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

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Executive Summary

Summary of Changes in Assessment Inputs

Changes in input data

1. Fishery: 2011 total catch and catch at age.

2. NMFS bottom trawl survey: 2011 age composition.

3. ADFG crab/groundfish trawl survey: 2012 biomass and length composition.

4. The pre-1984 trawl survey data were removed from the model.

5. The egg production index (1981-1992) was removed from the model.

Changes in assessment methodology

Based on recommendations of the July 2012 CIE review of the Gulf of Alaska pollock assessment, several changes in the assessment model are considered. The goal in this assessment was to implement recommendations that could be relatively easily accommodated within the existing model framework, and to postpone to future assessments those recommendations that require methodological development and substantial analysis. The following changes were implemented: 1) the model includes ages 1-10 rather than ages 2-10 as in previous assessments; 2) an accumulator age was added to initial age composition and stronger equilibrium assumptions were used to initialize the model; 3) mean unbiased log-normal likelihoods are used for survey biomass indices; 4) the historical trawl data (pre-1984) was removed from the model; 5) the egg production index (1981-1992) was removed from the model; 6) six selectivity blocks were used for fishery selectivity rather than allowing selectivity parameters to vary annually with a random walk; 7) reduced weights (input sample sizes) were used for the fishery age composition data; and finally, 8) the model begins in 1964 rather than 1961. A model that incorporates these changes was selected as the base model for this assessment, however a model with last year's configuration, and a model where NMFS trawl survey catchability is estimated using a prior are also provided for comparison. The age-structured assessment model was developed using AD Model Builder (a C++ software language extension and automatic differentiation library) and remains similar to the model used for assessments in 1999-2011.

Summary of Results

The base model projection of spawning biomass in 2013 is 259,843 t, which is 35.1% of unfished spawning biomass (based on average post-1977 recruitment) and below $B_{40\%}$ (297,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. New Shelikof Strait acoustic surveys and ADFG crab/groundfish surveys were conducted in 2012. The 2012 Shelikof Strait acoustic declined 22% from the 2010 estimate (no survey was conducted in winter of 2011). The ADFG crab/groundfish survey biomass estimate increased by 71% from the 2011 estimate. The estimated abundance of mature fish in 2013 is projected to be nearly the same as in 2012, and is projected to gradually decrease over the next five years.

The author's 2013 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 113,586 t, an increase of 5% from the 2012 ABC. This recommendation is based on a more conservative alternative to the maximum permissible F_{ABC} introduced in the 2001 SAFE applied to the base model. The OFL in 2013 is 150,817 t. In 2014, the recommended ABC and OFL are 104,157 t and 138,610 t, respectively.

An exempted fishing permit (EFP) has been proposed to evaluate the effect of salmon excluder devices in the pollock fishery. Projected pollock catches under the EFP will be 2,304 t in 2013 and 2,304 t in 2014 (Jeff Hartman, NMFS Alaska Regional Office, pers. comm. Oct. 22, 2012). We followed the Gulf of Alaska Plan Team recommendation, and accounted for the EFP catches in a projection model where the EFP catches were removed from the population at the start of year in 2013 and 2014. This resulted in a 2013 ABC of 113,099 t (487 t difference) and a 2014 ABC of 103,339 (818 t difference).

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendations for 2013 and 2014, presented in Appendix A, are 10,774 t and the OFL recommendation for 2013 and 2014 is 14,366 t. These recommendations are based on the estimated biomass in the southeast Alaska from the 2011 NMFS bottom trawl survey and are unchanged from last year.

Status Summary Table

Quantity/Status	As estimated or specified *last* year for 2012	2013	As estimated or specified *this* year for 2013	2014
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3b	3b	3b	3b
Projected total (age 3+) biomass (t)	863,840	926,890	981,791	885,420
Female spawning biomass (t)				
Projected	227,723	232,632	259,843	247,699
$B_{100\%}$	678,000	678,000	741,000	741,000
$B_{40\%}$	271,000	271,000	297,000	297,000
$B_{35\%}$	237,000	237,000	259,000	259,000
F_{OFL}	0.19	0.19	0.20	0.18
$maxF_{ABC}$	0.17	0.17	0.18	0.16
F_{ABC}	0.14	0.15	0.15	0.14
OFL (t)	143,720	155,400	150,817	138,610
maxABC (t)	125,560	135,790	131,630	115,977
ABC (t)	108,440	117,330	113,586	104,157
Status	As determined *last* year for 2010	2011	As determined *this* year for 2011	2012
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Responses to SSC and Plan Team Comments in General

The SSC requested that all assessments include a retrospective plot where data are removed year-by-year from the model. This is provided in Figure 1.23.

Responses to SSC and Plan Team Comments Specific to this Assessment

The SSC made several requests specific to the Gulf of Alaska pollock assessment in its December 2011 minutes. First, the SSC requested that the stock structure template be applied to Gulf of Alaska pollock. Appendix E gives the results of that analysis. Second, the SSC requested an evaluation of averaging procedures to apportion the stock between management areas. A working group of Plan Team members was convened this year to evaluate survey averaging methods. The working group is still developing final recommendations on apportionment. The Joint Plan Teams recommended status quo methods be used for the November 2012 SAFE report. Once a preferred approach is identified, it will be used for Gulf of Alaska pollock apportionment. Finally the SSC requested a report on the methodology used to derive the GHL for Prince William Sound. This request was addressed by the Gulf of Alaska Plan Team during its September meeting. A report of their discussion is included in the Gulf of Alaska Plan Team meeting minutes (see pages 44-45).

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. An evaluation of stock structure for Gulf of Alaska pollock according to the template developed by NPFMC stock structure working group is provided in Appendix E.

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 pollock target fishery 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 in deep-water troughs on the east side of Kodiak Island and 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 2007 and 2011, 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, squid, shallow-water flatfish, and various shark species (e.g., Pacific sleeper sharks, spiny dogfish, salmon shark). The most common non-target species are eulachon and other osmerids, grenadiers, and jellyfish. Bycatch estimates for prohibited species over the period 2007-2011 are given in Table 1.3. Chinook salmon are the most important prohibited species caught as bycatch in the pollock fishery. The peak in Chinook salmon bycatch in 2010 led the Council to adopt management measures to reduce Chinook salmon bycatch.

Kodiak is the major port for pollock in the Gulf of Alaska, with 67% of the 2007-2011 landings. In the western Gulf of Alaska, Sand Point, Dutch Harbor, King Cove, and Akutan are important ports, sharing 32% of 2007-2011 landings. Secondary ports, including Cordova, Homer, Juneau, Ketchikan, Seward, and Sitka account for less than 1% of the 2007-2011 landings.

Since 1992, the Gulf of Alaska pollock Total Allowable Catch (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 fall 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, acoustic survey estimates of biomass and age composition in Shelikof Strait, egg production estimates of spawning biomass in Shelikof Strait, ADFG 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. Some of the data sets listed are considered for removal from the assessment because of lower reliability and lack of information to inform on current stock status. 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 surveys.

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 (PWS). Non-commercial catches are reported in Appendix D. 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 2011 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 2011 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	382	348	358	90
	No. lengths	1711	6107	1909	461
	Catch (t)	8,398	27,650	6,453	3,786
2nd half (C and D seasons)	No. ages	348	344	352	----
	No. lengths	3471	3208	3914	----
	Catch (t)	12,196	9,533	13,291	----

The catch-at-age in 2011 was primarily age 3-6, with no year class strongly dominant (Fig. 1.2). Depending on the area and the season, the age-3 fish (2008 year class), the age-4 fish (2007 year class) or the age-5 fish (2006 year class) was the most common age in the catch-at-age estimates.

Fishery catch at age in 1976-2011 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. 2011). 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 ADFG in 1999, using a standard ADFG 400 mesh eastern trawl. The 1999 biomass estimate for PWS was 6,304 t ± 2,812 t (95% CI) (W. Bechtol, ADFG, 1999, pers. comm.). The PWS biomass estimate should be considered a minimum estimate because ADFG survey gear is less effective at catching pollock compared to the NMFS survey gear (von Szalay and Brown 2001). For 1999, the biomass estimates for the NMFS bottom trawl survey and the PWS survey were simply added to obtain a total biomass estimate. The adjustment factor for the 1999 survey, (PWS + NMFS)/NMFS, was applied to other triennial surveys, and increased biomass by 1.05%.

The Alaska Fisheries Science Center's (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted the twelfth comprehensive bottom trawl survey since 1984 during the summer of 2011. The 2011 gulfwide biomass estimate of pollock was 708,092 t, which is very close to the 2009 estimate (<1% increase). The biomass estimate for the portion of the Gulf of Alaska west of 140º W long. is 667,131 t.

Bottom Trawl Survey 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 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. Ages are now available for the 2011 survey, and show relatively high estimates of age-1 pollock abundance in all areas (Fig. 1.4). The relative abundance of age-two pollock increased from east to west. In the Central and Western portion of the Gulf of Alaska, pollock of ages 3-6 were relatively abundant in all areas. The age composition in the Shumagin area had a higher proportion of old fish (> age 6) compared to other areas.

Shelikof Strait Acoustic Survey

Acoustic 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 2012 are presented in a NMFS processed report (Jones 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* (MF) and the *R/V Oscar Dyson* (OD), which obtained an OD/MF ratio of 1.132 in Shelikof Strait.

The 2012 biomass estimate for Shelikof Strait is 335,836 t, a decrease of 22% from the 2010 biomass. The biomass of pollock ≥43 cm (a proxy for spawning biomass) declined only 6% from the 2010 estimate, suggesting greater stability in the spawning population. The Shelikof Strait acoustic survey was not conducted in 2011 due to scheduled repairs to the *R/V Oscar Dyson*. This is the first interruption in the annual Shelikof Strait acoustic survey time series since 1999

Additional acoustic surveys in winter 2012 covered the Shumagin Islands spawning area, Sanak Gully, and Chirikof. Estimates from these areas are given below.

2012 winter acoustic survey results

Area	Biomass ≥43 cm (t)	Percent	Total biomass (t)	Percent
Sanak Gully	24,215	8.0%	24,252	6.1%
Shumagin Is	15,492	5.1%	15,501	3.9%
Shelikof Strait	241,902	80.0%	335,836	84.6%
Chirikof Island	20,590	6.8%	21,181	5.3%
Total	302,199		396,769	

In comparison to 2010, biomass estimates were moderately lower with the exception of Chirikof Island, which more than doubled. For all areas outside of Shelikof Strait, biomass remains low compared to estimates during the previous decade (2001-2010) (Fig. 1.5).

Because there was inadequate time for the *R/V Oscar Dyson* to survey Marmot Bay this year, a Kodiak-based fishing vessel conducted a survey of Marmot Bay using a calibrated echo-sounder and pre-determined set of transects. Although no confirmation tows were made, a biomass estimate was produced by using length composition data from the fishery and assuming that pollock formed typical backscatter patterns. This resulted in a biomass estimate of approximately 23,000 t. Additional work is needed to confirm that this estimate is comparable to estimates produced by the *R/V Oscar Dyson*.

Some assessment models (including the model that was used last year) only include age 2 and older pollock. For these models, 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 acoustic biomass estimate.

Acoustic Trawl Survey Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.6) were obtained using an age-length key compiled from random otolith samples and applied to weighted length frequency samples. Otoliths collected during the 1994-2012 acoustic 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 some assessment models. 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. The egg production survey uses a fixed selectivity pattern equal to maturity at age. Egg production estimates were discontinued in 1992 because the Shelikof Strait acoustic survey provided similar information.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

The Alaska Department of Fish and Game (ADFG) 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 ADFG trawl gear and sampling procedures are in Blackburn and Pengilly (1994).

The 2012 biomass estimate for pollock for the ADFG crab/groundfish survey was 172,007 t, up 71% from the 2011 biomass estimate, indicating an increasing trend for this index (Table 1.7).

ADFG Survey Length Frequency

Pollock length-frequencies for the ADFG survey in 1989-2012 (excluding 1991 and 1995) typically show a mode at lengths greater than 45 cm (Fig. 1.7). The predominance of large fish in the ADFG survey may result from the selectivity of the gear, or because of greater abundance of large pollock in the areas surveyed. Length composition in 2012 is similar to previous surveys, with a mean length of 53 cm.

ADFG 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, 2008, and 2010 ADFG surveys (N = 559, 538, 591,588, 597, and 585). Comparison with fishery age composition shows that older fish (> age-8) are more common in the ADFG 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 ADFG 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 ADFG 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 information about the 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 acoustic 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 to 2008 (Fig. 1.8). All surveys show a strong increase since 2008.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.9). 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 45.0% in 2011. 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 old fish category. The percent of old fish has been decreasing since 2008 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 1976-2011 (Fig. 1.9).

McKelvey Index

McKelvey (1996) found a significant correlation between the abundance of age-1 pollock in the Shelikof Strait acoustic 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 acoustic 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 acoustic survey and year-class strength provides a recruitment forecast for the year following the most recent Shelikof Strait acoustic survey. No estimate of age-1 pollock abundance is available in 2011 due to cancellation of the Shelikof Strait acoustic survey.

Analytic Approach

Model Structure

An age-structured model covering the period from 1964 to 2012 (49 yrs) was used to assess Gulf of Alaska pollock. The modeled population includes individuals from age 1 to age 10, with age 10 defined as a “plus” group, i.e., all individuals age 10 and older. 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 Appendix B.

Based on recommendations of the July 2012 CIE review of the Gulf of Alaska pollock assessment, several changes in the assessment model are considered. The goal in this assessment was to implement recommendations that could be relatively easily accommodated within the existing model framework, and to postpone to future assessments those recommendations that require methodological development and substantial analysis. The following changes were implemented: the model includes ages 1-10 rather than ages 2-10 in previous assessments; an accumulator age was added to initial age composition and stronger equilibrium assumptions were used to initialize the model; mean unbiased log-normal likelihoods are used for survey biomass indices; the historical trawl data (pre-1984) was removed from the model; six selectivity blocks were used for fishery selectivity rather than allowing selectivity parameters to vary annually with a random walk; reduced weights (input sample size) were used for the fishery age composition data. Finally, the model begins in 1964 rather than 1961. An assessment model with last year's configuration and a model where NMFS trawl survey catchability is estimated using a prior are also provided for comparison.

Model parameters were estimated by maximizing the log likelihood of the data, viewed as a function of the parameters. Mean-unbiased log-normal 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 (1964-2011)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-2011)	Multinomial	Year-specific sample size = 20-200
Shelikof acoustic survey biomass (1981-2012)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof acoustic survey age comp. (1981-2012)	Multinomial	Sample size = 60
*Egg production biomass (1981-1992)	Log-normal	Survey-specific CV = 0.11-0.25
NMFS bottom trawl survey biom. (1984-2011)	Log-normal	Survey-specific CV = 0.12-0.38
NMFS bottom trawl survey age comp. (1984-2011)	Multinomial	Survey-specific sample size = 38-74
ADFG trawl survey biomass (1989-2012)	Log-normal	CV = 0.25
ADFG survey age comp. (2000, 2002, 2004, 2006, 2008, 2010)	Multinomial	Sample size = 10
ADFG survey length comp. (1989-2011)	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
Recruit process error (1964-1971,2012)	Log-normal	σ_R =1.0
**Proposed for removal from the assessment model*		

Recruitment

In most years, year-class abundance at age 1 was estimated as a free parameter. Initial age composition was estimated with a single log deviation for recruitment abundance, which was then decremented by natural mortality to fill out the initial age vector. A penalty was added to the log likelihood so that the log deviation in recruitment for 1964-71, and in 2012 would have the same variability as recruitment during the data-rich period (σ_R =1.0). Log deviations from mean log recruitment 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 2012 ≈ 1.0).

Modeling fishery data

To accommodate changes in selectivity we estimated six selectivity blocks, starting in 1964, 1972, 1982, 1989, 2001, and 2007. These periods roughly correspond to the foreign fishery targeting Pacific ocean perch, the foreign target fishery, the joint venture fishery, the three period of the domestic fishery. Previous modeling with random walk changes in selectivity also suggested that these breaks were reasonable.

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 base model fixed the NMFS bottom trawl survey catchability at one as in previous assessments, however an alternative model is presented where catchability is estimated and a lognormal prior on catchability is used. This prior had a median of 0.85 and log standard deviation 0.1, which implies 90% prior probability that catchability is in the range [0.72-1.00] (Fig. 1.10). 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 acoustic 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 acoustic 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 acoustic 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 ADFG 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).

Parameters Estimated Outside the Assessment Model

Pollock life history characteristics, including natural mortality, growth, and maturity, were estimated independently outside the assessment model. 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 (*M*) 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 simulation study, Clark (1999) evaluated 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 acoustic surveys in the Gulf of Alaska is 358 (Table 1.15).

Estimates of maturity at age in 2012 from winter acoustic surveys were slightly above the long-term average for ages 5-10, but slightly below average for age 4 (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 1983-2012 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 3.5 years in 1983 to 6.1 years in 1991, with an average of 4.9 years. Length at 50% mature is less variable than the age at 50% mature, suggesting that at least some of the variability in the age at maturity can be attributed to changes in length at age (Fig 1.12). Changes in year-class dominance could also potentially affect estimates of maturity at age. There is less evidence of trends in the length at 50% mature, with only the 1983 and 1984 estimates as unusually low values. The average length at 50% mature for all years is approximately 43 cm.

Weight at age

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a L^b$, were also estimated. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions. A plot of weight-at-age from the Shelikof Strait acoustic survey indicates that there has been a substantial increase in weight at age for older pollock (Fig. 1.13). For pollock greater than age 6, weight-at-age has nearly doubled since 1983-1990. Further analyses are proposed 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.

Parameters Estimated Inside the Assessment Model

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*
Recruitment	Years 1964-2012 = 49	Estimated as log deviances from the log mean; recruitment in 1964-71, and 2012 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated in the model
Fishing mortality	Years 1964-2012 = 49	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
Selectivity blocks	4 * 4 = 12	Estimated as deviations from mean selectivity
Survey catchability	No. of surveys + 2 = 5	AFSC bottom trawl survey catchability not estimated, other catchabilities estimated on a log scale. Three catchability periods were estimated for the acoustic survey.
Survey selectivity	8 (acoustic survey: 2, BT survey: 4, ADFG survey: 2)	Slope parameters estimated on a log scale.
Total	122 estimated parameters + 2 fixed parameters = 124	

Results

Model selection and evaluation

Model Selection

Three models were compared: a model with last year's configuration (12_LY), a new base model that incorporates some of the CIE review recommendations (12_BASE), and a model with bottom trawl catchability estimated with a Bayesian prior (12_BQ). The objective in this assessment was to implement recommendations that could be relatively easily accommodated within the existing model framework, and to postpone to future assessments those recommendations that require methodological development and substantial analysis. The model was extended to model age 1-10 rather than ages 2-10 in previous assessments to incorporate information from the NMFS bottom trawl survey and the Shelikof Strait acoustic survey on age-1 pollock. The historical trawl data and the egg production survey were removed from the model because these data sets had little influence on the model results and were of lower reliability than the other surveys used in the assessment. Changes in fishery selectivity was modeled by estimating selectivity in blocks rather than using random walk variation in selectivity parameters due to concern about over-fitting the fishery age composition data and to simplify the model. Making these changes to the model led to further tweaks to model ensure the robust model performance. These minor changes included making stronger equilibrium assumptions to initialize the model and starting the model in 1964 rather than in 1961. Finally mean unbiased log-normal likelihoods were used for survey biomass indices, which had no influence on the indices remaining in the model.

Overall these upgrades had little effect on biomass trends (Fig. 1.14) with the exception of the period 1970-1980, when there were high biomass estimates in the historical trawl data. Estimates of the 2013 ABC were higher for 12_LY because of a high initial estimate of 2010 year class (1.30 billion) compared to (0.73 billion when rescaled to abundance at age 2) for 12_BASE model (Table 1.16). Since the 12_LY model begins at age 2, this initial estimate would be determined solely by age-2 abundance in the 2012 Shelikof Strait acoustic survey. The 12_BASE model would incorporate information on age-1 abundance from the 2011 NMFS bottom trawl survey in addition to information from the Shelikof Strait acoustic survey, and results in a CV of 0.10 for the recruitment estimate of the 2010 year class compared to a CV of 0.27 for model 12_LY.

Model 12_BQ results in an estimate of trawl catchability of 0.72, which is lower than the median of the prior (0.85), indicating that data are more consistent with lower catchability given the model configuration. Biomass estimates for model 12_BQ are consistently about 30% higher than model 12_BASE, indicating that lower trawl catchability simply scales the population upwards without affecting the overall trend. Annual surplus production over the last fifteen years (1997-2011) is very similar for all models (Fig. 1.14), and averaged 71,000 t, similar to the mean catch over this period (72,000 t), which indicates that despite the differences in scale of the population, the estimates of stock productivity are robust, and consistent with the harvest recommendations during this period.

Model Evaluation

Model fit to age composition data was evaluated using plots of observed and predicted age composition in the fishery (Fig. 1.15), Shelikof Strait acoustic survey (Fig. 1.16), and the NMFS trawl survey (Fig. 1.17). Model fits to fishery age composition data are adequate in most years. The largest residuals tended to be at ages 1-2 for the Shelikof Strait acoustic survey and the NMFS bottom trawl survey due to inconsistencies between the initial estimates of abundance and subsequent information about year class size.

Model fits are similar to previous assessments, and general trends in survey time series are fit reasonably well (Dorn et al. 2009) (Figs. 1.18-1.19). The discrepancy between the NMFS trawl survey and the Shelikof Strait acoustic survey biomass estimates in the 1980s accounts for the poor model fit to both time series during those years. All survey time series are consistent in showing increase since 2007, but the magnitude of the increase is not same for all time series. The ADFG survey shows the strongest increase since 2007. The Shelikof Strait acoustic survey shows a much weaker increase, while the NMFS bottom trawl survey is intermediate. The model was unable to fit all survey estimates simultaneously, and shows an increase that is intermediate between the Shelikof Strait acoustic survey and the ADFG survey.

Time series 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 1.17 (see also Figure 1.20). Table 1.18 gives the estimated population numbers at age for the years 1961-2012. Table 1.19 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2011 (see also Fig. 1.21). Table 1.20 gives coefficients of variation and 95% confidence intervals for age-1 recruitment and spawning stock biomass. Stock size peaked in the early 1980s at the proxy for unfished stock size (B100% = mean 1979-2011 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR at F=0)). In 1997, the stock dropped below the $B_{40\%}$ for the first time since the 1970s, reached a minimum in 2003 of 18% of unfished stock size. Over the last five years (2008-2012) stock size has varied between 22% and 35% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2012 indicates the current estimated trend in spawning biomass for 1990-2012 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 2012 age composition from the current assessment is similar to projected 2012 age composition in the 2011 assessment (Fig. 1.22, bottom panel). The largest change is the estimate of the age-3 fish (2009 year class), which is less than half the size of the projected value in last year's assessment.

Retrospective analysis of base model

A retrospective analysis consists of dropping the data year-by-year from the current model, and provides a different perspective than a comparison of current assessment with previous assessments. Figure 1.23 shows a retrospective plot with data sequentially removed back to 2002, and indicates no consistent retrospective pattern.

Stock productivity

Recruitment of Gulf of Alaska pollock is more variable (CV = 1.19) 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 (~8 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 strong year classes produce in the 1970s were produced by an estimated spawning biomass below 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. 1.24). 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, though some increase is apparent since 2004.

All information on recent recruitment is now incorporated into the assessment model. The base model estimate of the 2010 year class (0.99 billion) is close to average, while the 2011 year class is estimated to be a weak year class (0.20 billion).

Projections and Harvest Alternatives

Reference fishing mortality rates and spawning biomass levels

Since 1997, Gulf pollock have been managed under Tier 3 of NPFMC harvest guidelines. In Tier 3, reference mortality rates are based on the spawning biomass per recruit (SPR), while biomass reference levels are estimated by multiplying the SPR by average recruitment. Estimates of the F_{SPR} harvest rates were obtained using the life history characteristics of Gulf of Alaska pollock (Table 1.21). Spawning biomass reference levels were based on mean 1978-2011 age-1 recruitment (985 million), which is about 5% higher than the post-1977 mean in the 2011 assessment (scaled to represent recruitment at age one. Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using mean weight at age for the Shelikof Strait acoustic surveys in 2007-2012 to estimate current reproductive potential. A substantial increase in pollock weight-at-age has been observed (Fig. 1.13), which may be a density-dependent response to low abundance or due to environmental forcing. The SPR at F=0 was estimated as 0.753 kg/recruit at age one. F_{SPR} rates depend on 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, selectivity was based on the average for 2007-2011 to reflect current selectivity patterns. Gulf of Alaska pollock F_{SPR} harvest rates are given below:

		Equilibrium under average 1978-2011 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	985	2378	741	0	0.0%
40.0%	0.203	985	1313	297	204	15.5%
35.0%	0.237	985	1216	259	219	18.0%

The $B_{40\%}$ estimate of 297,000 t represents a 9% increase from the $B_{40\%}$ estimate of 271,000 t in the 2011 assessment, whick is a result of both an increase in mean recruitment, and an increase in mean weight at age. The base model projection of spawning biomass in 2013 is 259,843 t, which is 35.1% of unfished spawning biomass (based on average post-1977 recruitment) and below $B_{40\%}$ (297,000 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).

2013 acceptable biological catch

The definitions of OFL and maximum permissible F_{ABC} under Amendment 56 provide a buffer between the overfishing level and the intended harvest rate, as required by NMFS national standard guidelines. Since estimates of stock biomass from assessment models are uncertain, the buffer between OFL and ABC provides a margin of safety so that assessment error will not result in the OFL being inadvertently exceeded. For Gulf of Alaska pollock, the maximum permissible F_{ABC} harvest rate is 85.8% 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 1.22). While there is always some probability of exceeding F_{OFL} due to imprecise stock assessments, it seemed unreasonable to reduce safety margin as the stock declines.

This alternative is given by the following

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

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

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

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

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

Projections for 2013 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 1.23.

ABC recommendation

There were two new surveys in 2012, the Shelikof Strait acoustic survey and ADFG crab/groundfish survey. The 2012 Shelikof Strait acoustic declined 22% from the 2010 estimate (no survey was conducted in winter of 2011). The ADFG crab/groundfish survey biomass estimate increased by 71% from the 2011 estimate. The estimated abundance of mature fish in 2013 is projected to be nearly the same as in 2012, and is projected to decrease gradually over the next five years. We considered the changes in this assessment to be improvements to the model. The more questionable data sets have been removed and the model structure has been simplified. However further changes to the assessment should be anticipated as we consider other recommendations by the CIE reviewers. We acknowledge that the CIE reviewers were unified in recommending trawl catchability be estimated, however they also recommended that major revisions to the assessment be implemented in an ABC framework that deals explicitly with scientific uncertainty and accounts for predatory impacts on pollock. The recommended ABC was based on model projection using the base model and the more conservative adjusted $F_{40\%}$ harvest rate described above. The author's recommended 2013 ABC is therefore 113,586 t, which is an increase of 5% from the 2012 ABC. In 2014, the ABC based an adjusted $F_{40\%}$ harvest rate is 104,157 t (Table 1.23). The OFL in 2013 is 150,817 t, and the OFL in 2014 if the recommended ABC is taken in 2013 is 138,610 t.

An exempted fishing permit (EFP) has been proposed to evaluate the effect of salmon excluder devices in the pollock fishery. Projected pollock catches under the EFP will be 2,304 t in 2013 and 2,304 t in 2014 Jeff Hartman, NMFS Alaska Regional Office, pers. comm. Oct. 22, 2012). We followed the Gulf of Alaska Plan Team recommendation, and accounted for the EFP catches in a projection model where the EFP catches were removed from the population at the start of year in 2013 and 2014. This resulted in a 2013 ABC of 113,099 t (487 t difference) and a 2014 ABC of 103,339 (818 t difference).

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 2012 numbers at age as estimated by the assessment model, and assume the 2012 catch will be equal to the TAC of 108,440 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 1978-2011 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 1.21. 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 2013, 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 (2008-2012). (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 2012 or 2) above 1/2 of its MSY level in 2012 and above its MSY level in 2022 under this scenario, then the stock is not overfished)
>
> *Scenario 7*: In 2013 and 2014, 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 2015, or 2) above 1/2 of its MSY level in 2015 and above its MSY level in 2025 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.23. A Under all harvest policies, mean spawning biomass is projected remain stable or to increase or decrease 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 (2011) is 81,307 t, which is less than the 2011 OFL of 118,030 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 262,071 in 2012 which is above $B_{35\%}$ (259,454 t). Therefore, Gulf of Alaska pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2015 is 221,549 t, which less than $B_{35\%}$, but greater than 1/2 the MSY level. In 2025, the projected mean spawning biomass is 294,777 t, which is 114% 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, 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 1.32), 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. 1.35). 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. 1.36, 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. 1.36, 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 2012 is for the area west of 140 ° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound (2,770 t). Research catches are reported in Appendix D.

Year	*Foreign*	*Joint Venture*	*Domestic*	*Total*	*TAC*
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
1978	96,392	34	509	96,935	168,800
1979	103,187	566	1,995	105,748	168,800
1980	112,997	1,136	489	114,622	168,800
1981	130,324	16,857	563	147,744	168,800
1982	92,612	73,917	2,211	168,740	168,800
1983	81,358	134,131	119	215,608	256,600
1984	99,260	207,104	1,037	307,401	416,600
1985	31,587	237,860	15,379	284,826	305,000
1986	114	62,591	25,103	87,809	116,000
1987		22,823	46,928	69,751	84,000
1988		152	65,587	65,739	93,000
1989			78,392	78,392	72,200
1990			90,744	90,744	73,400
1991			100,488	100,488	103,400
1992			90,857	90,857	87,400
1993			108,908	108,908	114,400
1994			107,335	107,335	109,300
1995			72,618	72,618	65,360
1996			51,263	51,263	54,810
1997			90,130	90,130	79,980
1998			125,098	125,098	124,730
1999			95,590	95,590	94,580
2000			73,080	73,080	94,960
2001			72,076	72,076	90,690
2002			51,937	51,937	53,490
2003			50,666	50,666	49,590
2004			63,934	63,934	65,660
2005			80,846	80,846	86,100
2006			71,976	71,976	81,300
2007			53,062	53,062	63,800
2008			52,500	52,500	53,590
2009			44,003	44,003	43,270
2010			76,860	76,860	77,150
2011			81,307	81,307	88,620
2012					108,440
Average (1977-2011)				101,913	117,775

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). 1991-2011--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 2007-2011. Species are ordered according to the cumulative catch during the period. Incidental catch estimates include both retained and discarded catch.

Managed species/species group	*2007*	*2008*	*2009*	*2010*	*2011*
Pollock	50646.3	47383.1	39334.5	73033.1	77292.4
Arrowtooth Flounder	1630.1	1569.6	761.0	2071.8	1993.7
Pacific Cod	275.1	579.2	557.0	1497.9	1500.5
Flathead Sole	327.7	423.5	215.7	360.2	217.4
Squid	410.0	91.8	320.9	129.0	208.8
Shallow Water Flatfish	157.0	230.0	17.0	78.5	291.0
Sharks	248.0	113.5	55.9	279.2	27.0
Pacific Ocean Perch	29.8	49.9	36.1	96.6	172.3
Rex Sole	43.0	58.1	35.5	60.7	90.0
Big Skate	38.1	21.7	33.8	47.1	92.6
Atka Mackerel	200.2	0.1	0.0	0.4	0.1
Shortraker Rockfish	55.9	70.3	26.2	9.4	24.4
Rougheye Rockfish	30.2	42.9	12.9	30.5	34.5
Longnose Skate	26.7	23.6	35.1	9.8	35.0
Sculpins	21.8	15.3	5.0	6.1	49.8
Northern Rockfish	12.0	7.9	11.7	2.2	13.7
Sablefish	3.2	1.3	0.1	1.3	31.7
Pelagic Shelf Rockfish	6.4	4.1	1.5	5.8	19.1
Deep Water Flatfish	5.5	5.8	2.4	3.1	14.6
Other Skate	9.1	5.9	2.6	7.0	1.9
Other Rockfish	2.0	4.5	0.2	0.4	6.8
Octopus	1.5	0.0	0.1	0.8	2.3
Thornyhead Rockfish	0.3	0.2	0.1	0.1	1.8
Percent non-pollock	*6.5%*	*6.5%*	*5.1%*	*6.0%*	*5.9%*

Non target species/species group	*2007*	*2008*	*2009*	*2010*	*2011*
Eulachon	220.98	760.17	217.62	227.44	308.83
Other osmerids	49.42	401.86	149.79	6.78	78.59
Giant Grenadier	4.71	217.09	26.35	1.93	108.30
Jellyfish	24.06	191.51	11.30	121.72	7.72
Miscellaneous fish	24.18	35.36	42.90	42.25	43.54
Grenadier	0.00	26.81	0.00	9.23	7.97
Sea star	4.73	6.58	0.00	4.74	3.65
Capelin	0.00	0.00	0.01	0.00	7.94
Pandalid shrimp	1.89	0.83	0.17	1.12	0.12
Sea anemone unidentified	0.68	0.26	0.00	0.47	0.55
Misc crabs	0.93	0.07	0.00	0.01	0.11
Snails	0.00	0.33	0.01	0.00	0.06
Stichaeidae	0.29	0.00	0.00	0.07	0.00
Bivalves	0.09	0.05	0.00	0.05	0.04
Eelpouts	0.00	0.00	0.13	0.09	0.00
Invertebrate unidentified	0.20	0.00	0.00	0.00	0.00
Surf smelt	0.00	0.16	0.00	0.00	0.00
Hermit crab unidentified	0.00	0.01	0.00	0.09	0.00
Benthic urochordata	0.00	0.00	0.00	0.00	0.09
urchins dollars cucumbers	0.00	0.04	0.00	0.00	0.00
Misc inverts (worms etc)	0.03	0.00	0.00	0.00	0.00

Table 1.3. Bycatch of prohibited species for trawls where pollock was the predominant species in the catch in the Gulf of Alaska during 2007-2011. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of fish.

Species/species group	*2007*	*2008*	*2009*	*2010*	*2011*
Bairdi Tanner Crab (nos.)	19,458	1,740	6,633	108	10,033
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	35,170	10,696	3,195	44,779	13,836
Golden (Brown) King Crab (nos.)	0	0	0	0	0
Halibut (t)	135.4	119.0	63.5	49.2	193.1
Herring (t)	19.6	0.9	8.1	0.9	10.7
Non-Chinook Salmon (nos.)	953	847	333	748	1247
Opilio Tanner (Snow) Crab (nos.)	15	0	0	0	0
Red King Crab (nos.)	0	0	0	0	0

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 2001-2011 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
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	
2010	Retained	25,960	28,015	18,373	1,625	1,660	2	75,635	
	Discarded	91	330	783	12	9	1	1,226	1.6%
	Total	26,051	28,345	19,156	1,637	1,669	3	76,860	
2011	Retained	20,472	36,072	19,014	2,268	1,535	0	79,360	
	Discarded	122	1,110	710	3	1	0	1,946	2.4%
	Total	20,594	37,183	19,724	2,271	1,536	0	81,307	
Average (2001-2011)		21,856	23,202	15,851	1,379	1,271	1	63,561	

Table 1.5. Catch at age (000,000s) of walleye pollock in the Gulf of Alaska in 1976-2011.

	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
2010	0.01	5.29	23.35	21.32	18.14	3.68	1.11	0.73	0.92	1.02	0.64	0.05	0.06	0.01	0.00	76.31
2011	0.00	2.49	12.18	26.78	20.88	13.12	2.97	0.61	0.38	0.21	0.36	0.35	0.07	0.00	0.00	80.40

Table 1.6. Number of aged and measured fish in the Gulf of Alaska pollock fishery used to estimate fishery age composition (1989-2011).

	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
2010	1,195	1,055	2,250	14,958	13,997	28,955
2011	1,197	1,025	2,222	9,625	11,023	20,648

Table 1.7. Biomass estimates (t) of walleye pollock from NMFS acoustic surveys in Shelikof Strait, NMFS bottom trawl surveys (west of 140 W. long.), egg production surveys in Shelikof Strait, and ADFG crab/groundfish trawl surveys. For models where age-1 fish were not included, the Shelikof Strait acoustic survey estimates in 1995, 2000, 2005 and 2008 reduced by 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° W lon., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

	Shelikof Strait acoustic survey					
	R/V Miller Freeman		*R/V Oscar*	*NMFS bottom trawl west of*	*Shelikof Strait egg*	*ADFG crab/groundfish*
Year	*Biosonics*	*EK500*	*Dyson*	*140° 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		763,612				
1996		777,172		666,521		122,477
1997		583,017				93,728
1998		504,774				81,215
1999				607,409		53,587
2000		448,638				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		356,117		358,017		79,089
2006		293,609				69,044
2007		180,881		282,356		76,674
2008			208,032			83,476
2009			265,971	669,505		145,438
2010			429,730			124,110
2011				667,131		100,839
2012			335,836			172,007

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.

Year	*No. of tows*	*No. of tows with pollock*	*Survey biomass CV*	*Number aged*			*Number measured*		
				Males	*Females*	*Total*	*Males*	*Females*	*Total*
1984	929	536	0.14	1,119	1,394	2,513	8,985	13,286	25,990
1987	783	533	0.20	672	675	1,347	15,843	18,101	34,797
1990	708	549	0.12	503	560	1,063	15,014	20,053	42,631
1993	775	628	0.16	879	1,013	1,892	14,681	18,851	35,219
1996	807	668	0.15	509	560	1,069	17,698	19,555	46,668
1999	764	567	0.38	560	613	1,173	10,808	11,314	24,080
2001	489	302	0.30	395	519	914	9,135	10,281	20,272
2003	807	508	0.12	514	589	1,103	10,561	12,706	25,052
2005	839	516	0.15	639	868	1,507	9,108	10,893	27,114
2007	820	554	0.14	646	675	1,321	10,018	11,638	24,768
2009	823	563	0.15	684	870	1,554	13,084	14,697	30,876
2011	670	492	0.15	705	941	1,646	11,851	13,832	27,326

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
2011	249.43	96.71	110.68	101.79	163.62	107.99	33.24	7.14	5.69	8.61	19.29	6.62	0.00	0.00	0.55	911.36

Table 1.10. Estimated number at age (000,000s) from the acoustic 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
2012	94.94	851.52	43.49	76.89	95.78	46.24	29.21	4.49	1.14	0.27	0.09	0.53	0.00	0.00	0.00	1,244.57

Table 1.11. Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Shelikof Strait acoustic survey. Survey CVs are reported for 1981-91, while relative estimation error using a geostatistical method are reported for 1992-2012.

Year	No. of midwater tows	No. of bottom trawl tows	Survey biomass CV	Number aged Males	Number aged Females	Number aged Total	Number measured Males	Number measured Females	Number measured Total
1981	38	13	0.12	1,921	1,815	3,736	NA	NA	NA
1983	40	0	0.16	1,642	1,103	2,745	NA	NA	NA
1984	45	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	39	0	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	582	545	1,127	NA	NA	NA
1990	28	13	0.17	1,034	1,181	2,215	NA	NA	NA
1991	16	2	0.35	468	567	1,035	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	44	9	0.05	553	632	1,185	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	5,380	6,104	11,484
1998	22	9	0.04	863	784	1,647	5,487	4,946	10,433
2000	31	0	0.05	422	363	785	6,007	5,196	11,203
2001	17	9	0.05	314	378	692	4,531	4,584	9,115
2002	18	1	0.07	278	326	604	2,876	2,871	5,747
2003	17	2	0.05	288	321	609	3,554	3,724	7,278
2004	13	2	0.09	492	440	932	3,838	2,552	6,390
2005	22	1	0.04	543	335	878	2,714	2,094	4,808
2006	17	2	0.04	295	487	782	2,527	3,026	5,553
2007	9	1	0.06	335	338	673	2,145	2,194	4,339
2008	10	2	0.06	171	248	419	1,641	1,675	3,316
2009	9	3	0.06	254	301	555	1,583	1,632	3,215
2010	13	2	0.03	286	244	530	2,590	2,358	4,948
2012	8	3	0.08	235	372	607	1,727	1,989	3,716

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 acoustic survey.

Year class	*FOCI prediction*	*Year of acoustic survey*	*McKelvey index*	*Rank abundance of McKelvey index*
1980		1981	0.078	16
1981				
1982		1983	0.001	28
1983		1984	0.062	19
1984		1985	2.092	3
1985		1986	0.579	6
1986				
1987		1988	0.017	26
1988		1989	0.399	7
1989		1990	0.049	24
1990		1991	0.022	25
1991		1992	0.228	11
1992	Strong	1993	0.063	18
1993	Average	1994	0.186	12
1994	Average	1995	10.688	1
1995	Average-Strong	1996	0.061	20
1996	Average	1997	0.070	17
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	27
2002	Average	2003	0.051	23
2003	Average	2004	0.053	22
2004	Average	2005	1.626	4
2005	Average	2006	0.162	13
2006	Average	2007	0.054	21
2007	Average	2008	1.368	5
2008	Average	2009	0.332	9
2009	Average	2010	0.090	15
2010	---	2011		
2011	---	2012	0.095	14

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 acoustic surveys in the Gulf of Alaska (1983-2012).

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
2012	0.000	0.000	0.204	0.659	0.885	1.000	1.000	1.000	1.000	372
Average										
All years	0.001	0.017	0.261	0.563	0.821	0.917	0.964	0.985	0.992	
2002-2012	0.000	0.006	0.289	0.596	0.832	0.943	0.969	0.995	1.000	
2007-2012	0.000	0.000	0.227	0.555	0.859	0.997	0.990	0.990	1.000	

Table 1.16. Results comparing model fits, stock status, and 2013 yield for different model configurations.

	Model 12_LY	*Model 12_BASE*	*Model 12_BQ*
Model fits			
Total log(Likelihood)	-1084.36	-1049.71	-1044.78
Catch	-0.50	-0.65	-0.36
Fishery age and length comp	-380.65	-421.98	-419.14
Acoustic survey biomass	-89.33	-98.01	-94.79
Acoustic survey age and length comp	-279.26	-345.09	-344.90
Bottom trawl survey biomass	-28.04	-30.65	-31.29
Bottom trawl survey age and length comp	-94.87	-99.24	-99.72
ADFG trawl survey biomass	-12.34	-10.31	-9.98
ADFG trawl survey age and length comp	-35.80	-38.81	-38.47
Penalties	-61.11	-4.96	-4.87
Prior on trawl catchability	---	---	-1.26
NMFS trawl q	1.00	1.00	0.73
Composition data			
Fishery age comp. effective N	329	108	112
Shelikof Strait acoustic age comp. effective N	29	22	21
NMFS bottom trawl age comp. effective N	48	40	41
ADF&G trawl age and length comp. effective N	36	38	39
Survey abundance			
Shelikof Strait Acoustic RMSE	0.42	0.43	0.42
NMFS bottom trawl RMSE	0.36	0.36	0.37
ADF&G trawl RMSE	0.26	0.24	0.24
Egg production survey RMSE	0.46	---	---
Historical trawl survey RMSE	1.53	---	---
Stock status (t)			
2013 Spawning biomass	253,622	259,843	335,388
(CV)	(11%)	(12%)	(14%)
Depletion (B2013/B0)	36%	35%	37%
$B_{40\%}$	284,161	296,519	344,869
2013 yield (000 t)			
Author's recommended ABC	139.27	113.59	158.38
MaxABC	161.26	131.63	182.89

Model descriptions (see text for details):

Model 12_LY--Last year's model with updated data

Model 12_BASE--Revised model with limited changes

Model 12_BQ--Same as 12_BASE except trawl catchabiility with Bayesian prior

Table 1.17. Estimated selectivity at age for Gulf of Alaska pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions.

Age	*POP fishery (1964-71)*	*Foreign (1972-81)*	*Foreign and JV (1982-1988)*	*Domestic (1989-2000)*	*Domestic (2001-2006)*	*Recent domestic (2007-2012)*	*Acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.000	0.002	0.016	0.004	0.029	0.030	0.584	0.358	0.011
2	0.000	0.020	0.082	0.022	0.102	0.171	0.974	0.202	0.039
3	0.003	0.187	0.339	0.110	0.304	0.578	0.933	0.314	0.131
4	0.438	0.727	0.771	0.405	0.632	0.902	0.870	0.478	0.358
5	1.000	0.977	0.989	0.796	0.881	0.984	0.778	0.692	0.673
6	0.793	1.000	1.000	0.964	0.981	0.998	0.657	0.905	0.884
7	0.504	0.966	0.859	1.000	1.000	1.000	0.519	1.000	0.966
8	0.254	0.820	0.528	0.985	0.938	0.998	0.380	0.904	0.991
9	0.108	0.476	0.202	0.836	0.628	0.930	0.259	0.690	0.998
10	0.042	0.159	0.056	0.374	0.188	0.323	0.168	0.477	1.000

Table 1.18. Total estimated abundance at age (numbers in 000,000s) of Gulf of Alaska pollock from the age-structured assessment model.

	Age									
	1	2	3	4	5	6	7	8	9	10
1964	262	194	144	106	79	58	43	32	24	68
1965	138	194	144	106	78	58	43	32	24	68
1966	187	102	144	106	78	57	42	31	23	68
1967	432	138	76	106	76	53	39	30	23	67
1968	815	320	102	56	77	53	37	28	22	66
1969	191	604	237	76	40	53	37	27	20	65
1970	474	142	448	175	50	23	32	24	19	62
1971	578	351	105	331	124	33	16	23	17	59
1972	579	428	260	78	238	86	23	11	16	57
1973	2,272	429	316	188	53	158	57	16	8	53
1974	571	1,683	317	229	128	35	104	37	10	44
1975	371	423	1,242	227	148	79	21	64	24	38
1976	2,317	275	312	894	150	94	50	14	42	44
1977	3,345	1,716	203	224	579	93	58	31	9	60
1978	3,542	2,477	1,266	145	144	356	57	36	20	49
1979	5,886	2,623	1,829	909	95	90	222	36	23	49
1980	3,070	4,360	1,938	1,323	614	62	59	146	24	51
1981	641	2,274	3,224	1,411	916	415	42	40	100	54
1982	856	475	1,682	2,350	982	624	282	29	28	111
1983	356	634	350	1,216	1,648	678	430	197	20	102
1984	672	264	466	251	840	1,116	459	295	139	90
1985	2,574	497	193	327	164	531	704	296	201	166
1986	960	1,900	361	132	203	97	312	428	194	263
1987	218	710	1,395	258	90	135	64	210	299	334
1988	448	162	522	1,000	177	61	91	44	148	464
1989	2,248	331	119	376	698	122	42	63	31	450
1990	1,262	1,665	245	87	270	485	83	28	43	345
1991	490	934	1,231	180	62	185	328	56	19	276
1992	309	363	690	899	126	42	121	213	37	207
1993	197	229	268	505	634	85	27	79	140	171
1994	248	146	169	196	354	423	55	18	52	214
1995	1,290	184	108	123	138	238	278	36	12	186
1996	455	955	136	79	88	95	161	188	24	141
1997	202	337	706	100	57	61	65	110	128	118
1998	220	149	249	513	69	36	38	40	68	163
1999	217	163	110	178	332	39	20	20	21	145
2000	1,211	160	120	79	118	198	22	11	11	110
2001	962	896	118	87	54	74	120	13	7	82
2002	153	709	650	82	56	33	45	72	8	63
2003	134	112	516	458	55	36	21	28	46	51
2004	102	99	82	366	310	36	23	13	18	68
2005	468	75	72	58	245	199	23	15	9	61
2006	816	345	54	50	38	152	121	14	9	49
2007	640	602	250	38	33	24	94	74	9	41
2008	1,042	472	436	172	25	22	15	61	49	35
2009	440	770	344	305	117	17	14	10	41	58
2010	163	325	564	245	213	81	12	10	7	70
2011	989	120	237	394	166	143	54	8	7	55
2012	201	730	87	165	264	110	95	36	5	44
Average	943	699	507	367	251	164	106	69	46	117

Table 1.19. Estimates of population biomass, recruitment, and harvest of Gulf of Alaska pollock from the age-structured assessment model.

Year	3+ total biomass (1,000 t)	Female spawn. biom. (1,000 t)	Age 1 recruits (million)	Catch (t)	Harvest rate	2011 Assessment results: 3+ total biomass	2011 Assessment results: Female spawn. biom.	2011 Assessment results: Age 2 recruits	2011 Assessment results: Harvest rate
1977	939	196	3,345	118,356	13%	1,986	465	1,949	6%
1978	1,197	205	3,542	96,935	8%	2,155	502	2,737	4%
1979	1,781	226	5,886	105,748	6%	2,671	512	2,562	4%
1980	2,426	307	3,070	114,622	5%	3,173	569	3,627	4%
1981	3,488	310	641	147,744	4%	3,881	471	1,844	4%
1982	3,931	442	856	168,740	4%	4,042	553	448	4%
1983	3,490	636	356	215,608	6%	3,434	687	502	6%
1984	2,907	722	672	307,401	11%	2,783	725	208	11%
1985	2,205	679	2,574	284,826	13%	2,064	657	477	14%
1986	1,798	581	960	87,809	5%	1,664	536	1,623	5%
1987	1,929	497	218	69,751	4%	1,727	451	550	4%
1988	1,876	463	448	65,739	4%	1,630	409	160	4%
1989	1,720	459	2,248	78,392	5%	1,478	396	376	5%
1990	1,455	418	1,262	90,744	6%	1,259	356	1,643	7%
1991	1,545	403	490	100,488	7%	1,380	338	1,024	7%
1992	1,805	355	309	90,857	5%	1,701	298	407	5%
1993	1,603	374	197	108,908	7%	1,544	334	241	7%
1994	1,328	411	248	107,335	8%	1,295	385	145	8%
1995	1,108	368	1,290	72,618	7%	1,089	353	219	7%
1996	905	325	455	51,263	6%	902	319	857	6%
1997	934	277	202	90,130	10%	918	274	408	10%
1998	846	211	220	125,098	15%	840	208	174	15%
1999	670	191	217	95,590	14%	679	190	159	14%
2000	585	178	1,211	73,080	12%	599	178	217	12%
2001	534	172	962	72,076	13%	566	174	889	13%
2002	681	143	153	51,937	8%	712	147	816	7%
2003	803	133	134	50,666	6%	869	139	119	6%
2004	706	141	102	63,934	9%	767	153	88	8%
2005	589	178	468	80,846	14%	644	196	75	13%
2006	503	185	816	71,976	14%	553	208	228	13%
2007	491	164	640	53,062	11%	509	186	574	10%
2008	709	164	1,042	52,500	7%	688	179	458	8%
2009	991	164	440	44,003	4%	941	168	650	5%
2010	1,113	219	163	76,860	7%	1,127	208	323	7%
2011	1,020	249	989	81,307	8%	1,159	238	388	7%
2012	909	257	201						
Average									
1977-2012	1,431	317	1,029	101,913	8%	1,527	348	776	8%
1979-2011			985						

Table 1.20. Uncertainty of estimates of recruitment and spawning biomass of Gulf of Alaska pollock from the age-structured assessment model.

Year	*Age-2 Recruits (millions)*	*CV*	*Lower 95% CI*	*Upper 95% CI*	*Spawning biomass (1,000 t)*	*CV*	*Lower 95% CI*	*Upper 95% CI*
1964	262	0.41	121	564	116	0.41	54	251
1965	138	0.49	55	343	116	0.41	53	250
1966	187	0.47	77	450	114	0.42	52	249
1967	432	0.42	196	951	110	0.43	49	247
1968	815	0.36	410	1621	105	0.44	47	238
1969	191	0.56	69	531	98	0.44	43	222
1970	474	0.35	244	919	92	0.44	40	207
1971	578	0.29	330	1011	103	0.39	49	218
1972	579	0.29	334	1005	118	0.37	59	238
1973	2273	0.16	1665	3101	125	0.36	63	248
1974	571	0.23	368	888	125	0.35	64	243
1975	371	0.25	230	598	127	0.33	67	240
1976	2317	0.13	1781	3014	162	0.28	95	276
1977	3345	0.12	2650	4223	196	0.25	120	319
1978	3542	0.11	2843	4412	205	0.26	125	335
1979	5886	0.09	4955	6993	226	0.24	143	357
1980	3070	0.10	2543	3707	307	0.19	212	443
1981	641	0.17	459	896	310	0.15	231	415
1982	856	0.12	672	1091	442	0.12	348	560
1983	356	0.20	240	530	636	0.10	519	780
1984	672	0.14	515	876	722	0.10	590	884
1985	2574	0.07	2225	2977	679	0.11	545	845
1986	960	0.10	792	1163	581	0.12	458	738
1987	218	0.19	151	316	497	0.12	390	634
1988	448	0.14	344	584	463	0.12	367	584
1989	2248	0.07	1977	2557	459	0.11	373	566
1990	1262	0.08	1077	1477	418	0.10	344	509
1991	490	0.12	387	619	403	0.10	331	490
1992	309	0.13	240	398	355	0.09	295	426
1993	197	0.15	148	263	374	0.09	316	442
1994	248	0.14	189	326	411	0.08	352	480
1995	1290	0.07	1130	1473	368	0.08	315	430
1996	455	0.10	373	555	325	0.08	279	380
1997	202	0.14	152	268	277	0.08	236	325
1998	220	0.13	172	282	211	0.09	178	250
1999	217	0.13	169	278	191	0.09	161	228
2000	1211	0.06	1072	1368	178	0.09	148	213
2001	962	0.07	846	1095	172	0.10	142	209
2002	153	0.16	112	208	143	0.11	116	176
2003	134	0.14	102	175	133	0.10	109	163
2004	102	0.17	73	142	141	0.08	119	166
2005	468	0.09	390	562	178	0.08	152	209
2006	816	0.09	685	973	185	0.08	156	218
2007	640	0.11	519	788	164	0.09	137	197
2008	1042	0.11	837	1298	164	0.10	136	198
2009	440	0.16	324	598	164	0.09	136	197
2010	163	0.33	87	304	219	0.09	183	261
2011	989	0.21	661	1479	249	0.09	207	299
2012	201	0.45	86	470	257	0.10	210	316

Table 1.21. 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 acoustic survey conducted in March. Proportion mature females is the average from winter acoustic survey specimen data for 1983-2012.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2007-2011)*	*Spawning (Avg. 2007-2012)*	*Population (Avg. 2007-2011)*	*Fishery (Avg. 2007-2011)*	*Proportion mature females*
1	0.3	0.030	0.010	0.038	0.125	0.000
2	0.3	0.171	0.080	0.222	0.338	0.001
3	0.3	0.578	0.253	0.458	0.570	0.017
4	0.3	0.902	0.556	0.816	0.901	0.261
5	0.3	0.984	0.878	1.149	1.262	0.563
6	0.3	0.998	1.263	1.436	1.523	0.821
7	0.3	1.000	1.648	1.613	1.705	0.917
8	0.3	0.998	1.793	1.734	1.870	0.964
9	0.3	0.930	1.999	1.954	2.024	0.985
10+	0.3	0.323	2.029	1.964	2.091	0.992

Table 1.22. Methods used to assess Gulf of Alaska pollock, 1977-2010. 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 1990-2010 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
2010	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	276,000
2011	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	271,000

Table 1.23. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2013-2025 under different harvest policies. All projections begin with estimated age composition in 2012 using the base run model with a projected 2012 catch of 108,440 t. The values for update! $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 741,000, 297,000, and 259,000 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}
2012	262,071	262,071	262,071	262,071	262,071	262,071	262,071
2013	258,578	259,843	262,020	264,373	267,375	257,209	258,578
2014	241,204	247,699	259,278	272,717	290,743	234,398	241,204
2015	222,486	232,104	249,712	272,962	305,620	212,791	221,549
2016	223,884	235,563	257,099	289,612	337,179	212,423	218,659
2017	237,458	250,418	276,854	317,954	380,000	224,528	228,406
2018	261,020	274,544	309,831	360,042	437,398	245,881	247,863
2019	288,165	301,977	350,740	412,547	509,554	269,625	270,430
2020	303,923	317,360	380,153	452,121	566,917	282,207	282,405
2021	312,614	325,639	401,729	482,889	614,226	288,208	288,192
2022	315,856	328,367	415,220	503,442	648,272	289,648	289,590
2023	318,914	330,956	426,335	519,751	674,693	291,515	291,468
2024	322,647	334,395	436,874	534,508	697,583	294,377	294,348
2025	323,740	335,234	443,519	544,528	714,119	294,793	294,777
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}**
2012	0.14	0.14	0.14	0.14	0	0.14	0.14
2013	0.18	0.15	0.11	0.06	0	0.20	0.18
2014	0.16	0.14	0.11	0.06	0	0.18	0.16
2015	0.15	0.13	0.11	0.06	0	0.17	0.17
2016	0.15	0.13	0.11	0.06	0	0.17	0.17
2017	0.15	0.14	0.11	0.06	0	0.17	0.17
2018	0.16	0.15	0.11	0.06	0	0.18	0.18
2019	0.17	0.16	0.11	0.06	0	0.19	0.19
2020	0.17	0.16	0.11	0.06	0	0.19	0.19
2021	0.17	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
2024	0.18	0.17	0.11	0.06	0	0.20	0.20
2025	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}**
2012	108,440	108,440	108,440	108,440	108,440	108,440	108,440
2013	131,630	113,586	81,853	46,572	0	150,817	131,630
2014	115,977	104,157	81,440	48,033	0	127,263	115,977
2015	107,624	98,961	83,944	50,725	0	115,295	123,710
2016	124,593	116,381	94,039	57,501	0	133,053	138,523
2017	147,128	140,653	105,549	64,981	0	158,353	161,008
2018	168,469	163,846	118,407	73,591	0	182,296	183,244
2019	185,484	181,751	128,034	80,417	0	200,678	200,790
2020	190,630	186,706	131,408	82,963	0	205,009	204,764
2021	197,352	193,334	136,736	87,023	0	210,987	210,739
2022	199,651	195,721	138,519	88,269	0	212,999	212,837
2023	201,243	196,892	140,024	89,318	0	214,081	214,000
2024	200,671	196,389	139,955	89,458	0	213,301	213,267
2025	197,620	193,404	139,044	89,028	0	209,935	209,922

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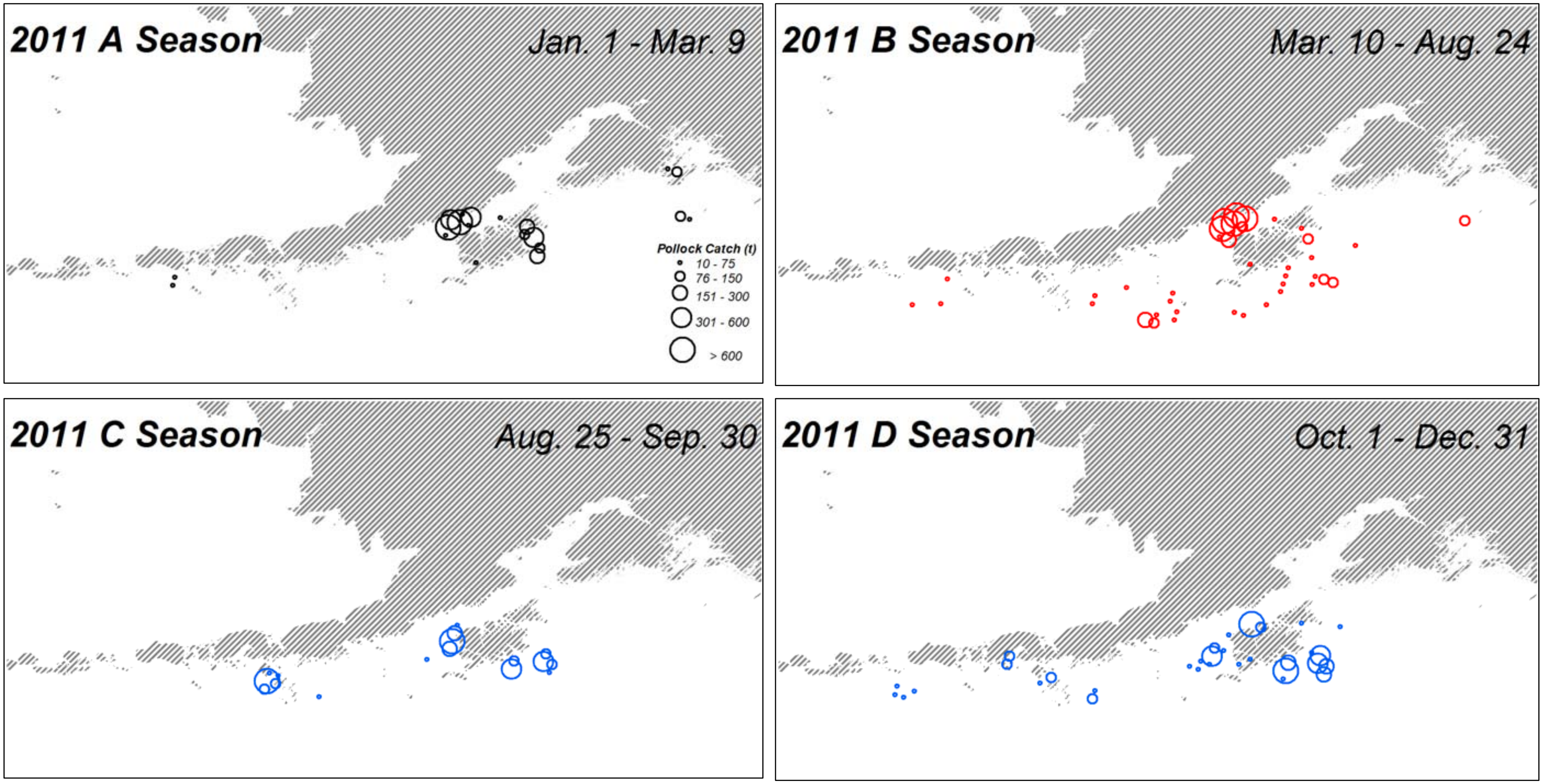


Figure 1.1 Pollock catch in 2011 by 20 X 20 km blocks by season in the Gulf of Alaska as determined by observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The size of the circle is proportional to the catch.

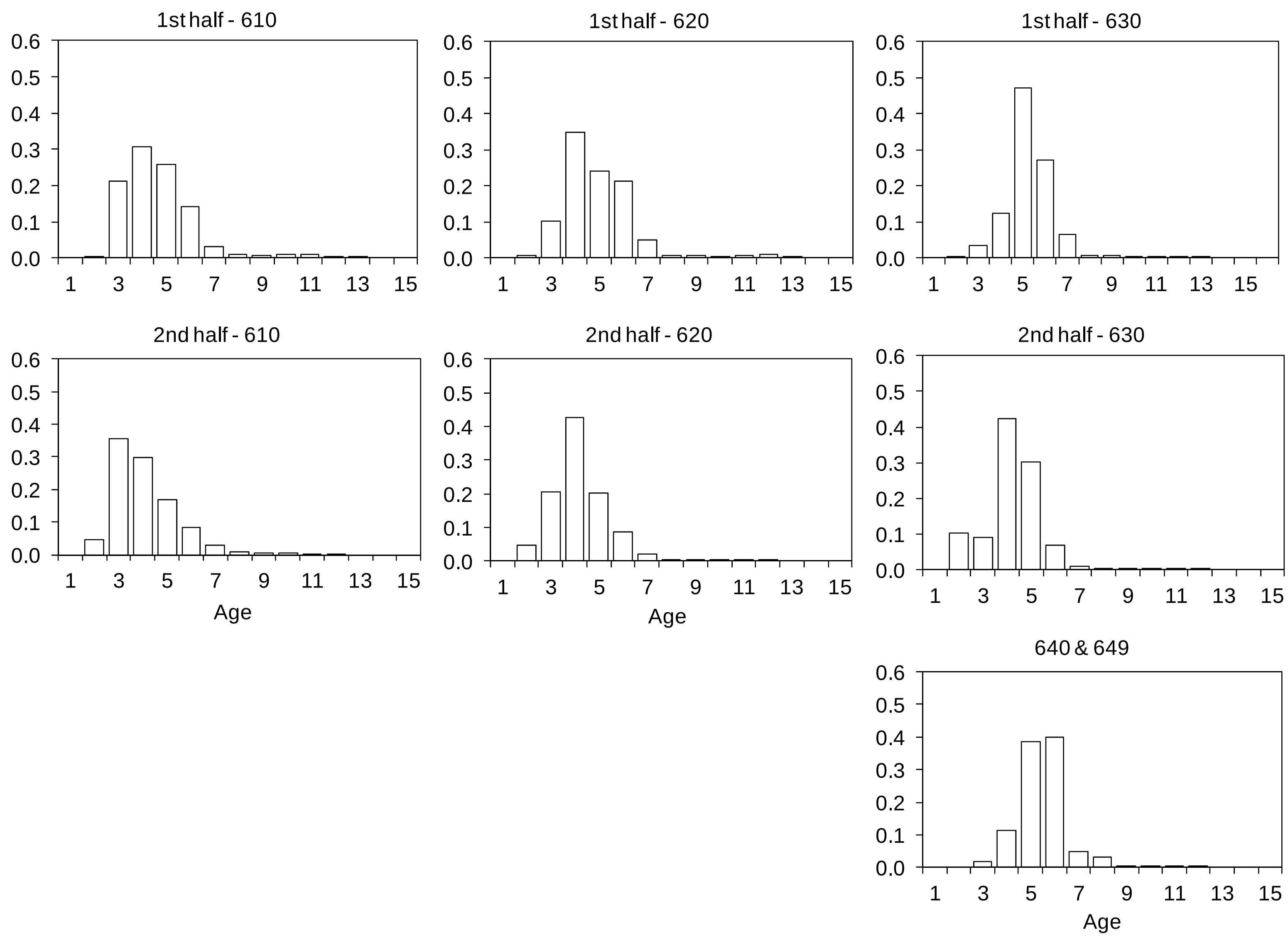


Figure 1.2. 2011 catch age composition by half year (January-June, July-December) and statistical area.

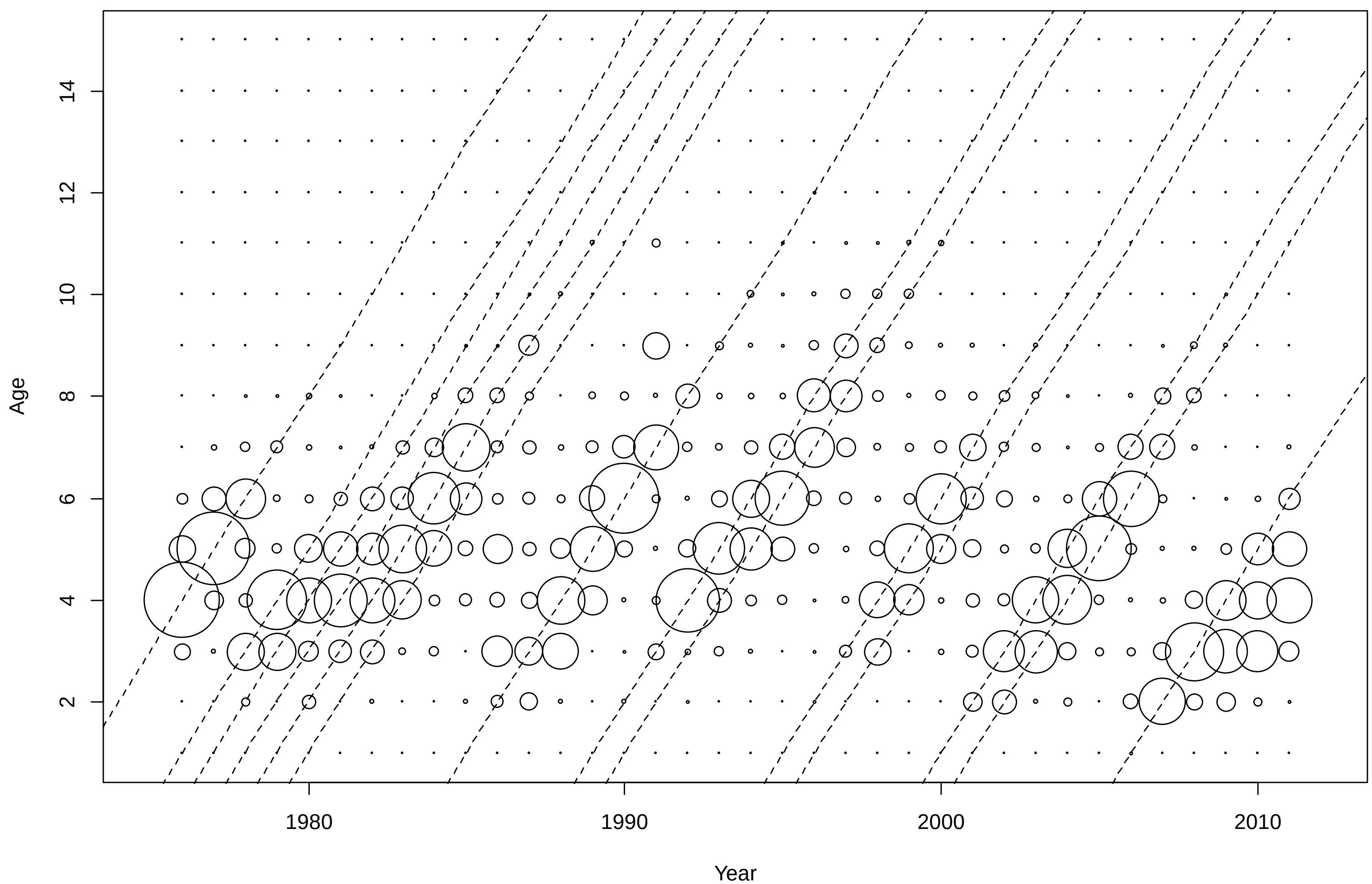


Figure 1.3. Gulf of Alaska pollock catch age composition (1976-2011). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, 1995, 1999, 2000, and 2005).

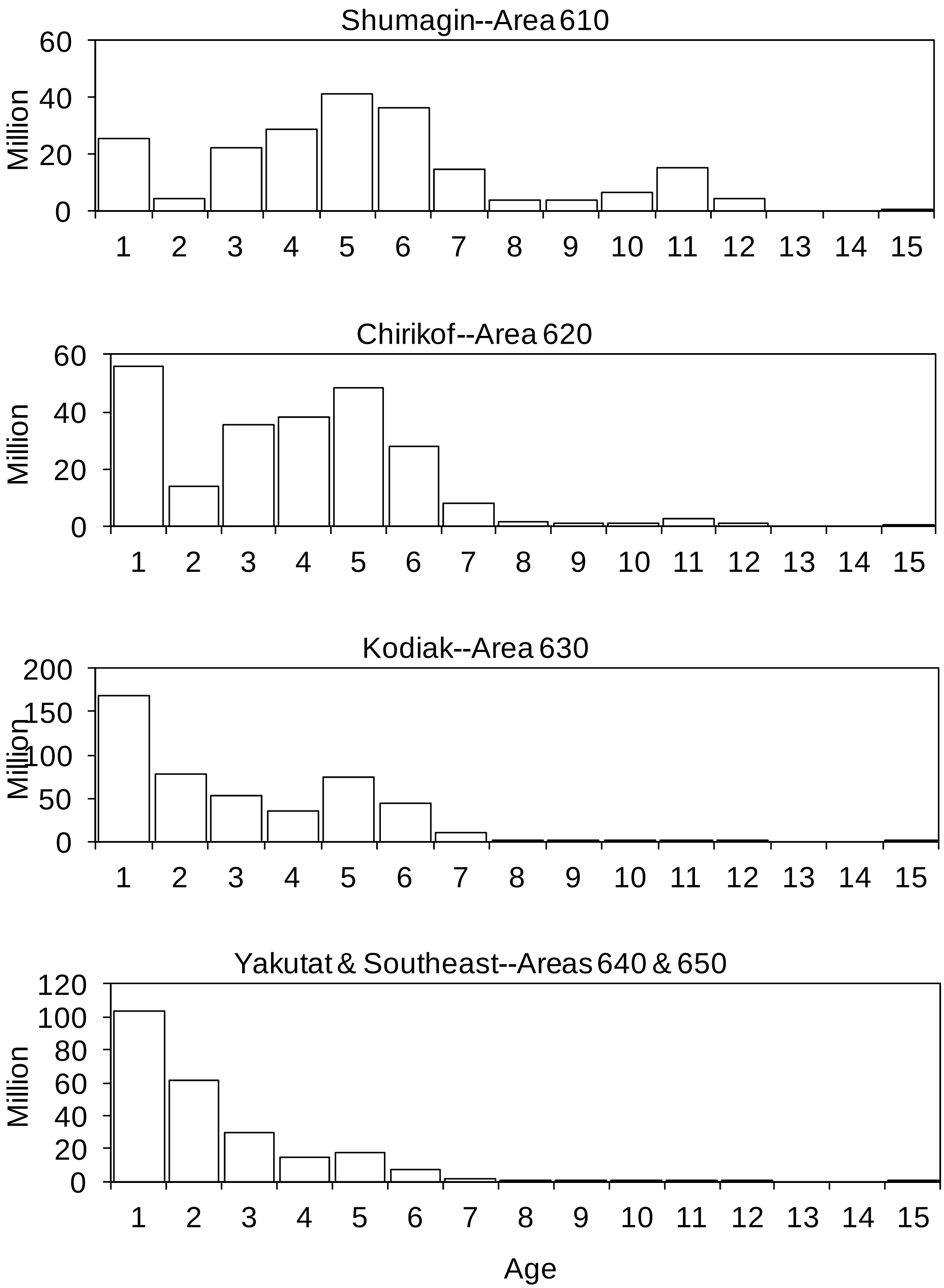


Figure 1.4. Age composition of pollock by statistical area for the 2011 NMFS bottom trawl survey.

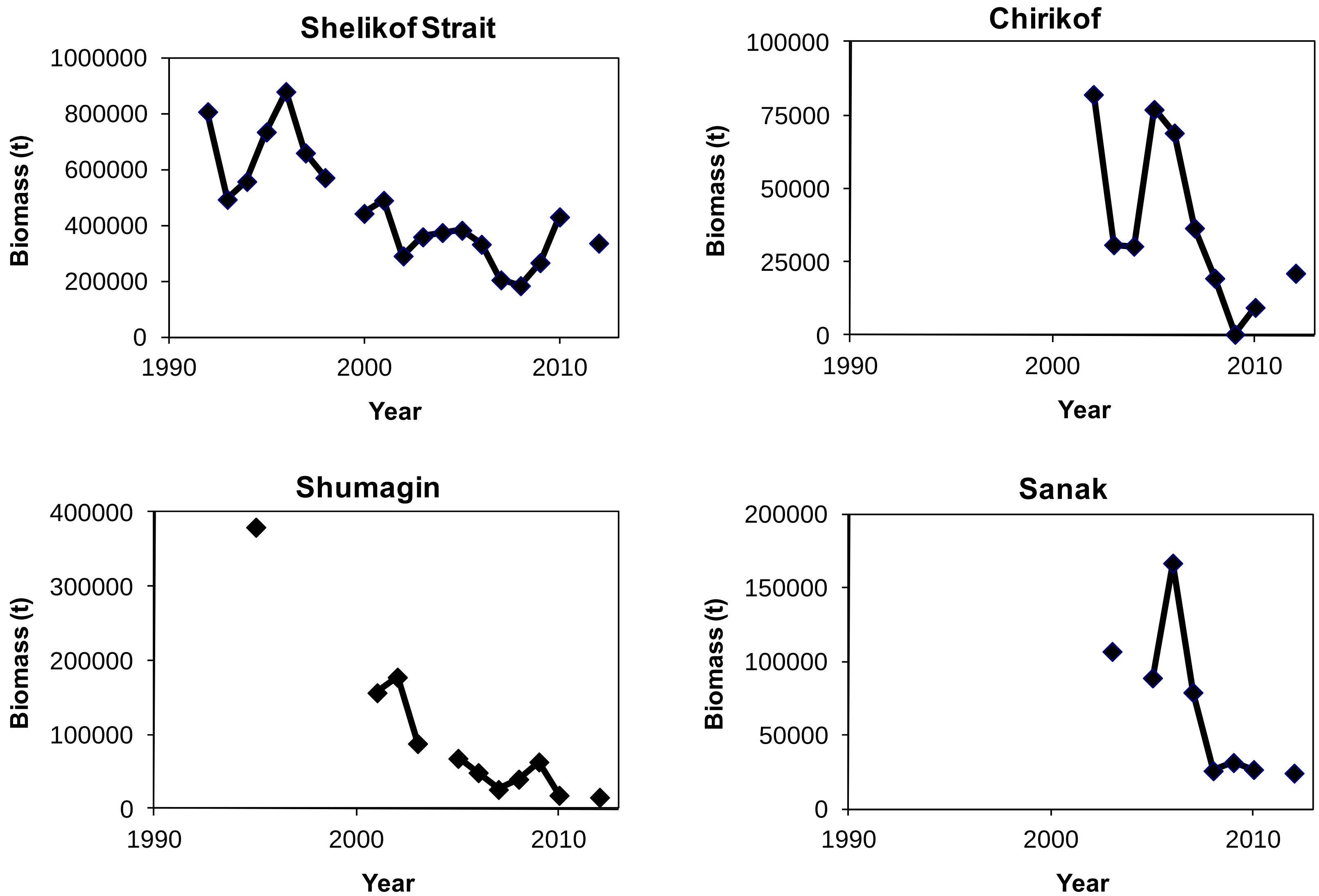


Figure 1.5. Trends in biomass estimates from winter acoustic surveys of pre-spawning aggregations of pollock in the Gulf of Alaska.

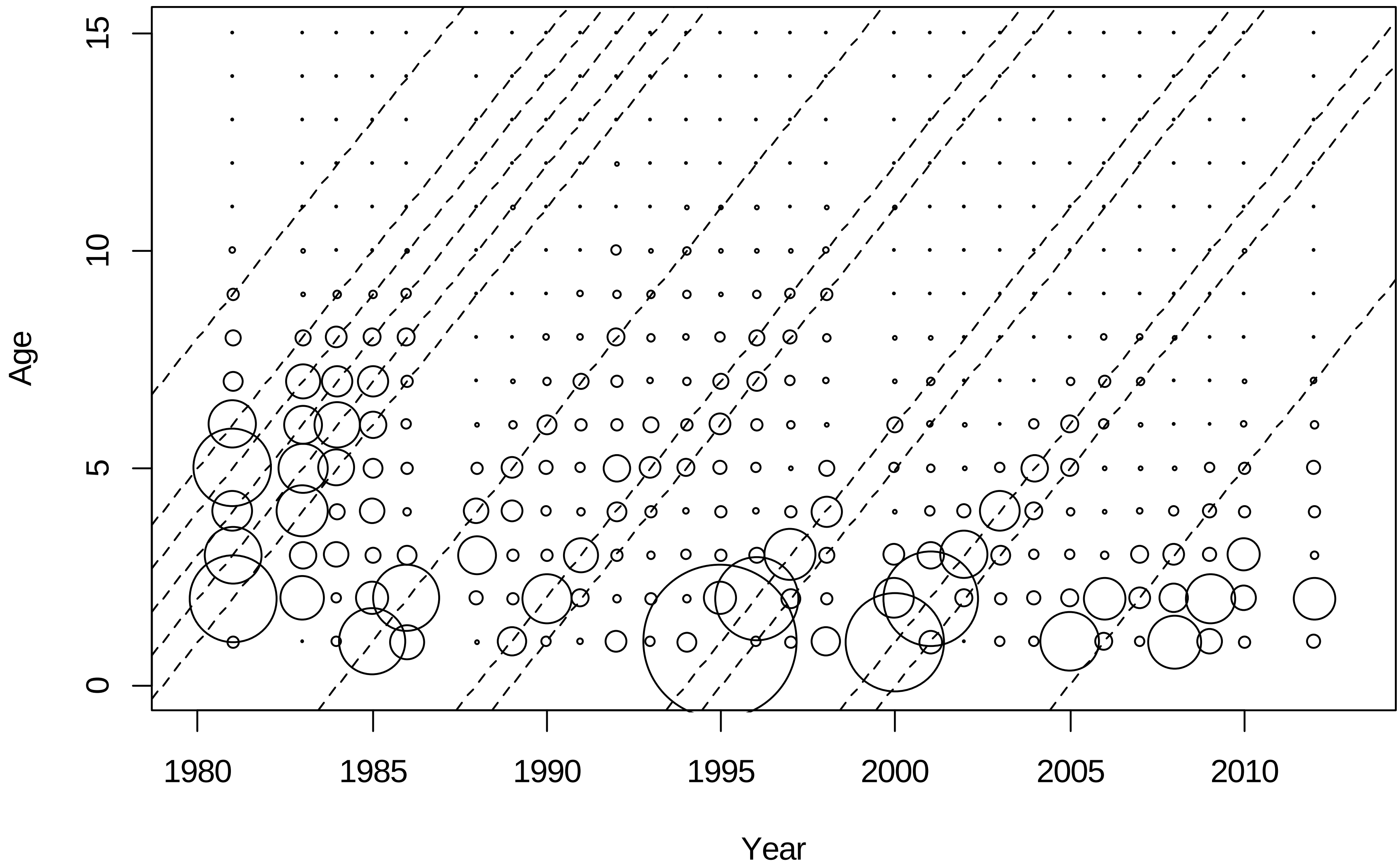


Figure 1.6. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2010, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

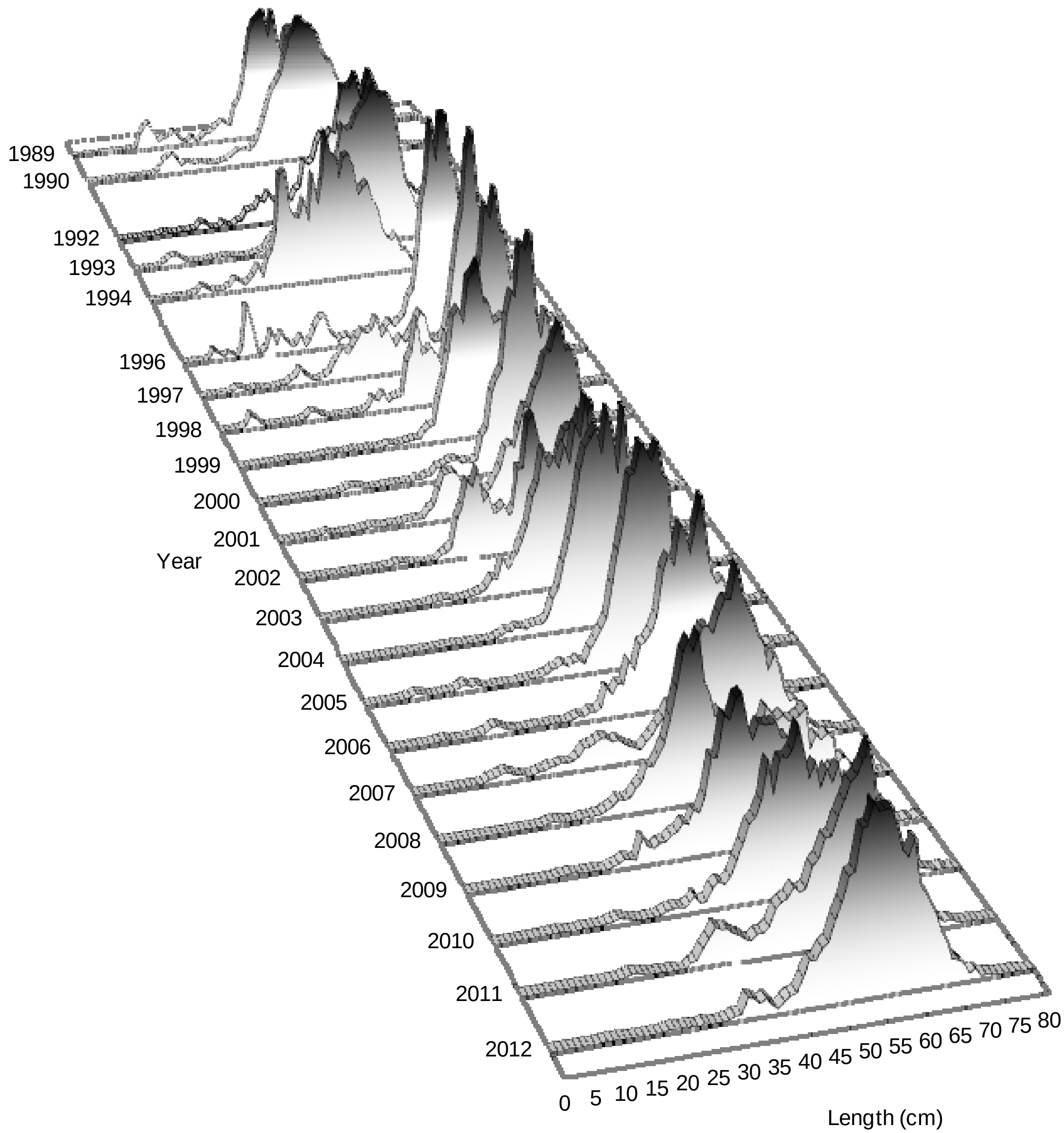


Figure 1.7. Length frequency of pollock in the ADFG crab/groundfish trawl survey (1989-2011, except 1991 and 1995).

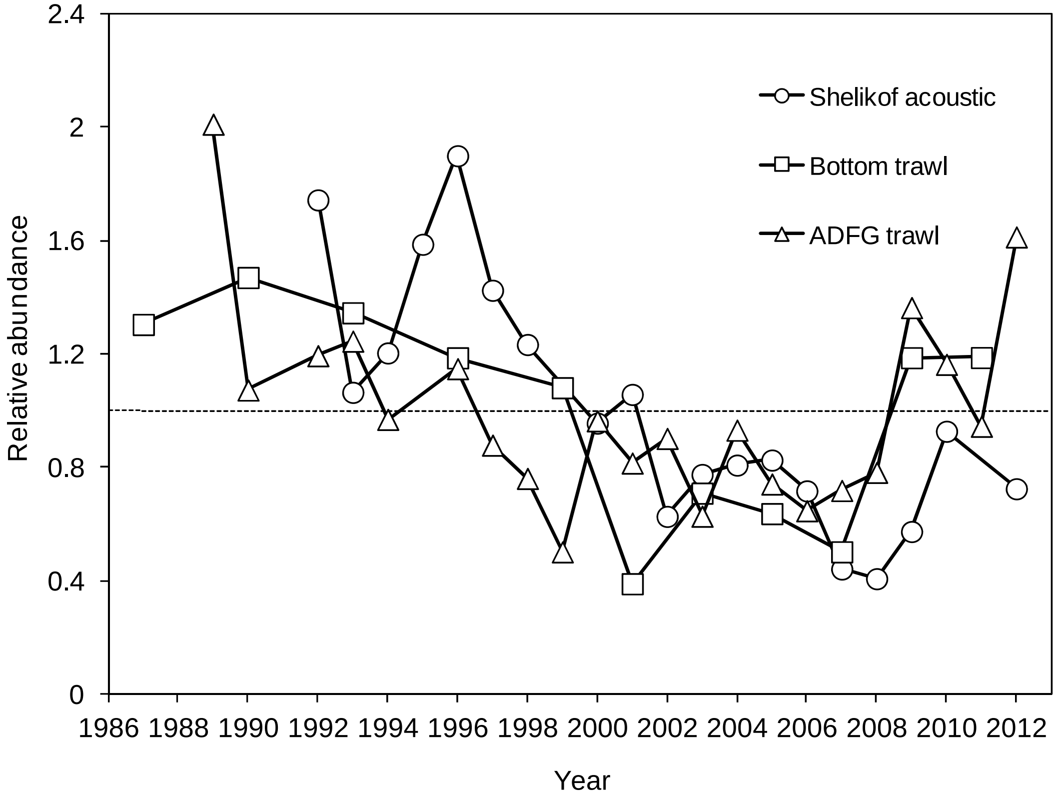


Figure 1.8. Relative trends in pollock biomass since 1987 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADFG crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the *R/V Oscar Dyson*.

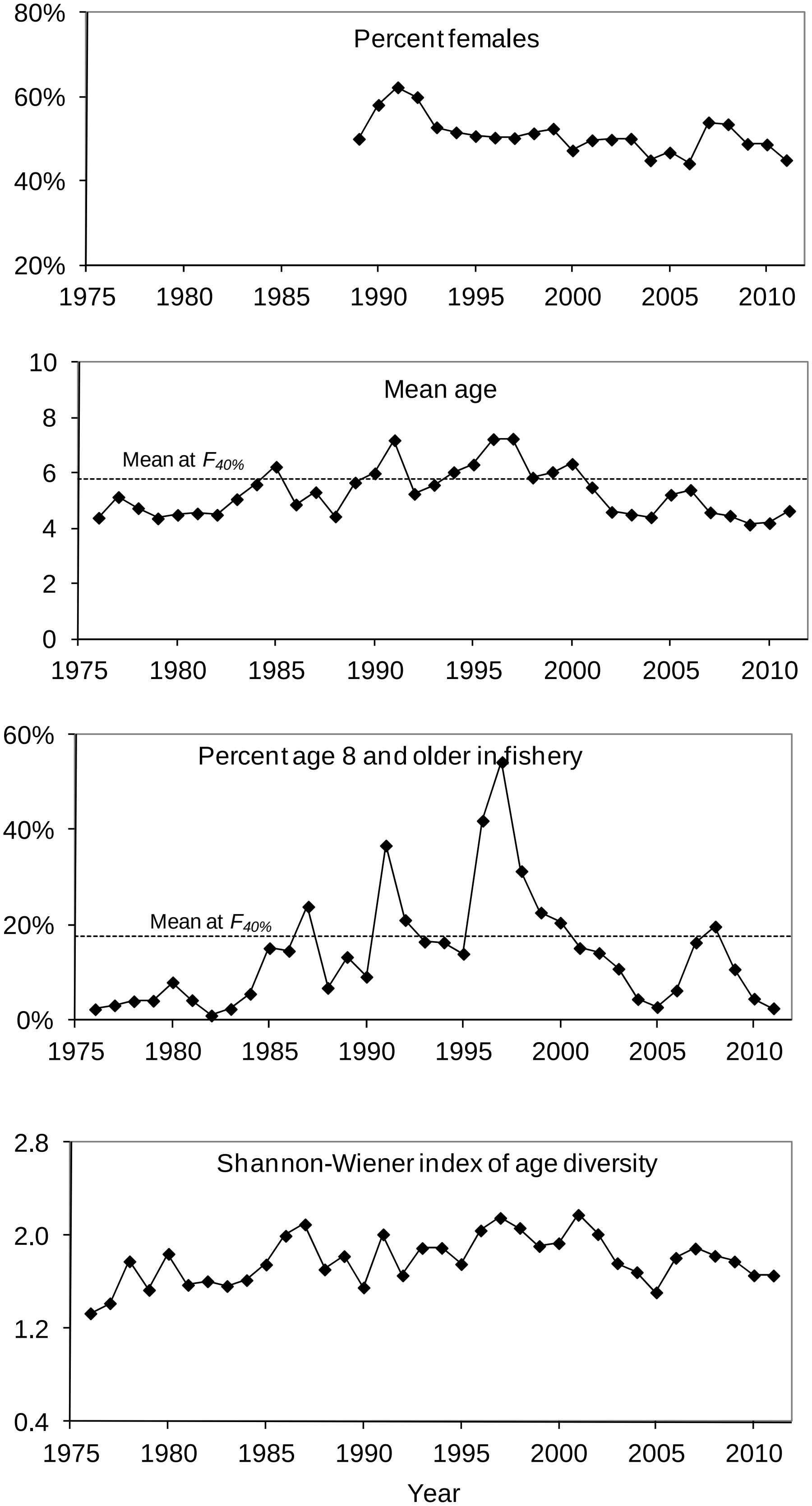


Figure 1.9. Gulf of Alaska pollock catch characteristics.

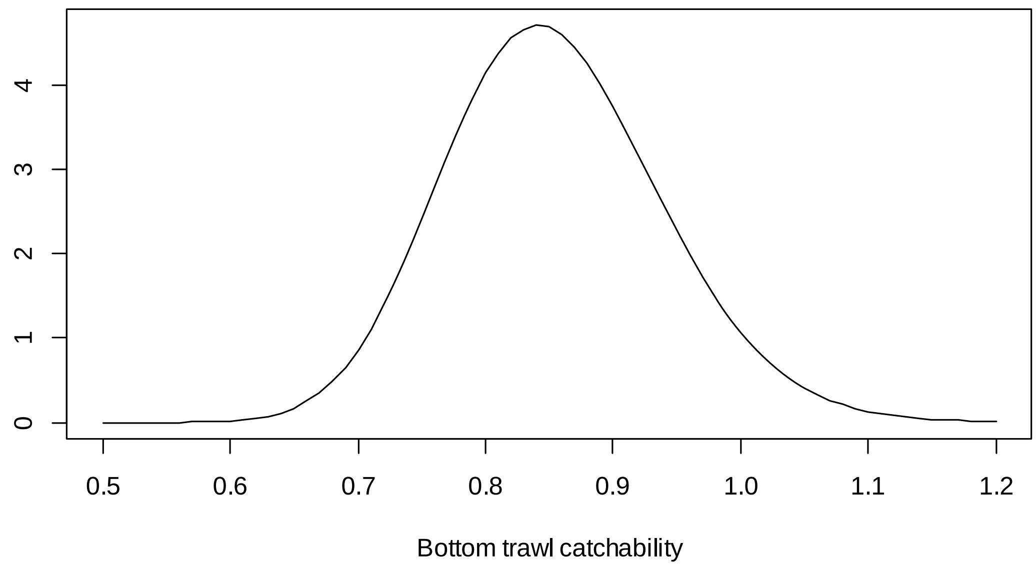


Figure 1.10. Prior on bottom trawl catchability used in some assessment models.

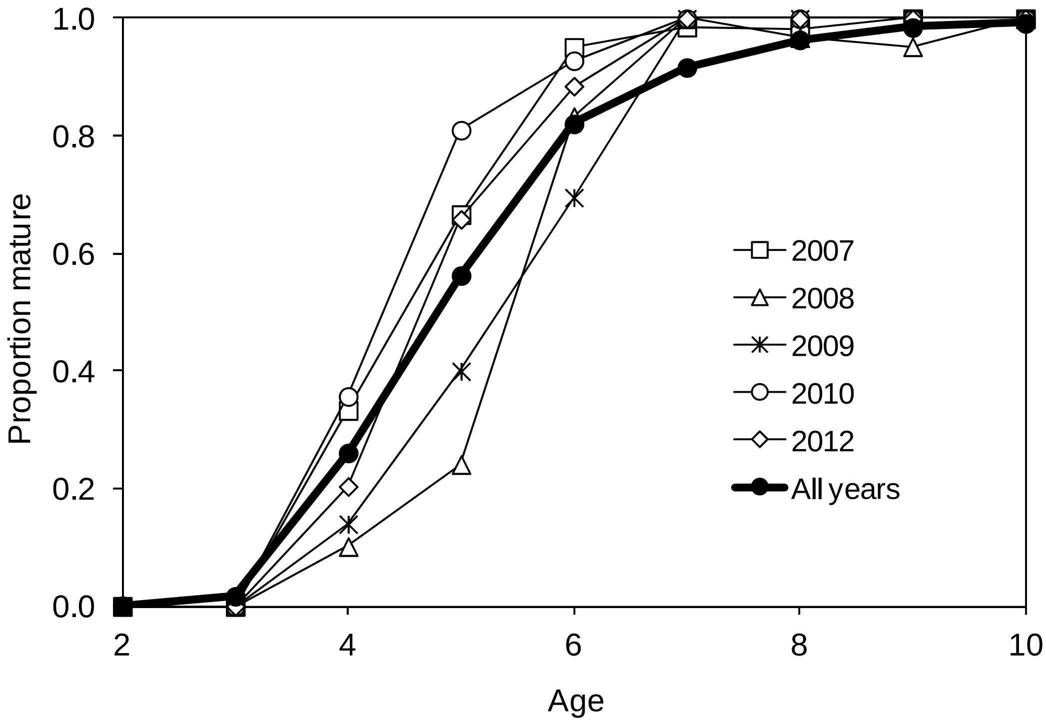


Figure 1.11. Estimates of the proportion mature at age from visual maturity data collected during 2007-2012 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2012).

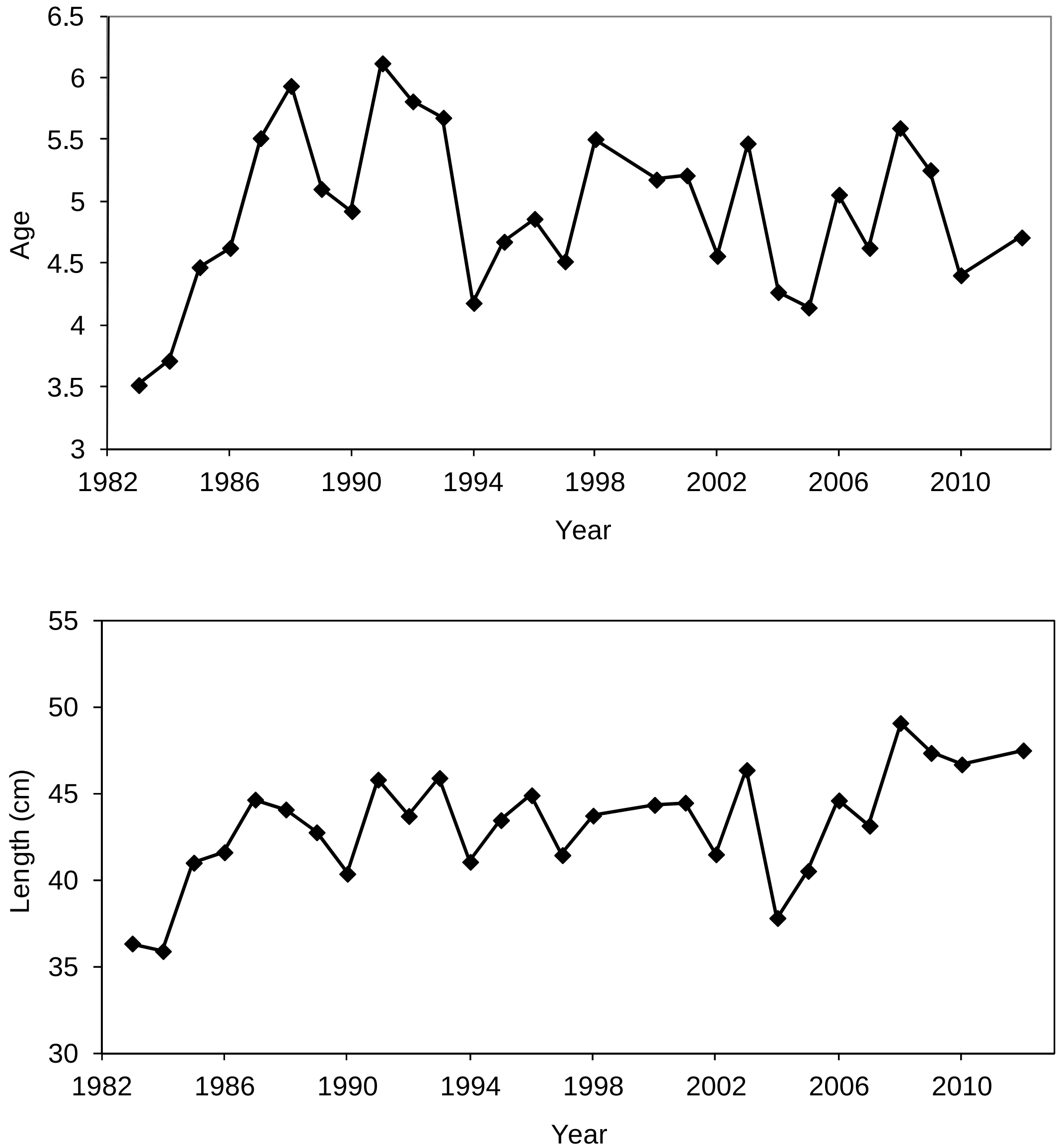


Figure 1.12. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2012.

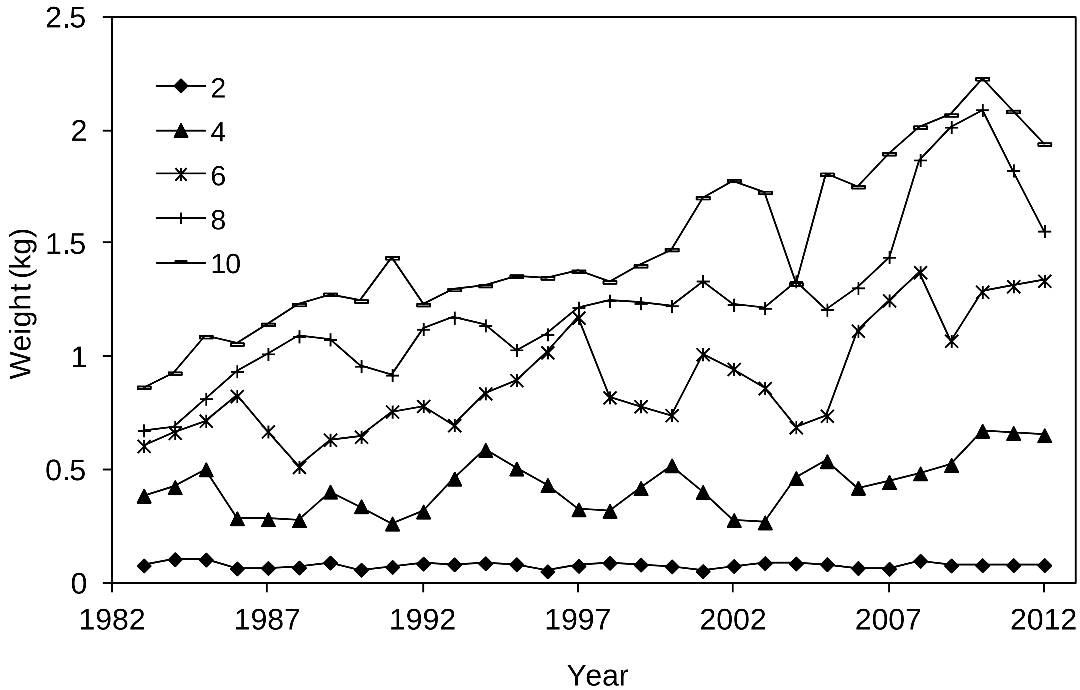
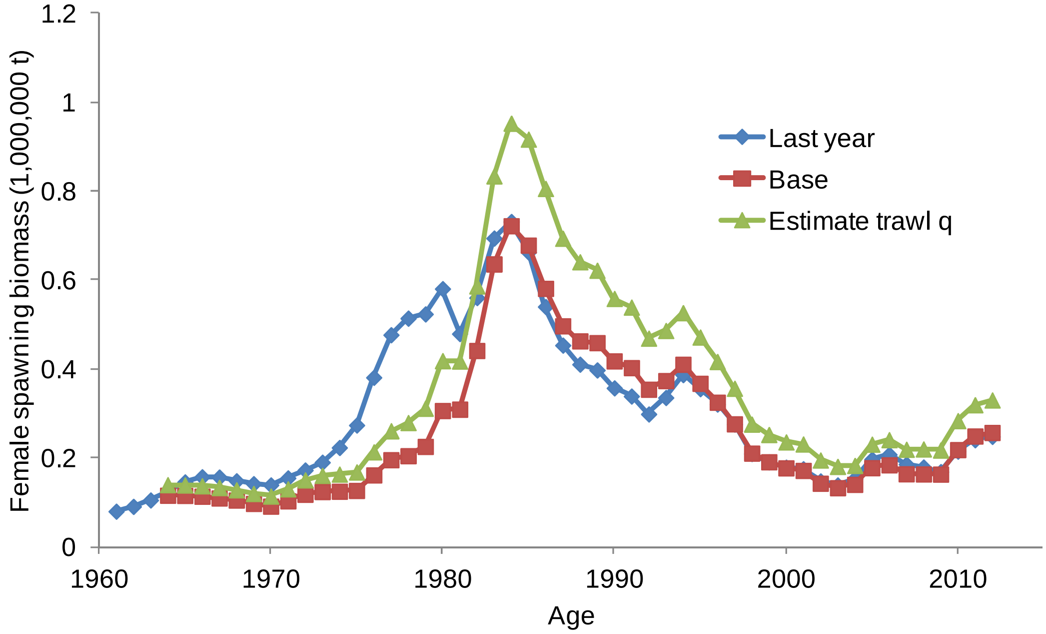


Figure 1.13. Estimated weight-at-age of Gulf of Alaska pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2012 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from adjacent years.



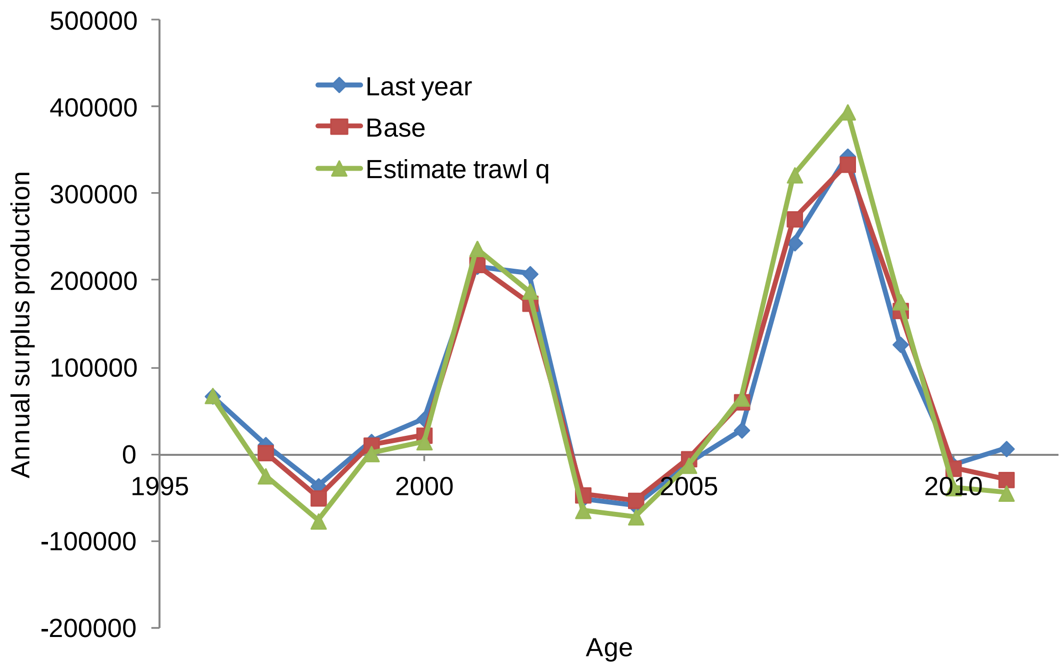


Figure 1.14. Comparison of alternative models. Top panel: estimates of spawning biomass. Bottom panel: annual surplus production 1997-2011 (most recent 15 years).

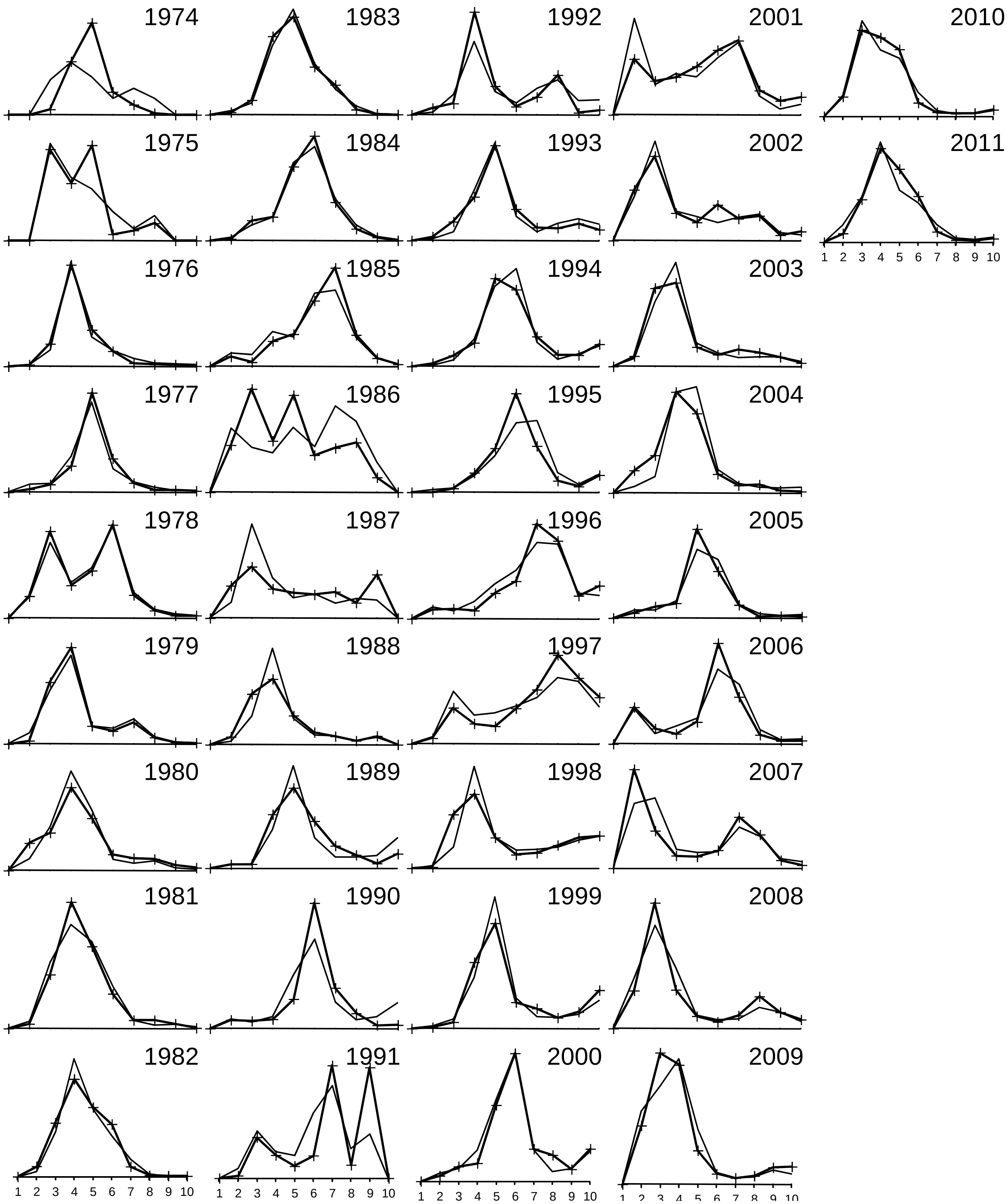


Figure 1.15. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

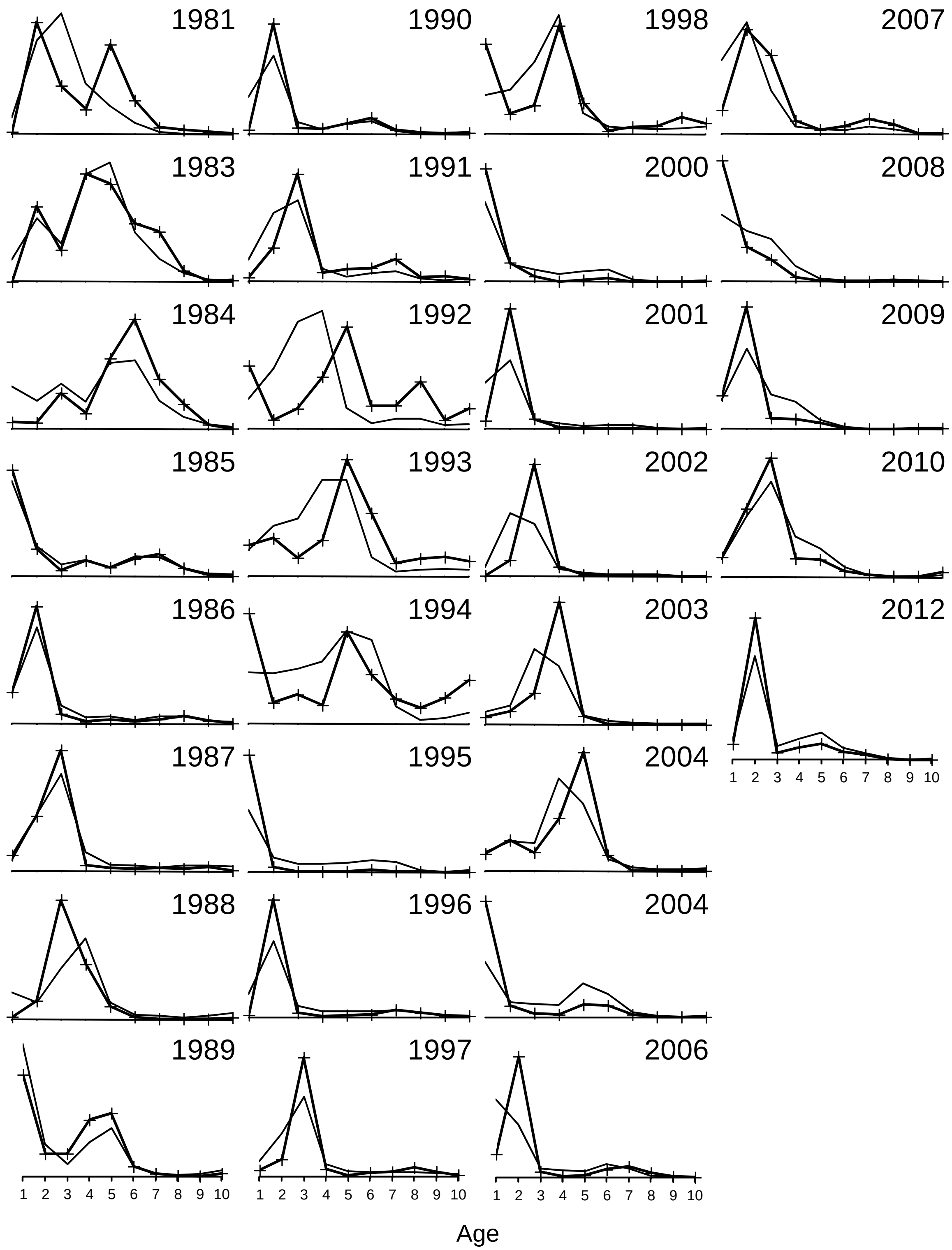


Figure 1.16. Observed and predicted Shelikof Strait acoustic survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

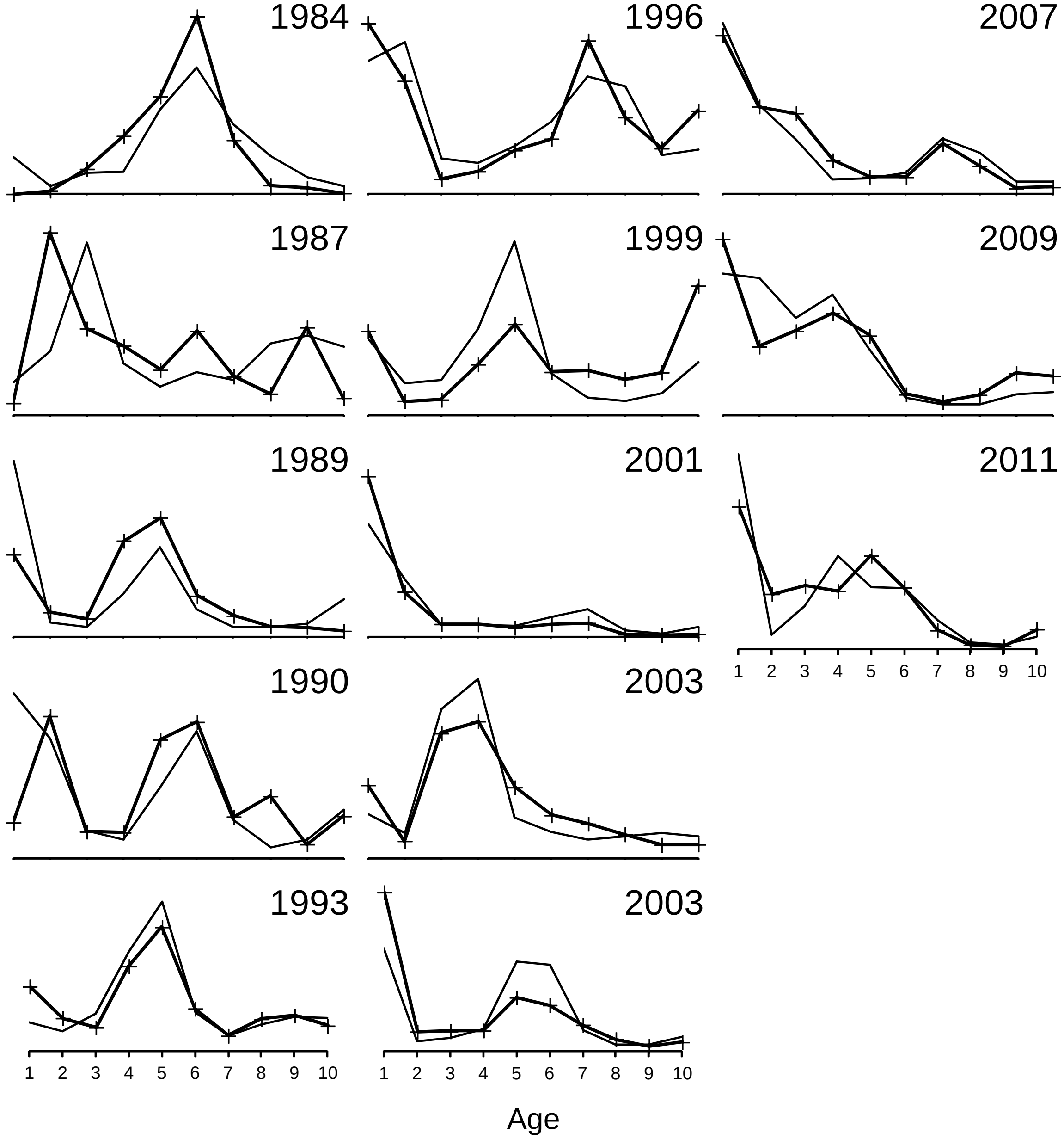


Figure 1.17. Observed and predicted NMFS bottom trawl age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

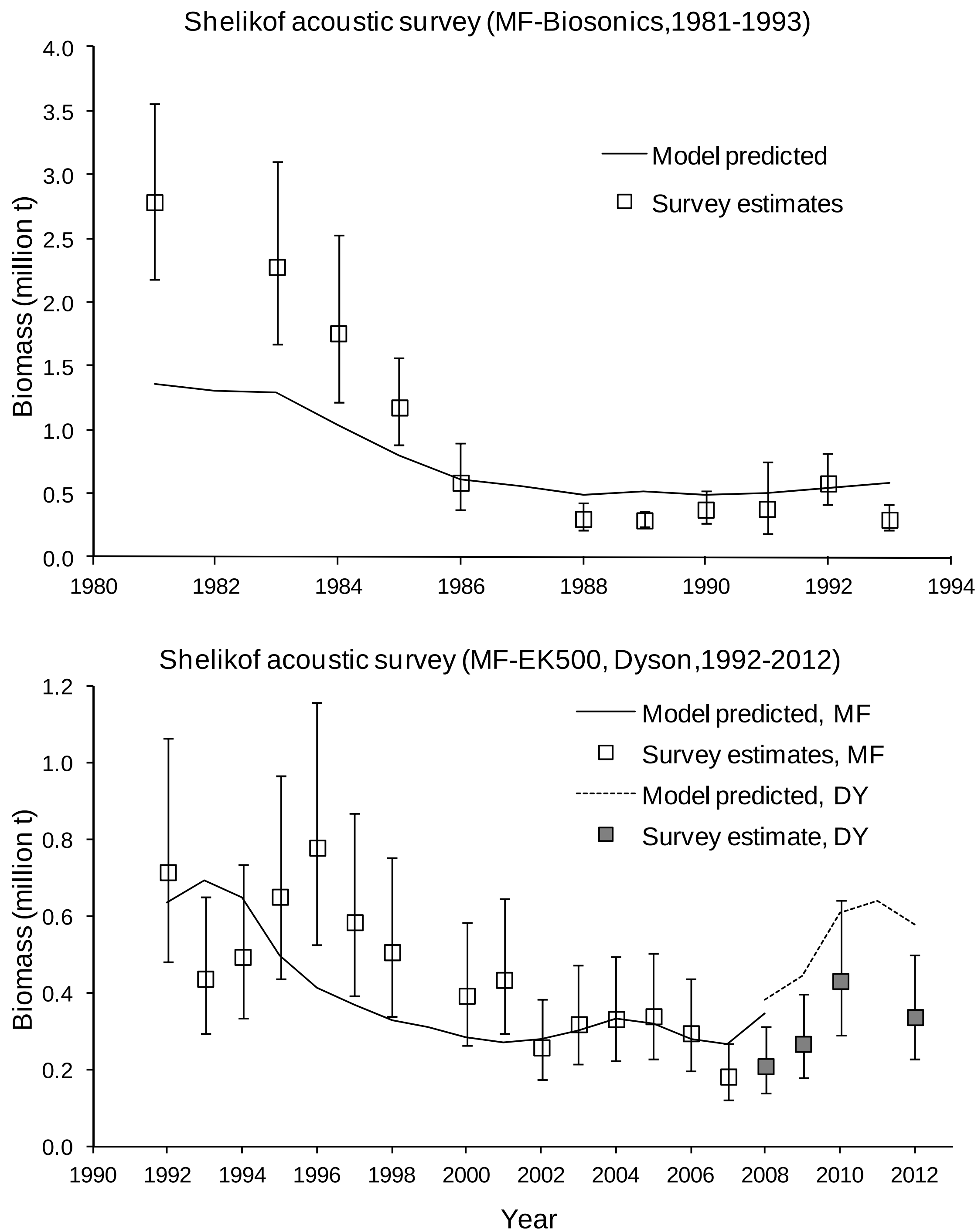


Figure 1.18. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey. The Shelikof acoustic survey is modeled with three catchability periods corresponding to the two acoustic systems used on the *R/V Miller Freeman* (MF), with an additional catchability period for the *R/V Oscar Dyson* (DY) in 2008-2010. Error bars indicate plus and minus two standard deviations.

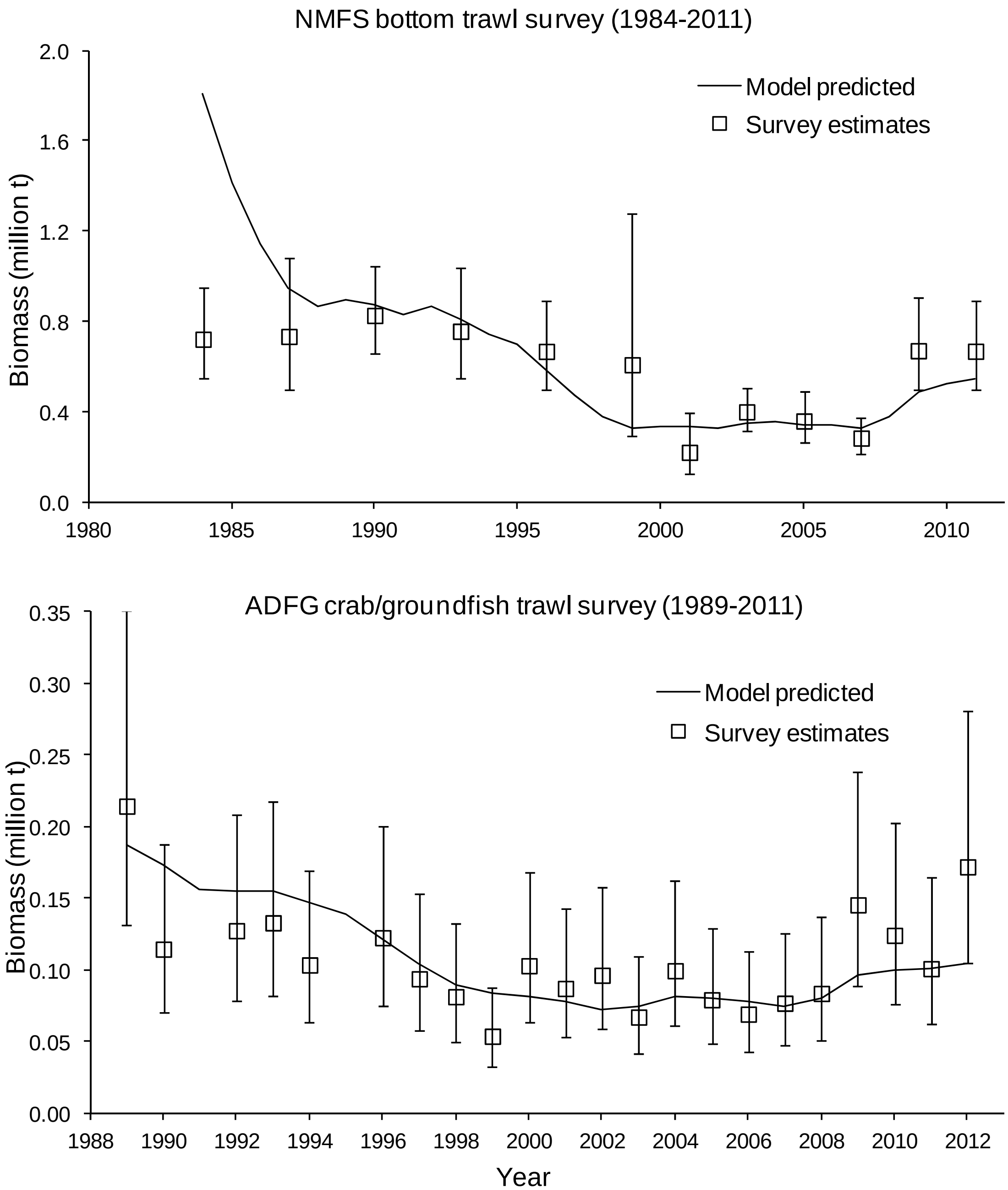


Figure 1.19. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom). Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used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

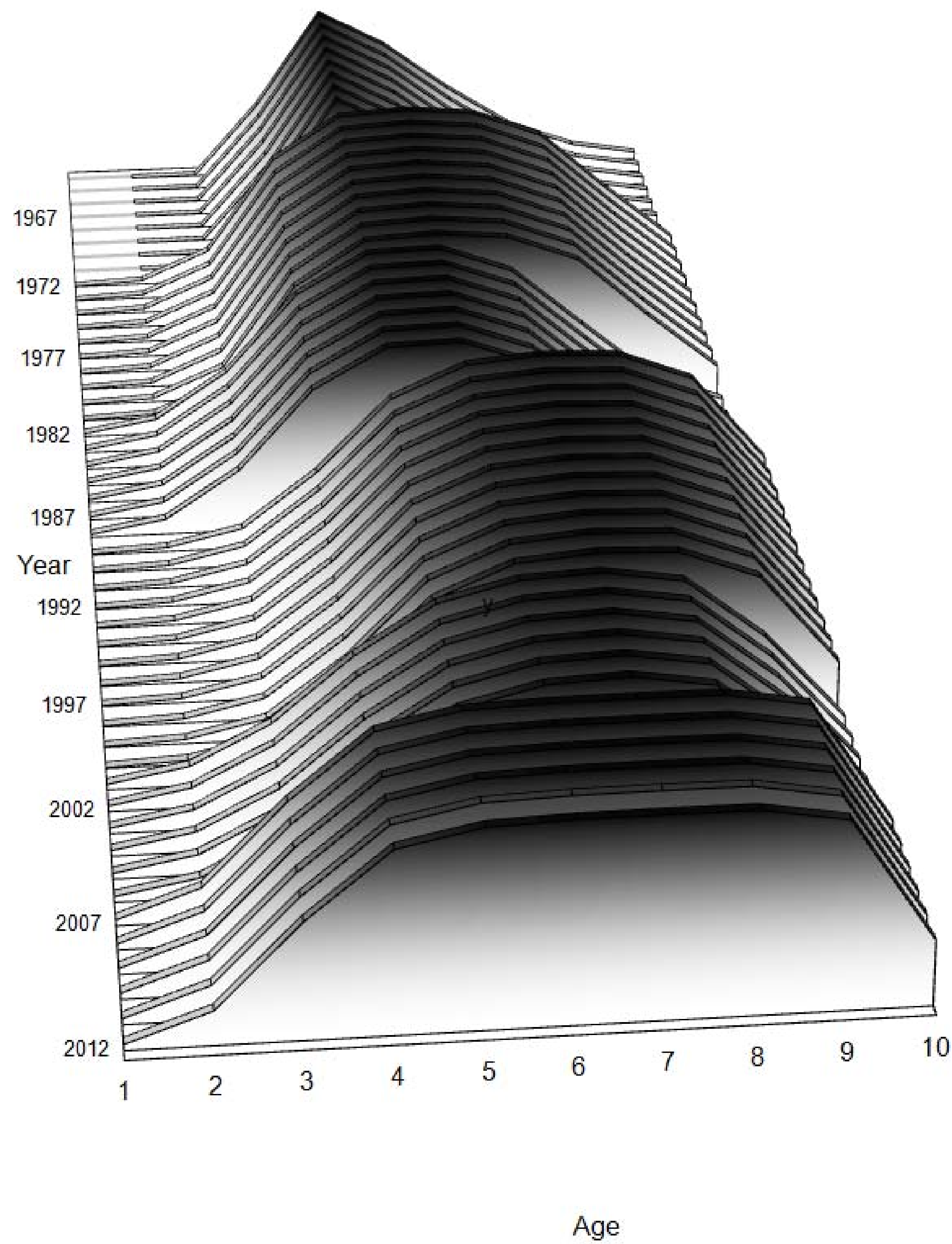
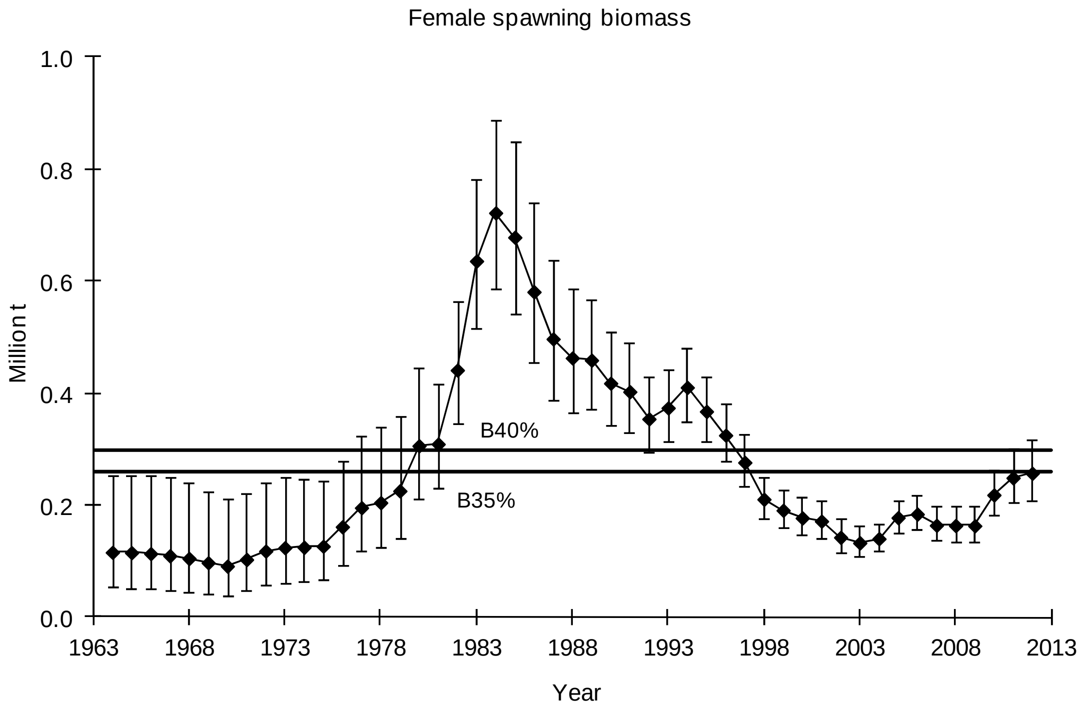


Figure 1.20. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock. The maximum selectivity in each year is 1.0.



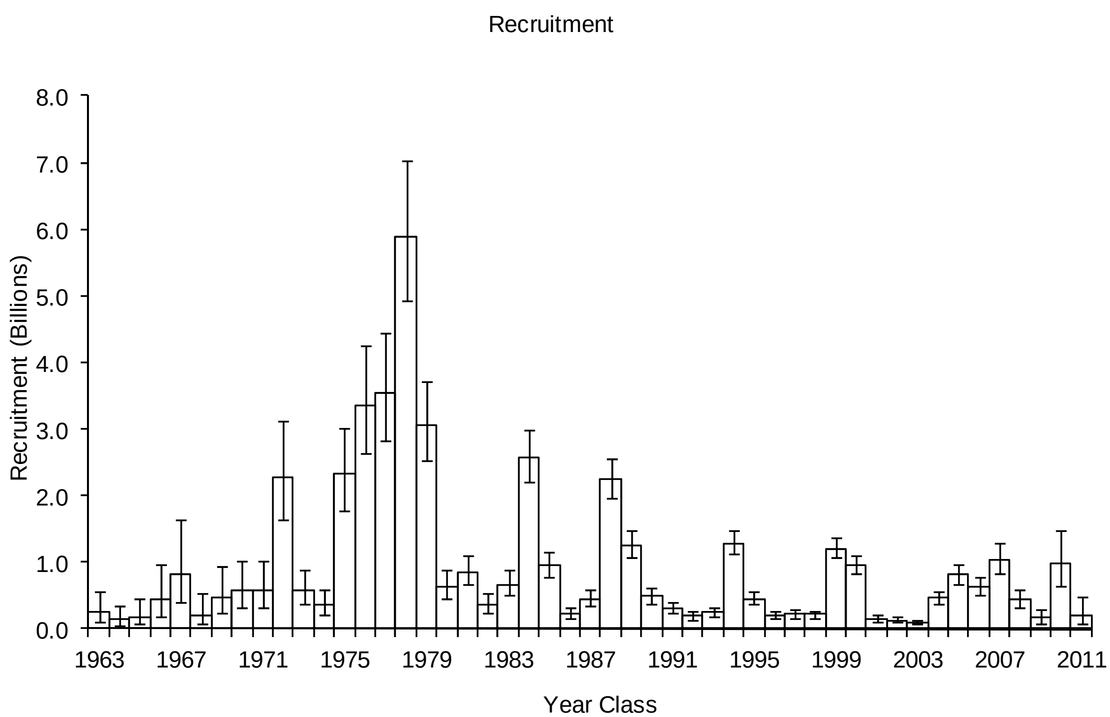
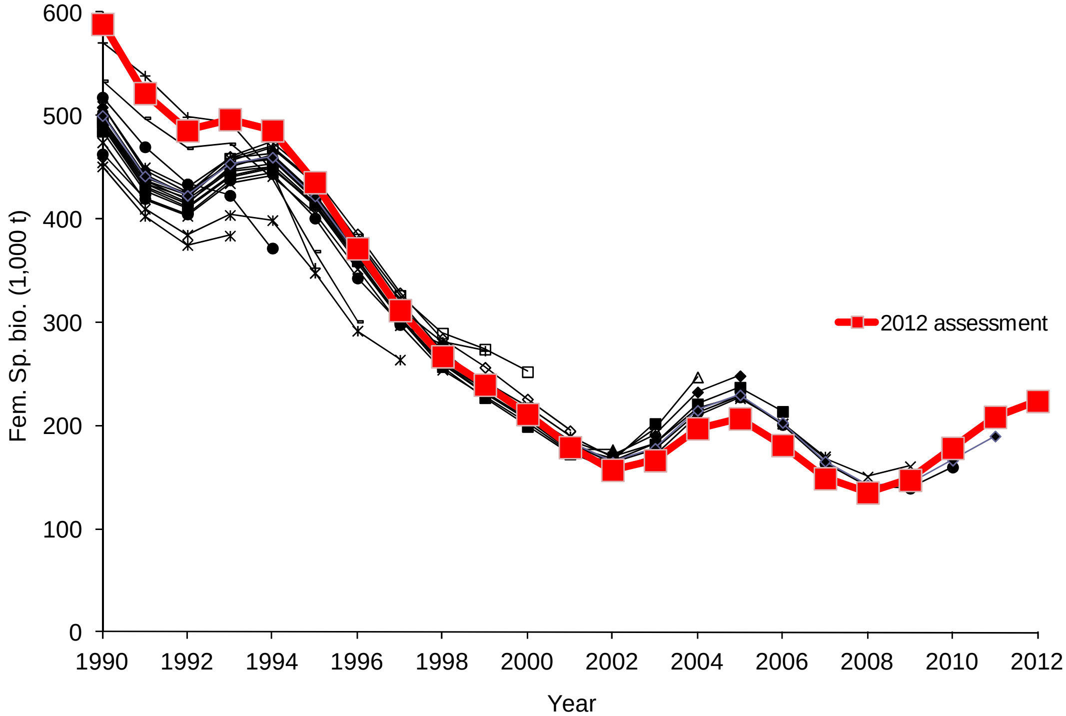


Figure 1.21. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1964 to 2012. Vertical bars represent two standard deviations. The $B_{35\%}$ and $B_{40\%}$ lines represent the current estimate of these benchmarks.



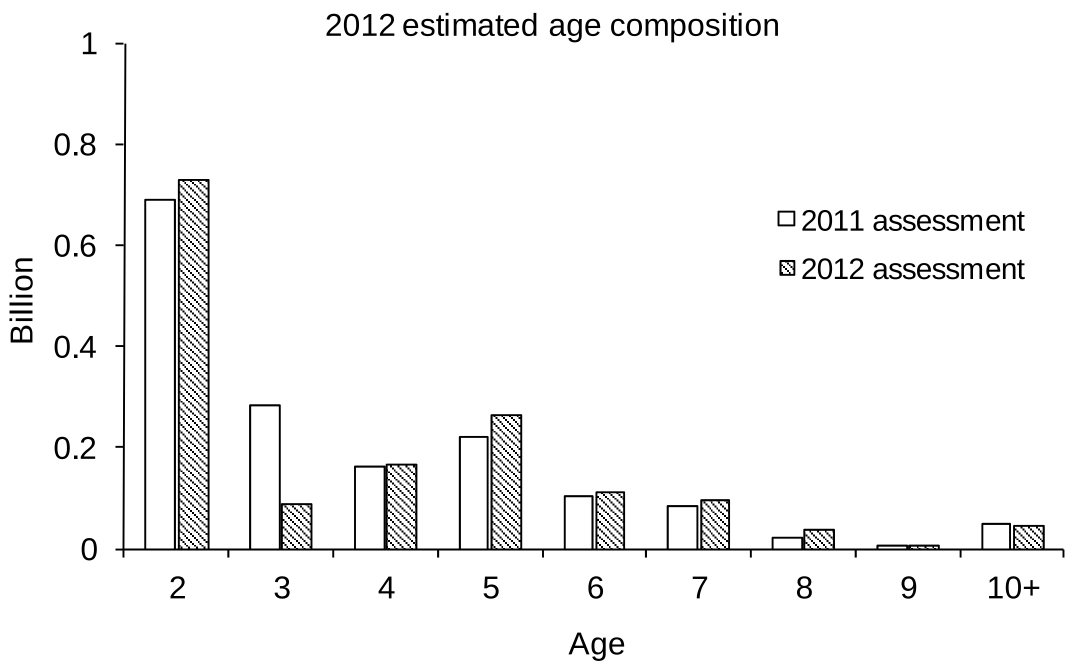


Figure 1.22. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1993-2012 (top). For this figure, the time series of female spawning biomass for the 2011 assessment was calculated using the weight and maturity at age used in pre-1999 assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2012 from the 2011 and 2012 assessments.

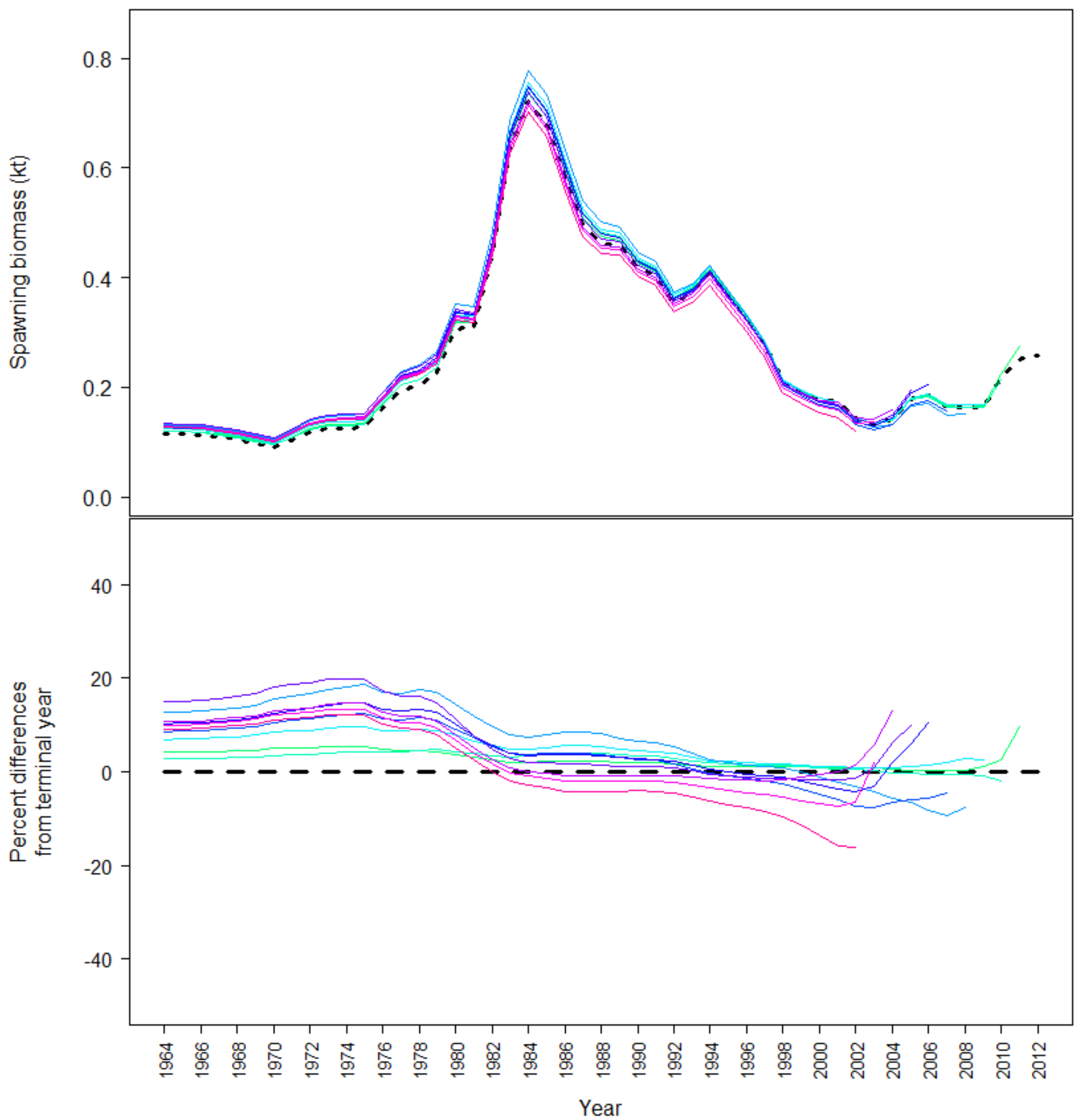


Figure 1.23. Retrospective plot of spawning biomass for the years 2002-2012 for the 2012 assessment model.

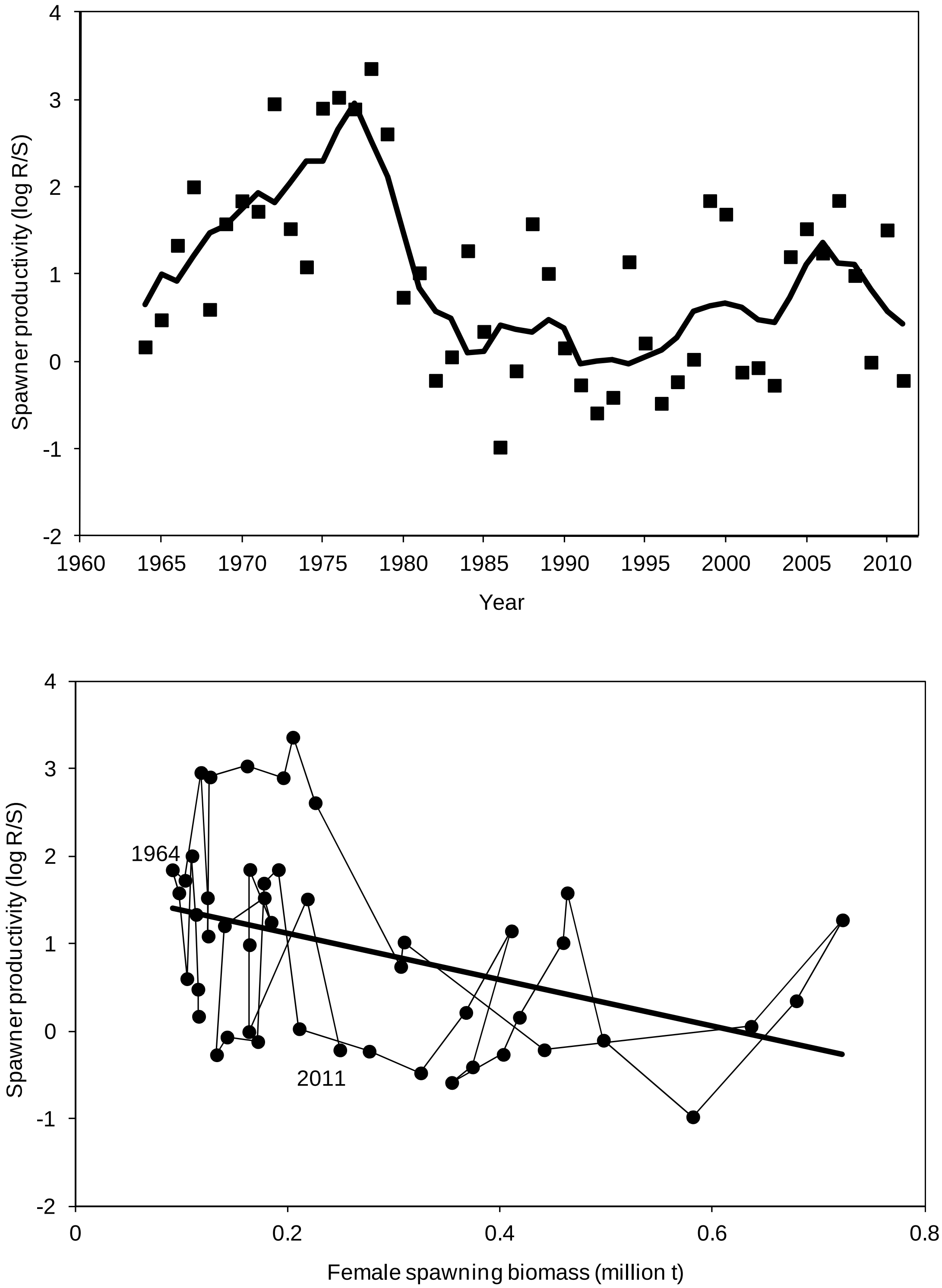
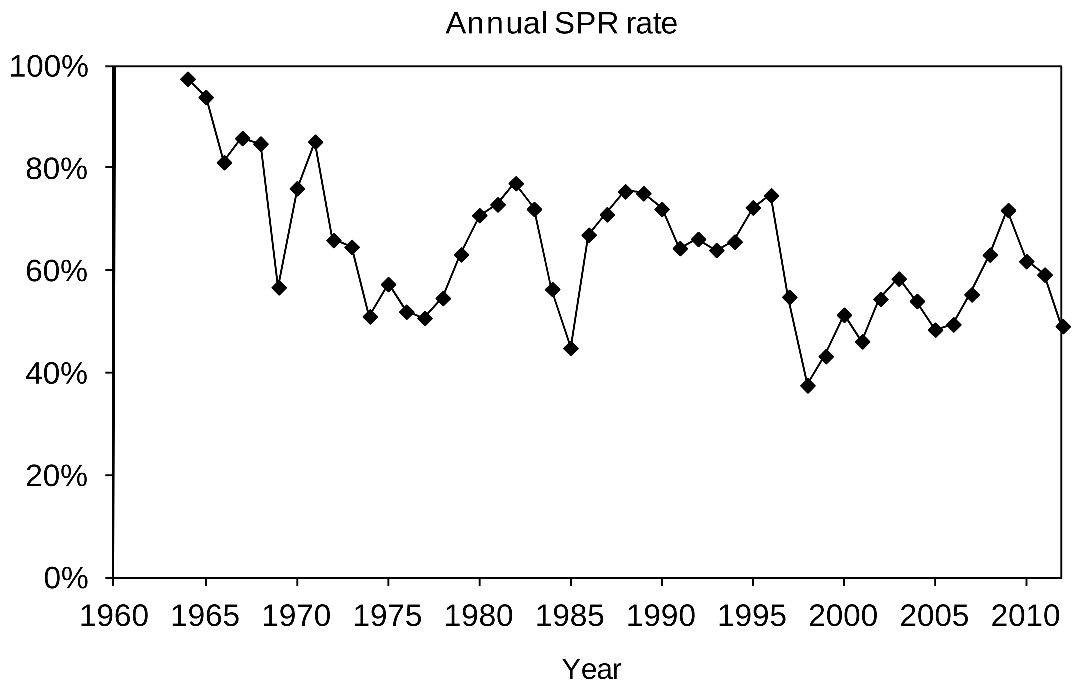


Figure 1.24. Gulf of Alaska pollock spawner productivity, *log(R/S)*, in 1961-2009 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.



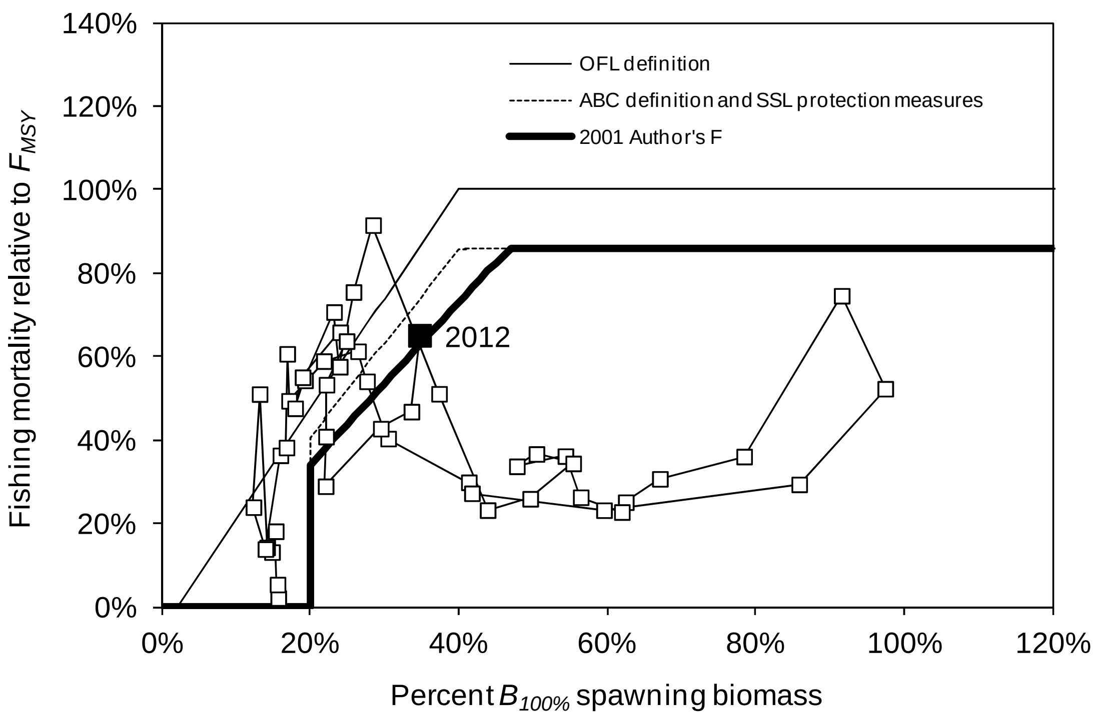


Figure 1.25. Annual fishing mortality as measured in percentage of unfished spawning per recruit (top). Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{MSY} (bottom). The ratio of fishing mortality to F_{MSY} is calculated using the estimated 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.

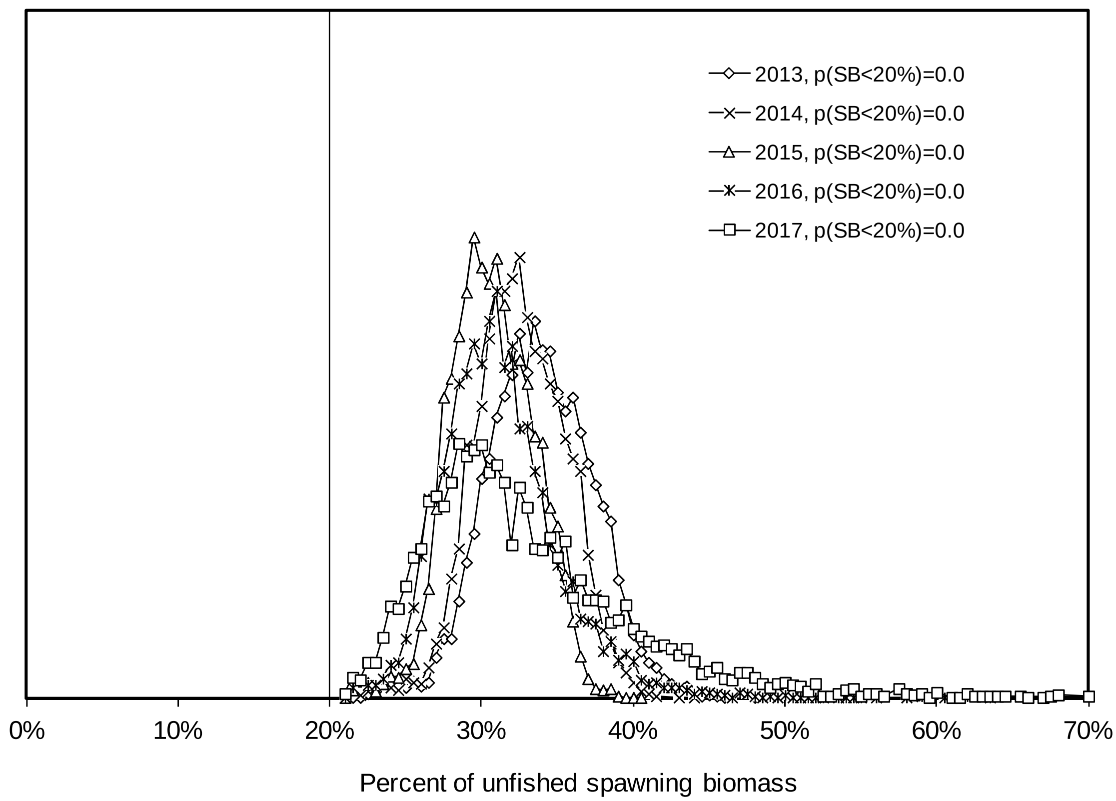
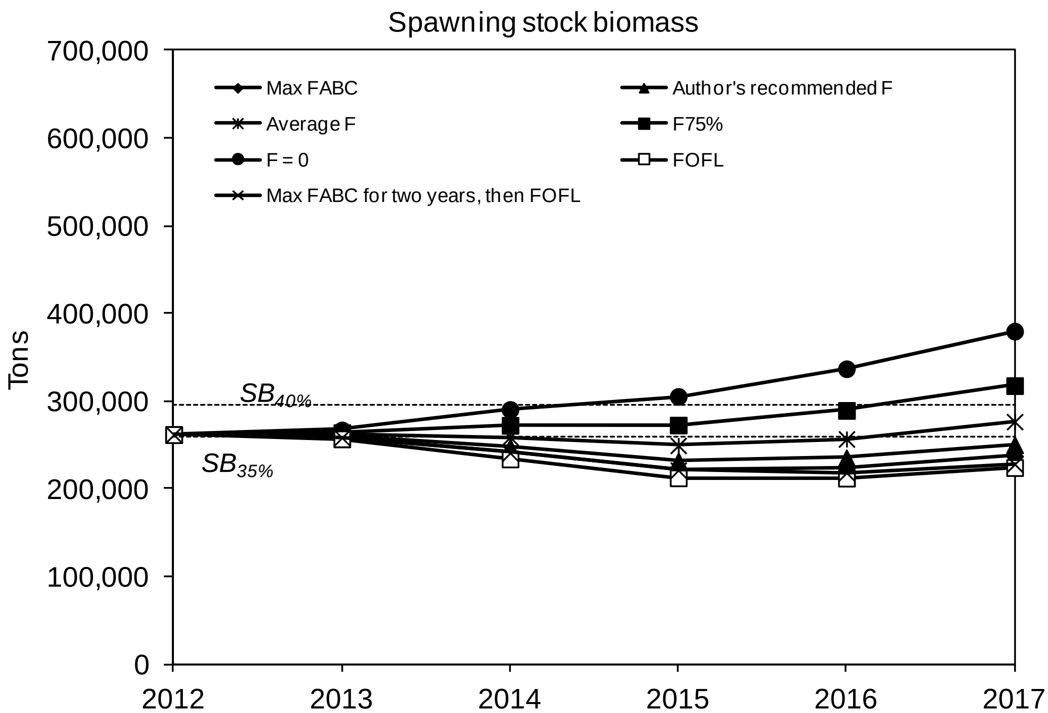


Figure 1.26. Uncertainty in spawning biomass in 2013-2017 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended F_{ABC}.



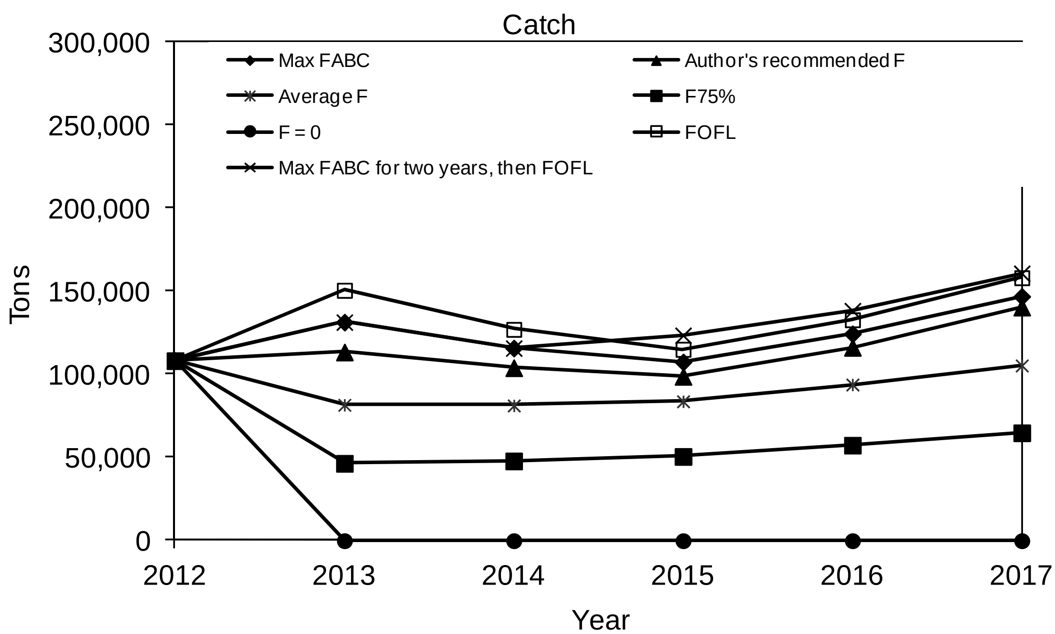
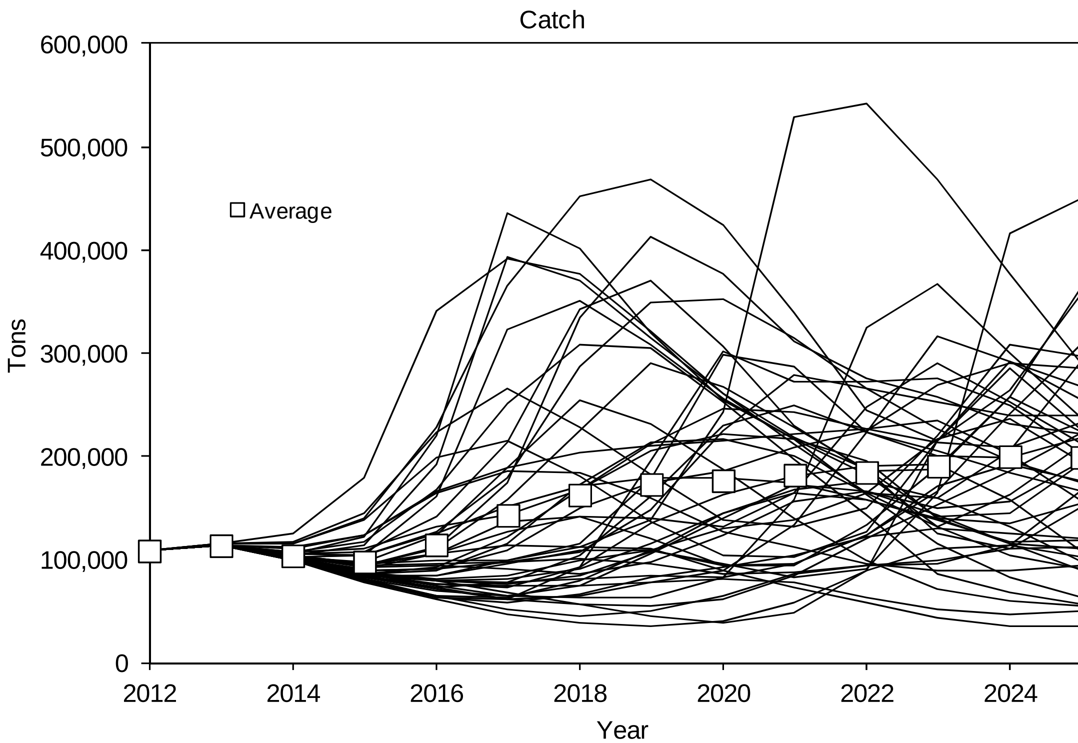


Figure 1.27. Projected spawning biomass and catches in 2013-17 under different harvest rates.



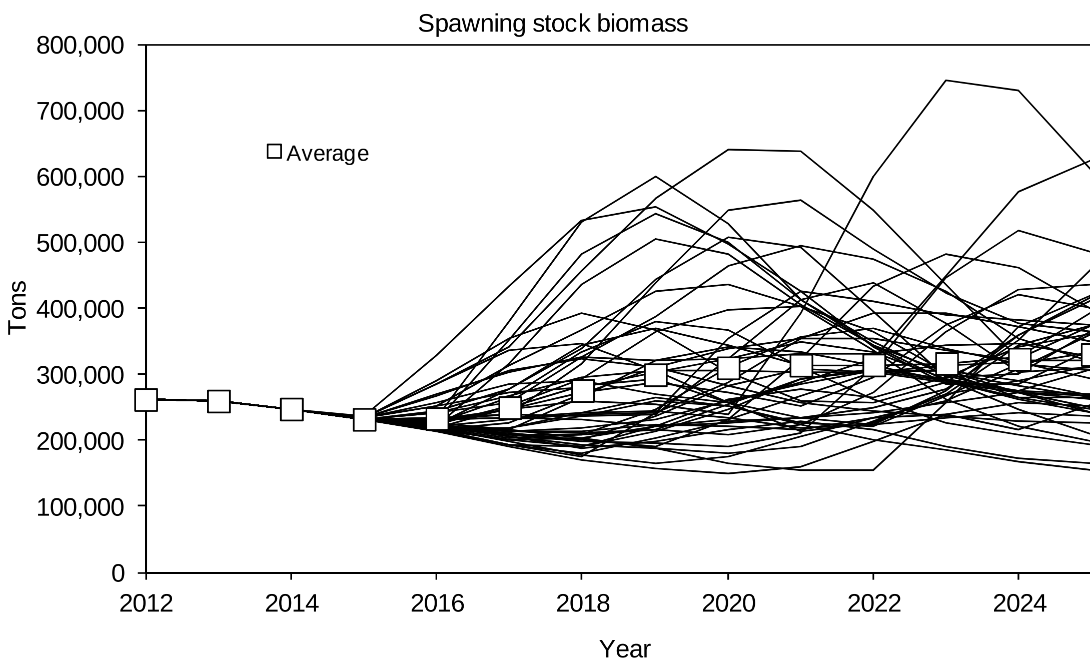


Figure 1.28. Variability in projected catch and spawning biomass in 2013-2025 for the base model under the author's recommended F_{ABC}.

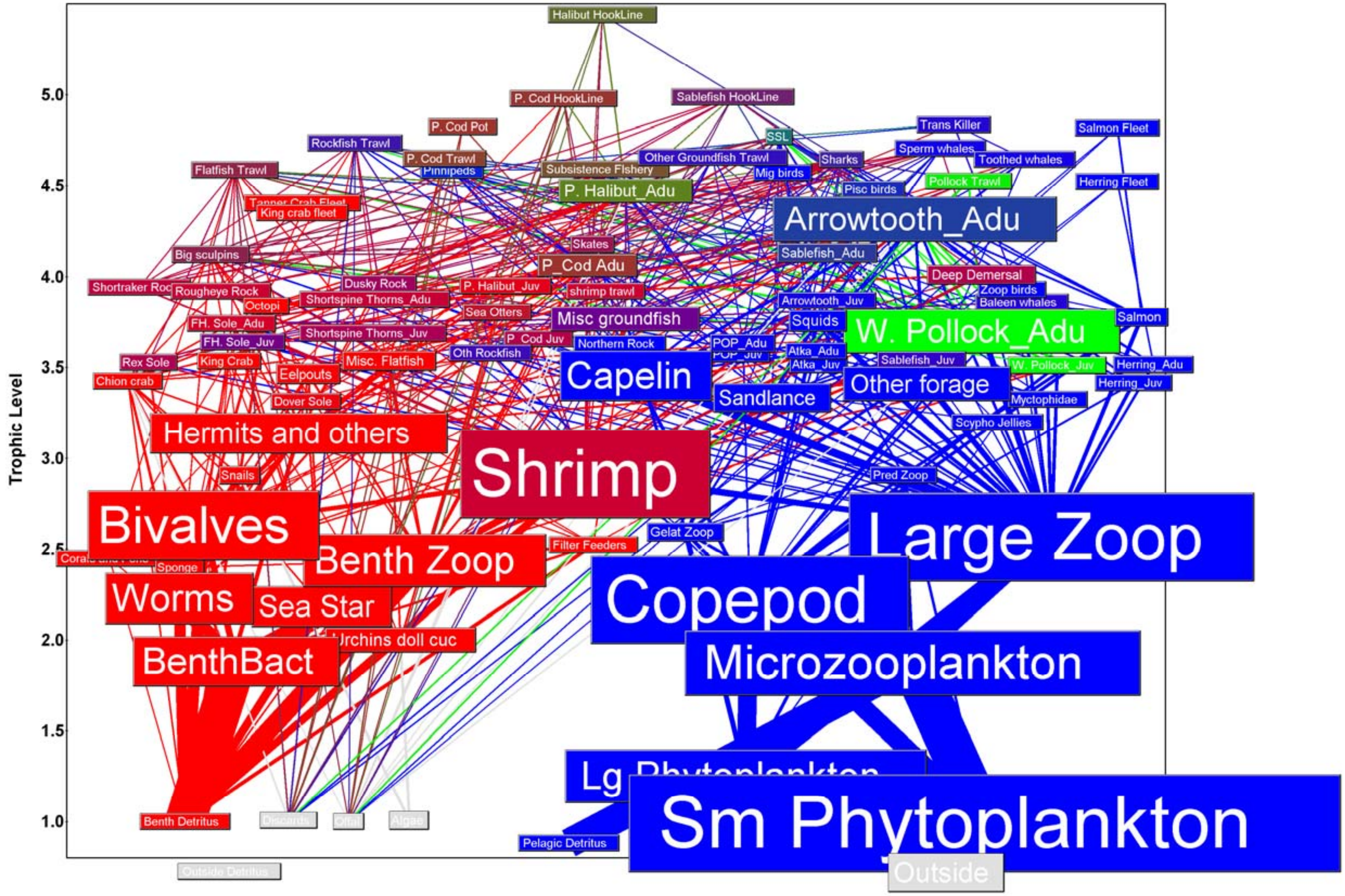
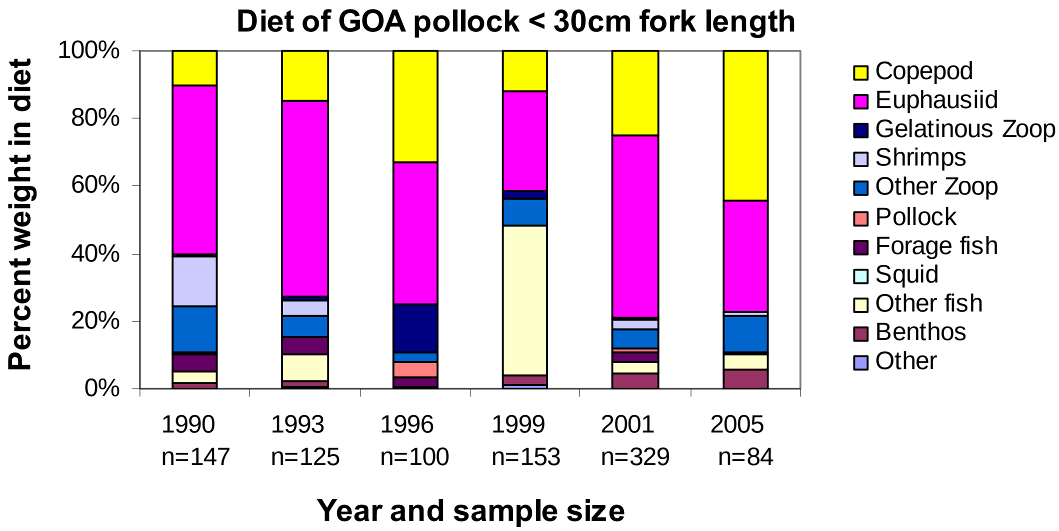


Figure 1.29. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



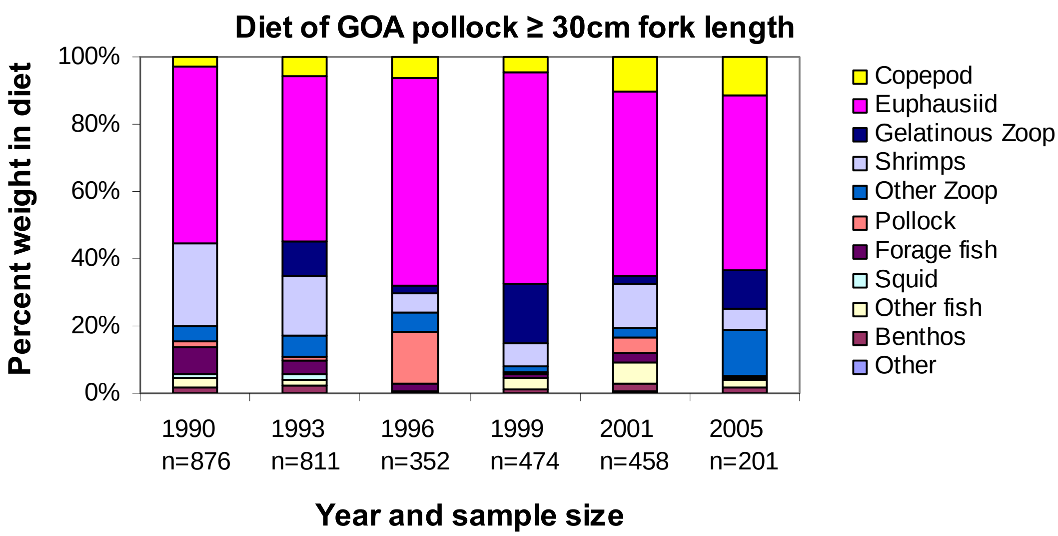
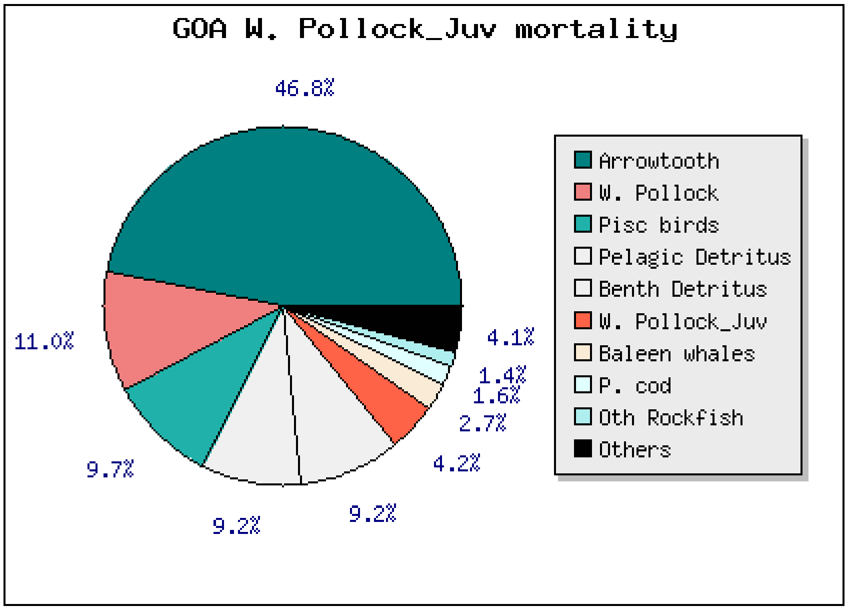


Figure 1.30. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



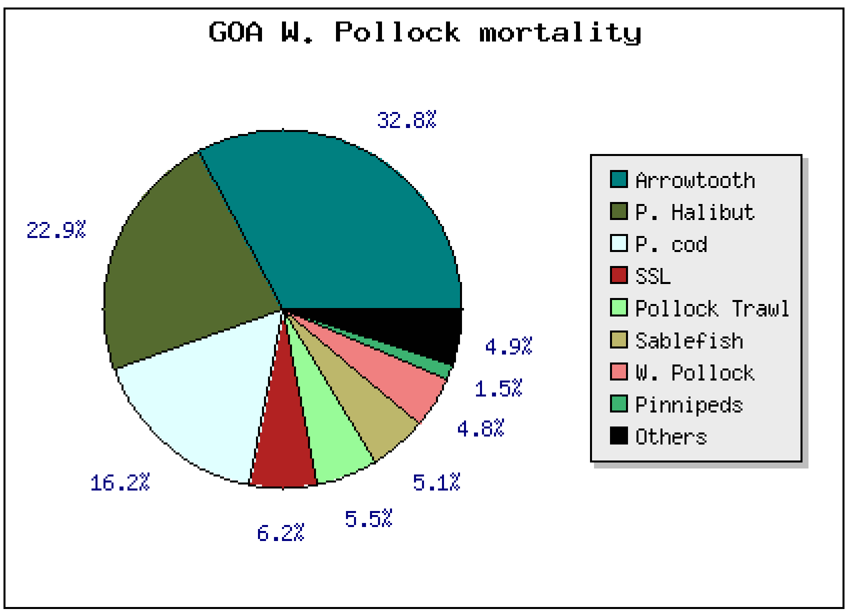


Figure 1.31. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

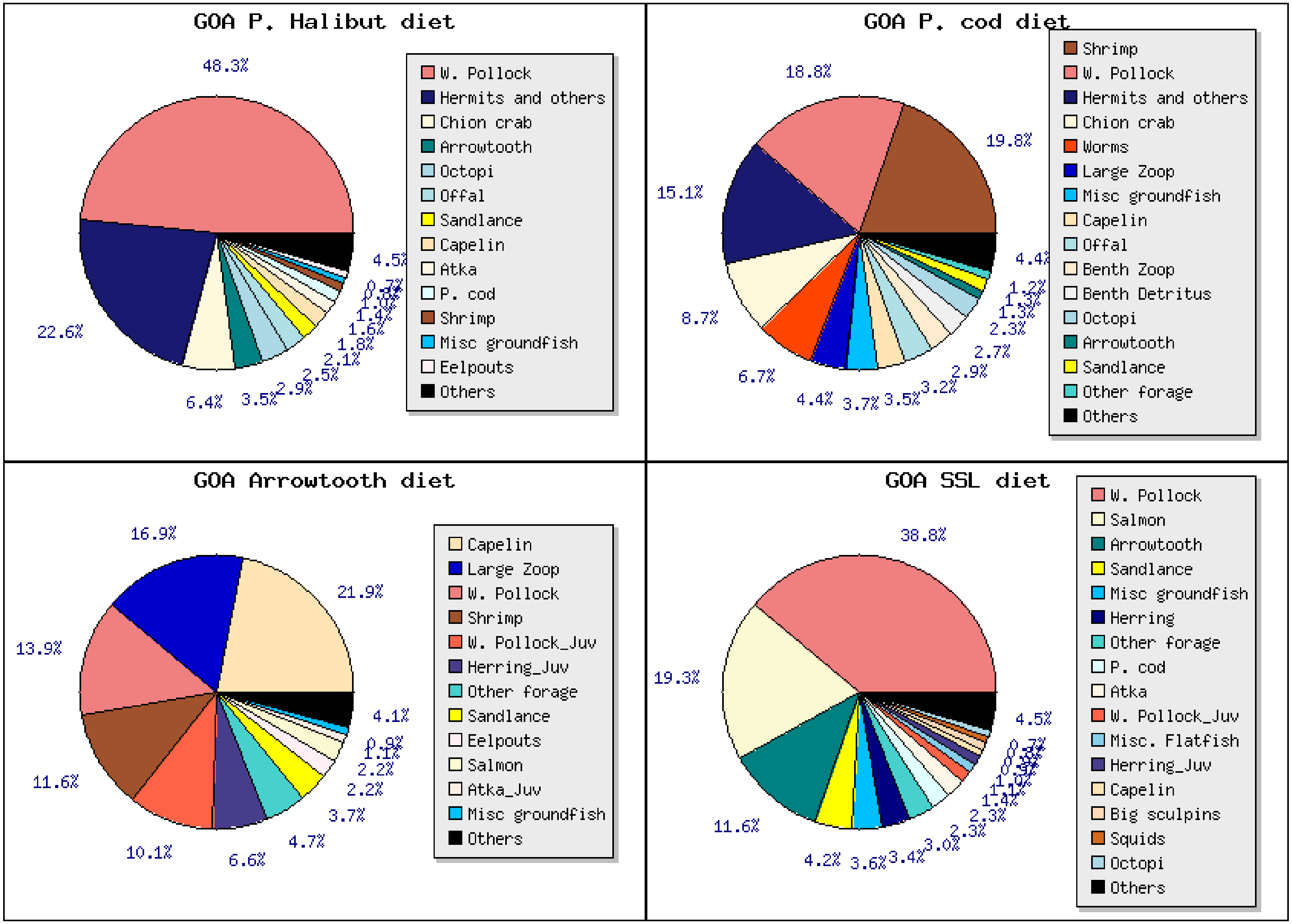


Figure 1.32. Diet diversity of major predators of walleye pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

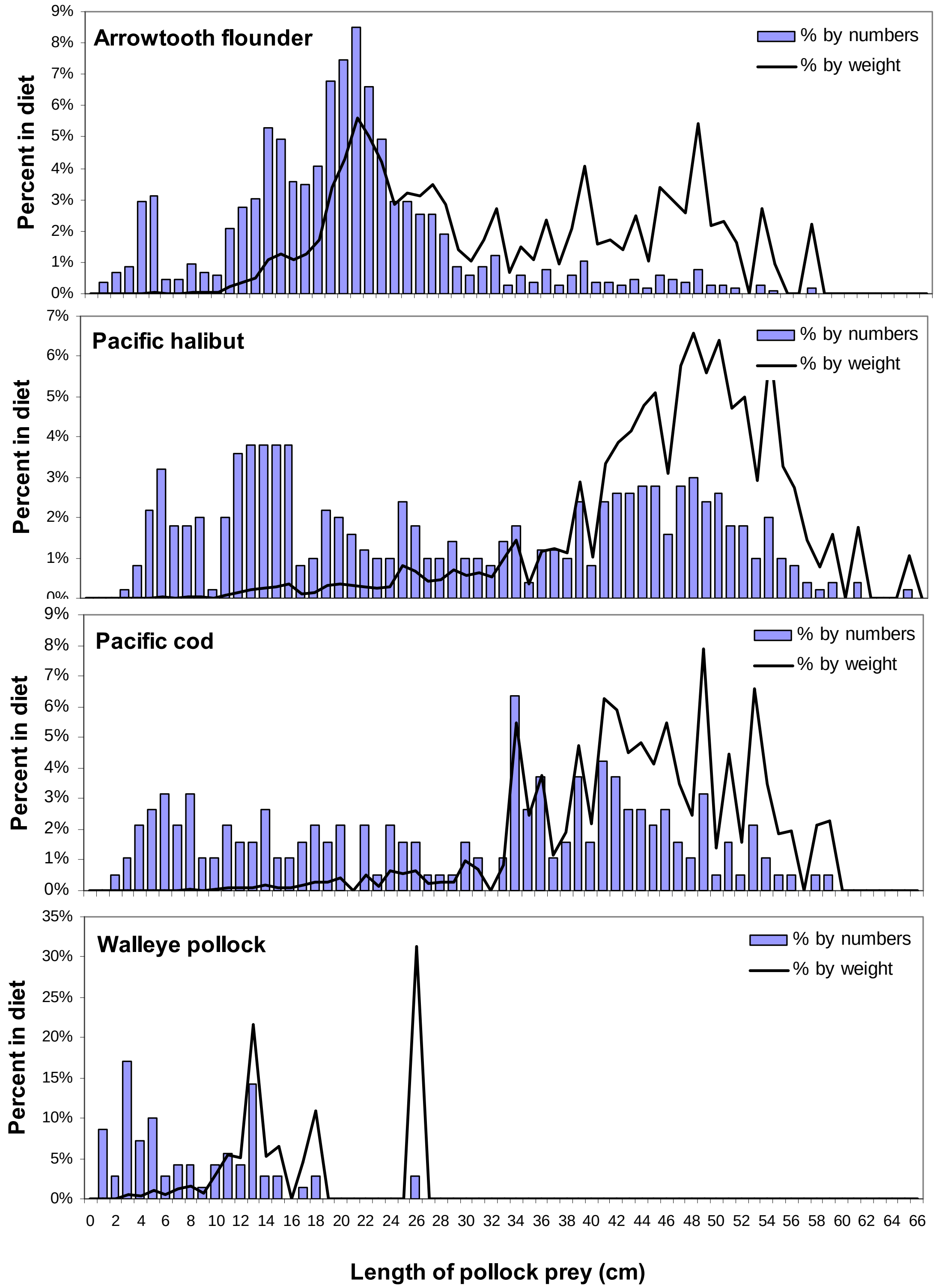
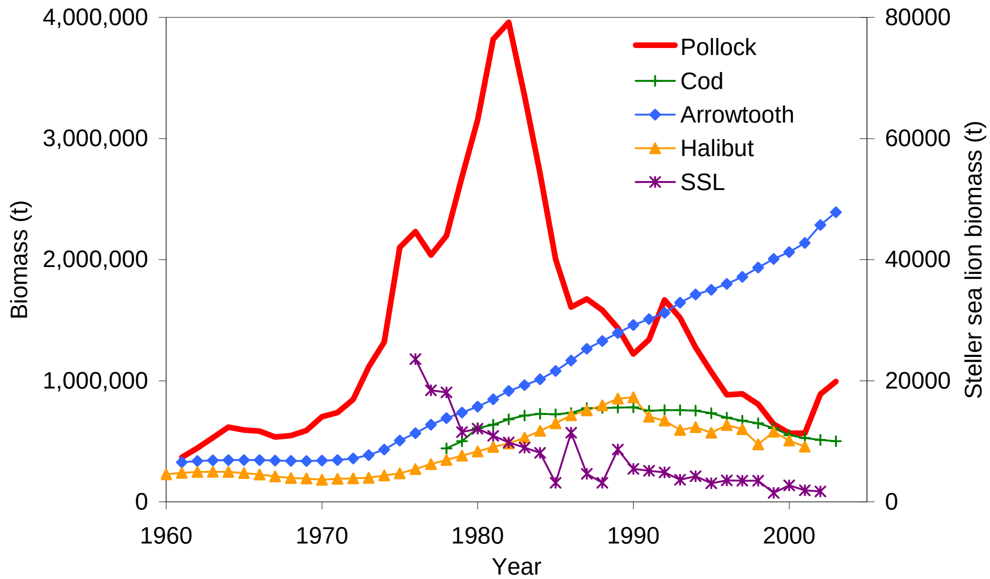


Figure 1.33. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



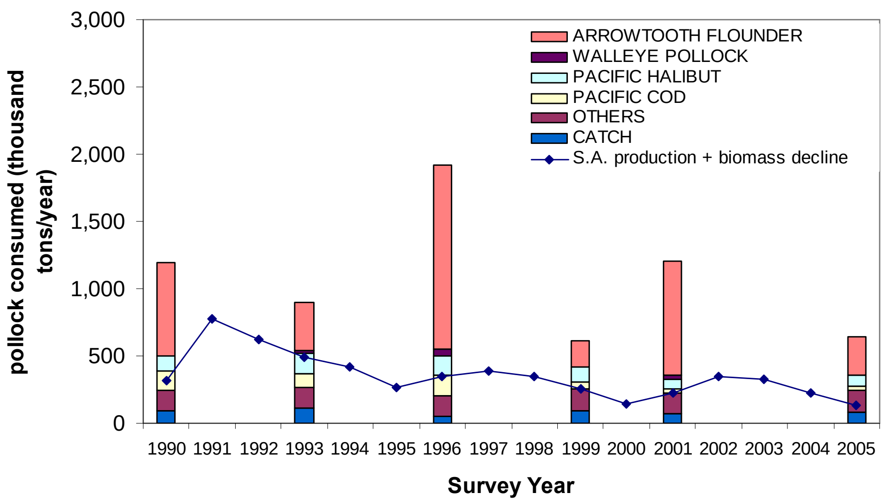
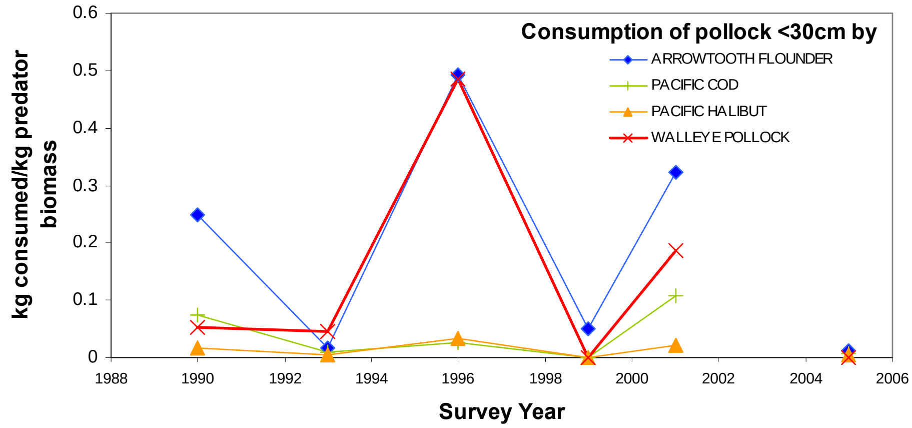
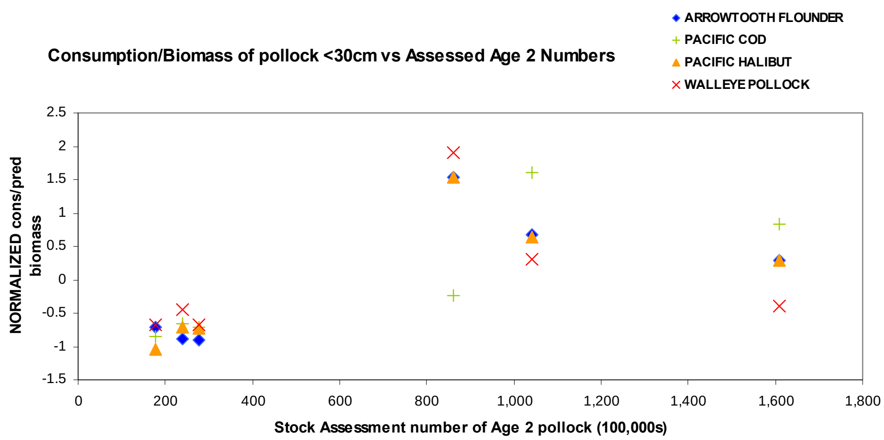


Figure 1.34. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock asessement data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current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





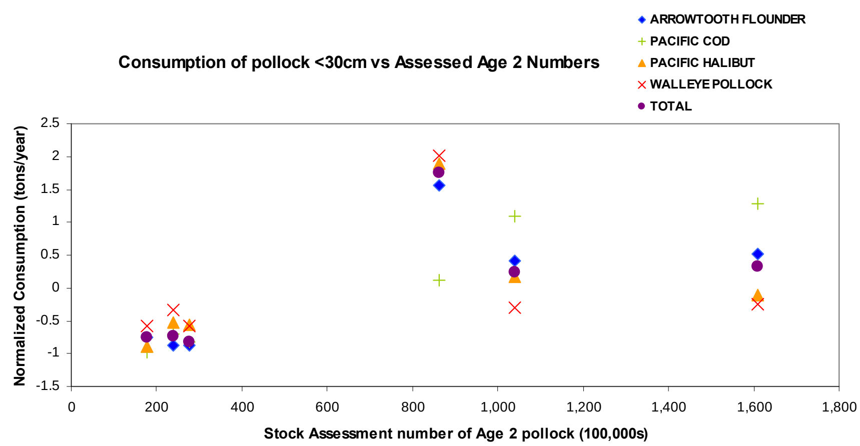


Figure 1.35. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers reported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

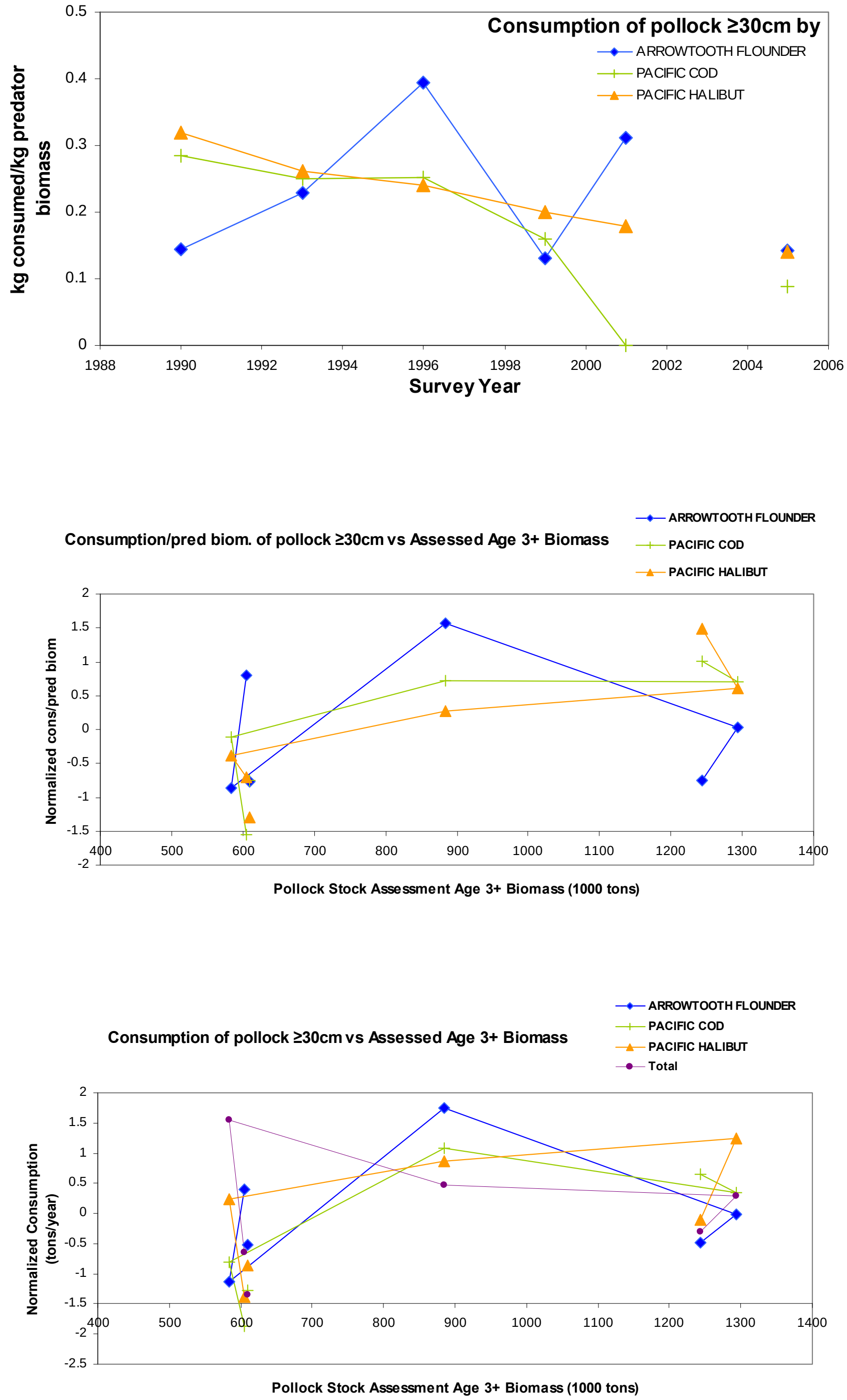


Figure 1.36. (Top) Consumption per unit predator survey biomass of GOA walleye pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass reported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

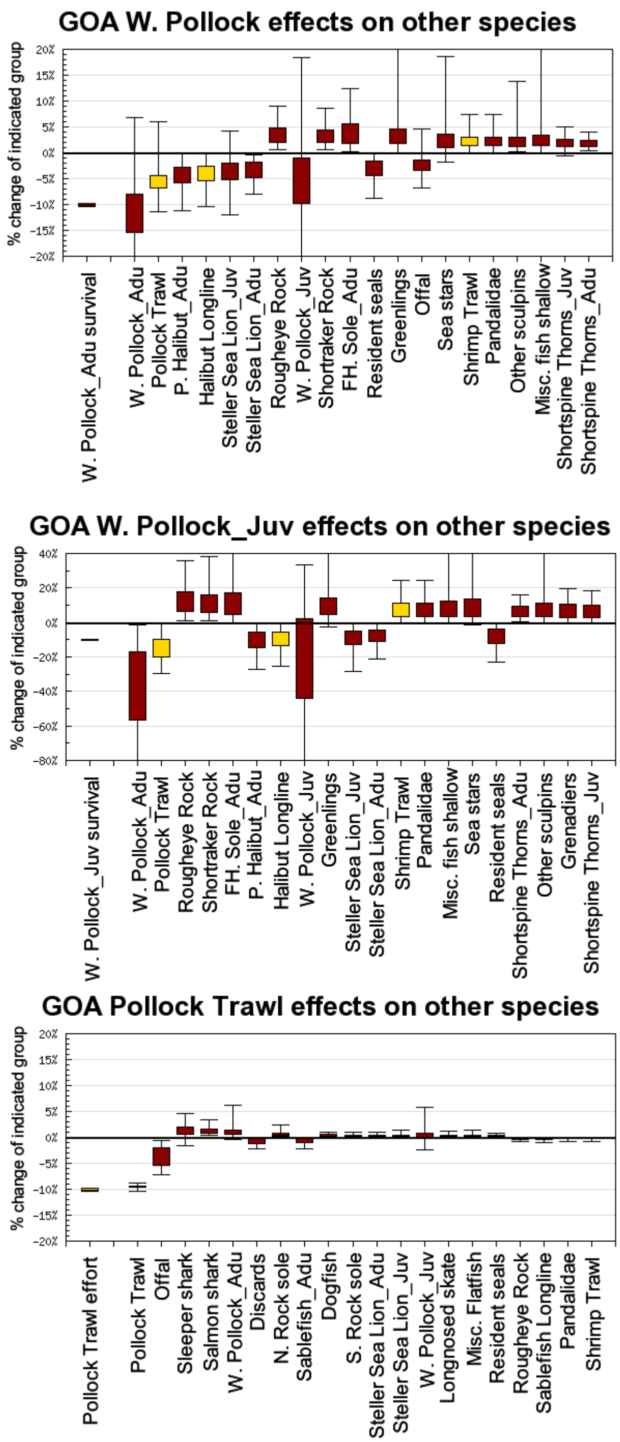
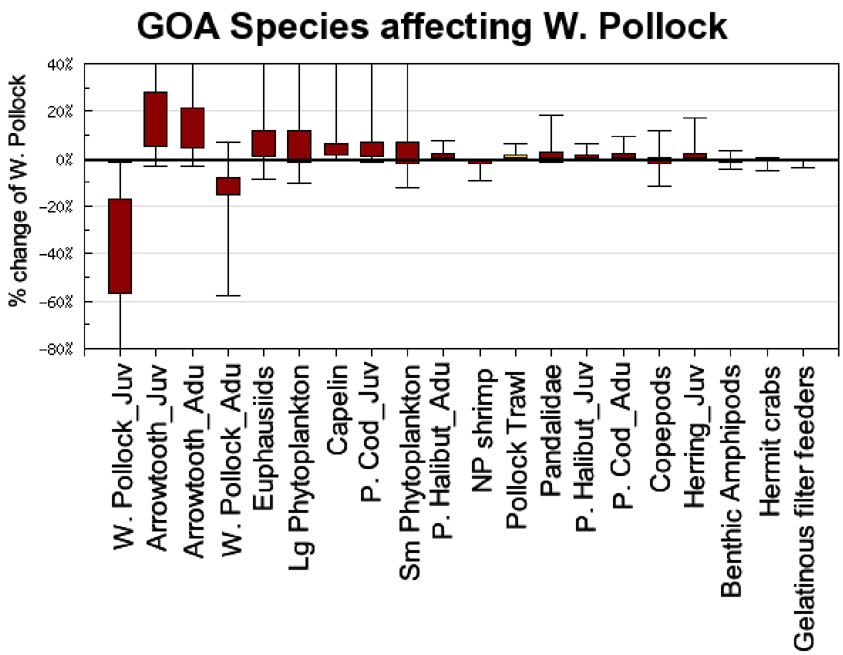


Figure 1.37. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled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



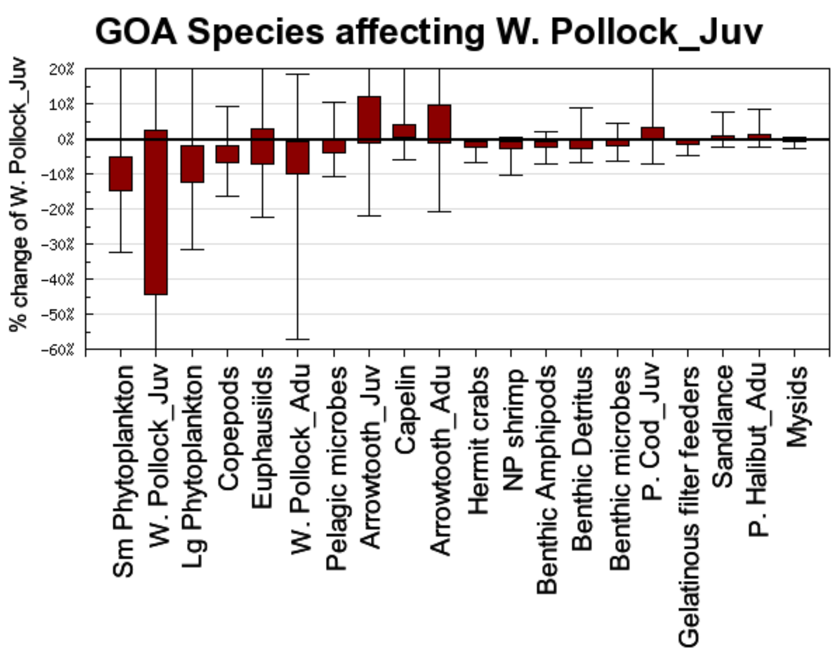


Figure 1.38. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs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

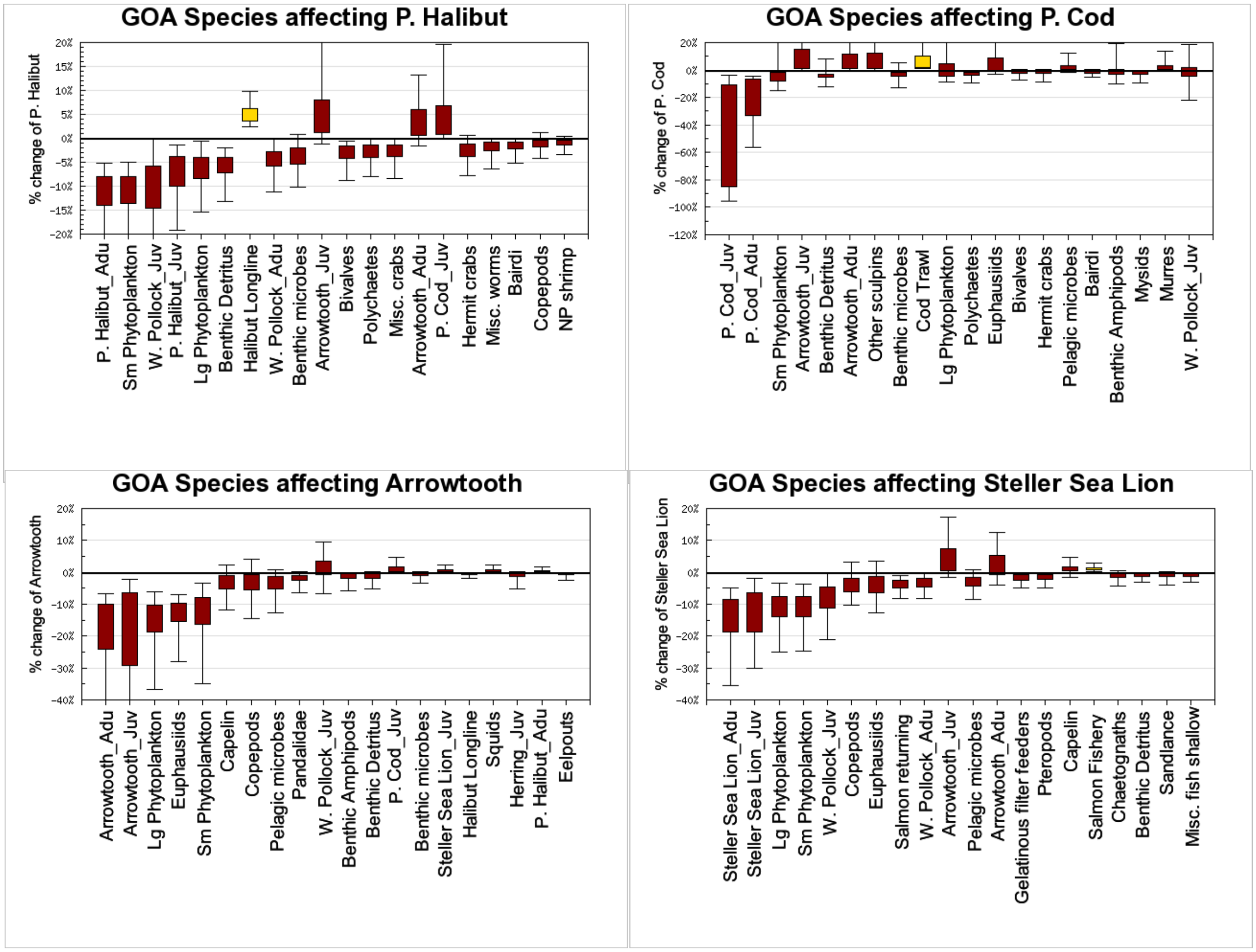


Figure 1.39. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs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

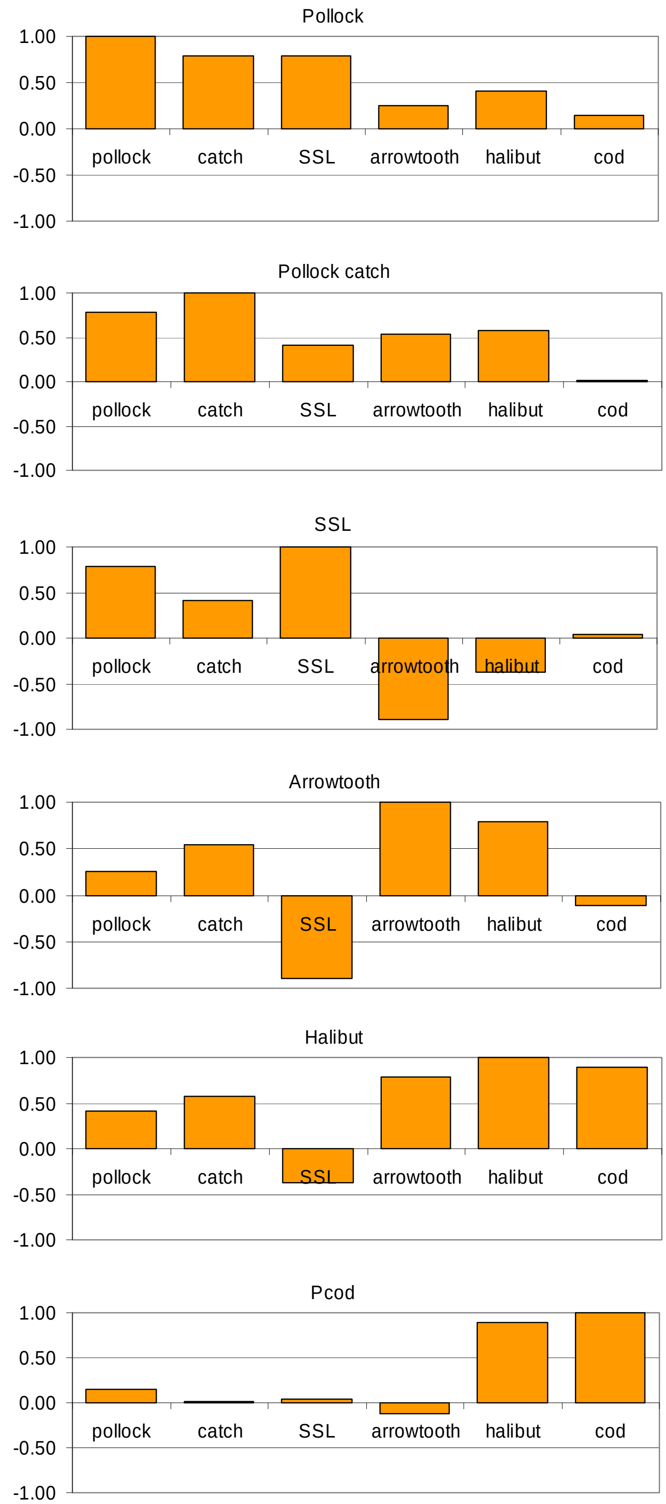


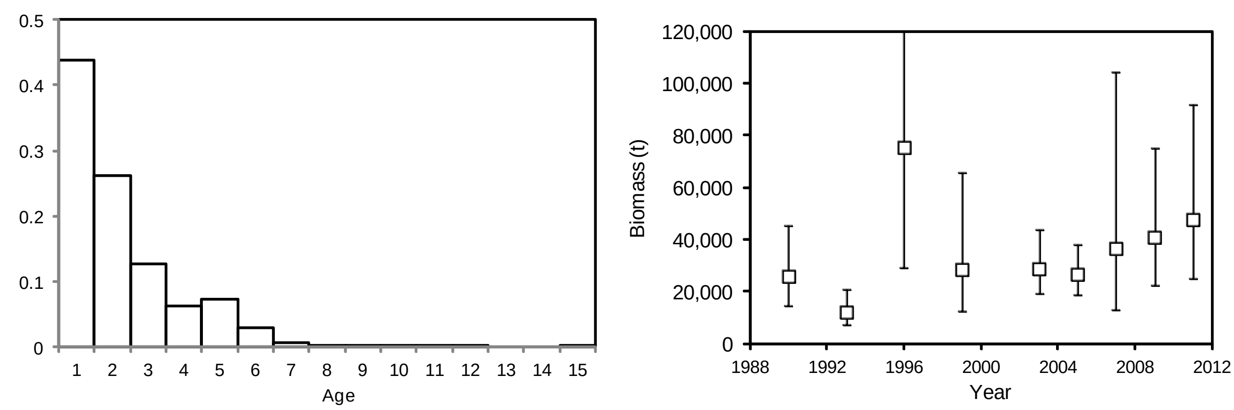
Figure 1.40. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for 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 length composition in the 2011 bottom trawl survey is dominated by age-1 pollock, with progressively decreasing proportions of larger pollock (Appendix Fig. A.1). There are very few larger pollock (> 50 cm). 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 Fig. A.1). There is a gradual increase in biomass since 2005, but confidence intervals are large. 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 2011 survey (47,885 t). **This results in a 2013 ABC of 10,774 t (47,885 t * 0.75 M), and a 2013 OFL of 14,366 t (47,885 t * M).**



Appendix Figure A.1. Pollock age composition in 2011 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2011 (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 2011 (51 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

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

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.

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

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

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

Winter apportionment

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 no winter surveys were conducted in 2011, estimates of the percentage by area could not be updated with recent survey information.

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. 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 C.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 56.48%, 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 16.06%, 74.14%, 9.80% in areas 610, 620, and 630 (Appendix Table C.1). In comparison to last year, the percentages in area 610 is 6.6 percentage points lower, and is 6.9 percentage points higher in area 620, and is nearly unchanged in area 630.

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 Gulf of Alaska 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, 16.06%; 620, 61.50%; 630, 22.45%.

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 an unweighted average of four most recent NMFS summer surveys. The four-survey average was updated with 2011 survey results in an average biomass distribution of 35.35%, 27.57%, 34.02%, and 3.07% in areas 610, 620, 630, and 640 (Appendix Fig. C.1). Including the 2011 survey and deleting the 2003 survey lowered the percentage in area 610 by 5 percentage points and raised the percentage in areas 620 and 630 by 2 and 3 percentage points respectively.

Apportionment for area 640

The apportionment for area 640, which is not managed by season, is based on the summer distribution of the biomass in the NMFS bottom trawl survey. The percentage (3.07%) of the TAC in area 640 is subtracted from the TAC before allocating the remaining TAC by season and region.

Example calculation of 2013 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 0.0307 x Total TAC = 3,069 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 – 3,069) = 24,333 t
B season 0.25 x (Total TAC – 3,069) = 24,333 t
C season 0.25 x (Total TAC – 3,069) = 24,333 t
D season 0.25 x (Total TAC – 3,069) = 24,333 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 0.1606 x 24,333 t = 3,891 t
620 0.6150 x 24,333 t = 14,902 t
630 0.2245 x 24,333 t = 5,440 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 0.1606 x 24,333 t = 3,891 t
620 0.7414 x 24,333 t = 17,967 t
630 0.0980 x 24,333 t = 2,375 t

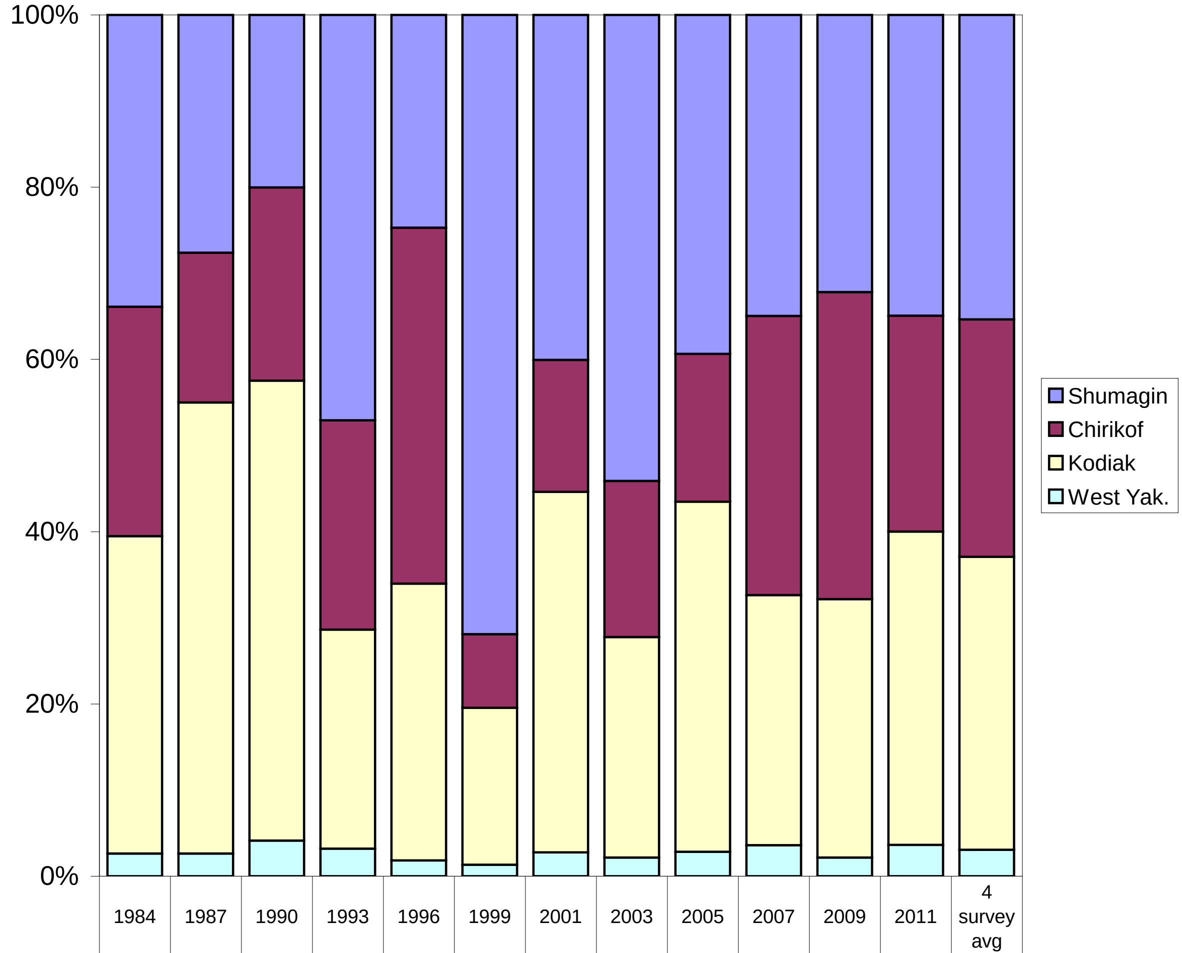
6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the average biomass distribution in areas 610, 620, 630, and 640 in the most recent four NMFS bottom trawl surveys of 35.35%, 27.57%, 34.02%, and 3.07%.

610 0.3535 / (1 – 0.0307) x 24,333 = 8,836 t
620 0.2757 / (1 – 0.0307) x 24,333 = 6,892 t
630 0.3402 / (1 – 0.0307) x 24,333 = 8,504 t

610 0.3535 / (1 – 0.0307) x 24,333 = 8,836 t
620 0.2757 / (1 – 0.0307) x 24,333 = 6,892 t
630 0.3402 / (1 – 0.0307) x 24,333 = 8,504 t

Appendix Table C.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 2008 and 2009 (9,339 t and 17,407 t respectively).

						Percent by management area		
Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*	*Multiplier from vessel comparison (OD/MF)*	*Percent*	*Area 610*	*Area 620*	*Area 630*
Shelikof	2008	555,680	188,942	1.00	34.0%	0.0%	93.4%	6.6%
Shelikof	2009	617,638	265,971	1.00	43.1%	0.0%	95.6%	4.4%
Shelikof	2010	811,571	429,730	1.00	53.0%	0.0%	93.7%	6.3%
Shelikof	2012	797,285	335,836	1.00	42.1%	0.0%	96.0%	4.0%
Shelikof	Average				43.0%	0.0%	94.7%	5.3%
	Percent of total 2+ biomass					0.0%	40.8%	2.3%
Chirikof	2008	555,680	22,055	1.00	4.0%	0.0%	50.2%	49.8%
Chirikof	2009	617,638	396	1.00	0.1%	0.0%	0.0%	100.0%
Chirikof	2010	811,571	9,544	1.00	1.2%	0.0%	0.0%	100.0%
Chirikof	2012	797,285	21,181	1.00	2.7%	0.0%	13.0%	87.0%
Chirikof	Average				2.0%	0.0%	15.8%	84.2%
	Percent of total 2+ biomass					0.0%	0.3%	1.7%
Marmot	2007	456,575	3,157	1.31	0.9%	0.0%	0.0%	100.0%
Marmot	2009	617,638	19,759	1.00	3.2%	0.0%	0.0%	100.0%
Marmot	2010	811,571	5,585	1.00	0.7%	0.0%	0.0%	100.0%
Marmot	Average				1.6%	0.0%	0.0%	100.0%
	Percent of total 2+ biomass					0.0%	0.0%	1.6%
Shumagin	2008	555,680	21,244	1.31	5.0%	77.2%	22.8%	0.0%
Shumagin	2009	617,638	45,357	1.00	7.3%	61.4%	38.6%	0.0%
Shumagin	2010	811,571	18,295	1.00	2.3%	94.9%	5.1%	0.0%
Shumagin	2012	797,285	15,501	1.00	1.9%	88.0%	12.0%	0.0%
Shumagin	Average				4.1%	80.4%	19.6%	0.0%
	Percent of total 2+ biomass					3.3%	0.8%	0.0%
Sanak	2008	555,680	19,750	1.31	4.7%	100.0%	0.0%	0.0%
Sanak	2009	617,638	31,435	1.00	5.1%	100.0%	0.0%	0.0%
Sanak	2010	811,571	26,678	1.00	3.3%	100.0%	0.0%	0.0%
Sanak	2012	797,285	24,252	1.00	3.0%	100.0%	0.0%	0.0%
Sanak	Average				4.3%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					4.3%	0.0%	0.0%
Mozhovoi	2006	469,216	11,679	1.31	3.3%	100.0%	0.0%	0.0%
Mozhovoi	2007	456,575	2,540	1.31	0.7%	100.0%	0.0%	0.0%
Mozhovoi	2010	811,571	1,650	1.00	0.2%	100.0%	0.0%	0.0%
Mozhovoi	Average				1.4%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					1.4%	0.0%	0.0%
Total					56.48%	9.07%	41.87%	5.54%
Rescaled total					100.00%	16.06%	74.14%	9.80%



	1984	1987	1990	1993	1996	1999	2001	2003	2005	2007	2009	2011	4 survey avg
Shumagin	33.88%	27.60%	20.03%	47.08%	24.69%	71.90%	40.06%	54.09%	39.35%	34.94%	32.16%	34.93%	35.35%
Chirikof	26.64%	17.38%	22.41%	24.27%	41.32%	8.55%	15.30%	18.14%	17.16%	32.42%	35.66%	25.04%	27.57%
Kodiak	36.87%	52.40%	53.42%	25.44%	32.16%	18.23%	41.88%	25.62%	40.64%	29.06%	29.99%	36.38%	34.02%
West Yak.	2.62%	2.62%	4.13%	3.20%	1.83%	1.32%	2.76%	2.15%	2.85%	3.59%	2.18%	3.65%	3.07%

Appendix Figure C.1. Percent distribution of Gulf of Alaska pollock biomass west of 140° W lon. in NMFS bottom trawl surveys in 1984-2011.

Appendix D: Supplemental catch data

To comply with the Annual Catch Limit (ACL) requirements, estimates have been developed for non-commercial catches and removals from NMFS-managed stocks in Alaska. Research catches have been routinely reported in the pollock assessment, but these catches are only for survey data that have been included in RACEBASE, and are not a comprehensive accounting of all research removals (Appendix Table D.1). One new data set is more a comprehensive accounting of research removals than had been available previously. This data set is relatively complete only for 2010 and 2011 (Appendix Table D.2). Comparison of research catches from RACEBASE with the more comprehensive information in 2010 and 2011 suggests that research catches have been substantially underreported. The estimates from RACEBACE ranged between 25% and 30% of the total research catch. Annual large-mesh and small-mesh trawl surveys conducted by ADFG account for most of the missing research catch of pollock. Even if research catches are four times those reported in RACEBACE, they would still amount to less than 1/2 of a percent on average of the ABC during 2002-2011, and would have a negligible effect on the pollock stock or the stock assessment.

An attempt was made using methods described in Tribuzio et. al (2011) to estimate the incidental catch of groundfish in the Pacific halibut fishery. Based on Plan Team recommendations, these estimates will not be continued. Estimates of pollock bycatch in the Pacific halibut fishery during 2001-2010 averaged 12.2 t, with a minimum of 0.9 t and a maximum of 62.4 t, suggesting that the bycatch of pollock (or the estimates thereof) are low and highly variable. Since some halibut fishery incidental catch as enters into the catch accounting system, it is unclear whether these catches have already been taken into account in the reported catch. However this seems unlikely for pollock. It is important to note that there is unreported incidental catch of pollock in other fisheries in Alaska, such as the salmon fishery, which, based on anecdotal reports, may be substantial on occasion.

Appendix Table D.1. Estimates of pollock research catch (t) in the Gulf of Alaska from RACEBASE during 1977-2011.

Year	*Catch (t)*
1977	89.2
1978	99.7
1979	52.4
1980	229.4
1981	433.3
1982	110.4
1983	213.1
1984	310.7
1985	167.2
1986	1201.8
1987	226.6
1988	19.3
1989	72.7
1990	158.0
1991	16.2
1992	39.9
1993	116.4
1994	70.4
1995	44.3
1996	146.9
1997	75.5
1998	63.6
1999	34.7
2000	56.3
2001	77.1
2002	77.6
2003	127.6
2004	53.0
2005	71.7
2006	63.5
2007	47.1
2008	26.2
2009	89.9
2010	37.4
2011	43.0

Appendix Table D.2. Estimates of pollock research catch (t) in the Gulf of Alaska by survey or research project in 2010 and 2011.

	Year	
Survey/research project	*2010*	*2011*
ADFG large-mesh trawl	83.0	81.3
ADFG small-mesh trawl	20.1	23.4
IPHC annual survey	0.8	0.3
NMFS Shelikof Strait acoustic survey	12.0	
NMFS Shumagin Islands acoustic survey	25.4	
NMFS bottom trawl survey		43.0
NMFS sablefish longline survey	2.5	1.4
GOA IERP research	0.1	
Western GOA cooperative acoustic survey	12.4	
Total	156.3	149.3

Appendix E. Evaluation of Stock Structure for Gulf of Alaska Walleye Pollock

Introduction

In 2009 a Stock Structure Working Group (SSWG), consisting of members of the North Pacific Fisheries Management Council's (NPFMC) Scientific and Statistical Committee (SSC), Groundfish Plan Teams, geneticists, and assessment scientists, was formed to develop a set of guidelines that will help promote a rigorous and consistent procedure for making management decisions on stock structure for Alaska stocks. The committee produced a report, originally presented at the September 2009 meeting of the joint Groundfish Plan Team and updated for the September 2010 meeting (Spencer et al. 2010), which contains a template that identifies various scientific data from which we may infer stock structure (AppendixTable E.1). The joint Plan Team at its September 2011 meeting recommended application of the template consistently to all stocks, and identified Gulf of Alaska walleye pollock as a candidate for initial application of the template.

This document considers evidence of pollock spatial structure in the Gulf of Alaska, and does not consider larger-scale issues such as connectivity between pollock in the Gulf of Alaska and the eastern Bering Sea or the Aleutian Islands. The template developed by the stock structure committee is used to summarize scientific information on walleye pollock in the Gulf of Alaska. The document evaluates whether the current spatial management measures for Gulf of Alaska walleye pollock are consistent with the scientific information and with the Council's broad objectives for fisheries management.

Walleye pollock (*Theragra chalcogramma*) is a semi-pelagic schooling fish widely distributed in the North Pacific Ocean and adjoining waters such as the Sea of Okhotsk and Bering Sea (Appendix Fig. E.1). Pollock in the Gulf of Alaska are managed as a single stock independently of pollock in the Bering Sea and Aleutian Islands. Currently pollock in the Gulf of Alaska are managed using seasonal openings by management area. ABCs are set by management area, while OFLs are set for Central/Western and Eastern stocks. This system was developed as a protection measure for Steller sea lions, listed as endangered under the ESA, but also serves to maintain historical participation in the fishery by different communities in the Gulf of Alaska.

Application of stock structure template to Gulf of Alaska walleye pollock

Harvest and trends

The purpose of examination of harvest data and survey population trends is twofold: 1) to evaluate whether fishing mortality is large enough that spatially disproportionate harvesting represents a potential conservation concern; and 2) to identify any differences in populations trends that may indicate demographic independence.

Fishing mortality (relative to target reference point)
The estimates of fishing mortality for the ten-year period 2002-2011, obtained from the 2011 assessment (Dorn et al. 2011), ranged from 0.07 to 0.17 with a mean of 0.12. The ratio of catch to the ABC during this period ranged from 0.83 to 1.02 with mean of 0.96, indicating that pollock are fully exploited in the Gulf of Alaska.

Spatial concentration of harvest relative to abundance
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. There is no independent way to evaluate how well the goal of harvesting pollock proportional to biomass has been achieved. Comparisons of the ratio of the catch to survey biomass will not be informative because allocation is itself based on survey biomass.

Population trends
The NMFS bottom trawl surveys beginning in 1990 are the most useful for studying spatial aspects of the pollock stock in the GOA because they cover the entire Gulf of Alaska (except in 2000 when the eastern Gulf of Alaska was not surveyed). The CPUE of pollock is the highest on average in the Shumagin area, declines to a minimum in the Yakutat INPFC, and then increases in the Southeast INPFC area (Appendix Fig. E.2). Estimates of biomass by area depend on both CPUE and the area surveyed. The continental shelf is very narrow along Southeast Alaska, but becomes much more extensive near Kodiak Island and along the Alaska Peninsula. Mean biomass is greater 100,000 t in Shumagin, Chirikof, and Kodiak INPFC area, but is less than 50,000 t in Yakutat and Southeast INPFC areas (Appendix Fig. E.3). Trends in relative biomass were broadly similar between INPFC areas, showing a decline followed by an increase over the period 1990-2011 (Appendix Fig. E.4). A possible exception is the Southeast area, where biomass was not high initially, but this may be due to sparse sampling of this area in the early years of the survey.

Barriers and phenotypic characters

Generation time
Generation time is a characteristic of a species that reflects longevity and reproductive output, with long generation times indicating increased time required to rebuild overfished stocks. The mean generation time (G) was computed as

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a} \qquad \text{Eq. 1}$$

where a is age, A is expected maximum age for an unfished stock, N is females per recruit in the absence of fishing, and E is fecundity at age (Restrepo et al. 1998). Because fecundity is unknown, E was replaced by the product of proportion mature and body weight, thus using spawning stock biomass rather than egg production (Restrepo et al. 1998).

The estimated mean generation time for GOA pollock is 7.9 years. This is on the low end of the range for groundfish in the North Pacific, and is much lower than rockfish. For example, the generation time of BSAI rougheye rockfish is 53 years. A low generation time implies that the GOA pollock population should show fairly rapid response to changes in environment and fisheries management measures.

Physical limitations (clear physical inhibitors to movement)
The Gulf of Alaska is a highly advective system, with strong currents that follow the arc of the coastline northwards then westwards (Appendix Fig E.5). The Alaska Coast Current, which reaches speeds of 25-100 cm s^{-1}, flows along the continental shelf and through Shelikof Strait, while the Alaska Stream flows offshore of the continental shelf (Stabeno et al. 2004). Oceanographic barriers that would limit mixing of populations are not evident. Since pollock

have pelagic eggs and larvae, transport would tend to be “downstream” from spawning locations in the prevailing currents. To avoid being transported out of the system, pelagic offspring will need to be retained in the nearshore areas long enough to develop locomotory capacity, and spawning sites may be situated to enhance retention of offspring. The primary spawning grounds of pollock in the Gulf of Alaska, Shelikof Strait, may be one such area. If these sites are scarce and widely-spaced, this would provide a potential mechanism to structure populations. A number of spawning areas in the central and western Gulf of Alaska have been identified (Apendix Fig. E.6), but all are relatively small in comparison to the Shelikof Strait spawning grounds (Appendix Fig. E.7). Less is known about pollock spawning locations in eastern Gulf of Alaska. Seasonal surveys of inside waters in Southeast Alaska have documented the presence of adult pollock throughout the year in areas such as Fredrick Sound (Sigler et al. 2009), suggesting that spawning occurs in this area, however no spawning sites have been identified. Pollock spawning aggregations have been reported in Dixon Entrance and northern British Columbia (Apendix Fig. E.8). Natal homing has not been demonstrated for walleye pollock.

Growth differences

Spatial differences in growth were evaluated use length and age data from the NMFS bottom trawl survey in 2005-2009. A total of 4331 samples were selected randomly from the survey catch. Five spatial strata were defined according to INPFC areas: Shumagin—Area 610, Chirikof—Area 620, Kodiak—Area 630, West Yakutat—Area 640 (west of 140°W long.), Southeast (remainder of the Yakutat and Southeast Alaska)—Area 650. von Bertalanffy growth curves were fit by sex using the NLS routine in R, which assumes deviations from the curve are distributed normally. In the years used in this analysis, the NMFS bottom trawl survey extended from late May to the beginning of August, and worked from west to east, finishing up in each year in Southeast Alaska. Pollock are grow rapidly during this time of the year, particularly the younger fish. Consequently spatial differences in growth are potentially confounded with seasonal differences. To take this into account, it was assumed that the growth year extended from 1-April to 31-October, and the age was adjusted according to the proportion of growth year before the sample was collected. This affected mainly the estimate of t_{zero}, and made this parameter much more similar across areas.

Length at age was similar in all areas for fish ages 1-4, but for the older fish there were differences between areas (Appendix Figs. E.9 and E.10). The West Yakutat and Southeast areas showed progressively lower L_{inf} and higher k, while the other three areas showed little differences in growth (Appendix Table E.2). To evaluate similarities between areas a little more rigorously, we used an iterative procedure to evaluate which combinations of areas produced the smallest increase in mean square error. First, all possible pair-wise comparisons were evaluated, and the pair of areas with the smallest increase in mean squared error was combined. This new combination was included in second round of pair-wise comparisons, and so on.

The combinations proceeded as follows (bolded areas indicate areas that were combined at each step):

Pairwise combinations	Areas	Δ MSE
1st step	**630&640**, 610, 620, 650	0.27
2nd step	**610&630&640**, 620, 650	0.45
3rd step	**610&620&630&640**, 650	0.56
Final step	**610&620&630&640&650**	1.15

The sequence of combinations generates a group that includes the western and central Gulf of Alaska together, and lastly adds Southeast Alaska. These results suggest that pollock growth in

Southeast Alaska is strongly dissimilar to growth in the other areas, and that growth in the western Yakutat area is closer to growth in the Kodiak area than Southeast Alaska.

Age composition data
The estimated age compositions of walleye were obtained from data from NMFS trawl surveys conducted from 2005 to 2009. To facilitate comparisons, the cumulative age distribution was plotted for each area using the same areas as the length at age analysis (Appendix Fig. E.11). There is consistent pattern of decreasing age from west to east. Southeast Alaska has the youngest fish, while the Shumagin area consistently contains the oldest fish. Age-1 and age-2 pollock are present in all areas, so it would be incorrect to conclude from this analysis that any area is preferred juvenile habitat. An example showing the widespread distribution of age-1 pollock is given in Appendix Figure E.12.

Spawning time differences
The time of peak spawning occurs at different times at different major spawning areas in the Gulf of Alaska. In the Shumagin area, including Sanak Trough and Shumagin Gully, spawning occurs in mid to late February. In the central Gulf of Alaska (including Shelikof Strait, and Prince William Sound), spawning occurs in late March to early April. It is unclear whether the difference in timing is due to the older fish in this area, which may tend to spawn earlier, or whether it reflects genetic differences between spawners, or a response to differing environmental conditions in the two areas.

Genetics

Genetic studies of pollock have tended to focus on larger scales, such as distinguishing Asiatic from North American stocks, or distinguishing eastern Bering Sea and Gulf of Alaska stocks. The studies have generally found that pollock lack strong genetic structure, which is not unusual for many marine species. However these results may reflect the choice of sampling locations and times and the types of genetic material studied. 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).

Pairwise genetic differences (significant differences between geographically distinct collections)
Olsen et al. (2002) specifically examined evidence of stock structure within the Gulf of Alaska, although their Gulf of Alaska samples came from only Shelikof Strait, Prince William Sound and Middleton Island, and did not include other spawning sites in Gulf of Alaska. Olsen et al. (2002) found evidence from allozyme frequency and mtDNA that spawning populations in the northern part of the Gulf of Alaska (Prince William Sound and Middleton Island) are genetically distinct from the Shelikof Strait spawning population. Shelikof Strait and Prince William Sound were found to be significantly different based on allozyme data but not based on mtDNA data, while in contrast Shelikof Strait and Middleton Island were found to be significantly different based on mtDNA but not based on allozyme data. In addition, 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 (i.e., the “sweepstakes” hypothesis), adult philopatry, source-sink population structure, or utilization of the same spawning areas by genetically distinct stocks with different spawning timing.

Isolation by distance
Isolation by distance was evaluated using microsatellite data from samples collected at Prince William Sound, Shelikof Strait and Unimak Pass (which is essentially contiguous with the Gulf of Alaska at that location). Replicate samples were taken over two years at the three locations. Genetic FST estimates plotted against geographic distances did not show a significant relationship of genetic differentiation with geographic distance over the scale of the Gulf of Alaska (Appendix Fig. E.13). A significant IBD pattern has been found for walleye pollock over larger spatial scales (O'Reilly et al. 2004; Grant et al. 2010). The data do indicate a substantial degree of homogeneity in the GOA that would be expected in large, recently-founded (evolutionarily) populations. Estimates of FST would be expected to fluctuate around zero (both positive and negative) in genetically well-mixed populations, in part due to random stochastic sampling errors. That FST values are consistently positive and that there appears to be some positive trend over distance (although statistically not significant) argue that some degree of population substructure may be present, but it is difficult to resolve given the limitations of the marker class and the history of the species.

Interpretation of the information regarding stock structure

A summary of the information in the template for Gulf of Alaska pollock is shown in Appendix Table E.3. For any given data type, there may be multiple explanations consistent with the observed pattern; thus, an advantage of considering several types of data is more information on the potential differences between areas.

The available information on pollock for areas 610-630 (Shumagin to Kodiak) supports considering pollock in these areas as a single stock, albeit with some spatial heterogeneity. Growth is similar among areas, and differences in age composition may be due to ontogenetic movement and to interannual variation in juvenile settlement. The role of different spawning areas in contributing to pollock recruitment is not well resolved, but clearly Shelikof Strait is important. In addition, spawning areas that are “upstream” in the prevailing currents such as the spawning that occurs in Prince William Sound and in Kenai Peninsula Bays may also be important.

From Prince William Sound to Southeast Alaska, there is stronger evidence of stock structure. Growth is very different in Southeast Alaska and age composition is shifted towards younger fish. Spawning from Prince William Sound and further west would not be expected to lead to settlement of juveniles in Southeast Alaska given current flow patterns. In addition, there is evidence of genetic distinctness of pollock near Prince William Sound, though the evidence is a little ambiguous. The available data supports consideration of Southeast Alaska as a separate pollock stock, but precise determination of where the split should be located is not possible. There is weaker support for identifying a stock in area 640 that may or may not include Prince William Sound. This area may be more usefully regarded as a transitional region with some affinities with both southeast Alaska and Central/Western stocks. A genetic study that is explicitly designed to address issues of pollock stock structure in the Gulf of Alaska would be very valuable. Sampling should be done on spawning aggregations with the objective of collecting samples from all known spawning areas in the Gulf of Alaska.

Management implications

History of spatial and seasonal management units for GOA walleye pollock
Spatial management has been used for pollock since the development of the domestic fishery in the late 1980s. Since at least 1988, separate ABCs were set for a Central/Western stock and an Eastern stock. In 1989-1991, a separate allocation was set for Shelikof Strait to reduce fishing

pressure on the pollock that were spawning in this area. In 1992, Amendment 25 provided for the spatial allocation by Shumagin, Chirikof and Kodiak regulatory areas for the Central/Western stock based on biomass distribution to reduce potential impacts on Steller Sea Lions. Overfishing levels were set at the stock level, i.e., for the Central/Western stock and Eastern stock, but ABCs were set for the regulatory subareas.

Seasonal apportionment began in 1995 with four quarterly allocations beginning January 1, June 1, July 1, and October 1, again to reduce potential impacts on Steller sea lions. The details of the seasonal allocation scheme were tweaked over time by changing the number of seasonal allocations, the dates of openings, and percentage that can be taken during each season. However the general objective was 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.

Although not pertaining to the Gulf of Alaska pollock, there was petition in 1999 to declare walleye pollock (among other species) in Puget Sound as endangered under the ESA. A biological review team (BRT) was convened and charged with establishing distinct population segment (DPS) for walleye pollock. The DPS concept developed under the ESA does not exactly correspond to a unit stock under the MSFCMA, and can consist of a number of demographically independent stocks. The BRT noted that most studies of genetic population structure in walleye pollock have revealed low levels of differentiation where physical barriers to migration are lacking, and identified a Lower boreal Eastern Pacific DPS for walleye pollock extending from Puget Sound to a provisional northern boundary of 140°W longitude, which corresponds to the current break between Eastern stock and the Central/Western stock.

Implications for stock sustainability and risks/costs to the fishery and regulatory system
The SSWG report (Spencer et al. 2010) suggests that an “evaluation of the risks (biological and fishery) under alternative hypotheses concerning stock structure” be considered in the stock structure evaluation report. In particular, the risk evaluation would involve consideration of alternative management approaches for dealing with stock structure, such as setting separate ABCs and OFLs by area, or separate stock assessments and status determination criteria by area.

With the possible exception of the split between the Eastern GOA and the Central/Western GOA, the current spatial and seasonal apportionment procedure for pollock in the GOA was not developed to account for stock structure. Overfishing levels are set at the stock level, and ABCs are used to manage harvest for regional subareas to reduce impacts on Steller sea lions. Harvesting proportionate to biomass is considered to provide the least impact on Steller sea lions, but at the same time it provides protection against unequal harvest of any unrecognized component of stock structure. For example, the current treatment of area 640 and Prince William Sound in the management system produces catch/biomass ratios that are similar to those that would result if they were managed separately using a Tier 5 assessment.

This evaluation of stock structure did not reveal any major concerns about the present management system for Gulf of Alaska pollock with respect to stock structure, and if anything may be overly precautionary. The current split between the Central/Western stock and an Eastern stock is well supported. Although there is evidence of additional structure in the population, it does not seem sufficiently resolved into a clear pattern that would warrant defining additional stocks for management. One risk when managing for multiple spatial and seasonal quotas is that biomass estimates for small areas have considerable uncertainty, so that an apportioning procedure could result in mistakenly allocating a large quota in an area where there is little biomass. The seasonal and spatial management system is perhaps one of the most complicated developed for any fishery, and likely requires substantial efforts from in-season managers to implement.

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Appendix Table E.1. Framework of types of information to consider when defining spatial management units (from Spencer et al. 2010).

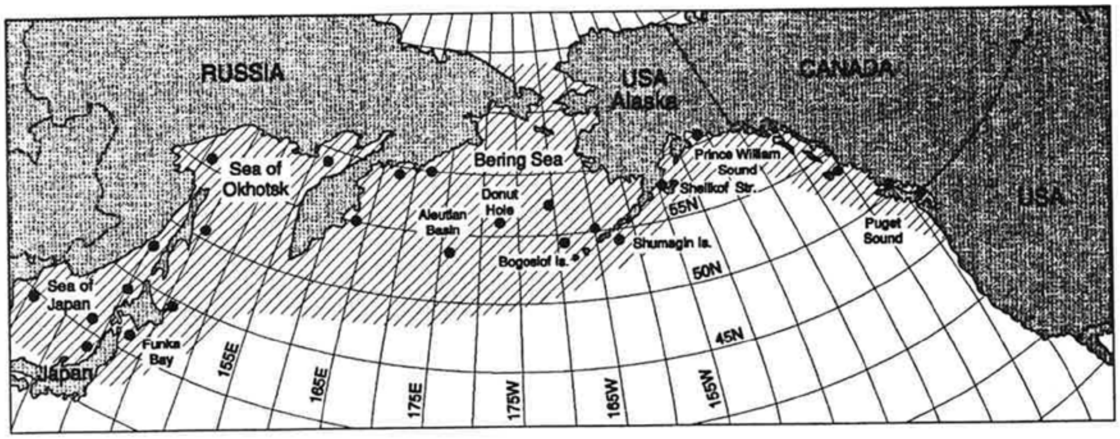
Harvest and trends	
Factor and criterion	Justification
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	If this value is low, then conservation concern is low
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	If fishing is focused on very small areas due to patchiness or convenience, localized depletion could be a problem.
Population trends (Different areas show different trend directions)	Differing population trends reflect demographic independence that could be caused by different productivities, adaptive selection, differing fishing pressure, or better recruitment conditions
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	If generation time is long, the population recovery from overharvest will be increased.
Physical limitations (Clear physical inhibitors to movement)	Sessile organism; physical barriers to dispersal such as strong oceanographic currents or fjord stocks
Growth differences (Significantly different LAA, WAA, or LW parameters)	Temporally stable differences in growth could be a result of either short term genetic selection from fishing, local environmental influences, or longer-term adaptive genetic change.
Age/size-structure (Significantly different size/age compositions)	Differing recruitment by area could manifest in different age/size compositions. This could be caused by different spawning times, local conditions, or a phenotypic response to genetic adaptation.
Spawning time differences (Significantly different mean time of spawning)	Differences in spawning time could be a result of local environmental conditions, but indicate isolated spawning stocks.
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	Temporally stable differences in maturity-at-age could be a result of fishing mortality, environmental conditions, or adaptive genetic change.
Morphometrics (Field identifiable characters)	Identifiable physical attributes may indicate underlying genotypic variation or adaptive selection. Mixed stocks w/ different reproductive timing would need to be field identified to quantify abundance and catch
Meristics (Minimally overlapping differences in counts)	Differences in counts such as gillrakers suggest different environments during early life stages.
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Primary indicator of limited dispersal or homing
Mark-recapture data (Tagging data may show limited movement)	If tag returns indicate large movements and spawning of fish among spawning grounds, this would suggest panmixia
Natural tags (Acquired tags may show movement smaller than management areas)	Otolith microchemistry and parasites can indicate natal origins, showing amount of dispersal
Genetics	
Isolation by distance (Significant regression)	Indicator of limited dispersal within a continuous population
Dispersal distance (<<Management areas)	Genetic data can be used to corroborate or refute movement from tagging data. If conflicting, resolution between sources is needed.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Indicates reproductive isolation.

Appendix Table E.2. von Bertalanffy growth parameters by area for walleye pollock in the Gulf of Alaska.

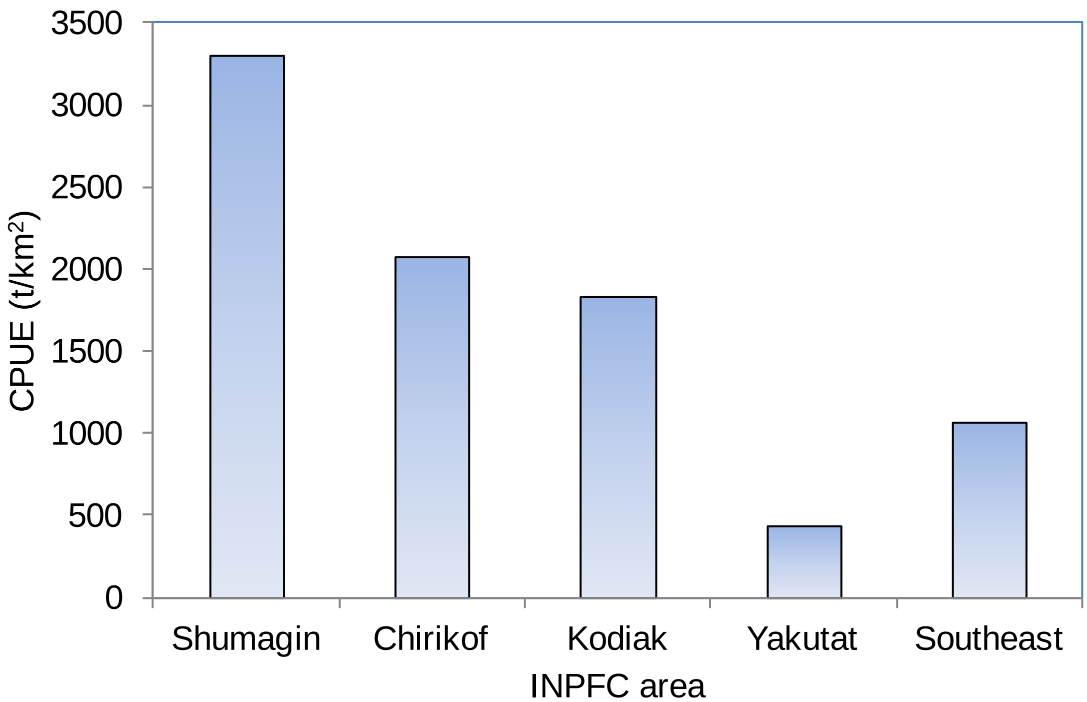
Area	Sex	Number aged	t_{izero}	K	L_{inf}
610	Male	474	0.43	0.298	61.6
620	Male	472	0.61	0.312	63.3
630	Male	478	0.46	0.332	60.8
640W	Male	144	0.47	0.391	55.9
650	Male	377	0.45	0.449	51.7
610	Female	487	0.38	0.256	67.9
620	Female	560	0.58	0.267	70.6
630	Female	580	0.49	0.288	67.9
640W	Female	212	0.46	0.353	61.3
650	Female	547	0.44	0.414	55.0

Appendix Table E.3. Summary of available data on stock identification for GOA walleye pollock.

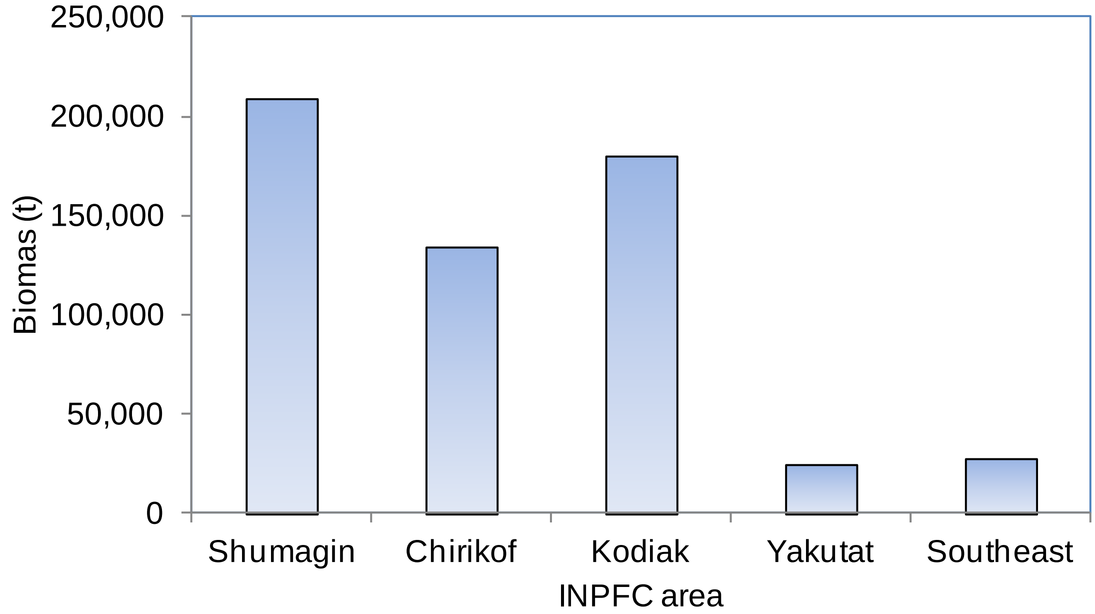
Harvest and trends	
Factor and criterion	Available information
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	Recent catches are very close the ABC.
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Catches are apportioned according to the seasonal distribution of biomass as estimated by running averages of assessment surveys. Catches are not allocated at a smaller scale than regional management areas.
Population trends (Different areas show different trend directions)	Population trends based on survey data show a decline followed by an increase over the period 1990-2011. Different areas in the GOA have roughly concordant trends given the uncertainties in the data.
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	The generation time is approximately 7.9 years
Physical limitations (Clear physical inhibitors to movement)	The northernmost point of GOA is considered biogeographic boundary. GOA is a strongly mixing and strongly advective system.
Growth differences (Significantly different LAA, WAA, or LW parameters)	Differences growth curves and length-at-age relationships between between INPFC area. The strongest differences are between eastern GOA and the other areas combined.
Age/size-structure (Significantly different size/age compositions)	Differences in age composition between areas in the GOA.
Spawning time differences (Significantly different mean time of spawning)	Spawning occurs earlier in the Western GOA.
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	Unknown
Morphometrics (Field identifiable characters)	Unknown
Meristics (Minimally overlapping differences in counts)	Unknown
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Unknown
Mark-recapture data (Tagging data may show limited movement)	Mark-recapture data not available
Natural tags (Acquired tags may show movement smaller than management areas)	Unknown
Genetics	
Isolation by distance (Significant regression)	IBD relationship is not significant over the scale of the Gulf of Alaska. A significant IBD pattern has been found for walleye pollock over larger spatial scales. No studies have been conducted within the GOA at the appropriate scale.
Dispersal distance (<<Management areas)	No dispersal distances estimated as no IBD pattern was observed.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Pairwise differences have been found between Shelikof Strait and Middleton Island (mtDNA data), and between Shelikof Strait and Prince William Sound (allozyme data).



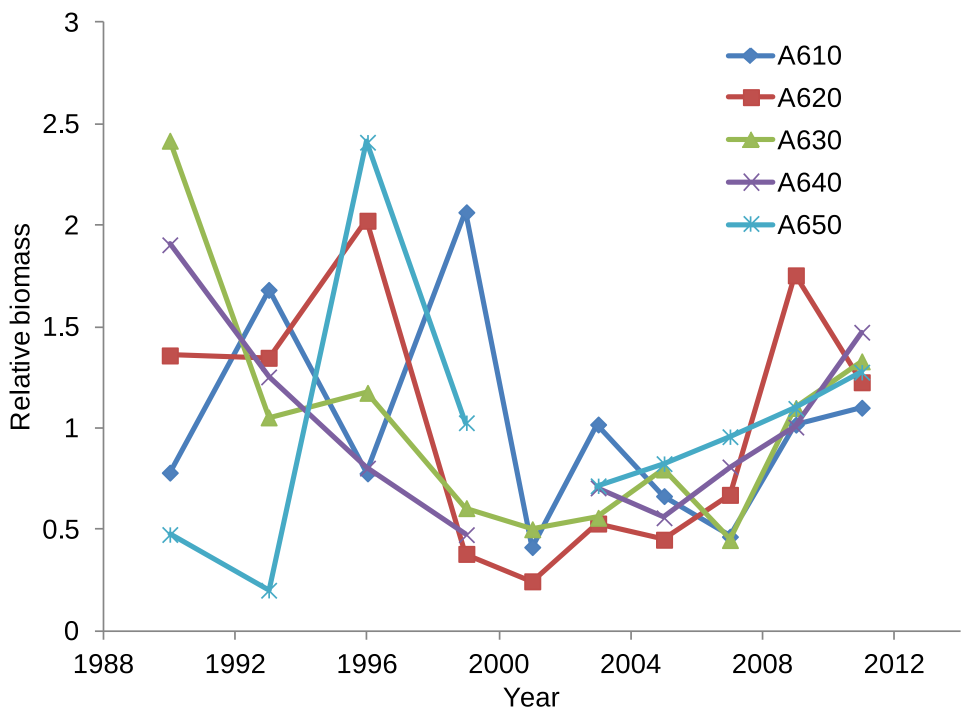
Appendix Figure E.1. Distribution of walleye pollock in the North Pacific. From Bailey et al. (1999).



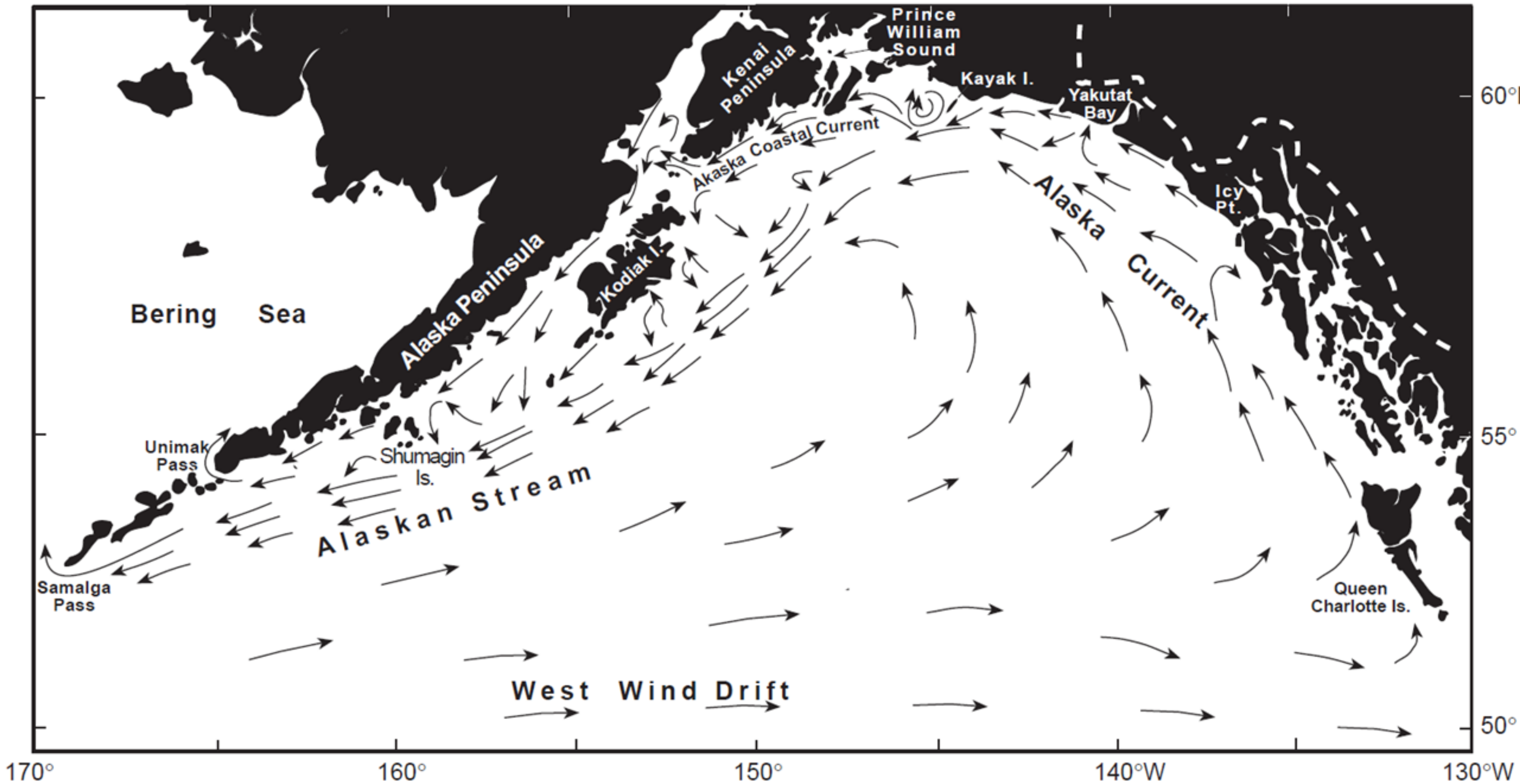
Appendix Figure E.2. Weighted mean CPUE (t/km^2) for walleye pollock by INMPFC area for the NMFS bottom trawl survey in 1990-2011.



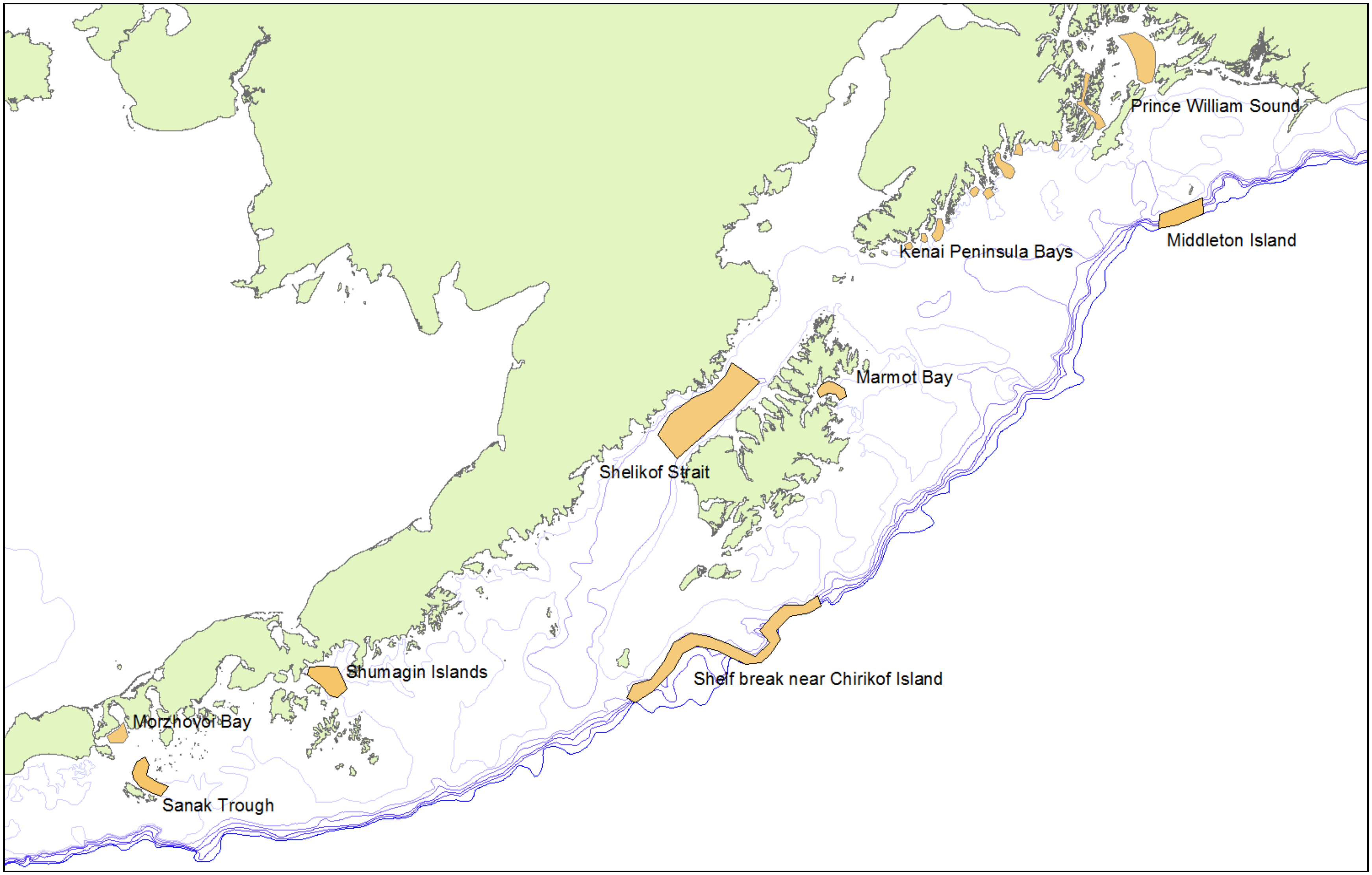
Appendix Figure E.3. Mean biomass of walleye pollock by INPFC area for the NMFS bottom trawl survey in 1990-2011.



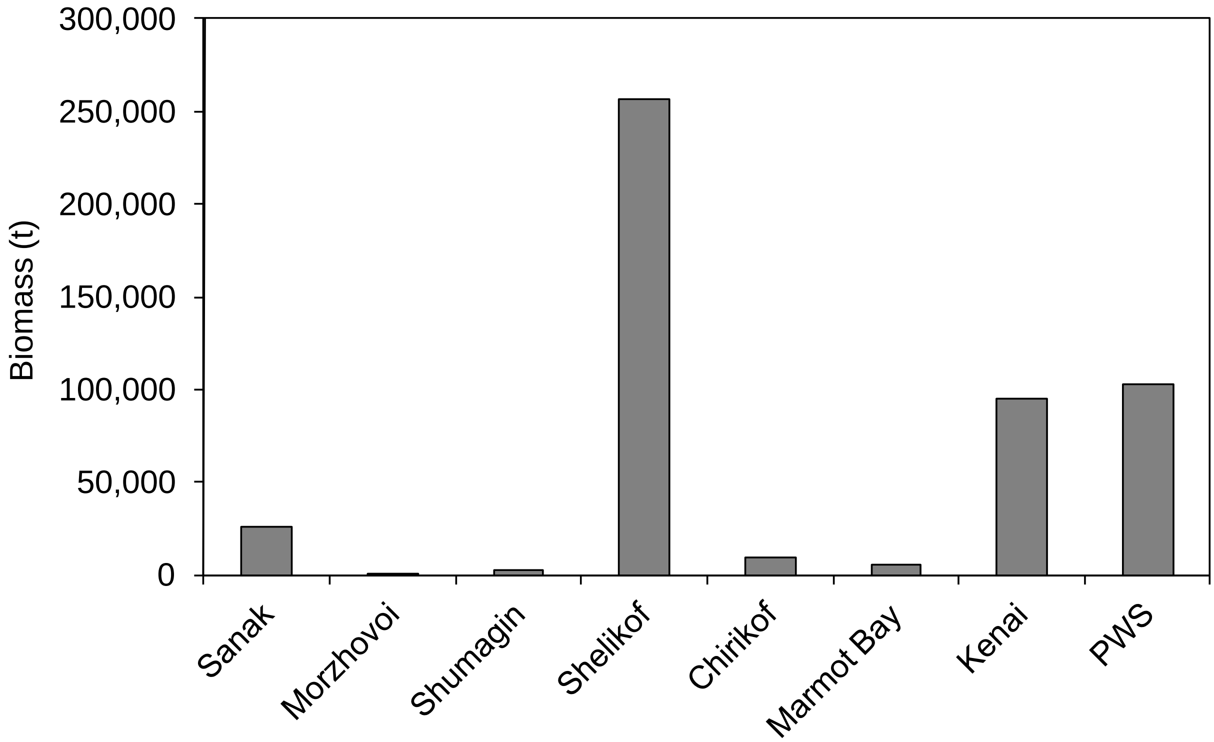
Appendix Figure E.4. Relative biomass trends by INPFC area for the NMFS bottom trawl survey in 1990-2011.



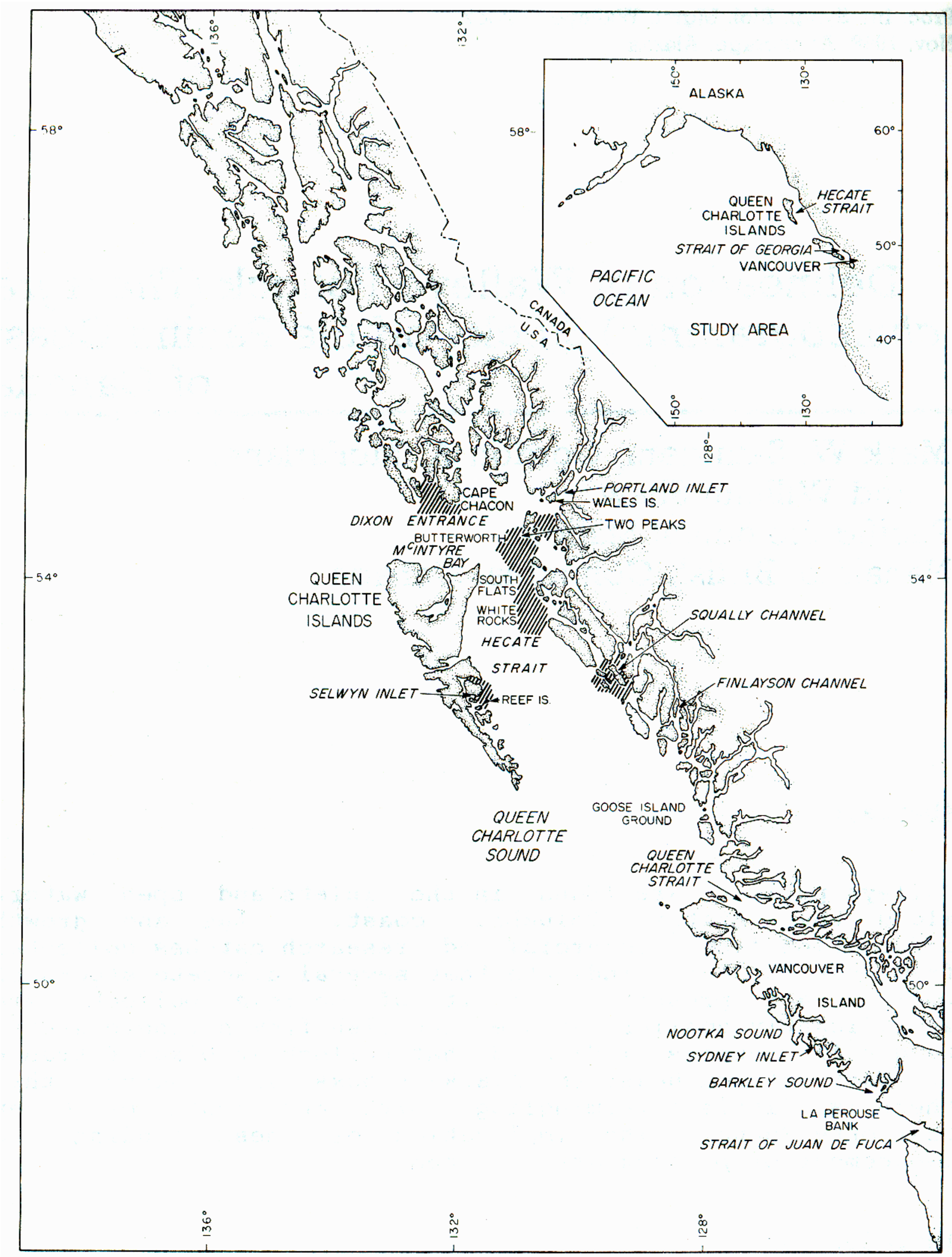
Appendix Figure E.5. Schematic of ocean currents in the Gulf of Alaska, showing the Alaska Current, the Alaska Coastal Current (ACC), and the Alaskan Stream (AS) (from Stabeno et al. 2005).



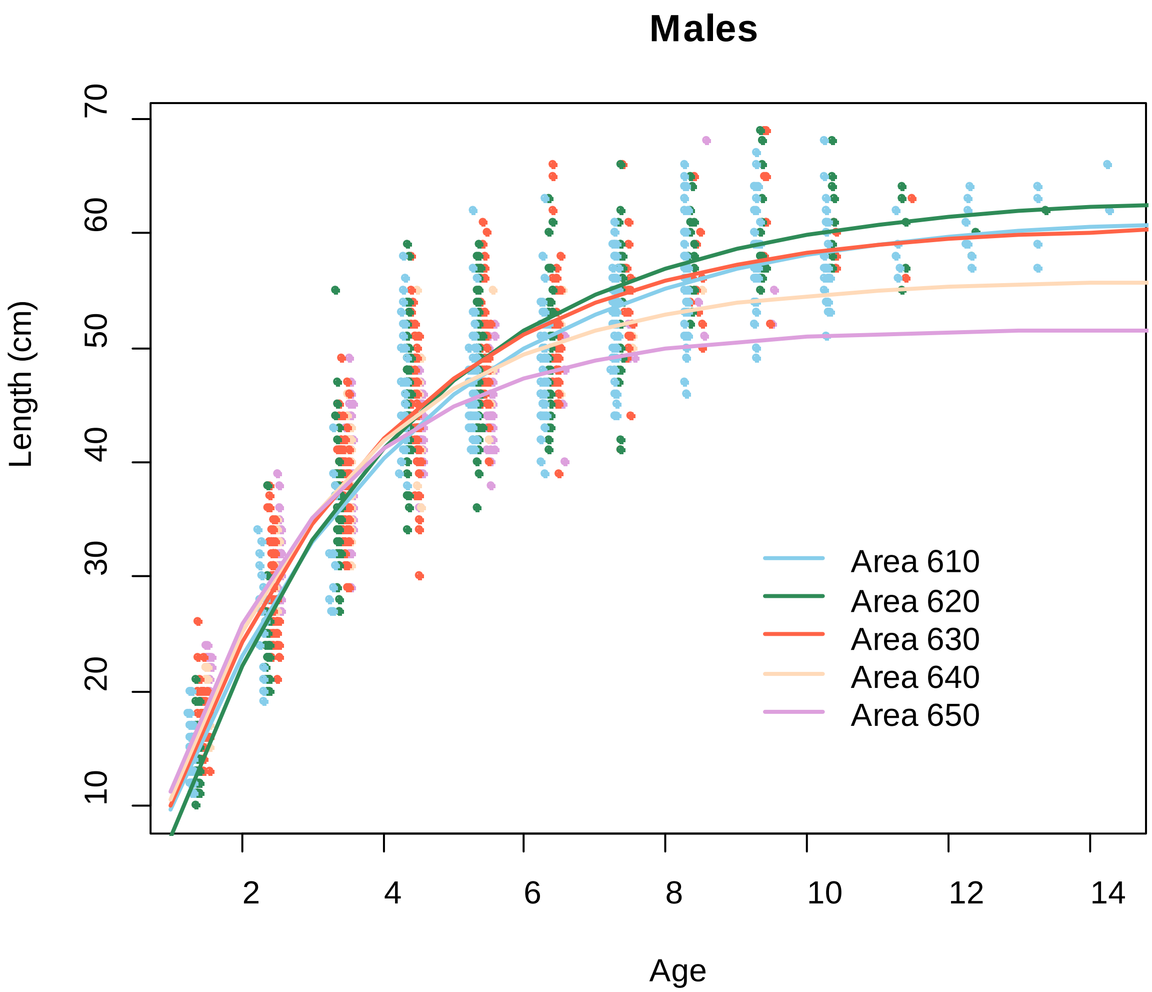
Appendix Figure E.6. Spawning areas of pollock in the Gulf of Alaska.



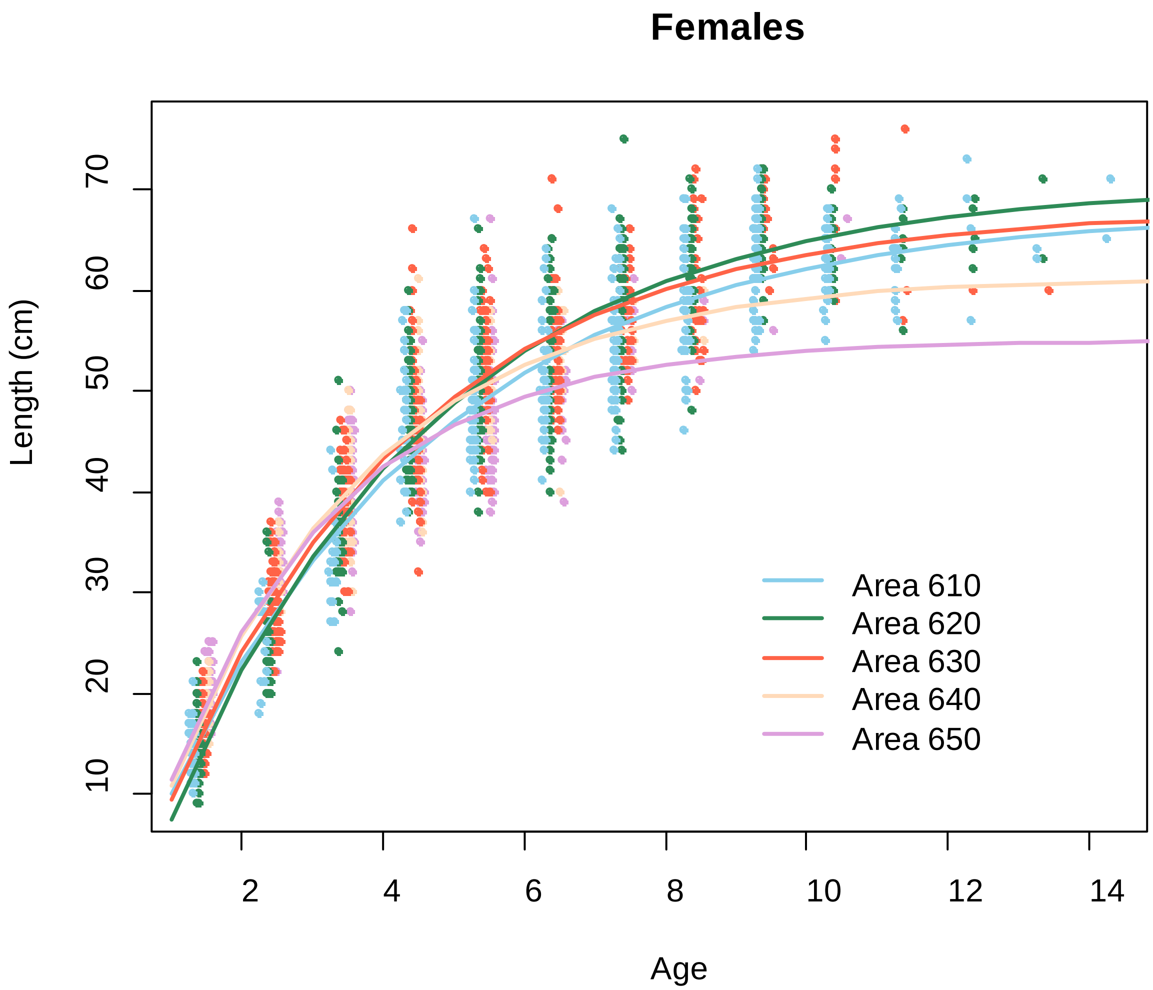
Appendix Figure E.7. Total spawning biomass by area in winter 2010. Spawning biomass in Shelikof Strait is 52% of the total estimated for all areas.



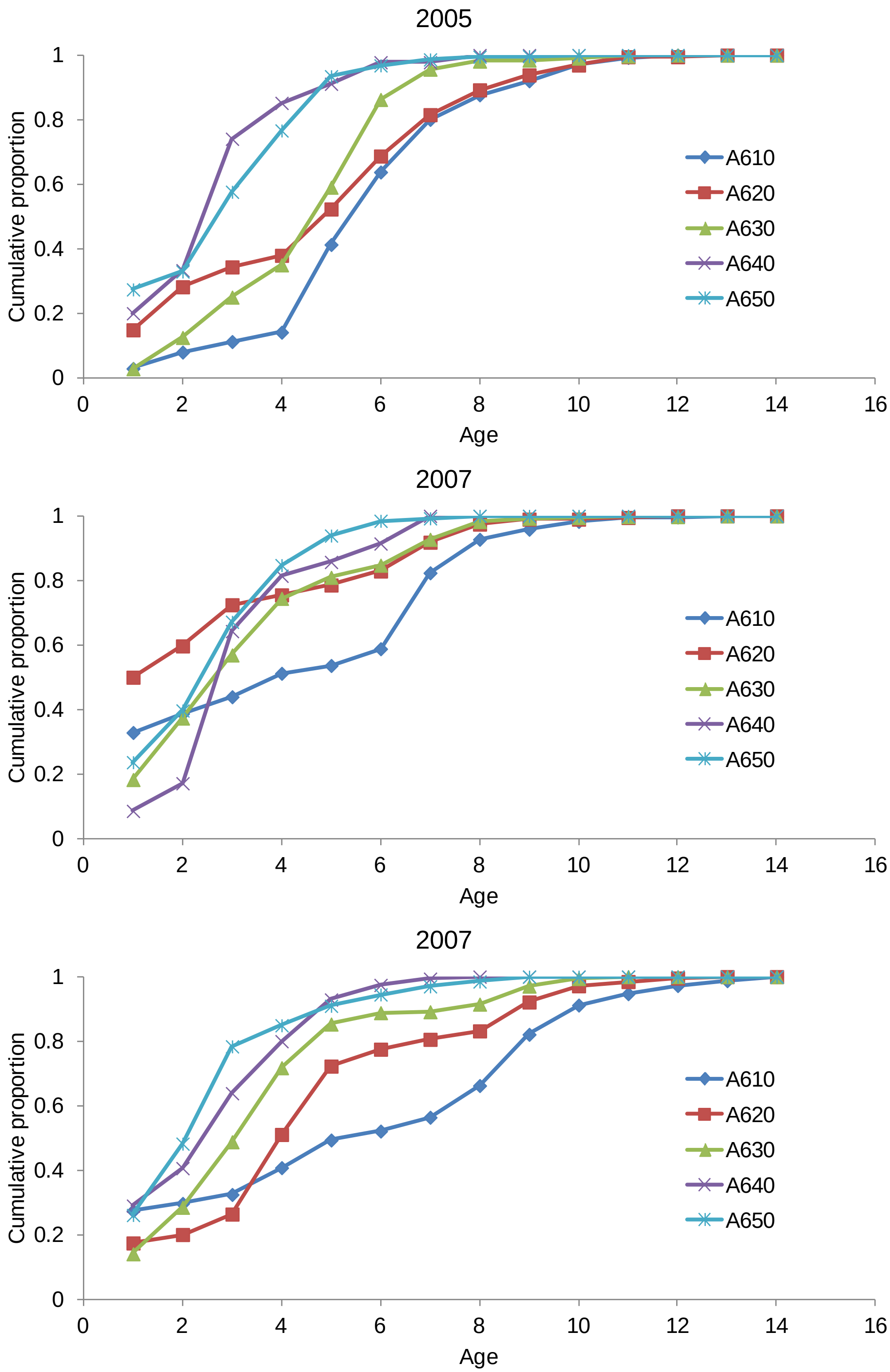
Appendix Figure E.8. Reported spawning areas of pollock the eastern Gulf of Alaska (from Saunders et al. 1989).



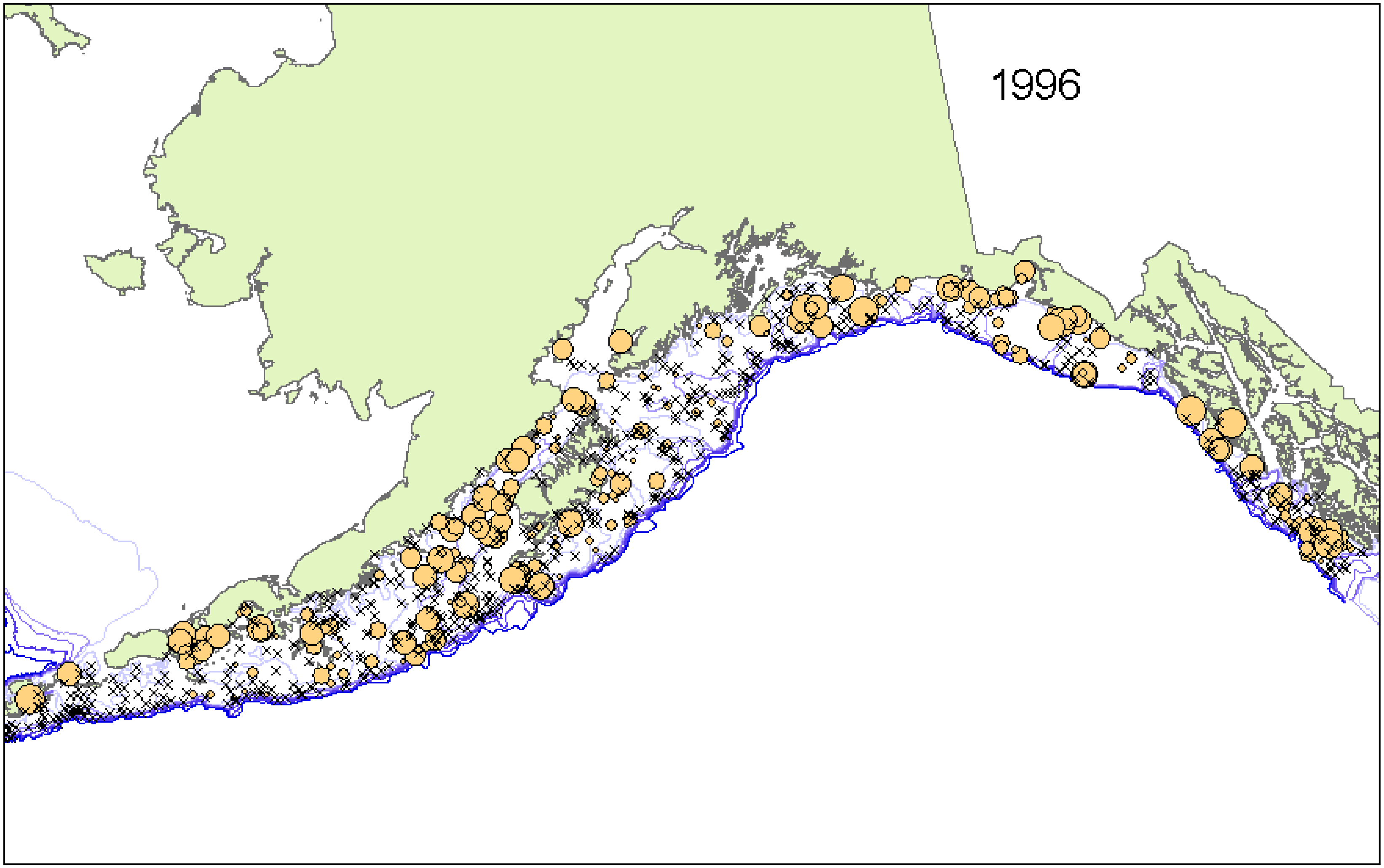
Appendix Figure E.9. Male length at age and estimated von Bertalanffy growth curves by INPFC area in the Gulf of Alaska from 2005-2009.



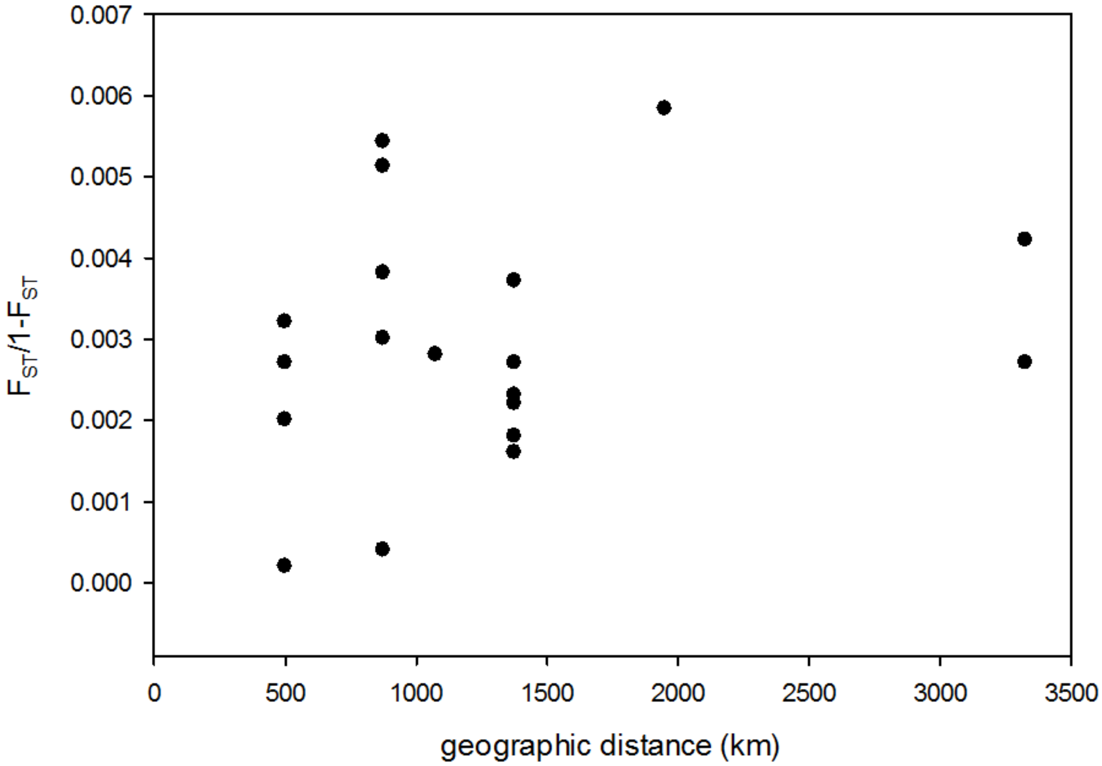
Appendix Figure E.10. Female length at age and estimated von Bertalanffy growth curves by INPFC area in the Gulf of Alaska from 2005-2009.



Appendix Figure E.11. Cumulative age composition of walleye pollock by area for NMFS bottom trawl surveys in 2007-2009.



Appendix Figure E.12. Distribution of age-1 pollock in the 1996 NMFS bottom trawl survey.



Appendix Figure E.13. Genetic isolation by distance for pollock mitochondrial DNA samples collected from Prince William Sound, Shelikof Strait and Unimak Pass.

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