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

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Executive Summary

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: 2009 total catch and catch at age.

2. Shelikof Strait EIT survey: 2010 biomass and age composition.

3. NMFS bottom trawl survey: 2009 age composition.

3. ADF&G crab/groundfish trawl survey: 2010 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 1999-2009 was used again for this year's assessment.

Assessment results

The model estimate of spawning biomass in 2011 is 198,767 t, which is 28.8% of unfished spawning biomass (based on average post-1977 recruitment) and below $B_{40\%}$ (276,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. New ADF&G crab/groundfish and Shelikof Strait EIT surveys were conducted in 2010. The Shelikof Strait EIT survey showed an increase of 62% from the 2009 biomass estimate. The ADFG crab/groundfish survey showed a decline of 15% from the 2009 biomass estimate, but is still up 60% from the mean of the previous three years. The aggregate biomass from Winter EIT surveys, which is not used in model, is similar to the model estimate of total biomass at spawning, lending support to model estimates of an increase in stock size. The abundance of mature fish in 2011 is projected to be 17% higher than in 2010, and is projected to increase further over the next five years.

The author's 2011 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 88,620 t, an increase of 15% from the 2010 ABC. This recommendation is based a more conservative alternative to the maximum permissible F_{ABC} introduced in the 2001 SAFE. The OFL in 2011 is 118,030 t. In 2012, the recommended ABC and OFL are 114,054 t and 151,030 t, respectively.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendations for 2011 and 2012 in Appendix A are 9,245 t and the OFL is 12,326 t (the same for both years). These recommendations are based on estimated biomass in the southeast Alaska from the 2009 NMFS bottom trawl survey.

Status summary

Quantity/Status	Last year 2010	Last year 2011	This year **2011**	This year 2012
M (natural mortality)	0.3	0.3	**0.3**	0.3
Specified/recommended Tier	3b	3b	**3b**	3b
Projected biomass (ages 3+)	754,104	840,061	**893,700**	988,580
Female spawning biomass (t)				
Projected	184,567	204,417	**198,767**	227,345
$B_{100\%}$	620,000		**690,000**	
$B_{40\%}$	248,000		**276,000**	
$B_{35\%}$	217,000		**242,000**	
F_{OFL}	0.19	0.21	**0.16**	0.18
$maxF_{ABC}$	0.17	0.18	**0.14**	0.16
Specified/recommended F_{ABC}	0.14	0.16	**0.12**	0.14
Specified/recommended OFL (t)	103,210	135,010	**118,030**	151,030
Specified/recommended Max. Permissible ABC (t)	89,800	114,360	**102,940**	127,990
Specified/recommended ABC (t)	77,150	101,50	**88,620**	114,054
Is the stock being subjected to overfishing?	No		**No**	
Is the stock currently overfished?	No		**No**	
Is the stock approaching a condition of being overfished?	No		**No**	

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

Comment 1. *The SSC encourages the author to re-evaluate data input sample sizes for the multinomial and other likelihood components.*

The assessment authors agree that this is a good idea; however we were unable to make progress on this recommendation for this assessment cycle. It remains on the list of potential model enhancements.

Comment 2. *The SSC encourages the author to model age-1 abundances to potentially improve recruitment estimates.*

The assessment authors agree that this is a good idea; however we were unable to make progress on this recommendation for this assessment cycle. It remains on the list of potential model enhancements.

Comment 3. *The authors should re-evaluate survey catchability. The catchability coefficient appears to be well estimated in the model and a 95% confidence interval for q based on the likelihood profile does not include 1. Therefore, we request that the authors bring forward results from a model that estimates q for next year's assessment. Indications from this year's survey that fish may have been more available to the survey due to environmental conditions suggests that including an environmental covariate in the estimation of q may prove useful, similar to the flatfish assessments and previous pollock assessments in the EBS.*

The pollock assessment has evaluated NMFS bottom trawl survey catchability in every assessment conducted in the last decade. Estimates of trawl survey *q* have ranged between 0.64 and 0.85 in assessments from 2001 to 2010. If trawl survey *q* is estimated with this year's assessment model, spawning biomass increases by 58%, with a corresponding (or larger) increase in the maximum permissible ABC. The assessment makes clear that assuming trawl survey *q* is 1.0 is a risk-adverse assumption that is considered appropriate due to relatively low abundance of the stock relative to historical levels, uncertainty in the stock assessment including conflicting survey trends, increases in predation on pollock, and the importance of pollock in the Gulf of Alaska ecosystem. A formal framework for considering scientific uncertainty and risk, as might be implemented under new ABC requirements, may be preferable to an informal approach to dealing with uncertainty. However until such a framework is in place, the assessment authors believe that it makes sense to continue with status quo assumptions.

Comment 3. *Changes in condition or weight-at-age of walleye pollock over time should be evaluated to help identify the relative importance of bottom-up vs. top-down forcing on walleye pollock.*

A plot of weight-at-age from the Shelikof Strait EIT survey indicates that there has been a substantial increase in weight at age for older pollock (Fig. 1.25). For pollock greater than age 6, weight-at-age has nearly doubled since 1983-1990. Further analyses are needed to evaluate whether these changes are a density-dependent response to declining pollock abundance, or whether they are environmentally forced. Since these changes are highly auto-correlated, a fairly sophisticated analysis would be needed to attribute causation. Changes in weight-at-age have potential implications for status determination and harvest policy. For example, if the mean weight-at-age and maturity-at-age from 1983-90 is considered representative of an unfished stock, and the current weight-at-age is attributed to a density-dependent response, current stock status would be at 51% of unfished stock size, rather than 28.8% of unfished stock size.

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 a response to differing environmental conditions in the two areas.

Fishery

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

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

Incidental catch in the Gulf of Alaska directed pollock fishery is low. For tows classified as pollock targets in the Gulf of Alaska between 2005 and 2009, on average about 94% of the catch by weight of FMP species 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), jellyfish, and grenadiers. Bycatch estimates for prohibited species over the period 2005-2009 are given in Table 1.3.

Kodiak is the major port for pollock in the Gulf of Alaska, with 63% of the 2005-2009 landings. In the western Gulf of Alaska, Sand Point, Dutch Harbor, King Cove, and Akutan are important ports, sharing 37% of 2005-2009 landings. Secondary ports, including Alitak Bay, Homer, Ninilchik, Seward, and Sitka account for less than 1% of the 2005-2009 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 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 2009 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 2009 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	199	407	270	109
	No. lengths	1656	5284	4897	987
	Catch (t)	5,939	10,979	5,730	1,224
2nd half (C and D seasons)	No. ages	437	216	407	----
	No. lengths	2628	1442	2526	----
	Catch (t)	8,997	3,021	6,507	----

Age-3 and age-4 fish (2006 and 2007 year classes) were dominant mode in catches in all area and both seasons (Fig. 1.2), with the age-4 fish being more prominent in the first half of the year in the western part of the Gulf of Alaska (areas 610 and 620). The 2000 and 1999 year classes (now age 9 and age 10) were still present as a secondary mode in the fishery age composition, primarily in the western Gulf of Alaska (area 610).

Fishery catch at age in 1976-2009 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 the west Yakutat region were obtained by splitting strata and survey CPUE data at 140° W lon. (M. Martin, AFSC, Seattle, WA, pers. comm. 2009). 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 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 for the 2009 NMFS bottom trawl survey were estimated by INPFC area (Shumagin, Chirikof, Kodiak, Yakutat and Southeastern) using a global age-length key and CPUE-weighted length frequency data by INPFC area. The combined Shumagin, Chirikof and Kodiak age composition was used in the assessment model. Mean age generally decreased from west to east (ranging from 6.5 years in the Shumagin area to 1.8 years in the Yakutat area). In Kodiak area there was a broad range of ages from age 1 to age 5 with no dominant mode (Fig. 1.4). The 2000 and 1999 year classes (age 9 and age 10) were present as a secondary mode in the fishery age composition in the western Gulf of Alaska (area 610).

Shelikof Strait Echo Integration Trawl Survey

Echo integration trawl (EIT) 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 2010 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. In 2008, the noise-reduced *R/V Oscar Dyson* became the designated survey vessel for acoustic surveys in the Gulf of Alaska. In winter of 2007, a vessel comparison experiment was conducted between the *R/V Miller Freeman* and the *R/V Oscar Dyson*, which obtained an OD/MF ratio of 1.132 in Shelikof Strait.

The 2010 biomass estimate for Shelikof Strait is 429,730 t, an increase of 62% from the 2009 biomass. Biomass of pollock ≥43 cm (a proxy for spawning biomass) increased 2.5 times from 2009 estimate, apparently due to increased recruitment to the spawning population (Fig. 1.5).

Additional EIT surveys in winter 2010 covered the Shumagin Islands spawning area, Sanak Gully, Morzhovoi Bay, Pavlov Bay, Chirikof, and Marmot Bay. An exploratory survey along the Kenai Peninsula and through Prince William Sound found significant quantities of pollock. Estimates from these areas are given below.

2010 EIT survey results

Area	Biomass ≥43 cm (t)	Percent	Total biomass (t)	Percent
Sanak Gully	26,009	5.2%	26,678	3.8%
Morzhovoi Bay	521	0.1%	1,650	0.2%
Shumagin Is	2,262	0.5%	18,295	2.6%
Shelikof Strait	256,444	51.6%	429,730	60.5%
Chirikof Island	9,544	1.9%	9,544	1.3%
Marmot Bay	5,021	1.0%	5,585	0.8%
Kenai Peninsula	94,504	19.0%	111,152	15.7%
Prince Wm Sound	102,442	20.6%	107,205	15.1%
Total	496,746		709,840	

In comparison to 2009, biomass estimates were lower in the western Gulf of Alaska, and generally higher in the central Gulf of Alaska (Fig. 1.6). In Sanak Gully, there was 15% decrease, while in the Shumagin area there was 71% decrease. For all areas surveyed, there was an 86% increase from the areas surveyed in 2009. However much of that increase came from the Kenai Peninsula and Prince William Sound which were not surveyed in previous years. The discovery of significant pre-spawning aggregations along the Kenai Peninsula is difficult in interpret at the population level because it is unclear whether these aggregations have always been present at this level of abundance, or whether they represent a eastward shift eastwards in spawning. If it does indicate an eastward shift in spawning, it is unclear what change in environmental conditions (if any) is responsible for the shift.

Since the assessment model only includes age 2 and older pollock, 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 2010 survey, the age-3 fish from the 2007 year class were both numerically dominant, and dominant in the biomass distribution by length. Since age composition estimates were already available from the 2010 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 - 2010 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 2010 biomass estimate for pollock for the ADF&G crab/groundfish survey was 124,110 t, down 15% from the 2009 biomass estimate, but still an increase of approximately 60% from the mean of the previous three years (2006-2008) (Table 1.7).

ADF&G Survey Length Frequency

Pollock length-frequencies for the ADF&G survey in 1989-2009 (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. Length composition in 2010 is similar to previous surveys, with a mean length of 53 cm.

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, 2006, and 2008 ADF&G surveys (N = 559, 538, 591,588, and 597). Ageing samples where collected during the 2010 survey, but have not yet been aged. Comparison with fishery age composition shows that older fish (> age-8) are more common in the ADF&G crab/groundfish survey. This is consistent with the assessment model, which estimates a domed-shaped selectivity pattern for the fishery, but an asymptotic selectivity pattern for the ADF&G survey.

Pre-1984 bottom trawl surveys

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

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

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

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

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

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

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

where q_1 is the catchability of the NMFS bottom trawl survey, q_2 is the catchability of historical 400-mesh eastern trawl surveys, $\hat{F}PC$ is the estimated fishing power correction (= 3.84), and σ_{FPC} is the standard error of the FPC estimate (= 1.26).

Estimates of pollock biomass were very low (<300,000 t) between 1961 and 1971, increased by at least a factor of ten in 1974 and 1975, and then declined to approximately 900,000 t in 1978 (Table 1.12). 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. Shelikof Strait EIT survey estimates prior to 2008 were rescaled to be comparable to subsequent surveys conducted by the *R/V Oscar Dyson*. 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). All surveys show a strong increase in the last two years. Both the NMFS and ADFG bottom trawl surveys are above the long-term average in the last two years, while the Shelikof Strait EIT survey is slightly below the long-term average in 2010.

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 downward trend, which may be related to changes in the seasonal distribution of the catch. The percent female was 48.8% in 2009. 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 from 2005 to 2008 as the large 1999 and 2000 year classes entered the age-8 plus group. In 2009 the percent of old fish dropped again as the fishery began to catch greater numbers of young fish from year classes recruiting to the fishery. 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 1976-2009 (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 2010 Shelikof EIT survey age-1 estimate is 0.090 billion (14th highest in abundance out of 27 surveys), which suggests that recruitment of the 2009 year class is likely to be below the median level of abundance.

Analytic Approach

Model description

An age-structured model covering the period from 1961 to 2010 (50 yrs) was used to assess Gulf of Alaska pollock. This is essentially the same model that has been used since the 1999 assessment. 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 (1964-2010)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-2009)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-2010)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-2010)	Multinomial	Sample size = 60
NMFS bottom trawl survey biom. (1984-2009)	Log-normal	Survey-specific CV = 0.12-0.38
NMFS bottom trawl survey age comp. (1984-2009)	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 (1989-2010)	Log-normal	CV = 0.25
ADF&G survey age comp. (2000,2002,2004,2006, 2008)	Multinomial	Sample size = 10
ADF&G survey length comp. (1989-2010)	Multinomial	Sample size = 10
Historical trawl survey biomass (1961-1982)	Log-normal	Survey-specific CV = 0.24-0.64
Historical trawl survey age comp. (1973)	Multinomial	Sample size = 60
Historical trawl survey length comp. (1961-1982)	Multinomial	Sample size = 10
Fishery selectivity random walk process error	Log-normal Normal	Slope CV = 0.10 (0.001 for 1961-71) Inflection age SD = 0.40 (0.004 for 1961-71)
Recruit process error (1961-1968,2010)	Log-normal	σ_R =1.0

Recruitment

In most years, year-class abundance at age 2 was estimated as a free parameter. A prior constraint was imposed on recruitment at the start of the modeled time period to improve parameter estimability. Instead of estimating the abundance of each age of the initial age composition independently, we parameterized the initial age composition with mean log recruitment plus a log deviation from an equilibrium age structure based on that mean initial recruitment. A penalty was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period (σ_R =1.0). We also used the same constraint for log deviations in recruitment for 1961-68, and in 2010. 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 2010 ≈ σ_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 2010, the process error standard deviation for those years was assumed to be very small, so that annual changes in selectivity are very 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. A likelihood profile on trawl catchability showed that the maximum likelihood estimate of trawl catchability was approximately 0.64. 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 in the EIT surveys 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, several methods were evaluated in the 2008 assessment for incorporating this result in the assessment model. The method that was adopted was to treat the MF and the OD time series as independent survey time series, and to include the vessel comparison results directly in the log likelihood of the assessment model. This likelihood component is given by

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

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_AOD)-log(s_AMF)] obtained from the vessel comparison, and σ_S = 0.0244 is the standard error of the mean.

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 reader 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, and 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^{-6}). 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 1961-2010 = 50	Estimated as log deviances from the log mean; recruitment in 1961-68, and 2010 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated in the model
Fishing mortality	Years 1961-2010 = 50	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) = 196	Estimated as deviations from mean selectivity and constrained by random walk process error
Survey catchability	No. of surveys + 2 = 8	AFSC bottom trawl survey catchability not estimated, other catchabilities estimated on a log scale. Three 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	129 primary parameters + 196 process error parameters + 2 fixed parameters = 327	

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

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 since 2000 from winter EIT surveys in the Gulf of Alaska is 360 (Table 1.15).

Estimates of maturity at age in 2010 from winter EIT surveys were above the long-term average for all ages (Fig. 1.11). Inter-annual changes in maturity at age may reflect environmental conditions, pollock population biology, effect of strong year classes moving through the population, or simply ageing error. Because there did not appear to be an objective basis for excluding data, the 1983-2010 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% maturity 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. Estimates of the age at 50% maturity in 2010 were low (4.4 years), but relatively high for the length at 50% maturity (47 cm) reflecting increases in length at age.

Weight at age

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

Model evaluation

Model fit to age composition data was evaluated using plots of observed and predicted age composition in the fishery (Fig. 1.13), Shelikof Strait EIT survey (Fig. 1.14), and the NMFS trawl survey (Fig. 1.15). Model fits to fishery age composition data are good in most years. The fit of Shelikof Strait EIT survey age composition shows large residuals at age 2 and age 3 in 2006-2009 due to inconsistencies between the initial estimates of abundance and subsequent information about the magnitude of these year classes.

Model fits are similar to previous assessments, and general trends in survey time series are fit reasonably well (Dorn et al. 2009) (Figs. 1.16-1.18). 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 those years. All survey time series in the last two years (2009 and 2010) are consistent showing in showing a strong increase, but the magnitude of the increase is not same for all time series. Therefore it was not possible for the model to fit all survey estimates simultaneously.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with catchability equal to 0.64 (Fig. 1.19), compared to the estimate of 0.70 in the 2009 assessment. The change in log likelihood is about 4.4 between models with fixed and estimated catchability, and as expected there is a relatively large increase in stock size when catchability is estimated (58% increase in 2010 spawning biomass). These results are similar to previous assessments. To be consistent with recommendations in previous assessments, we used a base model with fixed trawl survey catchability of 1.0.

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 1961-2010. Table 1.18 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1977-2009 (see also Fig. 1.21). Stock size peaked in the early 1980s at approximately 1.1 times the proxy for unfished stock size (B100% = mean 1979-2009 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR@F=0)). In 1997, the stock dropped below the $B_{40\%}$ for the first time since the 1970s, reached a minimum in 2003 of 20% of unfished stock size. Over the last five years (2006-2010) stock size has varied between 24% and 30% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2010 indicates the current estimated trend in spawning biomass for 1990-2009 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. There appear to be no consistent pattern of bias in estimates of ending year biomass, but assessment errors are clearly correlated over time, such that there are runs of over estimates and under estimates. The estimated 2010 age composition from the current assessment is similar to projected 2010 age composition in the 2009 assessment (Fig. 1.22, bottom panel). The largest discrepancies are the estimate of the age-2 fish (2008 year class), which is about half the size of last year's value of 0.7 billion (= mean recruitment), and the estimate of the age-3 fish (2007 year class), which is also lower than projected.

Stock and recruitment

Recruitment of Gulf of Alaska pollock is more variable (CV = 1.09) than Eastern Bering Sea pollock (CV = 0.62). Other North Pacific groundfish stocks, such as sablefish and Pacific ocean perch, also have high recruitment variability. 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 on average 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 2008 year class, estimates of age-1 abundance were very high in the Shumagin EIT survey, but not in the Shelikof Strait EIT survey. Available information on the 2009 year class suggests that it may be relatively weak year class.

Year of recruitment	2010	2011	2012
Year class	2008	2009	2010
FOCI prediction	*Average*	*Average*	*Not available*
Survey information	2009 Shelikof EIT survey age-1 estimate is 0.33 billion (9th in abundance out of 26 surveys) 2009 Shumagin EIT survey age-1 estimate is 2.2 billion	2010 Shelikof EIT survey age-1 estimate is 0.090 billion (14th in abundance out of 26 surveys)	

Projections and Harvest Alternatives

Reference fishing mortality rates and spawning biomass levels

Since 1997, Gulf pollock have been managed under Tier 3 of NPFMC harvest guidelines. In Tier 3, reference mortality rates are based on the spawning biomass per recruit (SPR), while biomass reference levels are estimated by multiplying the SPR by average recruitment. Estimates of the F_{SPR} harvest rates were obtained using the life history characteristics of Gulf of Alaska pollock (Table 1.19). Spawning biomass reference levels were based on mean 1979-2009 recruitment (703 million), which is slightly higher than the post-1979 mean in the 2009 assessment. The average did not include the recruitment in 2010 (2008 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 2006-2010 to estimate current reproductive potential. A substantial increase in pollock weight-at-age has been observed (Fig. 1.24), which may be a density-dependent response to low abundance or due to environmental forcing. The SPR at F=0 was estimated as 0.982 kg/recruit. This estimate represents a 9% increase from the 2009 estimate primarily due to increases in weight at age in the 2010 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 2005-2009 to reflect current selectivity patterns. Gulf of Alaska pollock F_{SPR} harvest rates are given below:

		Equilibrium under average 1979-2009 recruitment				
F_{SPR} rate	*Fishing mortality*	*Avg. Recr. (Million)*	*Total 3+ biom. (1000 t)*	*Female spawning biom. (1000 t)*	*Catch (1000 t)*	*Harvest rate*
100.0%	0.000	703	2119	690	0	0.0%
50.0%	0.148	703	1322	345	154	11.7%
45.0%	0.173	703	1237	311	168	13.6%
40.0%	0.200	703	1151	276	183	15.9%
35.0%	0.233	703	1063	242	196	18.5%

The $B_{40\%}$ estimate of 276,000 t represents an 11% increase from the $B_{40\%}$ estimate of 248,000 t in the 2009 assessment, and reflects both the increase in mean weight at age during spawning and the increase in average recruitment. The model estimate of spawning biomass in 2011 is 198,767 t, which is 28.8% of unfished spawning biomass and below $B_{40\%}$ (276,000 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).

2010 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 86.0% 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

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

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

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

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

This alternative has the same functional form as the maximum permissible F_{ABC}; the only difference is that it declines linearly from B^* ($= B_{47\%}$) to $0.05B^*$ (Fig. 1.25).

Projections for 2011 for F_{OFL}, the maximum permissible F_{ABC}, and an adjusted $F_{40\%}$ harvest rate with a constant buffer between F_{ABC} and F_{OFL} are given in Table 1.21.

ABC recommendation

There were two new surveys in 2010: the ADF&G crab/groundfish survey, and the Shelikof Strait EIT survey. The Shelikof Strait EIT survey showed an increase of 62% from the 2009 biomass estimate. The ADFG crab/groundfish survey showed a decline of 15% from the 2009 biomass estimate, but is still up 60% from the mean of the previous three years. The aggregate biomass from Winter EIT surveys, which is not used in model, is similar to the model estimate of total biomass at spawning, lending support to model estimates of an increase in stock size. The estimated abundance of mature fish in 2011 is projected to be 17% higher than in 2010, and is projected to increase further over the next five years.

Last year, the ABC recommendations were based on an assumed average for the 2007 year class instead of the model estimate, which was 1.7 times average recruitment. This year we used the model estimate of 0.794 billion recruits (which is now only 13% higher than average recruitment). Since additional information is available on the magnitude to this year class, we considered it appropriate to use the model estimate rather than assuming that it was equal to average recruitment.

Based on these considerations, we decided that the most straightforward approach for recommending an ABC was to use the standard model projection and the more conservative adjusted $F_{40\%}$ harvest rate described above. The author's recommended 2011 ABC is therefore 88,620 t. While there are some elements of risk-aversion in this recommendation, such as fixing trawl catchability at 1.0, our recommendation is to delay treating those elements until an ABC framework is in place that deals explicitly with scientific uncertainty. In 2012, the ABC based an adjusted $F_{40\%}$ harvest rate is 114,054 t (Table 1.21). The OFL in 2010 is 118,030 t, and the OFL in 2012 if the recommended ABC is taken in 2011 is 151,030 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. 1.26). A chain of 1,000,000 samples was thinned by selecting every 200th sample. Analysis of the thinned MCMC chain indicates that probability of the stock dropping below $B_{20\%}$ will be negligible in all years.

Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the 2010 numbers at age as estimated by the assessment model, and assume the 2010 catch will be equal to the TAC of 77,150 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 1979-2009 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 2011, 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 (2006-2010). (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. If the stock is expected to be 1) above its MSY level in 2011 or 2) above 1/2 of its MSY level in 2011 and above its MSY level in 2021 under this scenario, then the stock is not overfished)

Scenario 7: In 2011 and 2012, 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. If the stock is expected to be 1) above its MSY level in 2012, or 2) above 1/2 of its MSY level in 2012 and above its MSY level in 2023 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.21. A Under all harvest policies, mean spawning biomass is projected to increase gradually over the next five years (Fig. 1.27). Plots of individual projection runs are highly variable (Fig. 1.28), and may provide a more realistic view of potential pollock abundance in the future.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

The catch estimate for the most recent complete year (2009) is 44,003 t, which is less than the 2009 OFL of 58,590 t. Therefore, the stock is not being subject to overfishing.

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

Spawning biomass is estimated to be 198,767 t in 2010, which is less than $B_{35\%}$ (242,000 t), but greater than ½ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2021 is 273,512 t, 113% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2023 is 272,877 t, which is 113% 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. 1.29); 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 1.30). While there is an ontogenetic shift in diet from copepods to larger zooplankton (primarily euphausiids) and fish (Fig. 1.30), 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. 1.30). 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. 1.31). 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. 1.32). 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 1.31), 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. 1.33). 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 1.34, 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. 1.34, 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. 1.34 (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. 1.33). 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. 1.35, 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. 1.35, 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. 1.36, 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. 1.36, middle and bottom). Again, this result should be approached iteratively, but it suggests increasing predation mortality on age 3+ pollock during 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. 1.32), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.35 and 1.36 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. 1.29. 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. 1.37 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. 1.38), 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 1.39), 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. 1.40). 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. 1.40). 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 2008 is for the area west of 140 ^{o} W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound (1650 t). Research catches are also reported.

Year	*Foreign*	*Joint Venture*	*Domestic*	*Total*	*TAC*	*Research*
1964	1,126			1,126	---	
1965	2,749			2,749	---	
1966	8,932			8,932	---	
1967	6,276			6,276	---	
1968	6,164			6,164	---	
1969	17,553			17,553	---	
1970	9,343			9,343	---	
1971	9,458			9,458	---	
1972	34,081			34,081	---	
1973	36,836			36,836	---	
1974	61,880			61,880	---	
1975	59,512			59,512	---	
1976	86,527			86,527	---	
1977	117,834		522	118,356	150,000	75
1978	96,392	34	509	96,935	168,800	100
1979	103,187	566	1,995	105,748	168,800	52
1980	112,997	1,136	489	114,622	168,800	229
1981	130,324	16,857	563	147,744	168,800	433
1982	92,612	73,917	2,211	168,740	168,800	110
1983	81,358	134,131	119	215,608	256,600	213
1984	99,260	207,104	1,037	307,401	416,600	311
1985	31,587	237,860	15,379	284,826	305,000	167
1986	114	62,591	25,103	87,809	116,000	1202
1987		22,823	46,928	69,751	84,000	227
1988		152	65,587	65,739	93,000	19
1989			78,392	78,392	72,200	73
1990			90,744	90,744	73,400	158
1991			100,488	100,488	103,400	16
1992			90,857	90,857	87,400	40
1993			108,908	108,908	114,400	116
1994			107,335	107,335	109,300	70
1995			72,618	72,618	65,360	44
1996			51,263	51,263	54,810	147
1997			90,130	90,130	79,980	76
1998			125,098	125,098	124,730	64
1999			95,590	95,590	94,580	35
2000			73,080	73,080	94,960	56
2001			72,076	72,076	90,690	77
2002			51,937	51,937	53,490	78
2003			50,666	50,666	49,590	128
2004			63,934	63,934	65,660	53
2005			80,846	80,846	86,100	72
2006			71,976	71,976	81,300	63
2007			53,062	53,062	63,800	47
2008			52,500	52,500	53,590	26
2009			44,003	44,003	43,270	90
2010					77,150	37
Average (1977-2009)				106,848	123,560	141

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). 1991-2009 -- 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 2005-2009. 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	*2005*	*2006*	*2007*	*2008*	*2009*
Pollock	80097.8	69774.8	49815.5	46735.3	37719.0
Arrowtooth flounder	2313.4	2747.5	1630.0	1554.6	730.7
Pacific cod	352.3	709.8	276.4	578.7	556.3
Other (sharks, skates, squid, sculpin, octopus, but excluding skates in 2004)	924.6	1805.5	676.9	200.6	381.0
Flathead sole	180.2	594.4	329.6	414.0	213.9
Shortraker and rougheye rockfish	32.6	96.5	81.4	101.5	29.7
Pacific Ocean perch	35.5	71.2	29.8	49.9	20.4
Rex sole	21.1	153.6	44.8	57.4	35.5
Miscellaneous flatfish	4.6	438.8	157.0	230.2	17.0
Atka mackerel	3.5	15.2	200.2	0.1	0.0
Sablefish	3.6	5.6	3.2	1.3	0.1
Dover sole and Greenland turbot	0.7	11.7	5.5	5.8	2.4
Pelagic shelf rockfish complex	2.1	9.0	6.4	4.1	1.5
Unidentified skate	1.2	5.0	9.4	5.9	2.5
Big and longnose skate	6.7	35.8	64.8	45.3	63.2
Northern rockfish	0.8	14.5	12.0	7.9	4.2
Other rockfish complex	1.3	2.5	2.0	4.5	0.1
Thornyheads	0.3	0.2	0.3	0.2	0.1
Percent non-pollock	*4.6%*	*8.8%*	*6.6%*	*6.5%*	*5.2%*

Non target species/species group	*2005*	*2006*	*2007*	*2008*	*2009*
Squid	631.5	1517.8	405.2	77.9	313.6
Eulachon	826.8	392.3	219.0	756.1	216.8
Other osmerids	176.3	167.9	49.2	379.6	145.5
Pacific sleeper shark	199.3	153.5	58.9	47.2	30.2
Scyphozoan jellyfish	184.4	69.0	23.9	192.1	10.7
Grenadiers	53.9	73.1	4.7	249.3	29.0
Salmon shark	43.3	31.4	141.6	6.4	6.9
Spiny dogfish	15.8	50.0	47.6	59.6	17.6
Miscellaneous fish	16.5	38.4	24.1	35.0	37.9
Big skate	1.7	23.0	38.1	21.7	33.8
Other skates	35.2	40.9	13.9	4.3	10.4
Longnose skate	5.0	12.7	26.7	23.6	35.1
Large Sculpins	0.0	1.5	21.8	13.5	5.0
Skate, Other	1.2	5.0	9.1	5.9	2.6
Sea star	1.1	2.0	4.7	6.5	0.0
Pandalid shrimp	7.4	3.1	1.9	0.8	0.1
Octopus	0.1	3.4	1.5	0.0	0.1
Capelin	2.8	0.1	0.0	0.0	0.0
Sculpins	0.0	2.4	21.8	15.3	5.0
Sea anemone unidentified	0.0	0.2	0.7	0.3	0.0
Miscellaneous crabs	0.0	0.0	0.9	0.1	0.0
Stichaeidae	0.0	0.1	0.3	0.0	0.0
Snails	0.0	0.0	0.0	0.3	0.0
Sea pens whips	0.3	0.0	0.0	0.0	0.0
Eelpouts	0.1	0.0	0.0	0.0	0.1
Invertebrate unidentified	0.0	0.0	0.2	0.0	0.0

Table 1.3. Bycatch of prohibited species for trawls in the Gulf of Alaska during 2004-2008 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	*2005*	*2006*	*2007*	*2008*	*2009*
Herring (t)	12.163	8.789	19.529	0.421	7.821
Halibut (t)	3.833	115.576	135.392	120.041	62.481
Bairdi Tanner Crab (nos.)	6	84,005	19,458	322	6,565
Red King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	27,910	15,943	35,042	10,382	2,617
Non-chinook salmon (nos.)	781	1,413	982	847	329

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 2000-2009 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*
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	13,896	215	1,100	0	62,658	
	Discarded	342	438	459	11	26	0	1,276	2.0%
	Total	23,568	24,659	14,355	226	1,127	0	63,934	
2005	Retained	30,791	27,286	18,986	1,876	740	0	79,680	
	Discarded	136	621	350	9	50	0	1,166	1.4%
	Total	30,927	27,908	19,336	1,885	790	0	80,846	
2006	Retained	24,489	26,409	16,127	1,570	1,475	0	70,070	
	Discarded	203	750	951	2	1	0	1,906	2.6%
	Total	24,691	27,159	17,078	1,572	1,476	0	71,976	
2007	Retained	17,694	18,846	13,777	84	NA	0	50,401	
	Discarded	262	516	701	3	NA	1	1,483	2.8%
	Total	17,956	19,362	14,478	87	1,179	1	53,062	
2008	Retained	15,100	18,691	13,335	1,155	NA	0	48,281	
	Discarded	2,157	367	1,052	6	NA	2	3,584	6.8%
	Total	17,257	19,058	14,387	1,161	635	2	52,500	
2009	Retained	14,475	13,579	10,974	1,190	NA	0	40,219	
	Discarded	461	421	1,263	31	NA	0	2,177	4.9%
	Total	14,936	14,000	12,238	1,221	1,608	0	44,003	
Average (2000-2009)		21,585	20,145	17,141	1,337	1,198	1	61,408	

Table 1.5. Catch at age (000,000s) of walleye pollock in the Gulf of Alaska in 1976-2009.

	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
2008	0.32	6.29	21.94	6.76	2.15	1.16	2.27	5.60	2.84	0.87	0.36	0.21	0.06	0.04	0.02	50.89
2009	0.24	6.38	14.84	13.47	3.82	1.19	0.72	0.95	1.90	1.45	0.47	0.06	0.01	0.00	0.00	45.50

Table 1.6. Number of aged and measured fish in the Gulf of Alaska pollock fishery used to estimate fishery age composition (1989-2009).

	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
2008	961	1,090	2,051	7,430	8,536	15,966
2009	1,011	1,034	2,045	9,913	9,447	19,360

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			720,548		
1985	1,175,823				768,419	
1986	585,755				375,907	
1987				732,660	484,455	
1988	301,709				504,418	
1989	290,461				433,894	214,434
1990	374,731			825,609	381,475	114,451
1991	380,331				370,000	
1992	580,000	713,429			616,000	127,359
1993	295,785	435,753		755,786		132,849
1994		492,593				103,420
1995		649,401				
1996		777,172		666,521		122,477
1997		583,017				93,728
1998		504,774				81,215
1999				607,409		53,587
2000		391,327				102,871
2001		432,749		219,072		86,967
2002		256,743				96,237
2003		317,269		398,469		66,989
2004		330,753				99,358
2005		338,038		358,017		79,089
2006		293,609				69,044
2007		180,881		282,356		76,674
2008			188,942			83,476
2009			265,971	669,505		145,438
2009			429,730			124,110

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
2009	823	563	0.15	684	870	1,554	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
2009	222.94	87.33	106.82	129.35	101.26	27.21	17.59	26.60	53.90	29.46	9.68	7.00	2.78	1.61	0.00	823.53

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
2009	331.94	1,204.50	110.22	98.69	60.21	9.91	2.90	0.86	5.07	6.13	1.37	0.24	0.00	0.00	0.00	1,832.03
2010	90.04	305.57	531.65	84.46	78.93	28.52	11.78	5.46	5.25	10.82	9.36	3.45	0.00	0.00	0.00	1,165.29

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 1992-2009.

	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
2009	9	3	0.06	254	301	555	NA	NA	NA
2010	13	2	0.03	298	315	613	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	15
1981				
1982		1983	0.001	27
1983		1984	0.062	18
1984		1985	2.092	3
1985		1986	0.579	6
1986				
1987		1988	0.017	25
1988		1989	0.399	7
1989		1990	0.049	23
1990		1991	0.022	24
1991		1992	0.228	11
1992	Strong	1993	0.063	17
1993	Average	1994	0.186	12
1994	Average	1995	10.688	1
1995	Average-Strong	1996	0.061	19
1996	Average	1997	0.070	16
1997	Average	1998	0.395	8
1998	Average			
1999	Average	2000	4.484	2
2000	Average	2001	0.291	10
2001	Average-Strong	2002	0.008	26
2002	Average	2003	0.051	22
2003	Average	2004	0.053	21
2004	Average	2005	1.626	4
2005	Average	2006	0.162	13
2006	Average	2007	0.054	20
2007	Average	2008	1.368	5
2008	Average	2009	0.332	9
2009	Average	2010	0.090	14
2010	---		---	---

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 (1983-2010).

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
2009	0.000	0.000	0.140	0.400	0.696	1.000	1.000	1.000	1.000	296
2010	0.000	0.000	0.357	0.810	0.929	1.000	1.000	1.000	1.000	314
Average										
All years	0.001	0.018	0.263	0.559	0.819	0.913	0.963	0.985	0.992	
2001-2010	0.000	0.006	0.298	0.561	0.826	0.937	0.965	0.988	1.000	
2006-2010	0.000	0.000	0.195	0.520	0.871	0.987	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 (2002-2009)*	*EIT survey*	*Bottom trawl survey*	*ADF&G bottom trawl*	*400-mesh eastern trawl 1961-82*
2	0.001	0.041	0.040	0.232	0.962	0.210	0.059	0.119
3	0.021	0.260	0.146	0.606	0.933	0.341	0.139	0.384
4	0.414	0.752	0.404	0.865	0.884	0.526	0.292	0.742
5	1.000	1.000	0.731	0.961	0.806	0.744	0.515	0.930
6	0.947	0.924	0.939	0.991	0.693	0.933	0.733	0.984
7	0.702	0.680	1.000	0.999	0.552	1.000	0.880	0.997
8	0.362	0.348	0.941	0.978	0.402	0.901	0.954	0.999
9	0.132	0.129	0.739	0.733	0.268	0.691	0.987	1.000
10	0.040	0.042	0.318	0.186	0.166	0.466	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	367	192	118	73	54	38	28	21	16
1962	406	272	142	87	54	40	28	21	28
1963	434	301	201	105	65	40	30	21	36
1964	97	322	223	149	78	48	30	22	42
1965	252	72	238	165	110	58	35	22	47
1966	133	187	53	176	120	80	42	26	51
1967	333	99	138	39	125	86	58	31	57
1968	393	247	73	101	28	89	62	42	65
1969	685	291	183	53	71	20	64	45	79
1970	322	507	215	127	34	46	13	45	91
1971	695	239	375	155	89	24	33	9	100
1972	1,297	515	177	273	110	63	17	24	81
1973	987	960	381	126	183	74	43	12	77
1974	3,233	731	710	271	84	123	51	31	66
1975	662	2,395	540	501	174	54	83	36	71
1976	421	490	1,752	378	347	121	38	60	79
1977	1,975	311	353	1,212	260	241	86	28	102
1978	2,763	1,461	226	243	822	178	169	62	96
1979	2,576	2,040	1,048	155	166	567	126	122	116
1980	3,635	1,904	1,477	722	106	114	399	91	175
1981	1,842	2,684	1,381	1,034	499	73	80	286	195
1982	447	1,361	1,953	965	710	344	51	57	353
1983	502	328	971	1,357	667	493	243	37	303
1984	208	368	233	657	906	448	340	175	251
1985	476	152	254	147	397	548	285	237	314
1986	1,620	347	105	156	82	215	308	183	401
1987	549	1,183	244	69	98	51	137	213	430
1988	159	403	853	169	46	64	33	92	470
1989	375	117	293	598	114	30	42	22	411
1990	1,635	277	86	209	406	74	19	27	316
1991	1,019	1,208	203	62	143	260	45	12	251
1992	405	753	887	146	42	94	168	29	173
1993	240	299	547	619	97	27	60	107	145
1994	144	177	217	382	411	63	18	38	174
1995	218	106	129	153	258	271	41	11	146
1996	854	161	78	92	105	175	183	28	112
1997	406	632	118	56	65	73	120	125	98
1998	173	300	462	84	38	41	45	74	143
1999	157	126	210	298	50	22	23	26	134
2000	216	116	90	141	183	29	12	13	101
2001	884	159	84	63	91	111	17	7	77
2002	811	646	113	56	40	56	67	10	57
2003	117	591	458	77	37	26	36	43	47
2004	86	85	418	313	51	24	17	24	64
2005	73	61	58	277	206	34	16	11	63
2006	224	52	41	37	174	129	21	10	54
2007	523	159	35	26	23	109	81	13	46
2008	420	372	107	23	17	15	72	53	43
2009	795	306	256	72	15	11	10	48	67
2010	347	583	215	177	49	11	8	7	81
Average	752	553	394	272	182	120	81	56	140

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.

Year	*3+ total biomass (1,000 t)*	*Female spawn. biom. (1,000 t)*	*Age 2 recruits (million)*	*Catch (t)*	*Harvest rate*	*2009 Assessment results: 3+ total biomass*	*Female spawn. biom.*	*Age 2 recruits*	*Harvest rate*
1977	2,032	476	1,975	118,356	6%	1,909	445	1,872	6%
1978	2,203	515	2,763	96,935	4%	2,067	480	2,629	5%
1979	2,721	525	2,576	105,748	4%	2,559	488	2,467	4%
1980	3,222	582	3,635	114,622	4%	3,040	542	3,492	4%
1981	3,926	481	1,842	147,744	4%	3,719	450	1,778	4%
1982	4,080	562	447	168,740	4%	3,872	527	433	4%
1983	3,461	695	502	215,608	6%	3,287	654	488	7%
1984	2,804	732	208	307,401	11%	2,658	688	203	12%
1985	2,080	664	476	284,826	14%	1,960	619	463	15%
1986	1,678	542	1,620	87,809	5%	1,568	502	1,574	6%
1987	1,737	455	549	69,751	4%	1,636	421	538	4%
1988	1,637	412	159	65,739	4%	1,549	382	157	4%
1989	1,483	398	375	78,392	5%	1,405	372	370	6%
1990	1,262	358	1,635	90,744	7%	1,199	336	1,604	8%
1991	1,380	339	1,019	100,488	7%	1,323	318	1,000	8%
1992	1,698	299	405	90,857	5%	1,641	282	399	6%
1993	1,540	334	240	108,908	7%	1,491	319	237	7%
1994	1,291	384	144	107,335	8%	1,250	369	142	9%
1995	1,085	352	218	72,618	7%	1,050	338	214	7%
1996	898	317	854	51,263	6%	870	305	835	6%
1997	914	273	406	90,130	10%	887	263	396	10%
1998	836	207	173	125,098	15%	811	199	169	15%
1999	676	189	157	95,590	14%	653	181	155	15%
2000	595	177	216	73,080	12%	573	169	215	13%
2001	563	173	884	72,076	13%	543	165	885	13%
2002	707	146	811	51,937	7%	692	138	827	8%
2003	863	138	117	50,666	6%	857	131	125	6%
2004	761	152	86	63,934	8%	760	148	99	8%
2005	638	195	73	80,846	13%	643	192	89	13%
2006	547	206	224	71,976	13%	557	205	305	13%
2007	502	184	523	53,062	11%	535	186	715	10%
2008	663	177	420	52,500	8%	603	185	308	9%
2009	887	164	795	44,003	5%	652	182	1,156	7%
2010	1,136	198	347						
Average									
1977-2010	1,544	353	790	105,149	8%	1,479	339	798	8%
1979-2009			703					704	

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 based on a average for the bottom trawl survey conducted in June to August. Spawning weight at age is based on an average from the Shelikof Strait EIT survey conducted March. Proportion mature females is the average from winter EIT survey specimen data for 1983-2010.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2005-2009)*	*Spawning (Avg. 2006-2010)*	*Population (Avg. 2005-2009)*	*Fishery (Avg. 2005-2009)*	*Proportion mature females*
2	0.3	0.228	0.077	0.201	0.285	0.001
3	0.3	0.674	0.251	0.419	0.539	0.018
4	0.3	0.933	0.509	0.749	0.893	0.263
5	0.3	0.990	0.852	1.042	1.235	0.559
6	0.3	1.000	1.219	1.269	1.415	0.819
7	0.3	1.000	1.582	1.462	1.521	0.913
8	0.3	0.975	1.743	1.652	1.669	0.963
9	0.3	0.721	1.904	1.804	1.720	0.985
10+	0.3	0.189	1.991	1.906	1.898	0.992

Table 1.20. Methods used to assess Gulf of Alaska pollock, 1977-2009. 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 1990-2009 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
2008	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	237,000
2009	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000

Table 1.21. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2010-2023 under different harvest policies. All projections begin with estimated age composition in 2010 using the base run model with a projected 2010 catch of 77,150 t. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 690,000, 276,000, and 242,000 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}
2010	169,501	169,501	169,501	169,501	169,501	169,501	169,501
2011	198,129	198,767	198,939	200,664	202,541	197,448	198,129
2012	222,807	227,345	229,332	242,156	256,872	218,076	222,807
2013	239,254	248,176	256,264	283,318	316,004	230,159	238,105
2014	250,448	262,604	280,779	322,694	375,668	237,619	243,605
2015	262,921	276,406	307,243	363,510	437,237	246,802	250,777
2016	276,995	290,678	334,823	404,767	499,055	257,909	260,209
2017	286,751	299,975	356,052	437,527	549,758	265,303	266,443
2018	291,622	304,157	370,084	460,893	588,161	268,370	268,886
2019	293,813	305,704	379,141	477,036	616,235	269,339	269,567
2020	296,316	307,689	386,868	489,903	637,879	270,991	271,097
2021	299,526	310,582	394,551	501,741	656,695	273,512	273,563
2022	300,695	311,516	399,474	509,970	670,447	274,124	274,148
2023	299,740	310,341	401,020	513,751	678,153	272,864	272,877
Fishing mortality	Max F_{ABC}	Author's recommended F	Average F	$F_{75\%}$	F = 0	F_{OFL}	Max F_{ABC} for two years, then F_{OFL}
2010	0.12	0.12	0.12	0.12	0	0.12	0.12
2011	0.14	0.12	0.11	0.06	0	0.16	0.14
2012	0.16	0.14	0.11	0.06	0	0.18	0.16
2013	0.17	0.15	0.11	0.06	0	0.19	0.20
2014	0.17	0.16	0.11	0.06	0	0.19	0.19
2015	0.17	0.16	0.11	0.06	0	0.19	0.19
2016	0.17	0.16	0.11	0.06	0	0.19	0.19
2017	0.17	0.16	0.11	0.06	0	0.19	0.19
2018	0.17	0.17	0.11	0.06	0	0.20	0.20
2019	0.18	0.17	0.11	0.06	0	0.20	0.20
2020	0.18	0.17	0.11	0.06	0	0.20	0.20
2021	0.18	0.17	0.11	0.06	0	0.20	0.20
2022	0.18	0.17	0.11	0.06	0	0.20	0.20
2023	0.18	0.17	0.11	0.06	0	0.20	0.20
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}
2010	77,150	77,150	77,150	77,150	77,150	77,150	77,150
2011	102,938	88,621	84,718	44,910	0	118,030	102,938
2012	127,989	114,054	95,270	52,577	0	141,742	127,989
2013	150,313	139,371	106,127	60,320	0	162,635	171,897
2014	162,025	156,187	115,662	67,103	0	174,198	179,395
2015	168,252	164,521	122,771	72,252	0	180,266	182,783
2016	172,577	169,527	126,549	75,214	0	184,744	185,685
2017	173,821	170,858	128,212	76,727	0	185,849	186,025
2018	176,656	173,054	130,456	78,458	0	188,328	188,245
2019	178,710	174,998	131,703	79,238	0	190,466	190,324
2020	180,031	176,060	132,644	79,871	0	191,672	191,580
2021	179,692	175,672	132,182	79,708	0	191,121	191,072
2022	177,240	173,316	131,183	79,219	0	188,495	188,470
2023	175,276	171,542	130,133	78,705	0	186,325	186,312

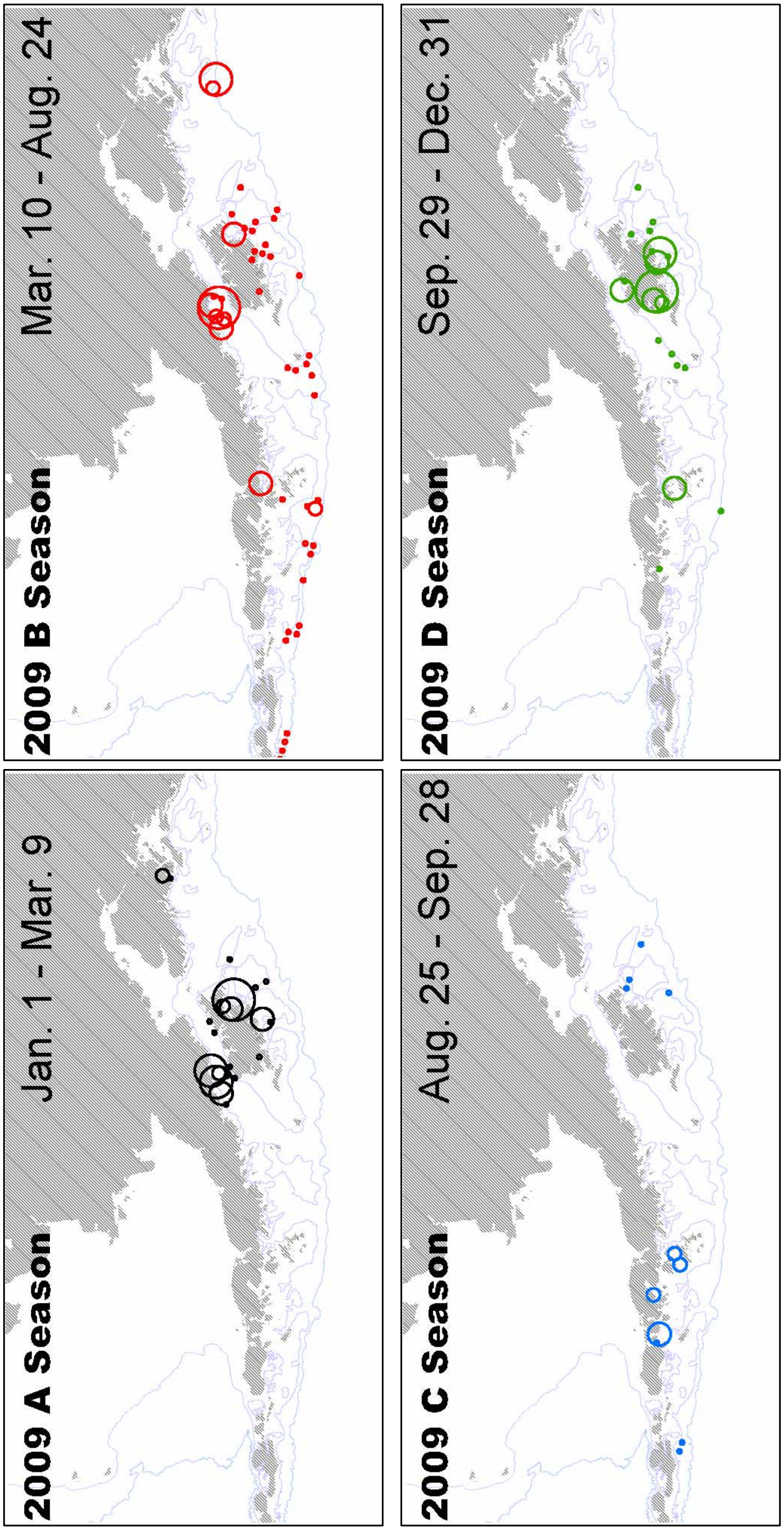


Figure 1.1 Pollock catch in 2009 by 20 X 20 km blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

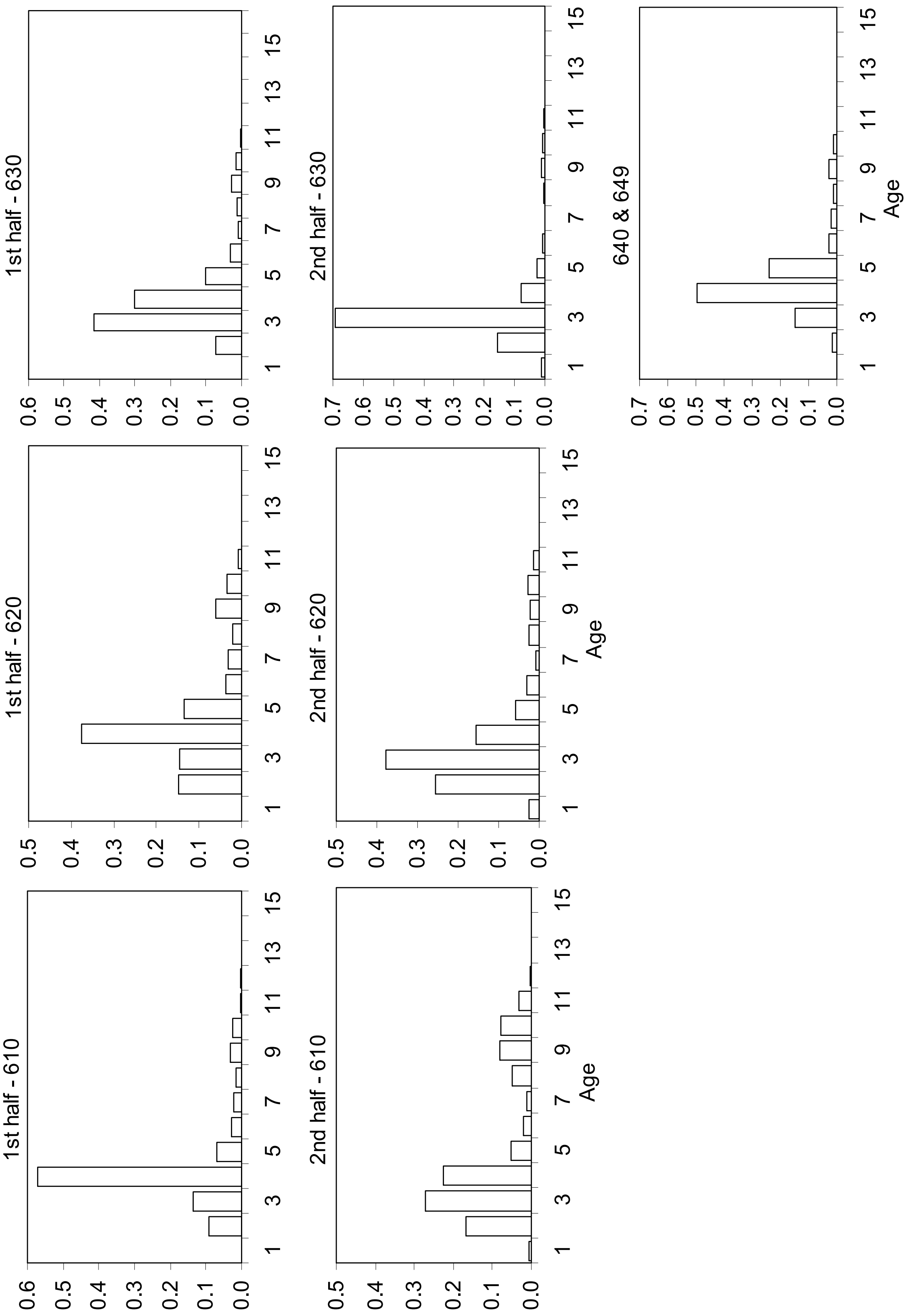


Figure 1.2. 2009 catch age composition by half year and statistical area.

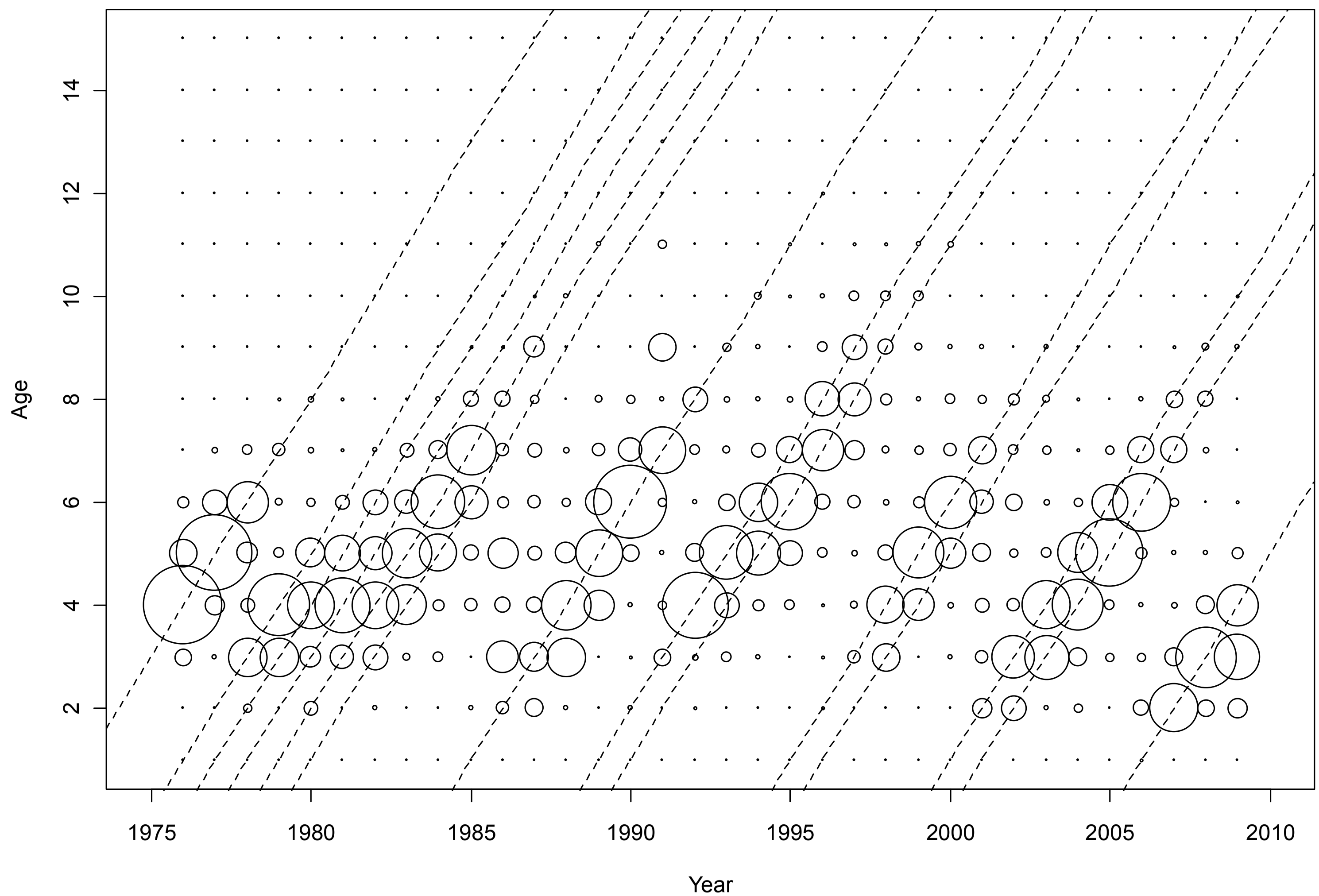


Figure 1.3. Gulf of Alaska pollock catch age composition (1976-2009). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, 1995, 1999, 2000, and 2005).

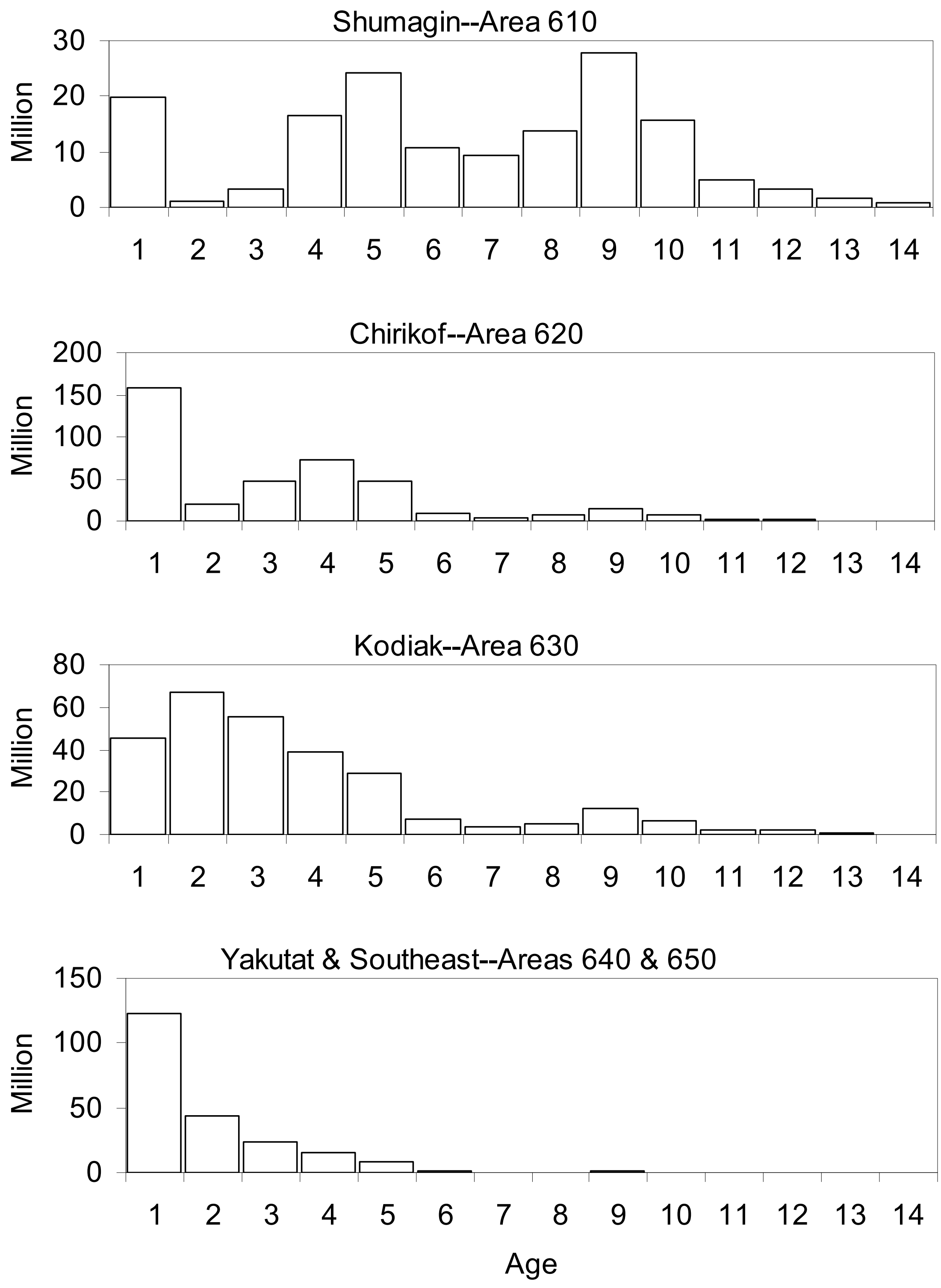


Figure 1.4. Age composition of pollock by statistical area for the 2009 NMFS bottom trawl survey.

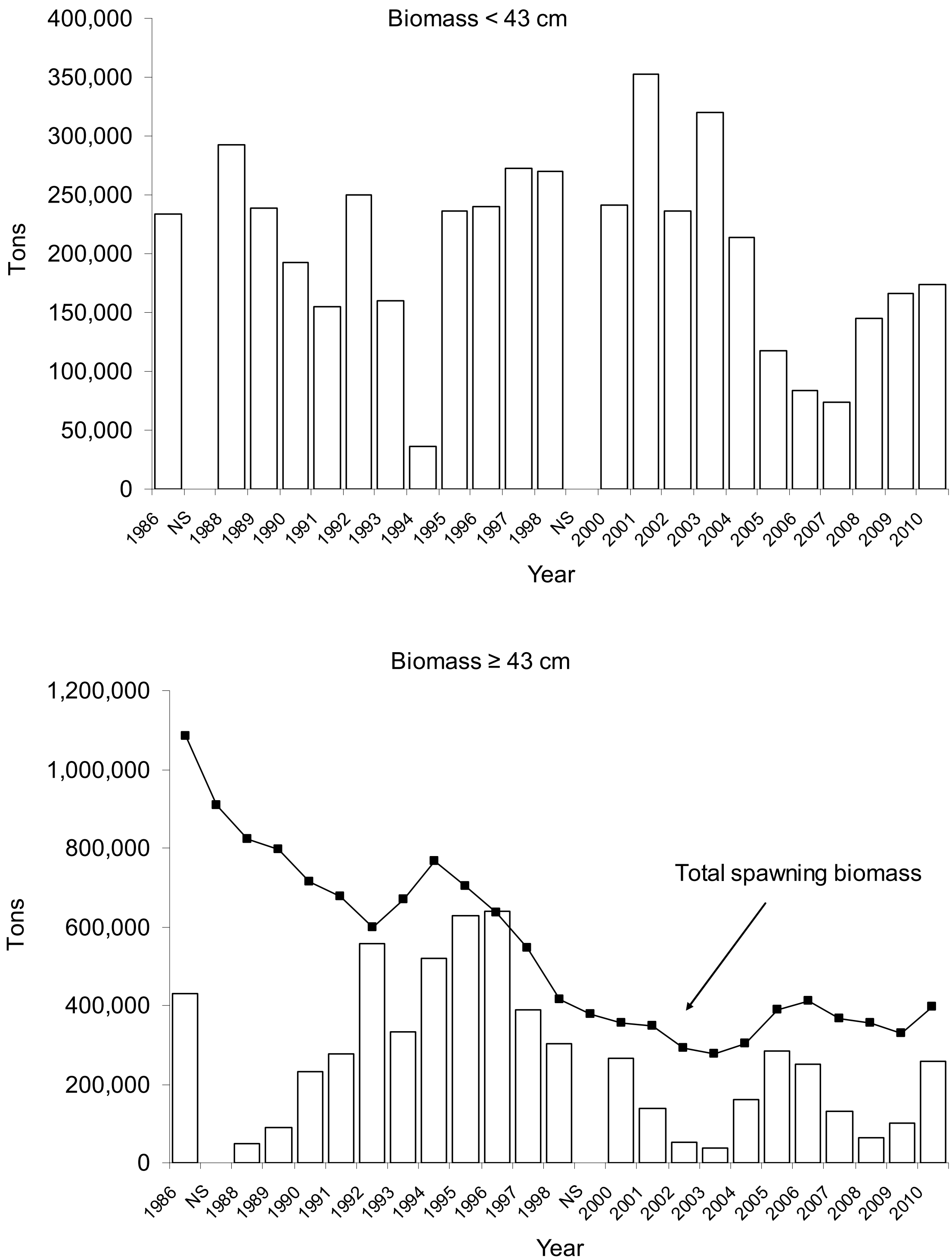


Figure 1.5. Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2010 Shelikof Strait EIT surveys. Bottom panel also shows the model estimate of total spawning biomass.

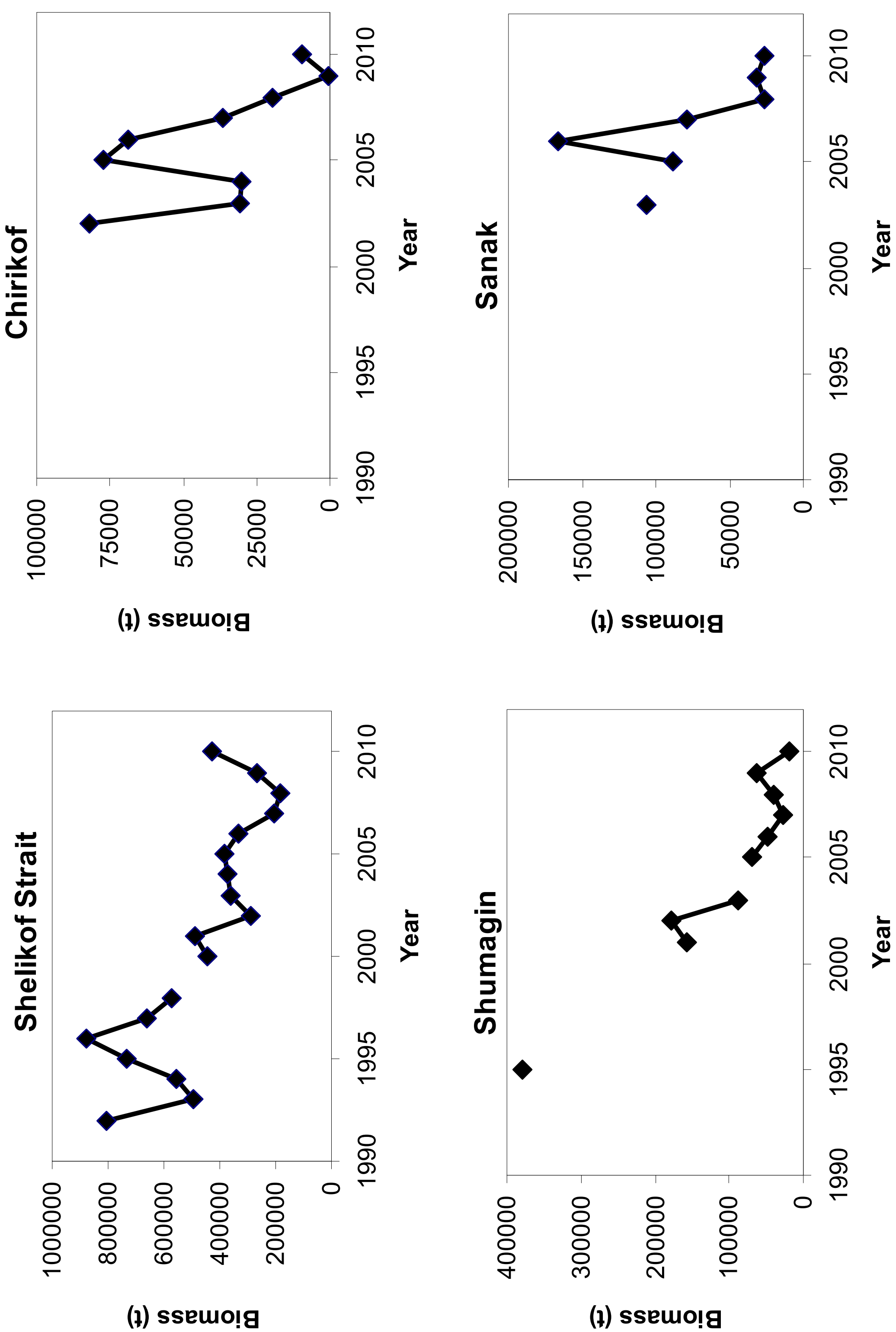


Figure 1.6. Trends in biomass estimates of from winter acoustic surveys of pre-spawning aggregations of pollock in the Gulf of Alaska.

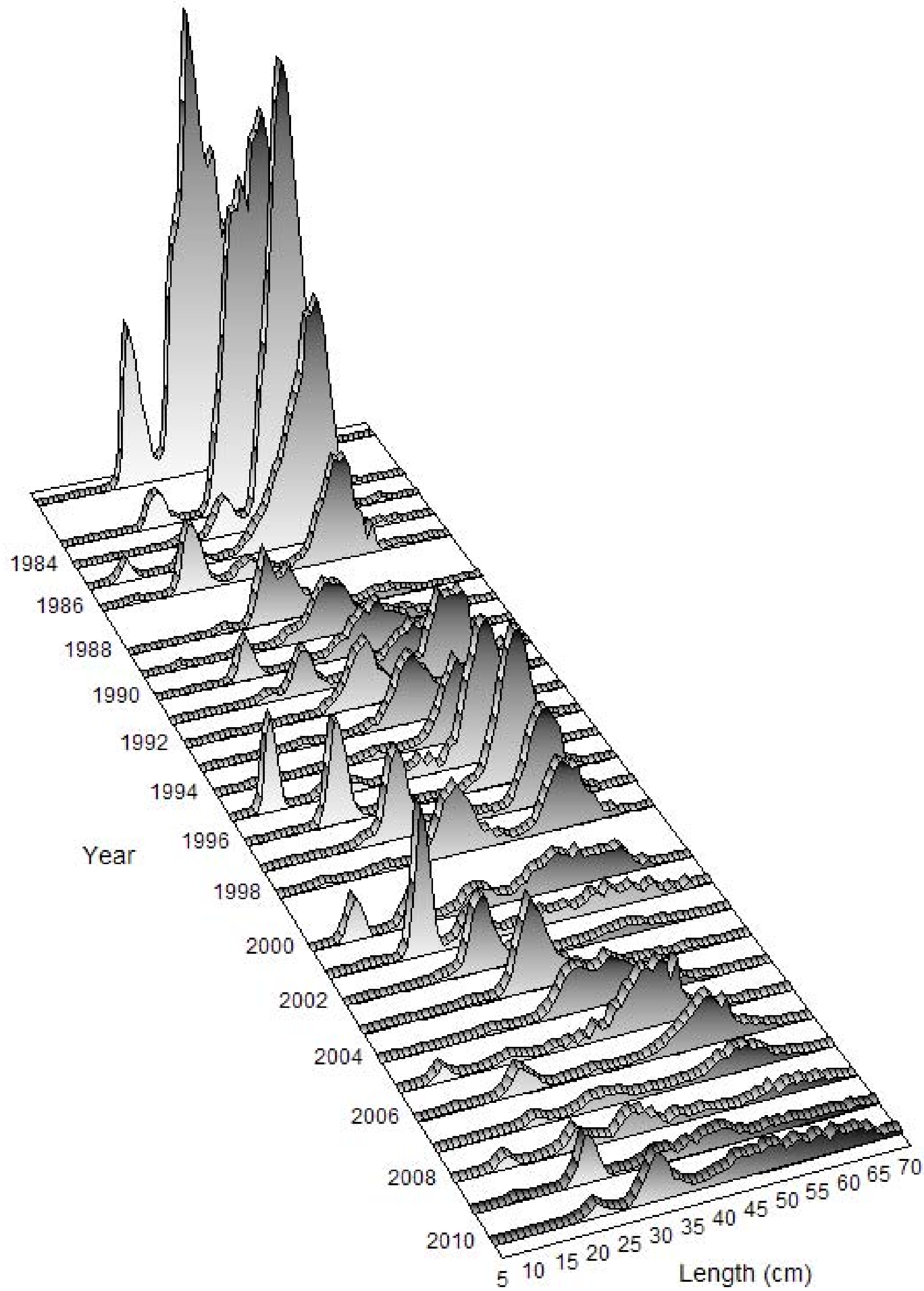


Figure 1.7. Biomass by length for pollock in the Shelikof Strait EIT survey (1981-2010, except 1982,1987 and 1999).

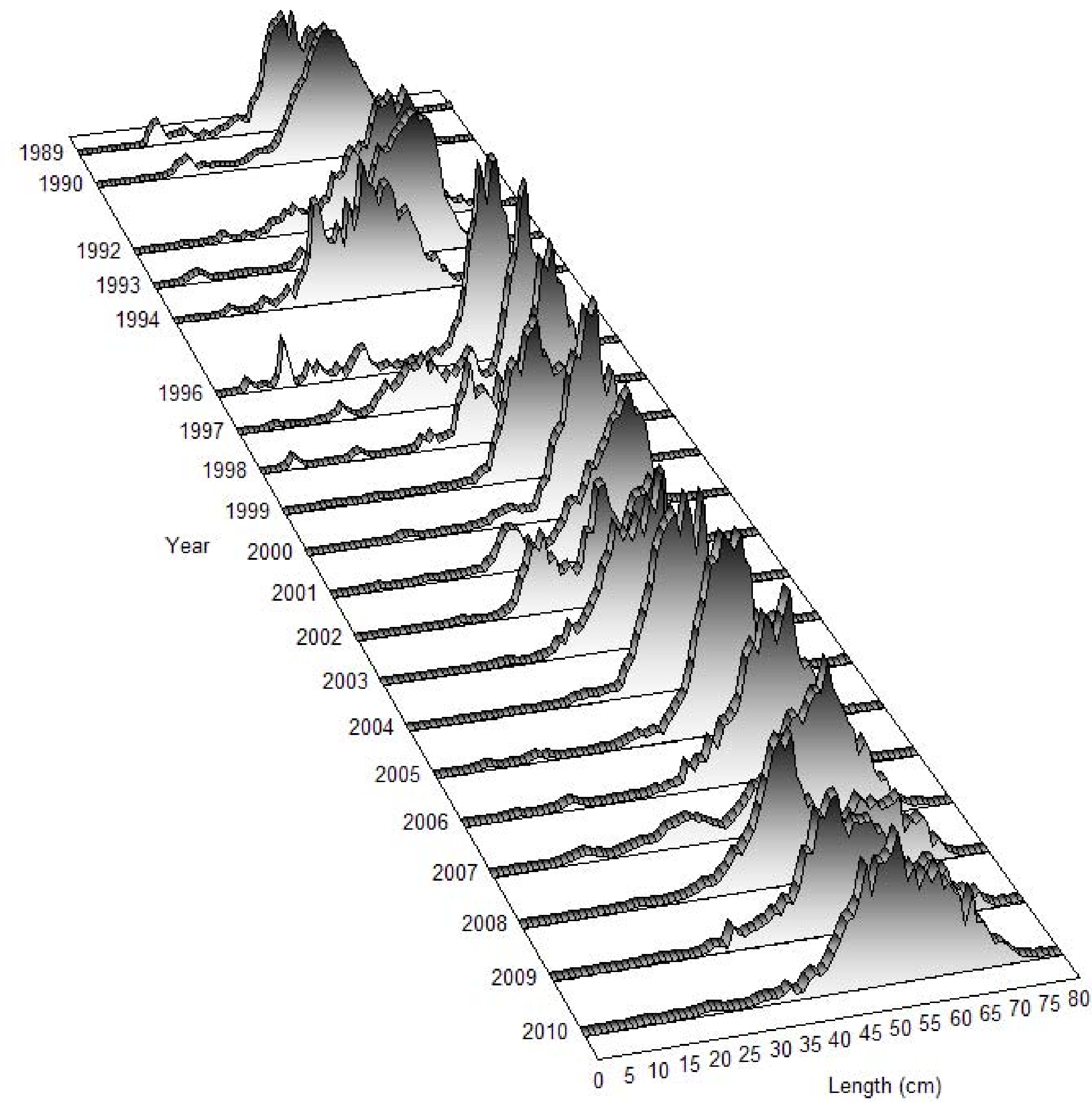


Figure 1.8. Length frequency of pollock in the ADF&G crab/groundfish trawl survey (1989-2010, except 1991 and 1995).

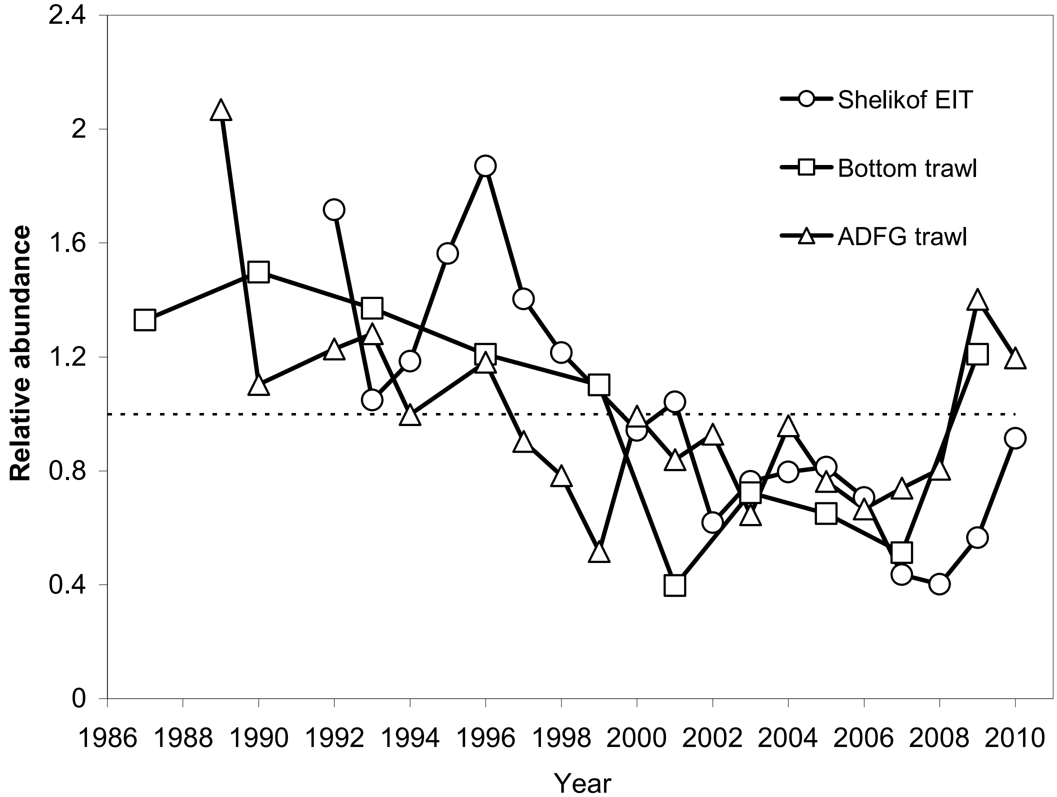


Figure 1.9. Relative trends in pollock biomass since 1987 for the Shelikof Strait EIT survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987. Shelikof Strait EIT surveys prior to 2008 were re-scaled to be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

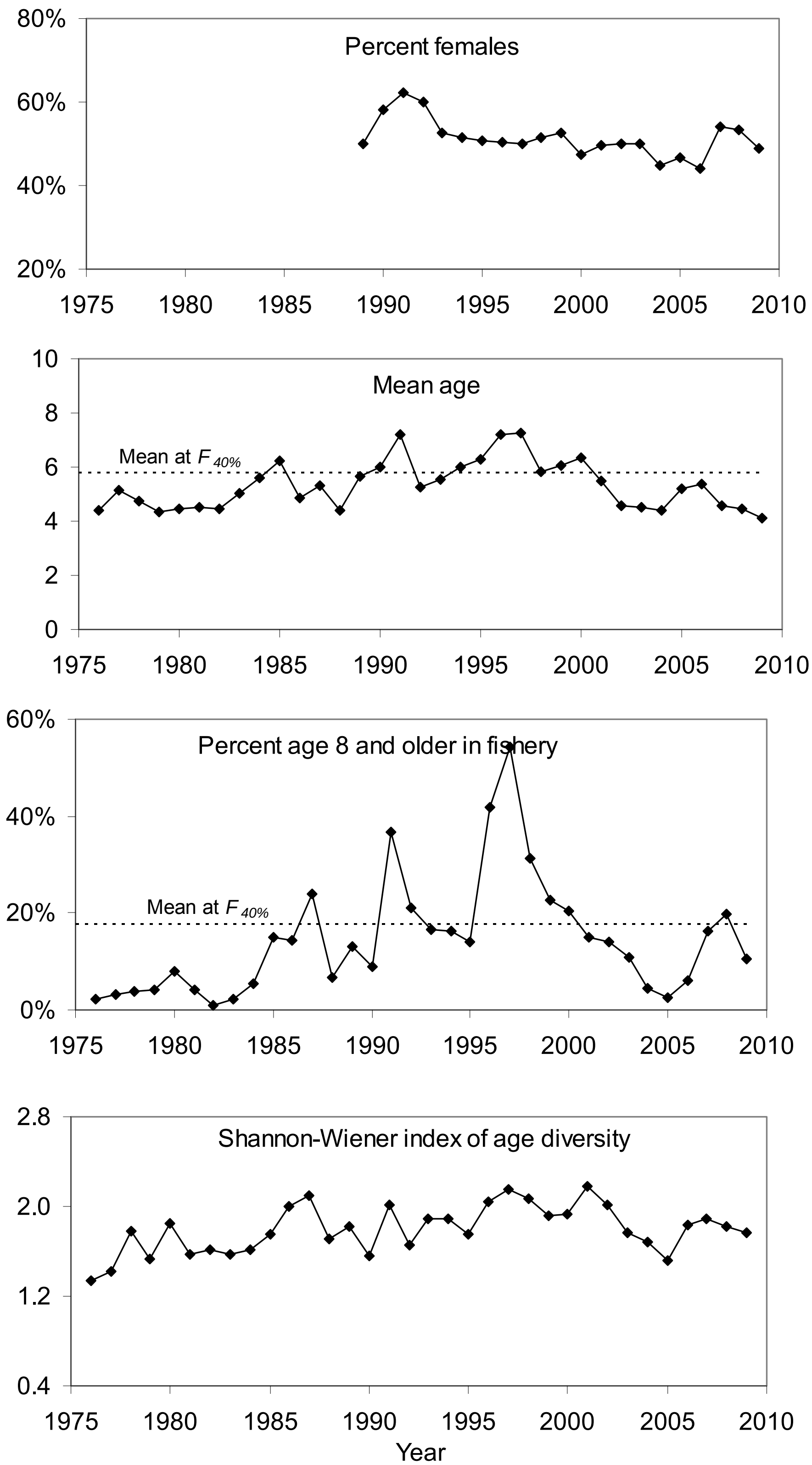


Figure 1.10. Gulf of Alaska pollock catch characteristics.

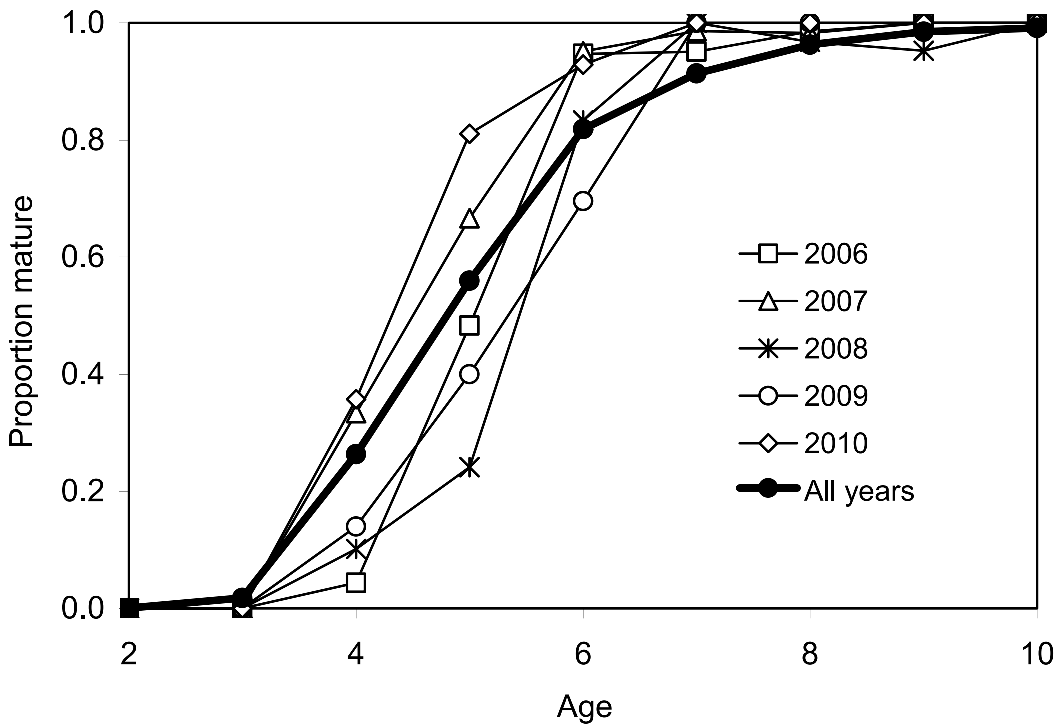


Figure 1.11. Estimates of the proportion mature at age from visual maturity data collected during 2006-2010 winter EIT surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2010).

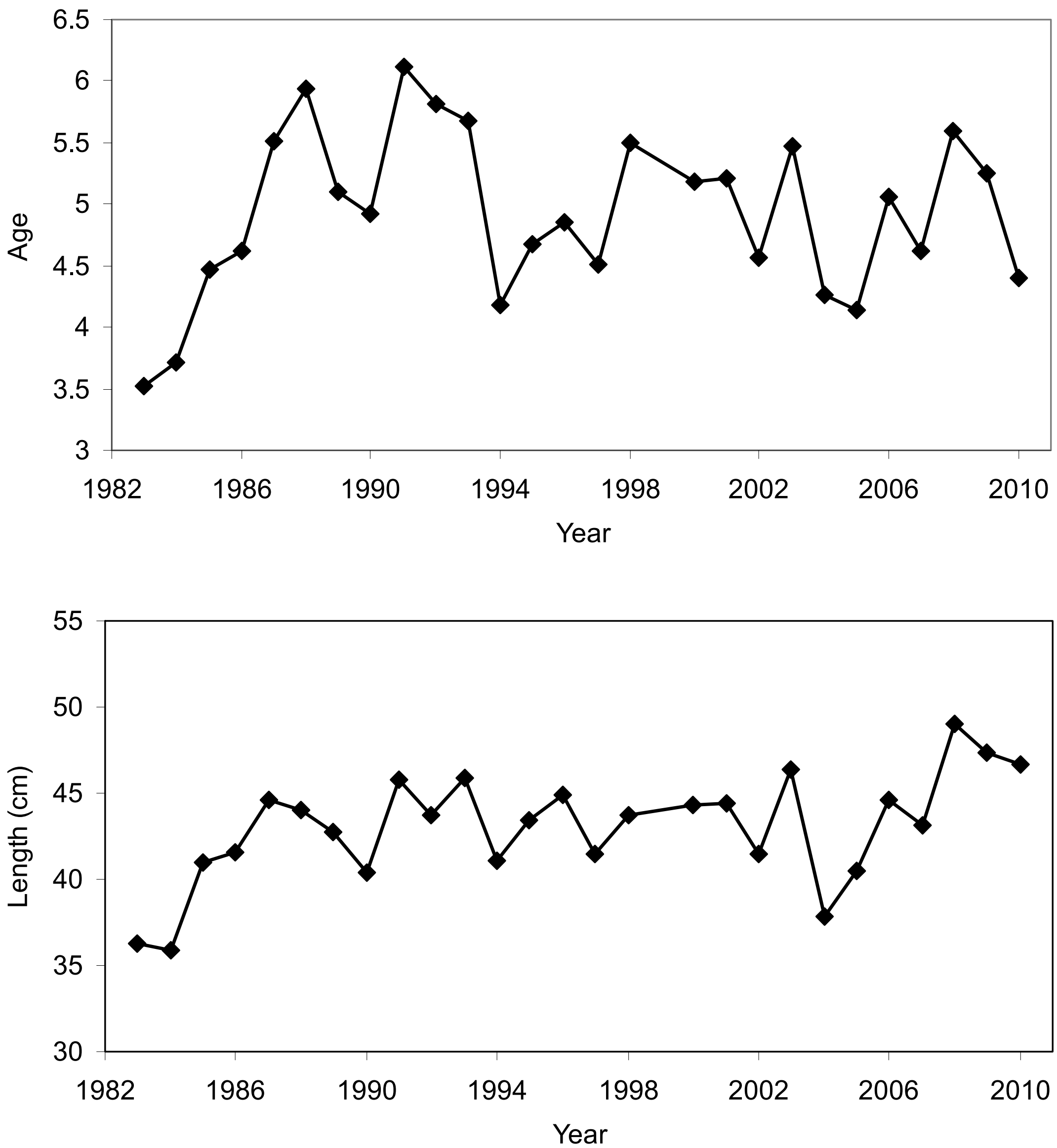


Figure 1.12. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter EIT survey data in the Gulf of Alaska, 1983-2010.

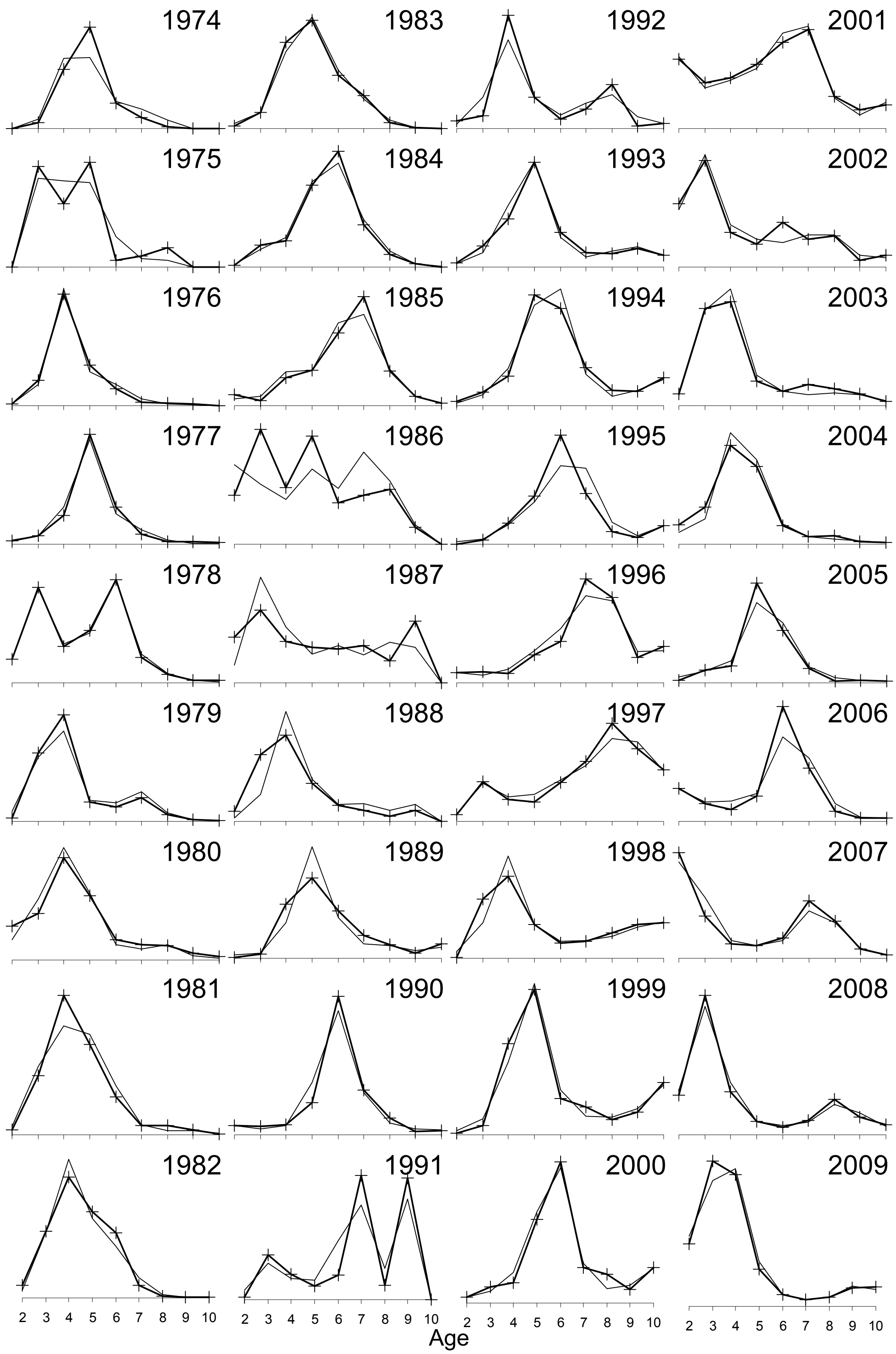


Figure 1.13. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

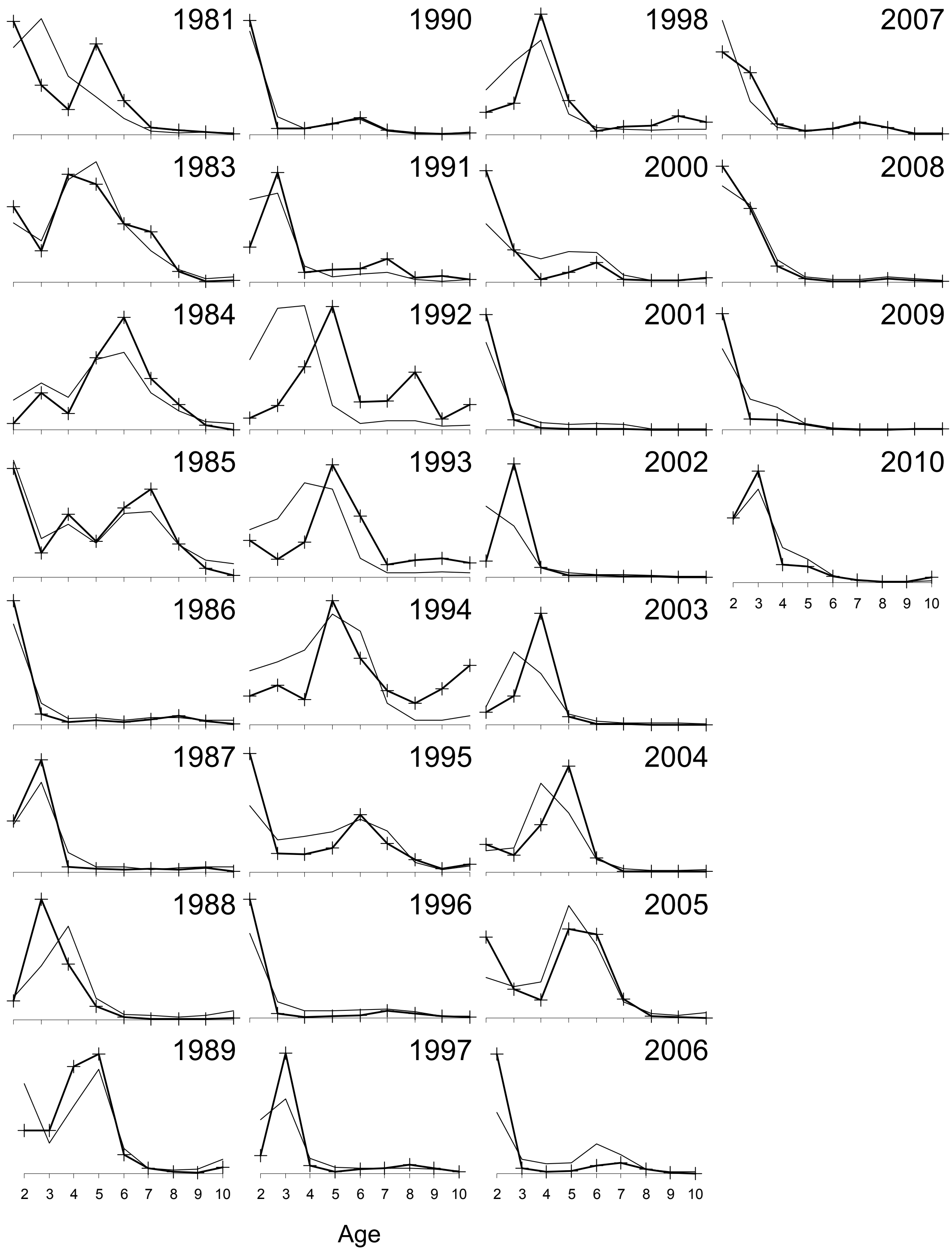


Figure 1.14. Observed and predicted Shelikof Strait EIT survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

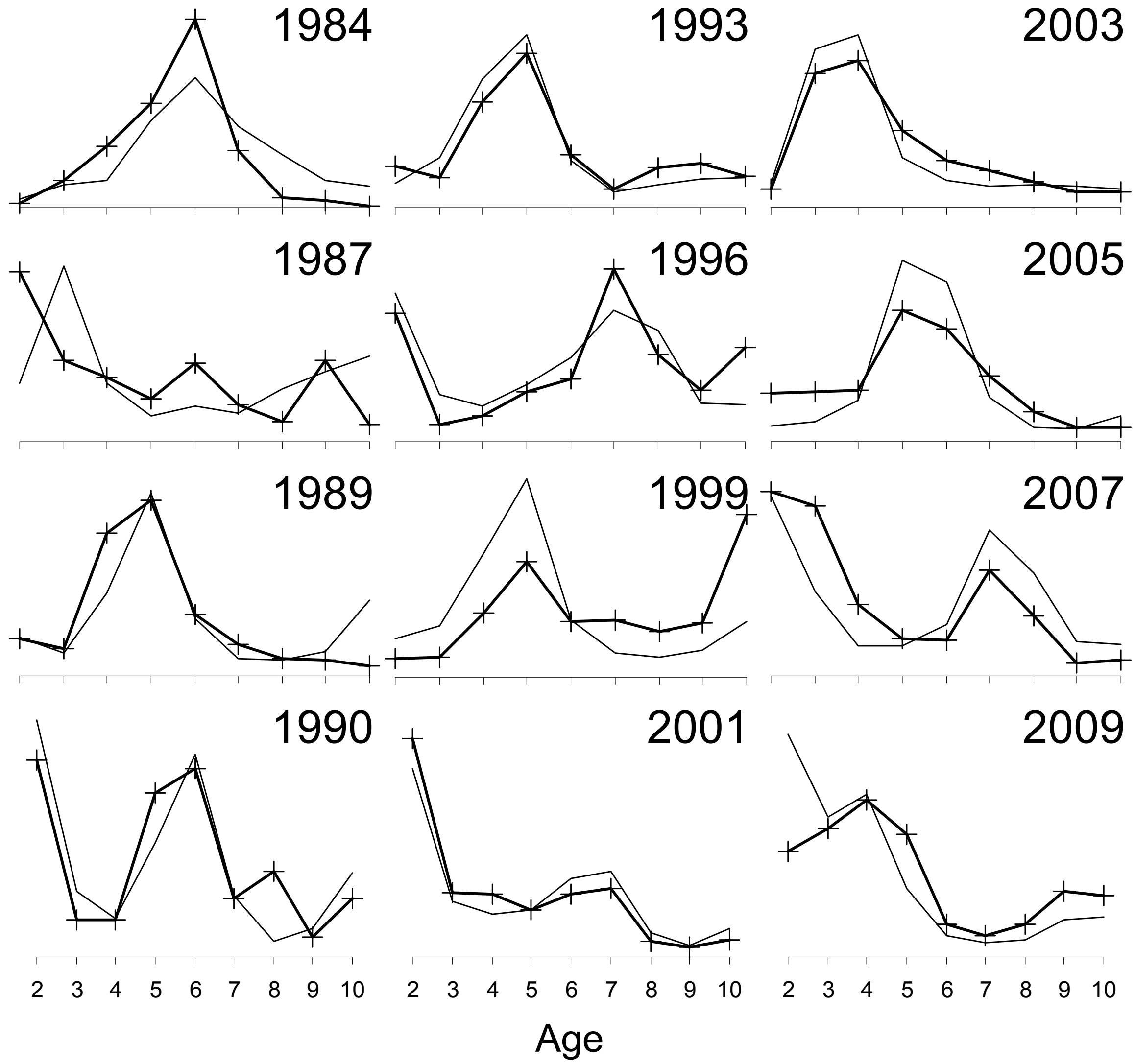
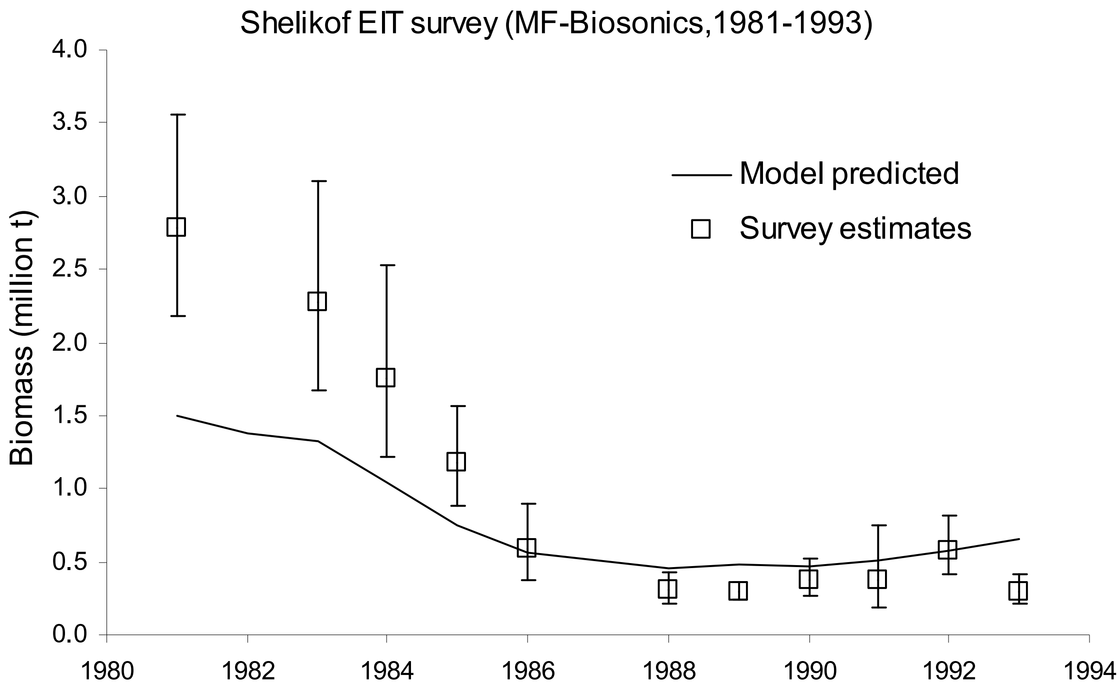


Figure 1.15. Observed and predicted NMFS bottom trawl age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.



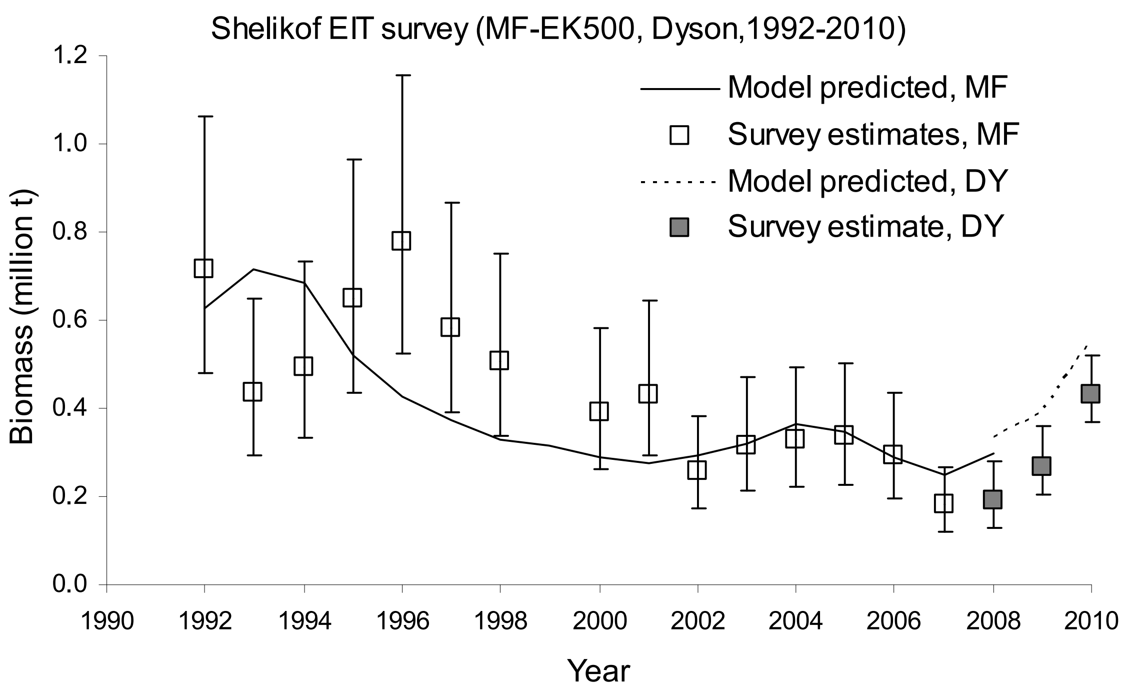
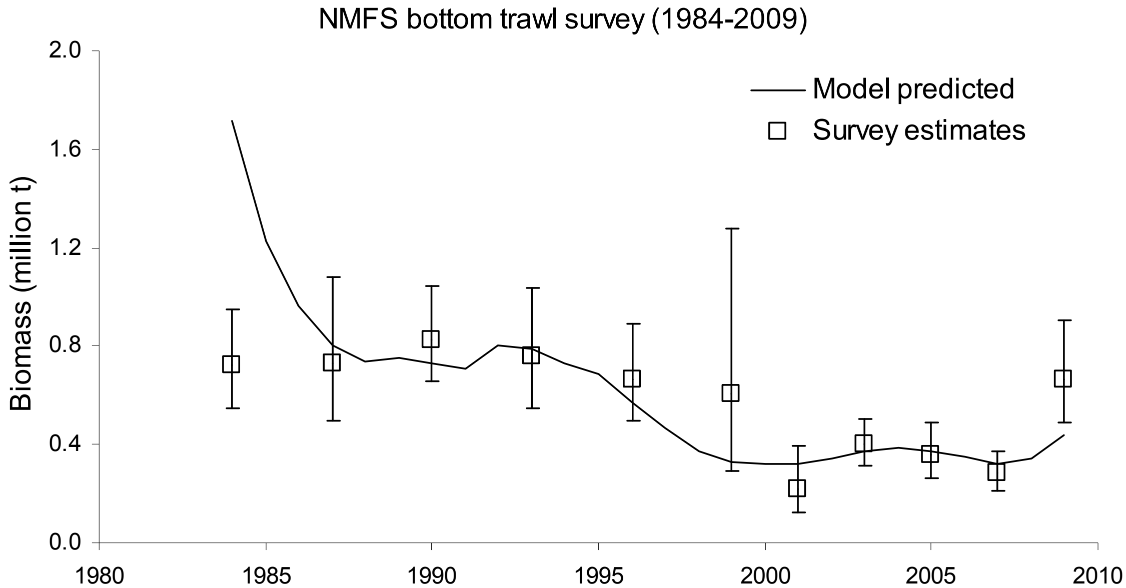


Figure 1.16. Model predicted and observed survey biomass for the Shelikof Strait EIT survey. The Shelikof EIT survey is modeled with three catchability periods corresponding to the two acoustic systems used on the *R/V Miller Freeman* (MF), with an additional catchability period for the *R/V Dyson* (DY) in 2008-2010. Error bars indicate plus and minus two standard deviations.



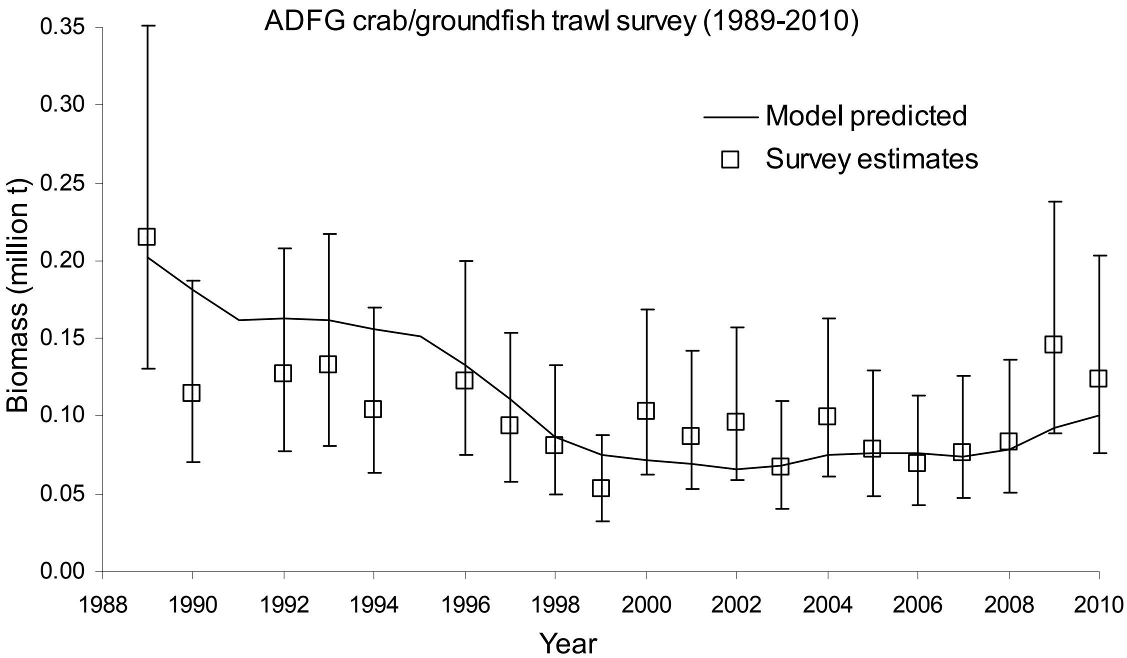
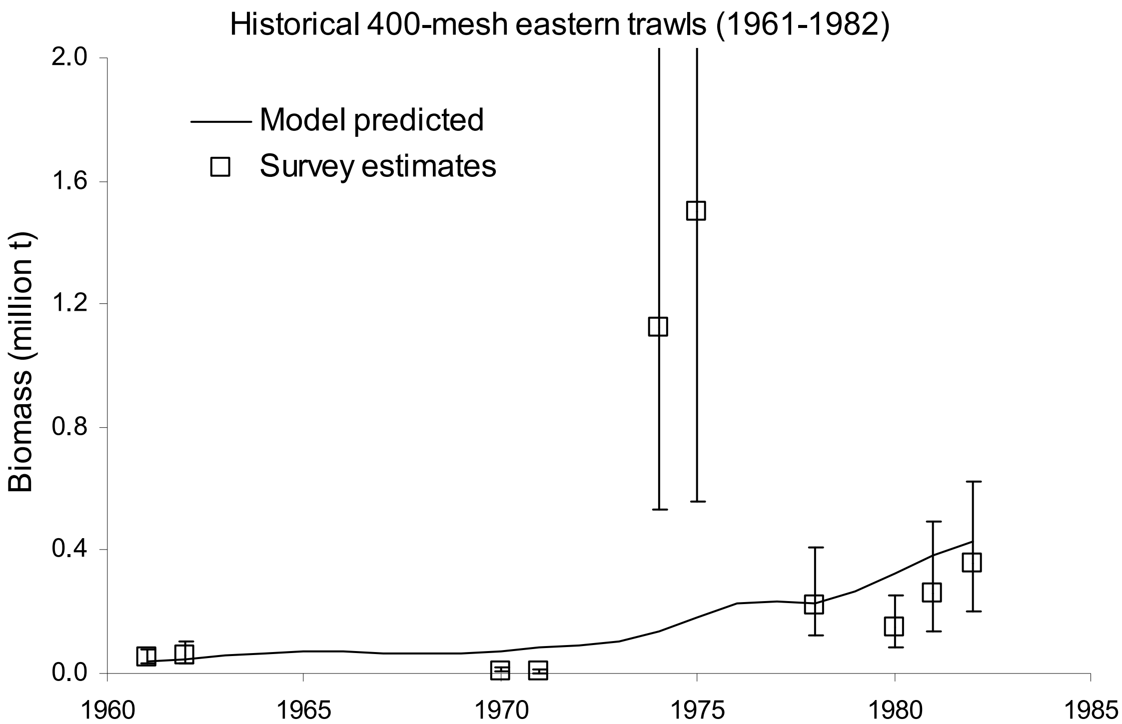


Figure 1.17. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used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



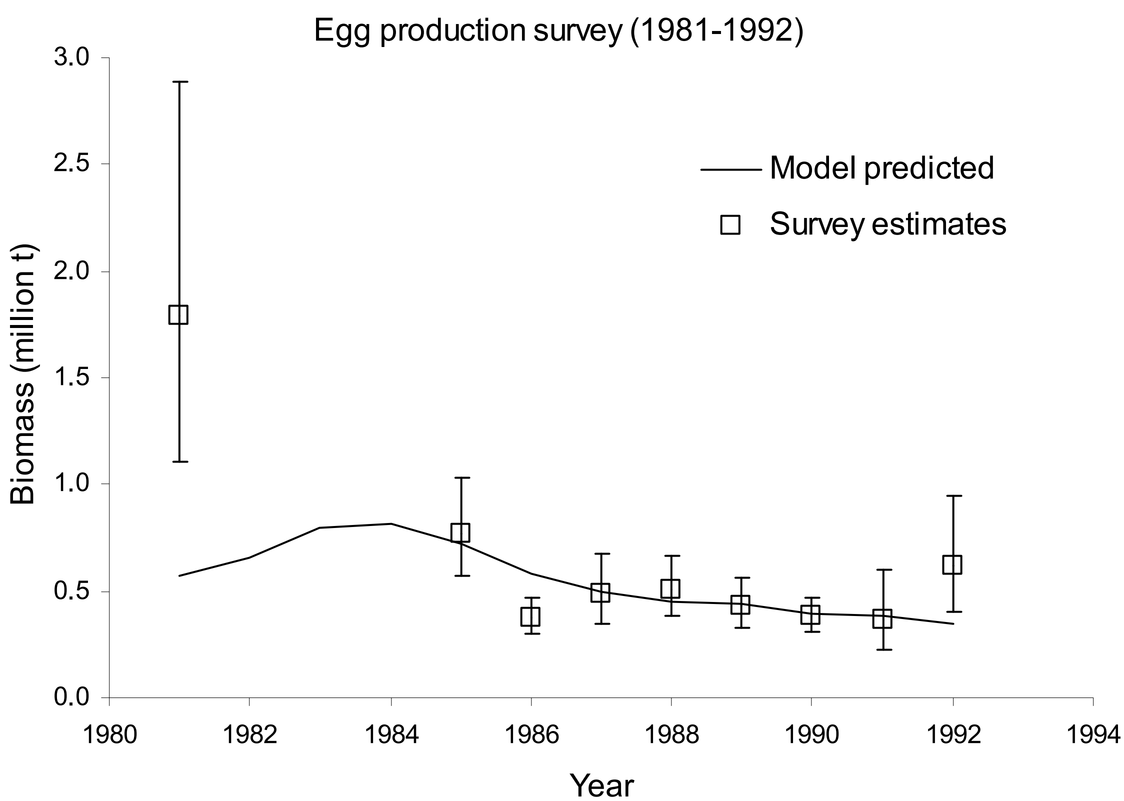


Figure 1.18. Model predicted and observed survey biomass for the historical 400-mesh eastern trawl surveys (top), and the egg production survey (bottom). Error bars indicate plus and minus two standard deviations.

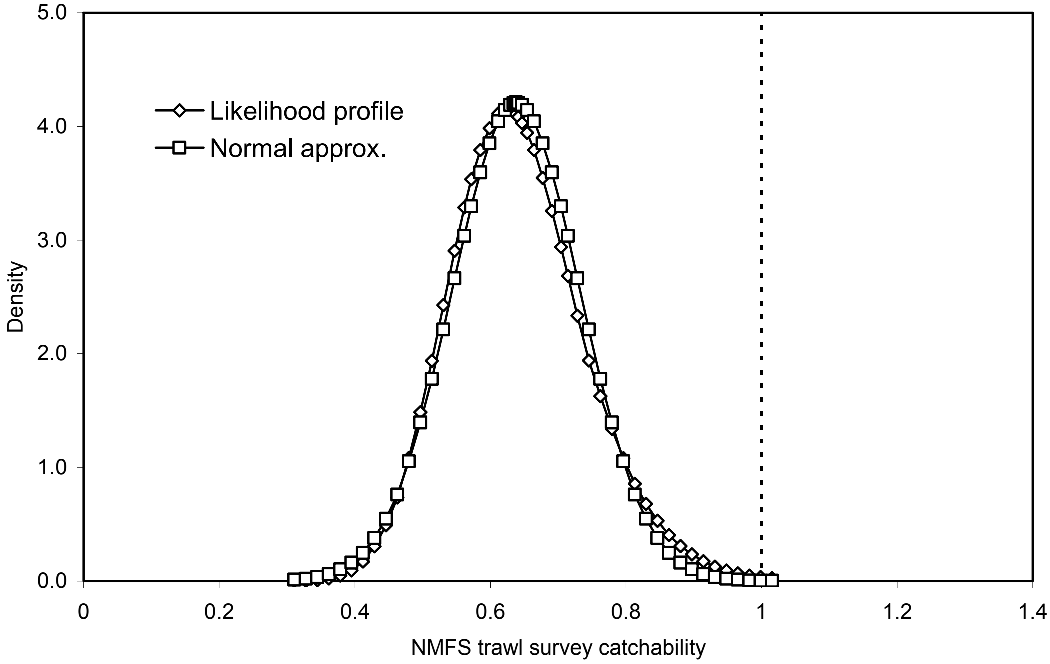


Figure 1.19. Uncertainty in the catchability coefficient for the NMFS trawl survey from a likelihood profile for the base model.

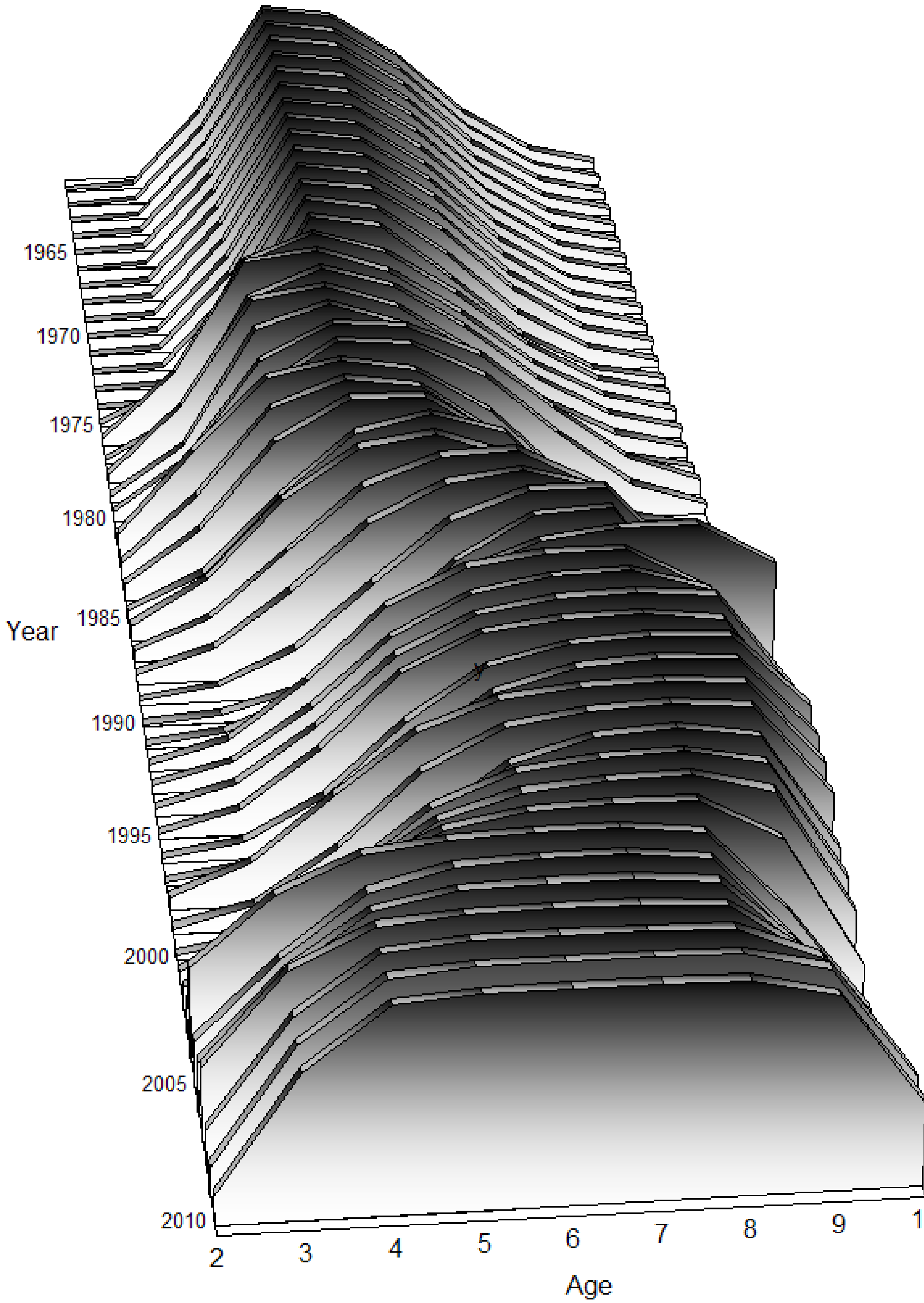
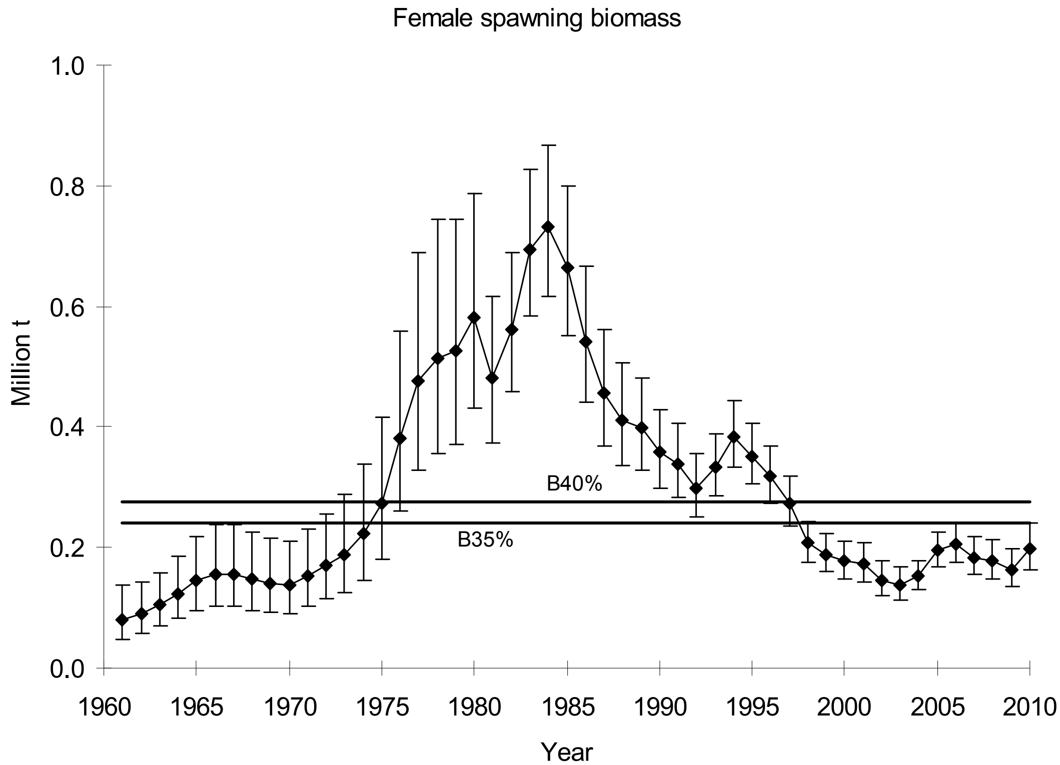


Figure 1.20. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock. The maximum selectivity in each year is 1.0.



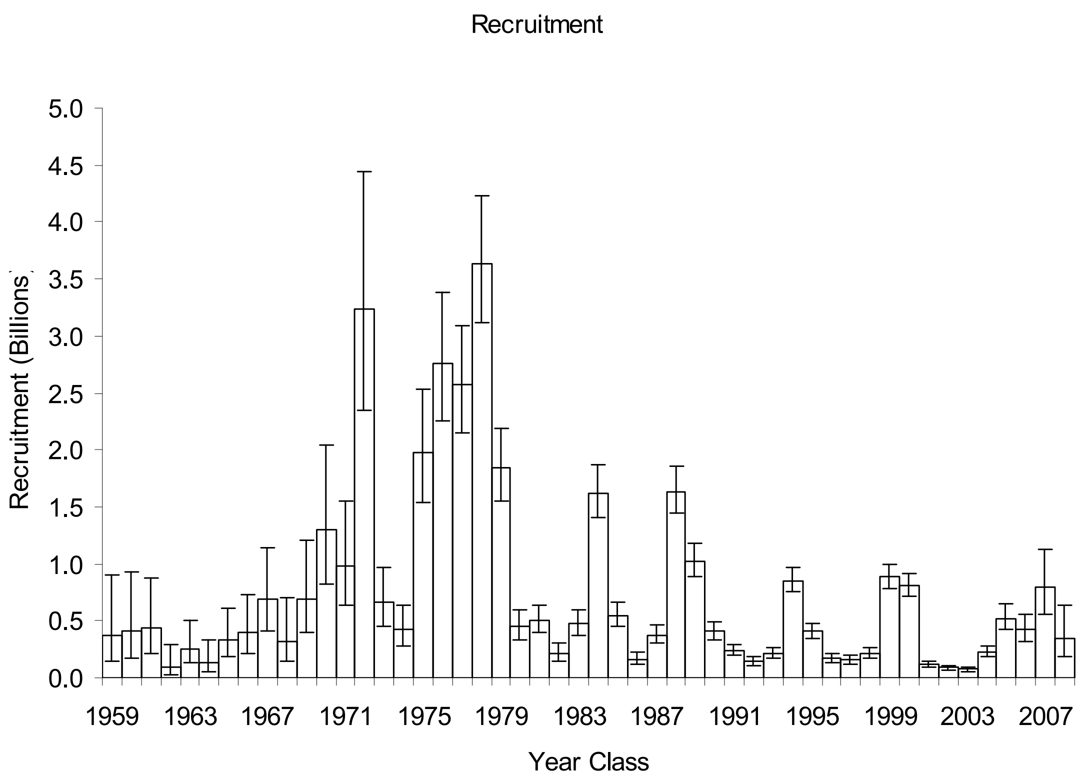
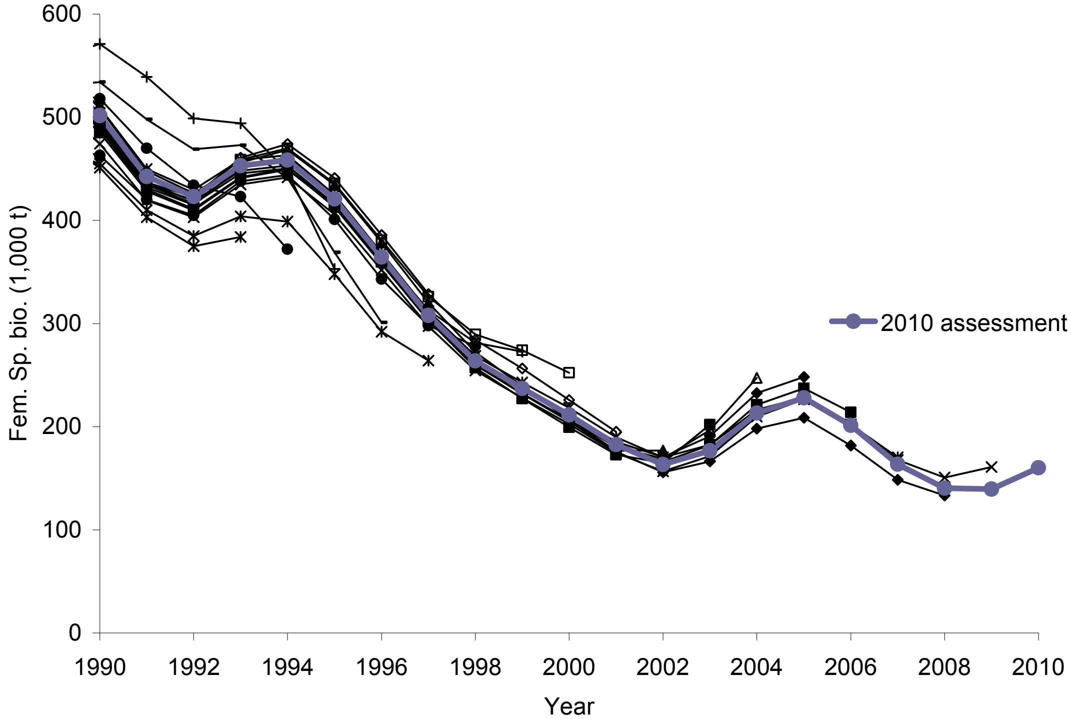


Figure 1.21. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-2 recruitment (billions of fish, bottom) from 1961 to 2010. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



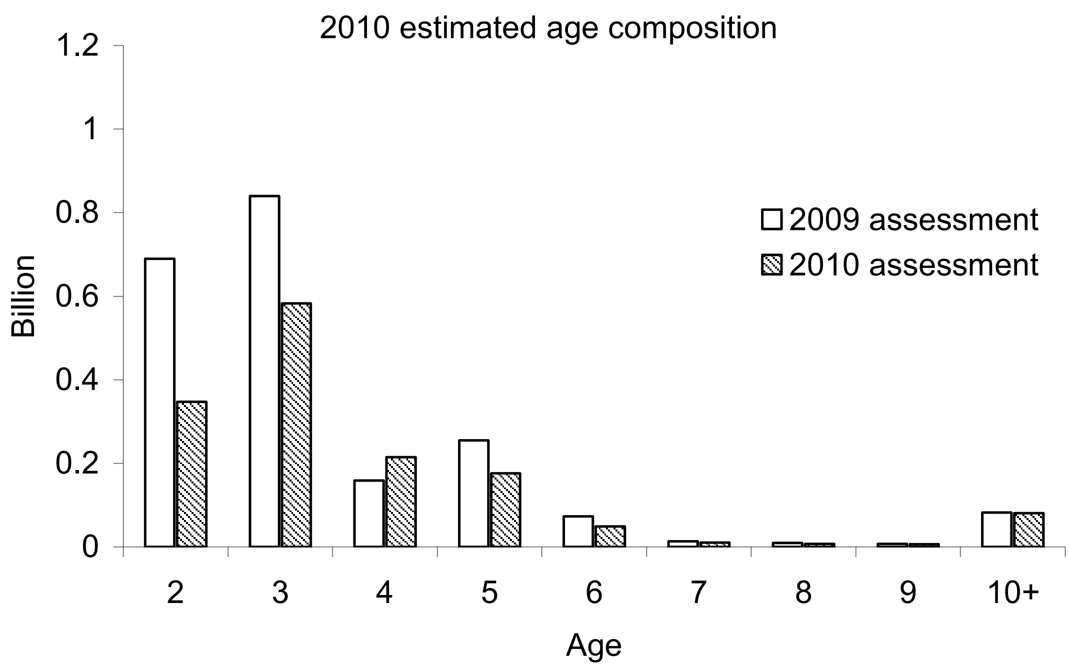
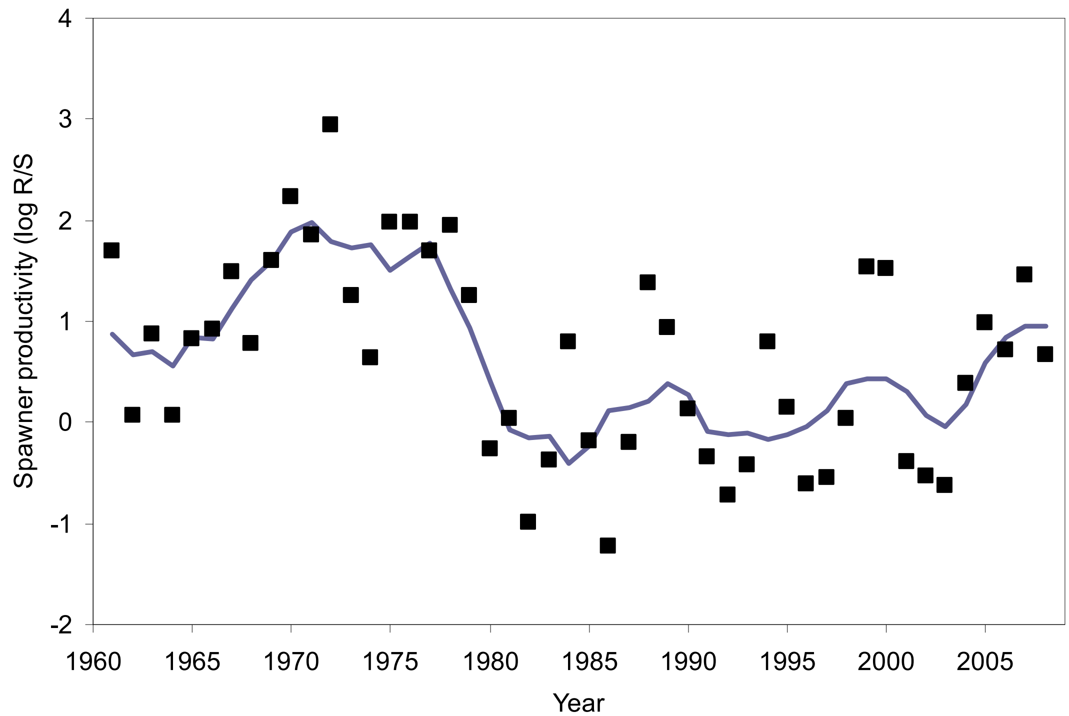


Figure 1.22. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1993-2010 (top). For this figure, the time series of female spawning biomass for the 2010 assessment was calculated using the weight and maturity at age used in pre-1999 assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2010 from the 2009 and 2010 assessments.



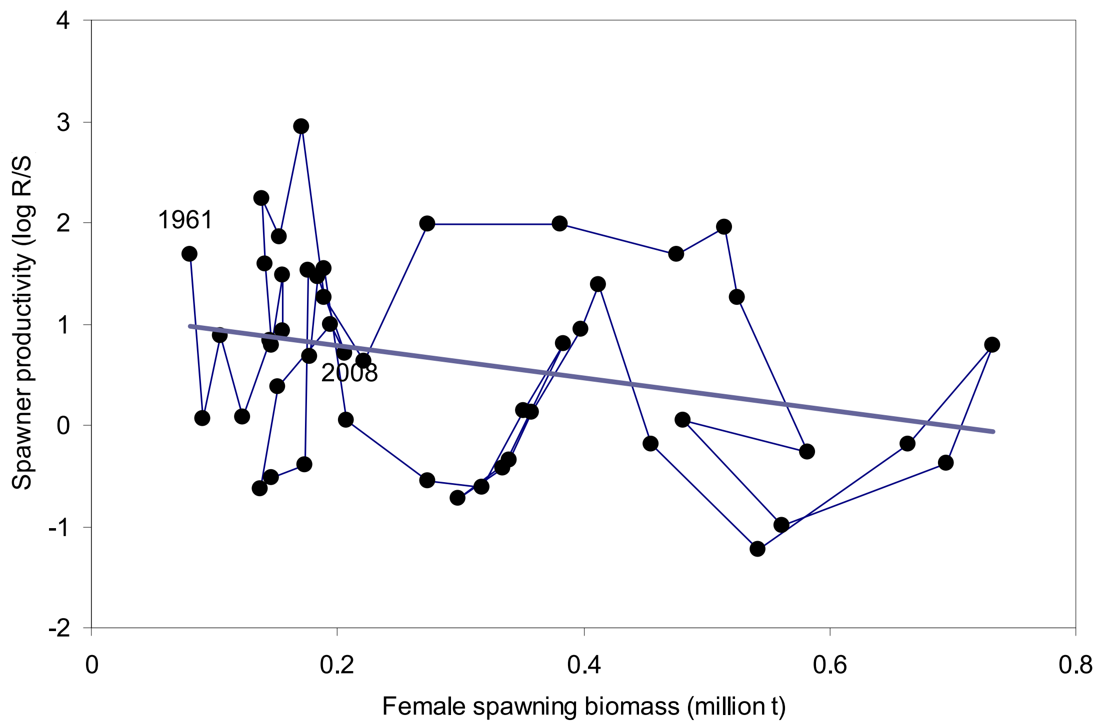


Figure 1.23. Gulf of Alaska pollock spawner productivity *log(R/S)* in 1961-2008 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

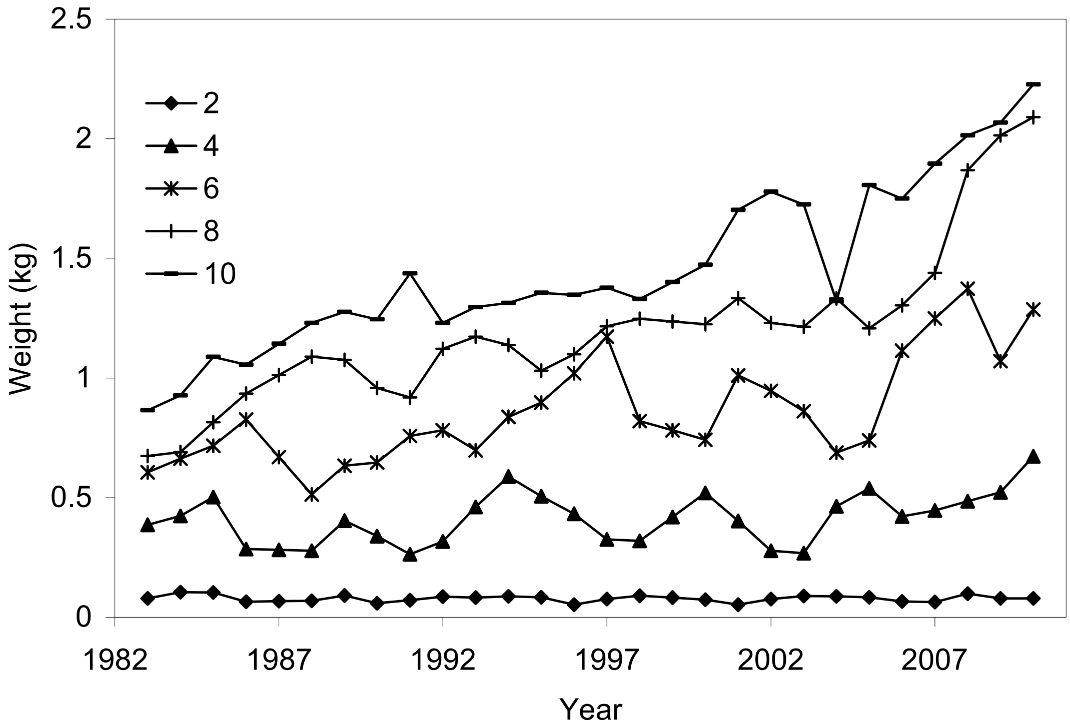


Figure 1.24. Estimated weight-at-age of Gulf of Alaska pollock (ages 2, 4, 6,10) from Shelikof Strait EIT surveys in 1983-2010. In 1999, when the EIT survey was not conducted, weights-at-age were interpolated from adjacent years.

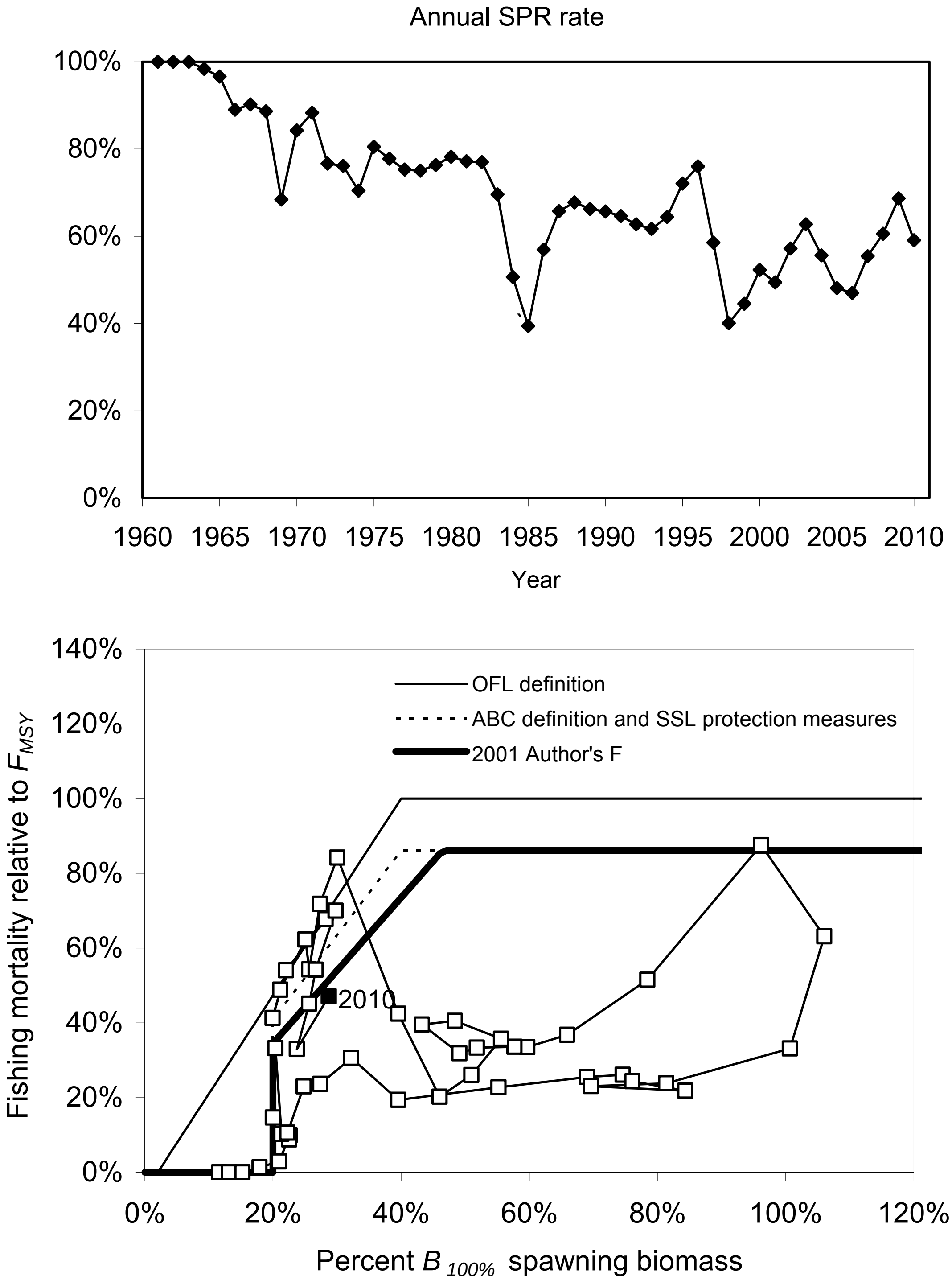


Figure 1.25. Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{MSY} (1961-2010). The ratio of fishing mortality to F_{MSY} is calculated using the estimated selectivity pattern in that year. Estimates of $B_{100\%}$ spawning biomass are based 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.

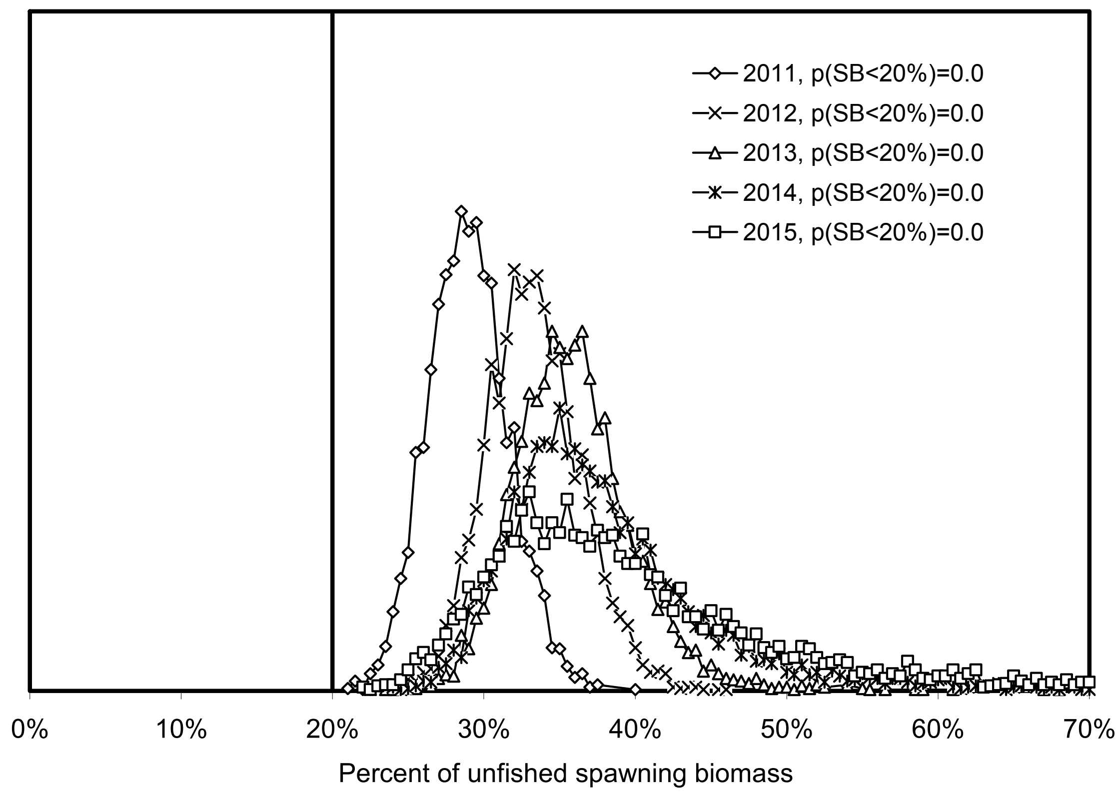


Figure 1.26. Uncertainty in spawning biomass in 2011-2015 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended FABC.

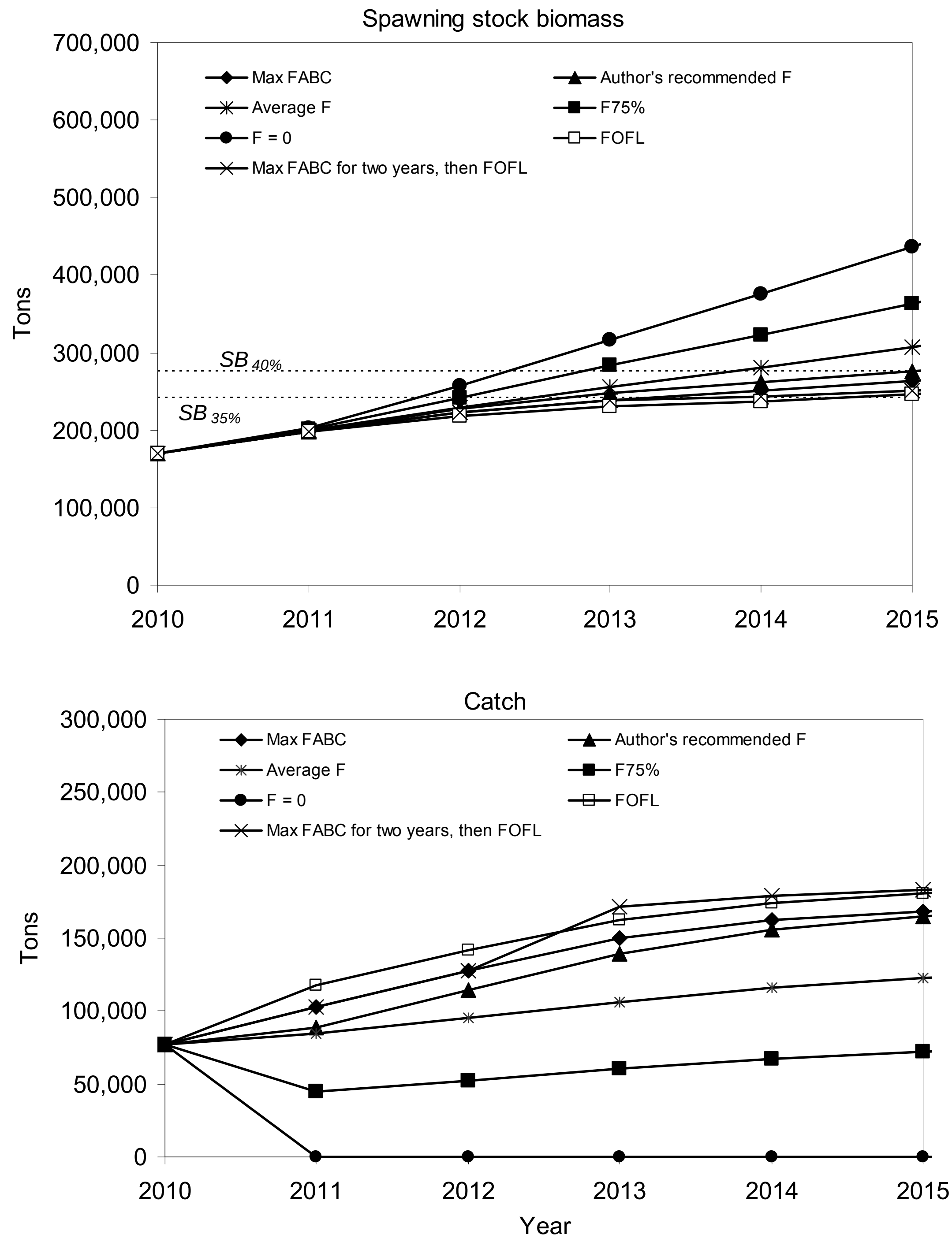


Figure 1.27. Projected spawning biomass and catches in 2011-15 under different management strategies.

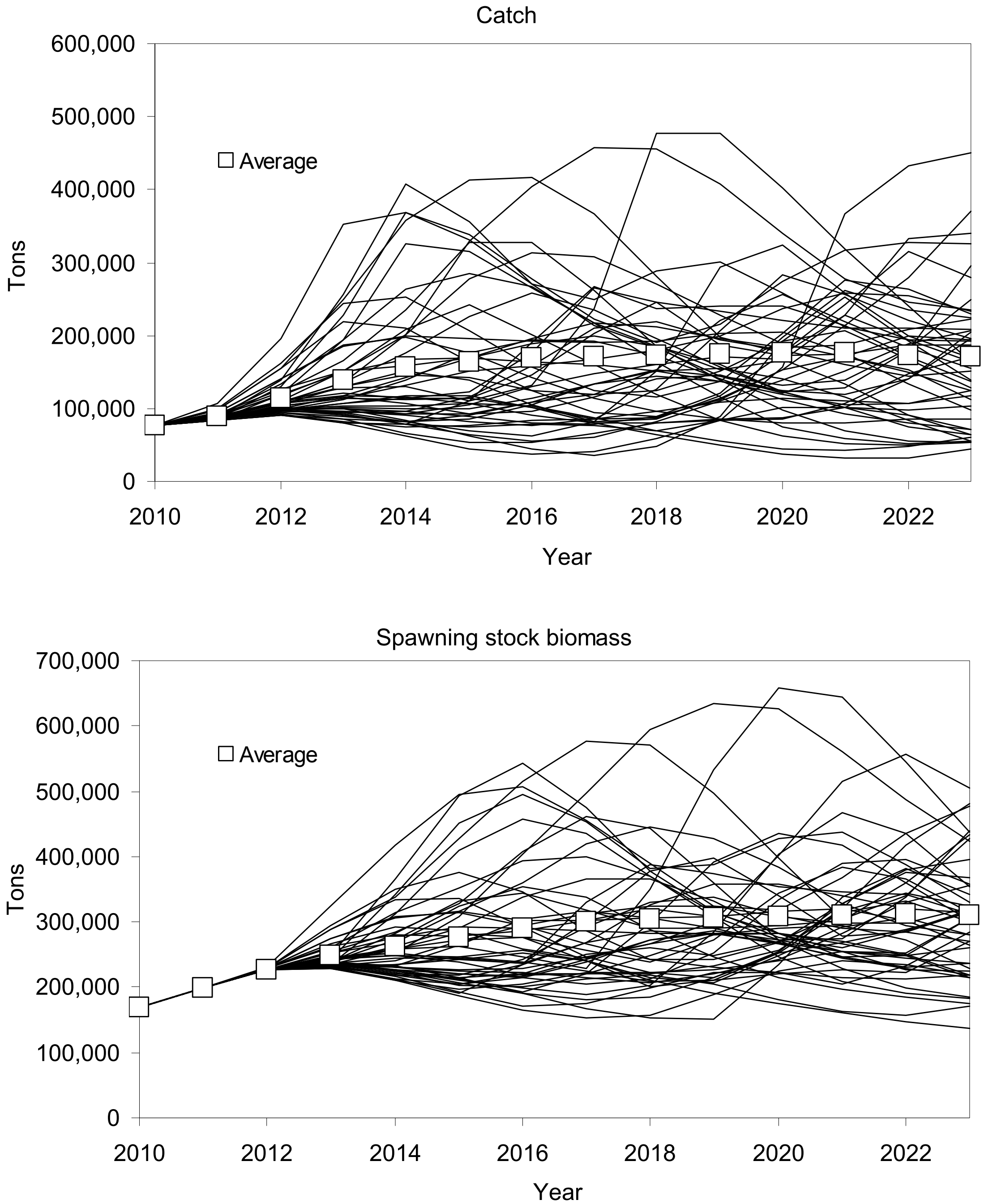


Figure 1.28. Variability in projected catch and spawning biomass in 2011-2023 under the author's recommended F_{ABC}.

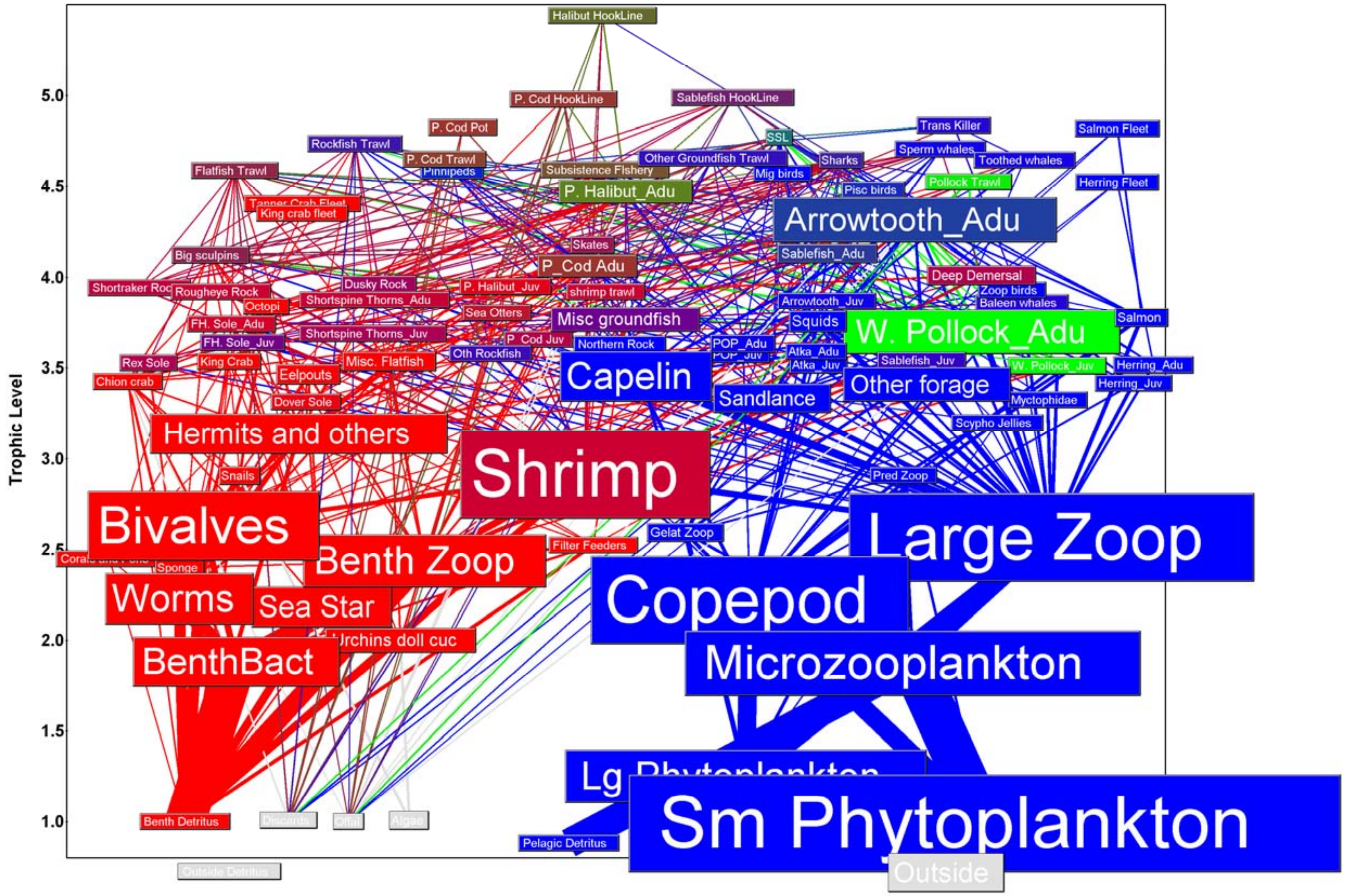
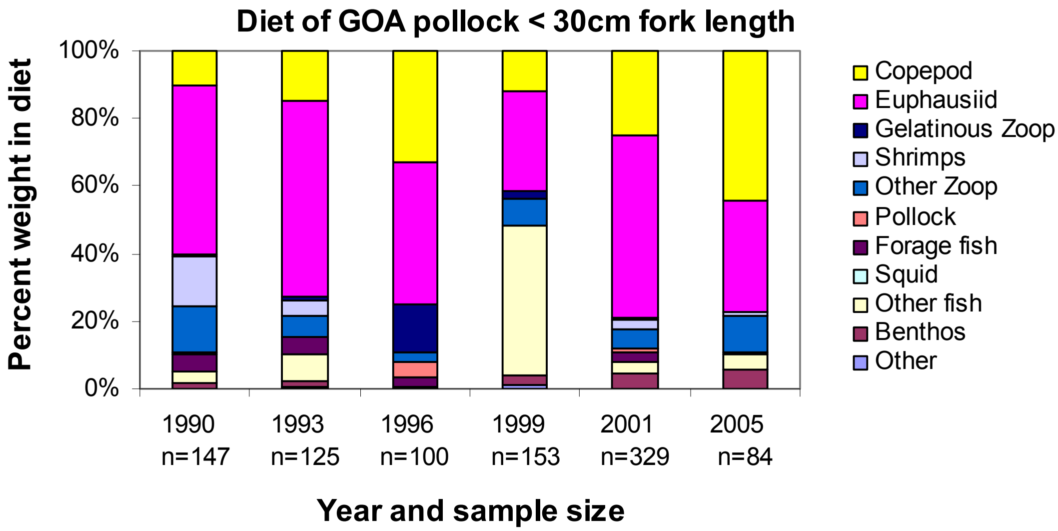


Figure 1.29. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



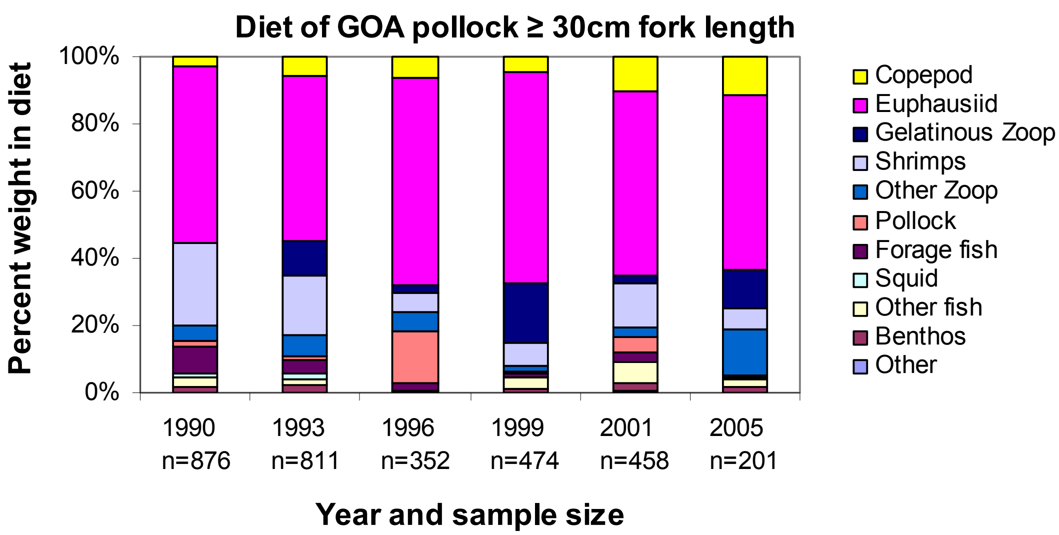
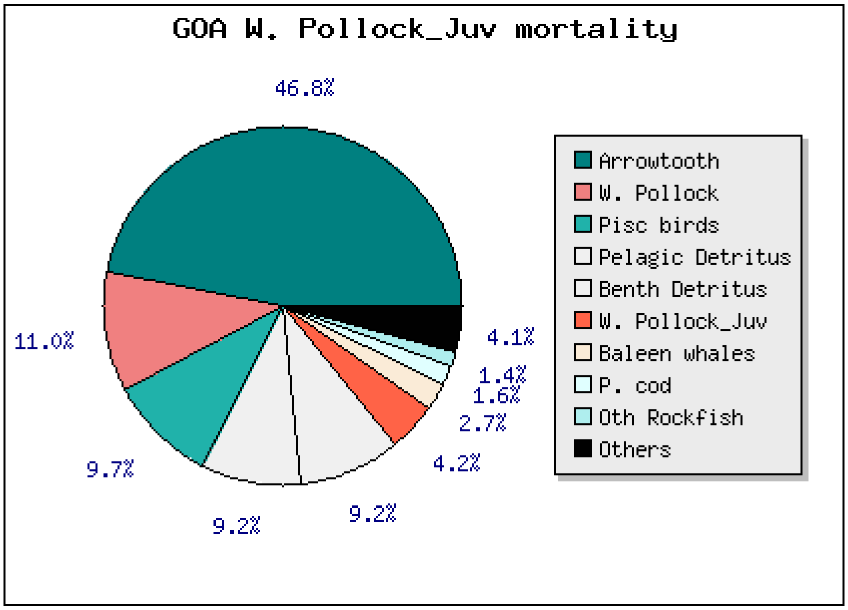


Figure 1.30. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



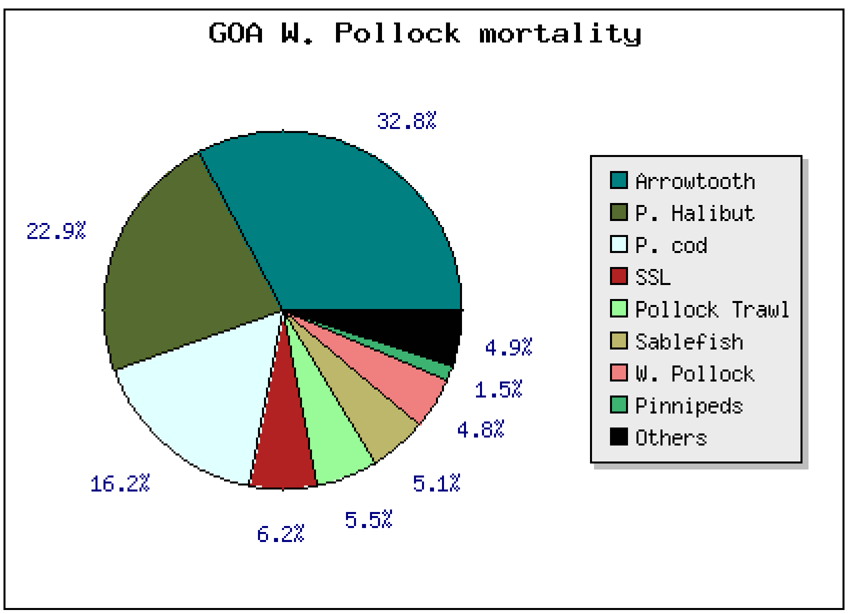


Figure 1.31. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

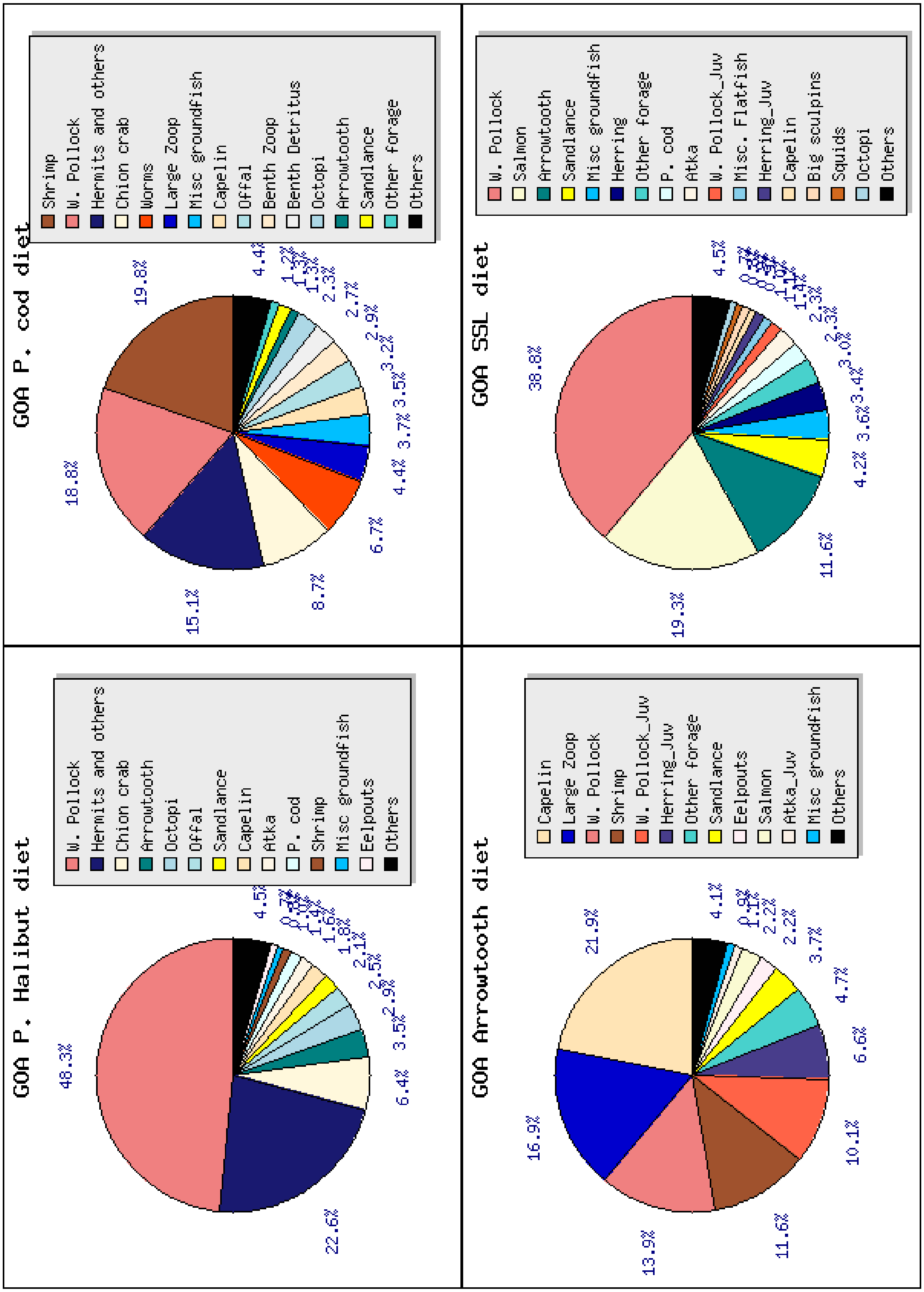


Figure 1.32. Diet diversity of major predators of walleye pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

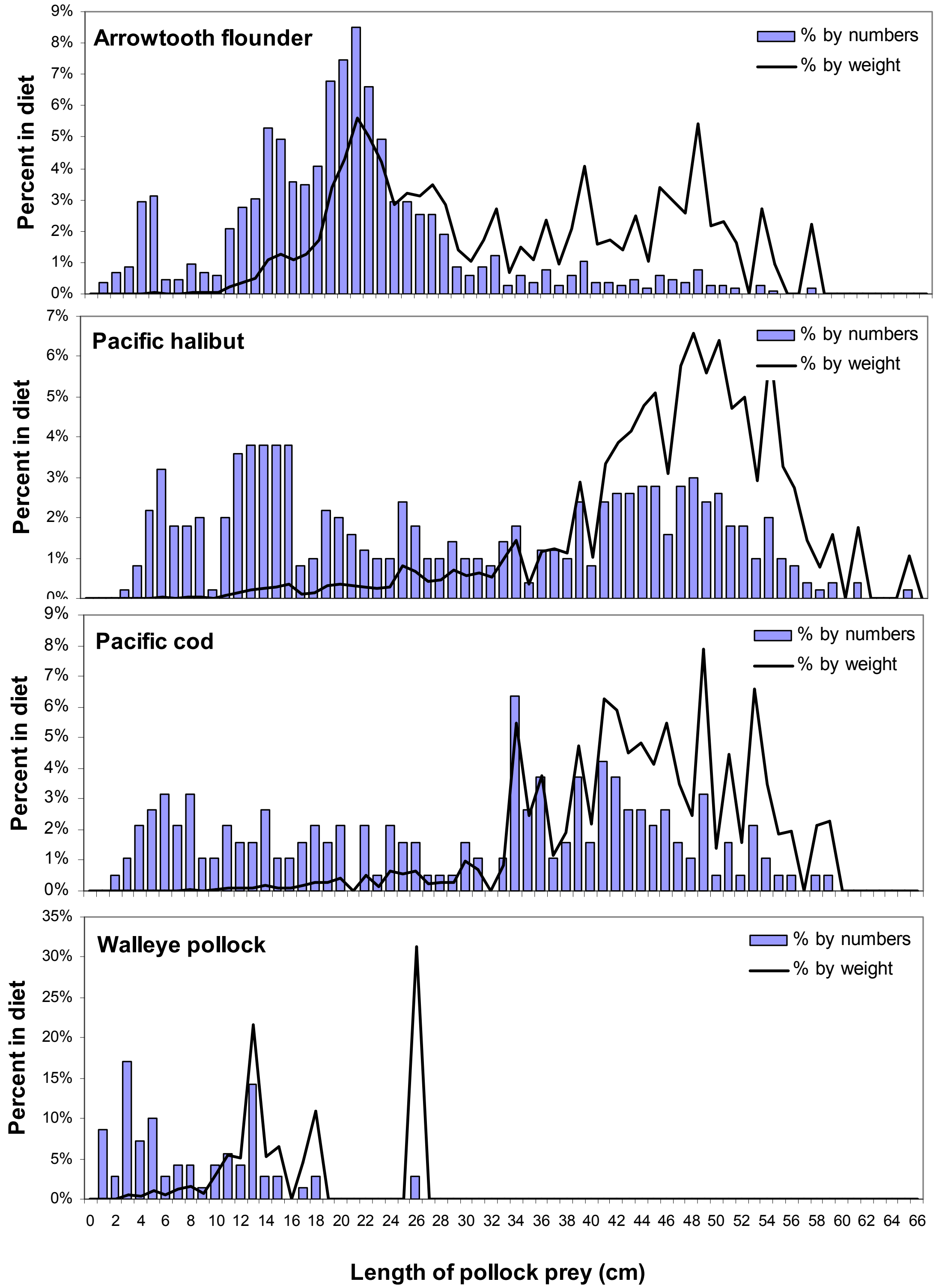
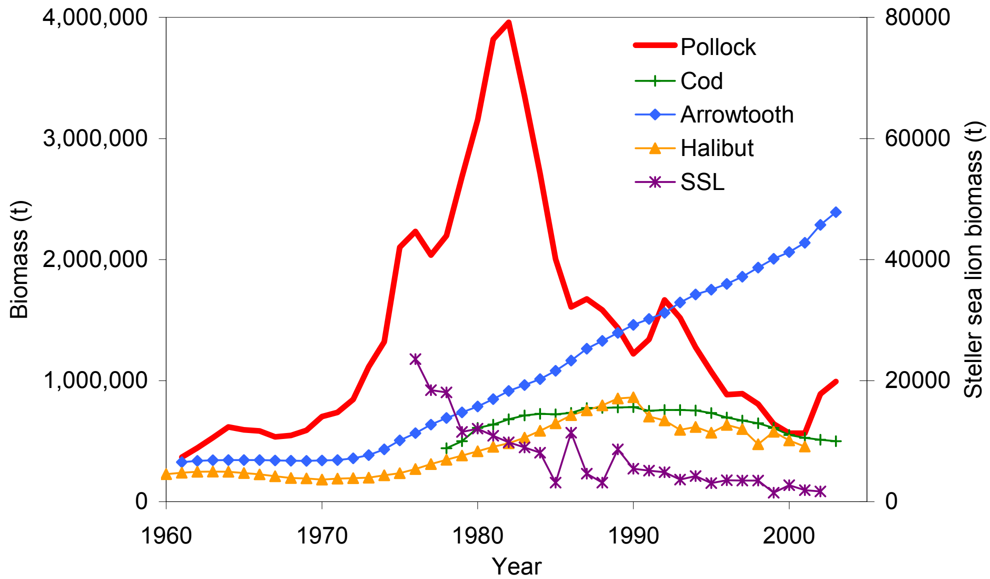


Figure 1.33. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



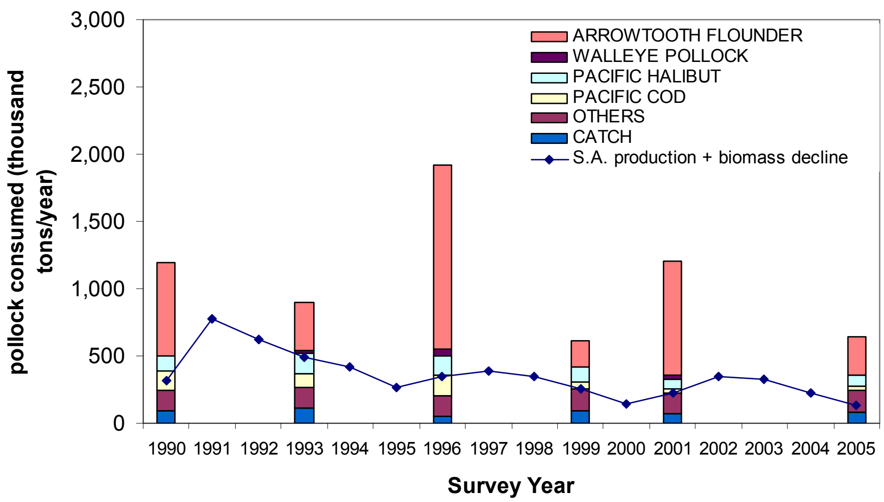
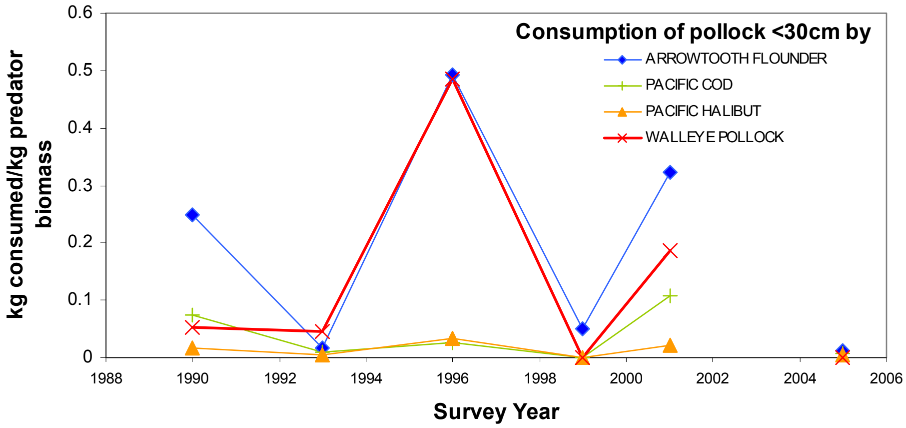
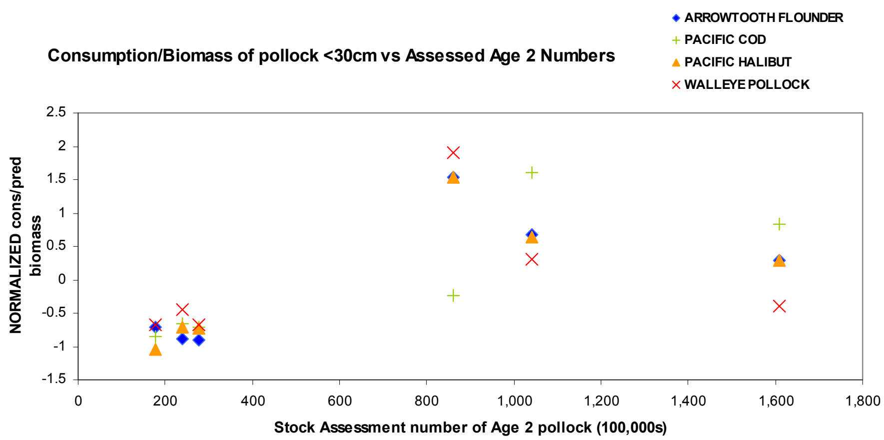


Figure 1.34. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock asessement data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line). See text for calculation methods.





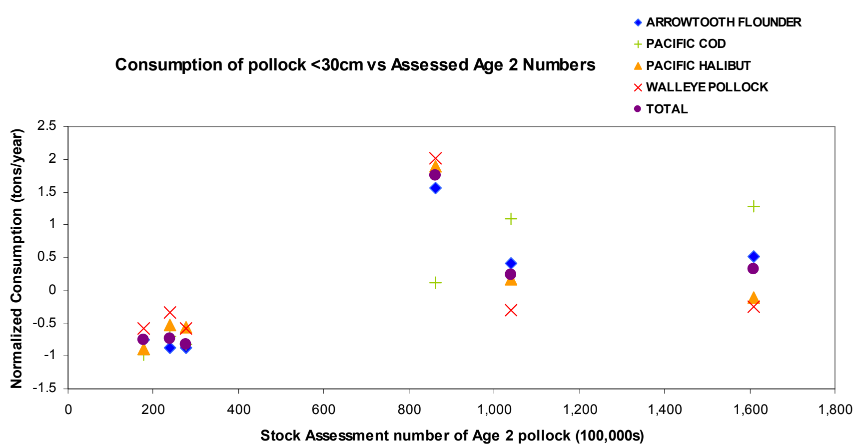


Figure 1.35. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers reported in Table 1.16.

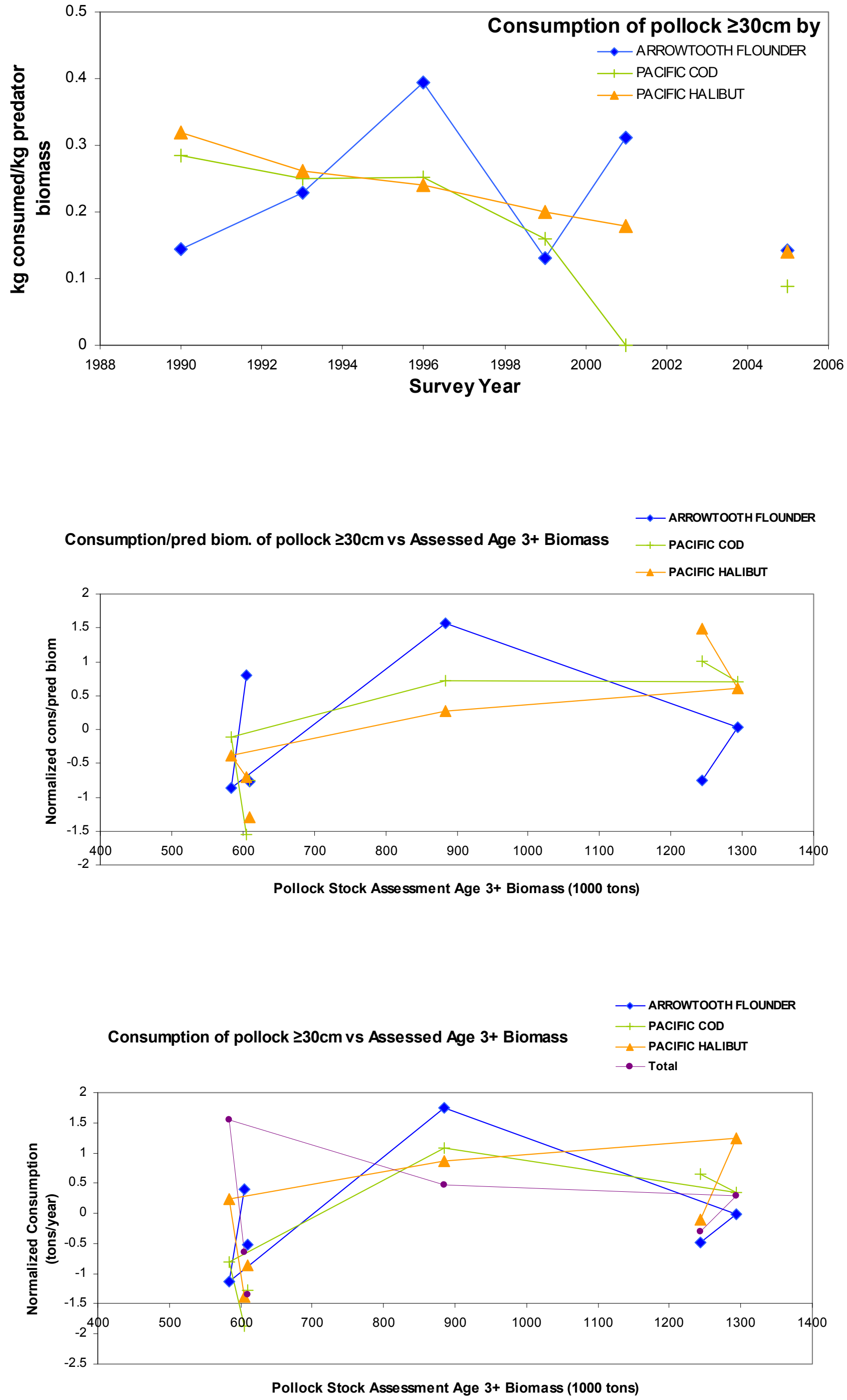


Figure 1.36. (Top) Consumption per unit predator survey biomass of GOA walleye pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass reported in Table 1.17.

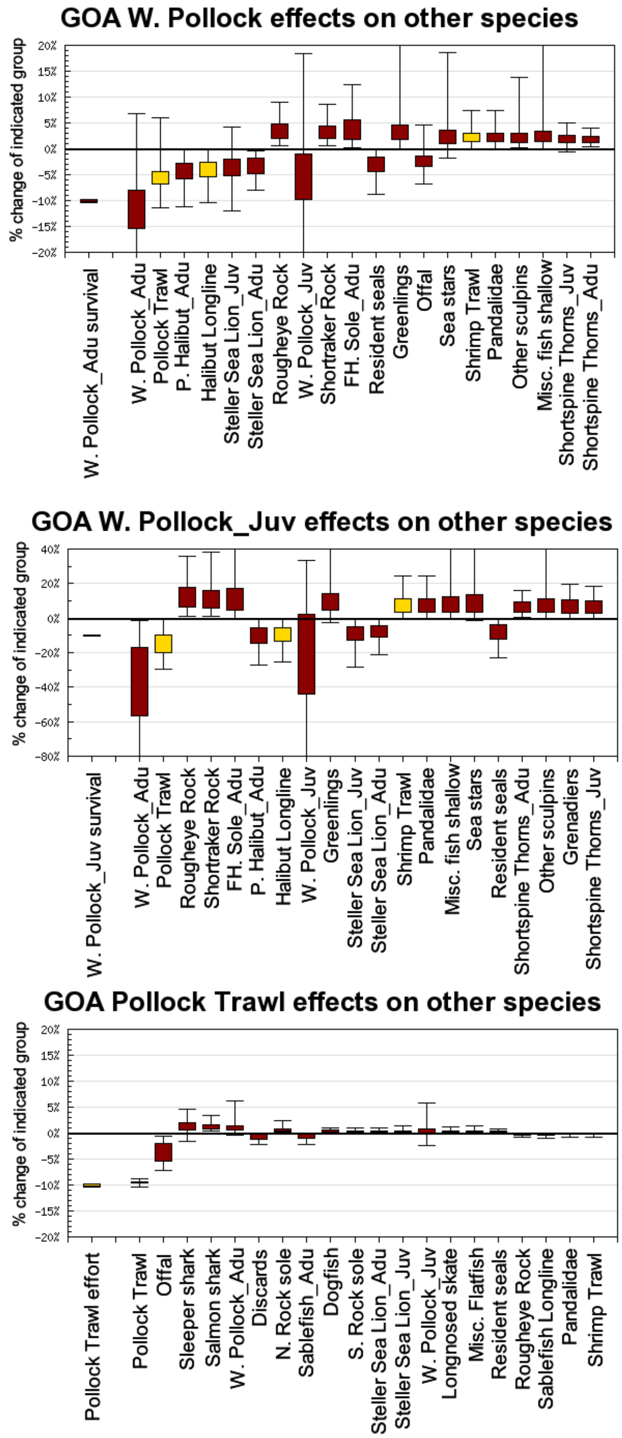


Figure 1.37. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled 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.

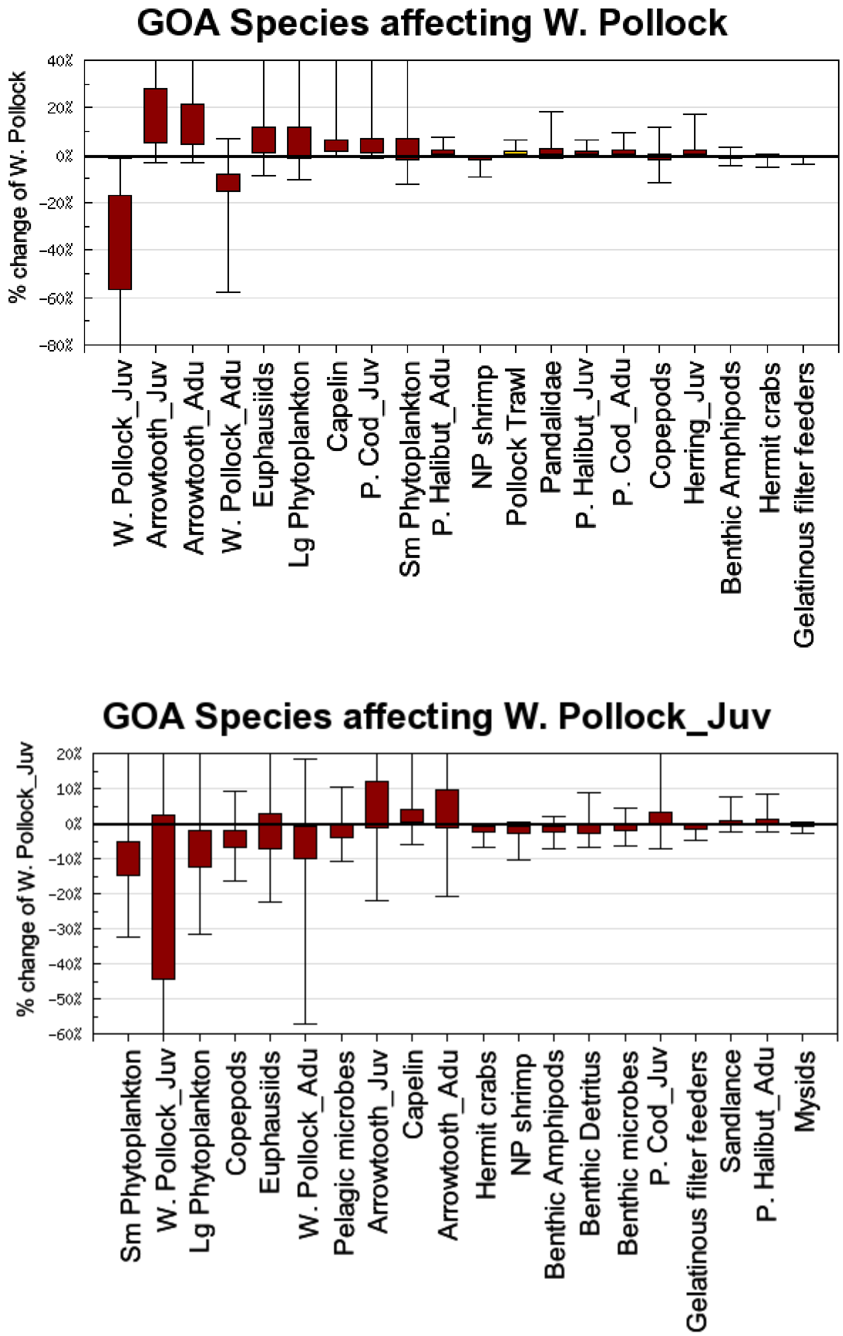


Figure 1.38. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs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

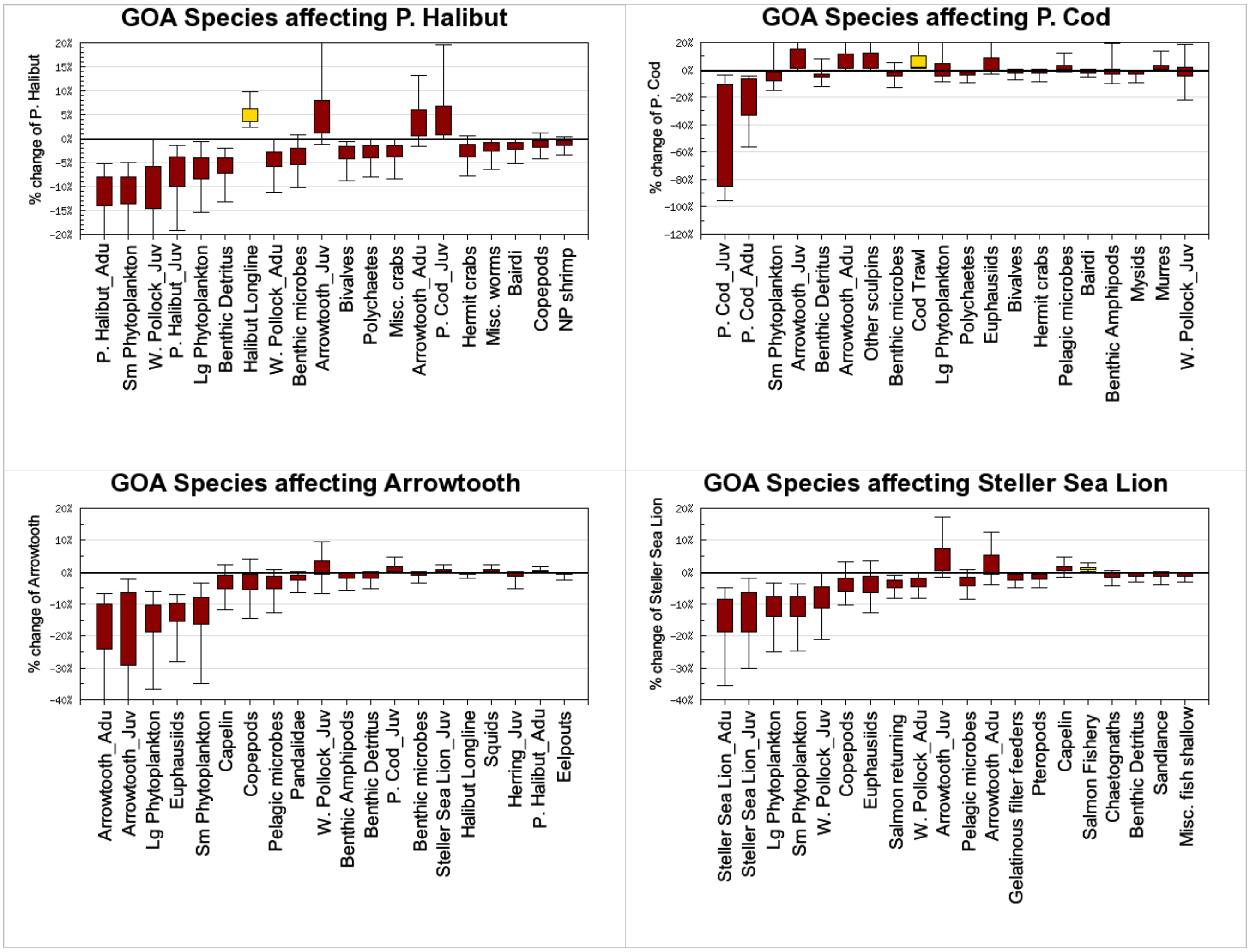


Figure 1.39. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

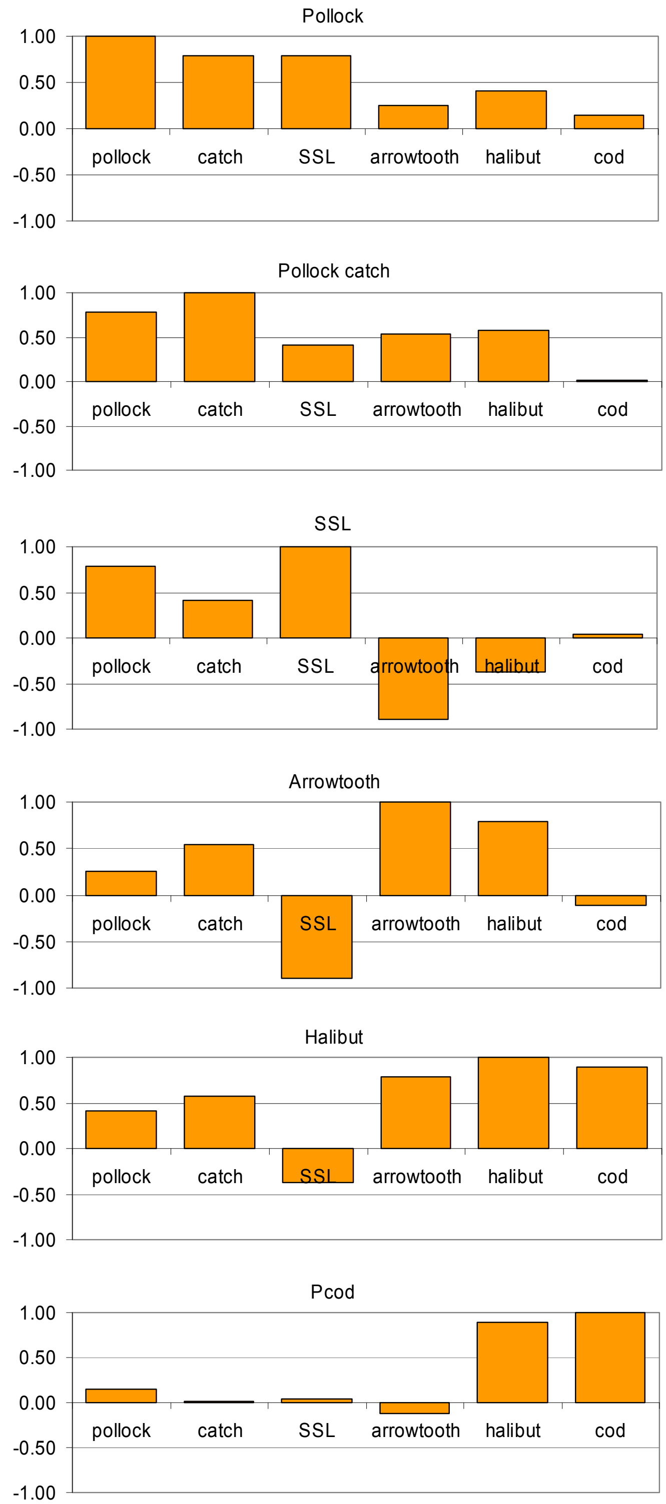


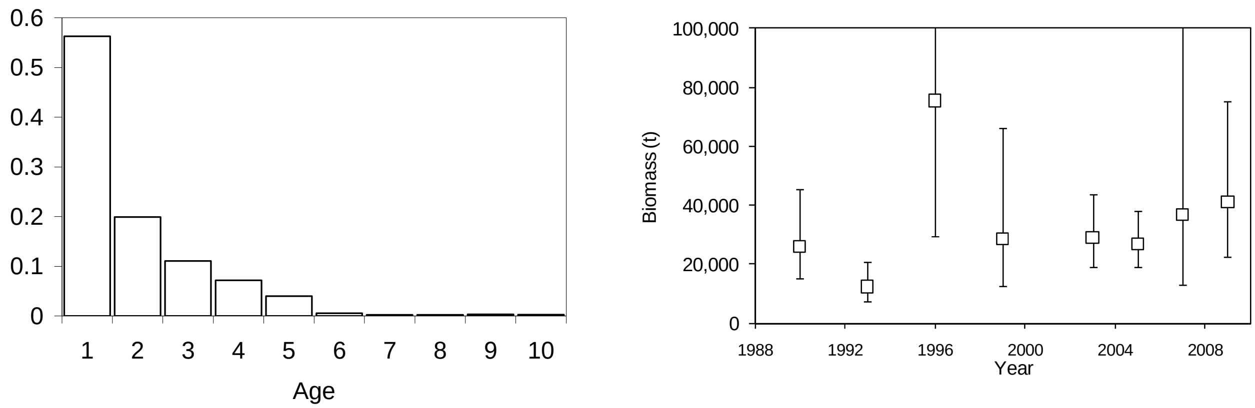
Figure 1.40. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for 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 2009 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Pollock age composition in the 2009 bottom trawl survey is dominated by age-1 pollock, with progressively decreasing proportions of age-2 to age-5 pollock (Appendix Fig. 1.1). There are very few older pollock (> age 5). 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). Pollock catch the Southeast and East Yakutat statistical areas has averaged about 1 t since 2000 (Table 1.4). The 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. 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. 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 2009 survey (41,088 t). **This results in a 2011 ABC of 9,245 t (41,088 t * 0.75 M), and a 2012 OFL of 12,326 t (41,088 t * M).** These recommendations are the same as last year because no new survey information is available.



Appendix Figure 1.1. Pollock age composition in 2009 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2009 (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 2010 (50 years). The Baranov (1918) catch equations are assumed, so that

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

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

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

except for the plus group, where

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

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

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

$$F_{ij} = s_j f_i$$

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

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

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

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

Measurement error

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

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

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

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

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

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

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

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

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

where q = survey catchability, w_{ij} is the survey weight at age *j* in year *i* (if available), s_j = selectivity at age for the survey, and ϕ_i = fraction of the year to the mid-point of the survey. Although there are multiple surveys for Gulf pollock, a subscript to index a particular survey has been suppressed in the above and subsequent equations in the interest of clarity. Survey selectivity was modeled using a either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the *i*th year are given by

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

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

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

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

Process error

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the pollock model, these annual recruitment and fishing mortality parameters are generally estimated as free parameters, with no additional error constraints. We use process error to describe changes in fisheries selectivity over time. To model temporal variation in a parameter γ , the year-specific value of the parameter is given by

$$\gamma_i = \bar{\gamma} + \delta_i$$

where $\bar{\gamma}$ is the mean value (on either a log scale or an arithmetic scale), and δ_i is an annual deviation subject to the constraint $\sum \delta_i = 0$. For a random walk where annual *changes* are normally distributed, the log-likelihood is

$$\log L_{Proc.Err.} = -\sum \frac{(\delta_i - \delta_{i+1})^2}{2\sigma_i^2}$$

where σ_i is the standard deviation of the annual change in the parameter. We use a process error model for all four parameters of the fishery double-logistic curve. Variation in the intercept selectivity parameters is modeled using a random walk on an arithmetic scale, while variation in the slope parameters is modeled using a log-scale random walk.

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

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

Appendix C: Seasonal distribution and apportionment of walleye pollock among management areas in the Gulf of Alaska

Since 1992, the Gulf of Alaska pollock TAC has been apportioned between management areas based on the distribution of biomass in groundfish surveys. Both single species and ecosystem considerations provide the rationale for apportioning the TAC. From an ecosystem perspective, apportioning the TAC will spatially distribute the effects of fishing on other pollock consumers (i.e., Steller sea lions), potentially reducing the overall intensity of any averse effects. Apportioning the TAC also ensures that no smaller component of the stock experiences higher mortality than any other. Although no sub-stock units of pollock have yet been identified in the Gulf of Alaska, it would be precautionary to manage the fishery so that if these sub-units do exist they would not be subject to high fishing mortality. Protection of sub-stock units would be most important during spawning season, when they are spatially separated. The Steller sea lion protection measures implemented in 2001 require apportionment of pollock TAC based on the seasonal distribution of biomass. Although spatial apportionment is intended to reduce the potential impact of fishing on endangered Steller sea lions, it is important to recognize that apportioning the TAC based on an inaccurate or inappropriate estimate of biomass distribution could be detrimental, both to pollock population itself, and on species that depend on pollock.

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

Winter distribution

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, Sanak Gully, Morzhovoi Bay, and Marmot Bay. We excluded an acoustic survey in 1990 along the shelf break and on east side of Kodiak Island (Karp 1990), since this information is more than 20 years old and the survey overlaps with some of the other areas included in the calculations. While the spawning aggregations found in 2010 along the Kenai Peninsula and in Prince William Sound are clearly important, before including them in the apportionment calculations the surveys in these areas need to be repeated to confirm stability of spawning in these areas There are also several potentially difficult issues that would need to dealt with, for example, whether including biomass along Kenai Peninsula would lead increased harvests on the east side of Kodiak, both of which are in area 630. In addition, the fishery inside Prince William Sound (area 649) is managed by the State of Alaska, and state management objectives for Prince William Sound need to be taken into account.

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, Marmot Bay, or Morzhovoi Bay. A vessel specific multiplier of 1.0 was applied in the Chirikof area 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). A vessel specific multiplier of 1.31 was applied in Marmot Bay and Morzhovoi Bay because the fish in these areas were at similar depths as at the Sanak and Shumagin area.

The sum of the percent biomass for all surveys combined was 64.86%, which may reflect sampling variability, or interannual variation in spawning location, but also reflects the recent trend that the aggregate biomass of pollock surveyed acoustically in winter (at least in those area that have been surveyed repeatedly) is lower than the assessment model estimates of abundance. After rescaling, the resulting average biomass distribution was 22.62%, 67.26%, 10.11% in areas 610, 620, and 630 (Appendix table 1.1). In comparison to last year's assessment, the percentage in area 610 decreased by 7.6 percentage points, area 620 increased 13.2 percentage points, and area 630 decreased by 5.6 percentage points. These changes reflect decreases in spawning aggregations outside Shelikof Strait and increases inside Shelikof Strait.

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, 22.62%; 620, 56.22%; 630, 21.15%.

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 2,340 t for the author's 2011 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 and unweighted average of four most recent NMFS summer surveys. The four-survey average was updated with 2009 survey results in an average biomass distribution of 40.14%, 25.84%, 31.32%, and 2.69% in areas 610, 620, 630, and 640 (Appendix Fig. 1.2). Inclusion of the 2009 survey raised the percentage in area 620 by 5 percentage points, and decreased the percentage in 610 and 630 by 2 and 3 percentage points respectively.

Example calculation of 2011 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 0.0269 x Total TAC = 2,694 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 – 2,694) = 24,326 t
B season 0.25 x (Total TAC – 2,694) = 24,326 t
C season 0.25 x (Total TAC – 2,694) = 24,326 t
D season 0.25 x (Total TAC – 2,694) = 24,326 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 0.2262 x 24,326 t = 5,504 t
620 0.5622 x 24,326 t = 13,677 t
630 0.2115 x 24,326 t = 5,146 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 distribution1

610 0.2262 x 24,326 t = 5,504 t
620 0.6726 x 24,326 t = 16,362 t
630 0.1011 x 24,326 t = 2,461 t

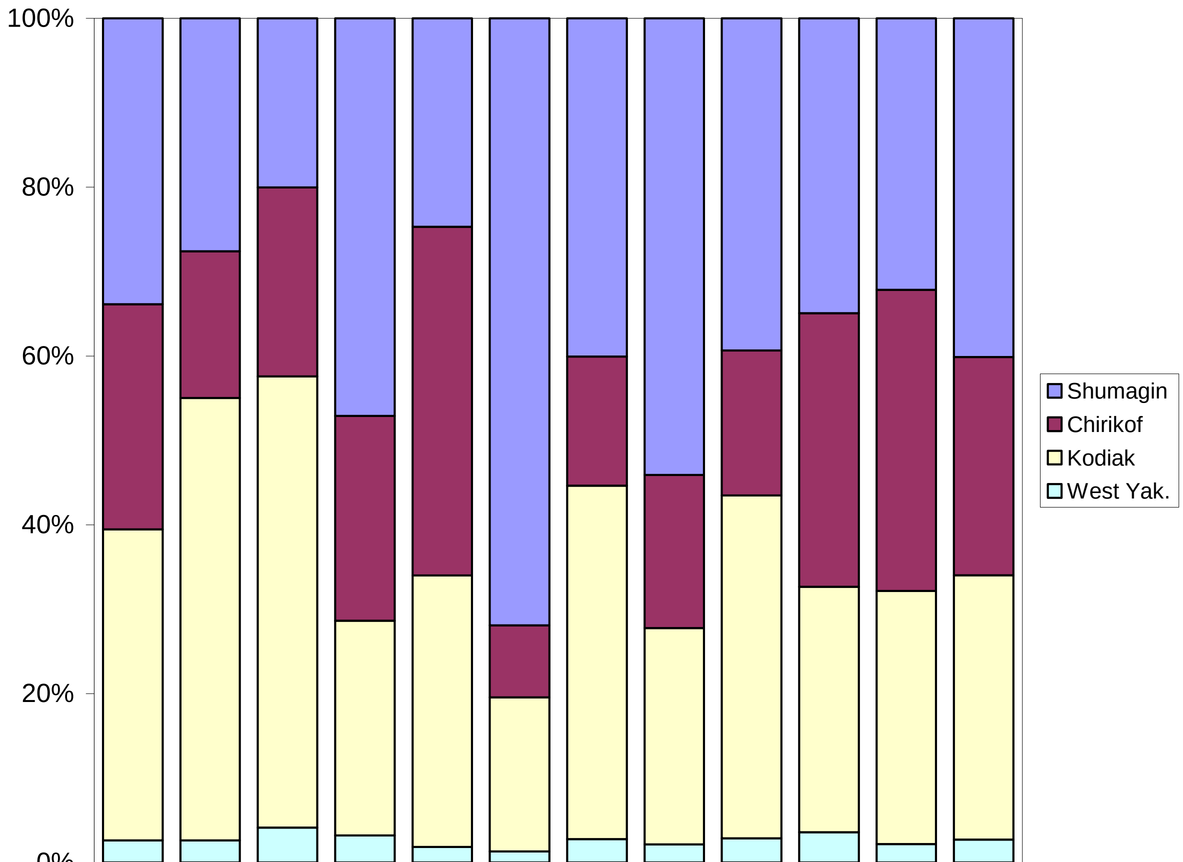
6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the average biomass distribution in areas 610, 620 and 630 in the most recent four NMFS bottom trawl surveys of 40.14%, 25.84%, 31.32%, and 2.69%.

610 0.4014 / (1 – 0.0269) x 24,326 = 10,034 t
620 0.2584 / (1 – 0.0269) x 24,326 = 6,461 t
630 0.3132 / (1 – 0.0269) x 24,326 = 7,831 t

610 0.4014 / (1 – 0.0269) x 24,326 = 10,034 t
620 0.2584 / (1 – 0.0269) x 24,326 = 6,461 t
630 0.3132 / (1 – 0.0269) x 24,326 = 7,831 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 2008 (19,090 t), and Shumagin survey estimates in 2006, 2008 and 2009 (12,310 t, 9,339 t and 17,407 t respectively).

Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*	*Multiplier from vessel comparison (OD/MF)*	*Percent*	*Percent by management area*		
						Area 610	*Area 620*	*Area 630*
Shelikof	2007	471,555	180,881	1.13	38.4%	0.0%	97.1%	2.9%
Shelikof	2008	538,893	188,942	1.00	35.1%	0.0%	93.4%	6.6%
Shelikof	2009	579,086	265,971	1.00	45.9%	0.0%	95.6%	4.4%
Shelikof	2010	739,818	429,730	1.00	58.1%	0.0%	93.7%	6.3%
Shelikof	Average				44.4%	0.0%	95.0%	5.0%
	Percent of total 2+ biomass					0.0%	42.1%	2.2%
Chirikof	2007	471,555	35,573	1.00	7.5%	0.0%	24.0%	76.0%
Chirikof	2008	538,893	22,055	1.00	4.1%	0.0%	50.2%	49.8%
Chirikof	2009	579,086	396	1.00	0.1%	0.0%	0.0%	100.0%
Chirikof	2010	739,818	9,544	1.00	1.3%	0.0%	0.0%	100.0%
Chirikof	Average				3.2%	0.0%	18.5%	81.5%
	Percent of total 2+ biomass					0.0%	0.6%	2.6%
Marmot	2007	471,555	3,157	1.31	0.9%	0.0%	0.0%	100.0%
Marmot	2009	579,086	19,759	1.00	3.4%	0.0%	0.0%	100.0%
Marmot	2010	739,818	5,585	1.00	0.8%	0.0%	0.0%	100.0%
Marmot	Average				1.7%	0.0%	0.0%	100.0%
	Percent of total 2+ biomass					0.0%	0.0%	1.7%
Shumagin	2007	471,555	20,009	1.31	5.6%	98.5%	1.5%	0.0%
Shumagin	2008	538,893	21,244	1.31	5.2%	77.2%	22.8%	0.0%
Shumagin	2009	579,086	45,357	1.00	7.8%	61.4%	38.6%	0.0%
Shumagin	2010	739,818	18,295	1.00	2.5%	94.9%	5.1%	0.0%
Shumagin	Average				5.3%	83.0%	17.0%	0.0%
	Percent of total 2+ biomass					4.4%	0.9%	0.0%
Sanak	2007	471,555	60,289	1.31	16.7%	100.0%	0.0%	0.0%
Sanak	2008	538,893	19,750	1.31	4.8%	100.0%	0.0%	0.0%
Sanak	2009	579,086	31,435	1.00	5.4%	100.0%	0.0%	0.0%
Sanak	2010	739,818	26,678	1.00	3.6%	100.0%	0.0%	0.0%
Sanak	Average				9.0%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					9.0%	0.0%	0.0%
Mozhovoi	2006	506,400	11,679	1.31	3.0%	100.0%	0.0%	0.0%
Mozhovoi	2007	471,555	2,540	1.31	0.7%	100.0%	0.0%	0.0%
Mozhovoi	2010	739,818	1,650	1.00	0.2%	100.0%	0.0%	0.0%
Mozhovoi	Average				1.3%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					1.3%	0.0%	0.0%
Total					64.86%	14.67%	43.62%	6.56%
Rescaled total					100.00%	22.62%	67.26%	10.11%



	1984	1987	1990	1993	1996	1999	2001	2003	2005	2007	2009	4 survey avg (2003-
Shumagin	33.88%	27.60%	20.03%	47.08%	24.69%	71.90%	40.06%	54.09%	39.35%	34.94%	32.16%	40.14%
Chirikof	26.64%	17.38%	22.41%	24.27%	41.32%	8.55%	15.30%	18.14%	17.16%	32.42%	35.66%	25.84%
Kodiak	36.87%	52.40%	53.42%	25.44%	32.16%	18.23%	41.88%	25.62%	40.64%	29.06%	29.99%	31.32%
West Yak.	2.62%	2.62%	4.13%	3.20%	1.83%	1.32%	2.76%	2.15%	2.85%	3.59%	2.18%	2.69%

Appendix Figure 1.2. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2009. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.