

# Chapter 1: Assessment of Walleye Pollock in the Gulf of Alaska

by

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## Summary of major changes

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

### *New Input data:*

1. Fishery: 2005 total catch and catch at age.
2. Shelikof Strait EIT survey: 2006 biomass and age composition.
3. NMFS bottom trawl survey: 2005 age composition
3. ADF&G crab/groundfish trawl survey: 2006 biomass and length 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 1999-2005 was used again for this year's assessment.

### *Assessment results*

The model estimate of spawning biomass in 2007 is 160,670 t, which is 29% of unfished spawning biomass and below  $B_{40\%}$  (220,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. Estimates of stock status in 2007 indicate a 16% decline in spawning biomass from 2006. These results are consistent with survey trend estimates (13% decline in the Shelikof Strait EIT survey, 13% decline in the ADFG trawl survey). The dip in spawning biomass is expected to be short-lived, as projections indicate an increase in spawning biomass after 2007. These results depend critically on the magnitude of the 2004 year class, which appears to be above average, but is still uncertain. The author's 2007 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 63,800 t, a decrease of 22% from the 2006 ABC. This recommendation is based on a more conservative alternative to the maximum permissible  $F_{ABC}$  introduced in the 2001 SAFE. The OFL in 2007 is 87,220 t. In 2008, the recommended ABC and OFL are 76,960 t and 105,490 t, respectively.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendations for 2007 and 2008 in Appendix A are 6,157 t and the OFL is 8,209 t (the same for both years).

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

From the December, 2005 minutes:

*"The SSC notes that FOCI predictions of year-class strength have been done for many years, so it might be timely to do a formal evaluation of the ability to forecast recruitment from environmental variables. The SSC requests that the authors do a retrospective analysis of the FOCI forecasts (and the components going into the forecasts) to determine the accuracy of these forecasts."*

FOCI continues to develop, evaluate and test its recruitment forecast methodology. A recent “white paper” (Megrey and Macklin, 2006, unpublished) reviews the history behind the current forecast, and the efficacy of the forecast. It also describes current research to improve the forecast.

*Current research to improve the forecast:* FOCI continues to examine different methodologies to improve the forecast. A recent paper (Megrey et al. 2006) examined the performance of various forecasting statistical models in a simulation modeling framework. We also are preparing for publication the results of another project which looks at the utility of resampling to evaluate forecast performance in a real-world data situation (Lee et al. in prep. ). We also continue to improve on our Gulf of Alaska pollock IBM model. Our current effort is to incorporate juvenile life history and predation mortality processes into the model to acknowledge the importance of shifting control of recruitment (Bailey, 2000; Hollowed et al. 2000). Initial results of this effort are a recruitment forecast scheme and comparison of the forecast to stock assessment results (Parada et al. submitted). Last, but not least, in 2007 we will begin to calculate the expected number of late larvae to survive to a fixed length (15 mm) based on the abundance and length frequency information collected during the late larvae survey (Bailey, proposed).

*Recruitment forecast workshop:* We participated and contributed to an internal AFSC Recruitment Forecasting Workshop in August of this year. Scientists from the Resource Ecology and Ecosystem Modeling program, the Recruitment Processes (FOCI) program, the Ocean Carrying Capacity program, Auke Bay Laboratory’s groundfish assessment program, and the Pacific Marine Environmental Laboratory attended. Based on workshop discussions, we plan to begin development of a new prediction scheme that follows a year class through time much like hurricane prediction follows the storm along its path and predicts its intended target. This prediction scheme will require the cooperation and collaboration of several groups at the AFSC. Furthermore, FOCI will complete in the new fiscal year our white paper summarizing the history, status, and future steps for the walleye pollock recruitment prediction. This white paper will incorporate an integrated assessment of workshop results to define FOCI’s revised pollock prediction strategy. It will be available for the Council to review in February 2007.

*“The authors should consider reducing the number of selectivity parameters estimated in the model, in which selectivity is allowed to change each year. Perhaps an approach like the EBS pollock assessment, in which selectivity varies every three years, would be better.”*

Although fishery selectivity is parameterized so that annual variation in selectivity is possible, the parameters are constrained in the amount that they can vary from one year to the next. This is achieved using a penalty on the first differences of the selectivity parameters. The effective degrees of freedom are less than the simple count of parameters. Allowing selectivity to vary every third year is an alternative way to constrain selectivity that would be most appropriate when changes occur gradually over time. However, if the fishery targets strong incoming year classes this would imply a different pattern: a sudden shift, followed by a gradual return to the mean. Three-year step changes selectivity would be unable to capture the pattern. The advantage of allowing penalized annual changes in selectivity is that the data determine the years in which selectivity changes, so that no arbitrary pattern is imposed on the data. A disadvantage is that the penalty on the deviations is somewhat arbitrary, but this shortcoming is also shared by three-year step change approach.

*“The SSC also appreciates the discussion of maturity-at-age and notes that walleye pollock in the GOA is the only stock off Alaska with a time series of maturity-at-age. In the long term, the SSC recommends that the authors investigate the changes in maturity-at-age over time and evaluate the consequences on population dynamics of walleye pollock.”*

Although a long time series of maturity-at-age data are available from the Shelikof Strait EIT survey, an initial concern before starting more detailed modeling and analysis was the reliability of these data, which are based on visual stage determinations. A paper (K. Williams in review) addresses this issue and validates visual stage determinations (with minor reservations). We have conducted preliminary analyses to estimate trends in maturation reaction norms for pollock (similar to the work by Heino et al. 2002 on Atlantic cod); however this work is ongoing and definitive results are unavailable at this time.

## **Introduction**

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

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

## **Fishery**

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

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

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

Kodiak is the major port for pollock in the Gulf of Alaska, with 59% of the 2001-2005 landings. Sand Point and Dutch Harbor are also important ports, sharing 28% of 2001-2005 landings. Secondary ports,

including Cordova, Port Moller, King Cove, Akutan, Seward, account for the remaining 13% of the 2001-2005 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 unfished levels.

### **Data Used in the Assessment**

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

### ***Total Catch***

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

### ***Fishery Age Composition***

Estimates of fishery age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). Pollock otoliths collected during the 2005 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 2005 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    | 225          | 385          | 403        | 113                            |
|                            | No. lengths | 1270         | 4019         | 1393       | 339                            |
|                            | Catch (t)   | 9,568        | 26,968       | 8,516      | 2,666                          |
| 2nd half (C and D seasons) | No. ages    | 397          | 100          | 410        | ---                            |
|                            | No. lengths | 3142         | 308          | 2640       | ---                            |
|                            | Catch (t)   | 21,405       | 936          | 10,814     | 3                              |

In the first half of 2005, the age-5 and age-6 fish (2000 and 1999 year classes respectively) were dominant in all areas. In the second half of 2005, the age distribution was similar, with age-5 and age-6 fish dominant in all areas. Younger fish (< age-5) were relatively more common in areas 620 and 630 compared to area 610 (Fig. 1.2).

Fishery catch at age in 1976-2005 is presented in Table 1.4 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.5.

### ***Gulf of Alaska Bottom Trawl Survey***

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) every three years (beginning in 1984) to assess the abundance of groundfish in the Gulf of Alaska (Table 1.6). Starting in 2001, the survey frequency was increased to every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and management area (Martin 1997). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized poly-Nor' eastern high opening bottom trawls rigged with roller gear. In a typical survey, 800 tows are completed. On average, 70% of these tows contain pollock (Table 1.7).

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

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

### *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 1.8). 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. Age composition estimates for the 2005 survey were dominated by age-1 fish, which were only common in areas 620 and 630 (Fig. 4). The estimated abundance of age-1 fish was 270 million, which is the second largest estimate during ten bottom trawl surveys conducted in the Gulf of Alaska. The age-5 and age-6 fish (2000 and 1999 year classes respectively) were the most common of the older age groups (i.e., > age-1), which was similar to the fishery age composition in 2005.

### *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 and Yasnak, 2006). 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. Since eulachon abundance has increased since 2000, the more recent surveys increased by a greater percentage than the pre-2000 surveys, though not enough to significantly alter the overall pattern in the time series. The 2006 biomass estimate for Shelikof Strait is 293,609 t, a decrease of 13% from the 2005 biomass (Table 1.6). Biomass  $\geq 43$  cm (a proxy for spawning biomass) decreased by 10% from the 2005 estimate due to ageing of the relatively strong 1999 and 2000 year classes without significant recruitment of later year classes to the spawning population (Fig. 1.5). The estimate of age-2 abundance in Shelikof Strait was 0.8 billion, which is consistent with the age-1 estimate in 2005 (1.6 billion), suggesting that 2004 year class may be above average.

Additional EIT surveys in winter 2006 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.

2006 EIT survey results

|                      |         | <i>Shumagin</i> | <i>Sanak/<br/>Morzhovoi Bay</i> | <i>Shelikof</i> | <i>Chirikof Island</i> | <i>Total</i> |
|----------------------|---------|-----------------|---------------------------------|-----------------|------------------------|--------------|
| Total                | Tons    | 37,338          | 138,893                         | 293,609         | 69,012                 | 538,852      |
|                      | Percent | 7%              | 26%                             | 54%             | 13%                    |              |
| Biomass $\geq 43$ cm | Tons    | 23,345          | 137,647                         | 219,670         | 68,818                 | 449,480      |
|                      | Percent | 5%              | 31%                             | 49%             | 15%                    |              |

In comparison to 2005, biomass estimates are lower in the Shumagin area (28% decrease), Shelikof Strait (13% decrease), and Chirikof Island (10% decrease), but more than 2 times higher in the Sanak Trough/Morzhovoi Bay area. The total biomass  $> 43$  cm, a proxy for spawning biomass, is comparable to the assessment model's estimate of male + female spawning biomass of 424,000 t in 2006. Since surveys

outside Shelikof Strait are not used in the model, these estimates provide independent support for the assessment results. Large biomass changes from one year to the next in a spawning aggregation suggest that either pollock are spawning in different locations, or interannual differences in the timing of spawning.

Since the assessment model only includes individuals age 2 and older, the biomass of age-1 fish in the 1995, 2000, and 2005 surveys was subtracted from the total biomass for those years, reducing the biomass by 15%, 13%, and 5% respectively (Table 1.6). In all other years, the biomass of age-1 fish was less than 2% of the total EIT biomass estimate.

#### *Echo Integrated Trawl Survey Length Frequency*

Annual biomass distributions by length from the Shelikof Strait EIT survey show the progression of strong year classes through the population (Fig. 1.6). 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 are not used in the assessment model because estimates of age composition are available for all surveys.

#### *Echo Integrated Trawl Survey Age Composition*

Estimates of numbers at age from the Shelikof Strait EIT survey (1981 - 1991, 1993 -1998, 2000-2005 (Table 1.9) were obtained from random otolith samples and length frequency samples. Otoliths collected during the 1994 - 2006 EIT surveys were aged using the revised criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.10.

#### *Egg Production Estimates of Spawning Biomass*

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

#### *Alaska Department of Fish and Game Crab/Groundfish Trawl Survey*

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

The 2006 biomass estimate for pollock for the ADF&G crab/groundfish survey was 69,044 t, a decrease of 13% from the 2005 biomass estimate (Table 1.6).

#### *ADF&G Survey Length Frequency*

Pollock length-frequencies for the ADF&G survey in 1989-2002 (excluding 1991 and 1995) typically show a primary mode at lengths greater than 45 cm (Fig. 1.7). 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 ADF&G 400-mesh eastern trawl of 3.84 (SE = 1.26), indicating that 400-mesh eastern trawl CPUE for pollock would need to be multiplied by this factor to be comparable to the NMFS poly-Nor' eastern trawl.

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

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

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

1977), in which the sum of the NMFS survey biomass estimates for an INPFC area for 1984-99 is divided by the sum of the proxy biomass estimates for the same period.

Variances were obtained by bootstrapping data within site-depth strata and repeating the biomass estimation algorithm. A parametric bootstrap assuming a lognormal distribution was used for the INPFC area correction factors. Variance estimates do not reflect the uncertainty in the FPC estimate. In the assessment model, we do not apply the FPC to the biomass estimates, but instead include the information about FPC estimate (mean and variance) as a likelihood component for relative survey catchability,

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

where  $q_1$  is the catchability of the NMFS bottom trawl survey,  $q_2$  is the catchability of historical 400-mesh eastern trawl surveys,  $\hat{FPC}$  is the estimated fishing power correction (= 3.84), and  $\sigma_{FPC}$  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 1.11). 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 1.11), and indicate a large increase in pollock biomass in the Gulf of Alaska occurred between the early 1960s (~200,000 t) and the mid 1970s (>2,000,000 t). Increases in pollock biomass between the 1960s and 1970s were also noted by Alton et al. (1987). In the 1961 survey, pollock were a relatively minor component of the groundfish community with a mean CPUE of 16 kg/hr (Ronholt et al. 1978). Arrowtooth flounder was the most common groundfish with a mean CPUE of 91 kg/hr. In the 1973-76 surveys, the CPUE of arrowtooth flounder was similar to the 1961 survey (83 kg/hr), but pollock CPUE had increased 20-fold to 321 kg/hr, and was by far the dominant groundfish species in the Gulf of Alaska. Meuter and Norcross (2002) also found that pollock was low in the relative abundance in 1960s, became the dominant species in Gulf of Alaska groundfish community in the 1970s, and subsequently declined in relative abundance.

Questions concerning the comparability of pollock CPUE data from historical trawl surveys with later surveys probably can never be fully resolved. However, because of the large magnitude of the change in CPUE between the surveys in the 1960s and the early 1970s using similar trawling gear, the conclusion that there was a large increase 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 euphausiid prey (Somerton et al. 1979, Alton et al. 1987). More recent work has focused on role of climate change (Anderson and Piatt 1999, Bailey 2000). The occurrence of large fluctuations in pollock abundance without large changes in direct fishing impacts suggests a need for precautionary management. If pollock abundance is controlled primarily by the environment, or through indirect ecosystem effects, it may be difficult to reverse population declines, or to achieve rebuilding targets should the stock become depleted. Reliance on sustained pollock harvests in the Gulf of Alaska, whether by individual fishermen, processing companies, or fishing communities, may be difficult over the long-term.

### ***Qualitative trends***

To assess qualitatively recent trends in abundance, we standardized each survey time series by dividing the annual estimate by the average since 1986 so all could be plotted on the same scale. The Shelikof Strait EIT survey was split into separate time series corresponding to the two acoustic systems used for the survey. Although there is considerable variability in each survey time series, a fairly clear downward trend is evident to 2000, followed by a stable, though variable, trend (Fig. 1.8).

We also evaluated indices derived from fisheries catch data for trends in biological characteristics (Fig. 1.9). The percent of females in the catch is close to 50-50, but shows a slight, though non-significant, downward trend, which may be related to changes in the seasonal distribution of the catch. The mean age shows interannual variability due to strong year classes passing through the population, but no downward trends that would suggest excessive mortality rates. The percent of old fish in the catch (nominally defined as age 8 and older) is also highly variable due to variability in year class strength, but increased to a peak in 1997, and has since declined due to weaker recruitment in the 1990s 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%. We computed an index of catch at age diversity using the Shannon-Wiener information index,

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

where  $p_a$  is the proportion at age. Increases in fishing mortality would tend to reduce age diversity, but year class variability would also influence age diversity. The index of age diversity is relatively stable during 1976-2005 (Fig. 1.9).

### ***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 1.12). 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 2006 Shelikof EIT survey age-1 estimate is 162 million (11th in abundance out of 23 surveys), which suggests recruitment for the 2005 year class is not exceptional. In 2006, the EIT survey in the Shumagin area estimated an abundance of 1.7 billion age-1 pollock. Had this many age-1 pollock been found during the Shelikof Strait EIT survey it would have been an indication of strong recruitment, but the time series of Shumagin area surveys is too short to make inferences.

### ***2006 Pollock Year-Class Prediction***

#### *Data*

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

1. Observed 2006 Kodiak monthly precipitation. The Kodiak Weather Service Office (<http://padq.arh.noaa.gov/>) prepares monthly precipitation totals (inches) from hourly observations. Data for 2006 were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.
2. Wind mixing energy at [57°N, 156°W] estimated from 2006 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<sup>-3</sup>) 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 2006.
4. Rough counts of pollock larvae from a survey conducted in late May–early June 2006.
5. Estimates of age-2 pollock abundance and spawner biomass from the 2006 assessment.

#### *Analysis*

*Kodiak Precipitation:* Kodiak precipitation is a proxy for fresh-water runoff that contributes to the density contrast between coastal and Alaska Coastal Current water in Shelikof Strait. The greater the contrast, the more likely that eddies and other instabilities will form. Such secondary circulations have attributes that make them beneficial to survival of larval pollock.

The season began with lower than normal precipitation during January, February and March. This decreased the potential for formation of baroclinic instabilities prior to and during spawning. April and May brought a return toward normal, however the potential for instabilities forming from increased freshwater input to coastal water was still lower than expected. June was wet (at 151% of the 30-yr June average), and this may have presented favorable habitat for late larval- and early juvenile-stage walleye pollock.

Kodiak precipitation for 2006

| <i>Month</i> | <i>% 30-yr average</i> |
|--------------|------------------------|
| Jan          | 44                     |
| Feb          | 63                     |
| Mar          | 69                     |
| Apr          | 92                     |
| May          | 77                     |
| June         | 151                    |

Based on this information, the forecast element for Kodiak 2006 rainfall has a score of 1.72. This is "weak to average" recruitment on the 5-category continuum from 1 (weak) to 3 (strong), and "average" using three categories.

*Wind Mixing:* Following the decadal trend established in the late 1990s, wind mixing at the southern end of Shelikof Strait was again below the long-term average for all winter and spring months of 2006, except June.

Wind mixing at the exit of Shelikof Strait for 2006

| <i>Month</i> | <i>% 30-yr average</i> |
|--------------|------------------------|
| Jan          | 30                     |
| Feb          | 85                     |
| Mar          | 52                     |
| Apr          | 65                     |
| May          | 56                     |
| June         | 140                    |

Strong mixing in winter helps transport nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak spring mixing is thought to better enable first feeding pollock larvae

to locate and capture food. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment. This year's scenario produces a wind mixing score of 1.98, which equates to "average".

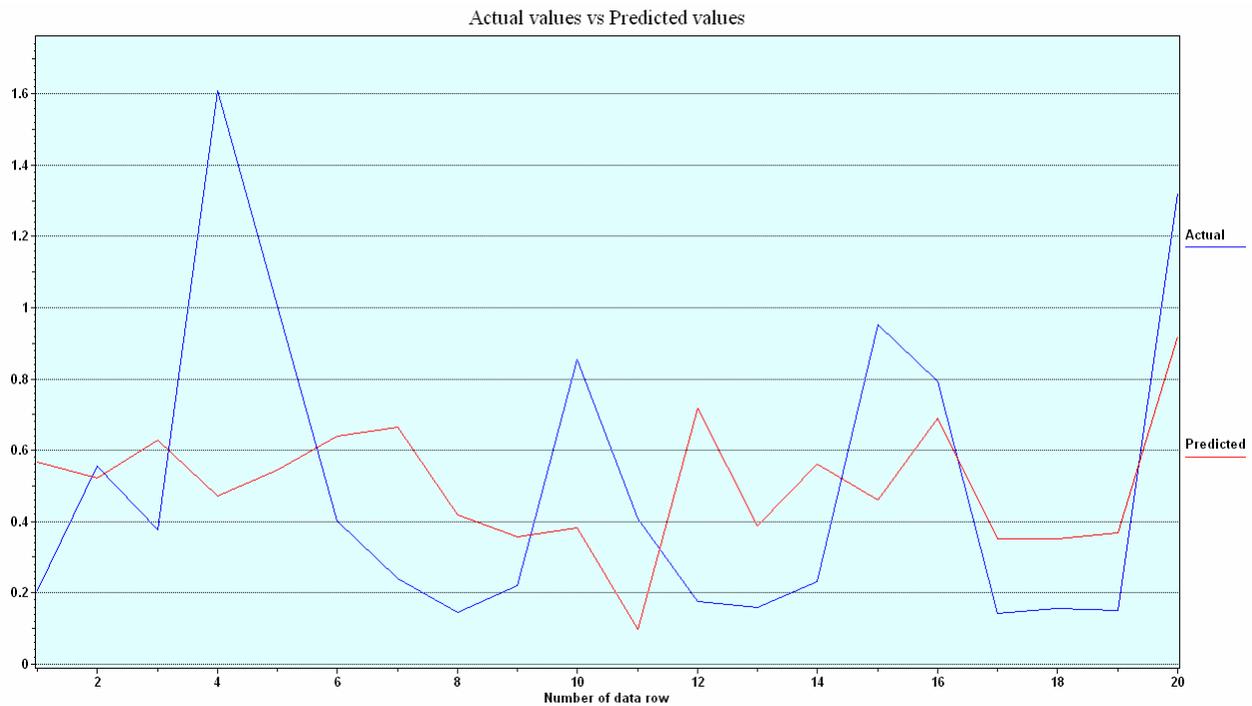
*Winds and Transport in Alaska Coastal Current:* The transport in the Alaska Coastal Current is strongly correlated with along shore winds. While the winds in March 2006 were moderate for the time of year, April had 3-4 major storms that resulted in strong currents in the Alaska Coastal Current. This flow would tend to advect the larvae downstream out of the preferred nursery grounds in the Shelikof Sea valley and into the basin. Conditions in May were calmer resulting in weaker transport, and retention of larvae in the sea valley and along the Alaska Peninsula.

Observations from two satellite-tracked drifters that entered Shelikof Strait in the spring of 2006 support this pattern. One drifter quickly traveled down the strait in April and exited the sea valley by mid-May. Based on these observations, the 2006 pollock year-class prediction has a score of 1.72, which equates to weak to average based on transport in the Alaska Coastal Current.

*Relating the Larval Index to Recruitment:* As in last year's analysis, a nonlinear neural network model with one input neuron (larval abundance), three hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (CPUA, average catch, m<sup>-2</sup>) to age-2 recruitment abundance (billions). The model estimated eight weighting parameters. The neural network model, which used the 20 observation pairs of the table below to fit the model, had a very low R<sup>2</sup> of 0.078. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) are given in the figure below, where row number corresponds to the rows of the data matrix given in table.

Data used in the neural network model.

| <i>Year Class</i> | <i>Mean CPUA</i> | <i>Recruit</i> |
|-------------------|------------------|----------------|
| 1982              | 71.14            | 0.206506       |
| 1985              | 80.42            | 0.554497       |
| 1987              | 329.74           | 0.376806       |
| 1988              | 260.21           | 1.610350       |
| 1989              | 537.29           | 1.004960       |
| 1990              | 335.00           | 0.401599       |
| 1991              | 54.22            | 0.239704       |
| 1992              | 562.79           | 0.145232       |
| 1993              | 185.34           | 0.219996       |
| 1994              | 126.58           | 0.853329       |
| 1995              | 610.33           | 0.406418       |
| 1996              | 477.69           | 0.174581       |
| 1997              | 568.42           | 0.158482       |
| 1998              | 72.20            | 0.230184       |
| 1999              | 96.14            | 0.951485       |
| 2000              | 492.04           | 0.794435       |
| 2001              | 171.30           | 0.140742       |
| 2002              | 175.64           | 0.155498       |
| 2003              | 135.36           | 0.150900       |
| 2004              | 21.22            | 1.320550       |



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

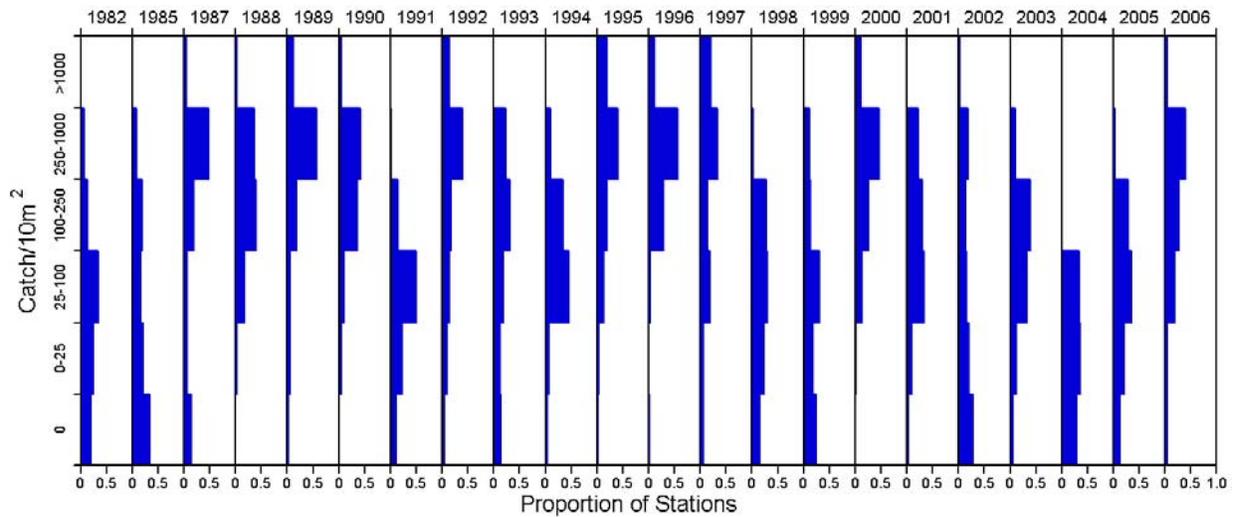
The trained network was then used to predict the recruitment for 2005 and 2006. The predictions are given in the table below.

Neural network model predictions for 2005 and 2006

| <i>Year</i> | <i>Actual Recruitment</i> | <i>Predicted Recruitment</i> |
|-------------|---------------------------|------------------------------|
| 2005        | n/a                       | 0.542                        |
| 2006        | n/a                       | 0.623                        |

These values, using the 33% (0.3469) and 66% (0.7340) cutoff points given below, correspond to an average 2005 year class and an average 2006 year class.

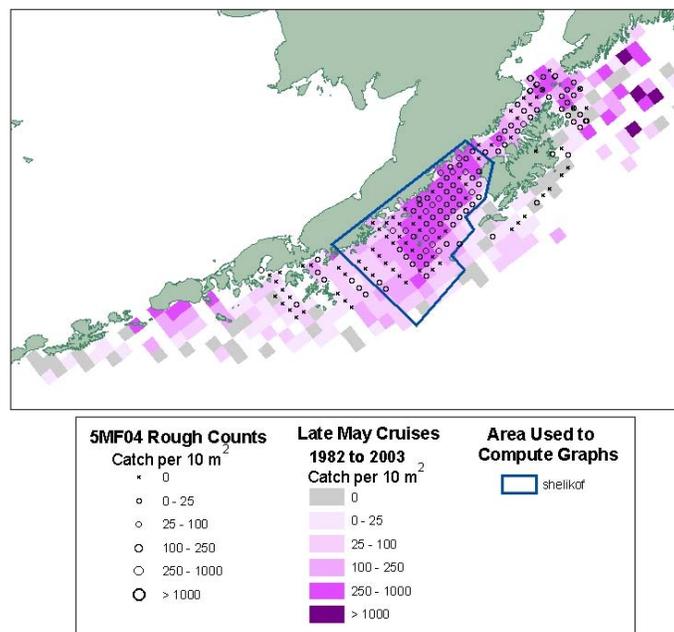
*Larval Index Counts:* Plotting the data by year and binning the data into catch/10 m<sup>2</sup> categories (given below) provides another view of the data. The pattern for 2006 (based on rough counts) show patterns different from last year in that the frequency distribution is skewed towards the higher binning categories. These patterns indicate that the 2006 year class may be above average.



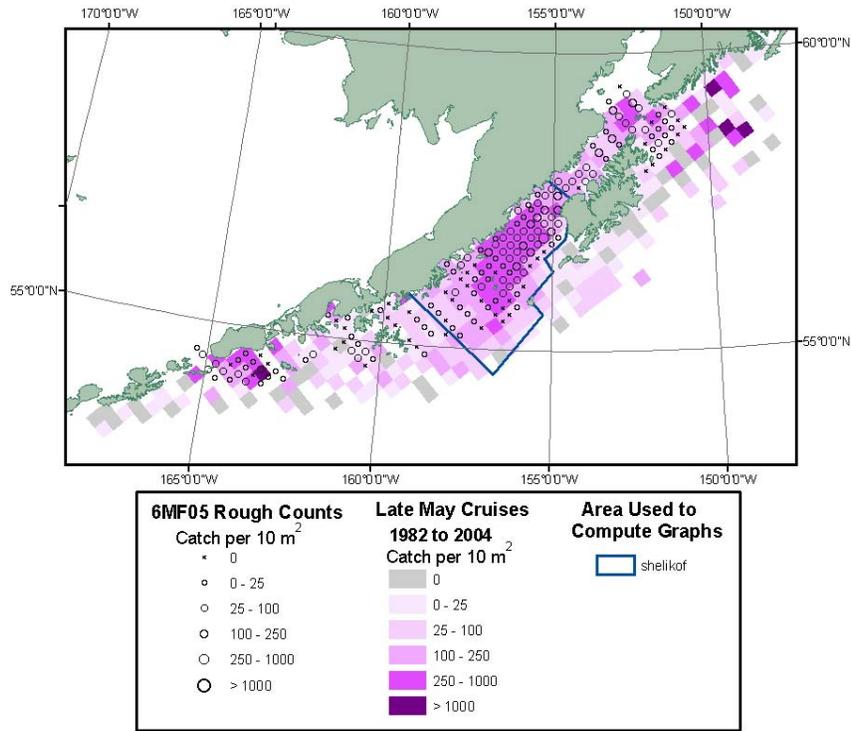
Histogram of larval walleye pollock density in late May (1982-2006).

Data were binned into catch/10 m<sup>2</sup> categories. The data from 2000-2005 are rough counts taken at sea, and the 2006 data are from the 4MF06 cruise that was completed in late May.

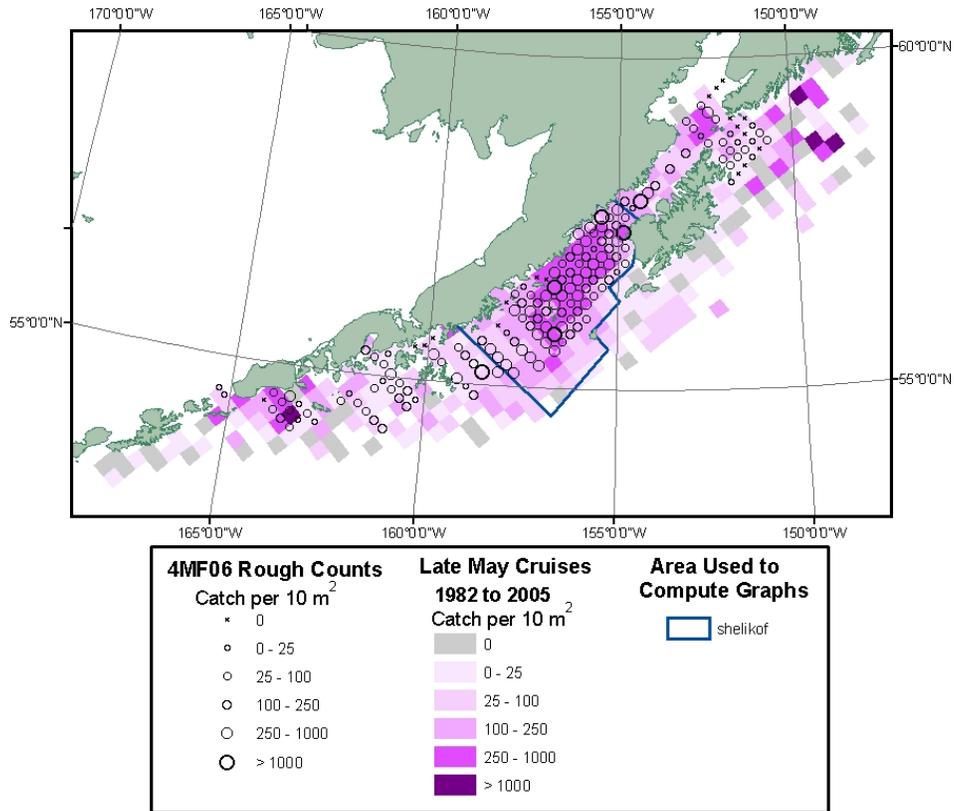
The data for the above figure are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae. This year's distribution of pollock appears to be centered in the typical reference area, and the larval abundance figures in the middle of the reference area seem to be average. Also, the distribution of larvae in 2005 are further to the west compared to 2004, suggesting that some of the Shelikof larvae might be in their nursery area at the time of the survey. Comparing the three maps shows that the 2006 rough counts seem to be higher compared to 2005 and the distribution of larvae at high densities was spatially broader. Given these two pieces of information, the score for larval index is set to the high end of average or 2.33.



Mean catch per 10 m<sup>2</sup> for late May cruises during 1982-2003, with observed rough counts for 2004.



Mean catch per 10 m<sup>2</sup> for late May cruises during 1982-2004, with observed rough counts for 2005.



Mean catch per 10 m<sup>2</sup> for late May cruises during 1982-2005, with observed rough counts for 2006.

*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 abundance estimates from 1961-2006, representing the 1959-2004 year classes. There were a total of 46 recruitment data points. The 33% (0.3469 billion) and 66% (0.7340 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 2006 year class could be predicted from the size of the 2004 year class. The 2004 year class was estimated to be 1.3206 billion and was classified as strong. The probabilities of other recruitment states following a strong year class for a lag of 2 years (n=46) are given below:

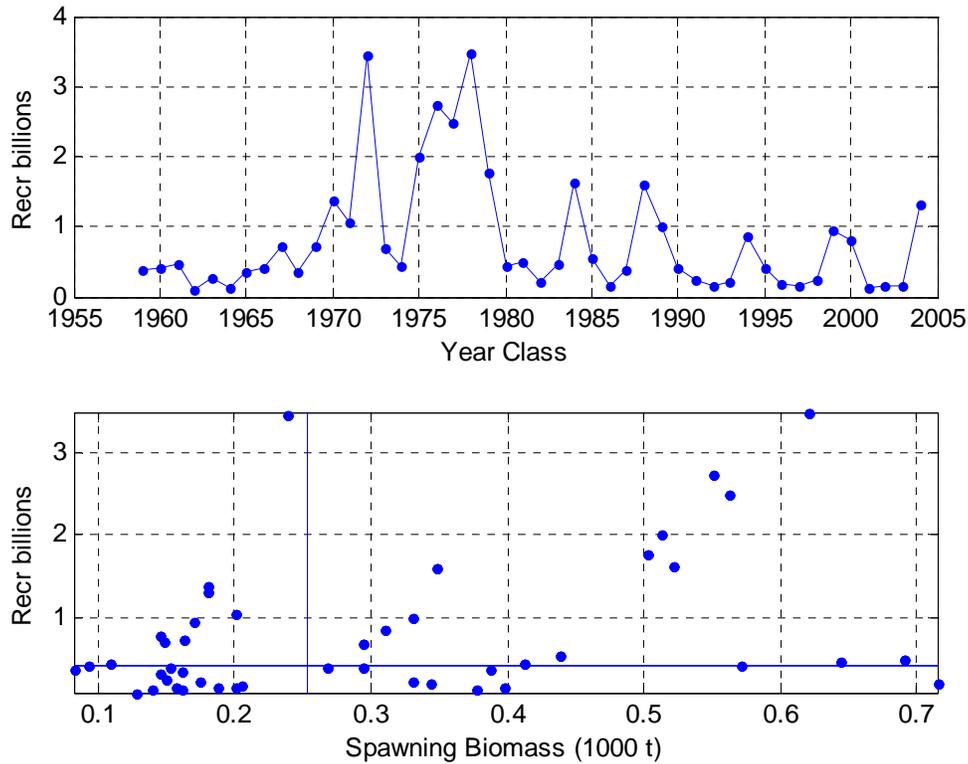
Probability of the 2006 year class being weak, average and strong following a strong 2004 year class

| 2006 Year Class |         | 2004 Year Class |  | Probability | N |
|-----------------|---------|-----------------|--|-------------|---|
| Weak            | Follows | Strong          |  | 0.11364     | 5 |
| Average         | follows | Strong          |  | 0.11364     | 5 |
| Strong          | follows | Strong          |  | 0.11364     | 5 |

The probability for all possibilities were the same. We classified this data element as a neutral, giving it a score of average or 2.0 but we will use a weighting factor of 0.0 since it does not contribute any information to the forecast.

*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 (0.2531 million tons) and recruitment (0.435 billion). These values were used to partition the spawner-recruit space into 4 tiles, 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 the figure below. 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 the figure below.



Time series of recruitment and the 2x2 classification of the 2006 spawning biomass and recruitment data.

Transition matrix calculated from data above figure.

| <i>Transition Probability Matrix</i> | <i>To state 1</i> | <i>To state 2</i> | <i>To state 3</i> | <i>To state 4</i> |
|--------------------------------------|-------------------|-------------------|-------------------|-------------------|
| 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                         | 0.1112            | 0.0000            | 0.4444            | 0.4444            |
| From state 4                         | 0.0000            | 0.0000            | 0.3571            | 0.6429            |

To calculate the score from takes two steps. First, we determine which state is the current state by taking the estimate of spawning biomass in 2006 (0.1803 million tons) and note that it falls below the median value of 0.2531. We can see that in 2006 we are in either state 1 or state 2. The probabilities of transitioning from state 1 or state 2 to other states are given in the first two rows of above table. If we are in state 1, then recruitment can either be below (a recruitment score of 1) or above the median (a recruitment score of 3). Note the probability for transitioning from state 1 to state 3 or 4 is 0.0. 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 2006 is below the median, giving a final score of 1.98, or average. One final calculation 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 the table below. For example, it would take 7.75 years for Gulf of Alaska pollock in State 2 to return to State 1.

Expected First Passage Time

| <i>State</i> | <i>1</i> | <i>2</i> | <i>3</i> | <i>4</i> |
|--------------|----------|----------|----------|----------|
| 1            | 3.76     | 2.80     | 22.00    | 19.20    |
| 2            | 7.75     | 5.27     | 19.20    | 16.40    |
| 3            | 20.20    | 23.00    | 4.68     | 5.64     |
| 4            | 23.00    | 25.80    | 2.80     | 3.01     |

### Conclusion

A very low weighting score of 0.0 was assigned to the time sequence of recruitment because the results were neutral and did not contribute any information to the forecast. The larval index data element was weighted low (0.1) because the recruitment variability explained by larval abundance was very low. The advection element was weighted higher than the low elements (0.14) but lower than the quantitative elements. Rain, wind and spawner-recruit time series elements received the highest weighing scores because their forecast was based on quantitative data.

Based on these six elements and the weights assigned in the table below the FOCI forecast of the 2006 year class is average.

Final 2006 pollock recruitment forecast

| <i>Element</i>                       | <i>Weights</i> | <i>Score</i> | <i>Total</i>           |
|--------------------------------------|----------------|--------------|------------------------|
| Rain                                 | 0.22           | 1.72         | 0.3784                 |
| Wind Mixing                          | 0.22           | 1.98         | 0.4356                 |
| Advection                            | 0.14           | 1.72         | 0.2408                 |
| Larval Index-abundance               | 0.10           | 2.00         | 0.2000                 |
| Larval Rough Counts and Distribution | 0.10           | 2.33         | 0.2330                 |
| Time Sequence of R                   | 0.00           | 2.00         | 0.0000                 |
| Spawner-Recruit Time Series          | 0.22           | 1.98         | 0.4356                 |
| <i>Total</i>                         | <i>1.00</i>    |              | <i>1.9324= Average</i> |

## Analytic Approach

### *Model description*

An age-structured model covering the period from 1961 to 2006 (46 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.

| <i>Likelihood component</i>                      | <i>Statistical model for error</i> | <i>Variance assumption</i>                   |
|--|------------------------------------|--|
| Fishery total catch (1964-2006)                  | Log-normal                         | CV = 0.05                                    |
| POP fishery length comp. (1964-71)               | Multinomial                        | Sample size = 60                             |
| Fishery age comp. (1972-2005)                    | Multinomial                        | Year-specific sample size = 60-400           |
| Shelikof EIT survey biomass (1981-2006)          | Log-normal                         | Survey-specific CV = 0.10-0.35               |
| Shelikof EIT survey age comp. (1981-2006)        | Multinomial                        | Sample size = 60                             |
| NMFS bottom trawl survey biomass (1984-2005)     | Log-normal                         | Survey-specific CV = 0.11-0.38               |
| NMFS bottom trawl survey age comp. (1984-2005)   | Multinomial                        | Survey-specific sample size = 38-74          |
| Egg production biomass (1981-92)                 | Log-normal                         | Survey specific CV = 0.10-0.25               |
| ADF&G trawl survey biomass (1989-2006)           | Log-normal                         | CV = 0.25                                    |
| ADF&G survey age comp. (2000,2002,2004)          | Multinomial                        | Sample size = 10                             |
| ADF&G survey length comp. (1989-2006)            | 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                         | Slope CV = 0.10 (0.001 for 1961-71)          |
|  | Normal                             | Inflection age SD = 0.40 (0.004 for 1961-71) |
| Recruit process error (1961-1968,2006)           | Log-normal                         | CV = 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. We also

used the same constraint for log deviations in recruitment for 1961-68, and in 2006. 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 1.6). Biomass estimates similar to the Biosonics acoustic system can be obtained using the EK500 when a volume backscattering ( $S_v$ ) threshold of -58.5 dB is used (Hollowed et al. 1992). Because of the newer system's lower noise level, abundance estimates since 1992 have been based on a  $S_v$  threshold of -69 dB. We split the Shelikof Strait EIT survey time series into two periods corresponding to the two acoustic systems, and estimated separate survey catchability coefficients for each period. For the 1992 and 1993 surveys, biomass estimates using both noise thresholds were used to provide 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 1.13). 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 validated pollock ageing criteria using radiometric methods (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  $1 \times 10^{-4}$ ). ADModel builder includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest.

A list of model parameters is shown below:

| <i>Population process modeled</i>     | <i>Number of parameters</i>  | <i>Estimation details</i>   |
|---------------------------------------|--|---|
| Initial age structure                 | Ages 3-10 = 8  | Estimated as log deviances from the log mean; constrained by random deviation process error from an equilibrium unfished age structure                          |
| Recruitment                           | Years 1961-2006 = 46   | Estimated as log deviances from the log mean; recruitment in 1961-68, and 2005 constrained by random deviation process error.                                   |
| Natural mortality                     | Age- and year-invariant = 1  | Not estimated in the model  |
| Fishing mortality                     | Years 1961-2006 = 46   | 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) = 180   | 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                                 | 120 primary parameters + 180 process error parameters + 2 fixed parameters = 302         |   |

### ***Parameters Estimated Independently***

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

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

#### *Natural mortality*

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

Hollowed et al. (2000) developed a model for Gulf of Alaska pollock that accounted for predation

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

#### *Maturity at age*

In the 2002 assessment, maturity at age for Gulf of Alaska pollock was estimated using maturity stage data collected during winter EIT surveys in the Gulf of Alaska during 1983-2002. These new estimates replaced a maturity at age vector estimated by Hollowed et al. (1991) using maturity stage data collected during 1983-89. Maturity stages for female pollock describe a continuous process of ovarian development between immature and post-spawning. For the purposes of estimating a maturity vector (the proportion of an age group that has been or will be reproductively active during the year) for stock assessment, all fish greater than or equal to a particular maturity stage are assumed to be mature, while those less than that stage are assumed to be immature. We assumed that maturity stages in which ovarian development had progressed to the point where ova were distinctly visible were mature. Maturity stage data should not be considered the most reliable data to estimate maturity at age. The stages are qualitative rather than quantitative, so there is subjectivity in assigning stages, and a potential for different technicians to apply criteria differently. Because the link between pre-spawning maturity stages and eventual reproductive activity later in the season is not well established, the division between mature and immature stages is problematic. Changes in the timing of spawning could also affect maturity at age estimates. Merati (1993) compared visual maturity stages with ovary histology and a blood assay for vitellogenin and found general consistency between the different approaches. Merati (1993) noted that ovaries classified as late developing stage (i.e., immature) may contain yolked eggs, but it was unclear whether these fish would spawn later in the year. The average sample size of female pollock maturity stage data per year from winter EIT surveys in the Gulf of Alaska is 850 (Table 1.14).

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. 1.10). Because there did not appear to be an objective basis for excluding data, we used the 1983-2006 average maturity at age in the assessment.

Logistic regression (McCullagh and Nelder 1983) was also used to estimate the age and length at 50% mature at age for each year. Annual estimates of age at 50% maturity are highly variable and range from 3.7 years in 1984 to 6.1 years in 1991, with an average of 4.9 years. Length at 50% mature is less variable than the age at 50% mature, suggesting that at least some of the variability in the age at maturity can be attributed to changes in length at age (Fig 1.11). 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. 1.12), Shelikof Strait EIT survey (Fig. 1.13), and the NMFS trawl survey (Fig. 1.14). Model fits to fishery age composition data are good in most years. In 2003-2005, 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. 2003) (Figs. 1.15-1.17). General trends in survey time series are fit reasonably well. For example, both the model and all surveys show a declining trend in the 1990s. But since each survey time series shows a different pattern of decline, the model is unable to fit all surveys simultaneously. The ADF&G survey matches the model trend better than any other survey, despite receiving less weight in model fitting. The discrepancy between the NMFS trawl survey and the Shelikof Strait EIT survey biomass estimates in the 1980s accounts for the poor model fit to both time series during in those years. More recently, the model fits extremely well both the biomass estimates from the both the NMFS bottom trawl survey and the ADF&G trawl survey in 2005, but shows a poorer fit to recent Shelikof Strait EIT survey biomass estimates.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.81 (Fig. 1.18). The change in log likelihood is small (less than one) between models with fixed and estimated catchability, indicating that despite the large change in biomass, there is little objective basis for choosing one model over the other. 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 1.15 (see also Figure 1.19). Table 1.16 gives the estimated population numbers at age for the years 1961-2006. Table 1.17 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1969-2006 (see also Fig. 1.20). Stock size peaked in the early 1980s at approximately twice the proxy for unfished stock size ( $B_{100\%}$  = mean 1979-2005 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, and by 2006 had increased to 39% of unfished stock size.

### ***Retrospective comparison of assessment results***

A retrospective comparison of assessment results for the years 1996-2006 indicates the current estimated trend in spawning biomass for 1990-2006 is consistent with previous estimates (Fig. 1.21). 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. Assessment results since 2002 have been very consistent with a slight overestimate of ending year abundance. The estimated 2006 age composition from the current assessment is similar to projected 2006 age composition in the 2005 assessment (Fig. 1.21). The most significant difference is that age-2 recruitment is now estimated at 1.3 billion rather than assumed average in magnitude.

### ***Stock and recruitment***

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

Since 1980, strong year classes have occurred every four to six years (Fig. 1.20). Because of high recruitment variability, the mean relationship between spawning biomass and recruitment is not apparent despite good contrast. 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. 1.22). 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 2001, 2002, and the 2003 year classes have been rare in the Shelikof Strait EIT surveys and fishery sampling, and apparently are weak in comparison to the 1999 and 2000 year classes. The initial estimate of the 2004 year class is 1.3 billion at age 2, suggesting that it may be larger than average. This estimate is supported by the Shelikof Strait EIT surveys in 2005 and 2006, the summer gulfwide EIT survey in 2005, and the NMFS bottom trawl survey in 2005. The 2005 year class was not abundant 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.

|                     |  |  |                |
|---------------------|--|--|----------------|
| Year of recruitment | 2006   | 2007   | 2008           |
| Year class          | 2004   | 2005   | 2006           |
| FOCI prediction     | <i>Average</i>   | <i>Average</i>   | <i>Average</i> |
| Survey information  | 2005 Shelikof EIT survey age-1 estimate is 1.6 billion (4th in abundance out of 22 surveys)<br>2005 summer EIT survey age-1 estimate is 1.2 billion<br>2005 NMFS bottom trawl estimate is 155 million (4th in abundance out of 10 surveys) | 2006 Shelikof EIT survey age-1 estimate is 162 million (11th in abundance out of 23 surveys)<br>2006 Shumagin EIT survey age-1 estimate is 1.7 billion |                |

## Projections and Harvest Alternatives

### *Reference fishing mortality rates and spawning biomass levels*

Since 1997, Gulf pollock have been managed under Tier 3 of NPFMC harvest guidelines. In Tier 3, reference mortality rates are based on the spawning biomass per recruit (SPR), while biomass reference levels are estimated by multiplying the SPR by average recruitment. Estimates of the  $F_{SPR}$  harvest rates were obtained using the life history characteristics of Gulf of Alaska pollock (Table 1.18). Spawning biomass reference levels were based on mean 1979-2005 recruitment (731 million), which is 3% lower than the post-1979 mean in the 2005 assessment due to the inclusion of the weak 2003 year class in the average. The average did not include the recruitment in 2006 (2004 year class) due to uncertainty in the estimates of year class strength. Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using mean weight at age for the Shelikof Strait EIT surveys in 2002-2006 to estimate current reproductive potential. The SPR at  $F=0$  was estimated as 0.751 kg/recruit, which is nearly the same as the estimate in last year's assessment (1% higher). This  $F_{SPR}$  rates depend the selectivity pattern of the fishery. Selectivity in the Gulf of Alaska pollock fishery changed as the fishery evolved from a foreign fishery occurring along the shelf break to a domestic fishery on spawning aggregations and in nearshore waters (Fig. 1.1). Since 1992, Gulf of Alaska pollock have been managed with time and area restrictions, and selectivity has been fairly stable (Fig. 1.19). For SPR calculations, we used a selectivity pattern based on an average for 1992-2005.

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

| $F_{SPR}$ rate | Fishing mortality | Equilibrium under average 1979-2005 recruitment |                            |                                   |                   |                 |
|----------------|-------------------|---|----------------------------|-----------------------------------|-------------------|-----------------|
|                |                   | Avg. Recr.<br>(Million)                         | Total 3+ biom.<br>(1000 t) | Female spawning<br>biom. (1000 t) | Catch<br>(1000 t) | Harvest<br>rate |
| 100.0%         | 0.000             | 731   | 1793                       | 549                               | 0                 | 0.0%            |
| 50.0%          | 0.196             | 731   | 1195                       | 275                               | 127               | 10.7%           |
| 45.0%          | 0.231             | 731   | 1131                       | 247                               | 140               | 12.3%           |
| 40.0%          | 0.271             | 731   | 1066                       | 220                               | 151               | 14.2%           |
| 35.0%          | 0.320             | 731   | 998                        | 192                               | 163               | 16.4%           |

The  $B_{40\%}$  estimate of 220,000 t is 2% lower than the  $B_{40\%}$  estimate of 224,000 t in the 2005 assessment due to the lower post-1977 mean recruitment. The model estimate of spawning biomass in 2007 is 160,670 t, which is 29% of unfished spawning biomass and below  $B_{40\%}$  (220,000 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).

### **2007 acceptable biological catch**

The definitions of OFL and maximum permissible  $F_{ABC}$  under Amendment 56 provide a buffer between the overfishing level and the intended harvest rate, as required by NMFS national standard guidelines. Since estimates of stock biomass from assessment models are uncertain, the buffer between OFL and ABC provides a margin of safety so that assessment error will not result in the OFL being inadvertently exceeded. For Gulf of Alaska pollock, the maximum permissible  $F_{ABC}$  harvest rate is 84.3% of the OFL harvest rate. In the 2001 assessment, based on an analysis that showed that the buffer between the maximum permissible  $F_{ABC}$  and OFL decreased when the stock is below approximately  $B_{50\%}$ , we developed a more conservative alternative that maintains a constant buffer between ABC and  $F_{ABC}$  at all stock levels (Table 1.19). While there is always some probability of exceeding  $F_{OFL}$  due to imprecise stock assessments, it seemed unreasonable to reduce safety margin as the stock declines.

This alternative is given by the following

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

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

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

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

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. 1.23).

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 1.20.

### ***ABC recommendation***

There are two major sources of new information about abundance trends in 2006. The 2006 Shelikof Strait EIT survey indicated a 13% decrease in total biomass since 2005, but significant quantities of age-2 fish were found in Shelikof Strait (0.8 billion), suggesting that 2004 year class may be above average. The 2005 ADF&G crab/groundfish survey biomass decreased by 13% from the 2005 estimate, but is 3% higher than the 2003 estimate, suggesting that these differences may be due to sampling variability. Model estimates of stock status in 2007 are generally consistent with survey trends and with model projections in previous assessments. The model adequately fits the new survey and age composition information.

The primary concerns about Gulf of Alaska pollock for the short-term are the actual magnitude of 2004 year class, and lower than expected spawning biomass estimates for Shelikof Strait. Although there is evidence from several sources that the 2004 year class will be above average in abundance, previous experience with apparently strong year classes that ended up considerably smaller than their initial estimates should be considered (e.g., the 1999 year class). The concern over the decline in spawning activity in Shelikof Strait is mitigated by the additional winter surveying efforts in 2006, which in aggregate resulted in an estimate of spawning biomass larger than the model estimate. Nevertheless, the cause of these changes in utilization of spawning habitat is unknown, and there is concern that changes in spawning behavior alone could impact pollock abundance in the future.

Based on these considerations, we used the base model with an adjusted  $F_{40\%}$  harvest rate for the author's recommended 2007 ABC of 63,800 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 64% of the model point estimate.

In 2008, the ABC based an adjusted  $F_{40\%}$  harvest rate is 76,960 t (Table 1.20). The OFL in 2007 is 87,220 t, and the OFL in 2008 if the recommended ABC is taken in 2008 is 105,490 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. 1.24). 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 2006 numbers at age as estimated by the assessment model and remove the 2006 TAC from the population. In each year, the

fishing mortality rate is determined by the spawning biomass in that year and the respective harvest scenario. Recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments during 1979-2005 as estimated by the assessment model. Spawning biomass is computed in each year based on the time of peak spawning (March 15) using the maturity and weight schedules in Table 1.18. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2007, 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 2002-2006 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 2007 and 2008,  $F$  is set equal to  $max F_{ABC}$ , and in all subsequent years,  $F$  is set equal to  $F_{OFL}$ . (Rationale: This scenario determines whether a stock is approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.20. Under all harvest policies except the  $F_{OFL}$  policy, mean spawning biomass is projected to decrease in 2007 and then increase as 2004 year class begins to mature (Fig. 1.25). Plots of individual projection runs are highly variable (Fig. 1.26), 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 158,909 t in 2007 for an  $F_{OFL}$  harvest rate, which is less than  $B_{35\%}$  (192,000 t), but greater than  $\frac{1}{2}$  of  $B_{35\%}$ . Under scenario 6, the projected mean spawning biomass in 2017 is 215,796 t, 112% of  $B_{35\%}$ . Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2009 is 189,724 t, which is less than  $B_{35\%}$ , but greater than  $\frac{1}{2}$  of  $B_{35\%}$ . Projected mean spawning biomass in 2019 is 215,228 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. 1.27); 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 1.28). While there is an ontogenetic shift in diet from copepods to larger zooplankton (primarily euphausiids) and fish (Fig. 1.28), 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. 1.28). While indices of stomach fullness exist for these survey years, a more detailed bioenergetic modeling approach would be required to examine if feeding and growth conditions have changed over time, especially given the fluctuations in GOA water temperature in recent years (Fig. 15, Ecosystem Considerations Appendix), as water temperature has a considerable effect on digestion and other energetic rates.

### ***Predators of pollock***

Initial ECOPATH model results show that the top five predators on pollock >20 cm by relative importance are arrowtooth flounder, Pacific halibut, Pacific cod, Steller sea lion (SSL), and the directed pollock fishery (Fig. 1.29). 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. 1.30). 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 1.29), arrowtooth depend less on pollock in their diets than 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. 1.31). 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 1.32, 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. 1.32, 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. 1.32 (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. 1.31). 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. 1.33, top). Correlation coefficients of consumption rates were 0.98 between arrowtooth and halibut, and 0.90 for both of these species with pollock. Correlation coefficients of these three species with cod were ~0.55 for arrowtooth and halibut and ~0.20 with pollock. The majority of this predation by weight occurred on age 2 pollock.

Plotted against age 2 pollock numbers calculated from the stock assessment, consumption/biomass and total consumption by predators shows a distinct pattern (Fig. 1.33, 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 consumption 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  $\geq 30$ cm shows a different pattern over time. A decline of consumption per unit biomass is evident for halibut and cod (Fig. 1.34, top). Arrowtooth shows a nonsignificant decline; it is possible that the noise in the arrowtooth trend, mirroring the consumption of  $<30$ cm 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. 1.34, 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. 1.30), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.33 and 1.34 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. 1.27. 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. 1.35 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. 1.36), 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 1.37), 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. 1.38). 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. 1.38). Since the harvest policy for pollock is modified fixed harvest rate strategy, a positive correlation between catch and abundance would be expected. The Steller sea lion trend is more strongly correlated with pollock abundance than pollock catches, but this correlation is based on data since 1976, and does not include earlier years of low pollock abundance. The only strong inverse correlation is between arrowtooth flounder and Steller sea lions. A strong positive correlation exists between Pacific cod and Pacific halibut, and, from the 1960s to the present, between Pacific halibut and arrowtooth flounder.

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

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

## Summary

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Natural mortality = 0.3

Tier: 3b

### 2007 harvests

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|                          |   |                  |
|--------------------------|---|------------------|
| Maximum permissible ABC: | $F_{40\%} \text{ (adjusted)} = 0.19$          | Yield = 75,150 t |
| Recommended ABC:         | $F_{40\%} \text{ (author's adjusted)} = 0.16$ | Yield = 63,800 t |
| Overfishing (OFL):       | $F_{35\%} \text{ (adjusted)} = 0.23$          | Yield = 87,220 t |

### 2008 harvests

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|                          |   |                   |
|--------------------------|---|-------------------|
| Maximum permissible ABC: | $F_{40\%} \text{ (adjusted)} = 0.19$          | Yield = 87,570 t  |
| Recommended ABC:         | $F_{40\%} \text{ (author's adjusted)} = 0.17$ | Yield = 76,960 t  |
| Overfishing (OFL):       | $F_{35\%} \text{ (adjusted)} = 0.22$          | Yield = 105,490 t |

### Equilibrium female spawning biomass

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$B_{100\%} = 549,000$  t

$B_{40\%} = 220,000$  t

$B_{35\%} = 192,000$  t

### Projected 2007 biomass

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Age 3+ biomass = 833,710 t

Female spawning biomass = 160,670 t

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Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The TAC for 2006 is for the area west of 140 ° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound (1650 t). Research catches are also reported.

| <i>Year</i>                | <i>Foreign</i> | <i>Joint Venture</i> | <i>Domestic</i> | <i>Total</i> | <i>TAC</i> | <i>Research</i> |
|----------------------------|----------------|----------------------|-----------------|--------------|------------|-----------------|
| 1964                       | 1,126          |                      |                 | 1,126        | ---        |                 |
| 1965                       | 2,749          |                      |                 | 2,749        | ---        |                 |
| 1966                       | 8,932          |                      |                 | 8,932        | ---        |                 |
| 1967                       | 6,276          |                      |                 | 6,276        | ---        |                 |
| 1968                       | 6,164          |                      |                 | 6,164        | ---        |                 |
| 1969                       | 17,553         |                      |                 | 17,553       | ---        |                 |
| 1970                       | 9,343          |                      |                 | 9,343        | ---        |                 |
| 1971                       | 9,458          |                      |                 | 9,458        | ---        |                 |
| 1972                       | 34,081         |                      |                 | 34,081       | ---        |                 |
| 1973                       | 36,836         |                      |                 | 36,836       | ---        |                 |
| 1974                       | 61,880         |                      |                 | 61,880       | ---        |                 |
| 1975                       | 59,512         |                      |                 | 59,512       | ---        |                 |
| 1976                       | 86,527         |                      |                 | 86,527       | ---        |                 |
| 1977                       | 117,834        |                      | 522             | 118,356      | 150,000    | 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                       |                |                      |                 |              | 81,300     | 49              |
| <i>Average (1977-2005)</i> |                |                      |                 | 109,905      | 127,078    | 160             |

Sources: 1964-85--Megrey (1988); 1986-90--Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission. Domestic catches in 1986-90 were adjusted for discard as described in Hollowed et al. (1991). 1991-2005--NMFS Alaska Regional Office.

Table 1.2. Incidental catch (t) of FMP species (upper table) and non-target species (bottom table) in the walleye pollock directed fishery in the Gulf of Alaska in 2003-2005. 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.

| <i>Managed species/species group</i>  | <i>2003</i> | <i>2004</i> | <i>2005</i> |
|---|-------------|-------------|-------------|
| Pollock   | 49346.0     | 62712.2     | 80133.5     |
| Arrowtooth flounder   | 667.6       | 1033.7      | 2282.8      |
| Pacific cod   | 275.7       | 499.7       | 358.2       |
| Other (sharks, skates, squid, sculpin, octopus, but excluding skates in 2004) | 201.4       | 292.2       | 870.2       |
| Flathead sole   | 141.0       | 268.3       | 174.7       |
| Shortraker and rougheye rockfish  | 118.8       | 38.5        | 46.1        |
| Pacific Ocean perch   | 93.4        | 60.0        | 59.5        |
| Rex sole  | 15.5        | 35.4        | 19.6        |
| Miscellaneous flatfish  | 25.5        | 18.2        | 4.7         |
| Atka mackerel   | 0.0         | 17.9        | 3.5         |
| Sablefish   | 3.5         | 2.3         | 3.6         |
| Dover sole and Greenland turbot   | 2.0         | 1.7         | 0.7         |
| Pelagic shelf rockfish complex  | 2.1         | 1.5         | 2.0         |
| Unidentified skate  | NA          | 1.8         | 1.1         |
| Big and longnose skate  | NA          | 1.4         | 6.3         |
| Northern rockfish   | 0.3         | 0.5         | 0.8         |
| Other rockfish complex  | 0.5         | 0.1         | 1.3         |
| Thornyheads   | 0.5         | 0.0         | 0.3         |
| <i>Percent non-pollock</i>  | <i>3.0%</i> | <i>3.5%</i> | <i>4.6%</i> |
| <i>Non target species/species group</i>                                       | <i>2003</i> | <i>2004</i> | <i>2005</i> |
| Eulachon  | 16.050      | 168.260     | 822.976     |
| Squid   | 62.482      | 139.256     | 620.461     |
| Shark   | 117.132     | 152.342     | 245.783     |
| Scyphozoan jellyfish  | 43.628      | 22.368      | 210.855     |
| Other osmerids  | 350.239     | 66.030      | 176.008     |
| Giant Grenadier   |             |             | 44.268      |
| Miscellaneous fish  | 41.847      | 13.807      | 16.378      |
| Skate   | 10.607      | 2.879       | 13.580      |
| Grenadier   | 53.927      | 7.636       | 9.100       |
| Pandalid shrimp   | 0.544       | 1.455       | 7.304       |
| Capelin   | 6.220       | 67.980      | 2.736       |
| Sea star  | 0.194       | 0.000       | 1.134       |
| Sea pens whips  |             |             | 0.253       |
| Lanternfishes (myctophidae)   | 0.004       |             | 0.148       |
| Eelpouts  |             | 1.256       | 0.100       |
| Octopus   |             | 0.001       | 0.058       |
| Large Sculpins  |             | 0.066       | 0.020       |
| Birds   |             | 0.011       | 0.006       |
| Greenlings  | 0.291       |             |             |
| Gunnels   | 0.011       |             |             |
| Hermit crab unidentified  | 0.000       |             |             |
| Misc crabs  | 0.074       |             |             |
| Other Sculpins  | 0.884       |             |             |
| Pacific Sand lance  | 0.003       |             |             |
| Sea anemone unidentified  |             | 0.110       |             |
| Stichaeidae   |             | 0.108       |             |
| Surf smelt  |             | 0.442       |             |

Table 1.3. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 1994-2005 compiled by the Alaska Regional Office.

| <i>Year</i>                | <i>Utilization</i> | <i>Shumagin 610</i> | <i>Chirikof 620</i> | <i>Kodiak 630</i> | <i>West Yakutat 640</i> | <i>Prince William Sound 649 (state waters)</i> | <i>Southeast and East Yakutat 650 &amp; 659</i> | <i>Total</i> | <i>Percent discard</i> |
|----------------------------|--------------------|---------------------|---------------------|-------------------|-------------------------|--|---|--------------|------------------------|
| 1994                       | Retained           | 16,238              | 19,917              | 58,511            | 6,362                   | 0  | 0   | 101,028      |                        |
|                            | Discarded          | 1,028               | 2,321               | 2,453             | 499                     | 2  | 3   | 6,306        | 5.9%                   |
|                            | Total              | 17,266              | 22,239              | 60,963            | 6,862                   | 2  | 3   | 107,335      |                        |
| 1995                       | Retained           | 28,473              | 11,032              | 21,989            | 480                     | 2,739  | 46  | 64,759       |                        |
|                            | Discarded          | 1,905               | 2,048               | 3,778             | 53                      | 75   | 1   | 7,859        | 10.8%                  |
|                            | Total              | 30,378              | 13,080              | 25,768            | 533                     | 2,813  | 47  | 72,618       |                        |
| 1996                       | Retained           | 23,100              | 10,150              | 11,571            | 510                     | 775  | 0   | 46,107       |                        |
|                            | Discarded          | 1,100               | 2,143               | 1,789             | 103                     | 19   | 3   | 5,156        | 10.1%                  |
|                            | Total              | 24,200              | 12,293              | 13,361            | 613                     | 794  | 3   | 51,263       |                        |
| 1997                       | Retained           | 25,253              | 29,736              | 22,064            | 3,938                   | 1,807  | 89  | 82,888       |                        |
|                            | Discarded          | 1,009               | 3,179               | 2,998             | 30                      | 19   | 7   | 7,242        | 8.0%                   |
|                            | Total              | 26,262              | 32,916              | 25,062            | 3,968                   | 1,826  | 96  | 90,130       |                        |
| 1998                       | Retained           | 28,815              | 48,530              | 38,753            | 6,316                   | 1,655  | 8   | 124,077      |                        |
|                            | Discarded          | 370                 | 361                 | 262               | 25                      | 2  | 0   | 1,022        | 0.8%                   |
|                            | Total              | 29,185              | 48,892              | 39,015            | 6,341                   | 1,657  | 8   | 125,098      |                        |
| 1999                       | Retained           | 22,864              | 37,349              | 29,515            | 1,737                   | 2,178  | 1   | 93,643       |                        |
|                            | Discarded          | 521                 | 784                 | 578               | 22                      | 39   | 3   | 1,947        | 2.0%                   |
|                            | Total              | 23,385              | 38,133              | 30,093            | 1,759                   | 2,216  | 4   | 95,590       |                        |
| 2000                       | Retained           | 21,380              | 11,314              | 35,078            | 1,917                   | 1,181  | 0   | 70,870       |                        |
|                            | Discarded          | 694                 | 443                 | 854               | 191                     | 22   | 4   | 2,209        | 3.0%                   |
|                            | Total              | 22,074              | 11,757              | 35,933            | 2,108                   | 1,203  | 4   | 73,080       |                        |
| 2001                       | Retained           | 30,298              | 17,186              | 19,942            | 2,327                   | 1,590  | 0   | 71,344       |                        |
|                            | Discarded          | 173                 | 205                 | 330               | 24                      | 0  | 0   | 732          | 1.0%                   |
|                            | Total              | 30,471              | 17,391              | 20,272            | 2,351                   | 1,590  | 0   | 72,076       |                        |
| 2002                       | Retained           | 17,046              | 20,106              | 10,615            | 1,808                   | 1,216  | 0   | 50,791       |                        |
|                            | Discarded          | 416                 | 425                 | 287               | 10                      | 6  | 2   | 1,146        | 2.2%                   |
|                            | Total              | 17,462              | 20,531              | 10,902            | 1,818                   | 1,222  | 2   | 51,937       |                        |
| 2003                       | Retained           | 16,347              | 18,972              | 12,225            | 940                     | 1,118  | 0   | 49,603       |                        |
|                            | Discarded          | 161                 | 658                 | 210               | 2                       | 31   | 0   | 1,063        | 2.1%                   |
|                            | Total              | 16,508              | 19,630              | 12,435            | 943                     | 1,149  | 0   | 50,666       |                        |
| 2004                       | Retained           | 23,226              | 24,221              | 14,023            | 215                     | 1,100  | 0   | 62,785       |                        |
|                            | Discarded          | 229                 | 440                 | 421               | 11                      | 26   | 0   | 1,128        | 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       |                        |
| <i>Average (1994-2004)</i> |                    | 24,302              | 24,119              | 25,631            | 2,450                   | 1,366  | 14  | 77,882       |                        |

Table 1.4. Catch at age (000,000s) of walleye pollock in the Gulf of Alaska.

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

Table 1.5. Number of aged and measured fish in the Gulf of Alaska pollock fishery used to estimate fishery age composition (1989-2005).

| <i>Year</i> | <i>Number aged</i> |                |              | <i>Number measured</i> |                |              |
|-------------|--------------------|----------------|--------------|------------------------|----------------|--------------|
|             | <i>Males</i>       | <i>Females</i> | <i>Total</i> | <i>Males</i>           | <i>Females</i> | <i>Total</i> |
| 1989        | 882                | 892            | 1,774        | 6,454                  | 6,456          | 12,910       |
| 1990        | 453                | 689            | 1,142        | 17,814                 | 24,662         | 42,476       |
| 1991        | 1,146              | 1,322          | 2,468        | 23,946                 | 39,467         | 63,413       |
| 1992        | 1,726              | 1,755          | 3,481        | 31,608                 | 47,226         | 78,834       |
| 1993        | 926                | 949            | 1,875        | 28,035                 | 31,306         | 59,341       |
| 1994        | 136                | 129            | 265          | 24,321                 | 25,861         | 50,182       |
| 1995        | 499                | 544            | 1,043        | 10,591                 | 10,869         | 21,460       |
| 1996        | 381                | 378            | 759          | 8,581                  | 8,682          | 17,263       |
| 1997        | 496                | 486            | 982          | 8,750                  | 8,808          | 17,558       |
| 1998        | 924                | 989            | 1,913        | 78,955                 | 83,160         | 162,115      |
| 1999        | 980                | 1,115          | 2,095        | 16,304                 | 17,964         | 34,268       |
| 2000        | 1,108              | 972            | 2,080        | 13,167                 | 11,794         | 24,961       |
| 2001        | 1,063              | 1,025          | 2,088        | 13,731                 | 13,552         | 27,283       |
| 2002        | 1,036              | 1,025          | 2,061        | 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       |

Table 1.6. Biomass estimates (t) of walleye pollock from NMFS echo integration trawl surveys in Shelikof Strait, NMFS bottom trawl surveys (west of 140 W. long.), egg production surveys in Shelikof Strait, and ADF&G crab/groundfish trawl surveys. The biomass of age-1 fish is not included in Shelikof Strait EIT survey estimates in 1995, 2000 and 2005 (114,200, 57,300 and 18,100 t respectively). An adjustment of +1.05% was made to the AFSC bottom trawl biomass time series to account for unsurveyed biomass in Prince William Sound. In 2001, when the NMFS bottom trawl survey did not extend east of 147° W lon., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

| <i>Year</i> | <i>EIT Shelikof Strait survey</i> |                     | <i>NMFS bottom trawl west of 140° W lon.</i> |  | <i>Shelikof Strait egg production</i> | <i>ADF&amp;G crab/groundfish survey</i> |
|-------------|-----------------------------------|---------------------|--|--|---------------------------------------|---|
|             | <i>Biosonics</i>                  | <i>Simrad EK500</i> |  |  |                                       |   |
| 1981        | 2,785,755                         |                     |  |  | 1,788,908                             |   |
| 1982        |                                   |                     |  |  |                                       |   |
| 1983        | 2,278,172                         |                     |  |  |                                       |   |
| 1984        | 1,757,168                         |                     | 719,937                                      |  |                                       |   |
| 1985        | 1,175,823                         |                     |  |  | 768,419                               |   |
| 1986        | 585,755                           |                     |  |  | 375,907                               |   |
| 1987        |                                   |                     | 732,541                                      |  | 484,455                               |   |
| 1988        | 301,709                           |                     |  |  | 504,418                               |   |
| 1989        | 290,461                           |                     |  |  | 433,894                               | 214,434                                 |
| 1990        | 374,731                           |                     | 825,592                                      |  | 381,475                               | 114,451                                 |
| 1991        | 380,331                           |                     |  |  | 370,000                               |   |
| 1992        | 580,000                           | 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                                  |

Table 1.7. 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.

| Year | No. of tows | No. of tows with pollock | Survey biomass | Number aged |         | Total | Number measured |         | Total  |
|------|-------------|--------------------------|----------------|-------------|---------|-------|-----------------|---------|--------|
|      |             |                          |                | Males       | Females |       | Males           | Females |        |
| 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     |

Table 1.8. 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 1-9. 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. 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     |
|------|-----------|----------|----------|----------|----------|----------|--------|--------|-------|-------|-------|-------|------|------|------|-----------|
| 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 1.10. 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 1992-2006.

| Year | No. of midwater tows |  | No. of bottom trawl tows | Survey biomass CV |         | Number aged |         | Number measured |       |
|------|----------------------|--|--------------------------|-------------------|---------|-------------|---------|-----------------|-------|
|      |                      |  |                          | Males             | Females | Males       | Females | Total           | Total |
| 1981 | 36                   |  | 18                       | 0.12              | 1,921   | 1,815       | 3,736   | NA              | NA    |
| 1983 | 47                   |  | 1                        | 0.16              | 1,642   | 1,103       | 2,745   | NA              | NA    |
| 1984 | 42                   |  | 0                        | 0.18              | 1,739   | 1,622       | 3,361   | NA              | NA    |
| 1985 | 57                   |  | 0                        | 0.14              | 1,055   | 1,187       | 2,242   | NA              | NA    |
| 1986 | 38                   |  | 1                        | 0.22              | 642     | 618         | 1,260   | NA              | NA    |
| 1987 | 27                   |  | 0                        | ---               | 557     | 643         | 1,200   | NA              | NA    |
| 1988 | 26                   |  | 0                        | 0.17              | 537     | 464         | 1,001   | NA              | NA    |
| 1989 | 21                   |  | 0                        | 0.10              | 757     | 796         | 1,553   | NA              | NA    |
| 1990 | 25                   |  | 16                       | 0.17              | 988     | 1,117       | 2,105   | NA              | NA    |
| 1991 | 16                   |  | 2                        | 0.35              | 478     | 628         | 1,106   | NA              | NA    |
| 1992 | 17                   |  | 8                        | 0.04              | 784     | 765         | 1,549   | NA              | NA    |
| 1993 | 22                   |  | 2                        | 0.05              | 583     | 624         | 1,207   | NA              | NA    |
| 1994 | 42                   |  | 12                       | 0.05              | 554     | 633         | 1,187   | NA              | NA    |
| 1995 | 22                   |  | 3                        | 0.05              | 599     | 575         | 1,174   | NA              | NA    |
| 1996 | 30                   |  | 8                        | 0.04              | 724     | 775         | 1,499   | NA              | NA    |
| 1997 | 16                   |  | 14                       | 0.04              | 682     | 853         | 1,535   | NA              | NA    |
| 1998 | 22                   |  | 9                        | 0.04              | 863     | 784         | 1,647   | NA              | NA    |
| 2000 | 31                   |  | 0                        | 0.05              | 430     | 370         | 800     | NA              | NA    |
| 2001 | 15                   |  | 9                        | 0.05              | 314     | 378         | 692     | NA              | NA    |
| 2002 | 18                   |  | 1                        | 0.07              | 278     | 326         | 604     | NA              | NA    |
| 2003 | 17                   |  | 2                        | 0.05              | 294     | 322         | 616     | NA              | NA    |
| 2004 | 13                   |  | 2                        | 0.09              | 422     | 315         | 737     | NA              | NA    |
| 2005 | 22                   |  | 1                        | 0.04              | 543     | 335         | 878     | NA              | NA    |
| 2006 | 17                   |  | 2                        | 0.04              | 295     | 487         | 782     | NA              | NA    |

Table 1.11. Estimates of pollock biomass obtained from GLM model predictions of pollock CPUE and INPFC area expansions. Biomass estimates were multiplied by the von Szalay and Brown (2001) FPC of 3.84 for comparison to the NMFS triennial trawl survey biomass estimates. Coefficients of variation do not reflect the variance of the FPC estimate.

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

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

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

Table 1.12. Predictions of Gulf of Alaska pollock year-class strength. The FOCI prediction is the prediction of year-class strength made in the natal year of the year class, and was derived from environmental indices, larval surveys, and the time series characteristics of pollock recruitment. The McKelvey index is the estimated abundance of 9-16 cm pollock from the Shelikof Strait EIT survey.

| <i>Year class</i> | <i>FOCI prediction</i> | <i>Year of EIT survey</i> | <i>McKelvey index</i> | <i>Rank abundance of<br/>McKelvey index</i> |
|-------------------|------------------------|---------------------------|-----------------------|---|
| 1980              |                        | 1981                      | 0.078                 | 12  |
| 1981              |                        |                           |                       |   |
| 1982              |                        | 1983                      | 0.001                 | 23  |
| 1983              |                        | 1984                      | 0.062                 | 15  |
| 1984              |                        | 1985                      | 2.092                 | 3   |
| 1985              |                        | 1986                      | 0.579                 | 5   |
| 1986              |                        |                           |                       |   |
| 1987              |                        | 1988                      | 0.017                 | 21  |
| 1988              |                        | 1989                      | 0.399                 | 6   |
| 1989              |                        | 1990                      | 0.049                 | 19  |
| 1990              |                        | 1991                      | 0.022                 | 20  |
| 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                 | 22  |
| 2002              | Average                | 2003                      | 0.051                 | 18  |
| 2003              | Average                | 2004                      | 0.053                 | 17  |
| 2004              | Average                | 2005                      | 1.626                 | 4   |
| 2005              | Average                | 2006                      | 0.162                 | 11  |
| 2006              | Average                | 2007                      | ---                   | ---   |

Table 1.13. Ageing error transition matrix used in the Gulf of Alaska pollock assessment model.

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

Table 1.14. Maturity at age of female pollock derived from maturity stage data collected during winter EIT surveys in the Gulf of Alaska (1983-2006).

| Year                     | 2     |       | 3     |       | 4     |       | 5     |       | 6     |      | 7    |      | 8    |      | 9    |      | 10+  |      | Total |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|-------|
|                          | Mat.  | Tot.  | Mat.  | Tot.  | Mat.  | Tot.  | Mat.  | Tot.  | Mat.  | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. | Mat. | Tot. |       |
| 1983                     | 0     | 145   | 19    | 115   | 284   | 356   | 291   | 303   | 189   | 194  | 171  | 174  | 33   | 35   | 7    | 7    | 4    | 4    | 1333  |
| 1984                     | 0     | 39    | 25    | 173   | 97    | 141   | 349   | 364   | 507   | 512  | 237  | 237  | 132  | 133  | 21   | 21   | 1    | 1    | 1621  |
| 1985                     | 3     | 204   | 4     | 79    | 75    | 177   | 53    | 102   | 182   | 196  | 261  | 263  | 122  | 123  | 30   | 30   | 9    | 9    | 1183  |
| 1986                     | 0     | 93    | 1     | 48    | 6     | 57    | 62    | 73    | 46    | 51   | 71   | 74   | 151  | 151  | 57   | 57   | 14   | 14   | 618   |
| 1987                     | 0     | 39    | 2     | 171   | 5     | 47    | 18    | 53    | 30    | 39   | 69   | 78   | 57   | 60   | 116  | 117  | 34   | 34   | 638   |
| 1988                     | 0     | 49    | 0     | 136   | 24    | 115   | 12    | 68    | 20    | 33   | 10   | 15   | 13   | 13   | 6    | 7    | 27   | 28   | 464   |
| 1989                     | 0     | 35    | 0     | 50    | 52    | 175   | 122   | 276   | 71    | 100  | 57   | 62   | 16   | 16   | 12   | 12   | 70   | 70   | 796   |
| 1990                     | 0     | 86    | 0     | 109   | 19    | 99    | 182   | 270   | 468   | 620  | 202  | 222  | 103  | 109  | 58   | 60   | 268  | 269  | 1844  |
| 1991                     | 0     | 47    | 0     | 159   | 3     | 27    | 7     | 85    | 34    | 60   | 89   | 111  | 19   | 22   | 45   | 46   | 71   | 71   | 628   |
| 1992                     | 0     | 12    | 0     | 43    | 5     | 126   | 20    | 291   | 41    | 53   | 53   | 54   | 104  | 105  | 23   | 23   | 57   | 58   | 765   |
| 1993                     | 0     | 38    | 1     | 62    | 6     | 50    | 59    | 127   | 48    | 112  | 37   | 46   | 61   | 63   | 58   | 58   | 67   | 68   | 624   |
| 1994                     | 0     | 43    | 1     | 144   | 27    | 64    | 230   | 247   | 64    | 68   | 41   | 46   | 38   | 39   | 84   | 84   | 137  | 137  | 872   |
| 1995                     | 0     | 147   | 0     | 61    | 13    | 85    | 63    | 88    | 231   | 239  | 90   | 92   | 35   | 38   | 11   | 12   | 42   | 43   | 805   |
| 1996                     | 0     | 61    | 0     | 89    | 1     | 28    | 43    | 60    | 78    | 85   | 198  | 203  | 131  | 136  | 55   | 55   | 44   | 46   | 763   |
| 1997                     | 0     | 11    | 0     | 111   | 7     | 29    | 19    | 25    | 123   | 123  | 135  | 135  | 234  | 235  | 125  | 125  | 49   | 49   | 843   |
| 1998                     | 0     | 69    | 0     | 72    | 14    | 215   | 13    | 64    | 15    | 18   | 53   | 55   | 65   | 65   | 112  | 112  | 86   | 87   | 757   |
| 2000                     | 0     | 29    | 1     | 81    | 1     | 8     | 36    | 57    | 78    | 100  | 11   | 19   | 11   | 13   | 10   | 10   | 36   | 39   | 356   |
| 2001                     | 0     | 44    | 0     | 57    | 13    | 45    | 16    | 52    | 33    | 40   | 69   | 73   | 29   | 30   | 13   | 14   | 19   | 19   | 374   |
| 2002                     | 0     | 11    | 2     | 77    | 15    | 58    | 51    | 68    | 84    | 90   | 76   | 78   | 83   | 83   | 13   | 13   | 21   | 21   | 499   |
| 2003                     | 0     | 40    | 1     | 34    | 29    | 151   | 12    | 31    | 9     | 17   | 10   | 11   | 3    | 4    | 8    | 8    | 5    | 5    | 301   |
| 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   |
| <i>Proportion mature</i> |       |       |       |       |       |       |       |       |       |      |      |      |      |      |      |      |      |      |       |
|                          | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10+   |      |      |      |      |      |      |      |      |      |       |
| 1983                     | 0.000 | 0.165 | 0.798 | 0.960 | 0.974 | 0.983 | 0.943 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1984                     | 0.000 | 0.145 | 0.688 | 0.959 | 0.990 | 1.000 | 0.992 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1985                     | 0.015 | 0.051 | 0.424 | 0.520 | 0.929 | 0.992 | 0.992 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1986                     | 0.000 | 0.021 | 0.105 | 0.849 | 0.902 | 0.959 | 1.000 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1987                     | 0.000 | 0.012 | 0.106 | 0.340 | 0.769 | 0.885 | 0.950 | 0.991 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1988                     | 0.000 | 0.000 | 0.209 | 0.176 | 0.606 | 0.667 | 1.000 | 0.857 | 0.964 |      |      |      |      |      |      |      |      |      |       |
| 1989                     | 0.000 | 0.000 | 0.297 | 0.442 | 0.710 | 0.919 | 1.000 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1990                     | 0.000 | 0.000 | 0.192 | 0.674 | 0.755 | 0.910 | 0.945 | 0.967 | 0.996 |      |      |      |      |      |      |      |      |      |       |
| 1991                     | 0.000 | 0.000 | 0.111 | 0.082 | 0.567 | 0.802 | 0.864 | 0.978 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1992                     | 0.000 | 0.000 | 0.040 | 0.069 | 0.774 | 0.981 | 0.990 | 1.000 | 0.983 |      |      |      |      |      |      |      |      |      |       |
| 1993                     | 0.000 | 0.016 | 0.120 | 0.465 | 0.429 | 0.804 | 0.968 | 1.000 | 0.985 |      |      |      |      |      |      |      |      |      |       |
| 1994                     | 0.000 | 0.007 | 0.422 | 0.931 | 0.941 | 0.891 | 0.974 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1995                     | 0.000 | 0.000 | 0.153 | 0.716 | 0.967 | 0.978 | 0.921 | 0.917 | 0.977 |      |      |      |      |      |      |      |      |      |       |
| 1996                     | 0.000 | 0.000 | 0.036 | 0.717 | 0.918 | 0.975 | 0.963 | 1.000 | 0.957 |      |      |      |      |      |      |      |      |      |       |
| 1997                     | 0.000 | 0.000 | 0.241 | 0.760 | 1.000 | 1.000 | 0.996 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 1998                     | 0.000 | 0.000 | 0.065 | 0.203 | 0.833 | 0.964 | 1.000 | 1.000 | 0.989 |      |      |      |      |      |      |      |      |      |       |
| 2000                     | 0.000 | 0.012 | 0.125 | 0.632 | 0.780 | 0.579 | 0.846 | 1.000 | 0.923 |      |      |      |      |      |      |      |      |      |       |
| 2001                     | 0.000 | 0.000 | 0.289 | 0.308 | 0.825 | 0.945 | 0.967 | 0.929 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 2002                     | 0.000 | 0.026 | 0.259 | 0.750 | 0.933 | 0.974 | 1.000 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 2003                     | 0.000 | 0.029 | 0.192 | 0.387 | 0.529 | 0.909 | 0.750 | 1.000 | 1.000 |      |      |      |      |      |      |      |      |      |       |
| 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 |      |      |      |      |      |      |      |      |      |       |
| <i>Average</i>           |       |       |       |       |       |       |       |       |       |      |      |      |      |      |      |      |      |      |       |
| 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 1.15. Estimated selectivity at age for Gulf of Alaska pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions with random walk process error for the fishery logistic parameters. Fishery selectivity at age reported below is the average of the annual selectivity for the indicated time period, rescaled so that the maximum is one.

| Age | Early                    |                      |                       |                                |            | 400-mesh               |                       |                          |
|-----|--------------------------|----------------------|-----------------------|--------------------------------|------------|------------------------|-----------------------|--------------------------|
|     | POP fishery<br>(1961-71) | Foreign<br>(1972-84) | domestic<br>(1985-91) | Recent domestic<br>(1992-2005) | EIT survey | Bottom trawl<br>survey | ADF&G bottom<br>trawl | eastern trawl<br>1961-82 |
| 2   | 0.001                    | 0.041                | 0.041                 | 0.076                          | 1.000      | 0.198                  | 0.049                 | 0.120                    |
| 3   | 0.021                    | 0.265                | 0.154                 | 0.214                          | 1.000      | 0.304                  | 0.119                 | 0.389                    |
| 4   | 0.413                    | 0.758                | 0.415                 | 0.475                          | 0.998      | 0.458                  | 0.258                 | 0.748                    |
| 5   | 1.000                    | 1.000                | 0.731                 | 0.766                          | 0.993      | 0.665                  | 0.475                 | 0.932                    |
| 6   | 0.944                    | 0.916                | 0.949                 | 0.933                          | 0.974      | 0.885                  | 0.703                 | 0.985                    |
| 7   | 0.697                    | 0.661                | 1.000                 | 0.990                          | 0.907      | 1.000                  | 0.864                 | 0.997                    |
| 8   | 0.361                    | 0.332                | 0.829                 | 1.000                          | 0.717      | 0.903                  | 0.948                 | 0.999                    |
| 9   | 0.133                    | 0.123                | 0.429                 | 0.889                          | 0.396      | 0.663                  | 0.985                 | 1.000                    |
| 10  | 0.041                    | 0.040                | 0.151                 | 0.348                          | 0.145      | 0.429                  | 1.000                 | 1.000                    |

Table 1.16. Total estimated abundance at age (numbers in 000,000s) of Gulf of Alaska pollock from the age-structured assessment model.

|         | <i>Age</i> |       |       |       |     |     |     |     |     |
|---------|------------|-------|-------|-------|-----|-----|-----|-----|-----|
|         | 2          | 3     | 4     | 5     | 6   | 7   | 8   | 9   | 10  |
| 1961    | 385        | 200   | 123   | 75    | 56  | 39  | 29  | 22  | 17  |
| 1962    | 426        | 285   | 148   | 91    | 56  | 41  | 29  | 21  | 28  |
| 1963    | 456        | 315   | 211   | 110   | 67  | 41  | 31  | 21  | 37  |
| 1964    | 103        | 338   | 234   | 156   | 81  | 50  | 31  | 23  | 43  |
| 1965    | 265        | 76    | 250   | 173   | 115 | 60  | 37  | 23  | 49  |
| 1966    | 141        | 196   | 56    | 184   | 126 | 84  | 44  | 27  | 53  |
| 1967    | 351        | 105   | 145   | 41    | 131 | 90  | 61  | 32  | 59  |
| 1968    | 415        | 260   | 77    | 106   | 29  | 94  | 65  | 44  | 67  |
| 1969    | 723        | 308   | 192   | 56    | 75  | 21  | 67  | 47  | 82  |
| 1970    | 343        | 536   | 227   | 135   | 36  | 49  | 14  | 48  | 95  |
| 1971    | 741        | 254   | 397   | 164   | 94  | 25  | 35  | 10  | 105 |
| 1972    | 1,393      | 549   | 188   | 289   | 116 | 67  | 18  | 25  | 85  |
| 1973    | 1,061      | 1,032 | 406   | 134   | 194 | 79  | 46  | 13  | 82  |
| 1974    | 3,466      | 786   | 763   | 289   | 90  | 131 | 55  | 33  | 70  |
| 1975    | 702        | 2,567 | 581   | 540   | 188 | 59  | 90  | 39  | 76  |
| 1976    | 442        | 520   | 1,879 | 408   | 376 | 131 | 42  | 65  | 85  |
| 1977    | 2,013      | 326   | 375   | 1,306 | 283 | 263 | 93  | 30  | 110 |
| 1978    | 2,738      | 1,489 | 237   | 259   | 892 | 195 | 185 | 67  | 103 |
| 1979    | 2,495      | 2,021 | 1,069 | 163   | 178 | 618 | 138 | 134 | 126 |
| 1980    | 3,498      | 1,844 | 1,463 | 738   | 112 | 123 | 437 | 100 | 191 |
| 1981    | 1,776      | 2,582 | 1,336 | 1,025 | 511 | 78  | 87  | 314 | 214 |
| 1982    | 431        | 1,313 | 1,878 | 932   | 703 | 352 | 54  | 62  | 388 |
| 1983    | 491        | 316   | 934   | 1,302 | 643 | 487 | 248 | 39  | 333 |
| 1984    | 207        | 360   | 224   | 630   | 864 | 430 | 336 | 179 | 275 |
| 1985    | 480        | 151   | 248   | 140   | 376 | 517 | 272 | 235 | 334 |
| 1986    | 1,625      | 350   | 104   | 151   | 77  | 199 | 285 | 174 | 415 |
| 1987    | 556        | 1,187 | 246   | 68    | 94  | 47  | 126 | 197 | 434 |
| 1988    | 161        | 409   | 856   | 170   | 45  | 61  | 30  | 83  | 460 |
| 1989    | 377        | 119   | 297   | 600   | 114 | 29  | 39  | 20  | 398 |
| 1990    | 1,614      | 279   | 87    | 212   | 407 | 74  | 19  | 25  | 305 |
| 1991    | 1,008      | 1,193 | 205   | 63    | 145 | 261 | 45  | 11  | 241 |
| 1992    | 403        | 745   | 876   | 147   | 43  | 96  | 168 | 29  | 166 |
| 1993    | 240        | 297   | 541   | 611   | 98  | 28  | 61  | 108 | 140 |
| 1994    | 146        | 177   | 215   | 378   | 406 | 63  | 18  | 39  | 170 |
| 1995    | 221        | 107   | 129   | 152   | 254 | 267 | 41  | 12  | 144 |
| 1996    | 858        | 163   | 79    | 92    | 105 | 173 | 180 | 28  | 110 |
| 1997    | 409        | 634   | 120   | 57    | 65  | 72  | 118 | 123 | 97  |
| 1998    | 176        | 302   | 464   | 85    | 38  | 41  | 45  | 73  | 141 |
| 1999    | 161        | 128   | 212   | 299   | 51  | 22  | 23  | 25  | 131 |
| 2000    | 234        | 118   | 92    | 142   | 184 | 30  | 13  | 13  | 99  |
| 2001    | 946        | 173   | 86    | 64    | 92  | 112 | 17  | 7   | 75  |
| 2002    | 784        | 692   | 123   | 58    | 41  | 56  | 68  | 11  | 56  |
| 2003    | 141        | 572   | 492   | 84    | 38  | 26  | 36  | 43  | 47  |
| 2004    | 157        | 103   | 405   | 337   | 56  | 25  | 17  | 24  | 63  |
| 2005    | 146        | 112   | 70    | 270   | 222 | 37  | 17  | 12  | 63  |
| 2006    | 1,331      | 106   | 78    | 46    | 171 | 139 | 23  | 10  | 54  |
| Average | 810        | 580   | 422   | 294   | 199 | 130 | 86  | 59  | 150 |

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

| Year      | 3+ total             |           | Female                    |                        | Age 2                 |           | 2005 Assessment results |                     |                        |                   |                 |
|-----------|----------------------|-----------|---------------------------|------------------------|-----------------------|-----------|-------------------------|---------------------|------------------------|-------------------|-----------------|
|           | biomass<br>(1,000 t) | (1,000 t) | spawn. biom.<br>(1,000 t) | Female<br>spawn. biom. | recruits<br>(million) | Catch (t) | Harvest<br>rate         | 3+ total<br>biomass | Female<br>spawn. biom. | Age 2<br>recruits | Harvest<br>rate |
| 1972      | 894                  | 182       | 182                       | 182                    | 1,393                 | 34,081    | 4%                      | 879                 | 179                    | 1,374             | 4%              |
| 1973      | 1,187                | 201       | 201                       | 201                    | 1,061                 | 36,836    | 3%                      | 1,168               | 198                    | 1,049             | 3%              |
| 1974      | 1,412                | 238       | 238                       | 238                    | 3,466                 | 61,880    | 4%                      | 1,390               | 236                    | 3,434             | 4%              |
| 1975      | 2,252                | 295       | 295                       | 295                    | 702                   | 59,512    | 3%                      | 2,223               | 291                    | 697               | 3%              |
| 1976      | 2,393                | 413       | 413                       | 413                    | 442                   | 86,527    | 4%                      | 2,364               | 409                    | 439               | 4%              |
| 1977      | 2,190                | 516       | 516                       | 516                    | 2,013                 | 118,356   | 5%                      | 2,163               | 509                    | 2,003             | 5%              |
| 1978      | 2,348                | 557       | 557                       | 557                    | 2,738                 | 96,935    | 4%                      | 2,323               | 548                    | 2,724             | 4%              |
| 1979      | 2,837                | 566       | 566                       | 566                    | 2,495                 | 105,748   | 4%                      | 2,812               | 560                    | 2,480             | 4%              |
| 1980      | 3,293                | 622       | 622                       | 622                    | 3,498                 | 114,622   | 3%                      | 3,266               | 617                    | 3,479             | 4%              |
| 1981      | 3,933                | 503       | 503                       | 503                    | 1,776                 | 147,744   | 4%                      | 3,904               | 500                    | 1,768             | 4%              |
| 1982      | 4,048                | 572       | 572                       | 572                    | 431                   | 168,740   | 4%                      | 4,019               | 570                    | 429               | 4%              |
| 1983      | 3,410                | 693       | 693                       | 693                    | 491                   | 215,608   | 6%                      | 3,386               | 688                    | 489               | 6%              |
| 1984      | 2,753                | 719       | 719                       | 719                    | 207                   | 307,401   | 11%                     | 2,733               | 712                    | 206               | 11%             |
| 1985      | 2,036                | 647       | 647                       | 647                    | 480                   | 284,826   | 14%                     | 2,020               | 641                    | 478               | 14%             |
| 1986      | 1,638                | 524       | 524                       | 524                    | 1,625                 | 87,809    | 5%                      | 1,623               | 519                    | 1,622             | 5%              |
| 1987      | 1,704                | 440       | 440                       | 440                    | 556                   | 69,751    | 4%                      | 1,691               | 436                    | 555               | 4%              |
| 1988      | 1,611                | 400       | 400                       | 400                    | 161                   | 65,739    | 4%                      | 1,600               | 397                    | 161               | 4%              |
| 1989      | 1,461                | 389       | 389                       | 389                    | 377                   | 78,392    | 5%                      | 1,452               | 386                    | 377               | 5%              |
| 1990      | 1,247                | 350       | 350                       | 350                    | 1,614                 | 90,744    | 7%                      | 1,240               | 347                    | 1,609             | 7%              |
| 1991      | 1,365                | 332       | 332                       | 332                    | 1,008                 | 100,488   | 7%                      | 1,358               | 329                    | 1,002             | 7%              |
| 1992      | 1,680                | 295       | 295                       | 295                    | 403                   | 90,857    | 5%                      | 1,671               | 294                    | 400               | 5%              |
| 1993      | 1,524                | 331       | 331                       | 331                    | 240                   | 108,908   | 7%                      | 1,516               | 331                    | 239               | 7%              |
| 1994      | 1,278                | 379       | 379                       | 379                    | 146                   | 107,335   | 8%                      | 1,270               | 377                    | 145               | 8%              |
| 1995      | 1,074                | 346       | 346                       | 346                    | 221                   | 72,618    | 7%                      | 1,067               | 343                    | 220               | 7%              |
| 1996      | 890                  | 312       | 312                       | 312                    | 858                   | 51,263    | 6%                      | 884                 | 309                    | 862               | 6%              |
| 1997      | 910                  | 269       | 269                       | 269                    | 409                   | 90,130    | 10%                     | 906                 | 267                    | 416               | 10%             |
| 1998      | 834                  | 205       | 205                       | 205                    | 176                   | 125,098   | 15%                     | 834                 | 204                    | 181               | 15%             |
| 1999      | 675                  | 188       | 188                       | 188                    | 161                   | 95,590    | 14%                     | 677                 | 187                    | 177               | 14%             |
| 2000      | 597                  | 176       | 176                       | 176                    | 234                   | 73,080    | 12%                     | 604                 | 176                    | 252               | 12%             |
| 2001      | 571                  | 172       | 172                       | 172                    | 946                   | 72,076    | 13%                     | 585                 | 173                    | 1,040             | 12%             |
| 2002      | 737                  | 146       | 146                       | 146                    | 784                   | 51,937    | 7%                      | 783                 | 149                    | 729               | 7%              |
| 2003      | 881                  | 141       | 141                       | 141                    | 141                   | 50,666    | 6%                      | 903                 | 146                    | 164               | 6%              |
| 2004      | 787                  | 157       | 157                       | 157                    | 157                   | 63,913    | 8%                      | 809                 | 165                    | 146               | 8%              |
| 2005      | 677                  | 201       | 201                       | 201                    | 146                   | 80,876    | 12%                     | 709                 | 208                    | 276               | 11%             |
| 2006      | 543                  | 212       | 212                       | 212                    | 1,331                 |           |                         |                     |                        |                   |                 |
| Average   |                      |           |                           |                        |                       |           |                         |                     |                        |                   |                 |
| 1972-2006 | 1,648                | 363       | 363                       | 363                    | 940                   | 101,944   | 7%                      | 1,671               | 365                    | 930               | 7%              |
| 1979-2005 |                      |           |                           |                        | 731                   |           |                         |                     |                        |                   |                 |

Table 1.18. Gulf of Alaska pollock life history and fishery vectors used to estimate spawning biomass per recruit ( $F_{SPR}$ ) harvest rates. Population weight at age is the average for the bottom trawl survey in 2001-2005. Proportion mature females is the average for 1983-2005 from winter EIT survey specimen data. Spawning weight at age is the average for the Shelikof Strait EIT survey in 2002-2006.

| <i>Age</i> | <i>Natural mortality</i> | <i>Fishery selectivity (Avg. 1992-2005)</i> | <i>Weight at age (kg)</i>  |                               |                                 | <i>Proportion mature females</i> |
|------------|--------------------------|---|----------------------------|-------------------------------|---------------------------------|----------------------------------|
|            |                          |   | <i>Spawning (March 15)</i> | <i>Population (June-Aug.)</i> | <i>Fishery (Avg. 2001-2005)</i> |                                  |
| 2          | 0.3                      | 0.076                                       | 0.080                      | 0.158                         | 0.302                           | 0.001                            |
| 3          | 0.3                      | 0.214                                       | 0.230                      | 0.420                         | 0.484                           | 0.021                            |
| 4          | 0.3                      | 0.475                                       | 0.394                      | 0.638                         | 0.667                           | 0.269                            |
| 5          | 0.3                      | 0.766                                       | 0.626                      | 0.838                         | 0.860                           | 0.565                            |
| 6          | 0.3                      | 0.933                                       | 0.870                      | 0.972                         | 1.036                           | 0.813                            |
| 7          | 0.3                      | 0.990                                       | 1.126                      | 1.119                         | 1.144                           | 0.899                            |
| 8          | 0.3                      | 1.000                                       | 1.257                      | 1.280                         | 1.346                           | 0.959                            |
| 9          | 0.3                      | 0.889                                       | 1.454                      | 1.329                         | 1.427                           | 0.984                            |
| 10+        | 0.3                      | 0.348                                       | 1.676                      | 1.523                         | 1.635                           | 0.990                            |

Table 1.19. Methods used to assess Gulf of Alaska pollock, 1977-2005. 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 1990-2005 is the method used by the Plan Team to derive the ABC recommendation given in the SAFE summary chapter.

| <i>Year</i> | <i>Assessment method</i>                                 | <i>Basis for catch recommendation in following year</i>  | <i>B40% (t)</i> |
|-------------|--|--|-----------------|
| 1977        | Survey biomass, CPUE trends, $M=0.4$                     | $MSY = 0.4 * M * B_{zero}$   | ---             |
| 1978        | Survey biomass, CPUE trends                              | $MSY = 0.4 * M * B_{zero}$   | ---             |
| 1979        | Survey biomass, CPUE trends                              | $MSY = 0.4 * M * B_{zero}$   | ---             |
| 1980        | Survey biomass, CPUE trends                              | $MSY = 0.4 * M * B_{zero}$   | ---             |
| 1981        | Survey biomass, CPUE trends                              | $MSY = 0.4 * M * B_{zero}$   | ---             |
| 1982        | CAGEAN   | $MSY = 0.4 * M * B_{zero}$   | ---             |
| 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  | $\text{Max}[-\text{Pr}(\text{SB} < \text{Threshold}) + \text{Yld}]$  | ---             |
| 1993        | Stock synthesis  | $\text{Pr}(\text{SB} > \text{B}_{20}) = 0.95$  | ---             |
| 1994        | Stock synthesis  | $\text{Pr}(\text{SB} > \text{B}_{20}) = 0.95$  | ---             |
| 1995        | Stock synthesis  | $\text{Max}[-\text{Pr}(\text{SB} < \text{Threshold}) + \text{Yld}]$  | ---             |
| 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 $F_{ABC}$ )  | 224,000         |

Table 1.20. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2006-2018 under different harvest policies. All projections begin with estimated age composition in 2006 using base run model. The values for  $B_{100\%}$ ,  $B_{40\%}$ , and  $B_{35\%}$  are 549,000, 220,000, and 192,000 t, respectively.

| <i>Spawning biomass (t)</i> | <i>Max <math>F_{ABC}</math></i> | <i>Author's recommended <math>F</math></i> | <i>Average <math>F</math></i> | <i><math>F_{75\%}</math></i> | <i><math>F = 0</math></i> | <i><math>F_{OFL}</math></i> | <i>Max <math>F_{ABC}</math> for two years, then <math>F_{OFL}</math></i> |
|-----------------------------|---------------------------------|--|-------------------------------|------------------------------|---------------------------|-----------------------------|--|
| 2006                        | 190,288                         | 190,288                                    | 190,288                       | 190,288                      | 190,288                   | 190,288                     | 190,288  |
| 2007                        | 159,824                         | 160,670                                    | 160,999                       | 163,089                      | 165,212                   | 158,909                     | 159,824  |
| 2008                        | 160,068                         | 164,153                                    | 165,905                       | 176,783                      | 188,551                   | 155,795                     | 160,068  |
| 2009                        | 190,821                         | 197,828                                    | 202,517                       | 222,962                      | 246,065                   | 183,652                     | 189,724  |
| 2010                        | 220,476                         | 230,606                                    | 244,875                       | 277,747                      | 316,074                   | 209,411                     | 213,569  |
| 2011                        | 232,413                         | 243,718                                    | 272,713                       | 318,845                      | 374,603                   | 217,392                     | 219,925  |
| 2012                        | 234,476                         | 245,445                                    | 287,994                       | 345,842                      | 418,590                   | 216,703                     | 218,095  |
| 2013                        | 235,641                         | 246,101                                    | 299,553                       | 368,171                      | 457,782                   | 215,990                     | 216,705  |
| 2014                        | 235,499                         | 245,519                                    | 307,102                       | 384,648                      | 489,089                   | 214,684                     | 215,044  |
| 2015                        | 234,500                         | 243,994                                    | 310,275                       | 392,685                      | 505,625                   | 213,294                     | 213,476  |
| 2016                        | 235,254                         | 244,393                                    | 313,736                       | 399,572                      | 518,763                   | 213,853                     | 213,943  |
| 2017                        | 237,392                         | 246,361                                    | 318,042                       | 406,587                      | 530,704                   | 215,796                     | 215,839  |
| 2018                        | 238,074                         | 246,922                                    | 320,564                       | 411,273                      | 539,268                   | 216,224                     | 216,245  |
| 2019                        | 237,223                         | 245,961                                    | 320,911                       | 413,185                      | 544,102                   | 215,218                     | 215,228  |

| <i>Fishing mortality</i> | <i>Max <math>F_{ABC}</math></i> | <i>Author's recommended <math>F</math></i> | <i>Average <math>F</math></i> | <i><math>F_{75\%}</math></i> | <i><math>F = 0</math></i> | <i><math>F_{OFL}</math></i> | <i>Max <math>F_{ABC}</math> for two years, then <math>F_{OFL}</math></i> |
|--------------------------|---------------------------------|--|-------------------------------|------------------------------|---------------------------|-----------------------------|--|
| 2006                     | 0.21                            | 0.21                                       | 0.21                          | 0.21                         | 0                         | 0.21                        | 0.21   |
| 2007                     | 0.19                            | 0.16                                       | 0.15                          | 0.08                         | 0                         | 0.23                        | 0.19   |
| 2008                     | 0.19                            | 0.17                                       | 0.15                          | 0.08                         | 0                         | 0.22                        | 0.19   |
| 2009                     | 0.23                            | 0.20                                       | 0.15                          | 0.08                         | 0                         | 0.26                        | 0.27   |
| 2010                     | 0.25                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.28                        | 0.29   |
| 2011                     | 0.25                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.28                        | 0.28   |
| 2012                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.28   |
| 2013                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |
| 2014                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |
| 2015                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |
| 2016                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |
| 2017                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |
| 2018                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |
| 2019                     | 0.24                            | 0.23                                       | 0.15                          | 0.08                         | 0                         | 0.27                        | 0.27   |

| <i>Catch (t)</i> | <i>Max <math>F_{ABC}</math></i> | <i>Author's recommended <math>F</math></i> | <i>Average <math>F</math></i> | <i><math>F_{75\%}</math></i> | <i><math>F = 0</math></i> | <i><math>F_{OFL}</math></i> | <i>Max <math>F_{ABC}</math> for two years, then <math>F_{OFL}</math></i> |
|------------------|---------------------------------|--|-------------------------------|------------------------------|---------------------------|-----------------------------|--|
| 2006             | 81,300                          | 81,300                                     | 81,300                        | 81,300                       | 81,300                    | 81,300                      | 81,300   |
| 2007             | 75,145                          | 63,799                                     | 59,331                        | 30,437                       | 0                         | 87,224                      | 75,145   |
| 2008             | 87,573                          | 76,958                                     | 70,300                        | 37,341                       | 0                         | 98,031                      | 87,573   |
| 2009             | 124,095                         | 112,842                                    | 84,479                        | 45,919                       | 0                         | 136,889                     | 143,995  |
| 2010             | 147,242                         | 141,715                                    | 96,473                        | 53,796                       | 0                         | 161,402                     | 165,046  |
| 2011             | 152,208                         | 149,398                                    | 104,380                       | 59,711                       | 0                         | 164,784                     | 166,514  |
| 2012             | 153,689                         | 151,283                                    | 110,340                       | 64,538                       | 0                         | 164,586                     | 165,351  |
| 2013             | 151,853                         | 149,144                                    | 111,590                       | 66,183                       | 0                         | 161,559                     | 161,840  |
| 2014             | 147,267                         | 144,011                                    | 108,348                       | 64,223                       | 0                         | 156,682                     | 156,737  |
| 2015             | 147,228                         | 143,790                                    | 108,684                       | 64,581                       | 0                         | 156,744                     | 156,742  |
| 2016             | 148,311                         | 144,551                                    | 109,500                       | 65,144                       | 0                         | 157,875                     | 157,867  |
| 2017             | 149,431                         | 145,708                                    | 110,043                       | 65,527                       | 0                         | 159,239                     | 159,232  |
| 2018             | 148,604                         | 144,896                                    | 109,943                       | 65,590                       | 0                         | 158,218                     | 158,213  |
| 2019             | 147,311                         | 143,826                                    | 109,464                       | 65,473                       | 0                         | 156,854                     | 156,851  |

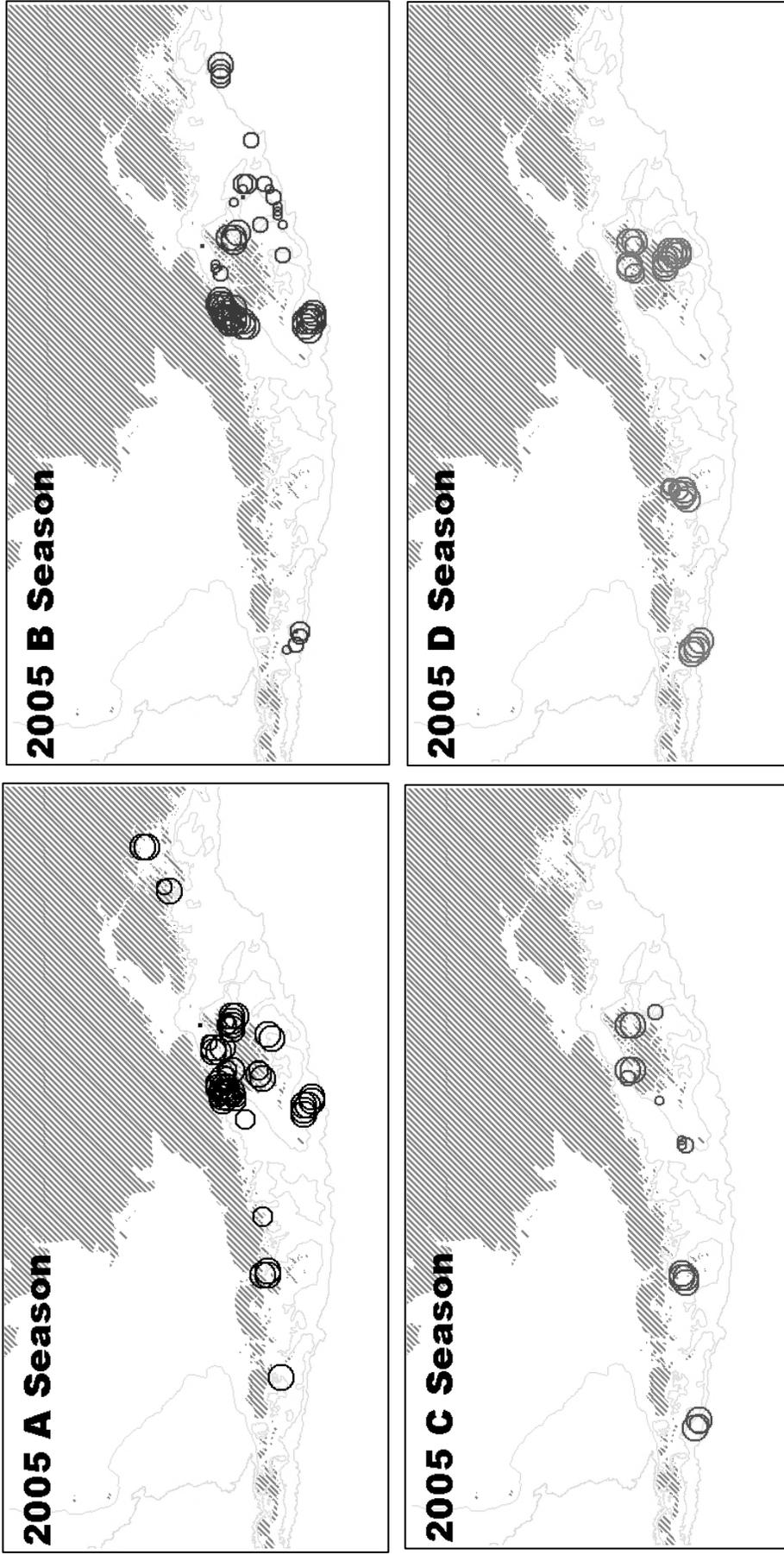


Figure 1.1 Pollock catch in 2005 by 10 sq. nmi. blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

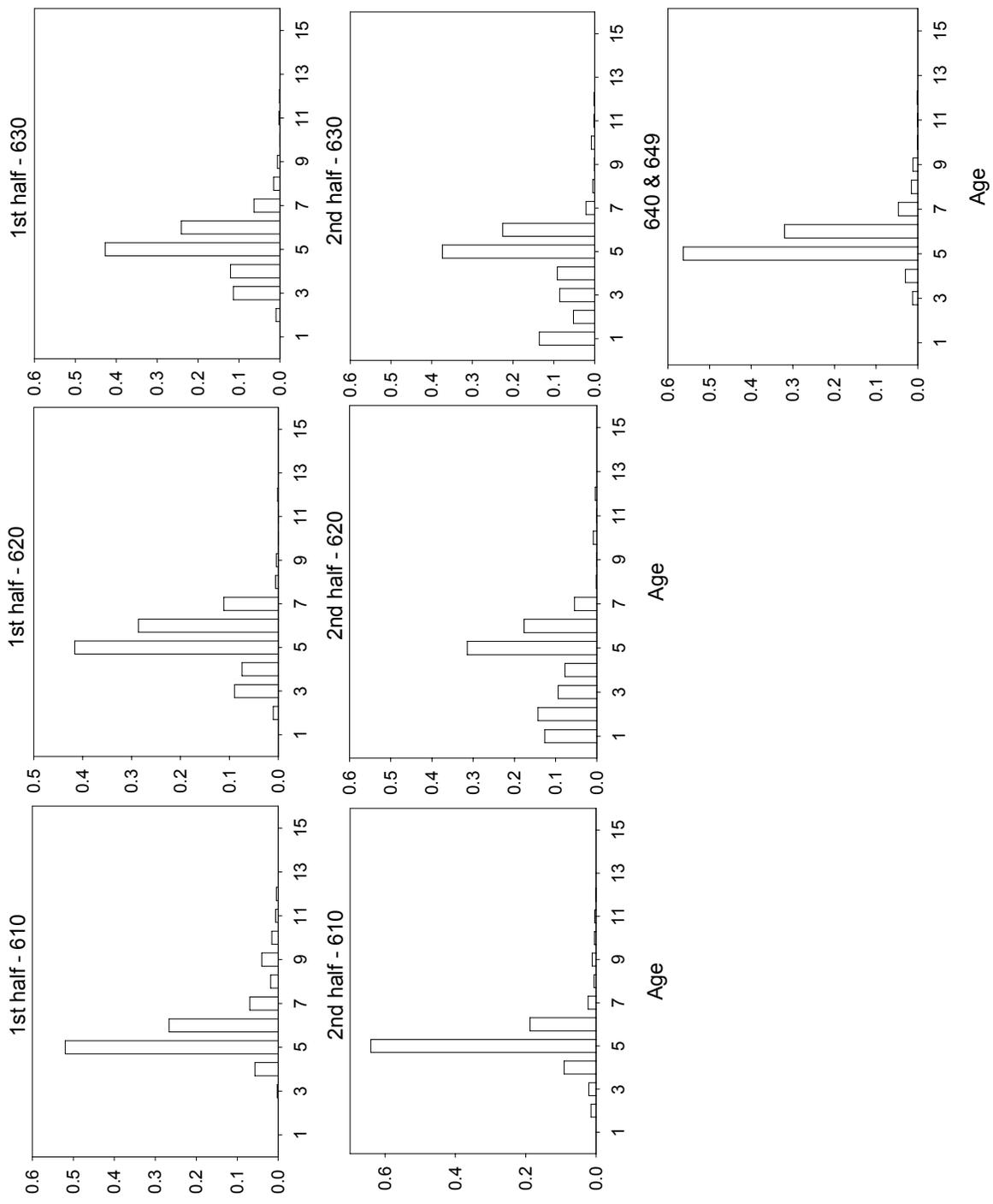


Figure 1.2. 2005 catch age composition by half year and statistical area.

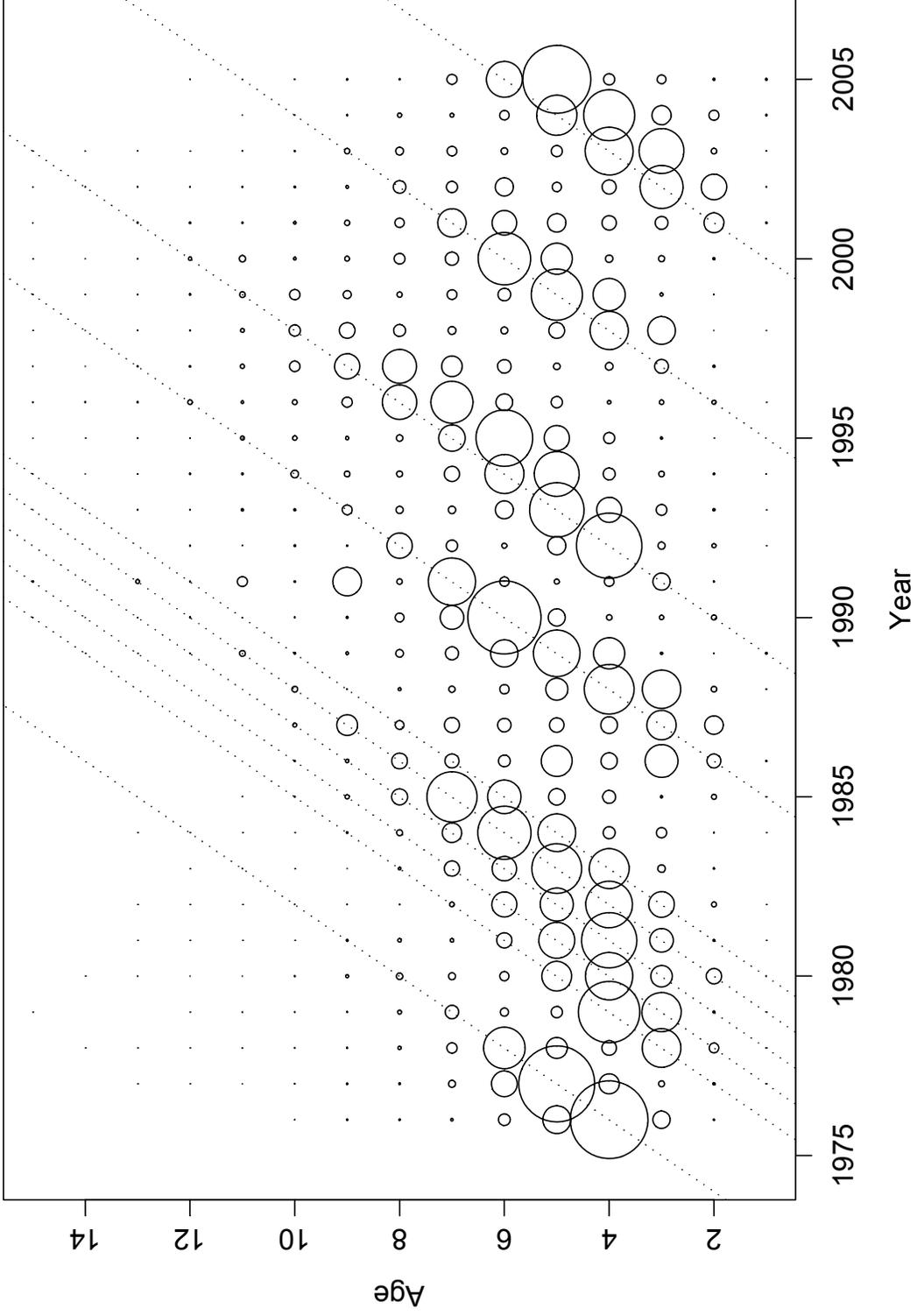


Figure 1.3. Gulf of Alaska pollock catch age composition (1976-2005). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1984, 1988, 1994, and 1999).

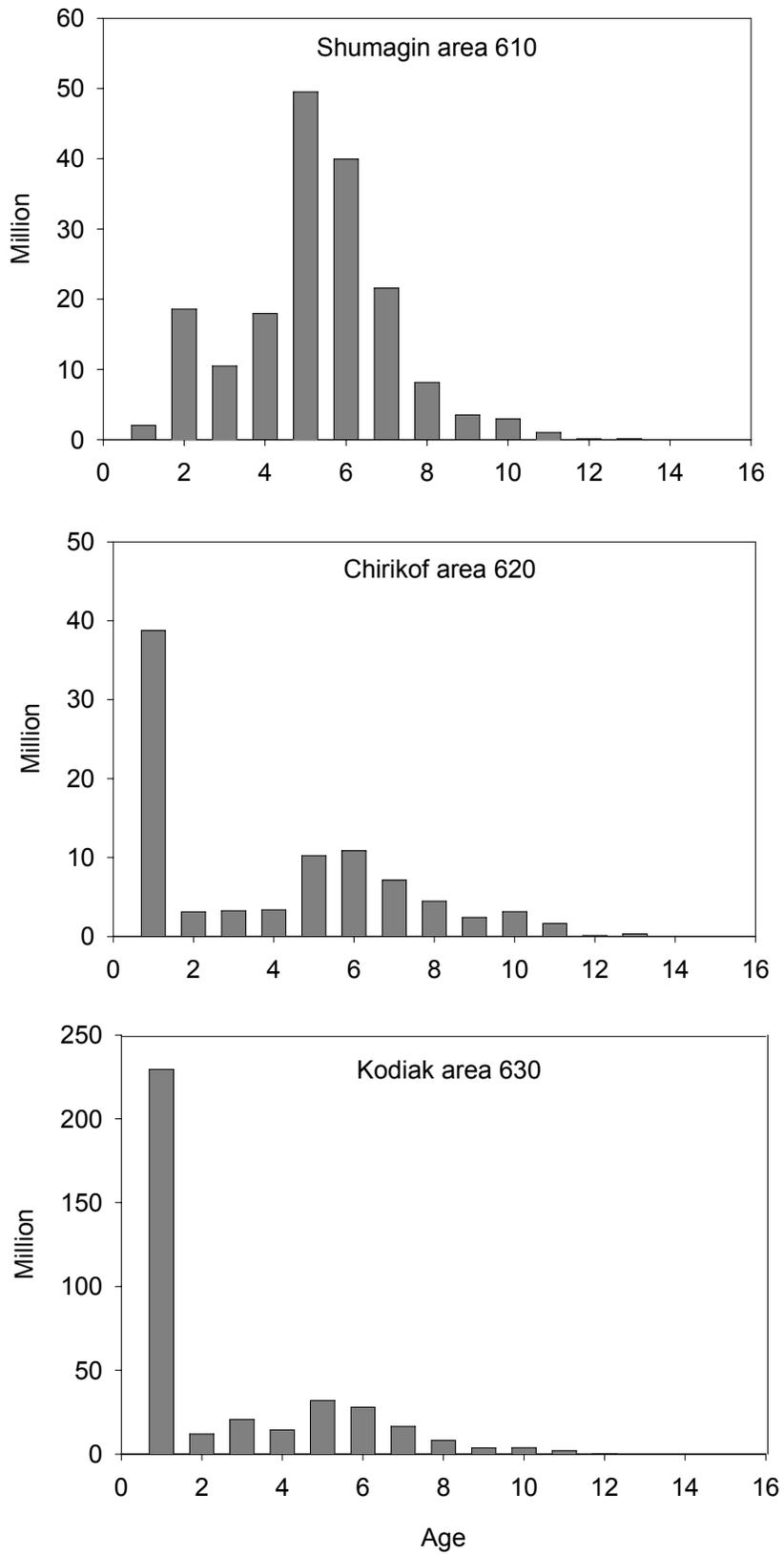


Figure 1.4. Age composition of pollock by statistical area for the 2005 NMFS bottom trawl survey.

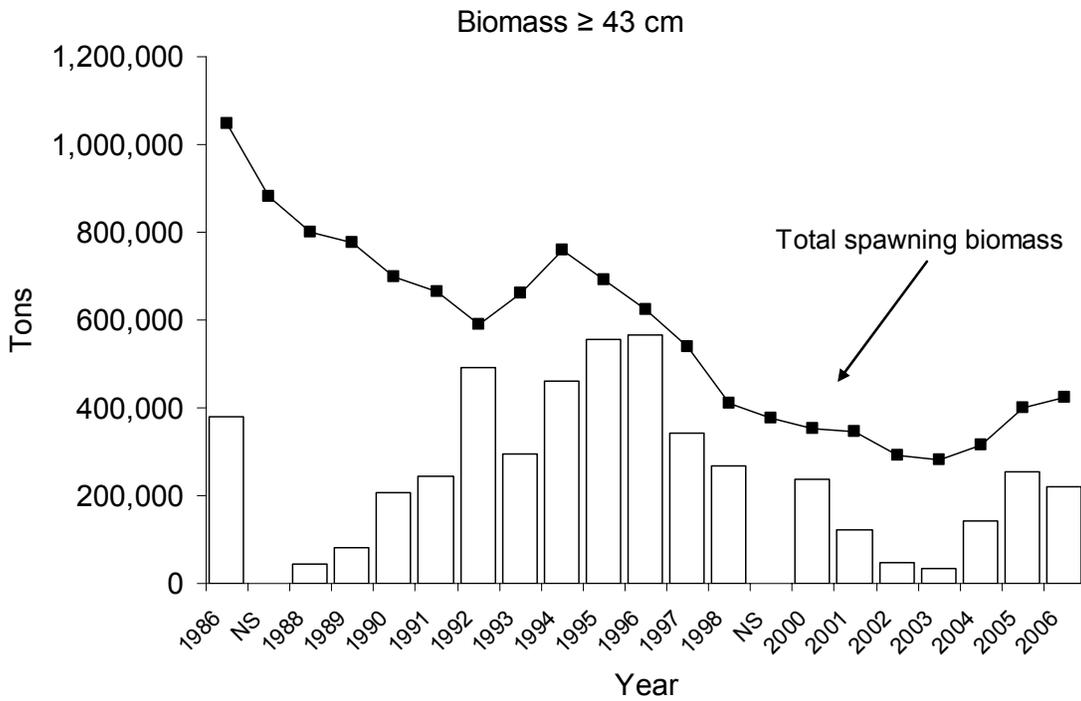
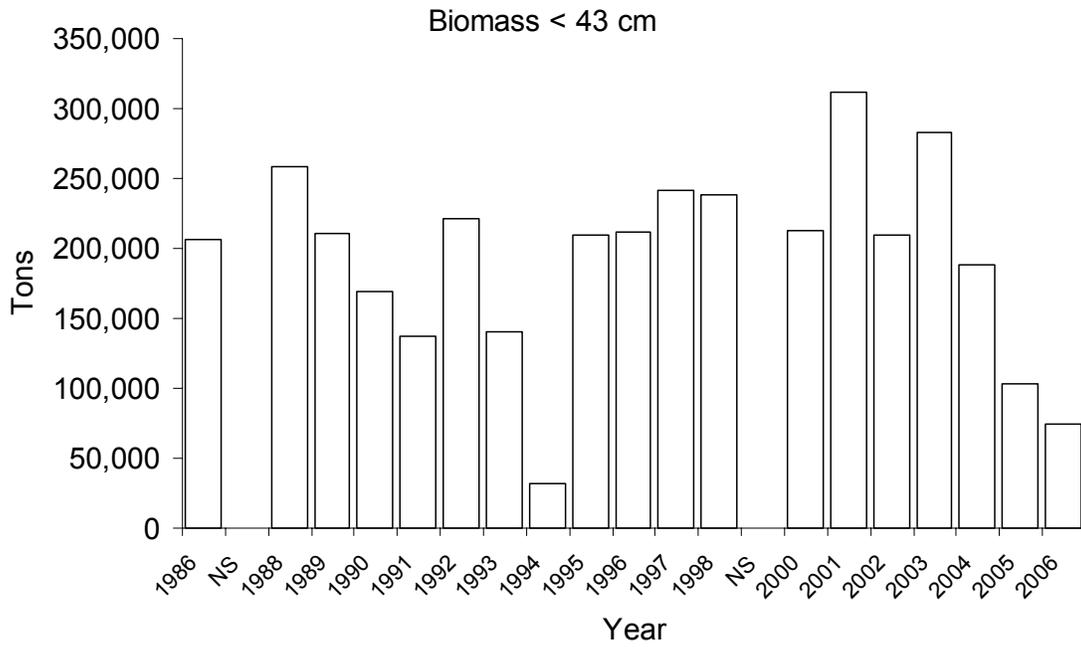


Figure 1.5. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2006 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

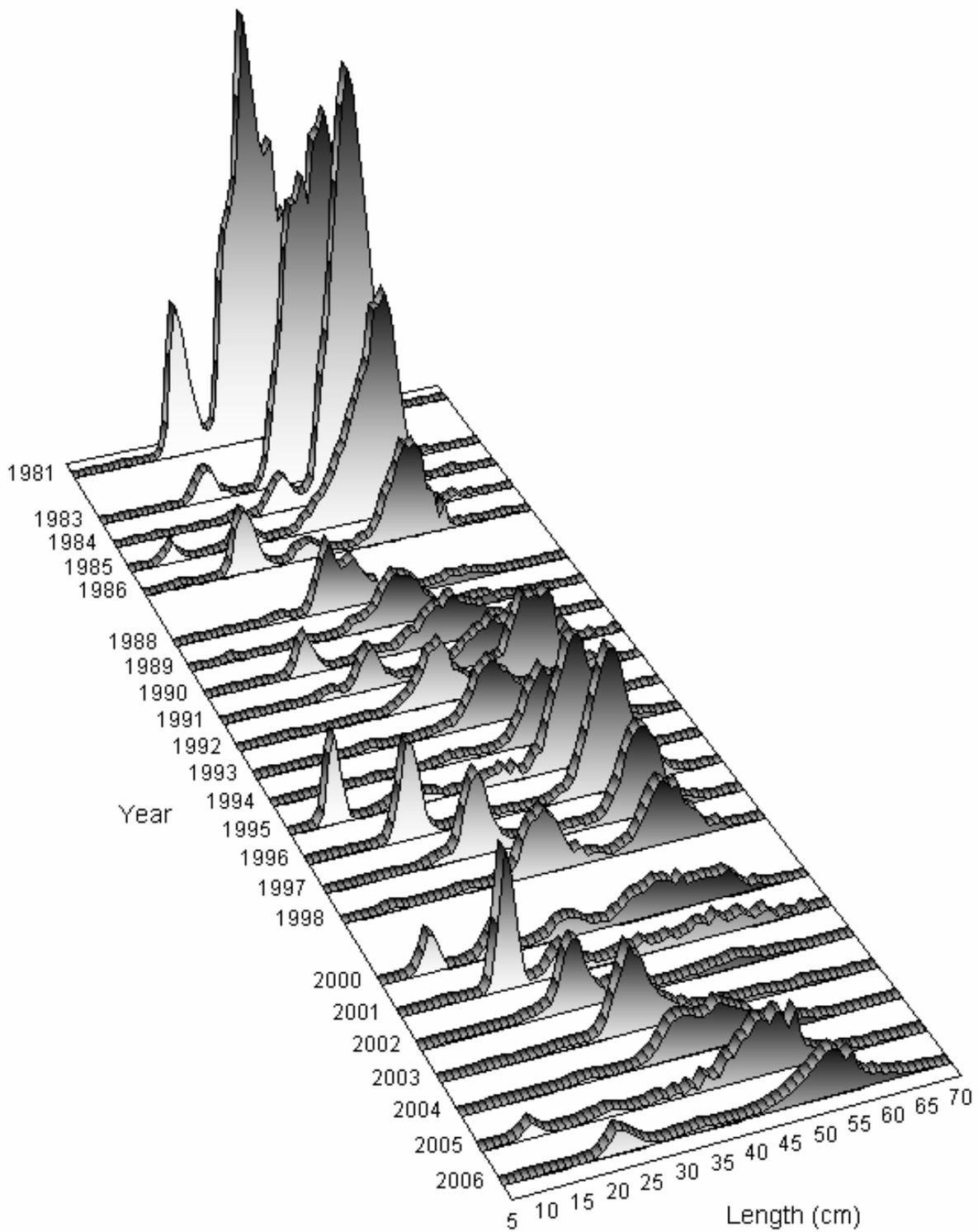


Figure 1.6. Biomass by length for pollock in the Shelikof Strait EIT survey (1981-2006, except 1982,1987 and 1999).

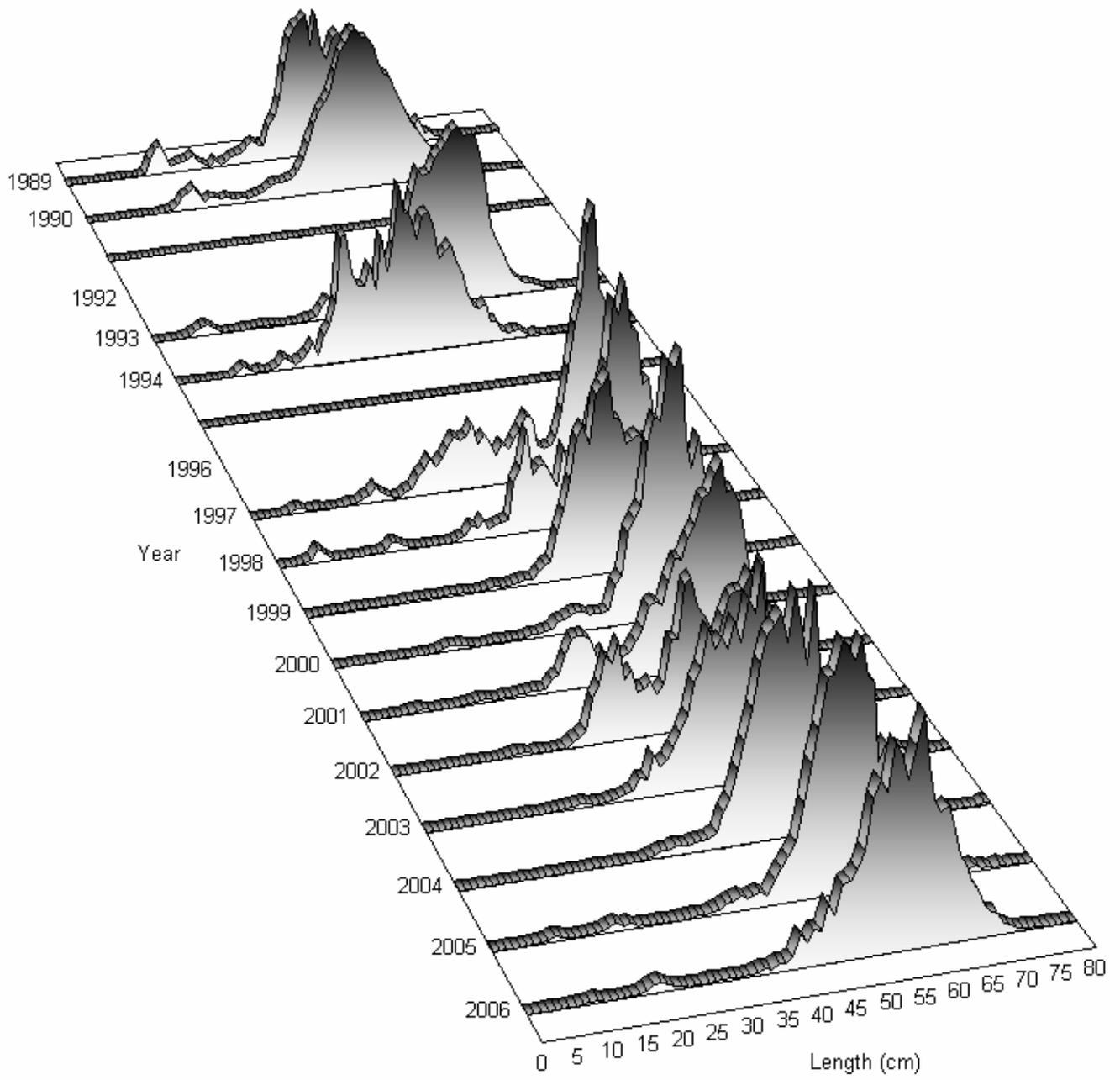


Figure 1.7. Length frequency of pollock in the ADF&G crab/groundfish trawl survey (1989-2006, except 1991 and 1995).

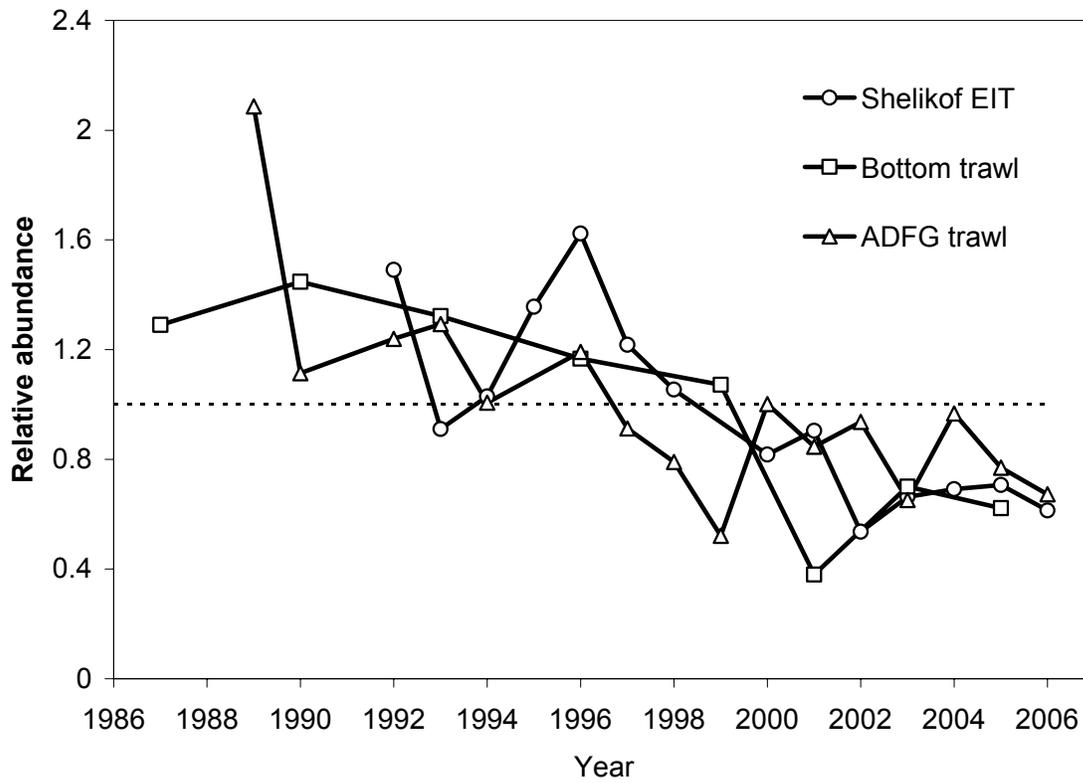


Figure 1.8. Relative trends in pollock biomass since 1987 for the Shelikof Strait EIT survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987.

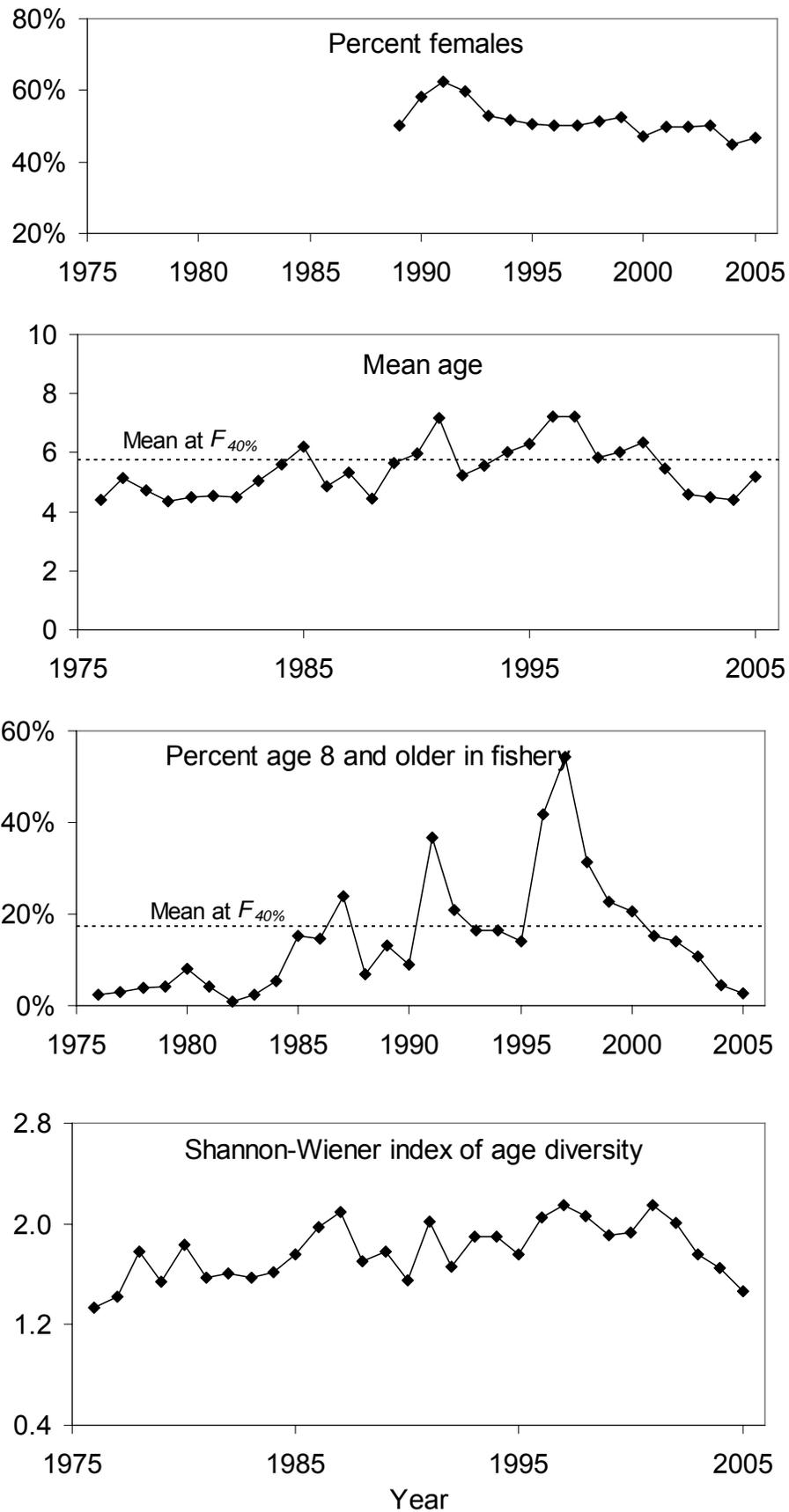


Figure 1.9. Gulf of Alaska pollock catch characteristics.

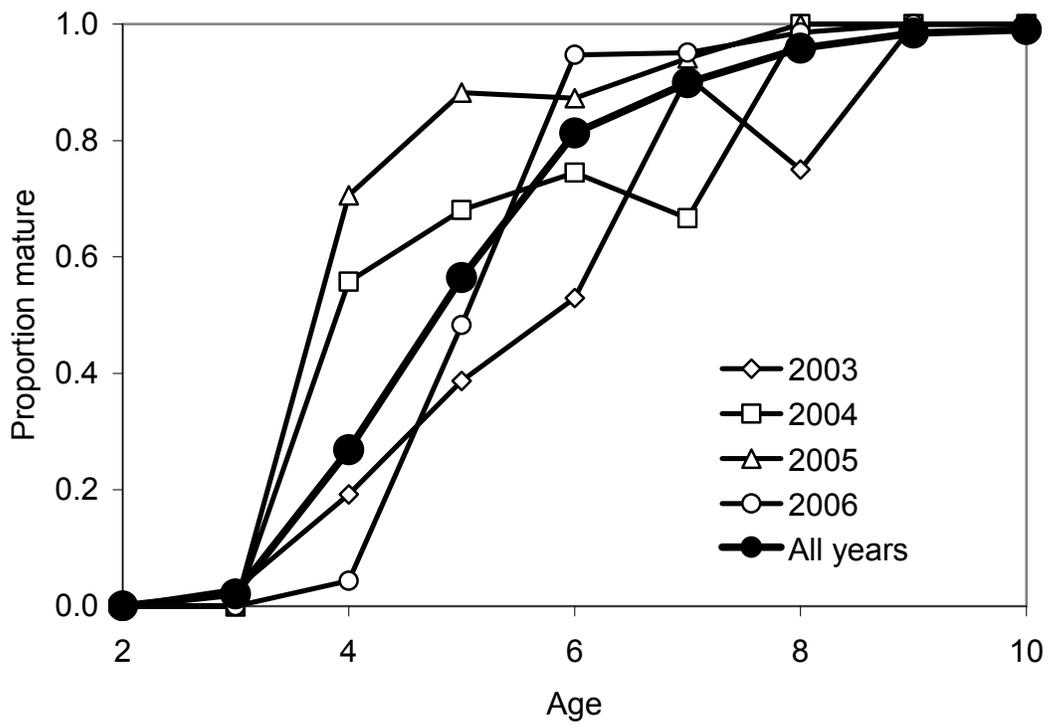


Figure 1.10. Estimates of the proportion mature at age from visual maturity data collected during 2003-2006 winter EIT surveys in the Gulf of Alaska.

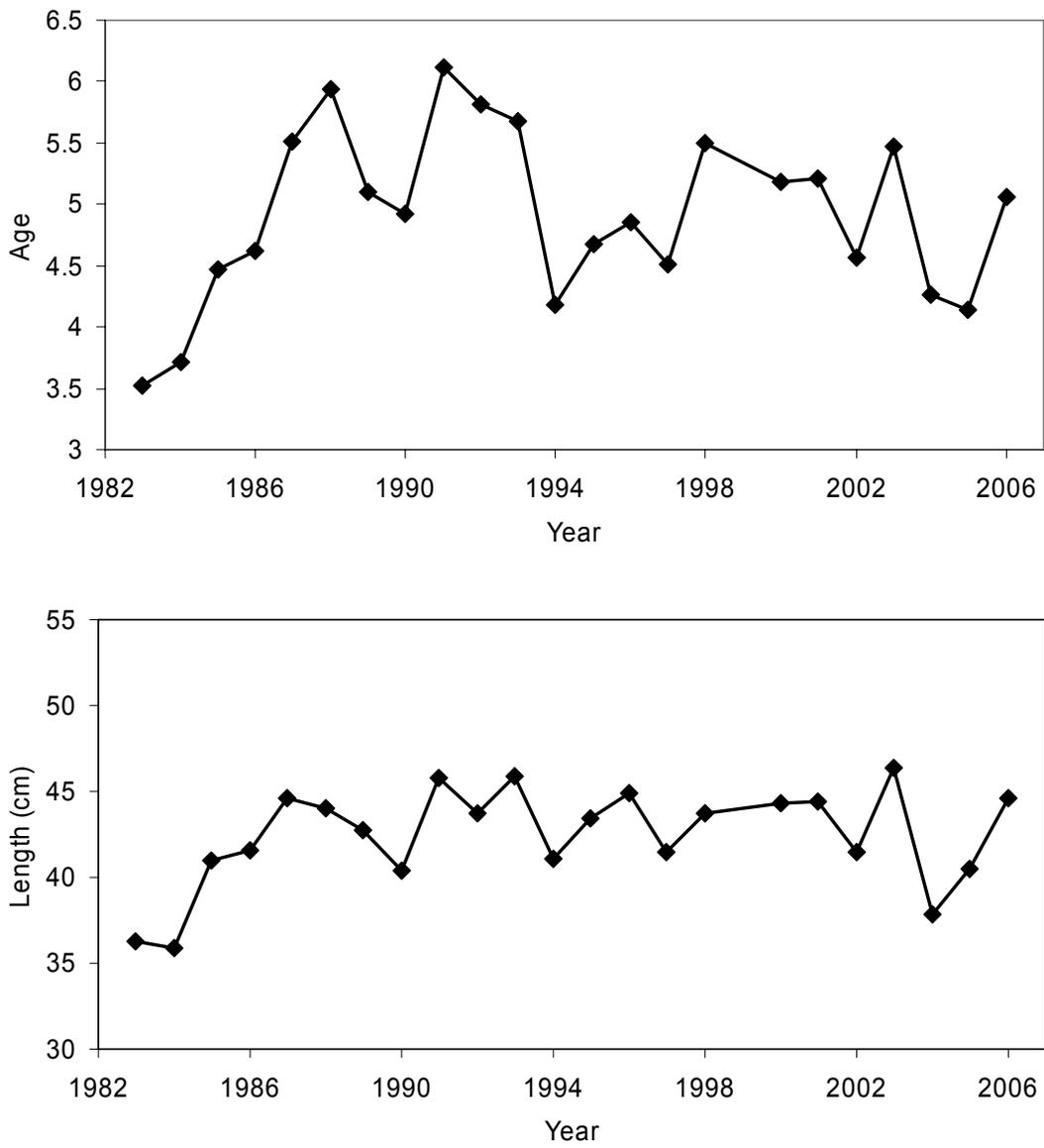


Figure 1.11. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2006.

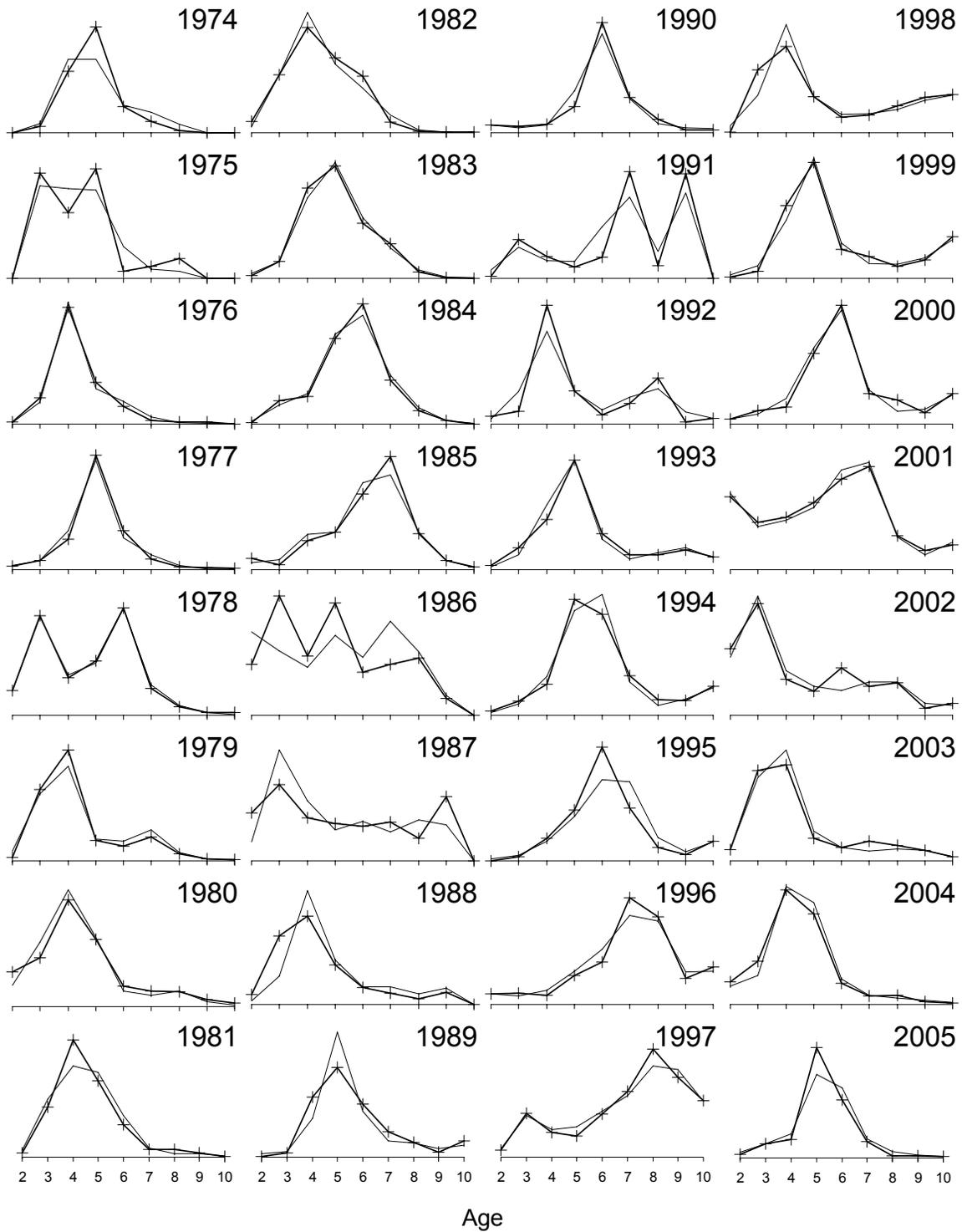


Figure 1.12. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

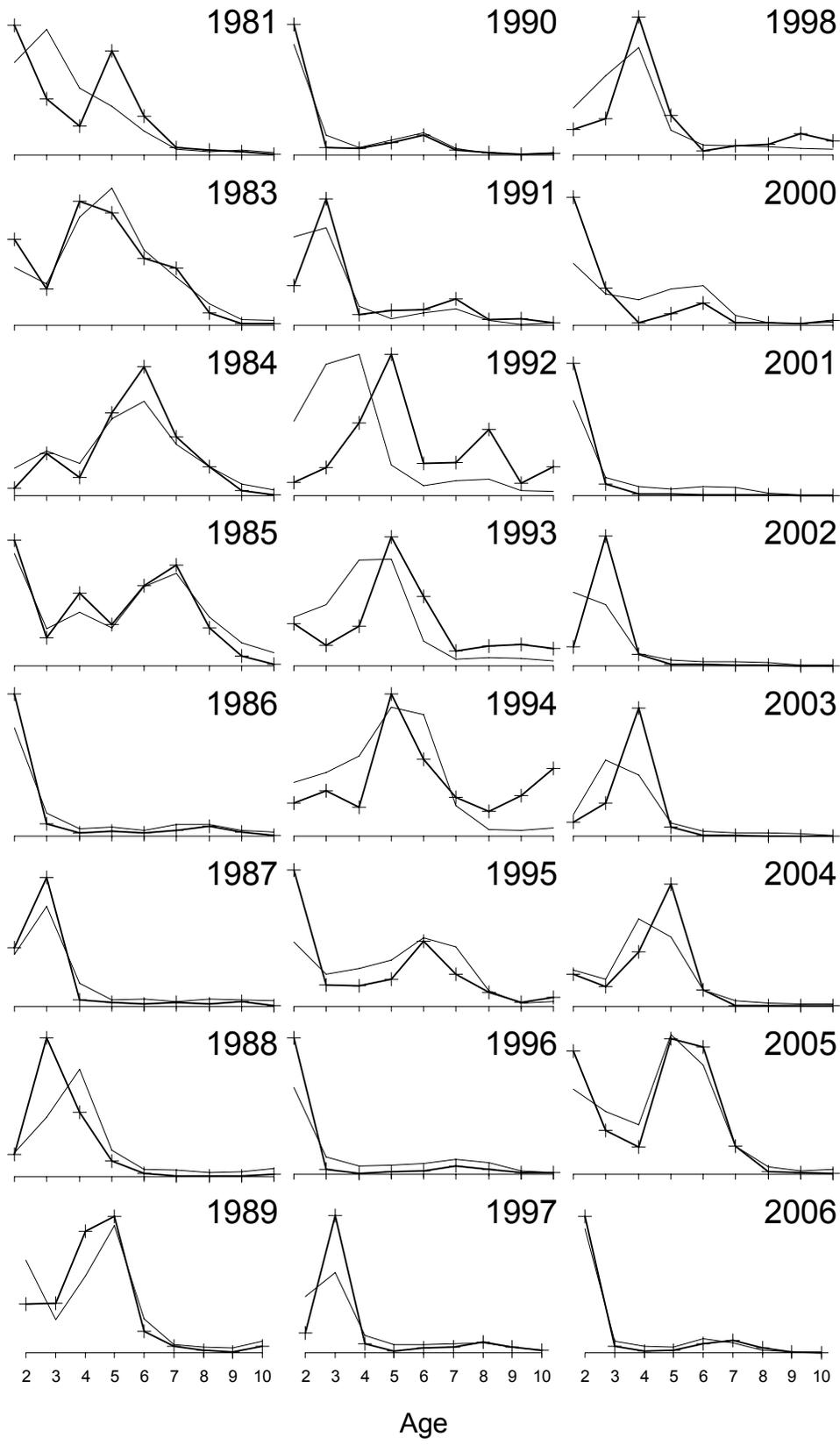


Figure 1.13. Observed and predicted Shelikof Strait EIT survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

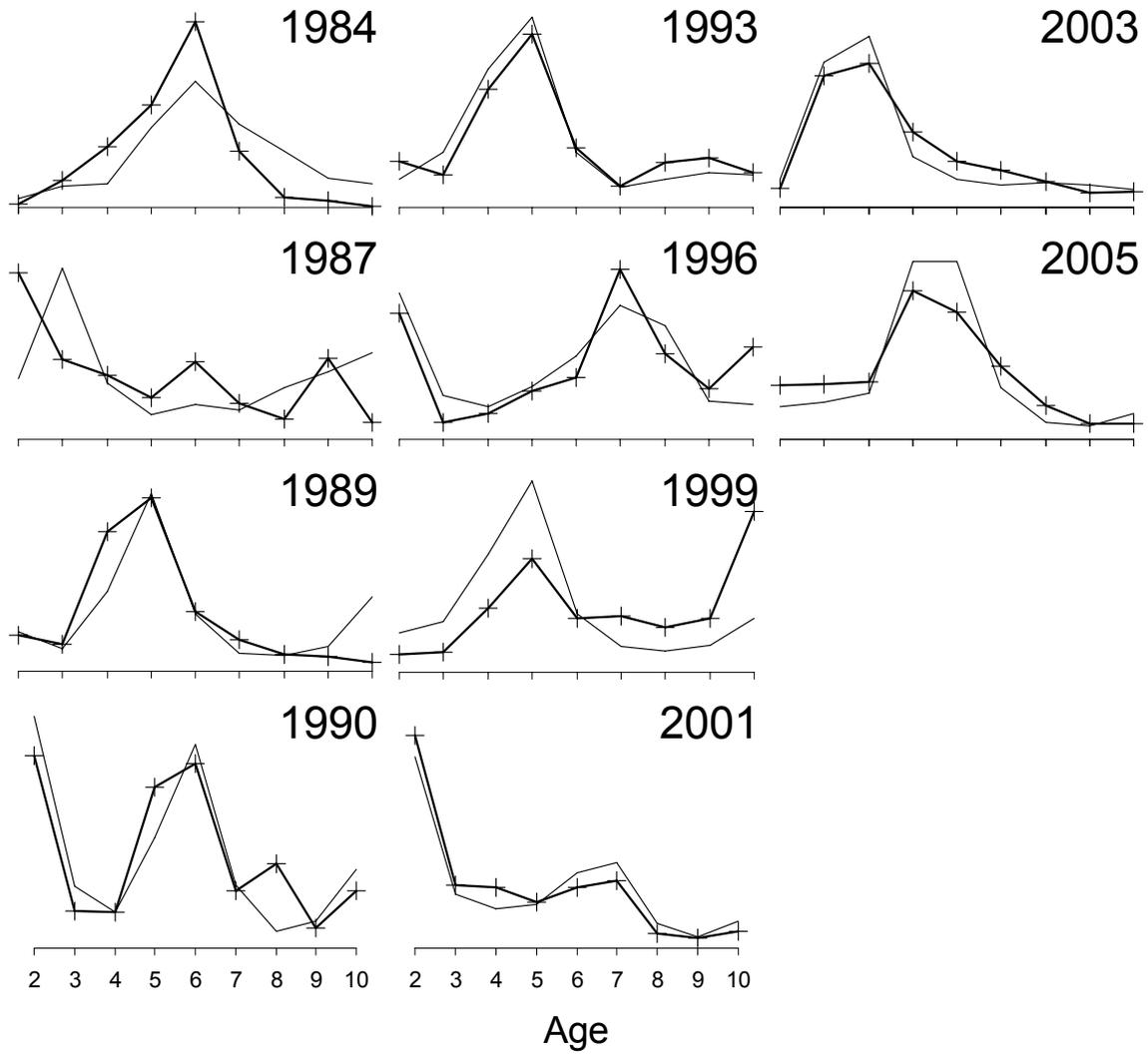


Figure 1.14. Observed and predicted NMFS bottom trawl age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

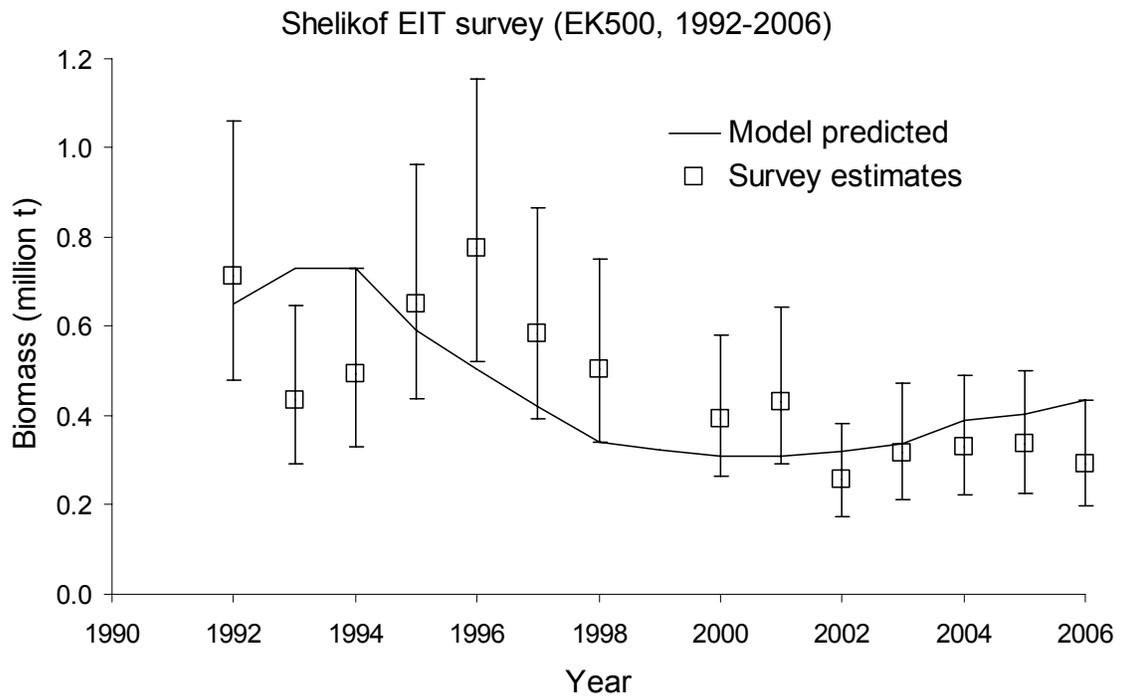
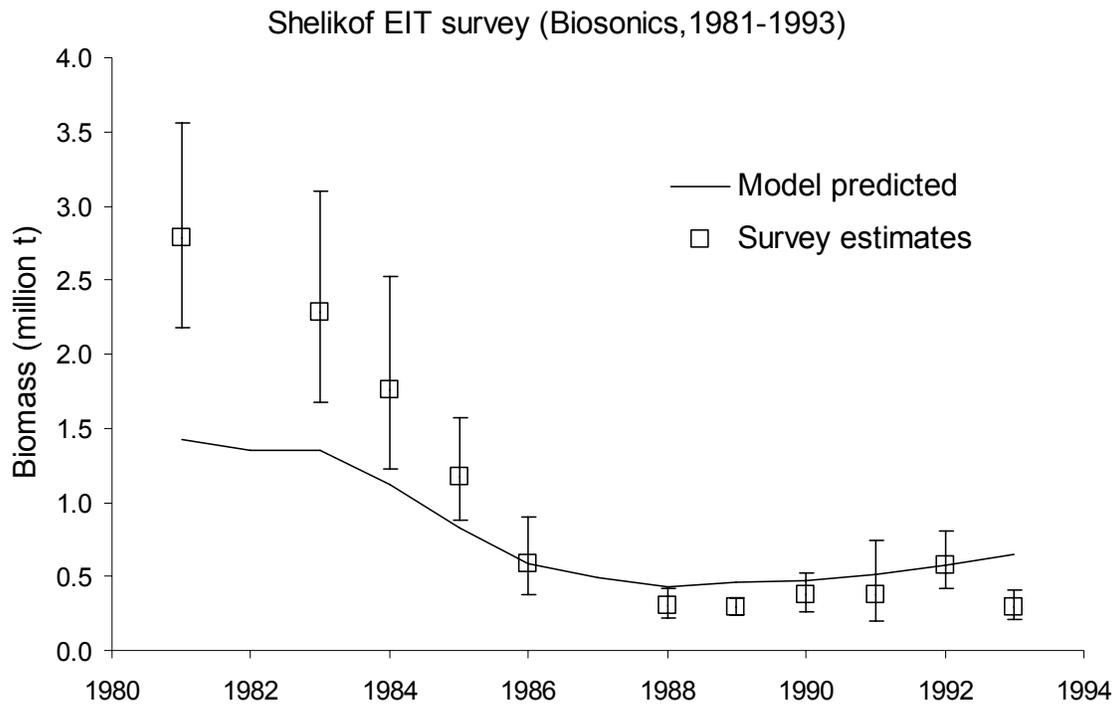


Figure 1.15. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with two catchability periods corresponding to the two acoustic systems used for the survey. Error bars indicate plus and minus two standard deviations.

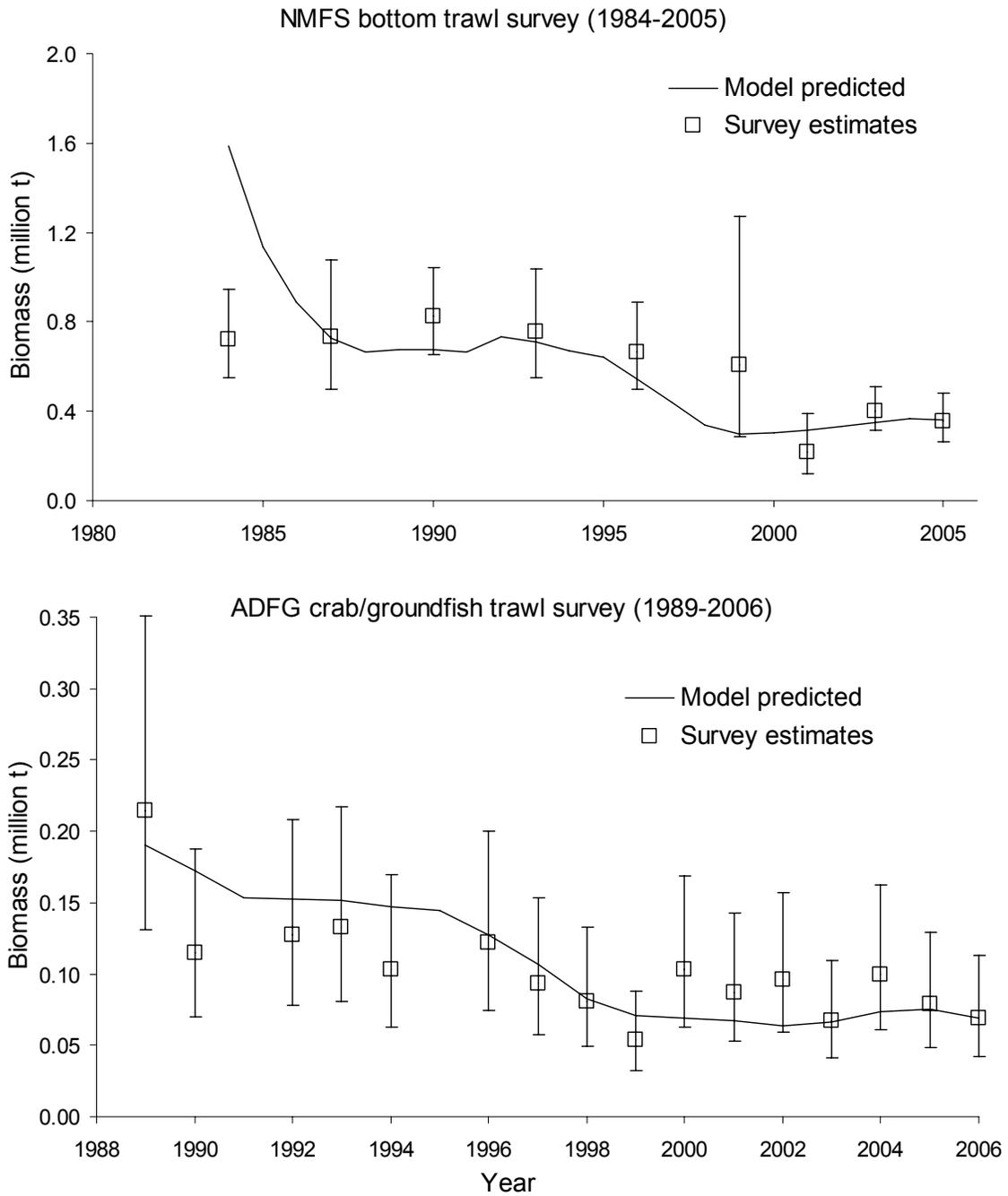


Figure 1.16. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.

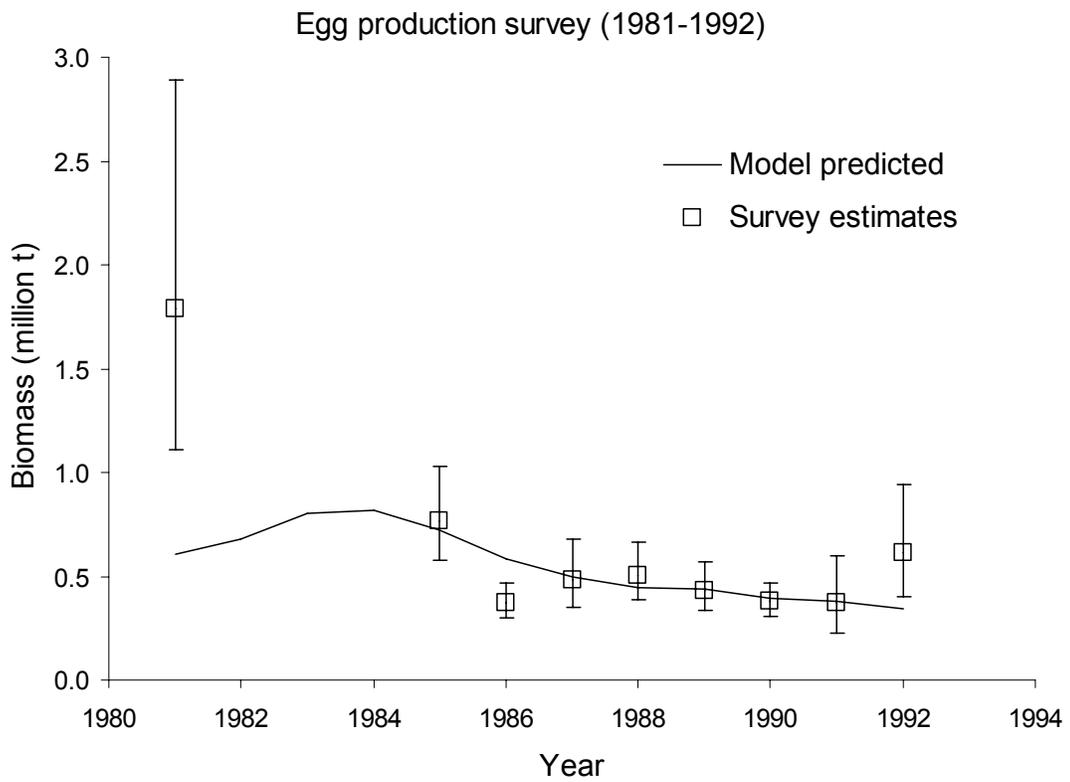
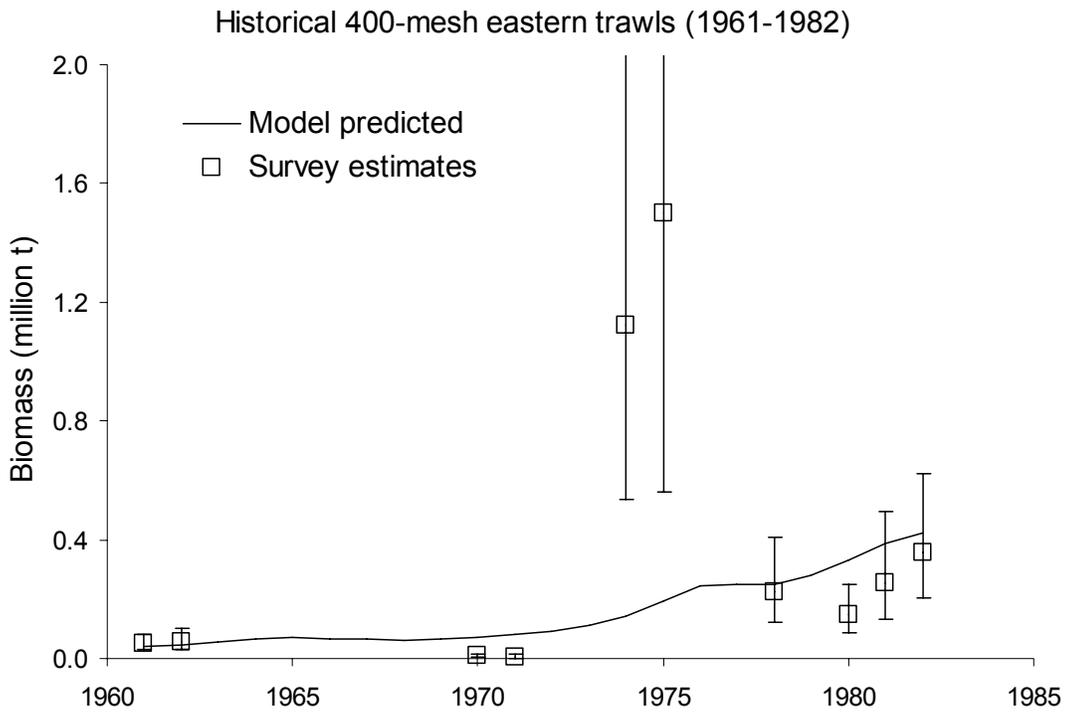


Figure 1.17. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top), and the egg production survey (bottom). Error bars indicate plus and minus two standard deviations.

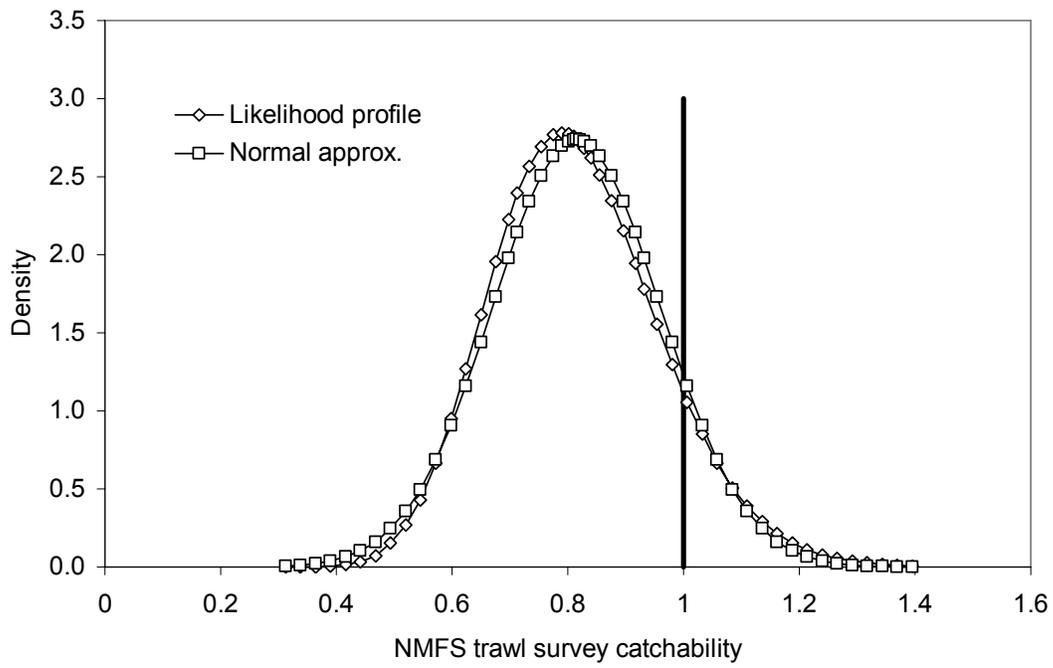


Figure 1.18. Uncertainty in the catchability coefficient for the NMFS trawl survey from a likelihood profile for Model 1.

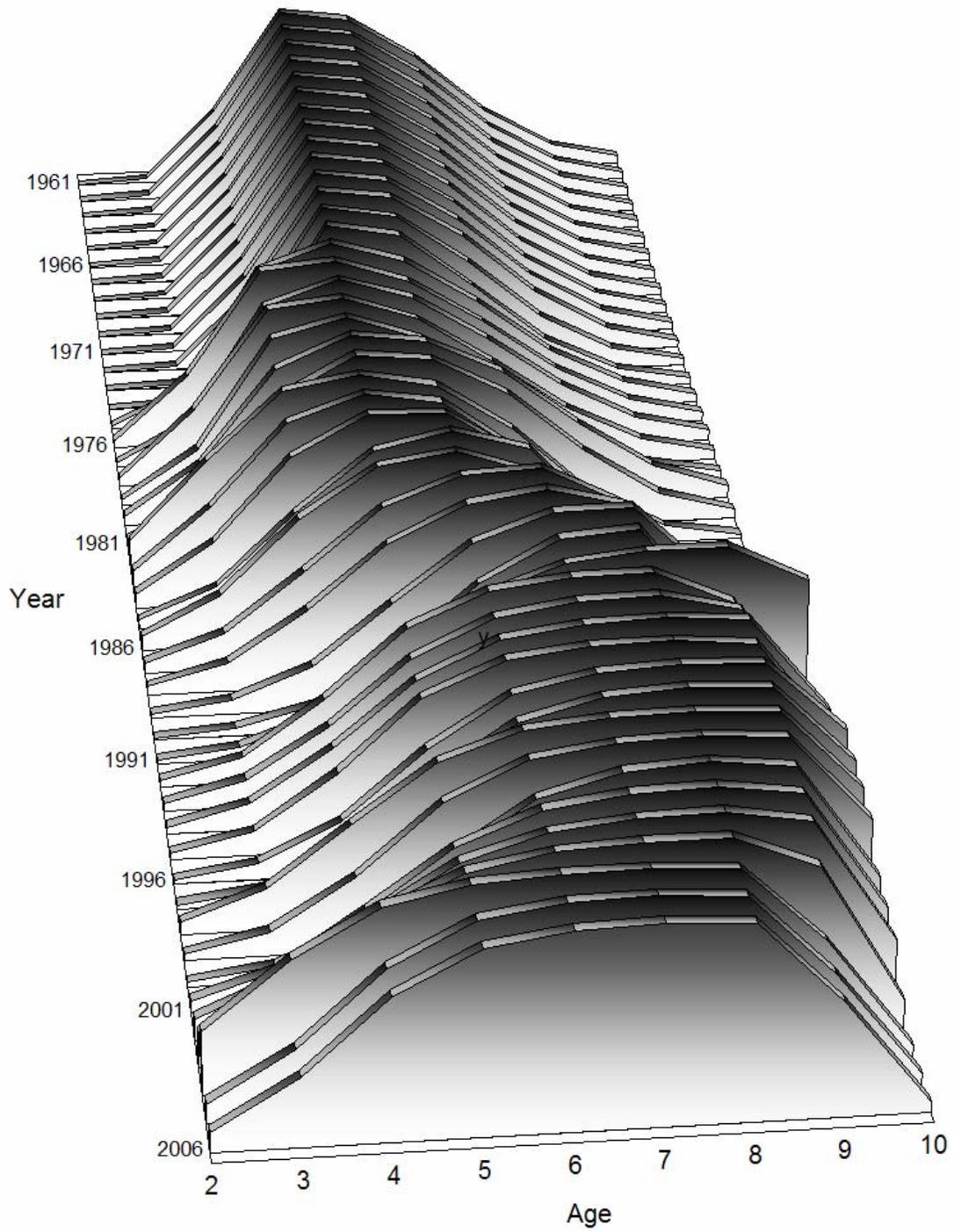


Figure 1.19. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock. The maximum selectivity in each year is 1.0.

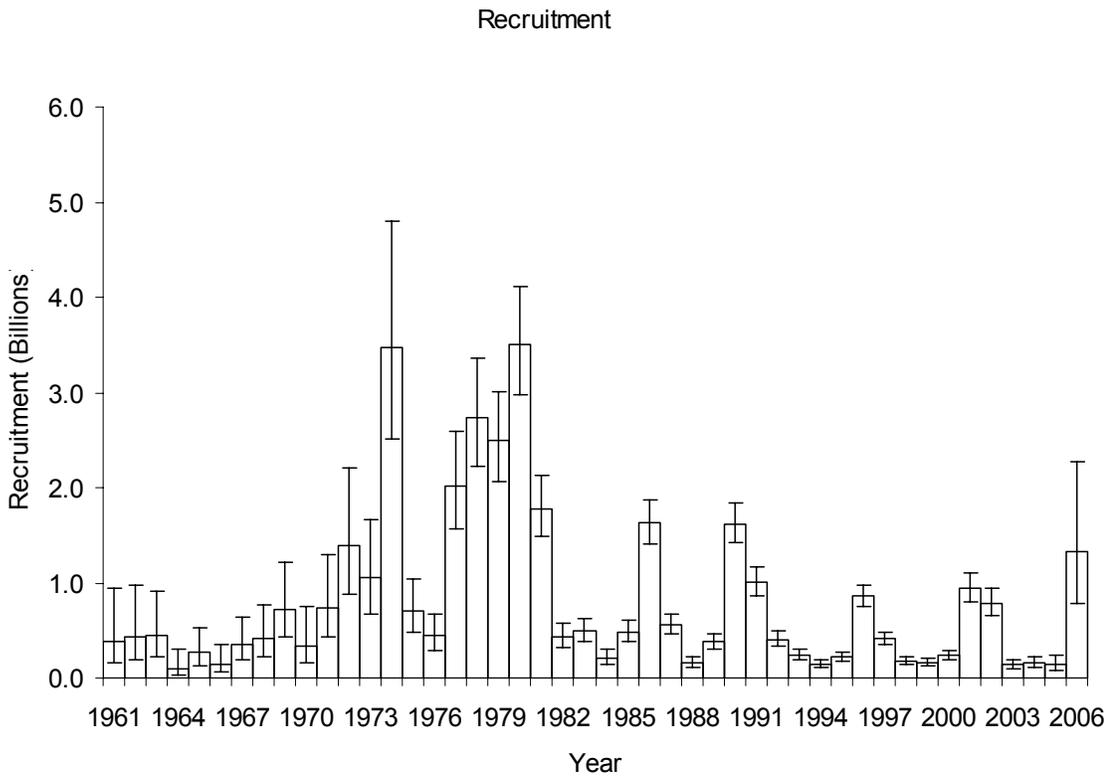
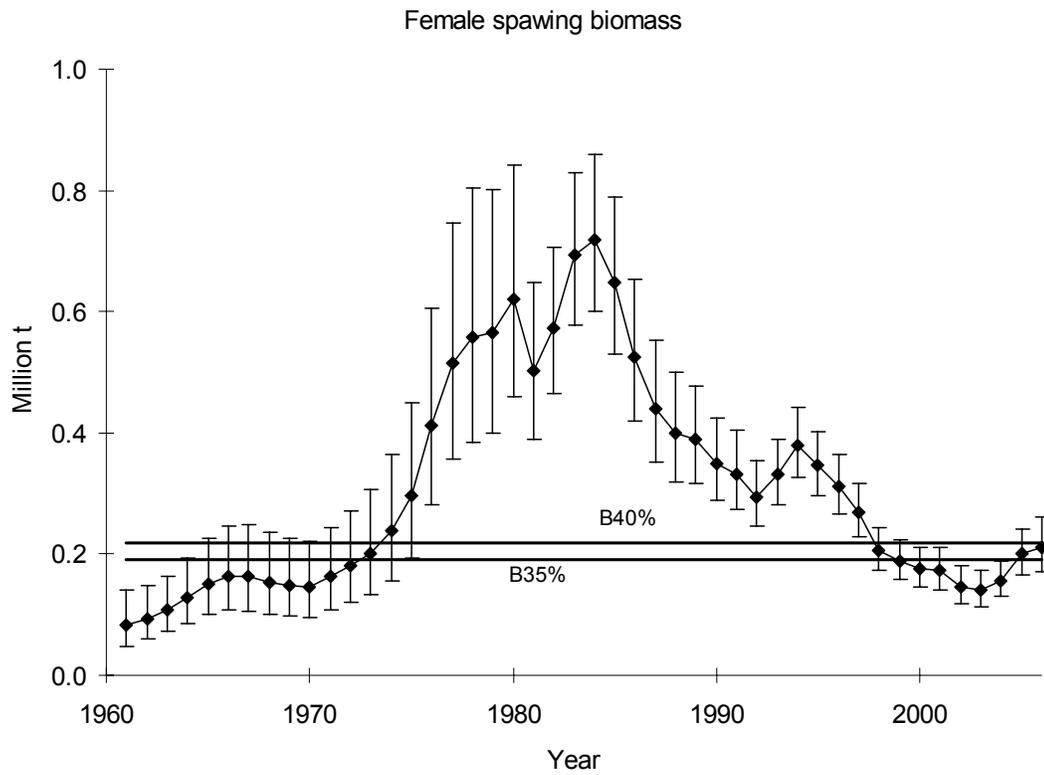


Figure 1.20. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-2 recruitment (billions of fish, bottom) from 1961 to 2006. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.

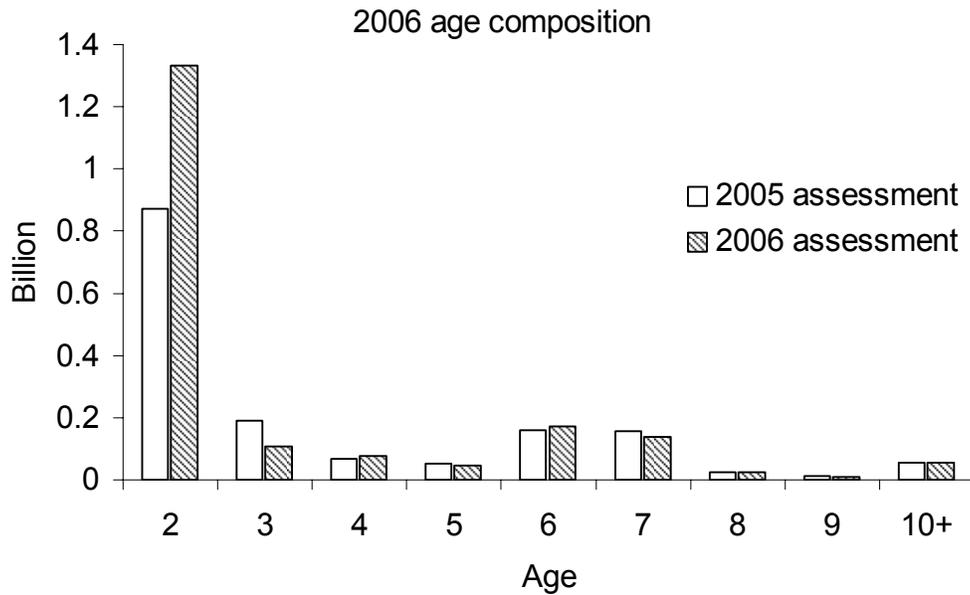
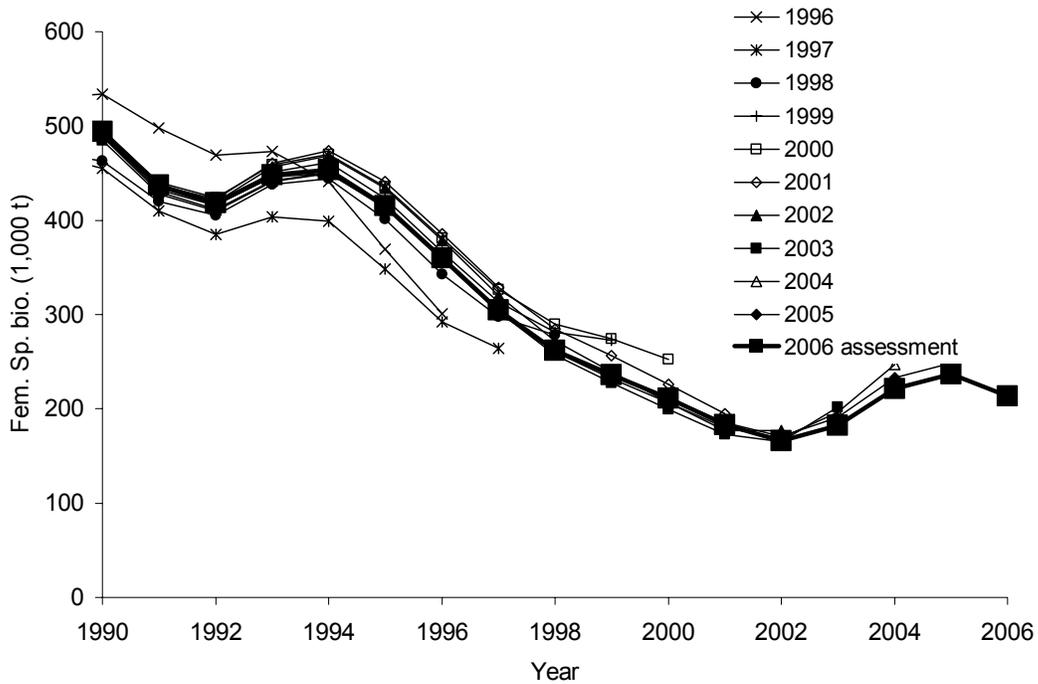


Figure 1.21. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1994-2006 (top). For this figure, the time series of female spawning biomass for the 2006 assessment was calculated using the weight and maturity at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2006 from the 2005 and 2006 assessments.

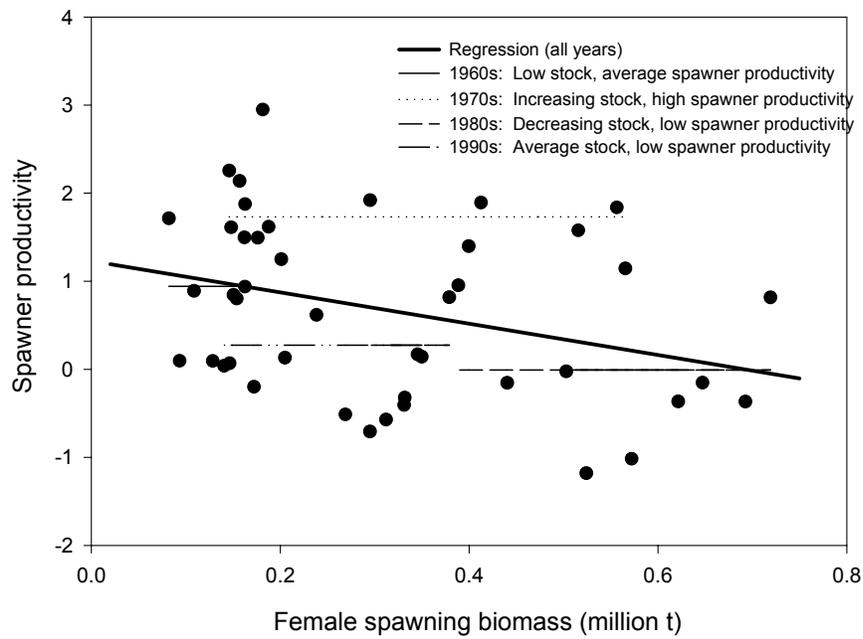
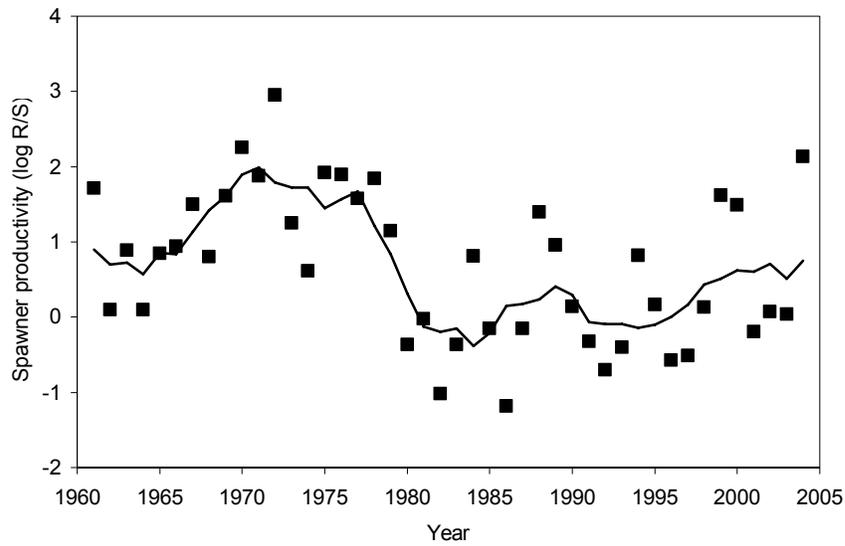


Figure 1.22. Gulf of Alaska pollock spawner productivity  $\log(R/S)$  in 1961-2004 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.

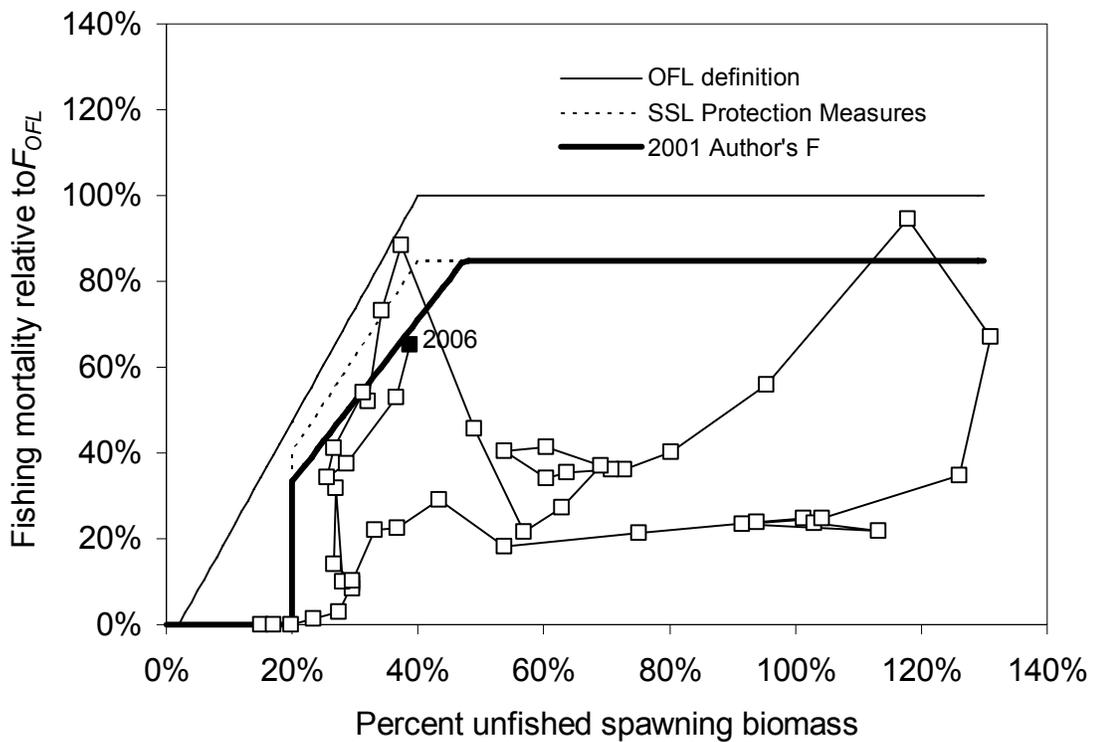
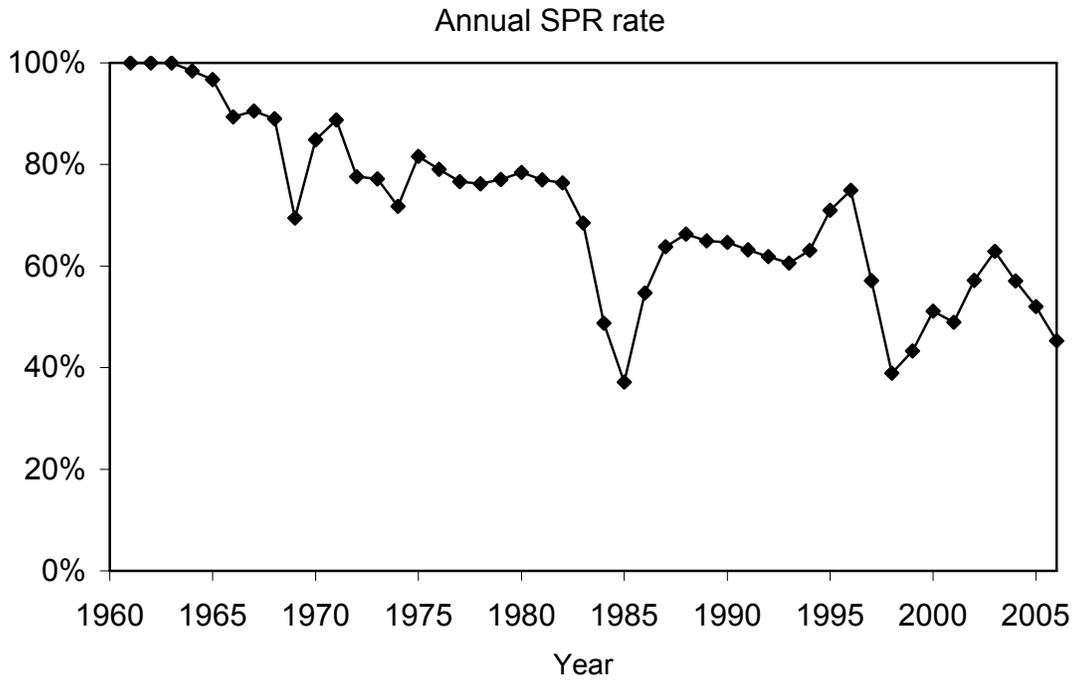


Figure 1.23. Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to  $F_{OFL}$  (1961-2006). The ratio of fishing mortality to  $F_{OFL}$  is calculated using the estimated selectivity pattern in that year. Estimates of unfished spawning biomass are based 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.

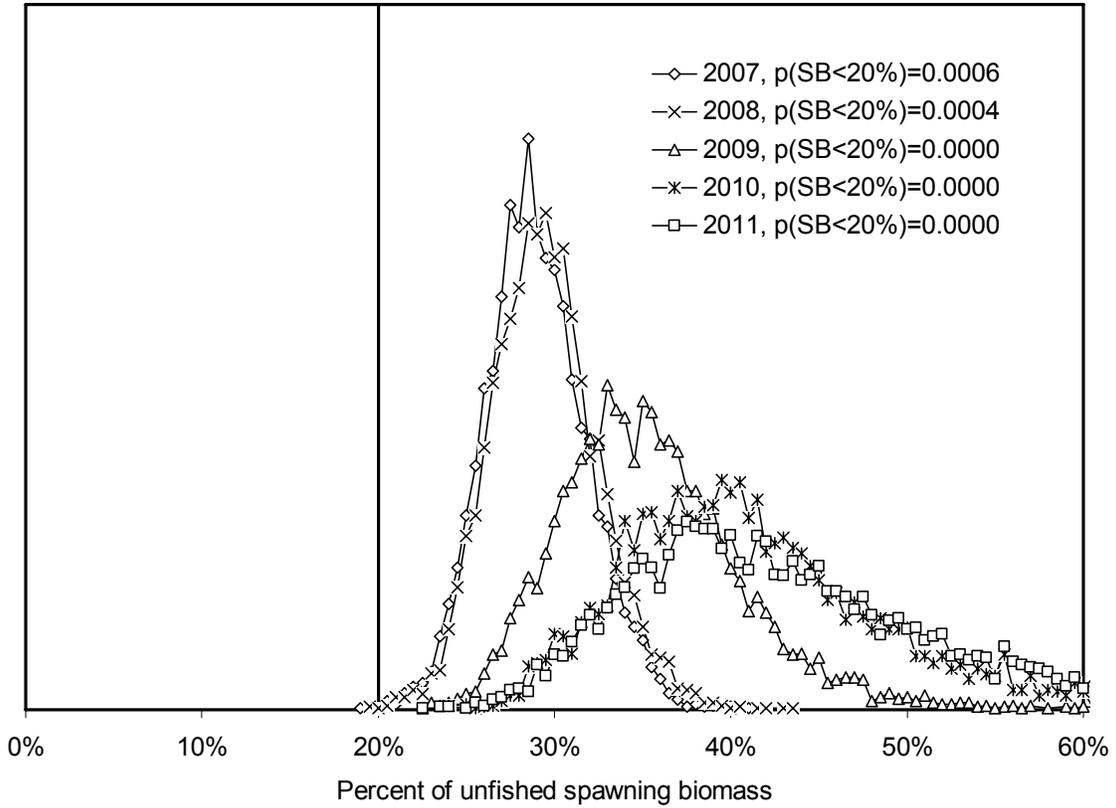


Figure 1.24. Uncertainty in spawning biomass in 2007-2011 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended FABC.

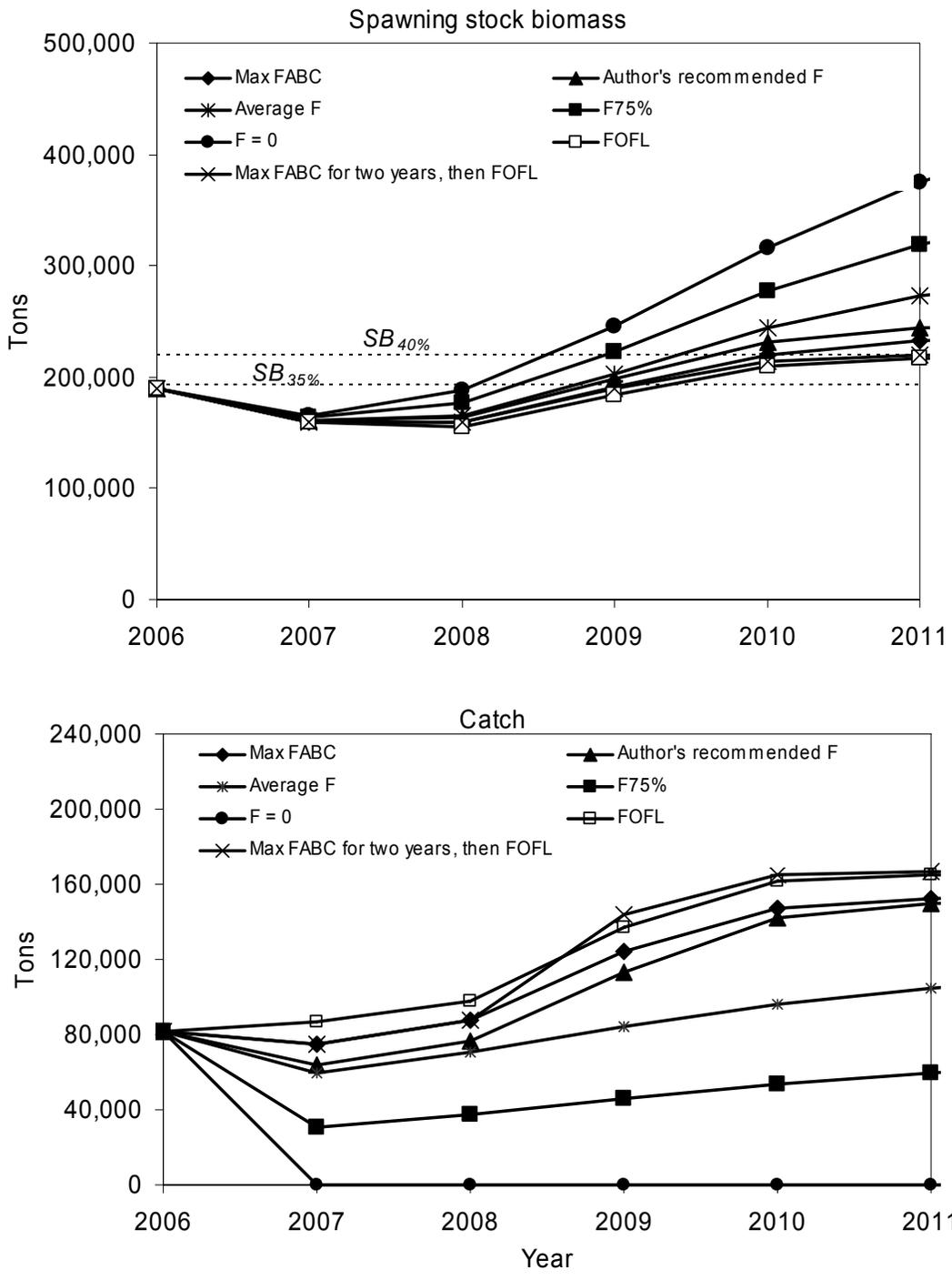


Figure 1.25. Projected spawning biomass and catches in 2006-11 under different management strategies.

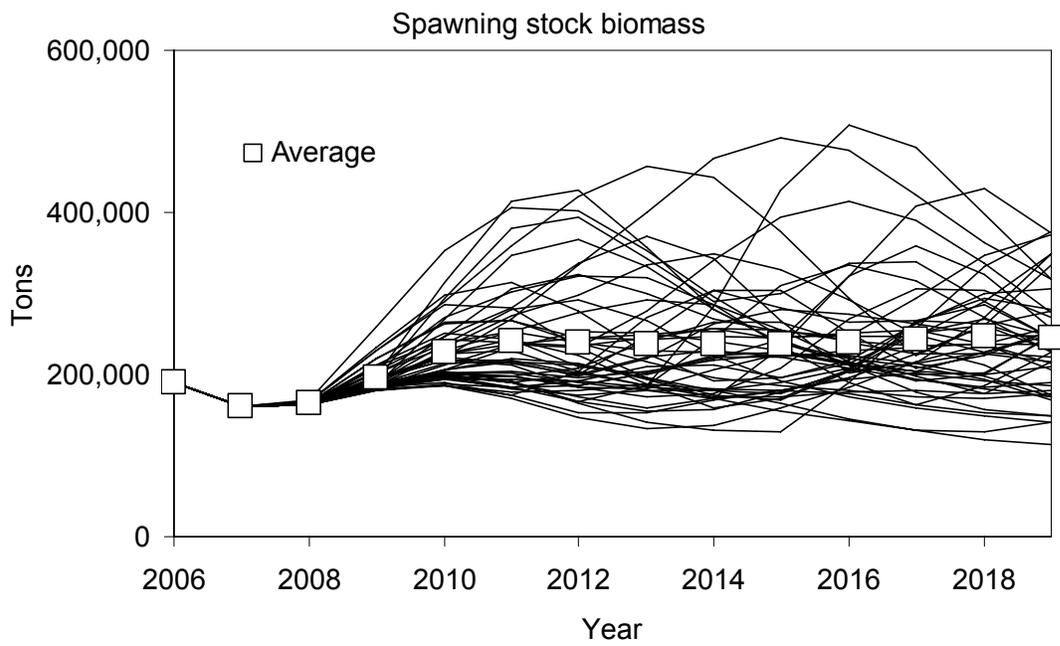
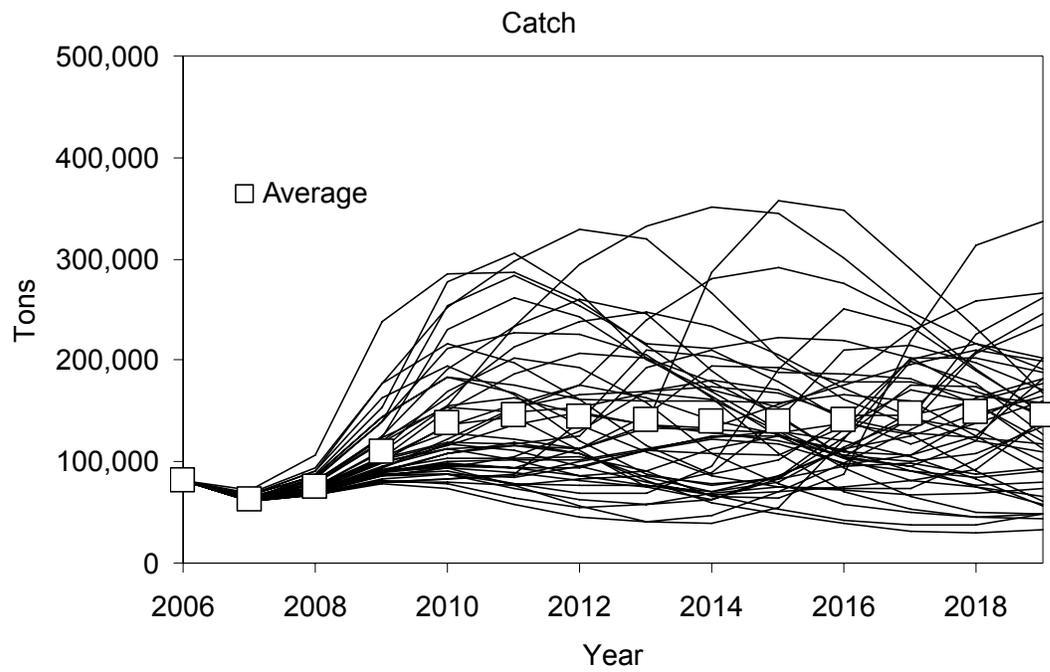


Figure 1.26. Variability in projected catch and spawning biomass in 2006-19 under the author's recommended FABC.

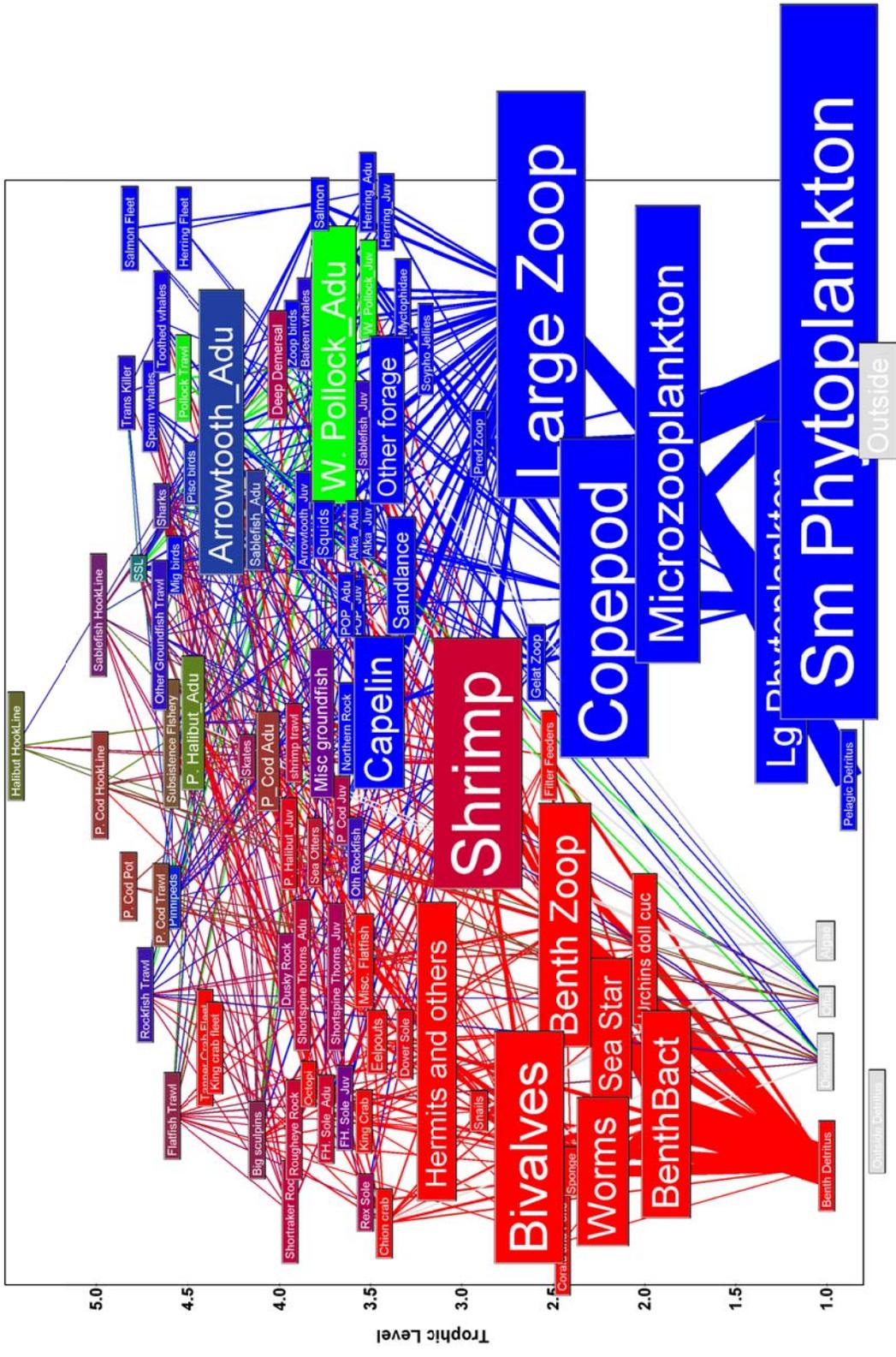


Figure 1.27. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.

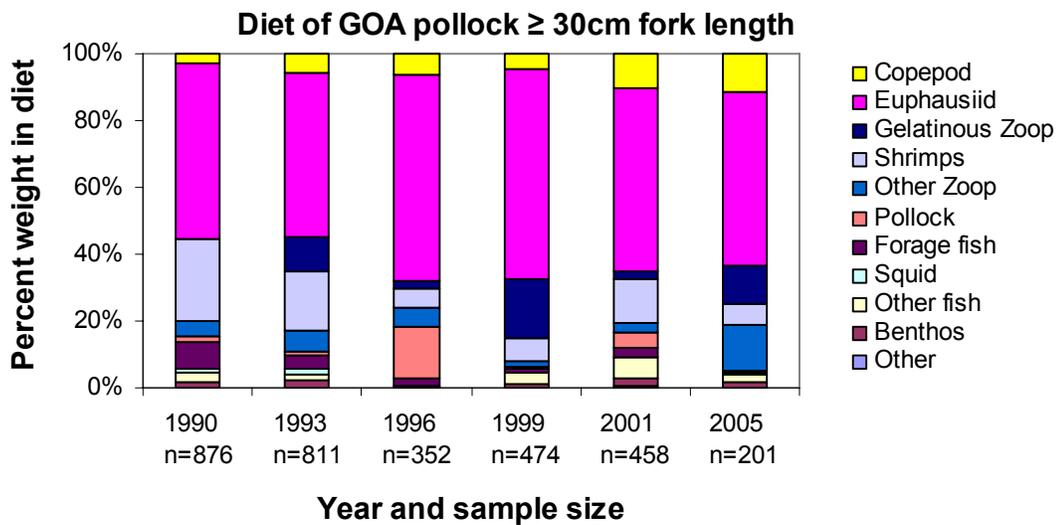
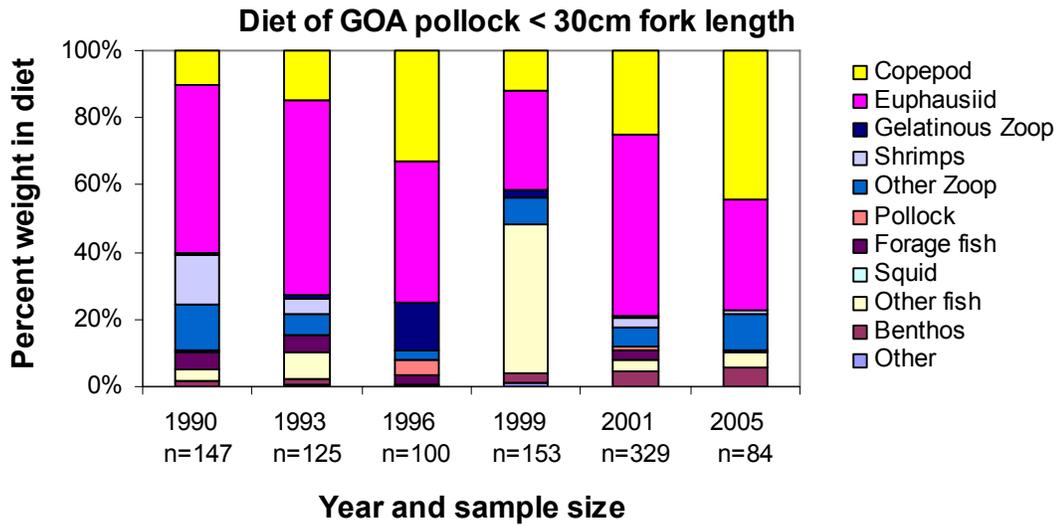


Figure 1.28. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.

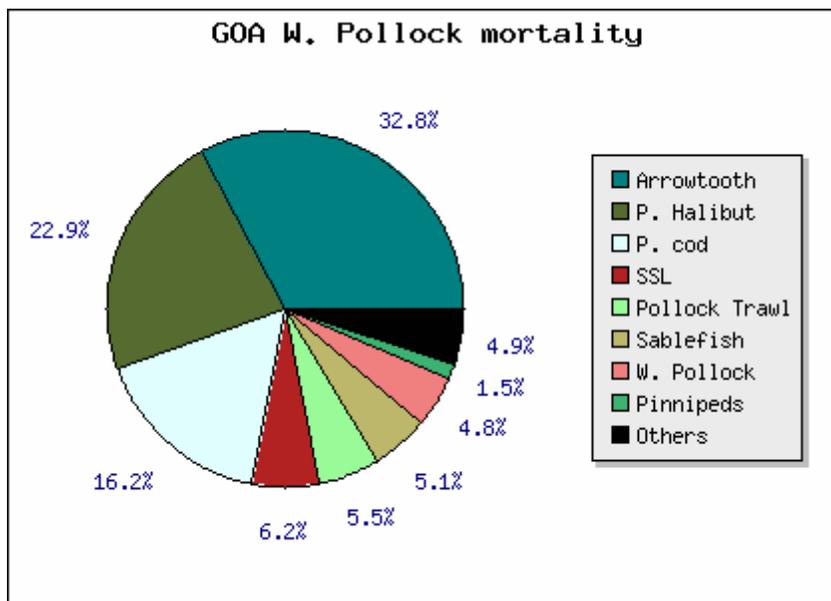
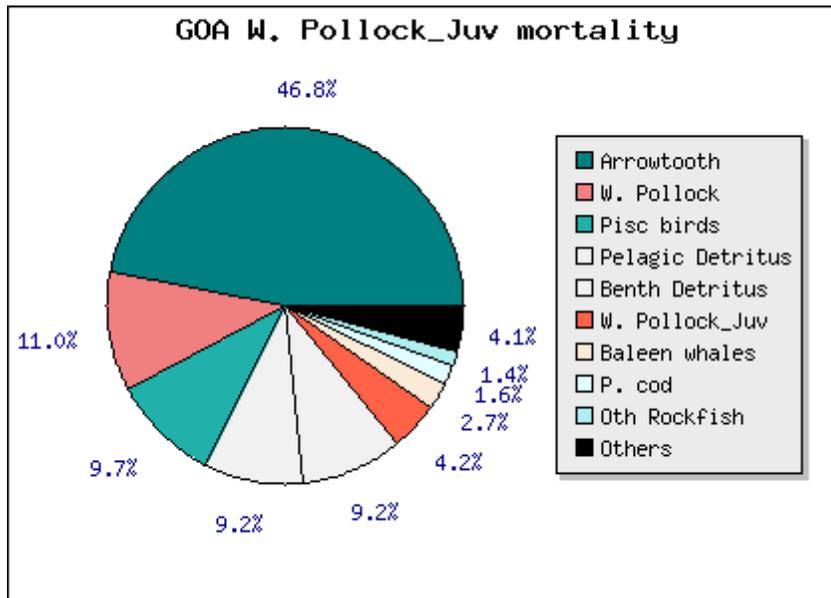


Figure 1.29. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

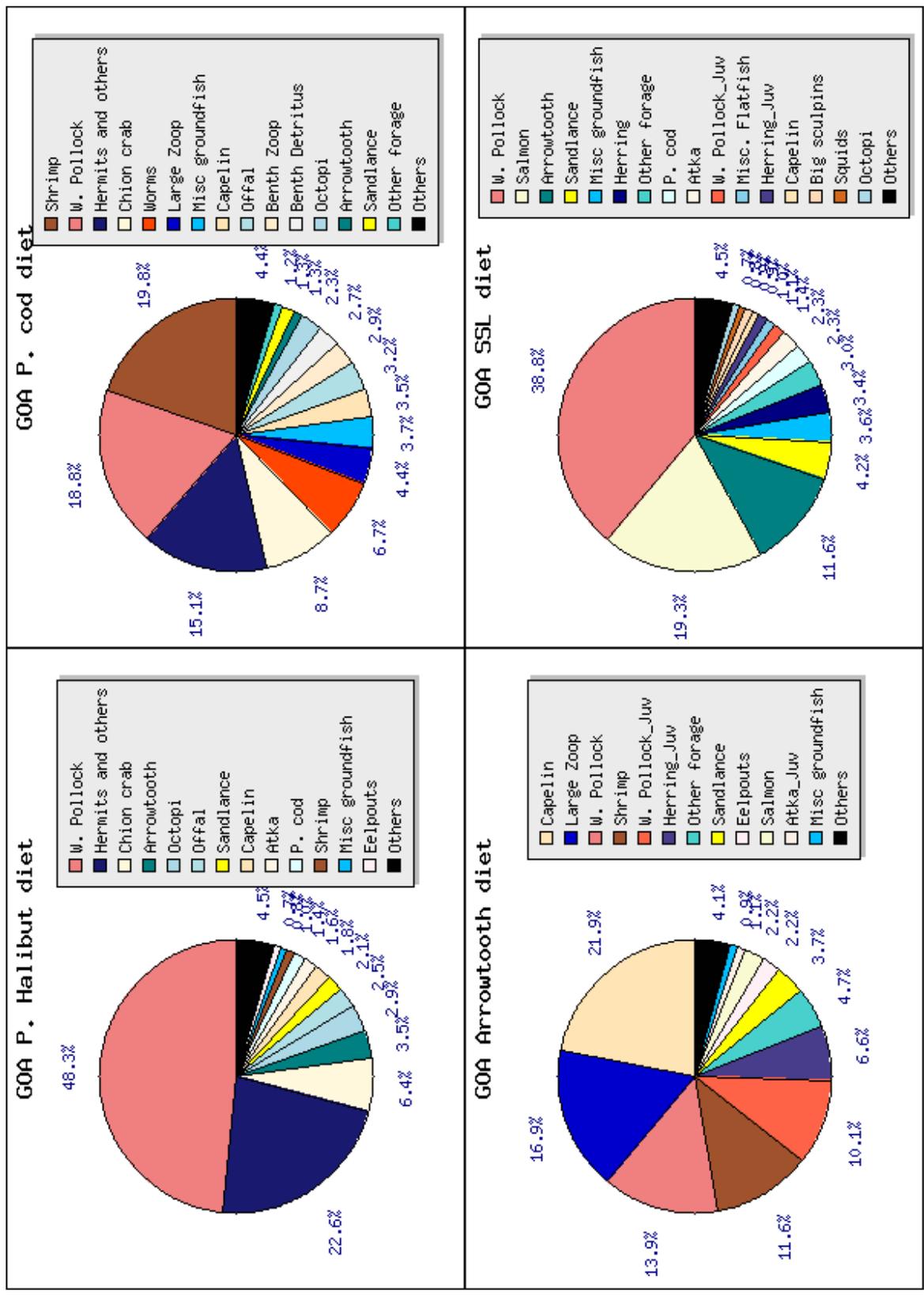


Figure 1.30. Diet diversity of major predators of walleye pollock from an ECOPEATH model for Gulf of Alaska during 1990-94.

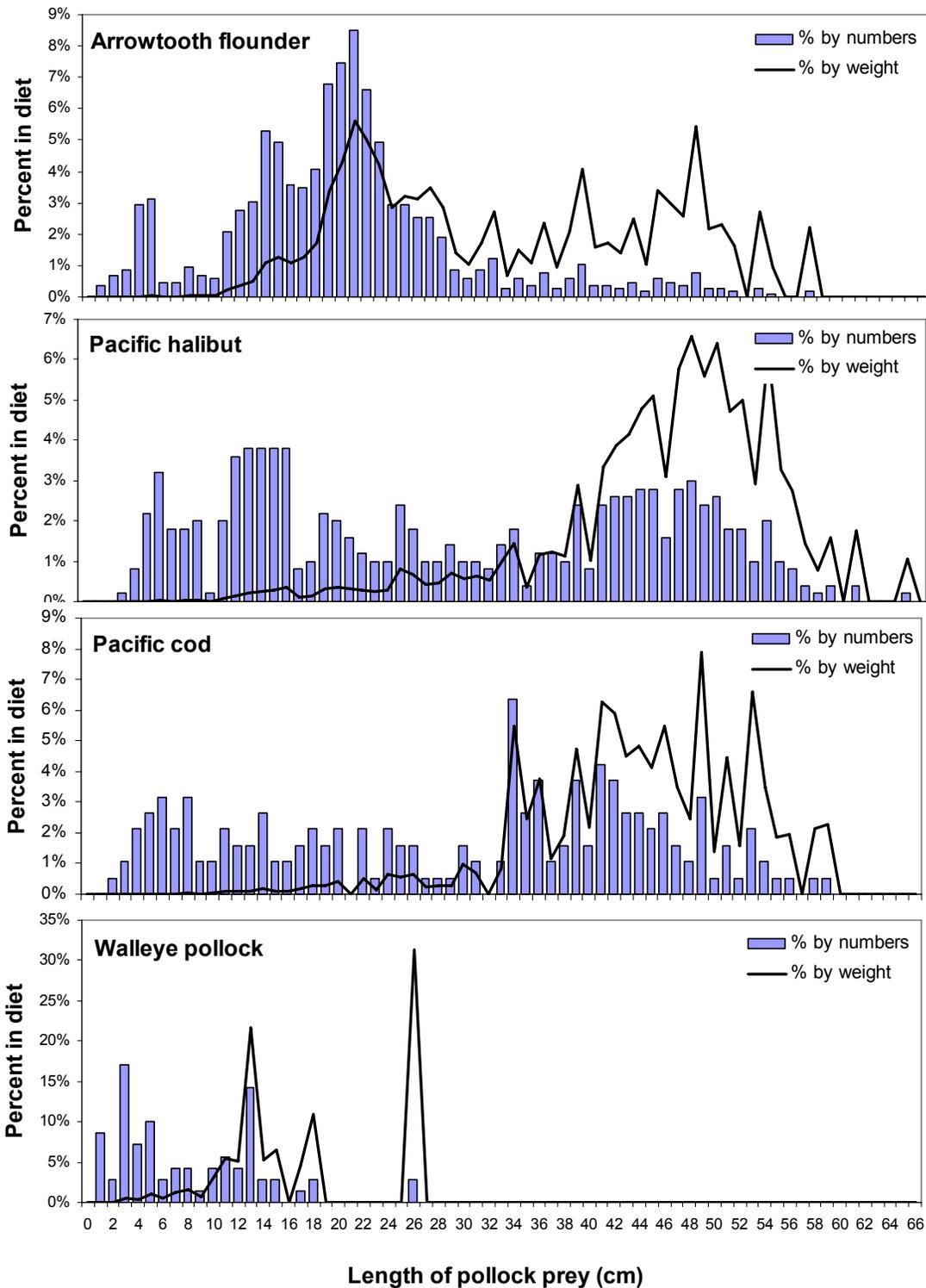


Figure 1.31. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.

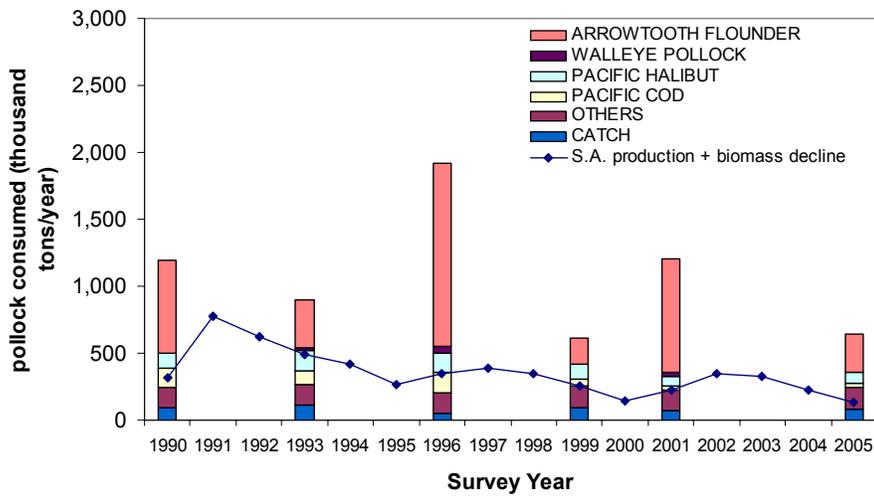
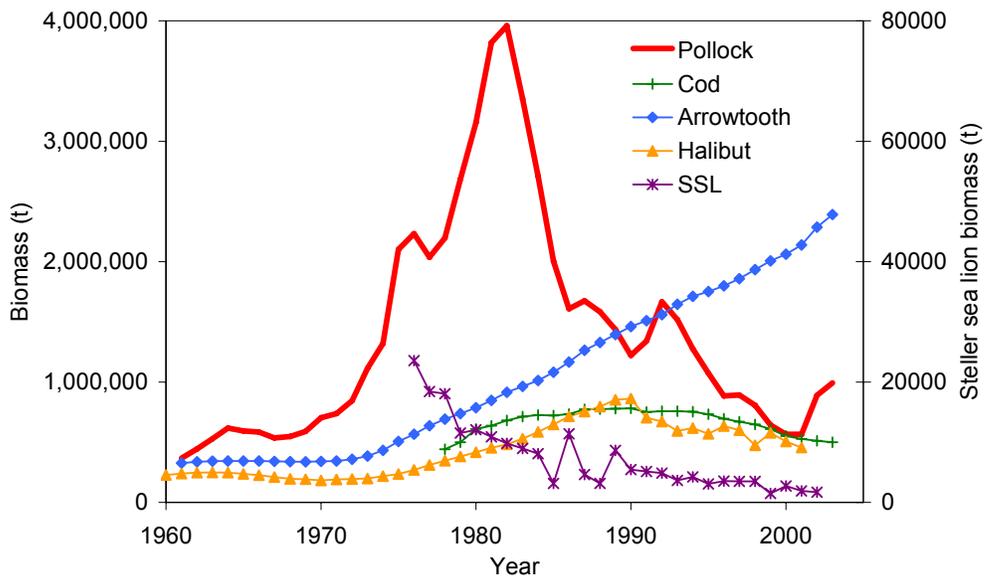


Figure 1.32. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock assessment data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line). See text for calculation methods.

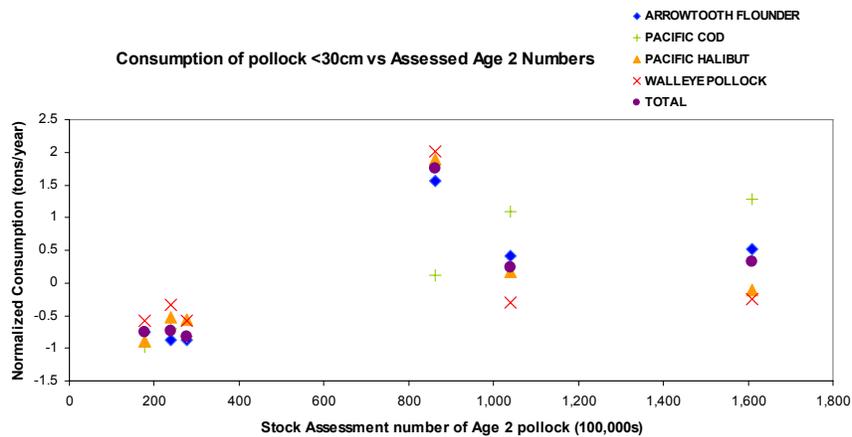
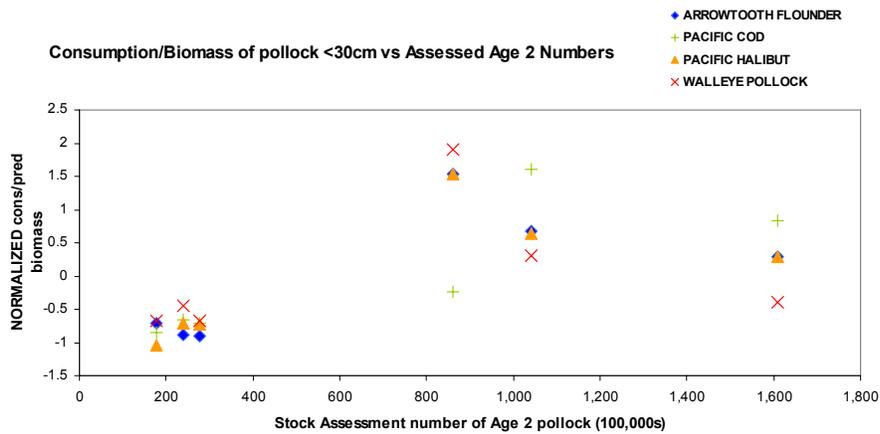
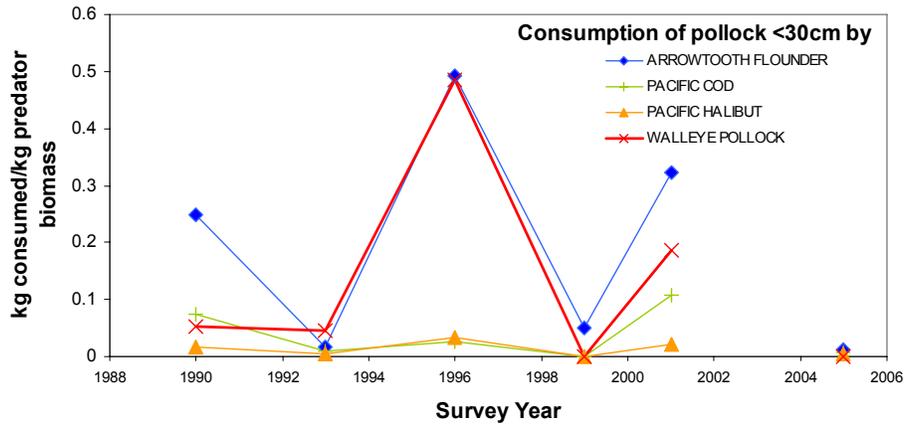


Figure 1.33. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers reported in Table 1.16.

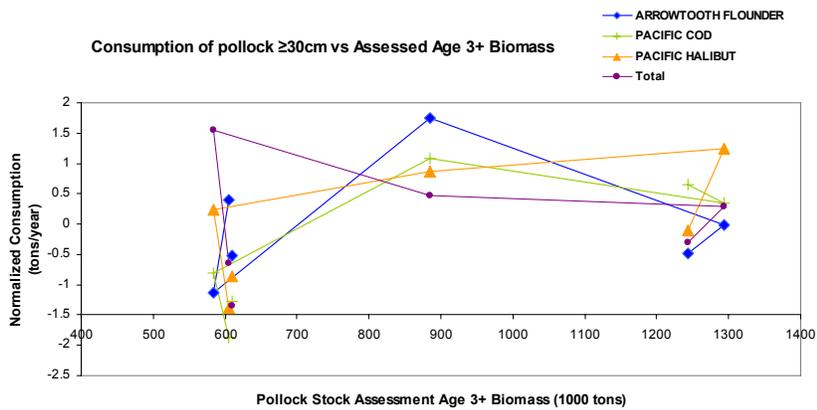
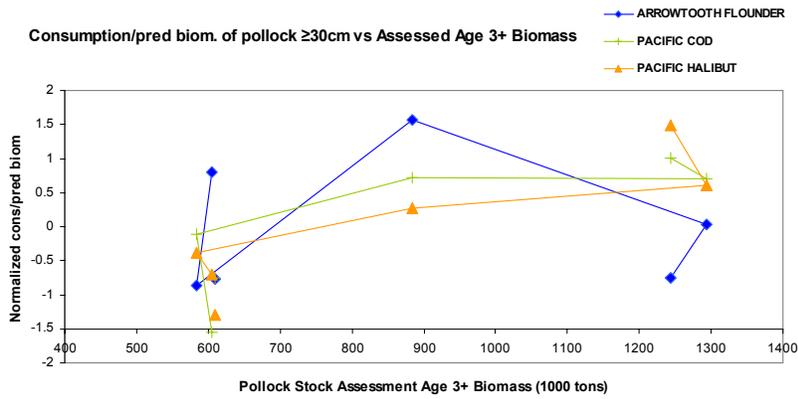
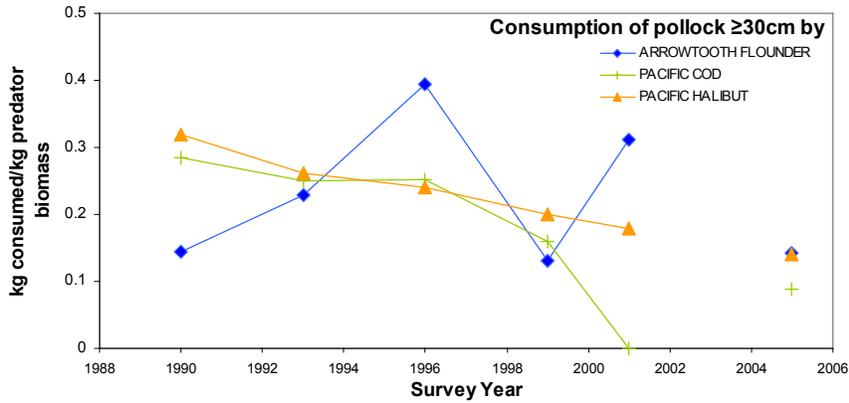


Figure 1.34. (Top) Consumption per unit predator survey biomass of GOA walleye pollock  $\geq 30\text{cm}$  fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock  $\geq 30\text{cm}$  fork length, plotted against age 3+ pollock biomass reported in Table 1.17.

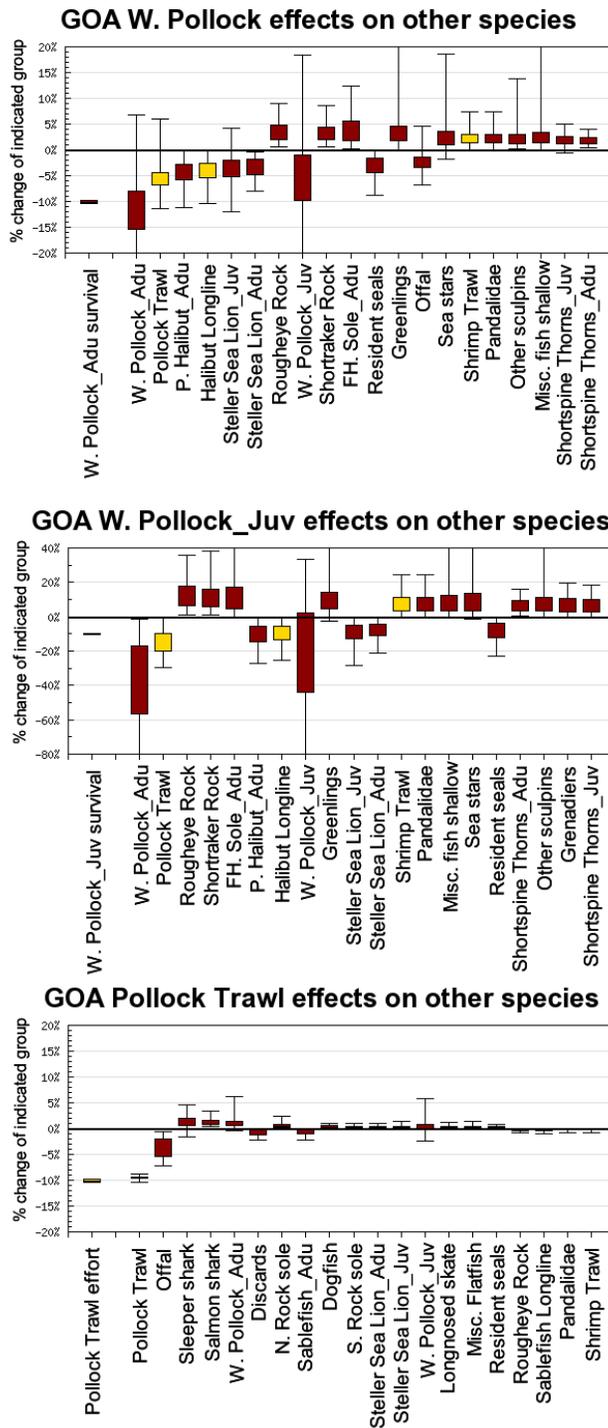


Figure 1.35. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled 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.

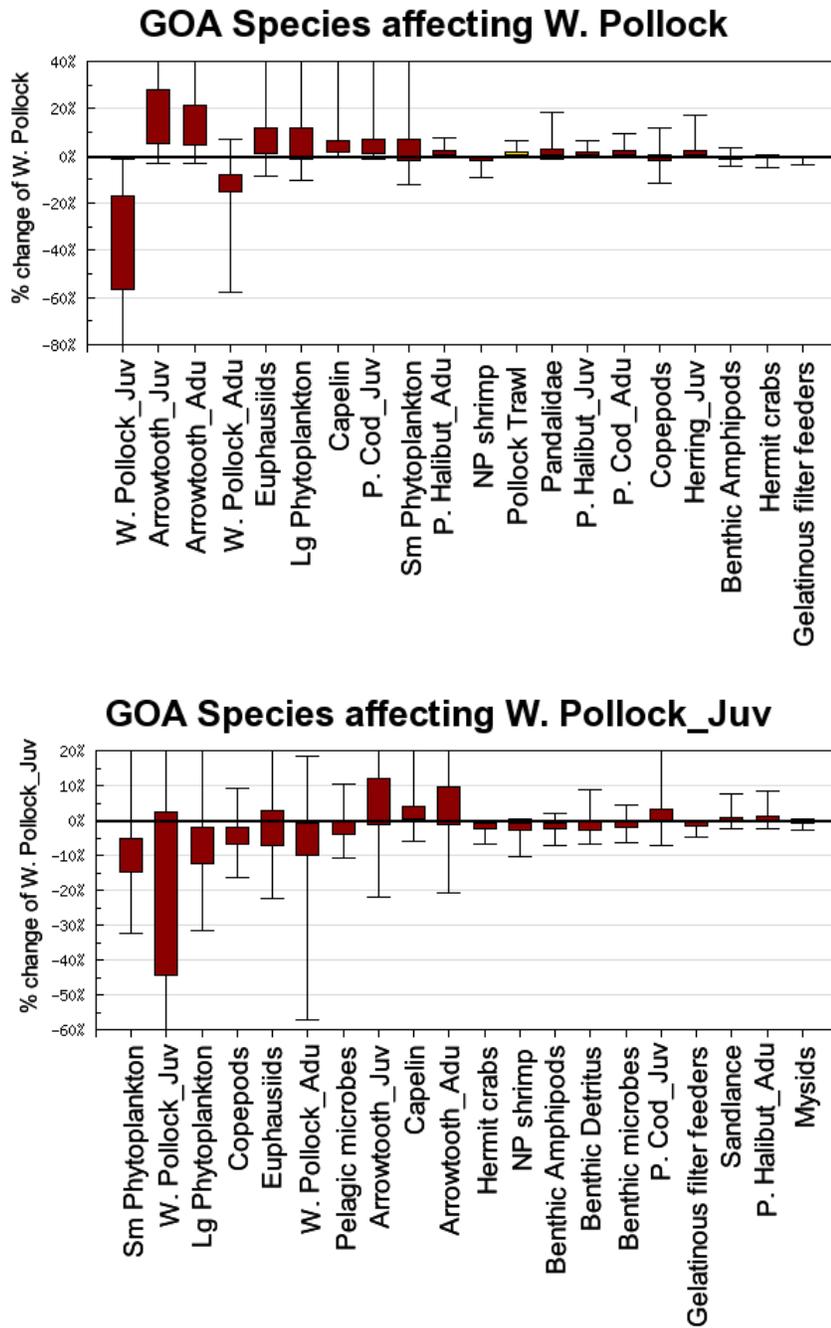


Figure 1.36. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

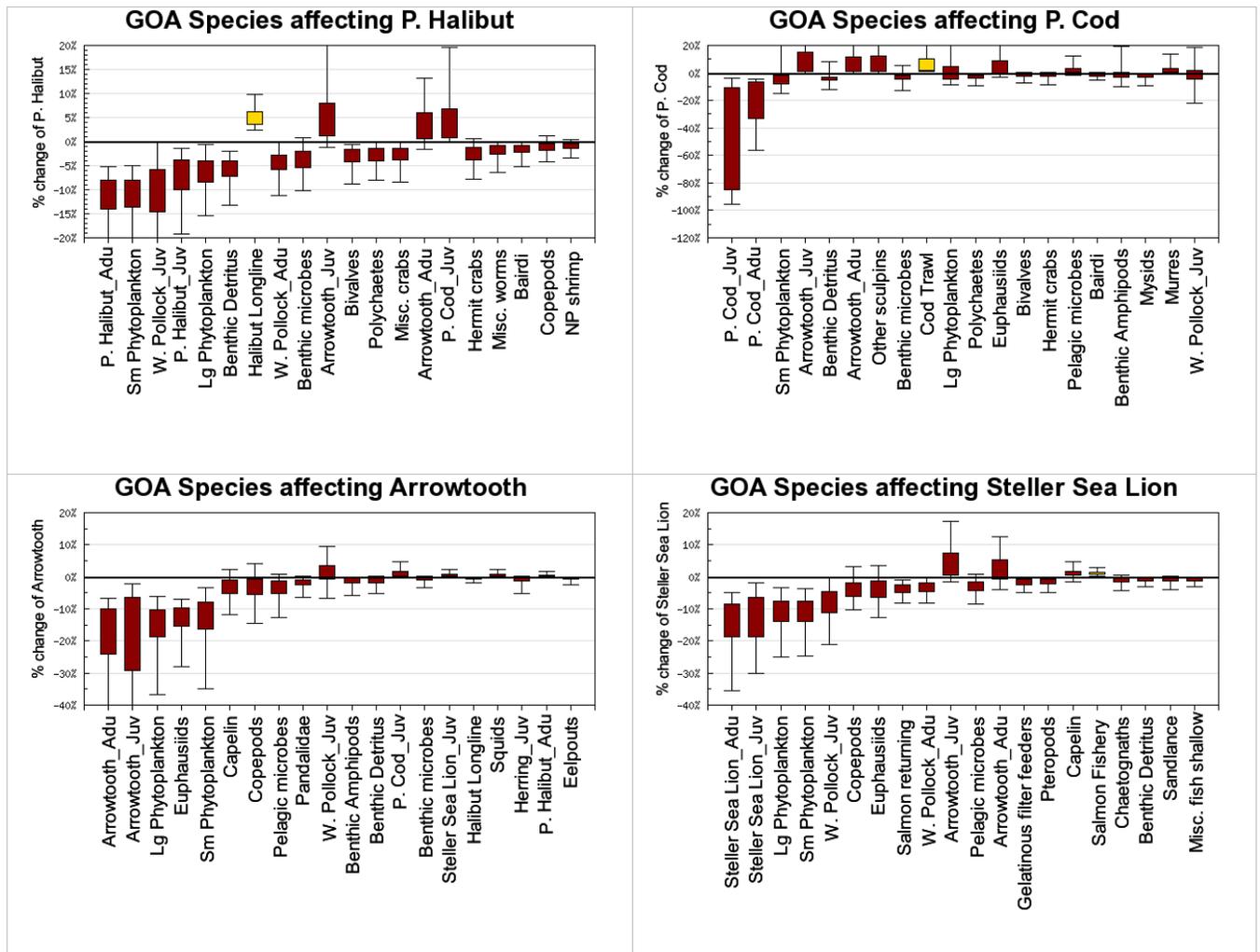


Figure 1.37. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs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

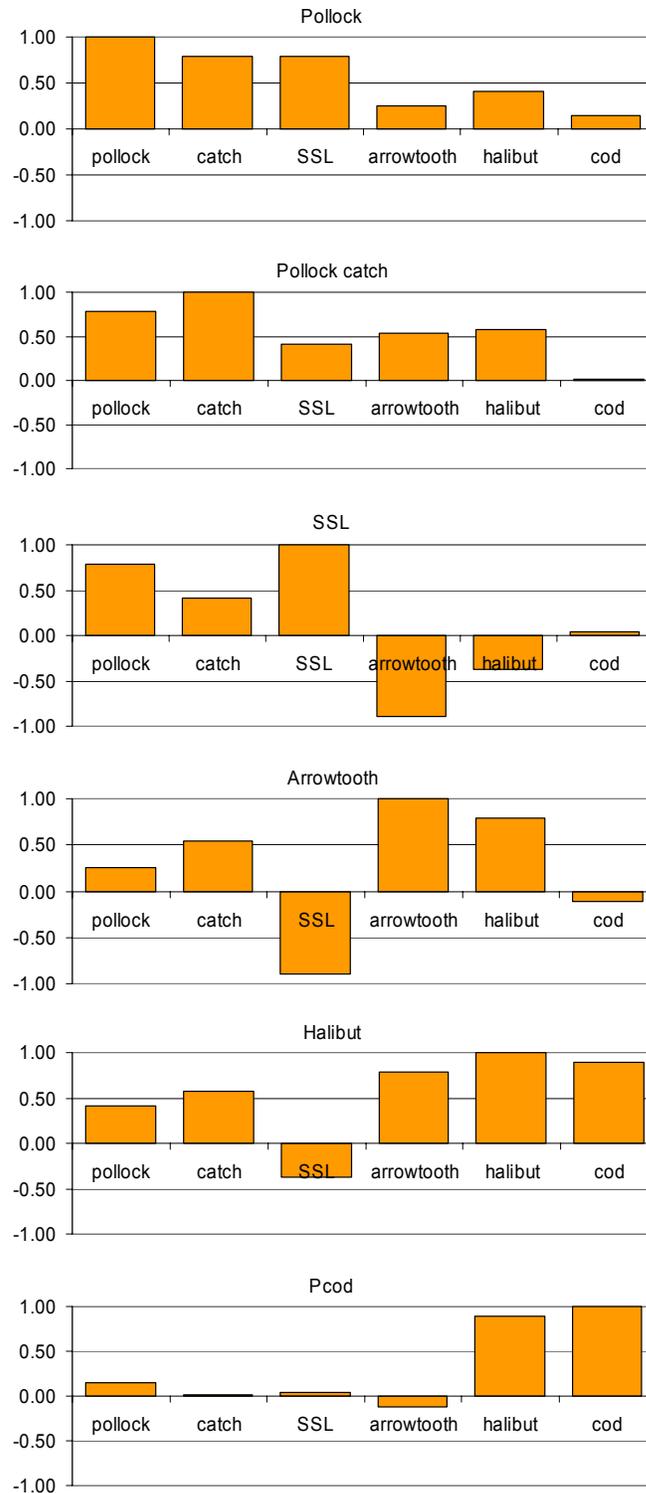


Figure 1.38. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for each pair.

## Appendix A: Southeast Alaska pollock

Bottom trawl surveys indicate a substantial reduction in pollock abundance east of 140° W. lon. Stock structure in this area is poorly understood. Bailey et al. (1999) suggest that pollock metapopulation structure in southeast Alaska is characterized by numerous fiord populations. In the 2005 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Typically, pollock size composition is dominated by smaller fish (<40 cm), but in the 2005 survey there was a strong mode centered on 42 cm (Fig. 1.43). Juveniles in this area are unlikely to influence the population dynamics of pollock in the central and western Gulf of Alaska. Ocean currents are generally northward in this area, suggesting that juvenile settlement is a result of spawning further south. Spawning aggregations of pollock have been reported from the northern part of Dixon Entrance (Saunders et al. 1988).

Historically, there has been little directed fishing for pollock in southeast Alaska (Fritz 1993). During 1993-2004, pollock catch the Southeast and East Yakutat statistical areas averaged 14 t (Table 1.3). The current ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska.

Pollock biomass estimates from the bottom trawl survey are highly variable, in part due to year-to-year differences in survey coverage. Surveys in 1996, 1999, 2003 and 2005 had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Fig. 1.39).

We recommend placing southeast Alaska pollock in Tier 5 of NPFMC harvest policy, and basing the ABC and OFL on natural mortality (0.3) and the biomass for the 2005 survey (27,362 t). Biomass in southeast Alaska was estimated by splitting survey strata and CPUE data in the Yakutat INPFC area at 140° W. lon. and combining the strata east of the line with comparable strata in the Southeastern INPFC area. **This results in a 2007 ABC of 6,157 t (27,362 t \* 0.75 M), and a 2007 OFL of 8,209 t (27,362 t \* M).** Since no new survey data will be available until summer of 2008, the preliminary 2008 ABC and OFL should be set equal to the 2007 values.

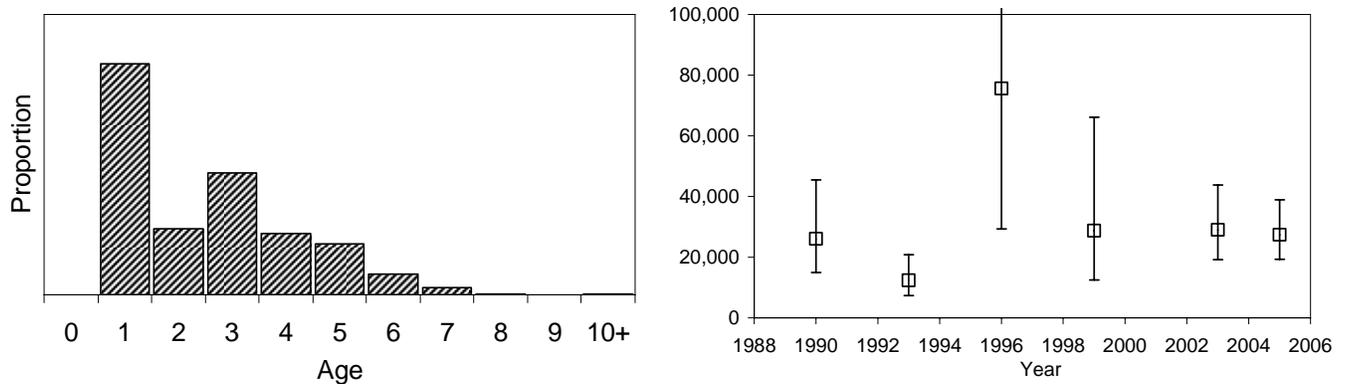


Figure 1.39. Pollock age composition in 2005 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2005 (right). Error bars indicate plus and minus two standard deviations.

## Appendix B: Gulf pollock stock assessment model

### Population dynamics

The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 10, with age 10 defined as a “plus” group, i.e., all individuals age 10 and older. The model extends from 1961 to 2006 (46 yrs). The Baranov (1918) catch equations are assumed, so that

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

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

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

except for the plus group, where

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

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

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

$$F_{ij} = s_j f_i$$

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

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

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

where  $\alpha_1$  = inflection age,  $\beta_1$  = slope at the inflection age for the ascending logistic part of the equation, and  $\alpha_2$ ,  $\beta_2$  = 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  $\sigma_i$  is standard deviation of the logarithm of total catch ( $\sim CV$  of total catch) and  $m_i$  is the size of the age sample. In the multinomial part of the likelihood, the expected proportions at age have been divided by the observed proportion at age, so that a perfect fit to the data for a year gives a log likelihood value of zero (Fournier and Archibald 1982). This formulation of the likelihood allows considerable flexibility to give different weights (i.e. emphasis) to each estimate of annual catch and age composition. Expressing these weights explicitly as CVs (for the total catch estimates), and sample sizes (for the proportions at age) assists in making reasonable assumptions about appropriate weights for estimates whose variances are not routinely calculated.

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

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

where  $q$  = survey catchability,  $w_{ij}$  is the survey weight at age  $j$  in year  $i$  (if available),  $s_j$  = selectivity at age for the survey, and  $\phi_i$  = 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 either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the  $i$ th year are given by

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

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

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

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

### **Process error**

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the pollock model, these annual recruitment and fishing mortality parameters are generally estimated as free parameters, with no additional error constraints. We use process error to describe changes in fisheries selectivity over time. To model temporal variation in a parameter  $\gamma$ , 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  $\delta_i$  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  $\sigma_i$  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 adverse 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 only once in 2006 with questionable timing), and Barnabas

and Chiniak Gullies (surveyed once in 2001). We also have not incorporated acoustic surveys in Marmot Bay conducted by researchers with the UAF School of Fisheries and Aquatic Sciences because it is not yet clear that survey methods and analytical approaches are comparable to those used by the NMFS acoustics group. We expect to be able to evaluate these surveys in the coming year and decide whether these surveys can be used in conjunction with the NMFS surveys. 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 103.9%, 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 29.70%, 58.76%, 11.54% in areas 610, 620, and 630 (Appendix table 1). In comparison to last year's assessment, which used only surveys in Shumagin Islands, Shelikof Strait and the Karp (1990) survey, a higher percentage of the biomass occurred in area 610 (+8 percentage points) and area 630 (+2 percentage points), and a lower percentage in area 620 (-10 percentage points). We expect to include other areas as additional survey results become available.

#### ***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, 29.70%; 620, 48.44%; 630, 21.86%.

#### ***Middleton Island winter EIT survey results in 2003***

The apportionment for area 640, which is not managed by season, has previously been based on the summer distribution of the biomass. Fishing, however, takes places primarily in winter or early spring on a spawning aggregation near Middleton Island. During 28-29 March 2003, this area was surveyed by the NOAA ship *Miller Freeman* for the first time and biomass estimate of 6900 t was obtained. Although maturity stage data suggested the timing of the survey was appropriate, discussions with fishing vessels contacted during the survey raised some questions about survey timing relative to peak biomass. Notwithstanding, a tier 5 calculation based on this spawning biomass gives an ABC of 1,550 t (6,901 t \* 0.75 M), compared to 1,438 t for the author's 2007 ABC recommendation and an apportionment based on the summer biomass distribution. This suggests that the current approach of basing the area 640 apportionment on the gulfwide ABC and the summer biomass distribution is at least consistent with the biomass present near Middleton Island in the winter. We recommend continuing this approach until sufficient survey information during winter has accumulated to evaluate interannual variation in the biomass present in this area.

#### ***Summer distribution***

The NMFS bottom trawl is summer survey (typically extending from mid-May to mid-August). Because of large shifts in the distribution of pollock between management areas one survey to the next, and the high variance of biomass estimates by management area, Dorn et al. (1999) recommended that the apportionment of pollock TAC be based upon the four most recent NMFS summer surveys. The four-survey average was updated with 2005 survey results in an average biomass distribution of 51.47%, 14.83%, 31.45%, and 2.25% in areas 610, 620, 630, and 640 (Fig. 1.40).

*Example calculation of 2007 Seasonal and Area TAC Allowances for W/C/WYK*

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

1) Deduct the Prince William Sound Guideline Harvest Level.

2) Use summer biomass distribution for the 640 allowance:

$$640 \quad 0.0225 \times \text{Total TAC} = 2,250 \text{ t}$$

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

$$\text{A season} \quad 0.25 \times (\text{Total TAC} - 2,250) = 24,437 \text{ t}$$

$$\text{B season} \quad 0.25 \times (\text{Total TAC} - 2,250) = 24,437 \text{ t}$$

$$\text{C season} \quad 0.25 \times (\text{Total TAC} - 2,250) = 24,438 \text{ t}$$

$$\text{D season} \quad 0.25 \times (\text{Total TAC} - 2,250) = 24,438 \text{ t}$$

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

$$610 \quad 0.2970 * 24,437 \text{ t} = 7,258 \text{ t}$$

$$620 \quad 0.4844 * 24,437 \text{ t} = 11,837 \text{ t}$$

$$630 \quad 0.2186 * 24,437 \text{ t} = 5,342 \text{ t}$$

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

$$610 \quad 0.2970 * 24,437 \text{ t} = 7,258 \text{ t}$$

$$620 \quad 0.5876 * 24,437 \text{ t} = 14,359 \text{ t}$$

$$630 \quad 0.1154 * 24,437 \text{ t} = 2,820 \text{ t}$$

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

$$610 \quad 0.5147 / (1 - 0.0225) \times 24,438 = 12,867 \text{ t}$$

$$620 \quad 0.1483 / (1 - 0.0225) \times 24,438 = 3,708 \text{ t}$$

$$630 \quad 0.3145 / (1 - 0.0225) \times 24,438 = 7,863 \text{ t}$$

$$610 \quad 0.5147 / (1 - 0.0225) \times 24,438 = 12,867 \text{ t}$$

$$620 \quad 0.1483 / (1 - 0.0225) \times 24,438 = 3,708 \text{ t}$$

$$630 \quad 0.3145 / (1 - 0.0225) \times 24,438 = 7,863 \text{ t}$$

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

| Survey          | Year                        | Model estimates<br>of total 2+<br>biomass at<br>spawning | Survey biomass<br>estimate <sup>1</sup> | Percent | Percent by management area |             |             |
|-----------------|-----------------------------|--|---|---------|----------------------------|-------------|-------------|
|                 |                             |  |   |         | Area 610                   | Area<br>620 | Area<br>630 |
| Shelikof Strait | 2003                        | 513,822  | 317,269                                 | 61.7%   | 0.0%                       | 97.6%       | 2.4%        |
| Shelikof Strait | 2004                        | 552,036  | 330,753                                 | 59.9%   | 0.0%                       | 97.6%       | 2.4%        |
| Shelikof Strait | 2005                        | 584,775  | 338,038                                 | 57.8%   | 0.0%                       | 97.8%       | 2.2%        |
| Shelikof Strait | 2006                        | 617,540  | 293,609                                 | 47.5%   | 0.0%                       | 96.1%       | 3.9%        |
| Shelikof Strait | Average                     |  |   | 56.8%   | 0.0%                       | 97.3%       | 2.7%        |
|                 | Percent of total 2+ biomass |  |   |         |                            | 0.0%        | 55.2%       |
| Chirikof        | 2003                        | 513,822  | 30,900                                  | 6.0%    | 0.0%                       | 45.6%       | 54.4%       |
| Chirikof        | 2004                        | 552,036  | 30,400                                  | 5.5%    | 0.0%                       | 88.8%       | 11.2%       |
| Chirikof        | 2005                        | 584,775  | 77,000                                  | 13.2%   | 0.0%                       | 47.8%       | 52.2%       |
| Chirikof        | 2006                        | 617,540  | 69,000                                  | 11.2%   | 0.0%                       | 28.3%       | 71.7%       |
|                 | Average                     |  |   | 9.0%    | 0.0%                       | 52.6%       | 47.4%       |
|                 | Percent of total 2+ biomass |  |   |         |                            | 0.0%        | 4.7%        |
| Shumagin        | 2002                        | 490,745  | 135,644                                 | 27.6%   | 100.0%                     | 0.0%        | 0.0%        |
| Shumagin        | 2003                        | 513,822  | 67,160                                  | 13.1%   | 99.7%                      | 0.3%        | 0.0%        |
| Shumagin        | 2005                        | 584,775  | 51,970                                  | 8.9%    | 99.9%                      | 0.1%        | 0.0%        |
| Shumagin        | 2006                        | 617,540  | 25,030                                  | 4.1%    | 92.8%                      | 7.2%        | 0.0%        |
| Shumagin        | Average                     |  |   | 13.4%   | 98.1%                      | 1.9%        | 0.0%        |
|                 | Percent of total 2+ biomass |  |   |         |                            | 13.2%       | 0.3%        |
| Sanak           | 2003                        | 513,822  | 81,500                                  | 15.9%   | 100.0%                     | 0.0%        | 0.0%        |
| Sanak           | 2005                        | 584,775  | 67,800                                  | 11.6%   | 100.0%                     | 0.0%        | 0.0%        |
| Sanak           | 2006                        | 617,540  | 127,214                                 | 20.6%   | 100.0%                     | 0.0%        | 0.0%        |
| Sanak           | Average                     |  |   | 16.0%   | 100.0%                     | 0.0%        | 0.0%        |
|                 | Percent of total 2+ biomass |  |   |         |                            | 16.0%       | 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%        |
| Total           |                             |  |   | 103.27% | 30.67%                     | 60.68%      | 11.92%      |
| Rescaled total  |                             |  |   | 100.00% | 29.70%                     | 58.76%      | 11.54%      |

<sup>1</sup> The biomass of age-1 pollock not included in Shelikof Strait survey biomass in 1995, 2000, and 2005 and Shumagin survey biomass in 2006.

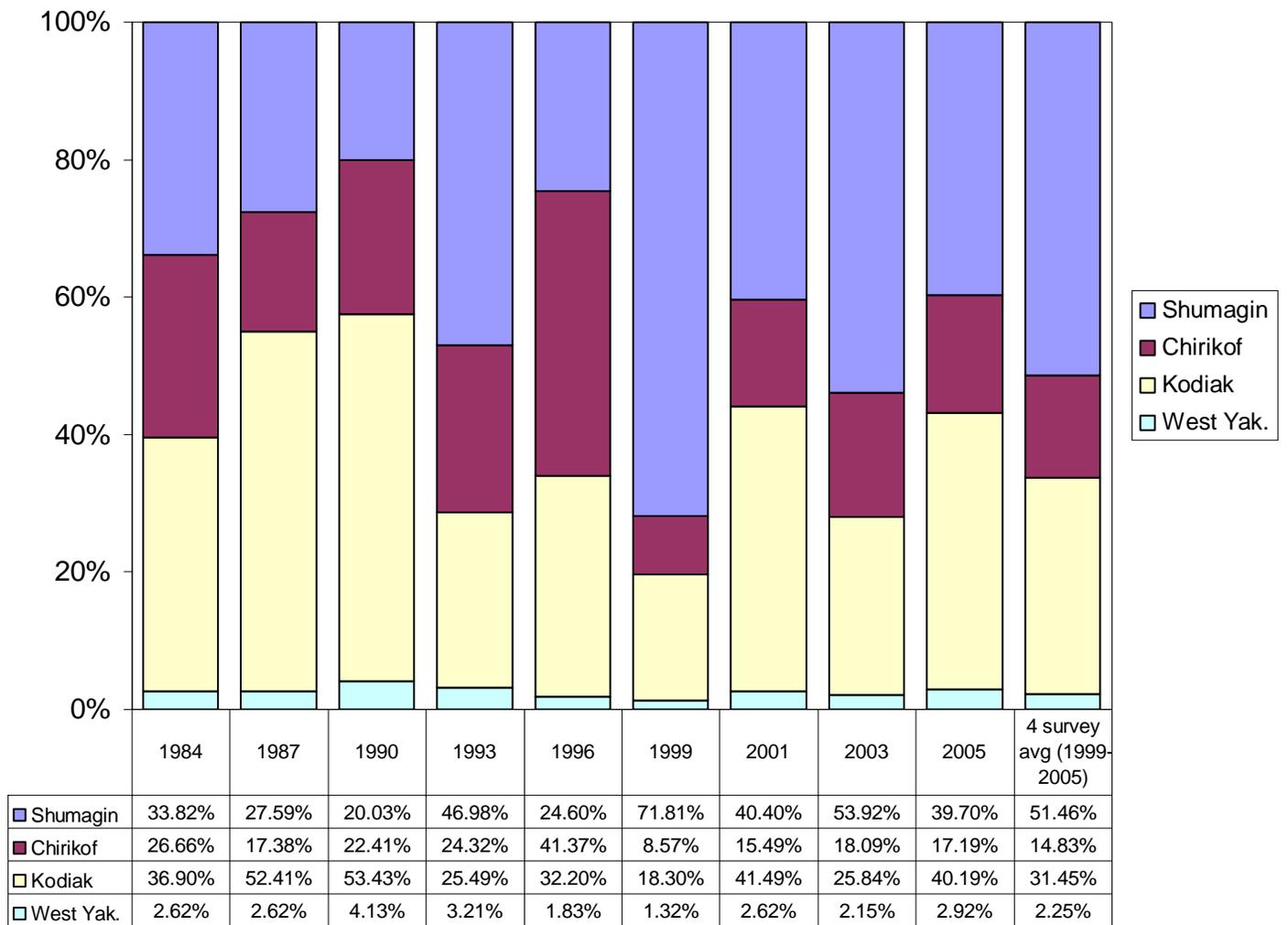


Figure 1.40. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2005. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.