# 1. Gulf of Alaska Walleye Pollock

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## Summary of major changes

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

### *New Input data*

1. Fishery: 2007 total catch and catch at age.

2. Shelikof Strait EIT survey: 2008 biomass and 2007 and 2008 age composition.

3. NMFS bottom trawl survey: 2007 age composition.

3. ADF&G crab/groundfish trawl survey: 2008 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 1999-2007 was used again for this year's assessment.

### *Assessment results*

The model estimate of spawning biomass in 2009 is 132,805 t, which is 22.4% of unfished spawning biomass (based on average post-1977 recruitment) and below $B_{40\%}$ (237,000 t). Spawning biomass in 2009 is projected to be similar to the low level of 2008. The biomass from the Shelikof Strait EIT survey in 2008 was similar to 2007, which was the lowest on record, but there was a 9% increase for the 2008 ADF&G survey biomass compared to 2007. All spawning aggregations surveyed acoustically in winter of 2008 remained at low levels of biomass. Model projections indicate that the spawning biomass in 2009 will remain close to the 2008 minimum, but will increase in subsequent years. The extent and rate of increase depends on the magnitude of incoming year classes that are highly uncertain. There is evidence that 2007 year class, which was abundant both in the Shumagin area and in Shelikof Strait, may be average or above average in abundance.

The author's 2009 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 43,270 t, a decrease of 19% from the 2008 ABC. This recommendation is based on a more conservative alternative to the maximum permissible $F_{ABC}$ introduced in the 2001 SAFE. The OFL in 2009 is 58,590 t. In 2010, the recommended ABC and OFL are 67,700 t and 90,920 t, respectively.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendations for 2009 and 2010 in Appendix A are 8,280 t and the OFL is 11,040 t (the same for both years). These recommendations are based on estimated biomass in the southeast area in the 2007 NMFS bottom trawl survey.

## Summary

Natural mortality = 0.3
Tier: 3b

2009 harvests

| | | |
|---|---|---|
| Maximum permissible ABC: | $F_{40\%\ \text{(adjusted)}} = 0.13$ | Yield = 50,770 t |
| Recommended ABC: | $F_{40\%\ \text{(author's adjusted)}} = 0.11$ | Yield = 43,270 t |
| Overfishing (OFL): | $F_{35\%\ \text{(adjusted)}} = 0.15$ | Yield = 58,590 t |

2010 harvests

| | | |
|---|---|---|
| Maximum permissible ABC: | $F_{40\%\ \text{(adjusted)}} = 0.16$ | Yield = 77,380 t |
| Recommended ABC: | $F_{40\%\ \text{(author's adjusted)}} = 0.13$ | Yield = 67,700 t |
| Overfishing (OFL): | $F_{35\%\ \text{(adjusted)}} = 0.18$ | Yield = 90,920 t |

Equilibrium female spawning biomass

$B_{100\%}$ = 593,000 t
$B_{40\%}$ = 237,000 t
$B_{35\%}$ = 208,000 t

Projected 2009 biomass

Age 3+ biomass = 638,950 t
Female spawning biomass = 132,810 t

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

There were no comments in the December 2007 minutes that were applicable to the Gulf of Alaska pollock assessment.

## Introduction

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

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

## Fishery

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

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

Incidental catch in the Gulf of Alaska directed pollock fishery is low. For tows classified as pollock targets in the Gulf of Alaska between 2003 and 2007, about 95% of the catch by weight consisted of pollock (Table 1.2). Nominal pollock targets are defined by the dominance of pollock in the catch, and may include tows where other species were targeted, but where pollock were caught instead. The most common managed species in the incidental catch are arrowtooth flounder, Pacific cod, flathead sole, Pacific Ocean perch, miscellaneous flatfish, and the shortraker/rougheye rockfish complex. The most common non-target species are squid, eulachon, various shark species (e.g., Pacific sleeper sharks, spiny dogfish, salmon shark), and grenadiers. Bycatch estimates for prohibited species over the period 2003-2007 are given in Table 1.3.

Kodiak is the major port for pollock in the Gulf of Alaska, with 62% of the 2003-2007 landings. In the western Gulf of Alaska, Sand Point, Dutch Harbor, King Cove, and Akutan are important ports, sharing 37% of 2003-2007 landings. Secondary ports, including Cordova, Seward, and Homer account for the remaining 1% of the 2003-2007 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 suspension of directed pollock fishing when spawning biomass declines below 20% of the reference unfished level.

## Data Used in the Assessment

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

### *Total Catch*

Estimated catch was derived by the NMFS Regional Office from shoreside electronic logbooks and observer estimates of at-sea discards (Table 1.4). Catches include the state-managed pollock fishery in Prince William Sound. Since 1996 the pollock Guideline Harvest Level (GHL) for the PWS fishery has been deducted from the Acceptable Biological Catch (ABC) by the NPFMC Gulf of Alaska Plan Team for management purposes.

### *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 2007 fishery were aged using the revised criteria described in Hollowed et al. (1995), which involved refinements in the criteria to define edge type. 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 sex and stratum specific length frequency data to estimate age composition, which were then weighted by the catch in numbers in each stratum to obtain an overall age composition. Age and length samples from the 2007 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 | 388 | 426 | 314 | 89 |
| | No. lengths | 2206 | 2604 | 659 | 191 |
| | Catch (t) | 8,904 | 17,118 | 6,398 | 360 |
| 2nd half (C and D seasons) | No. ages | 398 | 113 | 334 | ---- |
| | No. lengths | 2401 | 254 | 1374 | ---- |
| | Catch (t) | 9,050 | 2,242 | 8,046 | ---- |

In the first half of 2007, the age-7 and age-8 fish (2000 and 1999 year classes respectively) were dominant in all areas except in area 630, where age-2 and age-3 fish (2004 and 2005 year classes) also showed a mode (Fig. 1.2). In the second half of 2007, younger fish were dominant in all areas, particularly age-2 fish (2005 year class). Age-3 fish (2004 year class) were present in significant quantities only in area 620.

Fishery catch at age in 1976-2007 is presented in Table 1.5 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.6.

### *Gulf of Alaska Bottom Trawl Survey*

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) every three years (beginning in 1984) to assess the abundance of groundfish in the Gulf of Alaska (Table 1.7). Starting in 2001, the survey frequency was increased to every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and management area (Martin 1997). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized poly-Nor’eastern high opening bottom trawls rigged with roller gear. In a typical survey, 800 tows are completed. On average, 70% of these tows contain pollock (Table 1.8).

The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140° W lon., obtained by adding the biomass estimates for the Shumagin, Chirikof, Kodiak INPFC areas, and the western portion of Yakutat INPFC area. Biomass estimates for 1990, 1993, 1996, 1999, 2003, 2005 and 2007 for the west Yakutat region were obtained by splitting strata and survey CPUE data at 140° W lon. (M. Martin, AFSC, Seattle, WA, pers. comm. 2007). For surveys in 1984 and 1987, the average percent in West Yakutat in the 1990-99 surveys was used. The average was also used in 2001, when West Yakutat was not surveyed.

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

### *Bottom Trawl Age and Length Composition*

Estimates of numbers at age from the bottom trawl survey were obtained from random otolith samples and length frequency samples (Table 1.9). Numbers at age were estimated for three strata: Western GOA (Shumagin INPFC area), Central GOA (Chirikof and Kodiak INPFC areas), Eastern GOA (Yakutat and Southeastern INPFC areas) using age-length keys and CPUE-weighted length frequency data. The combined Western and Central age composition was used in the assessment model. Ages are now available for the 2007 survey and were used in this year's assessment model. In the Western and Central GOA, age-7 and age-8 fish were most abundant of the older pollock, with the age-7 fish (2000 year class) approximately twice as common as the age-8 fish (1999 year class) (Fig. 1.4). Juvenile fish (ages 1-3) were also relatively abundant, particularly in the Central GOA.

## *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 2008 are presented in a NMFS processed report (Guttormsen et. al. in review). Biomass estimates using the Simrad EK echosounder from 1992 onwards were re-estimated to take into account recently published work of eulachon acoustic target strength (Gauthier and Horne 2004). Previously, acoustic backscatter was attributed to eulachon based on the percent composition of eulachon in trawls, and it was assumed that eulachon had the same target strength as pollock. Since Gauthier and Horne (2004) determined that the target strength of eulachon was much lower than pollock, the acoustic backscatter could be attributed entirely to pollock even when eulachon were known to be present.

The 2008 acoustic survey is the first conducted using the *R/V Oscar Dyson*. The 2008 biomass estimate for Shelikof Strait is 208,032 t, an increase of 15% from the 2007 biomass. In winter of 2007, a vessel comparison experiment was conducted between the *R/V Miller Freeman* and the *R/V Oscar Dyson*, which obtained a OD/MF ratio of 1.132. These results suggest that biomass was relatively constant from 2007 to 2008 (Table 1.7). Biomass of pollock ≥43 cm (a proxy for spawning biomass) dropped by 52% from the 2007 estimate, apparently due to below average recruitment to the spawning population (Fig. 1.5).

Additional EIT surveys in winter 2008 covered the Shumagin Islands spawning area, Sanak Gully, Chirikof, and the shelf break from Chirikof to Middleton Island. Estimates from these areas are given below.

2008 EIT survey results

| | | *Sanak* | *Shumagin* | *Shelikof* | *Chirikof* | *Shelf break/Middleton Island* | *Total* |
|---|---|---|---|---|---|---|---|
| Total | Tons | 19,750 | 30,582 | 208,032 | 22,055 | 4,159 | 284,577 |
| | Percent | 7% | 11% | 73% | 8% | 1% | |
| Biomass ≥43 cm | Tons | 19,680 | 6,658 | 62,477 | 21,741 | 504 | 111,061 |
| | Percent | 18% | 6% | 56% | 20% | <1% | |

In comparison to 2007, biomass estimates were stable in Shelikof Strait and higher in the Shumagin area by 35%. Steep declines were observed in Sanak Gully (71% decrease), and Chirikof (47% decrease) (Fig

1.6). As in 2007, there was a near absence of mature fish in the Shumagin area in 2008. Although the estimates of spawning biomass present a pessimistic picture of stock status, there were large estimates of age-1 pollock in 2008 in both the Shumagin area (1.5 billion) and in Shelikof Strait (1.4 billion), suggesting that the 2007 year class is both abundant and widely distributed.

Since the assessment model only includes individuals age 2 and older, the biomass of age-1 fish in the 1995, 2000, 2005, and 2008 surveys was subtracted from the total biomass for those years, reducing the biomass by 15%, 13%, 5% and 9% respectively (Table 1.7). In all other years, the biomass of age-1 fish was less than 2% of the total EIT biomass estimate.

*Echo Integrated Trawl Survey Length Frequency*
Annual biomass distributions by length from the Shelikof Strait EIT survey show the progression of strong year classes through the population (Fig. 1.7). In the 2008 survey, the age-1 fish from the 2007 year class were numerically dominant, but appear as a secondary mode in the biomass distribution by length. Since age composition estimates were already available from the 2008 survey, size composition data were not used in the assessment model.

*Echo Integrated Trawl Survey Age Composition*
Estimates of numbers at age from the Shelikof Strait EIT survey (Table 1.10) were obtained from random otolith samples and length frequency samples. Otoliths collected during the 1994 - 2008 EIT surveys were aged using the criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.11.

## Egg Production Estimates of Spawning Biomass

Estimates of spawning biomass in Shelikof Strait based on egg production methods were included in the assessment model. A complete description of the estimation process is given in Picquelle and Megrey (1993). The estimates of spawning biomass in Shelikof Strait show a pattern similar to the acoustic survey (Table 1.7). The annual egg production spawning biomass estimate for 1981 is questionable because of sampling deficiencies during the egg surveys for that year (Kendall and Picquelle 1990). Coefficients of variation (CV) associated with these estimates were included in the assessment model. Egg production estimates were discontinued because the Shelikof Strait EIT survey provided similar information.

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

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

The 2008 biomass estimate for pollock for the ADF&G crab/groundfish survey was 83,476 t, up 9% from the 2007 biomass estimate (Table 1.7).

*ADF&G Survey Length Frequency*
Pollock length-frequencies for the ADF&G survey in 1989-2002 (excluding 1991 and 1995) typically show a mode at lengths greater than 45 cm (Fig. 1.8). The predominance of large fish in the ADF&G survey may result from the selectivity of the gear, or because of greater abundance of large pollock in the areas surveyed. Size composition in 2008 shows a mode at 44 cm, consistent with recruitment of a

strong year class (or year class) to the component of the population sampled by this survey.

*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, 2004, and 2006 ADF&G surveys (N = 559, 538, 591 & 588). Comparison with fishery age composition shows that older fish (> age-8) are more common in the ADF&G crab/groundfish survey. This is consistent with the assessment model, which estimates a domed-shaped selectivity pattern for the fishery, but an asymptotic selectivity pattern for the ADF&G survey.

### *Pre-1984 bottom trawl surveys*

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

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

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

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

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

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

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

where $q_1$ is the catchability of the NMFS bottom trawl survey, $q_2$ is the catchability of historical 400-mesh eastern trawl surveys, $\hat{FPC}$ is the estimated fishing power correction (= 3.84), and $\sigma_{FPC}$ 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 1.12). No trend in pollock abundance is noticeable since 1978, and biomass estimates during 1978-1982 are in the same range as the post-1984 triennial survey biomass estimates. The coefficients of variation (CV) for GLM-based biomass estimates range between 0.24 and 0.64, and, as should be anticipated, are larger than the triennial survey biomass estimates, which range between 0.12 and 0.38.

Results were generally consistent with the multi-year combined survey estimates published previously (Table 1.12), and indicate a large increase in pollock biomass in the Gulf of Alaska occurred between the early 1960s (~200,000 t) and the mid 1970s (>2,000,000 t). Increases in pollock biomass between the1960s and 1970s were also noted by Alton et al. (1987). In the 1961 survey, pollock were a relatively minor component of the groundfish community with a mean CPUE of 16 kg/hr (Ronholt et al. 1978). Arrowtooth flounder was the most common groundfish with a mean CPUE of 91 kg/hr. In the 1973-76 surveys, the CPUE of arrowtooth flounder was similar to the 1961 survey (83 kg/hr), but pollock CPUE had increased 20-fold to 321 kg/hr, and was by far the dominant groundfish species in the Gulf of Alaska. Meuter and Norcross (2002) also found that pollock was low in the relative abundance in 1960s, became the dominant species in Gulf of Alaska groundfish community in the 1970s, and subsequently declined in relative abundance.

Questions concerning the comparability of pollock CPUE data from historical trawl surveys with later surveys probably can never be fully resolved. However, because of the large magnitude of the change in CPUE between the surveys in the 1960s and the early 1970s using similar trawling gear, the conclusion that there was a large increase in pollock biomass seems robust. Model results suggest that population biomass in 1961, prior to large-scale commercial exploitation of the stock, may have been lower than at any time since then. Early speculation about the rise of pollock in the Gulf of Alaska in the early 1970s implicated the large biomass removals of Pacific Ocean perch, a potential competitor for euphausid prey (Somerton et al. 1979, Alton et al. 1987). More recent work has focused on role of climate change (Anderson and Piatt 1999, Bailey 2000). The occurrence of large fluctuations in pollock abundance without large changes in direct fishing impacts suggests a need for precautionary management. If pollock abundance is controlled primarily by the environment, or through indirect ecosystem effects, it may be difficult to reverse population declines, or to achieve rebuilding targets should the stock become depleted. Reliance on sustained pollock harvests in the Gulf of Alaska, whether by individual fishermen, processing companies, or fishing communities, may be difficult over the long-term.

### *Qualitative trends*

To assess qualitatively recent trends in abundance, each survey time series was standardized by dividing the annual estimate by the average since 1987. The Shelikof Strait EIT survey was split into separate time series corresponding to the two acoustic systems used for the survey. Although there is considerable variability in each survey time series, a fairly clear downward trend is evident to 2000, followed by a stable, though variable, trend (Fig. 1.9). The Shelikof Strait EIT survey and the ADFG crab/groundfish trawl survey show differing trends in 2007 and 2008, with the ADFG survey showing an increase, while the Shelikof Strait EIT survey showing a decline.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.10). The percent of females in the catch is close to 50-50, but shows a slight, though non-significant, downward trend, which may be related to changes in the seasonal distribution of the catch. The percent female jumped up to 54% in 2007 for reasons that are unclear. The mean age shows interannual variability due to strong year classes passing through the population, but no downward trends that would suggest excessive mortality rates. The percent of old fish in the catch (nominally defined as age 8 and older) is also highly variable due to variability in year class strength. The percent of old fish increased to a peak in 1997, declined due to weaker recruitment in the 1990s and increases in total mortality (both from fishing and predation), but increased in 2006 and 2007. Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch is approximately 17%. An index of catch at age diversity was computed using the Shannon-Wiener information index,

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

where $p_a$ is the proportion at age. Increases in fishing mortality would tend to reduce age diversity, but year class variability would also influence age diversity. The index of age diversity is relatively stable during 1976-2007 (Fig. 1.10).

### *McKelvey Index*

McKelvey (1996) found a significant correlation between the abundance of age-1 pollock in the Shelikof Strait EIT survey and subsequent estimates of year-class strength. The McKelvey index is defined as the estimated abundance of 9-16 cm fish in the Shelikof Strait EIT survey, and is an index of recruitment at age 2 in the following year (Table 1.13). The relationship between the abundance of age-1 pollock in the Shelikof Strait EIT survey and year-class strength provides a recruitment forecast for the year following the most recent Shelikof Strait EIT survey. The 2008 Shelikof EIT survey age-1 estimate is 1.37 billion (5th in abundance out of 25 surveys), which suggests that recruitment of the 2007 year class is likely to be above average.

## Analytic Approach

### *Model description*

An age-structured model covering the period from 1961 to 2008 (48 yrs) was used to assess Gulf of Alaska pollock. Population dynamics were modeled using standard formulations for mortality and fishery catch (e.g. Fournier and Archibald 1982, Deriso et al. 1985, Hilborn and Walters 1992). Year- and age-specific fishing mortality was modeled as a product of a year effect, representing the full-recruitment fishing mortality, and an age effect, representing the selectivity of that age group to the fishery. The age effect was modeled using a double-logistic function with time-varying parameters (Dorn and Methot 1990, Sullivan et al. 1997). The model was fit to time series of catch biomass, survey indices of abundance, and estimates of age and length composition from the fishery and surveys. Details of the population dynamics and estimation equations are presented in an appendix.

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

| *Likelihood component* | *Statistical model for error* | *Variance assumption* |
|---|---|---|
| Fishery total catch (1964-2008) | Log-normal | CV = 0.05 |
| POP fishery length comp. (1964-71) | Multinomial | Sample size = 60 |
| Fishery age comp. (1972-2007) | Multinomial | Year-specific sample size = 60-400 |
| Shelikof EIT survey biomass (1981-2008) | Log-normal | Survey-specific CV = 0.10-0.35 |
| Shelikof EIT survey age comp. (1981-2008) | Multinomial | Sample size = 60 |
| NMFS bottom trawl survey age comp. (1984-2007) | 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 (1989-2008) | Log-normal | CV = 0.25 |
| ADF&G survey age comp. (2000,2002,2004,2006) | Multinomial | Sample size = 10 |
| ADF&G survey length comp. (1989-2008) | 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<br>Normal | Slope CV = 0.10 (0.001 for 1961-71)<br>Inflection age SD = 0.40 (0.004 for 1961-71) |
| Recruit process error (1961-1968,2008) | Log-normal | $\sigma_R$ =1.0 |

*Recruitment*

In most years, year-class abundance at age 2 was estimated as a free parameter. A prior constraint was imposed on recruitment at the start of the modeled time period to improve parameter estimability. Instead of estimating the abundance of each age of the initial age composition independently, we parameterized the initial age composition with mean log recruitment plus a log deviation from an equilibrium age structure based on that mean initial recruitment. A penalty was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period ($\sigma_R$ =1.0). We also used the same constraint for log deviations in recruitment for 1961-68, and in 2008. Log deviations were estimated as free parameters in other years. These relatively weak constraints were sufficient to obtain fully converged parameter estimates while retaining an appropriate level of uncertainty (e.g. the CV of recruitment in 2008 ≈ $\sigma_R$).

*Modeling fishery data*

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 2008, 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 Simrad EK acoustic system has been used to estimate biomass since 1992. Earlier surveys (1981-91) were obtained with an older Biosonics acoustic system (Table 1.7). Biomass estimates similar to the Biosonics acoustic system can be obtained using the Simrad EK 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 -70 dB. The Shelikof Strait EIT survey time series was split into two periods corresponding to the two acoustic systems, and separate survey catchability coefficients were estimated for each period. For the 1992 and 1993 surveys, biomass estimates using both noise thresholds were used to provide to provide information on relative catchability.

A vessel comparison (VC) experiment was conducted in March 2007 during the Shelikof Strait acoustic-trawl survey. The VC experiment involved the *R/V Miller Freeman* (MF, the survey vessel used to conduct Shelikof Strait surveys since the mid-1980s), and the *R/V Oscar Dyson* (OD), a noise-reduced survey vessel designed to conduct surveys that have traditionally been done with the *R/V Miller Freeman*. The vessel comparison experiment was designed to collect data either with the two vessels running beside one another at a distance of 0.7 nmi, or with one vessel following nearly directly behind the other at a distance of about 1 nmi. The methods were similar to those used during the 2006 Bering Sea VC experiment (De Robertis et al. 2008). Results indicate that the ratio of 38 kHz pollock backscatter from the *R/V Oscar Dyson* relative to the *R/V Miller Freeman* was significantly greater than one (1.13), as would be expected if the quieter OD reduced the avoidance response of the fish. Because this difference was significant, methods to incorporate this result in the assessment model were explored.

Several modeling approaches were considered:

1. Use the 2008 OD estimate without adjustment.
2. Adjust the 2008 OD estimate to the MF time series using the vessel comparison results.

3. Conversely, adjust the MF time series to be consistent with the OD estimate in 2008. (One would surmise that these would give equivalent results since the Shelikof Strait survey is modeled as a relative index of abundance).
4. Treat the MF and the OD time series as independent survey time series, and include the vessel comparison results directly in the log likelihood of the assessment model. This likelihood component is given by

$$\log L = -\frac{1}{2\left(\sigma_P^2 + \sigma_S^2\right)}\left[\log(q_{OD}) - \log(q_{MF}) - \delta_{OD:MF}\right]^2,$$

where $log(q_{OD})$ is the log catchability of the *R/V Oscar Dyson*, $log(q_{MF})$ is the log catchability of the *R/V Oscar Dyson*, $\delta_{OD:MF}$ = 0.1240 is the mean of log scale paired difference in backscatter, mean[log($s_A$OD)-log($s_A$MF)] obtained from the vessel comparison, and $\sigma_S$ = 0.0244 is the standard error of the mean. This variance term is likely to underestimate the true uncertainty in the ratio because only a single experiment was performed. Conditions that were encountered during this experiment, which may affect the ratio in different years include, but are not limited to, the depth and age distribution of pollock, particularly the abundance of juvenile pollock. Thus, the variance estimated from a single experiment would not reflect the range of possible conditions that would be encountered in other years. To evaluate this possibility, we included a second variance term $\sigma_P$ to reflect this unquantified aspect of uncertainty.

*Ageing error*

An ageing error conversion matrix is used in the assessment model to translate model population numbers at age to expected fishery and survey catch at age (Table 1.14). Dorn et al. (2003) estimated this matrix using an ageing error model fit to the observed percent agreement at ages 2 and 9. Mean percent agreement is close to 100% at age 1 and declines to 40% at age 10. Annual estimates of percent agreement are variable, but show no obvious trend, hence a single conversion matrix for all years in the assessment model was adopted. The model is based on a linear increase in the standard deviation of ageing error and the assumption that ageing error is normally distributed. The model predicts percent agreement by taking into account the probability that both readers are correct, both readers are off by one year in the same direction, and both readers are off by two years in the same direction (Methot 2000). The probability that both agree and were off by more than two years was considered negligible. A recent study evaluated pollock ageing criteria using radiometric methods and found them to be unbiased (Kastelle and Kimura 2006).

*Length frequency data*

The assessment model was fit to length frequency data from various sources by converting predicted age distributions (as modified by age-specific selectivity) to predicted length distributions using an age-length conversion matrix. Because seasonal differences in pollock length at age are large, several conversion 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 conversion matrix estimated by Hollowed et al. (1998) was used for length-frequency data from the early period of the fishery. A conversion 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 conversion 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 conversion 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 x $10^{-4}$). ADModel builder includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest.

A list of model parameters is shown below:

| *Population process modeled* | *Number of parameters* | *Estimation details* |
|---|---|---|
| Initial age structure | Ages 3-10 = 8 | Estimated as log deviances from the log mean; constrained by random deviation process error from an equilibrium unfished age structure |
| Recruitment | Years 1961-2008 = 48 | Estimated as log deviances from the log mean; recruitment in 1961-68, and 2008 constrained by random deviation process error. |
| Natural mortality | Age- and year-invariant = 1 | Not estimated in the model |
| Fishing mortality | Years 1961-2008 = 48 | 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) = 188 | 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 | 124 primary parameters + 188 process error parameters + 2 fixed parameters = 314 | |

## Parameters Estimated Independently

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

- Natural mortality (M)
- Proportion mature at age

- Weight at age and year by fishery and by survey

*Natural mortality*

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

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

*Maturity at age*

In the 2002 assessment, maturity at age for Gulf of Alaska pollock was estimated using maturity stage data collected during winter EIT surveys in the Gulf of Alaska during 1983-2002. These estimates replaced a maturity at age vector estimated by Hollowed et al. (1991) using maturity stage data collected during 1983-89. Maturity stages for female pollock describe a continuous process of ovarian development between immature and post-spawning. For the purposes of estimating a maturity vector (the proportion of an age group that has been or will be reproductively active during the year) for stock assessment, all fish greater than or equal to a particular maturity stage are assumed to be mature, while those less than that stage are assumed to be immature. Maturity stages in which ovarian development had progressed to the point where ova were distinctly visible were assumed to be mature. Maturity stages are qualitative rather than quantitative, so there is subjectivity in assigning stages, and a potential for different technicians to apply criteria differently. Because the link between pre-spawning maturity stages and eventual reproductive activity later in the season is not well established, the division between mature and immature stages is problematic. Changes in the timing of spawning could also affect maturity at age estimates. Merati (1993) compared visual maturity stages with ovary histology and a blood assay for vitellogenin and found general consistency between the different approaches. Merati (1993) noted that ovaries classified as late developing stage (i.e., immature) may contain yolked eggs, but it was unclear whether these fish would spawn later in the year. The average sample size of female pollock maturity stage data per year from winter EIT surveys in the Gulf of Alaska is 850 (Table 1.15).

Estimates of maturity at age in 2008 from winter EIT surveys were below the long-term average for age 4 and age-5 pollock, but close to the long-term average for the older ages (Fig. 1.11). Because there did not appear to be an objective basis for excluding data, the 1983-2008 average maturity at age was used in the assessment.

Logistic regression (McCullagh and Nelder 1983) was also used to estimate the age and length at 50% mature at age for each year. Annual estimates of age at 50% maturity are highly variable and range from 3.7 years in 1984 to 6.1 years in 1991, with an average of 4.9 years. Length at 50% mature is less variable than the age at 50% mature, suggesting that at least some of the variability in the age at maturity can be attributed to changes in length at age (Fig 1.12). Changes in year-class dominance could also potentially affect estimates of maturity at age. There is less evidence of trends in the length at 50% mature, with only the 1983 and 1984 estimates as unusually low values. The average length at 50% mature for all years is approximately 43 cm.

*Weight at age*

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

## Model selection and evaluation

### Model selection

Model selection focused on treatment of the results of the vessel comparison experiment between the *R/V Miller Freeman* and the *R/V Oscar Dyson*. Several approaches were considered:

1. Use the 2008 OD estimate without adjustment.
2. Adjust the 2008 OD estimate to the MF time series using the vessel comparison results (OD to MF ratio = 1.132).
3. Adjust the MF time series to be consistent with the OD estimate in 2008.
4. Treat the MF and the OD time series as independent survey time series, and include the vessel comparison results directly in the log likelihood of the assessment model without a process error term.
5. Same as model 4, except a process error term was added, with an assumed standard deviation of 0.1 (loosely based on the two Eastern Bering Sea estimates of the OD to MF ratio of 0.98 and 1.08).

Despite the significant difference in the ratio of pollock backscatter between the *R/V Miller Freeman* (MF) and the *R/V Oscar Dyson* (OD), the impact on assessment results and recommended ABCs was minor regardless of the modeling approach (Table below). The 2009 spawning biomass and ABCs varied 5-7% across different model configurations, while population biomass varied by about 3%. We considered models that included a likelihood component for the vessel comparison experiment to be a better approach from a technical perspective, though there would be little consequence to using the simpler approach of rescaling the biomass estimates from one vessel to the other. As expected, it makes no difference which vessel biomass time series is rescaled to the other.

Although model 5 is arguably more realistic in incorporating uncertainty in the vessel comparison, we identified model 4 as the preferred base model for several reasons. First, the assumed value of process error is highly speculative and model results are sensitive to the assumed value. Secondly, the estimated ratio of catchabilities between the OD and MF for model 5 is 0.96, and none of the vessel comparison experiments resulted in a ratio this low. Finally, since the 2008 OD biomass estimate is low relative to the model expectation, a better model fit can be achieved by reducing the ratio in catchabilities between the OD to MF, since it implies that there is more spawning biomass present in Shelikof Strait in 2008, when the single survey by the OD was done. Other structural assumptions of the assessment may account for the lack of fit to the 2008 biomass estimate, such as the assumption that a constant fraction of the stock spawns in Shelikof Strait.

| *Model* | *Total log likelihood* | *OD:MF ratio* | *2009 Spawning biomass (1000 t)* | *2009 3+ biomass (1000 t)* | *2009 Author's ABC (t)* |
|---|---|---|---|---|---|
| 1. No adjustment to 2008 OD | 999.34 | 1 (assumed) | 136.5 | 661.3 | 46,099 |
| 2. Scale OD to MF | 1001.51 | 1.13 (assumed) | 133.8 | 636.8 | 43,792 |
| 3. Scale MF to OD | 1001.51 | 1.13 (assumed) | 133.8 | 636.8 | 43,792 |
| 4. Likelihood component for vessel comparison, No process error | 1001.41 | 1.12 (estimated) | 134.0 | 636.8 | 43,981 |
| 5. Likelihood component for vessel comparison, Process error SD = 0.1 | 999.97 | 0.96 (estimated) | 137.4 | 669.8 | 46,901 |

## *Model evaluation*

Model fit to age composition data was evaluated using plots of observed and predicted age composition in the fishery (Fig. 1.13 ), Shelikof Strait EIT survey (Fig. 1.14), and the NMFS trawl survey (Fig. 1.15). Model fits to fishery age composition data are good in most years. In 2007, the largest discrepancy between fishery data and the model expectation was a lower than expected abundance of the 2004 year class (age-3 fish), suggesting that this year class is less common than previously estimated. The abundance of this year class was also less than expected in the 2008 Shelikof Strait EIT survey.

Model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 2005) (Figs. 1.16-1.18). General trends in survey time series are fit reasonably well. For example, both the model and all surveys show a declining trend in the 1990s. But since each survey time series shows a different pattern of decline, the model is unable to fit all surveys simultaneously. The ADF&G survey matches the model trend better than any other survey, despite receiving less weight in model fitting. The discrepancy between the NMFS trawl survey and the Shelikof Strait EIT survey biomass estimates in the 1980s accounts for the poor model fit to both time series during in those years. The fit to the 2007 and 2008 EIT survey biomass is poor. The model prediction was for an increase in the survey biomass in those years, while the survey data indicates that the stock continues to remain at low levels. In contrast the ADFG crab/groundfish increased in 2007 and 2008. The 2007 NMFS trawl survey is nearly exactly equal to the model prediction. Since this survey is the most comprehensive survey, the consistency between the NMFS survey and the assessment lends support to assessment results.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.74 (Fig. 1.19). The change in log likelihood is small (about 1.5) between models with fixed and estimated catchability, indicating that despite the large change in biomass, there is little objective basis for choosing one model over the other. These results are similar to previous assessments. Consequently we used a base model with fixed trawl survey catchability of 1.0 to be consistent with recommendations in previous assessments.

## Assessment Model Results

Parameter estimates and model output are presented in a series of tables and figures. Estimated survey selectivity and fishery selectivity for different periods given in Table 1.16 (see also Figure 1.20). Table 1.17 gives the estimated population numbers at age for the years 1961-2008. Table 1.18 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1977-2008 (see also Fig. 1.21). Stock size peaked in the early 1980s at approximately 1.3 times the proxy for unfished stock size (B100% = mean 1979-2007 recruitment multiplied by the spawning biomass per recruit 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 22% of unfished stock size, increased to 31% of unfished in 2006. The stock then declined again, dropping to 27% of unfished stock size in 2008.

### *Retrospective comparison of assessment results*

A retrospective comparison of assessment results for the years 1996-2008 indicates the current estimated trend in spawning biomass for 1990-2008 is consistent with previous estimates (Fig. 1.22, top panel). 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 moderate, and, based on the current assessment, recent assessments have tended to overestimate ending year abundance by approximately 17%. The estimated 2008 age composition from the current assessment is similar to projected 2008 age composition in the 2007 assessment (Fig. 1.22, bottom panel). The largest discrepancy is the estimate of the age-4 fish (2004 year class), which is about half the size of last year's assessment. However the estimate of the age-3 fish (2005 year class) is about the same. Estimates of all of the older fish are all slightly lower than in the 2007 assessment.

### *Stock and recruitment*

Recruitment of Gulf of Alaska pollock is more variable (CV = 1.09) than Eastern Bering Sea pollock (CV = 0.64). Among North Pacific groundfish stocks with age-structured assessments, GOA pollock ranks third in recruitment variability after sablefish and Pacific Ocean perch (http://www.afsc.noaa.gov/refm/stocks/estimates.htm). However, unlike sablefish and Pacific Ocean perch, pollock have a short generation time (<10 yrs), so that large year classes do not persist in the population long enough to have a buffering effect on population variability. Because of these intrinsic population characteristics, the typical pattern of biomass variability for Gulf of Alaska pollock will be sharp increases due to strong recruitment, followed by periods of gradual decline until the next strong year class recruits to the population. Gulf of Alaska pollock is more likely to show this pattern than any other groundfish stock in the North Pacific due to the combination of a short generation time and high recruitment variability.

Since 1980, strong year classes have occurred every four to six years (Fig. 1.21). Because of high recruitment variability, the functional relationship between spawning biomass and recruitment is difficult to estimate despite good contrast in spawning biomass. Strong and weak year classes have been produced at high and low level of spawning biomass. The 1972 year class (one of the largest on record) was produced by an estimated spawning biomass close to current levels, suggesting that the stock has the potential to produce strong year classes. Spawner productivity is higher at low spawning biomass compared to high spawning biomass, indicating that survival of eggs to recruitment is density-dependent (Fig. 1.23). However, this pattern of density-dependent survival only emerges on a decadal scale, and could be confounded with environmental variability on the same temporal scale. 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. For the 2006 year class, the 2007 Shelikof Strait EIT survey estimate was very low, and neither the Shumagin EIT survey nor the 2007 bottom trawl survey saw higher than average numbers of age-1 fish. For the 2007 year class, the high estimates of age-1 fish in both the Shumagin and Shelikof Strait EIT surveys suggests that the 2007 year class is both abundant and widely distributed.

| Year of recruitment | 2008 | 2009 | 2010 |
|---|---|---|---|
| Year class | 2006 | 2007 | 2008 |
| FOCI prediction | *Average* | *Average* | *Average* |
| Survey information | 2007 Shelikof EIT survey age-1 estimate is 54 million (18th in abundance out of 25 surveys)<br>2007 Shumagin EIT survey age-1 estimate is 117 million<br>2007 NMFS bottom trawl survey age-1 estimate is 174 million (5th in abundance out of 11 surveys) | 2008 Shelikof EIT survey age-1 estimate is 1.4 billion (5th in abundance out of 25 surveys)<br>2008 Shumagin EIT survey age-1 estimate is 1.5 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 1.19). Spawning biomass reference levels were based on mean 1979-2007 recruitment (709 million), which slightly lower than the post-1979 mean in the 2007 assessment. The average did not include the recruitment in 2008 (2006 year class) due to uncertainty in the estimate of year class strength. Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using mean weight at age for the Shelikof Strait EIT surveys in 2004-2008 to estimate current reproductive potential. The SPR at F=0 was estimated as 0.836 kg/recruit. This estimate represents an 11% increase from the 2007 estimate primarily due to increases in weight at age in the 2007 and 2008 Shelikof Strait EIT survey. $F_{SPR}$ rates depend the selectivity pattern of the fishery. Selectivity in the Gulf of Alaska pollock fishery changed as the fishery evolved from a foreign fishery occurring along the shelf break to a domestic fishery on spawning aggregations and in nearshore waters (Fig. 1.1). For SPR calculations, we used a selectivity pattern based on an average for 2003-2007 to reflect current selectivity patterns. Gulf of Alaska pollock $F_{SPR}$ harvest rates are given below:

| $F_{SPR}$ rate | Fishing mortality | Equilibrium under average 1979-2007 recruitment | | | | |
|---|---|---|---|---|---|---|
| | | Avg. Recr. (Million) | Total 3+ biom. (1000 t) | Female spawning biom. (1000 t) | Catch (1000 t) | Harvest rate |
| 100.0% | 0.000 | 709 | 1771 | 593 | 0 | 0.0% |
| 50.0% | 0.181 | 709 | 1116 | 297 | 131 | 11.8% |
| 45.0% | 0.211 | 709 | 1046 | 267 | 144 | 13.8% |
| 40.0% | 0.245 | 709 | 975 | 237 | 157 | 16.1% |
| 35.0% | 0.286 | 709 | 903 | 208 | 169 | 18.7% |

The $B_{40\%}$ estimate of 237,000 t represents a 7% increase in the $B_{40\%}$ estimate of 221,000 t in the 2006 assessment, and reflects both the increase in mean weight at age during spawning and a decrease in average recruitment. The model estimate of spawning biomass in 2009 is 132,809 t, which is 22.4% of unfished spawning biomass and below $B_{40\%}$ (237,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. In sub-tier "b" the OFL and maximum permissible ABC fishing mortality rates are adjusted downwards as described by the harvest guidelines (see SAFE Summary Chapter).

### 2008 acceptable biological catch

The definitions of OFL and maximum permissible $F_{ABC}$ under Amendment 56 provide a buffer between the overfishing level and the intended harvest rate, as required by NMFS national standard guidelines. Since estimates of stock biomass from assessment models are uncertain, the buffer between OFL and ABC provides a margin of safety so that assessment error will not result in the OFL being inadvertently exceeded. For Gulf of Alaska pollock, the maximum permissible $F_{ABC}$ harvest rate is 85.9% of the OFL harvest rate. In the 2001 assessment, based on an analysis that showed that the buffer between the maximum permissible $F_{ABC}$ and OFL decreased when the stock is below approximately $B_{50\%}$ , we developed a more conservative alternative that maintains a constant buffer between ABC and $F_{ABC}$ at all stock levels (Table 1.20). While there is always some probability of exceeding $F_{OFL}$ due to imprecise stock assessments, it seemed unreasonable to reduce safety margin as the stock declines.

This alternative is given by the following

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

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

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

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

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

Projections for 2009 for $F_{OFL}$, the maximum permissible $F_{ABC}$, and an adjusted $F_{40\%}$ harvest rate with a constant buffer between $F_{ABC}$ and $F_{OFL}$ are given in Table 1.21.

### ABC recommendation

Although there was no NMFS bottom trawl survey in 2008, new information is available from the winter 2008 EIT surveys and the 2008 ADF&G crab/groundfish survey. Winter EIT surveys were either stable at low levels relative to 2007 (Shelikof Strait and Shumagin area), or showed steep declines (Sanak Gully, 71% decline; Chirikof, 47% decline). In contrast, the ADF&G survey biomass increased 9% from 2007. When this information is incorporated in the assessment, the estimated abundance of mature fish in 2009 stock size is lower than projected in the 2007 assessment, and the estimate of the size of the 2004 year class is reduced by about one-half. There continues to be evidence of moderate to strong recruitment to the population, in particular the 2007 year class, which was abundant both in Shelikof Strait and in the Shumagin area, is promising. Model projections indicate that the spawning biomass in 2009 will remain close to the 2008 minimum, but will increase in subsequent years. The extent and rate of that increase depends on the magnitude of incoming year classes, which are still highly uncertain. Model estimates of stock status in 2009 are broadly consistent with survey trends. In particular, the model achieves a good fit to the biomass estimate from the 2007 NMFS bottom trawl survey, which is the most comprehensive survey.

The primary concern about Gulf of Alaska pollock for the short-term continues to be the low spawning biomass in Shelikof Strait and other spawning areas in the Gulf of Alaska in 2008. Biomass in Shelikof Strait and the Shumagin area remained close to the 2007 minimum, and other spawning areas surveyed in winter of 2008 showed steep declines. In previous years, concern over the decline in spawning activity in Shelikof Strait was mitigated by the additional winter surveying efforts which in aggregate resulted in an estimate of spawning biomass that was close to the model estimate. In 2008, the aggregate spawning biomass was 34% of the model estimate, so this was not the case in 2008.

Based on these considerations, we used the base model with an adjusted $F_{40\%}$ harvest rate for the author's recommended 2009 ABC of 43,270 t. The elements of risk-aversion in this recommendation relative to using the point estimate of the model and the maximum permissible $F_{ABC}$ are the following: 1) fixing trawl catchability at 1.0; 2) applying a more conservative harvest rate than the maximum permissible $F_{ABC}$. These risk-averse elements reduce the recommended ABC to approximately 54% of the model point estimate. In 2010, the ABC based an adjusted $F_{40\%}$ harvest rate is 67,701 t (Table 1.21). The OFL in 2009 is 58,592 t, and the OFL in 2010 if the recommended ABC is taken in 2009 is 90,916 t.

To evaluate the probability that the stock will drop below the $B_{20\%}$ threshold, we projected the stock forward for five years and removed catches based on the spawning biomass in each year and the author's recommended fishing mortality schedule. This projection incorporates uncertainty in stock status, uncertainty in the estimate of $B_{20\%}$, and variability in future recruitment. We then sampled from the likelihood of future spawning biomass using Markov chain Monte Carlo (MCMC) (Fig. 1.25). A chain of 1,000,000 samples was thinned by selecting every 200th sample. Analysis of the thinned MCMC chain indicates that probability of the stock dropping below $B_{20\%}$ will be highest in 2009 with a probability of 0.12, but drops to less than 1% in subsequent years.

### Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the 2008 numbers at age as estimated by the assessment model and assume the 2008 catch will be equal to the TAC of 53,590 t 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 1979-2007 as estimated by the assessment model. Spawning biomass is computed in each year based on the time of peak spawning (March 15) using the maturity and weight schedules in Table 1.19. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2009, 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 five-year average *F* (2004-2008). (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 2009 and 2010, *F* is set equal to *max* $F_{ABC}$, and in all subsequent years, *F* is set equal to $F_{OFL}$. (Rationale: This scenario determines whether a stock is approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.21. Under all harvest policies mean spawning biomass is projected to be stable at low levels from 2008 to 2009, and then increase (Fig. 1.26). Plots of individual projection runs are highly variable (Fig. 1.27), and may provide a more realistic view of potential pollock abundance in the future.

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

Spawning biomass is projected to be 132,255 t in 2009 for an $F_{OFL}$ harvest rate, which is less than $B_{35\%}$ (208,000 t), but greater than ½ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2019 is 234,812 t, 113% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2011 is 185,632 t, which is less than $B_{35\%}$ , but greater than ½ of $B_{35\%}$ . Projected mean spawning biomass in 2021 is 233,374 t, 112% of $B_{35\%}$ . Therefore, Gulf of Alaska pollock is not approaching an overfished condition.

## Ecosystem considerations

### *Prey of pollock*

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

Pollock trophic interactions occur primarily in the pelagic pathway in the food web, which leads from phytoplankton through various categories of zooplankton to planktivorous fish species such as capelin and sandlance (Fig. 1.28); the primary prey of pollock are euphausiids. Pollock also consume shrimp, which are more associated with the benthic pathway, and make up approximately 18% of age 2+ pollock diet. All ages of GOA pollock are primarily zooplanktivorous during the summer growing season (>80% by weight zooplankton in diets for juveniles and adults; Fig 1.29). While there is an ontogenetic shift in diet from copepods to larger zooplankton (primarily euphausiids) and fish (Fig. 1.29), cannibalism is not as prevalent in the Gulf of Alaska as in the Eastern Bering Sea, and fish consumption is low even for large pollock (Yang and Nelson 2000).

There are no extended time series of zooplankton abundance for the shelf waters of the Gulf of the Alaska. Brodeur and Ware (1995) provide evidence that biomass of zooplankton in the center of the Alaska Gyre was twice as high in the 1980s than in the 1950s and 1960s, consistent with a shift to positive values of the PDO since 1977. The percentage of zooplankton in diets of pollock is relatively constant throughout the 1990s (Fig. 1.29). While indices of stomach fullness exist for these survey years, a more detailed bioenergetics modeling approach would be required to examine if feeding and growth conditions have changed over time, especially given the fluctuations in GOA water temperature in recent years (Fig. 15, Ecosystem Considerations Appendix), as water temperature has a considerable effect on digestion and other energetic rates.

### *Predators of pollock*

Initial ECOPATH model results show that the top five predators on pollock >20 cm by relative importance are arrowtooth flounder, Pacific halibut, Pacific cod, Steller sea lion (SSL), and the directed pollock fishery (Fig. 1.30). For pollock less than 20cm, arrowtooth flounder represent close to 50% of total mortality. All major predators show some diet specialization, and none depend on pollock for more than 50% of their total consumption (Fig. 1.31). Pacific halibut is most dependent on pollock (48%), followed by SSL (39%), then arrowtooth flounder (24% for juvenile and adult pollock combined), and lastly Pacific cod (18%). It is important to note that although arrowtooth flounder is the largest single source of mortality for both juvenile and adult pollock (Fig 1.30), arrowtooth depend less on pollock in their diets then do the other predators.

Arrowtooth consume a greater number of smaller pollock than do Pacific cod or Pacific halibut, which consume primarily adult fish. However, by weight, larger pollock are important to all three predators (Fig. 1.32). Length frequencies of pollock consumed by the western stock of Steller sea lions tend towards larger fish, and generally match the size frequencies of cod and halibut (Zeppelin et al. 2004). The diet of Pacific cod and Pacific halibut are similar in that the majority of their diet besides pollock is from the benthic pathway of the food web. Alternate prey for Steller sea lions and arrowtooth flounder are similar, and come primarily from the pelagic pathway.

Predation mortality, as estimated by ECOPATH, is extremely high for GOA pollock >20cm. Estimates for the 1990-1993 time period indicate that known sources of predation sum to 90%-120% of the total production of walleye pollock calculated from 2004 stock assessment growth and mortality rates; estimates greater than 100% may indicate a declining stock (as shown by the stock assessment trend in the early 1990s; Fig 1.33, top), or the use of mortality rates which are too low. Conversely, as >20cm pollock include a substantial number of 2-year olds, it may be that mortality rate estimates for this age range is low. In either case, predation mortality for pollock in the GOA is much greater a proportion of pollock production than as estimated by the same methods for the Bering Sea, where predation mortality (primarily pollock cannibalism) was up to 50% of total production.

Aside from long-recognized decline in Steller sea lion abundance, the major predators of pollock in the Gulf of Alaska are stable to increasing, in some cases notably so since the 1980s (Fig. 1.33, top). This high level of predation is of concern in light of the declining trend of pollock with respect to predator increases. To assess this concern, it is important to determine if natural mortality may have changed over time (e.g. the shifting control hypothesis; Bailey 2000). To examine predator interactions more closely than in the initial model, diet data of major predators in trawl surveys were examined in all survey years since 1990.

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

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

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

Fig. 1.33 (bottom) shows annual total estimates of consumption of pollock (all age classes) in survey years by the four major fish predators. Other predators, shown as constant, are taken from ECOPATH modeling results and displayed for comparison. Catch is shown as reported in Table 1.1. In contrast, the line in the figure shows the historical total production (tons/year) plus yearly change in biomass (positive or negative) from the stock assessment results. In a complete accounting of pollock mortality, the height of the bars should match the height of the line. As shown, estimates of consumption greatly surpass estimates of production; fishing mortality is a relatively small proportion of total consumption. Overestimates in consumption rates could arise through seasonal differences in diets; while ration is seasonally adjusted, diet proportions are based on summer data. Also, better energetic estimates of consumption would improve these estimates. In terms of the stock assessment, underestimates of production could result from underestimating natural mortality, especially at ages 2-3, underestimating the rate of decline which occurred between 1990-present, or underestimates of the total biomass of pollock; this analysis should be revisited using higher mortality at younger ages than assumed in the current stock assessment.

To better judge natural mortality, consumption was calculated for two size groups of pollock, divided at 30cm fork length. This size break, which differs from the break in the ECOPATH analysis, is based on finding minima between modes of pollock in predator diets (Fig. 1.32). This break is different from the conversion matrices used in the stock assessment; perhaps due to differences in size selection between predators and surveys. For this analysis, it is assumed that pollock<30cm are ages 0-2 while pollock ≥30cm are age 3+ fish.

Consumption of age 0-2 pollock per unit predator biomass (using survey biomass) varied considerably through survey years, although within a year all predators had similar consumption levels (Fig. 1.34, top). Correlation coefficients of consumption rates were 0.98 between arrowtooth and halibut, and 0.90 for both of these species with pollock. Correlation coefficients of these three species with cod were ~0.55 for arrowtooth and halibut and ~0.20 with pollock. The majority of this predation by weight occurred on age 2 pollock.

Plotted against age 2 pollock numbers calculated from the stock assessment, consumption/biomass and total consumption by predator shows a distinct pattern (Fig. 1.34, lower two graphs). In “low” recruitment years consumption is consistently low, while in high recruitment years consumption is high, but does not increase linearly, rather consumptions seems to level out at high numbers of juvenile pollock, resembling a classic “Type II” functional response. This suggests the existence bottom-up control of juvenile consumption, in which strong year classes of pollock “overwhelm” feeding rates of predators, resulting in potentially lower juvenile mortality in good recruitment years which may amplify the recruitment. However, this result should be examined iteratively within the stock assessment, as the back-calculated numbers at age 2 assume a constant natural mortality rate. Assuming a lower mortality rate due to predator satiation would lead to lower estimates of age 2 numbers, which would make the response appear more linear.

Consumption of pollock ≥30cm shows a different pattern over time. A decline of consumption per unit biomass is evident for halibut and cod (Fig. 1.35, top). Arrowtooth shows an insignificant decline; it is possible that the noise in the arrowtooth trend, mirroring the consumption of <30cm fish, is due to the choice of 30cm as an age cutoff. As a function of age 3+ assessment biomass, consumption per unit biomass and total consumption remained constant as the stock declined, and then fell off rapidly at low biomass levels in recent years (Fig. 1.35, middle and bottom). Again, this result should be approached iteratively, but it suggests increasing predation mortality on age 3+ pollock between 1990-2005, possibly requiring increased foraging effort from predators.

There has been a marked decline in Pacific halibut weight at age since the 1970s that Clark et al. (1999) attributed to the 1977 regime shift without being able to determine the specific biological mechanisms that produced the change. Possibilities suggested by Clark et al. (1999) include the physiological effect of an increase in temperature, intra- and interspecific competition for prey, or a change in prey quality. The two species most dependent on pollock in the early 1990s (Pacific halibut and Steller sea lion) have both shown an exceptional biological response during the post-1977 period consistent with a reduction in carrying capacity (growth for Pacific halibut, survival for Steller sea lions). In contrast, the dominant predator on pollock in the Gulf of Alaska (arrowtooth flounder) has increased steadily in abundance over the same period and shows no evidence of decline in size at age. Given that arrowtooth flounder has a range of potential prey types to select from during periods of low pollock abundance (Fig. 1.31), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.34 and 1.35 suggest that recruitment remains bottom-up controlled even under the current estimates of high predation mortality, and may lead to strong year classes. However, top-down control seems to have increased on age 3+ pollock in recent years, perhaps as predators have attempted to maintain constant pollock consumption during a period of declining abundance. It is possible that natural mortality on adult pollock will remain high in the ecosystem in spite of decreasing pollock abundance.

## Ecosystem modeling

To examine the relative role of pollock natural versus fishing mortality within the GOA ecosystem, a set of simulations were run using the ECOPATH model shown in Fig. 1.28. Following the method outlined in Aydin et al. (2005), 20,000 model ecosystems were drawn from distributions of input parameters; these parameter sets were subjected to a selection/rejection criteria of species persistence resulting in approximately 500 ecosystems with nondegenerate parameters. These models, which did not begin in an equilibrium state, were projected forward using ECOSIM algorithms until equilibrium conditions were reached. For each group within the model, a perturbation experiment was run in all acceptable ecosystems by reducing the species survival (increasing mortality) by 10%, or by reducing gear effort by 10%, and reporting the percent change in equilibrium of all other species or fisheries catches. The resulting changes are reported as ranges across the generated ecosystems, with 50% and 95% confidence intervals representing the distribution of percent change in equilibrium states for each perturbation.

Fig. 1.36 shows the changes in other species when simulating a 10% decline in adult pollock survival (top graph), a 10% decline in juvenile pollock survival (middle graph), and a 10% decline in pollock trawl effort. Fisheries in these simulations are governed by constant fishing mortality rates rather than harvest control rules. Only the top 20 effects are shown in each graph; note the difference in scales between each graph.

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

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

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

Of species affecting pollock (Fig. 1.37), arrowtooth have the largest impact on adult pollock, while bottom-up processes (phytoplankton and zooplankton) have the largest impact on juvenile pollock. It is interesting to note that the link between juvenile and adult pollock is extremely uncertain (wide error bars) within these models.

Finally, of the four major predators of pollock (Fig 1.38), all are affected by bottom-up forcing; Steller sea lions, Pacific cod, and Pacific halibut are all affected by pollock perturbations, while pollock effects on arrowtooth are much more minor.

Pair-wise correlations in predator trends were examined for consistent patterns (Fig. 1.39). For each pair-wise comparison, we used the maximum number of years available. Time series for Steller sea lions and Pacific cod begin in mid 1970s, while other time series extend back to the early 1960s. We make no attempt to evaluate statistical significance (biomass trends are highly autocorrelated), and emphasize that correlation does not imply causation. If two populations are strongly correlated in time, there are many possible explanations: both populations are responding to similar forcing, one or other is causative agent, etc.

Pollock abundance, fishery catches, and Steller sea lions are positively correlated (Fig. 1.39). Since the harvest policy for pollock is modified fixed harvest rate strategy, a positive correlation between catch and abundance would be expected. The Steller sea lion trend is more strongly correlated with pollock abundance than pollock catches, but this correlation is based on data since 1976, and does not include earlier years of low pollock abundance. The only strong inverse correlation is between arrowtooth flounder and Steller sea lions. A strong positive correlation exists between Pacific cod and Pacific halibut, and, from the 1960s to the present, between Pacific halibut and arrowtooth flounder.

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

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

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Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The TAC for 2007 is for the area west of 140 ° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound (1650 t). Research catches are also reported.

| *Year* | *Foreign* | *Joint Venture* | *Domestic* | *Total* | *TAC* | *Research* |
|---|---|---|---|---|---|---|
| 1964 | 1,126 | | | 1,126 | --- | |
| 1965 | 2,749 | | | 2,749 | --- | |
| 1966 | 8,932 | | | 8,932 | --- | |
| 1967 | 6,276 | | | 6,276 | --- | |
| 1968 | 6,164 | | | 6,164 | --- | |
| 1969 | 17,553 | | | 17,553 | --- | |
| 1970 | 9,343 | | | 9,343 | --- | |
| 1971 | 9,458 | | | 9,458 | --- | |
| 1972 | 34,081 | | | 34,081 | --- | |
| 1973 | 36,836 | | | 36,836 | --- | |
| 1974 | 61,880 | | | 61,880 | --- | |
| 1975 | 59,512 | | | 59,512 | --- | |
| 1976 | 86,527 | | | 86,527 | --- | |
| 1977 | 117,834 | | 522 | 118,356 | 150,000 | 75 |
| 1978 | 96,392 | 34 | 509 | 96,935 | 168,800 | 100 |
| 1979 | 103,187 | 566 | 1,995 | 105,748 | 168,800 | 52 |
| 1980 | 112,997 | 1,136 | 489 | 114,622 | 168,800 | 229 |
| 1981 | 130,324 | 16,857 | 563 | 147,744 | 168,800 | 433 |
| 1982 | 92,612 | 73,917 | 2,211 | 168,740 | 168,800 | 110 |
| 1983 | 81,358 | 134,131 | 119 | 215,608 | 256,600 | 213 |
| 1984 | 99,260 | 207,104 | 1,037 | 307,401 | 416,600 | 311 |
| 1985 | 31,587 | 237,860 | 15,379 | 284,826 | 305,000 | 167 |
| 1986 | 114 | 62,591 | 25,103 | 87,809 | 116,000 | 1202 |
| 1987 | | 22,823 | 46,928 | 69,751 | 84,000 | 227 |
| 1988 | | 152 | 65,587 | 65,739 | 93,000 | 19 |
| 1989 | | | 78,392 | 78,392 | 72,200 | 73 |
| 1990 | | | 90,744 | 90,744 | 73,400 | 158 |
| 1991 | | | 100,488 | 100,488 | 103,400 | 16 |
| 1992 | | | 90,857 | 90,857 | 87,400 | 40 |
| 1993 | | | 108,908 | 108,908 | 114,400 | 116 |
| 1994 | | | 107,335 | 107,335 | 109,300 | 70 |
| 1995 | | | 72,618 | 72,618 | 65,360 | 44 |
| 1996 | | | 51,263 | 51,263 | 54,810 | 147 |
| 1997 | | | 90,130 | 90,130 | 79,980 | 76 |
| 1998 | | | 125,098 | 125,098 | 124,730 | 64 |
| 1999 | | | 95,590 | 95,590 | 94,580 | 35 |
| 2000 | | | 73,080 | 73,080 | 94,960 | 56 |
| 2001 | | | 72,076 | 72,076 | 90,690 | 77 |
| 2002 | | | 51,937 | 51,937 | 53,490 | 78 |
| 2003 | | | 50,666 | 50,666 | 49,590 | 128 |
| 2004 | | | 63,913 | 63,913 | 65,660 | 53 |
| 2005 | | | 80,876 | 80,876 | 86,100 | 72 |
| 2006 | | | 71,998 | 71,998 | 81,300 | 63 |
| 2007 | | | 52,120 | 52,120 | 63,800 | 47 |
| 2008 | | | | | 53,590 | 21 |
| *Average (1977-2007)* | | | | 106,818 | 123,560 | 147 |

Sources: 1964-85--Megrey (1988); 1986-90--Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission. Domestic catches in 1986-90 were adjusted for discard as described in Hollowed et al. (1991). 1991-2007 -- NMFS Alaska Regional Office.

Table 1.2. Incidental catch (t) of FMP species (upper table) and non-target species (bottom table) in the walleye pollock directed fishery in the Gulf of Alaska in 2003-2007. Incidental catch estimates include both retained and discarded catch. The "other" FMP species group in the upper table is broken down by species (or less inclusive species groupings) in the lower table.

| *Managed species/species group* | *2003* | *2004* | *2005* | *2006* | *2007* |
|---|---|---|---|---|---|
| Pollock | 49346.9 | 62740.9 | 80086.8 | 69758.1 | 50086.4 |
| Arrowtooth flounder | 667.6 | 1036.4 | 2259.8 | 2739.4 | 1627.2 |
| Pacific cod | 275.7 | 388.1 | 352.3 | 708.8 | 276.4 |
| Other (sharks, skates, squid, sculpin, octopus, but excluding skates in 2004) | 200.9 | 292.7 | 877.3 | 1787.1 | 637.5 |
| Flathead sole | 141.0 | 266.3 | 174.4 | 593.3 | 329.6 |
| Shortraker and rougheye rockfish | 118.8 | 44.6 | 32.6 | 94.7 | 82.1 |
| Pacific Ocean perch | 93.4 | 73.5 | 35.4 | 68.2 | 29.1 |
| Rex sole | 15.5 | 35.2 | 19.6 | 153.6 | 44.8 |
| Miscellaneous flatfish | 25.5 | 9.8 | 4.6 | 438.7 | 156.6 |
| Atka mackerel | 0.0 | 17.9 | 3.5 | 15.2 | 193.9 |
| Sablefish | 3.5 | 2.4 | 3.6 | 5.6 | 3.2 |
| Dover sole and Greenland turbot | 2.0 | 1.7 | 0.7 | 11.7 | 5.5 |
| Pelagic shelf rockfish complex | 2.1 | 1.5 | 2.0 | 9.0 | 6.4 |
| Unidentified skate |  | 1.8 | 1.1 | 5.0 | 9.1 |
| Big and longnose skate | 0.0 | 1.4 | 6.3 | 35.8 | 64.5 |
| Northern rockfish | 0.3 | 0.5 | 0.8 | 14.5 | 11.9 |
| Other rockfish complex | 0.6 | 0.1 | 1.3 | 2.5 | 2.0 |
| Thornyheads | 0.5 | 0.0 | 0.3 | 0.2 | 0.3 |
| *Percent non-pollock* | *3.0%* | *3.3%* | *4.5%* | *8.7%* | *6.5%* |

| *Non target species/species group* | *2003* | *2004* | *2005* | *2006* | *2007* |
|---|---|---|---|---|---|
| Squid | 62.5 | 139.3 | 620.5 | 1514.5 | 406.8 |
| Eulachon | 16.1 | 168.3 | 823.0 | 392.3 | 219.1 |
| Other osmerids | 350.2 | 66.0 | 176.0 | 165.6 | 49.1 |
| Pacific sleeper shark | 68.1 | 119.5 | 166.1 | 145.3 | 58.5 |
| Scyphozoan jellyfish | 43.6 | 22.4 | 210.9 | 67.7 | 23.7 |
| Grenadiers | 53.9 | 7.6 | 53.4 | 72.9 | 4.7 |
| Spiny dogfish | 6.6 | 7.8 | 13.7 | 49.3 | 46.8 |
| Other sharks | 7.3 | 11.1 | 30.8 | 40.9 | 13.6 |
| Miscellaneous fish | 41.8 | 13.8 | 16.4 | 37.2 | 23.8 |
| Salmon shark | 35.0 | 13.9 | 35.2 | 25.6 | 85.3 |
| Big skate | 0.0 | 0.8 | 1.7 | 23.0 | 24.0 |
| Longnose skate | 0.0 | 0.3 | 4.4 | 12.3 | 21.3 |
| Octopus | 0.0 | 0.0 | 0.1 | 3.4 | 1.5 |
| Pandalid shrimp | 0.5 | 1.5 | 7.3 | 3.1 | 1.9 |
| Other skates | 10.6 | 1.7 | 7.5 | 2.1 | 2.6 |
| Sea star | 0.2 | 0.0 | 1.1 | 2.0 | 4.5 |
| Sculpins | 0.9 | 0.1 | 0.0 | 2.4 | 21.8 |
| Sea anemone unidentified | 0.0 | 0.1 | 0.0 | 0.2 | 0.6 |
| Capelin | 6.2 | 68.0 | 2.7 | 0.1 | 0.0 |
| Stichaeidae | 0.0 | 0.1 | 0.0 | 0.1 | 0.3 |
| Lanternfishes (myctophidae) | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Invertebrate unidentified | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| Sea pens whips | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| Greenlings | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Misc crabs | 0.1 | 0.0 | 0.0 | 0.0 | 0.9 |
| Eelpouts | 0.0 | 1.3 | 0.1 | 0.0 | 0.0 |

Table 1.3. Bycatch of prohibited species for trawls in the Gulf of Alaska during 2003-2007 where pollock was the predominant species in the catch. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of fish.

| *Species/species group* | *2003* | *2004* | *2005* | *2006* | *2007* |
|---|---|---|---|---|---|
| Herring (t) | 13.130 | 281.038 | 12.119 | 8.784 | 16.554 |
| Halibut (t) | 9.943 | 14.783 | 2.363 | 68.278 | 78.975 |
| Bairdi Tanner Crab (nos.) | 9 | 1,284 | 6 | 84,005 | 19,393 |
| Red King Crab (nos.) | 0 | 58 | 0 | 0 | 0 |
| Chinook Salmon (nos.) | 4,641 | 13,423 | 27,780 | 15,932 | 34,414 |
| Non-chinook salmon (nos.) | 6,423 | 607 | 781 | 1,413 | 904 |

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 1997-2007 compiled by the Alaska Regional Office.

| *Year* | *Utilization* | *Shumagin 610* | *Chirikof 620* | *Kodiak 630* | *West Yakutat 640* | *Prince William Sound 649 (state waters)* | *Southeast and East Yakutat 650 & 659* | *Total* | *Percent discard* |
|---|---|---|---|---|---|---|---|---|---|
| 1998 | Retained | 28,815 | 48,530 | 38,753 | 6,316 | 1,655 | 8 | 124,077 | |
| | Discarded | 370 | 361 | 262 | 25 | 2 | 0 | 1,022 | 0.8% |
| | Total | 29,185 | 48,892 | 39,015 | 6,341 | 1,657 | 8 | 125,098 | |
| 1999 | Retained | 22,864 | 37,349 | 29,515 | 1,737 | 2,178 | 1 | 93,643 | |
| | Discarded | 521 | 784 | 578 | 22 | 39 | 3 | 1,947 | 2.0% |
| | Total | 23,385 | 38,133 | 30,093 | 1,759 | 2,216 | 4 | 95,590 | |
| 2000 | Retained | 21,380 | 11,314 | 35,078 | 1,917 | 1,181 | 0 | 70,870 | |
| | Discarded | 694 | 443 | 854 | 191 | 22 | 4 | 2,209 | 3.0% |
| | Total | 22,074 | 11,757 | 35,933 | 2,108 | 1,203 | 4 | 73,080 | |
| 2001 | Retained | 30,298 | 17,186 | 19,942 | 2,327 | 1,590 | 0 | 71,344 | |
| | Discarded | 173 | 205 | 330 | 24 | 0 | 0 | 732 | 1.0% |
| | Total | 30,471 | 17,391 | 20,272 | 2,351 | 1,590 | 0 | 72,076 | |
| 2002 | Retained | 17,046 | 20,106 | 10,615 | 1,808 | 1,216 | 0 | 50,791 | |
| | Discarded | 416 | 425 | 287 | 10 | 6 | 2 | 1,146 | 2.2% |
| | Total | 17,462 | 20,531 | 10,902 | 1,818 | 1,222 | 2 | 51,937 | |
| 2003 | Retained | 16,347 | 18,972 | 12,225 | 940 | 1,118 | 0 | 49,603 | |
| | Discarded | 161 | 658 | 210 | 2 | 31 | 0 | 1,063 | 2.1% |
| | Total | 16,508 | 19,630 | 12,435 | 943 | 1,149 | 0 | 50,666 | |
| 2004 | Retained | 23,226 | 24,221 | 14,023 | 215 | 1,100 | 0 | 62,785 | |
| | Discarded | 229 | 440 | 421 | 11 | 26 | 0 | 1,128 | 1.8% |
| | Total | 23,455 | 24,661 | 14,444 | 226 | 1,127 | 0 | 63,913 | |
| 2005 | Retained | 30,843 | 27,286 | 18,986 | 1,876 | 740 | 0 | 79,731 | |
| | Discarded | 130 | 617 | 344 | 4 | 50 | 0 | 1,144 | 1.4% |
| | Total | 30,973 | 27,904 | 19,329 | 1,880 | 790 | 0 | 80,876 | |
| 2006 | Retained | 24,536 | 26,409 | 16,127 | 1,570 | 1,475 | 0 | 70,116 | |
| | Discarded | 203 | 747 | 929 | 2 | 1 | 0 | 1,881 | 2.6% |
| | Total | 24,738 | 27,156 | 17,056 | 1,572 | 1,476 | 0 | 71,998 | |
| 2007 | Retained | 17,694 | 18,846 | 13,777 | 84 | 268 | 0 | 50,668 | |
| | Discarded | 261 | 514 | 668 | 2 | 5 | 1 | 1,451 | 2.8% |
| | Total | 17,955 | 19,360 | 14,445 | 86 | 273 | 1 | 52,120 | |
| *Average (1998-2007)* | | 23,621 | 25,541 | 21,392 | 1,908 | 1,270 | 2 | 73,735 | |

Table 1.5. Catch at age (000,000s) of walleye pollock in the Gulf of Alaska.

| | *Age* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *Total* |
| 1976 | 0.00 | 1.91 | 24.21 | 108.69 | 39.08 | 16.37 | 3.52 | 2.25 | 1.91 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 198.25 |
| 1977 | 0.01 | 2.76 | 7.06 | 23.83 | 89.68 | 30.35 | 8.33 | 2.13 | 1.79 | 0.67 | 0.44 | 0.10 | 0.02 | 0.00 | 0.00 | 167.17 |
| 1978 | 0.08 | 12.11 | 48.32 | 18.26 | 26.39 | 51.86 | 12.83 | 4.18 | 1.36 | 1.04 | 0.32 | 0.04 | 0.01 | 0.00 | 0.00 | 176.80 |
| 1979 | 0.00 | 2.53 | 48.83 | 76.37 | 14.15 | 10.13 | 16.70 | 5.02 | 1.27 | 0.60 | 0.16 | 0.04 | 0.00 | 0.00 | 0.00 | 175.81 |
| 1980 | 0.25 | 19.01 | 26.50 | 58.31 | 36.63 | 11.31 | 8.61 | 8.00 | 3.89 | 1.11 | 0.50 | 0.21 | 0.08 | 0.03 | 0.00 | 174.42 |
| 1981 | 0.14 | 2.59 | 31.55 | 73.91 | 47.97 | 20.29 | 4.87 | 4.83 | 2.73 | 0.26 | 0.03 | 0.02 | 0.00 | 0.00 | 0.00 | 189.19 |
| 1982 | 0.01 | 10.67 | 55.55 | 100.77 | 71.73 | 54.25 | 10.46 | 1.33 | 0.93 | 0.55 | 0.03 | 0.02 | 0.02 | 0.00 | 0.00 | 306.31 |
| 1983 | 0.00 | 3.64 | 20.64 | 110.03 | 137.31 | 67.41 | 42.01 | 7.38 | 1.24 | 0.06 | 0.28 | 0.07 | 0.00 | 0.00 | 0.00 | 390.07 |
| 1984 | 0.34 | 2.37 | 33.00 | 38.80 | 120.80 | 170.72 | 62.55 | 19.31 | 5.42 | 0.10 | 0.07 | 0.03 | 0.03 | 0.00 | 0.00 | 453.54 |
| 1985 | 0.04 | 12.74 | 5.53 | 33.22 | 42.22 | 86.02 | 128.95 | 41.19 | 10.84 | 2.20 | 0.70 | 0.00 | 0.00 | 0.00 | 0.00 | 363.64 |
| 1986 | 0.66 | 8.63 | 20.34 | 10.12 | 19.13 | 7.32 | 8.70 | 9.78 | 2.13 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 87.59 |
| 1987 | 0.00 | 8.83 | 14.03 | 8.00 | 6.89 | 6.44 | 7.18 | 4.19 | 9.95 | 1.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 67.44 |
| 1988 | 0.17 | 3.05 | 20.80 | 26.95 | 11.94 | 5.10 | 3.45 | 1.62 | 0.34 | 3.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 76.62 |
| 1989 | 1.08 | 0.27 | 1.47 | 19.39 | 28.89 | 16.96 | 8.09 | 4.76 | 1.69 | 1.10 | 3.62 | 0.43 | 0.01 | 0.00 | 0.00 | 87.77 |
| 1990 | 0.00 | 2.77 | 2.40 | 2.99 | 9.49 | 40.39 | 13.06 | 4.90 | 1.08 | 0.41 | 0.01 | 0.56 | 0.01 | 0.07 | 0.06 | 78.20 |
| 1991 | 0.00 | 0.59 | 9.68 | 5.45 | 2.85 | 5.33 | 26.67 | 3.12 | 16.10 | 0.87 | 5.65 | 0.42 | 2.19 | 0.21 | 0.77 | 79.90 |
| 1992 | 0.05 | 3.25 | 5.57 | 50.61 | 14.13 | 4.02 | 8.77 | 19.55 | 1.02 | 1.49 | 0.20 | 0.73 | 0.00 | 0.00 | 0.00 | 109.41 |
| 1993 | 0.02 | 1.97 | 9.43 | 21.83 | 47.46 | 15.72 | 6.55 | 6.29 | 8.52 | 1.81 | 2.07 | 0.49 | 0.72 | 0.13 | 0.24 | 123.25 |
| 1994 | 0.06 | 1.26 | 4.49 | 9.63 | 35.92 | 31.32 | 12.20 | 4.84 | 4.60 | 6.15 | 1.44 | 1.02 | 0.29 | 0.09 | 0.08 | 113.37 |
| 1995 | 0.00 | 0.06 | 1.01 | 5.11 | 11.52 | 25.83 | 12.09 | 2.99 | 1.52 | 2.00 | 1.82 | 0.19 | 0.28 | 0.03 | 0.15 | 64.61 |
| 1996 | 0.00 | 1.27 | 1.37 | 1.12 | 3.50 | 5.11 | 12.87 | 10.60 | 3.14 | 1.53 | 0.80 | 1.43 | 0.35 | 0.23 | 0.16 | 43.48 |
| 1997 | 0.00 | 1.07 | 6.72 | 3.77 | 3.28 | 6.60 | 10.09 | 16.52 | 12.24 | 5.06 | 2.06 | 0.79 | 0.54 | 0.17 | 0.02 | 68.92 |
| 1998 | 0.31 | 0.27 | 26.44 | 36.44 | 15.06 | 6.65 | 7.50 | 11.36 | 14.96 | 10.76 | 3.75 | 0.75 | 0.38 | 0.21 | 0.11 | 134.95 |
| 1999 | 0.00 | 0.42 | 2.21 | 22.74 | 36.10 | 8.99 | 6.89 | 3.72 | 5.71 | 7.27 | 4.01 | 1.07 | 0.56 | 0.12 | 0.10 | 99.92 |
| 2000 | 0.08 | 0.98 | 2.84 | 3.47 | 14.65 | 24.63 | 6.24 | 5.05 | 2.30 | 1.24 | 3.00 | 1.52 | 0.30 | 0.14 | 0.04 | 66.48 |
| 2001 | 0.74 | 10.13 | 6.59 | 7.34 | 9.42 | 12.59 | 14.44 | 4.73 | 2.70 | 1.35 | 0.65 | 0.83 | 0.61 | 0.00 | 0.04 | 72.14 |
| 2002 | 0.16 | 12.31 | 20.72 | 6.76 | 4.47 | 8.75 | 5.37 | 6.06 | 1.33 | 0.82 | 0.43 | 0.30 | 0.33 | 0.22 | 0.13 | 68.16 |
| 2003 | 0.14 | 2.69 | 21.47 | 22.95 | 5.33 | 3.25 | 4.66 | 3.76 | 2.58 | 0.54 | 0.19 | 0.04 | 0.09 | 0.04 | 0.05 | 67.79 |
| 2004 | 0.85 | 6.28 | 11.91 | 31.84 | 25.09 | 5.98 | 2.43 | 2.63 | 0.77 | 0.22 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 88.24 |
| 2005 | 1.14 | 1.21 | 5.33 | 6.85 | 41.25 | 21.73 | 6.10 | 0.74 | 0.91 | 0.35 | 0.18 | 0.13 | 0.00 | 0.00 | 0.00 | 85.91 |
| 2006 | 2.20 | 7.79 | 4.16 | 2.75 | 5.97 | 27.38 | 12.80 | 2.45 | 0.83 | 0.46 | 0.23 | 0.10 | 0.07 | 0.03 | 0.00 | 67.22 |
| 2007 | 0.82 | 18.89 | 7.46 | 2.51 | 2.31 | 3.58 | 10.19 | 6.70 | 1.59 | 0.29 | 0.23 | 0.09 | 0.00 | 0.00 | 0.01 | 54.68 |

Table 1.6. Number of aged and measured fish in the Gulf of Alaska pollock fishery used to estimate fishery age composition (1989-2007).

| | *Number aged* | | | *Number measured* | | |
|---|---|---|---|---|---|---|
| *Year* | *Males* | *Females* | *Total* | *Males* | *Females* | *Total* |
| 1989 | 882 | 892 | 1,774 | 6,454 | 6,456 | 12,910 |
| 1990 | 453 | 689 | 1,142 | 17,814 | 24,662 | 42,476 |
| 1991 | 1,146 | 1,322 | 2,468 | 23,946 | 39,467 | 63,413 |
| 1992 | 1,726 | 1,755 | 3,481 | 31,608 | 47,226 | 78,834 |
| 1993 | 926 | 949 | 1,875 | 28,035 | 31,306 | 59,341 |
| 1994 | 136 | 129 | 265 | 24,321 | 25,861 | 50,182 |
| 1995 | 499 | 544 | 1,043 | 10,591 | 10,869 | 21,460 |
| 1996 | 381 | 378 | 759 | 8,581 | 8,682 | 17,263 |
| 1997 | 496 | 486 | 982 | 8,750 | 8,808 | 17,558 |
| 1998 | 924 | 989 | 1,913 | 78,955 | 83,160 | 162,115 |
| 1999 | 980 | 1,115 | 2,095 | 16,304 | 17,964 | 34,268 |
| 2000 | 1,108 | 972 | 2,080 | 13,167 | 11,794 | 24,961 |
| 2001 | 1,063 | 1,025 | 2,088 | 13,731 | 13,552 | 27,283 |
| 2002 | 1,036 | 1,025 | 2,061 | 9,924 | 9,851 | 19,775 |
| 2003 | 1,091 | 1,119 | 2,210 | 8,375 | 8,220 | 16,595 |
| 2004 | 1,217 | 996 | 2,213 | 4,446 | 3,622 | 8,068 |
| 2005 | 1,065 | 968 | 2,033 | 6,837 | 6,005 | 12,842 |
| 2006 | 1,127 | 969 | 2,096 | 7,248 | 6,178 | 13,426 |
| 2007 | 998 | 1,064 | 2,062 | 4,504 | 5,064 | 9,568 |

Table 1.7. Biomass estimates (t) of walleye pollock from NMFS echo integration trawl surveys in Shelikof Strait, NMFS bottom trawl surveys (west of 140 W. long.), egg production surveys in Shelikof Strait, and ADF&G crab/groundfish trawl surveys. The biomass of age-1 fish is not included in Shelikof Strait EIT survey estimates in 1995, 2000, 2005 and 2008 (114,200, 57,300, 18,100 t and 19,090 t respectively). An adjustment of +1.05% was made to the AFSC bottom trawl biomass time series to account for unsurveyed biomass in Prince William Sound. In 2001, when the NMFS bottom trawl survey did not extend east of 147$^o$ W lon., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

| | *EIT Shelikof Strait survey* | | | | | |
|---|---|---|---|---|---|---|
| | *R/V Miller Freeman* | | *R/V Oscar* | *NMFS bottom trawl west of* | *Shelikof Strait egg* | *ADF&G crab/groundfish* |
| *Year* | *Biosonics* | *EK500* | *Dyson* | *140$^o$ W lon.* | *production* | *survey* |
| 1981 | 2,785,755 | | | | 1,788,908 | |
| 1982 | | | | | | |
| 1983 | 2,278,172 | | | | | |
| 1984 | 1,757,168 | | | 719,937 | | |
| 1985 | 1,175,823 | | | | 768,419 | |
| 1986 | 585,755 | | | | 375,907 | |
| 1987 | | | | 732,541 | 484,455 | |
| 1988 | 301,709 | | | | 504,418 | |
| 1989 | 290,461 | | | | 433,894 | 214,434 |
| 1990 | 374,731 | | | 825,592 | 381,475 | 114,451 |
| 1991 | 380,331 | | | | 370,000 | |
| 1992 | 580,000 | 713,429 | | | 616,000 | 127,359 |
| 1993 | 295,785 | 435,753 | | 754,390 | | 132,849 |
| 1994 | | 492,593 | | | | 103,420 |
| 1995 | | 649,401 | | | | |
| 1996 | | 777,172 | | 665,745 | | 122,477 |
| 1997 | | 583,017 | | | | 93,728 |
| 1998 | | 504,774 | | | | 81,215 |
| 1999 | | | | 607,147 | | 53,587 |
| 2000 | | 391,327 | | | | 102,871 |
| 2001 | | 432,749 | | 216,777 | | 86,967 |
| 2002 | | 256,743 | | | | 96,237 |
| 2003 | | 317,269 | | 399,690 | | 66,989 |
| 2004 | | 330,753 | | | | 99,358 |
| 2005 | | 338,038 | | 354,912 | | 79,089 |
| 2006 | | 293,609 | | | | 69,044 |
| 2007 | | 180,881 | | 282,253 | | 76,674 |
| 2008 | | | 188,942 | | | 83,476 |

Table 1.8. Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Gulf of Alaska bottom trawl survey. The number of measured pollock is approximate due to subsample expansions in the database, and the total number measured includes both sexed and unsexed fish.

| | | | | *Number aged* | | | *Number measured* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Year* | *No. of tows* | *No. of tows with pollock* | *Survey biomass CV* | *Males* | *Females* | *Total* | *Males* | *Females* | *Total* |
| 1984 | 929 | 536 | 0.14 | 1,119 | 1,394 | 2,513 | 8,979 | 13,286 | 24,064 |
| 1987 | 783 | 533 | 0.20 | 672 | 675 | 1,347 | 8,101 | 15,654 | 24,608 |
| 1990 | 708 | 549 | 0.12 | 503 | 560 | 1,063 | 13,955 | 18,967 | 35,355 |
| 1993 | 775 | 628 | 0.16 | 879 | 1,013 | 1,892 | 14,496 | 18,692 | 34,921 |
| 1996 | 807 | 668 | 0.15 | 509 | 560 | 1,069 | 14,653 | 15,961 | 34,526 |
| 1999 | 764 | 567 | 0.38 | 560 | 613 | 1,173 | 10,808 | 11,314 | 24,080 |
| 2001 | 489 | 302 | 0.30 | 395 | 519 | 914 | NA | NA | NA |
| 2003 | 807 | 508 | 0.12 | 514 | 589 | 1,103 | NA | NA | NA |
| 2005 | 839 | 516 | 0.15 | 639 | 868 | 1,507 | NA | NA | NA |
| 2007 | 820 | 554 | 0.14 | 646 | 675 | 1,321 | NA | NA | NA |

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

| *Year* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1984 | 0.93 | 10.02 | 67.81 | 155.78 | 261.17 | 474.57 | 145.10 | 24.80 | 16.59 | 1.66 | 0.21 | 1.32 | 0.00 | 0.00 | 0.00 | 1159.96 |
| 1987 | 25.45 | 363.02 | 172.99 | 138.97 | 91.13 | 168.27 | 78.14 | 43.99 | 175.39 | 22.41 | 7.81 | 3.51 | 1.82 | 0.00 | 0.00 | 1292.88 |
| 1989 | 208.88 | 63.49 | 47.56 | 243.15 | 301.09 | 104.43 | 54.47 | 28.39 | 26.14 | 5.98 | 10.66 | 0.00 | 0.00 | 0.00 | 0.00 | 1094.23 |
| 1990 | 64.04 | 251.21 | 48.34 | 46.68 | 209.77 | 240.82 | 74.41 | 110.41 | 26.13 | 34.23 | 5.03 | 27.73 | 5.70 | 1.07 | 1.63 | 1147.19 |
| 1993 | 139.31 | 71.15 | 50.94 | 182.96 | 267.12 | 91.51 | 33.12 | 68.98 | 76.62 | 26.36 | 11.85 | 6.29 | 3.82 | 1.82 | 4.41 | 1036.25 |
| 1996 | 194.23 | 128.79 | 17.30 | 26.13 | 50.04 | 63.18 | 174.41 | 87.62 | 52.37 | 27.73 | 12.10 | 18.46 | 7.16 | 9.68 | 19.70 | 888.90 |
| 1999 | 109.73 | 19.17 | 20.94 | 66.76 | 118.94 | 56.80 | 59.04 | 47.71 | 56.40 | 81.97 | 65.18 | 9.67 | 8.28 | 2.50 | 0.76 | 723.85 |
| 2001 | 412.83 | 117.03 | 34.42 | 33.39 | 25.05 | 33.45 | 37.01 | 8.20 | 5.74 | 0.59 | 4.48 | 2.52 | 1.28 | 0.00 | 0.18 | 716.19 |
| 2003 | 75.46 | 18.40 | 128.41 | 140.74 | 73.27 | 44.72 | 36.10 | 25.27 | 14.51 | 8.61 | 3.23 | 1.79 | 1.26 | 0.00 | 0.00 | 571.77 |
| 2005 | 270.37 | 33.72 | 34.41 | 35.86 | 91.78 | 78.82 | 45.24 | 20.86 | 9.61 | 9.98 | 4.81 | 0.57 | 0.64 | 0.00 | 0.00 | 636.68 |
| 2007 | 174.01 | 95.96 | 88.59 | 37.11 | 19.23 | 18.90 | 54.98 | 31.11 | 6.64 | 3.04 | 2.78 | 1.00 | 1.13 | 0.00 | 0.00 | 534.48 |

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

| *Year* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 77.65 | 3,481.18 | 1,510.77 | 769.16 | 2,785.91 | 1,051.92 | 209.93 | 128.52 | 79.43 | 25.19 | 1.73 | 0.00 | 0.00 | 0.00 | 0.00 | 10,121.37 |
| 1983 | 1.21 | 901.77 | 380.19 | 1,296.79 | 1,170.81 | 698.13 | 598.78 | 131.54 | 14.48 | 11.61 | 3.92 | 1.71 | 0.00 | 0.00 | 0.00 | 5,210.93 |
| 1984 | 61.65 | 58.25 | 324.49 | 141.66 | 635.04 | 988.21 | 449.62 | 224.35 | 41.03 | 2.74 | 0.00 | 1.02 | 0.00 | 0.00 | 0.00 | 2,928.07 |
| 1985 | 2,091.74 | 544.44 | 122.69 | 314.77 | 180.53 | 347.17 | 439.31 | 166.68 | 42.72 | 5.56 | 1.77 | 1.29 | 0.00 | 0.00 | 0.00 | 4,258.67 |
| 1986 | 575.36 | 2,114.83 | 183.62 | 45.63 | 75.36 | 49.34 | 86.15 | 149.36 | 60.22 | 10.62 | 1.29 | 0.00 | 0.00 | 0.00 | 0.00 | 3,351.78 |
| 1987 | 7.5% | 25.5% | 55.8% | 2.9% | 1.7% | 1.2% | 1.6% | 1.2% | 2.1% | 0.4% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| 1988 | 17.44 | 109.93 | 694.32 | 322.11 | 77.57 | 16.99 | 5.70 | 5.60 | 3.98 | 8.96 | 1.78 | 1.84 | 0.20 | 0.00 | 0.00 | 1,266.41 |
| 1989 | 399.48 | 89.52 | 90.01 | 222.05 | 248.69 | 39.41 | 11.75 | 3.83 | 1.89 | 0.55 | 10.66 | 1.42 | 0.00 | 0.00 | 0.00 | 1,119.25 |
| 1990 | 49.14 | 1,210.17 | 71.69 | 63.37 | 115.92 | 180.06 | 46.33 | 22.44 | 8.20 | 8.21 | 0.93 | 3.08 | 1.51 | 0.79 | 0.24 | 1,782.08 |
| 1991 | 21.98 | 173.65 | 549.90 | 48.11 | 64.87 | 69.60 | 116.32 | 23.65 | 29.43 | 2.23 | 4.29 | 0.92 | 4.38 | 0.00 | 0.00 | 1,109.32 |
| 1992 | 228.03 | 33.69 | 73.54 | 188.10 | 367.99 | 84.11 | 84.99 | 171.18 | 32.70 | 56.35 | 2.30 | 14.67 | 0.90 | 0.30 | 0.00 | 1,338.85 |
| 1993 | 63.29 | 76.08 | 37.05 | 72.39 | 232.79 | 126.19 | 26.77 | 35.63 | 38.72 | 16.12 | 7.77 | 2.60 | 2.19 | 0.49 | 1.51 | 739.61 |
| 1994 | 185.98 | 35.77 | 49.30 | 31.75 | 155.03 | 83.58 | 42.48 | 27.23 | 44.45 | 48.46 | 14.79 | 6.65 | 1.12 | 2.34 | 0.57 | 729.49 |
| 1995 | 10,689.87 | 510.37 | 79.37 | 77.70 | 103.33 | 245.23 | 121.72 | 53.57 | 16.63 | 10.72 | 14.57 | 5.81 | 2.12 | 0.44 | 0.00 | 11,931.45 |
| 1996 | 56.14 | 3,307.21 | 118.94 | 25.12 | 53.99 | 71.03 | 201.05 | 118.52 | 39.80 | 13.01 | 11.32 | 5.32 | 2.52 | 0.03 | 0.38 | 4,024.36 |
| 1997 | 70.37 | 183.14 | 1,246.55 | 80.06 | 18.42 | 44.04 | 51.73 | 97.55 | 52.73 | 14.29 | 2.40 | 3.05 | 0.93 | 0.46 | 0.00 | 1,865.72 |
| 1998 | 395.47 | 88.54 | 125.57 | 474.36 | 136.12 | 14.22 | 31.93 | 36.30 | 74.08 | 25.90 | 14.30 | 6.88 | 0.27 | 0.56 | 0.56 | 1,425.05 |
| 2000 | 4,484.41 | 755.03 | 216.52 | 15.83 | 67.19 | 131.64 | 16.82 | 12.61 | 9.87 | 7.84 | 13.87 | 6.88 | 1.88 | 1.06 | 0.00 | 5,741.46 |
| 2001 | 288.93 | 4,103.95 | 351.74 | 61.02 | 41.55 | 22.99 | 34.63 | 13.07 | 6.20 | 2.67 | 1.20 | 1.91 | 0.69 | 0.50 | 0.24 | 4,931.27 |
| 2002 | 8.11 | 162.61 | 1,107.17 | 96.58 | 16.25 | 16.14 | 7.70 | 6.79 | 1.46 | 0.66 | 0.35 | 0.34 | 0.15 | 0.13 | 0.00 | 1,424.45 |
| 2003 | 51.19 | 89.58 | 207.69 | 802.46 | 56.58 | 7.69 | 4.14 | 1.58 | 1.46 | 0.85 | 0.28 | 0.00 | 0.10 | 0.00 | 0.00 | 1,223.60 |
| 2004 | 52.58 | 93.94 | 57.58 | 159.62 | 356.33 | 48.78 | 2.67 | 3.42 | 3.32 | 0.52 | 0.42 | 0.00 | 0.66 | 0.00 | 0.00 | 779.84 |
| 2005 | 1,626.13 | 157.49 | 55.54 | 34.63 | 172.74 | 162.40 | 36.02 | 3.61 | 2.39 | 0.00 | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 2,251.71 |
| 2006 | 161.69 | 835.96 | 40.75 | 11.54 | 17.42 | 55.98 | 74.97 | 32.25 | 6.90 | 0.83 | 0.75 | 0.53 | 0.00 | 0.00 | 0.00 | 1,239.57 |
| 2007 | 53.54 | 231.73 | 174.88 | 29.66 | 10.14 | 17.27 | 34.39 | 20.85 | 1.54 | 1.05 | 0.69 | 0.00 | 0.00 | 0.00 | 0.00 | 575.74 |
| 2008 | 1,368.02 | 391.20 | 249.56 | 53.18 | 12.01 | 2.16 | 4.07 | 10.66 | 6.69 | 2.01 | 0.53 | 0.00 | 0.00 | 0.00 | 0.00 | 2,100.10 |

Table 1.11. Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Shelikof Strait EIT survey. Survey CVs are reported for 1981-91, while relative estimation error using a geostatistical method are reported for 1992-2008.

| | *No. of midwater* | *No. of bottom trawl* | *Survey biomass* | *Number aged* | | | *Number measured* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Year* | *tows* | *tows* | *CV* | *Males* | *Females* | *Total* | *Males* | *Females* | *Total* |
| 1981 | 36 | 18 | 0.12 | 1,921 | 1,815 | 3,736 | NA | NA | NA |
| 1983 | 47 | 1 | 0.16 | 1,642 | 1,103 | 2,745 | NA | NA | NA |
| 1984 | 42 | 0 | 0.18 | 1,739 | 1,622 | 3,361 | NA | NA | NA |
| 1985 | 57 | 0 | 0.14 | 1,055 | 1,187 | 2,242 | NA | NA | NA |
| 1986 | 38 | 1 | 0.22 | 642 | 618 | 1,260 | NA | NA | NA |
| 1987 | 27 | 0 | --- | 557 | 643 | 1,200 | NA | NA | NA |
| 1988 | 26 | 0 | 0.17 | 537 | 464 | 1,001 | NA | NA | NA |
| 1989 | 21 | 0 | 0.10 | 757 | 796 | 1,553 | NA | NA | NA |
| 1990 | 25 | 16 | 0.17 | 988 | 1,117 | 2,105 | NA | NA | NA |
| 1991 | 16 | 2 | 0.35 | 478 | 628 | 1,106 | NA | NA | NA |
| 1992 | 17 | 8 | 0.04 | 784 | 765 | 1,549 | NA | NA | NA |
| 1993 | 22 | 2 | 0.05 | 583 | 624 | 1,207 | NA | NA | NA |
| 1994 | 42 | 12 | 0.05 | 554 | 633 | 1,187 | NA | NA | NA |
| 1995 | 22 | 3 | 0.05 | 599 | 575 | 1,174 | NA | NA | NA |
| 1996 | 30 | 8 | 0.04 | 724 | 775 | 1,499 | NA | NA | NA |
| 1997 | 16 | 14 | 0.04 | 682 | 853 | 1,535 | NA | NA | NA |
| 1998 | 22 | 9 | 0.04 | 863 | 784 | 1,647 | NA | NA | NA |
| 2000 | 31 | 0 | 0.05 | 430 | 370 | 800 | NA | NA | NA |
| 2001 | 15 | 9 | 0.05 | 314 | 378 | 692 | NA | NA | NA |
| 2002 | 18 | 1 | 0.07 | 278 | 326 | 604 | NA | NA | NA |
| 2003 | 17 | 2 | 0.05 | 294 | 322 | 616 | NA | NA | NA |
| 2004 | 13 | 2 | 0.09 | 422 | 315 | 737 | NA | NA | NA |
| 2005 | 22 | 1 | 0.04 | 543 | 335 | 878 | NA | NA | NA |
| 2006 | 17 | 2 | 0.04 | 295 | 487 | 782 | NA | NA | NA |
| 2007 | 9 | 1 | 0.06 | NA | NA | NA | NA | NA | NA |
| 2008 | 10 | 2 | 0.06 | 172 | 248 | 420 | NA | NA | NA |

Table 1.12. Estimates of pollock biomass obtained from GLM model predictions of pollock CPUE and INPFC area expansions. Biomass estimates were multiplied by the von Szalay and Brown (2001) FPC of 3.84 for comparison to the NMFS triennial trawl survey biomass estimates. Coefficients of variation do not reflect the variance of the FPC estimate.

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

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

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

Table 1.13. Predictions of Gulf of Alaska pollock year-class strength. The FOCI prediction is the prediction of year-class strength made in the natal year of the year class, and was derived from environmental indices, larval surveys, and the time series characteristics of pollock recruitment. The McKelvey index is the estimated abundance of 9-16 cm pollock from the Shelikof Strait EIT survey.

| *Year class* | *FOCI prediction* | *Year of EIT survey* | *McKelvey index* | *Rank abundance of McKelvey index* |
|---|---|---|---|---|
| 1980 | | 1981 | 0.078 | 13 |
| 1981 | | | | |
| 1982 | | 1983 | 0.001 | 25 |
| 1983 | | 1984 | 0.062 | 16 |
| 1984 | | 1985 | 2.092 | 3 |
| 1985 | | 1986 | 0.579 | 6 |
| 1986 | | | | |
| 1987 | | 1988 | 0.017 | 23 |
| 1988 | | 1989 | 0.399 | 7 |
| 1989 | | 1990 | 0.049 | 21 |
| 1990 | | 1991 | 0.022 | 22 |
| 1991 | | 1992 | 0.228 | 10 |
| 1992 | Strong | 1993 | 0.063 | 15 |
| 1993 | Average | 1994 | 0.186 | 11 |
| 1994 | Average | 1995 | 10.688 | 1 |
| 1995 | Average-Strong | 1996 | 0.061 | 17 |
| 1996 | Average | 1997 | 0.070 | 14 |
| 1997 | Average | 1998 | 0.395 | 8 |
| 1998 | Average | | | |
| 1999 | Average | 2000 | 4.484 | 2 |
| 2000 | Average | 2001 | 0.291 | 9 |
| 2001 | Average-Strong | 2002 | 0.008 | 24 |
| 2002 | Average | 2003 | 0.051 | 20 |
| 2003 | Average | 2004 | 0.053 | 19 |
| 2004 | Average | 2005 | 1.626 | 4 |
| 2005 | Average | 2006 | 0.162 | 12 |
| 2006 | Average | 2007 | 0.054 | 18 |
| 2007 | Average | 2008 | 1.368 | 5 |
| 2008 | Average | | --- | --- |

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

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

Table 1.15. Proportion mature at age for female pollock based on maturity stage data collected during winter EIT surveys in the Gulf of Alaska (1983-2008).

| Year | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ | Sample size |
|---|---|---|---|---|---|---|---|---|---|---|
| 1983 | 0.000 | 0.165 | 0.798 | 0.960 | 0.974 | 0.983 | 0.943 | 1.000 | 1.000 | 1333 |
| 1984 | 0.000 | 0.145 | 0.688 | 0.959 | 0.990 | 1.000 | 0.992 | 1.000 | 1.000 | 1621 |
| 1985 | 0.015 | 0.051 | 0.424 | 0.520 | 0.929 | 0.992 | 0.992 | 1.000 | 1.000 | 1183 |
| 1986 | 0.000 | 0.021 | 0.105 | 0.849 | 0.902 | 0.959 | 1.000 | 1.000 | 1.000 | 618 |
| 1987 | 0.000 | 0.012 | 0.106 | 0.340 | 0.769 | 0.885 | 0.950 | 0.991 | 1.000 | 638 |
| 1988 | 0.000 | 0.000 | 0.209 | 0.176 | 0.606 | 0.667 | 1.000 | 0.857 | 0.964 | 464 |
| 1989 | 0.000 | 0.000 | 0.297 | 0.442 | 0.710 | 0.919 | 1.000 | 1.000 | 1.000 | 796 |
| 1990 | 0.000 | 0.000 | 0.192 | 0.674 | 0.755 | 0.910 | 0.945 | 0.967 | 0.996 | 1844 |
| 1991 | 0.000 | 0.000 | 0.111 | 0.082 | 0.567 | 0.802 | 0.864 | 0.978 | 1.000 | 628 |
| 1992 | 0.000 | 0.000 | 0.040 | 0.069 | 0.774 | 0.981 | 0.990 | 1.000 | 0.983 | 765 |
| 1993 | 0.000 | 0.016 | 0.120 | 0.465 | 0.429 | 0.804 | 0.968 | 1.000 | 0.985 | 624 |
| 1994 | 0.000 | 0.007 | 0.422 | 0.931 | 0.941 | 0.891 | 0.974 | 1.000 | 1.000 | 872 |
| 1995 | 0.000 | 0.000 | 0.153 | 0.716 | 0.967 | 0.978 | 0.921 | 0.917 | 0.977 | 805 |
| 1996 | 0.000 | 0.000 | 0.036 | 0.717 | 0.918 | 0.975 | 0.963 | 1.000 | 0.957 | 763 |
| 1997 | 0.000 | 0.000 | 0.241 | 0.760 | 1.000 | 1.000 | 0.996 | 1.000 | 1.000 | 843 |
| 1998 | 0.000 | 0.000 | 0.065 | 0.203 | 0.833 | 0.964 | 1.000 | 1.000 | 0.989 | 757 |
| 2000 | 0.000 | 0.012 | 0.125 | 0.632 | 0.780 | 0.579 | 0.846 | 1.000 | 0.923 | 356 |
| 2001 | 0.000 | 0.000 | 0.289 | 0.308 | 0.825 | 0.945 | 0.967 | 0.929 | 1.000 | 374 |
| 2002 | 0.000 | 0.026 | 0.259 | 0.750 | 0.933 | 0.974 | 1.000 | 1.000 | 1.000 | 499 |
| 2003 | 0.000 | 0.029 | 0.192 | 0.387 | 0.529 | 0.909 | 0.750 | 1.000 | 1.000 | 301 |
| 2004 | 0.000 | 0.000 | 0.558 | 0.680 | 0.745 | 0.667 | 1.000 | 1.000 | 1.000 | 444 |
| 2005 | 0.000 | 0.000 | 0.706 | 0.882 | 0.873 | 0.941 | 1.000 | 1.000 | 1.000 | 321 |
| 2006 | 0.000 | 0.000 | 0.043 | 0.483 | 0.947 | 0.951 | 0.986 | 1.000 | 1.000 | 476 |
| 2007 | 0.000 | 0.000 | 0.333 | 0.667 | 0.951 | 0.986 | 0.983 | 1.000 | 1.000 | 313 |
| 2008 | 0.000 | 0.000 | 0.102 | 0.241 | 0.833 | 1.000 | 0.968 | 0.952 | 1.000 | 240 |
| *Average* | | | | | | | | | | |
| *All years* | 0.001 | 0.019 | 0.265 | 0.556 | 0.819 | 0.907 | 0.960 | 0.984 | 0.991 | |
| *1998-2008* | 0.000 | 0.007 | 0.267 | 0.523 | 0.825 | 0.892 | 0.950 | 0.988 | 0.991 | |
| *2003-2007* | 0.000 | 0.000 | 0.348 | 0.591 | 0.870 | 0.909 | 0.987 | 0.990 | 1.000 | |

Table 1.16. Estimated selectivity at age for Gulf of Alaska pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions with random walk process error for the fishery logistic parameters. Fishery selectivity at age reported below is the average of the annual selectivity for the indicated time period, rescaled so that the maximum is one.

| *Age* | *POP fishery (1961-71)* | *Foreign (1972-84)* | *Historical domestic (1985-2001)* | *Recent domestic (2002-2007)* | *EIT survey* | *Bottom trawl survey* | *ADF&G bottom trawl* | *400-mesh eastern trawl 1961-82* |
|---|---|---|---|---|---|---|---|---|
| 2 | 0.001 | 0.041 | 0.040 | 0.204 | 0.993 | 0.220 | 0.058 | 0.120 |
| 3 | 0.021 | 0.263 | 0.146 | 0.402 | 0.983 | 0.335 | 0.137 | 0.382 |
| 4 | 0.413 | 0.755 | 0.401 | 0.648 | 0.963 | 0.500 | 0.293 | 0.737 |
| 5 | 1.000 | 1.000 | 0.728 | 0.851 | 0.919 | 0.713 | 0.520 | 0.928 |
| 6 | 0.945 | 0.919 | 0.938 | 0.965 | 0.833 | 0.921 | 0.740 | 0.983 |
| 7 | 0.698 | 0.668 | 1.000 | 1.000 | 0.687 | 1.000 | 0.885 | 0.996 |
| 8 | 0.361 | 0.340 | 0.935 | 0.906 | 0.490 | 0.876 | 0.957 | 0.999 |
| 9 | 0.133 | 0.127 | 0.715 | 0.517 | 0.297 | 0.640 | 0.988 | 1.000 |
| 10 | 0.041 | 0.042 | 0.308 | 0.127 | 0.156 | 0.420 | 1.000 | 1.000 |

Table 1.17. Total estimated abundance at age (numbers in 000,000s) of Gulf of Alaska pollock from the age-structured assessment model.

| | *Age* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
| 1961 | 375 | 198 | 121 | 75 | 56 | 39 | 28 | 22 | 17 |
| 1962 | 417 | 278 | 147 | 90 | 55 | 41 | 29 | 21 | 28 |
| 1963 | 445 | 309 | 206 | 109 | 66 | 41 | 30 | 21 | 37 |
| 1964 | 99 | 330 | 229 | 153 | 80 | 49 | 30 | 23 | 43 |
| 1965 | 259 | 74 | 244 | 169 | 112 | 59 | 36 | 22 | 48 |
| 1966 | 137 | 192 | 55 | 180 | 124 | 82 | 44 | 27 | 53 |
| 1967 | 343 | 102 | 142 | 40 | 128 | 88 | 59 | 32 | 59 |
| 1968 | 406 | 254 | 75 | 104 | 28 | 91 | 64 | 43 | 67 |
| 1969 | 708 | 301 | 188 | 55 | 73 | 20 | 66 | 46 | 81 |
| 1970 | 335 | 525 | 222 | 131 | 35 | 48 | 14 | 46 | 94 |
| 1971 | 727 | 248 | 388 | 160 | 91 | 25 | 34 | 10 | 103 |
| 1972 | 1,364 | 538 | 184 | 282 | 114 | 65 | 18 | 25 | 83 |
| 1973 | 1,038 | 1,010 | 398 | 131 | 190 | 77 | 45 | 13 | 80 |
| 1974 | 3,402 | 769 | 747 | 284 | 87 | 128 | 53 | 32 | 68 |
| 1975 | 694 | 2,520 | 568 | 528 | 183 | 57 | 87 | 38 | 74 |
| 1976 | 440 | 514 | 1,844 | 398 | 367 | 128 | 41 | 63 | 82 |
| 1977 | 2,043 | 325 | 371 | 1,280 | 276 | 256 | 91 | 29 | 107 |
| 1978 | 2,820 | 1,511 | 236 | 256 | 873 | 190 | 180 | 66 | 100 |
| 1979 | 2,591 | 2,082 | 1,086 | 163 | 175 | 604 | 134 | 130 | 122 |
| 1980 | 3,636 | 1,915 | 1,508 | 750 | 111 | 121 | 427 | 97 | 185 |
| 1981 | 1,840 | 2,684 | 1,389 | 1,058 | 520 | 77 | 85 | 307 | 207 |
| 1982 | 446 | 1,360 | 1,953 | 971 | 727 | 358 | 54 | 61 | 377 |
| 1983 | 504 | 327 | 970 | 1,358 | 672 | 506 | 254 | 39 | 324 |
| 1984 | 210 | 370 | 232 | 656 | 906 | 451 | 350 | 183 | 269 |
| 1985 | 482 | 153 | 255 | 146 | 396 | 548 | 288 | 244 | 332 |
| 1986 | 1,629 | 351 | 106 | 157 | 81 | 214 | 308 | 185 | 420 |
| 1987 | 553 | 1,190 | 247 | 69 | 98 | 51 | 137 | 214 | 447 |
| 1988 | 160 | 407 | 858 | 171 | 46 | 64 | 33 | 92 | 482 |
| 1989 | 375 | 118 | 295 | 602 | 115 | 30 | 42 | 22 | 420 |
| 1990 | 1,617 | 277 | 86 | 211 | 409 | 75 | 19 | 27 | 323 |
| 1991 | 1,007 | 1,195 | 203 | 62 | 144 | 262 | 46 | 12 | 256 |
| 1992 | 400 | 744 | 877 | 146 | 43 | 95 | 169 | 29 | 177 |
| 1993 | 237 | 295 | 540 | 612 | 97 | 28 | 61 | 109 | 148 |
| 1994 | 142 | 174 | 214 | 377 | 406 | 62 | 18 | 39 | 177 |
| 1995 | 215 | 105 | 127 | 150 | 254 | 267 | 41 | 11 | 149 |
| 1996 | 830 | 159 | 77 | 90 | 104 | 172 | 180 | 27 | 114 |
| 1997 | 394 | 614 | 117 | 56 | 64 | 71 | 118 | 123 | 99 |
| 1998 | 167 | 291 | 448 | 82 | 37 | 40 | 44 | 73 | 143 |
| 1999 | 151 | 122 | 203 | 289 | 49 | 21 | 23 | 25 | 133 |
| 2000 | 206 | 111 | 87 | 136 | 176 | 28 | 12 | 13 | 100 |
| 2001 | 821 | 152 | 81 | 61 | 87 | 106 | 16 | 7 | 76 |
| 2002 | 745 | 599 | 108 | 54 | 38 | 53 | 63 | 10 | 56 |
| 2003 | 112 | 542 | 424 | 73 | 35 | 24 | 33 | 40 | 46 |
| 2004 | 93 | 81 | 382 | 289 | 48 | 23 | 16 | 22 | 61 |
| 2005 | 83 | 66 | 55 | 252 | 187 | 31 | 15 | 10 | 60 |
| 2006 | 307 | 59 | 45 | 35 | 156 | 113 | 19 | 9 | 51 |
| 2007 | 618 | 220 | 41 | 29 | 22 | 95 | 69 | 12 | 43 |
| 2008 | 600 | 443 | 154 | 27 | 19 | 14 | 61 | 45 | 40 |
| *Average* | 776 | 567 | 407 | 282 | 191 | 127 | 85 | 58 | 147 |

Table 1.18. Estimates of population biomass, recruitment, and harvest of Gulf of Alaska pollock from the age-structured assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

| | | | | | | *2007 Assessment results* | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Year* | *3+ total biomass (1,000 t)* | *Female spawn. biom. (1,000 t)* | *Age 2 recruits (million)* | *Catch (t)* | *Harvest rate* | *3+ total biomass* | *Female spawn. biom.* | *Age 2 recruits* | *Harvest rate* |
| 1977 | 2,145 | 502 | 2,043 | 118,356 | 6% | 2,170 | 510 | 2,029 | 5% |
| 1978 | 2,319 | 545 | 2,820 | 96,935 | 4% | 2,336 | 551 | 2,785 | 4% |
| 1979 | 2,840 | 555 | 2,591 | 105,748 | 4% | 2,842 | 561 | 2,562 | 4% |
| 1980 | 3,333 | 613 | 3,636 | 114,622 | 3% | 3,322 | 620 | 3,606 | 3% |
| 1981 | 4,020 | 502 | 1,840 | 147,744 | 4% | 3,998 | 505 | 1,830 | 4% |
| 1982 | 4,157 | 580 | 446 | 168,740 | 4% | 4,131 | 579 | 444 | 4% |
| 1983 | 3,515 | 709 | 504 | 215,608 | 6% | 3,491 | 707 | 504 | 6% |
| 1984 | 2,846 | 745 | 210 | 307,401 | 11% | 2,826 | 738 | 211 | 11% |
| 1985 | 2,114 | 675 | 482 | 284,826 | 13% | 2,097 | 667 | 487 | 14% |
| 1986 | 1,709 | 551 | 1,629 | 87,809 | 5% | 1,695 | 544 | 1,647 | 5% |
| 1987 | 1,763 | 463 | 553 | 69,751 | 4% | 1,757 | 458 | 561 | 4% |
| 1988 | 1,659 | 419 | 160 | 65,739 | 4% | 1,658 | 416 | 163 | 4% |
| 1989 | 1,502 | 404 | 375 | 78,392 | 5% | 1,504 | 403 | 380 | 5% |
| 1990 | 1,277 | 362 | 1,617 | 90,744 | 7% | 1,282 | 362 | 1,633 | 7% |
| 1991 | 1,388 | 343 | 1,007 | 100,488 | 7% | 1,397 | 343 | 1,021 | 7% |
| 1992 | 1,696 | 302 | 400 | 90,857 | 5% | 1,713 | 304 | 408 | 5% |
| 1993 | 1,535 | 335 | 237 | 108,908 | 7% | 1,554 | 340 | 243 | 7% |
| 1994 | 1,284 | 383 | 142 | 107,335 | 8% | 1,304 | 388 | 148 | 8% |
| 1995 | 1,078 | 349 | 215 | 72,618 | 7% | 1,097 | 354 | 225 | 7% |
| 1996 | 891 | 314 | 830 | 51,263 | 6% | 909 | 319 | 873 | 6% |
| 1997 | 902 | 270 | 394 | 90,130 | 10% | 929 | 276 | 418 | 10% |
| 1998 | 820 | 204 | 167 | 125,098 | 15% | 854 | 211 | 179 | 15% |
| 1999 | 659 | 185 | 151 | 95,590 | 15% | 694 | 193 | 164 | 14% |
| 2000 | 577 | 172 | 206 | 73,080 | 13% | 615 | 182 | 225 | 12% |
| 2001 | 542 | 167 | 821 | 72,076 | 13% | 585 | 179 | 874 | 12% |
| 2002 | 668 | 139 | 745 | 51,937 | 8% | 724 | 152 | 773 | 7% |
| 2003 | 804 | 130 | 112 | 50,666 | 6% | 863 | 144 | 117 | 6% |
| 2004 | 706 | 141 | 93 | 63,913 | 9% | 761 | 156 | 107 | 8% |
| 2005 | 589 | 178 | 83 | 80,876 | 14% | 641 | 196 | 120 | 13% |
| 2006 | 503 | 185 | 307 | 71,998 | 14% | 498 | 204 | 676 | 14% |
| 2007 | 481 | 164 | 618 | 52,120 | 11% | 558 | 163 | 629 | 9% |
| 2008 | 537 | 161 | 600 | | | | | | |
| *Average* | | | | | | | | | |
| *1977-2008* | 1,589 | | 814 | 106,818 | 8% | 1,639 | 378 | 840 | 8% |
| *1979-2007* | | | 709 | | | | | | |

Table 1.19. Gulf of Alaska pollock life history and fishery vectors used to estimate spawning biomass per recruit ($F_{SPR}$) harvest rates. Population weight at age is the average for the bottom trawl survey in 2003-2007. Proportion mature females is the average for 1983-2008 from winter EIT survey specimen data. Spawning weight at age is the average for the Shelikof Strait EIT survey in 2004-2008.

| | | | *Weight at age (kg)* | | | |
|---|---|---|---|---|---|---|
| *Age* | *Natural mortality* | *Fishery selectivity (Avg. 2003-2007)* | *Spawning (March 15)* | *Population (June-Aug.)* | *Fishery (Avg. 2003-2007)* | *Proportion mature females* |
| 2 | 0.3 | 0.222 | 0.080 | 0.172 | 0.302 | 0.001 |
| 3 | 0.3 | 0.426 | 0.259 | 0.386 | 0.507 | 0.019 |
| 4 | 0.3 | 0.669 | 0.471 | 0.601 | 0.775 | 0.265 |
| 5 | 0.3 | 0.861 | 0.739 | 0.859 | 0.964 | 0.556 |
| 6 | 0.3 | 0.969 | 1.033 | 1.018 | 1.110 | 0.819 |
| 7 | 0.3 | 1.000 | 1.308 | 1.191 | 1.215 | 0.907 |
| 8 | 0.3 | 0.887 | 1.430 | 1.301 | 1.398 | 0.960 |
| 9 | 0.3 | 0.458 | 1.549 | 1.484 | 1.481 | 0.984 |
| 10+ | 0.3 | 0.097 | 1.757 | 1.608 | 1.705 | 0.991 |

Table 1.20. Methods used to assess Gulf of Alaska pollock, 1977-2007. 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 1990-2007 is the method used by the Plan Team to derive the ABC recommendation given in the SAFE summary chapter.

| *Year* | *Assessment method* | *Basis for catch recommendation in following year* | *B40% (t)* |
|---|---|---|---|
| 1977-81 | Survey biomass, CPUE trends, M=0.4 | MSY = 0.4 * M * Bzero | --- |
| 1982 | CAGEAN | MSY = 0.4 * M * Bzero | --- |
| 1983 | CAGEAN | Mean annual surplus production | --- |
| 1984 | Projection of survey numbers at age | Stabilize biomass trend | --- |
| 1985 | CAGEAN, projection of survey numbers at age, CPUE trends | Stabilize biomass trend | --- |
| 1986 | CAGEAN, projection of survey numbers at age | Stabilize biomass trend | --- |
| 1987 | CAGEAN, projection of survey numbers at age | Stabilize biomass trend | --- |
| 1988 | CAGEAN, projection of survey numbers at age | 10% of exploitable biomass | --- |
| 1989 | Stock synthesis | 10% of exploitable biomass | --- |
| 1990 | Stock synthesis, reduce *M* to 0.3 | 10% of exploitable biomass | --- |
| 1991 | Stock synthesis, assume trawl survey catchability = 1 | FMSY from an assumed SR curve | --- |
| 1992 | Stock synthesis | Max[-Pr(SB<Threshold)+Yld] | --- |
| 1993 | Stock synthesis | Pr(SB>B20)=0.95 | --- |
| 1994 | Stock synthesis | Pr(SB>B20)=0.95 | --- |
| 1995 | Stock synthesis | Max[-Pr(SB<Threshold)+Yld] | --- |
| 1996 | Stock synthesis | Amendment 44 Tier 3 guidelines | 289,689 |
| 1997 | Stock synthesis | Amendment 44 Tier 3 guidelines | 267,600 |
| 1998 | Stock synthesis | Amendment 44 Tier 3 guidelines | 240,000 |
| 1999 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible $F_{ABC}$) | 247,000 |
| 2000 | AD model builder | Amendment 56 Tier 3 guidelines | 250,000 |
| 2001 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible $F_{ABC}$) | 245,000 |
| 2002 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible $F_{ABC}$) | 240,000 |
| 2003 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible $F_{ABC}$) | 248,000 |
| 2004 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible $F_{ABC}$, and stairstep approach for projected ABC increase) | 229,000 |
| 2005 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC) | 224,000 |
| 2006 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC) | 220,000 |
| 2007 | AD model builder | Amendment 56 Tier 3 guidelines (with a reduction from max permissible $F_{ABC}$) | 221,000 |

Table 1.21. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2008-2021 under different harvest policies. All projections begin with estimated age composition in 2008 using base run model, and a projected 2008 catch of 53,590 t. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 593,000, 237,000, and 208,000 t, respectively.

| *Spawning biomass (t)* | *Max $F_{ABC}$* | *Author's recommended F* | *Average F* | *$F_{75\%}$* | *F = 0* | *$F_{OFL}$* | *Max $F_{ABC}$ for two years, then $F_{OFL}$* |
|---|---|---|---|---|---|---|---|
| 2008 | 131,570 | 131,570 | 131,570 | 131,570 | 131,570 | 131,570 | 131,570 |
| 2009 | 132,539 | 132,809 | 132,014 | 133,337 | 134,323 | 132,255 | 132,539 |
| 2010 | 155,875 | 157,984 | 152,378 | 162,592 | 170,676 | 153,692 | 155,875 |
| 2011 | 186,449 | 191,546 | 181,795 | 206,079 | 226,516 | 181,246 | 185,632 |
| 2012 | 211,196 | 219,620 | 210,733 | 252,905 | 290,487 | 202,239 | 205,821 |
| 2013 | 227,887 | 238,226 | 236,101 | 297,011 | 354,040 | 215,167 | 217,613 |
| 2014 | 239,569 | 250,501 | 257,374 | 335,764 | 412,130 | 223,663 | 225,117 |
| 2015 | 247,197 | 258,083 | 273,573 | 366,989 | 460,736 | 228,852 | 229,635 |
| 2016 | 250,293 | 260,823 | 283,553 | 388,669 | 496,487 | 230,281 | 230,692 |
| 2017 | 251,922 | 262,007 | 290,503 | 404,320 | 522,971 | 230,818 | 231,047 |
| 2018 | 254,239 | 263,939 | 296,887 | 416,990 | 543,541 | 232,404 | 232,534 |
| 2019 | 257,254 | 266,707 | 303,312 | 428,540 | 561,345 | 234,812 | 234,882 |
| 2020 | 257,901 | 267,134 | 306,759 | 436,043 | 573,765 | 234,951 | 234,989 |
| 2021 | 256,566 | 265,588 | 307,278 | 439,231 | 580,410 | 233,353 | 233,374 |

| *Fishing mortality* | *Max $F_{ABC}$* | *Author's recommended F* | *Average F* | *$F_{75\%}$* | *F = 0* | *$F_{OFL}$* | *Max $F_{ABC}$ for two years, then $F_{OFL}$* |
|---|---|---|---|---|---|---|---|
| 2008 | 0.17 | 0.17 | 0.17 | 0.17 | 0 | 0.17 | 0.17 |
| 2009 | 0.13 | 0.11 | 0.17 | 0.07 | 0 | 0.15 | 0.13 |
| 2010 | 0.16 | 0.13 | 0.17 | 0.07 | 0 | 0.18 | 0.16 |
| 2011 | 0.19 | 0.17 | 0.17 | 0.07 | 0 | 0.21 | 0.22 |
| 2012 | 0.20 | 0.19 | 0.17 | 0.07 | 0 | 0.23 | 0.23 |
| 2013 | 0.21 | 0.19 | 0.17 | 0.07 | 0 | 0.23 | 0.23 |
| 2014 | 0.21 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2015 | 0.21 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2016 | 0.21 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2017 | 0.21 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2018 | 0.22 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2019 | 0.22 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2020 | 0.22 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |
| 2021 | 0.22 | 0.20 | 0.17 | 0.07 | 0 | 0.24 | 0.24 |

| *Catch (t)* | *Max $F_{ABC}$* | *Author's recommended F* | *Average F* | *$F_{75\%}$* | *F = 0* | *$F_{OFL}$* | *Max $F_{ABC}$ for two years, then $F_{OFL}$* |
|---|---|---|---|---|---|---|---|
| 2008 | 53,590 | 53,590 | 53,590 | 53,590 | 53,590 | 53,590 | 53,590 |
| 2009 | 50,772 | 43,271 | 65,189 | 28,412 | 0 | 58,592 | 50,772 |
| 2010 | 77,383 | 67,701 | 82,048 | 37,654 | 0 | 87,146 | 77,383 |
| 2011 | 114,878 | 104,270 | 99,418 | 47,669 | 0 | 126,425 | 131,759 |
| 2012 | 139,585 | 133,126 | 113,133 | 56,195 | 0 | 151,798 | 155,254 |
| 2013 | 149,104 | 145,325 | 122,000 | 62,175 | 0 | 160,730 | 162,509 |
| 2014 | 151,920 | 149,103 | 125,753 | 65,101 | 0 | 163,000 | 163,713 |
| 2015 | 152,239 | 149,368 | 127,133 | 66,407 | 0 | 162,701 | 162,887 |
| 2016 | 152,319 | 149,157 | 127,669 | 66,925 | 0 | 162,542 | 162,520 |
| 2017 | 153,256 | 149,973 | 128,512 | 67,373 | 0 | 163,540 | 163,476 |
| 2018 | 153,750 | 150,221 | 128,905 | 67,611 | 0 | 163,888 | 163,844 |
| 2019 | 153,572 | 150,070 | 128,640 | 67,556 | 0 | 163,668 | 163,640 |
| 2020 | 151,491 | 148,061 | 127,597 | 67,178 | 0 | 161,444 | 161,428 |
| 2021 | 149,907 | 146,481 | 126,524 | 66,764 | 0 | 159,515 | 159,506 |

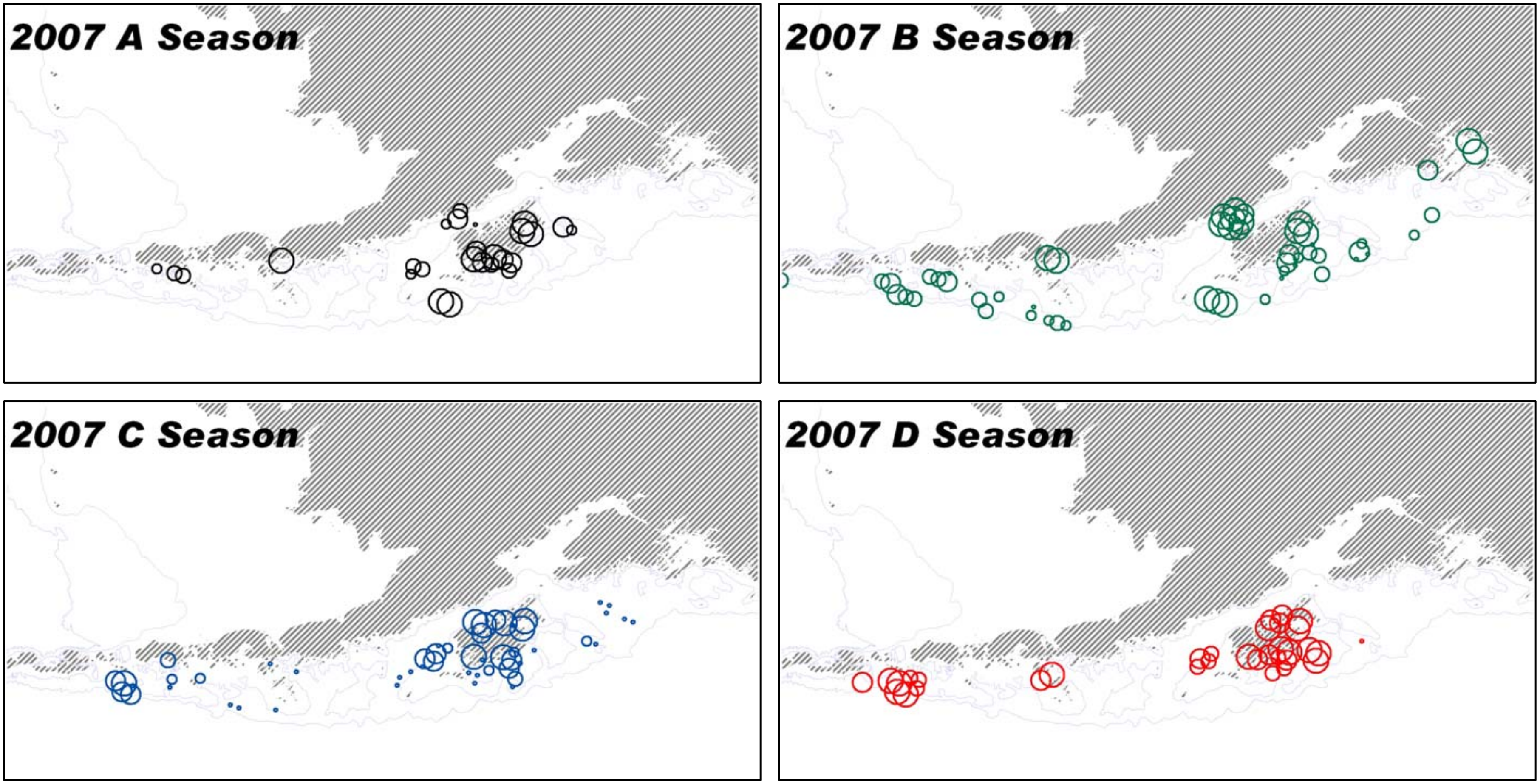


Figure 1.1 Pollock catch in 2007 by 20 X 20 km blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

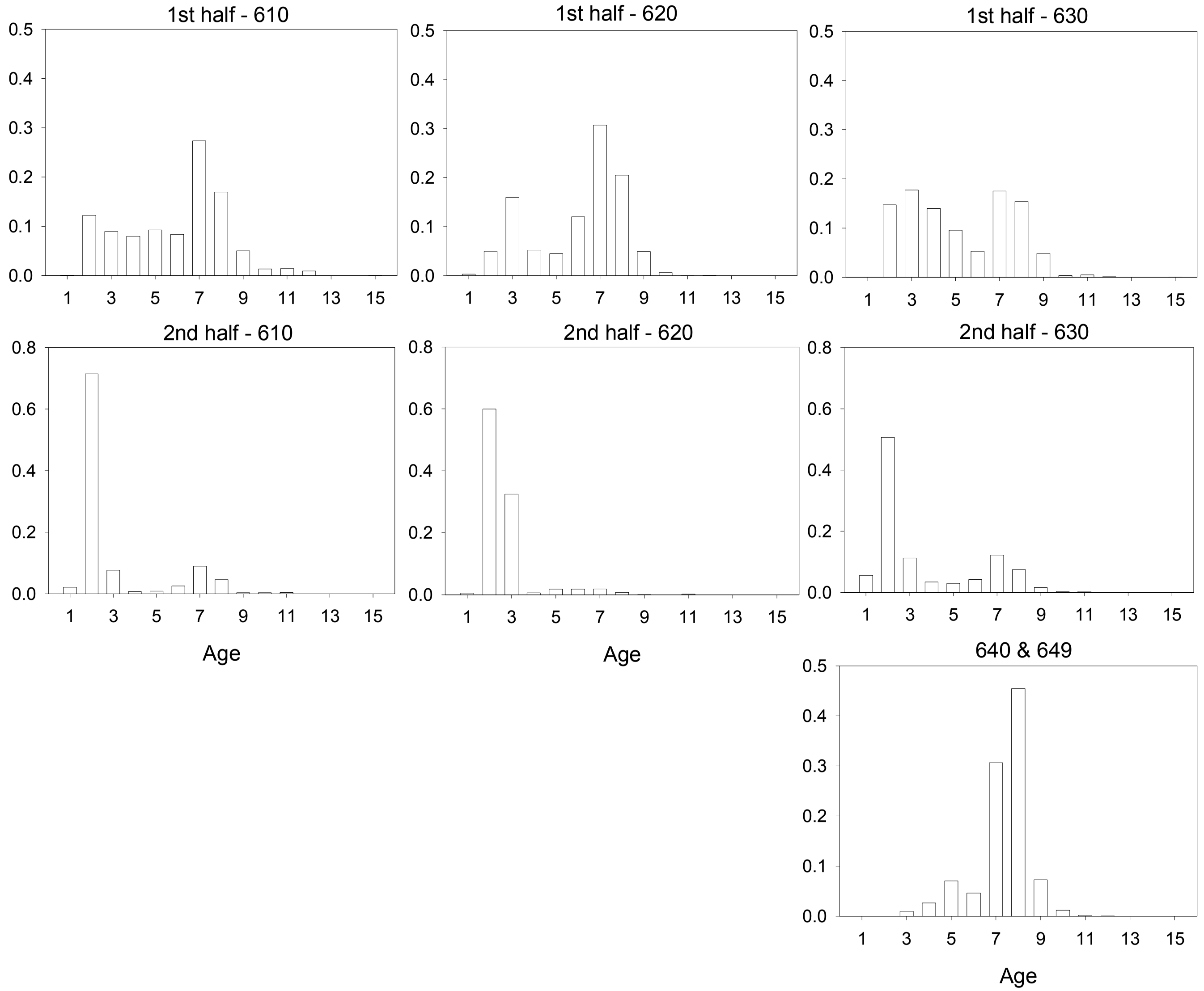


Figure 1.2. 2007 catch age composition by half year and statistical area.

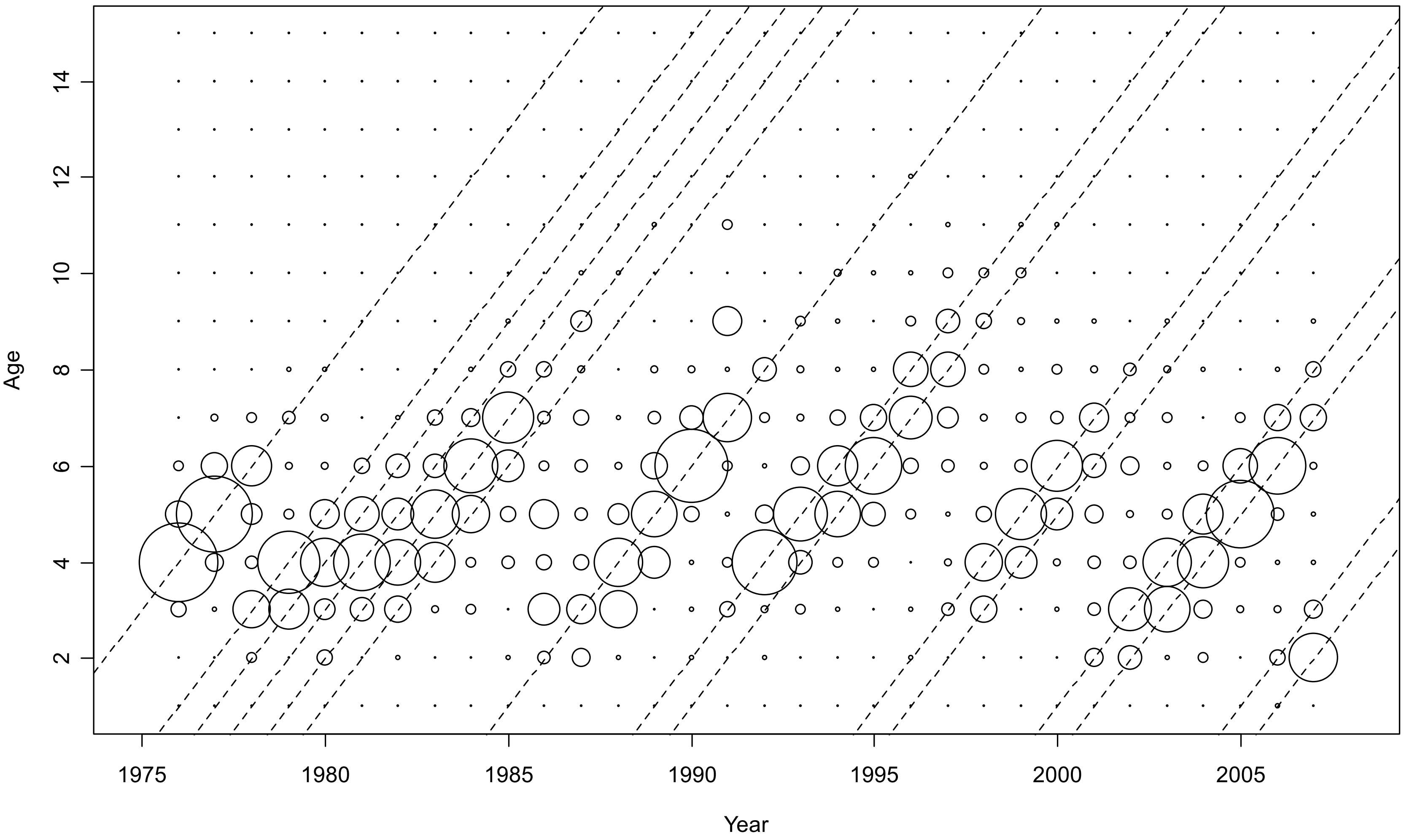


Figure 1.3. Gulf of Alaska pollock catch age composition (1976-2007). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, 1995, 1999, 2000, 2004, and 2005).
007 NMFS bottom trawl survey.

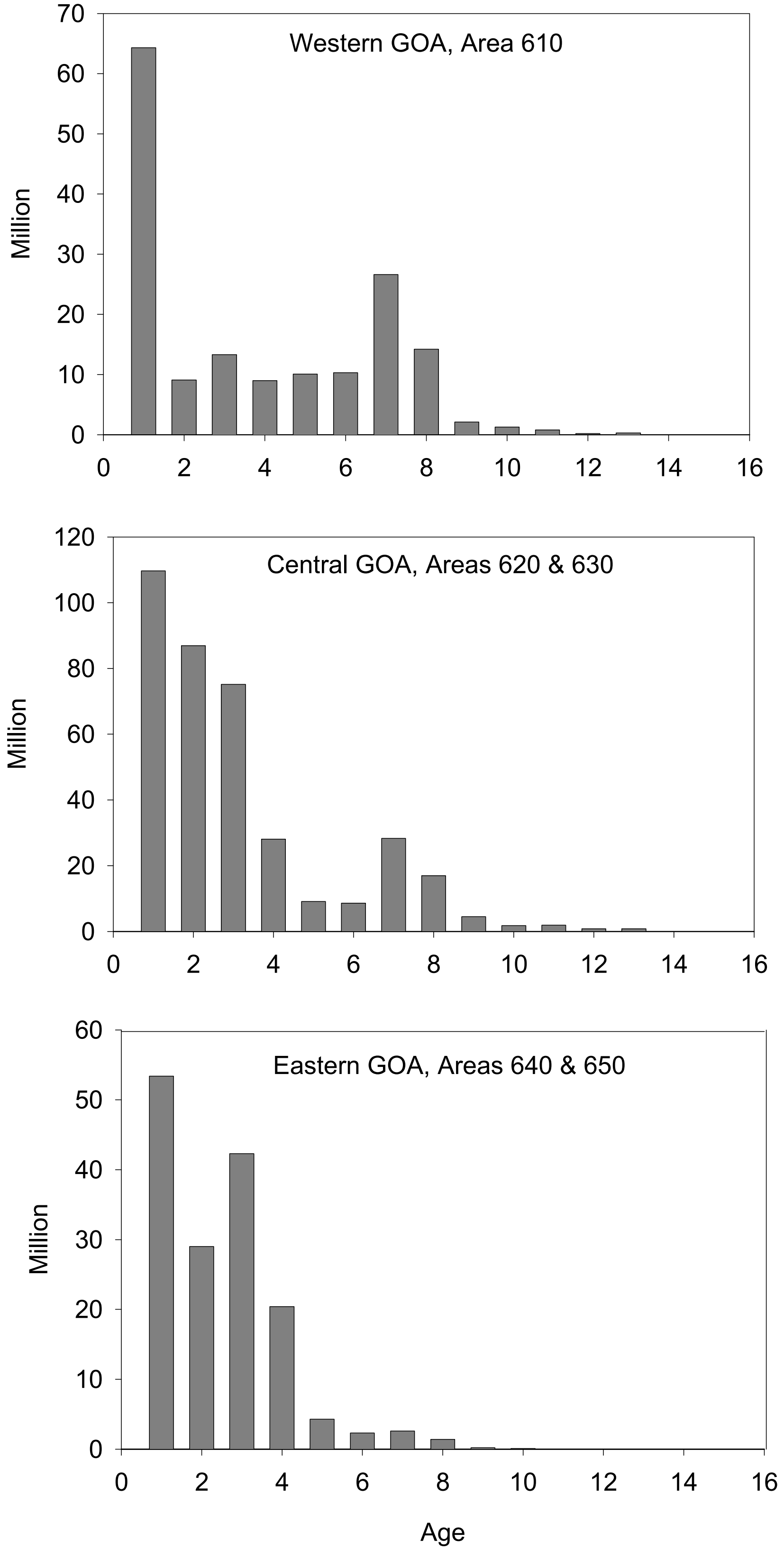


Figure 1.4. Age composition of pollock by management area for the 2007 NMFS bottom trawl survey.

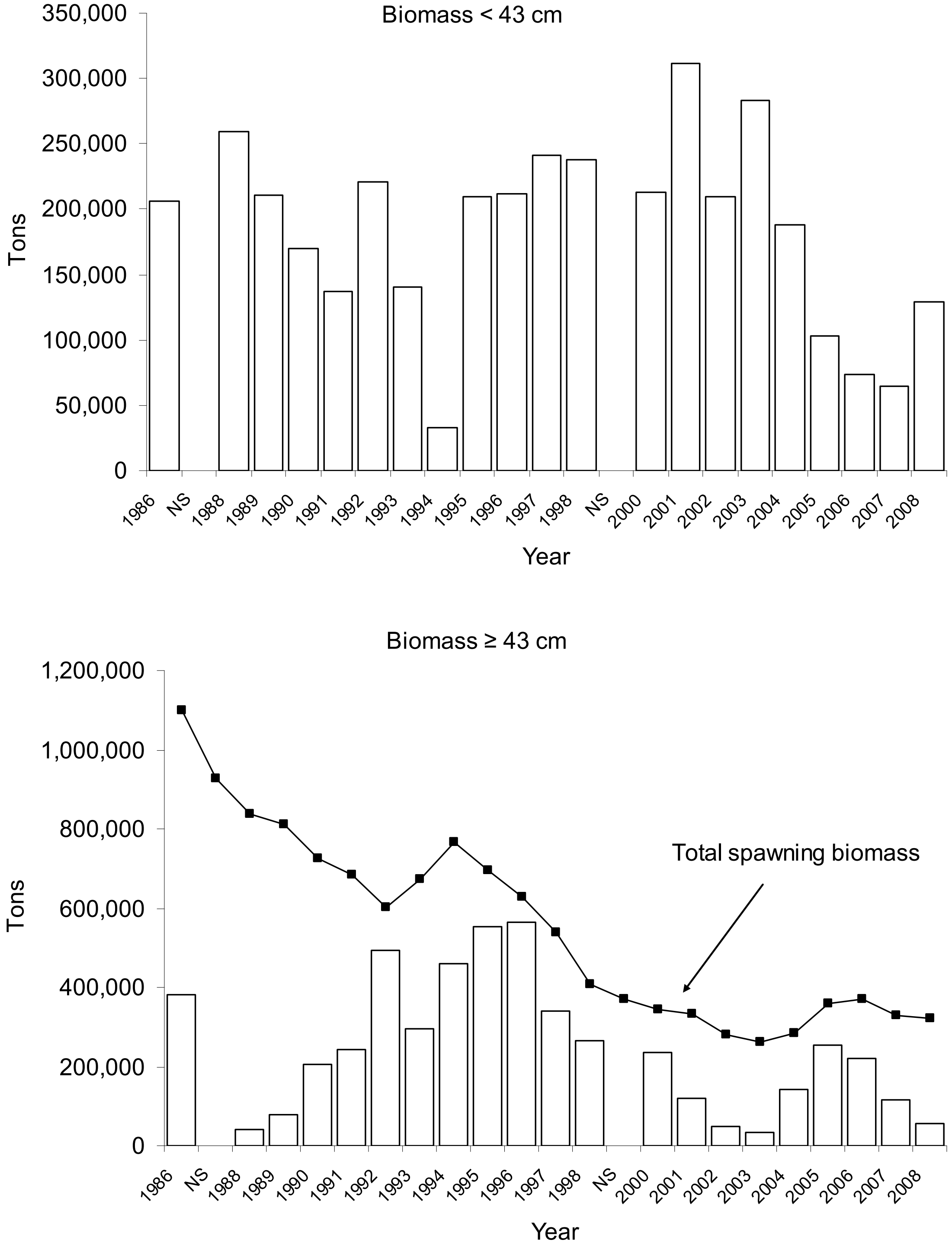


Figure 1.5. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2008 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

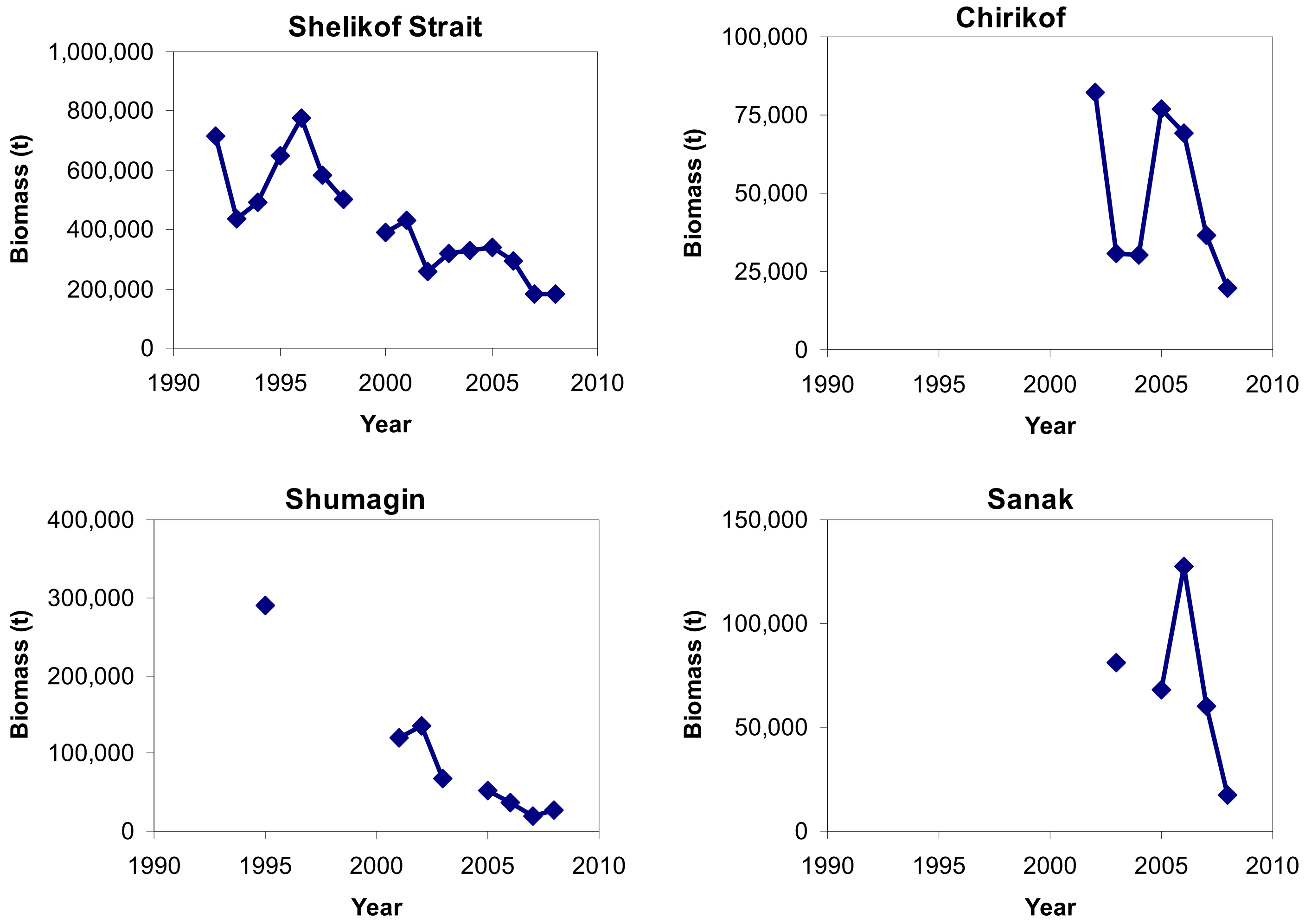


Figure 1.6. Trends in biomass estimates of from winter acoustic surveys of pre-spawning aggregations of pollock in the Gulf of Alaska.

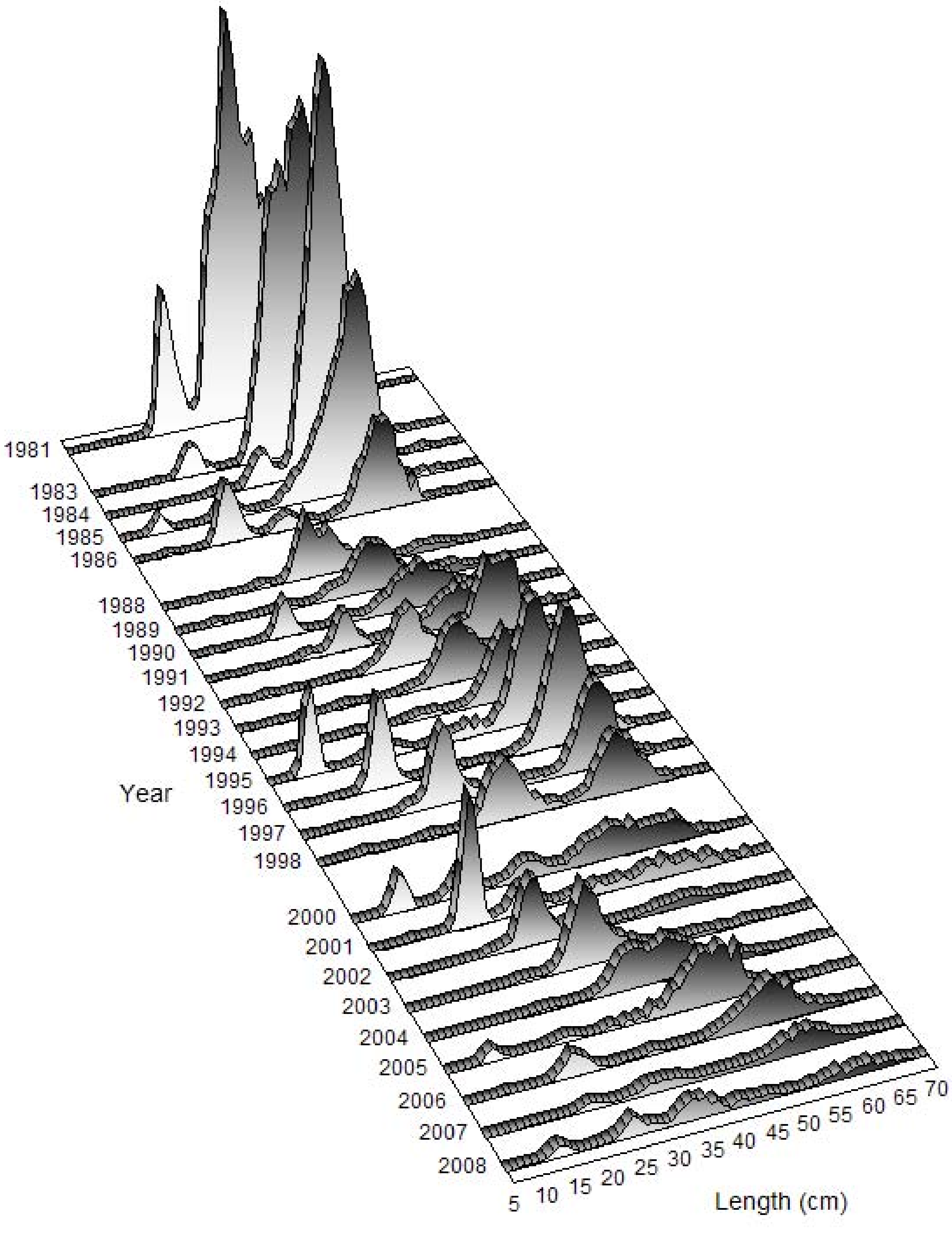


Figure 1.7. Biomass by length for pollock in the Shelikof Strait EIT survey (1981-2008, except 1982,1987 and 1999).

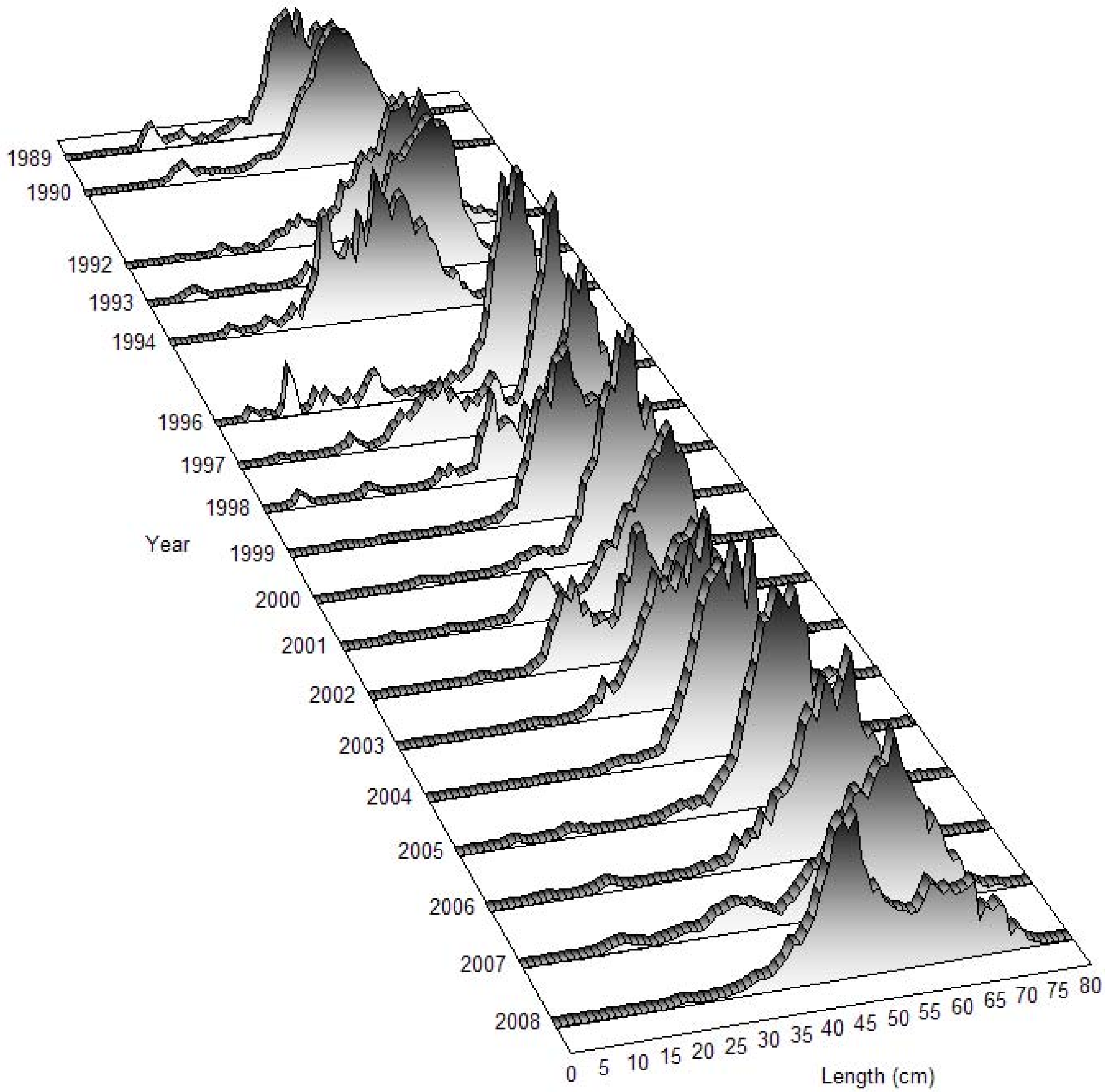


Figure 1.8. Length frequency of pollock in the ADF&G crab/groundfish trawl survey (1989-2008, except 1991 and 1995).

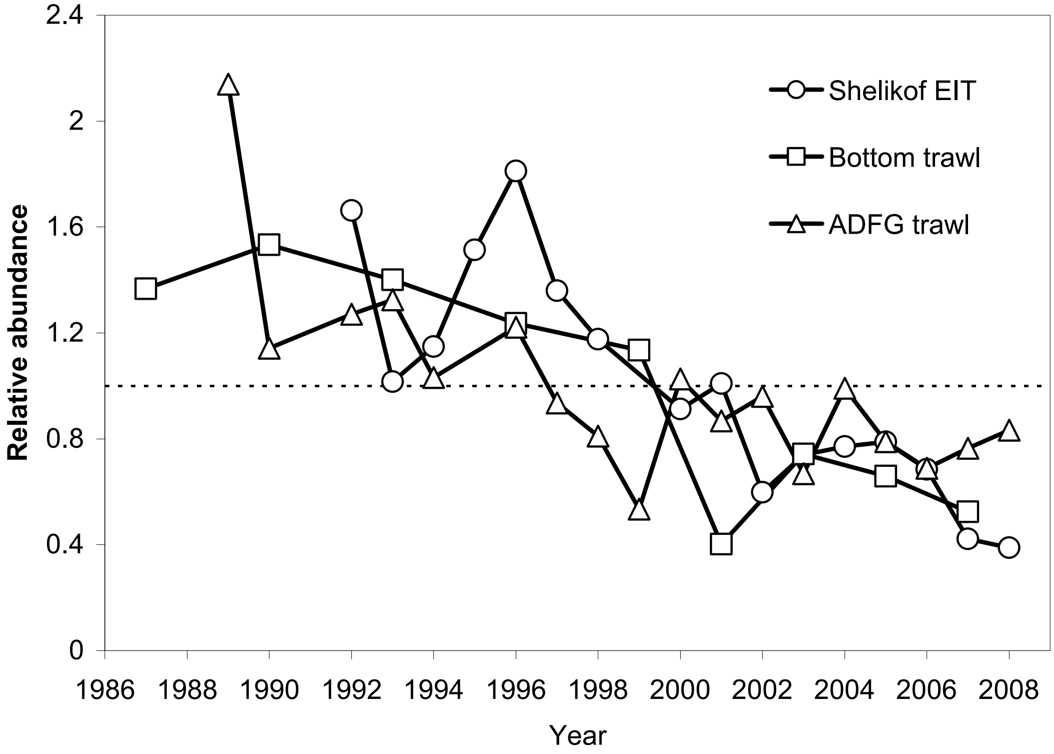


Figure 1.9. Relative trends in pollock biomass since 1987 for the Shelikof Strait EIT survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987. The 2008 Shelikof Strait EIT, conducted by the *R/V Oscar Dyson*, was re-scaled to be comparable to the earlier EIT surveys.

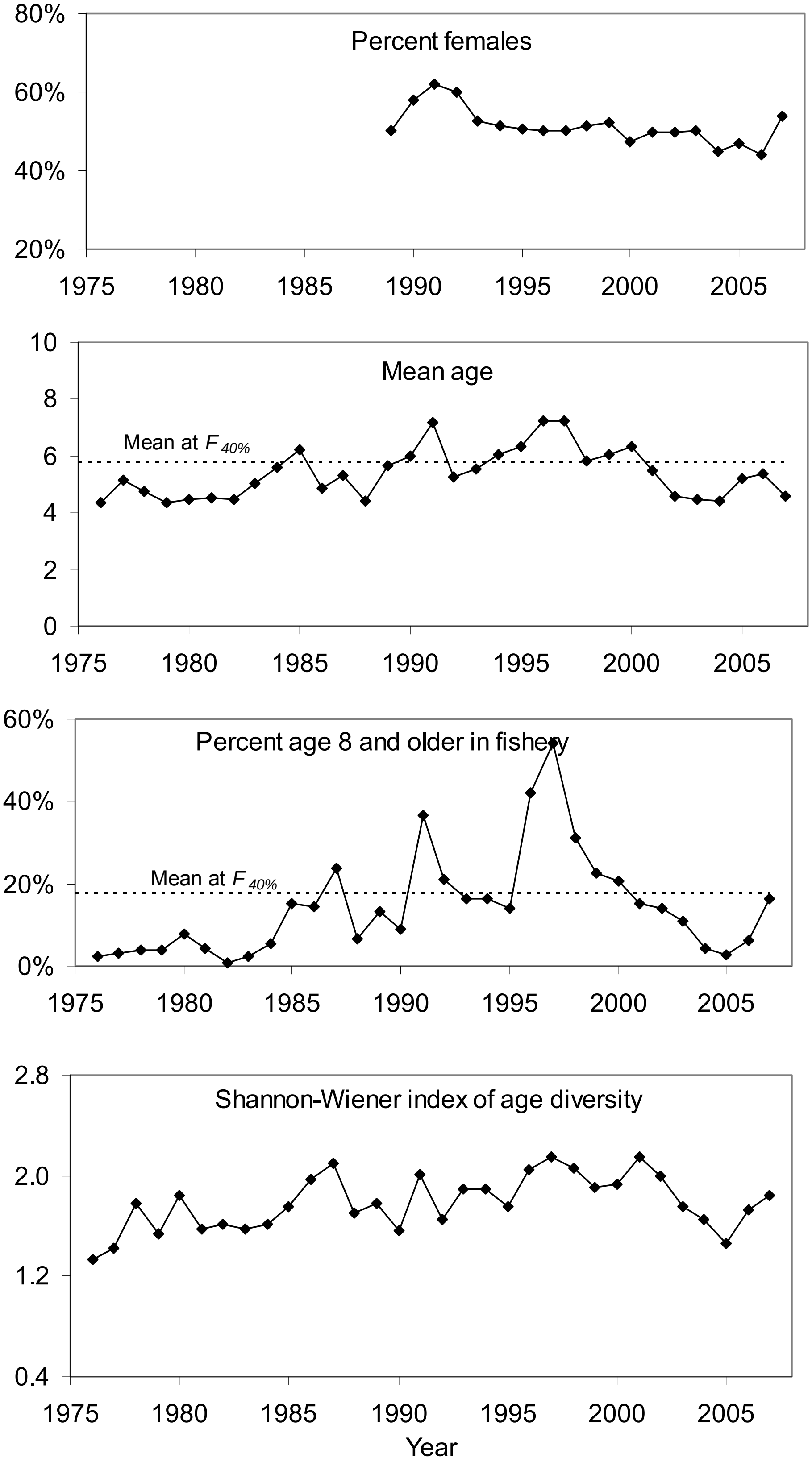


Figure 1.10. Gulf of Alaska pollock catch characteristics.

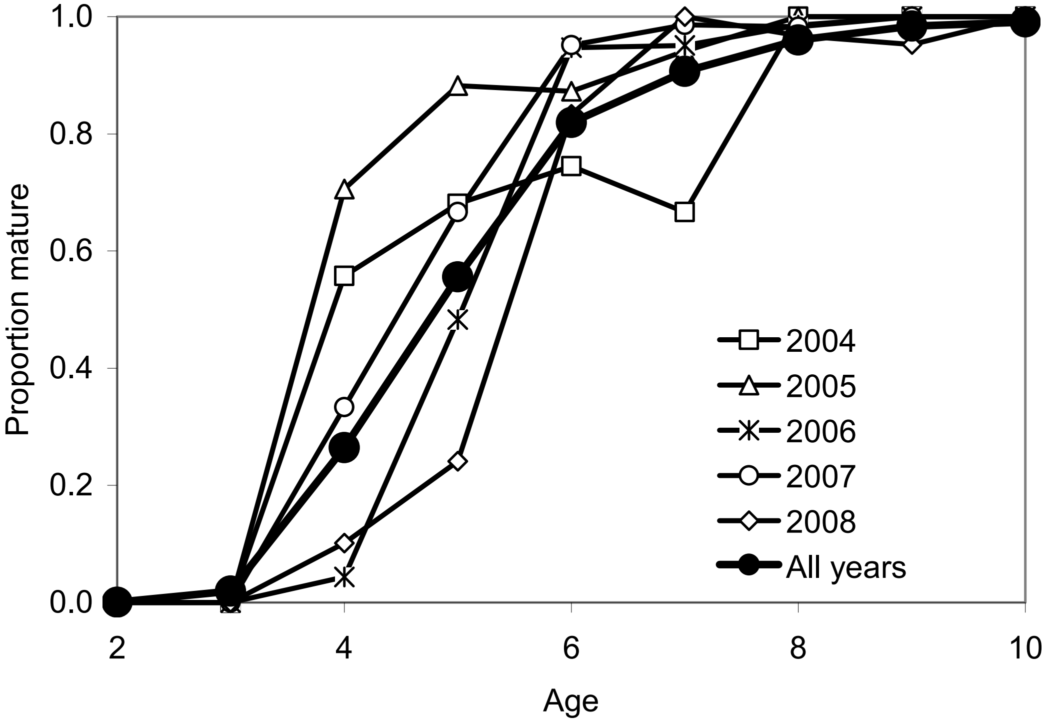


Figure 1.11. Estimates of the proportion mature at age from visual maturity data collected during 2004-2008 winter EIT surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2008).

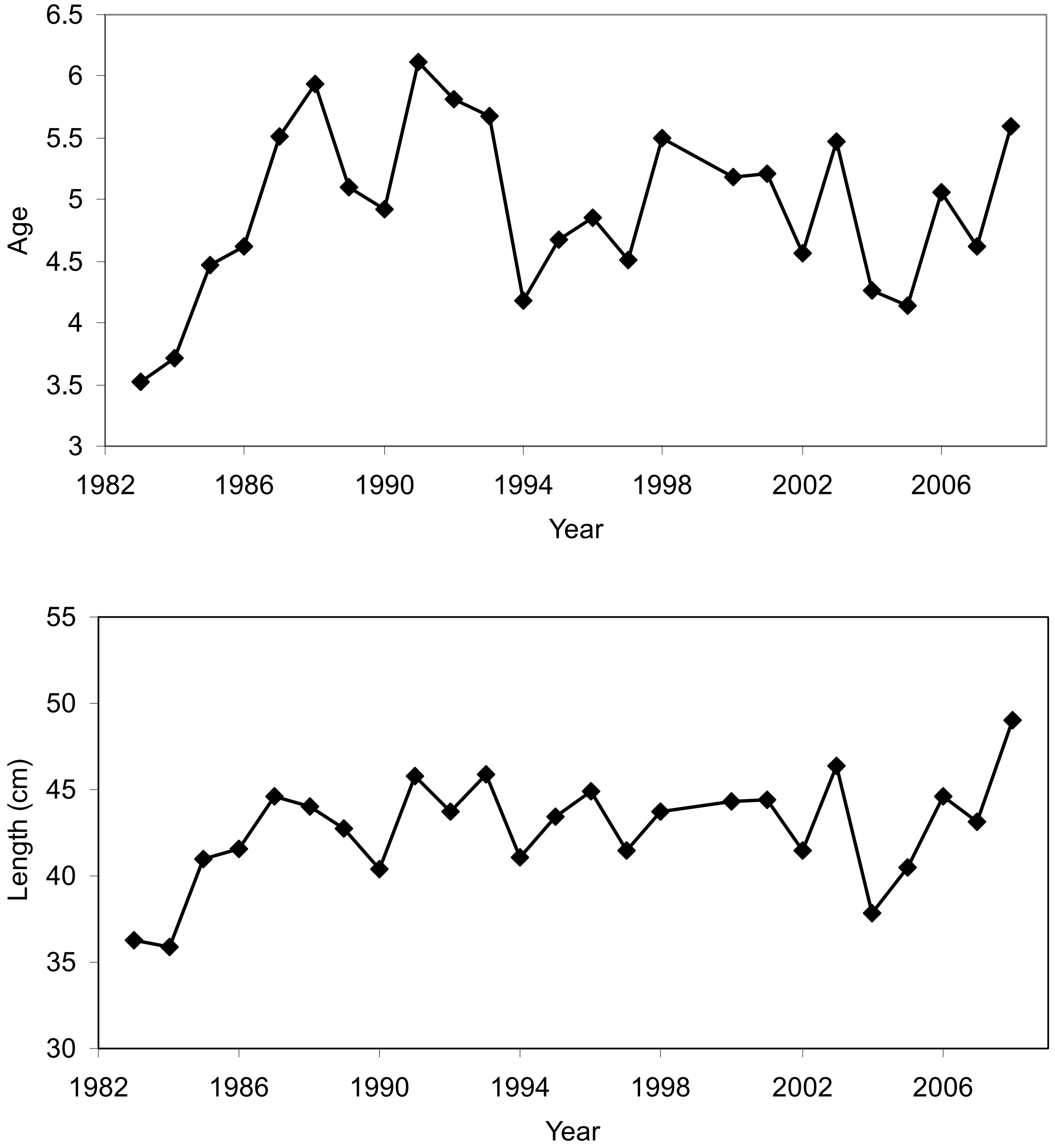


Figure 1.12. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2008.

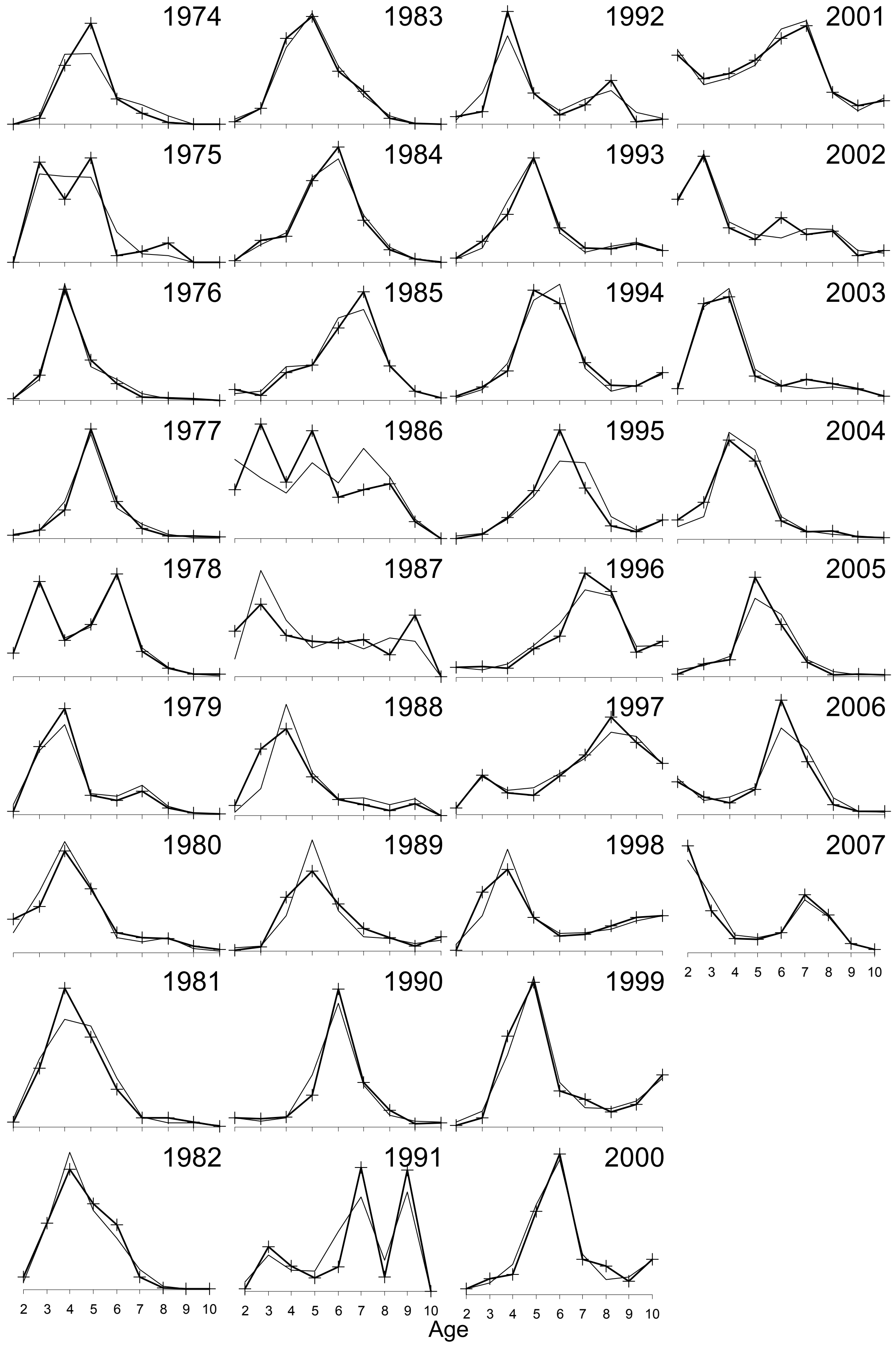


Figure 1.13. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

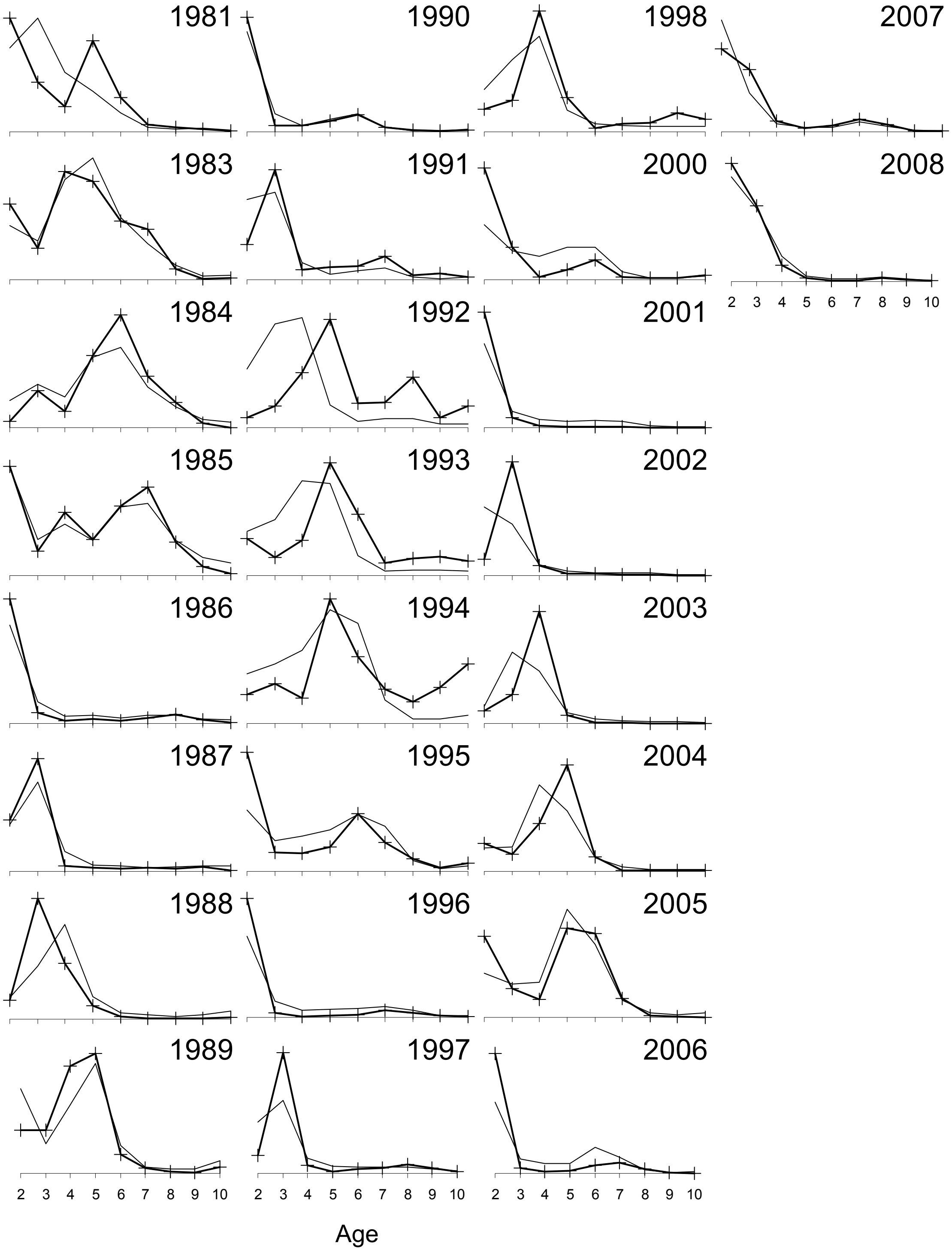


Figure 1.14. Observed and predicted Shelikof Strait EIT survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

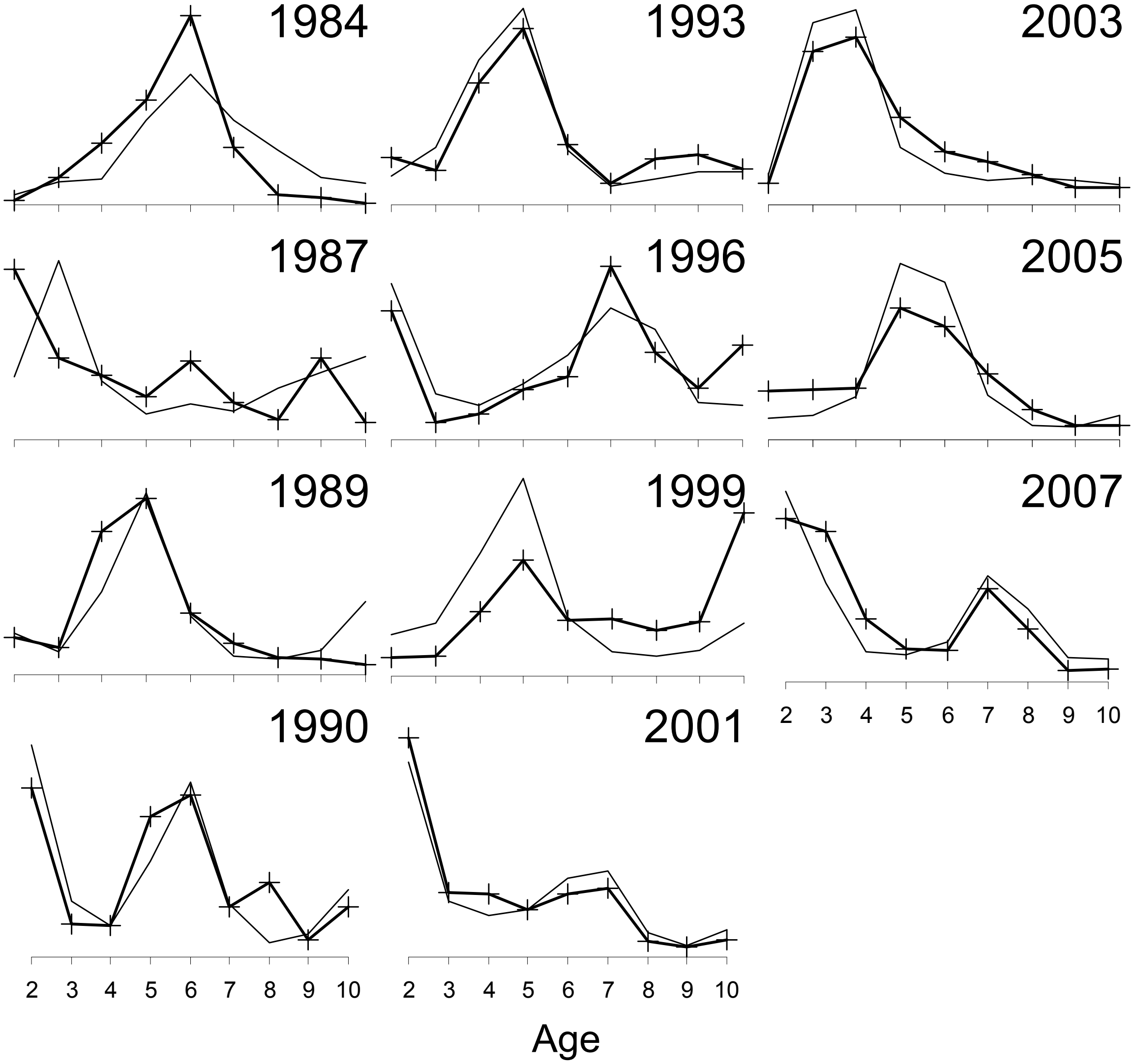


Figure 1.15. Observed and predicted NMFS bottom trawl age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

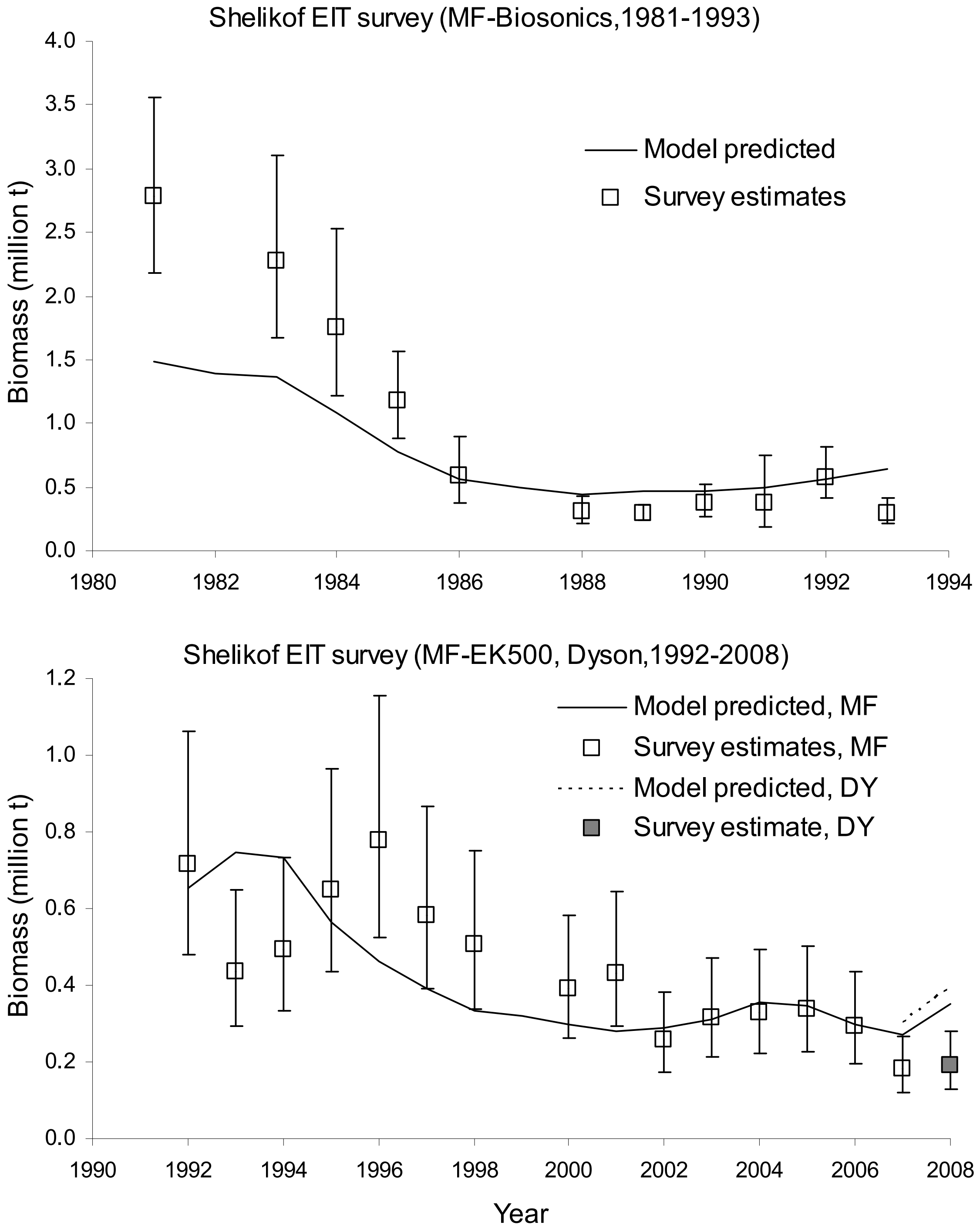


Figure 1.16. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with three catchability periods corresponding to the two acoustic systems used on the *R/V Miller Freeman* (MF), with an additional catchability period for the *R/V Dyson* (DY) in 2008. Error bars indicate plus and minus two standard deviations.

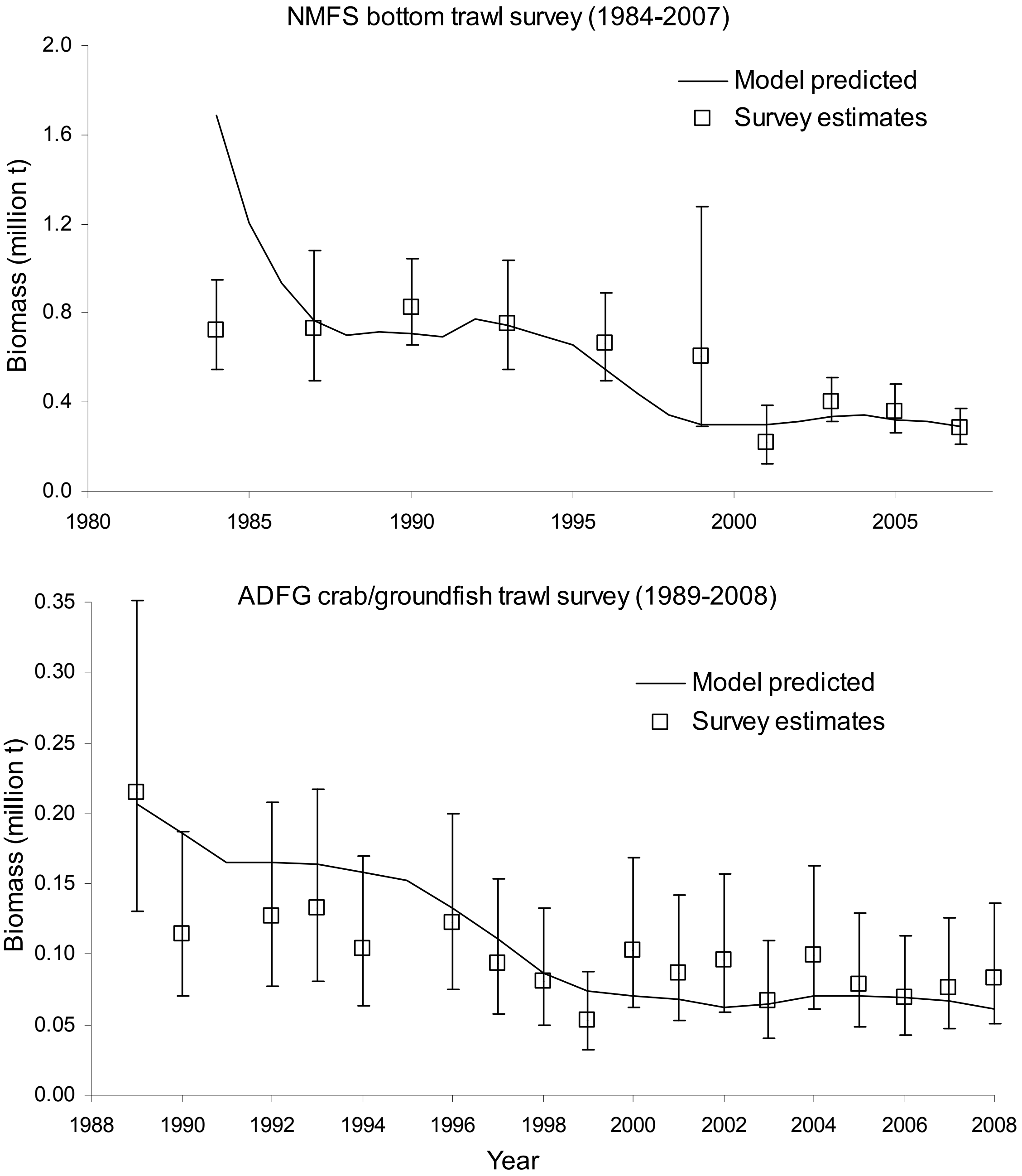


Figure 1.17. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used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

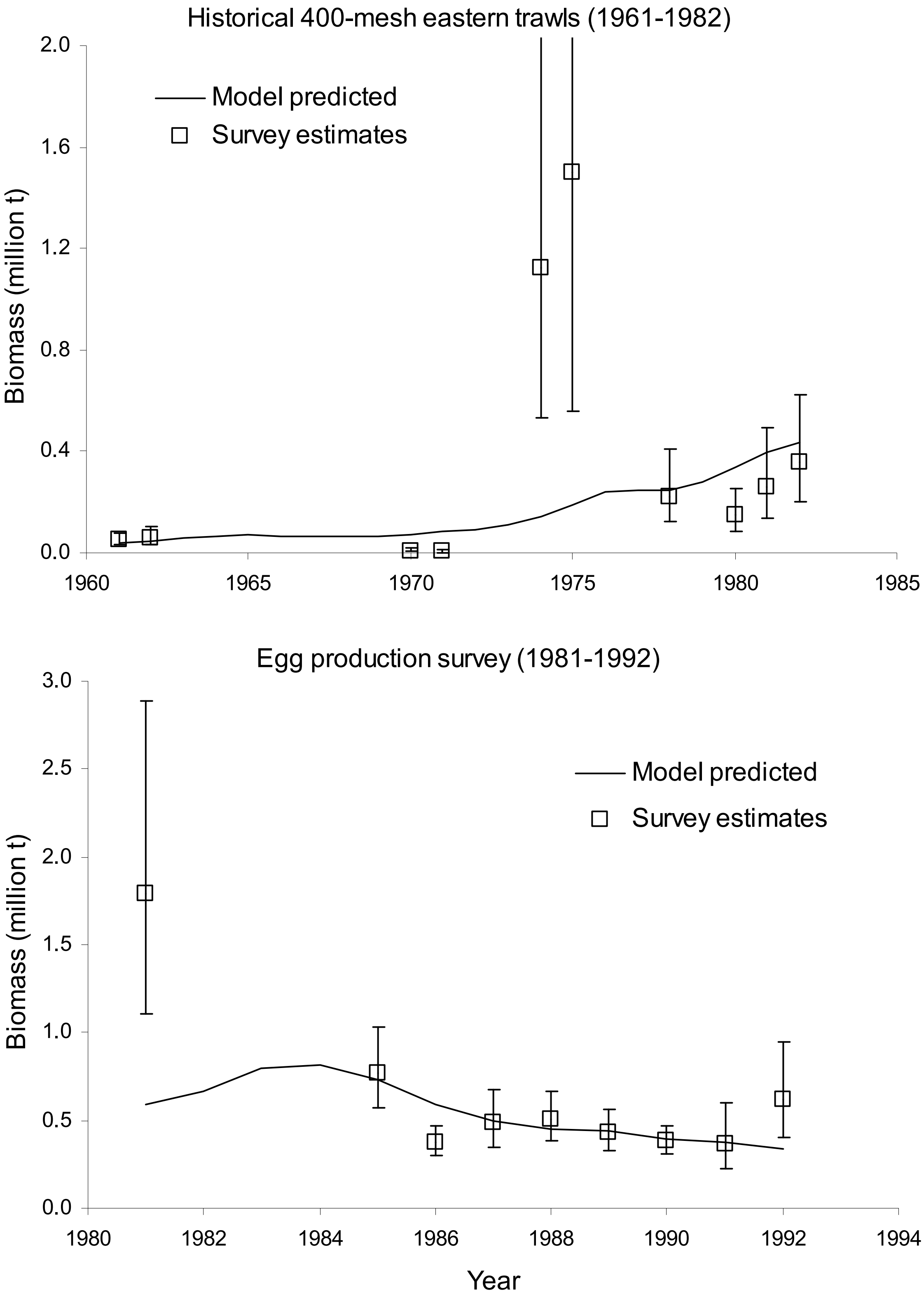


Figure 1.18. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top), and the egg production survey (bottom). Error bars indicate plus and minus two standard deviations.

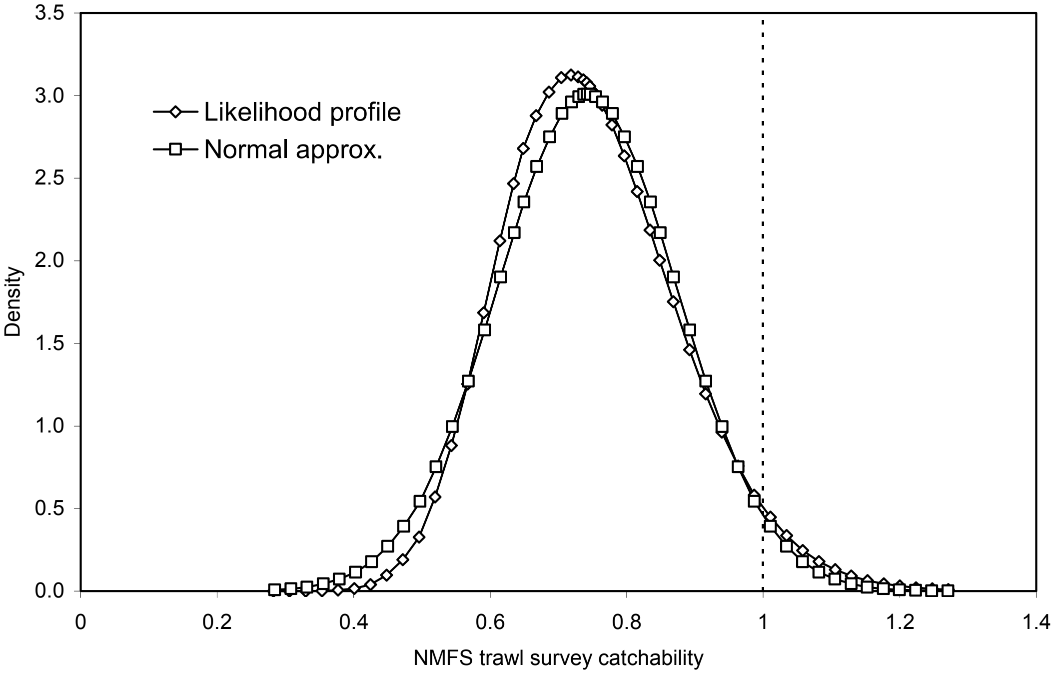


Figure 1.19. Uncertainty in the catchability coefficient for the NMFS trawl survey from a likelihood profile for the base model.

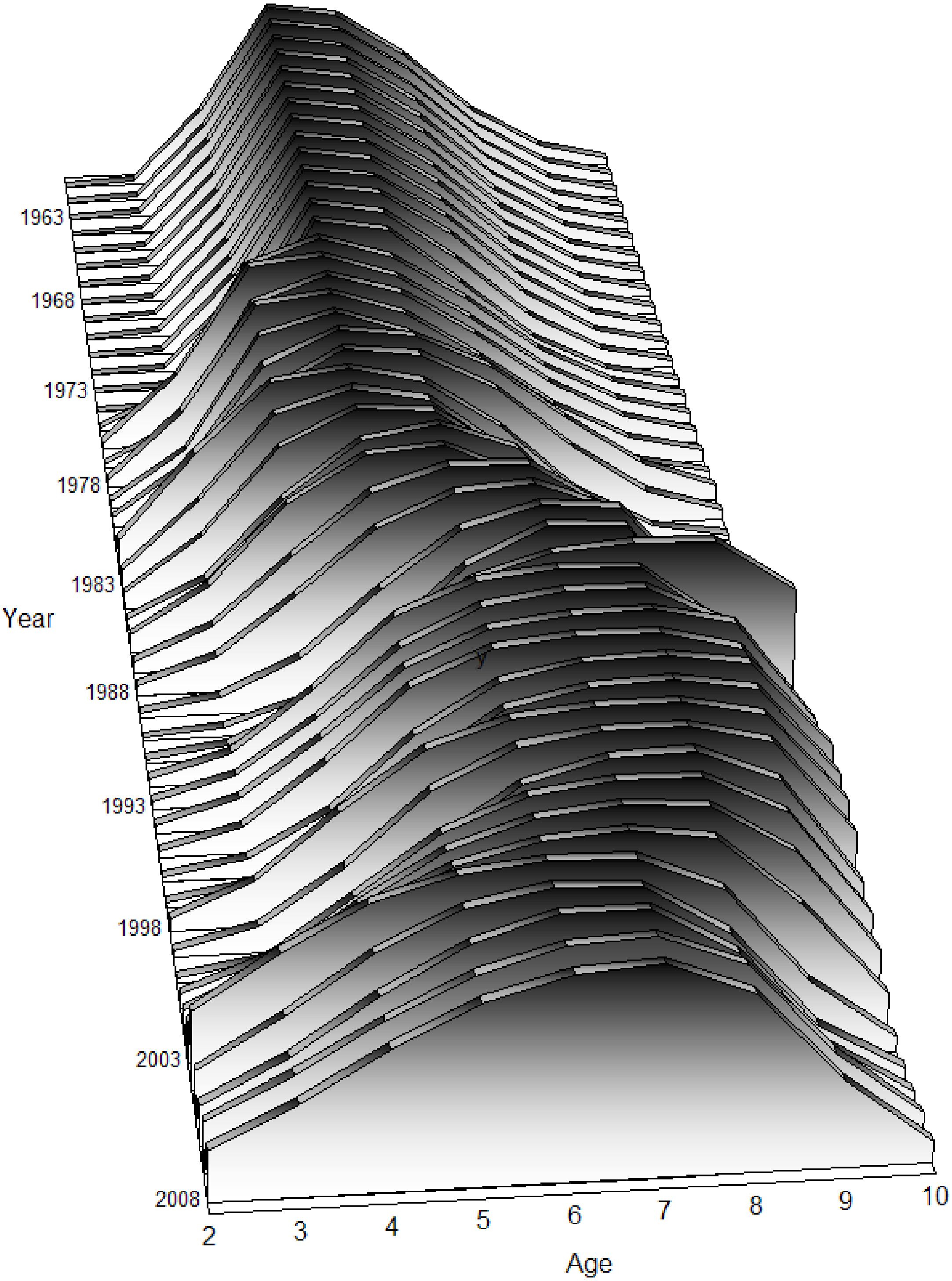
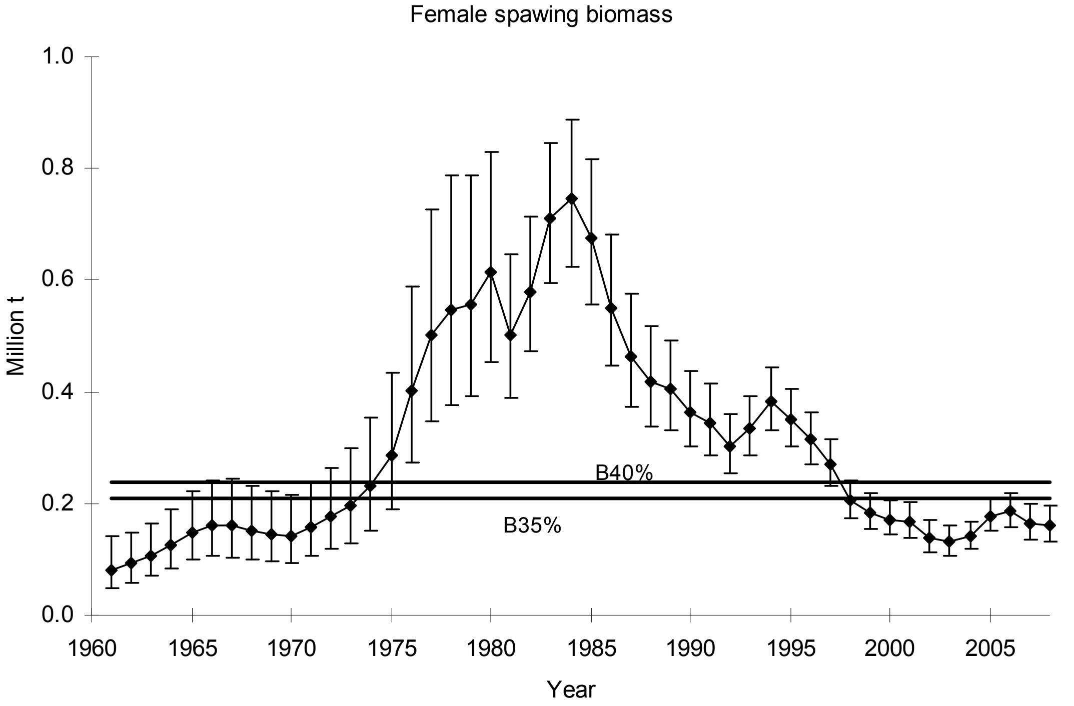


Figure 1.20. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock. The maximum selectivity in each year is 1.0.



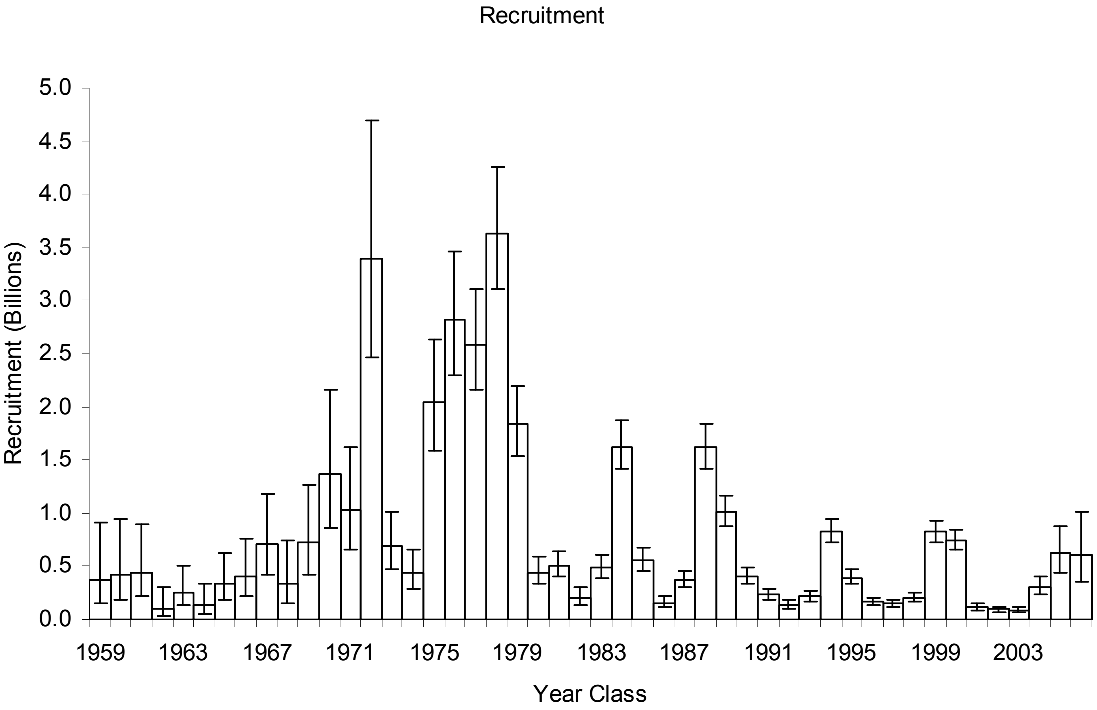


Figure 1.21. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-2 recruitment (billions of fish, bottom) from 1961 to 2008. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.

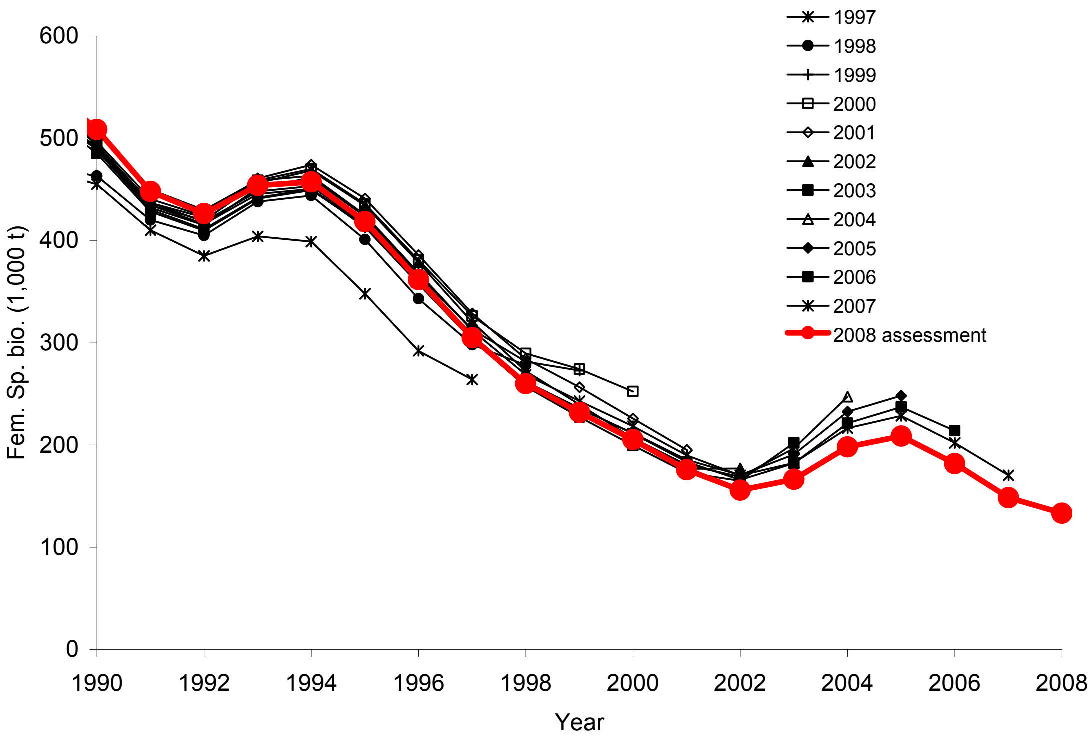
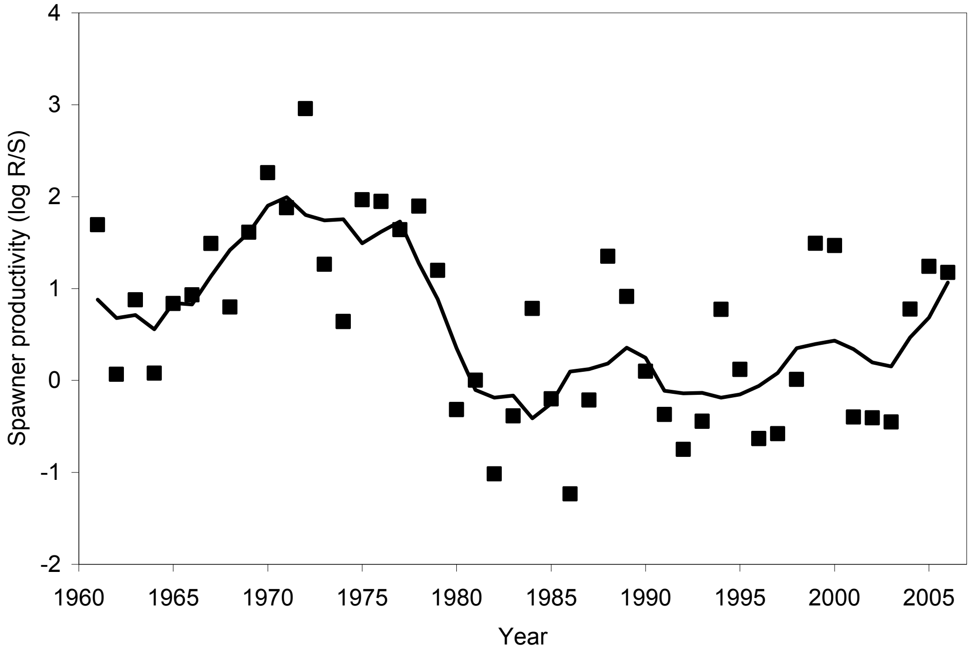


Figure 1.22. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1997-2008 (top). For this figure, the time series of female spawning biomass for the 2007 assessment was calculated using the weight and maturity at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2008 from the 2007 and 2008 assessments.



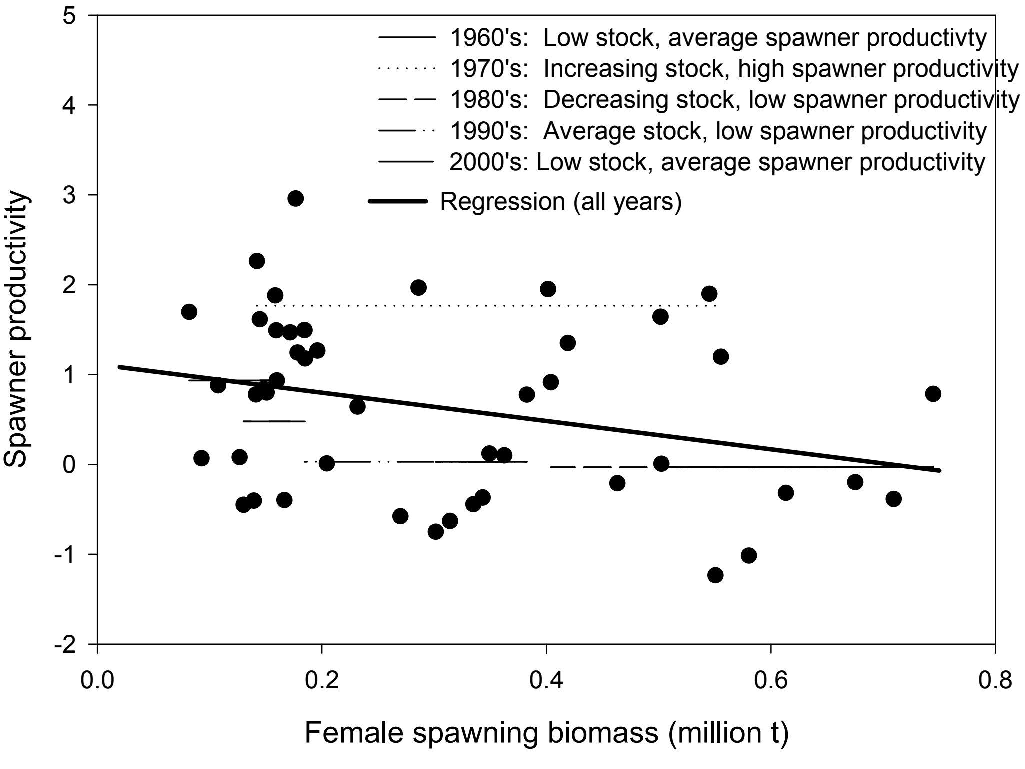


Figure 1.23. Gulf of Alaska pollock spawner productivity *log(R/S)* in 1961-2006 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.

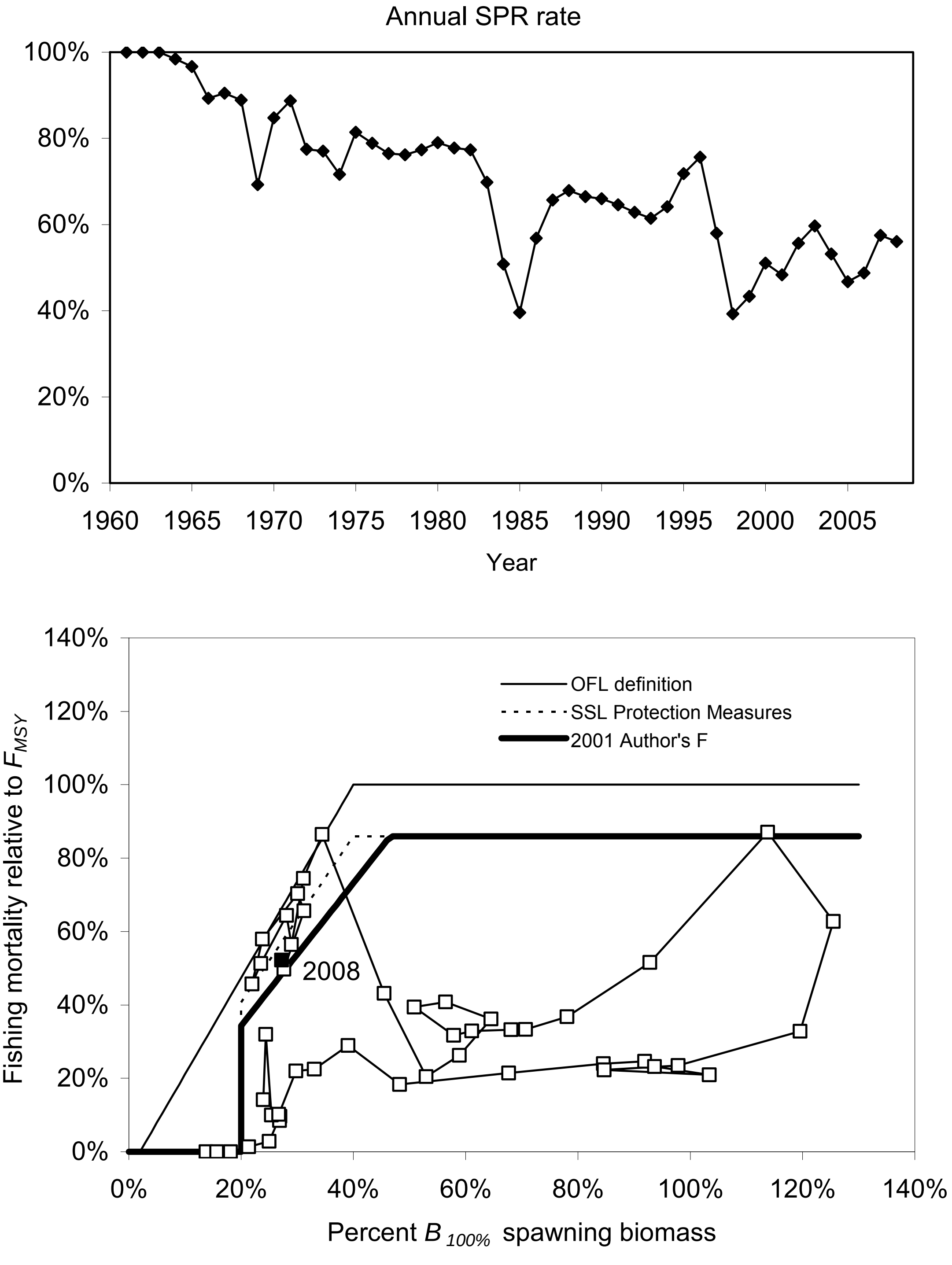


Figure 1.24. Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to $F_{MSY}$ (1961-2008). The ratio of fishing mortality to $F_{MSY}$ is calculated using the estimated selectivity pattern in that year. Estimates of $B_{100\%}$ spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

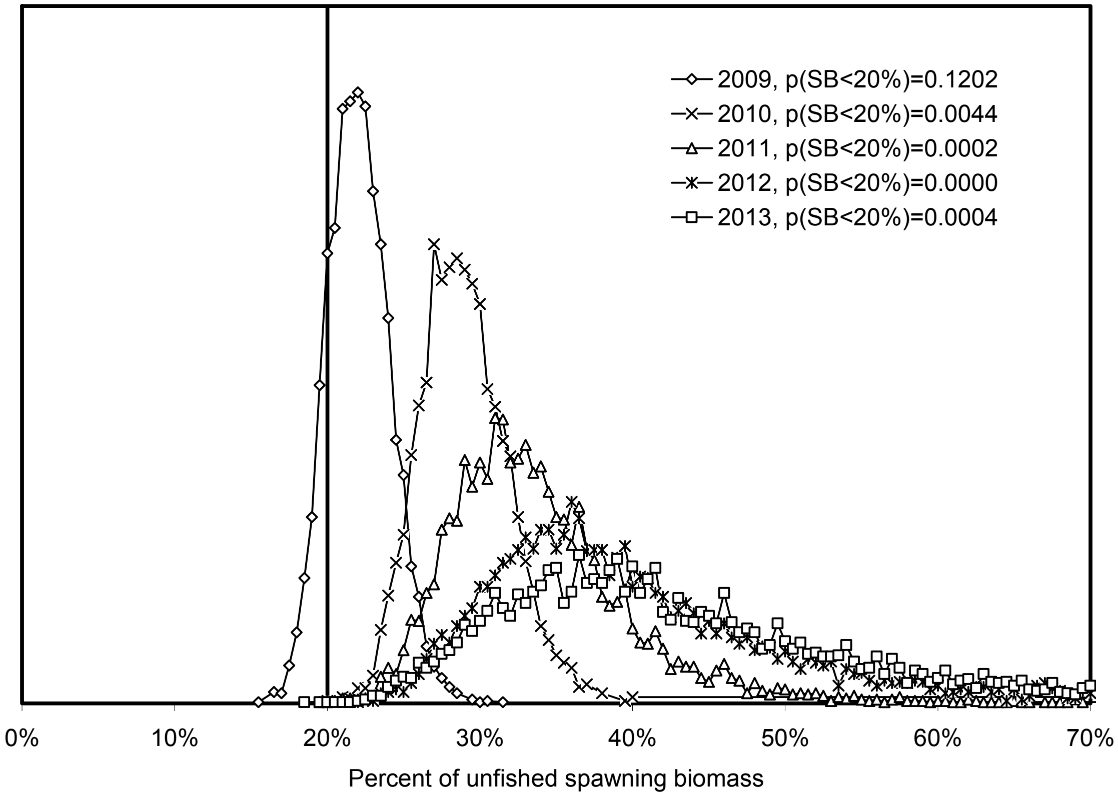


Figure 1.25. Uncertainty in spawning biomass in 2009-2013 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended FABC.

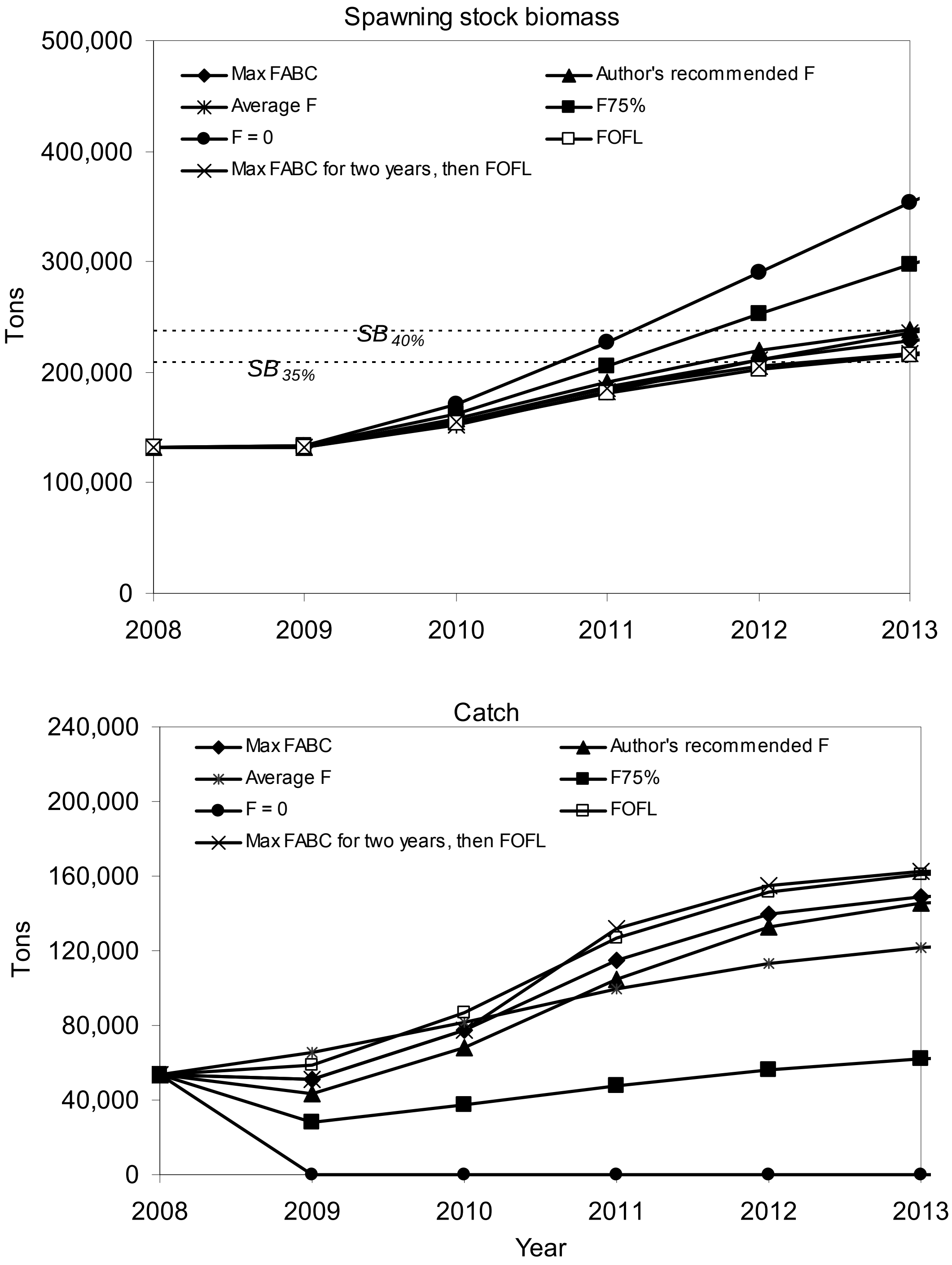
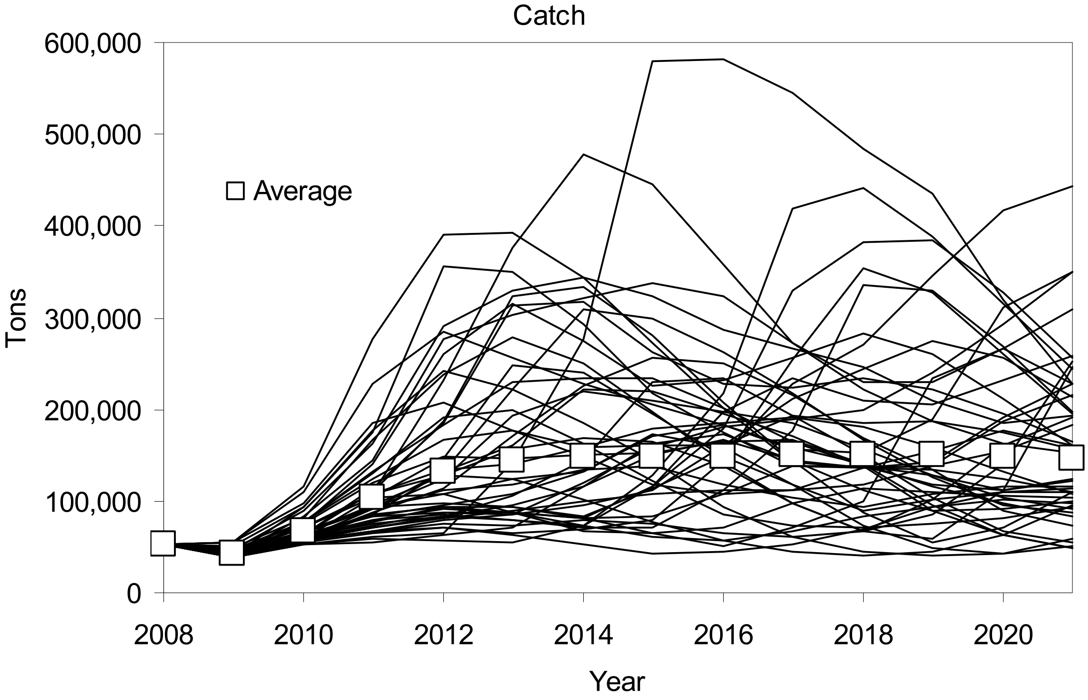


Figure 1.26. Projected spawning biomass and catches in 2007-12 under different management strategies.



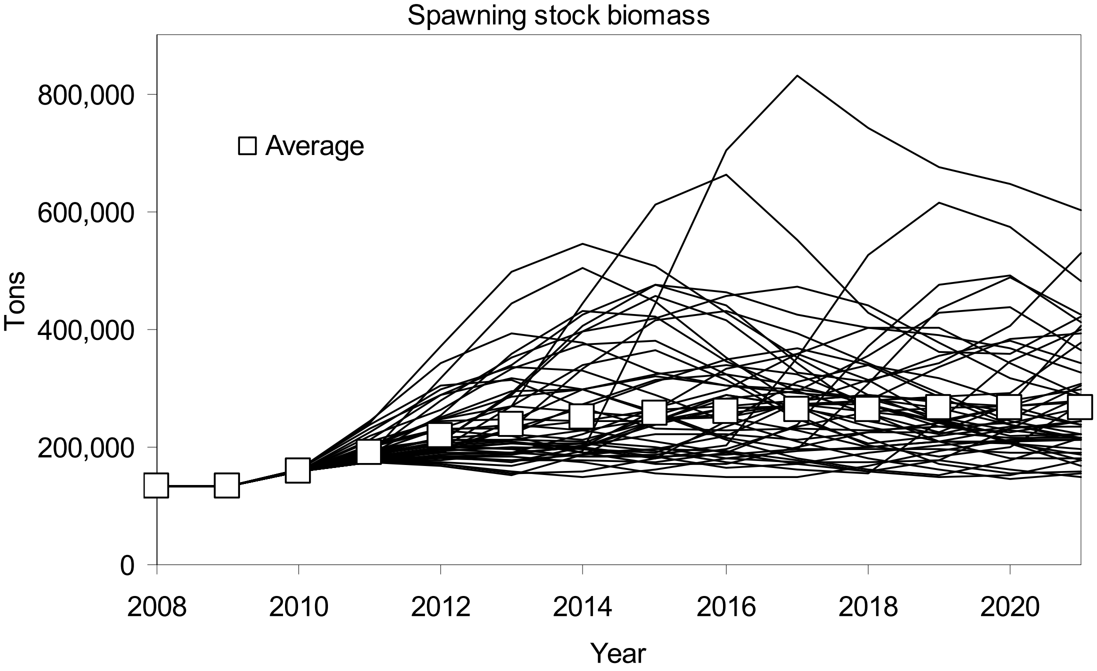


Figure 1.27. Variability in projected catch and spawning biomass in 2008-21 under the author's recommended FABC.

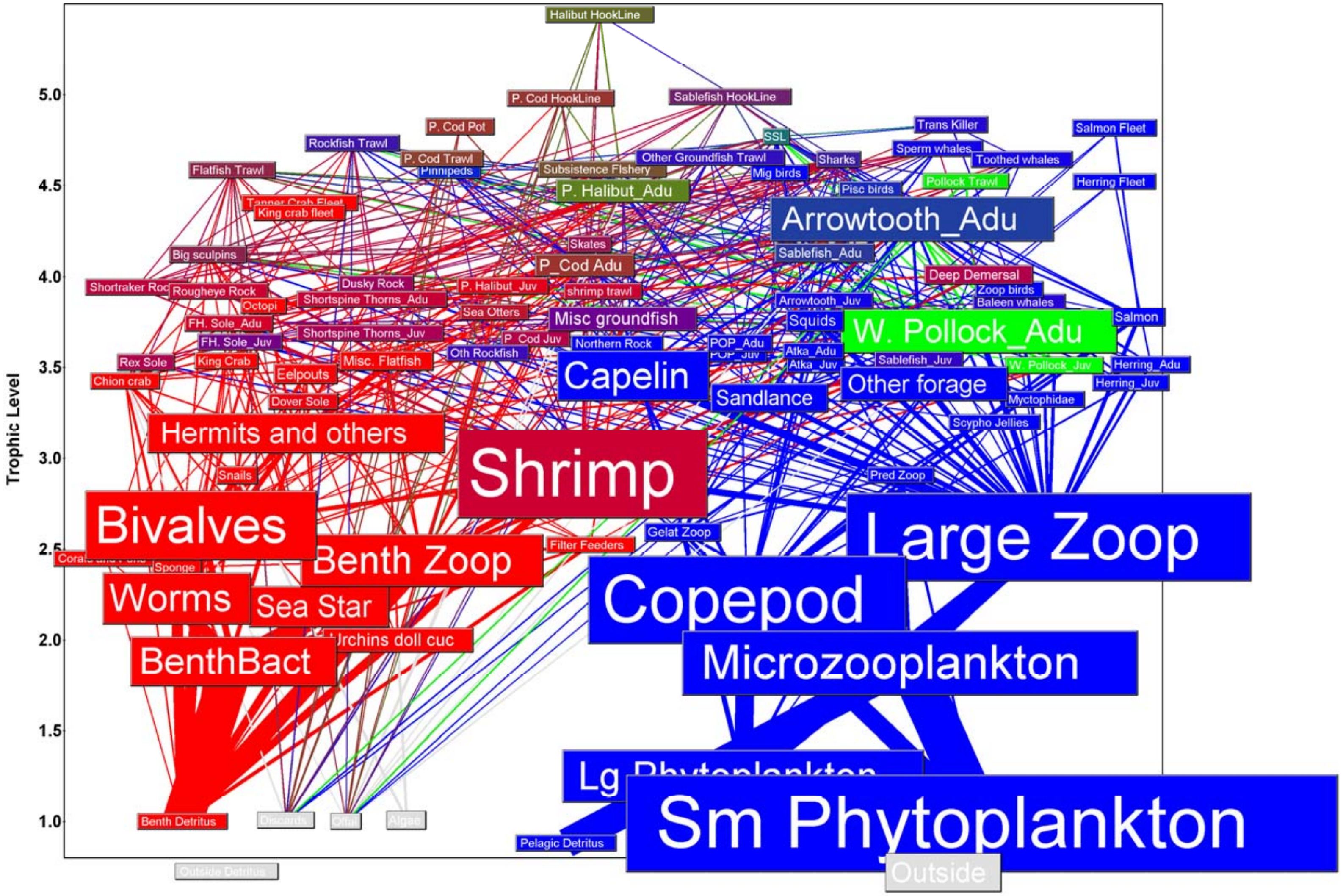
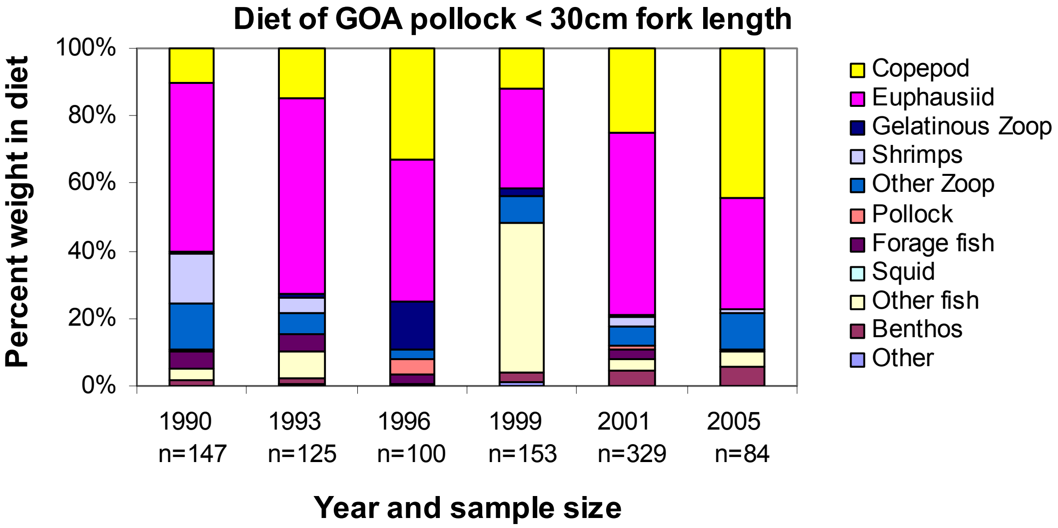


Figure 1.28. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



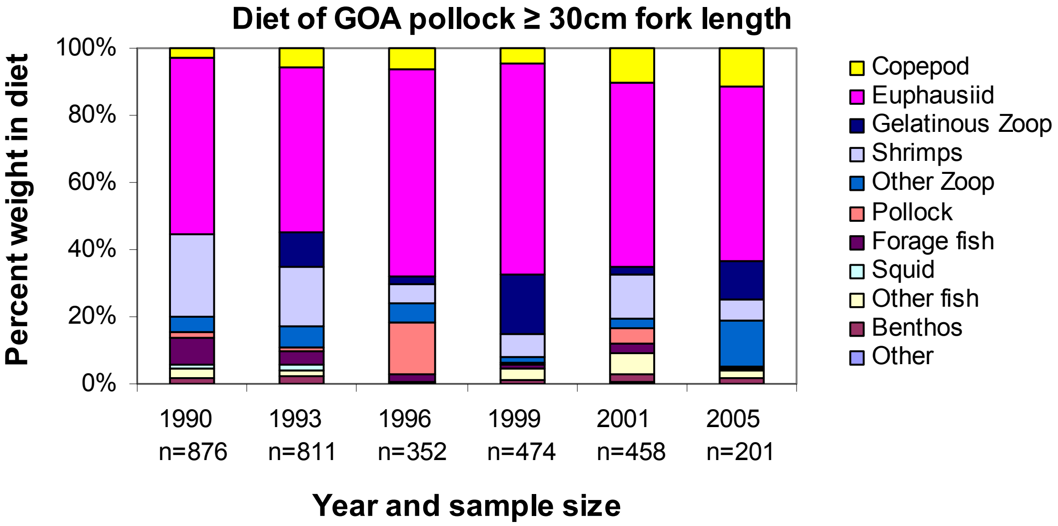
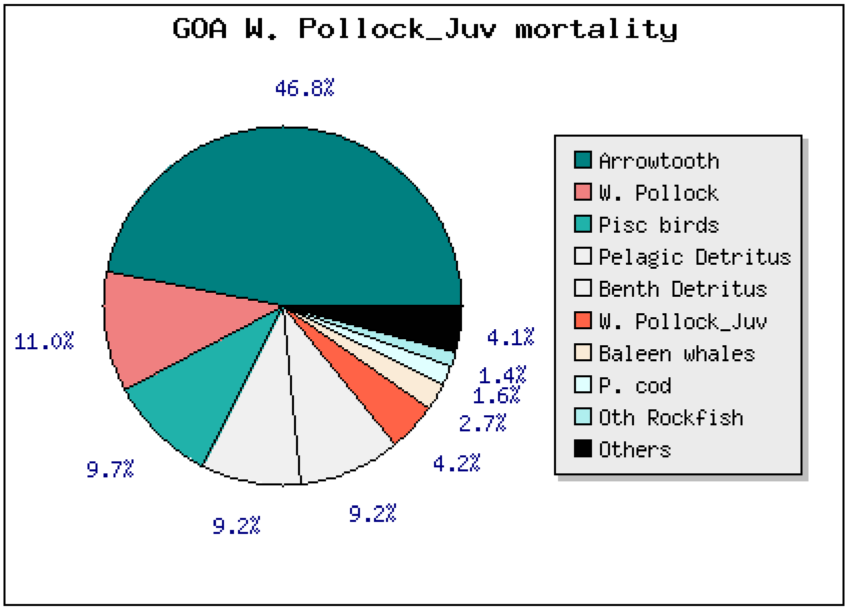


Figure 1.29. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



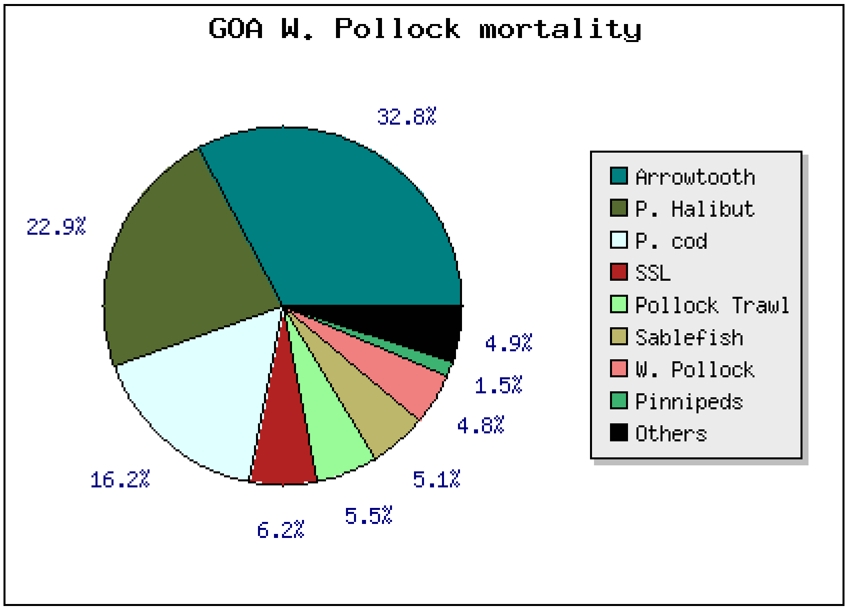


Figure 1.30. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

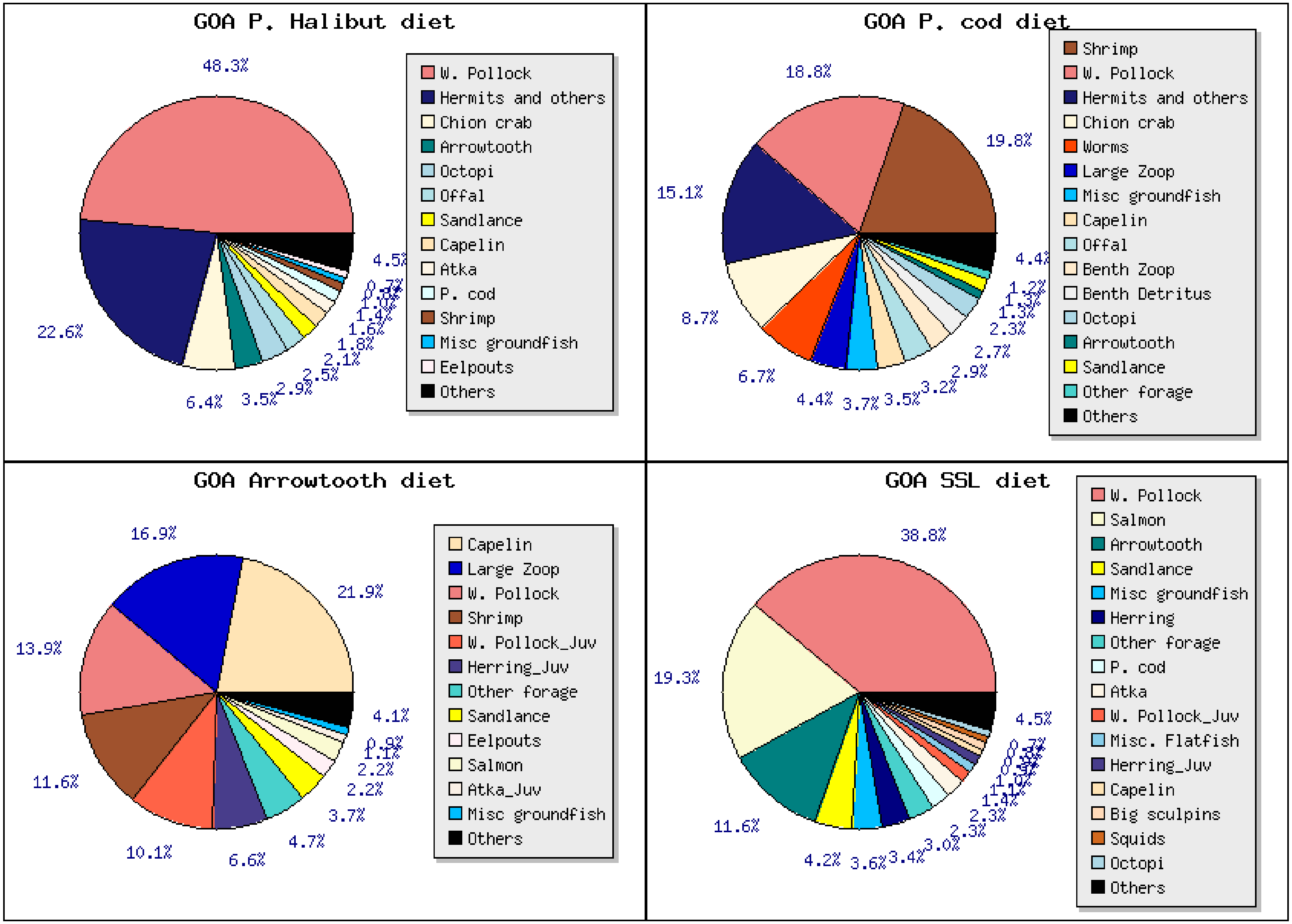


Figure 1.31. Diet diversity of major predators of walleye pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

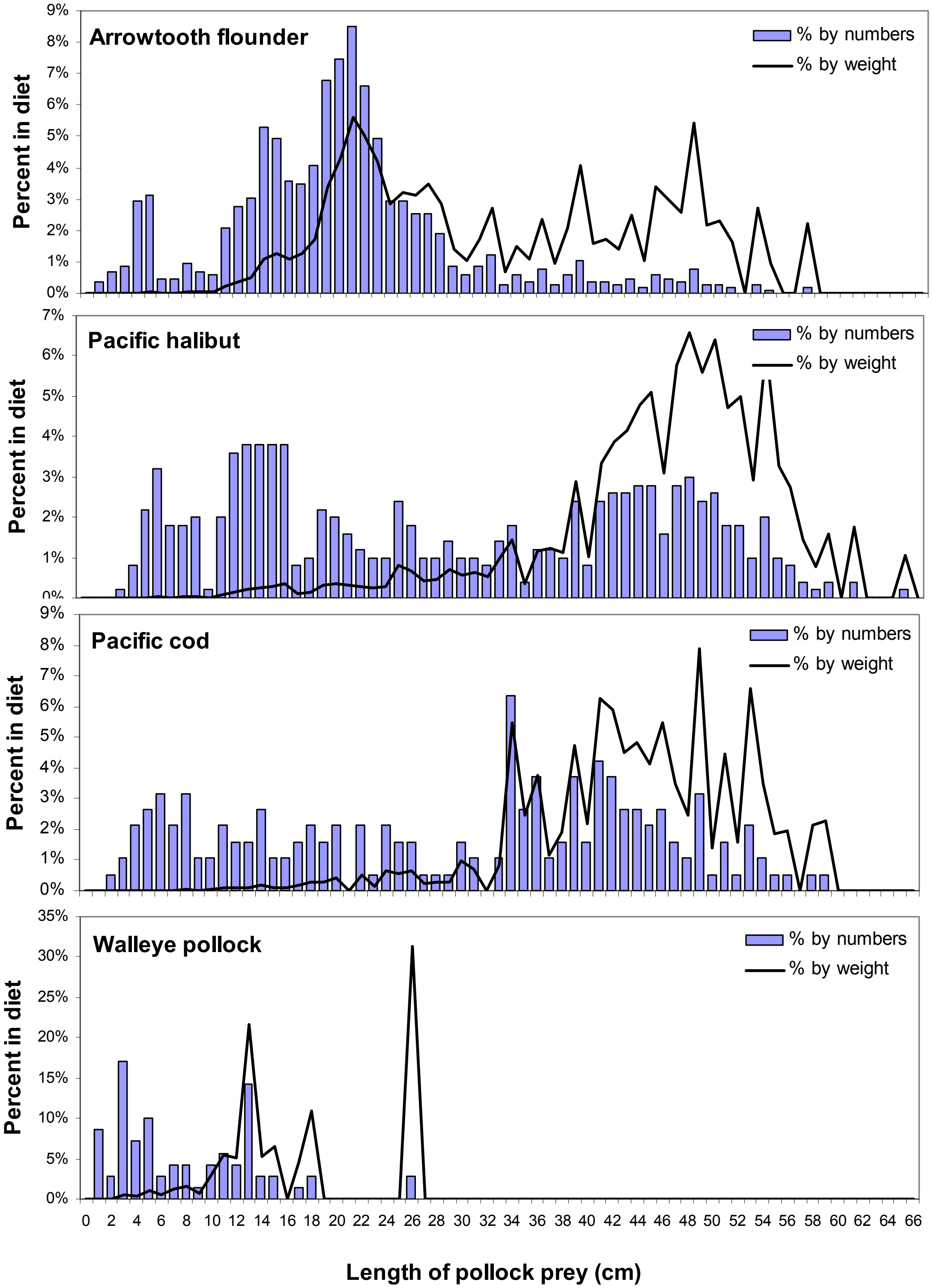
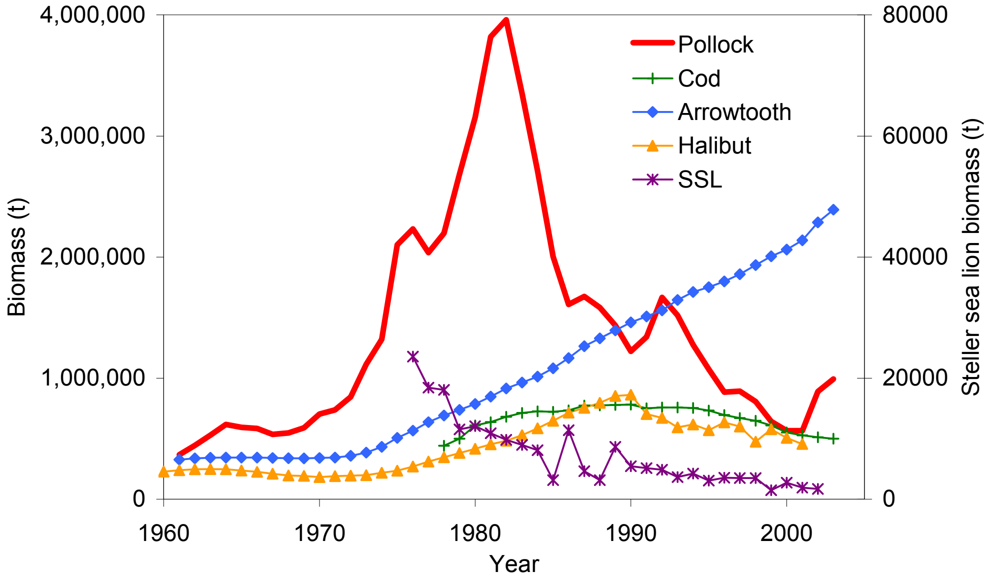


Figure 1.32**.** Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



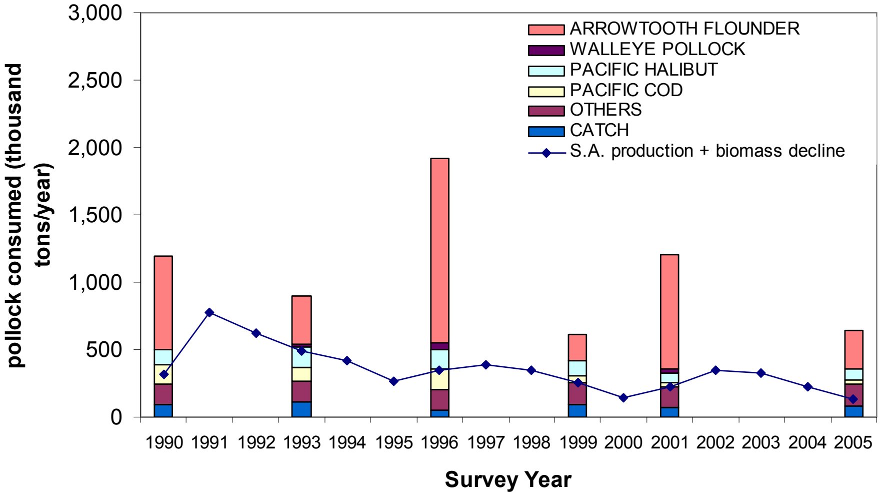


Figure 1.33. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock asessement data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current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

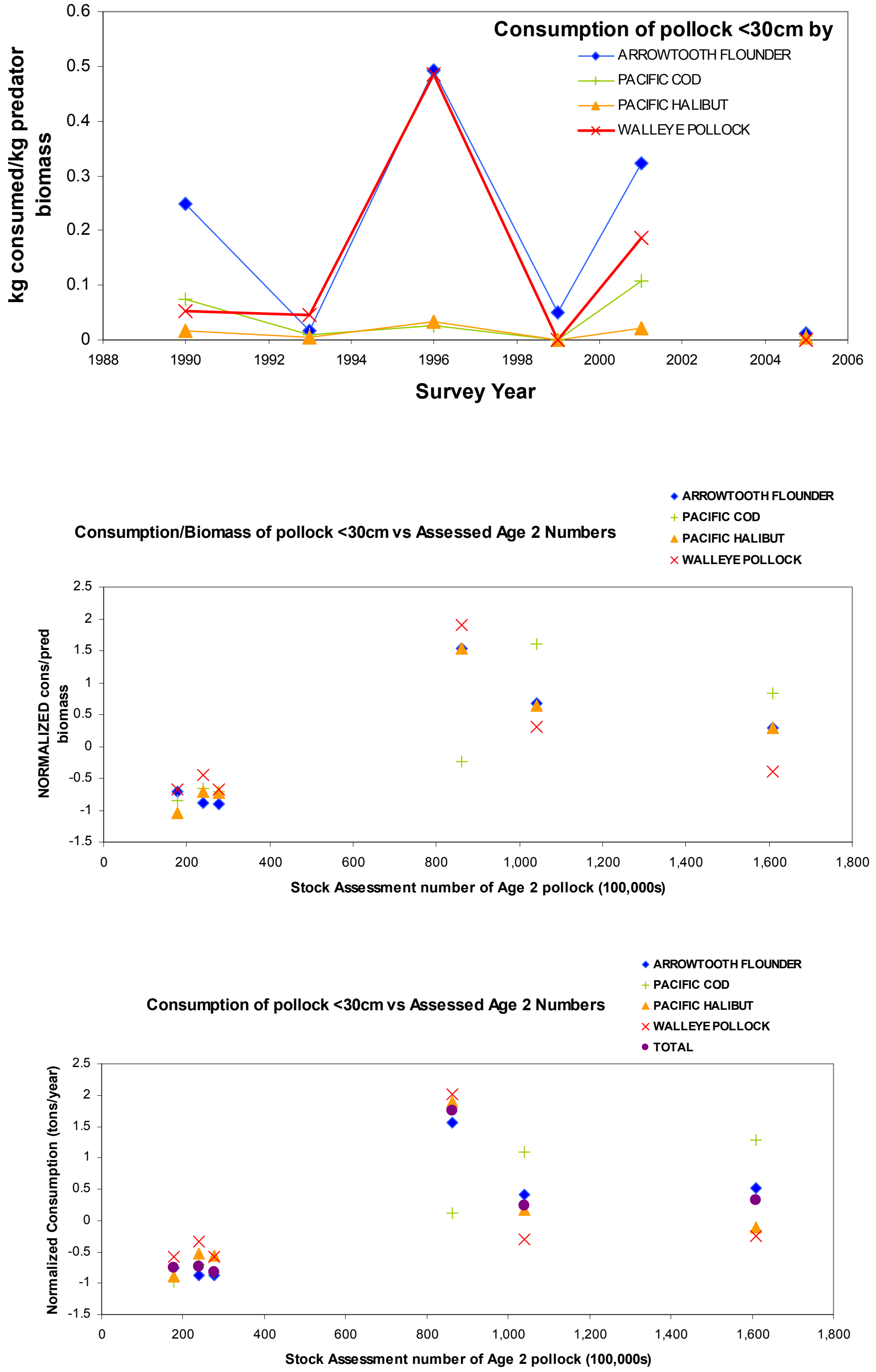


Figure 1.34. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers reported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

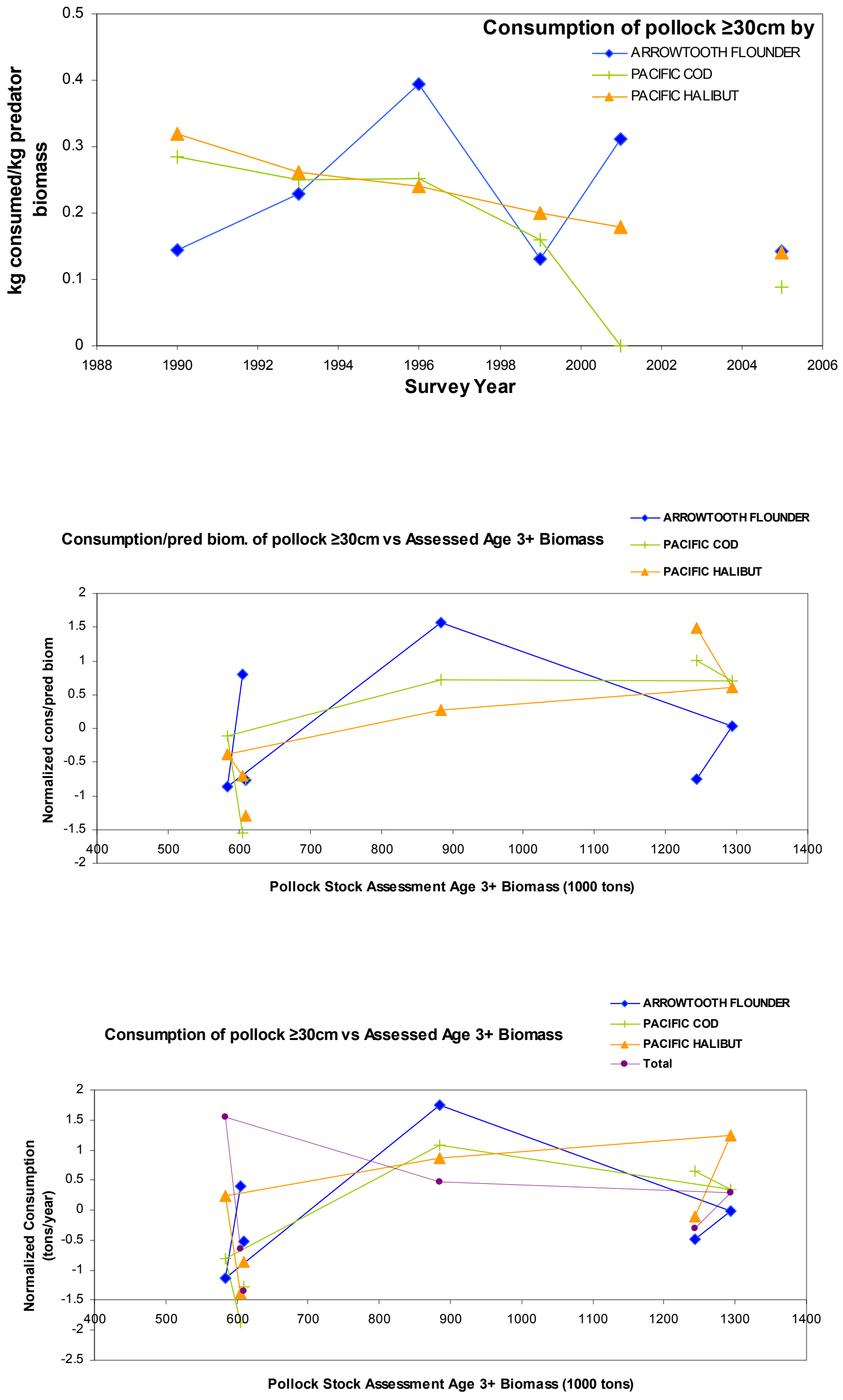


Figure 1.35. (Top) Consumption per unit predator survey biomass of GOA walleye pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass reported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

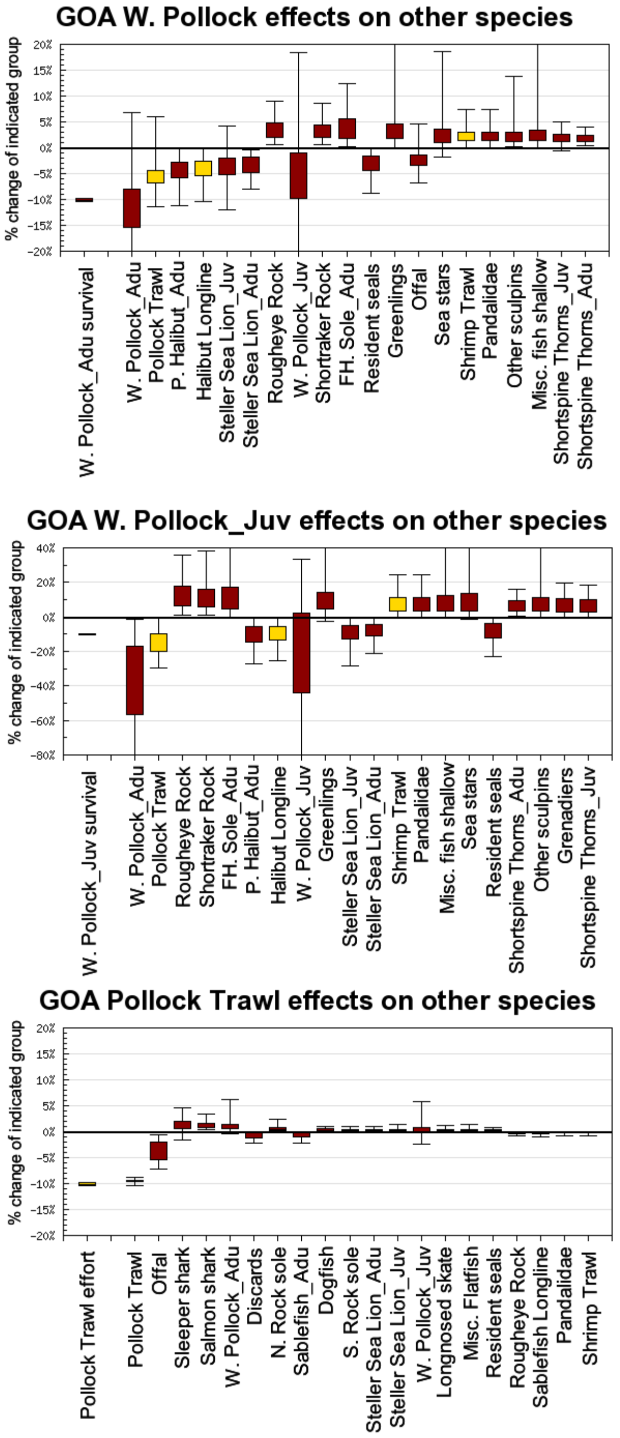
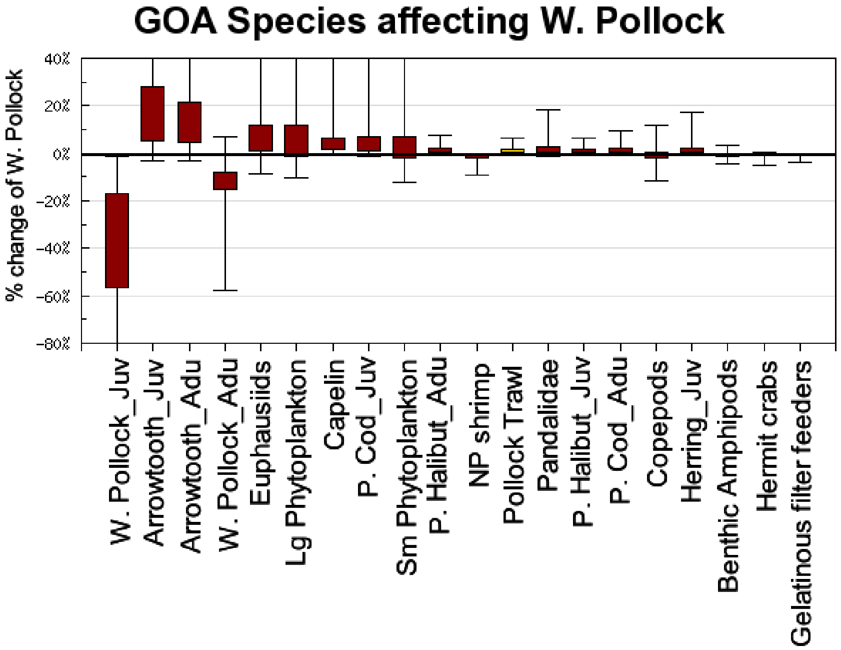


Figure 1.36. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled species, while light bars indicate changes in fisheries catch (landings+discards) assuming a constant fishing rate within the indicated fishery. Graphs show 50% and 95% confidence intervals (bars and lines respectively) summarized over 20,000 ecosystems drawn from error ranges of input parameters (see Aydin et al. 2005 for methodology). Only the top 20 effects, sorted by median, are shown for each perturbation.



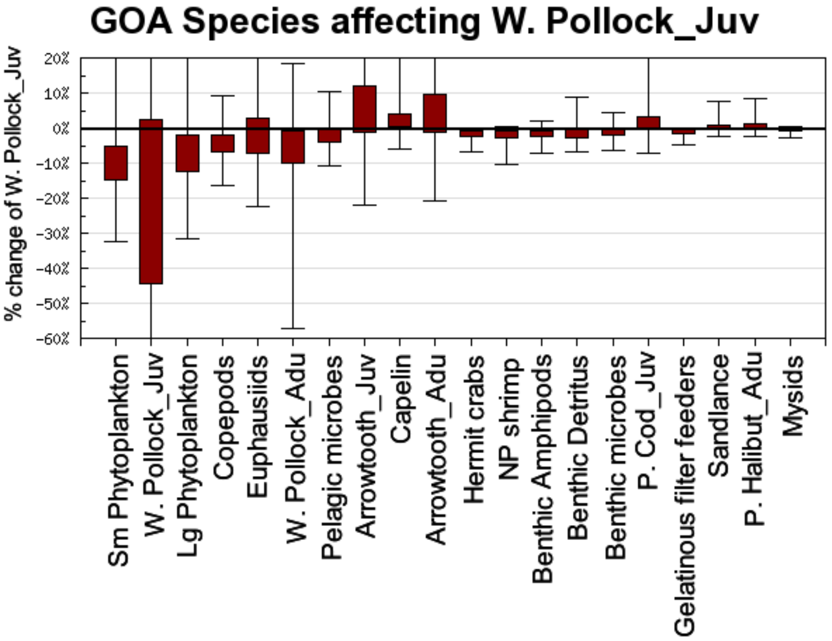


Figure 1.37. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50% and 95% confidence intervals (bars and lines respectively) summarized over 20,000 ecosystems drawn from error ranges of input parameters (see Aydin et al. 2005 for methodology). Only the top 20 effects, sorted by median, are shown for each perturbation.

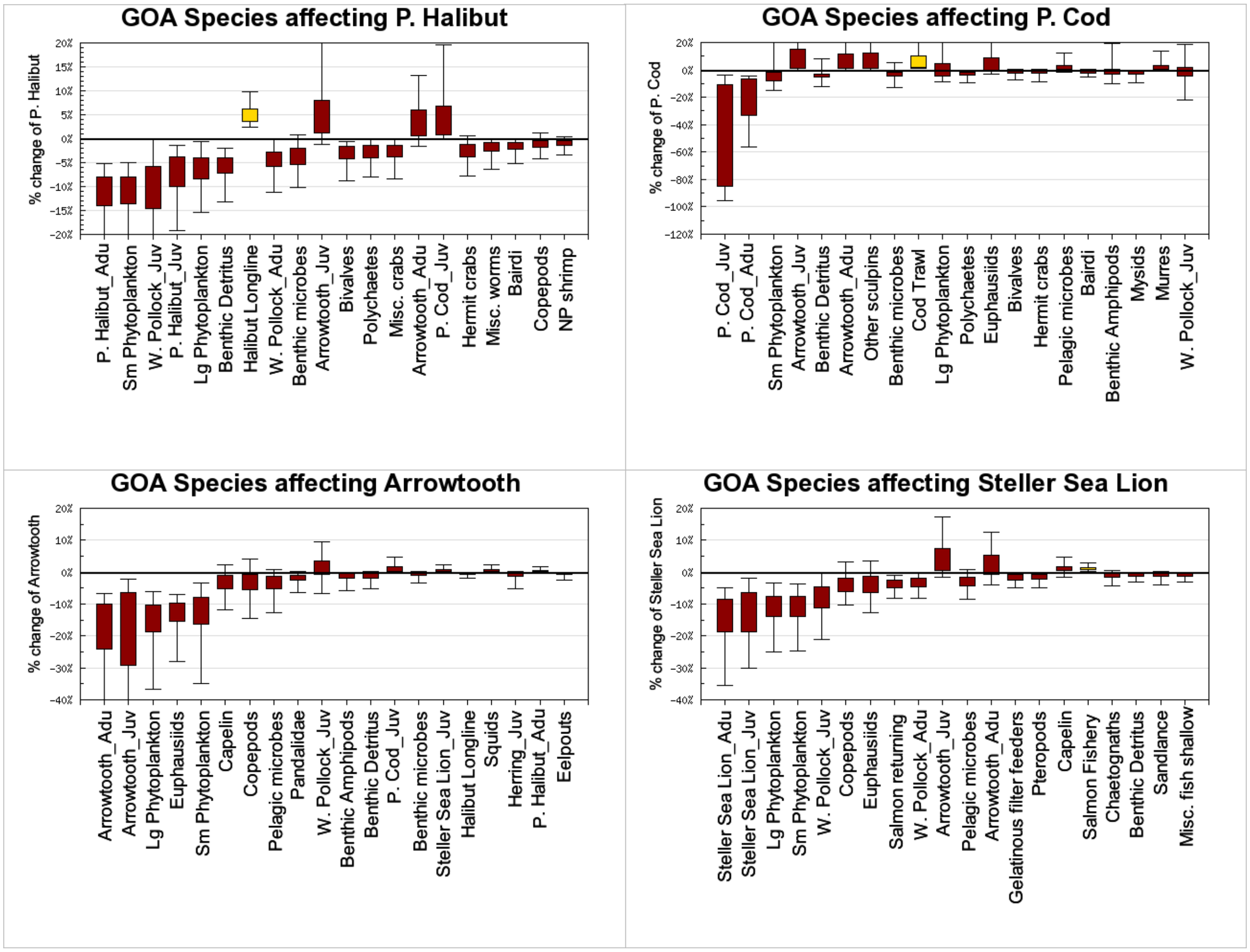


Figure 1.38. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50% and 95% confidence intervals (bars and lines respectively) summarized over 20,000 ecosystems drawn from error ranges of input parameters (see Aydin et al. 2005 for methodology). Only the top 20 effects, sorted by median, are shown for each perturbation.

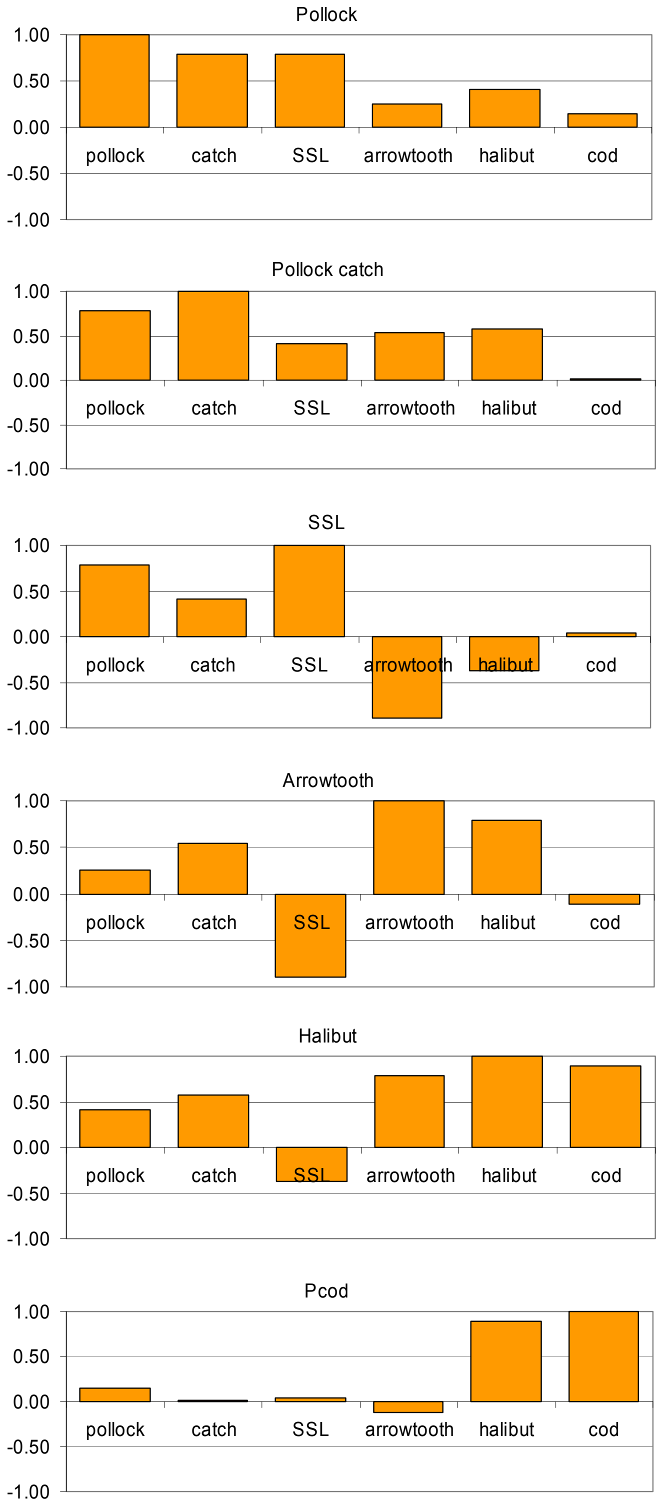


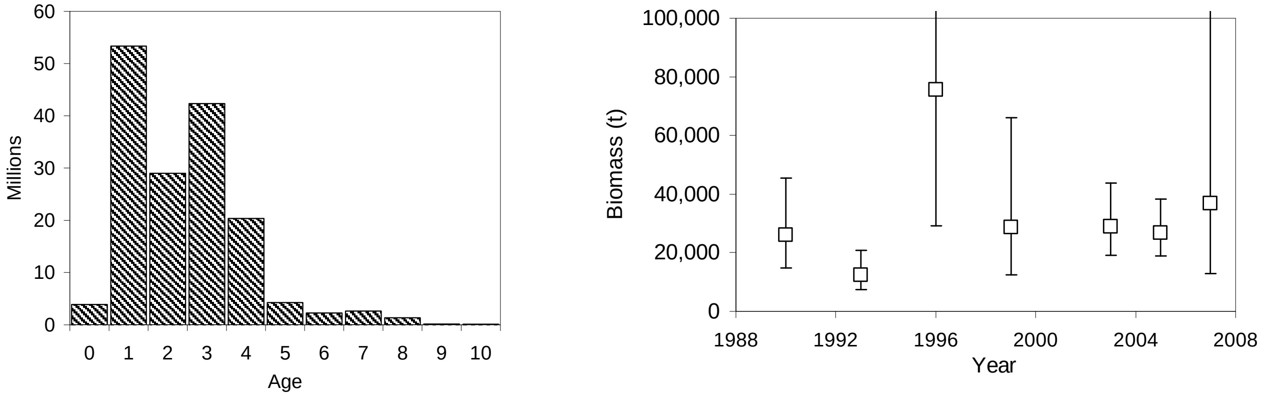
Figure 1.39. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for each pair.

## Appendix A: Southeast Alaska pollock

Bottom trawl surveys indicate a substantial reduction in pollock abundance east of 140° W. lon. Stock structure in this area is poorly understood. Bailey et al. (1999) suggest that pollock metapopulation structure in southeast Alaska is characterized by numerous fiord populations. In the 2005 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Typically, pollock size composition is dominated by smaller fish (<40 cm), but in the 2005 survey there was a strong mode centered on 42 cm (Appendix Fig. 1.1). Juveniles in this area are unlikely to influence the population dynamics of pollock in the central and western Gulf of Alaska. Ocean currents are generally northward in this area, suggesting that juvenile settlement is a result of spawning further south. Spawning aggregations of pollock have been reported from the northern part of Dixon Entrance (Saunders et al. 1988).

Historically, there has been little directed fishing for pollock in southeast Alaska (Fritz 1993). During 1993-2006, pollock catch the Southeast and East Yakutat statistical areas averaged 15 t, but less 1 t since 2000 (Table 1.4). The current ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska.

Pollock biomass estimates from the bottom trawl survey are variable, in part due to year-to-year differences in survey coverage. Surveys since 1996 had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Appendix Figure 1.1). There are no obvious trends in biomass since 1990. We recommend placing southeast Alaska pollock in Tier 5 of NPFMC harvest policy, and basing the ABC and OFL on natural mortality (0.3) and the biomass for the 2007 survey (36,799 t). Biomass in southeast Alaska was estimated by splitting survey strata and CPUE data in the Yakutat INPFC area at 140° W. lon. and combining the strata east of the line with comparable strata in the Southeastern INPFC area. **This results in a 2009 ABC of 8,280 t (36,799 t * 0.75 M), and a 2009 OFL of 11,040 t (36,799 t * M).** These recommendations represent an increase of 37% from 2006 and 2007 recommendations due to the higher estimated biomass in the southeast area in the 2007 NMFS bottom trawl survey. Since no bottom trawl surveys are planned in this area until summer of 2009, the preliminary 2010 ABC and OFL should be set equal to the 2009 values.



Appendix Figure 1.1. Pollock age composition in 2007 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2007 (right). Error bars indicate plus and minus two standard deviations.

# Appendix B: Gulf pollock stock assessment model

## Population dynamics

The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 10, with age 10 defined as a “plus” group, i.e., all individuals age 10 and older. The model extends from 1961 to 2008 (48 yrs). The Baranov (1918) catch equations are assumed, so that

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

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

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

except for the plus group, where

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

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

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

$$F_{ij} = s_j f_i$$

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

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

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

where $\alpha_1$ = 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 (~ $CV$ 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 a either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the *i*th year are given by

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

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

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

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

### *Process error*

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the pollock model, these annual recruitment and fishing mortality parameters are generally estimated as free parameters, with no additional error constraints. We use process error to describe changes in fisheries selectivity over time. To model temporal variation in a parameter $\gamma$, 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 averse effects. Apportioning the TAC also ensures that no smaller component of the stock experiences higher mortality than any other. Although no sub-stock units of pollock have yet been identified in the Gulf of Alaska, it would be precautionary to manage the fishery so that if these sub-units do exist they would not be subject to high fishing mortality. Protection of sub-stock units would be most important during spawning season, when they are spatially separated. The Steller sea lion protection measures implemented in 2001 require apportionment of pollock TAC based on the seasonal distribution of biomass. Although spatial apportionment is intended to reduce the potential impact of fishing on endangered Steller sea lions, it is important to recognize that apportioning the TAC based on an inaccurate or inappropriate estimate of biomass distribution could be detrimental, both to pollock population itself, and on species that depend on pollock.

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

### *Winter distribution*

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

As in previous assessments, a “composite” approach was used to estimate the percent of the total stock in each management area. The estimated biomass for each survey was divided by the total biomass of pollock estimated by the assessment model in that year and then split into management areas for surveys that crossed management boundaries. The percent for each survey was added together to form a composite biomass distribution, which was then rescaled so that it summed to 100%. Model estimates of biomass at spawning took into account the total mortality between the start of the year and spawning, and used mean weight at age from Shelikof Strait surveys.

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

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

Vessel comparison experiments conducted between the *R/V Miller Freeman* and the *R/V Oscar Dyson* in Shelikof Strait in 2007 and in the Shumagin/Sanak area in 2008 found significant differences in the ratio of backscatter between the two vessels. The estimated *R/V Oscar Dyson* to *R/V Miller Freeman* ratio for the Shelikof Strait was 1.132, while the ratio for the Shumagin and Sanak areas (taken together) was 1.31. Since the *R/V Oscar Dyson* was designed to minimize vessel avoidance, biomass estimates produced by *R/V Oscar Dyson* should be considered better estimates of the true biomass than those produced by the *R/V Miller Freeman*. These results imply that the biomass in the western GOA (Sanak and Shumagin areas) has historically been underestimated relative to the central GOA. The leading hypothesis for the higher ratio in the western GOA is that the fish are distributed shallower than in Shelikof Strait, and consequently are exposed to a stronger stimulus from the vessel. When calculating the distribution of biomass by area, multipliers were applied to surveys conducted by the *R/V Miller Freeman* to make them comparable to the *R/V Oscar Dyson* (Appendix table 1.1). No vessel comparisons were conducted in the Chirikof area. A vessel specific multiplier of 1.0 was applied as differential avoidance is not expected at fish depths observed in the Chirikof area, where pollock are distributed primarily at depths greater than 300 m (e.g. in 2008 90% of pollock biomass was deeper than 275 m). No evidence for differential backscatter was found for fish deeper than 275 m in vessel comparison experiments conducted during the Shelikof and Bogoslof surveys (no pollock were observed at these depths in the Shumigans), although significant differences were observed at shallower depths.

The sum of the percent biomass for all surveys combined was 101.8%, 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 32.01%, 53.59%, 14.40% in areas 610, 620, and 630 (Appendix table 1.1). In comparison to last year’s assessment, a higher percentage was estimated in area 610 (+5 percentage points) and area 630 (+1 percentage points), and lower percentage in area 620 (-7 percentage points).

### *A-season apportionment between areas 620 and 630*

In the 2002 assessment, based on evaluation of fishing patterns which suggested that the migration to spawning areas was not complete by January 20, the plan team recommended an alternative apportionment scheme for areas 620 and 630 based on the midpoint of the summer and winter distributions in area 630. This approach was not used for area 610 because fishing patterns during the A season suggested that most of the fish captured in area 610 would eventually spawn in area 610. The resulting A season apportionment using updated survey data is: 610, 32.01%; 620, 43.22%; 630, 24.77%.

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

The apportionment for area 640, which is not managed by season, has previously been based on the summer distribution of the biomass. Fishing, however, takes places primarily in winter or early spring on a spawning aggregation near Middleton Island. During 28-29 March 2003, this area was surveyed by the NOAA ship *Miller Freeman* for the first time and biomass estimate of 6,900 t was obtained. Although maturity stage data suggested the timing of the survey was appropriate, discussions with fishing vessels contacted during the survey raised some questions about survey timing relative to peak biomass. Notwithstanding, a tier 5 calculation based on this spawning biomass gives an ABC of 1,550 t (6,901 t * 0.75 M), compared to 1,560 t for the author’s 2008 ABC recommendation and an apportionment based on the summer biomass distribution. This suggests that the current approach of basing the area 640 apportionment on the gulfwide ABC and the summer biomass distribution is at least consistent with the biomass present near Middleton Island in the winter. We recommend continuing this approach until sufficient survey information during winter has accumulated to evaluate interannual variation in the biomass present in this area.

### *Summer distribution*

The NMFS bottom trawl is summer survey (typically extending from mid-May to mid-August). Because of large shifts in the distribution of pollock between management areas one survey to the next, and the high variance of biomass estimates by management area, Dorn et al. (1999) recommended that the apportionment of pollock TAC be based upon the four most recent NMFS summer surveys. The four-survey average was updated with 2005 survey results in an average biomass distribution of 42.20%, 20.76%, 34.12%, and 2.92% in areas 610, 620, 630, and 640 (Appendix Fig. 1.2).

***Example calculation of 2008 Seasonal and Area TAC Allowances for W/C/WYK***

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

1) Deduct the Prince William Sound Guideline Harvest Level.

2) Use summer biomass distribution for the 640 allowance:

640 0.0292 x Total TAC = 2,920 t

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

A season 0.25 x (Total TAC – 2,920) = 24,270 t
B season 0.25 x (Total TAC – 2,920) = 24,270 t
C season 0.25 x (Total TAC – 2,920) = 24,270 t
D season 0.25 x (Total TAC – 2,920) = 24,270 t

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

610 0.3201 x 24,270 t = 7,769 t
620 0.4322 x 24,270 t = 10,489 t
630 0.2477 x 24,270 t = 6,012 t

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

610 0.3201 x 24,270 t = 7,769 t
620 0.5359 x 24,270 t = 13,006 t
630 0.1440 x 24,270 t = 3,495 t

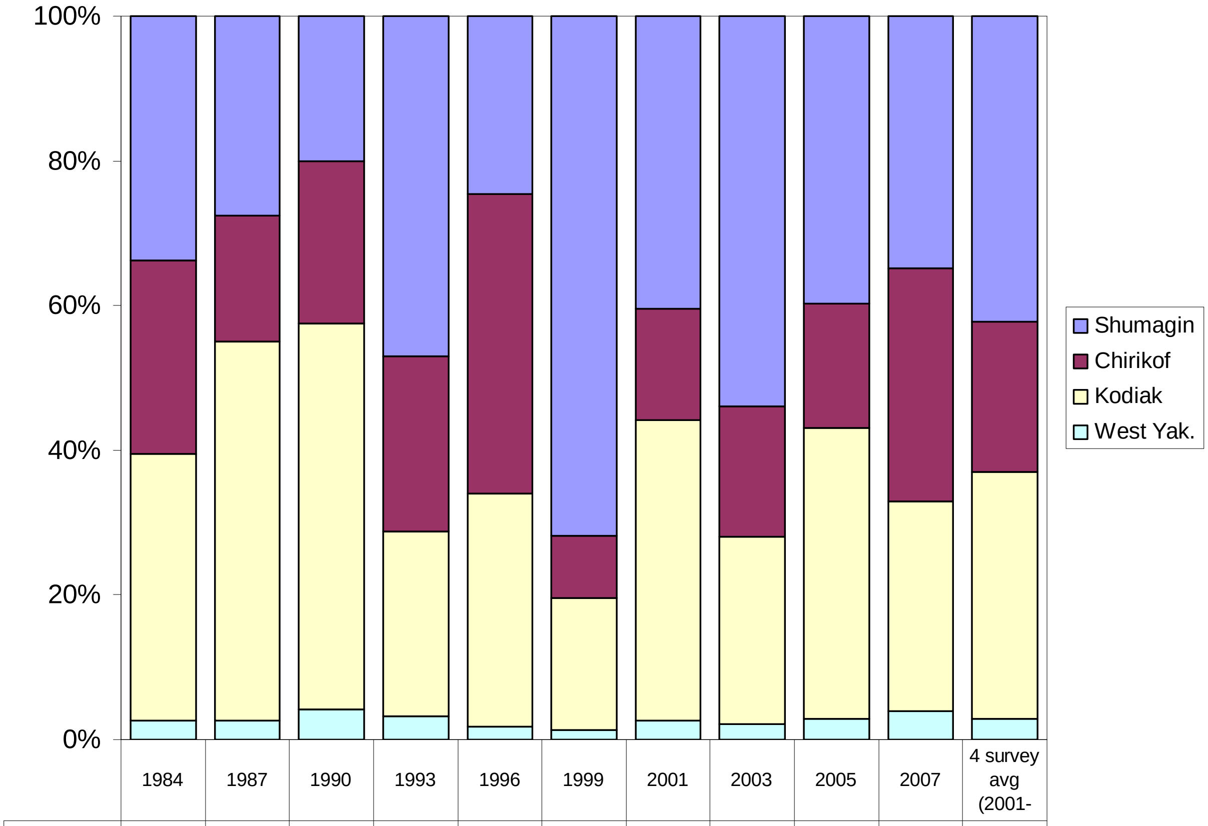
6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the average biomass distribution in areas 610, 620 and 630 in the most recent four NMFS bottom trawl surveys of 42.20%, 20.76%, 34.12%, and 2.92%.

610 0.4220 / (1 – 0.0292) x 24,270 = 10,552 t
620 0.2076 / (1 – 0.0292) x 24,270 = 5,189 t
630 0.3412 / (1 – 0.0292) x 24,270 = 8,529 t

610 0.4220 / (1 – 0.0292) x 24,270 = 10,552 t
620 0.2076 / (1 – 0.0292) x 24,270 = 5,189 t
630 0.3412 / (1 – 0.0292) x 24,270 = 8,529 t

Appendix Table 1. Estimates of percent pollock in areas 610-630 during winter EIT surveys in the Gulf of Alaska. The biomass of age-1 pollock The biomass of age-1 fish is not included in Shelikof Strait EIT survey estimates in 2005 and 2008 (18,100 t and 19,090 t respectively), and Shumagin survey estimates in 2006 and 2008 (12,310 t and 9,339 t respectively).

| | | | | | | *Percent by management area* | | |
|---|---|---|---|---|---|---|---|---|
| *Survey* | *Year* | *Model estimates of total 2+ biomass at spawning* | *Survey biomass estimate* | *Multiplier from vessel comparison (OD/MF)* | *Percent* | *Area 610* | *Area 620* | *Area 630* |
| Shelikof | 2005 | 506,927 | 338,038 | 1.13 | 66.7% | 0.0% | 97.8% | 2.2% |
| Shelikof | 2006 | 468,520 | 293,609 | 1.13 | 62.7% | 0.0% | 96.1% | 3.9% |
| Shelikof | 2007 | 451,632 | 180,881 | 1.13 | 40.1% | 0.0% | 97.1% | 2.9% |
| Shelikof | 2008 | 557,950 | 188,942 | 1.00 | 33.9% | 0.0% | 93.4% | 6.6% |
| Shelikof | Average | | | | 50.8% | 0.0% | 96.1% | 3.9% |
| | Percent of total 2+ biomass | | | | | 0.0% | 48.8% | 2.0% |
| Chirikof | 2005 | 506,927 | 77,000 | 1.00 | 15.2% | 0.0% | 47.8% | 52.2% |
| Chirikof | 2006 | 468,520 | 69,000 | 1.00 | 14.7% | 0.0% | 28.3% | 71.7% |
| Chirikof | 2007 | 451,632 | 35,573 | 1.00 | 7.9% | 0.0% | 24.0% | 76.0% |
| Chirikof | 2008 | 557,950 | 22,055 | 1.00 | 4.0% | 0.0% | 50.2% | 49.8% |
| Chirikof | Average | | | | 10.4% | 0.0% | 37.6% | 62.4% |
| | Percent of total 2+ biomass | | | | | 0.0% | 3.9% | 6.5% |
| Shumagin | 2005 | 506,927 | 51,970 | 1.31 | 13.4% | 99.9% | 0.1% | 0.0% |
| Shumagin | 2006 | 468,520 | 25,028 | 1.31 | 7.0% | 92.8% | 7.2% | 0.0% |
| Shumagin | 2007 | 451,632 | 20,009 | 1.31 | 5.8% | 98.5% | 1.5% | 0.0% |
| Shumagin | 2008 | 557,950 | 21,244 | 1.31 | 5.0% | 77.2% | 22.8% | 0.0% |
| Shumagin | Average | | | | 7.8% | 92.1% | 7.9% | 0.0% |
| | Percent of total 2+ biomass | | | | | 7.2% | 0.6% | 0.0% |
| Sanak | 2005 | 506,927 | 67,800 | 1.31 | 17.5% | 100.0% | 0.0% | 0.0% |
| Sanak | 2006 | 468,520 | 127,214 | 1.31 | 35.6% | 100.0% | 0.0% | 0.0% |
| Sanak | 2007 | 451,632 | 60,289 | 1.31 | 17.5% | 100.0% | 0.0% | 0.0% |
| Sanak | 2008 | 557,950 | 19,750 | 1.31 | ` | 100.0% | 0.0% | 0.0% |
| Sanak | Average | | | | 23.5% | 100.0% | 0.0% | 0.0% |
| | Percent of total 2+ biomass | | | | | 23.5% | 0.0% | 0.0% |
| Karp (1990) | 1990 | 986,372 | 78,134 | 1.00 | 7.9% | 18.4% | 6.3% | 75.3% |
| | Average | | | | 7.9% | 18.4% | 6.3% | 75.3% |
| | Percent of total 2+ biomass | | | | | 1.5% | 0.5% | 6.0% |
| Total | | | | | 100.51% | 32.17% | 53.86% | 14.47% |
| Rescaled total | | | | | 100.00% | 32.01% | 53.59% | 14.40% |



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

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

## Appendix D: FOCI Gulf of Alaska Walleye Pollock 2008 Year-Class Prediction

### DATA

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

1. Kodiak total monthly precipitation.(inches) prepared by the Kodiak National Weather Service office (http://padq.arh.noaa.gov/) from hourly observations. Data for 2008 were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.

2. Wind mixing energy at [57°N, 156°W] estimated from sea-level pressure analyses for 2008. Monthly estimates of wind mixing energy (W $m^{-2}$) were computed for a location near the southwestern end of Shelikof Strait. To make the estimates, twice-daily gradient winds were computed for that location using the METLIB utility (Macklin *et al.*, 1984). Gradient winds were converted to surface winds using an empirical formula based on Macklin *et al.* (1993). Estimates of wind mixing energy were computed using constant air density (1.293 kg $m^{-3}$) and the drag coefficient formulation of Large and Pond (1982).

3. Advection of ocean water near Shelikof Strait inferred from wind and transport data during the spring of 2008.

4. Rough estimates of pollock larvae abundance from a survey conducted in late May 2008.

5. Estimates of age-2 pollock abundance and spawner biomass from the 2008 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.

It was a year of extremes. The season began with drying in January, followed by wetter than normal (30-year mean) conditions through March (Table 1). This increased the potential for formation of baroclinic instabilities prior to and during spawning. April was relatively dry, however the later spring months brought record rain, with May 2008 being the all-time wettest May. The spring may have presented favorable eddy habitat for late larval- and early juvenile-stage walleye pollock, although one might question the contribution of such extreme rain to favorable larval survival.

**TABLE 1. Kodiak precipitation for 2008.**

| Month | % 30-yr average |
|---|---|
| Jan | 58 |
| Feb | 161 |
| Mar | 174 |
| Apr | 54 |
| May | 267 |
| June | 147 |

Based on this information, the forecast element for Kodiak 2008 rainfall has a score of 2.49. This is "average to strong" recruitment on the 5-category continuum from 1 (weak) to 3 (strong), and “strong” using three categories.

***Wind Mixing****:* Wind mixing at the southern end of Shelikof Strait was below the long-term average for five of the first six months of 2008 (Table 2).

**TABLE 2. Wind mixing at the exit of Shelikof Strait for 2008.**

| Month | % 30-yr average |
|---|---|
| Jan | 67 |
| Feb | 64 |
| Mar | 44 |
| Apr | 81 |
| May | 105 |
| June | 50 |

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 produced a wind mixing score of 1.97, which equates to "average" on 3- and 5-category scales.

***Winds and Transport in the Alaska Coastal Current:*** There were very limited direct oceanographic measurements of transport during 2008, but transport in Shelikof Strait is well correlated with the along-shore winds. An examination of the atmospheric pressure patterns and available wind data indicates that wind forcing in spring 2008 was average. This supports the few direct observations taken. Thus, the prediction is that transport was average for 2008. Very strong transport tends to remove larvae from the sea valley and is often associated with poor year classes. Weak to moderate transport after hatching is necessary (but not sufficient) to support an above- average year class.

Based on these observations, the 2008 pollock year-class prediction from transport information would indicate an average year class. We give this element a score of 2.0, which equates to average.

***Relating the Larval Index to Recruitment**:* As in previous analyses, a nonlinear neural network model with one input neuron (larval abundance), three hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (CPUA, average catch, $m^{-2}$) to age-2 recruitment abundance (billions). The model estimated eight weighting parameters.

The neural network model, which used the 22 observation pairs of Table 3 to fit the model, had a very low $R^2$ of 0.041. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) is given in Fig. 1, where row number corresponds to the rows of the data matrix given in Table 3 and thus indicates year class.

**TABLE 3. Data used in the neural network model.**

| Year Class | Mean CPUA | Recruit |
|---|---|---|
| 1982 | 71.14 | 0.212121 |
| 1985 | 80.42 | 0.562104 |
| 1987 | 329.74 | 0.381159 |
| 1988 | 260.21 | 1.64472 |
| 1989 | 537.29 | 1.02849 |
| 1990 | 335 | 0.411432 |
| 1991 | 54.22 | 0.245024 |
| 1992 | 562.79 | 0.149022 |
| 1993 | 185.34 | 0.226235 |
| 1994 | 126.58 | 0.880295 |
| 1995 | 610.33 | 0.422492 |
| 1996 | 477.69 | 0.180603 |
| 1997 | 568.42 | 0.164458 |
| 1998 | 72.2 | 0.223236 |
| 1999 | 96.14 | 0.857654 |
| 2000 | 492.04 | 0.746177 |
| 2001 | 171.3 | 0.110101 |
| 2002 | 175.64 | 0.096409 |
| 2003 | 135.36 | 0.100795 |
| 2004 | 21.22 | 0.528081 |
| 2005 | 76.22 | 0.502001 |
| 2006 | 327.69 | 0.693409 |
| 2007 | 71.15 | |
| 2008 | 111.83 | |

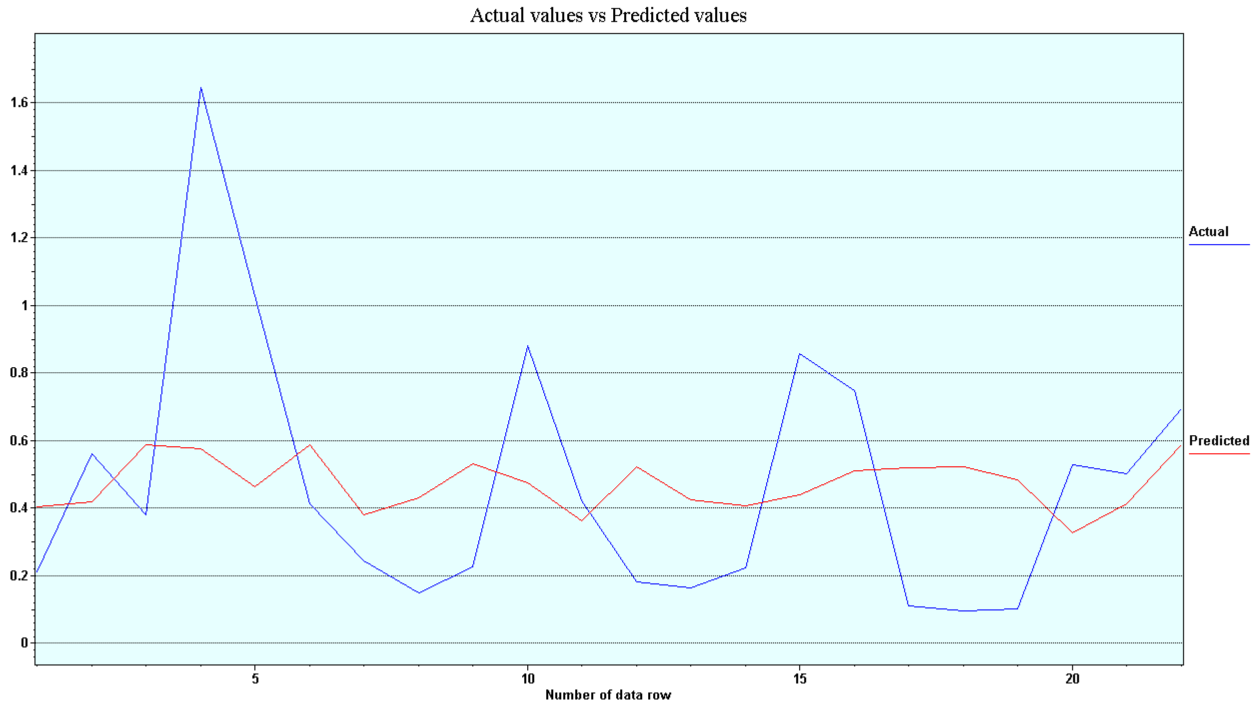


**FIGURE 1. Observed and predicted recruitment values from the larval index-recruitment neural network model.**

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

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

| Year | Actual Recruitment | Predicted Recruitment |
|---|---|---|
| 2006 | n/a | 0.430 |
| 2007 | n/a | 0.458 |

These values, using the 33% (0.3579) and 66% (0.7011) cutoff points given below, correspond to an average 2006 year class and an average 2007 year class or a score of 2.0.

***Larval Index Counts:*** Plotting the larval abundance data by year and binning the data into catch/10 $m^2$ categories (given below) provides another view of the data. The pattern for 2008 (based on rough counts) differs from last year in that the frequency distribution is skewed towards lower binning categories (Figure 2). These patterns indicate that the 2008 year class may be average because, in general, other years with low binning categories correspond to average recruitment.

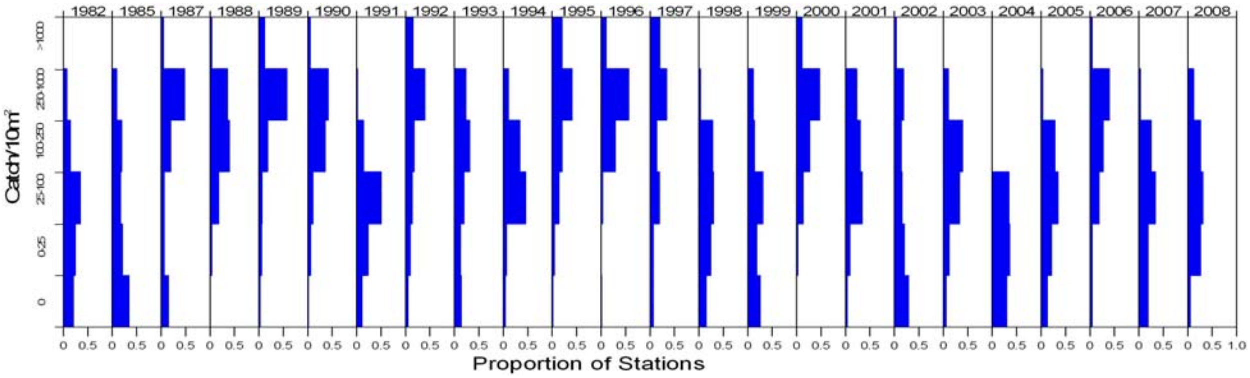


**FIGURE 2. A series of histograms for larval walleye pollock densities in late May from 1982 to 2008. Data were binned into catch/10 m$^2$ categories. The data from 2000-2006 are actual verified larval counts, 2007 are unverified counts from the Polish Plankton Sorting Institute, and 2008 data are rough counts from the 4DYF08 FRV *Oscar Dyson* survey cruise that was completed in late May.**

The data for Figures 3-7 are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae. This year's distribution of pollock (Fig. 7) appears to be centered in the typical reference area, and the spatial pattern is similar compared to previous years. The larval abundance figures in the middle of the reference of Figure 7 seem to be average. Comparing the catch rates (Fig. 2) shows that the 2008 rough counts seem to be distributed to middle to high values compared to 2007, and the distribution of larvae in 2008 (Fig. 7) compared to last year (Fig. 6) was spatially similar. Given these two pieces of information, the score for larval index is set to the high end of average or 2.33.

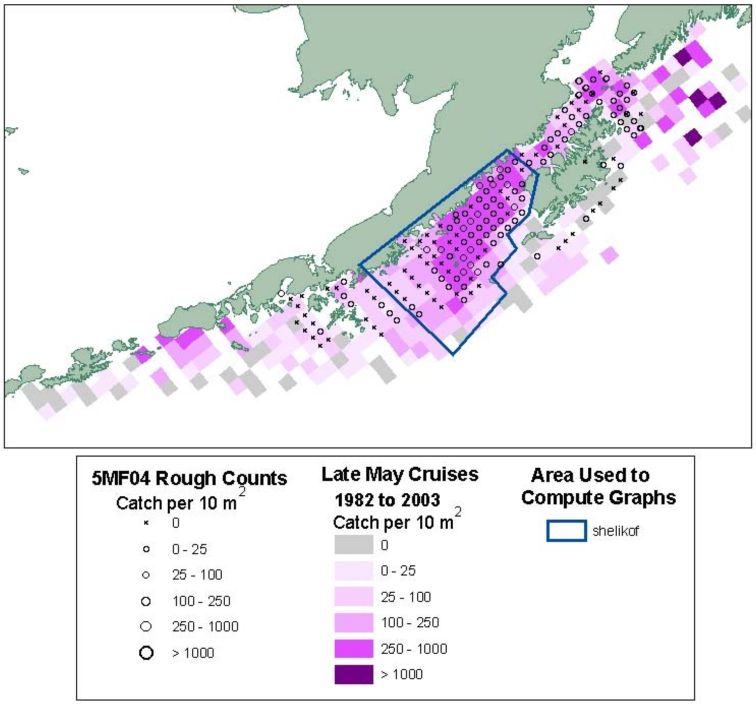


**FIGURE 3. Mean catch per 10 m$^2$ for late May cruises during 1982-2003, with observed rough counts overlayed for 2004.**

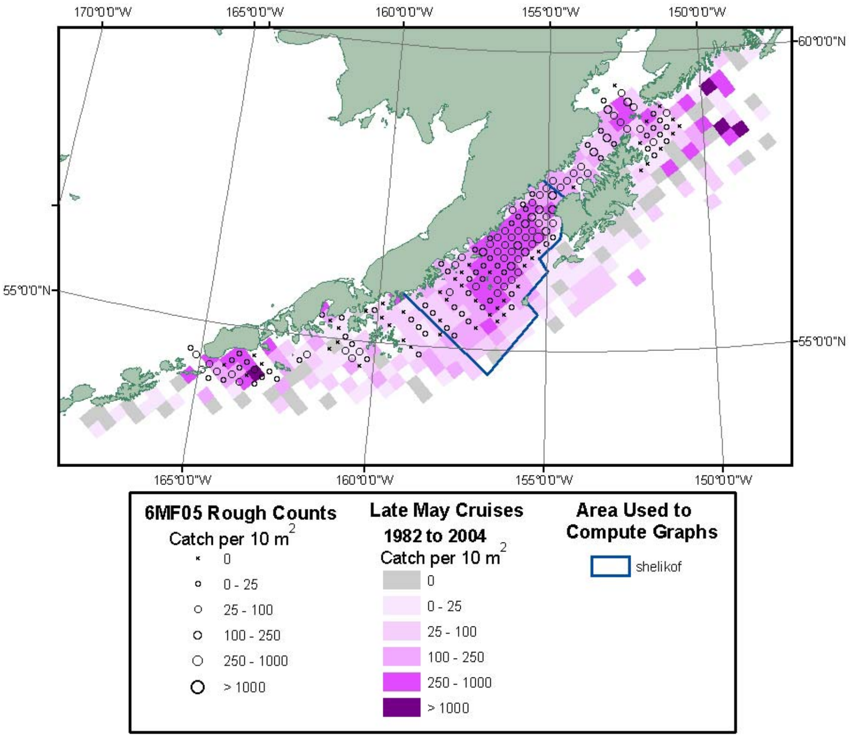


**FIGURE 4. Mean catch per 10 m$^2$ for late May cruises during 1982-2004, with observed rough counts overlayed for 2005.**

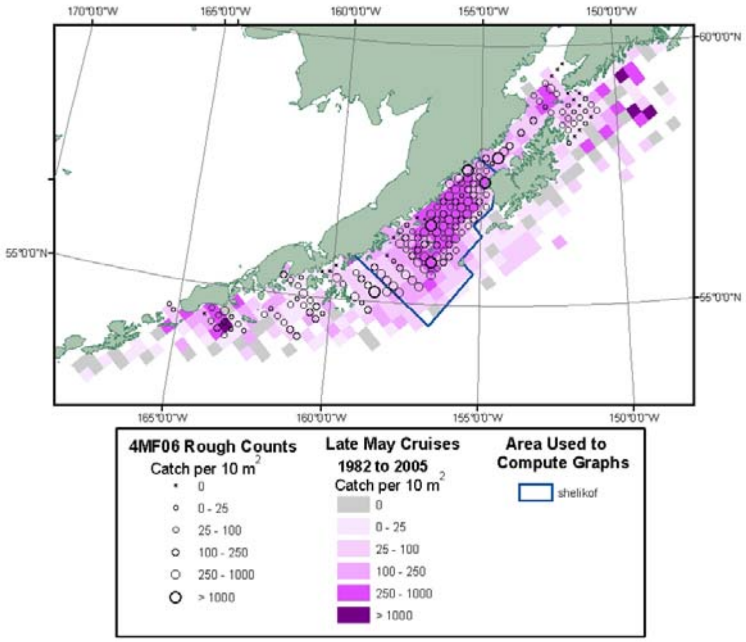


**FIGURE 5. Mean catch per 10 m$^2$ for late May cruises during 1982-2005, with observed rough counts overlayed for 2006.**

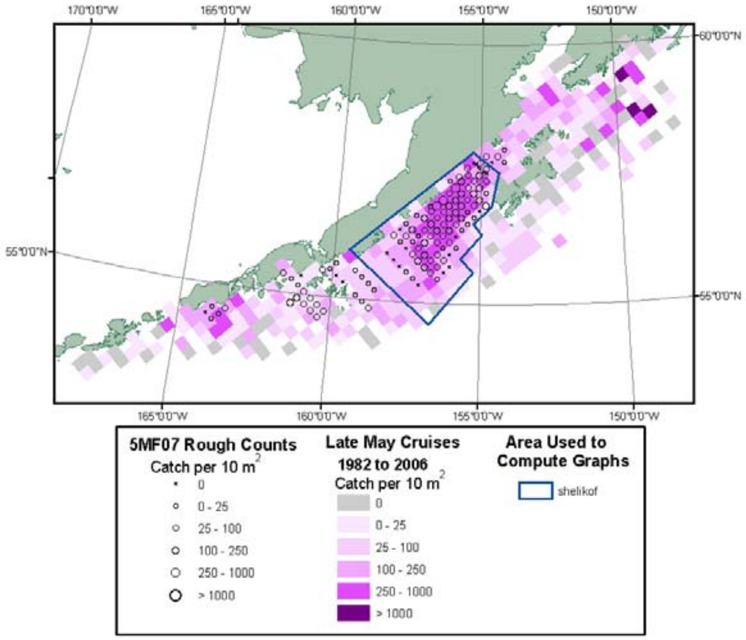


**FIGURE 6. Mean catch per 10 m$^2$ for late May cruises during 1982-2006, with observed rough counts overlayed for 2007.**

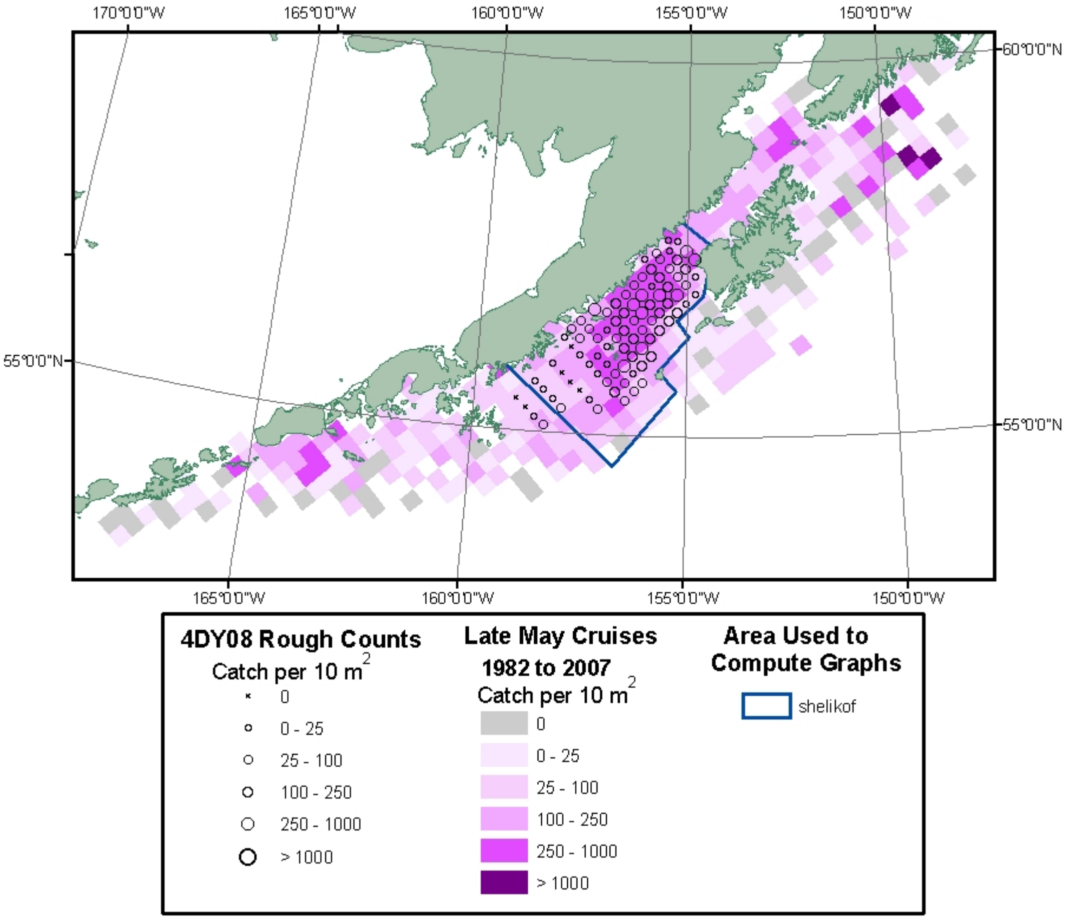


**FIGURE 7. Mean catch per 10 m$^2$ for late May cruises during 1982-2007, with observed rough counts overlayed for 2008.**

***Recruitment Time Series***: The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition in time. The data set consisted of age-2 pollock abundance estimates from 1961-2008, representing the 1959-2006 year classes. There were a total of 48 recruitment data points. The 33% (0.3579 billion) and 66% (0.7011 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 2008 year class could be predicted from the size of the 2006 year class. The 2006 year class was estimated to be 0.6934 billion and was classified as average. The probabilities of other recruitment states following an average year class for a lag of 2 years (n=48) are given below:

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

| 2008 Year Class | | 2006 Year Class | Probability | N |
|---|---|---|---|---|
| Weak | Follows | Average | 0.1304 | 6 |
| Average | Follows | Average | 0.1087 | 5 |
| Strong | Follows | Average | 0.0652 | 3 |

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

***Spawner/Recruit Time Series**:* The data from the previous analysis only looked at the time sequence of the recruitment data points. This section looks at both the recruitment (R) and the spawning biomass (SB) in the context of transition probabilities after Rothschild and Mullin (1985). The benefit is that it is non-parametric, and it provides a way to predict recruitment without applying a presumed functional spawner-recruit relationship. It involves partitioning the spawning stock into N-tiles and the recruitment into N-tiles, classifying the stock into NxN states. We used the 50% percentile of the data to calculate the median spawning biomass (0.2241 million tons) and recruitment (0.4495 billion). These values were used to partition the spawner-recruit space into 4 states. State 1:low SB-low R, state 2:low SB-high R, state 3:high SB-low R, and state 4:high SB-high R. These areas correspond to the lower left, upper left, lower right, and upper right quadrants of the lower panel in Figure 8. The classification then makes it possible to study the probability of any state and the transitions between the states.

The time series of recruitment data and the 2x2 spawning biomass-recruitment plot are shown in Figure 8.

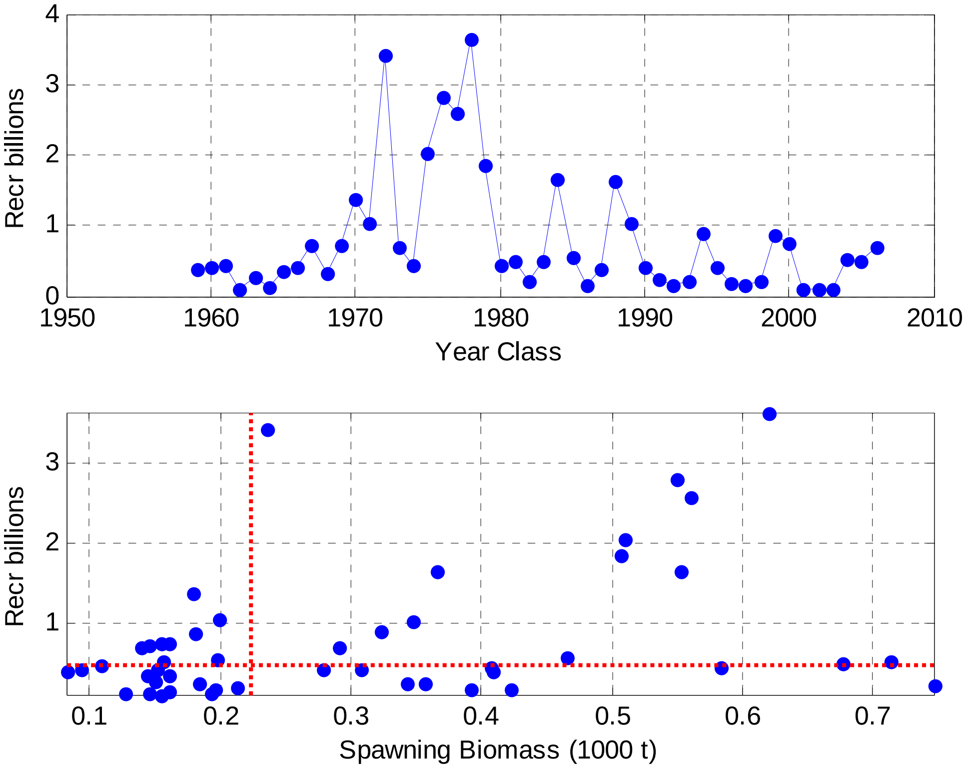


**FIGURE 8. Time series of recruitment and the 2x2 classification of the 2008 spawning biomass and recruitment data.**

**TABLE 6. Transition matrix calculated from data in Figure 8.**

| Transition Probability Matrix | To state 1 | To state 2 | To state 3 | To state 4 |
|---|---|---|---|---|
| From state 1 | 0.6429 | 0.3571 | 0.0000 | 0.0000 |
| From state 2 | 0.3333 | 0.5556 | 0.0000 | 0.1111 |
| From state 3 | 0.1000 | 0.0000 | 0.4000 | 0.5000 |
| From state 4 | 0.0000 | 0.0000 | 0.4286 | 0.5714 |

To calculate the score from Figure 8 takes two steps. First, we determine which state is the current state by taking the estimate of spawning biomass in 2007 (0.15586 million tons) and note that it falls below the median value of 0.2241. We can see that in 2007 we are in either state 1 or state 2 (low spawning biomass). The probabilities of transitioning from state 1 or state 2 to other states are given in the first two rows of Table 6.

If we are in state 1, then recruitment can either be below (a recruitment score of 1) or above (a recruitment score of 3) the median of 0.4495 billion (a recruitment score of 2). Note the probability for transitioning from state 1 to state 3 or 4 is 0.0. If we start in state 1, then the combined recruitment score would be the weighted average of the recruitment scores for each possible transition, where the weighting factors are the transition probabilities. So, the calculations for the second step proceed as described below.

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

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

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

$$= \frac{(3*0.5556)+(1*0.3333)+(3*0.1111)}{(0.5556+0.3333+0.1111)} = 2.33$$

We average over these two weighted scores because starting from either state 1 or state 2 is equally likely if the starting spawning biomass in 2007 is below the median, giving a final score of 2.02, or average.

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

**TABLE 7. Expected First Passage Time.**

| **State** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| 1 | 3.9464 | 2.8000 | 22.5333 | 20.2000 |
| 2 | 8.2500 | 4.9111 | 19.7333 | 17.4000 |
| 3 | 21.6667 | 24.4667 | 4.4200 | 5.0333 |
| 4 | 24.0000 | 26.8000 | 2.3333 | 3.1571 |

## CONCLUSION

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

Based on these seven elements and the weights assigned in Table 8, below, the FOCI forecast of the 2008 year class is average.

**TABLE 8. Final 2008 pollock recruitment forecast.**

| Element | Weights | Score | Total |
|---|---|---|---|
| Rain | 0.15 | 2.49 | 0.37 |
| Wind Mixing | 0.15 | 1.97 | 0.30 |
| Advection | 0.15 | 2.00 | 0.30 |
| Larval Index-abundance | 0.10 | 2.00 | 0.20 |
| Larval Rough Counts and Distribution | 0.15 | 2.33 | 0.35 |
| Time Sequence of R | 0.15 | 1.66 | 0.25 |
| Spawner-Recruit Time Series | 0.15 | 2.02 | 0.30 |
| **Total** | **1.00** | | **2.07= Average** |

## APPENDIX D REFERENCES

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