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: 2015 total catch and catch at age.

2. Shelikof Strait acoustic survey: 2016 biomass and age composition.

3. NMFS bottom trawl survey: 2015 age composition.

4. ADFG crab/groundfish trawl survey: 2016 biomass. A delta-GLM index is proposed for the base model.

5. Summer acoustic survey: 2015 age composition.

6. An economic performance report for GOA pollock has been added to the assessment.

Changes in assessment methodology

The age-structured assessment model is similar to the model used for the 2015 assessment and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library).

Summary of Results

The base model projection of female spawning biomass in 2017 is 363,800 t, which is 54.5% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (267,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3. The new survey data for 2016 included the Shelikof Strait acoustic survey, and the ADFG bottom trawl survey. The Shelikof Strait acoustic survey remains at high levels and is consistent with assessment model results. The large and unexplained decline in pollock biomass in the 2015 ADFG survey continued in 2016 with a further 56% percent decline, which is a concern, especially since this time series has been the most stable used in the assessment. Since these low observations are included in the model, the estimated ABCs and OFLs are lower as a result of this declining trend. Although the GOA pollock stock is currently estimated to be at relatively high abundance, it is apparent that we have entered into a period of increased uncertainty regarding future abundance trends. There has been a marked decline in pollock weight at age, a lack of recruitment to the stock for three years, and most of stock consists of a single very strong year class. In 2017, there will be full complement of assessment surveys in the Gulf of Alaska, so it is reasonable to expect that this uncertainty will be reduced when the results of these surveys are available.

The authors' 2017 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 203,769 t, which is a decrease of 20% from the 2016 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 2018, the ABC based an adjusted $F_{40\%}$ harvest rate is 157,496 t. The OFL in 2017 is 235,807 t, and the OFL in 2018 if the recommended ABC is taken in 2017 is 182,204 t. It should be noted that declines in ABC over the next few years should be expected, particularly if low recruitment continues. ABCs as low as 100,000 t may occur by 2019.

For pollock in southeast Alaska (Southeast Outside region), the ABC recommendation for both 2017 and 2018 is 9,920 t (see Appendix A) and the OFL recommendation for both 2017 and 2018 is 13,226 t. These recommendations are based on a Tier 5 assessment using the estimated biomass in 2017 and 2018 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	2016	2017	2017	2018
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	1,937,900	1,543,100	1,391,290	991,030
Female spawning biomass (t)	321,626	357,193	363,800	348,330
$B_{100\%}$	750,000	750,000	667,000	667,000
$B_{40\%}$	300,000	300,000	267,000	267,000
$B_{35\%}$	262,000	262,000	234,000	234,000
F_{OFL}	0.29	0.29	0.30	0.30
$maxF_{ABC}$	0.25	0.25	0.25	0.25
F_{ABC}	0.23	0.25	0.25	0.25
OFL (t)	322,858	289,937	235,807	182,204
maxABC (t)	278,385	250,544	203,769	157,496
ABC (t)	254,310	250,544	203,769	157,496
	As determined *last* year for		As determined *this* year for	
Status	2014	2015	2015	2016
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: 2016	2017	As estimated or *recommended this* year for: 2017	2018
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)				
Upper 95% confidence interval	70,015	76,781	76,781	83,089
Point estimate	44,087	44,087	44,087	44,087
Lower 95% confidence interval	27,761	25,315	25,315	23,393
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)	13,226	13,226	13,226	13,226
maxABC (t)	9,920	9,920	9,920	9,920
ABC (t)	9,920	9,920	9,920	9,920
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments in General

The SSC in its December 2015 minutes continued to recommend that a standard naming convention be used for different models presented in assessments.

In this assessment, we used the naming convention recommended by the SSC, and used option C in the SAFE guidelines for naming model runs. The base model in last year's assessment was designated model 15.1a. The recommended base model in this assessment is model 16.2.

Responses to SSC and Plan Team Comments Specific to this Assessment

The GOA plan team recommended in its November 2015 minutes further exploration, documentation and vetting of the net selectivity corrections for the Shelikof Strait acoustic survey.

In this assessment, we brought forward a model run with the net-selectivity correction applied retrospectively.

The GOA plan team recommended in its November 2015 minutes further exploration of hypotheses regarding temperature and fish distribution that may relate to the low abundance index in the ADFG trawl survey

We developed a delta GLM model for the ADFG survey, and included it in the base model. The abundance of pollock in the ADFG survey showed a further substantial decline in 2016.

The GOA plan team recommended in its November 2015 minutes a re-evaluation of the form of the selectivity curve used for the summer acoustic trawl survey in the next assessment.

We explored dome-shaped double logistic models for selectivity for the summer acoustic survey using the two years of age composition data available for this survey. While we were able to successfully estimate a domed-shape selectivity curve, one of the parameters would end always end up at a bound despite varying the estimation procedure. In addition, the catchability estimated for the survey considerably exceeded one (q= 1.8) when attempting to estimate the selectivity pattern, which was considered unlikely for an acoustic survey. We concluded that additional data were needed to reliably estimate selectivity for this survey.

The SSC its December 2015 minutes supported the November 2015 plan team recommendations but made no new stock-specific recommendations for GOA pollock.

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 2011 and 2015, 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, jellyfish, and grenadiers (Table 1.2). Bycatch estimates for prohibited species over the period 2011-2015 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.

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	1970-2015
Fishery	Age composition	1975-2015
Shelikof Strait acoustic survey	Biomass	1992-2016
Shelikof Strait acoustic survey	Age composition	1992-2016
Summer acoustic survey	Biomass	2013-2015
Summer acoustic survey	Age composition	2013,2015
NMFS bottom trawl survey	Area-swept biomass	1990-2015
NMFS bottom trawl survey	Age composition	1990-2015
ADFG trawl survey	Area-swept biomass	1989-2016
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 1991-2015 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.

Estimates of fishery age composition from 2000 onwards were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). The length composition and ageing data were obtained from the NORPAC database maintained at AFSC. 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. A background age-length key is used fill the gaps in age-length keys by sex and stratum. Sampling levels by stratum for 2000-2014 is documented in the assessments available online at http://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm.

Age and length samples from the 2015 fishery were stratified by half year and statistical area as follows:

Time strata		Shumagin-610	Chirikof-620	Kodiak, W. Yakutat and PWS-630, 640 and 640
1st half (A and B seasons)	Num. ages	168	406	399
	Num. lengths	1075	15564	3558
	Catch (t)	2,219	70,464	18,107
2nd half (C and D seasons)	Num. ages	435	347	415
	Num. lengths	8678	2287	13086
	Catch (t)	26,520	10,967	39,276

The catch-at-age in the first half of 2015 (A and B season) was a range of ages, with the age-3 fish (2012 year class) dominant in area 610, but age-5 fish dominant is areas 620 and 630 (Fig. 1.2). In the second half of 2015 (C and D seasons), there was a switch to younger fish, with very strong mode of age-3 fish in all areas. Fishery catch at age in 1975-2015 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 statistical 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-610, Chirikof-620, Kodiak-630 statistical areas, and the western portion of Yakutat-640 statistical area. Biomass estimates for the west Yakutat area 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 for use in the assessment model.

Surveys from 1990 onwards are used in the assessment due to uncertainties in standardizing the surveys in 1984 and 1987, when Japanese vessels with different gear were used.

Indices from a spatial GLMM (J. Thorson pers. comm. Oct 19, 2016) were evaluated as an alternative to the area-swept estimates for the bottom trawl survey (Fig. 1.4). Spatial GLMMs have been routinely used to analyze West Coast survey data for use in stock assessments, and the purpose here was simply to evaluate the feasibly of using them in the GOA pollock assessment.

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 statistical area (Shumagin-610, Chirikof-620, Kodiak-630, Yakutat-640 and Southeastern-650) using a global age-length key, and CPUE-weighted length frequency data by statistical area (Fig. 1.5). The combined Shumagin, Chirikof and Kodiak age composition is used in the assessment model. Ages are now available for the 2015 survey and are used in preference to length composition. In contrast to the 2013 survey, when age-1 pollock were abundant in all areas, age-1 pollock were only abundant in the Chirikof-620 area (Fig. 1.6). In the Central and Western portion of the Gulf of Alaska, age-3 pollock (2012 year class) were very abundant in the Shumagin-610 area, and declined in relative abundance in areas further east (Statistical areas 620 and 630).

Shelikof Strait Acoustic Survey

Winter acoustic surveys to assess the biomass of pre-spawning aggregations pollock in Shelikof Strait 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 are 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 2016 are presented in a NMFS processed report (McCarthy and Stienessen, in press). 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 2016 biomass estimate for Shelikof Strait is 665,059 t, which is a 21% percent decrease from the 2015 estimate. In addition to the Shelikof Strait survey, acoustic surveys in winter 2016 covered the Shumagin Islands, Sanak Gully, Pavlof Bay, Morzhovoi Bay, and Marmot Gully. A survey of the shelf break near Chirikof Island had been planned but was unable to be completed due to adverse weather and scheduling issues on *R/V Oscar Dyson*. The following table provides results from the 2016 winter acoustic surveys:

Area	Biomass ≥43 cm (t)	Percent	Total biomass (t)	Percent
Morzhovoi Bay	6,864	5.2%	11,414	1.5%
Pavlof Bay	900	0.7%	2,128	0.3%
Shumagin Islands	3,977	3.0%	20,706	2.8%
Sanak Gully	1,442	1.1%	3,556	0.5%
Shelikof Strait	100,037	75.7%	665,059	89.8%
Marmot Gully	18,908	14.3%	37,931	5.1%
Total	132,129		740,794	

The pollock biomass in 2016 for all surveys is 29% lower than the 2015 estimate, but the Kenai Bays were not surveyed in 2016, where 80,000 t of pollock were found in 2015. Biomass was lower in most surveyed areas in 2016 compared to 2015. Biomass estimates in Shumagin Islands and Sanak Gully were lower by 66% and 80% respectively (Fig. 1.7). In contrast, biomass in Marmot Bay increased by 69% from 2015 to 2016.

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 1994-2016 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 highly variable but 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 1993-2016 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. 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. Age composition in 2015 indicated that 80% of the biomass consisted of a very abundant 2012 year class (age-3 fish) (Fig. 1.9). 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 (Fig. 1.10). The average number of tows completed during the survey is 360. On average, 86% of these tows contain pollock. Details of the ADFG trawl gear and sampling procedures are in Spalinger (2012).

The 2016 biomass estimate for pollock for the ADFG crab/groundfish survey was 18,470 t, down by 56% from the 2015 biomass estimate, which was already a large decline from the previous year (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 remain relatively high.

Delta GLM indices
A simple delta GLM model was applied to the ADFG tow by tow data for 1988-2016 to obtain annual abundance indices. Data were filtered to exclude missing latitude and longitudes (1 tow) and missing depths (14 tows). Tows made in lower Shelikof Strait (between 154.7° W lon. and 156.7° W lon.) were excluded because these stations occupied irregularly. A delta GLM model fits a separate model to the presence-absence observations and to the positive observations. A fixed effects model was used with the year, geographic area, and depth as factors. Strata were defined according to ADFG district (Kodiak, Chignik, South Peninsula) and depth (<30 fm, 30-100 fm, >100 fm). Alternative depth strata were evaluated, and model results were found to be robust to different depth strata assumptions. The same model structure was used for both the presence-absence observations and the positive observations. The error assumption of presence-absence observations was assumed to be binomial, and, as usual, several alternative error assumptions were evaluated for the positive observations, including lognormal, gamma, and inverse Gaussian. The inverse Gaussian model did not converge, and AIC statistic strongly indicated the gamma distribution was more appropriate than the lognormal (ΔAIC= 602.7). A qqplot for the gamma model residuals was not ideal, but was considered marginally acceptable (Fig. 1.11). Comparison of delta-GLM indices the area-swept estimates indicated similar trends (Fig. 1.12). Variances were based on a bootstrap procedure, and CVs for the annual index ranged from 0.09 to 0.20. These values probably understate the uncertainty of the indices with respect to population trends, since the area covered by the survey is a relatively small percentage of the GOA shelf area.

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. 1.13). Ageing data for 2016 have been collected but are not yet available. 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. 1.14). 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 strong downward trend, while both the Shelikof Strait acoustic survey and the NMFS bottom trawl survey indicate that biomass has declined slightly in the last few years, but remains above the long term average.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.15). The percent of females in the catch shows some variability but no obvious trend, and is close to 50-50. The percent female was 52% in 2015. 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 had been decreasing since 2008 as the fishery began to catch greater numbers of young fish from year classes recruiting to the fishery, then increased in strongly in 2013 and 2014, but declined in 2015 as the strong 2012 year class began to recruit to the fishery. Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch is approximately 8%. 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 1975-2015 (Fig. 1.15).

Analytic Approach

Model Structure

An age-structured model covering the period from 1970 to 2016 (47 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. The following table lists the likelihood components used in fitting the model.

Likelihood component	*Statistical model for error*	*Variance assumption*
Fishery total catch (1970-2016)	Log-normal	CV = 0.05
Fishery age comp. (1975-2015)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2016)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2016)	Multinomial	Initial sample size = 60
Winter acoustic survey age-1 and age-2 indices (1994-2016)	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, 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. (1990-2015)	Multinomial	Initial sample size = 60
ADFG trawl survey biomass (1989-2016)	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 2015 and 2016 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. 1.16). 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, but was only used for the age-1 index in the models considered this year.

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).

Initial data weighting
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.

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. 1.17). 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 2016 from winter acoustic surveys were above the long term mean for all ages (Fig. 1.18). 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 1983-2016 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 1.19). 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.

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 1.18, 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. 1.20). For pollock greater than age 6, weight-at-age has nearly doubled since 1983-1990. However, weight at age in the last five years, 2012-2016, has been stable to decreasing, with a strong decline in the last two years. 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.

A random effects model for weight at age (Ianelli et al. 2016) was used to improve estimates of fishery weight at age, and to propagate the uncertainty of weight at age when doing catch projections. The structural part of the model is an underlying von Bertalanffy growth curve. Year and cohort effects are estimated as random effects using the ADMB RE module. Further details are provided in Ianelli et al. (2016). Input data included fishery weight age for 1975-2015. The model also incorporates survey data by modeling an offset between fishery and survey weight at age. Weight at age for the Shelikof Strait acoustic survey (1981-2016) and the NMFS bottom trawl survey (1984-2015) were used. This is an important feature of the model since it allows more recent survey data, for example, the Shelikof Strait acoustic survey data in 2016, to inform fishery weight at age in a year when the actual fishery data are not available. The model also requires input standard deviations for the weight at age data. Since these are not available for GOA pollock, a generalized variance function was developed using a quadratic curve to match the mean standard deviations at ages 3-10 for the EBS data (Fig 1.21). The standard deviation at age one was assumed to be equal to the standard deviation at age 10. Survey weights at age were assumed to have standard deviations that were 1.5 times the fishery weights at age. These “best guess” estimates of uncertainty were contrasted with the assumption of constant standard deviations to evaluate sensitivity (Fig 1.21). Since results were not strongly dependent on the different variance assumptions, we concluded that it was appropriate to use “best guess” variance assumptions.

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 1×10^{-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 1970-2016 = 47	Estimated as log deviances from the log mean; recruitment in 1970-77, and 2015 and 2016 constrained by random deviation process error.
Natural mortality	Age-specific= 10	Not estimated in the model
Fishing mortality	Years 1970-2016 = 47	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) = 92	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	111 estimated parameters + 92 process error parameters + 10 fixed parameters = 213	

Results

Model selection and evaluation

Model Selection

Several model configurations were evaluated that focused on the weight at age used for yield projections, and the development of abundance indices from survey data. To a large 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, though we did not use changes in spawning biomass as criteria for distinguishing between major and minor model changes. Alternative models that were evaluated are listed below.

Model 15.1a—last year's base model with new data.
Model 16.1—use random effects model for fishery weight at age in 2016 and 2017.
Model 16.2—model 16.1 plus new indices for the ADFG survey from a delta-GLM model instead of area-swept estimates.
Model 16.3— model 16.2 plus revised Shelikof Strait acoustic survey estimates for net selectivity.
Model 16.4—model 16.2 plus a spatial GLMM index for the NMFS bottom trawl survey instead of area-swept estimates.

Models were compared by examining model fits (Table 1.19) and plotting the estimated spawning biomass (Fig. 1.22). Last year's base model, Model 15.1a, used iterative re-weighting for composition data based on the harmonic mean of effective sample size. These weights were maintained for all of the model alternatives. Once a base model was identified, the model was re-tuned, though in most cases the change in weight was small and did not affect results. All models also showed similar patterns of spawning biomass, especially prior to 2008.

Model 16.1 used estimated fishery weight at age from the random effects model for 2016, the last assessment year, and in 2017, for OFL and ABC calculations. As expected, this had very effect on model fits or estimated biomass trends. For model 15.1a, we used an ad hoc but consistently applied procedure that has performed reasonably well in the past. Weight at age in the final year was assumed equal to the previous year, and weight at age for stock projections was assumed to be equal to the average of most recent five years of estimates. Due to recent and relatively rapid changes in environmental conditions affecting growth, it is apparent that using a running average is not the best approach. The weight at age estimates from the random effects model appeared to better track recent patterns, and therefore model 16.1 was regarded as an improvement over last year's base model. The change from model 16.1 has relatively strong influence on the 2017 ABC, producing a 32% reduction in the ABC.

Model 16.2 replaced the area-swept biomass estimates for the ADFG trawl survey with delta-GLM indices. We used the bootstrap estimates of the CV from the delta GLM model, but rescaled them so that the average was equal to 0.25, which has been the assumed CV for the ADFG survey. An advantage of this approach is that the model does not need to work as hard to fit the 2015 and 2016 survey estimates, which were very low, but also had higher CVs. The fits to model 16.2 were nearly the same as the fit to model 16.1 even though model 16.2 added an additional three years to the ADFG survey time series. Model 16.2 resulted in higher spawning biomass in recent years (about 11% higher over the last five years of the assessment model). We consider 16.2 to be an improvement over model 16.1 because the delta-GLM model is a more robust way to analyze the ADFG survey data, and because the uncertainty estimates from the delta-GLM model allow the annual surveys to be weighted according to their uncertainty.

Model 16.3 uses net-selectivity corrected acoustic biomass and age composition estimates for the Shelikof Strait survey. This approach was also evaluated last year, but a decision was made not to use the revised estimates pending further review and investigation. The model estimates that 44% of the adult biomass spawns in Shelikof Strait (i.e., catchability=0.44), which is difficult to reconcile with information from acoustic surveys conducted elsewhere in the Gulf of Alaska. Results for model 16.3 indicates that biomass trends are not strongly affected by the net selectivity correction, but spawning biomass about 7% higher since 2010 compared to model 16.2. Use of the net-selectivity correction results in a poorer model fit to acoustic biomass estimates, and results in a less plausible selectivity pattern (full selectivity to age 9 followed by a steep decline in selectivity at the age 10 plus group). We are still reluctant to make the change to model 16.3, and in particular do not think it is a good idea to revise an entire time series on the basis of experiments only conducted relatively recently. One possibility for moving forward is to correct for net selectivity only for surveys conducted on the Dyson, and to collect addition information on net selectivity to better understand interannual variability.

Model 16.4 uses indices developed from a spatial GLMM model for the NMFS bottom trawl survey. Overall biomass trends were similar, but spawning biomass was slightly higher (about 4% on average) compared to model 16.2. Since the CVs from spatial GLMM model are smaller and more uniform, there was increased weight on fitting the indices, which resulted in an improved fit (lower RMSE). These results suggest that it would be feasible to use the spatial GLMM indices in the assessment, nevertheless we would prefer to investigate the method further before including it in the assessment model

We also tested models where selectivity was estimated for the summer acoustic survey, though we do not report results for these runs. We explored dome-shaped double logistic models for selectivity using the two years of age composition data available for this survey. The current assumption is for full selectivity at all ages. While we were able to successfully estimate a domed-shape selectivity curve, one of the parameters would end always end up at a bound despite varying the estimation procedure. In addition, the catchability estimated for the survey considerably exceeded one when selectivity was estimated (q= 1.8), which was considered unlikely. We concluded that additional data were needed to reliably estimate selectivity for this survey.

Model 16.2 was selected as the base model, and a final turning step was done. The age-1 and the age-2 Shelikof acoustic indices were also iteratively reweighted using RMSE as a tuning variable. All composition data components were reweighted slightly. The age-2 acoustic index was down weighted substantially (from a CV of 0.8 to a CV of 1.33), because the 2016 observed and predicted values of the age-2 index were not consistent with the relationship established with previous values.

Model Evaluation

The fit of model 16.2 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. 1.22, Fig. 1.24), Shelikof Strait acoustic survey age composition (Fig. 1.25, Fig. 1.26), NMFS trawl survey age composition (Fig. 1.27, Fig. 1.28), and ADFG trawl survey age composition (Fig. 1.28, Fig. 1.29). 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. 1.30 and1.31). 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 extremely low values for the ADFG survey in 2015 and 2016, though otherwise the fit to this survey is quite good. The fit to the age-1 and age-2 acoustic indices appeared adequate though variable (Fig. 1.32). The addition of the 2016 data point to the age-2 acoustic indices resulted in a large outlier that degraded the fit to the entire time series.

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 1.33). Table 1.21 gives the estimated population numbers at age for the years 1970-2016. Table 1.22 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2016 (see also Fig. 1.34). 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 70% of the proxy for unfished stock size ($B_{100\%}$ = mean 1979-2015 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 25% of unfished stock size. Over the years 2009-2013 stock size has shown a strong upward trend from 32% to 60% of unfished stock size, but declined to 33% of unfished stock size in 2016. The spawning stock is projected to increase again in 2017 as the strong 2012 year class starts maturing.

Figure 1.35 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 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 1993-2016 indicates the current estimated trend in spawning biomass for 1990-2016 is consistent with previous estimates (Fig. 1.36, 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. A moderate retrospective pattern is evident for recent assessments, where the spawning biomass was revised upwards with each assessment. The estimated 2016 age composition from the current assessment is reasonably consistent with the projected 2016 age composition from the 2015 assessment (Fig. 1.36, bottom panel). The largest change is the estimate of the age-1 fish (2015 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 1.37 shows a retrospective plot with data sequentially removed back to 2006. 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 -0.019, which would be considered a very low value.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 0.93) 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. 1.34). 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. 1.38). 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. In the last couple of year spawner productivity has dropped very steeply, and age-1 recruitment in 2016 is estimated to be the lowest in the time series, though there estimates are very uncertain.

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 1978-2015 age-1 recruitment (5.779 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 long-term increase in pollock weight-at-age has been observed, though recently weight-at-age has declined sharply (Fig. 1.20), which may be a density-dependent response to low abundance or due to environmental forcing. The SPR at F=0 was estimated as 0.115 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 2011-2015 to reflect current selectivity patterns.

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

		Equilibrium under average 1978-2015 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	5779	2276	667	0	0.0%
40.0%	0.251	5779	1311	267	170	13.0%
35.0%	0.296	5779	1225	234	184	15.0%

The $B_{40\%}$ estimate of 267,000 t represents an 11% decrease from the $B_{40\%}$ estimate of 300,000 t in the 2015 assessment, which is due to the continuing decline in spawning weight at age and mean recruitment. The base model projection of female spawning biomass in 2017 is 363,800 t, which is 54.5% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (267,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3.

2017 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* $F = F_{40\%}\, x\, (B/ B^{*} - 0.05) / (1 - 0.05)$

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. 1.35).

Projections for 2017 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. Because the stock is above the inflection point in the harvest control rule, this alternative gives the same ABC as the maximum permissible F_{ABC}. The author's recommended 2017 ABC is therefore 203,769 t, which is a decrease of 20% from the 2016 ABC. The recommended 2017 ABC is lower than the projected 2017 ABC in the 2015 assessment (19% lower). The primary difference is the projected lower fishery weights at age. In 2018, the ABC based an adjusted $F_{40\%}$ harvest rate is 157,496 t. The OFL in 2017 is 235,807 t, and the OFL in 2018 if the recommended ABC is taken in 2017 is 182,204 t. It should be noted that declines in ABC over the next few years should be expected, particularly if low recruitment continues. ABCs as low as 100,000 t may occur by 2019.

The new survey data for 2016 included the Shelikof Strait acoustic survey, and the ADFG bottom trawl survey. The Shelikof Strait acoustic survey remains at high levels and is consistent with assessment model results. The large and unexplained decline in pollock biomass in the 2015 ADFG survey continued in 2016 with a further 56% percent decline, which is a concern, especially since this time series has been the most stable used in the assessment. Since these low observations are included in the model, the estimated ABCs and OFLs are lower as a result of this declining trend. Although the GOA pollock stock is currently estimated to be at relatively high abundance, it is apparent that we have entered into a period of increased uncertainty regarding future abundance trends. There has been a marked decline in pollock weight at age, a lack of recruitment to the stock for three years, and most of stock consists of a single very strong year class. In 2017 there will be full complement of assessment surveys in the Gulf of Alaska, so it is reasonable to expect that this uncertainty will be reduced to a considerable extent.

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 close to zero until 2021, when the probability is estimated to be 0.0014 (Fig. 1.39).

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 2016 numbers at age at the start of the year as estimated by the assessment model, and assume the 2016 catch will be equal to 178,938 t (70.3% of the ABC, the estimated catch as of Oct 1, plus all of the D season quota). 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 1978-2015 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 2017, 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 (2012-2016). (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 2016 or 2) above 1/2 of its MSY level in 2016 and above its MSY level in 2026 under this scenario, then the stock is not overfished)
>
> *Scenario 7*: In 2017 and 2018, 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 2018, or 2) above 1/2 of its MSY level in 2018 and above its MSY level in 2028 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

2018, and begin declining under full exploitation scenarios, but will remain high under the F=0 and other low exploitation scenarios (Fig. 1.40). 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. 1.41), 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 (2015) is 167,553 t, which is less than the 2015 OFL of 256,545 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 320,094 t in 2016, which is above $B_{35\%}$ (234,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2018 is 348,330 t, which is above $B_{35\%}$ (234,000 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.

Economic Performance Report

Pollock is important component of the catch portfolio in the Gulf of Alaska (GOA). In the decade before 2012 catch typically ranged between 50-80 thousand t (EPR Table 1). Recent increases in the total allowable catch have resulted in a doubling of the total catch from 2011 to 2015. Retained catch of pollock increased 16% in 2015 to 163 thousand t. GOA pollock first-wholesale value was $99 million 2015 (EPR Table 2).

EPR Table 1. Pollock in the Gulf of Alaska first-wholesale market data. Total catch and federal fisheries catch and retained catch (1000 t), ex-vessel value (million US$), price (US$ per pound), and number of trawl vessels; 2005-2007 average, 2008-2010 average and 2011-2015.

	Avg 05-07	Avg 08-10	2011	2012	2013	2014	2015
Total Catch K mt	68.6	57.8	81.4	104	96.4	142.6	167.6
Federal Catch K mt	67.0	56.7	80	101	93	140	163
Retained Catch K mt	65.47	54.20	78	99	90.6	138.5	161.7
Ex-vessel Value M $	$ 19.7	$ 21.4	$ 28.1	$ 38.5	$ 36.4	$ 38.2	$ 43.8
Ex-vessel Price/lb $	$ 0.136	$ 0.179	$ 0.161	$ 0.171	$ 0.176	$ 0.123	$ 0.120
Trawl Vessels #	65.3	62.3	65	68	67	70	63

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN.

EPR Table 2. Pollock in the Gulf of Alaska first-wholesale market data. First-wholesale production (1000 t), value (million US$), price (US$ per pound), and head and gut, fillet, surimi, and roe production volume (1000 t) value share and price (US$ per pound); 2005-2007 average, 2008-2010 average, and 2011-2015.

		Avg 05-07	Avg 08-10	2011	2012	2013	2014	2015
All Products	**Volume K mt**	23.7	18.0	30.7	38.5	40.1	55.0	60.3
All Products	**Value M $**	$ 53.7	$ 49.7	$ 73.0	$ 88.0	$ 94.2	$ 106.4	$ 98.6
All Products	**Price lb $**	$ 1.03	$ 1.25	$ 1.08	$ 1.04	$ 1.07	$ 0.88	$ 0.74
Head & Gut	**Volume K mt**	6.9	7.7	14.8	19.0	21.3	29.7	30.3
Head & Gut	**Price lb $**	$ 0.63	$ 0.75	$ 0.66	$ 0.60	$ 0.78	$ 0.62	$ 0.49
Head & Gut	**Value share**	18.02%	25.77%	29.55%	28.40%	38.73%	38.24%	33.56%
Fillets	**Volume K mt**	4.6	3.2	5.7	6.0	5.8	8.2	9.1
Fillets	**Price lb $**	$ 1.30	$ 1.82	$ 1.62	$ 1.56	$ 1.61	$ 1.35	$ 1.28
Fillets	**Value share**	24.69%	26.21%	27.96%	23.43%	21.98%	22.95%	26.02%
Surimi	**Volume K mt**	7.1	4.5	7.1	9.9	8.6	12.3	14.6
Surimi	**Price lb $**	$ 0.91	$ 1.62	$ 1.25	$ 1.26	$ 1.07	$ 0.89	$ 0.87
Surimi	**Value share**	26.63%	32.13%	26.81%	31.12%	21.55%	22.61%	28.47%
Roe	**Volume K mt**	1.8	0.9	1.3	1.7	2.2	3.5	3.1
Roe	**Price lb $**	$ 3.37	$ 2.91	$ 3.12	$ 3.31	$ 2.80	$ 2.03	$ 1.24
Roe	**Value share**	25.24%	12.20%	11.91%	13.91%	14.48%	14.81%	8.65%

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

In contrast to the BSAI pollock fisheries, the GOA pollock fishery is not managed using catch shares and currently is a limited entry open access fishery. Total allowable catch is allocated spatially based on biomass to the inshore fleet of catcher vessels using trawl gear that deliver to inshore processors in the Central and Western Gulf of Alaska. The ports at Kodiak accounts for about 80% of the GOA delivered volume and Sand Point about 12%. Almost all of the pollock delivered to Kodiak was caught in the GOA and approximately 90% of Sand Point's pollock delivered volume is from GOA caught pollock. A comparatively smaller share of GOA caught pollock is also delivered to King Cove. The GOA pollock fishery is subject to prohibited species catch (PSC) restrictions, in particular of Chinook salmon. As of fall 2016 the NPFMC continues deliberating over how best to manage bycatch in the groundfish trawl fisheries in the GOA which may include a catch share management option. GOA pollock fisheries became certified by the Marine Stewardship Council (MSC) in 2005, a NGO based third-party sustainability certification, which some buyers seek. In 2015 the official U.S. market name changed from “Alaska pollock” to “pollock” enabling U.S. retailers to differentiate between pollock caught in Alaska and Russia.

The value of pollock deliveries by vessels to inshore processors (shoreside ex-vessel value) increased 15% to $48.3 million in 2015 (EPR Table 2). The significant in increase in catch was partly offset by 2% decrease in the ex-vessel price to $0.120 per pound. The change in price coincides in direction of change with the larger 16% decrease in the average first-wholesale price of pollock products. The increase in catch resulted in a 10% increase in production of pollock products in 2015 to 60 thousand t. First-wholesale value was $99 million 2015, which was down from $108 million in 2014 but above the 2005-2007 average of $54 million ($62 million in 2015 dollars) (EPR Table 2). The higher revenue in recent years is largely the result of increased catch and production levels as the average first-wholesale price of pollock products have declined to $0.74 per pound since peaking in 2008-2010 at $1.25 per pound ($1.38 per pound in 2015 dollars) and since 2013 have been below the 2005-2007 average of $1.03 ($1.19 per pound in 2015 dollars), though this varies across products types. The wholesale prices of products and the consequent revenue from production must be viewed from within the context of the broader market for pollock which is largely driven by activity in the BSAI and globally.

Since 2005 the volume of catch in the GOA has been roughly 5%-10% the size of the catch volume in the BSAI and approximately 3% of the global pollock catch. Fluctuations in GOA catch and production volumes have at most only a marginal impact on global pollock markets. Furthermore, one of the main product produced for GOA pollock is head-and-gut (H&G), a low price product type which is produced in high quantities by Russia. While the GOA pollock fishery experienced low catch years in 2007-2009, that approximately coincided with the lows in the BSAI from 2008-2010, it was the low catch volumes in the BSAI and other global market events which ultimately drove price changes and will be explored in more detail below.

EPR Tables 1-3 display three distinguishable periods in pollock markets. From 2001-2008 pollock catches in Alaska were high at approximately 1.5 million t. The U.S. (Alaska) accounted for over 50% of the global pollock catch (EPR Table 3). Between 2008-2010 conservation reductions in the pollock total allowable catch (TAC) trimmed catches in Alaska to an average 930 thousand t. The supply reduction resulted in price increases for most pollock products, which mitigated the short-term revenue loss (EPR Table 2). Over this same period, the pollock catch in Russia increased from an average of 1 million t in 2005-2007 to 1.4 million t in 2008-2010 and Russia's share of global catch increased to over 50% and the U.S. share decreased to 35%. Russia lacks the primary processing capacity of the U.S. and much of their catch is exported to China and is re-processed as twice-frozen fillets. Around the mid- to late-2000s, buyers in Europe, an important segment of the fillet market, started to source fish products with the MSC sustainability certification, and some major retailers in the U.S. later began to follow suit. Asian markets, an important export destination for a number of pollock products, have shown less interest in requiring MSC certification. The U.S. was the only producer of MSC certified pollock until 2013 when roughly 50% of the Russian catch became MSC certified. Since 2010 the U.S. pollock stock rebounded with catches in the BSAI ranging from 1.3-1.5 million t and Russia's catch has stabilized at 1.5 to 1.6 million t. The majority of pollock is exported; consequently exchange rates can have a significant impact on market dynamics, particularly the Dollar-Yen and Dollar-Euro. Aggregate exports in EPR Table 3 may not fully account for all pollock exports as products such as meal, minced fish and other ancillary product may be coded as generic fish type for export purposes. Additionally, pollock more broadly competes with other whitefish that, to varying degrees, can serve as substitutes depending on the product.

Table 3. Pollock U.S. trade and global market data. Global production (1000 t), U.S. share of global production, Russian share of global production, U.S. export volume (1000 t), U.S. export value (million US$), U.S. export price (US$ per pound), the share of U.S. export volume and value with Japan, China and Germany, the share of U.S. export volume and value of meats (including H&G and fillets), surimi and roe; 2005-2007 average, 2008-2010 average, and 2011-2015.

		Avg 05-07	Avg 08-10	2011	2012	2013	2014	2015	2016 (thru June)
Global Pollock Catch K mt		2,854	2,662	3,211	3,272	3,239	3,214	-	-
U.S. Share of Global Catch		52%	35%	39.7%	39.8%	42.1%	44.4%	-	-
Russian Share of global catch		37%	53%	49%	50%	48%	47%	-	-
Export Volume K mt		278.9	192.2	303.5	314.7	360.4	395.0	377.8	157.6
Export Value M US$		$ 867.4	$ 635.2	$ 924.3	$ 938.4	$ 968.1	$ 1,081.7	$ 1,038.2	$ 459.6
Export Price lb US$		1.41	1.50	$ 1.38	$ 1.35	$ 1.22	$ 1.24	$ 1.25	$ 1.32
Japan	Volume Share	34.4%	26.6%	20.6%	24.0%	18.2%	22.1%	25.0%	21.8%
	Value share	38.1%	26.3%	18.7%	22.1%	17.2%	21.7%	25.5%	23.2%
China	Volume Share	3.1%	9.0%	13.1%	11.2%	14.7%	14.7%	12.7%	11.1%
	Value share	2.2%	6.9%	10.8%	9.0%	11.8%	12.0%	10.5%	8.4%
Germany	Volume Share	16.7%	19.9%	20.6%	22.2%	22.8%	23.4%	21.4%	15.8%
	Value share	14.5%	21.2%	21.1%	22.8%	24.2%	24.3%	21.3%	14.7%
Meat/Fillets	Volume Share	32.7%	52.2%	50.5%	47.0%	51.2%	53.8%	49.2%	43.7%
	Value share	27.2%	48.5%	48.8%	45.4%	50.8%	51.6%	46.2%	37.4%
Surimi	Volume Share	56.9%	45.7%	43.8%	48.0%	44.6%	40.7%	45.4%	47.7%
	Value share	37.5%	32.7%	34.1%	42.1%	37.4%	34.3%	39.2%	39.4%
Roe	Volume Share	10.4%	8.2%	5.8%	5.1%	4.2%	5.5%	5.4%	8.5%
	Value share	35.3%	22.8%	17.1%	12.6%	11.8%	14.1%	14.6%	23.2%

Notes: Exports are from the US and are note specific to the GOA region.
Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

This market environment accounts for some of the major trends in prices and production across product types. Fillet prices peaked in 2008-2010 but declined afterwards because of the greater supply from U.S. and Russia. The 2013 MSC certification of Russian-caught pollock enabled access to segments of European and U.S. fillet markets, which has put continued downward pressure on prices. Pollock roe prices and production have declined steadily over the last decade as international demand has waned with changing consumer preferences in Asia. Additionally, the supply of pollock roe from Russia has increased with catch. The net effect has been not only a reduction in the supply of roe from the U.S. industry, but also a significant reduction in roe prices which are roughly half pre-2008 levels. Prior to 2008, roe comprised 23% of the U.S. wholesale value share, and since 2011 it has been roughly 10%. With U.S. the supply reduction in 2008-2010 surimi production from pollock came under increased pressure as U.S. pollock prices rose and markets sought cheaper sources of raw materials. This contributed to a growth in surimi from warm-water fish of Southeast Asia. Surimi prices spiked in 2008-2010 and have since tapered off as production from warm-water species have increased, coupled with the supply increases from pollock. Only a small fraction of Russia caught pollock is processed as surimi. Surimi is consumed globally, but Asian markets dominate the demand for surimi and demand has remained strong.

The portfolios of products produced in the GOA differs somewhat from the BSAI. The primary products processed from pollock in the BSAI are fillets, surimi and roe, with each accounting for approximately 40%, 35%, and 10% of first-wholesale value. In the GOA the primary products are head-and-gut, surimi, fillets, and roe, each accounted for approximately 35%, 25%, 25%, and 13% of first-wholesale value in recent years. In terms of GOA production, head-and-gut, surimi, and fillets each accounted for approximately 50%, 25%, and 15% of production in recent years. The production shares have changed since 2005-2007, particularly for H&G. When surimi production decreased with average catch volumes in 2008-2010, but H&G production increased. Since 2011 proportionally more of the increases from catch have gone towards H&G production, though surimi and fillet production has increased as well at a slower rate.

Prices for pollock products in the GOA, a shoreside fishery, are close to the prices for the corresponding products produces by the BSAI shoreside sector. The price of fillet produced in the GOA are on average about 5% higher than those on produced in the BSAI shoreside. The price of roe is on average about 10% lower in the GOA than the BSAI shoreside sector. The price of products produced at-sea in the BSAI tend to be higher than comparable products produced shoreside because of the shorter time span between catch, processing and freezing.

The majority of fillet produced in the GOA are pin-bone-out (PBO). Total fillet production increase 11% to 9.1 thousand t in 2015, aggregate production and catch. The average price of fillet products in the GOA decreased 5% to $1.28 per pound and is below the inflation adjusted average price of fillets in 2005-2007 of $1.51 per pound. In general for AK pollock producers, price negotiations with European buyers in 2015 were difficult with buyers citing exchange rates as an impediment. While still a small portion of their primary production, Russia producers increased fillet production in 2015 and report plans to upgrade their production capacity in the near future. Much of the Russian catch already goes to China for secondary processing into fillets so this would do little to increase the overall volume, however, increased primary fillet processing in Russia could increase competition with U.S. produced single-frozen fillet products. Approximately 30% of the fillets produced in Alaska are estimated to remain in the domestic market, which accounts for roughly 45% of domestic pollock fillet consumption. Additionally, roughly 10% of the at-sea BSAI production is processed as H&G which is mostly exported, primarily to China, where is reprocessed as fillets and some share of which returns to the U.S.. China also processes H&G from Russia into fillets which are also imported into the domestic market. Current data collection does not allow us to estimate the share of U.S. returning imports. As recent fillet markets have become increasingly tight, the industry has tried to maintain value by increasing domestic marketing for fillet based product and creating product types that are better suited to the American palette, in addition to increased utilization of by-products.

Surimi production continued an increasing trend through 2015, rising 19% to 14.6 thousand t which is above the 2005-2007 average. Prices have decreased since 2013 to an average of $0.87 per pound in the GOA in 2015. This change is in contrast to the price increase in the BSAI particularly in for the at-sea sector. Media reports indicate a reduction in the international supply of surimi, particularly from Thailand, that reduced Japanese inventories.

Roe is a high priced product that is the focus of the A season catch destined primarily for Asian markets. Roe production in the GOA tapered off in 2008-2010 but has since rebounded with catch levels. Compared to 2005-2007, roe production in the GOA since 2014 has been high because of the increased catch levels. Despite the substantial increase in 2015 catch roe production decreased in 2015 11% to 3.1 thousand pounds. However, the value of roe as a share of total value is low as result of prices. Prices peaked in the mid-2000s and prices have followed a decreasing trend over the last decade which continued through 2015 with a 39% drop price to $1.24 per pound. The weakness in the Yen against the U.S. Dollar has been cited as a factor in the 2015 price drop. Additionally, the Japanese Yen has remained strong against the Russian Rubble, which makes Russian products relatively cheaper than U.S. products for Japanese buyers. Also, the production volume from Russia has contributed to a carryover of roe inventory in Asian markets, which puts downward pressure on prices. Industry reports further indicate that harvests yielded comparatively more over-mature lower grade roe in 2015 which also contributed to low prices.

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. 1.42). 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 1.43). 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. 1.43). 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. 1.44). 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. 1.45). 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 1.44), 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. 1.46). 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 1.47, 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. 1.47, 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. 1.47 (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. 1.48). 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. 1.49, 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. 1.49, 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. 1.49 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. 1.49, 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. 1.45), we do not expect that arrowtooth would decline simply due to declines in pollock.

Taken together, Figs. 1.48 and 1.49 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. 1.42. 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. 1.50 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. 1.51), 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 1.52), 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. 1.53). 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. 1.53). 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.

Literature Cited

Alton, M. S., M. O. Nelson, and B. A. Megrey. 1987. Changes in the abundance and distribution of walleye pollock (*Theragra chalcogramma*) in the western Gulf of Alaska. Fish. Res. 5: 185-197.

Alverson, D. L. And M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. Cons. int. Explor. Mer, 133-143.

Anderson, P. J. and J. F. Piatt 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Mar. Ecol. Prog. Ser. 189:117-123.

Aydin, K., G.A. McFarlane, J.R. King, B.A. Megrey, and K.W. Myers. 2005. Linking oceanic food webs to coastal production and growth rates of Pacific salmon (*Oncorhynchus* spp.), using models on three scales. Deep-sea Res, II. 52: 757-780.

Bailey, K.M., P.J. Stabeno, and D.A. Powers. 1997. The role of larval retention and transport features in mortality and potential gene flow of walleye pollock. J. Fish. Biol. 51(Suppl. A):135-154.

Bailey, K.M., T.J. Quinn II, P. Bentzen, and W.S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theragra chalcogramma*. Advances in Mar. Biol. 37: 179-255.

Bailey, K.M. 2000. Shifting control of recruitment of walleye pollock *Theragra chalcogramma* after a major climatic and ecosystem change. Mar. Ecol. Prog. Ser. 198:215-224.

Bailey, K. M and S. J. Picquelle. 2002. Larval distribution of offshore spawning flatfish in the Gulf of Alaska: potential transport pathways and enhanced onshore transport during ENSO events. Mar. Ecol. Prog. Ser. 236:205-217.

Baranov, F.I. 1918. On the question of the biological basis of fisheries. Nauchn. Issed. Ikhtiologicheskii Inst. Izv. 1:81-128.

Barbeaux, S.J., S. Gaichas, J. Ianelli, and M.W. Dorn. 2005. Evaluation of biological sampling protocols for at-sea groundfish observers in Alaska. Alaska Fishery Research Bulletin. 11:82-101.

Brodeur, R. D. and Ware, D.M. 1995. Interdecadal variability in distribution and catch rates of epipelagic nekton in the Northeast Pacific Ocean. pp. 329-356 in R. J. Beamish [Ed.] Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121. National Research Council of Canada, Ottawa.

Brodziak, J., J. Ianelli, K. Lorenzen, and R.D. Methot Jr. (eds). 2011. Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119, 38 p.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured model. Can. J. Fish. Aquat. Sci. 56:1721-1731.

Clark, W. G., S. R. Hare, A. M. Parma, P. J. Sullivan, and R. J. Trumble. 1999. Decadal changes in growth and recruitment of Pacific halibut (*Hippoglossus stenolepis*). Can. J. Fish. Aquat. Sci. 56(2): 242-252.

Deriso, R.B., T.J. Quinn II, and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42: 815-824.

De Robertis, A., Hjellvik, V., Williamson, N. J., and Wilson, C. D. 2008. Silent ships do not always encounter more fish: comparison of acoustic backscatter recorded by a noise-reduced and a conventional research vessel. – ICES Journal of Marine Science, 65: 623–635.

Dorn, M. W., and R. D. Methot. 1990. Status of the coastal Pacific whiting resource in 1989 and recommendation to management in 1990. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-182, 84 p.

Dorn, M.W., S. Barbeaux, B, M. Guttormsen, B. Megrey, A. Hollowed, M. Wilkins, and K. Spalinger. 2003. Assessment of the walleye pollock stock in the Gulf of Alaska. *In* Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Dorn, M.W., K. Aydin, S. Barbeaux, D. Jones, K. Spalinger, and W. Palsson. 2012. Assessment of the walleye pollock stock in the Gulf of Alaska. *In* Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska.

Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Dorn, M.W., K. Aydin, D. Jones, W. Palsson, and K. Spalinger. 2014. Assessment of the walleye pollock stock in the Gulf of Alaska. *In* Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Doubleday, W.G. 1976. A least-squares approach to analyzing catch at age data. Res. Bull. Int. Comm. Northw. Atl. Fish. 12:69-81.

Forrester, C.R., A.J. Beardsley, and Y. Takahashi. 1978. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific—historical catch through 1970. International North Pacific Fisheries Commission, Bulletin Number 37. 150 p.

Forrester, C.R., R.G. Bakkala, K. Okada, and J.E. Smith. 1983. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific—historical catch statistics, 1971-1976. International North Pacific Fisheries Commission, Bulletin Number 41. 108 p.

Fournier, D. and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Fritz, L. W. 1993. Trawl locations of walleye pollock and Atka mackerel fisheries in the Bering Sea, Aleutian Islands, and Gulf of Alaska from 1977-92. AFSC Processed Report 93-08. NMFS, AFSC, 7600 Sand Point Way, NE, Seattle, WA 98115. 162 p.

Gislason, H, N. Daan, J. C. Rice and J. G. Pope. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries 11:149–158.

Grant, W.S. and F.M. Utter. 1980. Biochemical variation in walleye pollock *Theragra chalcogramma*: population structure in the southeastern Bering Sea and Gulf of Alaska. Can. J. Fish. Aquat. Sci. 37:1093-1100.

Greiwank, A., and G.F. Corliss (eds.) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. and Applied Mathematics, Philadelphia.

Gunderson, D. R. and P. H. Dygert. 1988. Reproductive effort as a predictor of natural mortality rate. J. Cons. int. Mer, 44:200-209.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York, N.Y. 570 p.

Hollowed, A.B. and B.A. Megrey. 1990. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for the 1991 Gulf of Alaska Groundfish Fishery. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

Hollowed, A.B., E. Brown, P. Livingston, B.A. Megrey and C. Wilson. 1995. Walleye pollock. In Stock Assessment and Fishery Evaluation Report for Gulf of Alaska As Projected for 1996. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Hollowed, A.B., J.N. Ianelli, P. Livingston. 2000. Including predation mortality in stock assessments: a case study for Gulf of Alaska pollock. ICES J. Mar. Sci. 57:279-293.

Jones, D. T., P. H. Ressler, S. C. Stienessen, A. L. McCarthy, and K. A. Simonsen. 2014. Results of the acoustic-trawl survey of walleye pollock (Gadus chalcogrammus) in the Gulf of Alaska, June-August 2013 (DY2013-07). AFSC Processed Rep. 2014-06, 95 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Kastelle, C. R. and D. K. Kimura. 2006. Age validation of walleye pollock (*Theragra chalcogramma*) from the Gulf of Alaska using the disequilibrium of Pb-210 and Ra-226. ICES Journal of Marine Science 63:1520-1529.

Kendall, A.W. Jr. and S.J. Picquelle. 1990. Egg and larval distributions of walleye pollock *Theragra chalcogramma* in Shelikof Strait, Gulf of Alaska. Fish. Bull., U.S. 88:133-154.

Kimura, D.K. 1989. Variability, tuning, and simulation for the Doubleday-Deriso catch-at-age model. Can. J. Fish. Aquat. Sci. 46:941-949.

Kimura, D.K. 1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47:2364-2374.

Kimura, D.K. 1991. Improved methods for separable sequential population analysis. Unpublished. Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, Washington 98115.

Kimura, D. K. and S. Chikuni. 1989. Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. *In* R.J. Beamish and G.A. McFarlane (eds.), Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108:57-66.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49:627-647.

McCarthy, A.L. and S. Stienessen. In Press. Results of the Acoustic-trawl Surveys of Walleye Pollock (Gadus chalcogrammus) in the Gulf of Alaska, February-March 2015 (DY2015-02 and DY2015-03). AFSC Processed Rep. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

McCullagh, P., and J. A. Nelder. 1983. Generalized linear models. Chapman and Hall, London. 261 p.
McKelvey, D. 1996. Juvenile walleye pollock, *Theragra chalcogramma*, distribution and abundance in Shelikof Strait–What can we learn from acoustic survey results? p. 25-34. *In* U.S. Dep. Commer. NOAA Tech. Rep. NMFS 126.

Martin, M.H. 1997. Data Report: 1996 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-82, 235 p.

Megrey, B.A. 1989. Exploitation of walleye pollock resources in the Gulf of Alaska, 1964-1988: portrait of a fishery in transition. Proc. International Symp. on the Biology and Management of Walleye Pollock, Lowell Wakefield Fisheries Symp., Alaska Sea Grant Rep. 89-1, 33-58.

Merati, N. 1993. Spawning dynamics of walleye pollock, *Theragra chalcogramma*, in Shelikof Strait, Gulf of Alaska. Unpublished MS thesis. University of Washington. 134 p.

Methot, R.D. 2000. Technical description of the stock synthesis assessment program. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-43, 46 p.

Mueter, F.J. and B.L. Norcross. 2002. Spatial and temporal patterns in the demersal fish community on the shelf and upper slope regions of the Gulf of Alaska. Fish. Bull. 100:559-581.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56: 473-488.

Mulligan, T.J., Chapman, R.W. and B.L. Brown. 1992. Mitochondrial DNA analysis of walleye pollock, *Theragra chalcogramma*, from the eastern Bering Sea and Shelikof Strait, Gulf of Alaska. Can. J. Fish. Aquat. Sci. 49:319-326.

Olsen, J.B., S.E. Merkouris, and J.E. Seeb. 2002. An examination of spatial and temporal genetic variation in walleye pollock (*Theragra chalcogramma*) using allozyme, mitochondrial DNA, and microsatellite data. Fish. Bull. 100:752-764.

Pauly, D.. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. int. Explor. Mer, 39(2):175-192.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. 1992. Numerical recipes in C. Second ed. Cambridge University Press. 994 p.

Picquelle, S.J., and B.A. Megrey. 1993. A preliminary spawning biomass estimate of walleye pollock, *Theragra chalcogramma*, in Shelikof Strait, Gulf of Alaska, based on the annual egg production method. Bulletin of Marine Science 53(2):728:749.

Rigby, P.R. 1984. Alaska domestic groundfish fishery for the years 1970 through 1980 with a review of two historic fisheries—Pacific cod (*Gadus microcephalus*) and sablefish (*Anoplopoma fimbria*). ADF&G Technical Data Report 108. 459 p.

Ronholt, L. L., H. H. Shippen, and E. S. Brown. 1978. Demersal fish and shellfish resources of the Gulf of Alaska from Cape Spencer to Unimak Pass 1948 - 1976 (A historical review). Northwest and Alaska Fisheries Center Processed Report.

Saunders, M.W., G.A. McFarlane, and W. Shaw. 1988. Delineation of walleye pollock (*Theragra chalcogramma*) stocks off the Pacific coast of Canada. Proc. International Symp. on the Biology and Management of Walleye Pollock, Lowell Wakefield Fisheries Symp., Alaska Sea Grant Rep. 89-1, 379-402.

Schnute, J.T. and L.J. Richards. 1995. The influence of error on population estimates from catch-age models. Can. J. Fish. Aquat. Sci. 52:2063-2077.

Somerton, D. 1979. Competitive interaction of walleye pollock and Pacific ocean perch in the northern Gulf of Alaska. *In* S. J. Lipovsky and C.A. Simenstad (eds.) Gutshop '78, Fish food habits studies: Proceedings of the second Pacific Northwest Technical Workshop, held Maple Valley, WA (USA), 10-13 October, 1978., Washington Sea Grant, Seattle, WA.

Spalinger, K. 2012. Bottom trawl survey of crab and groundfish: Kodiak, Chignik, South Peninsula, and Eastern Aleutian Management Districts, 2012. Alaska Department of Fish and Game, Regional Management Report No. 13-27. 127p.

Sullivan, P.J., A.M. Parma, and W.G. Clark. 1997. Pacific halibut assessment: data and methods. Int. Pac. Halibut Comm. SCI. Rept. 97. 84 p.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams of the North Pacific Fishery Management Council.

Van Kirk, K., Quinn, T.J., and Collie, J. 2010. A multispecies age-structured assessment model for the Gulf of Alaska. Canadian Journal of Fisheries and Aquatic Science 67: 1135 – 1148

Van Kirk, K., Quinn, T.J., Collie, J., and T. A'mar. 2012. Multispecies age-structured assessment for groundfish and sea lions in Alaska. In: G.H. Kruse, H.I. Browman, K.L. Cochrane, D. Evans, G.S. Jamieson, P.A. Livingston, D. Woodby, and C.I. Zhang (eds.), Global Progress in Ecosystem-Based Fisheries Management. Alaska Sea Grant, University of Alaska Fairbanks.

von Szalay, P. G., and E. Brown. 2001. Trawl comparisons of fishing power differences and their applicability to National Marine Fisheries Service and the Alaska Department of Fish and Game trawl survey gear. Alaska Fishery Research Bulletin 8:85-95.

Wilberg, M.J., J.T. Thoron, B.C. Linton, and J. Berkson. 2010. Incorporating time-varying catchability into population dynamic stock assessment models. Reviews in Fisheries Science, 18(1):7–24.

Williams, K., Punt, A. E., Wilson, C. D., and Horne, J. K. 2011. Length-selective retention of walleye pollock, Theragra chalcogramma, by midwater trawls. ICES Journal of Marine Science, 68: 119–129.

Yang, M-S. and M. W. Nelson. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-112, 174 p.

Zeppelin, TK., DJ. Tollit, KA. Call, TJ. Orchard, and CJ. Gudmundson. 2004. Sizes of walleye pollock (*Theragra chalcogramma*) and Atka mackerel (*Pleurogrammus monopterygius*) consumed by the western stock of Steller sea lions (Eumetopias jubatus) in Alaska from 1998 to 2000. Fish. Bull. 102:509-521.

Table 1.1. Pollock catch (t) in the Gulf of Alaska. The ABC for 2016 is for the area west of 140° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound. 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			76,744	76,744	77,150
2011			81,382	81,382	88,620
2012			103,984	103,984	108,440
2013			96,353	96,353	113,099
2014			142,632	142,632	167,657
2015			167,553	167,553	191,309
2016					254,310
Average (1977-2015)				104,345	119,833

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 2011-2015. Species are ordered according to the cumulative catch during the period. Incidental catch estimates include both retained and discarded catch.

Managed species/species group	*2011*	*2012*	*2013*	*2014*	*2015*
Pollock	77297.5	99643.9	91514.2	137611.0	163899.6
Arrowtooth Flounder	2008.6	1328.6	1765.3	2464.3	1671.1
Pacific Cod	1500.5	1267.0	1041.7	3286.8	1711.4
Pacific Ocean Perch	172.3	294.6	426.9	529.9	175.5
Flathead Sole	217.3	189.5	381.4	355.9	438.7
GOA Shallow Water Flatfish	289.4	171.2	183.4	248.9	357.6
Squid	208.8	6.7	346.2	143.5	465.3
GOA Rex Sole	90.0	48.8	151.1	270.8	145.9
GOA Big Skate	92.6	47.8	228.0	171.0	62.8
Salmon Shark	5.7	52.9	2.8	144.0	368.7
GOA Longnose Skate	35.0	9.0	25.2	179.7	87.4
Sablefish	32.5	6.7	12.6	30.4	129.9
Sculpin	53.4	20.2	17.5	43.3	26.8
Northern Rockfish	13.7	60.7	5.6	15.1	16.6
GOA Shortraker Rockfish	24.4	21.8	22.6	27.7	14.0
GOA Rougheye Rockfish	34.5	21.2	8.9	25.2	12.4
Spiny Dogfish Shark	16.5	19.2	11.5	13.6	35.6
GOA Deep Water Flatfish	14.6	3.0	12.8	35.3	15.0
GOA Thornyhead Rockfish	1.8	0.5	0.6	42.3	24.2
GOA Other Skates	1.9	5.5	23.9	17.0	17.7
GOA Dusky Rockfish	19.1	4.1	6.5	13.1	15.0
Pacific Sleeper Shark	3.6	3.9	15.3	6.3	12.0
Atka Mackerel	0.1	0.3	0.4	3.5	25.2
Octopus	2.3	0.4	0.3	7.2	4.3
Other Sharks	1.1	3.7	1.0	2.2	6.1
Other Rockfish	6.8	0.8	0.7	1.3	1.8
Percent non-pollock	*5.9%*	*3.5%*	*4.9%*	*5.5%*	*3.4%*

Non target species/species group	*2011*	*2012*	*2013*	*2014*	*2015*
Eulachon	262.53	181.55	25.23	246.82	79.84
Miscellaneous fish	38.25	46.52	350.34	73.61	56.64
Jellyfish	6.80	122.96	34.56	23.08	169.50
Other Osmerids	68.38	81.87	11.06	75.27	13.29
Giant Grenadier	103.26	14.02	47.50	19.36	9.16
Rattail Grenadier	7.87	63.26	0.00	0.00	0.00
Sea Stars	3.34	0.68	3.29	6.21	1.11
Capelin	6.19	0.02	0.01	4.61	3.62
Sponge Unidentified	0.00	0.00	0.03	1.16	0.20
Sea Anemone Unidentified	0.54	0.00	0.20	0.00	0.55
Eelpouts	0.00	0.01	0.13	0.00	0.68
Stichaeidae	0.00	0.07	0.55	0.00	0.04
Bivalves	0.04	0.00	0.16	0.38	0.00
Snails	0.06	0.01	0.34	0.01	0.06
Pandalid shrimp	0.11	0.05	0.01	0.04	0.17
Benthic Urochordata	0.09	0.02	0.21	0.00	0.00
Sea Urchins, Sand Dollars, Sea Cucumbers	0.00	0.00	0.01	0.11	0.01
Hermit Crab Unidentified	0.00	0.11	0.00	0.00	0.00
Miscellaneous Crabs	0.10	0.00	0.00	0.00	0.01
Pacific Sandfish	0.00	0.00	0.00	0.00	0.10

Table 1.3. Bycatch of prohibited species for trawls where pollock was the predominant species in the catch in the Gulf of Alaska during 2011-2015. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of individuals.

Species/species group	*2011*	*2012*	*2013*	*2014*	*2015*
Bairdi Tanner Crab (nos.)	10,029	727	7,999	2,062	2,340
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	12,859	16,295	12,951	10,883	13,612
Golden (Brown) King Crab (nos.)	0	0	0	0	0
Halibut (t)	190.6	87.1	256.5	137.4	168.1
Herring (t)	10.7	1.3	10.5	4.6	78.2
Non-Chinook Salmon (nos.)	1233	282	739	1422	909
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 2005-2015 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
2005	Retained	30,791	27,418	18,986	1,876	740	0	79,811	
	Discarded	136	622	350	9	50	0	1,167	1.4%
	Total	30,927	28,040	19,336	1,885	790	0	80,978	
2006	Retained	24,489	26,409	16,127	1,570	1,475	0	70,070	
	Discarded	203	750	951	2	1	0	1,906	2.6%
	Total	24,691	27,159	17,078	1,572	1,476	0	71,976	
2007	Retained	17,470	18,848	13,777	84	1,046	0	51,224	
	Discarded	262	516	701	3	8	0	1,490	2.8%
	Total	17,731	19,363	14,478	87	1,055	0	52,714	
2008	Retained	15,099	18,692	13,336	1,155	613	1	48,896	
	Discarded	2,160	378	1,121	6	20	2	3,688	7.0%
	Total	17,260	19,070	14,456	1,161	633	3	52,584	
2009	Retained	14,475	13,578	10,974	1,190	1,474	0	41,692	
	Discarded	604	422	1,496	31	1	0	2,554	5.8%
	Total	15,079	14,000	12,470	1,222	1,476	0	44,247	
2010	Retained	25,960	28,015	18,373	1,625	1,660	2	75,635	
	Discarded	91	234	761	12	9	2	1,110	1.4%
	Total	26,051	28,249	19,134	1,637	1,669	4	76,744	
2011	Retained	20,472	36,114	18,987	2,268	1,535	0	79,376	
	Discarded	125	1,134	743	3	1	0	2,007	2.5%
	Total	20,597	37,248	19,731	2,271	1,536	0	81,382	
2012	Retained	27,355	44,597	25,089	2,353	2,622	0	102,015	
	Discarded	538	500	896	28	5	1	1,969	1.9%
	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	
	Discarded	67	511	1,830	13	17	2	2,440	2.5%
	Total	7,711	53,114	29,963	2,940	2,623	2	96,353	
2014	Retained	13,228	82,526	41,727	1,314	2,368	0	141,163	
	Discarded	137	555	768	3	3	3	1,469	1.0%
	Total	13,364	83,082	42,494	1,317	2,371	3	142,632	
2015	Retained	28,663	80,938	51,982	248	4,454	0	166,285	
	Discarded	77	493	662	1	31	3	1,268	0.8%
	Total	28,739	81,431	52,645	250	4,485	3	167,553	
Average (2005-2015)		20,913	39,623	24,343	1,520	1,886	2	88,286	

Table 1.5. Catch at age (millions) of pollock in the Gulf of Alaska in 1975-2015.

	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
2015	0.00	8.58	107.27	15.31	32.09	10.00	12.25	11.94	5.79	1.84	1.29	0.15	0.11	0.05	0.08	206.74

Table 1.6. Number of aged and measured fish in the GOA pollock fishery used to estimate fishery age composition (1989-2015).

	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
2015	1,048	1,069	2,117	21,104	23,144	44,248

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° 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
2016	665,059				18,470

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	492	664	1,156	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 (statistical areas 610-630).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1984	38.69	15.65	74.51	158.78	194.66	271.24	85.94	37.36	13.55	2.37	0.54	0.28	0.21	0.00	0.00	893.78
1987	26.07	325.15	150.41	111.72	70.64	135.13	64.32	37.03	146.40	18.87	6.66	2.89	1.46	0.00	0.00	1096.75
1990	58.06	201.33	44.56	39.44	189.70	222.16	67.30	102.42	25.18	36.56	5.72	24.03	5.98	0.73	1.05	1024.20
1993	76.85	44.71	55.15	129.75	264.85	89.84	34.99	64.20	65.56	18.72	9.28	5.90	2.48	1.44	3.88	867.59
1996	196.89	129.07	17.24	26.17	50.13	63.21	174.42	87.55	52.31	27.70	12.09	18.43	7.15	9.66	2.86	874.88
1999	109.73	19.16	20.95	66.81	119.04	56.84	59.07	47.74	56.41	81.99	65.20	9.67	8.29	2.50	0.76	724.16
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	75.07	18.29	128.10	140.40	73.08	44.63	36.00	25.20	14.43	8.57	3.21	1.78	1.26	0.00	0.00	570.02
2005	269.99	33.56	34.35	35.85	91.71	78.82	45.23	20.86	9.61	9.98	4.81	0.57	0.64	0.00	0.00	635.98
2007	175.42	96.39	87.70	36.51	19.16	18.88	54.97	31.09	6.63	3.05	2.78	1.00	1.11	0.00	0.00	534.71
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	47.94	65.41	84.72	144.62	156.91	115.55	25.05	5.42	2.40	2.46	3.83	3.01	0.91	1470.46
2015	93.03	63.63	452.62	109.61	113.20	70.83	56.57	52.99	25.96	21.00	3.59	0.57	0.14	0.00	0.89	1064.65

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
2016	0.00	1.26	77.16	1,447.49	43.32	33.43	15.43	3.54	7.23	1.64	0.00	0.00	0.00	0.00	0.00	1,630.51

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 is reported for 1992-2016.

	No. of midwater	No. of bottom trawl	Survey	Number aged			Number lengthed		
Year	tows	tows	biomass CV	Males	Females	Total	Males	Females	Total
1981	38	13	0.12	1,921	1,815	3,736	NA	NA	NA
1983	40	0	0.16	1,642	1,103	2,745	NA	NA	NA
1984	45	0	0.18	1,739	1,622	3,361	NA	NA	NA
1985	57	0	0.14	1,055	1,187	2,242	NA	NA	NA
1986	39	0	0.22	642	618	1,260	NA	NA	NA
1987	27	0	---	557	643	1,200	NA	NA	NA
1988	26	0	0.17	537	464	1,001	NA	NA	NA
1989	21	0	0.10	582	545	1,127	NA	NA	NA
1990	28	13	0.17	1,034	1,181	2,215	NA	NA	NA
1991	16	2	0.35	468	567	1,035	NA	NA	NA
1992	17	8	0.04	784	765	1,549	NA	NA	NA
1993	22	2	0.05	583	624	1,207	NA	NA	NA
1994	44	9	0.05	553	632	1,185	NA	NA	NA
1995	22	3	0.05	599	575	1,174	NA	NA	NA
1996	30	8	0.04	724	775	1,499	NA	NA	NA
1997	16	14	0.04	682	853	1,535	5,380	6,104	11,484
1998	22	9	0.04	863	784	1,647	5,487	4,946	10,433
2000	31	0	0.05	422	363	785	6,007	5,196	11,203
2001	17	9	0.05	314	378	692	4,531	4,584	9,115
2002	18	1	0.07	278	326	604	2,876	2,871	5,747
2003	17	2	0.05	288	321	609	3,554	3,724	7,278
2004	13	2	0.09	492	440	932	3,838	2,552	6,390
2005	22	1	0.04	543	335	878	2,714	2,094	4,808
2006	17	2	0.04	295	487	782	2,527	3,026	5,553
2007	9	1	0.06	335	338	673	2,145	2,194	4,339
2008	10	2	0.06	171	248	419	1,641	1,675	3,316
2009	9	3	0.06	254	301	555	1,583	1,632	3,215
2010	13	2	0.03	286	244	530	2,590	2,358	4,948
2012	8	3	0.08	235	372	607	1,727	1,989	3,716
2013	29	5	0.05	376	386	778	2,198	2,436	8,158
2014	19	2	0.05	389	430	854	3,940	3,377	10,841
2015	20	0	0.04	354	372	755	4,556	4,227	8,936
2016	19	0	0.07	269	337	606	2,106	3,452	8,405

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 Age	St. dev.	Observed Age 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 (1983-2016).

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
2016	0.000	0.000	0.512	0.875	1.000	1.000	1.000	1.000	1.000	269
Average										
All years	0.000	0.015	0.272	0.573	0.837	0.923	0.967	0.987	0.993	
2007-2016	0.000	0.000	0.280	0.596	0.898	0.984	0.988	0.995	1.000	
2012-2016	0.000	0.000	0.318	0.650	0.934	0.974	0.988	1.000	1.000	

Table 1.16. Fishery weight at age (kg) of pollock in the Gulf of Alaska in 1975-2015.

	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	0.157	0.312	0.434	0.773	0.991	0.998	1.202	1.271	1.456	1.663
2001	0.108	0.292	0.442	0.701	1.003	1.208	1.286	1.473	1.540	1.724
2002	0.145	0.316	0.480	0.615	0.898	1.050	1.146	1.263	1.363	1.522
2003	0.136	0.369	0.546	0.507	0.715	1.049	1.242	1.430	1.511	1.700
2004	0.112	0.259	0.507	0.720	0.677	0.896	1.123	1.262	1.338	1.747
2005	0.127	0.275	0.446	0.790	1.005	0.977	0.921	1.305	1.385	1.485
2006	0.129	0.260	0.566	0.974	1.229	1.242	1.243	1.358	1.424	1.653
2007	0.127	0.345	0.469	0.885	1.195	1.385	1.547	1.634	1.749	1.940
2008	0.143	0.309	0.649	0.856	1.495	1.637	1.894	1.896	1.855	2.204
2009	0.205	0.235	0.566	0.960	1.249	1.835	2.002	2.151	2.187	2.208
2010	0.133	0.327	0.573	0.972	1.267	1.483	1.674	2.036	2.329	2.191
2011	0.141	0.473	0.593	0.833	1.107	1.275	1.409	1.632	1.999	1.913
2012	0.194	0.294	0.793	0.982	1.145	1.425	1.600	1.869	2.051	2.237
2013	0.140	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
2015	0.141	0.349	0.502	0.860	0.993	1.141	1.393	1.527	1.650	1.783

Table 1.17. Weight at age (kg) of pollock in the Shelikof Strait acoustic survey in 1981-2016.

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1981	0.017	0.089	0.226	0.332	0.383	0.472	0.635	0.719	0.857	0.764
1983	0.013	0.079	0.308	0.408	0.555	0.652	0.555	0.717	0.764	1.058
1984	0.012	0.112	0.256	0.551	0.587	0.692	0.736	0.720	0.878	1.006
1985	0.012	0.099	0.331	0.505	0.601	0.729	0.803	0.828	0.818	1.157
1986	0.008	0.066	0.216	0.381	0.748	0.835	0.881	0.940	0.966	1.066
1988	0.010	0.069	0.187	0.283	0.403	0.538	0.997	1.118	1.131	1.281
1989	0.011	0.092	0.230	0.397	0.447	0.623	0.885	1.033	1.131	1.221
1990	0.008	0.055	0.204	0.356	0.530	0.665	0.777	1.087	1.087	1.364
1991	0.011	0.072	0.155	0.268	0.510	0.779	0.911	0.969	1.211	1.521
1992	0.011	0.086	0.211	0.321	0.392	0.811	1.087	1.132	1.106	1.304
1993	0.010	0.082	0.304	0.469	0.583	0.714	1.054	1.197	1.189	1.332
1994	0.010	0.090	0.284	0.639	0.817	0.899	1.120	1.238	1.444	1.431
1995	0.011	0.091	0.295	0.526	0.804	0.898	0.949	1.034	1.147	1.352
1996	0.011	0.055	0.206	0.469	0.923	1.031	1.052	1.115	1.217	1.374
1997	0.010	0.079	0.157	0.347	0.716	1.200	1.179	1.231	1.279	1.424
1998	0.011	0.089	0.225	0.322	0.386	0.864	1.217	1.295	1.282	1.362
2000	0.013	0.084	0.279	0.570	0.810	0.811	1.010	1.319	1.490	1.551
2001	0.009	0.052	0.172	0.416	0.641	1.061	1.166	1.379	1.339	1.739
2002	0.012	0.082	0.148	0.300	0.714	0.984	1.190	1.241	1.535	1.765
2003	0.012	0.091	0.207	0.277	0.436	0.906	1.220	1.280	1.722	1.584
2004	0.010	0.085	0.246	0.486	0.502	0.749	1.341	1.338	1.446	1.311
2005	0.011	0.084	0.305	0.548	0.767	0.734	0.798	1.169	1.205	1.837
2006	0.009	0.066	0.262	0.429	0.828	1.124	1.163	1.327	1.493	1.884
2007	0.011	0.063	0.222	0.446	0.841	1.248	1.378	1.439	1.789	1.896
2008	0.014	0.099	0.267	0.484	0.795	1.373	1.890	1.869	1.882	2.014
2009	0.011	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	0.013	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
2016	0.013	0.133	0.303	0.390	0.557	0.751	0.860	1.120	1.115	1.178

Table 1.18. Weight at age (kg) of pollock in the NMFS bottom trawl survey in 1984-2015.

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1984	0.062	0.157	0.530	0.661	0.740	0.834	0.904	0.960	0.991	1.196
1987	0.028	0.170	0.379	0.569	0.781	0.923	1.021	1.076	1.157	1.264
1990	0.048	0.173	0.306	0.564	0.776	0.906	1.112	1.134	1.275	1.472
1993	0.041	0.164	0.475	0.680	0.797	0.932	1.057	1.304	1.369	1.412
1996	0.030	0.097	0.325	0.716	0.925	1.009	1.085	1.186	1.243	1.430
1999	0.023	0.144	0.374	0.593	0.700	0.787	0.868	1.069	1.223	1.285
2001	0.031	0.105	0.410	0.698	0.925	1.060	1.201	1.413	1.293	1.481
2003	0.049	0.201	0.496	0.593	0.748	0.950	1.146	1.149	1.381	1.523
2005	0.025	0.182	0.423	0.653	0.836	0.943	1.024	1.228	1.283	1.527
2007	0.022	0.148	0.307	0.589	0.987	1.199	1.415	1.477	1.756	1.737
2009	0.023	0.237	0.492	0.860	1.081	1.421	1.637	1.839	1.955	2.020
2011	0.028	0.243	0.441	0.708	0.980	1.345	1.505	1.656	1.970	2.037
2013	0.020	0.216	0.420	0.894	1.146	1.334	1.497	1.574	1.665	2.037
2015	0.033	0.207	0.366	0.575	0.863	1.069	1.270	1.374	1.432	1.525

Table 1.19. Results comparing model fits, stock status, and 2017 yield for different model configurations. 2017 ABC estimates are from a projection module associated with assessment model, and are based on different assumptions and give different results than the standard projection software.

	Model 15.1a	*Model 16.1*	*Model 16.2*	*Model 16.3*	*Model 16.4*
Model fits					
Total log(Likelihood)	-390.84	-389.95	-390.53	-400.09	-405.75
Catch	-0.10	-0.10	-0.09	-0.09	-0.09
Fishery age	-137.69	-137.72	-138.69	-138.38	-137.49
Acoustic survey biomass	-44.61	-44.68	-44.26	-52.49	-45.03
Age-1 and age-2 indices	-25.34	-25.34	-25.18	-25.11	-25.22
Acoustic survey age	-38.05	-38.03	-38.68	-38.43	-38.50
Bottom trawl survey biomass	-9.37	-9.38	-8.44	-6.38	-19.67
Bottom trawl survey age and length comp	-36.95	-36.97	-37.67	-37.57	-37.31
ADFG trawl survey biomass	-40.09	-39.06	-39.19	-44.34	-44.83
ADFG trawl survey age	-25.99	-25.98	-25.89	-25.84	-25.50
Summer acoustic biomass	-1.29	-1.29	-1.08	-0.92	-1.05
Summer acoustic age and length comp.	-2.28	-2.27	-2.06	-1.87	-2.04
Priors/Penalties	-29.09	-29.13	-29.30	-28.67	-29.01
Composition data					
Fishery age comp. effective N	118	118	119	119	119
Shelikof Strait acoustic age comp. effective N	10	10	10	10	10
NMFS bottom trawl age comp. effective N	29	29	28	28	28
ADF&G trawl age comp. effective N	33	33	32	32	33
Survey abundance					
Shelikof Strait Acoustic RMSE					
EK500	0.26	0.26	0.27	0.38	0.28
Dyson	0.56	0.56	0.55	0.52	0.55
Age-1 index	1.31	1.31	1.30	1.30	1.30
Age-2 index	1.25	1.25	1.25	1.25	1.25
NMFS bottom trawl RMSE	0.27	0.27	0.26	0.25	0.23
ADFG trawl RMSE	0.44	0.43	0.43	0.46	0.46
Summer acoustic RMSE	0.28	0.28	0.26	0.24	0.26
Catchability estimates					
NMFS trawl	0.89	0.89	0.86	0.86	0.88
Shelikof Strait acoustic					
Miller Freeman	0.56	0.56	0.52	0.39	0.50
Dyson	0.62	0.62	0.58	0.44	0.55
Age-1 index linear term	0.09	0.09	0.08	0.07	0.07
Age-1 index power term	1.20	1.20	1.19	1.16	1.17
Age-2 index	0.63	0.64	0.59	0.56	0.56
Summer acoustic	0.98	0.98	0.87	0.77	0.79
ADFG trawl	0.16	0.17	0.63	0.64	0.62
Stock status (t)					
2017 Spawning biomass	315,340	292,682	352,850	419,258	400,216
Depletion (B2017/B0)	49%	46%	53%	62%	58%
$B_{40\%}$	257,075	255,713	265,457	271,403	275,740
2017 yield (t)					
Author's recommended ABC	231,263	156,859	197,906	235,919	221,539

Model descriptions (see text for details):

- Model 15.1a—last year's base model with new data.
- Model 16.1—use random effects model for fishery weight at age in 2016 and 2017.
- Model 16.2—model 16.1 plus new indices for the ADFG survey from a delta-GLM model instead of area-swept estimates.
- Model 16.3— model 16.2 plus revised Shelikof Strait acoustic survey estimates for net selectivity.
- Model 16.4—model 16.2 plus a spatial GLMM index for the NMFS bottom trawl survey instead of area-swept estimates.

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 (2001-2010)*	*Recent domestic (2011-2015)*	*Shelikof acoustic survey*	*Summer acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.004	0.002	0.013	0.003	0.389	1.000	0.120	0.004
2	0.011	0.028	0.012	0.085	0.030	0.932	1.000	0.205	0.027
3	0.123	0.180	0.072	0.395	0.240	1.000	1.000	0.329	0.163
4	0.633	0.616	0.321	0.808	0.762	1.000	1.000	0.483	0.575
5	0.955	0.921	0.744	0.964	0.972	0.999	1.000	0.643	0.903
6	0.997	0.990	0.954	0.996	0.998	0.997	1.000	0.779	0.985
7	1.000	1.000	1.000	1.000	1.000	0.986	1.000	0.878	0.998
8	0.991	0.992	0.999	0.992	0.991	0.938	1.000	0.942	1.000
9	0.883	0.884	0.891	0.884	0.883	0.771	1.000	0.979	1.000
10	0.357	0.357	0.360	0.357	0.357	0.427	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	1,184	295	182	126	90	66	49	37	28	83
1971	3,248	295	148	112	85	61	47	35	27	81
1972	3,639	809	148	91	75	58	44	34	25	79
1973	10,607	906	405	89	55	44	35	27	21	71
1974	2,119	2,641	453	242	52	30	25	20	15	61
1975	2,128	528	1,320	268	133	26	16	13	11	48
1976	8,396	530	264	794	161	77	16	9	8	40
1977	11,459	2,091	265	157	454	87	43	9	5	32
1978	14,131	2,853	1,045	157	86	229	45	22	5	24
1979	25,051	3,519	1,425	618	87	45	122	24	12	18
1980	12,518	6,238	1,759	850	358	48	25	69	14	20
1981	6,937	3,117	3,123	1,068	525	209	29	15	42	22
1982	7,031	1,728	1,561	1,901	676	321	132	18	10	43
1983	5,005	1,751	864	944	1,207	426	210	86	12	37
1984	5,721	1,246	873	515	582	739	270	133	55	34
1985	14,607	1,423	620	513	305	337	441	161	80	58
1986	4,494	3,635	710	369	304	168	188	246	91	86
1987	1,829	1,119	1,818	432	241	198	113	127	167	125
1988	5,031	455	560	1,114	287	161	137	78	89	210
1989	12,198	1,253	228	343	743	193	112	95	55	217
1990	8,641	3,037	627	140	228	493	132	77	66	197
1991	3,529	2,152	1,522	386	94	151	334	89	52	188
1992	2,415	879	1,078	937	259	61	99	215	58	169
1993	1,676	601	440	663	626	168	40	64	140	159
1994	1,827	417	301	270	440	405	110	26	42	208
1995	6,735	455	209	185	180	286	267	72	17	177
1996	3,324	1,677	228	129	124	120	196	182	49	140
1997	1,530	828	841	140	87	84	83	135	126	137
1998	1,458	381	414	514	92	55	53	52	86	180
1999	1,804	363	190	250	320	53	31	30	30	172
2000	6,495	449	181	115	158	188	31	18	18	136
2001	7,201	1,617	225	110	75	98	118	19	11	107
2002	947	1,792	806	135	69	45	61	73	12	82
2003	862	236	892	482	86	44	30	40	49	67
2004	752	214	117	534	310	56	30	20	27	82
2005	2,124	187	106	69	337	199	37	20	14	78
2006	6,165	528	92	62	42	209	128	24	13	65
2007	5,995	1,533	261	54	38	26	135	83	16	55
2008	7,112	1,491	760	154	34	25	18	90	56	50
2009	3,589	1,770	743	454	99	22	17	12	62	76
2010	1,569	893	884	449	300	67	16	12	9	101
2011	4,849	390	446	529	290	198	46	11	8	79
2012	1,320	1,207	195	268	341	190	135	31	7	63
2013	19,950	329	604	118	171	219	127	90	21	51
2014	2,422	4,968	164	366	76	111	147	85	61	51
2015	754	603	2,483	98	222	45	68	91	53	75
2016	210	188	300	1,453	58	129	27	41	55	86
Average	5,587	1,396	700	421	248	155	98	63	41	94

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.

						2015 Assessment results			
Year	*3+ total biomass (1,000 t)*	*Female spawn. biom.*	*Age 1 recruits (million)*	*Catch (t)*	*Harvest rate*	*3+ total biomass*	*Female spawn. biom.*	*Age 1 recruits*	*Harvest rate*
1977	733	127	11,459	118,092	16%	745	137	11,732	16%
1978	939	112	14,131	95,408	10%	899	128	14,486	11%
1979	1,311	116	25,051	106,161	8%	1,258	131	25,752	8%
1980	1,771	159	12,518	115,158	7%	1,719	172	12,920	7%
1981	2,776	175	6,937	147,818	5%	2,665	177	7,183	6%
1982	2,885	302	7,031	169,045	6%	2,905	270	7,282	6%
1983	2,616	426	5,005	215,625	8%	2,742	406	5,227	8%
1984	2,317	477	5,721	307,541	13%	2,399	461	5,955	13%
1985	1,872	432	14,607	286,900	15%	1,958	442	15,122	15%
1986	1,563	388	4,494	86,910	6%	1,600	399	4,618	5%
1987	1,910	363	1,829	68,070	4%	1,969	372	1,842	3%
1988	1,823	373	5,031	63,391	3%	1,883	380	4,990	3%
1989	1,617	389	12,198	75,585	5%	1,706	422	11,873	4%
1990	1,502	403	8,641	88,269	6%	1,552	402	8,365	6%
1991	1,859	399	3,529	100,488	5%	1,735	399	3,261	6%
1992	1,954	368	2,415	90,858	5%	2,094	370	2,363	4%
1993	1,858	406	1,676	108,909	6%	1,823	404	1,558	6%
1994	1,580	487	1,827	107,335	7%	1,518	449	1,739	7%
1995	1,293	411	6,735	72,618	6%	1,268	405	6,431	6%
1996	1,092	382	3,324	51,263	5%	1,061	368	3,128	5%
1997	1,106	339	1,530	90,130	8%	1,093	322	1,446	8%
1998	1,067	264	1,458	125,460	12%	969	247	1,381	13%
1999	801	244	1,804	95,638	12%	771	220	1,695	12%
2000	713	232	6,495	73,080	10%	678	203	6,166	11%
2001	683	219	7,201	72,077	11%	643	197	6,714	11%
2002	862	183	947	51,934	6%	812	167	844	6%
2003	1,084	169	862	50,684	5%	1,015	154	781	5%
2004	903	186	752	63,844	7%	825	164	695	8%
2005	759	224	2,124	80,978	11%	681	206	1,973	12%
2006	649	244	6,165	71,976	11%	583	215	5,725	12%
2007	617	217	5,995	52,714	9%	559	194	5,694	9%
2008	858	216	7,112	52,584	6%	873	191	6,957	6%
2009	1,220	216	3,589	44,247	4%	1,352	191	3,469	3%
2010	1,431	295	1,569	76,744	5%	1,529	263	1,488	5%
2011	1,387	347	4,849	81,382	6%	1,399	315	4,767	6%
2012	1,311	372	1,320	103,984	8%	1,271	342	1,216	8%
2013	1,319	407	19,950	96,353	7%	1,256	376	16,895	8%
2014	1,058	317	2,422	142,632	13%	1,134	294	2,931	13%
2015	1,608	273	754	167,553	10%	1,728	251	893	10%
2016	1,434	217	210						
Average									
1977-2015	1,403	299	5,925	104,345	8%	1,402	287	5,835	8%
1978-2015			5,779					5,442	

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	1,184	0.25	732	1,916	117	0.25	72	189
1971	3,248	0.35	1,670	6,317	111	0.26	68	183
1972	3,639	0.29	2,087	6,345	102	0.27	61	172
1973	10,607	0.13	8,289	13,574	85	0.31	47	153
1974	2,119	0.23	1,347	3,333	76	0.28	44	129
1975	2,128	0.22	1,391	3,255	79	0.21	52	118
1976	8,396	0.15	6,264	11,252	114	0.14	87	150
1977	11,459	0.14	8,637	15,202	127	0.14	96	167
1978	14,131	0.14	10,671	18,712	112	0.17	81	157
1979	25,051	0.12	19,781	31,726	116	0.18	82	165
1980	12,518	0.15	9,301	16,848	159	0.17	115	221
1981	6,937	0.18	4,852	9,918	175	0.16	129	236
1982	7,031	0.18	4,923	10,041	302	0.13	233	392
1983	5,006	0.26	3,025	8,284	426	0.13	333	547
1984	5,721	0.24	3,587	9,125	477	0.13	367	619
1985	14,607	0.13	11,389	18,735	432	0.15	321	580
1986	4,494	0.21	2,975	6,790	388	0.17	281	536
1987	1,829	0.33	980	3,413	363	0.16	265	495
1988	5,031	0.18	3,531	7,169	373	0.15	281	496
1989	12,198	0.12	9,743	15,272	389	0.12	306	496
1990	8,641	0.13	6,711	11,127	403	0.12	320	508
1991	3,529	0.20	2,389	5,214	399	0.12	317	503
1992	2,415	0.21	1,604	3,635	368	0.11	295	460
1993	1,676	0.23	1,079	2,604	406	0.10	331	498
1994	1,827	0.20	1,231	2,711	487	0.10	401	591
1995	6,735	0.10	5,546	8,179	411	0.10	338	499
1996	3,324	0.13	2,570	4,299	382	0.10	314	464
1997	1,530	0.19	1,066	2,197	339	0.10	277	414
1998	1,458	0.18	1,037	2,049	264	0.11	214	326
1999	1,804	0.16	1,327	2,452	244	0.11	196	304
2000	6,495	0.10	5,364	7,863	232	0.12	185	291
2001	7,201	0.09	6,041	8,584	219	0.12	172	278
2002	947	0.21	627	1,430	183	0.13	142	235
2003	862	0.18	604	1,231	169	0.13	132	216
2004	752	0.21	499	1,133	186	0.11	151	230
2005	2,124	0.14	1,624	2,777	224	0.11	182	277
2006	6,165	0.11	5,009	7,588	244	0.11	196	304
2007	5,995	0.11	4,823	7,452	217	0.12	172	274
2008	7,112	0.11	5,741	8,810	216	0.12	170	275
2009	3,589	0.14	2,745	4,692	216	0.12	171	272
2010	1,569	0.21	1,053	2,336	295	0.11	239	364
2011	4,849	0.15	3,655	6,434	347	0.10	284	425
2012	1,320	0.29	753	2,314	372	0.10	304	456
2013	19,950	0.15	14,753	26,978	407	0.11	328	504
2014	2,422	0.38	1,174	4,994	317	0.12	252	397
2015	754	0.42	341	1,669	273	0.13	211	352
2016	210	0.55	77	578	217	0.14	167	283

Table 1.24. GOA pollock life history and fishery characteristics 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 1983-2016.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2011-2015)*	*Spawning (Avg. 2012-2016)*	*Population (Avg. 2011-2015)*	*Fishery (Est. 2017 from RE model)*	*Proportion mature females*
1	1.39	0.003	0.012	0.027	0.150	0.000
2	0.69	0.030	0.098	0.222	0.381	0.000
3	0.48	0.240	0.285	0.409	0.470	0.015
4	0.37	0.762	0.561	0.726	0.713	0.272
5	0.34	0.972	0.847	0.996	0.823	0.573
6	0.30	0.998	1.161	1.250	1.091	0.837
7	0.30	1.000	1.342	1.424	1.236	0.923
8	0.29	0.991	1.495	1.535	1.404	0.967
9	0.28	0.883	1.612	1.689	1.631	0.987
10+	0.29	0.357	1.740	1.866	1.710	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 1990-2015 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	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
2015	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	300,000

Table 1.26. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2016-2029 under different harvest policies. For these projections, fishery weight at age was assumed to be equal to the estimated weight at age in 2017 for the RE model. All projections begin with initial age composition in 2016 using the base run model with a projected 2016 catch of 178,938 t. The values for B100%, B40%, and B35% are 667,000 t, 267,000 t, 234,000 t, respectively.

Spawning biomass (t)	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2016	320,094	320,094	320,094	320,094	320,094	320,094	320,094
2017	363,800	363,800	369,379	375,547	380,214	360,949	363,800
2018	348,330	348,330	381,340	421,031	453,433	332,464	348,330
2019	264,127	265,958	311,398	373,414	428,065	243,749	262,116
2020	215,623	223,048	263,947	335,601	403,446	198,264	207,705
2021	213,821	223,253	255,754	332,245	408,577	198,583	203,485
2022	239,520	250,468	280,050	365,478	452,681	223,612	225,967
2023	260,538	271,880	302,977	396,257	491,461	242,638	243,726
2024	272,902	284,306	319,806	423,008	529,089	252,438	252,939
2025	277,504	288,806	329,452	442,480	560,535	254,980	255,230
2026	280,632	291,799	337,161	458,869	588,456	256,677	256,810
2027	283,961	294,992	344,372	472,656	611,163	259,086	259,159
2028	287,546	298,490	351,346	485,061	630,877	261,968	262,009
2029	287,795	298,575	354,320	492,266	643,859	261,669	261,692
Fishing mortality	*Max F_{ABC}*	*Author's recommended F*	*Average F*	*$F_{75\%}$*	*F = 0*	*F_{OFL}*	*Max F_{ABC} for two years, then F_{OFL}*
2016	0.18	0.18	0.18	0.18	0	0.18	0.18
2017	0.25	0.25	0.16	0.07	0	0.30	0.25
2018	0.25	0.25	0.16	0.07	0	0.30	0.25
2019	0.25	0.21	0.16	0.07	0	0.27	0.29
2020	0.20	0.17	0.16	0.07	0	0.21	0.22
2021	0.19	0.17	0.16	0.07	0	0.21	0.21
2022	0.20	0.18	0.16	0.07	0	0.22	0.23
2023	0.21	0.19	0.16	0.07	0	0.24	0.24
2024	0.21	0.20	0.16	0.07	0	0.24	0.24
2025	0.22	0.20	0.16	0.07	0	0.25	0.25
2026	0.22	0.21	0.16	0.07	0	0.25	0.25
2027	0.22	0.21	0.16	0.07	0	0.25	0.25
2028	0.22	0.21	0.16	0.07	0	0.25	0.25
2029	0.22	0.21	0.16	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 years, then F_{OFL}*
2016	178,938	178,938	178,938	178,938	178,938	178,938	178,938
2017	203,769	203,769	138,279	61,408	0	235,807	203,769
2018	157,496	157,496	115,355	55,703	0	175,254	157,496
2019	121,761	104,631	95,110	48,976	0	122,419	140,209
2020	107,642	97,956	99,895	51,912	0	110,964	118,609
2021	119,073	112,008	108,647	56,492	0	126,581	130,047
2022	131,811	126,784	110,293	55,855	0	143,648	144,520
2023	148,053	143,744	120,575	61,842	0	161,407	161,553
2024	157,373	153,267	127,799	66,861	0	169,807	169,734
2025	163,153	159,074	132,987	70,788	0	174,878	174,771
2026	165,907	161,751	134,937	71,996	0	177,306	177,260
2027	167,358	163,000	136,278	72,900	0	178,409	178,393
2028	168,116	164,117	136,958	73,444	0	179,305	179,302
2029	165,641	161,363	135,870	73,158	0	176,232	176,232

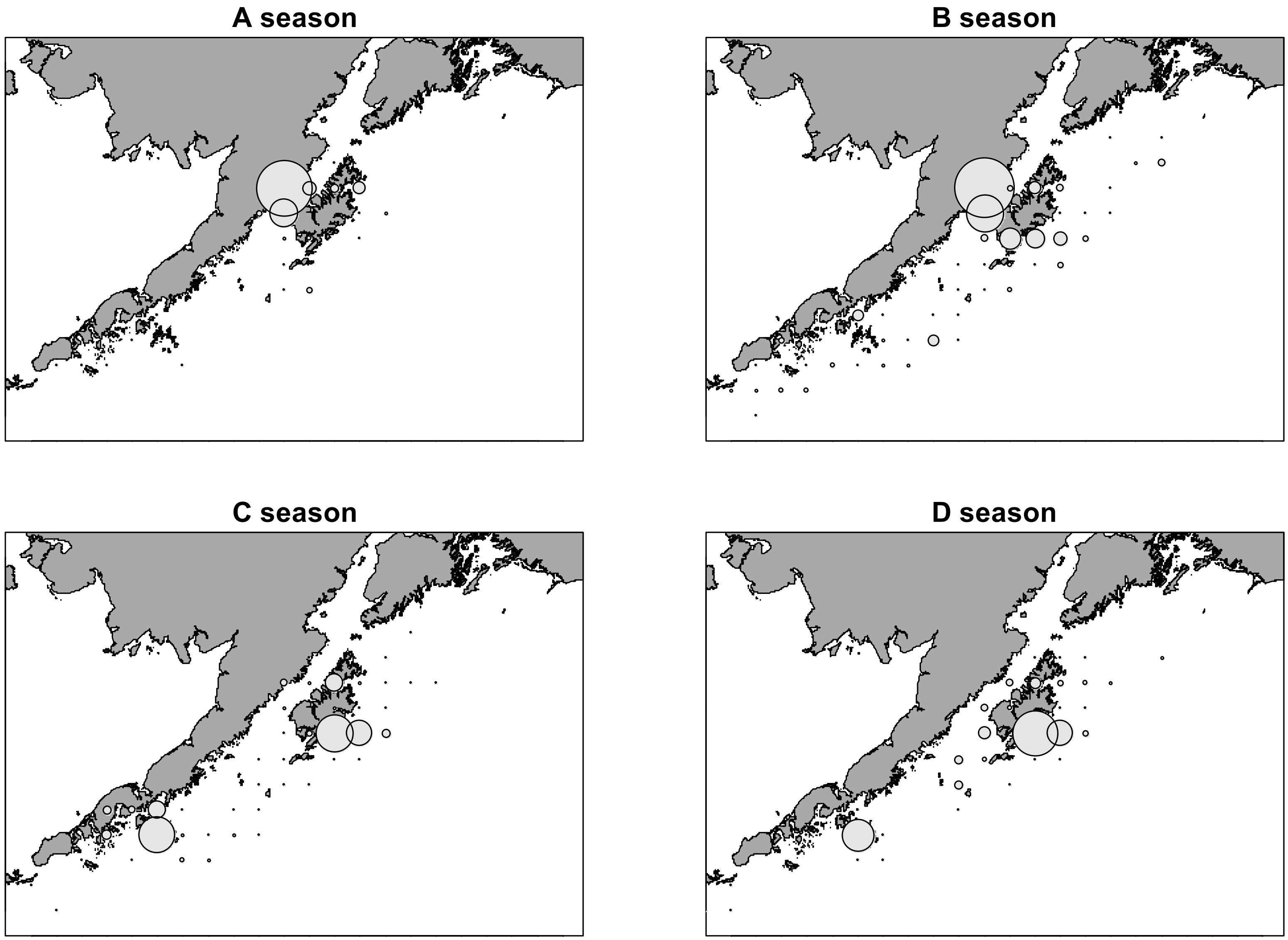


Figure 1.1. Pollock catch in 2015 for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

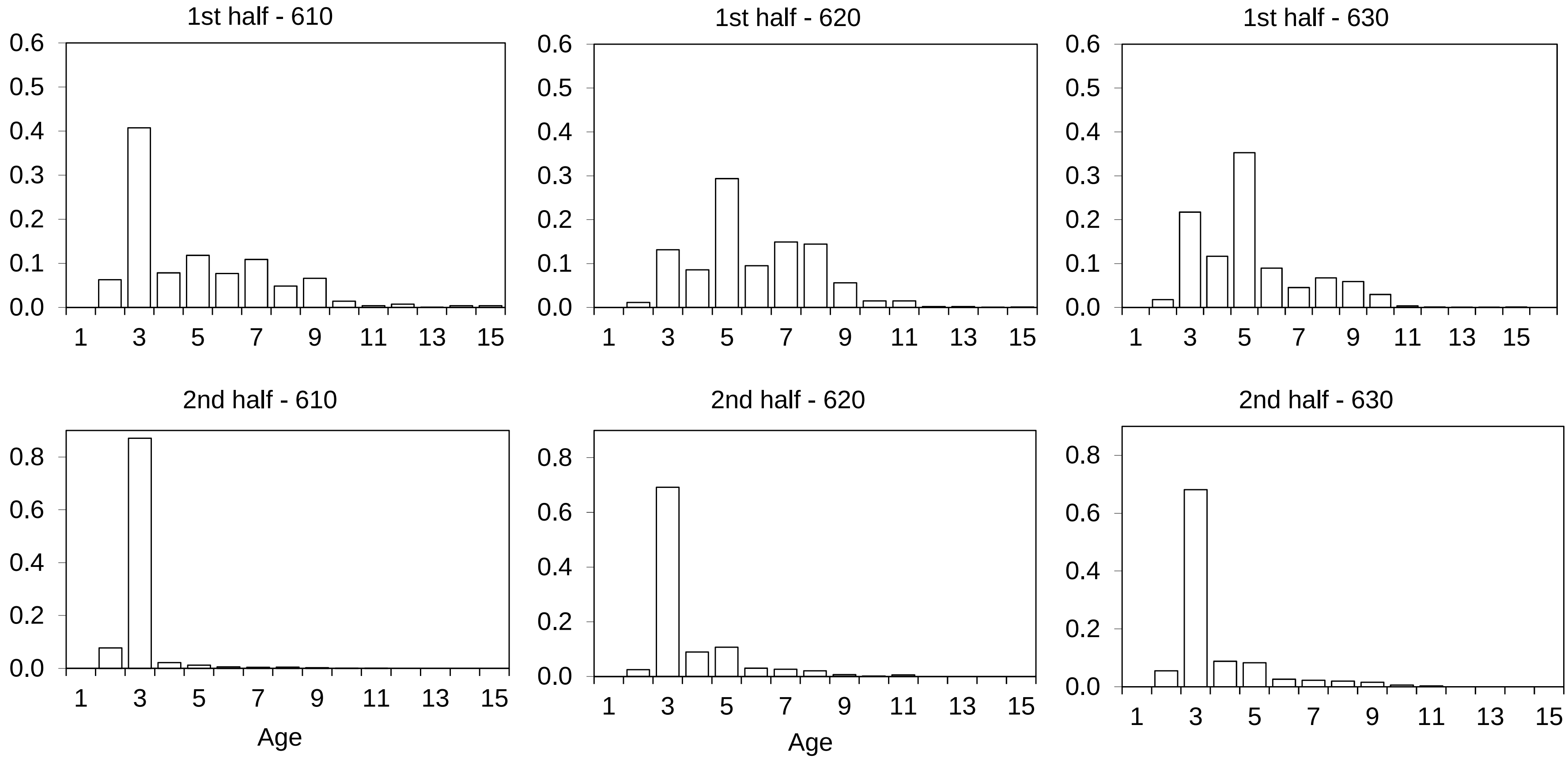


Figure 1.2. 2015 fishery age composition by half year (January-June, July-December) and statistical area.

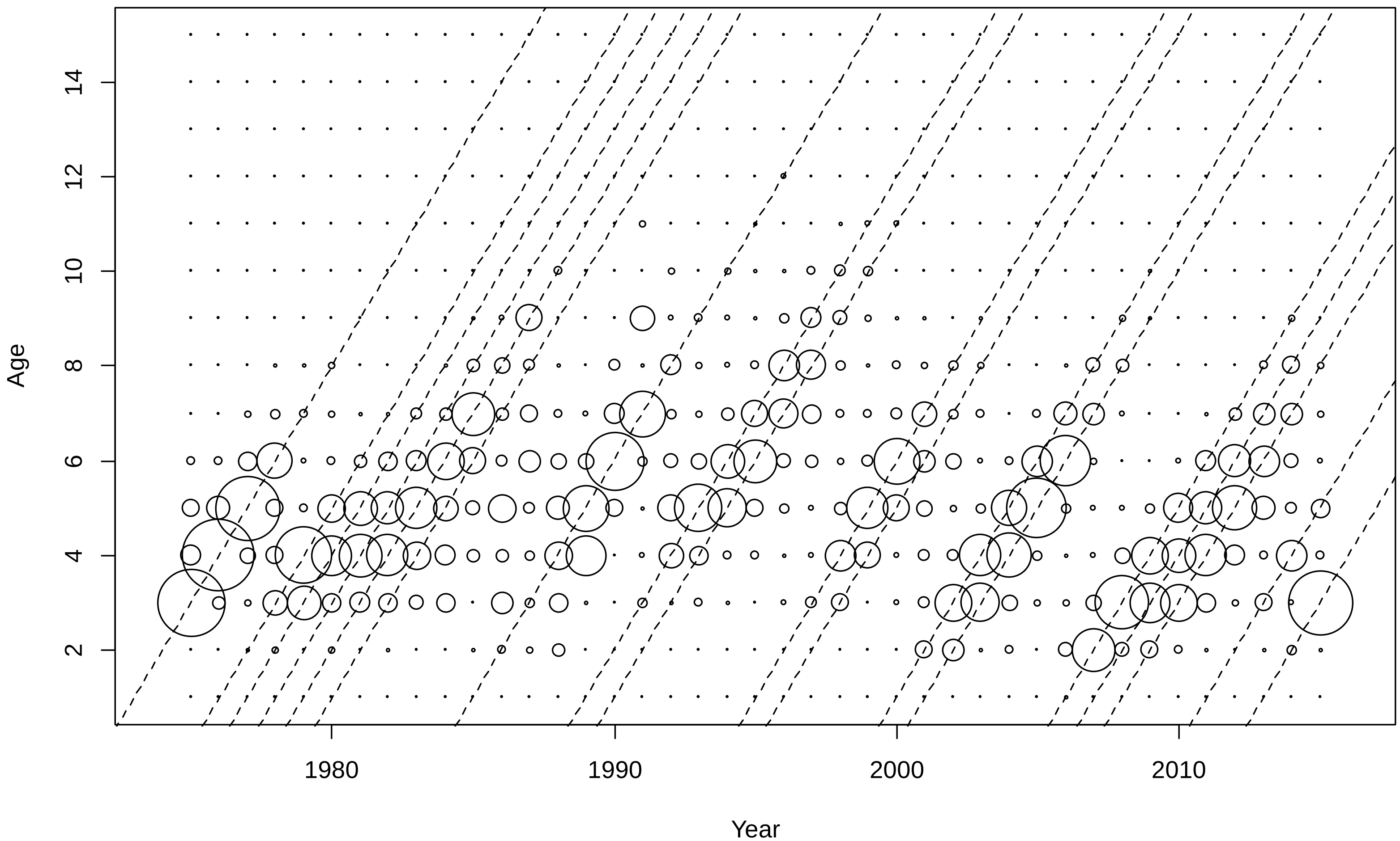


Figure 1.3. GOA pollock fishery age composition (1975-2015). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes.

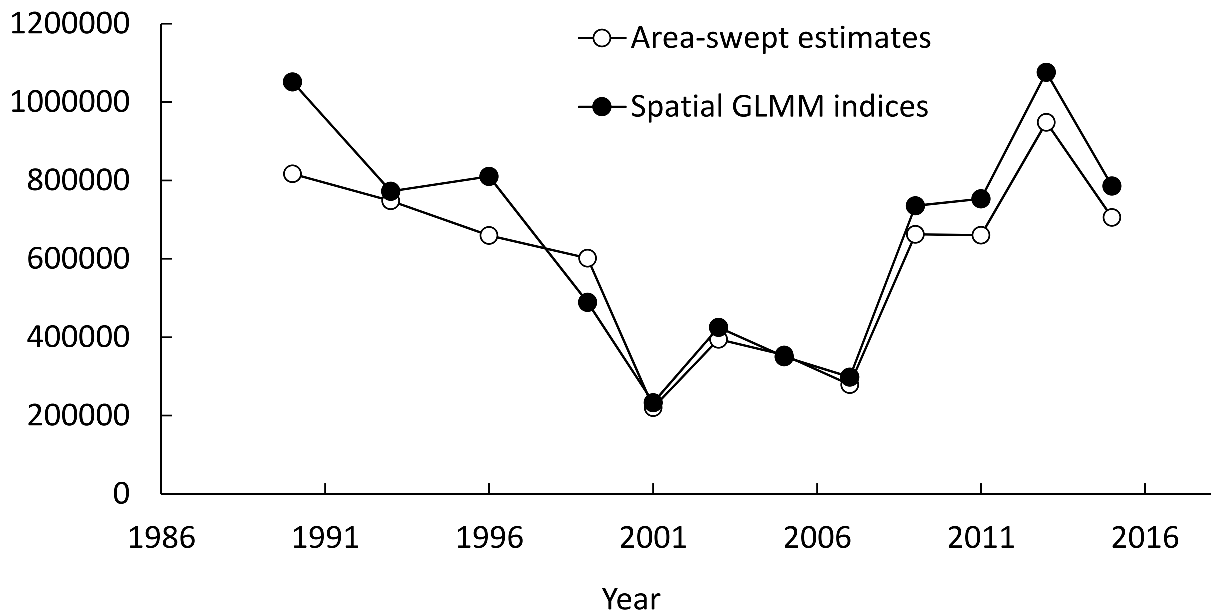


Figure 1.4. Comparison of area-swept estimates and indices from a spatial GLMM analysis for the NMFS bottom trawl survey.

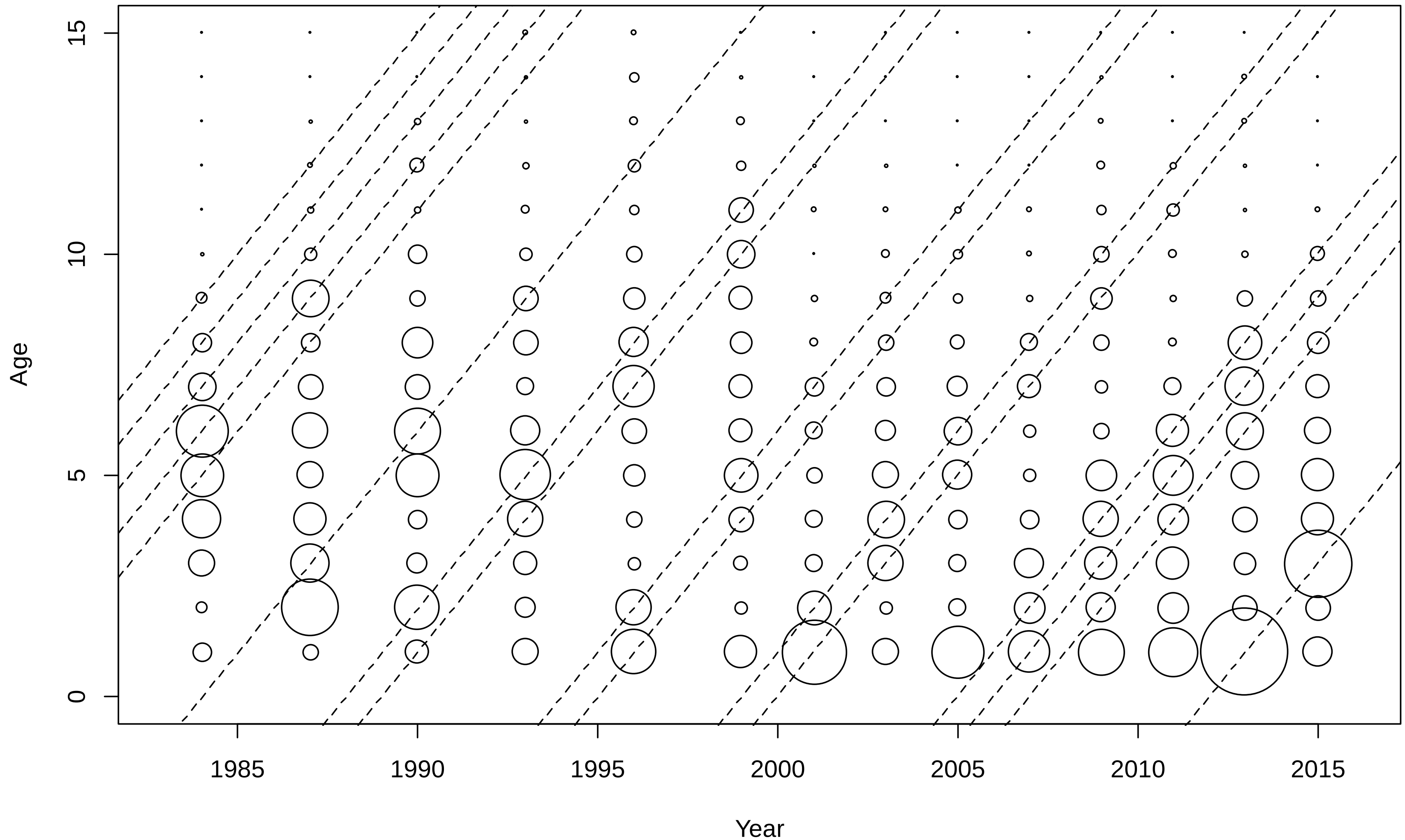


Figure 1.5. Estimated abundance at age in the NMFS bottom trawl survey (1984-2015). The area of the circle is proportional to the estimated abundance.

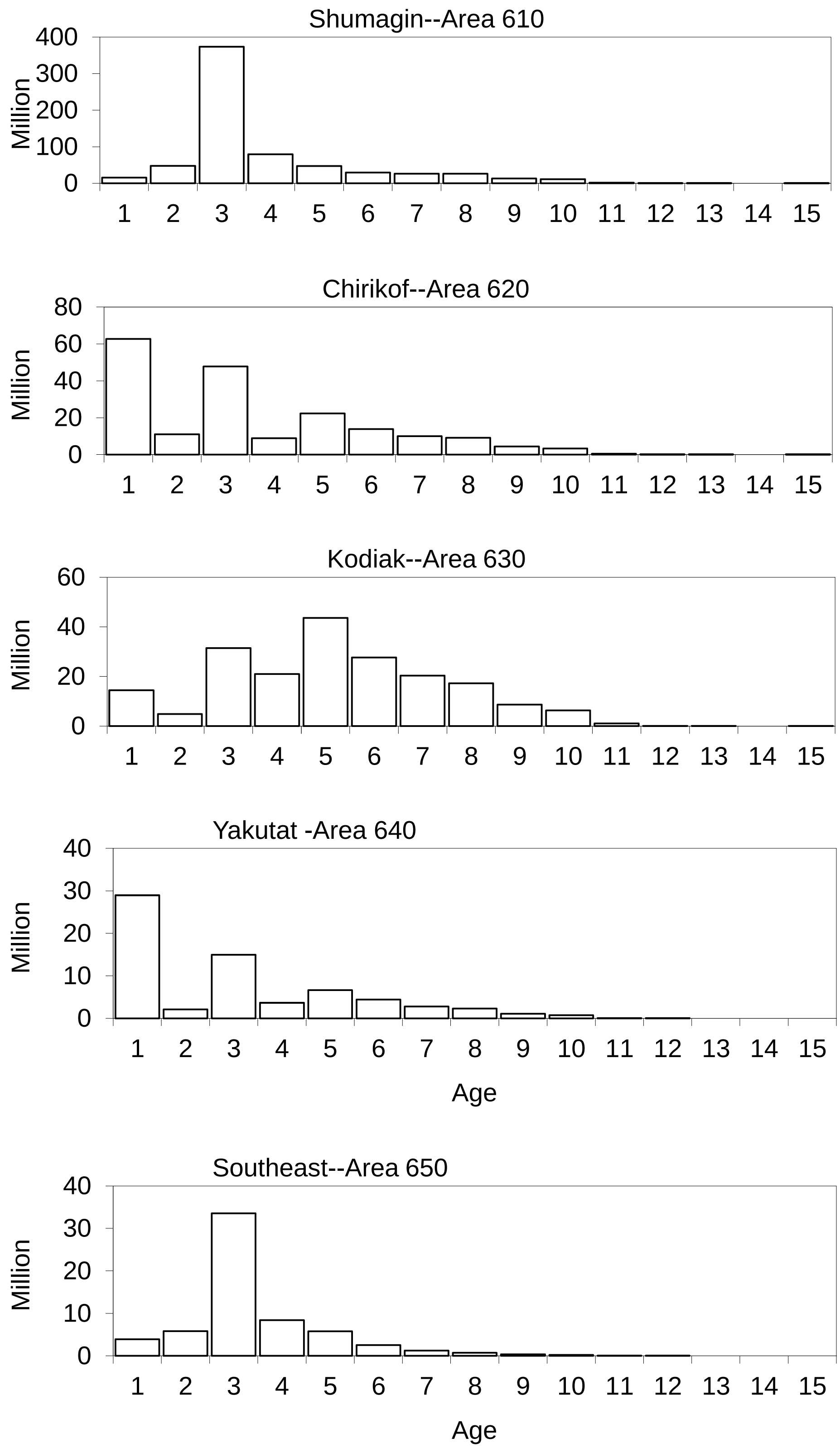


Figure 1.6. Age composition of pollock by statistical area for the 2015 NMFS bottom trawl survey.

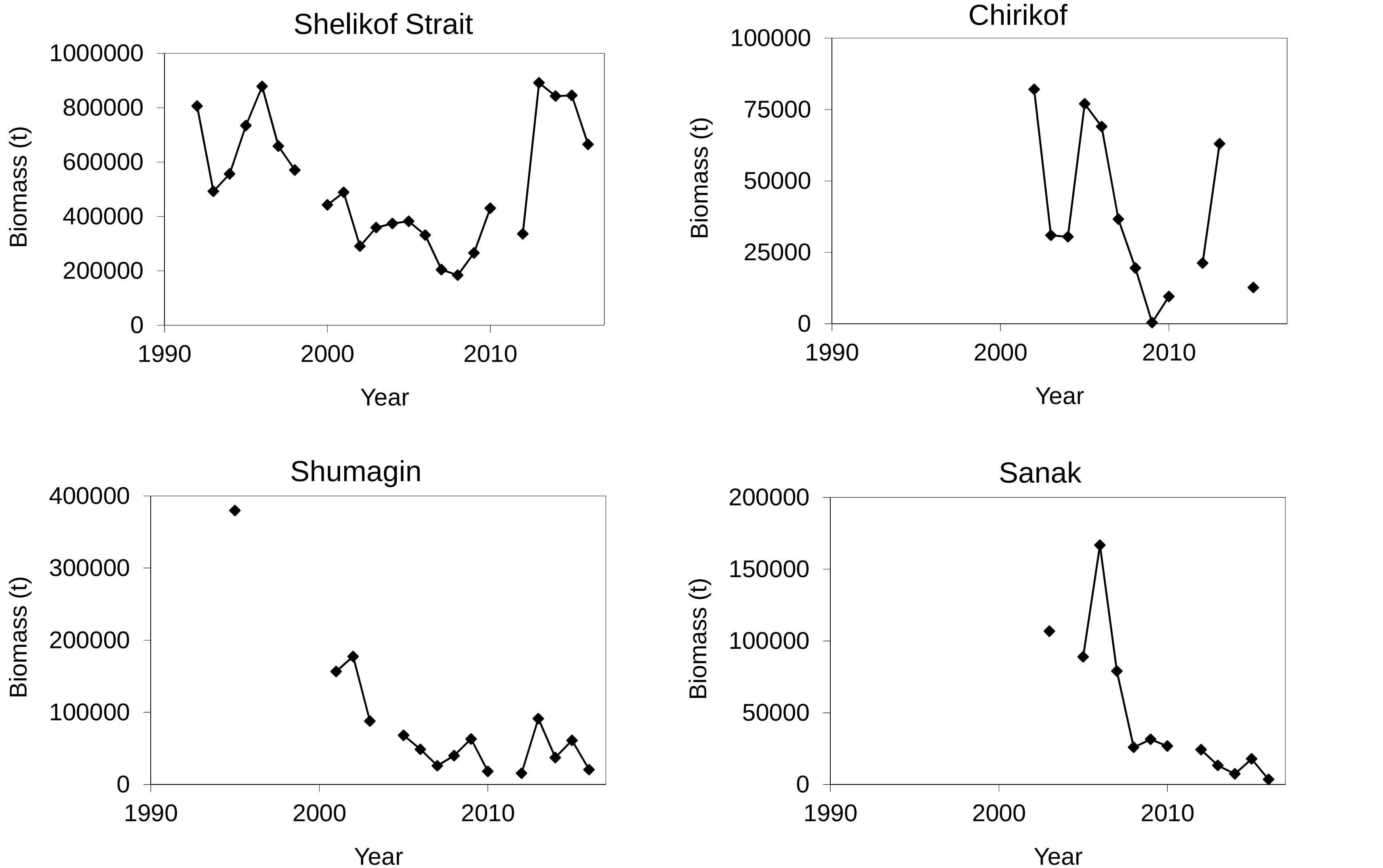


Figure 1.7. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

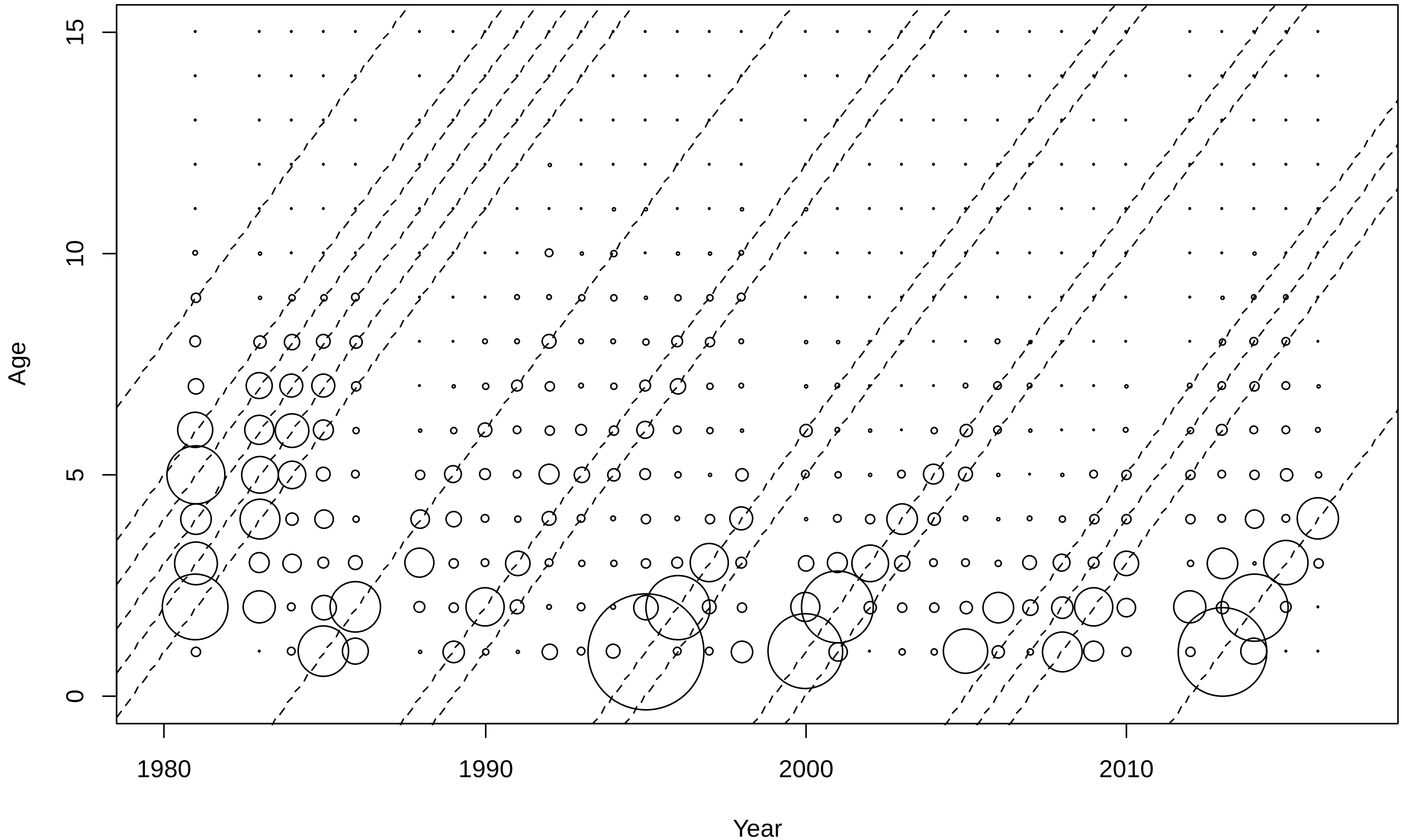


Figure 1.8. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2015, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

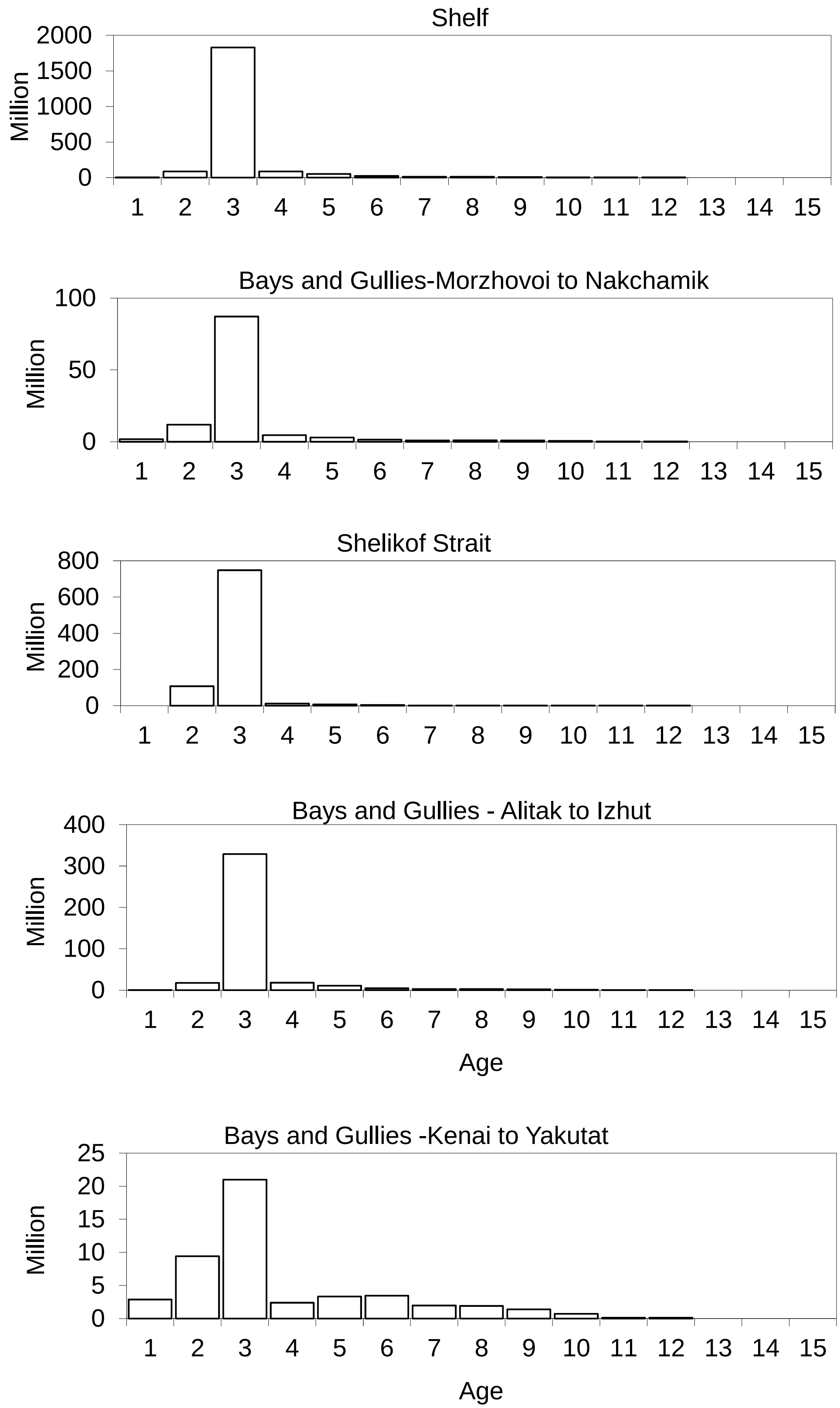


Figure 1.9. Age composition of pollock by statistical area for the 2015 NMFS summer acoustic survey.

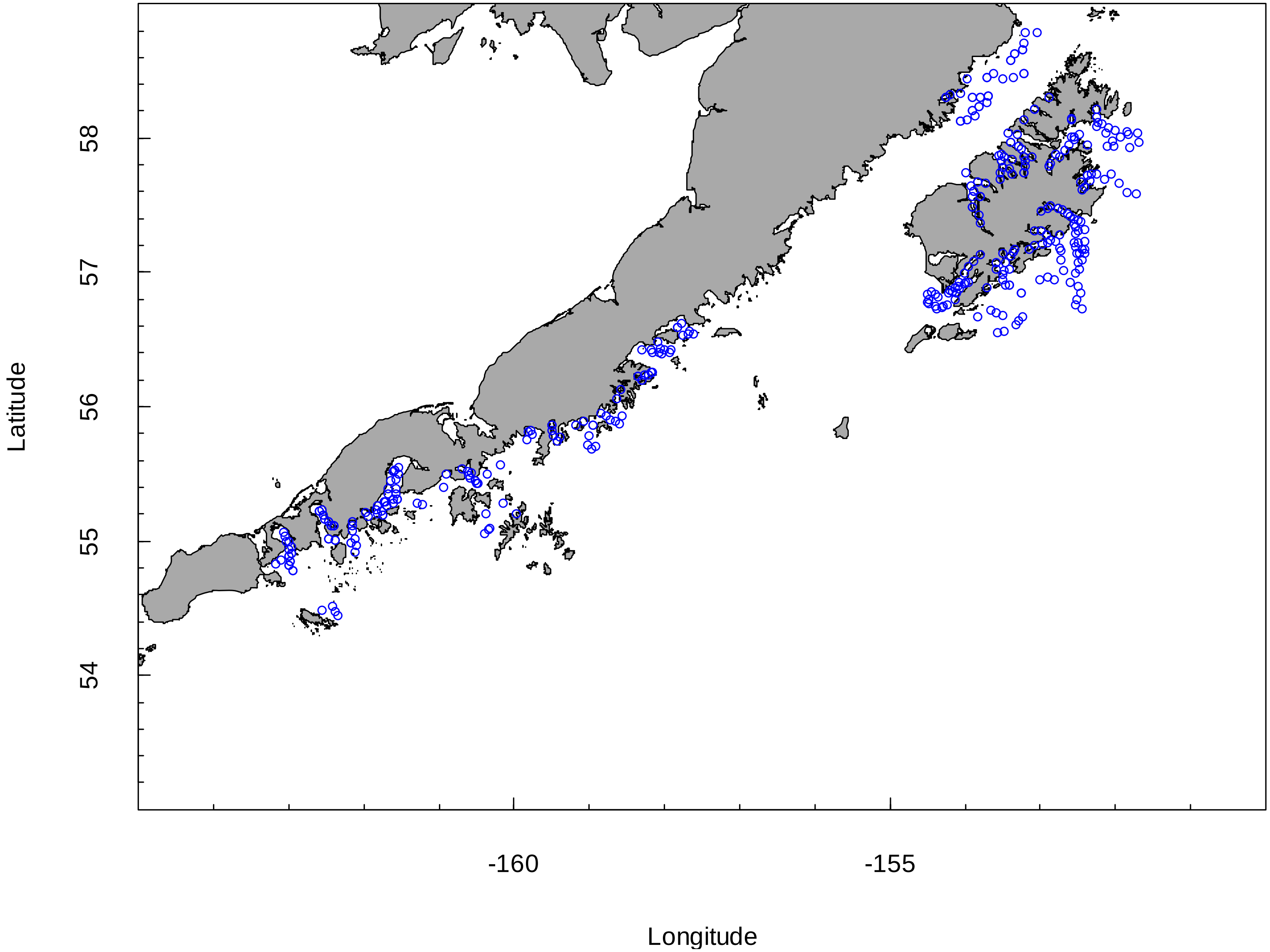


Figure 1.10. Tow locations for the 2016 ADFG bottom trawl survey.

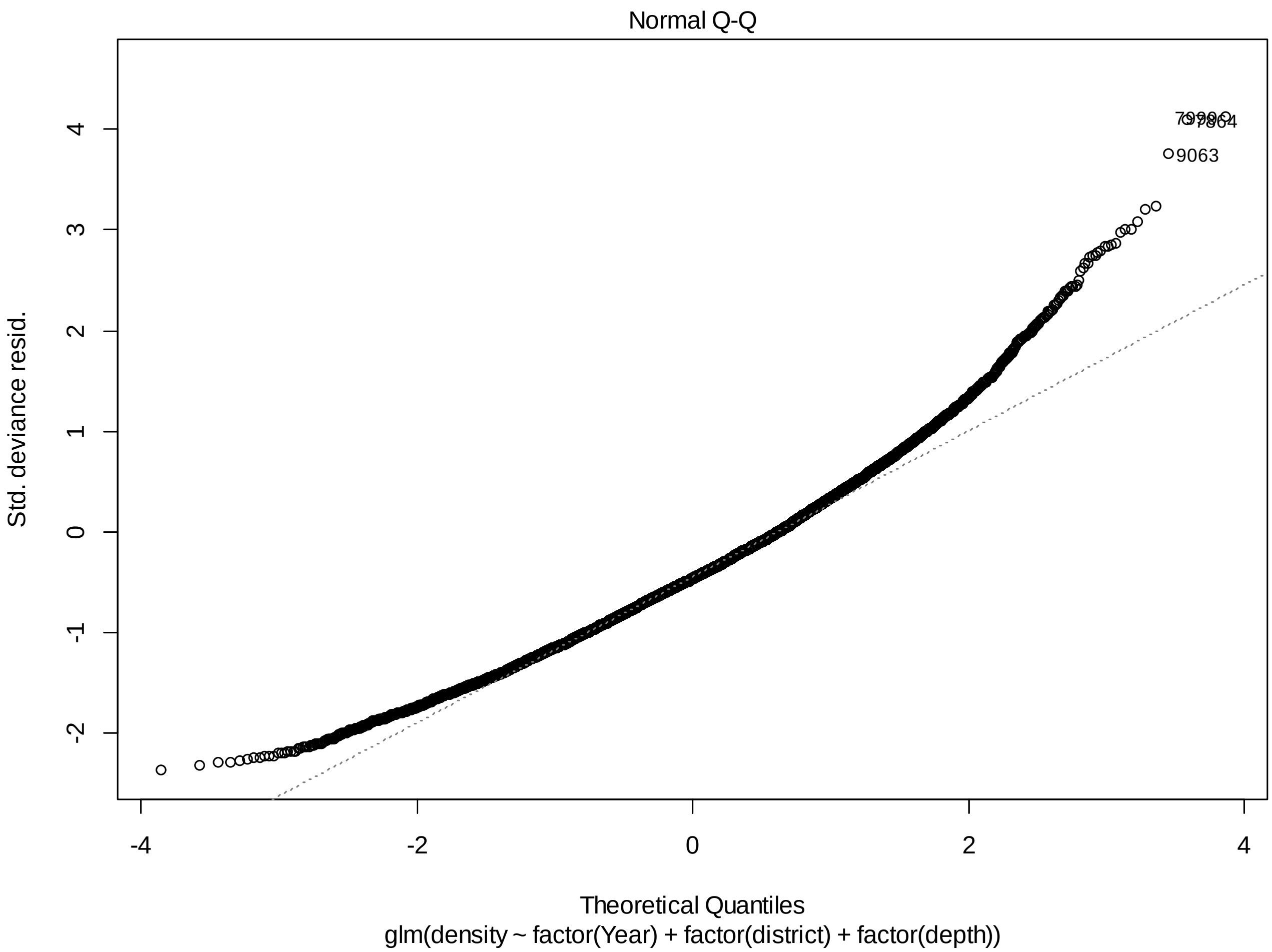


Figure 1.11. QQ plot for residuals for the GLM model for the positive observations with a gamma error assumption.

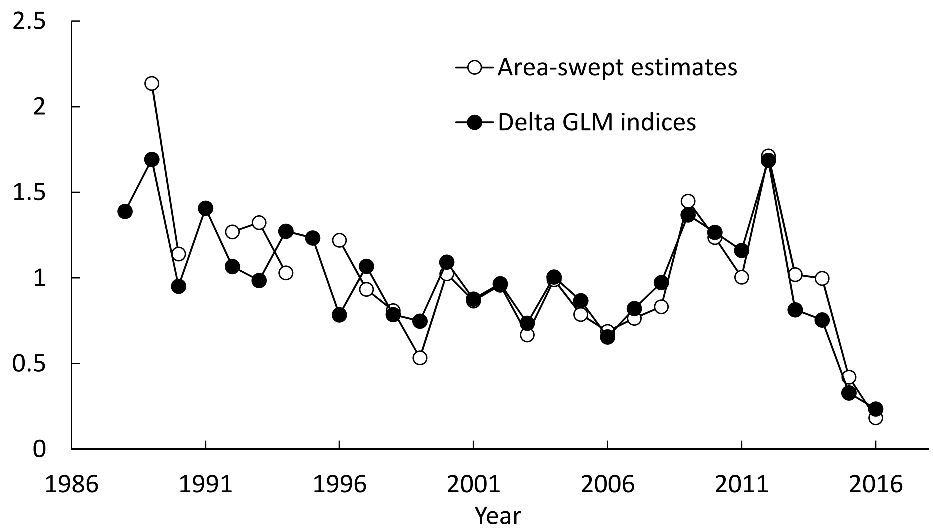


Figure 1.12. Comparison of ADFG bottom trawl area-swept indices with year indices for a delta GLM model with a gamma error assumption for the positive observations. Both time series have been scaled by the mean for the time series.

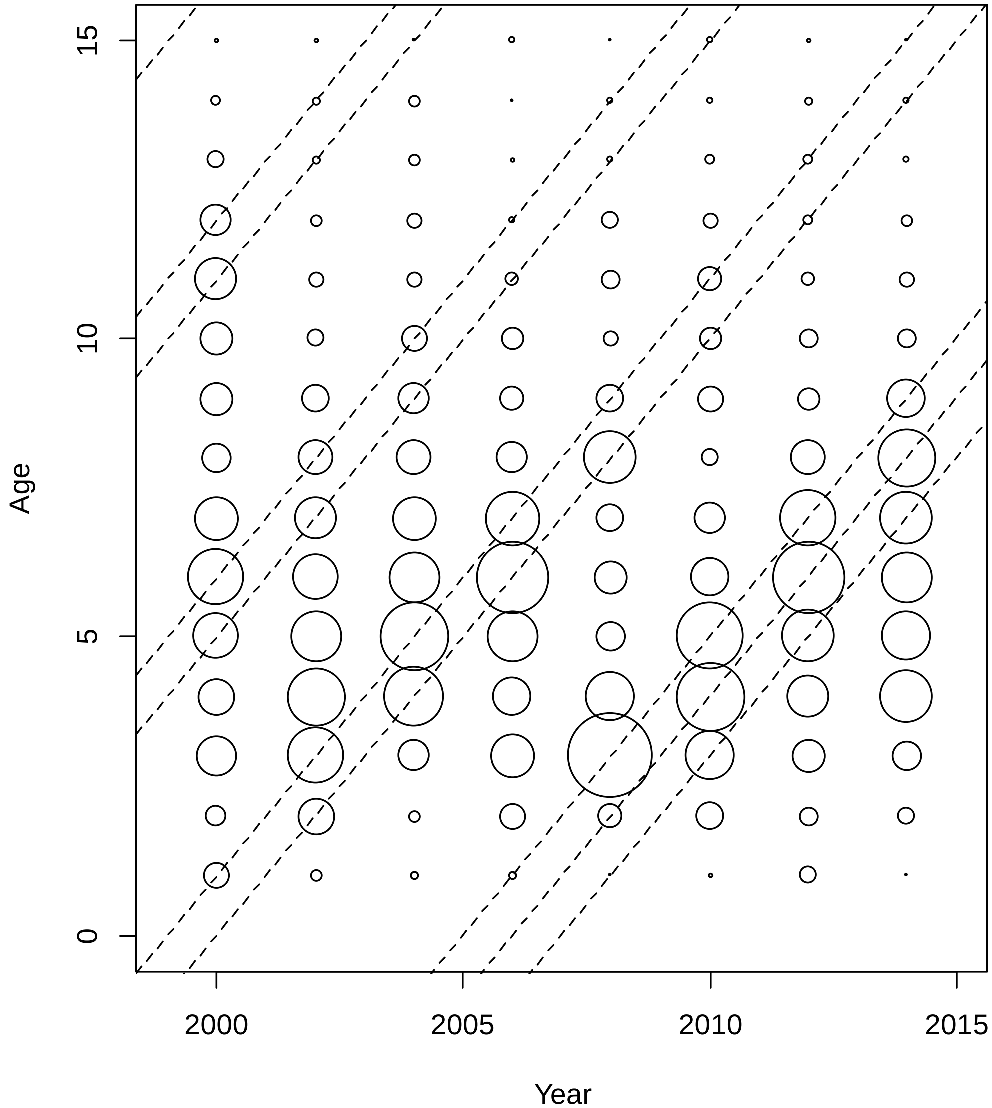


Figure 1.13. Estimated proportions at age in the ADFG crab/groundfish survey (2000-2014). The area of the circle is proportional to the estimated abundance.

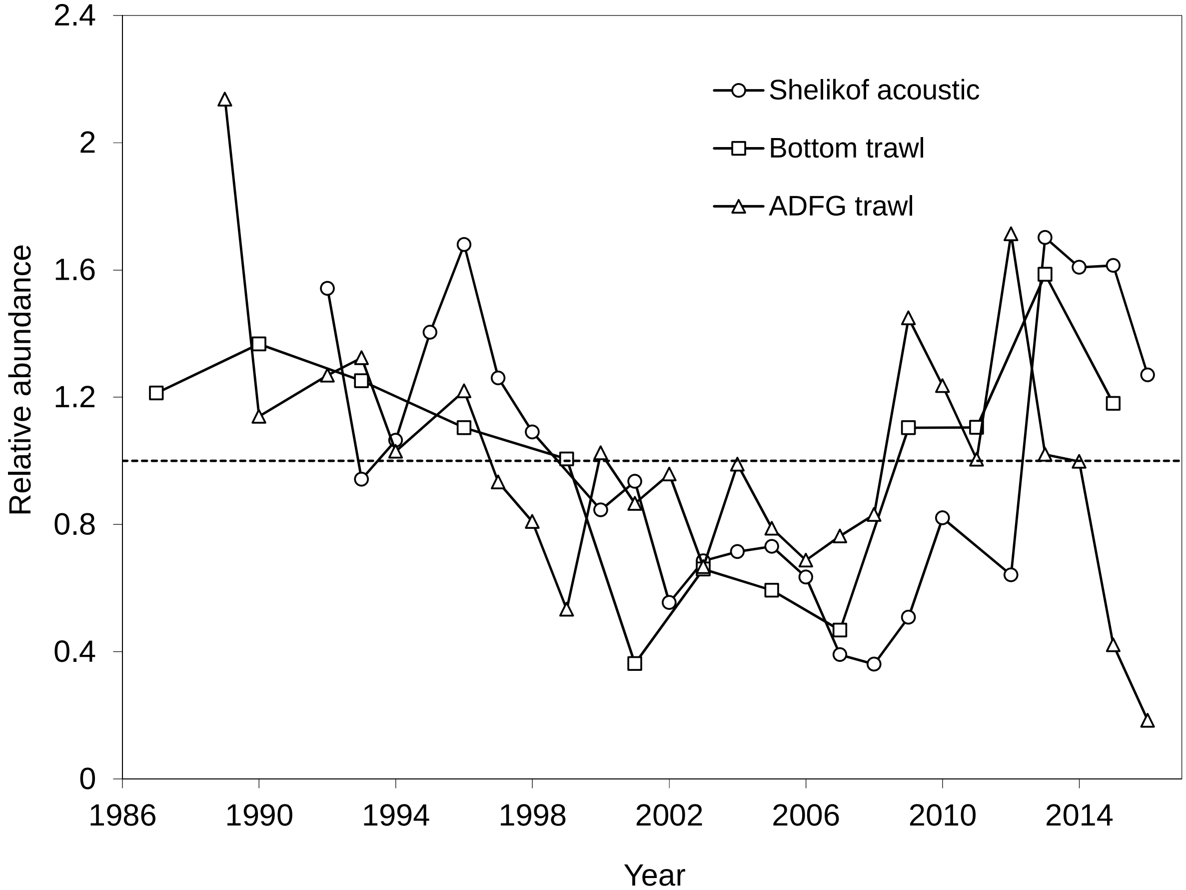


Figure 1.14. Relative trends in pollock biomass since 1987 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADFG crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1987. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the *R/V Oscar Dyson*.

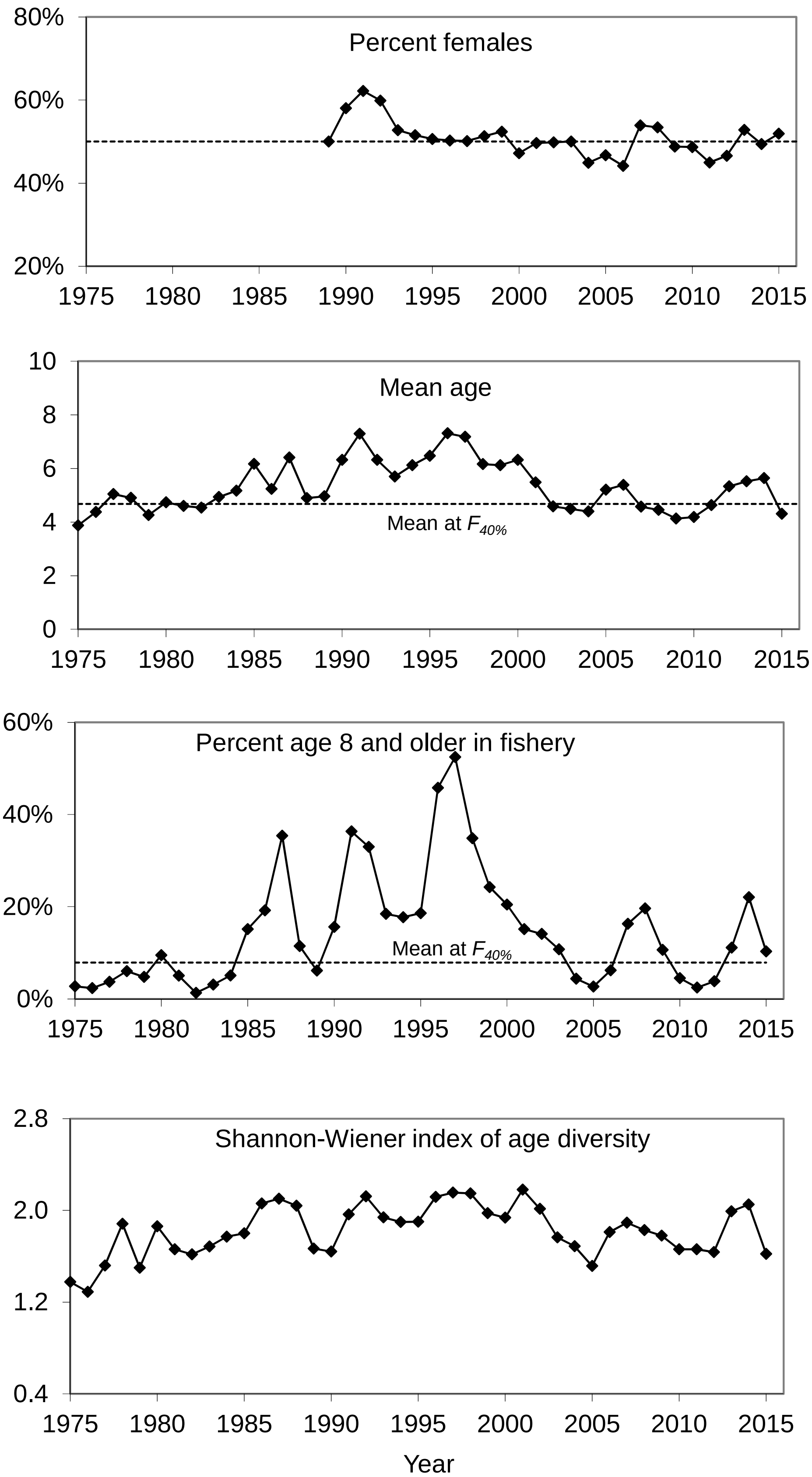


Figure 1.15. GOA pollock fishery catch characteristics.

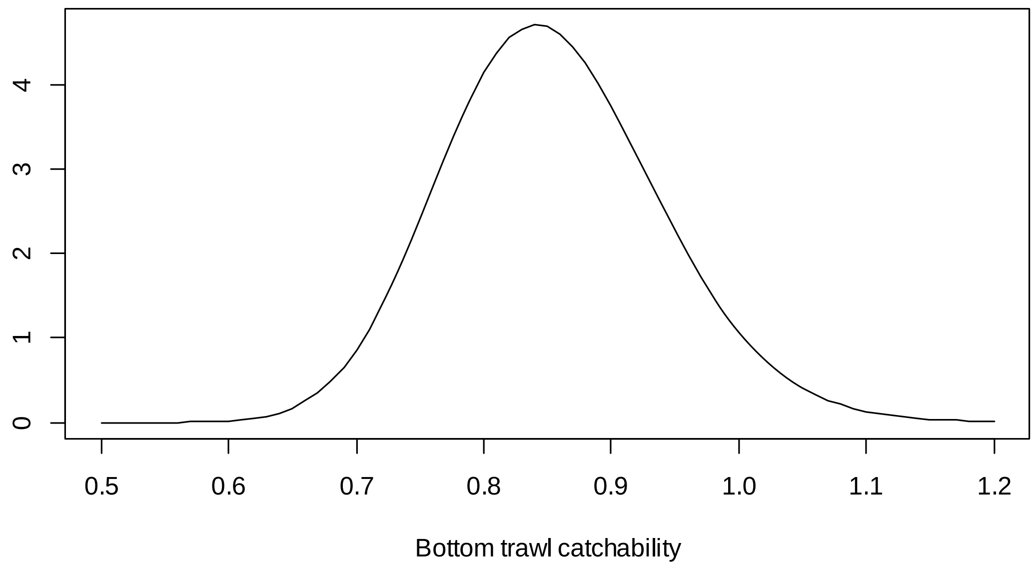


Figure 1.16. Prior on bottom trawl catchability used in the base model.

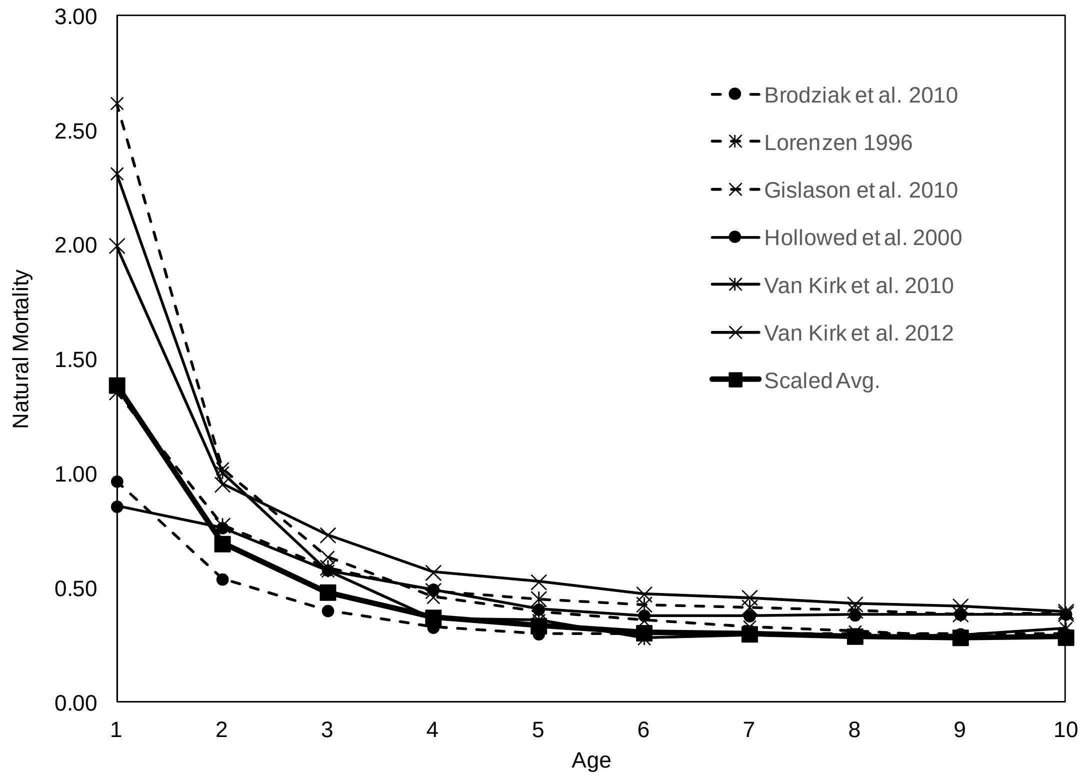


Figure 1.17. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

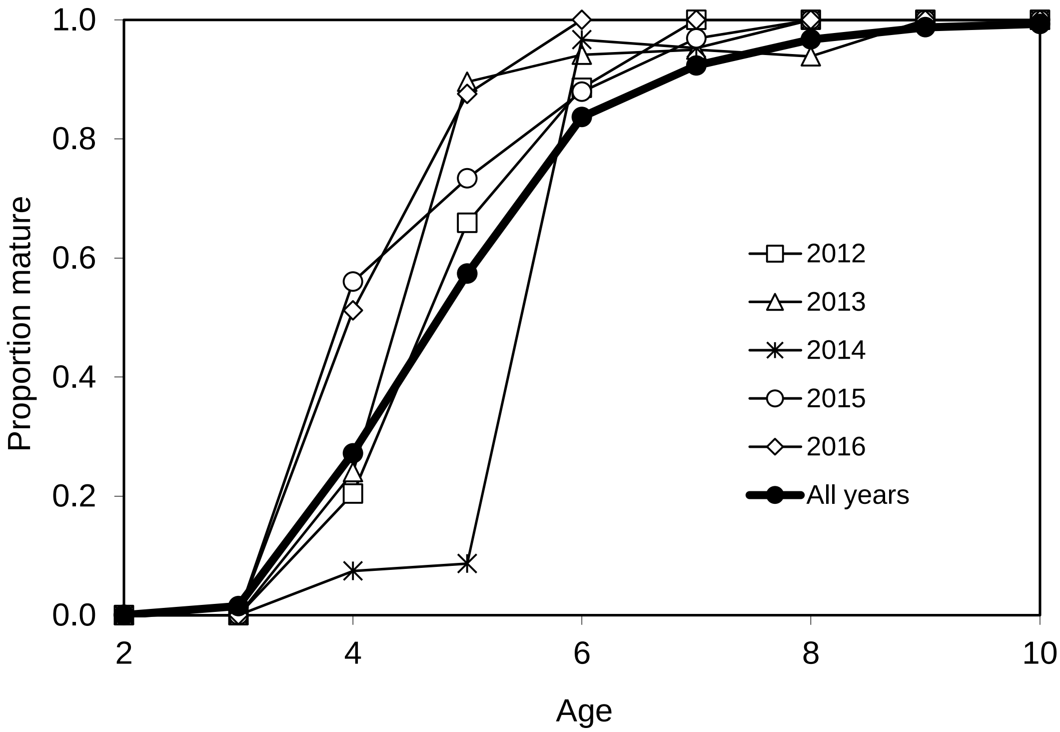
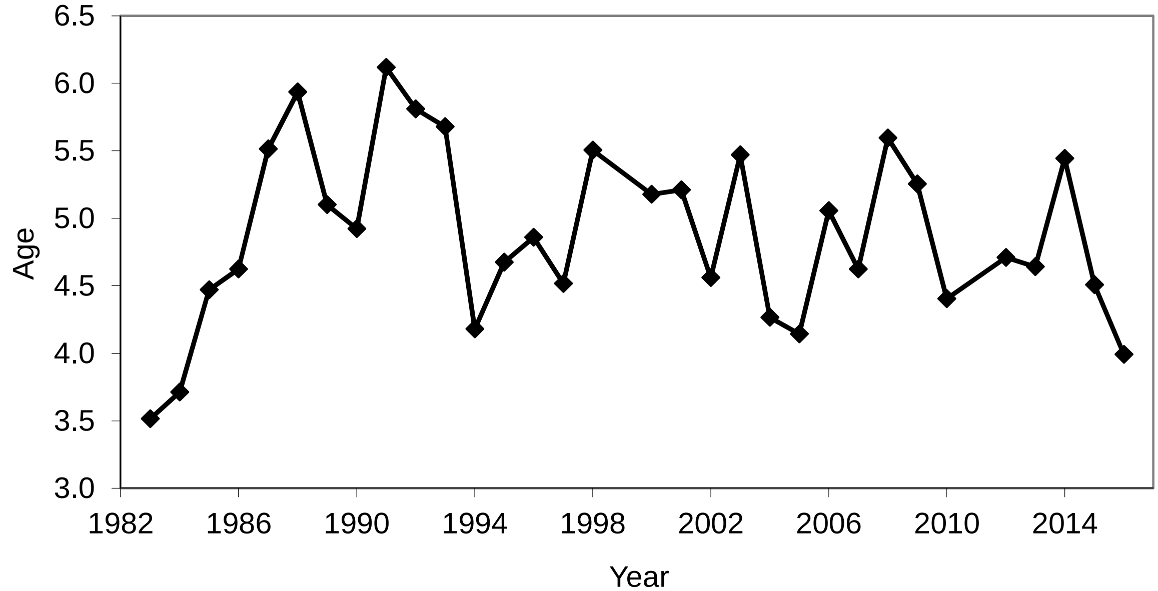


Figure 1.18. Estimates of the proportion mature at age from visual maturity data collected during 2012-2016 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2016).



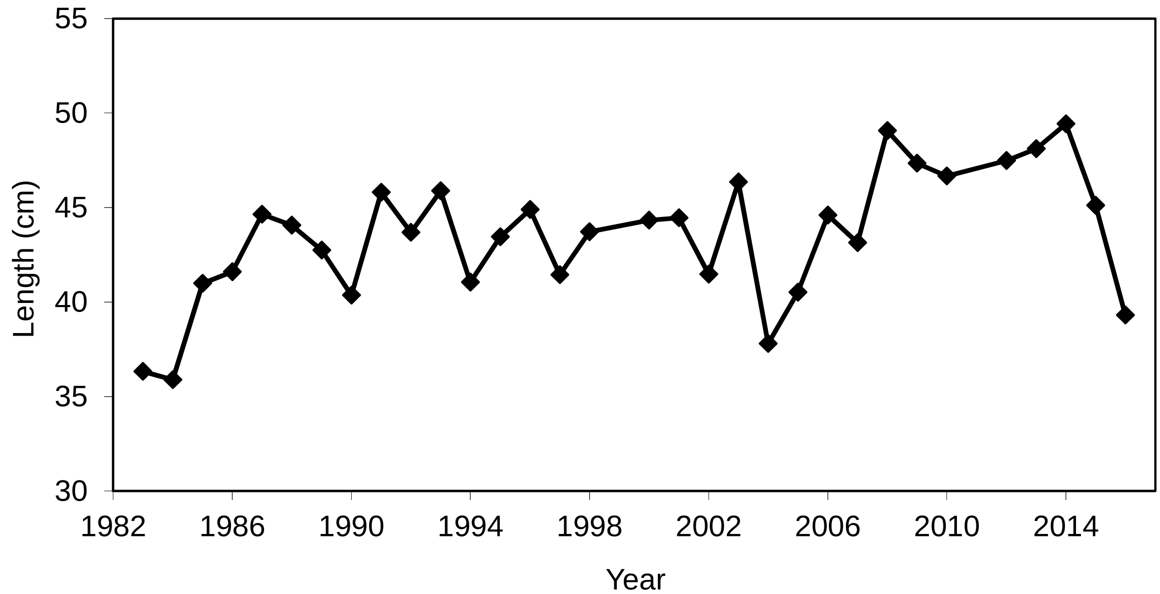


Figure 1.19. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2016.

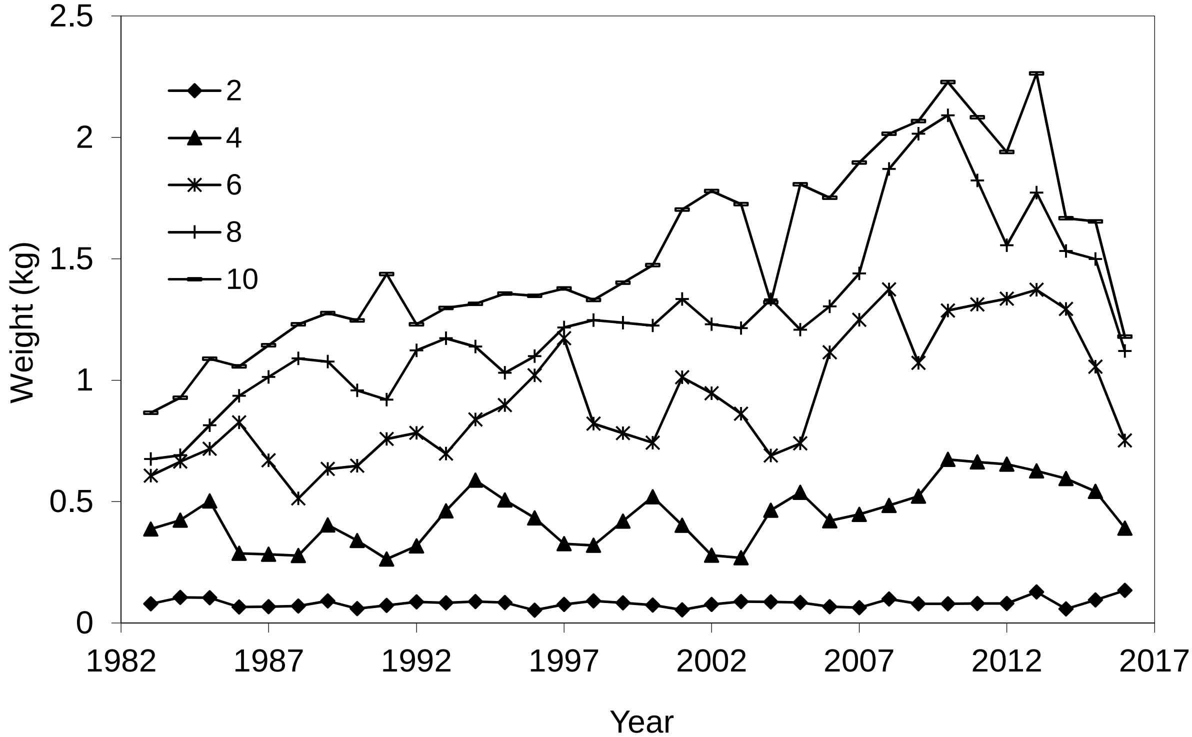


Figure 1.20. Estimated weight at age of GOA pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2016 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from adjacent years.

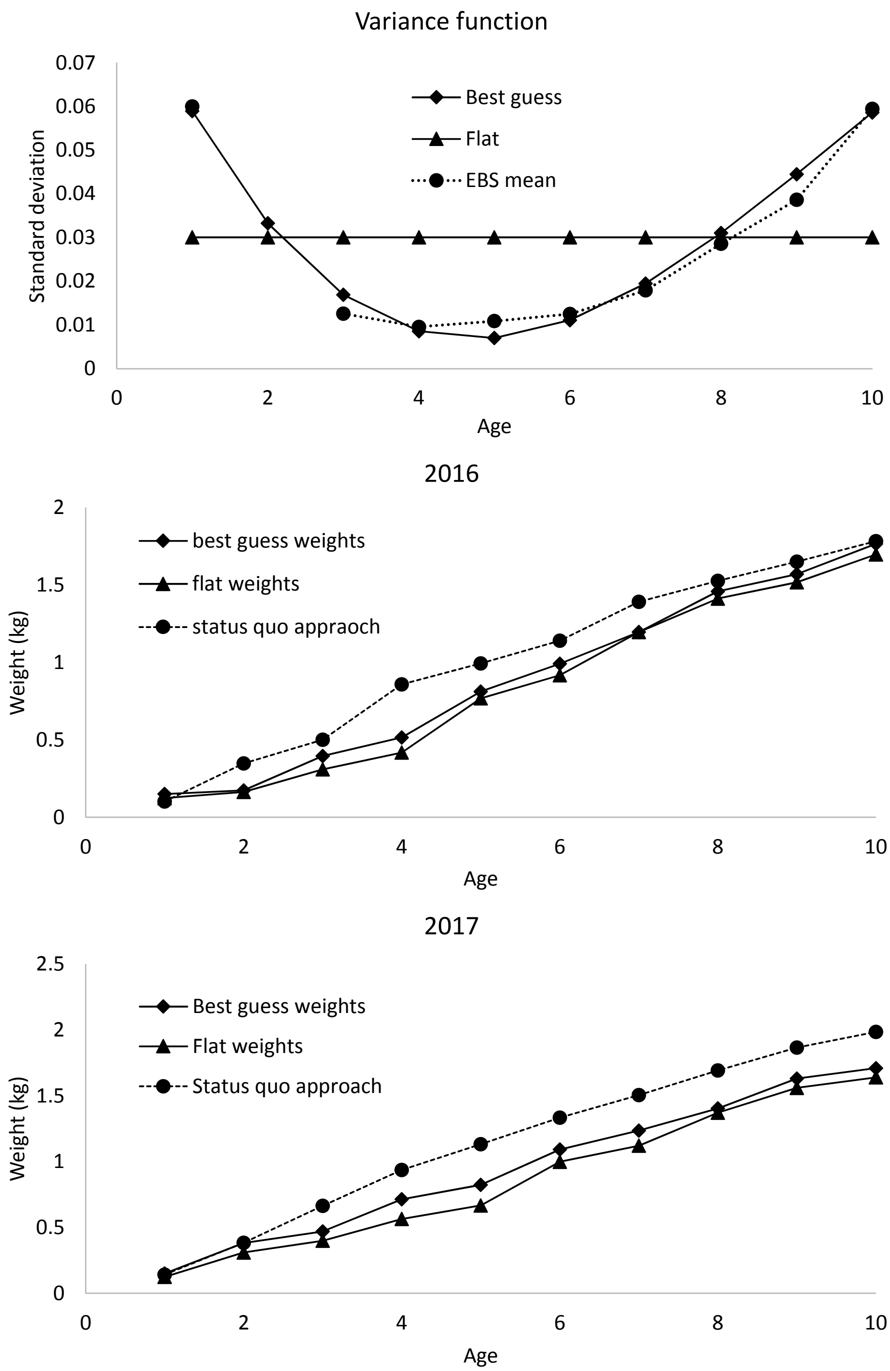


Figure 1.21. Variance assumptions for the fishery weight at age random effects model (top panel). Comparison of alternative methods of estimating/projecting fishery weight at age in 2016 and 2017 (middle and bottom panels). The status quo approach is to use 2015 estimates for 2016, and to use an average of the most recent five years for 2017.

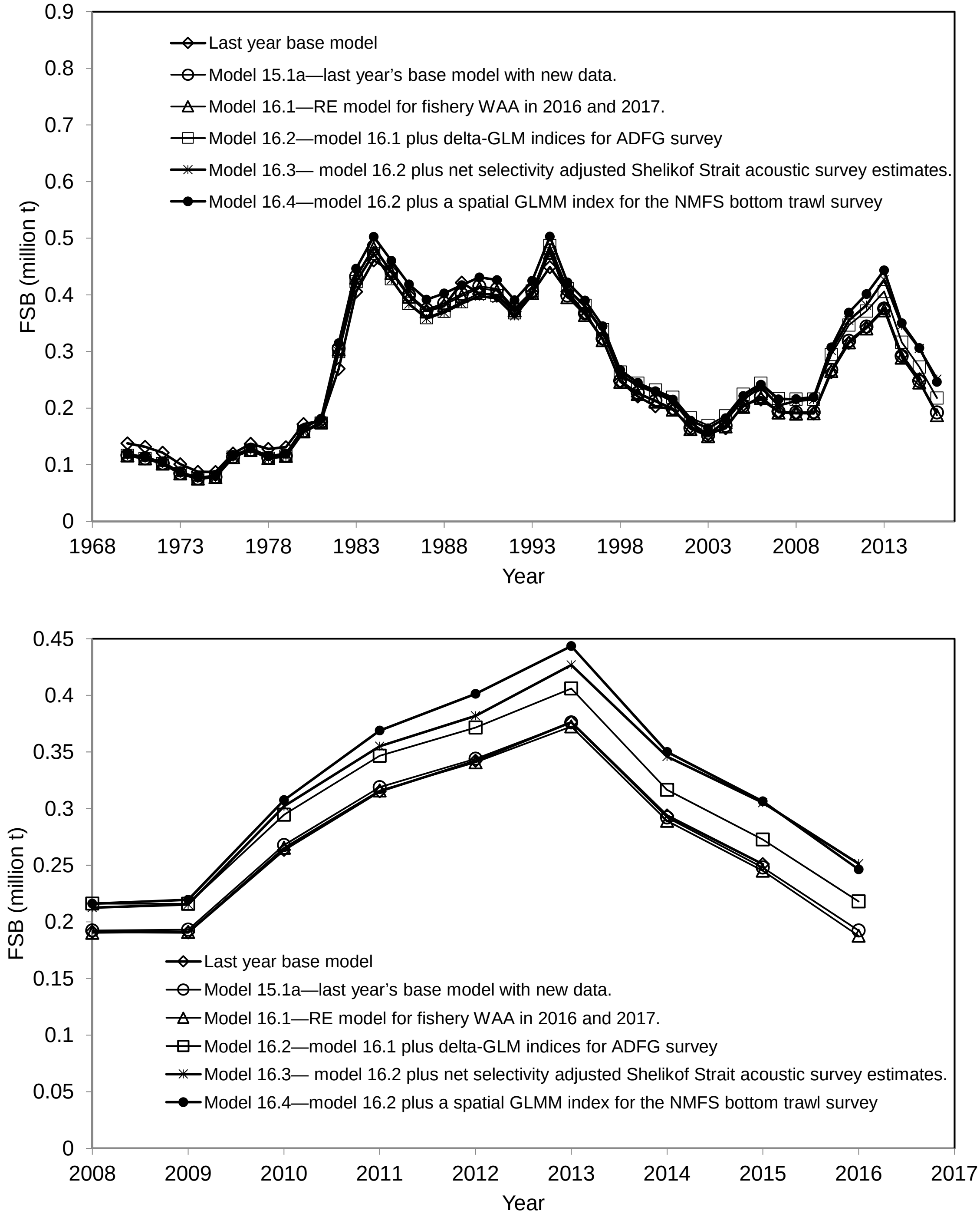


Figure 1.22. Comparison of estimated spawning biomass from alternative models. The lower panel shows the years 2008-2016 with an expanded scale to highlight differences. Model 15.1a was the base model last year. Models are described in more detail in the text.

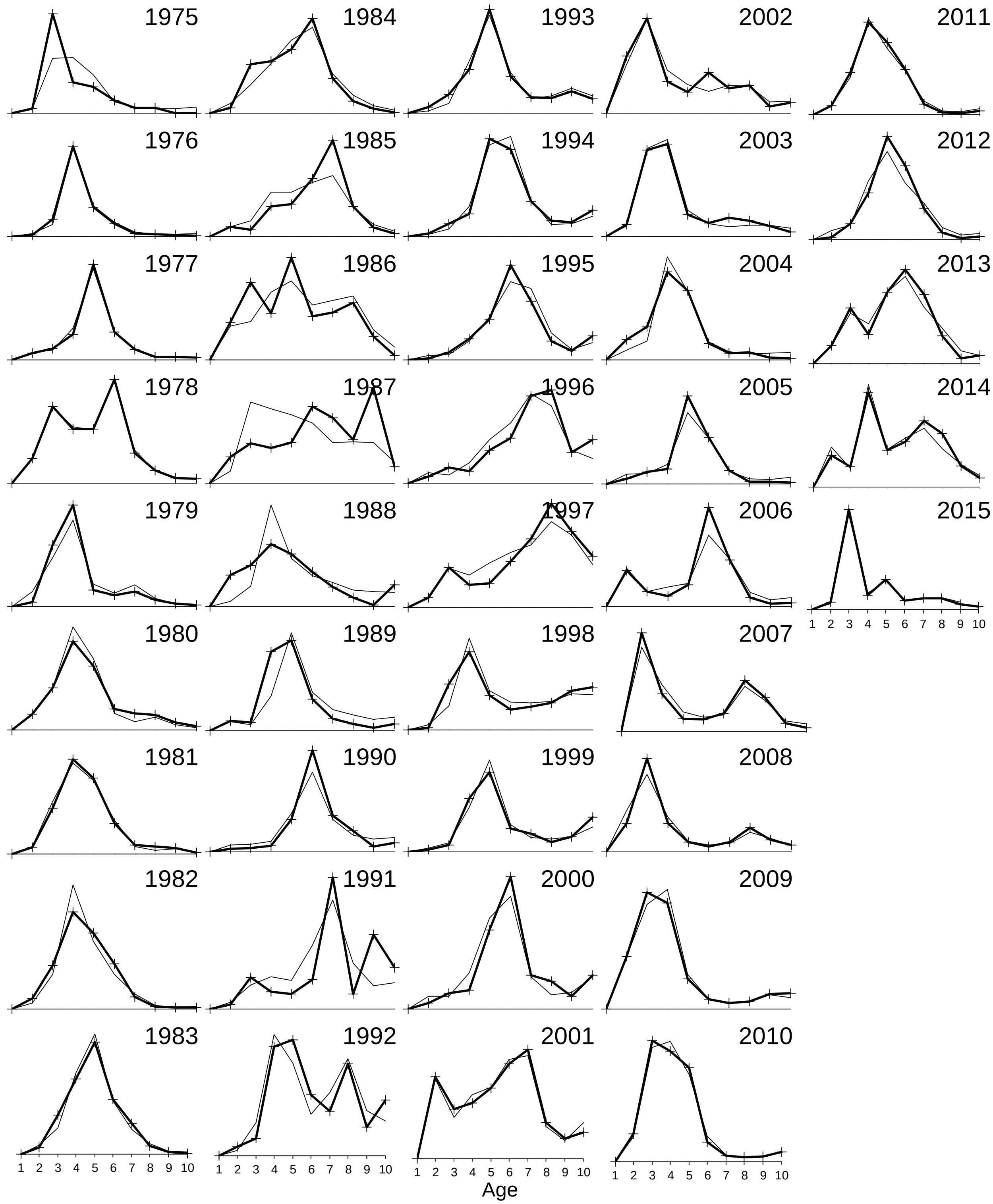


Figure 1.23. Observed and predicted fishery age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

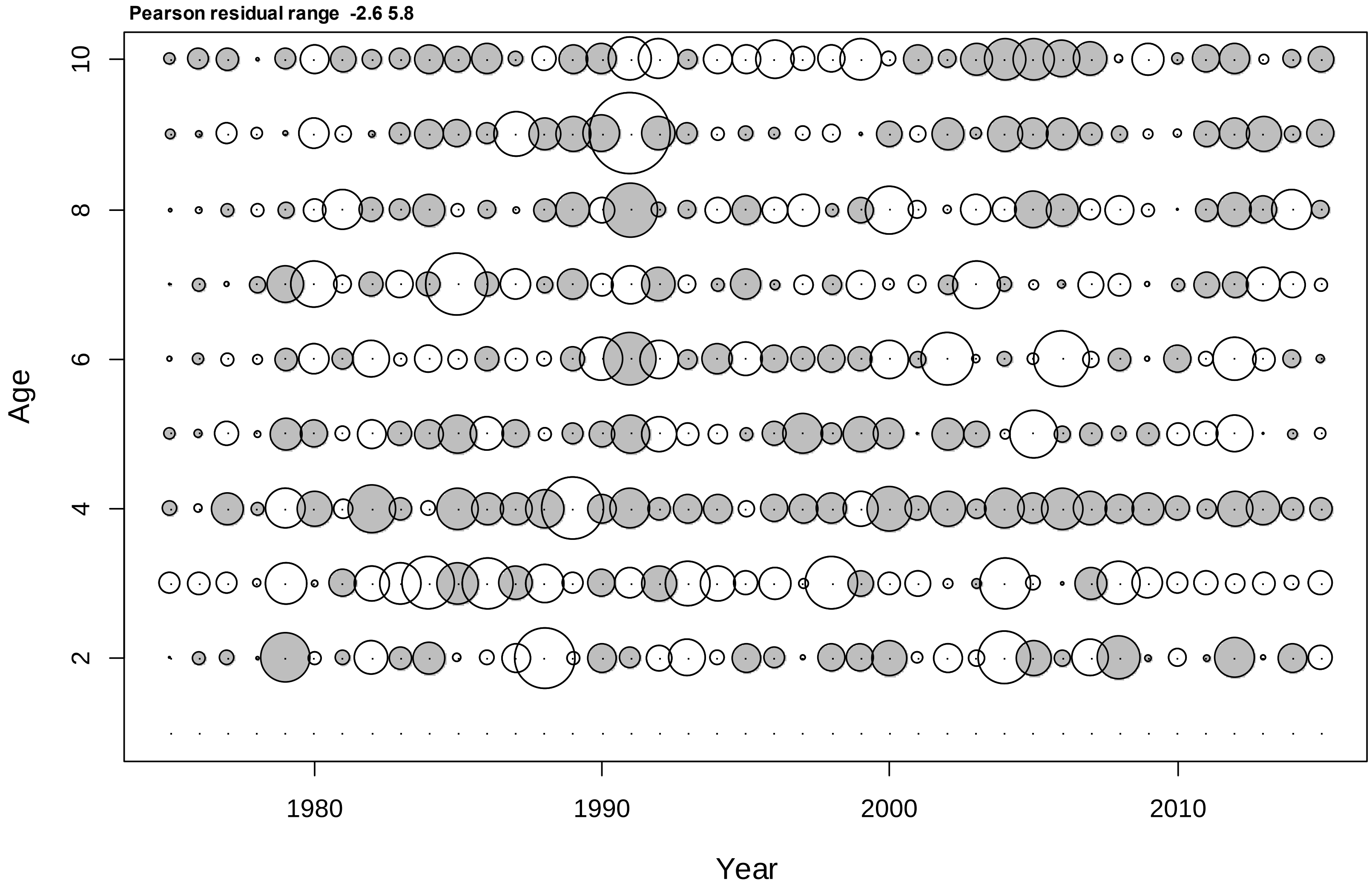


Figure 1.24. Pearson residuals for fishery age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

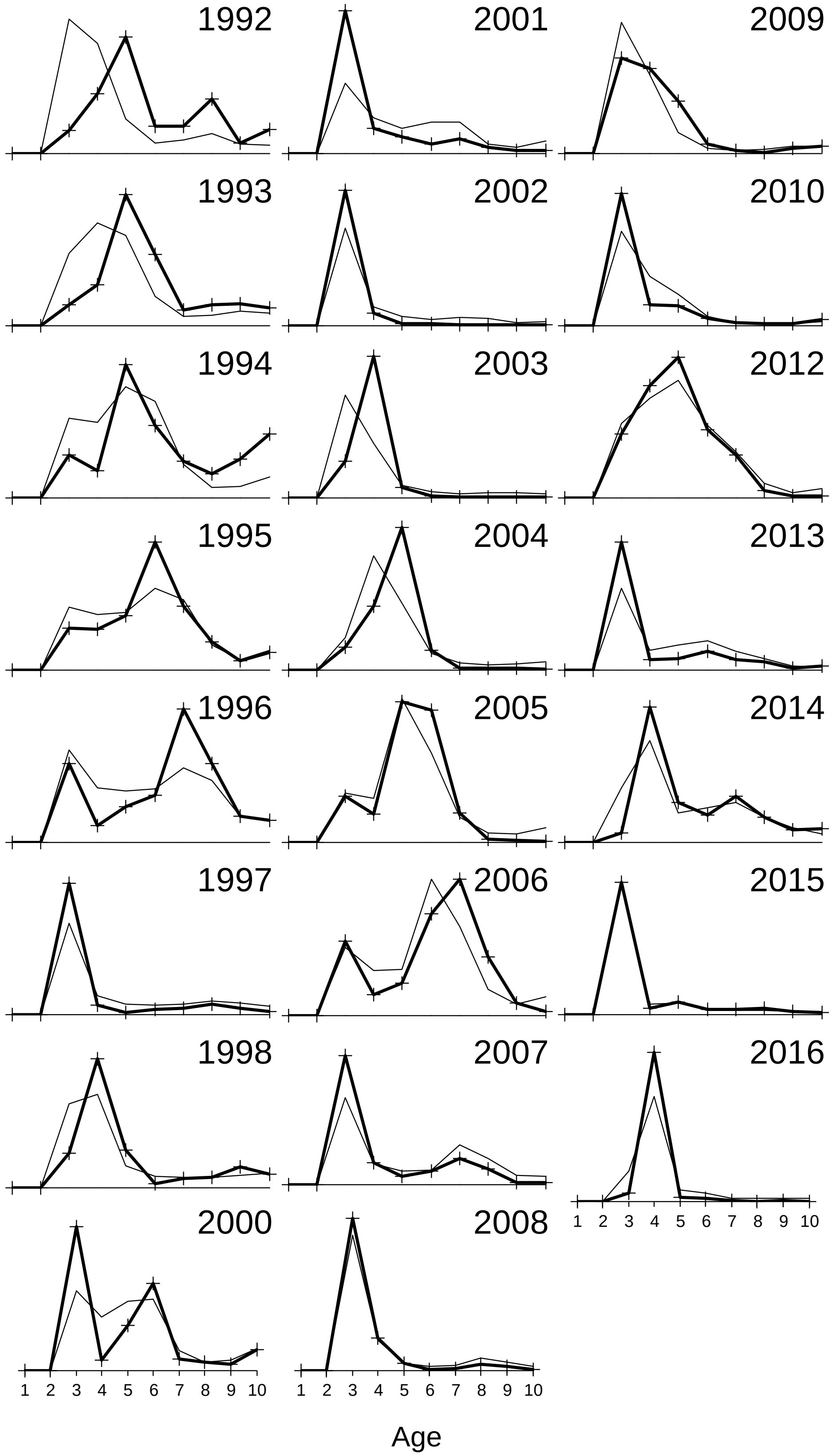


Figure 1.25. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

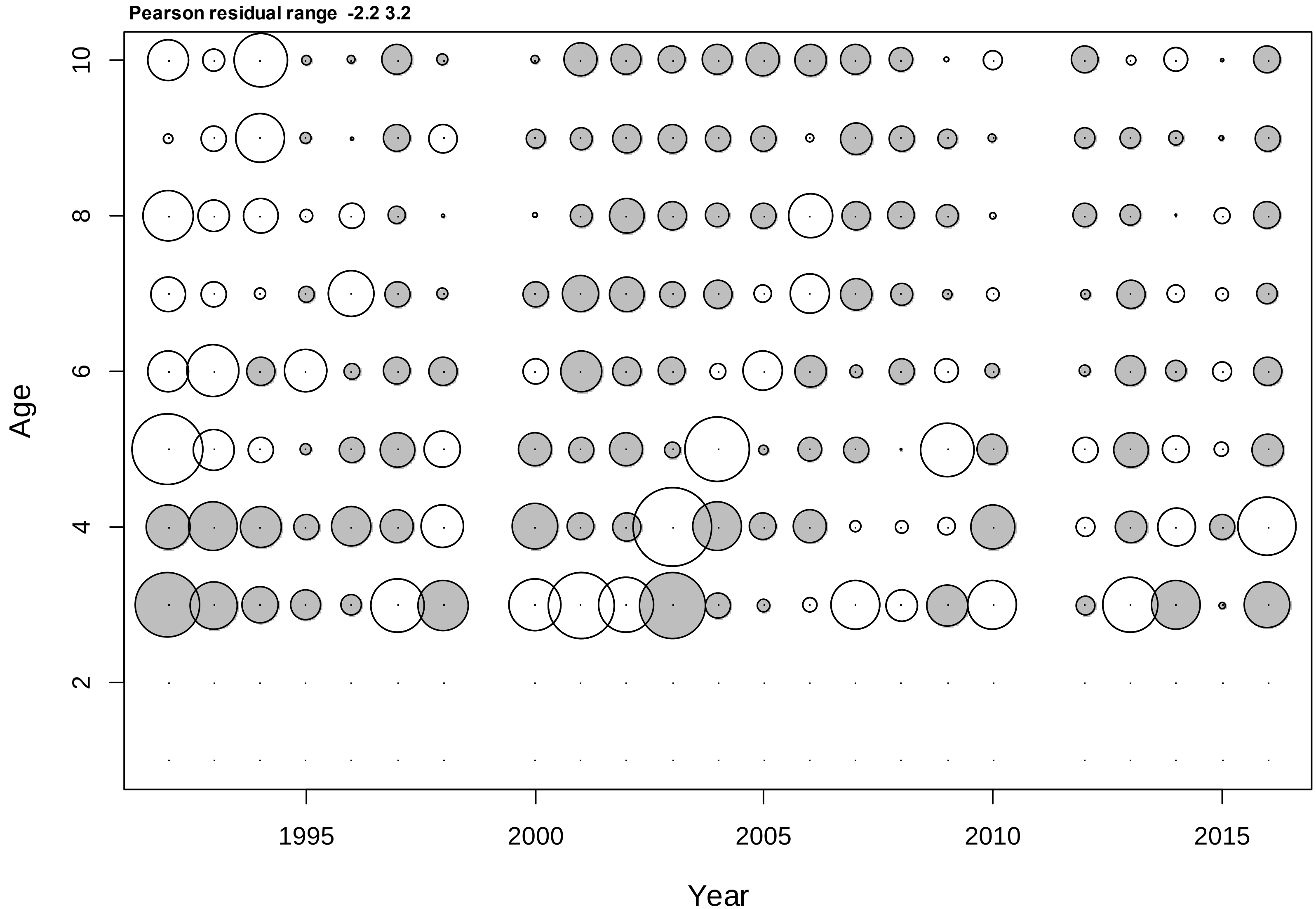


Figure 1.26. Pearson residuals for Shelikof Strait acoustic survey age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

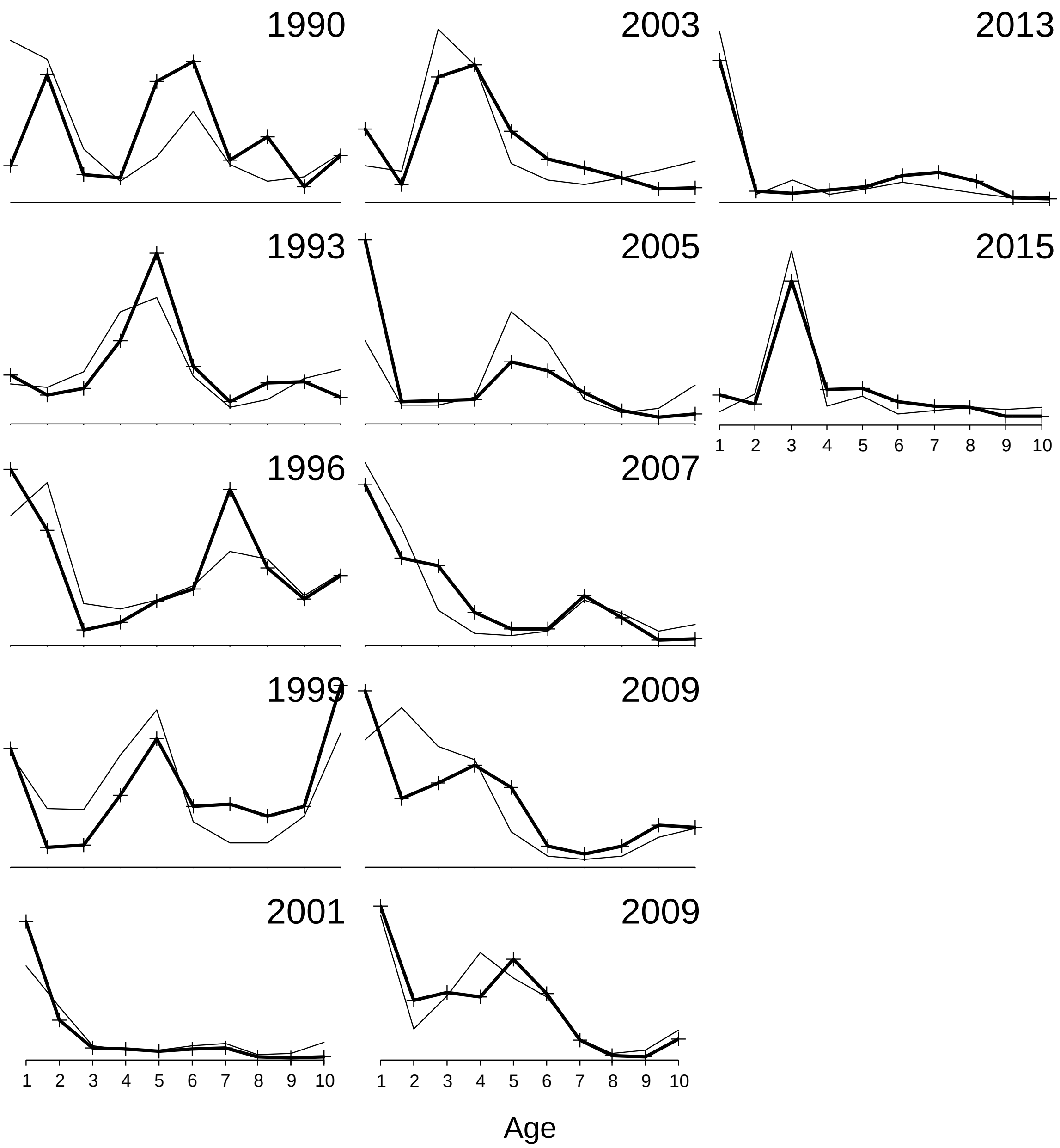


Figure 1.27. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

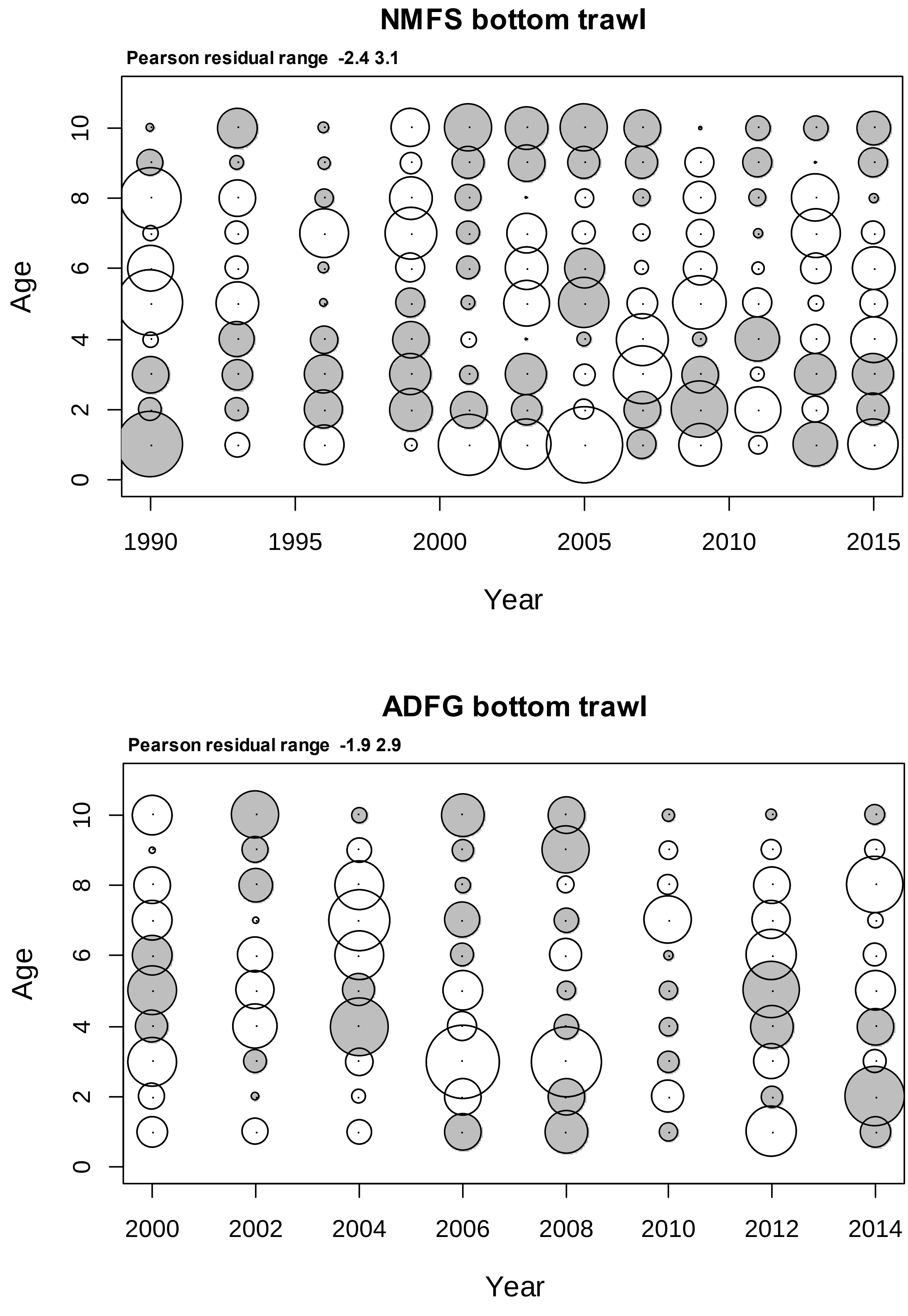


Figure 1.28. Pearson residuals for NMFS bottom trawl survey (top) and ADFG crab/groundfish survey (bottom) age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

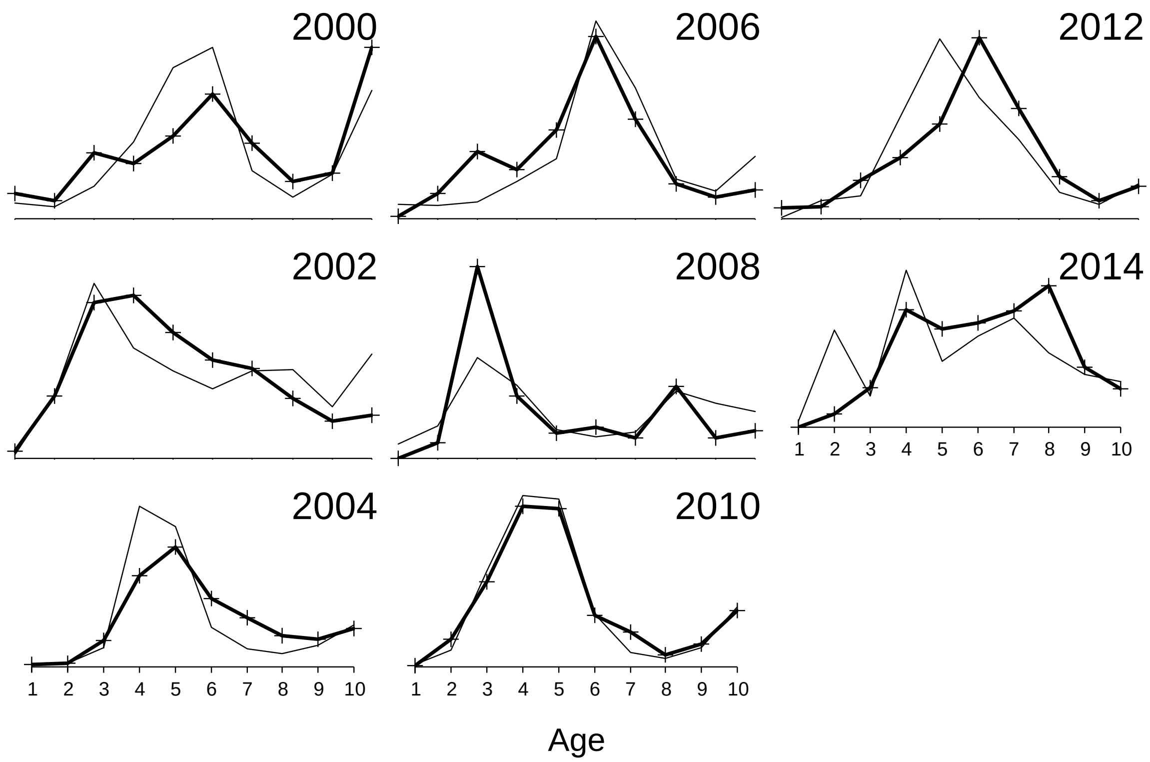


Figure 1.29. Observed and predicted ADFG crab/groundfish survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbols are observed proportions at age.

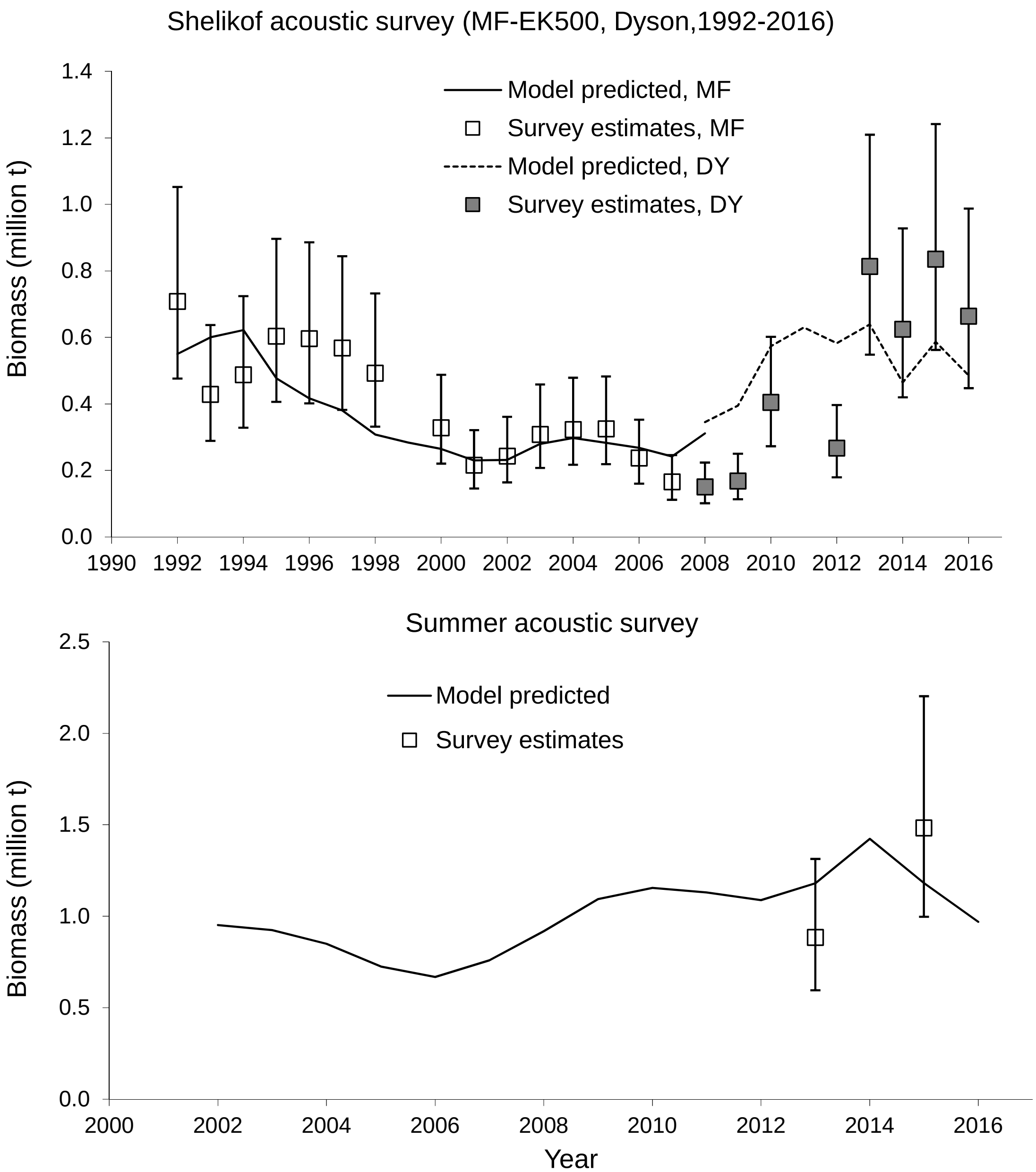


Figure 1.30. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey for the base model (top panel). The Shelikof acoustic survey is modeled with two catchability periods corresponding to the estimates produced by the *R/V Miller Freeman* (MF) in 1992-2007 and the *R/V Oscar Dyson* (DY) in 2008-2016. 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.

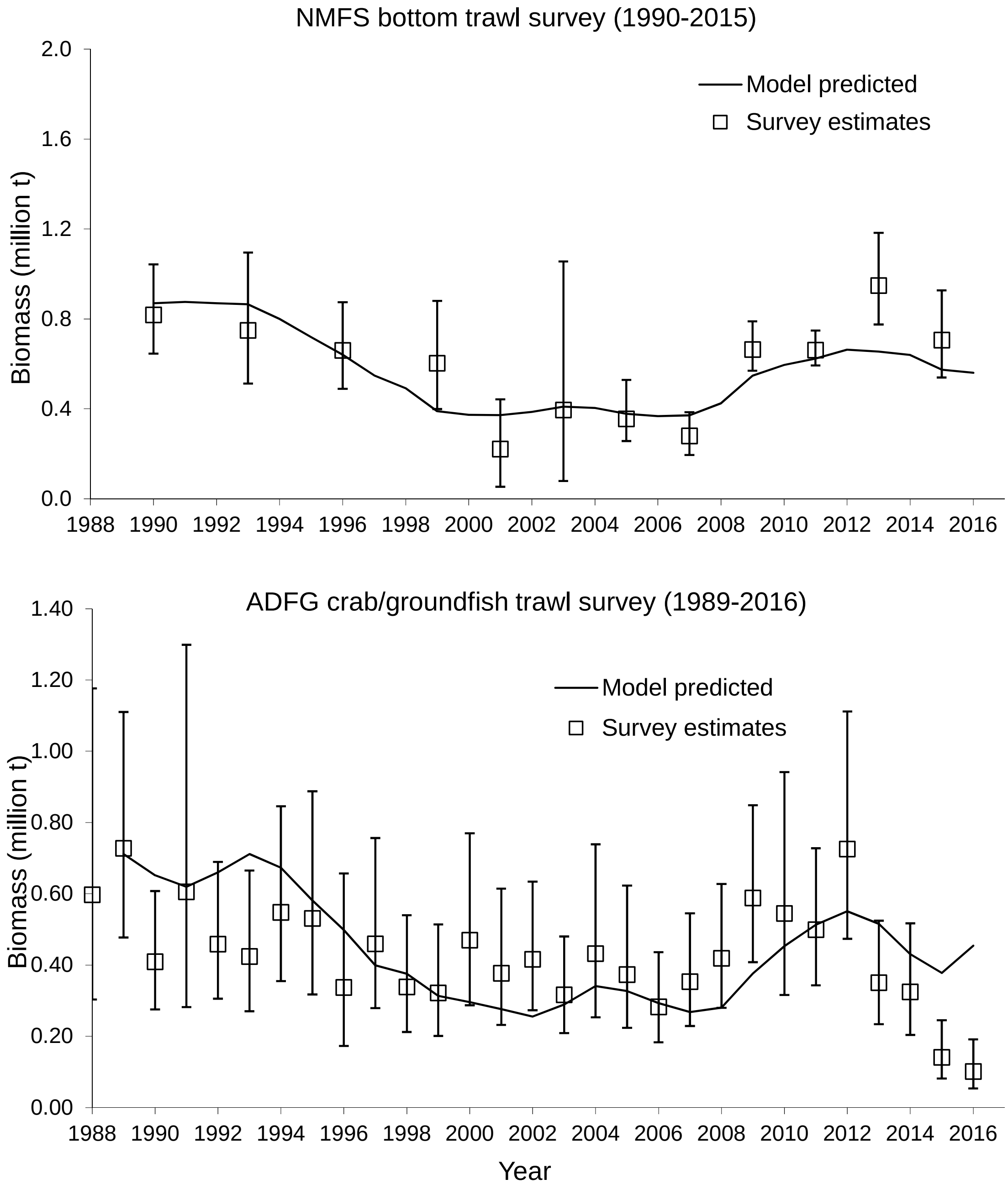
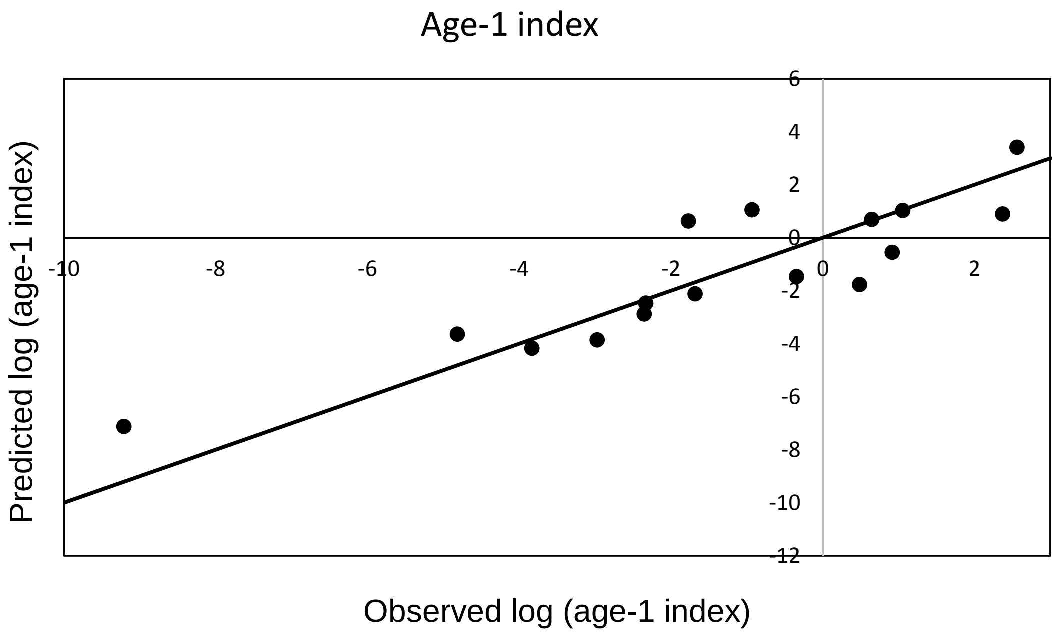


Figure 1.31. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top), and the ADFG crab/groundfish survey (bottom) for the base model. Error bars indicate plus and minus two standard deviations.



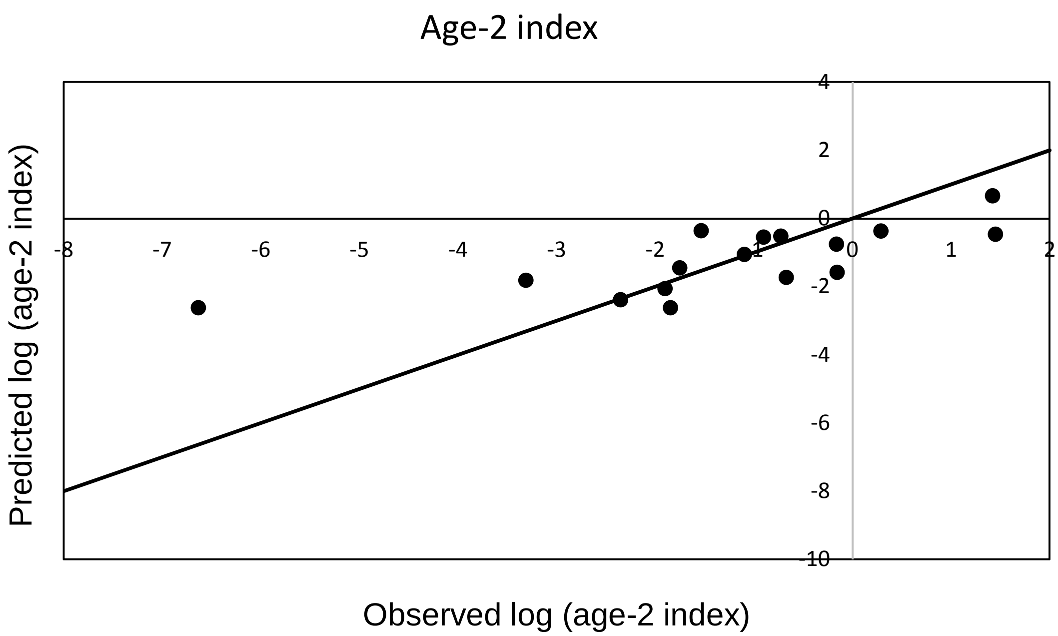


Figure 1.32. Observed and model predicted age-1 (top) and age-2 indices (bottom) for the winter acoustic estimates combined for Shelikof Strait and the Shumagin Islands.

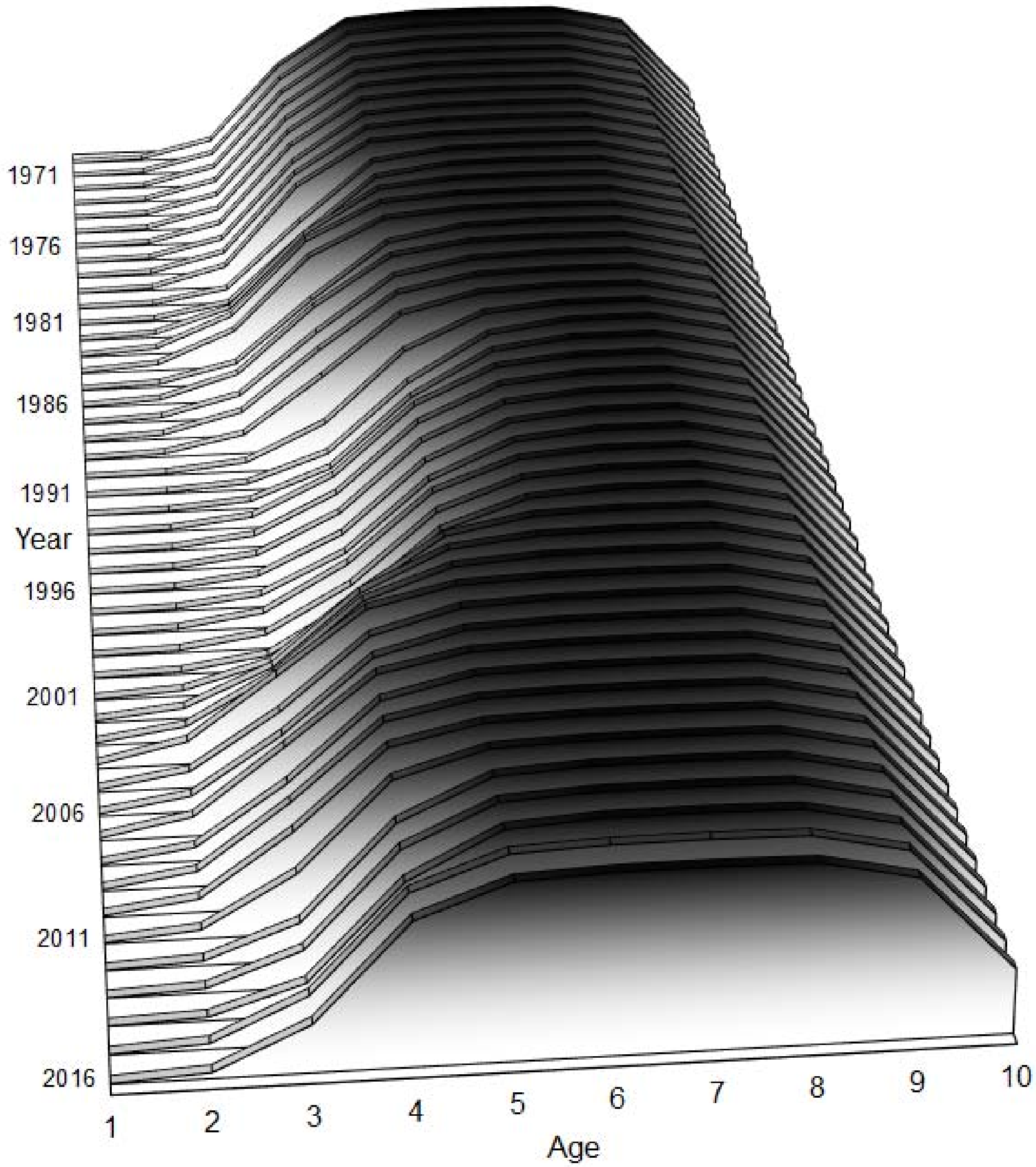


Figure 1.33. Estimates of time-varying fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.

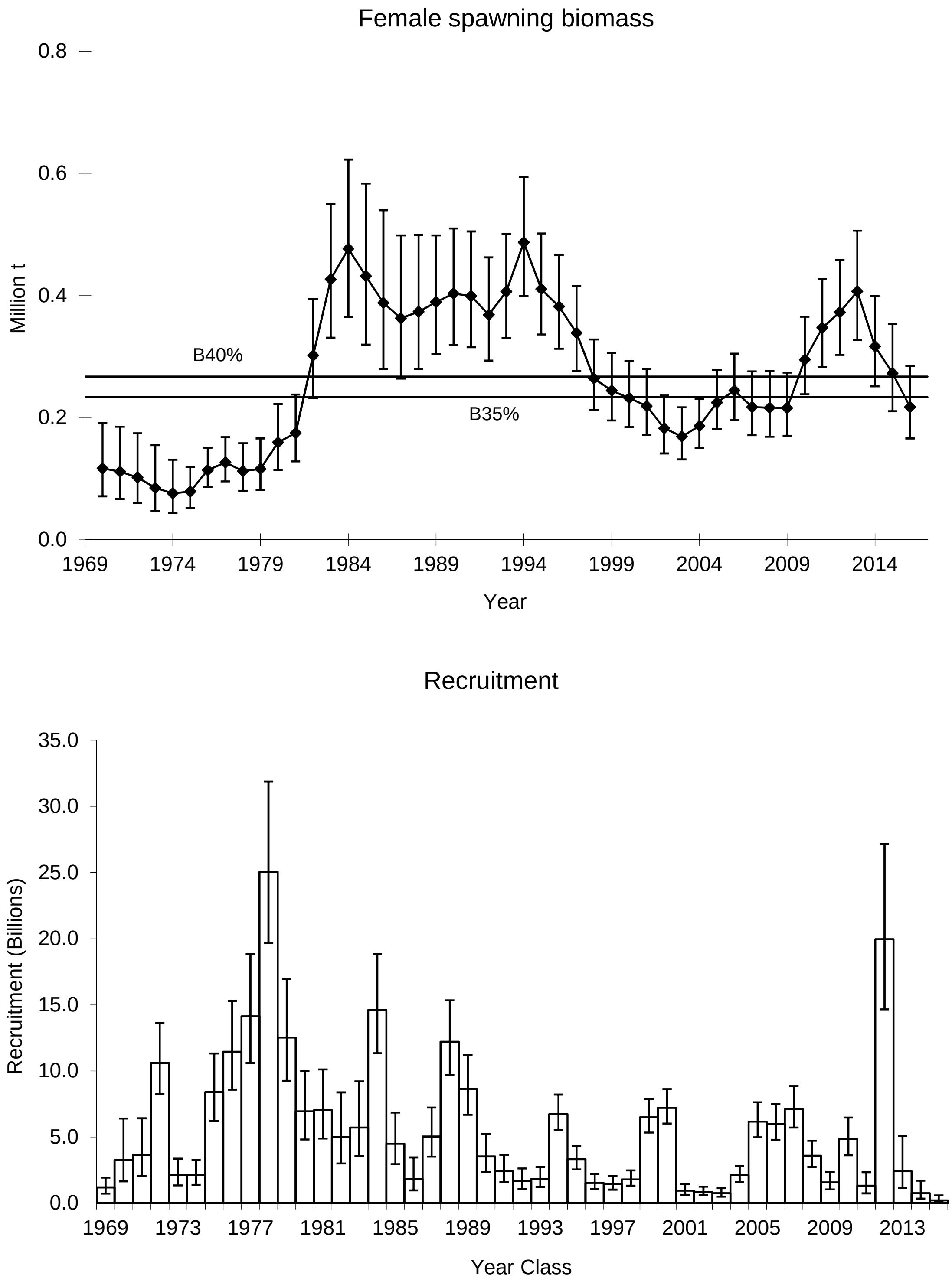
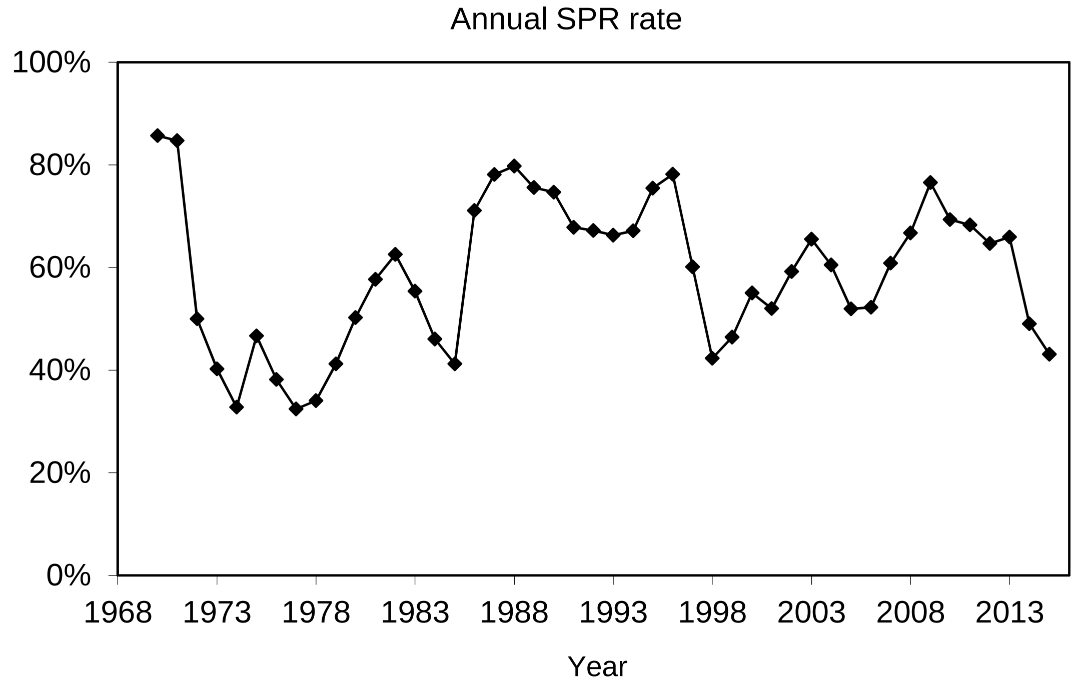


Figure 1.34. Estimated time series of GOA pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1970 to 2016 for the base model. Vertical bars represent two standard deviations. The $B_{35\%}$ and $B_{40\%}$ lines represent the current estimate of these benchmarks.



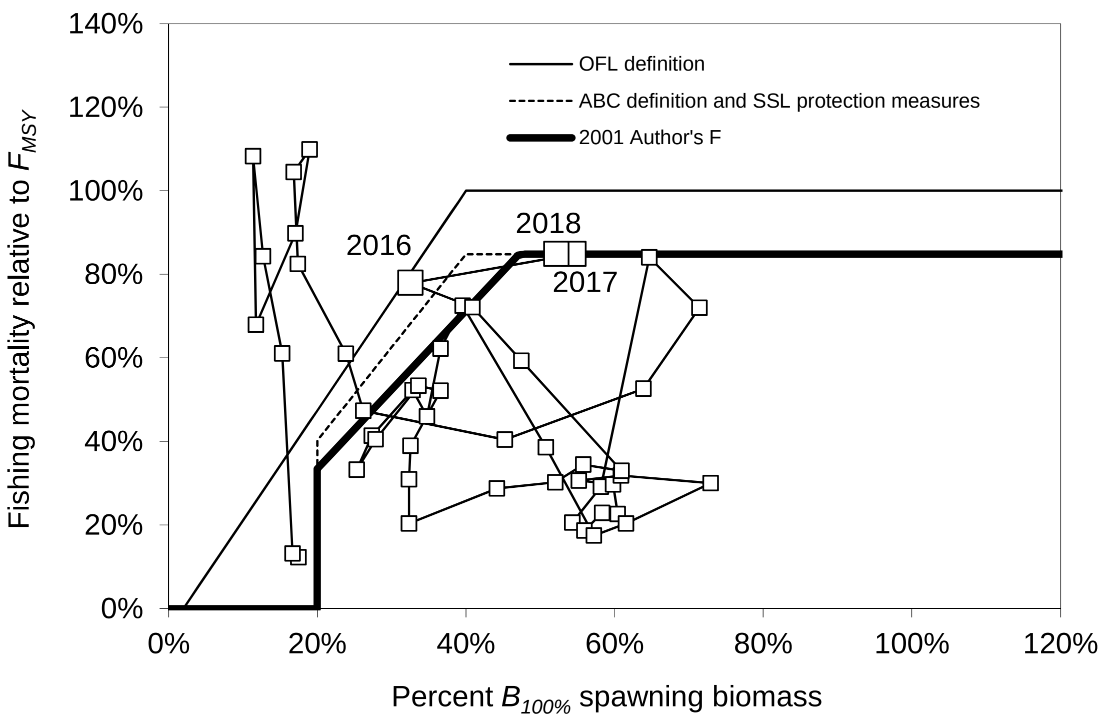
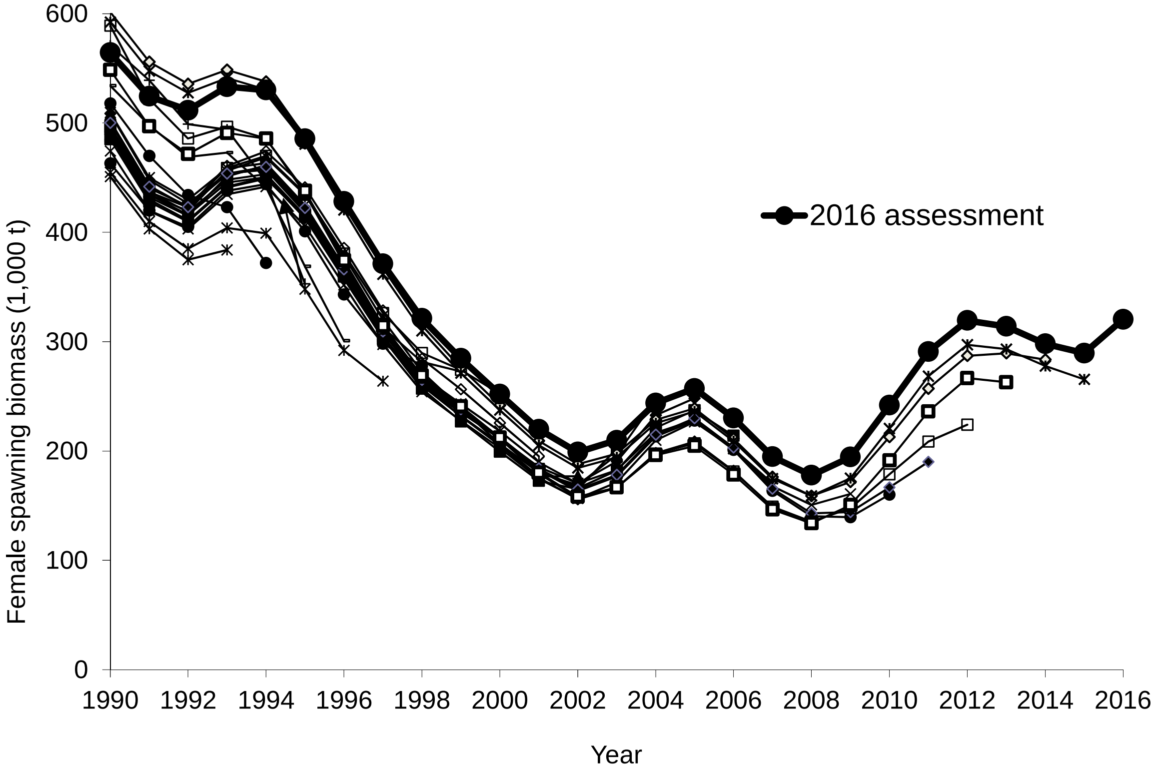


Figure 1.35. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to F_{MSY} (bottom). The ratio of fishing mortality to F_{MSY} is calculated using the estimated selectivity 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.



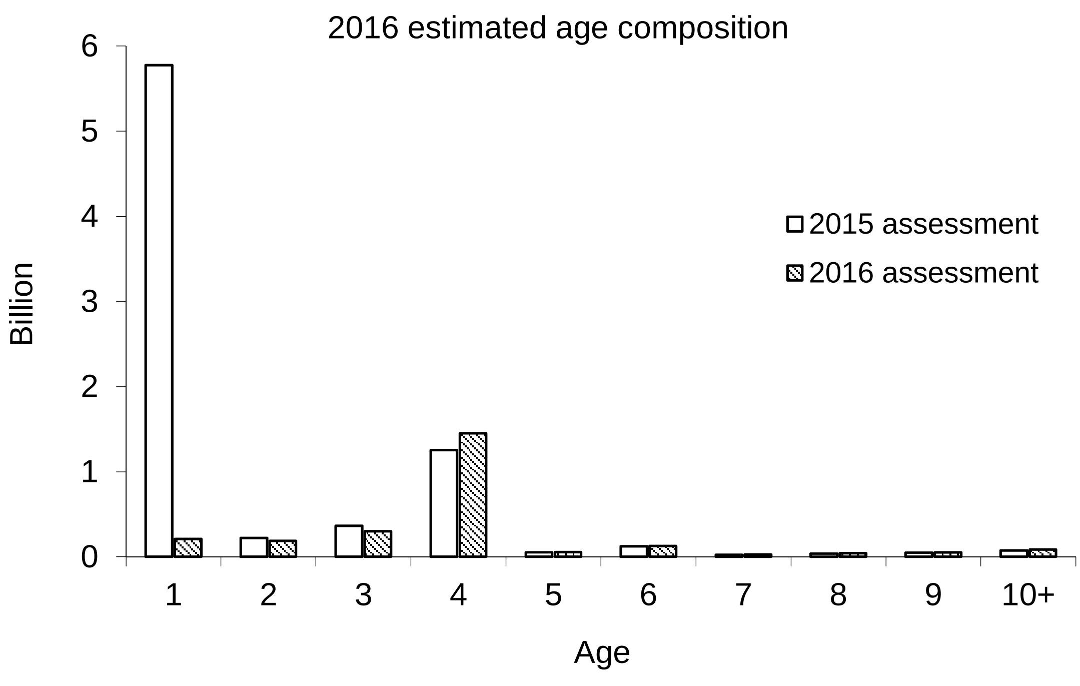


Figure 1.36. Retrospective plot of estimated GOA pollock female spawning biomass for stock assessments in the years 1993-2016 (top). For this figure, the time series of female spawning biomass was calculated using the same maturity and spawning weight at age for all assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2016 from the 2015 and 2016 assessments.

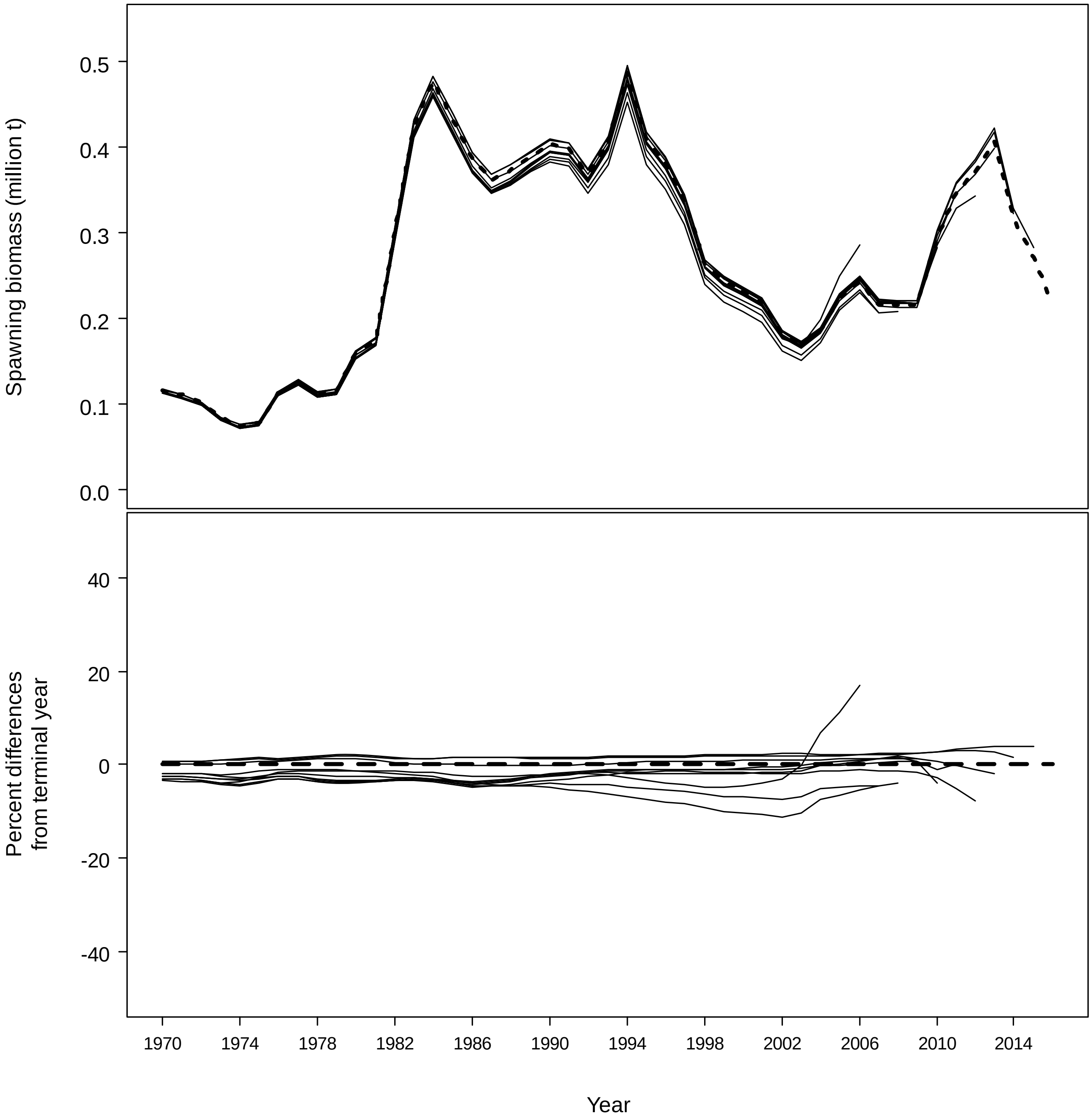
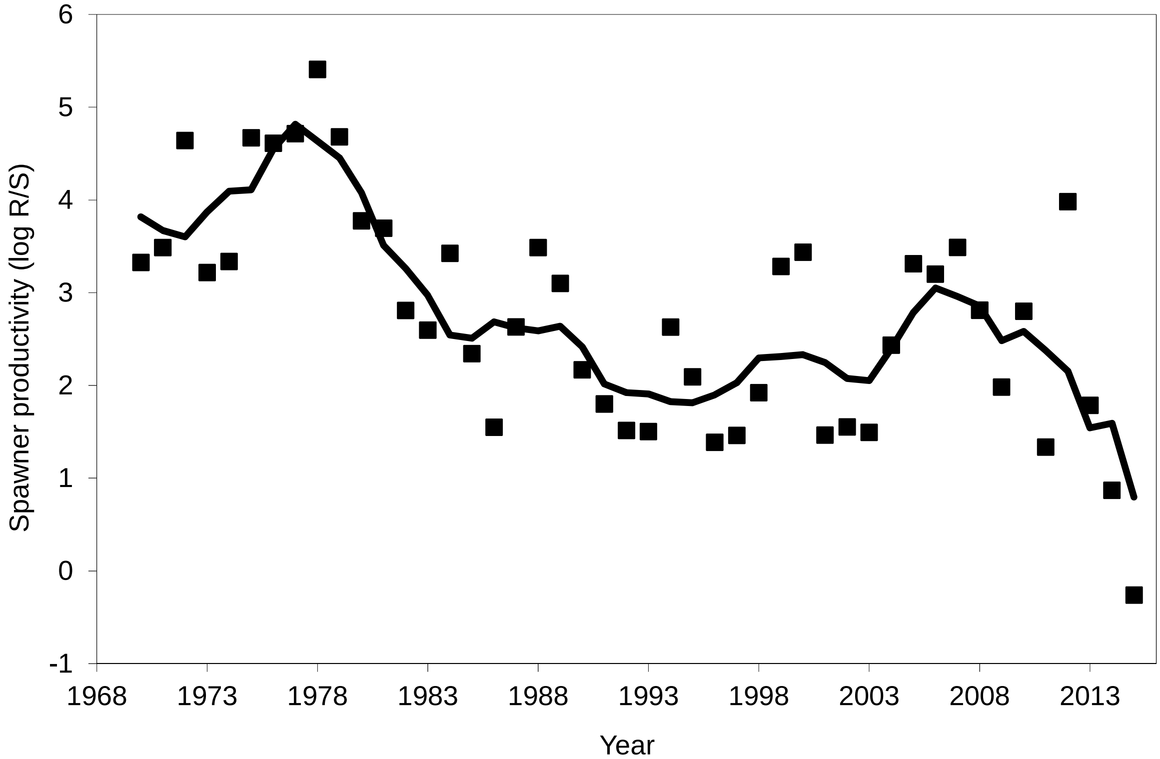


Figure 1.37. Retrospective plot of spawning biomass for the years 2006-2016 for the 2016 base model. The revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is -0.019.



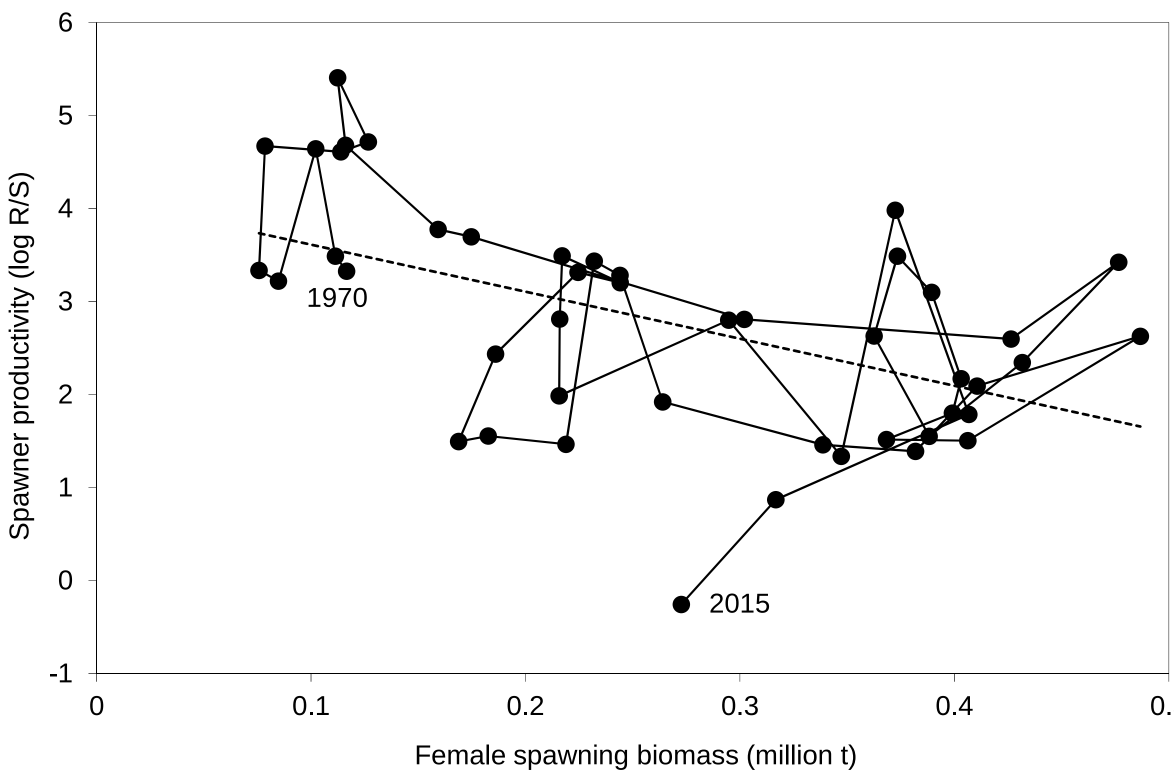


Figure 1.38. GOA pollock spawner productivity, *log(R/S)*, in 1970-2015 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

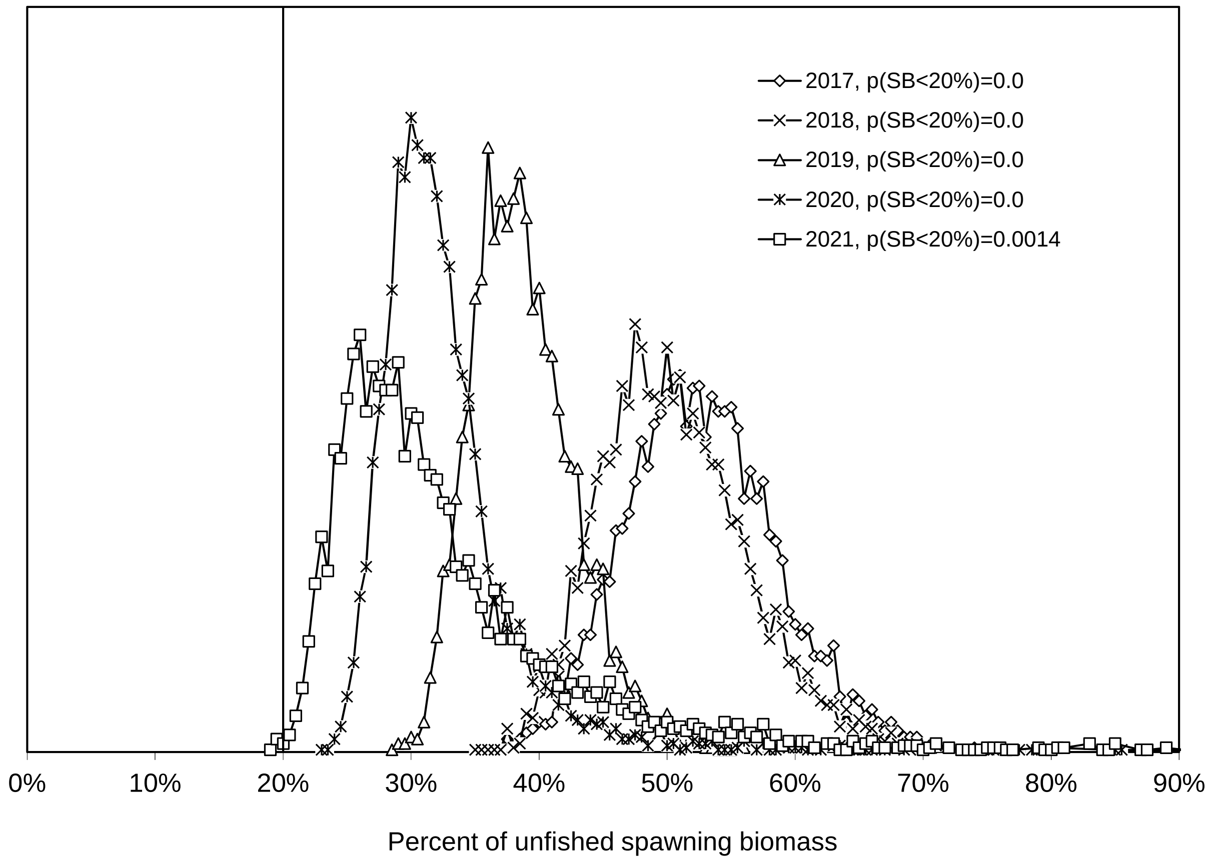
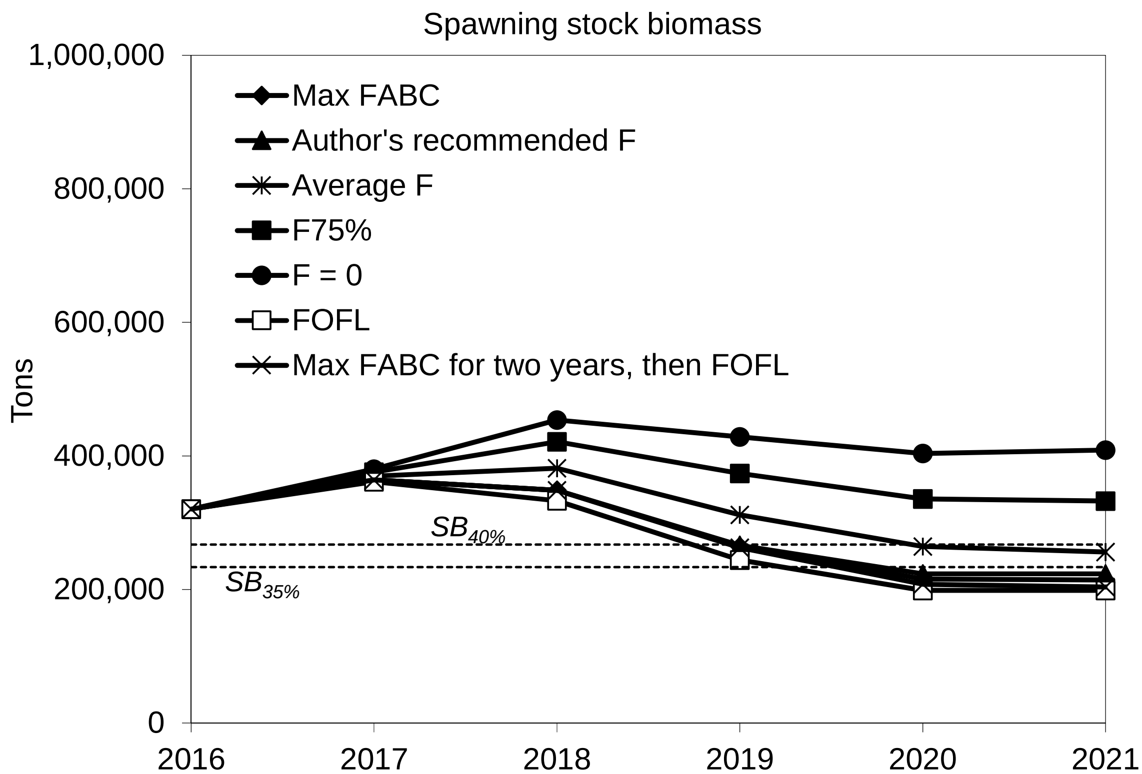


Figure 1.39. Uncertainty in spawning biomass in 2017-2021 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended F_{ABC}.



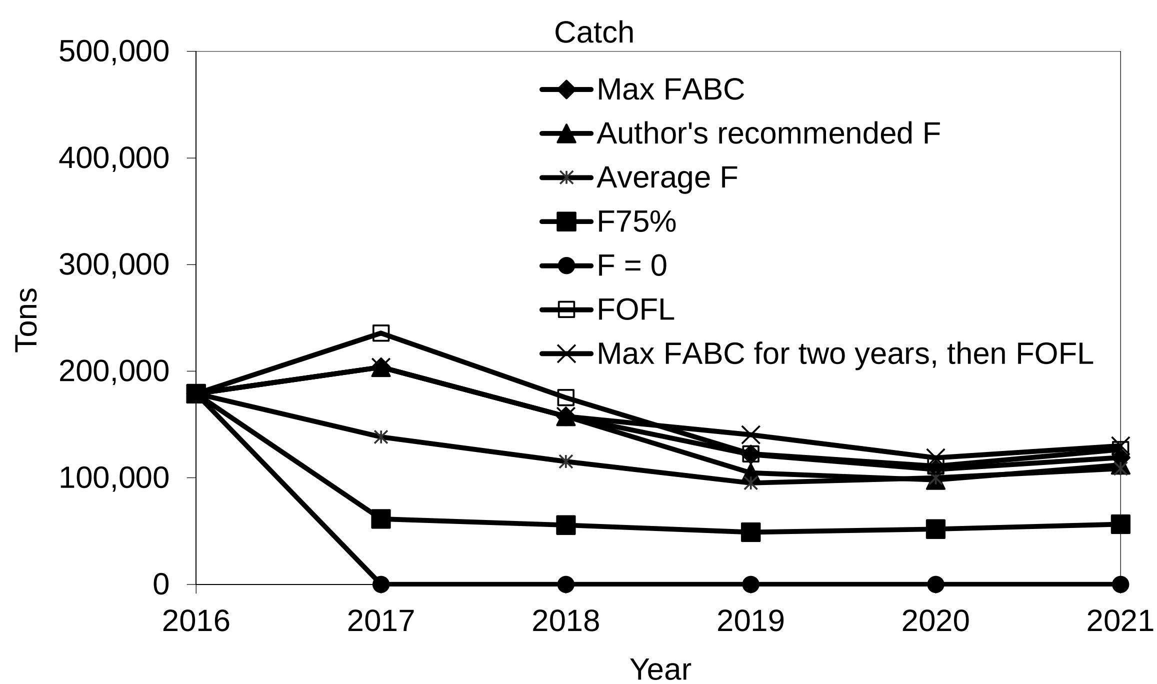
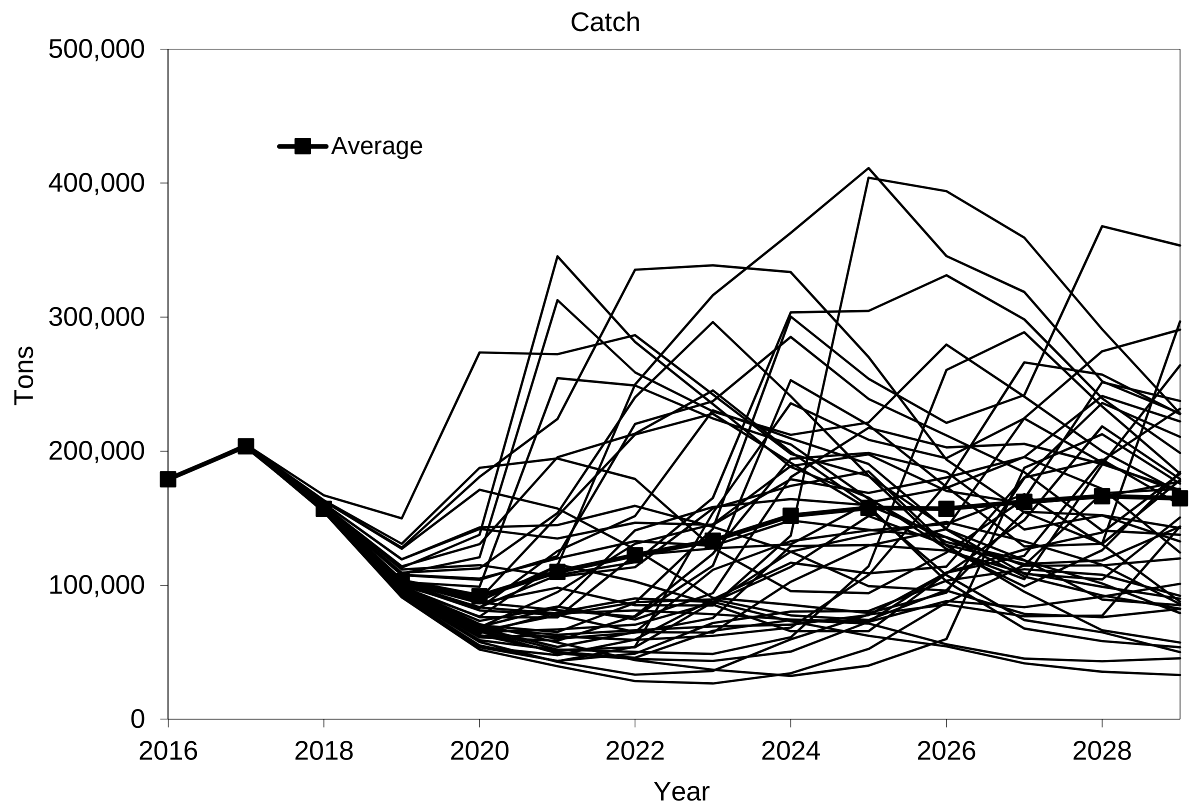


Figure 1.40. Projected spawning biomass and catches in 2016-2021 under different harvest rates.



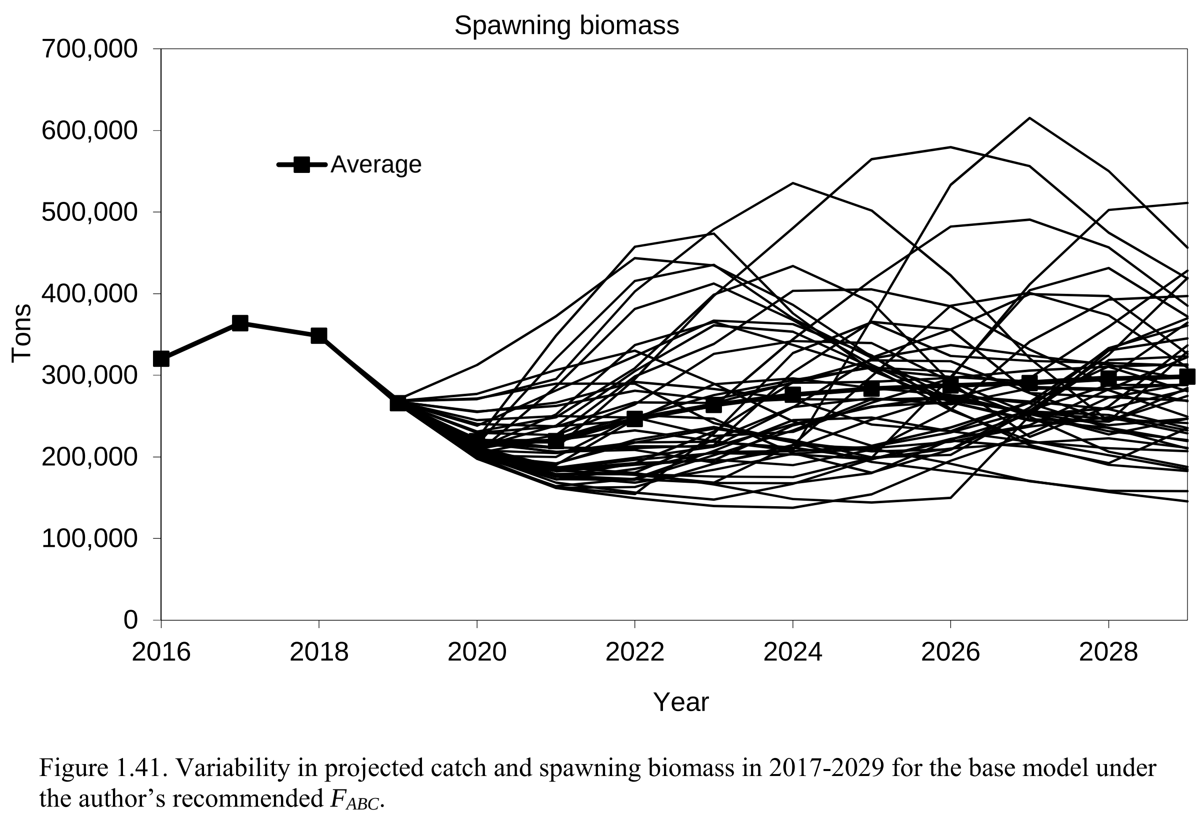


Figure 1.41. Variability in projected catch and spawning biomass in 2017-2029 for the base model under the author's recommended F_{ABC}.

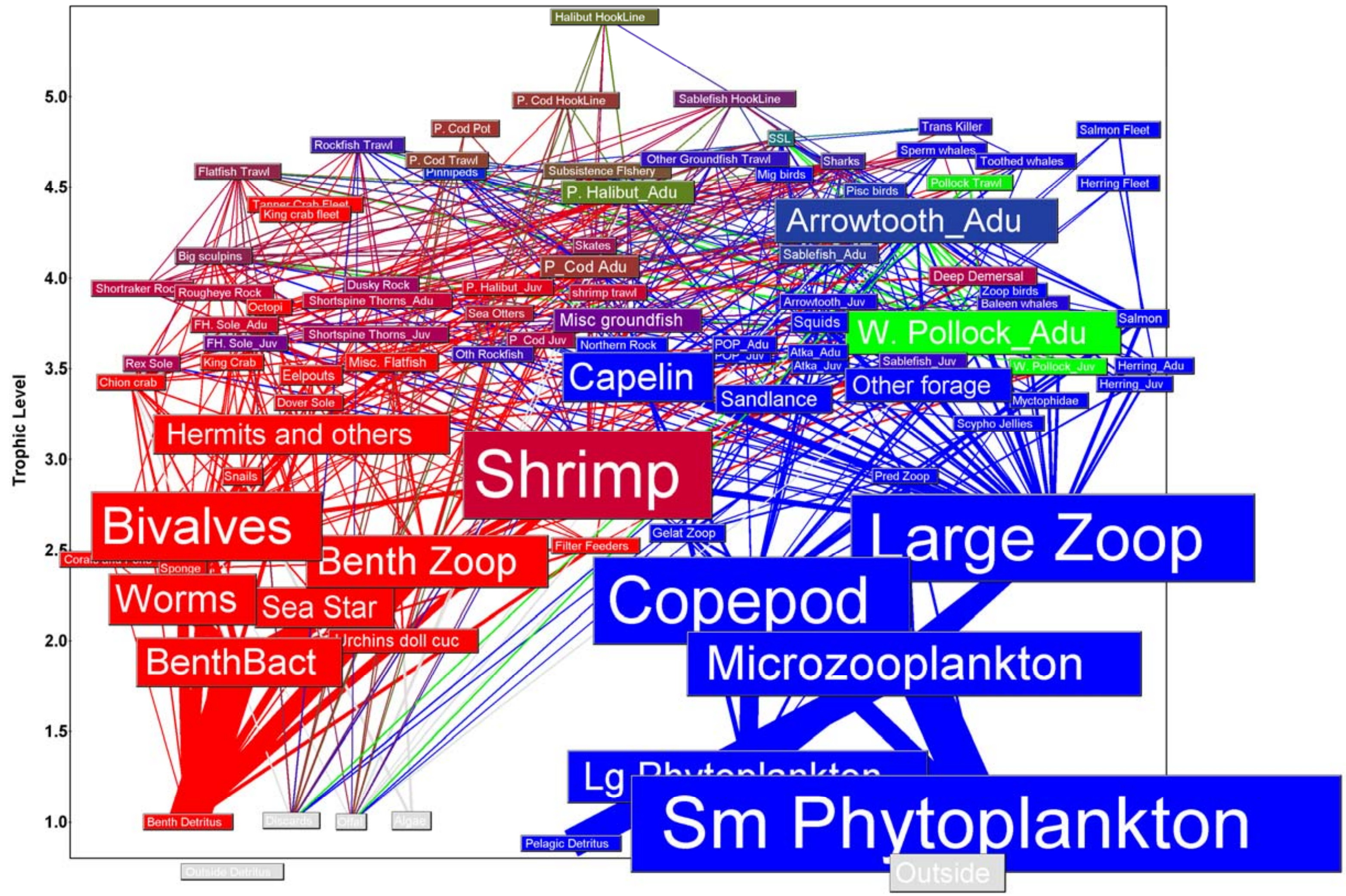
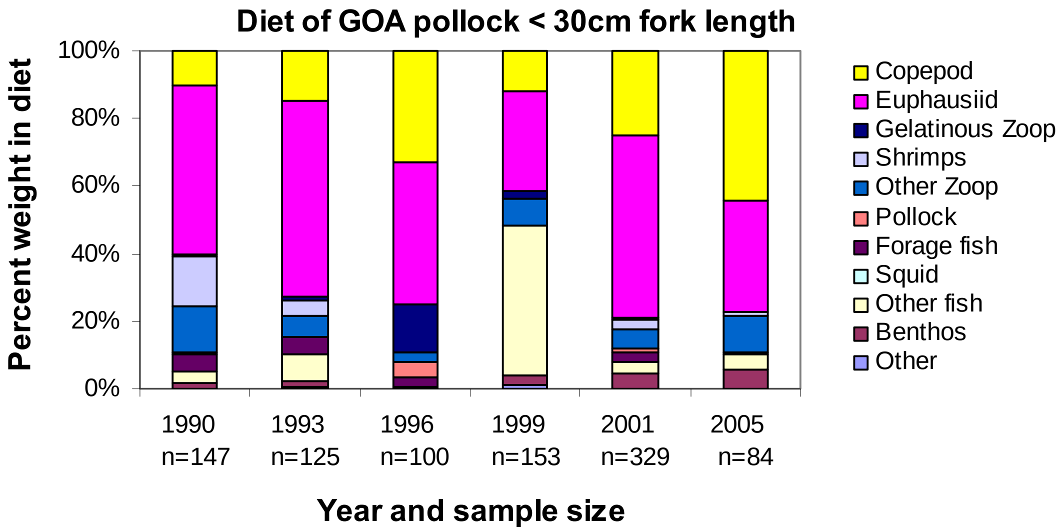


Figure 1.42. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



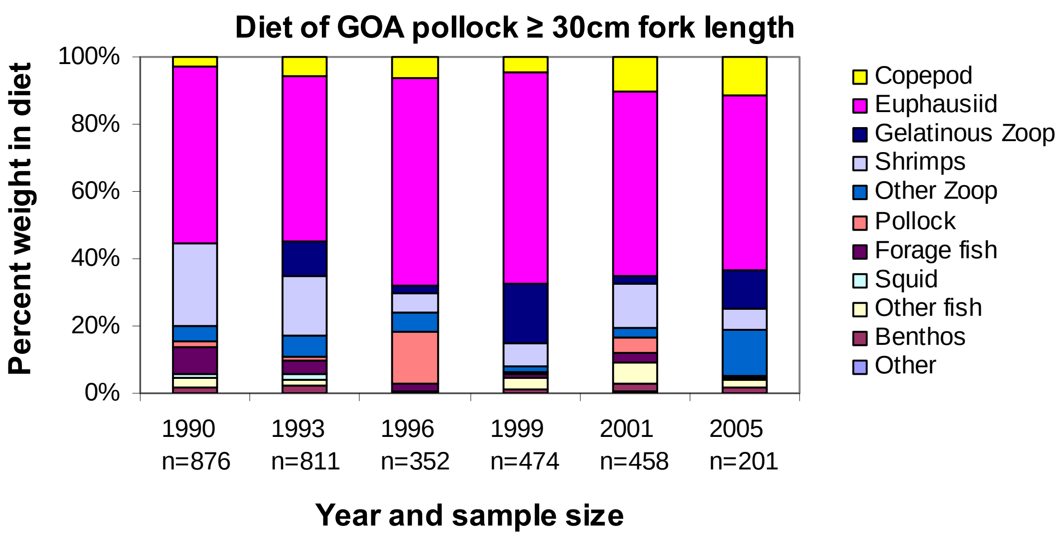
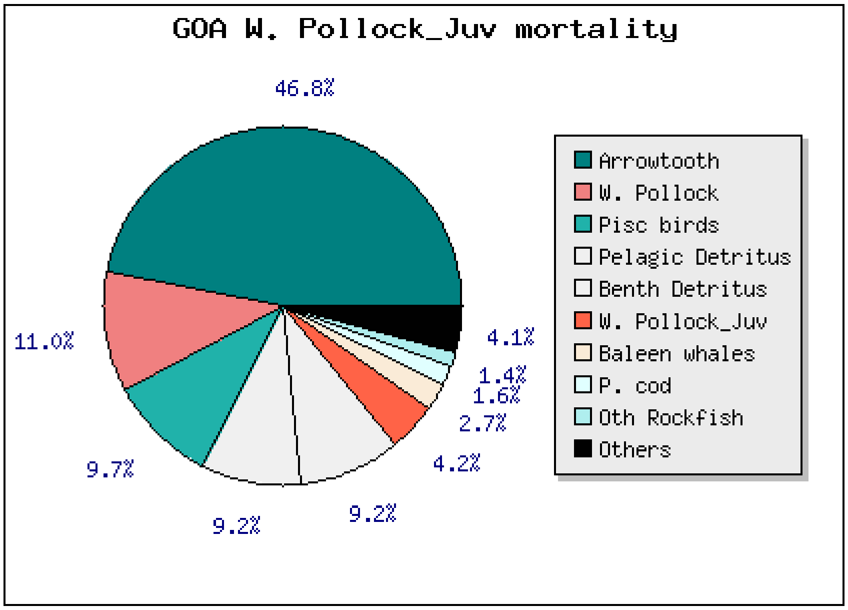


Figure 1.43. Diet (percent wet weight) of GOA pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



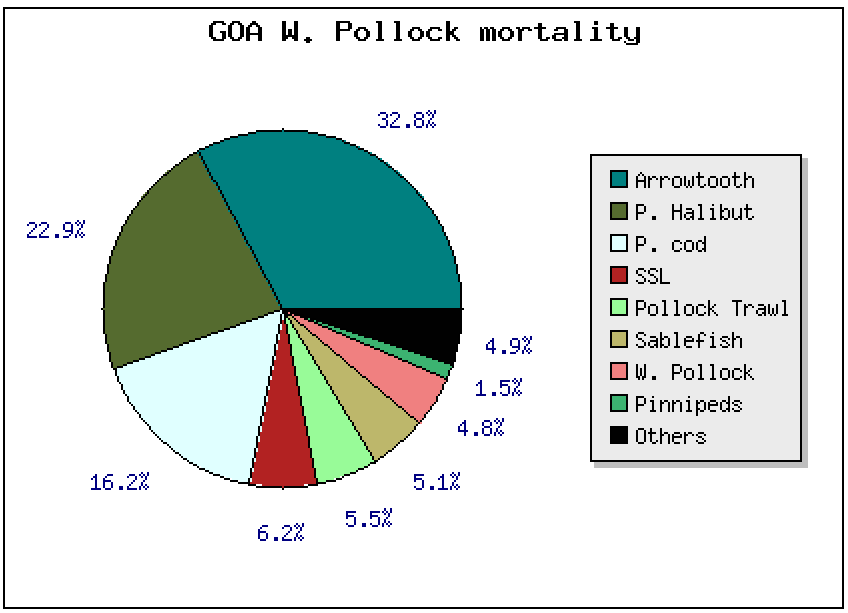


Figure 1.44. Sources of mortality for pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

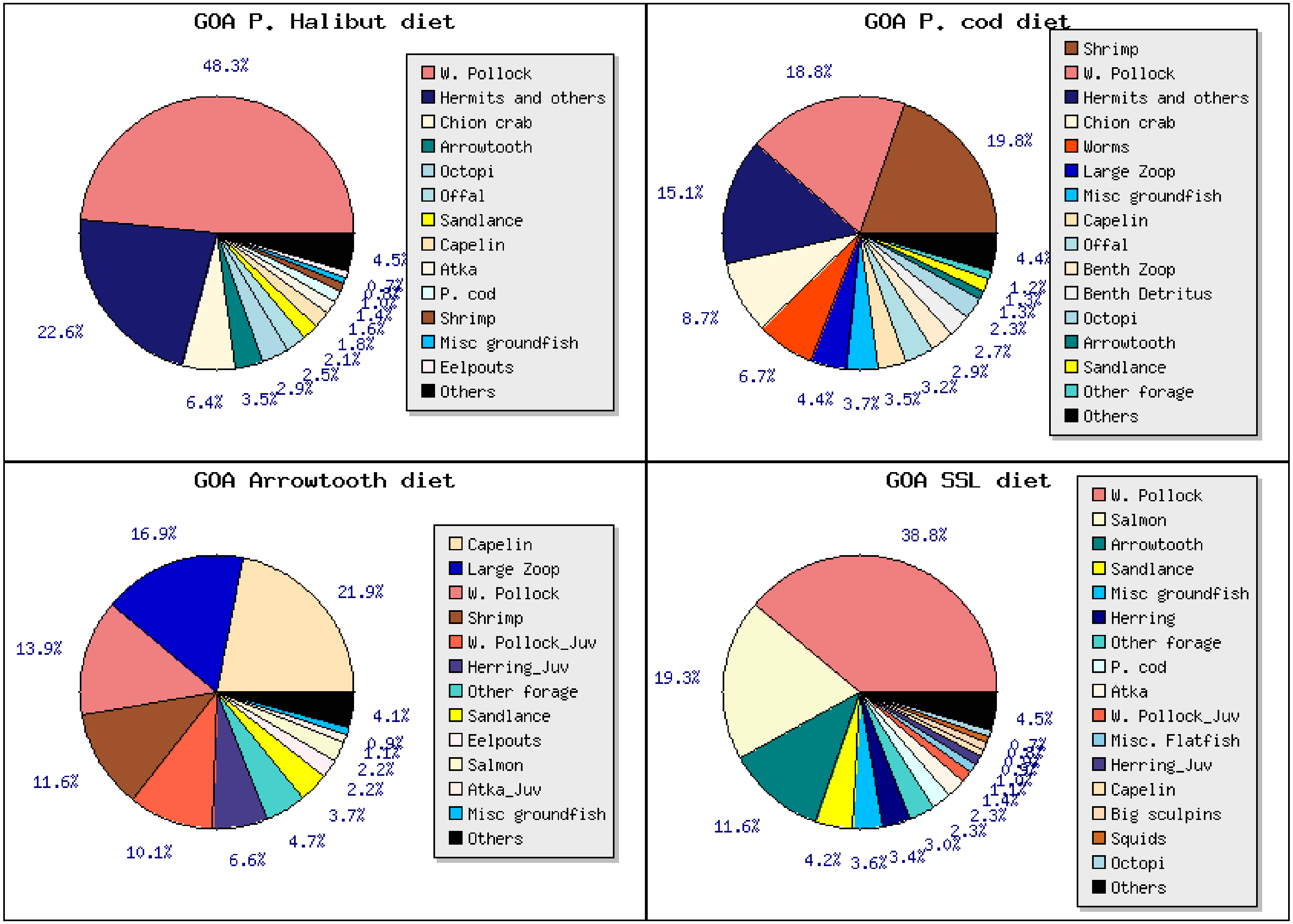


Figure 1.45. Diet diversity of major predators of pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

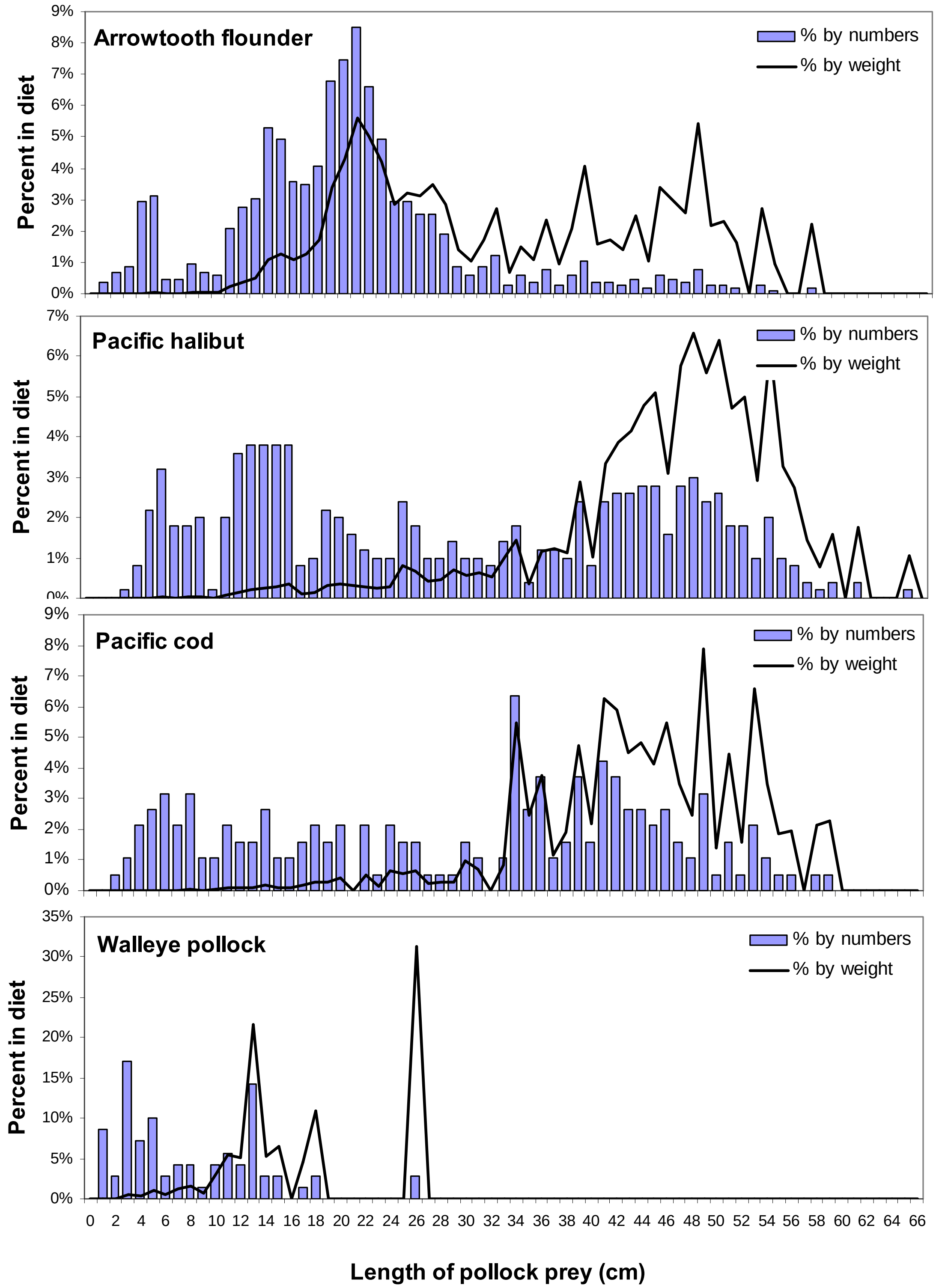
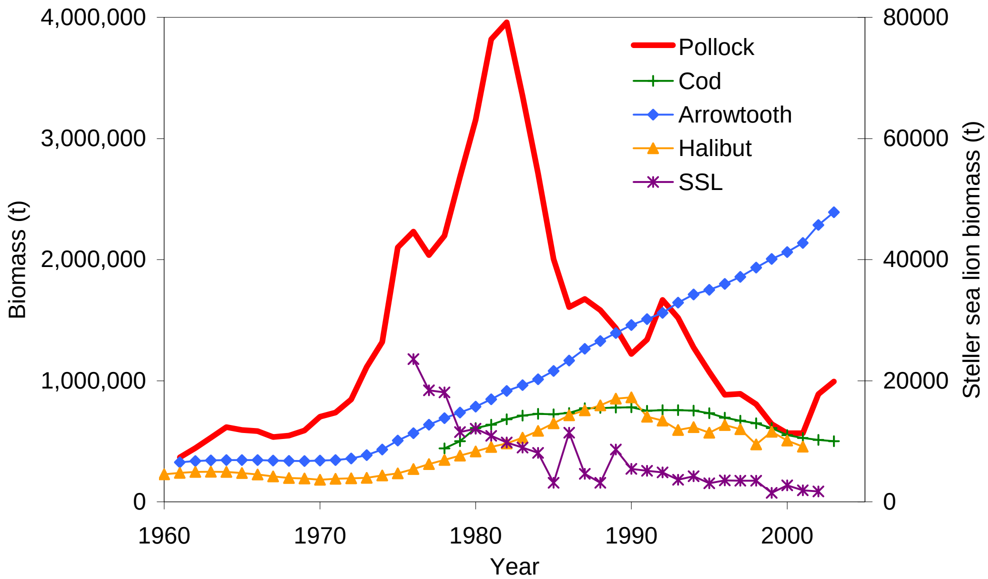


Figure 1.46. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.



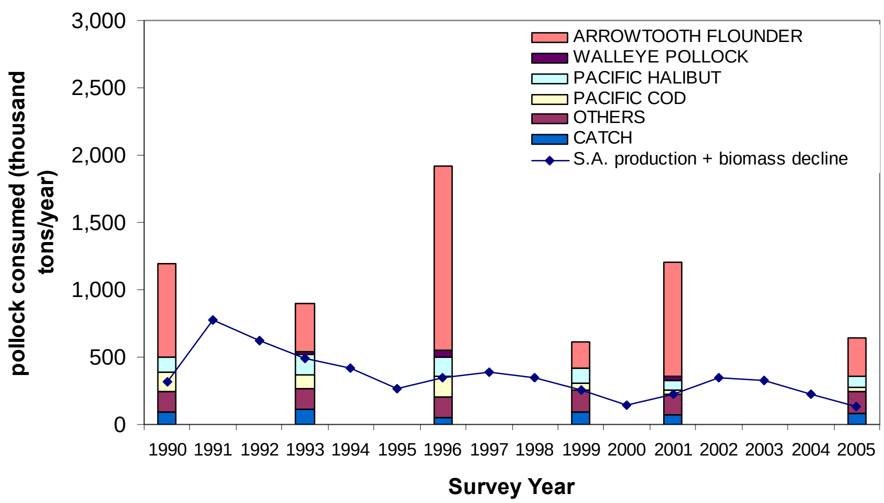


Figure 1.47. Historical trends in GOA pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock assessment data (top). Total catch and consumption of pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results (line) (bottom). See text for calculation methods.

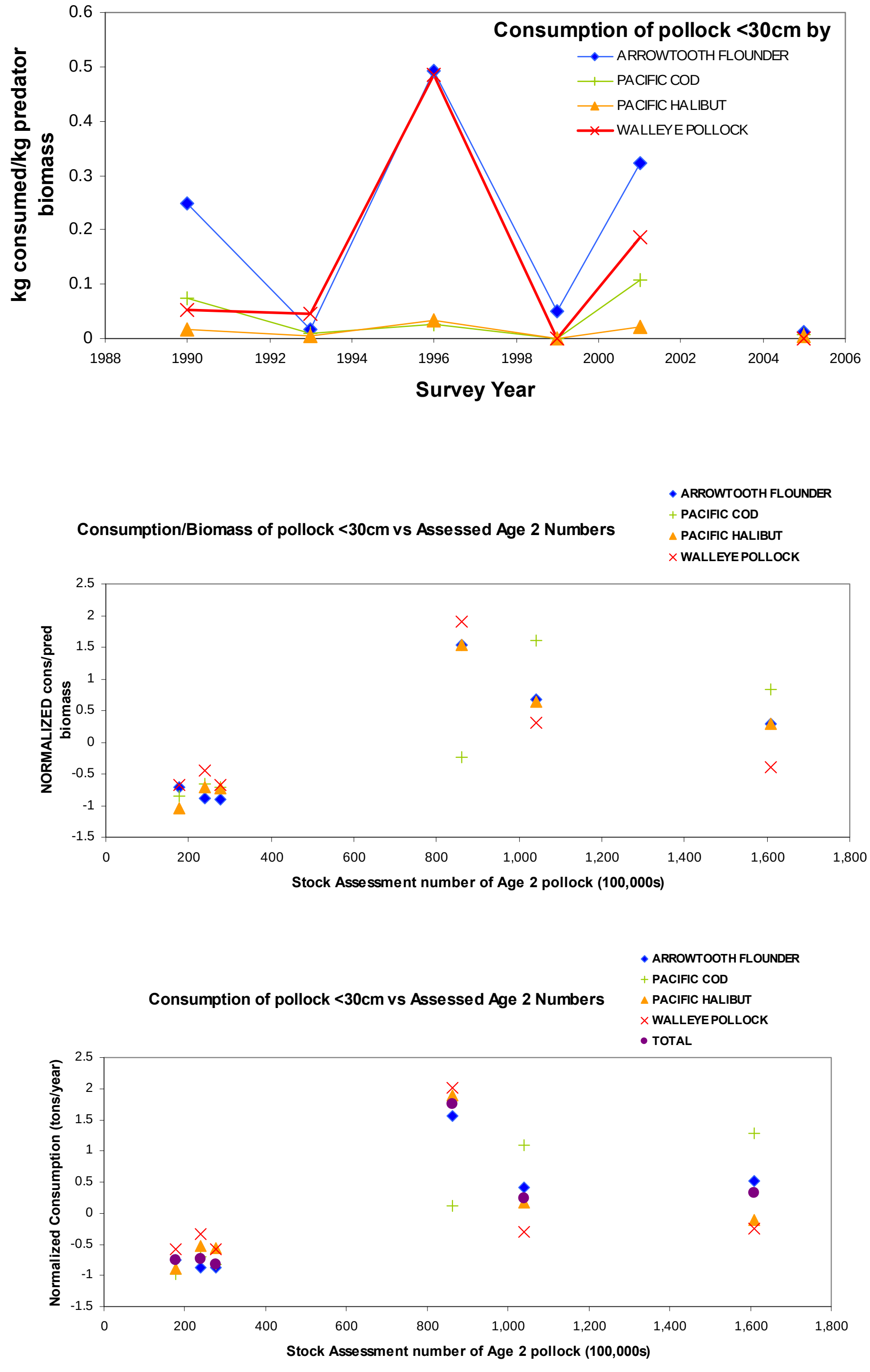
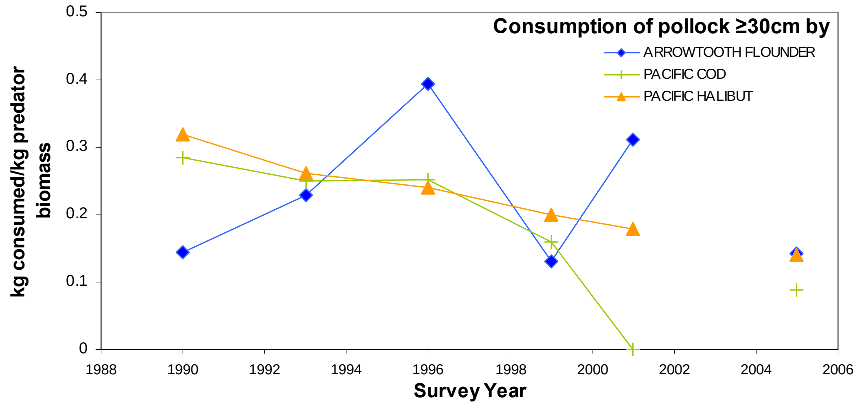
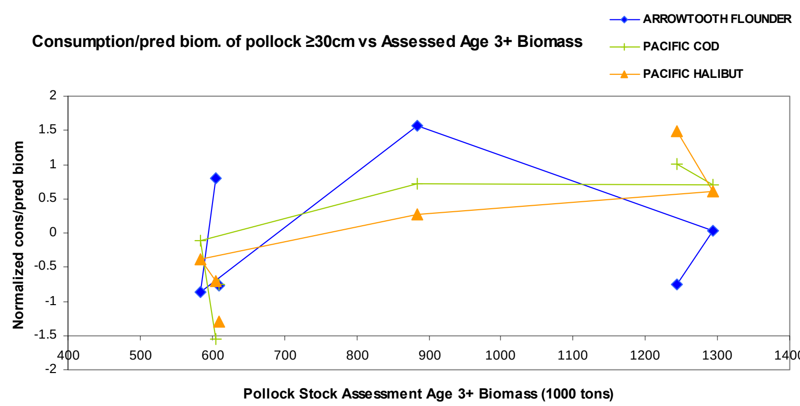


Figure 1.48. Consumption per unit predator survey biomass of GOA pollock <30cm fork length in diets, shown for each survey year (top). Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers (middle and bottom).





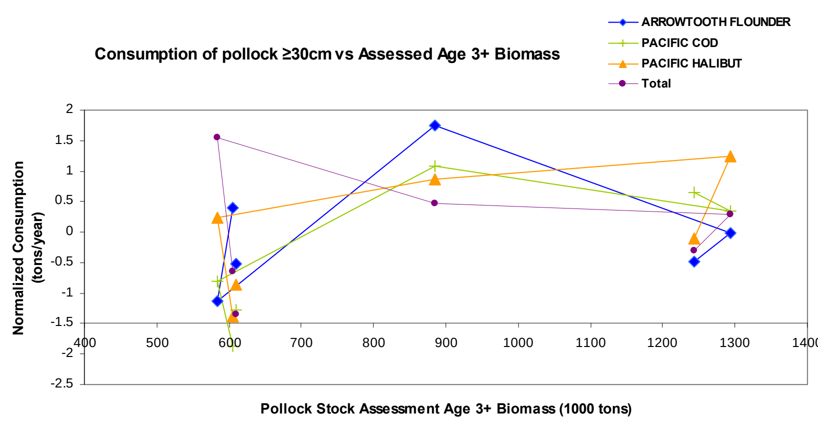


Figure 1.49. Consumption per unit predator survey biomass of GOA pollock ≥30cm fork length in diets, shown for each survey year (top). Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass (middle and bottom).

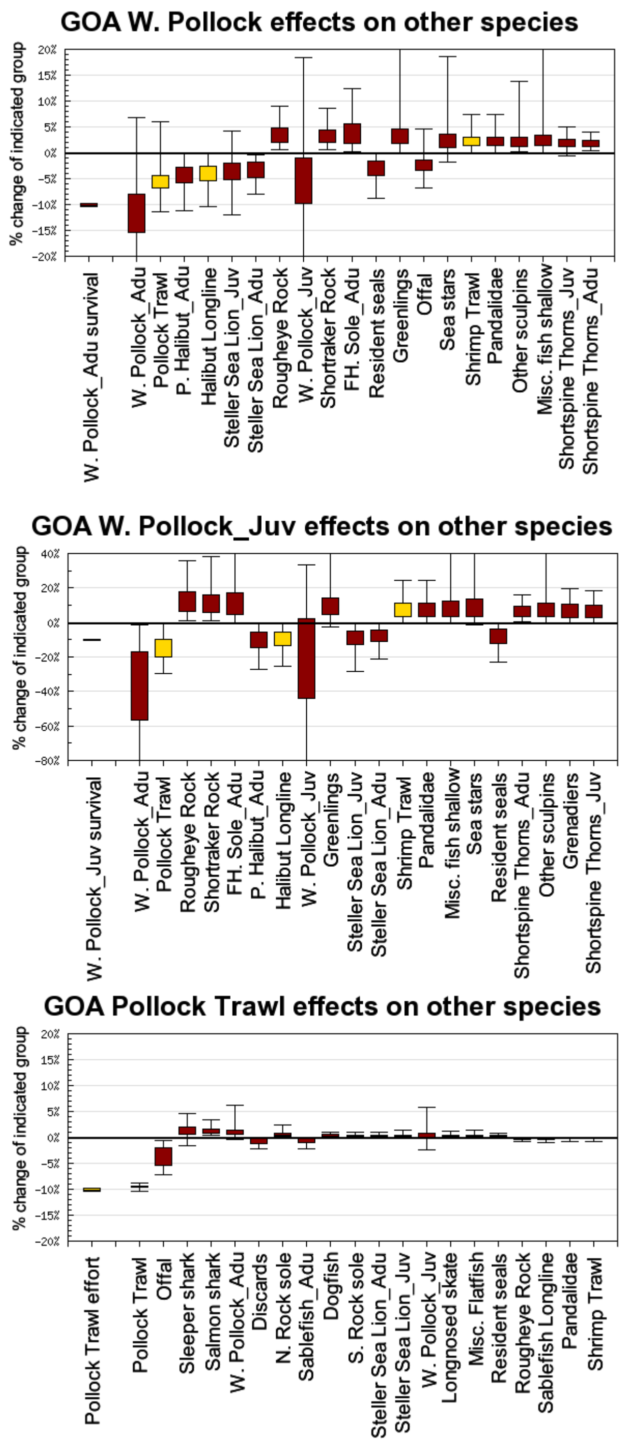


Figure 1.50. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top), reducing juvenile pollock survival by 10% (middle), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled species, 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.

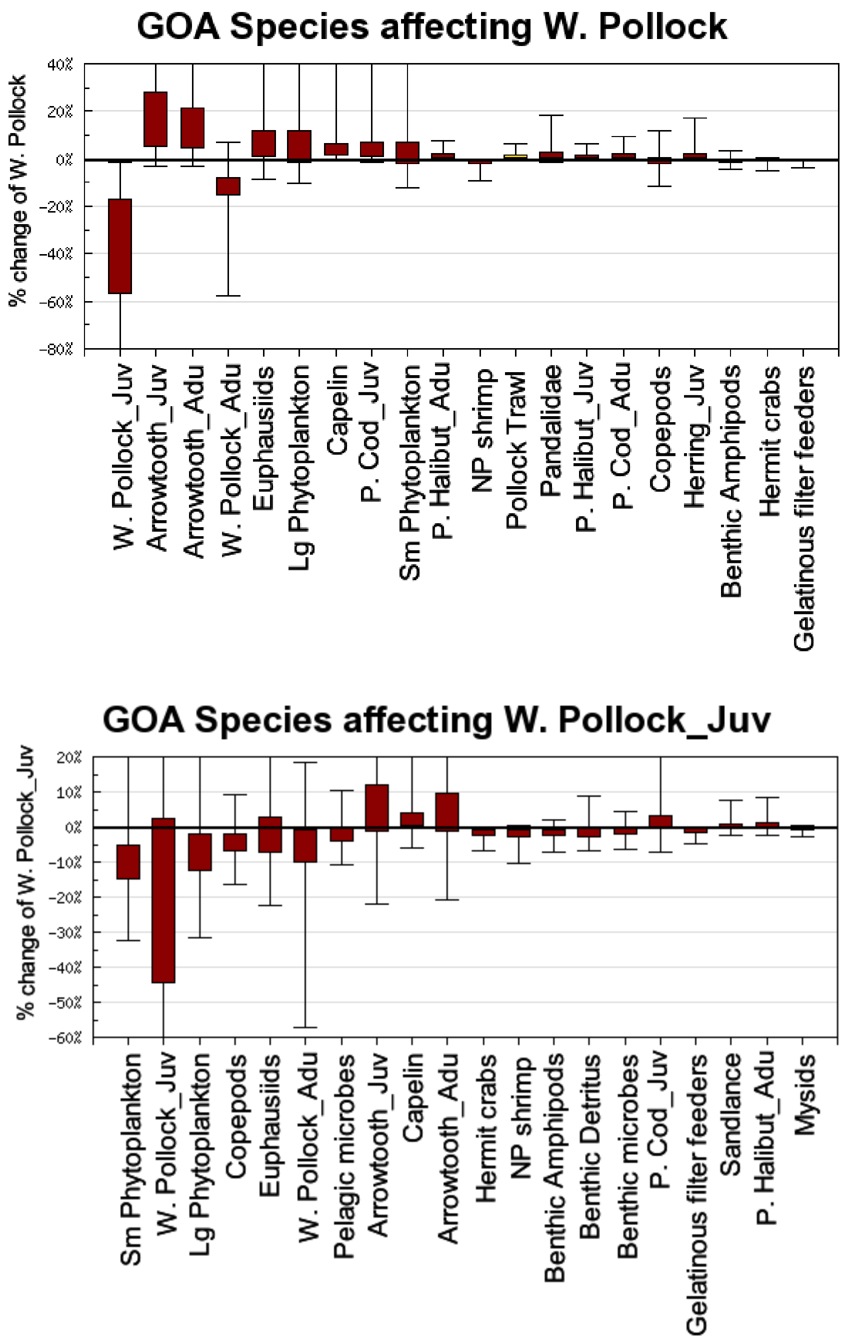


Figure 1.51. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs 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.

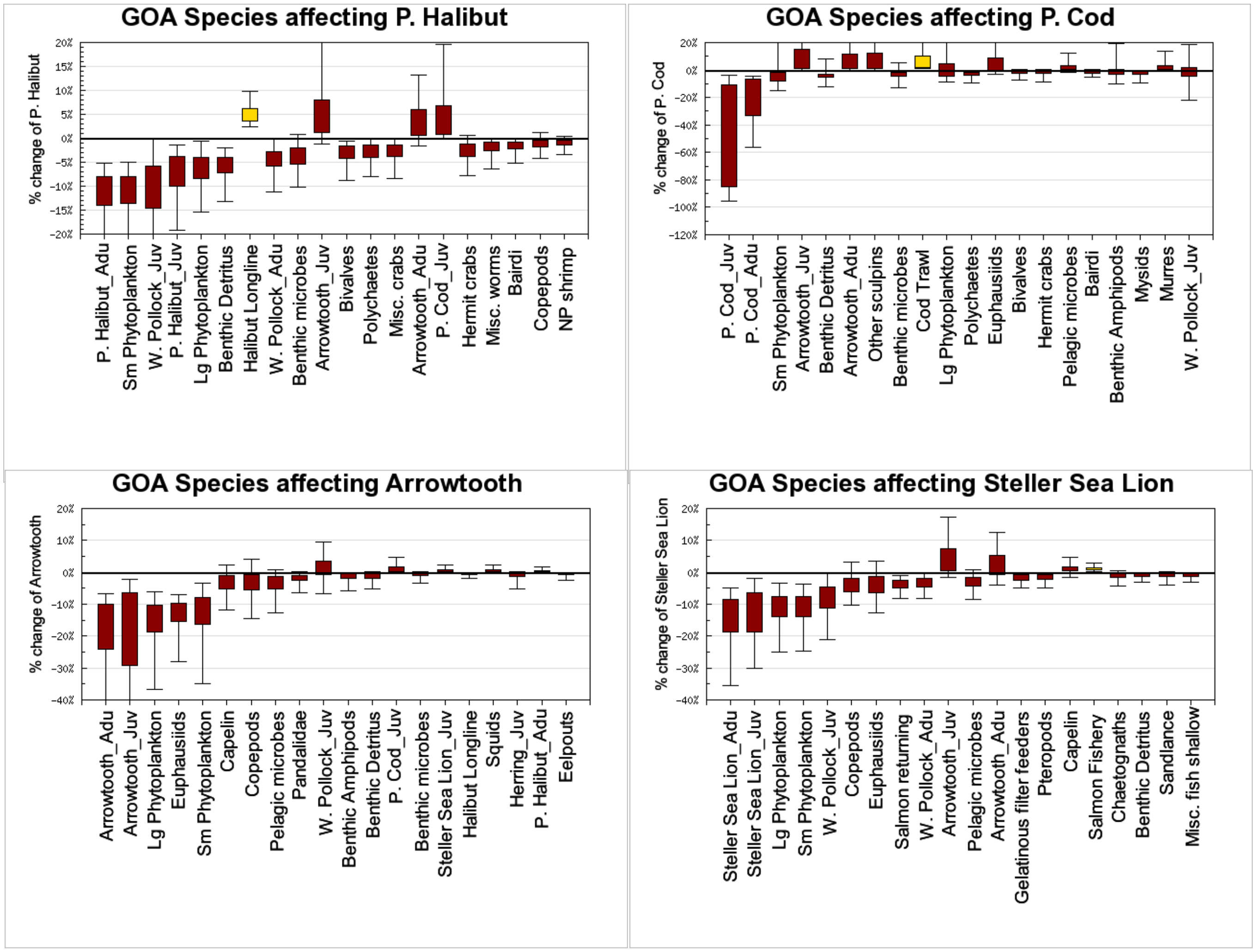


Figure 1.52. Ecosystem model output, shown as percent change at future equilibrium of four major predators on pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50% 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.

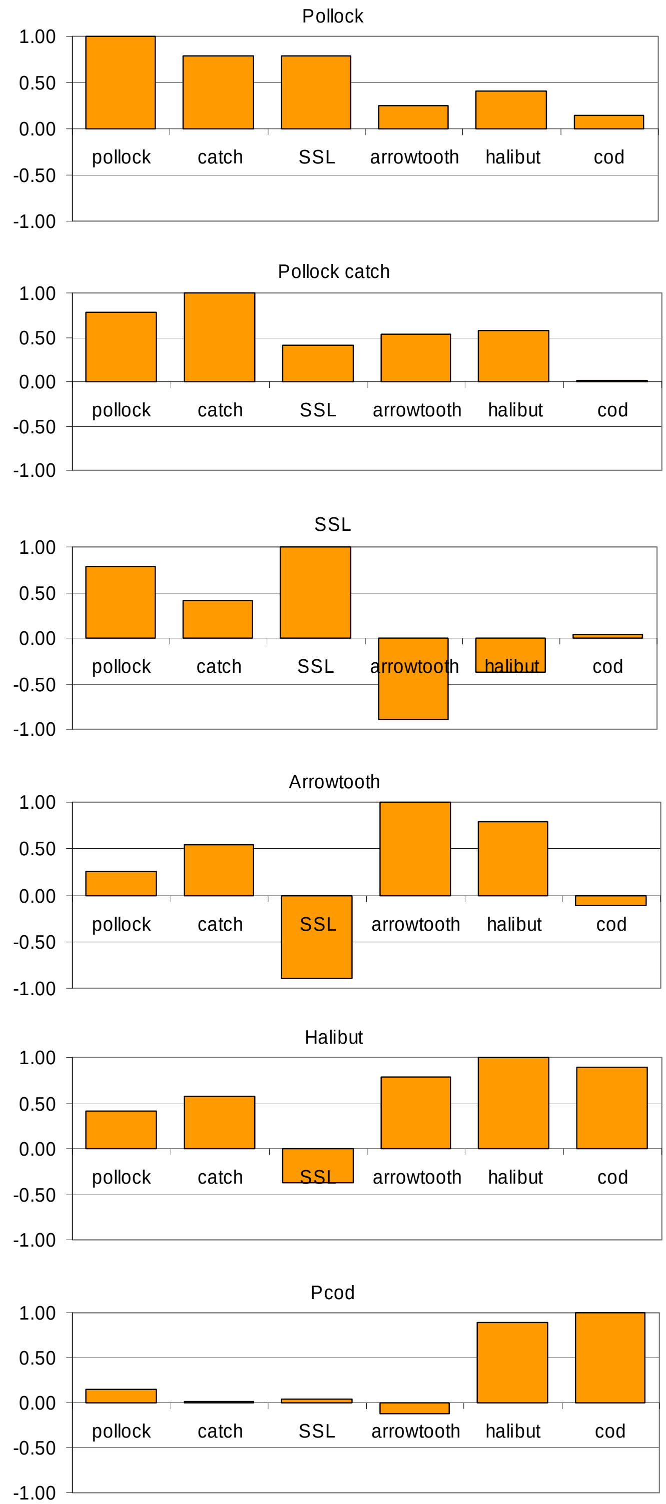


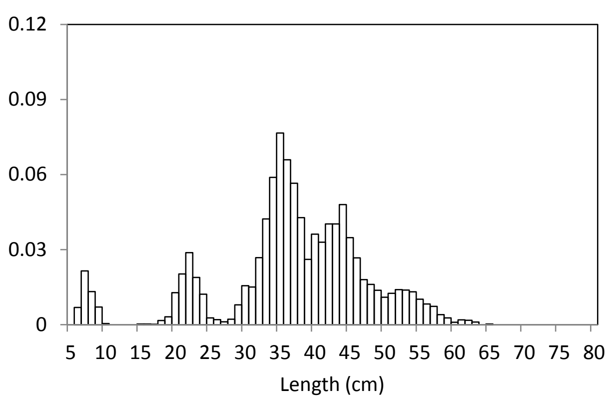
Figure 1.53. Pair-wise Spearman rank correlation between abundance trends of pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for each pair.

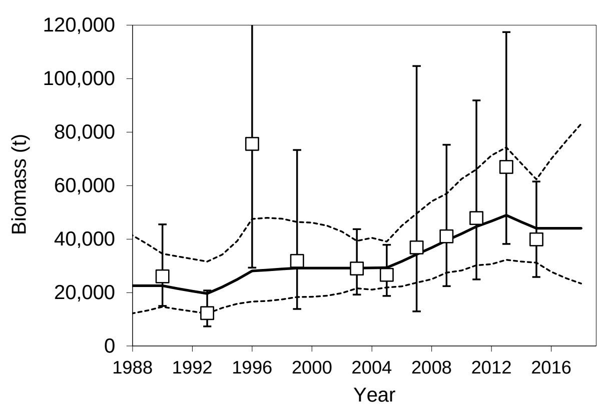
Appendix A. Southeast Alaska pollock assessment

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 2 t since 2005 (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 statistical area at 140° W. lon. and combining the strata east of the line with comparable strata in the Southeastern statistical 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 2017 ABC of 9,920 t (44,087 t * 0.75 M), and a 2017 OFL of 13,226 t (44,087 t * M). The same ABC and OFL is recommended for 2018.**





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

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

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

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

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_{ij} is the population abundance at the start of year *i* for age *j* fish, F_{ij} = fishing mortality rate in year *i* for age *j* fish, and c_{ij} = catch in year *i* for age *j* fish. 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_{ij} . Predicted values from the model are obtained from

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

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

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

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

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

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

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

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

where q = survey catchability, w_{ij} is the survey weight at age *j* in year *i* (if available), s_j = selectivity at age for the survey, and ϕ_i = fraction of the year to the mid-point of the survey. Although there are multiple surveys for 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. Steller sea lion protection measures that were implemented in 2001 require apportionment of pollock TAC based on the seasonal distribution of biomass. 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, such as 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 separated spatially.

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. A successful survey of Pavlof Bay was completed in 2016, but no biomass estimates could be produced from previous surveys of Pavlof Bay because of the lack of identification tows. 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 also require consideration.

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). A multiplier was needed only for Morzhovoi Bay in 2007 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 areas.

The sum of the percent biomass for all surveys combined was 81.92%, 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 4.67%, 82.48%, and 12.85% in areas 610, 620, and 630 (Appendix Table C.1). In comparison to last year, the percentage in area 610 is 1.7 percentage points lower, 2.6 percentage points lower in area 620, and 4.3 percentage points higher 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 average 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, 4.67%; 620, 72.29%; 630, 23.04%.

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 estimated biomass distribution in areas 610, 620, 630, and 640 was 50.00%, 17.52%, 29.27%, and 3.22% respectively (Fig. C.2). 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. Last year, the plan team recommended that summer acoustic survey data also be used to determine the summer allocation. The estimated biomass distribution from the 2015 summer acoustic survey in areas 610, 620, 630, and 640 was 28.80%, 32.18%, 34.70%, and 4.32%, respectively. Averaging the results from the random effects model and the 2015 acoustic survey distribution, as recommended by the plan team, gives a summer allocation in areas 610, 620, 630, and 640 of 39.40%, 24.85%, 31.98%, and 3.77%, respectively. This approach was regarded by the plan team and the SSC as a temporary solution that will need to be revisited as new data become available.

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 (3.77%) of the TAC in area 640 is subtracted from the TAC before allocating the remaining TAC by season and region.

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

Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*	*Multiplier from vessel comparison (OD/MF)*	*Percent*	*Percent by management area* Area 610	*Area 620*	*Area 630*
Shelikof	2013	1,227,590	831,486	1.00	67.7%	0.0%	95.0%	5.0%
Shelikof	2014	1,130,420	883,177	1.00	78.1%	0.0%	96.7%	3.3%
Shelikof	2015	1,160,190	845,210	1.00	72.9%	0.0%	91.9%	8.1%
Shelikof	2016	934,934	665,059	1.00	71.1%	0.0%	79.3%	20.7%
Shelikof	Average				72.5%	0.0%	90.7%	9.3%
	Percent of total 2+ biomass					0.0%	65.7%	6.7%
Chirikof	2010	1,184,280	9,544	1.00	0.8%	0.0%	0.0%	100.0%
Chirikof	2012	1,169,010	21,181	1.00	1.8%	0.0%	13.0%	87.0%
Chirikof	2013	1,227,590	63,008	1.00	5.1%	0.0%	70.2%	29.8%
Chirikof	2015	1,160,190	12,685	1.00	1.1%	0.0%	26.3%	73.7%
Chirikof	Average				2.2%	0.0%	27.4%	72.6%
	Percent of total 2+ biomass					0.0%	0.6%	1.6%
Marmot	2013	1,227,590	19,899	1.00	1.6%	0.0%	0.0%	100.0%
Marmot	2014	1,130,420	13,403	1.00	1.2%	0.0%	0.0%	100.0%
Marmot	2015	1,160,190	22,470	1.00	1.9%	0.0%	0.0%	100.0%
Marmot	2016	934,934	37,931	1.00	4.1%	0.0%	0.0%	100.0%
Marmot	Average				2.2%	0.0%	0.0%	100.0%
	Percent of total 2+ biomass					0.0%	0.0%	2.2%
Shumagin	2013	1,227,590	47,388	1.00	3.9%	55.2%	44.8%	0.0%
Shumagin	2014	1,130,420	36,160	1.00	3.2%	54.7%	45.3%	0.0%
Shumagin	2015	1,160,190	61,216	1.00	5.3%	71.0%	29.0%	0.0%
Shumagin	2016	934,934	20,706	1.00	2.2%	84.6%	15.4%	0.0%
Shumagin	Average				3.6%	66.4%	33.6%	0.0%
	Percent of total 2+ biomass					2.4%	1.2%	0.0%
Sanak	2013	1,227,590	12,967	1.00	1.1%	100.0%	0.0%	0.0%
Sanak	2014	1,130,420	7,319	1.00	0.6%	100.0%	0.0%	0.0%
Sanak	2015	1,160,190	17,863	1.00	1.5%	100.0%	0.0%	0.0%
Sanak	2016	934,934	3,556	1.00	0.4%	100.0%	0.0%	0.0%
Sanak	Average				0.9%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					0.9%	0.0%	0.0%
Mozhovoi	2007	620,334	2,540	1.31	0.5%	100.0%	0.0%	0.0%
Mozhovoi	2010	1,184,280	1,650	1.00	0.1%	100.0%	0.0%	0.0%
Mozhovoi	2013	1,227,590	1,520	1.00	0.1%	100.0%	0.0%	0.0%
Mozhovoi	2016	934,934	11,414	1.00	1.2%	100.0%	0.0%	0.0%
Mozhovoi	Average				0.5%	100.0%	0.0%	0.0%
	Percent of total 2+ biomass					0.5%	0.0%	0.0%
Total					81.92%	3.83%	67.57%	10.53%
Rescaled total					100.00%	4.67%	82.48%	12.85%

Appendix Table C.2. Calculation of 2017 Seasonal and Area TAC Allowances for the W/C/WYK region.

Proposed ABC for W/C/WYK (t): 203,769

Winter biomass distribution			
Area	610	620	630
Percent	4.67%	82.48%	12.85%

Summer biomass distribution				
Area	610	620	630	640
Percent	39.40%	24.85%	31.98%	3.77%

1) Deduct the Prince William Sound State Guideline Harvest Level.

PWS percent	2.50%	GHL (t)	5,094
Federal percent	97.50%	Federal TAC	198,675

2) Use summer biomass distribution for the 640 allowance:

640 percent	3.77%	640 TAC (t)	7,492
610-630 percent	96.23%	610-630 TAC (t)	191,183

3) Calculate seasonal apportionments of TAC for the A, B, C, and D seasons for areas 610-630

Season	Percent	TAC (t)
A season TAC (t)	25%	47,796
B season TAC (t)	25%	47,796
C season TAC (t)	25%	47,796
D season TAC (t)	25%	47,796

4) For the A season, the TAC allocation in 630 is based on an average of winter and summer distributions.

	A season	
Area	Percent	TAC (t)
610	4.67%	2,232
620	72.29%	34,549
630	23.04%	11,014

5) For the B season, the allocation of TAC is based on the winter biomass distribution.

	B season	
Area	Percent	TAC (t)
610	4.67%	2,232
620	82.48%	39,420
630	12.85%	6,143

6) For the C and D seasons, the allocation is based on the summer biomass distribution.

	C season	
Area	Percent	TAC (t)
610	40.94%	19,569
620	25.82%	12,341
630	33.24%	15,886

	D season	
Area	Percent	TAC (t)
610	40.94%	19,569
620	25.82%	12,341
630	33.24%	15,886

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

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