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: 2017 total catch and catch at age.
2. Shelikof Strait acoustic survey: 2018 biomass and age composition.
3. NMFS bottom trawl survey: 2017 age composition.
4. Summer acoustic survey: 2017 age composition.
5. ADFG crab/groundfish trawl survey: 2018 biomass.

Changes in assessment methodology

The age-structured assessment model is similar to the model used for the 2017 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 2019 is 345,352 t, which is 62.4% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (221,000 t), thereby placing GOA pollock in sub-tier “a” of Tier 3. New survey data in 2018 are highly contrasting, with the 2018 Shelikof Strait acoustic survey indicating high biomass, and the ADFG trawl survey indicating relatively low biomass (though increased from the previous two years). The risk matrix table recommended by the SSC was used to determine whether to recommend an ABC lower than the maximum permissible. The table is applied by evaluating the severity of three types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. We identified substantially increased concerns for the stock assessment, the population dynamics of pollock, and environmental/ecosystem factors that are likely to affect pollock.

Assessment considerations: In the last several years, there have been strongly contrasting trends in the survey abundance indices, with bottom trawl indices showing a steep decline, while acoustic surveys showing record highs. The model is unable to fit strongly contrasting trends, which has resulted in very poor model fits to the most recent survey indices. This increases the uncertainty of the assessment.

Population dynamics considerations*:* The age structure of pollock in the Gulf of Alaska has been being strongly perturbed by an unusual sequence of events. The first event was the very strong recruitment of the 2012 year class. Recruitment since then has been very weak until 2017, where there is evidence of an average year class based on acoustic surveys conducted in winter of 2018. The age-diversity of pollock has dropped rapidly, and both the fishery and population are now completely dominated by a single large year class. The 2012 year class has showed reduced growth, early maturation, and apparent reduced natural mortality.

Environmental/Ecosystem considerations: Limited information indicates age-0 pollock may have been relatively abundant in summer of 2018, but conditions do not appear to be favorable for winter survival with the recent onset of a marine heatwave in the GOA, and forecasted warm temperatures through winter of 2018/19. If the 2018 year class turns out to be weak, this would likely lead to downward trend in adult pollock biomass, since the 2017 year class is the first since 2012 that is estimated to be of average size. There are mixed signals regarding current foraging conditions for largely planktivorous adult pollock. Increases in large copepods and euphausiids suggest improved foraging conditions this past year. In contrast, planktivorous parakeet auklets nesting in the Semidi Islands had poor reproductive success in summer 2018, suggesting a lack of forage for pollock.

The authors’ 2019 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 134,740 t, which is a decrease of 17% from the 2018 ABC. The author’s recommended ABC was obtained by applying a 15% buffer to the maximum permissible ABC, based on the considerations detailed above. A buffer of 15% corresponds to the mode of historical buffers that have been recommended by plan teams (Thompson unpublished document) when recommending an ABC below the maximum permissible ABC. The author’s recommended ABC for 2020 is 108,892 t, using the same 15% buffer to the maximum permissible ABC in 2020. The OFL in 2019 is 194,230 t, and the OFL in 2020 if the recommended ABC is taken in 2019 is 148,968 t. It should be noted that the stock may begin to stabilize over the next few years, particularly if recent increases in recruitment continue.

For pollock in southeast Alaska (Southeast Outside region), the ABC recommendation for both 2019 and 2020 is 8,773 t (see Appendix A) and the OFL recommendation for both 2019 and 2020 is 11,697 t. These recommendations are based on a Tier 5 assessment using the projected biomass in 2019 and 2020 from a random effects model fit to the 1990-2017 bottom trawl survey biomass estimates in Southeast Alaska. No new data are available this year.

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

Quantity/Status	As estimated or specified *last* year for 2018	2019	As estimated or recommended *this* year for 2019	2020
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	1,124,930	804,586	1,126,750	1,068,760
Female spawning biomass (t)	342,683	264,349	345,352	257,794
$B_{100\%}$	596,000	596,000	553,000	553,000
$B_{40\%}$	238,000	238,000	221,000	221,000
$B_{35\%}$	209,000	209,000	194,000	194,000
F_{OFL}	0.30	0.30	0.32	0.32
$maxF_{ABC}$	0.26	0.26	0.27	0.27
F_{ABC}	0.26	0.24	0.22	0.22
OFL (t)	187,059	131,170	194,230	148,968
maxABC (t)	161,492	113,153	158,518	128,108
ABC (t)	161,492	106,568	134,740	108,892
	As determined *last* year for		As determined *this* year for	
Status	2016	2017	2017	2018
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: 2018	2019	As estimated or *recommended this* year for: 2019	2020
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)				
Upper 95% confidence interval	70,502	75,820	75,820	80,954
Point estimate	38,989	38,989	38,989	38,989
Lower 95% confidence interval	21,562	20,050	20,050	18,778
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)	11,697	11,697	11,697	11,697
maxABC (t)	8,773	8,773	8,773	8,773
ABC (t)	8,773	8,773	8,773	8,773
	As determined *last* year for:		As determined *this* year for:	
Status	2016	2017	2017	2018
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments in General

The SSC in its October 2018 minutes recommended that assessment authors and plan teams use the risk matrix table developed last summer by a plan team working group when determining whether to recommend an ABC lower than the maximum permissible.

In this assessment, we have used the risk matrix table to evaluate stock assessment, population dynamics and ecosystem concerns relevant to Gulf of Alaska pollock.

Responses to SSC and Plan Team Comments Specific to this Assessment

The GOA plan team in its November 2017 minutes recommended that trawl survey catchability relative to age structure be examined. That is, evaluate the extent that pollock of different ages vary in availability to bottom gear.

Acoustic data are routinely collected during the NMFS bottom trawl survey, but these data have never been processed. We are exploring options for processing these data, which could potentially be used to evaluate pollock catchability. This project would need to obtain outside funding since the GOA/AI survey group currently does not have the resources to analyze these data.

The GOA plan team in its November 2017 minutes recommended that when using the Francis weighting approach that age/length composition data sets with small numbers of years be paired with other similar data sources with increased number of years in order to estimate data weights.

Since reasonable results were obtained using the Francis approach for all age composition data sets, this did not seem to be a problem with pollock assessment. The ADFG survey has the fewest years of age composition data (9 years), but the Francis tuning procedure seemed to work appropriately.

The GOA plan team in its November 2017 minutes recommended that pollock vertical distribution in the water column be evaluated.

We plan to work with acoustic survey group to produce statistics on pollock vertical distribution during the summer acoustic survey. Such an index could potentially be used to inform catchability for bottom trawl surveys conducted during the summer.

The GOA plan team recommended in its November 2017 minutes that assessment authors to continue examining environmental covariates in the delta-GLMM survey abundance estimate.

The delta-GLM model for the ADFG survey was included again included in the assessment. We were unable to explore environmental covariates in the model. The model fit to this index was much improved in the current assessment, which may make this less of an issue.

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 within 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 2013 and 2017, on average about 96% 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 grenadiers, miscellaneous fish, eulachon, jellyfish, and other osmerids (Table 1.2). Bycatch estimates for prohibited species over the period 2013-2017 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 the peak in 2010, but increased in 2016 and 2017.

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, summer acoustic survey estimates of biomass and age composition, 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	1970-2017
Fishery	Age composition	1975-2017
Shelikof Strait acoustic survey	Biomass	1992-2018
Shelikof Strait acoustic survey	Age composition	1992-2018
Summer acoustic survey	Biomass	2013-2017
Summer acoustic survey	Age composition	2013-2017
NMFS bottom trawl survey	Area-swept biomass	1990-2017
NMFS bottom trawl survey	Age composition	1990-2017
ADFG trawl survey	Delta-GLM index	1989-2018
ADFG survey	Age composition	2000-2016

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 1991-2017 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 2000-2015 is documented in the assessments available online at http://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm.

Age and length samples from the 2017 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	53	634	223
	Num. lengths	706	7919	3024
	Catch (t)	4,111	60,679	8,456
2nd half (C and D seasons)	Num. ages	657	209	391
	Num. lengths	10960	3494	7531
	Catch (t)	45,432	20,933	46,547

The estimated age composition in all areas and all seasons was very similar (Fig. 1.2). The catch-at-age in both the first half and the second half of 2017 (A and B season) and in all areas was dominated by age-5 fish (2012 year class). Fishery catch at age in 1975-2017 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 once every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and statistical area (von Szalay et al.

2010). 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, 73% 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 the difficulty in standardizing the surveys in 1984 and 1987, when Japanese vessels with different gear were used.

Bottom Trawl Survey Age Composition

Estimates of numbers at age from the bottom trawl survey are obtained from random otolith samples and length frequency samples (Table 1.9). Numbers at age are estimated by 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. The combined Shumagin, Chirikof and Kodiak age composition is used in the assessment model (Fig. 1.4). Ages are now available for the 2017 survey and are used in preference to length composition. In the Central and Western portion of the Gulf of Alaska, age-5 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) (Fig. 1.5). In contrast, age-1 pollock increased in abundance moving eastwards from the Chirikof-620 area and were particularly abundant in Southeast Alaska.

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 2018 are presented in a NMFS processed report (Stienessen et al, 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.

Estimates of biomass and age composition for the survey conducted by the *R/V Oscar Dyson* (2008-2018) were revised to account for trawl selectivity. Escapement of small pollock (primarily age-1) through the mesh of the midwater trawl used to sample echosign was evaluated by attaching pocket nets with small mesh. Trawl selectivity was estimated experimentally in 2008 and 2013 by attaching the pocket nets to the trawl as it was being deployed, and removing them upon trawl retrieval. In the 2018 survey, the midwater trawl was permanently configured with pocket nets made of tough material that could be rolled up on the net reel. Data from 2018 were combined with the earlier experiments to provide a historical time-series selectivity correction. To derive the selectivity curve parameters, a generalized linear mixed effects model was fit with a logistic link function and binomial error where variation between tows in selectivity was modeled with random effects. The estimated mean selectivity curve was used to scale up the number of retained pollock to account for net escapement. Selectivity parameters from 2018 were estimated separately and used to correct the 2018 survey results. The revised biomass estimates from the entire time series were 2.8% lower on average, and ranged between zero and 5.1% lower depending on whether small fish were present in the survey area. Estimates of age-1 pollock increased by 122%, while estimates of other year classes declined slightly. Estimation of trawl selectivity will become a routine survey activity, with pocket nets becoming a permanent gear accessory for the midwater trawls used in the survey.

The 2018 biomass estimate for Shelikof Strait is 1,320,867 t, which is a 9.9% percent decrease from the 2017 estimate (Fig. 1.6). In addition to the Shelikof Strait survey, acoustic surveys in winter 2018 included other pollock spawning areas in the Central and Western Gulf of Alaska, including the Shumagin Islands, Sanak Gully, Pavlof Bay, Morzhovoi Bay, and Marmot Gully. Survey effort in the Gulf of Alaska is reduced in even years to accommodate the Bogoslof Island survey in the Aleutian Islands. The following table provides results from the 2018 winter acoustic surveys:

Area	Total biomass (t)	Percent
Morzhovoi Bay	3,772	0.3%
Pavlof Bay	4,619	0.3%
Sanak Gully	1,317	0.1%
Shumagin Islands	17,390	1.3%
Shelikof Strait	1,320,867	97.0%
Marmot Bay	13,497	1.0%
Total	1,361,461	

The total biomass in 2018 for all surveys is 23% lower than in 2017, but fewer areas were surveyed in 2018. In areas that were surveyed in 2017 and 2018, there were both declines and increases. There were increases in Pavlof Bay (107%), Sanak Gully (38%), and Marmot Bay (5%), but decreases in Morzhovoi Bay (-4%), and Shumagin Islands (-41%).

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 1994-2017 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. Estimates of age composition in Shelikof Strait in 2018 indicate that the age-6 2012 year class made up 83% of the biomass.

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 sum of the 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.

Summer Acoustic Survey

Three complete acoustic surveys, in 2013, 2015, 2017, 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 2017, nearshore survey transects in Izhut Bay, Kenai Bays and Prince William Sound were cancelled due to equipment breakdown and repair on the *R/V Oscar Dyson*, but these areas accounted less than 2% of the total biomass in 2013 and 2015. The survey consists of widely-spaced parallel transects along the shelf, and more closely spaced transects in troughs, bays, and Shelikof Strait. Mid-water and bottom trawls are used to identify acoustic targets. Age composition in 2017 indicated that the very abundant 2012 year class (age-5 fish) was dominant, though a secondary mode of age-1 pollock was present in the central GOA (Fig. 1.8). Analysis of the 2017 survey was complicated by the presence of age-0 pollock, which were very abundant, widely-distributed, and mixed with juvenile and adult pollock backscatter. Since both the summer bottom trawl and summer acoustic surveys are conducted from west to east on roughly a similar timetable, methods described by Kotwicki et al. (2017) could be applied to combine data from both surveys.

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. 1.9). 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 2018 area-swept biomass estimate for pollock for the ADFG crab/groundfish survey was 49,788 t, more than double (228%) from the 2017 biomass estimate (Table 1.7). This indicates that the recent pollock estimates for this survey continue remain at very low levels relative to historical levels.

Delta GLM indices

A simple delta GLM model was applied to the ADFG tow by tow data for 1988-2017 to obtain annual abundance indices. Data were filtered to exclude missing latitude and longitudes (1 tow) and missing depths (4 tows). Tows made in lower Shelikof Strait (between 154.7° W lon. and 156.7° W lon.) were excluded because these stations were sampled irregularly (157 tows). The delta GLM model fit 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= 494.2). A quantile-quantile plot for the gamma model residuals was not ideal, but was considered acceptable (Fig. 1.10). Comparison of delta-GLM indices the area-swept estimates indicated similar trends (Fig. 1.11). Variances were based on a bootstrap procedure, and CVs for the annual index ranged from 0.09 to 0.20. These values 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 2000-2016 ADFG surveys in even-numbered years (average sample size = 580) (Table 1.12, Fig. 1.12). 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). 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 1973-1976. 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 qualitatively assess recent trends in abundance, each survey time series was standardized by dividing the annual estimate by the average since 1990. 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, followed by a strong increase to 2013 (Fig. 1.13). In last few years there has been strong divergence the trends, particularly in 2017. Both the ADFG and the bottom trawl surveys indicate a steep decline in abundance, while the Shelikof Strait acoustic survey in 2017 increased to more than twice the long-term average.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.14). The percent of females in the catch shows some variability but no obvious trend, and is usually close to 50-50. In 2016, the percent female dropped to 40%, but increased to 43% in 2017. Evaluation of sex ratios by season indicated that this decrease was mostly due a low percentage of females during the A and B seasons prior to spawning. However the sex ratio during the C and D seasons was close to 50-50, suggesting the skewed sex in winter was related to spawning behavior, rather than an indication of a population characteristic. 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 declined in 2015-2017 as the strong 2012 year class recruited 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, but declined sharply in 2016 and remained low in 2017 due to the dominance of the 2012 year class in the catch (Fig. 1.14). A remarkable number of indicators that showed unusual values in 2016 and 2017, which raises concern, though the implications for pollock population dynamics are unclear.

The 2012 year class, which is both very strong, and which has experienced anomalous environmental conditions during the marine heatwave in the North Pacific during 2015-2017, has displayed unusual life history characteristics. These include early maturation, reduced growth, and potentially reduced total mortality (Fig. 1.15). It is unclear whether these changes are a result of density dependence or environmental forcing.

Analytic Approach

Model Structure

An age-structured model covering the period from 1970 to 2018 (49 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-selection 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 Francis (2011) method. 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 (1970-2018)	Log-normal	CV = 0.05
Fishery age comp. (1975-2017)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2018)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2018)	Multinomial	Initial sample size = 60
Winter acoustic survey age-1 and age-2 indices (1994-2018)	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, 2017)	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. (1990-2017)	Multinomial	Initial sample size = 60
ADFG trawl survey index (1989-2018)	Log-normal	Survey-specific CV from delta GLM model x 2= 0.18-0.40
ADFG survey age comp. (2000-2016)	Multinomial	Initial sample size = 30
Recruit process error (1970-1977, 2017, 2018)	Log-normal	σ_R =1.0

Recruitment

In most years, year-class abundance at age 1 was estimated as a free parameter. Age composition in the first year 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 2017 and 2018 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 independently estimated catchability coefficients (i.e., no selectivity is estimated). A density-dependent power coefficients were evaluated for catchability for both indices, but ended up not being used in the final model.

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. Previously we included a likelihood component to incorporate this information in the assessment model, but dropped it because this survey is now modeled with a random walk in catchability, and a relatively small systematic change in catchability is inconsequential compared to other factors affecting catchability.

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: 5-24, 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_∞ = 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 method 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 (Neidetcher et al. 2014). 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 379 (Table 1.15).

Estimates of maturity at age in 2018 from winter acoustic surveys substantially above the long term mean for all ages (Fig. 1.18), though except for the age-6 females from the 2012 year class the sample sizes were small and the estimates should not be considered reliable. 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 1983-2018 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 to evaluate long-term changes in maturation. Annual estimates of age at 50% maturity are highly variable and range from 2.6 years in 2017 to 6.1 years in 1991, with an average of 4.8 years. The last few years has shown a decrease in the age at 50% mature, which is largely being driven by the maturation of 2012 years at younger ages than is typical. 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 the 1983 and 1984 estimates as unusually low values, the last few years showing a decline in the length at 50%. The average length at 50% mature for all years is approximately 43 cm.

Weight at age

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a\,L^b$, were also estimated. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions. 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 since 2012 has trended strongly downward, with some stabilization in the last couple of 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 (RE) 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 1975-2017. 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 (1981-2017) and the NMFS bottom trawl survey (1984-2015) were used. The model also requires input standard deviations for the weight at age data, which are not available for GOA pollock. In the 2016 assessment, a generalized variance function was developed using a quadratic curve to match the mean standard deviations at ages 3-10 for the eastern Bering Sea pollock data. 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. A comparison of RE model estimates from last year of the 2017 fishery weight at age with the data now available indicate that the model tended to under-predict the weight at age for younger fish and over-predict the weight at age for older pollock (Fig. 1.21). However there was good agreement for age-5 pollock, which made up 91% of the catch at age. In this assessment, RE model estimates of weight at age are used for the fishery in 2018, and yield projections and spawning biomass per recruit calculations used the RE model estimates for 2019 (Fig. 1.21).

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 for the base model is shown below:

Population process modeled	*Number of parameters*	*Estimation details*
Recruitment	Years 1970-2018 = 49	Estimated as log deviances from the log mean; recruitment in 1970-77, and 2016 and 2017 constrained by random deviation process error.
Natural mortality	Age-specific= 10	Not estimated in the model
Fishing mortality	Years 1970-2017 = 49	Estimated as log deviances from the log mean
Mean fishery selectivity	4	Slope parameters estimated on a log scale, intercept parameters on an arithmetic scale
Annual changes in fishery selectivity	2 * (No. years-1) = 96	Estimated as deviations from mean selectivity and constrained by random walk process error
Mean survey catchability	No. of surveys = 6	Catchabilities estimated on a log scale. Separate catchabilities were also estimated for age-1 and age-2 winter acoustic indices.
Annual changes in survey catchability	2 * (No. years-1) = 96	Annual catchability for winter acoustic surveys and ADF&G surveys estimated as deviations from mean catchability and constrained by random walk process error
Survey selectivity	6 (Shelikof acoustic survey: 2, BT survey: 2, ADFG survey: 2)	Slope parameters estimated on a log scale.
Total	110 estimated parameters + 192 process error parameters + 10 fixed parameters = 312	

Results

Model selection and evaluation

Model Selection

Prior to identifying a set of models for consideration, several sensitivity analyses were done. An analysis was conducted of the impact of each new data element on model results. Figure 1.22 shows the changes in estimated spawning biomass as total catch, catch at age, survey numbers at age, the 2018 ADFG survey, and the 2018 Shelikof Strait acoustic survey estimates were added sequentially. The addition of total catch, catch at age, survey numbers at age, and the 2018 ADFG survey did not change the biomass trend appreciably. Adding the 2018 Shelikof Strait acoustic survey pulled the biomass trend strongly upwards.

The intent of this year's assessment is to provide a straightforward update without considering major changes to the model. We evaluated the inclusion on net-selectivity corrected estimates of biomass and age composition for the Shelikof Strait acoustic survey. Since revised estimates were calculated only for surveys on the *R/V Oscar Dyson* from 2008 onwards, inclusion of the new estimates required some choices to be made about how to model the age 1 and age 2 indices, which were most affected by the new approach. Several models evaluated alternative ways to model these data. Alternative models that were evaluated are listed below.

Model 17.2--last year's base model
Model 17.2 new data--last year's base model with new data
Model 18.1--Net-selectivity corrected acoustic estimates, age-1 and age-2 indices for 2009-2018 for Shelikof + Shumagin surveys.
Model 18.2--Same as 18.1, but age-1 and age-2 indices for 2008-2018 Shelikof surveys only.
Model 18.3--Same as 18.2, but without a power term for age-1 index.

To provide a common basis for model comparison, all models used the final weights for composition data for last year's base model, model 17.2, obtained using the Francis (2011) approach for iterative reweighting. Models were compared by examining model fits (Table 1.19) and plotting the estimated spawning biomass (Fig. 1.23).

Models 18.1, 18.2, and 18.3 models explored different ways of modeling the net-selectivity corrected acoustic estimates. The estimated numbers at age one were most strongly affected by this new approach, so it would not be possible to combine both revised and unrevised estimates in a single time series. Since the age-one index is most useful for providing initial estimates of recruitment strength, prior to appearing in other surveys and the catch at age, there did not appear to be any rationale for modeling the corrected and uncorrected age-one indices with different catchabilities. Therefore we focus on models that used only the corrected indices since 2009. Since the *R/V Oscar Dyson* did not survey the Shumagin area, the options considered were an index from 2009 onwards for a Shumagin plus Shelikof Strait index (model 18.1), and from 2008 onwards index for Shelikof Strait only (model 18.2). Both age-1 and age-2 indices where treated in the same way.

Comparison of model 18.1 with model 17.2 indicated that there were minimal impacts on the results due to the switch to the revised estimates. Comparison of model 18.1 and 18.2 indicated slighting lower mean square error for age-1 and age-2 indices for the Shelikof Strait only times series. Therefore model 18.2 was considered an improvement over model 18.1, though these two approaches should be re-evaluated as more net-selectivity corrected estimates accumulate. Finally we compared model 18.2 with model 18.3, where the power term for the age-1 index was removed. This comparison was considered of interest because the net-selectivity corrected estimates may no longer need the power term to improve model fit. The change in log likelihood for model 18.3 compared to model 18.2 was 0.29, indicating that including a power term did not significantly improve model fit. Therefore model 18.3 was selected as the base model, and a final turning step was done using the Francis (2011) approach. 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, but model results were nearly unchanged.

Model Evaluation

The fit of model 18.2 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. 1.24, Fig. 1.25), Shelikof Strait acoustic survey age composition (Fig. 1.26, Fig. 1.27), NMFS trawl survey age composition (Fig. 1.28, Fig. 1.29), and ADFG trawl survey age composition (Fig. 1.29, Fig. 1.30). Model fits to fishery age composition data are adequate in most years, though the very strong 2012 year class shows up as a positive residual in for the 2016 and 2017 age composition due to stronger than expected abundance in the age composition. The largest residuals tended to be at ages 1-2 in 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 follow general trends in survey time series are fit reasonably well (Fig. 1.31 and Fig. 1.32), although large positive residuals are evident in 2017 and 2018 for the Shelikof Strait acoustic survey and the 2017 NMFS bottom trawl survey shows a strong negative residual. In addition, the model is unable to fit the extremely low values for the ADFG survey in 2015-2017, though the fit to the ADFG survey in 2018 is much improved, and the fit to the ADFG survey is quite good overall. The fit to the age-1 and age-2 acoustic indices was much improved compared to previous years (Fig. 1.33).

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 Fig. 1.34). Table 1.21 gives the estimated population numbers at age for the years 1970-2018. Table 1.22 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2018 (see also Fig. 1.35). 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 80% of the proxy for unfished stock size ($B_{100\%}$ = mean 1978-2017 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR@F=0)). In 2001, the stock dropped below the $B_{40\%}$ for the first time since the early 1980s, reached a minimum in 2003 of 29% of unfished stock size. Over the years 2009-2013 stock size showed a strong upward trend, increasing from 38% to 69% of unfished stock size, but declined to 47% of unfished stock size in 2015. The spawning stock peaked in 2017 as the strong 2012 year class matured, and is projected to decline subsequently.

Figure 1.36 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 1993-2018 indicates the current estimated trend in spawning biomass for 1990-2017 is consistent with previous estimates (Fig. 1.37). 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 successive assessment. The estimated 2018 age composition from the current assessment is reasonably consistent with the projected 2018 age composition from the 2017 assessment (Fig. 1.37). The largest change is the estimate of the age-6 fish (2012 year class), which has been revised upwards due the high acoustic survey biomass in 2018, and the dominance of this year class in recent fishery and survey data. The estimate of age-1 recruits in 2018 is similar the average recruitment that 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 an evaluation of the stability of the current model as new data are added. Figure 1.38 shows a retrospective plot with data sequentially removed back to 2008. There is up to 23% error in the estimates of spawning biomass (if the current assessment is accepted as truth), but usually the errors are much smaller. There is relatively modest positive retrospective pattern to errors in the assessment, and the revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.024, which does not indicate a concern with retrospective bias.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 1.33) than Eastern Bering Sea pollock (CV = 0.60). 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. 1.39). The 2012 year class still appears even stronger based on the current assessment, and it now appears to be strongest year class since 1970s when the assessment model starts. 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. 1.39). 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. Age-1 recruitment in 2017 is estimated to be below average, and age-1 recruitment in 2018 is estimated to be close to the long-term average, though these estimates will remain very uncertain until additional data become available.

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 1978-2017 age-1 recruitment (5.901 billion), which is 6% higher than the mean value in last year's assessment due to the stronger showing of the 2012 year class. 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 2014-2018 to estimate current reproductive potential. A substantial long-term increase in pollock weight-at-age has been observed, though recently the trend in weight-at-age has reversed, begun to decline steeply (Fig. 1.20). The factors which caused this pattern are unclear, but are likely to involve both density-dependent factors and environmental forcing. The SPR at F=0 was estimated as 0.094 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 2013-2017 to reflect current selectivity patterns.

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

		Equilibrium under average 1978-2017 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	5901	2203	553	0	0.0%
40.0%	0.267	5901	1328	221	180	13.6%
35.0%	0.317	5901	1250	194	196	15.7%

The $B_{40\%}$ estimate of 221,000 t represents a 7% decrease from the $B_{40\%}$ estimate of 238,000 t in the 2017 assessment (Table 1.25), which is caused by the continuing decline in spawning weight at age, but is moderated by the increase in mean recruitment. The base model projection of female spawning biomass in 2019 is 345,352 t, which is 62.4% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (221,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3.

2019 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 84.6% of the OFL harvest rate. Projections for 2019 for the F_{OFL} and the maximum permissible F_{ABC} are given in Table 1.26.

Should the ABC be reduced below the maximum permissible ABC?

The SSC in its October 2018 minutes recommended that assessment authors and plan teams use the risk matrix table below when determining whether to recommend an ABC lower than the maximum permissible.

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals but the pattern is not consistent across all indicators.
Level 3: Major Concern	Major problems with the stock assessment, very poor fits to data, high level of uncertainty, strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level, and/or b) up or down trophic levels (i.e., predators and prey of stock)
Level 4: Extreme concern	Severe problems with the stock assessment, severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented. More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock. Potential for cascading effects on other ecosystem components

The table is applied by evaluating the severity of three types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, and environmental/ecosystem considerations. Examples of the types of concerns that might be relevant include the following:

Assessment considerations—

   a. Data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data
   b. Model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs.
   c. Model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds.
   d. Estimation uncertainty: poorly-estimated but influential year classes.
   e. Retrospective bias in biomass estimates.
2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

Assessment considerations

The GOA pollock assessment does not show a strong retrospective bias, and fits to the age composition data for the fishery and surveys are generally adequate. The pollock assessment is one of a handful of assessments in the North Pacific that is fit to multiple abundance indices. In the last several years, there have been strongly contrasting trends in the survey abundance indices, with bottom trawl indices showing a steep decline, while acoustic surveys showing record highs (Figures 1.31 and 1.32). Since the model is unable to fit strongly contrasting trends, this has resulted in very poor model fits to the most recent survey indices. Although this divergence in trend is a recent phenomenon, it is worth mentioning a similar problems have been seen in past. Specifically, in the 1980s a major assessment issue was the difficulty in reconciling acoustic and bottom trawl estimates. We rated the assessment-related concern as level 2, a substantially increased concern, because the contrasting trends in survey indices add to the uncertainty of the assessment relative to other North Pacific assessments where this is not an issue. However other aspects of the assessment seem relatively robust, so we could not justify going to a higher risk level.

Population dynamics considerations

The age structure of pollock in the Gulf of Alaska is being strongly perturbed by an unusual sequence of events. The first event was the very strong recruitment of the 2012 year class. The current assessment estimates this year class as the largest by a considerable margin. However, recruitment since then has been very weak until 2017, where there is evidence of a moderately strong year class based on acoustic surveys conducted in winter of 2018. A gap of 4 years without recruitment to the population relatively rare for pollock, but has occurred in the past. Because of this sequence of events, the age-diversity of pollock has dropped rapidly (Fig 1.14), and both the fishery and population are now dominated by a single large year class. There are been other unusual phenomena associated with 2012 year class, including reduced growth, early maturation, and apparent reduced natural mortality (Fig 1.15). Yet the stock is estimated to be above spawning biomass target at present, and the presence of moderately strong recruitment in 2017 is a positive though uncertain sign. Overall we rated the population-dynamic concern as level 2, a substantially increased concern.

Environmental/Ecosystem considerations

Evaluating this category will ideally use information from both Ecosystem Status Report (ESR) and Ecosystem and Socio-economic Profile (ESP) for GOA pollock, which will not be available until next year. Here we summarize information in the ESR relevant to larval pollock (age-0) and older pollock (juveniles and adults).

While limited information suggests that there were many age-0 pollock during summer 2018, fall and winter 2018-19 environmental conditions do not appear to be favorable. Indications of a strong 2018 year class are based on beach seine surveys (Laurel, unpub. data) and above average reproductive success of piscivorous seabirds that forage on age-0 gadids in the western GOA. However, the GOA has recently crossed a threshold into a marine heatwave state based on approach developed Hobday et al. (2018). It is unclear whether the heatwave will be of long or short duration. It is currently at a lower intensity than the 2014-2016 heatwave. Also, anomalously warm sea surface temperatures and a weak-moderate El Nino are predicted through winter 2018/19. It is reasonable to expect that the current heat wave may negatively impact age-0 pollock during a time when they are growing to a size that promotes over winter survival. Also, warm conditions tend to be associated with zooplankton communities that are dominated by less lipid rich species. If the 2018 year class turns out to be weak, this would likely lead to downward trend in adult pollock biomass, since only the 2017 year class estimated to be of average size subsequent to the 2012 year class.

There are mixed signals for current foraging conditions for largely planktivorous adult pollock. Copepod community size anomalies were larger for the Alaskan Shelf and oceanic habitats in 2017, after a period of smaller size copepods during the marine heat wave (2014-2016). Biomass of copepods and euphausiids were above the long-term mean during May 2018 along the Seward Line. A suite of indicators suggest that while small copepods were abundant during the heat wave, the more lipid-rich large copepods and euphausiids were less so. Thus, increases in large copepods and euphausiids suggest improved foraging conditions this past year. Also, the lipid content of all zooplankton taxa examined increased from 2017 to 2018, indicating an increase in the nutritional quality of the prey field utilized by larval and juvenile fish in Icy Strait, northern southeast Alaska. In contrast, planktivorous parakeet auklets nesting in the Semidi Islands had poor reproductive success in summer 2018, in contrast to the multiple piscivorous species that also nest there. Given that the indicators are mixed for GOA pollock, we scored this category as level 2, a substantially increased concern.

These results are summarized in the table below:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Overall score (highest of the individual scores)*
Level 2: Substantially increased concerns	Level 2: Substantially increased concerns	Level 2: Substantially increased concerns	Level 2: Substantially increased concerns

The overall score of level 2 suggests that it is appropriate to consider setting the ABC below the maximum permissible. The SSC recommended against using a table that showed example alternatives to select buffers based on that risk level. Thompson (unpublished Sept 2018 plan team document) tabulated the magnitude of buffers applied by the plan teams for the period 2003-2017, and found that the mode of the buffers recommended was 10-20 percent. Taking this as guideline, we therefore recommend application of a buffer of 15% to obtain the author's recommended ABC.

The author's recommended 2019 ABC, based on applying 15% buffer to the maximum permissible ABC, is 134,740 t, which is a decrease of 17% from the 2018 ABC. The author's recommended 2020 ABC is 108,892 t, based on applying the 15% buffer to the maximum permissible ABC in 2020. The appropriateness of the 15% buffer for 2020 will be re-evaluated in next year's stock assessment. The OFL in 2019 is 194,230 t, and the OFL in 2020 if the recommended ABC is taken in 2019 is 148,968 t. It should be noted that the ABC may begin to stabilize over the next few years, particularly if recent increases in recruitment continue.

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 2023 (Fig. 1.40).

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 2018 numbers at age at the start of the year as estimated by the assessment model, and assume the 2018 catch will be equal to 161,492 t (100% of the ABC). 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 1978-2017 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 2018, 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 (2014-2018). (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 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 overfished)

> *Scenario 7*: In 2019 and 2020, *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 2020, or 2) above 1/2 of its MSY level in 2020 and above its MSY level in 2030 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. 1.41). Catches are likely to decline until 2020 as the 2012 year class declines in abundance, and then stabilize as weaker year classes subsequent to 2012 begin to affect the population.

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 (2017) is 186,157 t, which is less than the 2017 OFL of 237,807 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 441,655 t in 2018, which is above $B_{35\%}$ (194,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2020 is 258,628 t, which is above $B_{35\%}$ (194,000 t). Therefore, GOA pollock is not approaching an overfished condition.

Options for 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

Alaska pollock is important component of the catch portfolio in the 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 roughly doubled catch between 2011 and 2017. Retained catch of pollock increased 5.1% in 2017 to 186 thousand t. GOA pollock ex-vessel value was $35.6 million and first-wholesale value was $92.7 million 2016 (EPR Tables 1 and 2).

EPR Table 1. Pollock in the Gulf of Alaska ex-vessel market data. Total and retained catch (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), the Central Gulf's share of value, and number of trawl vessels; 2005-2007 average, 2008-2010 average, 2011-2013 average, and 2014-2017.

	Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017
Total Catch K mt	68.6	57.8	94.0	142.6	167.6	177.1	186.2
Retained Catch K mt	66.3	53.9	91.6	141.1	163.0	176.0	184.3
Ex-vessel Value M $	$ 19.6	$ 21.4	$ 34.3	$ 37.8	$ 43.8	$ 32.5	$ 35.6
Ex-vessel Price/lb $	$ 0.134	$ 0.180	$ 0.170	$ 0.122	$ 0.119	$ 0.084	$ 0.088
Central Gulf Share of Value	61%	62%	75%	88%	80%	63%	72%
Vessels #	67.0	63.0	70.0	72.0	65.0	70.0	67.0

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 (thousand metric tons), value (million US$), price (US$ per pound), and head and gut, fillet, surimi, and roe production volume (thousand metric tons), price (US$ per pound), and value share; 2005-2007 average, 2008-2010 average, 2011-2013 average, and 2014-2017.

		Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017
All Products	Volume K mt	23.5	17.6	36.1	54.7	59.8	75.1	78.1
All Products	Value M $	$ 53.4	$ 48.9	$ 84.5	$ 105.8	$ 105.4	$ 105.3	$ 92.7
All Products	Price lb $	$ 1.03	$ 1.26	$ 1.06	$ 0.88	$ 0.80	$ 0.64	$ 0.54
Head & Gut	Volume K mt	6.9	7.8	18.4	29.7	30.3	27.8	37.4
Head & Gut	Price lb $	$ 0.63	$ 0.75	$ 0.68	$ 0.62	$ 0.61	$ 0.43	$ 0.40
Head & Gut	Value share	18%	26%	33%	38%	39%	25%	36%
Fillets	Volume K mt	4.6	3.2	5.8	8.2	9.1	14.3	15.7
Fillets	Price lb $	$ 1.30	$ 1.82	$ 1.59	$ 1.35	$ 1.30	$ 1.11	$ 0.86
Fillets	Value share	25%	26%	24%	23%	25%	33%	32%
Surimi	Volume K mt	7.1	4.5	8.5	12.3	14.7	13.4	10.6
Surimi	Price lb $	$ 0.91	$ 1.62	$ 1.19	$ 0.89	$ 0.85	$ 0.97	$ 0.70
Surimi	Value share	27%	33%	27%	23%	26%	27%	18%
Roe	Volume K mt	1.8	0.9	1.7	3.5	3.1	0.5	1.1
Roe	Price lb $	$ 3.36	$ 2.92	$ 3.04	$ 2.03	$ 1.30	$ 1.34	$ 1.68
Roe	Value share	25%	12%	14%	15%	8%	2%	4%

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 typically account 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. These restrictions have resulted in periodic closures of the fishery in the past. In December 2016 the NPFMC decided to postpone work on bycatch management for the GOA groundfish trawl fisheries indefinitely.

The value of pollock deliveries by vessels to inshore processors (shoreside ex-vessel value) increased 9% to $35.6 million in 2017, which was the result of the increase in catch and a 5% increase in the ex-vessel price to $0.088 per pound. While the ex-vessel prices remained low relative to levels over much of the last decade, the minimal increase in 2017 comes despite decreased first-wholesale prices for H&G prices and fillet products. The average first-wholesale price of pollock products decreased 16% to $0.54 per pound. The increase in catch resulted in a 4% increase in production of pollock products in 2016 to 78 thousand t. First-wholesale value was $92.7 million in 2017, which was roughly equal to the value in 2013 when retained catch volume was roughly half the 2017 level but the price was twice as high (EPR Table 2). The revenue levels 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 $0.54 per pound in 2016 since peaking in 2008-2010 at $1.26 per pound ($1.43 per pound in 2017 dollars) and since 2013 have been below the 2005-2007 average of $1.03 ($1.23 per pound in 2016 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%-12% the size of the catch volume in Alaska and 2%-5% of the global pollock catch. Fluctuations in GOA catch and production volumes have at most 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 also 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. Additionally, pollock more broadly competes with other whitefish that, to varying degrees, can serve as substitutes depending on the product. 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.

EPR Table 3. Pollock U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, Russian share of global production, U.S. export volume (thousand metric tons), 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, 2011-2013 average, and 2014-2018.

		Avg 05-07	Avg 08-10	Avg 11-13	2014	2015	2016	2017	2018 (thru July)
Global Pollock Catch K mt		2,854	2,662	3,241	3,245	3,373	3,476	-	-
U.S. Share of Global Catch		52%	35%	40%	44%	44%	44%	-	-
Russian Share of global catch		37%	53%	49%	47%	48%	50%	-	-
GOA share of global		2%	2%	3%	4%	5%	5%	-	-
Export Volume K mt		278.9	192.2	326.2	395.0	377.8	379.6	398.0	243.8
Export Value M US$		$ 867.4	$ 635.2	$ 943.6	$ 1,081.7	$ 1,038.2	$ 990.5	$ 1,007.6	$ 671.5
Export Price lb US$		$ 1.41	$ 1.50	$ 1.31	$ 1.24	$ 1.25	$ 1.18	$ 1.15	$ 1.25
Japan	Volume Share	34.4%	26.6%	20.8%	22.1%	25.0%	20.1%	21.7%	23.4%
	Value share	38.1%	26.3%	19.3%	21.7%	25.5%	20.2%	22.9%	29.4%
China	Volume Share	3.1%	9.0%	13.1%	14.7%	12.7%	11.9%	14.8%	13.8%
	Value share	2.2%	6.9%	10.5%	12.0%	10.5%	9.9%	12.6%	9.9%
Germany	Volume Share	16.7%	19.9%	21.9%	23.4%	21.4%	19.3%	10.9%	8.0%
	Value share	14.5%	21.2%	22.7%	24.3%	21.3%	19.2%	11.0%	7.6%
Meat/Fillets	Volume Share	32.7%	46.1%	49.6%	53.8%	49.2%	49.4%	48.8%	48.6%
	Value share	27.2%	44.5%	48.3%	51.6%	46.2%	46.4%	46.6%	40.2%
Surimi	Volume Share	56.9%	45.7%	45.4%	40.7%	45.4%	46.9%	46.6%	42.9%
	Value share	37.5%	32.7%	37.9%	34.3%	39.2%	42.4%	42.3%	39.3%
Roe	Volume Share	10.4%	8.2%	4.9%	5.5%	5.4%	3.7%	4.6%	8.5%
	Value share	35.3%	22.8%	13.8%	14.1%	14.6%	11.2%	11.1%	20.5%

Notes: Exports are from the US and are note specific to the GOA region. Aggregate exports 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. 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 have typically accounted for approximately 35%, 25%, 30%, and 10% of first-wholesale value in recent years. In terms of GOA production, head-and-gut, surimi, and fillets each have typically accounted for approximately 50%, 20%, and 17% 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. In 2011-2015 proportionally more of the increases from catch went gone towards H&G production, though surimi and fillet production has increased as well at a slower rate. Since 2015 fillets production has accounted for a larger share of production increasing from 15% in 2015 to 20% in 2017, and the share of value increased from 25% to 32%. H&G's relative share of volume and value were 48% and 36%, respectively.

Prices for pollock products in the GOA, a shoreside fishery, were typically close to the prices for the corresponding products produces by the BSAI shoreside sector. The price of fillet produced in the GOA through 2015 were on average about 5% higher than those on produced in the BSAI shoreside. Though in 2016 and 2017 the BSAI price was higher than in the GOA. The price of roe was on average about 10% lower in the GOA than the BSAI shoreside sector and difference has grown 21% in 2017. 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.

Low prices for pollock H&G, fillets, and surimi were impediments to revenue generation in 2017. For H&G and fillets, media reports indicated that high inventories, particularly early in the year as a contributing factor in the low prices for these products. H&G pollock is largely exported to China for secondary processing, additionally, much of the Russian catch also goes to China as H&G for secondary processing and the weak value of the Russian Ruble in recent years could have been a contributing factor. The low price for H&G may have contributed to the increased production of fillets where prices were comparatively better. Total fillet production increase 10% to 15.7 thousand t in 2017. The average price of fillet products in the GOA decreased 23% to $0.86 per pound and is below the inflation adjusted average price of fillets in 2005-2007 of $1.56 per pound. The majority of fillets produced in the GOA are pin-bone-out (PBO). 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 (AFSC 2016). 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. Reductions in whitefish supplies in 2018 has put upward pressure on pollock prices, however, U.S.-China trade policy uncertainty could negatively affect the market.

Surimi production decreased 21% to 10.4 thousand t in 2017 but remains high. Surimi production peaked in 2015 and the 2016 level was the second highest. The price for surimi decreased 28% to $0.70. Surimi prices decreased in the GOA from 2013 through 2015. This trend was in contrast to the price increase in the BSAI particularly for the at-sea sector. The supply of raw surimi material continues to be constrained in Japan, a trend which is expected to continue through 2018. Increasing Atka mackerel prices (another source of raw material for surimi) could also increase demand for pollock based surimi.

Roe is a high priced product that is the focus of the A season catch and destined primarily for Asian markets. Compared to 2005-2007, GOA roe production in recent years had been high because of the increased catch levels. Roe production in the GOA tapered off in 2008-2010 but rebounded with catch levels up through 2015. In 2016 roe production increased 101% to 1.1 thousand t, but is still roughly one-third 2014-2015 levels. The Yen to U.S. Dollar exchange rate, which can influence prices, has remained relatively stable. The average roe price in the GOA was up 25% in 2017 to $1.68 per pound, with an increase in value to $4 million.

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 2017 CIE review of the Gulf of Alaska pollock assessment, the following research priorities are identified:

- Consider to explore alternative modeling platforms in parallel to the ADMB assessment.
- Continue to develop spatial GLMM models for survey indices of GOA pollock
- Evaluate pollock population dynamics in a multi-species context using the CEATTLE model.
- Develop an Ecosystem and Socioeconomic Profile (ESP) for GOA pollock.
- Explore implications of non-constant natural mortality on pollock assessment and management.

Literature Cited

Alaska Fisheries Science Center (AFSC). 2016. Wholesale market profiles for Alaska groundfish and crab fisheries. 134 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

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.

Axelsen, B.E., Anker-Nilssen, T., Fossum, P., Kvamme, C., and Nottestad, L. 2001. Pretty patterns but a simple strategy: predator-prey interactions between juvenile herring and Altlantic puffins observed with multibeam sonar. Can. J. Zool. 79:1586-1596.

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.

Engelhard, G.H., and M. Heino. 2006. Climate change and the condition of herring (Clupea harengus) explain long-term trends in extent of skipped reproduction. Oecologia 149:593-603.

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.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68:1124-1138.

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.

Kotwicki, S. P.H. Ressler, J.N. Ianelli, A.E. Punt and J.K. Horne. 2017. Combining data from bottom-trawl and acoustic-trawl surveys to estimate and index of abundance for semipelagic species. Can. J. Fish. Aquat. Sci. 00: 1–12 (0000) dx.doi.org/10.1139/cjfas-2016-0362

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.

McAllister, M.K., and J.N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance algorithm. Can. J. Fish. Aquat. Sci. 54(2): 284-300.

McCarthy, A., S. Stienessen, M. Levine. In Press. Results of the acoustic-trawl surveys of walleye pollock (Gadus chalcogrammus) in the Gulf of Alaska, February-March 2017 (DY2017-01, DY2017-02, and DY2017-03). AFSC Processed Rep. 2017-XX, XX p. 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.

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.

Neidetcher, S.K., T.P. Hurst, L. Ciannelli, E.A. Logerwell. 2014. Spawning phenology and geography of Aleutian Islands and eastern Bering Sea Pacific Cod (Gadus microcephalus). Deep-Sea Research II 109:204–214.

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.

Thorson, J.T., A.C. Hicks, and R.D. Methot. 2015. Random effect estimation of time-varying factors in Stock Synthesis. ICES J. of Mar. Sci., 72(1): 178–185.

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.

von Szalay P.G., Raring N.W., Shaw F.R., Wilkins M.E., and Martin M.H. 2010. Data report: 2009 Gulf of Alaska bottom trawl survey. U S Dep Commer , NOAA Tech Memo NMFS-AFSC-208 245 p.

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, T.K., D.J. Tollit, K.A. Call, T.J. Orchard, and C.J. 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. Walleye pollock catch (t) in the Gulf of Alaska. The ABC for 2018 is for the area west of 140 º W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound. 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			81,485	81,485	88,620
2012			103,970	103,970	108,440
2013			96,364	96,364	113,099
2014			142,632	142,632	167,657
2015			167,553	167,553	191,309
2016			177,134	177,134	254,310
2017			186,157	186,157	203,769
2018					161,492
Average (1977-2017)				108,118	125,160

Table 1.2. Incidental catch (t) of FMP species (upper table) and non-target species (bottom table) in the walleye pollock directed fishery in the Gulf of Alaska in 2013-2017. Species are in descending order according to the cumulative catch during the period. Incidental catch estimates include both retained and discarded catch.

Managed species/species group	*2013*	*2014*	*2015*	*2016*	*2017*
Pollock	91525.5	137611.0	163899.5	175296.6	183041.7
Arrowtooth Flounder	1765.4	2464.4	1671.1	1233.3	1185.0
Pacific Cod	1041.7	3287.3	1712.3	853.4	612.0
Pacific Ocean Perch	426.9	530.0	175.5	681.9	1265.8
Flathead Sole	381.4	355.9	438.7	309.8	181.4
GOA Shallow Water Flatfish	183.4	248.9	357.6	265.7	358.3
Majestic squid	346.2	143.5	465.3	182.2	15.5
GOA Rex Sole	151.1	270.8	145.9	113.4	67.3
Big Skate	228.0	171.0	62.8	100.5	114.6
Salmon Shark	2.8	144.0	369.0	79.5	10.3
Longnose Skate	25.2	179.7	87.4	46.9	33.2
Sablefish	12.6	30.4	129.9	89.0	46.5
GOA Shortraker Rockfish	22.6	27.7	14.0	181.4	1.6
Atka Mackerel	0.4	3.5	25.2	169.5	33.3
Spiny Dogfish	11.5	13.6	35.6	50.3	49.1
GOA Thornyhead Rockfish	0.6	42.3	24.2	72.2	3.4
Sculpin	17.5	38.9	26.8	20.6	25.8
GOA Rougheye Rockfish	8.9	25.2	12.4	44.5	3.0
GOA Deep Water Flatfish	12.8	35.3	15.0	24.0	1.6
Pacific sleeper shark	15.2	6.3	12.0	37.6	0.6
GOA Dusky Rockfish	6.5	13.1	15.0	23.2	12.1
Other Skate	23.5	15.3	16.9	4.4	4.5
Northern Rockfish	5.6	14.9	16.6	15.7	5.2
North Pacific Octopus	0.3	7.2	4.3	5.7	0.2
Other Shark	1.0	2.2	6.1	0.6	3.6
Other Rockfish	0.7	1.3	1.8	0.7	0.4
Alaskan Skate	0.4	1.7	0.8	0.1	0.1
Percent non-pollock	*4.9%*	*5.5%*	*3.4%*	*2.6%*	*2.2%*

Non target species/species group	*2013*	*2014*	*2015*	*2016*	*2017*
Giant Grenadier	47.50	19.36	9.16	657.92	0.00
Miscellaneous fish	349.66	73.59	56.64	16.83	18.76
Eulachon	25.20	246.81	79.84	83.59	39.80
Jellyfish	34.47	23.09	169.61	157.19	14.48
Other Osmerids	11.03	75.28	13.28	8.78	0.89
Rattail Grenadier	0.00	0.00	0.00	27.89	0.00
Sea Stars	3.29	6.20	1.11	3.34	0.81
Capelin	0.01	4.61	3.62	0.02	0.00
State-managed Rockfish	0.00	0.05	0.00	5.50	0.06
Sea anemone unidentified	0.20	0.00	0.55	2.42	0.00
Sponge unidentified	0.03	1.16	0.20	0.08	0.00
Pandalid shrimp	0.01	0.04	0.17	0.50	0.13
Eelpouts	0.13	0.00	0.68	0.00	0.00
Stichaeidae	0.55	0.00	0.04	0.03	0.00
Snails	0.34	0.01	0.06	0.20	0.00
Bivalves	0.16	0.38	0.00	0.00	0.00
Benthic urochordata	0.21	0.00	0.00	0.00	0.00
Corals Bryozoans	0.00	0.00	0.02	0.18	0.00
Sea urchins, Sand Dollars, Sea cucumbers	0.01	0.11	0.01	0.03	0.00
Pacific Sandfish	0.00	0.00	0.10	0.00	0.00
Brittle Star	0.00	0.00	0.00	0.00	0.06

Table 1.3. Bycatch of prohibited species for trawls where pollock was the predominant species in the catch in the Gulf of Alaska during 2013-2017. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of fish.

Species/species group	*2013*	*2014*	*2015*	*2016*	*2017*
Bairdi Tanner Crab (nos.)	8,000	2,062	2,340	3,431	3,010
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	12,909	10,882	13,612	20,882	21,392
Golden (Brown) King Crab (nos.)	0	0	0	549	8
Halibut (t)	256.3	137.1	168.1	226.1	109.0
Herring (t)	10.4	4.6	78.2	147.3	5.4
Non-Chinook Salmon (nos.)	641	1421	909	1975	4413
Opilio Tanner (Snow) Crab (nos.)	0	0	0	171	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 2008-2017 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
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	1,109	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	845	4	1	2	2,110	2.6%
	Total	20,597	37,248	19,832	2,271	1,536	2	81,485	
2012	Retained	27,352	44,597	25,089	2,353	2,622	0	102,012	
	Discarded	528	500	895	28	5	1	1,958	1.9%
	Total	27,880	45,097	25,984	2,381	2,627	1	103,970	
2013	Retained	7,644	52,614	28,134	2,927	2,605	0	93,925	
	Discarded	67	511	1,830	13	17	2	2,440	2.5%
	Total	7,711	53,125	29,964	2,940	2,623	2	96,364	
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	83,081	42,494	1,317	2,371	3	142,632	
2015	Retained	28,663	80,950	51,971	248	4,454	0	166,285	
	Discarded	77	493	662	1	31	3	1,268	0.8%
	Total	28,739	81,443	52,633	250	4,485	3	167,553	
2016	Retained	61,013	46,810	64,281	121	3,893	0	176,117	
	Discarded	239	214	535	12	14	3	1,017	0.6%
	Total	61,252	47,024	64,816	133	3,907	3	177,134	
2017	Retained	49,246	80,855	52,336	39	1,881	0	184,357	
	Discarded	297	757	727	0	16	3	1,800	1.0%
	Total	49,543	81,612	53,063	40	1,897	3	186,157	
Average (2008-2017)		26,748	48,995	33,485	1,335	2,322	2	112,887	

Table 1.5. Catch at age (millions) of pollock in the Gulf of Alaska in 1975-2017.

	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
2016	0.00	1.33	15.97	272.64	11.17	10.72	2.42	1.13	0.47	0.19	0.00	0.15	0.00	0.00	0.00	316.19
2017	0.00	0.00	0.09	18.77	259.68	4.63	2.97	0.10	0.10	0.03	0.00	0.00	0.00	0.00	0.00	286.38

Table 1.6. Number of aged and measured fish in the GOA pollock fishery used to estimate fishery age composition.

	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
2016	1,433	959	2,392	28,904	20,347	49,251
2017	1,245	925	2,170	18,627	15,007	33,634

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	197,922				83,476
2009	257,422		662,557		145,438
2010	421,575				124,110
2011			660,207		100,839
2012	334,061				172,007
2013	807,838	884,049	947,877		102,406
2014	827,338				100,158
2015	847,970	1,606,171	707,774		42,277
2016	667,003				18,470
2017	1,465,229	1,318,396	288,943		21,855
2018	1,320,867				49,788

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
2017	536	424	0.44	221	240	461	6,304	5,186	13,782

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
2017	159.39	3.82	10.90	30.32	294.79	27.01	15.28	4.22	0.42	0.18	0.70	0.00	0.00	0.14	0.00	547.18

Table 1.10. Estimated number at age (millions) for the acoustic survey in Shelikof Strait. Estimates for 2008-2018 account for net escapement.

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	1,778.16	359.21	230.18	49.03	11.16	2.03	3.73	9.82	6.19	1.87	0.50	0.00	0.00	0.00	0.00	2,451.89
2009	814.12	1,127.16	105.85	95.81	57.76	9.46	2.71	0.81	4.67	5.61	1.28	0.23	0.00	0.00	0.00	2,225.45
2010	270.52	299.06	538.69	82.86	76.28	27.70	11.22	5.08	5.02	10.25	8.84	3.22	0.00	0.00	0.00	1,338.73
2012	193.77	842.35	43.29	76.61	94.74	45.86	28.95	4.44	1.13	0.28	0.09	0.52	0.00	0.00	0.00	1,332.04
2013	9,178.41	117.10	687.95	51.34	64.42	104.03	58.73	42.83	10.46	4.94	4.46	0.49	1.42	3.99	2.02	10,332.59
2014	1,590.79	3,492.94	17.39	279.93	82.80	57.66	98.47	54.64	25.65	17.63	7.33	0.70	2.33	0.00	0.66	5,728.91
2015	19.82	103.95	1,637.34	72.38	152.81	62.39	56.75	68.07	30.02	10.97	5.61	3.67	0.94	0.64	2.41	2,227.76
2016	0.00	1.82	78.21	1,451.78	43.43	33.52	15.48	3.63	7.37	1.69	0.00	0.00	0.00	0.00	0.00	1,636.92
2017	744.72	0.00	9.40	126.40	2,576.24	125.99	31.13	9.29	0.33	0.69	0.00	0.00	0.00	0.00	0.00	3,624.17
2018	1,819.56	142.60	1.57	9.91	166.40	1,803.87	86.06	46.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,076.52

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 1992-2018.

Year	No. of midwater tows	No. of bottom trawl tows	Survey biomass CV	Number aged Males	Number aged Females	Number aged Total	Number lengthed Males	Number lengthed Females	Number lengthed 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
2017	16	1	0.04	241	314	613	2,501	2,781	5,760
2018	14	4	0.04	303	359	662	367	430	5,364

Table 1.12. Estimated proportions at age for the ADFG crab/groundfish survey, 2000-2016.

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
2016	0.0000	0.0201	0.0351	0.3545	0.1722	0.2709	0.0686	0.0418	0.0217	0.0084	0.0067	0.0000	0.0000	0.0000	0.0000	598

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

		Observed Age									
True Age	*St. dev.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.18	0.9970	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.23	0.0138	0.9724	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.27	0.0000	0.0329	0.9342	0.0329	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.32	0.0000	0.0000	0.0571	0.8858	0.0571	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.36	0.0000	0.0000	0.0000	0.0832	0.8335	0.0832	0.0000	0.0000	0.0000	0.0000
6	0.41	0.0000	0.0000	0.0000	0.0001	0.1090	0.7817	0.1090	0.0001	0.0000	0.0000
7	0.45	0.0000	0.0000	0.0000	0.0000	0.0004	0.1333	0.7325	0.1333	0.0004	0.0000
8	0.50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0012	0.1554	0.6868	0.1554	0.0012
9	0.54	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0028	0.1747	0.6450	0.1775
10	0.59	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0052	0.1913	0.8035

Table 1.14. 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 (1983-2018).

Year	2	3	4	5	6	7	8	9	10+	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
2017	0.000	0.250	1.000	0.953	0.933	1.000	1.000	1.000	1.000	423
2018	0.000	0.000	---	0.957	0.973	1.000	1.000	---	---	404
Average										
All years	0.000	0.022	0.294	0.596	0.844	0.927	0.969	0.988	0.993	
2009-2018	0.000	0.028	0.354	0.628	0.896	0.986	0.990	0.995	1.000	
2014-2018	0.000	0.050	0.536	0.721	0.950	0.984	1.000	1.000	1.000	

Table 1.16. Fishery weight at age (kg) of pollock in the Gulf of Alaska in 1975-2017.

	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
2016	0.141	0.402	0.473	0.534	0.705	0.825	1.035	1.171	1.169	1.179
2017	0.141	0.402	0.615	0.606	0.644	0.805	0.890	0.967	1.025	1.403

Table 1.17. Weight at age (kg) of pollock in the Shelikof Strait acoustic survey in 1981-2018.

	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
2017	0.011	0.133	0.345	0.451	0.505	0.578	0.912	0.951	1.383	1.339
2018	0.008	0.089	0.181	0.516	0.539	0.609	0.679	0.892	1.383	1.339

Table 1.18. Weight at age (kg) of pollock in the NMFS bottom trawl survey in 1984-2017.

	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
2017	0.038	0.224	0.640	0.690	0.743	0.886	1.095	1.298	1.283	1.504

Table 1.19. Results comparing model fits, stock status, and 2019 yield for different model configurations. 2019 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 17.2 last year	Model 17.2 new data	Model 18.1	Model 18.2	Model 18.3
Model fits					
Total log(Likelihood)	-312.18	-342.15	-333.19	-333.04	-333.33
Catch	-0.07	-0.08	-0.08	-0.08	-0.08
Fishery age	-96.98	-105.39	-104.46	-104.47	-104.36
Acoustic survey biomass	-35.93	-40.20	-40.03	-40.00	-40.07
Age-1 and age-2 indices	-17.25	-11.91	-2.77	-2.42	-2.49
Acoustic survey age	-27.57	-34.16	-34.62	-34.64	-34.53
Bottom trawl survey biomass	-8.51	-9.06	-9.21	-9.23	-9.22
Bottom trawl survey age and length comp	-20.80	-25.48	-25.67	-25.73	-25.99
ADFG trawl survey biomass	-30.90	-35.95	-36.04	-36.13	-36.14
ADFG trawl survey age	-23.52	-32.68	-32.78	-32.75	-32.85
Summer acoustic biomass	-2.34	-1.78	-1.76	-1.74	-1.75
Summer acoustic age and length comp.	-5.48	-2.56	-2.58	-2.64	-2.56
Priors/Penalties	-42.85	-42.88	-43.20	-43.21	-43.28
Composition data					
Fishery age comp. effective N	90	76	77	77	78
Shelikof Strait acoustic age comp. effective N	10	11	11	11	11
NMFS bottom trawl age comp. effective N	23	18	18	18	18
ADF&G trawl age comp. effective N	30	18	18	18	18
Survey abundance					
Shelikof Strait Acoustic RMSE					
EK500	0.35	0.36	0.36	0.36	0.36
Age-1 index	1.37	1.19	0.64	0.58	0.62
Age-2 index	1.49	1.13	0.94	0.83	0.81
NMFS bottom trawl RMSE	0.31	0.34	0.34	0.34	0.34
ADFG trawl RMSE	0.36	0.37	0.37	0.37	0.37
Summer acoustic RMSE	0.31	0.27	0.27	0.27	0.27
Catchability estimates					
NMFS trawl	0.87	0.85	0.85	0.85	0.85
Shelikof Strait acoustic					
3+ Biomass	0.63	0.61	0.61	0.61	0.61
Age-1 index linear term	0.08	0.31	0.81	0.53	0.63
Age-1 index power term	1.21	0.30	0.28	0.20	0.00
Age-2 index	1.03	1.15	0.98	0.87	0.95
Summer acoustic	1.03	0.82	0.83	0.82	0.82
ADFG trawl	0.68	0.64	0.64	0.64	0.64
Stock status (t)					
2018 Spawning biomass	342,683	321,620	320,869	322,342	322,564
Depletion (B2018/B0)	58%	58%	58%	58%	58%
$B_{40\%}$	238,000	222,693	222,456	222,835	222,914
2019 yield (t)					
Maximum permissible ABC	113,153	156,065	155,693	156,889	156,523

Model descriptions (see text for details):

Model 17.2--last year's base model

Model 17.2 new data--last year's base model with new data

Model 18.1--Net-selectivity corrected acoustic estimates, age-1 and age-2 indices for 2009-2018 Shelikof + Shumagin.

Model 18.2--Same as 18.1, but age-1 and age-2 indices for 2008-2018 Shelikof only.

Model 18.3--Same as 18.2, but without a power term for age-1 index.

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.

Age	*Foreign (1970-81)*	*Foreign and JV (1982-1988)*	*Domestic (1989-2000)*	*Domestic (2001-2012)*	*Recent domestic (2013-2017)*	*Shelikof acoustic survey*	*Summer acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.004	0.002	0.010	0.001	0.336	1.000	0.131	0.006
2	0.011	0.027	0.012	0.074	0.013	0.419	1.000	0.219	0.023
3	0.118	0.176	0.074	0.375	0.146	1.000	1.000	0.343	0.089
4	0.609	0.619	0.340	0.812	0.682	1.000	1.000	0.495	0.289
5	0.949	0.926	0.772	0.970	0.965	0.998	1.000	0.650	0.629
6	0.997	0.992	0.963	0.997	0.998	0.991	1.000	0.782	0.876
7	1.000	1.000	1.000	1.000	1.000	0.966	1.000	0.879	0.967
8	0.988	0.989	0.993	0.988	0.988	0.880	1.000	0.941	0.992
9	0.861	0.862	0.867	0.862	0.861	0.657	1.000	0.979	0.999
10	0.347	0.348	0.350	0.347	0.347	0.333	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	1,255	312	193	134	95	70	52	39	30	88
1971	3,178	312	157	119	90	65	50	37	28	86
1972	3,638	792	157	96	80	62	46	36	27	84
1973	10,546	906	396	95	59	48	38	28	22	76
1974	2,189	2,626	453	238	56	33	27	22	16	66
1975	2,210	545	1,312	269	133	29	17	14	12	53
1976	8,661	550	273	791	162	77	17	10	9	44
1977	11,710	2,157	275	163	454	87	42	9	6	35
1978	14,321	2,916	1,077	163	90	230	45	22	5	26
1979	25,425	3,566	1,457	639	91	47	122	24	12	20
1980	12,959	6,331	1,783	870	373	51	27	70	14	21
1981	7,231	3,227	3,169	1,081	539	220	31	16	43	23
1982	7,229	1,801	1,616	1,928	686	332	140	20	10	45
1983	4,968	1,800	901	979	1,227	433	217	91	13	39
1984	5,933	1,237	898	539	606	753	275	138	59	36
1985	14,760	1,476	616	530	321	353	452	165	84	62
1986	4,315	3,673	736	366	313	178	200	255	94	92
1987	1,789	1,074	1,838	448	239	205	121	135	175	133
1988	4,998	446	538	1,126	298	160	142	84	95	222
1989	11,469	1,245	223	330	752	201	112	99	59	230
1990	8,452	2,856	623	137	219	500	138	76	68	209
1991	3,251	2,105	1,431	383	92	145	338	93	52	199
1992	2,362	810	1,055	880	256	59	95	219	61	177
1993	1,666	588	406	648	587	166	39	61	143	167
1994	1,701	415	295	249	429	377	108	25	40	216
1995	6,739	424	208	181	165	277	247	70	16	181
1996	3,155	1,678	212	128	121	110	189	168	48	143
1997	1,455	786	841	131	86	82	76	130	116	138
1998	1,402	362	393	514	85	54	51	47	82	173
1999	1,758	349	181	237	318	48	30	28	26	165
2000	6,625	438	174	110	149	185	28	17	17	129
2001	7,114	1,649	219	106	70	91	115	17	11	101
2002	1,004	1,770	823	131	66	42	56	71	11	78
2003	777	250	882	492	83	42	28	37	47	63
2004	732	193	124	527	315	54	28	19	25	78
2005	1,879	182	96	73	333	202	36	19	13	74
2006	6,026	467	90	56	45	206	130	23	12	61
2007	5,689	1,498	231	52	34	28	133	84	15	51
2008	7,025	1,415	743	136	33	22	19	89	57	47
2009	3,109	1,748	705	443	87	22	15	13	61	74
2010	1,216	774	873	425	291	59	15	10	9	98
2011	5,273	303	386	522	274	192	40	10	7	78
2012	857	1,313	151	232	335	179	130	27	7	62
2013	37,179	213	657	91	147	214	119	86	18	49
2014	2,039	9,259	107	399	58	94	142	79	58	48
2015	38	508	4,634	64	242	34	57	86	48	70
2016	6	9	254	2,779	38	138	20	34	51	78
2017	2,124	1	5	153	1,709	23	87	13	21	89
2018	5,415	529	1	3	93	1,020	14	54	8	76
Average	5,813	1,426	712	432	274	169	96	62	40	95

Table 1.22. Estimates of population biomass, recruitment, and harvest of GOA pollock from the age-structured assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

						2017 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	746	132	11,710	118,092	16%	726	127	11,321	16%
1978	965	117	14,321	95,408	10%	933	112	13,803	10%
1979	1,346	124	25,425	106,161	8%	1,298	119	24,555	8%
1980	1,812	172	12,959	115,158	6%	1,743	163	12,504	7%
1981	2,832	189	7,231	147,818	5%	2,724	179	6,969	5%
1982	2,956	323	7,229	169,045	6%	2,840	306	6,995	6%
1983	2,691	451	4,968	215,625	8%	2,580	426	4,955	8%
1984	2,391	501	5,933	307,541	13%	2,287	473	5,755	13%
1985	1,930	456	14,760	286,900	15%	1,844	427	14,654	16%
1986	1,622	412	4,315	86,910	5%	1,543	384	4,361	6%
1987	1,966	384	1,789	68,070	3%	1,895	359	1,737	4%
1988	1,864	395	4,998	63,391	3%	1,805	372	4,867	4%
1989	1,647	408	11,469	75,585	5%	1,598	388	11,261	5%
1990	1,525	418	8,452	88,269	6%	1,479	400	8,020	6%
1991	1,840	412	3,251	100,488	5%	1,791	396	3,152	6%
1992	1,922	377	2,362	90,858	5%	1,860	365	2,307	5%
1993	1,809	411	1,666	108,909	6%	1,748	395	1,535	6%
1994	1,533	482	1,701	107,335	7%	1,479	463	1,789	7%
1995	1,252	402	6,739	72,618	6%	1,202	385	6,557	6%
1996	1,052	371	3,155	51,263	5%	1,013	354	3,012	5%
1997	1,073	327	1,455	90,130	8%	1,038	312	1,404	9%
1998	1,032	255	1,402	125,460	12%	995	243	1,394	13%
1999	769	237	1,758	95,638	12%	737	224	1,744	13%
2000	681	224	6,625	73,080	11%	652	211	6,414	11%
2001	651	209	7,114	72,077	11%	625	197	6,820	12%
2002	844	174	1,004	51,934	6%	811	164	898	6%
2003	1,065	163	777	50,684	5%	1,021	154	843	5%
2004	891	184	732	63,844	7%	849	174	748	8%
2005	745	223	1,879	80,978	11%	713	209	2,130	11%
2006	636	241	6,026	71,976	11%	607	227	6,059	12%
2007	596	214	5,689	52,714	9%	580	201	5,718	9%
2008	827	212	7,025	52,584	6%	821	202	6,887	6%
2009	1,170	212	3,109	44,247	4%	1,170	206	3,437	4%
2010	1,381	290	1,216	76,744	6%	1,375	286	1,483	6%
2011	1,317	340	5,273	81,485	6%	1,330	338	5,023	6%
2012	1,224	360	857	103,970	8%	1,254	360	1,184	8%
2013	1,256	385	37,179	96,364	8%	1,277	390	24,098	8%
2014	995	299	2,039	142,632	14%	1,024	305	2,403	14%
2015	2,345	261	38	167,553	7%	1,771	265	601	9%
2016	2,307	282	6	177,134	8%	1,595	234	137	11%
2017	1,672	352	2,124	186,157	11%	1,345	258	1,098	14%
2018	1,186	326	5,415						
Average									
1977-2017	1,443	302	6,043	108,118	8%	1,365	287	5,625	8%
1978-2017			5,901					5,269	

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	1,255	0.31	698	2,255	125	0.31	69	226
1971	3,178	0.44	1,396	7,237	120	0.32	65	219
1972	3,638	0.37	1,819	7,277	110	0.33	58	208
1973	10,545	0.16	7,661	14,514	92	0.37	46	187
1974	2,189	0.30	1,241	3,861	83	0.34	43	158
1975	2,210	0.28	1,293	3,775	85	0.26	51	142
1976	8,661	0.19	5,985	12,533	121	0.18	85	172
1977	11,709	0.19	8,173	16,775	132	0.18	93	189
1978	14,321	0.18	10,007	20,494	117	0.22	77	180
1979	25,425	0.15	18,843	34,307	124	0.23	80	193
1980	12,959	0.19	8,884	18,903	172	0.21	115	259
1981	7,232	0.24	4,581	11,416	189	0.19	130	274
1982	7,229	0.23	4,595	11,373	323	0.17	233	447
1983	4,968	0.34	2,575	9,582	451	0.16	330	614
1984	5,934	0.31	3,267	10,777	501	0.17	362	693
1985	14,760	0.17	10,701	20,359	456	0.19	317	655
1986	4,315	0.28	2,501	7,447	412	0.20	278	611
1987	1,790	0.42	807	3,968	384	0.20	262	563
1988	4,998	0.23	3,197	7,815	395	0.18	278	560
1989	11,469	0.15	8,590	15,312	408	0.15	302	551
1990	8,452	0.16	6,131	11,651	418	0.15	313	557
1991	3,251	0.26	1,957	5,399	412	0.15	308	550
1992	2,362	0.27	1,404	3,975	377	0.14	285	499
1993	1,666	0.30	940	2,952	411	0.13	318	531
1994	1,701	0.29	975	2,967	483	0.13	377	617
1995	6,740	0.13	5,265	8,627	402	0.13	313	515
1996	3,155	0.17	2,254	4,416	371	0.13	289	475
1997	1,455	0.24	908	2,330	327	0.13	254	422
1998	1,402	0.23	904	2,174	255	0.14	195	334
1999	1,758	0.21	1,175	2,629	237	0.14	179	312
2000	6,625	0.13	5,160	8,507	224	0.15	168	298
2001	7,114	0.12	5,633	8,984	209	0.16	155	284
2002	1,004	0.28	583	1,728	174	0.16	126	240
2003	777	0.26	467	1,291	163	0.16	119	223
2004	732	0.28	427	1,254	184	0.14	140	242
2005	1,879	0.19	1,287	2,744	223	0.14	169	292
2006	6,026	0.14	4,558	7,966	241	0.15	181	321
2007	5,689	0.15	4,245	7,625	214	0.16	157	292
2008	7,025	0.14	5,307	9,299	212	0.17	154	293
2009	3,109	0.18	2,193	4,406	212	0.16	155	291
2010	1,216	0.27	721	2,050	290	0.15	217	386
2011	5,273	0.17	3,779	7,357	340	0.14	257	449
2012	857	0.31	471	1,559	360	0.15	271	478
2013	37,179	0.14	28,466	48,559	385	0.15	285	521
2014	2,039	0.30	1,147	3,625	299	0.16	217	411
2015	38	0.37	19	76	261	0.18	183	373
2016	6	0.36	3	12	282	0.17	204	391
2017	2,124	0.31	1,175	3,839	352	0.17	250	494
2018	5,415	0.45	2,330	12,584	326	0.20	221	480

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 1983-2018.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2013-2017)*	*Spawning (Avg. 2014-2018)*	*Population (Avg. 2013-2017)*	*Fishery (Est. 2019 from RE model)*	*Proportion mature females*
1	1.39	0.001	0.011	0.030	0.162	0.000
2	0.69	0.013	0.101	0.216	0.413	0.000
3	0.48	0.146	0.267	0.475	0.533	0.022
4	0.37	0.682	0.499	0.720	0.778	0.294
5	0.34	0.965	0.638	0.918	1.071	0.596
6	0.30	0.998	0.857	1.097	1.023	0.844
7	0.30	1.000	1.043	1.287	1.008	0.927
8	0.29	0.988	1.198	1.415	1.142	0.969
9	0.28	0.861	1.409	1.460	1.281	0.988
10+	0.29	0.347	1.435	1.688	1.427	0.993

Table 1.25. Methods used to assess Gulf of Alaska pollock, 1977-2017. 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 1990-2017 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
2016	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	267,000
2017	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	238,000

Table 1.26. Projections of Gulf of Alaska pollock spawning biomass, full recruitment fishing mortality, and catch for 2018-2031 under different harvest policies. For these projections, fishery weight at age was assumed to be equal to the estimated weight at age in 2019 for the RE model. All projections begin with initial age composition in 2018 using the base run model with a projected 2018 catch of 161,492 t. The values for B100%, B40%, and B35% are 553,000 t, 221,000 t, 194,000 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}*
2018	441,655	441,655	441,655	441,655	441,655	441,655	441,655
2019	342,413	345,352	366,331	375,327	380,710	358,099	361,526
2020	245,563	257,415	278,258	318,594	345,119	245,388	258,628
2021	205,459	219,035	240,059	298,950	341,125	197,954	212,502
2022	192,496	199,576	220,376	285,623	334,954	181,232	188,475
2023	201,297	205,082	219,475	289,723	343,782	184,008	188,046
2024	206,369	208,294	225,981	304,549	366,608	191,379	193,648
2025	213,065	214,084	232,493	321,003	393,351	197,135	198,424
2026	219,143	219,671	249,568	349,211	433,357	211,931	212,639
2027	236,254	236,495	251,009	361,179	456,179	209,620	210,043
2028	236,465	236,595	255,165	374,183	477,543	211,142	211,393
2029	239,648	239,723	254,722	379,788	488,938	209,795	209,945
2030	239,096	239,140	257,561	387,663	501,336	211,770	211,860
2031	241,731	241,757	257,028	391,428	508,859	210,228	210,282
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}*
2018	0.16	0.16	0.16	0.16	0.16	0.16	0.16
2019	0.27	0.22	0.20	0.07	0	0.32	0.27
2020	0.27	0.22	0.20	0.07	0	0.32	0.27
2021	0.25	0.26	0.20	0.07	0	0.28	0.30
2022	0.23	0.24	0.20	0.07	0	0.23	0.24
2023	0.22	0.22	0.20	0.07	0	0.21	0.21
2024	0.20	0.20	0.20	0.07	0	0.19	0.19
2025	0.18	0.18	0.20	0.07	0	0.18	0.18
2026	0.13	0.13	0.20	0.07	0	0.17	0.17
2027	0.11	0.11	0.20	0.06	0	0.17	0.17
2028	0.11	0.11	0.20	0.05	0	0.16	0.16
2029	0.11	0.11	0.20	0.05	0	0.16	0.16
2030	0.11	0.11	0.20	0.05	0	0.16	0.16
2031	0.11	0.11	0.20	0.05	0	0.17	0.17
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}*
2018	161,492	161,492	161,492	161,492	161,492	161,492	161,492
2019	158,518	134,740	128,331	50,100	0	194,230	167,431
2020	123,870	108,892	104,094	44,635	0	144,746	129,236
2021	121,717	135,203	108,638	48,164	0	133,336	148,991
2022	121,665	126,880	108,141	47,223	0	125,958	130,289
2023	136,727	138,501	117,395	52,520	0	138,686	140,321
2024	139,309	139,810	127,877	58,255	0	151,542	152,240
2025	145,375	145,517	139,376	64,569	0	167,233	167,505
2026	148,981	149,131	150,859	70,247	0	183,459	183,540
2027	161,128	161,152	145,896	67,356	0	172,069	172,147
2028	152,953	152,959	142,450	64,945	0	168,410	168,453
2029	150,226	150,235	146,712	66,828	0	173,895	173,922
2030	155,707	155,712	146,582	66,928	0	174,316	174,332
2031	156,461	156,457	144,198	66,101	0	171,622	171,632

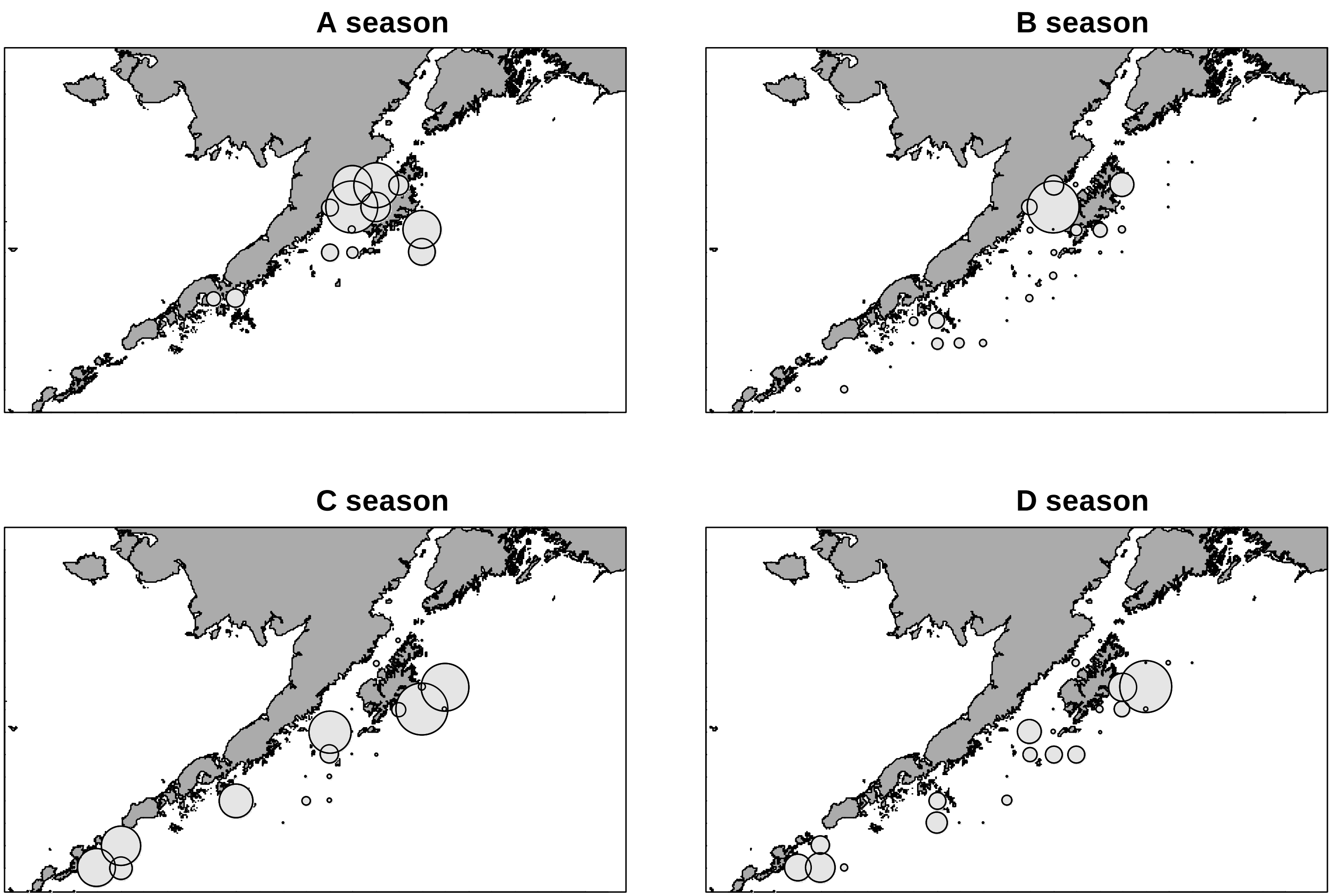


Figure 1.1. Pollock catch in 2017 for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

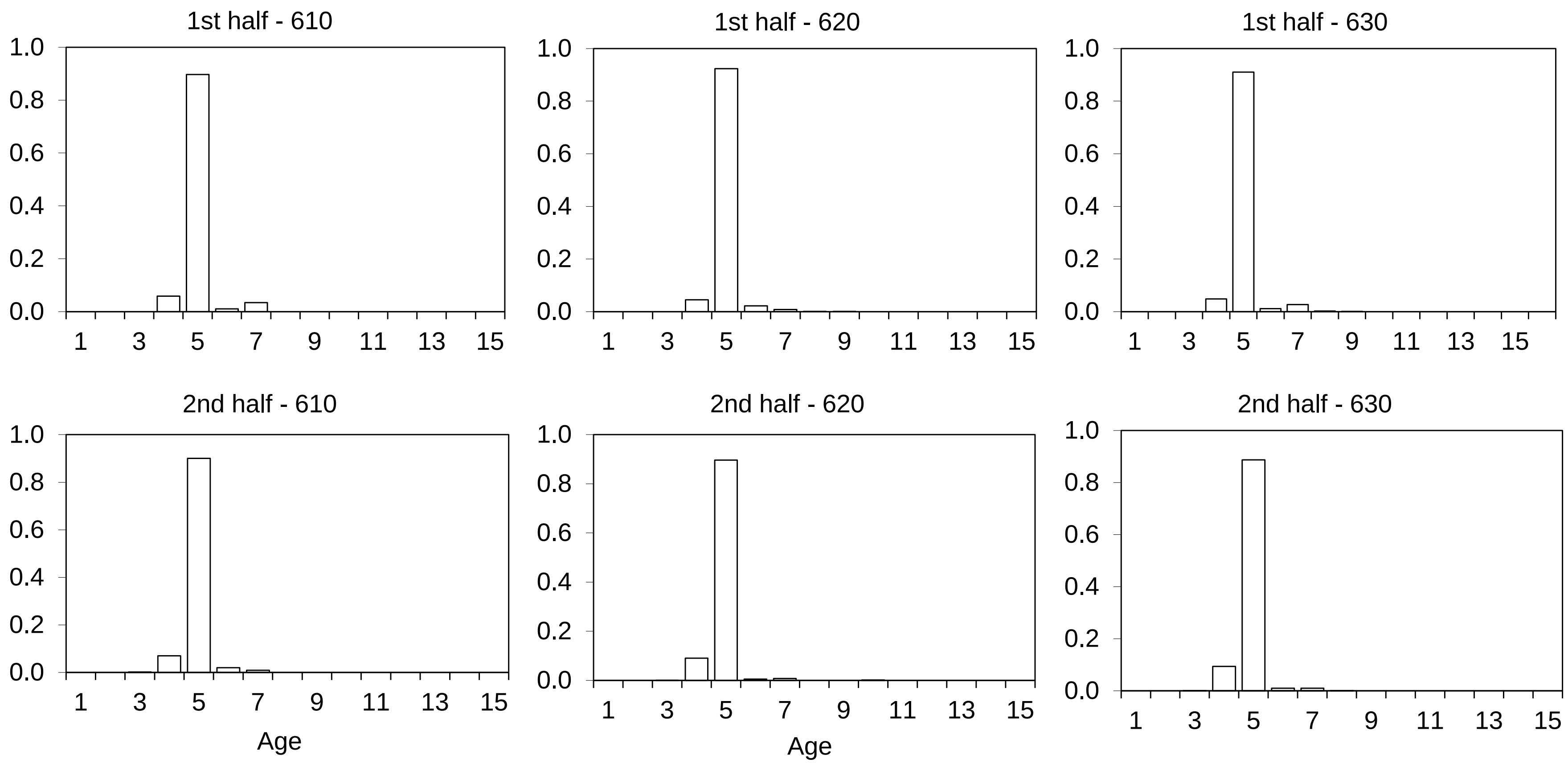


Figure 1.2. 2017 fishery age composition by half year (January-June, July-December) and management area.

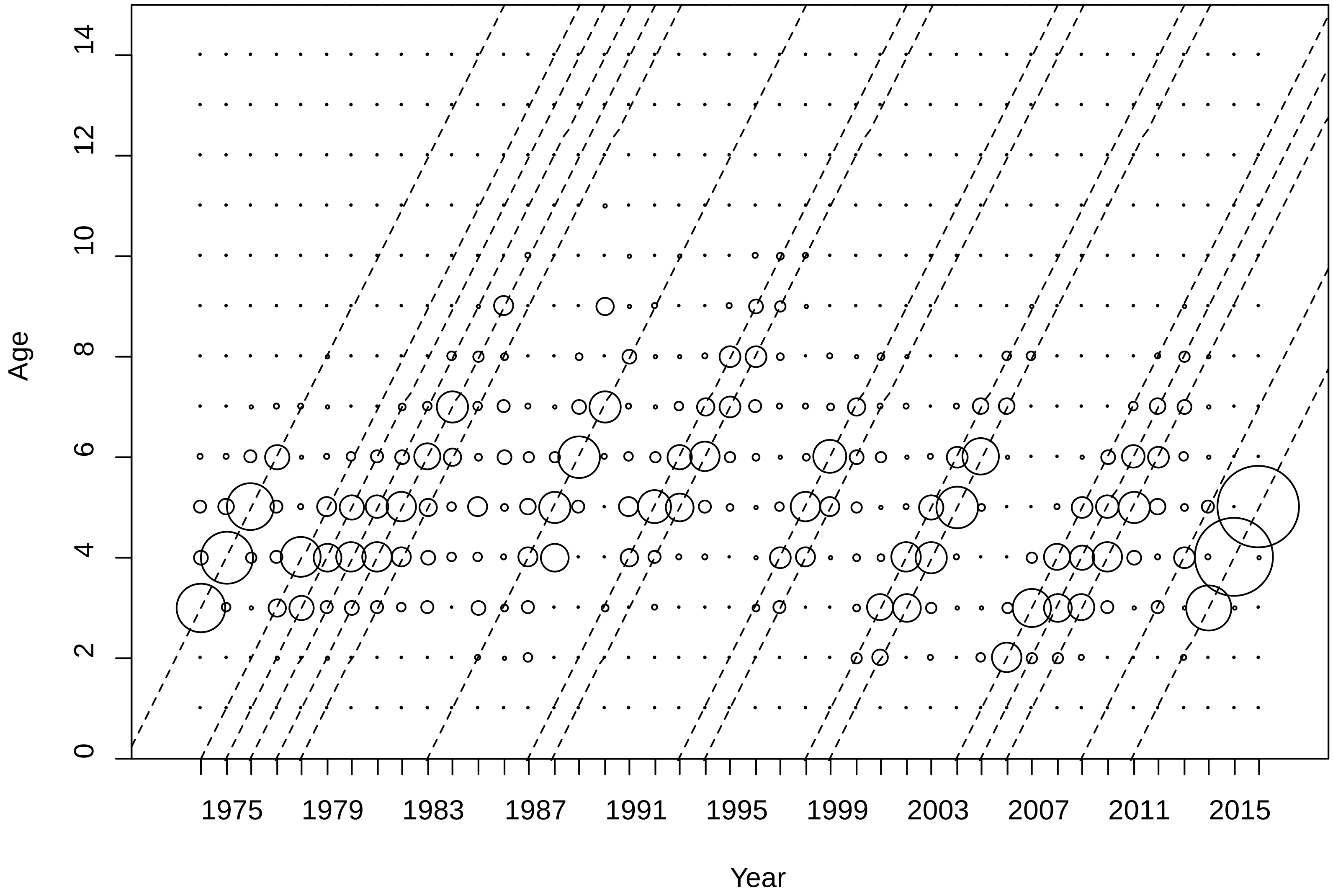


Figure 1.3. GOA pollock fishery age composition (1975-2017). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes.

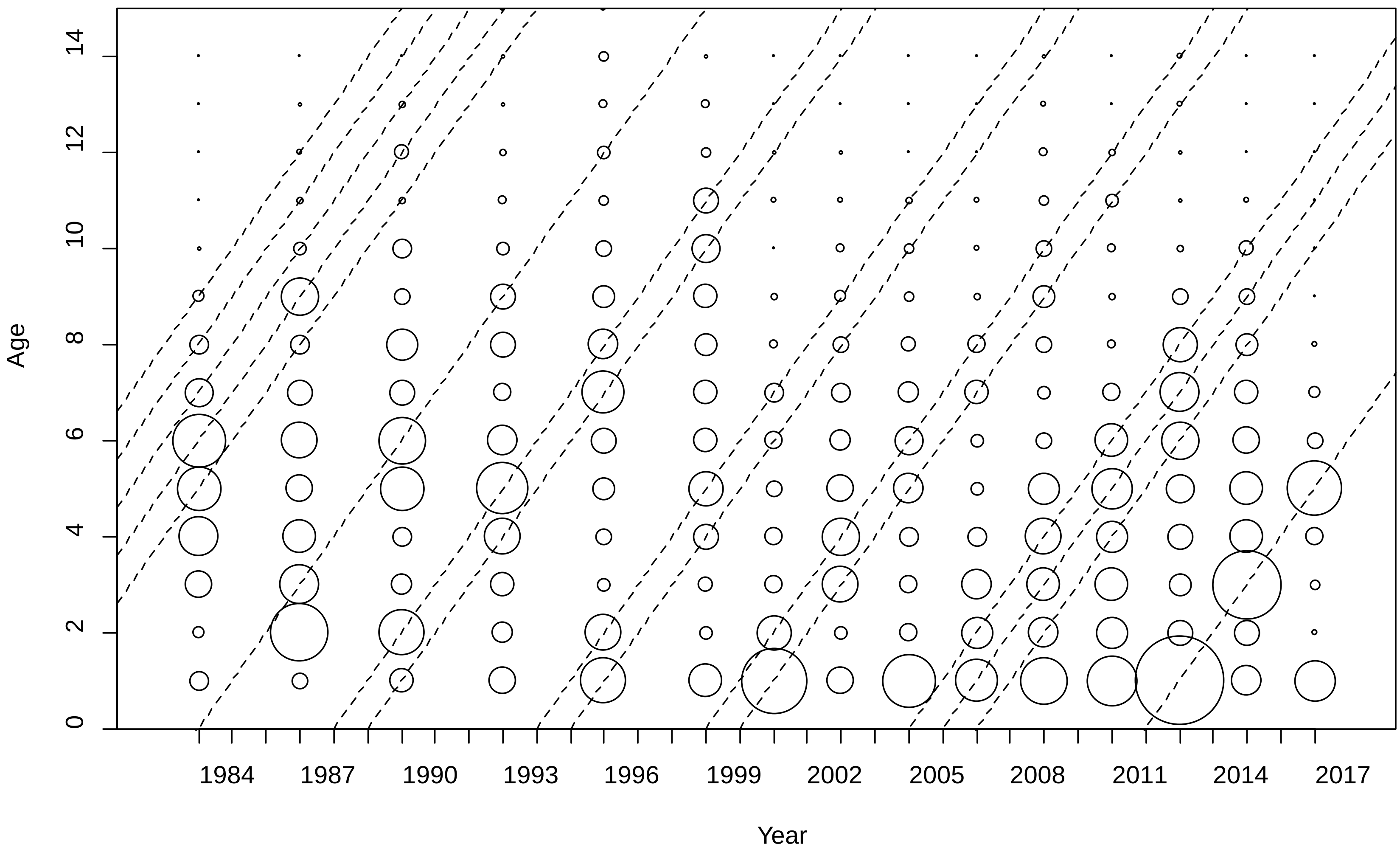


Figure 1.4. Estimated abundance at age in the NMFS bottom trawl survey (1984-2017). The area of the circle is proportional to the estimated abundance.

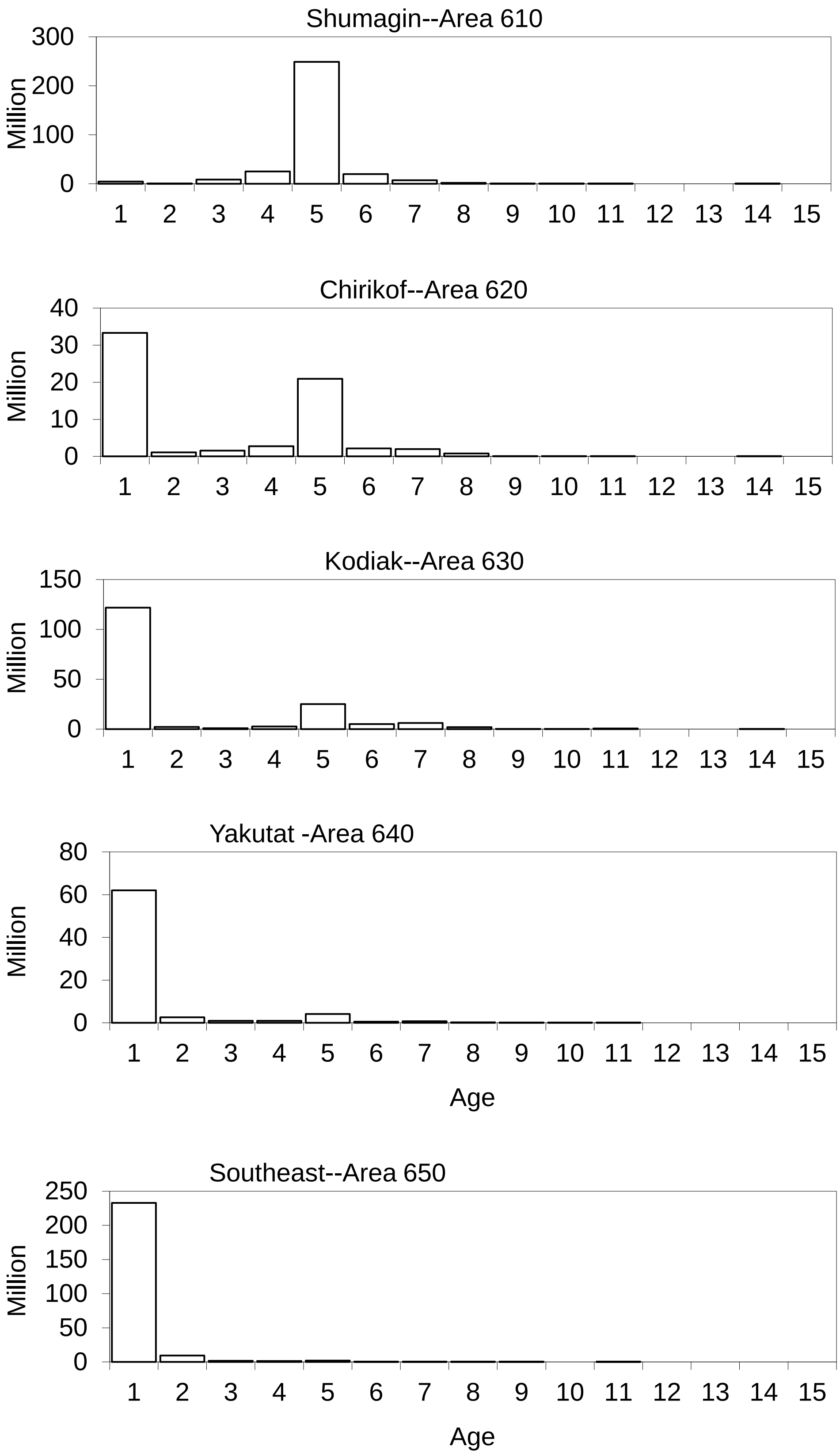


Figure 1.5. Estimated abundance at age in the 2017 NMFS bottom trawl survey by statistical area.

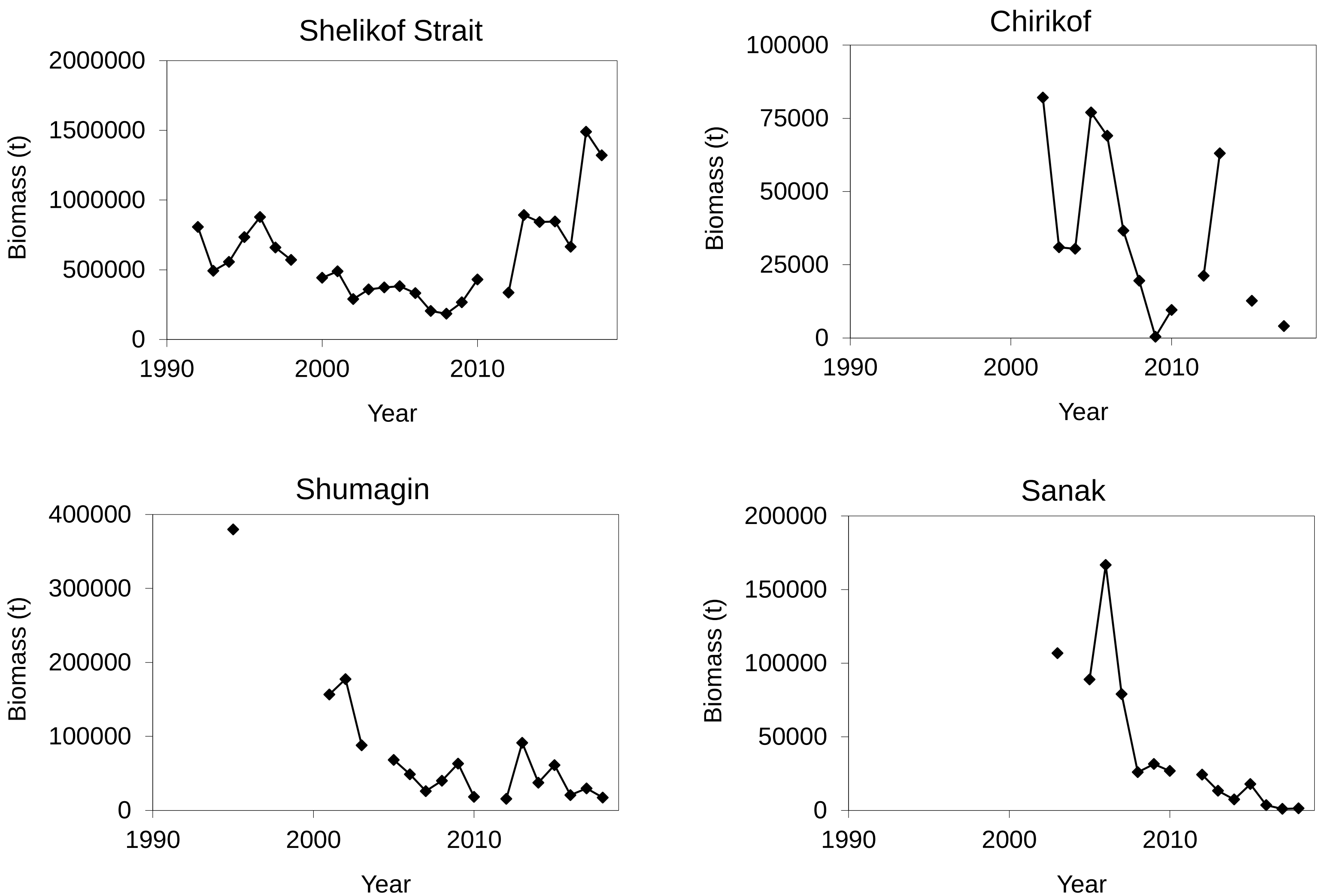


Figure 1.6. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

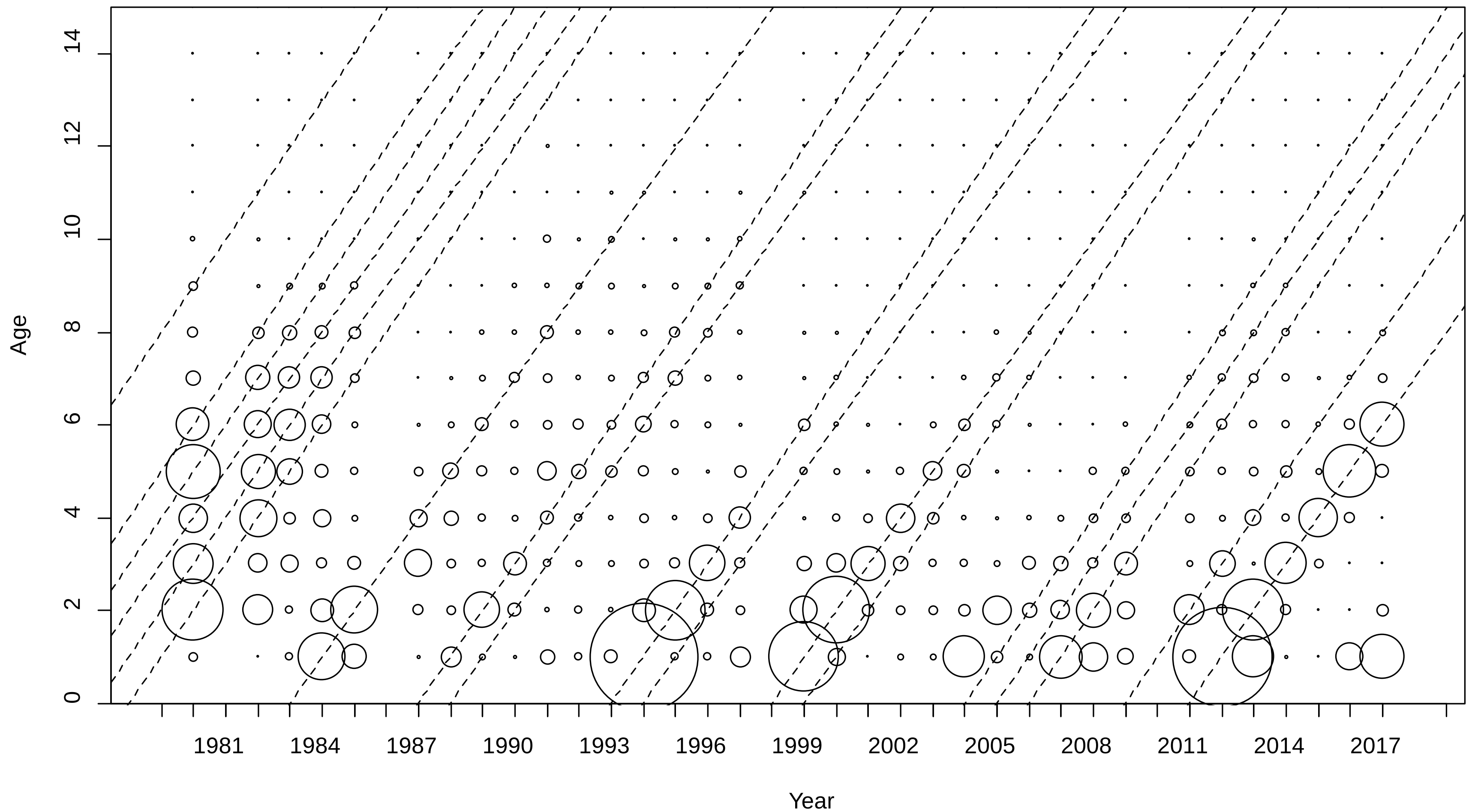


Figure 1.7. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2017, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

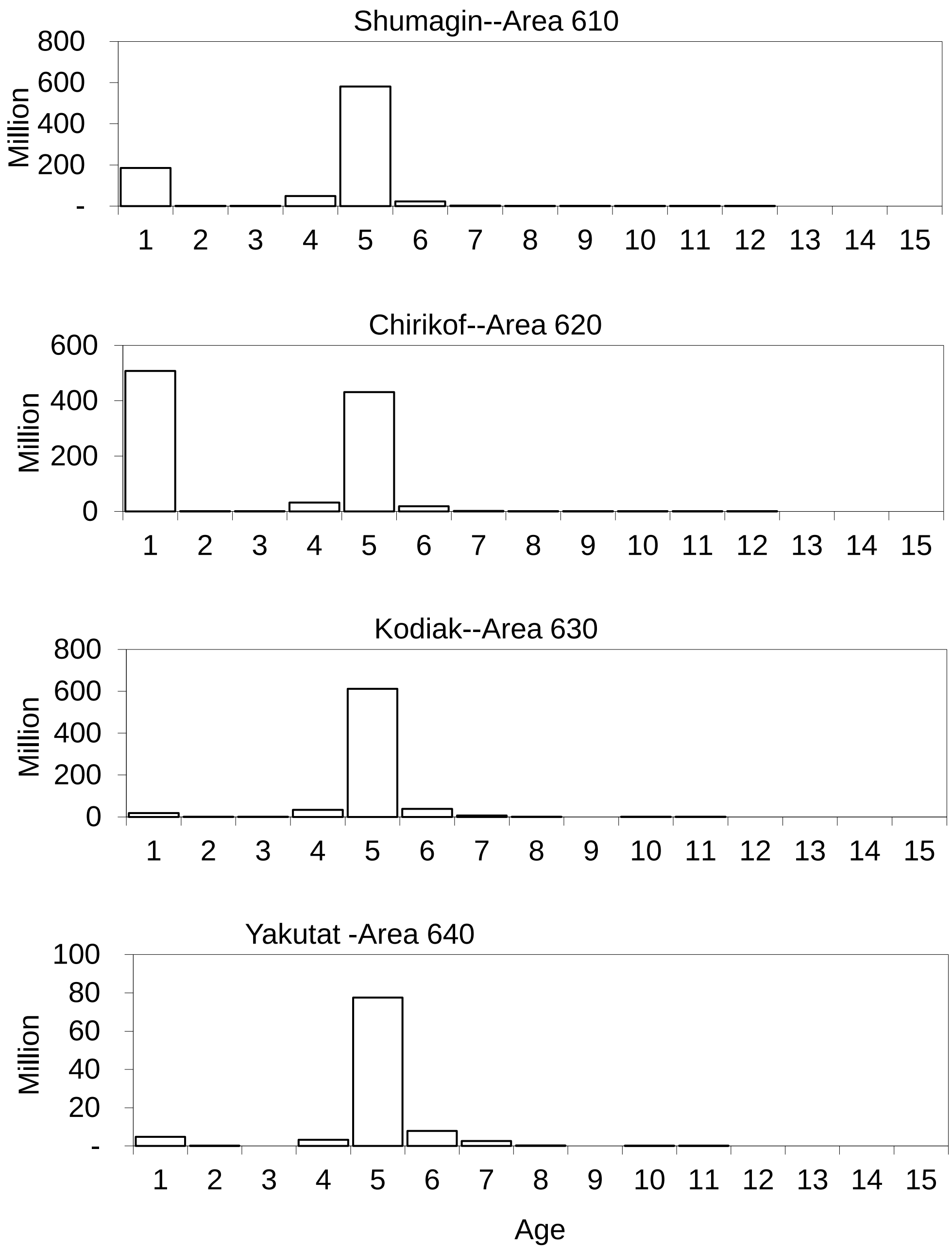


Figure 1.8. Estimated abundance at age in the 2017 summer acoustic survey by statistical area.

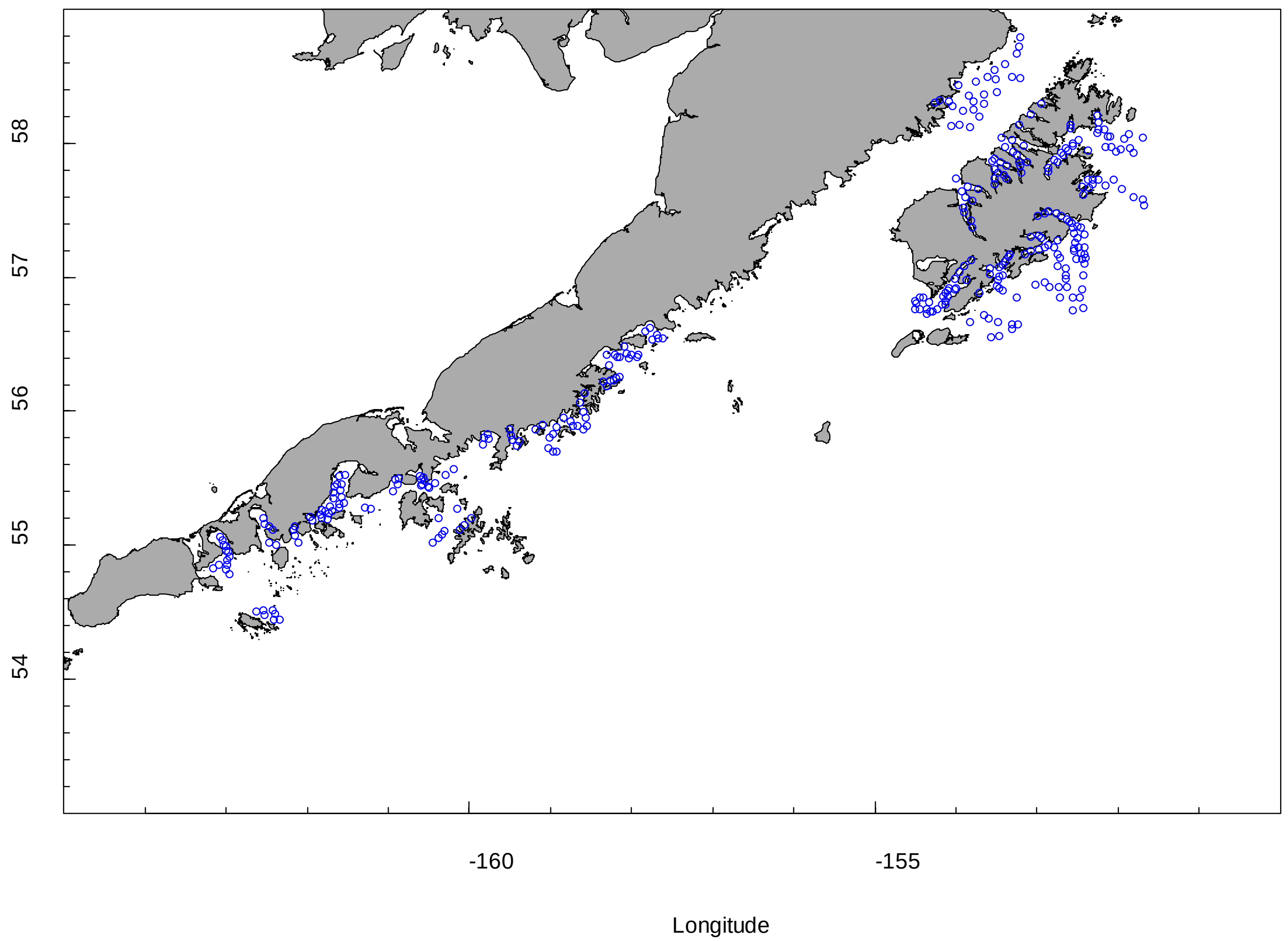


Figure 1.9. Haul locations for the 2018 ADFG bottom trawl survey.

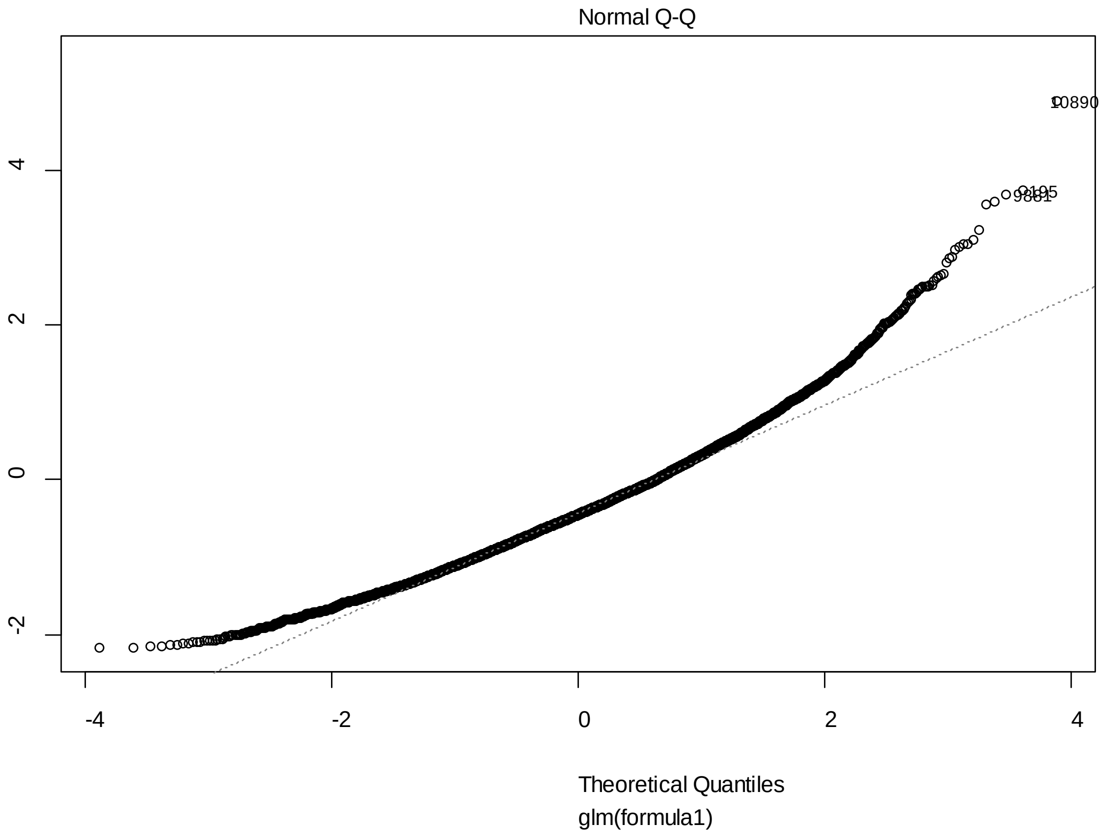


Figure 1.10. QQ plot for residuals for the GLM model for the positive observations with a gamma error assumption.

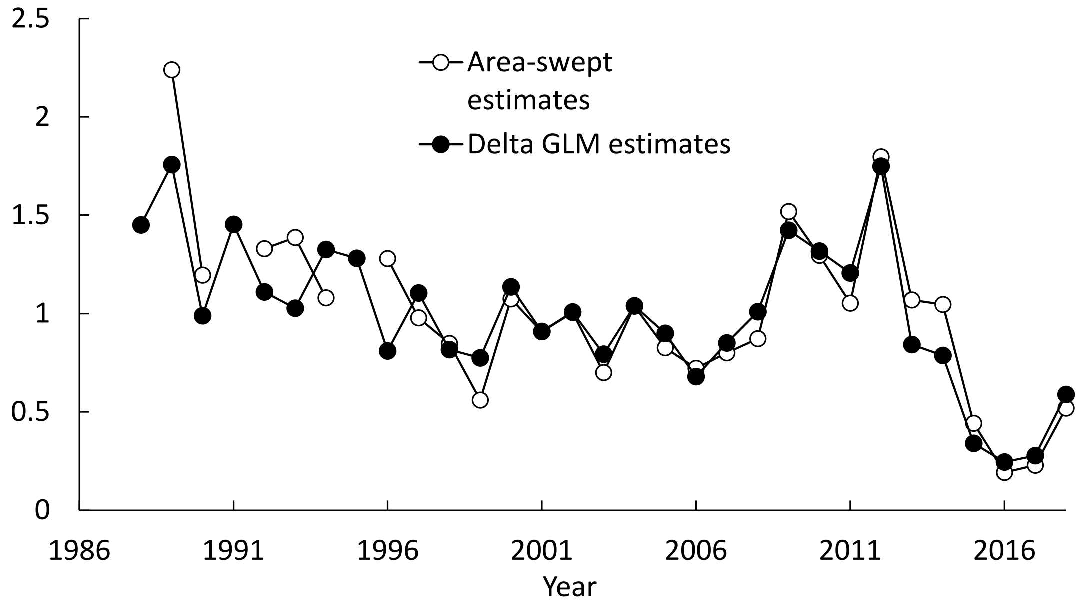


Figure 1.11. Comparison of ADFG bottom trawl area-swept indices with year indices for a delta GLM model with a gamma error assumption for the positive observations. Both time series have been scaled by the mean for the time series.

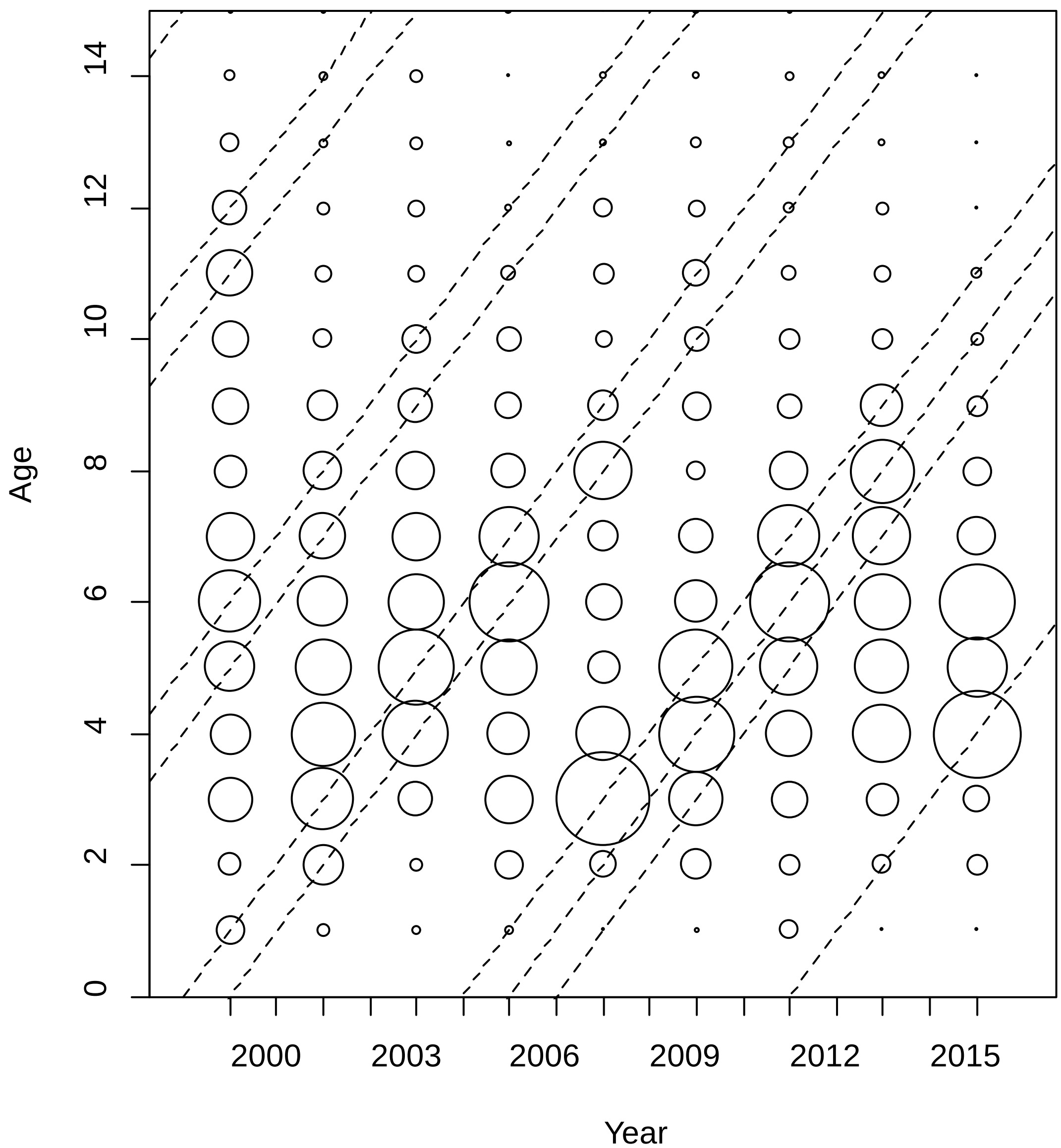


Figure 1.12. Estimated proportions at age in the ADFG crab/groundfish survey (2000-2016). The area of the circle is proportional to the estimated abundance.

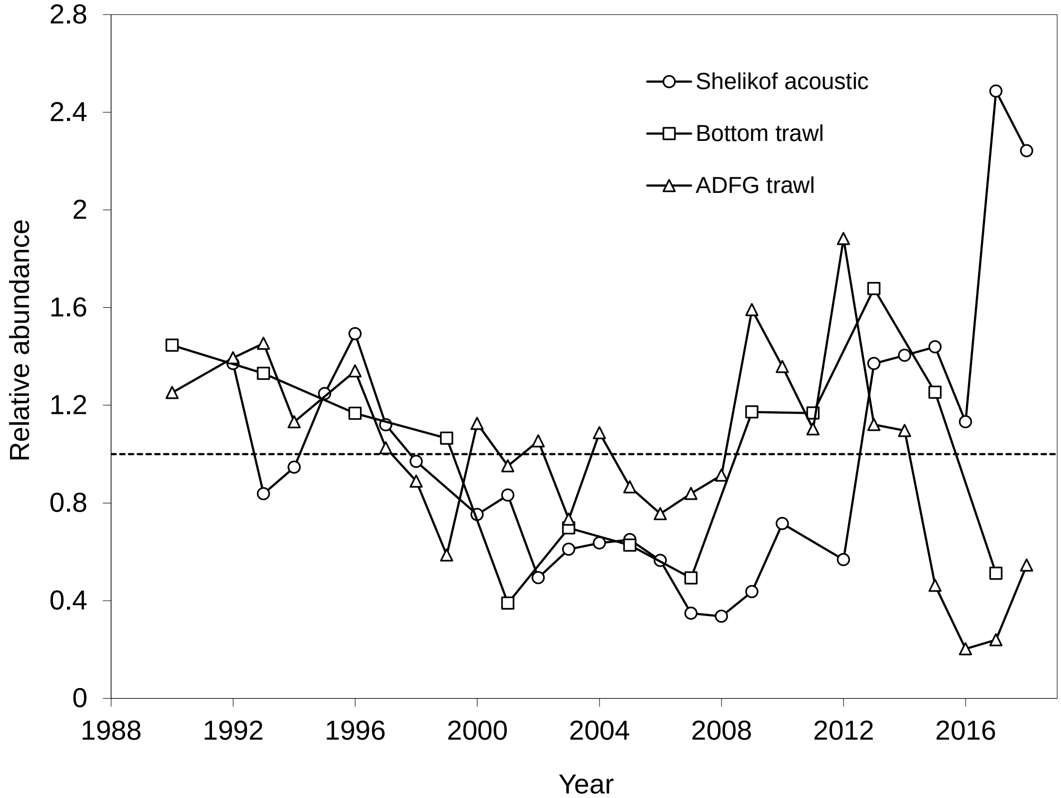


Figure 1.13. Relative trends in pollock biomass since 1990 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADFG crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1990. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the R/V Oscar Dyson.

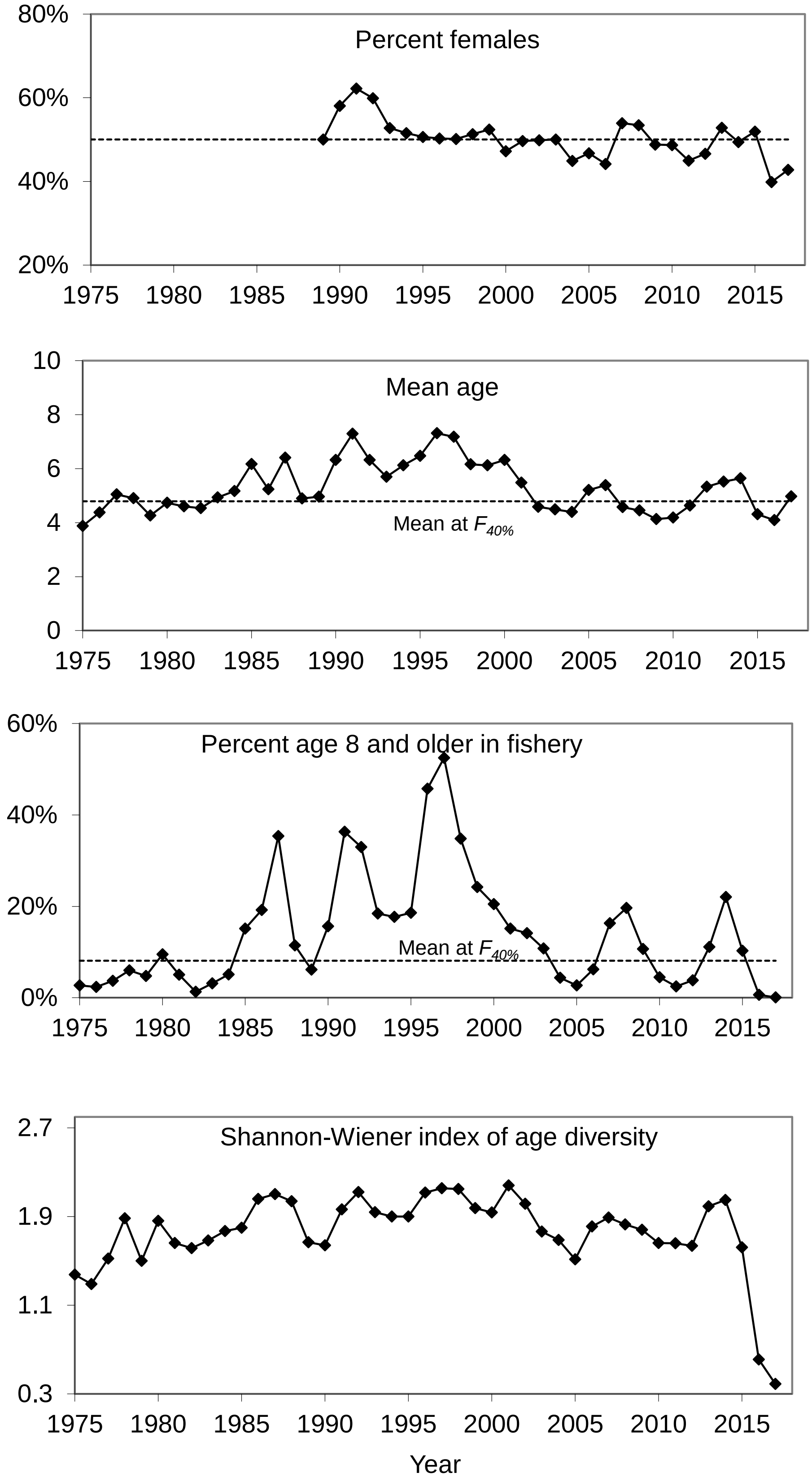


Figure 1.14. GOA pollock fishery catch characteristics.

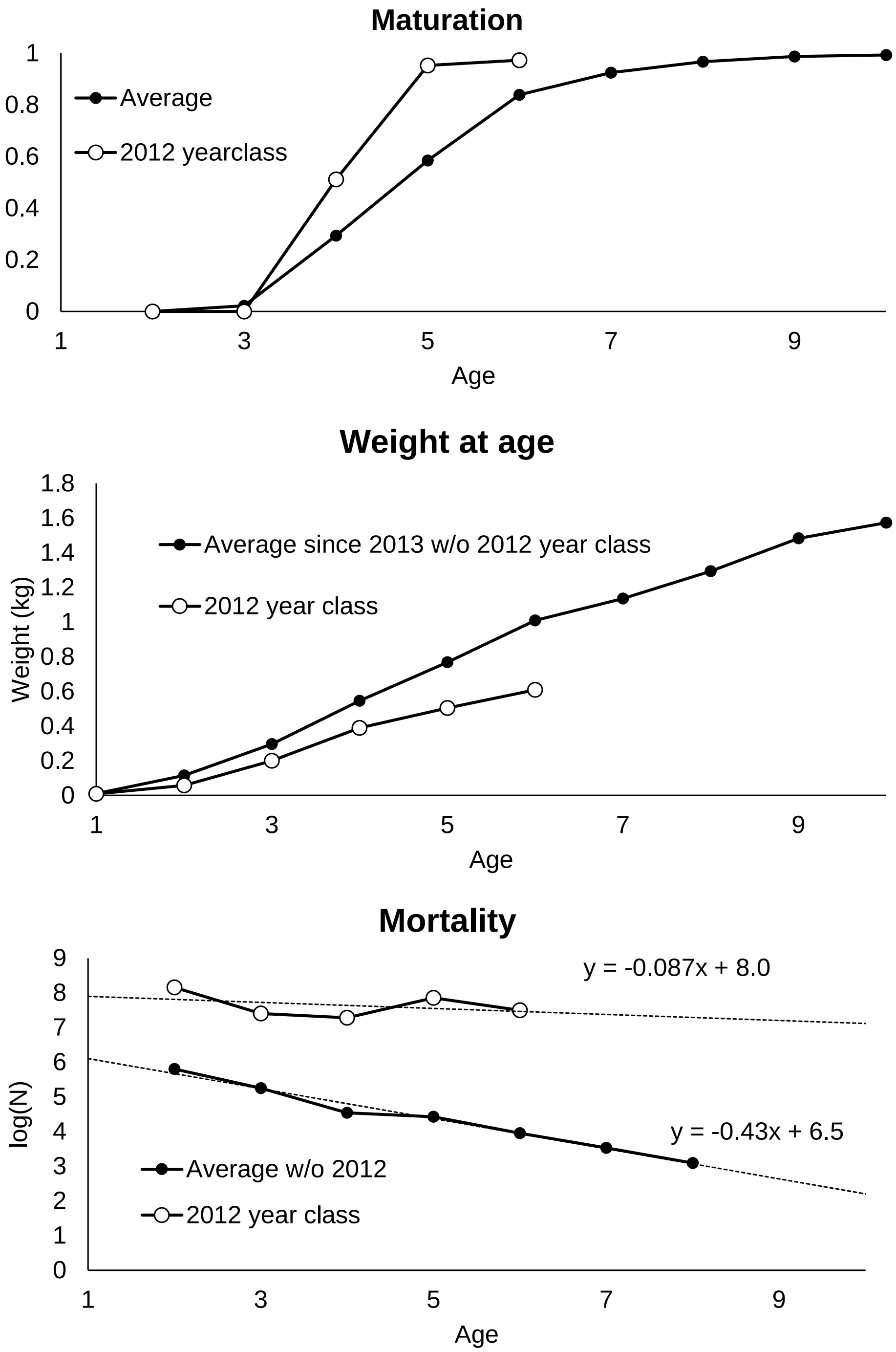


Figure 1.15. Comparison of 2012 year class maturation, growth, and mortality with average characteristic. Maturity is based on sampling during winter acoustic surveys. Weight at age is a comparison of the 2012 year class in the winter acoustic survey with the average weight at age since 2013 excluding the 2012 year class. The mortality plot is catch curve analysis of the Shelikof Strait survey. The negative of the slope of a linear regression of log(N) on age is an estimate of total mortality (*Z*).

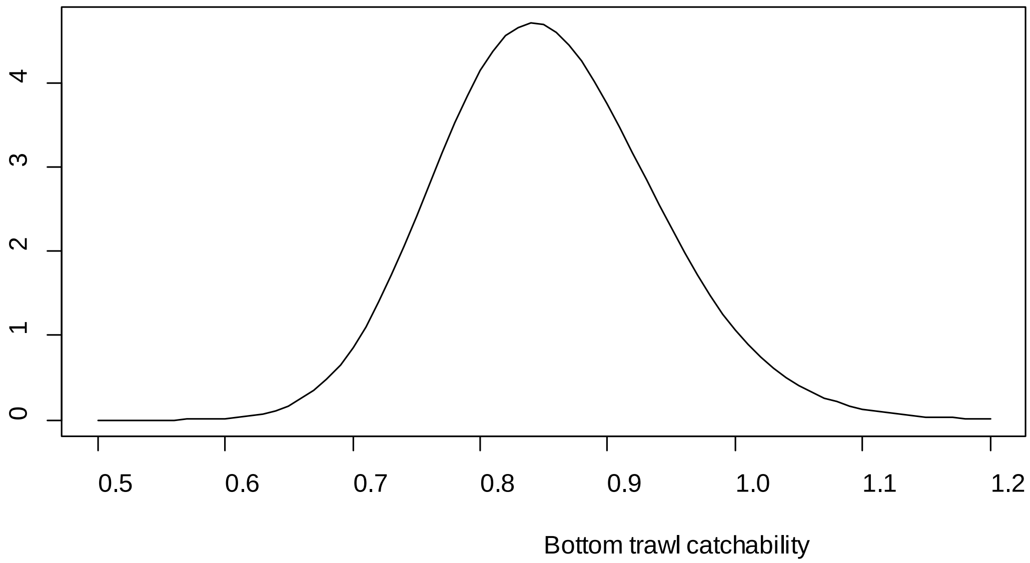


Figure 1.16. Prior on bottom trawl catchability used in the base model.

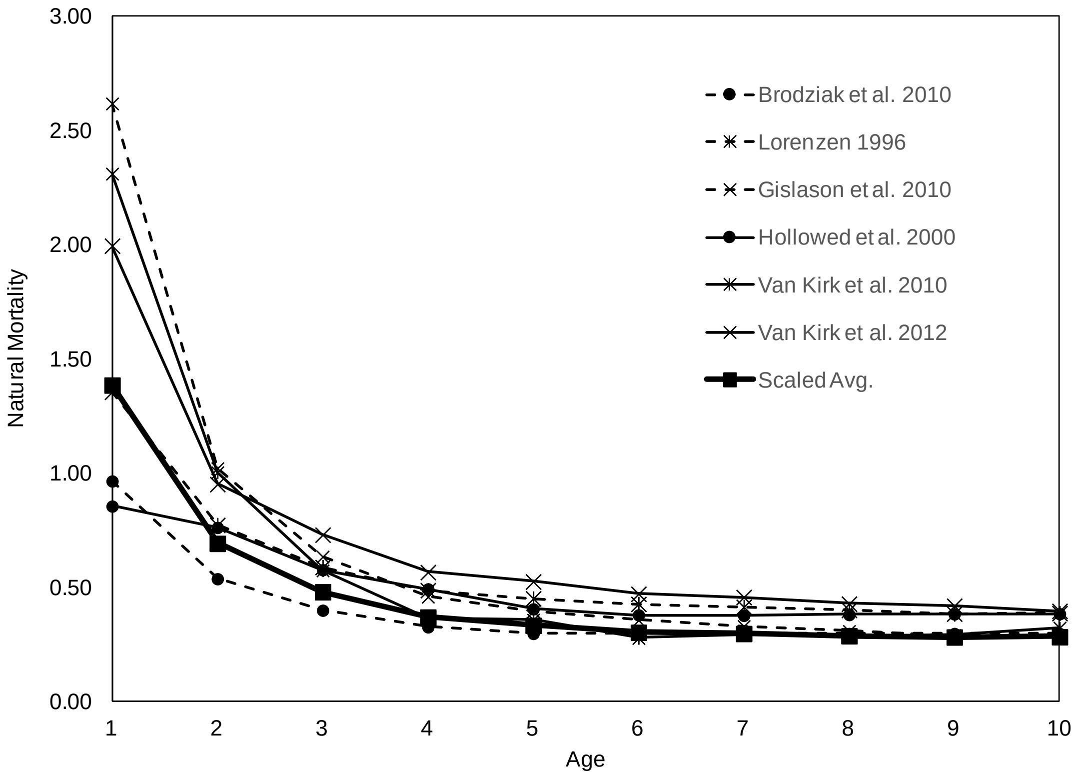


Figure 1.17. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

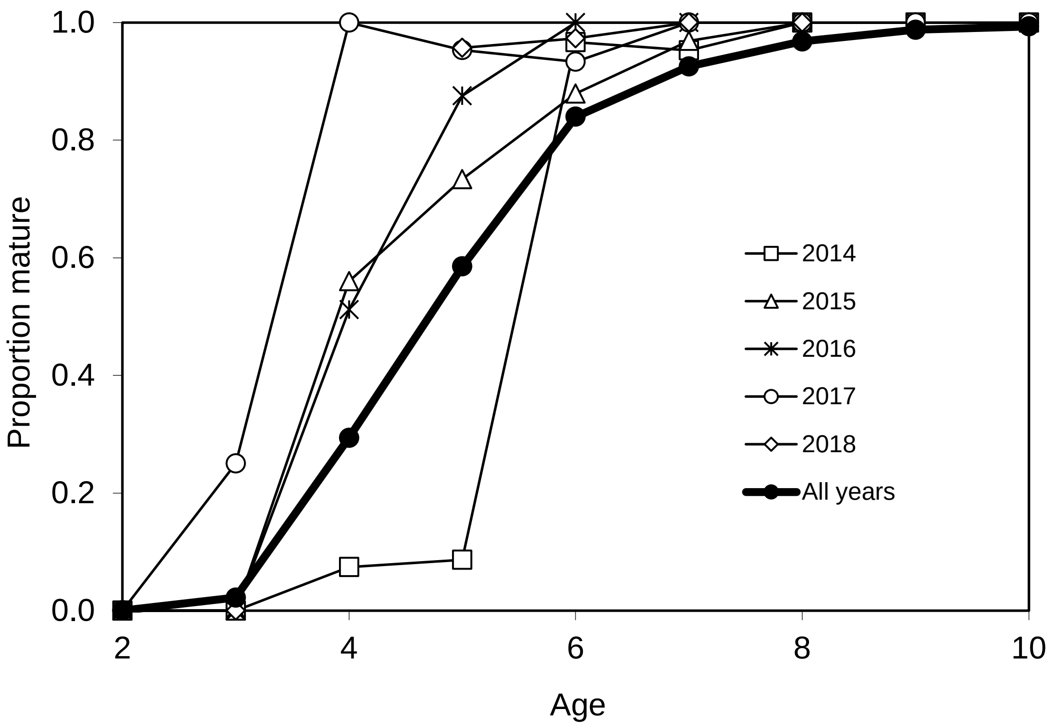


Figure 1.18. Estimates of the proportion mature at age from visual maturity data collected during 2014-2018 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2018).

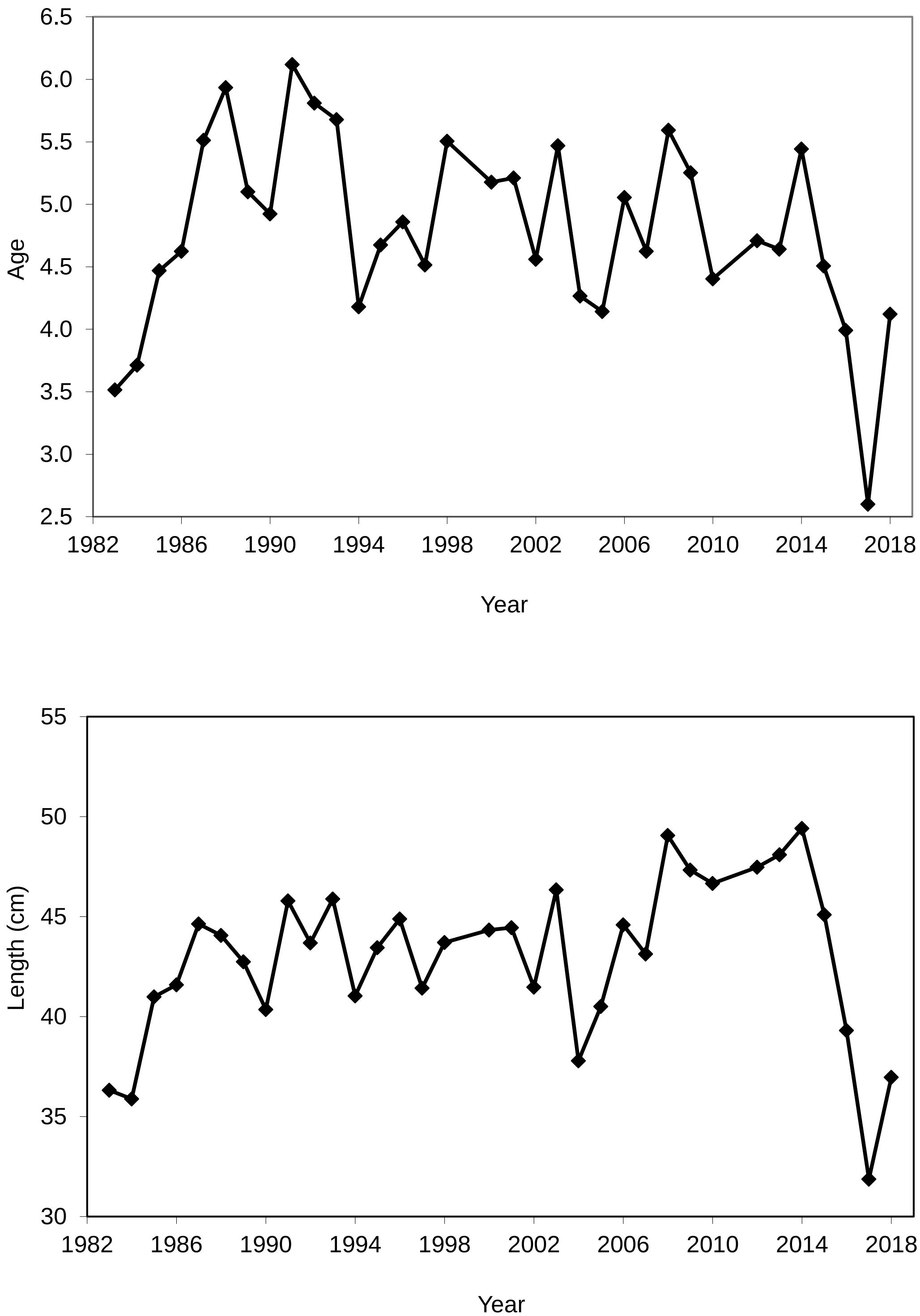


Figure 1.19. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2018.

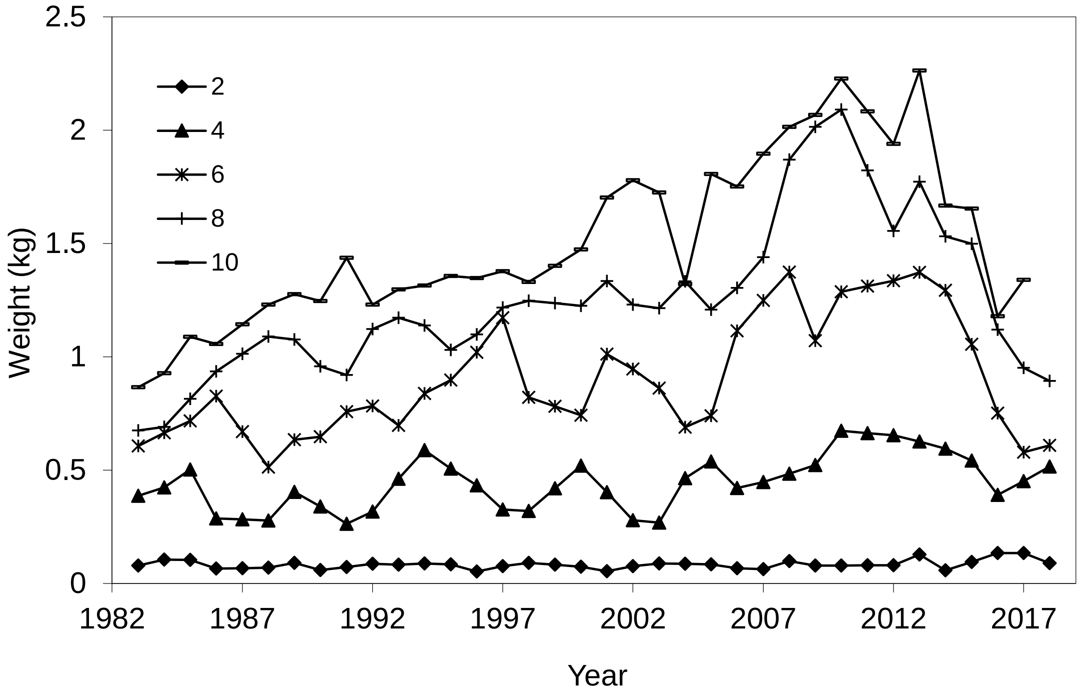


Figure 1.20. Estimated weight at age of GOA pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2018 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from surveys in adjacent years.

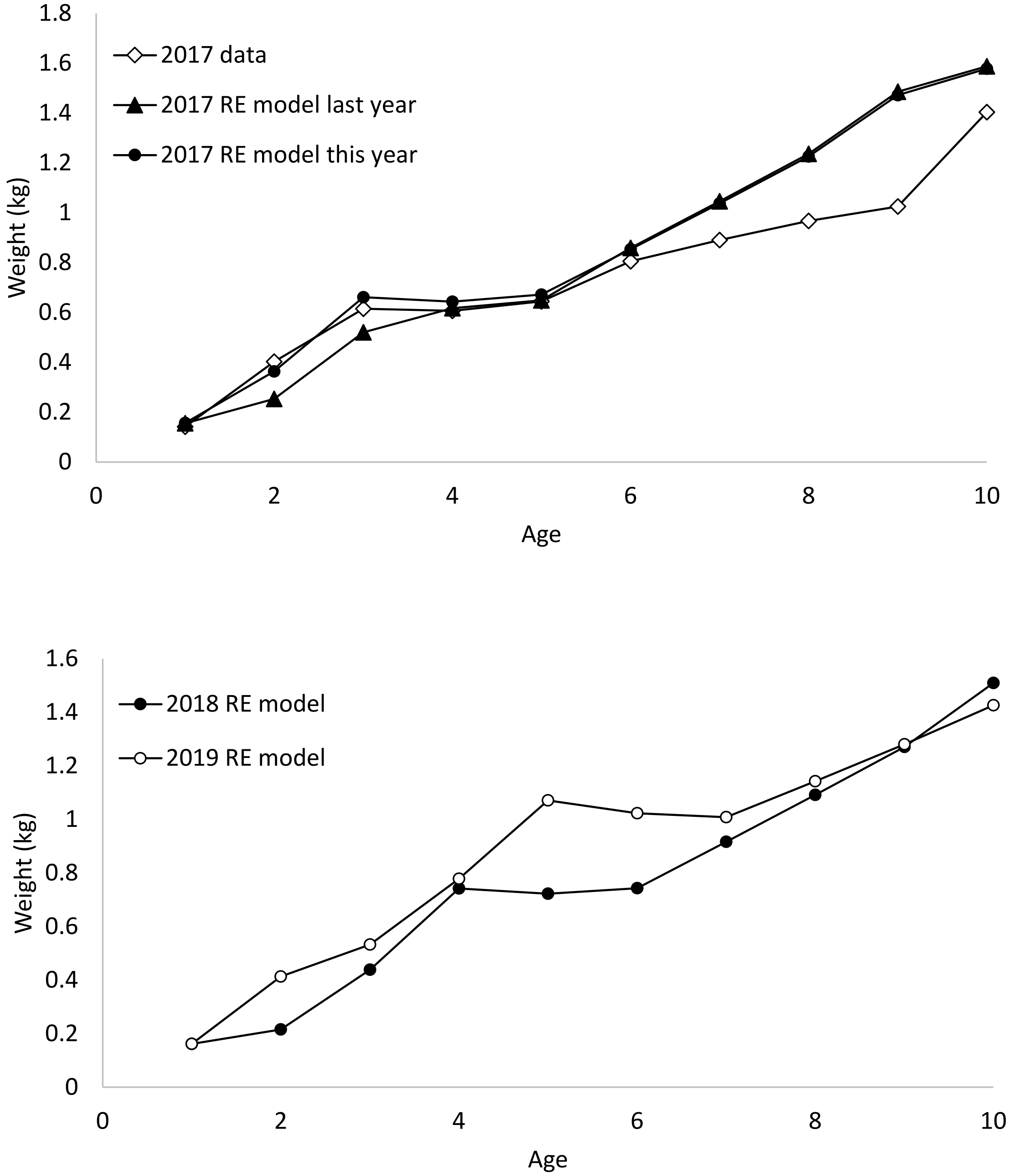


Figure 1.21. Comparison of fishery weight at age for 2017 with estimates from the random effects model last year and this year' assessment (top panel). Random effects model estimates for 2018-2019 used in the assessment model and for yield projections (bottom panel).

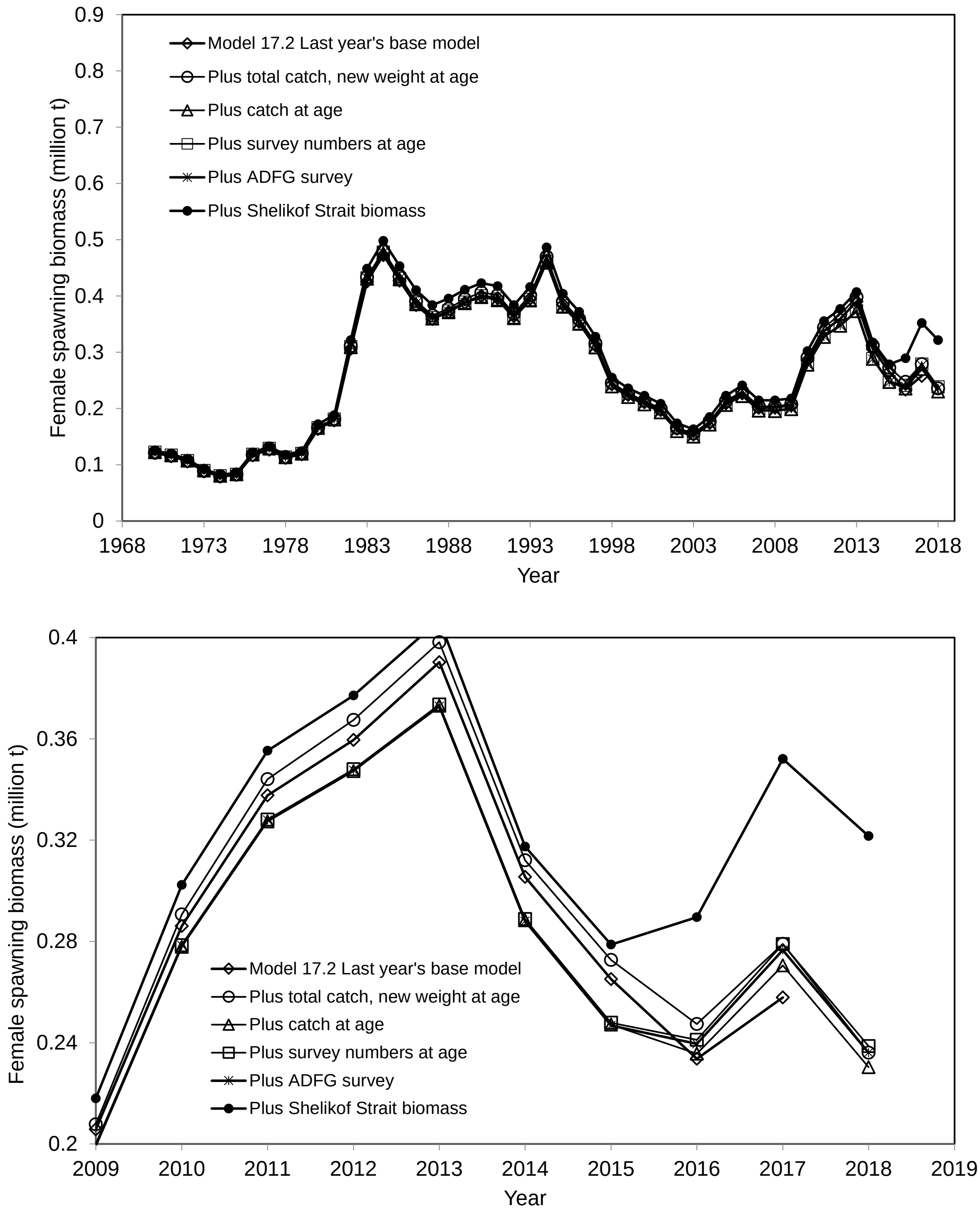


Figure 1.22. Changes in estimated spawning biomass as new data were added successively to last year's base model. The lower panel shows the years 2009-2018 with an expanded scale to highlight differences.

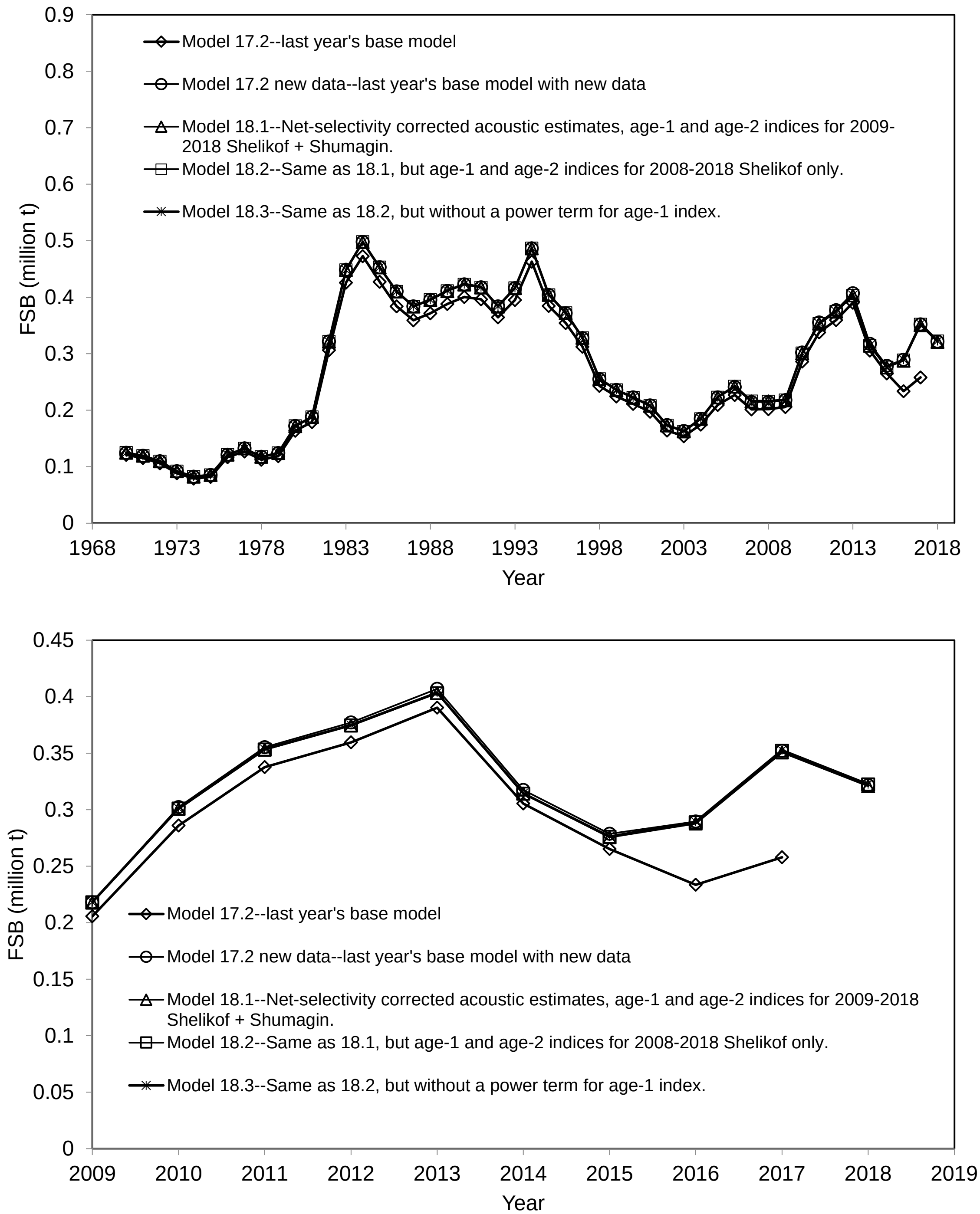


Figure 1.23. Comparison of estimated spawning biomass from alternative models. The lower panel shows the years 2009-2018 with an expanded scale to highlight differences. Model 17.2 was the base model last year. Models are described in more detail in the text.

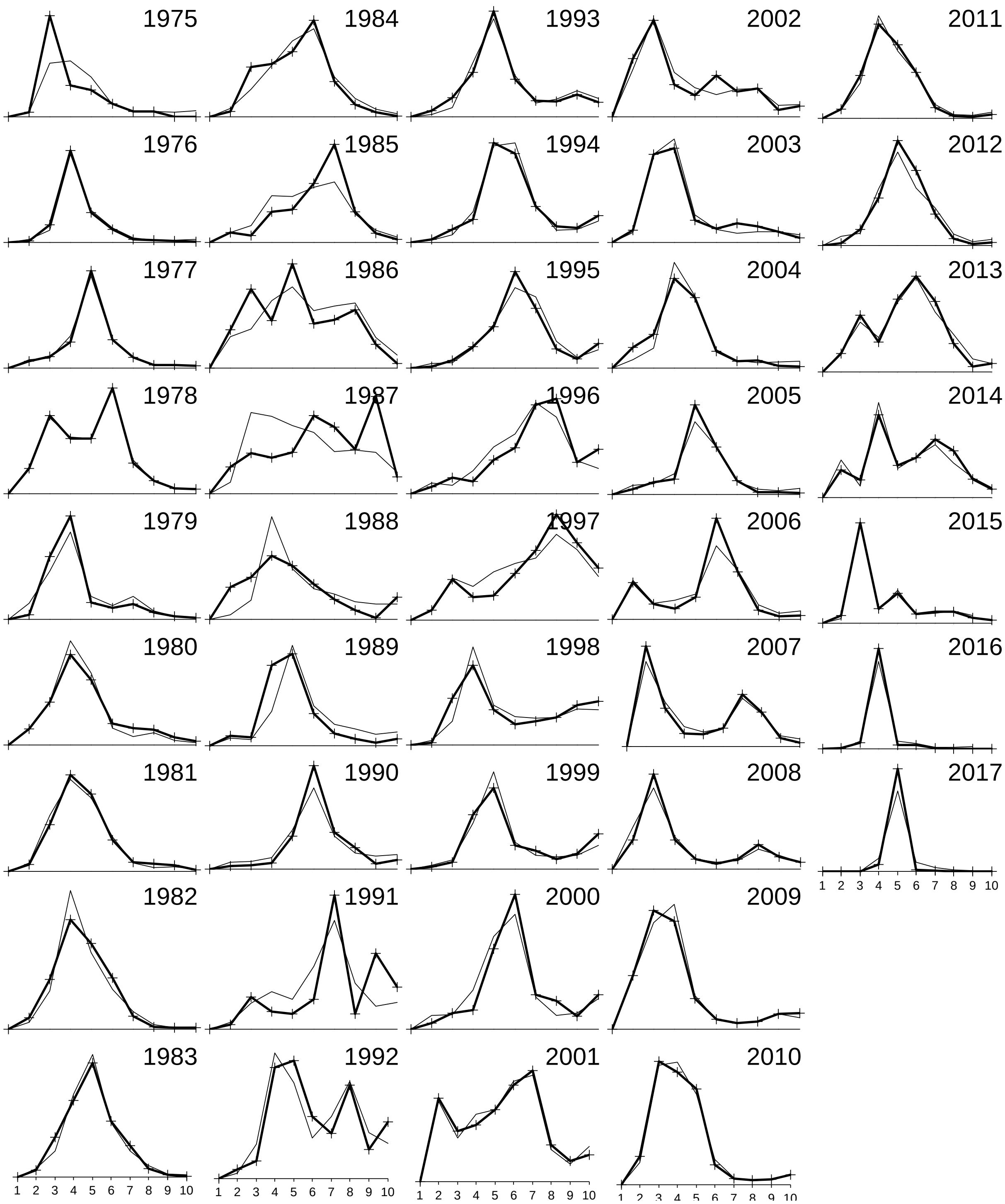


Figure 1.24. Observed and predicted fishery age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

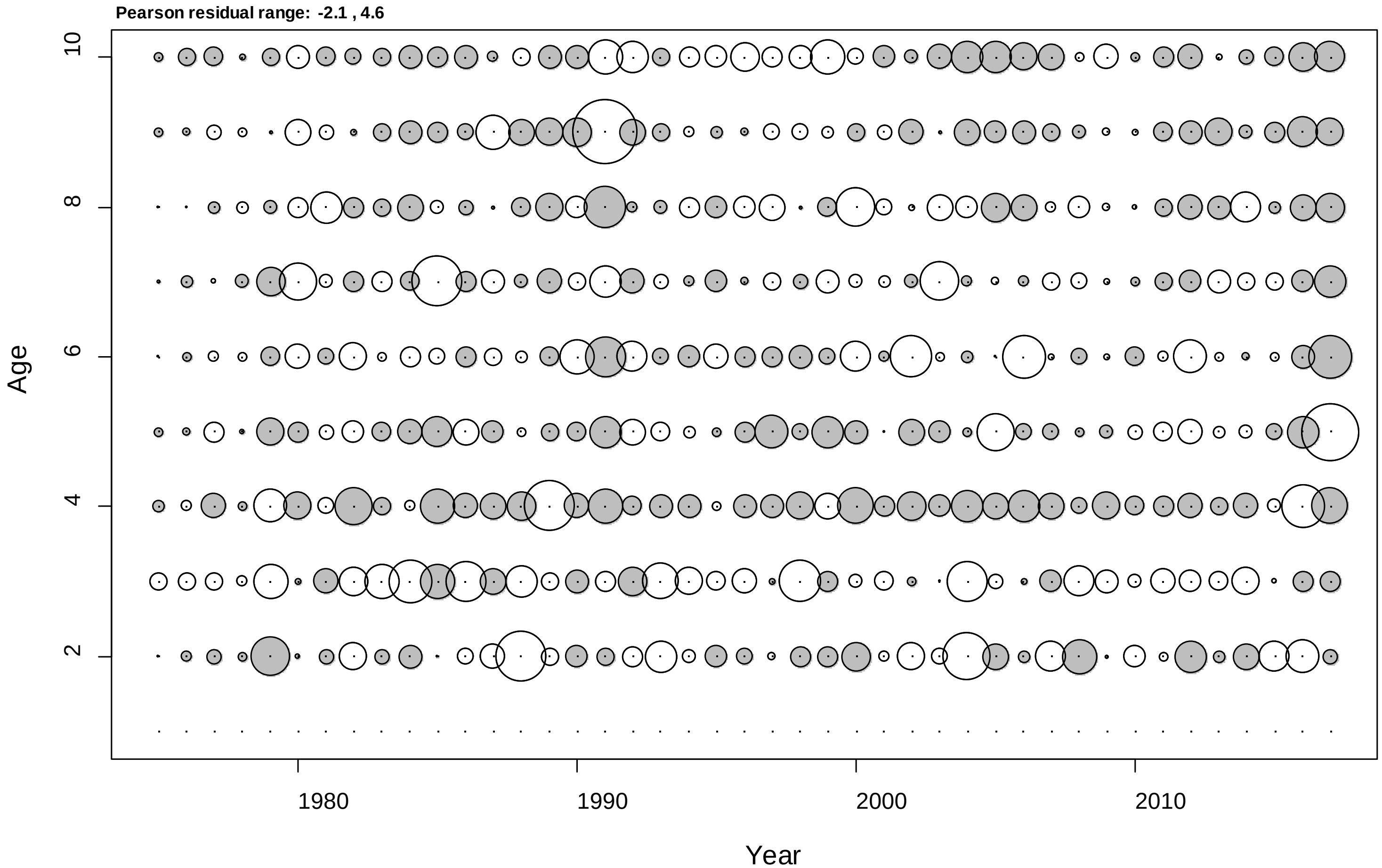


Figure 1.25. Pearson residuals for fishery age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

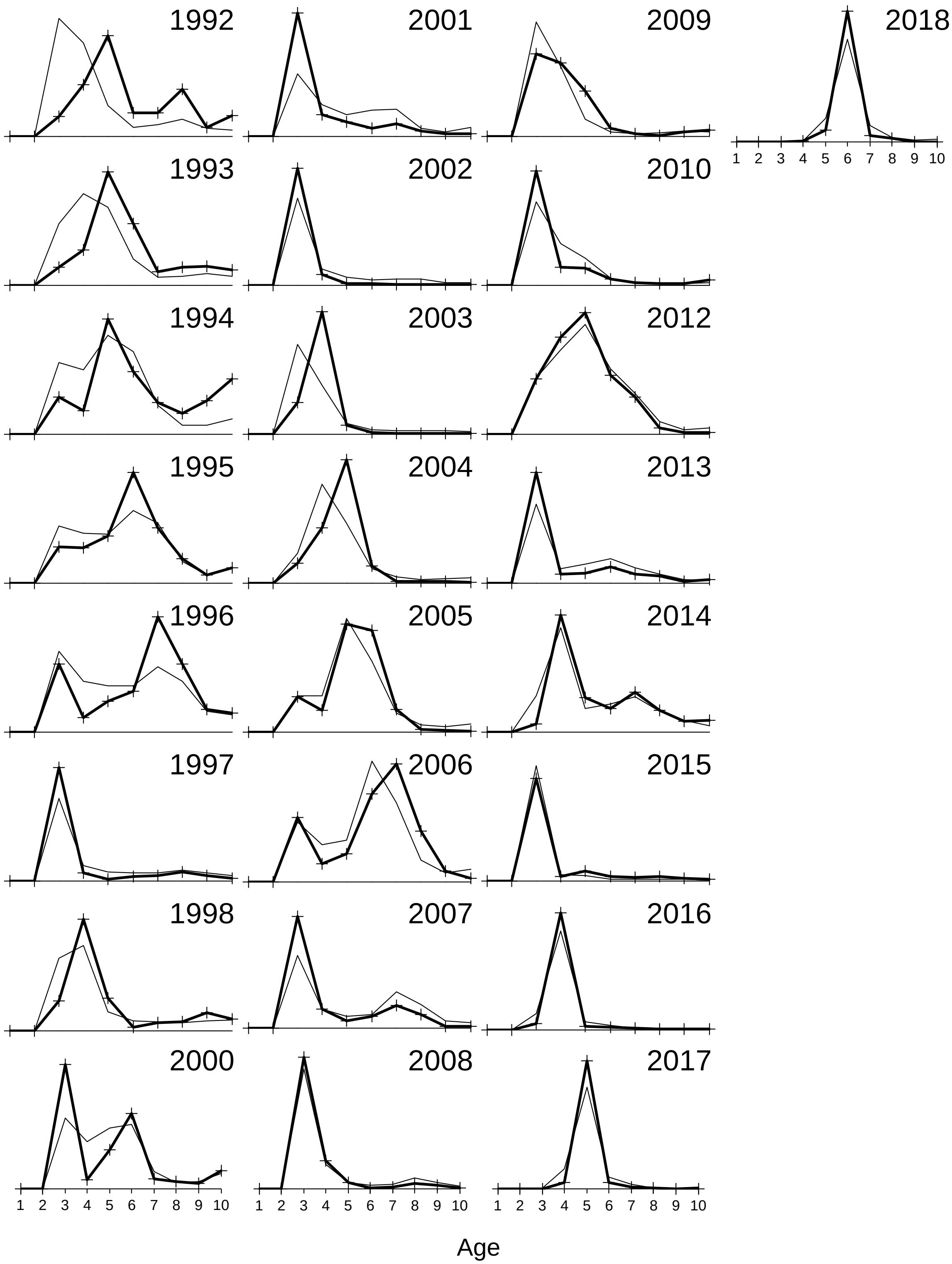


Figure 1.26. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

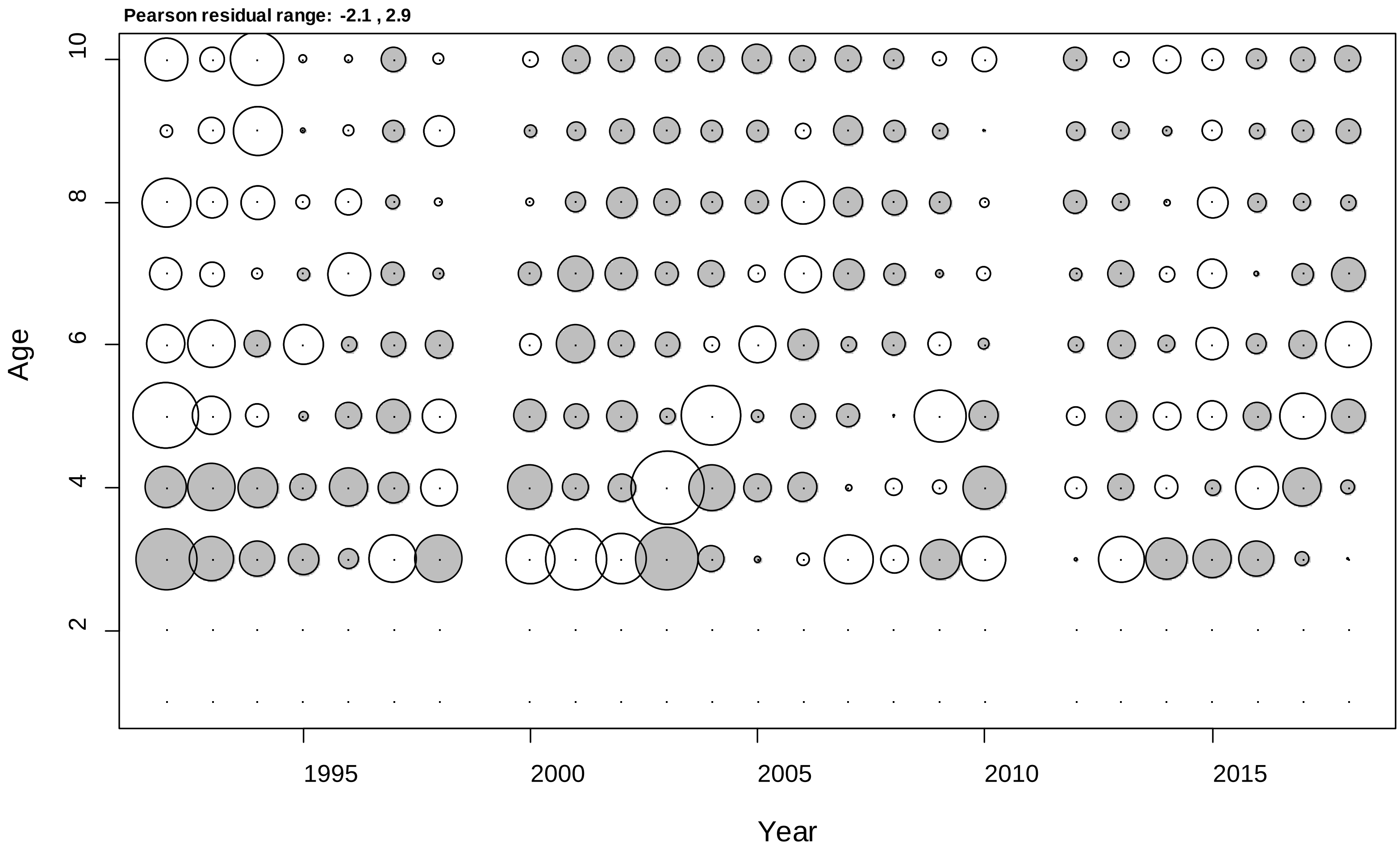


Figure 1.27. Pearson residuals for Shelikof Strait acoustic survey age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

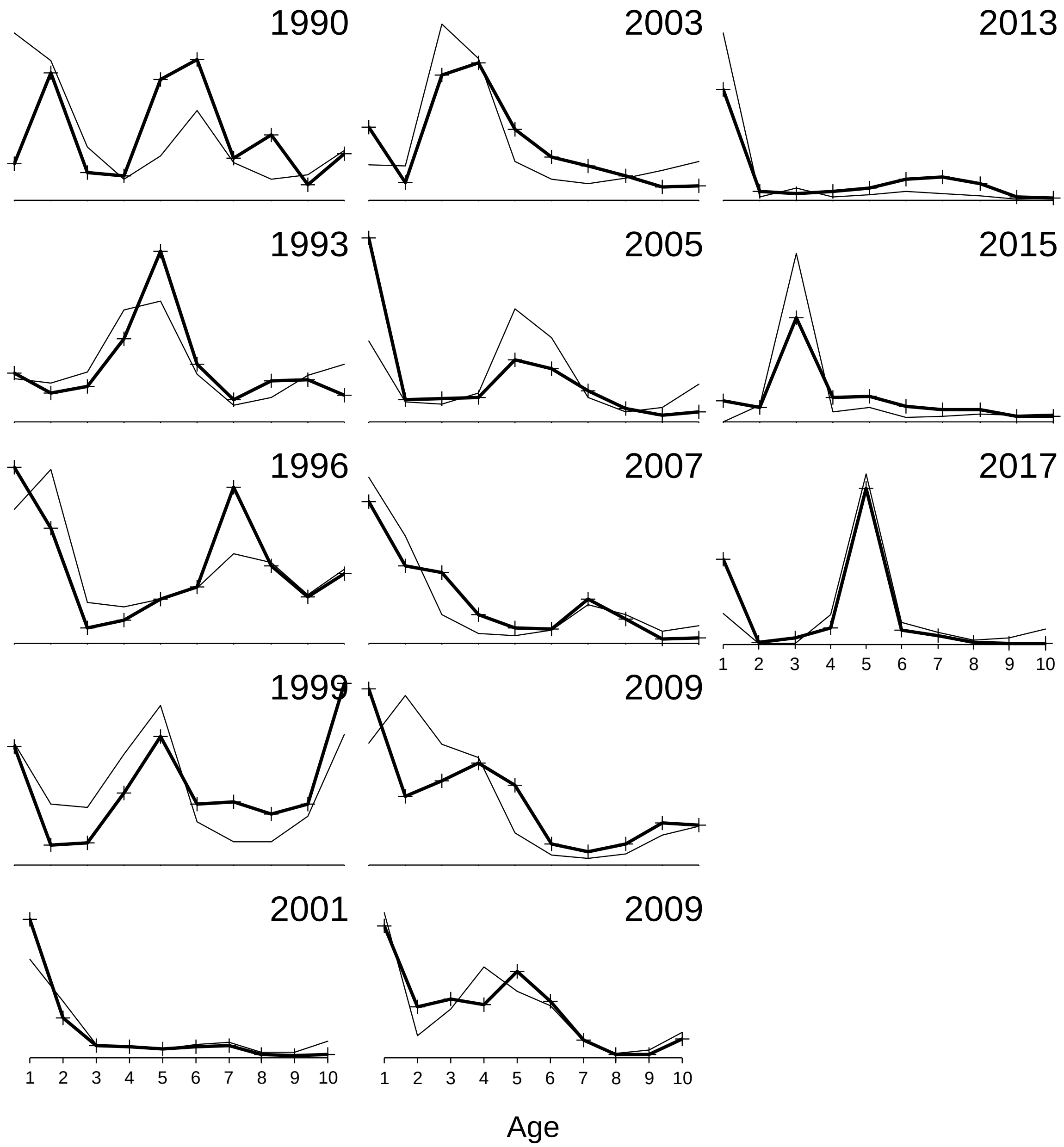
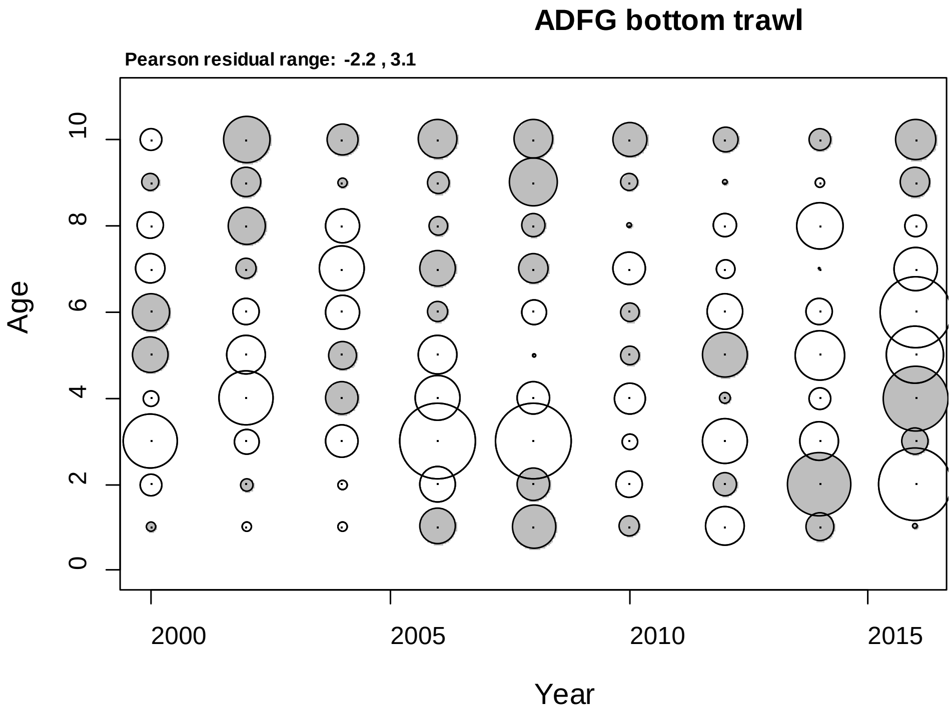


Figure 1.28. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.



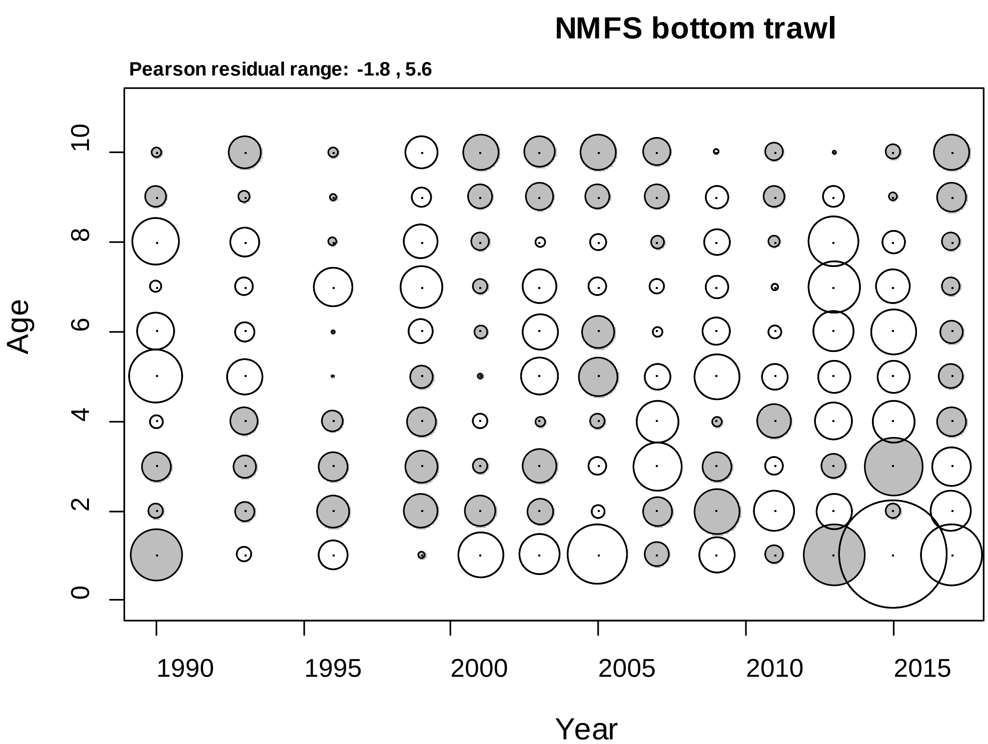


Figure 1.29. Pearson residuals for NMFS bottom trawl survey (top) and ADFG crab/groundfish survey (bottom) age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

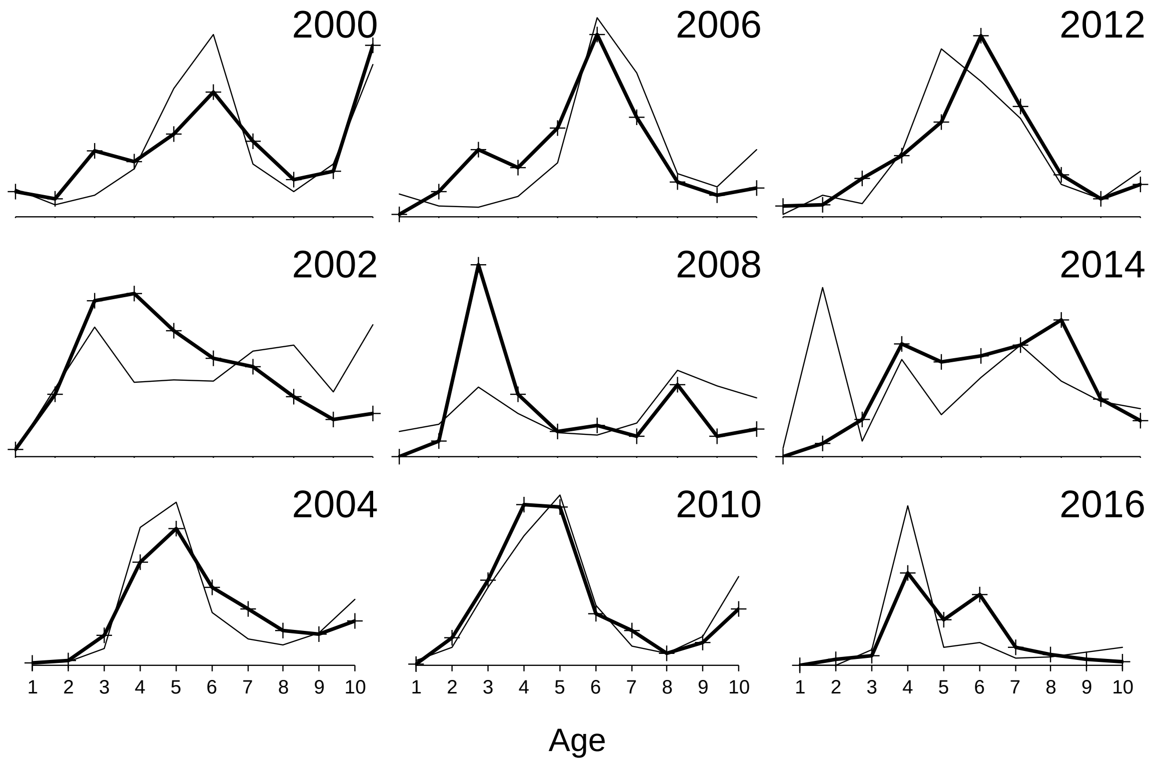


Figure 1.30. Observed and predicted ADFG crab/groundfish survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbols are observed proportions at age.

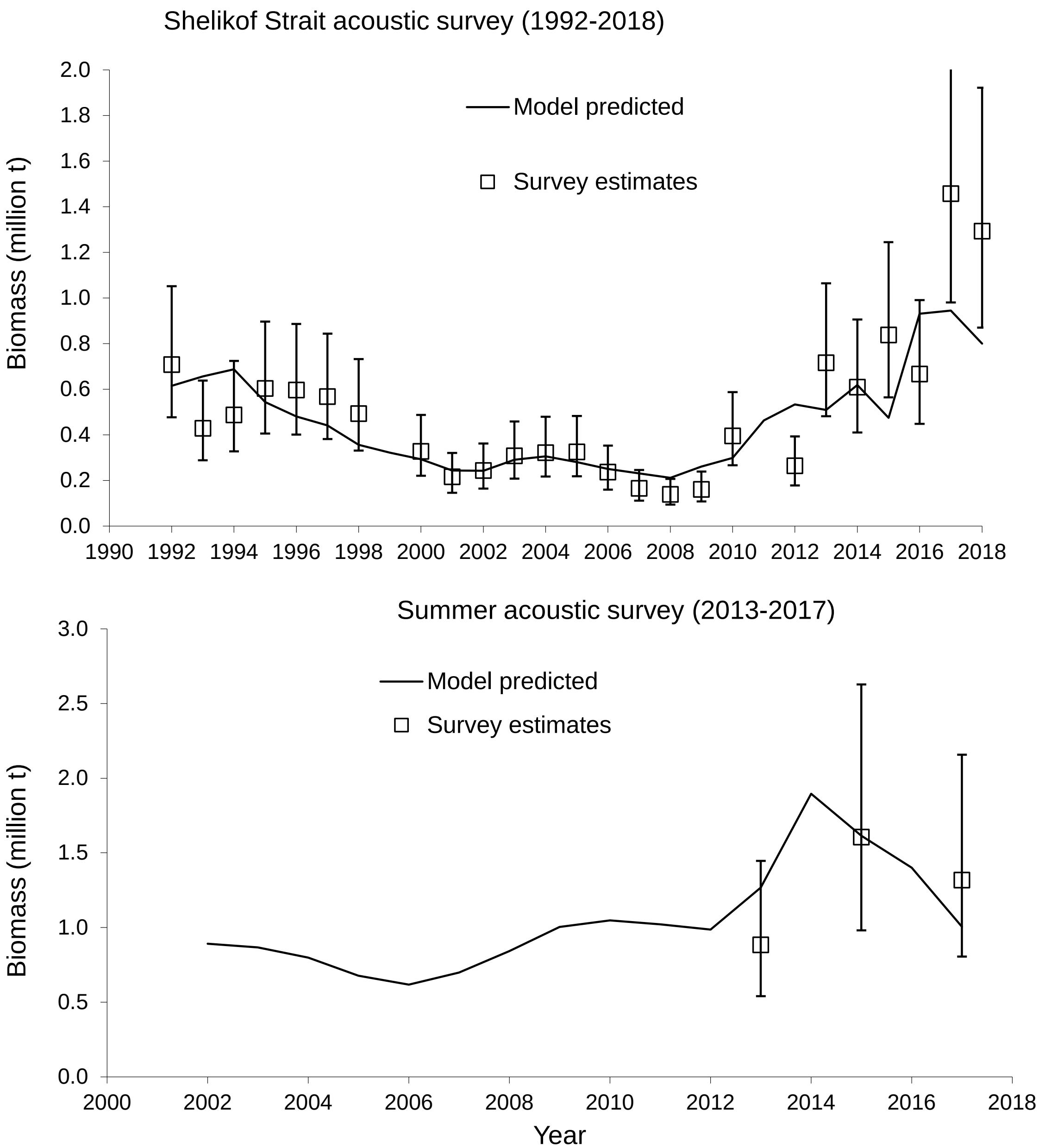


Figure 1.31. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey for the base model (top panel). The bottom panel shows model predicted and observed survey biomass for the summer acoustic survey. Error bars indicate plus and minus two standard deviations.

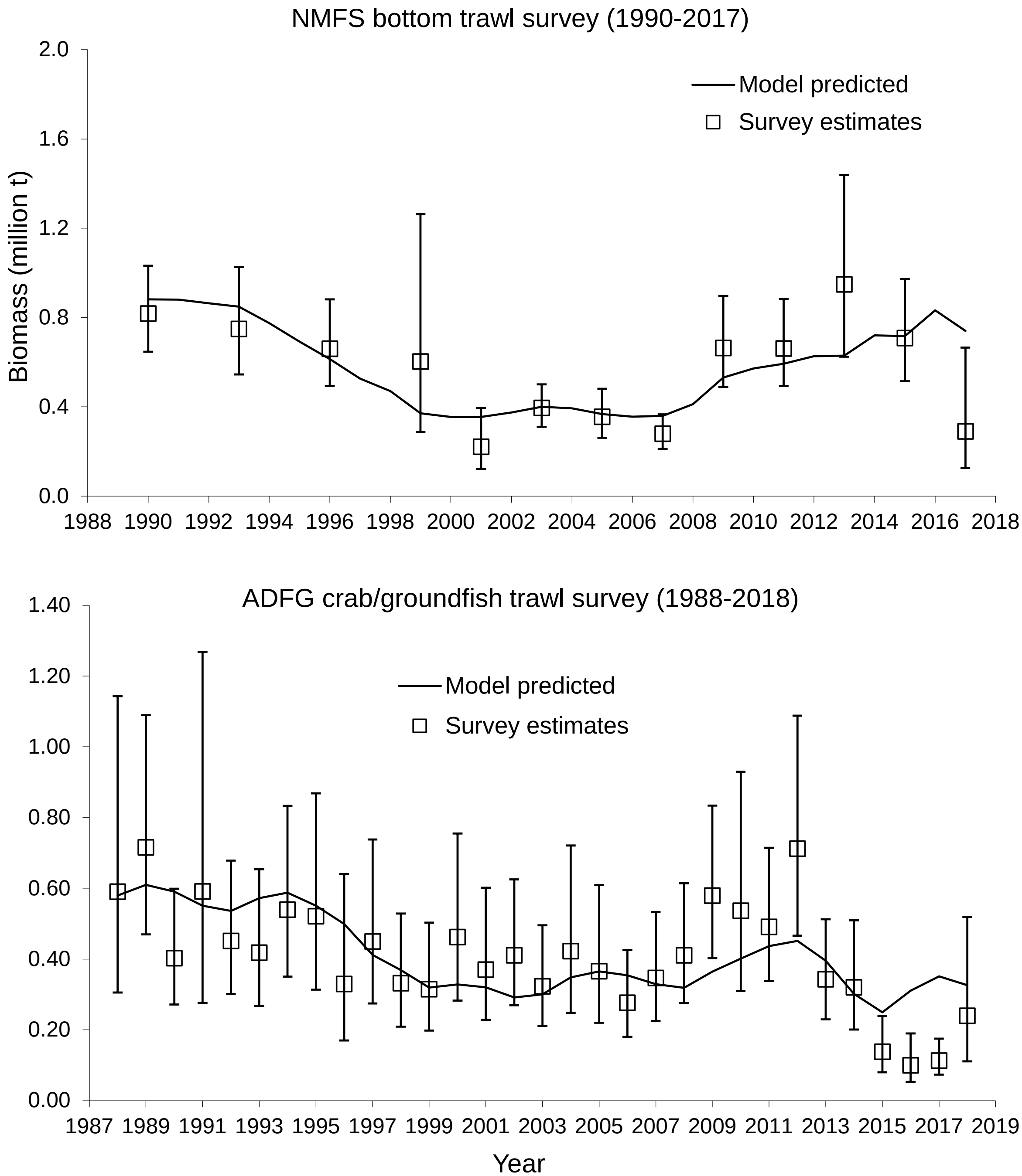
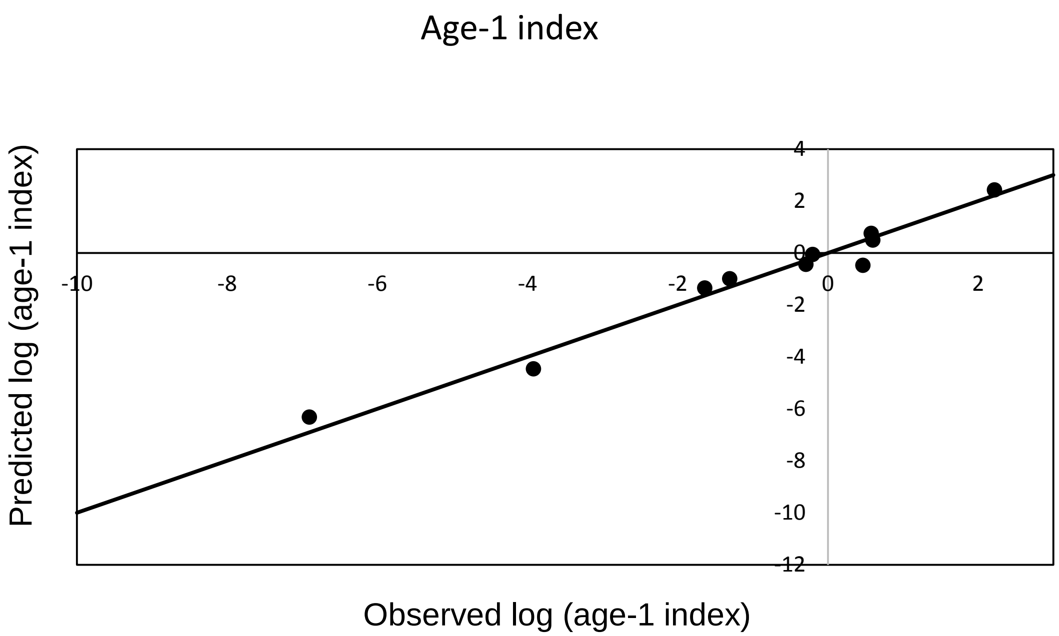


Figure 1.32. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top panel), and the ADFG crab/groundfish survey (bottom panel) for the base model. Error bars indicate plus and minus two standard deviations.



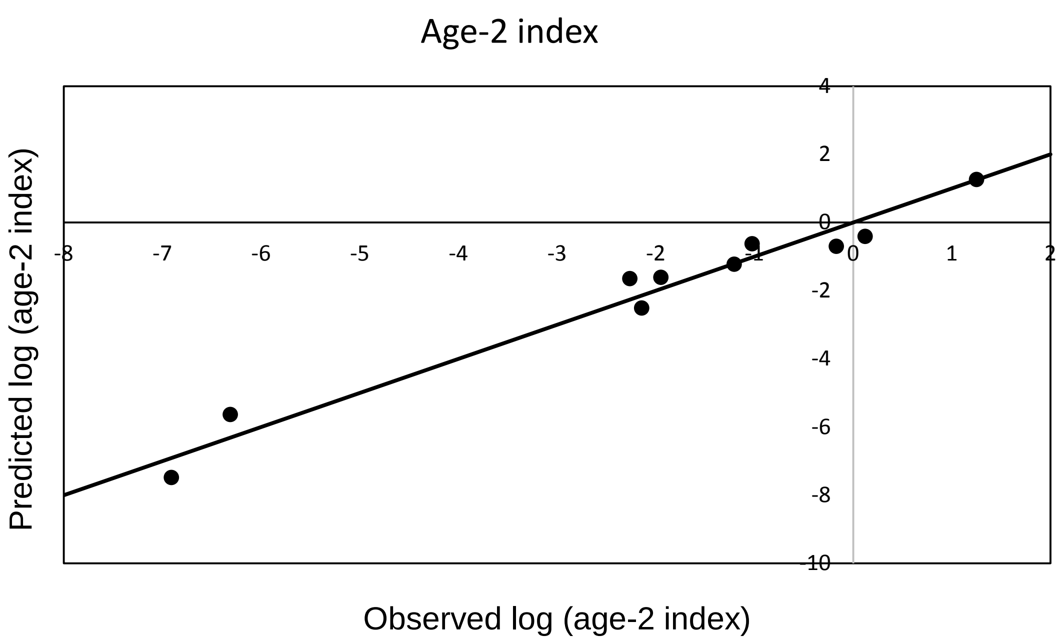


Figure 1.33. Observed and model predicted age-1 (top) and age-2 indices (bottom) for the winter acoustic estimates combined for Shelikof Strait and the Shumagin Islands.

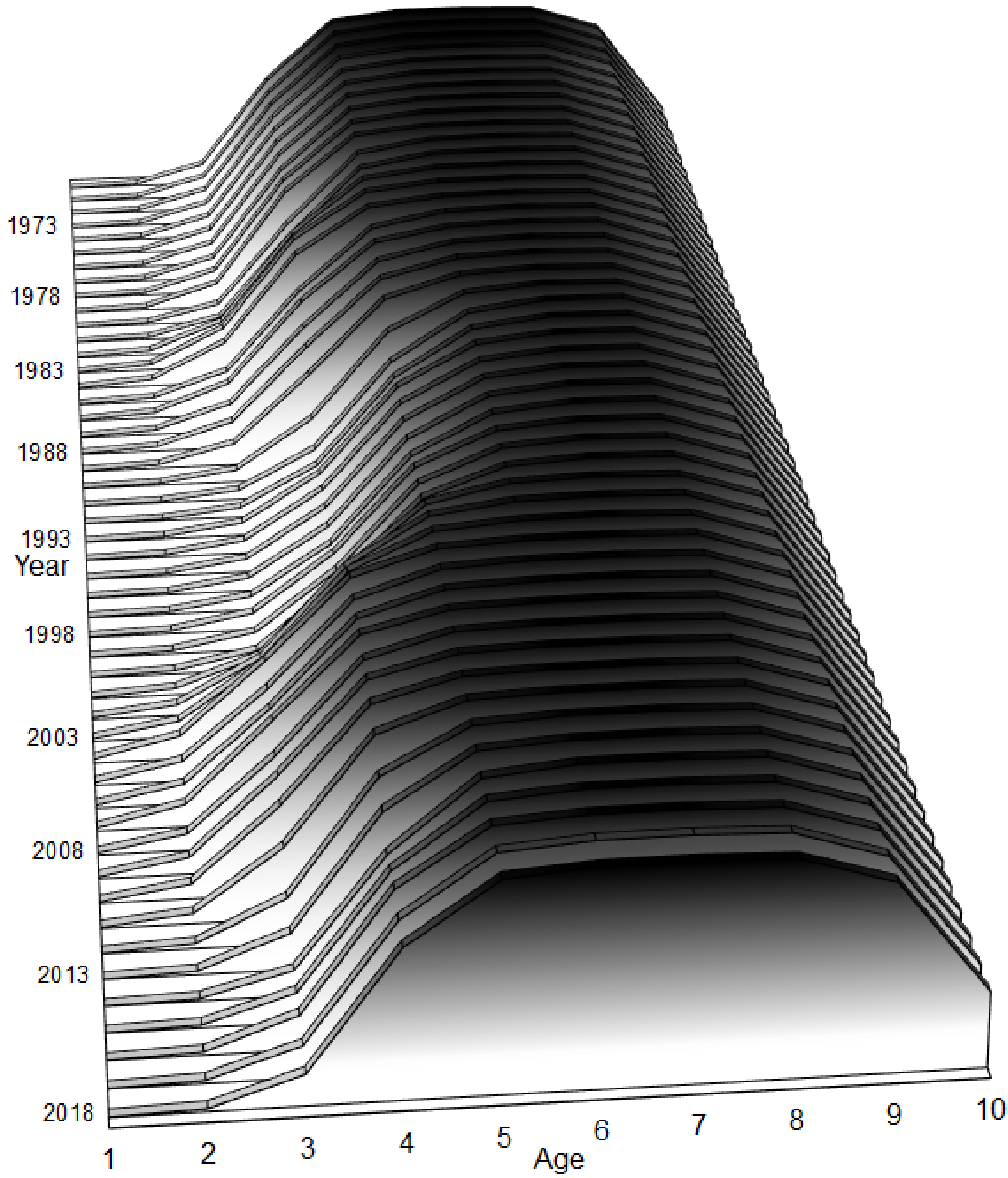


Figure 1.34. Estimates of time-varying fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.

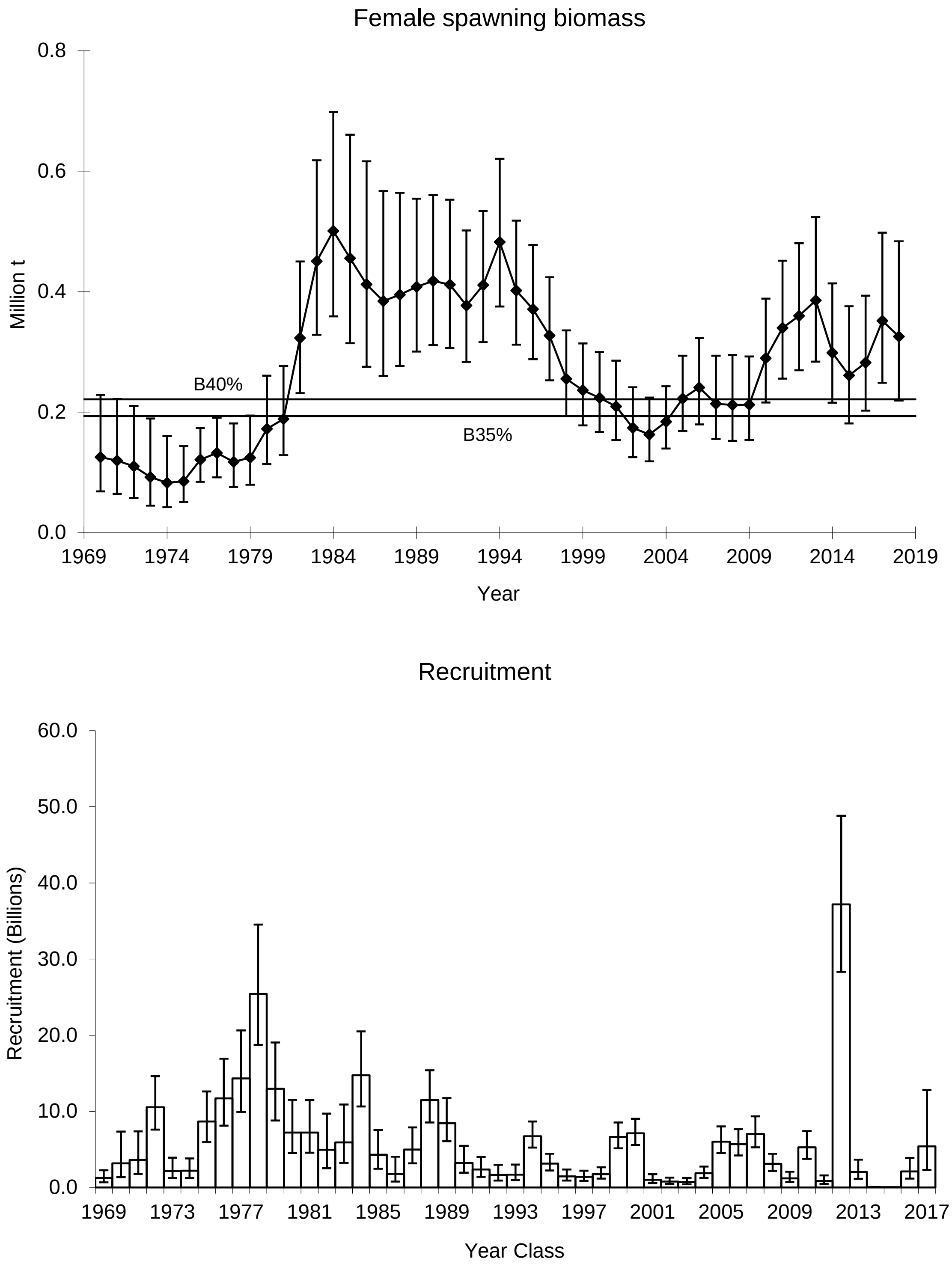
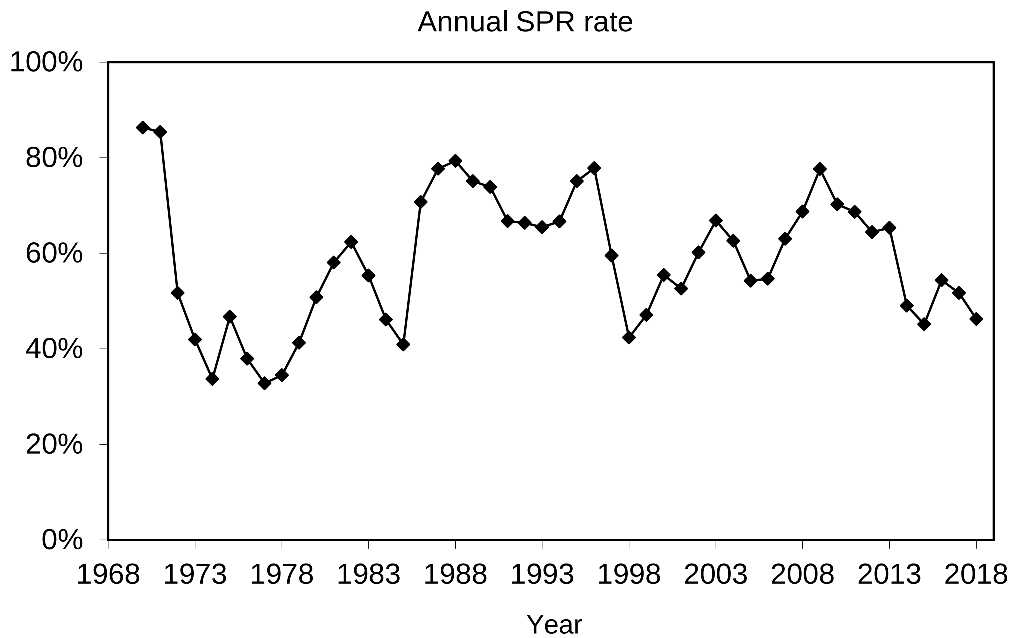


Figure 1.35. Estimated time series of GOA pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1970 to 2018 for the base model. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



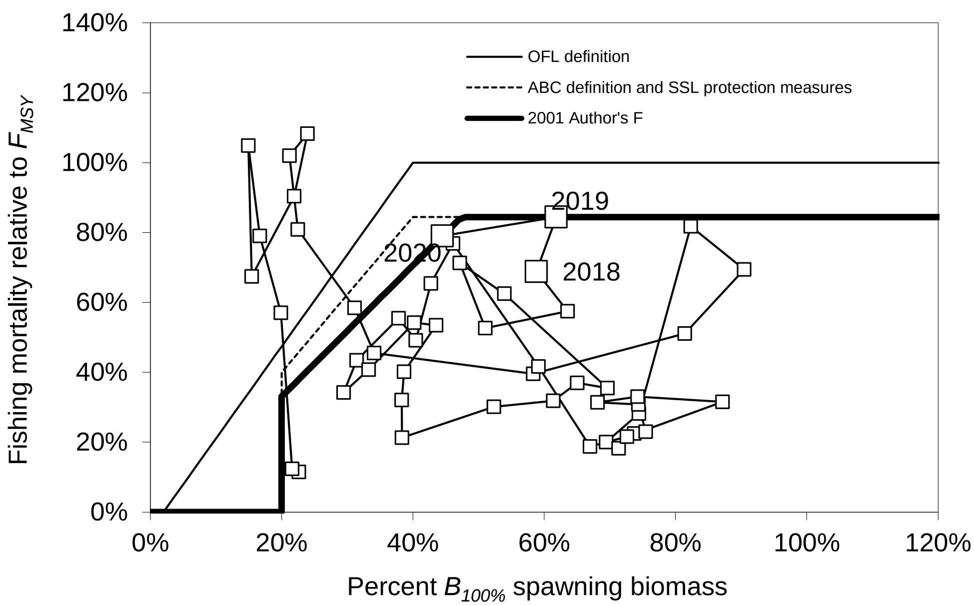
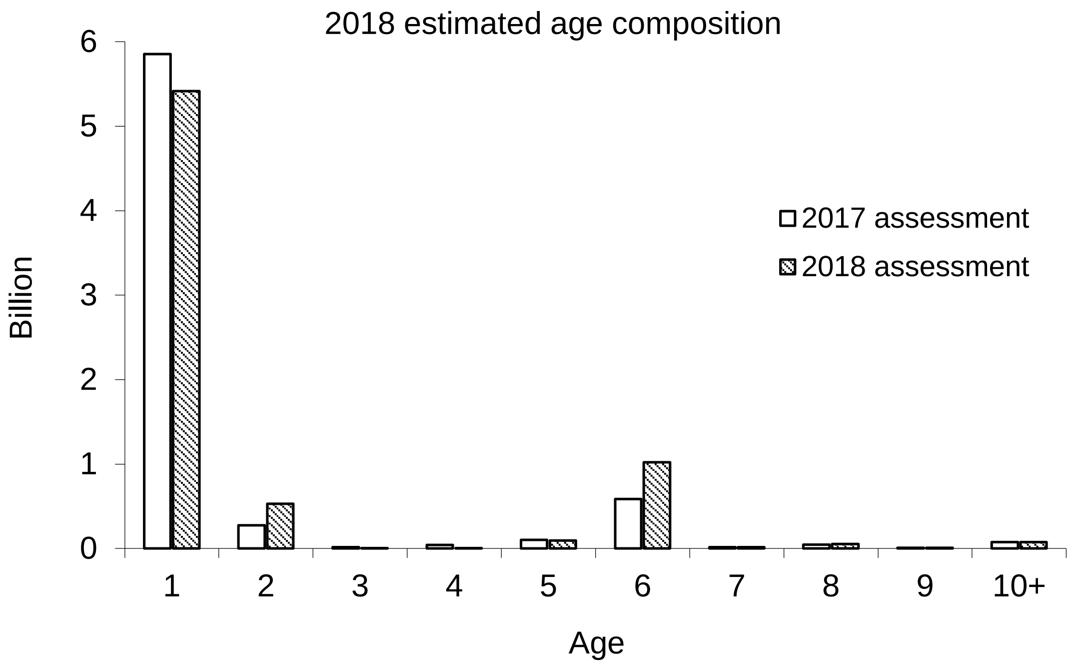


Figure 1.36. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to FMSY (bottom). The ratio of fishing mortality to FMSY is calculated using the estimated selectivity pattern in that year. Estimates of B100% 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.



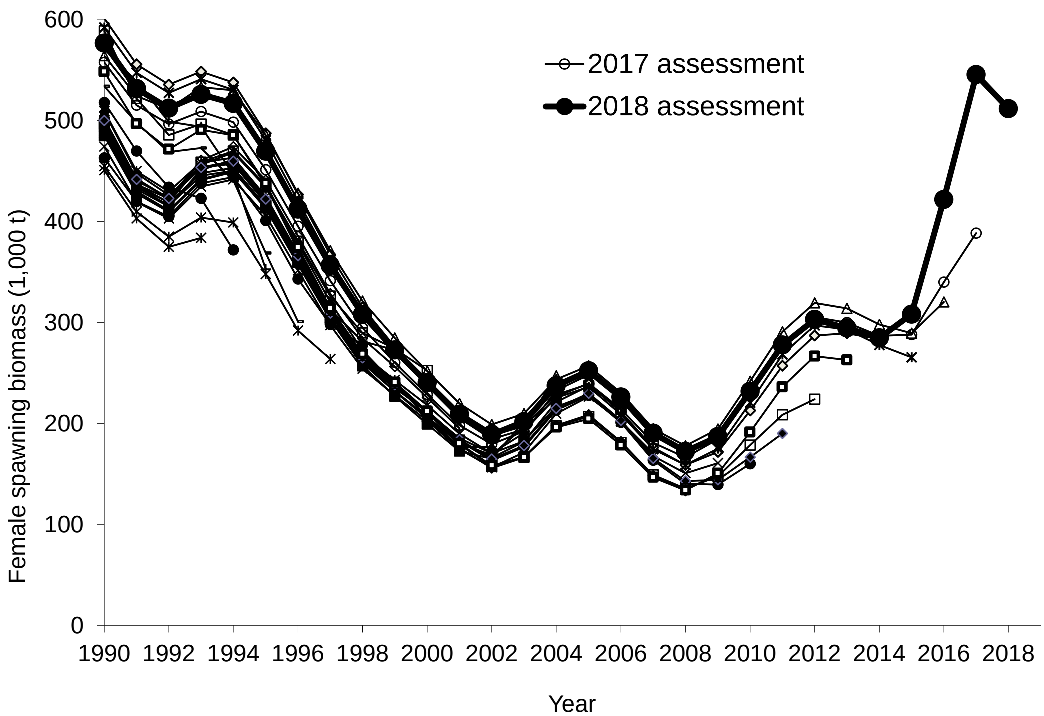


Figure 1.37. Retrospective plot of estimated GOA pollock female spawning biomass for stock assessments in the years 1993-2018 (top). For this figure, the time series of female spawning biomass was calculated using the same maturity and spawning weight at age for all assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2018 from the 2017 and 2018 assessments.

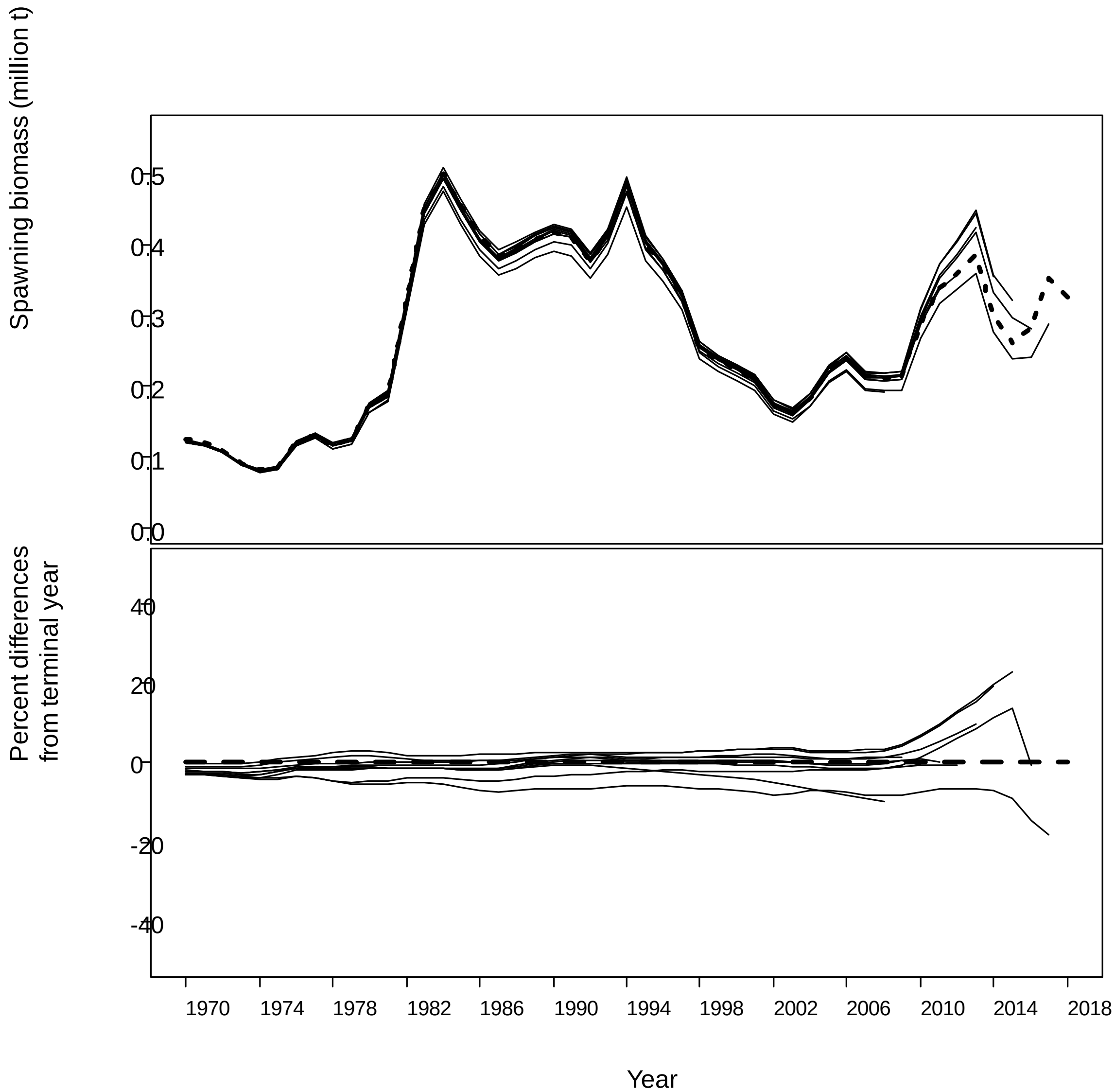
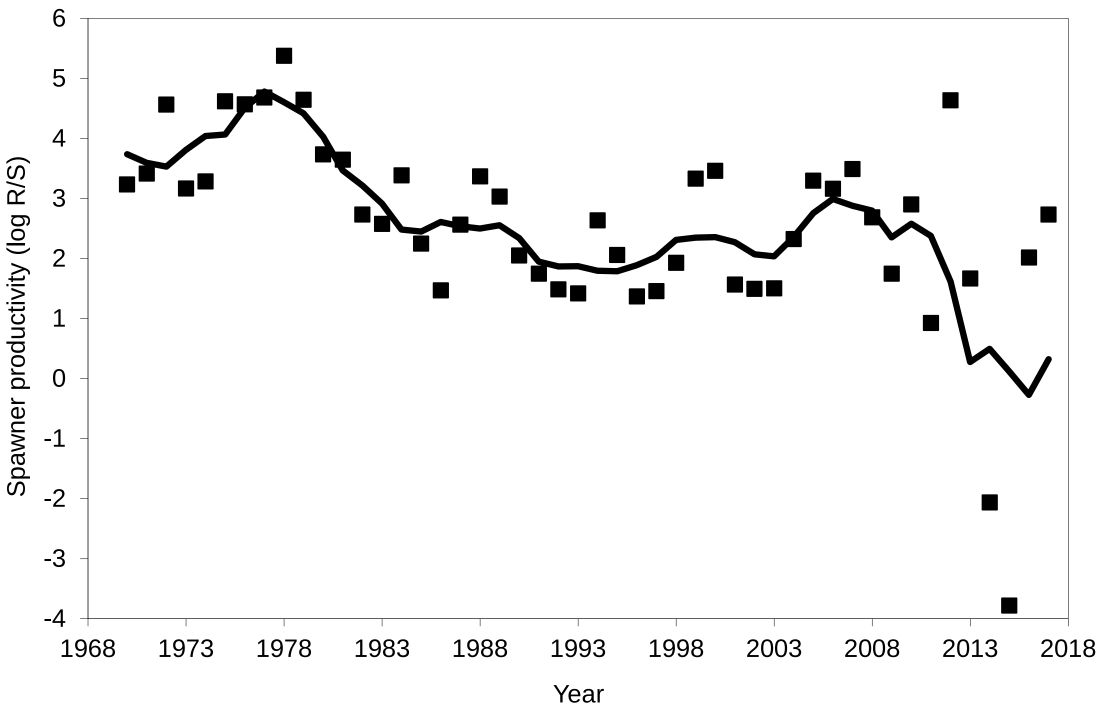


Figure 1.38. Retrospective plot of spawning biomass for models ending in years 2008-2017 for the 2018 base model. The revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.024.



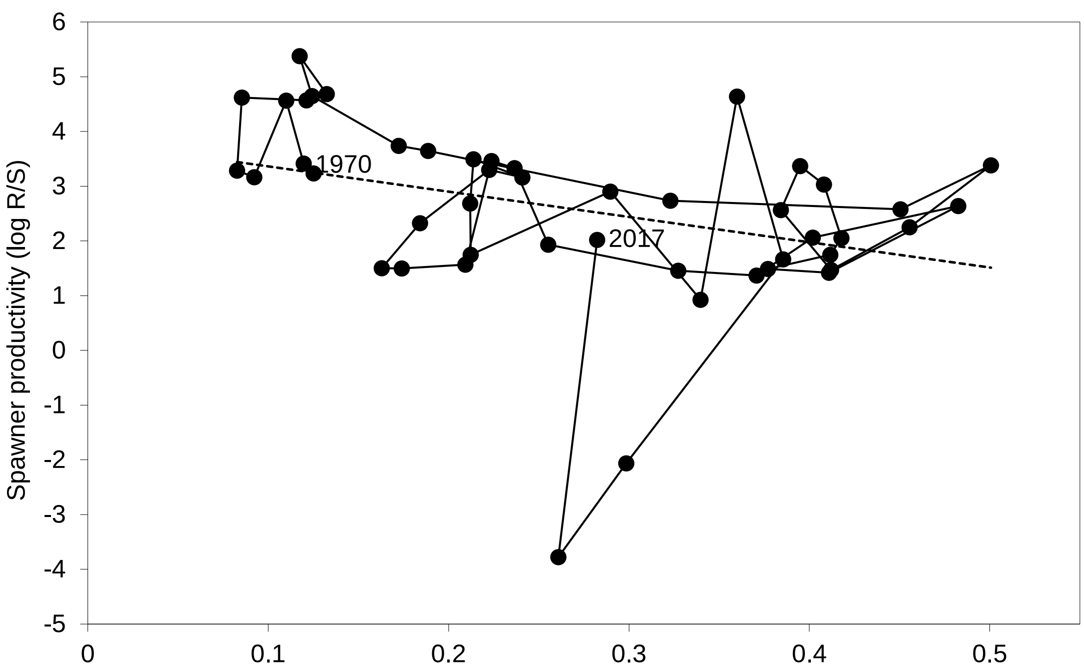


Figure 1.39. GOA pollock spawner productivity, log(R/S), in 1970-2017 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

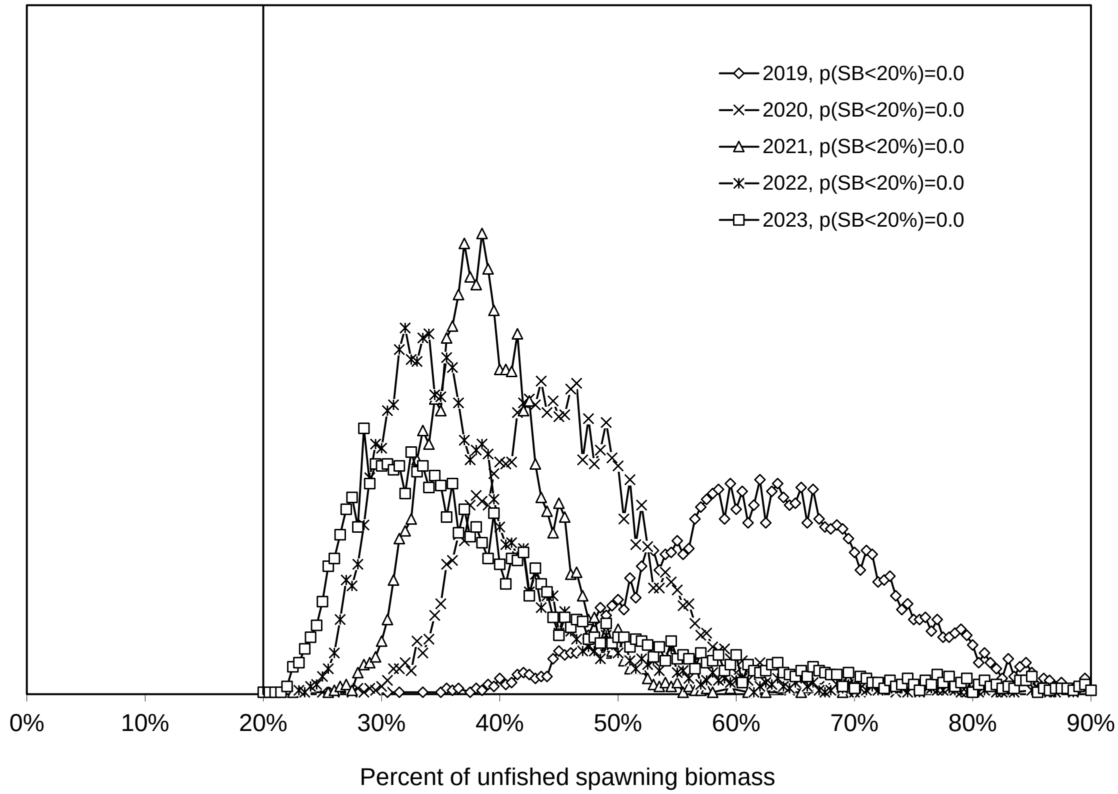


Figure 1.40. Uncertainty in spawning biomass in 2019-2023 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the author's recommended F_{ABC}.

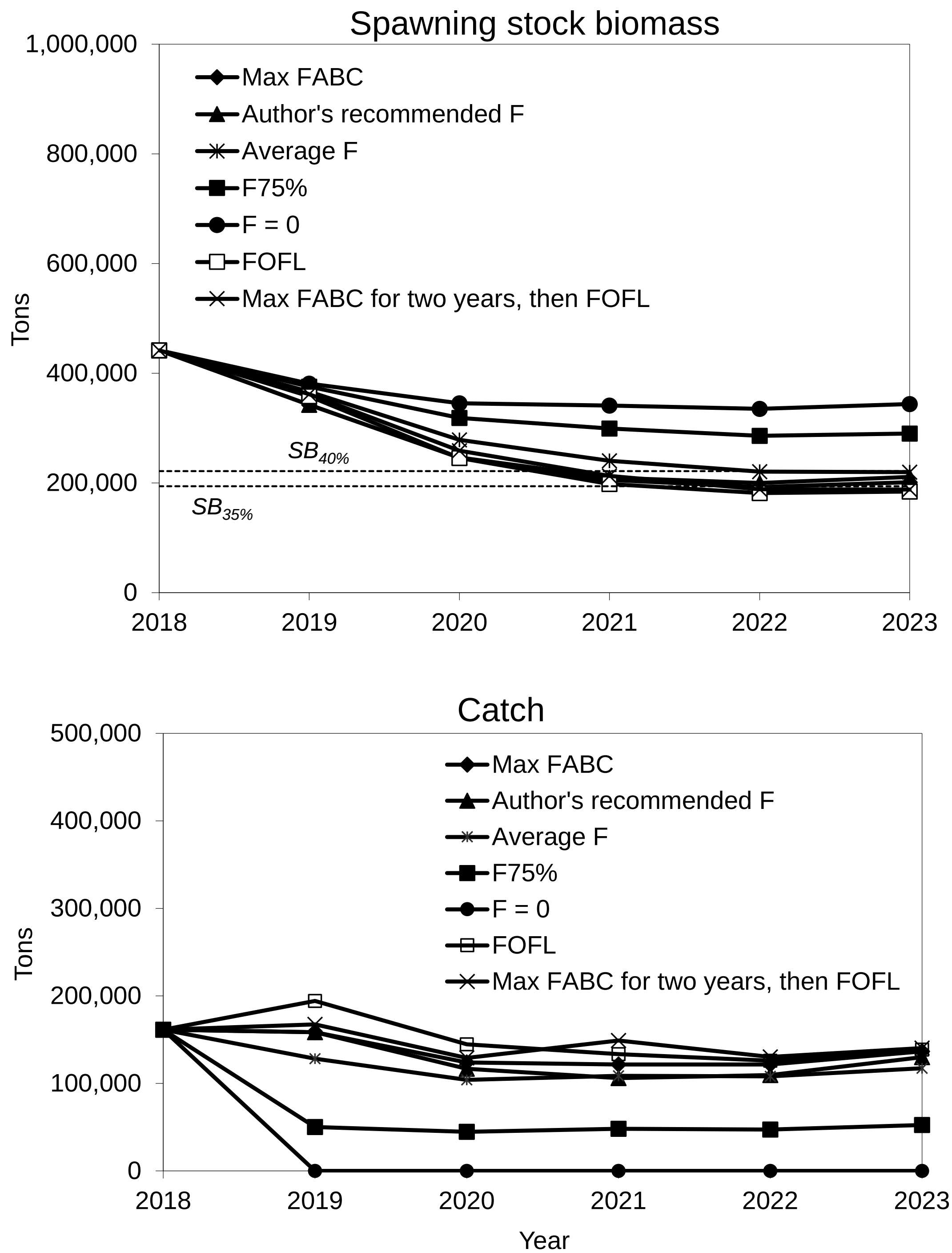


Figure 1.41. Projected mean spawning biomass and catches in 2019-2023 under different harvest rates.

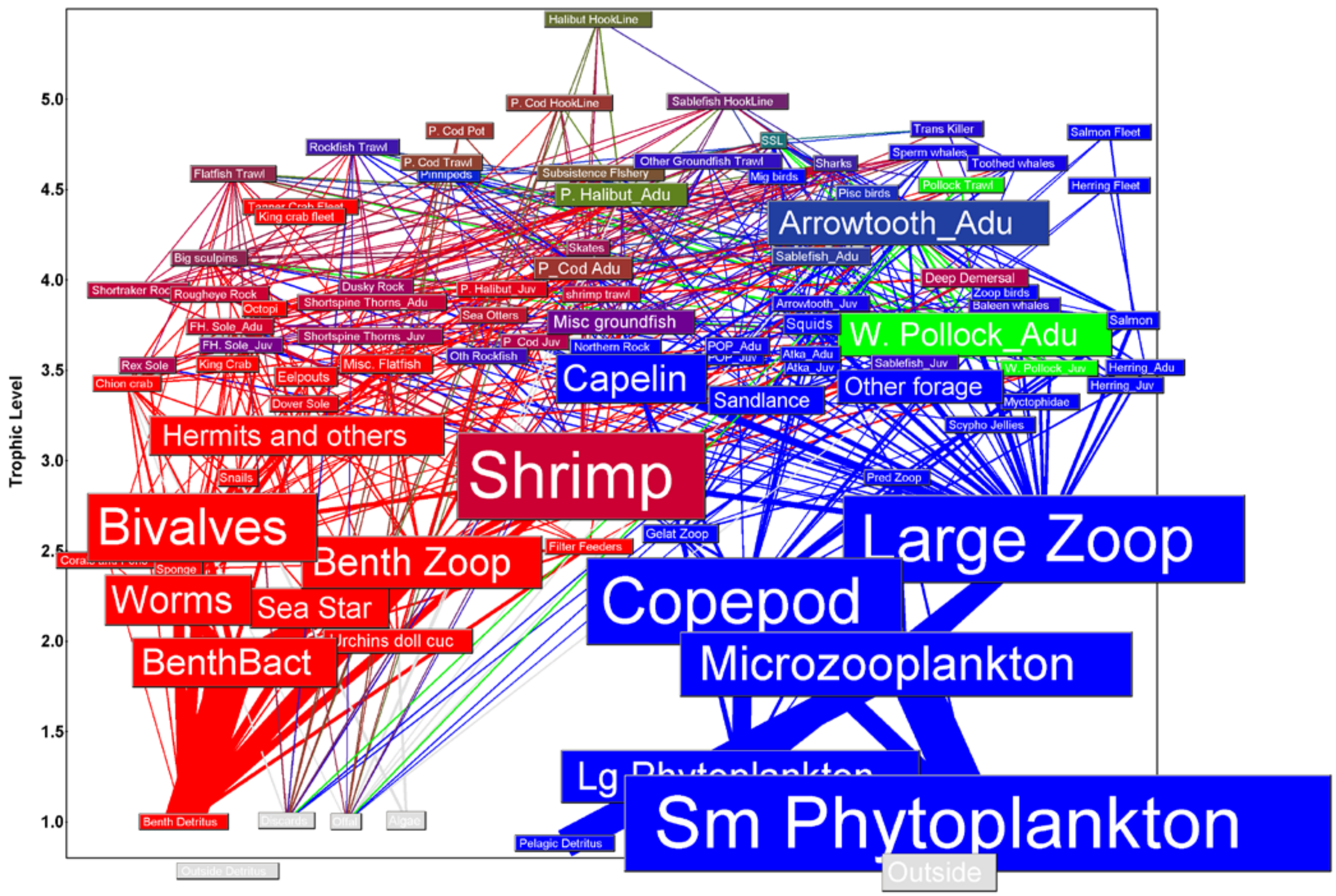
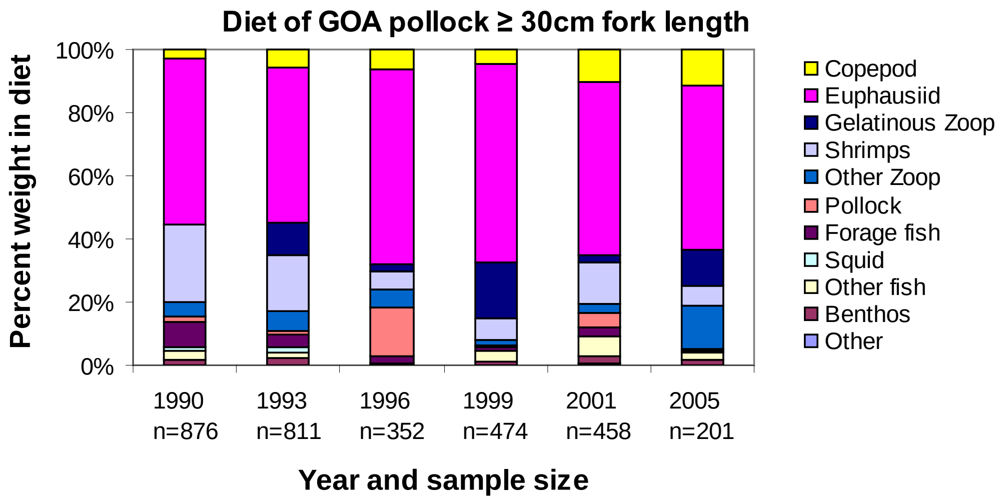


Figure 1.42. Gulf of Alaska food web showing demersal (red) and pelagic (blue) pathways. Pollock is shown in green. Pollock consumers stain green according to the importance of pollock in their diet.



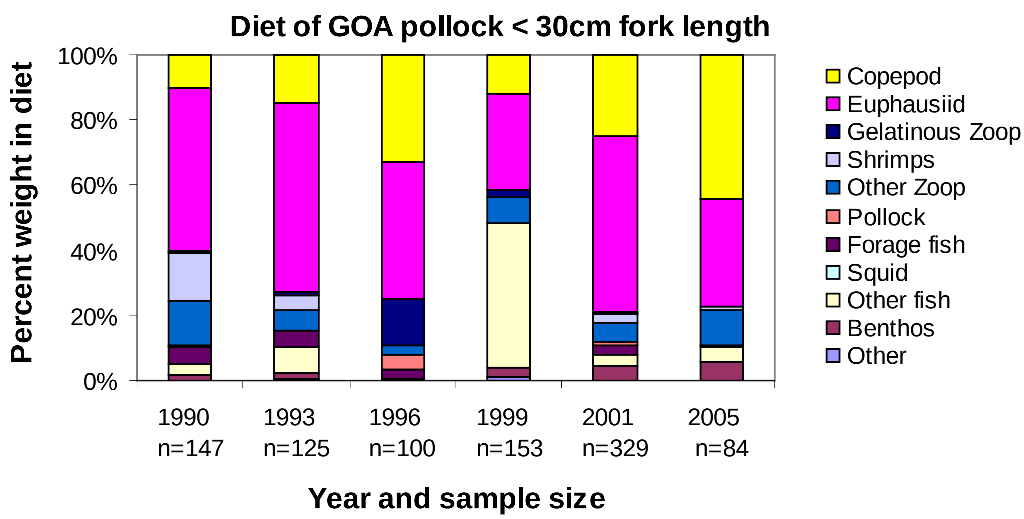
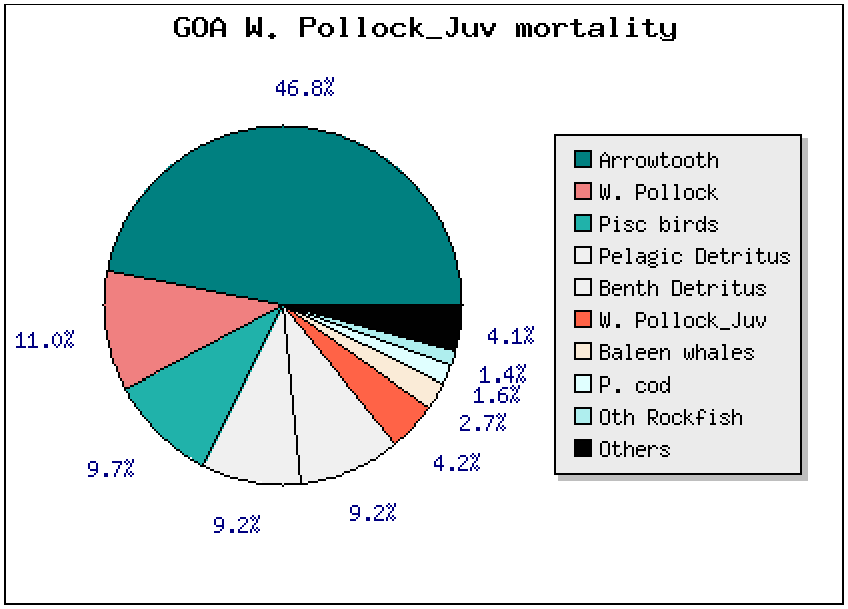


Figure 1.43. Diet (percent wet weight) of GOA pollock juveniles (top) and adults (bottom) from summer food habits data collected on NMFS bottom trawl surveys, 1990-2005.



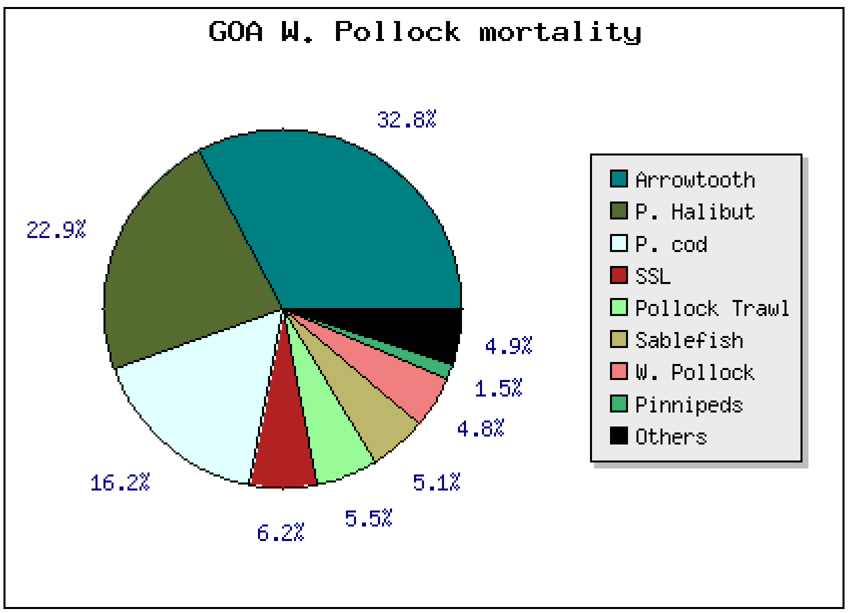


Figure 1.44. Sources of mortality for pollock juveniles (top) and adults (bottom) from an ECOPATH model of the Gulf of Alaska. Pollock less than 20cm are considered juveniles.

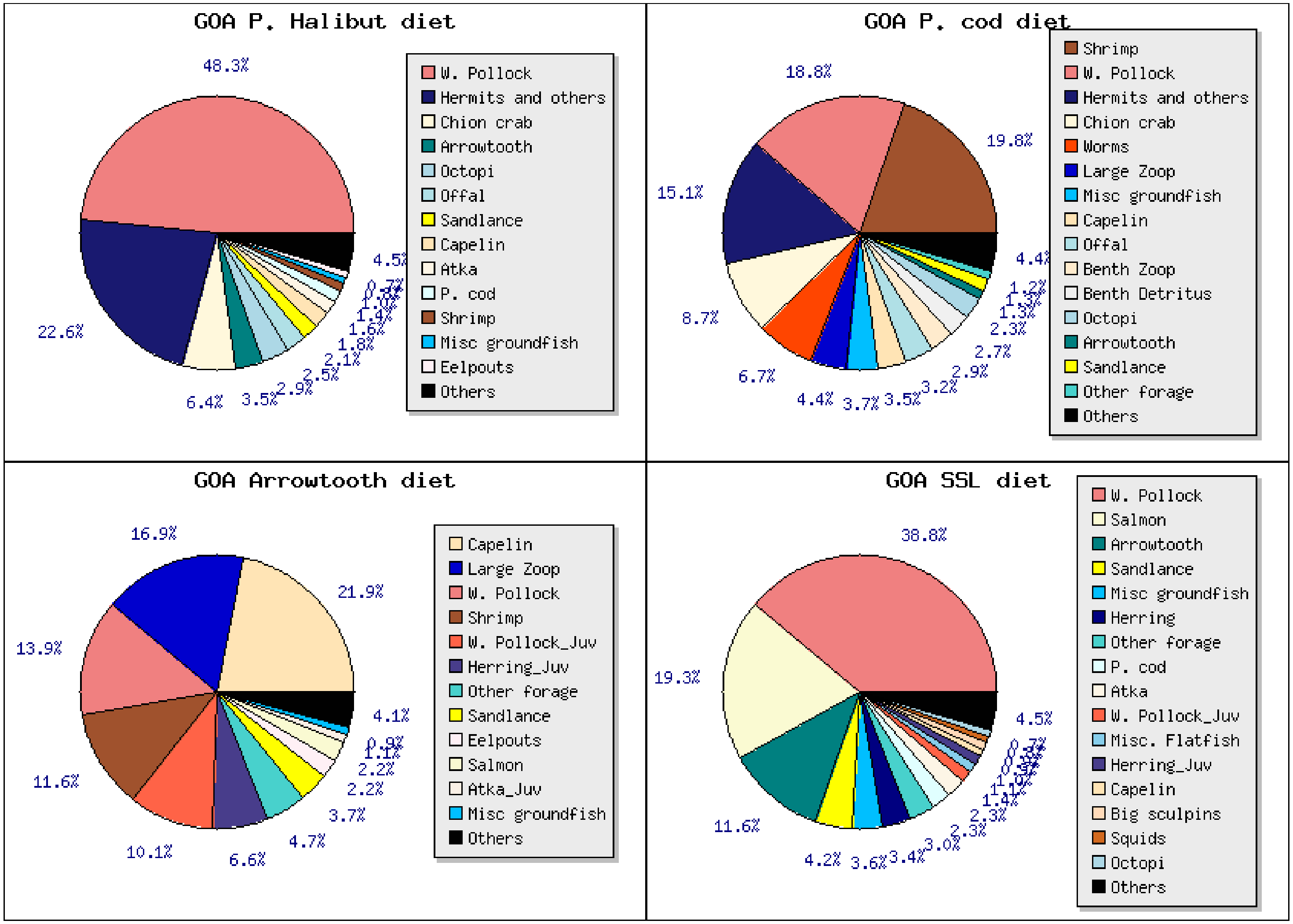


Figure 1.45. Diet diversity of major predators of pollock from an ECOPATH model for Gulf of Alaska during 1990-94.

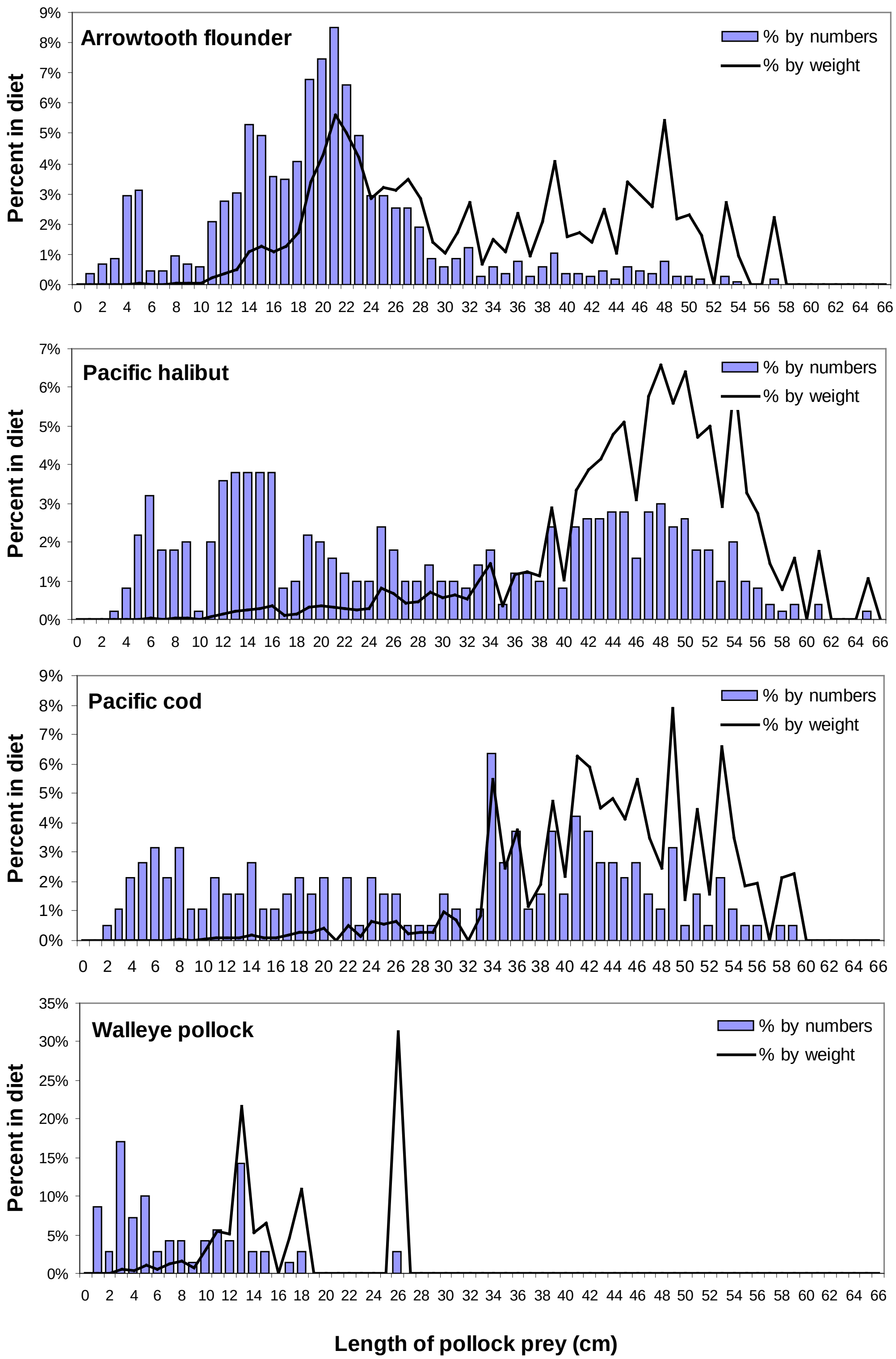


Figure 1.46. Length frequencies and percent by weight of each length class of pollock prey (cm fork length) in stomachs of four major groundfish predators, from AFSC bottom-trawl surveys 1987-2005. Length of prey is uncorrected for digestion state.

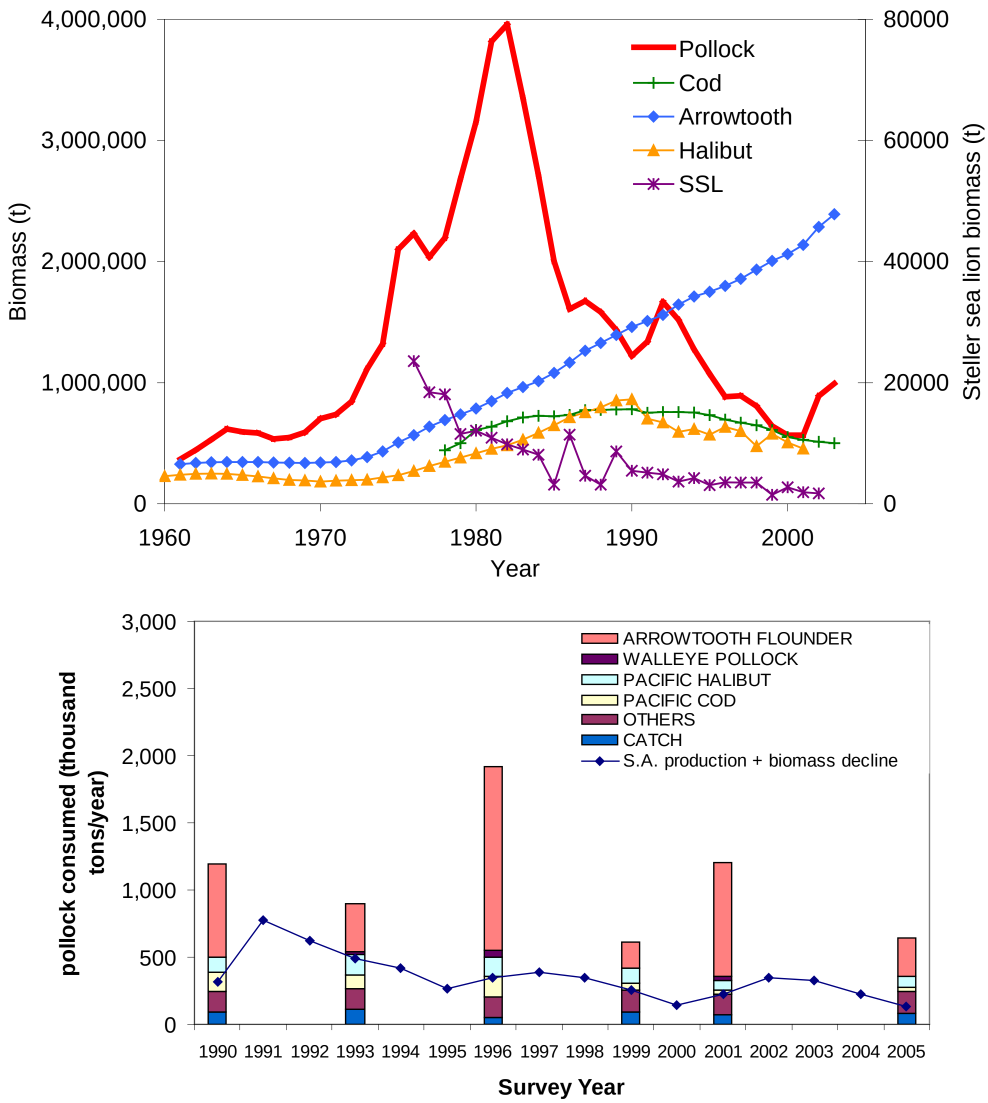


Figure 1.47. Historical trends in GOA pollock, Pacific cod, Pacific halibut, arrowtooth flounder, and Steller Sea Lions, from stock assessment data (top). Total catch and consumption of pollock in survey years (bars) and production + biomass change as calculated from the current stock assessment results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

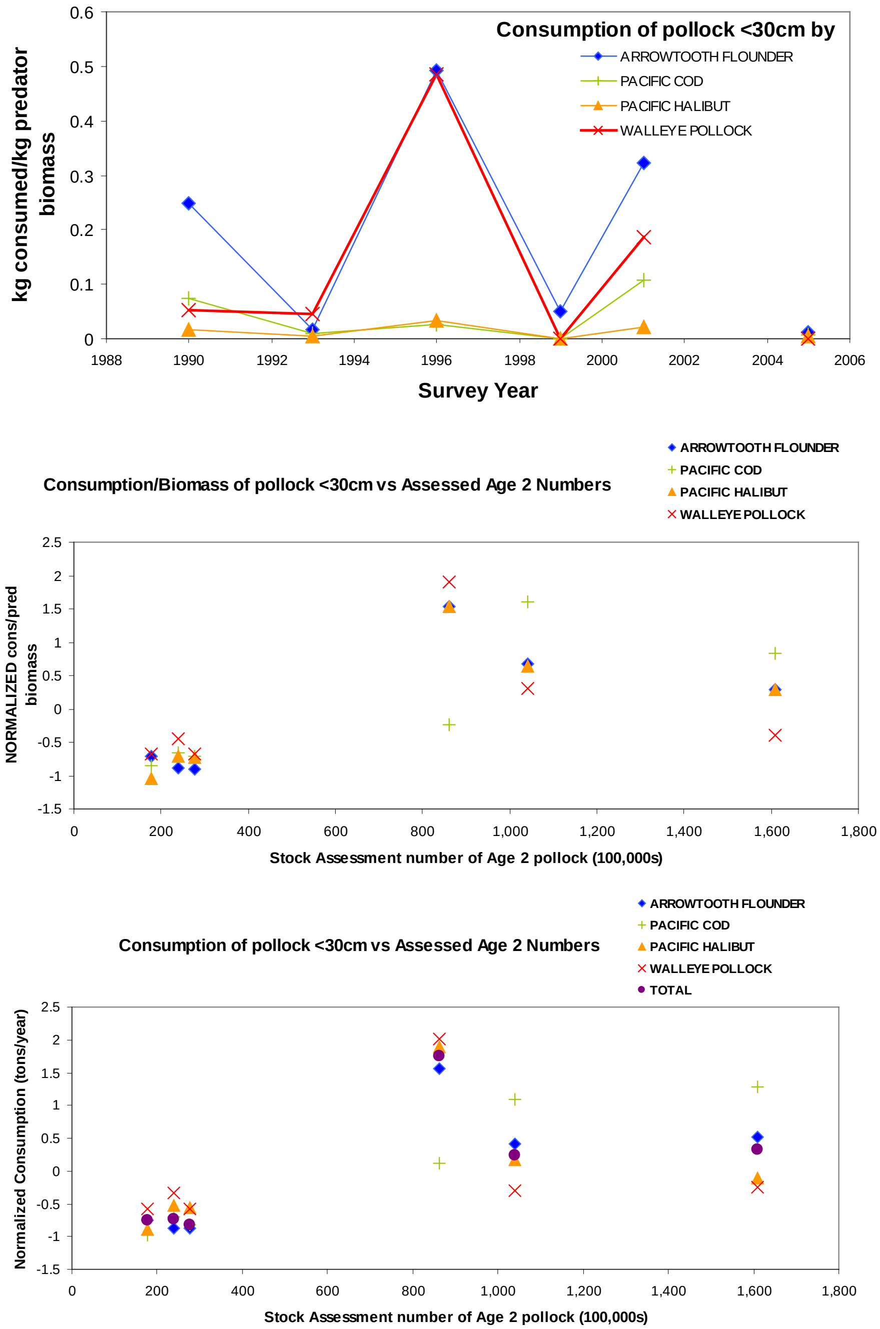


Figure 1.48. Consumption per unit predator survey biomass of GOA pollock <30cm fork length in diets, shown for each survey year (top). Normalized consumption/biomass and normalized total consumption of pollock <30cm fork length, plotted against age 2 pollock numbers (middle and bottom).

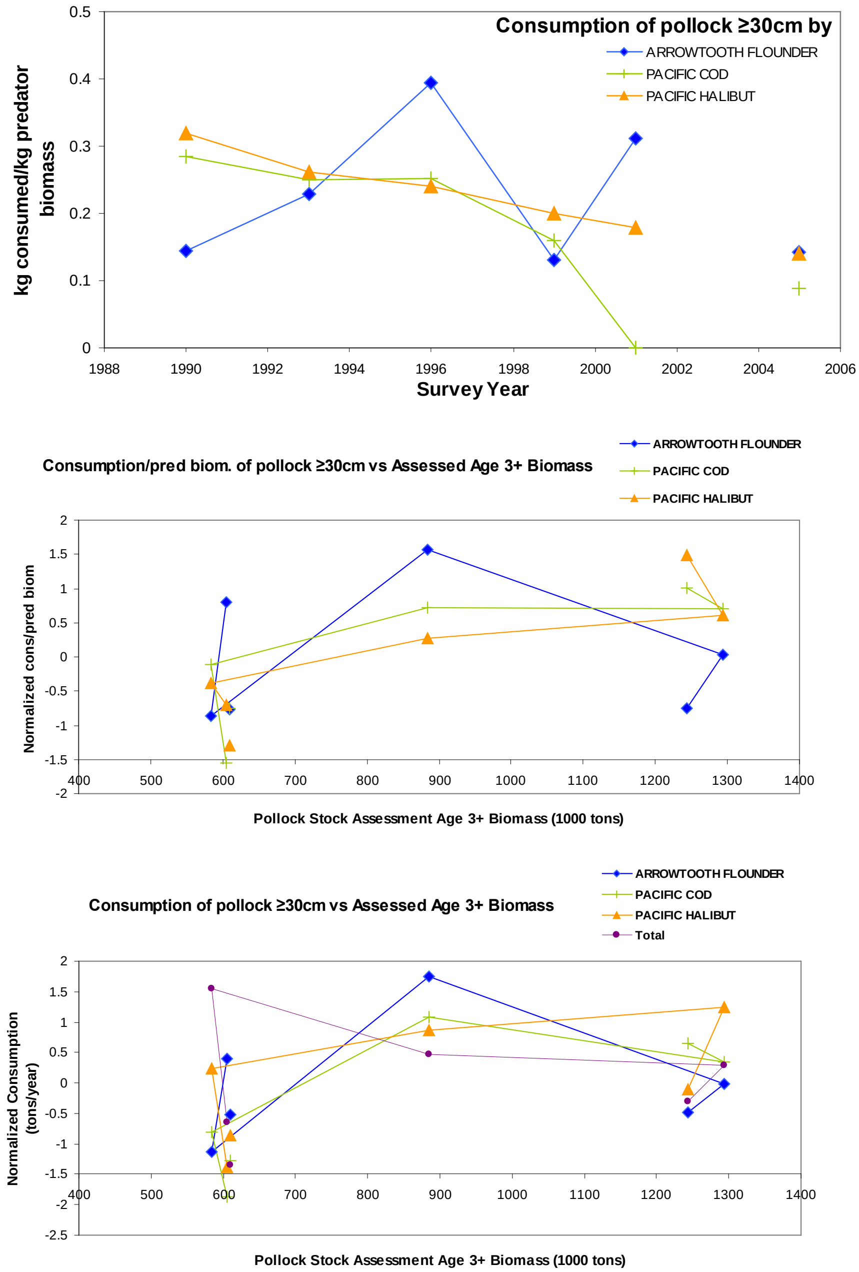


Figure 1.49. Consumption per unit predator survey biomass of GOA pollock ≥30cm fork length in diets, shown for each survey year (top). Normalized consumption/biomass and normalized total consumption of pollock ≥30cm fork length, plotted against age 3+ pollock biomass (middle and bottom).

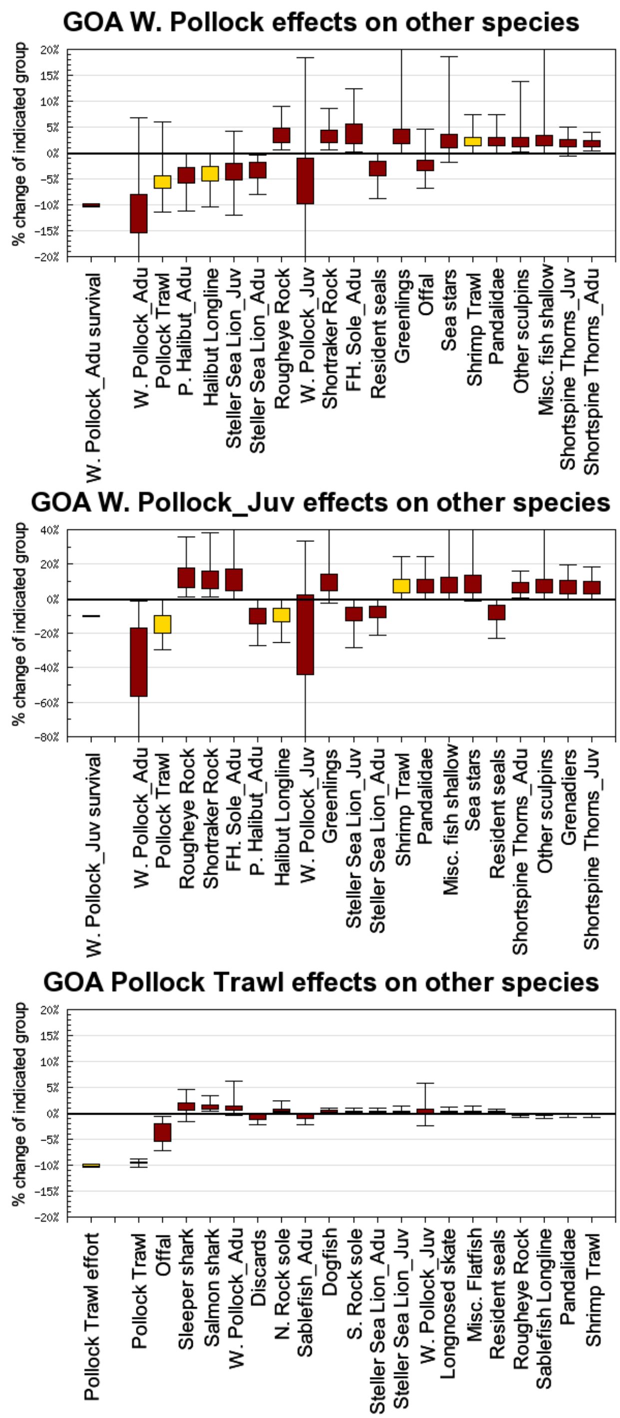
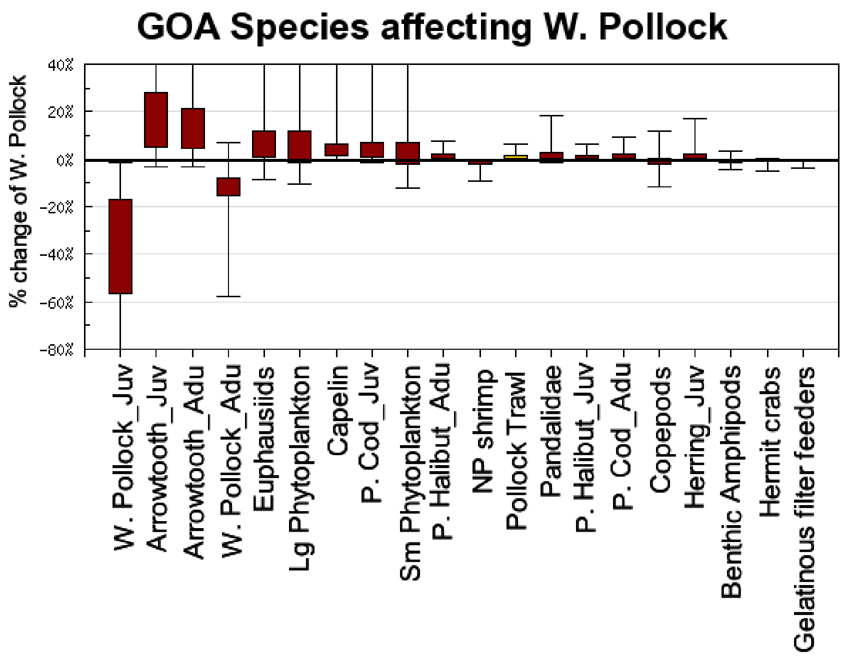


Figure 1.50. Ecosystem model output (percent change at future equilibrium of indicated groups) resulting from reducing adult pollock survival by 10% (top), reducing juvenile pollock survival by 10% (middle), and reducing pollock trawl effort by 10%. Dark bars indicate biomass changes of modeled species,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



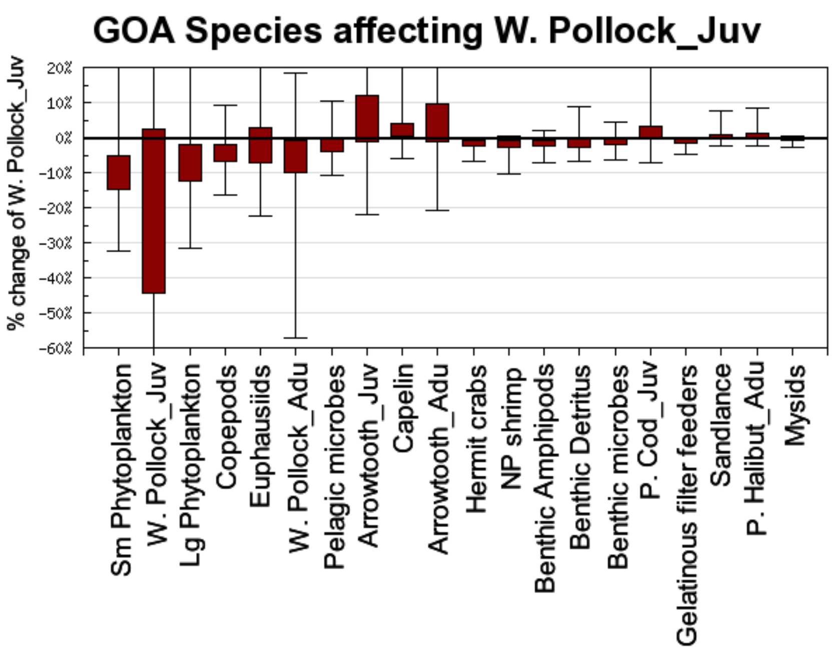


Figure 1.51. Ecosystem model output, shown as percent change at future equilibrium of adult pollock (top) and juvenile pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs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

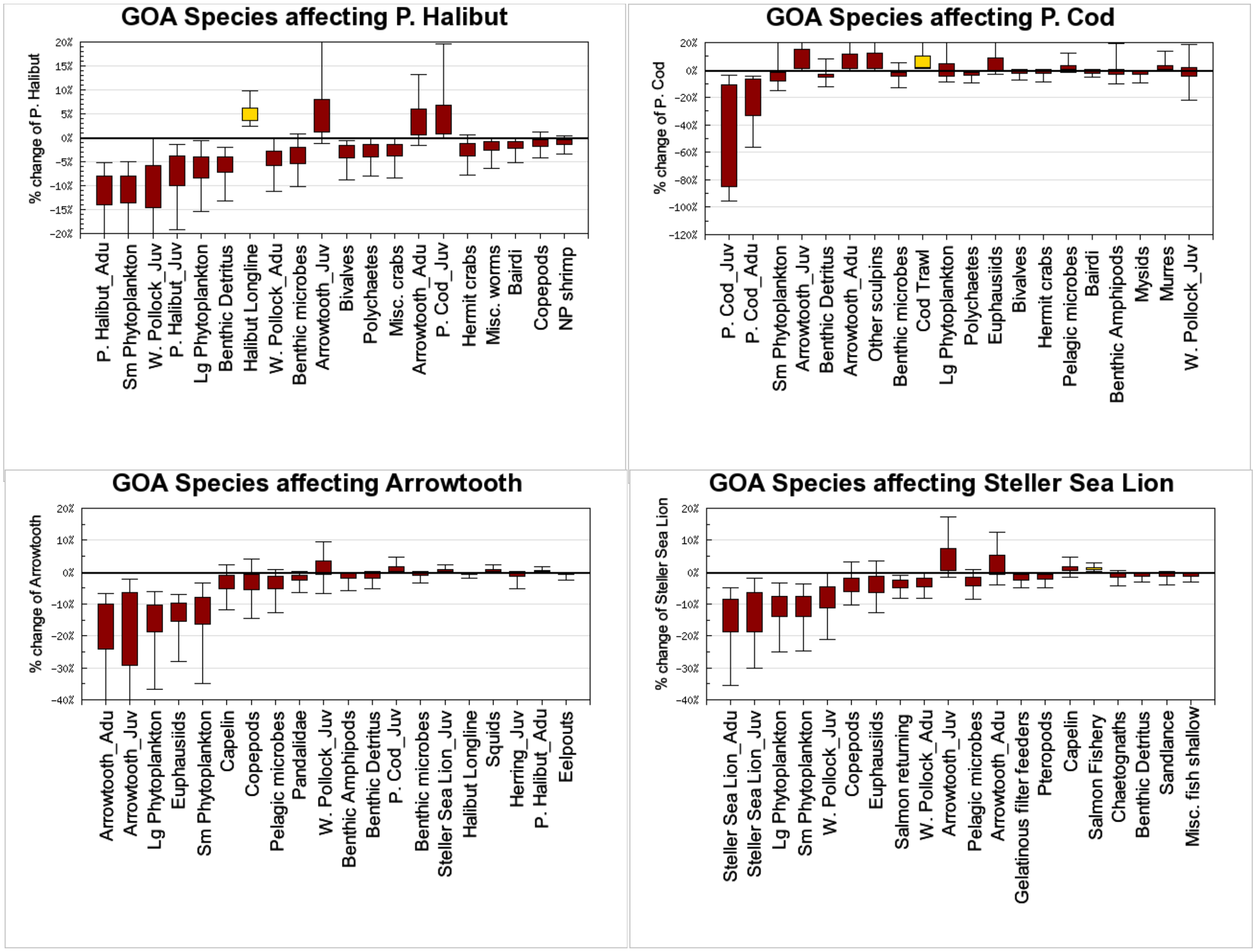


Figure 1.52. Ecosystem model output, shown as percent change at future equilibrium of four major predators on pollock, resulting from independently lowering the indicated species' survival rates by 10% (dark bars) or by reducing fishing effort of a particular gear by 10% (light bars). Graphs show 50%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

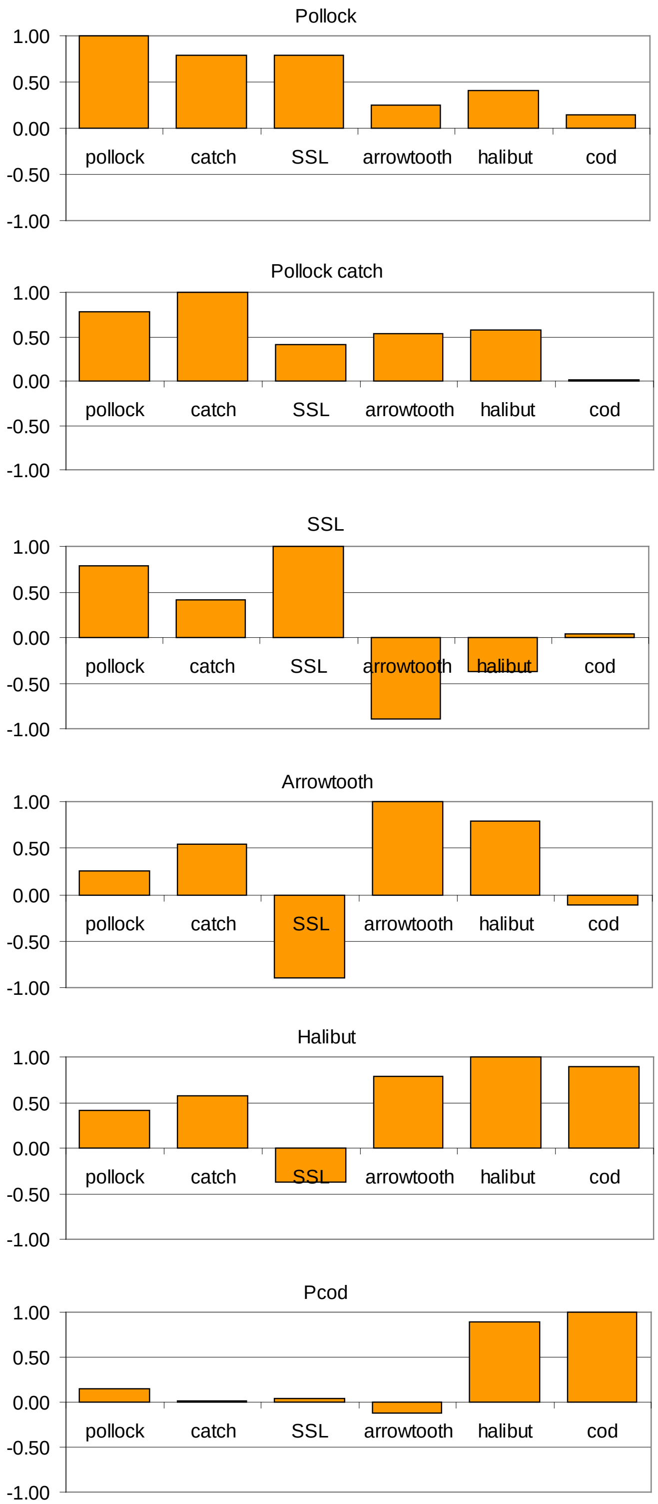


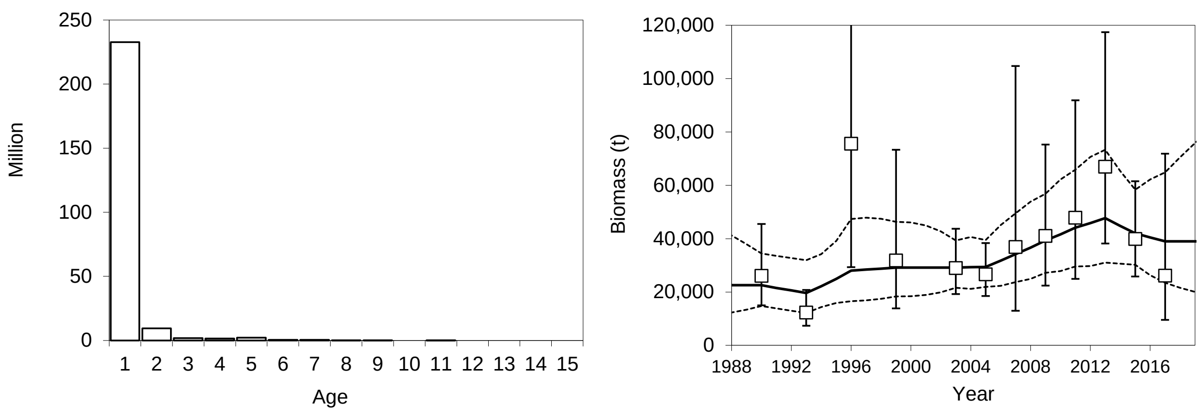
Figure 1.53. Pair-wise Spearman rank correlation between abundance trends of pollock, pollock fishery catches, Steller sea lions, arrowtooth flounder, Pacific halibut, and Pacific cod in the Gulf of Alaska. Rank correlations are based on the years in which abundance estimates are available for each pair.

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 2017 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Baranof Island south to Dixon Entrance, where the shelf is broader. Pollock age composition in the 2017 bottom trawl survey showed a very strong dominance of age-1 pollock, and a smattering of larger pollock (Appendix Fig. A.1). 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 2007 (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 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 1990-2017 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 (38,989 t). **This results in a 2019 ABC of 8,773 t (38,989 t * 0.75 M), and a 2019 OFL of 11,697 t (38,989 t * M). The same ABC and OFL is recommended for 2020.**



Appendix Figure A.1. Pollock age composition in 2017 (left) and biomass trend in southeast Alaska from a random effects model fit to NMFS bottom trawl surveys in 1990-2017 (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 2018 (49 years). The Baranov (1918) catch equations are assumed, so that

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

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

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

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. We also use a process error model for catchability for the Shelikof Strait acoustic survey and the ADFG bottom trawl survey to account for changes in the proportion of the stock surveyed.

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. This criterion is 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 this criterion were Shelikof Strait, the shelf break near Chirikof Island, the Shumagin area, Sanak Gully, Morzhovoi Bay, and Marmot Bay. Successful surveys of Pavlof Bay were completed in 2016-2018, so therefore Pavlof Bay was included this year, though the biomass in this area was relatively low. While the spawning aggregations found in the Kenai Bays, and in Prince William Sound are likely important, additional surveys are needed 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 would need to be considered.

The sum of the percent biomass for all surveys combined was 108.49%, which may reflect sampling variability, or interannual variation in spawning location. After rescaling, the resulting average biomass distribution was 2.68%, 86.20%, and 11.12% in areas 610, 620, and 630 (Appendix Table C.1). In comparison to last year, the percentage in area 610 is 0.8 percentage points lower, 0.8 percentage points higher in area 620, and the same in area 630.

A-season apportionment between areas 620 and 630

In 2002, 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, 2.78%; 620, 73.31%; 630, 23.91%.

Summer distribution

In 2014, assessment we followed the recommendation of the survey averaging working group to evaluate random effects models to fit smoothed biomass trends for each management area. Although performance of the random effects model appeared satisfactory (Appendix Fig. C.1), it is apparent that the random effects model leads to an estimated biomass distribution that is more strongly influenced by the most recent survey than the 4-survey average that had been used previously. In 2015, the plan team recommended that summer acoustic survey data also be used to determine the summer allocation, and averaged the biomass distribution from the 2015 summer acoustic survey with the results from the random effects model. 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. Several allocation options were presented to the plan team in 2017 to account for the variability and lack of consistency in the bottom trawl and the acoustic surveys. The option that was recommended and adopted by the plan team was a 3-survey weighted average of the sum of the acoustic and bottom trawl biomass estimates for each area. The weighted average gave weights of 1.0, 0.5, and 0.25 to 2017, 2015, and 2013, respectively. This approach is based on combining acoustic and bottom trawl survey data and using all three years of the summer acoustic survey. The resulting apportionment is 610, 35.00%; 620, 25.44%; 630, 35.22%; 640, 4.34%. Since no new data are available, this apportionment is again recommended for 2019.

Apportionment for area 640

The apportionment for area 640, which is not managed by season, is based on the estimated summer distribution of the biomass. The percentage (4.34%) of the TAC in area 640 is subtracted from the TAC before allocating the remaining TAC by season and region. The overall allocation by season and area is given in Appendix Table C.2.

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. Reported non-commercial catches primarily include catches associated with surveys and research projects. Small amounts of pollock catch are attributed to subsistence and bait for crab. An exempted research permit to study salmon excluders in 2013 and 2014 accounted for approximately 2300 t in each year (Appendix Table D.1).

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 excluded from the acoustic survey biomass estimates.

Survey	Year	Model estimates of total 2+ biomass at spawning	Survey biomass estimate	Percent	Percent by management area Area 610	Area 620	Area 630
Shelikof	2015	1,491,680	847,542	56.8%	0.0%	91.9%	8.1%
Shelikof	2016	1,350,790	666,801	49.4%	0.0%	79.3%	20.7%
Shelikof	2017	1,070,970	1,457,295	136.1%	0.0%	99.1%	0.9%
Shelikof	2018	801,084	1,306,107	163.0%	0.0%	93.9%	6.1%
Shelikof	Average			101.3%	0.0%	91.1%	8.9%
	Percent of total biomass				0.0%	92.3%	9.1%
Chirikof	2012	1,107,410	21,173	1.9%	0.0%	26.8%	73.2%
Chirikof	2013	1,155,270	63,224	5.5%	0.0%	70.2%	29.8%
Chirikof	2015	1,491,680	12,705	0.9%	0.0%	26.3%	73.7%
Chirikof	2017	1,070,970	2,485	0.2%	0.0%	0.4%	99.6%
Chirikof	Average			2.1%	0.0%	30.9%	69.1%
	Percent of total biomass				0.0%	0.7%	1.5%
Marmot	2015	1,491,680	22,489	1.5%	0.0%	0.0%	100.0%
Marmot	2016	1,350,790	24,859	1.8%	0.0%	0.0%	100.0%
Marmot	2017	1,070,970	13,129	1.2%	0.0%	0.0%	100.0%
Marmot	2018	801,084	12,905	1.6%	0.0%	0.0%	100.0%
Marmot	Average			1.5%	0.0%	0.0%	100.0%
	Percent of total biomass				0.0%	0.0%	1.5%
Shumagin	2015	1,491,680	60,967	4.1%	71.5%	28.5%	0.0%
Shumagin	2016	1,350,790	20,392	1.5%	84.3%	15.7%	0.0%
Shumagin	2017	1,070,970	29,753	2.8%	95.0%	5.0%	0.0%
Shumagin	2018	801,084	7,777	1.0%	47.4%	52.6%	0.0%
Shumagin	Average			2.3%	74.6%	25.4%	0.0%
	Percent of total biomass				1.7%	0.6%	0.0%
Sanak	2015	1,491,680	17,905	1.2%	100.0%	0.0%	0.0%
Sanak	2016	1,350,790	3,571	0.3%	100.0%	0.0%	0.0%
Sanak	2017	1,070,970	831	0.1%	100.0%	0.0%	0.0%
Sanak	2018	801,084	1,316	0.2%	100.0%	0.0%	0.0%
Sanak	Average			0.4%	100.0%	0.0%	0.0%
	Percent of total biomass				0.4%	0.0%	0.0%
Mozhovoi	2013	1,155,270	600	0.1%	100.0%	0.0%	0.0%
Mozhovoi	2016	1,350,790	11,459	0.8%	100.0%	0.0%	0.0%
Mozhovoi	2017	1,070,970	3,924	0.4%	100.0%	0.0%	0.0%
Mozhovoi	2018	801,084	3,759	0.5%	100.0%	0.0%	0.0%
Mozhovoi	Average			0.4%	100.0%	0.0%	0.0%
	Percent of total biomass				0.4%	0.0%	0.0%
Pavlof	2016	1,350,790	2,140	0.2%	100.0%	0.0%	0.0%
Pavlof	2017	1,070,970	2,092	0.2%	100.0%	0.0%	0.0%
Pavlof	2018	801,084	4,413	0.6%	100.0%	0.0%	0.0%
Pavlof	Average			0.3%	100.0%	0.0%	0.0%
	Percent of total biomass				0.3%	0.0%	0.0%
Total				108.49%	2.90%	93.52%	12.06%
Rescaled total				100.00%	2.68%	86.20%	11.12%

Appendix Table C.2. Calculation of 2019 Seasonal and Area TAC Allowances for the W/C/WYK region.

Proposed ABC for W/C/WYK (t):	134,740

Winter biomass distribution			
Area	610	620	630
Percent	2.68%	86.20%	11.12%

Summer biomass distribution				
Area	610	620	630	640
Percent	35.00%	25.44%	35.22%	4.34%

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

PWS percent	2.50%	GHL (t)	3,369
Federal percent	97.50%	Federal TAC	131,372

2) Use summer biomass distribution for the 640 allowance:

640 percent	4.34%	640 TAC (t)	5,701
610-630 percent	95.66%	610-630 TAC (t)	125,671

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%	31,418
B season TAC (t)	25%	31,418
C season TAC (t)	25%	31,418
D season TAC (t)	25%	31,418

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	2.68%	841
620	73.35%	23,046
630	23.97%	7,531

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

	B season	
Area	Percent	TAC (t)
610	2.68%	841
620	86.20%	27,083
630	11.12%	3,493

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

	C season	
Area	Percent	TAC (t)
610	36.59%	11,495
620	26.59%	8,354
630	36.82%	11,568

	D season	
Area	Percent	TAC (t)
610	36.59%	11,495
620	26.59%	8,354
630	36.82%	11,568

Appendix Table D.1. Non-commercial catch (t) of pollock in the Gulf of Alaska by reporting agency. NMFS-EFP is catch associated with exempted research permits.

		Reporting Agency		
Year	ADFG	IPHC	NMFS	NMFS-EFP
1982	0.067		0.000	
1986	0.055		0.000	
1989	0.001		0.000	
1990			0.487	
1991	0.092		0.486	
1992	0.161		0.672	
1993	0.168		0.567	
1994			0.293	
1995			0.445	
1996	0.004		0.232	
1997	0.171		0.412	
1998	1.232		0.239	
1999	4.663		0.132	
2000	5.635		0.118	
2001	1.536		0.020	
2002	2.664		0.102	
2003	3.721		0.142	
2004	4.669		0.080	
2005	8.970		0.085	
2006	2.424		0.311	
2007	3.052		0.632	
2008	2.290		0.804	
2009	3.620		3.224	
2010	103.098	0.774	52.434	
2011	104.670	0.252	44.397	
2012	134.312	0.070	13.143	
2013	91.696	0.553	53.387	2284.311
2014	75.318	0.620	1.955	2387.918
2015	35.391	0.395	62.938	
2016	15.619	0.027	0.162	
2017	30.448	0.055	105.973	