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: 2019 total catch and catch at age.
2. Shelikof Strait acoustic survey: 2020 biomass and age composition.
3. NMFS bottom trawl survey: 2019 age composition.
4. Summer acoustic survey: 2019 age composition.
5. ADF&G crab/groundfish trawl survey: 2020 biomass.

Changes in assessment methodology

The age-structured assessment model is identical to the model used for the 2019 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 2021 is 184,530 t, which is 41.7% of unfished spawning biomass (based on average post-1977 recruitment) and above B40% (177,000 t), thereby placing GOA pollock in sub-tier “a” of Tier 3. New surveys in 2020 include the Shelikof Strait acoustic survey and 2020 ADF&G bottom trawl. These surveys indicated similar relative abundance in 2020, unlike previous year when the surveys showed strongly contrasting trends. 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 four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. Although we identified some aspects of the stock that merit close tracking, there were no elevated concerns about stock assessment, population dynamics, environment/ecosystem, or fisheries performance categories.

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 showed record highs. This year, the results from new surveys conducted in 2020 showed consistent relative trends, and were able to be fit adequately by the model. A new assessment issue is the severe decline in the 2018 year class abundance between the 2019 and 2020 Shelikof Strait acoustic surveys. The 2019 estimate was indicative of a strong year class, but the 2020 estimate is only 10% of the long-term average. Over the full Shelikof Strait time series, high age-1 estimates have always been followed by high age-2 estimates in the next year.

Population dynamics considerations: The age structure of pollock in the Gulf of Alaska has been strongly perturbed by recruitment of the very strong 2012 year class, which was followed by very weak recruitment until 2017. The 2017 and 2018 year classes are estimated to be close to the long-term average, and population age structure is continuing to shift away from the extreme dominance of the 2012 year class. The conflicting signals concerning the size of the 2018 year class are a potential population dynamics concern, in addition to being an assessment concern. Fishery age-diversity increased in 2019, but remains below the long-term average.

Environmental/Ecosystem considerations: In 2019, spring and late summer young of the year surveys and other evidence suggested low abundance of the 2019 year class, which was confirmed by the 2020 Shelikof Strait acoustic survey. For pollock in the GOA, it is not unusual for a strong year class to be followed by several year of weak year classes.

The GOA largely remained in a heatwave state throughout 2019, with summer sea surface temperatures exceeding those during the 2014-2016 heatwave. Sea surface temperatures returned to the mean during 2020, except for the western GOA, where summer temperatures periodically met the heatwave threshold. In general, higher ambient temperatures incur bioenergetic costs for ectothermic fish such that, all else being equal, consumption must increase to maintain fish condition. Pollock adult biomass, but not age-1 recruitment, fared well during the 2014-2016 heatwave, likely due in part to the apparently abundant, yet smaller, zooplankton prey present during those years, so the 2019 temperatures alone did not pose an elevated concern for pollock adult biomass.

Temperatures are forecast to be near normal through the 2020/2021 winter. Winds in Shelikof Strait appear to have been favorable for the 2020 larvae. Also, beach seines observed some age-0 pollock, in contrast to their absence during the heatwave years of 2015, 2016, and 2019, but not as high as during the average years of 2017 and 2018. The phytoplankton bloom timing in 2020 was early, similar to that in 2017 and 2018, suggesting a pattern that appears recently to coincide with years of good age-1 recruitment. Zooplankton biomass estimates were moderate for both euphausiids and large copepods during spring suggesting that zooplankton prey were not limiting for pollock. Forage fish-eating seabirds at Middleton found sufficient prey to successfully rear chicks, although chick diets were diverse, suggesting that the more typical forage fish, such as sand lance and capelin that pollock also prey upon, were not abundant.

Fishery performance considerations: CPUE has been relatively high but has declined in the last two years (up until the A and B seasons of 2020). Fishery CPUE is either above (A and B seasons) or close to (C and D seasons) the long-term average, and is very consistent with the abundance trend of exploitable biomass from the assessment. There were numerous reports of undersize pollock being caught in C and D season in 2020. This may suggest incoming recruitment to the exploitable stock.

The authors' 2021 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 105,722 t, which is a decrease of 3% from the 2020 ABC. The author's recommended 2022 ABC is 91,934 t. The OFL in 2021 is 123,455 t, and the OFL in 2022 if the ABC is taken in 2021 is 106,767 t. It should be noted that the ABC is projected to decrease over the next few years due to weaker recruitment to the population.

For pollock in southeast Alaska (Southeast Outside region), the ABC recommendation for both 2021 and 2022 is 10,148 t (see Appendix 1B) and the OFL recommendation for both 2021 and 2022 is 13,531 t. These recommendations are based on a Tier 5 assessment using the projected biomass in 2021 and 2022 from a random effects model fit to the 1990-2019 bottom trawl survey biomass estimates in Southeast Alaska.

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

Quantity/Status	As estimated or specified *last* year for 2020	2021	As estimated or recommended *this* year for 2021	2022
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3a	3a	3a	3b
Projected total (age 3+) biomass (t)	1,007,850	1,270,080	1,097,340	812,182
Female spawning biomass (t)	206,664	184,094	184,530	169,577
$B_{100\%}$	485,000	485,000	443,000	443,000
$B_{40\%}$	194,000	194,000	177,000	177,000
$B_{35\%}$	170,000	170,000	155,000	155,000
F_{OFL}	0.33	0.30	0.33	0.30
$maxF_{ABC}$	0.28	0.26	0.28	0.26
F_{ABC}	0.23	0.28	0.28	0.26
OFL (t)	140,674	149,988	123,455	106,767
maxABC (t)	120,549	124,320	105,722	91,934
ABC (t)	108,494	111,888	105,722	91,934

Status	As determined *last* year for 2018	2019	As determined *this* year for 2019	2020
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: 2020	2021	As estimated or *recommended this* year for: 2021	2022
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)	45,103	45,103	45,103	45,103
F_{OFL}	0.30	0.30	0.30	0.30
$maxF_{ABC}$	0.23	0.23	0.23	0.23
F_{ABC}	0.23	0.23	0.23	0.23
OFL (t)	13,531	13,531	13,531	13,531
maxABC (t)	10,148	10,148	10,148	10,148
ABC (t)	10,148	10,148	10,148	10,148

Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments in General

SSC in its December 2019 minutes provided responses to ten specific inquiries regarding how to appropriately fill out the risk table and develop ABC recommendations using the table.

In this assessment, we have again used the risk matrix table to evaluate stock assessment, population dynamics, ecosystem, and fishery performance concerns relevant to Gulf of Alaska pollock. We followed the SSC's helpful advice in evaluating concerns and developing ABC recommendations.

Responses to SSC and Plan Team Comments Specific to this Assessment

The GOA plan team in its November 2019 minutes recommended the author examine fishery selectivity, as persistent patterns in the catch-at-age residuals may represent artifacts of the selectivity functional form used.

We did not do this in this assessment due to lack of time, but will plan to do so in future assessments.

The GOA plan team in its November 2019 minutes recommended the author ensures adequate fishery data is collected and available due to the observer program implementation of Electronic Monitoring.

We have worked with Julie Bonney, Ruth Christiansen and Charlotte Levy, the leads for the Electronic Monitoring EFP, to ensure continued monitoring of the pollock fishery in the GOA. As usual in the first year of a major program, there have been some unanticipated difficulties, but the collection of biological information for pollock appears to be adequate for stock assessment needs. We have been able to obtain electronic logbook information for a portion of the fleet, but did not have the time to evaluate whether it could be used to track fishery CPUE as observer data has been used in the past.

The GOA plan team in its November 2019 minutes recommended the author explore better methods for constraining the time varying catchability parameter to be under 1 for the Shelikof Strait acoustic survey.

We were unable to come up with a better way of constraining time-varying catchability to be less than one for the Shelikof Strait acoustic survey. There seemed to be less of a need of constrain catchability to be less than one given the decline in survey biomass in 2020.

The GOA plan team in its November 2019 minutes recommended an exploration of combining the acoustic summer survey and the GOA bottom trawl survey using a VAST framework, similar to the approach used by Cole Monahan for EBS pollock surveys.

We explored models that used VAST estimates in place of area-swept biomass estimates for the NMFS bottom trawl survey. The VAST estimates did not fit as well as the area-swept estimates when given similar weighting, and we concluded that additional model evaluation was needed before using the VAST estimates. Methods for analyzing acoustic data using VAST are under development for the Shelikof Strait and the summer acoustic survey. Methods to combine both acoustic and bottom trawl surveys to produce a single index for stock assessment probably should be regarded as more of a long-term research objective rather than something that can be done when developing a stock assessment.

The GOA plan team in its November 2018 minutes recommended investigating model behavior sensitivity to abundance indices by incrementally dropping survey indexes to clarify how the data affect the model(s).

We did not do this in this assessment due to lack of time, but will plan to do so in future assessments. We have done this exercise in several previous assessments, so we feel we have a good understanding of model sensitivity to different surveys. For example, a summary of an analysis reported in the 2004 assessment states “comparison of models that down weight either the ADFG trawl survey or the Shelikof EIT survey indicate the estimated biomass trends are broadly consistent with the base model. All show a similar pattern of increase and decline, suggesting that no survey has a dominant influence on the estimated trend in abundance.” In addition, the model runs in which each new data input is added incrementally to the previous year’s assessment provide good information on sensitivity to new survey information.

The SSC in its December 2019 minutes supported including GOA pollock in the ongoing genetic studies to better understand the relationship between pollock in the NBS and EBS, specifically to evaluate support for continued separation of SE outside waters in the OFL specifications.

A whole genome sequencing project is underway for pollock throughout its range in Alaska waters. This study will provide a critical baseline for future studies of genetic differentiation and adaptation.

The GOA plan team in its November 2019 minutes recommended a re-analysis of maturity at length and age be made for individual cohorts, which would prevent poor estimates for years where age and size diversity is low, such as 2004 and 2017.

A draft analysis estimates mature by length and age for individual cohorts was developed in response to this recommendation. Maturity at age is usually computed for each survey year. The issue with this is that due to age composition, some survey years do not yield accurate results because of very low abundance of fish in the “transition” age to maturity, e.g. 3-4 years old. A good example is in 2017 when ages 2-4 were at very low abundance, and maturity at age was fitted to almost entirely immature age 1 fish and almost completely mature age 5 fish (2012 year class), yielding high uncertainty. This analysis attempts to look at maturity not by survey year but by each cohort as it ages across survey years. A cohort based approach is more likely to lead to more a biologically representative estimate of maturity at age.

Recent analyses of maturity at length used weighted specimen samples, where the weights at each sampling location are determined by estimates of the local abundance based on converting acoustic backscatter into fish density. To compute the haul weights, only abundance of fish >30 cm was used to prevent the potential of high number of juvenile fish from over-weighting samples of adult fish sampled for maturity. In brief, pollock abundance aggregated was aggregated across all acoustic survey sampling units (EDSU’s) that are closest to a given haul (e.g. “nearest haul”). The weights are computed as

$$W_h = \frac{\sum A_h}{\left(\frac{\sum A}{n_h}\right)}$$

Where *h* is the haul, and *A* is the abundance of 30+ cm fish at each EDSU that is nearest to that haul.

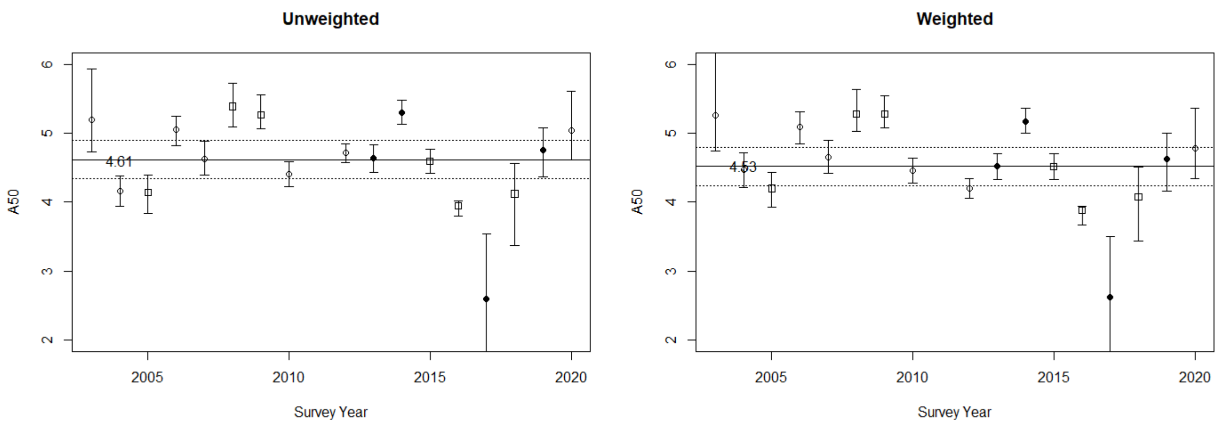
The weights were applied to maturity-at-age data using the following steps:

1. For each haul sample, the number of fish mature at each age and the total number sampled for maturity and age were scaled by the haul-specific weight, computed as above.
2. Number mature and total number were summed by age across all hauls for each survey
3. Proportion mature at age was computed as number mature/total number for each age class

4. The total number of fish sampled at age for the survey were multiplied by the Proportion mature at age, with the resulting value representing a weighted number mature at age.

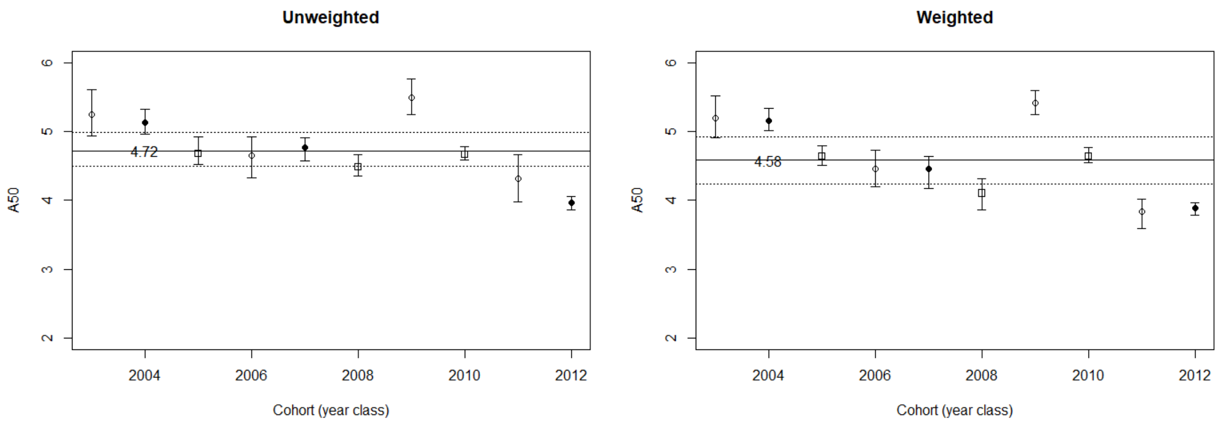
Unweighted data simply aggregate maturity state by age across all specimen samples in a survey. To compare a cohort-based approach to the traditional method, both were computed for weighted and unweighted data. The Age at 50% mature (A50) was computed by fitting a GLM (family = binomial with a logit link function) to the data for each survey year, or for each cohort. The cohort analysis was limited to fish born in 2003 – 2012, because year classes 2013-15 were extremely low in abundance and year classes 2017-19 have not yet had an opportunity to become mature. Variance was estimated by resampling slope and intercept parameters from the covariance matrix and computing the 2.5 and 97.5 percentiles. The overall time series mean was determined by fitting a mixed model GLM with year or cohort as the random effect.

Results. The figure below shows the maturity at age by survey year.



The filled circles represent the five most abundant survey years, open squares are the middle five years, and open circles are the lowest abundance seven years. No discernable pattern of abundance relative to maturity is seen. Overall trend is stable with estimates for 2017 exhibiting a low estimate with very high uncertainty due to very small abundances of 2013-2015 year classes, making the model fit inaccurate. Recent years show a pattern of increasing A50, however, these are driven by the procession of the “gap” in abundance between the 2012 and 2017 year classes. Weighted data appear to reduce overall mixed model derived mean slightly, possibly due to greater weighting toward younger age classes.

The figure below shows the maturity at age by cohort.



As with above, the filled circles represent the largest three cohorts, open squares the middle three cohorts and open circles the least abundant three cohorts. The 2012 year class is many times larger than the next two most abundant year classes (5.8 times larger than the mean across all cohorts, compared with 1.2 and 0.9). No obvious pattern with cohort abundance and A50 was noted. Maturity by cohort shows less variability overall and a slight declining trends with the year-specific data, abundance weighted estimates are slightly lower, and seem to impact the 2008 cohort the most.

Conclusions. The year specific estimates of maturity are more variable, and are susceptible to issues with getting good model fits when data in the transitionary period (ages 3, 4) are few. Annual trends observed from 2016-2020 seem to indicate an increase in A50, while this is probably a result of the progression of a gap in age composition as indicated above. Cohort-based analysis represents a more stable estimate that may be easier to interpret, and seems to show a decline in age of maturity, with potential outliers being the 2009 age class, although it ranks second to lowest in relative cohort abundance (0.16 of the overall cohort mean) and therefore may be a low sample effect. Cohort specific maturity however is more easily assessed retroactively, as there has to be at least 5-6 years of data on a cohort before it can be used, potentially making it more complicated for use in the assessment. Its value may be greater as an independent population metric or indicator. Also of note is that overall mean maturity at age values are remarkably similar in the two approaches, in terms of mean and variance.

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 1B.

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 96% 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 2015 and 2019, 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, shallow-water flatfish, and flathead sole. Sablefish incidental catch has trended upwards in 2018 and 2019, perhaps reflecting both the recent increase in sablefish abundance and a wider spatial distribution. The most common non-target species are grenadiers, jellyfish, capelin, and miscellaneous fish (Table 1.2). Bycatch estimates for prohibited species over the period 2015-2019 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, and again in 2019.

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.

Recently NMFS approved the final rule for Amendment 109 to GOA Fishery Management Plan developed by the North Pacific Fisheries Management Council. Amendment 109 combines pollock fishery A and B seasons into a single season (redesignated as the A season), and the C and D seasons into a single season (redesignated as the B season), and changes the annual start date of the redesignated pollock B season from August 25 to September 1. These changes will be implemented beginning in 2021 and affect the seasonal allocation only in the Central and Western GOA.

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 ADF&G 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	1970-2019
Fishery	Age composition	1975-2019
Shelikof Strait acoustic survey	Biomass	1992-2020
Shelikof Strait acoustic survey	Age composition	1992-2020
Summer acoustic survey	Biomass	2013-2019
Summer acoustic survey	Age composition	2013-2019
NMFS bottom trawl survey	Area-swept biomass	1990-2019
NMFS bottom trawl survey	Age composition	1990-2019
ADF&G trawl survey	Delta-GLM index	1988-2020
ADF&G survey	Age composition	2000-2018

Although many surveys in the North Pacific were cancelled in 2020 due health concerns associated with the COVID-19 pandemic, there was no loss of survey information used in the GOA pollock assessment.

Total Catch

Total catch estimates were obtained from INPFC and ADF&G 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 1991-2019 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 1E.

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 are documented in the assessments available online at http://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm.

Age and length samples from the 2019 fishery were stratified by half year and statistical area as follows:

Time strata		Shumagin-610	Chirikof-620	Kodiak-630	W. Yakutat and PWS-640 and 649
1st half (A and B seasons)	Num. ages	130	402	242	116
	Num. lengths	857	6,528	1,550	801
	Catch (t)	1,467	50,104	9,050	9,398
2nd half (C and D seasons)	Num. ages	404	403	414	---
	Num. lengths	6,935	2,736	6,457	---
	Catch (t)	20,401	14,017	15,805	---

The estimated age composition in 2019 in all areas and all seasons was dominated by age-7 fish (2012 year class) (Fig. 1.2). The catch-at-age in the second half of 2019 (C and D season) shows the appearance of age-2 and age-3 fish, most strongly in the Kodiak area (630). Younger fish are likely to become increasingly prominent in the catch-at-age as the 2012 year class begins age out of the population. Fishery catch at age in 1975-2019 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 full three-boat survey, 800 tows are completed, but the recent average has been closer to 600 tows. 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 long., 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 long. 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.

The Alaska Fisheries Science Center’s (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted the sixteenth comprehensive bottom trawl survey since 1984 during the summer of 2019. The 2019 gulfwide biomass estimate of pollock was 307,158 t, which is a decrease of 2.5% from the 2017 estimate, and is the second lowest in the time series after 2001. The biomass estimate for the portion of the Gulf of Alaska west of 140º W long. used in the assessment model is 257,604 t. The coefficient of variation (CV) of this estimate was 0.24, which is slightly higher than the average for the entire time series. This increase in uncertainty may be partly due to lower survey effort (two boats were used instead of three, and the number of tows was reduced to 541 (Table 1.8). 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 2019 survey, and indicated the continued dominance of the 2012 year class (age-7 fish) in the Western and Central GOA (Fig. 1.5). Age-1 pollock were strongly present in the Chirikof, Kodiak, and Yakutat statistical areas, but much less abundant in the Shumagin and Southeast Alaska areas (Fig. 1.5).

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 2020 are presented in a NMFS processed report (McCarthy et al., in prep.). In 2008, the noise-reduced *R/V Oscar Dyson* became the designated survey vessel for acoustic surveys in the Gulf of Alaska. In winter of 2007, a vessel comparison experiment was conducted between the *R/V Miller Freeman* (MF) and the *R/V Oscar Dyson* (OD), which obtained an OD/MF ratio of 1.132 for the acoustic backscatter detected by the two vessels in Shelikof Strait.

The 2020 biomass estimate for Shelikof Strait is 456,713 t, which is a 64% percent decrease from the 2019 estimate (Fig. 1.6). This estimate accounts for trawl selectivity by scaling up the number of retained pollock by selectivity curves estimated with pocket nets attached to the midwater trawl used to sample echosign, continuing an approach that was started in 2018 assessment. In addition to the Shelikof Strait survey, acoustic surveys in winter 2020 included only a survey the Shumagin area. Other planned surveys in winter 2020, including surveys in the western GOA and near Kodiak Island (Kenai to Prince William Sound) were unable to be completed due to delays in vessel readiness. The following table provides results from the 2020 winter acoustic surveys:

Area	Total biomass (t)	Percent
Shelikof Strait	456,713	99.0%
Shumagin Islands	4,798	1.0%
Total	461,511	

Biomass in the Shumagin Islands in 2020 was reduced by 72% compared to 2018, the last year the Shumagin Islands were surveyed. Overall there appears to be a concentration of spawning activity in Shelikof Strait compared to other areas in the Gulf of Alaska, but the reduced survey coverage outside of Shelikof Strait limits the conclusions that can be drawn.

Shelikof Acoustic Survey Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.7) were obtained using an age-length key compiled from random otolith samples and applied to weighted length frequency samples. Sample sizes for ages and lengths are given Table 1.11. Estimates of age composition in Shelikof Strait in 2020 indicate reduced dominance of the eight year old 2012 year class, and a mode of age 3 fish (2017 year class), indicating a new year class is starting to enter the spawning and exploitable portion of the population.

Winter Acoustic Survey Age-1 and Age-2 Indices

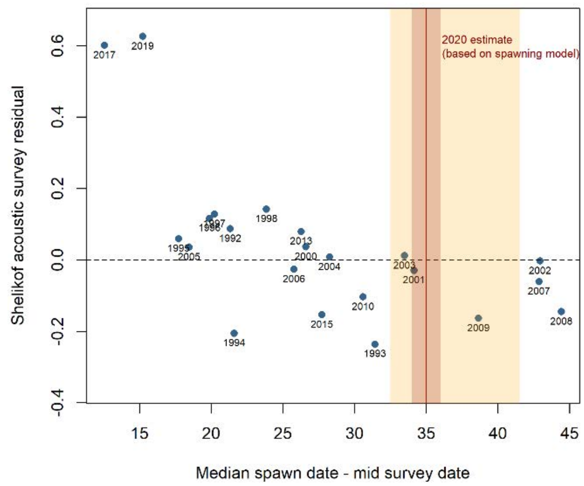
Based on recommendations from the 2012 CIE review, we developed an approach to model the age-1 and age-2 pollock estimates separately from the Shelikof Strait acoustic survey biomass and age composition. Age-1 and age-2 pollock are highly variable but occasionally very abundant in winter acoustic surveys, and by fitting them separately from the 3+ fish it is possible utilize an error distribution that better reflects that variability. Indices are available for both the Shelikof Strait and Shumagin surveys, but a longer time series of net-selectivity corrected indices are available for Shelikof Strait. In addition, model comparisons in the 2018 assessment indicates that a slightly better fit could be obtained with only Shelikof Strait indices. Therefore this time series was used in the model, but this decision should be revisited as additional data become available. The age-2 index in 2020 showed a marked reduction in comparison to the age-1 index in 2019, which indicated high abundance of the 2018 year class. Typically year classes that are abundant in Shelikof Strait at age 1 are also abundant at age 2 in the survey in the following year. Consequently there is considerable uncertainty regarding the fate of 2018 year class, which may have exited Shelikof Strait for some reason and be distributed elsewhere in the GOA, or suffered extremely high mortality.

Spawn timing and availability of pollock to the winter Shelikof survey

The Shelikof Strait winter acoustic survey is timed to correspond to the aggregation of pre-spawning pollock in Shelikof Strait. However, the timing of spawning has been found to vary from year to year, which may affect the availability of pollock to the survey. Variation in spawn timing is not random, but has been linked to thermal conditions in March and the age structure of the spawning stock (Rogers and Dougherty 2019); spawning tends to occur earlier when temperatures are warmer and when the spawning stock is older on average. Greater age diversity also results in a more protracted spawning period, presumably due to both early (old) and late (young) spawners, although this has not been verified in the field.

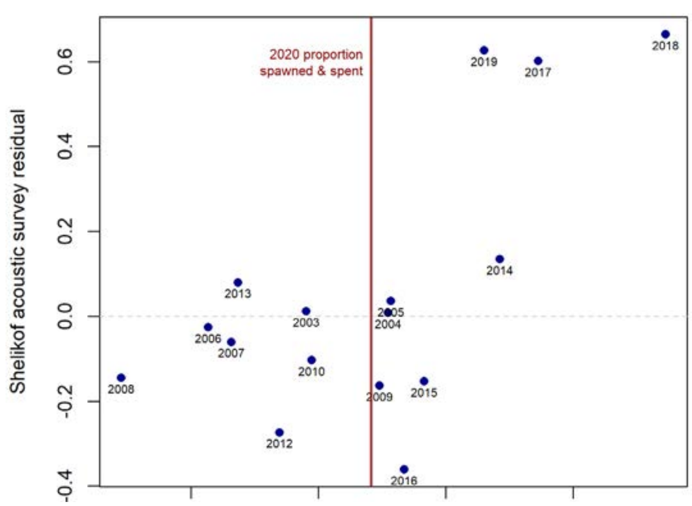
Relative spawn timing can be inferred from two independent data sources. First, dates of spawning can be back-calculated from length, age, and CPUE of pollock larvae captured during spring larval surveys, conducted since 1981 by EcoFOCI (details in Rogers and Dougherty 2019). This method was used to determine the historical importance of temperature and age structure for interannual variation in spawn timing and duration. Second, the relative proportion of pollock in spawning or spent stages relative to pre-spawning stages during the winter Shelikof acoustic survey can be used as an indicator of spawn timing relative to survey timing, or of spawn timing alone if corrected for survey date (as in Rogers and Dougherty 2019). The MACE program has long used the proportion of pollock in spawning or spent stages as a metric for the relative timing of the survey compared to spawning (e.g. Lauffenburger et al. 2019).

Mismatches in timing between the acoustic survey and spawning have been correlated with residuals in the stock assessment model, such that larger mismatches in timing (i.e. when the survey is early relative to spawning) result in survey biomass estimates being low compared to model estimates (figure below).



Estimated mismatch of Shelikof acoustic survey timing with the median spawn date, as back calculated from larval otoliths (Rogers and Dougherty 2019), and its relationship with survey biomass estimate residuals from the 2019 stock assessment model (as in Figure 1.36 in Dorn et al. 2019). The survey estimates tend to be high relative to the model (positive residuals) in years when the survey is closer in timing (i.e. later) relative to peak spawning. The 2020 estimate of timing mismatch is shown, predicted based on the best (red line) and top six supported (yellow shading) models of spawn timing.

Conversely, when the survey is closer in timing to peak spawning, survey estimates tend to be high relative to model estimates. This pattern is also evident in maturity specimen data. In recent years (2017 – 2019) a relatively high proportion of fish were already in spawning or spent stages by the time of the survey, suggesting that the survey was closer in timing to peak spawning. Survey biomass estimates were also relatively high for these years compared to the assessment model (figure below).



The biomass-weighted proportion of pollock in Shelikof Strait (females >30cm) in spawning or spent stages during the acoustic survey, logit transformed, plotted against the corresponding survey biomass residual as in the previous figure. The vertical red line shows the value for 2020.

We compiled information on spawn timing and survey timing in 2020 to give an indication of whether the survey biomass estimate would be expected to be high, average, or low relative to the assessment model estimate. No larval survey occurred in 2020, however, observations of temperature and age structure can be used to predict whether spawning would have been earlier or later than average. In 2020, sea surface temperatures in March, which are highly correlated with temperatures at depth, were 3.1 C, slightly colder than the 1981-2019 average of 3.6 C (SD = 0.74). This would suggest later-than-average spawning in 2020. Age composition of the spawning stock is harder to assess, as the stock assessment model suggests that the mean age of the stock (age 3 and older) was approximately average, primarily composed of old (8 yo) and young (3 yo) fish, whereas the Shelikof survey encountered an older than average stock. Predictions of median spawn timing in 2020 based on best-fit linear and generalized additive models (updated from Rogers and Dougherty 2019) vary from day 103 to day 112, relative to a long-term average of day 108. Thus, spawn timing was likely close to normal in 2020, in contrast to recent years (2017, 2019, no data for 2018) when larval data suggest spawning was 2-3 weeks early; Rogers *unpublished*). The acoustic survey, however, was more than a week earlier than average in 2020, which may have resulted in a slightly larger-than-average mismatch in timing between the survey and spawning. The proportion of females (>30 cm) in spawning or spent stages was typical in 2020. Together, indicators of spawn timing relative to survey timing suggest the Shelikof survey biomass estimate in 2020 is likely to be low to average (relative to true stock biomass), in contrast to the previous 3 years.

Summer Acoustic Survey

Four complete acoustic surveys, in 2013, 2015, 2017, and 2019, have been conducted by AFSC on the *R/V Oscar Dyson* in the Gulf of Alaska during summer (Jones et al. 2017, 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. 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. The 2019 biomass estimate for summer acoustic survey is 580,543 t, which is a 60% percent decrease from the 2017 estimate (Table 1.7). Age composition in 2019 indicated that the very abundant 2012 year class (age-7 fish) was still very abundant, though there were strong modes of both age-1 and age-2 fish distributed broadly throughout the GOA (Fig. 1.8). Analysis of the 2019 survey was not complicated by the presence of age-0 pollock, which have been a problem in previous summer acoustic surveys.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

The Alaska Department of Fish and Game (ADF&G) 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 352. On average, 87% of these tows contain pollock. Details of the ADF&G trawl gear and sampling procedures are in Spalinger (2012).

The 2020 area-swept biomass estimate for pollock for the ADF&G crab/groundfish survey was 59,377 t, and increase of 16.5% from the 2019 biomass estimate (Table 1.7). The 2020 pollock estimate for this survey is approximately 64% of the long-term average.

Delta GLM indices

A simple delta GLM model was applied to the ADF&G tow by tow data for 1988-2020 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 ADF&G 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 a gamma error assumption was used for the positive observations after evaluation of several alternatives, including lognormal, gamma, and inverse Gaussian. The model was fit using bmrs package in R, which fits Bayesian non-linear regression models using 'Stan.' Comparison of delta-GLM indices the area-swept estimates indicated similar trends (Fig. 1.10). Variances were based on MCMC sampling from the posterior distribution, and CVs for the annual index ranged from 0.10 to 0.18. These values likely 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.

ADF&G Survey Age Composition

Ages were determined by age readers in the AFSC age and growth unit from samples of pollock otoliths collected during 2000-2018 ADF&G surveys in even-numbered years (average sample size = 580) (Table 1.12, Fig. 1.11). Comparison with fishery age composition shows that older fish (> age-8) are more common in the ADF&G 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 ADF&G 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 ADF&G 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. 1.12). In the last few years there has been strong divergence among the trends, starting in 2016 and continuing to 2020. Given the large reduction in biomass in 2020 for the Shelikof Strait survey, and an increase in the ADF&G index, relative abundance has come back into reasonable alignment in 2020.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.13). 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 and remained similar in 2018 and 2019. 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 2015-2018 as the strong 2012 year class recruited to the fishery, but is poised to increase when the 2012 year class becomes age 8 in 2020. 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 was relatively stable during 1975-2015, but declined sharply in 2016 and remained low in 2017 and 2018 due to the dominance of the 2012 year class in the catch (Fig. 1.13). In 2019 the age diversity increased towards the long-term average, but still remains anomalously low.

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. 1.14). 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 2020 (51 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 1C.

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. The following table lists the likelihood components used in fitting the model.

Likelihood component	*Statistical model for error*	*Variance assumption*
Fishery total catch (1970-2020)	Log-normal	CV = 0.05, 2020 catch is projected
Fishery age comp. (1975-2019)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2020)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2020)	Multinomial	Initial sample size = 60
Shelikof acoustic survey age-1 and age-2 indices (1994-2020)	Log-normal	Tuned CVs = 0.45 and 0.45
Summer acoustic survey biomass (2013-2019)	Log-normal	CV = 0.25
Summer acoustic survey age comp. (2013, 2015, 2017, 2019)	Multinomial	Initial sample size = 10
NMFS bottom trawl survey biom. (1990-2019)	Log-normal	Survey-specific CV from random-stratified design = 0.12-0.38
NMFS bottom trawl survey age comp. (1990-2019)	Multinomial	Initial sample size = 60
ADF&G trawl survey index (1989-2020)	Log-normal	Survey-specific CV from delta GLM model rescaled so mean is 0.25=0.20-0.35
ADF&G survey age comp. (2000-2018)	Multinomial	Initial sample size = 30
Recruit process error (1970-1977, 2019, 2020)	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 2019 and 2020 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 based on expert judgement as a constraint on potential values (Fig. 1.15). 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 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 1992-1998 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 (1989-1998), 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 ADF&G crab/groundfish survey was given a weight of 30.

Parameters Estimated Outside the Assessment Model

Pollock life history characteristics, including natural mortality, weight at age, and maturity at age, were estimated independently outside the assessment model. These parameters are used in the model to estimate spawning and population biomass and obtain predictions of fishery catch and survey biomass. Pollock life history parameters include:

- Natural mortality (*M*)
- Proportion mature at age
- Weight at age and year by fishery and by survey

Natural mortality

Hollowed and Megrey (1990) estimated natural mortality (*M*) using a variety of methods including estimates based on: a) growth parameters (Alverson and Carney 1975, and Pauly 1980), b) GSI (Gunderson and Dygert, 1988), c) monitoring cohort abundance, and d) estimation in the assessment model. These methods produced estimates of natural mortality that ranged from 0.22 to 0.45. The maximum age observed was 22 years. Up until the 2014 assessment, natural mortality has been assumed to be 0.3 for all ages.

Hollowed et al. (2000) developed a model for Gulf of Alaska pollock that accounted for predation mortality. The model suggested that natural mortality declines from 0.8 at age 2 to 0.4 at age 5, and then remains relatively stable with increasing age. In addition, stock size was higher when predation mortality was included. In a simulation study, Clark (1999) evaluated the effect of an erroneous *M* on both estimated abundance and target harvest rates for a simple age-structured model. He found that "errors in estimated abundance and target harvest rate were always in the same direction, with the result that, in the short term, extremely high exploitation rates can be recommended (unintentionally) in cases where the natural mortality rate is overestimated and historical exploitation rates in the catch-at-age data are low." Clark (1999) proposed that the chance of this occurring could be reduced by using an estimate of natural mortality on the lower end of the credible range, which is the approach used in this assessment.

In the 2014 assessment, several methods to estimate of the age-specific pattern of natural mortality were evaluated. Two general types of methods were used, both of which are external to the assessment model. The first type of method is based initially on theoretical life history or ecological relationships that are then evaluated using meta-analysis, resulting in an empirical equation that relates natural mortality to some more easily measured quantity such as length or weight. The second type of method is an age-structured statistical analysis using a multispecies model or single species model where predation is modeled. There are three examples of such models for pollock in Gulf of Alaska, a single species model with predation by Hollowed et al. (2000), and two multispecies models that included pollock by Van Kirk et al. (2010 and 2012). These models were published in the peer-reviewed literature, but likely did not receive the same level of scrutiny as stock assessment models. Although these models also estimate time-varying mortality, we averaged the total mortality (residual natural mortality plus predation mortality) for the last decade in the model to obtain a mean age-specific pattern (in some cases omitting the final year when estimates were much different than previous years). Use of the last decade was an attempt to use estimates with the strongest support from the data. Approaches for inclusion of time-varying natural mortality will be considered in future pollock assessments. The three theoretical/empirical methods used were the following:

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

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

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

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

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

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

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

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

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

Results were reasonably consistent and suggest use of a higher mortality rate for age classes younger than the age at maturity (Table 1.14 and Fig. 1.16). 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 388 (Table 1.15).

In 2019, a new approach was introduced to estimate maturity at age using specimen data from the Shelikof Strait acoustic survey. Maturity estimates from 2003 onwards were revised using this method. The approach uses local abundance to weight the maturity data collected in a haul. To estimate abundance, each acoustic survey distance unit (0.5 nmi of trackline) was assigned to a stratum representing nearest survey haul. Each haul's biological data was then used to scale the corresponding acoustic backscatter by within that stratum into abundance. To generate abundance weights for specimen data taken for each haul location, the abundance estimates of adult pollock (≥ 30 cm fork length) were summed for each haul-stratum. The 30 cm length threshold represents the length at which pollock are 5 % mature in the entire Shelikof Strait historic survey data. Total adult pollock abundances in each stratum scaled by dividing by the mean abundance per stratum (total abundance /number of haul-strata). Weights range from 0.05 to 6, as some hauls were placed in light sign while others sampled very dense aggregations. For each haul, the number of female pollock considered mature (prespawning, spawning, or spent) and immature (immature or developing) were computed for each age. The maturity ogive for maturity-at-age was estimated as a logistic regression using a weighted generalized linear model where the dependent variable was the binomial spawning state, the independent variable was the age, and data from each haul weighted by the appropriate values as computed above. The length and age at 50% maturity was derived (L50%, A50%) from the ratio of the regression coefficients. The new maturity estimates had a relatively minor impact on assessment results, and usually reduced estimates of spawning biomass by about 2 percent.

Estimates of maturity at age in 2020 from winter acoustic surveys using the new method are similar to the 2019 estimates and close to the long-term mean for all ages (Fig. 1.17). 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 1983-2019 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 the 2012 year class at younger ages than is typical, however the 2019 and 2020 estimates of age at 50% mature are near the long-term average. 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 1.18). 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% mature. 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 and the summer acoustic survey are given in Table 1.16, Table 1.17, and Table 1.18. A plot of weight-at-age from the Shelikof Strait acoustic survey indicates that there has been a substantial changes in weight at age for older pollock (Fig. 1.19). For pollock greater than age 6, weight-at-age nearly doubled by 2012 compared to 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 1975-2019. 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 (1981-2020) and the NMFS bottom trawl survey (1984-2019) 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 2019 fishery weight at age with the data now available indicate that the model did reasonably well for younger pollock but tended to over-predict the weight at age for older pollock (Fig. 1.20). However there was good agreement for age-7 pollock, which made up 67% of the catch at age. In this assessment, RE model estimates of weight at age in 2020 are used for the fishery in 2020 and for yield projections (Fig. 1.20).

Parameters Estimated Inside the Assessment Model

A large number of parameters are estimated when using this modeling approach, though many are year-specific deviations in fishery selectivity coefficients. Parameters were estimated using AD Model Builder (Version 10.1), a C++ software language extension and automatic differentiation library (Fournier et al. 2012). Parameters in nonlinear models are estimated in ADModel Builder using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. The optimizer in AD Model Builder is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1 x 10^{-6}). AD Model Builder includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest.

A list of model parameters for the base model is shown below:

Population process modeled	*Number of parameters*	*Estimation details*
Recruitment	Years 1970-2020 = 51	Estimated as log deviances from the log mean; recruitment in 1970-77, and 2018 and 2019 constrained by random deviation process error.
Natural mortality	Age-specific= 10	Not estimated in the model
Fishing mortality	Years 1970-2020 = 51	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) = 100	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) = 100	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, ADF&G survey: 2)	Slope parameters estimated on a log scale.
Total	118 estimated parameters + 200 process error parameters + 10 fixed parameters = 328	

Results

Model selection and evaluation

Model Selection

Prior to identifying a model for consideration, an analysis was conducted of the impact of each new data element on model results. Figure 1.21 shows the changes in estimated spawning biomass as the 2020 catch projection, the 2019 catch at age, 2020 Shelikof Strait acoustic survey estimates, 2020 ADF&G

survey index, and age composition for the 2019 NMFS bottom trawl survey and the summer acoustic surveys were added sequentially. In general, the addition of new data elements did not strongly affect the estimates of recent spawning biomass, unlike a similar analysis that was conducted last year. The strongest effect was an increase in spawning biomass when the model was updated to 2020, and the projected 2020 catch was included. This suggests that the new data are reasonably consistent with previous modeling and with each other. Since previous assessments have identified inconsistent input data sets as a major assessment concern, the overall consistency this year suggests that those concerns are much reduced.

The intent of this year's assessment was to provide a straightforward update without considering major changes to the model. We explored models that used VAST estimates in place of area-swept biomass estimates for the NMFS bottom trawl survey. The VAST estimates did not fit as well as the area-swept estimates when given similar weighting, and we concluded that additional model evaluation was needed before using the VAST estimates. Several other modeling approaches for GOA pollock are under development, including incorporation of predator consumption (Barnes et al. 2020) in the assessment model, and use of mean hatch date from the EcoFOFI early larval survey to inform catchability to the Shelikof Strait survey. We selected model 19.1 as the preferred model, and a final turning step was done using the Francis (2011) approach. Only the fishery and bottom trawl age composition data components were reweighted, resulting in slightly larger input sample sizes, but model results were nearly unchanged.

Model Evaluation

The fit of model 19.1 to age composition data was evaluated using plots of observed and predicted age composition and residual plots. Figure 1.22 show the estimates of time-varying catchability for the Shelikof Strait acoustic survey and the ADF&G crab/groundfish survey. The catchability for the Shelikof Strait acoustic survey approaches one but does not exceed it. Plots show the fit to fishery age composition (Fig. 1.23, Fig. 1.24), Shelikof Strait acoustic survey age composition (Fig. 1.25, Fig. 1.26), NMFS trawl survey age composition (Fig. 1.27, Fig. 1.28), and ADF&G trawl survey age composition (Fig. 1.28, Fig. 1.29). 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 2016-2019 due to stronger than expected abundance in the age composition, while the older ages tended to have negative residuals. This may indicate that the fishery is targeting on the 2012 year class. 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 survey biomass estimates are reasonably good for all surveys until recently (Fig. 1.30 and Fig. 1.31). There are large positive residuals for the Shelikof Strait acoustic survey in 2017, 2018 and 2019, and strong negative residuals for the NMFS bottom trawl survey for 2017 and 2019. In addition, the model is unable to fit the extremely low values for the ADF&G survey in 2015-2017, but recent values in 2018-2020 are fit adequately, and the fit to the ADF&G survey is quite good overall. The fit to the summer acoustic survey is reasonable even during the most recent period. The model shows very good fits to both the 2020 Shelikof Strait acoustic survey and the 2020 ADF&G survey. The fit to the age-1 and age-2 acoustic indices was considered acceptable (Fig. 1.32).

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 1.19 (see also Fig. 1.33). Table 1.20 gives the estimated population numbers at age for the years 1970-2019.   Table 1.21 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2020 (see also Fig. 1.34). Table 1.22 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

116% of the proxy for unfished stock size ($B_{100\%}$ = mean 1978-2019 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR@F=0)). In 2002, the stock dropped below the $B_{40\%}$ for the first time since the early 1980s, reached a minimum in 2003 of 35% of unfished stock size. Over the years 2009-2013 stock size showed a strong upward trend, increasing from 43% to 80% of unfished stock size, but declined to 55% of unfished stock size in 2015. The spawning stock peaked in 2017 as the strong 2012 year class matured, and has declined subsequently.

Figure 1.35 shows the historical pattern of exploitation of the stock both as a time series of SPR and fishing mortality compared to the current estimates of biomass and fishing mortality reference points. Except from the mid-1970s to mid-1980s fishing mortalities has generally been lower than the current OFL definition, and in nearly all years was lower than the F_{MSY} proxy of $F_{35\%}$.

Comparison of historical assessment results

A comparison of assessment results for the years 1993-2020 indicates the current estimated trend in spawning biomass for 1990-2020 is consistent with previous estimates (Fig. 1.36). 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. The estimated 2020 age composition from the current assessment shows some large differences from the projected 2020 age composition from the 2019 assessment (Fig. 1.36). The estimate of age-2 abundance is much lower in the 2020 assessment due to low abundance of age-2 pollock in the 2020 Shelikof Strait survey. In addition, age-1 recruits in 2020 is estimated to be weak year class, again due low abundance in the 2020 Shelikof Strait survey, rather than the average recruitment that was assumed in last year's assessment. Both of these changes do not strongly affect the OFL and ABC for next year, but do suggest the stock is entering a period of lower abundance and reduced yield compared to last's year relatively optimistic projections.

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 1.37 shows a retrospective plot with data sequentially removed back to 2010. There is up to 31% error in the estimates of spawning biomass (if the current assessment is accepted as truth), but usually the errors are much smaller (median absolute error is 3%). There is relatively minor positive retrospective pattern to errors in the assessment, and the revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.057, which does not indicate a concern with retrospective bias.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 1.18) 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 periodically every four to six years (Fig. 1.34). Because of high recruitment variability, the mean relationship between spawning biomass and recruitment is difficult to estimate despite good contrast in spawning biomass. Strong and weak year classes have been produced at high and low level of spawning biomass. Spawner productivity is higher on average at low spawning biomass compared to high spawning biomass, indicating that survival of eggs to recruitment is density-dependent (Fig. 1.38). However, this pattern of density-dependent survival only emerges on a decadal scale, and could be confounded with environmental variability on the same temporal scale. The decadal trends in spawner productivity have produced the pattern of increase and decline in the GOA pollock population. The last two decades have been a period of relatively low spawner productivity, though there appears to be a recent increase. Age-1 recruitment in 2019 is estimated to be close to the long-term mean, and age-1 recruitment in 2020 is estimated to be very weak, 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 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 1.23). Spawning biomass reference levels were based on mean 1978-2019 age-1 recruitment (5.858 billion), which is 4% higher than the mean value in last year's assessment. Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using mean weight at age for the Shelikof Strait acoustic surveys in 2016-2020 to estimate current reproductive potential. Pollock weight-at-age is highly variable, showing a sustained increase, followed by a steep decline (Fig. 1.19). The factors causing this pattern are unclear, but are likely to involve both density-dependent factors and environmental forcing. The SPR at F=0 was estimated as 0.076 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. For SPR calculations, selectivity was based on the average for 2015-2019 to reflect current selectivity patterns.

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

		Equilibrium under average 1978-2019 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	5858	1948	443	0	0.0%
40.0%	0.276	5858	1163	177	126	10.9%
35.0%	0.328	5858	1093	155	137	12.5%

The $B_{40\%}$ estimate of 177,000 t represents a 9% decrease from the $B_{40\%}$ estimate of 194,000 t in the 2019 assessment (Table 1.24), which is primarily caused by the continuing decline in spawning weight at age. The base model projection of female spawning biomass in 2021 is 184,530 t, which is 41.7% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (177,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3.

2020 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 84.2% of the OFL harvest rate. Projections for 2021 for the F_{OFL} and the maximum permissible F_{ABC} are given in Table 1.25.

Should the ABC be reduced below the maximum permissible ABC?

The following template is used to complete the risk table:

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
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	No apparent fishery/resource-use performance and/or behavior 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 adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing 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 as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
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	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four 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, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; 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.

4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings."

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 the few assessments in the North Pacific that is fit to multiple abundance indices. Last year, we gave this element a score of 2 because of strongly contrasting trends in the survey abundance indices, with bottom trawl indices showing a steep decline, while acoustic surveys showing record highs (Figures 1.30 and 1.31). This year, the results from new surveys conducted in 2020 showed consistent trends, and were able to be fit adequately by model. While the historical pattern of conflicting survey trends remains, the consistency of 2020 survey results leads to reduced concern. A new assessment issue is the severe decline in the 2018 year class abundance between the 2019 and 2020 Shelikof Strait acoustic surveys. The 2019 estimate was indicative of a strong year class, but the 2020 estimate is only 10% of the long-term average. Over the full Shelikof Strait time series, high age-1 estimates have always been followed by high age-2 estimates in the next year (Fig. 1.7). At this point it is impossible to say whether the 2018 year class moved out of Shelikof Strait for some reason, experienced unusually high mortality, or was just subject to uncertain survey estimates. We fit a model in which the high 2019 age-1 estimate was removed, and found that the 2021 OFL and ABC were not strongly affected (~5% decrease). This is because this year class will not enter the fishery until later. While weaker recruitment will likely lead to lower harvests in coming years, it did not seem appropriate to raise the concern level this year (and potentially recommend a reduction in the 2021 ABC), and so consequently we gave assessment considerations a score of 1—no increased concerns.

Population dynamics considerations

The age structure of pollock in the Gulf of Alaska has been strongly perturbed recruitment of the very strong 2012 year class that was followed very weak recruitment until 2017. Because of this sequence of events, the age-diversity of pollock dropped rapidly (Fig 1.13), though there has been a rebound in age diversity in the last two years. There are been other unusual phenomena associated with 2012 year class, including reduced growth, early maturation, and apparent reduced natural mortality (Fig 1.14). Despite these unusual events, last year we reduced the concern level for population dynamics to level 1, because of the recruitment of a strong 2018 year class. Survey data from this year suggest much lower abundance of the 2018 year class, but a larger 2017 year class. Population age structure is continuing to shift away from the extreme dominance of the 2012 year class, but the conflicting signals concerning the size of the 2018 year class is a potential population dynamics concern, in addition to being an assessment concern.

At this point, the assessment uncertainty seems the primary issue rather than population dynamics issues, given the uncertainty of initial estimates of year class strength. Consequently we gave populations dynamics considerations a score of 1—no increased concerns.

Environmental/Ecosystem considerations

The GOA largely remained in a heatwave state throughout 2019, with summer sea surface temperatures exceeding those during the 2014-2016 heatwave. Sea surface temperatures returned to the mean during 2020, except for the western GOA, where summer temperatures periodically met the heatwave threshold. In general, higher ambient temperatures incur bioenergetic costs for ectothermic fish such that, all else being equal, consumption must increase to maintain fish condition. Pollock adult biomass, but not age-1 recruitment, fared well during the 2014-2016 heatwave, likely due in part to the apparently abundant, yet smaller, zooplankton prey present during those years, so the 2019 temperatures alone did not pose an elevated concern for pollock adult biomass.

Last year, multiple lines of evidence suggested that GOA pollock from the 2018 year class were abundant as age-1s during 2019. Evidence included estimates of year class strength in the bottom trawl and winter acoustic survey, favorable prey abundance, and the potential for lower natural mortality due to declines in groundfish predator stock sizes. There are fewer data available this year due to COVID-induced survey and fieldwork cancellations as well as the biennial schedule of the AFSC bottom trawl survey. The winter acoustic survey is currently the only data source in 2020 to directly estimate pollock by age class. The few age-2 pollock observed overall in this survey suggests low survival of the 2018 year class. However, the assessment model incorporates other data from last year, when they seemed abundant, and with the result that the model estimates numbers of age-2s as close to average. It is unknown whether the 2018 year class (1) was present, but not observed, (2) experienced high mortality between late summer and early winter, or (3) moved out of the survey area. However, there are few data to provide strong support for any of these possibilities. In the winter acoustic survey time series, strong age-1 year classes have always shown up as age-2s, which suggests that it is unlikely that the 2018 year class was present but not observed. Also, survey timing and the distribution of the fish observed were similar to that in previous years. No information is available to support whether they moved out of the area.

One hypothesis to support increased mortality of this year class is that there was an increase in predation pressure during summer and fall 2019 by other groundfish that experienced increased metabolic demands due to the heatwave. Major predators of age-2 pollock are arrowtooth flounder and sablefish. Arrowtooth flounder comprise the largest groundfish biomass in the GOA, despite that recent trends have shown a slightly declining trend. Increased energetic demands due to the extreme heatwave in the western GOA during summer may have incurred an increase in predation pressure on age-2 pollock. Arrowtooth diet data from 2019 are not yet available to inform this. Also, there is a large pulse of sablefish in the GOA that are of the size that eats age-2 pollock. It is reasonable to assume that the large increase in sablefish biomass could reflect an increase in predation pressure on age-2 pollock.

Ecosystem conditions in 2020 do not appear to pose elevated concerns for the pollock stock. As mentioned above, temperatures were normal during spring and elevated during summer, although some residual heat persists at depth as measured on the Seward Line. Temperatures are forecast to be near normal through the 2020/2021 winter. Winds in Shelikof Strait appear to have been favorable for the 2020 larvae. Also, beach seines observed some age-0 pollock, in contrast to their absence during the heatwave years of 2015, 2016, and 2019, but not as high as during the average years of 2017 and 2018. The phytoplankton bloom timing in 2020 was early, similar to that in 2017 and 2018, suggesting a pattern that appears recently to coincide with years of good age-1 recruitment. Zooplankton biomass estimates were moderate for both euphausiids and large copepods during spring suggesting that zooplankton prey were not limiting for pollock. Forage fish-eating seabirds at Middleton found sufficient prey to successfully rear chicks, although chick diets were diverse, suggesting that the more typical forage fish, such as sand lance and capelin that pollock also prey upon, were not abundant. Potential competitors of pollock for zooplankton prey include pink salmon and Pacific Ocean perch. Pink salmon harvests were low in 2020 due to the smaller even-year stock sizes and reflecting lower potential for pink salmon to exert a competitive impact this year. Pacific Ocean perch have been increasing, although the potential for competitive pressure on pollock is considered inconclusive.

Taken together, we consider the current level of concern to be 1—no apparent environmental/ecosystem concerns. However, there are aspects that need to be closely monitored, such as whether the 2018 year class has indeed become scarce, leaving the average-sized 2017 year class as the largest one to potentially recruit to the fishery since the 2012 year class.

Fishery performance:

Trends in fishery CPUE were examined in the ESP (Appendix 1A) for two seasons, the pre-spawning fishery (A and B seasons) and the summer/fall fishery (C and D seasons). CPUE has been relatively high but has declined in the last two years (up until the A and B seasons of 2020). Fishery CPUE is either above (A and B seasons) or close to (C and D seasons) the long-term average, and is very consistent with the abundance trend of exploitable biomass from the assessment. There were numerous reports of undersize pollock being caught in C and D season in 2020. This may suggest incoming recruitment to the exploitable stock. No concerns regarding fishery performance were identified and this element was given a score of 1.

These results are summarized in the table below:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: substantially increased concerns	Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns

Given the lack of elevated scores in the risk table, the author's recommended ABC is based on the maximum permissible ABC, resulting in a 2021 ABC of 105,722 t, which is a decrease of 3% from the 2020 ABC. The author's recommended 2022 ABC is 91,934 t. The OFL in 2021 is 123,455 t, and the OFL in 2022 if the ABC is taken in 2021 is 106,767 t. It should be noted that the ABC is projected to decrease over the next few years due to weaker recruitment to the population.

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 less than 1% until 2025 (Fig. 1.39).

Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the 2020 numbers at age at the start of the year as estimated by the assessment model, and assume the 2020 catch will be equal to the

ABC of 108,494 t (Mary Furuness, pers. comm. Oct. 18, 2020). 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 1978-2019 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 1.23. 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 2021, 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* (2016-2020). (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 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 overfished)
>
> *Scenario 7*: In 2021 and 2022, *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 2022, or 2) above 1/2 of its MSY level in 2022 and above its MSY level in 2032 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.25. Mean spawning biomass is projected decline to 2021, and will continue to decline under full exploitation scenarios, but will increase under the F=0 and other low exploitation scenarios (Fig. 1.40). Catches are projected to drop slightly 2021, and will continue to decline over the next several years before beginning to increase again.

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 (2019) is 120,243 t, which is less than the 2019 OFL of 194,230 t. Therefore, the stock is not subject to overfishing. The fishing mortality associated with the 2019 OFL based on the recommended model is 0.378.

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 184,000 t in 2020 (see Table 1.21), which is above $B_{35\%}$ (155,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2022 is 169,154 t, which is above $B_{35\%}$ (155,000 t). Therefore, GOA pollock is not approaching an overfished condition.

The recommended area apportionment to management areas in the central and western portions of the Gulf of Alaska (central/western/west Yakutat) are provided in Appendix 1D.

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.

Last year, a full ESP was developed for GOA pollock and reviewed Plan Team at its September and November 2019 meetings. The GOA Groundfish Plan Team encouraged the authors to consider potential avenues for updating ESPs rather than producing full ESPs in the future. This year we provide a partial ESP in Appendix 1A that updates key indicators and reruns the Bayesian adaptive sampling model. We are soliciting feedback from the Plan Team and the SSC on the appropriate format and information to be included in an ESP update.

Literature Cited

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

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

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

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.

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

Barnes, C. L., A. H. Beaudreau, M. W. Dorn, K. K. Holsman, and F. J. Mueter. 2020. Developmentof a predation index to assess trophic stability in the Gulf of Alaska. Ecological Applications 30(7): e02141. https://doi.org/10.1002/eap.2141

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.

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.

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.

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

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

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

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., 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.

Ianell, J., S. Kotwicki, T. Honkalehto, K. Holsman, and B. Fissel. 2016. Assessment of the walleye pollock stock in the Eastern Bering Sea. *In* Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Bering Sea and Aleutians Islands. Prepared by the Bering Sea and Aleutian Islands Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510. North Pacific Fisheries Management Council, Anchorage, AK.

Jones, D.T., S. Stienessen, and N. Lauffenburger. 2017. Results of the acoustic-trawl survey of walleye pollock (Gadus chalcogrammus) in the Gulf of Alaska, June-August 2015 (DY2015-06). AFSC Processed Rep. 2017-03, 102 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.

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.

Lauffenburger, N., K. Williams, and D. Jones. 2019. Results of the acoustic-trawl surveys of walleye pollock (Gadus chalcogrammus) in the Gulf of Alaska, March 2019 (SH2019-04). AFSC Processed Rep. 2019-10, 76 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

McCarthy, A., M. Levine, and D. Jones. 2020. Results of the Acoustic-Trawl Surveys of Walleye Pollock (Gadus chalcogrammus) in the Shumagin Islands and Shelikof Strait, February and March 2020 (DY-202001 and DY-202003). AFSC Processed Rep. In prep. 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.

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.

Rogers, L. A., and A.B. Dougherty. 2019. Effects of climate and demography on reproductive phenology of a harvested marine fish population. *Global Change Biology*, *25*(2), 708–720. https://doi.org/10.1111/gcb.14483

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.

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.

Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The ABC is for the area west of 140° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound. Research catches are reported in Appendix 1E.

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			76,748	76,748	77,150
2011			81,503	81,503	88,620
2012			103,954	103,954	108,440
2013			96,363	96,363	113,099
2014			142,640	142,640	167,657
2015			167,549	167,549	191,309
2016			177,129	177,129	254,310
2017			186,155	186,155	203,769
2018			158,070	158,070	161,492
2019			120,243	120,243	135,850
2020					108,494
Average (1977-2019)				109,561	126,254

Table 1.2. Incidental catch (t) of FMP species (upper table) and non-target species (bottom table) in the directed pollock fishery in the Gulf of Alaska. 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	*2015*	*2016*	*2017*	*2018*	*2019*
Pollock	163756.7	175241.9	183044.0	155002.1	117649.7
Arrowtooth Flounder	1758.2	1292.0	1335.7	2670.4	2019.5
Pacific Cod	2200.9	1087.8	886.6	846.8	811.3
Pacific Ocean Perch	178.9	691.0	1273.0	1629.5	1083.5
GOA Shallow Water Flatfish	509.8	271.6	370.7	393.3	263.2
Flathead Sole	465.9	318.3	198.7	322.8	197.2
Sablefish	139.0	102.0	60.6	360.0	409.2
Shark	415.8	192.5	69.9	78.8	59.0
Squid	466.4	185.3	15.5	9.5	0.0
GOA Rex Sole	154.9	120.1	75.1	138.9	89.7
GOA Skate, Big	66.1	110.4	139.0	110.5	66.5
Atka Mackerel	25.0	208.2	33.5	64.4	122.4
GOA Skate, Longnose	89.1	50.6	37.0	44.6	20.7
GOA Shortraker Rockfish	14.3	195.0	1.6	0.5	8.4
GOA Rougheye Rockfish	13.3	49.6	3.0	9.7	41.6
GOA Dusky Rockfish	15.7	23.7	13.2	43.2	16.4
GOA Thornyhead Rockfish	22.1	79.7	3.5	2.6	0.2
Sculpin	29.6	21.6	27.3	18.4	10.2
Northern Rockfish	16.7	15.8	5.7	59.4	7.2
GOA Deep Water Flatfish	15.6	26.7	1.6	5.6	12.7
GOA Skate, Other	19.4	5.2	5.9	5.0	3.5
Octopus	4.2	5.7	0.2	6.4	8.3
Other Rockfish	1.9	0.7	0.4	1.6	4.6
Percent non-pollock	*3.9%*	*2.8%*	*2.4%*	*4.2%*	*4.3%*

Non target species/species group	*2015*	*2016*	*2017*	*2018*	*2019*
Giant Grenadier	5.48	864.05	4.75	3.12	9.32
Jellyfish	173.34	158.57	13.96	12.83	121.44
Capelin	93.18	99.25	33.12	77.02	80.62
Miscellaneous fish	59.45	17.76	19.27	55.94	87.81
Rattail Grenadier	7.80	38.74	9.07	25.53	37.68
Other osmerids	13.17	8.78	0.89	24.38	47.00
Sea stars	1.35	3.54	0.81	45.05	2.50
Squid	0.00	0.00	0.00	0.00	47.52
Eulachon	12.22	1.86	2.83	8.68	7.63
State-managed Rockfish	0.00	5.50	0.07	1.53	0.00
Sea anemone unidentified	0.62	2.65	0.00	0.28	0.10
Greenlings	0.00	0.00	0.00	1.56	0.00
Pandalid shrimp	0.17	0.58	0.12	0.28	0.19
Snails	0.06	0.23	0.00	0.05	0.46
Eelpouts	0.76	0.00	0.00	0.01	0.00
Surf smelt	0.13	0.04	0.38	0.00	0.15
Bivalves	0.00	0.00	0.00	0.00	0.62
Sponge unidentified	0.20	0.08	0.00	0.00	0.00
Corals, Bryozoans	0.02	0.17	0.00	0.00	0.00
Miscellaneous crabs	0.01	0.00	0.00	0.00	0.12
Brittle star unidentified	0.00	0.00	0.07	0.00	0.00

Table 1.3. Bycatch of prohibited species for the directed pollock fishery in the Gulf of Alaska. Herring and halibut bycatch is reported in metric tons, while crab and salmon are reported in number of fish.

Species/species group	*2015*	*2016*	*2017*	*2018*	*2019*
Bairdi Tanner Crab (nos.)	2,616	3,626	3,281	6,832	41,889
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	13,650	20,840	21,575	14,846	20,983
Golden (Brown) King Crab (nos.)	0	581	9	1	0
Halibut (t)	187.8	243.5	120.4	340.6	274.0
Herring (t)	77.4	142.9	5.4	41.8	64.3
Non-Chinook Salmon (nos.)	896	1957	4455	8308	5056
Opilio Tanner (Snow) Crab (nos.)	0	184	0	0	0
Red King Crab (nos.)	0	0	0	0	0

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska 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
2010	Retained	25,960	28,033	18,414	1,625	1,660	2	75,693	
	Discarded	90	216	724	12	9	3	1,055	1.4%
	Total	26,050	28,249	19,138	1,637	1,669	5	76,748	
2011	Retained	20,472	36,397	19,013	2,268	1,535	0	79,684	
	Discarded	125	849	838	4	1	2	1,819	2.2%
	Total	20,597	37,247	19,851	2,271	1,536	2	81,503	
2012	Retained	27,352	44,779	25,125	2,380	2,624	0	102,261	
	Discarded	521	301	856	12	3	1	1,693	1.6%
	Total	27,873	45,080	25,981	2,392	2,627	1	103,954	
2013	Retained	7,644	52,692	28,169	2,933	2,622	0	94,062	
	Discarded	67	433	1,792	7	0	2	2,301	2.4%
	Total	7,711	53,125	29,962	2,940	2,623	2	96,363	
2014	Retained	13,228	82,611	41,791	1,314	2,368	0	141,312	
	Discarded	136	470	712	3	3	3	1,328	0.9%
	Total	13,364	83,081	42,503	1,317	2,371	3	142,640	
2015	Retained	28,679	80,950	51,973	248	4,455	0	166,305	
	Discarded	60	489	657	1	33	3	1,244	0.7%
	Total	28,739	81,439	52,630	250	4,488	3	167,549	
2016	Retained	61,019	46,810	64,281	121	3,893	0	176,123	
	Discarded	233	214	529	12	14	3	1,005	0.6%
	Total	61,252	47,024	64,810	133	3,907	3	177,129	
2017	Retained	49,246	80,855	52,338	39	1,881	0	184,359	
	Discarded	297	748	733	0	16	2	1,796	1.0%
	Total	49,542	81,603	53,071	40	1,897	2	186,155	
2018	Retained	30,580	79,024	39,325	4,054	3,086	0	156,069	
	Discarded	94	1,030	769	71	35	1	2,000	1.3%
	Total	30,675	80,053	40,094	4,125	3,122	1	158,070	
2019	Retained	21,723	63,610	24,259	6,424	2,959	0	118,976	
	Discarded	144	510	403	188	18	3	1,267	1.1%
	Total	21,868	64,120	24,662	6,612	2,978	3	120,243	
Average (2010-2019)		28,767	60,102	37,270	2,172	2,722	3	131,035	

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

							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
2018	1.11	3.13	0.17	0.79	35.52	160.14	7.28	1.55	0.23	0.10	0.00	0.00	0.00	0.00	0.00	210.03
2019	0.44	10.41	7.23	1.22	0.85	20.00	101.70	8.86	1.09	0.34	0.00	0.00	0.00	0.00	0.00	152.15

Table 1.6. Number of aged and measured fish in the Gulf of Alaska 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
2018	1,254	1,008	2,262	16,022	13,024	29,046
2019	1,175	936	2,111	13,989	11,875	25,864

Table 1.7. Biomass estimates (t) of walleye pollock from acoustic surveys in Shelikof Strait, summer gulfwide acoustic surveys, NMFS bottom trawl surveys (west of 140 W. long.), egg production surveys in Shelikof Strait, and ADF&G 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
2019	1,281,083	580,543	257,604		50,960
2020	456,713				59,377

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
2019	541	446	0.24	247	224	473	6,994	8,748	16,509

Table 1.9. Estimated number at age (millions) from the NMFS bottom trawl survey (top). Estimates are for the Western and Central Gulf of Alaska only (Management areas 610-630). Estimated number at age (millions) from the summer acoustic survey (bottom).

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
2019	126.12	69.72	27.32	15.63	10.24	28.95	178.10	20.40	3.11	0.07	0.29	0.00	0.00	0.14	0.00	480.08

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Total*
2013	7793.36	90.59	366.70	57.03	71.96	106.50	83.88	38.16	10.82	4.49	2.02	2.14	0.59	1.06	0.24	8629.53
2015	6.57	233.41	3014.34	123.34	76.21	36.66	17.57	18.33	12.87	7.23	0.95	1.10	0.00	0.00	0.00	3548.56
2017	717.32	0.80	0.98	118.58	1702.37	88.19	12.71	1.36	0.00	0.67	0.38	0.00	0.00	0.00	0.00	2643.36
2019	2894.31	1303.13	95.89	7.05	4.95	54.69	255.27	23.86	1.70	1.63	0.07	0.00	0.00	0.56	0.00	4643.10

Table 1.10. Estimated number at age (millions) for the acoustic survey in Shelikof Strait. Estimates starting in 2008 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
2019	7,361.19	1,671.67	155.54	6.05	6.58	261.73	1,127.49	53.86	11.09	9.01	0.07	0.07	0.00	0.00	0.00	10,664.36
2020	17.07	79.98	343.50	71.73	15.44	26.80	68.15	191.69	116.13	36.98	7.99	2.73	0.00	0.00	0.00	978.19

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 starting in 1992.

Year	No. of midwater tows	No. of bottom trawl tows	Survey biomass CV	Number aged Males	Number aged Females	Total	Number lengthed Males	Number lengthed Females	Total
1981	38	13	0.12	1,921	1,815	3,736	NA	NA	NA
1983	40	0	0.16	1,642	1,103	2,745	NA	NA	NA
1984	45	0	0.18	1,739	1,622	3,361	NA	NA	NA
1985	57	0	0.14	1,055	1,187	2,242	NA	NA	NA
1986	39	0	0.22	642	618	1,260	NA	NA	NA
1987	27	0	---	557	643	1,200	NA	NA	NA
1988	26	0	0.17	537	464	1,001	NA	NA	NA
1989	21	0	0.10	582	545	1,127	NA	NA	NA
1990	28	13	0.17	1,034	1,181	2,215	NA	NA	NA
1991	16	2	0.35	468	567	1,035	NA	NA	NA
1992	17	8	0.04	784	765	1,549	NA	NA	NA
1993	22	2	0.05	583	624	1,207	NA	NA	NA
1994	44	9	0.05	553	632	1,185	NA	NA	NA
1995	22	3	0.05	599	575	1,174	NA	NA	NA
1996	30	8	0.04	724	775	1,499	NA	NA	NA
1997	16	14	0.04	682	853	1,535	5,380	6,104	11,484
1998	22	9	0.04	863	784	1,647	5,487	4,946	10,433
2000	31	0	0.05	422	363	785	6,007	5,196	11,203
2001	17	9	0.05	314	378	692	4,531	4,584	9,115
2002	18	1	0.07	278	326	604	2,876	2,871	5,747
2003	17	2	0.05	288	321	609	3,554	3,724	7,278
2004	13	2	0.09	492	440	932	3,838	2,552	6,390
2005	22	1	0.04	543	335	878	2,714	2,094	4,808
2006	17	2	0.04	295	487	782	2,527	3,026	5,553
2007	9	1	0.06	335	338	673	2,145	2,194	4,339
2008	10	2	0.06	171	248	419	1,641	1,675	3,316
2009	9	3	0.06	254	301	555	1,583	1,632	3,215
2010	13	2	0.03	286	244	530	2,590	2,358	4,948
2012	8	3	0.08	235	372	607	1,727	1,989	3,716
2013	29	5	0.05	376	386	778	2,198	2,436	8,158
2014	19	2	0.05	389	430	854	3,940	3,377	10,841
2015	20	0	0.04	354	372	755	4,556	4,227	8,936
2016	19	0	0.07	269	337	606	2,106	3,452	8,405
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
2019	19	7	0.07	378	413	896	929	977	7,595
2020	23	0	0.05	275	237	524	628	537	1,196

Table 1.12. Estimated proportions at age for the ADF&G crab/groundfish survey.

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
2018	0.0000	0.0653	0.0235	0.0218	0.1005	0.5930	0.1357	0.0469	0.0050	0.0067	0.0017	0.0000	0.0000	0.0000	0.0000	597

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

		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 for GOA pollock 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 GOA. Estimates from 2003 to the present are based on a GLM model using local abundance weighting.

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	0.026	0.077	0.211	0.461	0.732	0.897	0.965	0.989	0.996	301
2004	0.081	0.221	0.480	0.749	0.906	0.969	0.990	0.997	0.999	444
2005	0.037	0.130	0.373	0.702	0.903	0.974	0.993	0.998	1.000	321
2006	0.004	0.023	0.124	0.466	0.842	0.970	0.995	0.999	1.000	476
2007	0.006	0.040	0.221	0.661	0.931	0.989	0.998	1.000	1.000	313
2008	0.001	0.009	0.060	0.321	0.779	0.963	0.995	0.999	1.000	240
2009	0.002	0.014	0.085	0.382	0.805	0.965	0.995	0.999	1.000	296
2010	0.003	0.033	0.265	0.791	0.976	0.998	1.000	1.000	1.000	314
2012	0.008	0.069	0.396	0.853	0.981	0.998	1.000	1.000	1.000	372
2013	0.000	0.009	0.210	0.884	0.995	1.000	1.000	1.000	1.000	622
2014	0.002	0.015	0.088	0.388	0.806	0.964	0.994	0.999	1.000	430
2015	0.018	0.087	0.323	0.706	0.924	0.984	0.997	0.999	1.000	372
2016	0.001	0.037	0.592	0.982	1.000	1.000	1.000	1.000	1.000	269
2017	0.232	0.594	0.877	0.972	0.994	0.999	1.000	1.000	1.000	423
2018	0.017	0.126	0.551	0.912	0.989	0.999	1.000	1.000	1.000	404
2019	0.002	0.019	0.159	0.644	0.946	0.994	0.999	1.000	1.000	551
2020	0.002	0.015	0.123	0.559	0.920	0.990	0.999	1.000	1.000	237
Average										
All years	0.013	0.055	0.273	0.611	0.862	0.941	0.979	0.989	0.994	
2011-2020	0.031	0.108	0.369	0.767	0.950	0.992	0.999	1.000	1.000	
2016-2020	0.051	0.158	0.460	0.814	0.970	0.996	1.000	1.000	1.000	

Table 1.16. Fishery weight at age (kg) for GOA pollock.

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	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
2018	0.098	0.372	0.479	0.593	0.726	0.769	0.825	1.003	1.004	1.135
2019	0.111	0.300	0.522	0.624	0.815	0.816	0.838	0.869	1.071	1.022

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

	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
2019	0.008	0.061	0.221	0.493	0.637	0.701	0.736	0.789	0.879	1.044
2020	0.015	0.072	0.172	0.311	0.480	0.711	0.808	0.806	0.800	0.848

Table 1.18. Weight at age (kg) of pollock in the (A) summer NMFS bottom trawl survey and (B) summer acoustic survey.

(A)

	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
2019	0.045	0.172	0.412	0.610	0.689	0.754	0.846	0.877	1.108	1.790

(B)

	Age									
Year	1	2	3	4	5	6	7	8	9	10
2013	0.028	0.235	0.498	0.812	1.128	1.257	1.364	1.443	1.465	1.783
2015	0.046	0.237	0.395	0.584	0.765	1.004	1.199	1.282	1.319	1.421
2017	0.035	0.374	0.393	0.614	0.681	0.794	1.028	1.251	1.829	1.154
2019	0.038	0.140	0.330	0.557	0.647	0.741	0.779	0.809	0.984	1.188

Table 1.19. Estimated selectivity at age for GOA pollock fisheries and surveys. The fisheries and surveys were modeled using double logistic selectivity functions. Acoustic survey catchablity at age 1 and age 2 are estimated separately.

Age	*Foreign (1970-81)*	*Foreign and JV (1982-1988)*	*Domestic (1989-2000)*	*Domestic (2001-2014)*	*Recent domestic (2015-2019)*	*Shelikof acoustic survey*	*Summer acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.004	0.002	0.009	0.002	0.358	1.000	0.132	0.005
2	0.011	0.027	0.012	0.064	0.017	0.415	1.000	0.230	0.020
3	0.117	0.177	0.073	0.332	0.157	1.000	1.000	0.371	0.074
4	0.606	0.623	0.338	0.779	0.668	1.000	1.000	0.539	0.236
5	0.948	0.928	0.769	0.966	0.958	1.000	1.000	0.700	0.545
6	0.997	0.992	0.963	0.997	0.998	0.998	1.000	0.826	0.823
7	1.000	1.000	1.000	1.000	1.000	0.988	1.000	0.909	0.948
8	0.985	0.986	0.991	0.985	0.985	0.936	1.000	0.958	0.987
9	0.847	0.848	0.853	0.848	0.847	0.720	1.000	0.986	0.997
10	0.338	0.338	0.340	0.338	0.338	0.309	1.000	1.000	1.000

Table 1.20. 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	1,270	316	196	135	96	71	53	40	30	89
1971	3,140	316	159	121	91	66	51	38	28	87
1972	3,613	782	159	98	81	63	47	36	27	85
1973	10,548	900	391	96	60	48	38	29	23	77
1974	2,179	2,627	450	235	57	33	28	22	17	67
1975	2,204	542	1,312	267	131	29	18	15	12	54
1976	8,680	549	271	791	161	76	17	10	9	45
1977	11,758	2,161	274	162	454	86	42	9	6	35
1978	14,433	2,928	1,080	163	90	230	45	22	5	27
1979	25,660	3,594	1,463	641	91	47	122	24	12	21
1980	13,100	6,389	1,796	874	374	50	27	70	14	21
1981	7,302	3,262	3,198	1,090	541	221	31	16	43	24
1982	7,256	1,818	1,633	1,946	691	334	140	19	10	45
1983	4,920	1,807	910	990	1,240	437	219	92	13	39
1984	5,897	1,225	902	544	613	761	278	139	59	36
1985	14,412	1,467	610	532	325	358	458	167	84	63
1986	4,135	3,587	731	362	314	181	203	260	96	94
1987	1,691	1,030	1,794	445	237	206	122	138	178	135
1988	4,723	421	516	1,099	296	159	143	85	96	226
1989	10,919	1,176	211	316	734	199	110	99	60	235
1990	8,182	2,719	589	129	210	487	136	75	69	213
1991	3,180	2,038	1,362	362	86	139	329	92	51	202
1992	2,358	792	1,021	838	241	56	90	212	60	179
1993	1,675	587	397	627	557	155	36	58	138	168
1994	1,697	417	294	243	415	357	100	23	38	212
1995	6,645	422	209	180	161	267	232	65	15	177
1996	3,085	1,655	212	128	121	107	181	157	44	139
1997	1,402	768	829	130	87	81	73	124	108	132
1998	1,339	349	385	507	85	54	51	46	78	163
1999	1,668	333	174	232	312	47	30	28	25	155
2000	6,221	415	166	105	145	180	27	17	16	122
2001	6,640	1,549	208	101	67	88	111	17	11	96
2002	923	1,652	772	124	63	40	54	68	10	74
2003	714	230	822	460	78	39	26	35	44	60
2004	666	177	114	491	294	50	26	17	24	74
2005	1,713	165	88	67	308	187	33	17	12	69
2006	5,539	426	82	51	41	188	118	21	11	57
2007	5,351	1,377	210	47	31	25	119	75	14	48
2008	6,494	1,330	682	123	30	20	16	79	50	44
2009	2,886	1,616	662	406	78	19	13	11	54	67
2010	1,094	718	807	399	265	52	13	9	8	87
2011	4,644	272	358	481	255	173	36	9	6	69
2012	747	1,156	136	215	307	165	116	24	6	54
2013	39,489	186	578	82	135	194	108	76	16	43
2014	2,269	9,834	93	351	52	85	127	71	50	42
2015	43	565	4,922	56	211	30	50	74	42	60
2016	5	11	283	2,957	33	116	17	28	42	66
2017	2,207	1	5	171	1,825	20	72	10	18	74
2018	6,965	550	1	3	105	1,098	12	45	7	64
2019	5,746	1,734	275	0	2	62	667	8	28	49
2020	104	1,431	865	162	0	1	37	397	5	51
Average	5,677	1,419	699	414	260	162	103	65	38	90

Table 1.21. 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.

						2019 Assessment results			
Year	*3+ total biomass (1,000 t)*	*Female spawn. biom. (1,000 t)*	*Age 1 recruits (million)*	*Catch (t)*	*Harvest rate*	*3+ total biomass*	*Female spawn. biom.*	*Age 1 recruits*	*Harvest rate*
1977	746	136	11,758	118,092	16%	738	135	11,489	16%
1978	965	124	14,433	95,408	10%	951	122	14,008	10%
1979	1,350	130	25,660	106,161	8%	1,323	129	24,828	8%
1980	1,821	181	13,100	115,158	6%	1,775	178	12,674	6%
1981	2,853	201	7,302	147,818	5%	2,766	196	7,061	5%
1982	2,981	330	7,256	169,045	6%	2,885	321	7,011	6%
1983	2,716	464	4,920	215,625	8%	2,622	448	4,799	8%
1984	2,413	516	5,897	307,541	13%	2,321	495	5,710	13%
1985	1,945	469	14,412	286,900	15%	1,864	446	14,125	15%
1986	1,633	425	4,135	86,910	5%	1,556	401	4,117	6%
1987	1,958	397	1,691	68,070	3%	1,881	375	1,713	4%
1988	1,848	399	4,723	63,391	3%	1,780	378	4,790	4%
1989	1,627	412	10,919	75,585	5%	1,571	393	11,030	5%
1990	1,496	421	8,182	88,269	6%	1,452	403	8,272	6%
1991	1,782	412	3,180	100,488	6%	1,754	396	3,186	6%
1992	1,855	371	2,358	90,858	5%	1,839	360	2,365	5%
1993	1,744	399	1,675	108,909	6%	1,733	393	1,662	6%
1994	1,477	468	1,697	107,335	7%	1,471	464	1,677	7%
1995	1,207	390	6,645	72,618	6%	1,203	387	6,608	6%
1996	1,016	359	3,085	51,263	5%	1,012	358	3,066	5%
1997	1,042	318	1,402	90,130	9%	1,037	317	1,393	9%
1998	1,003	246	1,339	125,460	13%	998	245	1,338	13%
1999	744	229	1,668	95,638	13%	740	228	1,670	13%
2000	655	217	6,221	73,080	11%	652	216	6,218	11%
2001	623	203	6,640	72,077	12%	620	201	6,601	12%
2002	798	169	923	51,934	7%	795	168	926	7%
2003	999	156	714	50,684	5%	994	156	713	5%
2004	832	172	666	63,844	8%	829	172	668	8%
2005	691	210	1,713	80,978	12%	688	209	1,699	12%
2006	583	224	5,539	71,976	12%	580	223	5,432	12%
2007	539	196	5,351	52,714	10%	537	195	5,149	10%
2008	748	194	6,494	52,584	7%	741	193	6,249	7%
2009	1,068	191	2,886	44,247	4%	1,046	190	2,747	4%
2010	1,264	264	1,094	76,748	6%	1,230	260	1,044	6%
2011	1,203	309	4,644	81,503	7%	1,164	302	4,600	7%
2012	1,112	330	747	103,954	9%	1,072	319	663	10%
2013	1,126	353	39,489	96,363	9%	1,087	339	36,171	9%
2014	882	268	2,269	142,640	16%	848	256	2,089	17%
2015	2,363	243	43	167,549	7%	2,186	231	35	8%
2016	2,365	260	5	177,129	7%	2,171	243	4	8%
2017	1,721	356	2,207	186,155	11%	1,563	324	1,944	12%
2018	1,151	340	6,965	158,070	14%	1,097	302	5,339	14%
2019	850	263	5,746	120,243	14%	941	227	9,391	13%
2020	932	184	104						
Average									
1977-2019	1,391	296	5,995	109,561	8%	1,351	286	5,867	9%
1978-2019			5,858					5,733	

Table 1.22. 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	1,270	0.31	699	2,308	128	0.31	70	234
1971	3,140	0.45	1,345	7,330	123	0.32	66	227
1972	3,613	0.38	1,773	7,363	113	0.34	59	215
1973	10,548	0.17	7,621	14,599	96	0.37	48	193
1974	2,179	0.30	1,221	3,889	86	0.34	45	165
1975	2,204	0.28	1,277	3,803	91	0.26	55	150
1976	8,680	0.19	5,969	12,623	121	0.19	84	173
1977	11,758	0.19	8,171	16,920	136	0.19	95	196
1978	14,433	0.19	10,047	20,733	124	0.22	82	189
1979	25,660	0.15	18,995	34,664	130	0.22	85	201
1980	13,100	0.20	8,949	19,177	181	0.20	122	270
1981	7,302	0.24	4,599	11,592	201	0.19	139	289
1982	7,256	0.24	4,590	11,469	330	0.17	239	456
1983	4,920	0.35	2,516	9,620	464	0.16	341	630
1984	5,897	0.32	3,223	10,789	516	0.16	374	711
1985	14,412	0.16	10,458	19,860	469	0.18	329	670
1986	4,135	0.29	2,372	7,208	425	0.20	289	625
1987	1,691	0.43	748	3,821	397	0.19	274	574
1988	4,723	0.23	3,000	7,437	399	0.18	284	561
1989	10,919	0.15	8,177	14,580	412	0.15	308	551
1990	8,182	0.17	5,932	11,286	421	0.14	319	556
1991	3,180	0.27	1,901	5,320	412	0.14	312	545
1992	2,359	0.27	1,393	3,993	371	0.14	283	486
1993	1,675	0.30	936	2,996	399	0.13	311	512
1994	1,697	0.29	963	2,988	468	0.12	369	594
1995	6,645	0.13	5,206	8,483	390	0.12	307	495
1996	3,085	0.17	2,203	4,321	359	0.12	283	456
1997	1,402	0.25	870	2,260	318	0.12	250	405
1998	1,339	0.23	860	2,084	246	0.13	190	318
1999	1,668	0.21	1,114	2,497	229	0.14	176	298
2000	6,221	0.12	4,895	7,904	217	0.14	165	285
2001	6,640	0.11	5,333	8,267	203	0.15	152	271
2002	923	0.29	532	1,602	169	0.16	124	230
2003	714	0.27	428	1,190	156	0.15	116	211
2004	666	0.28	387	1,146	172	0.13	133	223
2005	1,713	0.19	1,180	2,486	210	0.13	163	270
2006	5,539	0.13	4,264	7,194	224	0.14	171	293
2007	5,351	0.14	4,065	7,042	196	0.15	147	263
2008	6,494	0.13	5,010	8,417	194	0.16	143	262
2009	2,886	0.17	2,066	4,032	191	0.15	143	257
2010	1,094	0.27	655	1,828	264	0.13	203	343
2011	4,644	0.16	3,425	6,297	309	0.13	241	398
2012	747	0.32	405	1,377	330	0.13	256	425
2013	39,489	0.10	32,750	47,614	353	0.14	270	462
2014	2,269	0.26	1,365	3,771	268	0.15	201	357
2015	43	0.39	20	89	243	0.16	178	332
2016	5	0.39	3	11	260	0.13	200	339
2017	2,207	0.27	1,305	3,732	356	0.13	275	460
2018	6,965	0.27	4,159	11,662	340	0.14	256	451
2019	5,746	0.30	3,223	10,245	263	0.17	190	364
2020	104	0.44	45	237	184	0.20	125	270

Table 1.23. 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 a average for the bottom trawl survey conducted in June to August. Proportion mature females is the average from winter acoustic survey specimen data.

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2015-2019)*	*Spawning (Avg. 2016-2020)*	*Population (Avg. 2015-2019)*	*Fishery (Est. 2020 from RE model)*	*Proportion mature females*
1	1.39	0.002	0.011	0.039	0.166	0.000
2	0.69	0.017	0.098	0.201	0.146	0.013
3	0.48	0.157	0.244	0.472	0.319	0.055
4	0.37	0.668	0.432	0.625	0.523	0.273
5	0.34	0.958	0.543	0.765	0.665	0.611
6	0.30	0.998	0.670	0.903	0.820	0.862
7	0.30	1.000	0.799	1.071	0.854	0.941
8	0.29	0.985	0.912	1.183	0.854	0.979
9	0.28	0.847	1.112	1.274	0.992	0.989
10+	0.29	0.338	1.150	1.606	1.154	0.994

Table 1.24. Methods used to assess GOA pollock. 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 1990-2019 is the method used by the Plan Team to derive the ABC recommendation given in the SAFE summary chapter.

Year	*Assessment method*	*Basis for catch recommendation in following year*	*B40% (t)*
1977-81	Survey biomass, CPUE trends, M=0.4	MSY = 0.4 * M * Bzero	---
1982	CAGEAN	MSY = 0.4 * M * Bzero	---
1983	CAGEAN	Mean annual surplus production	---
1984	Projection of survey numbers at age	Stabilize biomass trend	---
1985	CAGEAN, projection of survey numbers at age, CPUE trends	Stabilize biomass trend	---
1986	CAGEAN, projection of survey numbers at age	Stabilize biomass trend	---
1987	CAGEAN, projection of survey numbers at age	Stabilize biomass trend	---
1988	CAGEAN, projection of survey numbers at age	10% of exploitable biomass	---
1989	Stock synthesis	10% of exploitable biomass	---
1990	Stock synthesis, reduce *M* to 0.3	10% of exploitable biomass	---
1991	Stock synthesis, assume trawl survey catchability = 1	FMSY from an assumed SR curve	---
1992	Stock synthesis	Max[-Pr(SB<Threshold)+Yld]	---
1993	Stock synthesis	Pr(SB>B20)=0.95	---
1994	Stock synthesis	Pr(SB>B20)=0.95	---
1995	Stock synthesis	Max[-Pr(SB<Threshold)+Yld]	---
1996	Stock synthesis	Amendment 44 Tier 3 guidelines	289,689
1997	Stock synthesis	Amendment 44 Tier 3 guidelines	267,600
1998	Stock synthesis	Amendment 44 Tier 3 guidelines	240,000
1999	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	247,000
2000	AD model builder	Amendment 56 Tier 3 guidelines	250,000
2001	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	245,000
2002	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	240,000
2003	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000
2004	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC}, and stairstep approach for projected ABC increase)	229,000
2005	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	224,000
2006	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	220,000
2007	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	221,000
2008	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	237,000
2009	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000
2010	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	276,000
2011	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	271,000
2012	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	297,000
2013	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	290,000
2014	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	312,000
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
2018	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	221,000
2019	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	194,000

Table 1.25. Projections of GOA pollock spawning biomass, full recruitment fishing mortality, and catch for 2021-2033 under different harvest policies. For these projections, fishery weight at age was assumed to be equal to the estimated weight at age in 2020 for the RE model. All projections begin with initial age composition in 2020 using the base run model with a projected 2020 catch of 108,494 t. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 443,000 t, 177,000 t, 155,000 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}*
2021	184,530	184,530	185,306	189,320	191,626	181,786	183,307
2022	169,577	169,577	178,348	198,844	211,545	162,547	169,154
2023	154,784	154,784	167,065	201,057	223,583	145,895	153,561
2024	145,455	145,455	156,232	200,708	232,544	135,165	139,752
2025	149,841	149,841	155,012	207,511	247,729	135,730	138,463
2026	158,363	158,363	163,260	224,962	274,741	143,734	145,404
2027	165,307	165,307	173,303	243,060	301,110	152,155	153,141
2028	172,068	172,068	187,077	263,325	327,307	163,091	163,682
2029	186,376	186,376	195,058	280,987	352,731	166,724	167,077
2030	190,679	190,679	197,742	291,979	370,795	166,597	166,809
2031	190,963	190,963	200,404	300,616	384,750	167,736	167,863
2032	192,194	192,194	203,331	308,478	397,047	169,295	169,371
2033	193,913	193,913	203,970	313,536	406,086	168,498	168,544
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}*
2021	0.28	0.28	0.21	0.08	0	0.33	0.28
2022	0.26	0.26	0.21	0.08	0	0.30	0.26
2023	0.24	0.24	0.21	0.08	0	0.26	0.28
2024	0.22	0.22	0.21	0.08	0	0.22	0.23
2025	0.21	0.21	0.21	0.08	0	0.19	0.20
2026	0.19	0.19	0.21	0.08	0	0.18	0.18
2027	0.16	0.16	0.21	0.08	0	0.18	0.18
2028	0.12	0.12	0.21	0.06	0	0.17	0.17
2029	0.12	0.12	0.21	0.05	0	0.17	0.17
2030	0.11	0.11	0.21	0.05	0	0.17	0.17
2031	0.11	0.11	0.21	0.05	0	0.17	0.17
2032	0.12	0.12	0.21	0.05	0	0.17	0.17
2033	0.12	0.12	0.21	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}*
2021	105,722	105,722	81,686	30,841	0	123,455	105,722
2022	91,934	91,934	77,192	31,447	0	100,599	91,934
2023	74,493	74,493	70,163	31,091	0	78,836	86,377
2024	76,034	76,034	73,209	33,414	0	79,593	82,809
2025	86,651	86,651	78,809	36,413	0	87,624	89,067
2026	92,659	92,659	86,872	40,355	0	100,228	100,896
2027	95,501	95,501	93,894	43,409	0	111,268	111,533
2028	99,151	99,151	104,099	46,519	0	125,427	125,539
2029	113,175	113,175	103,380	46,992	0	120,608	120,666
2030	108,452	108,452	104,210	47,423	0	121,689	121,723
2031	109,624	109,624	105,099	48,138	0	122,856	122,876
2032	110,950	110,950	105,628	48,466	0	123,932	123,943
2033	111,683	111,683	103,895	48,027	0	121,357	121,363

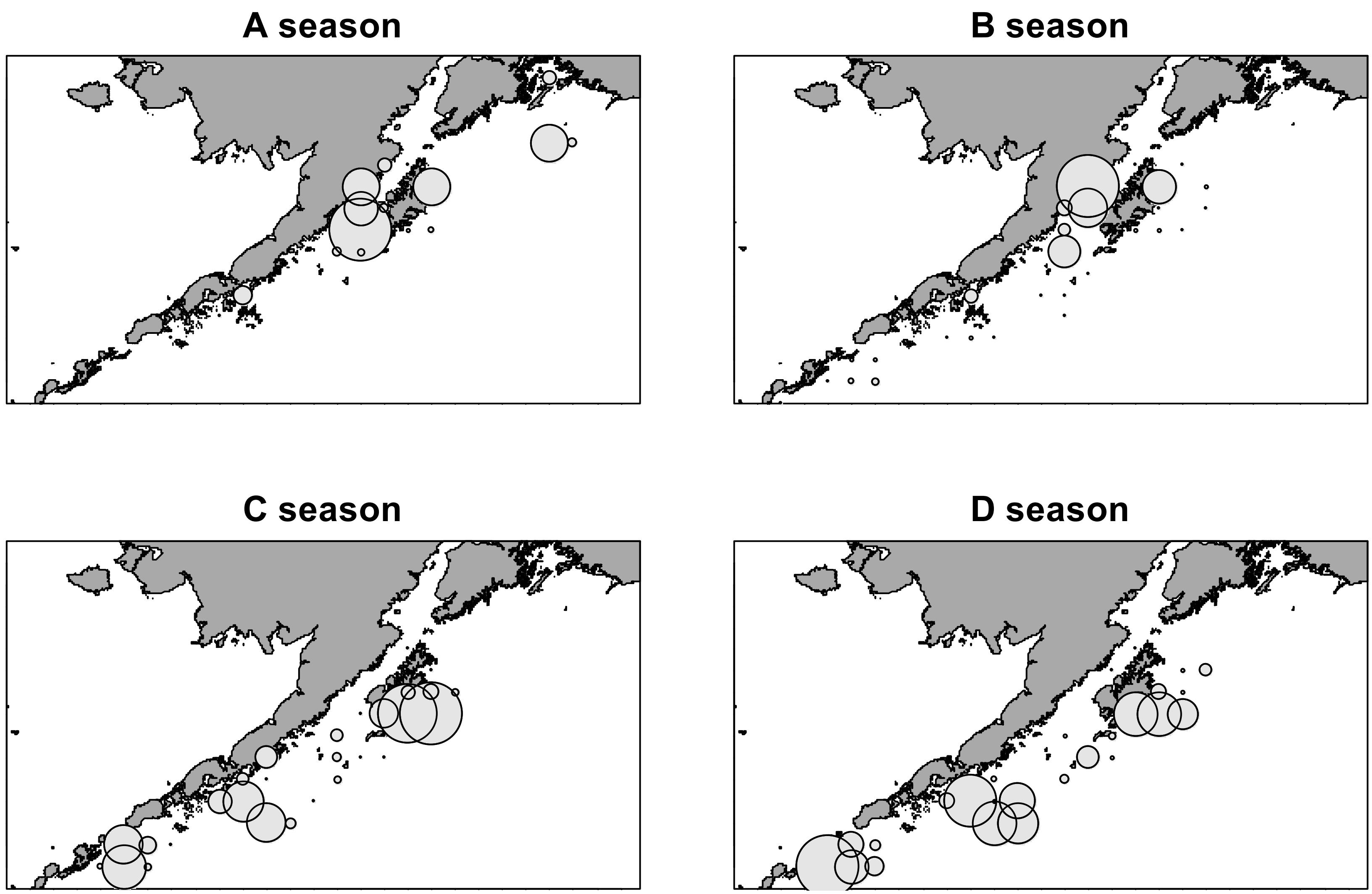


Figure 1.1. Pollock catch in 2019 for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

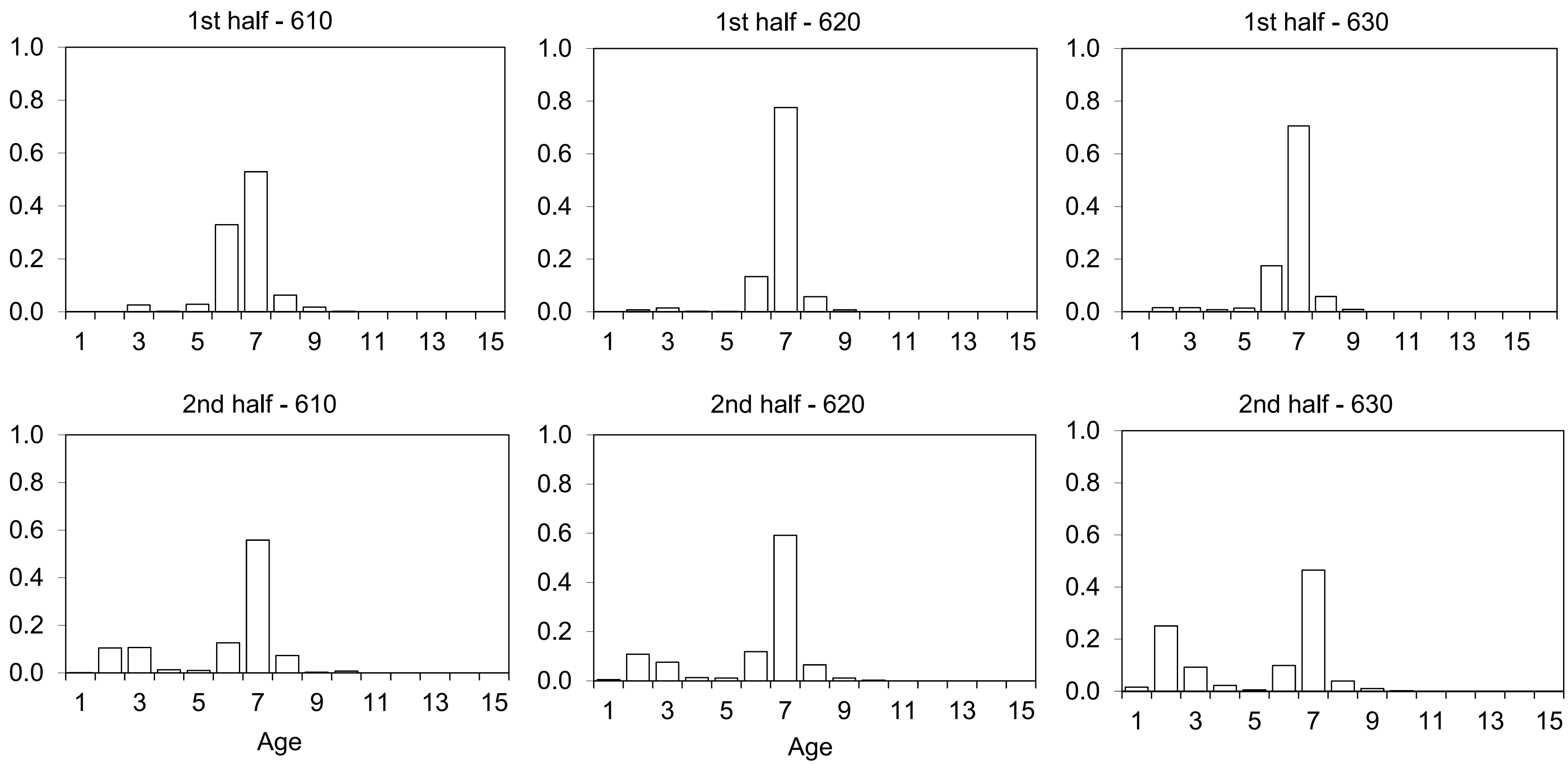


Figure 1.2. 2019 fishery age composition by half year (January-June, July-December) and management area.

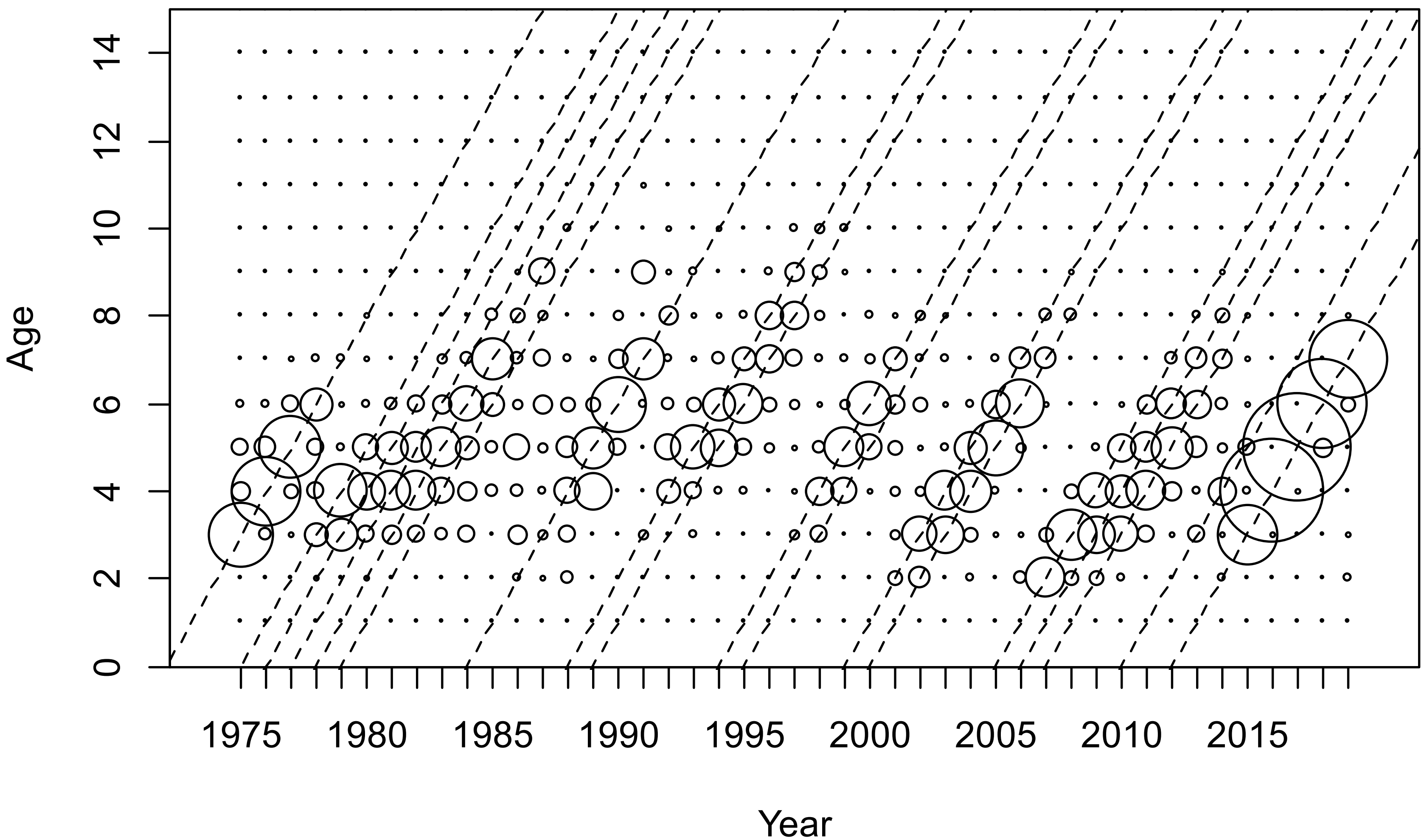


Figure 1.3. GOA pollock fishery age composition (1975-2019). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes.

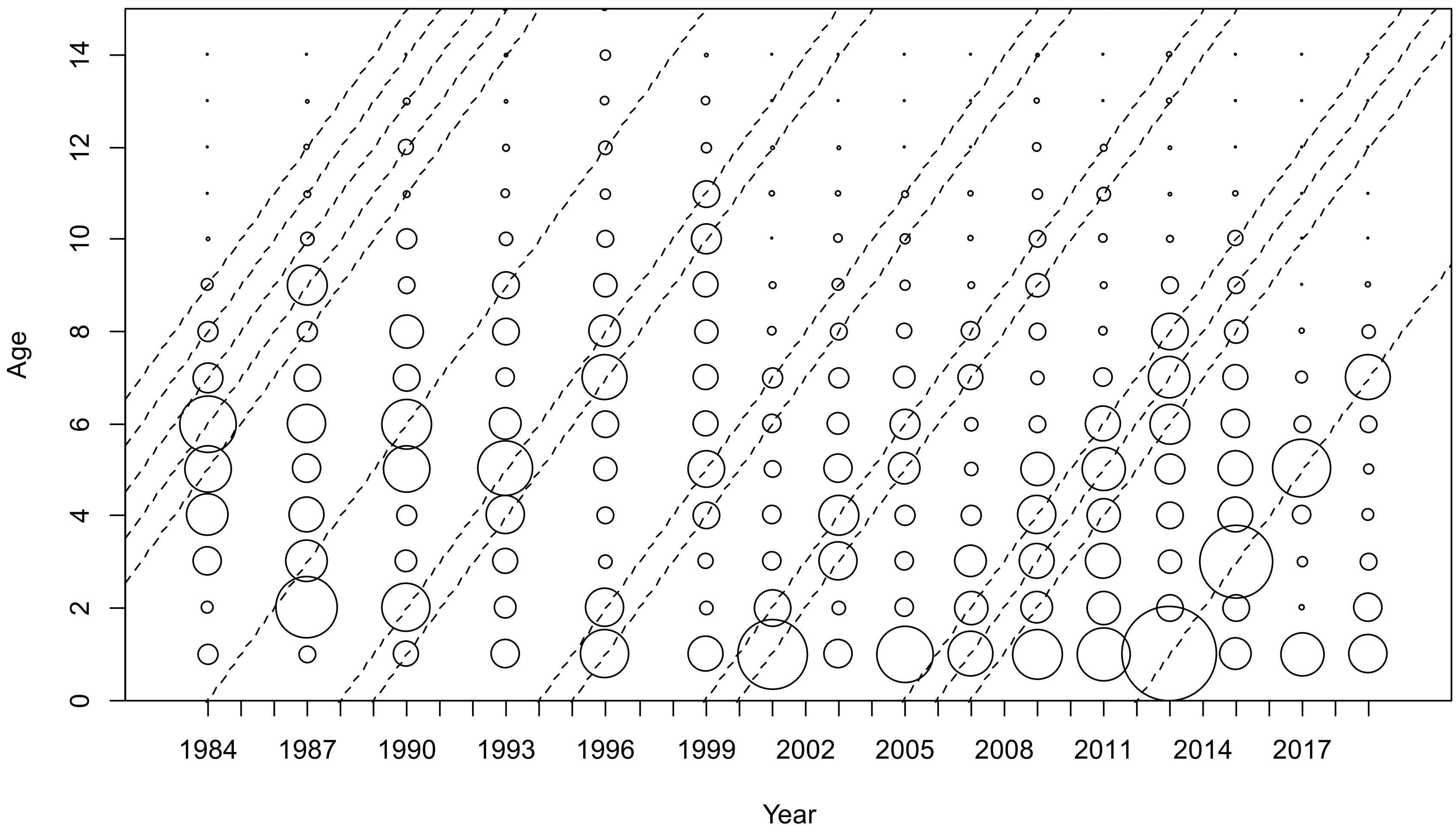


Figure 1.4. Estimated abundance at age in the NMFS bottom trawl survey (1984-2019). The area of the circle is proportional to the estimated abundance.

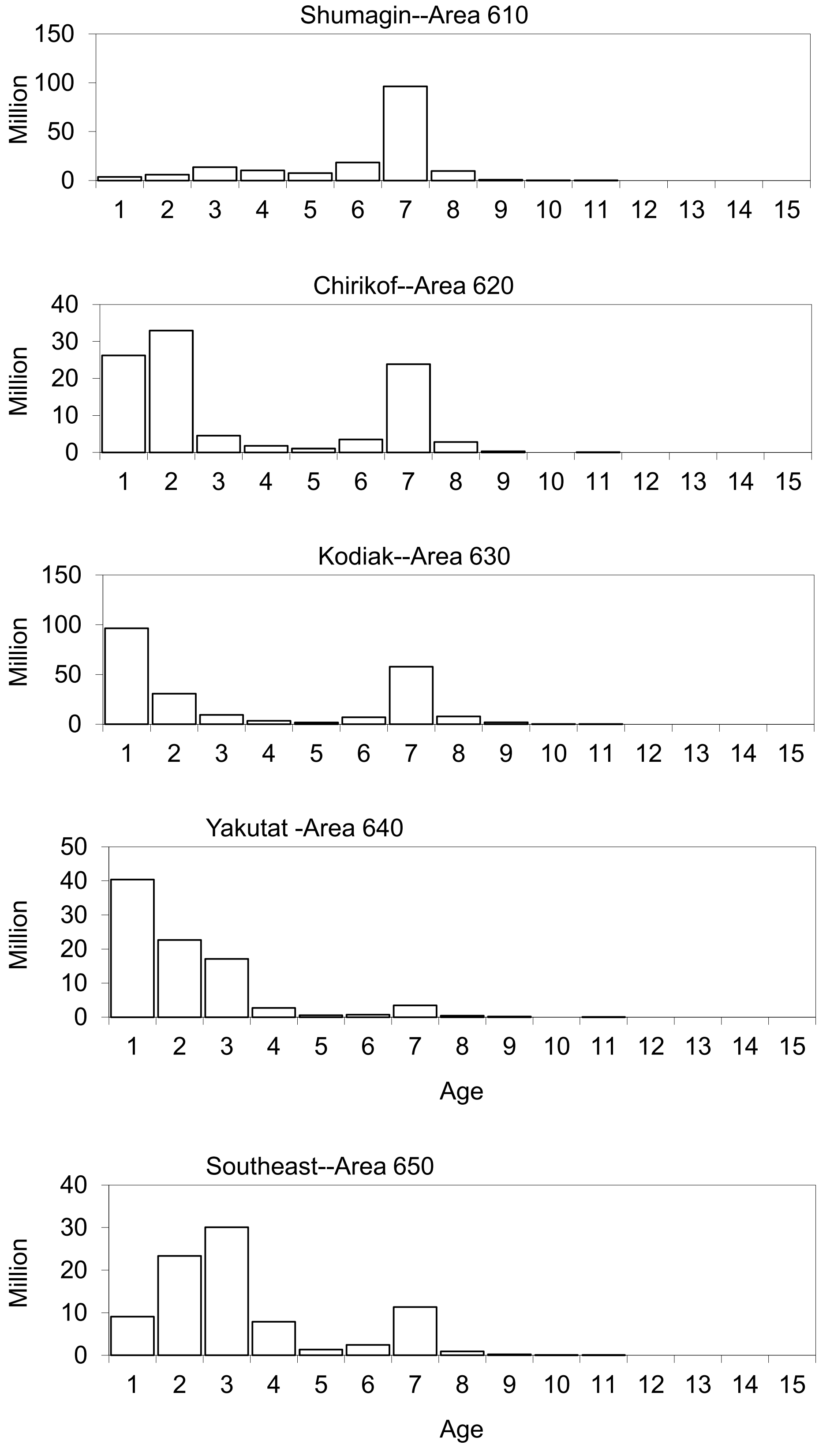


Figure 1.5. Age composition of pollock by statistical area for the 2019 NMFS bottom trawl survey.

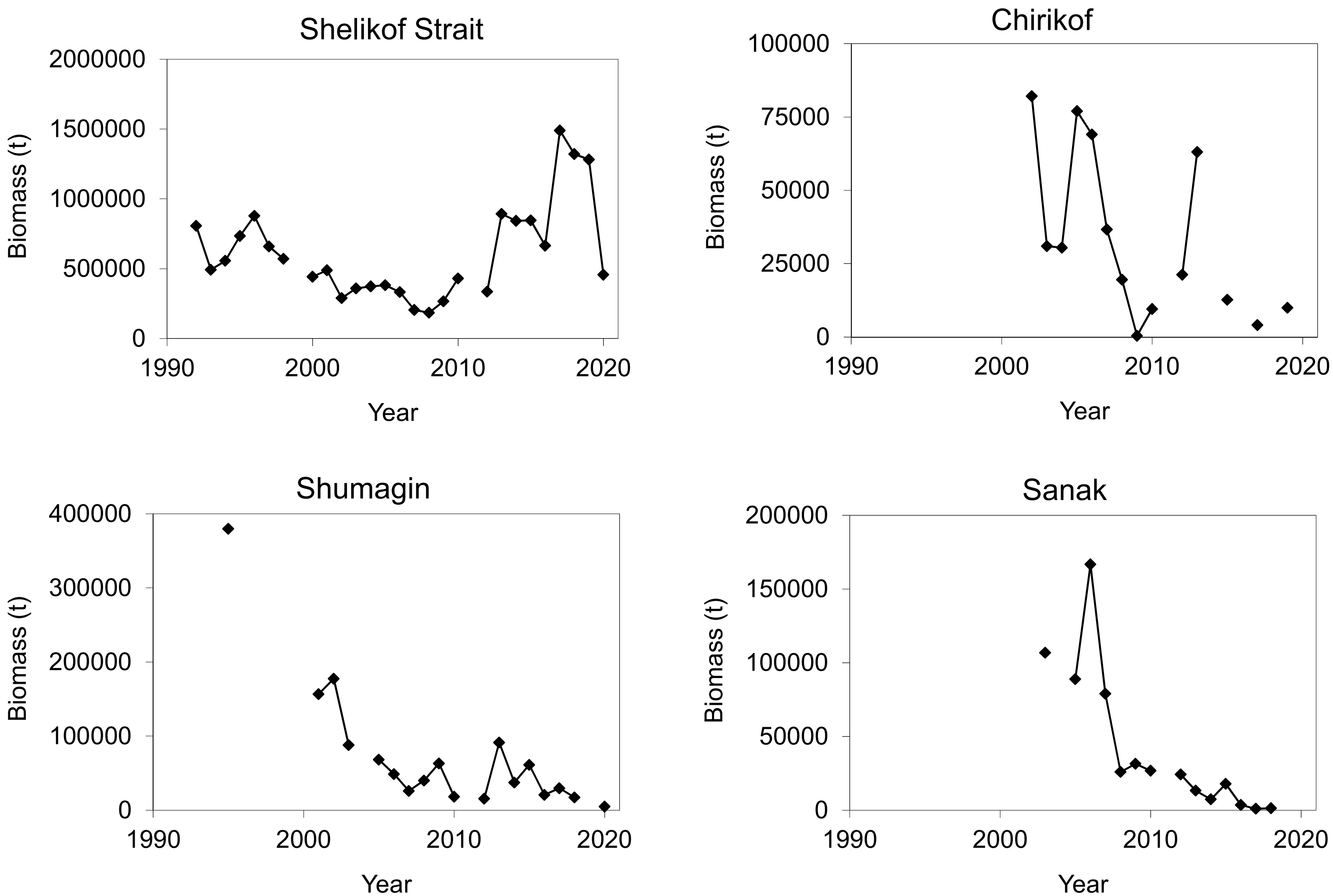


Figure 1.6. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

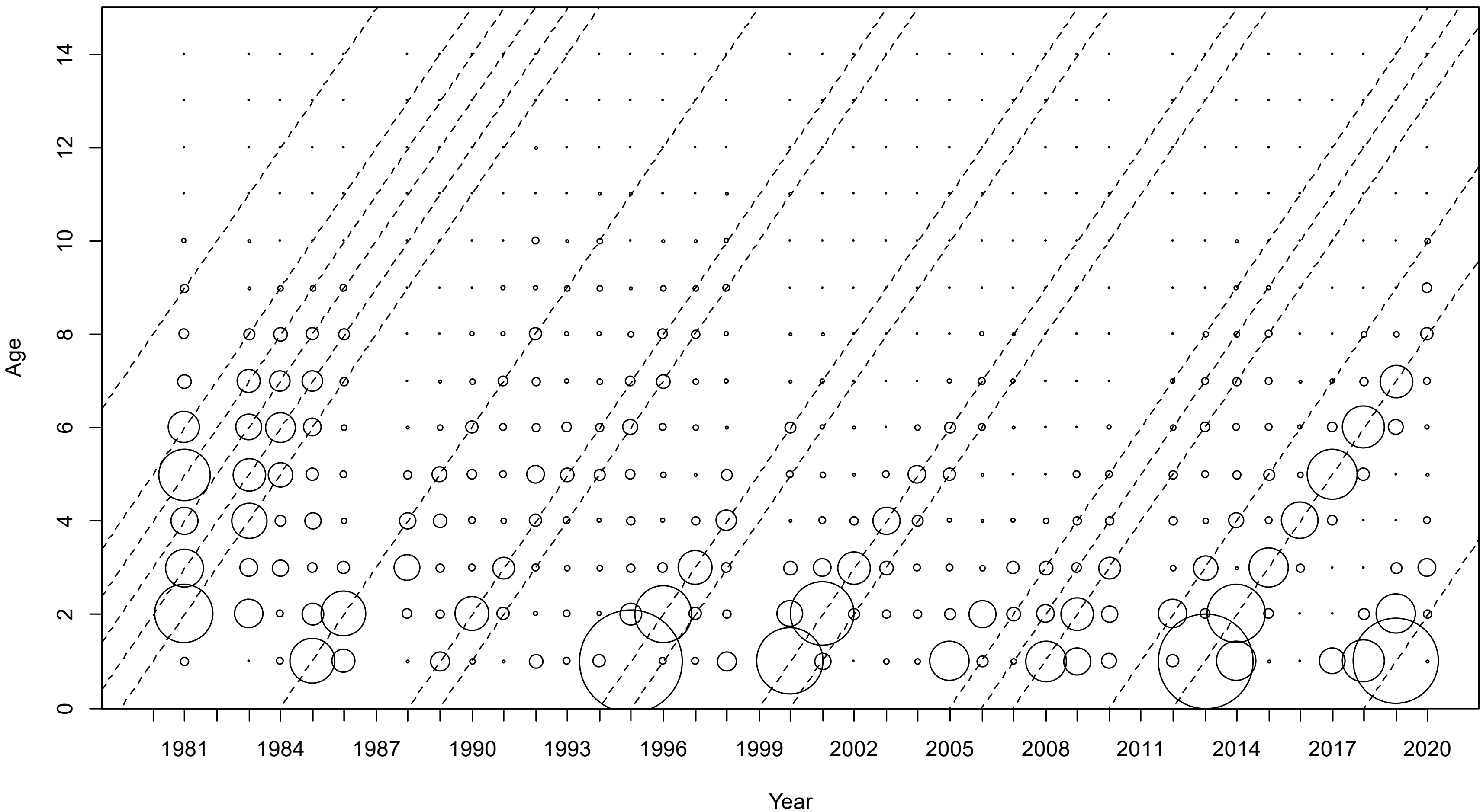


Figure 1.7. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2020, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

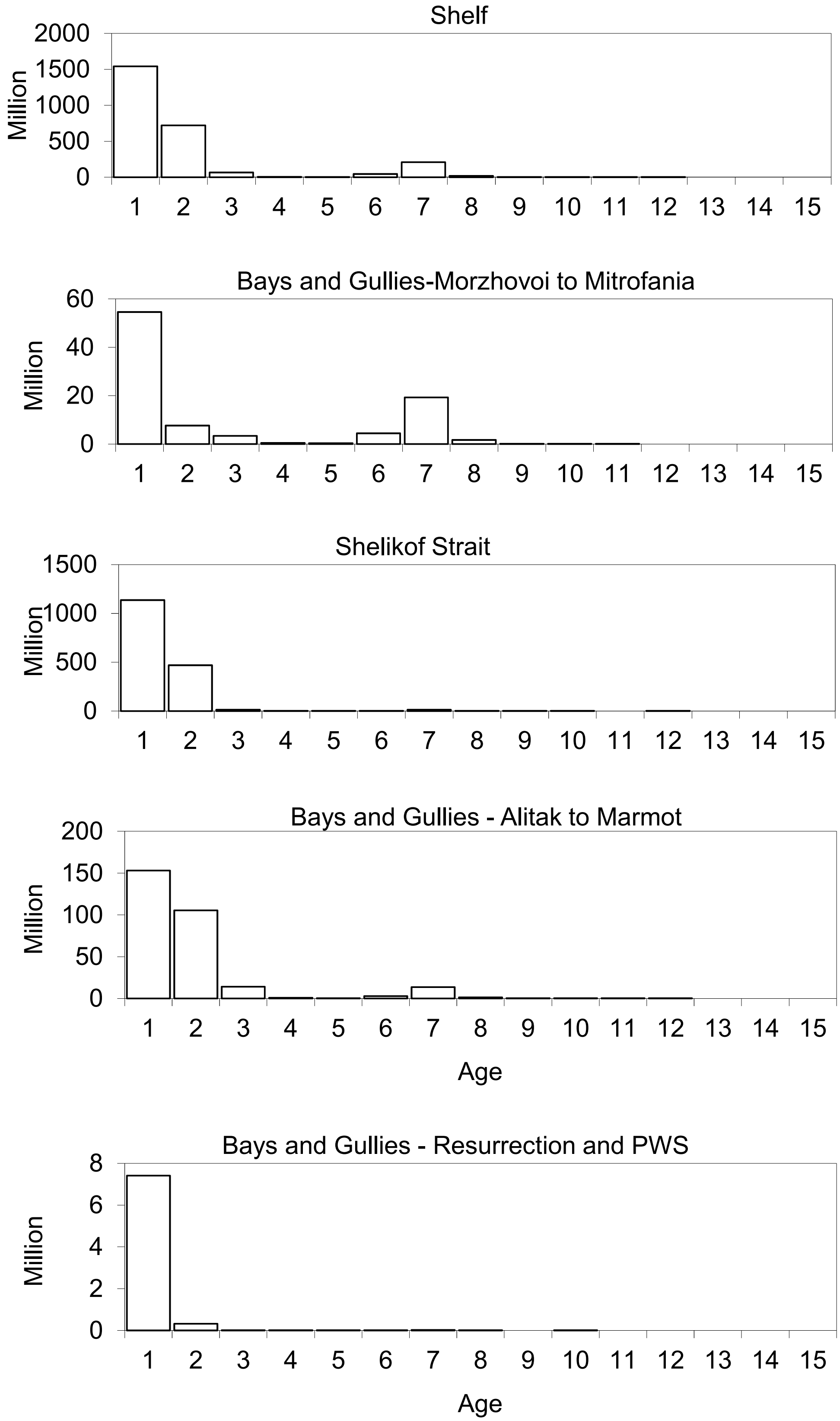


Figure 1.8. Age composition of pollock by survey strata for the 2019 summer acoustic survey.

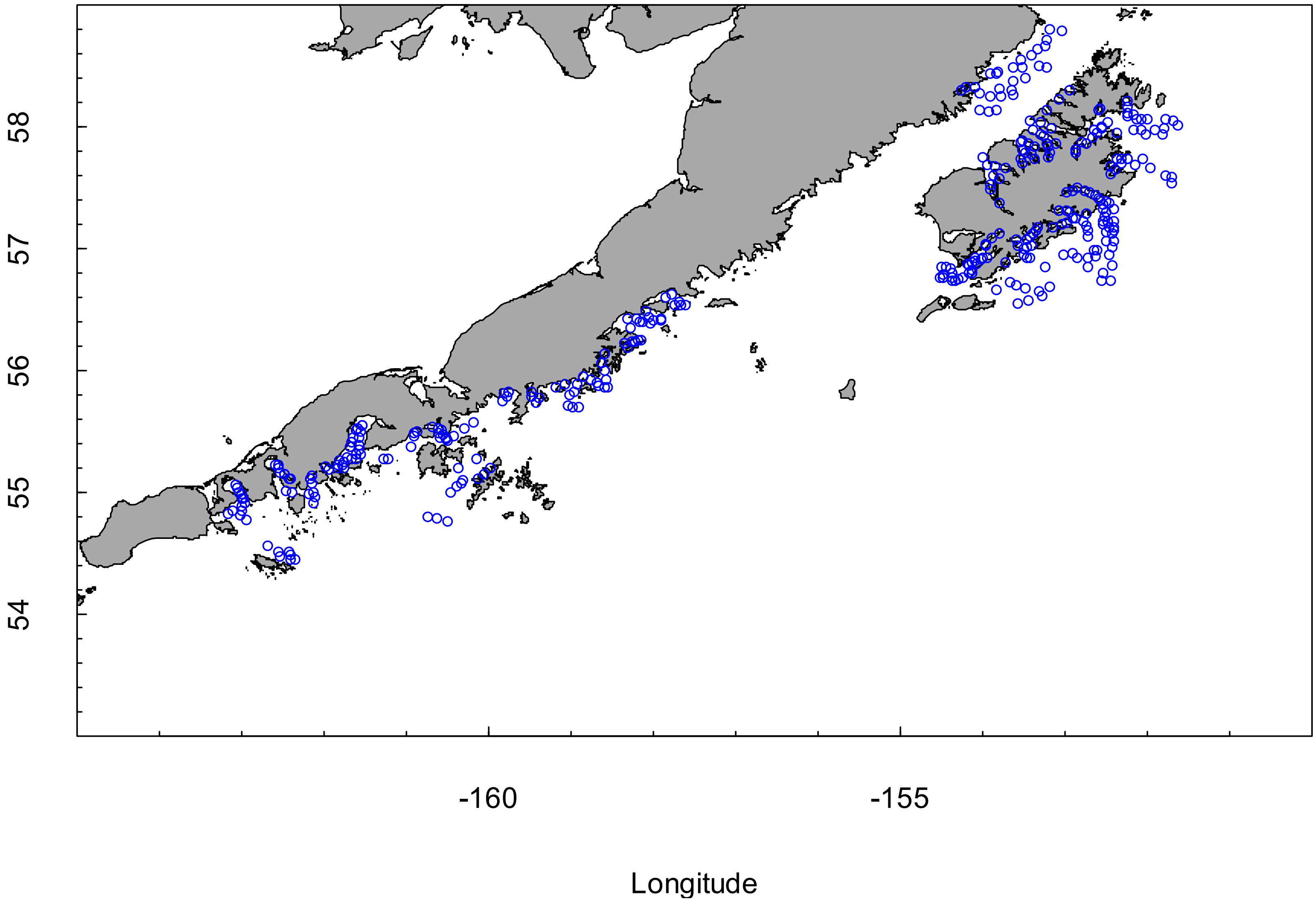


Figure 1.9. Tow locations for the 2020 ADF&G crab/groundfish trawl survey.

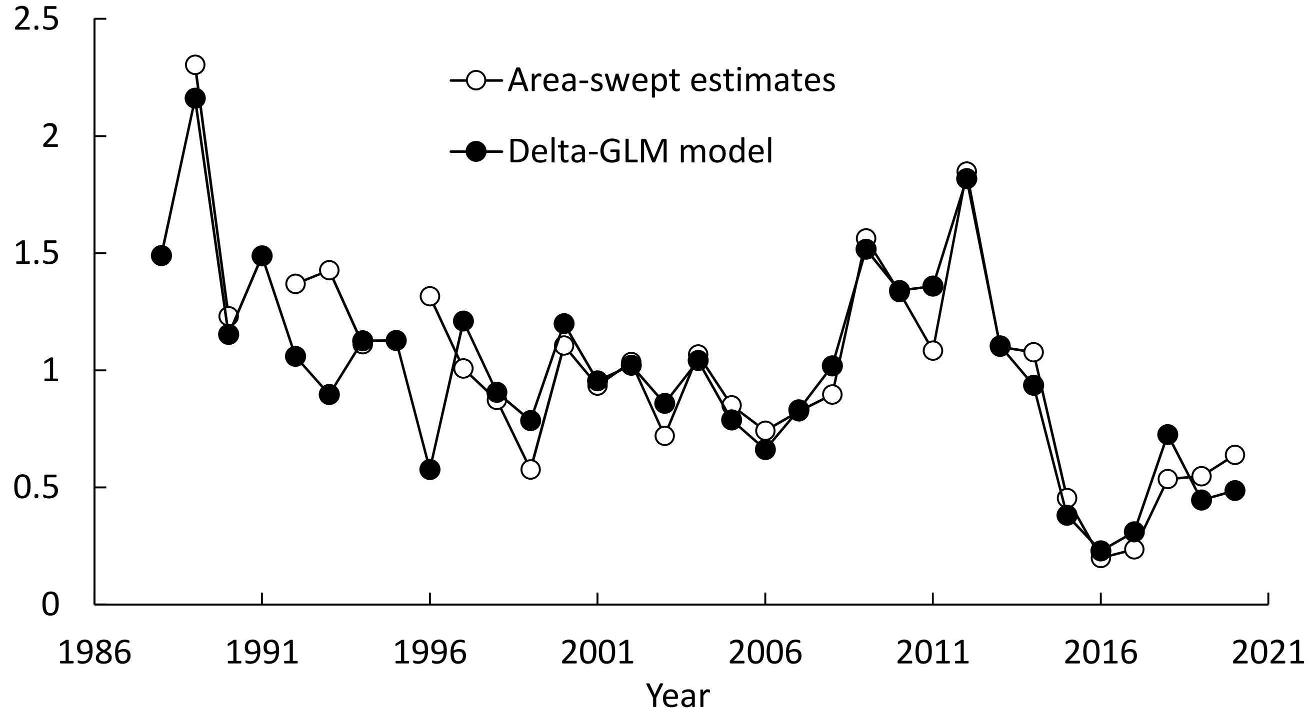


Figure 1.10. Comparison of ADF&G crab/groundfish trawl area-swept indices with year indices for a delta GLM model with a gamma error assumption for the positive observations. Both time series have been scaled by the mean for the time series.

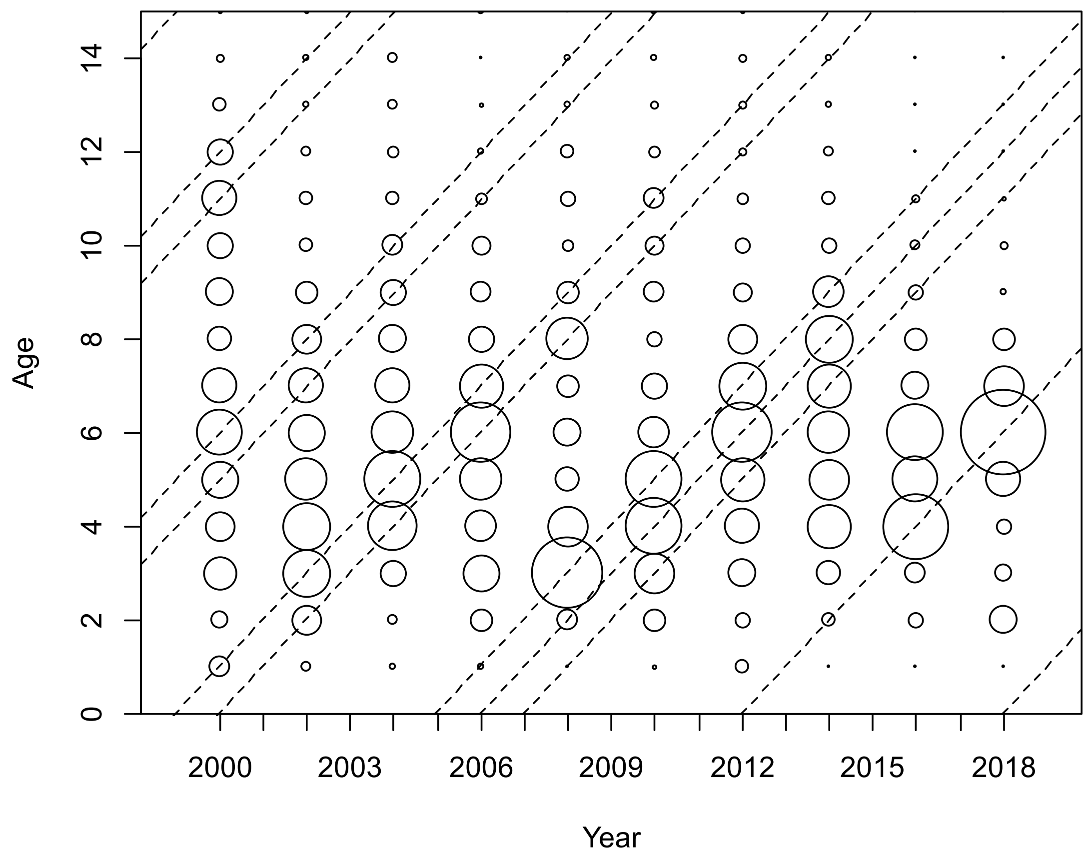


Figure 1.11. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2018). The area of the circle is proportional to the estimated abundance.

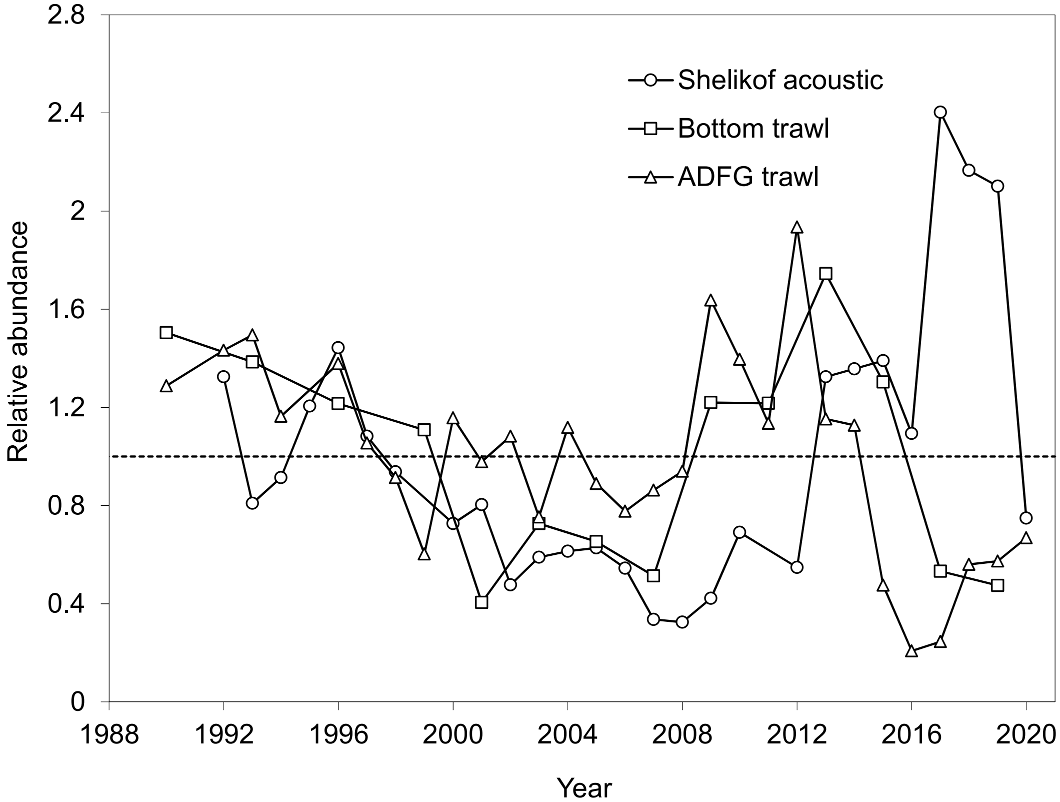


Figure 1.12. Relative trends in pollock biomass since 1990 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1990. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the R/V Oscar Dyson.

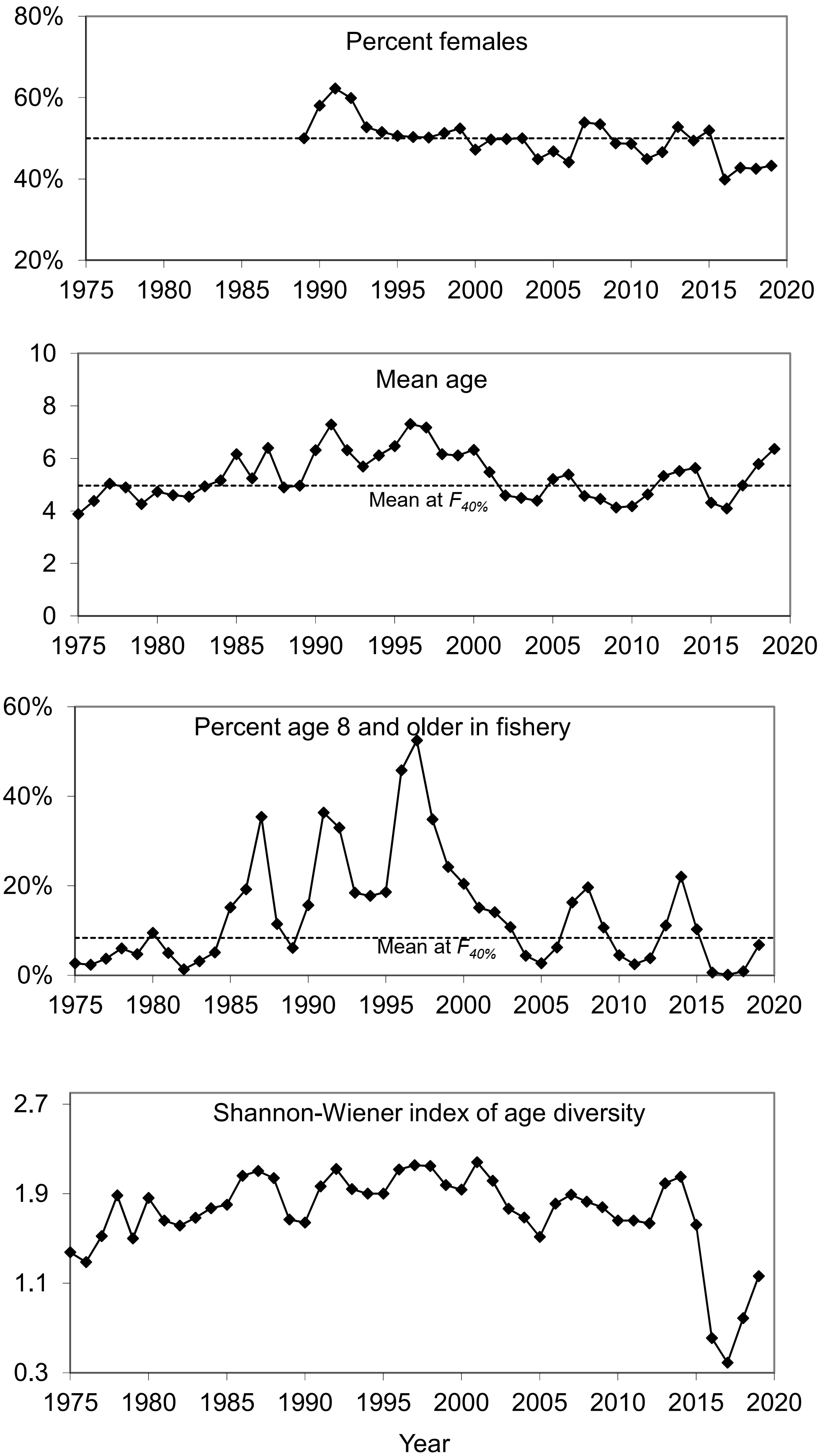


Figure 1.13. GOA pollock fishery catch characteristics.

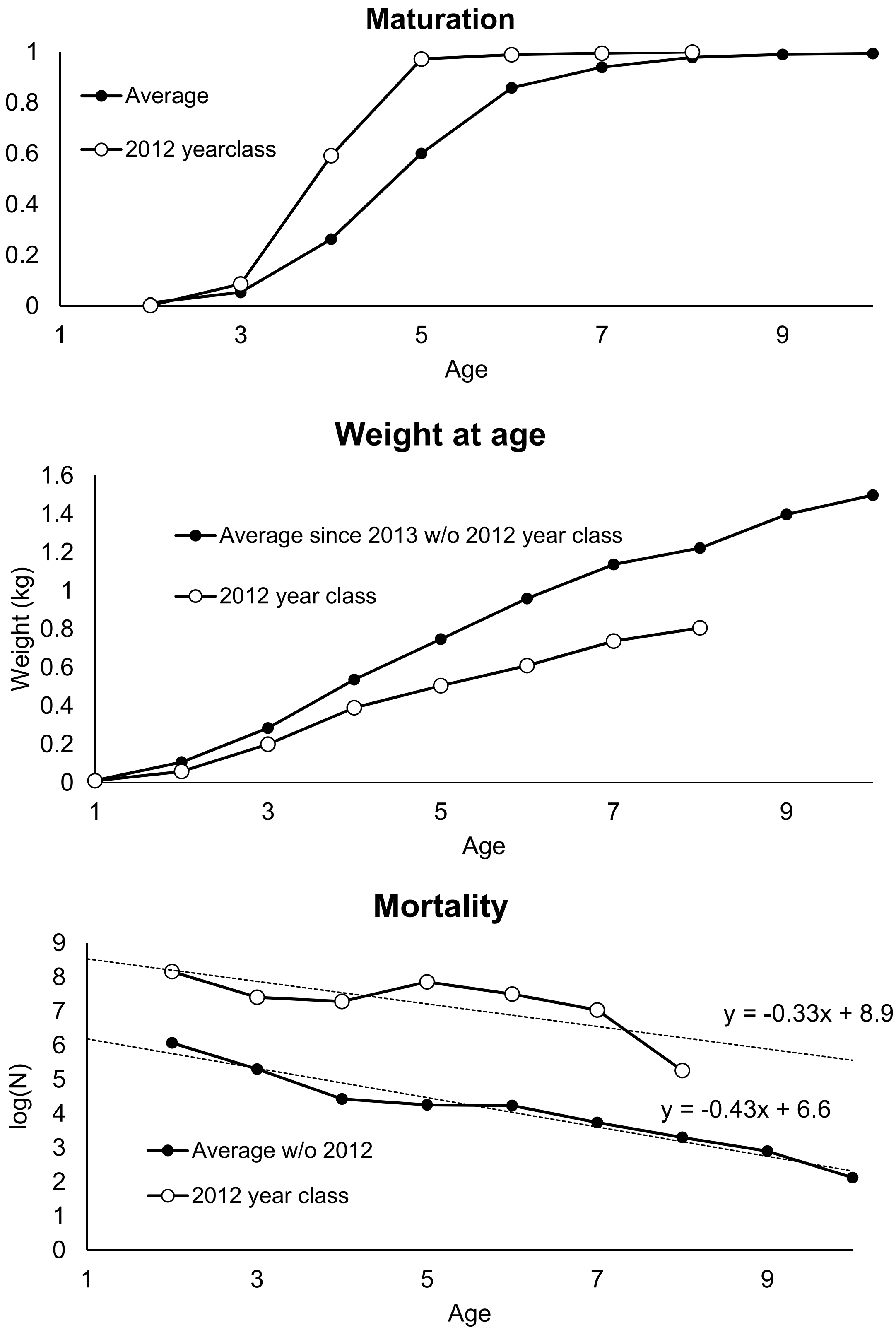


Figure 1.14. Comparison of 2012 year class maturation, growth, and mortality with average characteristics. Maturity is based on sampling during winter acoustic surveys. Weight at age is a comparison of the 2012 year class in the winter acoustic survey with the average weight at age since 2013 excluding 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*).

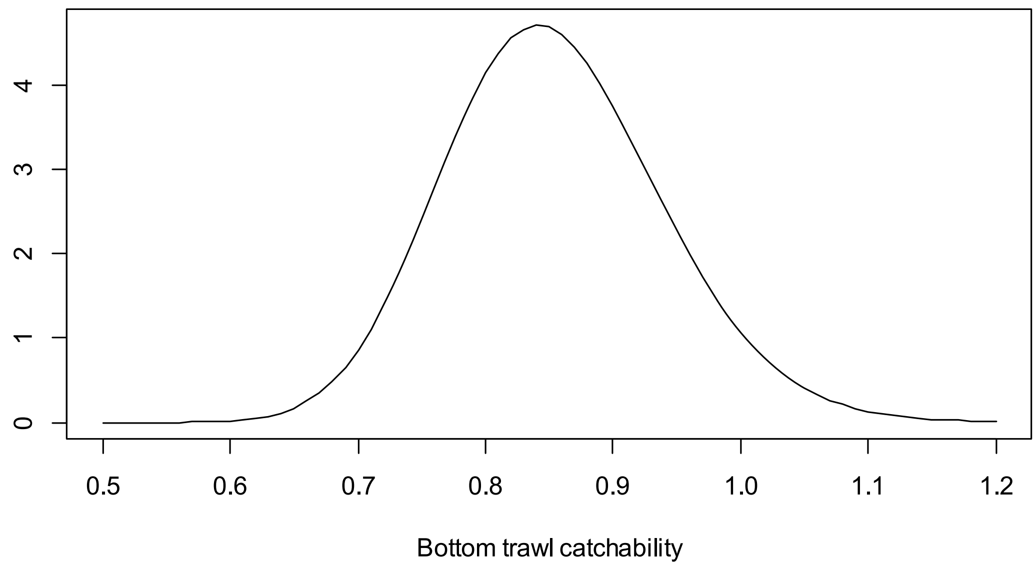


Figure 1.15. Prior on bottom trawl catchability used in the base model.

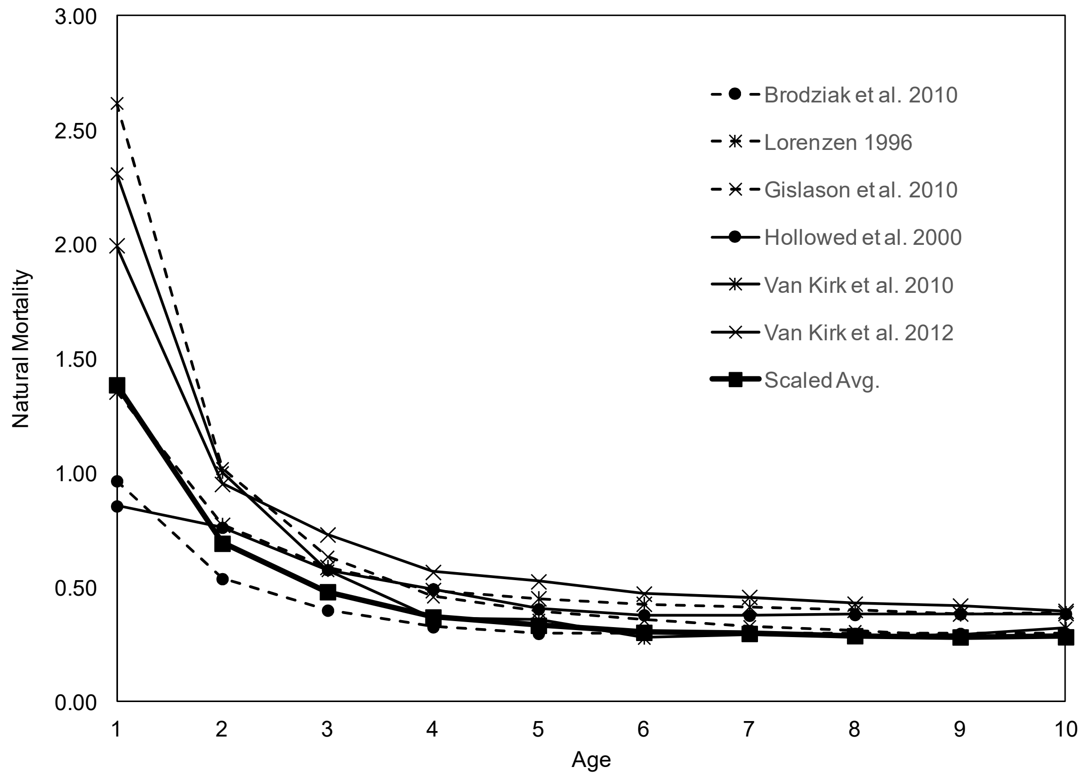


Figure 1.16. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

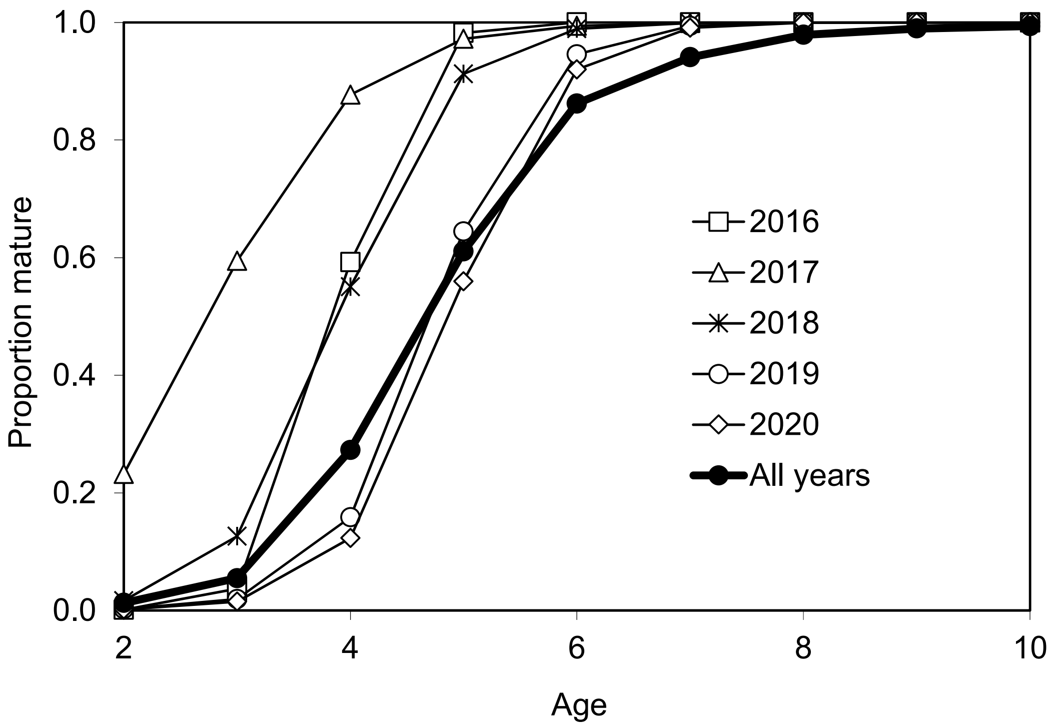


Figure 1.17. Estimates of the proportion mature at age from weighted visual maturity data collected during 2016-2020 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2020).

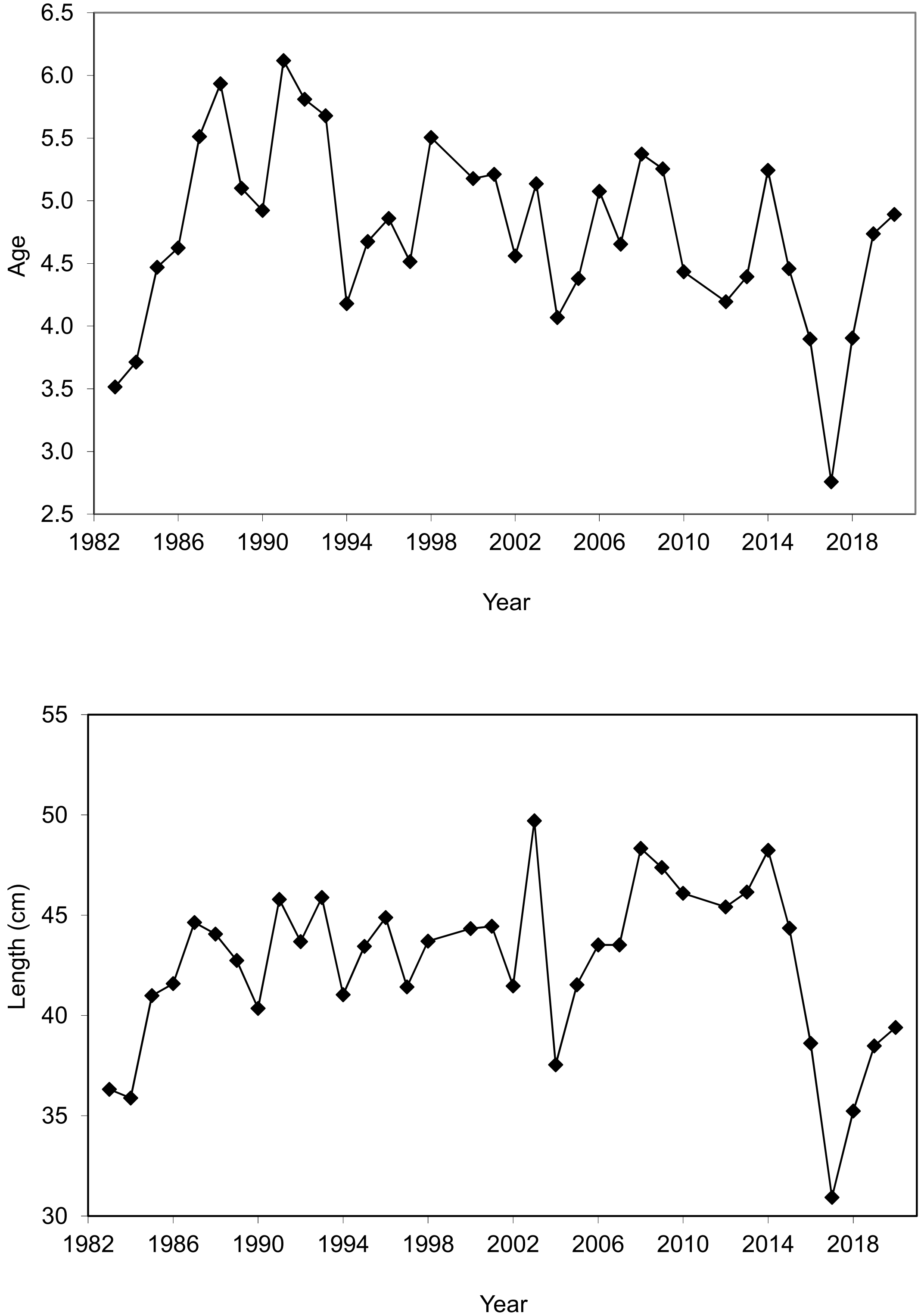


Figure 1.18. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2019. Estimates since 2003 are weighted by local abundance.

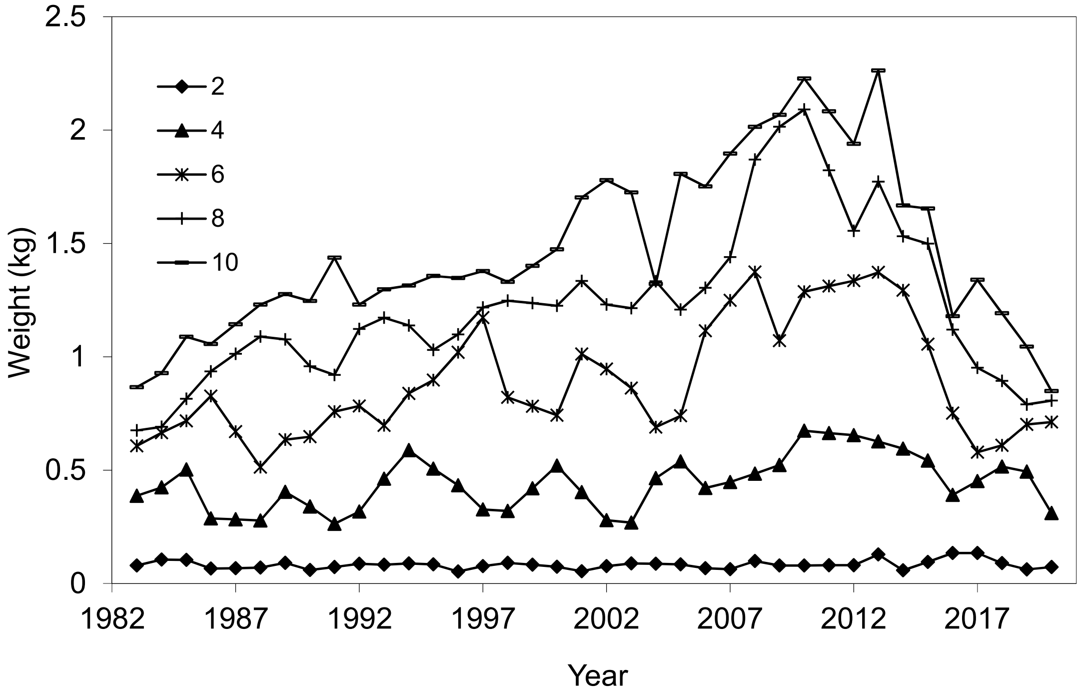


Figure 1.19. Estimated weight at age of GOA pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2020 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from surveys in adjacent years.

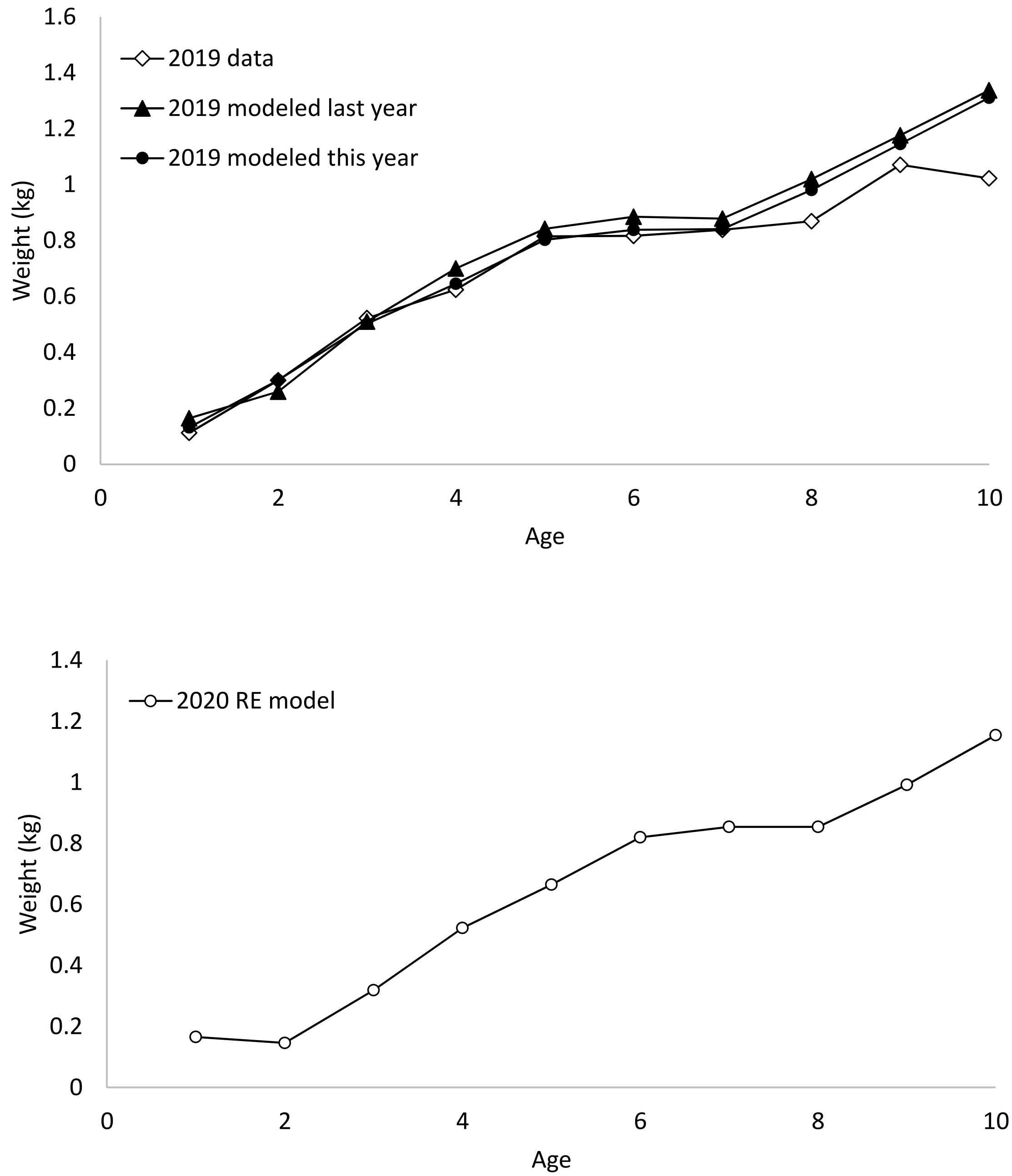


Figure 1.20. Comparison of fishery weight at age for 2019 with estimates from the random effects model last year and this year' assessment (top panel). Random effects model estimates for 2020 used in the assessment model and for yield projections (bottom panel).

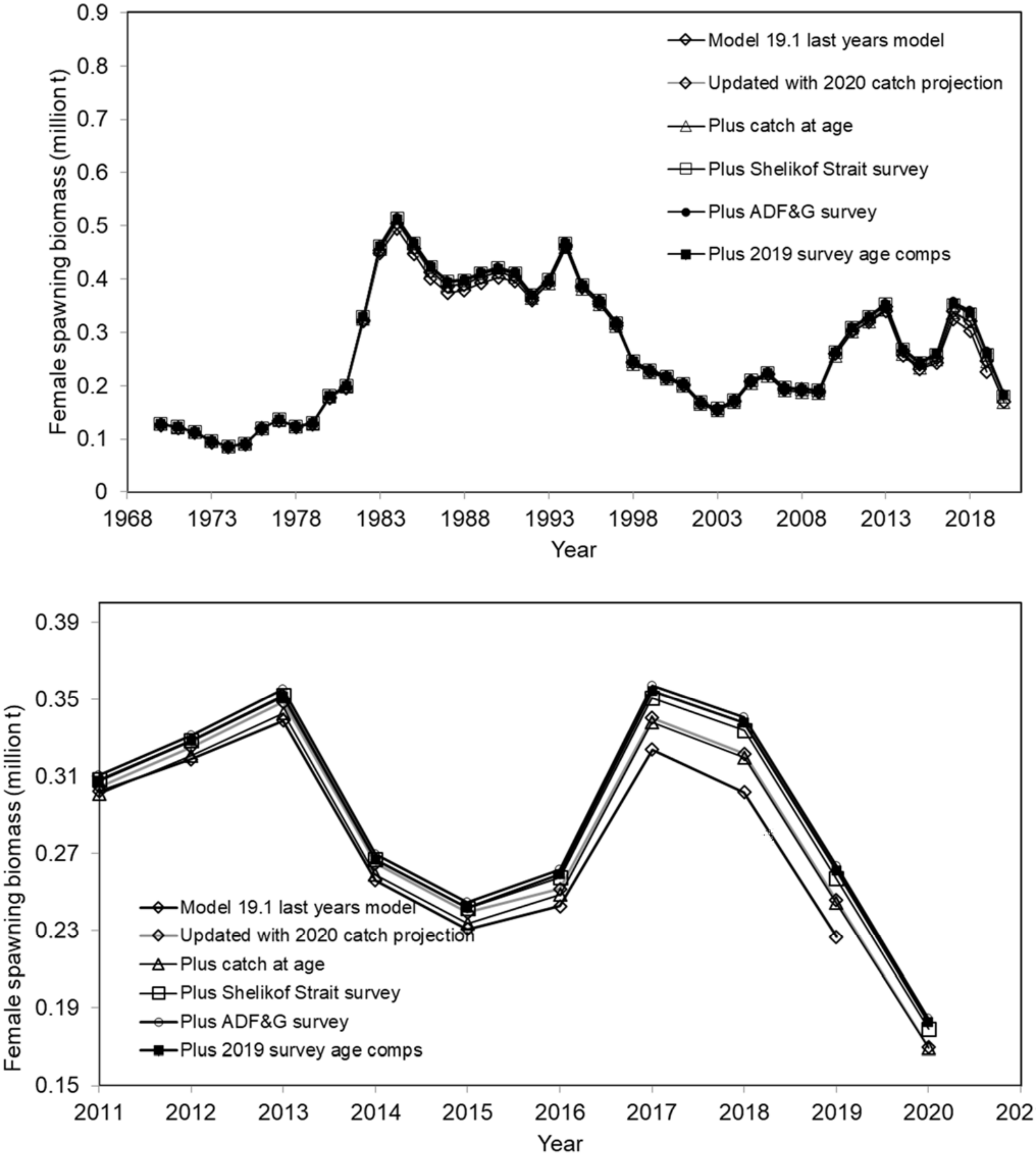


Figure 1.21. Changes in estimated spawning biomass as new data were added successively to last year's base model. The lower panel shows the years 2011-2020 with an expanded scale to highlight differences.

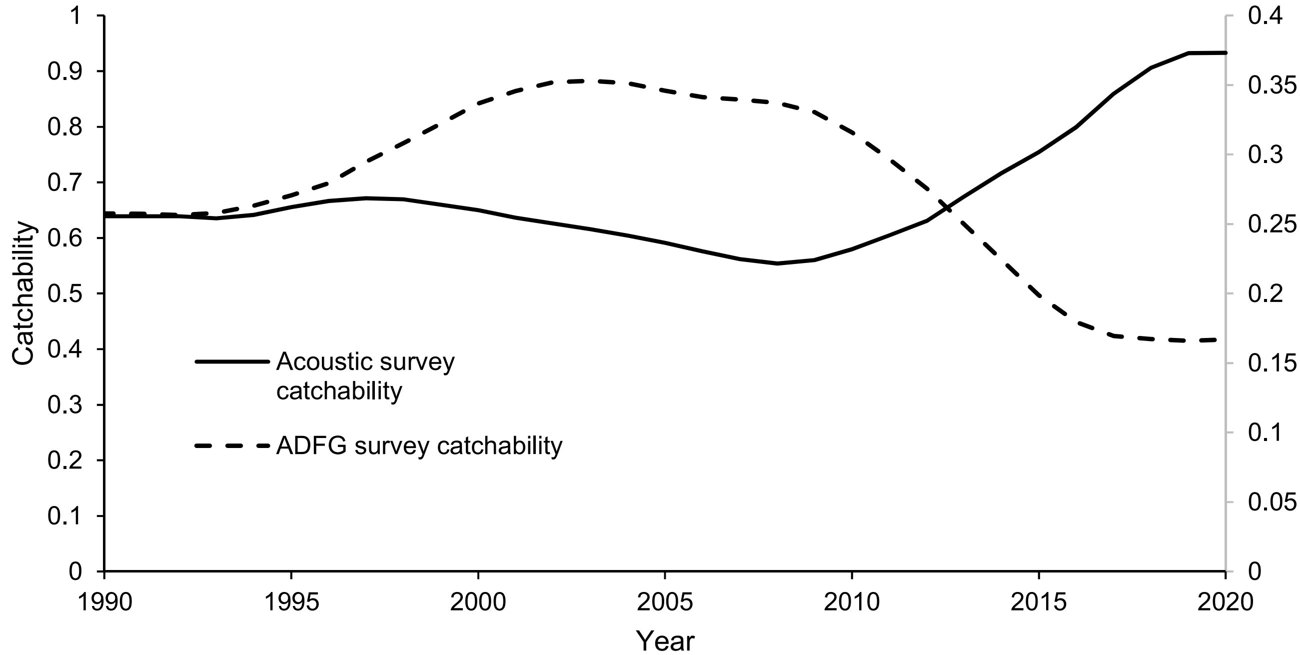


Figure 1.22. Time-varying catchability for the Shelikof Strait acoustic survey and the ADF&G crab/groundfish trawl survey for model 19.1.

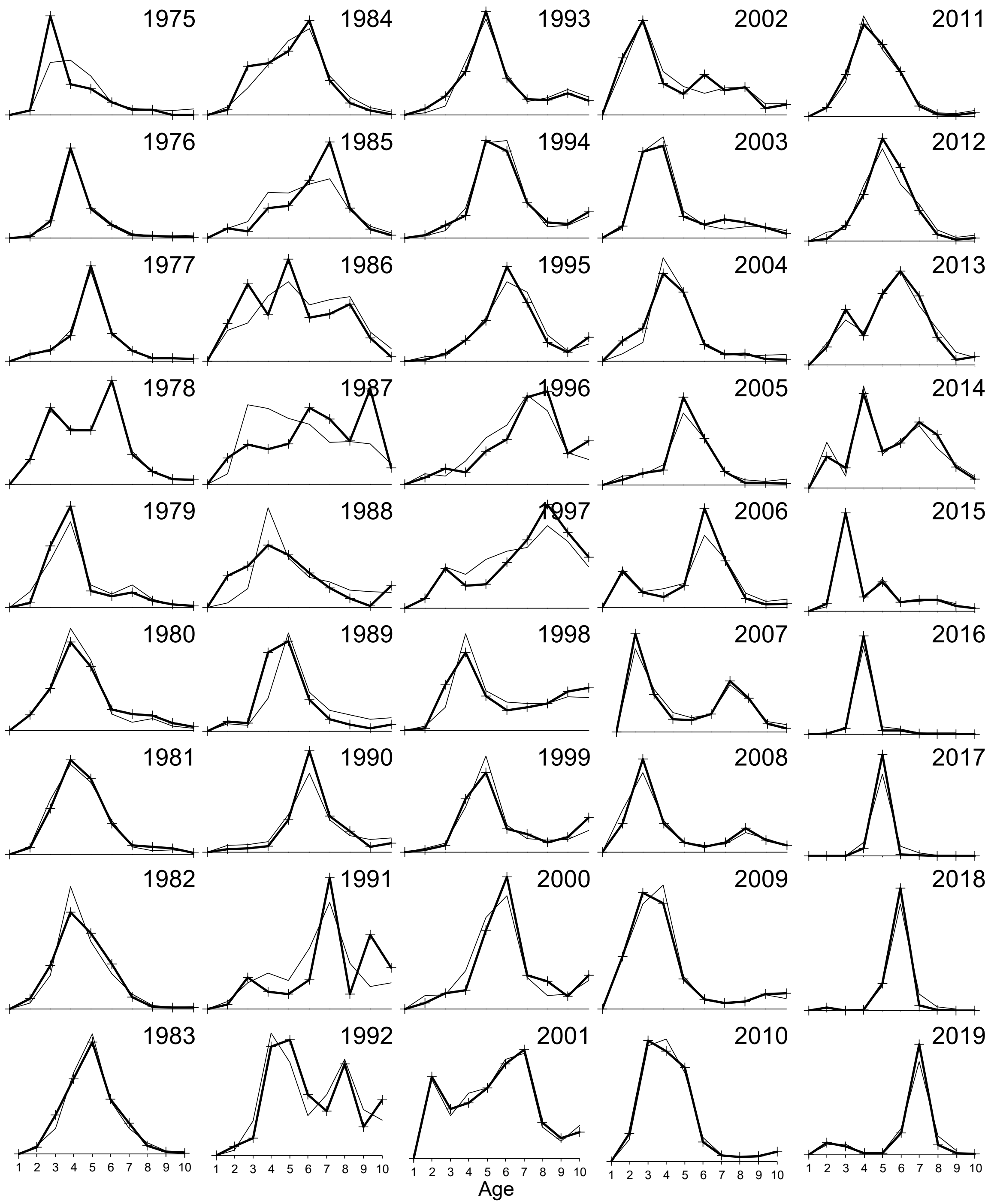


Figure 1.23. Observed and predicted fishery age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

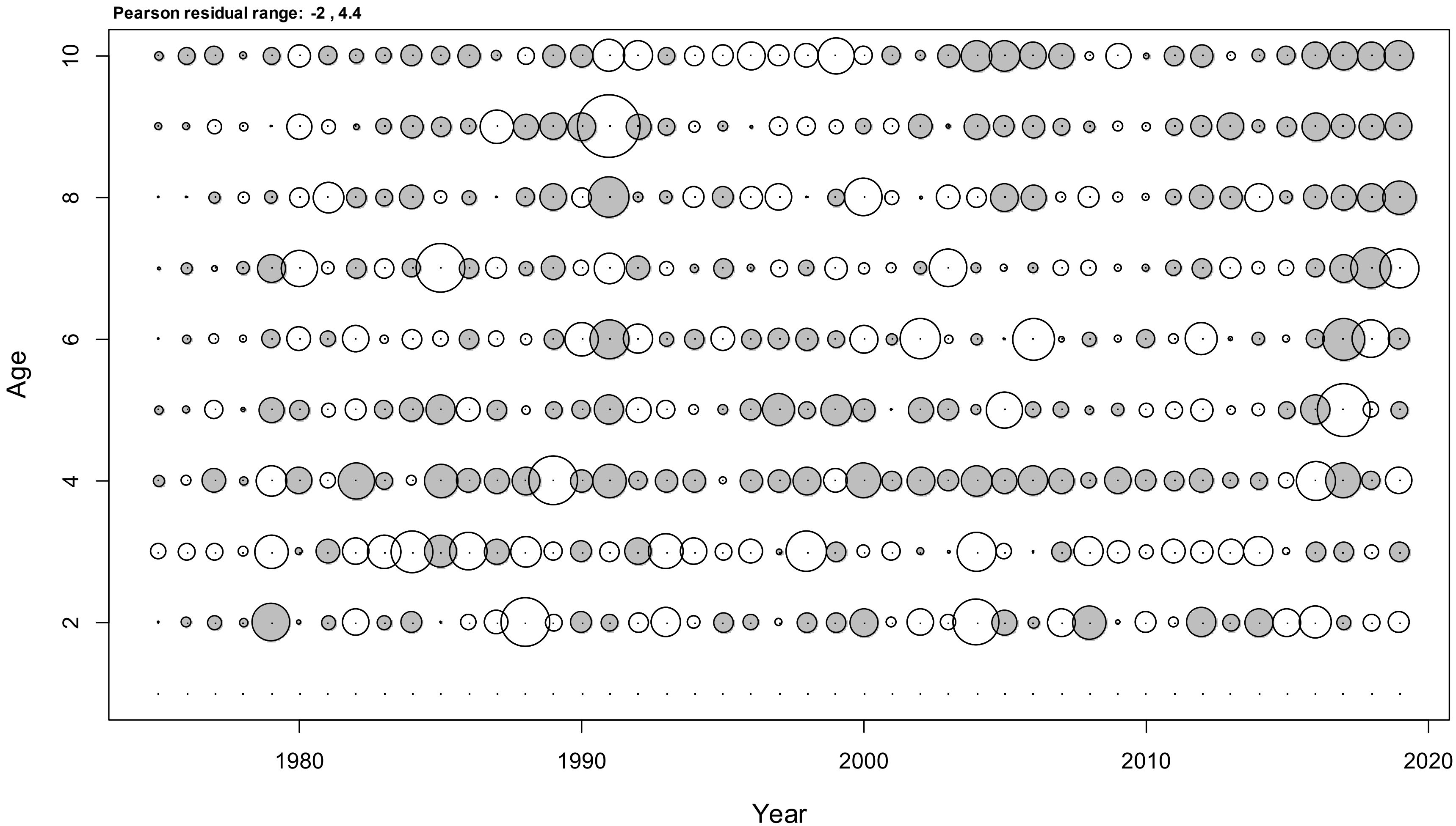


Figure 1.24. Pearson residuals for fishery age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

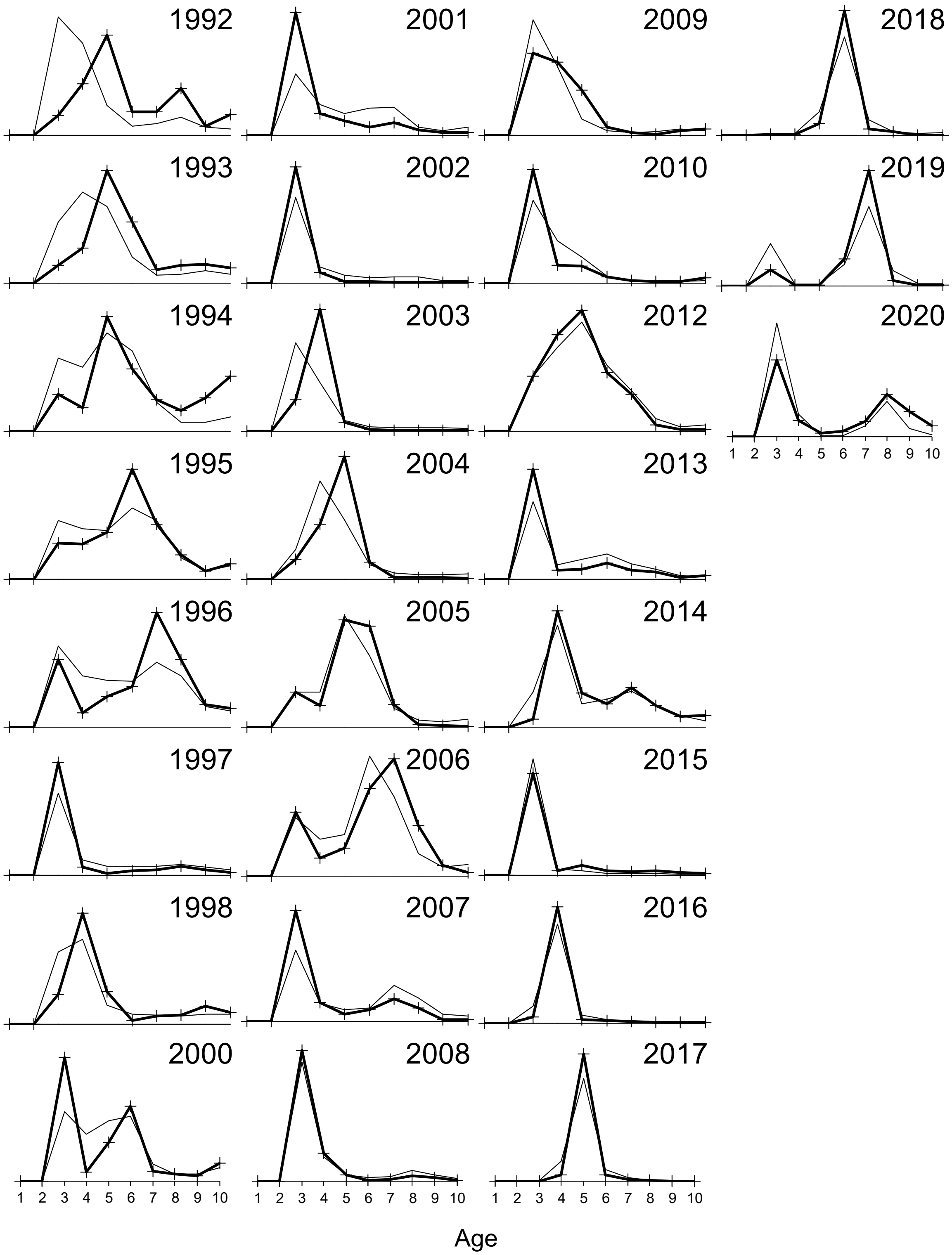


Figure 1.25. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

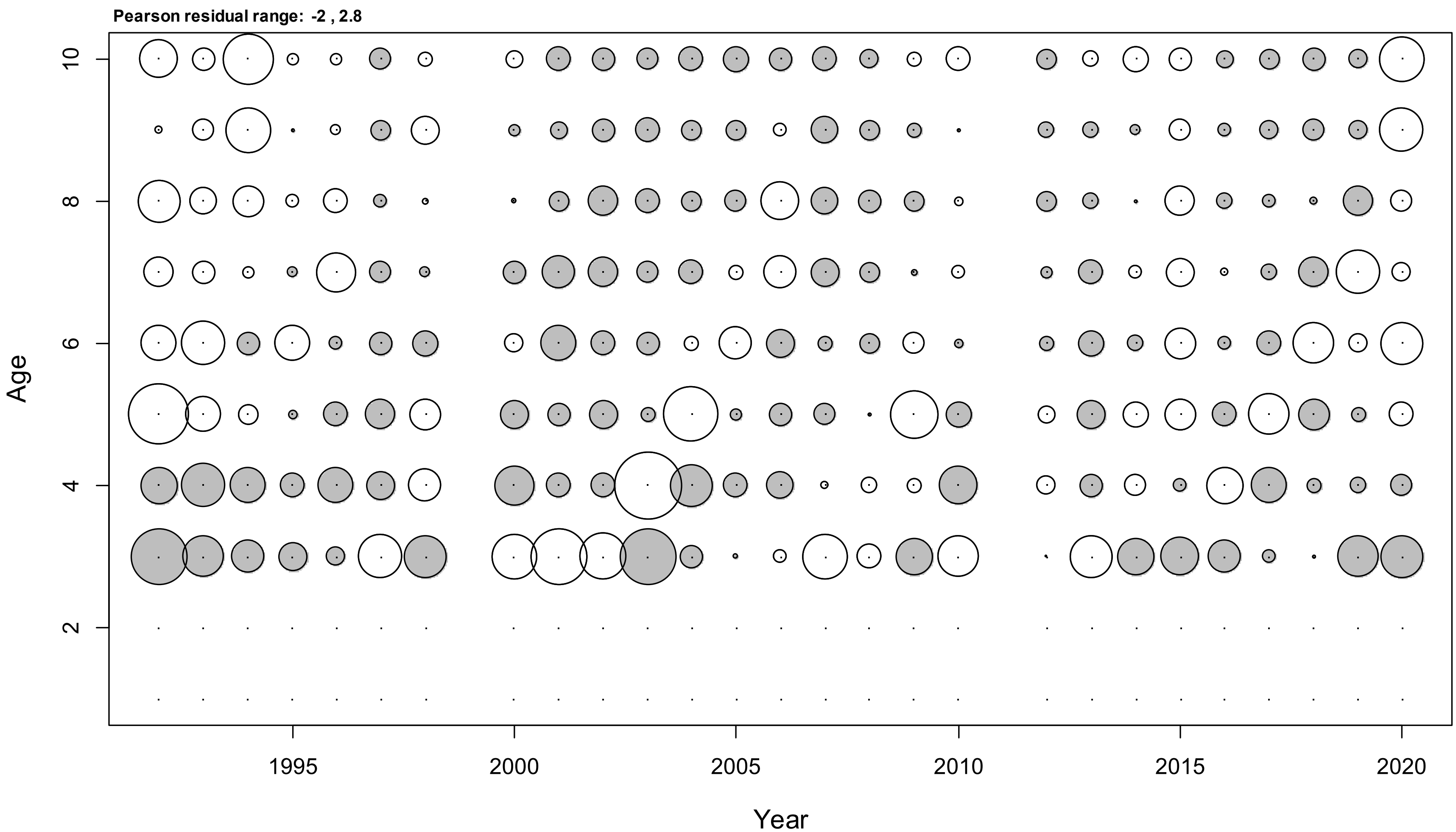


Figure 1.26. Pearson residuals for Shelikof Strait acoustic survey age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

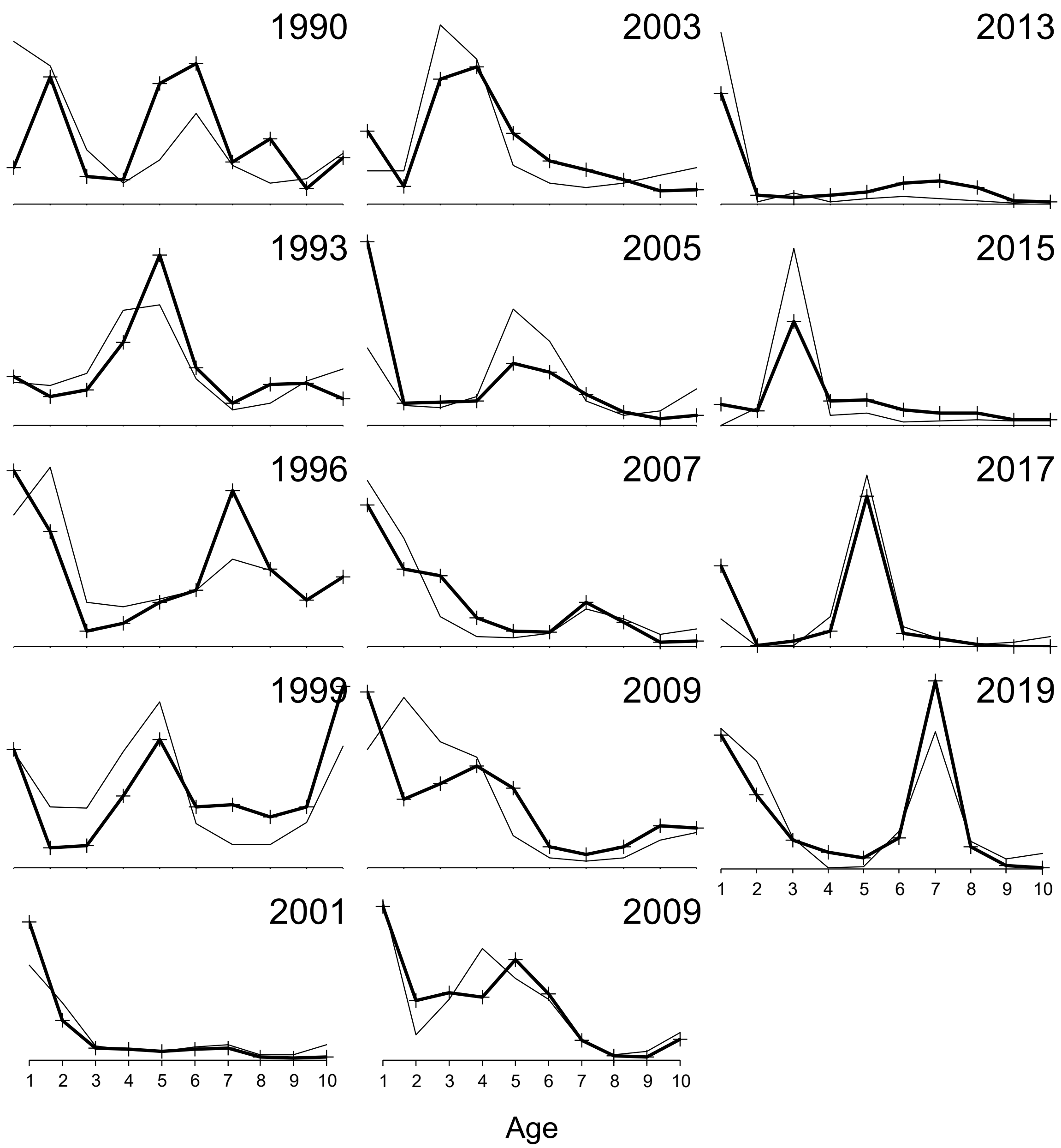
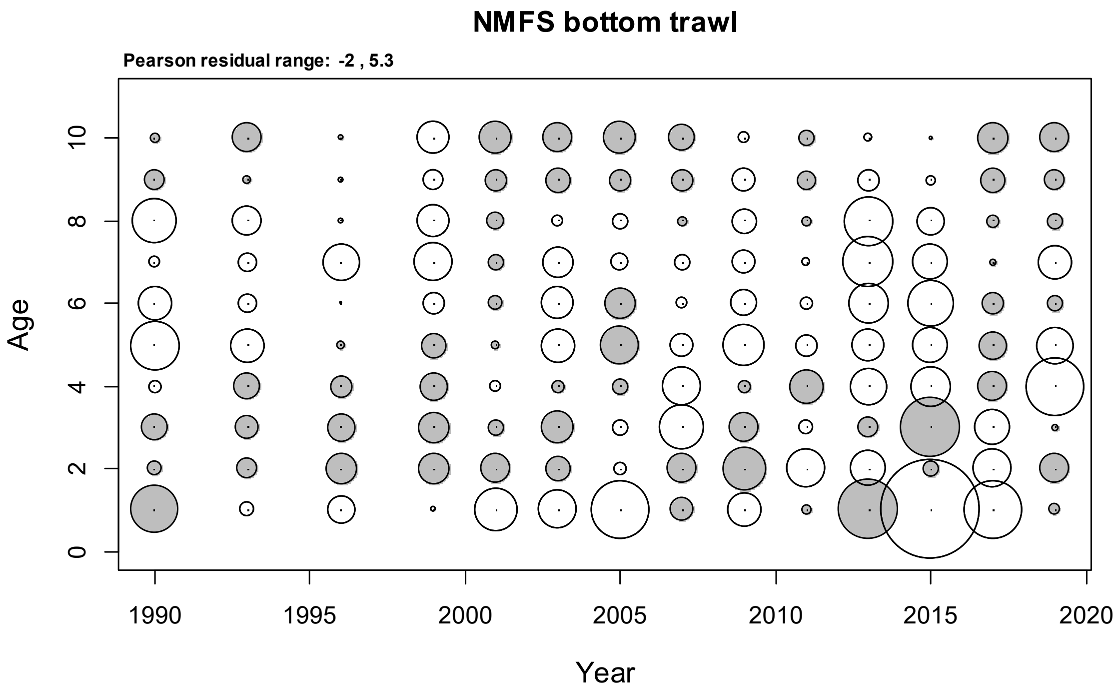


Figure 1.27. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.



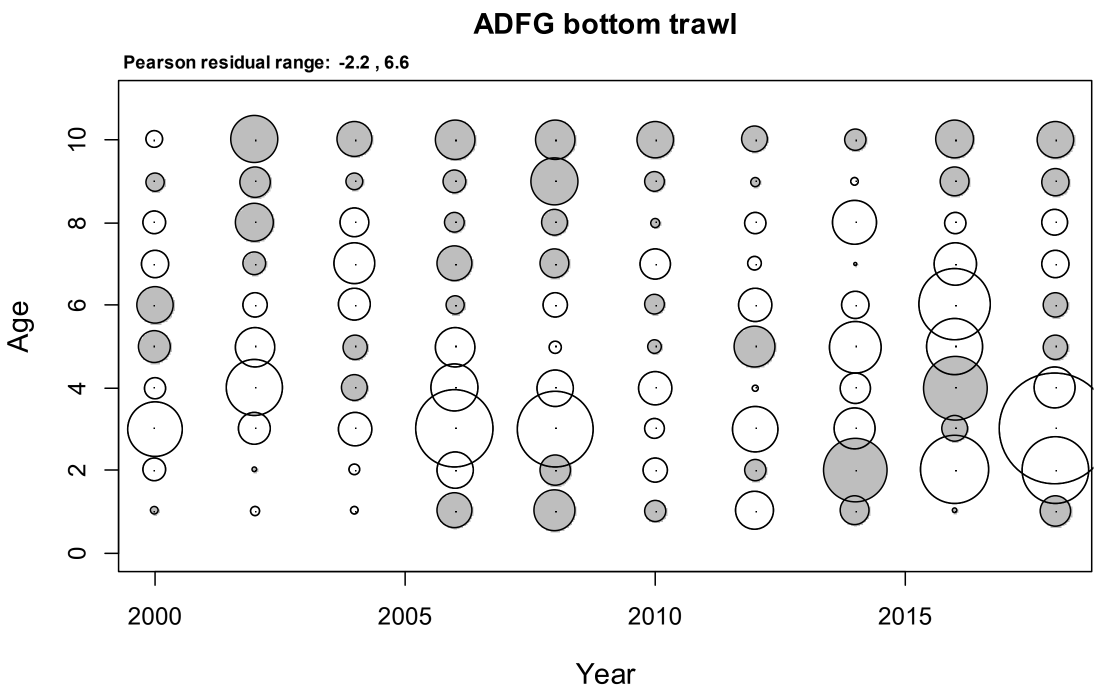


Figure 1.28. Pearson residuals for NMFS bottom trawl survey (top) and ADF&G crab/groundfish survey (bottom) age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

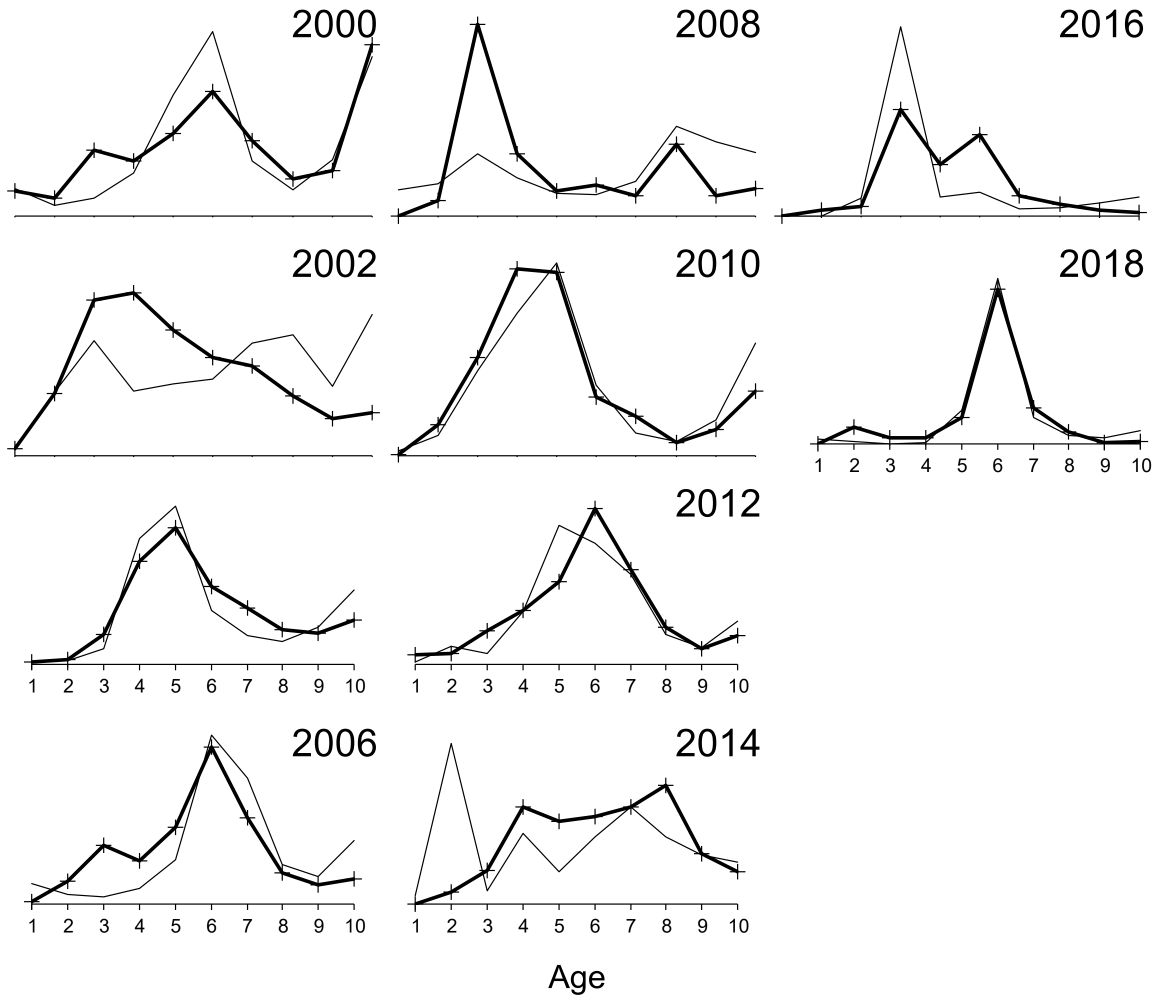


Figure 1.29. Observed and predicted ADF&G crab/groundfish survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbols are observed proportions at age.

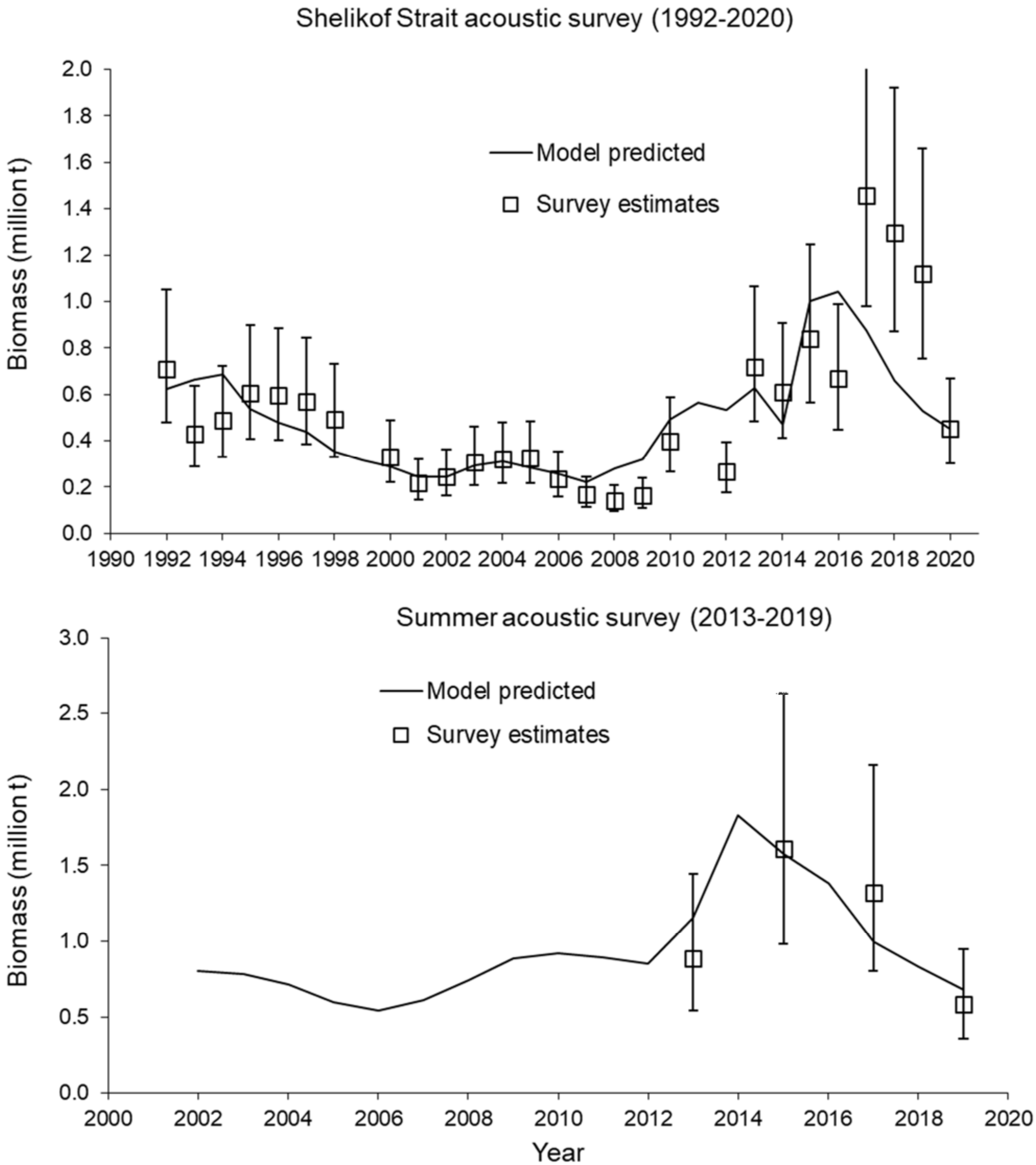


Figure 1.30. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey for the base model (top panel). The bottom panel shows model predicted and observed survey biomass for the summer acoustic survey. Error bars indicate plus and minus two standard deviations.

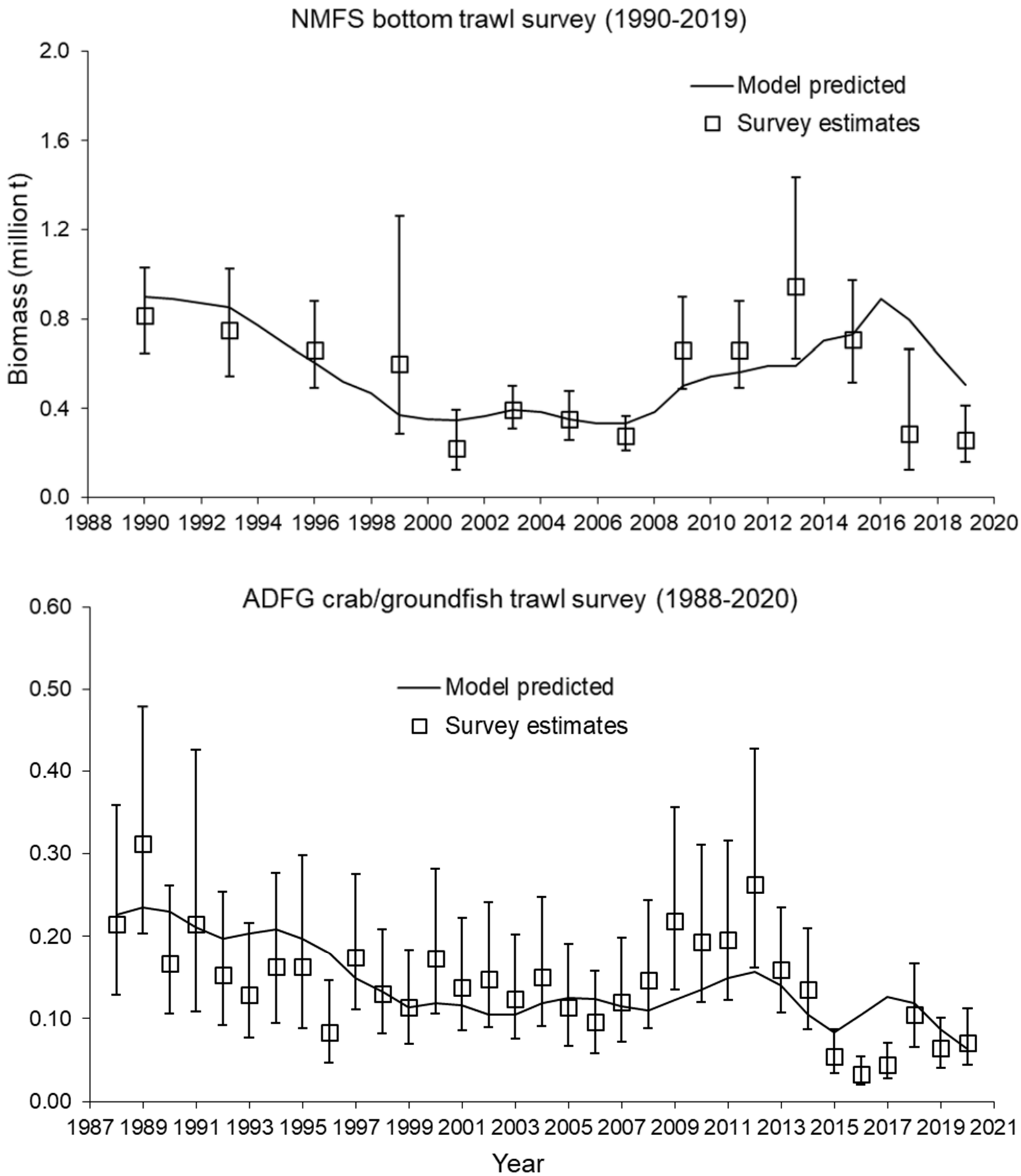


Figure 1.31. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top panel), and the ADF&G crab/groundfish survey (bottom panel) for the base model. Error bars indicate plus and minus two standard deviations.

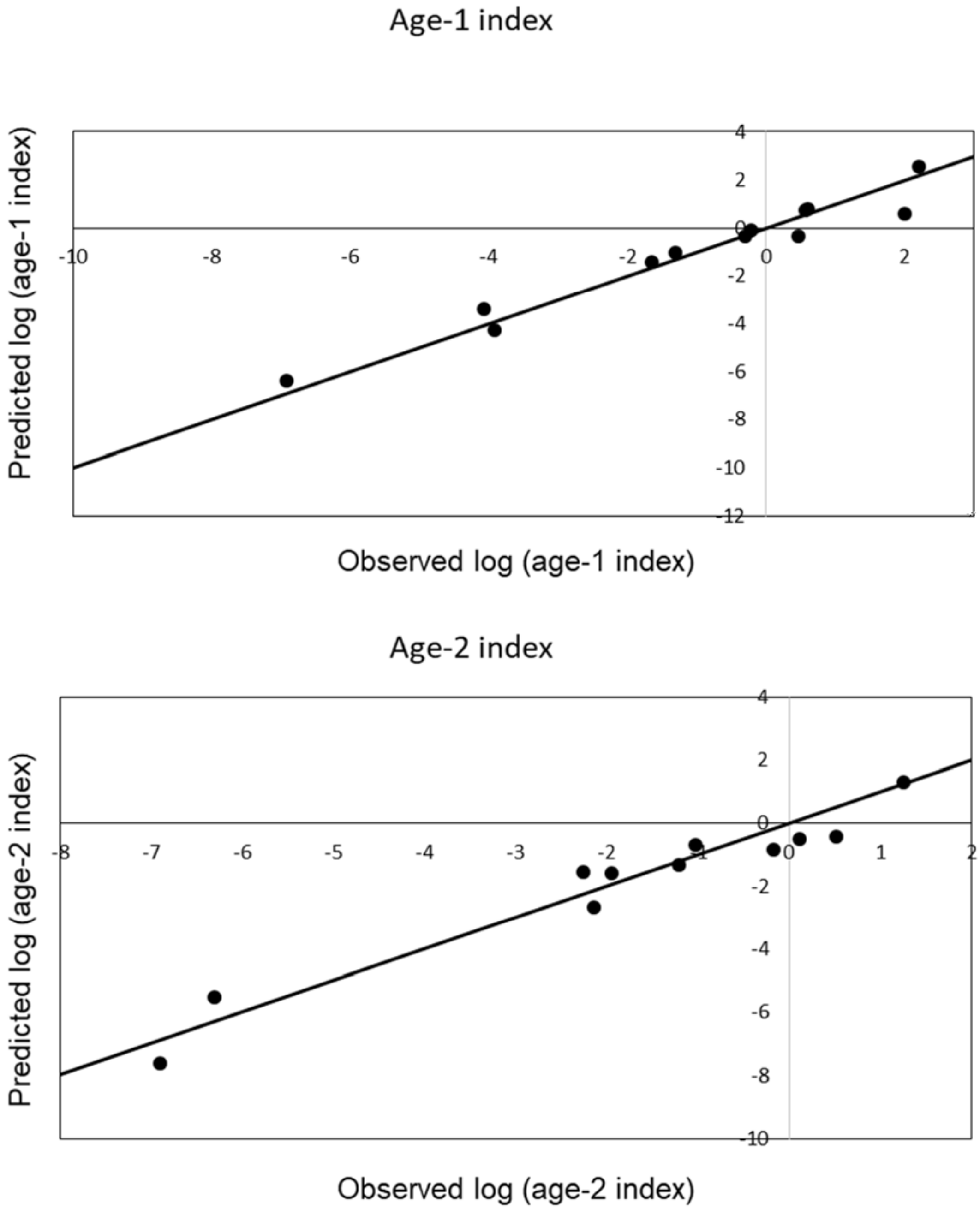


Figure 1.32. Observed and model predicted age-1 (top) and age-2 indices (bottom) for the winter acoustic estimates for Shelikof Strait.

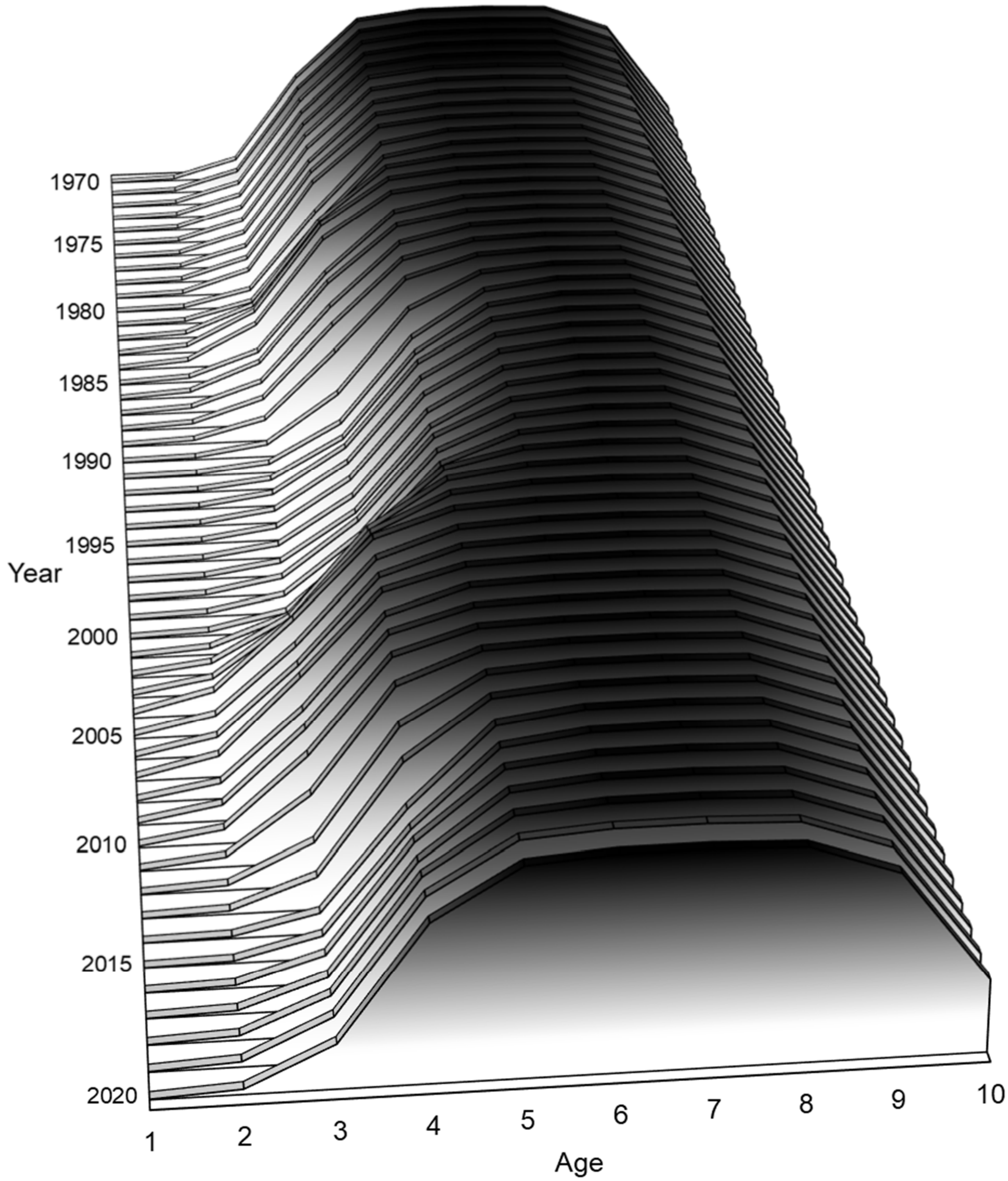


Figure 1.33. Estimates of time-varying fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.

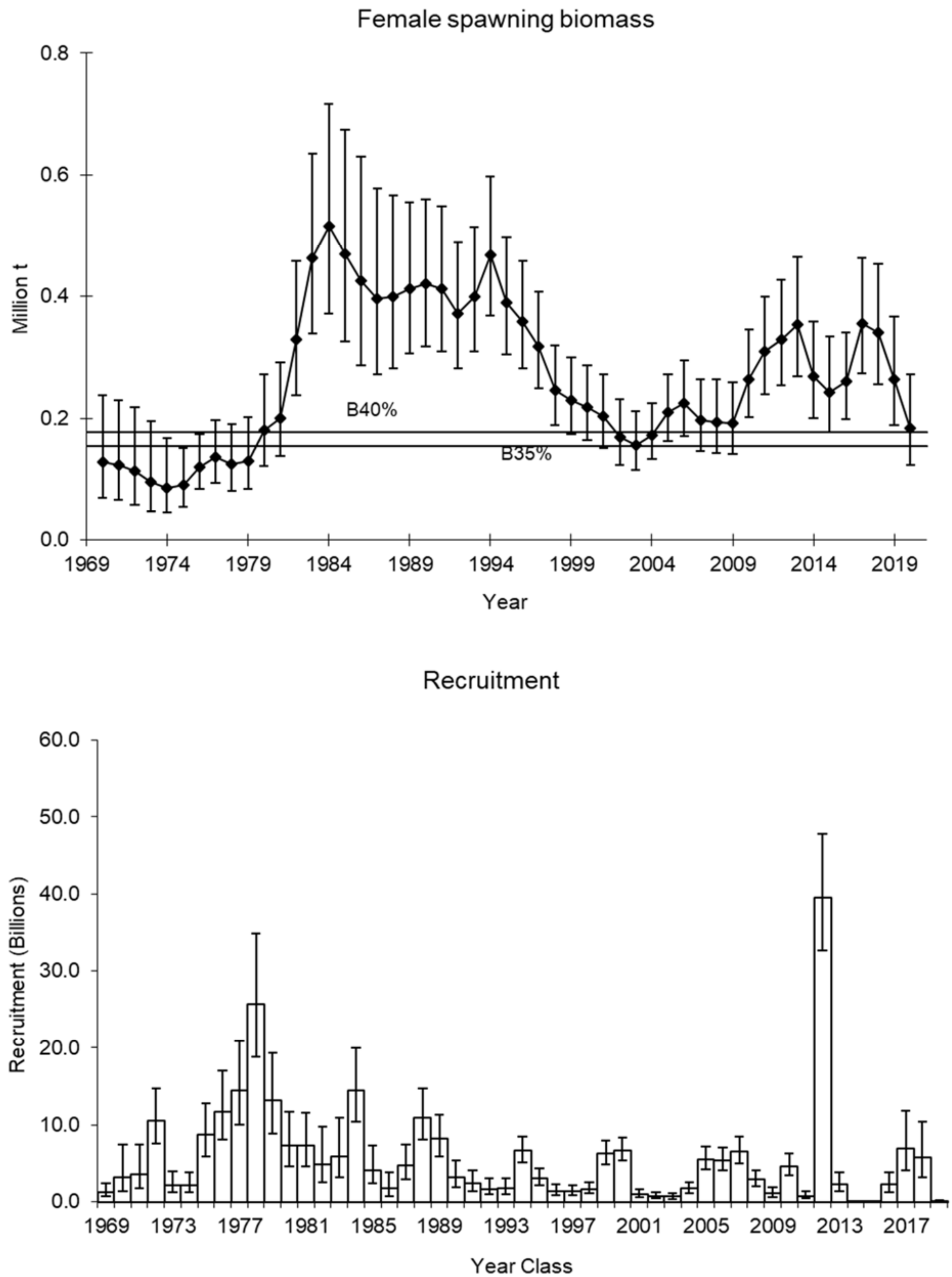


Figure 1.34. Estimated time series of GOA pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1970 to 2020 for the base model. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.

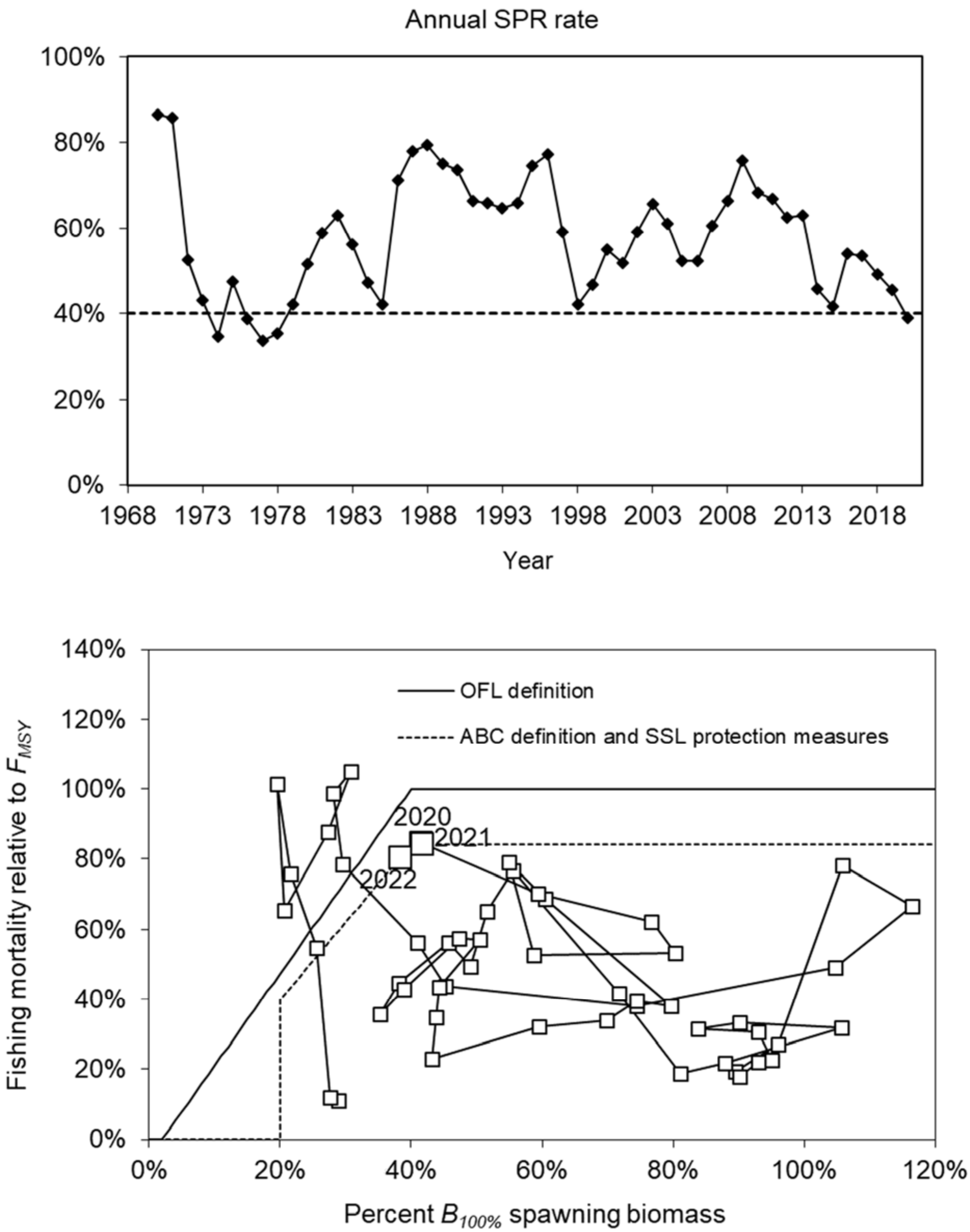


Figure 1.35. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to FMSY (bottom). The ratio of fishing mortality to F_{MSY} is calculated using the estimated selectivity pattern in that year. Estimates of $B_{100\%}$ spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

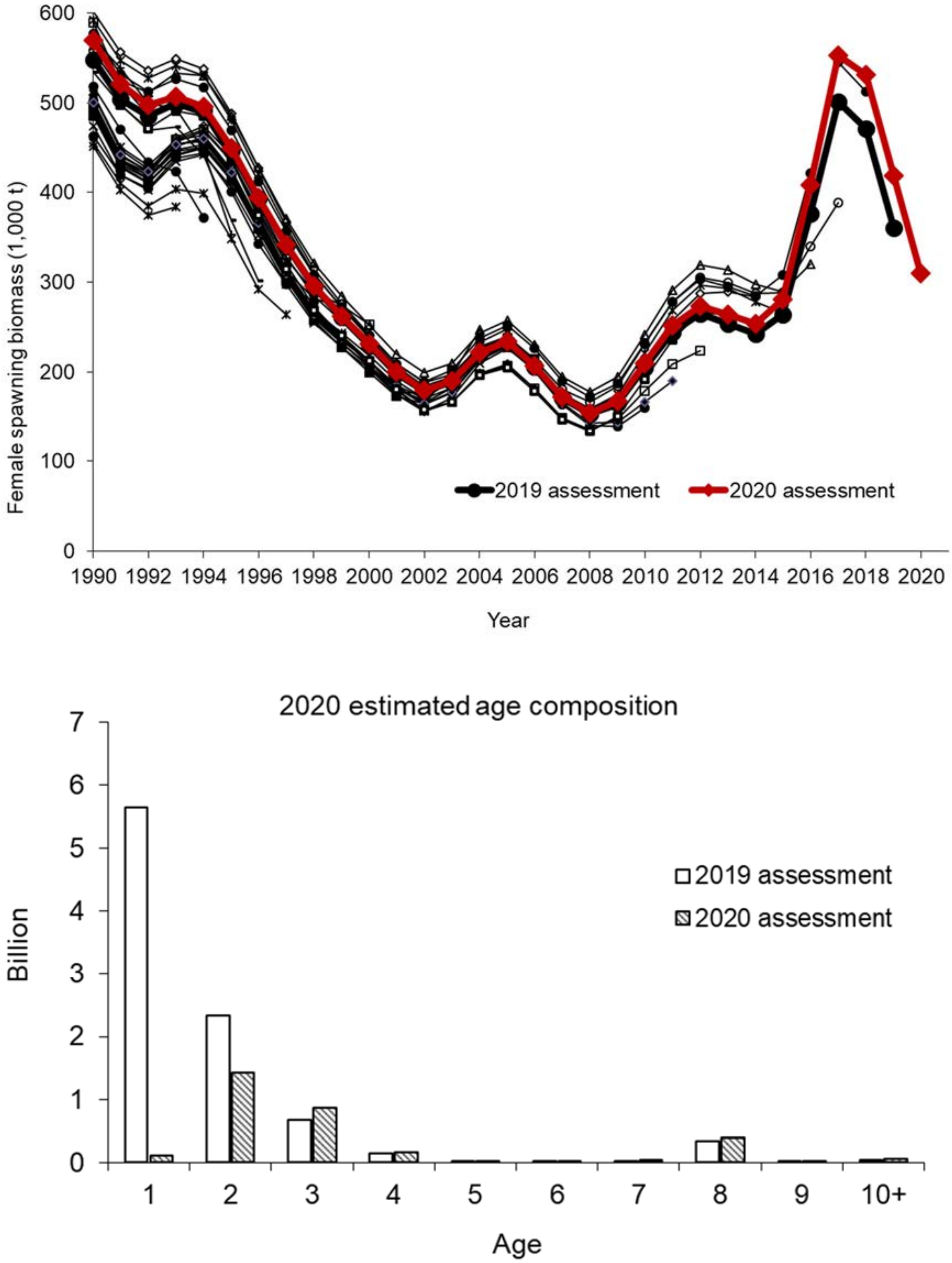


Figure 1.36. Estimated female spawning biomass for historical stock assessments in the years 1993-2020 (top). For this figure, the time series of female spawning biomass was calculated using the same maturity and spawning weight at age for all assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2020 from the 2019 and 2020 assessments.

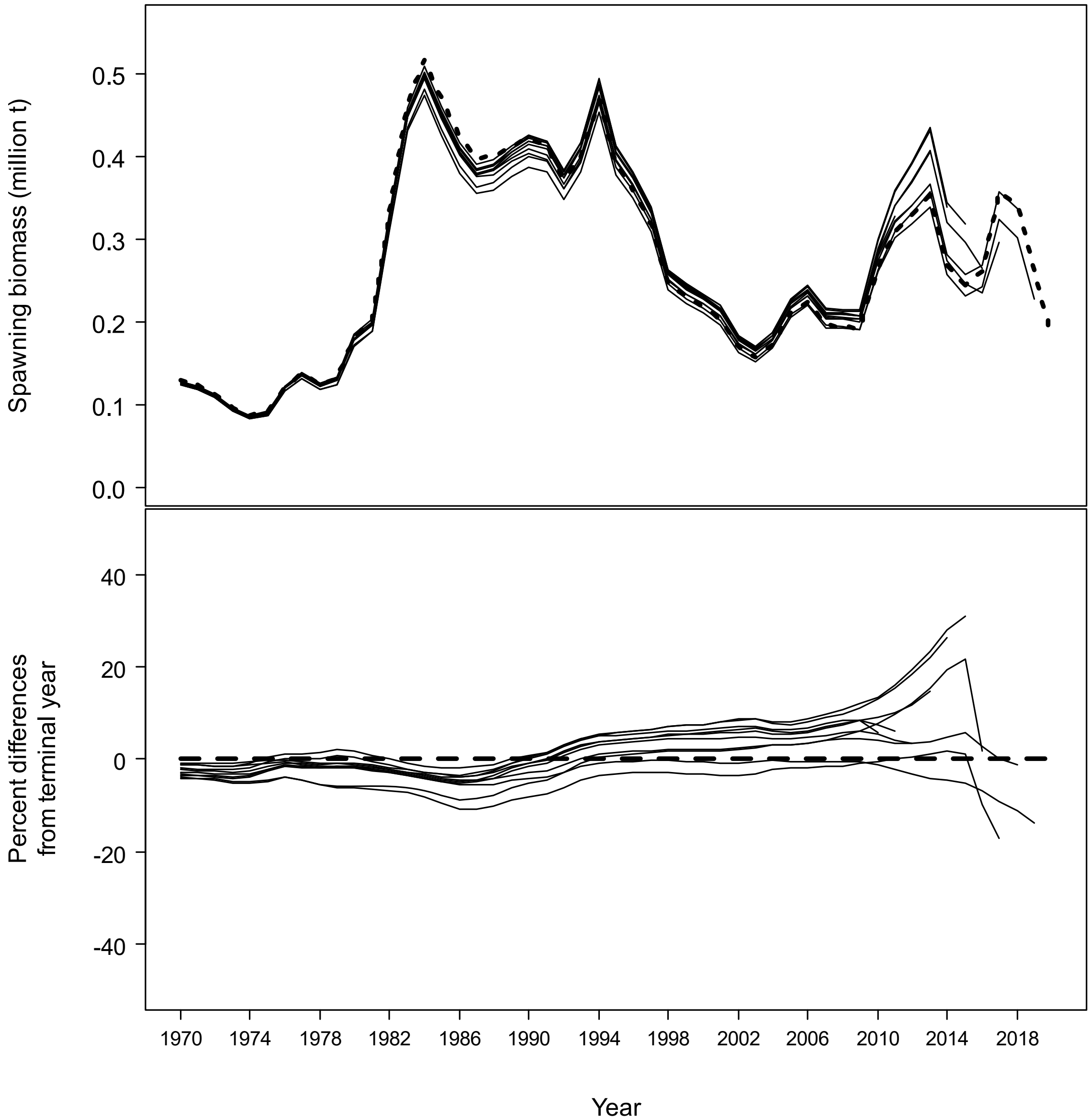
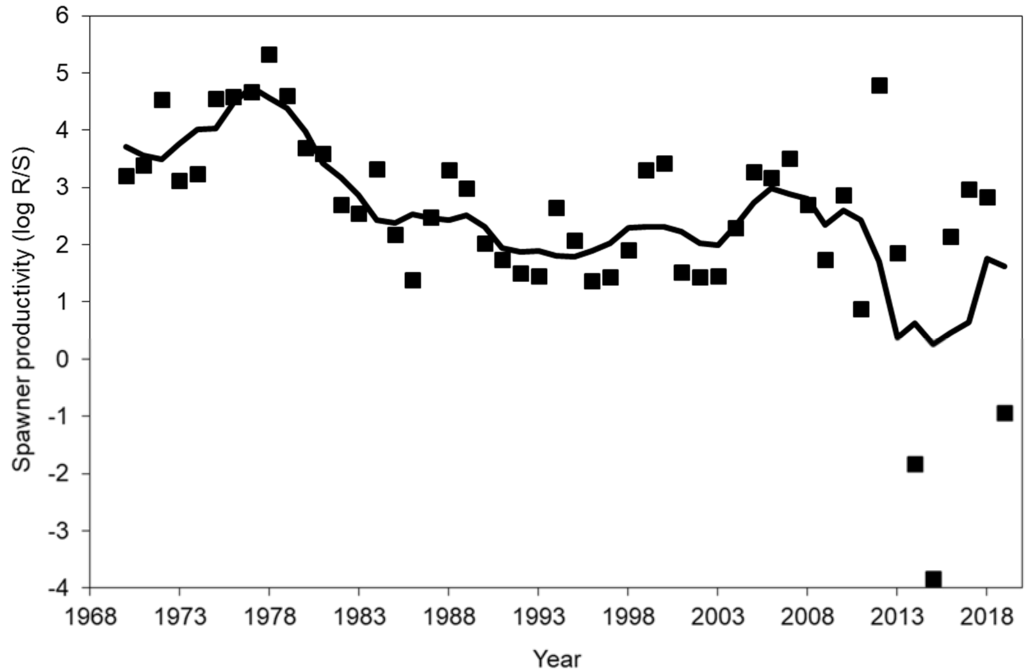


Figure 1.37. Retrospective plot of spawning biomass for models ending in years 2010-2019 for the 2020 base model. The revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.057.



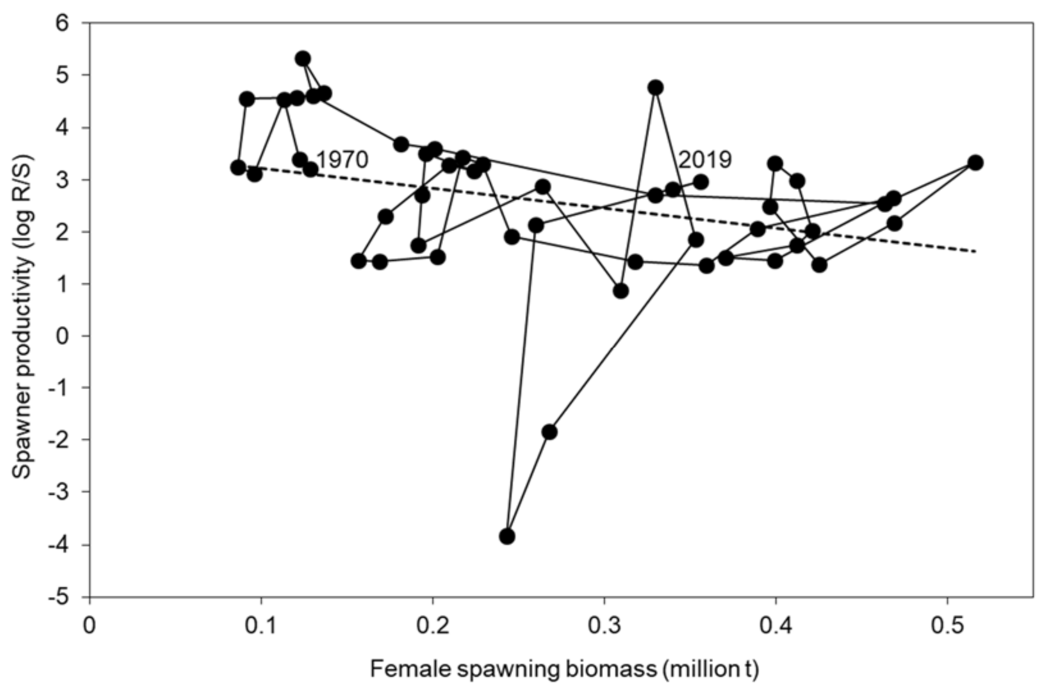


Figure 1.38. GOA pollock spawner productivity, log(R/S), in 1970-2018 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

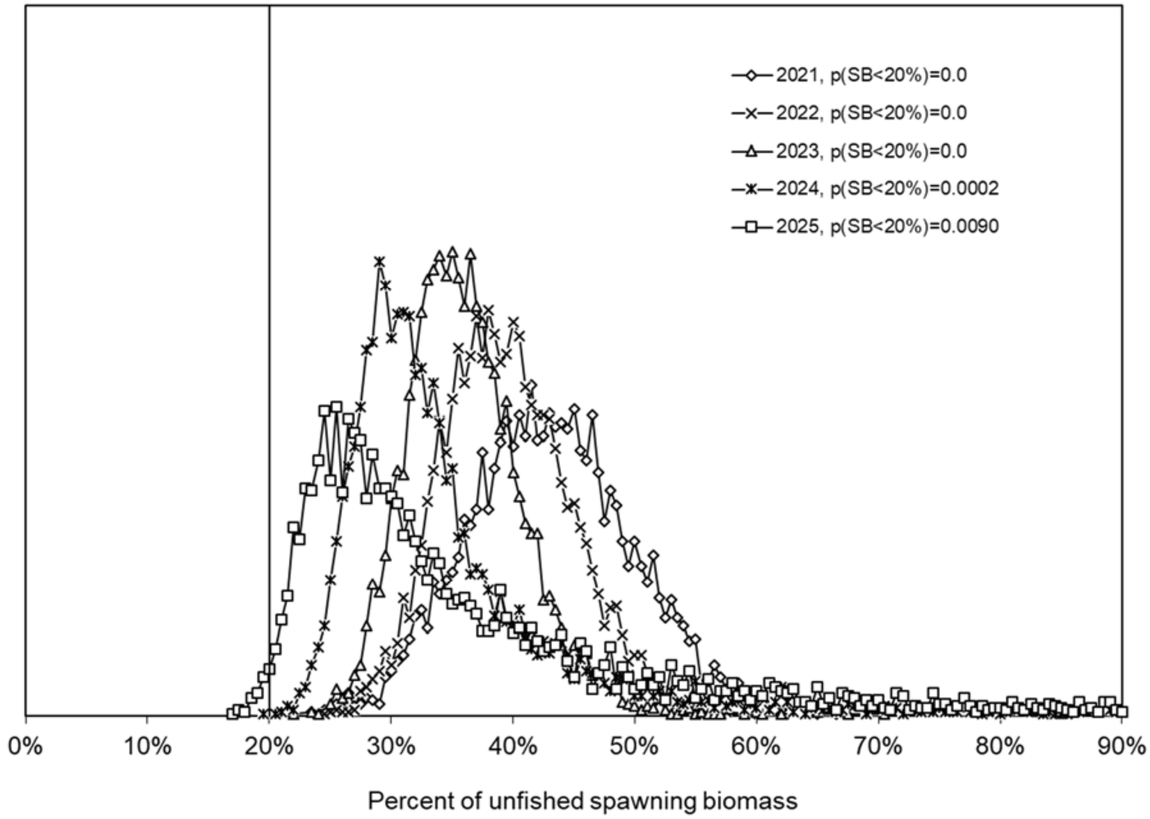
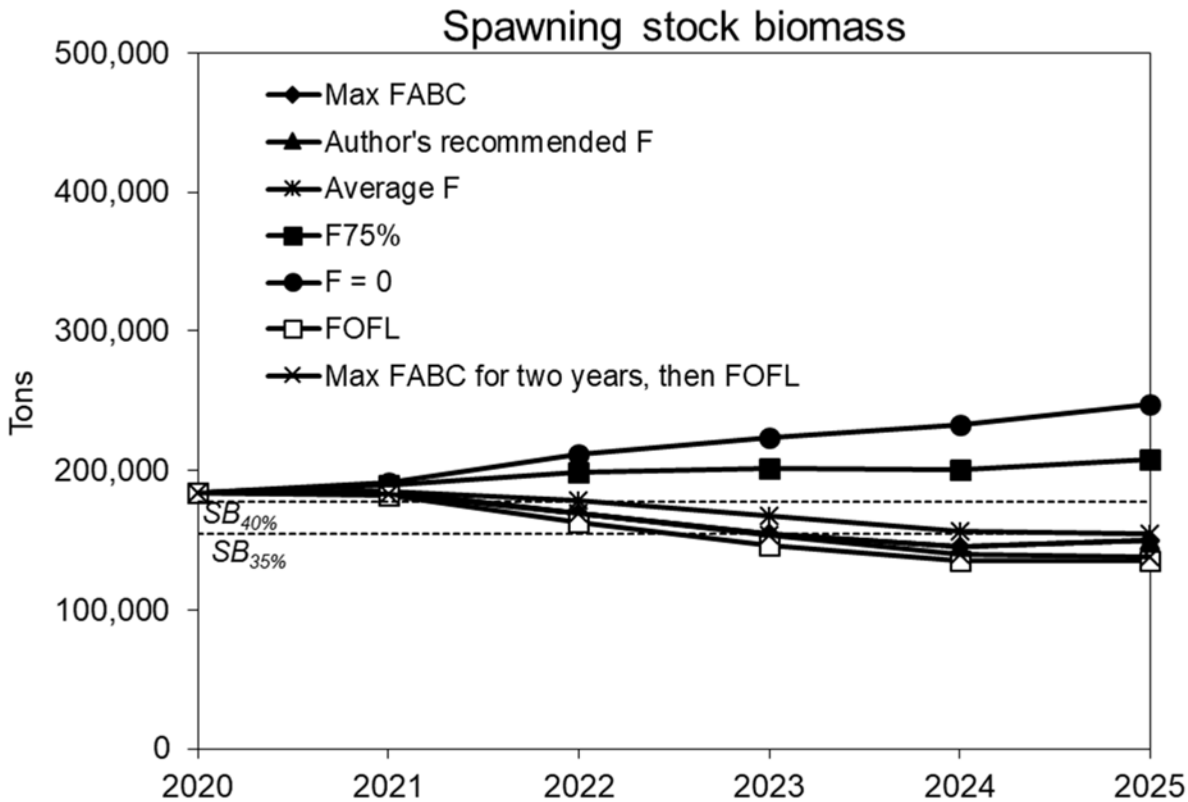


Figure 1.39. Uncertainty in spawning biomass in 2021-2025 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the maximum permissible F_{ABC}.



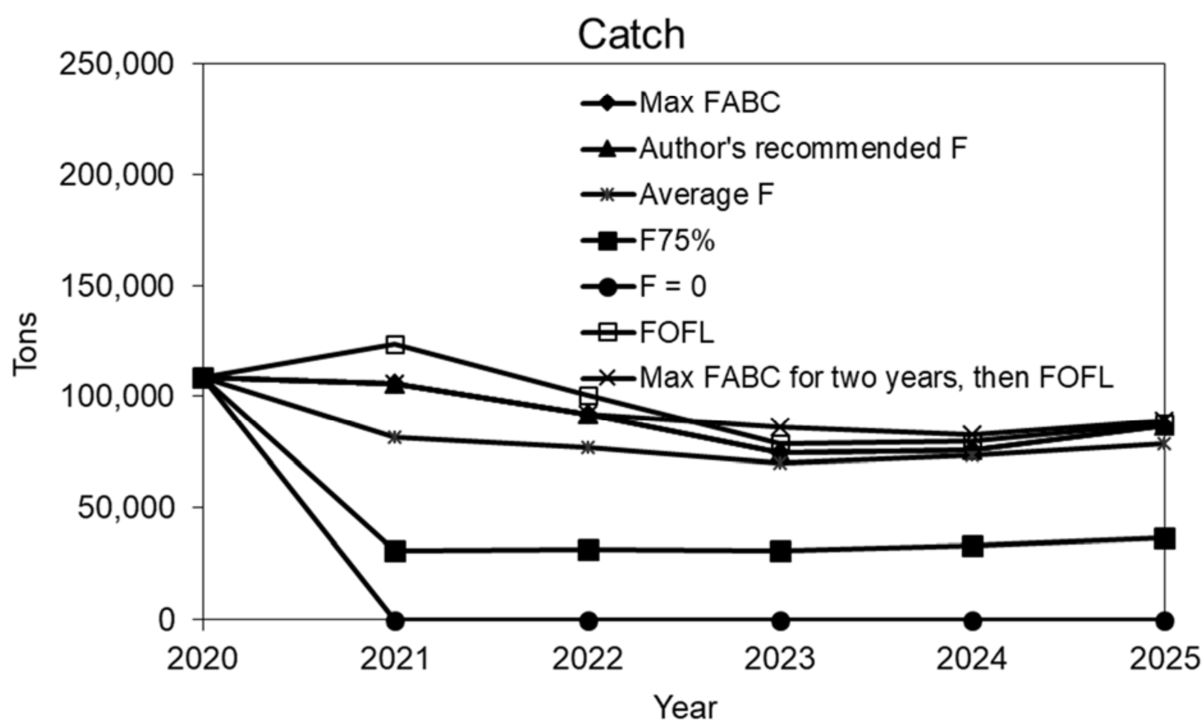


Figure 1.40. Projected mean spawning biomass and catches in 2020-2025 under different harvest rates.

Appendix 1A. Ecosystem and Socioeconomic Profile of the Walleye Pollock stock in the Gulf of Alaska

S. Kalei Shotwell, Martin Dorn, Alison L. Deary, Ben Fissel, Lauren Rogers, and Stephani Zador

November 2020

With Contributions from:

Grant Adams, Kerim Aydin, Steve Barbeaux, Cheryl Barnes, Lewis Barnett, Curry Cunningham, Dana Hanselman, Kirstin Holsman, David Kimmel, Ben Laurel, Cecilia O'Leary, Patrick Ressler, Dale Robinson, Matt Wilson, Sarah Wise

Executive Summary

National initiatives and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Gulf of Alaska (GOA) walleye pollock (*Gadus chalcogrammus*, hereafter referred to as pollock) due its highly variable recruitment trends. Scores for stock assessment prioritization, habitat prioritization, productivity and susceptibility, and data classification were moderate to high. Additionally, the Groundfish Plan Team and SSC supported updating the ESP for pollock and requested continued analysis on the recent recruitment fluctuations.

We follow the standardized template for conducting an ESP and present results of applying the ESP process through a metric and subsequent indicator assessment. We use information from a variety of data streams available for the GOA pollock stock. Analysis of the ecosystem and socioeconomic processes for GOA pollock by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment.

Please refer to the last full ESP document for further information regarding the ecosystem and socioeconomic linkages for this stock (Shotwell et al., 2019, available online within the GOA pollock stock assessment and fishery evaluation report of Dorn et al., 2019, Appendix 1A, pp. 105-151 at: https://archive.afsc.noaa.gov/refm/docs/2019/GOApollock.pdf).

Summary of changes in Assessment Inputs

Changes in the Data

We provide the data table from the last full ESP for reference and include any new data sources used to create this report (Appendix Table 1A.1). New datasets include daily sea surface temperatures (SST) from the NOAA Coral Reef Watch Program, chlorophyll *a* concentration from MODIS satellite sensors, and empirical wind measurements from buoy data. The SST and ocean color data are served through the ERDDAP maintained by NOAA CoastWatch West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division. The wind data are served from the National Data Buoy Center for site AMAA2 located in the NE Kodiak Archipelago.

Changes in the Ecosystem Processes

We include the ecosystem processes by life history stage table and associated conceptual model from the last full ESP for reference (Appendix Table 1A.2, Appendix Figure 1A.1). We updated the conceptual model with arrows that provide the direction of the ecosystem processes by life stage based on the indicator suite for the current year. We also include information regarding the importance of larval transport and changes in the abundance of competitors and predators to support the inclusion of three new indicators described in the indicator suite.

The spring time period is particularly important for pollock because eggs and larvae are in the water column and subject to wind-driven transport. Northeasterly wind has been associated with retention of pollock larvae (Stabeno et al., 1996) and juveniles (Wilson and Laman, 2020) in favorable areas in the Kodiak Island/Shelikof sea valley vicinity. Additionally, the recent study by Wilson and Laman (2020) found that northeasterly winds (i.e., trajectories down Shelikof Strait) for Apr-May had a positive relationship with recruitment estimates (age-1) of GOA pollock, presumably due to downwelling-related retention of larvae and juveniles in areas that favor survival.

With the increasing heat in the ecosystem and shifts in community composition, it is important to consider the potential impacts of other GOA pollock predators and competitors that may be on the rise and have an advantage in this new warming environment (e.g., sablefish and Pacific ocean perch [POP]). Several recent large year-classes are estimated for the sablefish stock, which has potential overlap as both a competitor with (juveniles eat euphausiids) and predator of GOA pollock as they return to their adult habitat on the continental slope. Estimates of total biomass for GOA POP have been steadily increasing for the past several decades and is now about 55% of the total biomass estimate for GOA pollock (Hulson et al., 2019). Juvenile and adult POP could be potential competitors of GOA pollock as they primarily feed on euphausiids. Recent estimates of incidental catch of POP in the pollock fishery are ~50 times higher for pelagic gear and ~30 times higher for non-pelagic gear in the current year compared with in the 2000s. Similarly, estimates of incidental catch of sablefish in the current year versus that in the year prior to the recent recruitment (starting with the 2014 year class) are ~35 times higher for non-pelagic gear in the pollock fishery. These estimates suggest an increasing amount of spatial overlap between the three stocks and likely increases in competition and predation given similar prey base as juveniles and the high growth rate of sablefish in their maturing years (age at 50% maturity is 6.5).

Changes in the Socioeconomic Processes

The GOA pollock fishery is managed as a limited entry open access fishery. Total allowable catch is annually 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 value of pollock deliveries by vessels to inshore processors (shoreside ex-vessel value) decreased 14% in 2019 from 2018 to $36.1 million, but is above the average for the previous 5 years of $34 million (real 2019 USD, Appendix table 1A.3a). This decrease was the net effect of a 24% decrease in retained catch to 119 thousand t and a 12% increase in the ex-vessel price to $0.138 per pound (Appendix Table 1A.3a). The number of vessels fishing for pollock decreased from 71 in 2018 to 62 in 2019 (Appendix Table 1A.3a). The increased ex-vessel price in 2019 coincided with increased first-wholesale prices for head-and-gut (H&G) and fillet products, which represent approximately two-thirds of annual production (Appendix Table 1A.3b). While year-over year prices for pollock H&G and fillets increased, the value of both products was higher than levels observed in 2010-2014. First-wholesale value was $86 million in 2019 (18% decrease) and production of pollock products was 51 thousand t (26% decrease) (Appendix Table 1A.3b). The average first-wholesale price of pollock products increased 10% to $0.76 per pound (Appendix Table 1A.3b).

Pollock is a global commodity with prices determined in the global market. GOA represents roughly 3%-5% of the global pollock catch volume (Appendix Table 1A.3c). In the GOA, the primary products are H&G, surimi, fillets, and roe, each have typically accounted for approximately 35%, 25%, 30%, and 10% of first-wholesale value in recent years, respectively (Appendix Table 1A.3b). H&G product is primarily exported to China and reprocessed for global markets and competes with the Russian supply of pollock. The majority of fillets produced are pin-bone-out (PBO) primarily destined for domestic and European markets. 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). Roe is a high-priced product destined primarily for Asian markets.

In order to examine participation trends for those communities substantially engaged in the commercial GOA pollock fishery, commercial processing and harvesting data were analyzed. This community engagement analysis has been conducted for several groundfish stocks in Alaska as part of the Annual Community Engagement and Participation Overview (ACEPO). This is a new summary document in preparation that focuses on providing an overview of harvesting and processing sectors of identified highly engaged communities for groundfish and crab fisheries in Alaska (S. Wise, *pers. commun.*). The analysis presented here is similar to that conducted for the ACEPO report but on the stock level rather than the community level. The analysis separates variables into two categories of fisheries involvement: commercial processing and commercial harvesting. Processing engagement is represented by the amount of landings and associated revenues from landings in the community, the number of vessels delivering in the community, and the number of processors in the community. Harvesting engagement is represented by: the landings, revenues associated with vessels owned by community residents, the number of vessel landings owned by residents in the community, and the number of distinct resident vessel owners whose vessels made landings in any community. By separating commercial processing from commercial harvesting, the engagement indices highlight the importance of fisheries in communities that may not have a large amount of landings or processing in their community, but have a large number of fishers and/or vessel owners that participate in commercial fisheries who are based in the community. To examine the relative harvesting and processing engagement of each community, a separate principal components factor analysis (PCFA) was conducted each year for each category to determine a community's engagement relative to all other Alaska communities. Top communities were then selected for each sector based on the value and volume of GOA pollock landed (for processing engagement) and value and volume harvested for harvesting engagement. Within the processing sector, the ports at Kodiak accounted for about 69% of the value attributed to GOA pollock over the past 5 years, while Sand Point, King Cove, and Akutan combined landed 20%.

One indication of community engagement in processing activities for the GOA pollock fishery is calculating the portion of the total GOA pollock fishery landed in each community as well as the percentage of the total revenue those communities get from the GOA Pollock fishery. In 2019, Kodiak ports landed the bulk of GOA pollock delivered by volume (71%), while Sand Point, King Cove and Akutan landed a total of 28%. In 2019, all communities saw shifts in both the percentage of volume landed within that community and the percentage of revenue attributed to GOA pollock landings (Appendix Figure 1A.2a). Sand Point saw an increase in the percentage of volume GOA pollock landed, while King Cove decreased and Akutan remained relatively stable. Together these three communities landed about 22%, while Kodiak fell from 75.8% to 69.6% of GOA pollock landed. Concurrently, each community saw slight decreases (less than 1%) in the percentage of revenue attributed to GOA pollock.

In order to explore community engagement in harvesting activities for GOA pollock, the associated value of GOA pollock harvested by vessels owned by community residents from 2000 to 2019 was examined. The number of vessels owned by community residents participating in the GOA pollock fishery increased by 3 vessels in Kodiak since 2015 (up 17%); decreased by 1 in the Seattle MSA (metropolitan statistical area) (down 4.8%), and remained unchanged in Sand Point. In 2019, Kodiak residents owned 21 vessels involved in GOA pollock harvesting, the Seattle MSA had 20, and Sand Point 6 vessels. Over the past five years, the average value of harvest by vessels owned by Kodiak residents increased from $ 13.2 million to $15 million (up 13%); however in the last year Kodiak saw a decline of $1.5 million (9.5%). The Seattle MSA saw a drop over five years from $11.7 million to $7.3 million (down 37%), and in the past year the value decreased a total of $2.1 million (22% from 2018). Sand Point saw the steepest decline from $2.3 million to $0.9 million (down 61%). Last year Sand Point value harvested fell by nearly $1 million (down 51%) (Appendix Figure 1A.2b).

Changes in the Indicator Suite

We included several updates to indicators using new data sources and new indicators that were identified as a data gap in last year's ESP. For the sea surface temperature indicators we have moved to using the NOAA Coral Reef Watch Program products as they are supported operationally by NOAA and NESDIS and are updated daily (Watson et al., 2020). For measures of primary producers we provide a combination indicator of chlorophyll *a* concentration and the timing of the spring bloom which utilizes ocean color data from the MODIS satellite sensor and are also available in real-time (Watson et al., 2020). We also added a new wind indicator to address the data gap of investigating cross-shelf transport during the early life history stages (Wilson and Laman, 2020).

Changes in the Indicator Monitoring Analysis

Indicators are monitored using three stages of statistical tests that gradually increase in complexity depending on the stability of the indicator for monitoring the ecosystem or socioeconomic process and the data availability for the stock (Shotwell et al., *In Review*). Following recommendations from the SSC in Febuary 2020, we have added a scoring calculation to the first stage traffic light test. Similar to last year, the indicator values are evaluated if they are greater than (+), less than (-), or within (•) one standard deviation of the long-term mean for the time series. A value is then provided for the traffic-light based on whether the indicator creates conditions that are good (1), neutral (0), or poor (-1) for GOA pollock (Caddy et al., 2015). This is based on the conceptual model and associated processes tables. We then assign a simple score based on the value compare to the long term mean and the traffic light code. If a high value of an indicator generates good conditions for GOA pollock and is also greater than one standard deviation from the mean, then that value receives a +1 score. If a high value generates poor conditions for GOA pollock and is greater than one standard deviation from the mean, then that value receives a -1 score. All values less than or equal to one standard deviation from the long-term mean are average and receive a 0 score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. We also calculate the overall ecosystem and socioeconomic score and provide these aggregated scores for the past twenty years as the majority of indicators were available throughout this time period. The scores over time allow for comparison of the indicator performance and the history of stock productivity.

Summary of Results

We have updated the indicator suite from the last full ESP as described above in the “Changes in the Indicator Suite” subsection (Appendix Figure 1A.3). The following list of indicators for GOA pollock is organized by categories, three for ecosystem indicators (physical, lower trophic, and upper trophic) and three for socioeconomic indicators (fishery performance, economic, and community) and provides information on whether the indicator was updated or new this year with references where possible. Please refer to the last full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions for this stock (Shotwell et al., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Appendix Figure 1A.3a and Appendix Figure 1A.3b, respectively.

Ecosystem Indicators

1. Physical Indicators (Appendix Figure 1A.3a.a-f)
    - Annual marine heatwave cumulative index over the central GOA (Barbeaux, 2018), 1982 to present (contact: S. Barbeaux).
    - UPDATED: Spring (April-May) daily sea surface temperatures (SST) for the western and central (combined) GOA (Watson, 2020) from the NOAA Coral Reef Watch Program which provides the Global 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018). The data are served through the ERDDAP maintained by NOAA CoastWatch West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division. Available from 1985 to present (contact: J. Watson).
    - Summer bottom temperatures (degrees Celsius) from the AFSC bottom trawl survey through AKFIN, 1984 to present on triennial and then biennial frequency (contact: K. Shotwell)
    - NEW: mean springtime (April-May) surface wind direction from National Data Buoy Center (www.NDBC.NOAA.gov) for site B-AMAA2 located in the NE Kodiak Archipelago (Wilson and Laman, 2020). Data are available from 2004-2006, 2009-2017 and 2019-2020 (contact: L. Rogers and M. Wilson)
    - NEW: Derived chlorophyll *a* concentration during spring seasonal peak (May) in the western and central (combined) GOA were obtained from MODIS satellite sensor at a 4x4 km resolution and aggregated 8-day composite. Peak timing of the spring bloom was calculated for the western and central GOA (WCGOA) region (Watson et al., 2020). The data are served through the ERDDAP maintained by NOAA CoastWatch West Coast

Regional Node and Southwest Fisheries Science Center's Environment Research Division. Data available from 2003 to present (contact: J. Watson).

2. Lower Trophic Indicators (Appendix Figure 1A.3a.g-o)
    - Spring small copepods for larvae and summer large copepods for young-of-the-year (YOY) GOA pollock from the EcoFOCI spring and summer surveys (Kimmel et al., 2019), 1987 to present, various years (contact: L. Rogers).
    - Summer euphausiid abundance for the Kodiak core survey area (Ressler et al., 2019) available for variable years historically and biennially since 2013 (contact: P. Ressler).
    - Parakeet auklet reproductive success at Chowiet Island (Higgins et al., 2018), 1998 to present, various years (contact: S. Zador).
    - Spring pollock larvae and summer young-of-the-year (YOY) pollock catch-per-unit-of-effort (CPUE) from the EcoFOCI spring and summer surveys (Dougherty and Rogers, 2019, Rogers et al., 2019b), 1981 to present, various years (contact: L. Rogers).
    - Summer pollock condition for YOY from EcoFOCI midwater trawl survey (Rogers et al., 2019a), 2000 to present, various years (contact: L. Rogers).
    - Summer pollock CPUE of YOY from the AFSC Kodiak beach seine survey, 2006 to present (contact: B. Laurel).
    - Pollock relative biomass of YOY from screening burrows of tufted puffins at Aiktak Island (Youngren et al., 2019), 1991 to present (contact: S. Zador).
3. Upper Trophic Indicators (Appendix Figure 1A.3a.p-w)
    - Summer pollock predation mortality for age-1 from RACE and IPHC (Barnes et al., *In Review*), 1990 to 2017 (contact: C. Barnes).
    - Summer pollock proportion-by-weight of euphausiids in the diets of juvenile (10-25 cm, likely age-1) GOA pollock from summer bottom-trawl surveys, 1990 to present, various years (contact: K.Aydin).
    - Fall pollock condition for adults from the fishery sampled by observers, 1989 to present (contact: M. Dorn).
    - Winter pollock condition for adults from the late winter acoustic surveys of pre-spawning pollock in the GOA, 1986 to present, various years (contact: M. Dorn).
    - Summer pollock center of gravity and area occupied estimated by a spatio-temporal delta-generalized linear mixed model using the package VAST on bottom trawl survey data, 1990 to present, various years (contact: L. Barnett).
    - Arrowtooth flounder total biomass (metric tons) from the most recent stock assessment model (Spies and Palsson, 2019), 1977 to present (contact: K. Shotwell).
    - Pacific ocean perch total biomass (metric tons) from the most recent stock assessment model (Hulson et al., 2019), 1977 to present (contact: K. Shotwell).
    - Sablefish total biomass (metric tons) from the most recent stock assessment model (Hanselman et al., 2019), 1977 to present (contact: K. Shotwell).
    - Steller sea lion non-pup estimates for the GOA portion of the western Distinct Population Segment (known as the west, central and east GOA) (Sweeney and Gelatt, 2020), 1978 to present (contact: K. Sweeney).

Socioeconomic Indicators

1. Fishery Performance Indicators (Appendix Figure 1A.3b.a-b)
    - Winter-spring and summer-fall pollock CPUE (catch of pollock in tons/hour) from fishery observer data, 1988 to present (contact: M. Dorn).
2. Economic Indicators (Appendix Figure 1A.3b.c-d)
    - Annual real Ex-vessel price per pound from fish ticket information, 2000-2019 (2018 USD) with a projected price for the most recent year (contact: B. Fissel).

- Annual pollock roe per-unit-catch during January to March, 2000-2019 with a projected catch for the most recent year (contact: B. Fissel).

3. Community Indicators (Appendix Figure 1A.3b.e-h)
    - NEW: the suite of community indicators are expressed as regional quotient (RQ) which is a measure of the importance of the community relative to all Alaska fisheries as calculated in pounds landed or revenue generated from specific fisheries. The RQ is calculated as the landings or revenue attributable to a community divided by the total landings or revenue from all communities and community groupings. Indicators of the annual RQ (expressed as percentage) for processing and harvesting revenue are evaluated for the highly engaged communities of Kodiak and a combined summary of three smaller highly engaged communities (Sand Point, King Cove, and Akutan). These three smaller communities were combined for confidentiality concerns. Data were available from 2000 to 2019 (contact: S. Wise).

At this time, we report the results of the first and second stage statistical tests of the indicator monitoring analysis for GOA pollock. The third stage will require more indicator development and review of the ESP modeling applications, but we provide updates of new ecosystem enhanced models in development.

Stage 1, Traffic Light Test:

We evaluate the set of ecosystem indicators to understand the pressures on the large year-class of 2012 which was the last major year class of GOA pollock and on the current near average year classes of 2017 and 2018. We start with the physical indicators and proceed through the increasing trophic levels as the indicators are listed above. There has been increased sea surface warming in the GOA ecosystem and the presence of a series of major heatwaves from 2014-2016 and again in 2019 (Appendix Fig.1A.3a.a) have likely influenced the early maturation of the 2012 year-class and negatively impact YOY pollock during a time when they are growing to a size that promotes over-winter survival. The warm conditions have persisted in the springtime surface temperatures from 2014-2016, then cooled in 2017-2018, increased again in 2019 and cooled in 2020. These warm temperature anomalies did not extend to the bottom during the 2017 survey but the 2015 and 2019 bottom temperatures throughout the western/central GOA were the highest on record for the bottom trawl survey (Appendix Fig.1A.3a.b-c). Warm surface temperatures tend to be associated with zooplankton communities that are dominated by smaller, less lipid rich species which may have adversely impacted the egg and larval habitat. The direction of the mean surface wind has shifted more toward the southwest (down Shelikof Strait) in 2020 (Appendix Fig. 1A.4) implying retention in favorable habitat of Kodiak Island and the Shelikof sea valley and potentially good conditions for recruitment.

Estimates of peak chlorophyll *a* concentration (derived chlorophyll *a* in May) were on a decreasing trend since 2013 but increased in 2020. Timing of the spring bloom has been variable over the time series but seems to be relatively late during warm years and early during colder years of 2017-2018 and 2020, potentially contributing to a mismatch of pollock larvae with production of their prey. Bloom timing has implications for subsequent food web dynamics. The result can be seen in the zooplankton time series (Appendix Fig.1A.3a.g-i) where small spring copepods were abundant in the 2013, 2015, and 2017 surveys and euphusiids were low in 2017 and 2019 survey and on a downward trend in the pollock age-1 diet (suggesting decreased availability, Appendix Fig.1A.3a.p). It is possible that the diet of planktivorous seabirds in the Kodiak region may serve as a proxy for zooplankton productivity in the region and this could be detected in the subsequent reproductive success of the seabirds. The auklet reproductive success on Chowiet (Appendix Fig.1A.3a.j) appears to be very high in 2016, very low in 2018, and average in 2019, suggesting there may be large spatial shifts in the available prey base.

The CPUE of larvae and YOY in the spring and summer offshore EcoFOCI surveys was unknown for 2012 but the highest in the time series in 2013, above average in 2017 and poor for 2015 and 2019 (Appendix Figure 1A.3a.k-m). Associated condition for YOY pollock has been on a decreasing trend since 2007 suggesting that the environmental conditions during the first year of life through overwinter were more favorable for the 2012 year class then subsequent year classes. The nearshore surveys in Kodiak showed above average CPUE in 2012 and very high abundance in both 2017 and 2018, but very poor abundance in 2019 with an slight increase in 2020 (Appendix Figure 1A.3a.n).

Relative biomass of pollock in tufted puffin diet has been variable since 2012 with overall downward trend to 2019. Additionally, relative biomass of pollock in tufted puffin diet was the highest in the time series near the western edge of the population (Aiktak, Appendix Fig.1A.3a.o) during 2012 supporting the large year class event even at the edge of the population distribution suggesting widespread favorable habitat for GOA pollock during 2012, but average for 2017 and 2018. Predation estimates on age-1 pollock have been relatively low since 2007 (Appendix Fig.1A.3a.p), but so has the percent of euphasiids in the diet for juveniles (Appendix Fig.1A.3a.q). This lack of large zooplankton and euphausiids in the prey base following the first overwinter suggests that there were poor feeding conditions as the juvenile pollock migrated to adult habitat. The 2012 year-class was subsequently in poor condition when they recruited to the fall fishery in 2015 and in the following 2016 winter acoustic survey (Appendix Fig.1A.3a.r-s). The 2016 through 2019 condition anomalies were all moderate to strongly negative, but the 2020 condition estimate has increased in the acoustic survey. Since 2001, there is a good correlation between condition in the late-season fall fishery and condition in the winter acoustic Shelikof Strait samples in the following year. This suggests that these indicators are measuring something real about the pollock stock condition and are not due to sampling variability.

The overall spatial distribution of the 2012 year-class (measured for adults in the 2015 survey) was also spread out substantially from previous years and more toward the southwest (area occupied is high with decrease in the northeast center of gravity). This suggests that some of the pollock population may potentially be expanding out of preferred habitat. A historical analysis on pollock distribution in the GOA found dispersion of the pollock stock up until 1996, which may be consistent with increasing trend in effective area occupied (Shima et al., 2002). Total biomass has decreased, while effective-area has remained high and northeast center of gravity has returned to average since 2015 (Appendix Fig.1A.3a.t-u). The decrease in total biomass has been associated with decreased density within the range and a slight increase in range.

Predator biomass of arrowtooth flounder and Steller sea lions has been decreasing and/or stable for the most recent years (Appendix Fig.1A.3a.v,y), suggesting that the primary pressure on the 2012 and recent year-classes may be the lack of preferred prey. However, recent increases in the incidental catch of Pacific ocean perch (POP) and sablefish in the pollock fishery suggest a higher degree of spatial overlap between these stocks and a different source of competition and predation may be impacting the juvenile and adult pollock stock. POP total biomass has been steadily increasing since mid 2000s and the sablefish stock has increased since the recent large 2014 year class began entering the survey and fishery (Appendix Fig.1A.3a.w-x).

For the socioeconomic indicators (Appendix Fig.1A.3b), fishery CPUE was high at the beginning of the time series, declined, and then increased toward the end of the time series and has declined again in 2019 and 2020, although still above average for the time series (Appendix Fig.1A.5). Higher fishery performance CPUE in the 1st trimester implies that the pollock were very concentrated, likely in pre-spawning aggregations, so catch rates were higher and roe may be in better condition. CPUE for the 1st and 3rd trimesters compared to model estimates of exploitable biomass track the estimated exploitable biomass from the assessment model reasonably well (Appendix Fig.1A.5b).

There has been a decreasing trend in real ex-vessel price since 2013 and more recently in roe per-unit catch in 2016. This is consistent with the lower adult condition in the fall fishery and winter acoustic survey (Appendix Fig.1A.3a.p-q). These decreases have somewhat rebounded in 2018 and 2019 but the projected value for 2020 remains low. Processing regional quotient (RQ) in Kodiak has been on an increasing trend since 2011 with a slight dip toward average revenue in 2016-2017. A more dramatic trend has occurred in small communities increasing rapidly from a low in 2013 likely with the onset of the large 2012 year class but has declined since 2016 and is near average in 2019. Harvesting RQ has been steadily rising in Kodiak since the beginning of the time series in 2000 reaching a peak in the time series in 2019. The opposite appears to be true for Sand Point with a decreasing trend in harvesting revenue since 2009 and has remained low since 2013 to 2019. These trends may be due to an increased level of reliance on GOA pollock by Kodiak residents and a potential switch to other fisheries in small communities as large year classes have not materialized since the 2012 year class.

Traffic light scores by category and overall are provided in Appendix Table 1A.4. For the indicators available in the current year, the traffic light analysis shows improved condition in the physical and lower trophic indicators, and a slight decrease in the upper trophic indicators. This is a switch from last year where the physical and lower trophic indicators were poor relative to the previous year with an slight improvement in the upper trophic indicators. It should be noted that only 10 of the potential 25 indicators were available this year for the ecosystem indicators (Appendix Table 1A.5a). Socioeconomic indicators were also a mix but with fishery performance indicators switching from very positive last year to average this year and economic indicators decreasing this year (Appendix Table 1A.5b). No community indicators were available this year as that information data lags the current year by at least one year. We also provide the direction of the current year score from the previous year score for these categories on the conceptual model graphic for quick reference (Figure 1A.1). The historical traffic light score over all ecosystem and socioeconomic indicators demonstrates a fairly strong positive relationship between the ecosystem and socioeconomic trends until 2017 when the two time series diverge (Figure 1A.6). This may reflect the delayed interaction between the increases in pollock revenue due to the large 2012 year class and subsequent lack of large year classes as reflected in overall poor ecosystem indicators.

Stage 2, Regression Test:

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and GOA pollock recruitment and to assess the strength of support for each hypothesis. In this second test, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment and highly correlated covariates are removed (Appendix Fig. 1A.7a). We further restrict potential covariates to those that can provide the longest model run and through the most recent estimate of recruitment that is well estimated in the current operational stock assessment model. This results in a model run from 1990 through the 2019 estimate of 1 year-olds or the 2018 year-class. We then provide the mean relationship between each predictor variable and log GOA pollock recruitment over time (Appendix Fig. 1A.7b, left side), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Appendix Fig. 1A.7b, right side). A higher probability indicates that the variable is a better candidate predictor of GOA pollock recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process were the spring SST in the WCGOA, the spring pollock larvae CPUE in Shelikof, the arrowtooth flounder biomass from the stock assessment, the fall pollock condition of adults in the fishery, and to a lesser extent sablefish total biomass from the stock assessment (Appendix Fig. 1A.7).The heatwave index was removed from this part of the analysis since it is a threshold indicator.

Stage 3, Modeling Test:

In the future, highly ranked predictor variables could be evaluated in the third stage statistical test, which is a modeling application that analyzes predictor performance and estimates risk probabilities within the operational stock assessment model. A new multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate- Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics; Holsman et al., 2016) has recently been developed for understanding trends in age 1 total mortality for walleye pollock, Pacific cod, and arrowtooth flounder from the GOA (Adams et al., 2020). Total mortality rates are based on residual mortality inputs (M1), model estimates of annual predation mortality (M2), and fishing mortality (F). CEATTLE has been modified for the GOA and implemented in Template Model Builder (Kristensen et al., 2015) to allow for the fitting of multiple sources of data, time-varying selectivity, time-varying catchability, and random effects. The model is based, in part, on the parameterization and data used for the most recent stock assessment model of each species (Barbeaux et al., 2019, Dorn et al., 2019, and Spies & Palsson, 2019). The model is fit to data from five fisheries and seven surveys, including both age and length composition data assumed to come from a multinomial distribution. Model estimates of M2 are empirically driven by bioenergetics-based consumption information and diet data from the GOA to inform predator-prey suitability. The model was fit to data from 1977 to 2020.

Once the GOA CEATTLE model is more developed and published, the age 1 mortality index could provide a gap-free estimate of predation mortality that could be tested in the operational stock assessment model. Additionally, the spring SST and condition indicators could be used directly to help explain the variability in recruitment deviations and predict pending recruitment events for GOA pollock.

Ecosystem Recommendations

The GOA pollock ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the changes in inputs and results from the last full ESP, we provide the following set of ecosystem considerations that may be used for reference in the main SAFE report.

- Survivial of pollock eggs and larvae and increases in recruitment have been associated with northeasterly wind and downwelling-related retention in favorable habitat in Kodiak/Shelikof.
- The degree of synchrony of first-feeding larval pollock with optimal prey conditions may be critical for larval survival and dependent on the thermal environment and onset of spring blooms.
- Juvenile pollock are sensitive to variations in foraging conditions, and spatial distribution may play a role in encounter of optimal prey such as euphausiids.
- Increases in incidental catch of other competitiors or predators of pollock (e.g., Pacific ocean perch and sablefish) suggest alternative sources of competition and predation
- Physical indicators for 2020 show a return to more average conditions with decreasing surface temperatures, increased northwesterly wind, slight increase in chlorophyll *a* concentration, and much earlier spring bloom timing in western/central GOA.
- The prey conditions for the 2018 year-class seem similar to that of the 2012 year-class, and may result in downstream poor condition when it reaches the fishery.
- Increased CPUE on the Kodiak beach seine survey suggest a stronger 2020 year-class than 2019
- Body condition of adult pollock improved in the 2020 acoustic survey with continued decease in the arrowtooth flounder biomass but the continued increases in POP and sablefish as competitors and predators may impact the incoming 2017 and 2018 year-classes
- Overall, physical and lower trophic indicators improved for GOA pollock while upper trophic indicators were mixed.

Socioeconomic Recommendations

The GOA pollock ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the changes in inputs and results from the last full ESP, we provide the following set of ecosystem considerations that may be used for reference in the main SAFE report.

- Fishery CPUE indicators have been above average since 2016, but had a decreasing trend in both the winter and spring fishery of 2019-2020 and summer and fall fishery in 2019 which is consistent with the stock trajectory over that past several years.
- There was a precipitous drop in ex-vessel price and roe per-unit-catch in 2016 and 2017 that rebounded in 2018 and 2019, which may be related to below average body condition of adult

pollock since 2015. Price is projected to decreased again in 2020 but roe-per-unit-catch is projected to remain stable

- Regional quotient (RQ) for processing and harvesting in Kodiak has increased steadily in recent years but the RQ for processing has declined sharply since 2016 in small communities, and for harvesting in Sand Point has declined since 2009 and remained low, which along with other data could suggest a level of reliance on the GOA pollock fishery by Kodiak residents and a switch to other fisheries for small communities.

Data Gaps and Future Research Priorities

While the metric and indicator assessments provide a relevant set of proxy indicators for evaluation at this time, there are certainly areas for improvement. The majority of indicators collected for GOA pollock have a fair number of gaps due to the biennial nature of survey sampling in the GOA. This causes issues with updating the ESP and the ecosystem considerations during off-cycle years and can lead to difficulty in identifying impending shifts in the ecosystem that may impact the GOA pollock population. Development of high-resolution remote sensing (e.g., regional surface temperature, transport estimates, primary production estimates) or climate model indicators (e.g., bottom temperature, NPZ variables) would assist with the current multi-year data gap for several indicators if they sufficiently capture the main trends of the survey data and are consistently and reliably available. NOAA National Center for Environmental Prediction (NCEP) model-based estimates of surface wind might be used in the future to extend the wind-recruitment comparison as the buoy data and the NCEP winds are correlated (r=0.67 for the u component, and r=0.77 for the v component), but further study is needed.

Additional refinement on the GOA CEATTLE model might also allow for a gap-free index of predation mortality for GOA pollock. An updated set of indicators may then be used in the second and third stage modeling applications that provide direction of relationships, inclusion probabilities, and evaluation of performance and risk within the operational stock assessment model.

We currently lack an indicator of predation on YOY pollock during their first autumn and winter, during a period when predation mortality is thought to be significant. Sampling of predator diets in fall and winter would help to fill this gap. Additionally, evaluating condition and energy density of juvenile and adult pollock samples at the outer edge of the population may be useful for understanding the impacts of shifting spatial statistics such as center of gravity and area occupied. Information is available from the GulfWatch Alaska program that could be helpful for evaluating the eastern edge of the GOA pollock population.

As indicators are improved or updated, they may replace those in the current set of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. This could be accomplished in the next full ESP assessment and the timing of that will depend on how the ESP process matures.

Responses to SSC and Plan Team Comments on ESPs in General

"Regarding ESPs in general, the SSC recommends development of a method to aggregate indices into a score that could be estimated over time and compared to stock history. One potential pathway forward may be to normalize and use an unweighted sum of all the indicators where all time series overlap, or just assign +1 or -1 to each indicator so that a neutral environment would be zero." (SSC, February 2020)

"The Teams discussed concerns of over-emphasizing the 1:1 weighting on the first stage. In the absence of information to indicate an appropriate weighting strategy, it is recommended to not rely too heavily on the uninformed 1:1 weighting to select appropriate indicators. The Teams also requested that the ESP team/authors consider appropriately caveating the indicators to ensure they are interpreted species-specific and not over generalized. The Teams support continuing with the current 3-stage indicator analyses for now, and re-evaluate as the ESP process develops, recognizing that the actual value of the

integrated index is yet to be clearly demonstrated although it is one high-level summary statistic that may be valuable to examine." (Joint Groundfish Plan Team, September 2020)

We provide a simple score following the SSC recommendation and compare the 1:1 weighting of indicators in this first stage score with the results of the second stage Bayesian Adapative Sampling (BAS) method that produces inclusion probabilies for a subset of indicators with the most potential for informing a stock assessment parameter of interest (in this case recruitment of GOA pollock). This second stage may provide insight on how to weight the indicators in the first stage for a more informed score.

"The Teams support the current formats and timelines for now. This question may need to be revisited as the ESP process develops." (Joint Groundfish Plan Team, September 2020)

We provide this partial ESP for the GOA pollock stock that follows the partial SAFE template in an effort to produce an executive summary version of the ESP. This template may go through some revision as the ESPs continue to develop.

Responses to SSC and Plan Team Comments Specific to this ESP

"*The SSC comments provided on the sablefish ESP (Agenda Item C1) with respect to socioeconomic processes and community indicators are also applicable to the GOA pollock ESP.*

Specific to the GOA pollock ESP, in the text on page 111, the engagement of Sand Point and King Cove in the fishery (in addition to the engagement of Kodiak) is briefly acknowledged. However, for the balance of the document, community indicators (page 116) and community profile information (page 144, Figure 1A.7) focus exclusively on Kodiak. It is a significant shortcoming to overlook the importance of pollock to the communities in western GOA, which the SSC recommends for inclusion in the next version of the ESP.

The SSC appreciates the authors' effort to identify fishery performance indicators that provide relevant insight into stock status. The SSC encourages the authors to continue to explore community related socioeconomic indicators and suggests that they focus on substantially engaged and/or substantially dependent communities recognizing that in small communities, even a low level of engagement in absolute terms can result in a relatively high level of dependence on that fishery. Further, communities selected for inclusion in the analysis should not be based on commercial landings alone, as engagement in the relevant commercial fishery(ies) can and does occur through locally owned vessel activity, crew employment and income, locally occurring processing activity, and support service activity. Dependency can usefully be measured via vessel and processing diversity and annual round activity and spatial variations, among other factors (recognizing that data availability will vary widely across communities, especially for support service activity). Additionally, as noted in public testimony, it is important to recognize that sablefish are economically important to community fleets across a variety of gear types.

To be useful in an ESP application, community engagement in and dependency on the relevant fishery(ies) need to be tracked with indicator time series data to allow for the recognition of trends that could serve as ecosystem "yellow flags" or "red flags," consistent with other indicators. Indices such as Regional Quotient and Local Quotient are particularly useful in a report card context for a variety of reasons, including the ability to provide information where data confidentiality considerations would be otherwise be a major analytic constraint, but they need to be clearly defined." (SSC, December 2019)

We have included a substantial community section in the Changes in the Socioeconomic Processes subsection and have added several new indicators on regional quotient processing and harvesting for both Kodiak and a set of smaller communities to include King Cove, Sand Point, and Akutan. We will continue to improve this section as we learn more about the ACEPO report and subsequent updates.

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Literature Cited

Barbeaux, S.J. 2018. Fall 2018 marine heatwave. In: S. Zador and E. Yasumiishi (Ed.), Ecosystem Considerations for 2018, Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Barbeaux , S., Aydin, K., Fissel, B, Holsman, K., Laurel, B., Palsson, W., Rogers, L., Shotwell, K., Yang, Q., and Zador, S., 2019. Assessment of the Pacific cod stock in the Gulf of Alaska *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Barnes, CL, Beaudreau AH, Dorn MW, Holsman KK, and Mueter FJ. *In Review*. Development of a predation index to assess trophic stability in the Gulf of Alaska. Ecological Applications.

Caddy, J.F. 2015. The traffic light procedure for decision making: its rapid extension from fisheries to other sectors of the economy. Glob. J. of Sci. Front. Res: 1 Mar. Sci. 15(1), 30 pp.

Dorn, M., Aydin, K., Fissel, B., Palsson, W., Spalinger, K., Stienessen, S., Williams, K., and Zador, S. 2018. Chapter 1 : Assessment of the walleye pollock stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Dorn, M., Aydin, K., Fissel, B., Palsson, W., Spalinger, K., Stienessen, S., Williams, K., and Zador, S. 2019. Chapter 1 : Assessment of the walleye pollock stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alasks. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Dougherty, A., Deary, A. and Rogers, L.A. 2019. Rapid larval assessment in the Gulf of Alaska, Spring 2019. *In* Zador, S., E., Yasumiishi,and G.A. Whitehouse. 2019. Ecosystem Status Report: Gulf of Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, A. Santos, C. Seung, and K. Sparks. 2019. Economic status of the groundfish fisheries off Alaska, 2018. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D.H., C.J. Rodgveller, K.H. Fenske, S.K. Shotwell, K.B. Echave, P.W. Malecha, and C.R. Lunsford. 2019. Assessment of the Sablefish stock in Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Higgins, B. R., J. M. Soller, and N. A. Rojek. 2018. Biological monitoring at Chowiet Island, Alaska in 2018. U.S. Fish and Wildl. Serv. Rep., AMNWR 2018/16. Homer, Alaska.

Holsman, K.K., Ianelli, J., Aydin, K., Punt, A.E. and Moffitt, E.A., 2016. A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models. Deep Sea Research Part II: 134: 360-378.

Hulson, P.J.F., Hanselman, D.H., Lunsford, C.R., Fissel, B., and Jones, D. 2019. Assessment of the Pacific ocean perch stock in the Gulf of Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Kimmel, D., Harpold, C., Lamb, J., Paquin, M., and Rogers, L. 2019. Leading zooplankton indicator for the Gulf of Alaska: spring and summer 2019 Rapid Zooplankton Assessment and long-term time-series. *In* Zador, S., E., Yasumiishi,and G.A. Whitehouse. 2019. Ecosystem Status Report: Gulf of Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H. and Bell, B., 2015. TMB: automatic differentiation and Laplace approximation. arXiv preprint arXiv:1509.00660.

Ressler, P.H. 2019. Gulf of Alaska Euphausiids. *In* Zador, S., E., Yasumiishi,and G.A. Whitehouse. 2019. Ecosystem Status Report: Gulf of Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Rogers, L.A., Wilson, M., and Cooper, D. 2019a. Body condition of Age-0 Pollock. *In* Zador, S., E., Yasumiishi,and G.A. Whitehouse. 2019. Ecosystem Status Report: Gulf of Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Rogers, L.A., Wilson, M., and Porter, S. 2019b. Abundance of YOY pollock and capelin in the Western Gulf of Alaska. *In* Zador, S., E., Yasumiishi,and G.A. Whitehouse. 2019. Ecosystem Status Report: Gulf of Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Shotwell, S.K., K., Blackhart, D., Hanselman, P., Lynch, S., Zador, B., Fissel, P., Spencer, and K., Aydin. *In Review*. Introducing a national framework for including stock-specific ecosystem and socioeconomic considerations within next generation stock assessments.

Shotwell, S.K., M. Dorn, A. Deary, B. Fissel, L. Rogers, and S. Zador. 2019. Ecosystem and socioeconomic profile of the walleye pollock stock in the Gulf of Alaska. Appendix 1A *In* Dorn, M.W., A.L. Deary, B.E. Fissel, D.T. Jones, N.E. Lauffenburger, W.A. Palsson, L.A. Rogers, S.A. Shotwell, K.A. Spalinger, and S.G. Zador. 2019. Assessment of the Walleye Pollock stock in the Gulf of Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501. Pp. 105-151.

Spies, I., and Palsson, W. 2019. Chapter 7 : Assessment of the arrowtooth flounder stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Stabeno, P. J., Schumacher, J. D., Bailey, K. M., Brodeur, R. D., & Cokelet, E. D. (1996). Observed patches of walleye pollock eggs and larvae in Shelikof Strait, Alaska: Their characteristics, formation and persistence. Fisheries Oceanography, 5(Suppl. 1), 81–91. https://doi.org/10.1111/j.1365-2419.1996.tb000 84.x

Sweeney, K., and Gelatt, T. 2020. Steller Sea Lions in the Gulf of Alaska. In Ferriss, B. and Zador, S., 2020. Ecosystem Status Report 2018: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Watson, J.T. 2020. Satellite-derived Sea Surface Temperature and Marine Heatwaves in the Gulf of Alaska. In Ferriss, B. and Zador, S., 2020. Ecosystem Status Report 2020: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Watson, J.T., Gann, J.C., Nielsen, J.M. 2020. Satellite-derived Chlorophyll-*a* Trends in the Gulf of Alaska. In Ferriss, B. and Zador, S., 2020. Ecosystem Status Report 2020: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Wilson, M. T., and Laman, N. 2020. Interannual variation in the coastal distribution of a juvenile gadid in the northeast Pacific Ocean: The relevance of wind and effect on recruitment. Fisheries Oceanography, 0, 1-20. doi:10.1111/fog.12499

Youngren, S. M., D. C. Rapp, and N. A. Rojek. 2019. Biological monitoring at Aiktak Island, Alaska in 2018. U.S. Fish and Wildl. Serv. Rep., AMNWR 2019/02. Homer, Alaska.

Zador, S., E., Yasumiishi,and G.A. Whitehouse. 2019. Ecosystem Status Report: Gulf of Alaska. In Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 215 p..

Tables

Appendix Table 1A.1: List of data sources used in the ESP evaluation. Please see the main GOA pollock SAFE document, the Ecosystem Status Report (Zador et al., 2019) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
EcoFOCI Spring Survey	Shelf larval survey in May-early June in Kodiak to Unimak Pass using oblique 60 cm bongo tows, fixed-station grid, catch per unit effort in numbers per 10 m^2	1978 – present	Western GOA annual, biennial
FBE Summer Survey	Age-0 gadid survey in mid-July through late August on 16 fixed-site stations, northeast Kodiak Island using 36-m demersal beach seine, gadids count, length in mm	2006 – present	Kodiak annual
EcoFOCI Late Summer Survey	Midwater trawl survey of groundfish and forage fish from August-September using Stauffer trawl and bongo tows from Kodiak to Unimak Pass, fixed-station grid	2000 – present	Western GOA biennial
RACE Bottom Trawl Survey	Bottom trawl survey of groundfish in June through August, Gulf of Alaska using Poly Nor'Eastern trawl on stratified random sample grid, catch per unit of effort in metric tons	1984 – present	GOA tri-, biennial
Seabird Surveys	Ecological monitoring for status and trend of suite of seabird species conducted by Alaska Maritime National Wildlife Refuge (AMNWR) at eight sites throughout Alaska	1991 – present	Alaska variable
MACE Acoustic Survey	Mid-water acoustic survey in March in Shelikof Strait for pre-spawning pollock and again in summer for age 1 pollock	1981 – present	GOA annual, biennial
NDBC Database	National Data Buoy Center (www.NDBC.NOAA.gov) wind trajectories and cumulative wind components for site B-AMAA2, Kodiak	2004 – present	national variable
REEM Diet Database	Food habits data and associated analyses collected by the Resource Ecology and Ecosystem Modeling (REEM) Program, AFSC on multiple platforms	1990 – present	GOA biennial
Coral Reef Watch Program	NOAA Coral Reef Watch Program, Global 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018)	1985 – present	Global
MODIS	4 km MODIS ocean color data aggregated 8-day composites.	2003-present	Global

Appendix Table 1A.1 (cont.): List of data sources used in the ESP evaluation. Please see the main GOA pollock SAFE document, the Ecosystem Considerations Report (Zador et al., 2019) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
Climate Model Output	Daily sea surface temperatures from the NOAA High-resolution Blended Analysis Data	1977 – present	Central GOA
FMA Observer Database	Observer sample database maintained by Fisheries Monitoring and Analysis Division	1988 – present	Alaska annual
NMFS Alaska Regional Office	Catch, economics, and social values for fishing industry, data processed and provided by Alaska Fisheries Information Network	1992 – 2018	Alaska annual
Reports & Online	ADFG Commercial Operators Annual Reports, AKRO At-sea Production Reports, Shoreside Production Reports, FAO Fisheries & Aquaculture Department of Statistics	2011 – 2018	Alaska, U.S., Global annual

Appendix Table 1A.2. Key processes affecting survival by life history stage for GOA pollock. See Shotwell et al. 2019 for a fully referenced description of processes in the table.

Stage		Processes Affecting Survival	Relationship to GOA Pollock
Adult	**Recruit**	1. Top-down predation increase on age 3+ 2. Bottom-up control on juvenile consumption	Increases in main predator of pollock would be negative but minor predators may indicate pollock biomass increase. Increases in primary prey biomass would be positive for pollock but may increase competition.
Adult	**Spawning**	1. Distribution 2. Surface and bottom temperature[10]	Increased distribution spread of adult pollock may be negative as pollock would experience non-preferred habitat and potentially lower quality prey options. Increases in temperature may be negative causing early maturation, mismatch with spring bloom.
Offshore to Nearshore Pelagic	**Egg**	1. Water column density 2. Advection/retention 3. Predation	Increases in density, advection, and predation would be negative for egg stage resulting in sinking or dispersal from preferred habitat and adequate zooplankton prey availability upon hatching from this stage.
Offshore to Nearshore Pelagic	**Yolk-sac Larvae**	1. Temperature-mediated metabolic rate 2. Currents that facilitate nearshore transport 3. Predation	Increases in temperature would increase metabolic rate and may result in rapid yolk-sac absorption that may lead to mismatch with prey. Current direction to preferred habitat would be positive for pollock. Increases in predation pressures would be negative.
Offshore to Nearshore Pelagic	**Feeding Larvae**	1. Temperature-mediated metabolic rate 2. Currents that facilitate nearshore transport 3. Predation	Increases in temperature would increase metabolic rate and may result in poor condition if feeding conditions are not optimal. Current direction to preferred habitat would be positive for pollock. Increases in predation pressures would be negative.
Offshore to Nearshore Pelagic	**Juvenile**	1. Spring/summer/fall abundance of zooplankton prey 2. Advection/retention (offshore) 3. Predation	Increases in preferred zooplankton prey would be positive for pollock condition and relative biomass of pollock may also be measured by minor predators of pollock. Advection offshore may have a positive effect for pollock to arrive at preferred habitat. Increases in predation pressures would be negative for pollock.
Offshore to Nearshore Pelagic	**Pre-Recruit**	1. Bottom-up control juvenile consumption 2. Top-down predation increase on age 3+	Increases in primary prey biomass would be positive for pollock but competition may also increase. Increases in main predator of pollock would be negative but minor predators such as seabirds may indicate pollock biomass increase.

Appendix Table 1A.3a. 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; 2010-2014 average, and 2015-2019.

	Avg 10-14	2015	2016	2017	2018	2019
Total Catch K mt	100.2	167.5	177.1	186.2	158.1	120.2
Retained Catch K mt	98	166	176	184	156	119
Ex-vessel Value M $	$ 34.0	$ 43.6	$ 32.3	$ 35.2	$ 42.2	$ 36.1
Ex-vessel Price/lb $	$ 0.157	$ 0.119	$ 0.083	$ 0.087	$ 0.123	$ 0.138
Central Gulf Share of Value	77%	81%	63%	72%	76%	74%
Vessels #	69.2	65	70	65	71	62

Appendix Table 1A.3b. 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; 2010-2014 average, and 2015-2019.

		Avg 10-14	2015	2016	2017	2018	2019
All Products	**Volume K mt**	37.7	59.8	75.1	78.1	69.1	51.1
All Products	**Value M $**	$84.8	$105.1	$106.4	$96.7	$104.9	$85.9
All Products	**Price lb $**	$1.02	$0.80	$0.64	$0.56	$0.69	$0.76
Head & Gut	**Volume K mt**	19.3	30.3	27.8	37.4	39.8	28.4
Head & Gut	**Value share**	34%	39%	22%	31%	35%	38%
Head & Gut	**Price lb $**	$0.67	$0.61	$0.38	$0.36	$0.41	$0.52
Fillets	**Volume K mt**	6.1	9.1	14.3	15.7	13.1	8.8
Fillets	**Value share**	24%	25%	37%	36%	32%	31%
Fillets	**Price lb $**	$1.56	$1.30	$1.26	$1.01	$1.16	$1.39
Surimi	**Volume K mt**	8.9	14.7	13.4	10.6	9.8	7.0
Surimi	**Value share**	27%	26%	27%	18%	20%	19%
Surimi	**Price lb $**	$1.15	$0.85	$0.97	$0.76	$0.96	$1.08
Roe	**Volume K mt**	2.0	3.1	0.5	1.1	2.4	1.9
Roe	**Value share**	13%	8%	2%	4%	9%	7%
Roe	**Price lb $**	$2.56	$1.22	$1.39	$1.80	$1.83	$1.42

Appendix Table 1A.3c. Pollock U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, GOA share of global production; 2010-2014 average, and 2015-2019.

	Avg 10-14	2015	2016	2017	2018	2019
Global Pollock Catch K mt	3,255	3,373	3,476	3,489	3,397	-
U.S. Share of Global Catch	42%	44%	44%	44%	45%	-
Russian Share of global catch	48%	48%	50%	50%	49%	-
GOA share of global	3%	4%	5%	5%	5%	-

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). FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NMFS Alaska Region Blend and Catch-accounting System estimates.

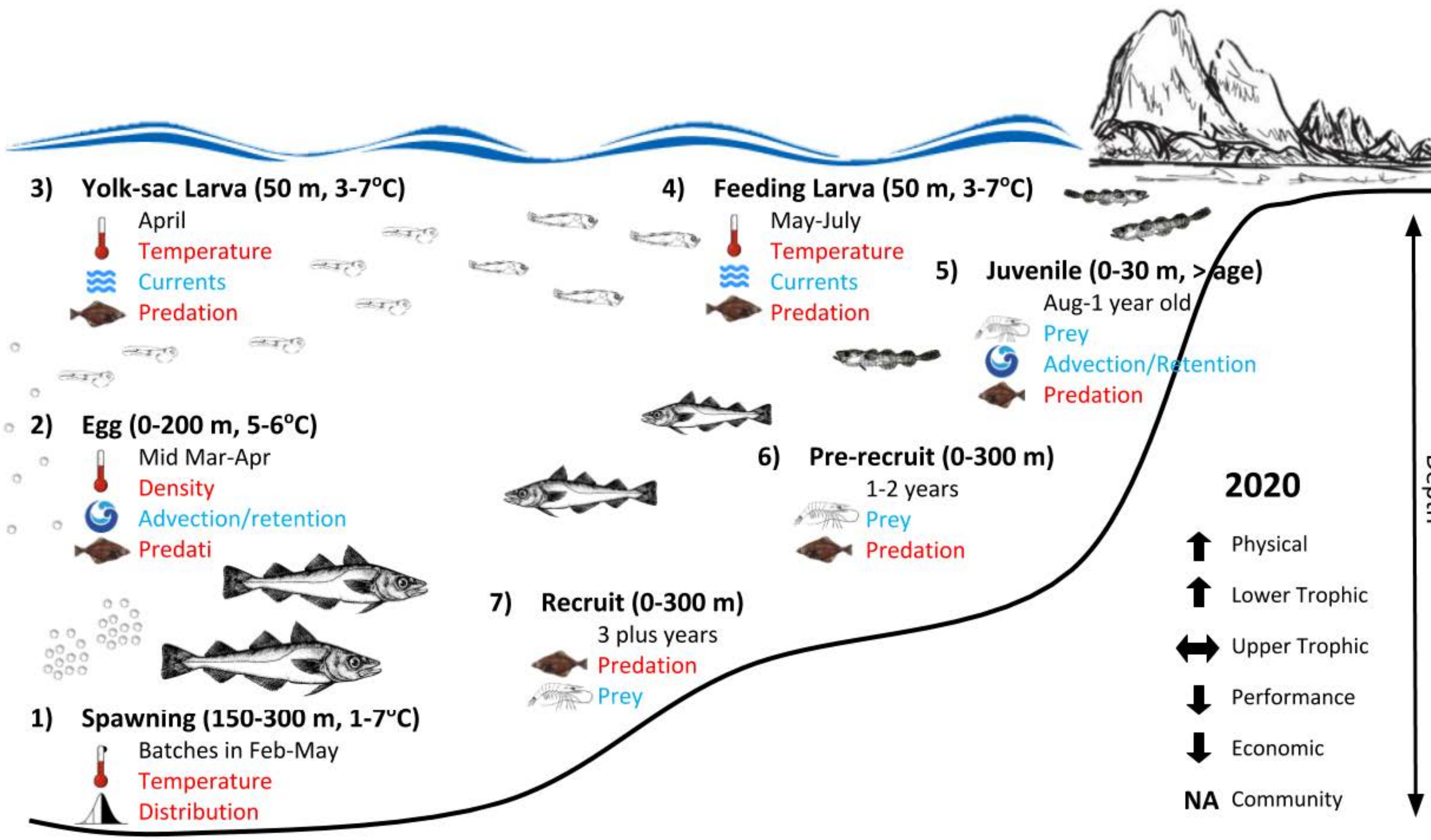
Appendix Table 1A.4a. First stage ecosystem indicator score analysis for GOA pollock by four main categories (physical, lower trophic, upper trophic, and overall ecosystem). Each indicator is scored based on the traffic light evaluation for that indicator (1 if a positive value increase creates good conditions for GOA pollock, -1 a if positive increase create poor conditions for GOA pollock, 0 otherwise), multiplied by the value relative to the long-term mean of the time series (greater than, less than, or within 1 standard deviation). These scores are summed by category and then divided by the total number of indicators for that category. Number of indicators for each category are also provided. NA = no indicators available. Color coding based on column, blue = 1 shading through white = 0 shading through red = -1.

	Physical		Lower Trophic		Upper Trophic		Total Ecosystem	
Year	Score	# Indicators	Score	# Indicators	Score	# Indicators	Score	# Indicators
2000	0.00	2	0.17	6	0.33	6	0.21	14
2001	0.00	3	0.00	6	-0.22	9	-0.11	18
2002	0.00	2	-0.33	3	-0.33	6	-0.27	11
2003	-0.40	5	0.33	6	-0.10	10	-0.05	21
2004	0.00	5	-0.33	3	-0.17	6	-0.14	14
2005	-0.33	6	-0.13	8	0.00	10	-0.13	24
2006	0.00	5	0.40	5	0.00	6	0.13	16
2007	0.60	5	-0.25	8	0.00	10	0.04	23
2008	0.50	4	-0.25	4	0.00	6	0.07	14
2009	0.50	6	-0.25	8	0.00	10	0.04	24
2010	0.00	5	0.40	5	0.17	6	0.19	16
2011	0.00	6	0.00	7	0.00	9	0.00	22
2012	0.40	5	0.33	3	0.00	6	0.21	14
2013	0.17	6	0.13	8	-0.20	10	0.00	24
2014	-0.40	5	0.00	3	0.00	6	-0.14	14
2015	-0.50	6	-0.22	9	0.22	9	-0.13	24
2016	-0.40	5	0.67	3	-0.50	6	-0.21	14
2017	-0.33	6	-0.11	9	-0.10	10	-0.16	25
2018	-0.50	4	0.00	3	-0.50	6	-0.38	13
2019	-0.50	6	-0.13	8	-0.22	9	-0.26	23
2020	-0.20	5	0.00	1	-0.25	4	-0.20	10

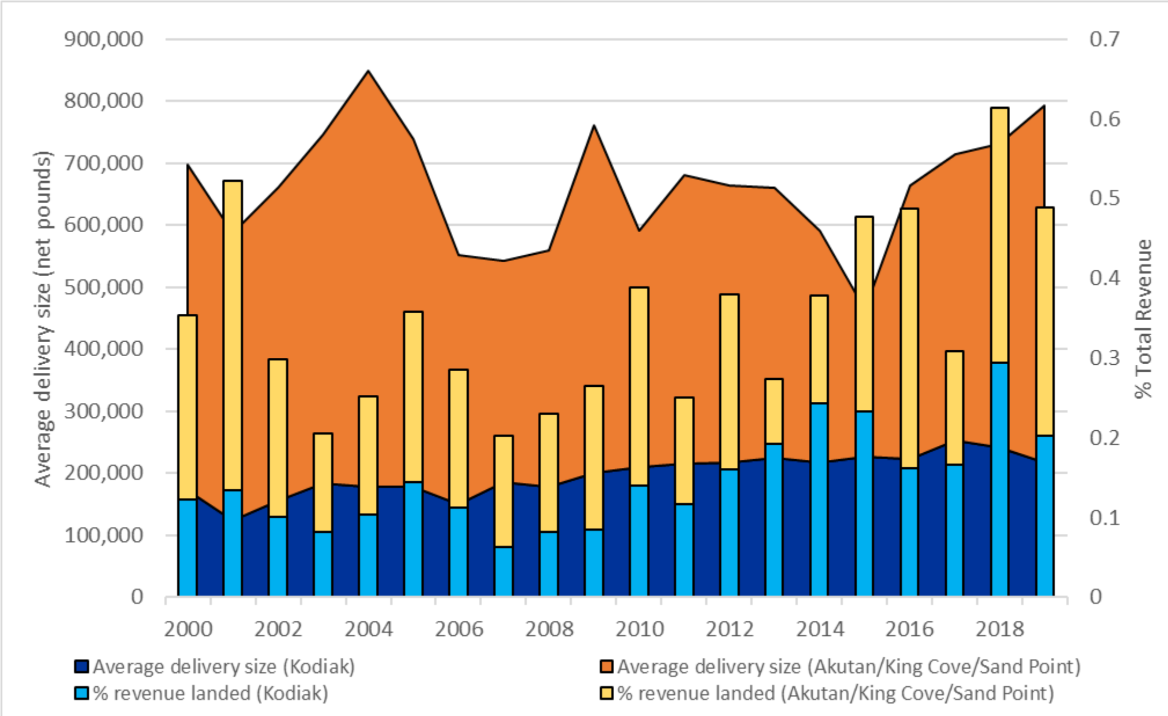
Appendix Table 1A.4b. First stage socioeconomic indicator score analysis for GOA pollock by four main categories (performance, economic, community, and overall socioeconomic). Each indicator is scored based on the traffic light evaluation for that indicator (1 if a positive value increase creates good socioeconomic environment for GOA pollock, -1 if positive increase create poor conditions for GOA pollock, 0 otherwise), multiplied by the value relative to the long-term mean of the time series (greater than, less than, or within 1 standard deviation). These scores are summed by category and then divided by the total number of indicators for that category. Number of indicators for each category are also provided. NA = no indicators available. Color coding based on column, blue = 1 shading through white = 0 shading through red = -1.

	Fishery Performance		Economic		Community		Total Ecosystem	
Year	Score	# Indicators	Score	# Indicators	Score	# Indicators	Score	# Indicators
2000	-0.50	2	0.00	2	0.00	4	-0.13	8
2001	-1.00	2	0.50	2	0.00	4	-0.13	8
2002	-1.00	2	0.00	2	0.25	4	-0.13	8
2003	0.00	2	0.00	2	-0.25	4	-0.13	8
2004	0.00	2	0.00	2	0.00	4	0.00	8
2005	0.00	2	0.00	2	0.00	4	0.00	8
2006	-0.50	2	0.00	2	0.00	4	-0.13	8
2007	-0.50	2	0.50	2	-0.25	4	-0.13	8
2008	-0.50	2	0.50	2	-0.25	4	-0.13	8
2009	0.00	2	0.50	2	0.00	4	0.13	8
2010	0.00	2	0.50	2	0.00	4	0.13	8
2011	1.00	2	0.00	2	0.00	4	0.25	8
2012	0.50	2	0.00	2	0.00	4	0.13	8
2013	0.00	2	0.00	2	-0.50	4	-0.25	8
2014	0.50	2	0.00	2	0.00	4	0.13	8
2015	0.00	2	0.00	2	0.00	4	0.00	8
2016	0.00	2	-1.00	2	0.25	4	-0.13	8
2017	1.00	2	-1.00	2	0.00	4	0.00	8
2018	0.50	2	0.00	2	0.25	4	0.25	8
2019	0.50	2	0.00	2	0.25	4	0.25	8
2020	0.00	1	-0.50	2	0.00	0	-0.33	3

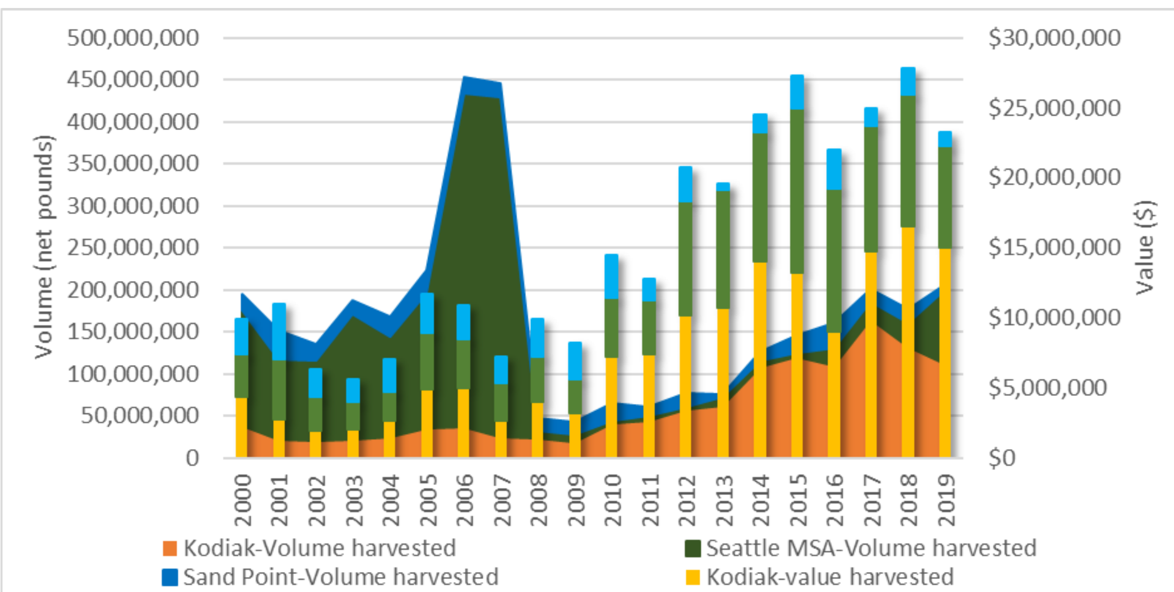
Figures



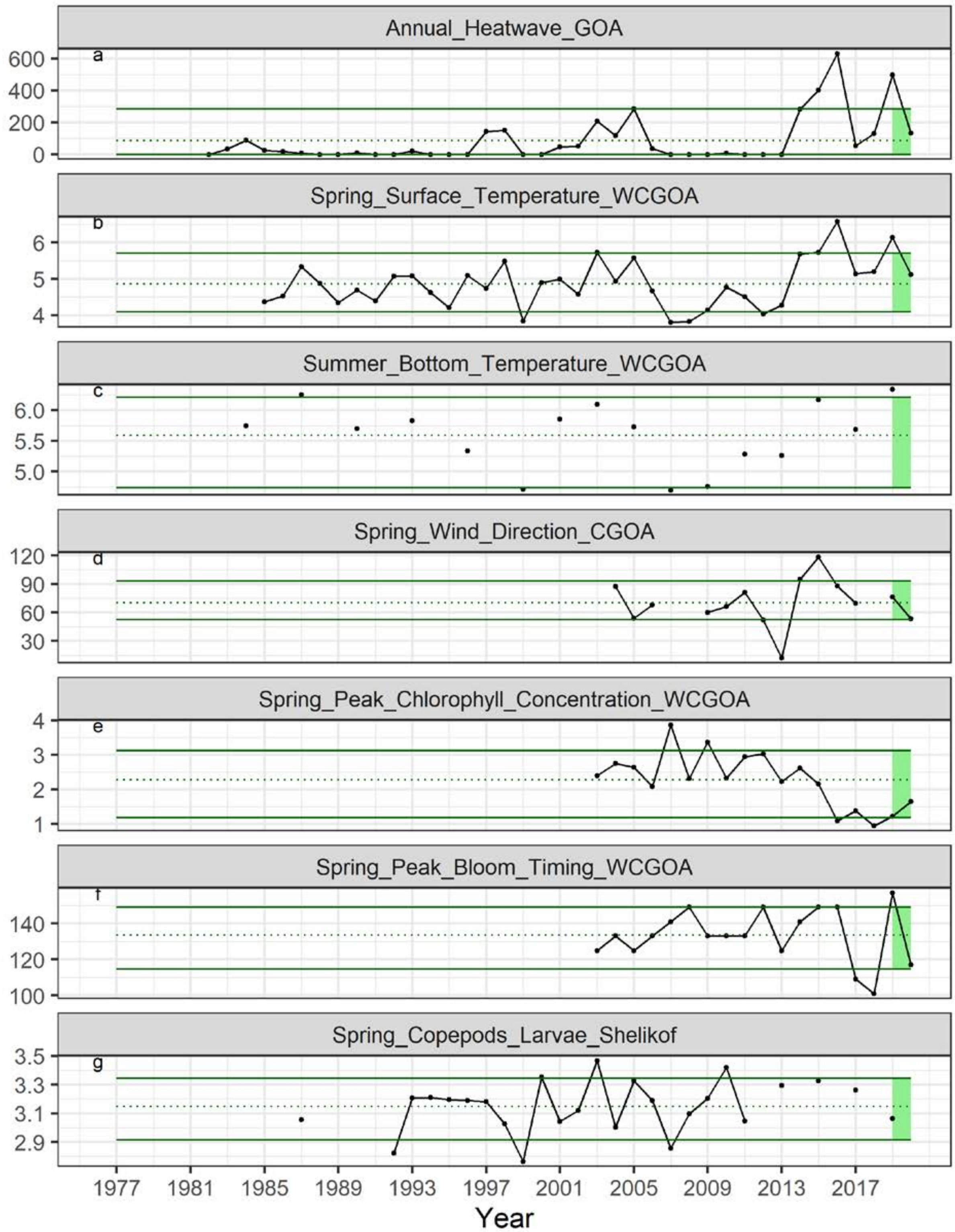
Appendix Figure 1A.1: Life history conceptual model for GOA pollock summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates increases in the process negatively affect survival, while blue text indicates increases in the process positively affect survival. Trend of current year value compared to last year's value depicted with arrows on the right. NA means no indicators for that category.



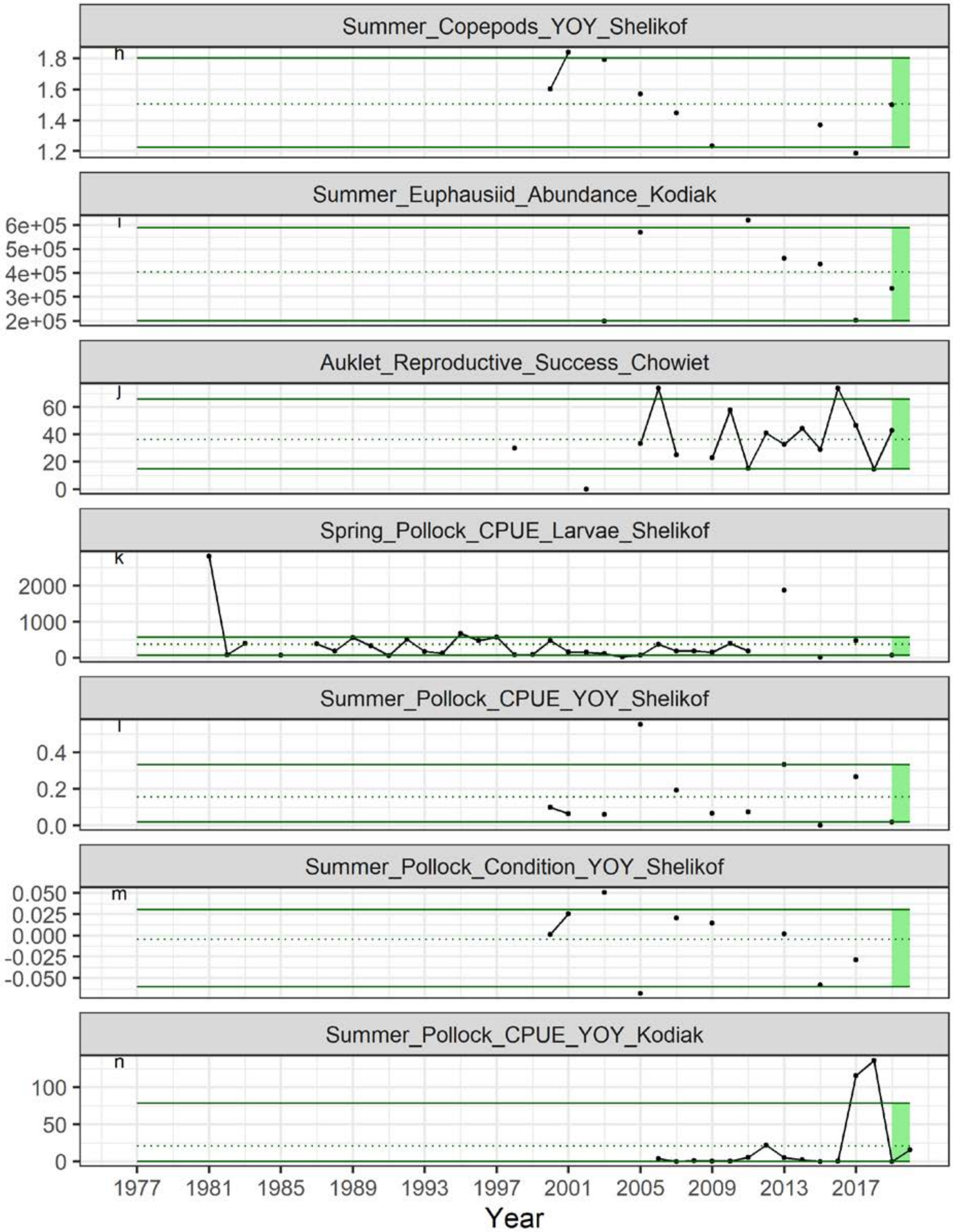
Appendix Figure 1A.2a: Processing engagement: Average pounds delivered and percentage of revenue landed attributed to GOA pollock (2000-2019).



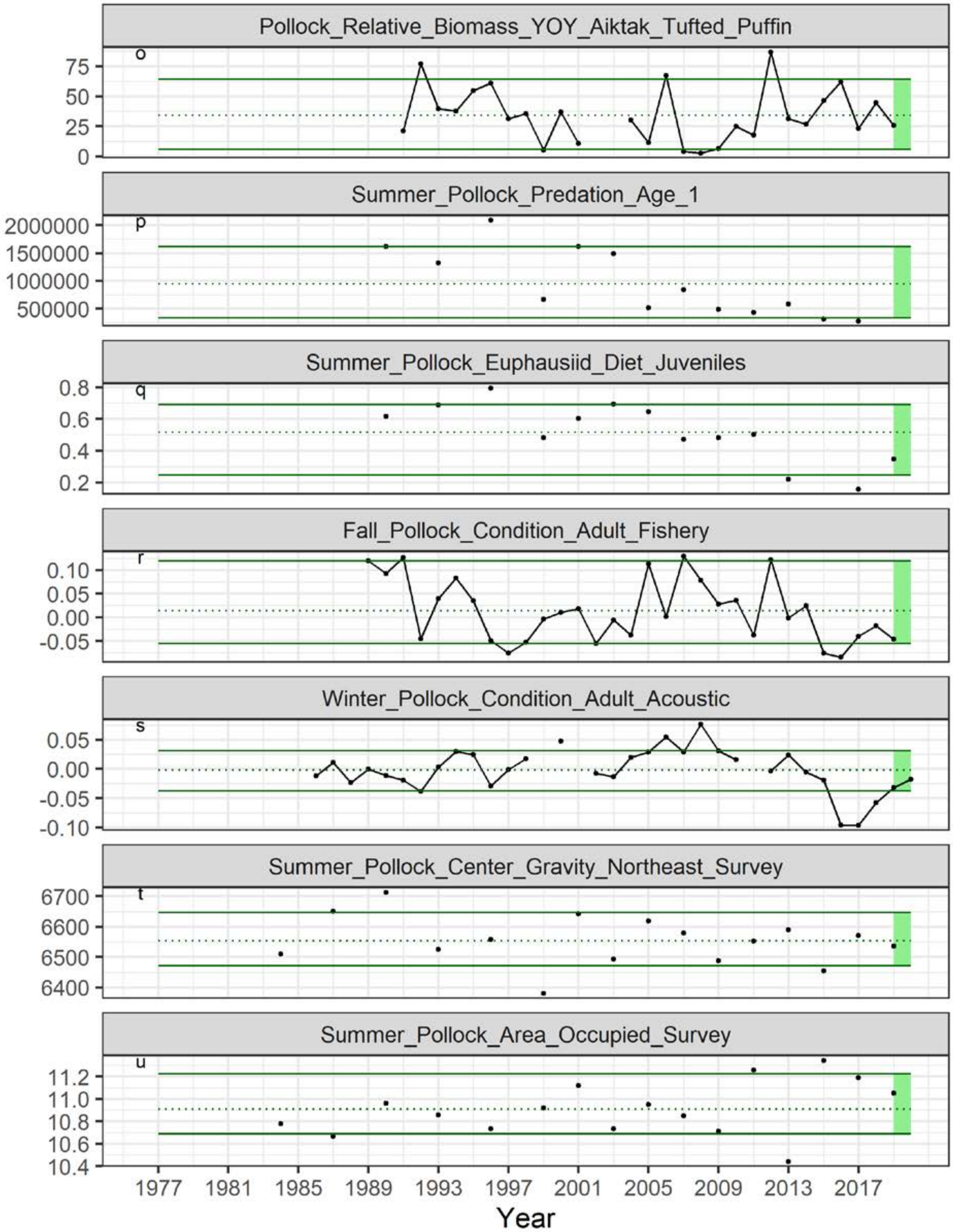
Appendix Figure 1A.2b: Harvesting engagement: Average volume and value of GOA pollock harvested by vessels owned by community residents (2000-2019).



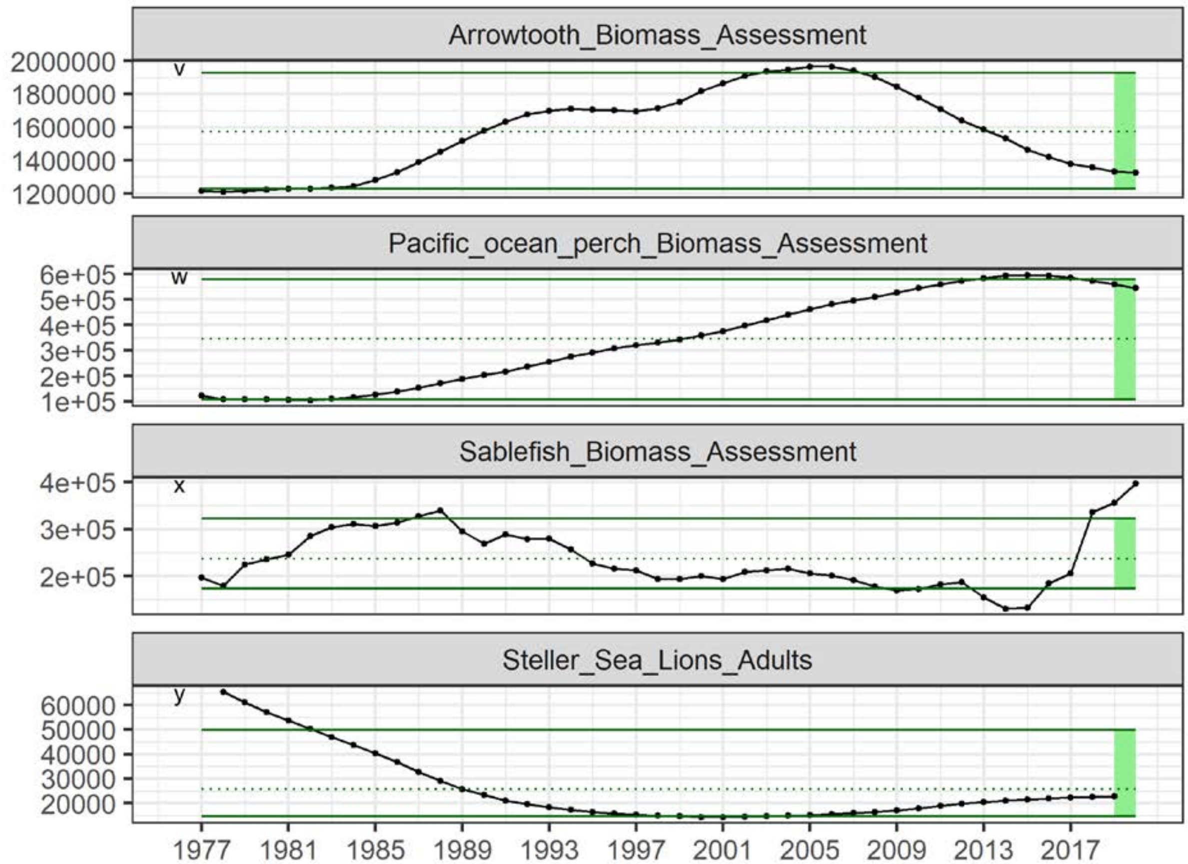
Appendix Figure 1A.3a: Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



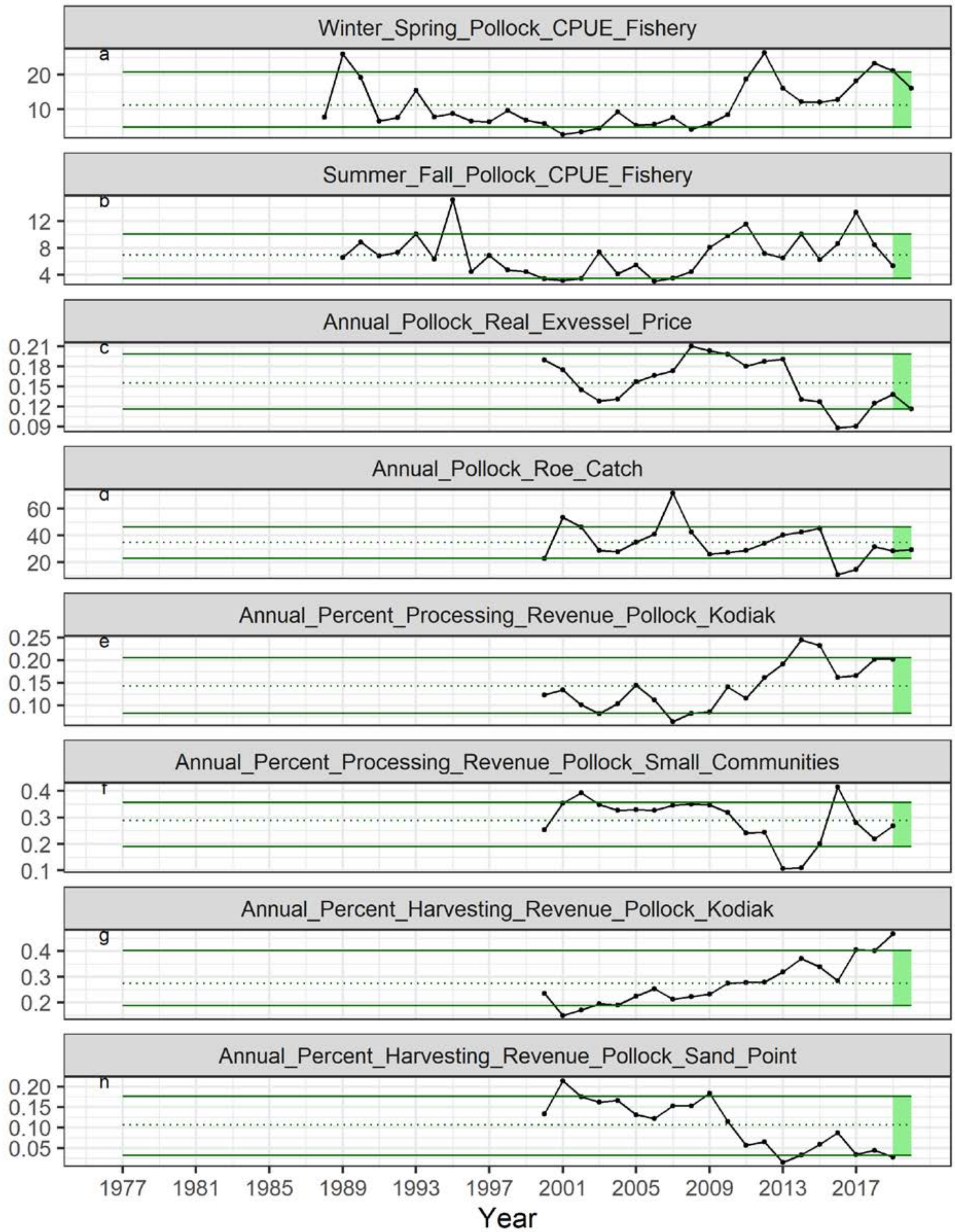
Appendix Figure 1A.3a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



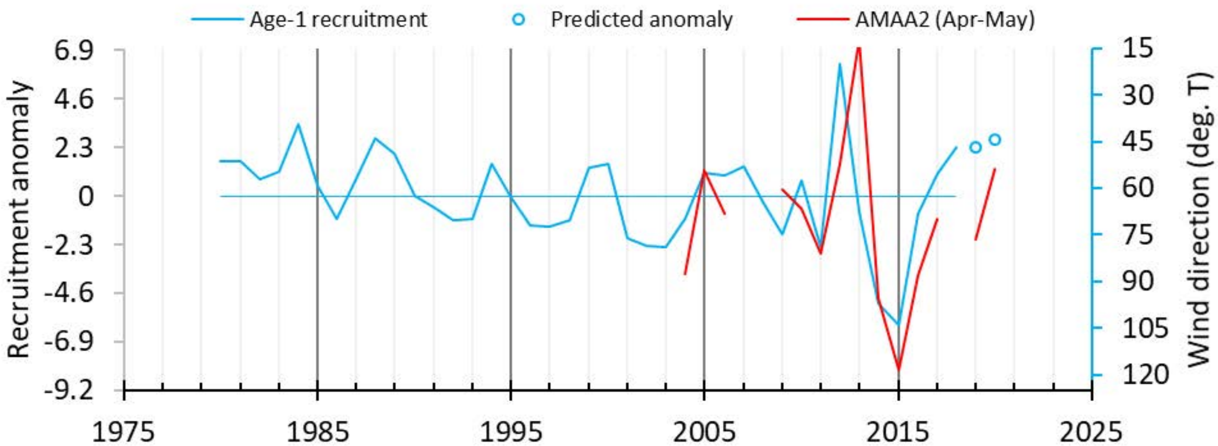
Appendix Figure 1A.3a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



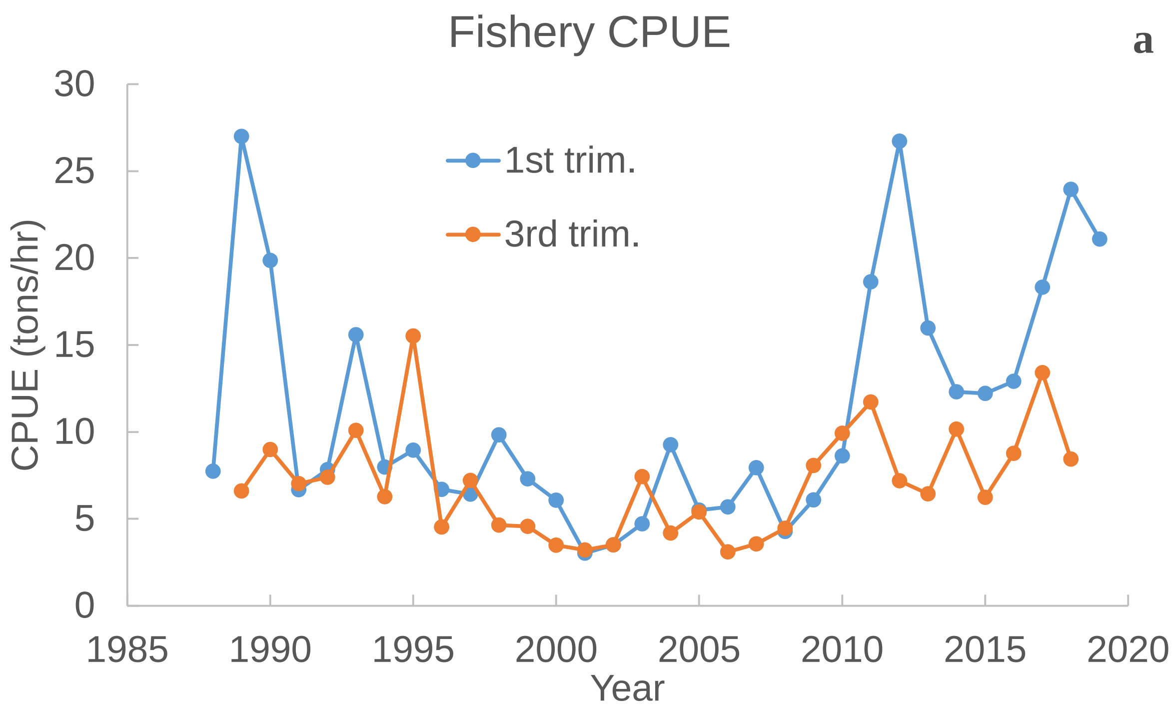
Appendix Figure 1A.3a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.

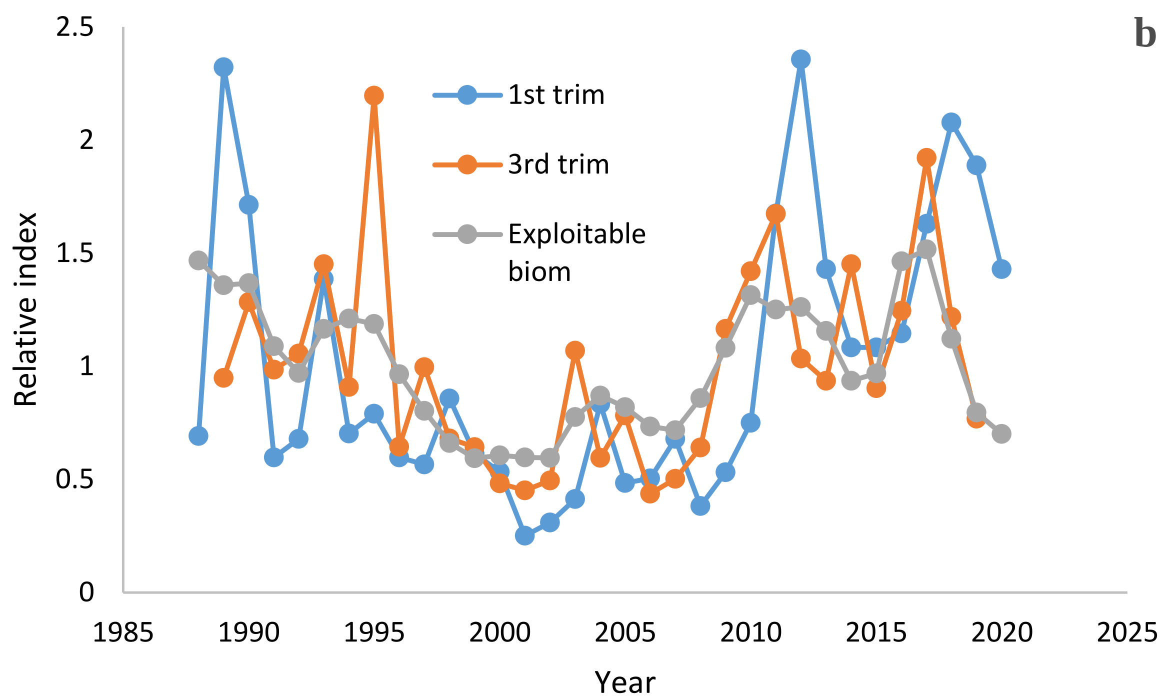


Appendix Figure 1A.3b: Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.

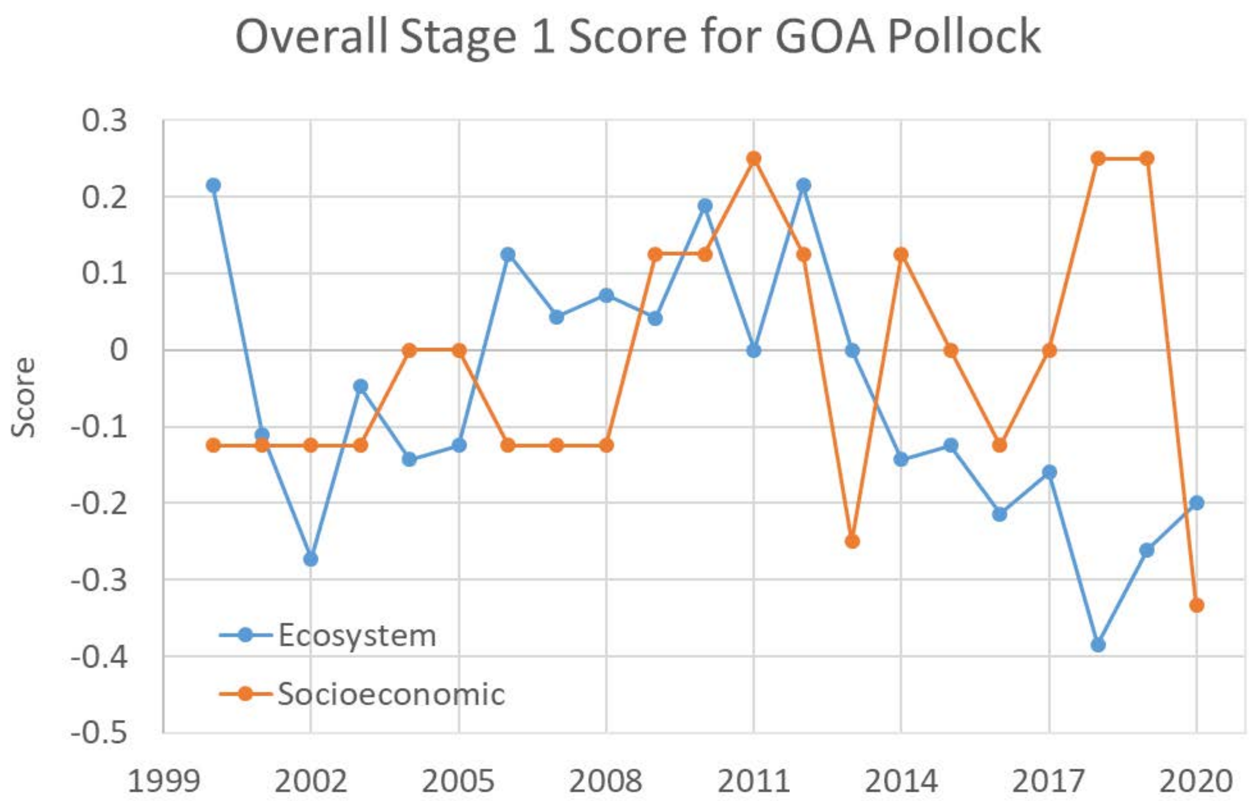


Appendix Figure 1A.4: Timeseries of wind direction from NOAA National Buoy Data. GOA pollock recruitment deviations (blue line) from the 1980-2018 mean (blue horizontal line) superimposed on mean springtime (April-May) surface wind direction from NDBC-AMAA2 (red line). Recruitment anomaly predictions for the 2019 and 2020 year classes (blue circles) following Wilson and Laman (2020).

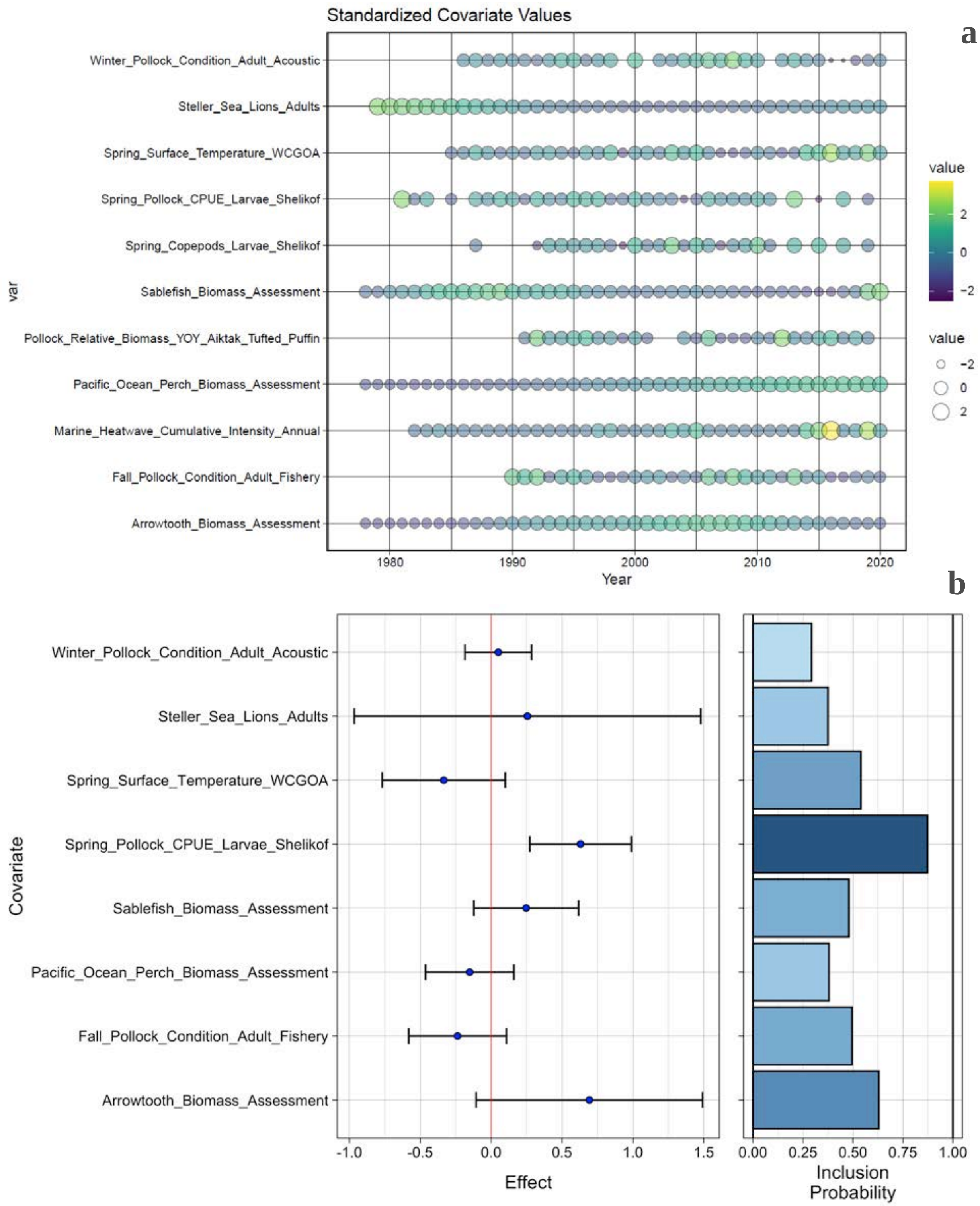




Appendix Figure 1A.5. Geometric mean CPUE for the 1st and 3rd trimester ("trim") compared to model estimates of exploitable biomass (sum of the product of numbers at age, fishery selectivity, and fishery weight at age). All time series have been rescaled so the average is one for the time series.



Appendix Figure 1A.6: Simple traffic light score for overall ecosystem and socioeconomic categories from 2000 to present.



Appendix Figure 1A.7: Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (95% confidence intervals) with log GOA pollock recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.