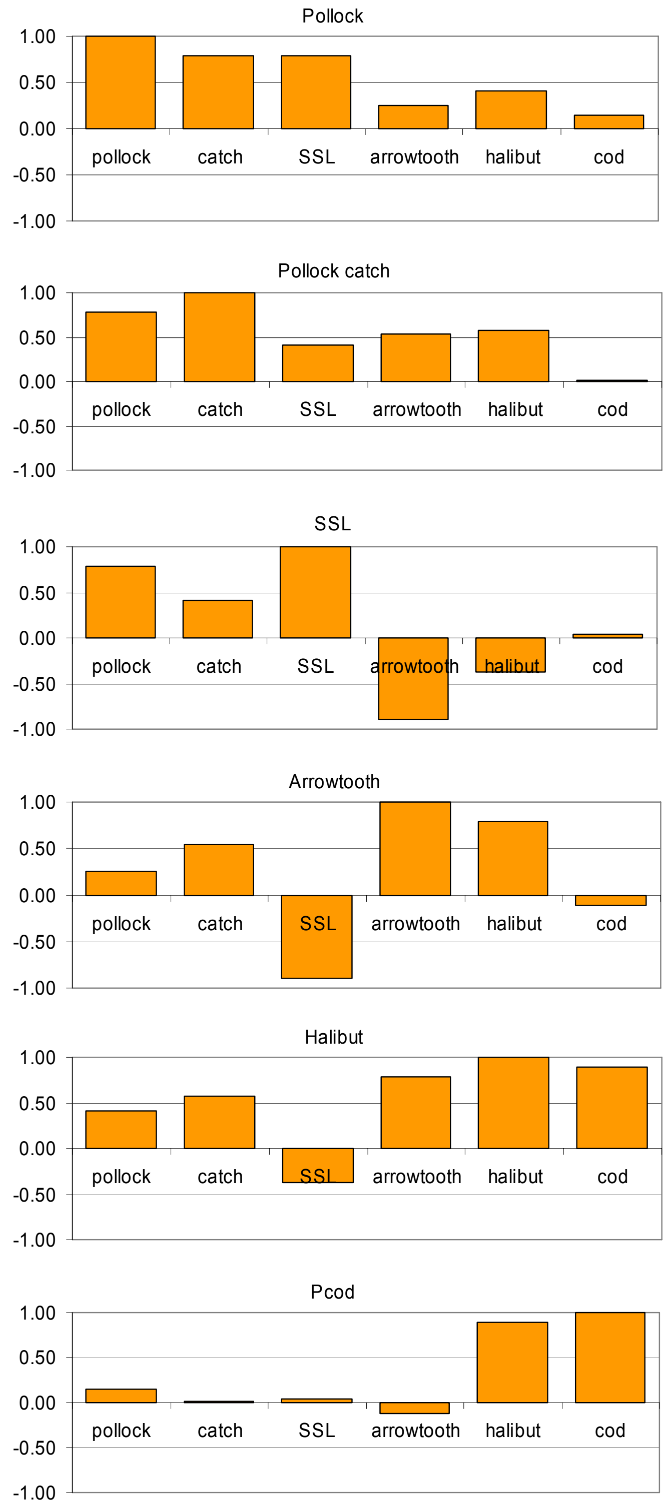


Figure 1.42. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for each pair.

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 2005 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Typically, pollock size composition is dominated by smaller fish (<40 cm), but in the 2005 survey there was a strong mode centered on 42 cm (Fig. 1.43). Juveniles in this area 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 1993-2004, pollock catch the Southeast and East Yakutat statistical areas averaged 14 t (Table 1.3). The current ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska.

Pollock biomass estimates from the bottom trawl survey are highly variable, in part due to year-to-year differences in survey coverage. Surveys in 1996, 1999, 2003 and 2005 had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Fig. 1.43). We recommend placing southeast Alaska pollock in Tier 5 of NPFMC harvest policy, and basing the ABC and OFL on natural mortality (0.3) and the biomass for the 2005 survey (27,362 t). 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 results in a 2006 ABC of 6,157 t (27,362 t * 0.75 M), and a 2006 OFL of 8,209 t (27,362 t * M).** Since no new survey data will be available until summer of 2007, the 2007 ABC and OFL should be set equal to the 2006 values.

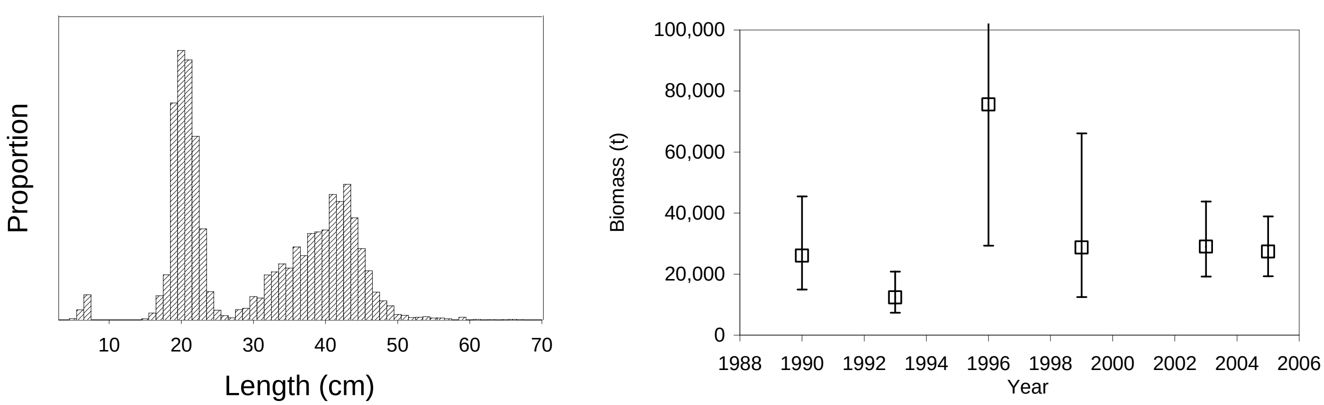


Figure 1.43. Pollock size composition in 2005 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2005 (right). Error bars indicate plus and minus two standard deviations.

Appendix B: Gulf pollock stock assessment model

Population dynamics

The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 10, with age 10 defined as a "plus" group, i.e., all individuals age 10 and older. The model extends from 1961 to 2004 (44 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 is age-specific selectivity, and f_i is the annual fishing mortality rate. To ensure that the selectivities are well determined, we require that $\max(s_j) = 1$. Following previous assessments, a scaled double-logistic function (Dorn and Methot 1990) was used to model age-specific selectivity,

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

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

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

Measurement error

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

$$\hat{C}_i = \sum_j w_{i\,j}\, c_{i\,j}$$

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

where $w_{i\,j}$ 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 $\pi_{i\,j}$. Predicted values from the model are obtained from

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

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 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 an arithmetic 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. Variation in the intercept selectivity parameters is modeled using a random walk on an arithmetic scale, while variation in the slope parameters is modeled using a log-scale random walk.

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

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

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

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

Winter distribution

In winter, an annual acoustic survey in Shelikof Strait has been conducted since 1981. A significant portion of the remaining shelf and upper slope waters in the Gulf of Alaska west of Cape Suckling has been surveyed at least once during winter by exploratory surveys and surveys with shorter time series. Therefore a “composite” approach was developed to use data from several different surveys. We used data from 1) Shelikof Strait surveys in 1992-2005, 2) surveys of the Shumagin Island area in 1995, and 2001-03, and 2005 (Wilson et al. 1995, Guttormsen et al. 2001, 2002, 2003, 2005), 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 1992-2005. Results indicate that an average of 68% of the pollock biomass was in Shelikof Strait in winter (Appendix table 1.1). For the Shumagin surveys in 1995, 2001-2003, and 2005 21% of the total stock biomass was surveyed on average. The sum of the percent biomass for all surveys was 99%, 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 21.63%, 68.81%, 9.56% in areas 610, 620, and 630. These estimates are within 3 percentage points of last year's estimates. We have not used recent survey results along the shelf break in areas 620 and 630, nor the 2003 and 2005 estimates of biomass in Sanak Gully in area 610 because the relationship between these newly surveyed aggregations and those in Shelikof Strait and the Shumagin Islands is unclear.

A-season apportionment between areas 620 and 630

Last year, based on evaluation of fishing patterns which suggested that the migration to spawning areas was not complete by January 20, the plan team recommended an alternative apportionment scheme for areas 620 and 630 based on the midpoint of the summer and winter distributions in area 630. This approach was not used for area 610 because fishing patterns during the A season suggested that most of the fish captured in area 610 would eventually spawn in area 610. The resulting A season apportionment updated with 2005 survey data is: 610, 21.63%; 620, 57.50%; 630, 20.87%.

Middleton Island winter EIT survey results in 2003

The apportionment for area 640, which is not managed by season, has previously been based on the summer distribution of the biomass. Fishing, however, takes places primarily in winter or early spring on a spawning aggregation near Middleton Island. During 28-29 March 2003, this area was surveyed by the NOAA ship *Miller Freeman* for the first time and biomass estimate of 6900 t was obtained. Although maturity stage data suggested the timing of the survey was appropriate, discussions with fishing vessels contacted during the survey raised some questions about survey timing relative to peak biomass. Notwithstanding, a tier 5 calculation based on this spawning biomass gives an ABC of 1,550 t (6,901 t * 0.75 M), compared to 1,829 t for the author's 2006 ABC recommendation and an apportionment based on the summer biomass distribution. This suggests that the current approach of basing the area 640 apportionment on the gulfwide ABC and the summer biomass distribution is at least consistent with the biomass present near Middleton Island in the winter. We recommend continuing this approach until sufficient survey information during winter has accumulated to evaluate interannual variation in the biomass present in this area.

Summer distribution

The NMFS bottom trawl is summer survey (typically extending from mid-May to mid-August). Because of large shifts in the distribution of pollock between management areas one survey to the next, and the high variance of biomass estimates by management area, Dorn et al. (1999) recommended that the apportionment of pollock TAC be based upon the four most recent NMFS summer surveys. The four-survey average was updated with 2005 survey results in an average biomass distribution of 51.47%, 14.83%, 31.45%, and 2.25% in areas 610, 620, 630, and 640 (Fig. 1.44).

Example calculation of 2006 Seasonal and Area TAC Allowances for W/C/WYK

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

1) Deduct the Prince William Sound Guideline Harvest Level.

2) Use summer biomass distribution for the 640 allowance:

640 0.0225 x Total TAC = 2,250 t

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

A season 0.25 x (Total TAC – 2,250) = 24,437 t
B season 0.25 x (Total TAC – 2,250) = 24,437 t
C season 0.25 x (Total TAC – 2,250) = 24,438 t
D season 0.25 x (Total TAC – 2,250) = 24,438 t

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

610 0.2163 * 24,437 t = 5,286 t
620 0.5750 * 24,437 t = 14,051 t
630 0.2087 * 24,437 t = 5,100 t

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

610 0.2163 * 24,437 t = 5,286 t
620 0.6881 * 24,437 t = 16,815 t
630 0.0956 * 24,437 t = 2,336 t

6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the average biomass distribution in areas 610, 620 and 630 in the most recent four NMFS bottom trawl surveys.
of 51.47%, 14.83%, 31.45%, and 2.25%

610 0.5147 / (1 – 0.0225) x 24,438 = 12,867 t
620 0.1483 / (1 – 0.0225) x 24,438 = 3,708 t
630 0.3145 / (1 – 0.0225) x 24,438 = 7,863 t

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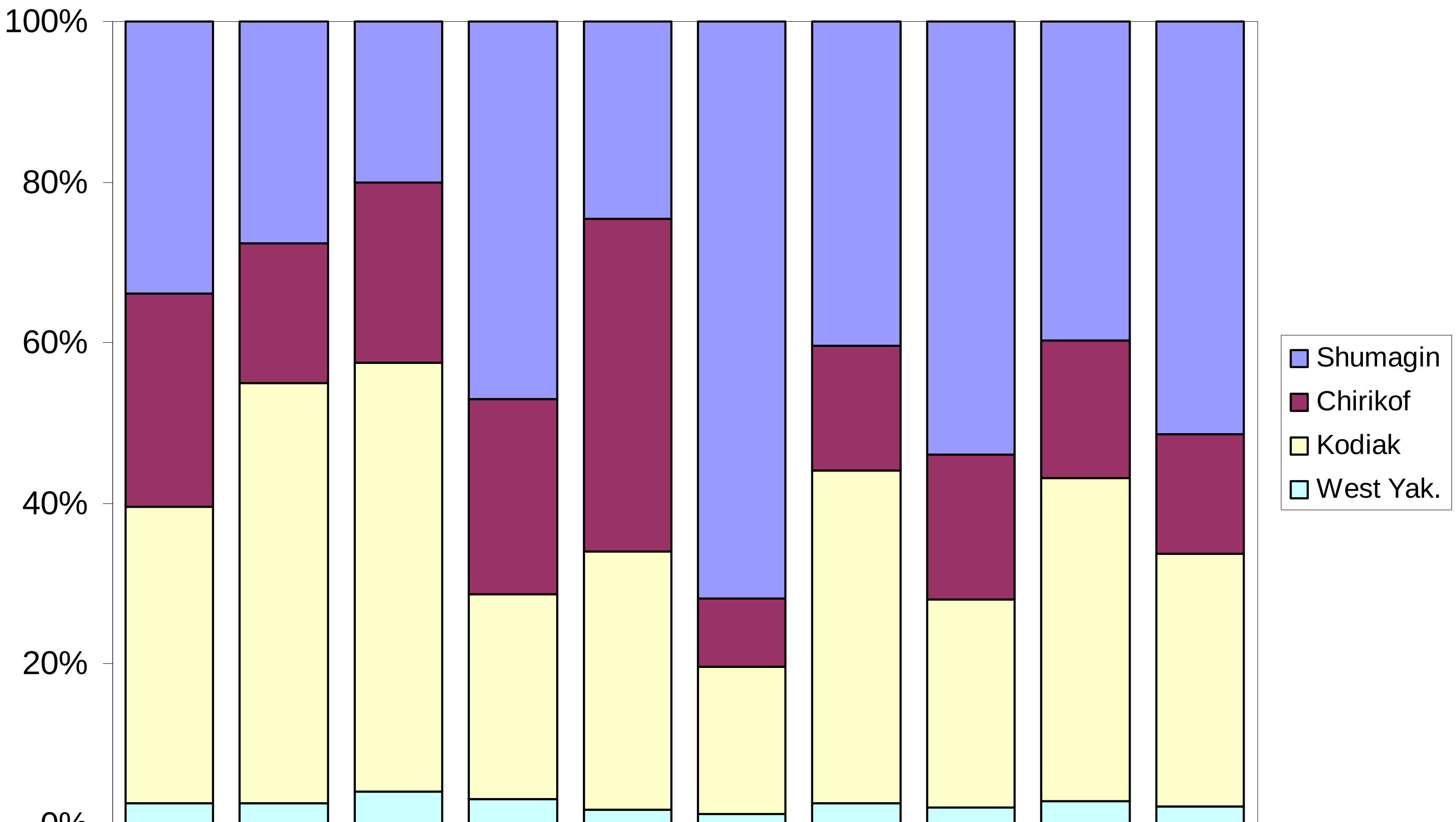
620 0.1483 / (1 – 0.0225) x 24,438 = 3,708 t
630 0.3145 / (1 – 0.0225) x 24,438 = 7,863 t

Appendix Table 1.1. Estimates of winter pollock biomass distribution in management areas 610-630 from EIT surveys in the Gulf of Alaska.

Survey	Year	Model estimates of total 2+ biomass at spawning	Survey biomass estimate[1]	Percent	Percent of biomass by management area: Area 610	Area 620	Area 630	Percent of total biomass: Area 610	Area 620	Area 630
Shelikof Strait	1992	994,522	713,429	71.7%						
Shelikof Strait	1993	1,087,620	435,753	40.1%						
Shelikof Strait	1994	1,076,680	492,593	45.8%						
Shelikof Strait	1995	889,717	649,401	73.0%						
Shelikof Strait	1996	791,894	777,172	98.1%						
Shelikof Strait	1997	722,641	583,017	80.7%	0.0%	98.8%	1.2%			
Shelikof Strait	1998	610,818	504,774	82.6%	0.0%	97.5%	2.5%			
Shelikof Strait	2000	503,676	391,327	77.7%	0.0%	97.8%	2.2%			
Shelikof Strait	2001	498,376	432,749	86.8%	0.0%	98.3%	1.7%			
Shelikof Strait	2002	504,409	256,743	50.9%	0.0%	97.7%	2.3%			
Shelikof Strait	2003	529,333	317,269	59.9%	0.0%	97.6%	2.4%			
Shelikof Strait	2004	568,676	330,753	58.2%	0.0%	97.6%	2.4%			
Shelikof Strait	2005	608,442	338,038	55.6%	0.0%	97.8%	2.2%			
Shelikof Strait	Average			67.8%	0.0%	97.9%	2.1%	0.0%	66.3%	1.4%
Shumagin	1995	889,717	290,100	32.6%	90.0%	10.0%	0.0%			
Shumagin	2001	498,376	119,565	24.0%	84.8%	15.2%	0.0%			
Shumagin	2002	504,409	135,644	26.9%	100.0%	0.0%	0.0%			
Shumagin	2003	529,333	67,160	12.7%	99.7%	0.3%	0.0%			
Shumagin	2005	608,442	51,970	8.5%	99.9%	0.1%	0.0%			
Shumagin	Average			20.9%	94.9%	5.1%	0.0%	19.9%	1.1%	0.0%
Shelf break/east side Kodiak	1990	949,901	96,610	10.2%	14.9%	6.2%	78.9%	1.5%	0.6%	8.0%
Total				98.89%				21.39%	68.05%	9.45%
Rescaled total				100.00%				21.63%	68.81%	9.56%

[1]The biomass of age-1 pollock was not included in Shelikof Strait survey biomass in 1995, 2000, and 2005.



	1984	1987	1990	1993	1996	1999	2001	2003	2005	4 survey avg (1999-2005)
Shumagin	33.82%	27.59%	20.03%	46.98%	24.60%	71.81%	40.40%	53.92%	39.70%	51.46%
Chirikof	26.66%	17.38%	22.41%	24.32%	41.37%	8.57%	15.49%	18.09%	17.19%	14.83%
Kodiak	36.90%	52.41%	53.43%	25.49%	32.20%	18.30%	41.49%	25.84%	40.19%	31.45%
West Yak.	2.62%	2.62%	4.13%	3.21%	1.83%	1.32%	2.62%	2.15%	2.92%	2.25%

Figure 1.44. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2005. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.