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

Martin W. Dorn[1], Alison L. Deary[1], Benjamin E. Fissel[1], Darin T. Jones[1], Nathan E. Lauffenburger[1], Wayne A. Palsson[1], Lauren A. Rogers[1], S. Kalei Shotwell[1], Kally A. Spalinger[2], and Stephani G. Zador[1]
[1]National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA
[2]Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, AK

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Executive Summary

Summary of Changes in Assessment Model Inputs

Changes in input data

1. Fishery: 2018 total catch and catch at age.
2. Shelikof Strait acoustic survey: 2019 biomass and age composition.
3. NMFS bottom trawl survey: 2019 biomass and size composition.
4. Summer acoustic survey: 2019 biomass and size composition.
5. ADF&G crab/groundfish trawl survey: 2019 biomass and 2018 age composition.

Changes in assessment methodology

The age-structured assessment model is similar to the model used for the 2018 assessment and was developed using AD Model Builder (a C++ software language extension and automatic differentiation library). Two minor methodology changes were implemented:

1. New maturity estimates were produced using a GLM model with weighting by local abundance.
2. The random walk in catchability for the Shelikof Strait acoustic survey was assumed to have a smaller standard deviation, resulting in a less flexible curve.

Summary of Results

The base model projection of female spawning biomass in 2020 is 206,664 t, which is 42.6% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (194,000 t), thereby placing GOA pollock in sub-tier “a” of Tier 3. New survey data in 2019 continue to show strong contrast, with the 2019 Shelikof Strait acoustic survey indicating high biomass, and the 2019 NMFS bottom trawl survey indicating relatively low biomass (the second lowest in the time series). The 2019 ADF&G bottom trawl is also low, while the 2019 summer acoustic survey is intermediate. 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. We identified substantially increased concerns (level 2) for the stock assessment. There were no elevated concerns about 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 showing record highs. The model is unable to fit strongly contrasting trends, which has resulted in very poor model fits to the most recent survey indices, and greater assessment uncertainty.

Population dynamics considerations: This category was scored as level 2 in the 2018 assessment due to the disruption of typical age structure caused by the very strong 2012 year class and lack of subsequent recruitment. This situation has changed by the recruitment of a strong 2018 year class, which showed up consistently in the surveys conducted this year. The fishery age-diversity remained low again in 2018, but we expect this to return to typical values as the 2018 year class enters the fishable population.

Environmental/Ecosystem considerations: Spring and late summer young of the year surveys and other evidence suggest low abundance of the 2019 year class, but we did not consider a this a concern given that the 2018 year class (and to a lesser extent the 2017 year class) appears to be above average. For pollock in the GOA, it is not unusual for a strong year class to be followed by 3-4 years of weak year classes.

Overall, foraging conditions for the current pollock stock appear neither strong or weak, but slightly below average. The abundance of large copepods and euphausiids during spring along the Seward Line was low. The abundance of pandalid and non-pandalid shrimp, another important pollock prey group, has been trending upwards in the NMFS bottom trawl survey. Acoustic estimates of euphausiid biomass during summer were slightly lower than average. Also, parakeet auklet reproductive success was moderate, indicating sufficient zooplankton (primarily euphausiid) prey to support chick-rearing.

The western GOA shelf area largely experienced heatwave conditions from September 2018 to October 2019. While the increased temperatures of the past year likely increased their metabolic demands as well as the metabolic demands of their groundfish predators, the conditions are not as concerning for pollock relative to other groundfish. Although recently the heatwave as appeared to abate somewhat (S. Barbeaux, pers. comm., Nov 5, 2019), the North American Multi-Model Ensemble forecast is for warm conditions to persist throughout the North Pacific in the upcoming winter.

Fishery performance: CPUE in both the pre-spawning fishery (A and B seasons) and during the summer/fall fishery (C and D seasons) has been relatively high in recent years (up until the A and B seasons of 2019), and consistent with the abundance trend of exploitable biomass from the assessment.

The authors' 2020 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 108,494 t, which is a decrease of 20% from the 2019 ABC, but very close to the projected 2020 ABC in last year's assessment. The author's recommended ABC was obtained by applying a 10% buffer to the maximum permissible ABC, based on the concerns about the stock assessment detailed above. A buffer of 10% to address substantially increased concerns is slightly lower than the buffer that was applied last year (14%) to address slightly more elevated concerns, and seemed an appropriate starting point for Plan Team and SSC deliberations. The author's recommended ABC for 2021 is 111,888 t, using the same 10% buffer to the maximum permissible ABC in 2021. The OFL in 2020 is 140,674 t, and the OFL in 2021 if the ABC is taken in 2020 is 149,988 t. It should be noted that the ABC is projected to stabilize over the next few years, due recruitment of the strong 2018 year class into the fishery.

For pollock in southeast Alaska (Southeast Outside region), the ABC recommendation for both 2020 and 2021 is 10,148 t (see Appendix 1B) and the OFL recommendation for both 2019 and 2020 is 13,531 t. These recommendations are based on a Tier 5 assessment using the projected biomass in 2020 and 2021 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 2019	2020	As estimated or recommended *this* year for 2020	2021
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	1,126,750	1,068,760	1,007,850	1,270,080
Female spawning biomass (t)	345,352	257,794	206,664	184,094
$B_{100\%}$	553,000	553,000	485,000	485,000
$B_{40\%}$	221,000	221,000	194,000	194,000
$B_{35\%}$	194,000	194,000	170,000	170,000
F_{OFL}	0.32	0.32	0.33	0.30
$maxF_{ABC}$	0.27	0.27	0.28	0.26
F_{ABC}	0.22	0.22	0.23	0.28
OFL (t)	194,230	148,968	140,674	149,988
maxABC (t)	158,518	128,108	120,549	124,320
ABC (t)	135,850	108,892	108,494	111,888
Status	As determined *last* year for 2017	2018	As determined *this* year for 2018	2019
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: 2019	2020	As estimated or *recommended this* year for: 2020	2021
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)	38,989	38,989	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)	11,697	11,697	13,531	13,531
maxABC (t)	8,773	8,773	10,148	10,148
ABC (t)	8,773	8,773	10,148	10,148
Status	As determined *last* year for: 2017	2018	As determined *this* year for: 2018	2019
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments in General

The SSC in its December 2019 minutes recommended that all assessment authors use the risk table below when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance

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

Responses to SSC and Plan Team Comments Specific to this Assessment

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

The acoustic survey group produced as series of plots of pollock vertical distribution during the summer acoustic survey that are included in the assessment.

The GOA plan team in its November 2018 minutes recommended the author investigate the use of alternative maturity at age estimation procedures.

In this assessment, we provide maturity estimates for Shelikof Strait acoustic survey from 2003 to the present with GLM approach that uses local abundance to weight the maturity data collected in a haul.

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.

The GOA plan team in its November 2018 minutes recommended the author check recent year estimates of fishery selectivity, specifically the rising edge of the selectivity curves, which appear overly static given the single cohort state of the population.

We checked those selectivity estimates and they appear to be estimated appropriately. Selectivity in the final year of the assessment set equal to the previous year because no fish age composition data are available in the final year.

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 95% 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 2014 and 2018, on average about 97% of the catch by weight of FMP species consisted of pollock (Table 1.2). Nominal pollock targets are defined by the dominance of pollock in the catch, and may include tows where other species were targeted, but pollock were caught instead. The most common managed species in the incidental catch are arrowtooth flounder, Pacific cod, Pacific ocean perch, flathead sole, shallow-water flatfish, and squid. Pacific ocean perch incidental catch has trended upwards in 2017 and 2018, perhaps reflecting changes in the distribution of pollock and Pacific ocean perch. The most common non-target species are grenadiers, capelin, jellyfish, eulachon, jellyfish, and miscellaneous fish (Table 1.2). Bycatch estimates for prohibited species over the period 2014-2018 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 then declined in 2018.

Since 1992, the Gulf of Alaska pollock Total Allowable Catch (TAC) has been apportioned spatially and temporally to reduce potential impacts on Steller sea lions. The details of the apportionment scheme have evolved over time, but the general objective is to allocate the TAC to management areas based on the distribution of surveyed biomass, and to establish three or four seasons between mid-January and fall during which some fraction of the TAC can be taken. The Steller Sea Lion Protection Measures implemented in 2001 established four seasons in the Central and Western GOA beginning January 20, March 10, August 25, and October 1, with 25% of the total TAC allocated to each season. Allocations to management areas 610, 620 and 630 are based on the seasonal biomass distribution as estimated by groundfish surveys. In addition, a harvest control rule was implemented that requires suspension of directed pollock fishing when spawning biomass declines below 20% of the reference unfished level.

Data Used in the Assessment

The data used in the assessment model consist of estimates of annual catch in tons, fishery age composition, NMFS summer bottom trawl survey estimates of biomass and age composition, acoustic survey estimates of biomass and age composition in Shelikof Strait, summer acoustic survey estimates of biomass and age composition, and 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	1970-2018
Fishery	Age composition	1975-2018
Shelikof Strait acoustic survey	Biomass	1992-2019
Shelikof Strait acoustic survey	Age composition	1992-2019
Summer acoustic survey	Biomass	2013-2019
Summer acoustic survey	Age composition	2013-2017
Summer acoustic survey	Length composition	2019
NMFS bottom trawl survey	Area-swept biomass	1990-2019
NMFS bottom trawl survey	Age composition	1990-2017
NMFS bottom trawl survey	Length composition	2019
ADF&G trawl survey	Delta-GLM index	1988-2019
ADF&G survey	Age composition	2000-2016

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 1991-2018 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 is documented in the assessments available online at http://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm.

Age and length samples from the 2018 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	110	403	341	138
	Num. lengths	756	7061	1898	906
	Catch (t)	3,114	61,550	9,428	7,014
2nd half (C and D seasons)	Num. ages	380	405	485	---
	Num. lengths	7847	3010	7651	---
	Catch (t)	27,561	18,503	30,925	---

The estimated age composition in all areas and all seasons was very similar (Fig. 1.2). The catch-at-age in both the first half and the second half of 2018 (A and B season) and in all areas was dominated by age-6 fish (2012 year class). Most of the rest of the catch was either age-5 or age age-7 fish. Fishery catch at age in 1975-2018 is presented in Table 1.5 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.6.

Gulf of Alaska Bottom Trawl Survey

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) beginning in 1984 to assess the abundance of groundfish in the Gulf of Alaska (Table 1.7). Starting in 2001, the survey frequency was increased from once every three years to once every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and statistical area (von Szalay et al. 2010). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized poly-Nor'eastern high opening bottom trawls rigged with roller gear. In a typical survey, 800 tows are completed. On average, 73% of these tows contain pollock (Table 1.8).

The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140° W 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 (Fig. 1.4). 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). Since ages are not available for the 2019 survey, length composition was used in the assessment model. Length composition in 2019 indicated the presence of several modes, a mode around 18 cm representing age-1 pollock, a mode around 28 cm representing age-2 pollock, and mode around 47 cm presumably consisting of primarily age-7 fish from the 2012 year class. 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. 1.6).

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 2019 are presented in a NMFS processed report (Lauffenburger et al., in press). In 2008, the noise-reduced *R/V Oscar Dyson* became the designated survey vessel for acoustic surveys in the Gulf of Alaska. In winter of 2007, a vessel comparison experiment was conducted between the *R/V Miller Freeman* (MF) and the *R/V Oscar Dyson* (OD), which obtained an OD/MF ratio of 1.132 for the acoustic backscatter detected by the two vessels in Shelikof Strait.

The 2019 biomass estimate for Shelikof Strait is 1,281,083 t, which is a 3.0% percent decrease from the 2018 estimate (Fig. 1.7). 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 2019 included only surveys in the Chirikof Island area and Marmot Bay. Other planned surveys in winter 2019, including surveys of the western GOA and the northern GOA (Kenai to Prince William Sound) were unable to be completed due to government shutdown. The following table provides results from the 2019 winter acoustic surveys:

Area	Total biomass (t)	Percent
Shelikof Strait	1,281,083	98.8%
Marmot Bay	6,275	0.5%
Chirikof Island	9,907	0.8%
Total	1,297,265	

The total biomass in 2019 for all surveys is 5% lower than in 2018, but fewer areas were surveyed in 2019. Other than Shelikof Strait, the only area that was surveyed in 2018 and in 2019 was Marmot Bay, which showed 53% decline.

Shelikof Acoustic Survey Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.8) were obtained using an age-length key compiled from random otolith samples and applied to weighted length frequency samples. Sample sizes for ages and lengths are given Table 1.11. Estimates of age composition in Shelikof Strait in 2019 indicate that the seven year old 2012 year class made up 65% of the biomass, indicating the continuing dominance of this year class.

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.

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). Size 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 (Fig. 1.9). 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. Since the distribution of pollock in the water column has a potential impact on survey catchablity for both the acoustic survey and the NMFS bottom trawl survey, plots of surface and bottom referenced biomass distribution were developed for the three regions of the survey with highest biomass (Figs. 1.10-1.12). Since both the summer bottom trawl and summer acoustic surveys are conducted from west to east on roughly a similar timetable, methods described by Kotwicki et al. (2017) could be applied to combine data from both surveys.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

The Alaska Department of Fish and Game (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. 1.13). 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 2019 area-swept biomass estimate for pollock for the ADF&G crab/groundfish survey was 50,960 t, and increase of 2.4% from the 2018 biomass estimate (Table 1.7). The recent pollock estimates for this survey continue remain at approximately 50% of the long-term average.

Delta GLM indices

A simple delta GLM model was applied to the ADF&G tow by tow data for 1988-2019 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, as usual, several alternative error assumptions were evaluated for the positive observations, including lognormal, gamma, and inverse Gaussian. The inverse Gaussian model did not converge, and AIC statistic strongly indicated the gamma distribution was more appropriate than the lognormal (ΔAIC= 494.2). A quantile-quantile plot for the gamma model residuals was not ideal, but was considered acceptable (Fig. 1.14). Comparison of delta-GLM indices the area-swept estimates indicated similar trends (Fig. 1.15). Variances were based on a bootstrap procedure, and CVs for the annual index ranged from 0.09 to 0.20. 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. 1.16). 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. 1.17). More recently there has been strong divergence the trends, starting in 2016 and continuing to the present. Both the ADF&G and the bottom trawl surveys indicate a steep decline in abundance, while the Shelikof Strait acoustic survey in 2017-2019 increased to more than twice the long-term average.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.18). 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 to 2018. 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. Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch is approximately 9%. An index of catch at age diversity was computed using the Shannon-Wiener information index,

$$-\sum p_a \ln p_a ,$$

where p_a is the proportion at age. Increases in fishing mortality would tend to reduce age diversity, but year class variability would also influence age diversity. The index of age diversity is relatively stable during 1975-2015, but declined sharply in 2016 and remained low in 2017 and 2018 due to the dominance of the 2012 year class in the catch (Fig. 1.18). A remarkable number of indicators that showed unusual values in 2016-2018, which raises concern, though the implications for pollock population dynamics are unclear.

The 2012 year class, which is both very strong, and which has experienced anomalous environmental conditions during the marine heatwave in the North Pacific during 2015-2017, has displayed unusual life history characteristics. These include early maturation, reduced growth, and potentially reduced total mortality (Fig. 1.19). 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 2019 (50 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 except for the age-1 and age-2 winter acoustic survey indices, where input coefficients of variation (CVs) were tuned using RMSE. The following table lists the likelihood components used in fitting the model.

Likelihood component	*Statistical model for error*	*Variance assumption*
Fishery total catch (1970-2019)	Log-normal	CV = 0.05
Fishery age comp. (1975-2018)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2018)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2019)	Multinomial	Initial sample size = 60
Shelikof acoustic survey age-1 and age-2 indices (1994-2019)	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)	Multinomial	Initial sample size = 10
Summer acoustic survey length comp. (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. (1990-2017)	Multinomial	Initial sample size = 60
NMFS bottom trawl survey length comp. (2019)	Multinomial	Initial sample size = 10
ADF&G trawl survey index (1989-2019)	Log-normal	Survey-specific CV from delta GLM model x 2= 0.18-0.40
ADF&G survey age comp. (2000-2018)	Multinomial	Initial sample size = 30
Recruit process error (1970-1977, 2018, 2019)	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 2018 and 2019 would have the same variability as recruitment during the data-rich period (σ_R =1.0). Log deviations from mean log recruitment were estimated as free parameters in other years. These relatively weak constraints were sufficient to obtain fully converged parameter estimates while retaining an appropriate level of uncertainty.

Modeling fishery data

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

Modeling survey data

Survey abundance was assumed to be proportional to total abundance as modified by the estimated survey selectivity pattern. Expected population numbers at age for the survey were based on the mid-date of the survey, assuming constant fishing and natural mortality throughout the year. Standard deviations in the log-normal likelihood were set equal to the sampling error CV (coefficient of variation) associated with each survey estimate of abundance (Kimura 1991).

Survey catchability coefficients can be fixed or freely estimated. The base model estimated the NMFS bottom trawl survey catchability, but used a log normal prior with a median of 0.85 and log standard deviation 0.1 as a constraint on potential values (Fig. 1.20). 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_∞ = 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. 1.21). 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).

This year, a new approach was used 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 2019 from winter acoustic surveys using the new method are slightly higher than the long-term mean for all ages (Fig. 1.22), though except for the age-7 females from the 2012 year class the sample sizes were small and the estimates probably are not reliable. Inter-annual changes in maturity at age may reflect environmental conditions, pollock population biology, effect of strong year classes moving through the population, or simply ageing error. Because there did not appear to be an objective basis for excluding data, the 1983-2019 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 2012 years at younger ages than is typical, however the estimate of age at 50% mature is 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 1.23). 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. Comparison of the unweighted and local-abundance weighted maturity estimates indicated that both methods gave similar results (Fig 1.23).

Weight at age

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a\,L^b$, were also estimated. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions. Weight at age for the fishery, the Shelikof Strait acoustic survey, and the NMFS bottom trawl survey are given in Table 1.16, Table 1.17, and Table 1.18, respectively. A plot of weight-at-age from the Shelikof Strait acoustic survey indicates that there has been a substantial increase in weight at age for older pollock (Fig. 1.24). For pollock greater than age 6, weight-at-age has nearly doubled since 1983-1990. However, weight at age since 2012 has trended strongly downward, with some stabilization in the last couple of years. Further analyses are needed to evaluate whether these changes are a density-dependent response to declining pollock abundance, or whether they are environmentally forced. Changes in weight-at-age have potential implications for status determination and harvest control rules.

A random effects (RE) model for weight at age (Ianelli et al. 2016) was used to improve estimates of fishery weight at age, and to propagate the uncertainty of weight at age when doing catch projections. The structural part of the model is an underlying von Bertalanffy growth curve. Year and cohort effects are estimated as random effects using the ADMB RE module. Further details are provided in Ianelli et al. (2016). Input data included fishery weight age for 1975-2018. 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 (1981-2019) and the NMFS bottom trawl survey (1984-2017) 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 2018 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. 1.25). However there was good agreement for age-6 pollock, which made up 76% of the catch at age. In this assessment, RE model estimates of weight at age are used for the fishery in 2019, and yield projections and spawning biomass per recruit calculations used the RE model estimates for 2020 (Fig. 1.25).

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 1970-2019 = 50	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 1970-2019 = 50	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) = 98	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) = 98	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	116 estimated parameters + 196 process error parameters + 10 fixed parameters = 322	

Results

Model selection and evaluation

Model Selection

Prior to identifying a set of models for consideration, an analysis was conducted of the impact of each new data element on model results. Figure 1.26 shows the changes in estimated spawning biomass as the 2018 catch at age, the 2019 NMFS bottom trawl survey, 2018 Shelikof Strait acoustic survey estimates, 2019 ADF&G survey, and the summer acoustic survey were added sequentially. Generally, the addition of new data elements tended to result in lower estimates of recent spawning biomass. The NMFS bottom trawl survey exerted a strong downward pull on estimated biomass that was counterbalanced to some extent when the high Shelikof Strait biomass in 2019 was added to the model. While this kind of model behavior is not unexpected, it does indicate that the input data provide a strongly contrasting signal about recent stock trends, which adds to the uncertainty in the assessment.

The intent of this year's assessment is to provide a straightforward update without considering major changes to the model. Last year's base model included a random walk in catchability for the Shelikof Strait acoustic survey to account for trends in the proportion of the stock spawning in Shelikof Strait. A criteria for accepting that model was that the estimate of catchability did not exceed one, since that would imply that greater than 100% of the stock was spawning in Shelikof Strait. After updating with model with all of the new fishery and survey data, the estimate of catchability in 2019 was 1.19. Therefore, an alternative model was considered that reduced the standard deviation parameter from 0.05 to 0.038. Alternative models that were evaluated are listed below.

Model 18.3--last year's base model
Model 18.3 new data--last year's base model with new data
Model 19.1--Increased penalty on random walk variation.

To provide a common basis for model comparison, all models used the final weights for composition data for last year's base model, model 18.3, obtained using the Francis (2011) approach for iterative reweighting. Comparison of model 19.1 with model 18.3 indicated that spawning biomass was slightly higher (Fig, 1.27), and that the 2019 catchability was estimated to be close to one (Fig. 1.28). This was regarded as a more reasonable result and therefore model 19.1 was selected as the base model, and a final turning step was done using the Francis (2011) approach. The age-1 and the age-2 Shelikof acoustic indices were also iteratively reweighted using RMSE as a tuning variable. All composition data components were reweighted slightly, generally resulting in smaller 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. Plots show the fit to fishery age composition (Fig. 1.29, Fig. 1.30), Shelikof Strait acoustic survey age composition (Fig. 1.31, Fig. 1.32), NMFS trawl survey age composition (Fig. 1.33, Fig. 1.34), and ADF&G trawl survey age composition (Fig. 1.34, Fig. 1.35). 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 2016-2018 due to stronger than expected abundance in the age composition, while the older ages tended to have negative residual. 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. 1.36 and Fig. 1.37). The model is unable to achieve adequate fit to recent estimates due to contrasting trends in the different surveys. 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 2015-2019, though the fit to the ADF&G survey in 2018 and 2019 is improved, and the fit to the ADF&G survey is quite good overall. This fit to the summer acoustic survey is reasonable even during the most recent period. The fit to the age-1 and age-2 acoustic indices was considered acceptable (Fig. 1.38).

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. 1.39). 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 1977-2019 (see also Fig. 1.40). 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 100% of the proxy for unfished stock size ($B_{100\%}$ = mean 1978-2018 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 32% of unfished stock size. Over the years 2009-2013 stock size showed a strong upward trend, increasing from 39% to 70% of unfished stock size, but declined to 48% of unfished stock size in 2015. The spawning stock peaked in 2017 as the strong 2012 year class matured, and has declined subsequently.

Figure 1.41 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 1993-2019 indicates the current estimated trend in spawning biomass for 1990-2019 is consistent with previous estimates (Fig. 1.42). 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 2019 age composition from the current assessment is very consistent with the projected 2019 age composition from the 2018 assessment (Fig. 1.42). The largest change is the estimate of age-1 recruits in 2019, which is now estimated to be a strong year class due to high abundance estimates in the surveys conducted in 2019, rather than the average recruitment that was assumed in last year's assessment.

Retrospective analysis of base model

A retrospective analysis consists of dropping the data year-by-year from the current model, and provides an evaluation of the stability of the current model as new data are added. Figure 1.43 shows a retrospective plot with data sequentially removed back to 2009. There is up to 38% error in the estimates of spawning biomass (if the current assessment is accepted as truth), but usually the errors are much smaller. There is relatively modest positive retrospective pattern to errors in the assessment, and the revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.134, which does not indicate a concern with retrospective bias.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 1.12) 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. 1.40). 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. 1.44). 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 2018 is estimated to be close to the long-term mean, and age-1 recruitment in 2019 is estimated to be relatively strong, 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 1978-2018 age-1 recruitment (5.644 billion), which is 4% lower 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 2015-2019 to estimate current reproductive potential. Pollock weight-at-age is highly variable, showing a sustained increase, followed by a steep (Fig. 1.24). 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 0.086 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 2014-2018 to reflect current selectivity patterns.

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

		Equilibrium under average 1978-2018 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	5644	2107	485	0	0.0%
40.0%	0.281	5644	1263	194	181	14.3%
35.0%	0.334	5644	1187	170	197	16.6%

The $B_{40\%}$ estimate of 194,000 t represents a 12% decrease from the $B_{40\%}$ estimate of 221,000 t in the 2018 assessment (Table 1.25), which is primarily caused by the continuing decline in spawning weight at age, but is also affected by the decrease in mean recruitment. The base model projection of female spawning biomass in 2020 is 206,664 t, which is 42.6% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (194,000 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 84.0% of the OFL harvest rate. Projections for 2020 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 SSC in its December 2019 minutes recommended that all assessment authors use the risk table below when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance.

	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 an 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 three types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, 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 a handful of assessments in the North Pacific that is fit to multiple abundance indices. In the last several years, there have been strongly contrasting trends in the survey abundance indices, with bottom trawl indices showing a steep decline, while acoustic surveys showing record highs (Figures 1.33 and 1.34). Since the model is unable to fit strongly contrasting trends, this has resulted in very poor model fits to the most recent survey indices. Although this divergence in trend is a recent phenomenon, it is worth mentioning a similar problems have been seen in past. Specifically, in the 1980s a major assessment issue was the difficulty in reconciling acoustic and bottom trawl estimates. We rated the assessment-related concern as level 2, a substantially increased concern, because the contrasting trends in survey indices add to the uncertainty of the assessment relative to other North Pacific assessments where this is not an issue. Last year we also gave this element a score of 2 for the same reason, and it is worthwhile noting that the survey inconsistencies are continuing to persist.

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 1.15), and up until last year both the fishery and population were dominated by a single large year class. There are been other unusual phenomena associated with 2012 year class, including reduced growth, early maturation, and apparent reduced natural mortality (Fig 1.16). Last year we rated the population dynamics concern as level 2, a substantially increased concern. This situation has changed by the recruitment of a strong 2018 year class, which showed up consistently in the surveys conducted this year. The fishery age-diversity remained low in 2018, but we expect this to return to typical levels as the 2018 year class and the average 2017 year class start to enter the fishery. Therefore we reduced the concern level for population dynamics to level 1—no increased concerns.

Environmental/Ecosystem considerations

Last year, there were concerns about the fate of the 2018 year class based on warm temperatures and predictions of poor recruitment. Surveys conducted this year are consistent in indicating a strong 2018 year class, so these concerns appear to have been unwarranted. A review of new ecosystem information suggests that over-winter survival may have been aided by favorable prey abundance as indicated by the record high abundance of euphausiids observed on the Seward Line during September 2018 and potentially lower natural mortality due to reduced stock sizes of juvenile pollock groundfish predators such as Pacific cod, arrowtooth flounder and adult pollock. An additional positive sign for the 2018 year class is that the condition of age-1 pollock sampled during the bottom trawl survey was at long-term mean, indicating sufficient prey resources.

Spring and late summer young of the year surveys and other evidence suggest low abundance of the 2019 year class, but we did not consider a this a concern given that the 2018 year class (and to a lesser extent the 2017 year class) seems strong. For pollock in the GOA, it is not unusual for a strong year class to be followed by 3-4 years of weak year classes.

Overall, foraging conditions for the current pollock stock appear neither strong or weak, but slightly below average. Age-2+ pollock sampled during the summer bottom trawl survey showed slightly negative anomalies in condition (length-weight residuals) relative to long-term mean. There appeared to be an east-to-west trend in condition with heavy pollock per length in the eastern areas of the GOA relative to the western areas. Further supporting evidence of below average foraging conditions is the negative anomalies in condition of POP, which have similar diets to pollock.

Indicators of zooplankton abundance suggest moderate-to-low abundance of prey for pollock. The abundance of large copepods during spring along the Seward Line large copepod was low, and notably lower than in previous years 2015-2018. Similarly, Seward Line euphausiid abundance during spring was low (although but very high in September 2018 as described above). The abundance of pandalid and non-pandalid shrimp, another important pollock prey group, has been trending upwards in the NMFS bottom trawl survey. Acoustically-determined estimates of euphausiid biomass during summer was slightly lower than average. Also, parakeet auklet reproductive success was moderate, indicating sufficient zooplankton (primarily euphausiid) prey to support chick-rearing. However, the bottom trawl survey encountered high abundances of jellyfish, which may act as competitors of zooplankton. Stock sizes of another zooplankton predator, pink salmon, have been lower in 2019 than recent odd-numbered years.

The western GOA shelf area largely experienced heatwave conditions from September 2018 to October 2019. While the increased temperatures of the past year likely increased their metabolic demands as well as the metabolic demands of their groundfish predators, the conditions are not as concerning for pollock relative to other groundfish. The GOA pollock stock fared reasonably well during the 2014-2016 heatwave. This was likely due to the continued availability of sufficient zooplankton prey abundance, although prey quality (i.e., copepod community size) appeared to be lower. Although recently the heatwave as appeared to abate somewhat (S. Barbeaux, pers. comm., Nov 5, 2019), the North American Multi-Model Ensemble forecast is for warm conditions to persist throughout the North Pacific in the upcoming winter.

Taken together, we consider the current level of concern to be 1—no apparent environmental/ecosystem concerns, though we were very much on the fence as to whether score should be 1 or a 2. There are several indicators need to be closely watched, such as whether the heatwave intensifies, whether conditions remain unfavorable for pollock recruitment, and whether indicators of prey availability for pollock become more strongly negative. These may trigger a higher level of concern next year or in subsequent years.

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 in recent years (up until the A and B seasons of 2019), and consistent with the abundance trend of exploitable biomass from the assessment. No concerns regarding fishery performance were identified.

These results are summarized in the table below:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance*	*Overall score (highest of the individual scores)*
Level 2: substantially increased concerns	Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns	Level 2: Substantially increased concerns

The overall score of level 2 suggests that it is appropriate to consider setting the ABC below the maximum permissible. A buffer of 10% to address substantially increased concerns is slightly lower than the buffer that was applied last year (14%) to address slightly more elevated concerns, and seemed an appropriate starting point for Plan Team and SSC deliberations.

The author's recommended 2020 ABC, based on applying 10% buffer to the maximum permissible ABC, is 108,494 t, which is a decrease of 20% from the 2019 ABC, but close to the projected 2020 ABC in last year's assessment. The author's recommended 2021 ABC is 111,888 t, based on applying the 10% buffer to the maximum permissible ABC in 2021. The appropriateness of the 10% buffer for 2021 will be re-evaluated in next year's stock assessment. The OFL in 2020 is 140,674 t, and the OFL in 2021 if the ABC is taken in 2020 is 149,988 t. It should be noted that the ABC is projected to stabilize over the next few years, due recruitment of the strong 2018 year class into the fishery.

To evaluate the probability that the stock will drop below the $B_{20\%}$ threshold, we projected the stock forward for five years using the author's recommended fishing mortality schedule. This projection incorporates uncertainty in stock status, uncertainty in the estimate of $B_{20\%}$, and variability in future recruitment. We then sampled from the likelihood of future spawning biomass using Markov chain Monte Carlo (MCMC). A chain of 1,000,000 samples was thinned by selecting every 200th sample. Analysis of the thinned MCMC chain indicates that probability of the stock dropping below $B_{20\%}$ will be close to zero until 2024 (Fig. 1.45).

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 2019 numbers at age at the start of the year as estimated by the assessment model, and assume the 2019 catch will be equal to 125,850 t (10,000 t less than the ABC, Mary Furuness, pers. comm. Oct 7, 2019). 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 1978-2018 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 2019, 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* (2015-2019). (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 2019 or 2) above 1/2 of its MSY level in 2019 and above its MSY level in 2029 under this scenario, then the stock is not overfished)

Scenario 7: In 2020 and 2021, *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 2021, or 2) above 1/2 of its MSY level in 2021 and above its MSY level in 2031 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.26. Mean spawning biomass is projected decline to 2020, and will continue to decline under full exploitation scenarios, but will increase under the F=0 and other low exploitation scenarios (Fig. 1.46). Catches are project to drop slightly 2020, but then increase gradually as the 2018 year class recruits into the fishery.

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 (2018) is 158,095 t, which is less than the 2018 OFL of 187,059 t. Therefore, the stock is not subject to overfishing.

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

Under scenario 6, spawning biomass is estimated to be 227,000 t in 2019 (see Table 1.21), which is above $B_{35\%}$ (170,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2021 is 178,292 t, which is above $B_{35\%}$ (170,000 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.

This year we initiated the GOA pollock ESP during an internal AFSC workshop that was held in May 2019 to discuss and develop the ESP process and products. A working group was formed to complete and present the draft GOA pollock ESP document for review during the 2019 September Plan Team. The GOA Groundfish Plan Team looked forward to seeing the updated and completed ESP in November, recommended including the conceptual model, and suggested the authors consider alternative community engagement indicators in the future. Additionally, the GOA Groundfish Plan Team encouraged the authors to consider potential avenues for updating ESPs rather than producing full ESPs in the future. We provide the completed GOA pollock ESP with this assessment in Appendix 1A. During the next ESP workshop planned for March 2020, we will discuss more standardized avenues for providing a summary of the ESP recommendations for use in the main SAFE document and for producing partial ESPs when there are only updates to the indicators and limited model evaluation.

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Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The ABC is for the area west of 140 o W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound. Research catches are reported in Appendix 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			76,744	76,744	77,150
2011			81,485	81,485	88,620
2012			103,970	103,970	108,440
2013			96,364	96,364	113,099
2014			142,633	142,633	167,657
2015			167,551	167,551	191,309
2016			177,133	177,133	254,310
2017			186,156	186,156	203,769
2018			158,095	158,095	161,492
2019					135,850
Average (1977-2018)				109,308	126,025

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	*2014*	*2015*	*2016*	*2017*	*2018*
Pollock	137611.4	163899.6	175296.9	183041.8	154888.0
Arrowtooth Flounder	2465.1	1672.0	1237.3	1185.0	2322.1
Pacific Cod	3287.3	1712.3	853.4	612.0	600.4
Pacific Ocean Perch	530.7	175.5	681.9	1266.0	1600.0
Flathead Sole	355.9	438.7	309.8	181.4	284.2
GOA Shallow Water Flatfish	248.9	357.6	265.7	358.5	276.2
Majestic squid	143.5	465.3	182.3	15.5	9.5
GOA Rex Sole	270.8	145.9	113.4	67.3	126.1
Sablefish	30.4	130.0	89.0	46.5	317.4
Salmon shark	144.0	369.0	79.5	10.3	3.8
Big skate	171.0	62.8	100.5	114.6	88.6
Longnose skate	179.8	87.4	46.9	33.2	34.9
Atka Mackerel	3.5	25.3	169.5	33.3	36.8
GOA Shortraker Rockfish	27.7	14.0	183.2	1.6	0.5
Spiny dogfish	13.6	35.7	50.7	49.1	58.3
GOA Thornyhead Rockfish	42.3	24.2	72.6	3.4	2.6
Sculpin	39.0	26.8	20.9	25.8	15.7
Northern Rockfish	14.9	16.6	15.7	5.2	53.3
GOA Dusky Rockfish	13.1	15.0	23.2	12.1	38.7
GOA Rougheye Rockfish	25.2	12.4	45.0	3.0	9.7
GOA Deep Water Flatfish	35.3	15.0	24.1	1.6	4.4
Pacific sleeper shark	6.3	12.0	37.6	0.6	7.6
Other skate	15.3	17.0	4.4	4.6	3.7
North Pacific octopus	7.2	4.3	5.7	0.2	5.6
Other sharks	2.2	6.1	0.6	3.6	0.2
Other Rockfish	1.3	1.8	0.7	0.4	1.6
Alaskan skate	1.7	0.8	0.1	0.1	0.3
Percent non-pollock	*5.5%*	*3.4%*	*2.6%*	*2.2%*	*3.7%*

Non target species/species group	*2014*	*2015*	*2016*	*2017*	*2018*
Giant grenadier	37.91	4.16	626.37	4.75	3.31
Capelin	112.16	93.14	99.25	33.13	77.02
Jellyfish	23.09	169.62	157.38	14.48	13.43
Eulachon	248.87	11.63	1.75	2.83	8.66
Miscellaneous fish	73.61	56.68	16.85	18.77	47.84
Other osmerids	75.28	13.28	8.78	0.89	23.69
Rattail grenadier	0.80	5.24	29.68	9.07	25.53
Sea stars	6.21	1.11	3.34	0.81	43.29
State-managed rockfish	0.05	0.00	5.50	0.06	1.90
Sea anemone unidentified	0.00	0.55	2.43	0.00	0.23
Sponge unidentified	1.16	0.20	0.08	0.00	0.00
Surf smelt	0.81	0.13	0.04	0.38	0.00
Greenlings	0.00	0.00	0.00	0.00	1.28
Pandalid shrimp	0.04	0.17	0.50	0.13	0.22
Eelpouts	0.00	0.68	0.00	0.00	0.00
Bivalves	0.38	0.00	0.00	0.00	0.00
Snails	0.01	0.06	0.20	0.00	0.04
Corals, bryozoans	0.00	0.02	0.18	0.00	0.00
Sea urchins, Sand Dollars, Sea cucumbers	0.11	0.01	0.03	0.00	0.00
Brittle star unidentified	0.00	0.00	0.00	0.06	0.00
Pacific sand lance	0.00	0.00	0.02	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	*2014*	*2015*	*2016*	*2017*	*2018*
Bairdi Tanner Crab (nos.)	2,064	2,343	3,441	3,015	5,374
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	10,883	13,612	20,891	21,392	14,820
Golden (Brown) King Crab (nos.)	0	0	551	8	5
Halibut (t)	137.2	168.3	226.7	109.1	290.0
Herring (t)	4.6	78.2	147.3	5.4	40.2
Non-Chinook Salmon (nos.)	1421	909	1975	4413	8014
Opilio Tanner (Snow) Crab (nos.)	0	0	172	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*
2009	Retained	14,475	13,578	10,974	1,190	1,474	0	41,692	
	Discarded	604	422	1,496	31	1	0	2,554	5.8%
	Total	15,079	14,000	12,470	1,222	1,476	0	44,247	
2010	Retained	25,960	28,033	18,414	1,625	1,660	2	75,693	
	Discarded	91	216	724	12	9	3	1,055	1.4%
	Total	26,051	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	851	832	4	1	2	1,815	2.2%
	Total	20,597	37,249	19,845	2,271	1,536	2	81,499	
2012	Retained	27,352	44,779	25,125	2,380	2,624	0	102,261	
	Discarded	528	318	867	1	3	1	1,718	1.7%
	Total	27,880	45,097	25,992	2,381	2,627	1	103,979	
2013	Retained	7,644	52,692	28,169	2,933	2,622	0	94,062	
	Discarded	67	433	1,795	7	0	2	2,304	2.4%
	Total	7,711	53,126	29,964	2,940	2,623	2	96,365	
2014	Retained	13,228	82,611	41,791	1,314	2,368	0	141,312	
	Discarded	136	471	706	3	3	3	1,323	0.9%
	Total	13,364	83,082	42,497	1,317	2,371	3	142,635	
2015	Retained	28,679	80,950	51,973	248	4,455	0	166,305	
	Discarded	60	493	661	1	30	3	1,249	0.7%
	Total	28,739	81,443	52,634	250	4,485	3	167,555	
2016	Retained	61,019	46,810	64,281	121	3,893	0	176,123	
	Discarded	233	215	535	12	14	3	1,012	0.6%
	Total	61,252	47,025	64,816	133	3,907	3	177,135	
2017	Retained	49,246	80,855	52,338	39	1,881	0	184,359	
	Discarded	297	757	727	0	16	3	1,800	1.0%
	Total	49,543	81,612	53,065	40	1,897	3	186,159	
2018	Retained	30,580	79,024	39,325	4,054	3,086	0	156,069	
	Discarded	94	1,029	797	71	35	1	2,027	1.3%
	Total	30,675	80,053	40,121	4,125	3,122	1	158,097	
Average (2009-2018)		28,089	55,094	36,054	1,631	2,571	2	123,442	

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

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

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

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	NA	NA	NA	6,994	8,748	16,509

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

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Total*
1984	38.69	15.65	74.51	158.78	194.66	271.24	85.94	37.36	13.55	2.37	0.54	0.28	0.21	0.00	0.00	893.78
1987	26.07	325.15	150.41	111.72	70.64	135.13	64.32	37.03	146.40	18.87	6.66	2.89	1.46	0.00	0.00	1096.75
1990	58.06	201.33	44.56	39.44	189.70	222.16	67.30	102.42	25.18	36.56	5.72	24.03	5.98	0.73	1.05	1024.20
1993	76.85	44.71	55.15	129.75	264.85	89.84	34.99	64.20	65.56	18.72	9.28	5.90	2.48	1.44	3.88	867.59
1996	196.89	129.07	17.24	26.17	50.13	63.21	174.42	87.55	52.31	27.70	12.09	18.43	7.15	9.66	2.86	874.88
1999	109.73	19.16	20.95	66.81	119.04	56.84	59.07	47.74	56.41	81.99	65.20	9.67	8.29	2.50	0.76	724.16
2001	412.83	117.03	34.42	33.39	25.05	33.45	37.01	8.20	5.74	0.59	4.48	2.52	1.28	0.00	0.18	716.19
2003	75.07	18.29	128.10	140.40	73.08	44.63	36.00	25.20	14.43	8.57	3.21	1.78	1.26	0.00	0.00	570.02
2005	269.99	33.56	34.35	35.85	91.71	78.82	45.23	20.86	9.61	9.98	4.81	0.57	0.64	0.00	0.00	635.98
2007	175.42	96.39	87.70	36.51	19.16	18.88	54.97	31.09	6.63	3.05	2.78	1.00	1.11	0.00	0.00	534.71
2009	222.94	87.33	106.82	129.35	101.26	27.21	17.59	26.60	53.90	29.46	9.68	7.00	2.78	1.61	0.00	823.53
2011	249.43	96.71	110.68	101.79	163.62	107.99	33.24	7.14	5.69	8.61	19.29	6.62	0.00	0.00	0.55	911.36
2013	750.15	62.07	47.94	65.41	84.72	144.62	156.91	115.55	25.05	5.42	2.40	2.46	3.83	3.01	0.91	1470.46
2015	93.03	63.63	452.62	109.61	113.20	70.83	56.57	52.99	25.96	21.00	3.59	0.57	0.14	0.00	0.89	1064.65
2017	159.39	3.82	10.90	30.32	294.79	27.01	15.28	4.22	0.42	0.18	0.70	0.00	0.00	0.14	0.00	547.18

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

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.

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

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+	Sample size
1983	0.000	0.165	0.798	0.960	0.974	0.983	0.943	1.000	1.000	1333
1984	0.000	0.145	0.688	0.959	0.990	1.000	0.992	1.000	1.000	1621
1985	0.015	0.051	0.424	0.520	0.929	0.992	0.992	1.000	1.000	1183
1986	0.000	0.021	0.105	0.849	0.902	0.959	1.000	1.000	1.000	618
1987	0.000	0.012	0.106	0.340	0.769	0.885	0.950	0.991	1.000	638
1988	0.000	0.000	0.209	0.176	0.606	0.667	1.000	0.857	0.964	464
1989	0.000	0.000	0.297	0.442	0.710	0.919	1.000	1.000	1.000	796
1990	0.000	0.000	0.192	0.674	0.755	0.910	0.945	0.967	0.996	1844
1991	0.000	0.000	0.111	0.082	0.567	0.802	0.864	0.978	1.000	628
1992	0.000	0.000	0.040	0.069	0.774	0.981	0.990	1.000	0.983	765
1993	0.000	0.016	0.120	0.465	0.429	0.804	0.968	1.000	0.985	624
1994	0.000	0.007	0.422	0.931	0.941	0.891	0.974	1.000	1.000	872
1995	0.000	0.000	0.153	0.716	0.967	0.978	0.921	0.917	0.977	805
1996	0.000	0.000	0.036	0.717	0.918	0.975	0.963	1.000	0.957	763
1997	0.000	0.000	0.241	0.760	1.000	1.000	0.996	1.000	1.000	843
1998	0.000	0.000	0.065	0.203	0.833	0.964	1.000	1.000	0.989	757
2000	0.000	0.012	0.125	0.632	0.780	0.579	0.846	1.000	0.923	356
2001	0.000	0.000	0.289	0.308	0.825	0.945	0.967	0.929	1.000	374
2002	0.000	0.026	0.259	0.750	0.933	0.974	1.000	1.000	1.000	499
2003	0.026	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
Average										
All years	0.013	0.056	0.277	0.612	0.860	0.939	0.978	0.989	0.993	
2010-2019	0.032	0.110	0.384	0.792	0.957	0.993	0.999	1.000	1.000	
2015-2019	0.054	0.173	0.500	0.843	0.970	0.995	0.999	1.000	1.000	

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

	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

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

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

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1984	0.062	0.157	0.530	0.661	0.740	0.834	0.904	0.960	0.991	1.196
1987	0.028	0.170	0.379	0.569	0.781	0.923	1.021	1.076	1.157	1.264
1990	0.048	0.173	0.306	0.564	0.776	0.906	1.112	1.134	1.275	1.472
1993	0.041	0.164	0.475	0.680	0.797	0.932	1.057	1.304	1.369	1.412
1996	0.030	0.097	0.325	0.716	0.925	1.009	1.085	1.186	1.243	1.430
1999	0.023	0.144	0.374	0.593	0.700	0.787	0.868	1.069	1.223	1.285
2001	0.031	0.105	0.410	0.698	0.925	1.060	1.201	1.413	1.293	1.481
2003	0.049	0.201	0.496	0.593	0.748	0.950	1.146	1.149	1.381	1.523
2005	0.025	0.182	0.423	0.653	0.836	0.943	1.024	1.228	1.283	1.527
2007	0.022	0.148	0.307	0.589	0.987	1.199	1.415	1.477	1.756	1.737
2009	0.023	0.237	0.492	0.860	1.081	1.421	1.637	1.839	1.955	2.020
2011	0.028	0.243	0.441	0.708	0.980	1.345	1.505	1.656	1.970	2.037
2013	0.020	0.216	0.420	0.894	1.146	1.334	1.497	1.574	1.665	2.037
2015	0.033	0.207	0.366	0.575	0.863	1.069	1.270	1.374	1.432	1.525
2017	0.038	0.224	0.640	0.690	0.743	0.886	1.095	1.298	1.283	1.504

Table 1.19. 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 (2001-2013)*	*Recent domestic (2014-2018)*	*Shelikof acoustic survey*	*Summer acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.003	0.002	0.010	0.001	0.406	1.000	0.127	0.006
2	0.011	0.026	0.012	0.069	0.012	0.547	1.000	0.231	0.023
3	0.117	0.174	0.073	0.356	0.129	1.000	1.000	0.382	0.086
4	0.604	0.616	0.339	0.800	0.633	1.000	1.000	0.561	0.270
5	0.947	0.925	0.771	0.968	0.954	0.999	1.000	0.727	0.595
6	0.996	0.991	0.963	0.997	0.997	0.997	1.000	0.849	0.853
7	1.000	1.000	1.000	1.000	1.000	0.984	1.000	0.925	0.959
8	0.991	0.992	0.997	0.991	0.991	0.919	1.000	0.967	0.990
9	0.880	0.881	0.886	0.880	0.880	0.676	1.000	0.989	0.998
10	0.349	0.349	0.351	0.349	0.349	0.276	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	1,253	312	193	133	95	70	52	39	29	88
1971	3,146	312	157	119	90	65	50	37	28	86
1972	3,614	784	157	96	80	62	46	36	27	84
1973	10,430	900	392	95	59	48	38	28	22	76
1974	2,176	2,597	450	235	56	33	27	22	16	65
1975	2,191	542	1,298	267	132	29	17	14	11	52
1976	8,538	546	271	782	161	76	17	10	9	43
1977	11,489	2,126	273	162	449	86	41	9	6	34
1978	14,008	2,861	1,062	162	90	226	44	21	5	26
1979	24,828	3,488	1,429	630	90	46	120	23	11	20
1980	12,674	6,182	1,743	853	367	50	26	68	13	20
1981	7,061	3,156	3,094	1,057	527	216	30	16	41	23
1982	7,011	1,758	1,580	1,882	669	324	137	19	10	43
1983	4,799	1,746	879	957	1,195	421	211	89	13	38
1984	5,710	1,195	871	526	591	730	266	133	57	35
1985	14,125	1,421	595	514	312	342	435	158	80	60
1986	4,117	3,515	708	353	301	172	192	243	90	88
1987	1,713	1,025	1,759	431	230	196	116	129	166	126
1988	4,790	426	513	1,077	286	154	136	80	90	210
1989	11,030	1,193	214	315	719	192	107	94	56	218
1990	8,272	2,747	597	131	209	476	131	73	65	197
1991	3,186	2,060	1,376	367	88	138	321	88	49	188
1992	2,365	793	1,032	846	245	56	89	206	57	167
1993	1,662	589	398	634	563	157	36	57	134	157
1994	1,677	414	295	244	420	360	102	23	37	201
1995	6,608	418	207	181	162	270	235	66	15	168
1996	3,066	1,646	209	127	121	107	183	159	45	132
1997	1,393	764	825	129	86	81	74	125	110	128
1998	1,338	347	382	504	84	54	51	46	79	161
1999	1,670	333	173	230	311	47	30	28	25	154
2000	6,218	416	166	105	144	179	27	17	16	120
2001	6,601	1,548	208	101	67	87	111	17	10	95
2002	926	1,643	772	124	62	40	54	68	10	73
2003	713	230	818	460	78	39	26	35	44	59
2004	668	177	115	488	294	50	26	17	23	73
2005	1,699	166	88	67	306	187	33	17	12	69
2006	5,432	422	82	51	41	187	118	21	11	56
2007	5,149	1,350	209	47	31	25	119	75	14	47
2008	6,249	1,280	669	122	30	20	16	78	50	43
2009	2,747	1,555	637	397	78	19	13	11	53	66
2010	1,044	684	776	384	260	52	13	9	8	87
2011	4,600	260	341	463	245	169	35	9	6	68
2012	663	1,145	130	204	294	158	113	24	6	54
2013	36,171	165	573	78	128	185	103	74	16	43
2014	2,089	9,008	83	347	49	81	120	67	49	41
2015	35	520	4,508	50	208	28	47	70	39	58
2016	4	9	260	2,701	29	113	16	26	39	62
2017	1,944	1	4	157	1,649	17	69	9	16	69
2018	5,339	484	1	3	95	973	10	42	6	58
2019	9,391	1,330	242	0	2	55	576	6	25	44
Average	5,672	1,372	676	408	257	159	100	57	37	87

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.

						2018 Assessment results			
Year	*3+ total biomass (1,000 t)*	*Female spawn. biom.*	*Age 1 recruits (million)*	*Catch (t)*	*Harvest rate*	*3+ total biomass*	*Female spawn. biom.*	*Age 1 recruits*	*Harvest rate*
1977	738	135	11,489	118,092	16%	746	132	11,710	16%
1978	951	122	14,008	95,408	10%	965	117	14,321	10%
1979	1,323	129	24,828	106,161	8%	1,346	124	25,425	8%
1980	1,775	178	12,674	115,158	6%	1,812	172	12,959	6%
1981	2,766	196	7,061	147,818	5%	2,832	189	7,231	5%
1982	2,885	321	7,011	169,045	6%	2,956	323	7,229	6%
1983	2,622	448	4,799	215,625	8%	2,691	451	4,968	8%
1984	2,321	495	5,710	307,541	13%	2,391	501	5,933	13%
1985	1,864	446	14,125	286,900	15%	1,930	456	14,760	15%
1986	1,556	401	4,117	86,910	6%	1,622	412	4,315	5%
1987	1,881	375	1,713	68,070	4%	1,966	384	1,789	3%
1988	1,780	378	4,790	63,391	4%	1,864	395	4,998	3%
1989	1,571	393	11,030	75,585	5%	1,647	408	11,469	5%
1990	1,452	403	8,272	88,269	6%	1,525	418	8,452	6%
1991	1,754	396	3,186	100,488	6%	1,840	412	3,251	5%
1992	1,839	360	2,365	90,858	5%	1,922	377	2,362	5%
1993	1,733	393	1,662	108,909	6%	1,809	411	1,666	6%
1994	1,471	464	1,677	107,335	7%	1,533	482	1,701	7%
1995	1,203	387	6,608	72,618	6%	1,252	402	6,739	6%
1996	1,012	358	3,066	51,263	5%	1,052	371	3,155	5%
1997	1,037	317	1,393	90,130	9%	1,073	327	1,455	8%
1998	998	245	1,338	125,460	13%	1,032	255	1,402	12%
1999	740	228	1,670	95,638	13%	769	237	1,758	12%
2000	652	216	6,218	73,080	11%	681	224	6,625	11%
2001	620	201	6,601	72,077	12%	651	209	7,114	11%
2002	795	168	926	51,934	7%	844	174	1,004	6%
2003	994	156	713	50,684	5%	1,065	163	777	5%
2004	829	172	668	63,844	8%	891	184	732	7%
2005	688	209	1,699	80,978	12%	745	223	1,879	11%
2006	580	223	5,432	71,976	12%	636	241	6,026	11%
2007	537	195	5,149	52,714	10%	596	214	5,689	9%
2008	741	193	6,249	52,584	7%	827	212	7,025	6%
2009	1,046	190	2,747	44,247	4%	1,170	212	3,109	4%
2010	1,230	260	1,044	76,744	6%	1,381	290	1,216	6%
2011	1,164	302	4,600	81,485	7%	1,317	340	5,273	6%
2012	1,072	319	663	103,970	10%	1,224	360	857	8%
2013	1,087	339	36,171	96,364	9%	1,256	385	37,179	8%
2014	848	256	2,089	142,633	17%	995	299	2,039	14%
2015	2,186	231	35	167,551	8%	2,345	261	38	7%
2016	2,171	243	4	177,133	8%	2,307	282	6	8%
2017	1,563	324	1,944	186,156	12%	1,672	352	2,124	11%
2018	1,097	302	5,339	158,095	14%	1,186	326	5,415	13%
2019	941	227	9,391						
Average									
1977-2018	1,361	287	5,783	109,308	9%	1,437	303	6,028	0
1978-2018			5,644					5,889	

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	1,253	0.31	689	2,281	127	0.31	69	231
1971	3,146	0.45	1,352	7,323	121	0.32	65	224
1972	3,614	0.38	1,773	7,367	112	0.34	59	213
1973	10,430	0.17	7,517	14,471	95	0.37	47	191
1974	2,176	0.30	1,215	3,896	85	0.34	45	163
1975	2,191	0.29	1,265	3,795	90	0.26	55	149
1976	8,538	0.19	5,859	12,441	120	0.19	84	172
1977	11,488	0.19	7,964	16,572	135	0.19	94	194
1978	14,008	0.19	9,719	20,189	122	0.22	80	187
1979	24,828	0.16	18,332	33,625	129	0.22	83	198
1980	12,674	0.20	8,619	18,637	178	0.21	119	266
1981	7,061	0.24	4,419	11,280	196	0.19	136	283
1982	7,011	0.24	4,407	11,152	321	0.17	232	444
1983	4,799	0.35	2,445	9,421	448	0.16	328	611
1984	5,710	0.32	3,094	10,536	495	0.17	357	686
1985	14,125	0.17	10,225	19,512	446	0.19	310	643
1986	4,117	0.29	2,352	7,206	401	0.20	270	597
1987	1,713	0.44	755	3,885	375	0.20	256	548
1988	4,790	0.24	3,030	7,572	378	0.18	266	537
1989	11,030	0.15	8,237	14,769	393	0.15	292	529
1990	8,272	0.17	5,974	11,453	403	0.15	304	535
1991	3,186	0.27	1,890	5,372	396	0.15	298	526
1992	2,365	0.28	1,388	4,029	360	0.14	274	474
1993	1,662	0.31	921	2,997	393	0.13	306	504
1994	1,677	0.30	945	2,974	464	0.12	365	589
1995	6,608	0.13	5,164	8,457	387	0.12	304	493
1996	3,067	0.18	2,181	4,311	358	0.12	281	456
1997	1,393	0.25	860	2,256	317	0.13	248	406
1998	1,338	0.23	856	2,091	245	0.13	189	319
1999	1,670	0.21	1,111	2,511	228	0.14	174	299
2000	6,218	0.12	4,884	7,916	216	0.14	164	285
2001	6,601	0.11	5,297	8,227	201	0.15	150	270
2002	926	0.29	532	1,610	168	0.16	123	229
2003	713	0.27	426	1,196	156	0.16	115	211
2004	668	0.28	387	1,154	172	0.13	133	223
2005	1,699	0.19	1,166	2,475	209	0.13	161	270
2006	5,432	0.14	4,173	7,071	223	0.14	170	292
2007	5,149	0.14	3,898	6,801	195	0.15	146	262
2008	6,249	0.13	4,804	8,129	193	0.16	142	262
2009	2,747	0.17	1,954	3,860	190	0.15	142	256
2010	1,044	0.27	618	1,765	260	0.14	200	339
2011	4,600	0.16	3,383	6,255	302	0.13	234	390
2012	663	0.33	352	1,251	319	0.13	246	413
2013	36,171	0.10	29,786	43,924	339	0.14	258	446
2014	2,089	0.29	1,207	3,614	256	0.15	191	343
2015	35	0.39	17	74	231	0.16	168	317
2016	4	0.39	2	9	243	0.14	185	318
2017	1,944	0.31	1,077	3,508	324	0.14	248	423
2018	5,340	0.29	3,052	9,340	302	0.15	223	407
2019	9,391	0.33	5,012	17,595	227	0.18	159	324

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 an 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. 2014-2018)*	*Spawning (Avg. 2015-2019)*	*Population (Avg. 2013-2017)*	*Fishery (Est. 2020 from RE model)*	*Proportion mature females*
1	1.39	0.001	0.011	0.030	0.164	0.000
2	0.69	0.012	0.102	0.216	0.415	0.013
3	0.48	0.129	0.250	0.475	0.575	0.056
4	0.37	0.633	0.478	0.720	0.846	0.277
5	0.34	0.954	0.623	0.918	1.025	0.612
6	0.30	0.997	0.739	1.097	1.139	0.860
7	0.30	1.000	0.923	1.287	1.146	0.939
8	0.29	0.991	1.050	1.415	1.102	0.978
9	0.28	0.880	1.271	1.460	1.206	0.989
10+	0.29	0.349	1.311	1.688	1.330	0.993

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 1990-2018 is the method used by the Plan Team to derive the ABC recommendation given in the SAFE summary chapter.

Year	*Assessment method*	*Basis for catch recommendation in following year*	*B40% (t)*
1977-81	Survey biomass, CPUE trends, M=0.4	MSY = 0.4 * M * Bzero	---
1982	CAGEAN	MSY = 0.4 * M * Bzero	---
1983	CAGEAN	Mean annual surplus production	---
1984	Projection of survey numbers at age	Stabilize biomass trend	---
1985	CAGEAN, projection of survey numbers at age, CPUE trends	Stabilize biomass trend	---
1986	CAGEAN, projection of survey numbers at age	Stabilize biomass trend	---
1987	CAGEAN, projection of survey numbers at age	Stabilize biomass trend	---
1988	CAGEAN, projection of survey numbers at age	10% of exploitable biomass	---
1989	Stock synthesis	10% of exploitable biomass	---
1990	Stock synthesis, reduce *M* to 0.3	10% of exploitable biomass	---
1991	Stock synthesis, assume trawl survey catchability = 1	FMSY from an assumed SR curve	---
1992	Stock synthesis	Max[-Pr(SB<Threshold)+Yld]	---
1993	Stock synthesis	Pr(SB>B20)=0.95	---
1994	Stock synthesis	Pr(SB>B20)=0.95	---
1995	Stock synthesis	Max[-Pr(SB<Threshold)+Yld]	---
1996	Stock synthesis	Amendment 44 Tier 3 guidelines	289,689
1997	Stock synthesis	Amendment 44 Tier 3 guidelines	267,600
1998	Stock synthesis	Amendment 44 Tier 3 guidelines	240,000
1999	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	247,000
2000	AD model builder	Amendment 56 Tier 3 guidelines	250,000
2001	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	245,000
2002	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	240,000
2003	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000
2004	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC}, and stairstep approach for projected ABC	229,000
2005	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	224,000
2006	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	220,000
2007	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	221,000
2008	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	237,000
2009	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000
2010	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	276,000
2011	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	271,000
2012	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	297,000
2013	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	290,000
2014	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	312,000
2015	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	300,000
2016	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	267,000
2017	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	238,000
2018	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	221,000

Table 1.25. Projections of GOA pollock spawning biomass, full recruitment fishing mortality, and catch for 2020-2032 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 2019 using the base run model with a projected 2019 catch of 125,850 t. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 485,000 t, 194,000 t, 170,000 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}
2020	205,503	206,664	218,621	224,923	228,082	214,552	216,653
2021	179,011	184,094	194,818	224,969	241,707	178,292	186,586
2022	185,665	191,987	199,656	244,399	271,002	179,556	188,163
2023	203,313	207,151	217,381	277,013	313,626	193,141	197,895
2024	206,219	208,731	220,099	298,283	348,782	191,669	194,124
2025	202,421	203,787	216,764	311,493	376,679	187,722	189,025
2026	199,248	200,018	214,276	321,395	399,739	186,062	186,795
2027	201,200	201,631	223,325	340,308	429,923	195,631	196,021
2028	213,591	213,829	226,196	350,790	448,400	196,733	196,971
2029	218,916	219,052	224,326	354,262	457,223	193,627	193,771
2030	218,141	218,202	223,743	358,418	465,505	192,406	192,494
2031	218,461	218,487	217,683	355,281	465,001	186,565	186,619
2032	213,351	213,364	212,218	352,301	464,346	181,395	181,429

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}
2020	0.28	0.23	0.23	0.08	0	0.33	0.28
2021	0.26	0.28	0.23	0.08	0	0.30	0.27
2022	0.27	0.28	0.23	0.08	0	0.30	0.32
2023	0.28	0.27	0.23	0.08	0	0.30	0.30
2024	0.27	0.23	0.23	0.08	0	0.26	0.26
2025	0.23	0.20	0.23	0.08	0	0.22	0.23
2026	0.20	0.14	0.23	0.08	0	0.20	0.20
2027	0.14	0.12	0.23	0.08	0	0.19	0.19
2028	0.12	0.11	0.23	0.07	0	0.18	0.18
2029	0.11	0.11	0.23	0.06	0	0.17	0.17
2030	0.11	0.11	0.23	0.05	0	0.17	0.17
2031	0.11	0.11	0.23	0.05	0	0.17	0.17
2032	0.11	0.11	0.23	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}
2020	120,549	108,494	105,958	36,974	0	140,674	126,258
2021	124,320	111,888	118,164	44,312	0	144,845	132,470
2022	162,508	170,642	145,409	55,270	0	179,003	190,638
2023	192,812	193,925	164,567	66,237	0	199,096	203,542
2024	182,858	184,800	160,581	68,494	0	180,767	182,116
2025	162,282	162,985	156,585	69,084	0	172,881	173,312
2026	155,484	155,735	158,607	70,528	0	177,123	177,274
2027	154,626	154,763	173,114	75,782	0	198,612	198,654
2028	172,096	172,158	165,223	73,256	0	186,377	186,431
2029	165,668	165,768	164,799	71,611	0	186,104	186,136
2030	166,008	166,045	161,727	70,159	0	181,080	181,100
2031	162,436	162,435	154,996	67,485	0	172,614	172,625
2032	155,026	155,023	148,662	64,815	0	164,884	164,892

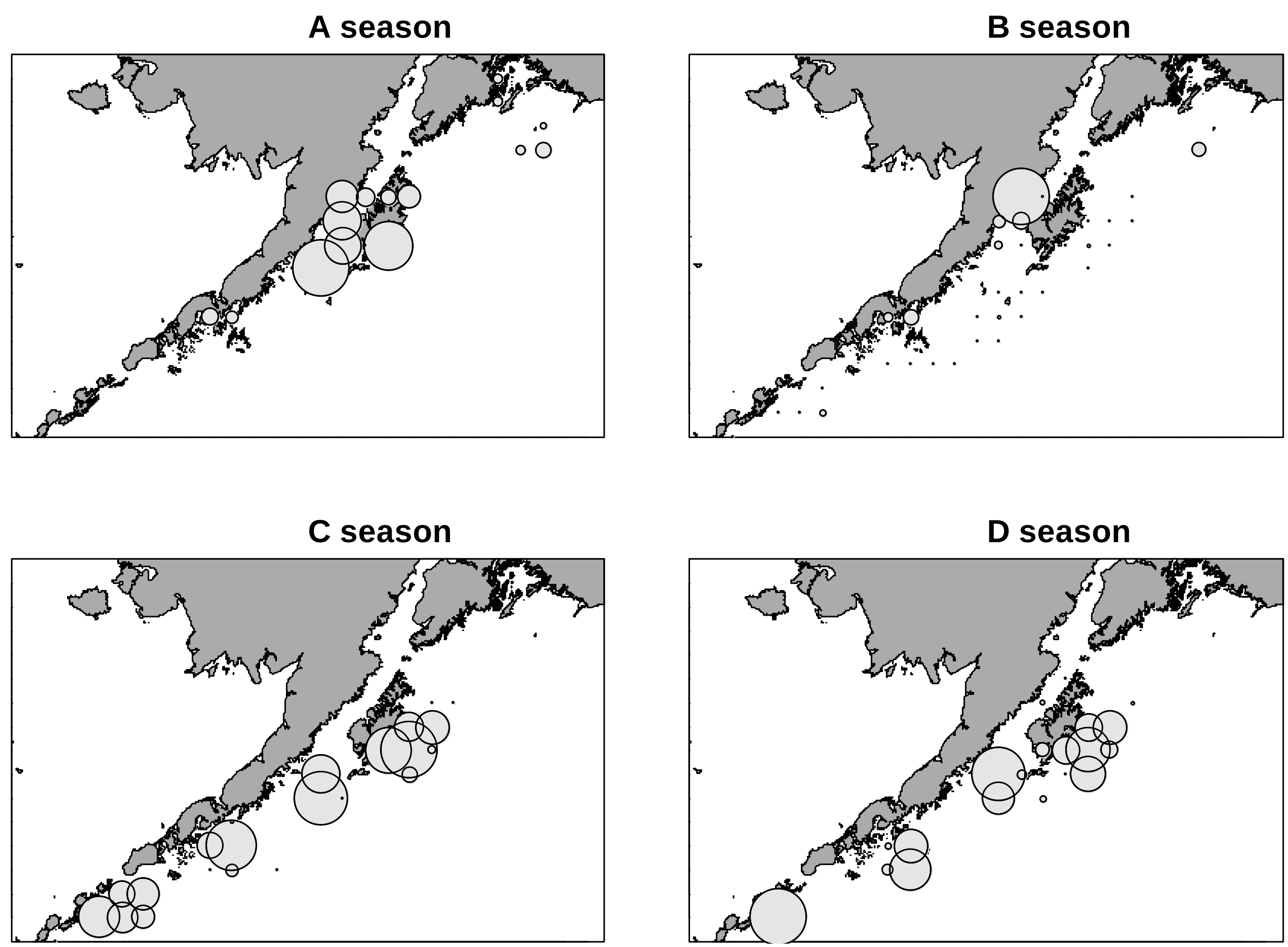


Figure 1.1. Pollock catch in 2018 for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

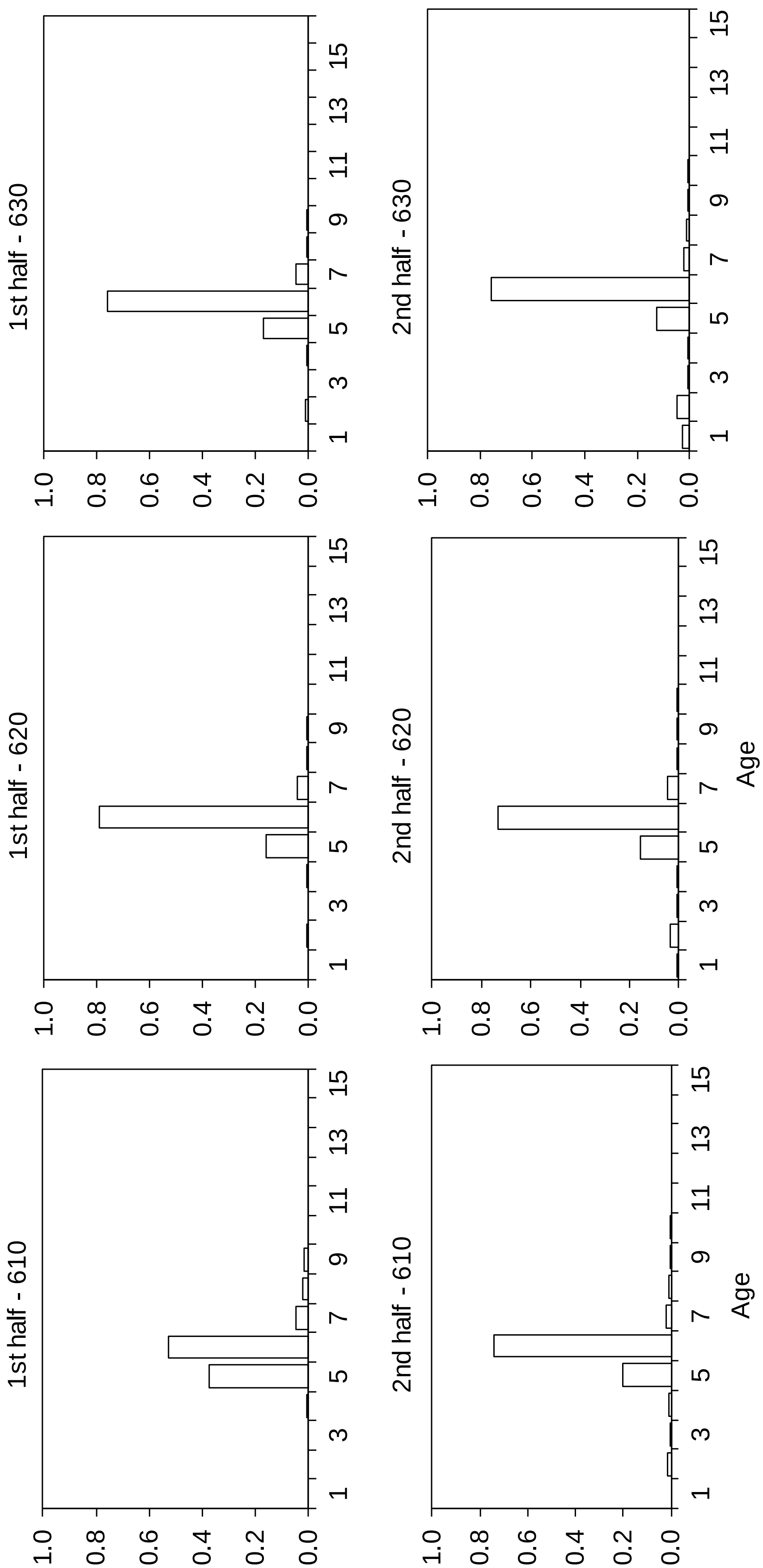


Figure 1.2. 2018 fishery age composition by half year (January-June, July-December) and management area.

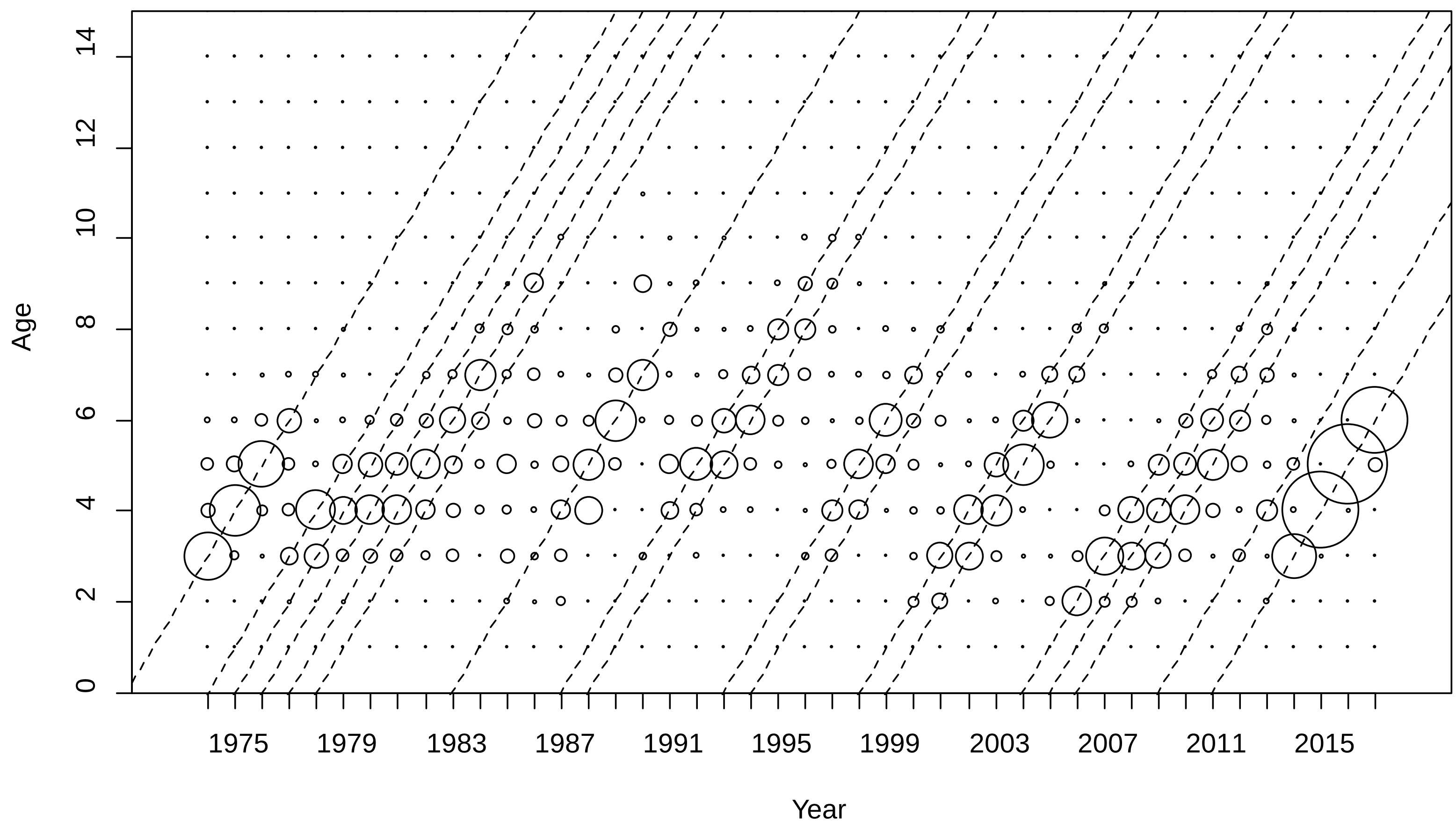


Figure 1.3. GOA pollock fishery age composition (1975-2018). The diameter of the circle is proportional to the catch. Diagonal lines show strong year classes.

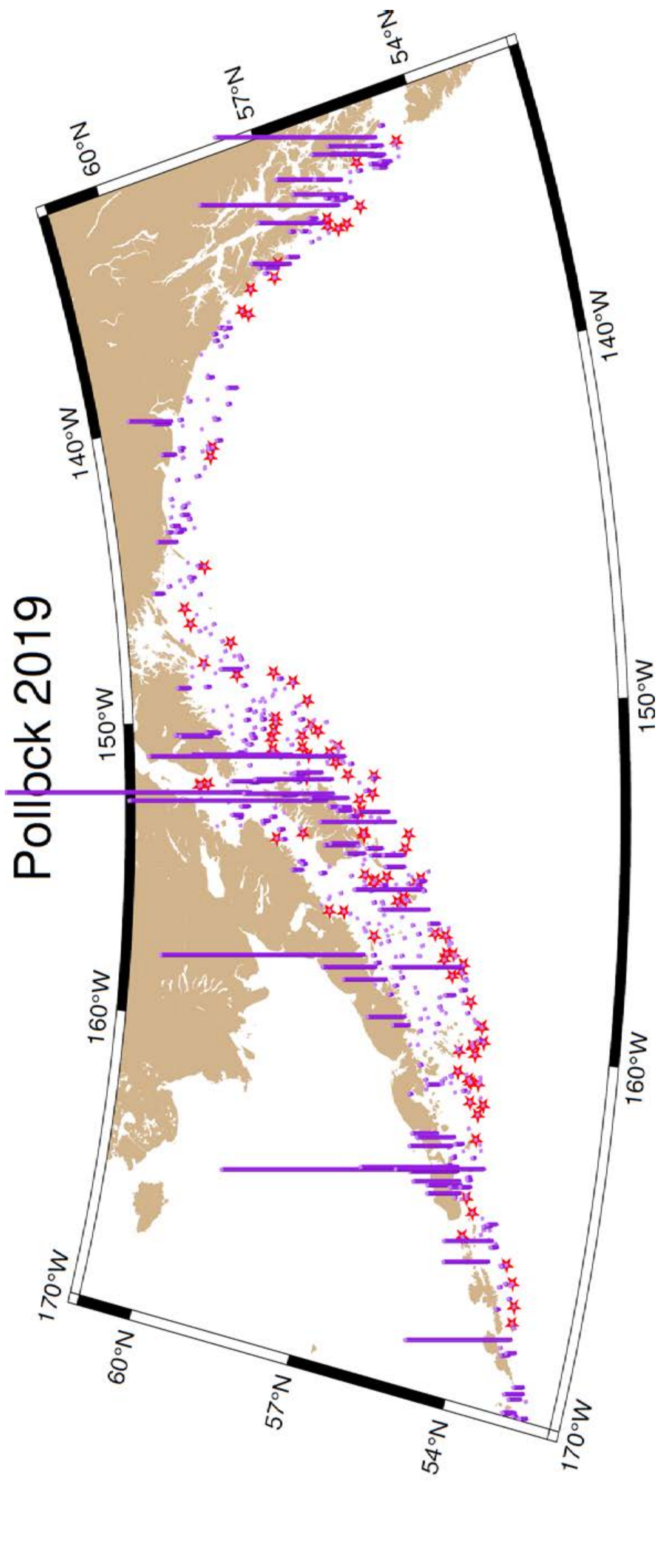


Figure 1.4. Pollock catch per unit effort (CPUE) for the 2019 NMFS bottom trawl survey in the Gulf of Alaska. Stars indicate hauls with no pollock catch.

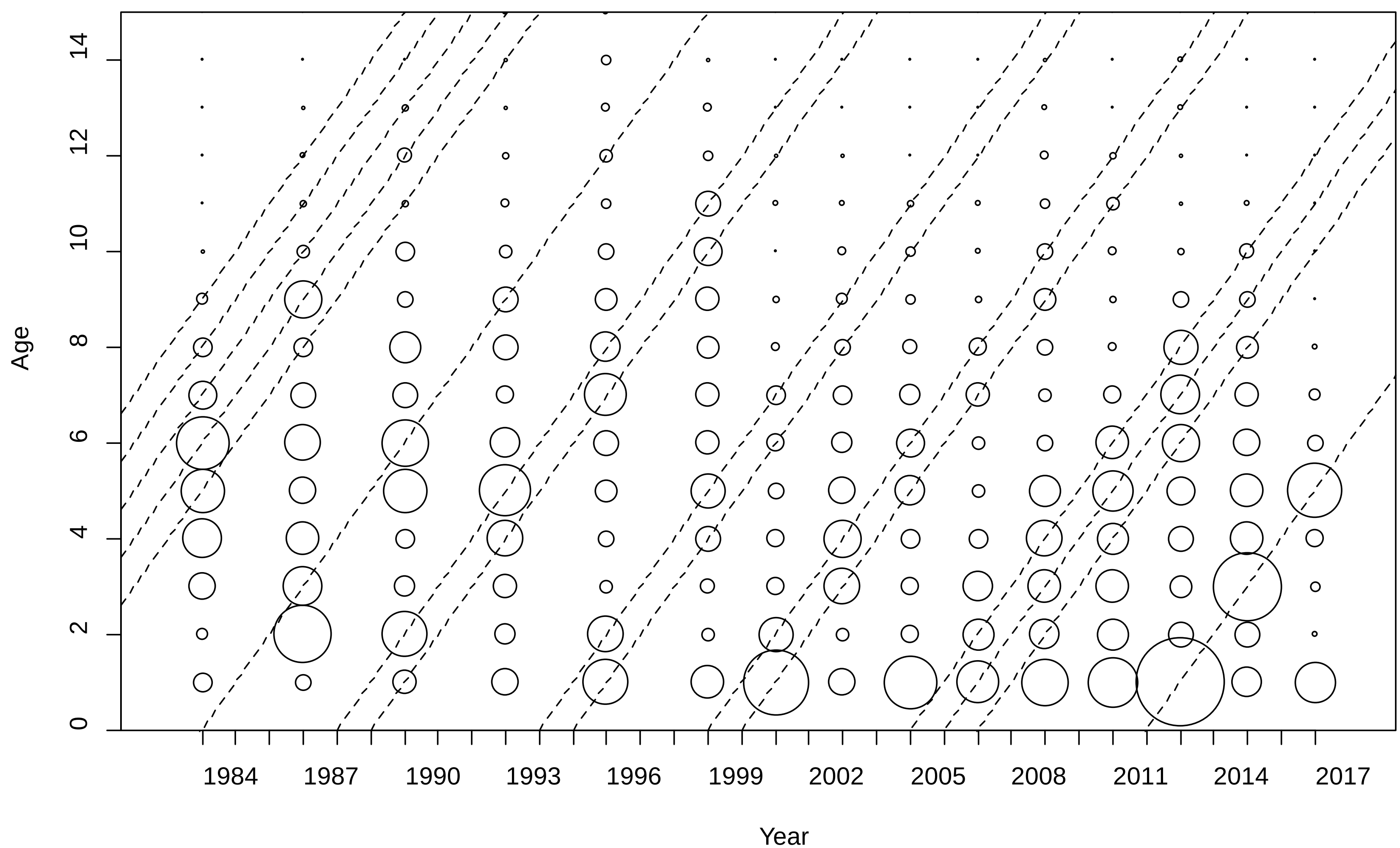


Figure 1.5. Estimated abundance at age in the NMFS bottom trawl survey (1984-2017). The area of the circle is proportional to the estimated abundance.

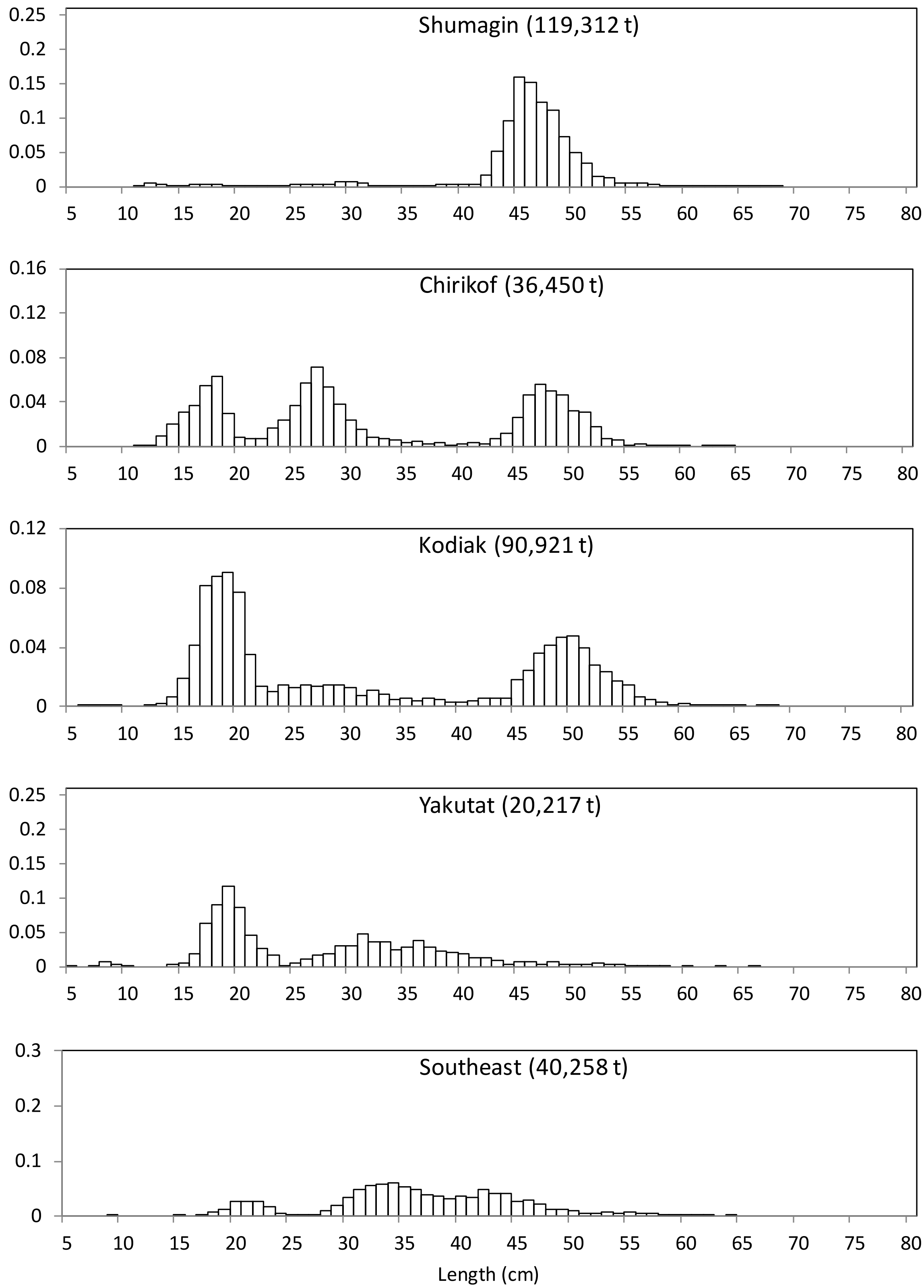


Figure 1.6. Size composition of pollock by statistical area for the 2019 NMFS bottom trawl survey.

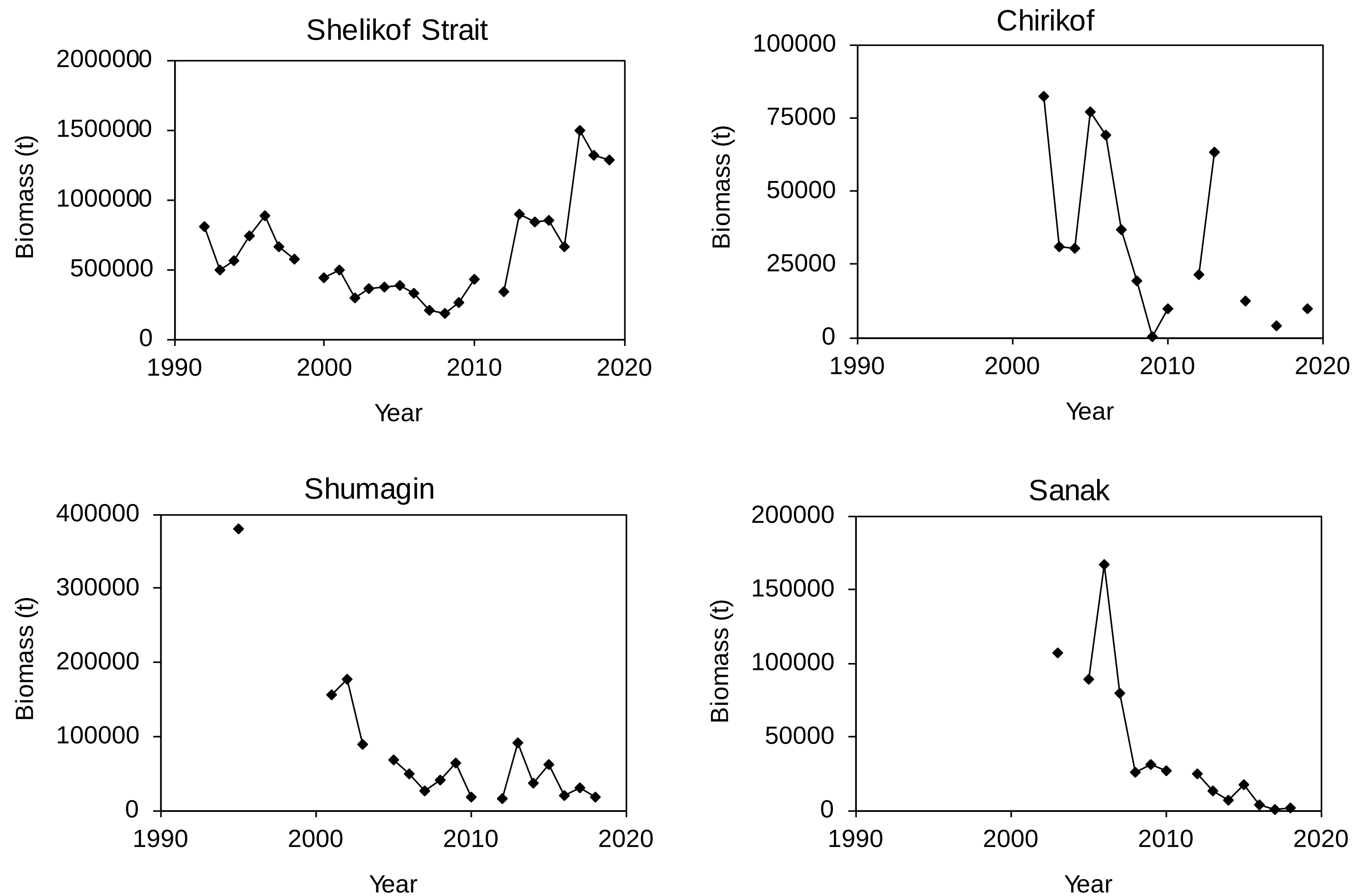


Figure 1.7. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

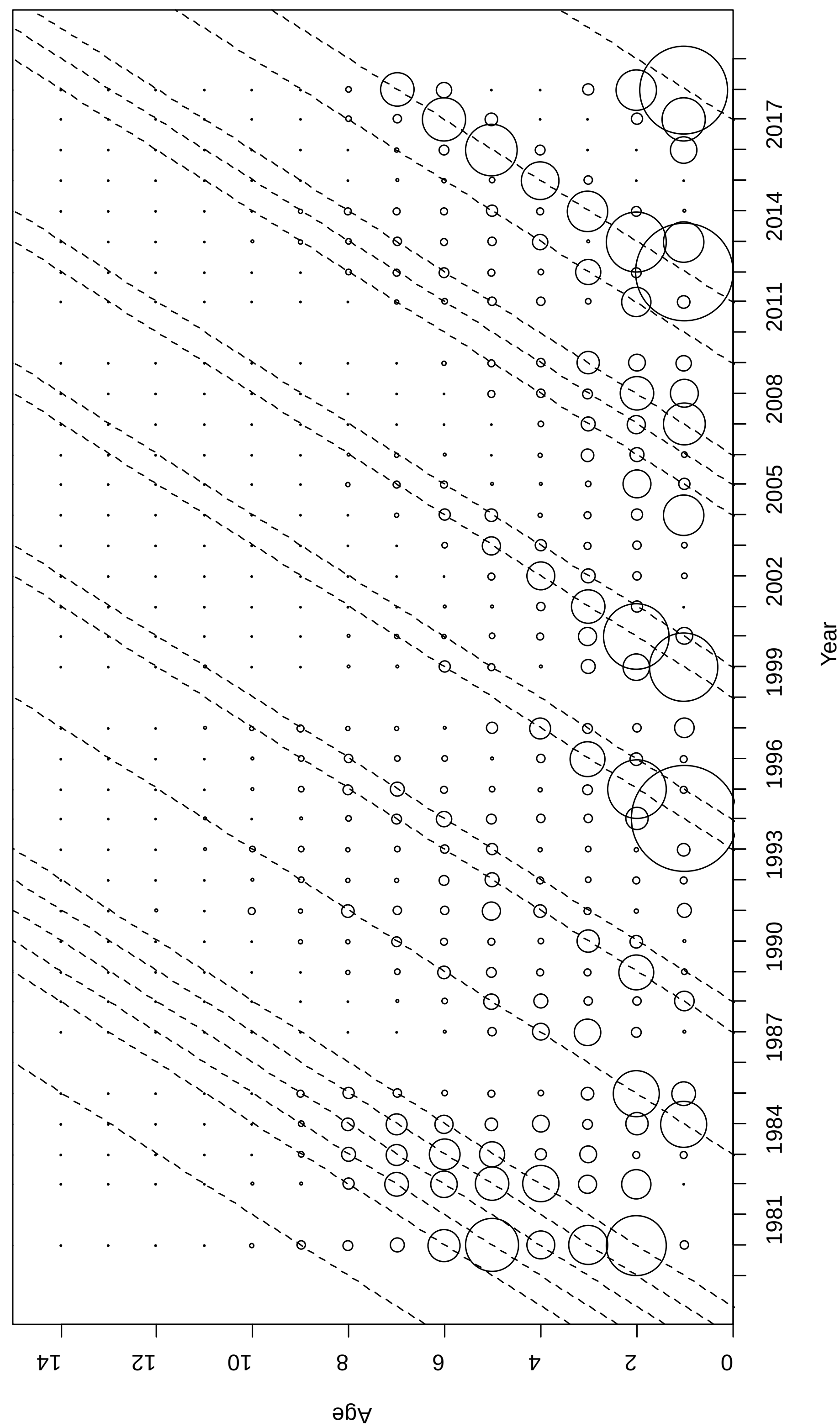


Figure 1.8. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2017, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

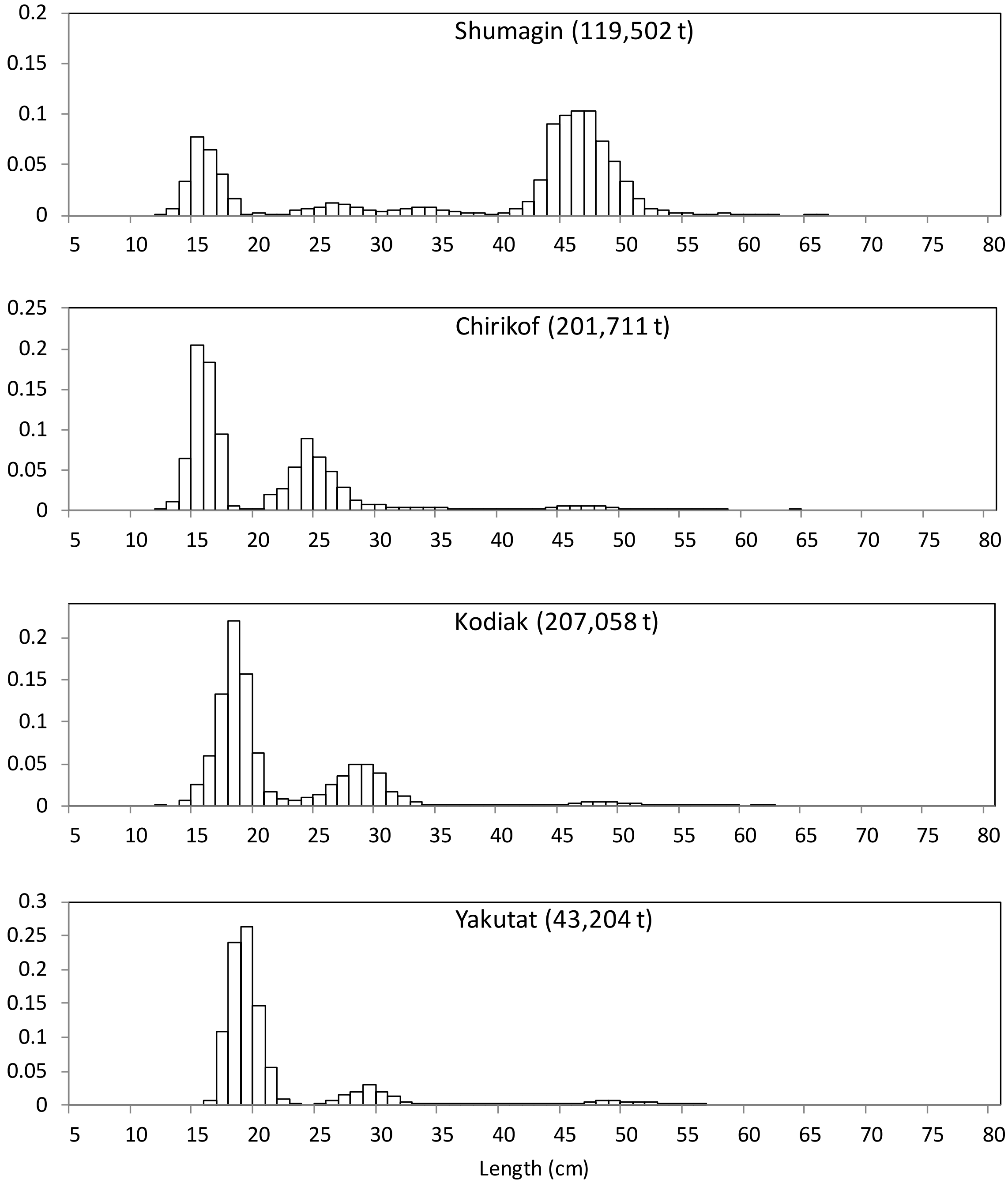


Figure 1.9. Size composition of pollock by statistical area for the 2019 summer acoustic survey.

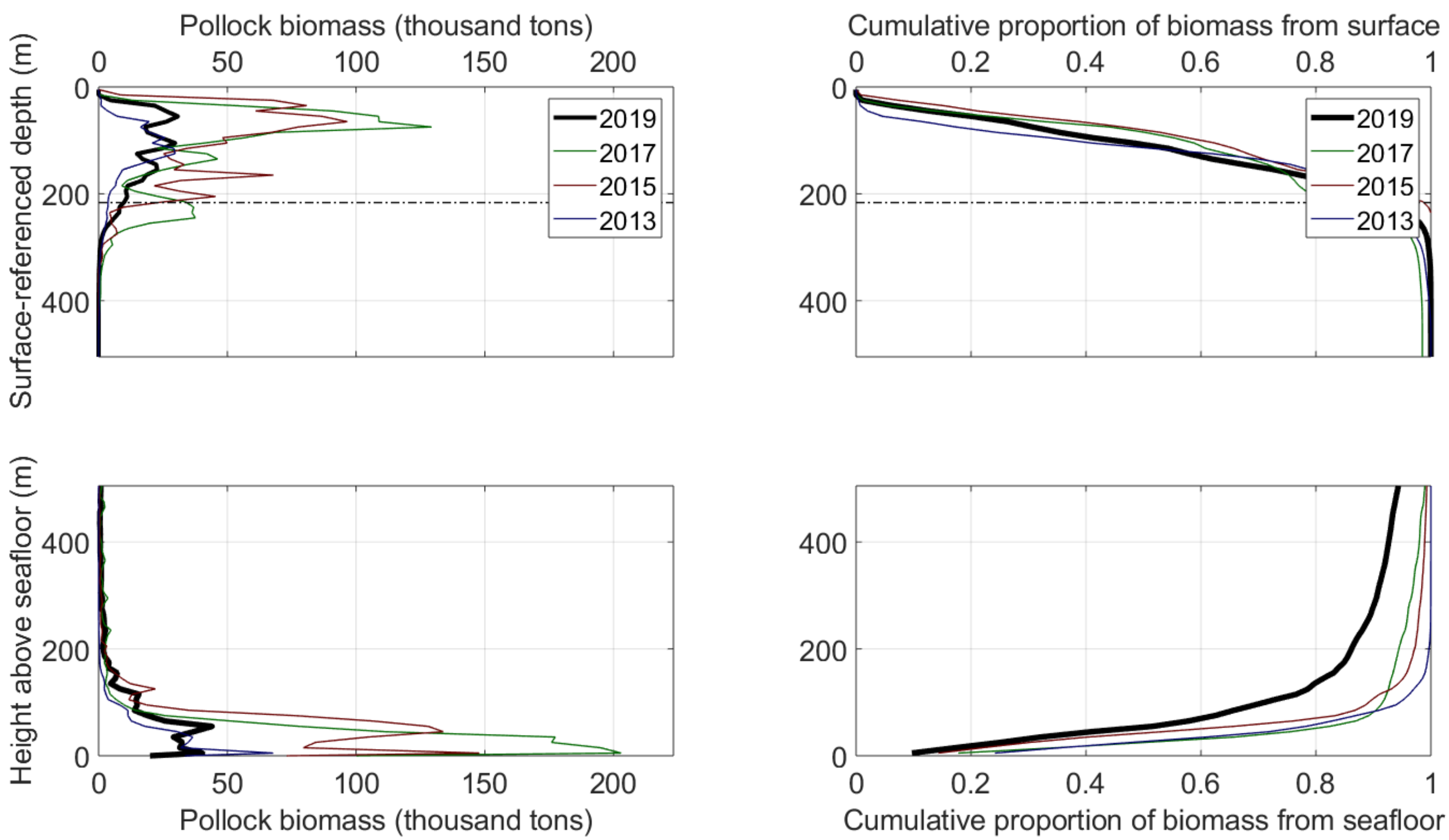


Figure 1.10. Surface-referenced and bottom-referenced distribution of biomass in the water column for the shelf transect region of summer acoustic surveys in the Gulf of Alaska.

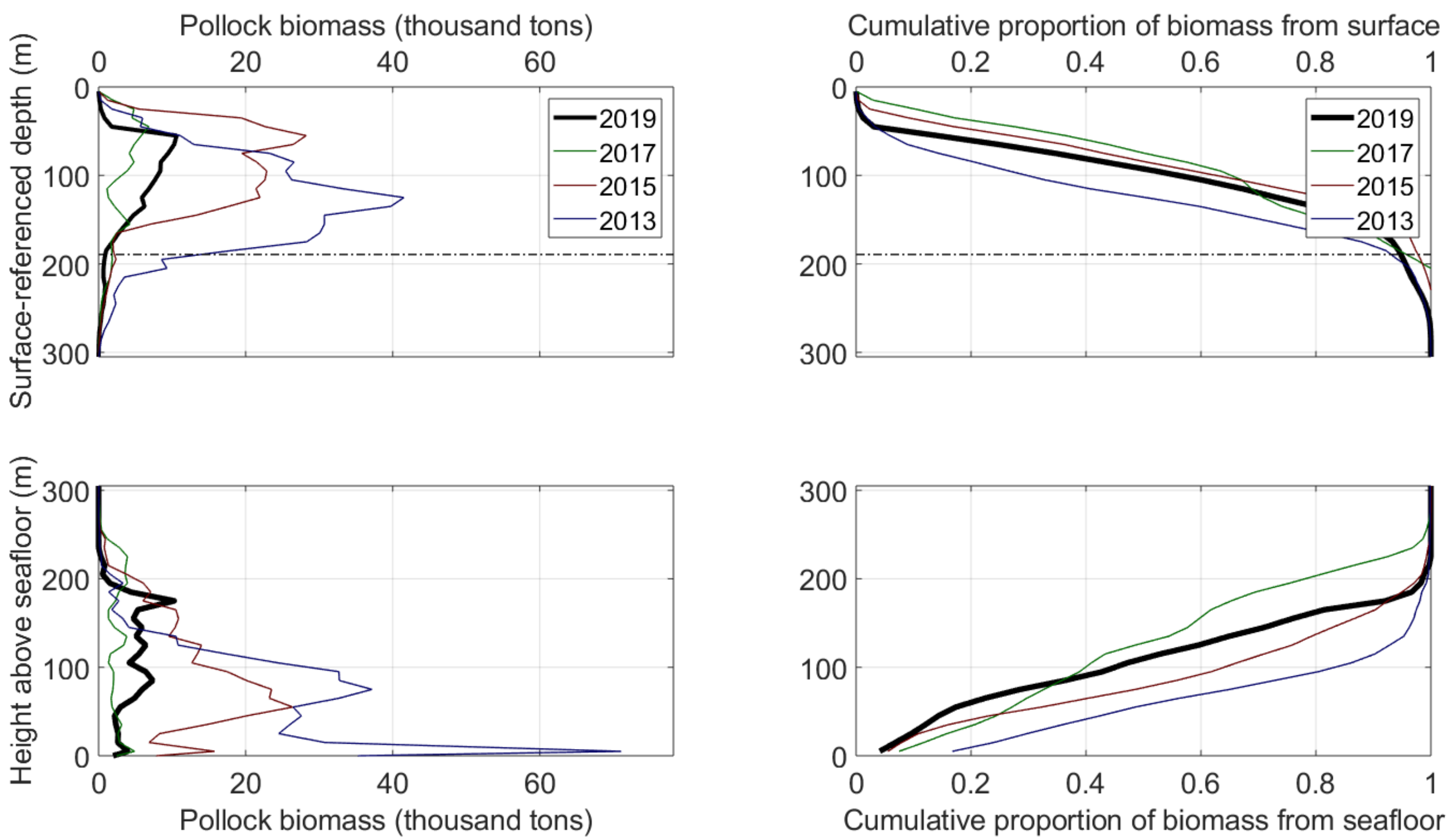


Figure 1.11. Surface-referenced and bottom-referenced distribution of biomass in the water column for the Shelikof Strait region of summer acoustic surveys in the Gulf of Alaska.

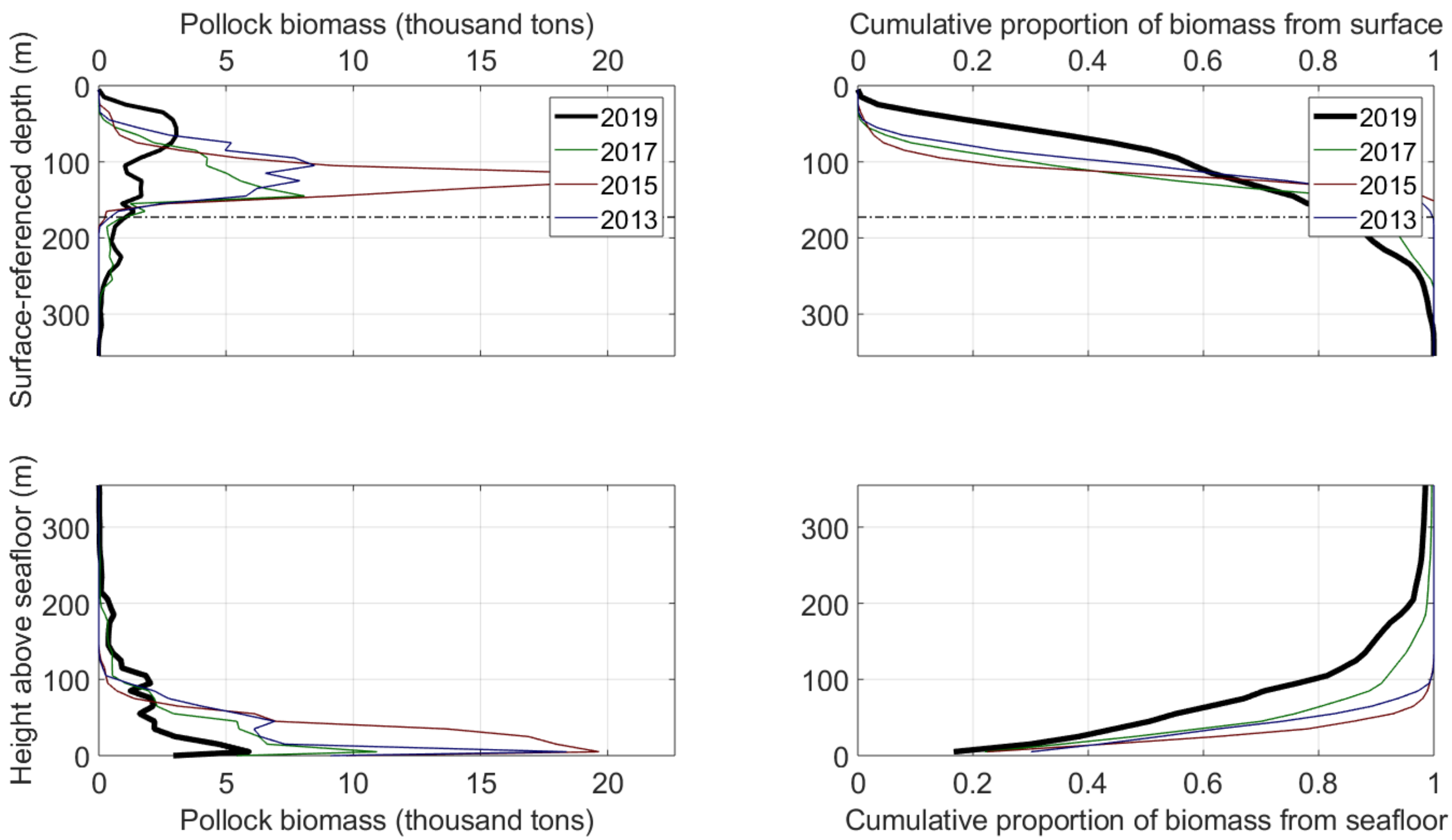


Figure 1.12. Surface-referenced and bottom-referenced distribution of biomass in the water column for the Barnabus Gully region of summer acoustic surveys in the Gulf of Alaska.

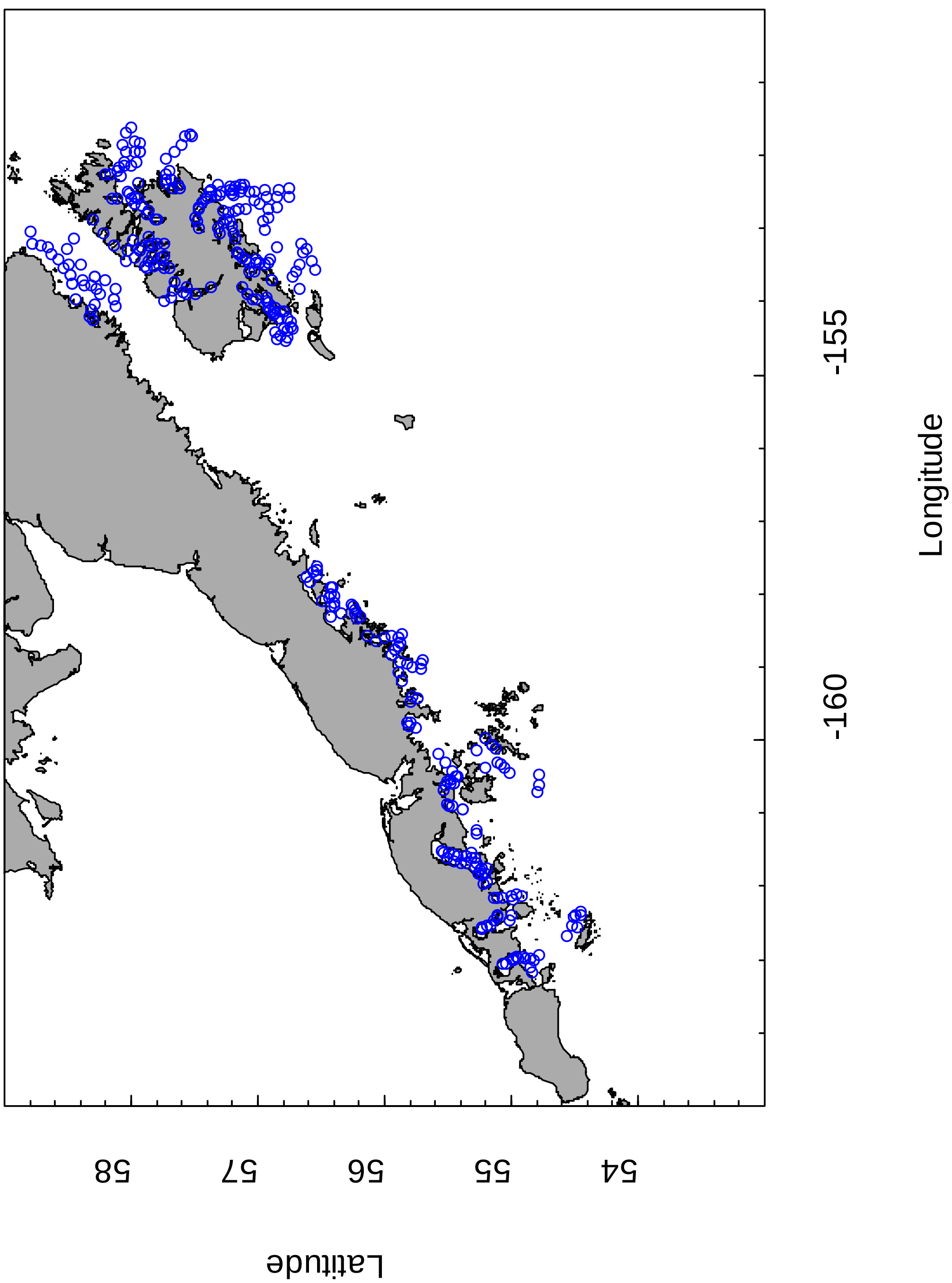


Figure 1.13. Tow locations for the 2019 ADF&G crab/groundfish trawl survey.

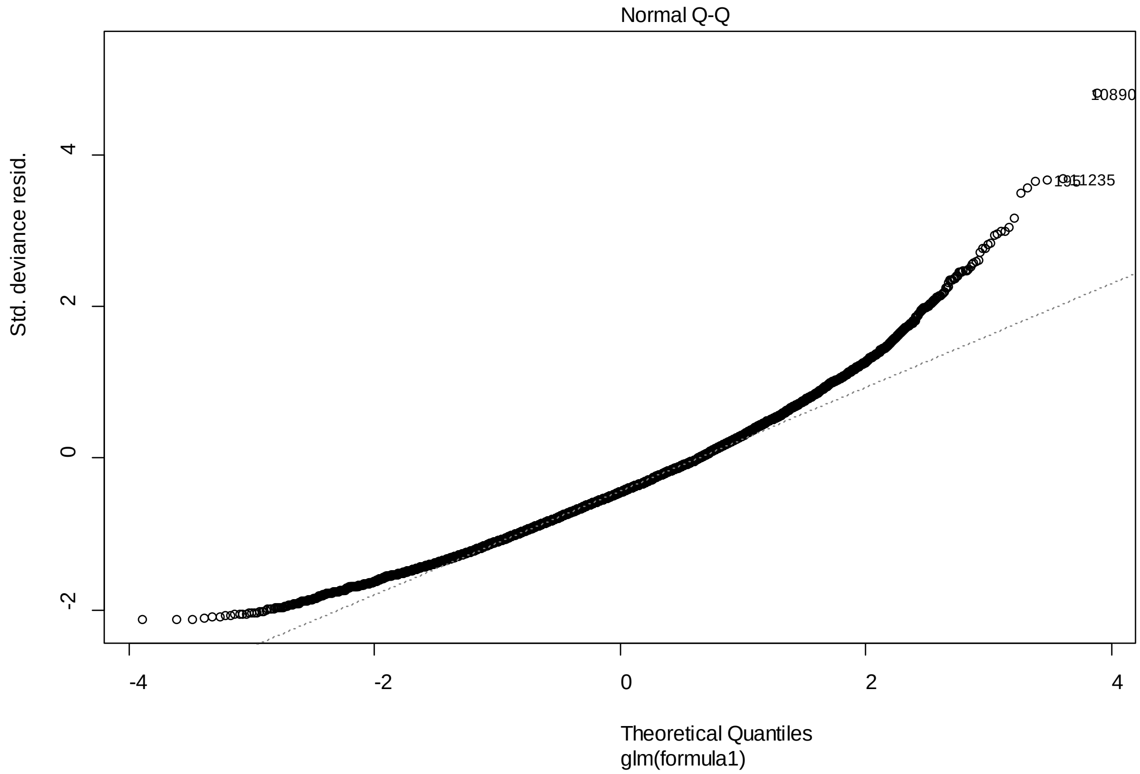


Figure 1.14. QQ plot for residuals for the GLM model for the positive observations with a gamma error assumption for the ADF&G crab/groundfish trawl survey.

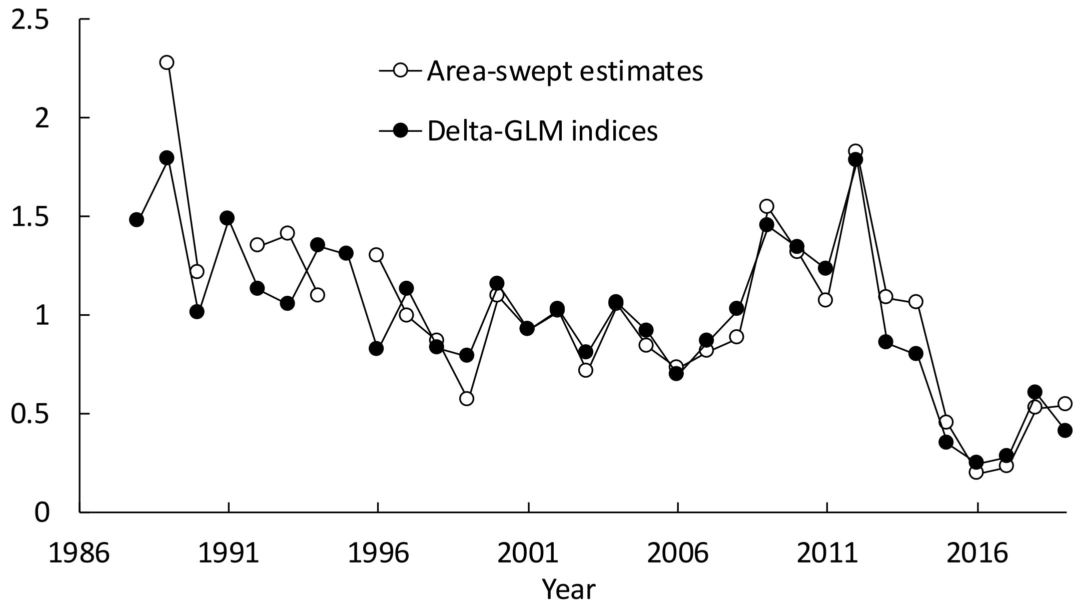


Figure 1.15. Comparison of ADF&G crab/groundfish trawl area-swept indices with year indices for a delta GLM model with a gamma error assumption for the positive observations. Both time series have been scaled by the mean for the time series.

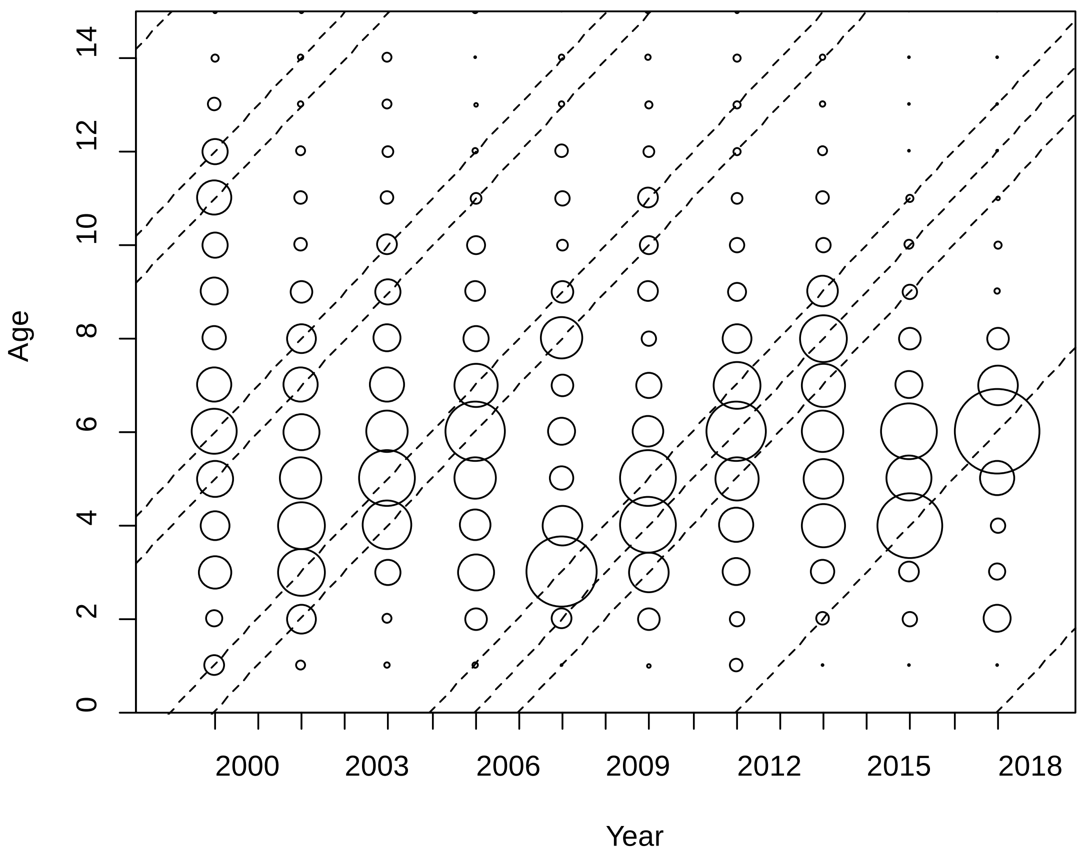


Figure 1.16. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2018). The area of the circle is proportional to the estimated abundance.

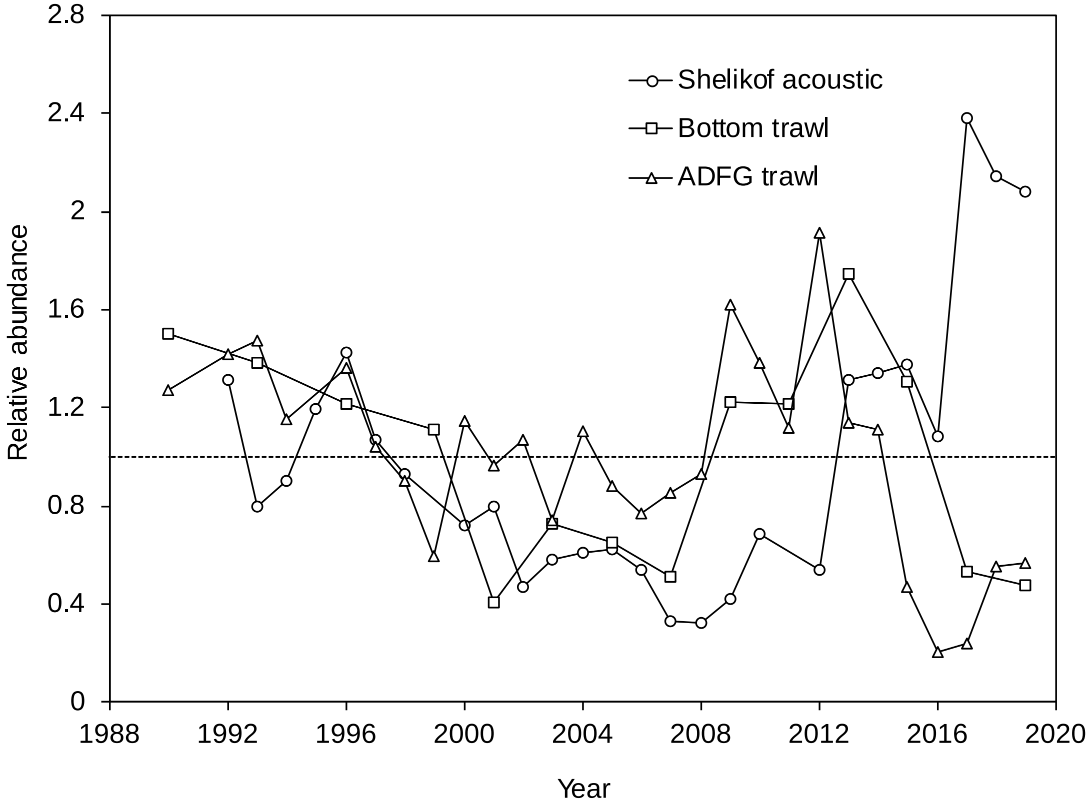


Figure 1.17. Relative trends in pollock biomass since 1990 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1990. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the R/V Oscar Dyson.

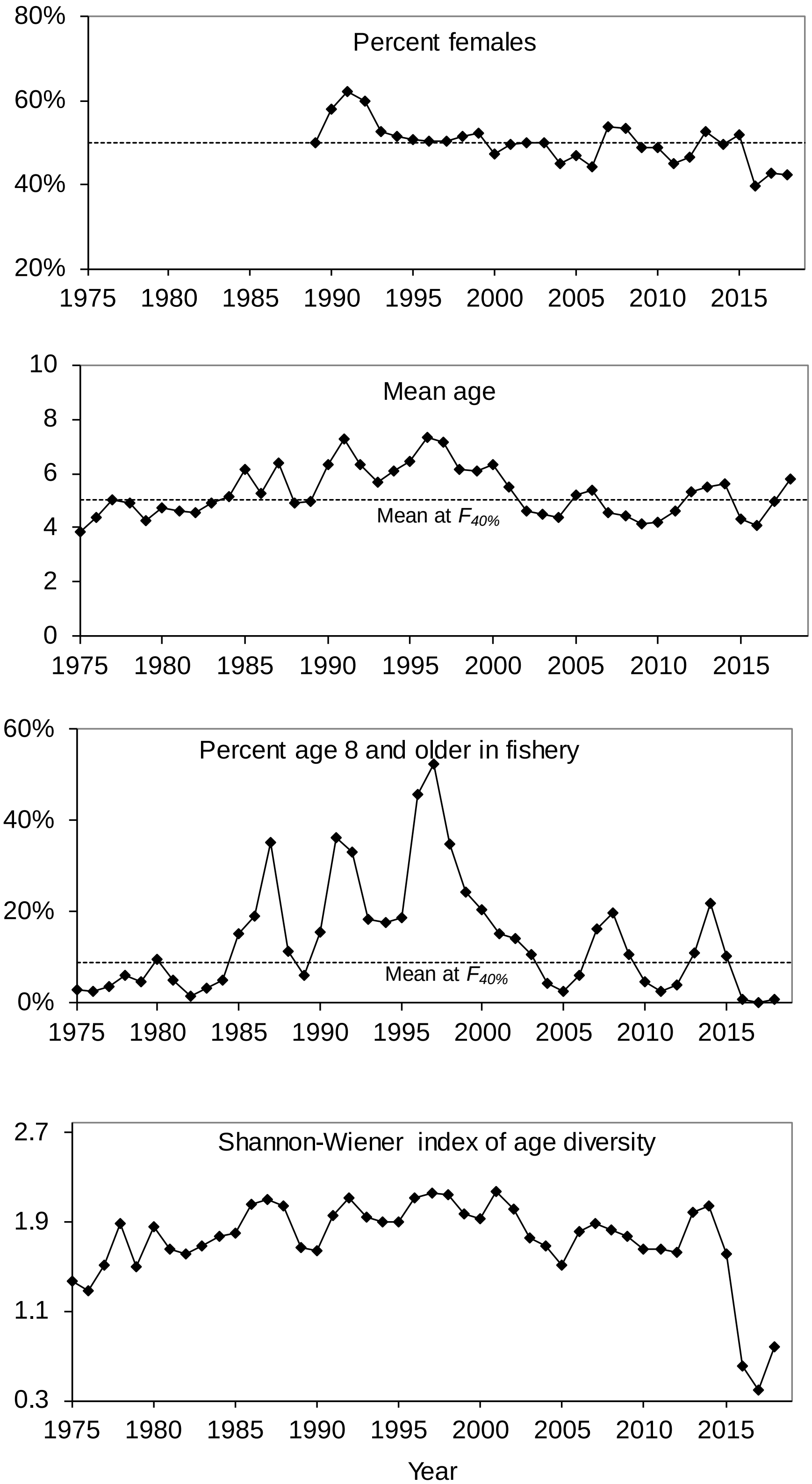


Figure 1.18. GOA pollock fishery catch characteristics.

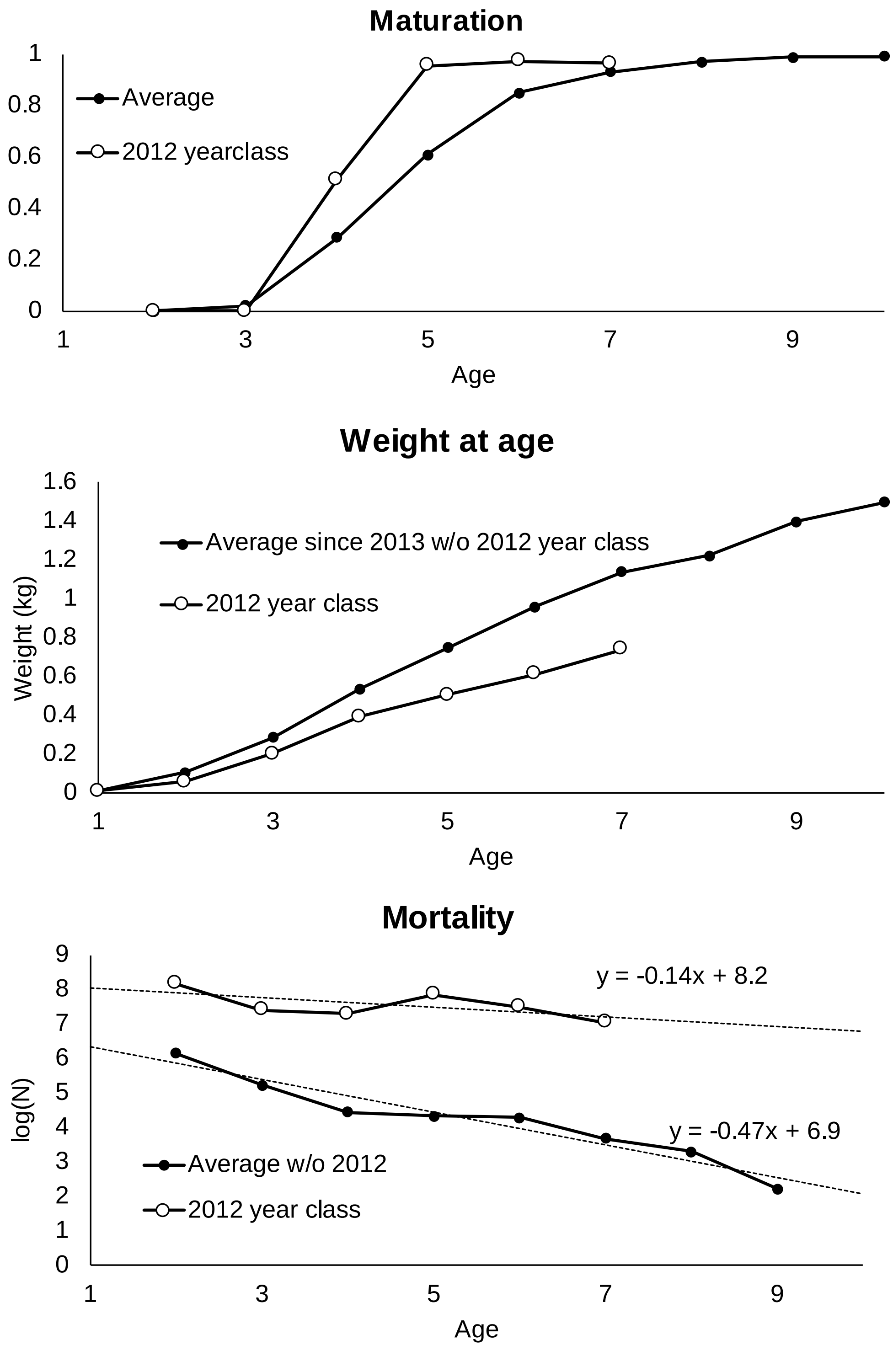


Figure 1.19. Comparison of 2012 year class maturation, growth, and mortality with average characteristics. Maturity is based on sampling during winter acoustic surveys. Weight at age is a comparison of the 2012 year class in the winter acoustic survey with the average weight at age since 2013 excluding 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*).

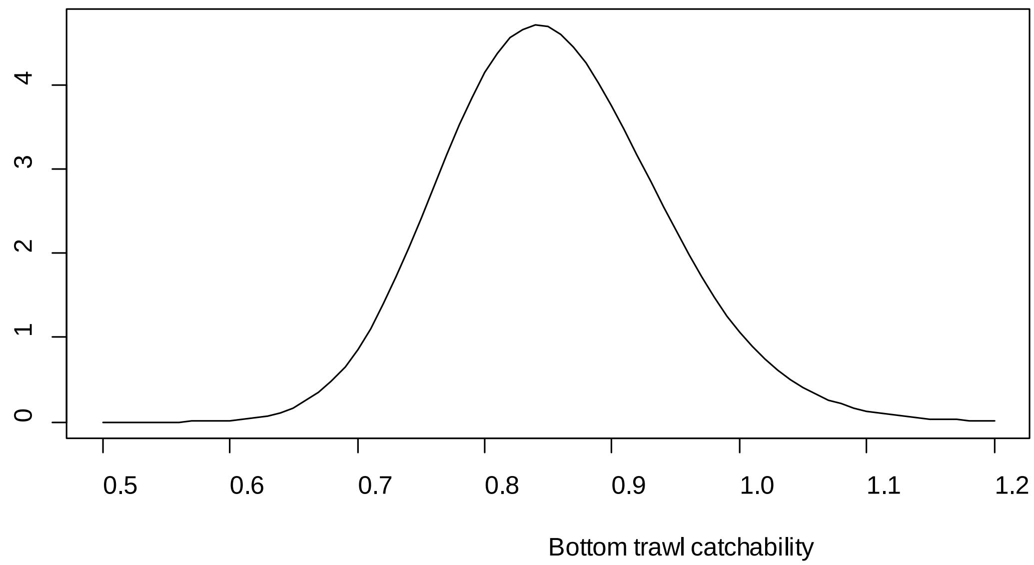


Figure 1.20. Prior on bottom trawl catchability used in the base model.

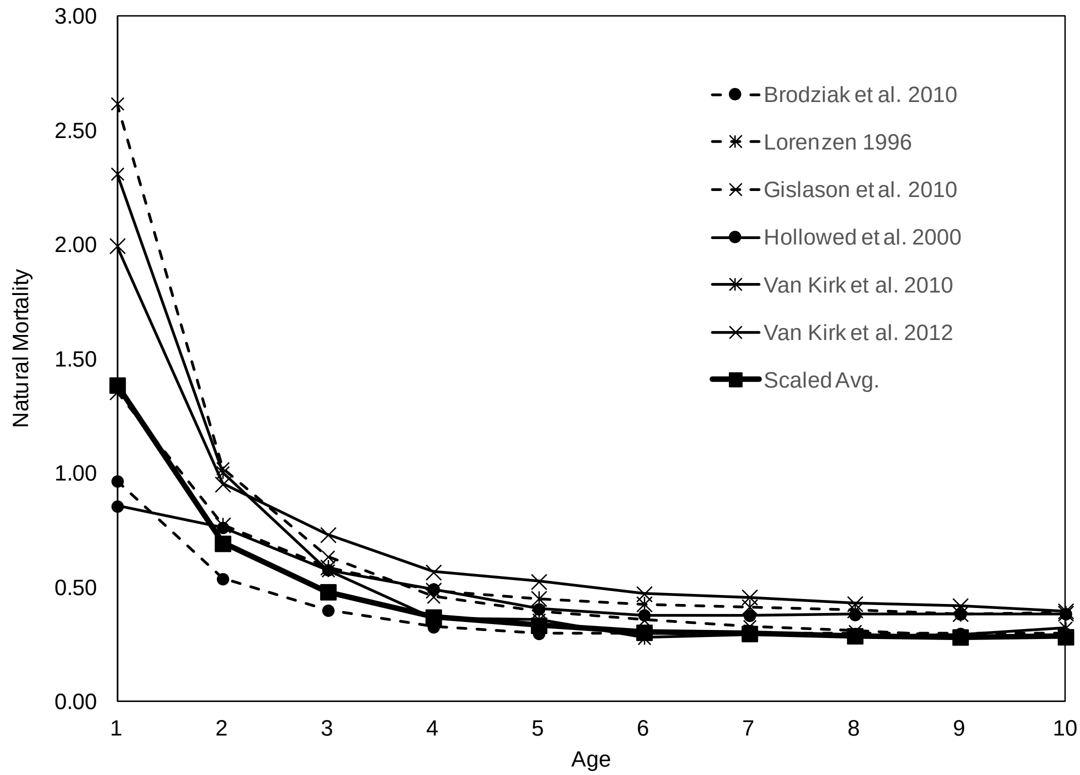


Figure 1.21. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

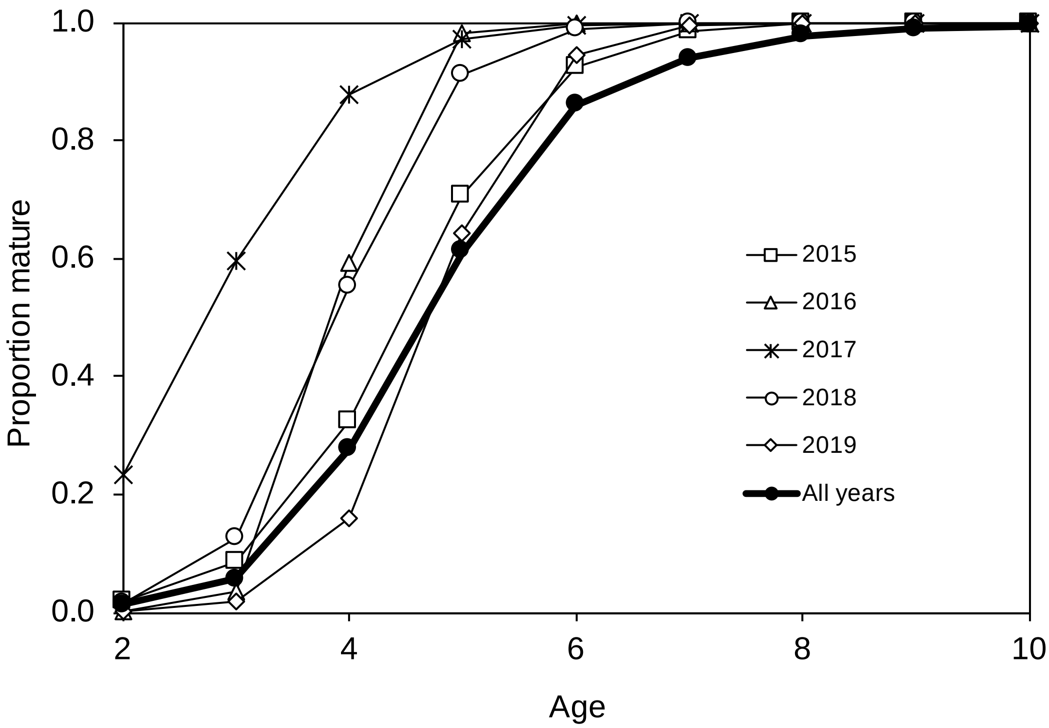
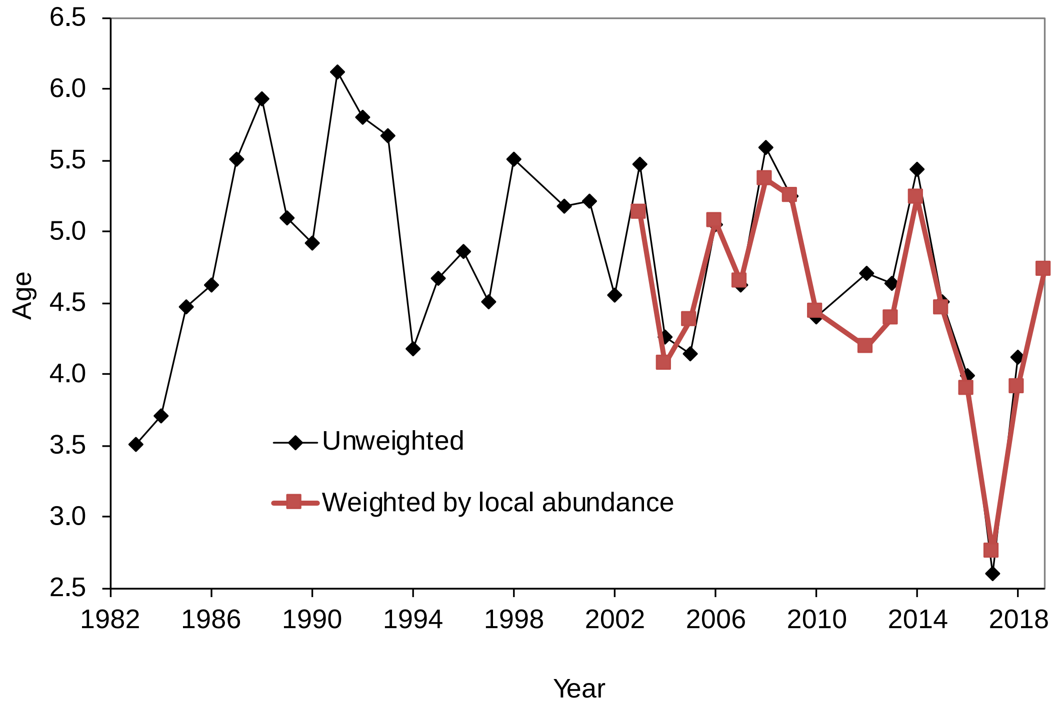


Figure 1.22. Estimates of the proportion mature at age from weighted visual maturity data collected during 2015-2019 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2019).



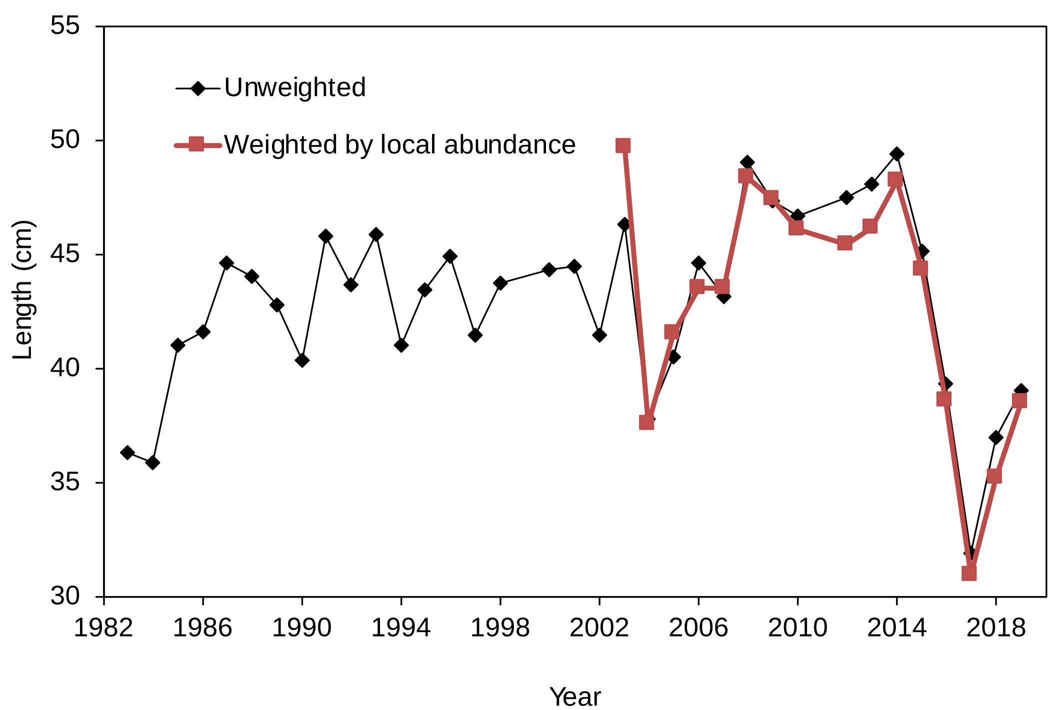


Figure 1.23. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska, 1983-2019.

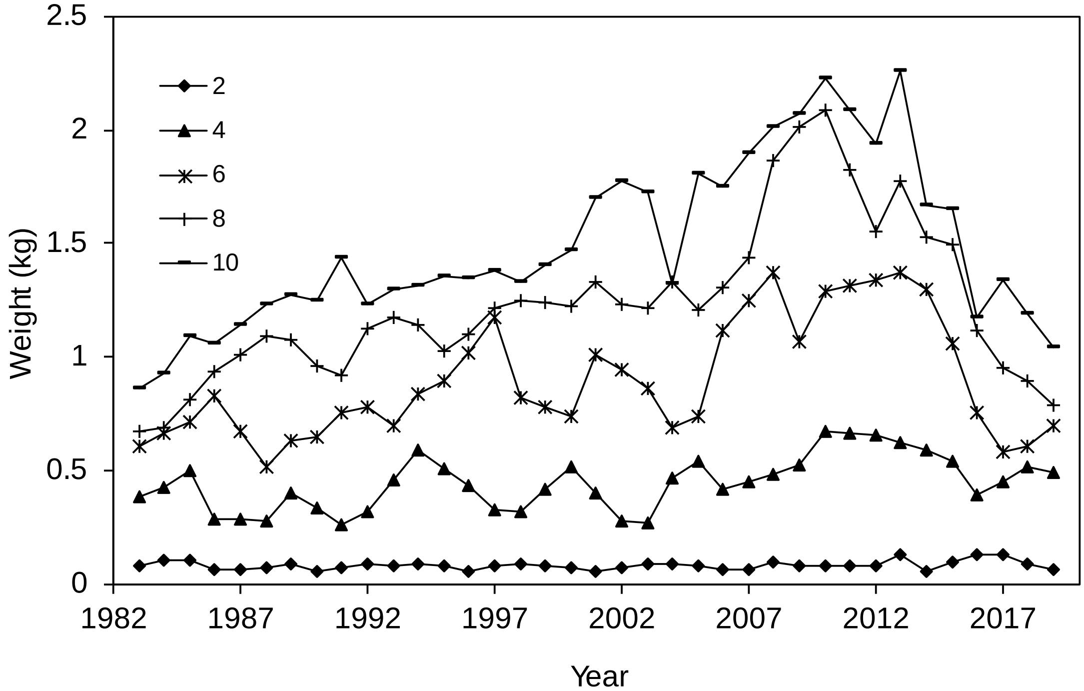
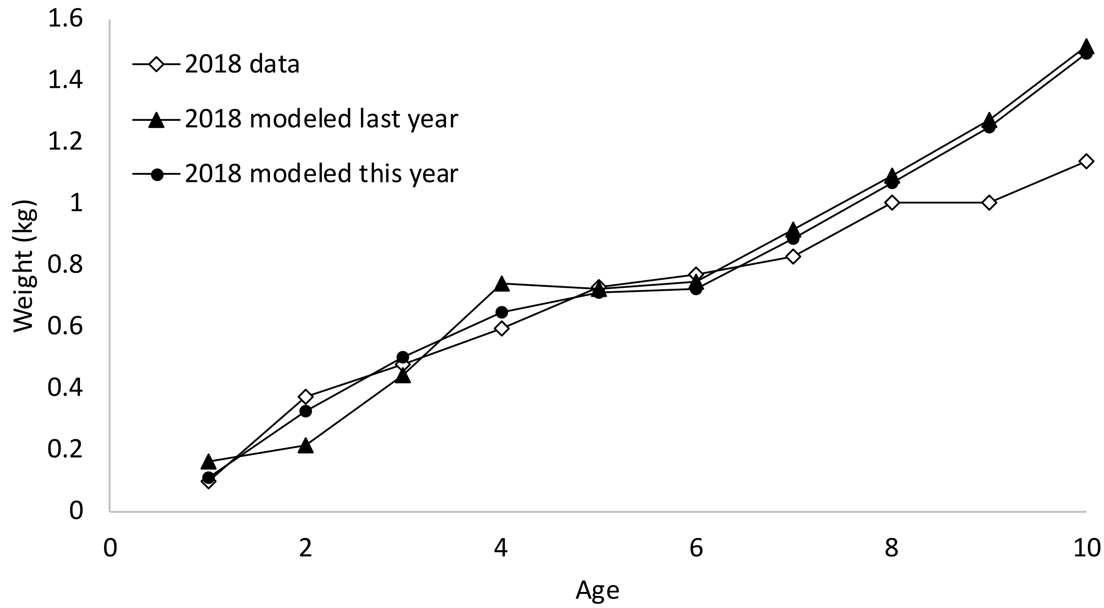


Figure 1.24. Estimated weight at age of GOA pollock (ages 2, 4, 6, and 10) from Shelikof Strait acoustic surveys in 1983-2019 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from surveys in adjacent years.



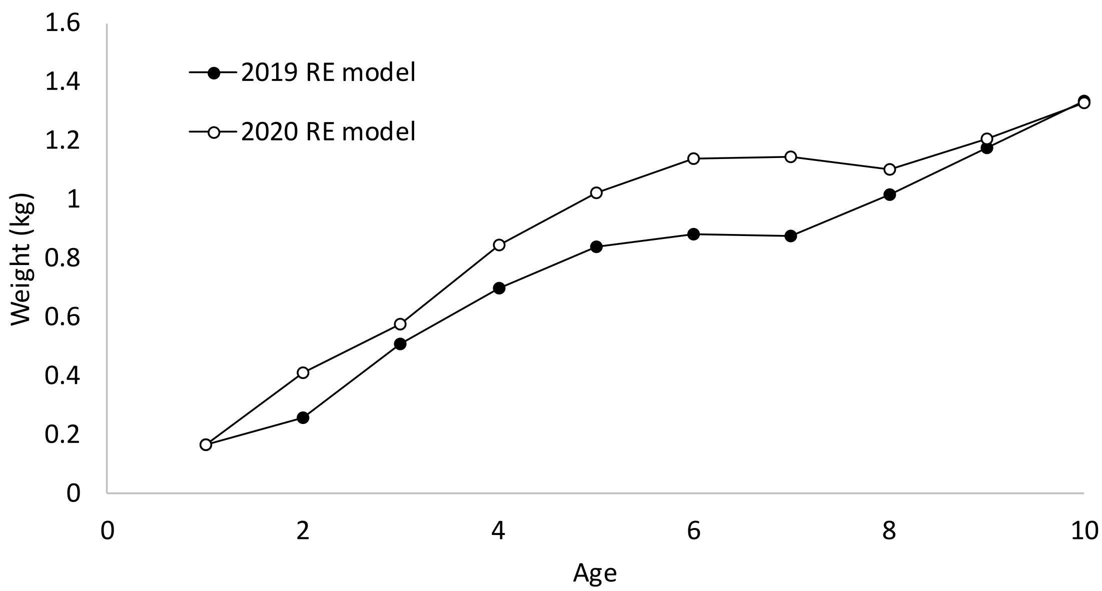
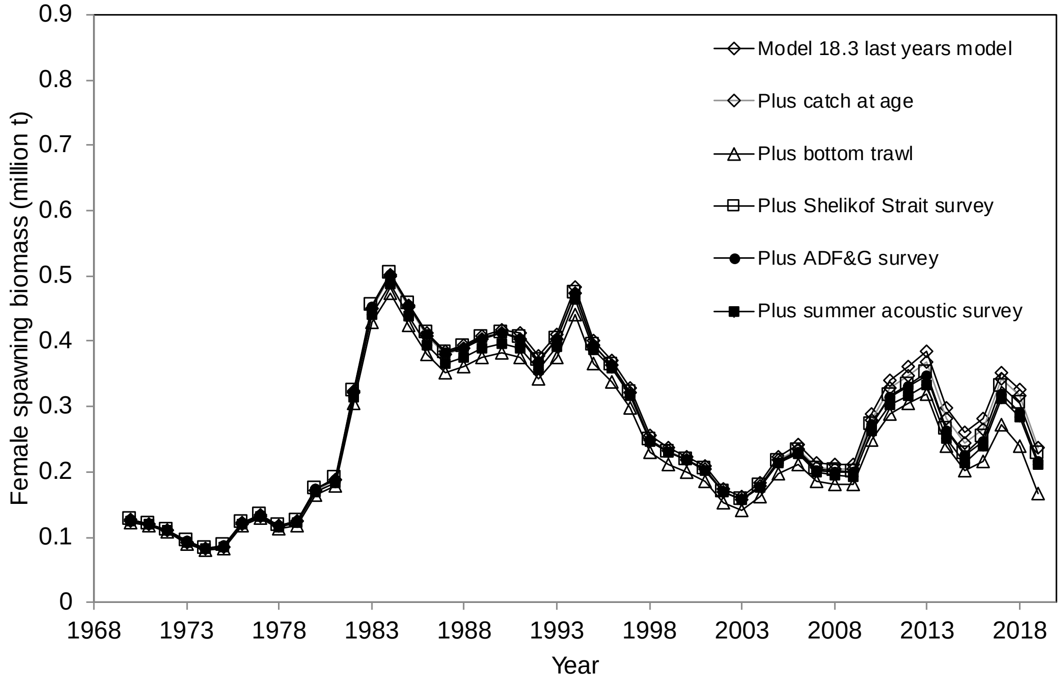


Figure 1.25. Comparison of fishery weight at age for 2018 with estimates from the random effects model last year and this year' assessment (top panel). Random effects model estimates for 2019-2020 used in the assessment model and for yield projections (bottom panel).



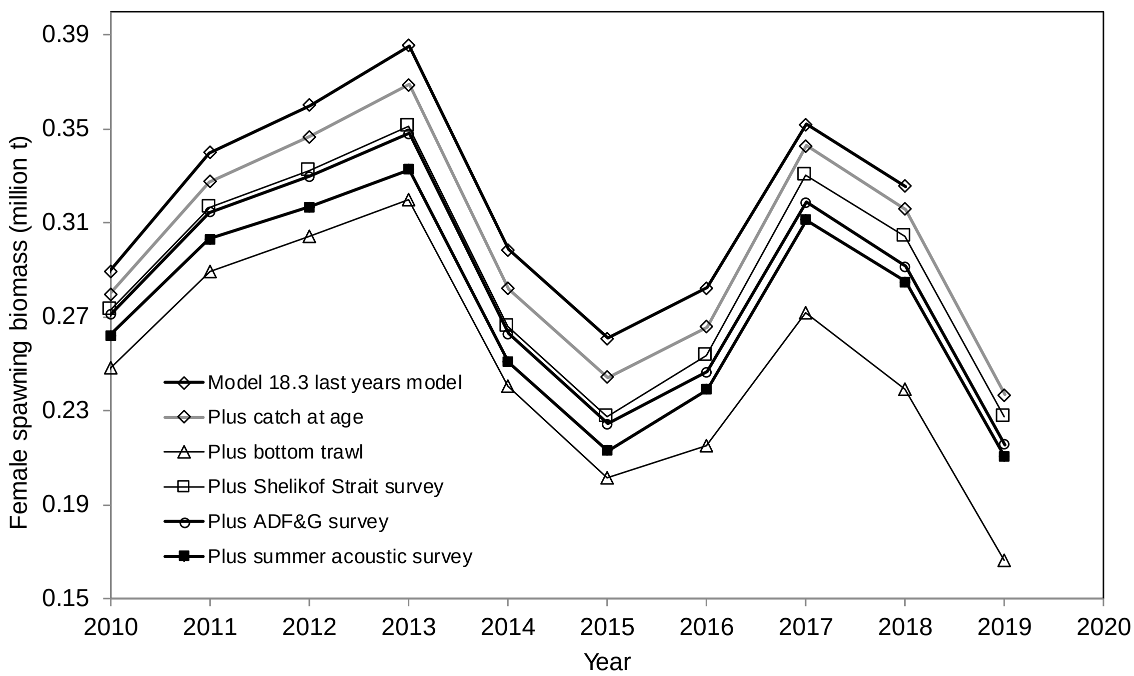


Figure 1.26. Changes in estimated spawning biomass as new data were added successively to last year's base model. The lower panel shows the years 2010-2019 with an expanded scale to highlight differences.

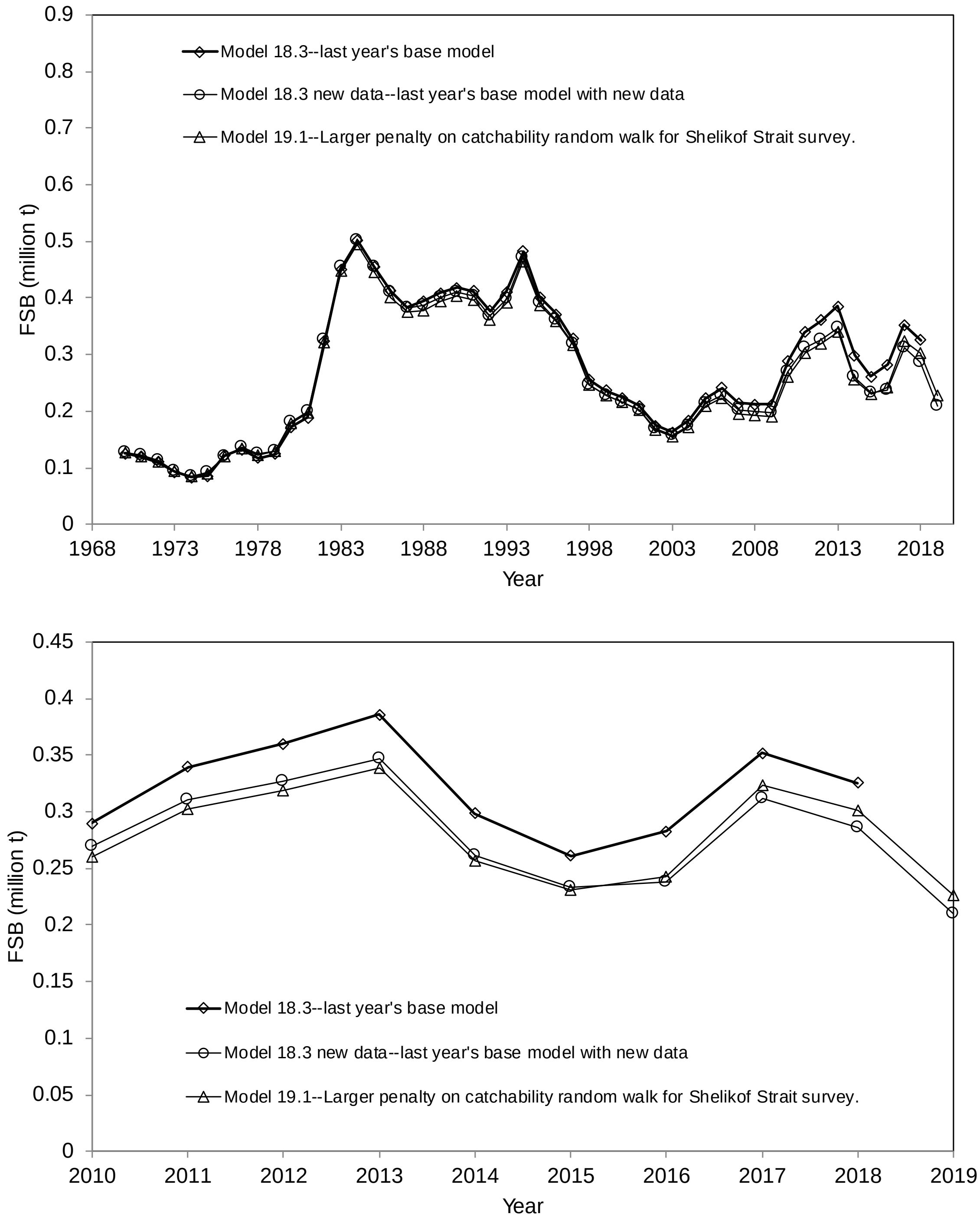


Figure 1.27. Comparison of estimated spawning biomass from alternative models. The lower panel shows the years 2010-2019 with an expanded scale to highlight differences. Model 18.3 was the base model last year. Models are described in more detail in the text.

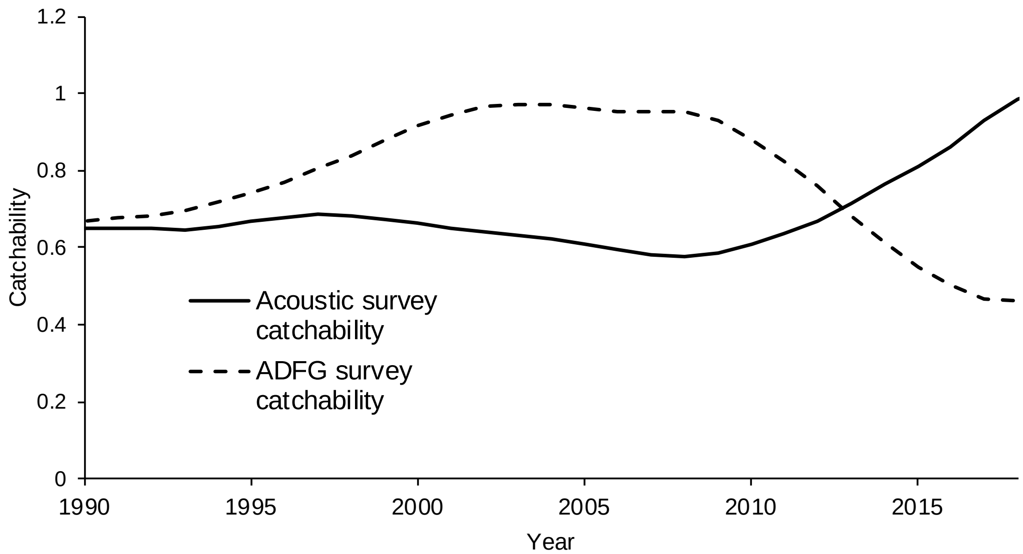


Figure 1.28. Time-varying catchability for the Shelikof Strait acoustic survey and the ADF&G crab/groundfish trawl survey for model 19.1.

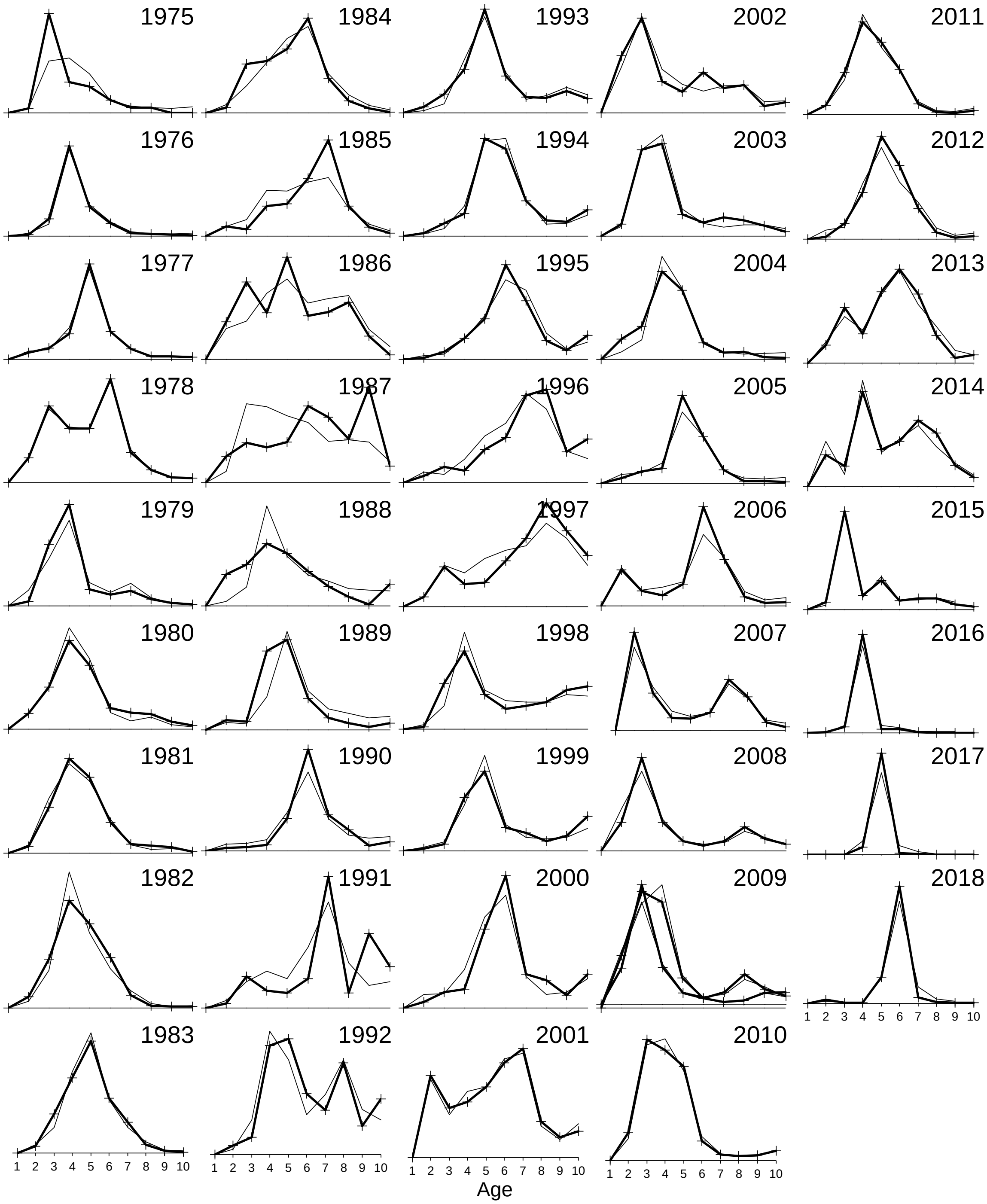


Figure 1.29. Observed and predicted fishery age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

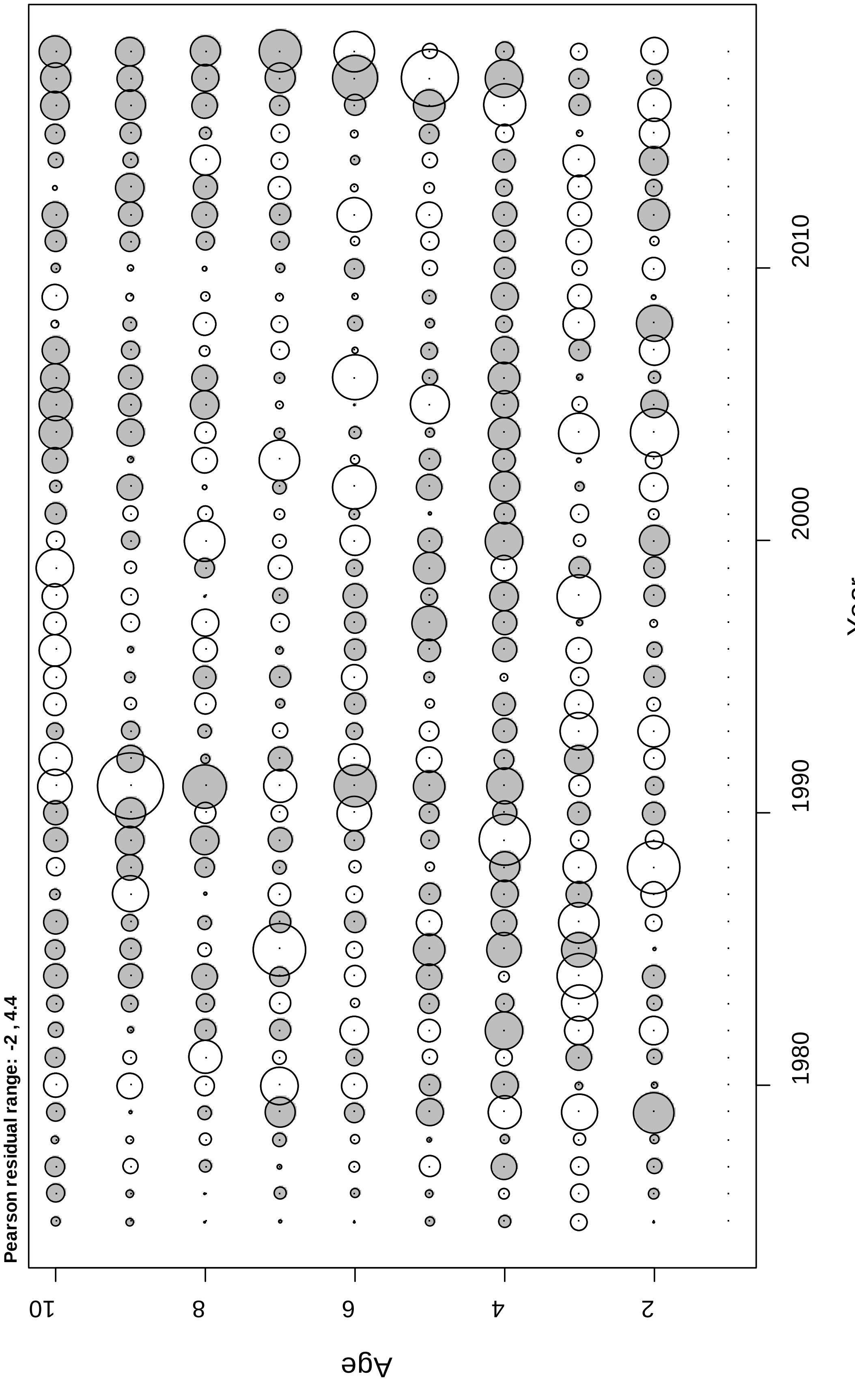


Figure 1.30. Pearson residuals for fishery age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

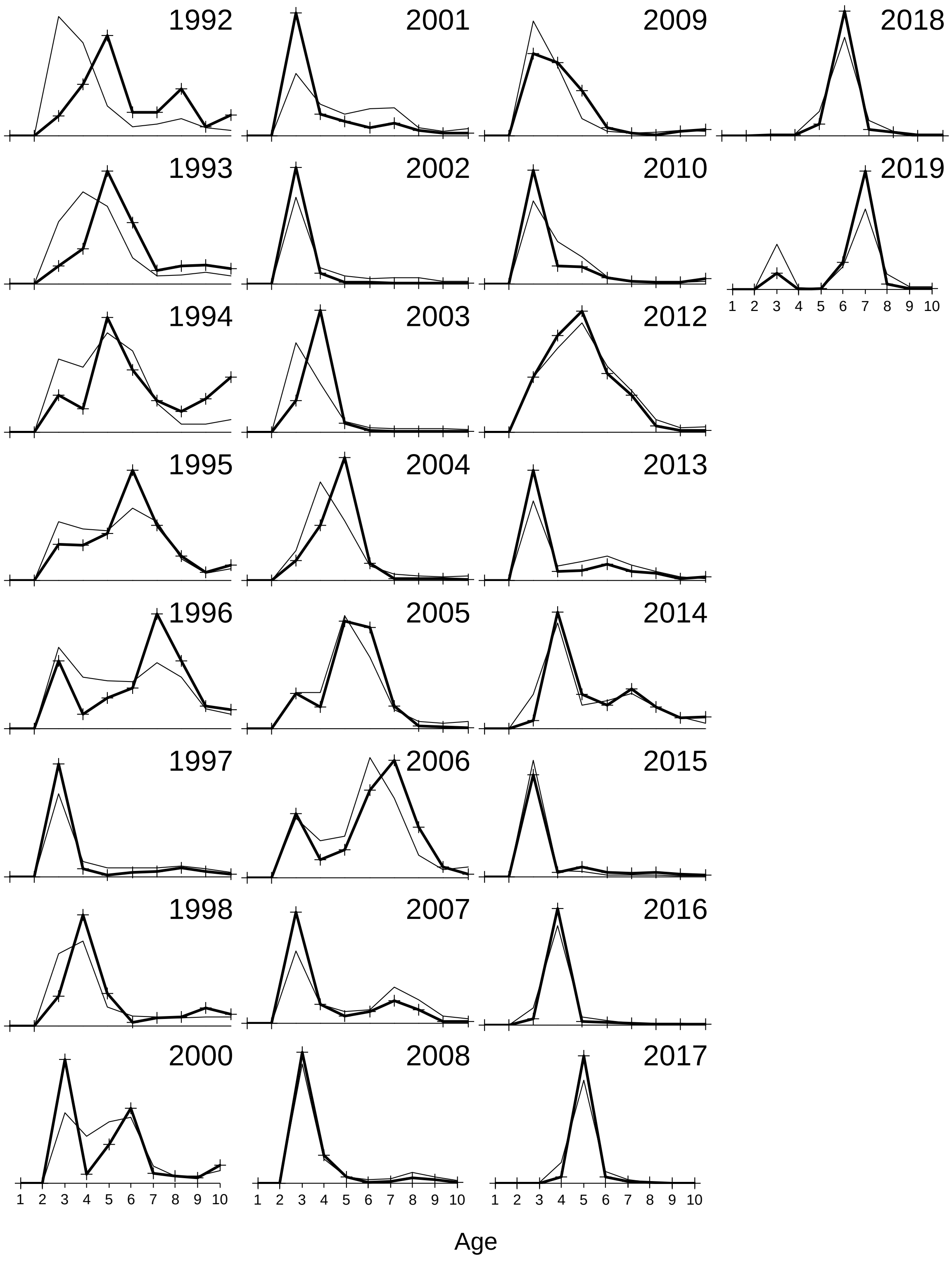


Figure 1.31. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.

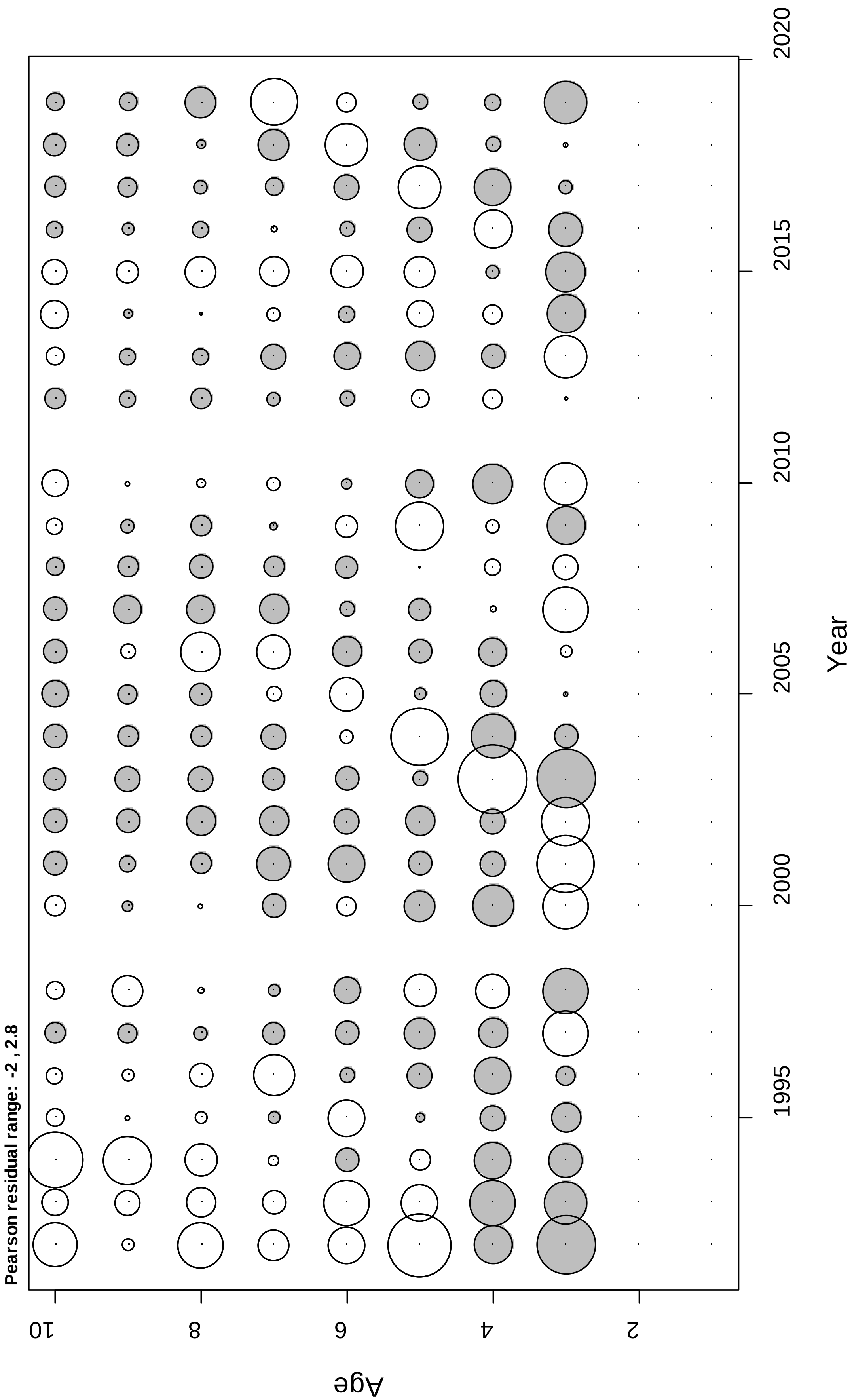


Figure 1.32. Pearson residuals for Shelikof Strait acoustic survey age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

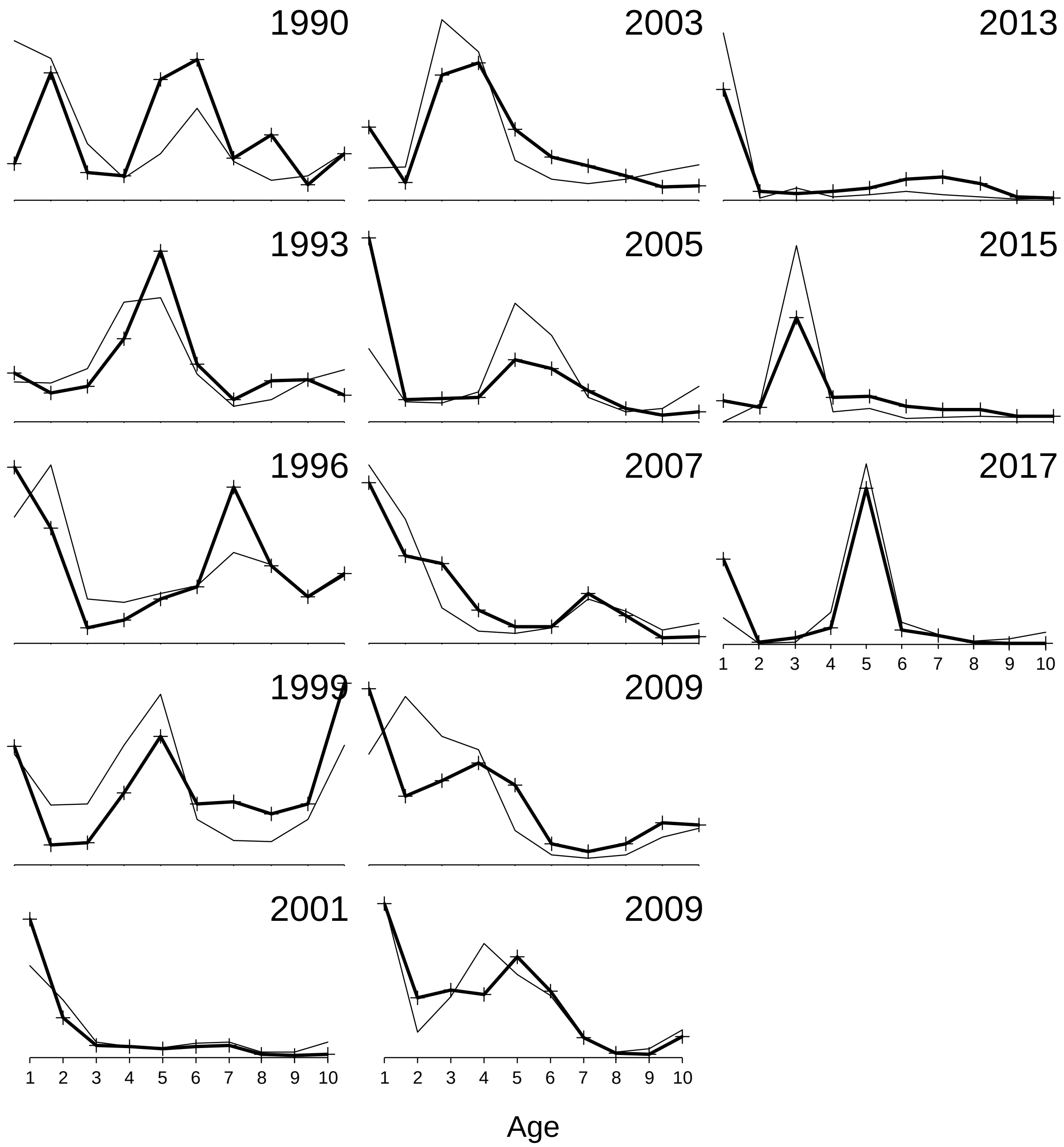
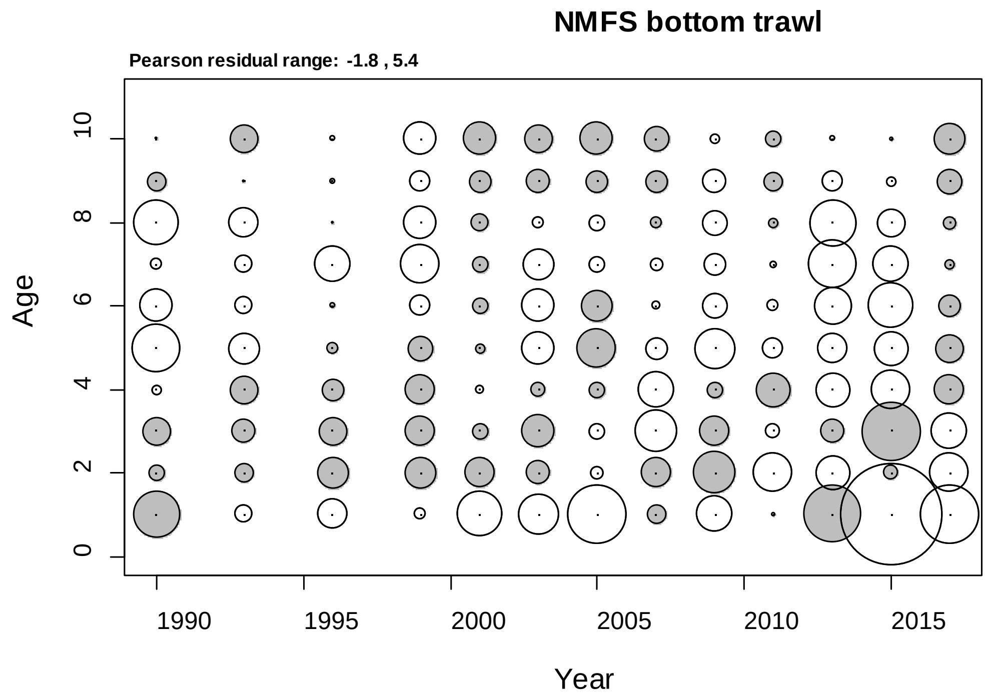


Figure 1.33. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbol are observed proportions at age.



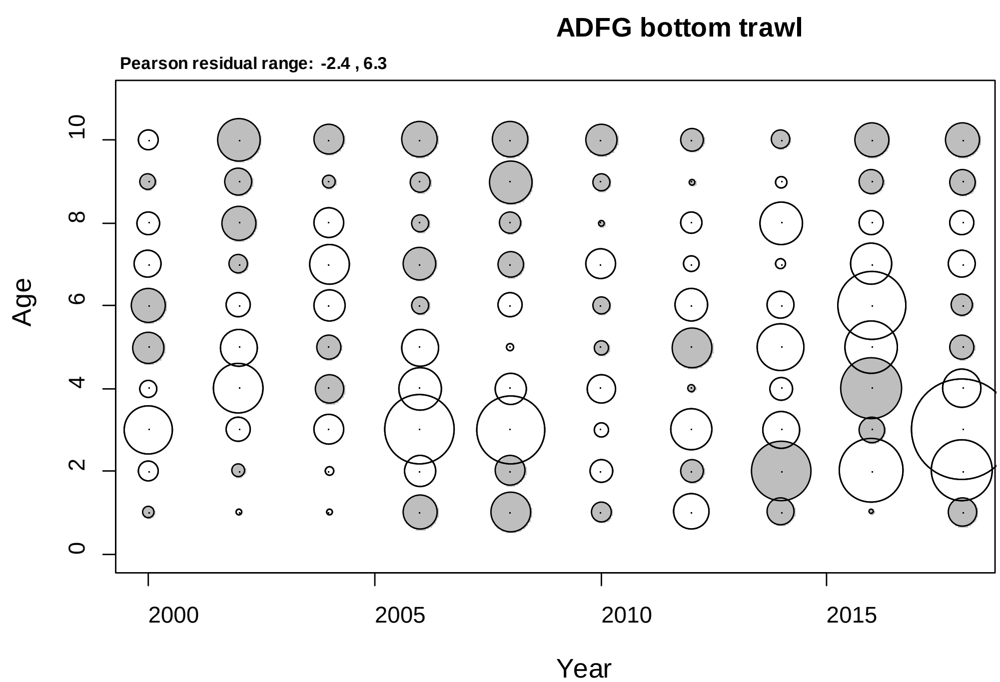


Figure 1.34. Pearson residuals for NMFS bottom trawl survey (top) and ADF&G crab/groundfish survey (bottom) age composition. Negative residuals are filled circles. Area of circle is proportional to magnitude of the residual.

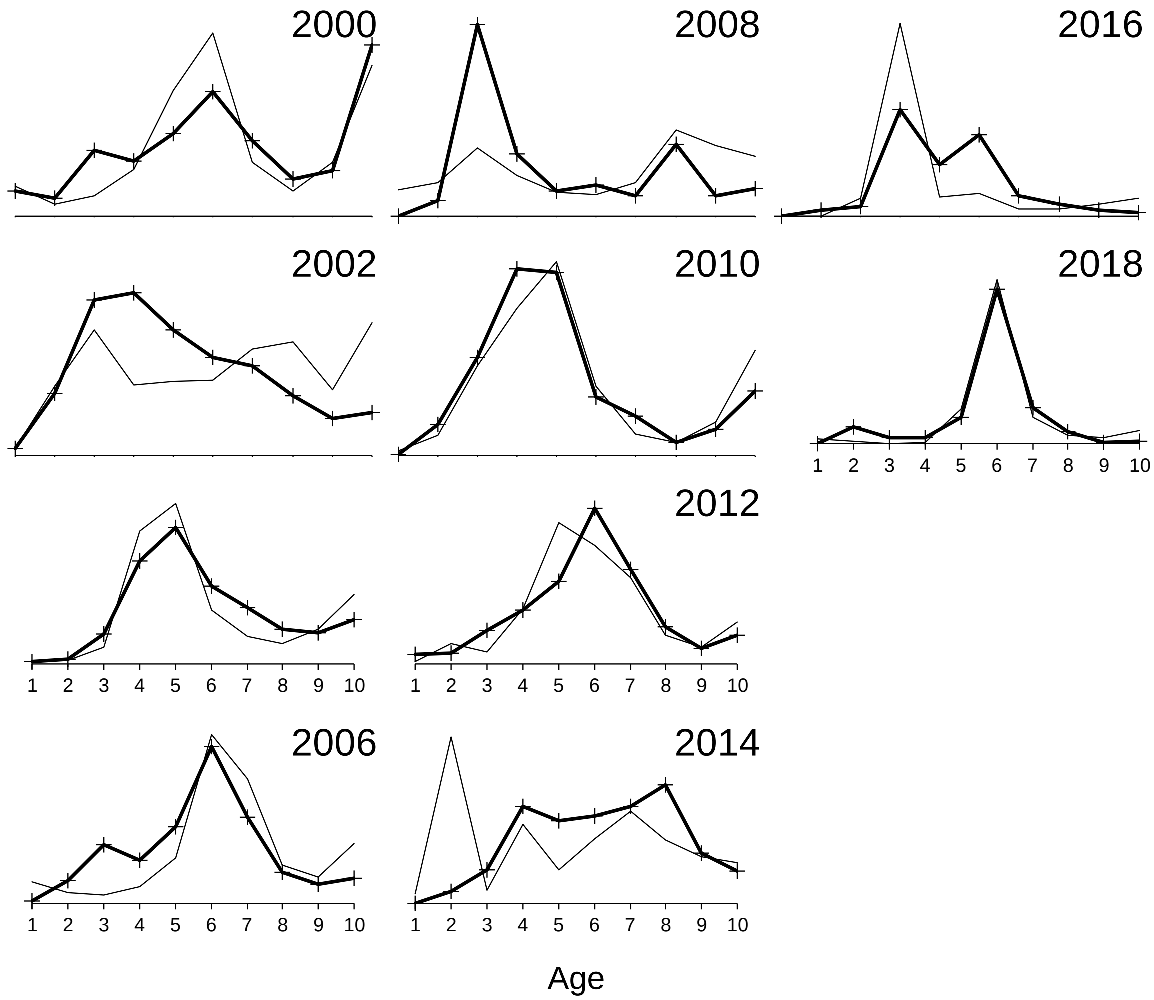


Figure 1.35. Observed and predicted ADF&G crab/groundfish survey age composition for GOA pollock from the base model. Continuous lines are model predictions and lines with + symbols are observed proportions at age.

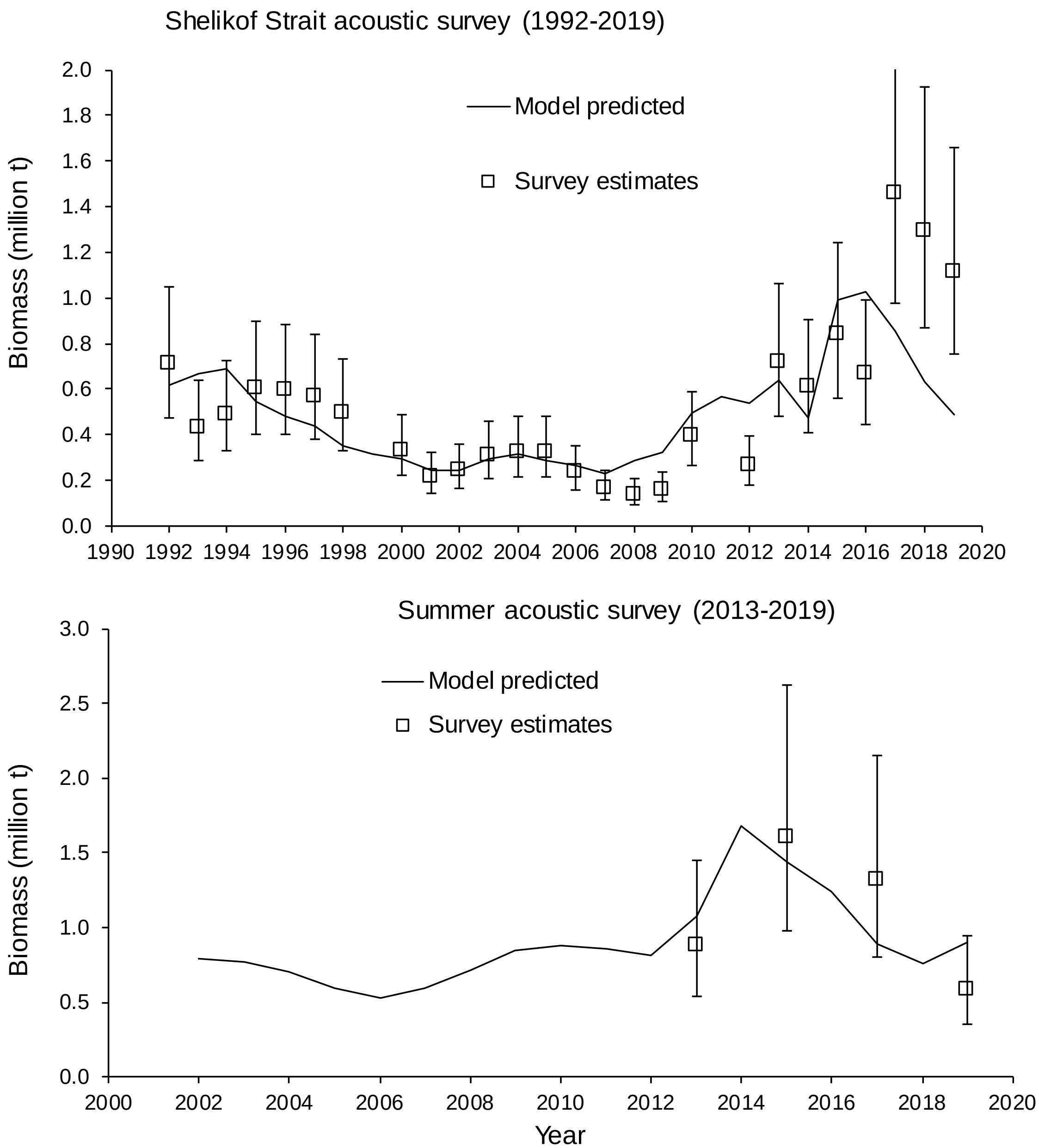


Figure 1.36. Model predicted and observed survey biomass for the Shelikof Strait acoustic survey for the base model (top panel). The bottom panel shows model predicted and observed survey biomass for the summer acoustic survey. Error bars indicate plus and minus two standard deviations.

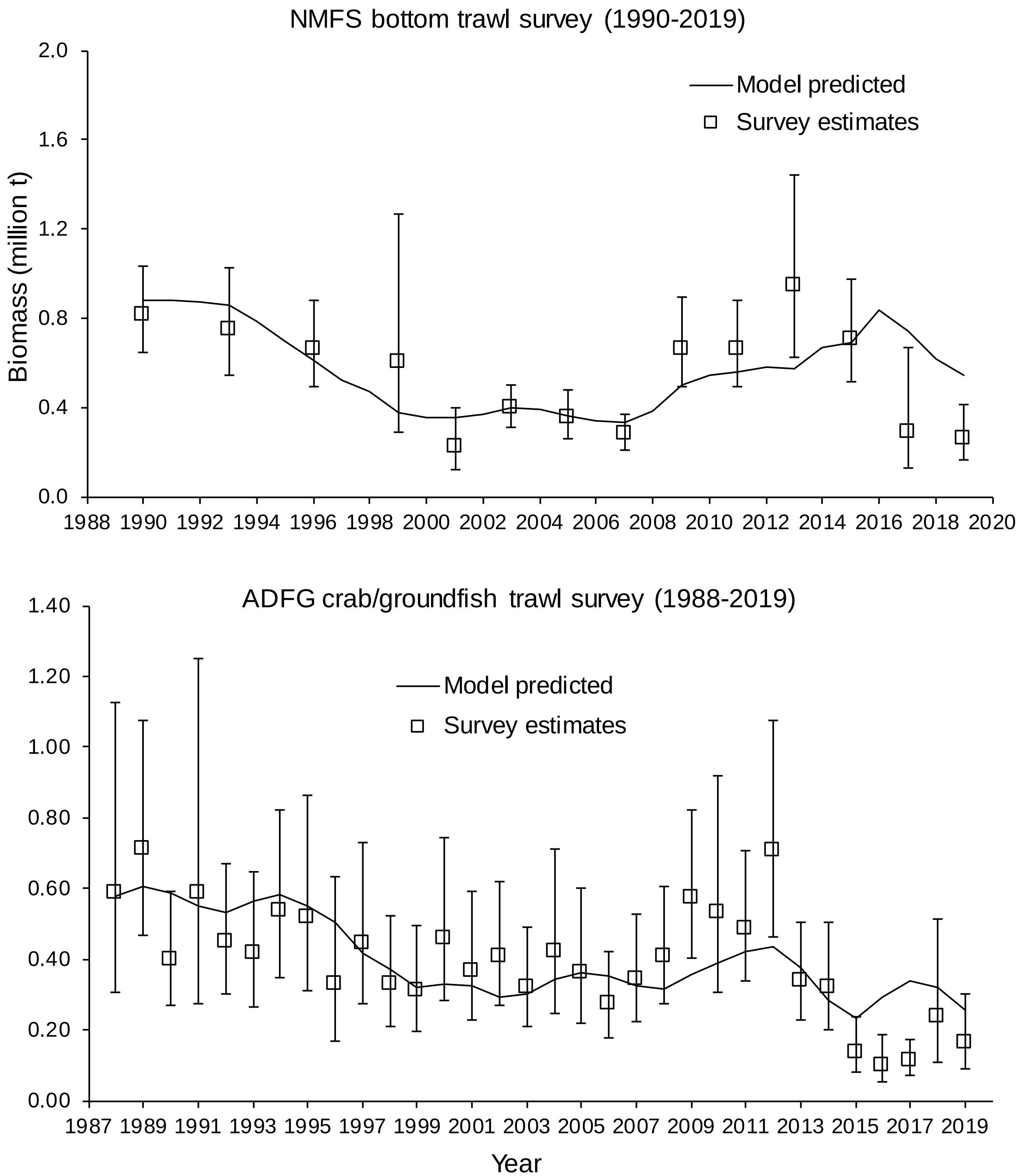


Figure 1.37. Model predicted and observed survey biomass for the NMFS bottom trawl survey (top panel), and the ADF&G crab/groundfish survey (bottom panel) for the base model. Error bars indicate plus and minus two standard deviations.

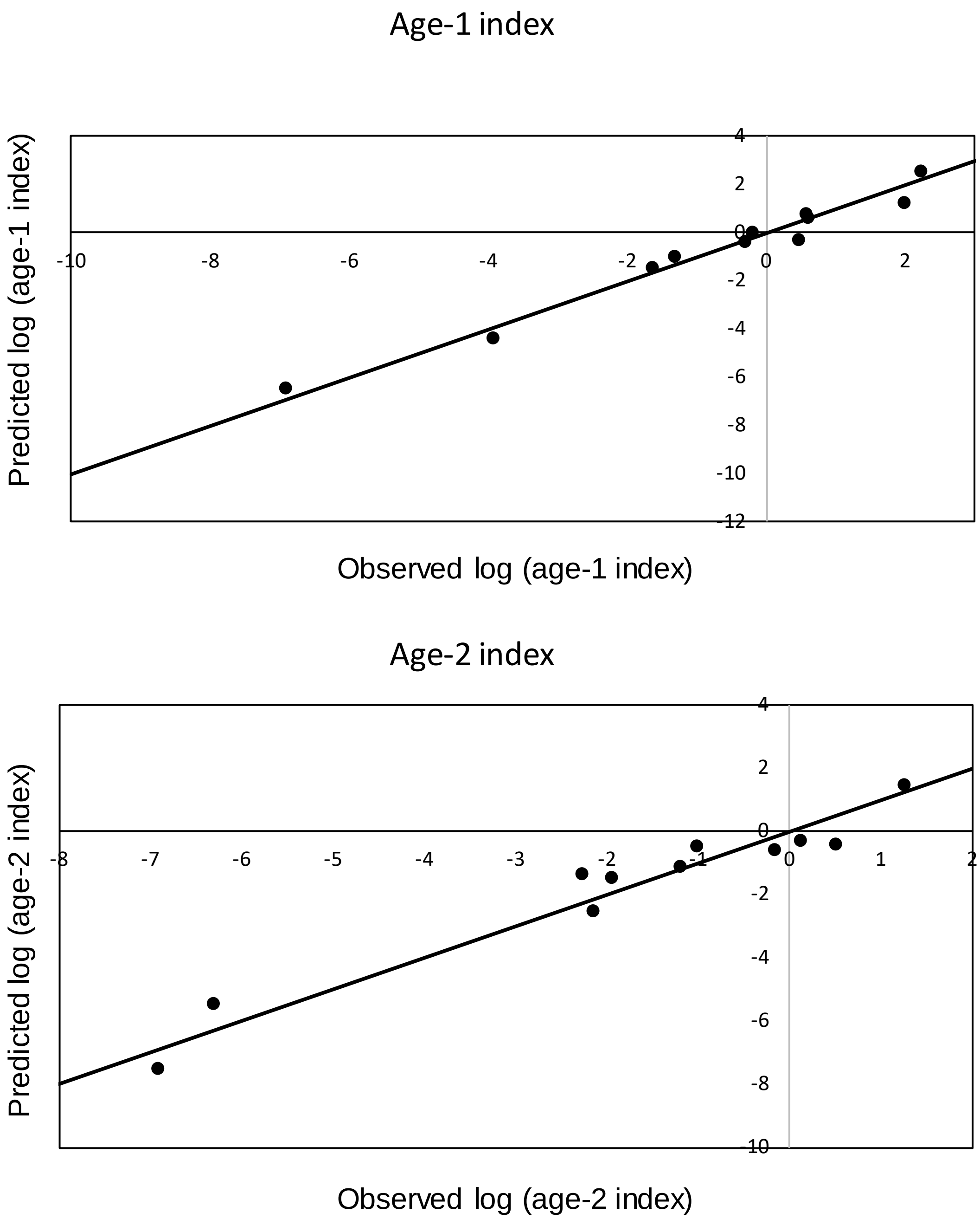


Figure 1.38. Observed and model predicted age-1 (top) and age-2 indices (bottom) for the winter acoustic estimates for Shelikof Strait.

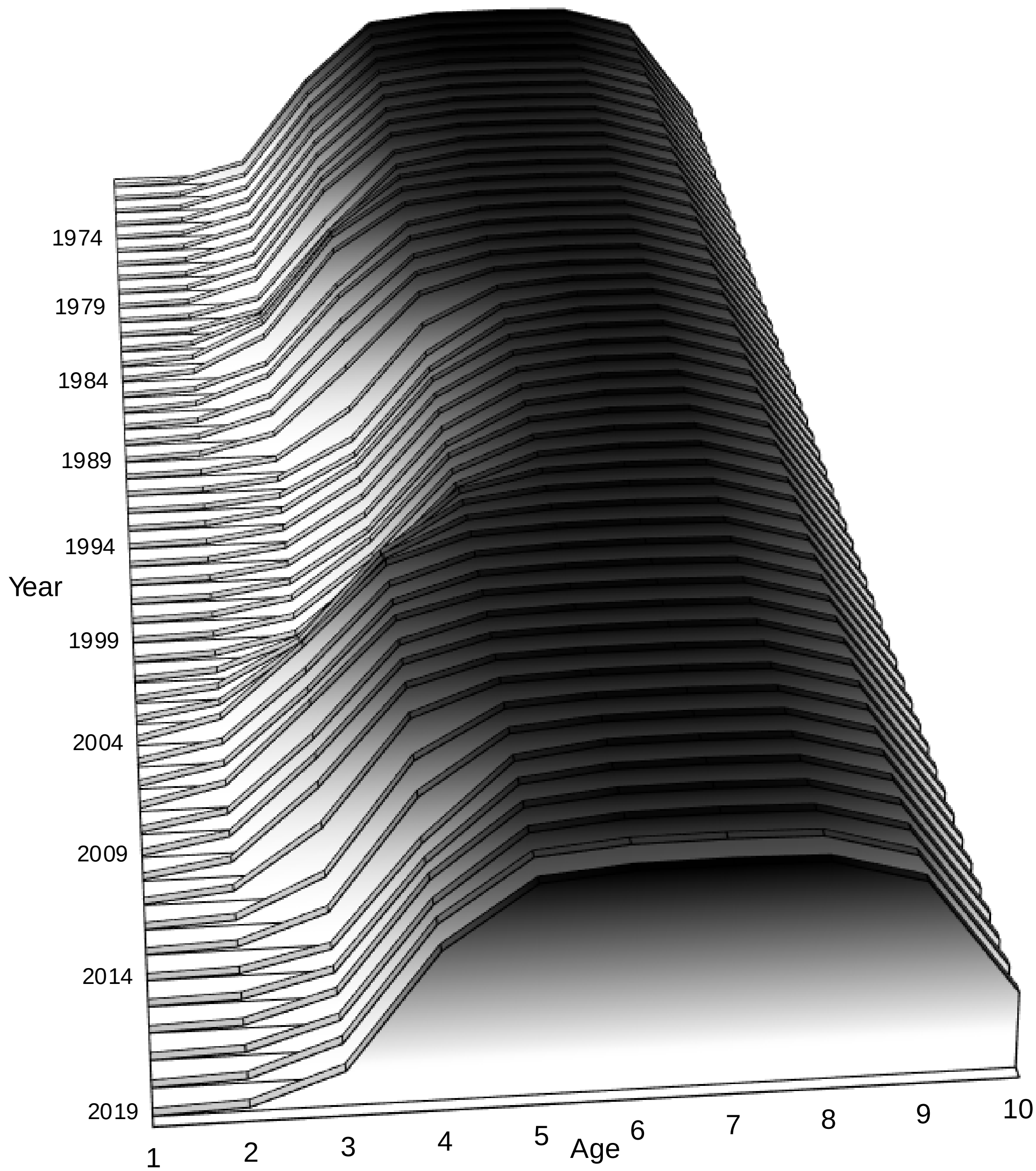
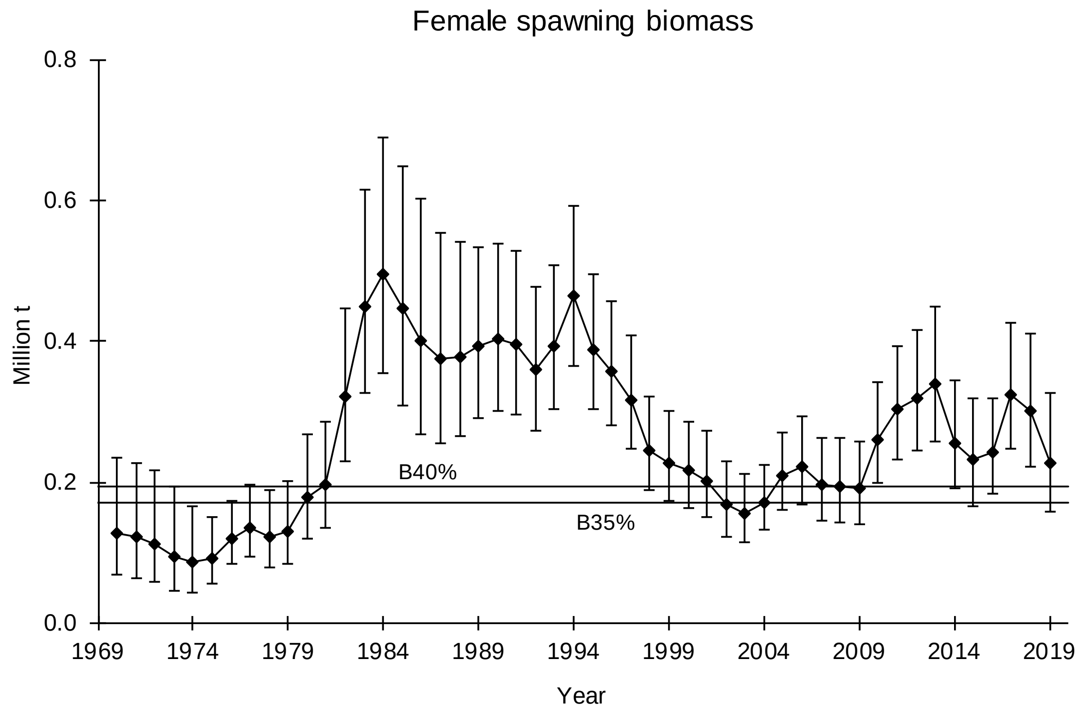


Figure 1.39. Estimates of time-varying fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.



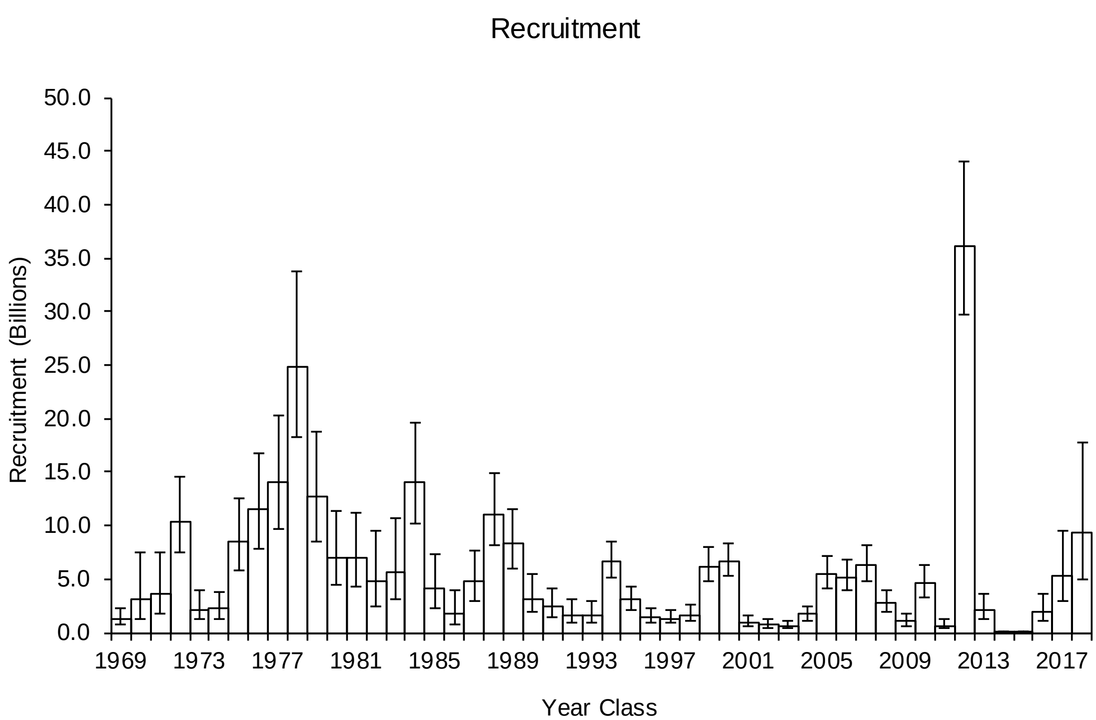
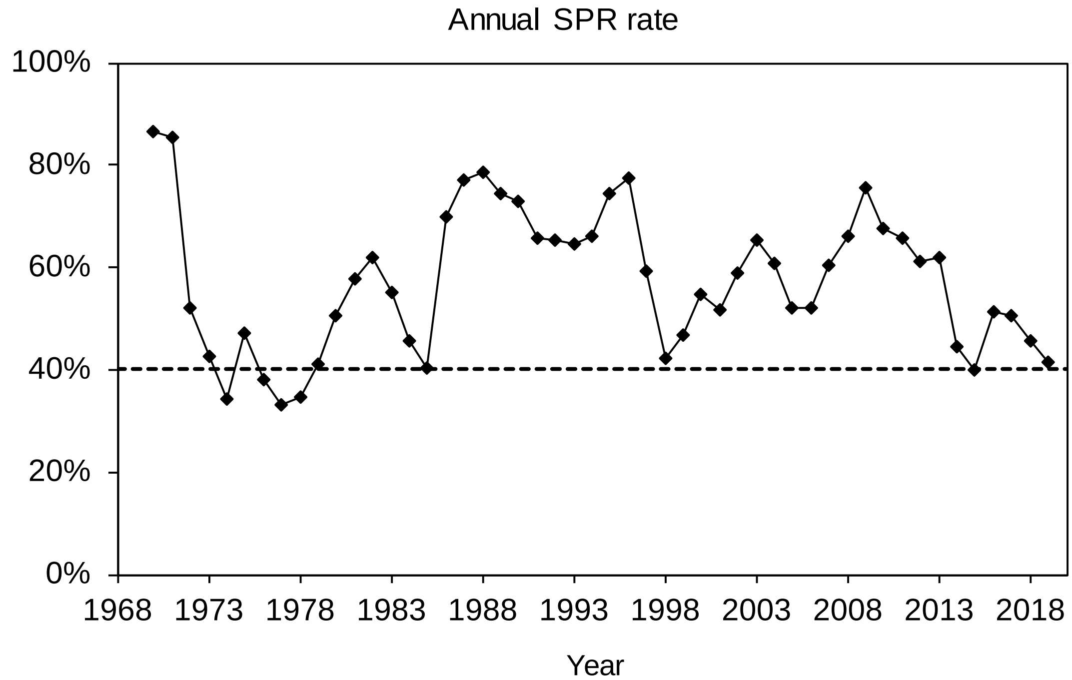


Figure 1.40. Estimated time series of GOA pollock spawning biomass (million t, top) and age-1 recruitment (billions of fish, bottom) from 1970 to 2019 for the base model. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



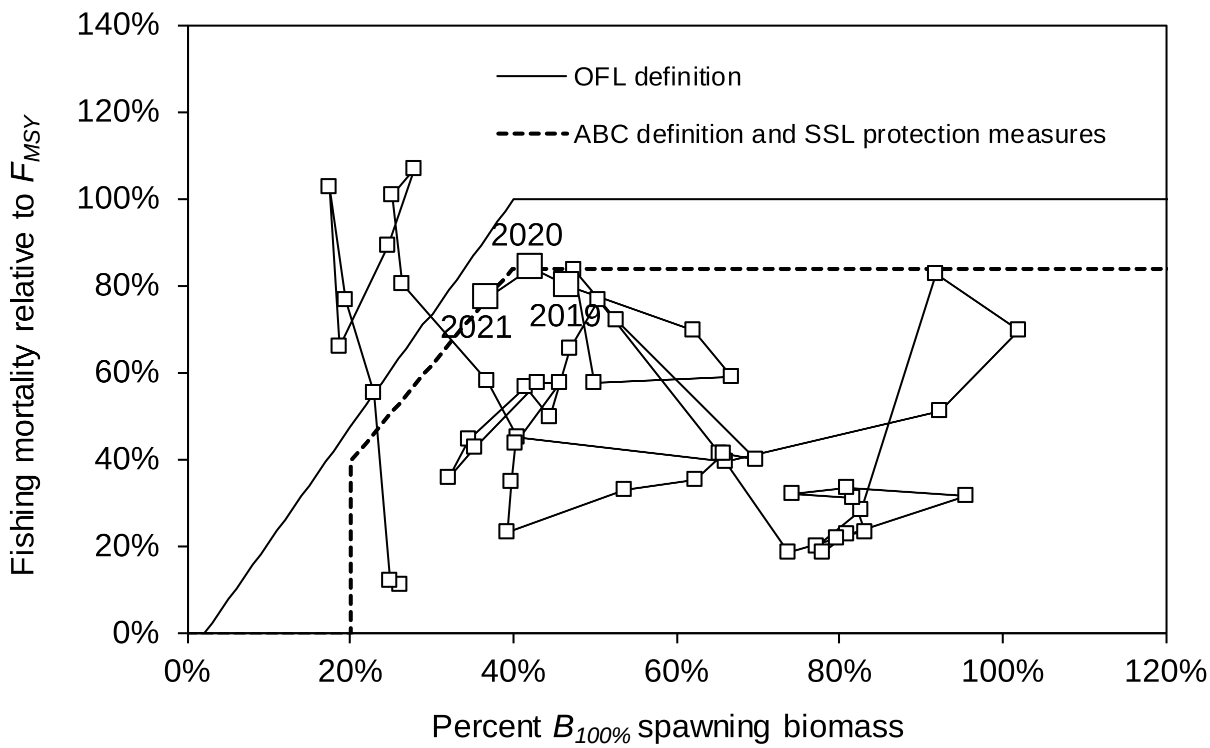
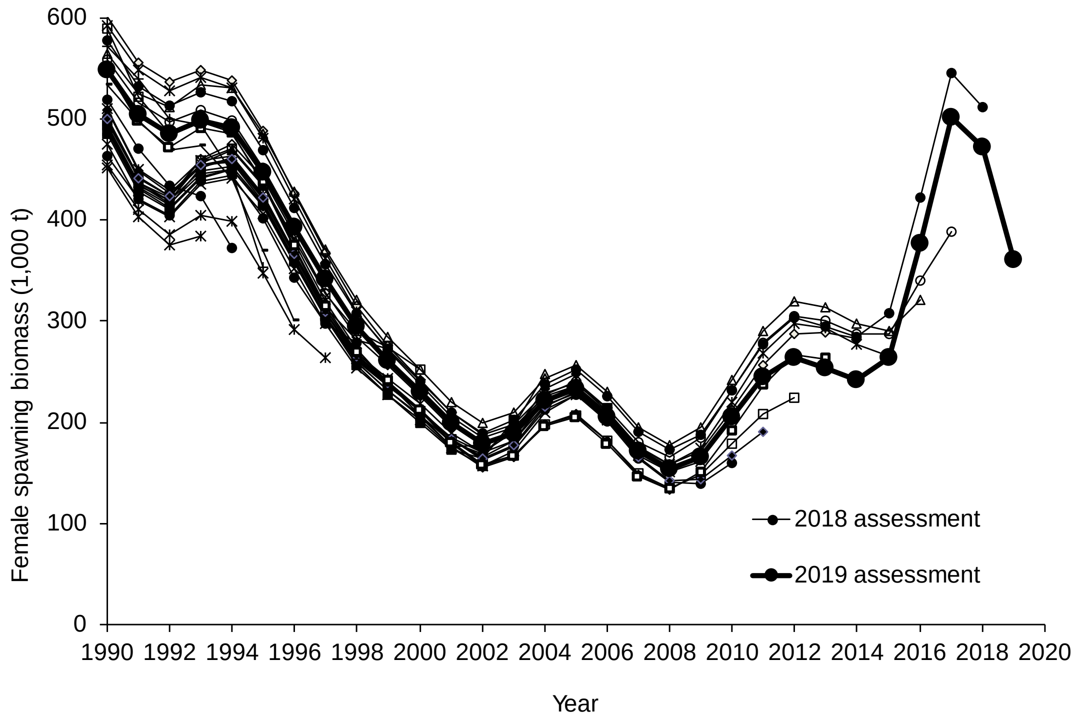


Figure 1.41. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to FMSY (bottom). The ratio of fishing mortality to FMSY is calculated using the estimated selectivity pattern in that year. Estimates of B100% spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.



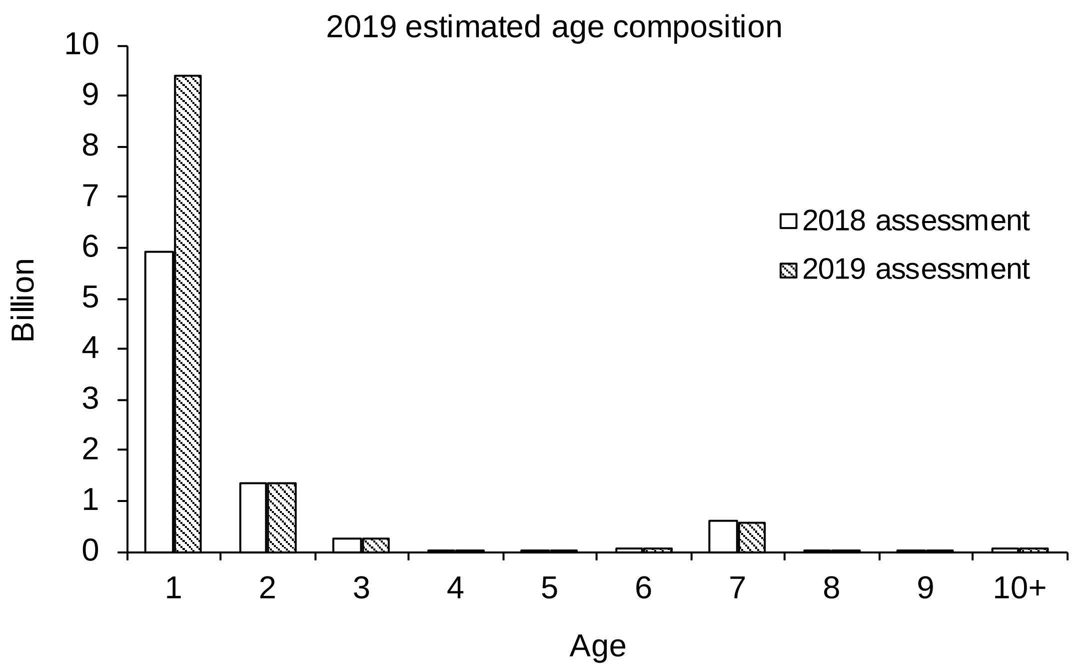


Figure 1.42. Estimated female spawning biomass for historical stock assessments in the years 1993-2019 (top). For this figure, the time series of female spawning biomass was calculated using the same maturity and spawning weight at age for all assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2019 from the 2018 and 2019 assessments.

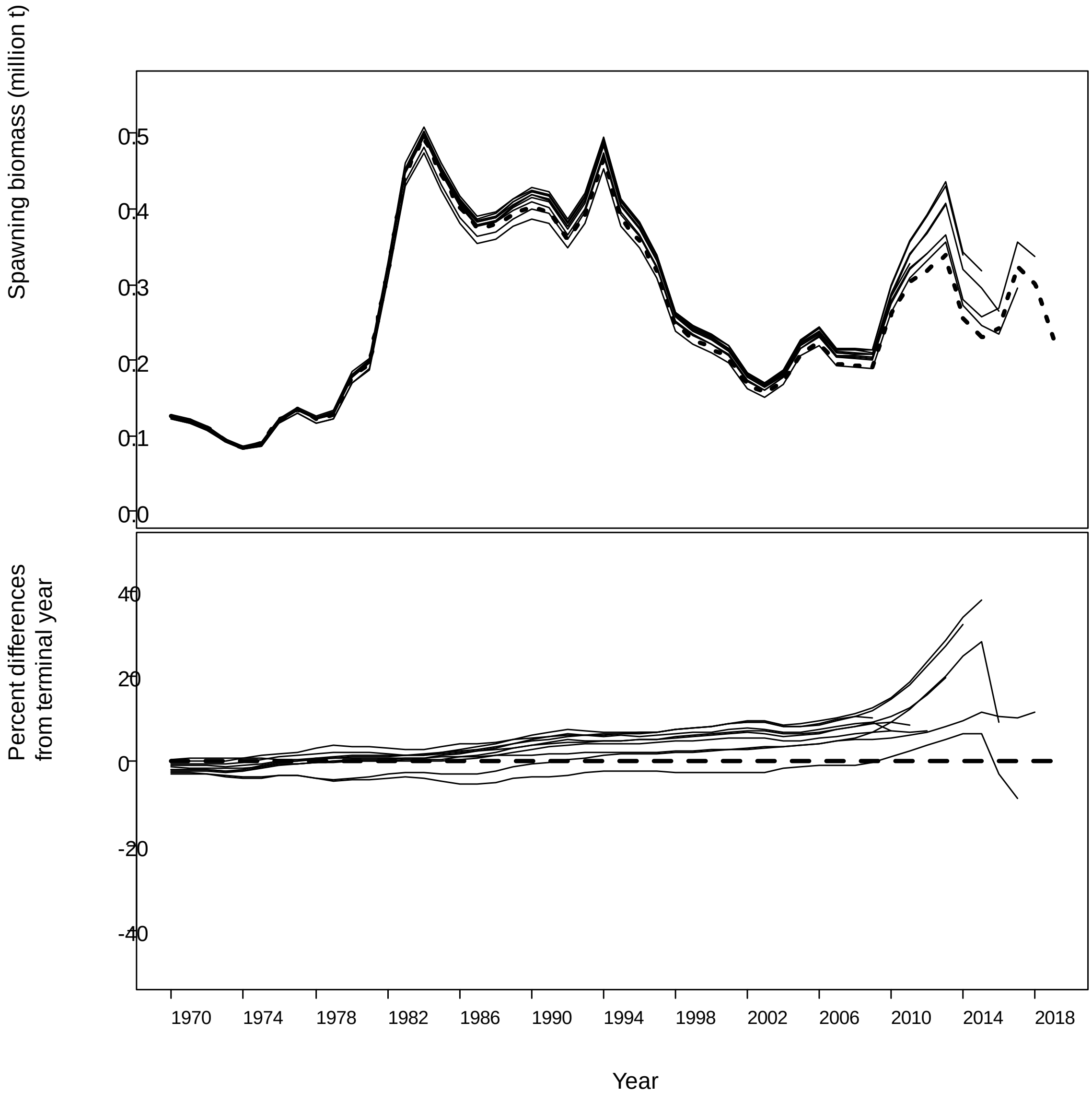


Figure 1.43. Retrospective plot of spawning biomass for models ending in years 2009-2018 for the 2019 base model. The revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.134.

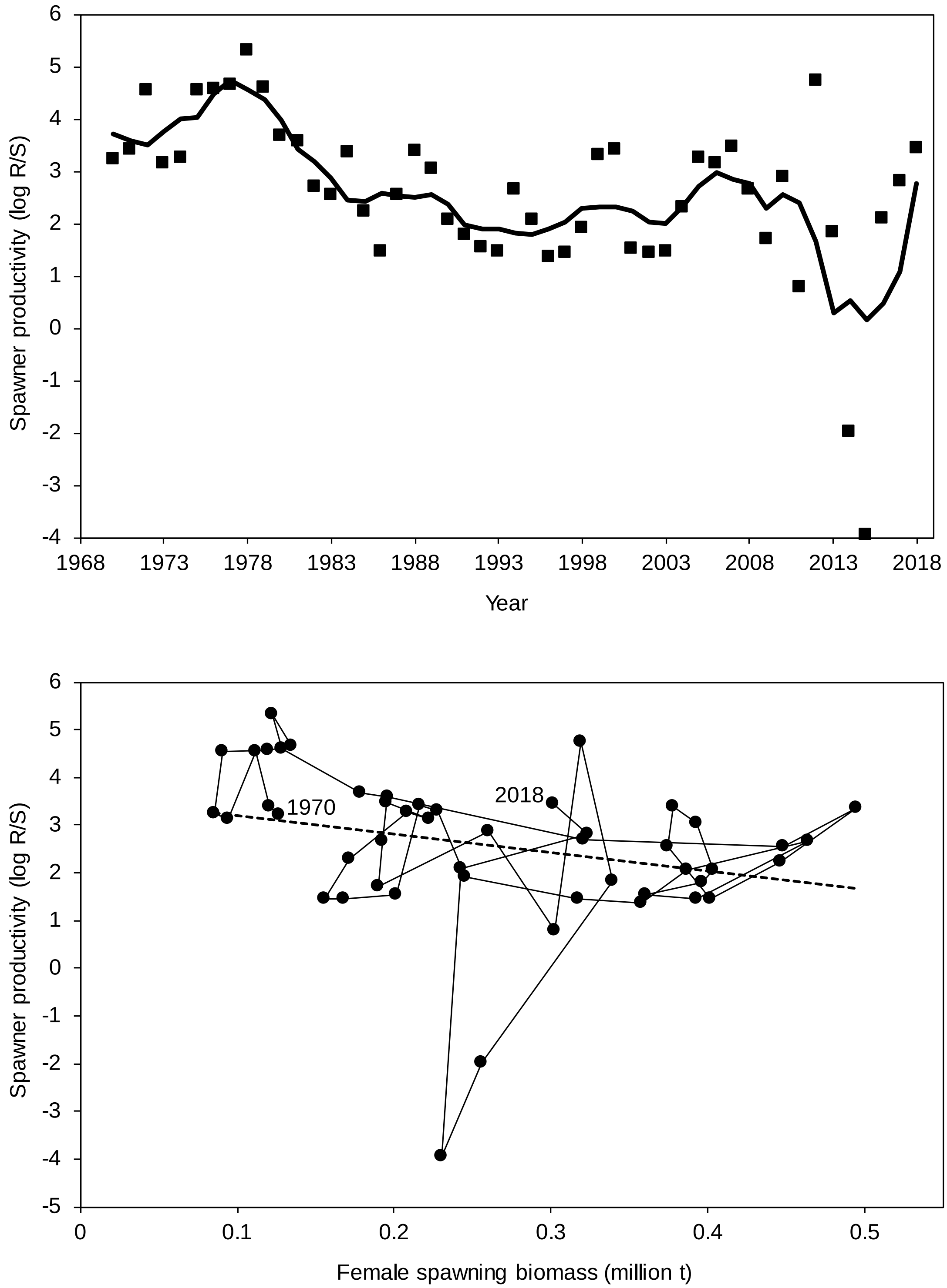


Figure 1.44. GOA pollock spawner productivity, log(R/S), in 1970-2018 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

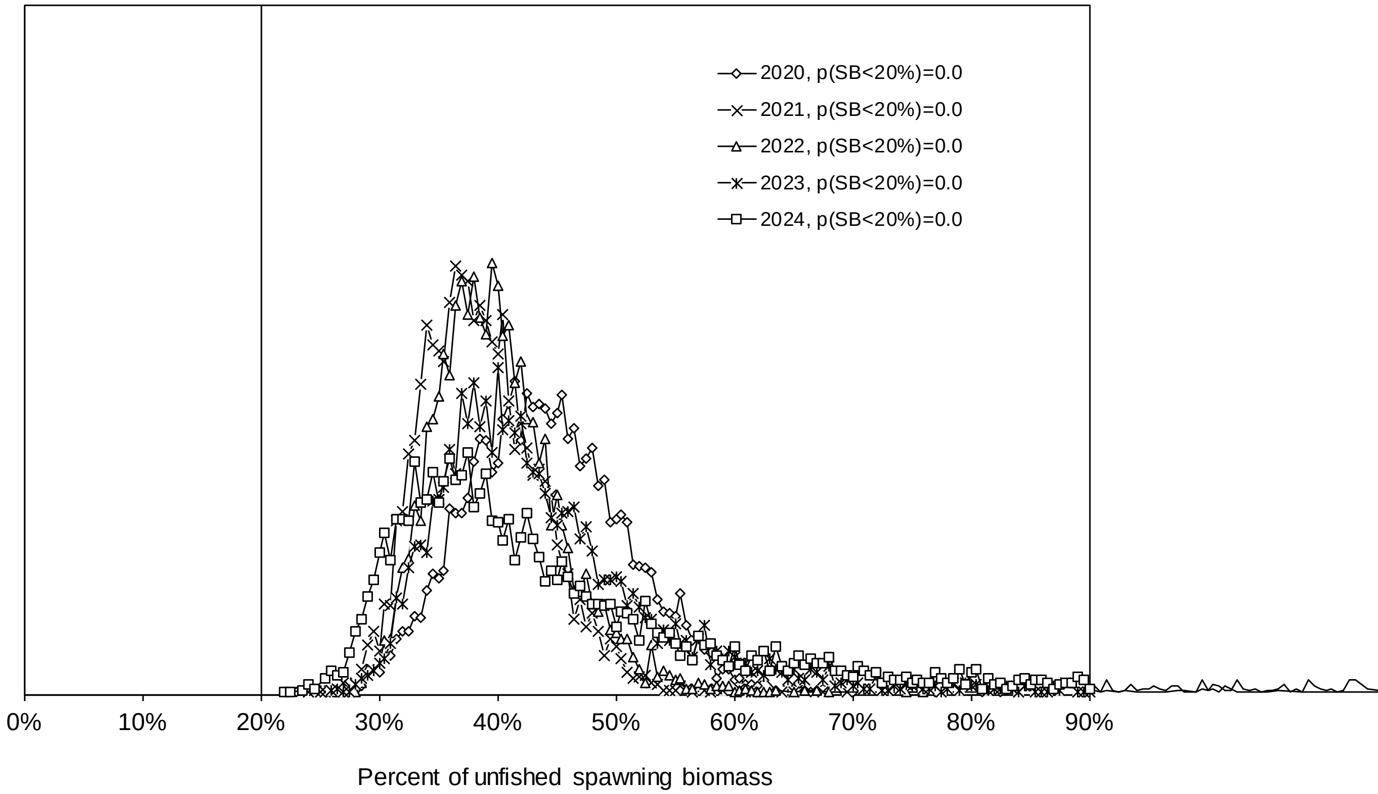


Figure 1.45. Uncertainty in spawning biomass in 2020-2024 based on a thinned MCMC chain from the joint marginal likelihood for the base model where catch is set to the maximum permissible F_{ABC}.

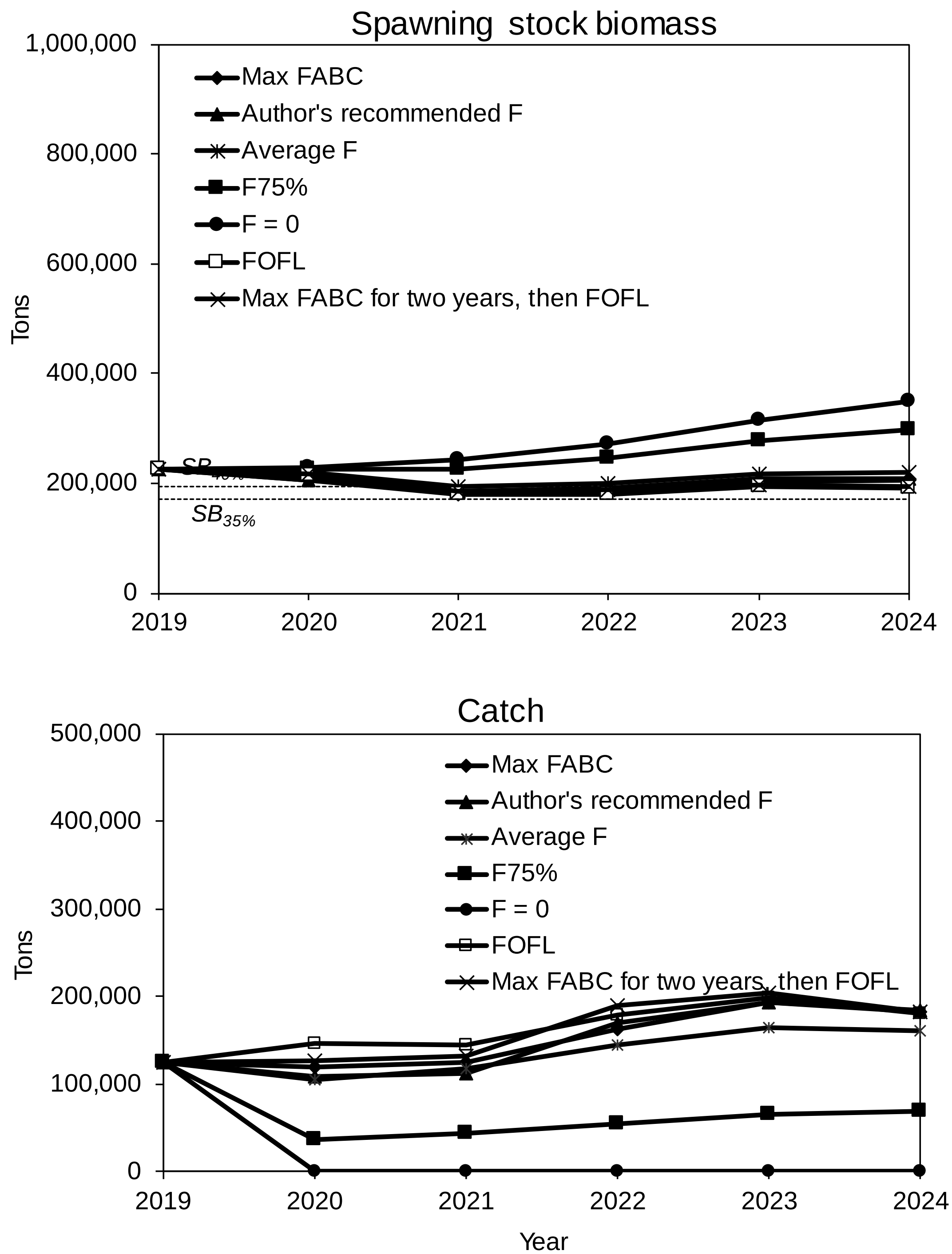


Figure 1.46. Projected mean spawning biomass and catches in 2019-2024 under different harvest rates.

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 2019

With Contributions from:

Grant Adams, Mayumi Arimitsu, Kerim Aydin, Steve Barbeaux, Lewis Barnett, Curry Cunningham, Dana Hanselman, Kirstin Holsman, David Kimmel, Ben Laurel, Jodi Pirtle, Patrick Ressler, Dale Robinson, Rob Suryan, James Thorson, Johanna Vollenweider, Cara Wilson, Sarah Wise

Executive Summary

National initiative scoring and AFSC research priorities suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Gulf of Alaska (GOA) walleye pollock. Annual guidelines for the AFSC support research that improves our understanding of environmental and climate forcing of ecosystem processes with a focus on variables that can provide direct input into or improve stock assessment and management. The GOA pollock ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for GOA pollock and may be considered a proving ground for potential use in the main stock assessment.

We use information from a variety of data streams available for the GOA pollock stock and present results of applying the ESP process through a metric and subsequent indicator assessment. 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.

Ecosystem Considerations

- An ontogenetic habitat shift occurs between the early juvenile and late juvenile stages with progression from WGOA hotspot areas to a fairly wide distribution along the continental shelf.
- Batch spawning may mitigate vulnerability in terms of synchrony with optimal levels of larval prey, but spawn timing and duration are impacted by both spawner age structure and temperature.
- 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.
- Physical indicators for 2019 show a return to “heat wave” conditions with high temperatures from surface to bottom and low primary production in western/central GOA.
- Spring and summer zooplankton and summer euphausiid prey base has returned to average conditions in 2019, suggesting improved prey conditions than in previous years.
- Early indicators of 2019 year-class strength suggest a weak year class, following average to moderately large year-classes in 2017 and 2018.
- Body condition of adult pollock has been below average since 2015 when the 2012 year-class entered the survey and fishery but improved slightly in the 2019 winter survey.
- 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.

Socioeconomic Considerations

- Fishery CPUE indicators have been above average since 2016, which is consistent with high stock levels in recent 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.
- The percent of revenue in Kodiak from GOA pollock reached a high in 2018, which along with other data could suggest a level of reliance on the GOA pollock fishery by Kodiak residents.

Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating with the stock assessment. A consistent approach has been lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. A new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process (Shotwell et al., *In Review*). The ESP uses data collected from a variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Sigler et al., 2017; Dorn et al., 2018; Lynch et al., 2018) and recommended by the North Pacific Fishery Management Council's (NPFMC) Groundfish and Crab Plan Teams and the Scientific and Statistical Committee (SSC).

This ESP for Gulf of Alaska (GOA) walleye pollock (*Gadus chalcogrammus*, hereafter referred to as pollock) follows a template for ESPs (Shotwell et al., *In Review*) and replaces the previous ecosystem considerations section in the main pollock stock assessment. Information from the original ecosystem considerations section may be found in Dorn et al. (2018).

The ESP process consists of the following four steps:

1.) Evaluate national initiative and stock assessment classification scores (Lynch et al., 2018) along with regional research priorities to assess the priority and goals for conducting an ESP.
2.) Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.
3.) Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.
4.) Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

Justification

The national initiative prioritization scores for GOA pollock are overall high due to the high commercial importance of this stock and differential growth rates of pollock larvae and juveniles in different habitat in the GOA (Hollowed et al., 2016, McConnaughey et al., 2017). The vulnerability scores were in the moderate range of all groundfish scores based on productivity and susceptibility (Ormseth and Spencer, 2011), and in the low range for sensitivity to future climate exposure (Spencer et al., 2019). The new data classification scores (Lynch et al., 2018) for western/central GOA pollock suggest a data-rich stock with high quality data over the categories of catch, size/age composition, abundance, and life history and a priority for improving the use of ecosystem linkages in the stock assessment. These initiative scores and data classification levels suggest a high priority for conducting an ESP for the western/central portion of the GOA pollock stock, particularly given the high level of current life history data and the high potential for exploring ecosystem linkages. GOA pollock interact strongly with other ecosystem components and incorporating those interactions is likely to be important to stock dynamics, model configuration, and management decisions.

Data

Initial information on GOA pollock was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 2016. These include (but were not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment classification. Data from an earlier productivity susceptibility analysis conducted for all groundfish stocks in Alaska were also included (Ormseth and Spencer, 2011). Data derived from this effort serve as the initial starting point for developing the ESP metrics for stocks in the BSAI and GOA groundfish fishery management plans (FMP). Please see Shotwell et al., *In Review*, for more details.

Supplementary data were also collected from the literature and a variety of process studies, surveys, laboratory analyses, accounting systems, and regional reports (Appendix Table 1A.1). Information for the first year of life was derived from ecosystem surveys and laboratory analyses run by multiple programs and divisions at the AFSC (e.g., Ecosystems and Fisheries Oceanography Coordinated Investigations (EcoFOCI), Recruitment Processes Alliance (RPA), Fisheries Behavioral Ecology (FBE) program, Resource Assessment and Conservation Engineering (RACE) Division, Resource Ecology and Fisheries Management (REFM) Division, Auke Bay Laboratory (ABL) Division) and by the Alaska Maritime National Wildlife Refuge (AMNWR), and GulfWatch Alaska (GWA). Data for early stage juveniles (less than 250 mm) through adult (greater than 410 mm) were consistently available from AMNWR, AFSC Midwater Assessment and Conservation Engineering (MACE) acoustic survey, the AFSC bottom trawl survey, and the North Pacific Observer Program administered by the Fisheries Monitoring and Analysis (FMA) division.

Data from Ecosystem Status Report (ESR) contributions were provided through personal communication with the contact author of the contribution (e.g., Rogers et al., 2019a). Essential fish habitat (EFH) model output and maps were provided by personal communication with the editors of the EFH update (e.g., Rooney et al., 2018). Remote sensing data were collected through coordination with CoastWatch personnel at the Southwest Fisheries Science Center and initial development of an AFSC-specific ERDDAP (Simons, 2019). High resolution regional ocean modeling system (ROMS) and nutrient-phytoplankton-zooplankton (NPZ) data were provided through personal communication with authors of various publications (e.g., Laman et al., 2017, Gibson et al., *In Press*) that use these data.

The majority of GOA pollock economic value data were compiled and provided by the Alaska Fisheries Information Network (AKFIN). GOA pollock ex-vessel data were derived from the NMFS Alaska Region Blend and Catch Accounting System, and the Alaska Department of Fish and Game (ADF&G) Commercial Operators Annual Reports (COAR). GOA pollock first-wholesale data were from the NMFS Alaska Region Blend and Catch Accounting System, the NMFS Alaska Region At-sea Production Reports, and the ADF&G COAR. Global catch statistics were found online at FAO Fisheries & Aquaculture Department of Statistics (http://www.fao.org/fishery/statistics/en).

Metrics Assessment

We first provide the analysis of the national initiative data used to generate the baseline metrics for this second step of the ESP process and then provide more specific analyses on relevant ecosystem and/or socioeconomic processes. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and lead to mechanistic understanding of ecosystem or socioeconomic pressures on the stock.

National Metrics

The national initiative form data were summarized into a metric panel (Appendix Fig. 1A.1) that acts as a first pass ecosystem and socioeconomic synthesis. Metrics range from estimated values to qualitative scores of population dynamics, life history, or economic data for a given stock (see Shotwell et al., *In Review* for more details). To simplify interpretation, the metrics are rescaled by using a percentile rank for GOA pollock relative to all other stocks in the groundfish FMP. Additionally, some metrics are inverted so that all metrics can be compared on a low to high scale between all stocks in the FMP. These adjustments allow for initial identification of vulnerable (percentile rank value is high) and resilient (percentile rank value is low) traits for GOA pollock. Data quality estimates are also provided from the lead stock assessment author (0 or green shaded means no data to support answer, 4 or purple shaded means complete data), and if there are no data available for a particular metric then an "NA" will appear in the panel. GOA pollock only had one data gap for the recreational index information. The data quality was rated as good to complete for nearly all metrics except transformation size, subsistence index, and non-catch value. The metric panel gives context for how GOA pollock relate to other groundfish stocks in the FMP and highlights the main categories of potential vulnerabilities for the GOA pollock stock.

The 80^{th} and 90^{th} percentile rank areas are provided to highlight metrics that cross into these zones indicating a high level of vulnerability for GOA pollock (Appendix Fig. 1A.1, yellow and red shaded area, respectively). For ecosystem metrics, recruitment variability and predator stressors fell within the 90^{th} percentile rank of vulnerability. Habitat dependence and bottom-up ecosystem value fell within the 80^{th} percentile rank when compared to other stocks in the groundfish FMP. For socioeconomic metrics, commercial value fell within the 90^{th} percentile rank and constituent demand fell within the 80^{th} percentile rank. GOA pollock were relatively resilient for adult growth rate, age at 50% maturity, mean age, breeding strategy, dispersal in early life, adult mobility, habitat specificity, and habitat vulnerability.

Recruitment variability (standard deviation of log recruitment) for the GOA pollock stock is above the value of 0.9 which is considered very high recruitment variability (Lynch et al., 2018) and habitat dependence of larvae and juveniles make GOA pollock particularly vulnerable during early life history stages. Predation pressures on adult GOA pollock are high due to their key role in the ecosystem as a major dietary component for a broad range of predators. GOA pollock is in the top 10% of the most highly valued Alaska groundfish stocks relative to other Alaska groundfish stocks. The high value also explains the high constituent demand for excellence in the stock assessment. These initial results suggest that additional evaluation of ecosystem and socioeconomic processes would be valuable for GOA pollock and assist with subsequent indicator development.

Ecosystem Processes

Data evaluated over ontogenetic shifts (e.g., egg, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. The first year of life for pollock is characterized by high mortality, where eggs, larvae, and juveniles must survive a series of transitions among habitats and life stages (Duffy-Anderson, et al. 2016). We evaluate the life history stages of GOA pollock along four organizational categories of 1) distribution, 2) timing, 3) condition, and 4) trophic interactions to gain mechanistic understanding of influential ecosystem processes. We include a detailed life history synthesis (Appendix Table 1A.2a), an associated summary of relevant ecosystem processes (Appendix Table 1A.2b), a conceptual model summarizing the life history and ecosystem processes tables (Appendix Fig. 1A.2), four life history graphics along the organizational categories (Appendix Fig. 1A.3-6, updated from Shotwell et al., *In Review* and Gaichas et al., 2015), and provide supportive information from the literature, surveys, process studies, laboratory analyses, and modeling applications.

A suite of habitat variables can be used to predict the distribution of the stock by life history stage and determine the preferred properties of suitable habitat. The recent EFH update for Alaska groundfish included models and maps of habitat suitability distributions by stage and species (Rooney et al., 2018; Pirtle et al., *In Press*). We collected model output on the depth ranges, percent contribution of predictor variables, sign of directional deviation from the mean predictor value, and associated maps for the larval (hatch-25 mm), early juvenile (<40 mm), late juvenile (>=40 mm & < 250 mm), and adult stages (>= 255 mm) of GOA pollock (Appendix Fig. 1A.3). Once hatched, larvae will move to the upper 50 m (Kendall et al., 1994) and are widely distributed along the GOA shelf but are most abundant in Shelikof Strait with other hot spots on the northeast side of the Kodiak Archipelago and proximal to the Shumagin Islands (Doyle and Mier, 2016). Early stages of pollock are generally much less abundant in the eastern GOA relative to the western GOA but there is a fair degree of annual variability in the eastern GOA (Siddon et al., 2016). Early juveniles are semi-demersal in nearshore areas as well as occurring in the upper 40 m (Bailey et al., 1989). The use of the nearshore zone by juvenile pollock seems especially transitory and this habitat may serve as stable refuge from adverse offshore conditions (O. Ormseth, *pers. comm.*). A clear ontogenetic habitat shift occurs between the larval to early juvenile stage and late juvenile to adult stages with progression from the hotspot areas in the western GOA to a fairly wide distribution along the continental shelf (Appendix Fig. 1A.3 b-d). The preferred habitat seems to switch from a reliance on a particular thermal environment during larval and early juvenile stages (Appendix Fig. 1A.3e, 3j) to low-gradient, low lying areas such as channels, gullies, and flats that are not rocky and within 20-300 m depth (Appendix Fig. 1A.3k, 3h) during late juvenile and adult stages (Pirtle et al., *In Press*).

The timing or phenology of the pre-adult life stages (Appendix Table 1A.2a) can be examined seasonally to understand match or mismatch with both physical and biological properties of the ecosystem (Appendix Fig. 1A.4). We synthesized data on the egg, larval, early juvenile and late juvenile life stages (Appendix Table 1A.2a) and restricted to the core sampling area (western GOA only) for consistency across years for the egg and larval data. Physical and biological seasonal climatologies were derived from ROMS/NPZ model output used in an individual based model and the EFH update (Laman et al., 2017; Rooney et al., 2018, Gibson et al., *In Press*). During the early spring, GOA pollock aggregate to spawn in high densities in the GOA, with females releasing 10-20 batches of eggs over a period of weeks (Hinckley, 1990). This species is a batch spawner, with spawning duration varying from 17 to 57 days in duration (Doyle and Mier, 2016; Rogers and Dougherty, 2018). This batch spawning is considered a "bet hedging" strategy that may mitigate vulnerability in terms of synchrony with optimal levels of larval prey (Doyle and Mier, 2016). In the Shelikof region, most spawning occurs from late March to early May, although spawn timing and duration are impacted by both spawner age structure and water temperature (Rogers and Dougherty, 2018). Pollock eggs are pelagic and vulnerable to physical processes that influence transport and buoyancy, which may result in the eggs sinking to the seafloor (M. Wilson, *pers. comm.*) as well as being vulnerable to invertebrate predators in the plankton (Brodeur et al., 1996). Peak egg abundance estimates over the season occur prior to the shallowing of the mixed layer and onset of stratification (Appendix Fig. 1A.4). Larvae hatch from the eggs after incubating for approximately 14 days at about 3 mm in length (Blood et al. 1994). Peak abundance of newly hatched larvae (less than 5 mm) corresponds to an increase in water temperature but prior to the peak temperatures and the onset of the zooplankton bloom (Doyle and Mier, 2016). Once feeding is initiated after yolk-sac absorption, larval pollock predominantly feed on copepod nauplii (Kendall et al., 1987, Strasburger et al. 2014), and may be susceptible to food-limited growth and subsequent increased predation mortality (Canino et al., 1991). The degree of match or mismatch of first-feeding larval pollock with optimal zooplankton prey production may thus be critical for larval survival and dependent on fluctuations in the thermal environment and onset of the spring plankton blooms (Appendix Fig. 1A.4). At 25 mm standard length, which corresponds to an age greater than 60 days, GOA pollock undergo juvenile transformation (Kendall et al., 1984, Brown et al., 2001). Early juveniles (<40 mm) appear more abundant in the late spring and early summer prior to the reduction of current speeds, which may enhance moderate transport offshore to preferred habitat. Juveniles are ubiquitous in the epipelagic zone of shelf and slope waters in the eastern and western GOA in summer and fall, which corresponds to the onset of the fall bloom but prior to the peak of bottom temperature which has a delayed onset from surface warming (Appendix Fig. 1A.4).

Information on body composition, percent lipid and percent protein by size, can be used to understand shifts in energy allocation through the different life history stages (Appendix Fig. 1A.5). Throughout their life history, there was no trend in the data suggesting that GOA pollock have a fairly stable lipid and protein content. This stability implies an energy allocation strategy toward increasing growth rather than toward energy storage. However, there may be a potential bottleneck just prior to overwintering (termed the "settlement stage", but pollock do not really settle) as there was an observed increase in the variability of the percent lipid. Overwintering during the first year of life may incur an energetic cost that results in a change in body condition with reduced lipid content. In the Bering Sea, high lipid storage prior to the first winter has been associated with stronger year-classes for pollock (Heintz et al., 2013, Siddon et al., 2013). Young fish with greater energy stores may be less susceptible to predation during their first winter. There may be an additional gain to the higher energy stores to mitigate high variability in maturation schedule, spawn timing, and spawning duration.

Pollock trophic interactions occur primarily in the pelagic pathway in the food web, which leads from phytoplankton through various categories of zooplankton to planktivorous fishes such as capelin and sandlance (Dorn et al., 2018). The primary prey of juvenile and adult pollock are euphausiids, but pollock also consume shrimp, which are more associated with the benthic pathway, and make up approximately 18% of age 2+ pollock diet. All ages of GOA pollock are primarily zooplanktivorous during the summer growing season (>80% by weight zooplankton in diets for juveniles and adults; Appendix Fig. 1A.6). While there is an ontogenetic shift in diet from copepods to larger zooplankton (primarily euphausiids) and fishes, cannibalism is not as prevalent in the Gulf of Alaska (5%) as in the Eastern Bering Sea (40%) for adult pollock, and consumption of fishes is low even for large pollock (Yang and Nelson, 2000, Gaichas et al., 2015). During mid- to late-summer, juvenile GOA pollock shift from a diet consisting of primarily copepods to one dominated by euphausiids (Wilson et al., 2011, 2013). Consumption of euphausiids has been associated with improved growth and body condition in the western GOA (Wilson et al., 2013). Fatty acid and stable isotope analysis of GOA pollock juvenile diets in the nearshore areas revealed a high level of geographic (habitat variability), seasonal, and interannual variability but a general ontogenetic trend was apparent with summer fish relying more heavily on calanoid copepods and autumn fish having a more diverse diet including benthic invertebrates, copepods, pteropods, and diatoms (Budge et al., *In Press*, Wang et al., *In Press*). This may suggest pollock in these nearshore areas do not have access to the high quality euphausiid prey of the offshore areas and must rely on a more diverse diet. In 2014 through 2015, poor body condition of juvenile pollock was associated with poor prey quality and increased metabolic demands due to warm temperatures during the marine heatwave (Rogers et al., *In Prep.*; J. Moss *pers. comm.*). Juvenile pollock are more sensitive to variations in foraging conditions than Pacific cod (Doyle and Mier, 2016), suggesting that environmental variability in prey availability is likely an important factor influencing juvenile GOA pollock.

The GOA community composition has undergone large shifts over the past several decades, likely in response to warming temperatures, which has had notable impacts on trophic stability of the GOA (Barnes et al., *In Review*). When the demersal community shifts from one dominated by forage species like pollock to one dominated by top-level predators, the likely pressures on pollock recruitment shift from environmental effects on larvae to predation control on juveniles (Baily et al., 2000). Food web models identify predation mortality as an important mechanism for changes in pollock biomass and show that the top five predators (excluding fisheries) on adult pollock (>20 cm) by relative importance are arrowtooth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), Pacific cod (*Gadus macrocephalus*), Steller sea lion (*Eumetopias jubatus*, SSL), and sablefish (*Anoplopoma fimbria*) (Appendix Fig. 1A.6, Barnes et al., *In Review*, Gaichas et al., 2015). These predators account for over 80% of total mortality for GOA pollock and synchronous consumption dynamics of these predators suggest strong top-down control over GOA pollock (Barnes et al., *In Review*). For juvenile pollock (< 20 cm), arrowtooth flounder account for 58% of total mortality, followed by adult pollock (19%) and seabirds (11%) (Appendix Fig. 1A.6, Dorn et al., 2018). All major predators show some diet specialization, and none depend on pollock for more than 50% of their total consumption. Pacific halibut is most dependent on pollock (48%), followed by SSL (39%), then arrowtooth flounder (24% for juvenile and adult pollock combined), and lastly Pacific cod (18%). It is important to note that although arrowtooth flounder is the largest single source of mortality for both juvenile and adult pollock (Appendix Fig. 1A.6a,b), they depend less on pollock in their diets than do other pollock predators (Dorn et al., 2018).

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) increased 20% in 2018 from 2017 to $42.2 million, the average for the previous 5 years was $38.8 million (real 2018 USD). This increase was the net effect of a 15% decrease in retained catch to 158 thousand t and a 41% increase in the ex-vessel price to $0.123 per pound (Appendix Table 1A.3a). The number of vessels fishing for pollock increased from 65 in 2017 to 71 in 2018. The increase ex-vessel price in 2018 coincided with increased first-wholesale prices for head-and-gut (H&G) prices and fillet products, which represent slightly less than 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 remained lower than levels observed in 2011-2016. First-wholesale value was $105 million in 2018 (8% increase) and production of pollock products was 69 thousand t (12% decrease, Appendix Table 1A.3b). The average first-wholesale price of pollock products increased 16% to $0.69 per pound (Appendix Table 1A.3b). The GOA pollock fishery is subject to prohibited species catch (PSC) restrictions, in particular of Chinook salmon. These restrictions have resulted in periodic closures of the fishery in the past. In December 2016, the NPFMC decided to postpone work on bycatch management for the GOA groundfish trawl fisheries indefinitely.

Pollock is a global commodity with prices determined in the global market. GOA represents roughly 2%-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. GOA pollock fisheries became certified by the Marine Stewardship Council (MSC) in 2005, an NGO based third-party sustainability certification, which some buyers in the U.S. and Europe seek. Pollock also obtained the Responsible Fisheries Management certification in 2011. Pollock more broadly competes with other whitefish that, to varying degrees, can serve as substitutes depending on the product. In 2015, the official U.S. market name changed from “Alaska pollock” to “pollock”. Previously all pollock was called “Alaska pollock” and it was not possible to determine origin of the product. The market name change enables U.S. retailers to differentiate between pollock caught in Alaska and Russia.

The ports at Kodiak and Sand Point account for about 80% and about 12%, respectively, of the GOA delivered pollock volume. A comparatively smaller share of GOA caught pollock is also delivered to King Cove. The communities of Kodiak are highly involved in both commercial processing and harvesting of groundfish. Fisheries taxes account for 13% of the local tax revenue. Pollock accounted for 16% of Kodiak’s 2013-2017 average ex-vessel value and the remainder of its ex-vessel value comes from a number of other fisheries. Kodiak is dependent upon commercial fisheries, as commercial fishing, processing, and service is a major industry contributing to the local community.

One indication of Kodiak’s engagement in processing activities for the GOA pollock fishery is calculating the portion of the total GOA pollock fishery landed in Kodiak as well as the percentage of the total revenue Kodiak gets from the GOA pollock fishery (Appendix Fig. 1A.7a). Overall, there has been an increase in the percentage of the fishery landed in Kodiak between 2000 and 2014 from 67% to 87% (Appendix Fig. 1A.7a, blue bars). After reaching a peak of 87% in 2014, the portion of the GOA pollock landed in Kodiak declined slightly to 80% and then dropped steeply to 62% in 2016 before turning upward. In 2018, 76% of GOA pollock was landed in Kodiak. The percentage of landings revenue in Kodiak that can be attributed to GOA pollock shows some fluctuation (Appendix Fig. 1A.7a, orange bars), dipping to 6.3% in 2007 before climbing slightly. The years with the highest percentages of revenues are 2014 and 2018 (24% and 29%, respectively). In 2018, there was a jump in the portion of revenue from GOA pollock (from 16% in 2017 to 29% in 2018, Appendix Fig. 1A.7a, orange bars).

In order to explore Kodiak's engagement in harvesting activities for GOA pollock, we examined the associated value of GOA pollock harvested by vessels owned by Kodiak residents from 2000 to 2018 (Appendix Fig. 1A.7b, yellow line). The number of Kodiak vessels participating in the GOA pollock fishery decreased from 21 vessels in 2000 to 11 in 2007 (a decline of 48%). Since then, the number of vessels has increased; however, more research is required to understand the circumstances for these changes. In 2018, Kodiak residents owned 20 vessels involved in GOA pollock harvesting. The average value of harvest per vessel owned by Kodiak residents fluctuated from a low of $128 thousand in 2002 to $228 thousand in 2009 (Appendix Fig. 1A.7b, blue bars). In 2010, the value then increased considerably to $479 thousand and continued to rise until sharply dropping in 2016, when there was a 35 % decrease. In 2018, the average value of GOA pollock harvested per vessel was $742 (Appendix Fig. 1A.7b, blue bars).

Indicators Assessment

We first provide information on how we selected the indicators for the third step of the ESP process and then provide results on the indicators analysis. In this indicator assessment a time-series suite is first created that represent the critical processes identified by the metric assessment. These indicators must be useful for stock assessment in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of stages that are statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al., *In Review*).

Indicator Suite

Studies into the survival of early life stages and recruitment of GOA pollock have identified important processes, which have in turn informed recruitment forecasting models incorporating a range of indicators. These models have included variables reflecting environmental conditions preceding or during the first few months of life, such as thermal conditions, advection, and wind mixing, and biological variables like predator biomass. For many years, a recruitment forecast model was included in the SAFE document for GOA pollock based on environmental data and larval counts (e.g. Dorn et al., 2007). The environmental indicators included winter-spring precipitation as a proxy for eddies or instabilities in the spring (hypothesized positive effect through concentration of prey; Bailey et al. 2005), winter wind mixing (strong mixing in winter is favorable due to increased nutrient mixing and spring blooms), spring wind mixing (weak mixing in spring is favorable for first-feeding larvae; Bailey and Macklin, 1994), and advection (weak or average transport in spring is favorable for retention of larvae in nursery habitats). Notably, the forecast model did not include any thermal indicators, although many studies have looked at the effect of thermal conditions on larval survival and recruitment. For instance, early studies found a positive relationship between springtime temperatures and larval pollock survival, with cold springs corresponding to lower rates of larval survival, especially during the first week post-hatch (Bailey et al., 1996). This was hypothesized to be related to the timing of microzooplankton production, particularly of copepod nauplii, which are a primary prey item of first-feeding larvae (Bailey et al. 1995). A subsequent time-series analysis found no apparent effect of spring temperatures on larval abundance (Doyle et al., 2009), although winter (January) temperatures were negatively associated with larval abundance. Another study found recruitment (as estimated in the assessment model) was negatively related to springtime temperatures (A'mar et al., 2009), but positively related to summer temperatures. Additionally, the spatial scale of the temperature time-series in these studies was not specifically tuned to the full spatial extent of the western-central GOA pollock stock. Current work (Rogers, *in prep*) suggests no consistent relationship between temperature and stage-specific survival rates of GOA pollock during their first year, emphasizing that temperature is only one of many factors, often interacting, that regulate survival and recruitment in this species.

Some models have also included SSB, larval abundance, or age-0 abundance, together with subsequent environmental conditions and/or density-dependence, to predict recruitment. For instance, Bailey et al., 2012 developed a recruitment forecasting model based on larval rough counts, wind speed in May, an interaction between the biomass of arrowtooth flounder and temperature, and an autocorrelation term to capture the empirical 5-year cycle in recruitment. Notably, the estimated environmental effects were often non-linear and sometimes included thresholds. Brodeur and Ware (1995) provided evidence that biomass of zooplankton in the center of the Alaska Gyre was twice as high in the 1980s than in the 1950s and 1960s, consistent with a shift to positive values of the PDO since 1977. The percentage of zooplankton in the diets of pollock is relatively constant throughout the 1990s (Dorn et al., 2018). While indices of stomach fullness exist for these survey years, a more detailed bioenergetics modeling approach would be required to examine if feeding and growth conditions have changed over time, especially given the fluctuations in GOA water temperature in recent years, as water temperature has a considerable effect on digestion and other energetic rates.

We generated a suite of ecosystem and socioeconomic indicators using the mechanisms and tested relationships listed above by previous studies and the relevant ecosystem processes identified in the metric assessment (Appendix Table 1A.2b, Appendix Fig. 1A.2). The following list of indicators is organized by trophic level similarly to the ecosystem status reports (Zador and Yasumiishi, 2018) and by GOA pollock life history stage. Indicator title and a brief description are provided in Appendix Table 1A.4a for ecosystem indicators and Appendix Table 1A.4b for socioeconomic indicators with references, where possible, for more information. Time series graphics of the ecosystem and socioeconomic indicators are provided in Appendix Fig. 1A.9a and Appendix Fig. 1A.9b, respectively.

Ecosystem Indicators:

1. Physical Indicators (Appendix Fig. 1A.9a.a-d)
    - Annual marine heatwave index is calculated from daily sea surface temperatures for 1981 through August 2019 from the NOAA High-resolution Blended Analysis Data for the central GOA (< 300 m). Daily mean sea surface temperature data were processed to obtain the marine heatwave cumulative intensity (MHWCI) (Hobday et al., 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the January 1983 through December 2012 time series (Zador and Yasumiishi, 2018).
    - Spring (April-May) sea surface temperatures (SST) for the western and central GOA were obtained from the monthly gridded 4 km Advanced Very High Resolution Radiometer (AVHRR) Pathfinder v5.3 dataset (Casey et al., 2010). These data were provided by Group for High Resolution SST (GHRSST) and the NOAA National Centers for Environmental Information (NCEI). This project was supported in part by a grant from the NOAA Climate Data Record (CDR) Program for satellites. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.
    - Summer bottom temperatures were obtained by averaging the haul-specific bottom temperature (degrees Celsius) collected on the AFSC bottom trawl survey over all hauls from 1984 to present. Data are available triennial since 1984 and biennial since 2000 and can be accessed from the Alaska Fisheries Information Network (AKFIN).
    - Derived chlorophyll *a* concentration data during spring seasonal peak (May) in the western and central GOA were obtained from the 4km Ocean Colour Climate Change Initiative (OC-CCI) version 4.0 monthly gridded dataset, European Space Agency available online at http://www.esa-oceancolour-cci.org. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.
2. Zooplankton Indicators (Appendix Fig. 1A.9a.e-h)
    - Spring small copepods for larvae and summer large copepods for young-of-the-year (YOY) GOA pollock were summarized as mean abundance for the core sampling area in Shelikof Strait of the EcoFOCI spring and summer surveys. The most recent survey year

is represented by a rapid zooplankton assessment to provide a preliminary estimate of zooplankton abundance and community structure (Kimmel et al., 2019). Ongoing work will determine the robustness of the rapid zooplankton assessment through comparison with quantitative data with high taxonomic resolution.

- Summer euphausiid abundance is represented as the acoustic backscatter per unit area (sA at 120 kHz, m2 nmi-2) classified as euphausiids and integrated over the water column and then across the surveyed area to produce an annual estimate of acoustic abundance (sA * area, proportional to the total abundance of euphausiids). The index is for the Kodiak core survey area available for variable years historically and biennially since 2013 (Ressler et al., 2019).
- Parakeet auklet reproductive success is measured at Chowiet Island during variable years since 1998. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that had eggs laid. This species is a diving plankton-feeder, like pollock, and reproductive success may be indicative of prey field in a central area to the GOA pollock population. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service (Higgins et al., 2018).

2. Larvae and Young-of-the-year (YOY) Indicators (Appendix Fig. 1A.9a.i-m)
    - Spring pollock larvae and summer pollock YOY catch-per-unit-of-effort (CPUE) were summarized as mean abundance for the core sampling area in Shelikof Strait of the EcoFOCI spring and summer surveys. The most recent survey year is represented by a rapid ichthyoplankton assessment to provide a preliminary estimate of pollock CPUE (Dougherty et al., 2019, Rogers et al., 2019b).
    - Summer pollock condition for YOY were provided from samples taken in the EcoFOCI midwater trawl survey. Body condition was measured as residuals from a weight-length regression model that also included day of year to account for variation in time of sampling. Fish with positive residuals are considered “fatter” with greater energetic reserves to survive life stage transitions such as first overwinter survival (Rogers et al., 2019a).
    - Summer pollock CPUE of YOY was estimated using the AFSC Kodiak beach seine survey available from 2006-present that targets summer YOY gadids (Pacific cod, pollock and saffron cod) at 16 fixed-site nearshore regions of Kodiak from mid-July through late August. Sites are sampled using a 36-m demersal beach seine deployed from a boat and pulled to shore by two people standing a fixed distance apart on shore. Maximum depth varies between 2 and 4 m among seine sites, and sites consist of eelgrass or sand-small cobble. Juvenile gadids from each seine haul are counted and measured (mm TL, Laurel et al., 2007).
    - Pollock relative biomass of YOY is measured from screening burrows of tufted puffins at Aiktak Island annually since 1991. This species is a diving fish-feeder and estimates of pollock relative biomass from feeding samples may be indicative of pollock densities near the western edge of the pollock population. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service (Youngren et al., 2019).
3. Juvenile Indicators (Appendix Fig. 1A.9a.n-o)
    - Summer pollock predation mortality for age-1 was quantified in the area encompassed by the GOA pollock stock assessment for 1990 to 2015. The predation index included estimates of total predator biomass from recent stock assessments, relative predator densities modeled from survey catch data (collected by RACE and the International Pacific Halibut Commission), mean annual rations obtained from bioenergetics models, and age-specific proportions of pollock consumed (as estimated from food habits data collected by REEM). The predation index accounted for annual variation in consumption

by five major groundfish species: arrowtooth flounder, Pacific cod, Pacific halibut, sablefish, and pollock conspecifics (Barnes et al., *In Review*).
- Summer pollock proportion-by-weight of euphausiids in the diets of juvenile (10-25 cm, likely age-1) GOA pollock collected on summer bottom-trawl surveys (Aydin et al., 2007).

4. Adult Indicators (Appendix Fig. 1A.9a.p-u)
    - Fall pollock condition for adults was estimated from length-weight data from the fishery sampled by observers (1989-2018). A log length-weight regression was fitted and then the residuals from the regression were averaged by year. Data only for the months of August, September, and October were used to measure condition at the end of production year. The length-weight regression included a slope term for month, and this term increased slightly in value from August to October, indicating that condition improved during these months (M. Dorn, *pers. commun.*).
    - Winter pollock condition for adults was estimated from length-weight data from the late winter acoustic surveys of pre-spawning pollock in the GOA. Most of the sampling occurred in Shelikof Strait, but data from outside Shelikof Strait were not excluded. A log length-weight regression was fitted and then the residuals from the regression were averaged by year. Fish in spawning or post-spawning condition were excluded, and the analysis was limited to fish greater or equal to 35 cm to exclude the age-1 and age-2 pollock. Estimates were produced for 1986-2019, excluding 1999, 2001, and 2011 (M. Dorn, *pers. commun.*).
    - Summer pollock center of gravity and area occupied were estimated by fitting a spatio-temporal delta-generalized linear mixed model using standard settings for an "index standardization" model (Thorson 2019), implemented using the package VAST (Thorson and Barnett 2017) in the R statistical environment (R Core Team 2017). This configuration includes spatial and spatio-temporal variation in two linear predictors of a Poisson-link delta model (Thorson 2018), using a lognormal distribution for residual variation in positive catch rates. We specified a model with 250 "knots" while using the "fine_scale=TRUE" feature to conduct bilinear interpolation from the location of knots to the location of extrapolation-grid cells (Appendix Fig. 1A.8). For extrapolation-grid, we used the standard "Gulf of Alaska" grid which covers the spatial domain from which the bottom trawl survey randomizes sampling stations. We then restricted this extrapolation-grid to cells West of -140˚W; knots where distributed proportional to the spatial distribution of extrapolation-grid cells within this spatial domain. We then calculated center of gravity as the biomass-weighted average of the location of extrapolation-grid cells in northings or eastings (Thorson et al. 2016a) when projecting Latitude/Longitude to UTM coordinates within UTM zone 5. We also calculated effective area occupied as the area required to contain the population at its average biomass (Thorson et al. 2016b).
    - Arrowtooth flounder total biomass (metric tons) from the most recent stock assessment model (Spies et al., 2017).
    - Steller sea lion non-pup estimates were developed using the R package agTrend model within the bounds of the GOA. As a predator of pollock, an index of adult counts may be indicative of the relative biomass GOA pollock. This region includes the GOA portion of the western Distinct Population Segment (known as the west, central and east GOA) (Sweeney, 2018)

Socioeconomic Indicators:

1. Fishery Performance Indicators (Appendix Fig. 1A.9b.a-b)
    - Winter-spring and summer-fall pollock CPUE (catch of pollock in tons/hour) was estimated from fishery observer data. Data were filtered to exclude catches less than 80%

pollock, and gears other than pelagic gear. Only tows with a performance code of "no problem" were used. The geometric mean CPUE was calculated by taking the log of the CPUE and then exponentiating. Mean CPUE was calculated for the first trimester (Jan-April), and the third trimester (Aug-Dec, mostly Aug.-Oct.).

2. Economic Indicators (Appendix Fig. 1A.9b.c-d)
    - Annual real Ex-vessel price per pound was calculated from 2000-2018 (2018 USD) with a projected price for 2019 based on fish ticket information in August 2019. Ex-vessel prices are revenue per pound of retained pollock delivered to processors. Prices influence the incentive to harvest fish as an increase in the price of fish increases the returns to fishing. Many other factors can influence the returns and the incentive to harvest including costs, activity in other fisheries in which harvesters may participate. The ex-vessel price metric has been inflation adjusted to 2018 USD to account for general trends in prices over time (Fissel et al., 2019).
    - Annual pollock roe per-unit-catch during January to March was calculated from 2000-2019. Production of roe per-unit catch during January to March, the peak roe production months, is potentially indicative of the fecundity of the stock. As a high priced pollock product, processors and harvesters have an incentive to maximize the production of roe subject to harvest controls. A number of other factors besides fecundity can potentially influence the relative share of roe to retained catch including roe prices and the timing of harvest. This metric is constructed as 1000*(roe production)/(retained catch) (Fissel et al., 2019).
3. Community Indicators (Appendix Fig. 1A.9b.e)
    - Annual percentage of the total revenue that Kodiak receives from the GOA pollock fishery from 2000 to 2018, also known as the local quotient was calculated to estimate community engagement. (S. Wise, *pers. commun.*).

Indicator Monitoring Analysis

We provide the list and time-series of indicators (Appendix Table 1A.4, Appendix Fig. 1A.9a and 9b) and then monitor the indicators 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*). 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.

Stage 1, Traffic Light Test:

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the current year where available (Appendix Table 1A.4). Both measures are based on one standard deviation from the long-term mean (log-transformed) of the time series. A symbol is provided if the most recent year of the time series is greater than (+), less than (-), or within (•) one standard deviation of the long-term mean for the time series. If the most recent year is also the current year then a color fill is provided for the traffic-light ranking based on whether the relative value creates conditions that are good (blue), average (white), or poor (red) for GOA pollock (Caddy et al., 2015). The blue or red coloring does not always correspond to a greater than (+) or less than (-) relative value. In some cases the current year data were not available. This identifies data gaps for evaluating ecosystem and socioeconomic data for GOA pollock and highlights potential future research priorities.

We first 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. We start with the physical indicators and proceed through the increasing trophic levels as the indicators are listed above. A major heatwave impacted the GOA ecosystem starting in 2014 (Appendix Fig.1A.9a.a), likely influencing the early maturation of the 2012 year-class. The heat was mixed from the sea surface to the bottom as can be seen in the western GOA spring surface and summer bottom temperatures (Appendix Fig.1A.9a.b-c) which would adversely impact the egg and larval habitat of offspring resulting from the 2012 year-class during the heatwave event. Additionally, estimates of peak primary production (derived chlorophyll *a* in May) has been on a steady downward trend since 2013, which has implications for subsequent food web dynamics. The result can be seen in the zooplankton time series (Appendix Fig.1A.9a.e-g) where small copepods were likely abundant when the 2012 year-class entered the system as YOY but lipid-rich large copepods were low and euphausiids were average to low and on a downward trend in the age-1 diet (suggesting decreased availability). 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.9a.h) appears to be very high in 2016 and very low in 2018 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 as was the condition, but were all high in the following survey year (2013, Appendix Figure 1A.9a.i-k) supporting that the environmental conditions during the first year of life through overwinter were quite favorable for pollock. The nearshore Kodiak survey showed above average abundance of YOY in 2012 (Appendix Fig.1A.9a.l). 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.9a.m) 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. Predation estimates for age-1 pollock have been relatively low since 2007 (Appendix Fig.1A.9a.n), but so has the percent of euphasiids in the diet for juveniles (Appendix Fig.1A.9a.o). 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.9a.p-q). The 2016 and 2017 annual anomalies were strongly negative, followed by an increase in 2018, but the 2018 and 2019 anomalies still remained negative. 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 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). In the spatial-temporal model results (Appendix Fig.1A.7), total biomass has decreased, while effective-area has remained high and northeast center of gravity has returned to average since 2015 (Appendix Fig.1A.9a.r-s). The decrease in total biomass has been associated with decreased density within the range and a slight increase in range. Main predator biomass has been decreasing and/or stable for the most recent years (Appendix Fig.1A.9a.t-u), suggesting that the primary pressure on the 2012 year class may be the lack of preferred prey.

The pressures and resulting impact to the 2012 GOA pollock year-class can be used to evaluate the potential impact to the newly emerging average year-class of 2017 and moderately large year-class of 2018. We are again entering another major heat wave in the GOA (Appendix Fig.1A.9a.a) and the 2017 and 2018 year-classes will likely experience similar feeding conditions to the 2012 year-class. Anomalously warm sea surface temperatures and a weak-moderate El Nino were predicted through winter 2018/19 and have continued through summer 2019. The current heat wave may 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 since the 2014 heat wave which tend to be associated with zooplankton communities that are dominated by smaller, less lipid rich species. These warm temperature anomalies did not extend to the bottom during the 2017 survey but the 2019 bottom temperatures throughout the western/central GOA were the highest on record for the bottom trawl survey and the phytoplankton production was also the lowest on record (Appendix Fig.1A.9a.b-d). Small copepods in spring were above average in 2017 and slightly below average in 2019, while large copepods in summer were very low in 2017 and average in 2019. Euphausiids were very low in 2017 and slightly below average in 2019. Reproductive success of auklets decreased recently to a low in 2018 and average in 2019. These suggests that the prey base is not in as bad a shape as with the 2012 year class (Appendix Fig.1A.9a.e-h). The CPUE of pollock larvae and YOY was above average for the 2017 year-class and poor for 2019 in the offshore surveys (although YOY were still within 1 standard deviation of the long-term mean). The condition for the 2017 YOY was below average. The nearshore surveys in Kodiak showed very high abundance in both 2017 and 2018, and very poor abundance in 2019. Relative biomass of pollock in tufted puffin diet has been variable since 2012 with overall downward trend to 2019. The percent euphausiids in the diet of juvenile pollock in 2017 was the lowest in the time series, however, the condition of adult pollock has been steadily increasing since the low of 2016 and 2017 for the fall fishery and winter survey. The spatial distribution of adult pollock has returned to near average conditions and major predators of pollock have remained below average.

For the socioeconomic indicators (Appendix Fig.1A.9b), fishery CPUE was high at the beginning of the time series, declined, and then increased toward the end of the time series. 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. Fishery CPUE remained relatively high during the first trimester of 2019. There has been a decreasing trend in 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.9a.p-q).). These decreases have somewhat rebounded in 2018 and in the projected values for 2019. CPUE in local communities (Kodiak) have been trending upwards since 2007, reaching a high in 2018. The trends may be due to an increased level of reliance on GOA pollock by Kodiak residents or a switch to pollock from other fisheries.

For the indicators available in the current year, the traffic light analysis shows mostly poor physical conditions and poor to average conditions for larval and YOY GOA pollock (Appendix Table 1A.4a). Juvenile and adult indicators are relatively stable with one good indicator for the winter/spring CPUE in the fishery (Appendix Table 1A.4a, 4b). In the future, a more quantitative summary measure across all indicators could be produced to generate an overall traffic light score for the ecosystem and socioeconomic indicators, respectively.

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. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). 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.10a). We then provide the mean relationship between each predictor variable and log GOA pollock recruitment over time (Appendix Fig. 1A.10b, left side), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Appendix Fig. 1A.10b, right side). A higher probability indicates that the variable is a better candidate predictor of GOA pollock recruitment. The highest ranked predictor variables based on this process were the annual heatwave, the arrowtooth flounder biomass index, and the fall pollock condition of adults in the fishery (Appendix Fig. 1A.10).

The BAS method requires observations of all predictor variables in order to fit a given data point. This method estimates the inclusion probability for each predictor, generally by looking at the relative likelihood of all model combinations (subsets of predictors). If the value of one predictor is missing in a given year, all likelihood comparisons cannot be computed. When the model is run, only the subset of observations with complete predictor and response time series are fit. It is possible to effectively “trick” the model into fitting all years by specifying a 0 (the long-term average in z-score space) for missing predictor values. However, this may bias inclusion probabilities for time series that have more zeros and result in those time series exhibiting low inclusion probability, independent of the strength of the true relationship. Due to this consideration of bias, we only fit years with complete observations for each covariate at the longest possible time frame. This resulted in a small final subset of covariates. In the future, we plan to explore alternate model runs (e.g., biennial) to hopefully include more covariates to explain recruitment and consider applying this method to explore indicators for other parameters in the assessment model (e.g., catchability or growth).

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., 2015) 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., 2019). 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., 2018, Dorn et al., 2018, and Spies & Palsson, 2018). The model is fit to data from five fisheries and seven surveys, including both age and length composition 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 2018.

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 heatwave and condition indicators could be used directly to help explain the variability in recruitment deviations and predict pending recruitment events for GOA pollock.

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 metric and indicator assessment we provide the following set of considerations:

Ecosystem Considerations

- An ontogenetic habitat shift occurs between the early juvenile and late juvenile stages with progression from WGOA hotspot areas to a fairly wide distribution along the continental shelf.
- Batch spawning may mitigate vulnerability in terms of synchrony with optimal levels of larval prey, but spawn timing and duration are impacted by both spawner age structure and temperature.

- 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.
- Physical indicators for 2019 show a return to “heat wave” conditions with high temperatures from surface to bottom and low primary production in western/central GOA.
- Spring and summer zooplankton and summer euphausiid prey base has returned to average conditions in 2019 suggesting improved prey conditions than previous years.
- Early indicators of 2019 year-class strength suggest a weak year class, following average to moderately large year-classes in 2017 and 2018.
- Body condition of adult pollock has been below average since 2015 when the 2012 year-class entered the survey and fishery but improved slightly in the 2019 winter survey.
- 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.

Socioeconomic Considerations

- Fishery CPUE indicators have been above average since 2016, which is consistent with high stock levels in recent 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.
- The percent of revenue in Kodiak from GOA pollock reached a high in 2018, which along with other data could suggest a level of reliance on the GOA pollock fishery by Kodiak residents.

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. 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.

It may also be important in the near future to consider the potential impacts of other GOA pollock predators and competitors that may be on the rise (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. Estimates of total biomass for GOA Pacific ocean perch have been steadily increasing for the past several decades and is now approximately half the total biomass estimate for GOA pollock (Hulson et al., 2017). Juveniles and adults of POP could be potential competitors of GOA pollock as they primarily feed on euphausiids and they have been increasingly sampled in midwater as recent estimates of bycatch in the pollock fishery show large increases of POP bycatch. 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.

In the future, a partial ESP may be requested as an update to the full ESP report provided here when no new information except indicator updates are available. We plan to create a simplified template for evaluating the ESP considerations during a partial update year.

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Tables

Appendix Table 1A.1: List of data sources used in the ESP evaluation. Please see the main GOA pollock SAFE document, the Ecosystem Considerations Report (Zador and Yasumiishi, 2018) and the Economic Status Report (Fissel et al., 2018) 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
RECA Energetics Database	Compositional data and associated analyses by the Recruitment Energetics and Coastal Assessment (RECA) Program, AFSC on multiple platforms	1997 – present	Alaska 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
AVHRR Pathfinder	4 km Advanced Very High Resolution Radiometer (AVHRR) version 5.3 monthly gridded sea surface temperature (SST) dataset (Group for High Resolution SST, GHRSST)	1981 – present	Global
Ocean Colour CCI	4km Ocean Colour Climate Change Initiative (OC-CCI) version 4.0 monthly gridded derived chlorophyll dataset, European Space Agency, (http://www.esa-oceancolour-cci.org)	1998 – 2018	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 and Yasumiishi, 2018) and the Economic Status Report (Fissel et al., 2018) 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
ROMS/NPZ Model Output	Coupled hydrographic Regional Ocean Modeling System and lower tropic Nutrient-Phytoplankton-Zooplankton dynamics model	1996 – 2013	Alaska variable
Essential Fish Habitat Models	Habitat suitability MaxEnt models for describing essential fish habitat of groundfish and crab in Alaska, EFH 2016 Update	1970 – 2016	Alaska
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.2a: Ecological information by life history stage for GOA pollock.

Stage		Habitat & Distribution	Phenology	Age, Length, Growth	Energetics	Diet	Predators/Competitors
Adult	**Recruit**	Shelf (0-300 m)	Recruit to survey and fishery ~age 1, length 5-16 cm (19)	Max: 31yrs (AFSC), 105♀/92♂ cm (AFSC) Average: 10 yrs (19) L_inf=65.2cm, K= 0.3 (19)		Euphausiids, shrimp, copepods, juvenile pollock (<1 %) (19)	Arrowtooth flounder, halibut, Pacific cod, steller sea lions, sablefish, shelf pelagic/benthic groundfish, fisheries (17,19)
Adult	**Spawning**	Shelf (150-300 m, x̄ 200 m), Shelikof Strait/Valley (5,9,*11)	February-May, peak mid-March, 13 wks (1,20,25)	1^{st} mature: 3-4 yr (11), 50%: 4.9 yr/44cm (19), ↑ size 50% to 48 since 2008 (19)	Oviparous, high fecundity (385-662·10^3) eggs (11), 1.1-7.2 °C at depth (11)	Euphausiids, shrimp, copepods, juvenile pollock (<1 %) (19)	Arrowtooth flounder, halibut, Pacific cod, steller sea lions, sablefish, shelf pelagic/benthic groundfish, fisheries (17,19)
Offshore to Nearshore Pelagic	**Egg**	Pelagic; shelf (0-200 m, x̄ 150-200 m), Shelikof St/Valley, canyons (2,5,6,8-11)	mid-March-April, ~2 wks (10,11,20,25-26)	Egg size: 1.2-1.77 mm (20, RACE)	5.0-5.5°C at 150-250 m depth (10,11)	Yolk (RACE)	Invertebrates, detritivores, pelagic fishes (23,24)
Offshore to Nearshore Pelagic	**Yolk-sac Larvae**	Pelagic; shelf and coastal areas (0-200 m, primarily upper 50 m), Shelikof St (2,3,5,6-8,10,11)	April (5), peak end April, 1 wk (20,25-26)	3-5 mm SL (2,3,5,6,8,10,11), growth rate 0.12-0.25 mm·day^{-1} (11)	Preferred, 31.5-32.2 ppt, 3.6-7.0 °C (8,10)	Yolk (RACE)	Planktonic predators (zooplankton, birds, fishes), larval groundfishes (5,6,8)
Offshore to Nearshore Pelagic	**Feeding Larvae**	Pelagic; shelf and coastal areas (0-200 m, primarily upper 50 m), Shelikof St (2,3,5,6-8,10,11)	May-July (5), peak May, 4-5 wks (22,25-26)	30-40 mm SL at transformation (RACE), growth rate 0.12-0.25 mm·day^{-1} (11)	Preferred salinity=31.5-32.2, temperature=3.6-7.0 °C (8,10)	Copepod eggs & nauplii, copepodites (8)	Planktonic predators (zooplankton, birds, fishes), Pollock (17), larval groundfishes (5,6,8)
Offshore to Nearshore Pelagic	**Juvenile**	Semi-demersal; shelf, coastal areas, bays, fjords, inlets (20-30 m and >30 m with age), mixed substrate (1,3,4,18)	Aug-Mar (1+ yr); 8-24 wks (25,26)	25-40 mm FL (offshore) (5); >40 mm SL (nearshore) (5); growth sensitive to diet, competition	Energy density ↑ with length, > over slope, spatial shifts due to +/- *C. marshallae*	Copepods, euphausiids (16)	Arrowtooth flounder, sablefish, cod, pollock (17), juvenile groundfish, macroalgae (12,18), macroinvertebrates (18)
Offshore to Nearshore Pelagic	**Pre-Recruit**	Semi-demersal; shelf, coastal areas, bays, fjords, inlets, mixed substrate, mud (18)		>250 mm FL (11), age 2+ yrs (10)		Euphausiids, copepods, pollock (16),	Arrowtooth flounder (~50% <20 cm) (19), sablefish, Pacific cod, Pollock (17), juvenile groundfish, macroalgae (12,18), macroinvertebrates (18)

Appendix Table 1A.2b. Key processes affecting survival by life history stage for GOA pollock.

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 (6,8,10) 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 while predation increases would be negative.
Offshore to Nearshore Pelagic	**Feeding Larvae**	1. Temperature-mediated metabolic rate 2. Currents that facilitate nearshore transport (6,8,10) 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 while predation increases would be negative.
Offshore to Nearshore Pelagic	**Juvenile**	1. Spring/summer/fall abundance of zooplankton prey (11) 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 be positive for pollock to arrive at preferred habitat. Predation 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 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; 2011-2013 average, and 2014-2018.

	Avg 11-13	2014	2015	2016	2017	2018
Total Catch K mt	94.0	142.6	167.6	177.1	186.2	158.1
Retained Catch K mt	91.8	141.2	163.0	176.0	184.3	155.7
Ex-vessel Value M $	$ 34.4	$ 37.9	$ 43.6	$ 32.3	$ 35.2	$ 42.2
Ex-vessel Price/lb $	$ 0.169	$ 0.122	$ 0.119	$ 0.083	$ 0.087	$ 0.123
Central Gulf Share of Value	75%	88%	80%	63%	72%	76%
Vessels #	70.0	72.0	65.0	70.0	65.0	71.0

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; 2011-2013 average, and 2014-2018.

		Avg 11-13	2014	2015	2016	2017	2018
All Products	**Volume K mt**	36.1	54.7	59.8	75.1	78.1	69.1
All Products	**Value M $**	$ 84.5	$ 105.8	$ 105.1	$ 106.4	$ 96.7	$ 104.9
All Products	**Price lb $**	$ 1.06	$ 0.88	$ 0.80	$ 0.64	$ 0.56	$ 0.69
Head & Gut	**Volume K mt**	18.4	29.7	30.3	27.8	37.4	39.8
Head & Gut	**Price lb $**	$ 0.68	$ 0.62	$ 0.61	$ 0.38	$ 0.36	$ 0.41
Head & Gut	**Value share**	33%	38%	39%	22%	31%	35%
Fillets	**Volume K mt**	5.8	8.2	9.1	14.3	15.7	13.1
Fillets	**Price lb $**	$ 1.59	$ 1.35	$ 1.30	$ 1.26	$ 1.01	$ 1.17
Fillets	**Value share**	24%	23%	25%	37%	36%	32%
Surimi	**Volume K mt**	8.5	12.3	14.7	13.4	10.6	9.8
Surimi	**Price lb $**	$ 1.19	$ 0.89	$ 0.85	$ 0.97	$ 0.76	$ 0.96
Surimi	**Value share**	27%	23%	26%	27%	18%	20%
Roe	**Volume K mt**	1.7	3.5	3.1	0.5	1.1	2.4
Roe	**Price lb $**	$ 3.07	$ 2.03	$ 1.22	$ 1.39	$ 1.80	$ 1.83
Roe	**Value share**	14%	15%	8%	2%	4%	9%

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; 2011-2013 average, and 2014-2019.

	Avg 11-13	2014	2015	2016	2017	2018
Global Pollock Catch K mt	3,243	3,245	3,373	3,476	3,488	-
U.S. Share of Global Catch	40%	44%	44%	44%	44%	-
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 analysis for GOA pollock including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for GOA pollock of the current year conditions relative to 1 standard deviation of the long-term mean (white = average, blue = good, red = poor, no fill shaded gray as table = no current year data).

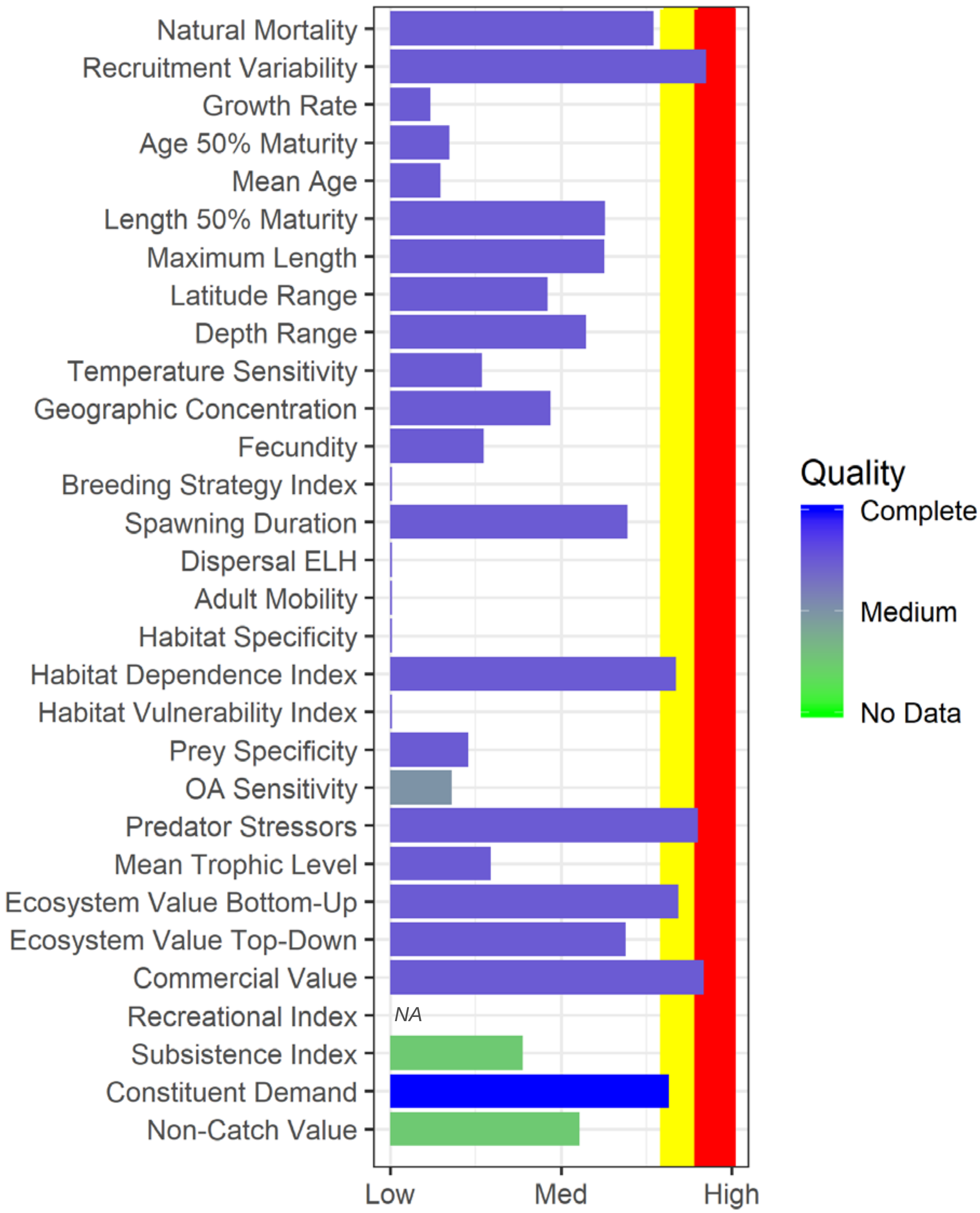
Title	Description	Recent
Annual Heatwave GOA	Regional daily mean sea surface temperatures from NOAA climate model processed following Hobday et al., 2016 to obtain marine heatwave cumulative intensity (Barbeaux, 2019)	+
Spring Sea Surface Temperature WCGOA	Western/central GOA spring (Apr-May) sea surface temperature from Pathfinder v5.3 gridded monthly dataset (Casey et al., 2010, GHRSST, CoastWatch)	+
Summer Bottom Temperature WCGOA	Average summer bottom temperature (°C) over all hauls of the RACE GOA shelf bottom trawl survey. Available from AKFIN or online survey database.	+
Spring Peak Phytoplankton Production WCGOA	Western/central GOA peak (May) derived chlorophyll *a* from Ocean Colour CCI v4.0 gridded monthly dataset (Jackson et at., 2017, European Space Agency, CoastWatch)	-
Spring Copepods Larvae Shelikof	Mean abundance of small copepods (< 2 mm) in core Shelikof area measured in log scale numbers per meter cubed with associated rapid zooplankton assessment (Kimmel et al., 2019)	●
Summer Copepods YOY Shelikof	Mean abundance of large copepods (> 2 mm) in core Shelikof area measured in log scale numbers per meter cubed with associated rapid zooplankton assessment (Kimmel et al., 2019)	●
Summer Euphausiid Abundance Kodiak	Acoustic backscatter per unit area classified as euphausiids and integrated over the water column and across Kodiak core survey area from MACE summer survey (Ressler et al., 2019)	●
Auklet Reproductive Success Chowiet	Proportion of parakeet auklet nest sites with fledged chicks from total nest sites with eggs laid from Chowiet Island (Higgins et al., 2018)	●
Spring Pollock CPUE Larvae Shelikof	Mean abundance of larval pollock taken in bongos from core sampling area in Shelikof Strait during EcoFOCI spring survey with rapid assessment (Dougherty et al., 2019)	-
Summer Pollock CPUE YOY Shelikof	Mean abundance of YOY pollock taken in midwater trawl from core area in WGOA area during EcoFOCI summer survey with rapid assessment (Rogers et al., 2019b)	●

Title	Description	Recent
Summer Pollock Condition YOY Shelikof	Body condition of YOY pollock taken in midwater trawl from core area in WGOA area during EcoFOCI summer survey with rapid assessment (Rogers et al., 2019a)	●
Summer Pollock CPUE YOY Kodiak	Catch per unit effort of YOY pollock in beach seine from fixed sites in nearshore Kodiak survey (Laurel et al., 2019)	-
Pollock Relative Biomass YOY Aiktak	Relative biomass of pollock measured from screening burrows of tufted puffins diets at Aiktak Island (Youngren et al., 2019)	●
Summer Pollock Predation Age-1	Predation mortality estimates of age-1 pollock from multiple data sources and models (Barnes et al., *In Review*)	●
Summer Pollock Euphausiid Diet Juvenile	Proportion-by-weight of euphausiids in the diets of juvenile pollock collected on summer bottom trawl survey samples in GOA (Aydin et al., 2007)	-
Fall Pollock Condition Adult Fishery	Length-weight regression of pollock sampled by observers in the fall pollock fishery (M. Dorn, *pers. commun.*)	●
Winter Pollock Condition Adult Acoustic	Length-weight regression of pollock sampled in Shelikof Strait during the late winter MACE acoustic survey (M. Dorn, *pers. commun.*)	●
Summer Pollock Center of Gravity Northeast	Biomass-weighted average of the location of extrapolation-grid cells in northeasting direction from spatio-temporal model of pollock in the summer bottom trawl survey (Thorson and Barnett, 2017)	●
Summer Pollock Area Occupied	Area required to contain the population at its average biomass from spatio-temporal model of pollock in the summer bottom trawl survey (Thorson and Barnett, 2017)	●
Arrowtooth Biomass Assessment	Total biomass estimates from arrowtooth flounder stock assessment model output (Spies et al., 2017)	●
Steller Sea Lion Adult Counts	Non-pup estimates of Steller sea lions from the GOA portion of the western Distinct Population Segment (Sweeney, 2017)	●

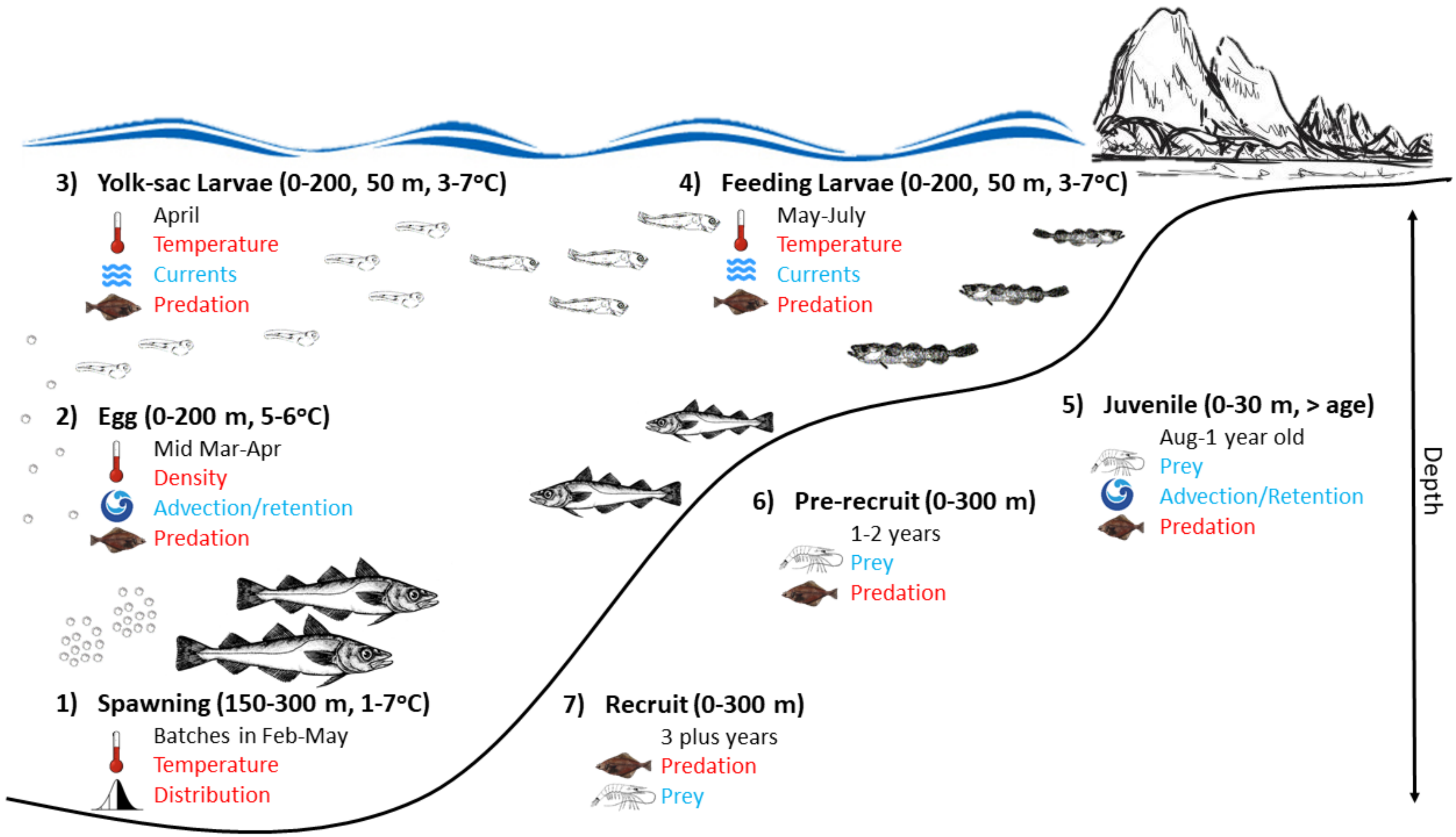
Appendix Table 1A.4b. First stage socioeconomic indicator analysis for GOA pollock including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for GOA pollock of the current year conditions relative to 1 standard deviation of the long-term mean (yellow = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Winter-Spring Pollock CPUE Fishery	Catch of pollock in tons/hour from the winter-spring (first trimester) of the pollock fishery (M. Dorn, *pers. commun.*)	+
Summer-Fall Pollock CPUE Fishery	Catch of pollock in tons/hour from the summer-fall (third trimester) of the pollock fishery (M. Dorn, *pers. commun.*)	●
Annual Pollock Real Ex-vessel Price	Estimate of real ex-vessel value in price per pound inflation adjusted to 2018 USD (Fissel et al., 2019)	●
Annual Pollock Roe per unit Catch	Roe per-unit-catch calculated as 1000*(roe production)/(retained catch) (Fissel et al., 2019)	●
Annual Percent Revenue Pollock in Kodiak	Percentage of the total revenue Kodiak gets from the GOA pollock fishery (aka, local quotient) (S. Wise, *pers. commun.*)	+

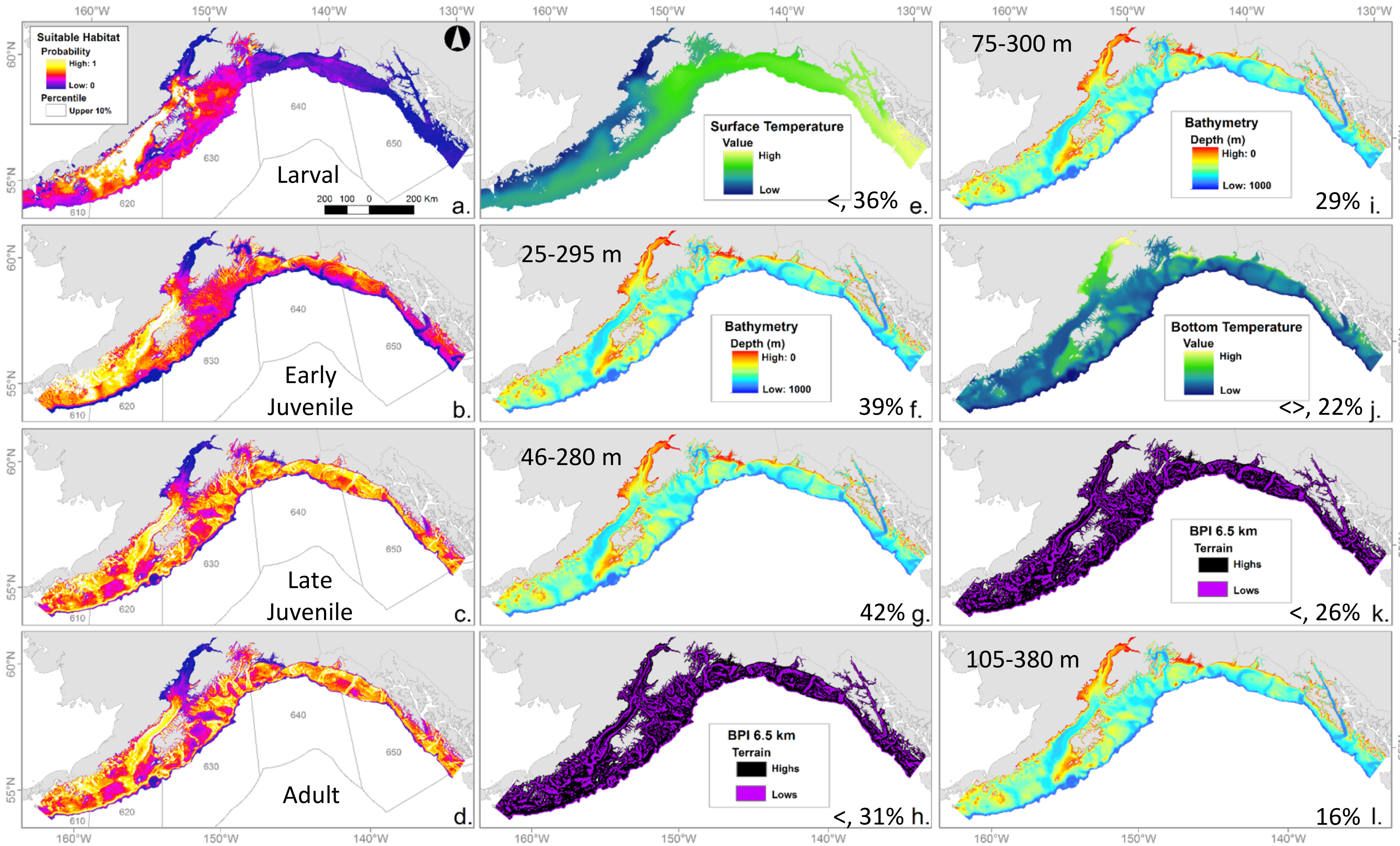
Figures



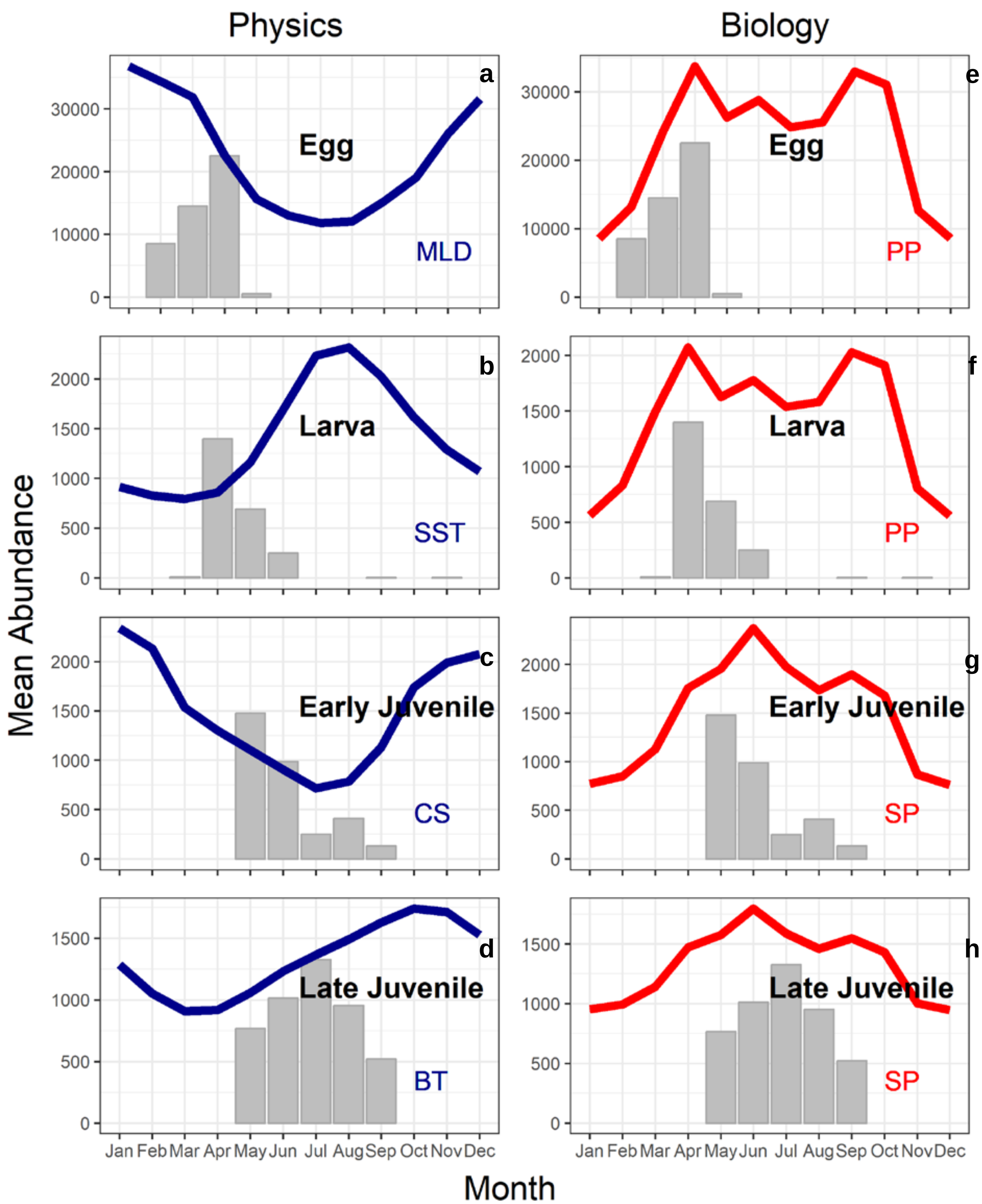
Appendix Figure 1A.1. Baseline metrics for pollock graded as percentile rank over all groundfish in the FMP. Red bar indicates 90th percentile, yellow bar indicates 80th percentile. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., In Review, for more details on the metric definitions).



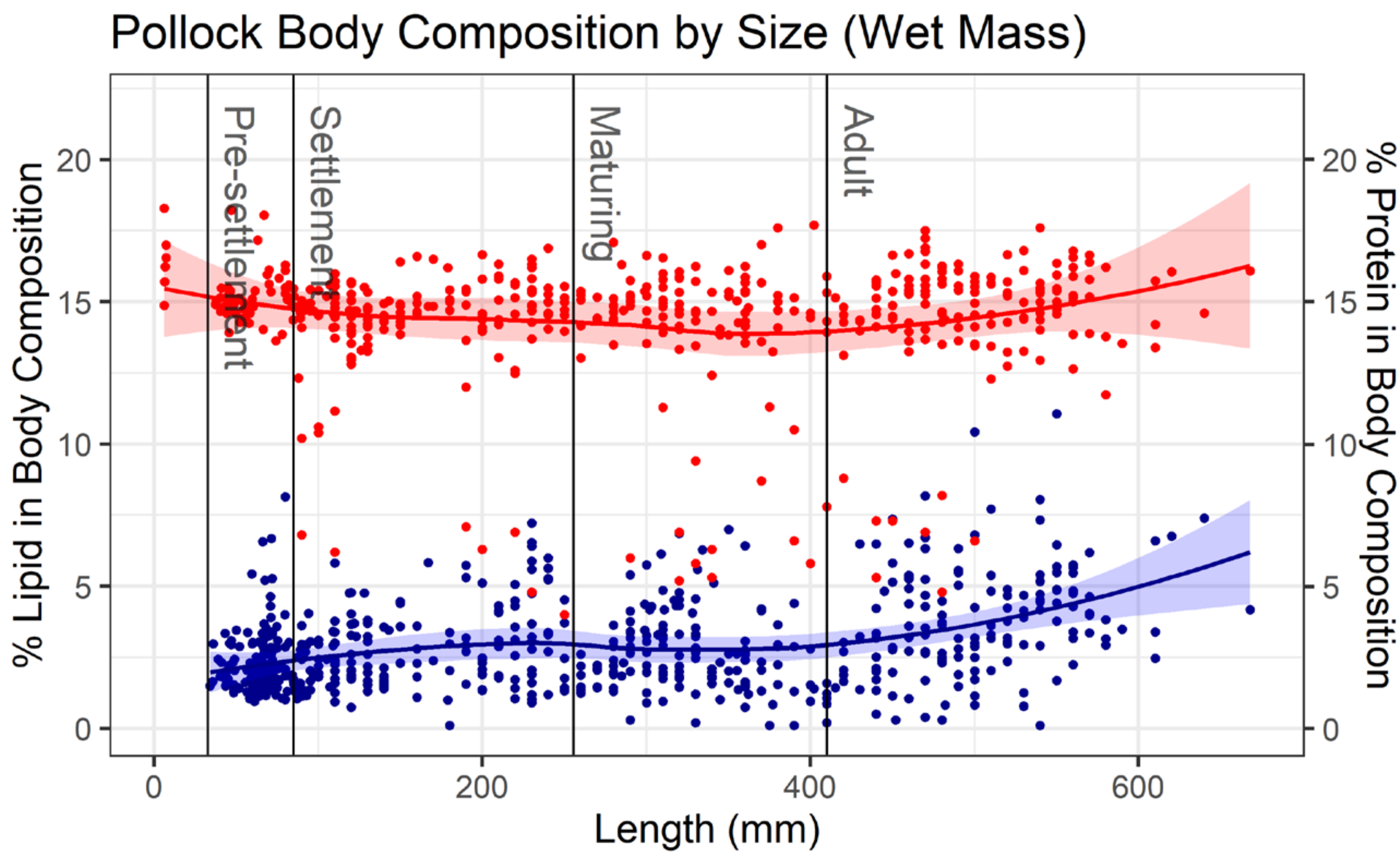
Appendix Figure 1A.2: Life history conceptual model for GOA pollock summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.



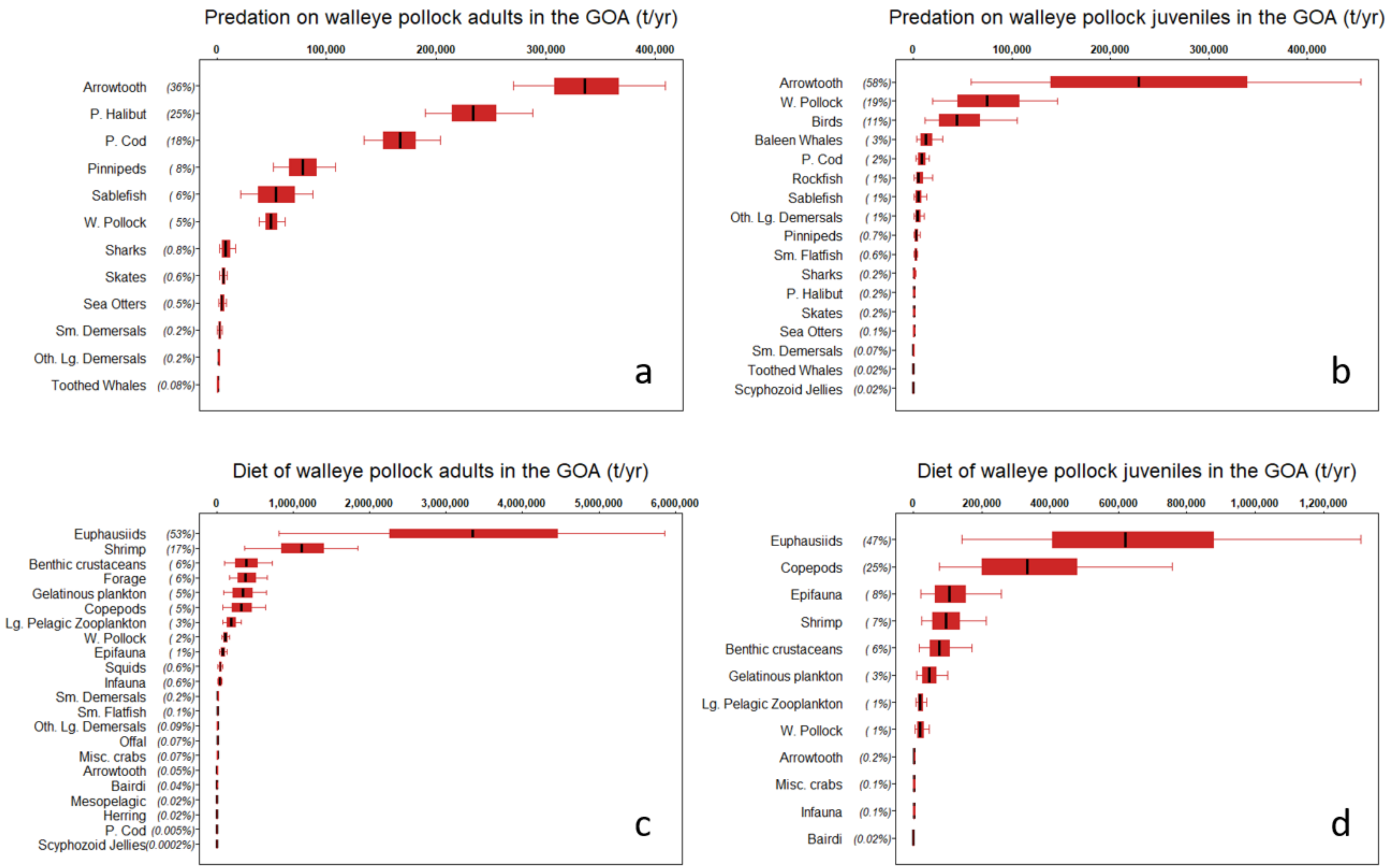
Appendix Figure 1A.3. Pollock probability of suitable habitat by life stage (a = larval, b = early juvenile, c = late juvenile, and d = adult) with corresponding predictor habitat variables representing the highest (e = surface temperature, f = depth, g = depth, h = bathymetric position index) and second highest contribution (i = depth, j = bottom temperature, k = bathymetric position index, and l = depth). Upper 10 percentile of suitable habitat is shown in white within the probability of suitable habitat range (yellow to purple). Sign (<, >, <>) of the deviation from mean direction and the percent of contribution to predict suitability provided for each non-depth variable. Range provided for depth. See Shotwell et al., In Review for more details.



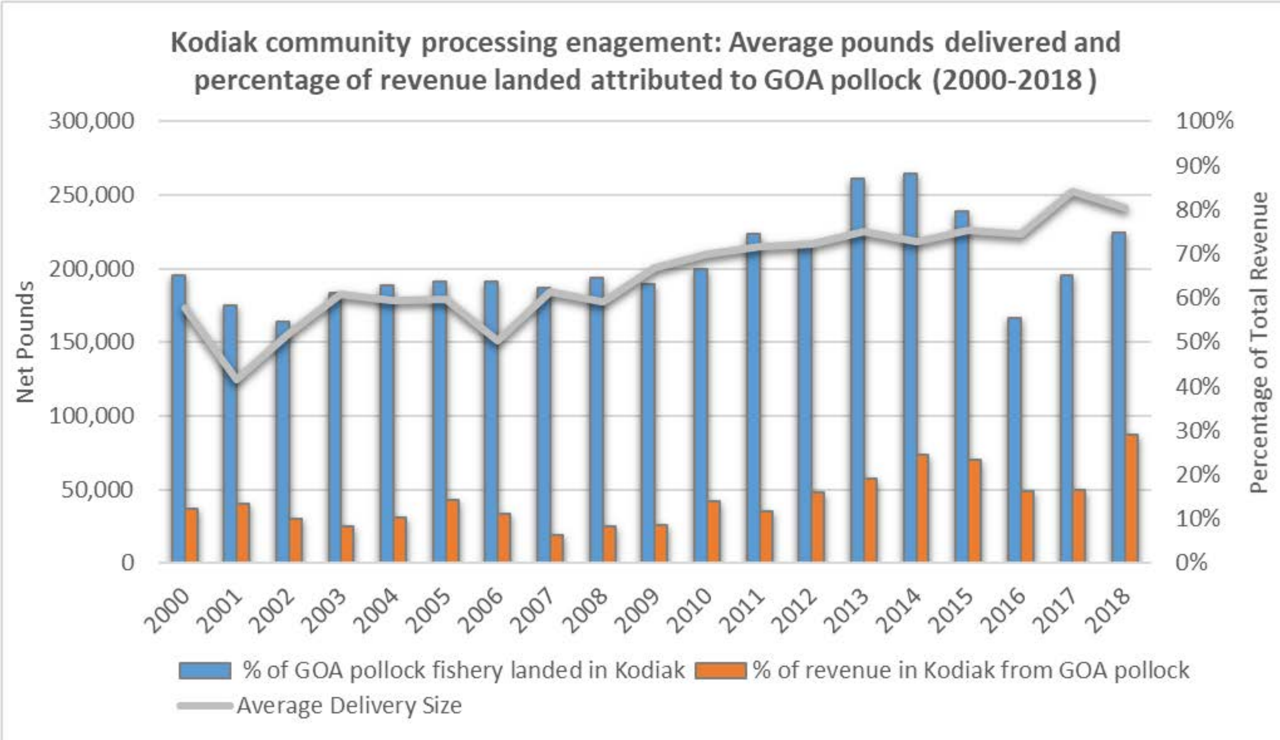
Appendix Figure 1A.4. Pollock average abundance by month over all years available for the egg, larval (yolk-sac and feeding), nearshore juvenile, and offshore juvenile stages. Relevant climatologies from the hydrographic and plankton models provide physical and biological indices (MLD = mixed layer depth, SST = surface temperature, CS = current speed, BT = bottom temperature, PP = primary productivity, and SP = secondary productivity, see Laman et al., 2017, Gibson et al., In Press, for more details).

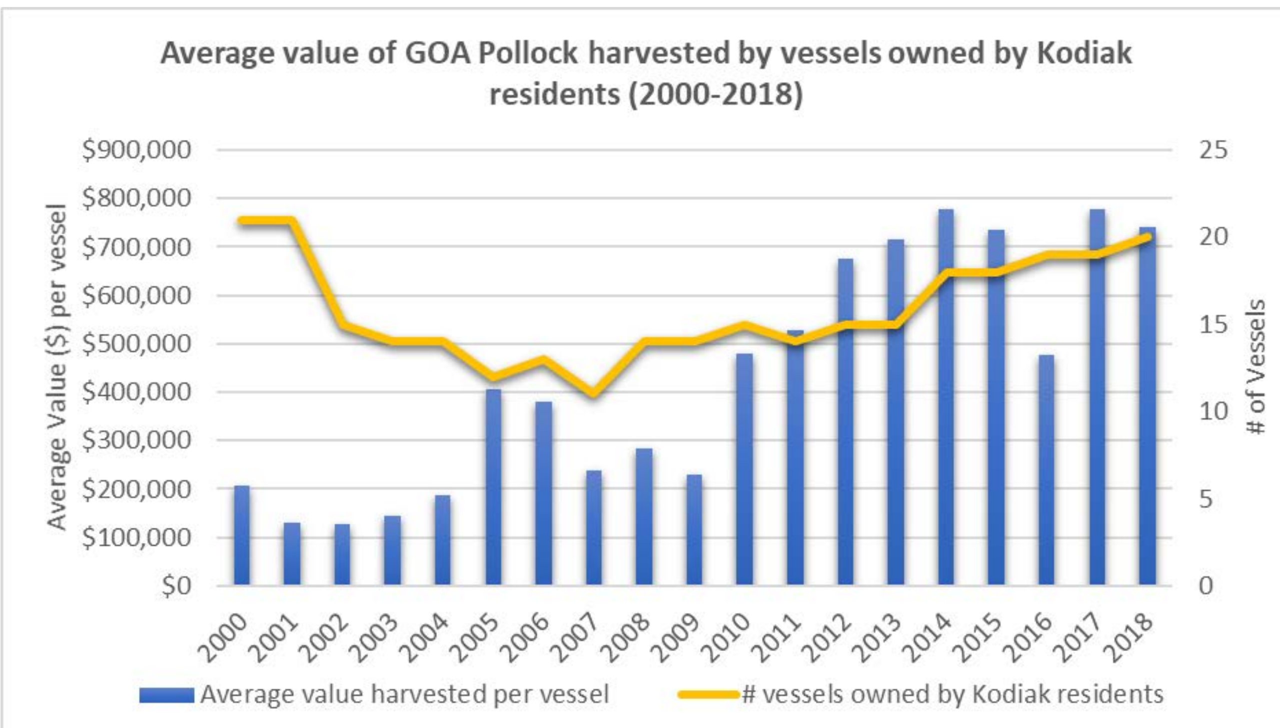


Appendix Figure 1A.5. Percent body composition by length (mm), blue dots are % lipid by size, red dots are % protein by size and lines represent smoother (loess) for trend visualization. Horizontal lines depict the average size at different life stage transitions and the adult transition is based on size at 50% female maturity.

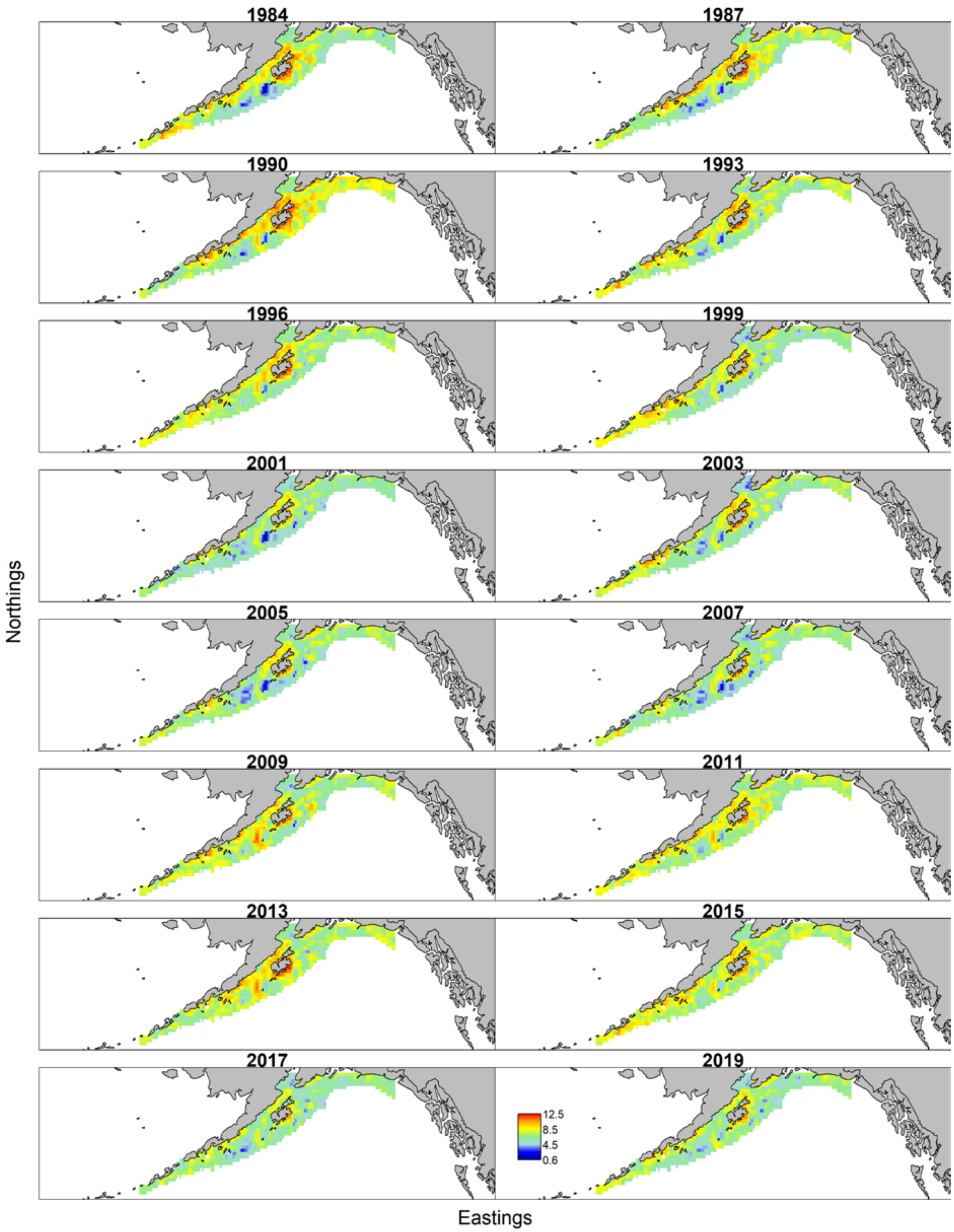


Appendix Figure 1A.6. Sources of predation mortality for (a) adult (>20 cm) and (b) juvenile pollock (<20 cm) in the GOA, and diet composition for (c) adult and (d) juvenile pollock in the GOA. Reproduced from Gaichas et al., 2015 and Dorn et al., 2018.

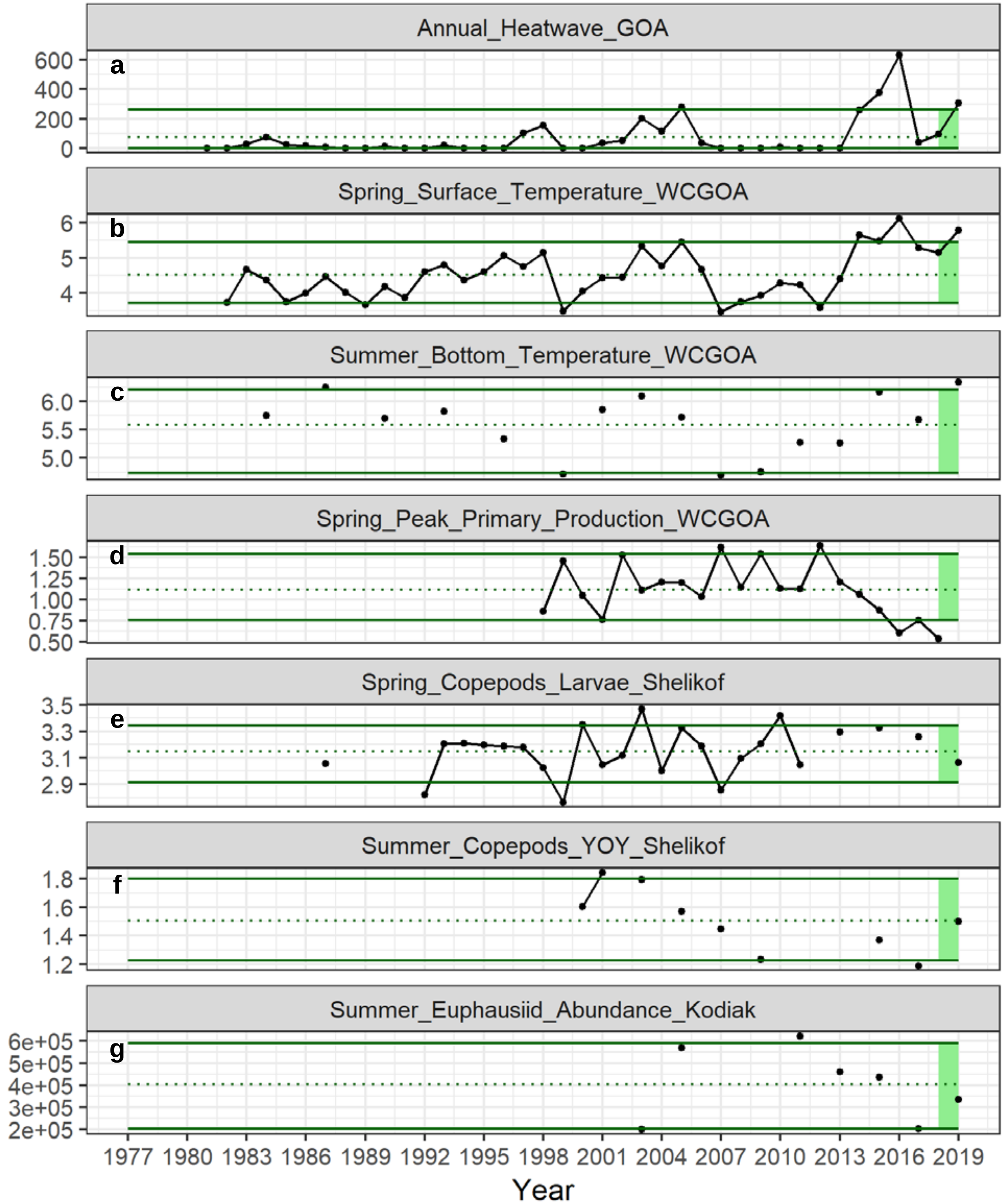




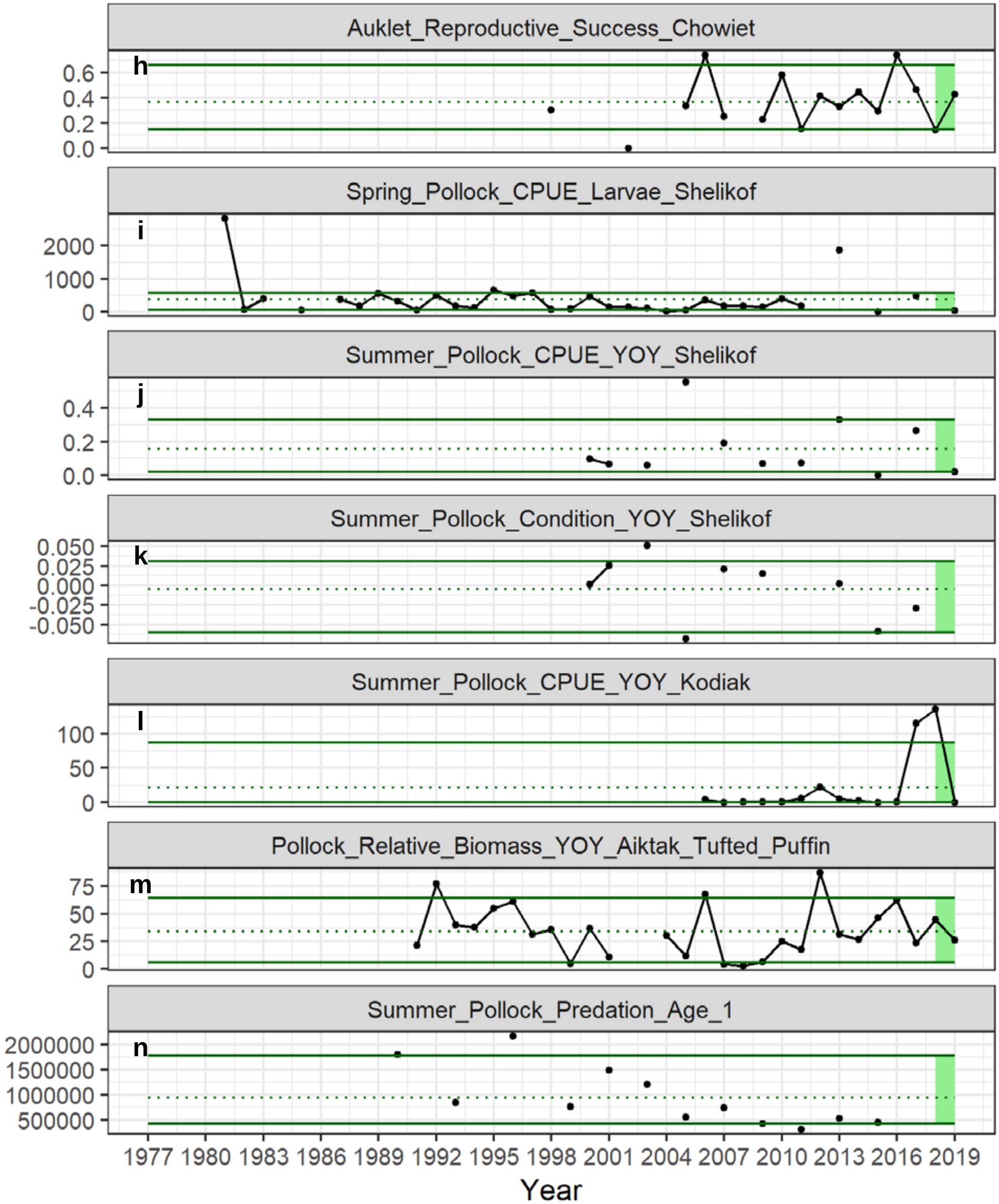
Appendix Figure 1A.7. Community profile information for GOA pollock with community engagement in processing GOA pollock for Kodiak expressed in average volume delivery, regional quotient, and local quotient percentage (a) and Kodiak harvest value per vessel and active vessels owned by residents (b).



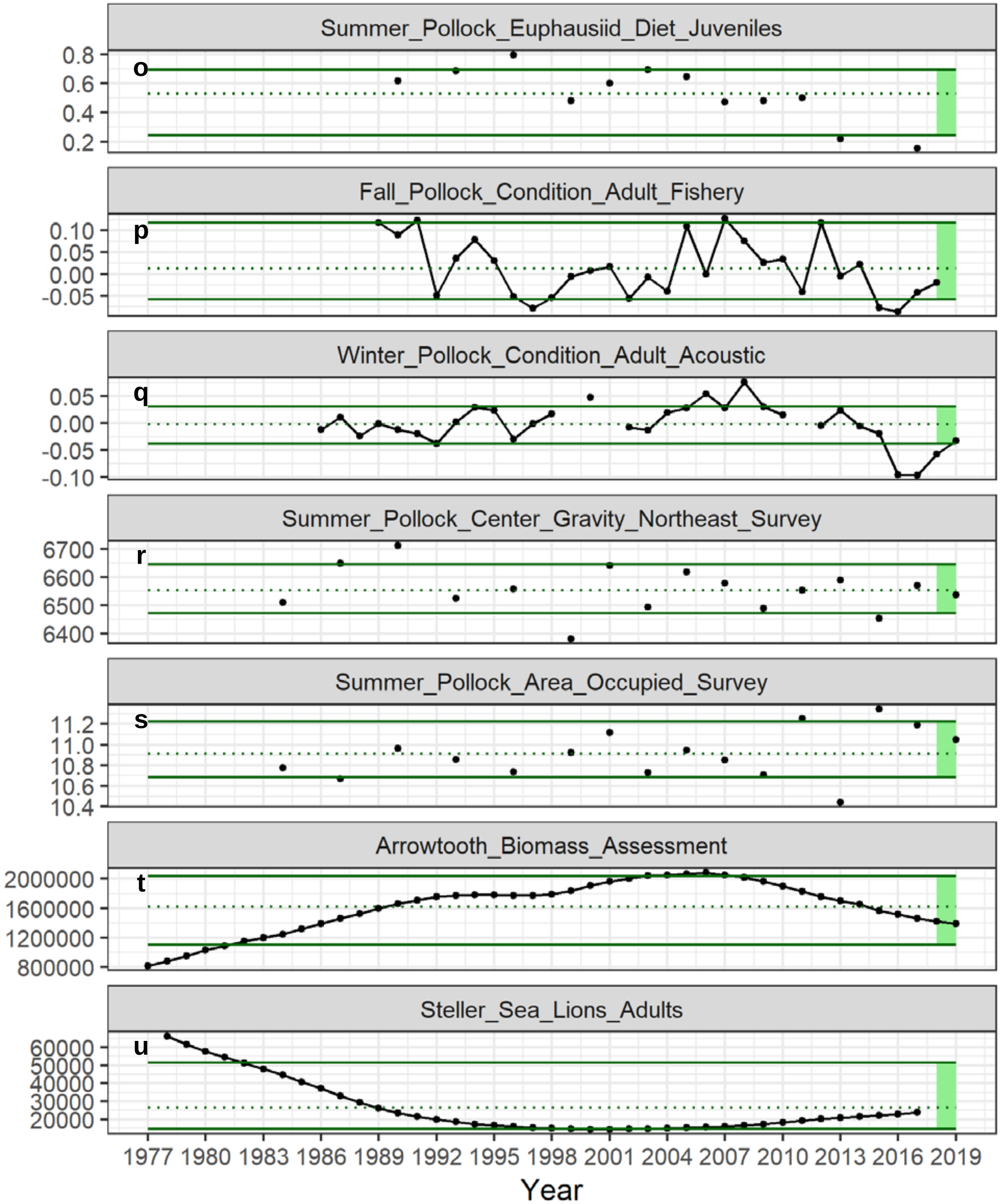
Appendix Figure 1A.8: Spatio-temporal delta-generalized linear mixed model using standard settings for an "index standardization" model (Thorson 2019), implemented using the package VAST (Thorson and Barnett 2017) in the R statistical environment (R Core Team 2017).



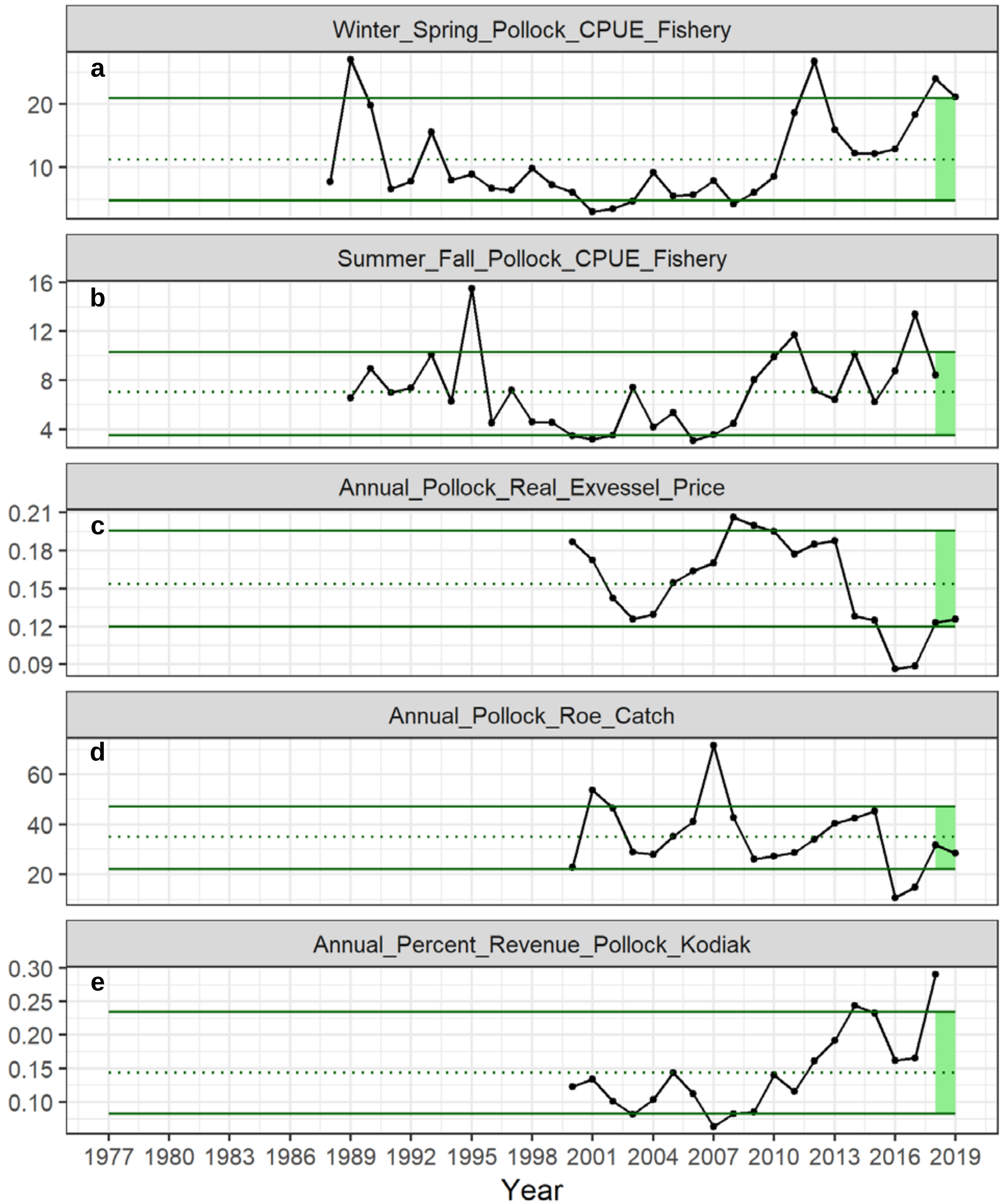
Appendix Figure 1A.9a. Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



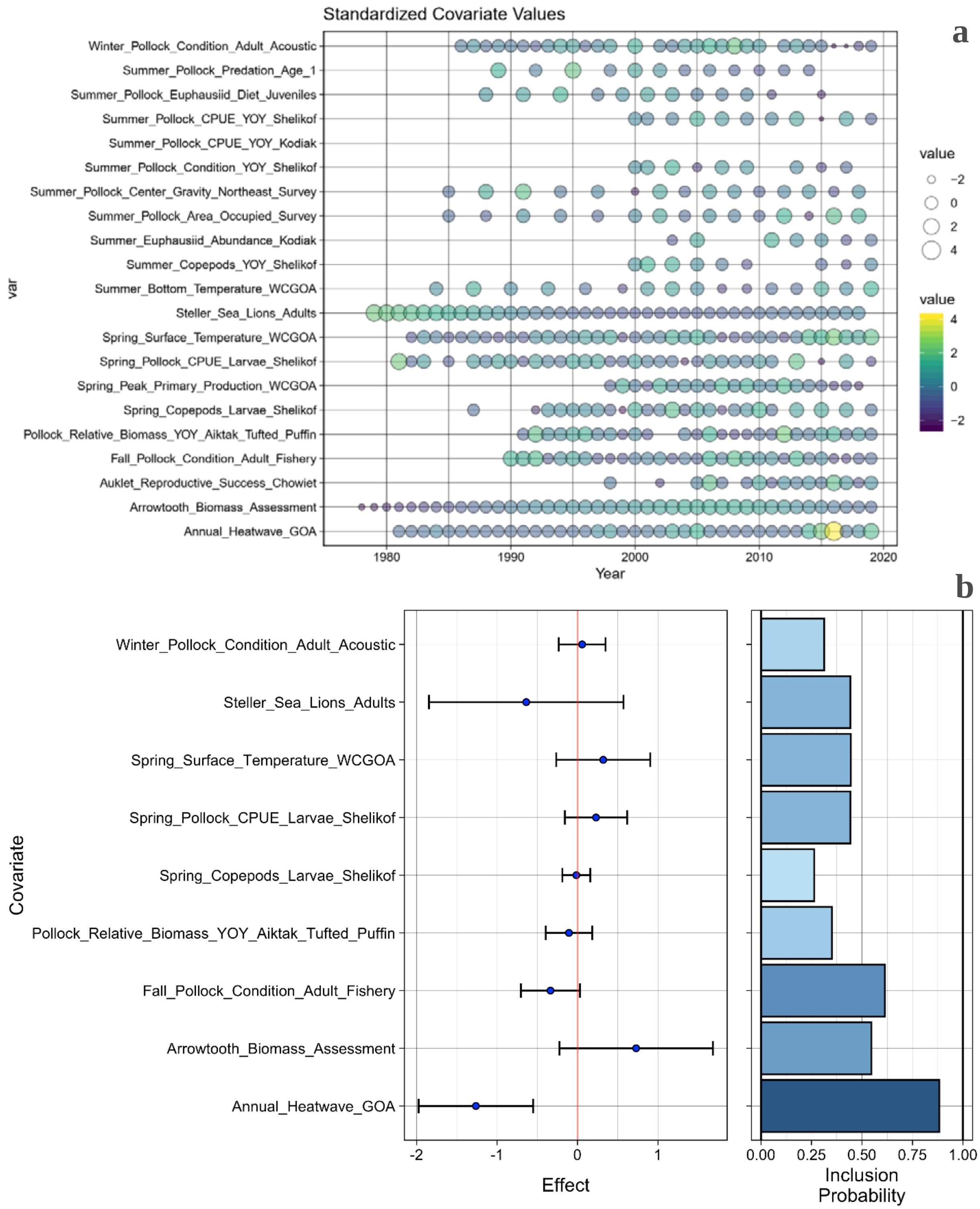
Appendix Figure 1A.9a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



Appendix Figure 1A.9a (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.9b. 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.



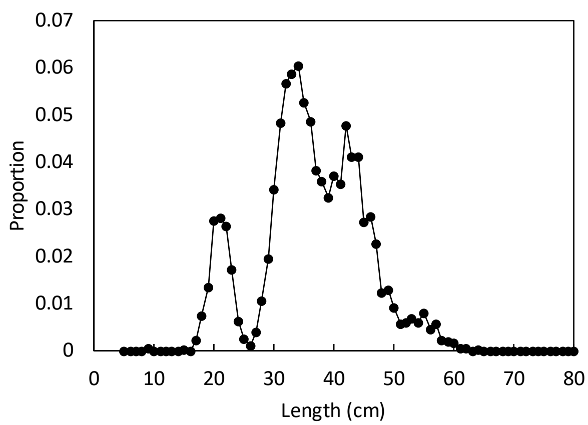
Appendix Figure 1A.10: Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (1 standard deviation) with log GOA pollock recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.

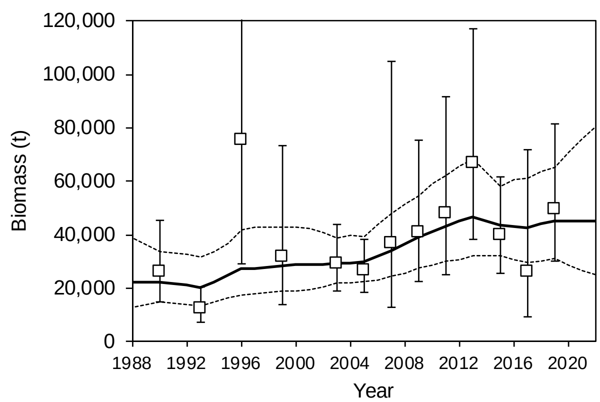
Appendix 1B. Southeast Alaska pollock assessment

Bottom trawl surveys indicate a substantial reduction in pollock abundance east of 140° W. lon. Stock structure in this area is poorly understood. Bailey et al. (1999) suggest that pollock metapopulation structure in southeast Alaska is characterized by numerous fiord populations. In the 2019 bottom trawl survey, higher pollock CPUE in southeast Alaska occurred primarily from Baranof Island south to Dixon Entrance, where the shelf is broader. Pollock size composition in the 2019 bottom trawl survey showed a small mode of age-1 pollock, unlike the very strong mode seen in the central GOA. There was another mode in 30-50 cm range that like reflects several year classes (Appendix Fig. A.1). Juveniles in this area are unlikely to influence the population dynamics of pollock in the central and western Gulf of Alaska. Ocean currents are generally northward in this area, suggesting that juvenile settlement is a result of spawning further south. Spawning aggregations of pollock have been reported from the northern part of Dixon Entrance (Saunders et al. 1988).

Historically, there has been little directed fishing for pollock in Southeast Alaska (Fritz 1993). Pollock catch the Southeast and East Yakutat statistical areas has averaged about 2 t since 2008 (Table 1.4). The ban on trawling east of 140° W. lon. prevents the development of a trawl fishery for pollock in Southeast Alaska, though recently there has been interest in directed pollock fishing using other gear types, such as purse seine.

Biomass in Southeast Alaska was estimated by splitting survey strata and CPUE data in the Yakutat statistical area at 140° W. lon. and combining the strata east of the line with comparable strata in the Southeastern statistical area. Surveys since 1996 had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Appendix Fig. A.1). There is a gradual increase in biomass since 2005, but confidence intervals are large. A random effects model was fit to the 1990-2019 bottom trawl survey biomass estimates in southeast Alaska. We recommend placing southeast Alaska pollock in Tier 5 of the NPFMC tier system, and basing the ABC and OFL on natural mortality (0.3) and the biomass estimate from the random effects model (45,103 t). **This results in a 2019 ABC of 10,148 t (45,103 t * 0.75 M), and a 2019 OFL of 13,531 t (45,103 t * M). The same ABC and OFL is recommended for 2020.**





Appendix figure 1B.1. Pollock size composition in 2019 (left) and biomass trend in southeast Alaska from a random effects model fit to NMFS bottom trawl surveys in 1990-2019 (right). Error bars indicate plus and minus two standard deviations. The solid line is the biomass trend from the random effects model, while dotted lines indicate the 95% confidence interval.

Appendix 1C. GOA pollock stock assessment model

Population dynamics

The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 1 to age 10, with age 10 defined as a "plus" group, i.e., all individuals age 10 and older. The Baranov (1918) catch equations are assumed, so that

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

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

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

except for the plus group, where

$$N_{i+1,10} = N_{i,9} \exp(-Z_{i,9}) + N_{i,10} \exp(-Z_{i,10})$$

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

Fishing mortality is modeled as a product of year-specific and age-specific factors (Doubleday 1976)

$$F_{ij} = s_j f_i$$

where s_j is age-specific selectivity, and f_i is the annual fishing mortality rate. To ensure that the selectivities are well determined, we require that $\max(s_j) = 1$. Following previous assessments, a scaled double-logistic function (Dorn and Methot 1990) was used to model age-specific selectivity,

$$s'_j = \left(\frac{1}{1 + \exp[-\beta_1 (j - \alpha_1)]} \right) \left(1 - \frac{1}{1 + \exp[-\beta_2 (j - \alpha_2)]} \right)$$

$$s_j = s'_j / \max(s'_j)$$

where α_1 = inflection age, β_1 = slope at the inflection age for the ascending logistic part of the equation, and α_2, β_2 = the inflection age and slope for the descending logistic part.

Measurement error

Model parameters were estimated by maximum likelihood (Fournier and Archibald 1982, Kimura 1989, 1990, 1991). Fishery observations consist of the total annual catch in tons, C_i, and the proportions at age in the catch, p_{ij}. Predicted values from the model are obtained from

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

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

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

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

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

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

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

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

where q = survey catchability, w_{ij} is the survey weight at age j in year i (if available), s_j = selectivity at age for the survey, and ϕ_i = fraction of the year to the mid-point of the survey. Although there are multiple surveys for GOA pollock, a subscript to index a particular survey has been suppressed in the above and subsequent equations in the interest of clarity. Survey selectivity was modeled using either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the *i*th year are given by

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

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

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

where σ_i is the standard deviation of the logarithm of total biomass (~ CV of the total biomass) and m_i is the size of the age sample from the survey.

Process error

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

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

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

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

where σ_i is the standard deviation of the annual change in the parameter. We use a process error model for the two parameters for the ascending portion of the fishery double-logistic curve. Variation in the intercept selectivity parameter is modeled using a random walk on an arithmetic scale, while variation in the slope parameter is modeled using a log-scale random walk. We also use a process error model for catchability for the Shelikof Strait acoustic survey and the ADFG bottom trawl survey to account for changes in the proportion of the stock surveyed.

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

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

Appendix 1D. Seasonal distribution and apportionment of pollock among management areas in the Gulf of Alaska

Since 1992, the GOA pollock TAC has been apportioned between management areas based on the distribution of biomass in groundfish surveys. Steller sea lion protection measures that were implemented in 2001 require apportionment of pollock TAC based on the seasonal distribution of biomass. Both single species and ecosystem considerations provide rationale for apportioning the TAC. From an ecosystem perspective, apportioning the TAC will spatially distribute the effects of fishing on other pollock consumers, such as Steller sea lions, potentially reducing the overall intensity of any adverse effects. Apportioning the TAC also ensures that no smaller component of the stock experiences higher mortality than any other. Although sub-stock units of pollock have not been identified in the Gulf of Alaska, managing the fishery so as to preserve the existing spatial structure could be regarded as a precautionary approach. Protection of sub-stock units would be most important during spawning season, when they would be separated spatially.

Pollock in the GOA undergo an annual migration between summer foraging habitats and winter spawning grounds. Since surveying effort has been concentrated during the summer months, and prior to spawning in late winter, the dynamics and timing of this migration are not well understood. Regional biomass estimates are highly variable, indicating either large sampling variability, large interannual changes in distribution, or, more likely, both. There is a comprehensive survey of the Gulf of Alaska in summer, but surveying during winter has historically focused on the Shelikof Strait spawning grounds. Recently there has been expanded acoustic surveying effort outside of Shelikof Strait in winter, but there have been only infrequent attempts to survey all or most of the known spawning areas in GOA.

Winter apportionment

An annual acoustic survey on pre-spawning aggregations in Shelikof Strait has been conducted since 1981. Since 2000, additional spawning areas have been surveyed multiple times, including Sanak Gully, the Shumagin Islands, the shelf break near Chirikof Island, and Marmot Bay. Although none of these spawning grounds are as important as Shelikof Strait, especially from a historical perspective, in some years the aggregate biomass surveyed outside Shelikof Strait has been comparable to that within Shelikof Strait.

As in previous assessments, a “composite” approach was used to estimate the percent of the total stock in each management area. The estimated 2+ biomass for each survey was divided by the total 2+ biomass of pollock estimated by the assessment model in that year and then split into management areas for surveys that crossed management boundaries. The percent for each survey was added together to form a composite biomass distribution, which was then rescaled so that it summed to 100%. Model estimates of 2+ biomass at spawning took into account the total mortality between the start of the year and spawning, and used mean weight at age from Shelikof Strait surveys.

We used the four most recent surveys at each spawning area, and used a rule that a minimum of three surveys was necessary to include an area. This criterion is intended to provide estimates that reflect recent biomass distribution while at the same time providing some stability in the estimates. The biomass in these secondary spawning areas tends to be highly variable from one year to the next. Areas meeting this criterion were Shelikof Strait, the shelf break near Chirikof Island, the Shumagin area, Sanak Gully, Morzhovoi Bay, Pavlof Bay, and Marmot Bay. While the spawning aggregations found in the Kenai Bays, and in Prince William Sound are likely important, additional surveys are needed to confirm stability of spawning in these areas before including them in the apportionment calculations. There are also several potentially difficult issues that would need to dealt with, for example, whether including biomass in the Kenai Bays would lead increased harvests on the east side of Kodiak, both of which are in area 630. In addition, the fishery inside Prince William Sound (area 649) is managed by the State of Alaska, and state management objectives for Prince William Sound would need to be considered.

The sum of the percent biomass for all surveys combined was 152.11%, which is driven by the recent high biomass estimates in Shelikof Strait, but may also reflect sampling variability, or interannual variation in spawning location. After rescaling, the resulting average biomass distribution was 2.06%, 88.68%, and 9.25% in areas 610, 620, and 630 (Appendix table 1D.1). In comparison to last year, the percentage in area 610 is 0.6 percentage points lower, 2.5 percentage points higher in area 620, and 1.9 percentage points lower in area 630.

A-season apportionment between areas 620 and 630

In 2002, based on evaluation of fishing patterns which suggested that the migration to spawning areas was not complete by January 20, the Gulf of Alaska plan team recommended an alternative apportionment scheme for areas 620 and 630 based on the average of the summer and winter distributions in area 630. This approach was not used for area 610 because fishing patterns during the A season suggested that most of the fish captured in area 610 would eventually spawn in area 610. The resulting A season apportionment is: 610, 2.06%; 620, 74.86%; 630, 23.05%.

Summer distribution

Several allocation options were presented to the plan team in 2017 to account for the variability and lack of consistency in the bottom trawl and the acoustic surveys. The option that was recommended and adopted by the plan team was a 3-survey weighted average of the sum of the acoustic and bottom trawl biomass estimates for each area. The weighted average gave weights of 1.0, 0.5, and 0.25 to 2017, 2015, and 2013, respectively. Updating this approach using 2019, 2017, and 2015 surveys gave the resulting apportionment is 610, 34.30%; 620, 25.48%; 630, 34.97%; 640, 5.25% (Appendix table 1D.2).

Apportionment for area 640

The apportionment for area 640, which is not managed by season, is based on the estimated summer distribution of the biomass. The percentage (4.34%) of the TAC in area 640 is subtracted from the TAC before allocating the remaining TAC by season and region. The overall allocation by season and area is given in Appendix table 1D.3.

Appendix 1E. Supplemental catch data

To comply with the Annual Catch Limit (ACL) requirements, estimates have been developed by the Alaska for non-commercial catches and removals from NMFS-managed stocks in Alaska. (Appendix table 1E.1). Reported non-commercial catches primarily include catches associated with surveys and research projects. Small amounts of pollock catch are attributed to subsistence and bait for crab. It is important to note that there is unreported incidental catch of pollock in other fisheries in Alaska, such as the salmon fishery, which, based on anecdotal reports, may be substantial on occasion.

Appendix table 1D.1. Estimates of percent pollock in areas 610-630 during winter EIT surveys in the GOA. The biomass of age-1 fish is excluded from the acoustic survey biomass estimates.

Survey	*Year*	*Model estimates of total 2+ biomass at spawning*	*Survey biomass estimate*	*Percent*	*Percent by management area* Area 610	*Area 620*	*Area 630*
Shelikof	2016	1,258,720	666,801	53.0%	0.0%	79.3%	20.7%
Shelikof	2017	990,320	1,457,295	147.2%	0.0%	99.1%	0.9%
Shelikof	2018	734,861	1,306,107	177.7%	0.0%	93.9%	6.1%
Shelikof	2019	597,124	1,219,160	204.2%	0.0%	97.1%	2.9%
Shelikof	Average			145.5%	0.0%	92.3%	7.7%
	Percent of total biomass				0.0%	134.4%	11.1%
Chirikof	2013	994,390	63,224	6.4%	0.0%	70.2%	29.8%
Chirikof	2015	1,357,500	12,705	0.9%	0.0%	26.3%	73.7%
Chirikof	2017	990,320	2,485	0.3%	0.0%	0.4%	99.6%
Chirikof	2019	597,124	9,907	1.7%	0.0%	36.4%	63.6%
Chirikof	Average			2.3%	0.0%	33.3%	66.7%
	Percent of total biomass				0.0%	0.8%	1.5%
Marmot	2016	1,258,720	24,859	2.0%	0.0%	0.0%	100.0%
Marmot	2017	990,320	13,129	1.3%	0.0%	0.0%	100.0%
Marmot	2018	734,861	12,905	1.8%	0.0%	0.0%	100.0%
Marmot	2019	597,124	5,407	0.9%	0.0%	0.0%	100.0%
Marmot	Average			1.5%	0.0%	0.0%	100.0%
	Percent of total biomass				0.0%	0.0%	1.5%
Shumagin	2015	1,357,500	60,967	4.5%	71.5%	28.5%	0.0%
Shumagin	2016	1,258,720	20,392	1.6%	84.3%	15.7%	0.0%
Shumagin	2017	990,320	29,753	3.0%	95.0%	5.0%	0.0%
Shumagin	2018	734,861	7,777	1.1%	47.4%	52.6%	0.0%
Shumagin	Average			2.5%	74.6%	25.4%	0.0%
	Percent of total biomass				1.9%	0.6%	0.0%
Sanak	2015	1,357,500	17,905	1.3%	100.0%	0.0%	0.0%
Sanak	2016	1,258,720	3,571	0.3%	100.0%	0.0%	0.0%
Sanak	2017	990,320	831	0.1%	100.0%	0.0%	0.0%
Sanak	2018	734,861	1,316	0.2%	100.0%	0.0%	0.0%
Sanak	Average			0.5%	100.0%	0.0%	0.0%
	Percent of total biomass				0.5%	0.0%	0.0%
Mozhovoi	2013	994,390	600	0.1%	100.0%	0.0%	0.0%
Mozhovoi	2016	1,258,720	11,459	0.9%	100.0%	0.0%	0.0%
Mozhovoi	2017	990,320	3,924	0.4%	100.0%	0.0%	0.0%
Mozhovoi	2018	734,861	3,759	0.5%	100.0%	0.0%	0.0%
Mozhovoi	Average			0.5%	100.0%	0.0%	0.0%
	Percent of total biomass				0.5%	0.0%	0.0%
Pavlof	2016	1,258,720	2,140	0.2%	100.0%	0.0%	0.0%
Pavlof	2017	990,320	2,092	0.2%	100.0%	0.0%	0.0%
Pavlof	2018	734,861	4,413	0.6%	100.0%	0.0%	0.0%
Pavlof	Average			0.3%	100.0%	0.0%	0.0%
	Percent of total biomass				0.3%	0.0%	0.0%
Total				153.11%	3.16%	135.78%	14.16%
Rescaled total				100.00%	2.06%	88.68%	9.25%

Appendix table 1D.2. Summer acoustic and NMFS bottom trawl biomass estimates of pollock by management area in the GOA. The weighted average for allocation gives weights of 1.0, 0.5, and 0.25 to 2019, 2017, and 2015, respectively.

		Summer acoustic estimates		
		Biomass (t)		
Year	*Area 610*	*Area 620*	*Area 630*	*Area 640*
2015	425,952	476,006	632,316	63,955
2017	408,334	338,923	498,460	72,679
2019	119,502	201,711	207,058	43,204
		Percent		
	Area 610	*Area 620*	*Area 630*	*Area 640*
2015	26.65%	29.78%	39.56%	4.00%
2017	30.97%	25.71%	37.81%	5.51%
2019	20.91%	35.30%	36.23%	7.56%

		Bottom trawl estimates		
		Biomass (t)		
Year	*Area 610*	*Area 620*	*Area 630*	*Area 640*
2015	403,884	98,001	181,482	24,408
2017	214,605	23,658	43,803	6,878
2019	119,312	36,450	90,921	10,921
		Percent		
	Area 610	*Area 620*	*Area 630*	*Area 640*
2015	57.06%	13.85%	25.64%	3.45%
2017	74.27%	8.19%	15.16%	2.38%
2019	46.32%	14.15%	35.29%	4.24%

Options for allocation

Option 5: Weighted average of acoustic plus bottom trawl biomass (2015-2019)

Area 610	*Area 620*	*Area 630*	*Area 640*
432,996	321,688	441,463	66,282
34.30%	25.48%	34.97%	5.25%

Appendix table 1D.3. Calculation of 2020 Seasonal and Area TAC Allowances for the W/C/WYK region.

Proposed ABC for W/C/WYK (t): 108,494

Winter biomass distribution			
Area	610	620	630
Percent	2.06%	88.68%	9.25%

Summer biomass distribution				
Area	610	620	630	640
Percent	34.30%	25.48%	34.97%	5.25%

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

PWS percent	2.50%	GHL (t)	2,712
Federal percent	97.50%	Federal TAC	105,782

2) Use summer biomass distribution for the 640 allowance:

640 percent	5.25%	640 TAC (t)	5,554
610-630 percent	94.75%	610-630 TAC (t)	100,228

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

Season	Percent	TAC (t)
A season TAC (t)	25%	25,057
B season TAC (t)	25%	25,057
C season TAC (t)	25%	25,057
D season TAC (t)	25%	25,057

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

	A season	
Area	Percent	TAC (t)
610	2.06%	517
620	74.86%	18,757
630	23.08%	5,783

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

	B season	
Area	Percent	TAC (t)
610	2.06%	517
620	88.68%	22,222
630	9.25%	2,318

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

	C season	
Area	Percent	TAC (t)
610	36.20%	9,070
620	26.89%	6,739
630	36.91%	9,248

	D season	
Area	Percent	TAC (t)
610	36.20%	9,070
620	26.89%	6,739
630	36.91%	9,248

Appendix table 1E.1. Non-commercial catch (t) of pollock in the GOA by collection agency.

	Collection Agency		
Year	ADF&G	IPHC	NMFS
1982	0.067		
1986	0.055		
1989	0.001		
1990			0.487
1991	0.093		0.486
1992	0.161		0.672
1993	0.168		0.567
1994	0.047		0.293
1995			0.445
1996	0.004		0.318
1997	0.171		1.390
1998	1.232		0.344
1999	4.663		2.187
2000	5.635		0.169
2001	1.536		3.986
2002	2.664		0.205
2003	3.721		3.238
2004	4.669		0.141
2005	8.970		1.162
2006	2.424		0.361
2007	3.052		1.562
2008	2.290		8.446
2009	3.620		4.649
2010	107.060	1.508	309.242
2011	107.939	0.473	1366.680
2012	136.744	0.228	242.403
2013	93.920	0.770	2518.680
2014	76.744	1.303	2716.497
2015	37.518	1.072	316.009
2016	20.463	0.898	210.404
2017	35.628	0.172	326.989
2018	44.027	0.160	224.368