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: 2014 total catch and catch at age.

2. Shelikof Strait acoustic survey: 2015 biomass and age composition.

3. NMFS bottom trawl survey: 2015 biomass and length composition.

4. ADFG crab/groundfish trawl survey: 2015 biomass and 2014 age composition.

5. A new survey time series was added to the assessment: summer acoustic survey in 2013 and 2015. Biomass estimates in 2013 and 2015, 2013 age composition, 2015 length composition.

Changes in assessment methodology

The age-structured assessment model is similar to the model used for the 2014 assessment and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library). The only changes made to the model were those necessary to include the summer acoustic survey in the assessment, and to estimate a power coefficient for the age-1 winter acoustic survey index catchability.

Summary of Results

The base model projection of female spawning biomass in 2016 is 321,626 t, which is 42.9% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (300,000 t), thereby placing Gulf of Alaska pollock in sub-tier “a” of Tier 3. In last few assessments, the magnitude of the 2012 year class was a major issue when deciding which ABCs and OFLs to recommend. New information about 2012 year class came from the 2015 Shelikof Strait survey, the 2015 NMFS bottom trawl survey, and the 2015 summer acoustic survey. All of this new information indicates that this year class is still very abundant. The 2015 Shelikof Strait acoustic survey estimate of age-3 pollock is 1.64 billion, which is the largest age-3 estimate in time series. Therefore we have continued the approach of using the 2012 year class abundance as estimated to project ABCs and OFLs.

The new survey data for 2015 included the Shelikof Strait acoustic survey, the summer acoustic survey, and the NMFS bottom trawl surveys, all of which remain at relatively high levels. There was a large and unexplained decline in pollock biomass in the 2015 ADFG survey (58% decline), which is a concern, especially since this time series has been the most stable used in the assessment. Since this low observation is included in the model, the estimated ABCs and OFLs somewhat factor in this concern. The estimated abundance of mature fish is projected to peak in 2017, and then decline as the strong 2012 year class passes through the population.

The author's 2016 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 254,310 t, which is an increase of 33% from the 2015 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 2017, the ABC for an adjusted $F_{40\%}$ harvest rate is 250,544 t. The OFL in 2016 is 322,858 t, and the OFL in 2017 if the recommended ABC is taken in 2016 is 289,937 t.

For pollock in southeast Alaska (Southeast Outside region), the ABC recommendation for both 2016 and 2017 is 9,920 t (see Appendix A) and the OFL recommendation for both 2016 and 2017 is 13,226 t. These recommendations are based on a Tier 5 assessment using the estimated biomass in 2016 and 2017 from a random effects model fit to the 1990-2015 bottom trawl survey biomass estimates in Southeast Alaska.

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

	As estimated or specified *last* year for		As estimated or specified *this* year for	
Quantity/Status	2015	2016	2016	2017
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3b	3a	3a	3a
Projected total (age 3+) biomass (t)	1,883,920	1,927,010	1,937,900	1,543,100
Female spawning biomass (t)				
Projected				
Upper 95% confidence interval	406,382	432,820	411,386	454,646
Point estimate	309,869	330,497	321,626	357,193
Lower 95% confidence interval	236,081	253,194	240,967	277,694
$B_{100\%}$	779,000	779,000	750,000	750,000
$B_{40\%}$	312,000	312,000	300,000	300,000
$B_{35\%}$	273,000	273,000	262,000	262,000
F_{OFL}	0.28	0.28	0.29	0.29
$maxF_{ABC}$	0.24	0.24	0.25	0.25
F_{ABC}	0.20	0.22	0.23	0.25
OFL (t)	256,545	321,067	322,858	289,937
maxABC (t)	222,774	272,165	278,385	250,544
ABC (t)	191,309	250,824	254,310	250,544
	As determined *last* year for		As determined *this* year for	
Status	2013	2014	2014	2015
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Status Summary for Pollock in the Southeast Outside Area

Quantity	As estimated or *specified last* year for: 2015	2016	As estimated or *recommended this* year for: 2016	2017
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)				
Upper 95% confidence interval	114,876	125,584	70,015	76,781
Point estimate	56,111	56,111	44,087	44,087
Lower 95% confidence interval	27,408	25,071	27,761	25,315
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	13,226	13,226
maxABC (t)	12,625	12,625	9,920	9,920
ABC (t)	12,625	12,625	9,920	9,920
Status	As determined *last* year for: 2013	2014	As determined *this* year for: 2014	2015
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments in General

The SSC in its October 2015 minutes recommended that a standard naming convention be used for different models presented in assessments.

In this assessment, we use the preferred option identified by the SSC by designating the base model in last year's assessment as model 14.9. The recommended base model in this assessment is model 15.1a.

Responses to SSC and Plan Team Comments Specific to this Assessment

There were no SSC comments specific to this assessment in its December 2014 minutes.

The GOA plan team recommended in its November 2014 minutes that a presentation of the summer 2015 acoustic survey be provided in September with an indication on whether a new data series would be included in November 2015.

The requested presentation was given in September. A model with the summer acoustic survey included is presented for consideration by the Plan Team and SSC.

The GOA plan team suggested in its November 2014 minutes that non-linearity in catchability for age-1 and age-2 Shelikof acoustic survey indices be evaluated.

We evaluated models with estimated power terms for catchability for the age-1 and age-2 winter acoustic survey indices. Only the power term for the age-1 index was significant and was included in the proposed base model.

Introduction

Walleye pollock (*Gadus chalcogrammus*; hereafter referred to as pollock) is a semi-pelagic schooling fish widely distributed in the North Pacific Ocean. Pollock in the central and western Gulf of Alaska (GOA) 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). Available information supported the current approach of assessing and managing pollock in the eastern portion of the Gulf of Alaska (southeast outside) separately from pollock in the central and western portions of the Gulf of Alaska (central/western/west Yakutat). The main part of this assessment deals only with the C/W/WYK stock, while results for a tier 5 assessment for southeast outside pollock are reported in Appendix A.

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, Pacific ocean perch, flathead sole, shallow-water flatfish, and squid. The most common non-target species are eulachon and other osmerids, miscellaneous fish, and jellyfish (Table 1.2). Bycatch estimates for prohibited species over the period 2010-2014 are given in Table 1.3. Chinook salmon are the most important prohibited species caught as bycatch in the pollock fishery. A sharp 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 peak in 2010.

Kodiak is the major port for pollock in the Gulf of Alaska, accounting for about 75% of the 2010-2014 landings. In the western Gulf of Alaska, Sand Point, King Cove, and Akutan are important ports, sharing 21% of recent landings. Minor ports, including Seward, Dutch Harbor, Homer, Sitka, Cordova, and Ketchikan account for less than 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	*Data*	*Years*
Fishery	Total catch	1970-2014
Fishery	Age composition	1975-2014
Shelikof Strait acoustic survey	Biomass	1992-2015
Shelikof Strait acoustic survey	Age composition	1992-2015
Summer acoustic survey	Biomass	2013-2015
Summer acoustic survey	Age composition	2013
Summer acoustic survey	Length composition	2015
NMFS bottom trawl survey	Area-swept biomass	1990-2015
NMFS bottom trawl survey	Age composition	1990-2013
NMFS bottom trawl survey	Length composition	2015
ADFG trawl survey	Area-swept biomass	1989-2015
ADFG survey	Age composition	2000-2014

Total Catch

Total catch estimates were obtained from 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 in the GOA, though there may have been some catches by Soviet Union vessels. Foreign catches 1971-1976 are reported by Forrester et al. (1983). During this period there are reported pollock catches for Japanese, Soviet Union, Polish, and South Korean vessels in the Gulf of Alaska. Foreign and joint venture catches for 1977-1988 are blend estimates from 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 1991-2014 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 the 2014 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. Use of an age-length key was considered necessary because observers used length-stratified sampling designs to collect otoliths prior to 1999 (Barbeaux et al. 2005). 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.

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 were downloaded from the NORPAC tables. 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 2014 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)	Num. ages	184	409	395	88
	Num. lengths	1125	6123	2456	421
	Catch (t)	4,203	58,707	13,730	3,417
2nd half (C and D seasons)	Num. ages	315	375	392	----
	Num. lengths	2090	4375	4207	----
	Catch (t)	9,162	24,374	29,041	----

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

The catch-at-age in the first half of 2014 (A and B season) was primarily ages 6-8, with the age-7 fish (2007 year class) dominant (Fig. 1.2). In the second half of 2014 (C and D seasons), there was a switch to younger fish, with mode of age-4 fish in all areas except for area 610, where there was a mode of age-2 fish. Fishery catch at age in 1975-2014 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) 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 from once every three years to 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, 75% 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. and re-estimating biomass for west Yakutat. In 2001, when eastern Gulf of Alaska was not surveyed, a random effects model was used to interpolate a value for west Yakutat.

The Alaska Fisheries Science Center’s (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted the fourteenth comprehensive bottom trawl survey since 1984 during the summer of 2015 (Fig. 1.4). The 2015 gulfwide biomass estimate of pollock was 745,322 t, which is a decrease of 26% from the 2013 estimate, but is similar to biomass estimates in 2009 and 2011. The biomass estimate for the portion of the Gulf of Alaska west of 140º W long. used in the assessment model is 705,443 t. The coefficient of variation (CV) of this estimate was 0.16, which is similar to other years when the usual level of sampling effort is deployed. Surveys from 1990 onwards are used in the assessment due to difficulties in standardizing the surveys in 1984 and 1987, when Japanese vessels with different gear were used.

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 (Fig. 1.5). Since ages are not yet available for the 2015 survey, length composition data were used in the model (Fig. 1.6).

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, 1999, and 2011). Only surveys from 1992 and later are used in the stock assessment due to the higher uncertainty associated with the acoustic estimates produced with the Biosonics echosounder used prior to 1992. Additionally, raw survey data is not easily recoverable for the earlier acoustic surveys, so there is no way to verify (i.e., to reproduce) the estimates. Survey methods and results for 2015 are presented in a NMFS processed report (McCarthy and Stienessen, in press). 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 2015 biomass estimate for Shelikof Strait is 845,306 t, which is nearly the same as the 2014 estimate. In addition to the Shelikof Strait survey, acoustic surveys in winter 2015 covered the Shumagin Islands, Sanak Gully, Marmot Gully, Chirikof, and Kenai Bays. Several other surveys had been planned for winter of 2015, including Pavlof Bay, Morzhovoi Bay and Prince William Sound, but were unable to be completed due to equipment failures and scheduling issues on *R/V Oscar Dyson*. The following table provides results from the 2015 winter acoustic surveys:

Area	Biomass ≥43 cm (t)	Percent	Total biomass (t)	Percent
Shumagin Islands	3,295	0.5%	61,369	5.9%
Sanak Gully	8,853	1.5%	17,863	1.7%
Shelikof Strait	486,325	81.2%	845,306	81.2%
Marmot Gully	16,318	2.7%	22,470	2.2%
Chirikof	8,026	1.3%	12,685	1.2%
Kenai Bays	76,433	12.8%	80,965	7.8%
Total	599,249		1,040,658	

The total biomass of pollock ≥43 cm (a proxy for spawning biomass) is 7% higher than the 2014 estimate, but there were more areas surveyed in 2015. In comparison to 2014, biomass estimates in Shumagin Islands, Sanak Gully and Marmot Bay were higher (64%, 144%, and 50% percent increases respectively), while Chirikof declined by 80% (Fig. 1.7). These results suggest that spawning was not as concentrated in Shelikof Strait as in 2014, when over 90% of the spawning biomass was found in Shelikof Strait.

Shelikof Acoustic Survey Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.8) were obtained using an age-length key compiled from random otolith samples and applied to weighted length frequency samples. Otoliths collected during the 1994-2015 Shelikof acoustic surveys were aged using the criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.11.

Winter Acoustic Survey Age-1 and Age-2 Indices

Based on recommendations from the 2012 CIE review, we developed an approach to model the age-1 and age-2 pollock estimates separately from the Shelikof Strait acoustic survey biomass and age composition. Age-1 and age-2 pollock are occasionally very abundant in winter acoustic surveys, and by fitting them separately from the 3+ fish it is possible utilize an error distribution that better reflects that variability. In addition, the 2014 assessment found that the combined estimates from both the Shumagin and the Shelikof Strait surveys was better correlated with eventual recruitment strength than the each estimate individually. Therefore combined Shelikof and Shumagin survey indices for age-1 and age-2 pollock were used in the model.

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 1993-2015 were evaluated in the assessment model.

Summer Acoustic Survey

Two complete acoustic surveys, in 2013 and 2015, have been conducted by AFSC on the *R/V Oscar Dyson* in the Gulf of Alaska during summer (Jones et al. 2014, Jones et al. in prep.). The area surveyed covers the Gulf of Alaska shelf and upper slope, and extends eastward to 140° W lon. Prince William Sound is also surveyed (Fig. 1.9). In 2015, the survey extended from mid-July to mid-August. The survey consists of widely-spaced parallel transects along the shelf, and more closely spaced transects in troughs, bays, Shelikof Strait, and Prince William Sound. Mid-water and bottom trawls are used to identify acoustic targets. Total biomass estimates in 2013 and 2015 were 884,049 t and 1,482,668 t, respectively. Length composition in 2015 indicated that a high percentage of the biomass (88%) consisted of fish 30-45 cm in length, most likely representing a very abundant 2012 year class (age-3 fish) (Fig. 1.10). Although a short survey time series is unlikely to be informative about pollock status and trend, including the survey in the assessment will relate survey results to population trends estimated with other data sets in the 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, 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 at fixed 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 2015 biomass estimate for pollock for the ADFG crab/groundfish survey was 42,277 t, down by 58% from the 2014 biomass estimate (Table 1.7). This is the lowest biomass estimate for the ADFG crab/groundfish time series, which seems unusual given that all the other indices used in the assessment are relatively high.

ADFG Survey Age Composition

Ages were determined by age readers in the AFSC age and growth unit from samples of pollock otoliths collected during 2000-2014 ADFG surveys in even-numbered years (average sample size = 575) (Table 1.12, Fig. 1.11). 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.

Data sets 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). These earlier surveys 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. 1.12). All surveys indicate a strong increase since 2008, though in the last few years there has been some divergence the trends. The ADFG suggests a downward trend, while both the Shelikof Strait acoustic survey and the NMFS bottom trawl survey indicate that biomass remains at high levels.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.13). 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 49% in 2014. The mean age shows interannual variability due to strong year classes passing through the population, but there are 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 mortality. 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 then increased in strongly in 2013 and 2014. 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 1976-2014 (Fig. 1.13).

Analytic Approach

Model Structure

An age-structured model covering the period from 1970 to 2015 (46 years) 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.

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. Model tuning for composition data was done by iterative re-weighting of input sample sizes using the harmonic mean of effective sample size. Variance estimates/assumptions for survey indices were not reweighted except for the age-1 and age-2 winter acoustic survey indices, where input coefficients of variation (CVs) were tuned using RMSE.

Likelihood component	*Statistical model for error*	*Variance assumption*
Fishery total catch (1970-2015)	Log-normal	CV = 0.05
Fishery age comp. (1975-2014)	Multinomial	200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2015)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2015)	Multinomial	Initial sample size = 60
Winter acoustic survey age-1 and age-2 indices (1994-2015)	Log-normal	Tuned CVs = 1.20 and 0.89
Summer acoustic survey biomass (2013-2015)	Log-normal	CV = 0.25
Summer acoustic survey age comp. (2013)	Multinomial	Initial sample size = 10
Summer acoustic survey length comp. (2015)	Multinomial	Initial sample size = 10
NMFS bottom trawl survey biom. (1990-2015)	Log-normal	Survey-specific CV from random-stratified design = 0.12-0.38
NMFS bottom trawl survey age comp. (1990-2013)	Multinomial	Initial sample size = 60
NMFS bottom trawl survey length comp. (2015)	Multinomial	Initial sample size = 15
ADFG trawl survey biomass (1989-2015)	Log-normal	CV = 0.25
ADFG survey age comp. (2000-2014)	Multinomial	Initial sample size = 30
Recruit process error (1970-1977, 2015, 2016)	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 2014 and 2015 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. 1.14). Catchability coefficients for other surveys were estimated as free parameters. The age-1 and age-2 winter acoustic survey indices are numerical abundance estimates, and were modeled using an independently estimated catchability coefficients (i.e., no selectivity is estimated). A density-dependent power coefficient was evaluated for catchability for both indices.

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 1.13). 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 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, particularly for the younger fish, 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 the 2014 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 the 2014 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 $L_\infty = 65.2$ 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 1.14 and Fig. 1.15). 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 trick 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 375 (Table 1.15).

Estimates of maturity at age in 2015 from winter acoustic surveys were above the long term mean for all ages (Fig. 1.16). 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 1983-2015 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 1.17). 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 increasing trend in the length at 50% mature to 49 cm, though in 2015 the average length at 50% mature dropped to 45 cm.

Weight at age

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a L^b$, were also estimated. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions. Weight at age for the fishery, the Shelikof Strait acoustic survey, and the NMFS bottom trawl survey are given in Table 1.16, Table 1.17, and Table 1.19, respectively. 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. 1.18). For pollock greater than age 6, weight-at-age has nearly doubled since 1983-1990. However, weight at age in the last five years, 2011-2015, 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, though many 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 x 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 1970-2015 = 46	Estimated as log deviances from the log mean; recruitment in 1970-77, and 2014 and 2015 constrained by random deviation process error.
Natural mortality	Age-specific= 10	Not estimated in the model
Fishing mortality	Years 1970-2015 = 46	Estimated as log deviances from the log mean
Mean fishery selectivity	4	Slope parameters estimated on a log scale, intercept parameters on an arithmetic scale
Annual changes in fishery selectivity	2 * (No. years-1) = 90	Estimated as deviations from mean selectivity and constrained by random walk process error
Survey catchability	No. of surveys + 1 = 7	Catchabilities estimated on a log scale. Two catchability periods were estimated for the Shelikof Strait acoustic survey. Separate catchabilities were also estimated for age-1 and age-2 winter acoustic indices.
Survey selectivity	6 (Shelikof acoustic survey: 2, BT survey: 2, ADFG survey: 2)	Slope parameters estimated on a log scale.
Total	109 estimated parameters + 90 process error parameters + 10 fixed parameters = 209	

Results

Model selection and evaluation

Model Selection

Several model configurations were evaluated that focused primarily on treatment of acoustic survey data, including a model incorporating the summer acoustic survey data into the assessment. To some extent these models reflect the work plan developed after the 2012 CIE review of the pollock assessment, and SSC and Plan Team comments. We attempted to follow the SSC's proposed naming conventions for assessment models, except that we did not apply the formal criteria using changes in spawning biomass for distinguishing between major and minor model changes (None of models considered here would meet the 10% change in average spawning biomass criteria for a major model change). Alternative models that were evaluated are listed below. Note that for each model the changes are cumulative:

Model 14.9—last year's base model with new data.
Model 15.1—add summer acoustic survey data.
Model 15.1a—add a power term for age-1 winter acoustic catchability.
Model 15.1b—revise Shelikof Strait acoustic survey estimates for net selectivity.

Models were compared by examining model fits (Table 1.19) and plotting the estimated spawning biomass (Fig. 1.19). Last year's base model, Model 14.9, used iterative re-weighting for composition data based on the harmonic mean of effective sample size (Dorn et al. 2014). After incorporating new data, an initial tuning step was done. This tuning step did not change the weights substantially (only the fishery age composition and the age-1 and age-2 winter acoustic survey indices needed to be re-weighted slightly), and had little effect on model results. To facilitate model comparison, subsequent models were not tuned until a potential base model was identified, and then a final tuning step was done for that model.

All model also showed very similar patterns of spawning biomass, especially prior to 2008. A comparison of Model 14.9 from last year with the same model with new data indicated that the addition of new data did not strongly affect model results. In particular the 2012 year class still appears to be very strong based on recent information, and increased slightly when new data were added.

Model 15.1 added the summer acoustic data as new survey time series, which includes two years of biomass estimates (2013 and 2013), age composition in 2013 and size composition in 2015 (otoliths were collected in 2015 but have not yet been aged). Modeling a survey time series required estimating a catchability coefficient (*q*) and a selectivity pattern. After some experimentation with different ways to model selectivity, we found that there was little evidence of less than full selectivity for the ascending portion of the selectivity curve, but that there was some evidence of reduced selectivity for older ages. Although it was possible to estimate the parameters for a descending logistic selectivity curve, the lack of data to inform selectivity would make the estimates highly uncertain. When descending selectivity was estimated, the catchability coefficient was greater than one, which seemed an unrealistic result. Therefore we adopted simpler approach and assumed full selectivity at all ages. This assumption will need to be revisited as additional data become available. Inclusion of these summer acoustic survey did not have a strong effect on model results, and the model was able to fit both years of data adequately.

Model 15.1a added a power term to the age-*j* catchability for the age-1 and age-2 Shelikof acoustic survey indices, making catchability in year *i*, q_i, a function of abundance:

$$q_i = q_1 N_{ij}^{q_2},$$

where q_1 and q_2 are catchability parameters to be estimated, and N_{ij} is the number of age-*j* fish in the population in year *i*. An estimated value greater than zero for the power term, q_2, indicates hyperdepletion, while a value less than zero indicates hyperstability (Wilberg et al. 2010). Initially power terms were estimated for both age-1 and age-2 catchability, but the estimated power term was close to zero for the age-2 index, and did not improve model fit, and so was not used. In the case of the age-1 index, the change in log likelihood when adding a power term was 2.4, which implies a significant improvement (i.e., > 2). The estimated power term, q_2, was positive (0.92) which indicates hyperdepletion. In the context of an age-1 index, this implies that a very large estimate of abundance at age 1 from the Shelikof acoustic survey will not result in a proportionately large estimate of recruitment, because catchability increases nonlinearly as the index increases (Fig. 1.20). This model was considered an improvement over the previous base model because the summer acoustic survey data are used, and the addition of a power term improved the fit to age-1 index data. Therefore we used Model 15.1a as the base model for model evaluation, reporting of time series estimates, and developing ABC and OFL recommendations.

Model 15.1b, which uses net-selectivity corrected acoustic biomass and age composition estimates for the Shelikof Strait survey, was also evaluated last year, but a decision was made not to use the revised estimates pending further review and investigation. Model 15.1b results in higher spawning biomass (about 6% higher over the last five years of the assessment model). Catchability increases for the age-1 pollock, and declines for the older pollock. The model estimates that 51% of the adult biomass spawns in Shelikof Strait (i.e., catchability=0.51), 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 time series increased, indicating a worse fit. Before using the net-selectivity corrected estimates for the base model, the method for making the net selectivity correction needs to be fully documented and vetted by the Plan Team, or in peer-reviewed publication. In addition, if net-selectivity corrected estimates are considered the best approach, other acoustic surveys the

GOA would also need to be corrected, since net selectivity would affect the summer acoustic biomass estimates, and winter surveys in other areas of the GOA, which are important in the calculations for apportioning the TAC in the A and B seasons.

The input sample sizes were initially standardized by data set before model tuning. 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/deliveries, in which case the number of hauls/deliveries was used. Both the Shelikof 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. Just a few 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 115, the bottom trawl age composition was down weighted to sample size of 28, and 3+ Shelikof survey 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 Shelikof 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. A final tuning step for Model 15.1a was used to obtain a base model. Only the age-1 and age-2 winter acoustic indices needed to be reweighted, resulting CVs of 1.2 and 0.9 respectively.

Model Evaluation

The fit of Model 15.1a to age composition data was evaluated using plots of observed and predicted age composition and residual plots. Plots show the fit to fishery age composition (Fig. 1.21, Fig. 1.22), Shelikof Strait acoustic survey age composition (Fig. 1.23, Fig. 1.24), NMFS trawl survey age composition (Fig. 1.25, Fig. 1.26), and ADFG trawl survey age composition (Fig. 1.27, Fig. 1.26). 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. 1.28 and1.29). 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. The model is unable to fit the extreme low value for the ADFG survey in 2015, though otherwise the fit to this survey is quite good. The fit to the age-1 and age-2 Shelikof acoustic indices appeared adequate though variable (Fig. 1.30).

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 1.20 (see also Figure 1.31). Table 1.21 gives the estimated population numbers at age for the years 1970-2015. Table 1.22 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2015 (see also Fig. 1.32). Table 1.23 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 1979-2014 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 21% of unfished stock size. Over the years 2009-2013 stock size has shown a strong upward trend from 25% to 50% of unfished stock size, but declined to 33% of unfished stock size in 2015. The spawning stock is projected to increase again in 2016 as the strong 2012 year class starts maturing.

Figure 1.33 shows the historical pattern of exploitation of the stock both as a time series of SPR and fishing mortality compared to the current estimates of biomass and fishing mortality reference points. Except from the mid-1970s to mid-1980s fishing mortalities has generally been lower than the current OFL definition, and in a nearly all years was lower than the F_{MSY} proxy of $F_{35\%}$.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2015 indicates the current estimated trend in spawning biomass for 1990-2015 is consistent with previous estimates (Fig. 1.34, 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. A moderate retrospective pattern is evident between the most recent two assessments and the three previous assessments, where the spawning biomass was revised upwards with each assessment. The estimated 2015 age composition from the current assessment is reasonably consistent with the projected 2015 age composition from the 2014 assessment (Fig. 1.34, bottom panel). The largest change is the estimate of the age-1 fish (2014 year class), which is much lower based on this year's survey results indicating weak age-1 recruitment instead of average recruitment as was assumed in last year's assessment.

Retrospective analysis of base model

A retrospective analysis consists of dropping the data year-by-year from the current model, and provides a different perspective than a comparison of current assessment with previous assessments. Figure 1.35 shows a retrospective plot with data sequentially removed back to 2005. There is up to 20% 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, and the revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is -0.016, which would generally be considered a very low value.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 0.91) than Eastern Bering Sea pollock (CV = 0.59). 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 years), 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 GOA 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. GOA 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. 1.32). The 2012 year class still appears to be very strong in based on the current assessment, and may be strongest year class since the 1970s. Because of high recruitment variability, the mean 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. 1.36). 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, GOA pollock have been managed under Tier 3 of the NPFMC tier system. 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 GOA pollock (Table 1.24). Spawning biomass reference levels were based on mean 1978-2014 age-1 recruitment (5.809 billion), which is similar to the mean value in last year's assessment. 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 2010-2015 to estimate current reproductive potential. A substantial increase in pollock weight-at-age has been observed (Fig. 1.18), which may be a density-dependent response to low abundance or due to environmental forcing. The SPR at F=0 was estimated as 0.129 kg/recruit at age one. 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 2010-2014 to reflect current selectivity patterns.

GOA pollock F_{SPR} harvest rates are given below:

		Equilibrium under average 1978-2014 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	5809	2691	750	0	0.0%
40.0%	0.247	5809	1583	300	228	14.4%
35.0%	0.291	5809	1482	262	246	16.6%

The $B_{40\%}$ estimate of 300,000 t represents a 4% decrease from the $B_{40\%}$ estimate of 312,000 t in the 2014 assessment, which is due small declines in spawning weight at age and mean recruitment. The base model projection of female spawning biomass in 2016 is 321,626 t, which is 42.9% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (300,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3.

2016 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 GOA pollock, the maximum permissible F_{ABC} harvest rate is 85.0% of the OFL harvest rate. In the 2001 assessment, based on an analysis that showed that the buffer between the maximum permissible F_{ABC} and OFL decreased when the stock is below approximately $B_{50\%}$, we developed a more conservative alternative that maintains a constant buffer between ABC and F_{ABC} at all stock levels (Table 1.25). 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: $0.05 < B / B^{*} \leq 1$, then $F = F_{40\%} \times (B/B^{*} - 0.05) / (1 - 0.05)$

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

This alternative has the same functional form as the maximum permissible F_{ABC}; the only difference is that it declines linearly from B^* (= $B_{47\%}$) to 0.05B^* (Fig. 1.33).

Projections for 2016 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 1.26.

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 2016 ABC is therefore 254,310 t, which is an increase of 33% from the 2015 ABC. The recommended 2016 ABC is very close to the projected 2016 ABC in the 2014 assessment (1% difference). In 2017, the ABC based an adjusted $F_{40\%}$ harvest rate is 250,544 t. The OFL in 2016 is 322,858 t, and the OFL in 2017 if the recommended ABC is taken in 2016 is 289,937 t.

In last few assessments, the magnitude of the 2012 year class was a major issue when deciding which ABCs and OFLs to recommend. New information about 2012 year class came from the 2015 Shelikof Strait survey, the 2015 NMFS bottom trawl survey, and the 2015 summer acoustic survey. All of this new information indicates that this year class is still very abundant. The 2015 Shelikof Strait acoustic survey estimate of age-3 pollock is 1.64 billion, which is the largest age-3 estimate in time series. Therefore we have continued the approach of using the 2012 year class abundance as estimated to project ABCs and OFLs.

The new survey data for 2015 included the Shelikof Strait acoustic survey, the summer acoustic survey, and the NMFS bottom trawl surveys, all of which remain at relatively high levels. There was a large and unexplained decline in pollock biomass in the 2015 ADFG survey (58% decline), which is a concern, especially since this time series has been the most stable used in the assessment. Since this low observation is included in the model, the estimated ABCs and OFLs somewhat factor in this concern.

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. 1.37).

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 2015 numbers at age at the start of the year as estimated by the assessment model, and assume the 2015 catch will be equal to 175,025 t (91.5% of the ABC, the average percent taken over the previous five years). 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 1978-2014 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 1.24. 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 2016, 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 (2011-2015). (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 follows (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 2015 or 2) above 1/2 of its MSY level in 2015 and above its MSY level in 2025 under this scenario, then the stock is not overfished)
>
> *Scenario 7*: In 2016 and 2017, 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 2017, or 2) above 1/2 of its MSY level in 2017 and above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.26. Mean spawning biomass is projected to peak in

2017, and begin declining under full exploitation scenarios, but will remain high under the F=0 and other low exploitation scenarios (Fig. 1.38). Catches are likely to peak in 2016 under full exploitation scenarios, and begin to decline in subsequent years. Plots of individual projection runs are highly variable (Fig. 1.39), 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 (2014) is 142,633 t, which is less than the 2014 OFL of 211,998 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 286,676 t in 2015, which is above $B_{35\%}$ (262,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2017 is 351,018 t, which is above $B_{35\%}$ (262,000 t). Therefore, GOA pollock is not approaching an overfished condition.

Area apportionment of pollock to management areas in the central and western portions of the Gulf of Alaska (central/western/west Yakutat) are provided in Appendix C.

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. 1.40). The primary prey of pollock are euphausiids, but 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 1.41). 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 summer 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. 1.41). 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. 1.42). 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. 1.43). 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 1.42), arrowtooth depend less on pollock in their diets than do other important pollock predators.

Arrowtooth consume a greater number of small 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. 1.44). 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 1.45, 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. 1.45, 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. 1.45 (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. Consumption rates could be overestimated because of 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 as is now assumed in the 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. 1.46). 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. 1.47, 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. 1.47, 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. 1.47 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. 1.47, 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. 1.43), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.46 and 1.47 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. 1.40. 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. 1.48 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. 1.49), 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 1.50), 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. 1.51). 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. 1.51). 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, and 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. Pollock catch (t) in the Gulf of Alaska. The ABC for 2014 is for the area west of 140° W long. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound. 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			81,359	81,359	88,620
2012			103,984	103,984	108,440
2013			96,353	96,353	113,099
2014			142,633	142,633	167,657
2015					191,309
Average (1977-2014)				102,681	117,952

Table 1.2. Incidental catch (t) of FMP species (upper table) and non-target species (bottom table) in the pollock directed fishery in the Gulf of Alaska in 2010-2014. Species are ordered according to the cumulative catch during the period. Incidental catch estimates include both retained and discarded catch.

Managed species/species group	*2010*	*2011*	*2012*	*2013*	*2014*
Pollock	73032.9	77297.5	99643.9	91514.2	137611.0
Arrowtooth Flounder	2066.8	2008.6	1328.6	1765.3	2464.3
Pacific Cod	1497.2	1500.5	1267.0	1041.7	3286.8
Pacific Ocean Perch	96.7	172.3	294.6	426.9	529.9
Flathead Sole	359.9	217.3	189.5	381.4	355.9
Shallow Water Flatfish	78.5	289.4	171.2	183.4	248.9
Squid		208.8	6.7	346.2	143.5
Rex Sole	60.3	90.0	48.8	151.1	270.8
Skate, Big	47.1	92.6	47.8	228.0	171.0
Shark, Salmon	103.7	5.7	52.9	2.8	144.0
Skate, Longnose	9.8	35.0	9.0	25.2	179.7
Pacific Sleeper Shark	155.6	3.6	3.8	15.3	6.3
Sculpin		53.4	20.2	17.5	43.3
Rougheye Rockfish	30.5	34.5	21.2	8.9	25.2
Shortraker Rockfish	9.4	24.4	21.8	22.6	27.7
Northern Rockfish	2.2	13.7	60.9	5.6	15.1
Sablefish	1.3	32.5	6.7	12.6	30.4
Shark, Spiny Dogfish	19.9	16.5	19.2	11.5	13.6
Deep Water Flatfish	2.9	14.6	3.0	12.8	35.3
Skate, Other	7.0	1.7	5.3	23.5	15.3
Thornyhead Rockfish	0.1	1.8	0.5	0.6	42.3
Pelagic Shelf Rockfish	5.8	19.1			
Shark, Other	3.7	1.1	3.7	1.0	2.2
Octopus, North Pacific	0.8	2.3	0.4	0.3	7.2
Other Rockfish	0.4	6.8	0.8	0.7	1.3
Atka Mackerel	0.4	0.1	0.3	0.4	3.5
Skate, Aleutian	0.0	0.2	0.3	0.4	1.7
Percent non-pollock	*5.9%*	*5.9%*	*3.5%*	*4.9%*	*5.5%*

Non target species/species group	*2010*	*2011*	*2012*	*2013*	*2014*
Eulachon	208.99	262.53	181.57	25.23	246.53
Miscellaneous fish	36.68	38.25	46.53	350.34	73.74
Jellyfish	112.08	6.80	122.98	34.56	23.06
Other Osmerids	6.61	68.38	81.88	11.06	75.28
Giant Grenadier	1.44	103.26	14.01	47.50	19.36
Grenadier	7.48	7.87	63.29	0.00	0.00
Sea Stars	4.09	3.34	0.68	3.29	6.21
Capelin	0.00	6.19	0.02	0.01	4.61
Pandalid Shrimp	0.98	0.11	0.05	0.01	0.04
Sponge Unidentified	0.00	0.00	0.00	0.03	1.16
Sea Anemone Unidentified	0.44	0.54	0.00	0.20	0.00
Stichaeidae	0.07	0.00	0.07	0.55	0.00
Bivalves	0.06	0.04	0.00	0.16	0.38
Snails	0.00	0.06	0.01	0.34	0.01
Benthic Urochordata	0.00	0.09	0.02	0.21	0.00
Eelpouts	0.09	0.00	0.01	0.13	0.00
Hermit Crab Unidentified	0.08	0.00	0.11	0.00	0.00
Sea Urchins, Sand Dollars, Sea Cucumbers	0.00	0.00	0.00	0.01	0.11
Miscellaneous Crabs	0.01	0.10	0.00	0.00	0.00
Invertebrate Unidentified	0.00	0.00	0.00	0.03	0.00

Table 1.3. Bycatch of prohibited species for trawls where pollock was the predominant species in the catch in the Gulf of Alaska during 2010-2014. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of individuals.

Species/species group	*2010*	*2011*	*2012*	*2013*	*2014*
Bairdi Tanner Crab (nos.)	119	10,151	729	7,999	2,062
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	44,819	14,590	17,310	12,951	10,877
Golden (Brown) King Crab (nos.)	0	0	0	0	0
Halibut (t)	48.0	191.2	87.1	256.5	137.4
Herring (t)	0.9	10.7	1.3	10.5	4.6
Non-Chinook Salmon (nos.)	750	1231	282	739	1420
Opilio Tanner (Snow) Crab (nos.)	0	0	0	0	0
Red King Crab (nos.)	0	0	0	0	0

Table 1.4. Catch (retained and discarded) of pollock (t) by management area in the Gulf of Alaska during 2004-2014 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*
2004	Retained	23,226	24,221	13,896	215	1,100	0	62,658	2.3%
	Discarded	282	438	428	11	26	0	1,186	
	Total	23,508	24,659	14,324	226	1,127	0	51,937	
2005	Retained	30,791	27,418	18,986	1,876	740	0	79,811	1.4%
	Discarded	136	622	350	9	50	0	1,167	
	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	2.6%
	Discarded	203	750	951	2	1	0	1,906	
	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	2.8%
	Discarded	262	516	701	3	8	0	1,490	
	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	7.0%
	Discarded	2,160	378	1,121	6	20	2	3,688	
	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	5.8%
	Discarded	604	422	1,496	31	1	0	2,554	
	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	1.4%
	Discarded	91	234	761	12	9	2	1,110	
	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	2.4%
	Discarded	125	1,113	743	3	1	0	1,985	
	Total	20,597	37,225	19,731	2,271	1,536	0	81,359	
2012	Retained	27,355	44,597	25,089	2,353	2,622	0	102,015	1.9%
	Discarded	538	500	896	28	5	1	1,969	
	Total	27,893	45,097	25,986	2,381	2,627	1	103,984	
2013	Retained	7,644	52,603	28,134	2,927	2,605	0	93,913	2.5%
	Discarded	67	511	1,830	13	17	2	2,440	
	Total	7,711	53,114	29,963	2,940	2,623	2	96,353	
2014	Retained	13,228	82,526	41,988	1,053	2,368	0	141,163	1.0%
	Discarded	137	555	769	3	3	3	1,471	
	Total	13,364	83,082	42,757	1,056	2,371	3	142,633	
Average (2004-2014)		20,437	34,460	20,883	1,494	1,580	1	77,774	

Table 1.5. Catch at age (millions) of pollock in the Gulf of Alaska in 1975-2014.

							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
2014	0.07	9.95	6.37	29.79	11.52	14.22	20.78	16.67	6.56	1.95	0.70	0.01	0.27	0.00	0.01	118.90

Table 1.6. Number of aged and measured fish in the GOA pollock fishery used to estimate fishery age composition (1989-2014).

	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
2014	1,085	1,040	2,125	10,353	10,444	20,797

Table 1.7. Biomass estimates (t) of pollock from acoustic surveys in Shelikof Strait, summer gulfwide acoustic surveys, NMFS bottom trawl surveys (west of 140° W lon.), egg production surveys in Shelikof Strait, and ADFG crab/groundfish trawl surveys.

Year	*Shelikof Strait acoustic survey*	*Summer gulfwide acoustic survey*	*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		726,229		
1985	1,175,823			768,419	
1986	585,755			375,907	
1987			737,900	484,455	
1988	301,709			504,418	
1989	290,461			433,894	214,434
1990	374,731		817,040	381,475	114,451
1991	380,331			370,000	
1992	713,429			616,000	127,359
1993	435,753		747,942		132,849
1994	492,593				103,420
1995	763,612				
1996	777,172		659,604		122,477
1997	583,017				93,728
1998	504,774				81,215
1999			601,969		53,587
2000	448,638				102,871
2001	432,749		220,141		86,967
2002	256,743				96,237
2003	317,269		394,333		66,989
2004	330,753				99,358
2005	356,117		354,209		79,089
2006	293,609				69,044
2007	180,881		278,541		76,674
2008	208,032				83,476
2009	265,971		662,557		145,438
2010	429,730				124,110
2011			660,207		100,839
2012	335,836				172,007
2013	891,261	884,049	947,877		102,406
2014	842,138				100,158
2015	845,306	1,482,668	705,443		42,277

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	809	508	0.12	514	589	1,103	10,561	12,706	25,052
2005	837	514	0.15	639	868	1,507	9,041	10,782	26,927
2007	816	552	0.14	646	675	1,321	9,916	11,527	24,555
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
2015	772	607	0.16	NA	NA	NA	12,258	15,296	27,831

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). Estimates for the 2015 survey are not yet available.

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
2015	7.43	103.86	1,635.80	72.18	152.45	62.24	56.51	67.75	29.85	10.89	5.57	3.65	0.94	0.63	2.39	2,212.15

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 1992-2015.

Year	*No. of midwater tows*	*No. of bottom trawl tows*	*Survey biomass CV*	*Number aged Males*	*Number aged Females*	*Number aged Total*	*Number measured Males*	*Number measured Females*	*Number measured Total*
1981	38	13	0.12	1,921	1,815	3,736	NA	NA	NA
1983	40	0	0.16	1,642	1,103	2,745	NA	NA	NA
1984	45	0	0.18	1,739	1,622	3,361	NA	NA	NA
1985	57	0	0.14	1,055	1,187	2,242	NA	NA	NA
1986	39	0	0.22	642	618	1,260	NA	NA	NA
1987	27	0	---	557	643	1,200	NA	NA	NA
1988	26	0	0.17	537	464	1,001	NA	NA	NA
1989	21	0	0.10	582	545	1,127	NA	NA	NA
1990	28	13	0.17	1,034	1,181	2,215	NA	NA	NA
1991	16	2	0.35	468	567	1,035	NA	NA	NA
1992	17	8	0.04	784	765	1,549	NA	NA	NA
1993	22	2	0.05	583	624	1,207	NA	NA	NA
1994	44	9	0.05	553	632	1,185	NA	NA	NA
1995	22	3	0.05	599	575	1,174	NA	NA	NA
1996	30	8	0.04	724	775	1,499	NA	NA	NA
1997	16	14	0.04	682	853	1,535	5,380	6,104	11,484
1998	22	9	0.04	863	784	1,647	5,487	4,946	10,433
2000	31	0	0.05	422	363	785	6,007	5,196	11,203
2001	17	9	0.05	314	378	692	4,531	4,584	9,115
2002	18	1	0.07	278	326	604	2,876	2,871	5,747
2003	17	2	0.05	288	321	609	3,554	3,724	7,278
2004	13	2	0.09	492	440	932	3,838	2,552	6,390
2005	22	1	0.04	543	335	878	2,714	2,094	4,808
2006	17	2	0.04	295	487	782	2,527	3,026	5,553
2007	9	1	0.06	335	338	673	2,145	2,194	4,339
2008	10	2	0.06	171	248	419	1,641	1,675	3,316
2009	9	3	0.06	254	301	555	1,583	1,632	3,215
2010	13	2	0.03	286	244	530	2,590	2,358	4,948
2012	8	3	0.08	235	372	607	1,727	1,989	3,716
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
2015	20	0	0.04	354	372	755	768	828	1,655

Table 1.12. Estimated proportions at age for the ADFG crab/groundfish survey, 2000-2014.

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
2014	0.0000	0.0186	0.0541	0.1605	0.1351	0.1436	0.1588	0.1943	0.0828	0.0220	0.0152	0.0084	0.0034	0.0034	0.0000	592

Table 1.13. Ageing error transition matrix used in the GOA pollock assessment model.

True	*St.*	*Observed Age*									
Age	*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 1.14. 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 1.15. Proportion mature at age for female pollock based on maturity stage data collected during winter acoustic surveys in the Gulf of Alaska (1983-2015).

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
2015	0.000	0.000	0.560	0.733	0.879	0.969	1.000	1.000	1.000	372
Average										
All years	0.000	0.016	0.264	0.564	0.831	0.920	0.966	0.987	0.993	
2005-2015	0.000	0.000	0.276	0.586	0.890	0.975	0.987	0.995	1.000	
2010-2015	0.000	0.000	0.287	0.637	0.920	0.974	0.988	1.000	1.000	

Table 1.16. Fishery weight at age (kg) of pollock in the Gulf of Alaska in 1975-2014.

					Age					
Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1975	0.103	0.225	0.412	0.547	0.738	0.927	1.020	1.142	1.142	1.142
1976	0.103	0.237	0.325	0.426	0.493	0.567	0.825	0.864	0.810	0.843
1977	0.072	0.176	0.442	0.525	0.616	0.658	0.732	0.908	0.894	0.955
1978	0.100	0.140	0.322	0.574	0.616	0.685	0.742	0.842	0.896	0.929
1979	0.099	0.277	0.376	0.485	0.701	0.796	0.827	0.890	1.017	1.111
1980	0.091	0.188	0.487	0.559	0.635	0.774	0.885	0.932	0.957	1.032
1981	0.163	0.275	0.502	0.686	0.687	0.769	0.876	0.967	0.969	1.211
1982	0.072	0.297	0.416	0.582	0.691	0.665	0.730	0.951	0.991	1.051
1983	0.103	0.242	0.452	0.507	0.635	0.686	0.689	0.787	0.919	1.078
1984	0.134	0.334	0.539	0.724	0.746	0.815	0.854	0.895	0.993	1.129
1985	0.121	0.152	0.481	0.628	0.711	0.813	0.874	0.937	0.985	1.156
1986	0.078	0.153	0.464	0.717	0.791	0.892	0.902	0.951	1.010	1.073
1987	0.123	0.272	0.549	0.684	0.896	1.003	1.071	1.097	1.133	1.102
1988	0.160	0.152	0.433	0.532	0.806	0.997	1.165	1.331	1.395	1.410
1989	0.068	0.201	0.329	0.550	0.667	0.883	1.105	1.221	1.366	1.459
1990	0.123	0.137	0.248	0.536	0.867	0.980	1.135	1.377	1.627	1.763
1991	0.123	0.262	0.423	0.582	0.721	0.943	1.104	1.189	1.296	1.542
1992	0.121	0.238	0.375	0.566	0.621	0.807	1.060	1.179	1.188	1.417
1993	0.136	0.282	0.550	0.688	0.782	0.842	1.048	1.202	1.250	1.356
1994	0.141	0.193	0.471	0.743	0.872	1.000	1.080	1.230	1.325	1.433
1995	0.123	0.302	0.623	0.966	1.050	1.107	1.198	1.292	1.346	1.440
1996	0.123	0.249	0.355	0.670	1.010	1.102	1.179	1.238	1.284	1.410
1997	0.123	0.236	0.380	0.659	0.948	1.161	1.233	1.274	1.297	1.358
1998	0.097	0.248	0.472	0.571	0.817	0.983	1.219	1.325	1.360	1.409
1999	0.123	0.323	0.533	0.704	0.757	0.914	1.049	1.196	1.313	1.378
2000	0.125	0.312	0.434	0.773	0.991	0.998	1.202	1.271	1.456	1.663
2001	0.125	0.292	0.442	0.701	1.003	1.208	1.286	1.473	1.540	1.724
2002	0.125	0.316	0.480	0.615	0.898	1.050	1.146	1.263	1.363	1.522
2003	0.125	0.369	0.546	0.507	0.715	1.049	1.242	1.430	1.511	1.700
2004	0.125	0.259	0.507	0.720	0.677	0.896	1.123	1.262	1.338	1.747
2005	0.125	0.275	0.446	0.790	1.005	0.977	0.921	1.305	1.385	1.485
2006	0.125	0.260	0.566	0.974	1.229	1.242	1.243	1.358	1.424	1.653
2007	0.125	0.345	0.469	0.885	1.195	1.385	1.547	1.634	1.749	1.940
2008	0.125	0.309	0.649	0.856	1.495	1.637	1.894	1.896	1.855	2.204
2009	0.125	0.235	0.566	0.960	1.249	1.835	2.002	2.151	2.187	2.208
2010	0.125	0.327	0.573	0.972	1.267	1.483	1.674	2.036	2.329	2.191
2011	0.125	0.473	0.593	0.833	1.107	1.275	1.409	1.632	1.999	1.913
2012	0.125	0.294	0.793	0.982	1.145	1.425	1.600	1.869	2.051	2.237
2013	0.125	0.561	0.685	1.141	1.323	1.467	1.641	1.801	1.913	2.167
2014	0.104	0.245	0.749	0.865	1.092	1.362	1.482	1.632	1.720	1.826

Table 1.17. Weight at age (kg) of pollock in the Shelikof Strait acoustic survey in 1981-2015.

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1981	0.010	0.090	0.230	0.330	0.380	0.470	0.630	0.720	0.860	0.780
1983	0.010	0.078	0.294	0.386	0.521	0.606	0.515	0.675	0.695	0.865
1984	0.010	0.105	0.234	0.423	0.557	0.663	0.704	0.691	0.770	0.927
1985	0.010	0.104	0.266	0.502	0.591	0.717	0.792	0.815	0.812	1.088
1986	0.010	0.065	0.190	0.286	0.727	0.826	0.874	0.935	0.950	1.055
1987	0.010	0.067	0.187	0.282	0.559	0.670	0.917	1.012	1.026	1.143
1988	0.010	0.069	0.185	0.278	0.390	0.513	0.960	1.090	1.102	1.230
1989	0.010	0.091	0.234	0.404	0.455	0.633	0.911	1.076	1.178	1.276
1990	0.010	0.059	0.209	0.339	0.525	0.647	0.771	0.958	1.075	1.246
1991	0.010	0.072	0.152	0.263	0.493	0.758	0.874	0.919	1.130	1.436
1992	0.010	0.086	0.209	0.316	0.384	0.782	1.052	1.122	1.052	1.230
1993	0.010	0.083	0.302	0.461	0.576	0.697	1.023	1.172	1.161	1.297
1994	0.010	0.087	0.269	0.588	0.763	0.838	1.030	1.138	1.322	1.314
1995	0.010	0.083	0.278	0.506	0.798	0.897	0.952	1.030	1.146	1.356
1996	0.010	0.052	0.196	0.433	0.906	1.019	1.039	1.099	1.200	1.347
1997	0.010	0.076	0.150	0.325	0.687	1.172	1.150	1.216	1.256	1.377
1998	0.010	0.090	0.224	0.319	0.375	0.820	1.165	1.247	1.244	1.330
2000	0.010	0.074	0.251	0.520	0.746	0.742	0.938	1.225	1.413	1.473
2001	0.010	0.053	0.171	0.402	0.621	1.011	1.115	1.334	1.298	1.702
2002	0.010	0.075	0.138	0.278	0.680	0.946	1.172	1.230	1.539	1.778
2003	0.010	0.088	0.205	0.268	0.394	0.862	1.185	1.214	1.659	1.725
2004	0.010	0.087	0.250	0.464	0.475	0.688	1.312	1.332	1.364	1.321
2005	0.010	0.084	0.292	0.538	0.790	0.739	0.803	1.208	1.256	1.806
2006	0.010	0.066	0.265	0.421	0.794	1.115	1.157	1.304	1.453	1.750
2007	0.010	0.063	0.222	0.446	0.841	1.248	1.378	1.439	1.789	1.896
2008	0.010	0.099	0.267	0.484	0.795	1.373	1.890	1.869	1.882	2.014
2009	0.010	0.078	0.262	0.522	0.734	1.070	1.658	2.014	2.103	2.067
2010	0.010	0.079	0.240	0.673	1.093	1.287	1.828	2.090	2.291	2.227
2012	0.010	0.079	0.272	0.653	0.928	1.335	1.485	1.554	1.930	1.939
2013	0.009	0.127	0.347	0.626	1.157	1.371	1.600	1.772	1.849	2.262
2014	0.012	0.058	0.304	0.594	0.712	1.294	1.336	1.531	1.572	1.666
2015	0.013	0.094	0.200	0.542	0.880	1.055	1.430	1.498	1.594	1.654

Table 1.18. Weight at age (kg) of pollock in the NMFS bottom trawl survey in 1984-2013.

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1984	0.038	0.149	0.527	0.659	0.737	0.833	0.904	0.960	0.991	1.245
1987	0.038	0.163	0.364	0.556	0.763	0.909	1.007	1.061	1.154	1.360
1990	0.038	0.168	0.301	0.565	0.767	0.893	1.101	1.127	1.258	1.492
1993	0.038	0.163	0.461	0.676	0.788	0.924	1.030	1.303	1.358	1.394
1996	0.038	0.096	0.309	0.663	0.924	0.992	1.085	1.199	1.281	1.451
1999	0.038	0.145	0.354	0.594	0.718	0.809	0.873	1.086	1.247	1.312
2001	0.038	0.105	0.412	0.702	0.930	1.066	1.208	1.422	1.300	1.491
2003	0.038	0.201	0.498	0.595	0.751	0.954	1.152	1.154	1.388	1.531
2005	0.038	0.167	0.351	0.617	0.834	0.895	0.998	1.263	1.299	1.546
2007	0.038	0.150	0.310	0.592	0.991	1.205	1.423	1.485	1.765	1.746
2009	0.038	0.288	0.595	1.038	1.302	1.708	1.966	2.208	2.347	2.425
2011	0.038	0.227	0.467	0.817	1.153	1.394	1.450	1.509	1.751	1.721
2013	0.038	0.216	0.423	0.901	1.151	1.340	1.503	1.581	1.674	2.056

Table 1.19. Results comparing model fits, stock status, and 2016 yield for different model configurations. 2016 ABC estimates are based on a projection module associated with assessment model, and are based on different assumptions and give different results than the standard projection software. Model descriptions (see text for details): Model 14.9—last year's model, Model 14.9—last year's model with new data, Model 15.1—add summer acoustic survey data, Model 15.1a—add a power term for age-1 acoustic catchability, Model 15.1b—revise Shelikof Strait acoustic survey estimates for net selectivity.

	Model 14.9 last year	*Model 14.9 new data*	*Model 15.1*	*Model 15.1a*	*Model 15.1b*
Model fits					
Total log(Likelihood)	-310.87	-339.27	-342.95	-340.64	-343.05
Catch	-0.08	-0.10	-0.10	-0.10	-0.10
Fishery age	-127.97	-135.29	-135.29	-135.77	-134.94
Acoustic survey biomass	-35.98	-42.38	-41.74	-41.76	-50.76
Age-1 and age-2 indices	-14.35	-16.46	-15.79	-13.50	-10.73
Acoustic survey age	-35.57	-36.48	-36.42	-36.44	-32.86
Bottom trawl survey biomass	-6.66	-6.55	-6.48	-6.51	-5.33
Bottom trawl survey age and length comp	-35.32	-35.10	-35.87	-35.49	-35.45
ADFG trawl survey biomass	-12.94	-19.46	-19.62	-19.59	-22.08
ADFG trawl survey age	-20.45	-25.55	-25.99	-25.85	-26.01
Summer acoustic biomass	0.00	0.00	-0.42	-0.43	-0.38
Summer acoustic age and length comp.	0.00	0.00	-2.56	-2.64	-2.35
Priors/Penalties	-21.56	-21.90	-22.68	-22.57	-22.05
Composition data					
Fishery age comp. effective N	109	117	117	117	117
Shelikof Strait acoustic age comp. effective N	10	10	10	10	11
NMFS bottom trawl age comp. effective N	28	28	28	28	28
ADF&G trawl age comp. effective N	34	32	32	32	32
Survey abundance					
Shelikof Strait Acoustic RMSE					
EK500	0.27	0.27	0.27	0.27	0.38
Dyson	0.54	0.57	0.57	0.57	0.53
Age-1 index	0.45	1.54	1.47	1.20	1.05
Age-2 index	0.91	0.89	0.89	0.89	0.80
NMFS bottom trawl RMSE	0.26	0.25	0.25	0.25	0.24
ADFG trawl RMSE	0.26	0.31	0.31	0.31	0.33
Summer acoustic RMSE	NA	NA	0.16	0.16	0.15
Catchability estimates					
NMFS trawl	0.86	0.87	0.87	0.87	0.88
Shelikof Strait acoustic					
Miller Freeman	0.53	0.54	0.54	0.54	0.46
Dyson	0.58	0.60	0.60	0.60	0.51
Age-1 index linear term	0.45	0.47	0.48	0.18	0.89
Age-1 index power term	NA	NA	NA	0.95	0.41
Age-2 index	0.87	0.76	0.75	0.74	0.77
Summer acoustic	NA	NA	0.85	0.85	0.78
ADFG trawl	0.15	0.16	0.16	0.16	0.16
Stock status (t)					
2016 Spawning biomass	331,037	310,639	318,366	316,552	350,896
Depletion (B2016/B0)	44%	42%	42%	42%	47%
$B_{40\%}$	311,605	297,847	300,156	299,861	301,366
2016 yield (1000 t)					
Author's recommended ABC	252,445	217,542	240,666	235,957	289,630

Table 1.20. Estimated selectivity at age for GOA pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions. Selectivity reported for the Shelikof acoustic survey age-1 and age-2 indices are the independently estimated catchabilities for these indices. Since age-1 catchability is density-dependent, reported value is median across the range of recruitment estimates.

Age	*Foreign (1970-81)*	*Foreign and JV (1982-1988)*	*Domestic (1989-2000)*	*Domestic (2001-2009)*	*Recent domestic (2010-2014)*	*Shelikof acoustic survey*	*Summer acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.004	0.002	0.013	0.004	0.438	1.000	0.124	0.004
2	0.011	0.029	0.013	0.083	0.037	0.784	1.000	0.209	0.026
3	0.123	0.183	0.075	0.376	0.251	1.000	1.000	0.331	0.163
4	0.633	0.623	0.332	0.788	0.740	1.000	1.000	0.482	0.584
5	0.955	0.924	0.755	0.959	0.964	1.000	1.000	0.638	0.910
6	0.997	0.990	0.956	0.994	0.997	0.998	1.000	0.774	0.987
7	1.000	1.000	0.999	1.000	1.000	0.991	1.000	0.873	0.998
8	0.994	0.995	1.000	0.994	0.994	0.958	1.000	0.938	1.000
9	0.899	0.900	0.906	0.900	0.899	0.826	1.000	0.978	1.000
10	0.352	0.353	0.355	0.353	0.352	0.495	1.000	1.000	1.000

Table 1.21. Total estimated abundance at age (millions) of GOA pollock from the age-structured assessment model.

	Age									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1970	1,199	299	185	128	91	67	50	37	28	84
1971	3,260	299	150	114	86	62	48	36	27	82
1972	3,677	812	150	92	76	59	44	34	25	80
1973	10,684	916	406	90	56	45	36	27	21	72
1974	2,154	2,661	458	243	52	31	26	20	15	62
1975	2,170	536	1,329	271	134	27	16	13	11	49
1976	8,578	540	268	800	163	78	16	10	8	41
1977	11,732	2,136	270	160	458	88	43	9	5	32
1978	14,486	2,921	1,067	160	88	233	46	22	5	24
1979	25,752	3,607	1,460	633	89	46	124	24	12	19
1980	12,920	6,413	1,803	871	368	50	26	71	14	20
1981	7,183	3,217	3,211	1,095	539	216	30	16	44	23
1982	7,282	1,789	1,611	1,955	695	332	137	19	10	45
1983	5,227	1,813	895	975	1,245	440	217	90	13	39
1984	5,955	1,301	905	534	603	765	280	138	58	36
1985	15,122	1,482	647	532	318	352	461	168	84	61
1986	4,618	3,764	739	386	317	177	200	261	96	91
1987	1,842	1,150	1,883	450	252	208	120	135	179	133
1988	4,990	459	576	1,153	300	169	144	83	95	225
1989	11,873	1,242	230	353	771	202	118	101	59	233
1990	8,365	2,956	622	141	235	513	139	81	70	211
1991	3,261	2,083	1,482	383	95	156	349	94	56	201
1992	2,363	812	1,044	912	257	62	102	227	62	181
1993	1,558	588	407	642	609	167	40	66	149	171
1994	1,739	388	295	249	425	393	109	26	44	222
1995	6,431	433	194	181	165	276	259	71	17	188
1996	3,128	1,602	217	119	121	110	188	176	49	149
1997	1,446	779	803	134	81	82	76	129	122	143
1998	1,381	360	390	491	88	51	52	48	82	180
1999	1,695	344	180	235	304	49	28	28	27	169
2000	6,166	422	172	109	148	177	29	16	16	131
2001	6,714	1,535	211	105	70	90	109	17	10	102
2002	844	1,671	765	126	65	42	56	67	11	78
2003	781	210	831	457	80	41	27	36	44	63
2004	695	194	104	496	292	52	27	18	24	76
2005	1,973	173	96	61	311	186	34	18	12	71
2006	5,725	490	85	56	37	191	118	22	12	58
2007	5,694	1,423	243	50	34	23	121	75	14	49
2008	6,957	1,416	705	143	31	22	15	80	50	45
2009	3,469	1,731	705	421	91	20	15	10	55	67
2010	1,488	864	864	426	276	61	14	10	7	89
2011	4,767	370	431	517	274	181	42	10	7	69
2012	1,216	1,187	185	259	332	178	123	28	7	55
2013	16,895	303	594	112	165	212	118	81	19	44
2014	2,931	4,207	151	360	72	106	142	79	55	45
2015	893	730	2,103	91	219	42	65	86	48	66
Average	5,636	1,405	698	397	252	155	100	63	41	95

Table 1.22. Estimates of population biomass, recruitment, and harvest of GOA 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.

						2014 Assessment results			
Year	*3+ total biomass (1,000 t)*	*Female spawn. biom. (1,000 t)*	*Age 1 recruits (million)*	*Catch (t)*	*Harvest rate*	*3+ total biomass*	*Female spawn. biom.*	*Age 1 recruits*	*Harvest rate*
1977	745	137	11,732	118,092	16%	757	138	11,881	16%
1978	899	128	14,486	95,408	11%	915	130	14,600	10%
1979	1,258	131	25,752	106,161	8%	1,280	133	25,906	8%
1980	1,719	172	12,920	115,158	7%	1,743	174	13,022	7%
1981	2,665	177	7,183	147,818	6%	2,694	179	7,251	5%
1982	2,905	270	7,282	169,045	6%	2,935	270	7,339	6%
1983	2,742	406	5,227	215,625	8%	2,771	407	5,282	8%
1984	2,399	461	5,955	307,541	13%	2,425	464	6,032	13%
1985	1,958	442	15,122	286,900	15%	1,983	446	15,278	14%
1986	1,600	399	4,618	86,910	5%	1,624	404	4,708	5%
1987	1,969	372	1,842	68,070	3%	1,996	377	1,857	3%
1988	1,883	380	4,990	63,391	3%	1,910	384	5,029	3%
1989	1,706	422	11,873	75,585	4%	1,731	426	11,962	4%
1990	1,552	402	8,365	88,269	6%	1,575	408	8,431	6%
1991	1,735	399	3,261	100,488	6%	1,757	405	3,295	6%
1992	2,094	370	2,363	90,858	4%	2,118	375	2,416	4%
1993	1,823	404	1,558	108,909	6%	1,845	407	1,594	6%
1994	1,518	449	1,739	107,335	7%	1,539	453	1,731	7%
1995	1,268	405	6,431	72,618	6%	1,286	410	6,493	6%
1996	1,061	368	3,128	51,263	5%	1,077	373	3,171	5%
1997	1,093	322	1,446	90,130	8%	1,108	327	1,440	8%
1998	969	247	1,381	125,460	13%	982	251	1,405	13%
1999	771	220	1,695	95,638	12%	782	224	1,726	12%
2000	678	203	6,166	73,080	11%	689	207	6,176	11%
2001	643	197	6,714	72,077	11%	655	201	6,748	11%
2002	812	167	844	51,934	6%	821	170	871	6%
2003	1,015	154	781	50,684	5%	1,025	157	749	5%
2004	825	164	695	63,844	8%	835	166	699	8%
2005	681	206	1,973	80,978	12%	687	208	1,880	12%
2006	583	215	5,725	71,976	12%	588	218	5,441	12%
2007	559	194	5,694	52,714	9%	561	196	5,215	9%
2008	873	191	6,957	52,584	6%	856	192	6,872	6%
2009	1,352	191	3,469	44,247	3%	1,292	188	3,808	3%
2010	1,529	263	1,488	76,745	5%	1,468	253	1,697	5%
2011	1,399	315	4,767	81,359	6%	1,367	299	6,003	6%
2012	1,271	342	1,216	103,984	8%	1,263	326	818	8%
2013	1,256	376	16,895	96,353	8%	1,321	366	15,058	7%
2014	1,134	294	2,931	142,633	13%	1,201	297	4,134	12%
2015	1,728	251	893						
Average									
1977-2014	1,393	288	5,965	102,681	8%	1,407	290	6,001	8%
1978-2014			5,809					5,598	

Table 1.23. Uncertainty of estimates of recruitment and spawning biomass of GOA 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	1,199	0.25	734	1,958	138	0.26	84	226
1971	3,260	0.35	1,662	6,394	132	0.26	79	219
1972	3,677	0.29	2,093	6,459	121	0.28	71	207
1973	10,684	0.13	8,278	13,789	101	0.31	55	184
1974	2,154	0.24	1,356	3,420	88	0.30	49	156
1975	2,170	0.23	1,403	3,355	87	0.24	55	138
1976	8,578	0.16	6,333	11,619	120	0.16	88	164
1977	11,732	0.15	8,752	15,727	137	0.15	102	185
1978	14,486	0.15	10,825	19,385	128	0.18	90	182
1979	25,752	0.13	20,125	32,952	131	0.19	90	191
1980	12,920	0.16	9,505	17,562	172	0.18	121	245
1981	7,183	0.19	4,975	10,370	177	0.16	129	243
1982	7,282	0.19	5,055	10,491	270	0.14	204	356
1983	5,227	0.27	3,132	8,725	406	0.13	313	526
1984	5,955	0.25	3,702	9,581	461	0.14	350	607
1985	15,121	0.13	11,746	19,466	442	0.16	325	600
1986	4,618	0.22	3,037	7,023	399	0.17	285	559
1987	1,842	0.33	978	3,468	372	0.17	269	513
1988	4,990	0.18	3,487	7,140	380	0.15	284	510
1989	11,873	0.12	9,466	14,892	422	0.13	329	541
1990	8,365	0.13	6,487	10,787	402	0.12	319	507
1991	3,261	0.21	2,182	4,873	399	0.12	317	504
1992	2,363	0.21	1,576	3,542	370	0.11	296	463
1993	1,558	0.23	999	2,429	404	0.10	329	495
1994	1,739	0.20	1,171	2,582	449	0.10	370	545
1995	6,431	0.10	5,295	7,810	405	0.10	333	493
1996	3,128	0.13	2,413	4,056	368	0.10	303	447
1997	1,446	0.19	1,003	2,085	322	0.10	264	393
1998	1,381	0.18	980	1,946	247	0.11	200	306
1999	1,695	0.16	1,244	2,309	220	0.11	176	275
2000	6,166	0.10	5,106	7,446	203	0.12	162	256
2001	6,714	0.09	5,645	7,985	197	0.12	155	251
2002	844	0.22	550	1,295	167	0.13	129	216
2003	781	0.19	542	1,125	154	0.13	120	199
2004	695	0.21	462	1,046	164	0.11	133	204
2005	1,973	0.14	1,506	2,584	206	0.11	167	254
2006	5,725	0.11	4,641	7,062	215	0.11	173	268
2007	5,694	0.11	4,570	7,095	194	0.12	153	246
2008	6,957	0.11	5,597	8,647	191	0.13	149	245
2009	3,469	0.14	2,630	4,575	191	0.12	150	242
2010	1,488	0.22	972	2,276	263	0.11	213	327
2011	4,767	0.16	3,458	6,570	315	0.10	257	387
2012	1,216	0.36	610	2,423	342	0.11	278	421
2013	16,895	0.20	11,377	25,088	376	0.11	303	468
2014	2,931	0.43	1,304	6,589	294	0.12	233	370
2015	893	0.45	385	2,073	251	0.13	193	326

Table 1.24. GOA 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 an average for the bottom trawl survey conducted in June to August. Proportion mature females is the average from winter acoustic survey specimen data for 1983-2015.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2010-2014)*	*Spawning (Avg. 2010-2015)*	*Population (Avg. 2009-2013)*	*Fishery (Avg. 2010-2014)*	*Proportion mature females*
1	1.39	0.004	0.011	0.038	0.121	0.000
2	0.69	0.037	0.087	0.244	0.380	0.000
3	0.48	0.251	0.272	0.495	0.679	0.016
4	0.37	0.740	0.617	0.919	0.959	0.264
5	0.34	0.964	0.954	1.202	1.187	0.564
6	0.30	0.997	1.268	1.481	1.403	0.831
7	0.30	1.000	1.536	1.640	1.561	0.920
8	0.29	0.994	1.689	1.766	1.794	0.966
9	0.28	0.899	1.847	1.924	2.003	0.987
10+	0.29	0.352	1.950	2.068	2.067	0.993

Table 1.25. Methods used to assess GOA pollock, 1977-2014. 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 1990-2014 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
2014	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	312,000

Table 1.26. Projections of GOA pollock spawning biomass, full recruitment fishing mortality, and catch for 2015-2028 under different harvest policies. For these projections, fishery weight at age was assumed to be equal to the average weight at age for 2010-2014. All projections begin with estimated age composition in 2015 using the base run model with a projected 2015 catch of 175,025 t (91.5% of ABC). The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 750,000, 300,000, and 262,000 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 yrs, then F_{OFL}*
2015	286,676	286,676	286,676	286,676	286,676	286,676	286,676
2016	320,409	321,626	325,583	329,864	333,625	318,119	320,409
2017	351,018	357,193	384,471	414,243	442,060	337,051	351,018
2018	335,594	341,696	398,331	458,636	518,773	310,979	332,913
2019	295,124	302,765	372,087	452,526	538,099	267,557	283,117
2020	277,051	287,919	355,670	446,363	548,148	252,812	261,084
2021	287,656	300,011	366,699	467,548	584,961	264,328	268,520
2022	302,181	315,091	383,141	493,375	624,443	278,149	280,137
2023	311,492	324,318	394,893	511,682	651,299	286,124	287,090
2024	314,746	327,364	401,254	524,939	674,304	288,005	288,492
2025	316,734	329,129	406,027	535,714	694,420	288,992	289,254
2026	319,508	331,753	411,242	545,388	711,201	291,096	291,242
2027	322,909	335,105	417,027	554,898	726,526	293,962	294,044
2028	323,289	335,351	419,502	560,371	736,660	293,863	293,909

Fishing mortality	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two yrs, then F_{OFL}*
2015	0.20	0.20	0.20	0.20	0	0.20	0.20
2016	0.25	0.23	0.15	0.07	0	0.29	0.25
2017	0.25	0.25	0.15	0.07	0	0.29	0.25
2018	0.25	0.24	0.15	0.07	0	0.29	0.29
2019	0.24	0.21	0.15	0.07	0	0.26	0.27
2020	0.21	0.19	0.15	0.07	0	0.23	0.24
2021	0.21	0.19	0.15	0.07	0	0.23	0.24
2022	0.21	0.20	0.15	0.07	0	0.24	0.24
2023	0.22	0.20	0.15	0.07	0	0.24	0.24
2024	0.22	0.21	0.15	0.07	0	0.25	0.25
2025	0.22	0.21	0.15	0.07	0	0.25	0.25
2026	0.22	0.21	0.15	0.07	0	0.25	0.25
2027	0.22	0.21	0.15	0.07	0	0.25	0.25
2028	0.22	0.21	0.15	0.07	0	0.25	0.25

Catch (t)	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two yrs, then F_{OFL}*
2015	175,025	175,025	175,025	175,025	175,025	175,025	175,025
2016	278,385	254,310	173,908	83,132	0	322,858	278,385
2017	246,494	250,544	165,832	84,266	0	276,623	246,494
2018	203,672	200,118	145,839	78,220	0	222,606	235,899
2019	193,738	177,851	146,789	80,491	0	197,163	213,143
2020	191,838	181,884	155,223	85,931	0	200,324	207,471
2021	203,035	195,992	162,985	90,810	0	216,029	218,957
2022	204,718	198,937	158,416	86,931	0	220,863	221,422
2023	212,126	206,649	164,139	91,042	0	228,192	228,248
2024	217,992	212,398	169,148	94,936	0	233,563	233,483
2025	221,188	215,488	170,830	95,978	0	236,636	236,589
2026	223,446	217,375	172,375	96,946	0	238,542	238,526
2027	224,265	218,632	172,737	97,285	0	239,512	239,510
2028	221,249	215,491	171,479	96,832	0	235,938	235,939

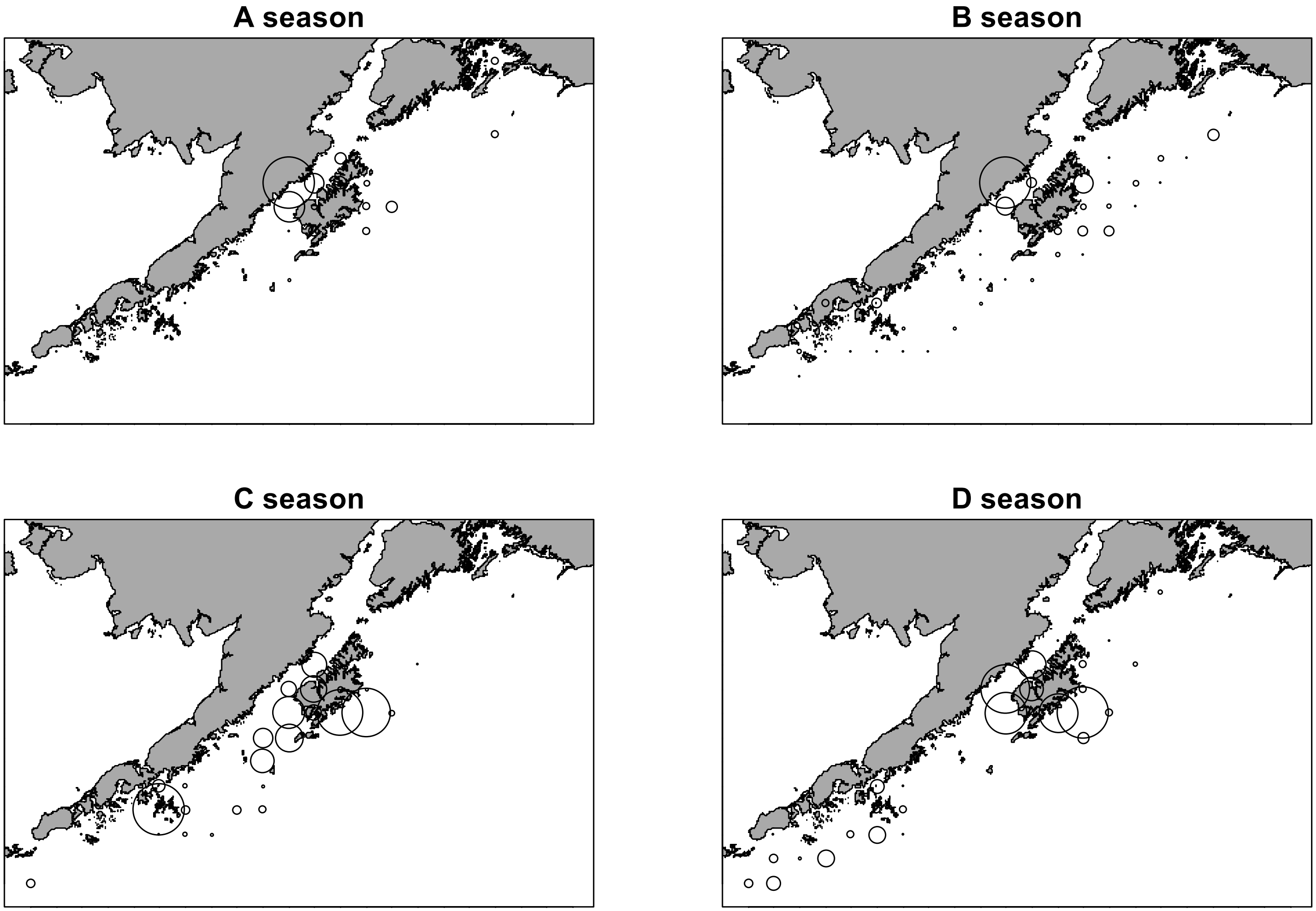


Figure 1.1. Pollock catch in 2014 for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

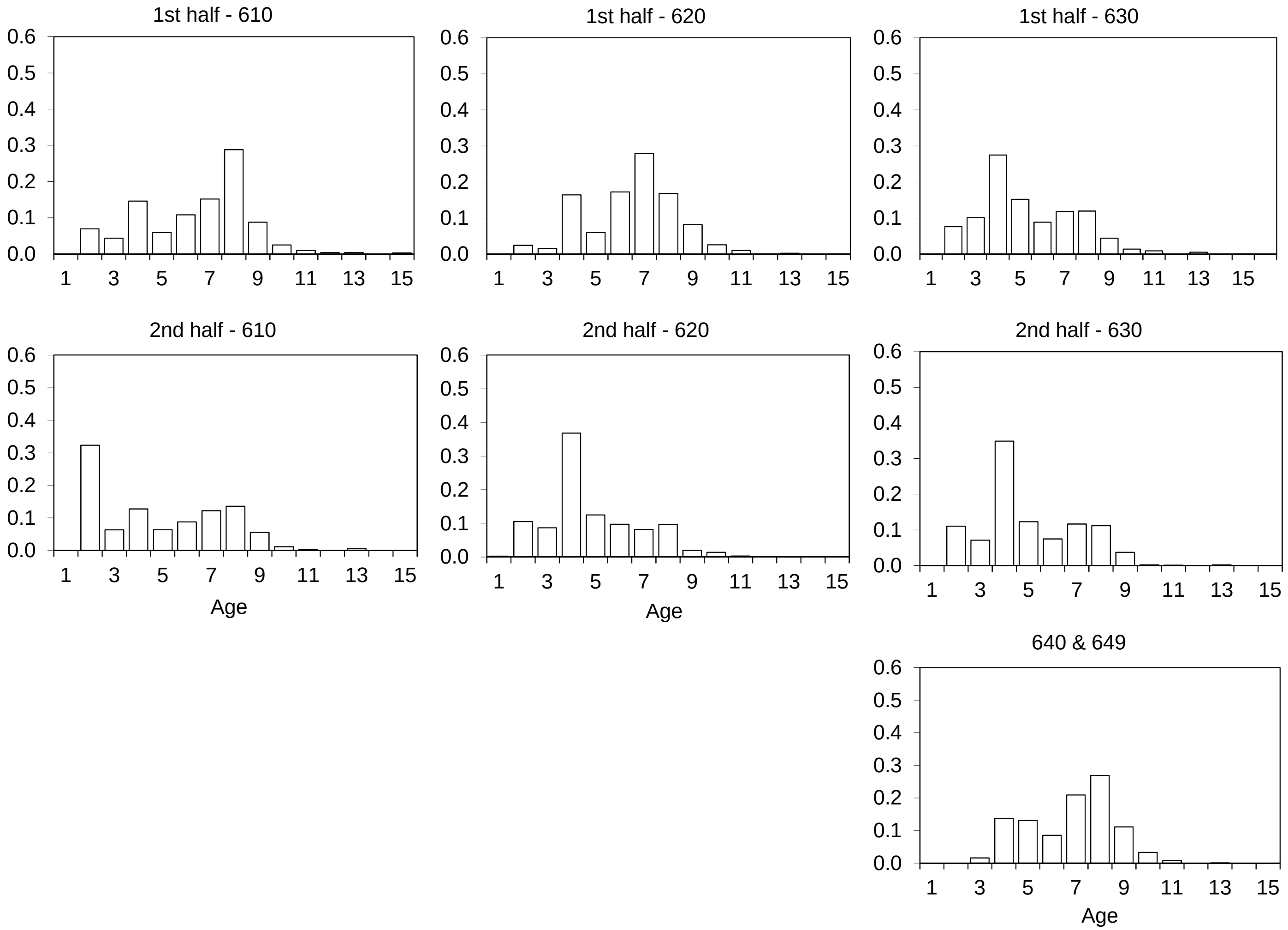


Figure 1.2. 2014 fishery age composition by half year (January-June, July-December) and statistical area.

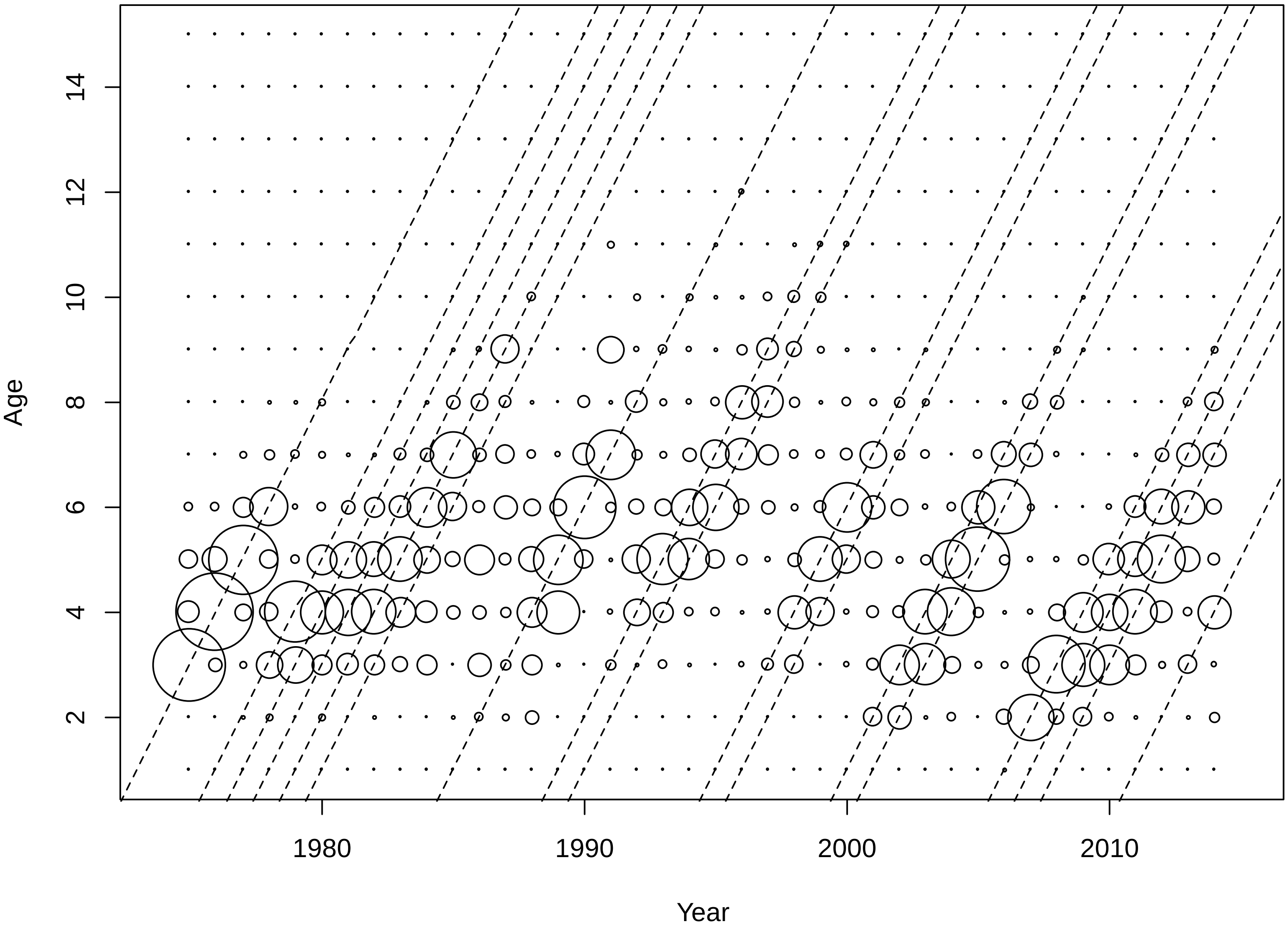


Figure 1.3. GOA pollock fishery age composition (1975-2014). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes.

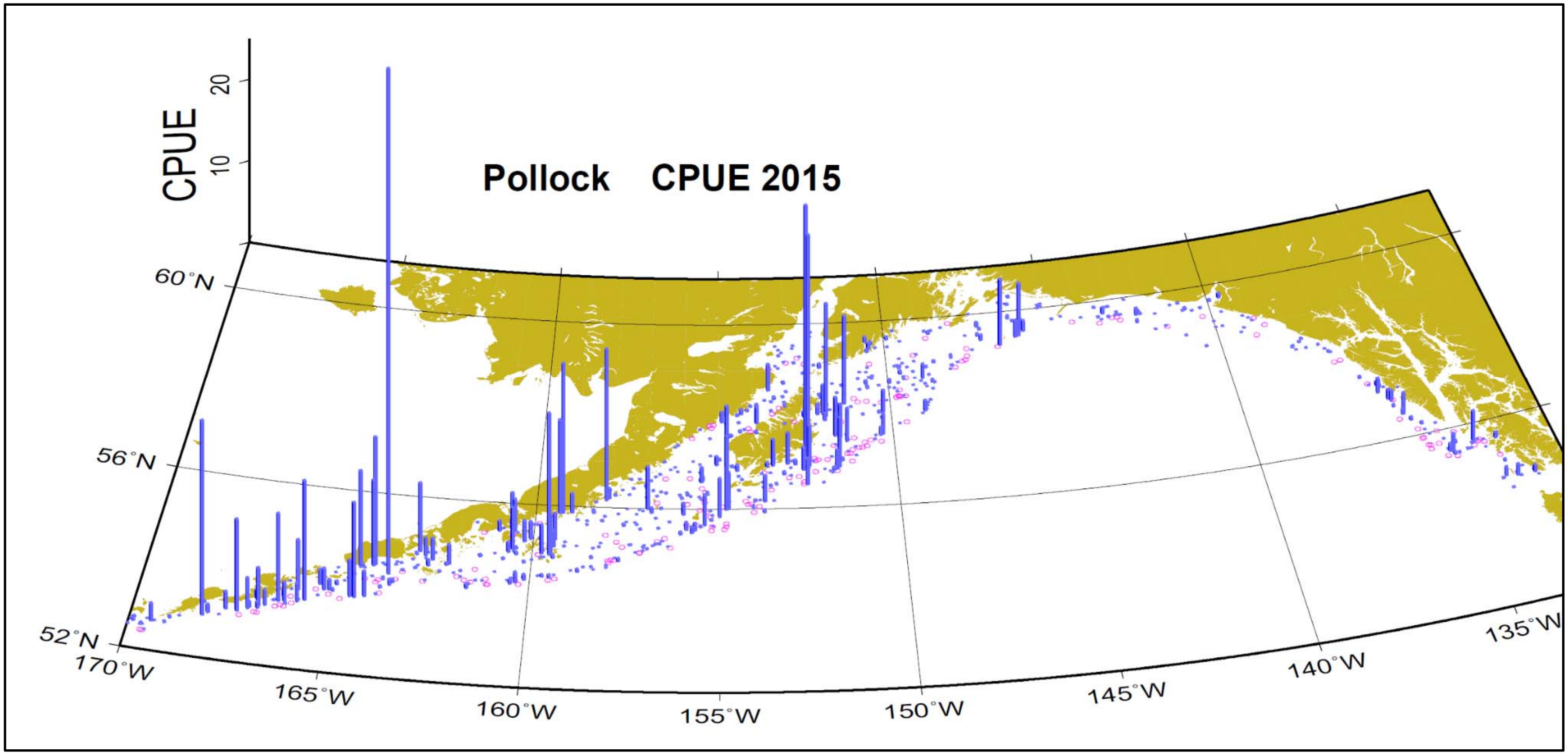


Figure 1.4. Pollock catch per unit effort (CPUE) for the 2015 NMFS bottom trawl survey in the GOA.

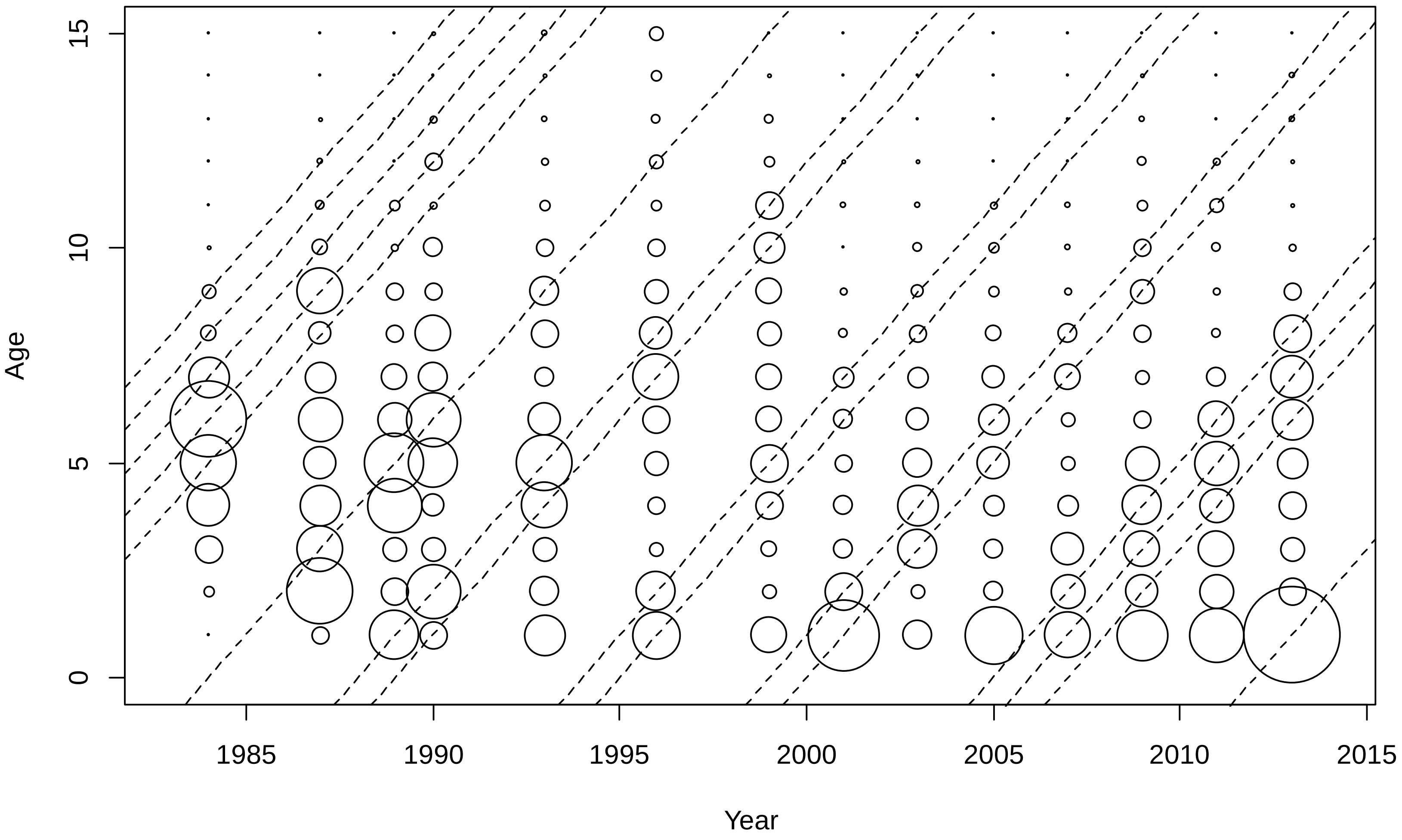


Figure 1.5. Estimated abundance at age in the NMFS bottom trawl survey (1984-2013). The area of the circle is proportional to the estimated abundance.

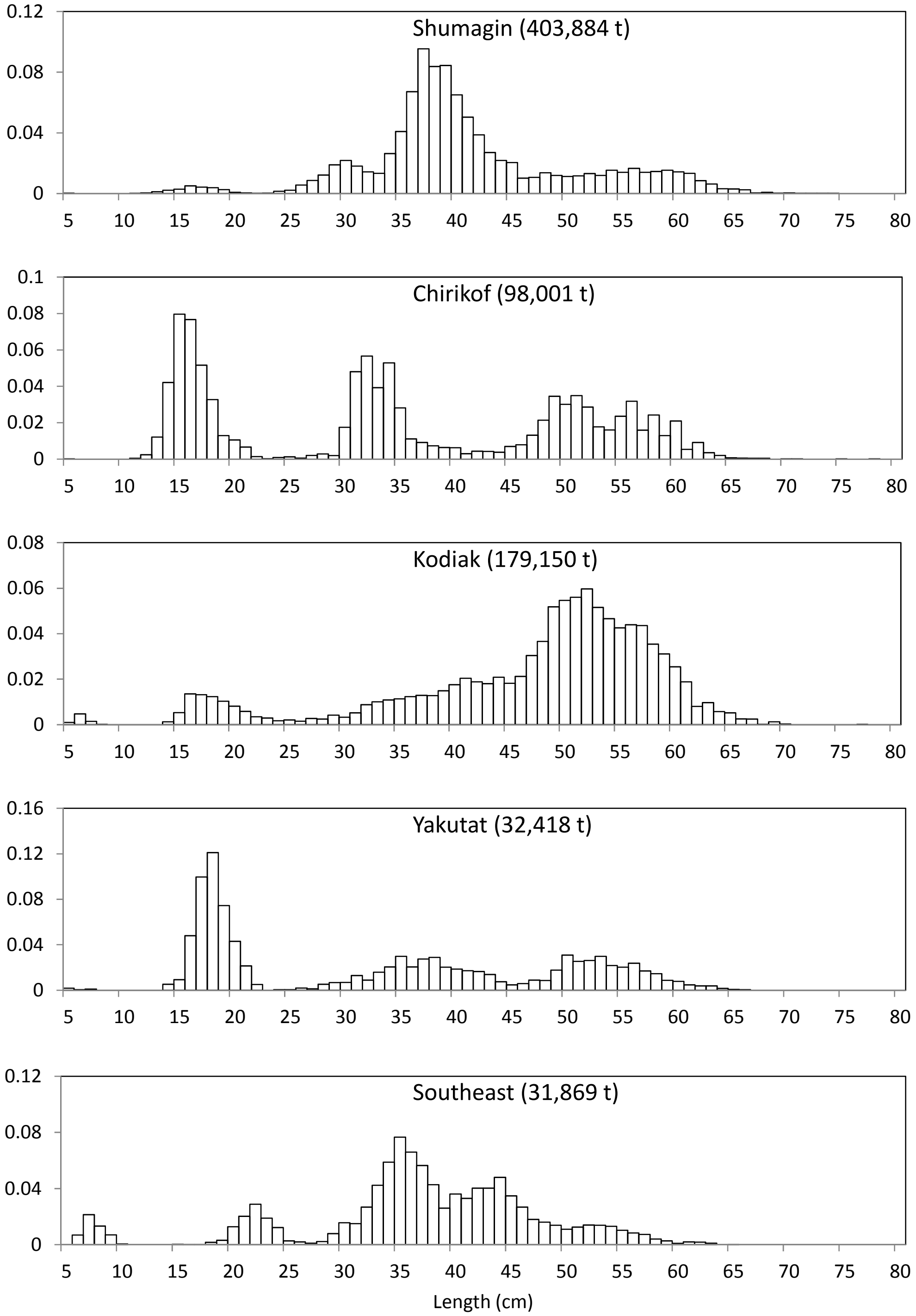


Figure 1.6. Size composition of pollock by statistical area for the 2015 NMFS bottom trawl survey.

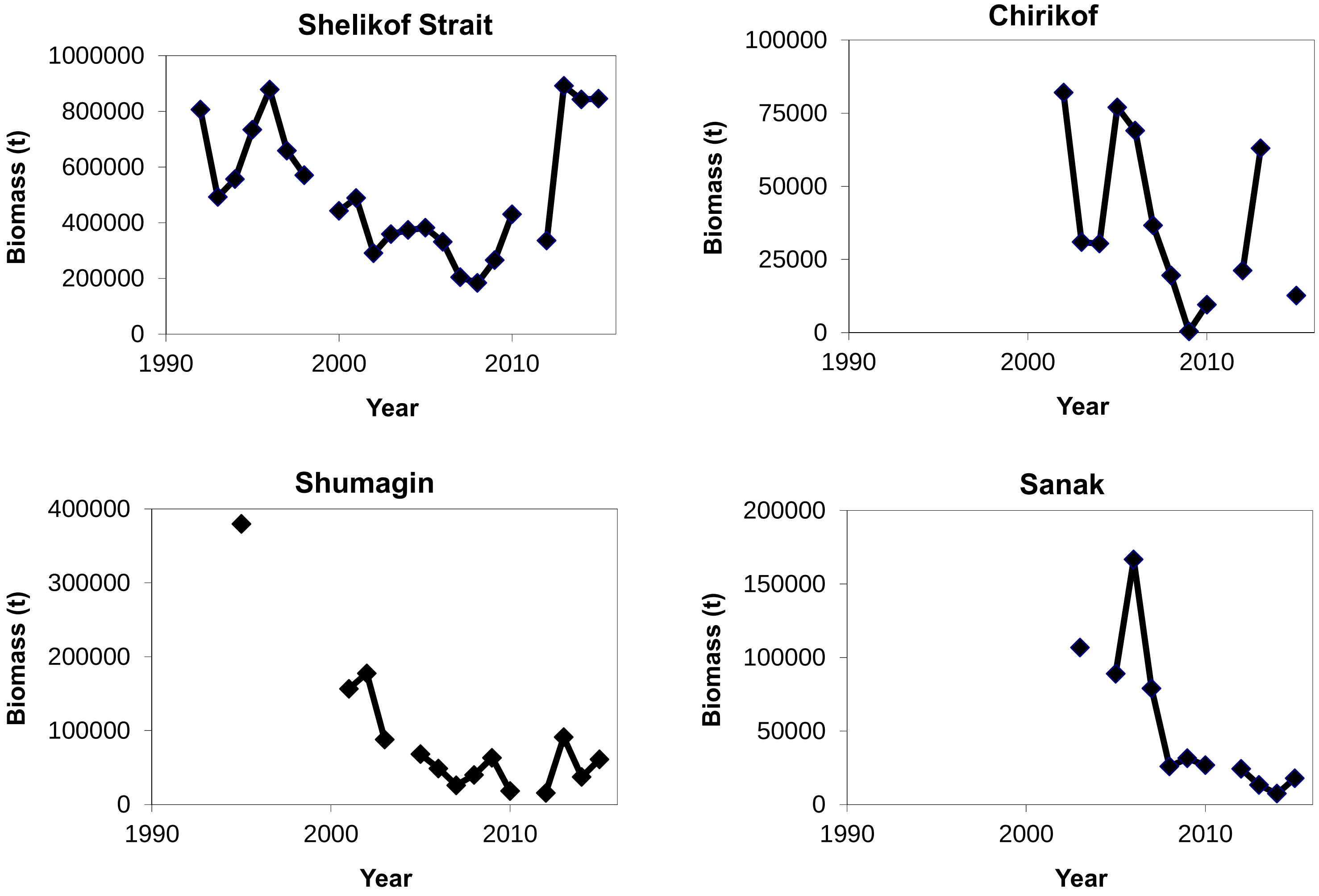


Figure 1.7. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

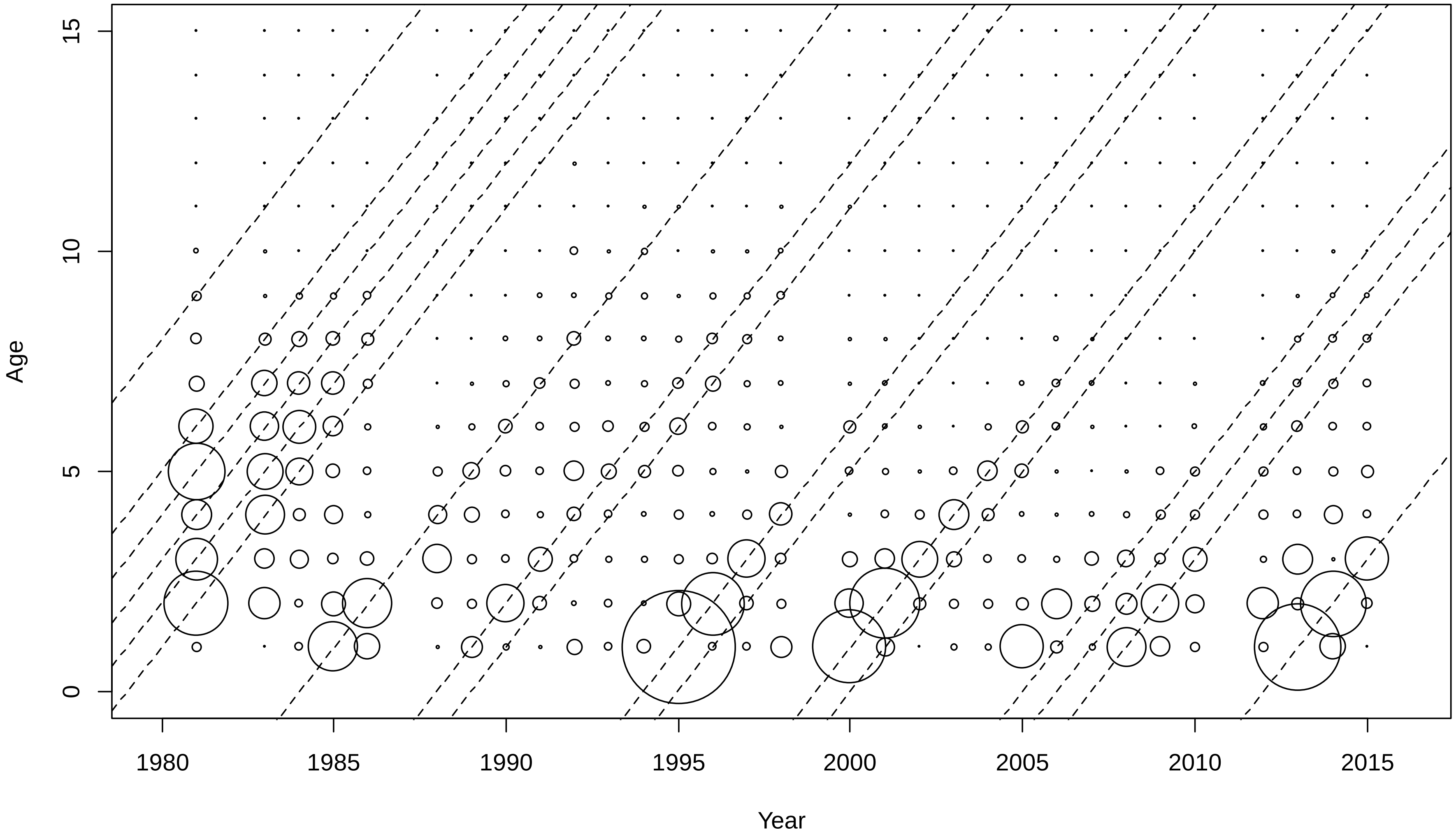


Figure 1.8. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2015, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

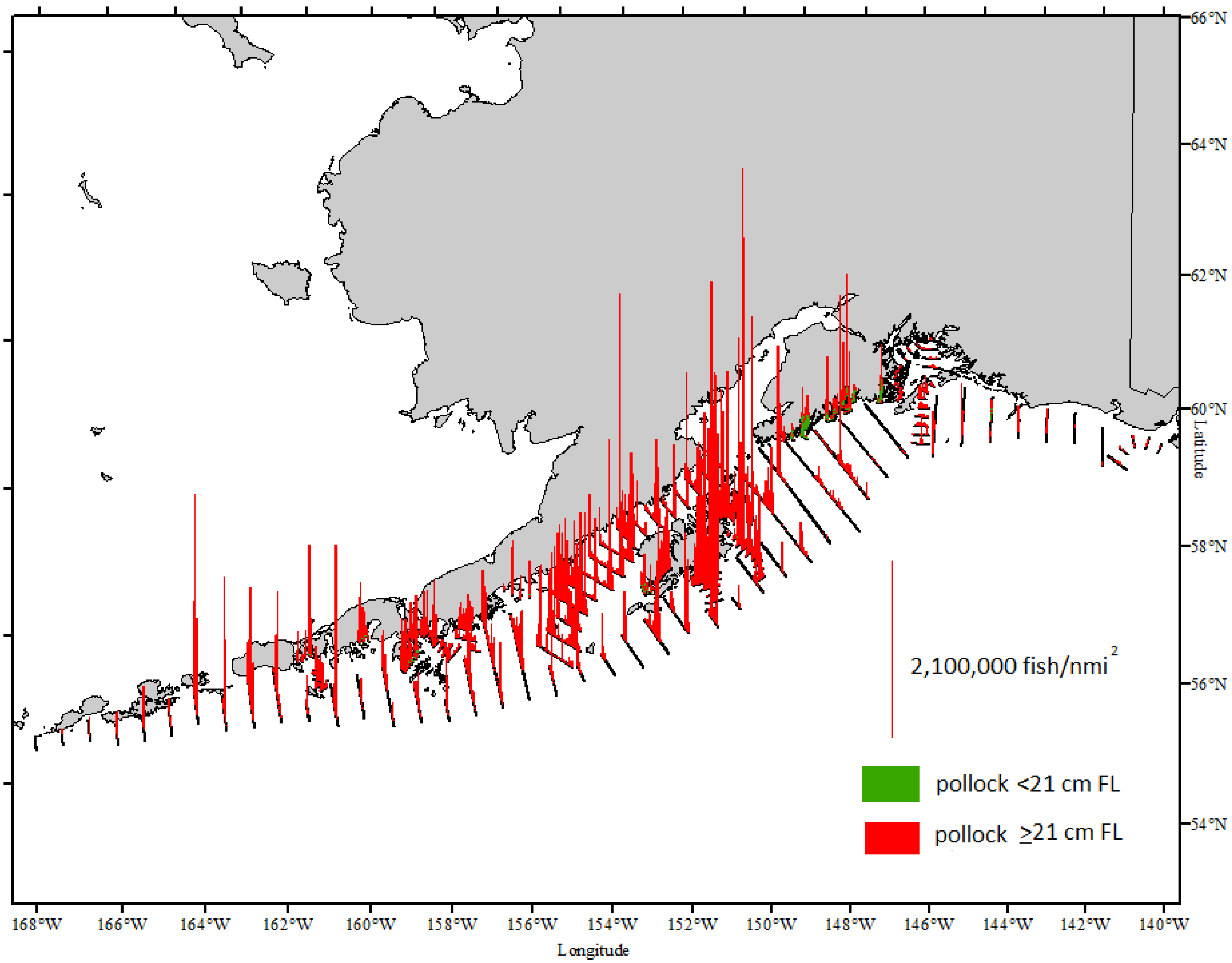


Figure 1.9. Survey transects and pollock backscatter for the 2015 summer acoustic survey.

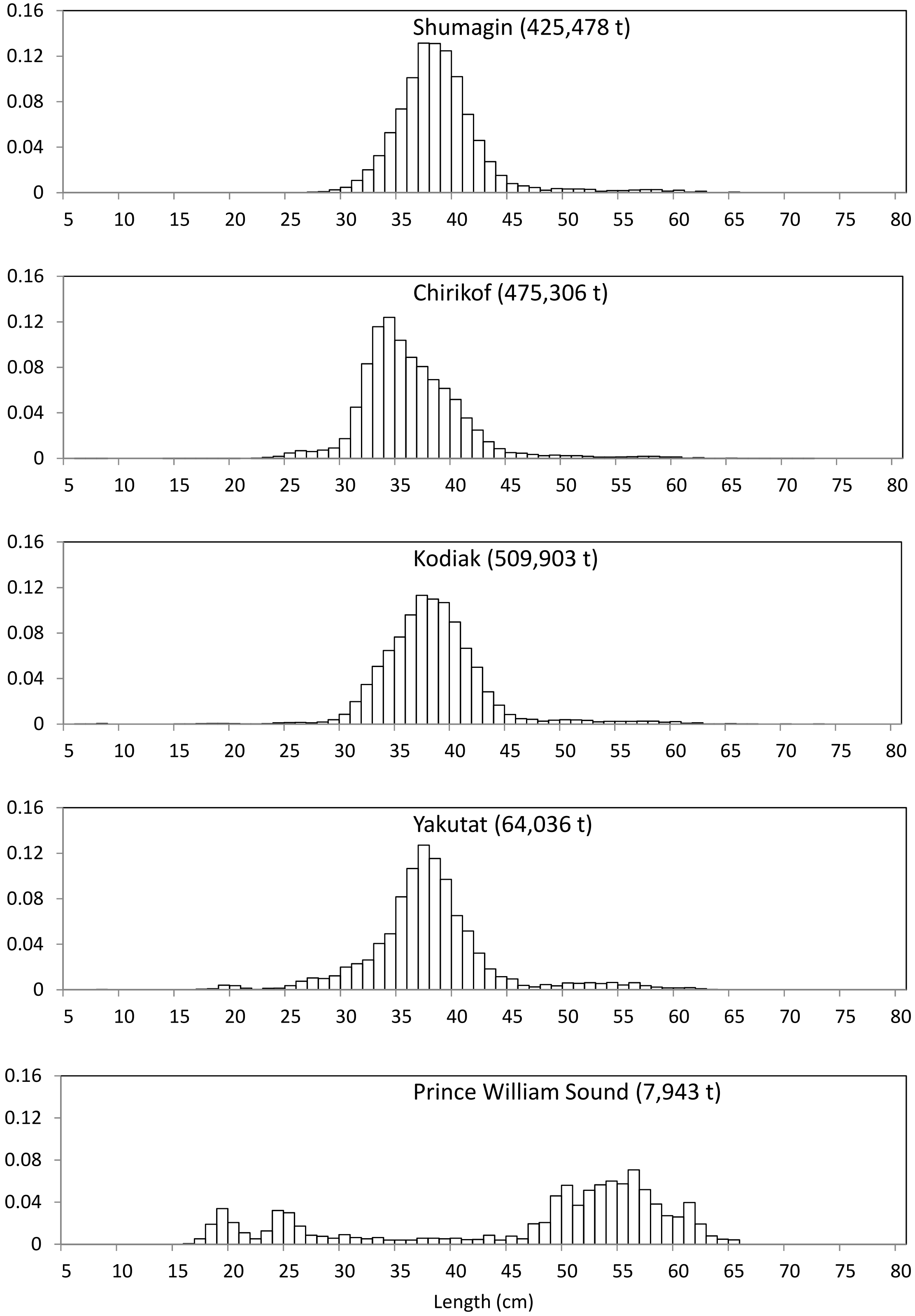


Figure 1.10. Size composition of pollock by statistical area for the 2015 NMFS summer acoustic survey.

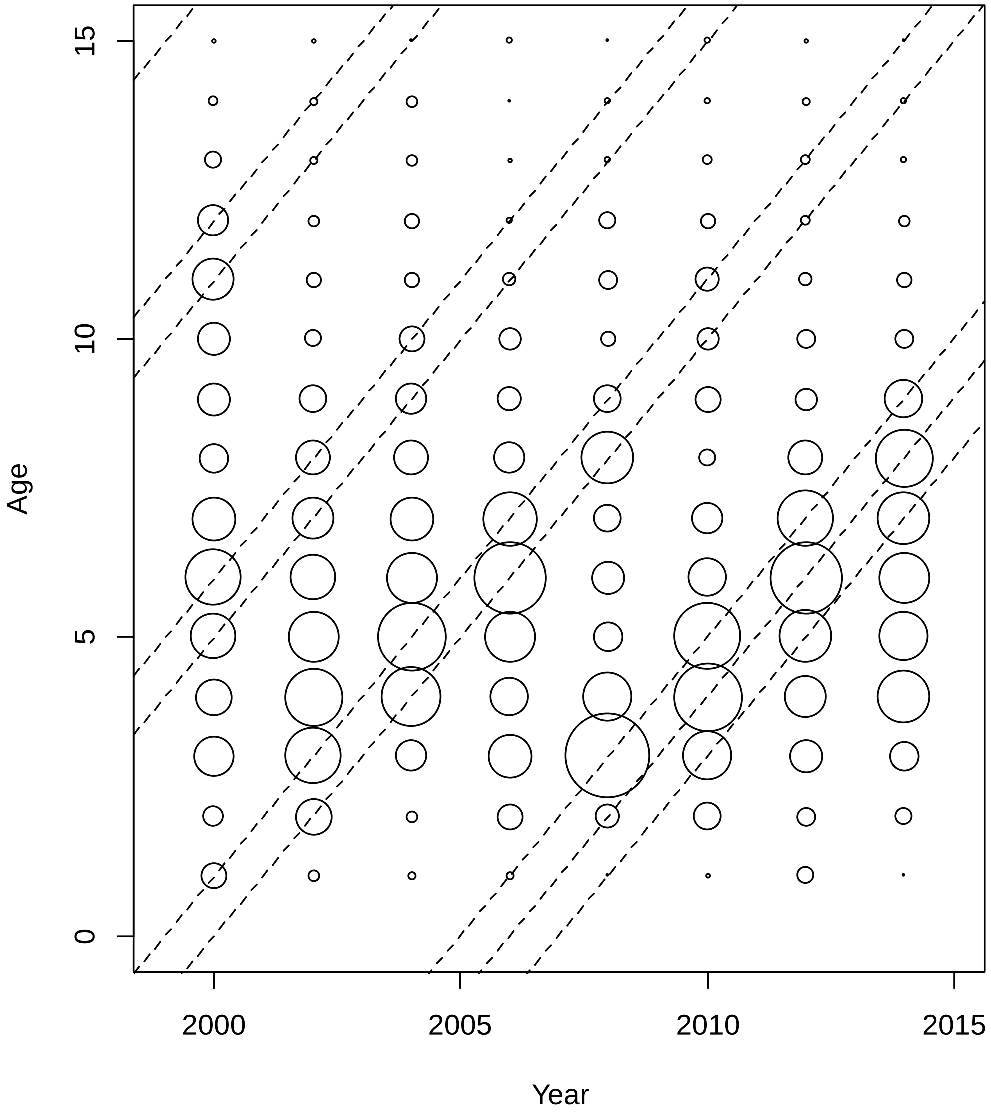


Figure 1.11. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2014). The area of the circle is proportional to the estimated abundance.

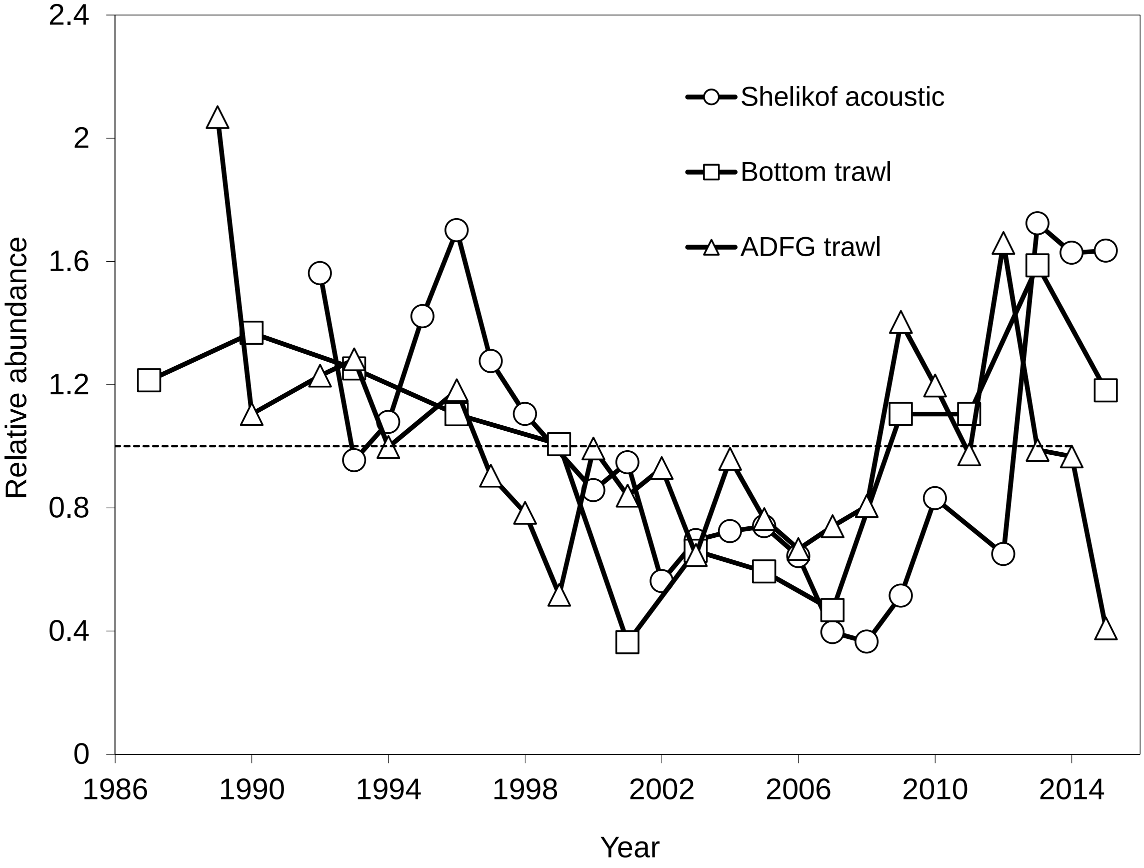


Figure 1.12. Relative trends in pollock biomass since 1987 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADFG crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the *R/V Oscar Dyson*.

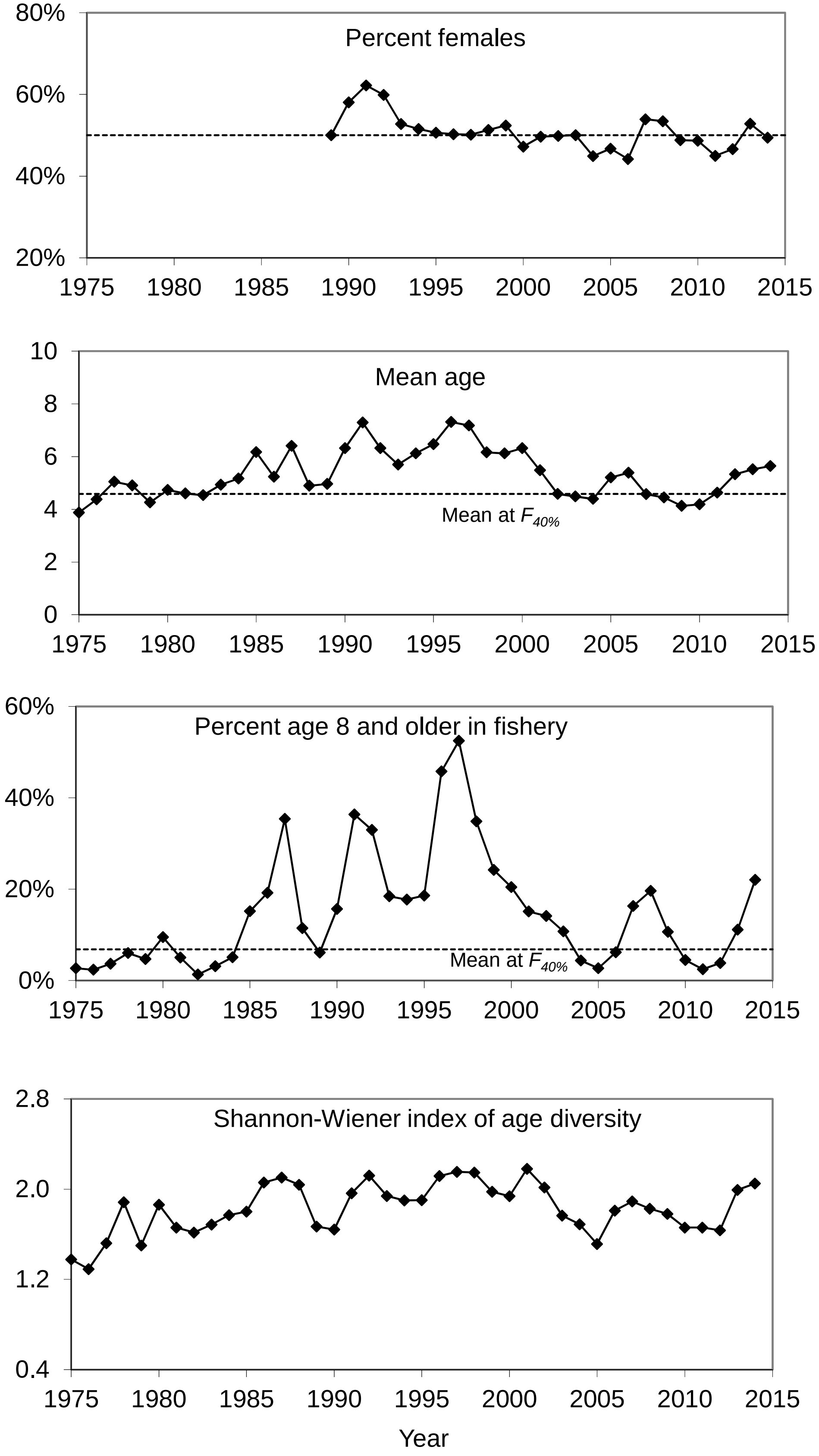


Figure 1.13. GOA pollock fishery catch characteristics.

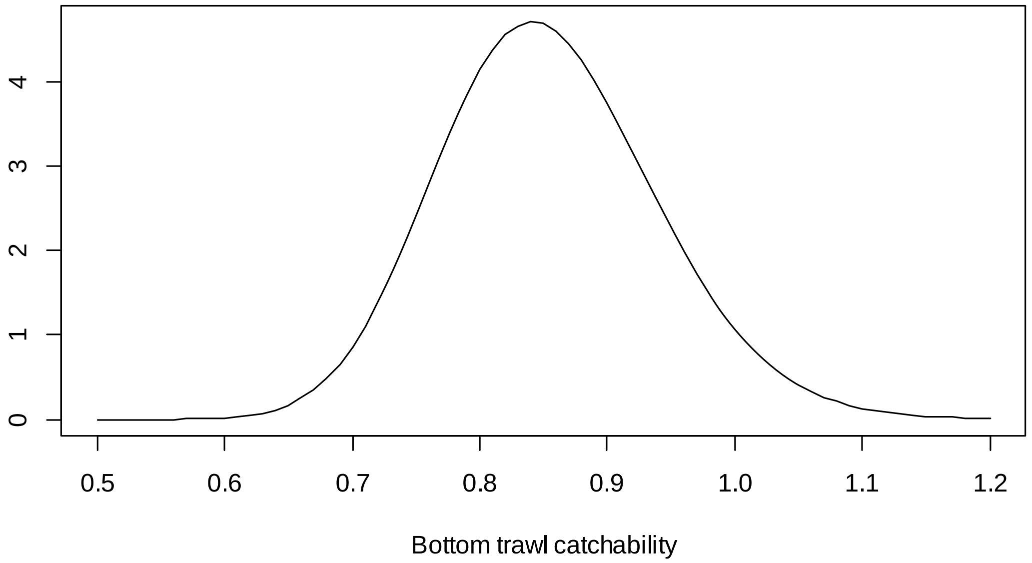


Figure 1.14. Prior on bottom trawl catchability used in the base model.

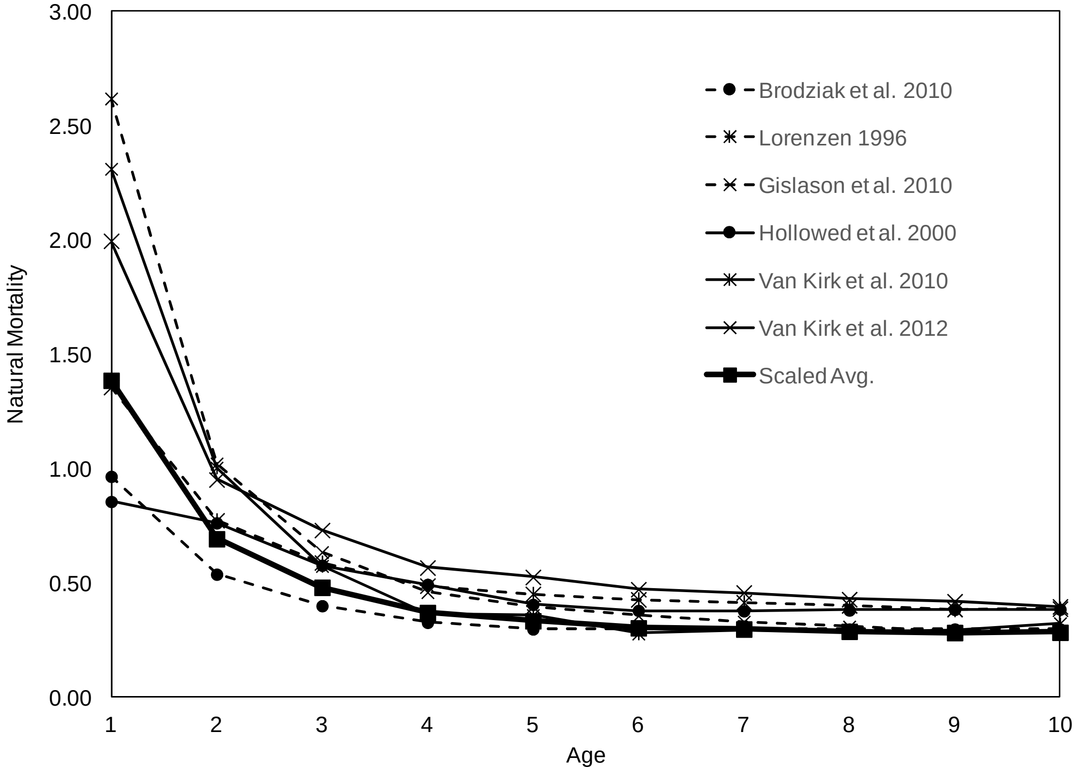


Figure 1.15. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

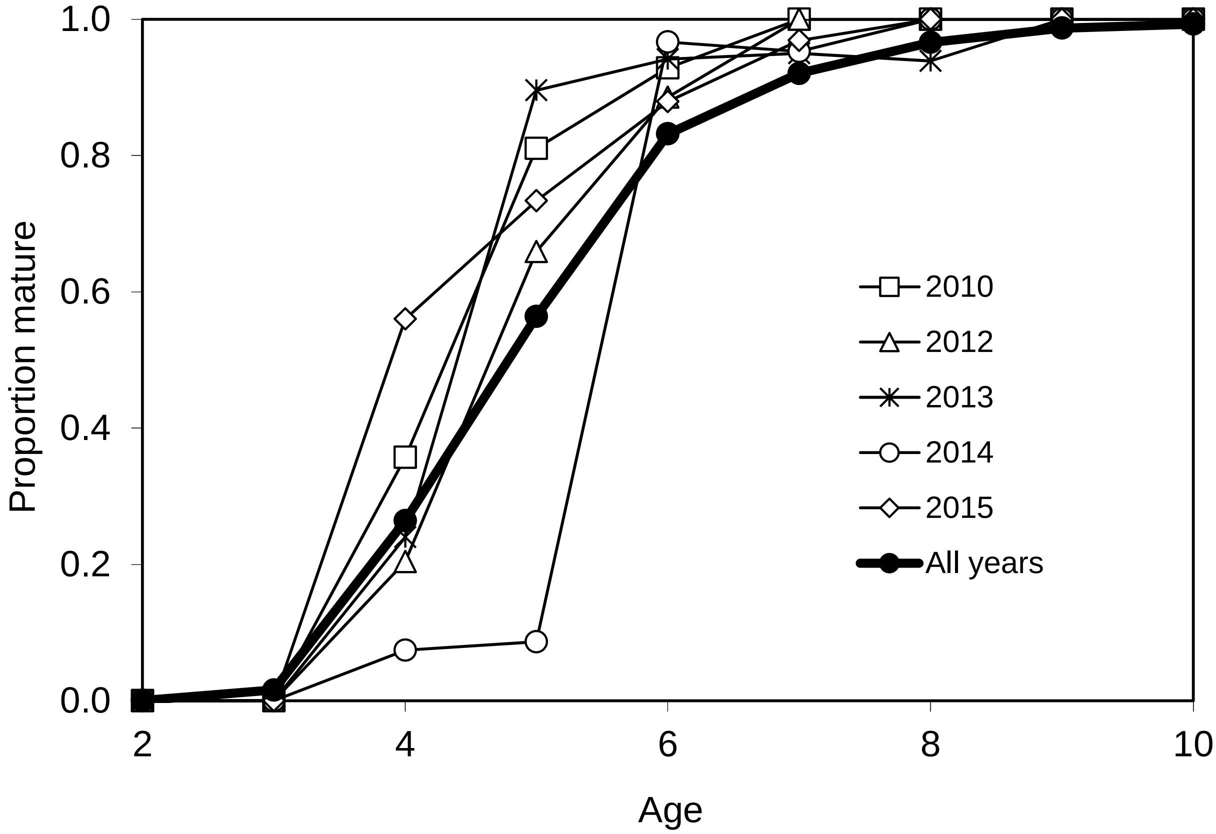
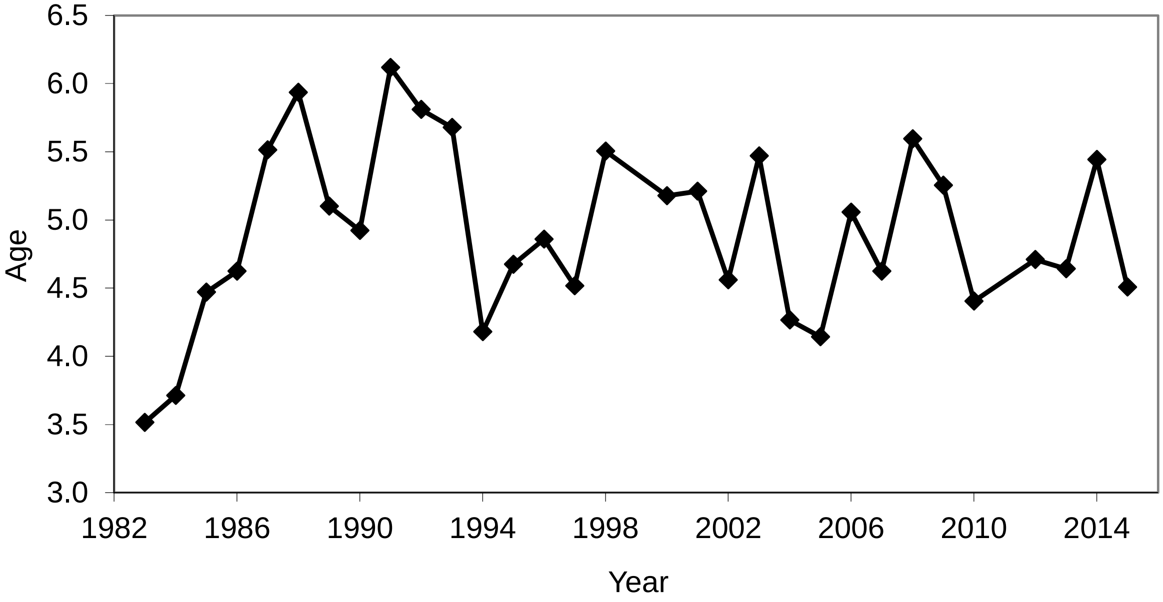


Figure 1.16. Estimates of the proportion mature at age from visual maturity data collected during 2010-2015 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2015).



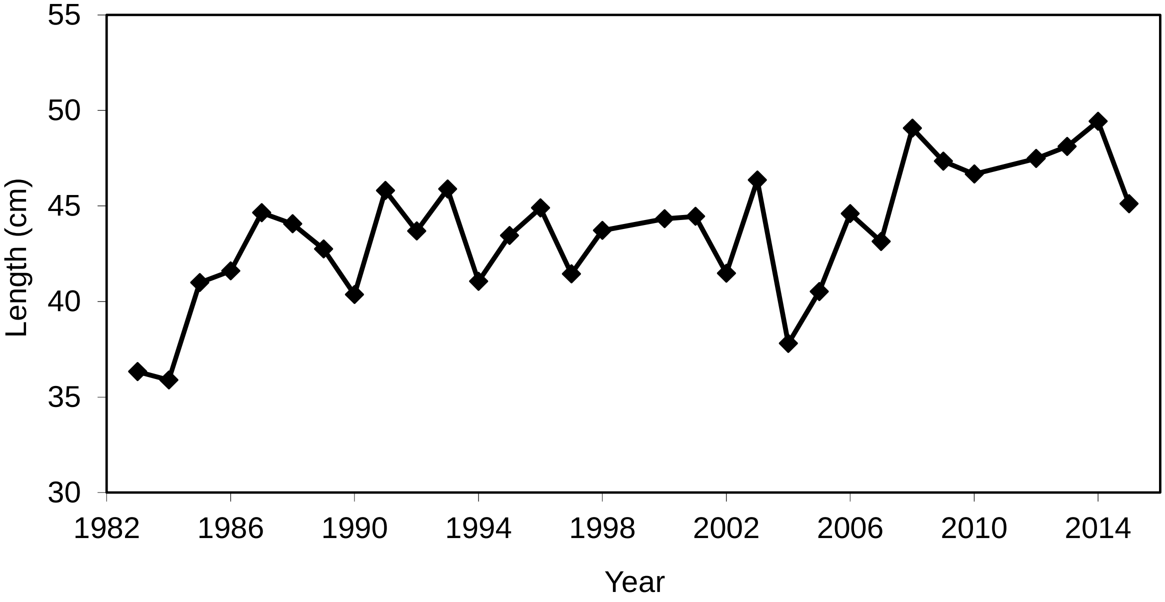


Figure 1.17. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2015.

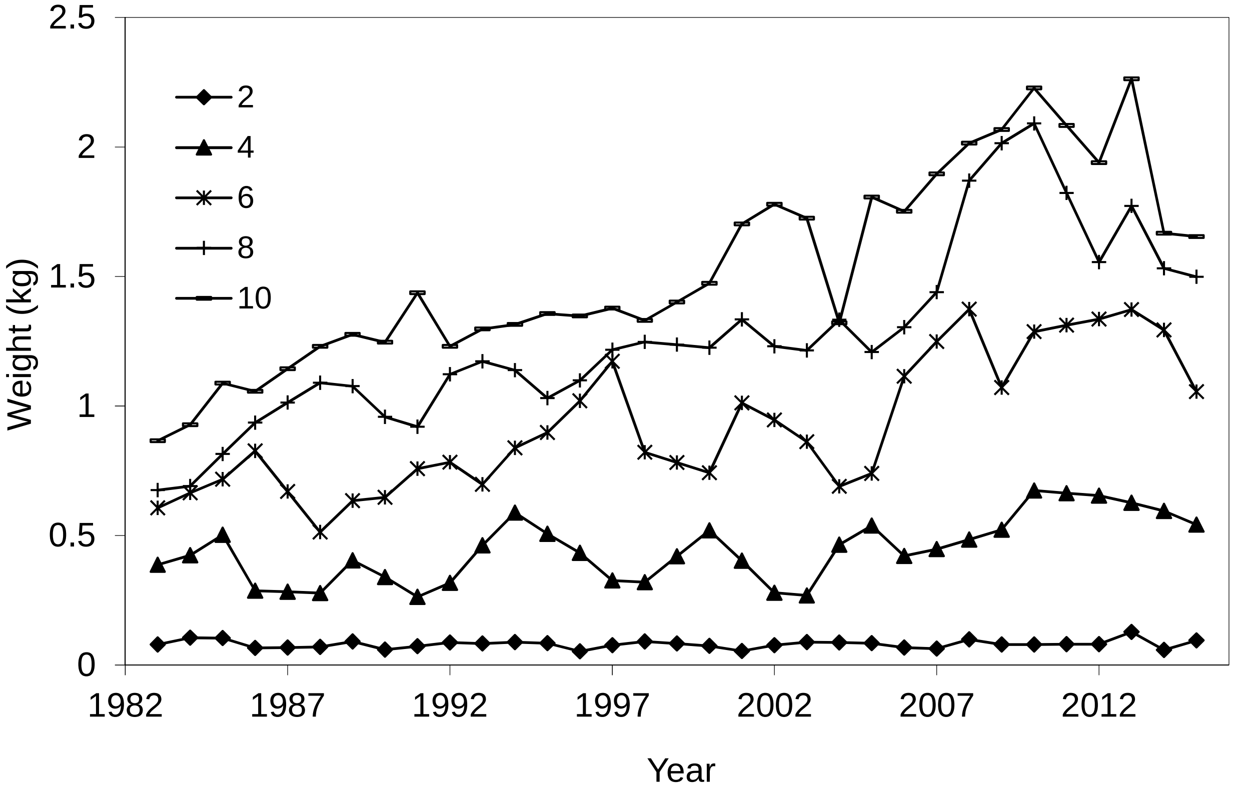
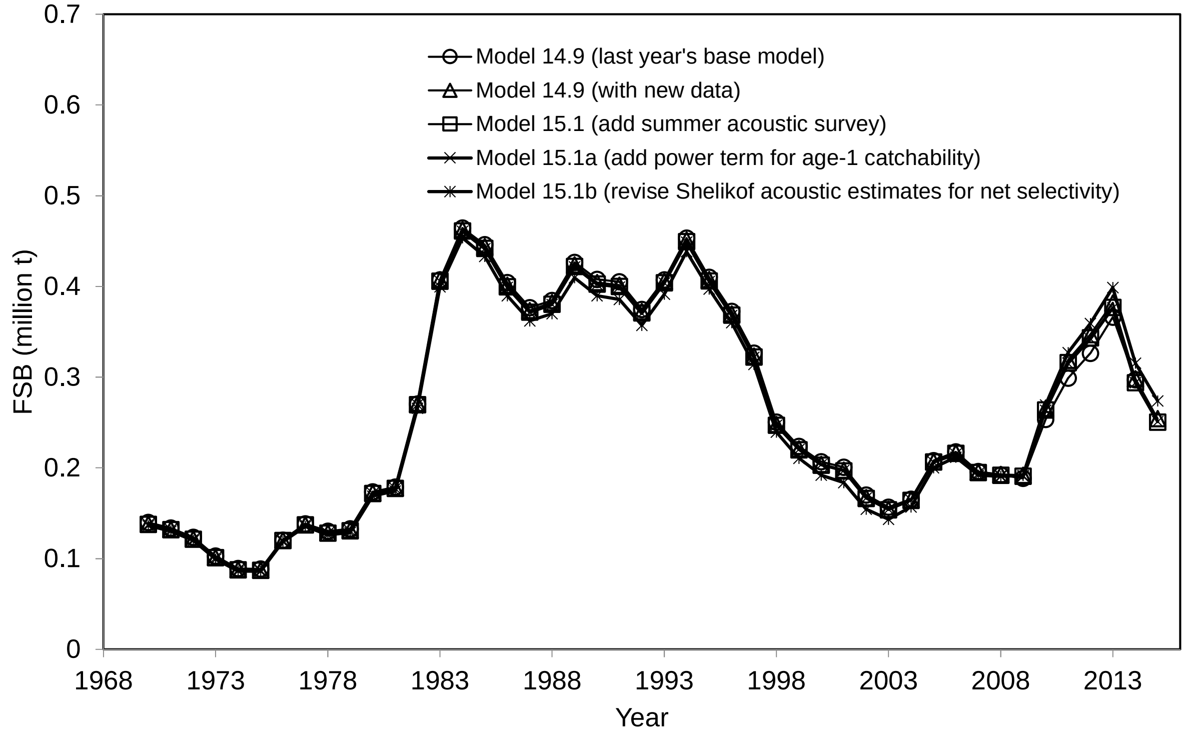


Figure 1.18. Estimated weight-at-age of GOA pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2015 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from adjacent years.



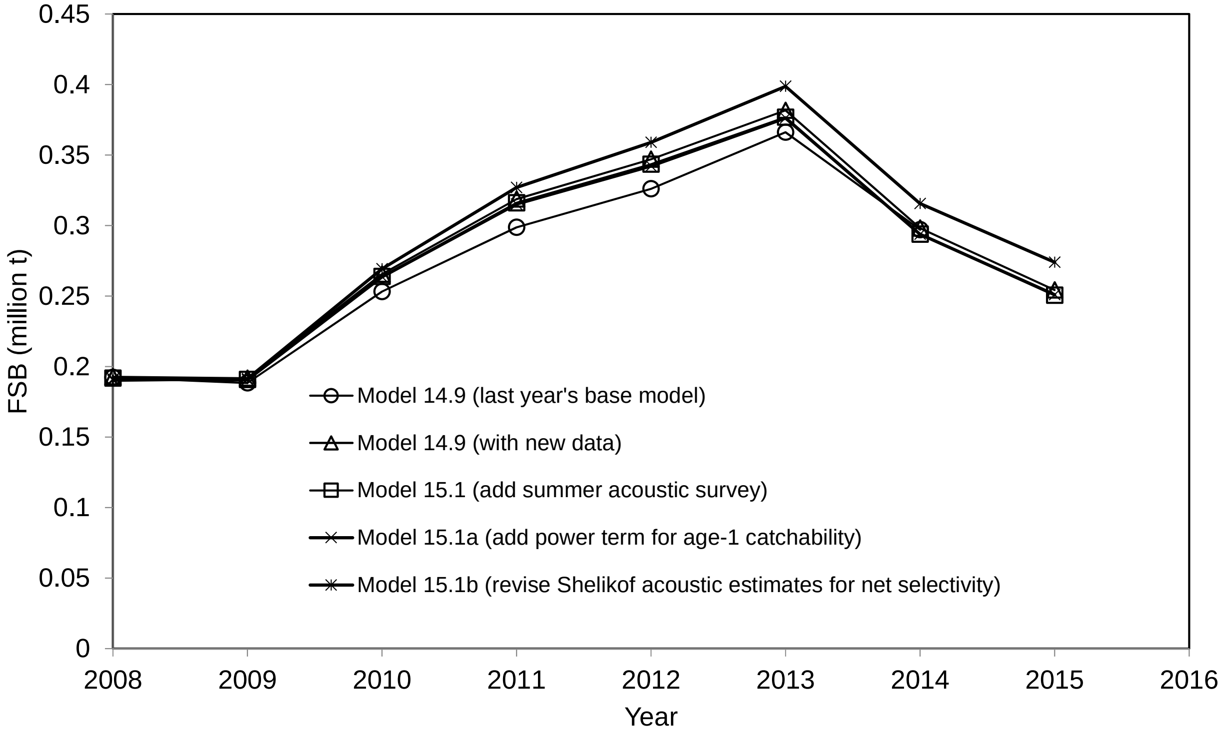


Figure 1.19. Comparison of estimated spawning biomass from alternative models. The lower panel shows the years 2008-2015 with an expanded scale to highlight differences. Model 14.9 was the base model last year. Model 15.1 includes the summer acoustic survey data and was considered a major model change, despite little change in spawning biomass. Model changes are cumulative, i.e., each model includes the features of previous models.

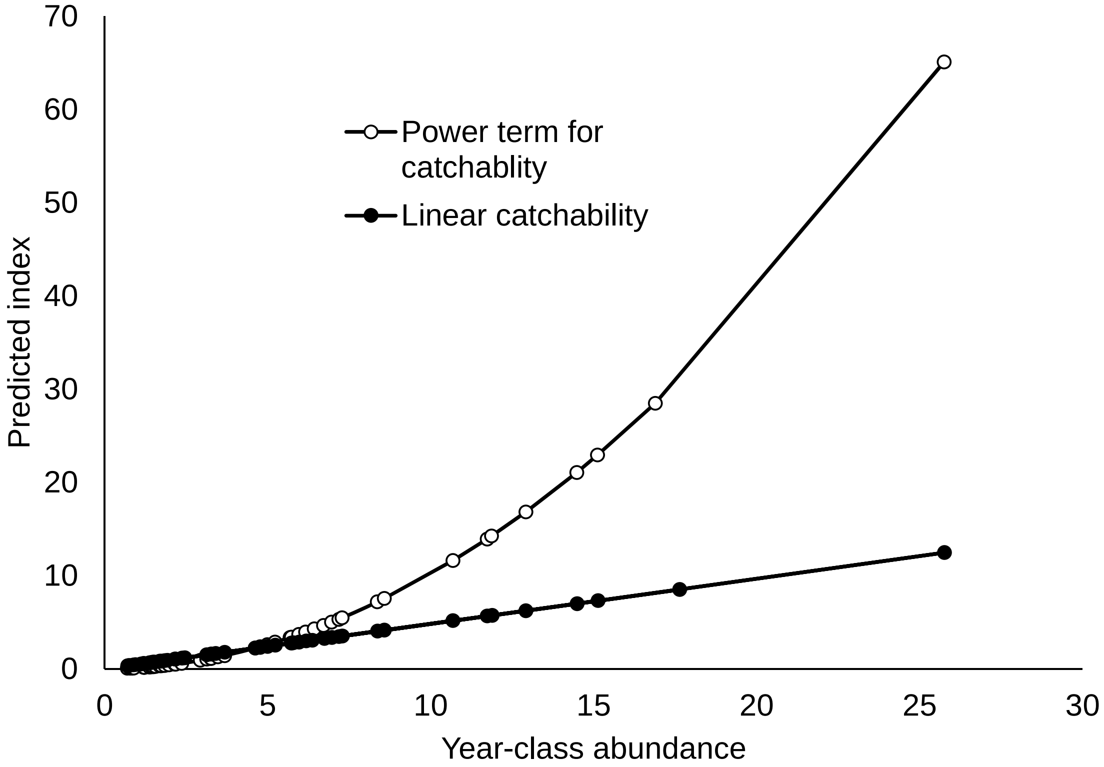


Figure 1.20. Comparison of the relationship between year-class abundance and the predicted age-1 index for the winter acoustic survey for constant (linear) catchability (Model 15.1) and where catchability is modeled as a function of abundance according to an estimated power term (Model 15.1a). The estimated power coefficient is 0.96.

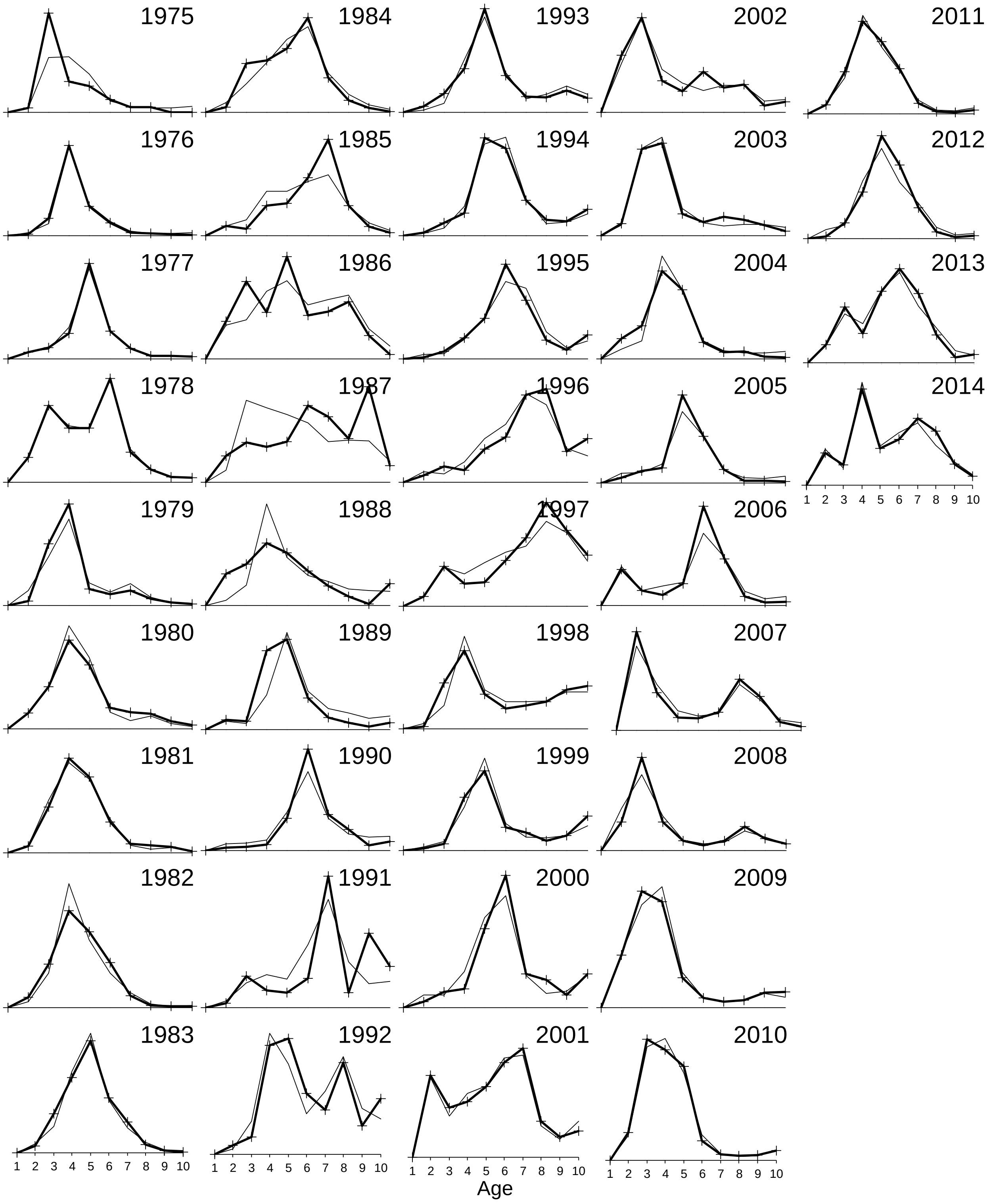


Figure 1.21. Observed and predicted fishery age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

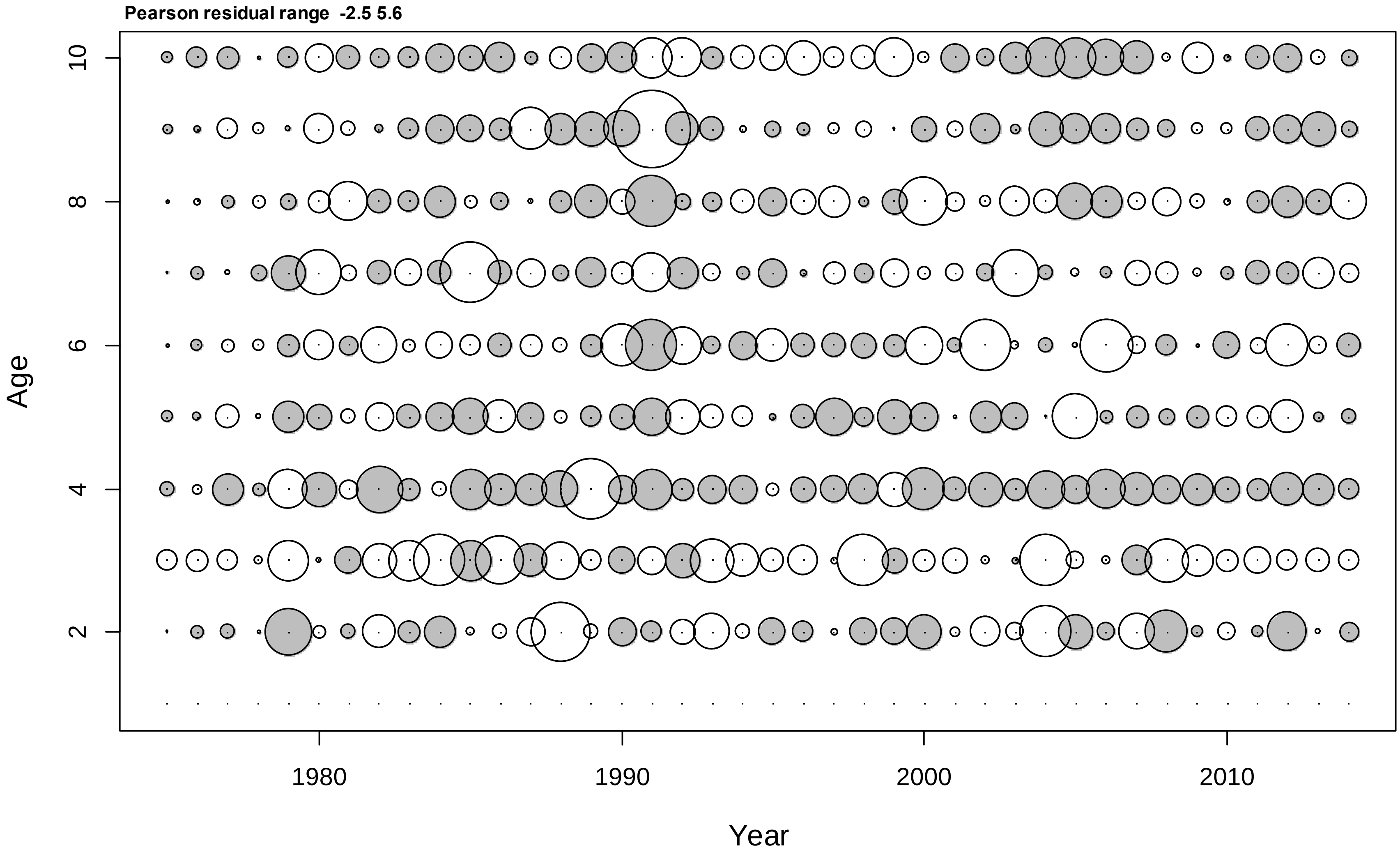


Figure 1.22. Pearson residuals for fishery age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

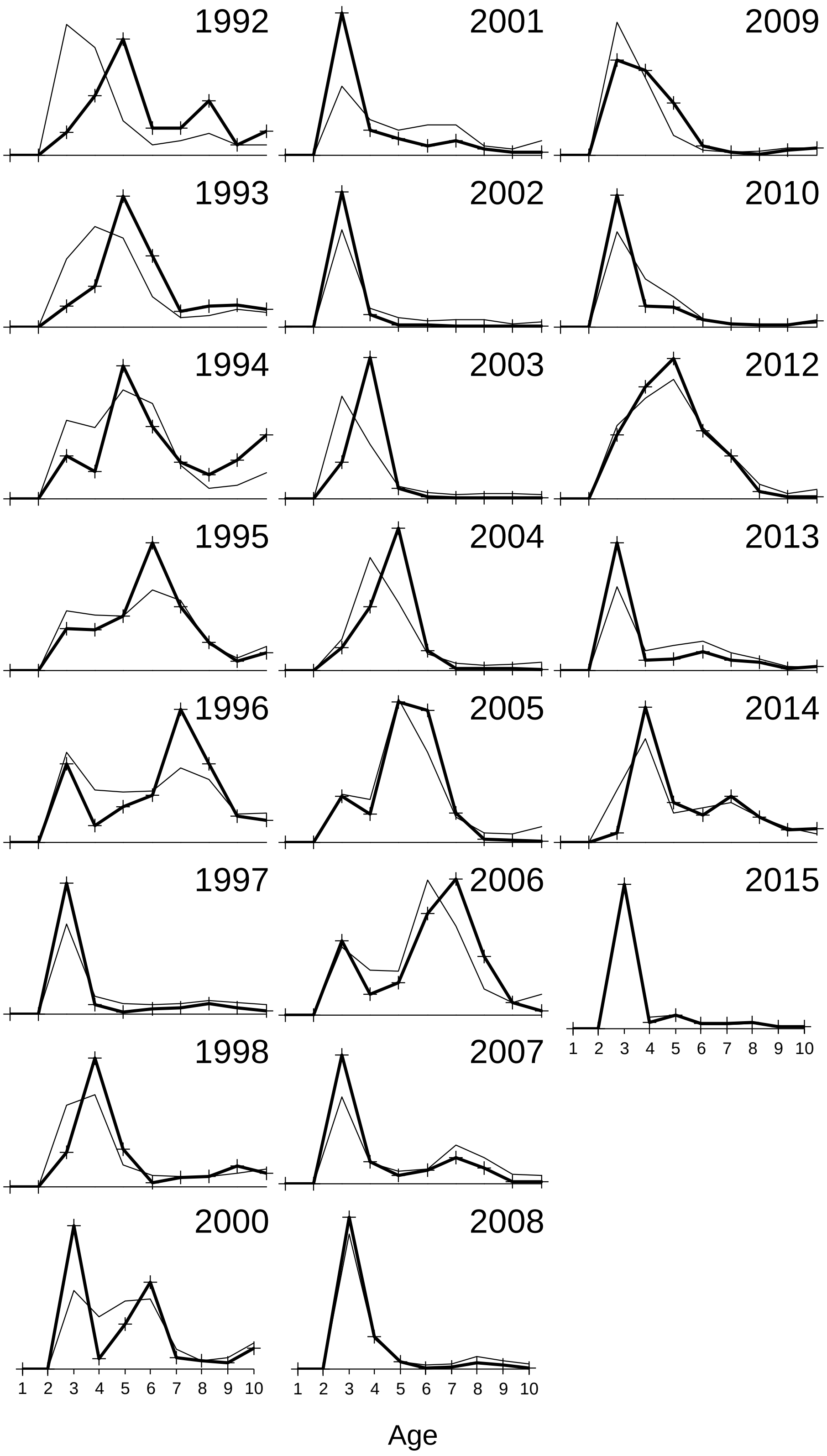


Figure 1.23. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

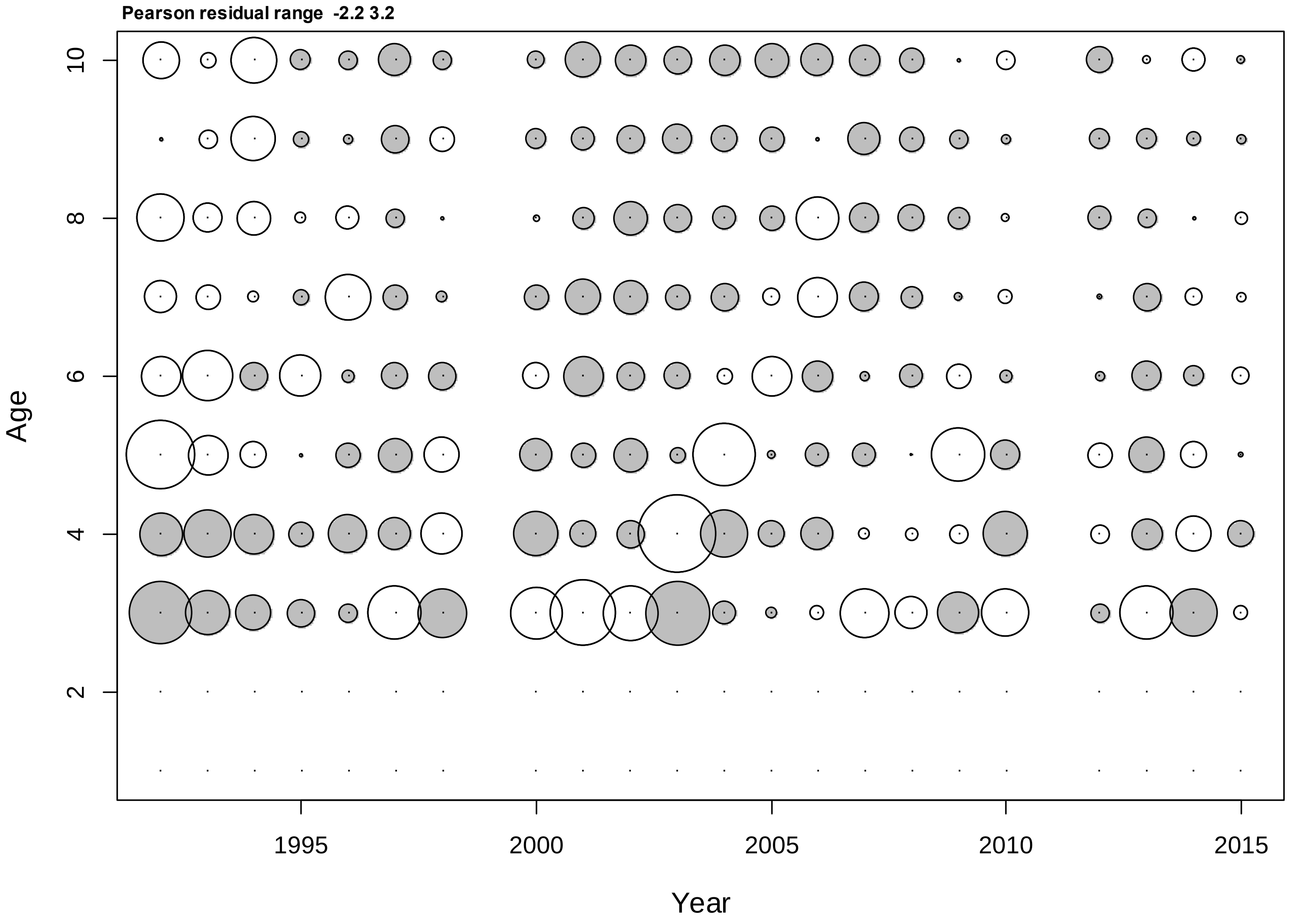


Figure 1.24. Pearson residuals for Shelikof Strait acoustic survey age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

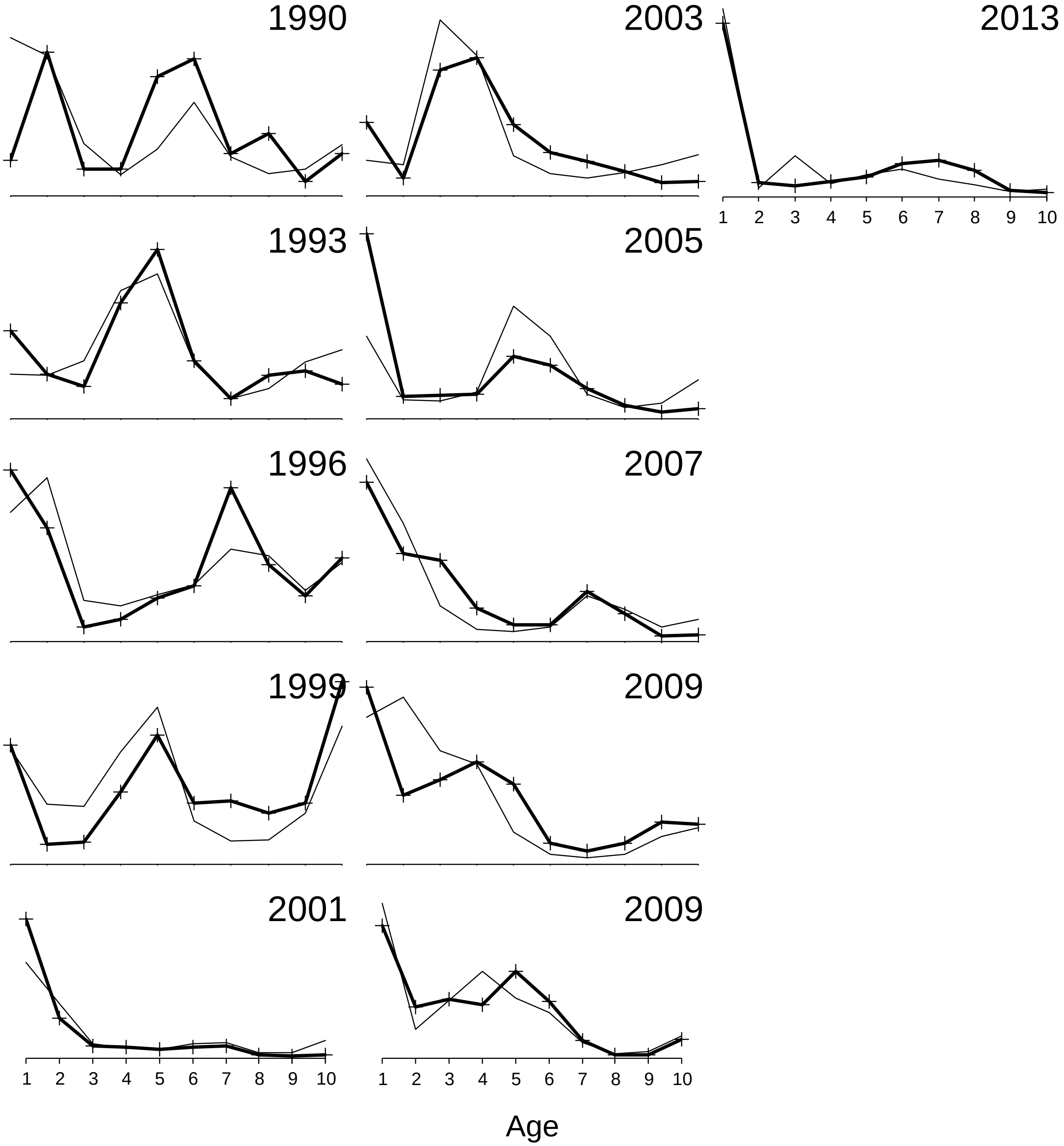
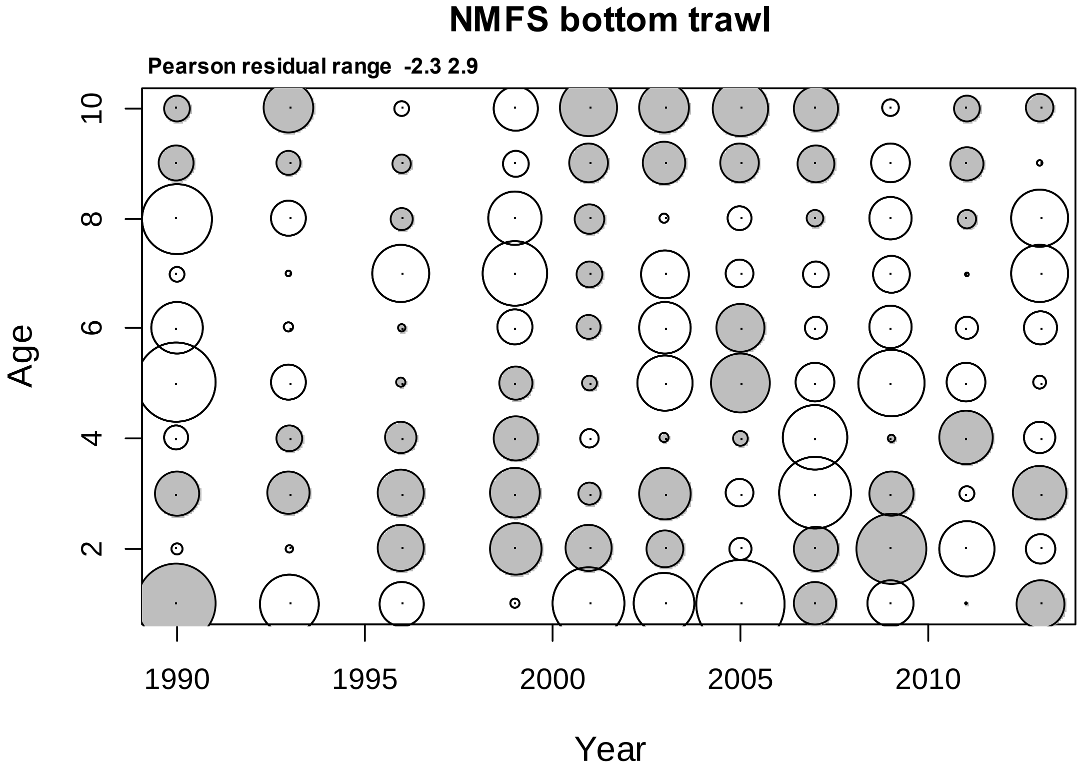


Figure 1.25. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.



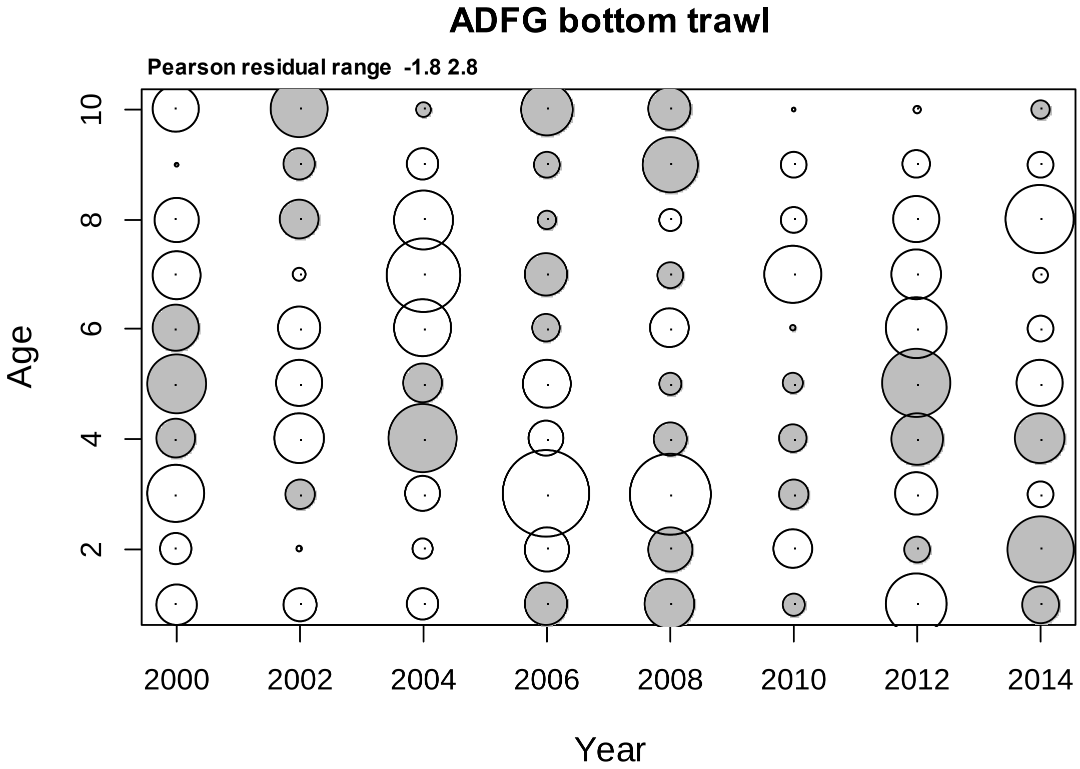


Figure 1.26. Pearson residuals for NMFS bottom trawl survey (top) and ADFG crab/groundfish survey (bottom) age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

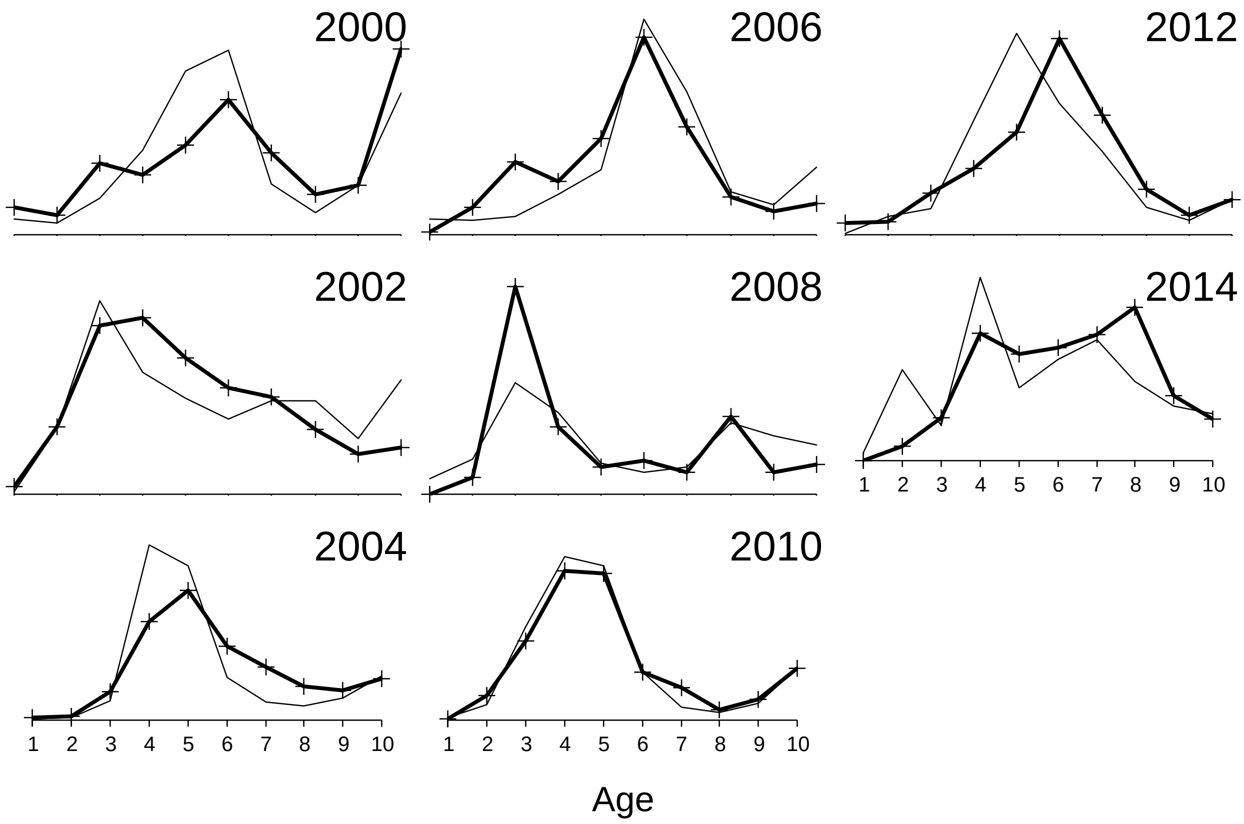


Figure 1.27. Observed and predicted ADFG crab/groundfish survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbols are observed proportions at age.

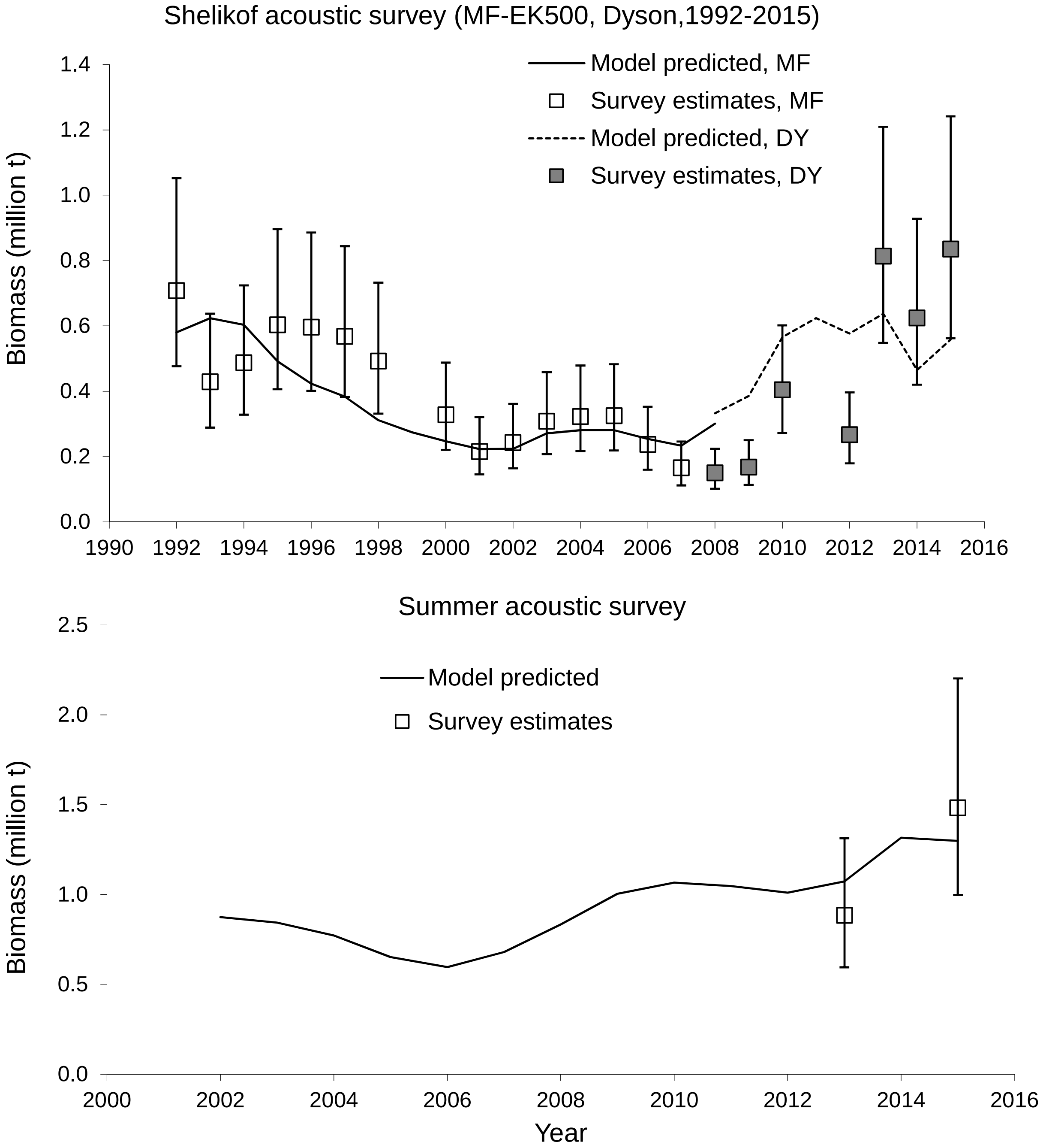


Figure 1.28. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey for the base model (top panel). The Shelikof acoustic survey is modeled with two catchability periods corresponding to the estimates produced by the *R/V Miller Freeman* (MF) in 1992-2007 and the *R/V Oscar Dyson* (DY) in 2008-2014. The bottom panel shows model predicted and observed survey biomass for the summer acoustic survey. Error bars indicate plus and minus two standard deviations. A CV of 0.2 is assumed for all acoustic surveys when fitting the model.

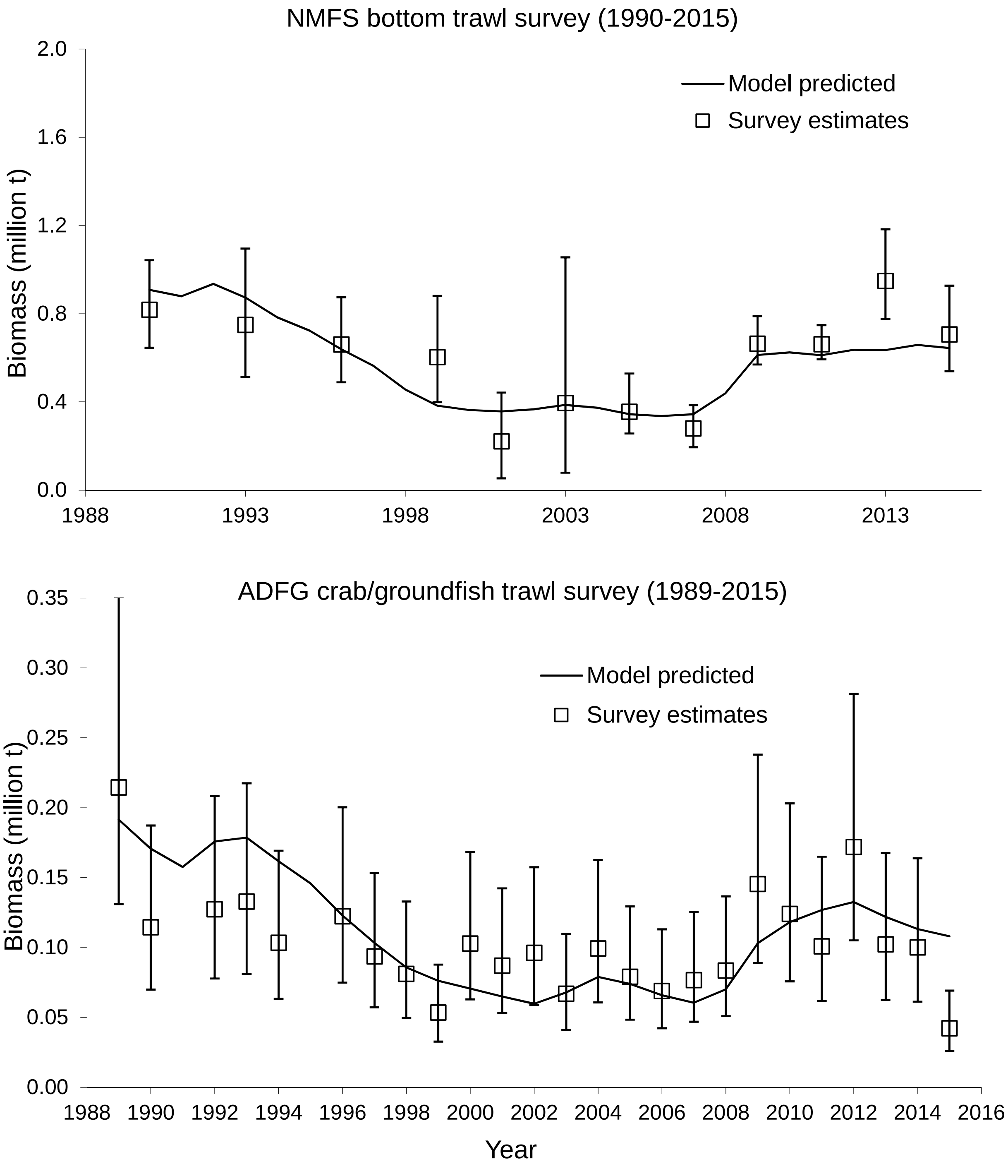
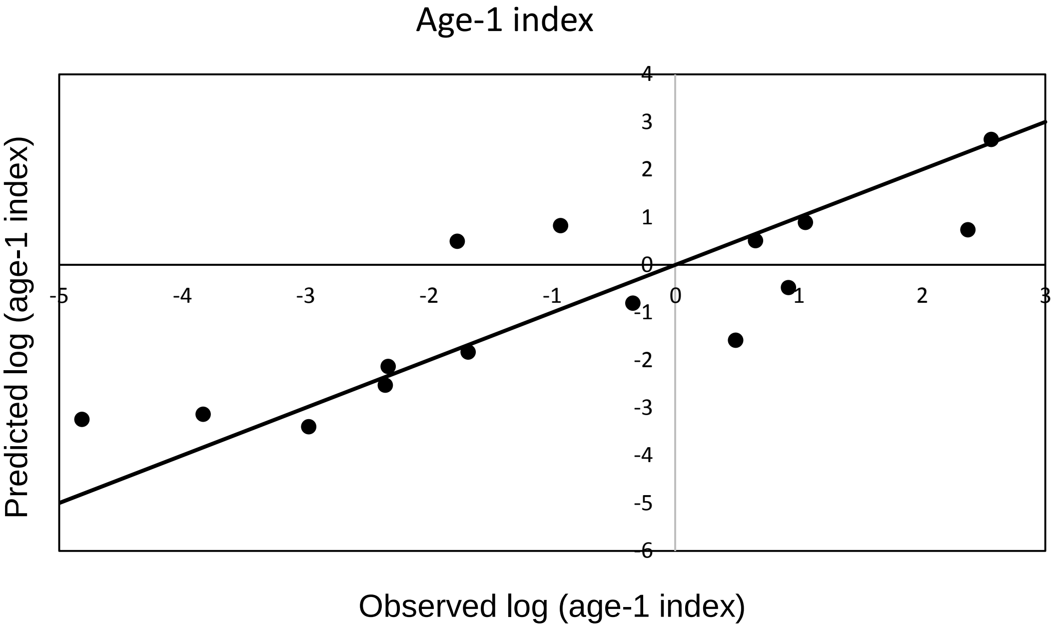


Figure 1.29. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom) for the base model. Error bars indicate plus and minus two standard deviations. Since variance estimates are unavailable for ADFG biomass estimates, an assumed CV of 0.25 is used in the assessment model.



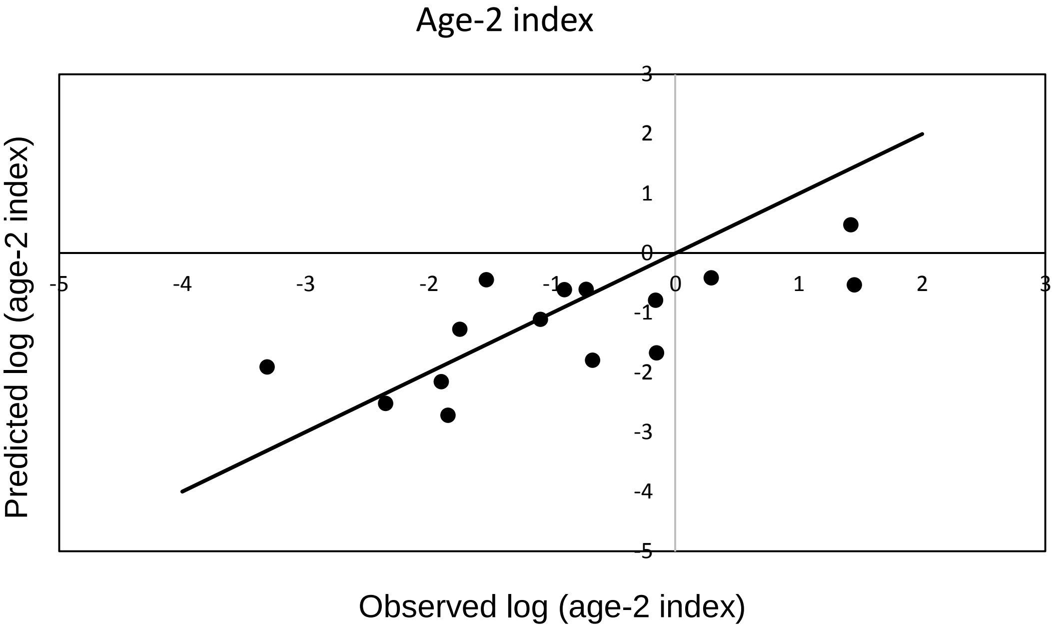


Figure 1.30. Observed and model predicted age-1 (top) and age-2 indices (bottom) for the winter acoustic estimates combined for Shelikof Strait and the Shumagin Islands.

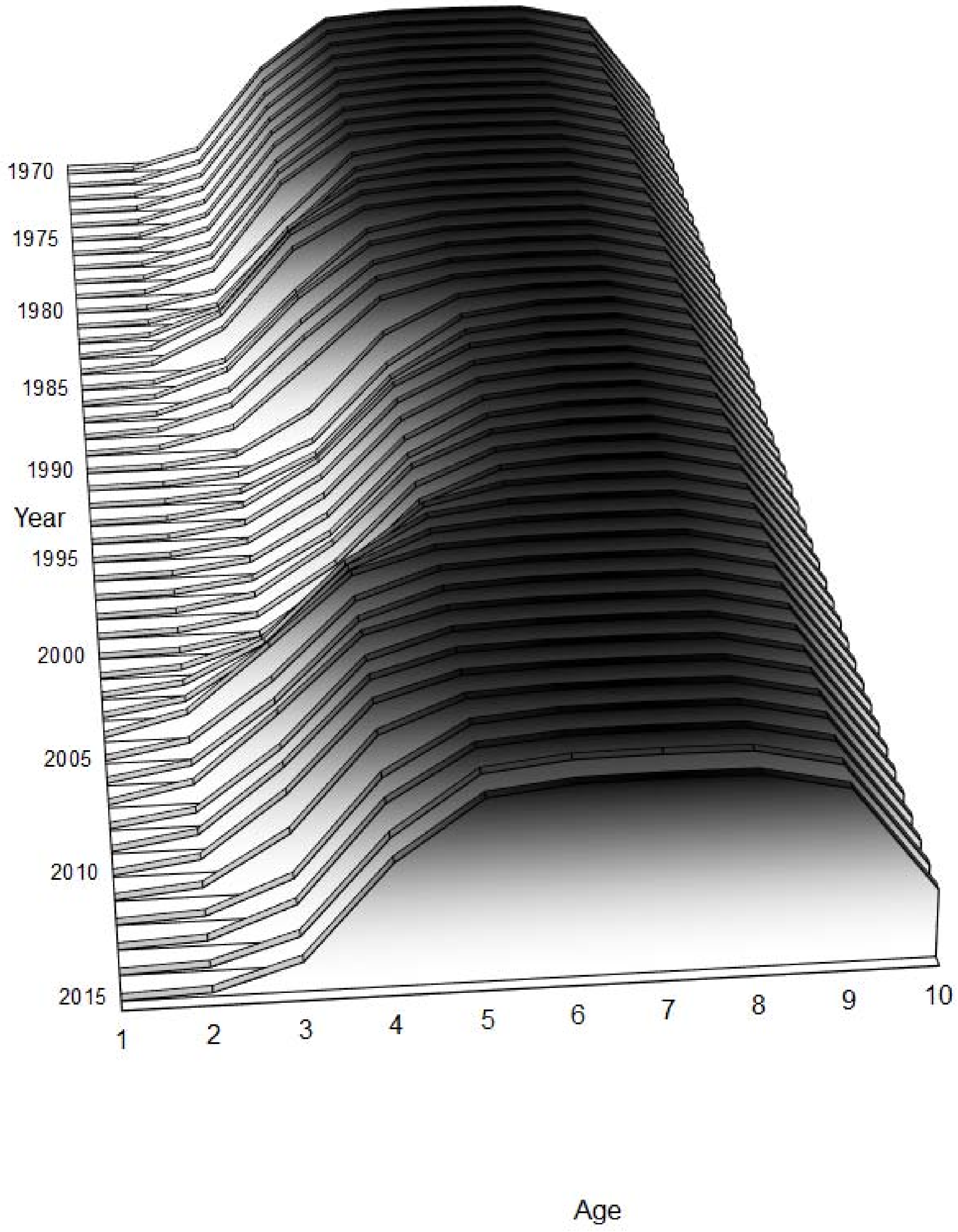
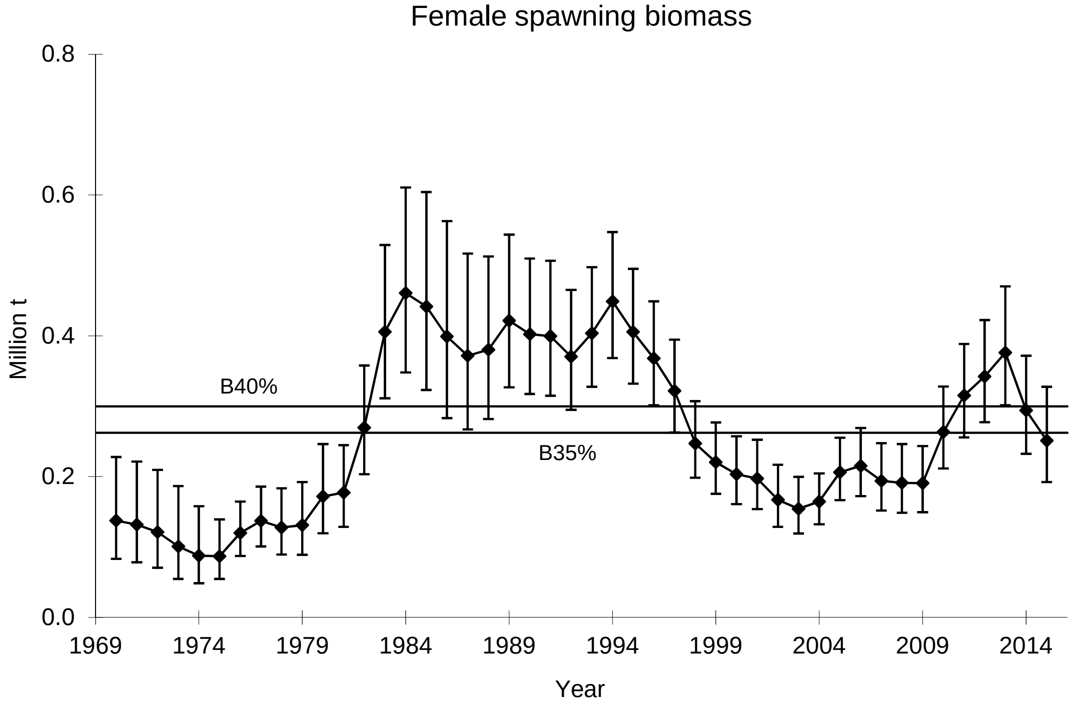


Figure 1.31. Estimates of time-varying fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.



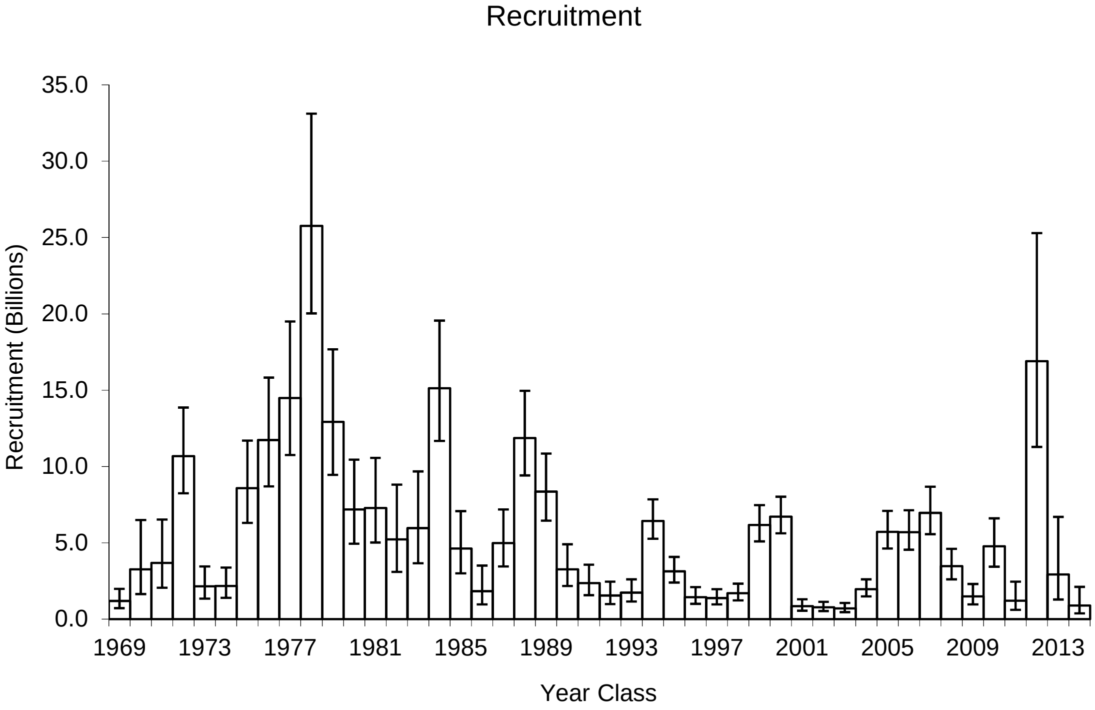
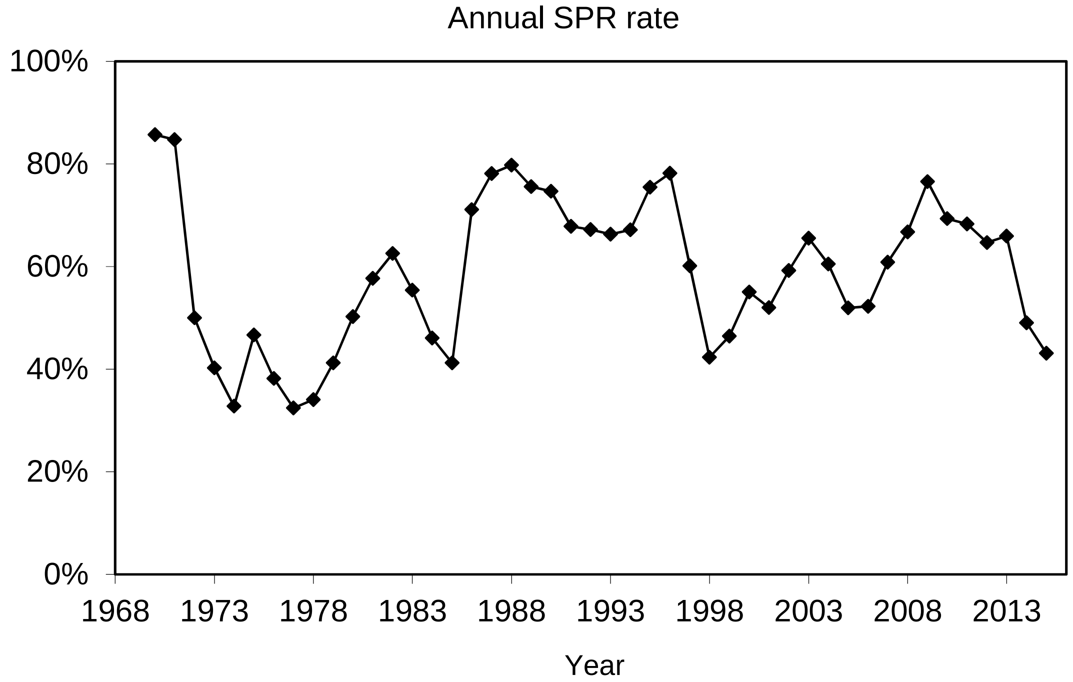


Figure 1.32. Estimated time series of GOA pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1970 to 2015 for the base model. Vertical bars represent two standard deviations. The $B_{35\%}$ and $B_{40\%}$ lines represent the current estimate of these benchmarks.



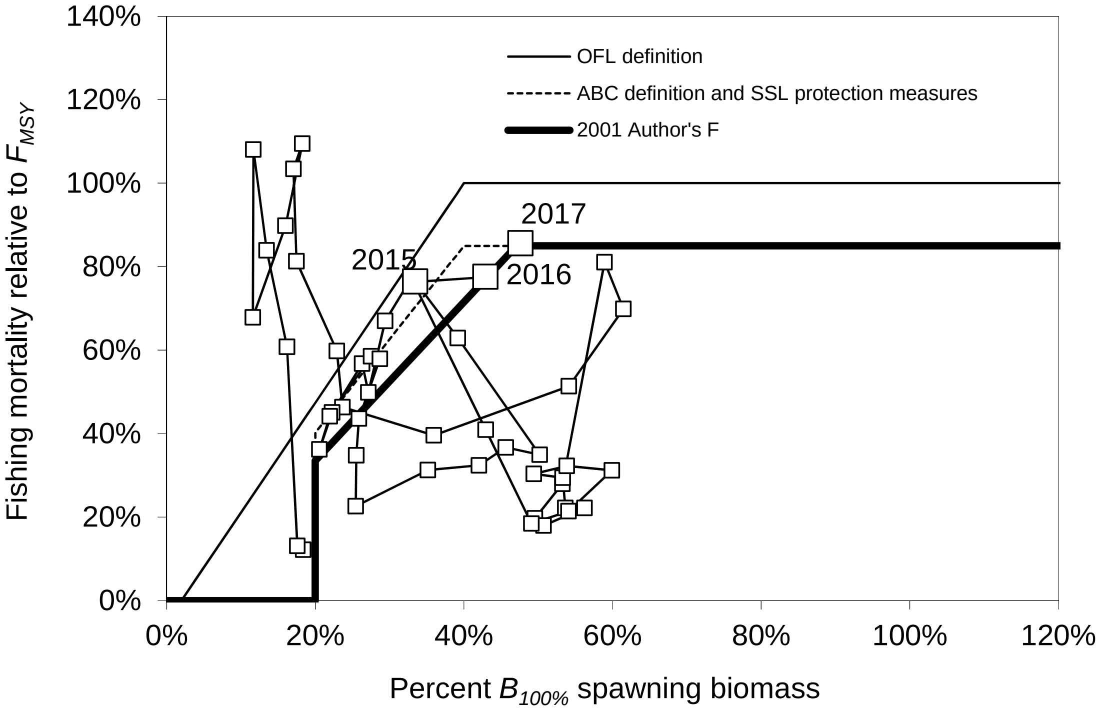
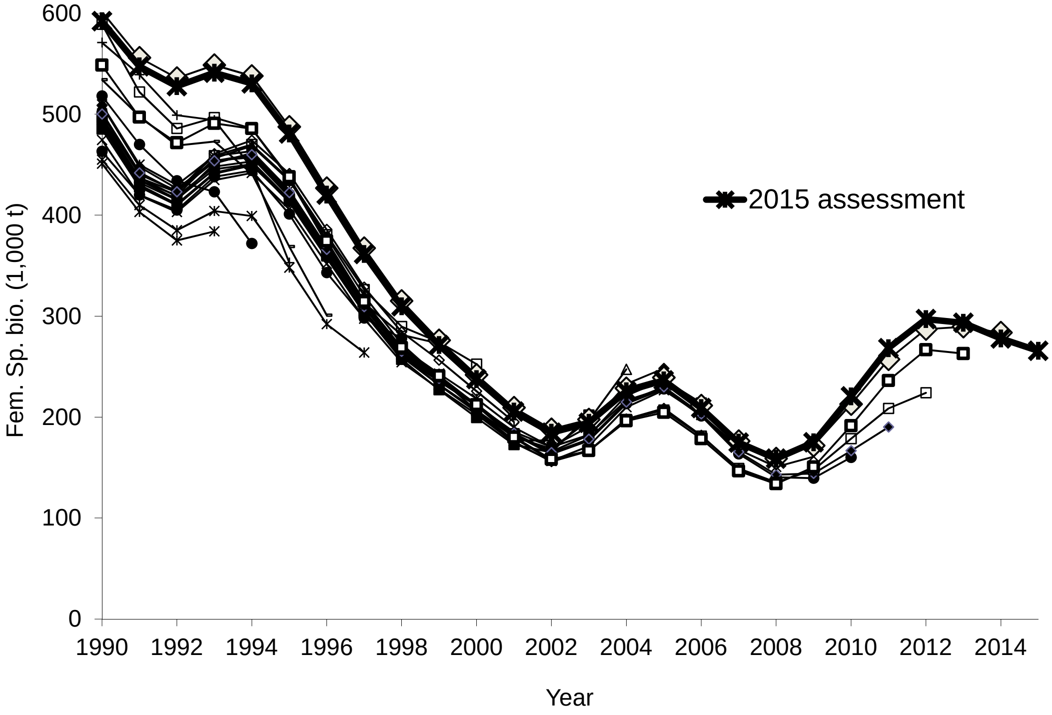


Figure 1.33. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{MSY} (bottom). The ratio of fishing mortality to F_{MSY} is calculated using the estimated selectivity 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.



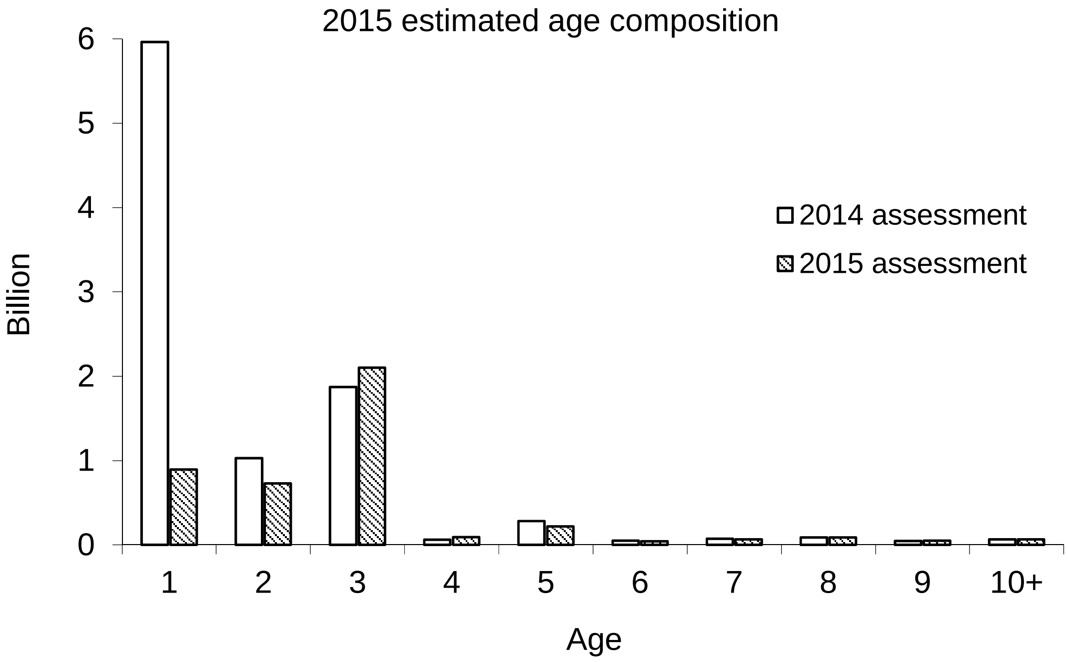


Figure 1.34. Retrospective plot of estimated GOA pollock female spawning biomass for stock assessments in the years 1993-2015 (top). For this figure, the time series of female spawning biomass was calculated using the same maturity and spawning weight at age for all assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2015 from the 2014 and 2015 assessments.

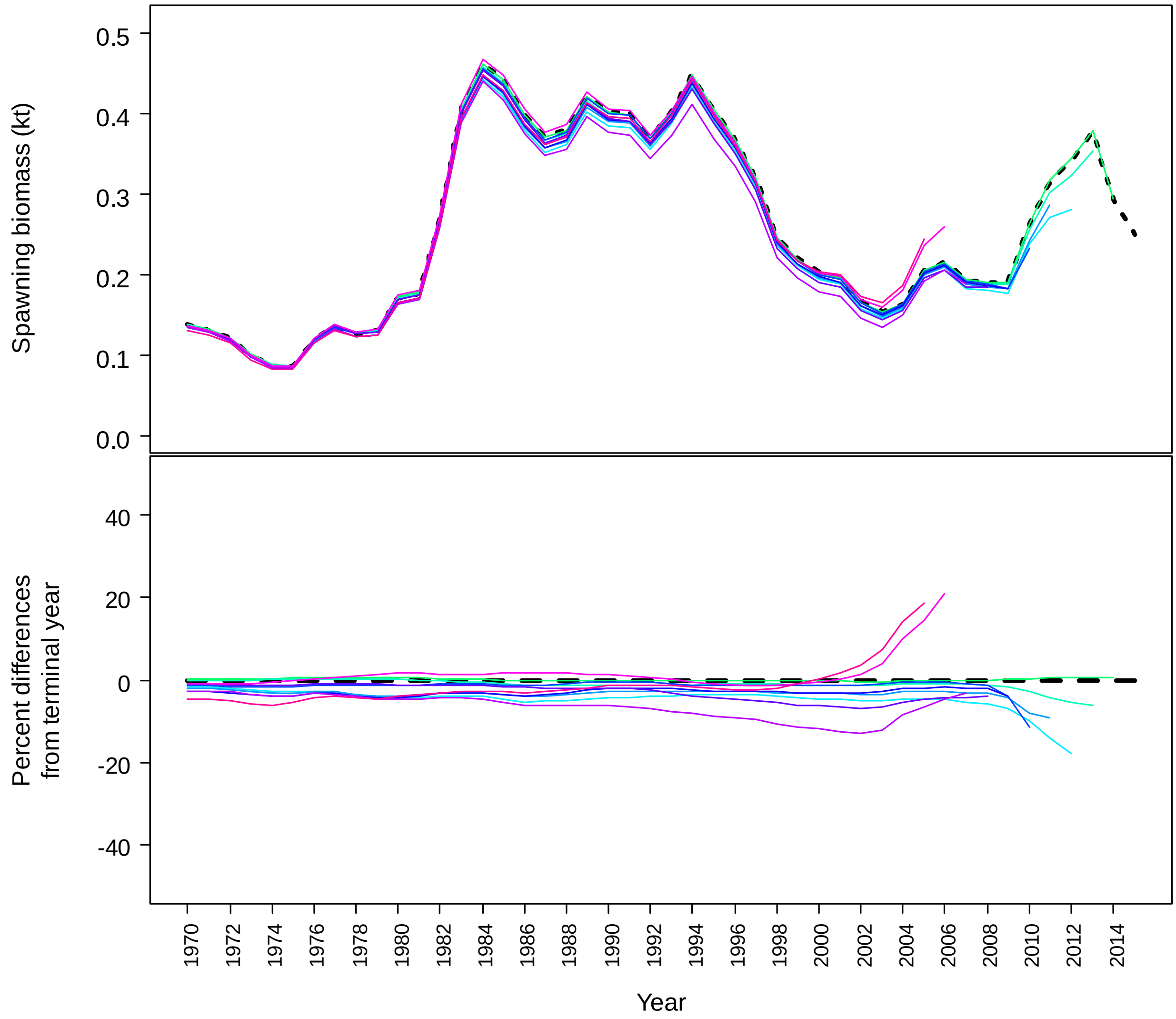


Figure 1.35. Retrospective plot of spawning biomass for the years 2005-2015 for the 2015 assessment model. The revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is -0.016.

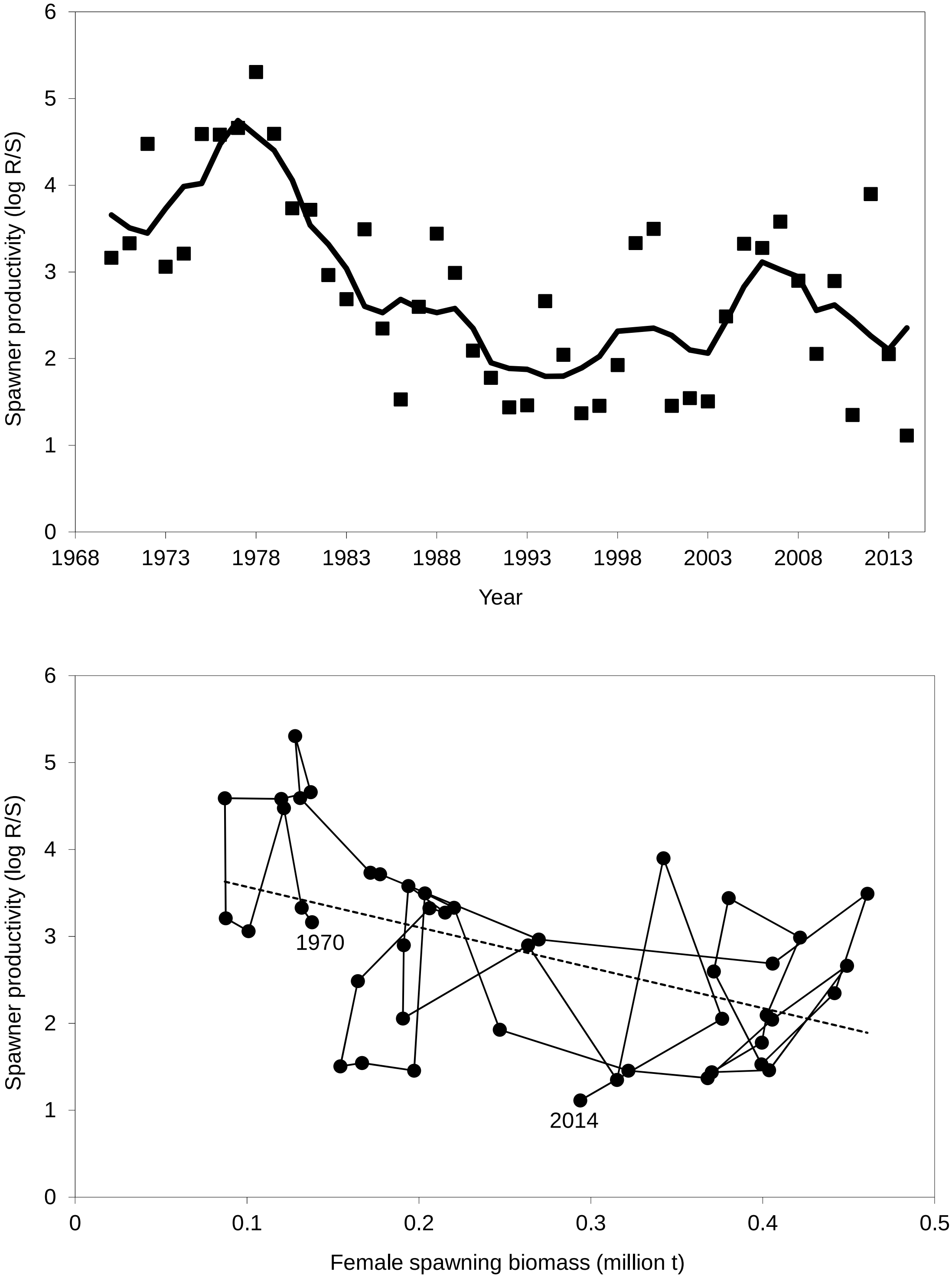


Figure 1.36. GOA pollock spawner productivity, *log(R/S)*, in 1970-2014 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

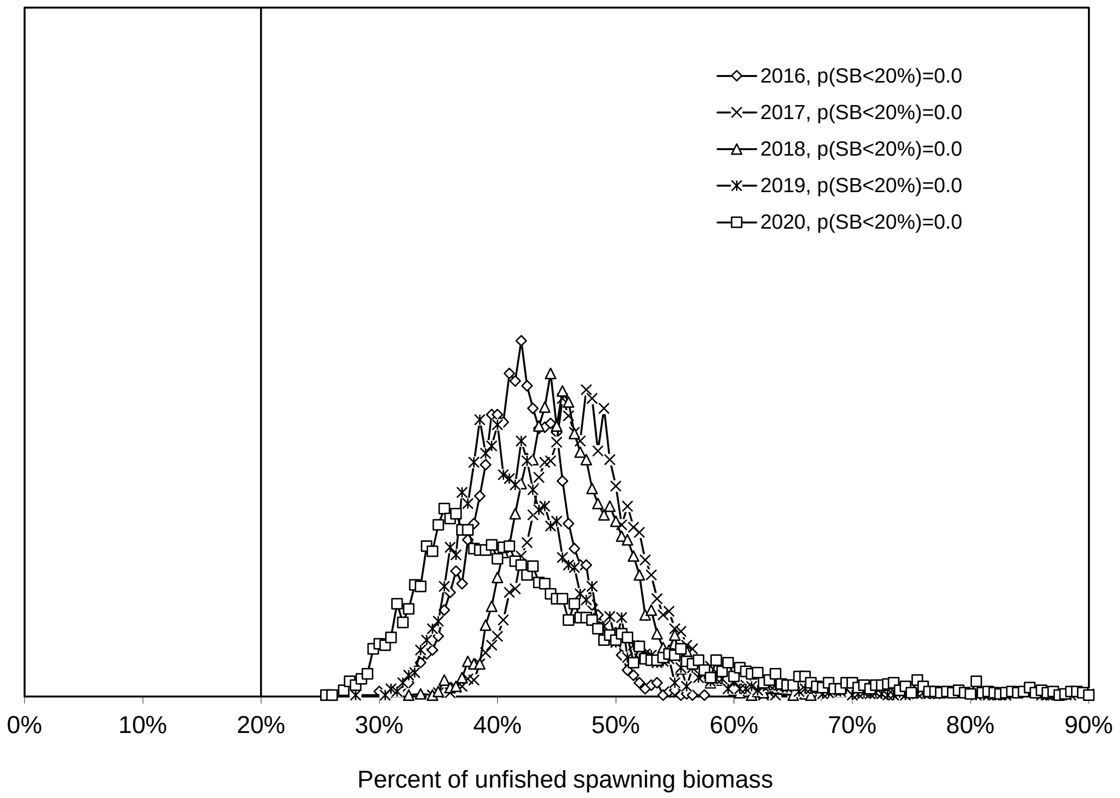
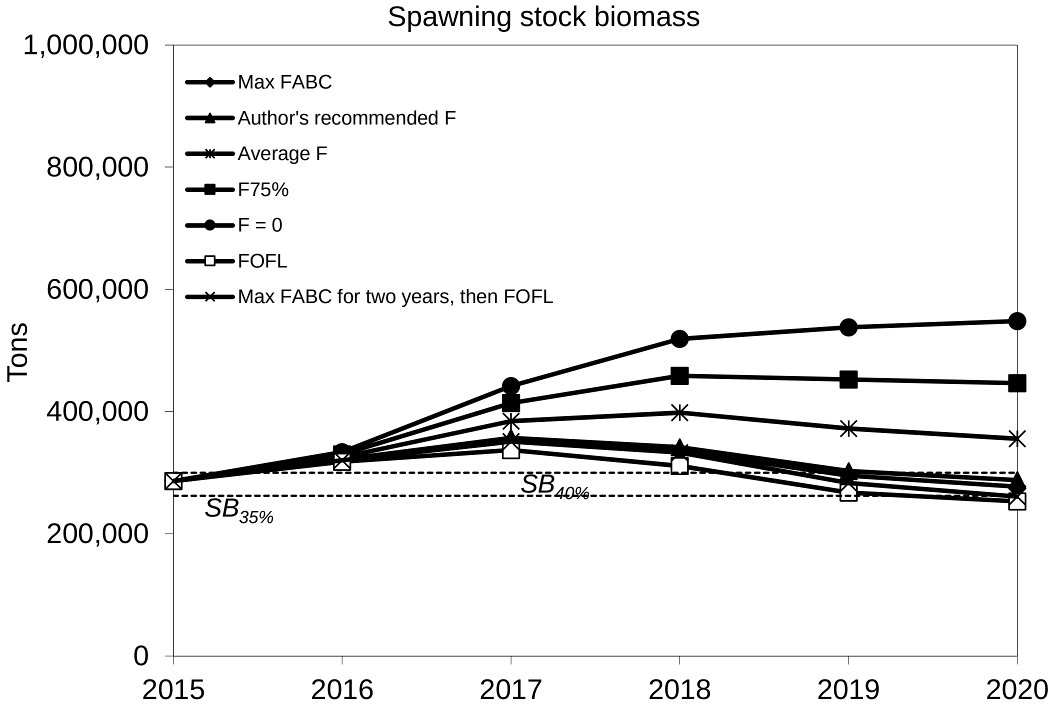


Figure 1.37. Uncertainty in spawning biomass in 2016-2020 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended F_{ABC}.



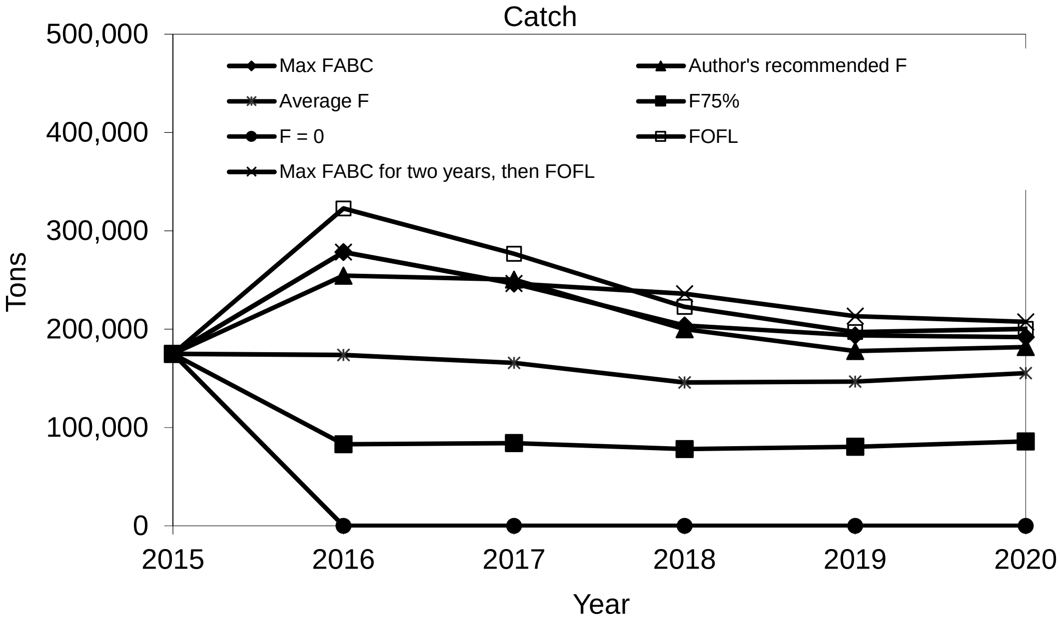
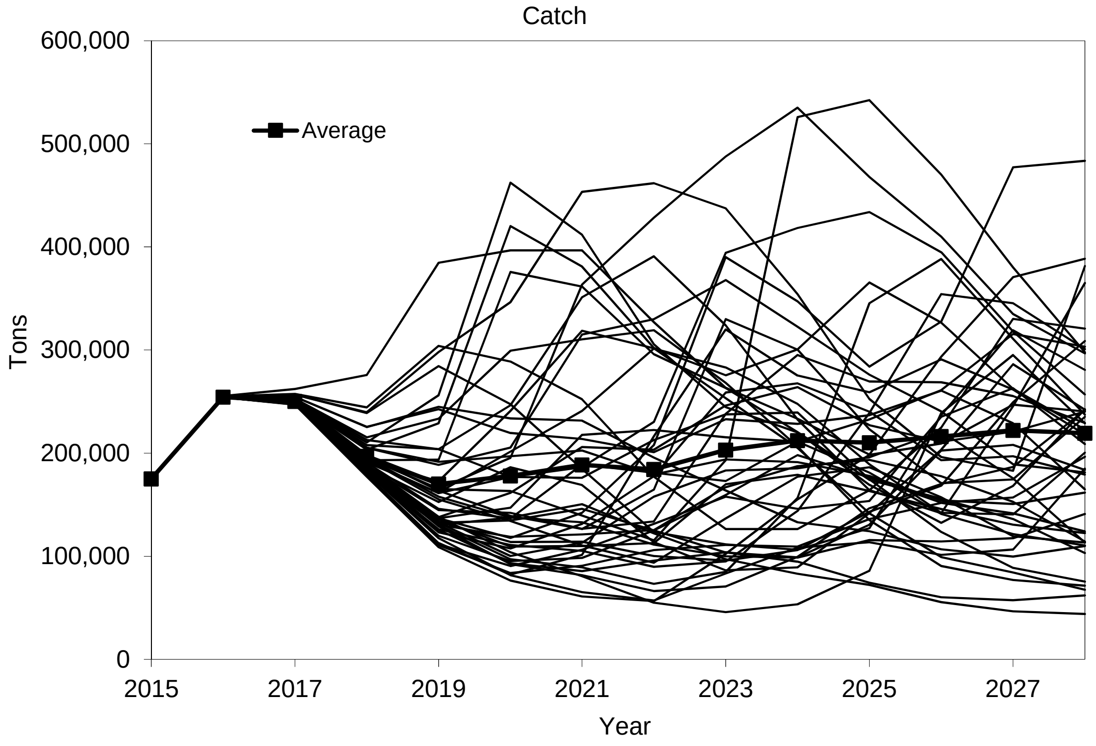


Figure 1.38. Projected spawning biomass and catches in 2016-2020 under different harvest rates.



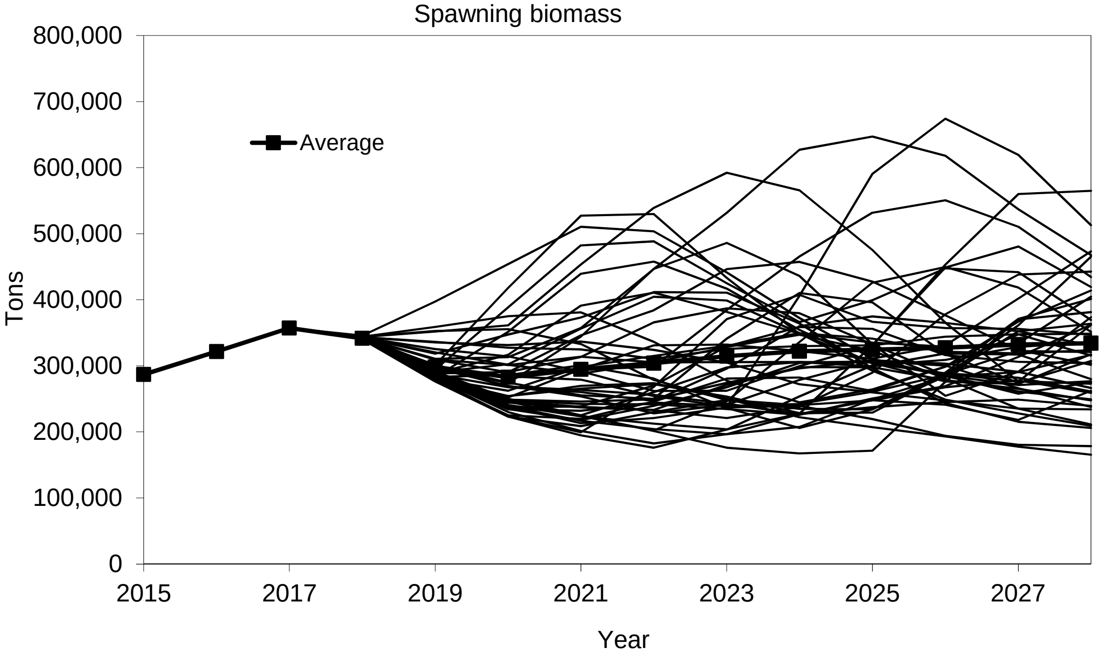


Figure 1.39. Variability in projected catch and spawning biomass in 2016-2028 for the base model under the author's recommended F_{ABC}.

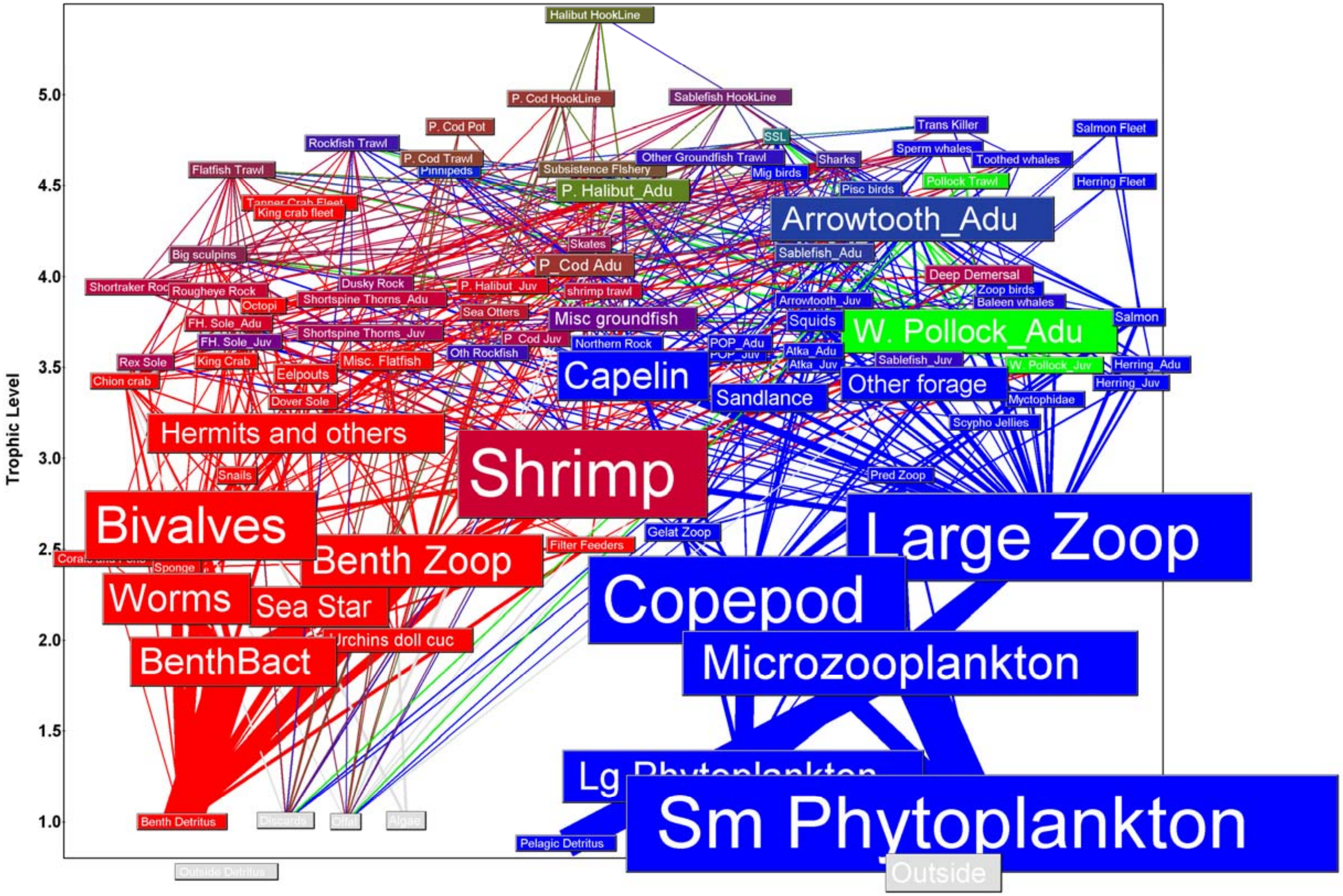


Figure 1.40. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.

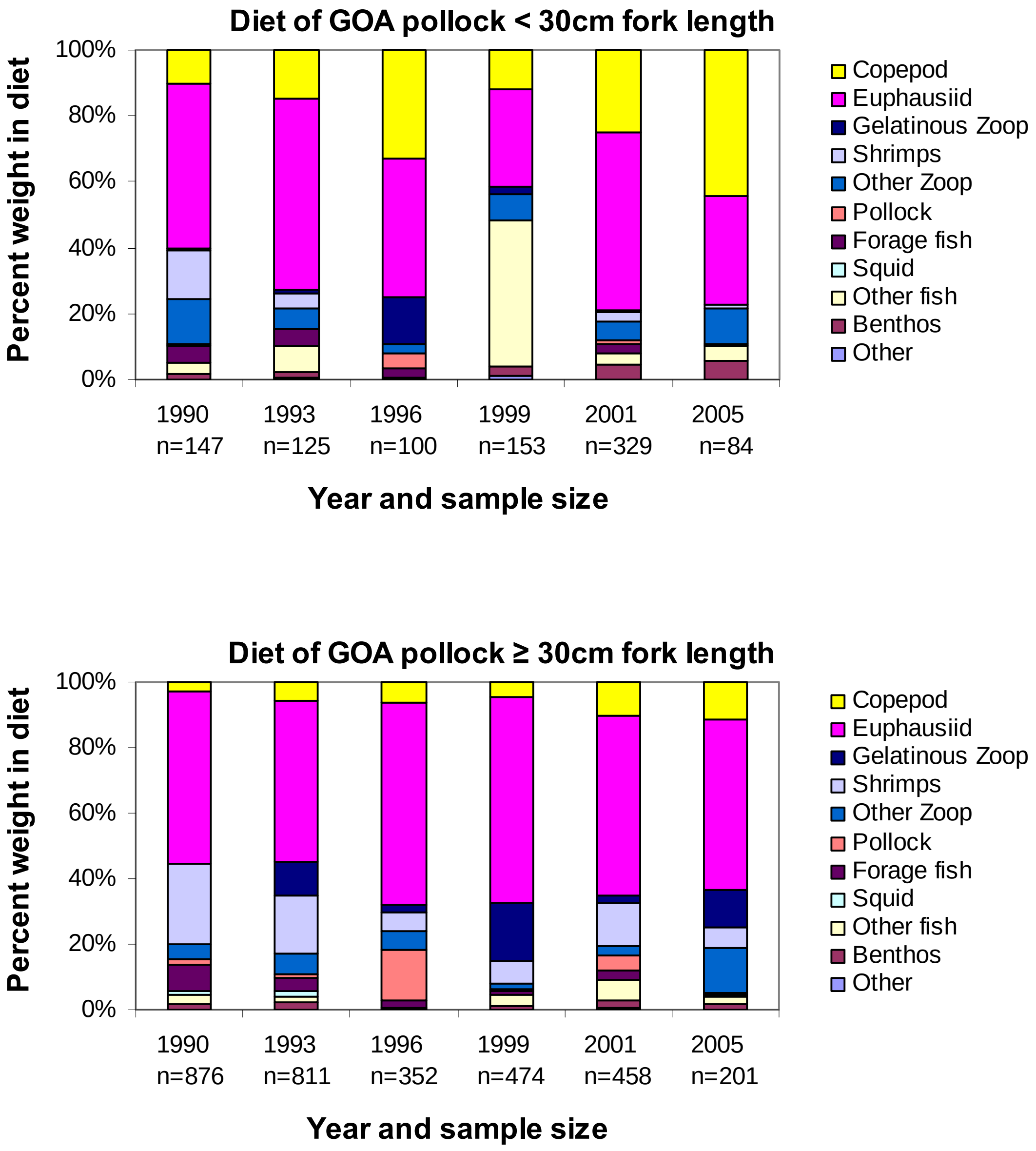
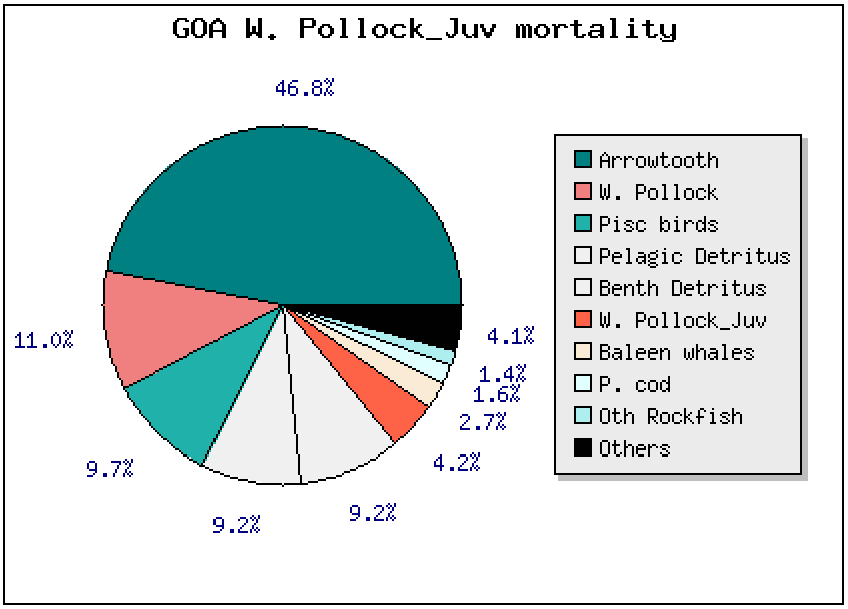


Figure 1.41. Diet (percent wet weight) of GOA pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



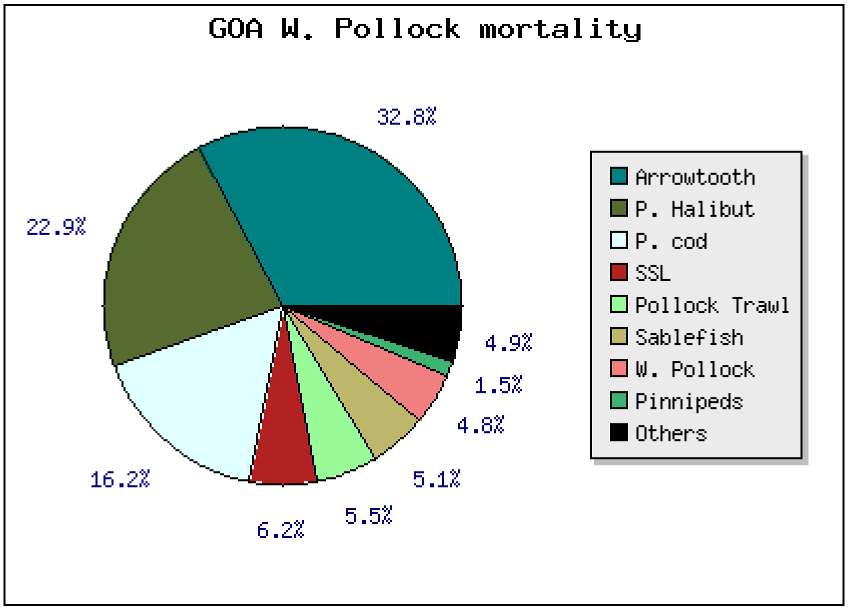


Figure 1.42. Sources of mortality for pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

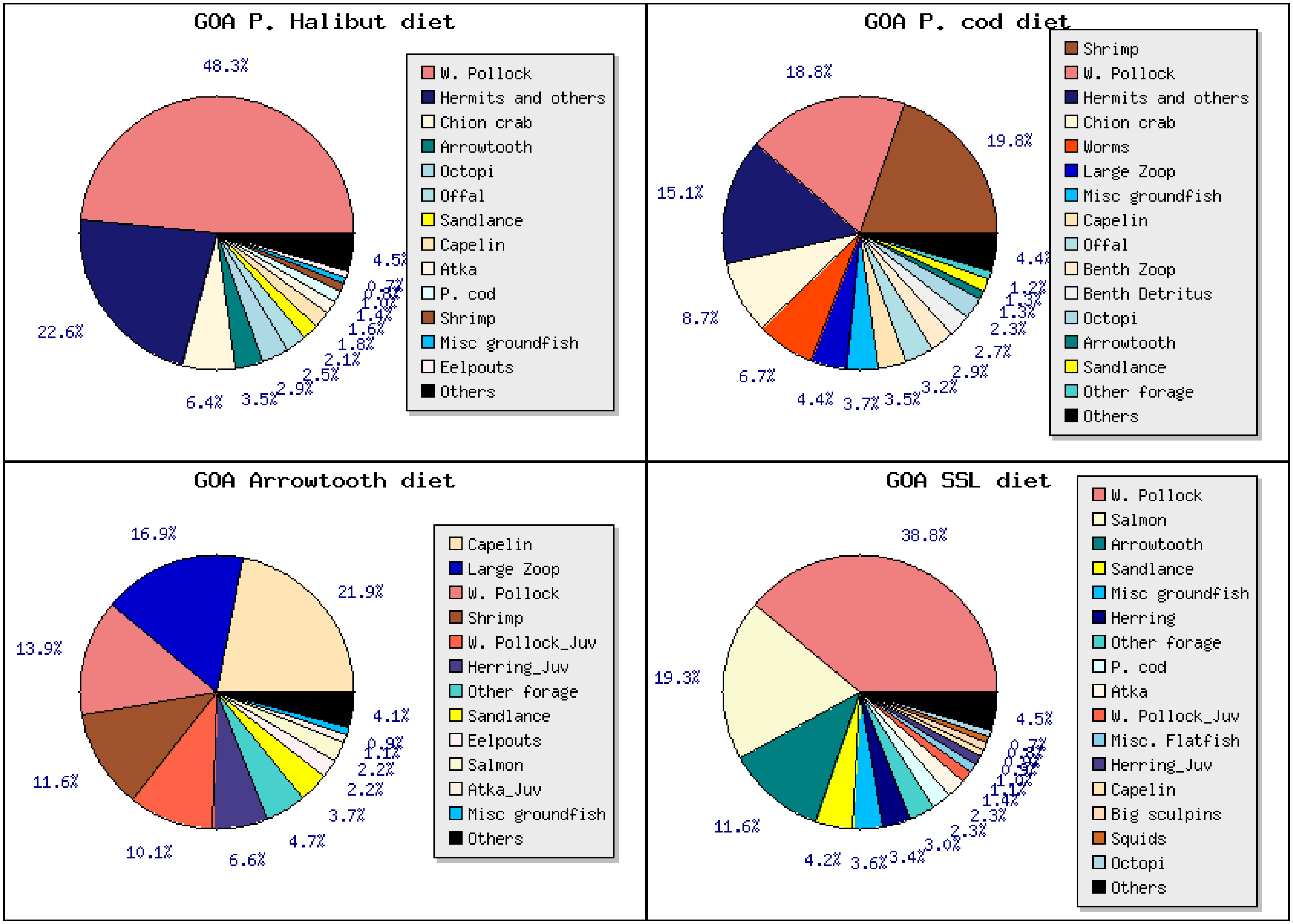


Figure 1.43. Diet diversity of major predators of pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

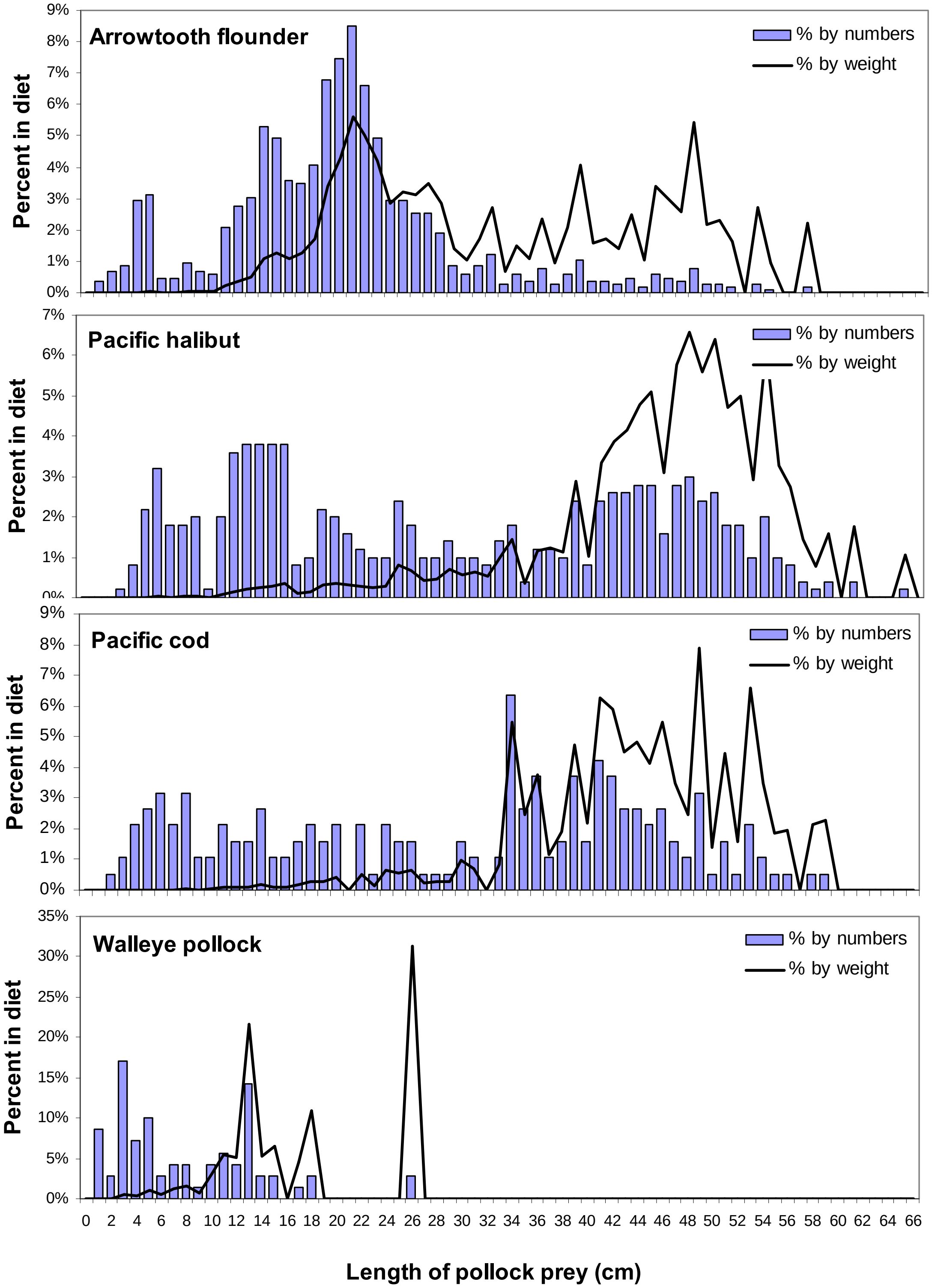
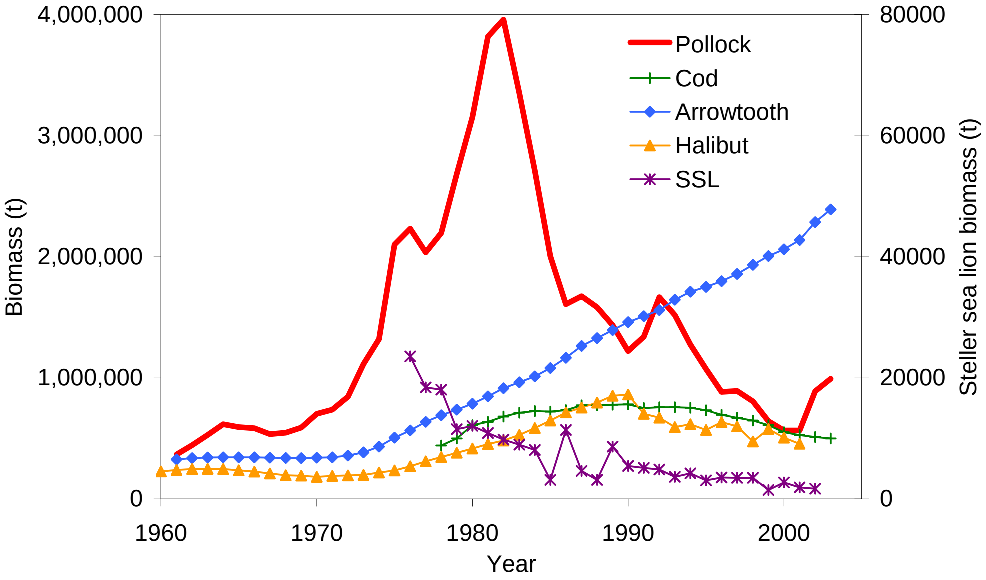


Figure 1.44**.** Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



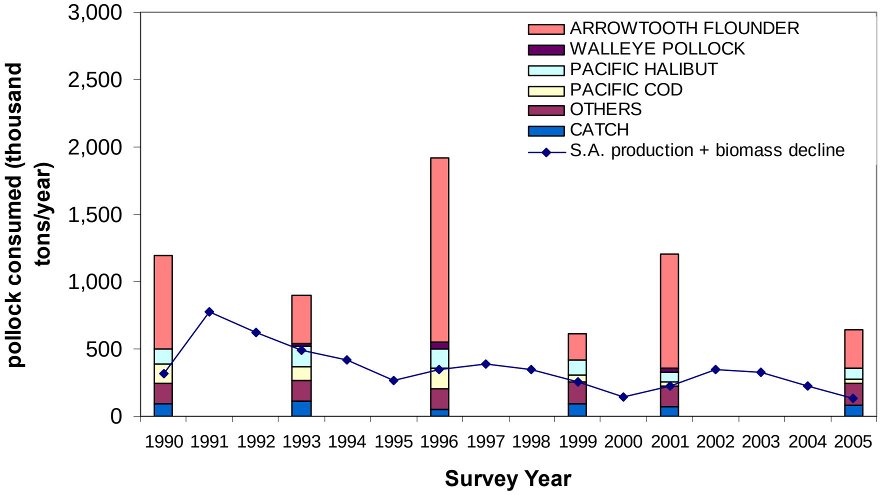


Figure 1.45. (Top) Historical trends in GOA pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock assessment data. (Bottom) Total catch and consumption of pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line). See text for calculation methods.

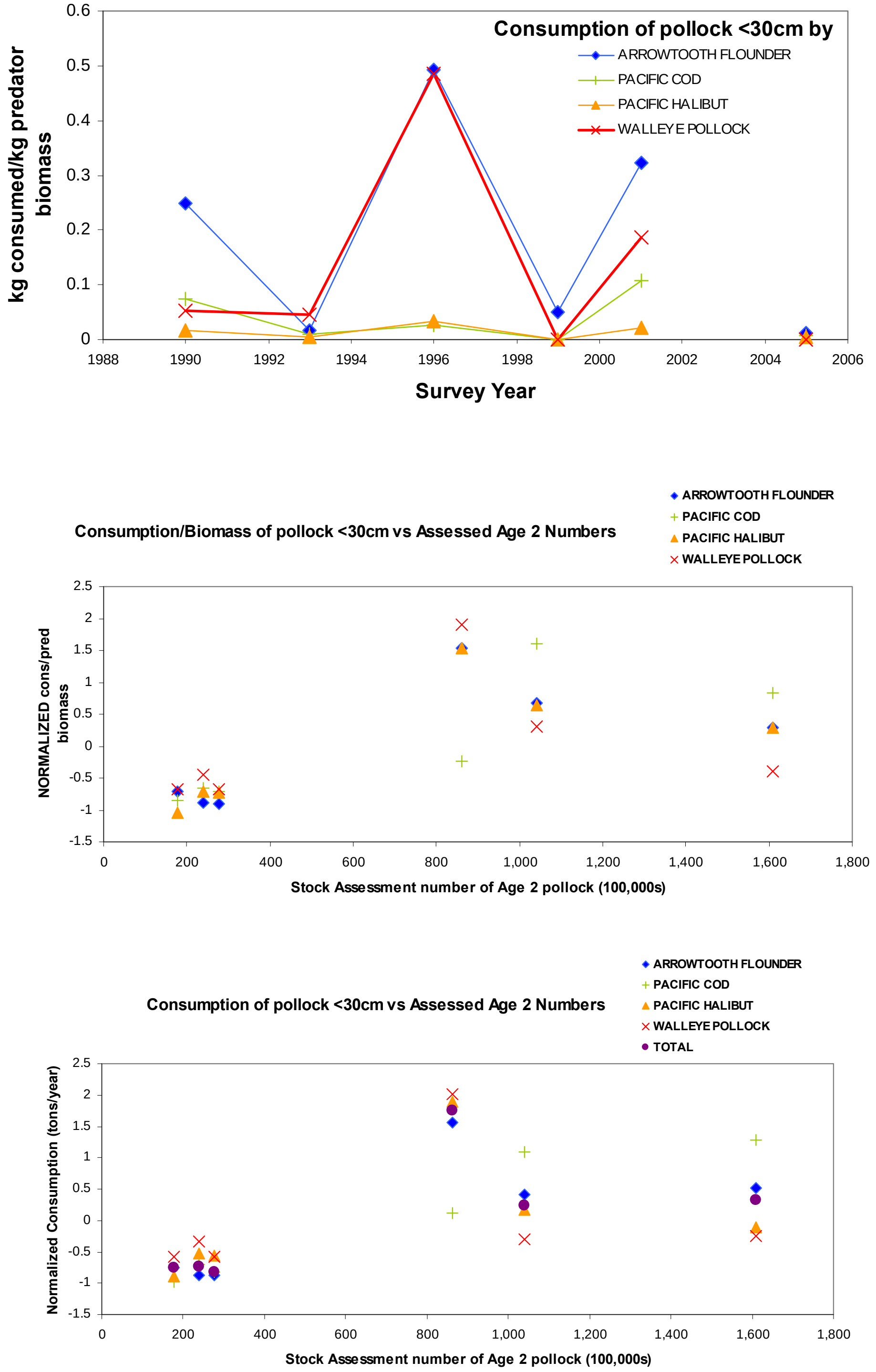


Figure 1.46. (Top) Consumption per unit predator survey biomass of GOA pollock <30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers.

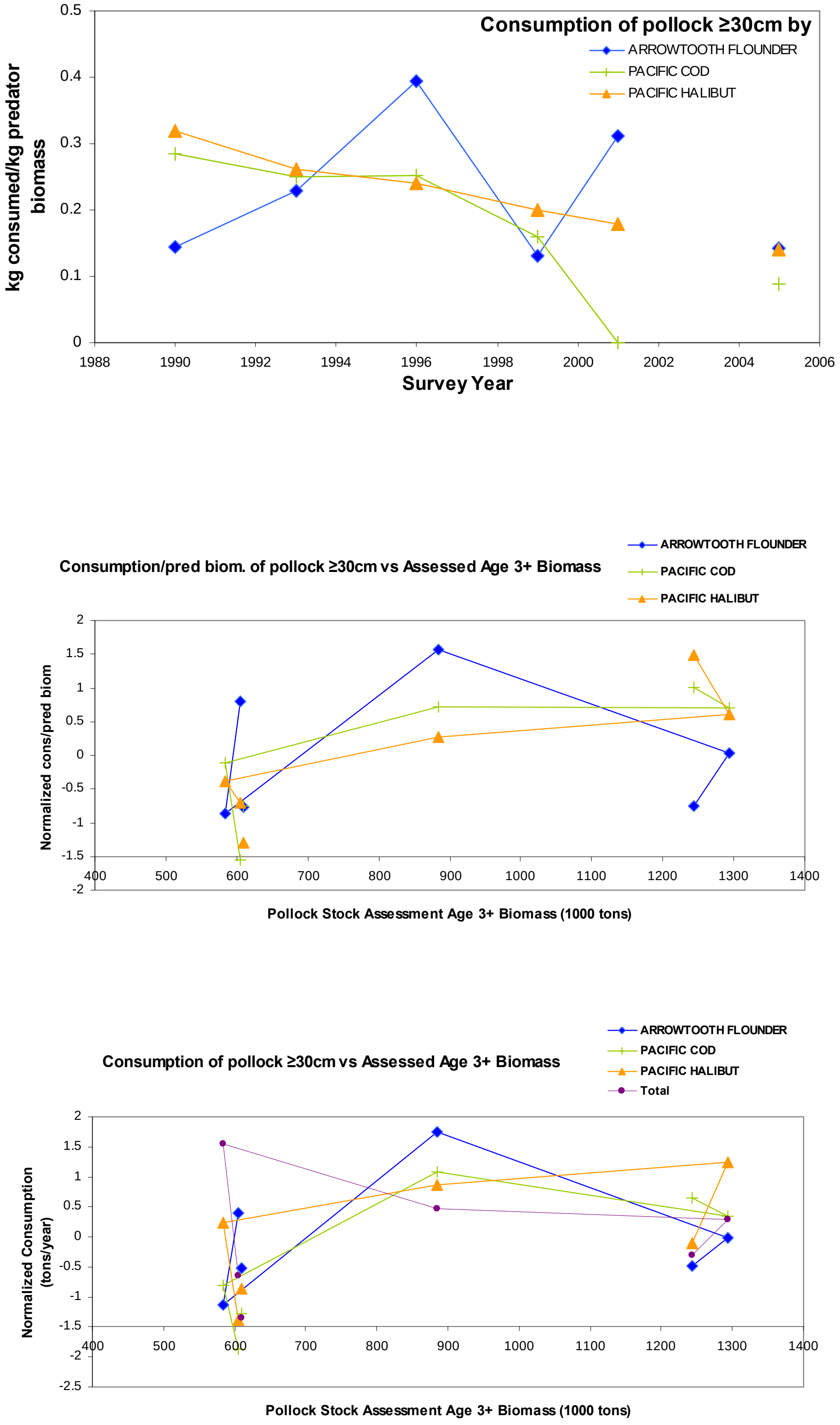


Figure 1.47. (Top) Consumption per unit predator survey biomass of GOA pollock ≥30cm fork length in diets, shown for each survey year. (Middle and bottom) Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass.

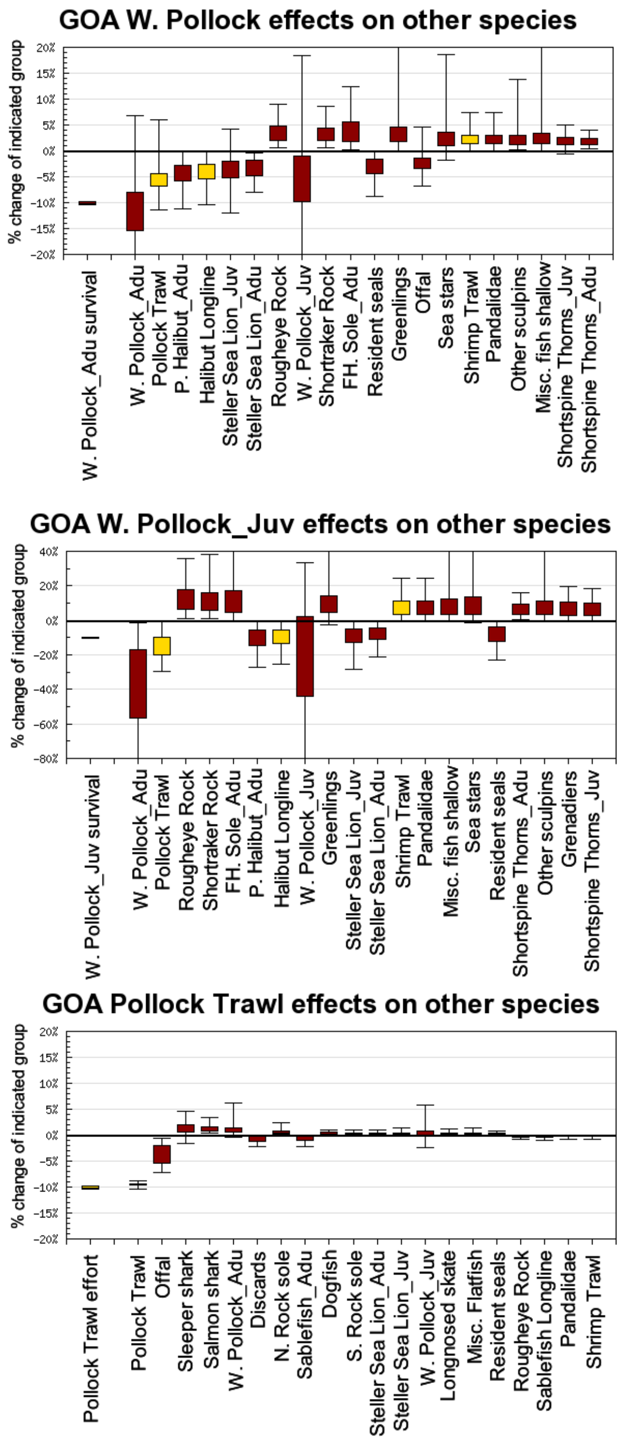
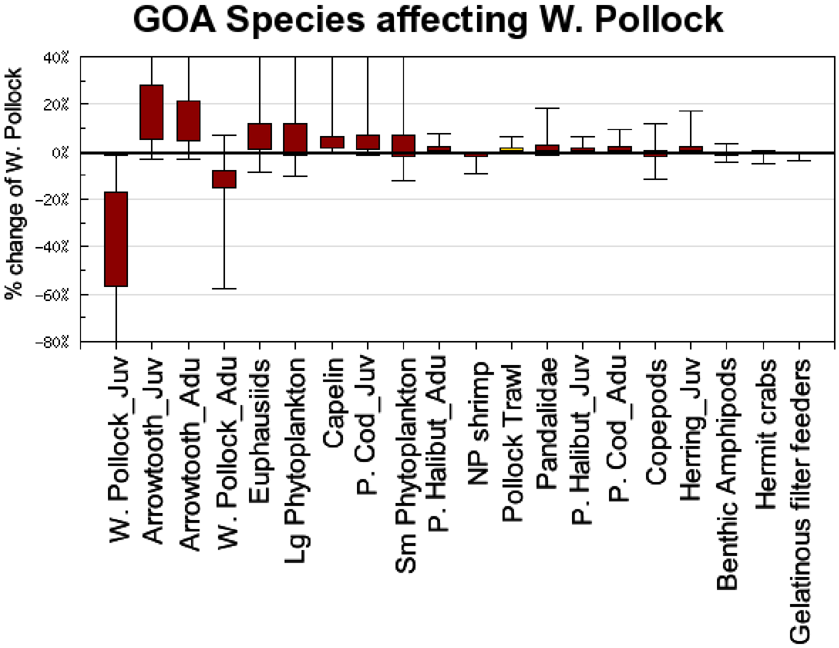


Figure 1.48. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top graph), reducing juvenile pollock survival by 10% (middle graph), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled species, while light bars indicate changes in fisheries catch (landings and 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.



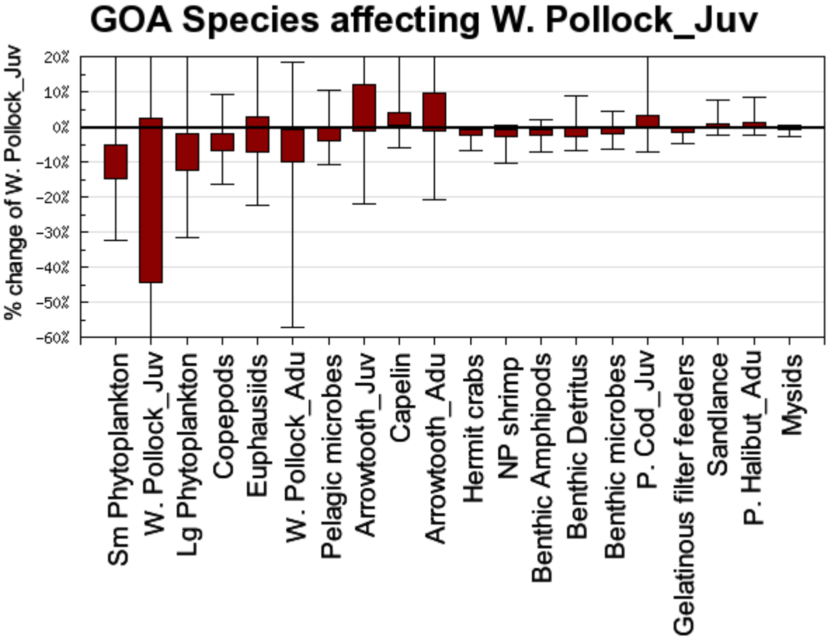


Figure 1.49. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

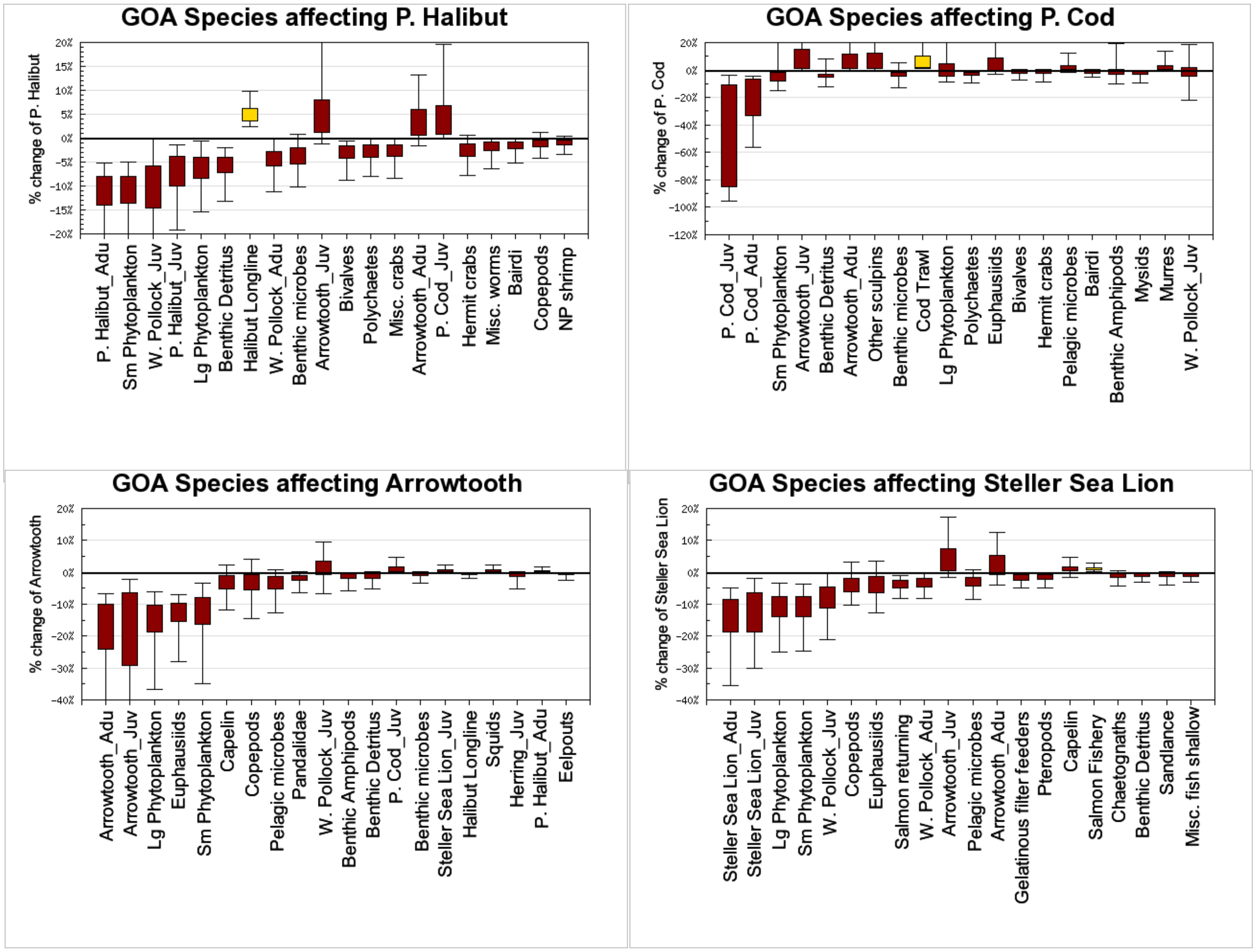


Figure 1.50. Ecosystem model output, shown as percent change at future equilibrium of four major predators on pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50% 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.

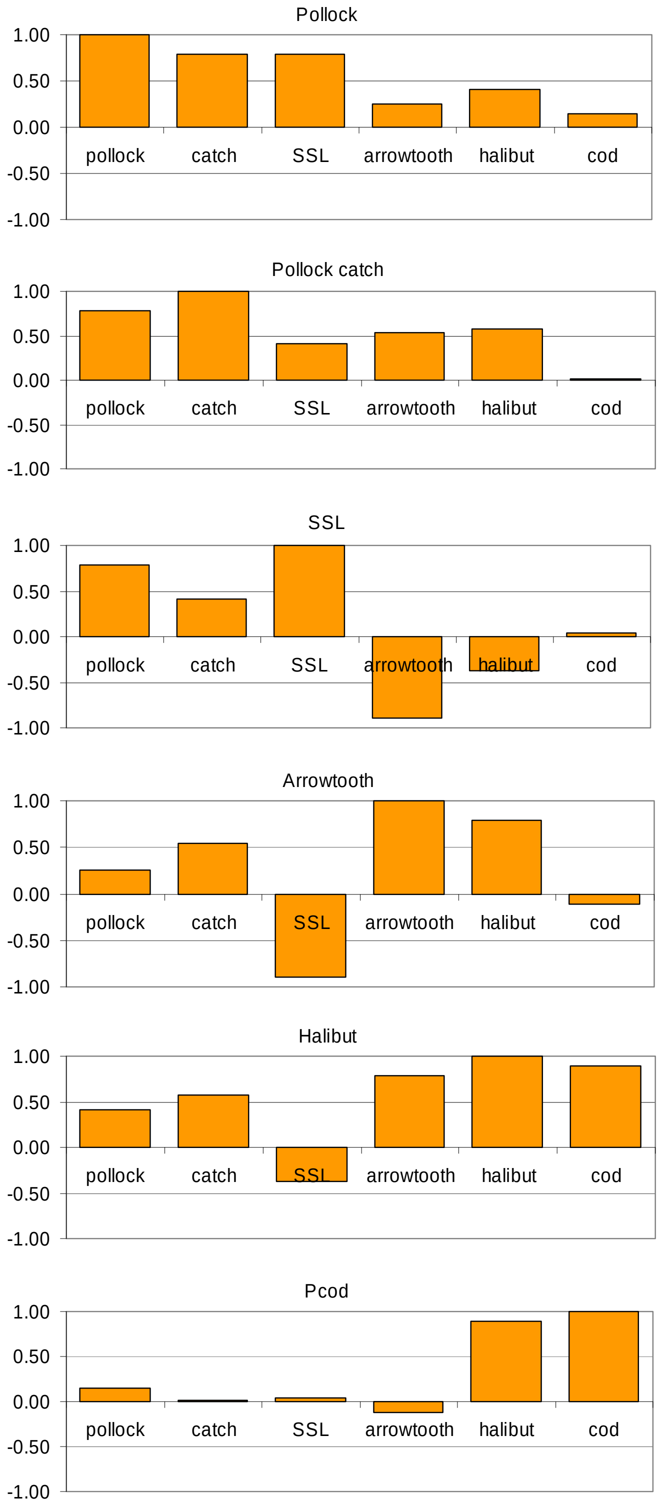


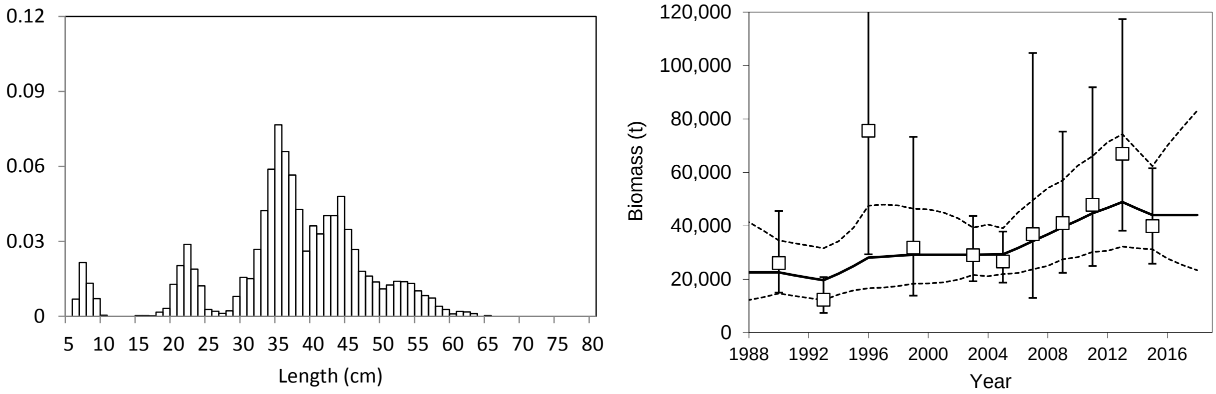
Figure 1.51. Pair-wise Spearman rank correlation between abundance trends of pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for each pair.

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 2015 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Baranof Island south to Dixon Entrance, where the shelf is broader. Pollock length composition in the 2015 bottom trawl survey showed a mode at 35 cm, most likely age-2 pollock, and secondary modes at 7 cm (age-0 pollock), 22 cm (age-1 pollock), and 44 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 2004 (Table 1.4). The ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska, though recently there has been increased interest in directed pollock fishing using other gear types such as purse seine.

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 1990-2015 bottom trawl survey biomass estimates in southeast Alaska. We recommend placing southeast Alaska pollock in Tier 5 of the NPFMC tier system, and basing the ABC and OFL on natural mortality (0.3) and the biomass estimate from the random effects model in 2015 (44,087 t). **This results in a 2016 ABC of 9,920 t (44,087 t * 0.75 M), and a 2016 OFL of 13,226 t (44,087 t * M). The same ABC and OFL is recommended for 2017.**



Appendix Figure A.1. Pollock size composition in 2015 (left) and biomass trend in southeast Alaska from a random effects model fit to NMFS bottom trawl surveys in 1990-2015 (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.

Appendix B: GOA 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 2015 (46 years). The Baranov (1918) catch equations are assumed, so that

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

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

$$Z_{i\,j} = \sum_k F_{i\,j} + M_j$$

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 $N_{i\,j}$ is the population abundance at the start of year *i* for age *j* fish, $F_{i\,j}$ = fishing mortality rate in year *i* for age *j* fish, and $c_{i\,j}$ = catch in year *i* for age *j* fish. The natural mortality rate, M_j, is age-specific, but does not vary by year (at least for now).

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, $p_{i\,j}$. Predicted values from the model are obtained from

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

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

where $w_{i\,j}$ 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 $\pi_{i\,j}$. Predicted values from the model are obtained from

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

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 GOA pollock, a subscript to index a particular survey has been suppressed in the above and subsequent equations in the interest of clarity. Survey selectivity was modeled using either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the *i*th year are given by

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

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

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

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 pollock among management areas in the Gulf of Alaska

Since 1992, the GOA pollock TAC has been apportioned between management areas based on the distribution of biomass in groundfish surveys. Both single species and ecosystem considerations provide 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 sub-stock units of pollock have not been identified in the Gulf of Alaska, managing the fishery so as to preserve the existing spatial structure would be a precautionary strategy. Protection of sub-stock units would be most important during spawning season, when they would be spatially distinct. The Steller sea lion protection measures implemented in 2001 require apportionment of pollock TAC based on the seasonal distribution of biomass.
Pollock in the GOA 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 and 2015 in the Kenai Bays, and in Prince William Sound in 2010 are likely important, the surveys need to be repeated to confirm stability of spawning in these areas before including them in the apportionment calculations. There are also several potentially difficult issues that would need to dealt with, for example, whether including biomass in the Kenai Bays 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 76.86%, which may reflect sampling variability, or interannual variation in spawning location, but also reflects the recent trend that the aggregate biomass of pollock surveyed acoustically in winter (at least in those areas that have been surveyed repeatedly) is lower than the assessment model estimates of abundance. After rescaling, the resulting average biomass distribution was 6.41%, 85.08%, and 8.52% in areas 610, 620, and 630 (Appendix Table C.1). In comparison to last year, the percentage in area 610 is 1.6 percentage points lower, 1.9 percentage points higher in area 620, and 0.3 percentage points lower in area 630.

A-season apportionment between areas 620 and 630

In the 2002 assessment, based on evaluation of fishing patterns which suggested that the migration to spawning areas was not complete by January 20, the Gulf of Alaska plan team recommended an alternative apportionment scheme for areas 620 and 630 based on the midpoint of the summer and winter distributions in area 630. This approach was not used for area 610 because fishing patterns during the A season suggested that most of the fish captured in area 610 would eventually spawn in area 610. The resulting A season apportionment is: 610, 6.41%; 620, 74.22%; 630, 19.38%.

Summer distribution

The NMFS bottom trawl, typically extending from mid-May to mid-August, was considered the most appropriate survey time series for apportioning the TAC during the C and D seasons. Previously apportionment of pollock TAC was based upon an unweighted average of four most recent NMFS summer surveys, however in 2014 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 2015 smoothed biomass estimates by area, which resulted in a biomass distribution of 50.00%, 17.52%, 29.27%, and 3.22% in areas 610, 620, 630, and 640 (Fig. C.2). In comparison to previous apportionment using a random effects model with survey data to 2013, the percent in area 610 increased by 23.9 percentage points, while 620 decreased by 13.9 percentage points, and 630 decreased by 10.7 percentage points. It is apparent that the random effects model leads to an estimated biomass distribution that is more strongly influenced by the most recent survey, unlike the 4-survey average that had been used previously.

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 using the random effects model. The percentage (3.22%) of the TAC in area 640 is subtracted from the TAC before allocating the remaining TAC by season and region.

Example calculation of 2016 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 0.0322 x Total TAC = 3,220 t

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

A season 0.25 x (Total TAC – 3,220) = 24,195 t
B season 0.25 x (Total TAC – 3,220) = 24,195 t
C season 0.25 x (Total TAC – 3,220) = 24,195 t
D season 0.25 x (Total TAC – 3,220) = 24,195 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 0.0641 x 24,195 t = 1,550 t
620 0.7422 x 24,195 t = 17,957 t
630 0.1938 x 24,195 t = 4,688 t

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

610 0.0641 x 24,195 t = 1,550 t
620 0.8508 x 24,195 t = 20,585 t
630 0.0852 x 24,195 t = 2,060 t

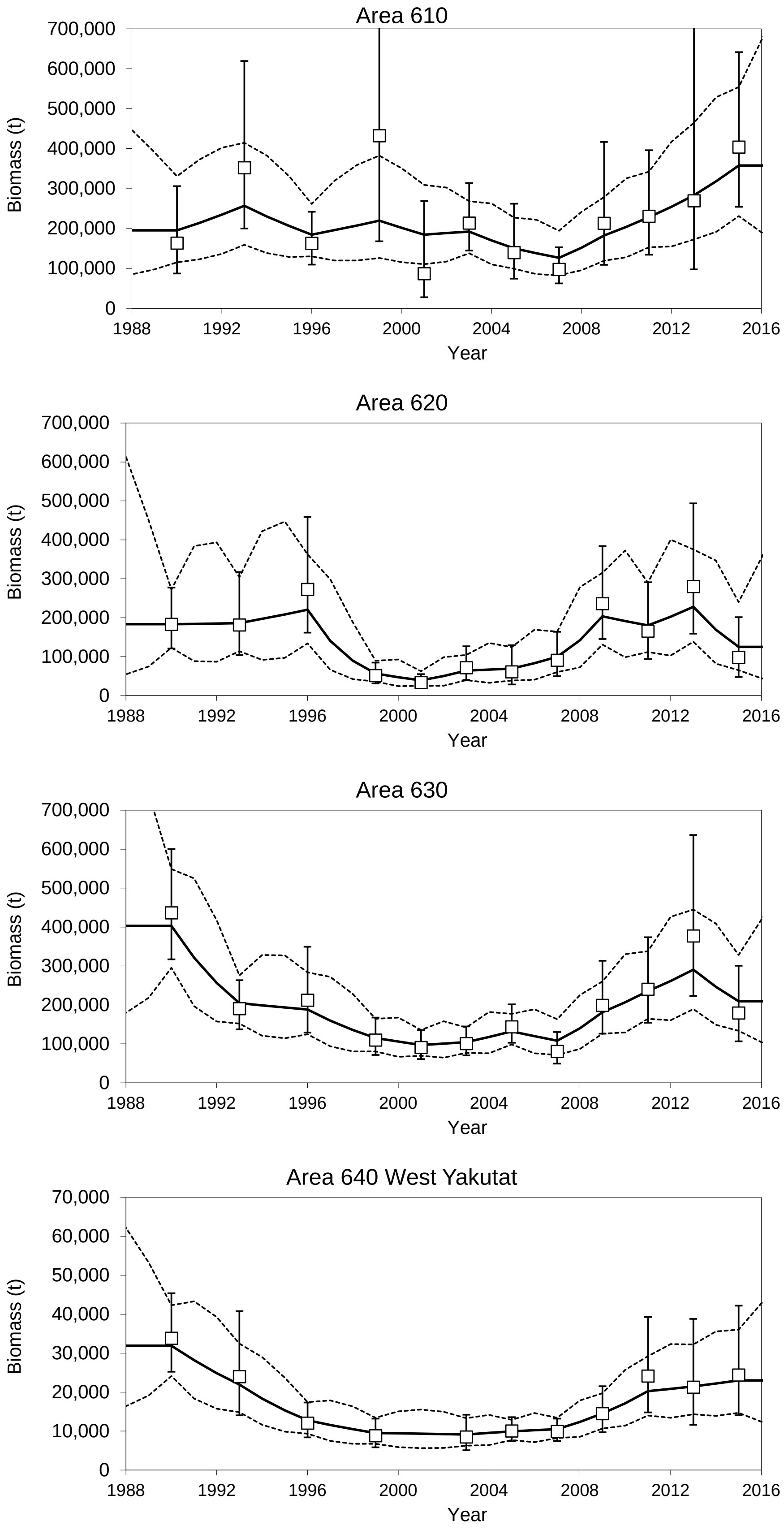
6) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based on the biomass distribution in areas 610, 620, 630, and 640 in 2015 based on the random effects model of 50.00%, 17.52%, 29.27%, and 3.22%.

610 0.5000 / (1 – 0.0322) x 24,195 = 12,500 t
620 0.1752 / (1 – 0.0322) x 24,195 = 4,379 t
630 0.2927 / (1 – 0.0322) x 24,195 = 7,316 t

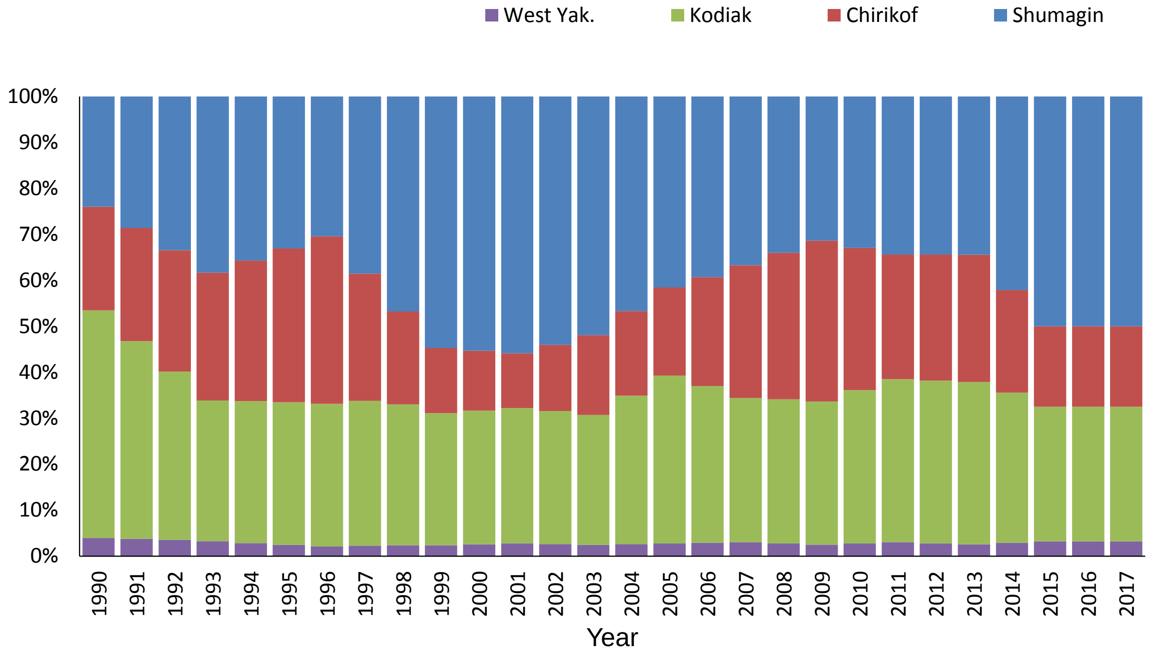
610 0.5000 / (1 – 0.0322) x 24,195 = 12,500 t
620 0.1752 / (1 – 0.0322) x 24,195 = 4,379 t
630 0.2927 / (1 – 0.0322) x 24,195 = 7,316 t

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.

						Percent by management area		
Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*	*Multiplier from vessel comparison (OD/MF)*	*Percent*	*Area 610*	*Area 620*	*Area 630*
Shelikof	2012	1,095,860	335,836	1.00	30.6%	0.0%	96.0%	4.0%
Shelikof	2013	1,154,450	831,486	1.00	72.0%	0.0%	95.0%	5.0%
Shelikof	2014	1,039,170	883,177	1.00	85.0%	0.0%	96.7%	3.3%
Shelikof	2015	1,057,370	845,210	1.00	79.9%	0.0%	91.9%	8.1%
Shelikof	Average				66.9%	0.0%	94.9%	5.1%
	Percent of total 2+ biomass					0.0%	63.5%	3.4%
Chirikof	2010	1,095,090	9,544	1.00	0.9%	0.0%	0.0%	100.0%
Chirikof	2012	1,095,860	21,181	1.00	1.9%	0.0%	13.0%	87.0%
Chirikof	2013	1,154,450	63,008	1.00	5.5%	0.0%	70.2%	29.8%
Chirikof	2015	1,039,170	12,685	1.00	1.2%	0.0%	26.3%	73.7%
Chirikof	Average				2.4%	0.0%	27.4%	72.6%
	Percent of total 2+ biomass					0.0%	0.6%	1.7%
Marmot	2010	1,095,090	5,585	1.00	0.5%	0.0%	0.0%	100.0%
Marmot	2013	1,154,450	19,899	1.00	1.7%	0.0%	0.0%	100.0%
Marmot	2014	1,039,170	13,403	1.00	1.3%	0.0%	0.0%	100.0%
Marmot	2015	1,057,370	22,470	1.00	2.1%	0.0%	0.0%	100.0%
Marmot	Average				1.4%	0.0%	0.0%	100.0%
	Percent of total 2+ biomass					0.0%	0.0%	1.4%
Shumagin	2012	1,095,860	15,501	1.00	1.9%	88.0%	12.0%	0.0%
Shumagin	2013	1,154,450	47,388	1.00	4.1%	55.2%	44.8%	0.0%
Shumagin	2014	1,039,170	36,160	1.00	3.5%	54.7%	45.3%	0.0%
Shumagin	2015	1,057,370	61,216	1.00	5.8%	71.0%	29.0%	0.0%
Shumagin	Average				3.8%	67.2%	32.8%	0.0%
	Percent of total 2+ biomass					2.6%	1.3%	0.0%
Sanak	2012	1,095,860	24,252	1.00	2.2%	100.0%	0.0%	0.0%
Sanak	2013	1,154,450	12,967	1.00	1.1%	100.0%	0.0%	0.0%
Sanak	2014	1,039,170	7,319	1.00	0.7%	100.0%	0.0%	0.0%
Sanak	2015	1,057,370	17,863	1.00	1.7%	100.0%	0.0%	0.0%
Sanak	Average				1.4%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					1.4%	0.0%	0.0%
Mozhovoi	2006	548,145	11,679	1.31	2.8%	100.0%	0.0%	0.0%
Mozhovoi	2007	558,297	2,540	1.31	0.6%	100.0%	0.0%	0.0%
Mozhovoi	2010	1,095,090	1,650	1.00	0.2%	100.0%	0.0%	0.0%
Mozhovoi	2013	1,154,450	1,520	1.00	0.1%	100.0%	0.0%	0.0%
Mozhovoi	Average				0.9%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					0.9%	0.0%	0.0%
Total					76.86%	4.92%	65.39%	6.54%
Rescaled total					100.00%	6.41%	85.08%	8.52%



Appendix Figure C.1. Random effects models fit to summer bottom trawl biomass estimates by management area for 1990-2015.



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

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