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

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Executive Summary

Summary of Changes in Assessment Model Inputs

Changes in input data

1. Fishery: 2013 total catch and catch at age.

2. Shelikof Strait acoustic survey: 2014 biomass and age composition.

3. NMFS bottom trawl survey: 2013 age composition.

4. ADFG crab/groundfish trawl survey: 2014 biomass.

5. Total catch for all years was re-estimated from original sources

6. Fishery catch at age and weight at age were re-estimated for 1975-1999 from primary databases maintained at AFSC.

Changes in assessment methodology

The age-structured assessment model is similar to the model used for the 2013 assessment and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library). The 2014 model implemented the following changes based on the 2012 CIE review, SSC and Plan Team comments, and other considerations: 1) starting the model in 1970 rather than 1964 and removing fishery length composition data for 1964-1971, 2) removing summer bottom trawl surveys in 1984 and 1987 and Shelikof Strait acoustic surveys in 1981-1991, 3) estimating summer bottom trawl catchability using a prior and modeling selectivity with an asymptotic curve, rather than fixing catchability at 1.0 and assuming a dome-shaped selectivity curve, 4) using a random walk for changing fishery selectivity parameters rather than time blocks, 5) using an age-specific mortality schedule with higher juvenile mortality, 6) modeling age-1 and age-2 pollock in the winter acoustic surveys as separate indices. All composition data sets were tuned so that input sample sizes were close to the harmonic mean of effective sample size.

Summary of Results

The base model projection of female spawning biomass in 2015 is 309,869 t, which is 39.7% of unfished spawning biomass (based on average post-1977 recruitment) and below $B_{40\%}$ (312,000 t), thereby placing Gulf of Alaska pollock in sub-tier “b” of Tier 3. There were two surveys in 2014: the Shelikof Strait acoustic survey and the ADFG crab/groundfish survey. The 2014 biomass estimate for Shelikof Strait is 842,138 t, which is a 6% decrease from 2013, but is still larger than any other biomass estimate in Shelikof Strait since 1985. The ADFG crab/groundfish survey 2014 biomass estimate is close to the 2013 estimate (2% lower). The estimated abundance of mature fish is projected to remain stable near $B_{40\%}$ or to increase in over the next five years.

The author's 2015 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK) is 191,309 t, which is an increase of 14% from the 2014 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. In 2016, the ABC based on an adjusted $F_{40\%}$ harvest rate is 250,824 t. The OFL in 2015 is 256,545 t, and the OFL in 2016 if the recommended ABC is taken in 2015 is 321,067 t.

For pollock in southeast Alaska (East Yakutat and Southeastern areas), the ABC recommendation for both 2015 and 2016 is 12,625 t (see Appendix A) and the OFL recommendation for both 2015 and 2016 is 16,833 t. These recommendations are based on a Tier 5 assessment using the estimated biomass in 2015 and 2016 from a random effects model fit to the 1990-2013 bottom trawl survey biomass estimates in Southeast Alaska, and are unchanged from last year.

Status Summary for Gulf of Alaska Pollock in W/C/WYK

Quantity/Status	As estimated or specified *last* year for		As estimated or specified *this* year for	
	2014	2015	2015	2016
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3a	3b	3b	3a
Projected total (age 3+) biomass (t)	972,750	1,723,060	1,883,920	1,927,010
Female spawning biomass (t)				
Projected				
Upper 95% confidence interval	379,861	319,342	406,382	432,820
Point estimate	308,541	267,477	309,869	330,497
Lower 95% confidence interval	250,611	224,035	236,081	253,194
$B_{100\%}$	726,000	726,000	779,000	779,000
$B_{40\%}$	290,000	290,000	312,000	312,000
$B_{35\%}$	254,000	254,000	273,000	273,000
F_{OFL}	0.26	0.22	0.28	0.28
$maxF_{ABC}$	0.22	0.20	0.24	0.24
F_{ABC}	0.20	0.17	0.20	0.22
OFL (t)	211,998	248,384	256,545	321,067
maxABC (t)	183,943	210,071	222,774	272,165
ABC (t)	167,657	185,830	191,309	250,824
Status	As determined *last* year for		As determined *this* year for	
	2012	2013	2013	2014
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 in its December 2012 minutes recommended that the authors consider whether it is possible to estimate M with at least two significant digits in all future stock assessments to increase validity of the estimated OFL.

We evaluated six methods to estimate the age-specific pattern of natural mortality external to the assessment model, and recommended an ensemble average for use in the assessment model. A more integrated approach to estimating natural mortality using a predation index is under development in a PCCRC project in collaboration with UAF researchers.

The SSC in its December 2013 minutes recommended that assessment authors give greater attention to how current year catch is determined.

Previously the assessment assumed that the full ABC/TAC would be taken in the current year. This year we averaged the percent of ABC taken in the previous five years, and applied that percentage (95%) to the current year ABC.

The SSC in its December 2013 minutes recommended that projections for two future years be shown on the phase plot figure.

The phase plot figure was modified as recommended.

The SSC in its December 2013 minutes recommended use of the random effects approach to determine area apportionments.

The appendix includes recommendations for apportioning the ABC by region for Western and Central stock using the random effects model to obtain smoothed biomass estimates by region for the summer bottom trawl survey. The random effects model was evaluated but not used for the winter apportionment calculations due to concerns about how the model performed with short, highly variable time series.

Responses to SSC and Plan Team Comments Specific to this Assessment

The GOA Plan Team suggested in its November 2012 minutes that inter-annual smoothing be used instead of blocks to avoid the undesirable effect of highly correlated recruitments between years. The SSC in its December 2012 minutes agreed with the Plan Team and recommended that the assessment authors explore whether there is a tradeoff between parsimony and introduction of retrospective error when using time blocks versus a penalized random walk for time varying selectivity.

We reintroduced random walks in the parameters governing the ascending portion of the selectivity curve with stiffer penalties on the amount that the parameter can change from one year to the next. The descending portion of the fishery selectivity curve is not allowed to vary based on our concern that changes in the descending portion of the curve were more likely to track error rather than signal.

The GOA Plan Team noted in its November 2012 minutes that the assumption of the multinomial error assumption for all ages is questionable. The Team suggested that younger ages, age-1 and possibly age-2, might be better treated separately, similar to the approach used for the eastern Bering Sea pollock model for both acoustic and bottom-trawl surveys. The SSC in its December 2012 minutes concurred with the Plan Team recommendation.

We separated the age-1 and the age-2 pollock from the remaining age classes for the Shelikof Strait acoustic survey biomass and age composition. New age-1 and age-2 indices were created by combining the Shelikof Strait and the Shumagin Island estimates for years when both surveys were conducted. These indices were fit with separate log-normal likelihood components in the model.

The SSC in its December 2012 minutes recommended that the assessment authors explore if there are variations in female relative abundance that may explain variations in spatial distributions by management areas.

We were unable to make progress on this recommendation in this assessment. It is unclear to us what kind of analysis is being recommended.

In their November 2013 minutes, the GOA Groundfish Plan Team recommends considering the results from the Plan Team stock-recruitment working group when determining which year classes to use when computing reference point. The SSC in its December 2013 minutes agreed with the Plan Team and noted a discrepancy between including the 2012 recruitment in projections but not in calculating the $B_{100\%}$ *reference point. The authors are encouraged to provide a justification for this approach and the Plan Team to discuss the need for a unified approach across stocks.*

After considering the results of the stock-recruitment working group we decided it was appropriate to maintain our practice of omitting the final year estimate of age-1 recruitment in calculation of average recruitment for status determination, but using that estimate for projecting ABCs and OFLs.

Introduction

Walleye pollock (*Gadus 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. An evaluation of stock structure for Gulf of Alaska pollock following the template developed by NPFMC stock structure working group was provided as an appendix to the 2012 assessment (Dorn et al., 2012). Evidence tended to support the current approach of assessing and managing pollock in the eastern portion of the Gulf of Alaska separately from pollock in the central and western portions of the Gulf of Alaska.

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 2009 and 2013, on average about 95% 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 pollock were caught instead. The most common managed species in the incidental catch are arrowtooth flounder, Pacific cod, flathead sole, Pacific ocean perch, squid, and shallow-water flatfish. The most common non-target species are eulachon and other osmerids, miscellaneous fish, and jellyfish. Bycatch estimates for prohibited species over the period 2009-2013 are given in Table 1.3. Chinook salmon are the most important prohibited species caught as bycatch in the pollock fishery. The spike in Chinook salmon bycatch in 2010 led the Council to adopt management measures to reduce Chinook salmon bycatch, including a cap of 25,000 Chinook salmon bycatch in directed pollock fishery. Estimated Chinook salmon bycatch since 2010 has been less than half of the 2010 spike.

Kodiak is the major port for pollock in the Gulf of Alaska, accounting for about 70% of the 2009-2013 landings. In the western Gulf of Alaska, Sand Point, King Cove, and Akutan are important ports, sharing

25% of recent landings. Minor ports, including Seward, Dutch Harbor, Homer, Sitka, Cordova, and Ketchikan account for only 2% of 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 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, and ADFG bottom trawl survey estimates of biomass and age composition. Binned length composition data are used in the model only when age composition estimates are unavailable, such as the most recent surveys. The following table specifies the data that were used in the GOA pollock assessment:

Source	*Type*	*Years*
Fishery	Total catch biomass	1970-2013
Fishery	Age composition	1975-2013
Shelikof Strait acoustic survey	Biomass	1992-2014
Shelikof Strait acoustic survey	Age composition	1992-2014
NMFS bottom trawl survey	Area-swept biomass	1990-2013
NMFS bottom trawl survey	Age composition	1990-2013
ADFG trawl survey	Area-swept biomass	1989-2013
ADFG survey	Age composition	2000, 2002, 2004, 2006, 2008, 2010, 2012

Total Catch

Total catch was re-estimated in this assessment from original sources, which included INPFC and ADFG publications, and databases maintained at the Alaska Fisheries Science Center and the Alaska Regional Office. Foreign catches for 1963-1970 are reported in Forrester et al. (1978). During this period only Japanese vessels reported catch of pollock, though there may have been some catches by Soviet vessels. Foreign catches 1971-1976 are reported by Forrester et al. (1983). During this period there are reported pollock catches for Japanese, Soviet, Polish, and ROK vessels in the Gulf of Alaska. Foreign and joint venture catches for 1977-1988 are blend estimates for the NORPAC database maintained by the Alaska Fisheries Science Center. Domestic catches for 1970-1980 are reported in Rigby (1984). Domestic catches for 1981-1990 were obtained from PacFIN (Brad Stenberg, pers. comm. Feb 7, 2014). A discard ratio (discard/retained) of 13.5% was assumed for all domestic catches prior to 1991 based on the 1991-1992 average discard ratio. Estimated catch for 1991-2013 was obtained from the Catch Accounting System database maintained by the Alaska Regional Office. These estimates are derived 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). 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. Non-commercial catches are reported in Appendix D.

Fishery Age Composition

Catch at age was re-estimated in this assessment for 1975-1999 from primary databases maintained at AFSC. A simple non-stratified estimator was used, which consisted of compiling a single annual age-length key and the applying the annual length composition to that key. Estimates were made separately for the foreign/JV and domestic fisheries in 1987 when both fisheries were sampled. There were no major discrepancies between the re-estimated age composition and estimates that have built up gradually from assessment to assessment. A more complex analysis using spatial and temporal strata was considered for the re-analysis, but this was regarded as lower priority because very few of the pre-2000 fish are present in the current population age structure.

Methods for estimating age composition from 2000 onward are documented in the assessments available online at http://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm. Estimates of fishery age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). All length composition and age data was downloaded from the NORPAC tables. Pollock otoliths collected during the 2013 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 2013 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	207	355	177	12
	No. lengths	1011	1919	921	55
	Catch (t)	5,885	35,994	9,046	5,524
2nd half (C and D seasons)	No. ages	106	240	360	----
	No. lengths	601	1304	2046	----
	Catch (t)	1,825	17,121	20,966	----

Sample sizes for both length and otoliths dropped substantially in 2013 due to implementation of the new observer deployment plan. Observer sampling instructions were changed to address this issue by increasing the number of ages and lengths collected per sampled haul, but this will only affect sample sizes in 2014 and later.

The catch-at-age in 2013 was primarily ages 5-7, with the age-6 fish (2007 year class) dominant (Fig. 1.2). A mode of age-3 fish was also present in most strata. Fishery catch at age in 1976-2013 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 (fishing power correction = 3.84, SE = 1.26) (von Szalay and Brown 2001). For 1999, the biomass estimates for the NMFS bottom trawl survey and the PWS survey were simply added to obtain a total biomass estimate. The adjustment factor for the 1999 survey, (PWS + NMFS)/NMFS, was applied to other triennial surveys, and increased biomass by 1.05%.

Bottom Trawl Survey Age Composition
Estimates of numbers at age from the bottom trawl survey are obtained from random otolith samples and length frequency samples (Table 1.9). Numbers at age are 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 is used in the assessment model (Fig. 1.4). Ages are now available for the 2013 survey, and show very high estimates of age-1 pollock abundance in all areas (Fig. 1.5). In the Central and Western portion of the Gulf of Alaska, pollock of ages 4-8 were relatively abundant in all areas. After excluding the age-1 fish, mean age decreased from Shumagin area (6.7 years) to the Southeast area (4.1 years).

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 2014 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 for the acoustic backscatter detected by the two vessels in Shelikof Strait.

The 2014 biomass estimate for Shelikof Strait is 842,138 t, which is a 6% decrease from 2013, but is still larger than any other biomass estimate in Shelikof Strait since 1985. The biomass of pollock ≥43 cm (a proxy for spawning biomass) is 17% lower than the 2013 estimate, but there were fewer areas surveyed in 2014. In addition to the Shelikof Strait survey, acoustic surveys in winter 2014 covered the Shumagin Islands spawning area, Sanak Gully, Marmot Gully, and Izhut Bay. Several other surveys had been planned for winter of 2014, including Pavlof Bay, and Chirikof, but were unable to be completed due to scheduling issues with the *R/V Oscar Dyson*. The following table provides results from the 2014 winter acoustic surveys:

Area	Biomass ≥43 cm (t)	Percent	Total biomass (t)	Percent
Sanak Gully	7,318	1.3%	7,319	0.8%
Shumagin Islands	5,899	1.1%	37,346	4.1%
Shelikof Strait	539,990	96.8%	842,138	93.3%
Marmot Gully	4,605	0.8%	14,992	1.7%
Izhut Bay	178	0.0%	454	0.1%
Total	557,990		902,249	

In comparison to 2013, biomass estimates in Sanak Gully and the Shumagin Islands were much lower (45% and 59% percent declines respectively), while the decline in Marmot Gully was more modest (25% decline) (Fig. 1.6). These results suggest that spawning has become much more concentrated in Shelikof Strait than in previous years.

Acoustic Survey Age Composition
Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.7) were obtained using an age-length key compiled from random otolith samples and applied to weighted length frequency samples. Otoliths collected during the 1994-2014 acoustic surveys were aged using the criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.11.

Net selectivity corrected biomass and age composition
The selectivity of midwater trawl used during acoustic surveys was evaluated using pocket nets attached to different locations on the net. Experiments conducted in Shelikof Strait using the *R/V Miller Freeman* in 2007 and the *R/V Oscar Dyson* in 2008 and 2013 indicated that there was substantial escapement of juvenile pollock through the net mesh, resulting in a bias in estimated length composition and biomass. A hierarchical Bayesian model was developed to model net selectivity (Williams et al. 2011). The model was used to infer the true length composition from samples of fish retained in the net, resulting in corrections to both the biomass time series and estimated length and age composition. Revised biomass and age composition estimates for acoustic surveys in Shelikof Strait for 1993-2014 were evaluated in the assessment model.

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 2014 biomass estimate for pollock for the ADFG crab/groundfish survey was 100,158 t, down 2% from the 2013 biomass estimate (Table 1.7).

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, 2010, and 2012 ADFG surveys (N = 559, 538, 591,588, 597, 585, and 562) (Table 1.12, Fig. 1.8). 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.

Datasets considered but not used

Egg Production Estimates of Spawning Biomass
Estimates of spawning biomass in Shelikof Strait based on egg production methods were produced during 1981-92 (Table 1.7). A complete description of the estimation process is given in Picquelle and Megrey (1993). 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). Egg production estimates were discontinued in 1992 because the Shelikof Strait acoustic survey provided similar information. The egg production estimates are not used in the assessment model because the surveys are no longer being conducted, and because the acoustic surveys in Shelikof Strait show a similar trend over the period when both were conducted.

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 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. 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. Due to the difficulty in constructing a consistent time series, the historical survey estimates are no longer used in the assessment model.

Multi-year combined survey estimates indicate a large increase in pollock biomass in the Gulf of Alaska occurred between the early 1960s and the mid 1970s. 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.

Mueter 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. 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 1979, Alton et al. 1987). More recent work has focused on role of climate change (Anderson and Piatt 1999, Bailey 2000). Model results suggest that population biomass in the 1960s, prior to large-scale commercial exploitation of the stock, may have been lower than at any time since then.

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. 1.9). All surveys indicate a strong increase since 2008.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.10). The percent of females in the catch is close to 50-50, but shows a slight downward trend, which may be related to changes in the seasonal distribution of the catch. The percent female was 52.8% in 2013, which may indicate a reversal in the trend. 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 had been decreasing since 2008 as the fishery began to catch greater numbers of young fish from year classes recruiting to the fishery, but increased in 2013 when the 2005 year became 8 years old. Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch is approximately 7%. 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 1976-2013 (Fig. 1.10).

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 year class strength in the previous year (Table 1.13). The correlation between the abundance of age-1 pollock in the Shelikof Strait acoustic survey and subsequent estimates of year-class strength remains relatively strong based on surveys conducted after 1992 (r =0.71), and there is a stronger correlation between the abundance of age-1 pollock in the Shumagin Islands survey and year-class strength (r = 0.73). The estimate of age-1 pollock abundance in 2014 is 0.58 billion fish, which is the eighth highest in the time series. In addition, 0.13 billion age-1 pollock were estimated for the acoustic survey of the Shumagin Islands in 2014. These values are suggestive of more modest age-1 recruitment in 2014.

Analytic Approach

Model Structure

An age-structured model covering the period from 1970 to 2014 (45 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 were implemented in the 2012 assessment model: 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; reduced weights (input sample size) were used for the fishery age composition data.

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 (1970-2014)	Log-normal	CV = 0.05
Fishery age comp. (1975-2013)	Multinomial	Year-specific sample size = 20-200
Shelikof acoustic survey biomass (1992-2014)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2014)	Multinomial	Sample size = 60
NMFS bottom trawl survey biom. (1990-2013)	Log-normal	Survey-specific CV = 0.12-0.38
NMFS bottom trawl survey age comp. (1990-2013)	Multinomial	Sample size = 60
ADFG trawl survey biomass (1989-2014)	Log-normal	CV = 0.25
ADFG survey age comp. (2000, 2002, 2004, 2006, 2008, 2010, 2012)	Multinomial	Sample size = 30
Recruit process error (1970-1977, 2013, 2014)	Log-normal	σ_R =1.0

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 1970-77, and in 2013 and 2014 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.

Modeling fishery data

To accommodate changes in selectivity we estimated year-specific parameters for the slope and the intercept parameter for the ascending logistic portion of selectivity curve. Variation in these parameters was constrained using a random walk penalty.

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 estimated the NMFS bottom trawl survey catchability, but used a log normal prior with a median of 0.85 and log standard deviation 0.1 as a constraint on potential values (Fig. 1.11). Catchability coefficients for other surveys were estimated as free parameters.

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). For models where the entire time series was used, it was split into two periods corresponding to the two acoustic systems, and separate survey catchability coefficients were estimated for each period.

A vessel comparison (VC) experiment was conducted in March 2007 during the Shelikof Strait acoustic 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

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

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. This approach was used only when age composition estimates were unavailable. 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 was estimated using 1992-98 Shelikof Strait acoustic survey data and used for winter survey length frequency data. The following length bins were used: 5-16, 17 - 27, 28 - 35, 36 - 42, 43 - 50, 51 - 55, 56 - 70 (cm). Age data for the most recent survey is now routinely available so this option does not need to be invoked. A conversion matrix was estimated using second and third trimester fishery age and length data during the years (1989-98), and was used when age composition data are unavailable for the summer bottom trawl survey, which is only for the most recent survey in the year that the survey is conducted. The following length bins were used: 5-16,25 - 34, 35 - 41, 42 - 45, 46 - 50, 51 - 55, 56 - 70 (cm), so that the first four bins would capture most of the summer length distribution of the age-1, 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 1-4).

Parameters Estimated Outside the Assessment Model

Pollock life history characteristics, including natural mortality, weight at age, and maturity at age, 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 catch 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 0.22 to 0.45. The maximum age observed was 22 years. Up until this assessment, natural mortality has been 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." Clark (1999) proposed that the chance of this occurring could be reduced by using an estimate of natural mortality on the lower end of the credible range, which is the approach used in this assessment.

In this assessment, several methods to estimate of the age-specific pattern of natural mortality were evaluated. Two general types of methods were used, both of which are external to the assessment model. The first type of method is based initially on theoretical life history or ecological relationships that are then evaluated using meta-analysis, resulting in an empirical equation that relates natural mortality to some more easily measured quantity such as length or weight. The second type of method is an age-structured statistical analysis using a multispecies model or single species model where predation is modeled. There are three examples of such models for pollock in Gulf of Alaska, a single species model with predation by Hollowed et al. (2000), and two multispecies models that included pollock by Van Kirk et al. (2010 and 2012). These models were published in the peer-reviewed literature, but likely did not receive the same level of scrutiny as stock assessment models. Although these models also estimate time-varying mortality, we averaged the total mortality (residual natural mortality plus predation mortality) for the last decade in the model to obtain a mean age-specific pattern (in some cases omitting the final year when estimates were much different than previous years). Use of the last decade was an attempt to use estimates with the strongest support from the data. Approaches for inclusion of time-varying natural mortality will be considered in future pollock assessments. The three theoretical/empirical methods used were the following:

Brodziak et al. 2011—Age-specific M is given by

$$M(a) = \begin{cases} M_c \dfrac{L_{mat}}{L(a)} & for\ a < a_{mat} \\ M_c & for\ a \geq a_{mat}, \end{cases}$$

where L_{mat} is the length at maturity, M_c = 0.30 is the natural mortality at L_{mat}, L(a) is mean length at age for the summer bottom trawl survey for 1984-2013.

Lorenzen 1996—Age-specific M for ocean ecosystems is given by

$$M(a) = 3.69\ \overline{W}_a^{-0.305},$$

where $\overline{W}_a$ is the mean weight at age from the summer bottom trawl survey for 1984-2013.

Gislason et al. 2010—Age-specific M is given by

$$\ln(M) = 0.55 - 1.61\ln(L) + 1.44\ln(L_\infty) + \ln(K),$$

where L_∞ = 65.2 cm and K = 0.30 were estimated by fitting von Bertalanffy growth curves using the NLS routine in R using summer bottom trawl age data for 2005-2009 for sexes combined in the central and western Gulf of Alaska.

Results were reasonably consistent and suggest use of a higher mortality rate for age classes younger than the age at maturity (Table 1.15 and Fig. 1.12). Somewhat surprisingly the theoretical/empirical estimates were similar on average to predation model estimates. To obtain an age-specific natural mortality schedule for use in the stock assessment, we used an ensemble approach and averaged the results for all methods. Then we used the tip recommended by Clay Porch in Brodziak et al (2011) to rescale the age-specific values so that the average for range of ages equals a specified value. Age-specific values were rescaled so that a natural mortality for fish greater than or equal to age 5, the age at 50% maturity, was equal to 0.3, the value of natural mortality used in previous pollock assessments.

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 (i.e., stage 3 in the 5-stage pollock maturity scale). 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 have spawned 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 1.16).

Estimates of maturity at age in 2014 from winter acoustic surveys were much below the long-term average for ages 4-5, but slightly above average for age 6 (Fig. 1.13). 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 1983-2014 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 1.14). 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 44 cm. Since 2008 there has been an increase in the length at 50% mature to 48 cm, possibly reflecting the increase in pollock growth.

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. 1.15). For pollock greater than age 6, weight-at-age has nearly doubled since 1983-1990. However, weight at age in the last four years, 2011-2014, has been stable to decreasing. Further analyses are needed to evaluate whether these changes are a density-dependent response to declining pollock abundance, or whether they are environmentally forced. Changes in weight-at-age have potential implications for status determination and harvest control rules.

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 AD Model Builder (Version 10.1), a C++ software language extension and automatic differentiation library (Fournier et al. 2012). 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 AD Model Builder is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-6}). AD Model 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 1970-2014 = 45	Estimated as log deviances from the log mean; recruitment in 1970-77, and 2013 and 2014 constrained by random deviation process error.
Natural mortality	Age-specific= 10	Not estimated in the model
Fishing mortality	Years 1970-2014 = 45	Estimated as log deviances from the log mean
Mean fishery selectivity	4	Slope parameters estimated on a log scale, intercept parameters on an arithmetic scale
Annual changes in fishery selectivity	2 * (No. years-1) = 88	Estimated as deviations from mean selectivity and constrained by random walk process error
Survey catchability	No. of surveys + 1 = 6	Catchabilities estimated on a log scale. Two catchability periods were estimated for the acoustic survey.
Survey selectivity	8 (acoustic survey: 2, BT survey: 2, ADFG survey: 2)	Slope parameters estimated on a log scale.
Total	108 estimated parameters +88 process error parameters + 10 fixed parameters = 206	

Results

Model selection and evaluation

Model Selection

This year a number of changes were implemented to the assessment model based on the 2012 CIE review, SSC and Plan Team comments. In our response to the CIE review, we articulated several general principles to guide improvements to the assessment moving forward. Two of these principles were 1) to reduce data sets to those that are informative about current status by removing earlier and more questionable data sets, 2) improve relative weightings given to different data sets. Additionally changes were considered that would make the assessment model more realistic biologically and reduced dependence on strong assumptions. To accomplish these goals we stepped through a series of models beginning with the base model from last year's assessment. Each model in the list below adds a feature to the previous model. Generally we tried to address the objective of removing earlier and more questionable data sets first, and then considered whether changes in the model configuration were an improvement. This is, of course, one of many possible paths that could have been evaluated, but it seemed the most straightforward and logical approach to us.

Alternative models that were evaluated are listed below (note that for each model the changes are cumulative):

Model 1—include all new data.
Model 2—use the revised total catch, catch at age, and weight at age estimates, correct several minor coding errors.
Model 3—start the model in 1970, and exclude length composition data for 1964-1971.
Model 4—remove summer bottom trawl surveys for 1984 and 1987, and Shelikof Strait acoustic surveys for 1981-1991.
Model 5—estimate summer bottom trawl catchability using a prior, and assume asymptotic selectivity.
Model 6—use random walks in fishery selectivity parameter to model fishery selectivity instead of blocks, and assume no interannual variation in the descending portion of the curve.
Model 7—use age-specific natural mortality.
Model 8—use indices for the age-1 and age-2 in the acoustic survey.
Model 9—iteratively tune age composition data (this is the proposed base model).
Model 10—evaluate a net selectivity correction for acoustic surveys.

Estimated spawning biomass was plotted for each model in a series of plots, Models 1-4 (Fig. 1.16), Models 4-7 (Fig. 1.17), and Models 7-10 (Fig. 1.18). Models 1-4 showed similar patterns of spawning biomass. Neither the new data nor the re-estimated historical data had a strong influence on model results. Shifting the initial year of the assessment model to 1970 also did not have a strong influence on model results. Removing the summer bottom trawl surveys for 1984 and 1987, and Shelikof Strait acoustic surveys for 1981-1991 had a larger influence on the spawning biomass trend, but mostly during 1980-85 period.

Models 4-7 also showed similar patterns of spawning biomass. In previous assessments, the bottom trawl survey was modeled with assumed catchability of 1.0 and a domed shaped selectivity pattern. However the domed-shaped selectivity was difficult to estimate reliably. Similar biomass levels biomass levels are estimated under the assumption of asymptotic selectivity and estimated catchability, which in our view is a better way of modeling the survey. Some experimentation with estimating catchability as a free parameter, i.e., without using a prior, indicated it was feasible but that likelihood surface was very flat across a broad range of catchabilities, and the maximum could change substantially with slight changes to model assumptions. Therefore use of a prior was considered necessary to obtain a stable outcome. Due to the flatness of the likelihood surface, the posterior estimate of catchability was 0.86, very close to the prior median of 0.85.

Models 7-10 also showed similar patterns of a spawning biomass. Use of an age-specific pattern of natural mortality increases the size of estimated age-1 recruitment by a factor of about five. Selectivity patterns for the fishery and the survey also shift when a higher juvenile mortality is assumed, but the overall effect on biomass trends and management parameters is minor. Modeling the age-1 and age-2 pollock as separate indices rather including them in the age-composition multinomial likelihood also had minor effects on the model, but this was considered a better approach because it will allow evaluation of non-linearity in the relationship between the acoustic age-1 and age-2 indices and recruitment.

Model 9, which used iterative reweighting of composition data, was developed by first standardizing the input sample sizes by data set to provide initial weights for the tuning procedure. Fishery age composition was given an initial sample size of 200 except when the age sample in a given year came from fewer than 200 hauls, in which case the number of hauls was used. This scheme gave lower weight to age composition in the first couple of years of data, 1975-77, and during most years during the period 1985-1998, when the number of hauls sampled tended to be low. Both the acoustic survey and the bottom trawl were given an initial sample size of 60, and the ADFG crab/groundfish survey was given a weight of 30. Only several steps were needed for the input sample size to approximate the harmonic mean of effective N. Fishery age composition was down weighted to a sample size of 107, the bottom trawl age composition was down weighted to sample size of 28, and 3+ acoustic age composition was down weighted to sample size of 10. The ADFG survey age composition input sample size did not need to be changed. The age-1 and the age-2 acoustic indices were also iteratively reweighted using RMSE as a tuning variable. Ultimately the tuning process did not change the estimated biomass trends, but there were improvements to the fit to the survey biomass time series as a result of reweighting.

Model 10, which used the net-selectivity corrected acoustic biomass, resulted in slightly higher spawning biomass (about 15% higher over the last five years of the assessment model). Selectivity increased for the age-1 pollock, and catchability for the older pollock declined. The model estimates that less than 50% of the adult biomass spawns in Shelikof Strait (i.e., catchability<0.5), which is difficult to reconcile with information from acoustic surveys conducted elsewhere in the Gulf of Alaska. There were improvements in the fit to the age-1 and age-2 pollock indices, but the RMSE for the biomass index increased, indicating a worse fit. Ultimately we decided that additional model exploration was needed before recommending model 10. In addition, the method for making the net selectivity correction to the historical surveys needs to be reviewed prior to incorporating the revised estimates in the model. There are other issues that need to be resolved as well, such as whether other acoustic surveys the GOA need to be corrected, and how these corrections may impact the calculations for apportioning the TAC in the A and B seasons. Therefore we concluded that Model 9 should be used as the base model for model evaluation, reporting of time series estimates, and developing ABC and OFL recommendations.

Model Evaluation

Model fit to age composition data was evaluated using plots of observed and predicted age composition in the fishery (Fig. 1.19), Shelikof Strait acoustic survey (Fig. 1.20), the NMFS trawl survey (Fig. 1.21), and the ADFG trawl survey (Fig. 1.22). Model fits to fishery age composition data are adequate in most years. The largest residuals tended to be at ages 1-2 the NMFS bottom trawl survey due to inconsistencies between the initial estimates of abundance and subsequent information about year class size.

Model fits to biomass estimates are similar to previous assessments, and general trends in survey time series are fit reasonably well (Figs. 1.23 and1.24). It is difficult for the model to fit the rapid increase in the Shelikof Strait acoustic survey and the NMFS survey in 2013 since an age-structured pollock population cannot increase as rapidly as is indicated by these surveys. In contrast, the model expectation is close to the ADFG survey in 2013 and 2014. The fit to the age-1 and age-2 acoustic indices appeared adequate though variable (Fig. 1.25). There is an indication of non-linearity in the fit to age-1 index needs to be explored further.

Time series results

Parameter estimates and model output are presented in a series of tables and figures. Estimated survey and fishery selectivity for different periods are given in Table 1.17 (see also Figure 1.26). Table 1.18 gives the estimated population numbers at age for the years 1970-2014. Table 1.19 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2014 (see also Fig. 1.27). 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 approximately 60% of the proxy for unfished stock size ($B_{100\%}$ = mean 1979-2013 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR@F=0)). In 1998, the stock dropped below the $B_{40\%}$ for the first time since the early 1980s, reached a minimum in 2003 of 20% of unfished stock size. Over the years 2009-2013 stock size has shown a strong upward trend from 24% to 47% of unfished stock size, but declined to 38% of unfished stock size in 2014.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2014 indicates the current estimated trend in spawning biomass for 1990-2013 is consistent with previous estimates (Fig. 1.28, top panel). All time series show a similar pattern of decreasing spawning biomass in the 1990s, a period of greater stability in 2000s, followed by an increase starting in 2008. 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. Because of the high survey biomass estimates in 2013, a moderate retrospective pattern is evident between the current assessment and the last three assessments, where the spawning biomass has been revised upwards with each assessment. The estimated 2014 age composition from the current assessment is reasonably consistent with the projected 2014 age composition in the 2013 assessment (Fig. 1.28, bottom panel). The largest change is the estimate of the age-1 fish (2013 year class), which is much higher due to the change in the natural mortality schedule. The 2013 year class was estimated by the assessment model to be slightly below the mean based on Shelikof Strait survey results.

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 1.29 shows a retrospective plot with data sequentially removed back to 2004. There is up to 40% error in the assessment (if the current assessment is accepted as truth), but usually the errors are much smaller. There is no consistent retrospective pattern to errors in the assessment.

Stock productivity

Recruitment of Gulf of Alaska pollock is more variable (CV = 0.88) 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 other groundfish stocks 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, although this pattern appears much weaker since 2004 (Fig. 1.27). 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. 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. 1.30). 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.

Harvest Recommendations

Reference fishing mortality rates and spawning biomass levels

Since 1997, Gulf of Alaska 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 1978-2013 age-1 recruitment (5.889 billion), which is more than five times the post-1977 mean in the 2013 assessment due to the use of new natural mortality schedule. 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 2009-2014 to estimate current reproductive potential. A substantial increase in pollock weight-at-age has been observed (Fig. 1.15), which may be a density-dependent response to low abundance or due to environmental forcing. The SPR at F=0 was estimated as 0.132 kg/recruit at age one. Again this value is much lower than previous estimates due to the change in natural mortality schedule. F_{SPR} rates depend on the selectivity pattern of the fishery. Selectivity has 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 2009-2013 to reflect current selectivity patterns.

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

		Equilibrium under average 1978-2013 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	5889	2728	779	0	0.0%
40.0%	0.243	5889	1617	312	235	14.5%
35.0%	0.285	5889	1515	273	254	16.8%

The $B_{40\%}$ estimate of 312,000 t represents a 7% increase from the $B_{40\%}$ estimate of 290,000 t in the 2013 assessment, which is a mostly a result of incorporating the larger 2012 recruitment in the average. As expected, the change in the natural mortality rate had little influence on the reference point estimates. The base model projection of female spawning biomass in 2015 is 309,869 t, which is 39.7% of unfished spawning biomass (based on average post-1977 recruitment) and below $B_{40\%}$ (312,000 t), thereby placing Gulf of Alaska pollock in sub-tier “b” of Tier 3.

2015 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 85.1% 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 the 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: $0.05 < B / B^* \le 1$, *then* $F = F_{40\%} \, x \, (B/B^* - 0.05) / (1 - 0.05)$

Stock status: $B / B^* \le 0.05$, *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. 1.31).

Projections for 2015 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

The recommended ABC was based on a model projection using the base model and the more conservative adjusted $F_{40\%}$ harvest rate described above. The author’s recommended 2014 ABC is therefore 191,309 t, which is an increase of 14% from the 2014 ABC. In 2016, the ABC based an adjusted $F_{40\%}$ harvest rate is 250,824 t. The OFL in 2015 is 256,545 t, and the OFL in 2016 if the recommended ABC is taken in 2015 is 321,067 t.

In last year’s assessment, the magnitude of the 2012 year class was a major issue when deciding which ABCs and OFLs to recommend. New information about this year class came from winter acoustic surveys in 2014 in Shelikof Strait and in the Shumagin Island. This new information indicates that this year class is still very abundant. The 2014 Shelikof Strait acoustic survey estimate of age-2 pollock is 3.6 billion, which is the second largest in time series. The 2014 Shumagin acoustic survey estimate of age-2 pollock is largest in the time series. This year, all of this information is incorporated into the assessment using age-1 and age-2 abundance indices. In last year’s assessment, the possibility of setting the 2012 year class equal to the average was considered but not recommended. The new information about the magnitude of the 2012 year class added in 2014 tends to support the decision that was made in last year's assessment. Therefore we have continued the approach of using the 2012 year class abundance as estimated to project ABCs and OFLs.

To evaluate the probability that the stock will drop below the $B_{20\%}$ threshold, we projected the stock forward for five years using 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). 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 (Fig. 1.32).

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 2014 numbers at age at the start of the year as estimated by the assessment model, and assume the 2014 catch will be equal to 159,149 t (95% of the TAC). 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 1978-2013 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 2015, 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 (2010-2014). (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 2014 or 2) above 1/2 of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished)

Scenario 7: In 2015 and 2016, 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 2016, or 2) above 1/2 of its MSY level in 2016 and above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.23. Under all harvest policies, mean spawning biomass is projected to remain stable or to increase in over the next five years (Fig. 1.33). Plots of individual projection runs are highly variable (Fig. 1.34), 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 (2013) is 96,363 t, which is less than the 2013 OFL of 150,817 t. Therefore, the stock is not subject to overfishing.

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

Under scenario 6, spawning biomass is estimated to be 340,111 t in 2014, which is above $B_{35\%}$ (273,000 t). Therefore, Gulf of Alaska pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2016 is 320,665 t, which is above $B_{35\%}$ (273,000 t). 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. 1.35); 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 1.35). 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—though Seward Line monitoring now extends from 1998 to the present, and efforts are underway at AFSC to develop Euphausiid abundance indices from acoustic surveys in the Gulf of 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. 1.36). 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, 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. 1.37). 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. 1.38). 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 1.39), 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. 1.39). Size composition of pollock consumed by the western stock of Steller sea lions tend towards larger fish, and are similar to the size of cod and halibut consumed (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 1.40, 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 the 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. 1.40, 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. 1.40 (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. 1.41). 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. 1.42, 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. 1.42, 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. 1.42, 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. 1.42, 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. 1.37), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.41 and 1.42 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. 1.35. 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. 1.43 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. 1.44), 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 1.45), 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. 1.46). 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. 1.46). Since the harvest policy for pollock is a 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 correlation between Pacific halibut and arrowtooth flounder (with quite different diets apart from pollock) may be due 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. 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.

Data Gaps and Research Priorities

Based on the 2012 CIE review of the Gulf of Alaska pollock assessment, the following research priorities are identified. Additional details on recommended pollock research are included in a document provided to the GOA Plan Team in September 2013 that summarized and responded to the CIE review.

- Reduce data sets to those that are informative about current status by removing earlier and more questionable data sets, and reducing the influence of the inconsistent data earlier in the time series.
- Improve relative weightings given to different data sets.
- Consider alternative modeling platforms.
- Conduct research to develop informative priors on acoustic and trawl survey selectivity and catchability, and consider different ways to model selectivity.
- Evaluate alternative ways to model fishery and survey selectivity (including asymptotic selectivity).
- Explore implications of non-constant natural mortality on pollock assessment and management.

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Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The ABC for 2014 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 (4,163 t). Research catches are reported in Appendix D.

Year	*Foreign*	*Joint Venture*	*Domestic*	*Total*	*ABC/TAC*
1964	1,126			1,126	---
1965	2,746			2,746	---
1966	8,914			8,914	---
1967	6,272			6,272	---
1968	6,137			6,137	---
1969	17,547			17,547	---
1970	9,331		48	9,379	---
1971	9,460		0	9,460	---
1972	38,128		3	38,131	---
1973	44,966		27	44,993	---
1974	61,868		37	61,905	---
1975	59,504		0	59,504	---
1976	86,520		211	86,731	---
1977	117,833		259	118,092	150,000
1978	94,223		1,184	95,408	168,800
1979	103,278	577	2,305	106,161	168,800
1980	112,996	1,136	1,026	115,158	168,800
1981	130,323	16,856	639	147,818	168,800
1982	92,612	73,918	2,515	169,045	168,800
1983	81,318	134,171	136	215,625	256,600
1984	99,259	207,104	1,177	307,541	416,600
1985	31,587	237,860	17,453	286,900	305,000
1986	114	62,591	24,205	86,910	116,000
1987		22,823	45,248	68,070	84,000
1988		152	63,239	63,391	93,000
1989			75,585	75,585	72,200
1990			88,269	88,269	73,400
1991			100,488	100,488	103,400
1992			90,858	90,858	87,400
1993			108,909	108,909	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			125,460	125,460	124,730
1999			95,638	95,638	94,580
2000			73,080	73,080	94,960
2001			72,077	72,077	90,690
2002			51,934	51,934	53,490
2003			50,684	50,684	49,590
2004			63,844	63,844	65,660
2005			80,978	80,978	86,100
2006			71,976	71,976	81,300
2007			52,714	52,714	63,800
2008			52,584	52,584	53,590
2009			44,247	44,247	43,270
2010			76,745	76,745	77,150
2011			81,357	81,357	88,620
2012			103,982	103,982	108,440
2013			96,363	96,363	113,099
2014					167,657
Average (1977-2013)				101,601	117,952

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 2009-2013. Species are ordered according to the cumulative catch during the period. Incidental catch estimates include both retained and discarded catch.

Managed species/species group	*2009*	*2010*	*2011*	*2012*	*2013*
Pollock	39334.5	73032.9	77297.5	99643.9	91436.2
Arrowtooth Flounder	761.0	2066.8	2008.5	1328.6	1764.2
Pacific Cod	552.6	1497.2	1500.5	1267.0	1041.7
Flathead Sole	215.7	359.9	217.3	189.5	381.4
GOA Shallow Water Flatfish	17.0	78.5	289.4	171.2	182.8
Squid	320.9	129.0	208.8	6.7	346.6
Pacific Ocean Perch	36.1	96.6	172.3	294.5	426.9
GOA Rex Sole	35.5	60.3	90.0	48.8	151.1
GOA Skate, Big	33.8	47.1	92.6	47.8	211.9
Shark, pacific sleeper	31.1	155.6	3.6	3.8	15.5
Shark, salmon	6.9	103.7	5.7	53.2	3.9
GOA Shortraker Rockfish	26.2	9.4	24.4	21.8	22.6
GOA Rougheye Rockfish	12.9	30.5	34.5	21.2	8.9
Shark, spiny dogfish	17.9	19.8	16.5	19.2	11.3
Sculpin	5.0	5.9	76.0	14.3	46.8
GOA Skate, Longnose	35.1	9.8	35.0	9.0	25.2
Northern Rockfish	11.7	2.2	13.7	60.9	5.6
Sablefish	0.1	1.3	32.5	6.7	12.6
GOA Pelagic Shelf Rockfish	1.5	5.8	19.1	4.1	6.5
GOA Deep Water Flatfish	2.4	2.9	14.6	3.0	12.8
Shark, Other	10.4	3.7	1.1	3.7	1.0
Skate, Other	2.6	7.0	1.9	5.5	23.9
GOA Skate, Other	2.6	7.0	1.9	5.5	23.9
Other Rockfish	0.2	0.4	6.8	0.8	0.8
Octopus	0.1	0.8	2.3	0.4	0.3
GOA Thornyhead Rockfish	0.1	0.1	1.8	0.5	0.6
Atka Mackerel	0.0	0.4	0.1	0.3	0.4
Percent non-pollock	*5.2%*	*6.0%*	*5.9%*	*3.5%*	*4.9%*

Non target species/species group	*2009*	*2010*	*2011*	*2012*	*2013*
Eulachon	214.61	227.22	308.87	193.76	28.31
Other osmerids	146.29	6.78	78.59	88.59	12.46
Misc fish	42.05	42.44	43.49	49.89	384.76
Jellyfish	11.30	121.72	7.67	132.45	38.36
Giant Grenadier	26.30	1.93	108.99	15.75	67.56
Grenadier	0.00	9.21	7.94	70.89	0.00
Sea star	0.00	4.64	3.64	0.74	5.34
Capelin	0.01	0.00	7.94	0.02	0.02
Pandalid shrimp	0.17	1.12	0.12	0.07	0.01
Sea anemone unidentified	0.00	0.47	0.54	0.00	0.32
Snails	0.01	0.00	0.06	0.01	0.55
Stichaeidae	0.00	0.08	0.00	0.07	0.63
Benthic urochordata	0.00	0.00	0.09	0.02	0.35
Eelpouts	0.13	0.09	0.00	0.01	0.21
Bivalves	0.00	0.06	0.04	0.00	0.27
Hermit crab unidentified	0.00	0.09	0.00	0.14	0.00
Misc crabs	0.00	0.01	0.11	0.00	0.00
Sea urchins, sand dollars, sea cucumbers	0.00	0.00	0.00	0.00	0.01
Sponge unidentified	0.00	0.00	0.00	0.00	0.04
Invertebrate unidentified	0.00	0.00	0.00	0.00	0.04

Table 1.3. Bycatch of prohibited species for trawls where pollock was the predominant species in the catch in the Gulf of Alaska during 2009-2013. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of fish.

Species/species group	*2009*	*2010*	*2011*	*2012*	*2013*
Bairdi Tanner Crab (nos.)	6,612	120	10,151	729	7,993
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	3,188	44,862	14,781	18,880	13,513
Golden (Brown) King Crab (nos.)	0	0	0	0	0
Halibut (t)	63.4	48.3	191.2	94.6	257.7
Herring (t)	8.1	0.9	10.7	1.3	10.6
Non-Chinook Salmon (nos.)	317	752	1247	283	752
Opilio Tanner (Snow) Crab (nos.)	0	0	0	0	0
Red King Crab (nos.)	0	0	0	0	6

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska during 2003-2013 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*
2003	Retained	16,346	18,970	12,225	940	1,118	0	49,601	
	Discarded	166	672	210	4	31	0	1,083	2.1%
	Total	16,512	19,642	12,435	944	1,149	0	51,937	
2004	Retained	23,226	24,221	13,896	215	1,100	0	62,658	
	Discarded	282	438	428	11	26	0	1,186	1.9%
	Total	23,508	24,659	14,324	226	1,127	0	63,844	
2005	Retained	30,791	27,418	18,986	1,876	740	0	79,811	
	Discarded	136	622	350	9	50	0	1,167	1.4%
	Total	30,927	28,040	19,336	1,885	790	0	80,978	
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	17,470	18,848	13,777	84	1,046	0	51,224	
	Discarded	262	516	701	3	8	0	1,490	2.8%
	Total	17,731	19,363	14,478	87	1,055	0	52,714	
2008	Retained	15,099	18,692	13,336	1,155	613	1	48,896	
	Discarded	2,160	378	1,121	6	20	2	3,688	7.0%
	Total	17,260	19,070	14,456	1,161	633	3	52,584	
2009	Retained	14,475	13,578	10,974	1,190	1,474	0	41,692	
	Discarded	604	422	1,496	31	1	0	2,554	5.8%
	Total	15,079	14,000	12,470	1,222	1,476	0	44,247	
2010	Retained	25,960	28,015	18,373	1,625	1,660	2	75,635	
	Discarded	91	234	761	12	9	2	1,110	1.4%
	Total	26,051	28,250	19,134	1,637	1,669	4	76,745	
2011	Retained	20,472	36,112	18,987	2,268	1,535	0	79,374	
	Discarded	125	1,113	741	3	1	0	1,983	2.4%
	Total	20,597	37,225	19,728	2,271	1,536	0	81,357	
2012	Retained	27,355	44,596	25,089	2,353	2,622	0	102,014	
	Discarded	538	500	896	28	5	1	1,969	1.9%
	Total	27,893	45,095	25,986	2,381	2,627	1	103,982	
2013	Retained	7,644	52,602	28,134	2,927	2,605	0	93,913	
	Discarded	67	513	1,833	13	22	2	2,450	2.5%
	Total	7,711	53,115	29,967	2,940	2,628	2	96,363	
Average (2003-2013)		20,724	28,693	18,127	1,484	1,470	1	70,611	

Table 1.5. Catch at age (millions) of walleye pollock in the Gulf of Alaska in 1975-2013.

	Age															
Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Total*
1975	0.00	2.59	59.62	18.54	15.61	7.33	3.04	2.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	109.69
1976	0.00	1.66	20.16	108.26	35.11	14.62	3.23	2.50	1.72	0.21	0.00	0.00	0.00	0.00	0.00	187.47
1977	0.05	6.93	11.65	26.71	101.29	29.26	10.97	2.85	2.52	1.14	0.52	0.07	0.06	0.00	0.00	194.01
1978	0.31	10.87	34.64	24.38	24.27	47.04	13.58	5.77	2.15	1.32	0.57	0.05	0.04	0.01	0.00	164.99
1979	0.10	3.47	54.61	89.36	14.24	9.47	12.94	5.96	2.32	0.56	0.21	0.08	0.00	0.00	0.01	193.33
1980	0.49	9.84	27.85	58.42	42.16	13.92	10.76	9.79	4.95	1.32	0.69	0.24	0.09	0.03	0.00	180.55
1981	0.23	4.82	35.40	73.34	58.90	23.41	6.74	5.84	4.16	0.59	0.02	0.04	0.03	0.00	0.00	213.53
1982	0.04	9.52	41.68	92.53	72.56	42.91	10.94	1.71	1.10	0.70	0.05	0.03	0.02	0.00	0.00	273.80
1983	0.00	6.96	42.29	81.51	121.82	59.42	33.14	8.72	1.70	0.18	0.44	0.10	0.00	0.00	0.00	356.28
1984	0.71	5.28	62.46	66.85	81.92	122.05	43.96	14.94	4.95	0.43	0.06	0.12	0.10	0.00	0.00	403.84
1985	0.20	11.60	7.43	36.26	39.31	70.63	117.57	36.73	10.31	2.65	0.85	0.00	0.00	0.00	0.00	333.55
1986	1.00	6.05	14.67	8.80	19.45	8.27	9.01	10.90	4.35	0.74	0.00	0.00	0.00	0.00	0.00	83.26
1987	0.00	4.25	6.43	5.73	6.66	12.55	10.75	7.07	15.65	1.67	0.98	0.00	0.00	0.00	0.00	71.74
1988	0.85	8.86	12.71	19.21	16.11	10.63	5.93	2.72	0.40	5.83	0.48	0.11	0.06	0.00	0.00	83.91
1989	2.94	1.33	3.62	34.46	39.31	13.57	5.21	2.65	1.08	0.50	2.00	0.20	0.06	0.05	0.02	106.99
1990	0.00	1.15	1.45	2.14	12.43	39.17	13.99	7.93	1.91	1.70	0.11	1.08	0.03	0.10	0.19	83.37
1991	0.00	1.14	8.11	4.34	3.83	7.39	33.95	3.75	19.13	0.85	6.00	0.40	2.39	0.20	0.83	92.29
1992	0.11	1.56	3.31	21.09	22.47	11.82	8.56	17.75	5.44	6.10	1.13	2.26	0.39	0.47	0.40	102.86
1993	0.04	2.46	8.46	19.94	47.83	16.69	7.21	6.86	9.73	2.38	2.27	0.54	0.92	0.17	0.30	125.80
1994	0.06	0.88	4.16	7.60	33.41	29.84	12.00	5.28	4.72	6.10	1.29	1.17	0.25	0.07	0.06	106.90
1995	0.00	0.23	1.73	4.82	9.46	21.96	13.60	4.30	2.05	2.15	2.46	0.41	0.28	0.04	0.12	63.62
1996	0.00	0.80	1.95	1.44	4.09	5.64	10.91	11.66	3.82	1.84	0.72	1.97	0.34	0.40	0.20	45.76
1997	0.00	1.65	7.20	4.08	4.28	8.23	12.34	18.77	13.71	5.62	2.03	0.88	0.50	0.14	0.04	79.49
1998	0.56	0.19	19.38	33.10	14.54	8.58	9.75	11.36	16.51	12.01	4.33	0.91	0.59	0.16	0.12	132.08
1999	0.00	0.75	2.61	22.91	34.47	10.08	7.53	4.00	6.20	8.16	4.70	1.18	0.58	0.13	0.08	103.40
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
2012	0.03	0.66	4.64	13.49	29.83	21.43	8.94	1.95	0.43	0.18	0.23	0.16	0.04	0.07	0.08	82.15
2013	0.58	2.70	10.20	5.31	13.00	17.18	12.57	5.13	1.01	0.53	0.30	0.18	0.28	0.22	0.04	69.23

Table 1.6. Number of aged and measured fish in the Gulf of Alaska pollock fishery used to estimate fishery age composition (1989-2013).

	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
2012	1,160	1,097	2,257	11,045	10,430	21,475
2013	683	774	1,457	3,565	4,084	7,649

Table 1.7. Biomass estimates (t) of walleye pollock from 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. An adjustment of +1.05% was made to the NMFS bottom trawl biomass time series to account for unsurveyed biomass in Prince William Sound. In 2001, when the NMFS bottom trawl survey did not extend east of 147^{o} W lon., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

	Shelikof Strait acoustic survey					
	R/V Miller Freeman					
Year	*Biosonics*	*EK500*	*R/V Oscar Dyson*	*NMFS bottom trawl west of 140^{o} W lon.*	*Shelikof Strait egg production*	*ADFG crab/groundfish 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		713,429			616,000	127,359
1993		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
2013			891,261	957,817		102,406
2014			842,138			100,158

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

				Number aged			*Number measured*		
Year	*No. of tows*	*No. of tows with pollock*	*Survey biomass CV*	*Males*	*Females*	*Total*	*Males*	*Females*	*Total*
1984	929	536	0.14	1,119	1,394	2,513	8,985	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	11,852	13,832	27,327
2013	548	439	0.21	763	784	1,547	14,941	16,680	31,880

Table 1.9. Estimated number at age (millions) 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
2013	750.15	62.07	47.95	65.43	84.78	144.80	157.23	115.85	25.15	5.46	2.42	2.49	3.86	3.10	0.94	1471.68

Table 1.10. Estimated number at age (millions) for the acoustic survey in Shelikof Strait.

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
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
2013	6,324.25	149.42	803.34	60.86	68.82	114.18	65.16	49.14	11.92	5.40	5.74	0.61	1.69	4.82	2.61	7,667.95
2014	575.69	3,640.17	19.09	295.35	86.87	58.48	99.51	54.93	25.79	17.75	7.40	0.71	2.30	0.00	0.67	4,884.69

Table 1.11. Survey sampling effort and estimation uncertainty for pollock in the Shelikof Strait acoustic survey. Survey CVs based on a cluster sampling design are reported for 1981-91, while relative estimation error using a geostatistical method are reported for 1992-2014.

Year	*No. of midwater tows*	*No. of bottom trawl tows*	*Survey biomass CV*	*Number aged*			*Number measured*		
				Males	*Females*	*Total*	*Males*	*Females*	*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
2013	29	5	0.05	376	386	778	2,198	2,436	8,158
2014	19	2	0.05	389	430	854	3,940	3,377	10,841

Table 1.12. Estimated proportions at age for the ADFG crab/groundfish survey, 2000-2012.

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Sample size*
2000	0.0372	0.0260	0.0948	0.0781	0.1171	0.1766	0.1078	0.0539	0.0651	0.0613	0.0985	0.0595	0.0167	0.0056	0.0019	538
2002	0.0093	0.0743	0.1840	0.1933	0.1487	0.1171	0.1059	0.0706	0.0446	0.0186	0.0149	0.0093	0.0037	0.0037	0.0019	538
2004	0.0051	0.0084	0.0572	0.1987	0.2626	0.1498	0.1077	0.0673	0.0589	0.0387	0.0152	0.0135	0.0084	0.0084	0.0000	594
2006	0.0051	0.0423	0.1117	0.0829	0.1472	0.3012	0.1658	0.0592	0.0355	0.0288	0.0118	0.0034	0.0017	0.0000	0.0034	591
2008	0.0000	0.0352	0.4070	0.1340	0.0536	0.0670	0.0436	0.1541	0.0452	0.0134	0.0218	0.0184	0.0034	0.0034	0.0000	597
2010	0.0017	0.0444	0.1402	0.2650	0.2598	0.0838	0.0564	0.0188	0.0376	0.0291	0.0359	0.0137	0.0068	0.0034	0.0034	585
2012	0.0177	0.0212	0.0637	0.1027	0.1575	0.2991	0.1823	0.0708	0.0301	0.0212	0.0124	0.0071	0.0071	0.0053	0.0018	565

Table 1.13. Predictions of Gulf of Alaska pollock year-class strength. The McKelvey index is the estimated abundance of 9-16 cm pollock (billions) from the Shelikof Strait acoustic survey.

Year class	*Year of acoustic survey*	*McKelvey index*	*Rank abundance of McKelvey index*
1980	1981	0.078	18
1981			
1982	1983	0.001	30
1983	1984	0.062	21
1984	1985	2.092	4
1985	1986	0.579	7
1986			
1987	1988	0.017	28
1988	1989	0.399	9
1989	1990	0.049	26
1990	1991	0.022	27
1991	1992	0.228	13
1992	1993	0.063	20
1993	1994	0.186	14
1994	1995	10.688	1
1995	1996	0.061	22
1996	1997	0.070	19
1997	1998	0.395	10
1998			
1999	2000	4.484	3
2000	2001	0.291	12
2001	2002	0.008	29
2002	2003	0.051	25
2003	2004	0.053	24
2004	2005	1.626	5
2005	2006	0.162	15
2006	2007	0.054	23
2007	2008	1.368	6
2008	2009	0.332	11
2009	2010	0.090	17
2010			
2011	2012	0.095	16
2012	2013	6.324	2
2013	2014	0.576	8

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. Estimates of natural mortality at age using alternative methods. The rescaled average has mean natural mortality of 0.30 for ages greater than or equal to the age at maturity.

Age	*Length (cm)*	*Weight (g)*	*Brodziak et al. 2010*	*Lorenzen 1996*	*Gislason et al. 2010*	*Hollowed et al. 2000*	*Van Kirk et al. 2010*	*Van Kirk et al. 2012*	*Average*	*Rescaled Avg.*
1	15.3	26.5	0.97	1.36	2.62	0.86	2.31	2.00	1.69	1.39
2	27.4	166.7	0.54	0.78	1.02	0.76	1.01	0.95	0.84	0.69
3	36.8	406.4	0.40	0.59	0.64	0.58	0.58	0.73	0.59	0.48
4	44.9	752.4	0.33	0.49	0.46	0.49	0.37	0.57	0.45	0.37
5	49.2	966.0	0.30	0.45	0.40	0.41	0.36	0.53	0.41	0.34
6	52.5	1154.2	0.30	0.43	0.36	0.38	0.28	0.47	0.37	0.30
7	55.1	1273.5	0.30	0.42	0.33	0.38	0.30	0.46	0.36	0.30
8	57.4	1421.7	0.30	0.40	0.31	0.38	0.29	0.43	0.35	0.29
9	60.3	1624.8	0.30	0.39	0.29	0.39	0.29	0.42	0.35	0.28
10	61.1	1599.6	0.30	0.39	0.28	0.39	0.33	0.40	0.35	0.29

Table 1.16. Proportion mature at age for female pollock based on maturity stage data collected during winter acoustic surveys in the Gulf of Alaska (1983-2014).

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
2013	0.000	0.000	0.240	0.896	0.941	0.950	0.939	1.000	1.000	622
2014	0.000	0.000	0.074	0.086	0.967	0.952	1.000	1.000	1.000	430
Average										
All years	0.000	0.016	0.254	0.558	0.830	0.919	0.965	0.986	0.992	
2004-2014	0.000	0.000	0.276	0.580	0.877	0.945	0.987	0.995	1.000	
2009-2014	0.000	0.000	0.203	0.570	0.883	0.980	0.988	1.000	1.000	

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	*Foreign (1970-81)*	*Foreign and JV (1982-1988)*	*Domestic (1989-2000)*	*Domestic (2001-2007)*	*Recent domestic (2008-2014)*	*Acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.004	0.002	0.015	0.006	0.450	0.125	0.004
2	0.011	0.028	0.013	0.087	0.046	0.865	0.212	0.037
3	0.123	0.183	0.075	0.372	0.275	1.000	0.339	0.271
4	0.632	0.624	0.334	0.773	0.740	1.000	0.494	0.784
5	0.955	0.925	0.758	0.954	0.960	0.999	0.653	0.973
6	0.997	0.991	0.958	0.994	0.996	0.997	0.787	0.997
7	1.000	1.000	1.000	1.000	1.000	0.987	0.883	1.000
8	0.991	0.992	0.998	0.992	0.991	0.947	0.944	1.000
9	0.879	0.880	0.886	0.880	0.879	0.812	0.980	1.000
10	0.347	0.347	0.349	0.347	0.347	0.509	1.000	1.000

Table 1.18. Total estimated abundance at age (millions) of Gulf of Alaska pollock from the age-structured assessment model.

	Age									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1970	1,220	304	188	130	92	69	51	38	29	85
1971	3,287	304	152	116	88	63	49	36	27	84
1972	3,712	819	152	94	78	60	45	35	26	82
1973	10,753	924	410	92	57	46	37	28	21	74
1974	2,192	2,678	462	245	54	32	26	21	16	63
1975	2,210	546	1,338	274	136	28	17	14	11	51
1976	8,712	550	273	806	165	79	16	10	8	42
1977	11,881	2,169	275	163	463	89	44	9	6	34
1978	14,600	2,958	1,084	163	90	236	47	23	5	25
1979	25,906	3,635	1,478	643	91	47	127	25	13	20
1980	13,022	6,451	1,818	883	375	51	27	73	15	21
1981	7,251	3,243	3,230	1,104	547	222	31	17	45	24
1982	7,339	1,806	1,624	1,967	701	338	141	20	11	47
1983	5,282	1,827	903	983	1,253	444	222	92	13	41
1984	6,032	1,315	912	539	609	772	283	141	60	38
1985	15,278	1,501	654	537	322	356	466	171	86	64
1986	4,708	3,803	749	390	320	180	203	264	98	95
1987	1,857	1,172	1,902	456	255	210	122	138	181	138
1988	5,029	462	587	1,166	304	171	146	85	96	230
1989	11,962	1,252	232	360	779	205	120	102	60	238
1990	8,431	2,979	627	142	239	519	141	82	71	216
1991	3,295	2,100	1,493	386	95	159	353	96	56	206
1992	2,416	821	1,052	918	259	62	105	230	63	185
1993	1,594	602	411	647	614	168	41	68	151	175
1994	1,731	397	301	252	429	397	110	27	45	227
1995	6,493	431	199	185	167	278	261	72	18	193
1996	3,171	1,617	216	122	124	112	190	178	50	152
1997	1,440	790	810	133	82	84	77	131	123	146
1998	1,405	359	395	496	87	52	53	48	83	184
1999	1,726	350	179	238	307	49	29	29	27	172
2000	6,176	430	175	108	150	179	29	17	17	134
2001	6,748	1,538	215	106	70	92	111	18	10	105
2002	871	1,679	767	129	66	42	57	68	11	80
2003	749	217	835	457	81	42	27	37	45	65
2004	699	186	108	499	293	53	28	18	25	78
2005	1,880	174	92	63	313	187	35	19	12	73
2006	5,441	467	86	53	38	192	119	22	12	60
2007	5,215	1,352	231	50	32	24	122	75	14	51
2008	6,872	1,297	670	136	31	21	16	81	51	46
2009	3,808	1,710	646	399	86	20	14	11	55	69
2010	1,697	948	854	389	261	58	14	10	7	90
2011	6,003	422	473	511	250	170	39	10	7	70
2012	818	1,495	211	285	328	162	114	26	6	55
2013	15,058	204	748	128	183	209	106	75	18	44
2014	4,134	3,750	102	454	83	118	139	71	51	44
Average	5,780	1,423	674	409	254	159	101	64	41	98

Table 1.19. Estimates of population biomass, recruitment, and harvest of Gulf of Alaska pollock from the age-structured assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

Year	3+ total biomass (1,000 t)	Female spawn. biom. (1,000	Age 1 recruits (million)	Catch (t)	Harvest rate	2013 Assessment results 3+ total biomass	Female spawn. biom.	Age 1 recruits	Harvest rate
1977	757	138	11,881	118,092	16%	774	160	2,748	15%
1978	915	130	14,600	95,408	10%	966	162	2,947	10%
1979	1,280	133	25,906	106,161	8%	1,431	174	5,103	7%
1980	1,743	174	13,022	115,158	7%	1,954	238	2,791	6%
1981	2,694	179	7,251	147,818	5%	2,871	243	610	5%
1982	2,935	270	7,339	169,045	6%	3,284	352	839	5%
1983	2,771	407	5,282	215,625	8%	2,941	521	365	7%
1984	2,425	464	6,032	307,541	13%	2,459	591	682	13%
1985	1,983	446	15,278	286,900	14%	1,848	547	2,686	16%
1986	1,624	404	4,708	86,910	5%	1,483	462	1,003	6%
1987	1,996	377	1,857	68,070	3%	1,703	396	225	4%
1988	1,910	384	5,029	63,391	3%	1,714	380	462	4%
1989	1,731	426	11,962	75,585	4%	1,594	400	2,302	5%
1990	1,575	408	8,431	88,269	6%	1,370	381	1,294	6%
1991	1,757	405	3,295	100,488	6%	1,498	374	498	7%
1992	2,118	375	2,416	90,858	4%	1,795	341	305	5%
1993	1,845	407	1,594	108,909	6%	1,605	369	196	7%
1994	1,539	453	1,731	107,335	7%	1,332	412	253	8%
1995	1,286	410	6,493	72,618	6%	1,113	370	1,289	7%
1996	1,077	373	3,171	51,263	5%	910	328	451	6%
1997	1,108	327	1,440	90,130	8%	939	279	202	10%
1998	982	251	1,405	125,460	13%	849	213	227	15%
1999	782	224	1,726	95,638	12%	672	193	222	14%
2000	689	207	6,176	73,080	11%	588	179	1,184	12%
2001	655	201	6,748	72,077	11%	539	173	948	13%
2002	821	170	871	51,934	6%	679	144	152	8%
2003	1,025	157	749	50,684	5%	796	134	131	6%
2004	835	166	699	63,844	8%	699	141	103	9%
2005	687	208	1,880	80,978	12%	582	178	472	14%
2006	588	218	5,441	71,976	12%	496	182	893	15%
2007	561	196	5,215	52,714	9%	485	162	783	11%
2008	856	192	6,872	52,584	6%	723	161	1,300	7%
2009	1,292	188	3,808	44,247	3%	1,067	163	534	4%
2010	1,468	253	1,697	76,745	5%	1,269	230	209	6%
2011	1,367	299	6,003	81,357	6%	1,203	279	758	7%
2012	1,263	326	818	103,982	8%	1,105	306	156	9%
2013	1,321	366	15,058	96,363	7%	1,074	340	4,084	9%
2014	1,201	297	4,134						
Average									
1977-2013	1,412	290	6,051	101,601	8%	1,308	288	1,065	9%
1978-2013			5,889					963	

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

Year	*Age-1 Recruits (millions)*	*CV*	*Lower 95% CI*	*Upper 95% CI*	*Spawning biomass (1,000 t)*	*CV*	*Lower 95% CI*	*Upper 95% CI*
1970	1,220	0.26	736	2,023	140	0.26	84	232
1971	3,287	0.36	1,650	6,547	134	0.27	79	226
1972	3,712	0.30	2,082	6,618	123	0.29	71	214
1973	10,753	0.14	8,234	14,042	103	0.32	55	191
1974	2,192	0.25	1,361	3,532	89	0.31	49	162
1975	2,210	0.23	1,409	3,469	88	0.25	55	143
1976	8,712	0.16	6,360	11,935	120	0.17	87	167
1977	11,881	0.16	8,772	16,092	138	0.16	101	190
1978	14,600	0.15	10,805	19,727	130	0.19	90	189
1979	25,906	0.13	20,098	33,392	133	0.20	89	197
1980	13,022	0.16	9,494	17,861	174	0.19	120	251
1981	7,251	0.19	4,967	10,585	179	0.17	129	248
1982	7,339	0.19	5,040	10,685	270	0.15	203	360
1983	5,282	0.27	3,116	8,952	407	0.14	311	532
1984	6,032	0.25	3,700	9,834	464	0.15	350	617
1985	15,278	0.13	11,801	19,780	446	0.16	326	611
1986	4,708	0.22	3,066	7,228	404	0.18	287	570
1987	1,857	0.34	969	3,557	377	0.17	271	523
1988	5,029	0.19	3,483	7,262	384	0.15	285	518
1989	11,962	0.12	9,489	15,079	426	0.13	331	549
1990	8,431	0.13	6,500	10,935	408	0.12	323	515
1991	3,295	0.21	2,182	4,975	405	0.12	321	512
1992	2,416	0.21	1,599	3,652	375	0.11	299	469
1993	1,594	0.23	1,012	2,510	407	0.11	332	500
1994	1,731	0.22	1,131	2,649	453	0.10	373	551
1995	6,493	0.10	5,318	7,928	410	0.10	337	499
1996	3,171	0.14	2,433	4,134	373	0.10	306	453
1997	1,440	0.19	988	2,099	327	0.10	267	399
1998	1,405	0.18	993	1,990	251	0.11	202	310
1999	1,726	0.16	1,260	2,364	224	0.11	179	280
2000	6,176	0.10	5,101	7,478	207	0.12	164	260
2001	6,748	0.09	5,656	8,050	201	0.12	158	256
2002	871	0.23	557	1,360	170	0.13	132	220
2003	749	0.20	508	1,105	157	0.13	122	202
2004	699	0.21	463	1,057	166	0.11	134	205
2005	1,880	0.14	1,418	2,493	208	0.11	169	257
2006	5,441	0.11	4,363	6,785	218	0.11	175	271
2007	5,216	0.12	4,109	6,621	196	0.12	154	249
2008	6,872	0.12	5,415	8,720	192	0.13	150	247
2009	3,808	0.16	2,798	5,184	188	0.12	148	240
2010	1,697	0.27	1,004	2,869	253	0.11	203	316
2011	6,003	0.22	3,901	9,237	299	0.11	241	371
2012	818	0.63	265	2,526	326	0.11	261	407
2013	15,058	0.34	7,832	28,950	366	0.12	289	463
2014	4,134	0.84	992	17,233	297	0.13	232	381

Table 1.21. Gulf of Alaska pollock life history and fishery vectors used to estimate spawning biomass per recruit (F_{SPR}) harvest rates. Spawning weight at age is based on an average from the Shelikof Strait acoustic survey conducted in March. Population weight at age is based on a average for the bottom trawl survey conducted in June to August. Proportion mature females is the average from winter acoustic survey specimen data for 1983-2014.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2009-2013)*	*Spawning (Avg. 2009-2014)*	*Population (Avg. 2009-2013)*	*Fishery (Avg. 2009-2013)*	*Proportion mature females*
1	1.39	0.005	0.010	0.038	0.125	0.000
2	0.69	0.044	0.084	0.244	0.378	0.000
3	0.48	0.272	0.285	0.495	0.642	0.016
4	0.37	0.741	0.613	0.919	0.978	0.254
5	0.34	0.960	0.925	1.202	1.218	0.558
6	0.30	0.996	1.271	1.481	1.497	0.830
7	0.30	1.000	1.582	1.640	1.665	0.919
8	0.29	0.991	1.792	1.766	1.898	0.965
9	0.28	0.879	1.949	1.924	2.096	0.986
10+	0.29	0.347	2.032	2.068	2.143	0.992

Table 1.22. Methods used to assess Gulf of Alaska pollock, 1977-2013. The basis for catch recommendation in 1977-1989 is the presumptive method by which the ABC was determined (based on the assessment and SSC minutes). The basis for catch recommendation given in 1990-2013 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
2012	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	297,000
2013	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	290,000

Table 1.23. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2014-2027 under different harvest policies. All projections begin with estimated age composition in 2014 using the base run model with a projected 2014 catch of 159,149 t (95% of the ABC). The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 779,000, 312,000 and 273,000 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}
2014	340,111	340,111	340,111	340,111	340,111	340,111	340,111
2015	307,899	309,869	314,535	317,301	321,152	305,746	307,899
2016	320,665	330,497	357,339	373,684	397,609	309,565	320,665
2017	342,977	357,051	412,328	444,724	494,109	323,091	340,489
2018	359,084	372,885	464,341	516,131	598,293	330,175	344,612
2019	349,307	361,603	479,224	546,771	658,336	316,122	326,113
2020	340,484	352,826	484,365	563,399	698,559	307,530	313,250
2021	337,374	349,711	488,031	575,420	729,062	305,201	308,296
2022	335,835	348,101	489,344	582,432	749,409	304,281	305,886
2023	334,333	346,520	488,155	584,249	758,365	303,199	304,044
2024	333,790	345,938	487,280	585,626	765,519	302,926	303,378
2025	335,255	347,365	488,417	588,359	772,498	304,453	304,699
2026	338,099	350,241	491,590	592,951	780,649	307,162	307,298
2027	338,170	350,279	492,357	594,937	785,586	306,982	307,058
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}
2014	0.17	0.17	0.17	0.17	0	0.17	0.17
2015	0.24	0.20	0.12	0.07	0	0.28	0.24
2016	0.24	0.22	0.12	0.07	0	0.28	0.24
2017	0.24	0.24	0.12	0.07	0	0.29	0.29
2018	0.24	0.24	0.12	0.07	0	0.28	0.29
2019	0.24	0.22	0.12	0.07	0	0.26	0.27
2020	0.22	0.21	0.12	0.07	0	0.25	0.25
2021	0.22	0.21	0.12	0.07	0	0.24	0.25
2022	0.22	0.20	0.12	0.07	0	0.24	0.24
2023	0.22	0.20	0.12	0.07	0	0.24	0.24
2024	0.22	0.20	0.12	0.07	0	0.24	0.24
2025	0.22	0.20	0.12	0.07	0	0.24	0.24
2026	0.22	0.20	0.12	0.07	0	0.24	0.24
2027	0.22	0.20	0.12	0.07	0	0.24	0.24
Catch (t)	*Max* F_{ABC}	*Author's recommended F*	*Average F*	$F_{75\%}$	$F = 0$	F_{OFL}	*Max* F_{ABC} *for two years, then* F_{OFL}
2014	159,149	159,149	159,149	159,149	159,149	159,149	159,149
2015	222,774	191,309	114,537	67,485	0	256,545	222,774
2016	272,165	250,824	147,426	89,224	0	307,150	272,165
2017	264,986	266,206	153,308	95,355	0	294,778	306,619
2018	258,976	261,455	157,512	100,180	0	282,741	291,479
2019	249,963	243,091	158,838	102,596	0	261,639	269,941
2020	239,779	232,891	159,841	104,191	0	251,158	255,157
2021	235,636	229,597	160,693	105,545	0	248,436	250,157
2022	225,721	219,686	152,261	99,487	0	239,729	240,202
2023	227,144	221,045	153,423	100,588	0	241,680	241,815
2024	229,576	223,700	154,303	101,180	0	244,868	244,898
2025	231,950	225,817	155,365	101,901	0	247,321	247,331
2026	232,797	227,051	155,479	102,036	0	248,402	248,405
2027	229,537	223,573	154,175	101,332	0	244,489	244,490

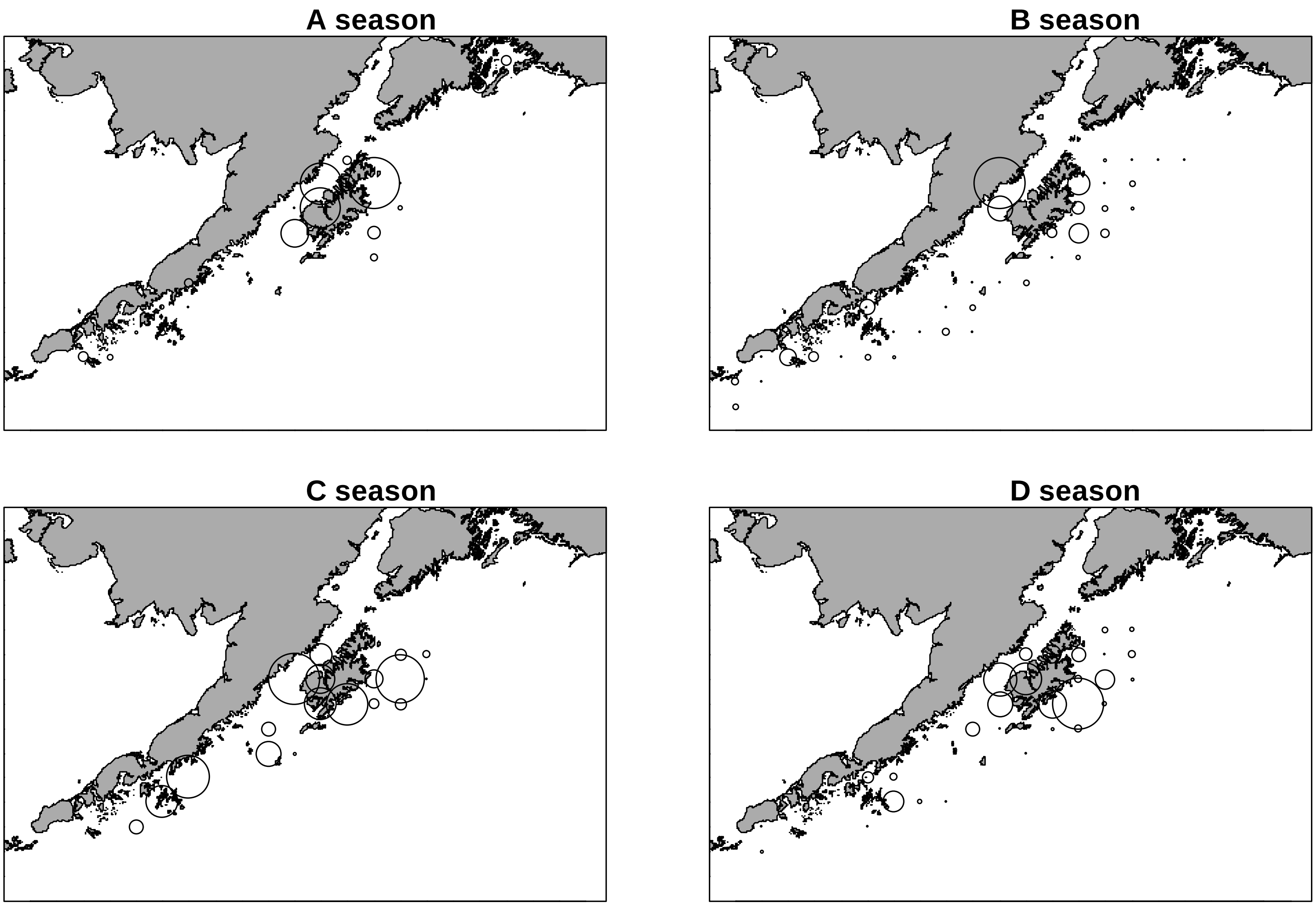


Figure 1.1. Pollock catch in 2013 for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

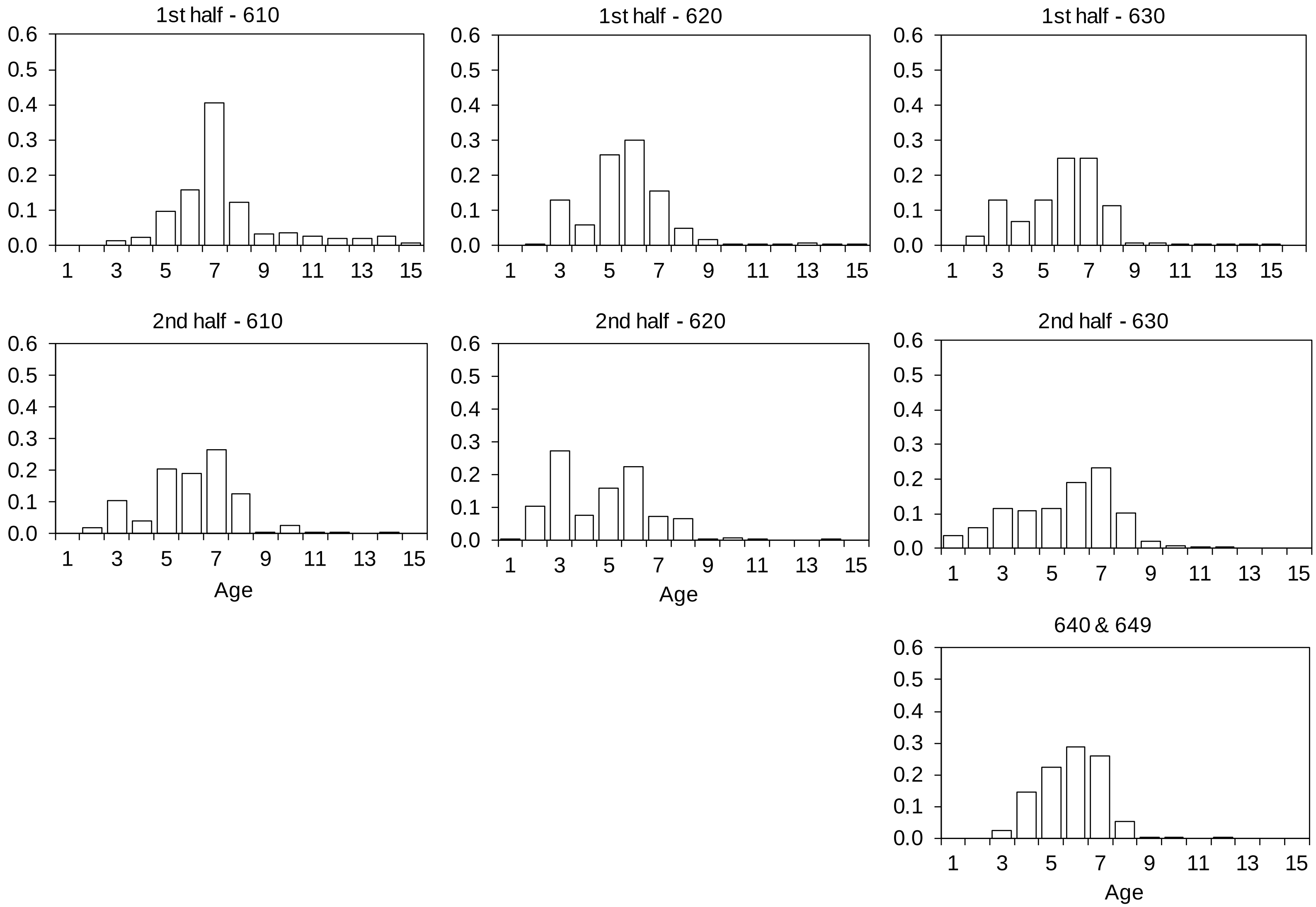


Figure 1.2. 2013 fishery age composition by half year (January-June, July-December) and statistical area.

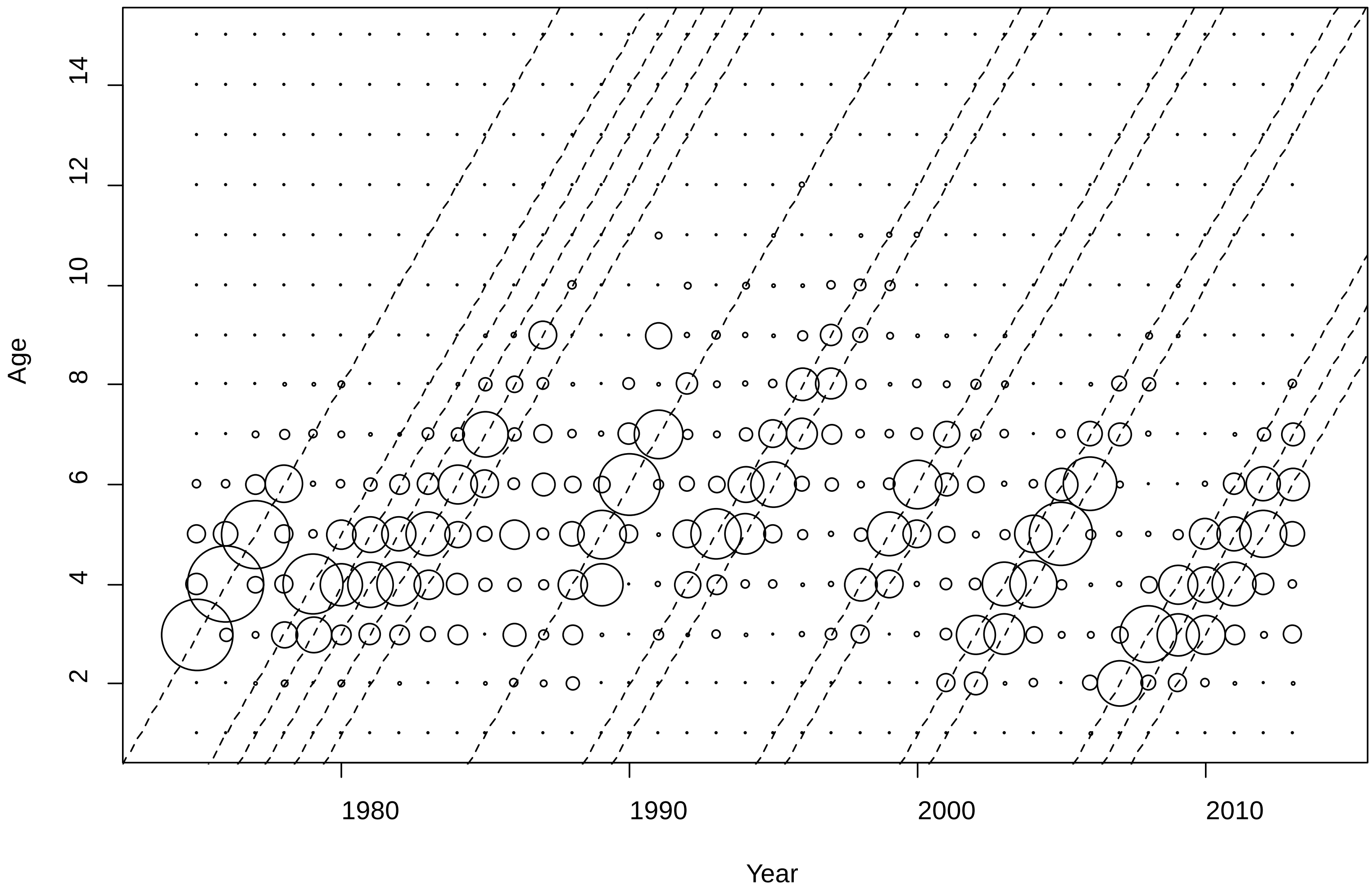


Figure 1.3. Gulf of Alaska pollock fishery age composition (1975-2013). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, 1994, 1995, 1999, 2000, 2005, 2006, and 2007).

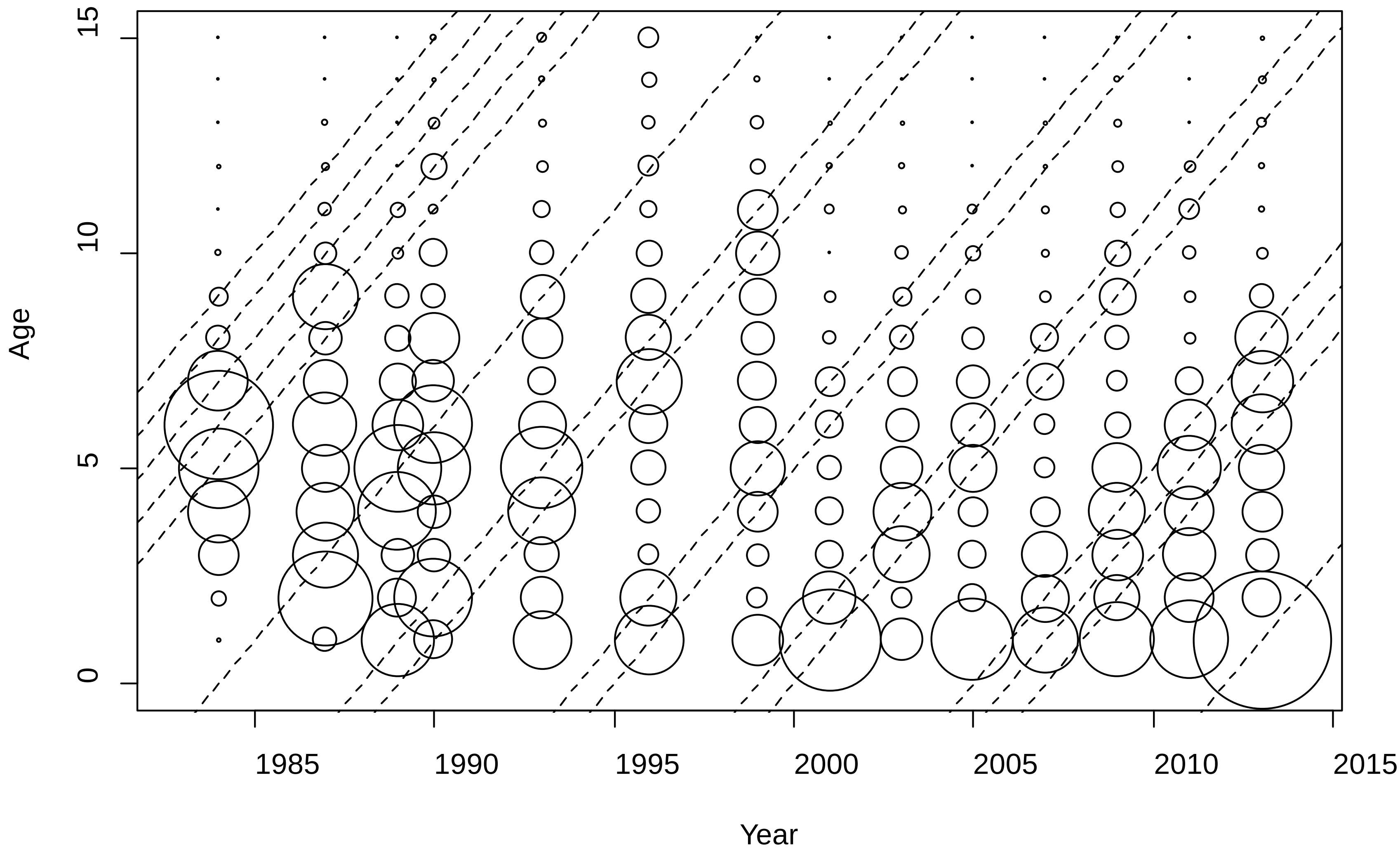


Figure 1.4. Estimated abundance at age in the NMFS bottom trawl survey (1984-2013). The area of the circle is proportional to the estimated abundance.

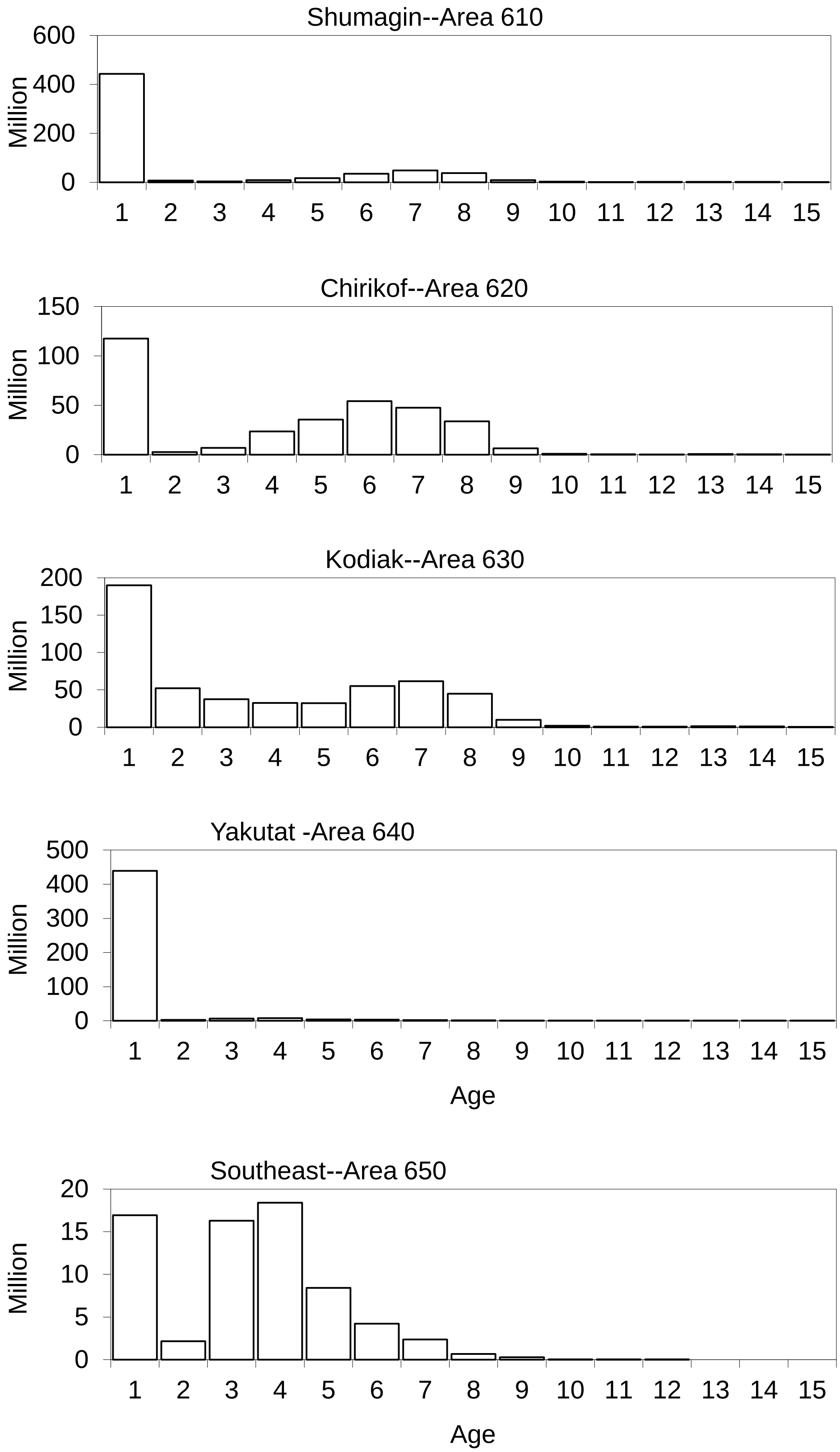


Figure 1.5. Age composition of pollock by statistical area for the 2013 NMFS bottom trawl survey.

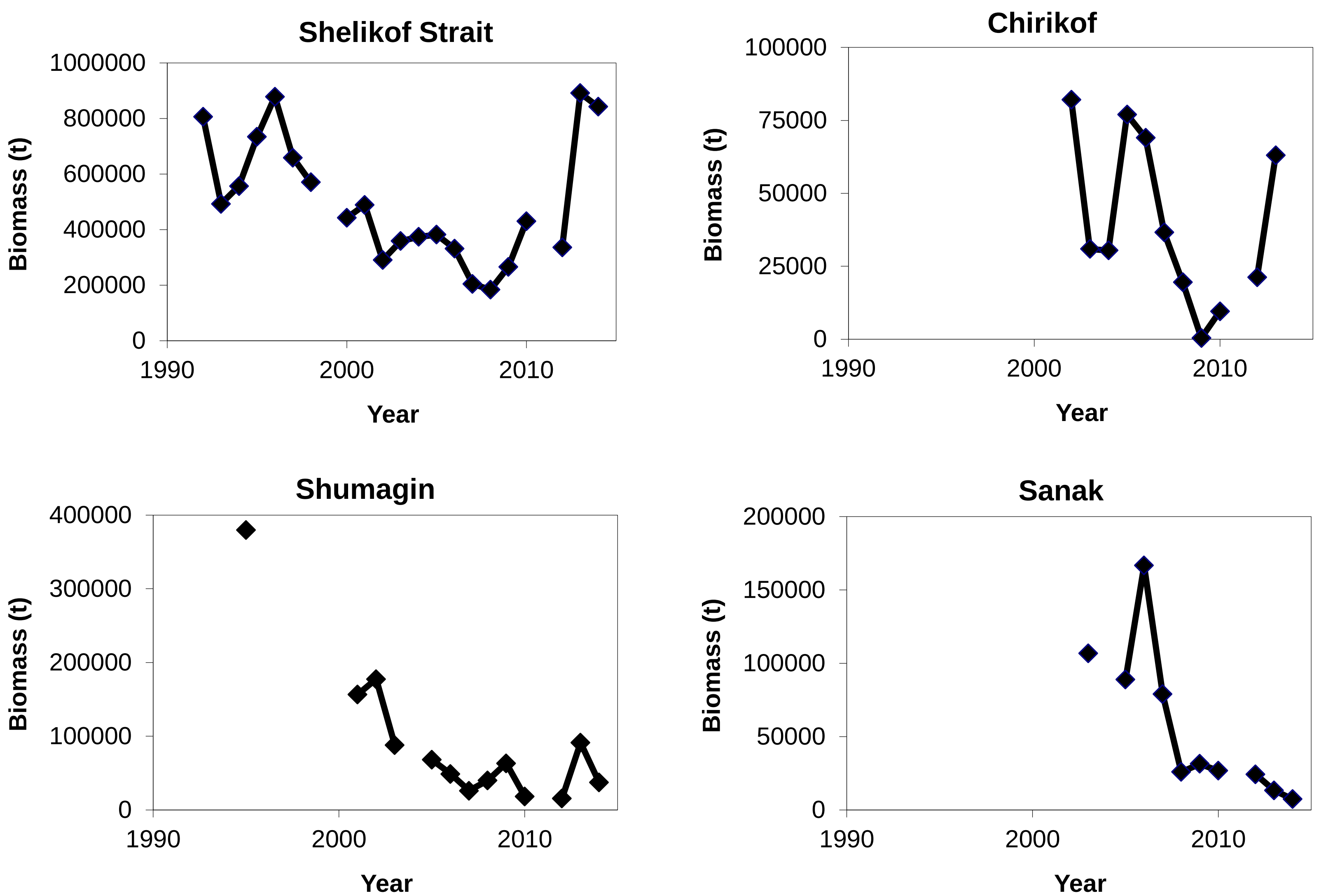


Figure 1.6. Trends in biomass estimates from winter acoustic surveys of pre-spawning aggregations of pollock in the Gulf of Alaska. No survey was conducted in the Chirikof area in 2014.

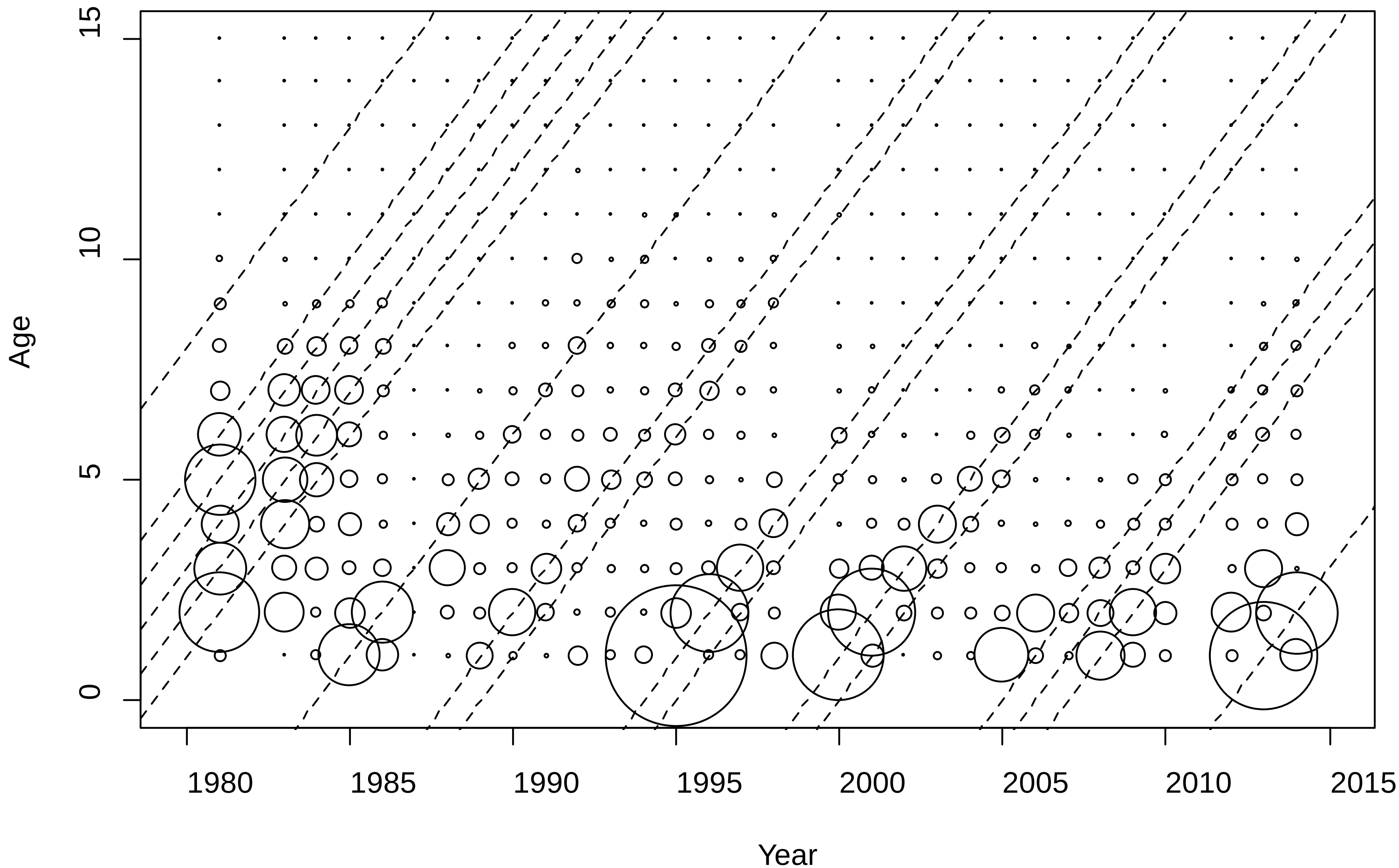


Figure 1.7. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2014, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

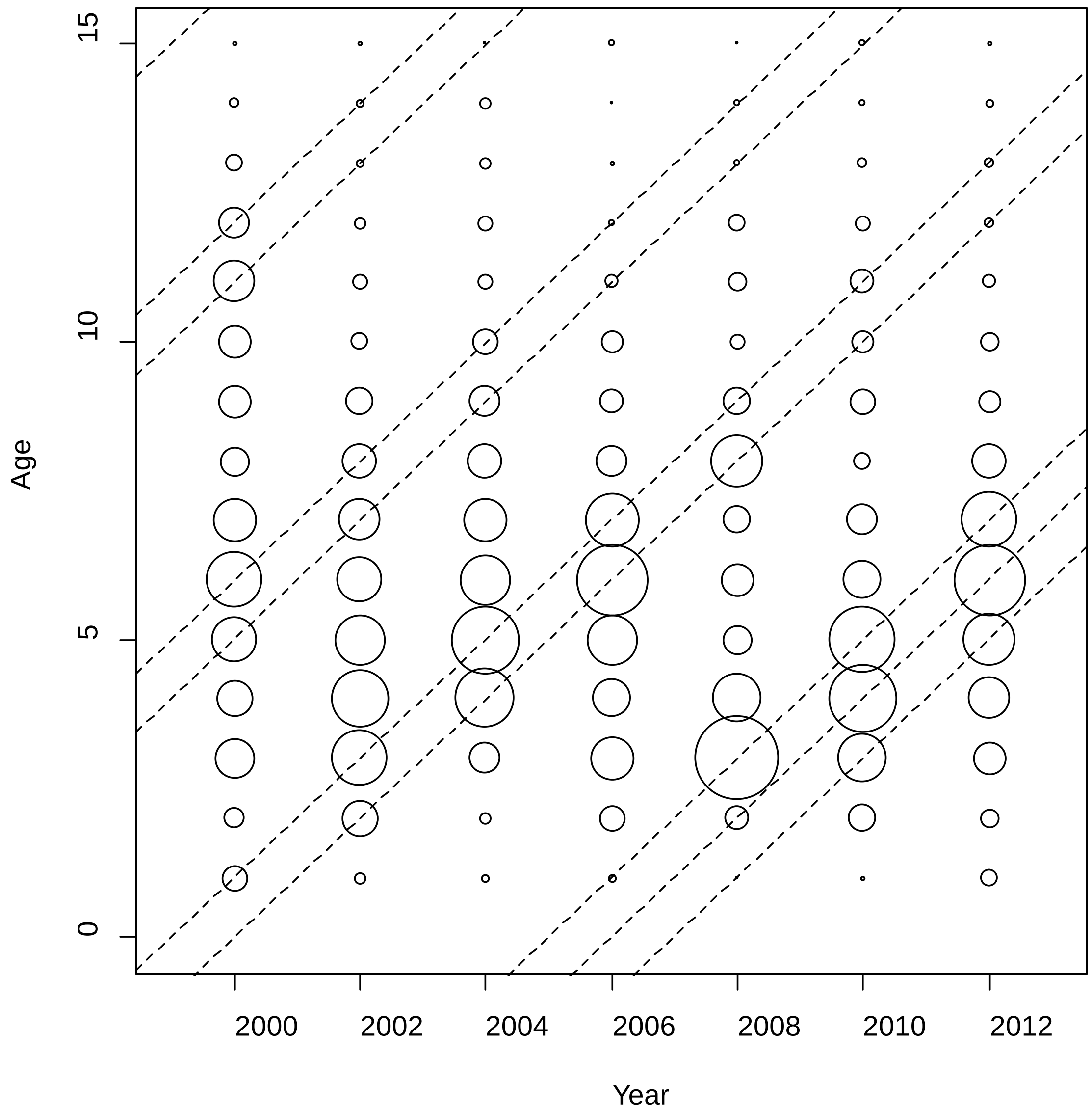


Figure 1.8. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2012). The area of the circle is proportional to the estimated abundance.

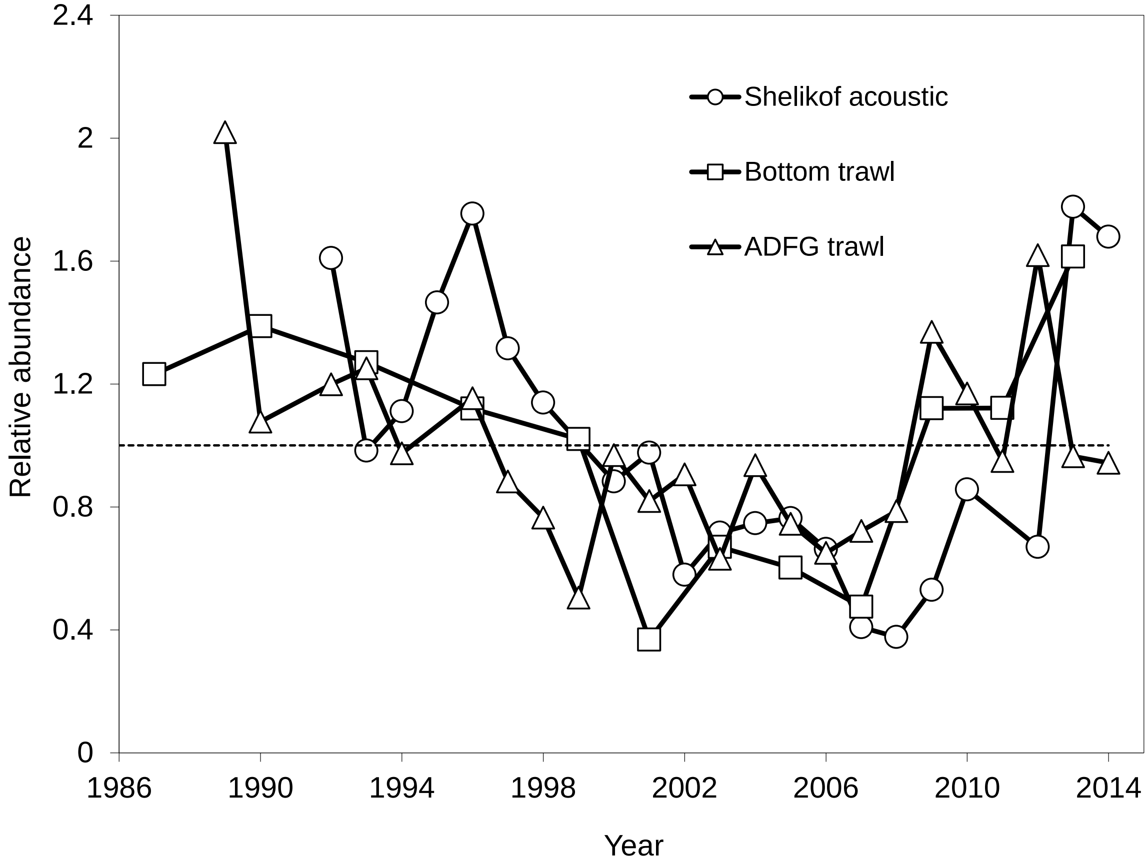


Figure 1.9. Relative trends in pollock biomass since 1987 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADFG crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987. Shelikof Strait acoustic surveys prior to 2008 were re-scaled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

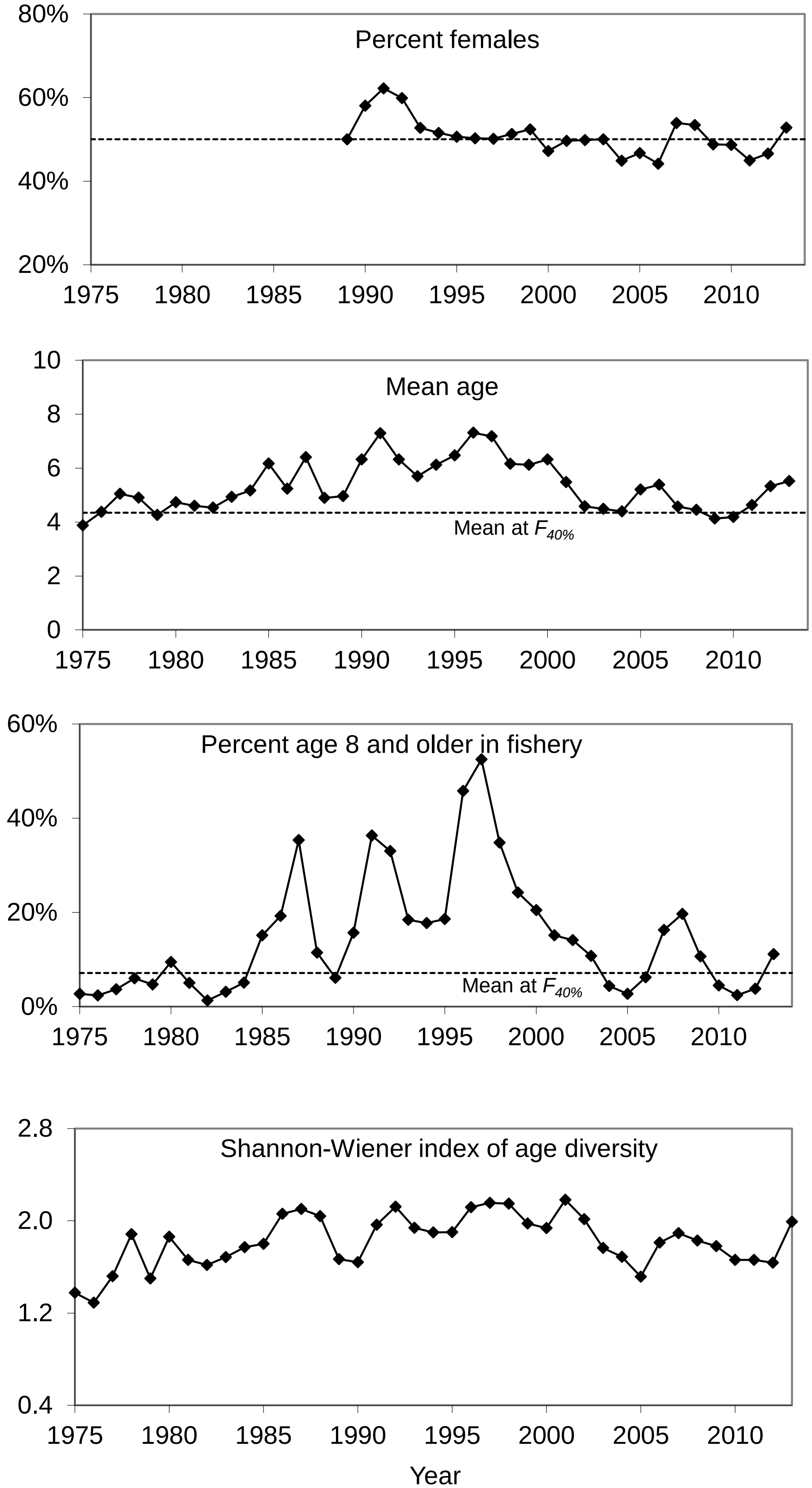


Figure 1.10. Gulf of Alaska pollock fishery catch characteristics.

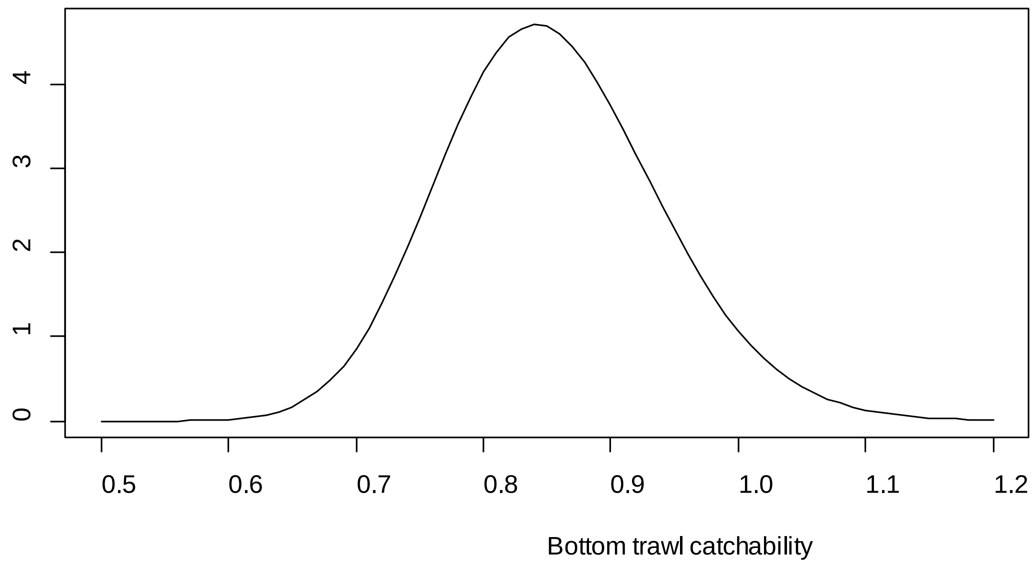


Figure 1.11. Prior on bottom trawl catchability used in the base model.

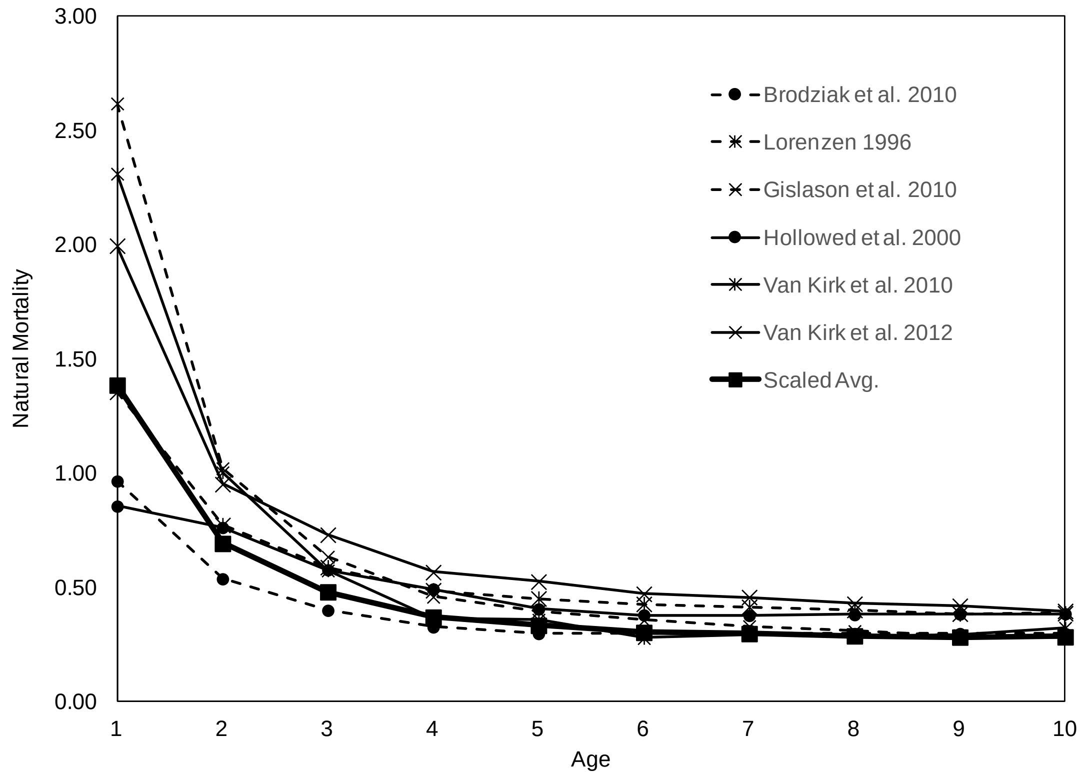


Figure 1.12. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

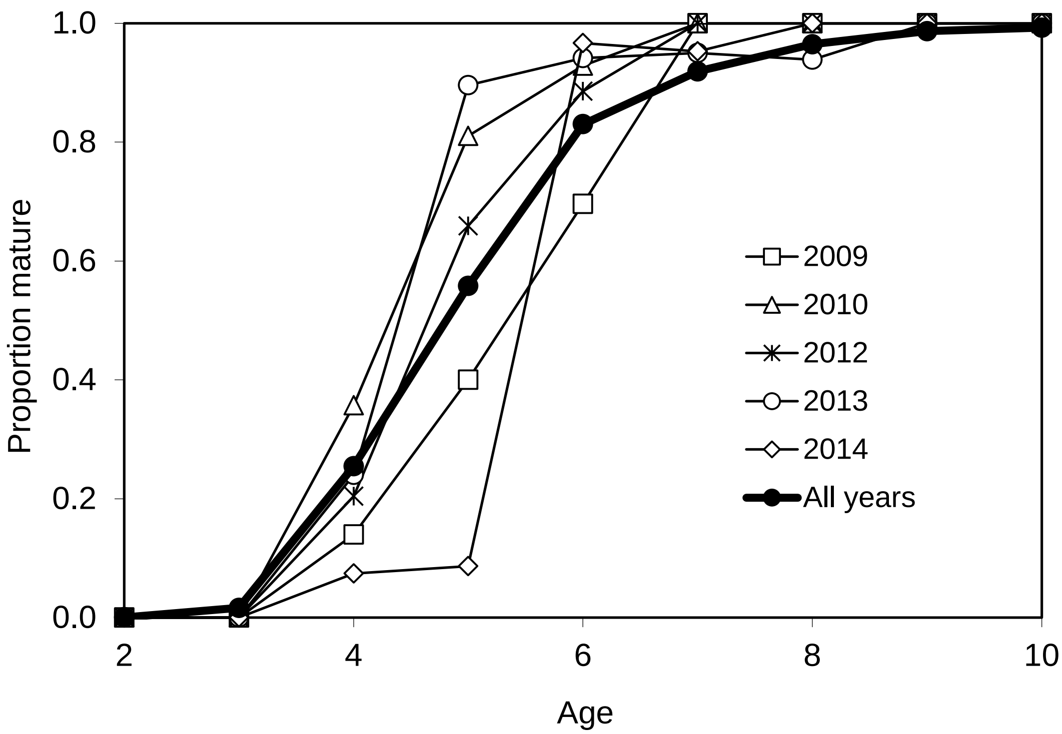


Figure 1.13. Estimates of the proportion mature at age from visual maturity data collected during 2009-2014 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2014).

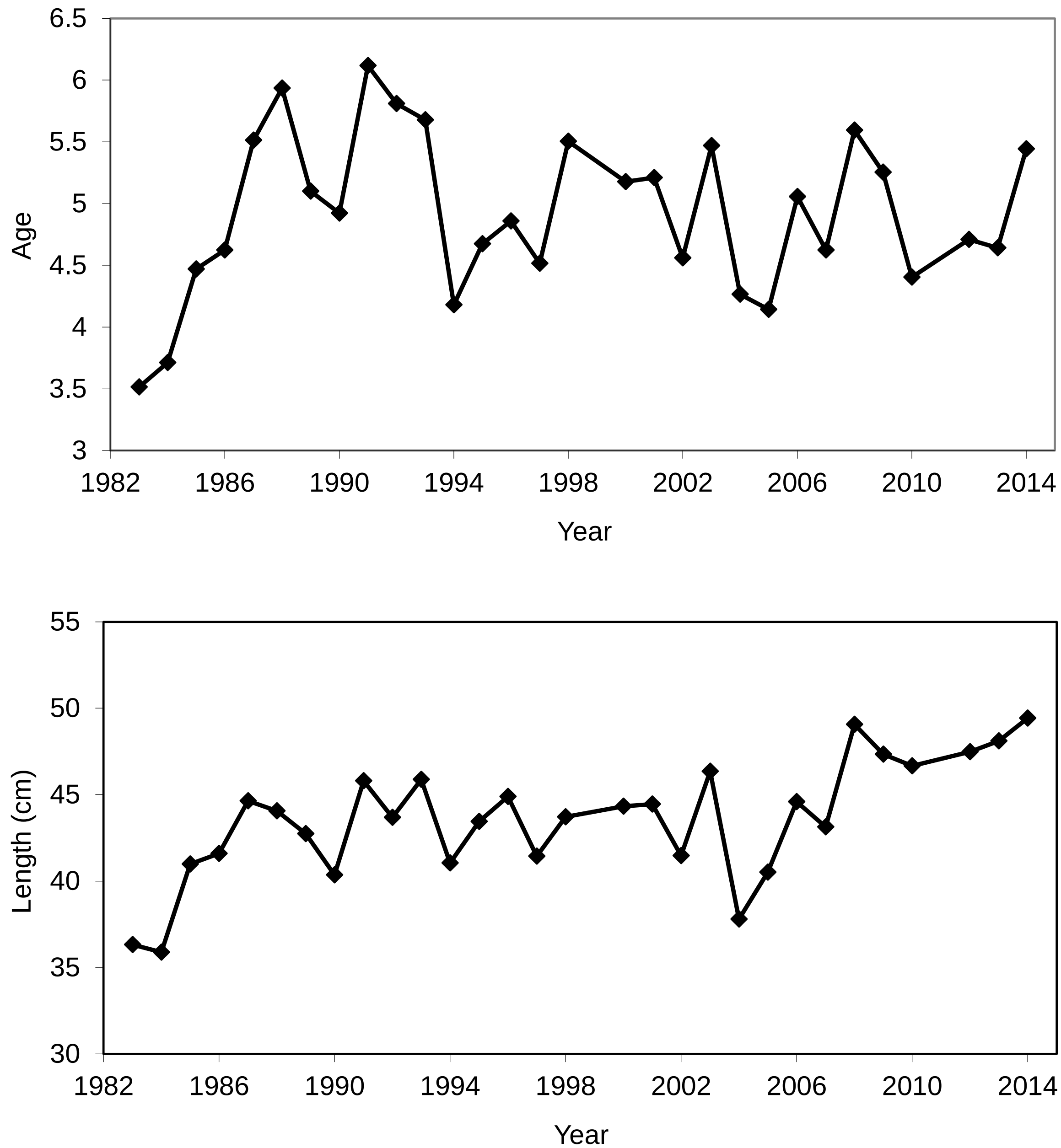


Figure 1.14. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2014.

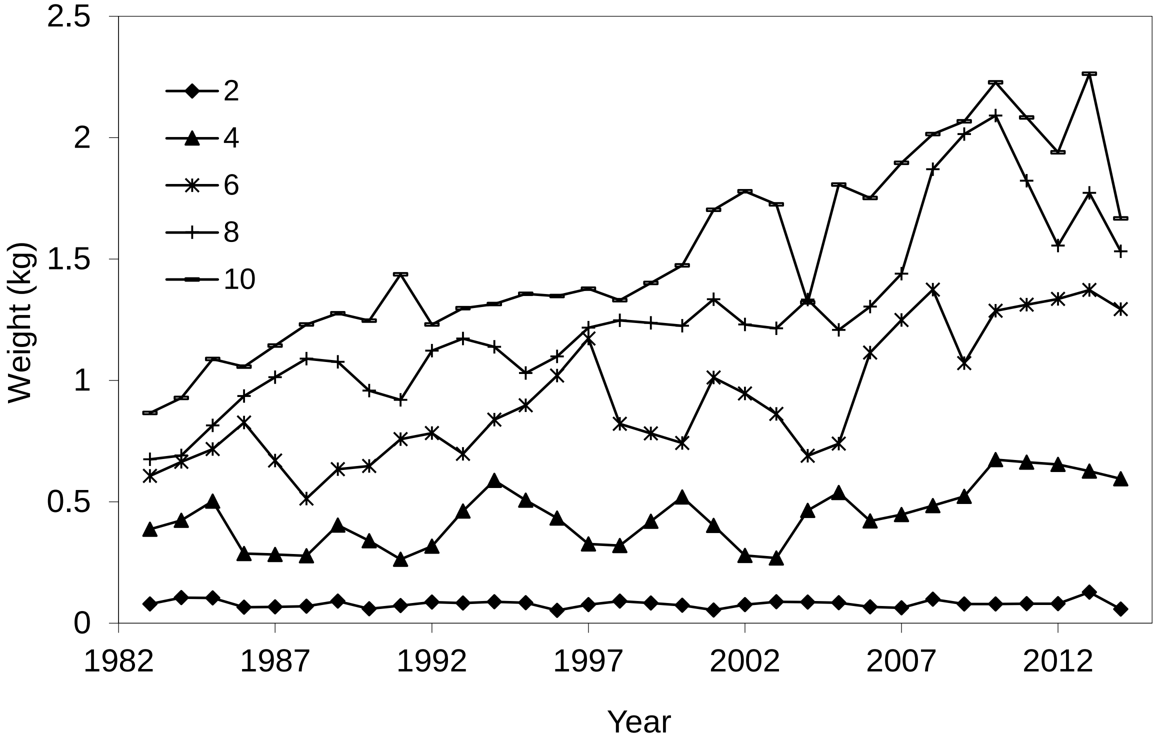


Figure 1.15. Estimated weight-at-age of Gulf of Alaska pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2014 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from adjacent years.

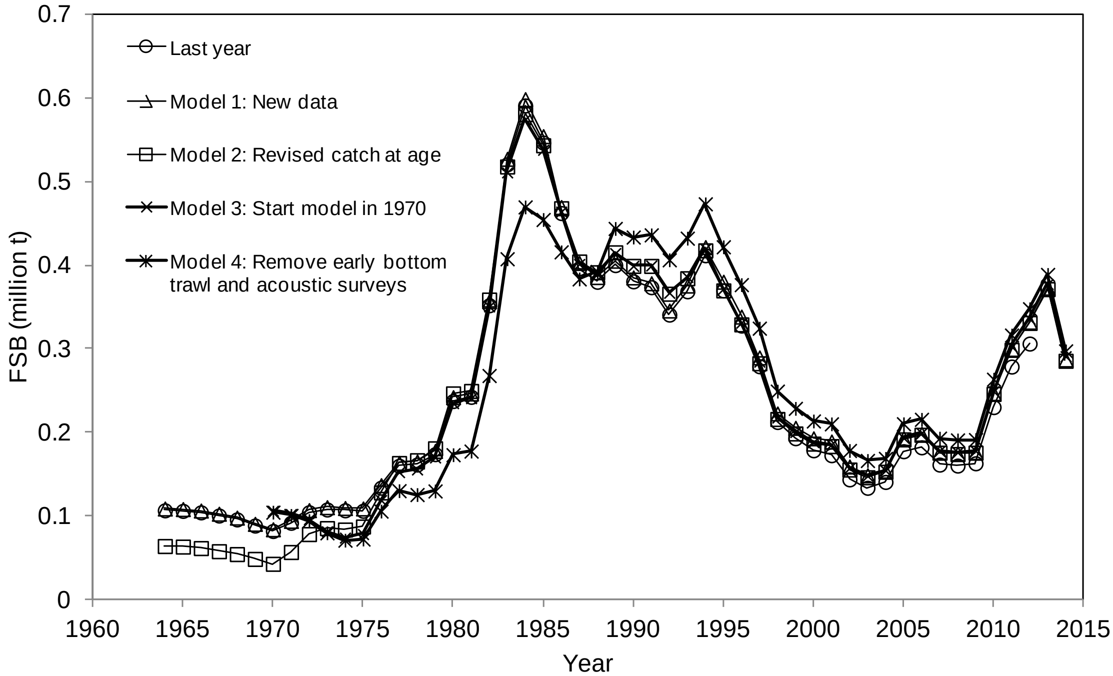


Figure 1.16. Comparison of estimated spawning biomass from alternative models. Model 1 updates the 2013 assessment model with new data but makes no changes to the model configuration. Model 2 incorporates re-estimated total catch, catch at age and fishery weight at age for 1975-1999 and corrects several minor coding errors. Model 3 starts in 1970 and remove fishery length composition data for 1964-1971. Model 4 removes bottom trawl surveys in 1984 and 1987, and acoustic surveys in Shelikof Strait for 1981-1991. Model changes are cumulative, i.e., each model includes the features of previous models.

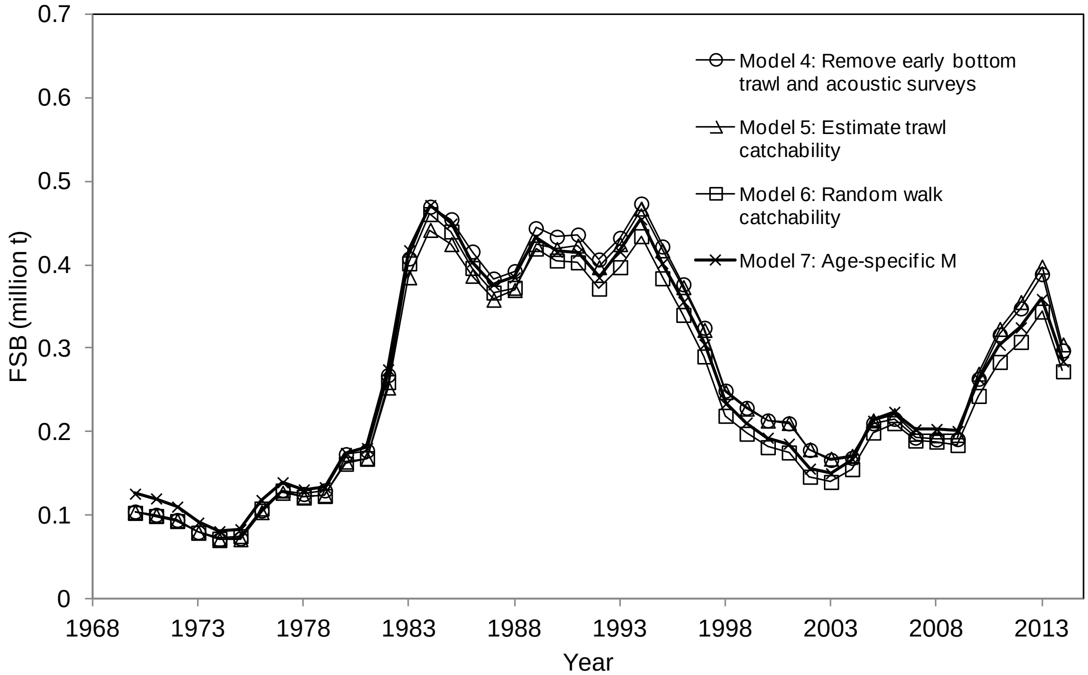


Figure 1.17. Comparison of estimated spawning biomass from alternative models. Model 4 removes bottom trawl surveys in 1984 and 1987, and acoustic surveys in Shelikof Strait for 1981-1991. Model 5 estimates summer bottom trawl survey catchability, adds prior for catchability to the likelihood function, and assumes that selectivity is asymptotic for the trawl survey. Model 6 uses random walks in fishery selectivity parameters to model fishery selectivity instead of blocks, and assume no interannual variation in the descending portion of the curve. Model 7 uses an age-specific natural mortality schedule based on an ensemble average of several methods. Model changes are cumulative, i.e., each model includes the features of previous models.

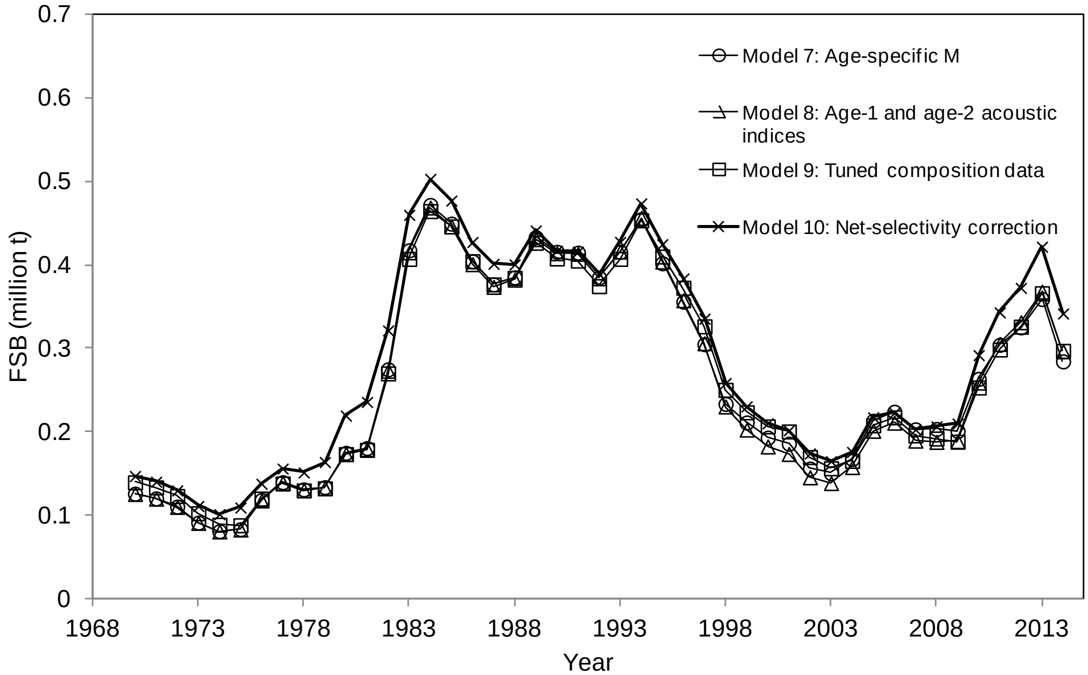


Figure 1.18. Comparison of estimated spawning biomass from alternative models. Model 7 uses an age-specific natural mortality schedule based on an ensemble average of several methods. Model 8 uses separate indices for age-1 and age-2 pollock in the acoustic survey. Model 9 iteratively tunes the age-composition data so that the input sample size is close to the harmonic mean of effective sample size. Model 10 evaluates acoustic biomass and age-composition estimates corrected for net selectivity. Model changes are cumulative, i.e., each model includes the features of previous models.

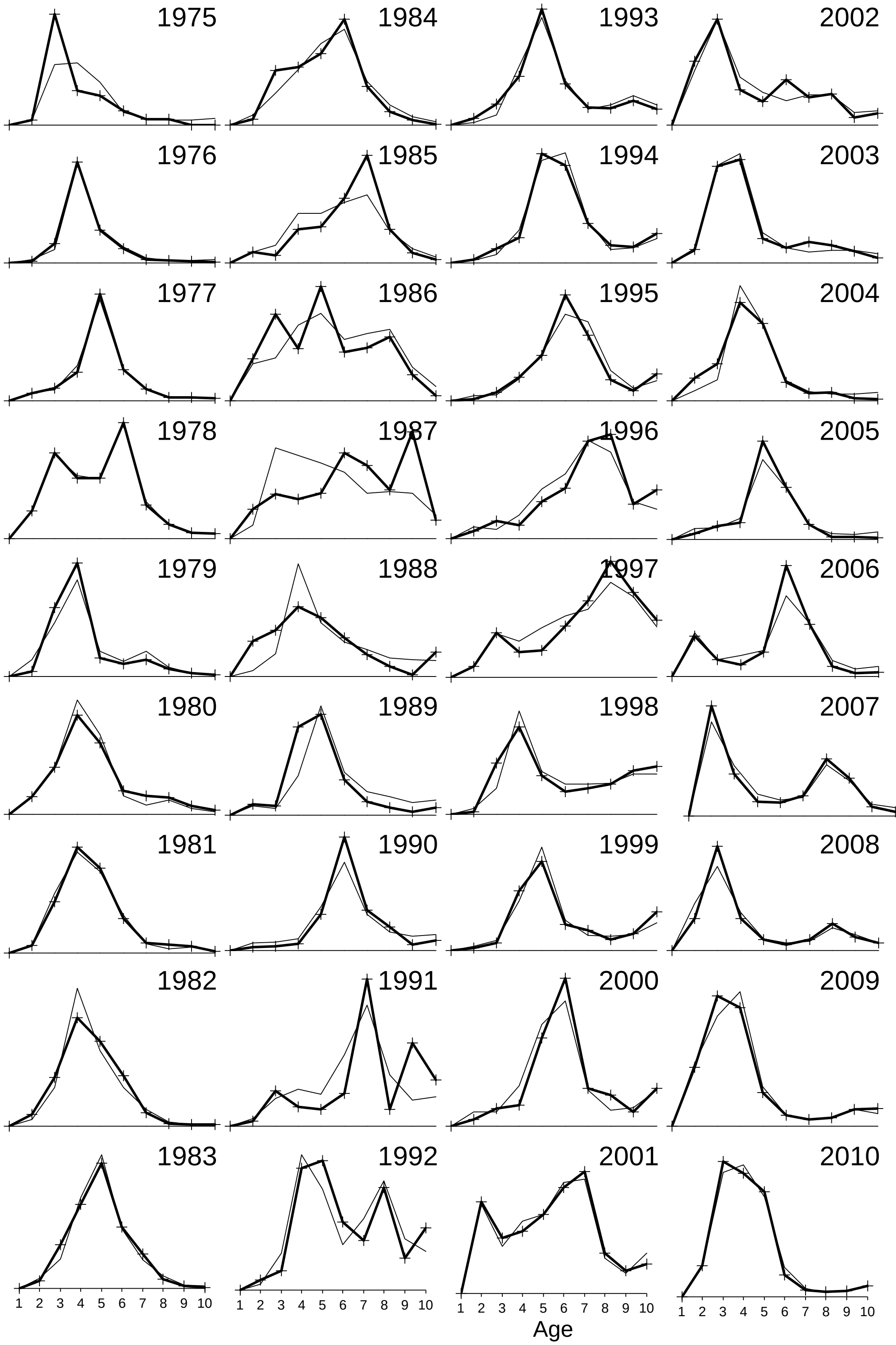


Figure 1.19. Observed and predicted fishery age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

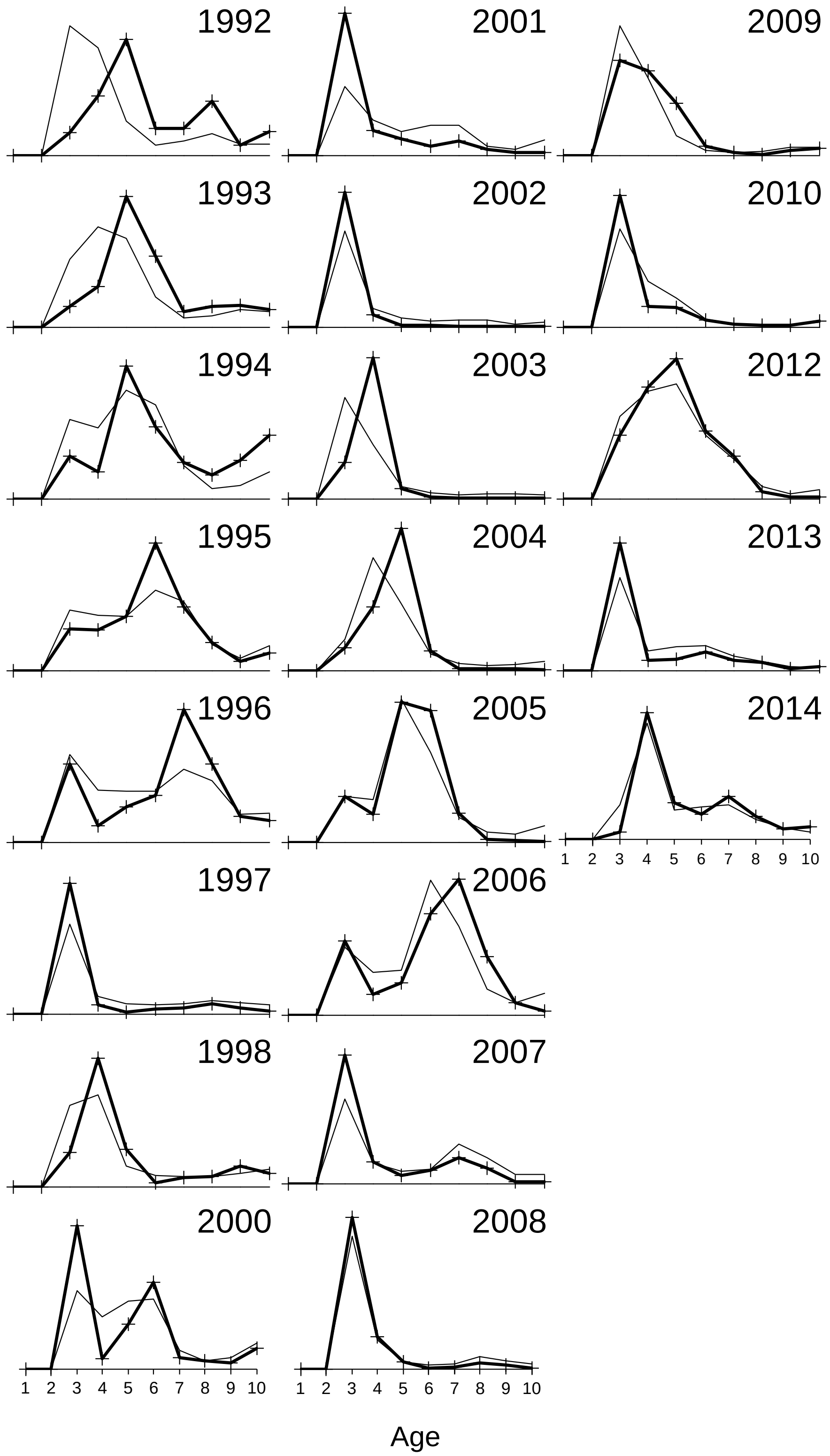


Figure 1.20. Observed and predicted Shelikof Strait acoustic survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

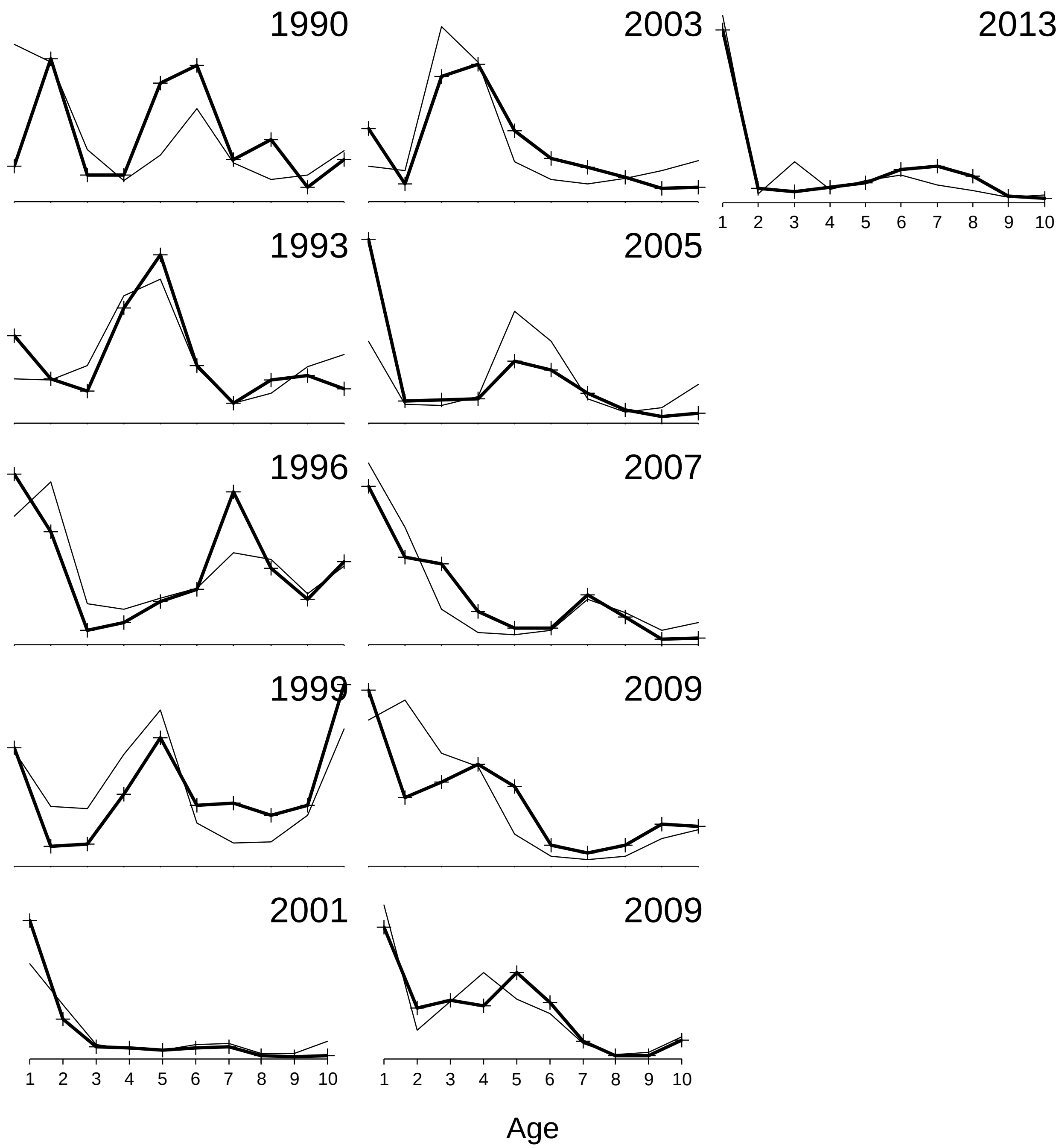


Figure 1.21. Observed and predicted NMFS bottom trawl age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

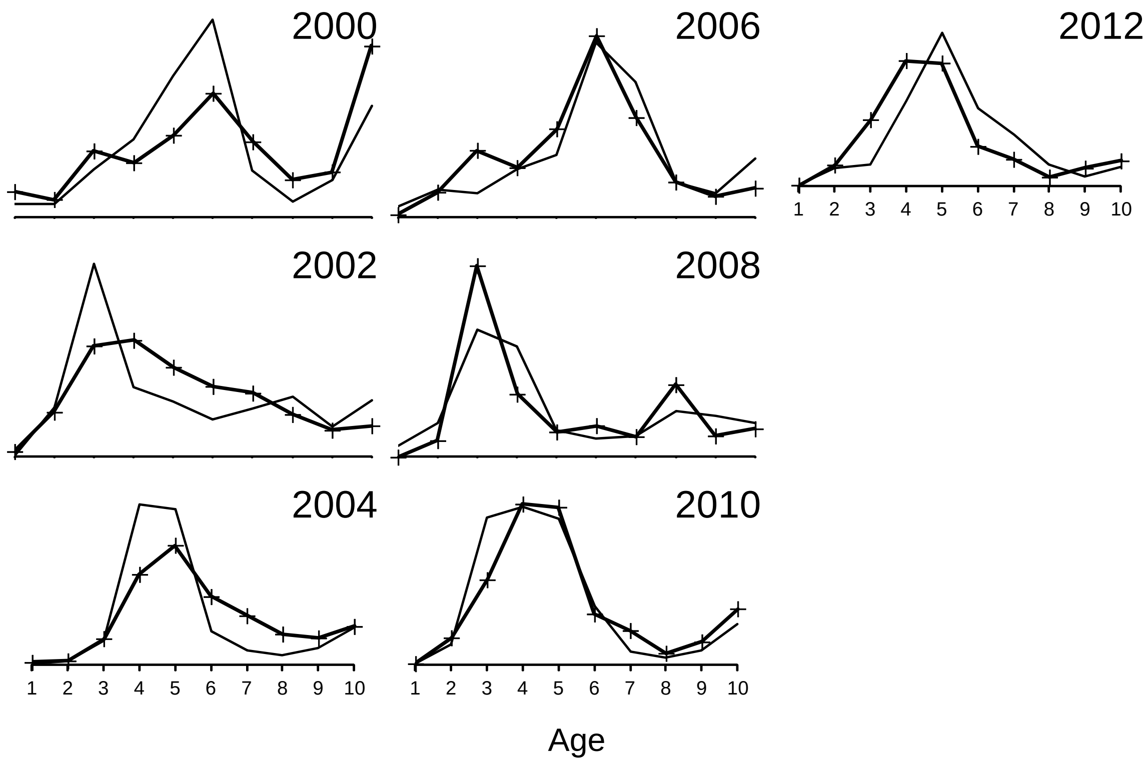


Figure 1.22. Observed and predicted ADFG crab/groundfish survey age composition for Gulf of Alaska pollock from the base model. Continuous lines are model predictions and lines with + symbols are observed proportions at age.

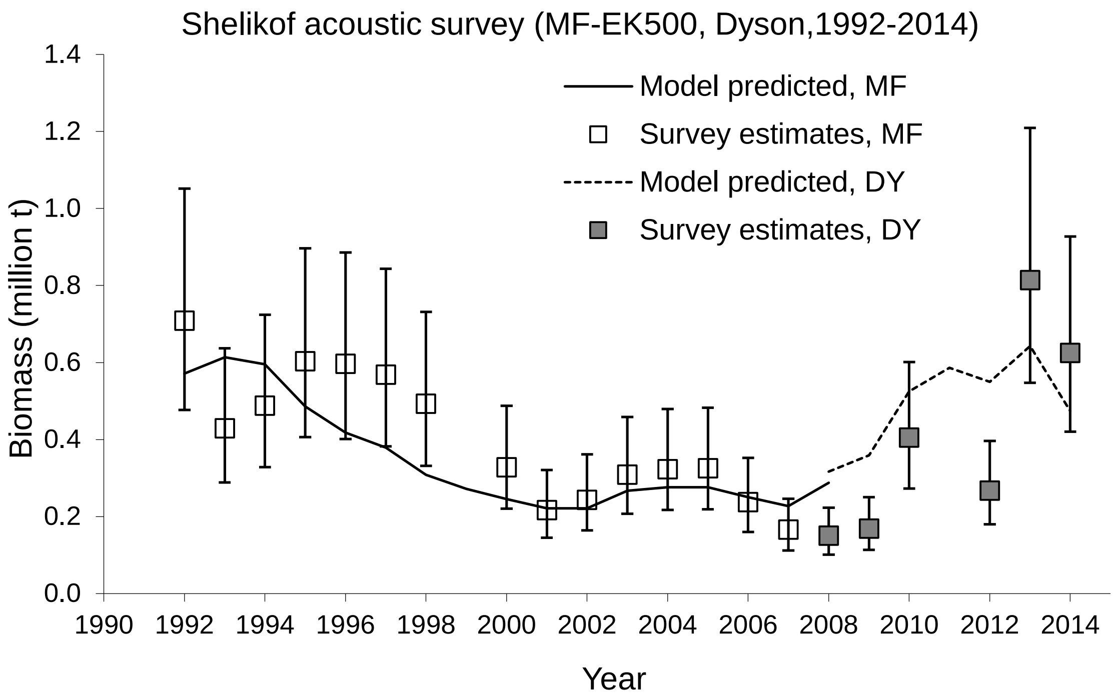


Figure 1.23. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey for the base model. The Shelikof acoustic survey is modeled with two catchability periods corresponding to the estimates produced by the *R/V Miller Freeman* (MF) in 1992-2007 and the *R/V Oscar Dyson* (DY) in 2008-2014. Error bars indicate plus and minus two standard deviations. A CV of 0.2 is assumed for all acoustic surveys when fitting the model.

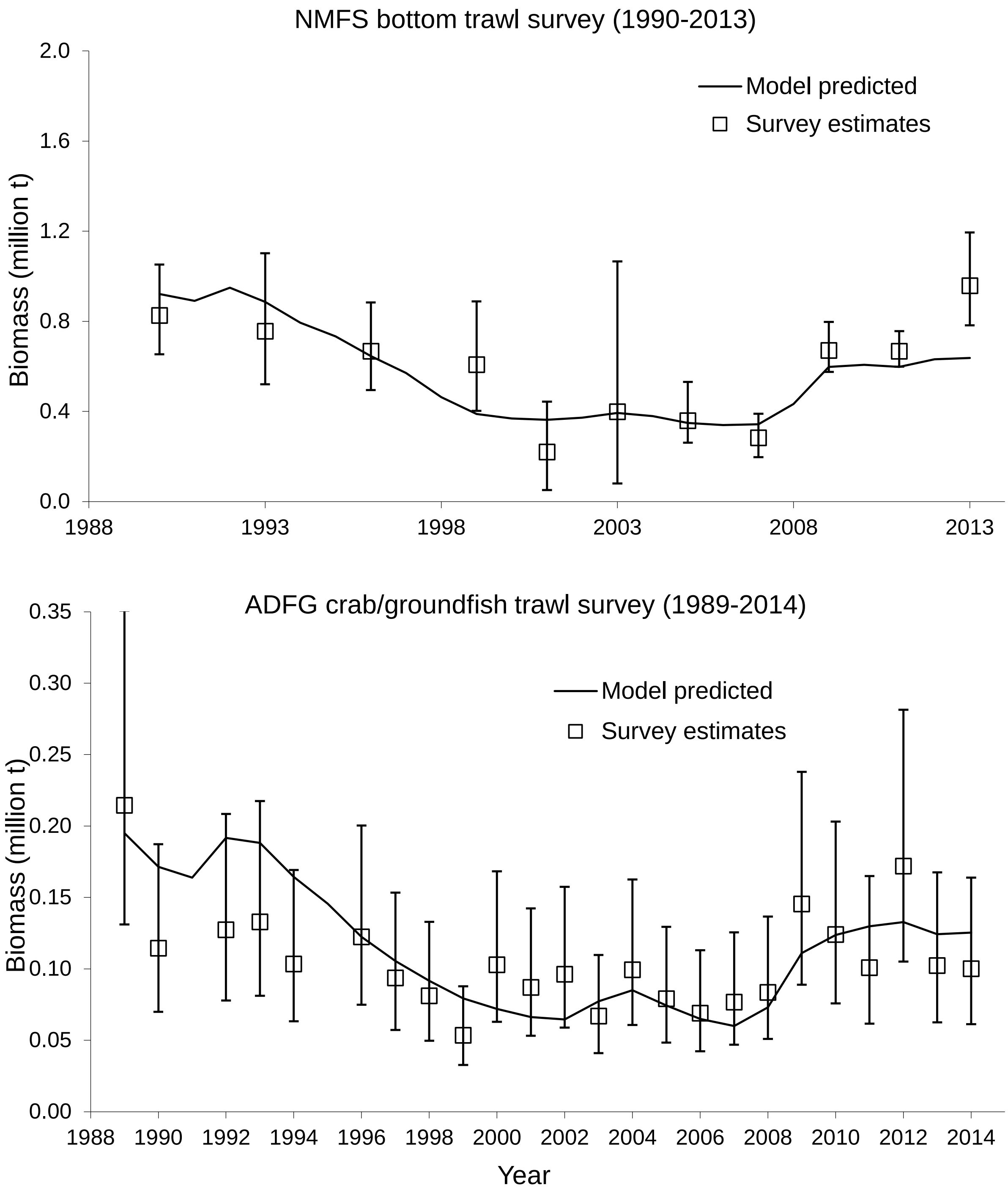
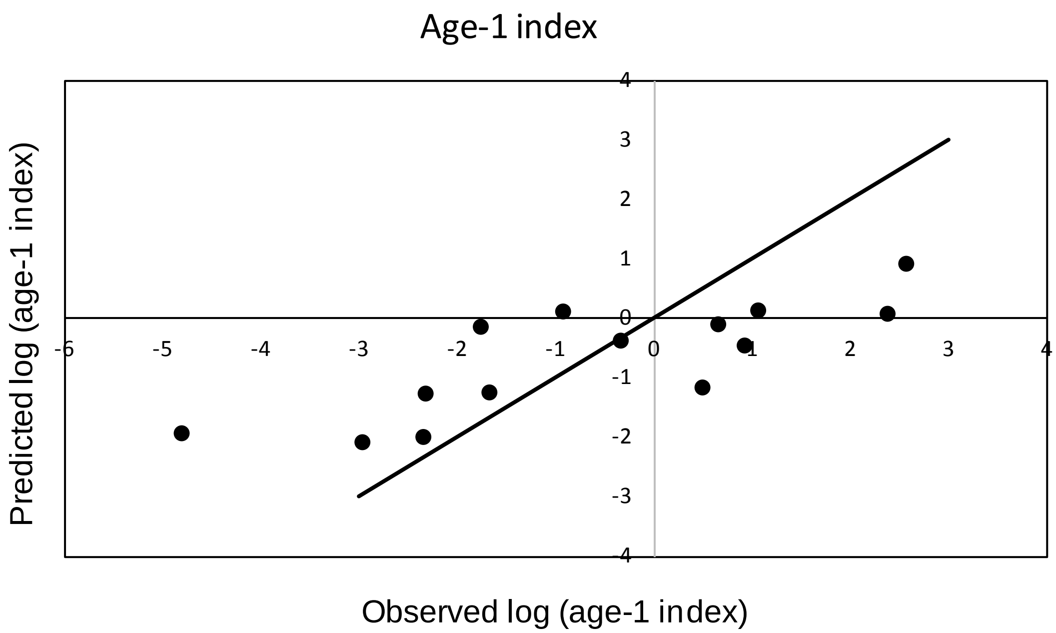


Figure 1.24. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom) for the base model. Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.



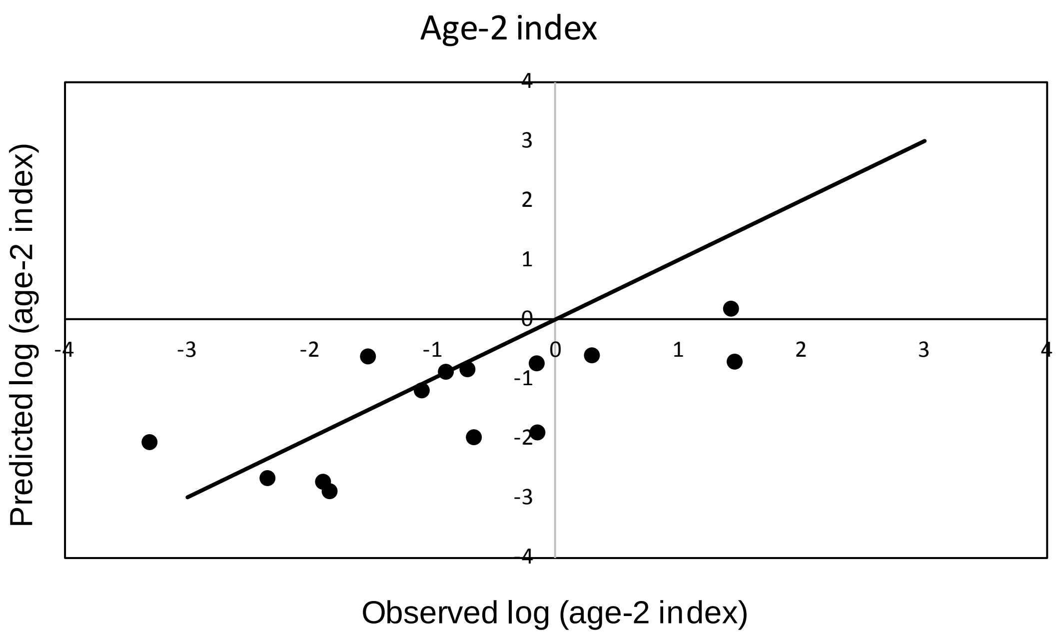


Figure 1.25. Observed and model predicted age-1 (top) and age-2 indices (bottom) for the winter acoustic estimates combined for Shelikof Strait and the Shumagin Islands.

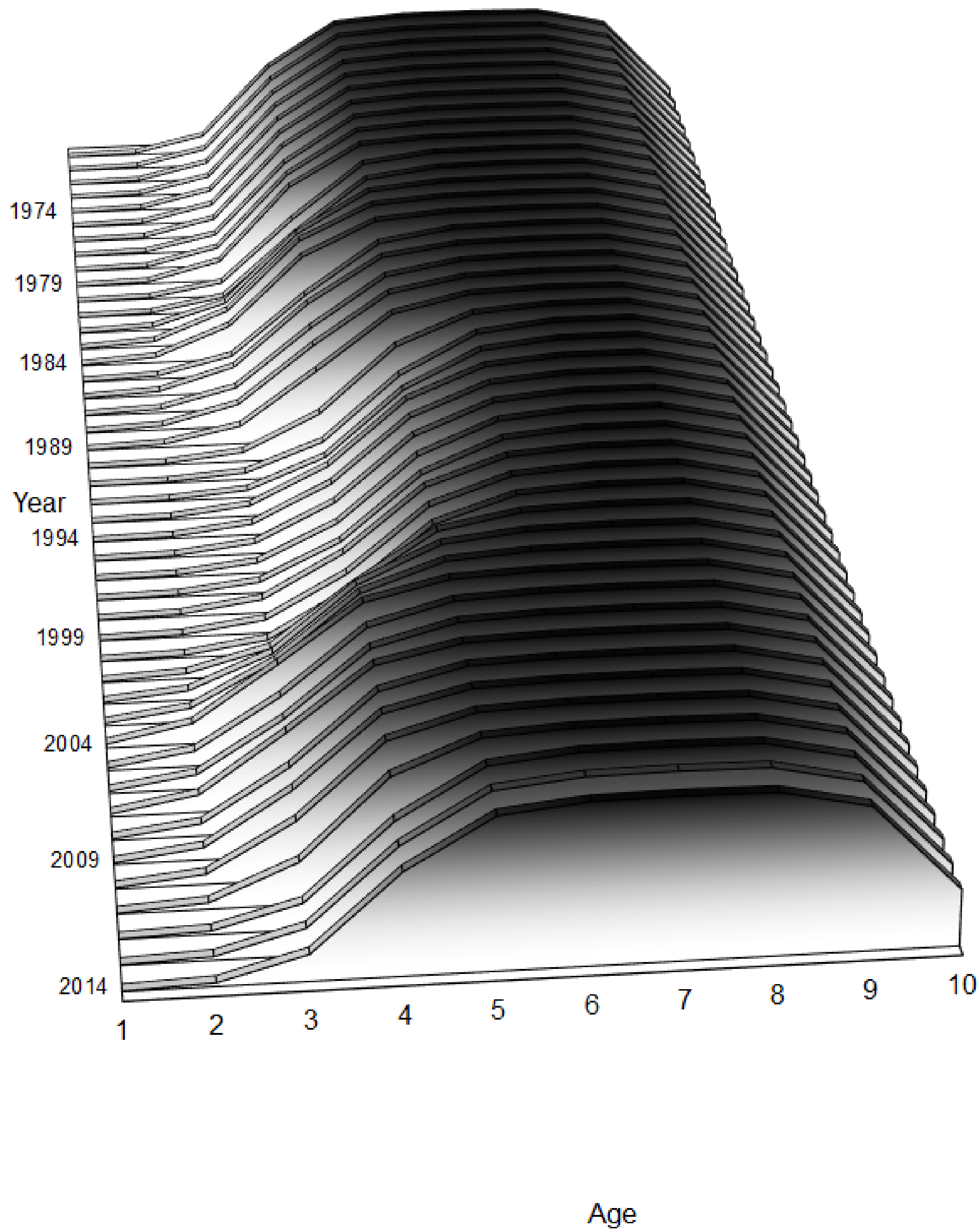
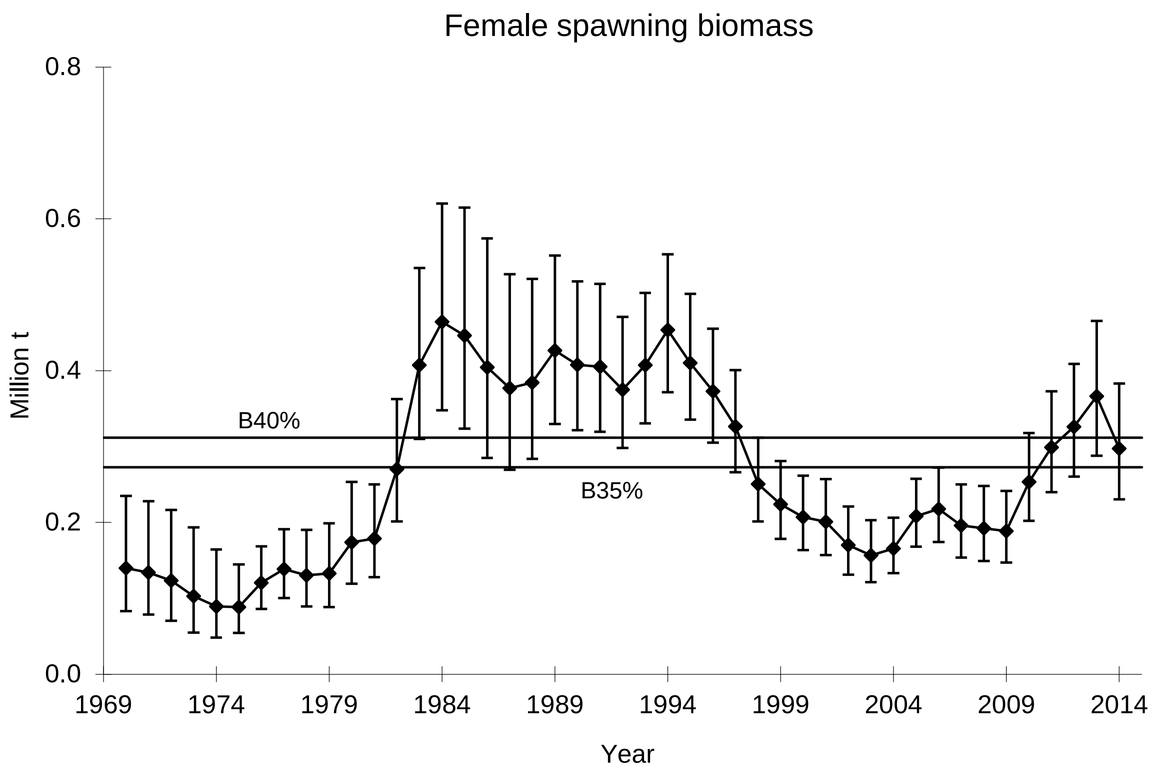


Figure 1.26. Estimates of time-varying fishery selectivity for Gulf of Alaska pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.



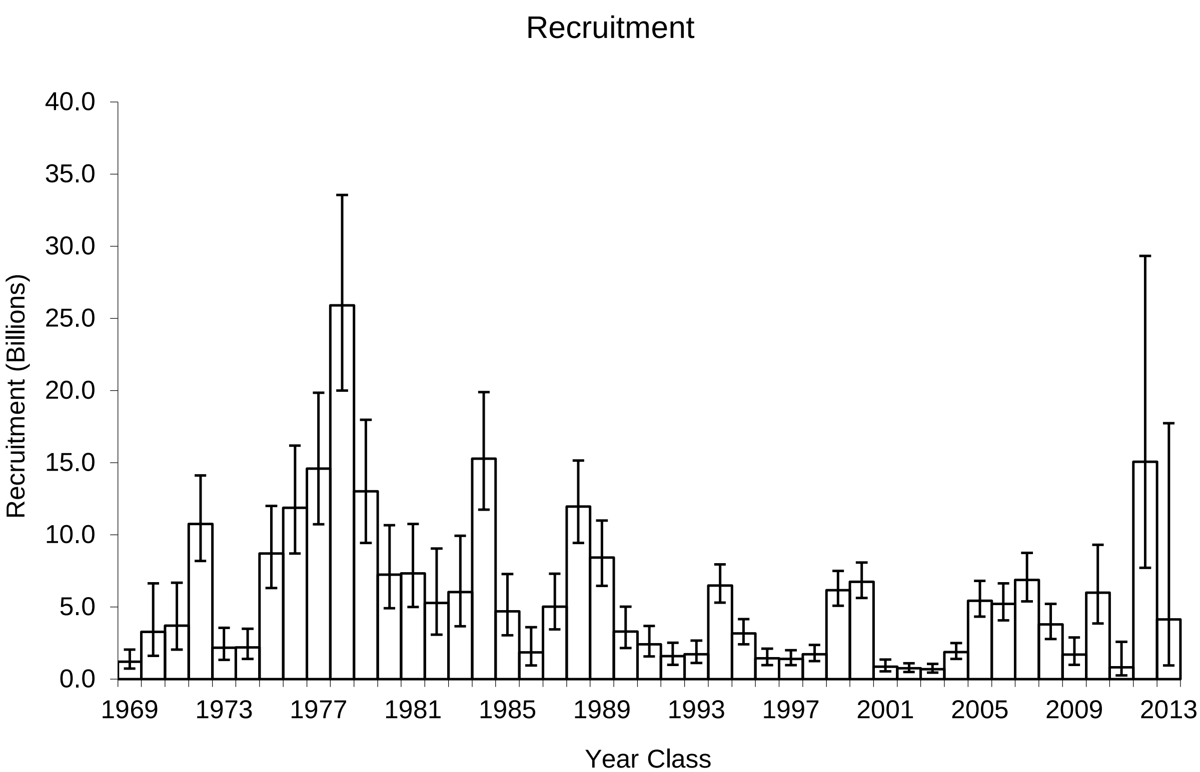


Figure 1.27. Estimated time series of Gulf of Alaska pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1970 to 2014 for the base model. Vertical bars represent two standard deviations. The $B_{35\%}$ and $B_{40\%}$ lines represent the current estimate of these benchmarks.

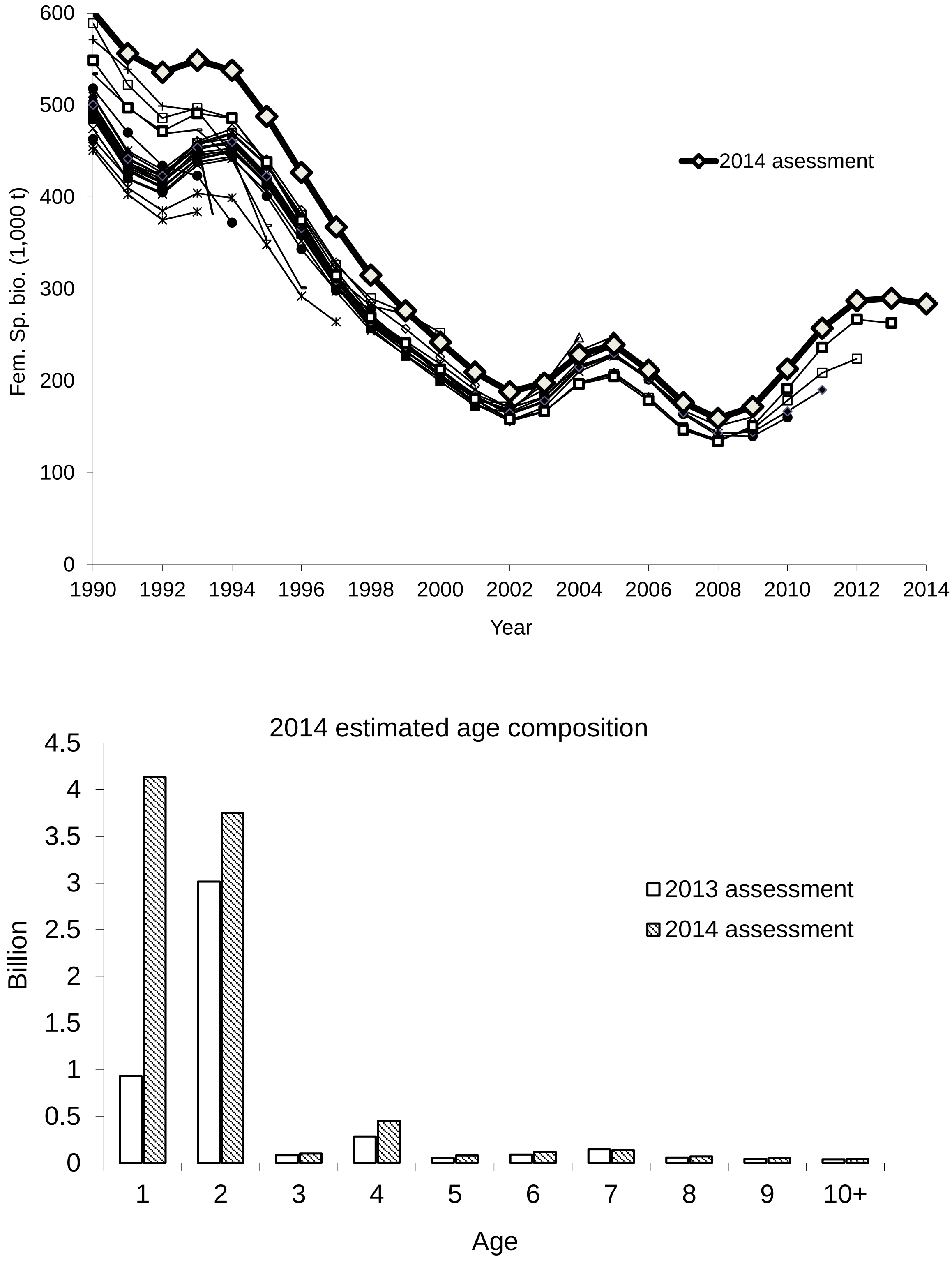


Figure 1.28. Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1993-2014 (top). For this figure, the time series of female spawning biomass was calculated using the same maturity and spawning weight at age for all assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2014 from the 2013 and 2014 assessments.

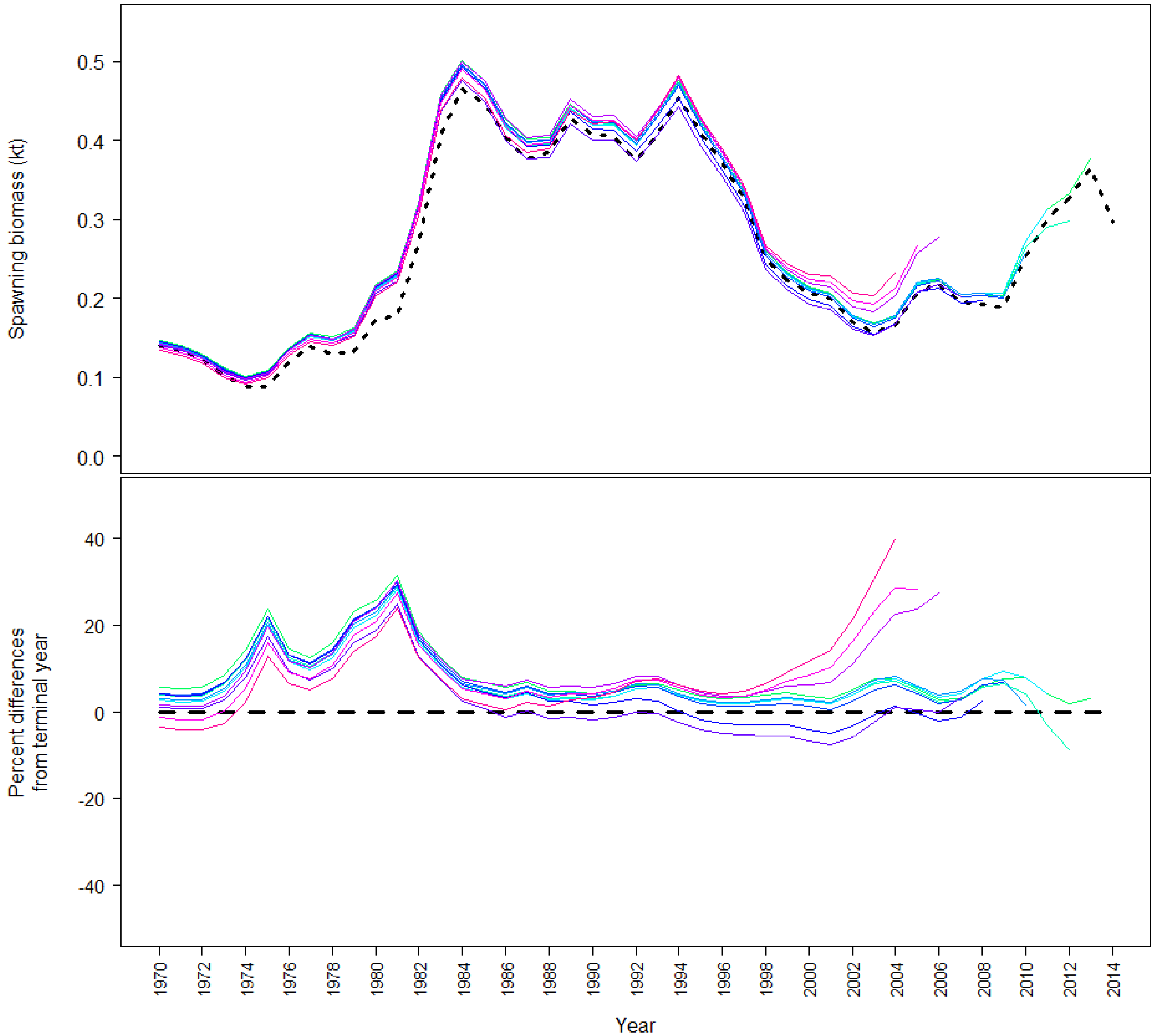


Figure 1.29. Retrospective plot of spawning biomass for the years 2004-2014 for the 2014 assessment model.

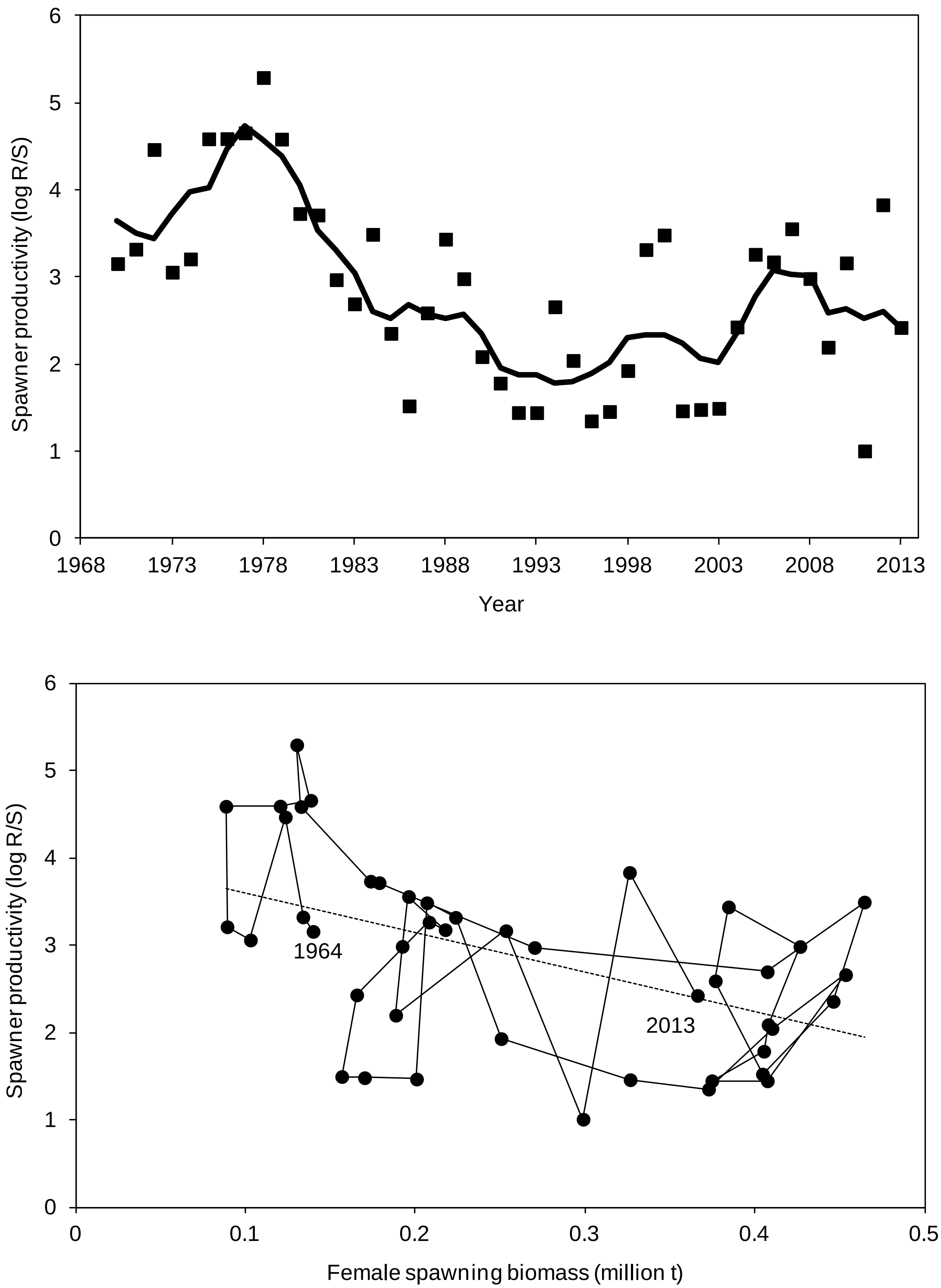
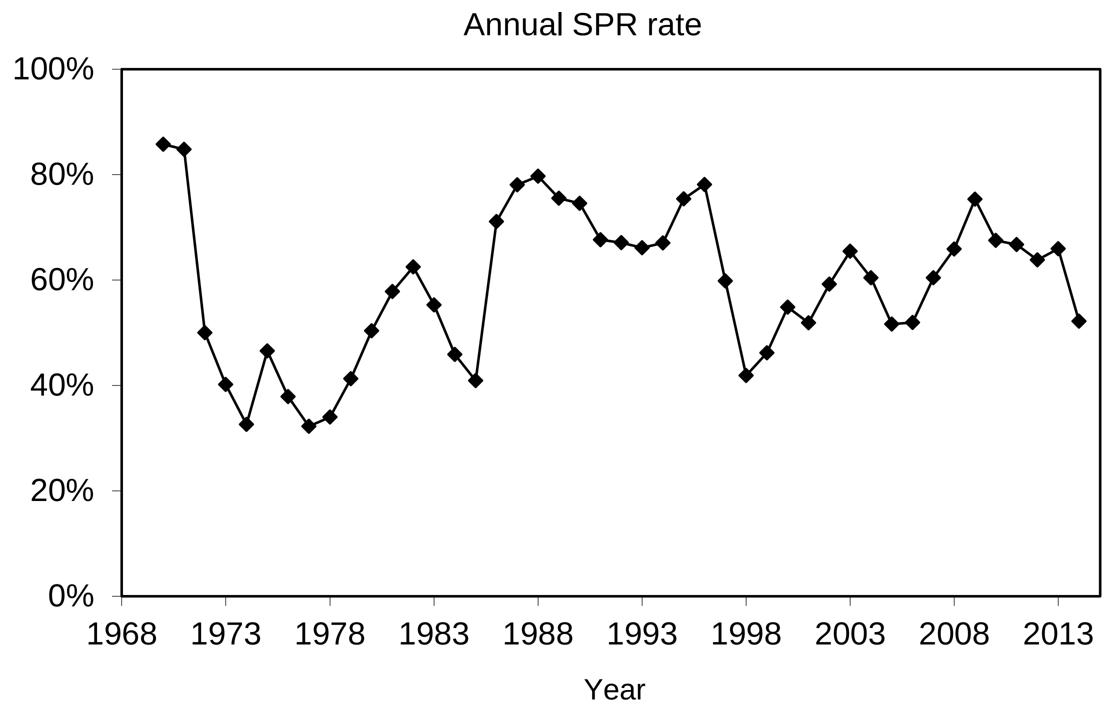


Figure 1.30. Gulf of Alaska pollock spawner productivity, *log(R/S)*, in 1970-2013 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.



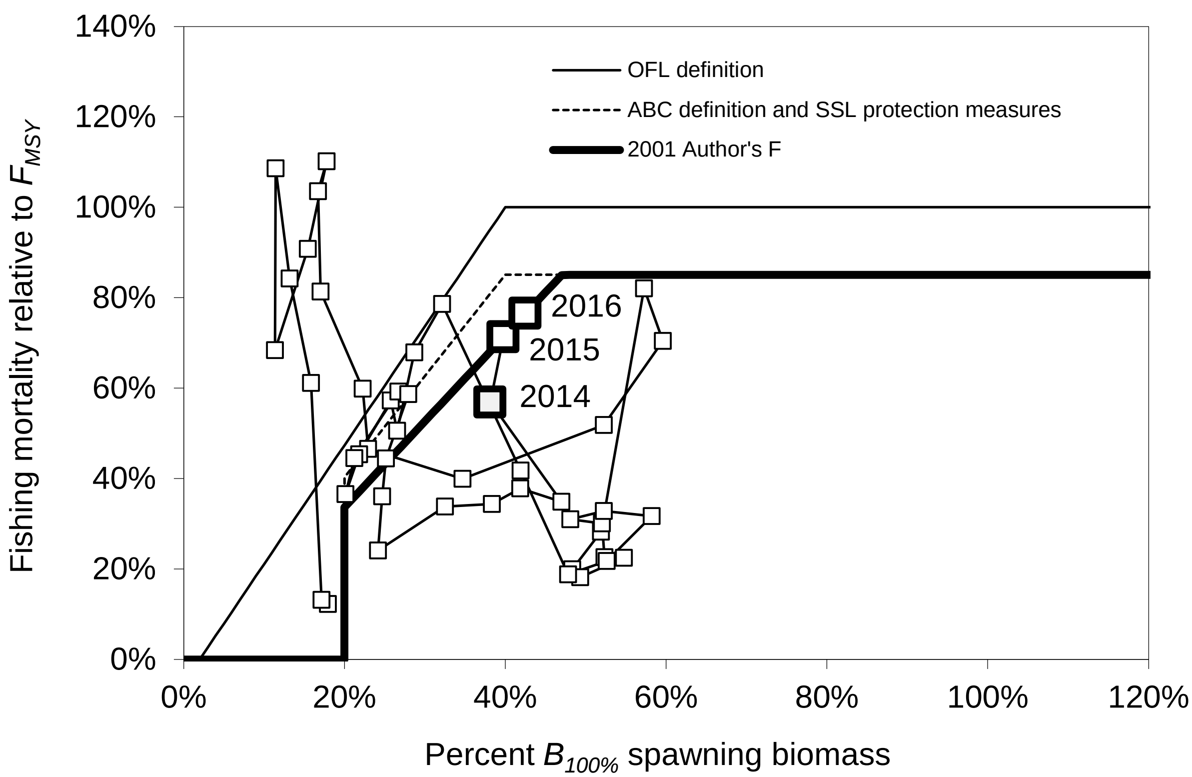


Figure 1.31. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). Gulf of Alaska pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{MSY} (bottom). The ratio of fishing mortality to F_{MSY} is calculated using the 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.

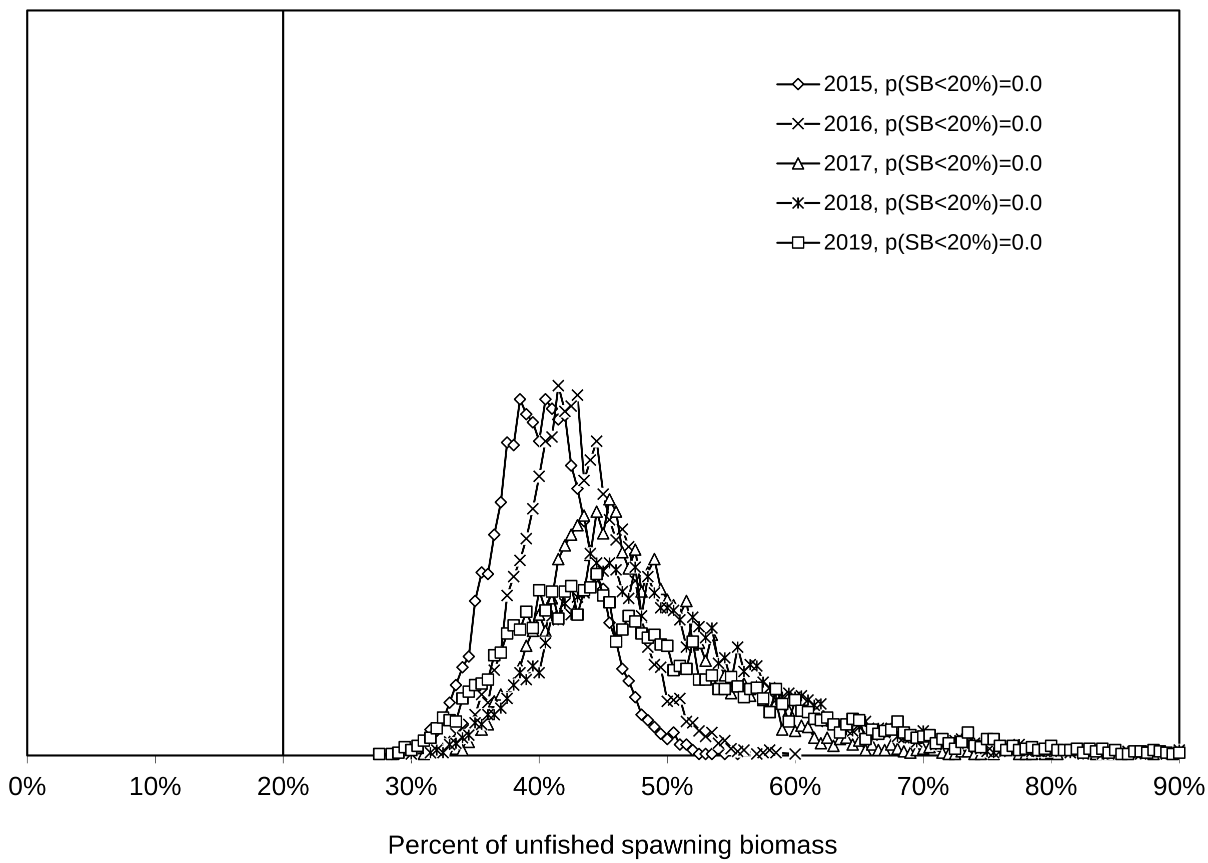


Figure 1.32. Uncertainty in spawning biomass in 2015-2019 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended F_{ABC}.

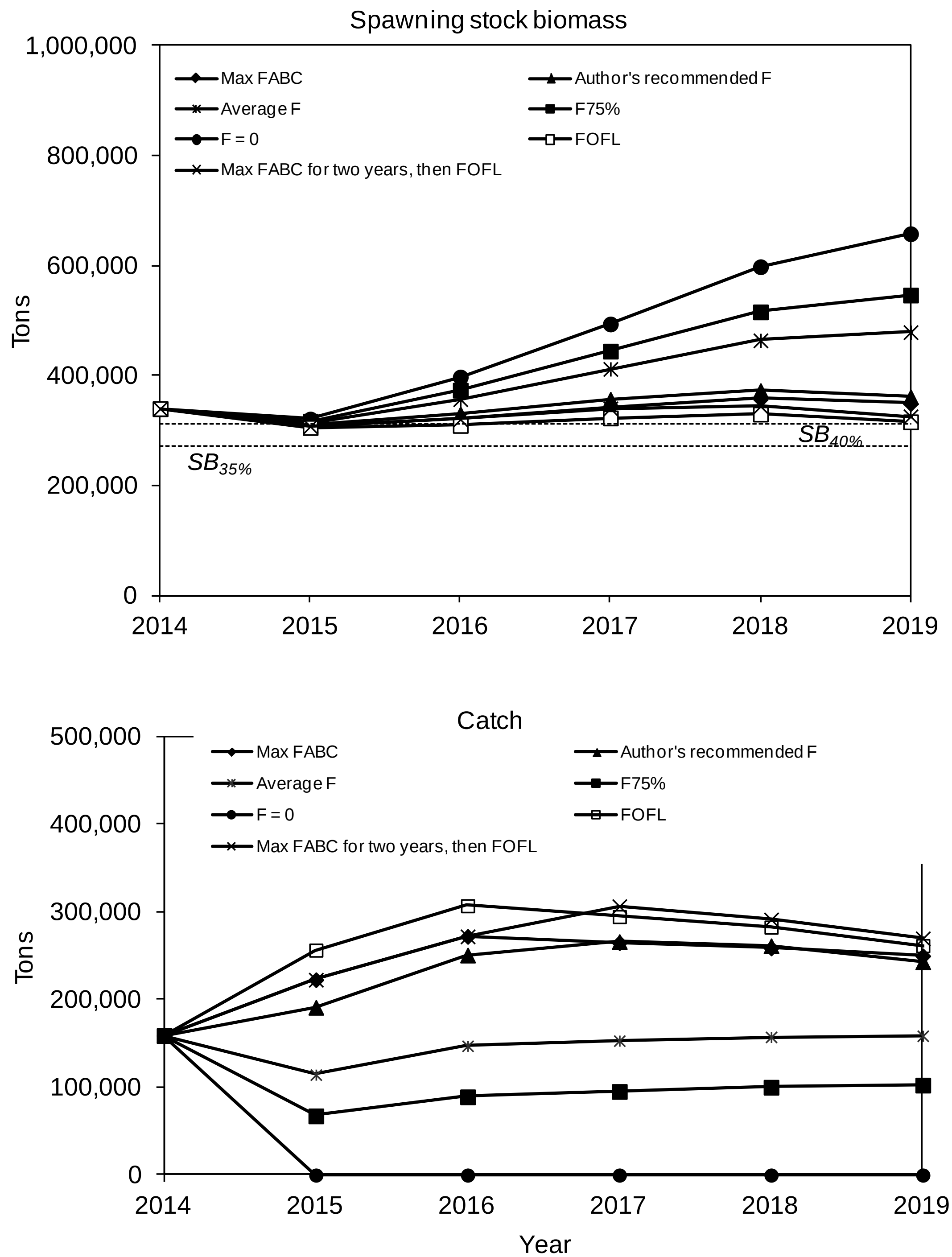


Figure 1.33. Projected spawning biomass and catches in 2015-2019 under different harvest rates.

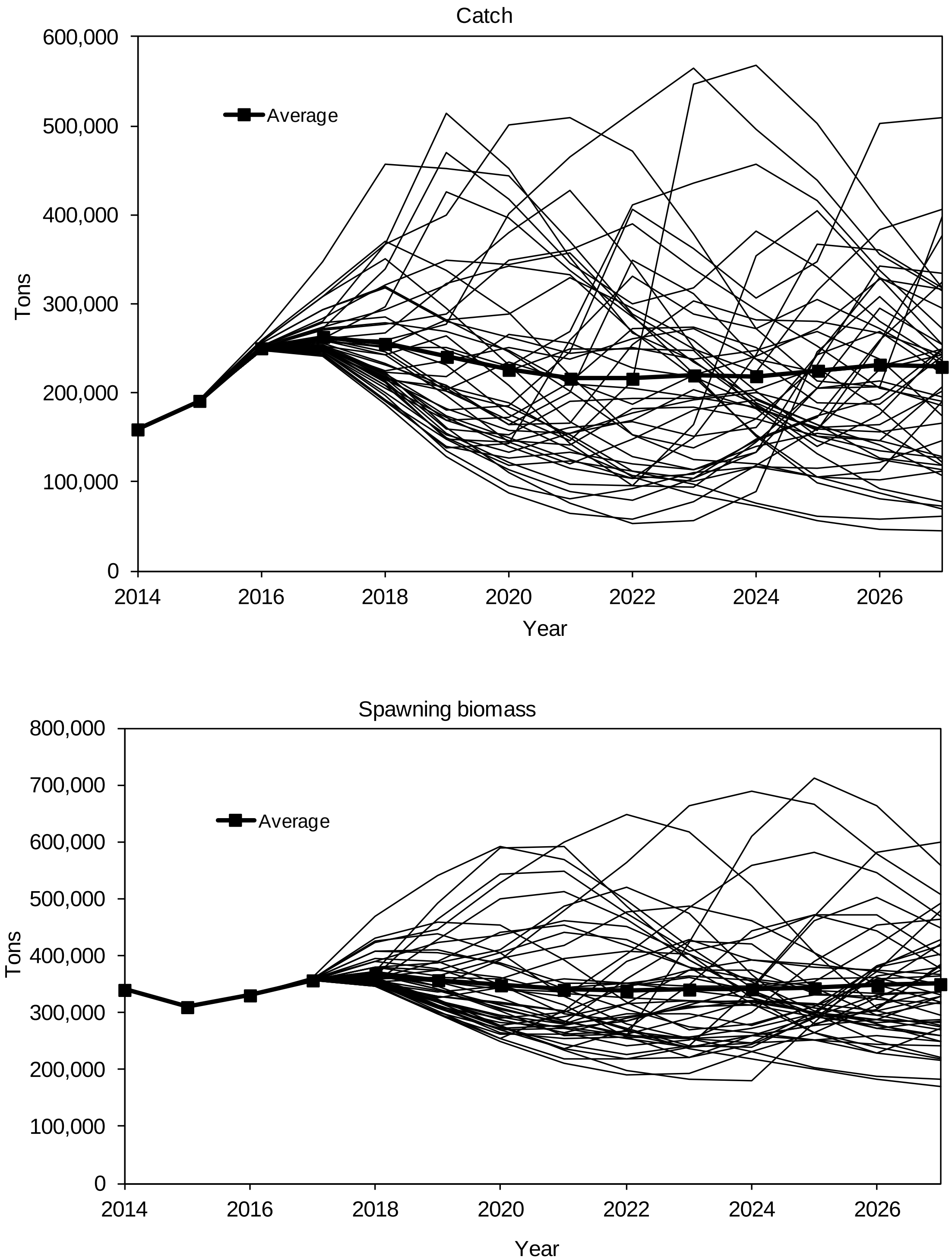


Figure 1.34. Variability in projected catch and spawning biomass in 2015-2027 for the base model under the author's recommended F_{ABC}.

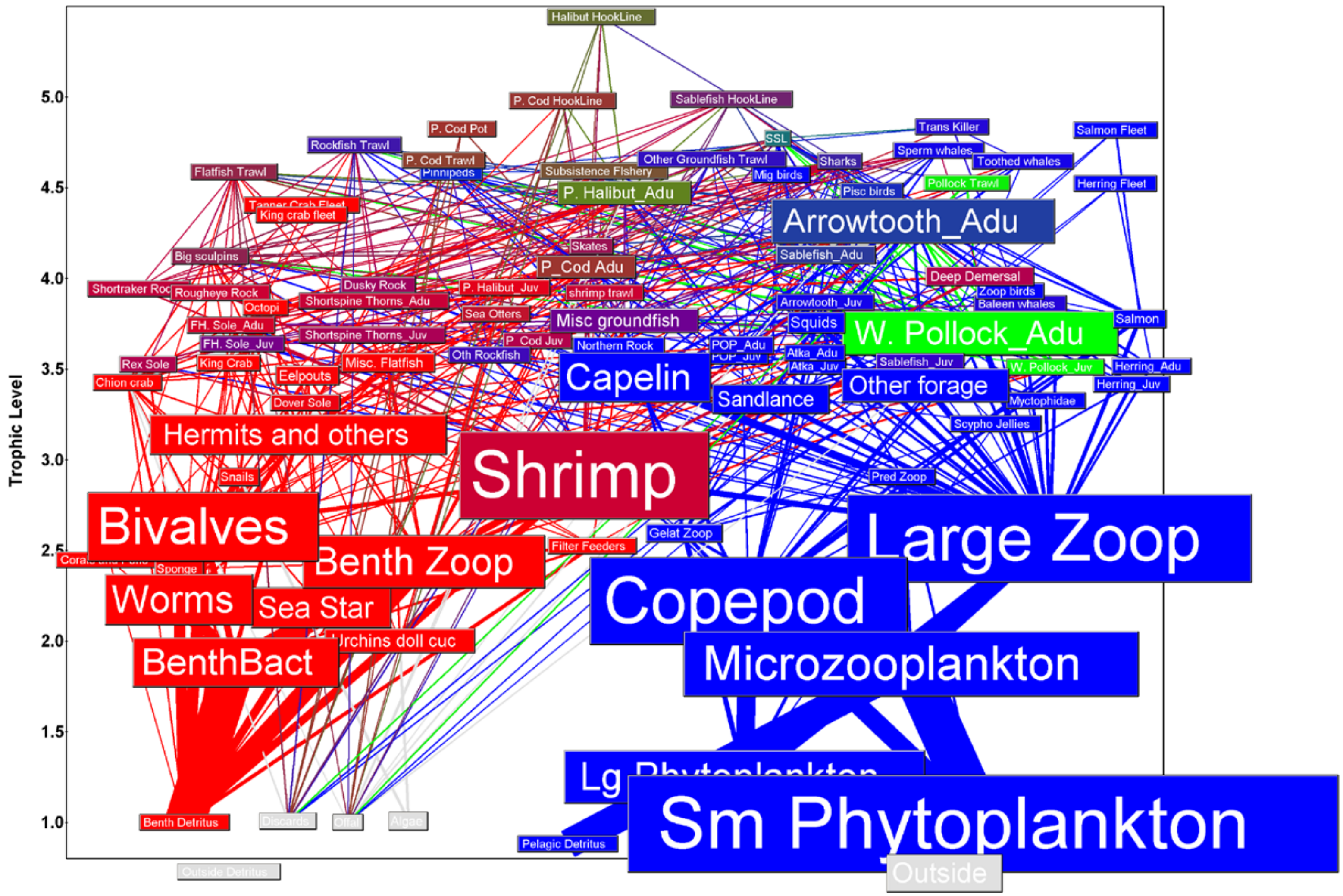
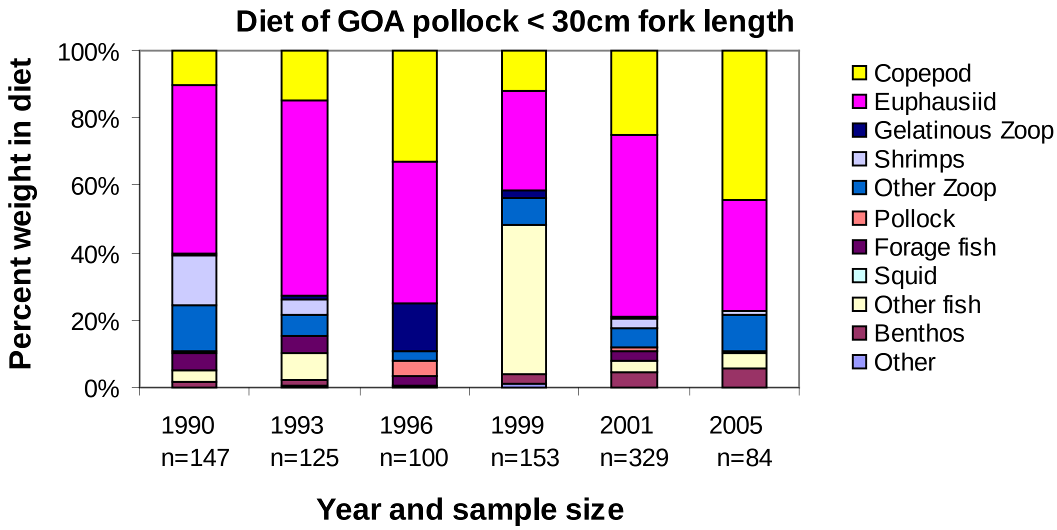


Figure 1.35. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Walleye pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



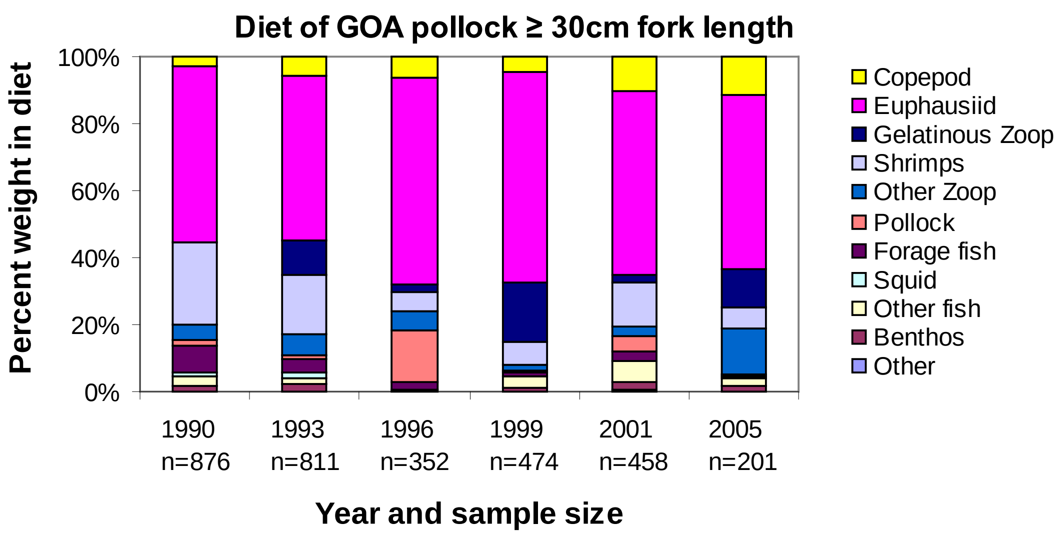
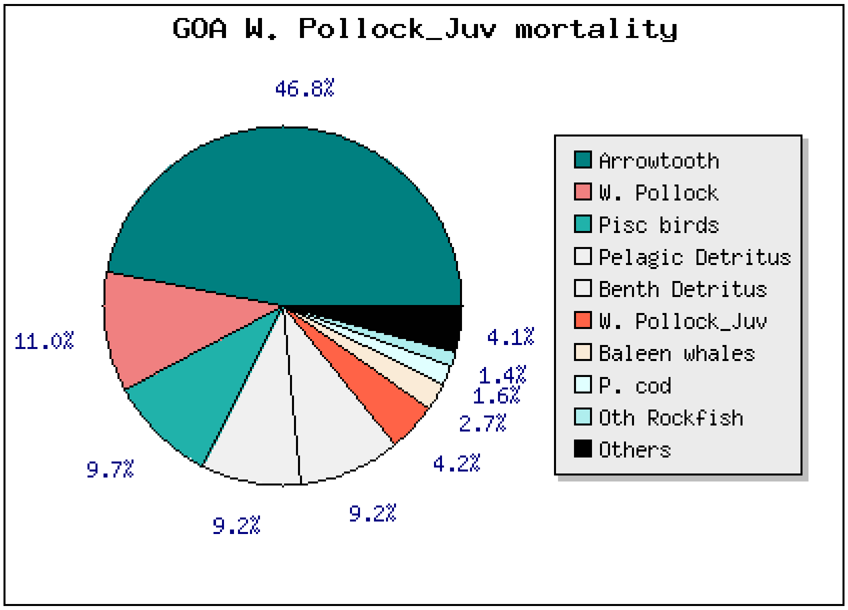


Figure 1.36. Diet (percent wet weight) of GOA walleye pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



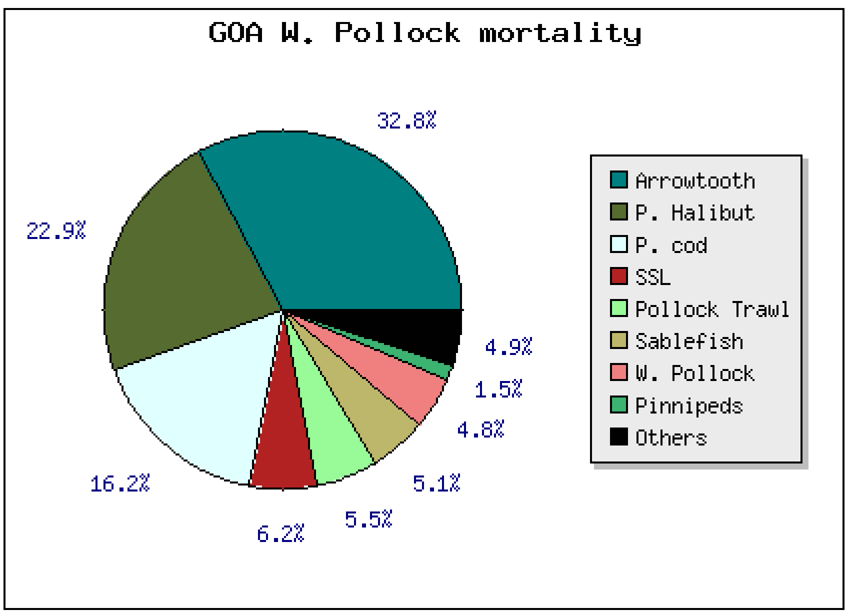


Figure 1.37. Sources of mortality for walleye pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

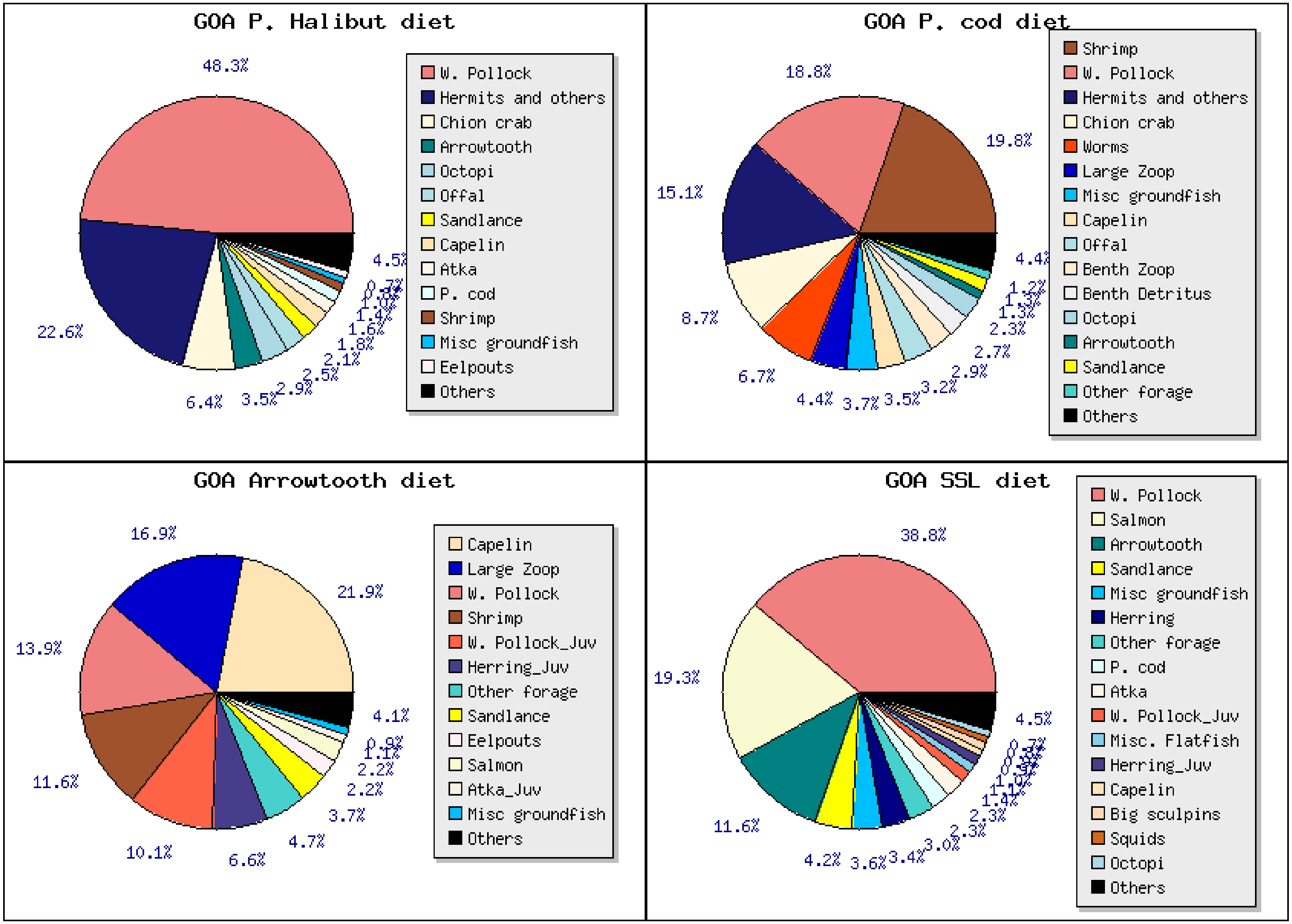


Figure 1.38. Diet diversity of major predators of walleye pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

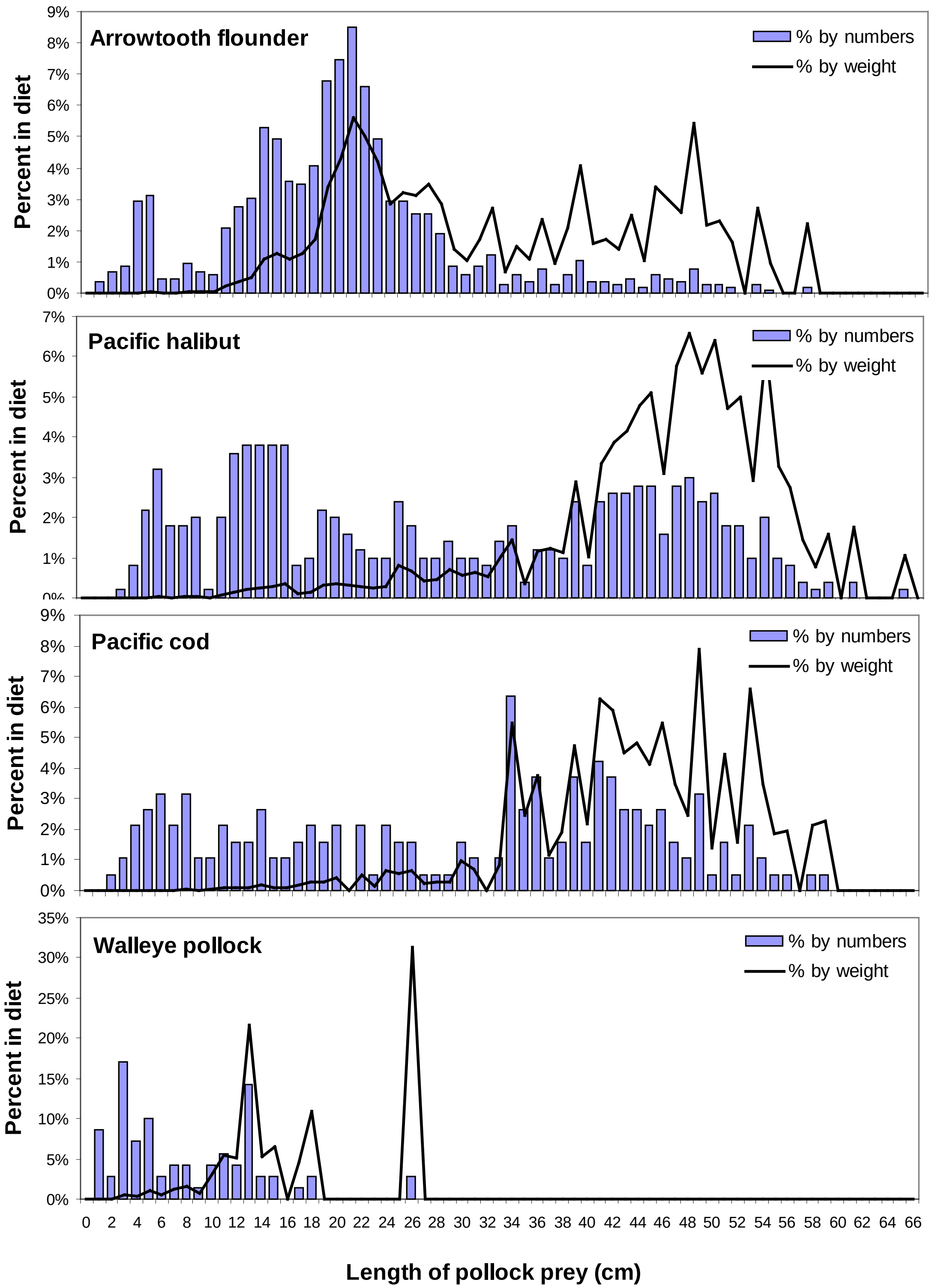
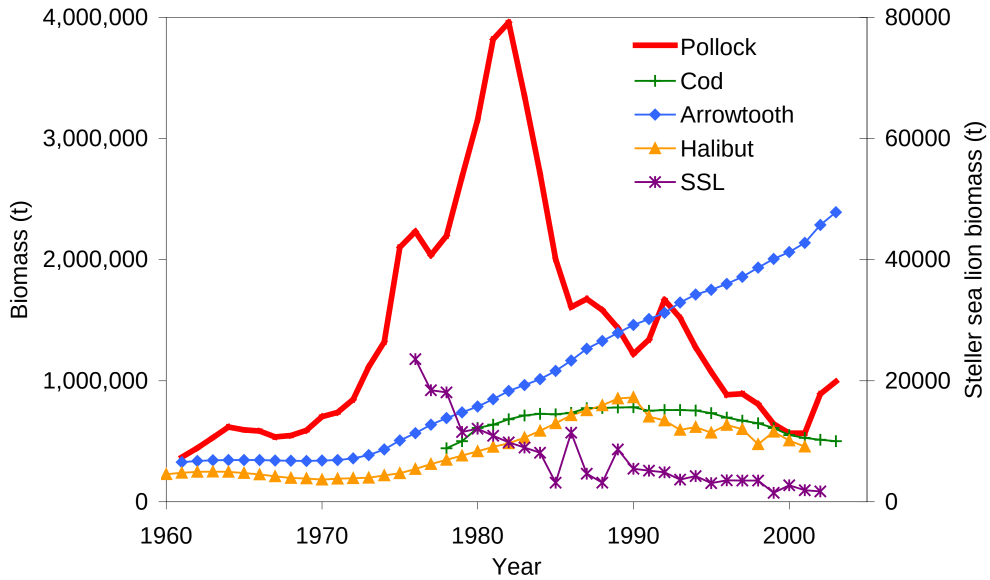


Figure 1.39**.** Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



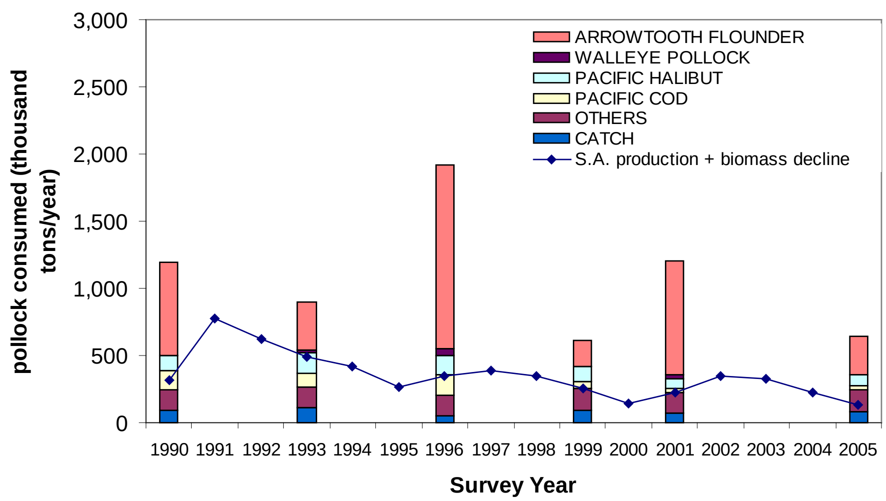


Figure 1.40. (Top) Historical trends in GOA walleye pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock asessement data. (Bottom) Total catch and consumption of walleye pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line). See text for calculation methods.

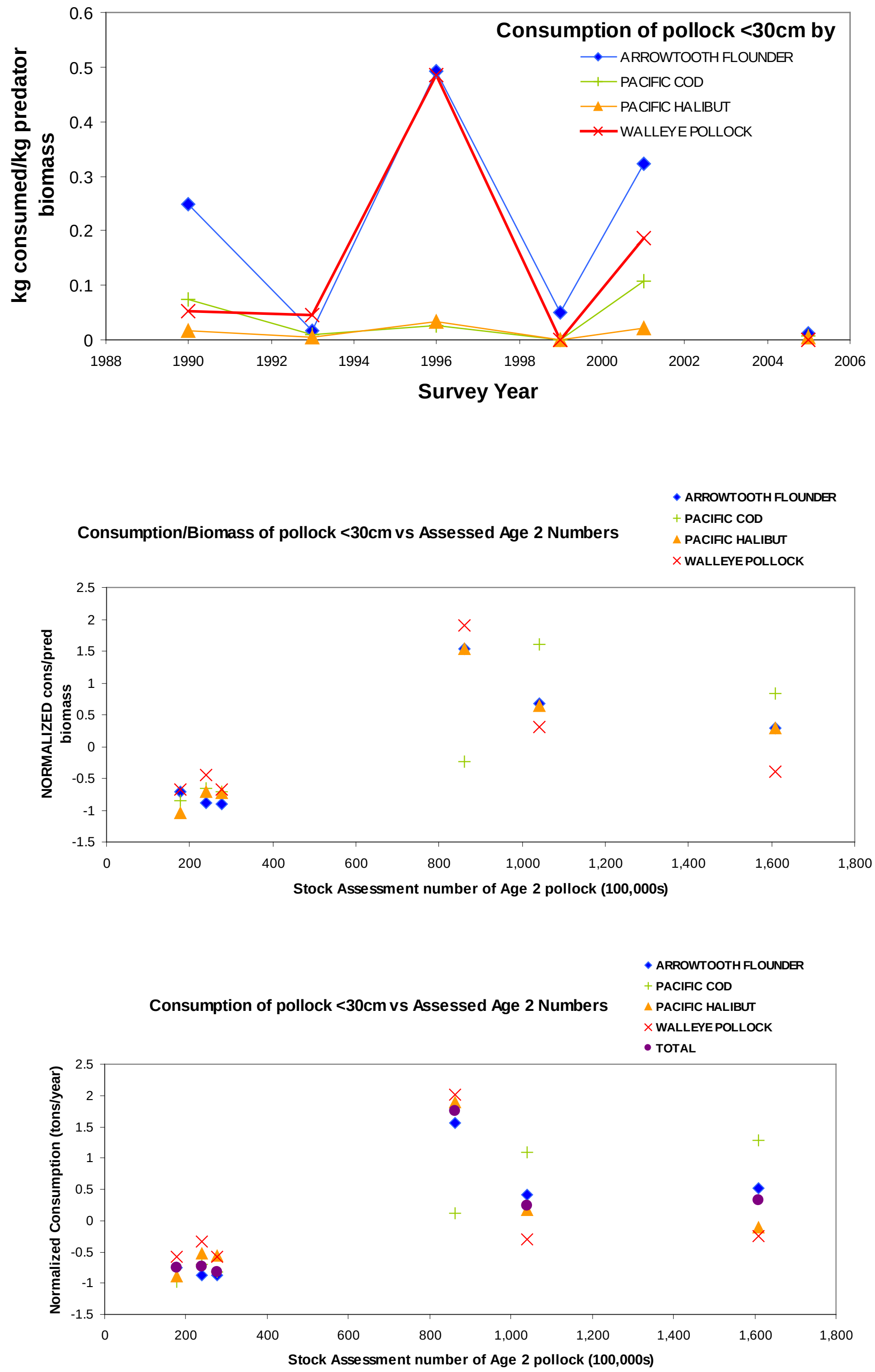


Figure 1.41. (Top) Consumption per unit predator survey biomass of GOA walleye pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers.

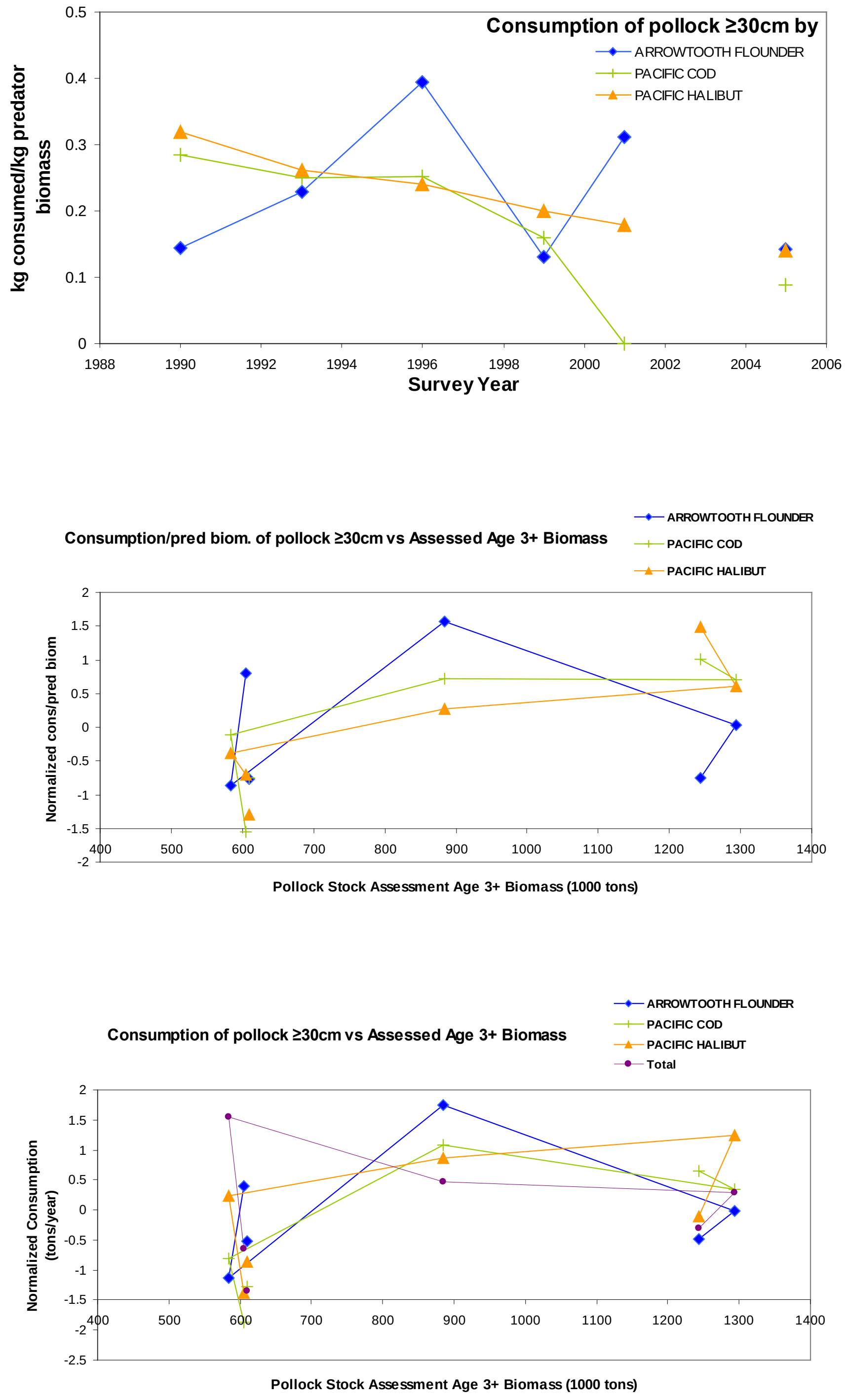


Figure 1.42. (Top) Consumption per unit predator survey biomass of GOA walleye pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass.

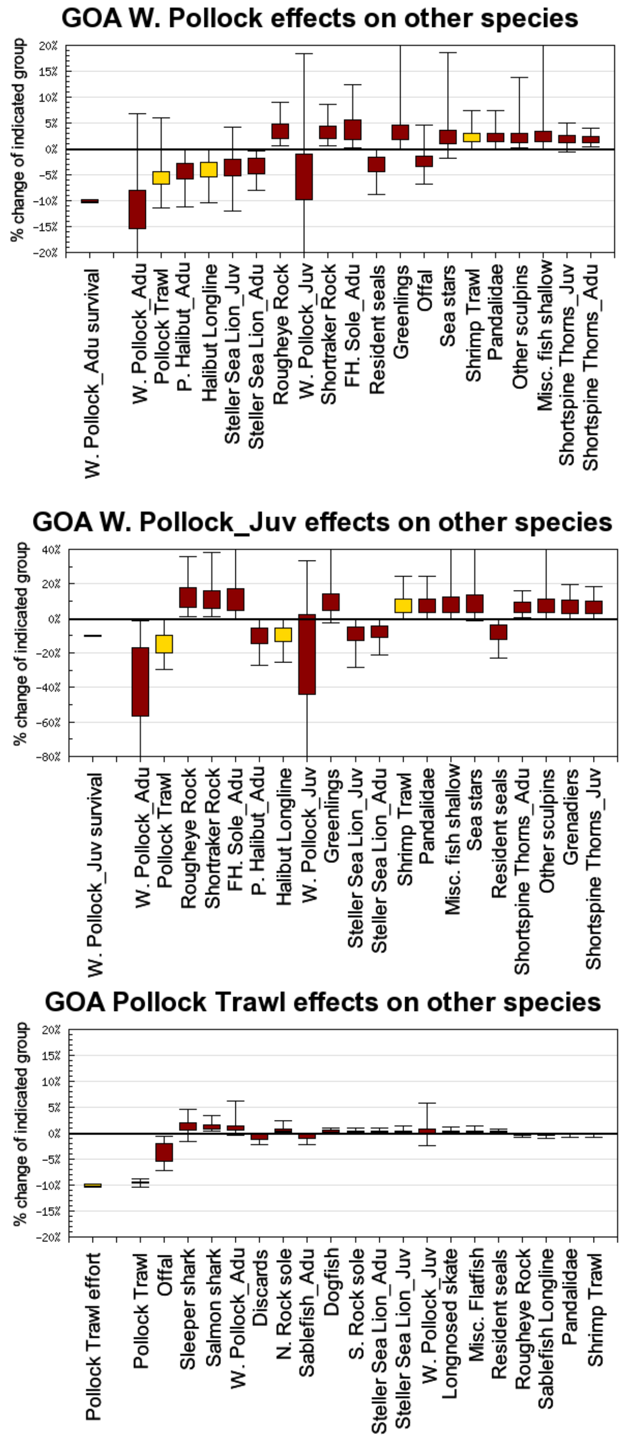


Figure 1.43. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled 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.

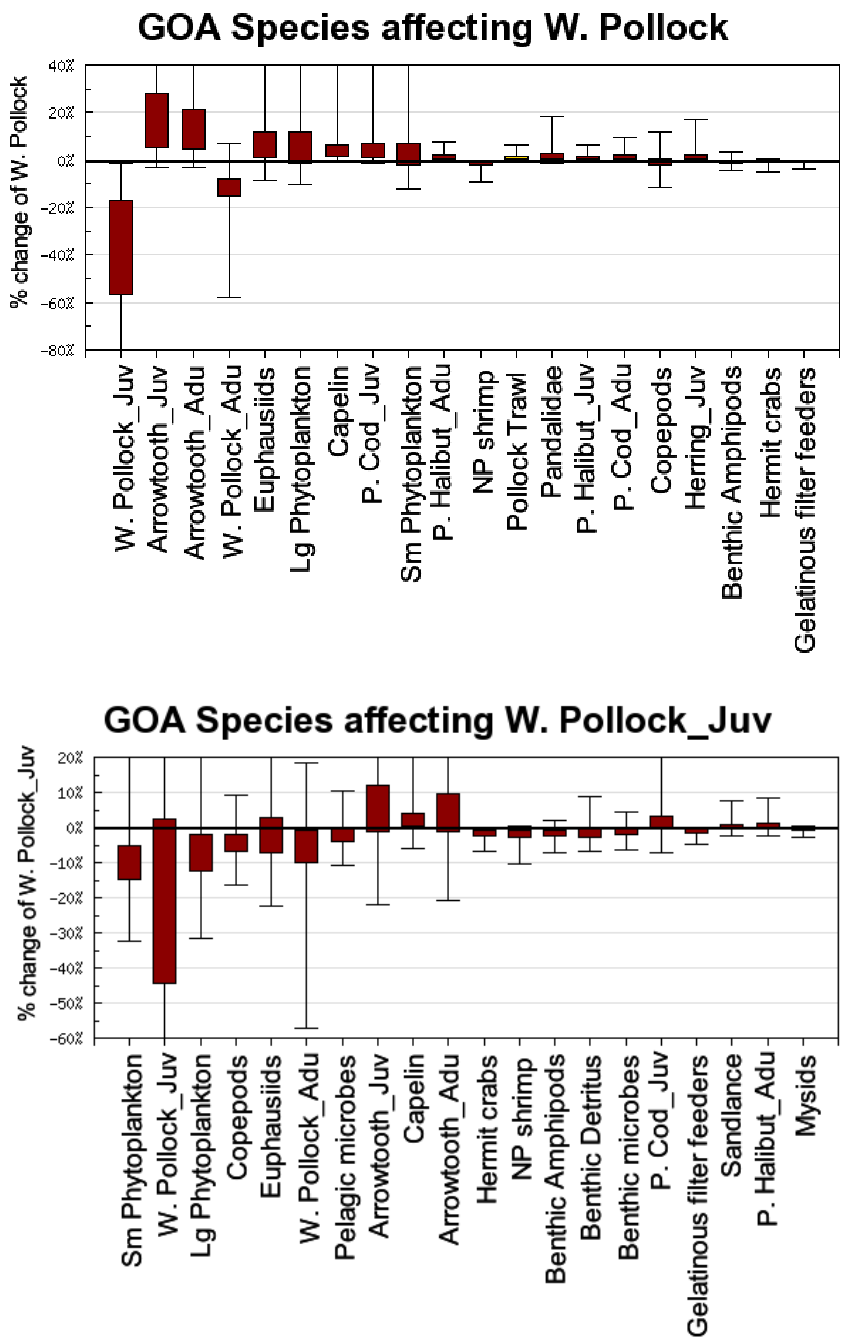


Figure 1.44. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

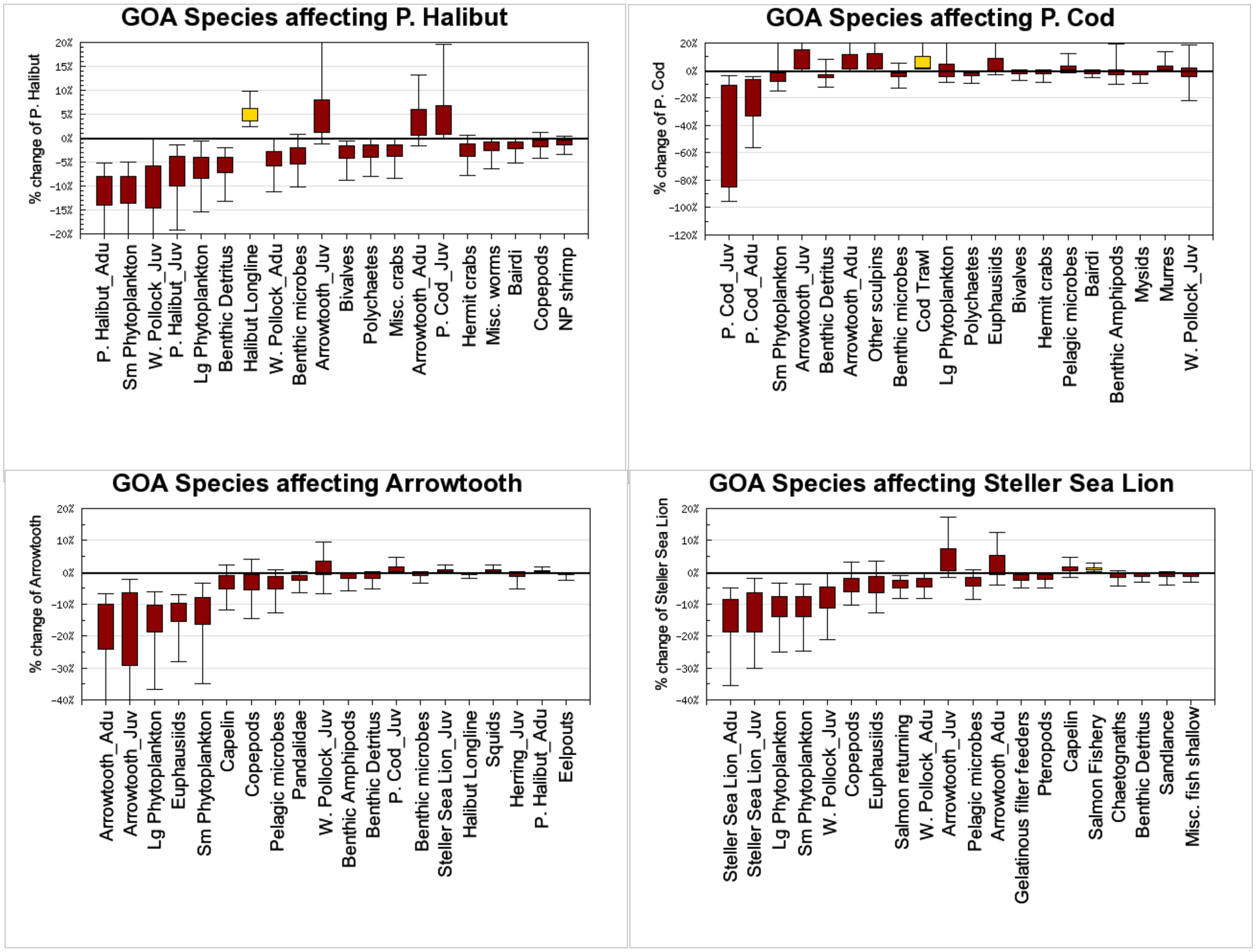


Figure 1.45. Ecosystem model output, shown as percent change at future equilibrium of four major predators on walleye pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

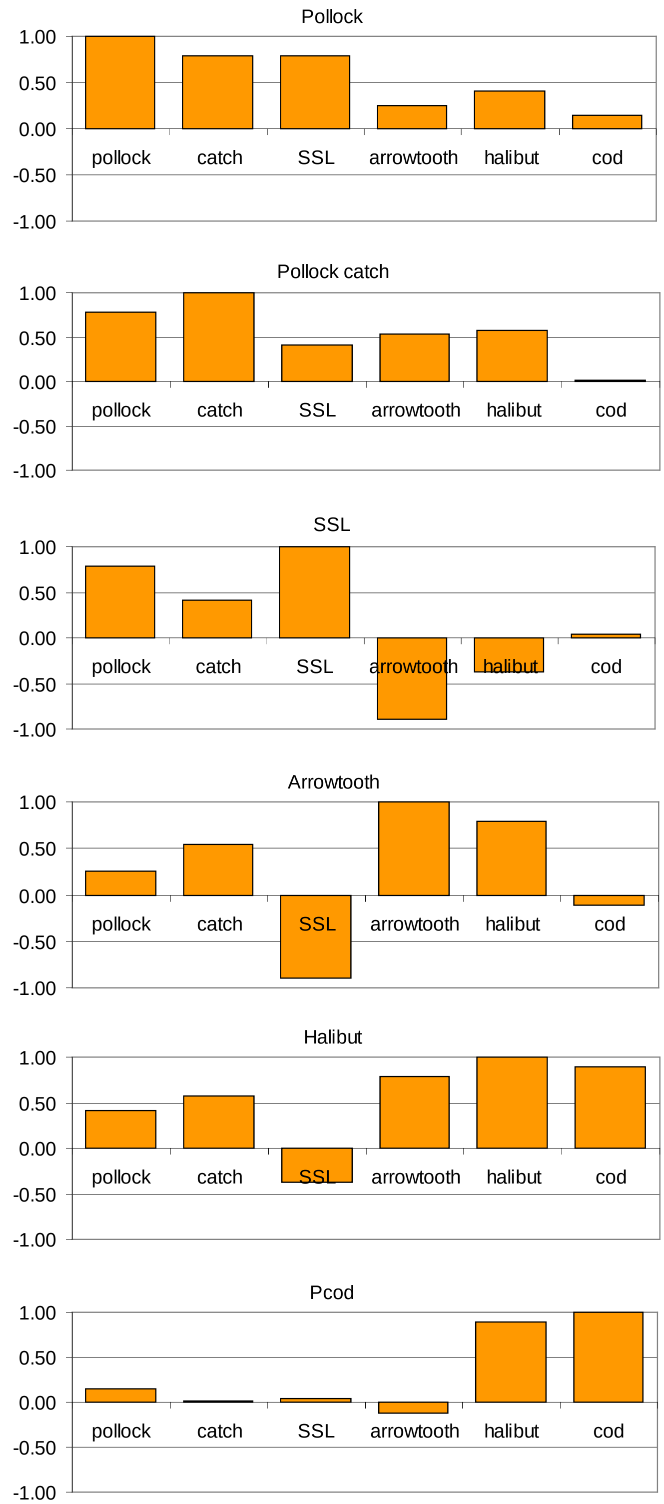


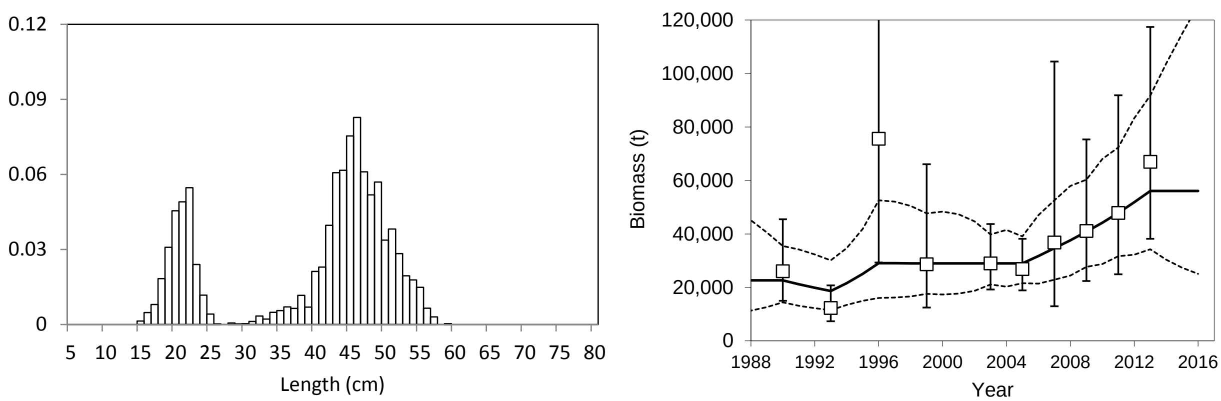
Figure 1.46. Pair-wise Spearman rank correlation between abundance trends of walleye pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for 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 2013 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is broader. Pollock length composition in the 2013 bottom trawl survey showed a mode of age-1 pollock, and a mode at 46 cm (Appendix Fig. A.1). Larger pollock (> 55 cm) were uncommon. 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 2002 (Table 1.4). The ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska.

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. A random effects model was fit to the 1990-2013 bottom trawl survey biomass estimates in southeast Alaska. 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 estimate from the random effects model in 2014 (56,111 t). **This results in a 2015 ABC of 12,625 t (56,111 t * 0.75 M), and a 2015 OFL of 16,833 t (56,111 t * M). The same ABC and OFL is recommended for 2016.**



Appendix Figure A.1. Pollock size composition in 2013 (left) and biomass trend in southeast Alaska from NMFS bottom trawl surveys in 1990-2013 (right). Error bars indicate plus and minus two standard deviations. The solid line is the biomass trend from the random effects model, while dotted lines indicate the 95% confidence interval.

Status Summary for Southeast Alaska Pollock

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)				
Upper 95% confidence interval	103,745	114,876	114,876	125,584
Point estimate	56,111	56,111	56,111	56,111
Lower 95% confidence interval	30,348	27,408	27,408	25,071
F_{OFL}	0.30	0.30	0.30	0.30
$maxF_{ABC}$	0.23	0.23	0.23	0.23
F_{ABC}	0.23	0.23	0.23	0.23
OFL (t)	16,833	16,833	16,833	16,833
maxABC (t)	12,625	12,625	12,625	12,625
ABC (t)	12,625	12,625	12,625	12,625
Status	As determined *last* year for: 2011	2012	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

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 1 to age 10, with age 10 defined as a "plus" group, i.e., all individuals age 10 and older. The model extends from 1970 to 2013 (45 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.

Process error

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

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

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

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

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

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

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

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

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

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 acoustic 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 some years the aggregate biomass surveyed outside Shelikof Strait has been comparable to that within Shelikof Strait.

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

Since time series of biomass estimates for spawning areas outside of Shelikof Strait are now available, we used the four most recent surveys at each spawning area, and used a rule that a minimum of three surveys was necessary to include an area. These criteria are intended to provide estimates that reflect recent biomass distribution while at the same time providing some stability in the estimates. The biomass in these secondary spawning areas tends to be highly variable from one year to the next. Areas meeting these criteria were Shelikof Strait, the shelf break near Chirikof Island, the Shumagin area, Sanak Gully, Morzhovoi Bay, and Marmot Bay. 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*. 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). Multipliers were needed only for Morzhovoi Bay because all other areas have been surveyed at least four times with the *R/V Oscar Dyson*. A vessel specific multiplier of 1.31 was applied in 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 65.46%, 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 areas that have been surveyed repeatedly) is lower than the assessment model estimates of abundance. After rescaling, the resulting average biomass distribution was 7.99%, 83.21%, 8.80% in areas 610, 620, and 630 (Appendix Table C.1). In comparison to last year, the percentage in area 610 is 4.2 percentage points lower, is 4.6 percentage points higher in area 620, and is 0.4 percentage points lower in area 630.

This year we evaluated using a random effects model rather than averaging to obtain the biomass distribution by area, but decided not to use it because of concerns about the performance of the random effects model when biomass estimates were highly variable and occasionally close to zero.

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 is: 610, 7.99%; 620, 67.11%; 630, 24.90%.

Summer distribution

The NMFS bottom trawl is summer survey (typically extending from mid-May to mid-August). Previously apportionment of pollock TAC was based upon an unweighted average of four most recent NMFS summer surveys, however in this assessment we considered the recommendation of the survey averaging working group to evaluate random effects models to fit smoothed biomass trends for each management area. Performance of the random effects model appeared satisfactory (Fig. C.1). The apportionment was based on the 2013 smoothed biomass estimates by area, which resulted in a biomass distribution of 26.13%, 31.37%, 39.97%, 2.53% in areas 610, 620, 630, and 640 (Fig. C.2). In comparison to previous apportionment method of using a four survey average, percent in area 610 dropped by 6.5 percentage points, while 620 increased by 0.7 percentage points, and 630 increased 6.2 percentage points.

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 (2.53%) of the TAC in area 640 is subtracted from the TAC before allocating the remaining TAC by season and region.

Example calculation of 2015 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 0.0253 x Total TAC = 2,526 t

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

A season 0.25 x (Total TAC – 2,526) = 24,369 t
B season 0.25 x (Total TAC – 2,526) = 24,369 t
C season 0.25 x (Total TAC – 2,526) = 24,369 t
D season 0.25 x (Total TAC – 2,526) = 24,369 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 0.0799 x 24,369 t = 1,946 t
620 0.6711 x 24,369 t = 16,353 t
630 0.2490 x 24,369 t = 6,069 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 0.0799 x 24,369 t = 1,946 t
620 0.8321 x 24,369 t = 20,277 t
630 0.0880 x 24,369 t = 2,145 t

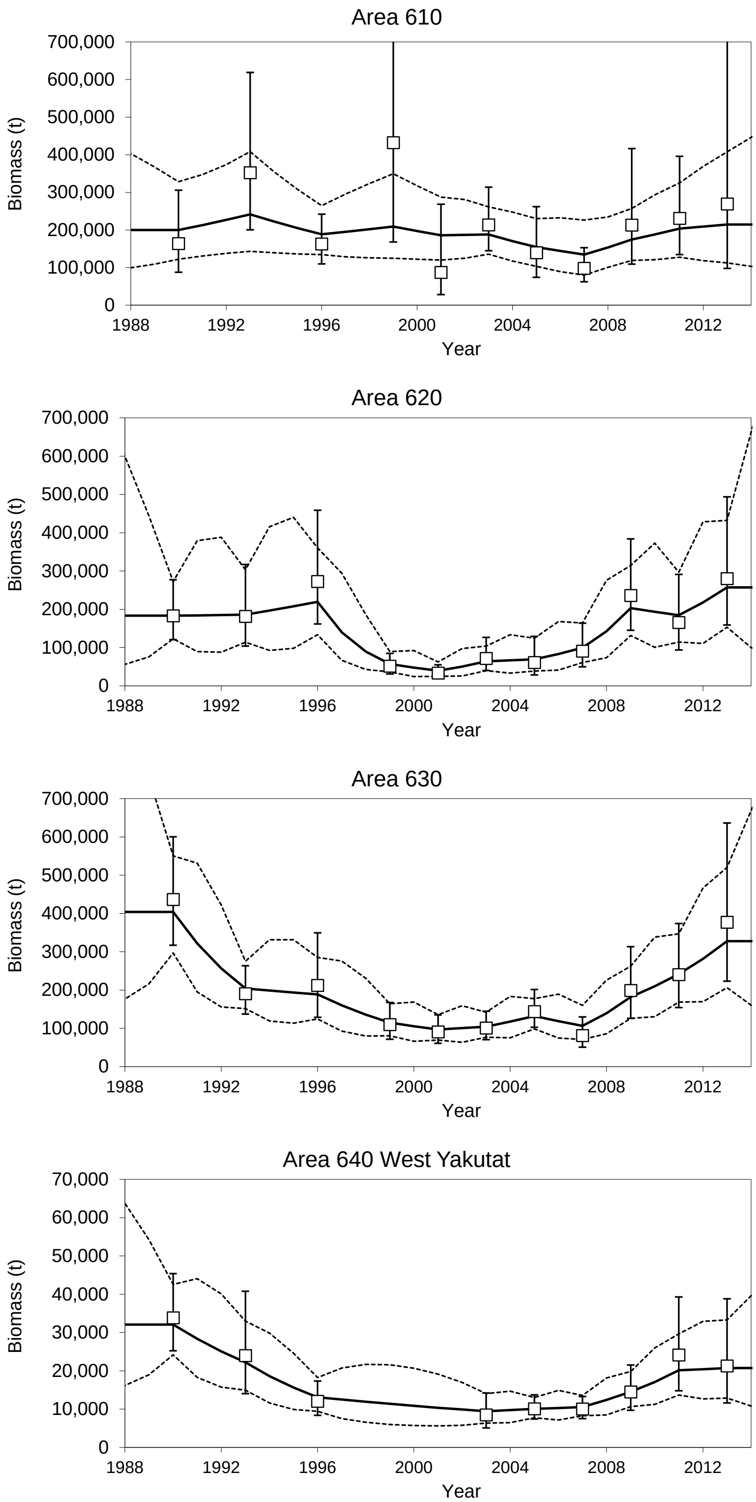
6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the biomass distribution in areas 610, 620, 630, and 640 in 2913 based on the random effects model of 26.13%, 31.37%, 39.97%, and 2.53%.

610 0.2613 / (1 – 0.0253) x 24,369 = 6,534 t
620 0.3137 / (1 – 0.0253) x 24,369 = 7,843 t
630 0.3997 / (1 – 0.0253) x 24,369 = 9,992 t

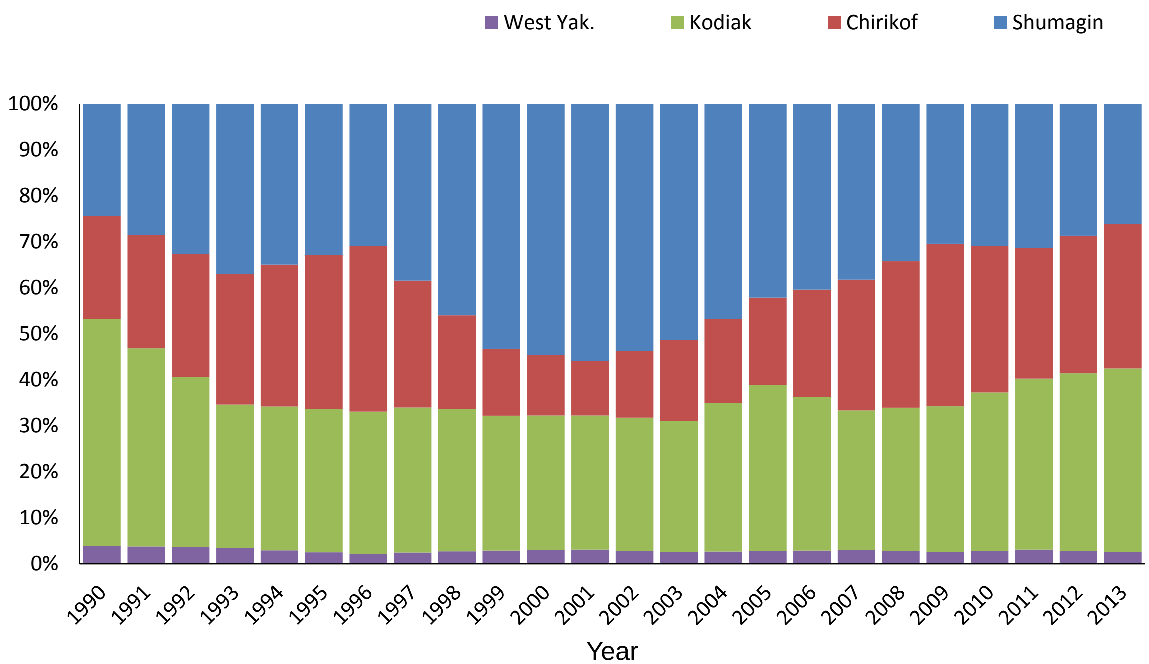
610 0.2613 / (1 – 0.0253) x 24,369 = 6,534 t
620 0.3137 / (1 – 0.0253) x 24,369 = 7,843 t
630 0.3997 / (1 – 0.0253) x 24,369 = 9,992 t

Appendix Table C.1. Estimates of percent pollock in areas 610-630 during winter acoustic surveys in the Gulf of Alaska. The biomass of age-1 fish is not included the acoustic survey biomass estimates.

Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*	*Multiplier from vessel comparison (OD/MF)*	*Percent*	*Percent by management area* *Area 610*	*Area 620*	*Area 630*
Shelikof	2010	1,062,110	429,730	1.00	40.5%	0.0%	93.7%	6.3%
Shelikof	2012	1,103,010	335,836	1.00	30.4%	0.0%	96.0%	4.0%
Shelikof	2013	1,187,700	831,486	1.00	70.0%	0.0%	95.0%	5.0%
Shelikof	2014	1,057,580	883,177	1.00	83.5%	0.0%	96.7%	3.3%
Shelikof	Average				56.1%	0.0%	95.4%	4.6%
	Percent of total 2+ biomass					0.0%	53.3%	2.6%
Chirikof	2009	818,555	396	1.00	0.0%	0.0%	0.0%	100.0%
Chirikof	2010	1,062,110	9,544	1.00	0.9%	0.0%	0.0%	100.0%
Chirikof	2012	1,103,010	21,181	1.00	1.9%	0.0%	13.0%	87.0%
Chirikof	2013	1,187,700	63,008	1.00	5.3%	0.0%	70.2%	29.8%
Chirikof	Average				2.0%	0.0%	20.8%	79.2%
	Percent of total 2+ biomass					0.0%	0.4%	1.6%
Marmot	2009	818,555	19,759	1.00	2.4%	0.0%	0.0%	100.0%
Marmot	2010	1,062,110	5,585	1.00	0.5%	0.0%	0.0%	100.0%
Marmot	2013	1,187,700	19,899	1.00	1.7%	0.0%	0.0%	100.0%
Marmot	2014	1,057,580	13,403	1.00	1.3%	0.0%	0.0%	100.0%
Marmot	Average				1.5%	0.0%	0.0%	100.0%
	Percent of total 2+ biomass					0.0%	0.0%	1.5%
Shumagin	2010	1,062,110	18,081	1.00	2.3%	94.9%	5.1%	0.0%
Shumagin	2012	1,103,010	15,501	1.00	1.9%	88.0%	12.0%	0.0%
Shumagin	2013	1,187,700	47,388	1.00	4.0%	55.2%	44.8%	0.0%
Shumagin	2014	1,057,580	36,160	1.00	3.4%	54.7%	45.3%	0.0%
Shumagin	Average				2.9%	73.2%	26.8%	0.0%
	Percent of total 2+ biomass					2.1%	0.8%	0.0%
Sanak	2010	1,062,110	26,678	1.00	2.5%	100.0%	0.0%	0.0%
Sanak	2012	1,103,010	24,252	1.00	2.2%	100.0%	0.0%	0.0%
Sanak	2013	1,187,700	12,967	1.00	1.1%	100.0%	0.0%	0.0%
Sanak	2014	1,057,580	7,319	1.00	0.7%	100.0%	0.0%	0.0%
Sanak	Average				1.9%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					1.9%	0.0%	0.0%
Mozhovoi	2006	554,369	11,679	1.31	2.8%	100.0%	0.0%	0.0%
Mozhovoi	2007	558,567	2,540	1.31	0.6%	100.0%	0.0%	0.0%
Mozhovoi	2010	1,062,110	1,650	1.00	0.2%	100.0%	0.0%	0.0%
Mozhovoi	2013	1,187,700	1,520	1.00	0.1%	100.0%	0.0%	0.0%
Mozhovoi	Average				1.2%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					1.2%	0.0%	0.0%
Total					65.46%	5.23%	54.47%	5.76%
Rescaled total					100.00%	7.99%	83.21%	8.80%



Appendix Figure C.1. Random effects models fit to summer bottom trawl biomass estimates by management area for 1990-2013.



Appendix Figure C.2. Percent biomass by management area based on random effects models.

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