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

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Executive Summary

Summary of Changes in Assessment Model Inputs

Changes in input data

1. Fishery: 2020 total catch and catch at age.
2. Shelikof Strait acoustic survey: 2021 biomass index and age composition.
3. NMFS bottom trawl survey: 2021 biomass index and length composition
4. Summer acoustic survey: 2021 biomass index and length composition
5. ADF&G crab/groundfish trawl survey: 2021 biomass index and 2020 age composition

Changes in assessment methodology

The age-structured assessment model is identical to the model used for the 2019 and 2020 assessments (Model 19.1).

Summary of Results

The base model projection of female spawning biomass in 2022 is 186,481 t, which is 43.4% of unfished spawning biomass (based on average post-1977 recruitment) and above B40% (172,000 t), thereby placing GOA pollock in sub-tier “a” of Tier 3. New surveys in 2021 include the winter Shelikof Strait acoustic survey, NMFS bottom trawl survey, summer acoustic survey, and ADF&G bottom trawl survey. These surveys indicated similar relative abundance in 2021, unlike previous years when the surveys showed strongly contrasting trends. The risk matrix table recommended by the SSC was used to determine whether to recommend an ABC lower than the maximum permissible. The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. Although we identified some aspects of the stock that merit close tracking, there were no elevated concerns about stock assessment, population dynamics, environment/ecosystem, or fisheries performance categories. We therefore recommend no reduction from maximum permissible ABC.

The authors’ 2022 ABC recommendation for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 133,081 t, which is an increase of 26% from the 2021 ABC. The author’s recommended 2023 ABC is 131,912 t. The OFL in 2022 is 154,983 t, and the OFL in 2023 if the ABC is taken in 2022 is 153,097 t. These calculations are based on a projected 2021 catch of 92,342 t (Mary

Furuness, pers. comm. Oct. 14, 2021). It should be noted that the ABC is projected to increase after 2023 even as the large 2012 year class continues to diminish due to new large cohorts entering the exploitable stock, although there is considerable uncertainty about the 2018 year class.

For pollock in southeast Alaska (Southeast Outside region, east of 140° W lon.), the ABC recommendation for both 2022 and 2023 is 11,363 t (see Appendix 1B) and the OFL recommendation for both 2022 and 2023 is 15,150 t. These recommendations are based on a Tier 5 assessment using the projected biomass in 2022 and 2023 from a random effects model fit to the 1990-2021 bottom trawl survey biomass estimates of the assessment area.

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

Quantity/Status	As estimated or specified *last* year for 2021	2022	As estimated or recommended *this* year for 2022	2023
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	3a	3b	3a	3b
Projected total (age 3+) biomass (t)	1,097,340	812,182	848,878	1,205,850
Female spawning biomass (t)	184,530	169,577	186,481	167,840
$B_{100\%}$	443,000	443,000	430,000	430,000
$B_{40\%}$	177,000	177,000	172,000	172,000
$B_{35\%}$	155,000	155,000	150,000	150,000
F_{OFL}	0.33	0.30	0.31	0.29
$maxF_{ABC}$	0.28	0.26	0.26	0.26
F_{ABC}	0.28	0.26	0.26	0.26
OFL (t)	123,455	106,767	154,983	153,097
maxABC (t)	105,722	91,934	133,081	131,912
ABC (t)	105,722	91,934	133,081	131,912
Status	As determined *last* year for 2019	2020	As determined *this* year for 2020	2021
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: 2021	2022	As estimated or *recommended this* year for: 2022	2023
M (natural mortality rate)	0.3	0.3	0.3	0.3
Tier	5	5	5	5
Biomass (t)	45,103	45,103	50,500	50,500
F_{OFL}	0.30	0.30	0.30	0.30
$maxF_{ABC}$	0.23	0.23	0.23	0.23
F_{ABC}	0.23	0.23	0.23	0.23
OFL (t)	13,531	13,531	15,150	15,150

maxABC (t)	10,148	10,148	11,363	11,363
ABC (t)	10,148	10,148	11,363	11,363
	As determined *last* year for:		As determined *this* year for:	
Status	2019	2020	2020	2021
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments Specific to this Assessment

The SSC in December 2020: "For the ESP socioeconomic indices, the SSC suggests using Kodiak and small community categories for the annual percent harvesting revenue indicators similar to what was done for the annual percent processing revenue indicators, for consistency with the text in this ESP (pg. 110) and the approach used in other ESPs, as well as for comprehensiveness"

In the future, we plan to conduct a thorough evaluation of the information provided in the Economic SAFE and ACEPO report to determine what socioeconomic indicators could be provided in the ESP that are not redundant with those reports and related directly to stock health. This may result in a transition of indicators currently reported in this ESP to a different series of socioeconomic indicators in future ESPs and may include aggregating small communities as suggested or focusing more on dependency rather than engagement. Additional considerations should be given for the timing of the economic and community reports that are delayed by 1-2 years depending on the data source from the annual stock assessment cycle and how this information might inform the stock assessment

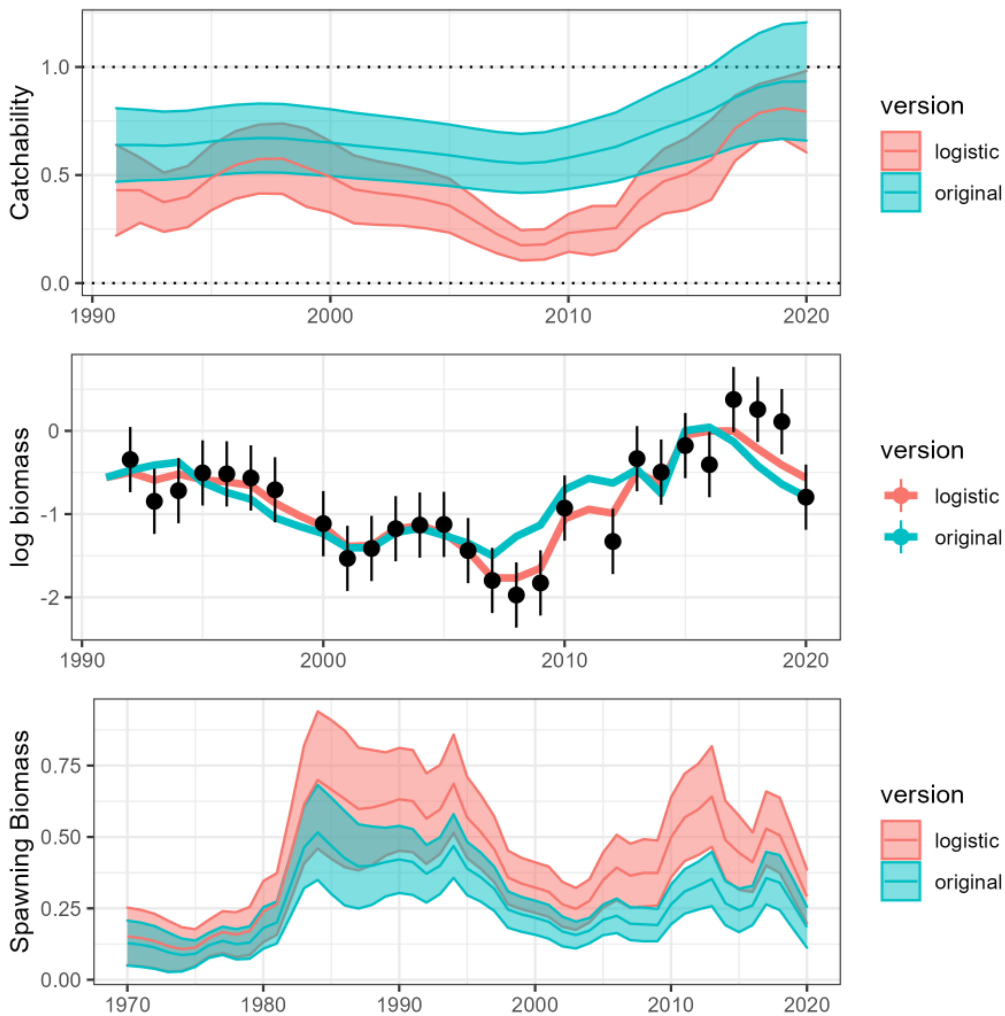
The GOA Plan Team in its November 2019 minutes recommended the author examine fishery selectivity, as persistent patterns in the catch-at-age residuals may represent artifacts of the selectivity functional form used.

We did not explore alternative functional forms in this assessment. We noticed that the initial inflection point of the double-logistic selectivity curve was about age 4, and hypothesized that if the time variation in this component were too small (too little annual flexibility) it could cause the aforementioned residual pattern. Thus, as a first step, we tried allowing for greater flexibility in both the time-varying initial inflection and slope used to control the selectivity of younger fish by increasing the process error on the random walk components. Despite this increased flexibility, we found no appreciable improvement to the age-4 residuals. We therefore agree that investigation of alternative functional forms is warranted, and will explore that in future assessments.

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

The model uses a random walk on log scale to estimate a time-varying catchability for the Shelikof biomass index. It is possible for the estimated catchability to be greater than 1. While this has not occurred to date, we note that the confidence intervals exceeded it in recent years. We therefore tried an alternative form by estimating the random walk in inverse logit (i.e., logistic) space, so that the estimated catchability and its uncertainty was naturally constrained between 0 and 1. Due to the change in parameterization, the assumed process error for the random walk needed to be increased to allow for a similar level of flexibility. The following figure shows the results of catchability, fit to the index, and estimated spawning biomass for the original and logistic versions, with the latter having more flexibility allowed.

The logistic transformation works to constrain the catchability to its assumed natural range, but results in a shift in absolute size of the stock for unclear reasons. The specification of the magnitude of the process error also needs further investigation. So despite its promise, we did not bring forward this as an alternative this year. Further investigations will be done for next year, with tentative plans to explore estimating the process error in a state-space approach.



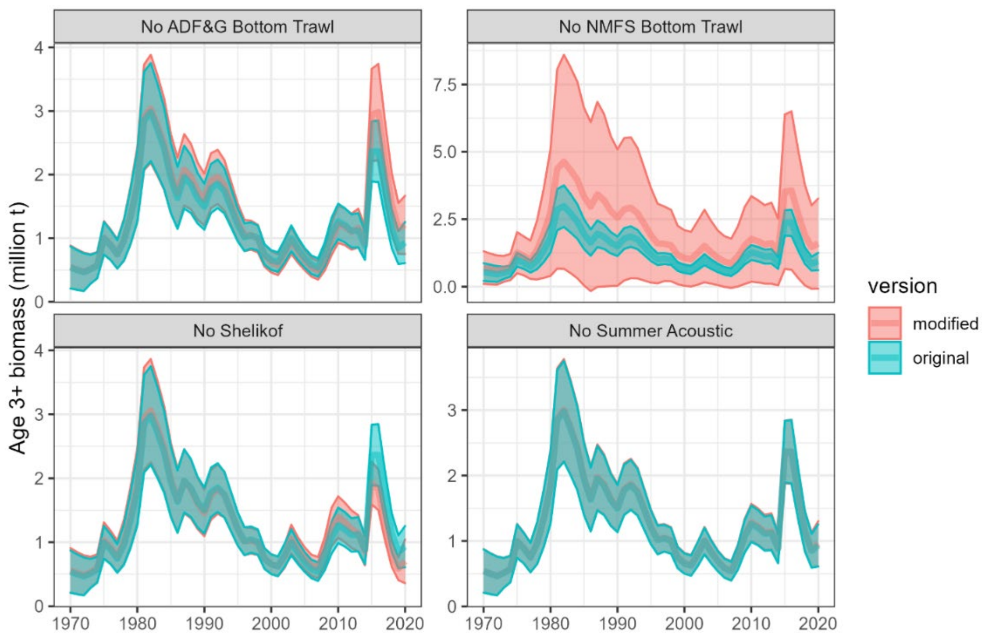
Results comparing the original log and new logistic transformation for the random-walk catchability of the Shelikof index. Estimated catchability (top) with 95% confidence intervals (ribbons) for the two parameterizations (colors). The expected indices (lines) are shown with the observed data (points and vertical lines; middle panel). Estimated spawning biomass with 95% confidence interval (ribbons) is shown at bottom.

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

Such an analysis would be extremely informative and valuable to improving this assessment. One of the most challenging tasks is reprocessing the acoustic data. We have initiated conversations with both the acoustic and bottom trawl survey groups about what it would take to have suitable data for this analysis. We will continue to work with them on the feasibility of this. However, we agree with previous authors' argument that this should be considered a long-term research objective.

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 performed this incremental leave-one-out experiment for the four surveys, but included the weight and length compositions in addition to the indices. Results are shown in the following figure where the model is fitted without each survey in turn. The trends are generally the same. The summer acoustic has little effect, due to only having four years of data. The ADF&G and Shelikof surveys have a relative minor impact if dropped, except in recent years with the notable divergence in index trends. Most noteworthy is that the NMFS bottom trawl survey sets the scale of the population (without it there is a notable increase in uncertainty and an absolute increase in estimates), which is tied to its catchability which is not well-estimated and instead is driven by an informative prior. This analysis suggests revisiting the formation of that prior and how it interacts with the scale of the population.



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. There are important recent preliminary results from a genetic analysis of 617 walleye pollock from Japan, Bering Sea, Chukchi Sea, Aleutian Islands, Alaska Peninsula, and Gulf of Alaska using low-coverage whole genome sequencing. Results suggests there is a temporally stable stock structure with a latitudinal gradient, i.e., Bering Sea pollock are distinguishable from those in the Gulf of Alaska and Aleutian Islands (I. Spies, personal communication, 2021). An evaluation of stock structure for Gulf of Alaska pollock following the template developed by NPFMC stock structure working group was provided as an appendix to the 2012 assessment (Dorn et al., 2012). Available information supported the current approach of assessing and managing pollock in the eastern portion of the Gulf of Alaska (Southeast Outside) separately from pollock in the central and western portions of the Gulf of Alaska (Central/Western/West Yakutat). The main part of this assessment deals only with the C/W/WYK stock, while results for a tier 5 assessment for southeast outside pollock are reported in Appendix 1B.

Fishery

The commercial fishery for walleye pollock in the Gulf of Alaska started as a foreign fishery in the early 1970s (Megrey 1989). Catches increased rapidly during the late 1970s and early 1980s (Table 1.1). A large spawning aggregation was discovered in Shelikof Strait in 1981, and a fishery developed for which pollock roe was an important product. The domestic fishery for pollock developed rapidly in the Gulf of Alaska with only a short period of joint venture operations in the mid-1980s. The fishery was fully domestic by 1988.

The pollock target fishery in the Gulf of Alaska is entirely shore-based with approximately 96% of the catch taken with pelagic trawls. During winter, fishing effort targets pre-spawning aggregations in Shelikof Strait and near the Shumagin Islands (Fig. 1.1). Fishing in summer is less predictable, but typically occurs in deep-water troughs on the east side of Kodiak Island and along the Alaska Peninsula.

Incidental catch in the Gulf of Alaska directed pollock fishery is low. For tows classified as pollock targets in the Gulf of Alaska between 2016 and 2020, on average about 96% of the catch by weight of FMP species consisted of pollock (Table 1.2). Nominal pollock targets are defined by the dominance of pollock in the catch, and may include tows where other species were targeted, but pollock were caught instead. The most common managed species in the incidental catch are arrowtooth flounder, Pacific ocean perch, Pacific cod, sablefish, shallow-water flatfish, and flathead sole (Table 1.2). Sablefish incidental catch has trended upwards since 2018, perhaps reflecting both the recent increase in sablefish abundance and a wider spatial distribution. The most common recent non-target species are grenadiers, squid, capelin, jellyfish and miscellaneous fish (Table 1.2). Bycatch estimates for prohibited species over the period 2016-2020 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 the directed pollock fishery. Estimated Chinook salmon bycatch since 2010 has been less than the peak in 2010, with increases in 2016, 2017, and 2019, and reduced to 10,867 in 2020.

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

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

Data Used in the Assessment

The data used in the assessment model consist of estimates of annual catch in tons, fishery age composition, NMFS summer bottom trawl survey estimates of biomass and age and length composition, acoustic survey estimates of biomass and age composition in Shelikof Strait, summer acoustic survey estimates of biomass and age and length 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	1970-2020
Fishery	Age composition	1975-2020
Shelikof Strait acoustic survey	Biomass	1992-2021
Shelikof Strait acoustic survey	Age composition	1992-2021
Summer acoustic survey	Biomass	2013-2021, biennially
Summer acoustic survey	Age composition	2013-2019, biennially
NMFS bottom trawl survey	Area-swept biomass	1990-2021, biennially
NMFS bottom trawl survey	Age composition	1990-2019, biennially
ADF&G trawl survey	Delta-GLM index	1988-2021
ADF&G survey	Age composition	2000-2020, biennially

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 1991-2020 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) of 2.5% for the PWS fishery has been deducted from the total Acceptable Biological Catch (ABC) by the NPFMC Gulf of Alaska Plan Team for management purposes (see SAFE introduction for further information). 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 age-length key for use in every year and the applying the annual length composition to that key. Use of an age-length key was considered necessary because observers used length-stratified sampling designs to collect otoliths prior to 1999 (Barbeaux et al. 2005). Estimates were made separately for the foreign/JV and domestic fisheries in 1987 when both fisheries were sampled. There were no major discrepancies between the re-estimated age composition and estimates that have built up gradually from assessment to assessment.

Estimates of fishery age composition from 2000 onwards were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). The length composition and ageing data were obtained from the NORPAC database maintained at AFSC. Catch age composition was estimated using methods described by Kimura and Chikuni (1989). Age samples were used to construct age-length keys by sex and stratum. These keys were applied to sex and stratum specific length frequency data to estimate age composition, which were then weighted by the catch in numbers in each stratum to obtain an overall age composition. A background age-length key is used fill the gaps in age-length keys by sex and stratum. Sampling levels by stratum for 2000-2015 are documented in the assessments available online at http://www.afsc.noaa.gov/REFM/stocks/Historic_Assess.htm.

Age and length samples from the 2020 fishery were stratified by half-year seasons 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	9	903	165	29
	Num. lengths	15	1,865	628	116
	Catch (t)	561	42,599	5,295	7,485
2nd half (C and D seasons)	Num. ages	1,360	776	1,206	0
	Num. lengths	2,481	1,773	3,608	0
	Catch (t)	18,444	12,800	20,280	6

The estimated age composition in 2020 in all areas and all seasons was notable because it was not dominated by age-8 fish (2012 year class) for the first time in many years (Fig. 1.2). Instead, the age-3 fish had the largest percentage with 38% while the age-8 fish only accounting for 29%. Younger fish are likely to become increasingly prominent in the catch-at-age as the 2012 year class begins age out of the population. Fishery catch at age in 1975-2020 is presented in Table 1.5 (See also Fig. 1.3). Sample sizes for ages and lengths are given in Table 1.6.

Gulf of Alaska Bottom Trawl Survey

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) beginning in 1984 to assess the abundance of groundfish in the Gulf of Alaska (Table 1.7). Starting in 2001, the survey frequency was increased from once every three years to once every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and statistical area (von Szalay et al. 2010). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized poly-Nor‘eastern high opening bottom trawls rigged with roller gear. In a full three-boat survey, 800 tows are completed, but the recent average has been closer to 600 tows. On average, 72% of these tows contain pollock (Table 1.8). Recent years have dropped stations in deeper water which are unlikely to affect the index due to pollock typically being in shallower depths with on average 90.9% below 200 m and 99.6% below 300 m from 1984-2021.

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 seventeenth comprehensive bottom trawl survey since 1984 during the summer of 2021 (Fig. 1.4). The 2021 gulfwide biomass estimate of pollock was 528,841 t, which is an increase of 72.2% from the 2019 estimate, which was 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 494,743 t. The coefficient of variation (CV) of this estimate was 0.17, which is slightly below the average for the entire time series. 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 for all strata in each single year, 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). No new ages were available this year, and instead length compositions were used in the model (Fig. 1.5) but 2019 ages indicated the continued dominance of the 2012 year class (age-7 fish) in the Western and Central GOA (Fig. 1.6). 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. 1.7).

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 2021 are presented in a NMFS processed report (Honkalehto et al., in prep.). In 2008, the noise-reduced *R/V Oscar Dyson* became the designated survey vessel for acoustic surveys in the Gulf of Alaska. In winter of 2007, a vessel comparison experiment was conducted between the *R/V Miller Freeman* (MF) and the *R/V Oscar Dyson* (OD), which obtained an OD/MF ratio of 1.132 for the acoustic backscatter detected by the two vessels in Shelikof Strait.

The 2021 biomass estimate for Shelikof Strait is 526,974 t, which is a 15% percent increase from the 2020 estimate (Fig. 1.8). 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. Originally, winter 2021 pre-spawning pollock surveys were also planned in the Shumagin Islands area, Chirikof shelf break, and in Prince William Sound and the Kenai Peninsula fjords. Due to travel, vessel, and staffing constraints stemming from protocols required to mitigate the COVID-19 pandemic, only Shelikof, Marmot, and Chirikof were attempted. Eventually Chirikof was dropped due to inclement weather and because real-time observations of the large age-1 2020 year class in Shelikof Strait necessitated collecting sufficient additional trawling to estimate net selectivity for pollock in 2021

The following table provides results from the 2021 winter acoustic surveys:

Area	Total biomass (t)	Percent
Shelikof Strait	526,974	98.6%
Marmot	7,401	1.4%
Total	534,375	100%

Biomass in Marmot Bay in 2021 increased by 18% compared to 2019, the last year it was surveyed. Overall, there appears to be a concentration of spawning activity in Shelikof Strait compared to other areas in the Gulf of Alaska, but the reduced survey coverage outside of Shelikof Strait limits the conclusions that can be drawn.

Shelikof Acoustic Survey Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.9) 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 2021 indicate reduced dominance of the nine year old 2012 year class, and a mode of age 4 fish (2017 year class), indicating a new year class is starting to comprise the majority of the spawning and exploitable portion of the population.

Winter Acoustic Survey Age-1 and Age-2 Indices

Based on recommendations from the 2012 CIE review, we developed an approach to model the age-1 and age-2 pollock estimates separately from the Shelikof Strait acoustic survey biomass and age composition. Age-1 and age-2 pollock are highly variable but occasionally very abundant in winter acoustic surveys, and by fitting them separately from the 3+ fish it is possible utilize an error distribution that better reflects that variability. Indices are available for both the Shelikof Strait and Shumagin surveys, but a longer time series of net-selectivity corrected indices are available for Shelikof Strait. In addition, model comparisons in the 2018 assessment indicates that a slightly better fit could be obtained with only Shelikof Strait indices. Therefore this time series was used in the model, but this decision should be revisited as additional data become available. The age-2 index in 2020 showed a marked reduction in comparison to the age-1 index in 2019, which indicated high abundance of the 2018 year class. Typically year classes that are abundant in Shelikof Strait at age 1 are also abundant at age 2 in the survey in the following year. The 2018 cohort comprised 15% of the age composition (excluding age 1 and 2 fish) as 3 year olds in 2021, giving further evidence for marked decrease from initial estimates as age 1 fish. Consequently, there is considerable uncertainty regarding the fate of 2018 year class, which may have exited Shelikof Strait for some reason and be distributed elsewhere in the GOA, or suffered extremely high mortality.

Spawn timing and availability of pollock to the winter Shelikof survey

The Shelikof Strait winter acoustic survey is timed to correspond to the aggregation of pre-spawning pollock in Shelikof Strait. However, the timing of spawning has been found to vary from year to year, which may affect the availability of pollock to the survey. Variation in spawn timing is not random, but has been linked to thermal conditions in March and the age structure of the spawning stock (Rogers and Dougherty 2019); spawning tends to occur earlier when temperatures are warmer and when the spawning stock is older on average. Greater age diversity also results in a more protracted spawning period, presumably due to both early (old) and late (young) spawners, although this has not been verified in the field. Dorn et al. (2020) discuss correlations with spawn timing and model residuals. No additional work was done this year but is an ongoing effort.

Summer Acoustic Survey

Five complete acoustic surveys, in 2013, 2015, 2017, 2019 and 2021, have been conducted by AFSC on the *R/V Oscar Dyson* in the Gulf of Alaska during summer (Jones et al. 2014, 2017, 2019, in prep.; Levine et al. in prep.). The area surveyed covers the Gulf of Alaska shelf and upper slope and associated bays and troughs, from a westward extent of 170° W Lon, and extends to an eastward extent of 140° W lon. Prince William Sound was also surveyed in 2013, 2015, and 2019. 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 2021 biomass estimate for summer acoustic survey is 431,148 t, which is a 25% percent decrease from the 2019 estimate (Table 1.7). Age composition data were not available, but preliminary results in 2021 indicated that the very abundant 2012 year class was present but with reduced contribution, and strong modes of both presumed age-1 and age-4 fish were distributed broadly throughout the GOA (Fig. 1.10). Analysis of the 2019 and 2021 survey was not complicated by the presence of age-0 pollock, which was a problem in previous summer acoustic surveys because age-0 pollock backscatter cannot be readily distinguished from age 1+ pollock.

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 (depths from 18-246 m, median of 106 m; Fig. 1.11). 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. 1.11). The average number of tows completed during the survey is 337. On average, 87% of these tows contain pollock. Details of the ADF&G trawl gear and sampling procedures are in Spalinger (2012).

The 2021 area-swept biomass estimate for pollock for the ADF&G crab/groundfish survey was 64,813 t, and increase of 9.2% from the 2020 biomass estimate (Table 1.7). The 2021 pollock estimate for this survey is approximately 70% of the long-term average.

Delta GLM indices

A simple delta GLM model was applied to the ADF&G tow by tow data for 1988-2021 to obtain annual abundance indices. Data from all years were filtered to exclude missing latitude and longitudes and missing tows made in lower Shelikof Strait (between 154.7° W lon. and 156.7° W lon.) were excluded because these stations were sampled irregularly. 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 assumed likelihoods were binomial for presence-absence observations and gamma for the positive observations, after evaluation of several alternatives, including lognormal, gamma, and inverse Gaussian, and which is in line with recommendations for index standardization (Thorson et al. 2021). The model was fit using brms package in R (Bürkner 2017, 2018), which fits Bayesian non-linear regression models using the modeling framework Stan (Stan Development Team 2020). Comparison of delta-GLM indices the area-swept estimates indicated similar trends (Fig. 1.12). Variances were based on MCMC sampling from the posterior distribution, and CVs for the annual index ranged from 0.10 to 0.18. These values likely understate the uncertainty of the indices with respect to population trends, since the area covered by the survey is a relatively small percentage of the GOA shelf area, and so the CVs are scaled up to have an average of 0.25.

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 2000-2020 ADF&G surveys in even-numbered years (average sample size = 583; Table 1.12, Fig. 1.13). 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. 1.14). From 2016 to 2019 there was a strong divergence among the trends, but with the large reduction in biomass in 2020 for the Shelikof Strait survey, and an increase in the ADF&G index, relative abundance has come back into reasonable alignment since 2020.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.15). The percent of females in the catch shows some variability but no obvious trend, and is usually close to 50-50. In 2016, percent female dropped to 40%, but increased to 43% in 2017 and remained similar through 2020. Evaluation of sex ratios by season indicated that this decrease was mostly due a low percentage of females during the A and B seasons prior to spawning. However the sex ratio during the C and D seasons was close to 50-50, suggesting the skewed sex in winter was related to spawning behavior, rather than an indication of a population characteristic. The mean age shows interannual variability due to strong year classes passing through the population, but there are no downward trends that would suggest excessive mortality rates. The percent of old fish in the catch (nominally defined as age 8 and older) is also highly variable due to variability in year class strength. The percent of old fish declined in 2015-2018 as the strong 2012 year class recruited to the fishery, but increased when the 2012 year class became age 8 in 2020. Under a constant $F_{40\%}$ harvest rate, the mean percent of age 8 and older fish in the catch would be approximately 8%. An annual 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 and higher values correspond to higher diversity. Increases in fishing mortality would tend to reduce age diversity, but year class variability would also influence it. Age diversity was relatively stable during 1975-2015, but declined sharply to a low in 2016 and has been increasing since due to the dominance of the 2012 year class in the catch (Fig. 1.15). In 2020 the age diversity returned to near the long-term average.

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, but apparently not reduced total mortality (Fig. 1.16). 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 2021 (52 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 joint log likelihood of the data, viewed as a function of the parameters. Mean-unbiased log-normal likelihoods were used for survey biomass and total catch estimates, and multinomial likelihoods were used for age and length composition data. Model tuning for composition data was done by iterative re-weighting of input sample sizes using the Francis (2011) method. Variance estimates/assumptions for survey indices were not reweighted. The following table lists the likelihood components used in fitting the model.

Likelihood component	*Statistical model for error*	*Variance assumption*
Fishery total catch (1970-2020)	Log-normal	CV = 0.05, 2021 catch is projected
Fishery age comp. (1975-2019)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2020)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2020)	Multinomial	Initial sample size = 60
Shelikof acoustic survey age-1 and age-2 indices (1994-2020)	Log-normal	Tuned CVs = 0.45 and 0.45
Summer acoustic survey biomass (2013-2019)	Log-normal	CV = 0.25
Summer acoustic survey age comp. (2013, 2015, 2017, 2019)	Multinomial	Initial sample size = 10
NMFS bottom trawl survey biom. (1990-2019)	Log-normal	Survey-specific CV from random-stratified design = 0.12-0.38
NMFS bottom trawl survey age comp. (1990-2019)	Multinomial	Initial sample size = 60
ADF&G trawl survey index (1989-2020)	Log-normal	Survey-specific CV from delta GLM model rescaled so mean is 0.25=0.20-0.35
ADF&G survey age comp. (2000-2018)	Multinomial	Initial sample size = 30
Recruit process error (1970-1977, 2019, 2020)	Log-normal	σ_R =1.0

Recruitment

In most years, year-class abundance at age 1 was estimated as a free parameter. Age composition in the first year was estimated with a single log deviation for recruitment abundance, which was then decremented by natural mortality to fill out the initial age vector. A penalty was added to the log likelihood so that the log deviation in recruitment for 1970-77, and in the last two years of the model, 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 (i.e., younger fish). Variation in these parameters was constrained using a random walk penalty.

Modeling survey data

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

Survey catchability coefficients can be fixed or freely estimated. The base model estimated the NMFS bottom trawl survey catchability, but used a log normal prior with a median of 0.85 and log standard deviation 0.1 based on expert judgement as a constraint on potential values (Fig. 1.17). 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, as occurs when the survey is the same as the assessment. 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 had been assumed to be 0.3 for all ages.

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

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

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

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

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

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

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

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

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

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

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

Results were reasonably consistent and suggest use of a higher mortality rate for age classes younger than the age at maturity (Table 1.14 and Fig. 1.18). 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 373 (Table 1.15).

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

Estimates of maturity at age in 2021 from winter acoustic surveys using the new method are higher for younger fish, but lower for older fish, compared to 2020 and the long-term mean for all ages (Fig. 1.19). 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 1983-2021 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 (Fig. 1.20). The last few years has shown a decrease in the age at 50% mature, which is largely being driven by the maturation of the 2012 year class at younger ages than is typical, however the 2019 to 2021 estimates of age at 50% mature are near the long-term average. Length at 50% mature is less variable than the age at 50% mature, suggesting that at least some of the variability in the age at maturity can be attributed to changes in length at age. Changes in year-class dominance also likely affect estimates of maturity at length, as a similar pattern is seen as with maturity at age with the 2012 cohort . The average length at 50% mature for all years is approximately 43 cm.

Weight at age

Year-specific fishery weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a\,L^b$, were also estimated. Weights at age were estimated by multiplying length at age by the predicted weight based on the length-weight regressions. Weight at age for the fishery, the Shelikof Strait acoustic survey, and the NMFS bottom trawl survey and the summer acoustic survey are given in Table 1.16, Table 1.17, and Table 1.18. Data from the Shelikof Strait acoustic survey indicates that there has been a substantial changes in weight at age for older pollock (Fig. 1.21). For pollock greater than age 6, weight-at-age nearly doubled by 2012 compared to 1983-1990. However, weight at age since 2012 has trended strongly downward, with some stabilization in the last couple of years, but a notable increase in 2021 for all ages, and the heaviest age 2 fish to date (0.191 kg) and fourth heaviest age 3 fish (0.321 kg) as well. 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 estimate of fishery weight at age in 2021 since age data were not available. 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 1975-2020. 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 (1981-2021) and the NMFS bottom trawl survey (1984-2019) were used. The model also requires input standard deviations for the weight at age data, which are not available for GOA pollock. In the 2016 assessment, a generalized variance function was developed using a quadratic curve to match the mean standard deviations at ages 3-10 for the eastern Bering Sea pollock data. The standard deviation at age one was assumed to be equal to the standard deviation at age 10. Survey weights at age were assumed to have standard deviations that were 1.5 times the fishery weights at age. A comparison of RE model estimates from last year of the 2020 fishery weight at age with the data now available indicate that the model underestimated weights except for ages 9-10 (Fig. 1.22). This includes underestimates of the age 3 and 8 fish in 2020 which made up the majority of catch (36% and 31%, respectively). In this assessment, RE model estimates of weight at age are used for the fishery in 2021 and for yield projections (Fig. 1.22).

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 12.3), a C++ software language extension and automatic differentiation library (Fournier et al. 2012). Parameters in nonlinear models are estimated in AD Model Builder using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. The optimizer in AD Model Builder is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-6}) and the Hessian matrix is invertible. 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 1970-2021 = 52	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 1970-2021 = 52	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) = 102	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) = 102	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	120 estimated parameters + 204 process error parameters + 10 fixed parameters = 334	

Results

Model selection and evaluation

Model Selection

Prior to identifying a model for consideration, an analysis was conducted of the impact of each new data element on model results. Figure 1.21 shows the changes in estimated spawning biomass as the updated catch projections, catch at age, and surveys were added sequentially. In general, the addition of new data elements did not strongly affect the estimates of recent spawning biomass, with the exception of the updated weight at age from the 2021 Shelikof survey, which was substantially larger than the 2020 estimates. This effect is discussed in the risk table below. This suggests that the new data are reasonably consistent with previous modeling and with each other. Since previous assessments have identified inconsistent input data sets as a major assessment concern, the overall consistency this year suggests that those concerns are much reduced (e.g., Fig. 1.23).

The intent of this year's assessment was to provide a straightforward update without considering major changes to the model. We recently explored models that used VAST estimates in place of area-swept biomass estimates for the NMFS bottom trawl survey. The VAST estimates did not fit as well as the area-swept estimates when given similar weighting, and we concluded that additional model evaluation was needed before using the VAST estimates. Several other modeling approaches for GOA pollock are under development, including incorporation of predator consumption (Barnes et al. 2020) in the assessment model, use of mean hatch date from the EcoFOFI early larval survey to inform catchability to the Shelikof Strait survey, and model-based estimates of Shelikof and summer acoustic indices using VAST. We selected model 19.1 as the preferred model, and a final turning step was done using the Francis (2011) approach which reweighted all composition components, including the summer acoustic age composition for the first time, but model results were nearly unchanged (Fig. 1.23).

Model Evaluation

The fit of model 19.1 to age composition data was evaluated using plots of observed and predicted age composition and residual plots. Figure 1.24 show the estimates of time-varying catchability for the Shelikof Strait acoustic survey and the ADF&G crab/groundfish survey. The catchability for the Shelikof Strait acoustic survey approaches one but does not exceed it and has declined in the last two years. Plots show the fit to fishery age composition (Fig. 1.25, Fig. 1.26), Shelikof Strait acoustic survey age composition (Fig. 1.27, Fig. 1.28), NMFS trawl survey age composition (Fig. 1.29), and ADF&G trawl survey age composition (Fig. 1.30). Model fits to fishery age composition data are adequate in most years, though the very strong 2012 year class shows up as a positive residual in for the 2016-2019 due to stronger than expected abundance in the age composition, while the older ages tended to have negative residuals. This may indicate that the fishery is targeting on the 2012 year class. The largest residuals tended to be at ages 1-2 in the NMFS bottom trawl survey due to inconsistencies between the initial estimates of abundance and subsequent information about year class size.

The fit to the 2021 Shelikof survey age was notably poor with a very large negative residual for age 3 fish (Fig. 1.27). A similar pattern is observed in the 2020 age 2 residual for the ADF&G compositional data (Fig. 1.30). These both point to a smaller 2018 cohort than originally observed and estimated. However, the fit to age 2 fish in the 2020 fishery data is much better, potentially due to lower selectivity at that age, and that it is time varying. Consequently, there is still conflict and uncertainty in the data about the size of the 2018 cohort. We anticipate new age composition data for the 2021 fishery, NMFS bottom trawl and summer acoustic surveys, and 2022 Shelikof survey to shed further light on the fate of this cohort.

Model fits to survey biomass estimates are reasonably good for all surveys except the period 2015-2019 (Fig. 1.31). There are large positive residuals for the Shelikof Strait acoustic survey in 2017, 2018 and 2019, and strong negative residuals for the NMFS bottom trawl survey for 2017 and 2019. In addition, the model is unable to fit the extremely low values for the ADF&G survey in 2015-2017. The fit to the summer acoustic survey is reasonable even during the most recent period. The model shows good fits to both the 2021 Shelikof Strait acoustic survey and the 2021 NMFS bottom trawl, while the 2021 ADF&G bottom trawl and 2021 summer acoustic survey fits were reasonable. The fit to the age-1 and age-2 Shelikof acoustic indices was considered acceptable (Fig. 1.32).

Time series results

Parameter estimates and model output are presented in a series of tables and figures. Estimated survey and fishery selectivity for different periods are given in Table 1.19 (see also Fig. 1.33). Table 1.20 gives the estimated population numbers at age for the years 1970-2021. Table 1.21 gives the estimated time series of age 3+ population biomass, age-1 recruitment, and harvest rate (catch/3+ biomass) for 1977-2021 (see also Fig. 1.34). Table 1.22 gives coefficients of variation and 95% confidence intervals for age-1 recruitment and spawning stock biomass. Stock size peaked in the early 1980s at approximately 120% of the proxy for unfished stock size ($B_{100\%}$ = mean 1978-2020 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR@F=0, see below for how this is calculated). In 2002, the stock dropped below the $B_{40\%}$ for the first time since the early 1980s, and reached a minimum in 2003 of 35% of unfished stock size. Over the years 2009-2013 stock size showed a strong upward trend, increasing from 43% to 78% of unfished stock size, but declined to 54% of unfished stock size in 2015. The spawning stock peaked in 2017 at 83% as the strong 2012 year class matured, and has declined subsequently to 46% in 2021.

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

Comparison of historical assessment results

A comparison of assessment results for the years 1993-2021 indicates the current estimated trend in spawning biomass for 1990-2021 is consistent with previous estimates (Fig. 1.36). All time series show a similar pattern of decreasing spawning biomass in the 1990s, a period of greater stability in 2000s, followed by an increase starting in 2008. The estimated 2021 age composition from the current assessment were very similar to the projected 2021 age composition from the 2020 assessment (Fig. 1.37). Generally, the two models agree except for the age 1 recruits, where the 2020 model assumed average recruitment, but the 2021 has data from the Shelikof survey which showed a strong year class. This difference does not strongly affect the OFL and ABC for next year because these fish are not in the exploitable population.

Retrospective analysis of base model

A retrospective analysis consists of dropping the data year-by-year from the current model, and provides an evaluation of the stability of the current model as new data are added. Figure 1.38 shows a retrospective plot with data sequentially removed back to 2011. There is up to 37% error in the estimates of spawning biomass (if the current assessment is accepted as truth), but usually the errors are much smaller (median absolute error is 11%). There is relatively minor positive retrospective pattern to errors in the assessment, and the revised Mohn's ρ (Mohn 1999) across all ten peels for ending year spawning biomass is 0.056, which does not indicate a concern with retrospective bias.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 1.27 over 1978-2020) than Eastern Bering Sea pollock (CV = 0.60). Other North Pacific groundfish stocks, such as sablefish and Pacific ocean perch, also have high recruitment variability. However, unlike sablefish and Pacific ocean perch, pollock have a short generation time (~8 years), so that large year classes do not persist in the population long enough to have a buffering effect on population variability. Because of these intrinsic population characteristics, the typical pattern of biomass variability for GOA pollock will be sharp increases due to strong recruitment, followed by periods of gradual decline until the next strong year class recruits to the population. GOA pollock is more likely to show this pattern than other groundfish stocks in the North Pacific due to the combination of a short generation time and high recruitment variability.

Since 1980, strong year classes have occurred periodically every four to six years (Fig. 1.34). Because of high recruitment variability, the mean relationship between spawning biomass and recruitment is difficult to estimate despite good contrast in spawning biomass. Strong and weak year classes have been produced at high and low level of spawning biomass. Spawner productivity is higher on average at low spawning biomass compared to high spawning biomass, indicating that survival of eggs to recruitment is density-dependent (Fig. 1.39). However, this pattern of density-dependent survival only emerges on a decadal scale, and could be confounded with environmental variability on the same temporal scale. 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 2020 is estimated to be to be very weak, but the 2021 recruitment is above average, although 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 1978-2020 age-1 recruitment (5.655 billion), which is 3% lower than the mean value in last year's assessment. Spawning was assumed to occur on March 15th, and a long-term average of maturity at age (1983-2021) was used with mean spawning weight at age from the Shelikof Strait acoustic surveys in 2017-2021 to estimate current reproductive potential. Fishery weight at age was assumed to be the most recent estimate from the RE model. Pollock weight-at-age is highly variable, showing a sustained increase, followed by a steep decline until a sharp increase in 2021 (Fig. 1.21). The factors causing this pattern are unclear, but are likely to involve both density-dependent factors and environmental forcing. The SPR at F=0 was estimated as 0.076 kg/recruit at age one. F_{SPR} rates depend on the selectivity pattern of the fishery. Selectivity has changed as the fishery evolved from a foreign fishery occurring along the shelf break to a domestic fishery on spawning aggregations and in nearshore waters. For SPR calculations, selectivity was based on the average for 2017-2021 to reflect current selectivity patterns. GOA pollock F_{SPR} harvest rates are given below:

		Equilibrium under average 1978-2020 recruitment				
F_{SPR} rate	*Fishing mortality*	*Avg. Recr. (Million)*	*Total 3+ biom. (1000 t)*	*Female spawning biom. (1000 t)*	*Catch (1000 t)*	*Harvest fraction*
100.0%	0.000	5,656	1,880	429	0	0.0%
40.0%	0.263	5,656	1,105	172	172	15.5%
35.0%	0.311	5,656	1,036	150	187	18.1%

The $B_{40\%}$ estimate of 172,000 t represents a 3% decrease from the $B_{40\%}$ estimate of 177,000 t in the 2020 assessment (Table 1.24), despite the increase in spawning weight at age in 2021. The base model projection of female spawning biomass in 2022 is 186,481 t, which is 43.4% of unfished spawning biomass (based on average post-1977 recruitment) and above $B_{40\%}$ (172,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3.

2022 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 (i.e., F_{ABC}/F_{OFL}) is 84.4% of the OFL harvest rate. Projections for 2022 for the F_{OFL} and the maximum permissible F_{ABC} are given in Table 1.25.

Should the ABC be reduced below the maximum permissible ABC?

The following template is used to complete the risk table:

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators

Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

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

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

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

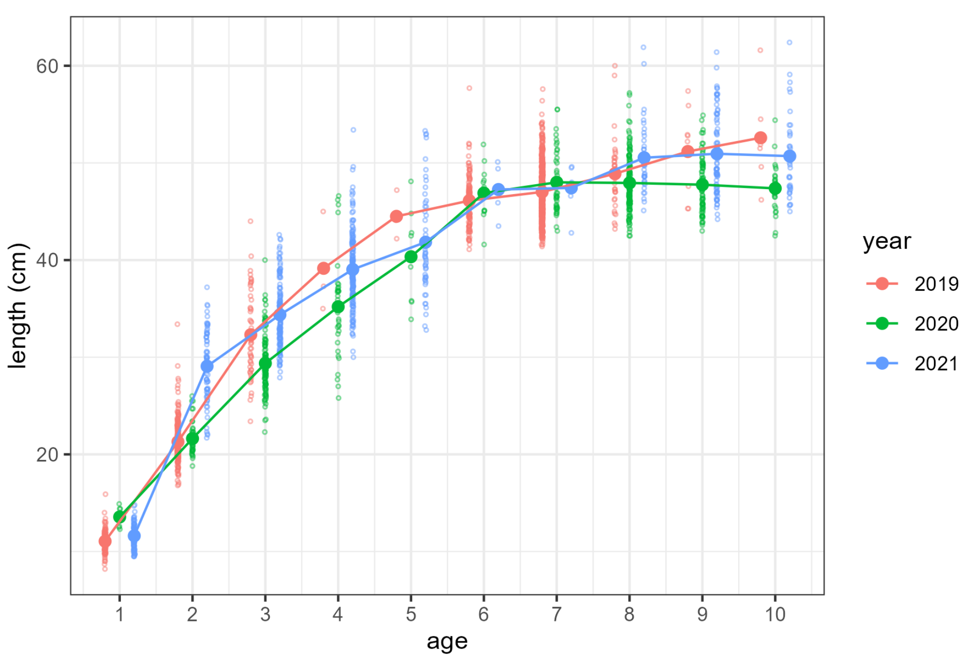
4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings."

Assessment considerations

The GOA pollock assessment does not show a strong retrospective bias, and fits to the age composition data for the fishery and survey biomass indices are generally adequate. The pollock assessment is one of the few assessments in the North Pacific that is fit to multiple abundance indices. An element a score of 2 was given in 2019 because of strongly contrasting trends in the survey abundance indices, with bottom trawl indices showing a steep decline, while acoustic surveys showing record highs (Fig. 1.31). This year, the results from new surveys conducted in 2021 showed consistent trends, and were able to be fit adequately by the model. While the historical pattern of conflicting survey trends remains, the consistency of 2020 and 2021 survey fits leads to reduced concern.

A continuing assessment issue is the severe decline in the 2018 year class abundance between the 2019 and 2020 Shelikof Strait acoustic surveys. The 2019 estimate was indicative of a strong year class, but the 2020 estimate of age 2 fish was only 10% of the long-term average. Over the full Shelikof Strait time series, high age-1 estimates have always been followed by high age-2 estimates in the next year (Fig. 1.9). It was previously hypothesized that the 2018 year class could have moved out of Shelikof Strait or experienced unusually high mortality. This year, both the 2020 age 2 ADF&G and 2021 age 3 Shelikof survey observed proportions were low relative to the model expectation (Figs. 1.27 and 1.30), providing further evidence of a reduced 2018 cohort. In contrast, the 2020 fishery catch at age was very close to expected for age-2 fish (Fig. 1.24), and there are some apparent age-3 fish in the 2021 length compositions from the summer surveys. So despite new data sources, the initial and current size of this cohort is equivocal. We fit a model in which the high 2019 age-1 estimate was removed, and found that the 2022 OFL and ABC were more strongly affected (~9% decrease) than the same exercise in the previous year (~5% decrease). This is because this year class will be more exploitable as age 4 fish in the 2022 fishery (selectivity of 0.76) vs. the 3 year olds in 2021 (selectivity of 0.24). As more observations accumulate the fate of this year class should become clearer, and if observations continue to be low we expect that the model will increasingly predict a smaller year class, essentially fitting other data over the large age-1 index value in 2019.

Another important issue is the notable increase in spawning weight at age data from the winter Shelikof survey from 2020 (Fig. 1.21), including the heaviest age 2 fish to date. The model results are sensitive to the spawning weights used. If instead the 2020 data were used in 2021, the 2022 ABC would increase by 8%. We used the 2021 for several reasons. First, comparing the last three years of data from Shelikof it is quite clear that there has been a shift in length at age, not weight at length, as can be seen in the following figure.



Length at age for specimen data from three years (colors), with small circles showing individual fish and larger ones the mean at age. Connecting lines are included to help highlight overall patterns by year.

Based on this data, the length at age for 2021 is more in line with 2019, and 2020 appears to be more of an anomaly. Second, there was nothing new about either survey protocol or execution, nor the ageing process that would explain these patterns. Finally, weight at age had been declining for older fish since about 2012, and the increase this year is well within historical and recent norms for most ages.

Another new issue identified this year is that the absolute scale of the population is driven heavily by the NMFS bottom trawl survey, which in turn is highly influenced by the prior on catchability (Fig. 1.17). A more thorough analysis is needed to expand and confirm these results, but it is clear that this prior has a large impact on the results of the assessment. The model fits all indices relatively well, except the divergent trends mentioned above, and we generally have no reason to believe the prior is out of line with expert opinion.

There are some issues to consider with the assessment, but taken together we do not believe they are serious enough to rise above a score of 1—no increased concerns.

Population dynamics considerations

The large 2012 year class had a strong impact on the recent pollock population, from a steep decline in age diversity (Fig. 1.15) to abnormal growth and maturation (but not mortality as previously suspected; Fig. 1.16), which had led to an increase in concern in 2018. However, this year class is no longer the predominant one in the fishery and another large one (2017) has entered the fishery (Fig. 1.3), resulting in a return to normal age diversity in 2020. The conflicting signals of the 2018 year class remain a potential population dynamics concern, especially if the large 2020 year class suffers a similar fate. Overall the assessment uncertainty seems the primary issue rather than population dynamics issues. Consequently, we gave populations dynamics considerations a score of 1—no increased concerns.

Environmental/Ecosystem considerations

Appendix 1A provides a detailed look at environmental/ecosystem considerations specific to this stock within the ecosystem and socioeconomic profile (ESP). Broad-scale information on environmental and ecosystem considerations are provided by the Gulf of Alaska Ecosystem Status Report (GOA ESR; Ferriss, 2021). The text below summarizes ecosystem information related to GOA pollock provided from both the ESP and GOA ESR.

We scored this category as level 1 (normal concern) for walleye pollock given moderate thermal conditions for adults and larvae, mixed trends of zooplankton abundance, above average trends for nearshore larvae surveys, and potential but unknown levels of competition with juvenile sablefish and pink salmon. While the 2021 age-0 pollock sampled in the ichthyoplankton survey appear low in abundance, the age-0 and age-1 year classes sampled in the beach seine survey have been observed in high numbers, and environmental conditions are cautiously favorable for them to persist into next year (cooler ocean temperatures, some concern regarding moderate prey base, moderate predation and competition pressure). Currently the 2017 and 2012 year classes are the dominant cohorts supporting the fishery, and there is no cause to suspect unfavorable conditions for those older cohorts.

Environmental Processes: It is reasonable to expect that the 2021 and predicted 2022 average deeper ocean temperatures will provide good spawning habitat and average to cooler surface temperatures during a time when they are growing to a size that promotes over-winter survival. However, relatively low abundance of age-0 pollock, along with larval cod and northern rock sole, were observed in beach seine surveys around Kodiak and on the Alaskan Peninsula, and in the EcoFOCI spring survey (Rogers, 2021), potentially reflecting poor feeding conditions. Low age-0 pollock have been observed in previous years (e.g., 2019, 2016) that had warmer ocean temperatures and average to late phytoplankton bloom timing. While 2021 was not characterized as a 'warm year', the WGOA spring surface temperatures were above average and WGOA bloom timing was average with relatively low chlorophyll-a abundance (Watson

2021). Ocean temperatures at the surface and at depth on the shelf were around the long-term average in 2021 (not a marine heatwave year, Watson 2021; AFSC Bottom Trawl Survey, Laman 2021; AFSC EcoFOCI survey, Rogers 2021; Seward Line Survey, Danielson 2021), although western GOA started the year with warmer surface waters (satellite data; Watson 2021). Numerous temperature time series show signs of cooling from previous surveys (returning to average from recent marine heatwave years 2014-2016, 2019) at the surface and at depth and 2022 surface temperatures are predicted to continue cooling, in alignment with La Niña conditions and a negative Pacific Decadal Oscillation. Spring northeasterly winds in Shelikof Strait (downwelling favorable, flowing south through Shelikof Strait) were downwelling favorable, contributing to retention of 2021 larvae and potential for a stronger age-1 year class in 2022, similar to conditions in 2012 and 2020. The center of gravity in the northeast direction and area occupied estimates for the GOA pollock population have decreased from 2019 (although area occupied is still high), implying a shift in distribution toward the southwest and a slightly reduced population spread.

Prey: Planktivorous foraging conditions were moderate and regionally variable across the GOA in 2021. The western GOA had lower spring biomass of small and large copepods around Kodiak, characteristics of previous warm, less productive years (e.g., 2019). Planktivorous seabird reproductive success, an indicator of zooplankton availability and nutritional quality, was below average just north of Kodiak (E. Amatuli Island; Drummond 2021), but average just south of Kodiak (Chowiet Island). Around the eastern edge of WGOA (Seward Line, Middleton Island) the biomass of large copepods was average to above-average (Seward Line Survey, Hopcroft 2021) and planktivorous seabirds had better reproductive success (Middleton Island, Hatch 2021), indicating improved forage conditions. The eastern GOA inside waters of Icy Strait had higher than average large copepods and euphausiids (AFSC SECM Survey, Icy Strait, Fergusson 2021), however planktivorous seabirds had mixed reproductive success. The body condition of age2+ pollock was below average (continuing a trend since 2015), although the high standard error around the mean coupled with increased size-at-age trends in 2021 suggest their condition might be recovering from the post 2014 heatwave warm years (Bottom Trawl Survey, O'Leary 2021). Winter adult pollock condition from the acoustic survey was average, continuing the increasing trend since very low condition in 2017.

Predators and Competitors: Potential competitors are large year classes of juvenile sablefish (2016, 2018), an increasing population of Pacific Ocean perch, and pink salmon which are returning in very high numbers in 2021 (Murphy 2021, Shaul 2021). The sablefish biomass appears to be shifting to deeper waters along the slope as they mature (Goethel 2021), reducing their overlap with pollock, and the potential for competitive pressure from Pacific Ocean perch on pollock is considered inconclusive.

Fishery performance:

Trends in effort-weighted 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). Fishery CPUE is either above (A and B seasons) or close to (C and D seasons) the long-term average, and is very consistent with the abundance trend of exploitable biomass from the assessment. No concerns regarding fishery performance were identified and this element was given a score of 1.

These results are summarized in the table below:

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

Given the lack of elevated scores in the risk table, the author's recommended ABC is based on the maximum permissible ABC, resulting in a 2022 ABC of 133,081 t, which is an increase of 26% from the 2021 ABC. The author's recommended 2023 ABC is 131,912 t. The OFL in 2022 is 154,983 t, and the OFL in 2023 if the ABC is taken in 2022 is 153,097 t. We project that the ABC will begin to increase starting in 2024.

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 probability of future spawning biomass using Markov chain Monte Carlo (MCMC) using the no-U-turn sampler available in ADMB (Monnahan and Kristensen 2019). Analysis of the posterior samples indicates that probability of the stock dropping below $B_{20\%}$ will be negligible through 2026, conditional upon the model specified here (Fig. 1.41).

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 2021 numbers at age at the start of the year as estimated by the assessment model, and assume the 2021 catch will be 92,342 t (Mary Furuness, pers. comm. Oct. 14, 2021). 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 1978-2020 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 2022, 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 (2017-2021). (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 2021 or 2) above 1/2 of its MSY level in 2021 and above its MSY level in 2030 under this scenario, then the stock is not overfished)

Scenario 7: In 2022 and 2023, 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 2023, or 2) above 1/2 of its MSY level in 2023 and above its MSY level in 2033 under this scenario, then the stock is not approaching an overfished condition.)

Results from scenarios 1-7 are presented in Table 1.25. Mean spawning biomass is projected decline to 2022, and will continue to decline under full exploitation scenarios, but will increase under the F=0, F=*max* F_{ABC}, and other low exploitation scenarios (Fig. 1.41). We project catches to increase in 2022, decrease slightly in 2023, and then remain higher in subsequent years.

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 (2020) is 107,471 t, which is less than the 2020 OFL of 140,674 t. Therefore, the stock is not subject to overfishing. The fishing mortality that would have produced a catch in 2020 equal to the 2020 OFL is 0.276.

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 197,000 t in 2021 (see Table 1.21), which is above $B_{35\%}$ (150,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2023 is 167,840 t, which is above $B_{35\%}$ (150,000 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

The following research priorities were identified based on previous CIE reviews and recent Plan Team and SSC discussions:

- Explore alternative functional forms for fishery selectivity.
- Jointly estimate process errors for time-varying components like selectivity, catchability and recruitment, using integration via the Laplace approximation or MCMC.
- Consider alternative modeling platforms in parallel to the current ADMB assessment.
- Explore priors on catchability and the effect on the population scale and potentially how it relates to results from the predation mortality model.
- Revisit initial data weights for compositional data, and assumed CVs for indices.
- Estimate input variances for weight at age components in the WAA RE model.

- Continue to develop spatial GLMM models for survey indices and age composition of GOA pollock
- Evaluate pollock population dynamics in a multi-species context using the CEATTLE model.
- Explore implications of non-constant natural mortality on pollock assessment and management.

Additional recommendations that could be done by other teams at the AFSC, but are unlikely to be specifically prioritized by the primary assessment author, include:

- Efforts to combine acoustic and bottom trawl information in a vertically integrated index
- Efforts to improve understanding of changes of weight at age or and maturity at age, either via linkage to copepods/euphausiids or directly to the physical environment

A full ESP was developed for GOA pollock in 2020 and reviewed by the Plan Team at its September and November 2019 meetings. The GOA Groundfish Plan Team encouraged the authors to consider potential avenues for updating ESPs rather than producing full ESPs in the future. This year we provide a partial ESP in Appendix 1A that updates key indicators and reruns the Bayesian adaptive sampling model. We are soliciting feedback from the Plan Team and the SSC on the appropriate format and information to be included in an ESP update.

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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° W lon. (Western, Central and West Yakutat management areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound. Research catches are reported in Appendix 1E.

Year	Foreign	Joint Venture	Domestic	Total	ABC/TAC
1964	1,126			1,126	---
1965	2,746			2,746	---
1966	8,914			8,914	---
1967	6,272			6,272	---
1968	6,137			6,137	---
1969	17,547			17,547	---
1970	9,331		48	9,379	---
1971	9,460		0	9,460	---
1972	38,128		3	38,131	---
1973	44,966		27	44,993	---
1974	61,868		37	61,905	---
1975	59,504		0	59,504	---
1976	86,520		211	86,731	---
1977	117,833		259	118,092	150,000
1978	94,223		1,184	95,408	168,800
1979	103,278	577	2,305	106,161	168,800
1980	112,996	1,136	1,026	115,158	168,800
1981	130,323	16,856	639	147,818	168,800
1982	92,612	73,918	2,515	169,045	168,800
1983	81,318	134,171	136	215,625	256,600
1984	99,259	207,104	1,177	307,541	416,600
1985	31,587	237,860	17,453	286,900	305,000
1986	114	62,591	24,205	86,910	116,000
1987		22,823	45,248	68,070	84,000
1988		152	63,239	63,391	93,000
1989			75,585	75,585	72,200
1990			88,269	88,269	73,400
1991			100,488	100,488	103,400
1992			90,858	90,858	87,400
1993			108,909	108,909	114,400
1994			107,335	107,335	109,300
1995			72,618	72,618	65,360
1996			51,263	51,263	54,810
1997			90,130	90,130	79,980
1998			125,460	125,460	124,730
1999			95,638	95,638	94,580
2000			73,080	73,080	94,960
2001			72,077	72,077	90,690
2002			51,934	51,934	53,490
2003			50,684	50,684	49,590
2004			63,844	63,844	65,660
2005			80,978	80,978	86,100
2006			71,976	71,976	81,300
2007			52,714	52,714	63,800
2008			52,584	52,584	53,590
2009			44,247	44,247	43,270
2010			76,748	76,748	77,150
2011			81,503	81,503	88,620
2012			103,954	103,954	108,440
2013			96,363	96,363	113,099
2014			142,640	142,640	167,657
2015			167,549	167,549	191,309
2016			177,129	177,129	254,310
2017			186,155	186,155	203,769
2018			158,070	158,070	161,492
2019			120,243	120,243	135,850
2020			107,471	107,471	108,494
2021					105,722
Average (1977-2020)				109,514	125,850

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	*2016*	*2017*	*2018*	*2019*	*2020*
Pollock	175,241.9	183,044.0	155,002.1	117,649.7	105,943.5
Arrowtooth Flounder	1,292.0	1,335.7	2,670.4	2,019.6	2,417.1
Pacific Ocean Perch	691.0	1,273.0	1,629.5	1,083.5	1,131.0
Pacific Cod	1,087.8	886.6	846.8	811.3	1,039.3
Sablefish	102.0	60.6	360.0	409.2	794.7
GOA Shallow Water Flatfish	271.6	370.7	393.3	263.2	151.3
Flathead Sole	318.3	198.7	322.8	197.2	227.1
GOA Rex Sole	120.1	75.1	138.9	89.7	100.4
GOA Skate, Big	110.4	139.0	110.5	66.5	78.3
Shark	192.5	69.9	78.8	59.1	100.4
Atka Mackerel	208.2	33.5	64.4	122.4	0.2
GOA Shortraker Rockfish	195.0	1.6	0.5	8.4	29.5
Squid	185.3	15.5	9.5	-	-
GOA Skate, Longnose	50.6	37.0	44.6	20.7	22.4
GOA Rougheye Rockfish	49.6	3.0	9.7	41.6	31.6
Sculpin	21.6	27.3	18.4	10.2	45.0
GOA Dusky Rockfish	23.7	13.2	43.2	16.4	24.6
Northern Rockfish	15.8	5.7	59.4	7.2	0.9
GOA Thornyhead Rockfish	79.7	3.5	2.6	0.2	0.5
GOA Deep Water Flatfish	26.7	1.6	5.6	12.7	12.1
Octopus	5.7	0.2	6.4	8.3	4.4
GOA Skate, Other	5.2	5.9	5.0	3.5	4.1
Other Rockfish	0.7	0.4	1.6	4.6	0.2
Percent non-pollock	*2.8%*	*2.4%*	*4.2%*	*4.3%*	*5.5%*

Non target species/species group	*2016*	*2017*	*2018*	*2019*	*2020*
Giant Grenadier	864.05	4.75	3.12	9.32	11.33
Squid	0.00	0.00	0.00	47.52	371.73
Capelin	99.25	33.12	77.02	80.62	54.00
Jellyfish	158.57	13.96	12.83	121.41	5.48
Miscellaneous fish	17.76	19.27	55.94	87.81	115.11
Rattail Grenadier	38.74	9.07	25.53	37.68	38.55
Other osmerids	8.78	0.89	24.38	46.98	6.62
Sea star	3.54	0.81	45.05	2.50	3.26
Eulachon	1.86	2.83	8.68	7.63	22.33
State-managed Rockfish	5.50	0.07	1.53	0.00	0.07
Sea anemone unidentified	2.65	0.00	0.28	0.10	0.00
Greenlings	0.00	0.00	1.56	0.00	0.00
Pandalid shrimp	0.58	0.12	0.28	0.19	0.15
Snails	0.23	0.00	0.05	0.46	0.00
Bivalves	0.00	0.00	0.00	0.62	0.00
Surf smelt	--	0.38	0.00	--	0.00
Corals, Bryozoans	0.17	0.00	0.00	0.00	0.00
Eelpouts	0.00	0.00	--	0.00	0.13
Misc crabs	0.00	0.00	0.00	0.12	0.00
Sponge unidentified	0.08	0.00	0.00	0.00	0.00
Brittle star unidentified	0.00	0.07	0.00	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	*2016*	*2017*	*2018*	*2019*	*2020*
Bairdi Tanner Crab (nos.)	3,626	3,281	6,832	41,889	19,003
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	20,840	21,575	14,846	20,983	10,867
Golden (Brown) King Crab (nos.)	581	9	1	0	2
Halibut (t)	244	120	341	274	136
Herring (t)	143	5	42	64	60
Non-Chinook Salmon (nos.)	1,957	4,455	8,308	5,056	2,162
Opilio Tanner (Snow) Crab (nos.)	184	0	0	0	0
Red King Crab (nos.)	0	0	0	0	5

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*
2011	Retained	20,472	36,397	19,013	2,268	1,535	0	79,684	
	Discarded	125	849	838	4	1	2	1,819	2.2%
	Total	20,597	37,247	19,851	2,271	1,536	2	81,503	
2012	Retained	27,352	44,779	25,125	2,380	2,624	0	102,261	
	Discarded	521	301	856	12	3	1	1,693	1.6%
	Total	27,873	45,080	25,981	2,392	2,627	1	103,954	
2013	Retained	7,644	52,692	28,169	2,933	2,622	0	94,062	
	Discarded	67	432	1,791	7	0	2	2,298	2.4%
	Total	7,711	53,124	29,961	2,940	2,622	2	96,360	
2014	Retained	13,228	82,611	41,791	1,314	2,368	0	141,312	
	Discarded	136	465	712	3	3	2	1,321	0.9%
	Total	13,364	83,076	42,503	1,317	2,371	2	142,633	
2015	Retained	28,679	80,950	51,973	248	4,455	0	166,305	
	Discarded	60	489	657	1	33	3	1,243	0.7%
	Total	28,739	81,439	52,629	250	4,488	3	167,548	
2016	Retained	61,019	46,810	64,281	121	3,893	0	176,123	
	Discarded	233	214	530	12	14	2	1,006	0.6%
	Total	61,252	47,024	64,811	133	3,907	2	177,129	
2017	Retained	49,246	80,855	52,338	39	1,881	0	184,359	
	Discarded	297	752	731	0	16	2	1,798	1.0%
	Total	49,542	81,607	53,069	40	1,897	2	186,157	
2018	Retained	30,580	79,024	39,325	4,054	3,086	0	156,069	
	Discarded	94	1,030	762	71	35	1	1,994	1.3%
	Total	30,675	80,054	40,087	4,125	3,122	1	158,063	
2019	Retained	21,723	63,610	24,259	6,424	2,959	0	118,976	
	Discarded	144	510	402	188	17	3	1,264	1.1%
	Total	21,867	64,120	24,661	6,612	2,977	3	120,240	
2020	Retained	18,988	55,074	25,407	5,152	2,309	0	106,931	
	Discarded	18	325	168	28	2	0	540	0.5%
	Total	19,005	55,399	25,575	5,180	2,311	0	107,471	
Average (2011-2020)		28,063	62,817	37,913	2,526	2,786	2	134,106	

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

						Age									
Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Total*
1975	0.00	2.59	59.62	18.54	15.61	7.33	3.04	2.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	109.69
1976	0.00	1.66	20.16	108.26	35.11	14.62	3.23	2.50	1.72	0.21	0.00	0.00	0.00	0.00	0.00	187.47
1977	0.05	6.93	11.65	26.71	101.29	29.26	10.97	2.85	2.52	1.14	0.52	0.07	0.06	0.00	0.00	194.01
1978	0.31	10.87	34.64	24.38	24.27	47.04	13.58	5.77	2.15	1.32	0.57	0.05	0.04	0.01	0.00	164.99
1979	0.10	3.47	54.61	89.36	14.24	9.47	12.94	5.96	2.32	0.56	0.21	0.08	0.00	0.00	0.01	193.33
1980	0.49	9.84	27.85	58.42	42.16	13.92	10.76	9.79	4.95	1.32	0.69	0.24	0.09	0.03	0.00	180.55
1981	0.23	4.82	35.40	73.34	58.90	23.41	6.74	5.84	4.16	0.59	0.02	0.04	0.03	0.00	0.00	213.53
1982	0.04	9.52	41.68	92.53	72.56	42.91	10.94	1.71	1.10	0.70	0.05	0.03	0.02	0.00	0.00	273.80
1983	0.00	6.96	42.29	81.51	121.82	59.42	33.14	8.72	1.70	0.18	0.44	0.10	0.00	0.00	0.00	356.28
1984	0.71	5.28	62.46	66.85	81.92	122.05	43.96	14.94	4.95	0.43	0.06	0.12	0.10	0.00	0.00	403.84
1985	0.20	11.60	7.43	36.26	39.31	70.63	117.57	36.73	10.31	2.65	0.85	0.00	0.00	0.00	0.00	333.55
1986	1.00	6.05	14.67	8.80	19.45	8.27	9.01	10.90	4.35	0.74	0.00	0.00	0.00	0.00	0.00	83.26
1987	0.00	4.25	6.43	5.73	6.66	12.55	10.75	7.07	15.65	1.67	0.98	0.00	0.00	0.00	0.00	71.74
1988	0.85	8.86	12.71	19.21	16.11	10.63	5.93	2.72	0.40	5.83	0.48	0.11	0.06	0.00	0.00	83.91
1989	2.94	1.33	3.62	34.46	39.31	13.57	5.21	2.65	1.08	0.50	2.00	0.20	0.06	0.05	0.02	106.99
1990	0.00	1.15	1.45	2.14	12.43	39.17	13.99	7.93	1.91	1.70	0.11	1.08	0.03	0.10	0.19	83.37
1991	0.00	1.14	8.11	4.34	3.83	7.39	33.95	3.75	19.13	0.85	6.00	0.40	2.39	0.20	0.83	92.29
1992	0.11	1.56	3.31	21.09	22.47	11.82	8.56	17.75	5.44	6.10	1.13	2.26	0.39	0.47	0.40	102.86
1993	0.04	2.46	8.46	19.94	47.83	16.69	7.21	6.86	9.73	2.38	2.27	0.54	0.92	0.17	0.30	125.80
1994	0.06	0.88	4.16	7.60	33.41	29.84	12.00	5.28	4.72	6.10	1.29	1.17	0.25	0.07	0.06	106.90
1995	0.00	0.23	1.73	4.82	9.46	21.96	13.60	4.30	2.05	2.15	2.46	0.41	0.28	0.04	0.12	63.62
1996	0.00	0.80	1.95	1.44	4.09	5.64	10.91	11.66	3.82	1.84	0.72	1.97	0.34	0.40	0.20	45.76
1997	0.00	1.65	7.20	4.08	4.28	8.23	12.34	18.77	13.71	5.62	2.03	0.88	0.50	0.14	0.04	79.49
1998	0.56	0.19	19.38	33.10	14.54	8.58	9.75	11.36	16.51	12.01	4.33	0.91	0.59	0.16	0.12	132.08
1999	0.00	0.75	2.61	22.91	34.47	10.08	7.53	4.00	6.20	8.16	4.70	1.18	0.58	0.13	0.08	103.40
2000	0.08	0.98	2.84	3.47	14.65	24.63	6.24	5.05	2.30	1.24	3.00	1.52	0.30	0.14	0.04	66.48
2001	0.74	10.13	6.59	7.34	9.42	12.59	14.44	4.73	2.70	1.35	0.65	0.83	0.61	0.00	0.04	72.14
2002	0.16	12.31	20.72	6.76	4.47	8.75	5.37	6.06	1.33	0.82	0.43	0.30	0.33	0.22	0.13	68.16
2003	0.14	2.69	21.47	22.95	5.33	3.25	4.66	3.76	2.58	0.54	0.19	0.04	0.09	0.04	0.05	67.79
2004	0.85	6.28	11.91	31.84	25.09	5.98	2.43	2.63	0.77	0.22	0.25	0.00	0.00	0.00	0.00	88.24
2005	1.14	1.21	5.33	6.85	41.25	21.73	6.10	0.74	0.91	0.35	0.18	0.13	0.00	0.00	0.00	85.91
2006	2.20	7.79	4.16	2.75	5.97	27.38	12.80	2.45	0.83	0.46	0.23	0.10	0.07	0.03	0.00	67.22
2007	0.82	18.89	7.46	2.51	2.31	3.58	10.19	6.70	1.59	0.29	0.23	0.09	0.00	0.00	0.01	54.68
2008	0.32	6.29	21.94	6.76	2.15	1.16	2.27	5.60	2.84	0.87	0.36	0.21	0.06	0.04	0.02	50.89
2009	0.24	6.38	14.84	13.47	3.82	1.19	0.72	0.95	1.90	1.45	0.47	0.06	0.01	0.00	0.00	45.50
2010	0.01	5.29	23.35	21.32	18.14	3.68	1.11	0.73	0.92	1.02	0.64	0.05	0.06	0.01	0.00	76.31
2011	0.00	2.49	12.18	26.78	20.88	13.12	2.97	0.61	0.38	0.21	0.36	0.35	0.07	0.00	0.00	80.40
2012	0.03	0.66	4.64	13.49	29.83	21.43	8.94	1.95	0.43	0.18	0.23	0.16	0.04	0.07	0.08	82.15
2013	0.58	2.70	10.20	5.31	13.00	17.18	12.57	5.13	1.01	0.53	0.30	0.18	0.28	0.22	0.04	69.23
2014	0.07	9.95	6.37	29.79	11.52	14.22	20.78	16.67	6.56	1.95	0.70	0.01	0.27	0.00	0.01	118.90
2015	0.00	8.58	107.27	15.31	32.09	10.00	12.25	11.94	5.79	1.84	1.29	0.15	0.11	0.05	0.08	206.74
2016	0.00	1.33	15.97	272.64	11.17	10.72	2.42	1.13	0.47	0.19	0.00	0.15	0.00	0.00	0.00	316.19
2017	0.00	0.00	0.09	18.77	259.68	4.63	2.97	0.10	0.10	0.03	0.00	0.00	0.00	0.00	0.00	286.38
2018	1.11	3.13	0.17	0.79	35.52	160.14	7.28	1.55	0.23	0.10	0.00	0.00	0.00	0.00	0.00	210.03
2019	0.44	10.41	7.23	1.22	0.85	20.00	101.70	8.86	1.09	0.34	0.00	0.00	0.00	0.00	0.00	152.15
2020	0.20	13.41	56.07	7.94	1.29	1.88	19.81	48.93	5.27	0.78	0.09	0.00	0.05	0.00	0.00	155.73

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

	Number aged			*Number measured*		
Year	*Males*	*Females*	*Total*	*Males*	*Females*	*Total*
1989	882	892	1,774	6,454	6,456	12,910
1990	453	689	1,142	17,814	24,662	42,476
1991	1,146	1,322	2,468	23,946	39,467	63,413
1992	1,726	1,755	3,481	31,608	47,226	78,834
1993	926	949	1,875	28,035	31,306	59,341
1994	136	129	265	24,321	25,861	50,182
1995	499	544	1,043	10,591	10,869	21,460
1996	381	378	759	8,581	8,682	17,263
1997	496	486	982	8,750	8,808	17,558
1998	924	989	1,913	78,955	83,160	162,115
1999	980	1,115	2,095	16,304	17,964	34,268
2000	1,108	972	2,080	13,167	11,794	24,961
2001	1,063	1,025	2,088	13,731	13,552	27,283
2002	1,036	1,025	2,061	9,924	9,851	19,775
2003	1,091	1,119	2,210	8,375	8,220	16,595
2004	1,217	996	2,213	4,446	3,622	8,068
2005	1,065	968	2,033	6,837	6,005	12,842
2006	1,127	969	2,096	7,248	6,178	13,426
2007	998	1,064	2,062	4,504	5,064	9,568
2008	961	1,090	2,051	7,430	8,536	15,966
2009	1,011	1,034	2,045	9,913	9,447	19,360
2010	1,195	1,055	2,250	14,958	13,997	28,955
2011	1,197	1,025	2,222	9,625	11,023	20,648
2012	1,160	1,097	2,257	11,045	10,430	21,475
2013	683	774	1,457	3,565	4,084	7,649
2014	1,085	1,040	2,125	10,353	10,444	20,797
2015	1,048	1,069	2,117	21,104	23,144	44,248
2016	1,433	959	2,392	28,904	20,347	49,251
2017	1,245	925	2,170	18,627	15,007	33,634
2018	1,254	1,008	2,262	16,022	13,024	29,046
2019	1,175	936	2,111	13,989	11,875	25,864
2020	1,062	1,051	2,113	11,545	11,746	23,291

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

Year	Shelikof Strait acoustic survey	Summer gulfwide acoustic survey	NMFS bottom trawl west of 140° W lon.	Shelikof Strait egg production	ADFG crab/groundfish survey
1981	2,785,755			1,788,908	
1982					
1983	2,278,172				
1984	1,757,168		726,229		
1985	1,175,823			768,419	
1986	585,755			375,907	
1987			737,900	484,455	
1988	301,709			504,418	
1989	290,461			433,894	214,434
1990	374,731		817,040	381,475	114,451
1991	380,331			370,000	
1992	713,429			616,000	127,359
1993	435,753		747,942		132,849
1994	492,593				103,420
1995	763,612				
1996	777,172		659,604		122,477
1997	583,017				93,728
1998	504,774				81,215
1999			601,969		53,587
2000	448,638				102,871
2001	432,749		220,141		86,967
2002	256,743				96,237
2003	317,269		394,333		66,989
2004	330,753				99,358
2005	356,117		354,209		79,089
2006	293,609				69,044
2007	180,881		278,541		76,674
2008	197,922				83,476
2009	257,422		662,557		145,438
2010	421,575				124,110
2011			660,207		100,839
2012	334,061				172,007
2013	807,838	884,049	947,877		102,406
2014	827,338				100,158
2015	847,970	1,606,171	707,774		42,277
2016	667,003				18,470
2017	1,465,229	1,318,396	288,943		21,855
2018	1,320,867				49,788
2019	1,281,083	580,543	257,604		50,960
2020	456,713				59,377
2021	526,974	431,148	494,743		64,813

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.

		No. of tows	Survey	Number aged			Number measured		
Year	*No. of tows*	*with pollock*	*biomass CV*	*Males*	*Females*	*Total*	*Males*	*Females*	*Total*
1984	929	536	0.14	1,119	1,394	2,513	8,985	13,286	25,990
1987	783	533	0.20	672	675	1,347	15,843	18,101	34,797
1990	708	549	0.12	503	560	1,063	15,014	20,053	42,631
1993	775	628	0.16	879	1,013	1,892	14,681	18,851	35,219
1996	807	668	0.15	509	560	1,069	17,698	19,555	46,668
1999	764	567	0.38	560	613	1,173	10,808	11,314	24,080
2001	489	302	0.30	395	519	914	9,135	10,281	20,272
2003	809	508	0.12	514	589	1,103	10,561	12,706	25,052
2005	837	514	0.15	639	868	1,507	9,041	10,782	26,927
2007	816	552	0.14	646	675	1,321	9,916	11,527	24,555
2009	823	563	0.15	684	870	1,554	13,084	14,697	30,876
2011	670	492	0.15	705	941	1,646	11,852	13,832	27,327
2013	548	439	0.21	763	784	1,547	14,941	16,680	31,880
2015	772	607	0.16	492	664	1,156	12,258	15,296	27,831
2017	536	424	0.44	221	240	461	6,304	5,186	13,782
2019	541	446	0.24	247	224	473	6,983	8,748	16,476
2021	529	425	0.17	NA	NA	NA	10,234	12,251	23,218

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Total*
1984	38.69	15.65	74.51	158.78	194.66	271.24	85.94	37.36	13.55	2.37	0.54	0.28	0.21	0.00	0.00	893.78
1987	26.07	325.15	150.41	111.72	70.64	135.13	64.32	37.03	146.40	18.87	6.66	2.89	1.46	0.00	0.00	1096.75
1990	58.06	201.33	44.56	39.44	189.70	222.16	67.30	102.42	25.18	36.56	5.72	24.03	5.98	0.73	1.05	1024.20
1993	76.85	44.71	55.15	129.75	264.85	89.84	34.99	64.20	65.56	18.72	9.28	5.90	2.48	1.44	3.88	867.59
1996	196.89	129.07	17.24	26.17	50.13	63.21	174.42	87.55	52.31	27.70	12.09	18.43	7.15	9.66	2.86	874.88
1999	109.73	19.16	20.95	66.81	119.04	56.84	59.07	47.74	56.41	81.99	65.20	9.67	8.29	2.50	0.76	724.16
2001	412.83	117.03	34.42	33.39	25.05	33.45	37.01	8.20	5.74	0.59	4.48	2.52	1.28	0.00	0.18	716.19
2003	75.07	18.29	128.10	140.40	73.08	44.63	36.00	25.20	14.43	8.57	3.21	1.78	1.26	0.00	0.00	570.02
2005	269.99	33.56	34.35	35.85	91.71	78.82	45.23	20.86	9.61	9.98	4.81	0.57	0.64	0.00	0.00	635.98
2007	175.42	96.39	87.70	36.51	19.16	18.88	54.97	31.09	6.63	3.05	2.78	1.00	1.11	0.00	0.00	534.71
2009	222.94	87.33	106.82	129.35	101.26	27.21	17.59	26.60	53.90	29.46	9.68	7.00	2.78	1.61	0.00	823.53
2011	249.43	96.71	110.68	101.79	163.62	107.99	33.24	7.14	5.69	8.61	19.29	6.62	0.00	0.00	0.55	911.36
2013	750.15	62.07	47.94	65.41	84.72	144.62	156.91	115.55	25.05	5.42	2.40	2.46	3.83	3.01	0.91	1470.46
2015	93.03	63.63	452.62	109.61	113.20	70.83	56.57	52.99	25.96	21.00	3.59	0.57	0.14	0.00	0.89	1064.65
2017	159.39	3.82	10.90	30.32	294.79	27.01	15.28	4.22	0.42	0.18	0.70	0.00	0.00	0.14	0.00	547.18
2019	126.12	69.72	27.32	15.63	10.24	28.95	178.10	20.40	3.11	0.07	0.29	0.00	0.00	0.14	0.00	480.08

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

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

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Total*
1981	77.65	3,481.18	1,510.77	769.16	2,785.91	1,051.92	209.93	128.52	79.43	25.19	1.73	0.00	0.00	0.00	0.00	10,121.37
1983	1.21	901.77	380.19	1,296.79	1,170.81	698.13	598.78	131.54	14.48	11.61	3.92	1.71	0.00	0.00	0.00	5,210.93
1984	61.65	58.25	324.49	141.66	635.04	988.21	449.62	224.35	41.03	2.74	0.00	1.02	0.00	0.00	0.00	2,928.07
1985	2,091.74	544.44	122.69	314.77	180.53	347.17	439.31	166.68	42.72	5.56	1.77	1.29	0.00	0.00	0.00	4,258.67
1986	575.36	2,114.83	183.62	45.63	75.36	49.34	86.15	149.36	60.22	10.62	1.29	0.00	0.00	0.00	0.00	3,351.78
1988	17.44	109.93	694.32	322.11	77.57	16.99	5.70	5.60	3.98	8.96	1.78	1.84	0.20	0.00	0.00	1,266.41
1989	399.48	89.52	90.01	222.05	248.69	39.41	11.75	3.83	1.89	0.55	10.66	1.42	0.00	0.00	0.00	1,119.25
1990	49.14	1,210.17	71.69	63.37	115.92	180.06	46.33	22.44	8.20	8.21	0.93	3.08	1.51	0.79	0.24	1,782.08
1991	21.98	173.65	549.90	48.11	64.87	69.60	116.32	23.65	29.43	2.23	4.29	0.92	4.38	0.00	0.00	1,109.32
1992	228.03	33.69	73.54	188.10	367.99	84.11	84.99	171.18	32.70	56.35	2.30	14.67	0.90	0.30	0.00	1,338.85
1993	63.29	76.08	37.05	72.39	232.79	126.19	26.77	35.63	38.72	16.12	7.77	2.60	2.19	0.49	1.51	739.61
1994	185.98	35.77	49.30	31.75	155.03	83.58	42.48	27.23	44.45	48.46	14.79	6.65	1.12	2.34	0.57	729.49
1995	10,689.87	510.37	79.37	77.70	103.33	245.23	121.72	53.57	16.63	10.72	14.57	5.81	2.12	0.44	0.00	11,931.45
1996	56.14	3,307.21	118.94	25.12	53.99	71.03	201.05	118.52	39.80	13.01	11.32	5.32	2.52	0.03	0.38	4,024.36
1997	70.37	183.14	1,246.55	80.06	18.42	44.04	51.73	97.55	52.73	14.29	2.40	3.05	0.93	0.46	0.00	1,865.72
1998	395.47	88.54	125.57	474.36	136.12	14.22	31.93	36.30	74.08	25.90	14.30	6.88	0.27	0.56	0.56	1,425.05
2000	4,484.41	755.03	216.52	15.83	67.19	131.64	16.82	12.61	9.87	7.84	13.87	6.88	1.88	1.06	0.00	5,741.46
2001	288.93	4,103.95	351.74	61.02	41.55	22.99	34.63	13.07	6.20	2.67	1.20	1.91	0.69	0.50	0.24	4,931.27
2002	8.11	162.61	1,107.17	96.58	16.25	16.14	7.70	6.79	1.46	0.66	0.35	0.34	0.15	0.13	0.00	1,424.45
2003	51.19	89.58	207.69	802.46	56.58	7.69	4.14	1.58	1.46	0.85	0.28	0.00	0.10	0.00	0.00	1,223.60
2004	52.58	93.94	57.58	159.62	356.33	48.78	2.67	3.42	3.32	0.52	0.42	0.00	0.66	0.00	0.00	779.84
2005	1,626.13	157.49	55.54	34.63	172.74	162.40	36.02	3.61	2.39	0.00	0.76	0.00	0.00	0.00	0.00	2,251.71
2006	161.69	835.96	40.75	11.54	17.42	55.98	74.97	32.25	6.90	0.83	0.75	0.53	0.00	0.00	0.00	1,239.57
2007	53.54	231.73	174.88	29.66	10.14	17.27	34.39	20.85	1.54	1.05	0.69	0.00	0.00	0.00	0.00	575.74
2008	1,778.16	359.21	230.18	49.03	11.16	2.03	3.73	9.82	6.19	1.87	0.50	0.00	0.00	0.00	0.00	2,451.89
2009	814.12	1,127.16	105.85	95.81	57.76	9.46	2.71	0.81	4.67	5.61	1.28	0.23	0.00	0.00	0.00	2,225.45
2010	270.52	299.06	538.69	82.86	76.28	27.70	11.22	5.08	5.02	10.25	8.84	3.22	0.00	0.00	0.00	1,338.73
2012	193.77	842.35	43.29	76.61	94.74	45.86	28.95	4.44	1.13	0.28	0.09	0.52	0.00	0.00	0.00	1,332.04
2013	9,178.41	117.10	687.95	51.34	64.42	104.03	58.73	42.83	10.46	4.94	4.46	0.49	1.42	3.99	2.02	10,332.59
2014	1,590.79	3,492.94	17.39	279.93	82.80	57.66	98.47	54.64	25.65	17.63	7.33	0.70	2.33	0.00	0.66	5,728.91
2015	19.82	103.95	1,637.34	72.38	152.81	62.39	56.75	68.07	30.02	10.97	5.61	3.67	0.94	0.64	2.41	2,227.76
2016	0.00	1.82	78.21	1,451.78	43.43	33.52	15.48	3.63	7.37	1.69	0.00	0.00	0.00	0.00	0.00	1,636.92
2017	744.72	0.00	9.40	126.40	2,576.24	125.99	31.13	9.29	0.33	0.69	0.00	0.00	0.00	0.00	0.00	3,624.17
2018	1,819.56	142.60	1.57	9.91	166.40	1,803.87	86.06	46.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,076.52
2019	7,361.19	1,671.67	155.54	6.05	6.58	261.73	1,127.49	53.86	11.09	9.01	0.07	0.07	0.00	0.00	0.00	10,664.36
2020	17.07	79.98	343.50	71.73	15.44	26.80	68.15	191.69	116.13	36.98	7.99	2.73	0.00	0.00	0.00	978.19
2021	7,730.11	36.69	94.22	150.67	55.39	7.32	12.51	64.01	133.92	63.40	14.26	2.23	0.00	0.00	0.00	8,364.73

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*	*Unsexed*	*Total*	*Males*	*Females*	*Unsexed*	*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	287	329		616	3,554	3,724		7,278
2004	13	2	0.09	492	440		932	3,838	2,552	91	6,481
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	163	3,479
2009	9	3	0.06	254	301	5	560	1,583	1,632	747	3,962
2010	13	2	0.03	286	244		530	2,590	2,358		4,948
2012	8	3	0.08	235	372	10	617	1,727	1,989	297	4,013
2013	29	5	0.05	376	386	26	788	2,198	2,436	171	4,805
2014	19	2	0.05	389	430	35	854	3,940	3,377	635	7,952
2015	20	0	0.04	354	372	29	755	4,552	4,227	176	8,955
2016	19	0	0.07	337	269		606	5,115	3,290		8,405
2017	16	1	0.04	241	314	58	613	2,501	2,781	515	5,797
2018	14	4	0.04	303	359	65	727	367	430	4,742	5,539
2019	19	7	0.07	378	413	100	891	929	977	5,693	7,599
2020	23	0	0.05	275	237	12	524	628	537	6,090	7,255
2021	24	0	0.03	253	260	90	603	575	658	7,581	8,814

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	0.037	0.026	0.095	0.078	0.117	0.177	0.108	0.054	0.065	0.061	0.099	0.059	0.017	0.006	0.002	538
2002	0.009	0.074	0.184	0.193	0.149	0.117	0.106	0.071	0.045	0.019	0.015	0.009	0.004	0.004	0.002	538
2004	0.005	0.008	0.057	0.199	0.263	0.150	0.108	0.067	0.059	0.039	0.015	0.013	0.008	0.008	0.000	594
2006	0.005	0.042	0.112	0.083	0.147	0.301	0.166	0.059	0.036	0.029	0.012	0.003	0.002	0.000	0.003	591
2008	0.000	0.035	0.407	0.134	0.054	0.067	0.044	0.154	0.045	0.013	0.022	0.018	0.003	0.003	0.000	597
2010	0.002	0.044	0.140	0.265	0.260	0.084	0.056	0.019	0.038	0.029	0.036	0.014	0.007	0.003	0.003	585
2012	0.018	0.021	0.064	0.103	0.158	0.299	0.182	0.071	0.030	0.021	0.012	0.007	0.007	0.005	0.002	565
2014	0.000	0.019	0.054	0.160	0.135	0.144	0.159	0.194	0.083	0.022	0.015	0.008	0.003	0.003	0.000	592
2016	0.000	0.020	0.035	0.355	0.172	0.271	0.069	0.042	0.022	0.008	0.007	0.000	0.000	0.000	0.000	598
2018	0.000	0.065	0.023	0.022	0.101	0.593	0.136	0.047	0.005	0.007	0.002	0.000	0.000	0.000	0.000	597
2020	0.000	0.000	0.097	0.228	0.057	0.057	0.215	0.294	0.050	0.002	0.000	0.000	0.000	0.000	0.000	618

		Observed Age									
True Age	*St. dev.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.18	0.997	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.23	0.014	0.972	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.27	0.000	0.033	0.934	0.033	0.000	0.000	0.000	0.000	0.000	0.000
4	0.32	0.000	0.000	0.057	0.886	0.057	0.000	0.000	0.000	0.000	0.000
5	0.36	0.000	0.000	0.000	0.083	0.834	0.083	0.000	0.000	0.000	0.000
6	0.41	0.000	0.000	0.000	0.000	0.109	0.782	0.109	0.000	0.000	0.000
7	0.45	0.000	0.000	0.000	0.000	0.000	0.133	0.732	0.133	0.000	0.000
8	0.50	0.000	0.000	0.000	0.000	0.000	0.001	0.155	0.687	0.155	0.001
9	0.54	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.175	0.645	0.177
10	0.59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.191	0.804

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
2020	0.002	0.015	0.123	0.559	0.920	0.990	0.999	1.000	1.000	237
2021	0.047	0.132	0.319	0.591	0.816	0.932	0.977	0.992	0.997	228
Average										
All years	0.014	0.057	0.274	0.610	0.861	0.940	0.979	0.989	0.994	
2011-2021	0.033	0.110	0.364	0.749	0.937	0.986	0.997	0.999	1.000	
2016-2021	0.050	0.154	0.437	0.777	0.944	0.986	0.996	0.999	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
2019	0.111	0.300	0.522	0.624	0.815	0.816	0.838	0.869	1.071	1.022
2020	0.202	0.310	0.423	0.616	0.796	0.944	0.942	0.954	0.943	0.948

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

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1981	0.017	0.089	0.226	0.332	0.383	0.472	0.635	0.719	0.857	0.764
1983	0.013	0.079	0.308	0.408	0.555	0.652	0.555	0.717	0.764	1.058
1984	0.012	0.112	0.256	0.551	0.587	0.692	0.736	0.720	0.878	1.006
1985	0.012	0.099	0.331	0.505	0.601	0.729	0.803	0.828	0.818	1.157
1986	0.008	0.066	0.216	0.381	0.748	0.835	0.881	0.940	0.966	1.066
1988	0.010	0.069	0.187	0.283	0.403	0.538	0.997	1.118	1.131	1.281
1989	0.011	0.092	0.230	0.397	0.447	0.623	0.885	1.033	1.131	1.221
1990	0.008	0.055	0.204	0.356	0.530	0.665	0.777	1.087	1.087	1.364
1991	0.011	0.072	0.155	0.268	0.510	0.779	0.911	0.969	1.211	1.521
1992	0.011	0.086	0.211	0.321	0.392	0.811	1.087	1.132	1.106	1.304
1993	0.010	0.082	0.304	0.469	0.583	0.714	1.054	1.197	1.189	1.332
1994	0.010	0.090	0.284	0.639	0.817	0.899	1.120	1.238	1.444	1.431
1995	0.011	0.091	0.295	0.526	0.804	0.898	0.949	1.034	1.147	1.352
1996	0.011	0.055	0.206	0.469	0.923	1.031	1.052	1.115	1.217	1.374
1997	0.010	0.079	0.157	0.347	0.716	1.200	1.179	1.231	1.279	1.424
1998	0.011	0.089	0.225	0.322	0.386	0.864	1.217	1.295	1.282	1.362
2000	0.013	0.084	0.279	0.570	0.810	0.811	1.010	1.319	1.490	1.551
2001	0.009	0.052	0.172	0.416	0.641	1.061	1.166	1.379	1.339	1.739
2002	0.012	0.082	0.148	0.300	0.714	0.984	1.190	1.241	1.535	1.765
2003	0.012	0.091	0.207	0.277	0.436	0.906	1.220	1.280	1.722	1.584
2004	0.010	0.085	0.246	0.486	0.502	0.749	1.341	1.338	1.446	1.311
2005	0.011	0.084	0.305	0.548	0.767	0.734	0.798	1.169	1.205	1.837
2006	0.009	0.066	0.262	0.429	0.828	1.124	1.163	1.327	1.493	1.884
2007	0.011	0.063	0.222	0.446	0.841	1.248	1.378	1.439	1.789	1.896
2008	0.014	0.099	0.267	0.484	0.795	1.373	1.890	1.869	1.882	2.014
2009	0.011	0.078	0.262	0.522	0.734	1.070	1.658	2.014	2.103	2.067
2010	0.010	0.079	0.240	0.673	1.093	1.287	1.828	2.090	2.291	2.227
2012	0.013	0.079	0.272	0.653	0.928	1.335	1.485	1.554	1.930	1.939
2013	0.009	0.127	0.347	0.626	1.157	1.371	1.600	1.772	1.849	2.262
2014	0.012	0.058	0.304	0.594	0.712	1.294	1.336	1.531	1.572	1.666
2015	0.013	0.094	0.200	0.542	0.880	1.055	1.430	1.498	1.594	1.654
2016	0.013	0.133	0.303	0.390	0.557	0.751	0.860	1.120	1.115	1.178
2017	0.011	0.133	0.345	0.451	0.505	0.578	0.912	0.951	1.383	1.339
2018	0.008	0.089	0.181	0.516	0.539	0.609	0.679	0.892	1.383	1.339
2019	0.008	0.061	0.221	0.493	0.637	0.701	0.736	0.789	0.879	1.044
2020	0.015	0.072	0.172	0.311	0.480	0.711	0.808	0.806	0.800	0.848
2021	0.009	0.191	0.321	0.494	0.682	0.856	0.876	1.019	1.054	1.059

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

(A)

Year	1	2	3	4	5	6	7	8	9	10
1984	0.062	0.157	0.530	0.661	0.740	0.834	0.904	0.960	0.991	1.196
1987	0.028	0.170	0.379	0.569	0.781	0.923	1.021	1.076	1.157	1.264
1990	0.048	0.173	0.306	0.564	0.776	0.906	1.112	1.134	1.275	1.472
1993	0.041	0.164	0.475	0.680	0.797	0.932	1.057	1.304	1.369	1.412
1996	0.030	0.097	0.325	0.716	0.925	1.009	1.085	1.186	1.243	1.430
1999	0.023	0.144	0.374	0.593	0.700	0.787	0.868	1.069	1.223	1.285
2001	0.031	0.105	0.410	0.698	0.925	1.060	1.201	1.413	1.293	1.481
2003	0.049	0.201	0.496	0.593	0.748	0.950	1.146	1.149	1.381	1.523
2005	0.025	0.182	0.423	0.653	0.836	0.943	1.024	1.228	1.283	1.527
2007	0.022	0.148	0.307	0.589	0.987	1.199	1.415	1.477	1.756	1.737
2009	0.023	0.237	0.492	0.860	1.081	1.421	1.637	1.839	1.955	2.020
2011	0.028	0.243	0.441	0.708	0.980	1.345	1.505	1.656	1.970	2.037
2013	0.020	0.216	0.420	0.894	1.146	1.334	1.497	1.574	1.665	2.037
2015	0.033	0.207	0.366	0.575	0.863	1.069	1.270	1.374	1.432	1.525
2017	0.038	0.224	0.640	0.690	0.743	0.886	1.095	1.298	1.283	1.504
2019	0.045	0.172	0.412	0.610	0.689	0.754	0.846	0.877	1.108	1.790

(B)

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

Age	*Foreign (1970-81)*	*Foreign and JV (1982-1988)*	*Domestic (1989-2000)*	*Domestic (2001-2014)*	*Recent domestic (2015-2019)*	*Shelikof acoustic survey*	*Summer acoustic survey*	*Bottom trawl survey*	*ADF&G bottom trawl*
1	0.001	0.004	0.002	0.009	0.003	0.000	1.000	0.131	0.005
2	0.011	0.028	0.012	0.064	0.028	0.000	1.000	0.239	0.020
3	0.118	0.182	0.072	0.336	0.241	1.000	1.000	0.398	0.074
4	0.612	0.629	0.333	0.784	0.767	1.000	1.000	0.581	0.235
5	0.950	0.929	0.763	0.967	0.975	1.000	1.000	0.746	0.542
6	0.997	0.992	0.961	0.997	0.999	0.999	1.000	0.863	0.821
7	1.000	1.000	1.000	1.000	1.000	0.992	1.000	0.934	0.947
8	0.987	0.988	0.993	0.987	0.987	0.951	1.000	0.971	0.986
9	0.856	0.856	0.862	0.856	0.857	0.755	1.000	0.991	0.997
10	0.336	0.337	0.339	0.336	0.337	0.326	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	1,263	315	195	134	96	71	53	39	30	88
1971	3,160	315	158	120	91	66	51	37	28	87
1972	3,629	787	158	97	81	62	47	36	27	85
1973	10,594	904	394	95	60	48	38	29	22	77
1974	2,178	2,638	452	236	56	33	27	22	17	66
1975	2,203	542	1,318	268	132	29	17	14	12	54
1976	8,688	549	271	794	162	76	17	10	9	44
1977	11,780	2,163	274	162	456	87	42	9	6	35
1978	14,459	2,933	1,081	163	90	231	45	22	5	27
1979	25,669	3,600	1,465	641	91	47	123	24	12	21
1980	13,044	6,392	1,800	876	374	51	27	70	14	21
1981	7,248	3,248	3,200	1,092	542	221	31	16	43	24
1982	7,168	1,805	1,626	1,947	693	335	141	19	10	45
1983	4,806	1,785	903	985	1,240	438	219	92	13	40
1984	5,771	1,196	891	540	610	762	279	139	59	37
1985	14,056	1,436	596	525	321	356	459	168	85	63
1986	4,005	3,498	716	353	310	179	202	260	96	94
1987	1,664	997	1,750	436	231	203	121	137	178	136
1988	4,588	414	499	1,071	290	154	140	84	96	226
1989	10,810	1,143	207	306	715	195	108	98	59	234
1990	8,208	2,692	572	127	203	474	133	73	67	212
1991	3,204	2,044	1,349	352	85	134	319	89	50	200
1992	2,340	798	1,024	829	234	55	87	205	58	176
1993	1,681	583	400	629	552	151	35	55	133	164
1994	1,680	419	292	245	416	352	97	23	36	205
1995	6,546	418	210	179	162	267	229	62	15	170
1996	3,109	1,630	210	129	120	108	181	154	43	134
1997	1,399	774	817	129	87	81	74	124	106	127
1998	1,287	348	388	500	84	54	50	46	78	159
1999	1,595	320	174	234	308	47	30	27	25	152
2000	6,048	397	160	105	146	177	27	17	16	119
2001	6,638	1,506	198	97	67	89	109	16	10	93
2002	916	1,652	750	119	60	40	54	66	10	72
2003	697	228	822	447	74	37	26	35	43	58
2004	637	173	113	490	285	48	25	17	24	72
2005	1,616	158	86	66	307	181	32	17	12	68
2006	5,391	401	78	50	40	187	114	20	11	56
2007	5,240	1,340	198	45	30	24	118	72	13	47
2008	6,289	1,303	664	116	28	19	16	78	48	42
2009	2,757	1,565	649	394	73	18	13	11	53	64
2010	1,032	686	781	390	257	49	13	9	8	85
2011	4,418	257	342	465	249	167	33	9	6	67
2012	677	1,100	128	205	295	161	112	22	6	52
2013	40,574	169	550	77	128	186	105	73	15	42
2014	2,187	10,104	84	333	49	81	121	68	48	40
2015	38	545	5,058	51	199	27	46	69	40	57
2016	5	10	272	3,040	30	107	15	26	39	62
2017	1,706	1	5	165	1,877	18	67	9	16	69
2018	7,051	425	1	3	101	1,132	11	42	6	59
2019	5,221	1,755	212	0	2	59	691	7	26	45
2020	156	1,299	874	123	0	1	36	414	4	48
2021	10,760	39	650	498	71	0	1	21	252	36
Average	5,728	1,381	694	413	255	157	100	64	41	88

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.

Year	3+ total biomass (1,000 t)	Female spawn. biom.	Age 1 recruits (million)	Catch (t)	Harvest rate	2020 Assessment results: 3+ total biomass	Female spawn. biom.	Age 1 recruits	Harvest rate
1977	747	137	11,767	118,092	16%	746	136	11,758	16%
1978	966	125	14,441	95,408	10%	965	124	14,433	10%
1979	1,351	131	25,637	106,161	8%	1,350	130	25,660	8%
1980	1,822	182	13,028	115,158	6%	1,821	181	13,100	6%
1981	2,852	202	7,238	147,818	5%	2,853	201	7,302	5%
1982	2,977	331	7,158	169,045	6%	2,981	330	7,256	6%
1983	2,709	464	4,799	215,625	8%	2,716	464	4,920	8%
1984	2,400	515	5,761	307,541	13%	2,413	516	5,897	13%
1985	1,929	467	14,033	286,900	15%	1,945	469	14,412	15%
1986	1,611	422	3,998	86,910	5%	1,633	425	4,135	5%
1987	1,922	393	1,661	68,070	4%	1,958	397	1,691	3%
1988	1,810	394	4,581	63,391	4%	1,848	399	4,723	3%
1989	1,590	404	10,792	75,585	5%	1,627	412	10,919	5%
1990	1,459	412	8,194	88,269	6%	1,496	421	8,182	6%
1991	1,742	402	3,199	100,488	6%	1,782	412	3,180	6%
1992	1,822	361	2,337	90,858	5%	1,855	371	2,358	5%
1993	1,717	389	1,679	108,909	6%	1,744	399	1,675	6%
1994	1,455	458	1,678	107,335	7%	1,477	468	1,697	7%
1995	1,190	382	6,536	72,618	6%	1,207	390	6,645	6%
1996	1,002	353	3,103	51,263	5%	1,016	359	3,085	5%
1997	1,026	313	1,397	90,130	9%	1,042	318	1,402	9%
1998	989	242	1,284	125,460	13%	1,003	246	1,339	13%
1999	735	225	1,591	95,638	13%	744	229	1,668	13%
2000	645	213	6,035	73,080	11%	655	217	6,221	11%
2001	609	199	6,624	72,077	12%	623	203	6,640	12%
2002	776	165	914	51,934	7%	798	169	923	7%
2003	980	153	695	50,684	5%	999	156	714	5%
2004	815	168	636	63,844	8%	832	172	666	8%
2005	676	205	1,611	80,978	12%	691	210	1,713	12%
2006	568	218	5,377	71,976	13%	583	224	5,539	12%
2007	522	191	5,227	52,714	10%	539	196	5,351	10%
2008	722	188	6,274	52,584	7%	748	194	6,494	7%
2009	1,033	185	2,750	44,247	4%	1,068	191	2,886	4%
2010	1,221	254	1,030	76,748	6%	1,264	264	1,094	6%
2011	1,158	298	4,406	81,503	7%	1,203	309	4,644	7%
2012	1,066	316	676	103,954	10%	1,112	330	747	9%
2013	1,072	337	40,454	96,363	9%	1,126	353	39,489	9%
2014	834	254	2,181	142,640	17%	882	268	2,269	16%
2015	2,371	230	38	167,549	7%	2,363	243	43	7%
2016	2,377	255	5	177,129	7%	2,365	260	5	7%
2017	1,730	354	1,696	186,155	11%	1,721	356	2,207	11%
2018	1,159	341	7,020	158,070	14%	1,151	340	6,965	14%
2019	829	266	5,260	120,243	14%	850	263	5,746	14%
2020	915	188	156	107,471	12%	932	184	104	12%
2021	982	197	10,760	92,342					
Average									
1977-2020	1,361	288	5,794	109,514	9%	1,380	293	5,861	9%
1978-2020			5,656					5,724	

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	1,262	0.30	706	2,254	128	0.30	71	229
1971	3,159	0.44	1,393	7,162	122	0.31	67	222
1972	3,628	0.36	1,826	7,205	112	0.33	60	210
1973	10,587	0.16	7,745	14,473	95	0.36	48	188
1974	2,176	0.29	1,244	3,806	86	0.33	46	161
1975	2,201	0.27	1,300	3,725	91	0.25	57	147
1976	8,678	0.19	6,044	12,461	121	0.18	85	171
1977	11,767	0.18	8,283	16,717	137	0.18	97	194
1978	14,441	0.18	10,184	20,478	125	0.21	83	187
1979	25,637	0.15	19,164	34,296	131	0.21	87	199
1980	13,028	0.19	9,020	18,816	182	0.20	124	268
1981	7,238	0.23	4,640	11,292	202	0.18	142	287
1982	7,158	0.23	4,609	11,116	331	0.16	242	452
1983	4,799	0.34	2,515	9,158	464	0.15	344	625
1984	5,761	0.30	3,226	10,288	515	0.16	377	704
1985	14,033	0.16	10,311	19,099	467	0.18	330	661
1986	3,998	0.28	2,334	6,849	422	0.19	290	615
1987	1,661	0.42	757	3,645	393	0.19	274	564
1988	4,581	0.23	2,938	7,142	394	0.17	282	550
1989	10,792	0.14	8,148	14,293	404	0.15	304	537
1990	8,194	0.16	5,992	11,203	412	0.14	314	540
1991	3,199	0.26	1,938	5,279	402	0.14	306	527
1992	2,337	0.27	1,393	3,921	361	0.13	278	469
1993	1,679	0.30	951	2,963	389	0.12	306	494
1994	1,678	0.29	963	2,924	458	0.12	365	576
1995	6,536	0.12	5,155	8,288	382	0.12	304	481
1996	3,103	0.17	2,242	4,296	353	0.12	281	444
1997	1,397	0.24	879	2,220	313	0.12	248	395
1998	1,284	0.23	827	1,994	242	0.13	189	309
1999	1,591	0.21	1,065	2,376	225	0.13	174	290
2000	6,035	0.12	4,790	7,604	213	0.13	164	277
2001	6,624	0.11	5,379	8,156	199	0.14	151	263
2002	914	0.28	535	1,562	165	0.15	123	222
2003	695	0.26	421	1,149	153	0.15	115	203
2004	636	0.28	371	1,087	168	0.12	132	214
2005	1,611	0.19	1,116	2,325	205	0.12	161	260
2006	5,377	0.13	4,194	6,894	218	0.13	169	281
2007	5,227	0.13	4,029	6,780	191	0.14	145	251
2008	6,274	0.13	4,913	8,011	188	0.15	141	250
2009	2,750	0.17	1,995	3,792	185	0.14	140	243
2010	1,030	0.26	623	1,703	254	0.13	199	325
2011	4,406	0.15	3,305	5,872	298	0.12	236	376
2012	676	0.31	370	1,235	316	0.12	250	400
2013	40,454	0.08	34,588	47,314	337	0.13	263	432
2014	2,181	0.24	1,370	3,472	254	0.14	195	331
2015	38	0.38	19	79	230	0.15	172	306
2016	5	0.38	2	10	255	0.12	203	321
2017	1,696	0.20	1,151	2,500	354	0.11	285	441
2018	7,020	0.18	4,978	9,901	341	0.12	269	433
2019	5,260	0.21	3,527	7,843	266	0.14	202	349
2020	156	0.36	79	308	188	0.16	137	258
2021	10,760	0.32	5,875	19,707	197	0.17	142	274

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 last five Shelikof Strait acoustic surveys conducted in March. Population weight at age is based on the average of the last three bottom trawl surveys conducted in June to August. Fishery selectivity is the current year as estimated by the RE model (see main text). Proportion mature females is the average from winter acoustic survey specimen data (1983-present).

			Weight at age (kg)			
	Natural mortality	*Fishery selectivity (Avg. 2017-2021)*	*Spawning (Avg. 2017-2021)*	*Population (Avg. 2015, 2017, 2019)*	*Fishery (Est. 2021 from RE model)*	*Proportion mature females (Avg. 1983-2021)*
1	1.39	0.003	0.010	0.039	0.165	0.000
2	0.69	0.028	0.109	0.201	0.458	0.014
3	0.48	0.241	0.248	0.472	0.604	0.057
4	0.37	0.767	0.453	0.625	0.744	0.274
5	0.34	0.975	0.569	0.765	0.908	0.610
6	0.30	0.999	0.691	0.903	1.033	0.861
7	0.30	1.000	0.802	1.071	1.139	0.940
8	0.29	0.987	0.891	1.183	1.125	0.979
9	0.28	0.857	1.100	1.274	1.081	0.989
10+	0.29	0.337	1.126	1.606	1.177	0.994

Table 1.24. Methods used to assess GOA pollock. The basis for catch recommendation in 1977-1989 is the presumptive method by which the ABC was determined (based on the assessment and SSC minutes). The basis for catch recommendation given in 1990-2018 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 increase)	229,000
2005	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	224,000
2006	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible FABC)	220,000
2007	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	221,000
2008	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	237,000
2009	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	248,000
2010	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	276,000
2011	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	271,000
2012	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	297,000
2013	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	290,000
2014	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	312,000
2015	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	300,000
2016	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	267,000
2017	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	238,000
2018	AD model builder	Amendment 56 Tier 3 guidelines (with a reduction from max permissible F_{ABC})	221,000
2019	AD model builder	Amendment 56 Tier 3 guidelines (with reduction 12,055 t from maxABC)	194,000
2020	AD model builder	Amendment 56 Tier 3 guidelines	177,000

Table 1.25. Projections of GOA pollock spawning biomass, full recruitment fishing mortality, and catch for 2022-2034 under different harvest policies. For these projections, fishery weight at age was assumed to be equal to the estimated weight at age in 2021 for the RE model. All projections begin with initial age composition in 2021 using the base run model with a projected 2021 catch of 92,342 t. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 430,000 t, 172,000 t, 150,000 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}*
2022	186,481	186,481	188,347	191,038	192,804	185,343	186,481
2023	167,840	167,840	178,092	194,287	205,736	162,071	167,840
2024	167,971	167,971	184,060	212,525	234,151	159,960	166,842
2025	178,273	178,273	200,052	242,452	276,408	168,190	171,981
2026	181,798	181,798	208,878	267,703	317,272	169,290	171,312
2027	177,459	177,459	205,879	276,353	338,695	163,509	164,636
2028	174,714	174,714	201,538	277,843	347,857	159,754	160,392
2029	186,203	186,203	210,932	294,838	374,302	168,406	168,751
2030	188,698	188,698	212,925	302,248	388,480	168,312	168,521
2031	189,051	189,051	213,043	305,757	395,965	167,283	167,410
2032	189,424	189,424	212,824	308,251	401,088	166,783	166,860
2033	188,666	188,666	211,755	309,899	405,055	165,371	165,418
2034	186,471	186,471	209,340	309,961	407,311	162,677	162,706
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}*
2022	0.26	0.26	0.18	0.07	0	0.31	0.26
2023	0.26	0.26	0.18	0.07	0	0.29	0.26
2024	0.25	0.25	0.18	0.07	0	0.28	0.30
2025	0.24	0.24	0.18	0.07	0	0.27	0.28
2026	0.22	0.22	0.18	0.07	0	0.24	0.24
2027	0.19	0.19	0.18	0.07	0	0.21	0.21
2028	0.14	0.14	0.18	0.07	0	0.19	0.19
2029	0.12	0.12	0.18	0.07	0	0.18	0.18
2030	0.11	0.11	0.18	0.07	0	0.17	0.17
2031	0.11	0.11	0.18	0.06	0	0.16	0.16
2032	0.11	0.11	0.18	0.05	0	0.16	0.16
2033	0.11	0.11	0.18	0.05	0	0.16	0.16
2034	0.11	0.11	0.18	0.05	0	0.16	0.16
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}*
2022	133,081	133,081	95,848	39,199	0	154,983	133,081
2023	131,912	131,912	101,322	44,077	0	145,200	131,912
2024	166,023	166,023	130,698	58,480	0	180,912	192,613
2025	170,646	170,646	139,539	65,164	0	185,024	189,761
2026	154,708	154,708	133,857	64,838	0	166,937	168,571
2027	146,678	146,678	130,991	64,493	0	158,748	159,256
2028	147,408	147,408	135,165	66,597	0	166,483	166,638
2029	156,111	156,111	141,566	69,871	0	176,964	177,017
2030	148,449	148,449	135,417	66,935	0	166,616	166,660
2031	151,267	151,267	137,272	66,258	0	169,749	169,773
2032	151,238	151,238	137,065	65,710	0	168,552	168,567
2033	146,844	146,844	133,622	64,125	0	163,890	163,899
2034	144,793	144,793	131,554	62,871	0	161,763	161,769

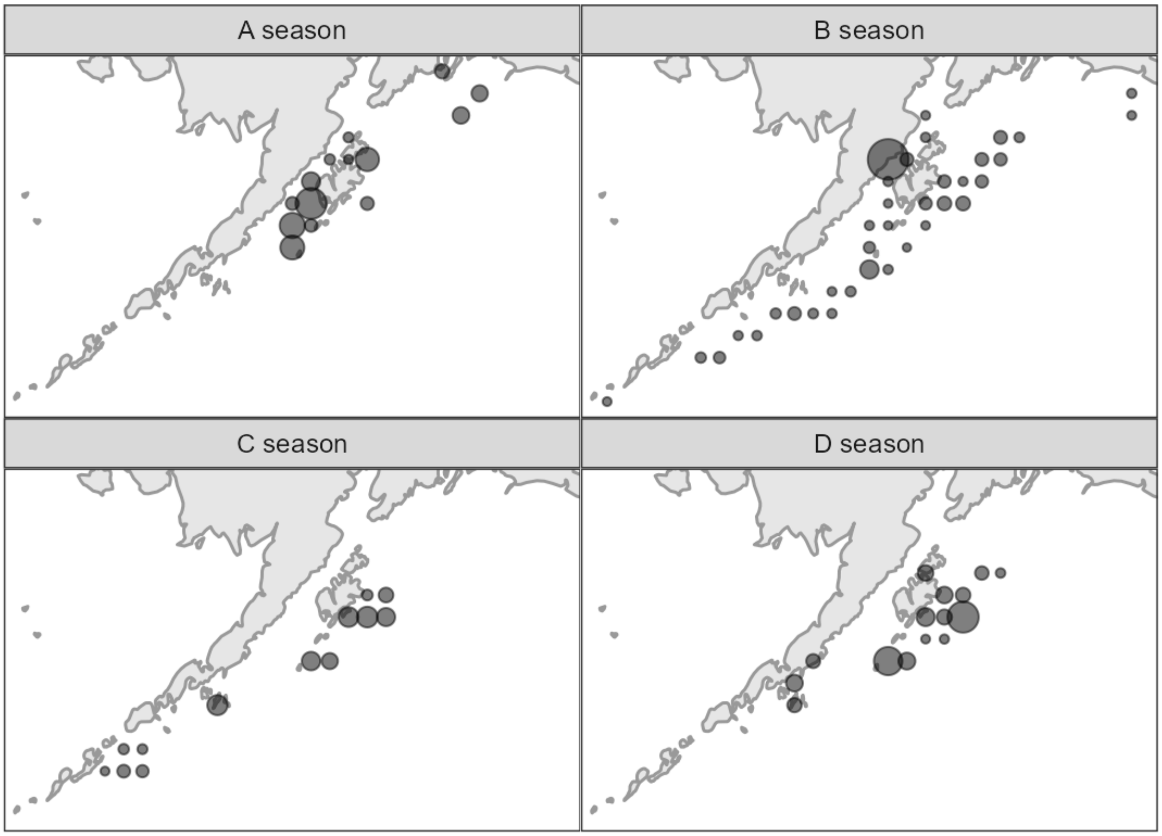


Figure 1.1. Distribution of pollock catch in the 2020 fishery shown for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

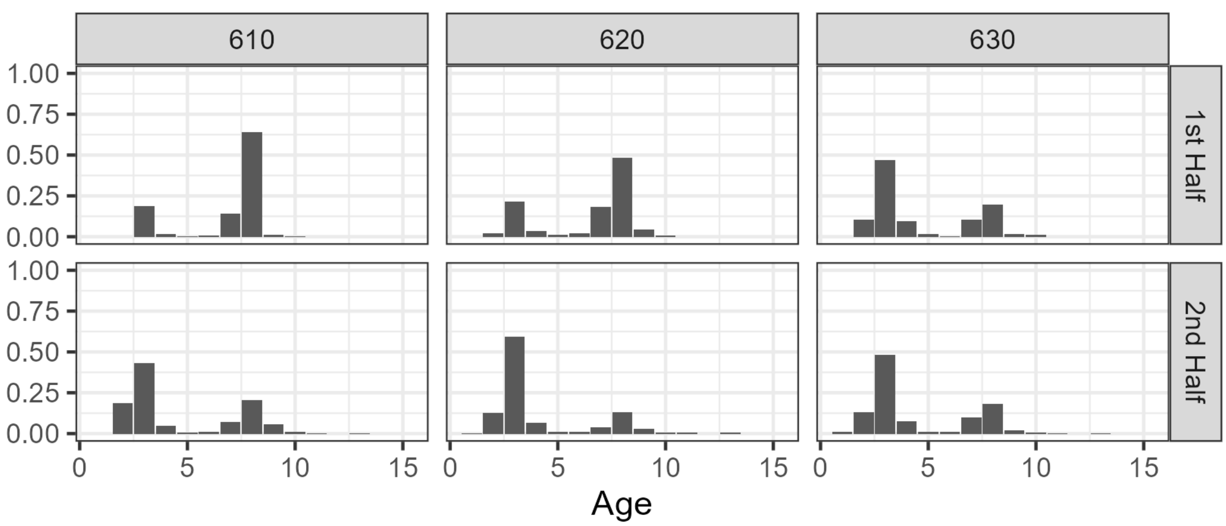


Figure 1.2. 2020 fishery age composition by half year (January-June, July-December) and management area.

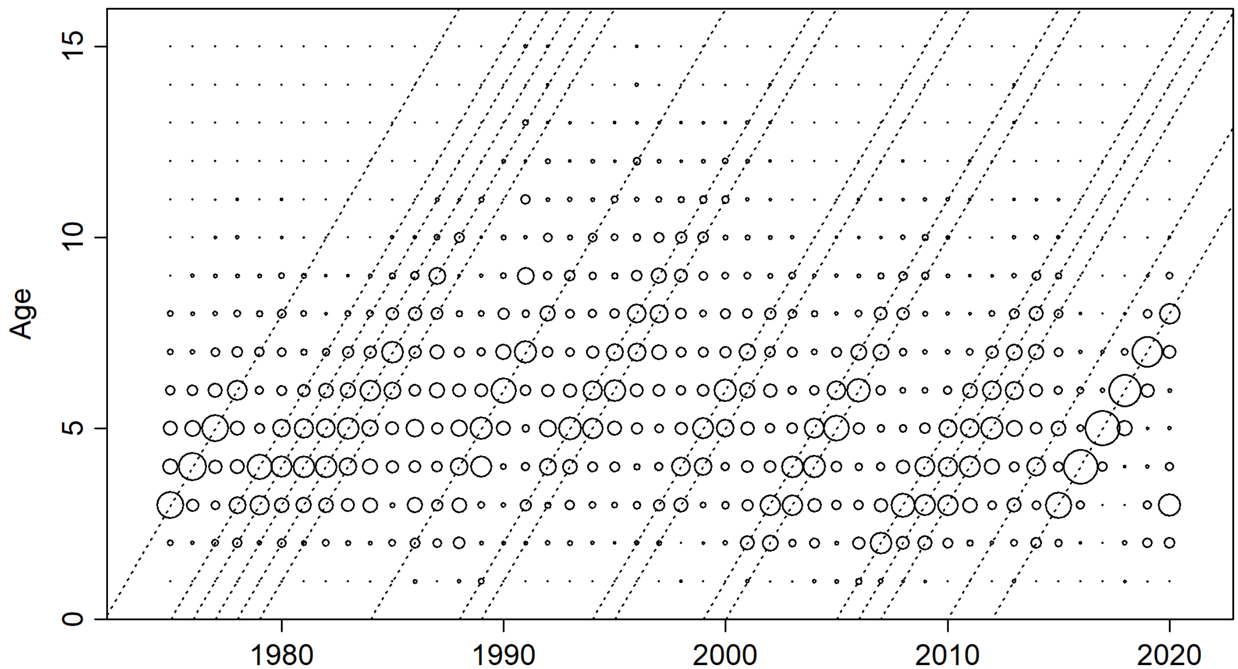


Figure 1.3. GOA pollock fishery age composition (1975-2020). The area of the circle is proportional to the catch. Diagonal lines show strong year classes.

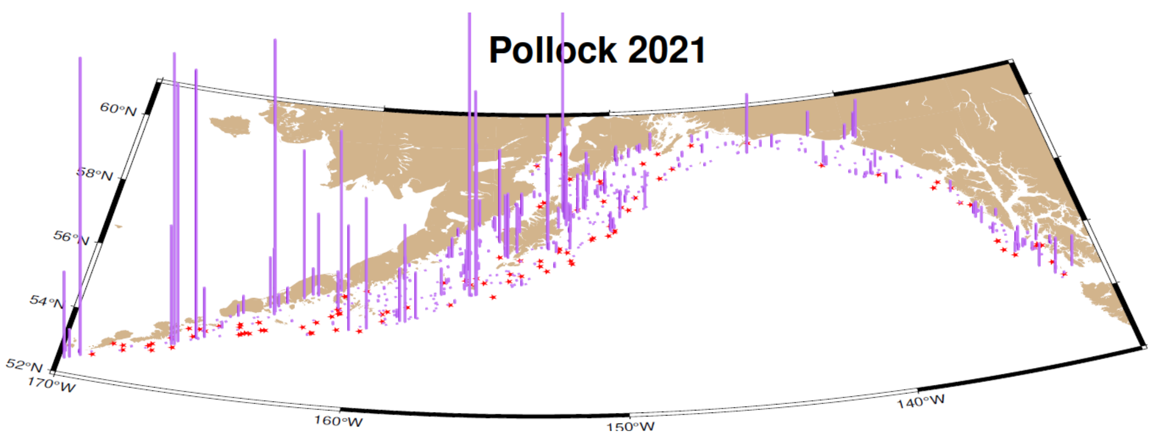


Figure 1.4. Pollock catch per unit effort (CPUE) for the 2021 NMFS bottom trawl survey in the Gulf of Alaska (heights of purple bars). Red stars indicate hauls with no pollock catch

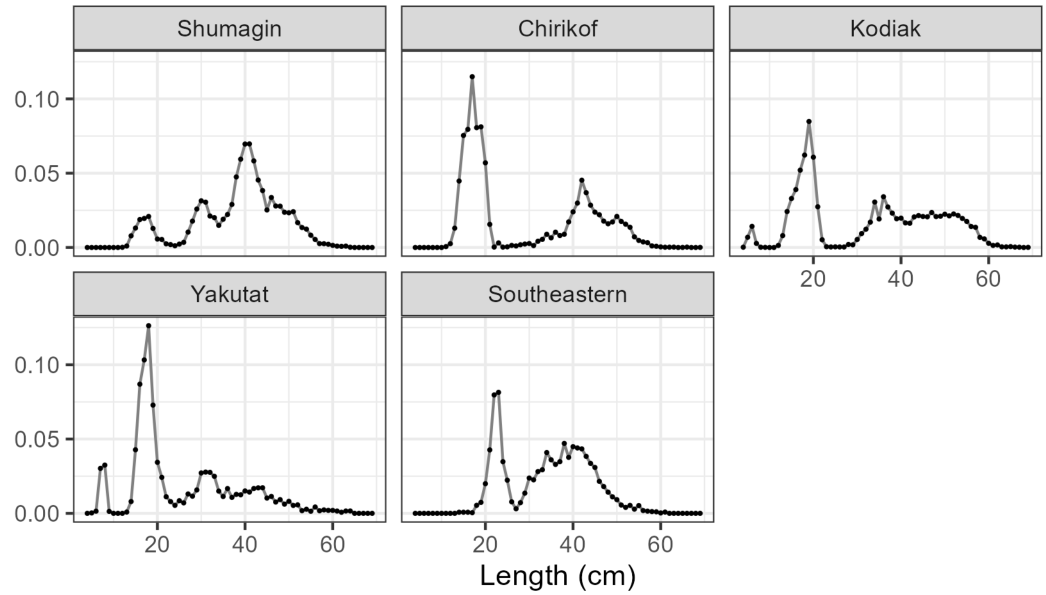


Figure 1.5. Length compositions by area for the NMFS bottom trawl survey in 2021.

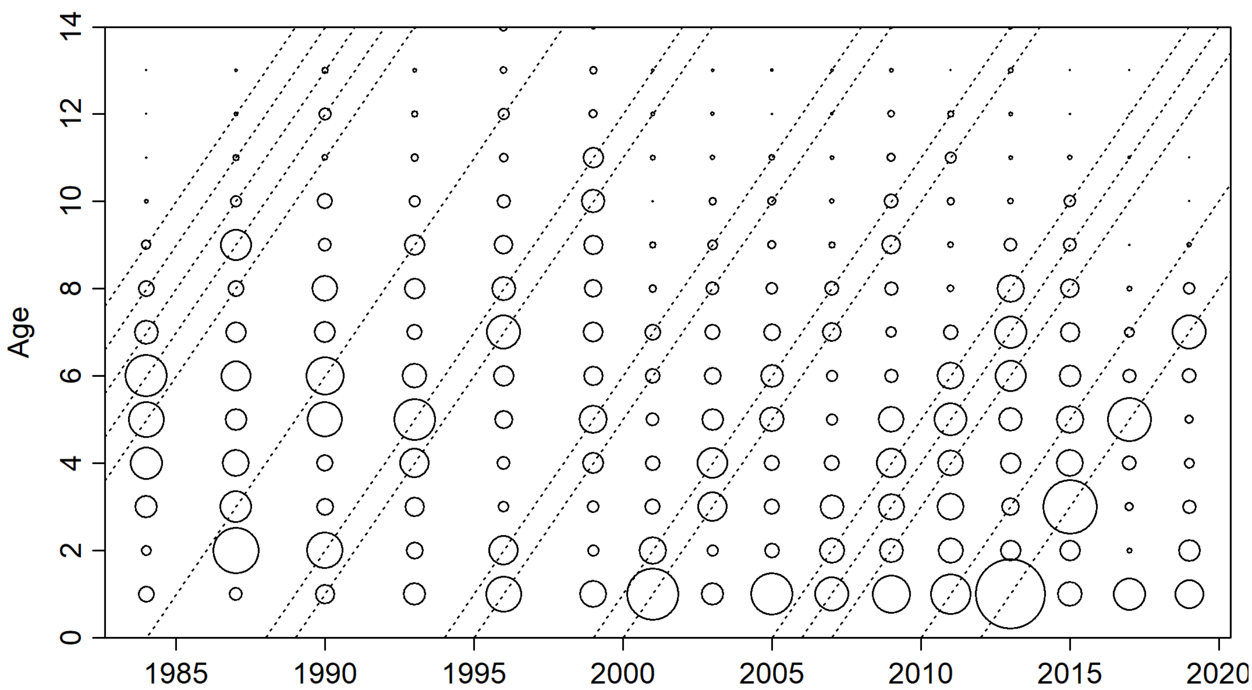


Figure 1.6. Estimated abundance at age in the NMFS bottom trawl survey (1984-2019). The area of the circle is proportional to the estimated abundance.

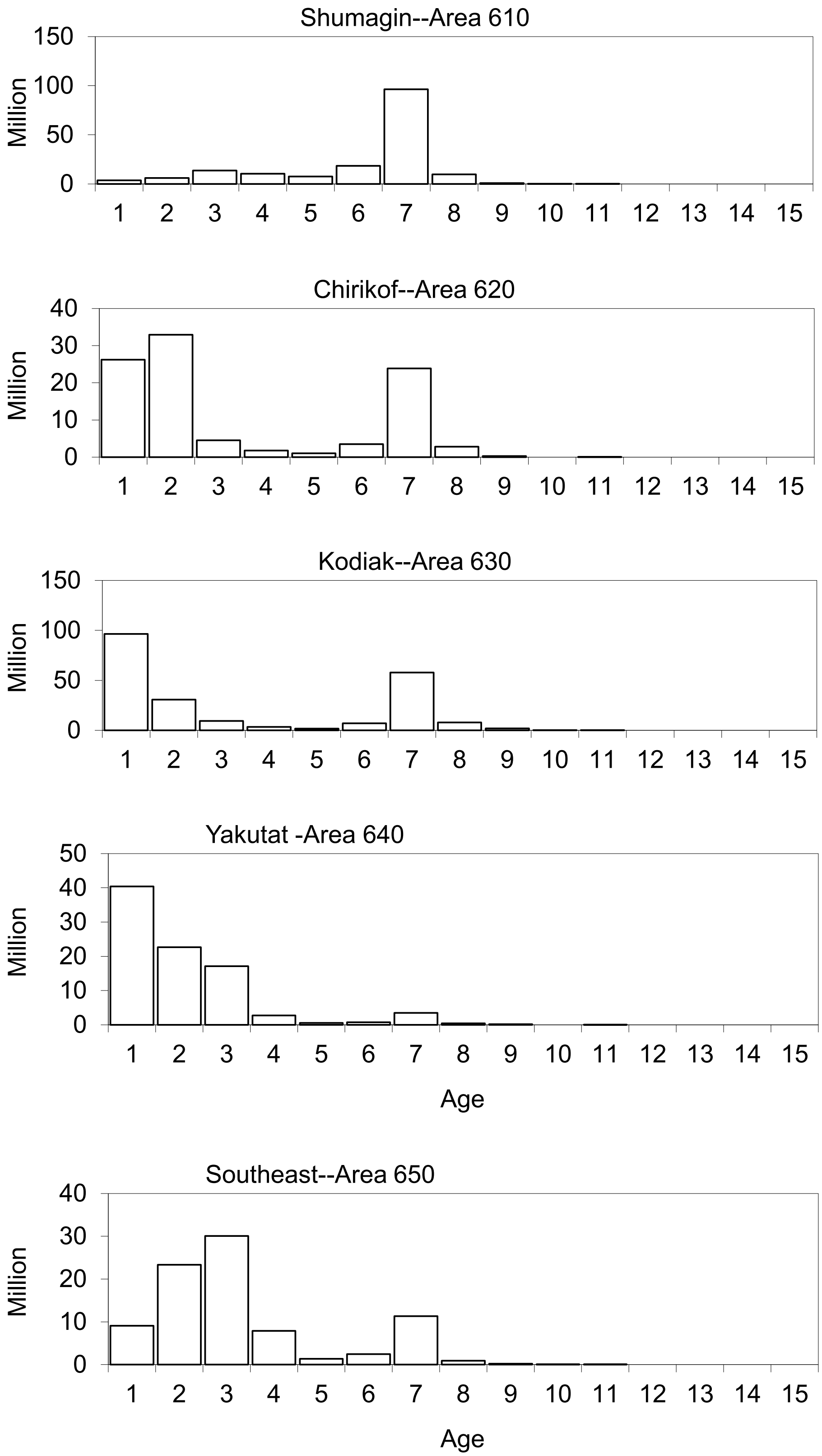


Figure 1.7. Age composition of pollock by statistical area for the 2019 NMFS bottom trawl survey.

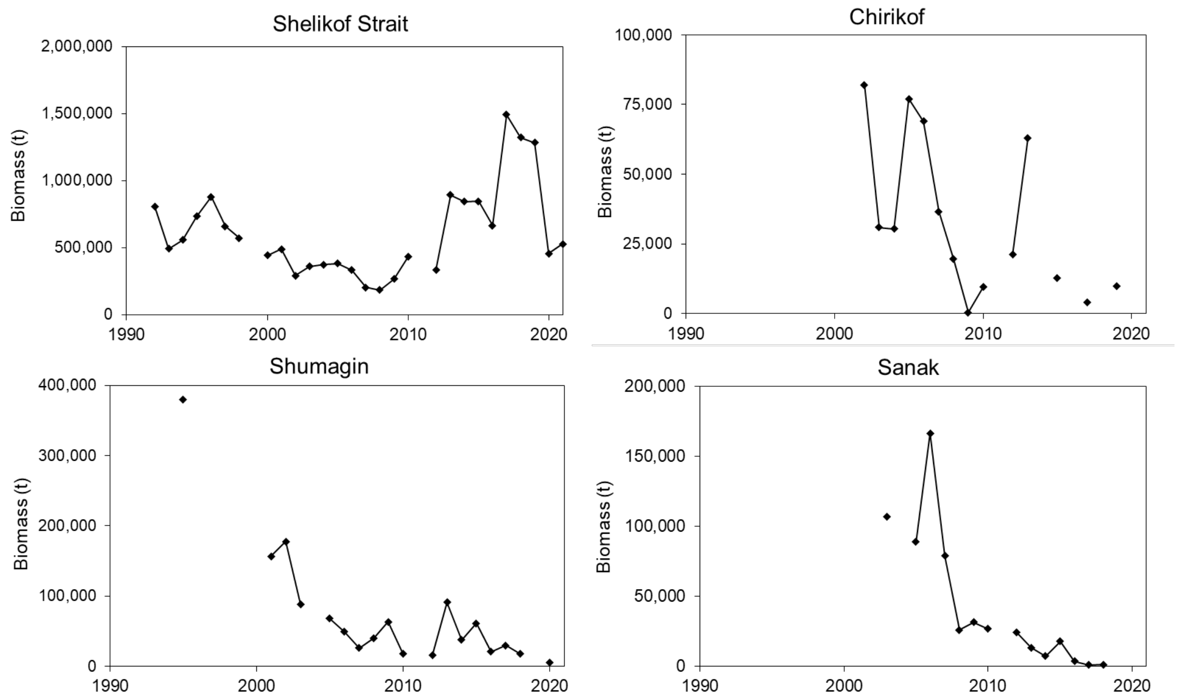


Figure 1.8. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

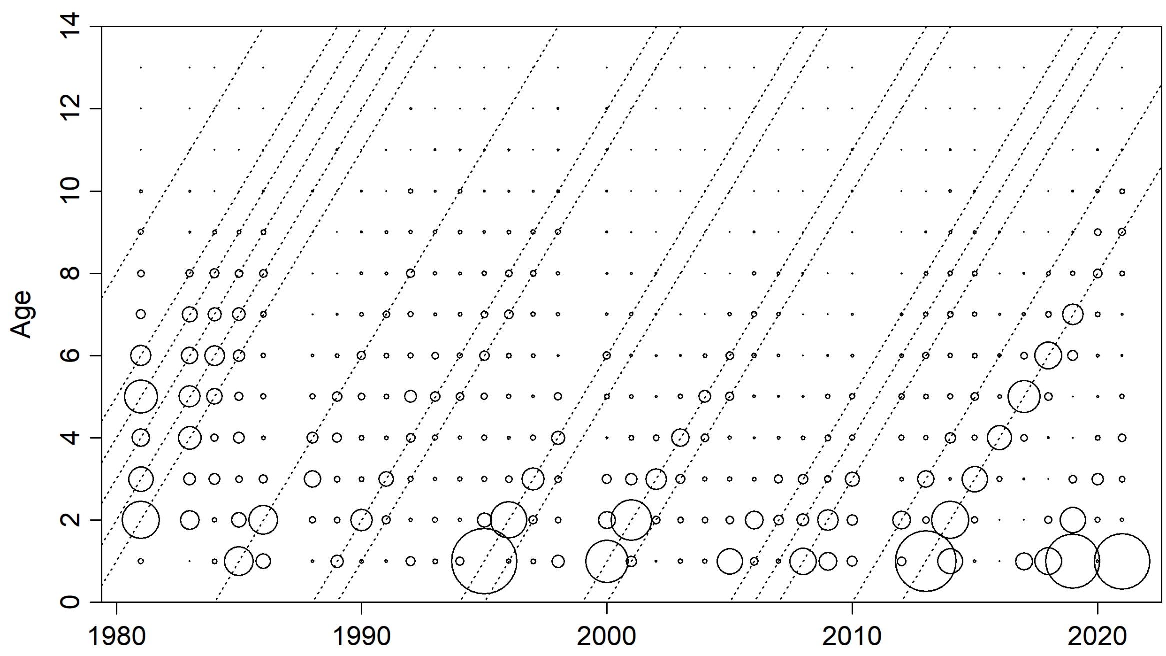


Figure 1.9. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2020, except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

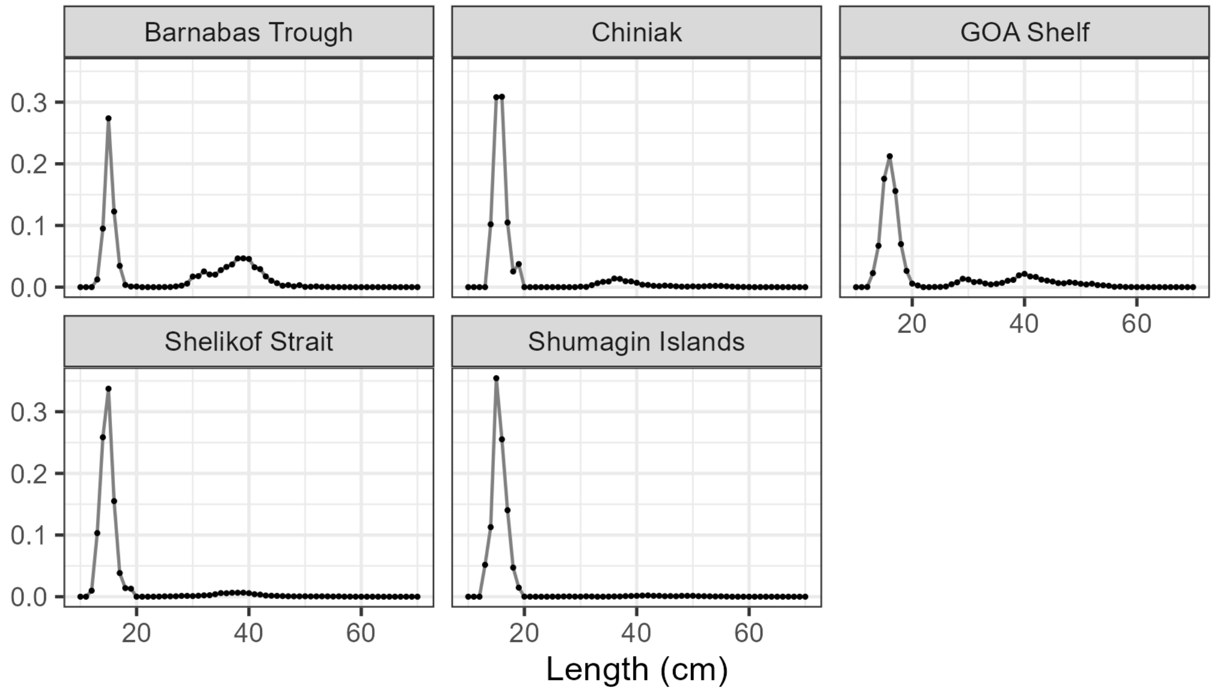


Figure 1.10. Length composition of pollock by survey area for the 2021 summer acoustic survey.

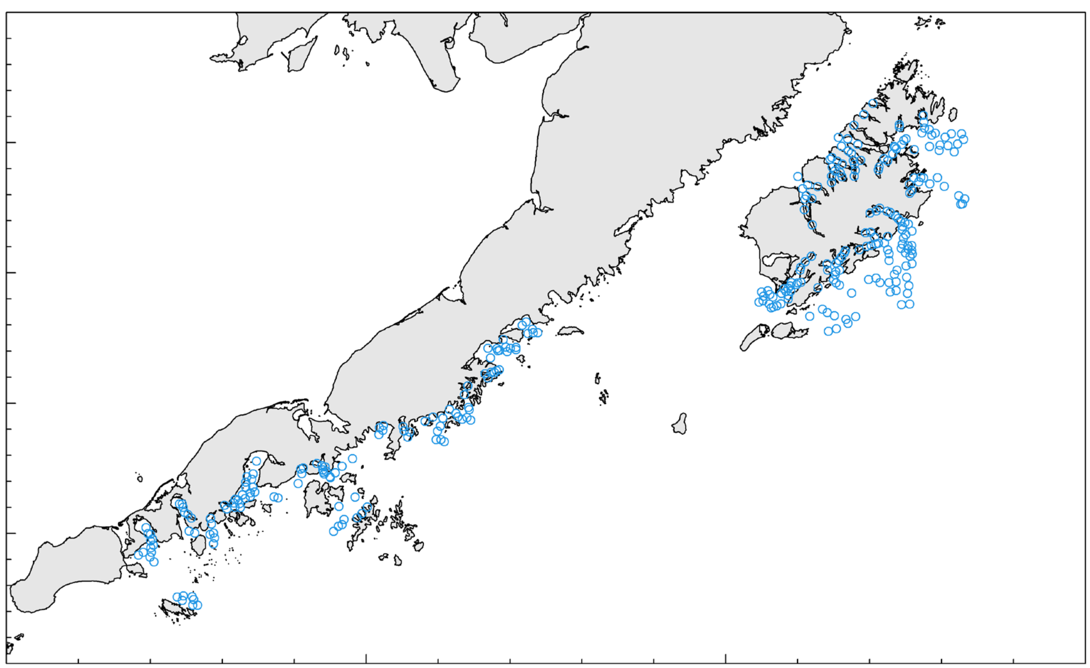
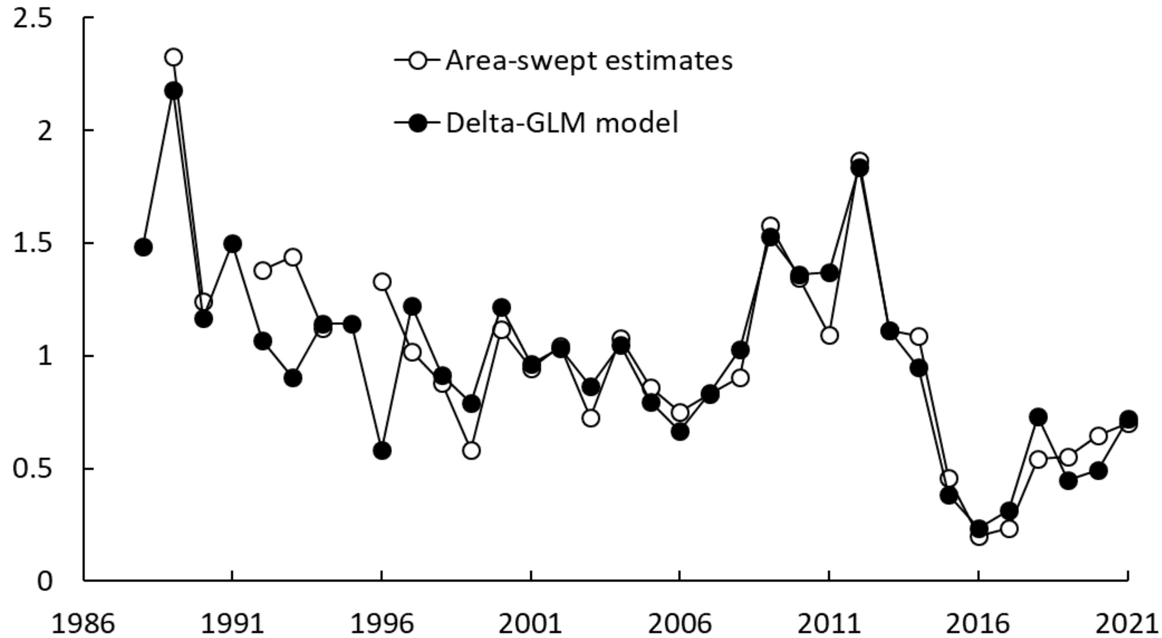


Figure 1.11. Tow locations for the 2021 ADF&G crab/groundfish trawl survey.



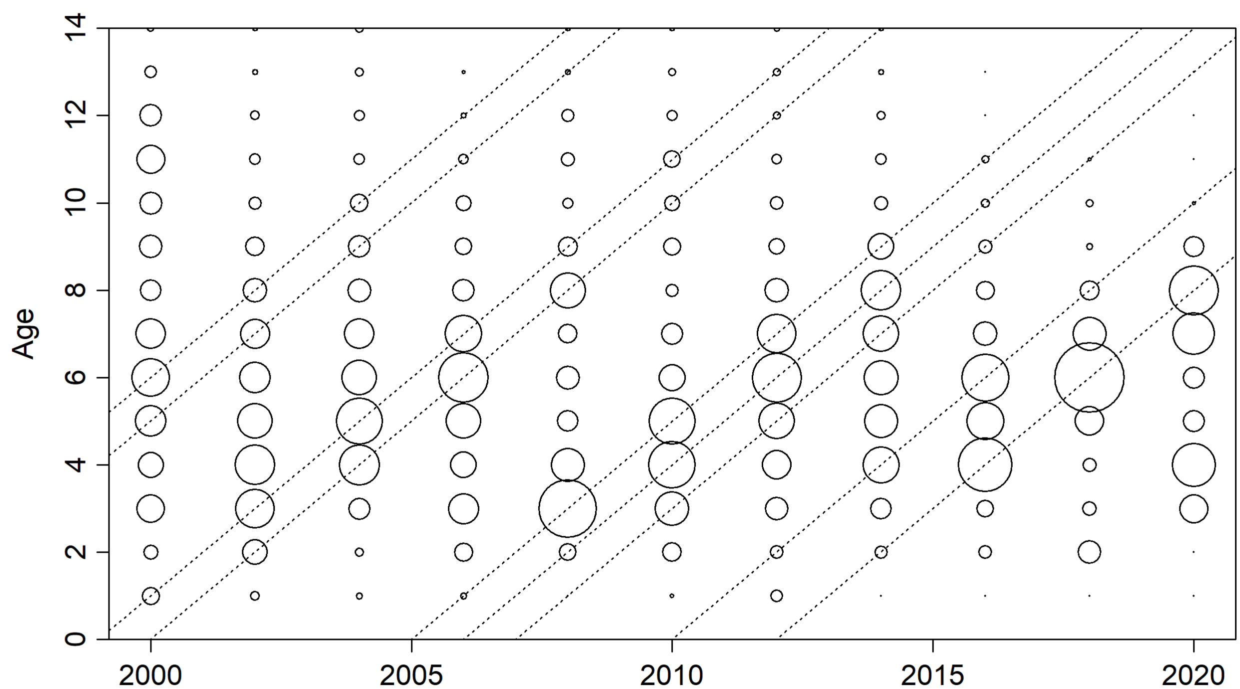


Figure 1.13. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2020). The area of the circle is proportional to the estimated abundance.

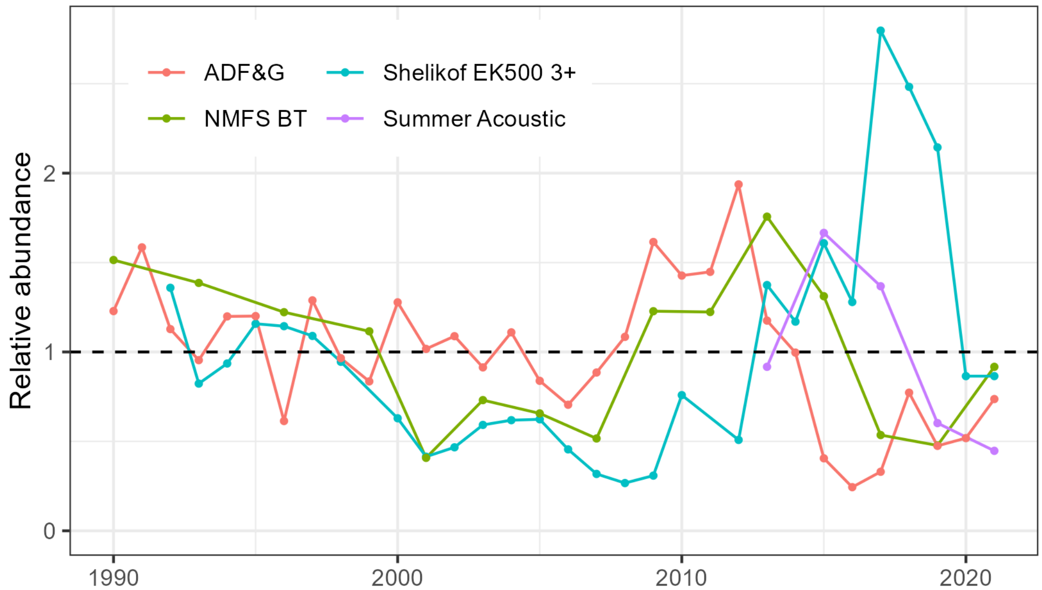
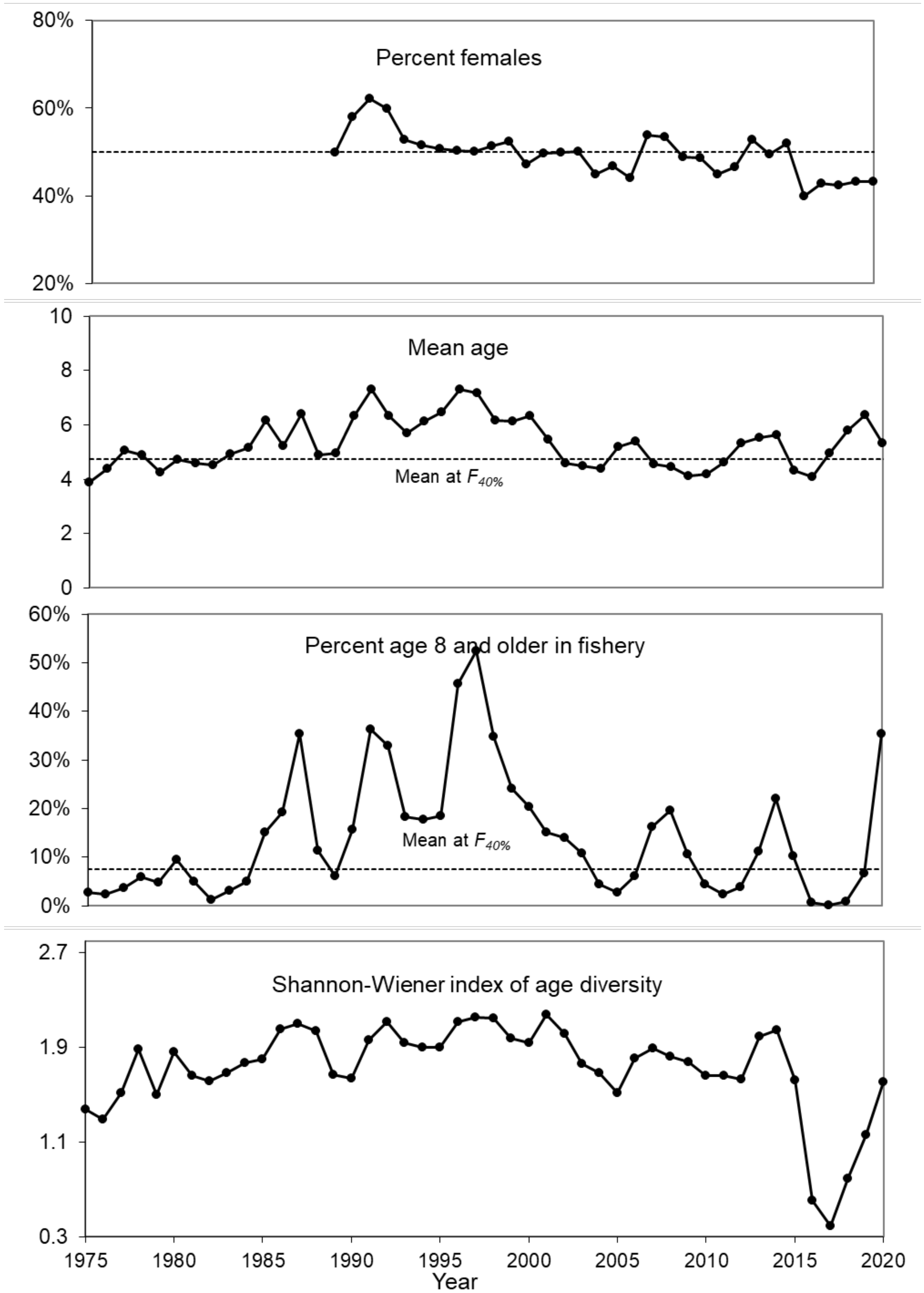
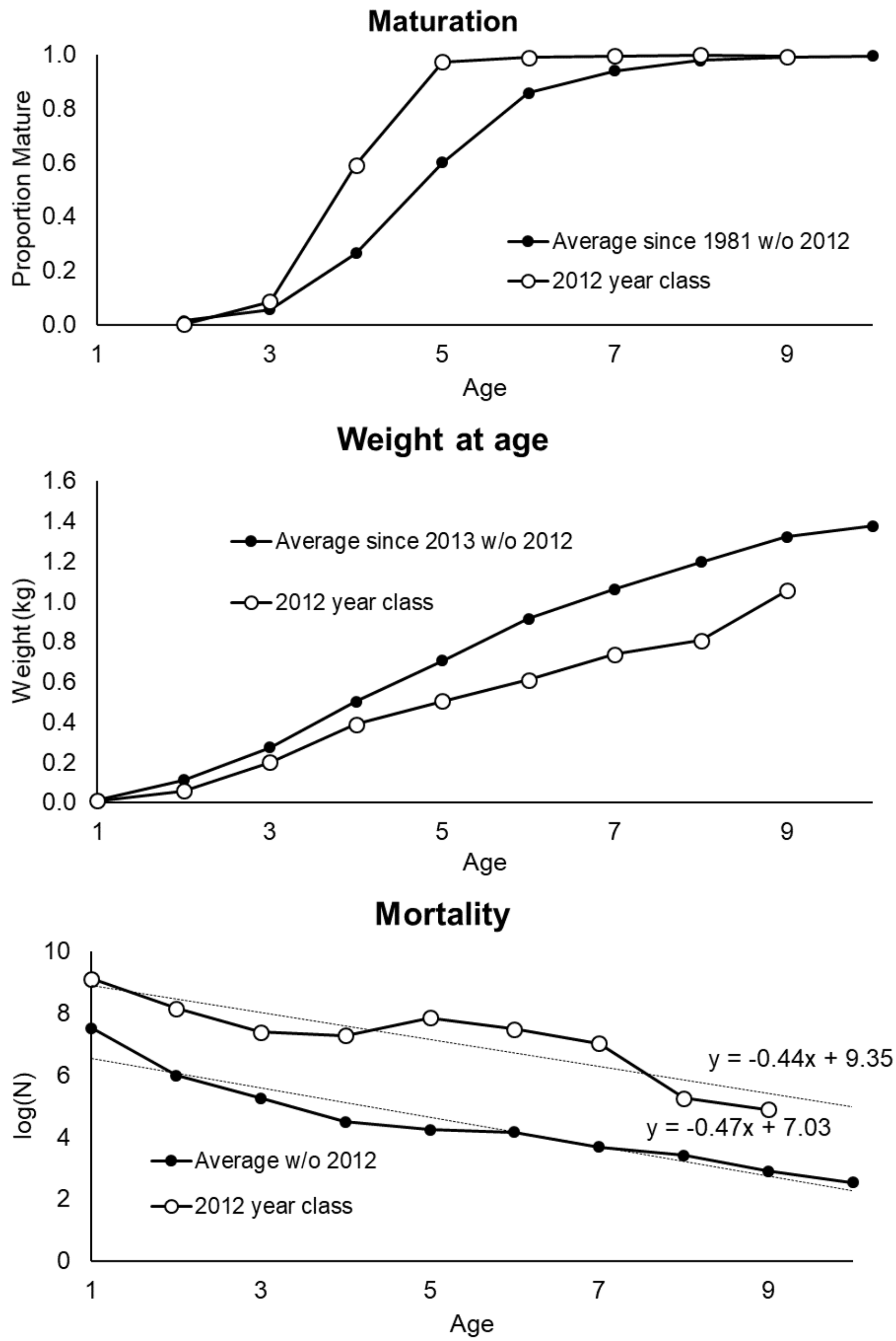


Figure 1.14. Relative trends in pollock biomass since 1990 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1990. Shelikof Strait acoustic surveys prior to 2008 were re-scaled to be comparable to the surveys conducted from 2008 onwards by the R/V Oscar Dyson.


Percent females
80%
60%
40%
20%
Mean age
10
8
6
4
2
0
Mean at $F_{40\%}$
Percent age 8 and older in fishery
60%
50%
40%
30%
20%
10%
0%
Mean at $F_{40\%}$
Shannon-Wiener index of age diversity
2.7
1.9
1.1
0.3
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year


Maturation
Proportion Mature
1.0
0.8
0.6
0.4
0.2
0.0
1
3
5
7
9
Age
Average since 1981 w/o 2012
2012 year class
Weight at age
Weight (kg)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Average since 2013 w/o 2012
2012 year class
Mortality
log(N)
10
8
6
4
2
0
y = -0.44x + 9.35
y = -0.47x + 7.03
Average w/o 2012
2012 year class

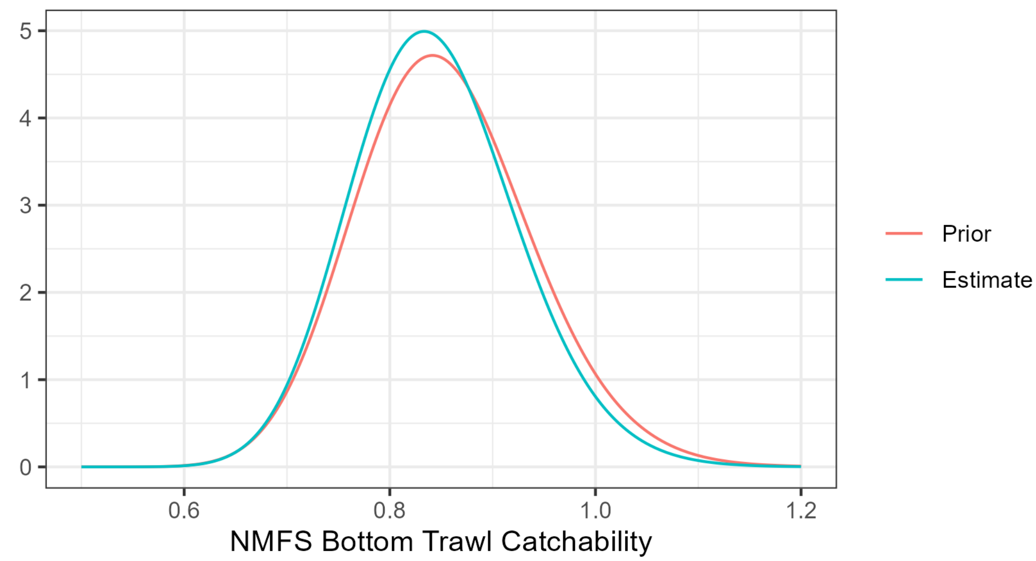
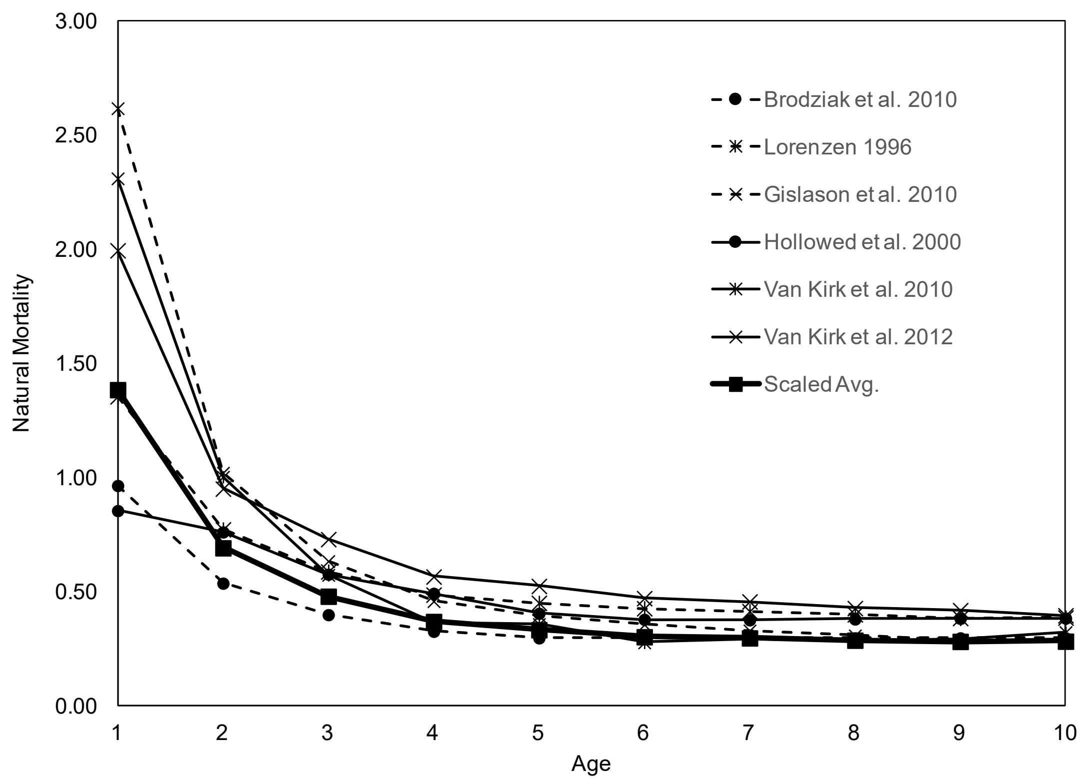


Figure 1.17. Prior on bottom trawl catchability used in the base model, and the estimate and uncertainty from the base model.



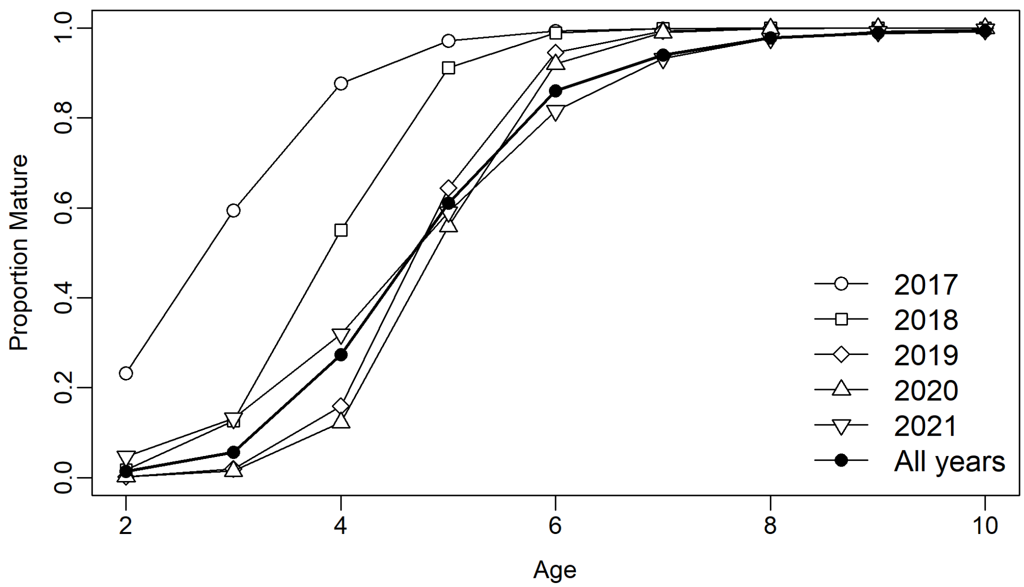
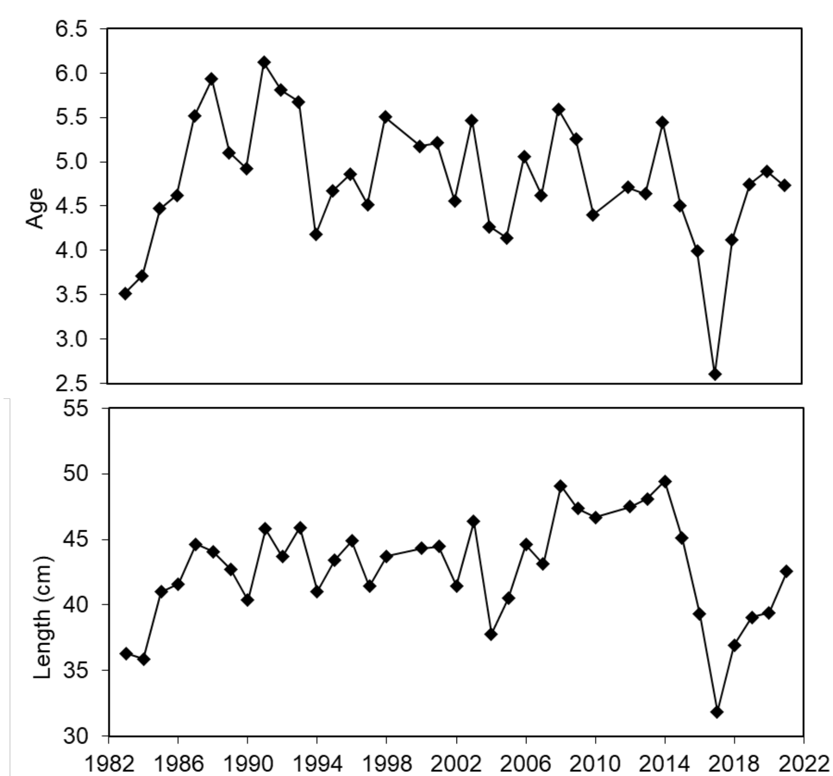


Figure 1.19. Estimates of the proportion mature at age from weighted visual maturity data collected during 2016-2020 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2020). Maturity for age-1 fish is assumed to be zero.



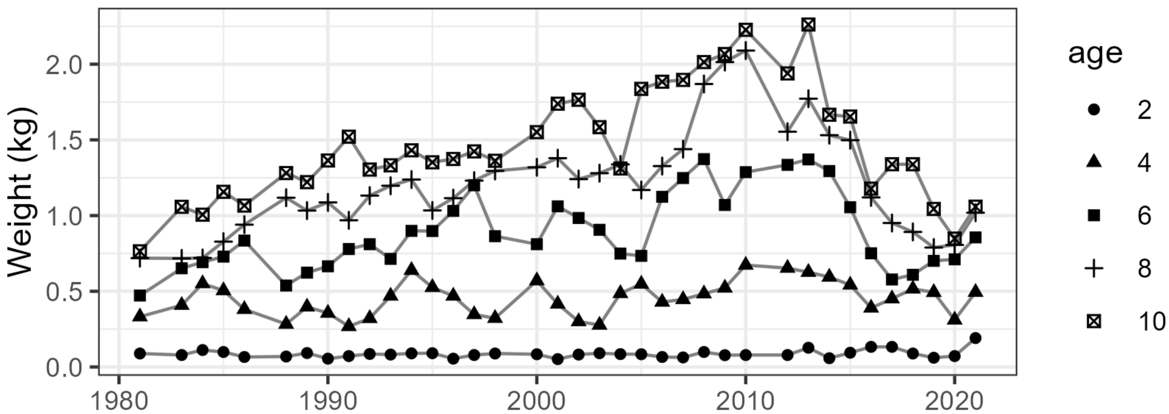
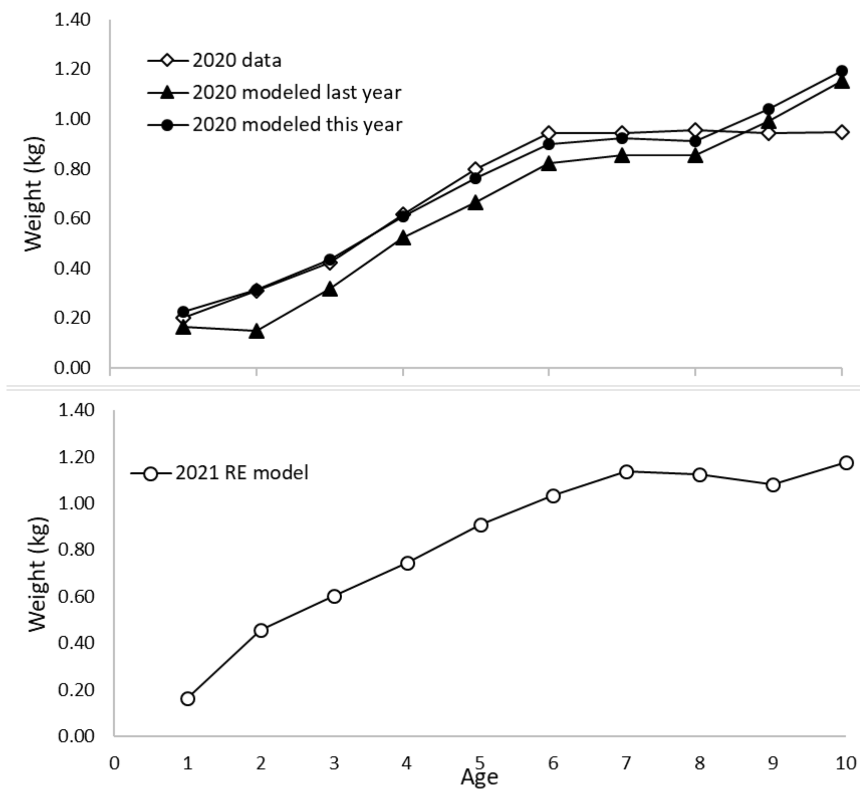


Figure 1.21. Estimated weight at age of GOA pollock (ages 2, 4, 6, 8, and 10) from Shelikof Strait acoustic surveys in 1983-2020 used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from surveys in adjacent years.



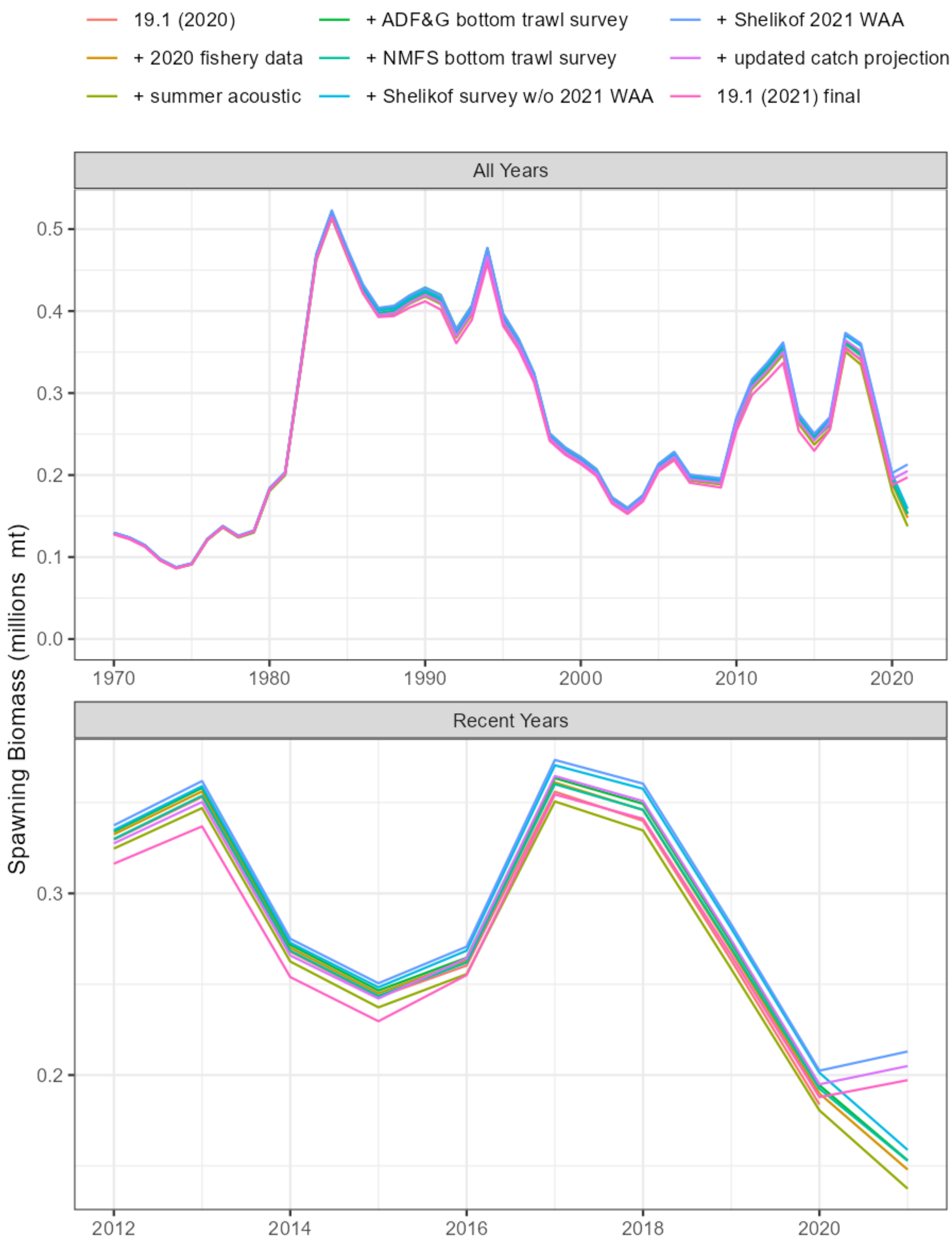


Figure 1.23. Changes in estimated spawning biomass as new data were added successively to last year's base model, ordered by row in the legend at the top. The lower panel shows the years 2012-2021 with an expanded scale to highlight differences. The notable change in SSB comes when adding the 2021 Shelikof weight at age (WAA).

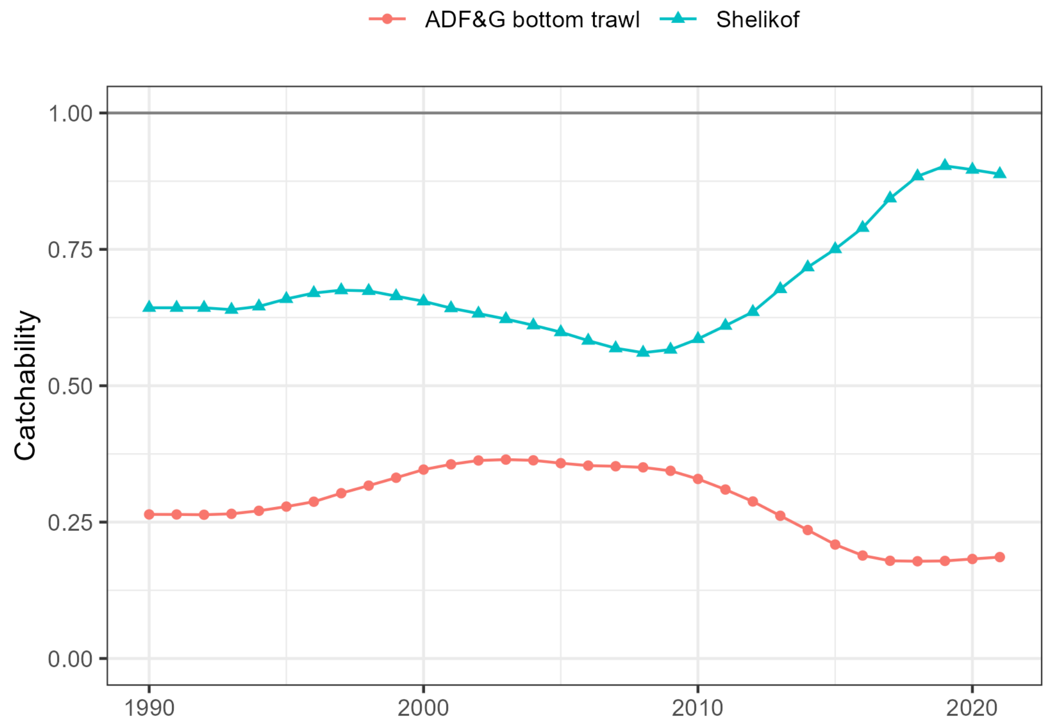


Figure 1.24. Time-varying catchability for the Shelikof Strait acoustic survey and the ADF&G crab/groundfish trawl survey for model 19.1 (2021).

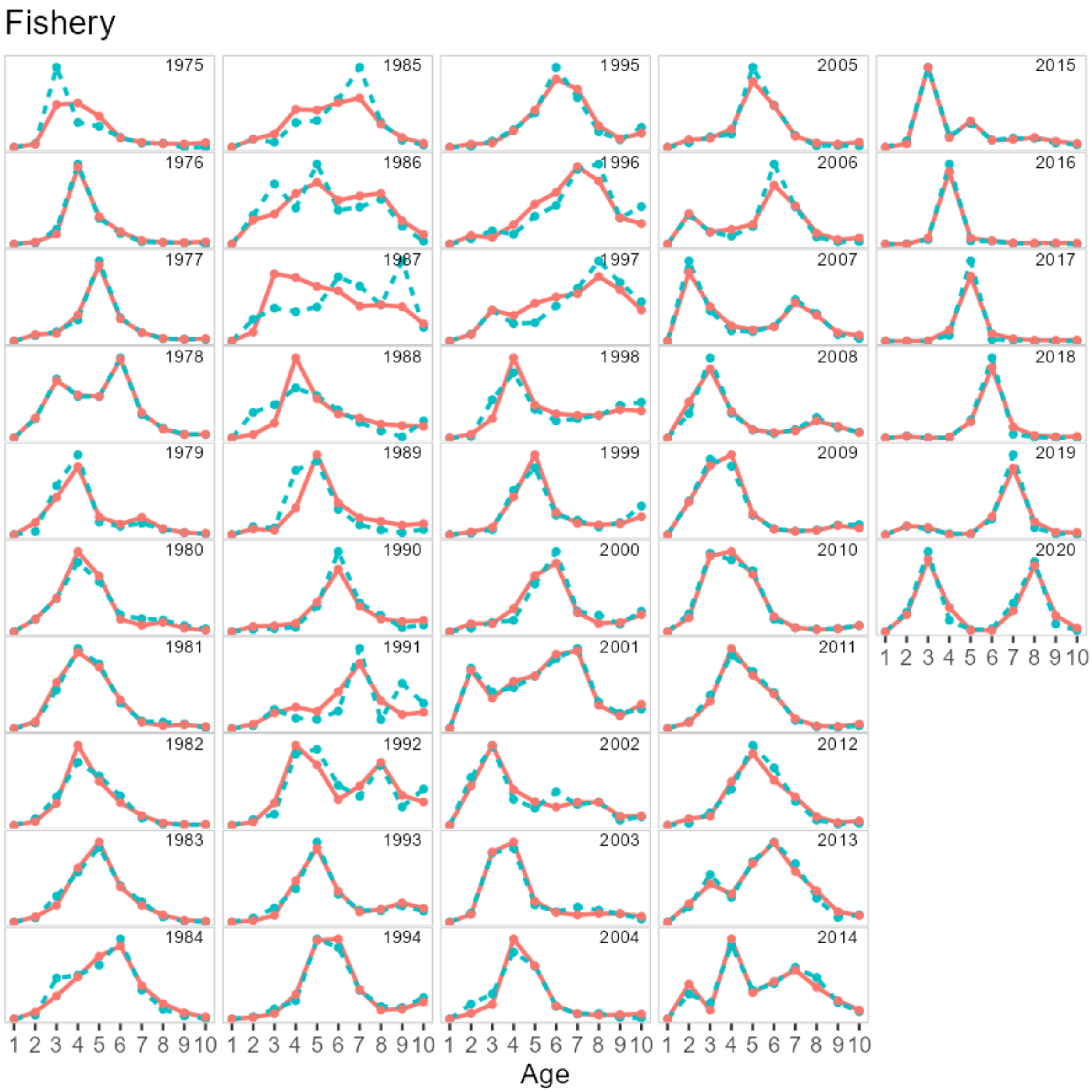


Figure 1.25. Observed and predicted fishery age composition for GOA pollock from the base model. Dashed blue lines are observations and solid red lines are model expectations.

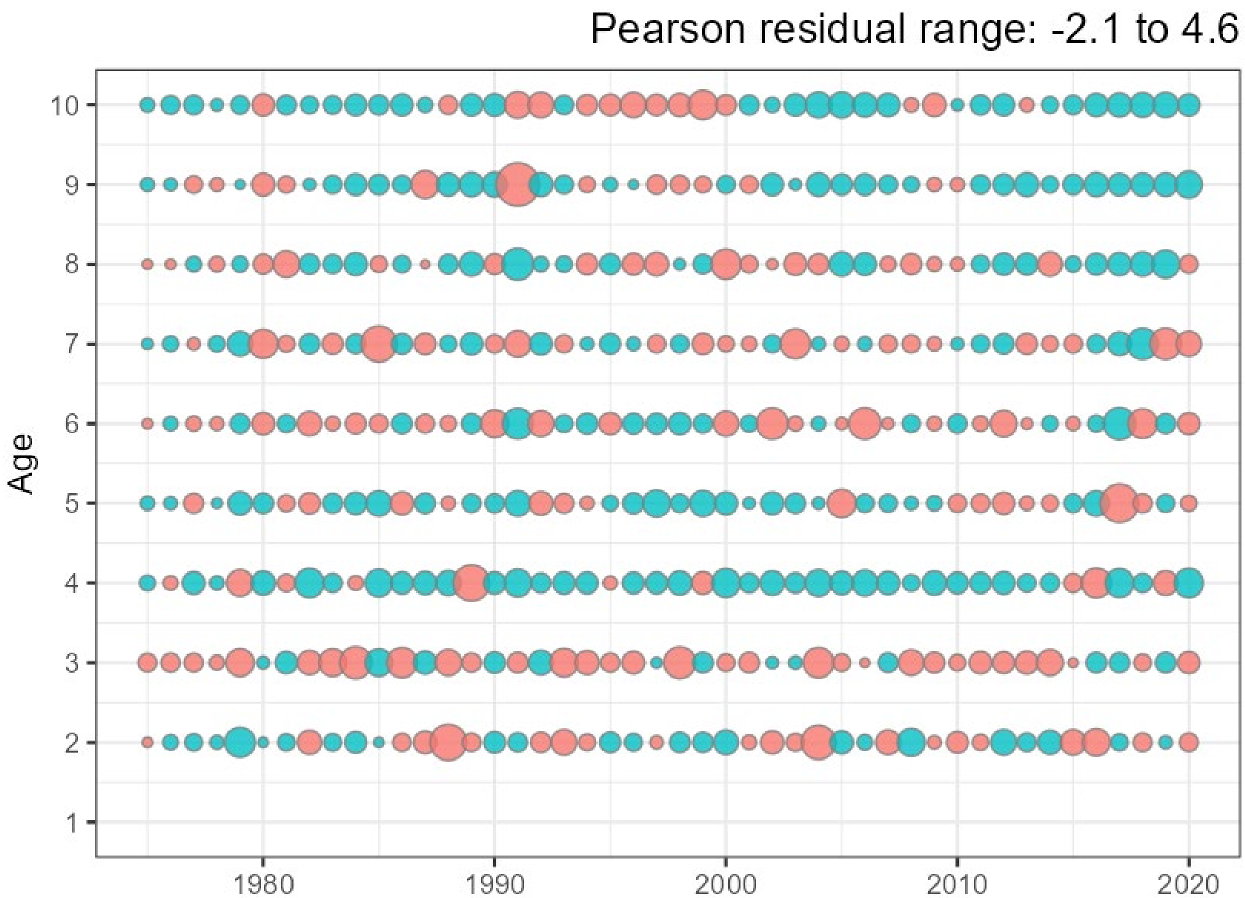


Figure 1.26. Pearson residuals for fishery age composition. Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

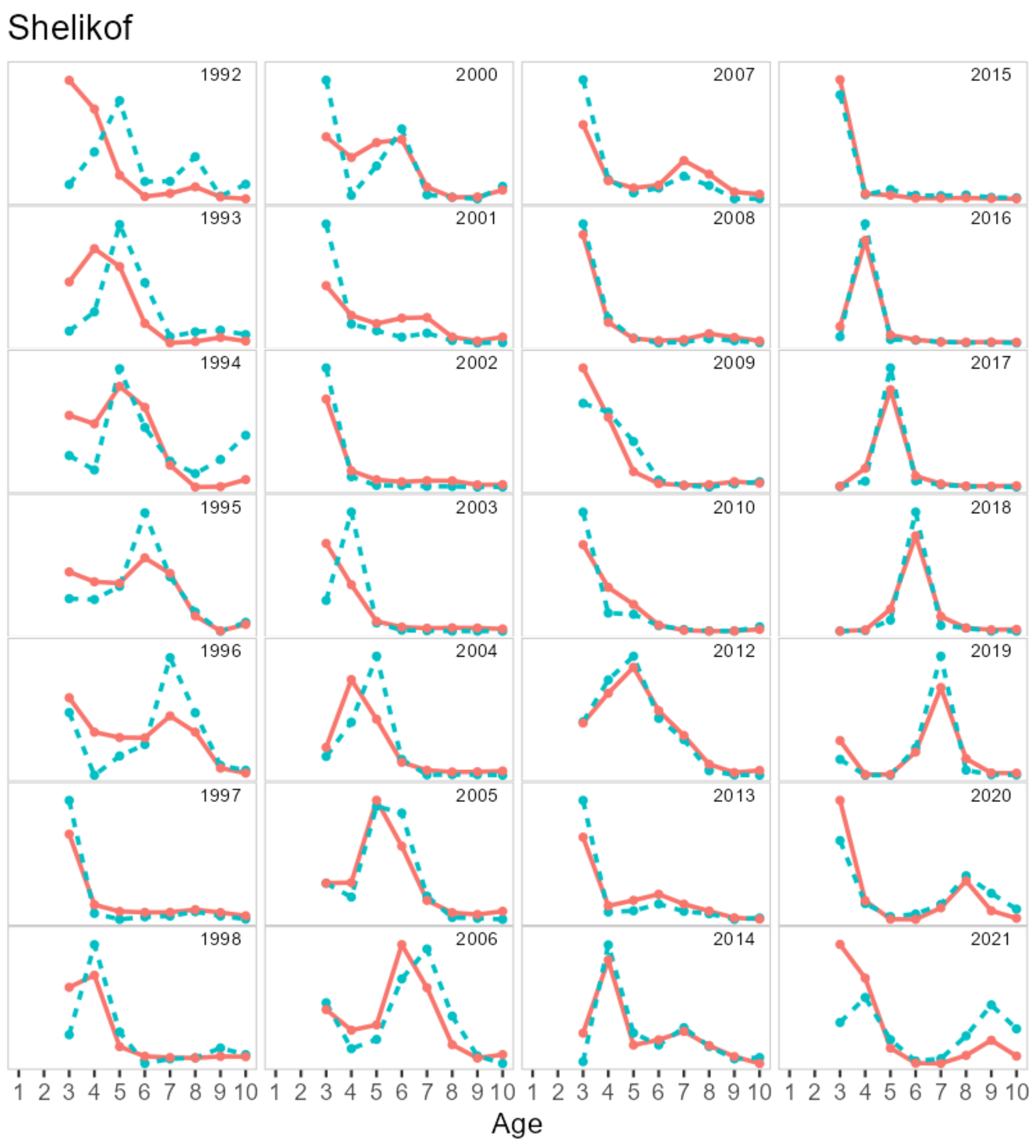


Figure 1.27. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Dashed blue lines are observations and solid red lines are model expectations. Age 1 and 2 fish are modeled separately and excluded.

Figure 1.28. Pearson residuals for Shelikof Strait acoustic survey age composition. Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

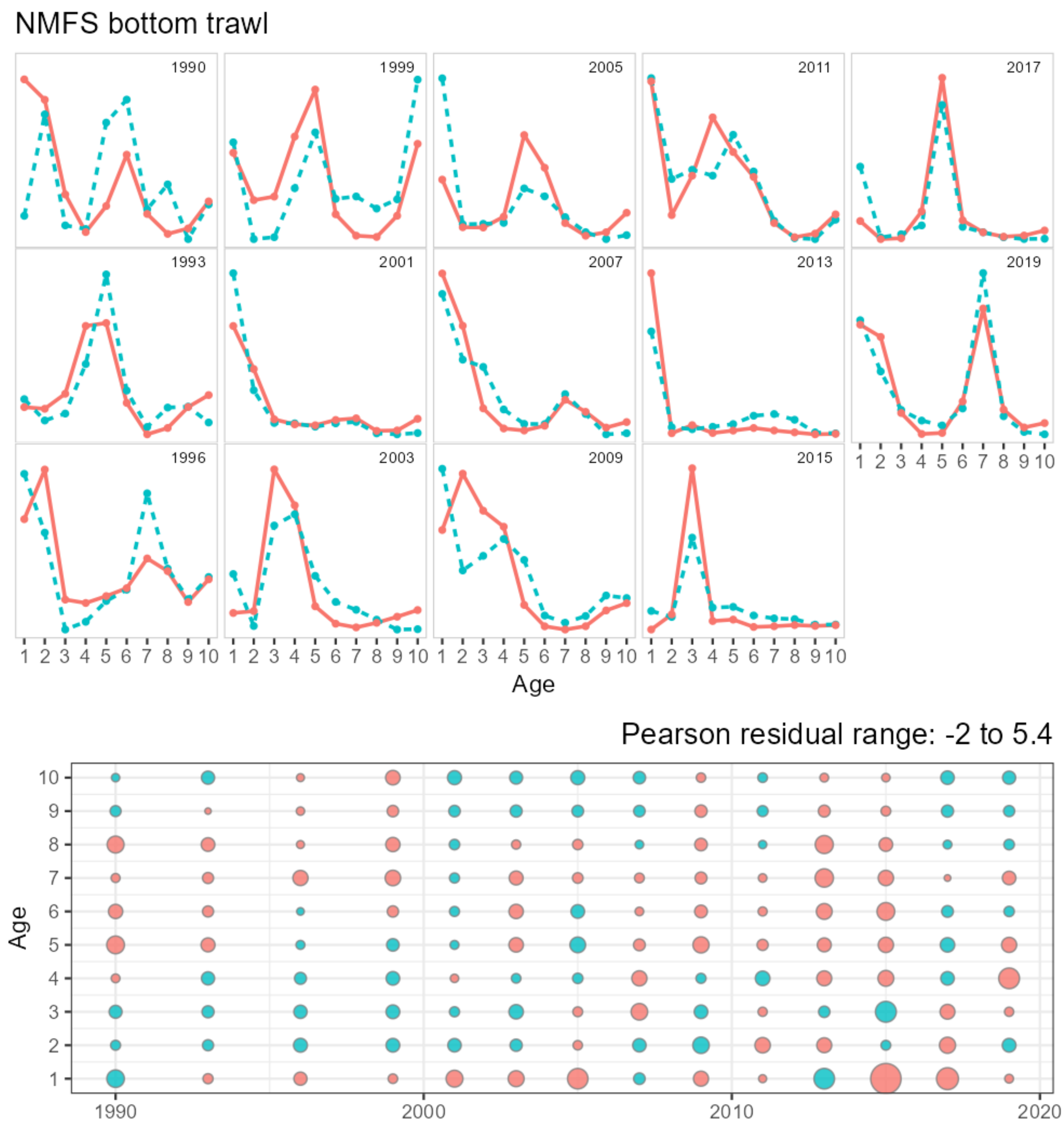


Figure 1.29. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. Pearson residuals for NMFS bottom trawl survey (bottom). Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

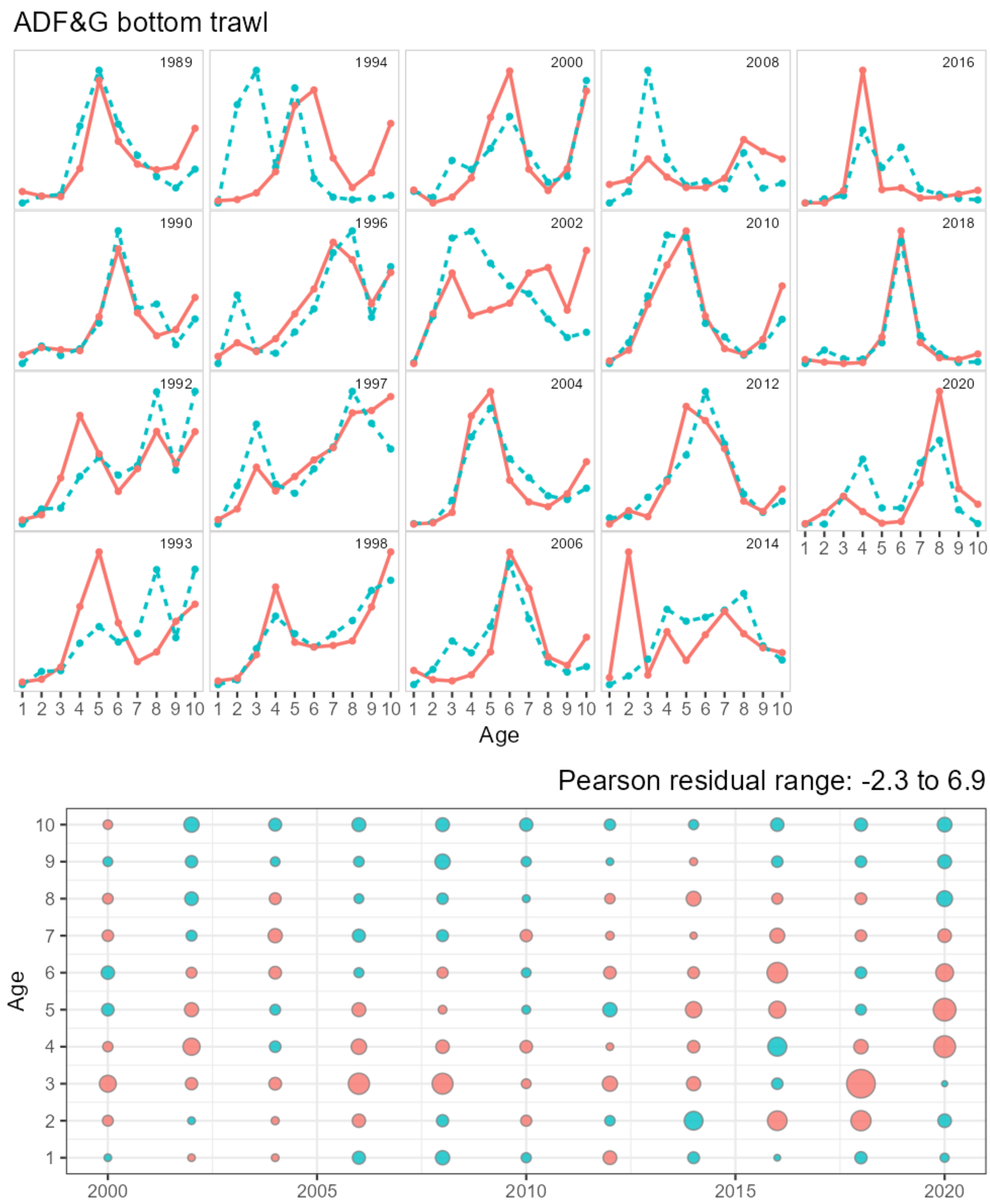


Figure 1.30. Observed and predicted ADF&G bottom trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. Pearson residuals for ADF&G bottom trawl survey (bottom). Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

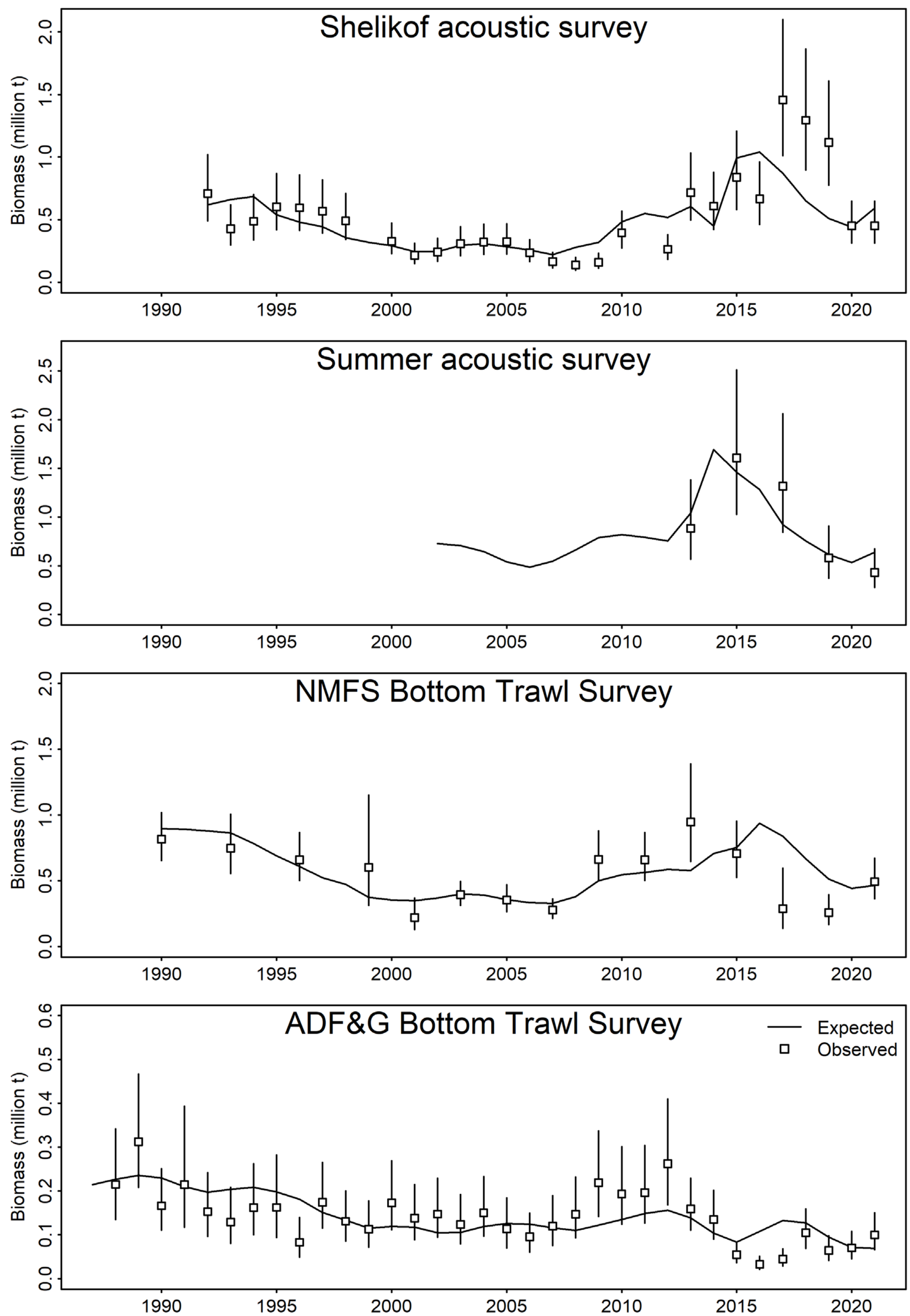


Figure 1.31. Model predicted (line) and observed survey biomass (points and 95% confidence intervals) for the four surveys. The Shelikof survey is only for ages 3+.

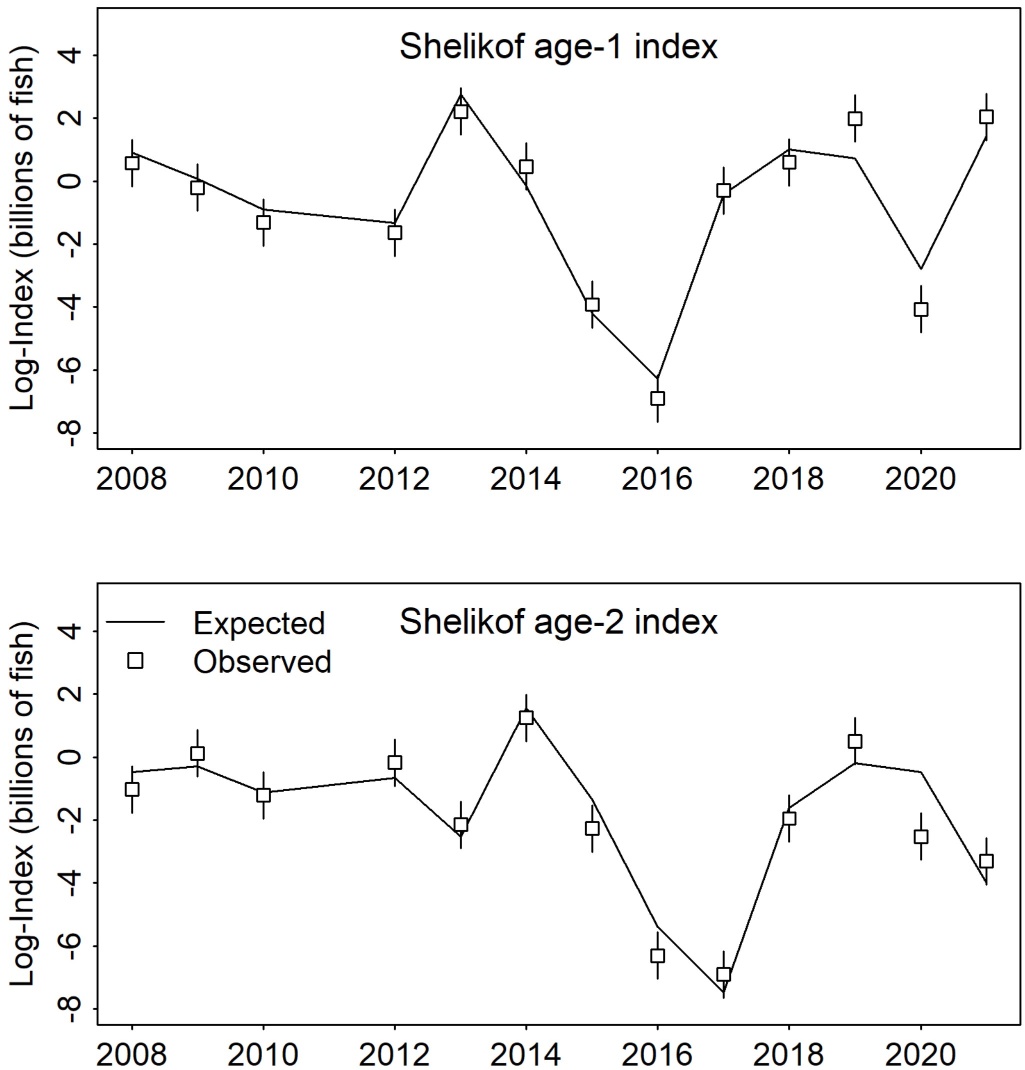


Figure 1.32. Model predicted (line) and observed survey biomass (points and 95% confidence intervals) for the age 1 and age 2 winter Shelikof surveys.

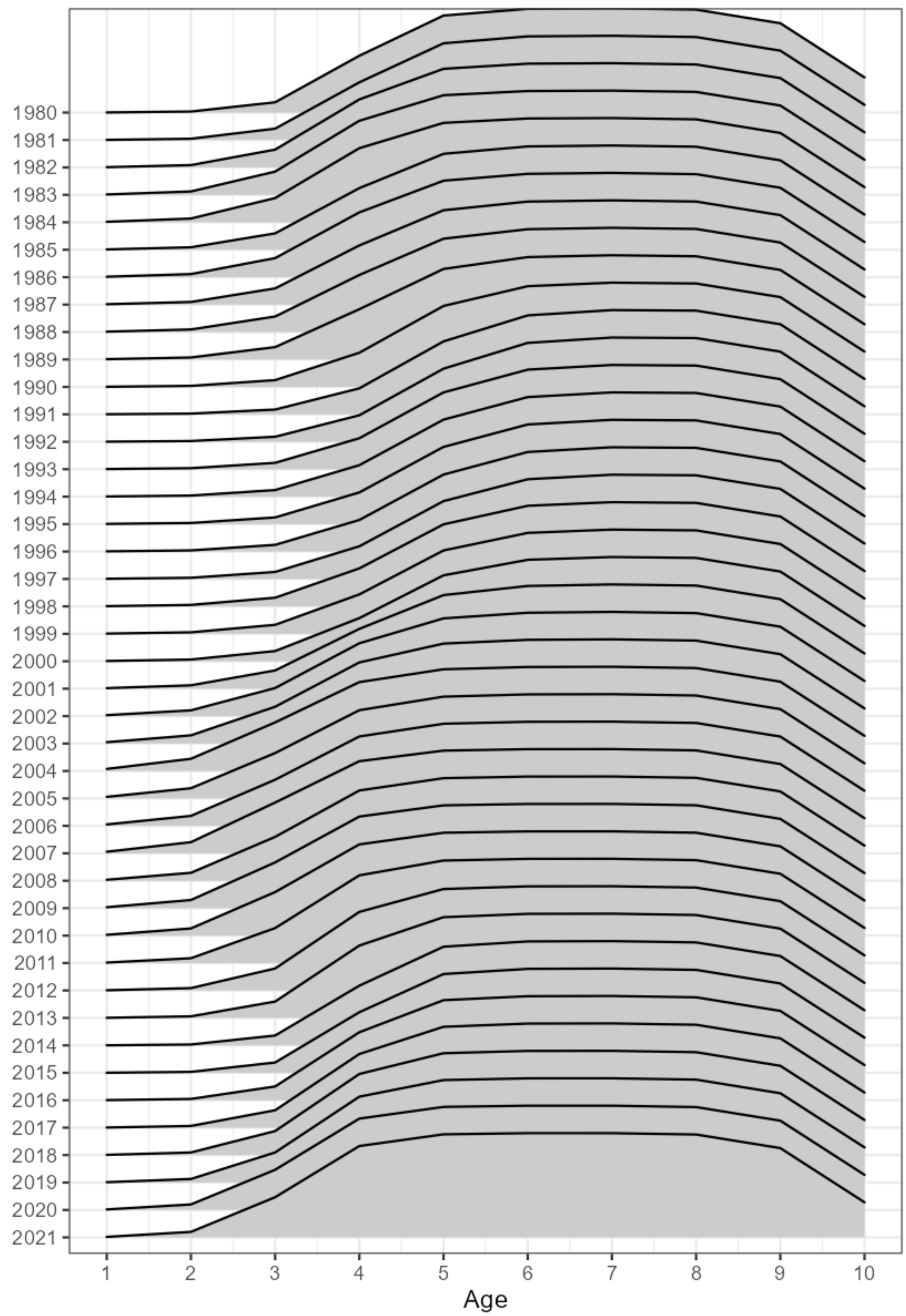


Figure 1.33. Estimates of time-varying double-logistic fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.

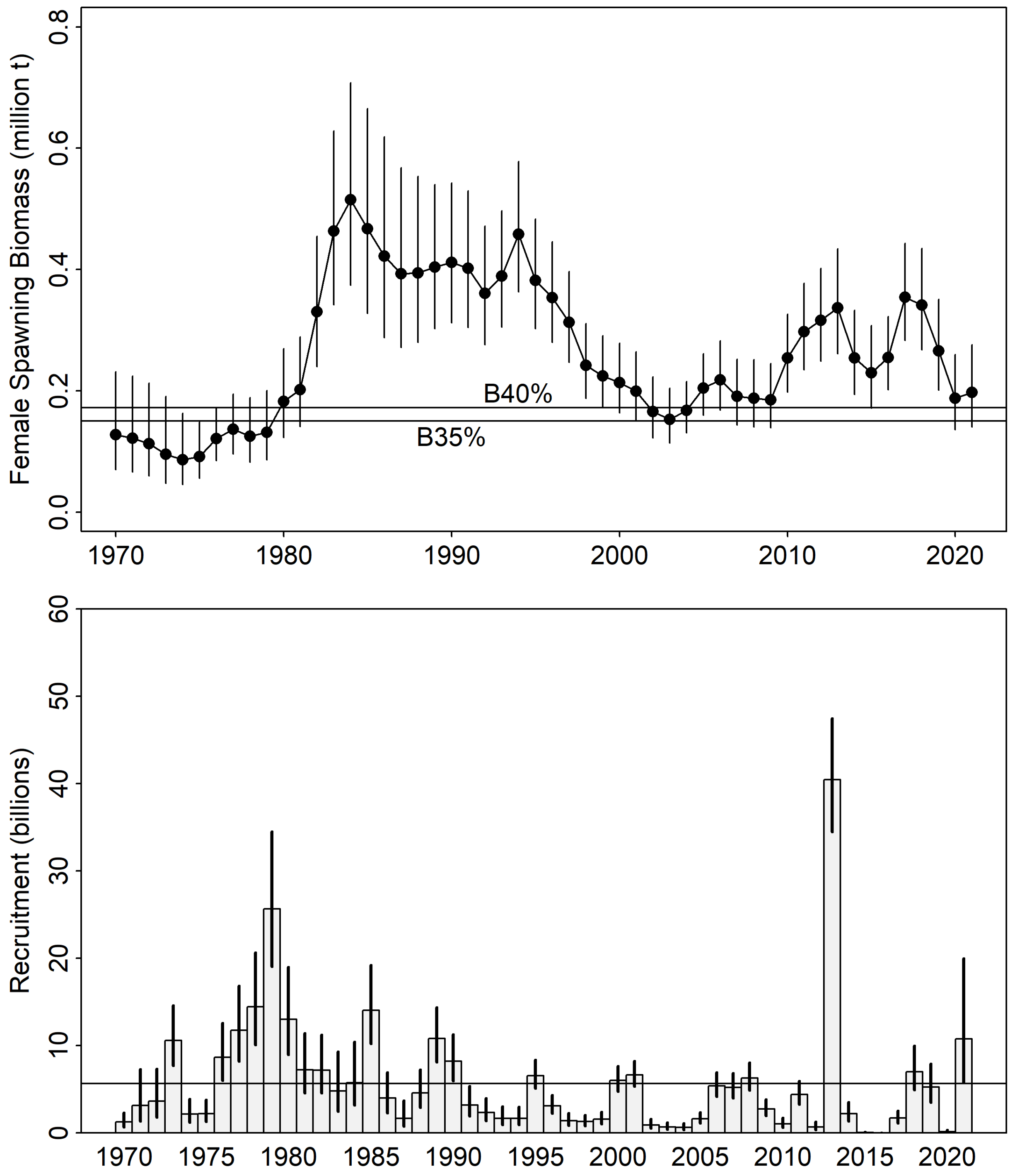
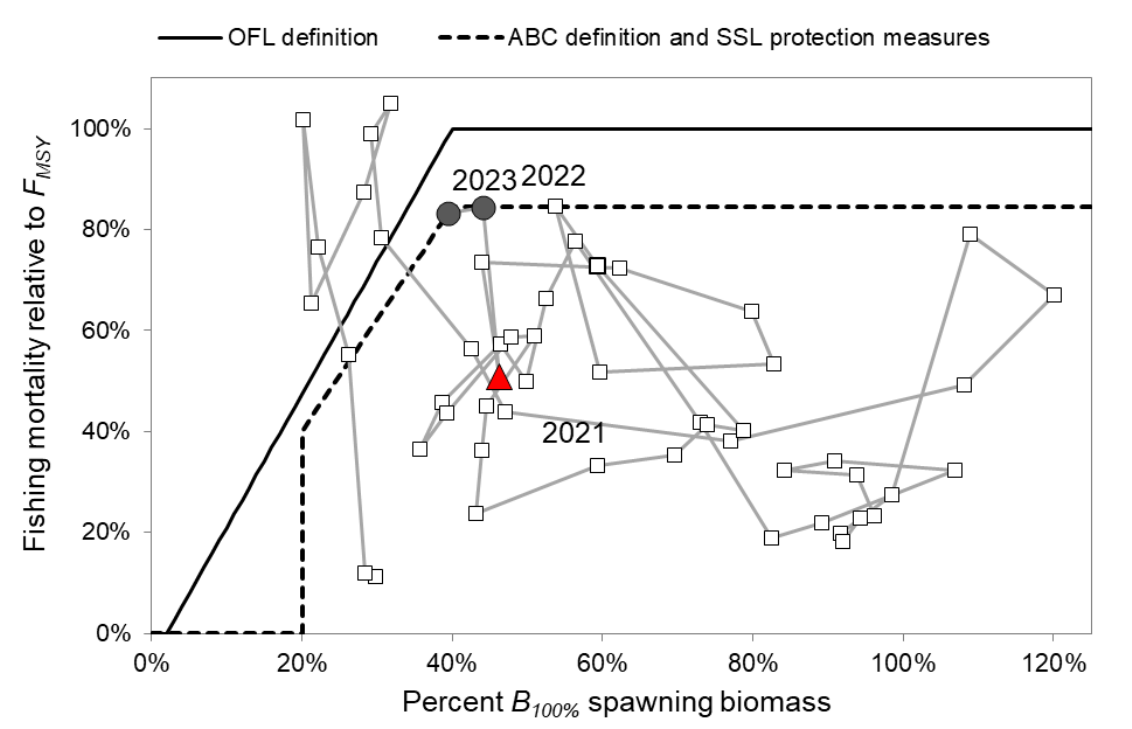


Figure 1.34. Estimated time series of GOA pollock spawning biomass (top) and age-1 recruitment (bottom) from 1970 to 2021 for the base model, with horizontal line at the average from 1978-2020. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



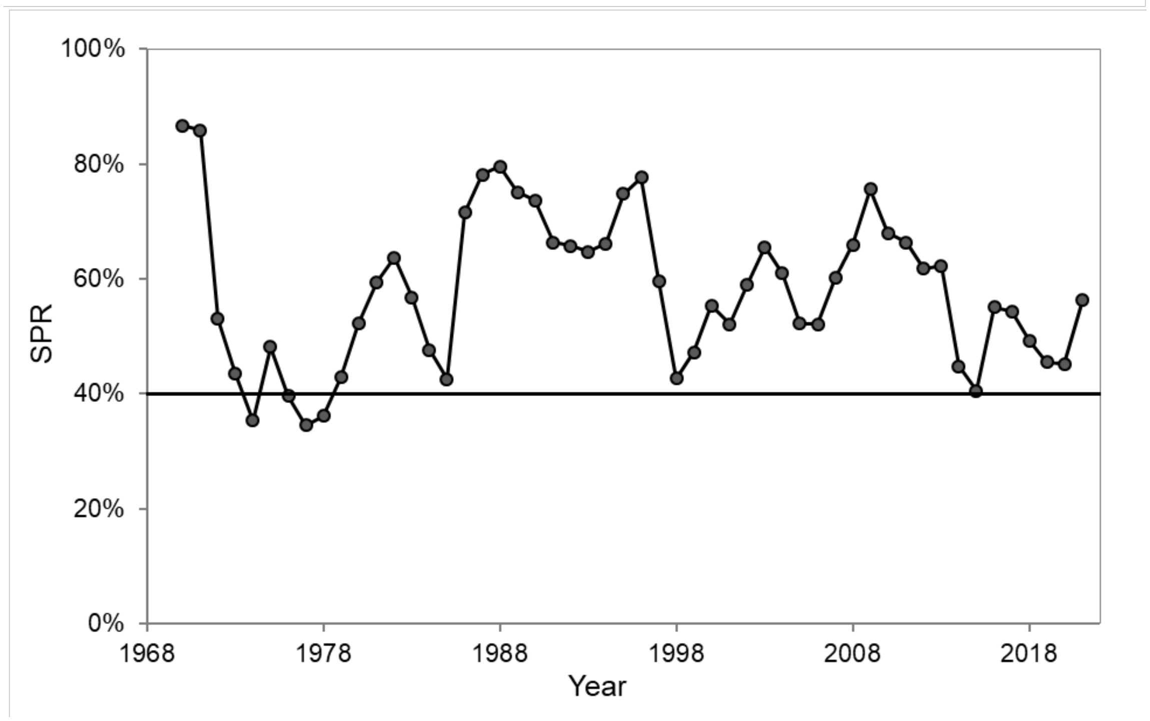


Figure 1.35. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to FMSY (bottom). The ratio of fishing mortality to F_{MSY} is calculated using the estimated selectivity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

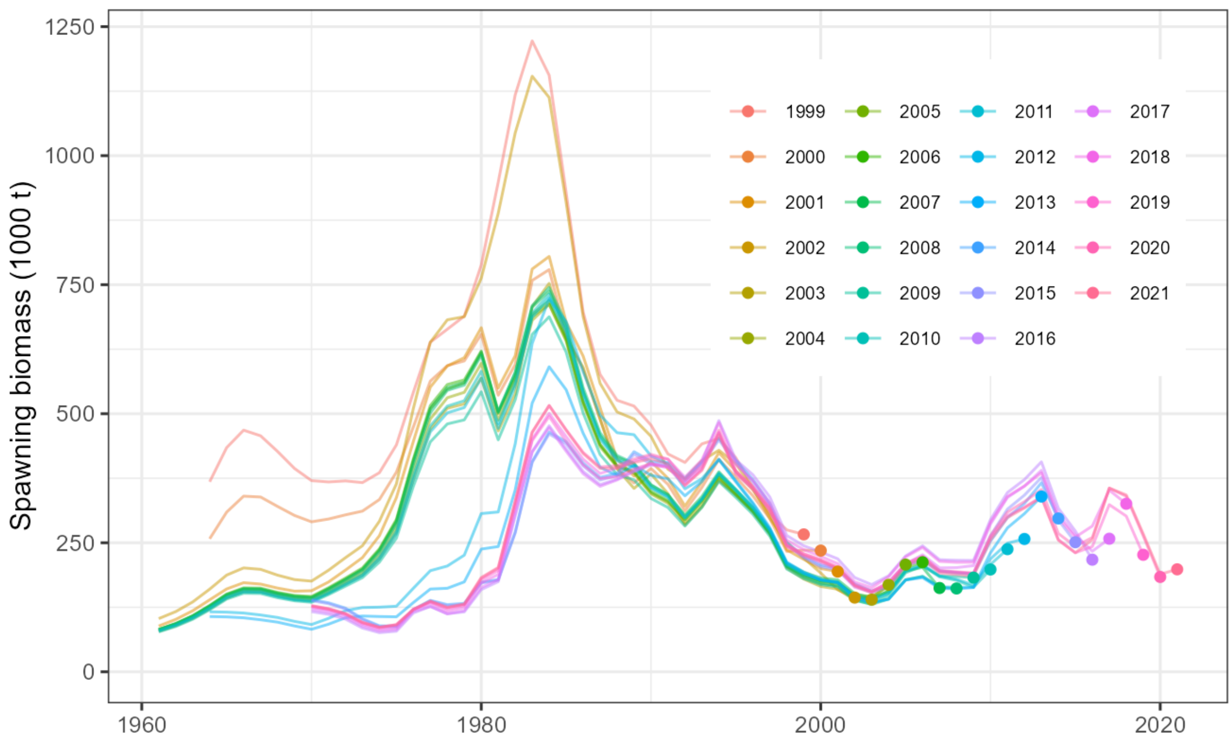


Figure 1.36. Estimated female spawning biomass for historical stock assessments conducted between 2000-2021. Lines reprsent the estimate in the assessment year and point is the terminal estimate in that year.

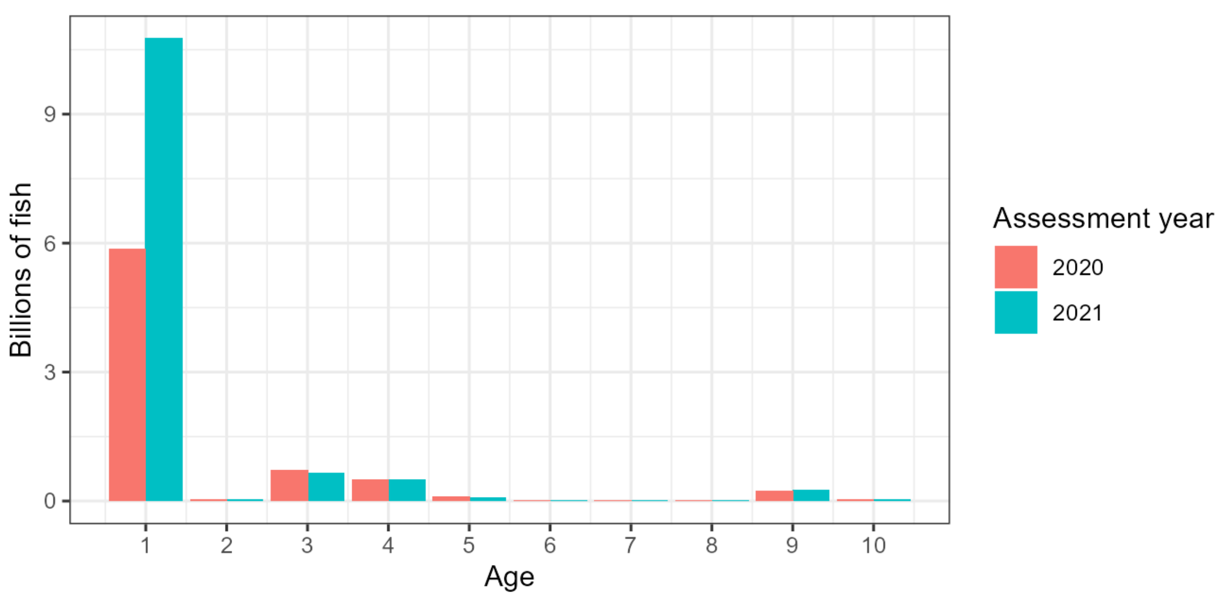


Figure 1.37. The bottom panel shows the estimated age composition in 2021 from the 2020 and 2021 assessments.

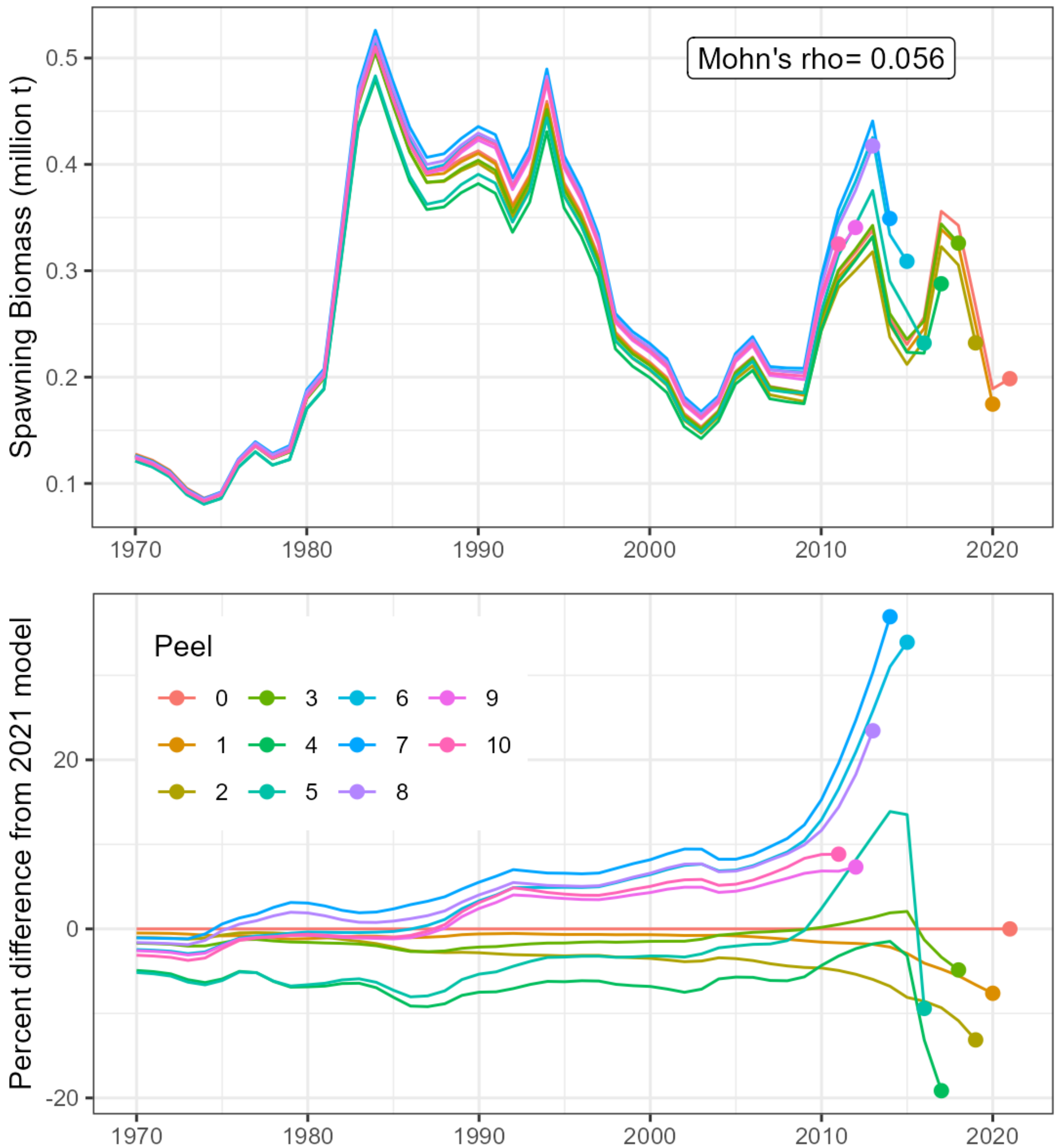


Figure 1.38. Retrospective plot of spawning biomass for models ending in years 2011-2020 for the 2021 base model. The revised Mohn's ρ (Mohn 1999) for ending year spawning biomass is 0.056.

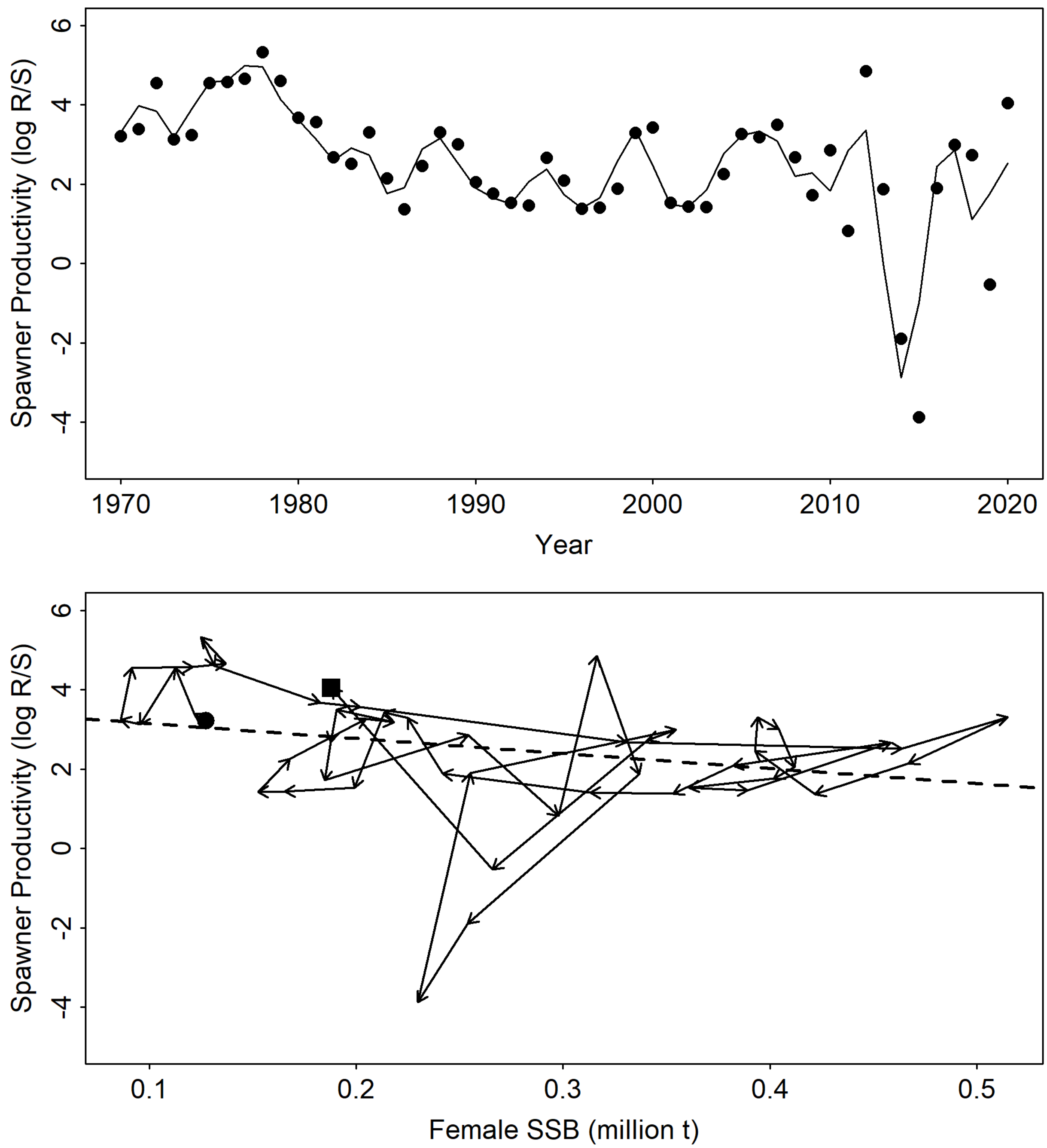


Figure 1.39. GOA pollock spawner productivity, log(R/S), in 1970-2019 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

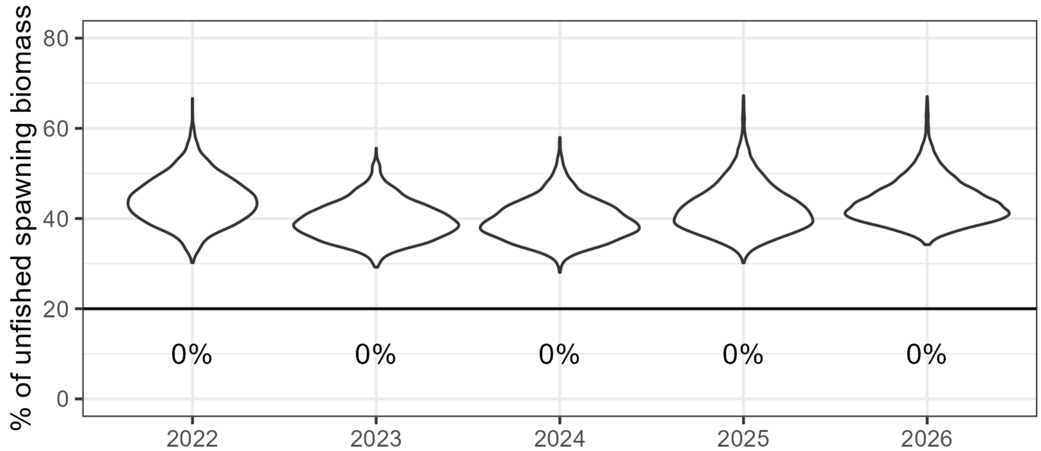


Figure 1.40. Uncertainty in spawning biomass in 2022-2026 based on a posterior samples from MCMC from the joint likelihood for the base model where catch is set to the maximum permissible F_{ABC}. Shown are the percentage below the horizontal line at 20% for each year.

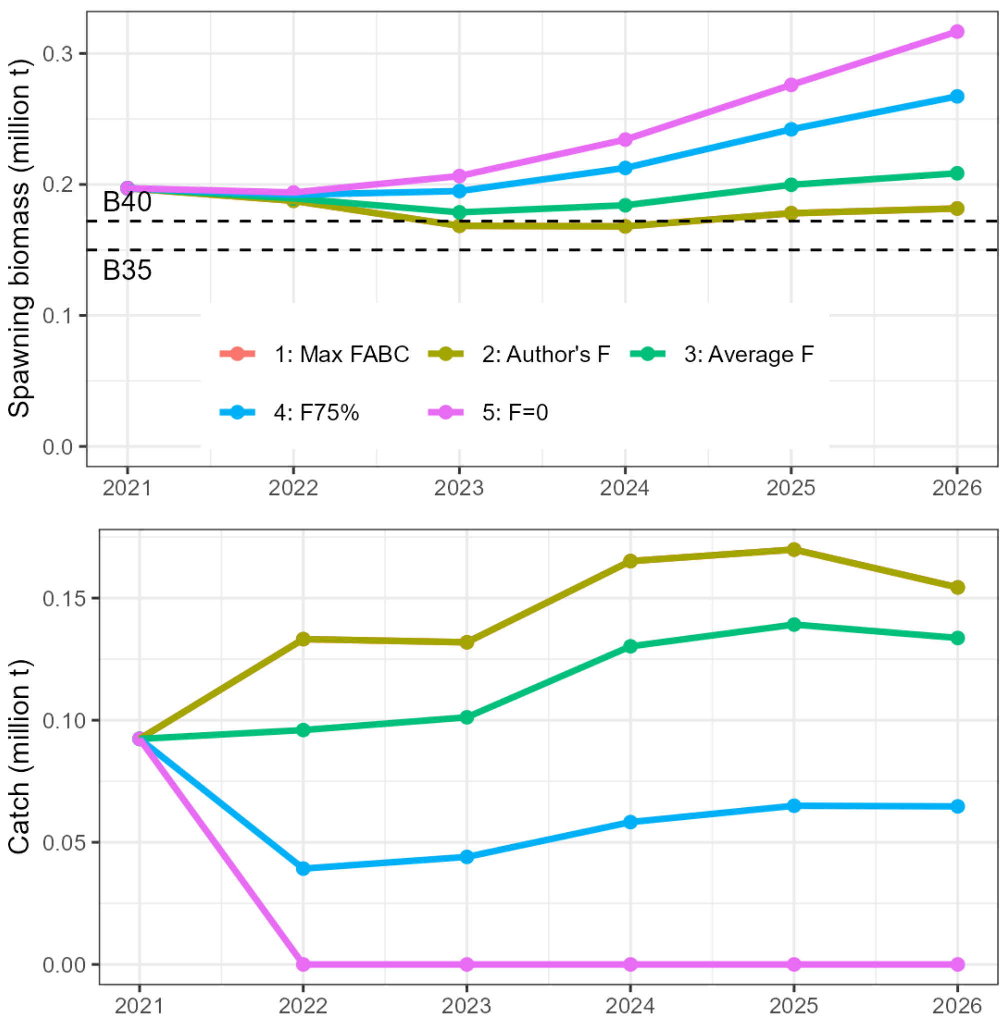


Figure 1.41. Projected mean spawning biomass and catches in 2020-2025 under different harvest rates.

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

S. Kalei Shotwell, Martin Dorn, Cole C. Monnahan, Alison L. Deary, Bridget Ferriss, Ben Fissel, Lauren Rogers, Abigail Tyrell, and Stephani Zador

November 2021

With Contributions from:

Kerim Aydin, Steve Barbeaux, Cheryl Barnes, Curry Cunningham, Dan Goethel, Peter-John Hulson, David Kimmel, Ben Laurel, Zack Oyafuso, Patrick Ressler, Katie Sweeney, Jordan Watson, Matt Wilson, Sarah Wise

Current Year Update

The ecosystem and socioeconomic profile or ESP is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., *In Review*). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

Please refer to the last full ESP and partial ESP documents for further information regarding the ecosystem and socioeconomic linkages for this stock (Shotwell et al., 2019, 2020, available online within the Gulf of Alaska (GOA) pollock stock assessment and fishery evaluation report of Dorn et al., 2019, Appendix 1A, pp. 105-151 and Dorn et al., 2020, Appendix 1A, pp. 104-135).

Management Considerations

The following are the summary considerations from current year updates to the ecosystem and socioeconomic indicators evaluated for GOA pollock:

- Cooling temperature both at surface and depth, low marine heatwave events and increased northwesterly wind suggest improved egg and larval habitat conditions
- Mixed lower trophic indicators (< in chlorophyll *a* concentration, later spring bloom peak, lower spring copepods and average planktivore success) suggest average larval prey resources
- Low larval spring larval CPUE contrasted by high nearshore CPUE in Kodiak suggest some potential for recruitment, but unknown due to loss of summer survey
- Percent euphausiids in the juvenile pollock diet is near average, and condition of fall and winter adult pollock were near average, suggesting adequate prey resources for juveniles and adults
- Center of gravity and area occupied have decreased since 2019 implying a shift in the distribution toward the southwest and slightly reduced population spread
- Bottom trawl survey estimates large increases in Pacific ocean perch and sablefish with a small increase in arrowtooth flounder as competitors and predators of GOA pollock
- Fishery CPUE in the winter spring was high in 2021 implying pollock were concentrated, so catch rates were higher and roe may be in better condition
- Exvessel price decreased in 2020 and roe-per-unit-catch in the fishery was low in 2021, cost pressure from COVID-19 mitigation efforts likely had upstream impacts on price and roe catch
- The impact of COVID-19 had only marginal effects on first-wholesale and export prices, as retail and food service are both significant components of the market for pollock products
- Overall, ecosystem indicators were average to above average in 2021 with socioeconomic indicators average in 2020 and good to poor in 2021 (based on only a couple indicators)

Modeling Considerations

The following are the summary results from the intermediate and advanced stage monitoring analyses for GOA pollock:

- Highest ranked predictors for the recruitment importance model were the spring sea surface temperature in western/central GOA, the spring pollock larvae CPUE in Shelikof, the fall pollock condition of adults in the fishery, the arrowtooth flounder biomass, and the sablefish biomass (inclusion probability > 0.5)
- Predation mortality based on the age-1 predation mortality indicator is being evaluated in a research track assessment for GOA pollock

Assessment

Ecosystem and Socioeconomic Processes

Walleye pollock (or pollock) are typically encountered between 0 and 300 m along the continental shelf. 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 juveniles are semi-demersal in nearshore areas as well as occurring in the upper 40 m in offshore areas of the continental shelf (Bailey, 1989). The preferred habitat seems to switch from a reliance on a particular thermal environment during larval and early juvenile stages to low-gradient, low lying areas such as channels, gullies, and flats that are not rocky and within 20-300 m depth during late juvenile and adult stages (Figure 1A.1). 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 which is a strategy that may mitigate vulnerability in terms of synchrony with optimal levels of larval prey (Doyle and Mier, 2016; Doyle et al., 2019). 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, 2019). Pollock eggs and larvae are pelagic in the spring time period and vulnerable to wind-driven transport. Northeasterly wind has been associated with retention of pollock larvae (Stabeno et al., 1996) and juveniles (Wilson and Laman, 2021) in favorable nursery areas in the Kodiak Island/Shelikof sea valley vicinity. 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). GOA pollock complete juvenile transformation by ~40 mm (Kendall et al., 1994, Brown et al., 2001). GOA pollock have a fairly stable lipid and protein content throughout their life history implying an energy allocation strategy toward increasing growth rather than toward energy storage. However, 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.

The primary prey of juvenile and adult pollock are euphausiids, and cannibalism is not as prevalent in the GOA as in the eastern Bering Sea (Yang and Nelson, 2000, Gaichas et al., 2015). Consumption of euphausiids has been associated with improved growth and body condition in the western GOA (Wilson et al., 2013). 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., 2020). 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, 2000). Top predators on pollock include arrowtooth flounder, Pacific halibut, Pacific cod, Steller sea lion, and sablefish (Barnes et al., 2020, Gaichas et al., 2015). It is important to consider the potential impacts of other GOA pollock predators and competitors that may be on the rise and have an advantage in this new warming environment (e.g., sablefish and Pacific ocean perch or POP). Several recent large year-classes are estimated for the sablefish stock, which has potential overlap as both a competitor with (juveniles eat euphausiids) and predator of GOA pollock as they return to their adult habitat on the continental slope. Estimates of total biomass for GOA POP have been steadily increasing for the past several decades and are now about 55% of the total biomass estimate for GOA pollock (Hulson et al., 2019). Juvenile and adult POP could be potential competitors of GOA pollock as they primarily feed on euphausiids. Recent estimates of incidental catch for both sablefish and POP suggest an increasing amount of spatial overlap among the three stocks.

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. Pollock is a global commodity with prices determined in the global market. GOA represents roughly 3%-5% of the global pollock catch volume. In the GOA, the primary products are H&G, surimi, fillets, and roe, each have typically accounted for approximately 35%, 20%, 30%, and 10% of first-wholesale value in recent years, respectively. In 2020 minced fish production and value increased substantially, although it still only accounts for 5% of volume and value. The increase in minced production, which also occurred in the BSAI was attributed, in part, to small fish size, though the pivot to retail as a result of COVID-19 may have been a factor. 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 (Fissel et al., 2021). Pollock roe is a high-priced product destined primarily for Asian markets.

An analysis of commercial processing and harvesting data may be conducted to examine sustained participation for those communities substantially engaged in a commercial fishery. The Annual Community Engagement and Participation Overview (ACEPO) is a new report that evaluates engagement at the community level and focuses on providing an overview of harvesting and processing sectors of identified highly engaged communities for groundfish and crab fisheries in Alaska (Wise et al., 2021). To date, the most highly engaged communities with the GOA pollock fishery are Kodiak, Sand Point, King Cove, and Akutan accounting for almost 89% of the regional value landed.

Indicator Suite

The following list of indicators for GOA pollock are organized by categories, three for ecosystem indicators (physical, lower trophic, and upper trophic) and three for socioeconomic indicators (fishery performance, economic, and community). A short description and contact name for the indicator contributor are provided. Please refer to the last full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions for this stock (Shotwell et al., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Figure 1A.2a and Figure 1A.2b, respectively.

Ecosystem Indicators:

Physical Indicators (Figure 1A.2a.a-d)

- a.) Annual marine heatwave cumulative index over the central GOA (contact: S. Barbeaux).
- b.) Spring (April-May) daily sea surface temperatures (SST) for the western and central (combined) GOA from the NOAA Coral Reef Watch Program (contact: J. Watson).
- c.) Summer bottom temperatures from the AFSC bottom trawl survey (contact: K. Shotwell)
- d.) Mean springtime (April-May) surface wind direction from National Data Buoy Center for site B-AMAA2 located in the NE Kodiak Archipelago (contact: L. Rogers)

Lower Trophic Indicators (Figure 1A.2a.e-o)

- e.) Derived chlorophyll *a* concentration during spring seasonal peak (May) in the western and central GOA regions from the MODIS satellite (contact: J. Watson).
- f.) Peak timing of the spring bloom averaged across individual ADF&G statistical areas in the western and central GOA region from the MODIS satellite (contact: J. Watson).
- g.) Spring small copepods for larvae GOA pollock from the EcoFOCI spring survey (contact: L. Rogers).

h.) Summer large copepods for young-of-the-year (YOY) from the EcoFOCI summer survey (contact: L. Rogers).
i.) Summer euphausiid abundance from the AFSC acoustic survey for the Kodiak core survey area (contact: P. Ressler).
j.) Parakeet auklet (planktivores) reproductive success at Chowiet Island (contact: S. Zador).
k.) Spring pollock larvae catch-per-unit-of-effort (CPUE) from the EcoFOCI spring survey (contact: L. Rogers).
l.) Summer young-of-the-year (YOY) pollock catch-per-unit-of-effort (CPUE) from the EcoFOCI summer survey (contact: L. Rogers).
m.) Summer pollock condition for young-of-the-year (YOY) from EcoFOCI summer survey (contact: L. Rogers).
n.) Summer pollock catch-per-unit-of-effort (CPUE) of young-of-the-year (YOY) from the AFSC beach seine survey in the Kodiak region (contact: B. Laurel).
o.) Pollock relative biomass of young-of-the-year (YOY) from screening burrows of tufted puffins at Aiktak Island (contact: S. Zador).

Upper Trophic Indicators (Figure 1A.2a.p-y)

p.) Summer pollock predation mortality for age-1 from RACE and IPHC surveys (contact: C. Barnes).
q.) Proportion-by-weight of euphausiids in the diets of juvenile GOA pollock from summer bottom-trawl surveys (contact: K.Aydin).
r.) Fall pollock condition for adults from the pollock fishery sampled by observers (contact: M. Dorn).
s.) Winter pollock condition for adults from the late winter AFSC acoustic survey of pre-spawning pollock in the GOA (contact: M. Dorn).
t.) Summer pollock center of gravity northeastings estimated by a spatio-temporal model using the package VAST on bottom trawl survey data (contact: Z. Oyafuso)
u.) Summer pollock area occupied estimated by a spatio-temporal model using the package VAST on bottom trawl survey data (contact: Z. Oyafuso).
v.) Arrowtooth flounder total biomass from the most recent stock assessment model (contact: K. Shotwell).
w.) Pacific ocean perch total biomass from the most recent stock assessment model (contact: K. Shotwell).
x.) Sablefish total biomass from the most recent stock assessment model (contact: K. Shotwell).
y.) Steller sea lion non-pup estimates for the GOA portion of the western Distinct Population Segment (contact: K. Sweeney).

Socioeconomic Indicators:

Fishery Performance Indicators (Figure 1A.2b.a-b)

a.) Winter-spring pollock catch-per-unit-of-effort (CPUE) from fishery observer data (contact: M. Dorn)
b.) Summer-fall pollock catch-per-unit-of-effort (CPUE) from fishery observer data (contact: M. Dorn).

Economic Indicators (Figure 1A.2b.c-d)

c.) Annual real ex-vessel price per pound of GOA pollock from fish ticket information (contact: B. Fissel).
d.) Annual pollock roe per-unit-catch during January to March (contact: B. Fissel).

Community Indicators (Figure 1A.2b.e-h)

e.) Regional quotient of pollock for harvesting revenue of the highly engaged community of Kodiak (contact: S. Wise)

f.) Regional quotient of pollock for processing revenue of the highly engaged community of Kodiak (contact: S. Wise)
g.) Regional quotient of pollock for harvesting revenue of three smaller highly engaged communities (Sand Point, King Cove, and Akutan) combined (contact: S. Wise)
h.) Regional quotient of pollock for processing revenue of three smaller highly engaged communities (Sand Point, King Cove, and Akutan) combined (contact: S. Wise)

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, biomass, catchability). These regression techniques provide a simple predictive performance for the variable of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for testing a research ecosystem linked model and output can be compared with the current operational model to understand information on retrospective patterns, prediction performance, and comparisons of other model output such as terminal spawning stock biomass or mean recruitment. This stage provides an on-ramp for introducing an alternative ecosystem linked stock assessment model to the current operational stock assessment model and can be used to understand the potential reduction in uncertainty by including the ecosystem information.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light evaluation. Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long-term mean. A sign based on the anticipated relationship between the indicator and the stock (Figure 1A.1) is also assigned to the indicator where possible. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a +1 score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a -1 score. All values less than or equal to one standard deviation from the long-term mean are average and receive a 0 score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 1A.3). We also provide five year indicator status tables with a color or text code for the relationship with the stock (Tables 1A.1a,b) and evaluate the current year status in the historical indicator time series graphic (Figures 1A.2a,b) for each ecosystem and socioeconomic indicator.

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the GOA pollock stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels, fishery performance, economic, and community indicators as listed above. Here we concentrate on updates since the last ESP. Overall both the physical and upper trophic indicators scored average for 2021, while the lower trophic and fishery performance indicators were above average, and the economic indicator was below average (Figure 1A.3). Compared to last year, this is the same value for the physical indicators, an improvement from below average for the lower trophic and upper trophic indicators, an improvement from average for the fishery performance indicators, and a drop in the economic indicator. We also note caution when comparing scores between odd to even years as there are many lower and upper trophic indicators missing in even years due to the off-cycle year surveys in the GOA. Also, there have been other cancellations due to COVID-19 or other survey delays in 2020 and 2021 that have limited production of several indicators. Economic and community indicators are all lagged by at least one year (with the exception of one indicator) due to timing of the availability of the current year information and the production of this report. Economic indicators scored average for 2020 and one economic indicator was low in 2021. There were no updates for community indicators.

For physical indicators (Table 1A.1a, Figure 1A.2a.a-d), there has been increased sea surface and bottom warming in the GOA ecosystem and the presence of a series of major marine heatwaves for the past several years (Figure 1A.2a.a-c). However, in 2020 and 2021 there were reduced temperatures both at the surface and bottom and reduced annual marine heatwave events. Cooler temperatures tend to be associated with zooplankton communities that are dominated by larger, more lipid rich species and lowers the susceptibility for starvation, which suggests improved conditions for egg and larval stages. The direction of the mean surface wind had shifted more toward the southwest (down Shelikof Strait) in 2020 and continued southwest in 2021 (Figure 1A.2a.d) implying retention in favorable habitat of Kodiak Island and the Shelikof sea valley and potentially good conditions for recruitment.

For lower trophic indicators (Table 1A.1a, Figure 1A.2a.e-o), estimates of chlorophyll *a* concentration decreased to below average in 2021 with a concurrent later peak timing of the spring bloom, which may have implications for larval mismatch with prey (Figure 1A.2a.e-f). Spring small copepods decreased from a high during the heatwave years to below average suggesting a shift in the size composition of the zooplankton community (Figure 1A.2a.g). Reproductive success of planktivorous parakeet auklet seabirds on Chowiet decreased slightly but remains near average suggesting sufficient zooplankton prey resources (Figure 1A.2a.j). Years of high larval abundance for the late winter to early spring shelf spawners (i.e., Pacific cod, walleye pollock, and northern rock sole) were associated with cooler winters and enhanced alongshore winds during spring (Deary et al., 2021). Since physical indicators appear average this year the expectation was average abundances of pollock in the larval survey. The predominant wind pattern during the spring 2021 survey was to the southwest, which is consistent with enhanced larval retention and increased age-1 abundance the following year. However, larval abundances were especially low and the highest catches were outside of the core area, which is unusual (Figure 1A.2a.k). Conversely, the nearshore surveys in Kodiak showed high CPUE in 2021 (Figure 1A.2a.n) suggesting some potential recruitment, although this survey has limited spatial coverage.

For upper trophic indicators (Table 1A.1a, Figure 1A.2a.p-y), predation estimates on age-1 pollock have been relatively low and stable from 2009 to 2019 (Figure 1A.2a.p). The percent of euphasiids in the diet for juveniles has returned to near average conditions suggesting declines from the 2019 survey in the available prey base (Figure 1A.2a.q) and average feeding conditions as juvenile pollock migrated to adult habitat following their first overwinter. Condition of adult pollock in the fall fishery of 2020 was improved from 2019 to slightly below average and subsequent condition of winter adult pollock from the acoustic survey also improved from 2020 to very near average in 2021, continuing the good correlation between the two indicators (Figure 1A.2a.r-s). The center of gravity in the northeast direction and area occupied estimates for the GOA pollock population have decreased from 2019 (although area occupied is still high), implying a shift in distribution toward the southwest and a slightly reduced population spread (Figure 1A.2a.t-u). Potential competitors to GOA pollock are the recent multiple large year classes of juvenile sablefish, an increasing population of Pacific Ocean perch (POP), and pink salmon which are returning in very high numbers in 2021 (Murphy 2021, Shaul 2021). Major predators of pollock include arrowtooth flounder and Steller sea lions (SSL). There were no updates for these four indicators as sablefish, POP, or arrowtooth flounder stock assessments are currently in review and the SSL survey data are not available until mid-winter. However, recent estimates for sablefish and POP in the bottom trawl survey are much higher than in 2019 suggesting more competition from juvenile sablefish and POP with pollock (Goethel et al., 2021; Hulson et al., 2021). Recent bottom trawl survey estimates of arrowtooth flounder were also larger in 2019, but still well below average (Shotwell et al., 2021).

For fishery performance indicators (Table 1A.1b, Figure 1A.2b.a-b), the CPUE in the winter spring remains high in 2021 and the summer fall CPUE update increased from below average in 2019 to above average in 2020. 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.

The value of pollock deliveries by vessels to inshore processors (shoreside ex-vessel value) decreased 27% in 2020 from 2019 to $27.8 million, and was below the average for the previous 5 years (Table 1A.1b, Figure 1A.2b.c). This decrease was the combined effect of a 10% decrease in retained catch to 107 thousand t and a 14% decrease in the ex-vessel price to $0.118 per pound (Table 1A.1b, Figure 1A.2b.c). The number of vessels fishing for pollock decreased from 62 in 2019 to 61 in 2020 (Fissel et al., 2021). The decreased ex-vessel price in 2020 was despite stable first-wholesale prices for head-and-gut (H&G) and fillet products, which represent approximately two-thirds of annual production (Fissel et al., 2021). First-wholesale value was $70.6 million in 2020 (18% decrease) and production of pollock products was 40 thousand t (22% decrease). The average first-wholesale price of pollock products increased 5% to $0.80 per pound (Fissel et al., 2019). In 2020 COVID-19 closures resulted in increased demand for retail products and frozen products, and decreased foodservice and fresh products. Retail and foodservice are both significant components of the market for pollock products. As such, the impact of COVID-19 on prices appears muted with only marginal changes in first-wholesale and export prices. Cost pressure from COVID-19 mitigation efforts likely had upstream impacts on ex-vessel prices, which decreased significantly. In 2021, there was a decrease in roe-per-unit-catch to low levels (Figure 1A.1b.d).

The community indicators evaluated in the ESP are similar to those presented in the ACEPO report but on the stock level rather than the community level. The indicators are separated into two categories of fisheries involvement: commercial processing and commercial harvesting (Wise et al., 2021). By separating commercial processing from commercial harvesting, the engagement indices highlight the importance of fisheries in communities that may not have a large amount of landings or processing in their community, but have a large number of fishers and/or vessel owners that participate in commercial fisheries who are based in the community. At this time there are no updates to the community indicators. In the future we plan to evaluate how to reference the products available in the ACEPO report for use in the ESPs to inform on stock health.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used for the intermediate stage statistical test to quantify the association between hypothesized predictors and GOA pollock recruitment and to assess the strength of support for each hypothesis. In this stage, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment and highly correlated covariates are removed. We further restrict potential covariates to those that can provide the longest model run and through the most recent estimate of recruitment that is well estimated in the current operational stock assessment model (Figure 1A.4a). This results in a model run from 1990 through the 2019 year-class. We then provide the mean relationship between each predictor variable and log GOA pollock recruitment over time (Figure 1A.4b, left side), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 1A.4b, right side). A higher probability indicates that the variable is a better candidate predictor of GOA pollock recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process continue to be the spring sea surface temperature in the western central GOA, the spring pollock larvae catch-per-unit-effort in Shelikof, the fall pollock condition of adults in the fishery, the arrowtooth flounder biomass from the stock assessment, and the sablefish total biomass from the stock assessment (Figure 1A.4).

Advanced Stage: Research Model Test

An indicator of predation mortality for age-1 pollock has been included in the GOA pollock ESP as an upper trophic level indicator (Figure 1A.2a.p). This indicator utilizes diet data from RACE surveys and stock assessment information from major predators (Barnes et al., 2020). The index of predation accounted for spatiotemporal variation in predator biomass, bioenergetics-based rations, and age-specific proportions of pollock consumed. To evaluate population-level impacts of predation on GOA pollock, a research model was developed that included indices of pollock predation and modeled the predation component of natural mortality as time-varying. An index of total predation (rather than age-1 predation) was utilized, representing the consumption of pollock by the dominant predators on pollock in the GOA ecosystem, including arrowtooth flounder, Pacific cod, Pacific halibut, pollock, and sablefish. There was evidence of intense and highly variable predation on Gulf of Alaska pollock (ranging from 2.00 to 7.07 million MT). Of those examined, arrowtooth flounder was, by far, the dominant pollock predator (relative consumption: 0.65 ± 0.16).

These data were modeled in the GOA pollock assessment model as a survey-like index of removals attributable to the predation component of natural mortality. This formulation allowed for non-annual data inputs and included a proportionality constant to scale predation estimates to the pollock population. Age-specific natural mortality was allowed to vary according to a penalized random walk. We found that natural mortality ranged from 40% higher to 20% lower than the long-term mean when predation was included in the model (Figure 1A.5, top panel). Predation in biomass is highly variable for both constant mortality and time-varying predation mortality due to fluctuations in overall pollock biomass (Figure 1A.5, middle panel). Fits to the survey estimates of predation were improved when the model was configured with time-varying predation mortality (Figure 1A.5, middle panel). Resulting estimates of exploitable pollock biomass differed by as much as 15% between models with and without time-varying predation mortality (Figure 1A.5, bottom panel), however deviations of this magnitude are probably not large enough to cause inadvertent overfishing.

Data Gaps and Future Research Priorities

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

Refinements or updates to current indicators may also be helpful. The chlorophyll *a* concentration and timing of the spring bloom indicators were only partially specialized for GOA pollock. More specific phytoplankton indicators tuned to the spatial and temporal distribution of GOA pollock larvae as well as phytoplankton community structure information (e.g., hyperspectral information for size fractionation) could be more useful for understanding pollock larval fluctuations. Current estimates of zooplankton biomass are only available at smaller spatial scales and regional to gulf-wide estimates of zooplankton biomass would help elucidate prey trends at the spatial scales relevant to fisheries management. 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. The GOA CEATTLE model is now more developed and has potential to provide a gap-free index of predation mortality for age-1 GOA pollock (Adams et al., 2021). This could be skill tested with the current estimate of predation mortality for age-1 GOA pollock from the surveys and eventually incorporated within the operational stock assessment model. 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.

We plan to evaluate the information provided in the Economic SAFE and ACEPO report to determine what socioeconomic indicators could be provided in the ESP that are not redundant with those reports and related directly to stock health. This may result in a transition of indicators currently reported in this ESP to a different series of socioeconomic indicators in future ESPs and may include a shift in focus from engagement to dependency. Additional considerations should be given for the timing of the economic and community reports that are delayed by 1-2 years depending on the data source from the annual stock assessment cycle. The Scientific and Statistical Committee (SSC) recently recommended that local knowledge, traditional knowledge and subsistence information may be helpful for understanding recent fluctuations in stock health, shifts in stock distributions, or changes in size or condition of species in the fishery. We could include this information as supportive evidence and perspective on many indicators monitored within the ESP.

As indicators are improved or updated, they may replace those in the current set of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. The annual request for indicators (RFI) for the GOA pollock ESP will include these data gaps and research priorities along with a list of potential new indicators that could be developed for the next full ESP assessment.

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Tables

Table 1A.1a. Beginning stage ecosystem indicator analysis for GOA pollock, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and GOA pollock (blue or italicized text = good conditions for GOA pollock, red or bold text = poor conditions, white = average conditions). A gray fill and text = “NA” will appear if there were no data for that year.

Category	Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
Physical	Annual Heatwave GOA Model	neutral	neutral	**high**	neutral	neutral
	Spring Temperature Surface WCGOA Satellite	neutral	neutral	**high**	neutral	neutral
	Summer Temperature Bottom GOA Survey	neutral	NA	**high**	NA	neutral
	Spring Wind Direction Kodiak Buoy	neutral	NA	neutral	neutral	neutral
Lower Trophic	Spring Chlorophylla Biomass WCGOA Satellite	**low**	**low**	**low**	neutral	neutral
	Spring Chlorophylla Peak WCGOA Satellite	**low**	**low**	*high*	**low**	neutral
	Spring Small Copepod Abundance Shelikof Survey	neutral	NA	*high*	NA	neutral
	Summer Large Copepod Abundance Shelikof Survey	**low**	NA	neutral	NA	NA
	Summer Euphausiid Abundance Kodiak Survey	**low**	NA	neutral	NA	NA
	Annual Auklet Reproductive Success Chowiet Survey	neutral	**low**	neutral	NA	neutral
	Spring Pollock CPUE Larvae Shelikof Survey	neutral	NA	neutral	NA	neutral
	Summer Pollock CPUE YOY Shelikof Survey	neutral	NA	neutral	NA	NA
	Summer Pollock Condition YOY Shelikof Survey	neutral	NA	**low**	NA	NA

Category	Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
	Summer Pollock CPUE YOY Nearshore Kodiak Survey	*high*	*high*	neutral	neutral	*high*
	Annual Pollock Relative Biomass Aiktak Survey	neutral	neutral	neutral	NA	NA
Upper Trophic	Summer Pollock MT Consumed Age1 GOA Model	neutral	NA	neutral	NA	NA
	Summer Pollock Euphausiid Diet Juvenile GOA Survey	neutral	NA	*high*	NA	neutral
	Fall Pollock Condition Adult GOA Fishery	neutral	neutral	neutral	neutral	NA
	Winter Pollock Condition Adult GOA Survey	**low**	**low**	neutral	neutral	neutral
	Summer Pollock Center Gravity Northeast WCGOA Model	*low*	NA	neutral	NA	neutral
	Summer Pollock Area Occupied WCGOA Model	**low**	NA	neutral	NA	neutral
	Annual Arrowtooth Biomass GOA Model	neutral	neutral	neutral	neutral	NA
	Annual Pacific Ocean Perch Biomass GOA Model	**high**	**high**	**high**	**high**	NA
	Annual Sablefish Biomass GOA Model	neutral	**high**	**high**	**high**	NA
	Annual Steller Sea Lion Adult GOA Survey	neutral	neutral	neutral	NA	NA

Table 1A.1b: Beginning stage socioeconomic indicator analysis for GOA pollock, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and GOA pollock (blue or italicized text = good conditions for GOA pollock, red or bold text = poor conditions, white = average conditions). A gray fill and text = "NA" will appear if there were no data for that year.

Category	Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
Fishery Performance	Winter Spring Pollock CPUE Adult GOA Fishery	*high*	*high*	*high*	neutral	*high*
	Summer Fall Pollock CPUE Adult GOA Fishery	*high*	neutral	neutral	neutral	NA
Economic	Annual Pollock Real Exvessel Price Fishery	**low**	neutral	neutral	neutral	NA
	Winter Spring Pollock Roe Per Unit Catch Fishery	**low**	neutral	neutral	neutral	**low**
Community	Annual Pollock RQ Harvesting Revenue Kodiak Fishery	*high*	*high*	*high*	NA	NA
	Annual Pollock RQ Processing Revenue Kodiak Fishery	neutral	*high*	*high*	NA	NA
	Annual Pollock RQ Harvesting Revenue Small Communities GOA Fishery	**low**	**low**	**low**	NA	NA
	Annual Pollock RQ Processing Revenue Small Communities GOA Fishery	neutral	neutral	neutral	NA	NA

Figures

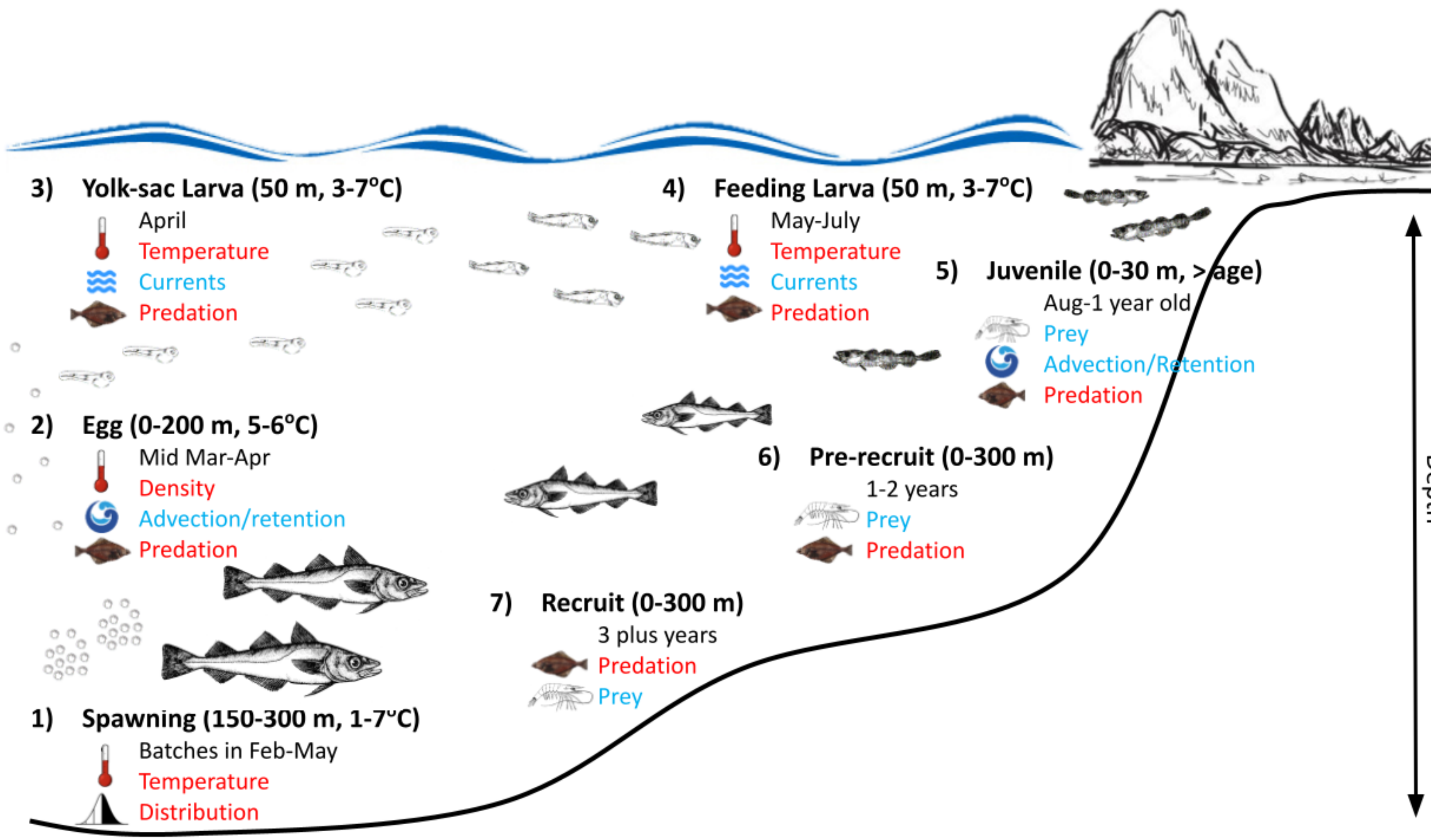


Figure 1A.1: Life history conceptual model for GOA pollock summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text indicates increases in the process positively affect survival. NA means no indicators for that category.

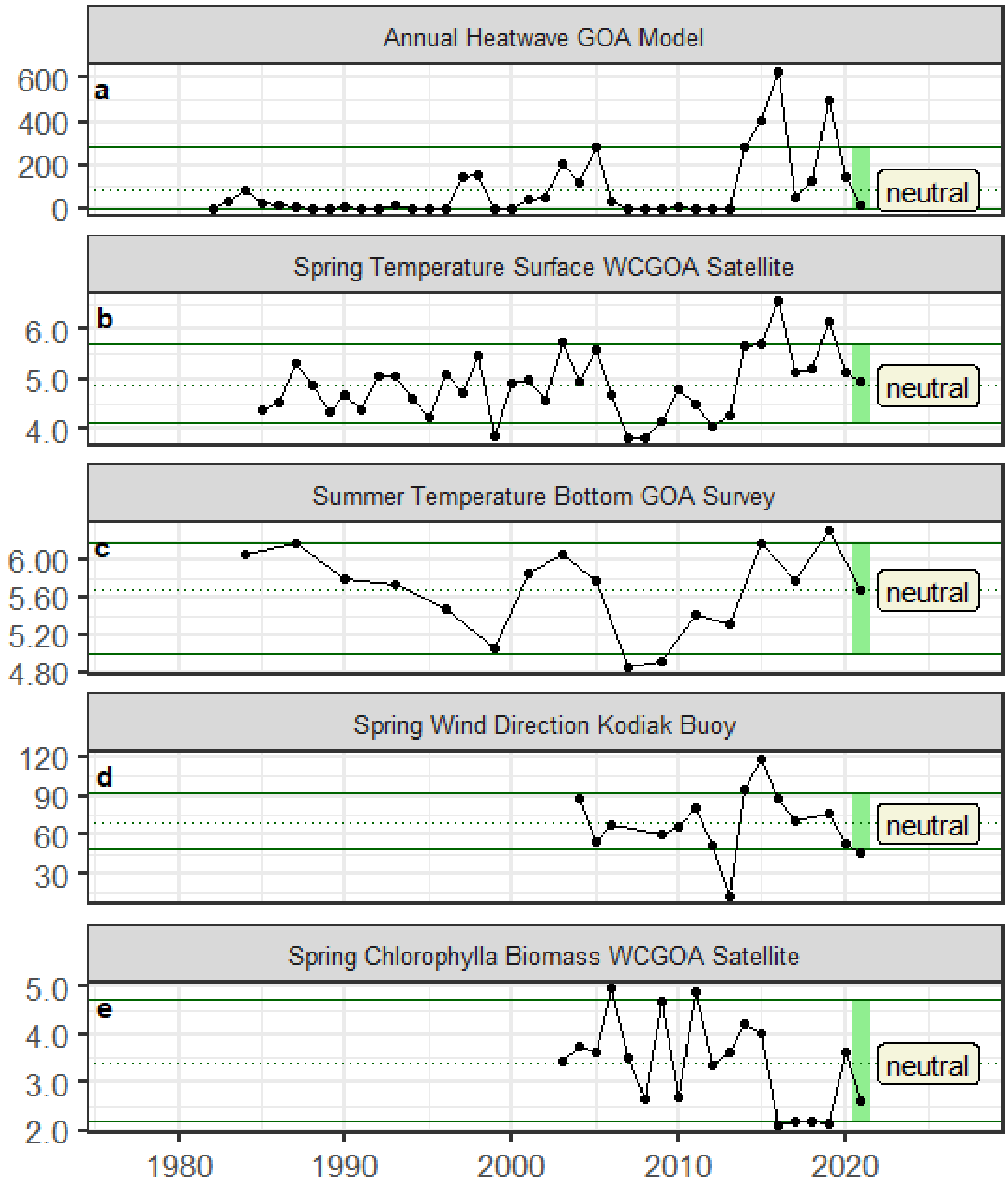


Figure 1A.2a. Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

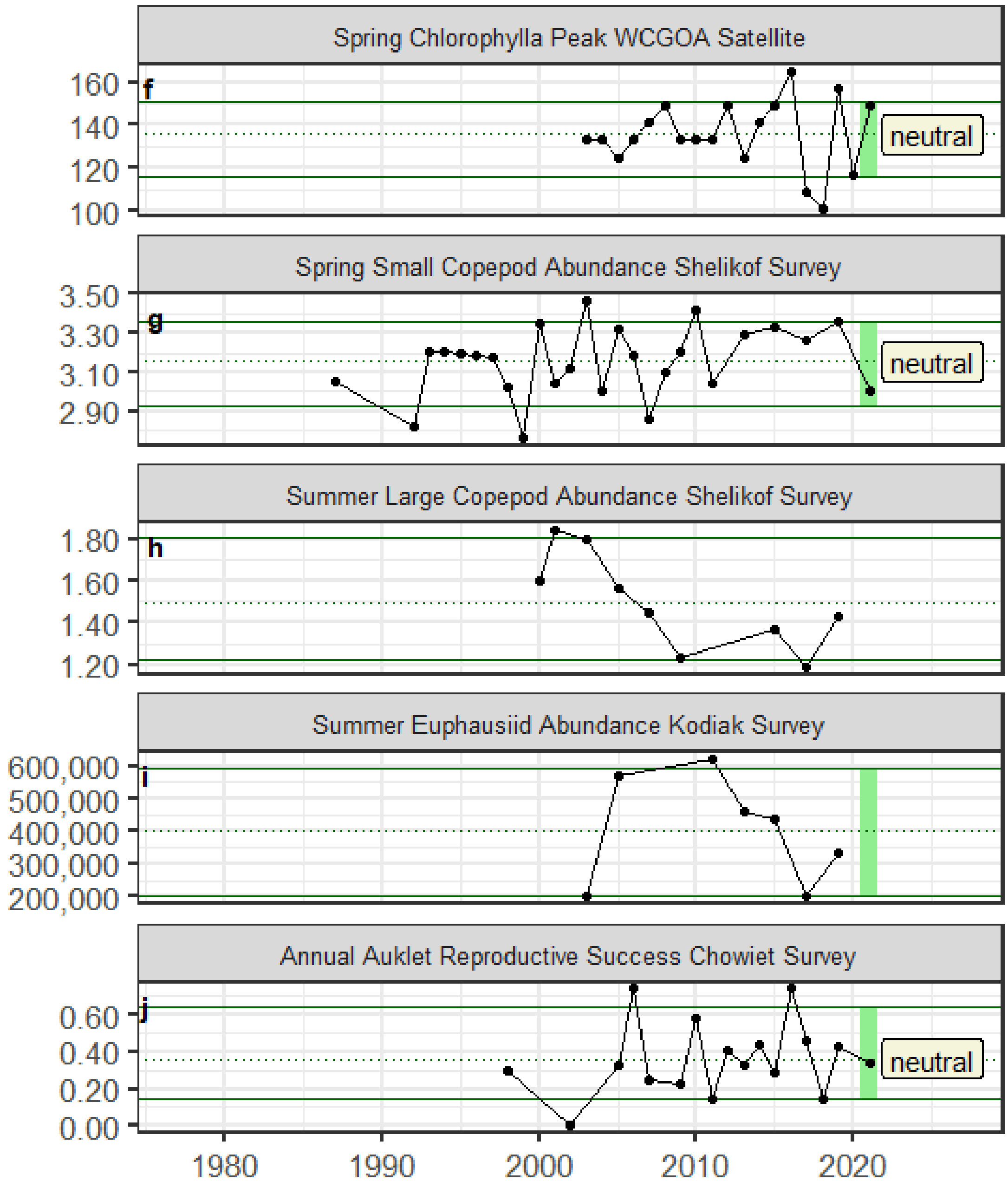


Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

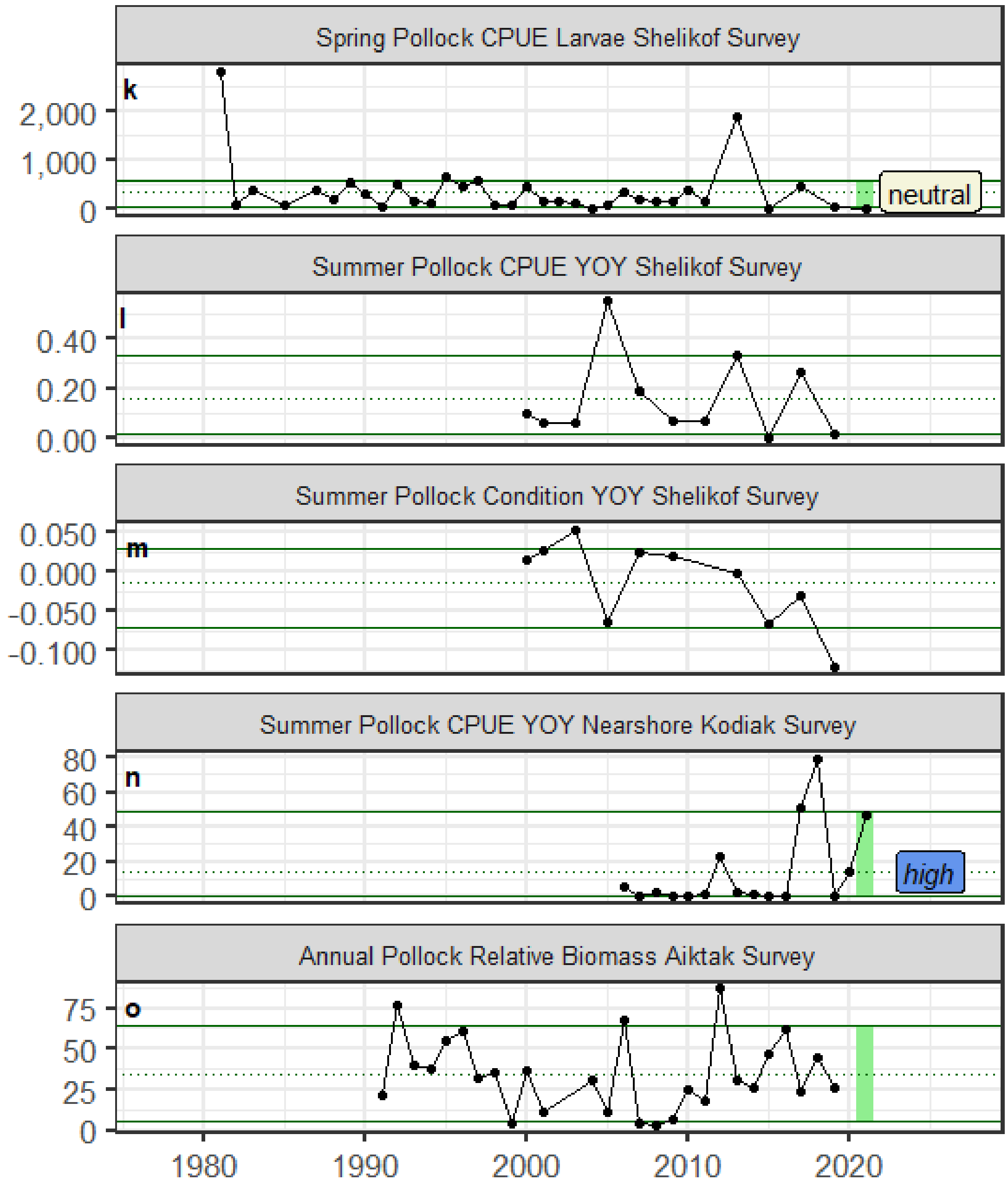


Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

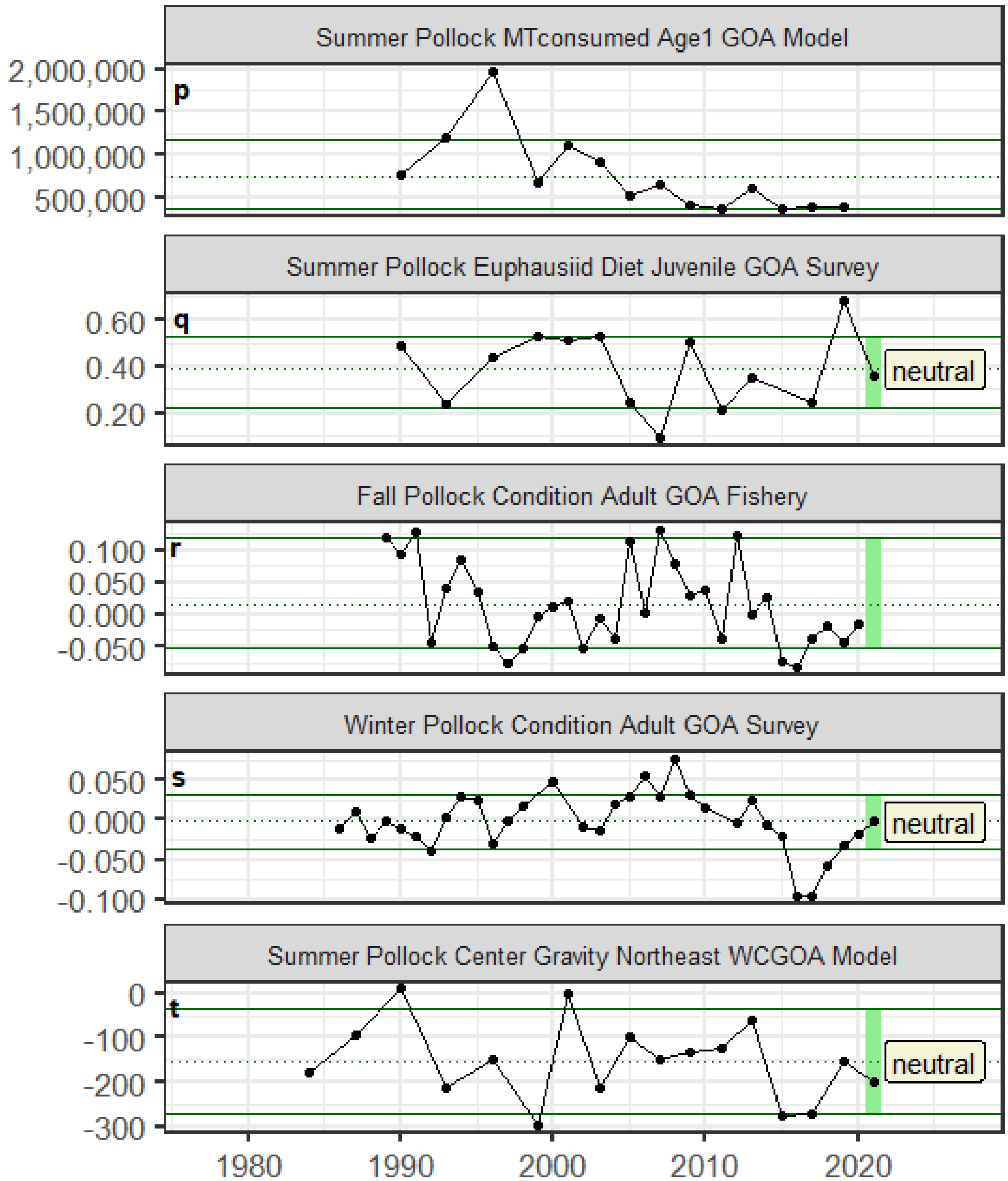


Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

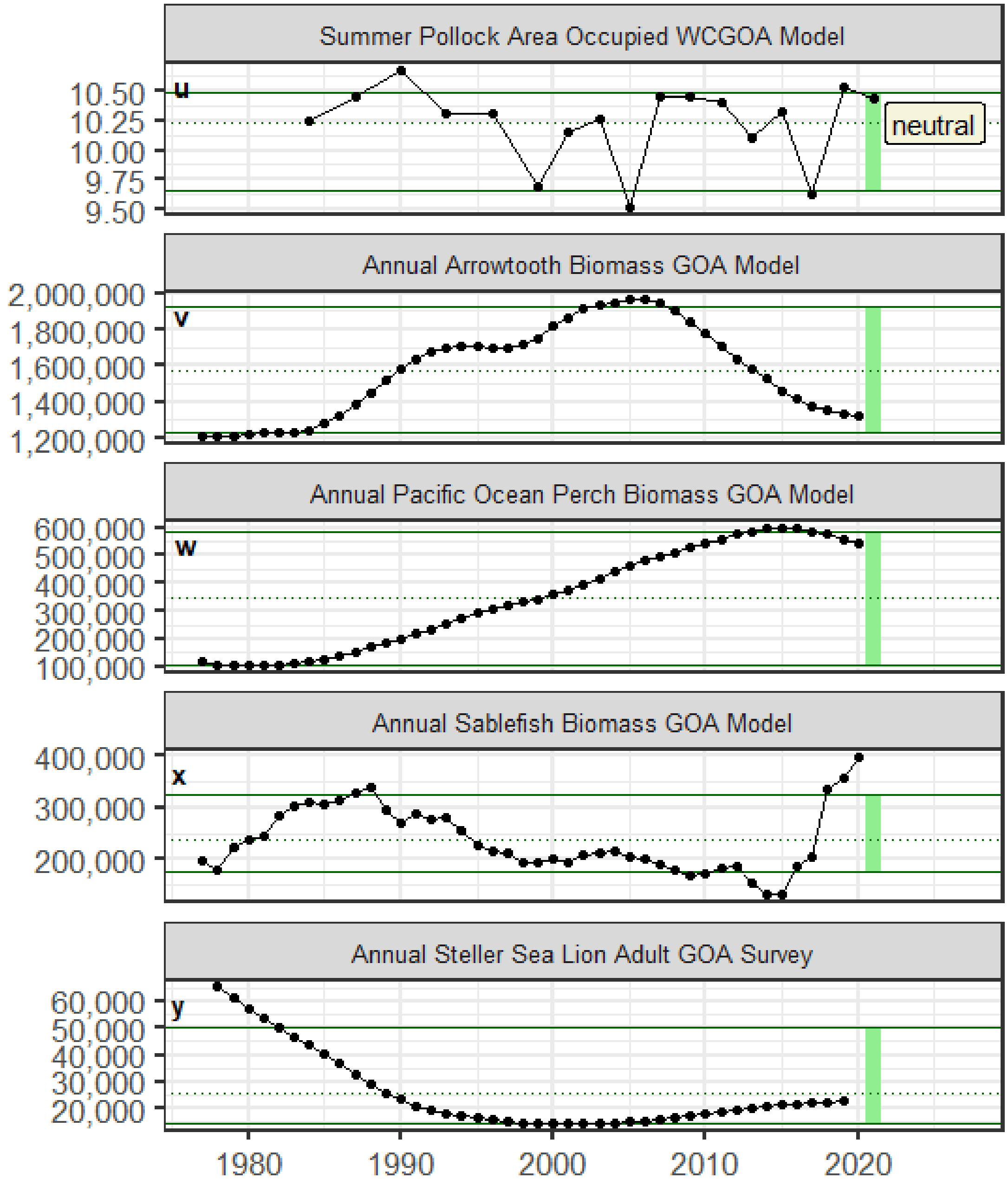


Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

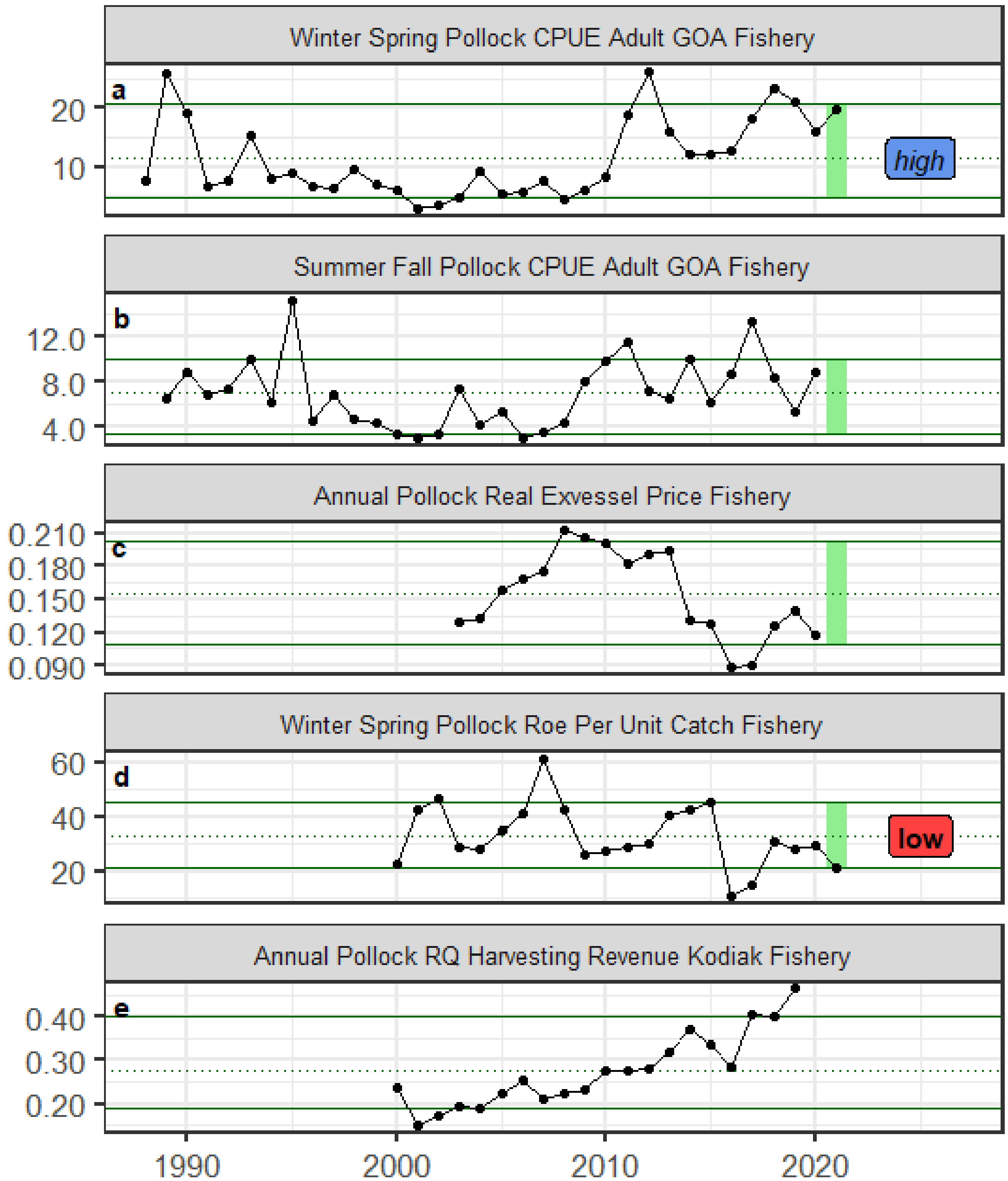


Figure 1A.2b. Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

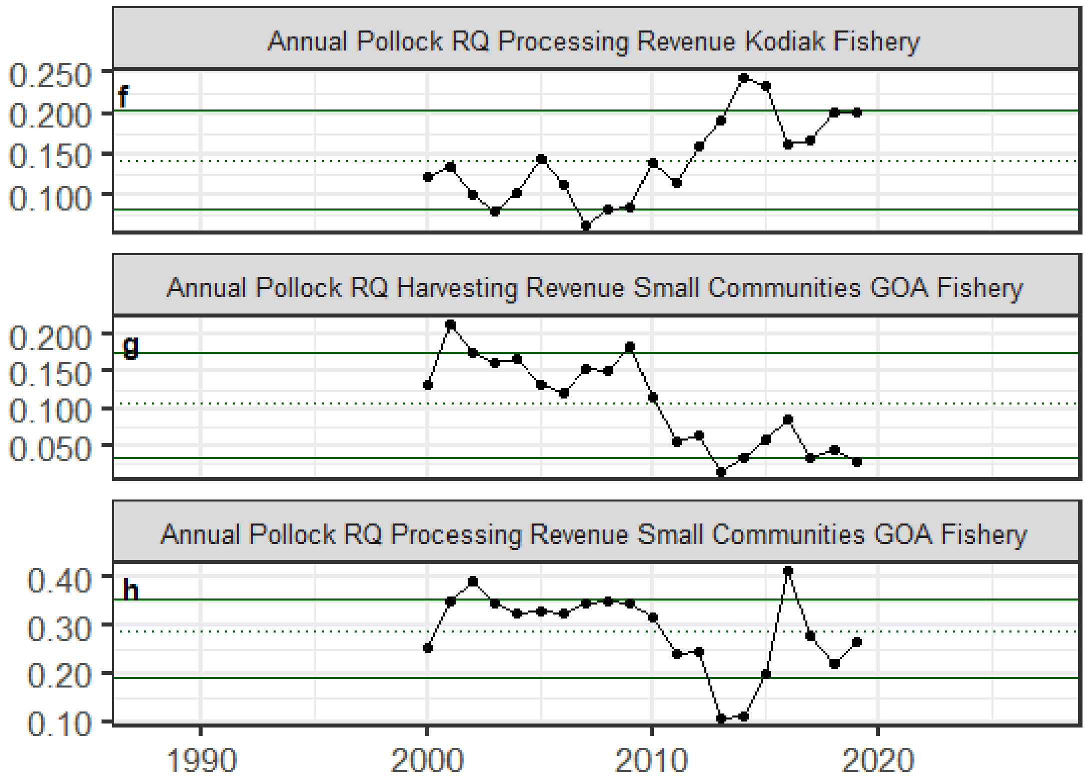


Figure 1A.2b (cont.). Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results. Text box follows the traffic light status table for the current year.

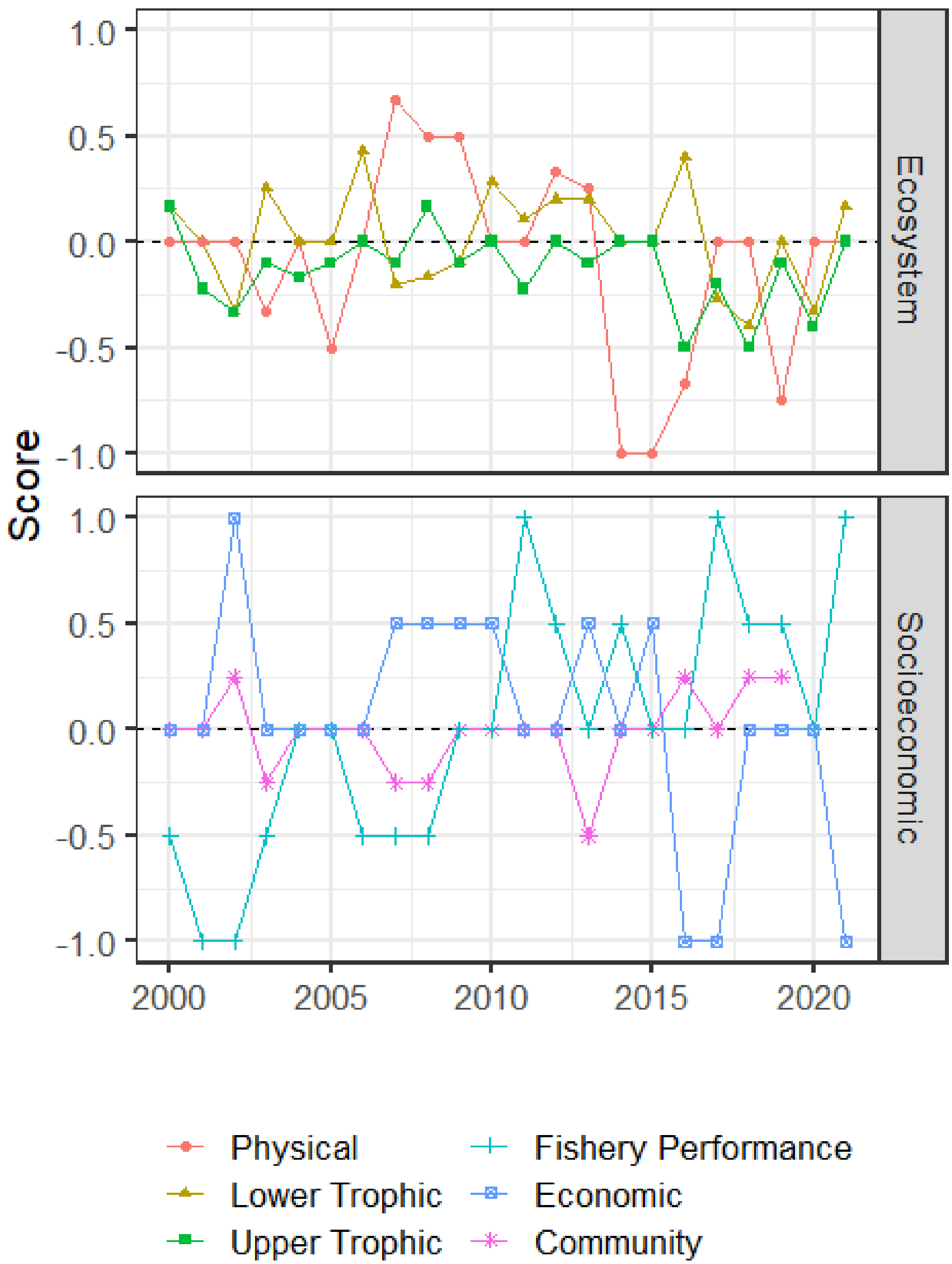


Figure 1A.3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present

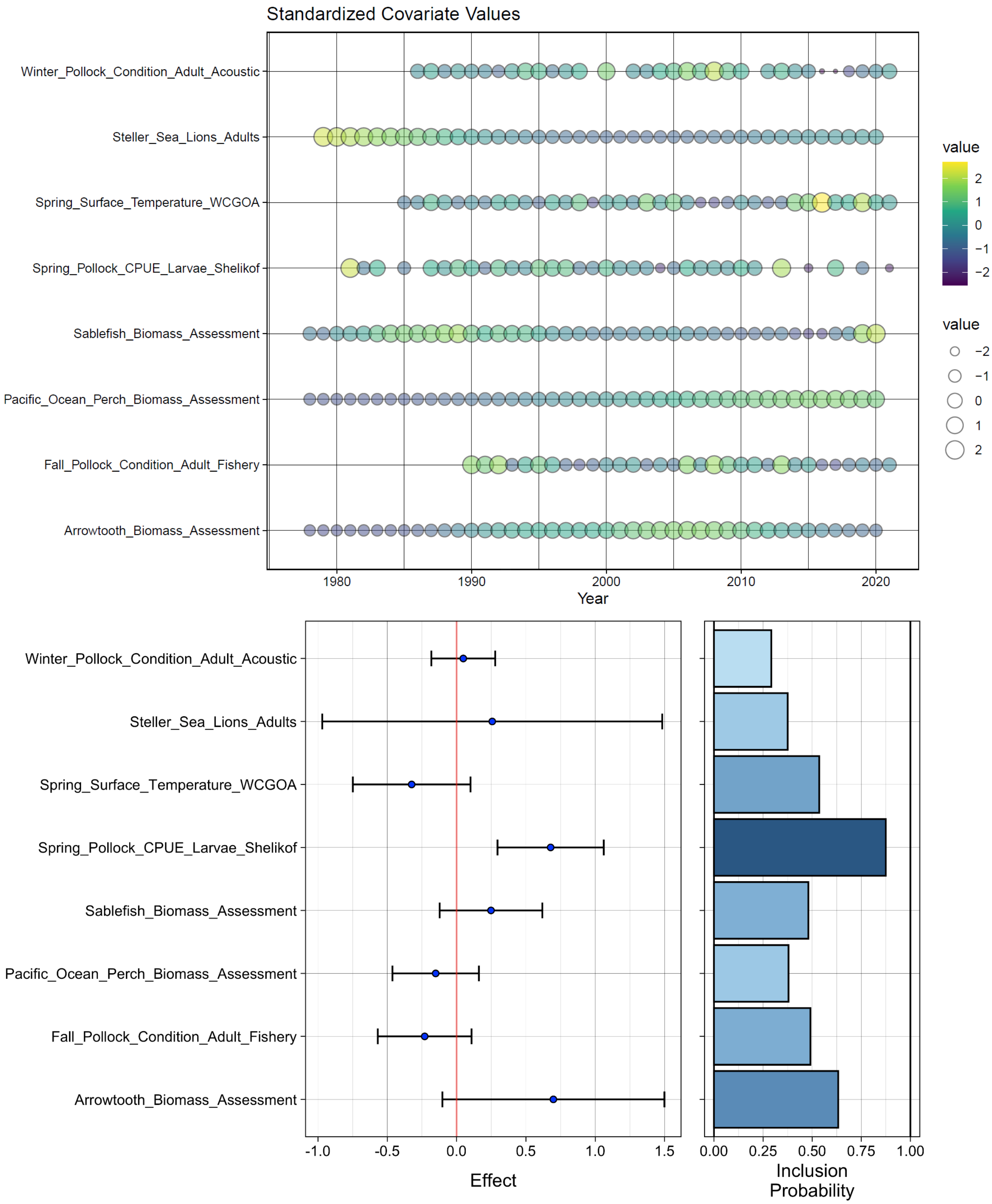


Figure 1A.4: Bayesian adaptive sampling output showing (top graph) standardized covariates and (bottom graph) the mean relationship and uncertainty (95% confidence intervals) with log GOA pollock recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.

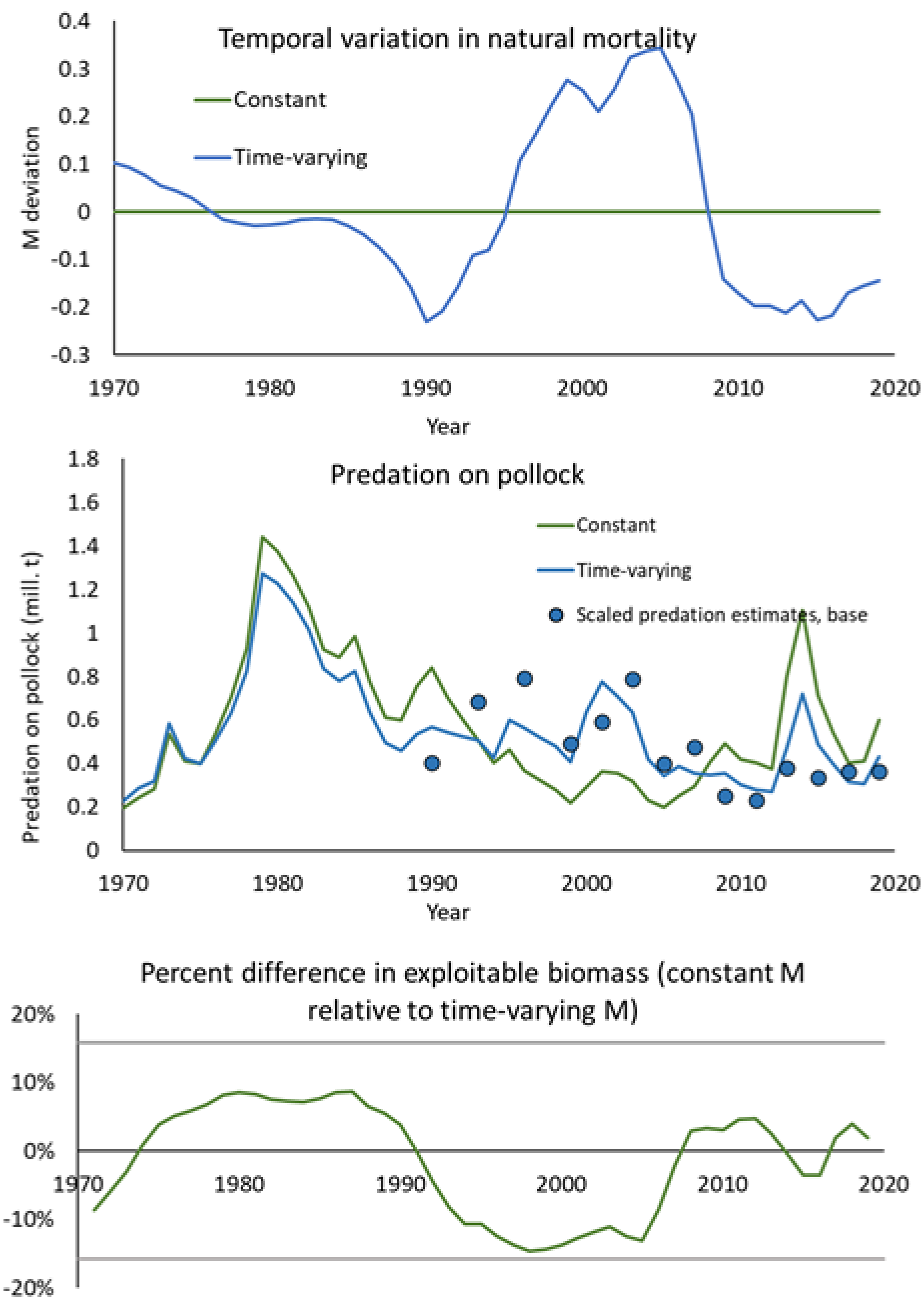


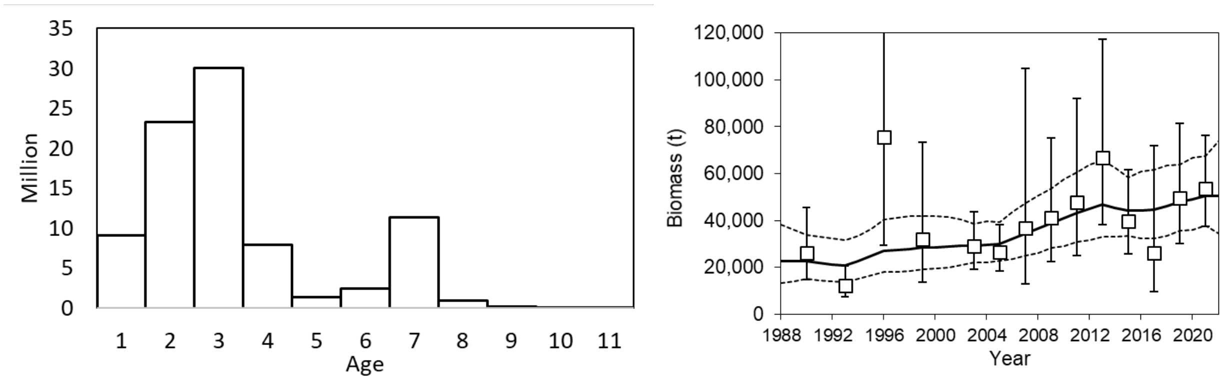
Figure 1A.5: Preliminary results from a research model for GOA pollock that included modeled time-varying predation mortality. Top panel is the estimated annual log-scale deviation in predation mortality, while the second panel shows model-estimated predation in biomass for models with and without predation and the scaled survey estimates of predation biomass that the model is attempting to fit. The third panel compares estimates of exploitable biomass for models with and without time-varying predation mortality. The upper and lower grey line represent the percent difference (15.8%) between F35% (the overfishing limit) and F40% (the ABC level).

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 age composition in the 2019 bottom trawl survey showed ages 1-4 were represented, plus a mode of age-7 fish (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 1990-2021 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 (50,500 t). **This results in a 2022 ABC of 11,363 t (50,500 t * 0.75 M), and a 2022 OFL of 15,150 t (50,500 t * M). The same ABC and OFL is recommended for 2023.**



Appendix figure 1B.1. Pollock age 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.

Recently NMFS approved the final rule for Amendment 109 to GOA Fishery Management Plan developed by the North Pacific Fisheries Management Council. Amendment 109 combines pollock fishery A and B seasons into a single season (redesignated as the A season), and the C and D seasons into a single season (redesignated as the B season), and changes the annual start date of the redesignated pollock B season from August 25 to September 1. The TAC is still allocated 50% to a pre-spawning season (new A season) and 50% to a late summer season (new B season). These changes will be implemented beginning in 2021 and affect the seasonal allocation only in the Central and Western GOA. Our approach to implementing this regulation change is to use the same methodology as was used previously to apportion the TAC into the A, B, C, and D seasons, and then to aggregate the A and B seasons allocation to form the allocation for the new A season, and similarly to aggregate the C and D season allocations into the new B season. This approach ensures that there is no net redistribution between management areas due to the new season structure.

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 125.41%, 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 1.84%, 92.56%, and 5.60% in areas 610, 620, and 630 (Appendix table 1D.1). In comparison to last year, the percentage in area 610 is 0.2 percentage points higher, 0.9 percentage points lower in area 620, and 0.7 percentage points higher in area 630.

A1-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 A1 season suggested that most of the fish captured in area 610 would eventually spawn in area 610. The resulting A1 season apportionment is: 610, 1.85%; 620, 77.50%; 630, 20.66%. Under the new season structure, 25% of the TAC allocated in this way, and 25% is allocated based on the winter survey-estimated distribution in the previous section to comprise the new A season allocation.

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 2021, 2019, and 2017 surveys gave the resulting apportionment is 610, 34.81%; 620, 26.12%; 630, 33.89%; 640, 5.18%.

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 (5.18%) 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.2.

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	2018	822,246	1,306,107	158.8%	0.0%	93.9%	6.1%
Shelikof	2019	695,832	1,219,160	175.2%	0.0%	97.1%	2.9%
Shelikof	2020	614,997	456,457	74.2%	0.0%	97.7%	2.3%
Shelikof	2021	757,993	526,974	69.5%	0.0%	96.6%	3.4%
Shelikof	Average			119.4%	0.0%	96.3%	3.7%
	Percent of total biomass				0.0%	115.1%	4.4%
Chirikof	2013	982,953	63,224	6.4%	0.0%	70.2%	29.8%
Chirikof	2015	1,445,130	12,705	0.9%	0.0%	26.3%	73.7%
Chirikof	2017	1,095,850	2,485	0.2%	0.0%	0.4%	99.6%
Chirikof	2019	695,832	9,907	1.4%	0.0%	36.4%	63.6%
Chirikof	Average			2.2%	0.0%	33.3%	66.7%
	Percent of total biomass				0.0%	0.7%	1.5%
Marmot	2017	1,095,850	13,129	1.2%	0.0%	0.0%	100.0%
Marmot	2018	822,246	12,905	1.6%	0.0%	0.0%	100.0%
Marmot	2019	695,832	5,407	0.8%	0.0%	0.0%	100.0%
Marmot	2021	757,993	7,401	1.0%	0.0%	0.0%	100.0%
Marmot	Average			1.1%	0.0%	0.0%	100.0%
	Percent of total biomass				0.0%	0.0%	1.1%
Shumagin	2016	1,374,860	20,392	1.5%	84.3%	15.7%	0.0%
Shumagin	2017	1,095,850	29,753	2.7%	95.0%	5.0%	0.0%
Shumagin	2018	822,246	7,777	0.9%	47.4%	52.6%	0.0%
Shumagin	2020	614,997	4,637	0.8%	96.9%	3.1%	0.0%
Shumagin	Average			1.5%	80.9%	19.1%	0.0%
	Percent of total biomass				1.2%	0.3%	0.0%
Sanak	2015	1,445,130	17,905	1.2%	100.0%	0.0%	0.0%
Sanak	2016	1,374,860	3,571	0.3%	100.0%	0.0%	0.0%
Sanak	2017	1,095,850	831	0.1%	100.0%	0.0%	0.0%
Sanak	2018	822,246		0.0%	100.0%	0.0%	0.0%
Sanak	Average			0.4%	100.0%	0.0%	0.0%
	Percent of total biomass				0.4%	0.0%	0.0%
Mozhovoi	2013	982,953	600	0.1%	100.0%	0.0%	0.0%
Mozhovoi	2016	1,374,860	11,459	0.8%	100.0%	0.0%	0.0%
Mozhovoi	2017	1,095,850	3,924	0.4%	100.0%	0.0%	0.0%
Mozhovoi	2018	822,246	3,759	0.5%	100.0%	0.0%	0.0%
Mozhovoi	Average			0.4%	100.0%	0.0%	0.0%
	Percent of total biomass				0.4%	0.0%	0.0%
Pavlof	2016	1,374,860	2,140	0.2%	100.0%	0.0%	0.0%
Pavlof	2017	1,095,850	2,092	0.2%	100.0%	0.0%	0.0%
Pavlof	2018	822,246	4,413	0.5%	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				125.41%	2.31%	116.08%	7.02%
Rescaled total				100.00%	1.84%	92.56%	5.60%

Appendix table 1D.2. Summer acoustic and NMFS bottom trawl biomass estimates of walleye pollock by management area. The weighted average for allocation gives weights of 1.0, 0.5, and 0.25 to 2021, 2019, and 2017, respectively.

Summer acoustic estimates

Biomass (t)

Year	*Area 610*	*Area 620*	*Area 630*	*Area 640*
2017	408,334	338,923	498,460	72,679
2019	119,502	201,711	207,058	43,204
2021	78,468	131,625	197,118	23,937

Percent

	Area 610	*Area 620*	*Area 630*	*Area 640*
2017	30.97%	25.71%	37.81%	5.51%
2019	20.91%	35.30%	36.23%	7.56%
2021	18.20%	30.53%	45.72%	5.55%

Bottom trawl estimates

Biomass (t)

Year	*Area 610*	*Area 620*	*Area 630*	*Area 640*
2017	214,605	23,658	43,803	6,878
2019	119,312	36,450	90,921	10,921
2021	252,827	113,737	108,813	19,367

Percent

	Area 610	*Area 620*	*Area 630*	*Area 640*
2017	74.27%	8.19%	15.16%	2.38%
2019	46.32%	14.15%	35.29%	4.24%
2021	51.10%	22.99%	21.99%	3.91%

Options for allocation

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

Area 610	*Area 620*	*Area 630*	*Area 640*
346,535	260,050	337,421	51,575
34.81%	26.12%	33.89%	5.18%

Appendix table 1D.3. Calculation of 2021 Seasonal and Area TAC Allowances for the W/C/WYK region.

Proposed ABC for W/C/WYK (t):			133,081

Winter biomass distribution			
Area	610	620	630
Percent	1.84%	92.56%	5.60%

Summer biomass distribution				
Area	610	620	630	640
Percent	34.81%	26.12%	33.89%	5.18%

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

PWS percent	2.50%	GHL (t)	3,327
Federal percent	97.50%	Federal TAC	129,754

2) Use summer biomass distribution for the 640 allowance:

640 percent	5.18%	640 TAC (t)	6,722
610-630 percent	94.82%	610-630 TAC (	123,032

3) Calculate seasonal apportionments of TAC for the A1, A2, B1, and B2 seasons for areas 610-630

Season	Percent	TAC (t)
A1 season TAC (t)	25%	30,758
A2 season TAC (t)	25%	30,758
B1 season TAC (t)	25%	30,758
B2 season TAC (t)	25%	30,758

4) For the A1 season, the TAC allocation in 630 is based on an average of winter and summer distributions.

	A1 season	
Area	Percent	TAC (t)
610	1.84%	566
620	77.49%	23,834
630	20.67%	6,358

5) For the A2 season, the allocation of TAC is based on the winter biomass distribution.

	A2 season	
Area	Percent	TAC (t)
610	1.84%	566
620	92.56%	28,470
630	5.60%	1,722

6) For the B1 and B2 seasons, the allocation is based on the summer biomass distribution.

	B1 season			B2 season	
Area	Percent	TAC (t)	Area	Percent	TAC (t)
610	36.71%	11,291	610	36.71%	11,291
620	27.55%	8,473	620	27.55%	8,473
630	35.74%	10,994	630	35.74%	10,994

7) For the A and B seasons, add A1 plus A2, and B1 plus B2. Area 640 catch is not portioned by season.

	TAC (t)		Percent	
Area	Season A	Season B	Season A	Season B
610	1,132	22,582	0.9%	17.4%
620	52,304	16,946	40.3%	13.1%
630	8,080	21,988	6.2%	16.9%
640	6,722		5.2%	

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

	ADF&G	IPHC	NMFS
1982	0.07	0.00	0.00
1986	0.06	0.00	0.00
1988	0.00	0.00	0.11
1989	0.00	0.00	0.23
1990	0.00	0.00	0.49
1991	0.09	0.00	0.49
1992	0.16	0.00	0.67
1993	0.17	0.00	0.57
1994	0.00	0.00	0.29
1995	0.00	0.00	0.44
1996	0.00	0.00	0.23
1997	0.17	0.00	0.41
1998	1.23	0.00	0.24
1999	4.66	0.00	0.13
2000	5.63	0.00	0.12
2001	1.54	0.00	0.02
2002	2.66	0.00	0.10
2003	3.72	0.00	0.14
2004	4.67	0.00	0.08
2005	8.97	0.00	0.09
2006	2.42	0.00	0.31
2007	3.05	0.00	0.63
2008	2.29	0.00	0.80
2009	3.62	0.00	3.22
2010	103.10	0.77	52.43
2011	104.67	0.25	44.40
2012	134.31	0.07	13.14
2013	91.70	0.55	2337.70
2014	75.32	0.62	2389.87
2015	35.39	0.40	62.94
2016	15.62	0.03	0.16
2017	30.45	0.06	105.97
2018	42.21	0.06	19.66
2019	31.41	0.06	76.14
2020	36.51	0.07	26.42