1. Gulf of Alaska Walleye Pollock

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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: 2006 total catch and catch at age.

2. Shelikof Strait EIT survey: 2007 biomass and length composition.

3. NMFS bottom trawl survey: 2007 biomass and length composition

3. ADF&G crab/groundfish trawl survey: 2007 biomass and length composition, 2006 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 1999-2006 was used again for this year's assessment.

Assessment results

The model estimate of spawning biomass in 2008 is 145,101 t, which is 26% of unfished spawning biomass (assuming average post-1977 recruitment) and below $B_{40\%}$ (221,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. Estimates of 2008 stock status indicate a 7% decline in spawning biomass from 2007. Surveys estimates in 2007 were variable with a 38% drop in the Shelikof Strait EIT survey from 2006, a 20% drop in the NMFS bottom trawl survey from 2005, and an 11% increase for the ADF&G survey from 2006. All spawning aggregations surveyed acoustically in winter of 2007 were low, and the total estimated biomass in Shelikof Strait in 2007 was the lowest on record. Projections indicate that the spawning biomass will be at a minimum in 2008, and will increase in subsequent years. The extent and rate of increase depends on the magnitude of incoming year classes that are highly uncertain. There is evidence that the three year classes from 2004 to 2006 may be near average or above average in abundance. The author's 2008 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 53,590 t, a decrease of 16% from the 2007 ABC, but close to the projected catch in 2007. This recommendation is based on a more conservative alternative to the maximum permissible F_{ABC} introduced in the 2001 SAFE. The OFL in 2008 is 72,110 t. In 2009, the recommended ABC and OFL are 71,580 t and 95,940 t, respectively.

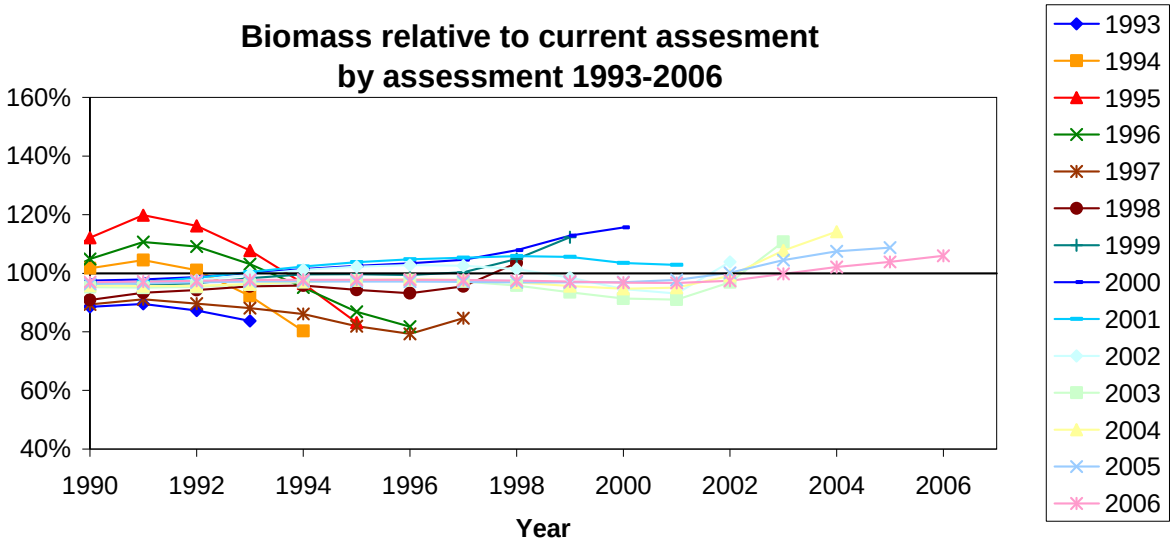
For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendations for 2008 and 2009 in Appendix A are 8,280 t and the OFL is 11,040 t (the same for both years). These recommendations represent an increase of 37% from 2006 and 2007 recommendations due to the higher estimated biomass in the southeast area in the 2007 NMFS bottom trawl survey.

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

From the December, 2006 minutes:

There is an interesting retrospective pattern, in which the female spawning biomass in the last year is generally smaller than in the previous year (see Figure 1.21: it appears to have occurred in 8 of 11 retrospectives). Is there anything in the assessment that might cause this?

There is a pattern, at least since 1999, for the estimated stock size to be somewhat higher in the final year than estimates for the same year in subsequent assessments. It is unclear whether this is indicative of a bias in the assessment, or just random, but autocorrelated, assessment error. For all assessments in the period 1993-1996, estimates of ending year biomass are nearly unbiased compared to the current assessment (Figure below).



This pattern, which does not exceed ±20%, is relatively modest compared to other assessments, both in the North Pacific and in other areas. Management Strategy Evaluations (MSE) of the assessment model suggest that the assessment is slightly biased in the opposite direction, i.e., the model tends to underestimate stock biomass by about 10% on average (A'mar et al. in press). However this evaluation only considered the case where population dynamics correspond to the assumptions of the stock assessment, which suggests that the pattern may be due to an incorrect model assumption. For example, natural mortality may be increasing instead of being constant as is assumed in the model. Simulation/estimation experiments reported in Dorn (2004) demonstrate that a step increase in natural mortality would impart a positive bias to ending year biomass. Ecosystem models of the Gulf of Alaska suggest that pollock natural mortality is increasing due to increased predation (Gaichas 2006). However, under the harvest policies adopted by the North Pacific Council, a higher natural mortality would result in an increase in the harvest rate under a F40% target mortality, an approach that does not seem wise. The assessment authors would appreciate SSC guidance on a way forward.

The SSC shares with the public the desire for better information about spatial abundance by areas and supports development of a comprehensive winter survey.

The MACE group has expanded its survey effort in the Gulf of Alaska. Areas surveyed in 2007 included Morzhovoi Bay, Sanak Trough, Shumagin Islands, Shelikof Strait, the shelf break near Chirikof Islands,

and, for the first time, Marmot Bay. In 2008, there are plans to survey additional areas along the shelf east of the Chirikof Island. While this effort presents a significant increase, it falls short of a comprehensive survey. The exploratory acoustic surveys that are being done in the Gulf of Alaska provide the necessary groundwork for design of a comprehensive survey. The timing of pre-spawning acoustic surveys of pollock is critical, and there is strong evidence of heterogeneity in the timing of peak spawning in different areas of the Gulf of Alaska. It may be logistically impossible for a single vessel to conduct comprehensive winter survey in the GOA. We are also developing capacity to conduct acoustic surveys from fishing vessels equipped with scientific-grade acoustic transducers. A pilot study in October 2007 conducted on the *F/V Temptation*, a limit-seiner based in Sand Point, Alaska, indicated that it was feasible to conduct small-scale surveys and collect high-quality acoustic data using local fishing vessels.

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 apparently occurs between February 15- March 1, while in Shelikof Strait peak spawning occurs later, typically 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 between 2004 and 2006, about 94% of the catch by weight consisted of pollock (Table 1.2). Nominal pollock targets are defined by the dominance of pollock in the catch, and

may include tows where other species were targeted, but caught pollock inadvertently. The most common managed species in the incidental catch are arrowtooth flounder, Pacific cod, flathead sole, Pacific Ocean perch, rex sole, and the shortraker/rougheye rockfish complex. The most common non-target species are eulachon, capelin, squid, grenadiers, and various shark species. Bycatch estimates for prohibited species over the period 2003-2006 are given in Table 1.3.

Kodiak is the major port for pollock in the Gulf of Alaska, with 61% of the 2002-2006 landings. In the western Gulf of Alaska, Sand Point, Dutch Harbor, King Cove, and Akutan are important ports, sharing 38% of 2002-2006 landings. Secondary ports, including Cordova, Seward, and Homer account for the remaining 1% of the 2002-2006 landings.

Since 1992, the Gulf of Alaska pollock TAC has been apportioned spatially and temporally to reduce potential 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 the reference unfished level.

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 and the most recent survey. The FOCI year class prediction (Appendix D) 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 1.4). Catches include the state-managed pollock fishery in Prince William Sound. In 1996-2007, 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 2006 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 2006 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	317	398	300	143
	No. lengths	1488	3840	1047	488
	Catch (t)	12,091	24,037	5,060	3,048
2nd half (C and D seasons)	No. ages	417	128	393	----
	No. lengths	3796	82	3059	----
	Catch (t)	12,647	3,118	11,996	----

In the first half of 2006, the age-6 and age-7 fish (2000 and 1999 year classes respectively) were dominant in all areas except in 630, where age-2 fish (2004 year class) also showed a strong mode. In the second half of 2006, age-6 and age-7 fish were again prominent in all areas, however younger fish (< age-6) were relatively more common in areas 620 and 630 compared to area 610 (Fig. 1.2). Age-1 fish (2005 year class) were present in all areas in the second half of the year, and the catch of age-1 fish was higher than in any previous year.

Fishery catch at age in 1976-2006 is presented in Table 1.5 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.6.

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 1.7). 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 1.8).

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, 2003, 2005 and 2007 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. 2007). 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 tenth comprehensive bottom trawl survey since 1984 during the summer of 2007. 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 2007 gulfwide biomass estimate of pollock was 316,122 t, representing a decrease 17% of from the 2005 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 282,253 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 ages are not yet available for the 2007 survey, size composition estimates were used to fit the assessment model. Size composition by statistical area showed a strong mode of age-1 fish in all areas that became progressively larger from the Chirikof area to the Southeast area, most likely due to seasonal growth during the course of the survey (Fig. 1.5). This pattern has been seen in previous bottom trawl surveys. Additional modes of juvenile pollock are present in the Kodiak area, with a mode centered at 28 cm representing age-2 pollock (2005 year class) and the mode centered at 35 cm representing age-3 pollock (2004 year class). These modes are not as prominent in other areas.

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 2006 are presented in a NMFS processed report (Guttormsen 2007). Biomass estimates using the EK500 echosounder 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. The 2007 biomass estimate for Shelikof Strait is 180,881 t, 293,609 t, a decrease of 38% from the 2005 biomass, and representing the lowest biomass ever estimated in Shelikof Strait (Table 1.7). Biomass ≥43 cm (a proxy for spawning biomass) dropped by 47% from the 2007 estimate due to continued ageing of the relatively strong 1999 and 2000 year classes without significant recruitment of later year classes to the spawning population (Fig. 1.6). The 2007 estimate is not the lowest spawning biomass ever measured, since spawning biomass was lower in 1988, 1989, 2003 and 2004.

Additional EIT surveys in winter 2007 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.

2007 EIT survey results

		Sanak/ Morzhovoi Bay	*Shumagin*	*Shelikof*	*Chirikof Island*	*Marmot Bay*	*Total*
Total	Tons	62,829	20,009	180,881	35,573	3,157	302,448
	Percent	21%	7%	60%	12%	1%	
Biomass ≥43 cm	Tons	62,671	4,620	115,933	35,536	1,342	220,103
	Percent	28%	2%	53%	16%	1%	

In comparison to 2006, biomass estimates are lower in all areas. Declines ranged as follows: Sanak/Morzhovoi—55% drop, Chirikof Island—48% drop, Shumagin—46% drop, and Shelikof Strait—38% drop. A particular concern was the near absence of mature fish in the Shumagin area in 2007. A survey of Marmot Bay was attempted for the first time in 2007, but the patchy distribution of pollock resulted in a highly uncertain biomass estimate, particularly for the mature fish. The total biomass >43 cm, a proxy for spawning biomass, is approximately 68% of the assessment model's estimate of male + female spawning biomass of 325,000 t in 2007. In previous years, the spawning biomass for all winter EIT surveys was similar to the model estimate of total spawning biomass. As this is not the case in winter of 2007, there is increased assessment concern. The survey in the Sanak area found mostly post-spawning fish, indicating that the timing of the survey was not appropriate to assess peak biomass in the area, however the timing of the surveys in other areas was appropriate.

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 1.7). 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 2006 survey, the age-2 fish from the 2004 year class were numerically dominant, but appear as a secondary mode in the biomass distribution by length. Length frequency data were used for the 2007 survey to fit the assessment model because estimates of age composition are unavailable. Size composition in the 2007 consisted of distinct modes of juvenile age-1, age-2, and age-3 pollock, and an additional mode of adult pollock. None of the three modes of juvenile pollock were particularly abundant in a historical context.

Echo Integrated Trawl Survey Age Composition
Estimates of numbers at age from the Shelikof Strait EIT survey (Table 1.10) were obtained from random otolith samples and length frequency samples. Otoliths collected during the 1994 - 2006 EIT surveys were aged using the criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.11.

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 1.7). 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 2007 biomass estimate for pollock for the ADF&G crab/groundfish survey was 76,674 t, up 11% from the 2006 biomass estimate, but very close to the 2005 estimate (3% difference) (Table 1.7).

ADF&G Survey Length Frequency
Pollock length-frequencies for the ADF&G survey in 1989-2002 (excluding 1991 and 1995) typically show a 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.

An annual gulfwide index of pollock abundance was obtained using generalized linear models (GLM). Based on examination of historical survey trawl locations, four index sites were identified (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. A generalized linear model (GLM) was fit 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 a GLM model with Poisson error and a logarithmic link was used (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. A comparison between these proxy biomass estimates by INPFC area and the actual NMFS triennial survey estimates by INPFC area for 1984-99 was used 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, the FPC is not applied to the biomass estimates, but instead include the information about FPC estimate (mean and variance) was used as a likelihood component for relative survey catchability,

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

where q_1 is the catchability of the NMFS bottom trawl survey, q_2 is the catchability of historical 400-mesh eastern trawl surveys, $\hat{F}PC$ 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 1.12). 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 1.12), 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 in 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, each survey time series was standardized 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).

Indices derived from fisheries catch data were also evaluated 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. The percent of old fish increased to a peak in 1997, and has since declined due to weaker recruitment in the 1990s and increases in total mortality (both from fishing and predation). Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch is approximately 17%. An index of catch at age diversity was computed 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 1976-2006 (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 1.13). 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 2007 Shelikof EIT survey age-1 estimate is 54 million (17th in abundance out of 24 surveys), which suggests recruitment for the 2006 year class is unlikely to be above average.

Analytic Approach

Model description

An age-structured model covering the period from 1961 to 2007 (47 yrs) was 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 (1964-2007)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-2006)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-2007)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-2006)	Multinomial	Sample size = 60
Shelikof EIT survey length comp. (2007)	Multinomial	Sample size = 60
NMFS bottom trawl survey age comp. (1984-2005)	Multinomial	Survey-specific sample size = 38-74
NMFS bottom trawl survey length comp. (2007)	Multinomial	Sample size = 60
Egg production biomass (1981-92)	Log-normal	Survey specific CV = 0.10-0.25
ADF&G trawl survey biomass (1989-2007)	Log-normal	CV = 0.25
ADF&G survey age comp. (2000,2002,2004,2006)	Multinomial	Sample size = 10
ADF&G survey length comp. (1989-2007)	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 (1961-1968,2007)	Log-normal	σ_R =1.0

Recruitment

In most years, year-class abundance at age 2 was estimated as a free parameter. A prior constraint was 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 prior constraint was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period (σ_R =1.0). We also used the same constraint for log deviations in recruitment for 1961-68, and in 2007. 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 2006, 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. The NMFS bottom trawl survey catchability was fixed at one in this and previous assessments 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. 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 estimated by 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 1.7). 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. The Shelikof Strait EIT survey time series was split into two periods corresponding to the two acoustic systems, and separate survey catchability coefficients were estimated 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 1.14). 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 recent study evaluated pollock ageing criteria using radiometric methods and found them to be unbiased (Kastelle and Kimura 2006).

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 1961-2007 = 47	Estimated as log deviances from the log mean; recruitment in 1961-68, and 2007 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated in the model
Fishing mortality	Years 1961-2007 = 47	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) = 184	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	122 primary parameters + 184 process error parameters + 2 fixed parameters = 308	

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 a 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 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. Maturity stages in which ovarian development had progressed to the point where ova were distinctly visible were assumed to be mature. Maturity 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 1.15).

Estimates of maturity at age in 2006 from winter EIT surveys were below the long-term average for age 4 and age-5 pollock, but higher than the long-term average for the older ages (Fig. 1.11). Because there did

not appear to be an objective basis for excluding data, the 1983-2006 average maturity at age was used in the assessment. Maturity at age data are not yet available for the 2007 EIT surveys.

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 evaluation

Model fit to age composition data was evaluated using plots of observed and predicted age composition in the fishery (Fig. 1.13), Shelikof Strait EIT survey (Fig. 1.14), and the NMFS trawl survey (Fig. 1.15). Model fits to fishery age composition data are good in most years. In 2003-2006, the fishery tended to see more of the 2000 year class and less of the 1999 year class than expected by the model. The reverse pattern is seen in the Shelikof Strait EIT survey age composition, where 1999 year class is more common than expected by the model and 2000 year class less common. Since the Shelikof Strait EIT survey covers only a portion of winter habitat of juvenile fish, this pattern could be explained by differences in spatial distribution of the two year classes.

Model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 2005) (Figs. 1.16-1.18). General trends in survey time series are fit reasonably well. For example, both the model and all surveys show a declining trend in the 1990s. But since each survey time series shows a different pattern of decline, the model is unable to fit all surveys simultaneously. The ADF&G survey matches the model trend better than any other survey, despite receiving less weight in 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. The fit to the 2007 datum for each survey time series shows some contrast. The 2007 NMFS trawl survey nearly exactly equal to the model prediction, while the Shelikof Strait EIT survey is much lower than the model prediction, and the ADF&G survey is higher. Since the NMFS trawl survey is the most comprehensive survey, the consistency between the NMFS survey and the assessment lends support to assessment results.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.75 (Fig. 1.19). The change in log likelihood is small (about 1.5) 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. These results are similar to previous assessments. Consequently we used a base model with fixed trawl survey catchability of 1.0 to be consistent with recommendations in previous assessments.

Assessment Model Results

Parameter estimates and model output are presented in a series of tables and figures. Estimated survey selectivity and fishery selectivity for different periods given in Table 1.16 (see also Figure 1.20). Table 1.17 gives the estimated population numbers at age for the years 1961-2007. Table 1.18 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1977-2007 (see also Fig. 1.21). Stock size peaked in the early 1980s at approximately 1.3 times the proxy for unfished stock size (B100% = mean 1979-2006 recruitment multiplied by the spawning biomass in the absence of fishing (SPR@F=0)). 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, increased to 37% of unfished in 2006, but dropped to 29% of unfished stock size in 2007.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1996-2007 indicates the current estimated trend in spawning biomass for 1990-2006 is consistent with previous estimates (Fig. 1.22). All time series show a similar pattern of decreasing spawning biomass in the 1990s followed by a period of greater stability in 2000s. Retrospective biases in the assessment are relatively 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. Based on the current assessment using 2007 survey data, the assessments in 2004-2006 may have also overestimated ending year abundance. The estimated 2007 age composition from the current assessment is similar to projected 2007 age composition in the 2006 assessment (Fig. 1.22). The estimate of the age-3 fish (2004 year class) is now smaller, but the estimate of the age-2 fish (2005 year class) is larger. Estimates of all of the older fish are slightly smaller than in the 2006 assessment.

Stock and recruitment

Recruitment of Gulf of Alaska pollock is more variable (CV = 1.07) than Eastern Bering Sea pollock (CV = 0.64). 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. 1.21). Because of high recruitment variability, the mean relationship between spawning biomass and recruitment is not apparent despite good contrast in spawning biomass. Strong and weak year classes have been produced at high and low level of 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. 1.23). However, this pattern of density-dependent survival emerges from strong decadal trends in spawner productivity. These decadal trends in spawner productivity have produced the pattern of increase and decline in the GOA pollock population. The last two decades have been a period of relatively low spawner productivity.

We summarize information on recent year classes in the table below. The 2005 year class was below

average in the 2006 Shelikof Strait EIT survey, but the Shumagin Island EIT survey resulted in an estimate of 1.7 billion age-1 pollock, larger than any previous estimate in this area, and comparable to abundance estimates of strong year classes at age-one in the Shelikof Strait EIT survey. The fishery catch of age-1 fish in 2006 was higher than in any previous year, which also suggests that this year class might be strong. For the 2006 year class, the 2007 Shelikof Strait EIT survey estimate was very low, but the abundance estimate of this year class in the NMFS bottom trawl survey was at record levels. In summary, there is evidence that the three year classes from 2004 to 2006 may be near average or above average in abundance, but at present their magnitude remains highly uncertain.

Year of recruitment	2007	2008	2009
Year class	2005	2006	2007
FOCI prediction	*Average*	*Average*	*Average*
Survey information	2006 Shelikof EIT survey age-1 estimate is 162 million (11th in abundance out of 23 surveys) 2006 Shumagin EIT survey age-1 estimate is 1.7 billion	2007 Shelikof EIT survey age-1 estimate is 54 million (17th in abundance out of 24 surveys) 2007 NMFS bottom trawl estimate is 470 million (1st 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 1.19). Spawning biomass reference levels were based on mean 1979-2006 recruitment (736 million), which is nearly identical to the post-1979 mean in the 2006 assessment. The average did not include the recruitment in 2007 (2005 year class) due to uncertainty in the estimate 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 2002-2006 to estimate current reproductive potential. The SPR at F=0 was estimated as 0.751 kg/recruit. 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). For SPR calculations, we used a selectivity pattern based on an average for 2002-2006 to reflect current selectivity patterns. This represents a change from previous assessments, where a longer period was used to calculate the average, and was chosen because of indications that selectivity has shifted towards younger fish (Fig. 1.20).

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

F_{SPR} rate	Fishing mortality	Equilibrium under average 1979-2005 recruitment				
		Avg. Recr. (Million)	Total 3+ biom. (1000 t)	Female spawning biom. (1000 t)	Catch (1000 t)	Harvest rate
100.0%	0.000	736	1804	552	0	0.0%
50.0%	0.174	736	1170	276	128	11.0%
45.0%	0.203	736	1102	249	141	12.8%
40.0%	0.236	736	1033	221	153	14.8%
35.0%	0.275	736	961	193	166	17.2%

The $B_{40\%}$ estimate of 221,000 is very close to the $B_{40\%}$ estimate of 220,000 t in the 2006 assessment. The model estimate of spawning biomass in 2008 is 145,101 t, which is 26% of unfished spawning biomass and below $B_{40\%}$ (221,000 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).

2008 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 1.20). While there is always some probability of exceeding F_{OFL} due to imprecise stock assessments, it seemed unreasonable to reduce safety margin as the stock declines.

This alternative is given by the following

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

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

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

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

This alternative has the same functional form as the maximum permissible F_{ABC}; the only difference is that it declines linearly from B^* (= $B_{47\%}$) to $0.05B^*$ (Fig. 1.24).

Projections for 2007 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 1.21.

ABC recommendation

There are three major sources of new information about abundance trends in 2007, and they show conflicting trends. The Shelikof Strait EIT survey showed a very steep decrease of 38% from 2006. The NMFS bottom trawl survey showed an 11% annual decline since 2005, while the ADF&G survey biomass increased 11% from 2006. However, there is evidence that the three year classes from 2004 to 2006 may be near average or above average in abundance, and projections indicate that the spawning biomass will be at a minimum in 2008, and will increase in subsequent years. The extent and rate of that increase depends on the magnitude of incoming year classes, which are still highly uncertain. Model estimates of stock status in 2008 are broadly consistent with survey trends and with model projections in previous assessments. In particular, the model achieves a good fit to the biomass estimate from the 2007 NMFS bottom trawl survey, which is the most comprehensive survey.

The primary concern about Gulf of Alaska pollock for the short-term are the steep declines in spawning biomass estimates for Shelikof Strait and other spawning areas in the Gulf of Alaska in 2007. All spawning areas surveyed acoustically in winter of 2007 showed very steep declines, and the total estimated biomass in Shelikof Strait reached a new minimum in 2007. In previous years, concern over the decline in spawning activity in Shelikof Strait was mitigated by the additional winter surveying efforts which in aggregate resulted in an estimate of spawning biomass that was close to the model estimate. In 2007, the aggregate spawning biomass was 68% of the model estimate, so this was not the case in 2007.

Based on these considerations, we used the base model with an adjusted $F_{40\%}$ harvest rate for the author's recommended 2008 ABC of 53,590 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}. These risk-averse elements reduce the recommended ABC to approximately 54% of the model point estimate. In 2009, the ABC based an adjusted $F_{40\%}$ harvest rate is 71,580 t (Table 1.21). The OFL in 2008 is 72,110 t, and the OFL in 2009 if the recommended ABC is taken in 2008 is 95,940 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. 1.25). 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 2007 numbers at age as estimated by the assessment model and remove the 2007 expected catch of 51,244 t (Mary Furuness, Alaska Regional Office, pers. comm. October 22, 2007) from the population. Previous assessments have removed the current year TAC, but in 2007 the catch is projected to be at least 12,000 t below the TAC,

so it was considered important to have this reflected in the projections. 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 1979-2006 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 1.19. 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 2008, 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 the 2003-2007 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 4*: In all future years, F is set equal to $F_{75\%}$. (Rationale: This scenario represents a very conservative harvest rate and was requested by the Regional Office based on public comment.)
>
> *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 2008 and 2009, 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 1.21. Under all harvest policies mean spawning biomass is projected to bottom out in 2008 and then increase (Fig. 1.26). Plots of individual projection runs are highly variable (Fig. 1.27), 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 144,288 t in 2008 for an F_{OFL} harvest rate, which is less than $B_{35\%}$ (194,000 t), but greater than ½ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2018 is 217,636 t, 112% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2010 is 177,313 t, which is less than $B_{35\%}$, but

greater than ½ of $B_{35\%}$. Projected mean spawning biomass in 2020 is 216,877 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. 1.28); 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 1.29). While there is an ontogenetic shift in diet from copepods to larger zooplankton (primarily euphausiids) and fish (Fig. 1.29), 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. 1.29). While indices of stomach fullness exist for these survey years, a more detailed bioenergetics 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. 1.30). 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. 1.31). 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 1.30), 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. 1.32). 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 1.33, 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. 1.33, 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. 1.33 (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. 1.32). 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. 1.34, 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 predator shows a distinct pattern (Fig. 1.34, 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. 1.35, top). Arrowtooth shows an insignificant 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. 1.35, 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. 1.31), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.34 and 1.35 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. 1.28. 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 parameters. 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. 1.36 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. 1.37), 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 1.38), 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. 1.39). 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. 1.39). 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 it's 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

2008 harvests

Maximum permissible ABC:	$F_{40\%\ (adjusted)}$ = 0.15	Yield = 62,610 t
Recommended ABC:	$F_{40\%\ (author's\ adjusted)}$ = 0.13	Yield = 53,590 t
Overfishing (OFL):	$F_{35\%\ (adjusted)}$ = 0.17	Yield = 72,110 t

2009 harvests

Maximum permissible ABC:	$F_{40\%\ (adjusted)}$ = 0.16	Yield = 81,390 t
Recommended ABC:	$F_{40\%\ (author's\ adjusted)}$ = 0.14	Yield = 71,580 t
Overfishing (OFL):	$F_{35\%\ (adjusted)}$ = 0.19	Yield = 95,940 t

Equilibrium female spawning biomass

$B_{100\%}$ = 552,000 t
$B_{40\%}$ = 221,000 t
$B_{35\%}$ = 194,000 t

Projected 2008 biomass

Age 3+ biomass = 705,020 t
Female spawning biomass = 145,100 t

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Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The TAC for 2007 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 (1650 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	75
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	53
2005			80,876	80,876	86,100	72
2006			71,998	71,998	81,300	63
2007					63,800	42
Average (1977-2007)				108,642	123,560	147

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). 1991-2007 -- 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 2004-2006. 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	*2004*	*2005*	*2006*
Pollock	62712.2	80133.5	69752.5
Arrowtooth flounder	1033.7	2282.8	2737.6
Pacific cod	499.7	358.2	707.3
Other (sharks, skates, squid, sculpin, octopus, but excluding skates in 2004)	292.2	870.2	1787.0
Flathead sole	268.3	174.7	593.3
Shortraker and rougheye rockfish	38.5	46.1	94.7
Pacific Ocean perch	60.0	59.5	68.2
Rex sole	35.4	19.6	153.6
Miscellaneous flatfish	18.2	4.7	438.7
Atka mackerel	17.9	3.5	15.2
Sablefish	2.3	3.6	5.6
Dover sole and Greenland turbot	1.7	0.7	11.7
Pelagic shelf rockfish complex	1.5	2.0	9.0
Unidentified skate	1.8	1.1	5.0
Big and longnose skate	1.4	6.3	35.8
Northern rockfish	0.5	0.8	14.5
Other rockfish complex	0.1	1.3	2.5
Thornyheads	0.0	0.3	0.2
Percent non-pollock	*3.5%*	*4.6%*	*8.7%*

Non target species/species group	*2004*	*2005*	*2006*
Squid	139.256	620.461	1514.511
Eulachon	168.260	822.976	392.350
Pacific sleeper shark	119.487	166.099	145.280
Other osmerids	66.030	176.008	165.611
Scyphozoan jellyfish	22.368	210.855	67.690
Giant Grenadier	0.000	44.268	54.268
Other sharks	11.126	30.808	40.937
Salmon shark	13.937	35.182	25.611
Capelin	67.980	2.736	0.103
Spiny dogfish	7.792	13.694	49.332
Miscellaneous fish	13.807	16.378	37.201
Grenadiers	7.636	9.100	18.650
Big skate	0.849	1.687	23.043
Longnose skate	0.330	4.403	12.250
Pandalid shrimp	1.455	7.304	3.085
Other skate	1.700	7.490	2.146
Octopus	0.001	0.058	3.412
Sea star	0.000	1.134	1.987
Large Sculpins	0.066	0.020	1.488
Eelpouts	1.256	0.100	0.000
Other Sculpins	0.000	0.000	0.901
Surf smelt	0.442	0.000	0.000
Sea anemone unidentified	0.110	0.000	0.214
Sea pens whips	0.000	0.253	0.002
Stichaeidae	0.108	0.000	0.072
Lanternfishes (myctophidae)	0.000	0.148	0.012
Birds	0.011	0.006	0.000
Invertebrate unidentified	0.000	0.000	0.004

Table 1.3. Bycatch of prohibited species for trawls in the Gulf of Alaska during 2003-2006 where pollock was the predominant species in the catch. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of fish.

Species/species group	*2003*	*2004*	*2005*	*2006*
Herring (t)	13.130	281.038	12.328	8.637
Halibut (t)	9.943	14.783	2.399	82.065
Bairdi Tanner Crab (nos.)	9	1,284	6	86,259
Red King Crab (nos.)	0	58	0	0
Chinook Salmon (nos.)	4,641	13,423	28,015	14,722
Non-chinook salmon (nos.)	6,423	607	803	1,405

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 1997-2006 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*
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	1,128	1.8%
	Total	23,455	24,661	14,444	226	1,127	0	63,913	
2005	Retained	30,843	27,286	18,986	1,876	740	0	79,731	
	Discarded	130	617	344	4	50	0	1,144	1.4%
	Total	30,973	27,904	19,329	1,880	790	0	80,876	
2006	Retained	24,536	26,409	16,127	1,570	1,475	0	70,116	
	Discarded	203	747	929	2	1	0	1,881	2.6%
	Total	24,738	27,156	17,056	1,572	1,476	0	71,998	
Average (1997-2006)		24,420	26,868	23,054	2,377	1,420	13	78,152	

Table 1.5. 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
2005	1.14	1.21	5.33	6.85	41.25	21.73	6.10	0.74	0.91	0.35	0.18	0.13	0.00	0.00	0.00	85.91
2006	2.20	7.79	4.16	2.75	5.97	27.38	12.80	2.45	0.83	0.46	0.23	0.10	0.07	0.03	0.00	67.22

Table 1.6. Number of aged and measured fish in the Gulf of Alaska pollock fishery used to estimate fishery age composition (1989-2006).

	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
2005	1,065	968	2,033	6,837	6,005	12,842
2006	1,127	969	2,096	7,248	6,178	13,426

Table 1.7. 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° 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° 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
2006		293,609			69,044
2007		180,881	282,253		76,674

Table 1.8. Survey sampling effort and biomass coefficients of variation (CV) for pollock in 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.

				Number aged			*Number measured*		
Year	*No. of tows*	*No. of tows with pollock*	*Survey biomass CV*	*Males*	*Females*	*Total*	*Males*	*Females*	*Total*
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	639	868	1,507	NA	NA	NA
2005	820	554	0.14	NA	NA	NA	NA	NA	NA

Table 1.9. Estimated number at age (000,000s) from the NMFS bottom trawl survey. Estimates are for the Western and Central Gulf of Alaska only (Management areas 610-630).

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
2005	270.37	33.72	34.41	35.86	91.78	78.82	45.24	20.86	9.61	9.98	4.81	0.57	0.64	0.00	0.00	636.68

Table 1.10. Estimated number at age (000,000s) from the echo integration-trawl survey in Shelikof Strait. For the acoustic survey in 1987, when total abundance could not be estimated, the percent at age is given.

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
2006	161.69	835.96	40.75	11.54	17.42	55.98	74.97	32.25	6.90	0.83	0.75	0.53	0.00	0.00	0.00	1,239.57

Table 1.11. Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Shelikof Strait EIT survey. Survey CVs are reported for 1981-91, while relative estimation error using a geostatistical method are reported for 1992-2007.

				Number aged			Number measured		
Year	*No. of midwater tows*	*No. of bottom trawl tows*	*Survey biomass CV*	*Males*	*Females*	*Total*	*Males*	*Females*	*Total*
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
2006	17	2	0.04	295	487	782	NA	NA	NA
2007	9	1	0.06	NA	NA	NA	NA	NA	NA

Table 1.12. 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 1.13. 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	12
1981				
1982		1983	0.001	24
1983		1984	0.062	15
1984		1985	2.092	3
1985		1986	0.579	5
1986				
1987		1988	0.017	22
1988		1989	0.399	6
1989		1990	0.049	20
1990		1991	0.022	21
1991		1992	0.228	9
1992	Strong	1993	0.063	14
1993	Average	1994	0.186	10
1994	Average	1995	10.688	1
1995	Average-Strong	1996	0.061	16
1996	Average	1997	0.070	13
1997	Average	1998	0.395	7
1998	Average			
1999	Average	2000	4.484	2
2000	Average	2001	0.291	8
2001	Average-Strong	2002	0.008	23
2002	Average	2003	0.051	19
2003	Average	2004	0.053	18
2004	Average	2005	1.626	4
2005	Average	2006	0.162	11
2006	Average	2007	0.054	17
2007	Average	2008	---	---

Table 1.14. Ageing error transition matrix used in the Gulf of Alaska pollock assessment model.

		Observed Age									
True Ag	*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 1.15. Maturity at age of female pollock derived from maturity stage data collected during winter EIT surveys in the Gulf of Alaska (1983-2006).

	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
2006	0	31	0	65	1	23	14	29	90	95	136	143	68	69	15	15	6	6	476

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
2006	0.000	0.000	0.043	0.483	0.947	0.951	0.986	1.000	1.000
Average									
All years	0.001	0.021	0.269	0.565	0.813	0.899	0.959	0.984	0.990
1996-2006	0.000	0.007	0.251	0.580	0.838	0.891	0.951	0.993	0.987
2002-2006	0.000	0.011	0.352	0.637	0.805	0.888	0.947	1.000	1.000

Table 1.16. 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)*	*Historical domestic (1985-2001)*	*Recent domestic (2002-2006)*	*EIT survey*	*Bottom trawl survey*	*ADF&G bottom trawl*	*400-mesh eastern trawl 1961-82*
2	0.001	0.041	0.040	0.177	0.999	0.212	0.055	0.120
3	0.021	0.264	0.144	0.414	0.996	0.315	0.131	0.384
4	0.413	0.756	0.398	0.716	0.990	0.461	0.281	0.741
5	1.000	1.000	0.726	0.923	0.971	0.657	0.504	0.929
6	0.944	0.917	0.938	1.000	0.922	0.871	0.727	0.984
7	0.697	0.665	1.000	0.980	0.806	1.000	0.877	0.996
8	0.361	0.337	0.933	0.816	0.595	0.918	0.953	0.999
9	0.133	0.126	0.707	0.470	0.341	0.670	0.987	1.000
10	0.041	0.041	0.315	0.146	0.155	0.419	1.000	1.000

Table 1.17. 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	380	199	122	75	56	39	29	22	17
1962	421	282	148	91	56	41	29	21	28
1963	451	312	209	109	67	41	31	21	37
1964	101	334	231	155	81	50	31	23	43
1965	262	75	247	171	114	60	37	23	49
1966	139	194	55	182	125	83	44	27	53
1967	347	103	144	40	130	89	60	32	59
1968	411	257	76	105	29	93	64	44	67
1969	716	304	190	56	74	21	67	47	82
1970	339	530	225	133	36	48	14	47	94
1971	735	251	392	162	93	25	34	10	104
1972	1,381	544	186	285	115	66	18	25	84
1973	1,051	1,023	402	132	192	78	46	13	81
1974	3,437	778	756	287	89	130	54	33	69
1975	698	2,546	575	535	186	58	88	38	75
1976	441	517	1,864	404	372	130	41	64	83
1977	2,029	326	373	1,295	280	260	92	30	109
1978	2,785	1,501	237	258	884	193	183	67	102
1979	2,562	2,056	1,078	163	177	612	136	132	124
1980	3,607	1,894	1,488	744	112	122	433	98	188
1981	1,830	2,663	1,373	1,043	516	78	86	311	211
1982	444	1,352	1,937	959	717	355	54	62	383
1983	504	326	964	1,346	663	498	251	39	329
1984	211	370	231	652	897	445	344	181	272
1985	488	154	255	145	392	541	283	240	334
1986	1,648	355	106	156	80	211	303	182	418
1987	561	1,204	250	70	98	50	135	210	443
1988	163	413	869	173	46	64	32	90	477
1989	380	120	299	609	116	30	42	21	415
1990	1,635	281	88	214	414	75	19	26	319
1991	1,022	1,208	206	63	147	266	47	12	253
1992	409	755	887	148	44	97	172	30	175
1993	244	301	548	619	99	28	62	111	147
1994	148	179	219	383	412	64	18	40	178
1995	225	109	131	154	259	271	42	12	150
1996	874	166	80	93	106	176	183	28	115
1997	419	647	122	58	66	73	120	125	101
1998	180	309	473	87	39	42	46	75	146
1999	164	131	217	306	52	22	24	26	136
2000	225	121	94	146	189	30	13	14	103
2001	878	166	88	66	95	115	18	8	79
2002	776	641	118	59	42	59	70	11	59
2003	117	566	455	80	39	27	38	45	49
2004	108	85	400	311	54	26	18	25	67
2005	121	76	58	264	204	35	17	12	67
2006	680	87	53	38	165	126	22	11	57
2007	629	497	62	35	23	101	78	14	50
Average	795	581	417	291	197	131	87	59	151

Table 1.18. 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.

						2006 Assessment results			
Year	*3+ total biomass (1,000 t)*	*Female spawn. biom. (1,000 t)*	*Age 2 recruits (million)*	*Catch (t)*	*Harvest rate*	*3+ total biomass*	*Female spawn. biom.*	*Age 2 recruits*	*Harvest rate*
1977	2,170	510	2,029	118,356	5%	2,190	516	2,013	5%
1978	2,336	551	2,785	96,935	4%	2,348	557	2,738	4%
1979	2,842	561	2,562	105,748	4%	2,837	566	2,495	4%
1980	3,322	620	3,606	114,622	3%	3,293	622	3,498	3%
1981	3,998	505	1,830	147,744	4%	3,933	503	1,776	4%
1982	4,131	579	444	168,740	4%	4,048	572	431	4%
1983	3,491	707	504	215,608	6%	3,410	693	491	6%
1984	2,826	738	211	307,401	11%	2,753	719	207	11%
1985	2,097	667	487	284,826	14%	2,036	647	480	14%
1986	1,695	544	1,647	87,809	5%	1,638	524	1,625	5%
1987	1,757	458	561	69,751	4%	1,704	440	556	4%
1988	1,658	416	163	65,739	4%	1,611	400	161	4%
1989	1,504	403	380	78,392	5%	1,461	389	377	5%
1990	1,282	362	1,633	90,744	7%	1,247	350	1,614	7%
1991	1,397	343	1,021	100,488	7%	1,365	332	1,008	7%
1992	1,713	304	408	90,857	5%	1,680	295	403	5%
1993	1,554	340	243	108,908	7%	1,524	331	240	7%
1994	1,304	388	148	107,335	8%	1,278	379	146	8%
1995	1,097	354	225	72,618	7%	1,074	346	221	7%
1996	909	319	873	51,263	6%	890	312	858	6%
1997	929	276	418	90,130	10%	910	269	409	10%
1998	854	211	179	125,098	15%	834	205	176	15%
1999	694	193	164	95,590	14%	675	188	161	14%
2000	615	182	225	73,080	12%	597	176	234	12%
2001	585	179	874	72,076	12%	571	172	946	13%
2002	724	152	773	51,937	7%	737	146	784	7%
2003	863	144	117	50,666	6%	881	141	141	6%
2004	761	156	107	63,913	8%	787	157	157	8%
2005	641	196	120	80,876	13%	677	201	146	12%
2006	498	204	676	71,998	14%	543	212	1,331	13%
2007	558	163	629						
Average									
1977-2007	1,639		840	108,642	8%	1,651	379	861	8%
1979-2006			736						

Table 1.19. 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 2001-2005. Proportion mature females is the average for 1983-2006 from winter EIT survey specimen data. Spawning weight at age is the average for the Shelikof Strait EIT survey in 2002-2006.

			Weight at age (kg)			
Age	*Natural mortality*	*Fishery selectivity (Avg. 2002-2006)*	*Spawning (March 15)*	*Population (June-Aug.)*	*Fishery (Avg. 2002-2006)*	*Proportion mature females*
2	0.3	0.177	0.080	0.158	0.296	0.001
3	0.3	0.414	0.230	0.420	0.509	0.021
4	0.3	0.716	0.394	0.638	0.721	0.269
5	0.3	0.923	0.626	0.838	0.905	0.565
6	0.3	1.000	0.870	0.972	1.043	0.813
7	0.3	0.980	1.126	1.119	1.135	0.899
8	0.3	0.816	1.257	1.280	1.324	0.959
9	0.3	0.470	1.454	1.329	1.404	0.984
10+	0.3	0.146	1.676	1.523	1.621	0.990

Table 1.20. Methods used to assess Gulf of Alaska pollock, 1977-2006. 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 1990-2006 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)*
1977-81	Survey biomass, CPUE trends, M=0.4	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
2005	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	224,000
2006	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	220,000

Table 1.21. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2007-2020 under different harvest policies. All projections begin with estimated age composition in 2007 using base run model, and a projected 2007 catch of 51,244 t. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 553,000, 221,000, and 194,000 t, respectively.

Spawning biomass (t)	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2007	155,319	155,319	155,319	155,319	155,319	155,319	155,319
2008	144,707	145,101	144,532	146,126	147,365	144,288	144,707
2009	156,037	158,547	155,159	165,527	174,058	153,416	156,037
2010	178,028	183,221	178,030	200,261	219,597	172,708	177,313
2011	196,834	204,840	201,616	238,707	272,786	188,355	192,053
2012	210,336	219,990	223,012	276,009	327,138	198,673	201,183
2013	221,090	231,344	242,346	310,902	379,751	206,589	208,111
2014	228,818	239,146	257,966	340,518	425,973	211,999	212,872
2015	231,927	241,965	267,651	361,147	460,062	213,495	213,975
2016	233,519	243,169	274,391	376,001	485,259	214,051	214,312
2017	235,724	244,987	280,512	387,994	504,837	215,537	215,670
2018	238,425	247,401	286,479	398,694	521,533	217,636	217,698
2019	239,226	247,964	289,926	405,821	533,302	217,956	217,984
2020	238,390	246,928	290,875	409,270	540,080	216,864	216,877

Fishing mortality	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2007	0.14	0.14	0.14	0.14	0	0.14	0.14
2008	0.15	0.13	0.16	0.07	0	0.17	0.15
2009	0.16	0.14	0.16	0.07	0	0.19	0.16
2010	0.19	0.16	0.16	0.07	0	0.21	0.22
2011	0.20	0.18	0.16	0.07	0	0.22	0.23
2012	0.20	0.19	0.16	0.07	0	0.22	0.23
2013	0.20	0.19	0.16	0.07	0	0.23	0.23
2014	0.21	0.19	0.16	0.07	0	0.23	0.23
2015	0.21	0.20	0.16	0.07	0	0.23	0.23
2016	0.21	0.20	0.16	0.07	0	0.23	0.23
2017	0.21	0.20	0.16	0.07	0	0.23	0.23
2018	0.21	0.20	0.16	0.07	0	0.23	0.23
2019	0.21	0.20	0.16	0.07	0	0.23	0.23
2020	0.21	0.20	0.16	0.07	0	0.23	0.23

Catch (t)	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2007	51,244	51,244	51,244	51,244	51,244	51,244	51,244
2008	62,608	53,589	66,592	29,719	0	72,111	62,608
2009	81,393	71,583	79,546	37,231	0	91,227	81,393
2010	112,369	102,263	94,796	46,180	0	123,320	128,903
2011	134,461	128,076	108,000	54,327	0	146,118	149,644
2012	144,696	140,772	117,071	60,317	0	156,036	157,852
2013	148,457	145,433	120,912	63,233	0	159,415	160,136
2014	148,700	145,713	121,719	64,193	0	159,034	159,244
2015	148,750	145,408	122,025	64,601	0	158,768	158,772
2016	149,677	146,399	122,885	65,081	0	159,922	159,872
2017	150,592	147,147	123,638	65,510	0	160,823	160,786
2018	150,785	147,276	123,629	65,600	0	160,929	160,901
2019	149,063	145,521	122,860	65,359	0	158,963	158,945
2020	147,445	143,996	121,836	64,966	0	157,093	157,083

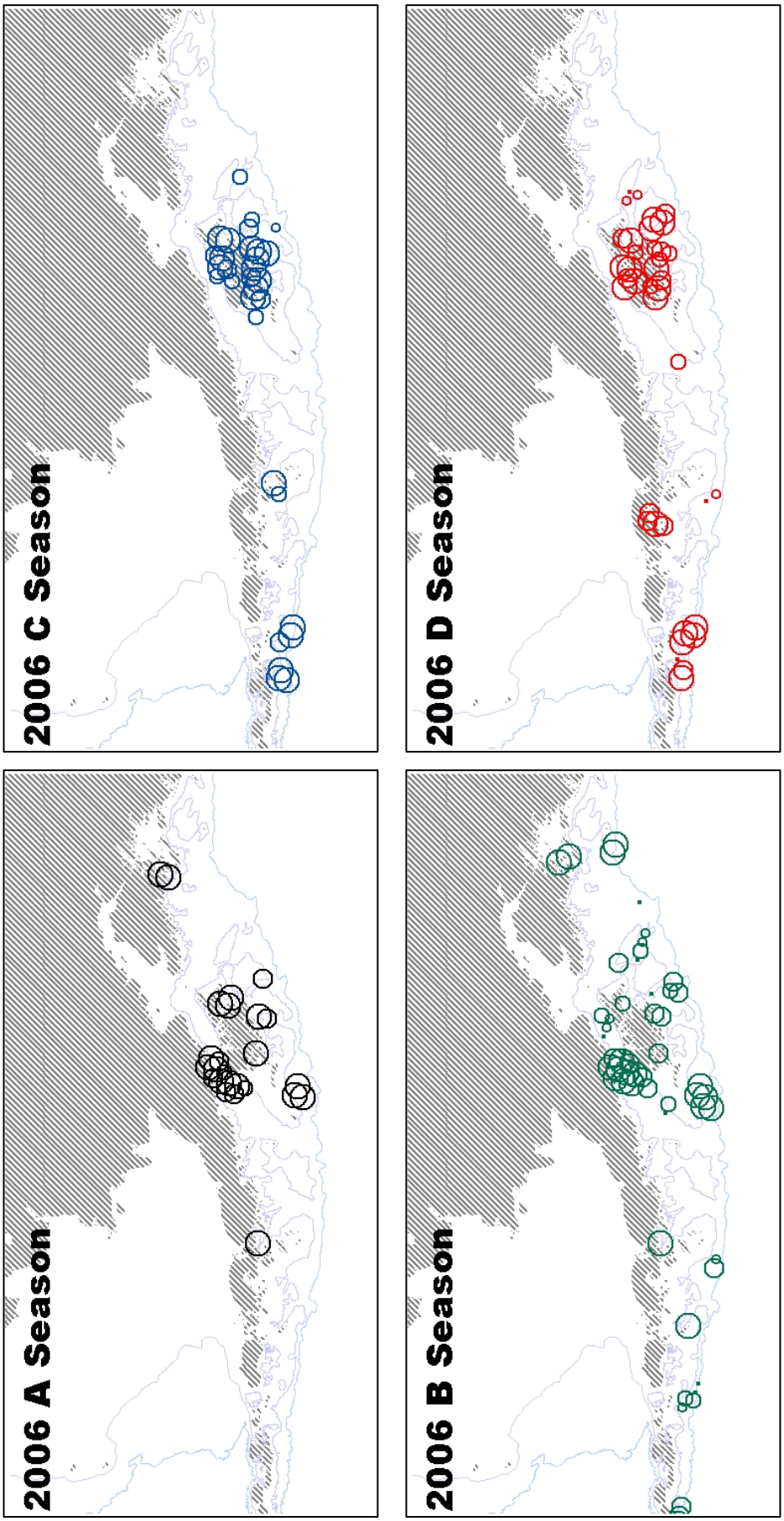


Figure 1.1 Pollock catch in 2006 by 20 X 20 km blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

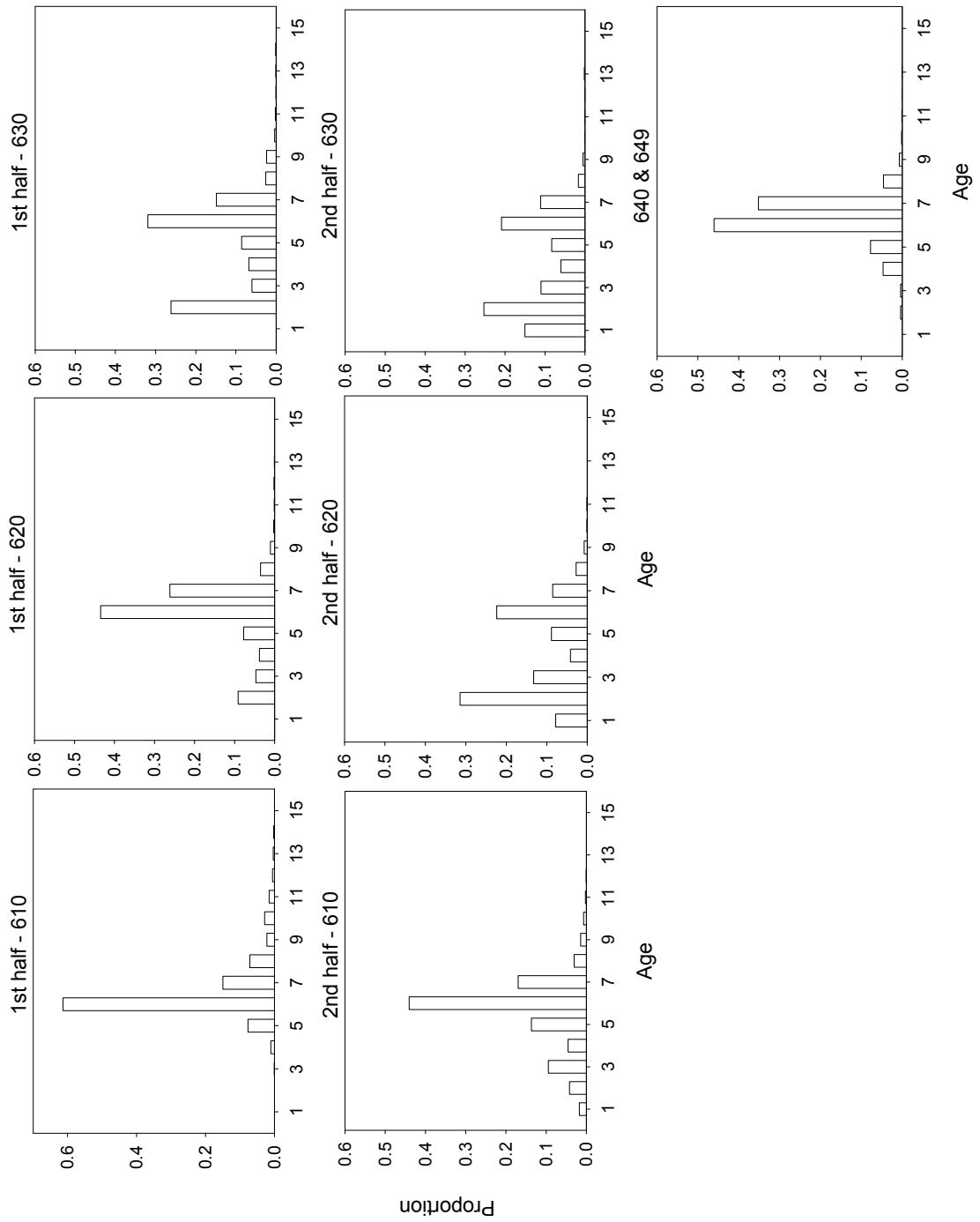


Figure 1.2. 2006 catch age composition by half year and statistical area.

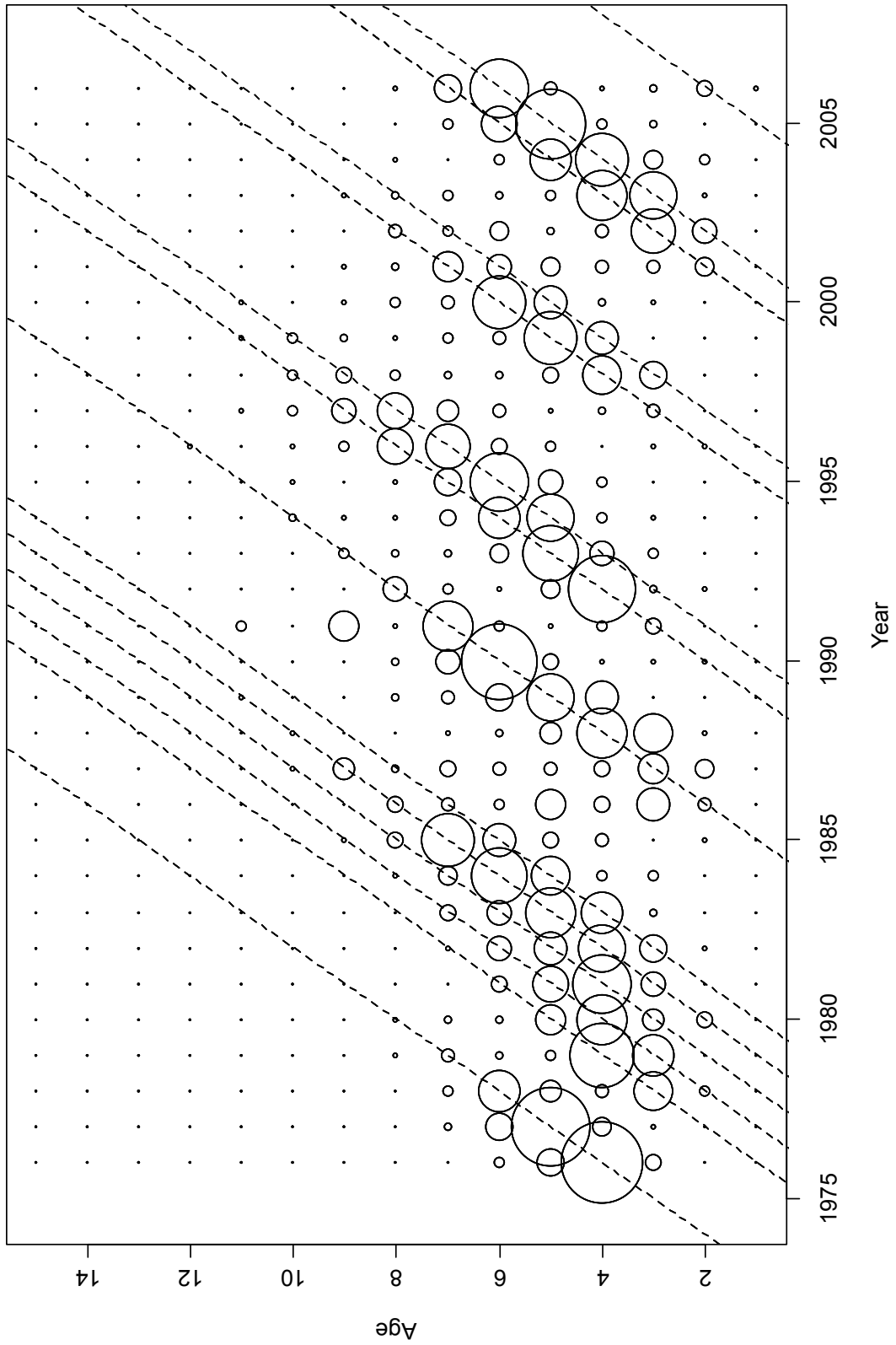


Figure 1.3. Gulf of Alaska pollock catch age composition (1976-2006). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, 1995, 1999, 2000, and 2004).

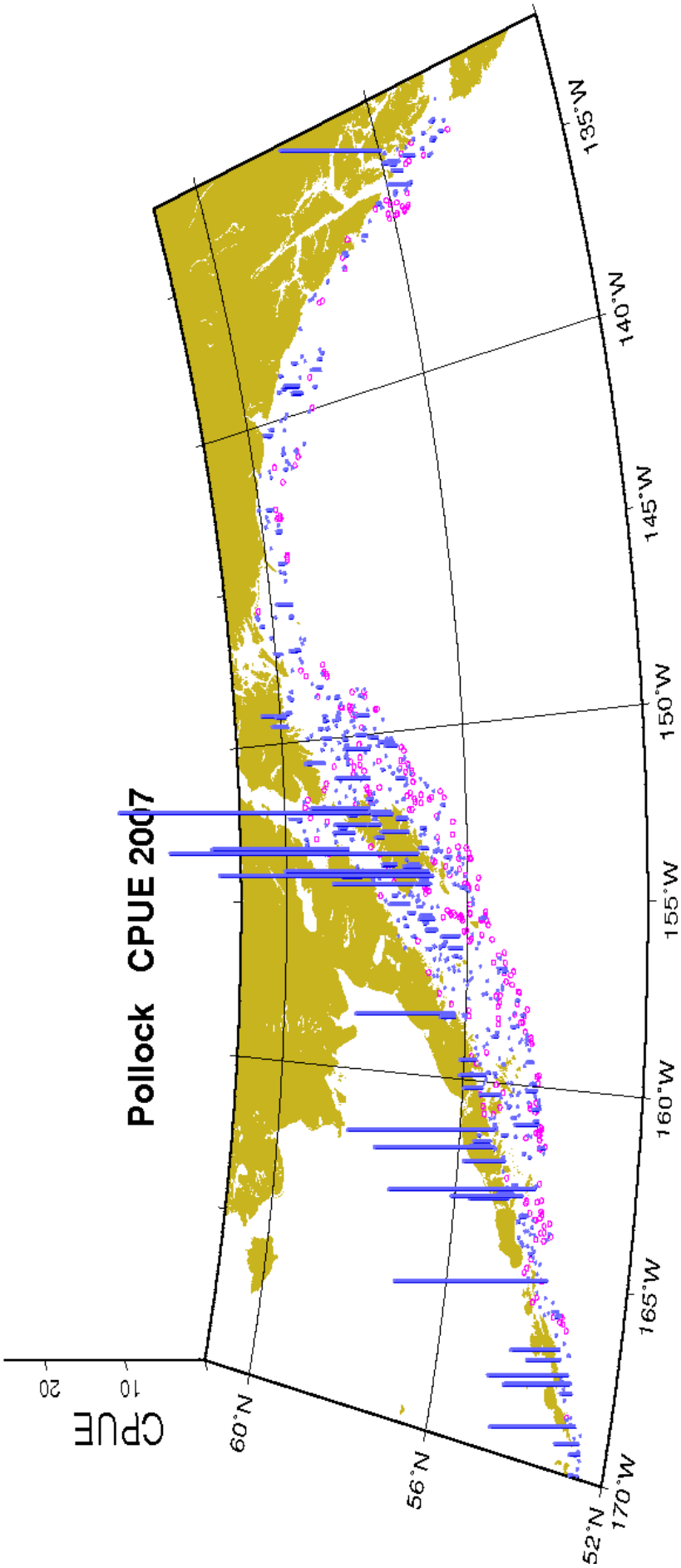


Figure 1.4. Pollock CPUE for the 2007 NMFS bottom trawl survey.

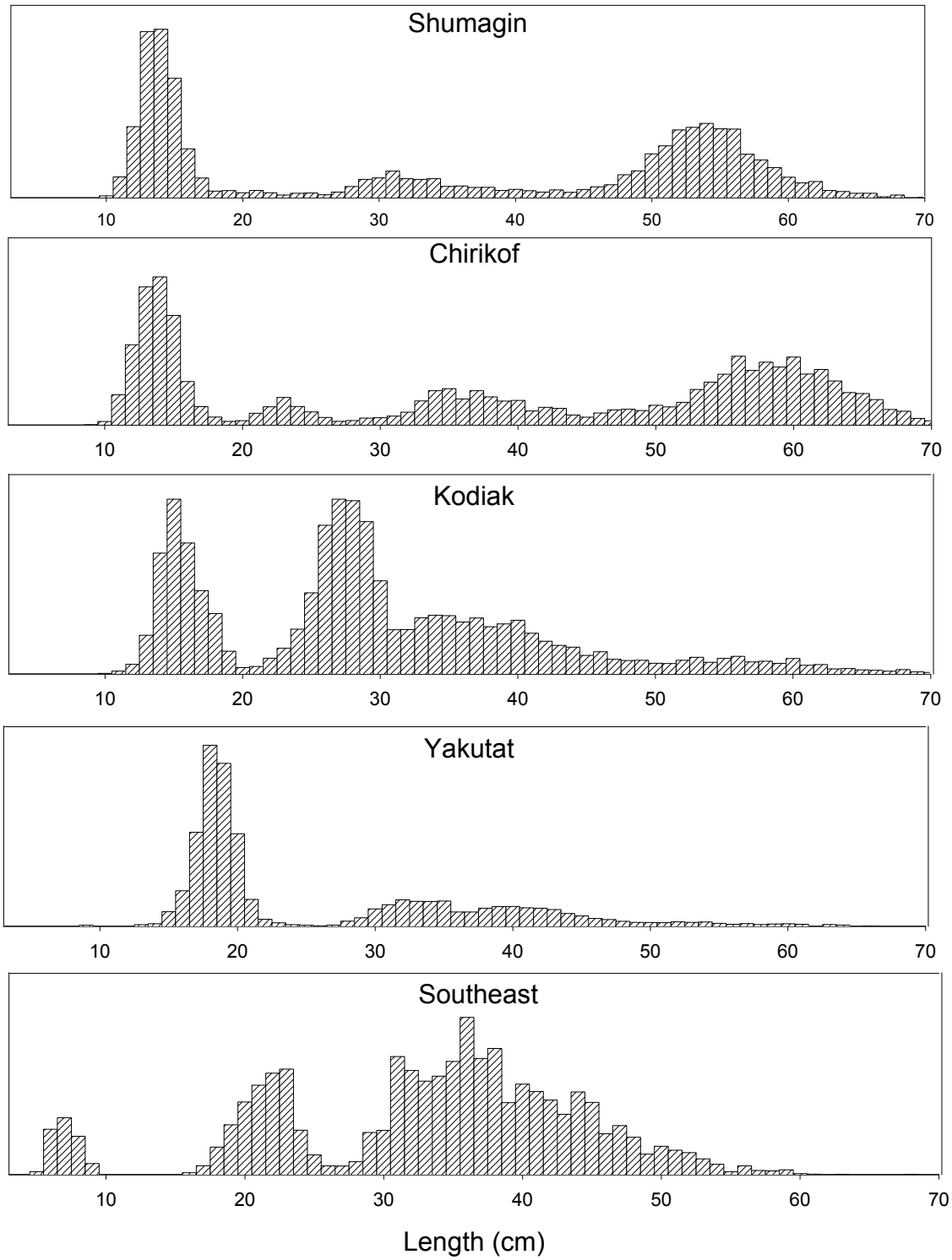


Figure 1.5. Size composition of pollock by statistical area for the 2007 NMFS bottom trawl survey.

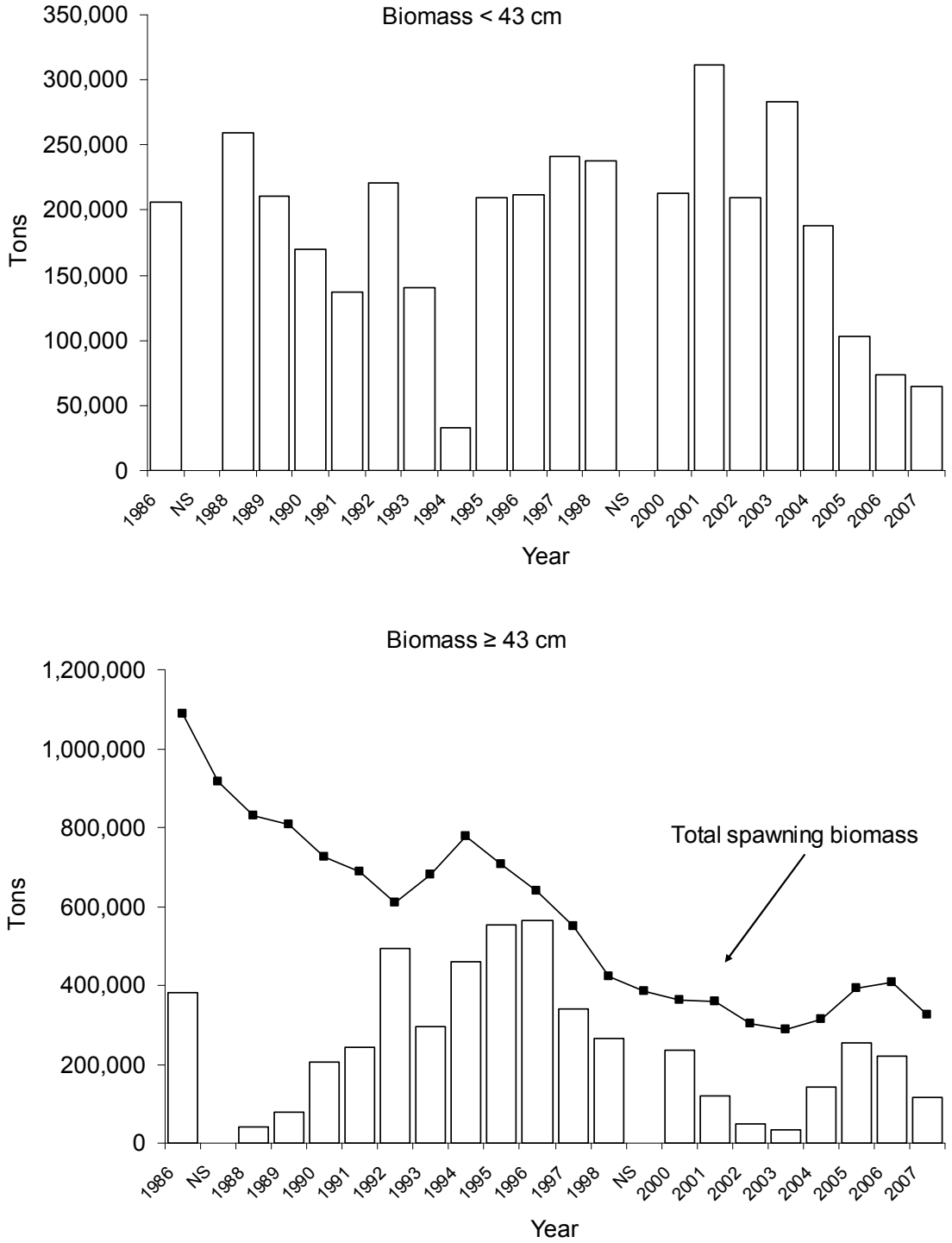


Figure 1.6. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2007 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

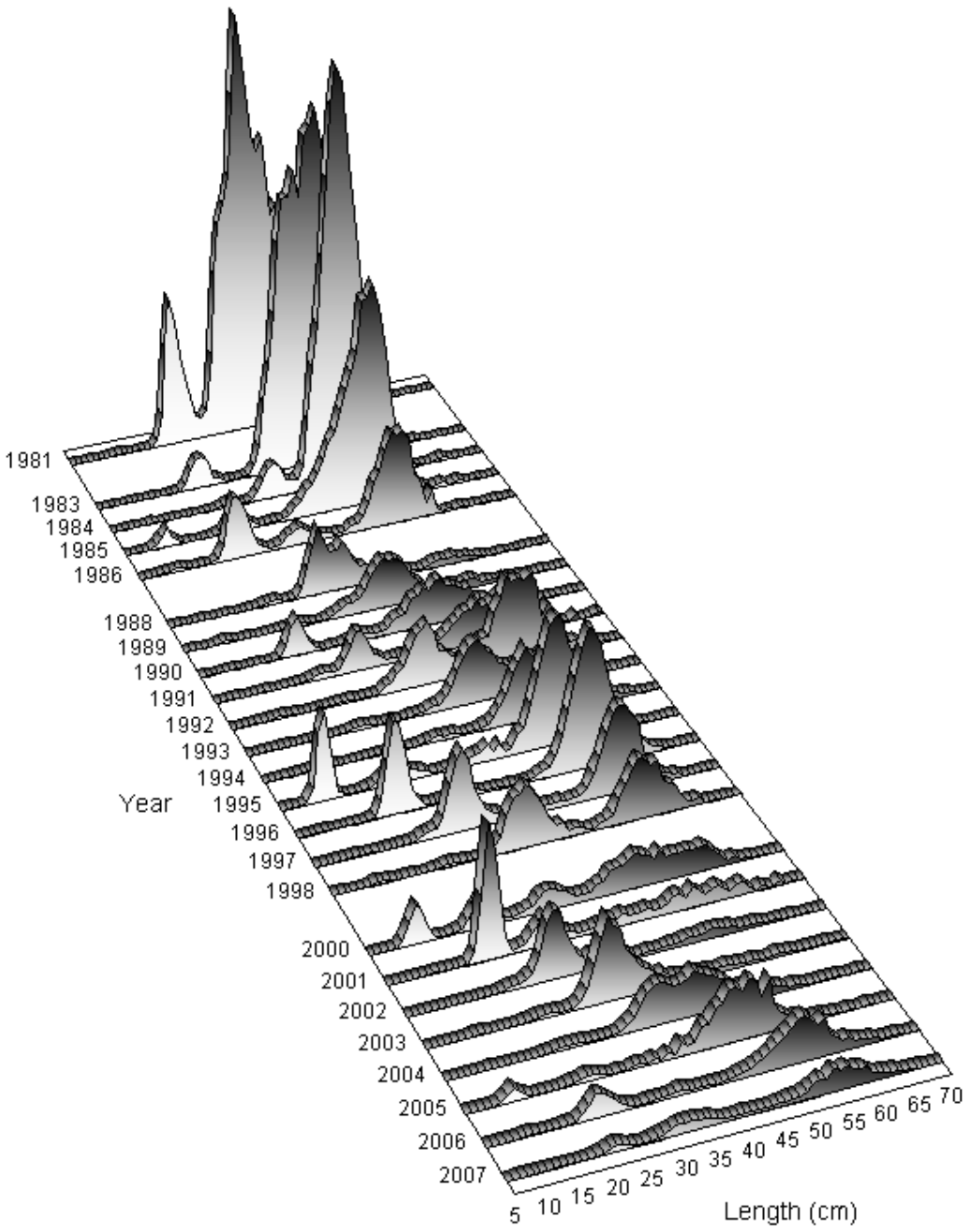


Figure 1.7. Biomass by length for pollock in the Shelikof Strait EIT survey (1981-2007, except 1982,1987 and 1999).

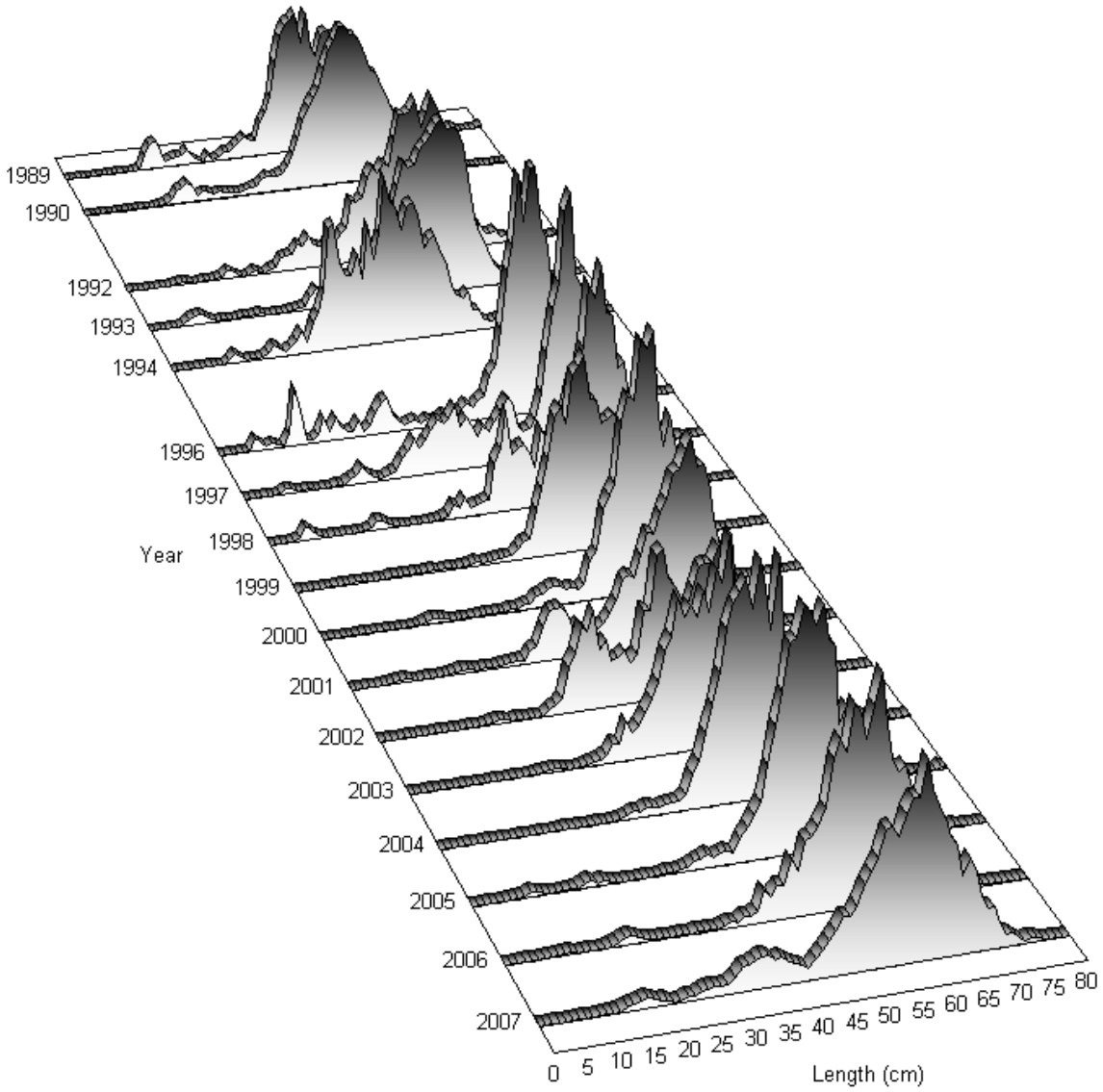


Figure 1.8. Length frequency of pollock in the ADF&G crab/groundfish trawl survey (1989-2007, except 1991 and 1995).

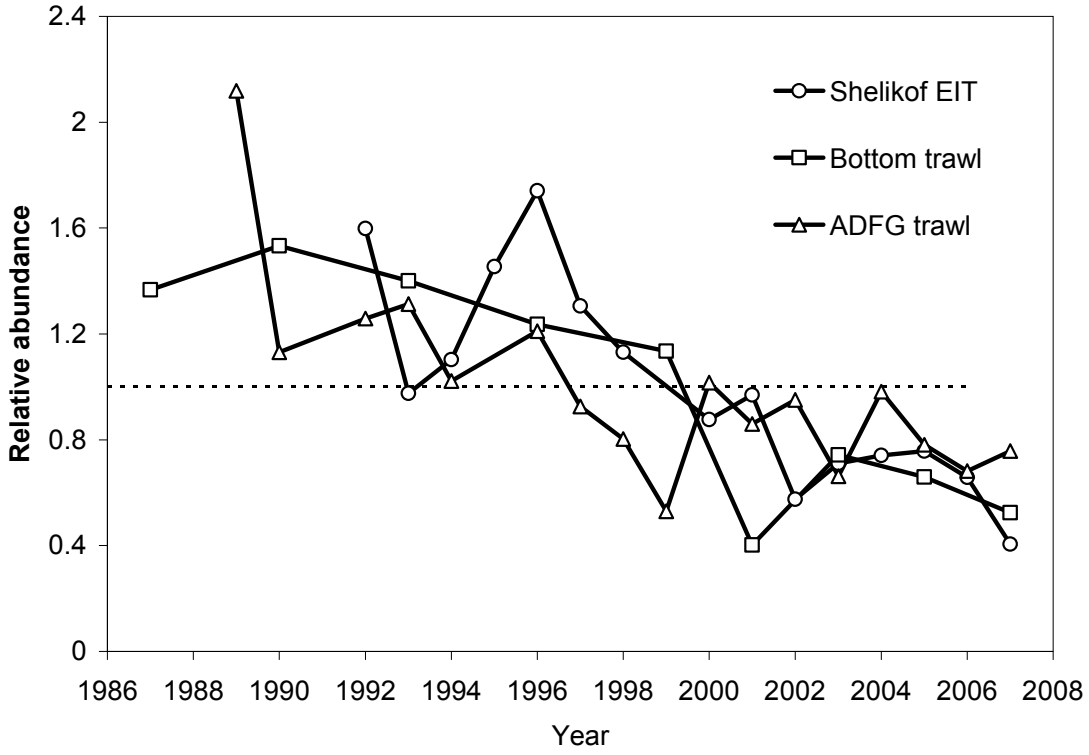


Figure 1.9. Relative trends in pollock biomass since 1987 for the Shelikof Strait EIT survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987.

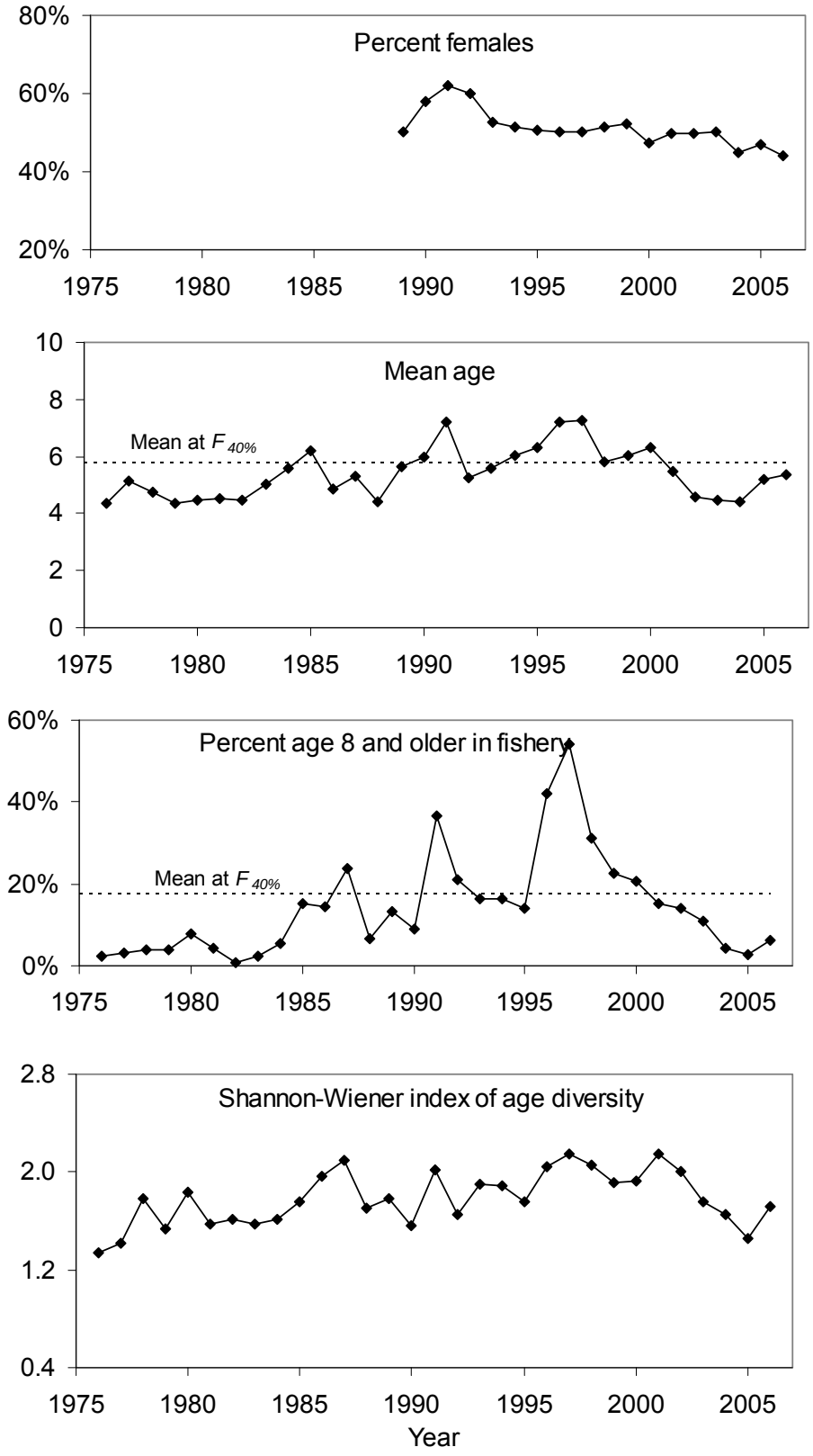


Figure 1.10. Gulf of Alaska pollock catch characteristics.

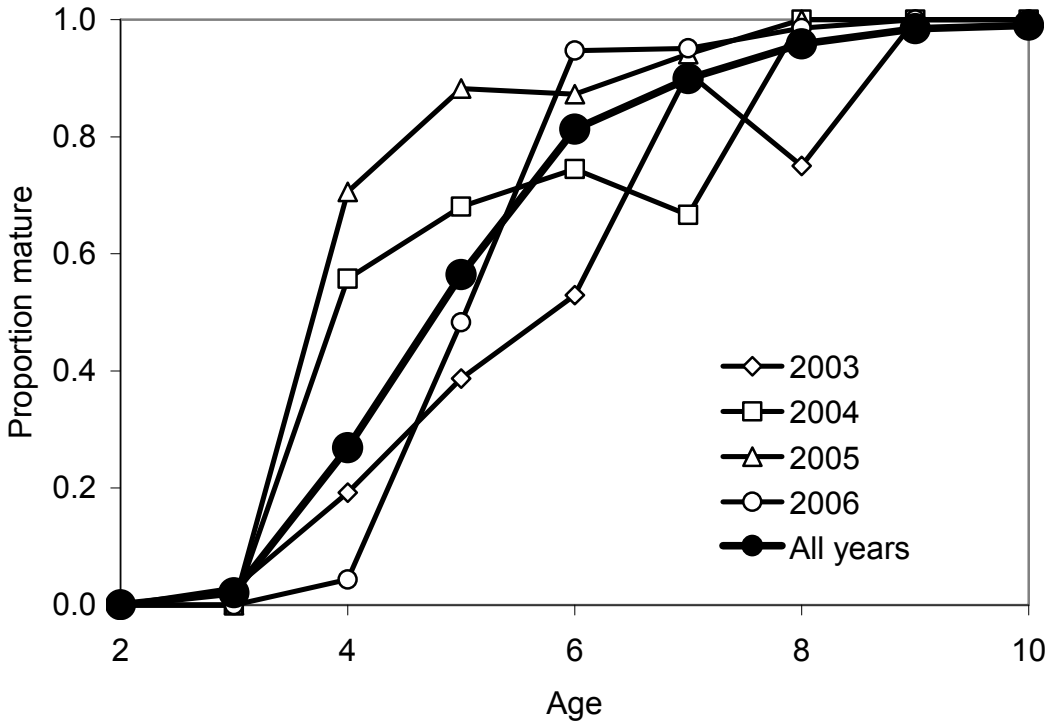


Figure 1.11. Estimates of the proportion mature at age from visual maturity data collected during 2003-2006 winter EIT surveys in the Gulf of Alaska.

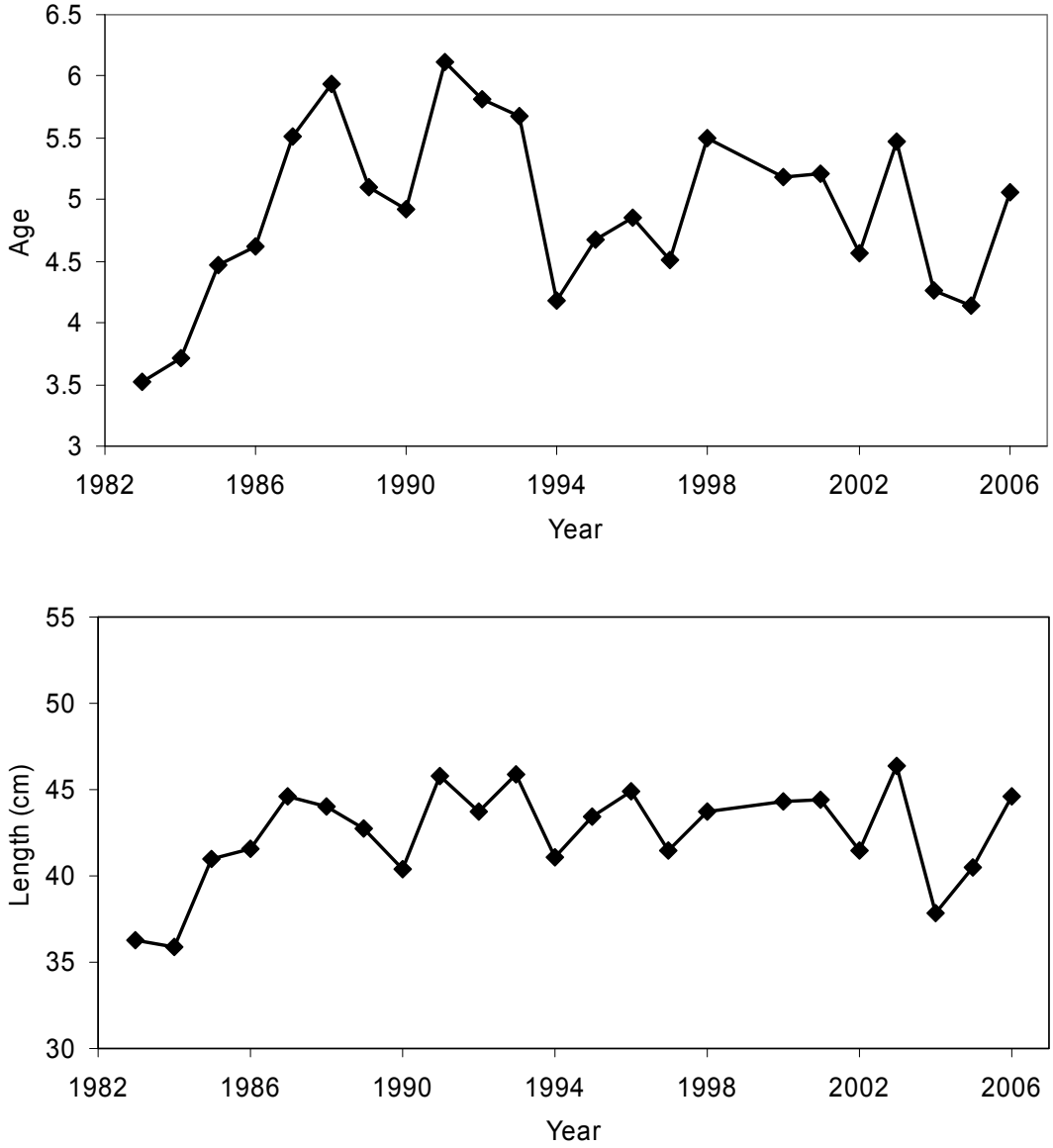


Figure 1.12. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2006.

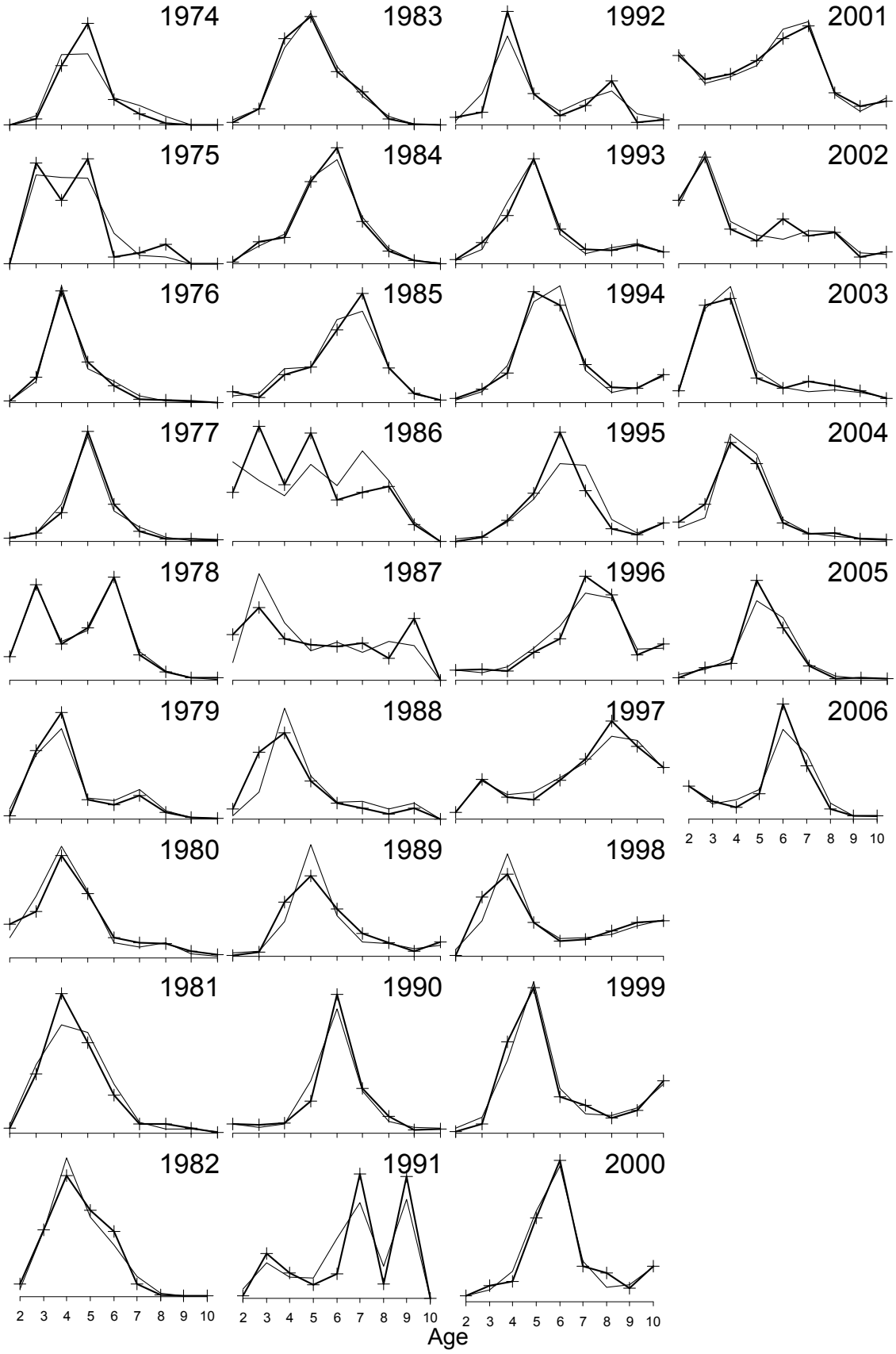


Figure 1.13. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

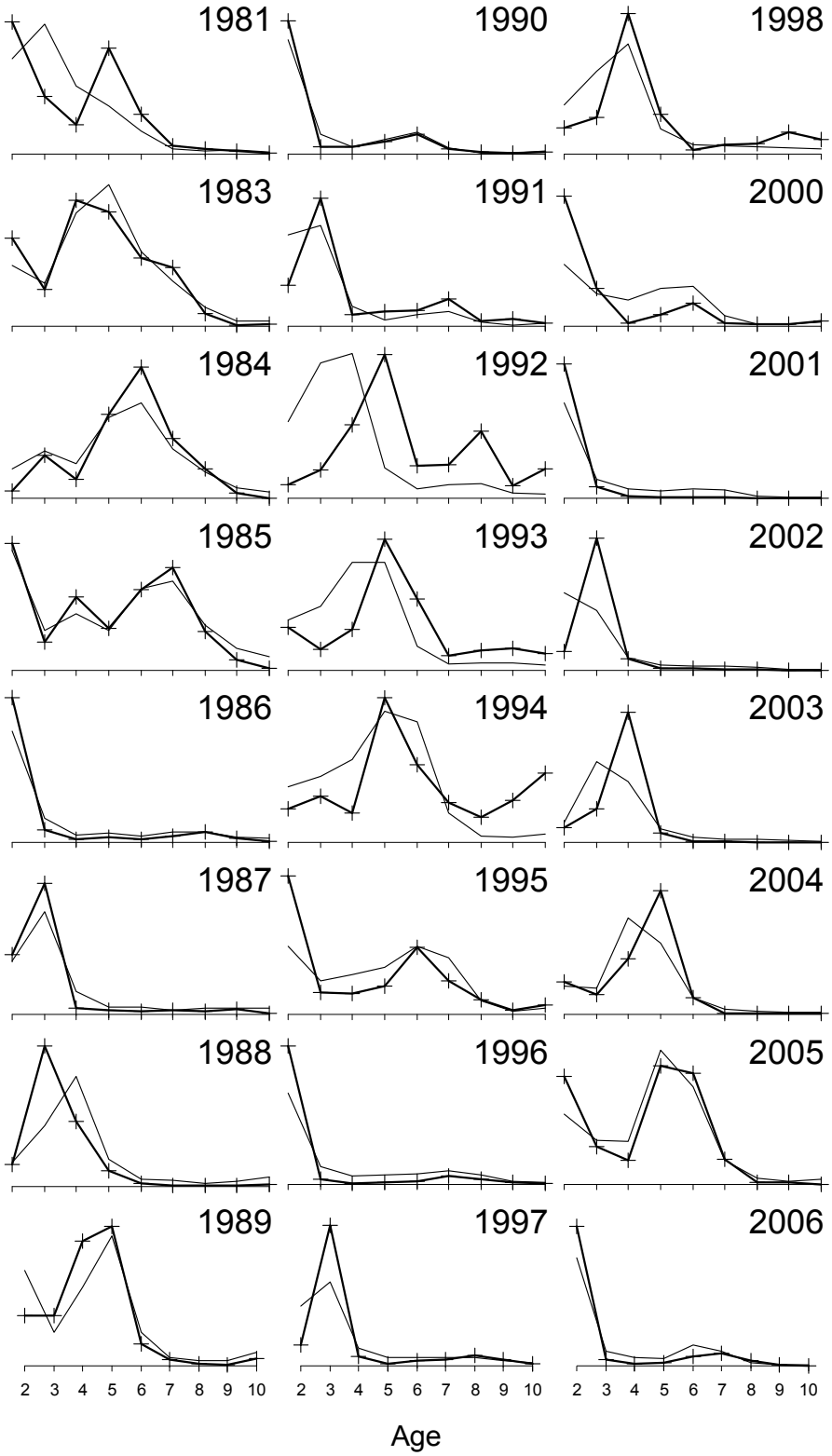


Figure 1.14. Observed and predicted Shelikof Strait EIT survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

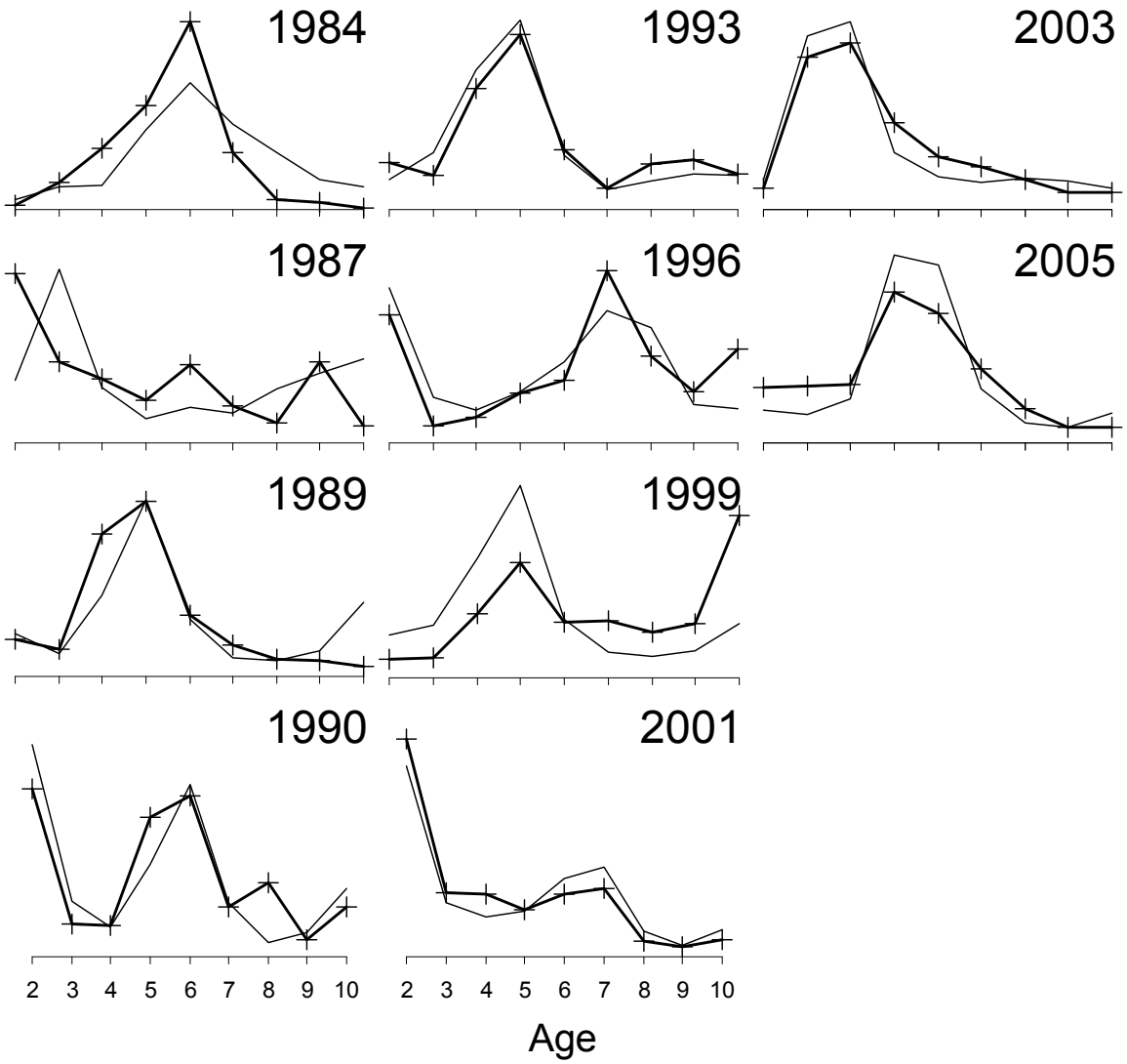


Figure 1.15. Observed and predicted NMFS bottom trawl age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

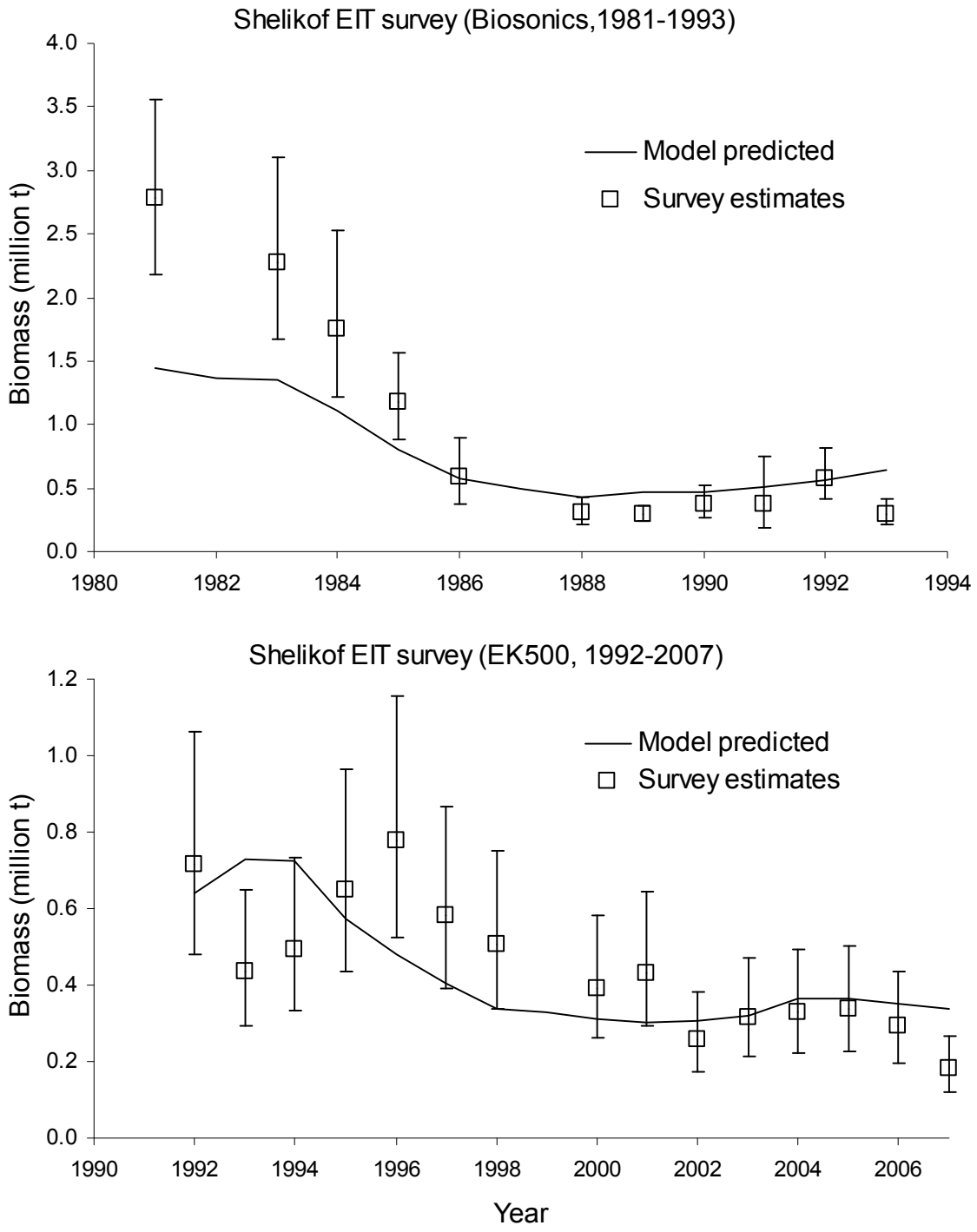


Figure 1.16. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with two catchability periods corresponding to the two acoustic systems used for the survey. Error bars indicate plus and minus two standard deviations.

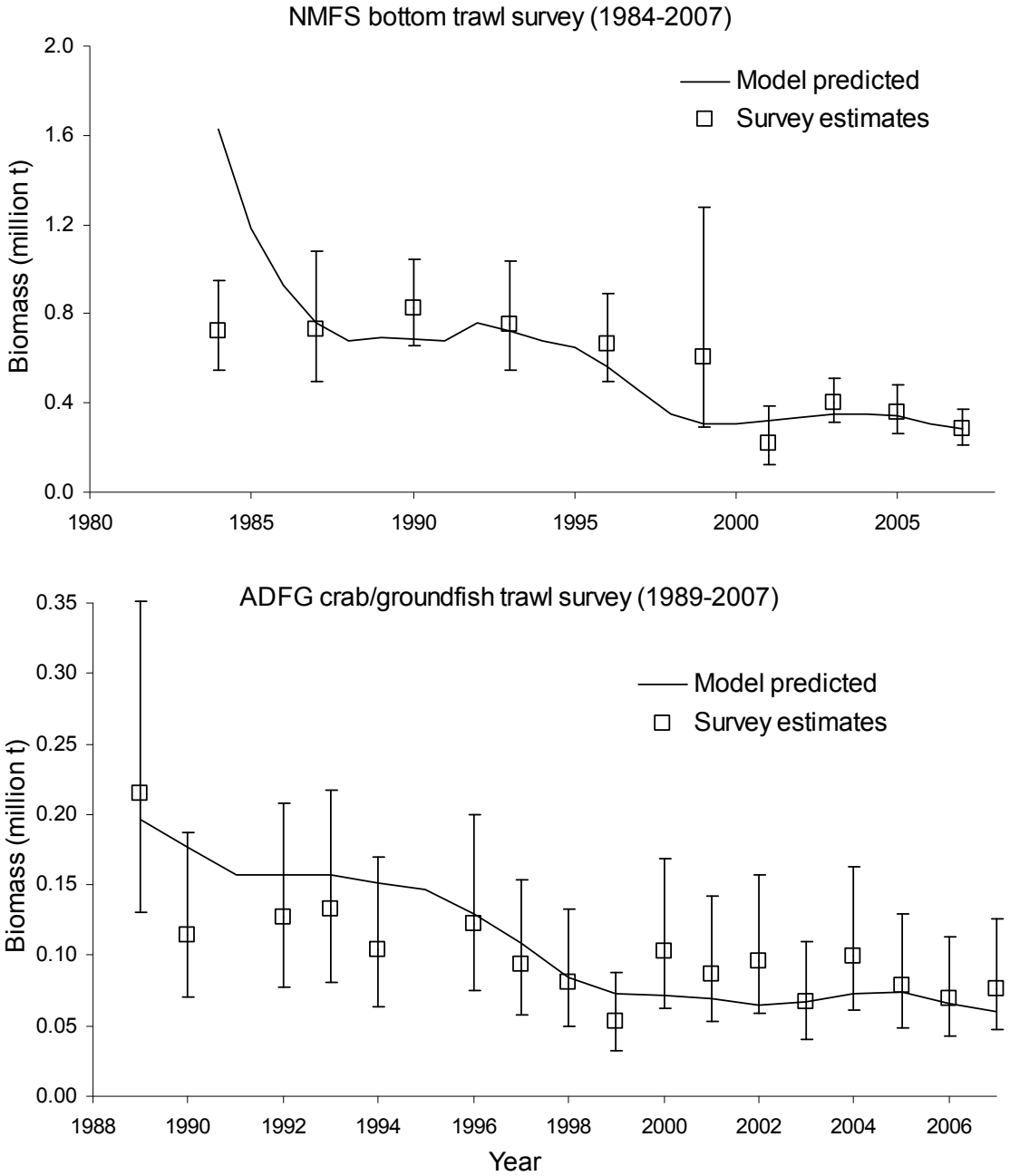


Figure 1.17. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.

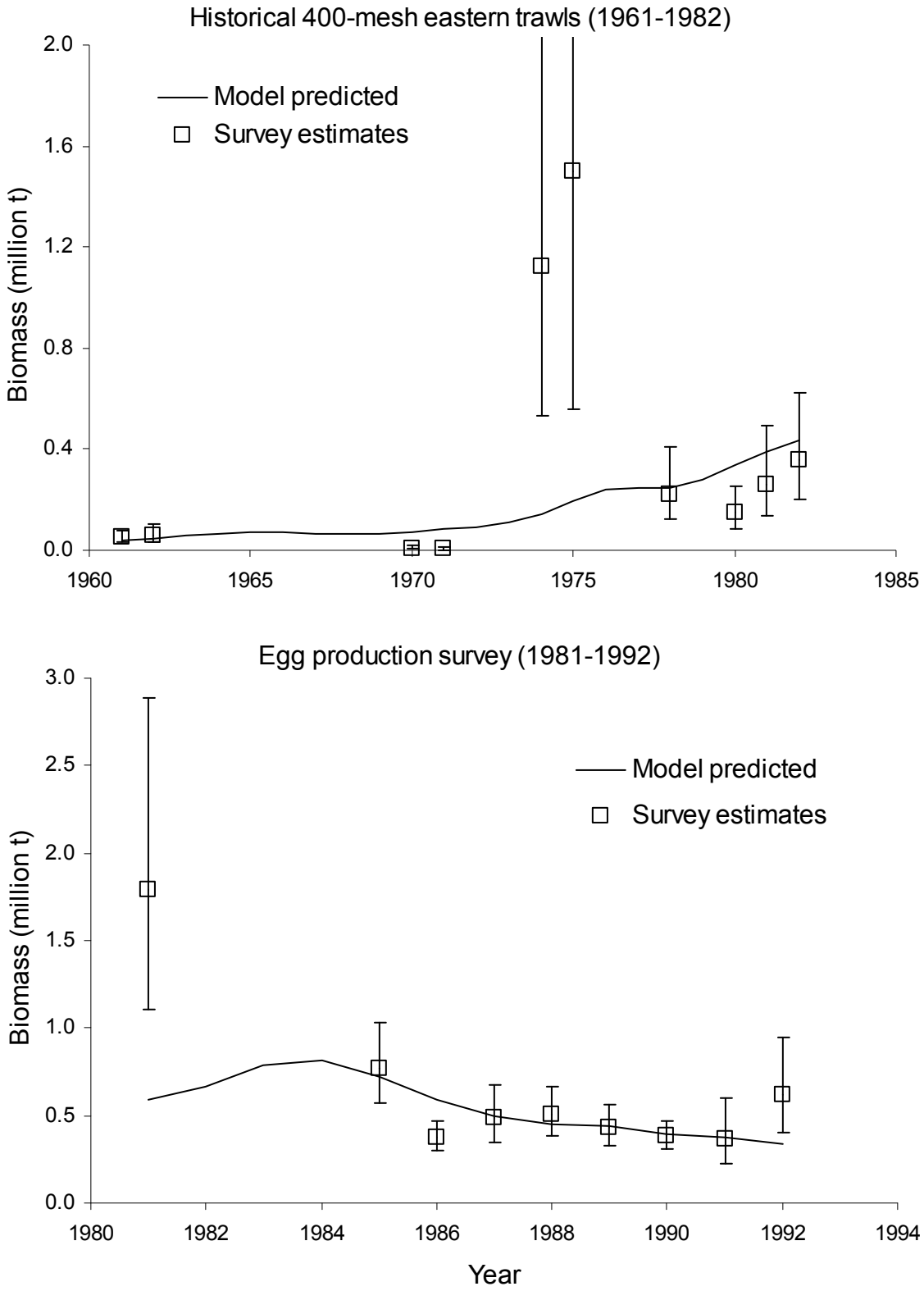


Figure 1.18. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top), and the egg production survey (bottom). Error bars indicate plus and minus two standard deviations.

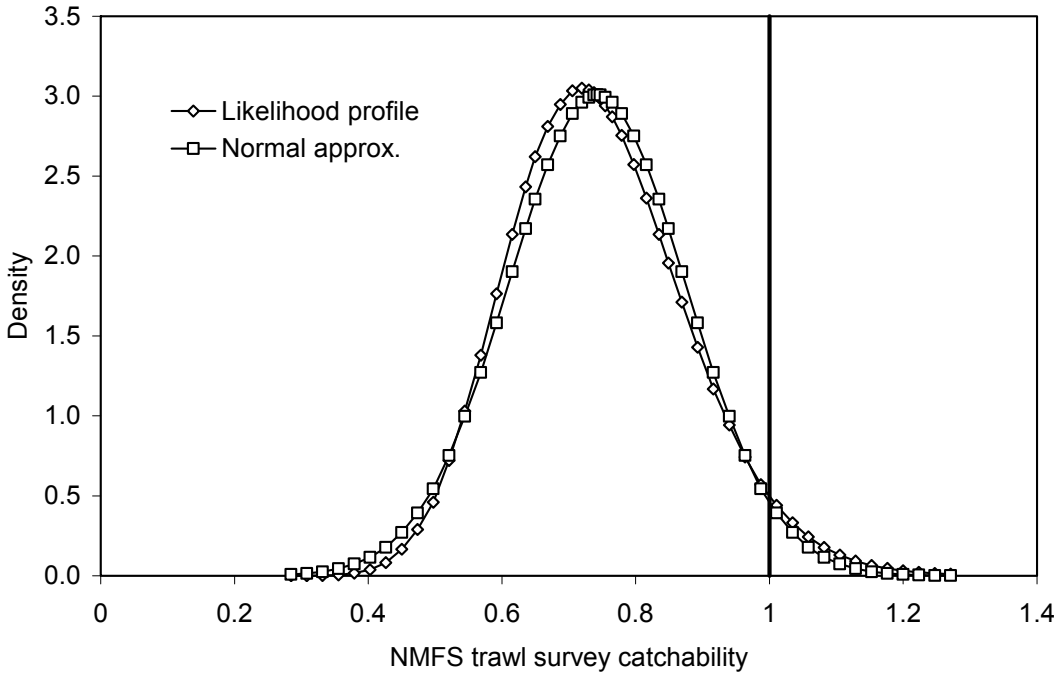


Figure 1.19. Uncertainty in the catchability coefficient for the NMFS trawl survey from a likelihood profile for Model 1.

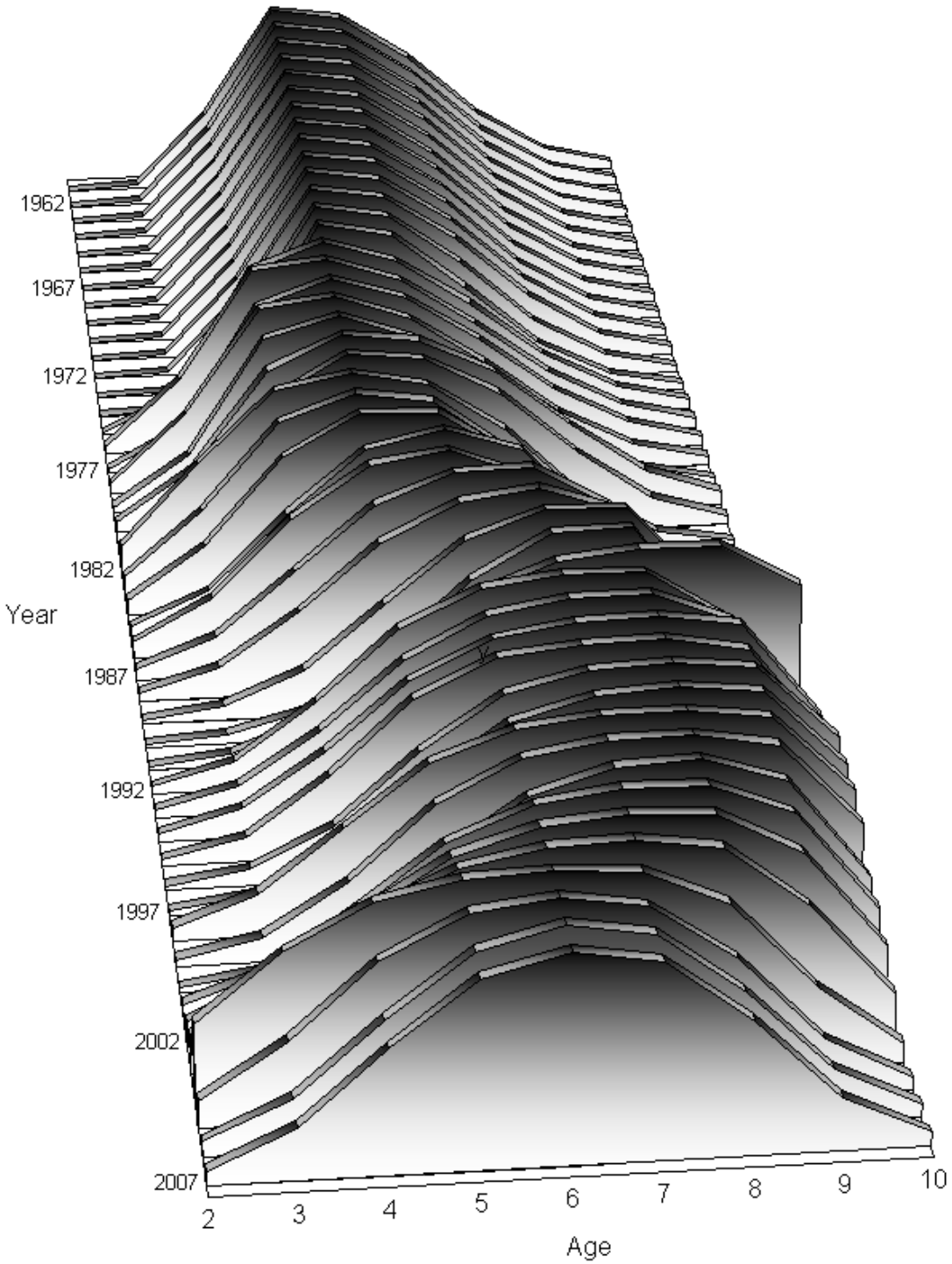


Figure 1.20. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock. The maximum selectivity in each year is 1.0.

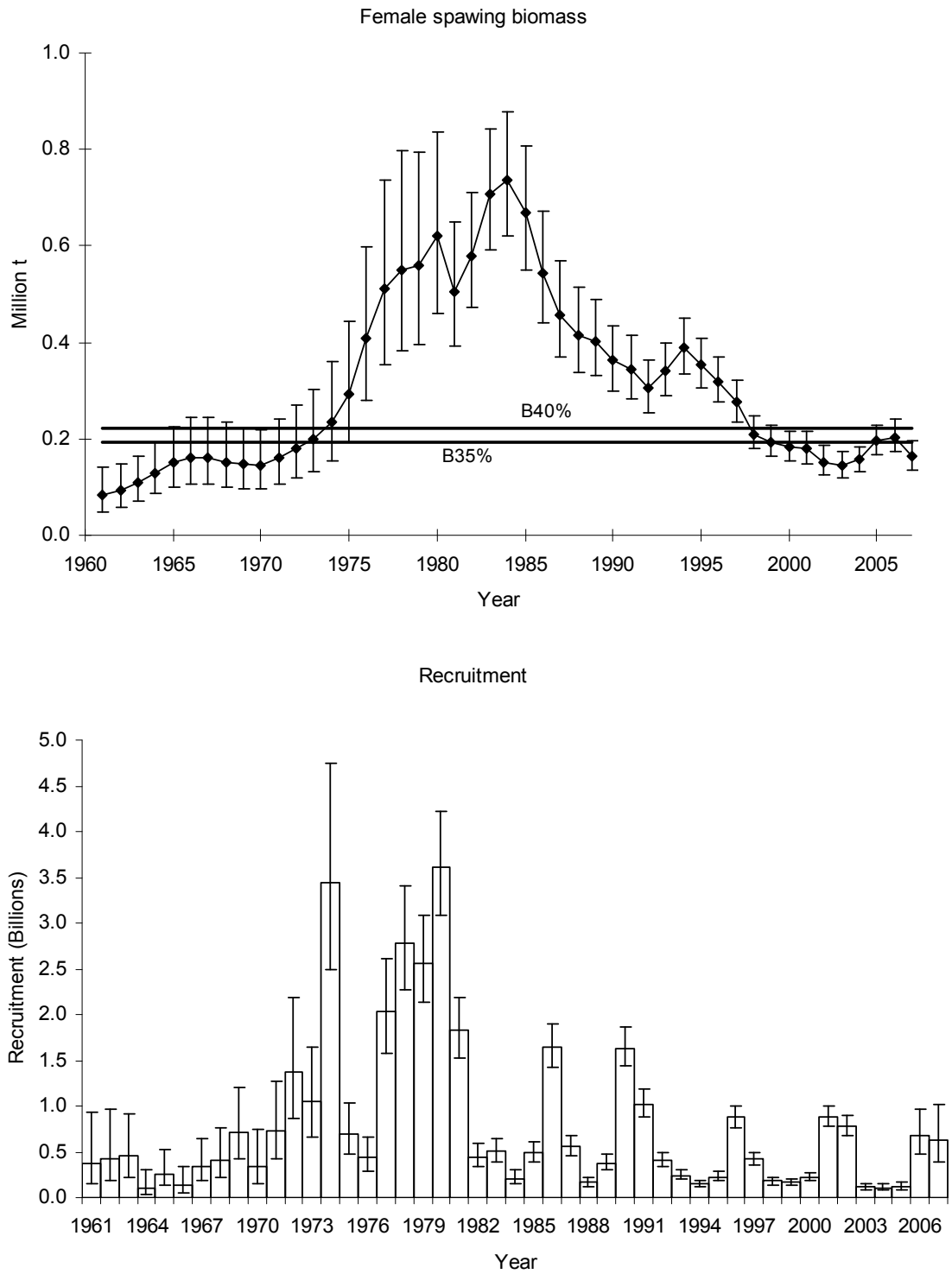
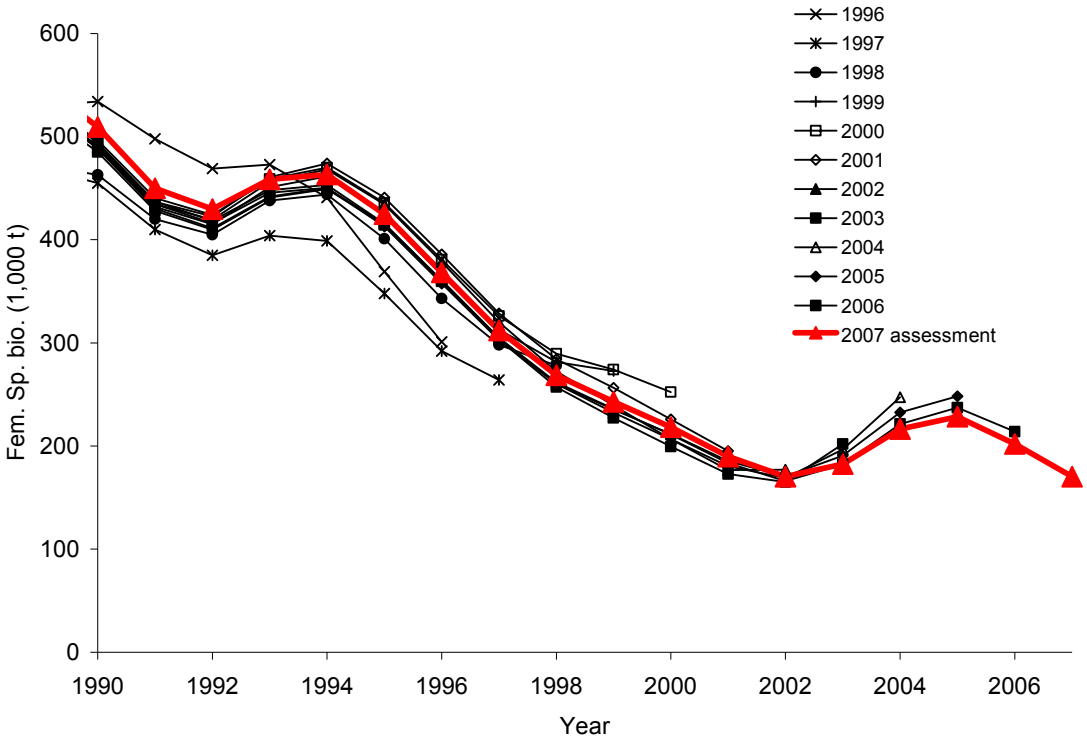


Figure 1.21. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-2 recruitment (billions of fish, bottom) from 1961 to 2007. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



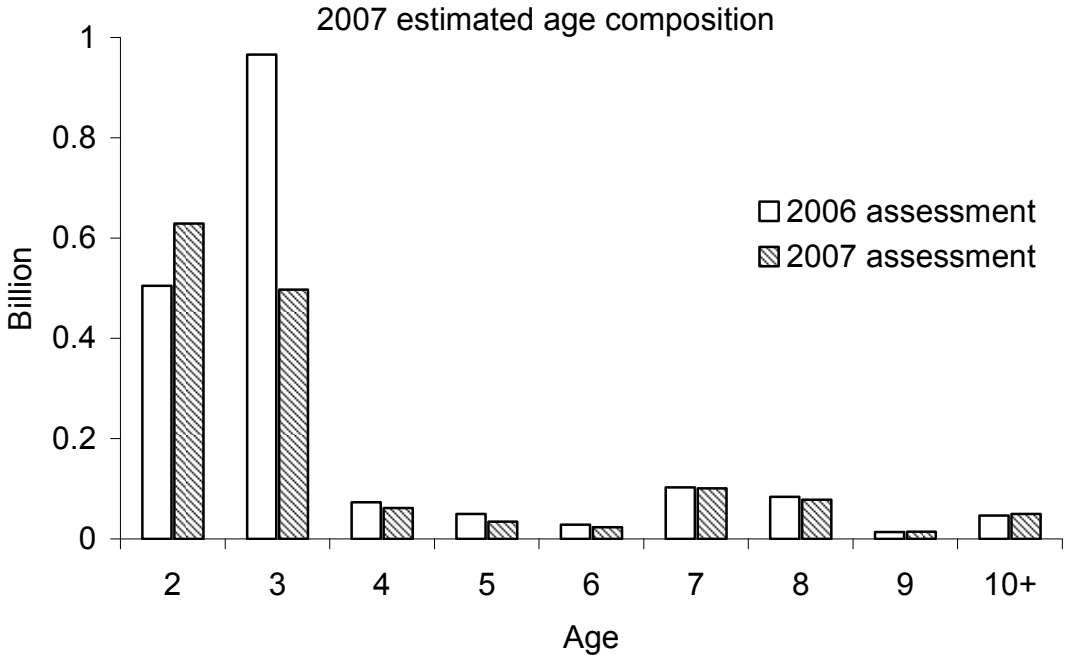


Figure 1.22. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1996-2007 (top). For this figure, the time series of female spawning biomass for the 2007 assessment was calculated using the weight and maturity at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2007 from the 2006 and 2007 assessments.

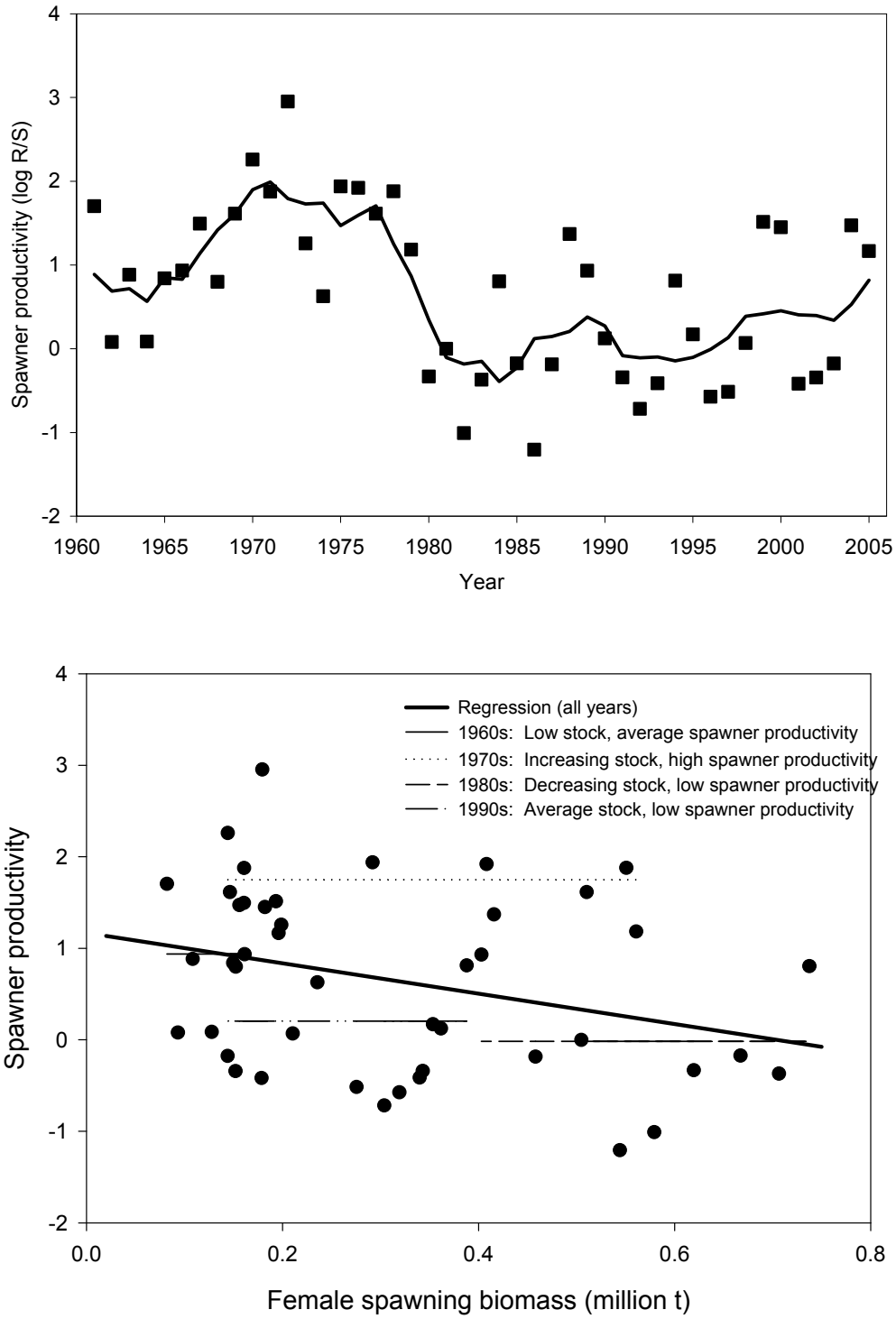


Figure 1.23. Gulf of Alaska pollock spawner productivity *log(R/S)* in 1961-2005 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.

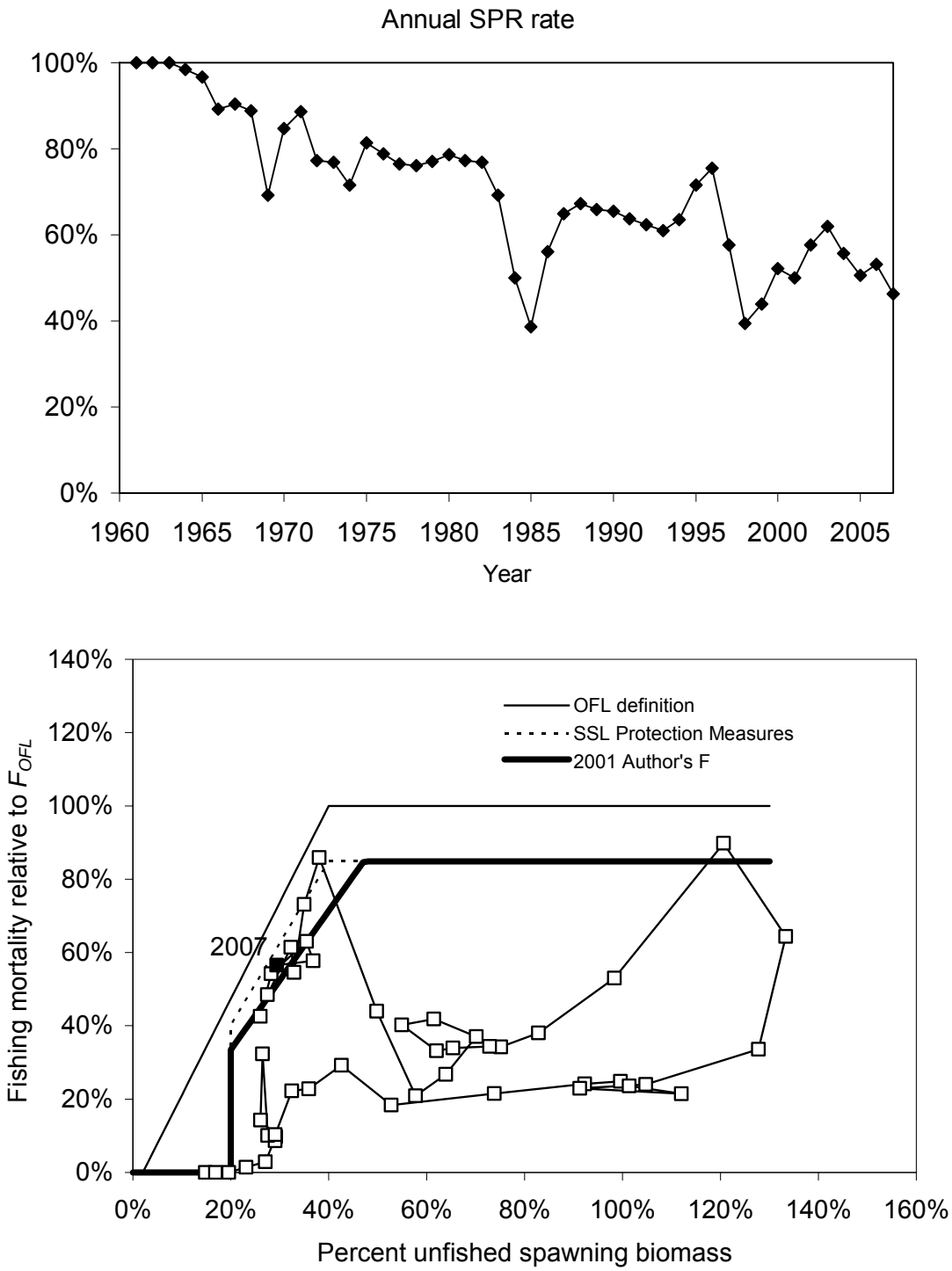


Figure 1.24. Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} (1961-2007). The ratio of fishing mortality to F_{OFL} is calculated using the estimated selectivity pattern in that year. Estimates of unfished spawning biomass are based on 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.

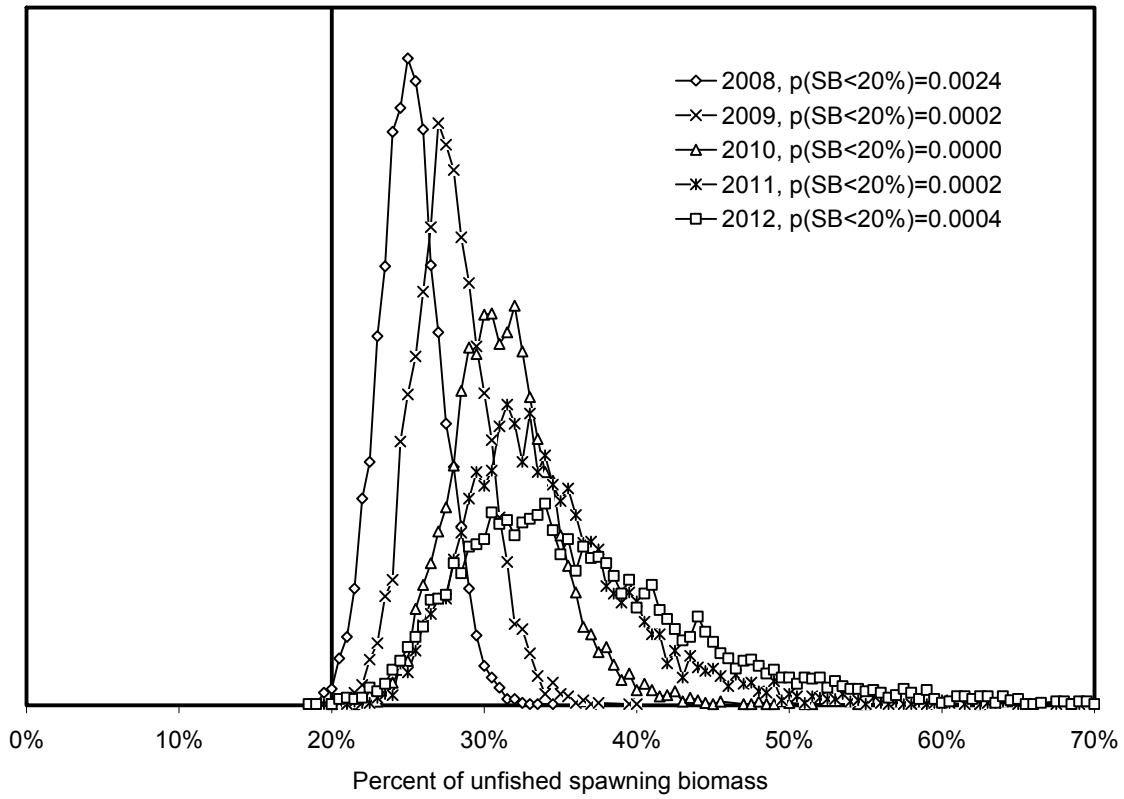


Figure 1.25. Uncertainty in spawning biomass in 2008-2012 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended FABC.

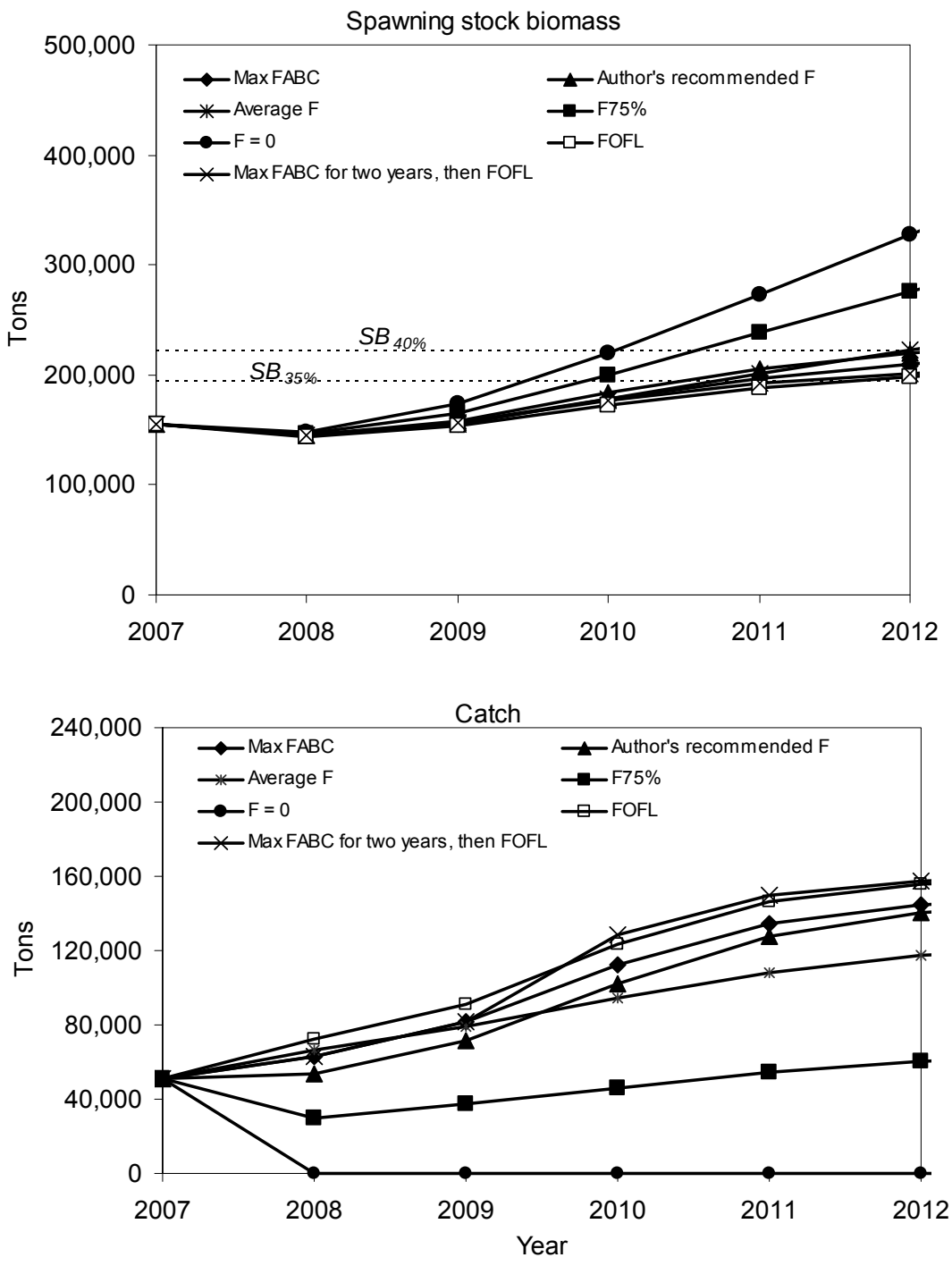
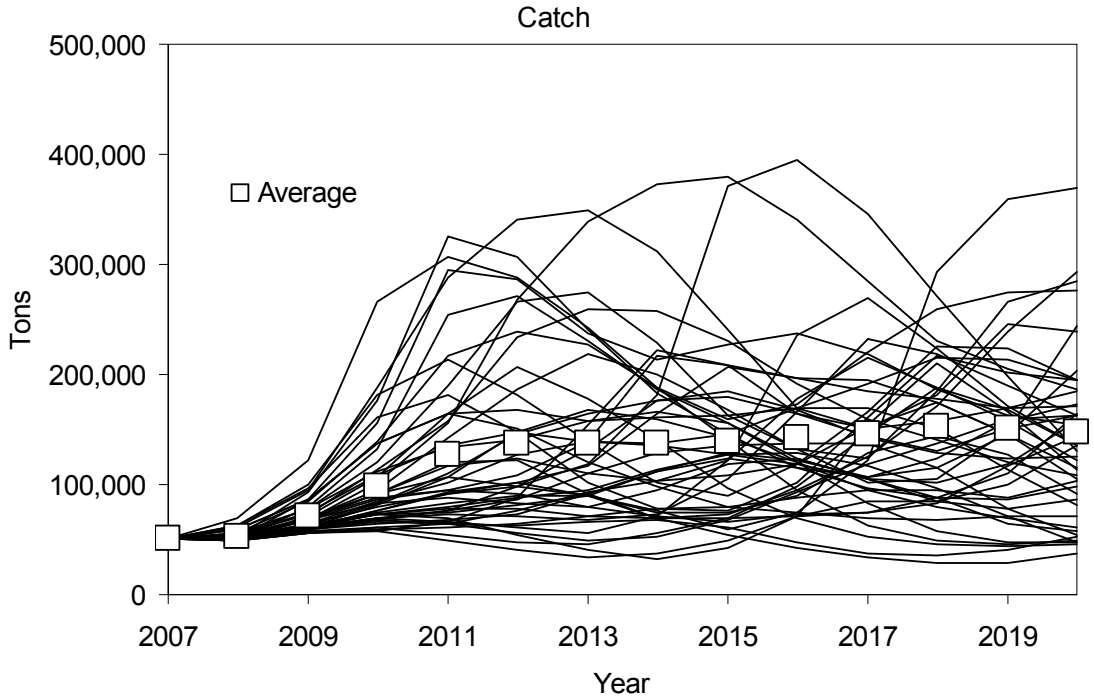


Figure 1.26. Projected spawning biomass and catches in 2007-12 under different management strategies.



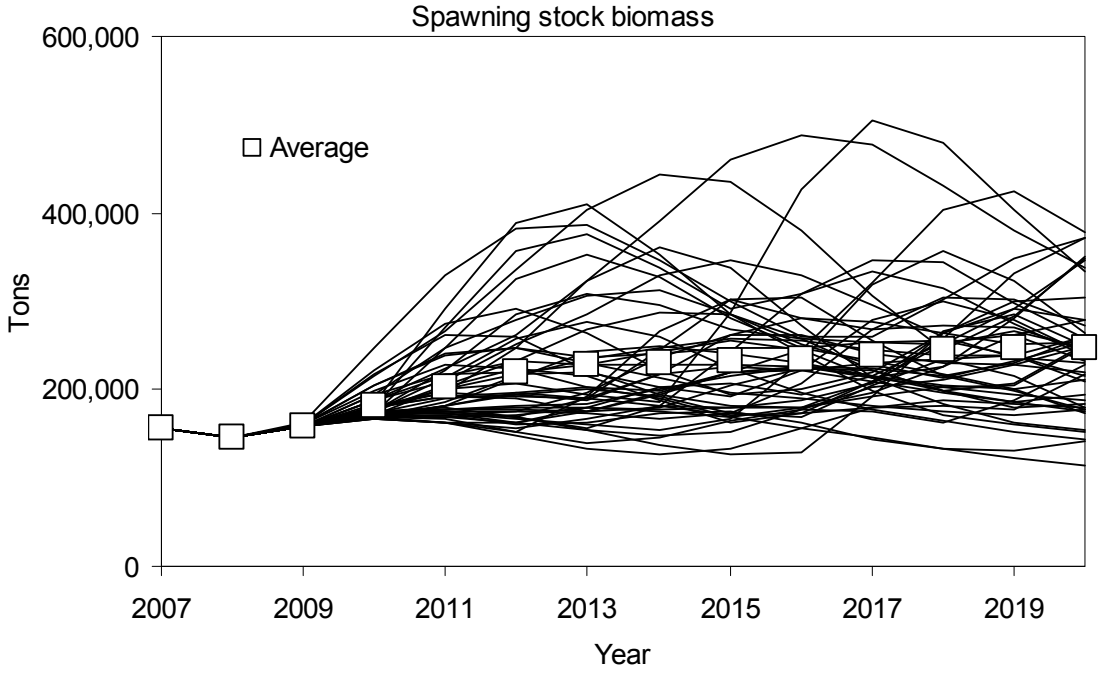


Figure 1.27. Variability in projected catch and spawning biomass in 2007-20 under the author's recommended FABC.

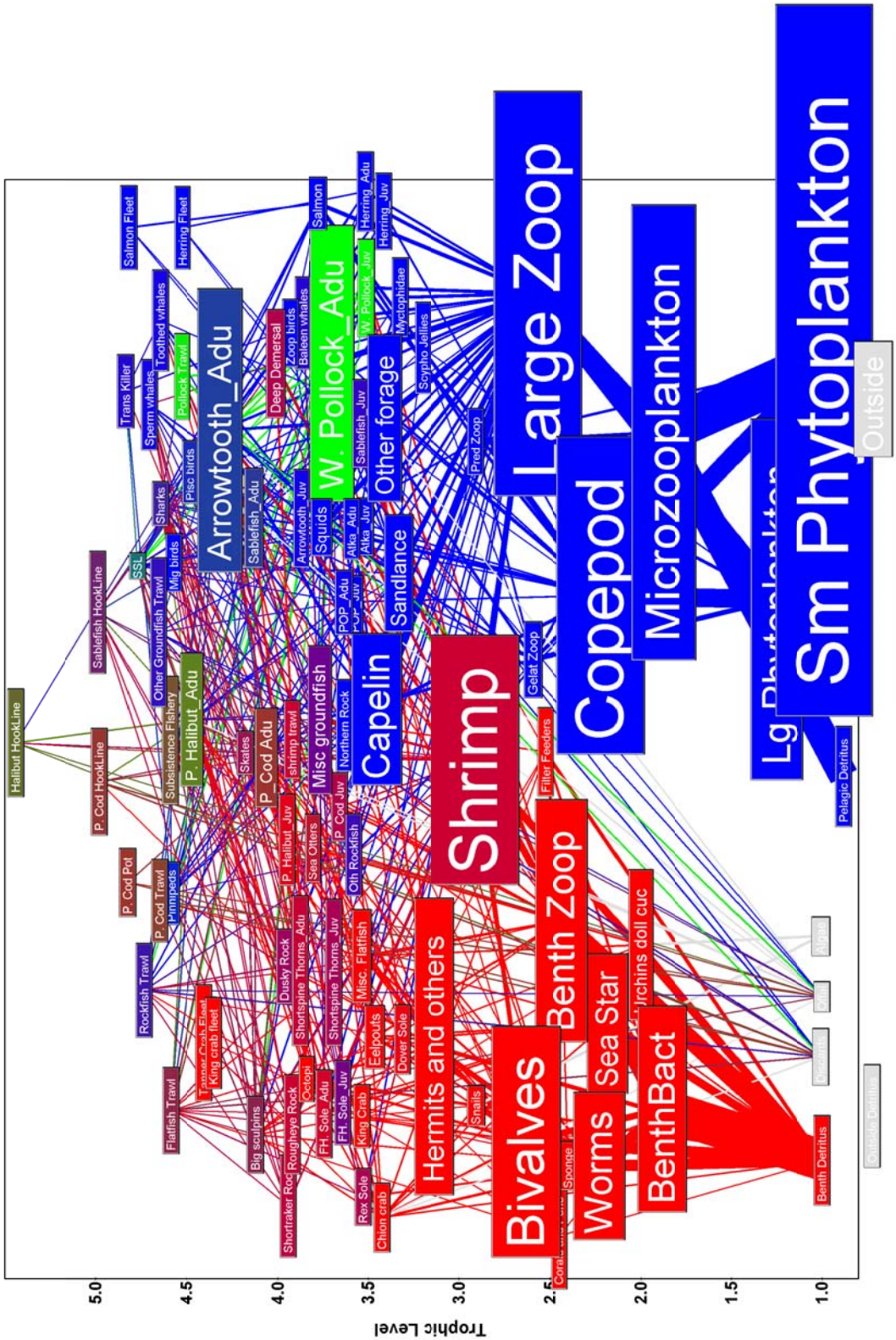


Figure 1.28. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.

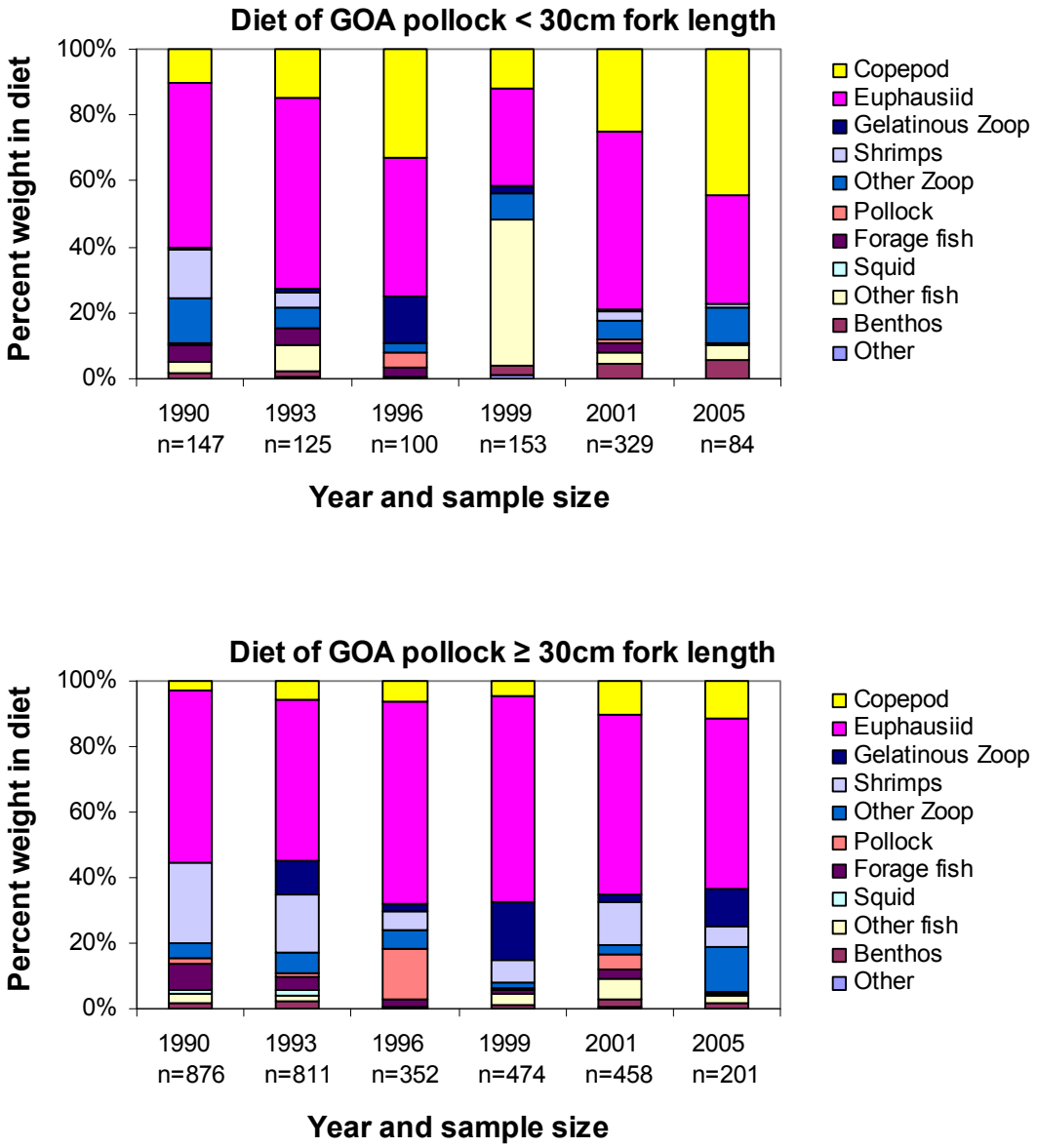
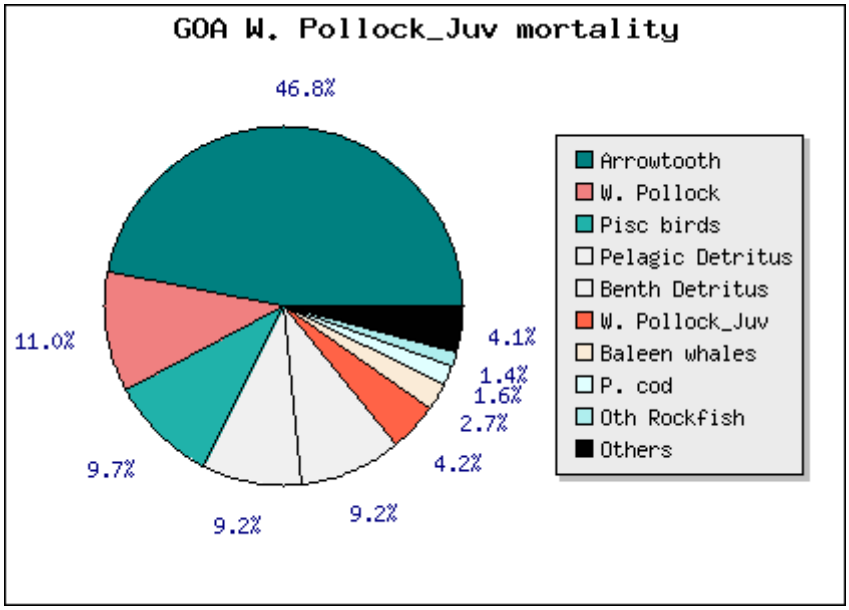


Figure 1.29. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



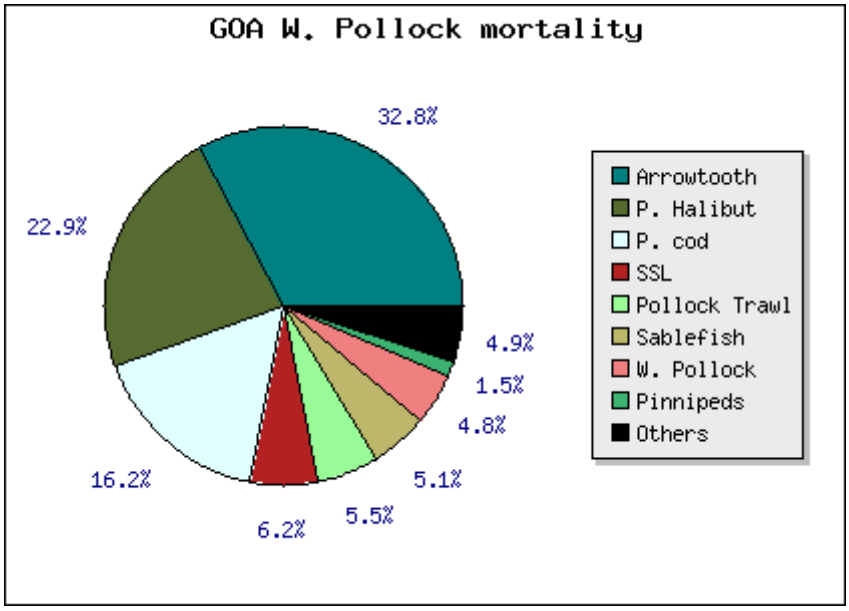


Figure 1.30. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

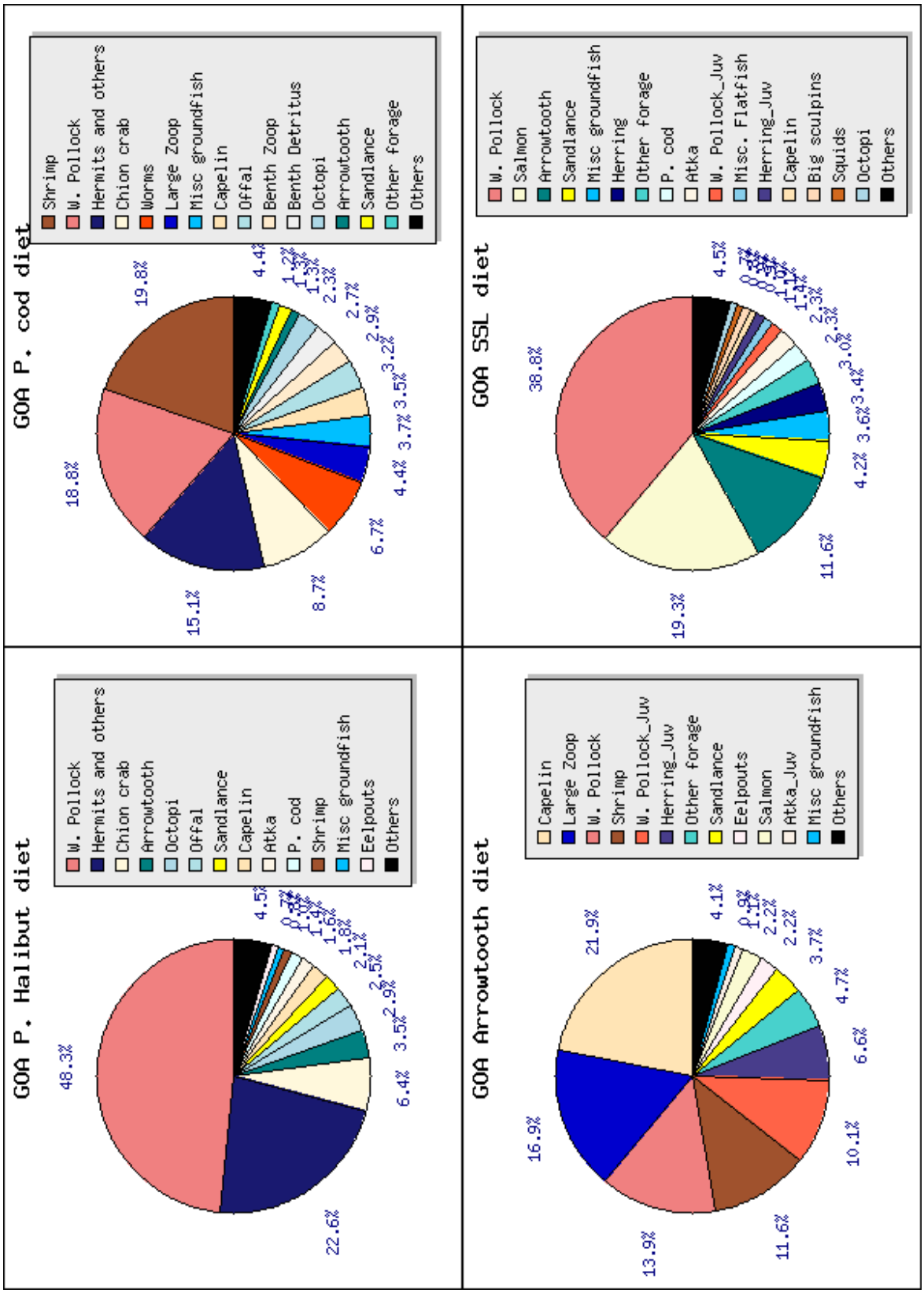


Figure 1.31. Diet diversity of major predators of walleye pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

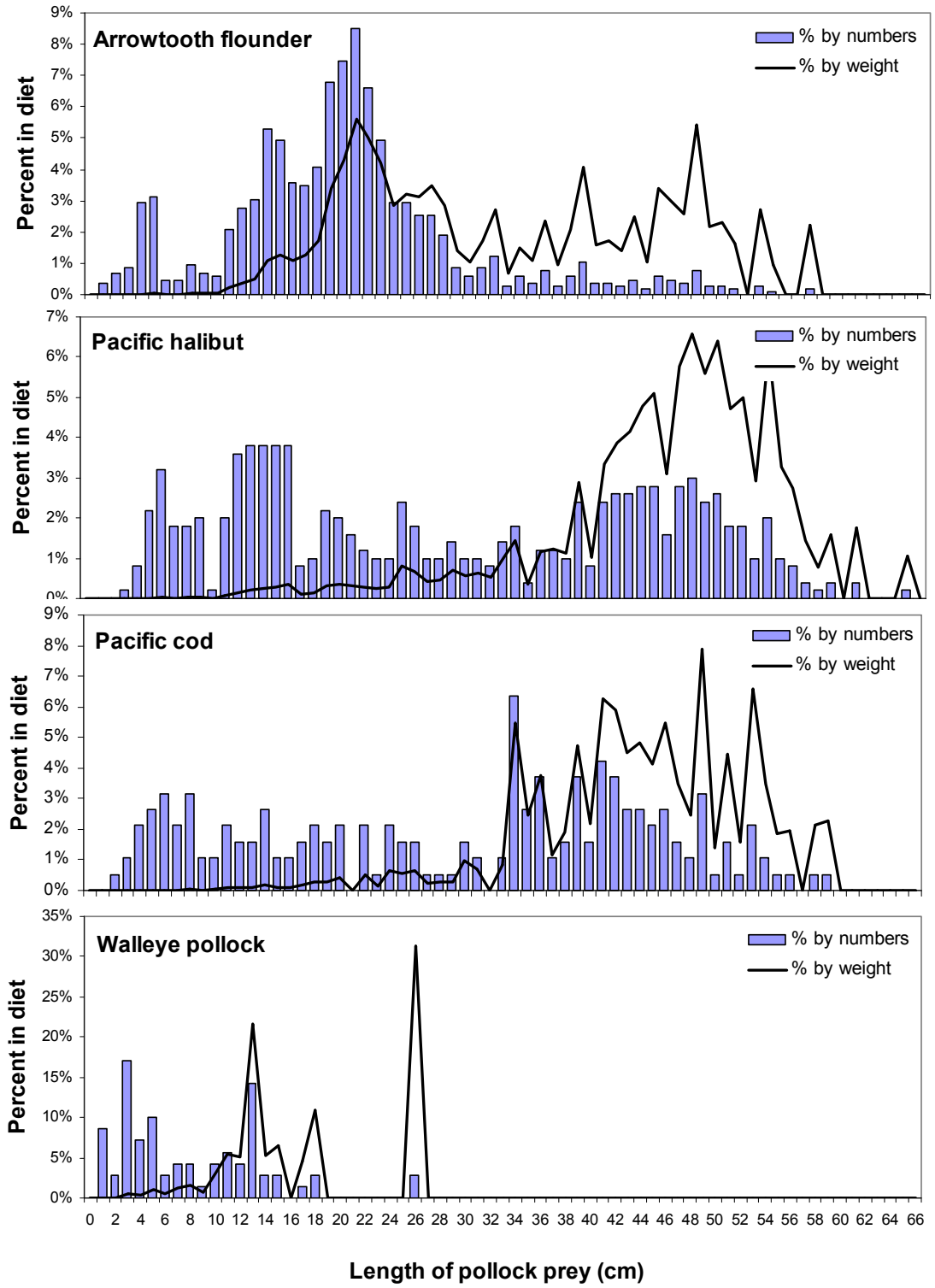


Figure 1.32. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.

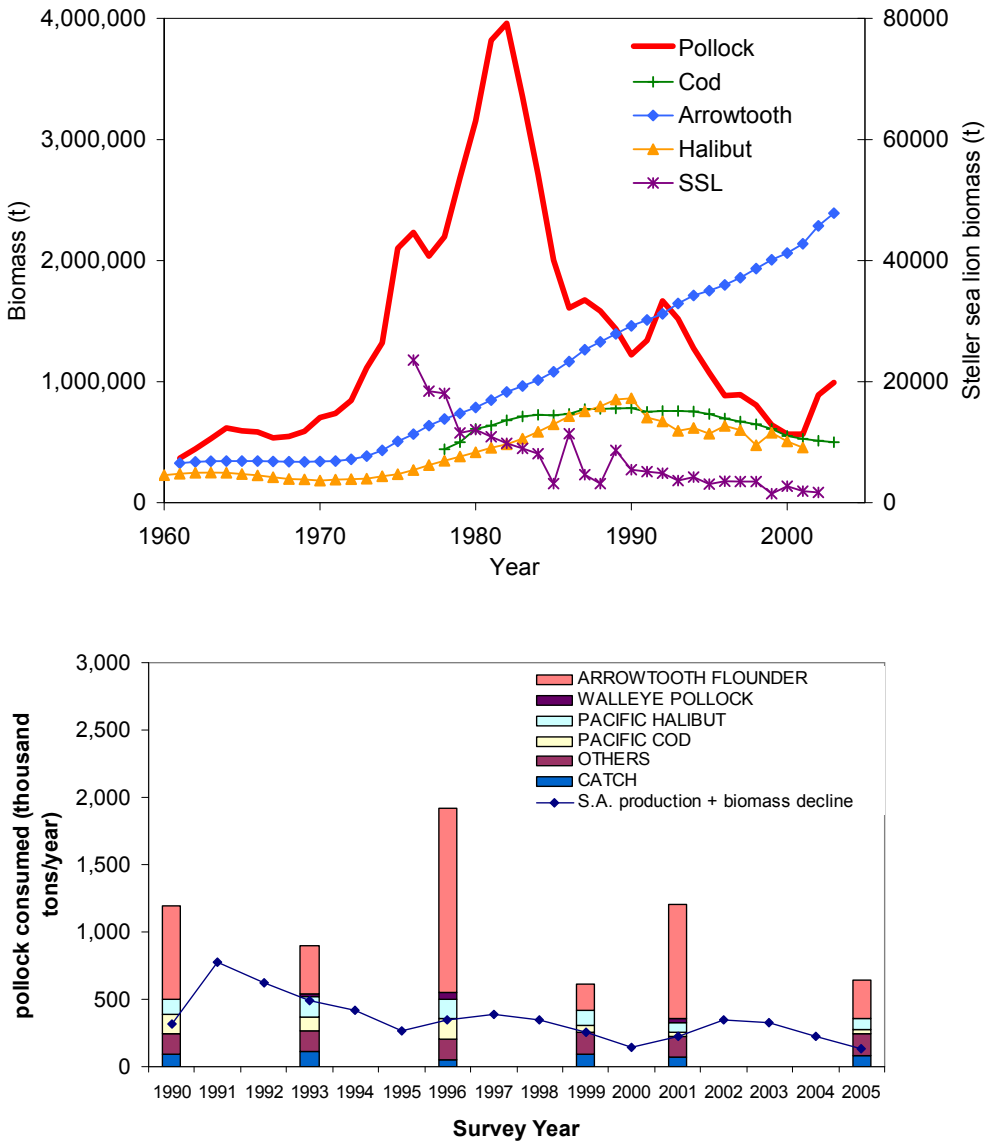


Figure 1.33. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock asessement data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line). See text for calculation methods.

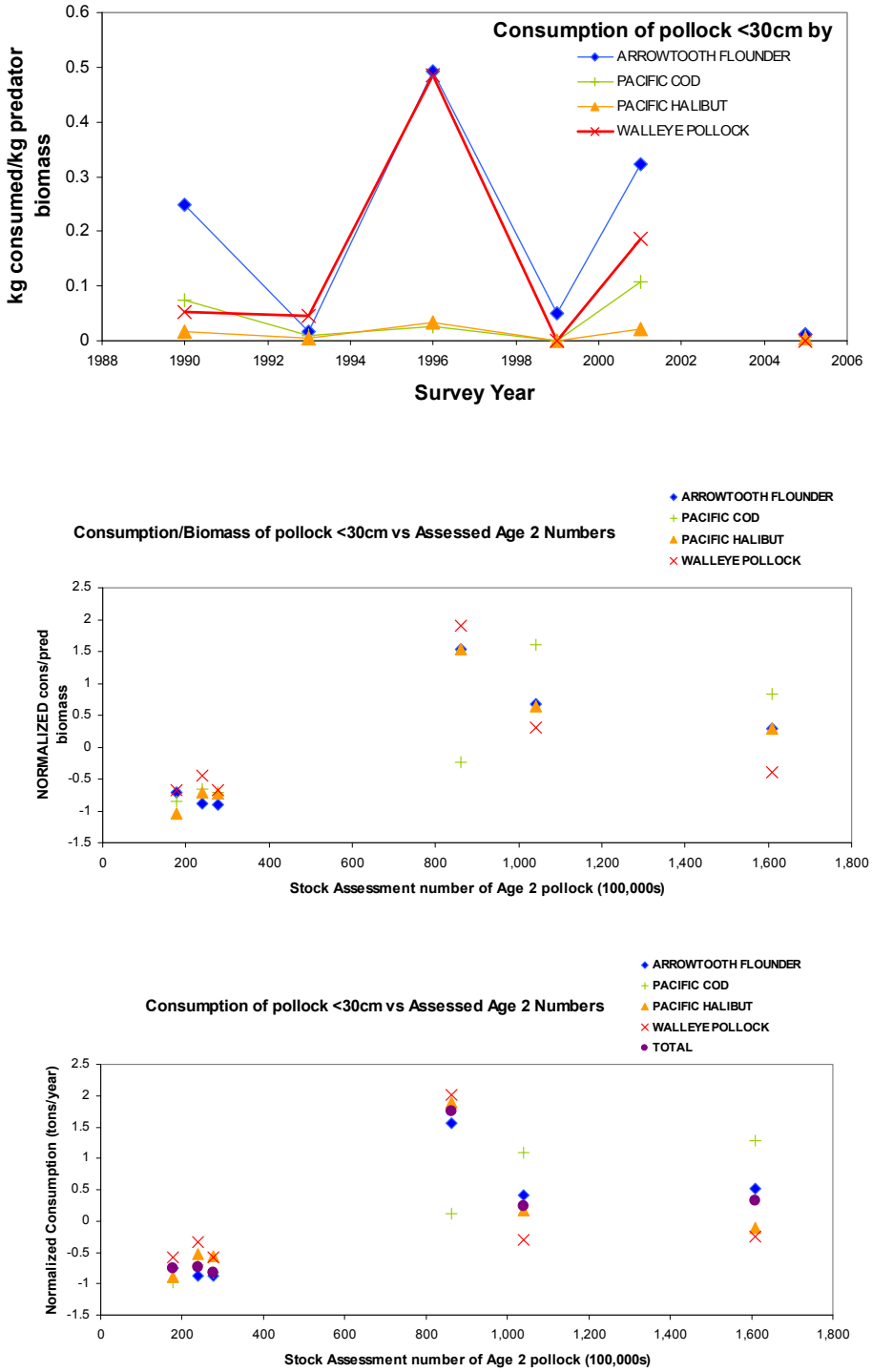
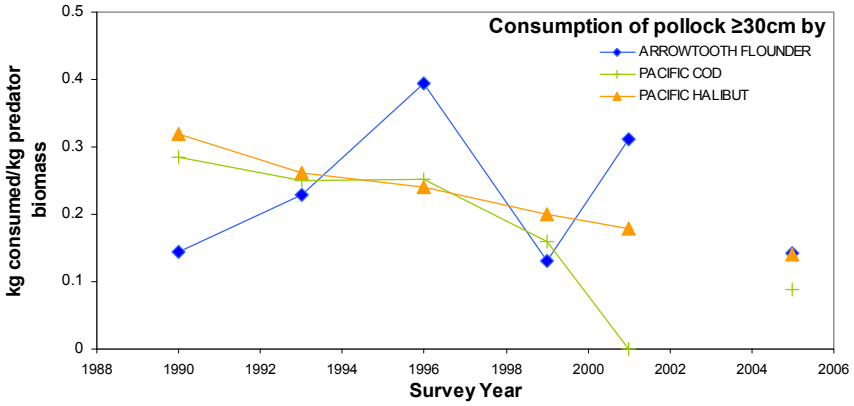
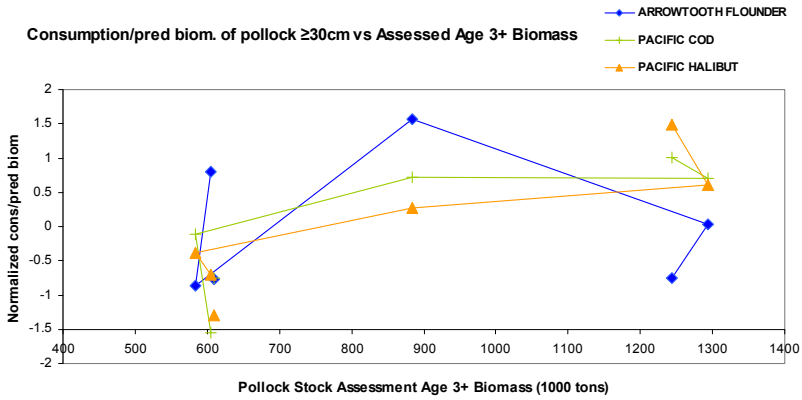


Figure 1.34. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers reported in Table 1.16.





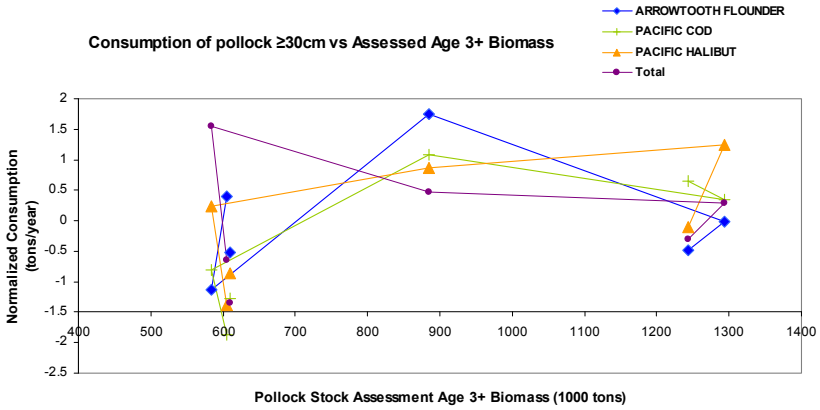


Figure 1.35. (Top) Consumption per unit predator survey biomass of GOA walleye pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass reported in Table 1.17.

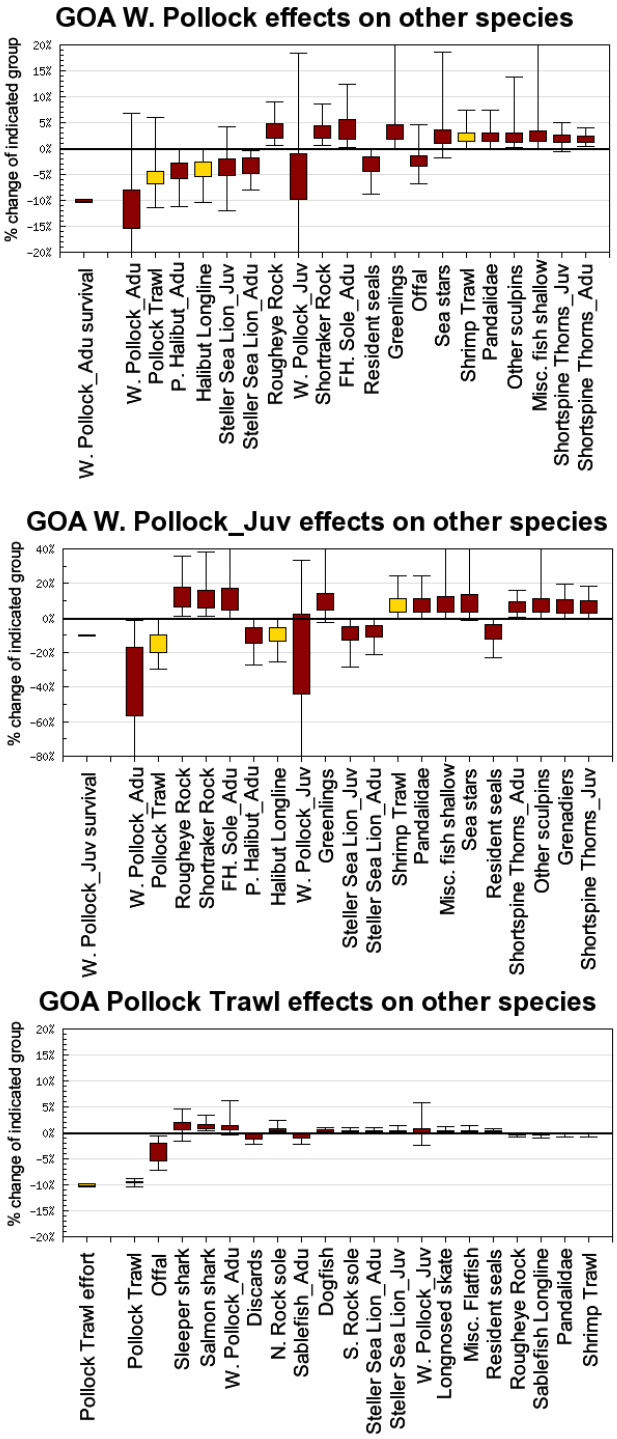


Figure 1.36. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled 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.

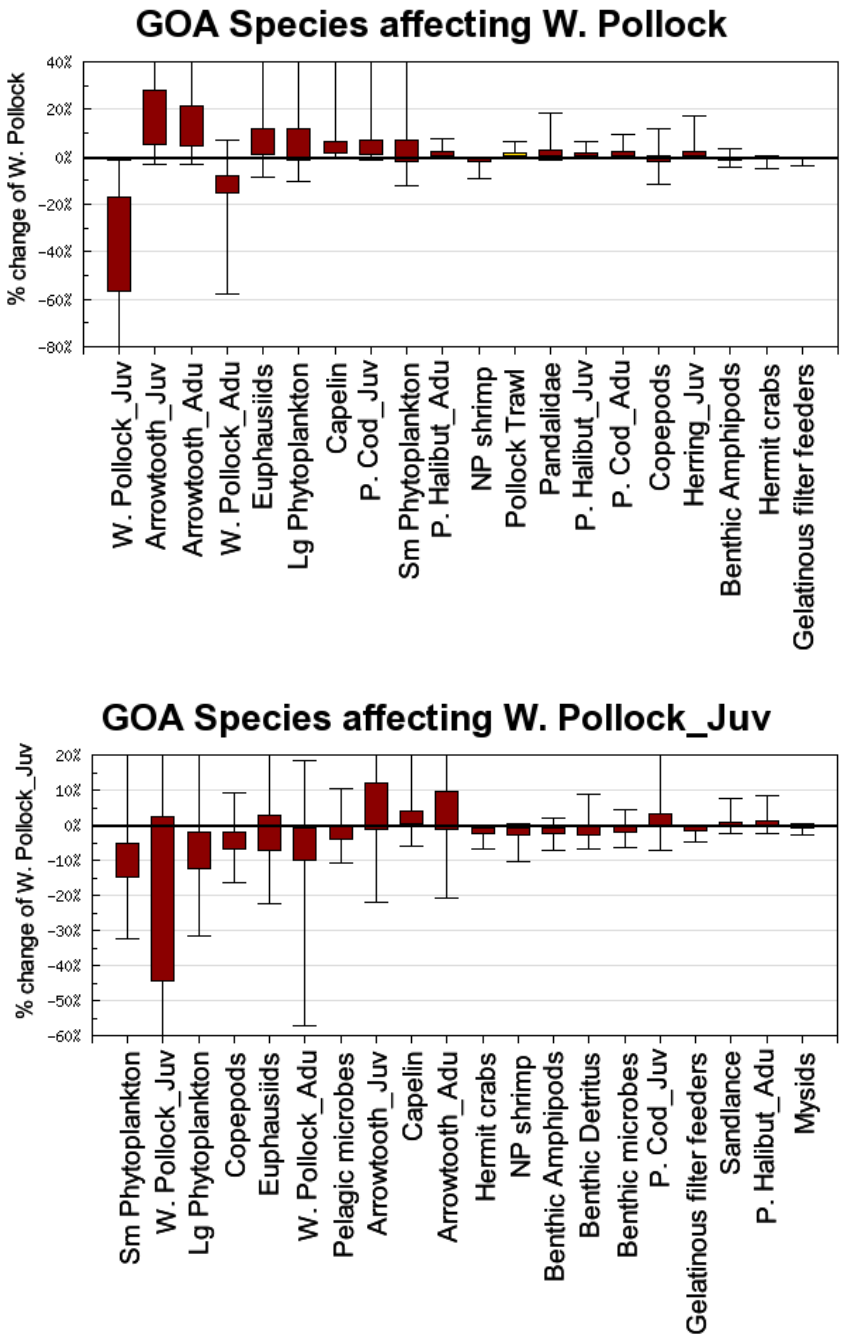


Figure 1.37. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

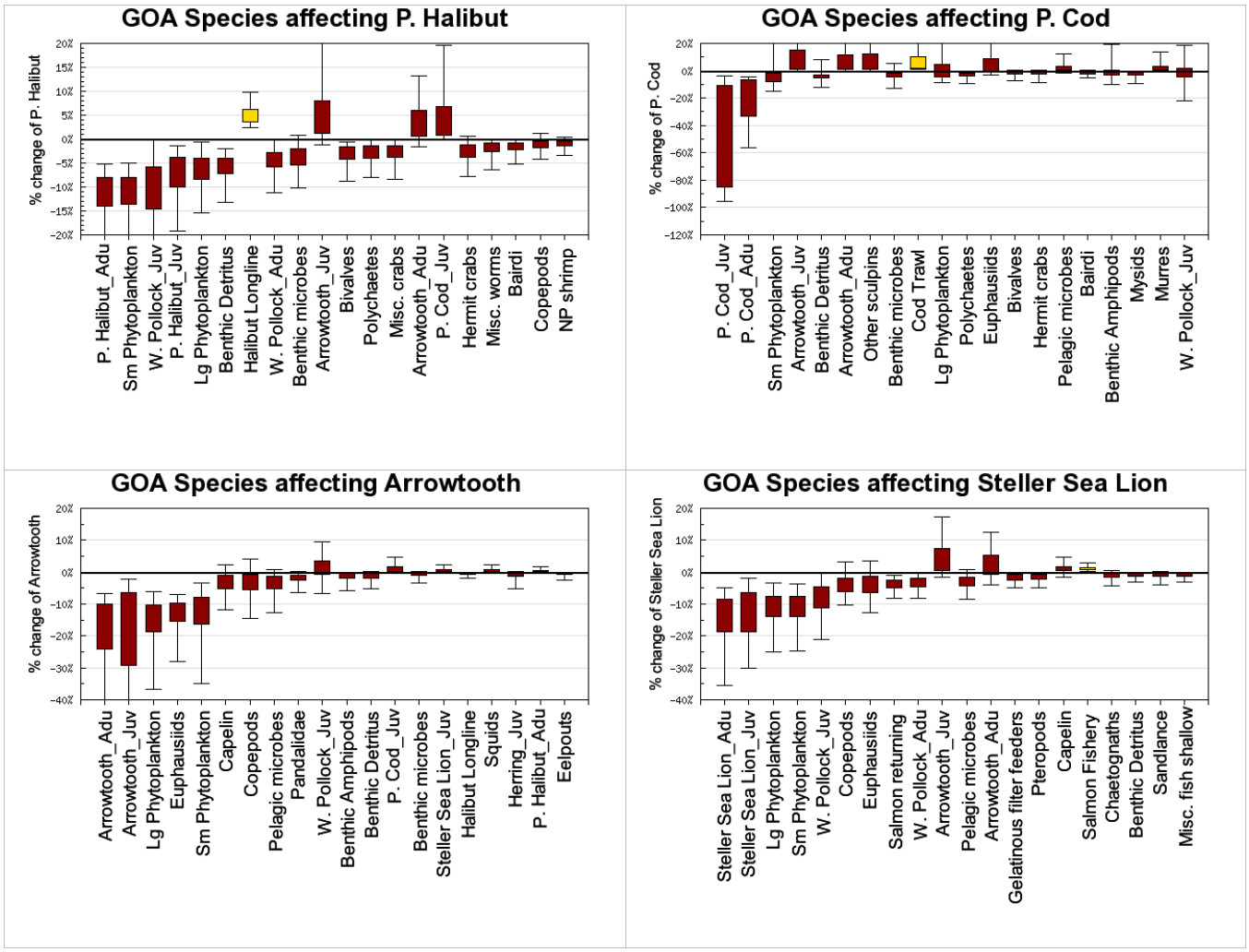


Figure 1.38. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

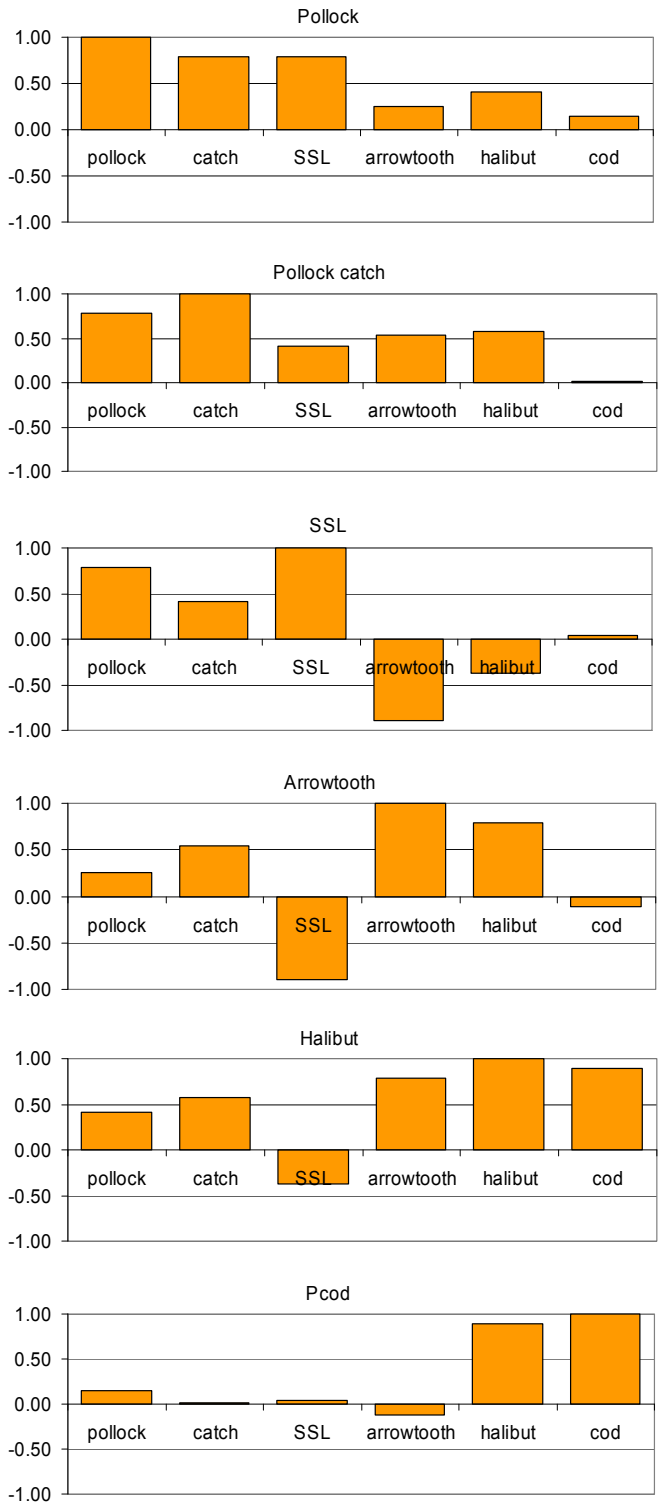


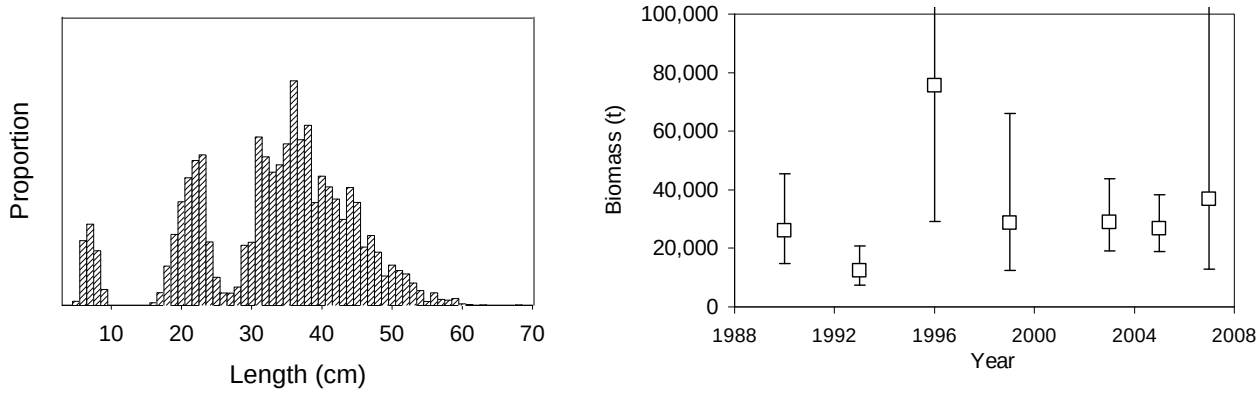
Figure 1.39. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for 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 (Appendix Fig. 1.1). 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 1993-2006, pollock catch the Southeast and East Yakutat statistical areas averaged 15 t, but less 1 t since 2000 (Table 1.4). 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 variable, in part due to year-to-year differences in survey coverage. Surveys since 1996 had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Appendix Figure 1.1). There are no obvious trends in biomass since 1990. 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 2007 survey (36,799 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 2008 ABC of 8,280 t (36,799 t * 0.75 M), and a 2008 OFL of 11,040 t (36,799 t * M).** These recommendations represent an increase of 37% from 2006 and 2007 recommendations due to the higher estimated biomass in the southeast area in the 2007 NMFS bottom trawl survey. Since no bottom trawl surveys are planned in this area until summer of 2009, the preliminary 2009 ABC and OFL should be set equal to the 2008 values.



Appendix Figure 1.1. Pollock size composition in 2007 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2007 (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 2006 (46 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_{ij} . Predicted values from the model are obtained from

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

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

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

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

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

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

Survey observations consist of a total biomass estimate, B_i, and survey proportions at age π_{ij}. Predicted values from the model are obtained from

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

where q = survey catchability, $w_{i\,j}$ 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

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

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

An annual acoustic survey on pre-spawning aggregations in Shelikof Strait has been conducted since 1981. Since 2000, several additional spawning areas have been surveyed multiple times, including Sanak Gully, the Shumagin Islands, the shelf break near Chirikof Island, and Marmot Bay. Although none of these spawning grounds are as important as Shelikof Strait, especially from a historical perspective, in recent years the aggregate biomass surveyed outside Shelikof Strait has been comparable to that within Shelikof Strait.

As in previous assessments, a “composite” approach was used to estimate the percent of the total stock in each management area. The estimated biomass for each survey was divided by the total biomass of pollock estimated by the assessment model in that year and then split into management areas for surveys that crossed management boundaries. The percent for each survey was added together to form a composite biomass distribution, which was then rescaled so that it summed 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.

Since time series of biomass estimates for spawning areas outside of Shelikof Strait are now available, we used the four most recent surveys at each spawning area, and used a rule that a minimum of three surveys was necessary to include an area. These criteria are intended to provide estimates that reflect recent biomass distribution while at the same time providing some stability in the estimates. The biomass in these secondary spawning areas tends to be highly variable from one year to the next. Areas meeting these criteria were Shelikof Strait, the shelf break near Chirikof Island, the Shumagin area, and Sanak Gully, but excludes Morzhovoi Bay (surveyed in 2006 and 2007 with questionable timing), Barnabas and

Chiniak Gullies (surveyed once in 2001), and Marmot Bay (surveyed once in 2007). Finally, an acoustic survey in 1990 along the shelf break and on east side of Kodiak Island (Karp 1990) was used for areas not covered in any of the above surveys.

The sum of the percent biomass for all surveys combined was 94.38%, 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 26.35%, 60.09%, 13.56% in areas 610, 620, and 630 (Appendix table 1). In comparison to last year's assessment, a lower percentage was estimated in area 610 (-3 percentage points) and a higher percentage in area 620 (+1 percentage point) and area 630 (+2 percentage points).

A-season apportionment between areas 620 and 630

In the 2002 assessment, 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 using updated survey data is: 610, 26.35%; 620, 49.30%; 630, 24.35%.

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 6,900 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 1,560 t for the author's 2008 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 42.20%, 20.76%, 34.12%, and 2.92% in areas 610, 620, 630, and 640 (Appendix Fig. 1.2).

Example calculation of 2008 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 0.0292 x Total TAC = 2,920 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 – 2,920) = 24,270 t
B season 0.25 x (Total TAC – 2,920) = 24,270 t
C season 0.25 x (Total TAC – 2,920) = 24,270 t
D season 0.25 x (Total TAC – 2,920) = 24,270 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 0.2635 x 24,270 t = 6,395 t
620 0.4930 x 24,270 t = 11,965 t
630 0.2435 x 24,270 t = 5,910 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 0.2635 x 24,270 t = 6,395 t
620 0.6009 x 24,270 t = 14,584 t
630 0.1356 x 24,270 t = 3,291 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 42.20%, 20.76%, 34.12%, and 2.92%.

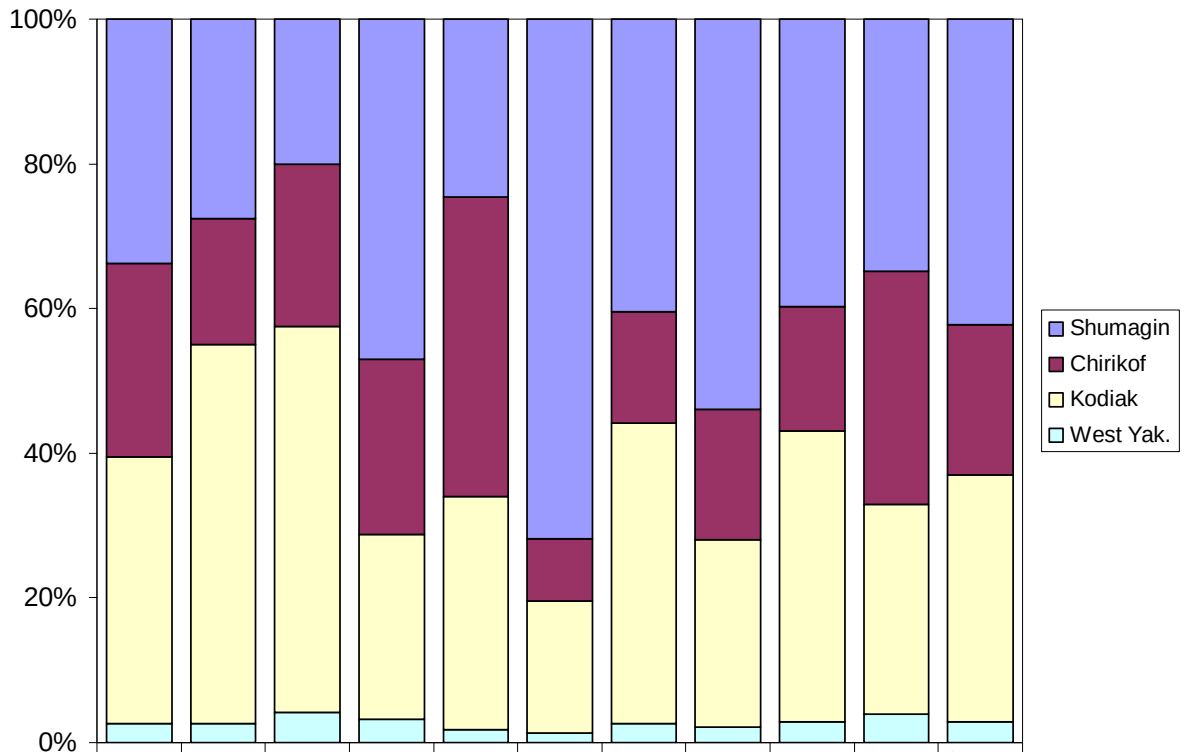
610 0.4220 / (1 – 0.0292) x 24,270 = 10,550 t
620 0.2076 / (1 – 0.0292) x 24,270 = 5,190 t
630 0.3412 / (1 – 0.0292) x 24,270 = 8,530 t

610 0.4220 / (1 – 0.0292) x 24,270 = 10,550 t
620 0.2076 / (1 – 0.0292) x 24,270 = 5,190 t
630 0.3412 / (1 – 0.0292) x 24,270 = 8,530 t

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

					Percent by management area		
Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*[1]	*Percent*	*Area 610*	*Area 620*	*Area 630*
Shelikof Strait	2004	532,769	330,753	62.1%	0.0%	97.6%	2.4%
Shelikof Strait	2005	552,225	338,038	61.2%	0.0%	97.8%	2.2%
Shelikof Strait	2006	540,389	293,609	54.3%	0.0%	96.1%	3.9%
Shelikof Strait	2007	530,864	180,881	34.1%	0.0%	97.1%	2.9%
Shelikof Strait	Average			52.9%	0.0%	97.1%	2.9%
	Percent of total 2+ biomass				0.0%	51.4%	1.5%
Chirikof	2004	532,769	30,400	5.7%	0.0%	88.8%	11.2%
Chirikof	2005	552,225	77,000	13.9%	0.0%	47.8%	52.2%
Chirikof	2006	540,389	69,000	12.8%	0.0%	28.3%	71.7%
Chirikof	2007	530,864	35,573	6.7%	0.0%	24.0%	76.0%
	Average			9.8%	0.0%	47.2%	52.8%
	Percent of total 2+ biomass				0.0%	4.6%	5.2%
Shumagin	2003	508,747	67,160	13.2%	99.7%	0.3%	0.0%
Shumagin	2005	552,225	51,970	9.4%	99.9%	0.1%	0.0%
Shumagin	2006	540,389	25,030	4.6%	92.8%	7.2%	0.0%
Shumagin	2007	530,864	20,009	3.8%	98.5%	1.5%	0.0%
Shumagin	Average			7.8%	97.7%	2.3%	0.0%
	Percent of total 2+ biomass				7.6%	0.2%	0.0%
Sanak	2003	508,747	81,500	16.0%	100.0%	0.0%	0.0%
Sanak	2005	552,225	67,800	12.3%	100.0%	0.0%	0.0%
Sanak	2006	540,389	127,214	23.5%	100.0%	0.0%	0.0%
Sanak	2007	530,864	60,289	11.4%	100.0%	0.0%	0.0%
Sanak	Average			15.8%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass				15.8%	0.0%	0.0%
Karp (1990)	1990	962,419	78,134	8.1%	18.4%	6.3%	75.3%
	Average			8.1%	18.4%	6.3%	75.3%
	Percent of total 2+ biomass				1.5%	0.5%	6.1%
Total				94.38%	24.87%	56.71%	12.79%
Rescaled total				100.00%	26.35%	60.09%	13.56%

[1] The biomass of age-1 pollock not included in Shelikof Strait survey biomass in 2005 and Shumagin survey biomass in 2006.



	1984	1987	1990	1993	1996	1999	2001	2003	2005	2007	4 survey avg (2001-
Shumagin	33.82%	27.59%	20.03%	46.98%	24.60%	71.81%	40.40%	53.92%	39.70%	34.81%	42.21%
Chirikof	26.66%	17.38%	22.41%	24.32%	41.37%	8.57%	15.49%	18.09%	17.19%	32.26%	20.76%
Kodiak	36.90%	52.41%	53.43%	25.49%	32.20%	18.30%	41.49%	25.84%	40.19%	28.95%	34.12%
West Yak.	2.62%	2.62%	4.13%	3.21%	1.83%	1.32%	2.62%	2.15%	2.92%	3.98%	2.92%

Appendix Figure 1.2. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2007. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.

Appendix D. FOCI Gulf of Alaska Walleye Pollock 2007 Year-Class Prediction.

DATA

This forecast is based on five information sources: two physical properties and two biological data sets. The information sources are:

1. Observed 2007 Kodiak monthly precipitation. The Kodiak National Weather Service office (http://padq.arh.noaa.gov/) prepares monthly precipitation totals (inches) from hourly observations. Data for 2007 were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.

2. Wind mixing energy at [57°N, 156°W] estimated from 2007 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 2007.

4. Rough estimates of pollock larvae abundance from a survey conducted in late May–early June 2007.

5. Estimates of age-2 pollock abundance and spawner biomass from the 2007 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.

Kodiak precipitation for the first half of 2007 showed extreme behavior compared to the 30-year average. The season began with a greater than seasonal drying trend from January through March (Table 1), with March being the fourth driest March since these records began in 1962. This diminshed the potential for formation of baroclinic instabilities prior to and during spawning. April and May brought record rain, with April 2007 being the all-time wettest April and May 2007 the fourth wettest since 1962. June was near normal. The spring may have presented favorable habitat for late larval- and early juvenile-stage walleye pollock, although one might question the contribution of such extreme rain to favorable larval survival.

TABLE 1. Kodiak precipitation for 2007.

Month	% 30-yr average
Jan	121
Feb	67
Mar	25
Apr	298
May	213
June	72

Based on this information, the forecast element for Kodiak 2007 rainfall has a score of 2.58. This is "average to strong" recruitment on the 5-category continuum from 1 (weak) to 3 (strong), and “strong” using three categories.

***Wind Mixing**:* Wind mixing at the southern end of Shelikof Strait was below the long-term average for the first two months of winter, near to above average for the end of winter and beginning of spring, and low for the final two months of spring 2007 (Table 2).

TABLE 2. Wind mixing at the exit of Shelikof Strait for 2007.

Month	% 30-yr average
Jan	77
Feb	39
Mar	103
Apr	135
May	44
June	36

Strong winds in winter help mix 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 produced a wind mixing score of 1.96, which is “average”.

Winds and Transport in the Alaska Coastal Current: The transport in the Alaska Coastal Current is strongly correlated with along shore winds. Winds in March 2007 were above average and rainfall during April and May was above average. The combination of these high winds and increased freshwater input contributed to conditions of above average advection. Strong flows would tend to advect the larvae downstream out of the preferred nursery grounds in the Shelikof Sea valley and into the basin.

Based on these observations, the 2007 pollock year-class prediction from transport information would indicate a below average year class. Based on transport in the Alaska Coastal Current, we give this element a score of 0..83, which equates to the middle of the range for the weak category.

Relating the Larval Index to Recruitment: As in previous analyses, 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 eight weighting parameters.

The neural network model, which used the 21 observation pairs of Table 3 to fit the model, had a very low R^2 of 0.017. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) is given in Fig. 1, where row number corresponds to the rows of the data matrix given in Table 3 and thus indicates year class.

TABLE 3. Data used in the neural network model.

Year Class	Mean CPUA	Recruit
1982	71.14	0.212014
1985	80.42	0.563229
1987	329.74	0.381621
1988	260.21	1.63617
1989	537.29	1.02169
1990	335.00	0.408532
1991	54.22	0.243326
1992	562.79	0.147321
1993	185.34	0.223502
1994	126.58	0.865454
1995	610.33	0.41281
1996	477.69	0.176586
1997	568.42	0.160661
1998	72.20	0.219708
1999	96.14	0.862862
2000	492.04	0.774696
2001	171.30	0.120526
2002	175.64	0.11364
2003	135.36	0.130498
2004	21.22	0.731638
2005	76.22	0.482537

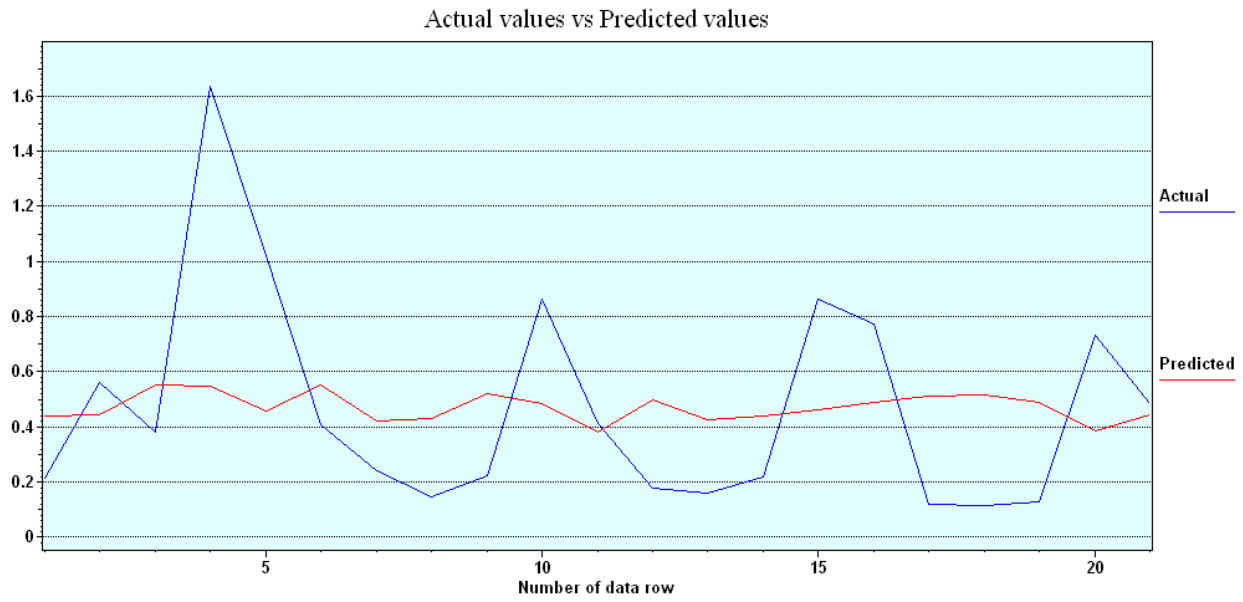


FIGURE 1. Observed and predicted recruitment values from the larval index-recruitment neural network model.

The trained network was then used to predict the recruitment for 2006 and 2007. The predictions are given in Table 4.

TABLE 4. Neural network model predictions for 2006 and 2007.

Year	Actual Recruitment	Predicted Recruitment
2006	n/a	0.531147
2007	n/a	0.445912

These values, using the 33% (0.3547) and 66% (0.7287) cutoff points given below, correspond to an average 2006 year class and an average 2007 year class or a score of 2.0.

Larval Index Counts: Plotting the larval abundance data by year and binning the data into catch/10 m^2 categories (given below) provides another view of the data. The pattern for 2007 (based on rough counts) show patterns different from last year in that the frequency distribution is skewed towards lower binning categories (Figure 2). These patterns indicate that the 2007 year class may be below average.

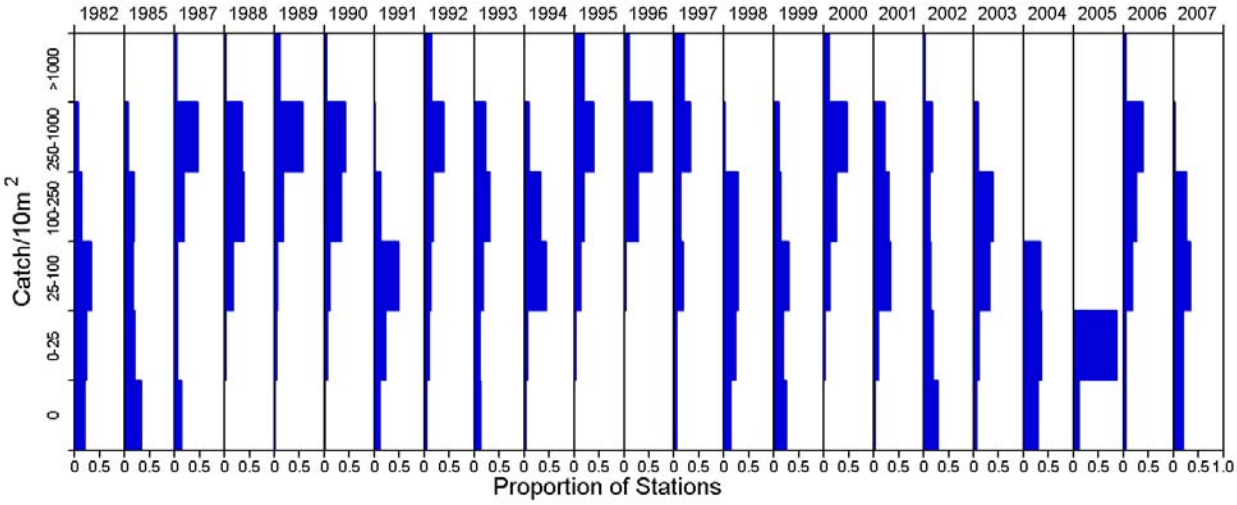


FIGURE 2. A series of histograms for larval walleye pollock densities in late May from 1982 to 2007. Data were binned into catch/10 m^2 categories. The data from 2000-2005 are actual verified larval counts, 2006 are unverified counts from the Polish Plankton Sorting Institute, and 2007 data are rough counts from the 5MF07 FRV *Miller Freeman* survey cruise that was completed in late May.

The data for Figures 3, 4, 5 and 6 are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae. This year's distribution of pollock (Fig. 6) 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. Comparing the catch rates (Fig. 2) shows that the 2007 rough counts seem to be distributed to lower values compared to 2006, and the distribution of larvae in 2007 (Fig. 6) compared to last year (Fig. 5) was spatially similar. Given these two pieces of information, the score for larval index is set to the low end of average or 1.67.

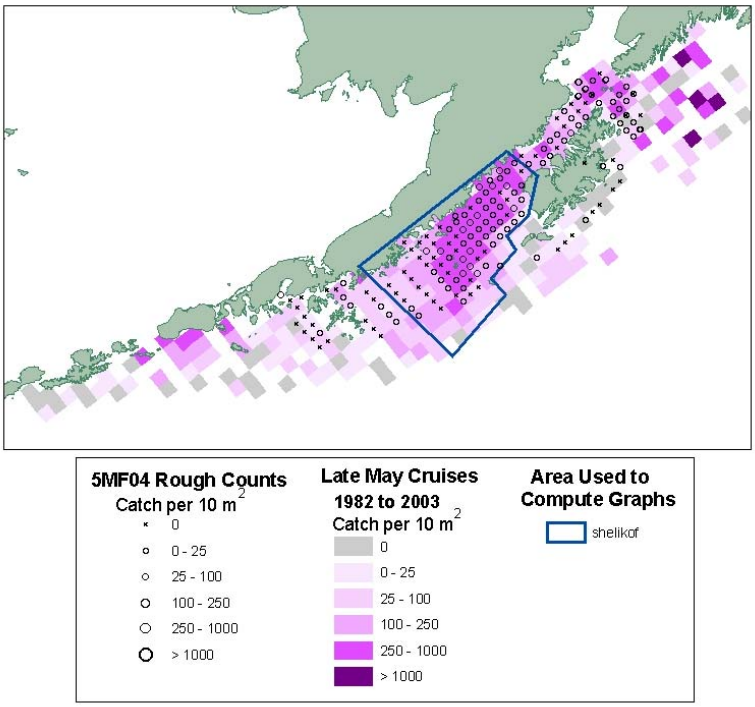


FIGURE 3. Mean catch per 10 m^2 for late May cruises during 1982-2003, with observed rough counts overlayed for 2004.

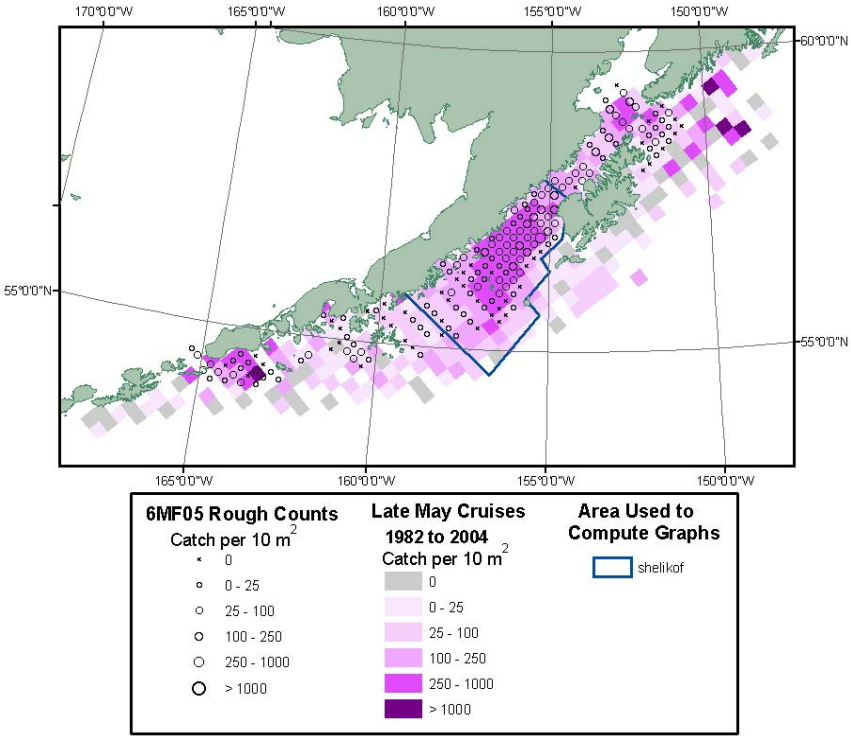


FIGURE 4. Mean catch per 10 m^2 for late May cruises during 1982-2004, with observed rough counts overlayed for 2005.

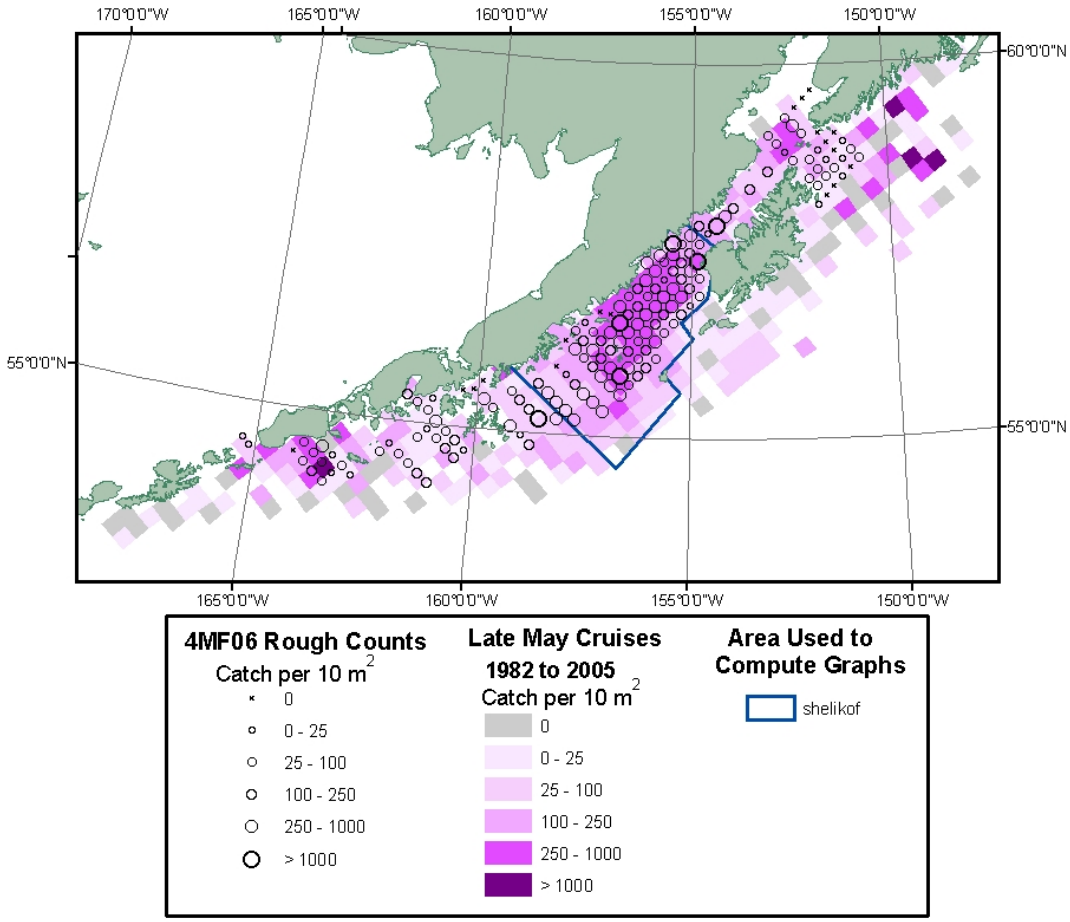


FIGURE 5. Mean catch per 10 m^2 for late May cruises during 1982-2005, with observed rough counts overlayed for 2006.

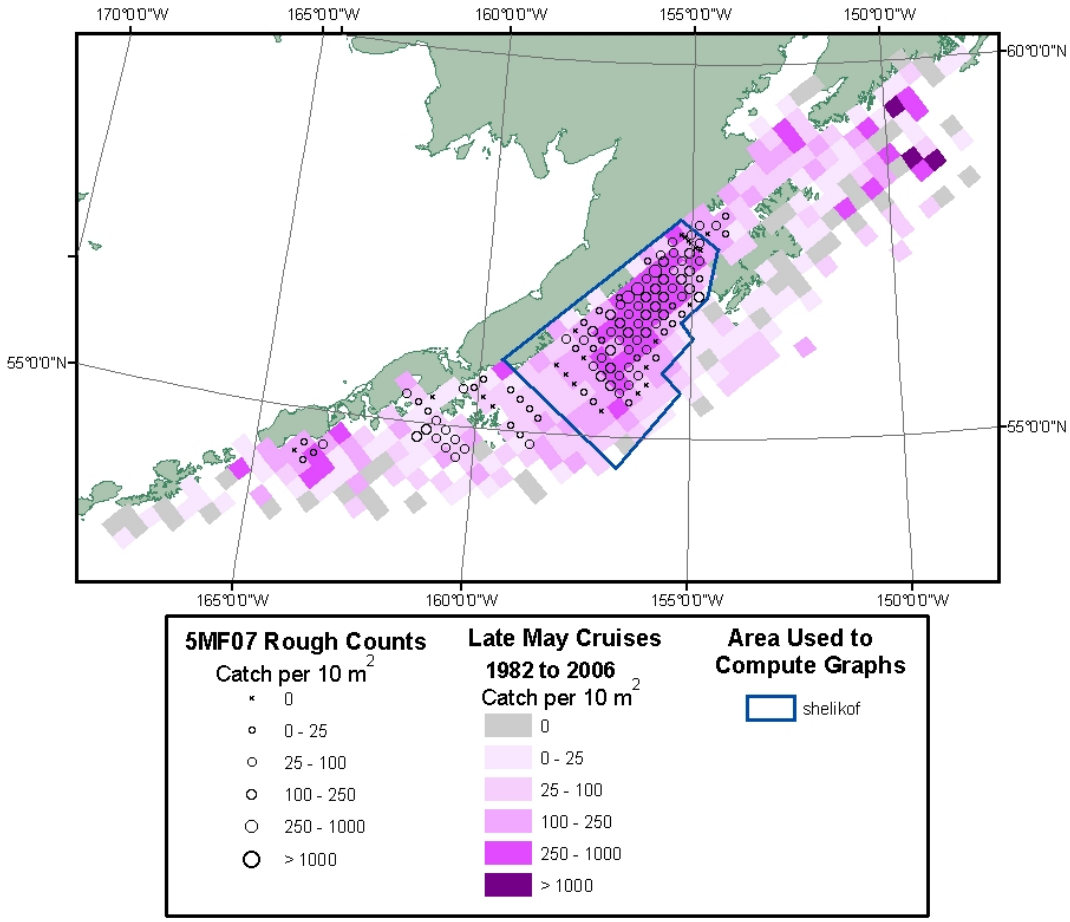


FIGURE 6. Mean catch per 10 m^2 for late May cruises during 1982-2006, with observed rough counts overlayed for 2007.

Recruitment Time Series: The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition in time. The data set consisted of age-2 pollock abundance estimates from 1961-2007, representing the 1959-2005 year classes. There were a total of 47 recruitment data points. The 33% (0.354736 billion) and 66% (0.728742 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 2007 year class could be predicted from the size of the 2005 year class. The 2005 year class was estimated to be 0.482537 billion and was classified as average. The probabilities of other recruitment states following an average year class for a lag of 2 years (n=47) are given below:

TABLE 5. Probability of the 2007 year class being weak, average and strong following an average 2005 year class.

2007 Year Class		2005 Year Class	Probability	N
Weak	Follows	Average	0.13333	6
Average	follows	Average	0.08889	8
Strong	follows	Average	0.08889	8

The probability was highest for a weak year class following an average year class and almost twice the other two probabilities. We classified this data element to be in the weak category but toward the higher end of the range, giving it a score of 1.66.

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 (0.2377 million tons) and recruitment (0.4475 billion). These values were used to partition the spawner-recruit space into 4 states. 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. These areas correspond to the lower left, upper left, lower right, and upper right quadrants of the lower panel in Figure 7. The classification then makes it possible to study the probability of any state and the transitions between the states.

The time series of recruitment data and the 2x2 spawning biomass-recruitment plot are shown in Figure 7.

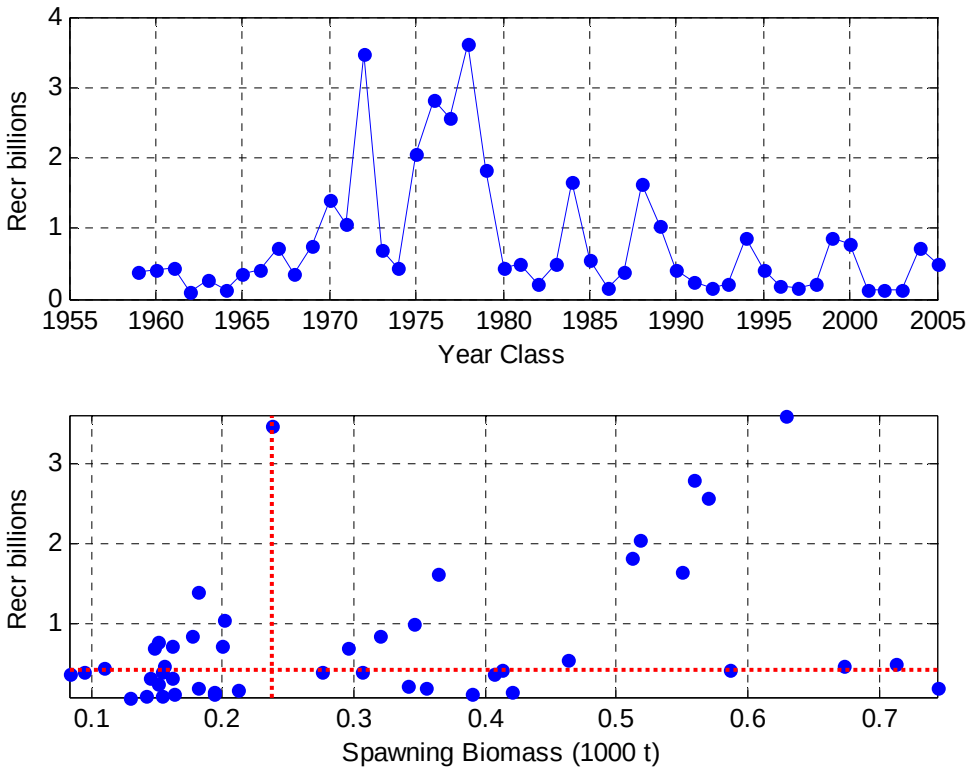


FIGURE 7. Time series of recruitment and the 2x2 classification of the 2007 spawning biomass and recruitment data.

TABLE 6. Transition matrix calculated from data in Figure 7.

Transition Probability Matrix	To state 1	To state 2	To state 3	To state 4
From state 1	0.6429	0.3571	0.0000	0.0000
From state 2	0.3750	0.5000	0.0000	0.1250
From state 3	0.1111	0.0000	0.4444	0.4444
From state 4	0.0000	0.0000	0.3333	0.6667

To calculate the score from Figure 7 takes two steps. First, we determine which state is the current state by taking the estimate of spawning biomass in 2007 (0.15527 million tons) and note that it falls below the median value of 0.2377. We can see that in 2007 we are in either state 1 or state 2 (low spawning biomass). The probabilities of transitioning from state 1 or state 2 to other states are given in the first two rows of Table 6.

If we are in state 1, then recruitment can either be below (a recruitment score of 1) or above (a recruitment score of 3) the median (a recruitment score of 2). Note the probability for transitioning from state 1 to state 3 or 4 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 transition 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.

$$= \frac{(1*0.6429)+(3*0.3571)}{(0.6429+0.3571)} = 1.714$$

Similarly, the weighted recruitment score (given we start in state 2) is the recruitment score for staying in state 2 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 2 back to state 2) plus the recruitment score for transitioning from state 2 to state 1 (recruitment below the median, score=1) times the weight (the probability of transitioning from state 2 to state 1), plus the recruitment score for transitioning from state 2 to state 4 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 2 to state 4), all divided by the sum of the weights.

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

We average over these two weighted scores because starting from either state 1 or state 2 is equally likely if the starting spawning biomass in 2007 is below the median, giving a final score of 1.98, or average.

One final calculation possible from these data is the expected first passage time or the number of years on average that a stock and recruitment system in a particular state will take to return to a particular state. These data are given in Table 7. For example, it would take 8.0 years for Gulf of Alaska pollock in State 2 to return to State 1.

TABLE 7. Expected First Passage Time.

State	1	2	3	4
1	3.8571	2.8000	22.2000	19.2000
2	8.0000	5.4000	19.4000	16.4000
3	21.0000	23.8000	4.8000	5.6400
4	24.0000	26.8000	3.0000	2.8800

CONCLUSION

The larval index data element was weighted low (0.1) because the recruitment variability explained by larval abundance was very low. All the remaining elements were weighted equally.

Based on these seven elements and the weights assigned in Table 8, below, the FOCI forecast of the 2007 year class is average.

TABLE 8. Final 2007 pollock recruitment forecast.

Element	Weights	Score	Total
Rain	0.15	2.58	0.3870
Wind Mixing	0.15	1.96	0.2940
Advection	0.15	0.83	0.1245
Larval Index-abundance	0.10	2.00	0.2000
Larval Rough Counts and Distribution	0.15	1.67	0.2505
Time Sequence of R	0.15	1.66	0.2490
Spawner-Recruit Time Series	0.15	1.98	0.2970
Total	**1.00**		**1.802= Average**

ADDENDUM

The information provided below is not used in the forecast but is presented for additional perspective. Figure 8 shows the latest and preliminary data on pollock from the 2007 late larval survey put into a historical context. Total larval numbers track the spawning biomass in the western and central GOA (Fig. 9) (taken from the 2006 SAFE report) fairly well. These trends follow estimates of spawning biomass from acoustic surveys (Fig. 10). We note that the 2007 numbers continue to trend in low numbers. It seems that since about 2002 we have been in a phase of very low larval numbers. Strong recruitment can arise from such low numbers for a number of reasons, for example, 1) a strong year class may be hidden in the total numbers but is better reflected by the size structure of the larval population, 2) lack of overlap in predators and prey may relax predation on juveniles to generate a strong cohort, especially in the current regime when predation seems very strong, or the 3) recruits are coming from or going to someplace else.

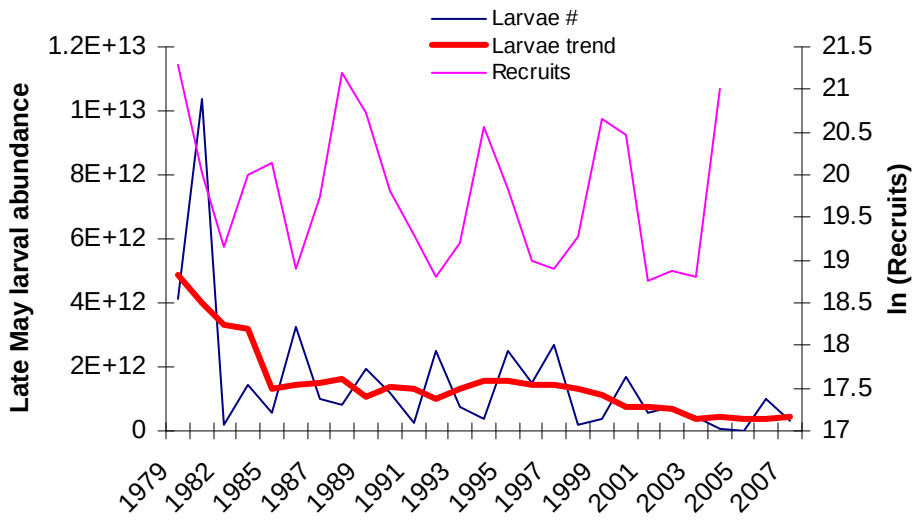


FIGURE 8. Late May larval abundance and running mean trend (red) in the Shelikof to Semidi region compared against the number of recruits.

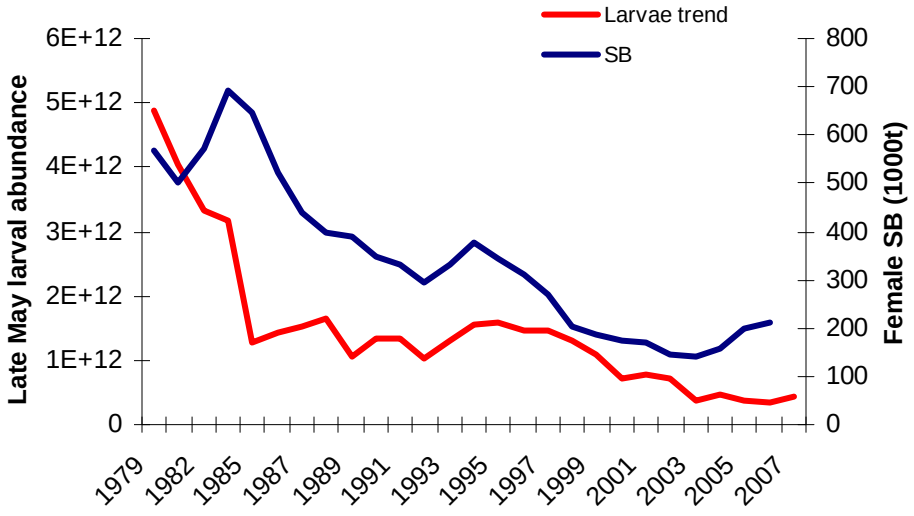


Figure 9. Late May larval abundance trend in the Shelikof to Semidi region (red) compared against the spawning biomass in the Gulf of Alaska (blue).

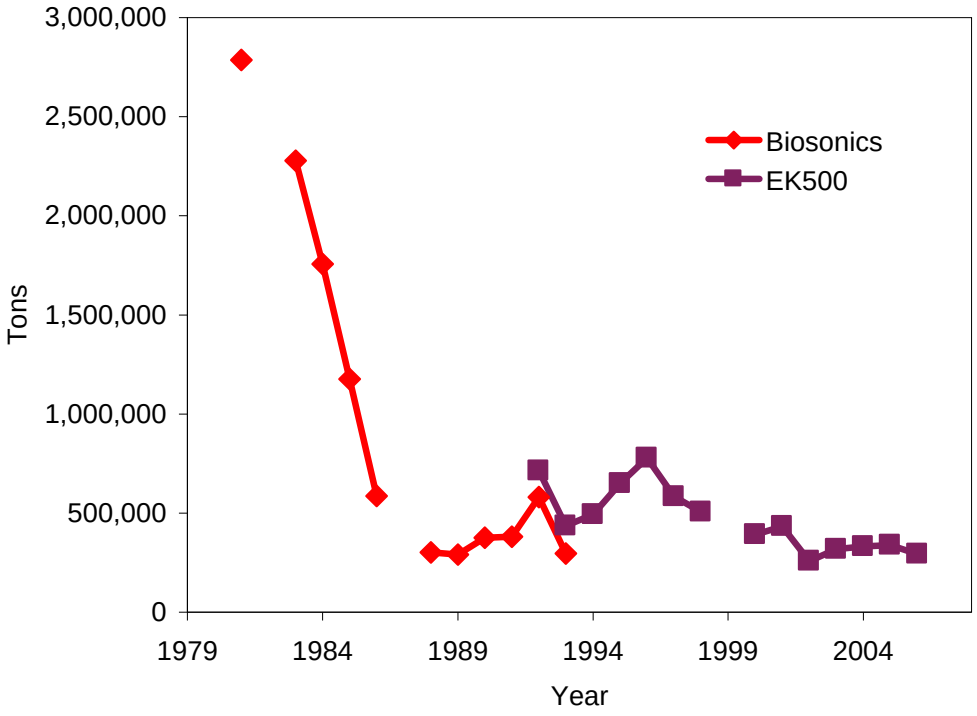


Figure 10. Comparison of estimates of GOA spawning biomass (tons) from AFSC hydroacoustic surveys using two different sets of instruments.

APPENDIX D REFERENCES

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