1. Assessment of the Walleye Pollock Stock in the Gulf of Alaska

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Executive Summary

Summary of Changes in Assessment Inputs

Changes to input data

1. Fishery: 2021 total catch and catch at age.
2. Shelikof Strait acoustic survey: 2022 biomass index and age composition.
3. NMFS bottom trawl survey: 2021 age compositions
4. Summer acoustic survey: 2021 age compositions
5. ADF&G crab/groundfish trawl survey: 2022 biomass index

Changes in assessment methodology

Two minor changes were made to the model. First, a penalty of 1.3 was added to recruitment deviations in all years. Previously the penalty of 1.0 was applied only to early and late deviations. Second, selectivity of the summer acoustic survey was estimated. Previously this was assumed 1.0 for all ages. Together these changes constitute model 19.1a.

Summary of Results

The base model projection of female spawning biomass in 2022 is 204,554 t, which is 43.61% of unfished spawning biomass (based on average post-1977 recruitment) and above B40% (188,000 t), thereby placing GOA pollock in sub-tier “a” of Tier 3. New surveys in 2022 include the winter Shelikof Strait acoustic survey and the ADF&G bottom trawl survey. These surveys showed similar trends in 2021 and 2022, unlike previous years when they showed strongly contrasting trends. The risk matrix table recommended by the Scientific and Statistical Comittee (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 recommended 2023 ABC for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 148,937 t, which is an increase of 11.9% from the 2022 ABC. The recommended 2024 ABC is 161,080 t. The OFL in 2023 is 173,470 t, and the OFL in 2024 if the ABC is taken in 2023 is 186,101 t. These calculations are based on a projected 2022 catch of 129,754 t. The estimated scale of the stock increased about 20% compared to previous years, driven both by new data and model changes.

For pollock in southeast Alaska (Southeast Outside region, east of 140° W lon.), the ABC recommendation for both 2023 and 2024 is 11,363 t (see Appendix 1B) and the OFL recommendation for both 2023 and 2024 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. There is no new index this year so this is a partial Tier 5 assessment update.

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

Quantity/Status	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023*	2024*
M (natural mortality)	0.300	0.300	0.300	0.300
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	848,878	1,205,850	1,281,980	889,889
Projected female spawning biomass (t)	186,481	167,840	204,554	188,277
$B_{100\%}$	430,000	430,000	469,000	469,000
$B_{40\%}$	172,000	172,000	188,000	188,000
$B_{35\%}$	150,000	150,000	164,000	164,000
F_{OFL}	0.311	0.301	0.304	0.302
$maxF_{ABC}$	0.263	0.256	0.257	0.257
F_{ABC}	0.263	0.256	0.257	0.257
OFL (t)	154,983	153,097	173,470	186,101
*max*ABC (t)	133,081	131,912	148,937	161,080
ABC (t)	133,081	131,912	148,937	161,080
Status	As determined *last* year for: 2021	2022	As determined *this* year for: 2022	2023
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on an estimated catch of 129,754 t for 2022 and the max ABC for 2023 and 2024.

Status Summary for Gulf of Alaska Pollock in the Southeast Outside Area

Quantity/Status	As estimated or *specified last* year for: 2022	2023	As estimated or *recommended this* year for: 2023	2024
M (natural mortality)	0.30	0.30	0.30	0.30
Tier	5	5	5	5
Biomass (t)	50,500	50,500	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)	15,150	15,150	15,150	15,150
*max*ABC (t)	11,363	11,363	11,363	11,363
ABC (t)	11,363	11,363	11,363	11,363
Status	As determined *last* year for: 2021	2022	As determined *this* year for: 2022	2023
Overfishing	No	n/a	No	n/a

Area Allocation of Harvest

The following table shows the recommended ABC apportionment for 2023 and 2024. Please refer to Appendix 1D for information regarding how apportionment is calculated. Area 640 is not portioned by season.

Year	Area	Season A ABC (t)	Season B ABC (t)
2023	610	1,685	25,272
	620	58,039	18,965
	630	9,121	24,608
	640	7,523	
2024	610	1,823	27,333
	620	62,771	20,511
	630	9,864	26,614
	640	8,136	

Responses to SSC and Plan Team Comments on Assessments in General

From the November 2021 GOA Plan Team minutes: *The Team recommends all GOA authors evaluate any bottom trawl survey information used in their assessment prior to 1990 including the 1984 and 1987 surveys and conduct sensitivity analyses to evaluate their usefulness to the assessment. This may apply for Aleutian Islands surveys but this was only raised during GOA assessment considerations.*

NMFS bottom trawl data before 1990 are not used in this assessment, as described in the data section below.

From the December 2021 SSC minutes: *With respect to Risk Tables, the SSC would like to highlight that "risk" is the risk of the ABC exceeding the true (but unknown) OFL, as noted in the October 2021 SSC Risk Table workshop report. Therefore, for all stocks with a risk table, assessment authors should evaluate the risk of the ABC exceeding the true (but unknown) OFL and whether a reduction from maximum ABC is warranted, even if past TACs or exploitation rates are low.*

This will be done.

The SSC recommends that groundfish, crab and scallop assessment authors do not change recommendations in documents between the Plan Team and the SSC meetings, because it makes it more difficult to understand the context of the Plan Team's rationale and seems counter to the public process without seeing a revision history of the document.

This will not be done.

Responses to SSC and Plan Team Comments Specific to this Assessment

Detailed analyses to SSC and Plan Team comments were presented at the September PT meeting, including a publically available document to which the interested reader is referred (link to pdf).

Brief summaries of responses are provided here.

In December 2021 the SSC noted "… *that recruitment deviations in the GOA pollock assessment are unconstrained except for the terminal two years, and suggests that exploring a moderate constraint on recruitment deviations in all years, as is commonly applied in other assessments, may be warranted. At a minimum, this would allow an assessment of the sensitivity of results to only constraining the last two years."*

Previous model versions applied a penalty of $\sigma_R = 1$ to the first eight and last two cohorts, with all other deviations being freely estimated. Historically this setup had no estimation issues, but there are some advantages to a consistent approach and so this approach was adopted. A value of $\sigma_R = 1.3$ was adopted, based on an estimate from a state-space version of the assessment, and applied to all deviates.

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.

Analyses performed in 2021 were extended to include an offset for age-4 fish, which did improve the fits to the data but had minimal impact on the assessment outputs. This showed that the persistent residuals were not adversely affecting management estimates, and that it is unlikely any parametric form would alleviate this issue. Consequently, no changes were made to this years model, but future analyses using non-parametric selectivity would be warranted.

Persistent patterns in Pearson residuals for older fish were also deemed not a concern at the moment. This is because a new way of calculating residuals using a "one step ahead" approach to account for correlations in the multinomial distribution (Trijoulet *et al.* 2023) did not show the same pattern, implying it was a consequence of the inadequateness of Pearson residuals and not a real misspecification of selectivity. These new residuals will be explored in the coming year.

In December 2021 the "*SSC suggests simplifying the computations in the Appendix to reflect the new season structure to the extent possible, without changing the underlying methodology. For example, it appears that seasons B1 & B2 (formerly C & D) could be combined as they use the same apportionment scheme."*

The apportionment table was simplified by combining the A1 and A2 tables (steps 5 and 6) together, and simplifying other steps. Note that this new structure was not supposed to change apportionment, and that motivates the current table which calculates by the previous four seasons and then sums them together into the new seasons.

…the SSC encourages the authors and GOA GPT to re-evaluate whether assessing Southeast Alaska walleye pollock as a separate stock is justified or whether the available data support a single, gulf-wide stock assessment. This evaluation may also benefit from considering recent studies on the genetic structure of walleye pollock across Alaska and the North Pacific

A genetic analysis using low-coverage whole genome sequencing was recently conducted, on which analysis is ongoing. This analysis included 617 walleye pollock from Japan, Bering Sea, Chukchi Sea, Aleutian Islands, Alaska Peninsula, and Gulf of Alaska. Results suggests there is 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). Samples from the eastern Gulf of Alaska are currently undergoing sequencing to determine whether eastern Gulf of Alaska pollock are genetically distinct from those in the western Gulf of Alaska. 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).

In December 2021 the SSC highlighted the need to examine how catchability for the winter Shelikof acoustic survey.

The SSC supports future research to identify the optimal level of constraint on among-year variation in Shelikof Survey catchability (q), including the potential to estimate the process error variance internally within the assessment model.

The SSC reiterates its recommendation from December 2020 to explore the use of covariates related to the timing of the survey to inform survey catchability in the Shelikof Strait survey. For example, the difference in timing between peak spawning and mean survey date or, alternatively, the proportion of mature fish in the survey, are likely to inform time-varying catchability in the survey.

Currently the winter Shelikof acoustic survey catchability is modeled as a random walk with assumed process error. The original logic was that some of the stock spawned outside of Shelikof Strait and thus were unavailable to the survey. Fish tended to spawn in other areas with some consistency, so a random walk on catchability was implemented to account for variation in spatial availability. Several overlapping efforts were done to explore alternative catchability structures. None of these are proposed for 2022, but were presented for Plan Team feedback in September 2022 and remains ongoing collaborative research for this stock. In particular a WHAM version of the GOA pollock assessment was used to explore estimating the constrait (process error), and to quantify the amount by which timing covariates can reduce that, in effect parsing spatial and temporal availability. Preliminary results are very promising and we anticipate having something formal to present in 2023.

Introduction

Biology and Distribution

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).

Stock Structure

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; Fig. 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.

Description of the Directed Fishery

Catch Patterns

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. 1.3). 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.

Bycatch and Discards

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 2021, 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 2017-2021 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 10,595 in 2021.

Management Measures

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 were implemented beginning in 2021 and affect the seasonal allocation only in the Central and Western GOA.

Data

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 (Figure 1.4). Binned length composition data are used in the model only when age composition estimates are unavailable. The following table specifies the data that were used in the GOA pollock assessment:

Source	Data	Years
Fishery	Total catch	1970-2022
Fishery	Age composition	1970-2021
Shelikof Strait acoustic survey	Biomass	1992-2022
Shelikof Strait acoustic survey	Age composition	1992-2022
Summer acoustic survey	Biomass	2013-2021, biennially
Summer acoustic survey	Age composition	2013-2021, biennially
NMFS bottom trawl survey	Area-swept biomass	1990-2021, biennially
NMFS bottom trawl survey	Age composition	1990-2021, biennially
ADF&G trawl survey	Delta-GLM index	1988-2022
ADF&G trawl survey	Age composition	2000-2020, biennially

Fishery

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.

Age and Size 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 then 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 2021 fishery were stratified by half-year seasons and statistical area as follows:

Time strata	Type	Shumagin-610	Chirikof-620	Kodiak-630	W. Yakutat and PWS-640 and 649
1st half (A and B seasons)	No. ages	18	397	275	119
	No. lengths	151	4,214	1,092	356
	Catch (t)	207	40,820	6,166	7,176
2nd half (C and D seasons)	No. ages	381	387	335	0
	No. lengths	3,579	1,596	1,999	0
	Catch (t)	17,808	11,609	17,265	107

The estimated age composition in 2021 in all areas and all seasons was notable because it was not dominated by age-9 fish (2012 year class) for the first time in many years (except last year), particularly for the B season (Fig. 1.2). Instead, the age-4 fish had the largest percentage with 38%, age-3 (2018 cohort) with 23%, and the age-9 fish only accounting for 17%. Younger fish are likely to become increasingly prominent in the catch-at-age as the 2012 year class begins to age out of the population. Fishery catch at age in 1975-2021 is presented in Table 1.5 (See also Fig. 1.5). 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 (Tables 1.7 and 1.8). 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 (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.

Biomass Estimates

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 the 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. 1.6). 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.

Age Composition

Estimates of numbers at age from the bottom trawl survey are obtained from random otolith samples and length frequency samples (Table 1.8). 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 new 2021 combined Shumagin, Chirikof and Kodiak age composition is used in the assessment model (Fig. 1.7, Table 1.9), and the 2021 length compositions were removed. Age-1 pollock (2020 cohort) were strongly present in the Chirikof, Kodiak, and Yakutat statistical areas, but much less abundant in the Shumagin and Southeast Alaska areas (Fig. 1.8).

Shelikof Strait Acoustic Survey

Winter acoustic surveys to assess the biomass of pre-spawning aggregations of pollock in Shelikof Strait have been conducted annually since 1981 (except 1982, 1987, 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 2022 are presented in a NMFS processed report (McGowan *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.

Biomass Estimates

The 2022 biomass estimate for Shelikof Strait in 2022 for all fish is 365,411 t, which is a 30.7% percent decrease from the 2021 estimate (Fig. 1.9). 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 the 2018 assessment. Originally, winter 2022 pre-spawning pollock surveys were also planned in the Shumagin Islands area, Chirikof shelf break, Marmot Bay, and Morzhovoi Bay. Due to travel, vessel, and staffing constraints stemming from protocols required to mitigate the COVID-19 pandemic, only Shelikof was completed in 2022.

Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.10) 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 in Table 1.11. Estimates of age composition in Shelikof Strait in 2022 indicate reduced dominance of the 2012 year class, and a mode of age 2 and 4-5 fish (2020, 2018 and 2017 year classes), indicating new year classes are starting to comprise the majority of the spawning and exploitable portion of the population.

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. These immature fish are not the main target of the pre-spawning survey, but age-1 and age-2 pollock are highly variable and occasionally are very abundant in winter acoustic surveys. 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 the following year. The 2018 cohort comprised 15% of the age composition in 2021 (excluding age 1 and 2 fish), but 29% as 4 year olds in 2022, giving contradictory 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. This point is addressed further in the risk table below.

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. A new approach was developed in 2022 and shows great promise, but was not put forward this year for consideration. Summaries of the work were presented to the Plan Team and further details can be found under the "Models under development" section of this document.

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.* in review, 2014, 2017, 2019; 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 available in 2022 and showed strong 2017, 2018, and 2020 year classes. Analysis of the 2019 and 2021 surveys 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 (Jones *et al.* 2019).

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 9-137 m, median of 60 m in 2022; 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 353. On average, about 87% of these tows contained pollock. Details of the ADF&G trawl gear and sampling procedures are in Spalinger (2012).

The 2022 area-swept biomass estimate for pollock for the ADF&G crab/groundfish survey was 71,196 t, an increase of 9.2% from the 2021 biomass estimate (Table 1.7). The 2022 pollock estimate for this survey is approximately 78% of the long-term average.

Biomass Estimates

A simple delta GLM model was applied to the ADF&G tow by tow data for 1988-2022 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 previously, 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 0.17. 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.

Age Compositions

Ages were determined by age readers in the AFSC age and growth unit from samples of pollock otoliths collected during 2000- 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 also 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. 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 has slowly increased up to 47% in 2022. 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. With large incoming cohorts and the decline of the 2012 cohort, the mean age has begun to decrease again. Under a constant F40% 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, H', defined as

$$H' = -\sum_{a} p_a \ln p_a$$

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 2021 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.

Analytical approach

General Model Structure

An age-structured model covering the period from 1970 to 2022 (53 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 and penalities, 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 (1970-2022)	Log-normal	CV = 0.05, 2022 catch is projected
Fishery age comp. (1975-2021)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2022)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2022)	Multinomial	Initial sample size = 60
Shelikof acoustic survey age-1 and age-2 indices (1994-2022)	Log-normal	Tuned CVs = 0.45 and 0.55
Summer acoustic survey biomass (2013-2021)	Log-normal	CV = 0.25
Summer acoustic survey age comp. (2013-2021)	Multinomial	Initial sample size = 10
NMFS bottom trawl survey biom. (1990-2021)	Log-normal	Survey-specific CV from random-stratified design = 0.12-0.38
NMFS bottom trawl survey age comp. (1990-2021)	Multinomial	Initial sample size = 60
ADF&G trawl survey index (1989-2022)	Log-normal	Survey-specific CV from delta GLM model rescaled so mean is 0.25=0.20-0.35
ADF&G survey age comp. (2000-2020)	Multinomial	Initial sample size = 30
Recruit process error (1970-2022)	Log-normal	Penalty of 1.3 (updated in 2022 model 19.1a)

Recruitment

Age composition in the first year is estimated with a single log deviation for recruitment abundance, which was then decremented by natural mortality to fill out the initial age vector. In previous versions of the model, a recruitment penalty of ($\sigma_R = 1.0$) was added only to recruitments for 1970-77, and in the last two years of the model and the rest were were estimated as free parameters. Starting in 2022 with model 19.1a the penalty was applied to all deviations, with a value of $\sigma_R = 1.3$ coming from an estimate of the state-space version of the model. This change had relatively small impact on the estimated recruits and management references.

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 (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 age compositions 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 1975; 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 Kirk (2010, 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

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

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

Lorenzen (1996): Age-specific M for ocean ecosystems is given by

$$M(a) = \bar{W_a}^{-0.305}$$

where $\bar{W_a}$ 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 372 (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 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 was 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 low-density regions 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 were 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 2022 from winter acoustic surveys using the new method are higher for younger fish, but lower for older fish, compared to 2021 and the long-term mean for all ages (Fig. 1.19 and 1.20). 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. 1.21). 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 2022 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, $W = aL^b$, 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 Tables 1.16, 1.17, and 1.18. Data from the Shelikof Strait acoustic survey indicates that there has been a substantial change in weight at age for older pollock (Fig. 1.22). 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 rebound in the last couple of years, including 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 2022 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 1975-2021. 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 (1981-2022) and the NMFS bottom trawl survey (1984-2021) 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 2021 fishery weight at age with the data now available indicate that the model overestimated weights slightly (Fig. 1.23). In this assessment, RE model estimates of weight at age are used for the fishery in 2022 and for yield projections and harvest recommendations.

Appendix 1F details an exploratory and promising approach using a state-space model to estimate the WAA within the assessment model.

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 13.0), 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 *et al.* (1991) and developed into C++ class libraries. The optimizer in AD Model Builder is a quasi-Newton routine (Press *et al.* 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1 x 10-6) 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 1970-2022 = 53	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 1970-2022 = 53	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) = 104	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) = 104	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	8 (2 each for the Shelikof and summer acoustic surveys, and the NMFS and ADF&G BT surveys)	Slope parameters estimated on a log scale.
Total	120 estimated parameters + 208 process error parameters + 10 fixed parameters = 338	

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 1.24 shows the changes in estimated spawning biomass as the updated catch projections, catch at age, and surveys were added sequentially. Most additions to the model did not change the trend but did increase the scale a fairly small amount, but it was consistently in the same direction, adding up to a nearly 30% larger recent spawning stock. This is not typically the case, and this year both the additions of new data and the model updates increased the scale of spawning biomass (Fig. 1.25). This change is driven largely by changes in recruits estimated (Fig. 1.26). Notably the 2012 year class estimates were impacted by both, presumably with the new age data suggesting the cohort is still large and the new selectivity on survey 6 being lower for those older ages. The change in scale is not particularly surprising given the known sensitivity for this model (as explored more thoroughly in e.g., Monnahan *et al.* (2021)) and the Plan Team presentations in 2022 (link to pdf). The stock trend was stable across data additions and model changes.

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 19.1a 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, resulting in similar model results (Fig. 1.24).

Model evaluation

The fit of model 19.1a to age composition data was evaluated using plots of observed and predicted age composition and residual plots. Figure 1.27 shows the estimates of time-varying catchability for the Shelikof Strait acoustic survey and the ADF&G crab/groundfish survey, as well as the constant catchabilities for the other surveys. The catchability for the Shelikof Strait acoustic survey continued to decrease away from 1. Catchability for the NMFS bottom trawl and summer acoustic surveys were similar (0.81 and 0.76 respectively), while the age-1 and age-2 Shelikof survey catchabilities were 0.30 and 0.34, respectively, reflecting the fact that the survey does not target these immature ages. Plots show the fit to fishery age composition (Figs. 1.28, 1.29), Shelikof Strait acoustic survey age composition (Figs. 1.30,1.31), NMFS trawl survey age composition (Fig. 1.32), and ADF&G trawl survey age composition (Fig. 1.33). 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 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. But overall there were no major issues in fitting the age composition data.

In recent assessments there was apparent conflict and uncertainty in the data about the size of the 2018 cohort. The new age composition data for the 2021 fishery, NMFS bottom trawl and summer acoustic surveys, and 2022 Shelikof survey provide further information to shed further light on the fate of this cohort. The fit to the 2022 Shelikof survey age was again negative for age 4 fish, making it the second year in a row with a negative residual for the 2018 cohort. In contrast, the 2021 NMFS bottom trawl survey and fishery saw large proportions of this cohort and were fitted well. This disparity in the 2018 cohort is discussed more in the risk table section, but the model estimate for this cohort increased 10% from 2021 (Table 1.21).

Model fits to survey biomass estimates are reasonably good for all surveys except the period 2015-2019 (Fig. 1.34). 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. 1.35).

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 Figs. 1.36 and 1.37. Table 1.20 gives the estimated population numbers at age for the years 1970-2022. Table 1.21 gives the estimated time series of age 3+ population biomass, age-1 recruitment, status, and harvest rate (catch/3+ biomass) for 1977-2022 (see also Fig. 1.38). 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 113% of the proxy for unfished stock size (B100% = mean 1978- 2021 recruitment multiplied by the spawning biomass per recruit in the absence of fishing (SPR at F=0), see below for how this is calculated). In 2002, the stock dropped below B40% for the first time since the early

1980s, and reached a minimum in 2003 of 36% of unfished stock size. Over the years 2009-2013 stock size showed a strong upward trend, increasing from 46% to 86% of unfished stock size, but declined to 54% of unfished stock size in 2015. The spawning stock peaked in 2017 at 90% as the strong 2012 year class matured, and has declined subsequently to 52% in 2022. Figure 1.39 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 FMSY proxy of F35% .

Comparison of historical assessment results

A comparison of assessment results for the years 1999-2022 indicates the current estimated trend in spawning biomass for 1990-2022 is consistent with previous estimates (Fig. 1.40). 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. 1.41). Generally, the two models agree except for the age 1 recruits, where the 2021 model assumed average recruitment, but the 2022 has data from the Shelikof survey which showed a weak 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 1.42 shows a retrospective plot with data sequentially removed back to 2012. The range of errors in the estimates of spawning biomass (if the current assessment is accepted as truth) is -28% to 17%, but usually the errors are much smaller (median absolute error is 15%). 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 -0.081, which does not indicate a concern with retrospective bias.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 1.3 over 1978-2021) 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. 1.38). 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. 1.43). 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 2022 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 (Figure 1.38).

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 FSPR harvest rates were obtained using the life history characteristics of GOA pollock (Table 1.23). Spawning biomass reference levels were based on mean 1978-2021 age-1 recruitment (6.139 billion), which is 8.5% higher 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- 2022) was used with mean spawning weight at age from the Shelikof Strait acoustic surveys in 2017-2022 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. 1.22). 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. FSPR 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 2018-2022 to reflect current selectivity patterns. GOA pollock FSPR harvest rates are given below:

FSPR rate	Fishing mortality	Avg. Recr. (Million)	Total 3+ biomass (kt)	SSB (kt)	Catch (kt)	Harvest fraction
100%	0	6,140	1,964	467	0	0.0%
40%	0	6,140	1,178	187	189	16.0%
35%	0	6,140	1,108	164	206	18.6%

2022 acceptable biological catch

The definitions of OFL and maximum permissible FABC 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 FABC harvest rate (i.e., FABC/FOFL) is 84.5% of the OFL harvest rate. Projections for 2023 for the FOFL and the maximum permissible FABC are given in Table 1.25.

Should the ABC be reduced below the maximum permissible ABC?

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. 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:

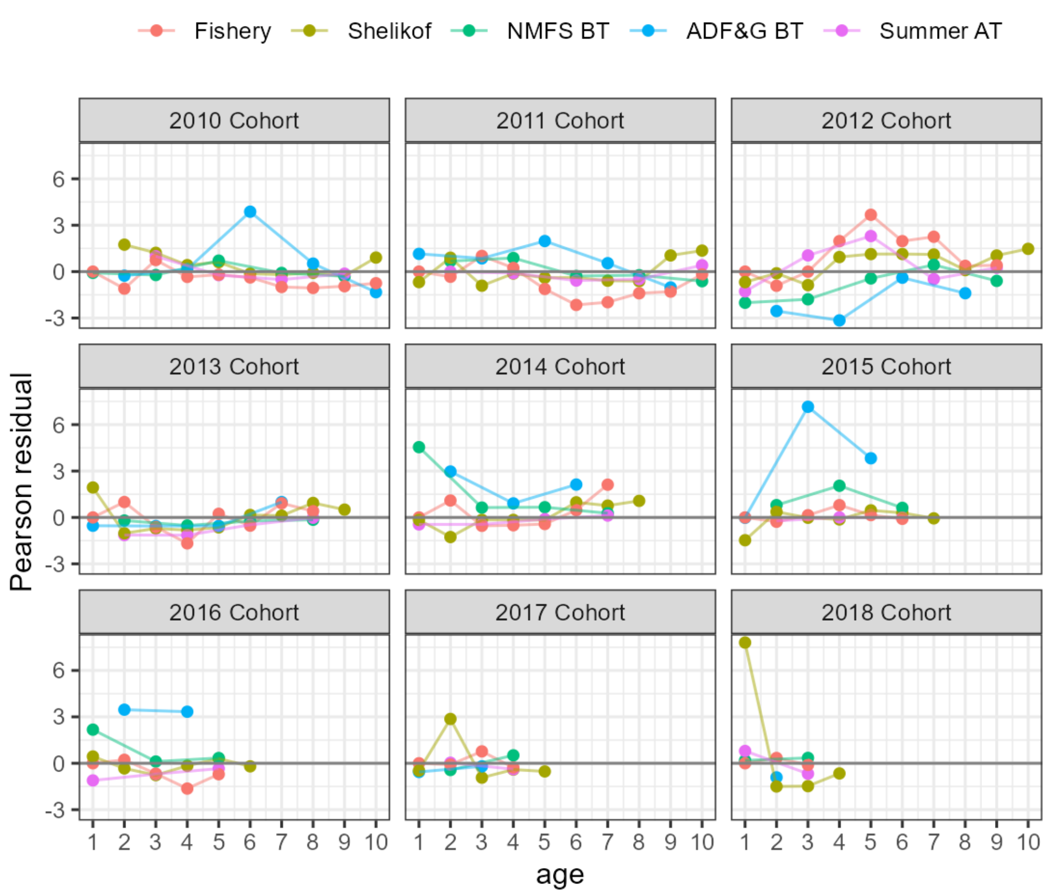
1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, 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.

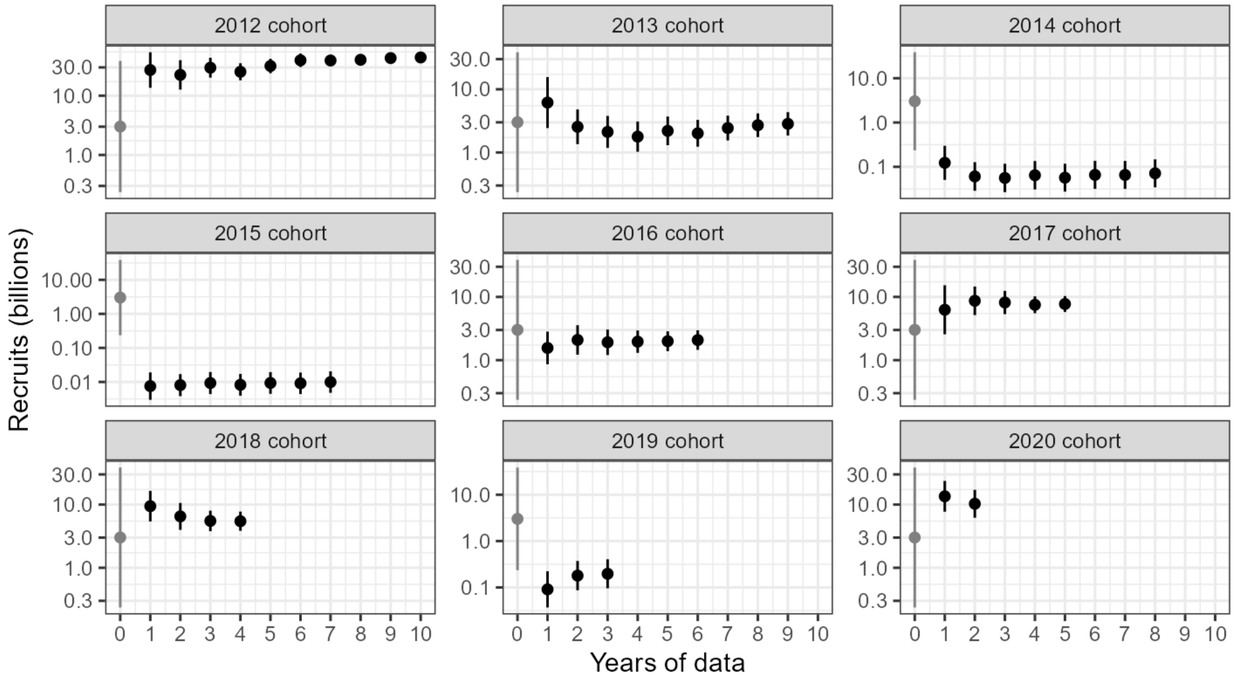
<u>Assessment considerations</u>

A continuing assessment issue is the conflicting size of the 2018 year class abundance between the sources of information. The winter pre-spawning Shelikof acoustic survey 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 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. In 2021, both the 2020 age 2 ADF&G and 2021 age 3 Shelikof survey observed proportions were low relative to the model expectation, 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, and there are some apparent age-3 fish in the 2021 length compositions from the summer surveys.

This year brings important new data sets to the table, which help to resolve this uncertainty. Shelikof age compositions provide information on the 2018 cohort as age-4s, while the 2021 fishery, NMFS bottom trawl and summer acoustic surveys provide information age-3s. By plotting Pearson residuals by cohort, it is immediately clear that the Shelikof survey is the main source of information suggesting a small cohort (i.e., negative residuals), while the other surveys and fishery generally suggest a larger cohort.



The estimated size of the cohort changed little between the 2021 and 2022 models, suggesting that the estimate likely has settled down at 5.45 billion (CV=18%). This cohort does not appear unusual compared to other recent cohort estimates as data are added.



In summary, the 2018 cohort is slightly larger than average, and the initial Shelikof estimate for age-1s was anomalously high, while all subseqeunt years were low. The other surveys and fishery appear to be in line with this estimate, building a consensus of the result. The one notable exception is the the 2020 ADF&G estimate which also had a large negative age-2 residual. Since this survey targets larger, older fish it is not compelling evidence, but it will be interesting to see how the age-4 residual turns out in the 2023 assessment when those data are available. The implication is that the 2018 cohort availability to the Shelikof survey has been low for the last three years after an anomolously high age-1 estimate. It is not apparent why this would be, and appears to have no historical precedent. The cohort maybe have been distributed in a different area as immature age 2-3 fish, with the cohort's availability to the Shelikof survey increasing as a larger proportion of the cohort reaches maturity, but since surveys for other winter spawning areas have been limited in recent years this can only be speculated. Future surveys of other spawning areas could prove valuable to help resolve this mystery. It could also be a statistical cooincidence.

Despite the unusual characteristics of this cohort there are no assessment model concerns, as cohort size is estimated consistently and other data sources are in agreement and the model fits them well. We thus gave assessment considerations a score of 1 — no increased concerns.

<u>Population dynamics considerations</u>

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. However, this year class is no longer the predominant one in the fishery and two large ones (2017 and 2018) have already entered the fishery, with another large one in 2020 to enter in the coming years (Figs. 1.5 and 1.38), resulting in a return to normal age diversity since 2020. 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 and Zador (2022)). The text below summarizes ecosystem information related to GOA pollock provided from both the ESP and GOA ESR.

Environmental Processes: The 2022 and predicted 2023 ocean temperatures are all within known optimal ranges for pollock life history stages (spawning 150-300m: 1-7°C, egg 0-200m, 5-6°C, larva surface 3-7°C, as referenced in the ESP). It is reasonable to expect that the 2022 and predicted 2023 average ocean temperatures will provide good spawning habitat, but warmer fall surface temperatures may negatively impact growth to a size that promotes over-winter survival for this year's age class. Spring surface temperatures over the western and central GOA were slightly above average (Appendix 1A: Spring Temperature Surface WCGOA Satellite indicator by M. Callahan). Western GOA surface temperatures were cooler than average in the winter (Satellite, Lemagie and Callahan (2022)), transitioned from cool to above average in spring (Satellite, Lemagie and Callahan (2022), 5.7°C Seward Line, Danielson and Hopcroft (2022)), above average in summer (12.3°C Seward Line, Danielson and Hopcroft (2022) and Satellite, Lemagie and Callahan (2022)) and fall (Satellite, Lemagie and Callahan (2022)). To-date, the western GOA is experiencing the 3rd consecutive non-marine heatwave year, with one short-term heatwave event in July (Satellite, Lemagie and Callahan (2022)); however, the central GOA experienced average heatwave events this year which is an increase from last year (Appendix 1A: Annual Heatwave GOA Model indicator by S. Barbeaux). Spring winds from the northeast in Shelikof Strait (downwelling favorable, flowing south through Shelikof Strait) were downwelling favorable, contributing to retention of 2022 larvae and potential for a stronger age-1 year class in 2023, similar to conditions in 2021, 2020, and 2012 (Appendix 1A: Spring Wind Direction Kodiak Buoy by L. Rogers). Over the western and central GOA, spring chlolorphyll *a* concentration increased to slightly below average while the peak was slightly earlier than last year by still later than average (Appendix 1A: Spring Chlorophylla Biomass and Peak WCGOA Satellite by M. Callahan). For the western GOA, spring primary productivity varied spatially from below to above average chlorophyll a concentrations, with slightly later than average spring bloom timing (Satellite, Gann *et al.* (2022)). Elevated spring productivity was observed along the Seward Line (CGOA), in terms of a high phytoplankton size index, inferring increased energy transfer from the base of the food web (Strom 2022). Upcoming 2023 winter and spring surface temperatures are predicted to be cooler than average, in alignment with La Nina conditions and a negative Pacific Decadal Oscillation.

Prey: Planktivorous foraging conditions were potentially above average across the GOA in 2022 with limited data in western GOA. Moderate and regionally variable across the GOA in 2021. The biomass of large calanoid copepods was average to above average at the eastern edge of western GOA (Seward Line, Hopcroft (2022)). Small and large calanoid copepods increased to above average, while euphausiid biomass decreased to approximately average in eastern GOA inside waters (AFSC SECM Survey, Icy Strait, Fergusson 2022). Planktivorous seabird reproductive success, an indicator of zooplankton availability and nutritional quality, was below average just south of Kodiak (Chowiet Island), and above average in central GOA (Middleton Island on shelf edge off Seward) and eastern GOA (St. Lazaria Island near Sitka; Drummond and Renner (2022); Hatch 2022, Appendix 1A: Annual Auklet Reproductive Success Chowiet Survey indicator by S. Zador). Catch-per-unit-effort of age-0 pollock decreased to just above average in the nearshore beach seine survey around Kodiak and along the Alaska Peninsula suggesting less productive feeding conditions in the nearshore.

Predators and Competitors: Predation pressure from key groundfish species (arrowtooth flounder, Pacific cod, Pacific halibut, and potentially sablefish) is expected to be moderate. Pacific cod and halibut biomass have remained relatively low, arrowtooth flounder assessment shows slight decline in 2022, (and a slight increase in 2022 ADF&G survey). The sablefish assessment shows a slight decline and the large 2016 age class of sablefish will have moved to adult slope habitat with little overlap with pollock, however a larger 2019 year class of sablefish may bring increased predation pressure (Appendix 1A: Annual Sablefish Biomass GOA Model by K. Shotwell). Western GOA Steller sea lions slightly increased but remain lower than previous biomass peaks (Appendix 1A: Annual Steller Sea Lion Adult GOA Survey by K. Sweeney). Cannibalism is less prevalent in the GOA as in other Alaskan waters. Potential competitors are a large year class of juvenile sablefish (2019) as well as other potential strong sablefish year classes, and a relatively large population of Pacific Ocean perch (Appendix 1A: Annual Sablefish and Pacific Ocean Perch Biomass GOA Model by K. Shotwell). Pink salmon contributed lower competitive pressure in 2022 given their predictably lower returns in even years (Vulstek and Russell 2022; Whitehouse 2022).

Summary for Environmental/Ecosystem Considerations

- Environment: Moderate thermal conditions for adults and larvae, with concerns of potential impacts of fall surface warmth on YOY winter survival.

*Prey: Planktivorous and piscivorous foraging conditions were above average in the WGOA and EGOA, with high uncertainty due to limited zooplankton data (especially euphausiid data which are primary prey for juveniles & adults). The age-0 year classes sampled in the beach seine survey decreased to slightly above average suggesting slightly limited prey resources.

*Competitors/Predators: Predation pressure is expected to be moderate from key groundfish species (arrowtooth flounder, Pacific cod, Pacific halibut, and potentially sablefish) and potential competitors for zooplankton may remain moderate given a large year class of juvenile sablefish (2019), and large population of Pacific Ocean perch but lower (even year) returns of pink salmon.

Currently the 2018, 2017 and 2012 year classes are the dominant year classes supporting the fishery, and there is no cause to suspect unfavorable conditions for those cohorts. Together, the most recent data available suggest an ecosystem risk Level 1— Normal: No apparent environmental/ecosystem concerns.

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.

Summary and ABC recommendation

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 2023 ABC of 148,937 t, which is a 11.9% increase from the 2022 ABC. The author's recommended 2024 ABC is 161,080 t. The OFL in 2023 is 173,470 t, and the OFL in 2024 if the ABC is taken in 2023 is 186,101 t.

To evaluate the probability that the stock will drop below the B20% 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 B20%, 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 2018). Analysis of the posterior samples indicates that probability of the stock dropping below B20% will be negligible through 2027, conditional upon the model specified here (Fig. 1.44).

Projections and Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the vector of 2022 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2023 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2022. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch after 2022 is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be 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 2023, are as follow (maxF_{ABC} refers to the maximum permissible value of F_{ABC} under Amendment 56):

- Scenario 1: In all future years, F is set equal to $maxF_{ABC}$. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

- Scenario 2: In 2022 and 2023, F is set equal to a constant fraction of $maxF_{ABC}$, where this fraction is equal to the ratio of the realized catches in 2019- 2021 to the ABC recommended in the assessment for each of those years. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In many fisheries the ABC is routinely not fully utilized, so assuming an average ratio catch to ABC will yield more realistic projections.)

- Scenario 3: In all future years, F is set equal to 50% of $maxF_{ABC}$. (Rationale: This scenario provides a likely lower bound on FABC that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

- Scenario 4: In all future years, F is set equal to the 2018-2022 average F. (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 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 2022 or 2) above 1/2 of its MSY level in 2022 and above its MSY level in 2031 under this scenario, then the stock is not overfished.

- Scenario 7: In 2023 and 2024, F is set equal to max F_{ABC}, and in all subsequent years F is set equal to FOFL. Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2024 or 2) above 1/2 of its MSY level in 2024 and expected to be 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 to decline to 2026 under full exploitation scenarios, but will increase under the F=0 and other low exploitation scenarios (Fig. 1.45). We project catches to increase through 2024, and then drop slightly 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 (2021) is 101,160 t, which is less than the 2021 OFL of 154,983 t. Therefore, the stock is not subject to overfishing. The fishing mortality that would have produced a catch in 2021 equal to the 2021 OFL is 0.233.

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 204,554 t in 2022 (see Table 1.25), which is above B35% (164,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2024 is 188,277 t, which is above B35% (164,000 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

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References

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

Alverson, D.L.A.M.J.C. (1975) A graphic review of the growth and decay of population cohorts. *Cons. int. Explor* Mer, 133–143.

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

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

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

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

Barnes, C.L., Beaudreau, A.H., Dorn, M.W., Holsman, K.K. and Mueter, F.J. (2020) Developmentof a predation index to assess trophic stability in the Gulf of Alaska. *Ecological Applications* 30, 02141.

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

Bürkner, P. (2018) Advanced Bayesian Multilevel Modeling with the R Package brms. *The R Journal* 10, 395–411.

Bürkner, P. (2017) brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software* 80, 1–28.

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

Danielson, S. and Hopcroft, R. (2022) Ocean temperature synthesis: Seward line May survey. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

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

Dorn, M.W., Aydin, K., Barbeaux, S., Jones, D., Spalinger, K. and Palsson, W. (2012) Assessment of the walleye pollock stock in the Gulf of Alaska. In: *Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska. Prepared by the Gulf of Alaska Groundfish Plan Team, P.O. Box 103136*. North Pacific Fisheries Management Council, Anchorage.

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

Dorn, M.W. and Methot, R.D. (1990) Status of the coastal Pacific whiting resource in 1989 and recommendation to management in 1990. In: *U.S. Dep. Commer., NOAA tech. Memo. NMFS f/NWC-182*. p 84.

Drummond, B. and Renner, H. (2022) Seabird synthesis: Alaska Maritime National Wildlife Refuge data. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Ferriss, B. and Zador, S. (2022) Ecosystem status report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 west third, suite 400.

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

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

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

Fournier, D.A., Skaug, H.J., Ancheta, J., et al. (2012) AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optim. Methods Softw* 27, 233–249.

Francis, R.I.C.C. (2011) Data weighting in statistical fisheries stock assessment models. *Can. J. Fish. Aquat. Sci* 68, 1124–1138.

Gann, J., Callahan, M.W., Nielsen, J.M. and Pelland, N. (2022) Satellite-derived chlorophyll for Gulf of Alaska ecosystem regions. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

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

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

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

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

Hilborn, R. and Walters, C.J. (1992) *Quantitative fisheries stock assessment: choice, dynamics, and uncertainty*. Chapman; Hall, New York.

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

Hollowed, A.B. and Megrey, B.A. (1990) Walleye pollock. In Stock Assessment and Fishery Evaluation Report for the 1991 Gulf of Alaska Groundfish Fishery. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Hopcroft, R. (2022) Seward Line: Large copepod & euphausiid biomass. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Ianelli, J., Kotwicki, S., Honkalehto, T., Holsman, K. and Fissel, B. (2016) Assessment of the walleye pollock stock in the Eastern Bering Sea. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Jones, D.T., Lauffenburger, N.E., Williams, K. and De Robertis, A. (2019) Results of the acoustic-trawl survey of walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska, June-August 2017 (DY2017-06). *AFSC Processed Rep. 2019-08, 110 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.*

Jones, D.T., Levine, M., Williams, K. and De Robertis, A. (in review) Results of the Acoustic-Trawl Survey of walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska, May-August 2019 (DY2019-06).

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

Jones, D.T., Stienessen, S.C. and Lauffenburger, N. (2017) Results of the acoustic-trawl survey of walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska, June-August 2015 (DY2015-06). *AFSC Processed Rep. 2017-03, 102 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.*

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

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

Kimura, D.K. and Chikuni, S. (1989) Variability in estimating catch-in-numbers-at-age and its impact on cohort analysis. *Can. Spec. Publ. Fish. Aquat. Sci* 108, 57–66.

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

Kirk, K., Quinn, T.J., Collie, J. and A'mar, T. (2012) Multispecies age-structured assessment for groundfish and sea lions in Alaska. In: *Global Progress in Ecosystem-Based Fisheries Management*. (eds G.H. Kruse, H.I. Browman, K.L. Cochrane, et al.). University of Alaska Fairbanks, Alaska Sea Grant.

Lemagie, E. and Callahan, M.W. (2022) Ocean temperature synthesis: Satellite data and marine heat waves. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Levine, M., Jones, D.T. and McGowan, D.W. (in prep.) Results of the Acoustic-Trawl Survey of walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska, June-July 2021 (DY2021-04).

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

McCullagh, P. and Nelder, J.A. (1983) *Generalized linear models*. Chapman; Hall, London.

McGowan, D., Jones, D.T. and McCarthey, A. (in prep.) Results of the acoustic-trawl survey of walleye pollock (*Gadus chalcogrammus*) in the Shelikof Strait March 2022 (DY2022-04). *AFSC Processed Rep. 2014-06, 50 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.*

Megrey, B.A. (1989) Exploitation of walleye pollock resources in the Gulf of Alaska, 1964-1988: portrait of a fishery in transition. In: *Proc. International Symp. on the Biology and Management of Walleye Pollock, Lowell Wakefield Fisheries Symp., Alaska sea grant rep*, Vol. 89-1. pp 33–58.

Merati, N. (1993) Spawning dynamics of walleye pollock, *Theragra chalcogramma*, in Shelikof Strait, Gulf of Alaska. Unpublished MS thesis.

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

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

Monnahan, C.C., Dorn, M.W., Deary, A.L., et al. (2021) Assessment of the walleye pollock stock in the Gulf of Alaska. In: *Stock Assessment and Fishery Evaluation Report for Groundfish Resources of the Gulf of Alaska. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136*. North Pacific Fisheries Management Council, Anchorage.

Monnahan, C.C. and Kristensen, K. (2018) No-u-turn sampling for fast bayesian inference in ADMB and TMB: Introducing the adnuts and tmbstan r packages. *PLOS ONE* 13, 1–10.

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

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

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

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

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

Press, W.H., Teukolsky, S.A., Vetterling, W.T. and Flannery, B.P. (1992) *Numerical recipes in C*. Cambridge University Press.

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

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

Rogers, L.A. and Dougherty, A.B. (2019) Effects of climate and demography on reproductive phenology of a harvested marine fish population. *Global Change Biology* 25, 708–720.

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

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

Stan Development Team (2020) RStan: the R interface to Stan.

Strom, S. (2022) Seward Line May phytoplankton size index. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

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

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

Szalay, P.G., Raring, N.W., Shaw, F.R., Wilkins, M.E. and Martin, M.H. (2010) Data report: 2009 Gulf of Alaska bottom trawl survey. In: *US Dep. Commer. , NOAA tech memo NMFS-AFSC-208 245 p.*

Thorson, J.T., Cunningham, C.J., Jorgensen, E., Havron, A., Hulson, P.J.F., Monnahan, C.C. and Szalay, P. (2021) The surprising sensitivity of index scale to delta-model assumptions: Recommendations for model-based index standardization. *Fisheries Research* 233.

Trijoulet, V., Albertsen, C.M., Kristensen, K., Legault, C.M., Miller, T.J. and Nielsen, A. (2023) Model validation for compositional data in stock assessment models: Calculating residuals with correct properties. *Fisheries Research* 257.

Vulstek, S. and Russell, J.R. (2022) Trends in survival of coho, sockeye, and pink salmon from Auke Creek, Southeast Alaska. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Whitehouse, G.A. (2022) Trends in Alaska commercial salmon catch – Gulf of Alaska. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Tables

Table 1.1. Walleye pollock catch (t) in the Gulf of Alaska. The ABC is for the area west of 140W 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		22,822	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			101,160	101,160	105,722
Average (1977-2021)				109,328	125,403

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	2017	2018	2019	2020	2021
Pollock	183,044.0	155,002.1	117,649.7	105,943.5	98,863.3
Arrowtooth Flounder	1,335.7	2,670.4	2,019.6	2,417.1	810.1
Pacific Cod	886.6	846.8	811.3	1,039.3	2,917.4
Pacific Ocean Perch	1,273.0	1,629.5	1,083.5	1,131.0	778.6
Sablefish	60.6	360.0	409.2	794.7	57.7
GOA Shallow Water Flatfish	370.7	393.3	263.2	151.3	197.4
Flathead Sole	198.7	322.8	197.2	227.1	109.1
GOA Skate, Big	139.0	110.5	66.5	78.3	53.4
GOA Rex Sole	75.1	138.9	89.7	100.4	51.2
Shark	69.9	78.8	59.1	100.4	83.7
Rougheye Rockfish	3.0	9.7	41.6	31.6	40.6
Atka Mackerel	33.5	64.4	122.4	0.2	4.1
GOA Dusky Rockfish	13.2	43.2	16.4	24.6	37.5
GOA Skate, Longnose	37.0	44.6	20.7	22.4	14.9
Shortraker Rockfish	1.6	0.5	8.4	29.5	30.8
Sculpin	27.3	18.4	10.2	45.0	
Northern Rockfish	5.7	59.4	7.2	0.9	1.9
GOA Deep Water Flatfish	1.6	5.6	12.7	12.1	0.9
BSAI Skate and GOA Skate, Other	5.9	5.0	3.5	4.1	3.6
Squid	15.5	9.5			
Other Rockfish	0.4	1.6	4.6	0.2	1.4
Octopus	0.2	6.4	8.3	4.4	0.3
GOA Thornyhead Rockfish	3.5	2.6	0.2	0.5	2.3
Percent non-pollock	0.0	0.0	0.0	0.1	0.0

Non target species/species group					
Squid	0.0	0.0	47.5	371.7	242.7
Misc fish	19.3	55.9	87.8	115.1	61.4
Capelin	33.1	77.0	80.6	54.0	0.0
Smelt (Family Osmeridae)	0.0	0.0	0.0	0.0	240.5
Other osmerids	0.9	24.4	47.0	6.6	89.2
Scypho jellies	14.0	12.8	121.4	5.5	9.9
Grenadier - Rattail Grenadier Unidentified	9.1	25.5	37.7	38.6	46.7
Sea star	0.8	45.0	2.5	3.3	0.9
Eulachon	2.8	8.7	7.6	22.3	0.0
Giant Grenadier	4.7	3.1	9.3	11.3	9.6
Sculpin	0.0	0.0	0.0	0.0	9.5
State-managed Rockfish	0.1	1.5	0.0	0.1	0.0
Greenlings	0.0	1.6	0.0	0.0	0.1
Bivalves	0.0	0.0	0.6	0.0	0.0
Snails	0.0	0.1	0.5	0.0	0.0
Stichaeidae	0.0	0.0	0.0	0.0	0.1
urchins dollars cucumbers	0.0	0.0	0.0	0.0	0.1
Brittle star unidentified	0.1	0.0	0.0	0.0	0.0
Pacific Sand lance	0.0	0.0	0.0	0.0	0.1
Hermit crab unidentified	0.0	0.0	0.0	0.0	0.0

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	2017	2018	2019	2020	2021
Bairdi Tanner Crab (nos.)	3,281	6,832	41,889	19,003	1,791
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	21,575	14,846	20,992	10,867	10,595
Golden (Brown) King Crab (nos.)	9	1	0	2	0
Halibut (t)	120	341	274	136	106
Herring (t)	5	42	64	60	16
Non-Chinook Salmon (nos.)	4,455	8,308	5,063	2,162	1,160
Opilio Tanner (Snow) Crab (nos.)	0	0	0	0	0
Red King Crab (nos.)	0	0	0	5	3

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
2012	Retained	27,352	44,779	25,125	2,380	2,624	0	102,261	
	Discarded	521	301	856	12	3	1	1,694	1.63%
	Total	27,873	45,080	25,981	2,392	2,627	1	103,954	
2013	Retained	7,644	52,692	28,169	2,933	2,622	0	94,062	
	Discarded	67	433	1,791	7	0	2	2,300	2.39%
	Total	7,711	53,125	29,960	2,940	2,623	2	96,362	
2014	Retained	13,228	82,611	41,791	1,314	2,368	0	141,312	
	Discarded	136	470	712	3	3	3	1,328	0.93%
	Total	13,364	83,081	42,503	1,317	2,371	3	142,640	
2015	Retained	28,679	80,950	51,973	248	4,455	0	166,305	
	Discarded	59	490	657	1	32	3	1,243	0.74%
	Total	28,739	81,439	52,630	250	4,487	3	167,548	
2016	Retained	61,019	46,810	64,281	121	3,893	0	176,123	
	Discarded	233	214	529	12	14	3	1,005	0.57%
	Total	61,252	47,024	64,810	133	3,907	3	177,128	
2017	Retained	49,246	80,855	52,338	39	1,881	0	184,359	
	Discarded	297	752	733	0	16	2	1,800	0.97%
	Total	49,542	81,607	53,071	40	1,897	2	186,158	
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	1.26%
	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	18	3	1,266	1.05%
	Total	21,868	64,120	24,661	6,612	2,977	3	120,242	
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	
2021	Retained	17,663	52,075	22,825	5,115	2,136	0	99,814	
	Discarded	352	354	606	30	3	2	1,347	1.33%
	Total	18,015	52,429	23,431	5,144	2,139	2	101,160	
Average (2012-2021)		27,804	64,336	38,271	2,813	2,846	2	136,073	

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

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
2021	0.12	6.60	31.78	47.84	8.28	0.76	3.19	9.47	23.61	6.08	0.51	0.00	0.00	0.00	0.00	138.24

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

Year	Aged Males	Aged Females	Aged Total	Lenghted Males	Lengthed Females	Lengthed 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
2021	1,003	919	1,922	6,430	6,435	12,865

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 140W	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
2022	365,411				71,196

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.

Year	No. tows	No. of tows with pollock	Survey biomass CV	Aged Males	Aged Females	Aged Total	Lengthed Males	Lengthed Females	Lengthed '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	605	738	1,343	10,234	12,251	23,218

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

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1984	38.7	15.7	74.5	158.8	194.7	271.2	85.9	37.4	13.6	2.4	0.5	0.3	0.2	0.0	0.0	893.8
1987	26.1	325.1	150.4	111.7	70.6	135.1	64.3	37.0	146.4	18.9	6.7	2.9	1.5	0.0	0.0	1,096.8
1990	58.1	201.3	44.6	39.4	189.7	222.2	67.3	102.4	25.2	36.6	5.7	24.0	6.0	0.7	1.1	1,024.2
1993	76.8	44.7	55.1	129.8	264.9	89.8	35.0	64.2	65.6	18.7	9.3	5.9	2.5	1.4	3.9	867.6
1996	196.9	129.1	17.2	26.2	50.1	63.2	174.4	87.6	52.3	27.7	12.1	18.4	7.2	9.7	2.9	874.9
1999	109.7	19.2	20.9	66.8	119.0	56.8	59.1	47.7	56.4	82.0	65.2	9.7	8.3	2.5	0.8	724.2
2001	412.8	117.0	34.4	33.4	25.1	33.5	37.0	8.2	5.7	0.6	4.5	2.5	1.3	0.0	0.2	716.2
2003	75.1	18.3	128.1	140.4	73.1	44.6	36.0	25.2	14.4	8.6	3.2	1.8	1.3	0.0	0.0	570.0
2005	270.0	33.6	34.4	35.9	91.7	78.8	45.2	20.9	9.6	10.0	4.8	0.6	0.6	0.0	0.0	636.0
2007	175.4	96.4	87.7	36.5	19.2	18.9	55.0	31.1	6.6	3.0	2.8	1.0	1.1	0.0	0.0	534.7
2009	222.9	87.3	106.8	129.3	101.3	27.2	17.6	26.6	53.9	29.5	9.7	7.0	2.8	1.6	0.0	823.5
2011	249.4	96.7	110.7	101.8	163.6	108.0	33.2	7.1	5.7	8.6	19.3	6.6	0.0	0.0	0.6	911.4
2013	750.2	62.1	47.9	65.4	84.7	144.6	156.9	115.5	25.1	5.4	2.4	2.5	3.8	3.0	0.9	1,470.5
2015	93.0	63.6	452.6	109.6	113.2	70.8	56.6	53.0	26.0	21.0	3.6	0.6	0.1	0.0	0.9	1,064.7
2017	159.4	3.8	10.9	30.3	294.8	27.0	15.3	4.2	0.4	0.2	0.7	0.0	0.0	0.1	0.0	547.2
2019	126.1	69.7	27.3	15.6	10.2	29.0	178.1	20.4	3.1	0.1	0.3	0.0	0.0	0.0	0.0	479.9
2021	353.0	128.8	183.0	225.8	64.5	16.0	10.2	37.2	65.1	8.3	1.2	0.0	0.0	0.0	0.0	1,093.2

2013	7,793.4	90.6	366.7	57.0	72.0	106.5	83.9	38.2	10.8	4.5	2.0	2.1	0.6	1.1	0.2	8,629.5
2015	6.6	233.4	3,014.3	123.3	76.2	36.7	17.6	18.3	12.9	7.2	0.9	1.1	0.0	0.0	0.0	3,548.6
2017	717.3	0.8	1.0	118.6	1,702.4	88.2	12.7	1.4	0.0	0.7	0.4	0.0	0.0	0.0	0.0	2,643.4
2019	2,894.3	1,303.1	95.9	7.1	4.9	54.7	255.3	23.9	1.7	1.6	0.1	0.0	0.0	0.6	0.0	4,643.1
2021	3,621.9	135.6	227.4	217.4	30.9	3.8	3.4	11.0	36.7	15.9	3.1	0.4	0.0	0.0	0.0	4,307.6

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	77.7	3,481.2	1,510.8	769.2	2,785.9	1,051.9	209.9	128.5	79.4	25.2	1.7	0.0	0.0	0.0	0.0	10,121.4
1983	1.2	901.8	380.2	1,296.8	1,170.8	698.1	598.8	131.5	14.5	11.6	3.9	1.7	0.0	0.0	0.0	5,210.9
1984	61.7	58.3	324.5	141.7	635.0	988.2	449.6	224.3	41.0	2.7	0.0	1.0	0.0	0.0	0.0	2,928.1
1985	2,091.7	544.4	122.7	314.8	180.5	347.2	439.3	166.7	42.7	5.6	1.8	1.3	0.0	0.0	0.0	4,258.7
1986	575.4	2,114.8	183.6	45.6	75.4	49.3	86.1	149.4	60.2	10.6	1.3	0.0	0.0	0.0	0.0	3,351.8
1988	17.4	109.9	694.3	322.1	77.6	17.0	5.7	5.6	4.0	9.0	1.8	1.8	0.2	0.0	0.0	1,266.4
1989	399.5	89.5	90.0	222.0	248.7	39.4	11.8	3.8	1.9	0.6	10.7	1.4	0.0	0.0	0.0	1,119.2
1990	49.1	1,210.2	71.7	63.4	115.9	180.1	46.3	22.4	8.2	8.2	0.9	3.1	1.5	0.8	0.2	1,782.1
1991	22.0	173.7	549.9	48.1	64.9	69.6	116.3	23.6	29.4	2.2	4.3	0.9	4.4	0.0	0.0	1,109.3
1992	228.0	33.7	73.5	188.1	368.0	84.1	85.0	171.2	32.7	56.4	2.3	14.7	0.9	0.3	0.0	1,338.8
1993	63.3	76.1	37.1	72.4	232.8	126.2	26.8	35.6	38.7	16.1	7.8	2.6	2.2	0.5	1.5	739.6
1994	186.0	35.8	49.3	31.7	155.0	83.6	42.5	27.2	44.4	48.5	14.8	6.6	1.1	2.3	0.6	729.5
1995	10,689.9	510.4	79.4	77.7	103.3	245.2	121.7	53.6	16.6	10.7	14.6	5.8	2.1	0.4	0.0	11,931.5
1996	56.1	3,307.2	118.9	25.1	54.0	71.0	201.0	118.5	39.8	13.0	11.3	5.3	2.5	0.0	0.4	4,024.4
1997	70.4	183.1	1,246.6	80.1	18.4	44.0	51.7	97.5	52.7	14.3	2.4	3.0	0.9	0.5	0.0	1,865.7
1998	395.5	88.5	125.6	474.4	136.1	14.2	31.9	36.3	74.1	25.9	14.3	6.9	0.3	0.6	0.6	1,425.0
2000	4,484.4	755.0	216.5	15.8	67.2	131.6	16.8	12.6	9.9	7.8	13.9	6.9	1.9	1.1	0.0	5,741.5
2001	288.9	4,103.9	351.7	61.0	41.6	23.0	34.6	13.1	6.2	2.7	1.2	1.9	0.7	0.5	0.2	4,931.3
2002	8.1	162.6	1,107.2	96.6	16.2	16.1	7.7	6.8	1.5	0.7	0.4	0.3	0.2	0.1	0.0	1,424.5
2003	51.2	89.6	207.7	802.5	56.6	7.7	4.1	1.6	1.5	0.9	0.3	0.0	0.1	0.0	0.0	1,223.6
2004	52.6	93.9	57.6	159.6	356.3	48.8	2.7	3.4	3.3	0.5	0.4	0.0	0.7	0.0	0.0	779.8
2005	1,626.1	157.5	55.5	34.6	172.7	162.4	36.0	3.6	2.4	0.0	0.8	0.0	0.0	0.0	0.0	2,251.7
2006	161.7	836.0	40.7	11.5	17.4	56.0	75.0	32.2	6.9	0.8	0.7	0.5	0.0	0.0	0.0	1,239.6
2007	53.5	231.7	174.9	29.7	10.1	17.3	34.4	20.9	1.5	1.0	0.7	0.0	0.0	0.0	0.0	575.7
2008	1,778.2	359.2	230.2	49.0	11.2	2.0	3.7	9.8	6.2	1.9	0.5	0.0	0.0	0.0	0.0	2,451.9
2009	814.1	1,127.2	105.8	95.8	57.8	9.5	2.7	0.8	4.7	5.6	1.3	0.2	0.0	0.0	0.0	2,225.5
2010	270.5	299.1	538.7	82.9	76.3	27.7	11.2	5.1	5.0	10.3	8.8	3.2	0.0	0.0	0.0	1,338.7
2012	193.8	842.3	43.3	76.6	94.7	45.9	28.9	4.4	1.1	0.3	0.1	0.5	0.0	0.0	0.0	1,332.0
2013	9,178.4	117.1	688.0	51.3	64.4	104.0	58.7	42.8	10.5	4.9	4.5	0.5	1.4	4.0	2.0	10,332.6
2014	1,590.8	3,492.9	17.4	279.9	82.8	57.7	98.5	54.6	25.6	17.6	7.3	0.7	2.3	0.0	0.7	5,728.9
2015	19.8	103.9	1,637.3	72.4	152.8	62.4	56.7	68.1	30.0	11.0	5.6	3.7	0.9	0.6	2.4	2,227.8
2016	0.0	1.8	78.2	1,451.8	43.4	33.5	15.5	3.6	7.4	1.7	0.0	0.0	0.0	0.0	0.0	1,636.9
2017	744.7	0.0	9.4	126.4	2,576.2	126.0	31.1	9.3	0.3	0.7	0.0	0.0	0.0	0.0	0.0	3,624.2
2018	1,819.6	142.6	1.6	9.9	166.4	1,803.9	86.1	46.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4,076.5
2019	7,361.2	1,671.7	155.5	6.1	6.6	261.7	1,127.5	53.9	11.1	9.0	0.1	0.1	0.0	0.0	0.0	10,664.4
2020	17.1	80.0	343.5	71.7	15.4	26.8	68.1	191.7	116.1	37.0	8.0	2.7	0.0	0.0	0.0	978.2
2021	7,730.1	36.7	94.2	150.7	55.4	7.3	12.5	64.0	133.9	63.4	14.3	2.2	0.0	0.0	0.0	8,364.7
2022	11.1	193.3	27.9	132.7	111.9	26.9	2.4	13.5	30.7	86.6	26.3	1.9	1.5	0.0	0.0	666.6

Table 1.11. Survey sampling effort and estimation uncertainty for pollock in the Shelikof Strait acoustic survey. Survey CVs based on a cluster sampling design are reported for 1981-91, while relative estimation error using a geostatistical method is reported starting in 1992.

Year	No. of midwater tows	No. of bottom trawl tows	Survey biomass CV	Aged Males	Aged Females	Aged Unsexed	Aged Total	Lengthed Males	Lengthed Females	Lengthed Unsexed	Lengthed Total
1981	38	13	0.12	1,921	1,815		3,736				
1983	40	0	0.16	1,642	1,103		2,745				
1984	45	0	0.18	1,739	1,622		3,361				
1985	57	0	0.14	1,055	1,187		2,242				
1986	39	0	0.22	642	618		1,260				
1987	27	0		557	643		1,200				
1988	26	0	0.17	537	464		1,001				
1989	21	0	0.10	582	545		1,127				
1990	28	13	0.17	1,034	1,181		2,215				
1991	16	2	0.35	468	567		1,035				
1992	17	8	0.04	784	765		1,549				
1993	22	2	0.05	583	624		1,207				
1994	44	9	0.05	553	632		1,185				
1995	22	3	0.05	599	575		1,174				
1996	30	8	0.04	724	775		1,499				
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
2022	19	1	0.10	322	347	91	760	548	572	5,632	6,752

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

Table 1.13. Ageing error transition matrix used in assessment model for GOA pollock. Relationship between true ages (rows) and observed ages (columns) determined by a normal distribution defined by a standard deviation (SD) and zero mean (unbiased reading).

True age	SD	1	2	3	4	5	6	7	8	9	10
1	0.182	0.997	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.227	0.014	0.972	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.272	0.000	0.033	0.934	0.033	0.000	0.000	0.000	0.000	0.000	0.000
4	0.317	0.000	0.000	0.057	0.886	0.057	0.000	0.000	0.000	0.000	0.000
5	0.361	0.000	0.000	0.000	0.083	0.834	0.083	0.000	0.000	0.000	0.000
6	0.406	0.000	0.000	0.000	0.000	0.109	0.782	0.109	0.000	0.000	0.000
7	0.451	0.000	0.000	0.000	0.000	0.000	0.133	0.732	0.133	0.000	0.000
8	0.496	0.000	0.000	0.000	0.000	0.000	0.001	0.155	0.687	0.155	0.001
9	0.541	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.175	0.645	0.177
10	0.585	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.191	0.804

Table 1.14. Estimates of natural mortality at age for GOA pollock using alternative methods. The rescaled average has mean natural mortality of 0.30 for ages greater than or equal to the age at maturity.

Age	Length (cm)	Weight (g)	Brodziak et al. 2010	Lorenzen 1996	Gislason et al. 2010	Hollowed et al. 2000	Van Kirk et al. 2010	Van Kirk et al. 2012	Average	Rescaled Avg.
1	15.27	26.5	0.97	1.36	2.62	0.86	2.31	2.00	1.69	1.39
2	27.38	166.7	0.54	0.78	1.02	0.76	1.01	0.95	0.84	0.69
3	36.78	406.4	0.40	0.59	0.64	0.58	0.58	0.73	0.59	0.48
4	44.94	752.4	0.33	0.49	0.46	0.49	0.37	0.57	0.45	0.37
5	49.24	966.0	0.30	0.45	0.40	0.41	0.36	0.53	0.41	0.34
6	52.55	1,154.2	0.30	0.43	0.36	0.38	0.28	0.47	0.37	0.30
7	55.06	1,273.5	0.30	0.42	0.33	0.38	0.30	0.46	0.36	0.30
8	57.40	1,421.7	0.30	0.40	0.31	0.38	0.29	0.43	0.35	0.29
9	60.25	1,624.8	0.30	0.39	0.29	0.39	0.29	0.42	0.35	0.28
10	61.11	1,599.6	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	1	2	3	4	5	6	7	8	9	10+	Sample size
1983	0.000	0.000	0.165	0.798	0.960	0.974	0.983	0.943	1.000	1.000	1,333
1984	0.000	0.000	0.145	0.688	0.959	0.990	1.000	0.992	1.000	1.000	1,621
1985	0.000	0.015	0.051	0.424	0.520	0.929	0.992	0.992	1.000	1.000	1,183
1986	0.000	0.000	0.021	0.105	0.849	0.902	0.959	1.000	1.000	1.000	618
1987	0.000	0.000	0.012	0.106	0.340	0.769	0.885	0.950	0.991	1.000	638
1988	0.000	0.000	0.000	0.209	0.176	0.606	0.667	1.000	0.857	0.964	464
1989	0.000	0.000	0.000	0.297	0.442	0.710	0.919	1.000	1.000	1.000	796
1990	0.000	0.000	0.000	0.192	0.674	0.755	0.910	0.945	0.967	0.996	1,844
1991	0.000	0.000	0.000	0.111	0.082	0.567	0.802	0.864	0.978	1.000	628
1992	0.000	0.000	0.000	0.040	0.069	0.774	0.981	0.990	1.000	0.983	765
1993	0.000	0.000	0.016	0.120	0.465	0.429	0.804	0.968	1.000	0.985	624
1994	0.000	0.000	0.007	0.422	0.931	0.941	0.891	0.974	1.000	1.000	872
1995	0.000	0.000	0.000	0.153	0.716	0.967	0.978	0.921	0.917	0.977	805
1996	0.000	0.000	0.000	0.036	0.717	0.918	0.975	0.963	1.000	0.957	763
1997	0.000	0.000	0.000	0.241	0.760	1.000	1.000	0.996	1.000	1.000	843
1998	0.000	0.000	0.000	0.065	0.203	0.833	0.964	1.000	1.000	0.989	757
2000	0.000	0.000	0.012	0.125	0.632	0.780	0.579	0.846	1.000	0.923	356
2001	0.000	0.000	0.000	0.289	0.308	0.825	0.945	0.967	0.929	1.000	374
2002	0.000	0.000	0.026	0.259	0.750	0.933	0.974	1.000	1.000	1.000	499
2003	0.000	0.026	0.077	0.211	0.461	0.732	0.897	0.965	0.989	0.996	301
2004	0.000	0.081	0.221	0.480	0.749	0.906	0.969	0.990	0.997	0.999	444
2005	0.000	0.037	0.130	0.373	0.702	0.903	0.974	0.993	0.998	1.000	321
2006	0.000	0.004	0.023	0.124	0.466	0.842	0.970	0.995	0.999	1.000	476
2007	0.000	0.006	0.040	0.221	0.661	0.931	0.989	0.998	1.000	1.000	313
2008	0.000	0.001	0.009	0.060	0.321	0.779	0.963	0.995	0.999	1.000	240
2009	0.000	0.002	0.014	0.085	0.382	0.805	0.965	0.995	0.999	1.000	296
2010	0.000	0.003	0.033	0.265	0.791	0.976	0.998	1.000	1.000	1.000	314
2012	0.000	0.008	0.069	0.396	0.853	0.981	0.998	1.000	1.000	1.000	372
2013	0.000	0.000	0.009	0.210	0.884	0.995	1.000	1.000	1.000	1.000	622
2014	0.000	0.002	0.015	0.088	0.388	0.806	0.964	0.994	0.999	1.000	430
2015	0.000	0.018	0.087	0.323	0.706	0.924	0.984	0.997	0.999	1.000	372
2016	0.000	0.001	0.037	0.592	0.982	1.000	1.000	1.000	1.000	1.000	269
2017	0.000	0.232	0.594	0.877	0.972	0.994	0.999	1.000	1.000	1.000	423
2018	0.000	0.017	0.126	0.551	0.912	0.989	0.999	1.000	1.000	1.000	404
2019	0.000	0.002	0.019	0.159	0.644	0.946	0.994	0.999	1.000	1.000	551
2020	0.000	0.002	0.015	0.123	0.559	0.920	0.990	0.999	1.000	1.000	237
2021	0.000	0.047	0.132	0.319	0.591	0.816	0.932	0.977	0.992	0.997	228
2022	0.000	0.073	0.221	0.506	0.788	0.931	0.980	0.994	0.998	1.000	347
Average											
All years	0.000	0.015	0.061	0.280	0.615	0.862	0.941	0.979	0.990	0.994	
2013-2022	0.000	0.039	0.126	0.375	0.743	0.932	0.984	0.996	0.999	1.000	
2017-2022	0.000	0.062	0.185	0.422	0.744	0.933	0.982	0.995	0.998	1.000	

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

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	1.337	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
2021	0.107	0.368	0.530	0.612	0.734	1.054	0.965	1.008	1.015	1.044

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

Year	1	2	3	4	5	6	7	8	9	10
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	0.239	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
2022	0.009	0.051	0.369	0.548	0.611	0.867	0.845	1.177	1.047	1.133

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

Year	1	2	3	4	5	6	7	8	9	10
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
2021	0.037	0.215	0.454	0.590	0.790	0.940	0.972	1.100	1.066	1.073
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
2021	0.026	0.217	0.408	0.556	0.713	0.971	0.926	0.990	0.978	0.980

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

Age	Foreign (1970-81)	Foreign and JV (1982-1988)	Domestic (1989-2000)	Domestic (2001-2014)	Recent domestic (2016-2021)	Shelikof acoustic survey	Summer acoustic survey	Bottom trawl survey	ADF&G bottom trawl
1	0.001	0.004	0.002	0.009	0.004	0.299	1.000	0.129	0.005
2	0.011	0.027	0.012	0.064	0.039	0.337	1.000	0.218	0.022
3	0.121	0.180	0.073	0.336	0.295	1.000	0.998	0.345	0.101
4	0.620	0.627	0.338	0.785	0.807	1.000	0.993	0.500	0.354
5	0.952	0.928	0.768	0.967	0.980	1.000	0.975	0.657	0.730
6	0.997	0.992	0.962	0.997	0.999	0.998	0.916	0.790	0.930
7	1.000	1.000	1.000	1.000	1.000	0.992	0.752	0.884	0.985
8	0.989	0.990	0.995	0.989	0.988	0.956	0.459	0.944	0.997
9	0.860	0.861	0.866	0.860	0.860	0.797	0.191	0.980	0.999
10	0.323	0.323	0.325	0.323	0.323	0.417	0.062	1.000	1.000

Table 1.20. Total estimated abundance at age (millions) of GOA pollock from the age-structured assessment model

Year	1	2	3	4	5	6	7	8	9	10
1970	1,241	309	191	132	94	70	52	39	29	87
1971	3,248	309	155	118	89	65	50	37	28	85
1972	3,688	809	155	95	79	61	46	35	26	83
1973	10,857	918	405	94	58	47	37	28	22	76
1974	2,188	2,703	459	243	55	32	27	21	16	65
1975	2,232	545	1,351	272	135	28	17	14	11	53
1976	8,953	556	273	814	164	78	17	10	8	44
1977	12,184	2,229	278	163	468	89	43	9	6	35
1978	14,532	3,034	1,114	165	91	239	46	23	5	27
1979	26,005	3,618	1,516	662	93	47	129	25	12	21
1980	13,166	6,476	1,809	907	388	52	27	74	15	22
1981	7,372	3,279	3,242	1,098	563	231	32	17	46	25
1982	7,376	1,836	1,642	1,973	698	349	148	20	11	48
1983	5,129	1,837	918	995	1,258	443	229	97	13	42
1984	6,122	1,277	917	549	617	776	282	146	62	39
1985	15,108	1,523	636	541	328	362	469	171	89	67
1986	4,289	3,760	760	378	321	184	207	268	99	100
1987	1,890	1,068	1,881	463	247	211	125	140	184	142
1988	4,887	471	535	1,153	308	166	146	87	99	235
1989	11,439	1,217	236	328	771	208	116	102	61	243
1990	8,504	2,848	609	145	218	513	143	80	71	221
1991	3,341	2,118	1,427	375	97	145	348	97	54	210
1992	2,396	832	1,061	878	250	63	95	226	63	187
1993	1,749	597	417	652	585	162	41	61	148	177
1994	1,783	436	299	256	432	377	106	27	40	226
1995	6,691	444	218	183	170	279	247	69	17	189
1996	3,187	1,666	223	134	123	113	190	167	47	150
1997	1,517	794	835	137	91	83	78	131	116	143
1998	1,452	378	397	511	90	57	52	49	83	177
1999	1,780	361	189	240	316	51	32	29	27	169
2000	6,425	443	181	114	151	184	29	18	17	133
2001	7,006	1,600	222	110	73	92	114	18	11	105
2002	1,041	1,743	798	133	68	44	57	71	11	81
2003	796	259	868	477	84	43	29	37	47	66
2004	767	198	129	519	305	54	29	19	25	80
2005	1,848	191	98	76	327	196	36	19	13	75
2006	6,092	459	94	57	46	202	125	23	13	63
2007	5,923	1,514	227	55	35	29	130	81	15	53
2008	7,061	1,473	751	134	35	22	19	87	54	49
2009	3,224	1,757	734	448	86	23	15	13	60	74
2010	1,311	803	878	443	295	58	16	11	9	97
2011	5,118	326	400	525	286	194	40	11	7	77
2012	932	1,274	163	241	337	187	132	27	7	61
2013	44,193	232	637	99	153	216	124	88	18	50
2014	2,840	11,006	116	388	63	98	144	82	59	48
2015	71	707	5,510	70	237	37	59	87	50	71
2016	10	18	354	3,320	42	136	22	35	52	81
2017	2,078	2	9	214	2,076	26	87	14	23	92
2018	7,727	517	1	5	133	1,280	17	56	9	81
2019	5,450	1,924	258	1	3	80	805	11	35	63
2020	197	1,357	958	151	0	2	50	502	7	68
2021	10,296	49	673	553	91	0	1	32	320	53
2022	65	2,562	24	391	335	56	0	1	20	251
Average	5,939	1,484	721	437	273	167	107	69	45	99

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.

	2022 assessment						2021 assessment			
Year	3+ total biomass (kt)	SSB (kt)	% of SB100	Age 1 recruits (millions)	Catch (t)	Harvest rate	3+ total biomass (kt)	SSB (kt)	Age 1 recruits (millions)	Harvest rate
1977	761	141	30%	12,184	118,092	16%	747	137	11,767	16%
1978	994	130	28%	14,532	95,408	10%	966	125	14,441	10%
1979	1,397	138	29%	26,005	106,161	8%	1,351	131	25,637	8%
1980	1,866	192	41%	13,166	115,158	6%	1,822	182	13,028	6%
1981	2,910	212	45%	7,372	147,818	5%	2,852	202	7,238	5%
1982	3,032	344	73%	7,376	169,045	6%	2,977	331	7,158	6%
1983	2,762	478	102%	5,129	215,625	8%	2,709	464	4,799	8%
1984	2,456	530	113%	6,122	307,541	13%	2,400	515	5,761	13%
1985	1,993	483	103%	15,108	286,900	14%	1,929	467	14,033	15%
1986	1,685	439	94%	4,289	86,910	5%	1,611	422	3,998	5%
1987	2,034	412	88%	1,890	68,070	3%	1,922	393	1,661	4%
1988	1,922	416	89%	4,887	63,391	3%	1,810	394	4,581	4%
1989	1,701	430	92%	11,439	75,585	4%	1,590	404	10,792	5%
1990	1,566	442	94%	8,504	88,269	6%	1,459	412	8,194	6%
1991	1,870	434	93%	3,341	100,488	5%	1,742	402	3,199	6%
1992	1,947	394	84%	2,396	90,858	5%	1,822	361	2,337	5%
1993	1,834	425	91%	1,749	108,909	6%	1,717	389	1,679	6%
1994	1,555	498	106%	1,783	107,335	7%	1,455	458	1,678	7%
1995	1,274	415	88%	6,691	72,618	6%	1,190	382	6,536	6%
1996	1,074	382	82%	3,187	51,263	5%	1,002	353	3,103	5%
1997	1,089	339	72%	1,517	90,130	8%	1,026	313	1,397	9%
1998	1,046	263	56%	1,452	125,460	12%	989	242	1,284	13%
1999	783	244	52%	1,780	95,638	12%	735	225	1,591	13%
2000	695	232	49%	6,425	73,080	11%	645	213	6,035	11%
2001	666	217	46%	7,006	72,077	11%	609	199	6,624	12%
2002	844	183	39%	1,041	51,934	6%	776	165	914	7%
2003	1,058	170	36%	796	50,684	5%	980	153	695	5%
2004	887	186	40%	767	63,844	7%	815	168	636	8%
2005	742	226	48%	1,848	80,978	11%	676	205	1,611	12%
2006	634	243	52%	6,092	71,976	11%	568	218	5,377	13%
2007	592	216	46%	5,923	52,714	9%	522	191	5,227	10%
2008	827	216	46%	7,061	52,584	6%	722	188	6,274	7%
2009	1,186	215	46%	3,224	44,247	4%	1,033	185	2,750	4%
2010	1,398	298	63%	1,311	76,748	5%	1,221	254	1,030	6%
2011	1,339	349	74%	5,118	81,503	6%	1,158	298	4,406	7%
2012	1,251	373	80%	932	103,954	8%	1,066	316	676	10%
2013	1,274	404	86%	44,193	96,363	8%	1,072	337	40,454	9%
2014	1,009	311	66%	2,840	142,640	14%	834	254	2,181	17%
2015	2,676	290	62%	71	167,549	6%	2,371	230	38	7%
2016	2,708	310	66%	10	177,129	7%	2,377	255	5	7%
2017	2,001	421	90%	2,078	186,155	9%	1,730	354	1,696	11%
2018	1,370	408	87%	7,727	158,070	12%	1,159	341	7,020	14%
2019	1,013	326	69%	5,450	120,243	12%	829	266	5,260	14%
2020	1,100	238	51%	197	107,471	10%	915	188	156	12%
2021	1,137	252	54%	10,296	101,160	9%	982	197	10,760	10%
2022	850	243	52%	65	129,754	15%				

Table 1.22. Uncertainty of estimates of recruitment and spawning biomass of GOA pollock from the age-structured assessment model.

	Age-1 Recruits (millions)				Spawning biomass (kt)			
Year	Estimate	CV	Lower 95% CI	Upper 95% CI	Estimate	CV	Lower 95% CI	Upper 95% CI
1970	1,241	0.32	677	2,273	126	0.32	68	231
1971	3,248	0.45	1,406	7,505	120	0.33	64	224
1972	3,688	0.37	1,836	7,406	111	0.34	58	213
1973	10,857	0.16	7,928	14,868	94	0.37	47	190
1974	2,188	0.30	1,240	3,862	86	0.34	45	163
1975	2,232	0.28	1,311	3,800	93	0.25	57	149
1976	8,953	0.19	6,218	12,890	124	0.18	88	176
1977	12,184	0.18	8,565	17,331	141	0.18	99	200
1978	14,532	0.18	10,242	20,619	130	0.21	86	195
1979	26,005	0.15	19,394	34,869	138	0.21	91	209
1980	13,165	0.19	9,112	19,021	192	0.20	131	282
1981	7,372	0.23	4,742	11,460	212	0.18	149	302
1982	7,376	0.23	4,763	11,422	344	0.16	251	472
1983	5,129	0.33	2,743	9,590	478	0.15	354	646
1984	6,122	0.30	3,456	10,845	530	0.16	387	727
1985	15,108	0.16	11,080	20,600	483	0.18	341	685
1986	4,289	0.27	2,532	7,263	439	0.19	302	640
1987	1,890	0.38	923	3,869	412	0.18	288	589
1988	4,886	0.23	3,160	7,557	416	0.17	299	578
1989	11,439	0.14	8,636	15,152	430	0.14	325	570
1990	8,504	0.16	6,228	11,611	442	0.14	338	578
1991	3,341	0.25	2,057	5,427	434	0.14	332	568
1992	2,396	0.26	1,455	3,946	394	0.13	304	512
1993	1,749	0.28	1,024	2,987	425	0.12	334	540
1994	1,784	0.27	1,060	3,002	498	0.12	396	627
1995	6,691	0.12	5,269	8,498	415	0.12	329	523
1996	3,187	0.17	2,311	4,395	382	0.12	303	482
1997	1,517	0.23	979	2,351	339	0.12	268	429
1998	1,452	0.21	961	2,192	263	0.13	205	338
1999	1,780	0.20	1,218	2,602	244	0.13	189	316
2000	6,425	0.12	5,078	8,129	232	0.14	178	303
2001	7,006	0.11	5,644	8,697	217	0.14	164	288
2002	1,041	0.26	635	1,707	183	0.15	136	246
2003	796	0.24	497	1,275	170	0.15	127	227
2004	767	0.26	469	1,256	186	0.13	145	239
2005	1,848	0.18	1,295	2,637	226	0.13	176	290
2006	6,092	0.13	4,728	7,850	243	0.13	187	316
2007	5,923	0.13	4,552	7,706	216	0.15	163	287
2008	7,061	0.13	5,496	9,072	216	0.15	162	290
2009	3,224	0.16	2,352	4,420	215	0.14	163	286
2010	1,311	0.24	822	2,092	298	0.13	231	383
2011	5,118	0.15	3,851	6,801	349	0.12	274	445
2012	932	0.29	534	1,628	373	0.12	293	476
2013	44,193	0.09	37,310	52,345	404	0.13	313	520
2014	2,840	0.22	1,865	4,324	311	0.14	239	406
2015	71	0.37	35	144	290	0.14	219	385
2016	10	0.37	5	20	310	0.12	245	392
2017	2,078	0.18	1,459	2,960	421	0.12	335	528
2018	7,727	0.15	5,786	10,319	408	0.12	320	521
2019	5,450	0.18	3,856	7,703	326	0.14	248	428
2020	197	0.37	98	396	238	0.16	175	323
2021	10,296	0.26	6,246	16,971	252	0.16	183	346
2022	65	0.45	28	151	243	0.17	176	336

Table 1.23. GOA pollock life history and fishery characteristics used to estimate spawning biomass per recruit (FSPR) harvest rates. Spawning weight at age (WAA, kg) is based on an average from the Shelikof Strait acoustic survey conducted in March. Population weight at age is based on a average for the last three bottom trawl survey conducted in June to August. Proportion mature females is the average from winter acoustic survey specimen data.

Age	Natural mortality	Fishery selectivity (Avg. 2018-2022)	Spawning WAA (Avg. 2018-2022)	Population WAA (Avg. 2017, 2019, 2021)	Fishery WAA (Est. 2022 from RE model)	Proportion mature females (Avg. 1983-2022)
1	1.39	0.004	0.010	0.040	0.165	0.000
2	0.69	0.043	0.093	0.204	0.278	0.015
3	0.48	0.322	0.253	0.502	0.630	0.061
4	0.37	0.830	0.472	0.630	0.791	0.280
5	0.34	0.983	0.590	0.741	0.847	0.615
6	0.30	0.999	0.749	0.860	0.997	0.862
7	0.30	1.000	0.789	0.971	1.139	0.941
8	0.29	0.988	0.937	1.092	1.211	0.979
9	0.28	0.860	1.033	1.152	1.187	0.990
10+	0.29	0.323	1.085	1.456	1.130	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 after 1989 is the method used by the Plan Team to derive the ABC recommendation given in the SAFE summary chapter.

Year	Assessment Method	Catch recommendation basis	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	Amend. 44 Tier 3	289,689
1997	Stock synthesis	Amend. 44 Tier 3	267,600
1998	Stock synthesis	Amend. 44 Tier 3	240,000
1999	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	247,000
2000	AD model builder	Amend. 56 Tier 3	250,000
2001	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	245,000
2002	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	240,000
2003	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	248,000
2004	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC), and stairstep approach for projected ABC increase)	229,000
2005	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	224,000
2006	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	220,000
2007	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	221,000
2008	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	237,000
2009	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	248,000
2010	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	276,000
2011	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	271,000
2012	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	297,000
2013	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	290,000
2014	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	312,000
2015	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	300,000
2016	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	267,000
2017	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	238,000
2018	AD model builder	Amend. 56 Tier 3 (with ABC < maxABC)	221,000
2019	AD model builder	Amend. 56 Tier 3 (with 12,055 t reduction from maxABC)	194,000
2020	AD model builder	Amend. 56 Tier 3	177,000
2021	AD model builder	Amend. 56 Tier 3	172,000

Table 1.25. Projections of GOA pollock spawning biomass, full recruitment fishing mortality, and catch for 2022 - 2035 under different harvest policies (columns). For these projections, fishery weight at age was assumed to be equal to the estimated weight at age in 2022 for the RE model. All projections begin with initial age composition in 2022 using the base run model with a projected 2022 catch of 129,754 t. The values for B100%, B40%, and B35% are 469,000 t, 188,000 t, 164,000 t, respectively

Spawning biomass (t)							
Year	Max FABC	Author's recommended F	Average F	F75%	F=0	FOFL	Max FABC for two years, then FOFL
2022	229,759	229,759	229,759	229,759	229,759	229,759	229,759
2023	204,554	204,554	206,973	209,895	211,989	203,237	204,554
2024	188,277	188,277	200,924	217,365	229,984	182,010	188,277
2025	170,833	170,834	192,148	222,923	248,143	161,572	169,703
2026	164,728	164,802	190,033	234,443	273,367	154,009	159,080
2027	156,415	157,054	180,252	230,589	277,139	145,611	148,459
2028	170,965	172,277	194,635	253,867	310,593	158,326	160,021
2029	181,386	183,190	203,956	269,958	334,766	165,652	166,626
2030	194,001	196,051	217,259	291,291	365,140	174,949	175,503
2031	195,864	198,616	220,297	300,756	381,392	174,681	175,003
2032	198,986	202,281	224,445	311,238	398,747	176,373	176,559
2033	201,048	204,059	226,878	317,686	409,559	177,813	177,922
2034	204,781	207,768	232,146	327,759	424,438	180,706	180,769
2035	203,504	206,139	231,527	329,816	429,170	179,053	179,090
Fishing mortality							
Year	Max FABC	Author's recommended F	Average F	F75%	F=0	FOFL	Max FABC for two years, then FOFL
2022	0.23	0.23	0.23	0.23	0.23	0.23	0.23
2023	0.26	0.26	0.17	0.07	0.00	0.30	0.26
2024	0.26	0.26	0.17	0.07	0.00	0.29	0.26
2025	0.23	0.23	0.17	0.07	0.00	0.26	0.27
2026	0.20	0.20	0.17	0.07	0.00	0.23	0.23
2027	0.17	0.17	0.17	0.07	0.00	0.19	0.19
2028	0.13	0.13	0.17	0.07	0.00	0.19	0.19
2029	0.12	0.12	0.17	0.07	0.00	0.18	0.18
2030	0.13	0.12	0.17	0.06	0.00	0.18	0.18
2031	0.13	0.13	0.17	0.06	0.00	0.18	0.18
2032	0.13	0.13	0.17	0.06	0.00	0.18	0.18
2033	0.14	0.14	0.17	0.06	0.00	0.18	0.18
2034	0.14	0.13	0.17	0.05	0.00	0.18	0.18
2035	0.13	0.13	0.17	0.06	0.00	0.18	0.18
Catch (t)							
Year	Max FABC	Author's recommended F	Average F	F75%	F=0	FOFL	Max FABC for two years, then FOFL
2022	129,754	129,754	129,754	129,754	129,754	129,754	129,754
2023	148,937	148,937	102,452	43,800	0	173,470	148,937
2024	161,080	161,080	116,740	53,158	0	177,246	161,080
2025	126,233	126,164	104,188	50,328	0	134,663	146,201
2026	128,122	125,010	110,316	54,442	0	137,995	143,167
2027	131,795	129,546	117,415	58,214	0	143,677	145,848
2028	142,911	138,862	129,205	64,257	0	163,508	164,512
2029	153,447	153,060	137,349	68,872	0	176,268	176,672
2030	157,816	151,325	139,385	69,252	0	178,723	178,832
2031	156,302	154,384	139,432	69,386	0	174,176	174,230
2032	165,492	163,619	144,780	71,467	0	184,191	184,208
2033	167,639	166,246	145,946	72,223	0	185,412	185,422
2034	164,873	164,205	143,650	71,072	0	182,989	182,993
2035	164,574	162,872	143,282	71,275	0	182,917	182,920

Figures

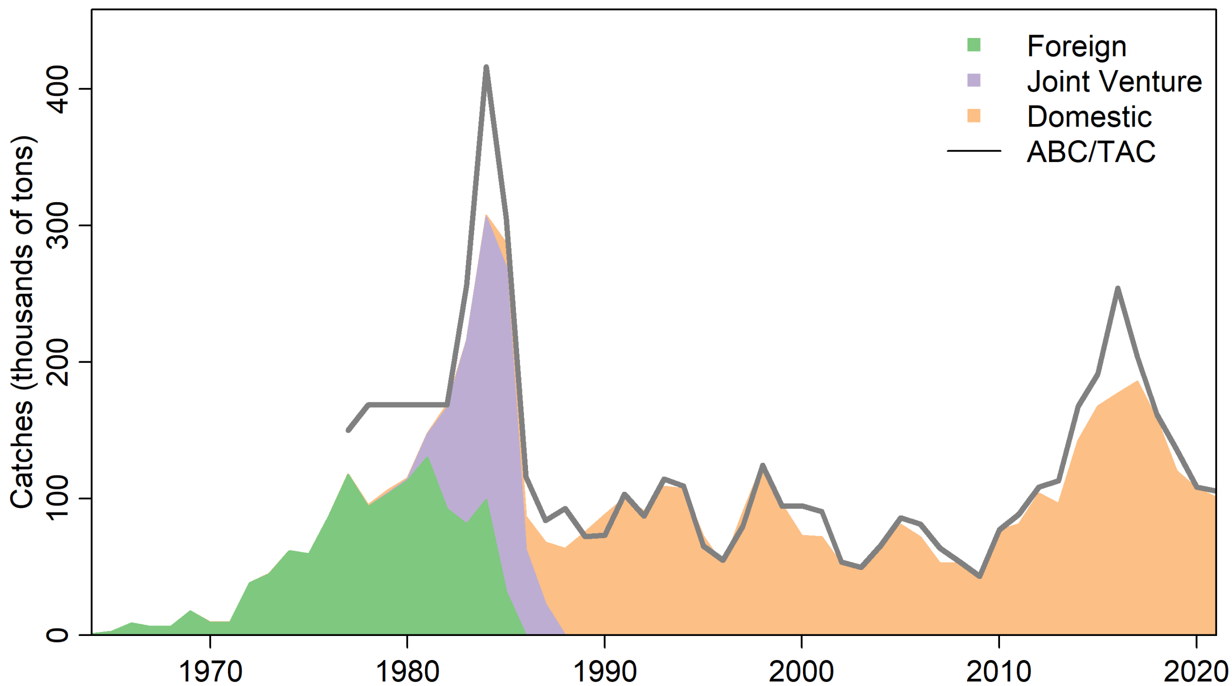


Figure 1.1. Overview of historical catches by source compared to the ABC/TAC

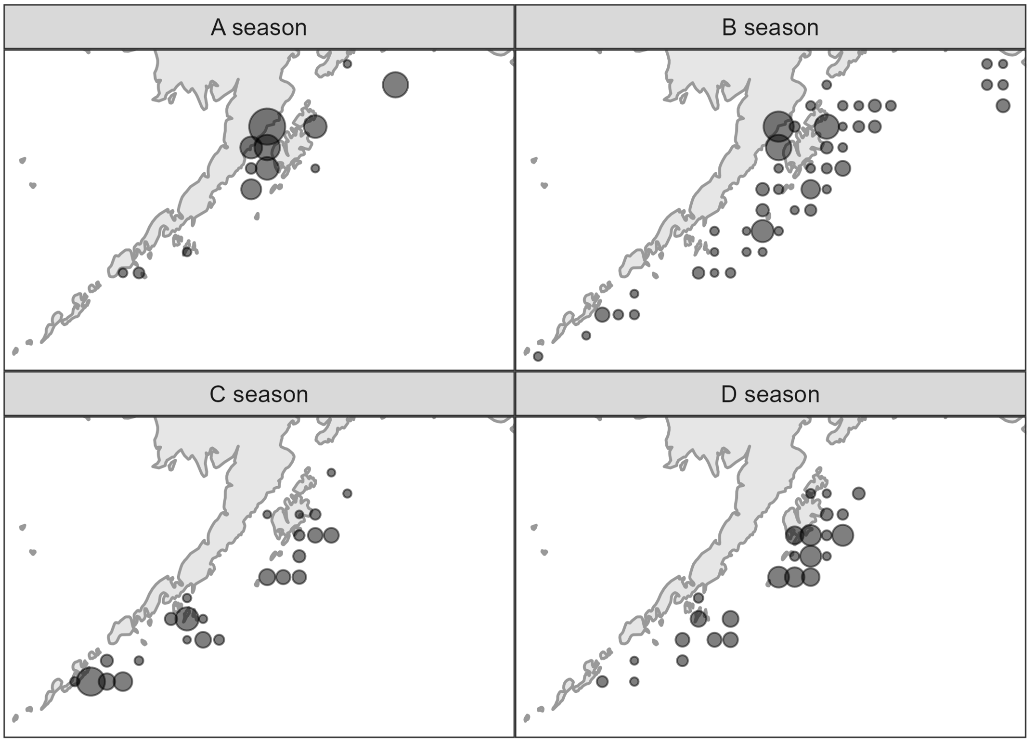


Figure 1.2. Distribution of pollock catch in the 2020 fishery shown for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

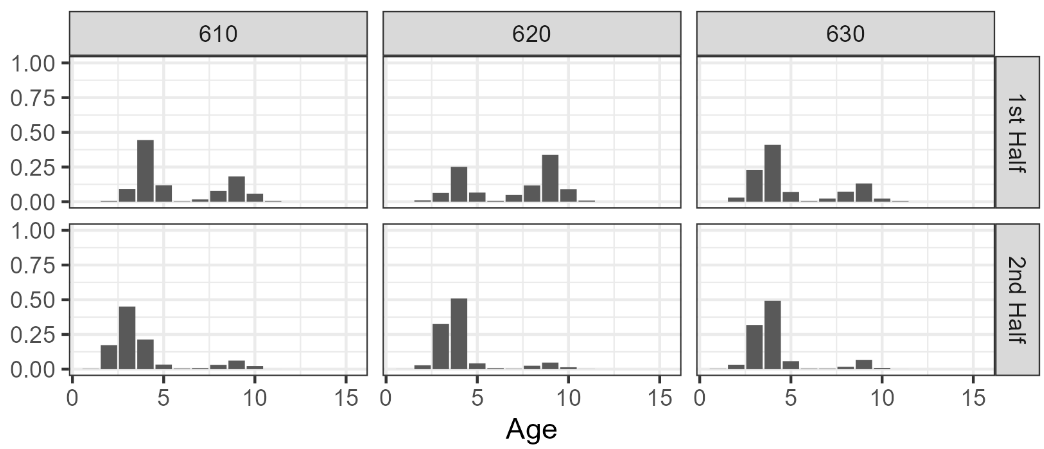


Figure 1.3. Distribution of pollock catch in the 2020 fishery shown for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle is proportional to the catch.

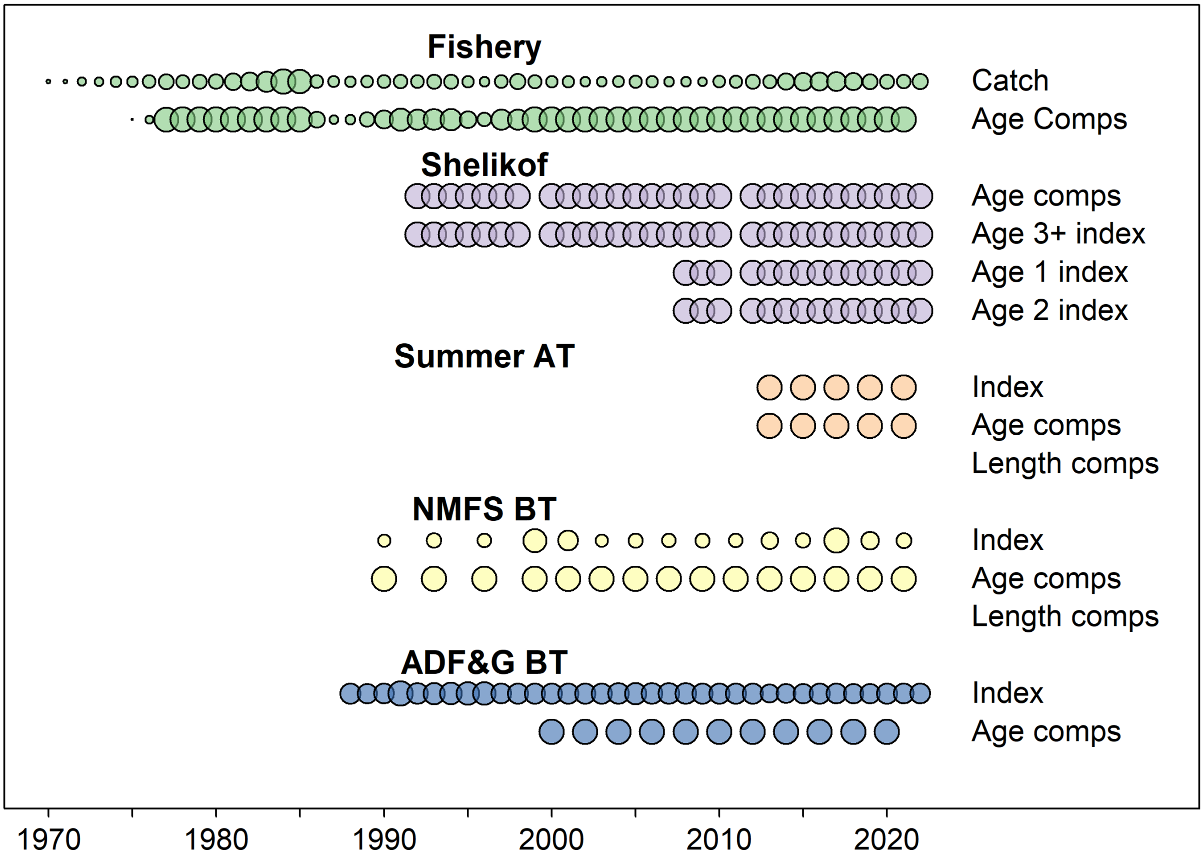


Figure 1.4. Overview of data sources and their relative weights. Circle sizes are relative to catches or data information for surveys within a row. Length compositions are only used in years without age compositions

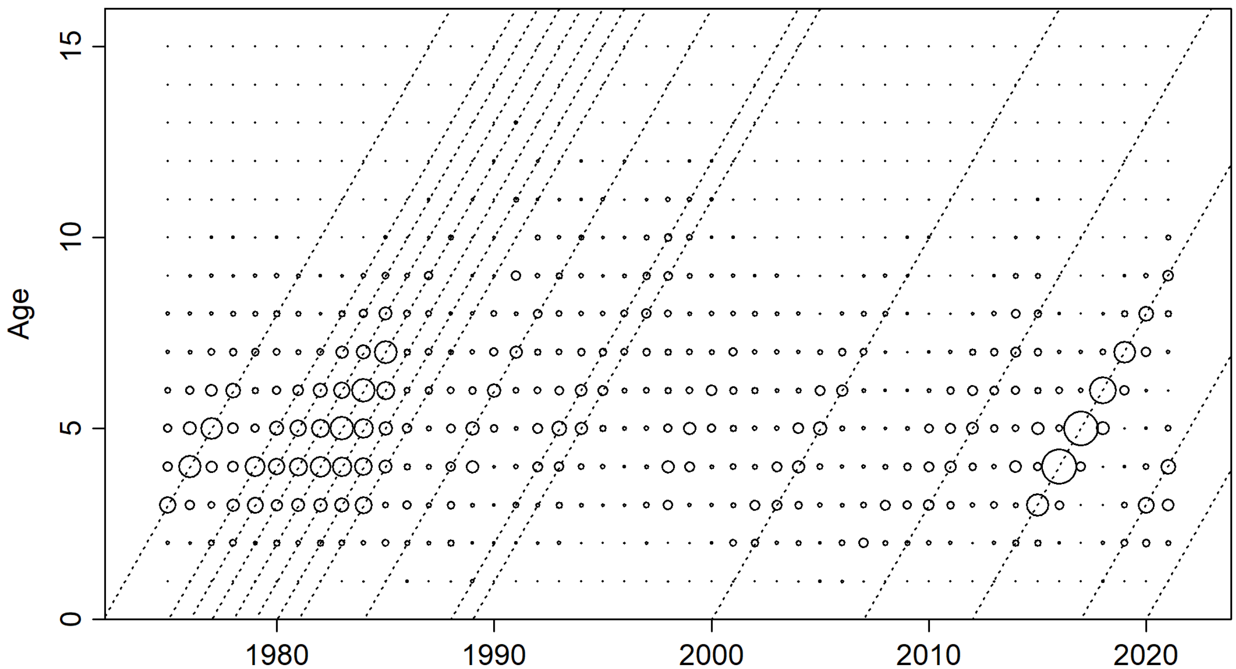


Figure 1.5. GOA pollock fishery age composition (1975- 2021).The area of the circle is proportional to the catch. Diagonal lines show strong year classes.

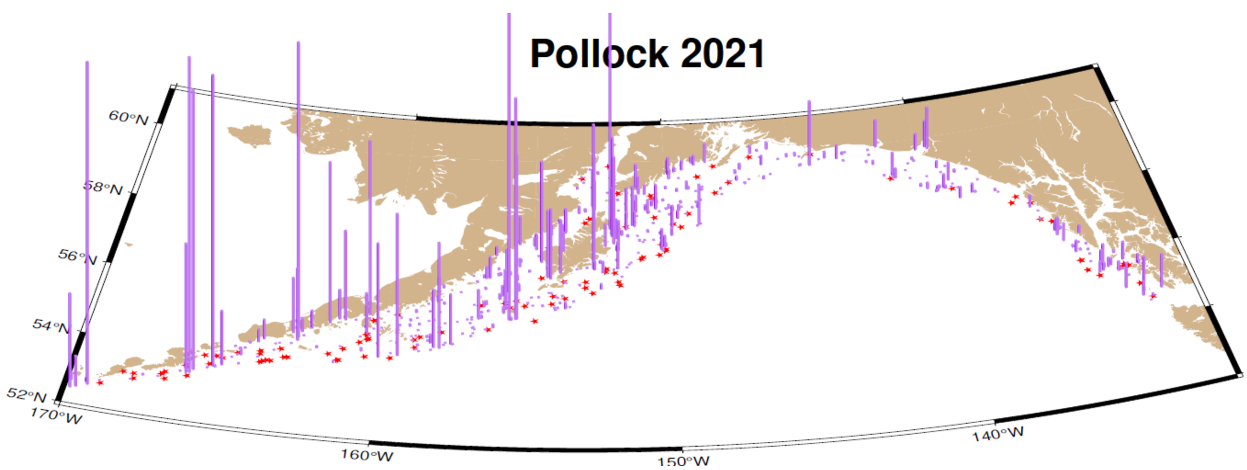


Figure 1.6. Pollock catch per unit effort (CPUE) for the 2021 NMFS bottom trawl survey in the Gulf of Alaska (heights of purple bars). Red stars indicate hauls with no pollock catch.

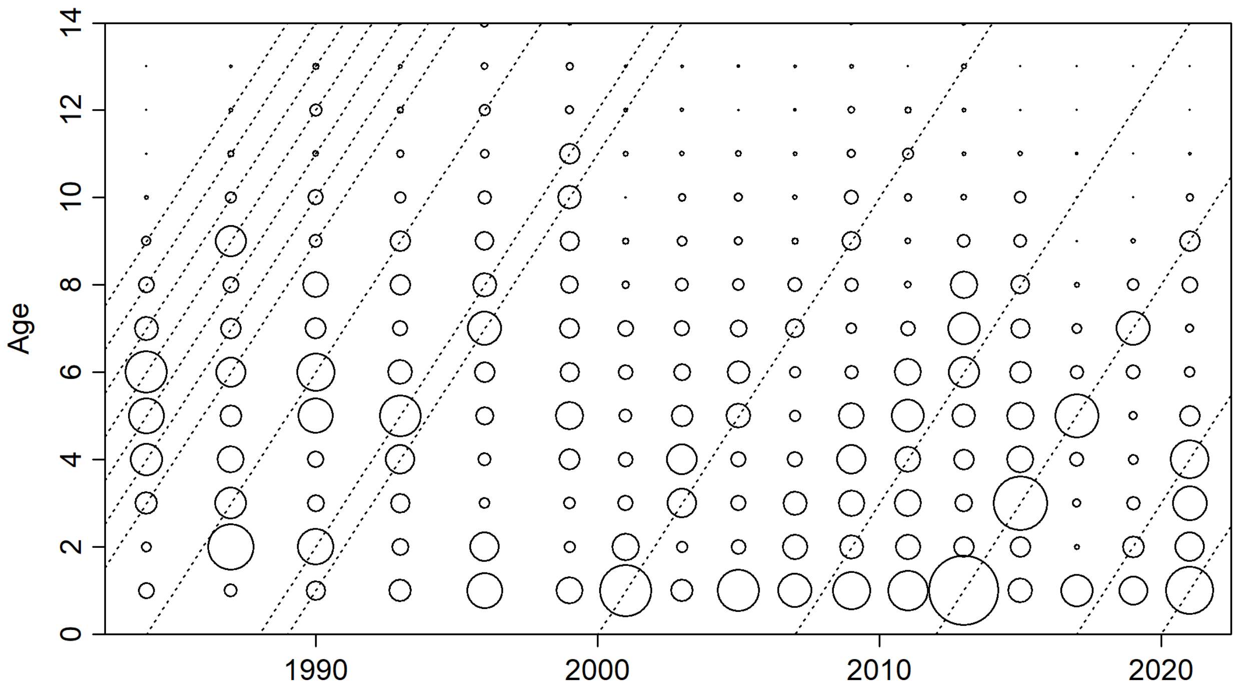


Figure 1.7. Estimated abundance at age in the NMFS bottom trawl survey (1984-2021). The area of the circle is proportional to the estimated abundance.

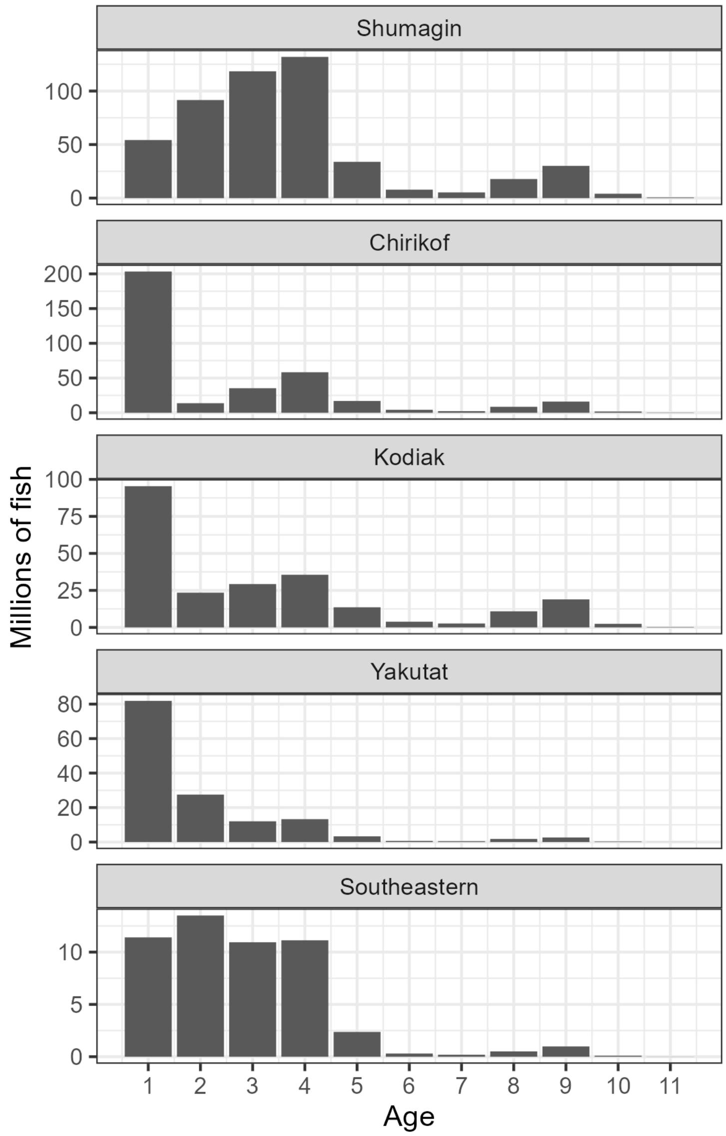


Figure 1.8. Age composition of pollock by statistical area for the2021 NMFS bottom trawl survey.

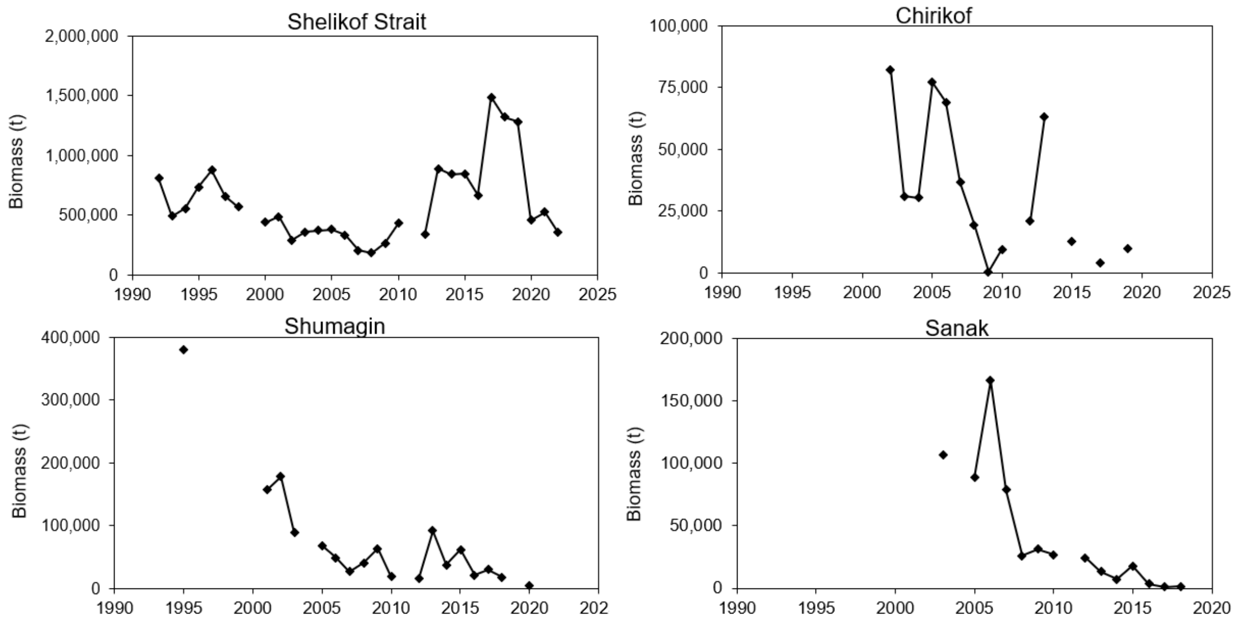


Figure 1.9. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

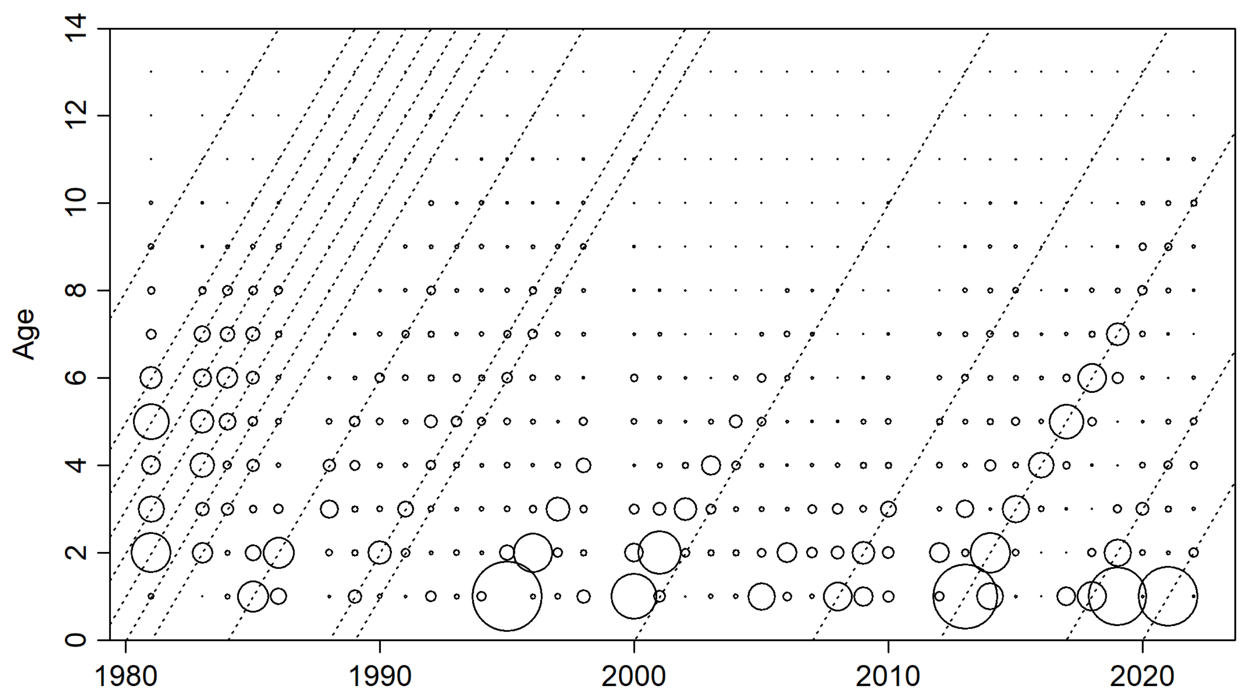


Figure 1.10. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2022 except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

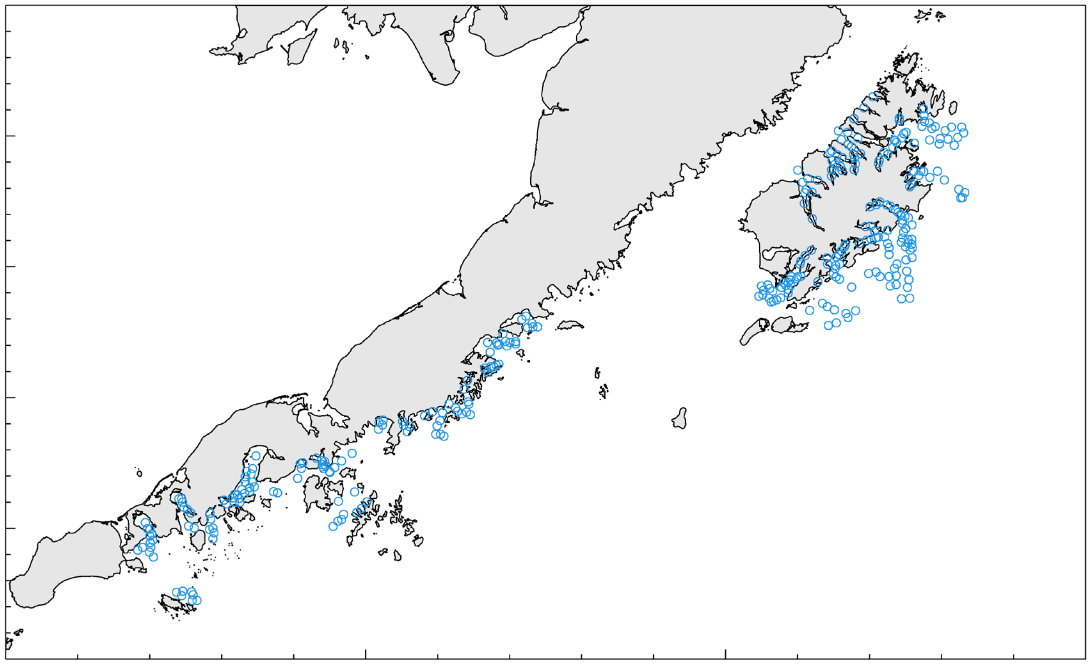


Figure 1.11. Tow locations for the 2022 ADF&G crab/groundfish trawl survey.

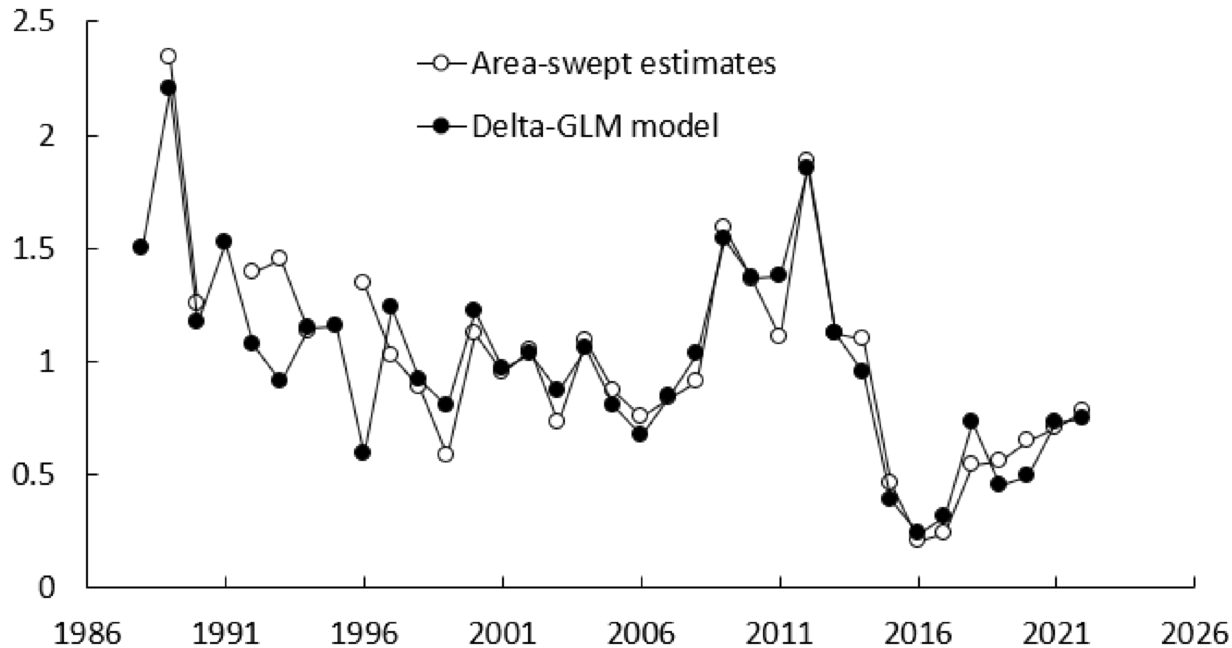


Figure 1.12. Comparison of ADF&G crab/groundfish trawl area-swept indices with year indices for a delta GLM model with a gamma error assumption for the positive observations. Both time series have been scaled by the mean for the time series.

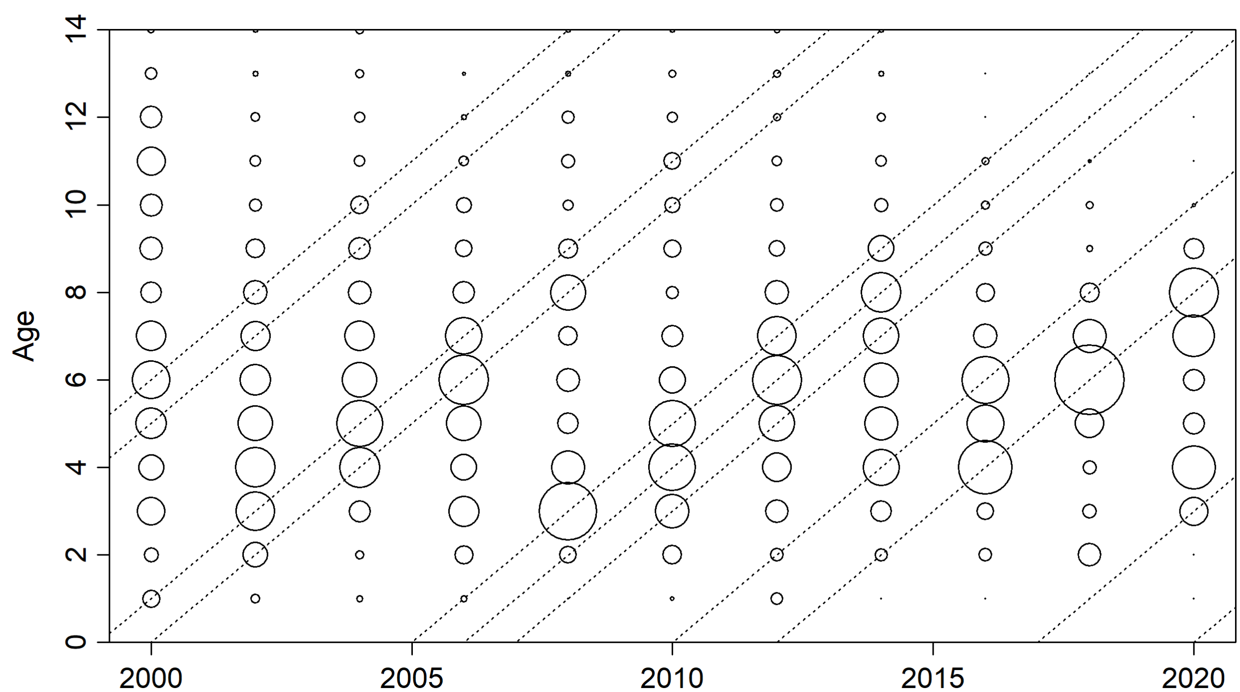


Figure 1.13. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2020). The area of the circle is proportional to the estimated abundance.

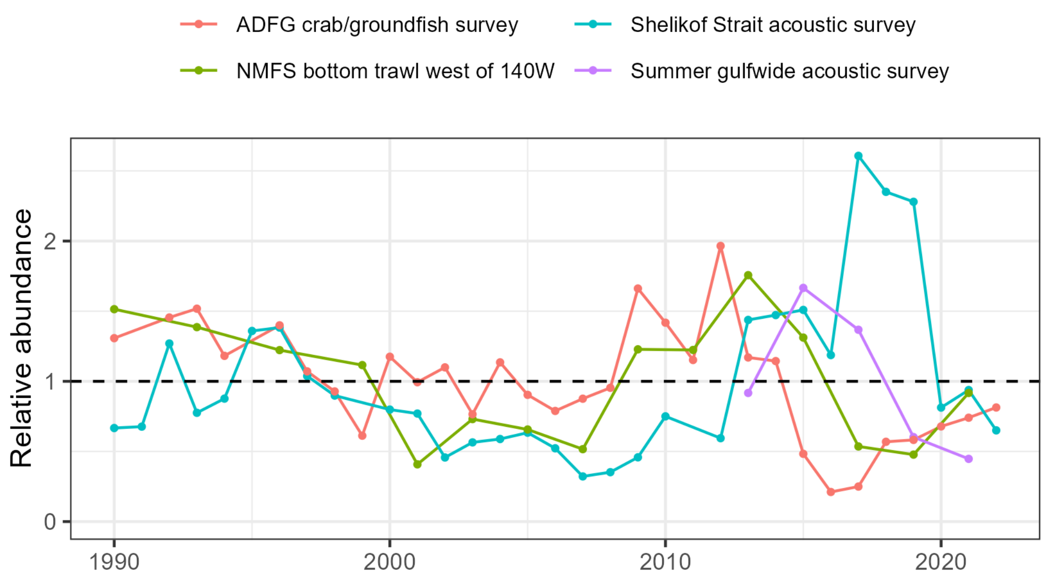


Figure 1.14. Relative trends in pollock biomass since 1990 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1990. Shelikof Strait acoustic surveys prior to 2008 were re-scaled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

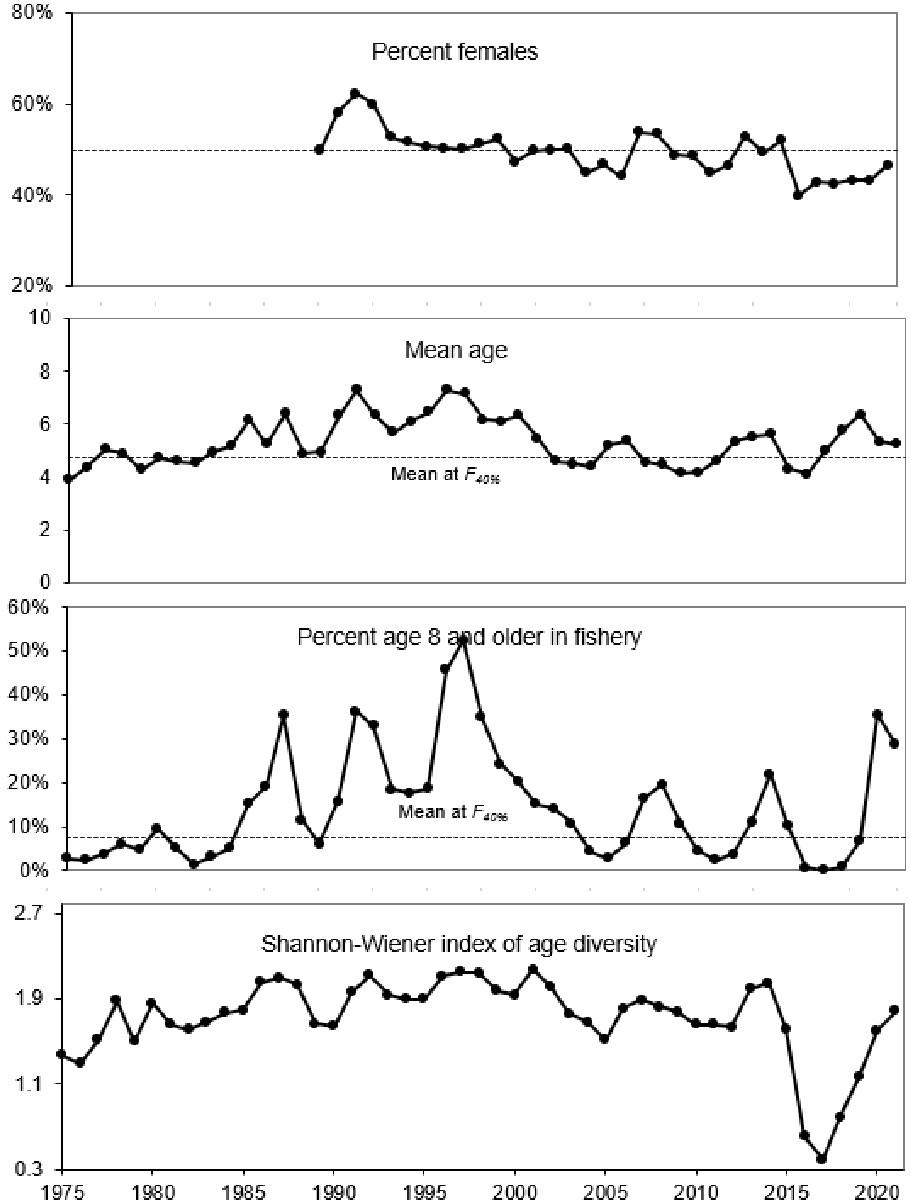


Figure 1.15. GOA pollock fishery catch characteristics.

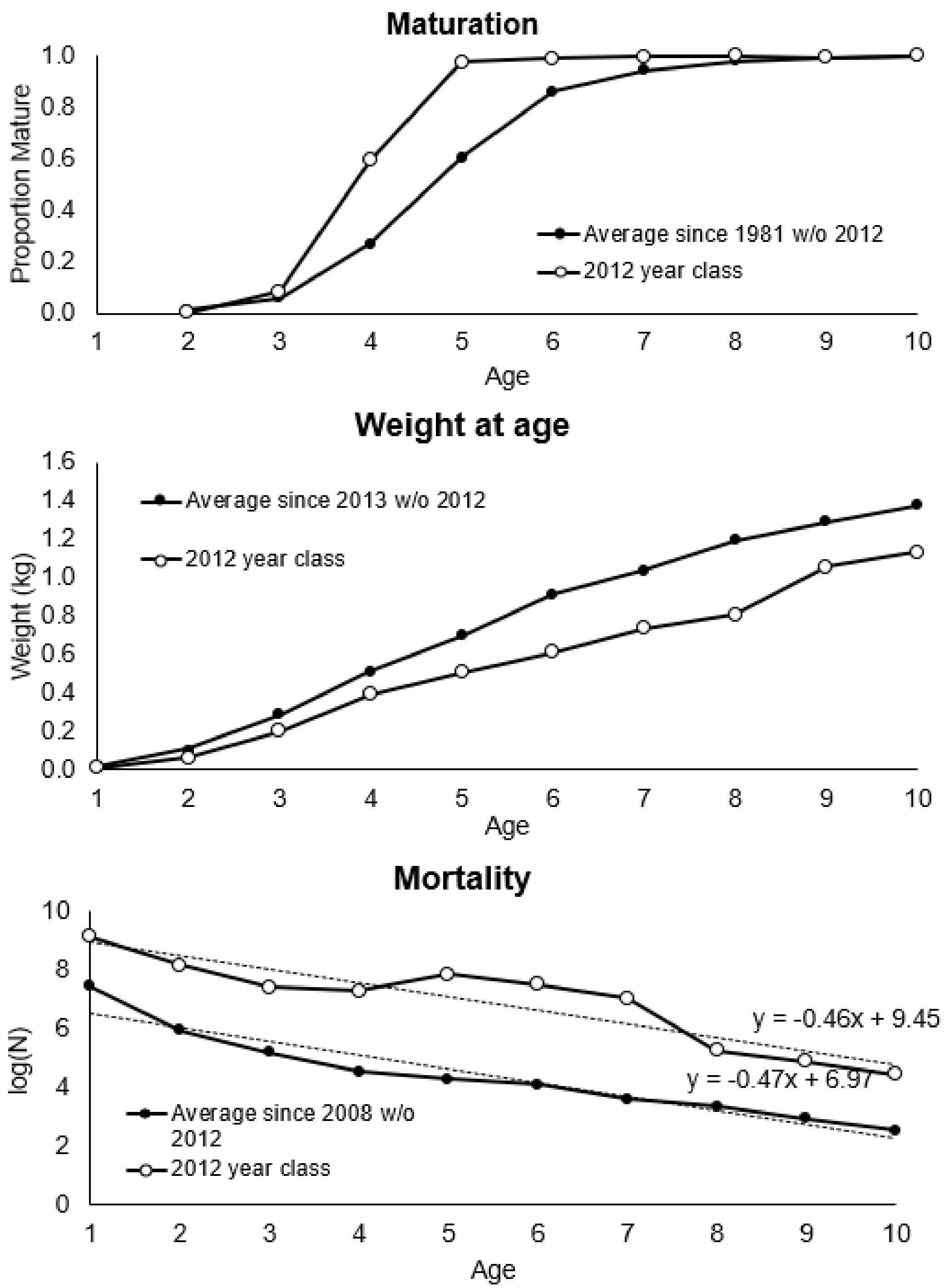


Figure 1.16. Comparison of 2012 year class maturation, growth, and mortality with average characteristics. Maturity is based on sampling during winter acoustic surveys. Weight at age is a comparison of the 2012 year class in the winter acoustic survey with the average weight at age since 2013 excluding the 2012 year class. The mortality plot is catch curve analysis of the Shelikof Strait survey. The negative of the slope of a linear regression of log(N) on age is an estimate of total mortality (Z).

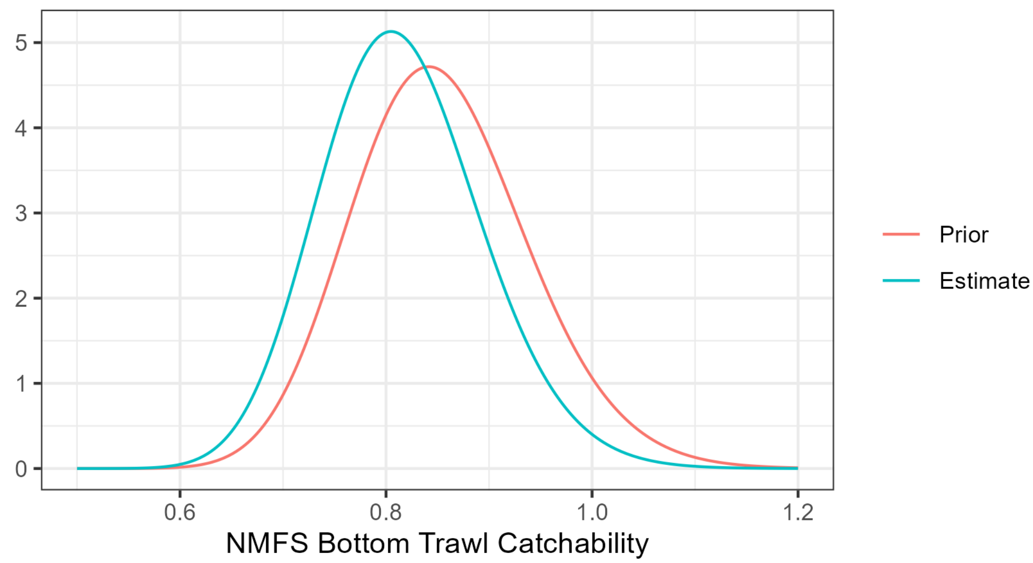


Figure 1.17. Prior on bottom trawl catchability used in the base model, and the estimate and uncertainty from the base model.

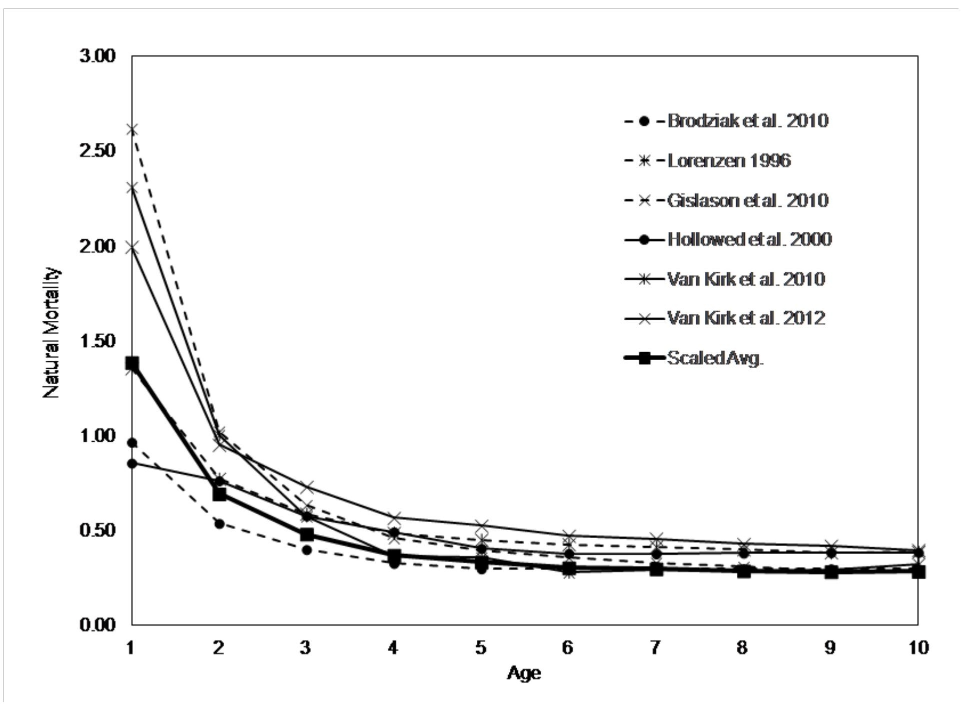


Figure 1.18. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model.

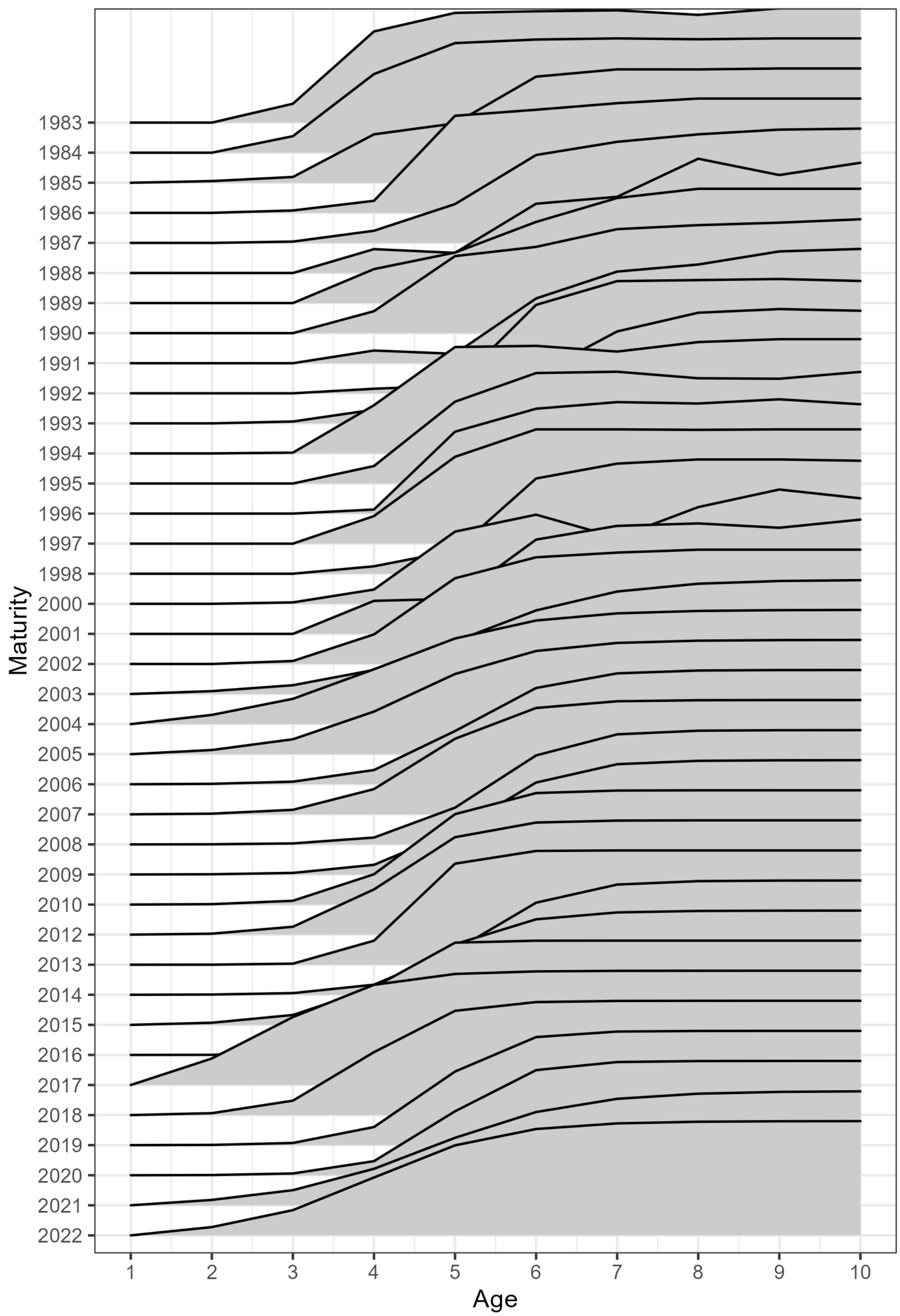


Figure 1.19. Estimates of the proportion mature at age from weighted visual maturity data collected on winter acoustic surveys in the Gulf of Alaska for all years. Maturity for age-1 fish is assumed to be zero.

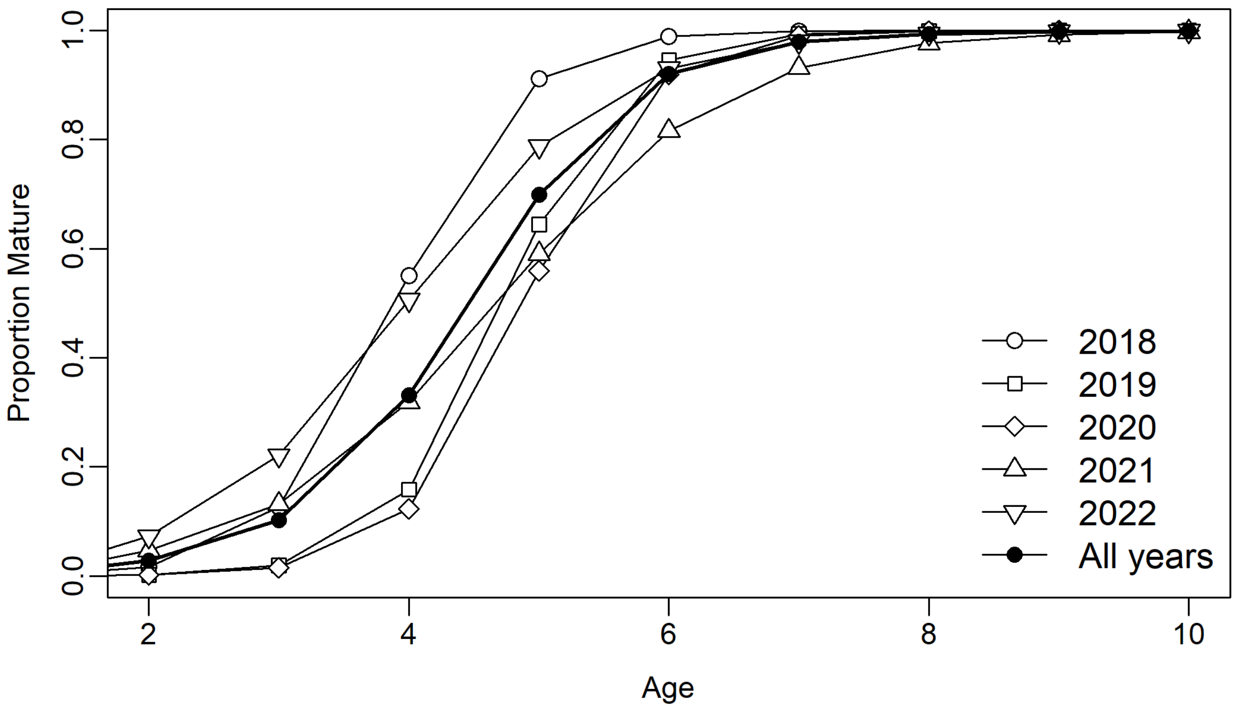


Figure 1.20. Estimates of the proportion mature at age from weighted visual maturity data collected during 2018-2022 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2022). Maturity for age-1 fish is assumed to be zero.

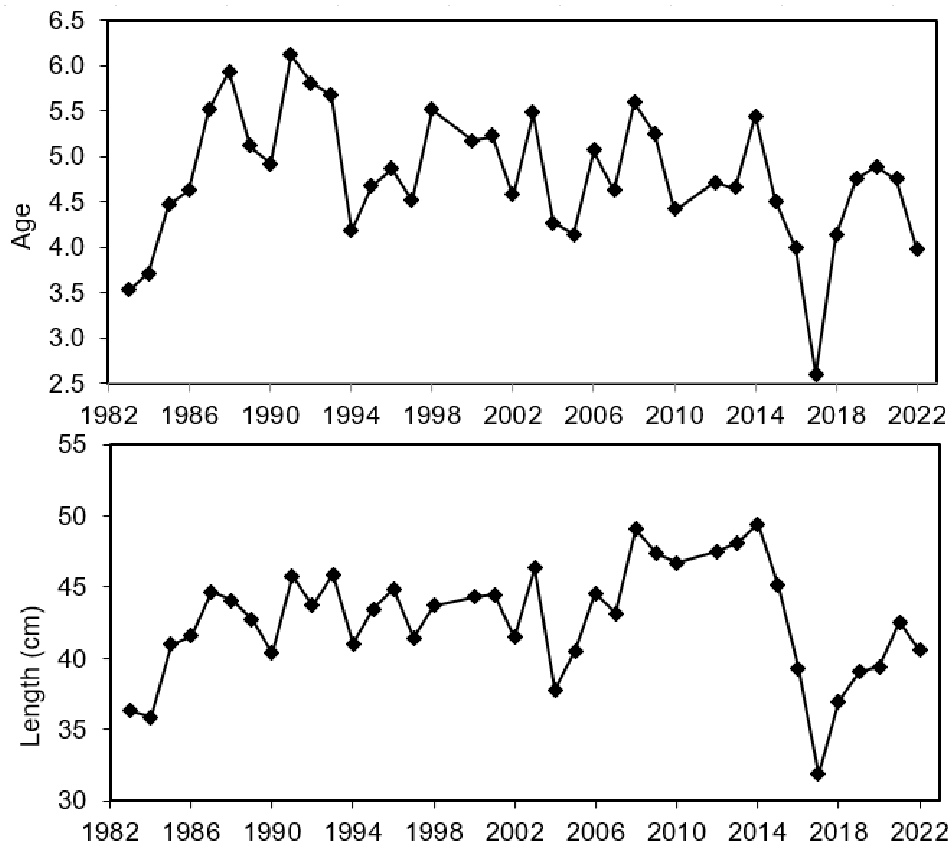


Figure 1.21. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska. Estimates since 2003 are weighted by local abundance.

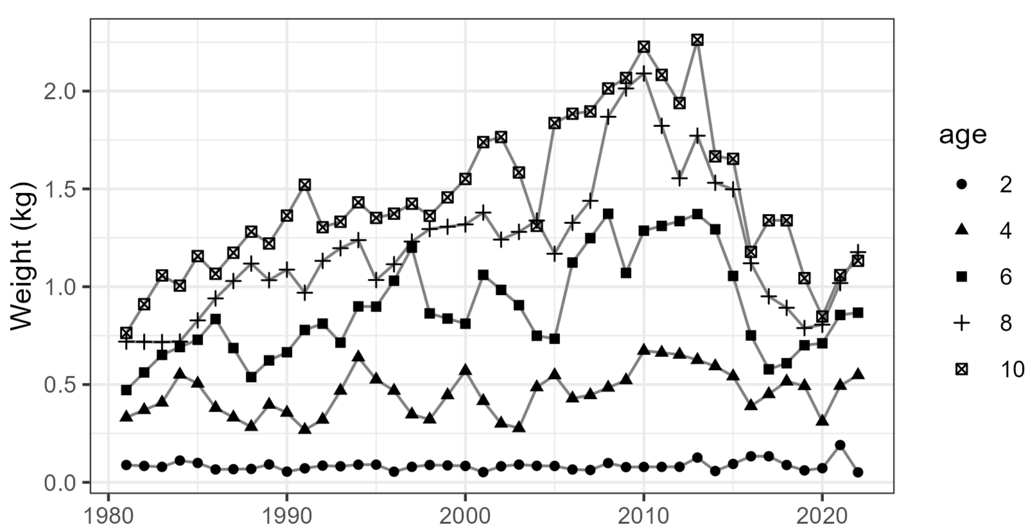


Figure 1.22. Estimated weight at age of GOA pollock (ages 2, 4, 6, 8, and 10) from Shelikof Strait acoustic surveys used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from surveys in adjacent years.

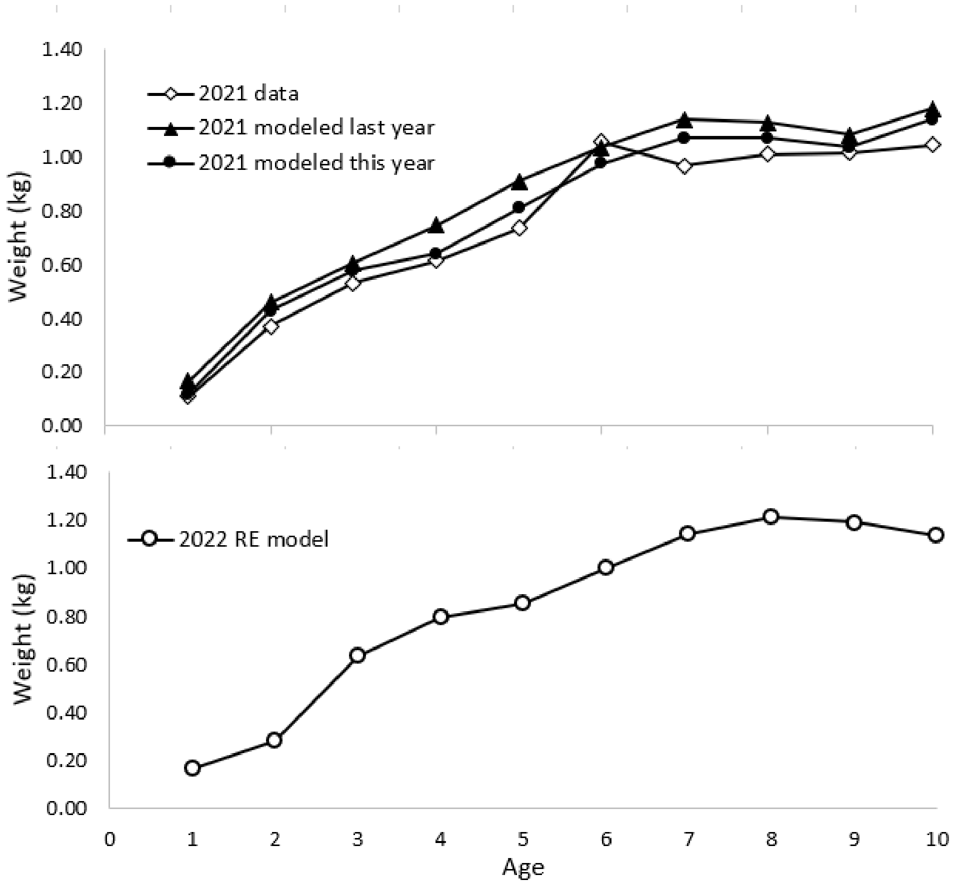


Figure 1.23. Comparison of fishery weight at age for 2021 with estimates from the random effects model last year and this year' assessment (top panel). Random effects model estimates for 2022 used in the assessment model and for yield projections (bottom panel).

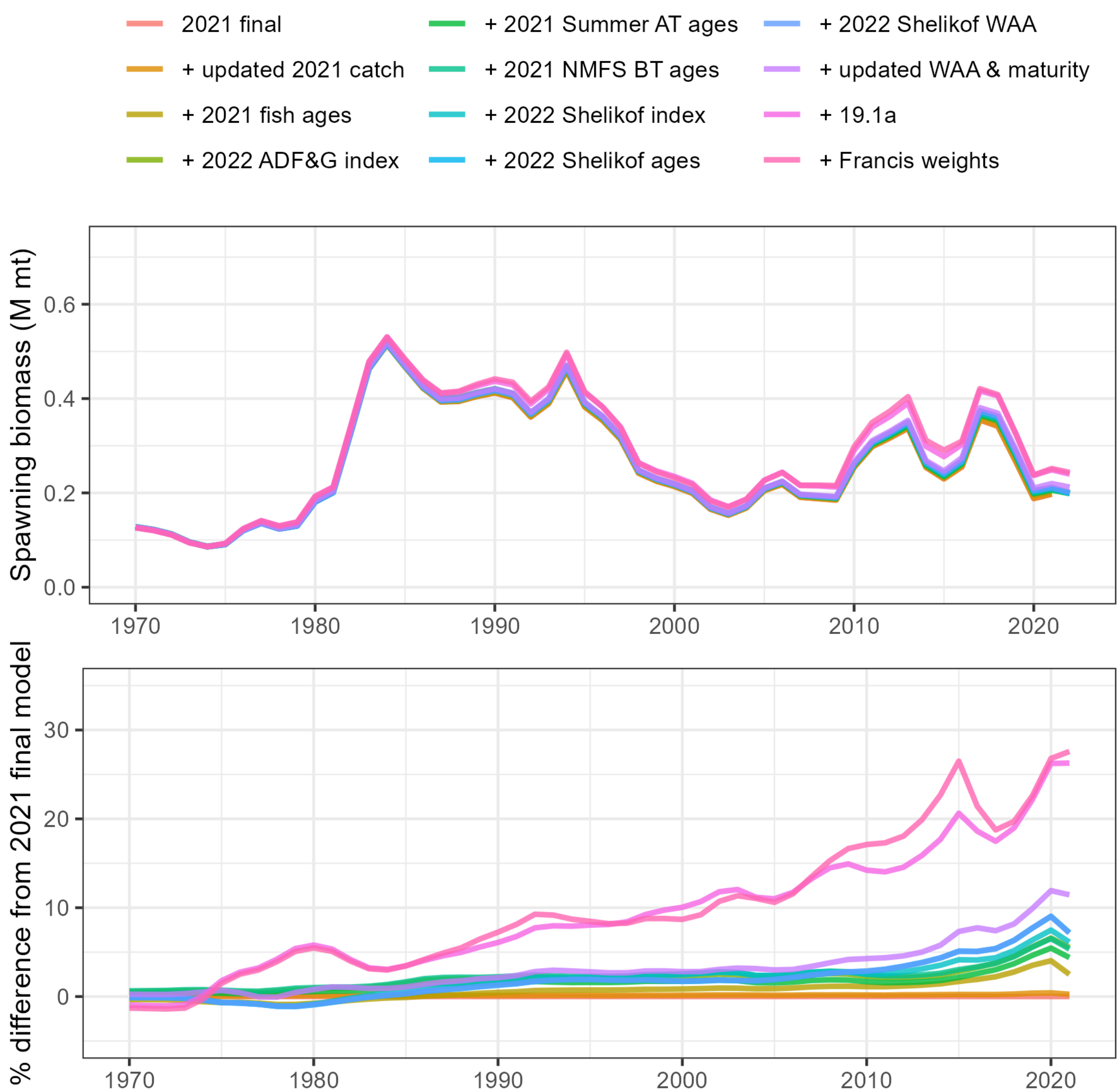


Figure 1.24. Changes in estimated spawning biomass as new data were added successively to last year's base model, ordered by row in the legend at the top. The lower panel shows recent years with an expanded scale to highlight differences.

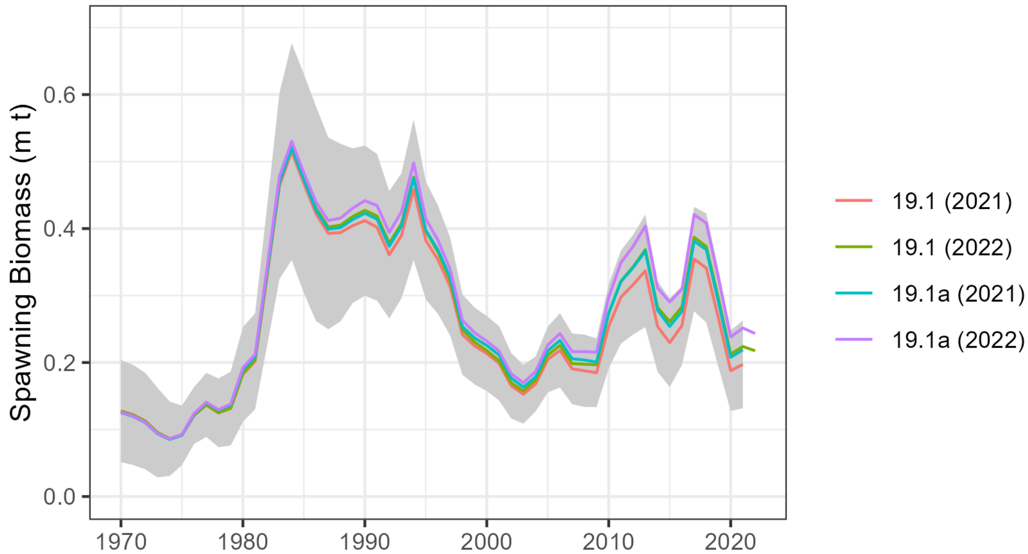


Figure 1.25. Estimated SSB for the previous (19.1) and new (19.1a) models run with the 2021 and 2022 data. The gray ribbon shows the 95% confidence intervals for the 2021 final model.

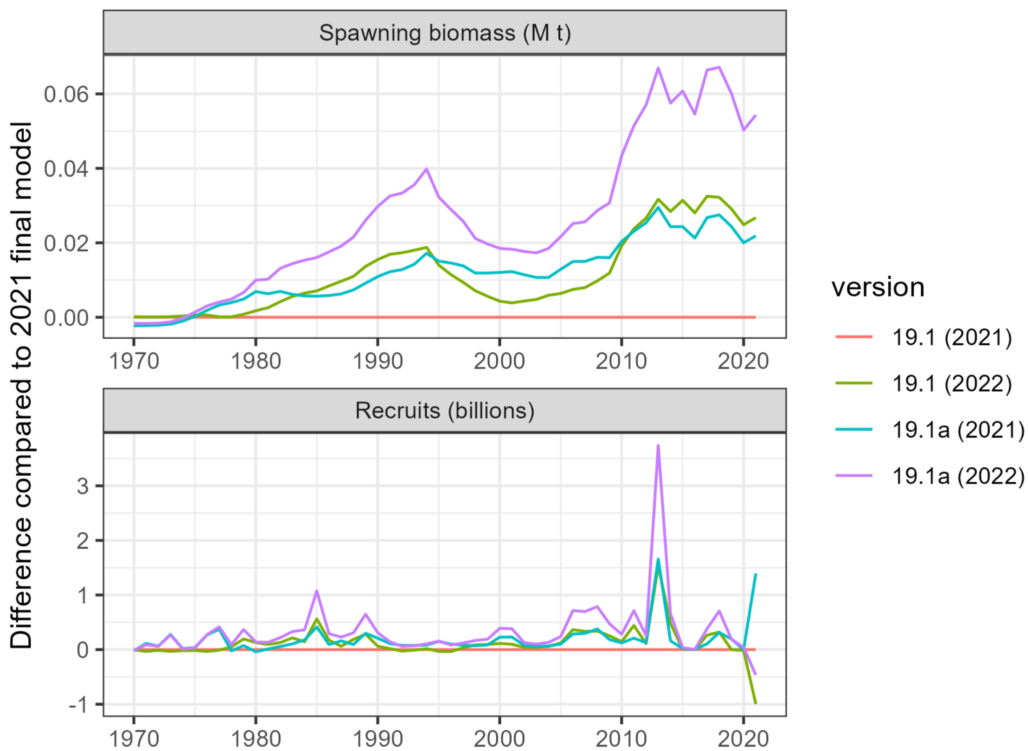


Figure 1.26. Absolute differences in SSB, summary biomass, and recruits (panels) from the final 2021 model for the previous (19.1) and new (19.1a) models run with the 2021 and 2022 data.

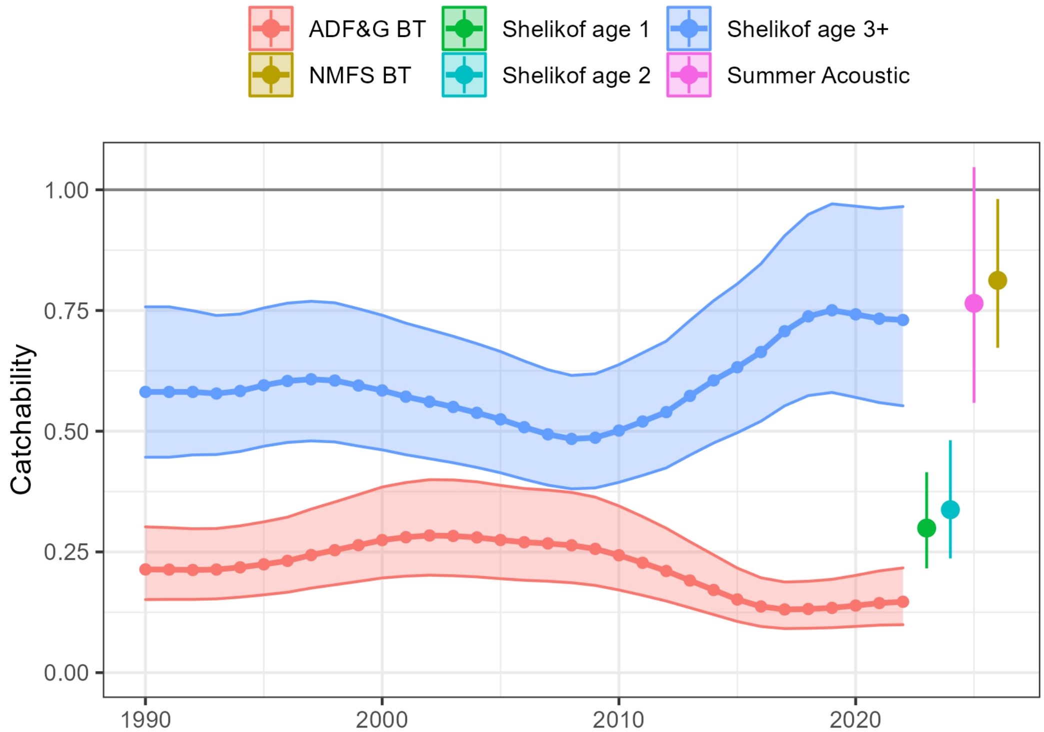


Figure 1.27. Time-varying catchability for the Shelikof Strait acoustic survey (Survey 1), the ADF&G crab/groundfish trawl survey (Survey 3), and constant catchability for the NMFS bottom trawl (Survey 2) and the age-1 and age-2 Shelikof indices (Surveys 4 and 5; representing selectivity), and for the summer NMFS acoustic survey (Survey 6), for model 19.1a. Ribbons and lines represent the 95% CI

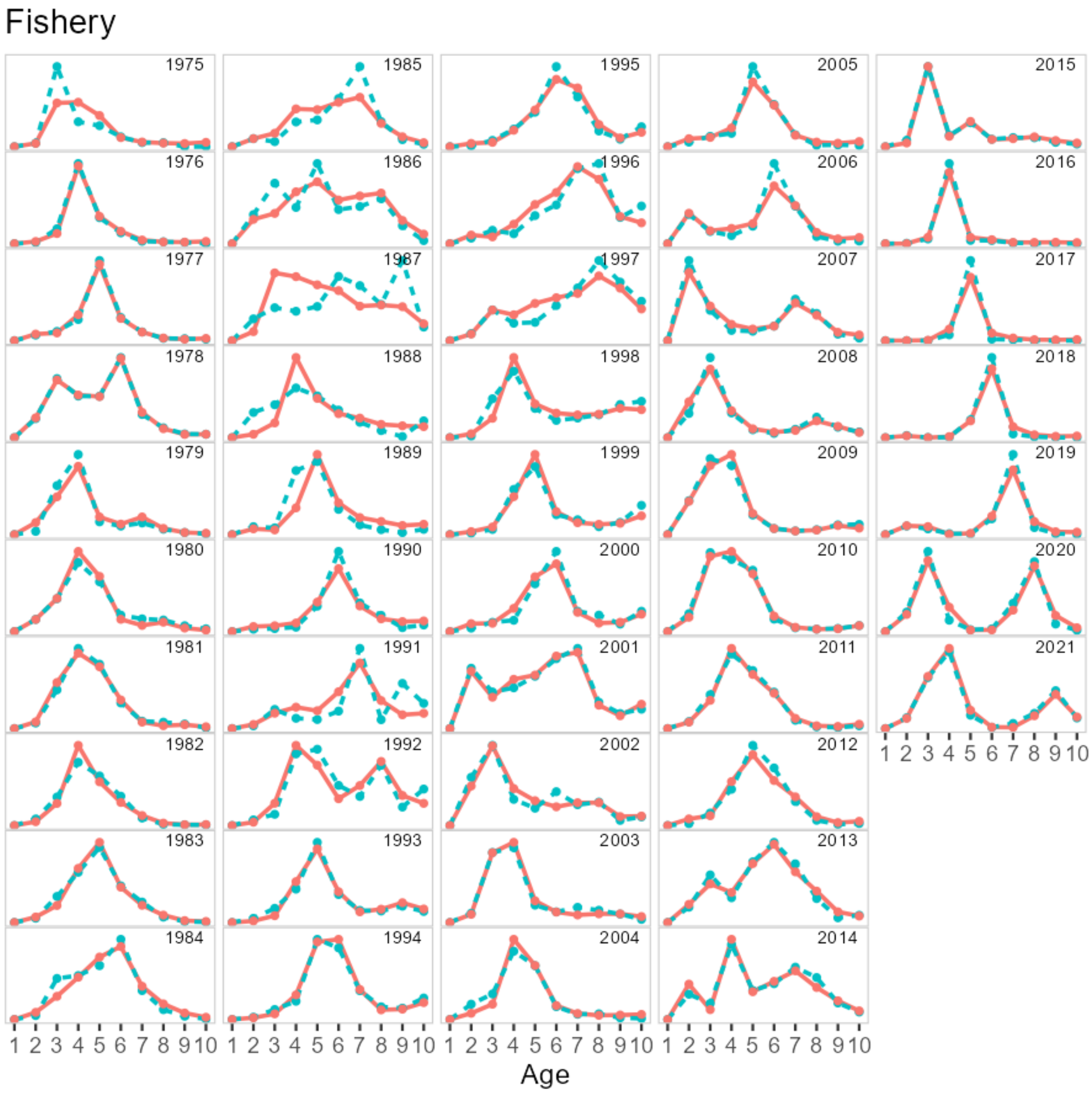


Figure 1.28. Observed and predicted fishery age composition for GOA pollock from the base model. Dashed blue lines are observations and solid red lines are model expectations.

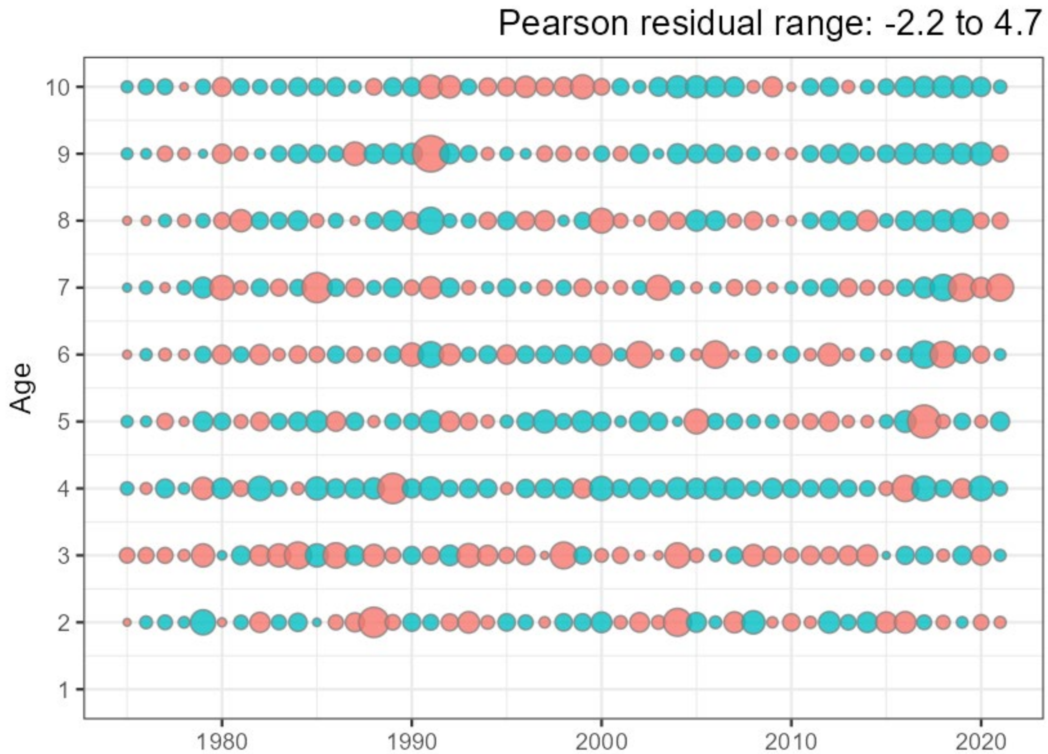


Figure 1.29. Pearson residuals for fishery age composition. Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

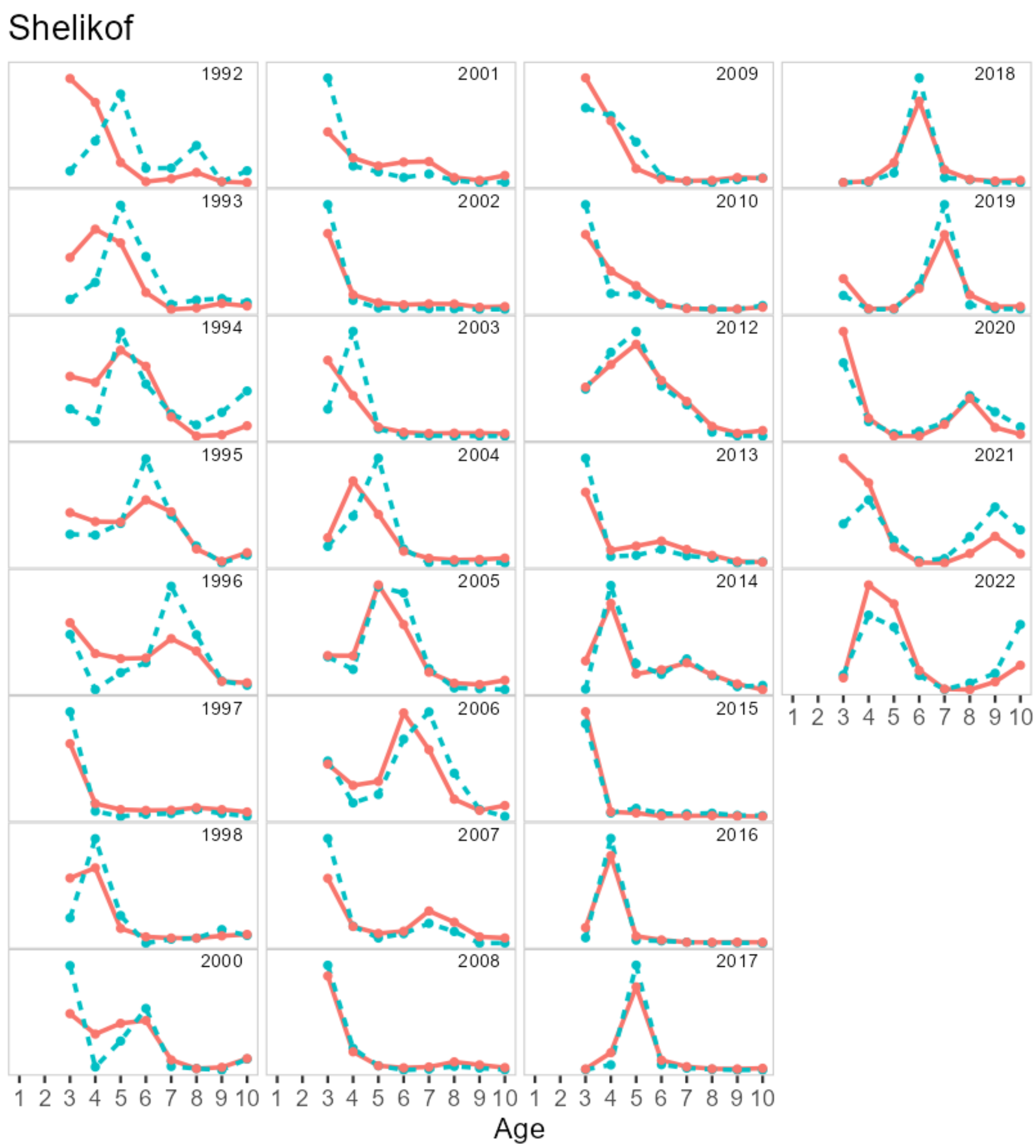


Figure 1.30. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Dashed blue lines are observations and solid red lines are model expectations. Age 1 and 2 fish are modeled separately and excluded.

Figure 1.31. 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.

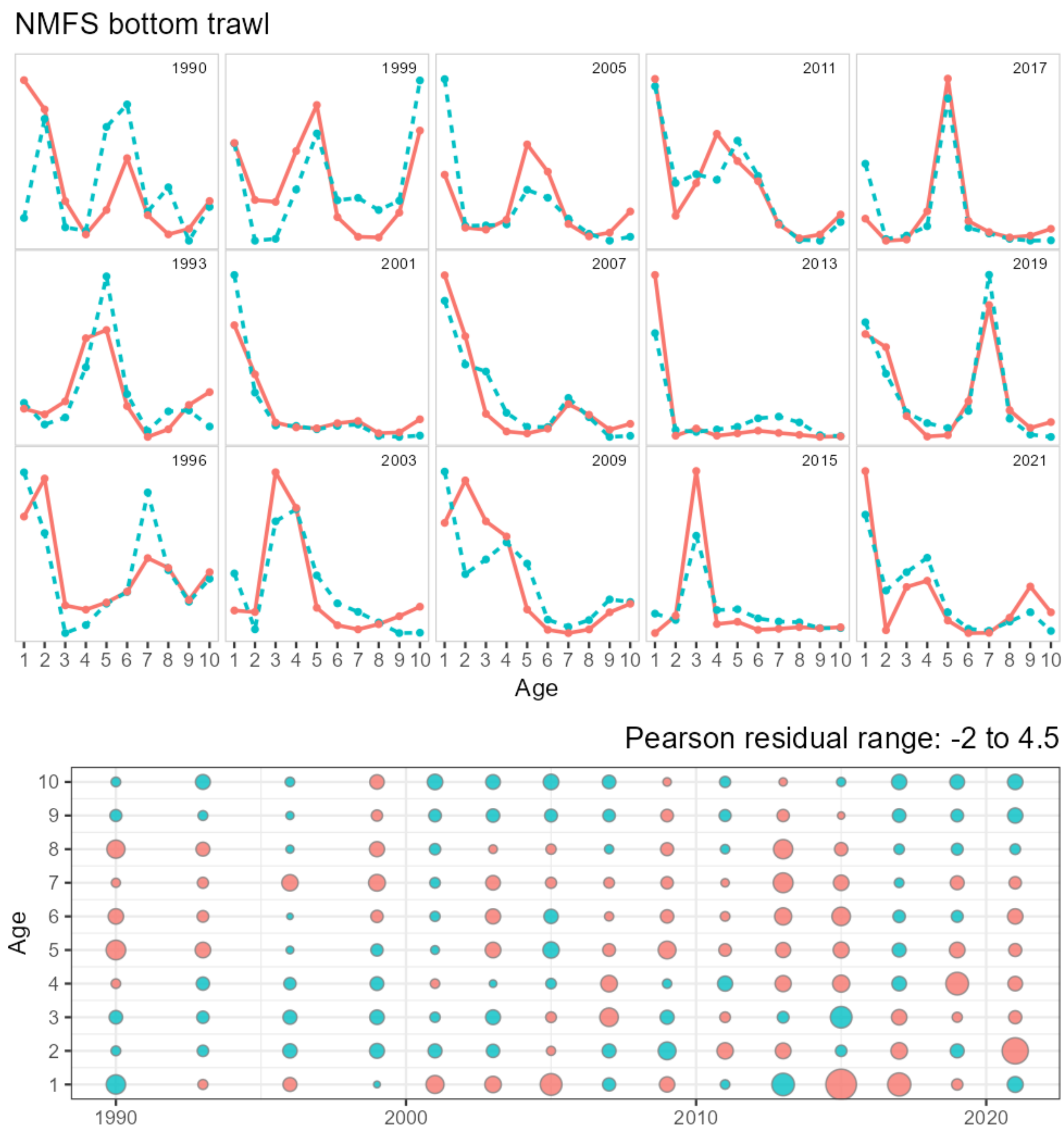


Figure 1.32. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. Pearson residuals for NMFS bottom trawl survey (bottom). Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

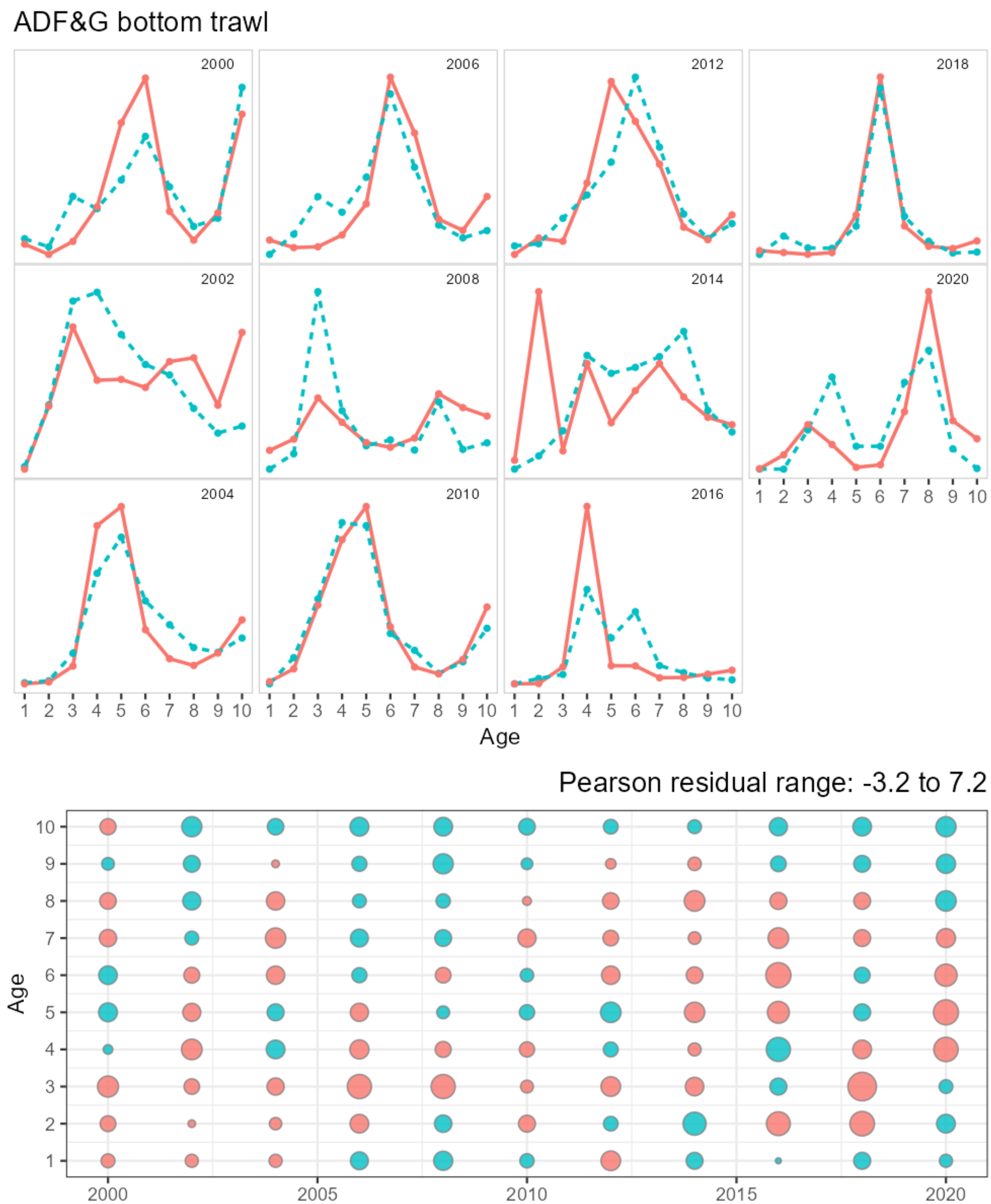


Figure 1.33. Observed and predicted ADF&G bottom trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. Pearson residuals for ADF&G bottom trawl survey (bottom). Negative residuals are filled blue and positive filled red. Circle area is proportional to the magnitude of the residual.

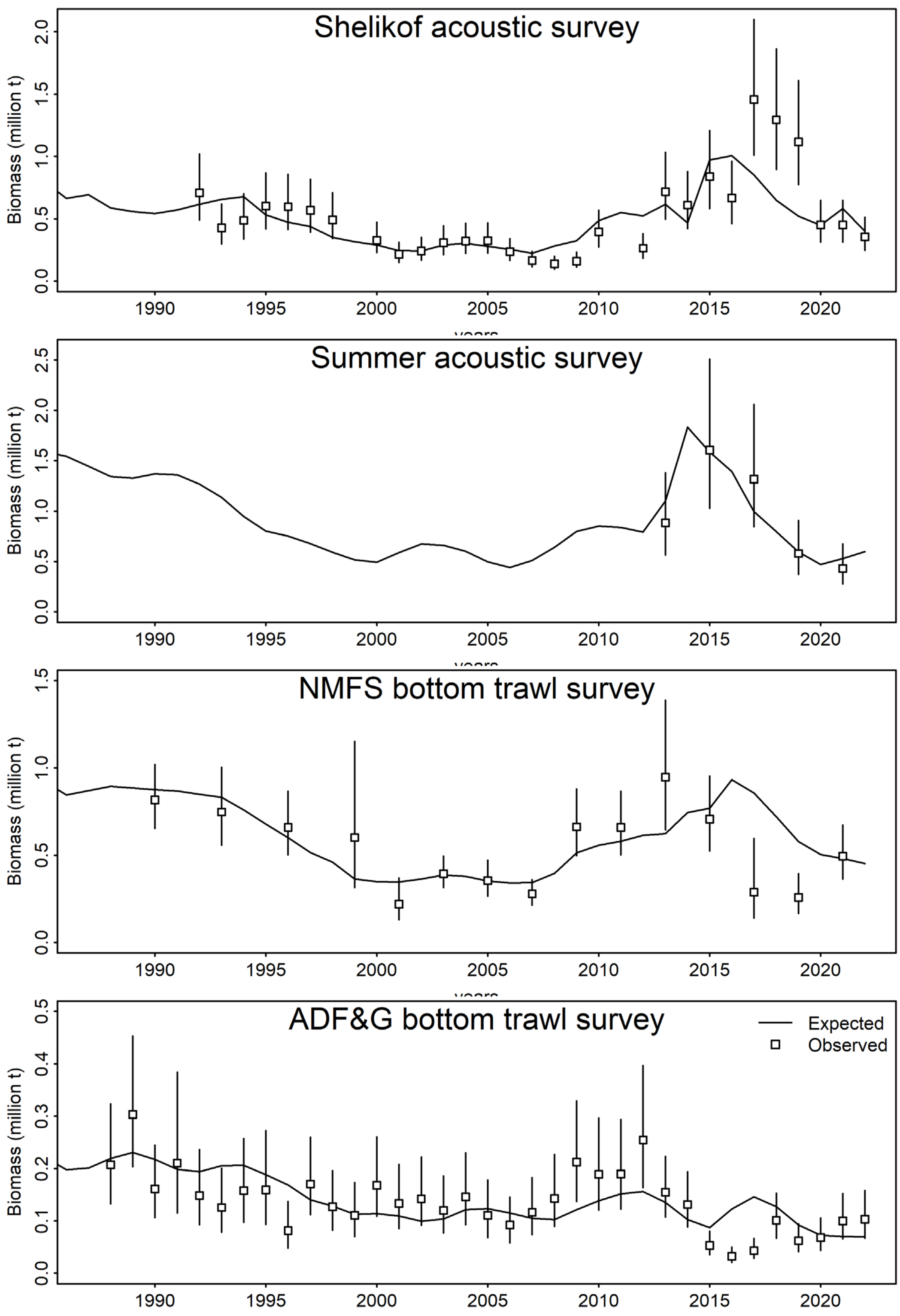


Figure 1.34. Model predicted (line) and observed survey biomass (points and 95% confidence intervals) for the four surveys. The Shelikof survey is only for ages 3+.

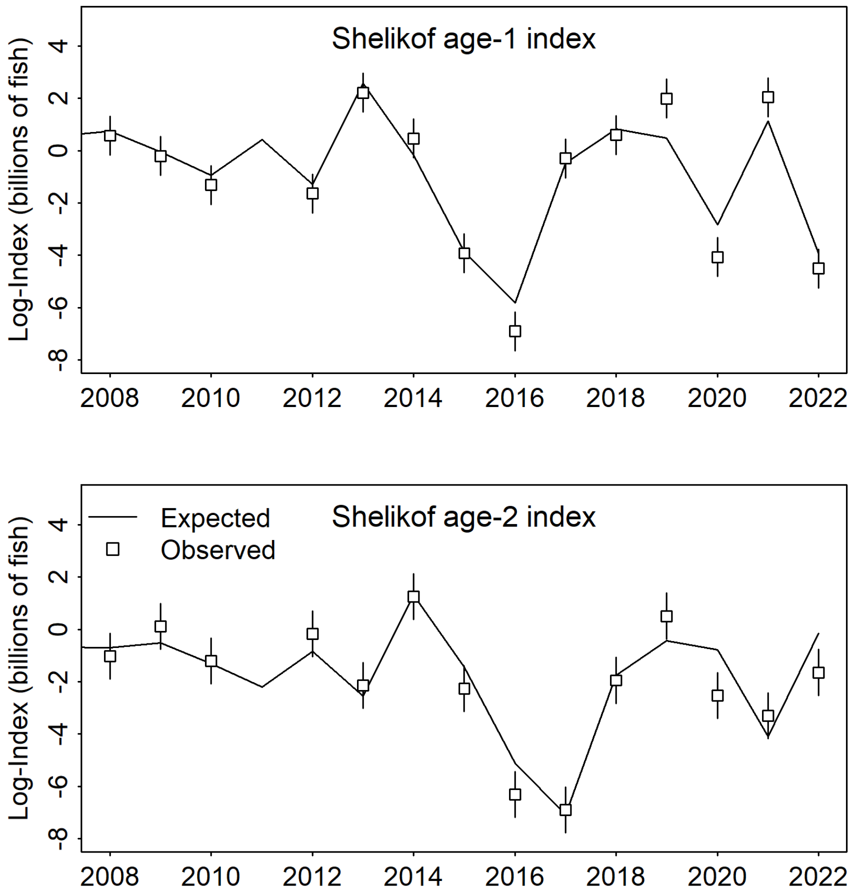


Figure 1.35. Model predicted (line) and observed survey biomass (points and 95% confidence intervals) for the age 1 and age 2 winter Shelikof surveys.

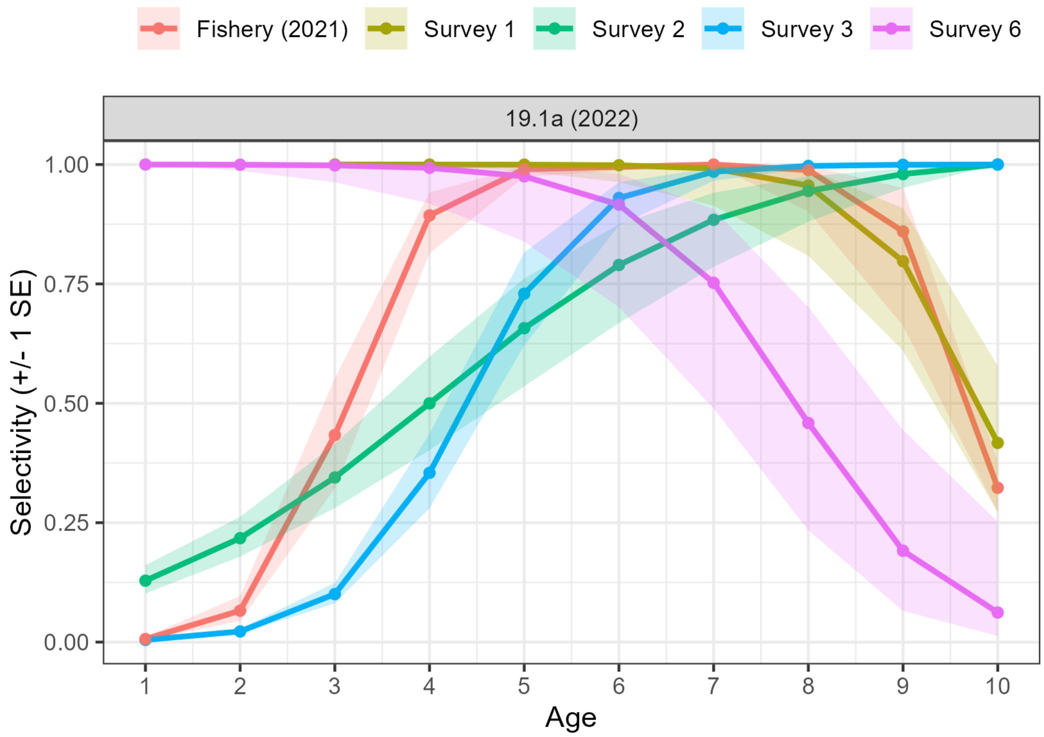


Figure 1.36. Estimated selectivity at age (lines) and uncertainty (+/- 1 SE; ribbons) for the fishery and surveys. Uncertainty calculations are done in logit space then converted and hence are asymmetric.

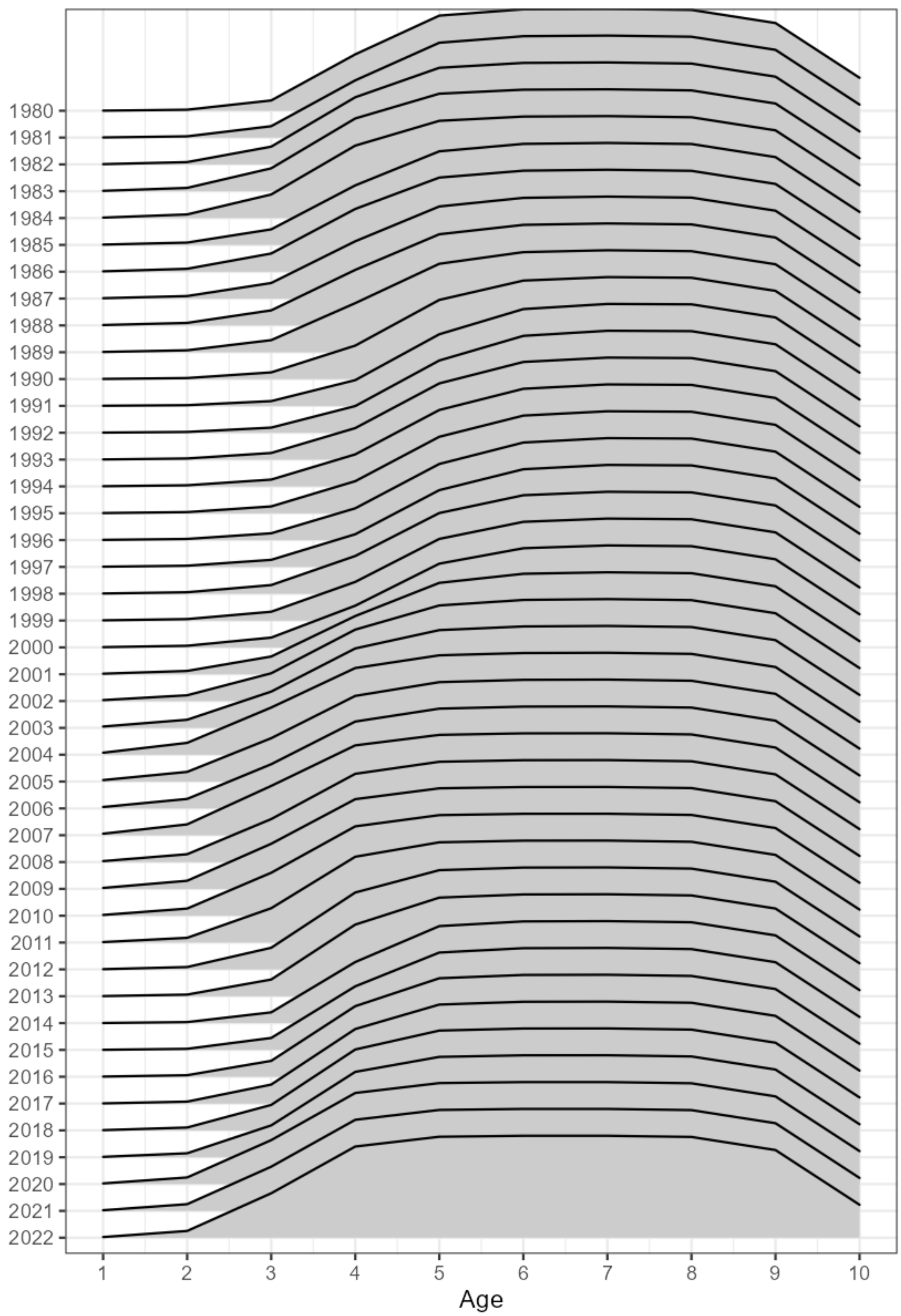


Figure 1.37. Estimates of time-varying double-logistic fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.

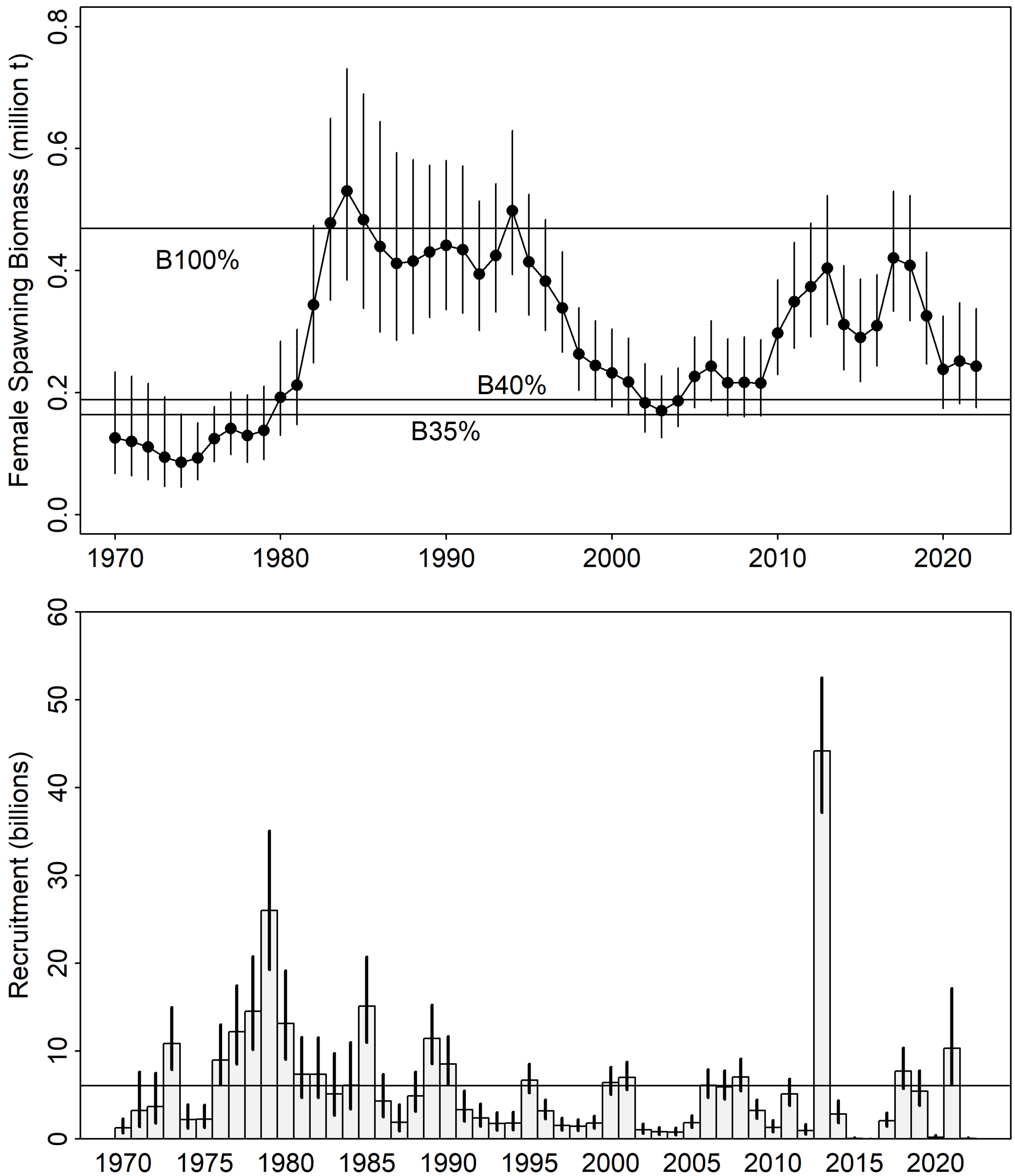
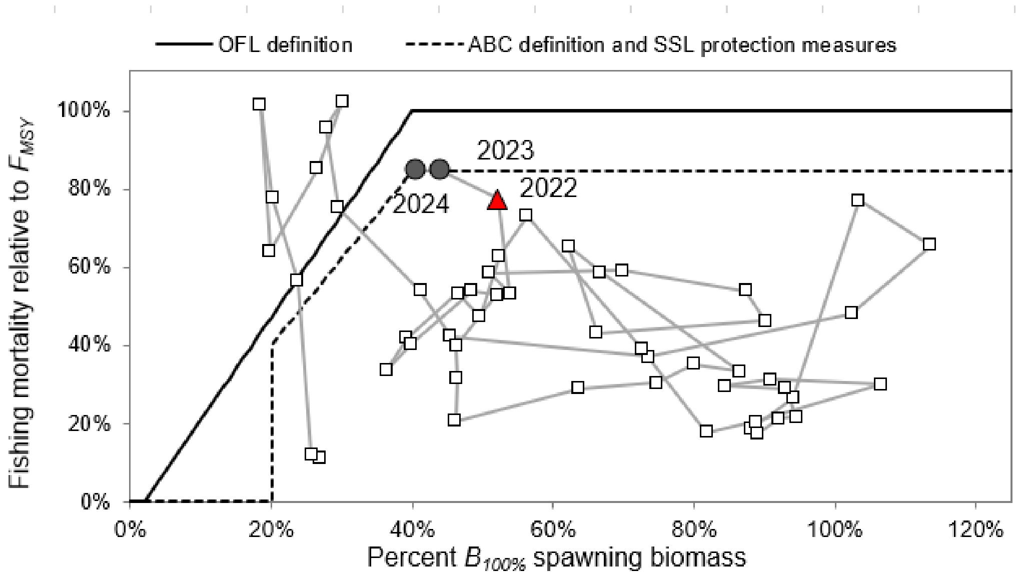


Figure 1.38. Estimated time series of GOA pollock spawning biomass (top) and age 1 recruitment (bottom) for the base model, with horizontal line at the average from 1978-2021. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.



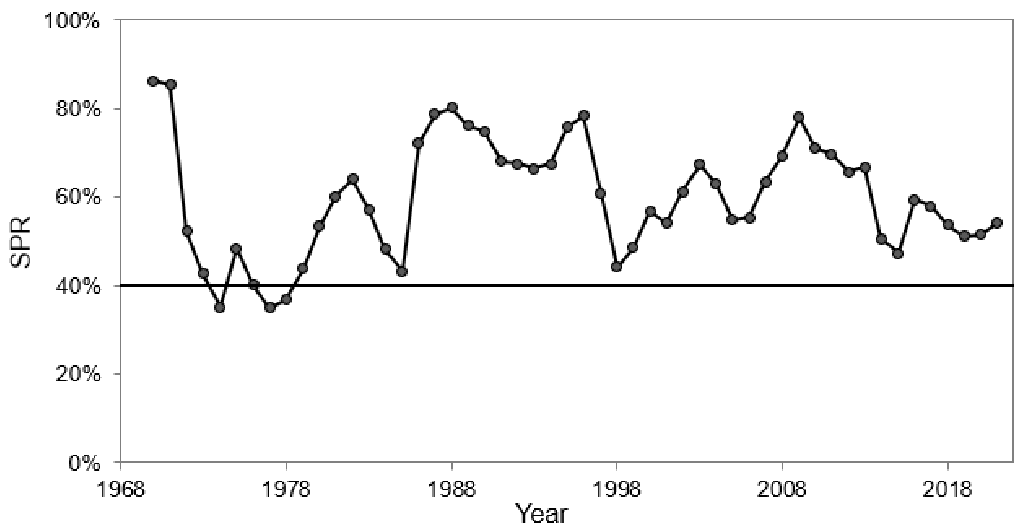


Figure 1.39. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to FMSY (bottom). The ratio of fishing mortality to FMSY is calculated using the estimated selectivity pattern in that year. Estimates of B100% spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

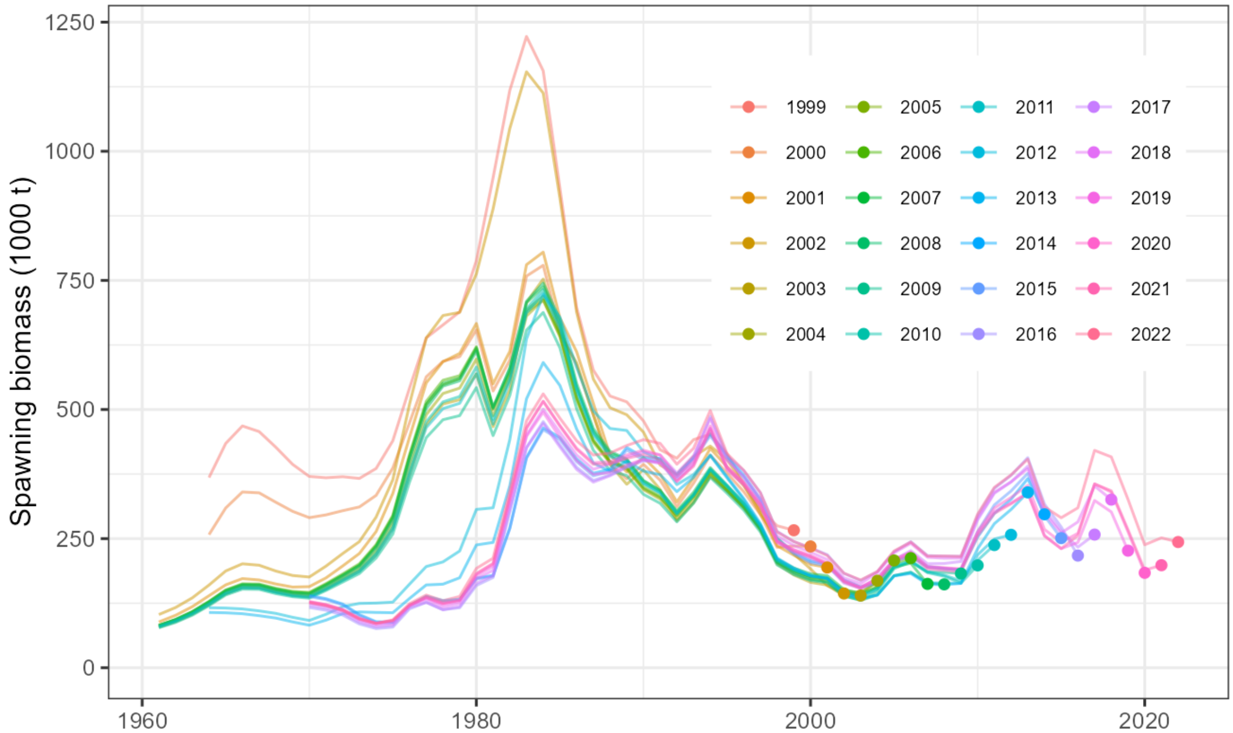


Figure 1.40. Estimated female spawning biomass for historical stock assessments conducted between 1999-2022. Lines reprsent the estimate in the assessment year and point is the terminal estimate in that year.

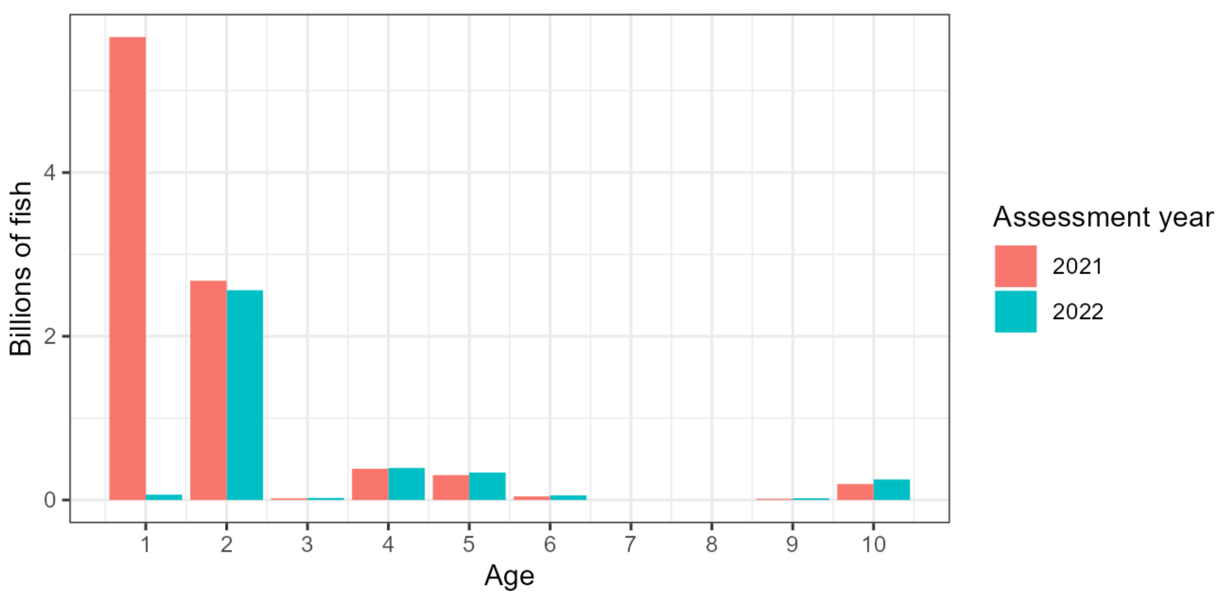


Figure 1.41. The estimated age composition in 2022 from the 2021 and 2022 assessments. The age-1 recruits have no information in the 2021 assessment and so are the average and hence not comparable

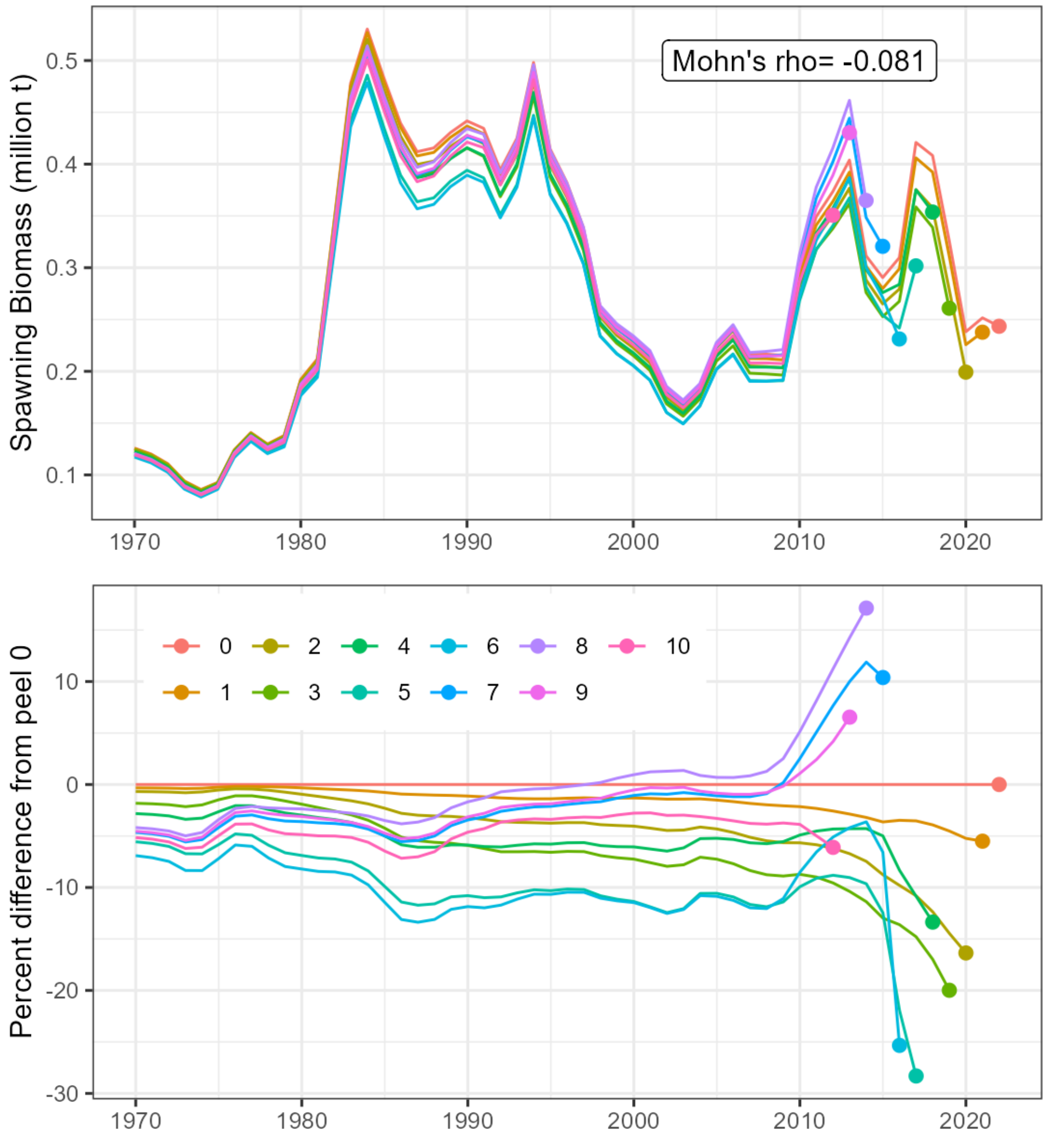


Figure 1.42. Retrospective plot of spawning biomass for models ending in years 2012-2021 for the 2022 base model. The revised Mohn's rho (Mohn 1999) for ending year spawning biomass is -0.081.

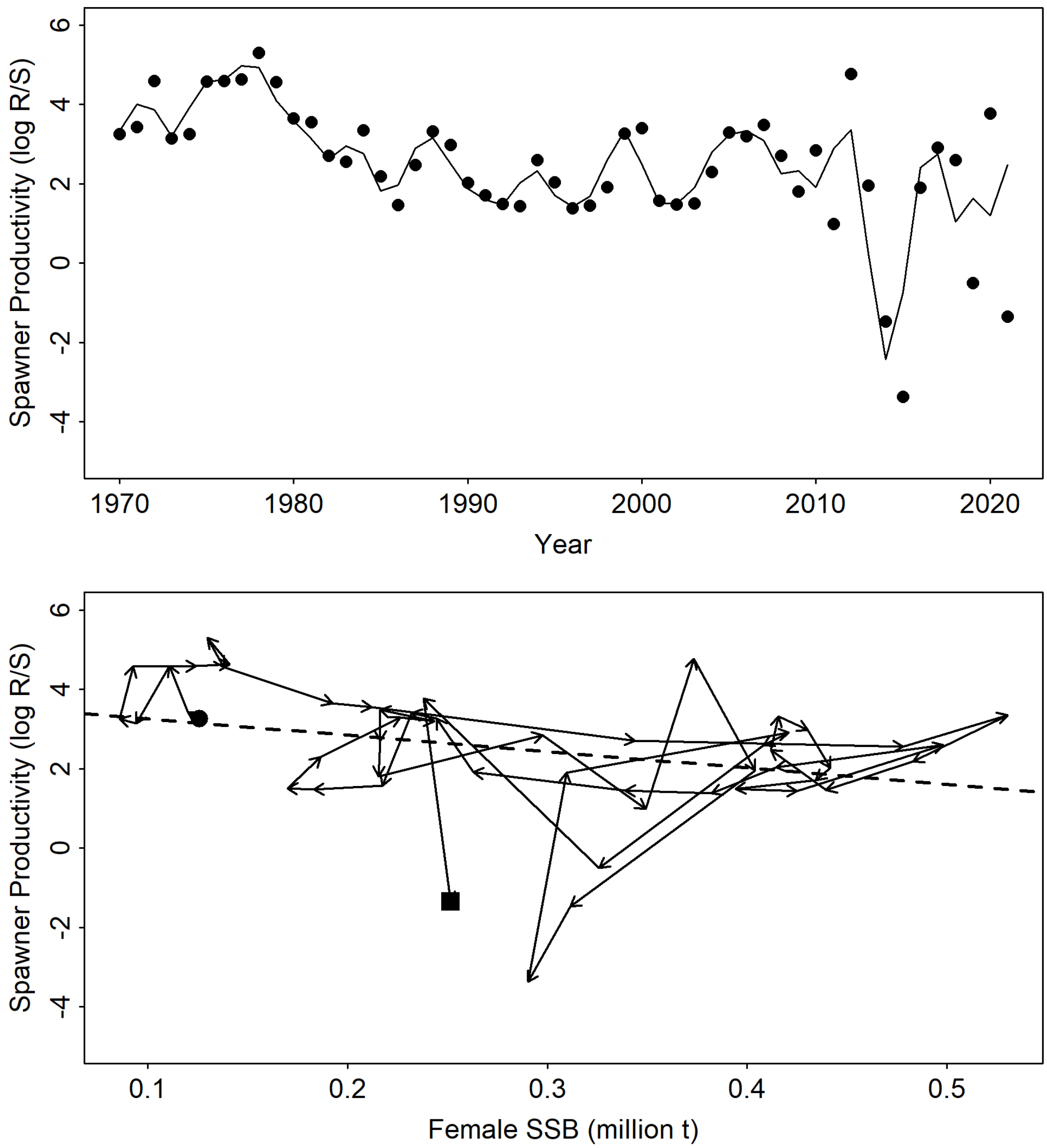


Figure 1.43. GOA pollock spawner productivity, log(R/S), in 1970-2019 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

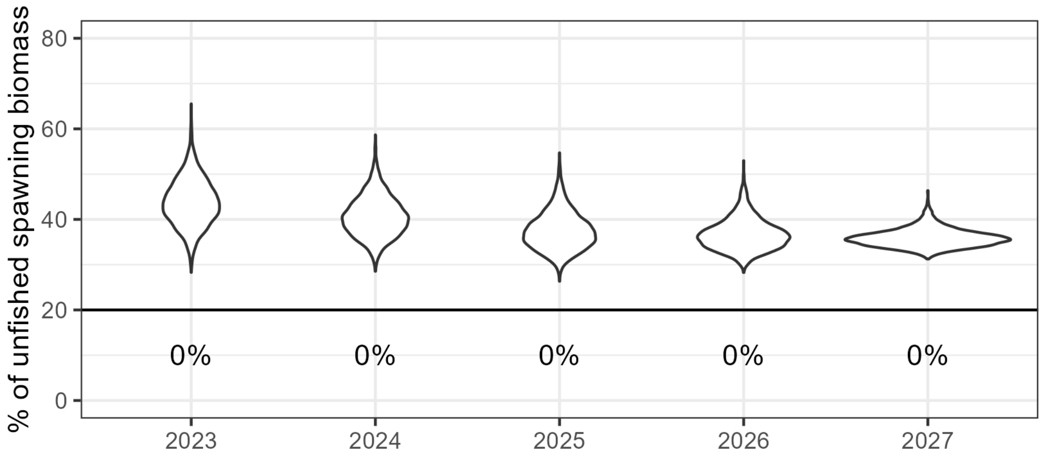


Figure 1.44. Uncertainty in spawning biomass in 2022-2026 based on a posterior samples from MCMC from the joint likelihood for the base model where catch is set to the maximum permissible FABC. Shown are the percentage below the horizontal line at 20% for each year.

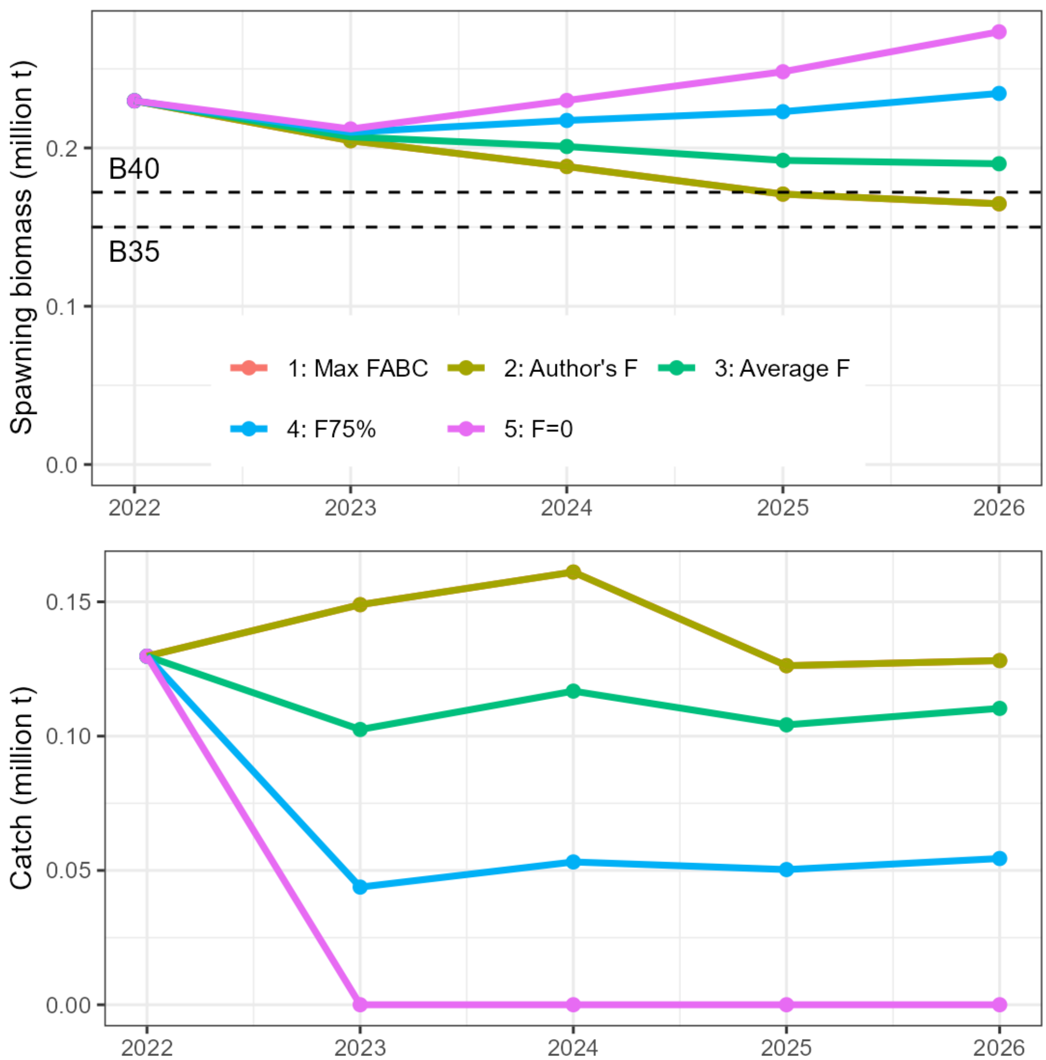


Figure 1.45. Projected mean spawning biomass and catches in 2022-2026 under different harvest rates.

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

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

November 2022

With Contributions from:

Kerim Aydin, Steve Barbeaux, Cheryl Barnes, Matt Callahan, Curry Cunningham, Ben Fissel, Dan Goethel, Peter-John Hulson, David Kimmel, Ben Laurel, Jean Lee, Mike Litzow, Krista Oke, Zack Oyafuso, Patrick Ressler, Katie Sweeney, Abigail Tyrell, Jordan Watson, 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) walleye pollock (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:

- Average temperature both at surface and depth, average marine heatwave events and average northwesterly wind suggest average egg and larval habitat conditions.
- Mixed lower trophic indicators (> in chlorophyll *a* concentration, earlier spring bloom peak (but still later than average), lower planktivore success) suggest average larval prey resources.
- Slightly above average nearshore CPUE in Kodiak suggest some potential for recruitment, but limited spatial coverage.
- Condition of fall and winter adult pollock were below average, suggesting some reduction of prey resources for juveniles and adults.
- Biomass estimates of Pacific ocean perch and sablefish continue to be large with a stable but low biomass estimate of arrowtooth flounder as competitors and predators of GOA pollock.
- Fishery CPUE in the winter spring decreased but remained above average in 2022 implying pollock were concentrated, so catch rates were higher and roe may be in better condition.
- Ex-vessel price remained stable and low in 2021 and roe-per-unit-catch in the fishery increased but remained low in 2022.
- Overall, ecosystem indicators were average to below average in 2022 (but fewer updates this year) with socioeconomic indicators above and below average in 2021 and average in 2022 (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 predictor variables of GOA pollock recruitment based on the importance methods in the intermediate stage indicator analysis 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 annual sablefish biomass, the annual Pacific ocean perch biomass, and the annual arrowtooth flounder 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

Figure 1A.1 provides a life history conceptual model for GOA pollock that summarizes ecological information and key ecosystem processes affecting survival by life stage. 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 (Bailey, 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.

Tables 1A.1a-c provide a stock specific summary for GOA pollock of the economic information presented in the current Economic SAFE (A. Ableman, *per. commun*.). 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. For ecosystem indicators, we also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant. 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). Proposed sign of relationship is negative.
b.) Spring (April-May) daily sea surface temperatures (SST) for the western and central (combined) GOA from the NOAA Coral Reef Watch Program (contact: M. Callahan). Proposed sign of relationship is negative and the time series is not lagged for the intermediate stage indicator analysis.
c.) Summer bottom temperatures from the AFSC bottom trawl survey (contact: K. Shotwell). Proposed sign of relationship is negative.

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). Proposed sign of relationship is negative.

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

e.) Derived chlorophyll *a* concentrations during spring seasonal peak (May) in the western and central GOA regions from the MODIS satellite (contact: M. Callahan). Proposed sign of relationship is positive.

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: M. Callahan). Proposed sign of relationship is positive.

g.) Spring small copepods for larvae GOA pollock from the EcoFOCI spring survey (contact: L. Rogers). Proposed sign of relationship is positive.

h.) Summer large copepods for young-of-the-year (YOY) from the EcoFOCI summer survey (contact: L. Rogers). Proposed sign of relationship is positive.

i.) Summer euphausiid abundance from the AFSC acoustic survey for the Kodiak core survey area (contact: P. Ressler). Proposed sign of relationship is positive.

j.) Parakeet auklet (planktivores) reproductive success at Chowiet Island (contact: S. Zador). Proposed sign of relationship is positive.

k.) Spring pollock larvae catch-per-unit-of-effort (CPUE) from the EcoFOCI spring survey (contact: L. Rogers and A. Deary). Proposed sign of relationship is positive and the time series is not lagged for the intermediate stage indicator analysis.

l.) Summer young-of-the-year (YOY) pollock catch-per-unit-of-effort (CPUE) from the EcoFOCI summer survey (contact: L. Rogers). Proposed sign of relationship is positive.

m.) Summer pollock condition for young-of-the-year (YOY) from EcoFOCI summer survey (contact: L. Rogers). Proposed sign of relationship is positive.

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 and M. Litzow). Proposed sign of relationship is positive.

o.) Pollock relative biomass of young-of-the-year (YOY) from screening burrows of tufted puffins at Aiktak Island (contact: S. Zador). Proposed sign of relationship is positive.

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

p.) Summer pollock predation mortality for age-1 from RACE and IPHC surveys (contact: C. Barnes). Proposed sign of relationship is negative.

q.) Proportion-by-weight of euphausiids in the diets of juvenile GOA pollock from summer bottom-trawl surveys (contact: K. Aydin). Proposed sign of relationship is positive.

r.) Fall pollock condition for adults from the pollock fishery sampled by observers (contact: C. Monnahan). Proposed sign of relationship is positive and the time series is lagged by minus one year for the intermediate stage indicator analysis.

s.) Winter pollock condition for adults from the late winter AFSC acoustic survey of pre-spawning pollock in the GOA (contact: C. Monnahan). Proposed sign of relationship is positive and the time series is not lagged for the intermediate stage indicator analysis.

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). Proposed sign of relationship is negative.

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). Proposed sign of relationship is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.

w.) Pacific ocean perch total biomass from the most recent stock assessment model (contact: K. Shotwell). Proposed sign of relationship is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.

x.) Sablefish total biomass from the most recent stock assessment model (contact: K. Shotwell). Proposed sign of relationship is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.

y.) Steller sea lion non-pup estimates for the GOA portion of the western Distinct Population Segment (contact: K. Sweeney). Proposed sign of relationship is negative and the time series is lagged by minus one year for the intermediate stage indicator analysis.

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: C. Monnahan)

b.) Summer-fall pollock catch-per-unit-of-effort (CPUE) from fishery observer data (contact: C. Monnahan).

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

c.) Annual real ex-vessel price per pound of GOA pollock from fish ticket information (contact: J. Lee).

d.) Annual pollock roe per-unit-catch during January to March (contact: J. Lee).

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 (generally shown in Figure 1A.1 and specifically by indicator in the Indicator Suite, Ecosystem Indicators section) 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 (ecosystem indicators only) for the relationship with the stock (Tables 1A.2a,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, then evaluate fishery performance, economic, and community indicators as listed above. Here we concentrate on updates since the last ESP. Overall both the physical and lower trophic indicators scored average for 2022, while the upper trophic indicators were below average, the fishery performance indicators were average, and the economic indicator was average (Figure 1A.3). Compared to last year's results, this is the same value for the physical indicators, a drop from above average for the lower trophic indicators, a drop from average for the upper trophic indicators, a drop from above average for the fishery performance indicators, and an improvement from below average in the economic indicator. We also note caution when comparing scores between odd and 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 through 2022 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 below average for 2021 and one economic indicator was average in 2022. There have been no updates for community indicators since 2019.

For physical indicators (Table 1A.2a, 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, from 2020 through 2022 there were reduced temperatures both at the surface and bottom and reduced annual marine heatwave events from the previous warm stanza. 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 back toward the northeast (up Shelikof Strait) and is near average for the time series in 2022 (Figure 1A.2a.d) implying less retention in favorable habitat off Kodiak Island and the Shelikof sea valley than the previous two years and average conditions for recruitment.

For lower trophic indicators (Table 1A.2a, Figure 1A.2a.e-o), estimates of chlorophyll *a* concentration increased to slightly below average in 2022 with a concurrent earlier peak timing of the spring bloom (but still later than average), which may have implications for larval mismatch with prey (Figure 1A.2a.e-f). There were no updates for copepods or euphausiids (Figure 1A.2a.g-i). Reproductive success of planktivorous parakeet auklet seabirds on Chowiet decreased to below average suggesting a reduction in sufficient zooplankton prey resources (Figure 1A.2a.j). There were no updates for spring or summer pollock larvae, or summer pollock YOY condition (Figure 1A.2a.k-m). CPUE of YOY pollock in the summer nearshore surveys in Kodiak decreased to just above average in 2022 (Figure 1A.2a.n) suggesting some potential recruitment, although this survey has limited spatial coverage. There were no updates for the pollock relative biomass in Aiktak (Figure 1A.2a.o).

For upper trophic indicators (Table 1A.2a, Figure 1A.2a.p-y), predation estimates on age-1 pollock have been relatively low and stable from 2009 to 2019 with a further decrease in 2021 (Figure 1A.2a.p). There were no updates for the percent of euphausiids in the diet for juveniles (Figure 1A.2a.q). Condition of adult pollock in the fall fishery of 2021 decreased from 2020 to below average and subsequent condition of winter adult pollock from the acoustic survey also decreased from average in 2021 to below average in 2022, continuing the good correlation between the two indicators (Figure 1A.2a.r-s). There were no updates to the center of gravity or the area occupied estimates of the GOA pollock population (Figure 1A.2a.t-u). Potential competitors to GOA pollock are the recent multiple large year classes of juvenile sablefish and an increasing population of Pacific Ocean perch (POP). Major predators of pollock include arrowtooth flounder and Steller sea lions (SSL). The 2021 biomass estimates from the most recent stock assessment for arrowtooth flounder remain low, while Pacific ocean perch and sablefish biomass estimates remain above average (Figure 1A.2a.v-x). Predicted adult counts of SSL for 2021 are stable and slightly below average (Figure 1A.2a.y).

For fishery performance indicators (Table 1A.2b, Figure 1A.2b.a-b), the CPUE in the winter spring decreased but remained above average in 2022 and the summer fall CPUE decreased from above average in 2020 to below average in 2021. 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.

For economic indicators (Table 1A.2b, Figure 1A.2b.c-d), ex-vessel price remained stable and low but within one standard deviation of the time series mean (Figure 1A.2b.c). 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. Roe per unit catch increased from 2021 but remains below average and within one standard deviation of the time series mean (Figure 1A.2b.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 (Table 1A.2b, Figure 1A.2b.e-h). 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 2020 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. Additionally, the Pacific ocean perch total biomass is now a high ranked predictor variable (Figure 1A.4).

Advanced Stage: Research Model Test

Considerable variation has occurred in the GOA pollock biomass over the past four decades and during that time the demersal fish community has transitioned from a pollock dominated community to one that is dominated by upper-trophic level predators (Anderson and Piatt 1999, Mueter and Norcross 2002). 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 from 1990 to 2019. 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 (Dorn and Barnes, 2022). An index of total predation (rather than age-1 predation) was utilized, representing the consumption of pollock by the dominant groundfish predators 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. When predation was included in the model, Dorn and Barnes (2022) found that natural mortality ranged from 37% higher to 17% lower than the long-term mean (Figure 1A.5, top panel). Predation was highly variable for both constant natural mortality and time-varying predation mortality models 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 14% 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. This method allows for an evaluation of the impacts of time-varying predation on GOA pollock, provides for a relatively simple way to incorporate ecological information into single species stock assessments, and can be used to identify inconsistencies in biomass estimates for future consideration (Dorn and Barnes, 2022).

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, but further study is needed.

Refinements or updates to current indicators may also be helpful. The chlorophyll *a* concentrations 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 substatial. 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., 2022). 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 regarding 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. Incorporating additional importance methods in the intermediate stage indicator analysis may also be useful for evaluating the full suite of indicators and may allow for identifying robust indicators for potential use in 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.

Literature Cited

Adams, G., K., Holsman, S., Barbeaux, M., Dorn, P., Hulson, J., Ianelli, C., Monnahan, K., Shotwell, I., Spies, I., Stewart, and A., Punt. 2022. Multispecies model estimates of time-varying natural mortality of groundfish in the Gulf of Alaska. *In* Ferriss, B., and Zador, S., 2022. Ecosystem Status

Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

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

Bailey, K.M. 1989. Interaction between the vertical distribution of juvenile walleye pollock *Theragra chalcogramma* in the eastern Bering Sea, and cannibalism. Mar. Ecol. Prog. Ser, 53, 205-213.

Bailey, K.M. 2000. Shifting control of recruitment of walleye pollock *Theragra chalcogramma* after a major climatic and ecosystem change. Marine Ecology Progress Series, 198: 215-224.

Barnes, C.L., A.H. Beaudreau, M.W. Dorn, K.H. Holsman, and F.J. Mueter. 2020. Development of a predation index to assess trophic stability in the Gulf of Alaska. Ecol Appl. 30(7):e02141.

Brown, A., Busby, M. and Mier, K., 2001. Walleye pollock *Theragra chalcogramma* during transformation from the larval to juvenile stage: otolith and osteological development. Marine Biology, 139(5), pp.845-851.

Canino, M.F., Bailey, K.M. and Incze, L.S., 1991. Temporal and geographic differences in feeding and nutritional condition of walleye pollock larvae *Theragra chalcogramma* in Shelikof Strait, Gulf of Alaska. Marine Ecology Progress Series, pp.27-35.

Deary, A., L. Rogers, and K. Axler. 2021. Larval fish abundance in the Gulf of Alaska 1981-2021. *In* Ferriss, B., and Zador, S., 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Dorn, M.W., and C.L., Barnes. 2022. Time-varying predation as a modifier of constant natural mortality for Gulf of Alaska walleye pollock. Fish Res. 254: 106391. https://doi.org/10.1016/j.fishres.2022.106391

Doyle, M.J., and K.L. Mier. 2016. Early life history pelagic exposure profiles of selected commercially important fish species in the Gulf of Alaska. Deep-Sea Res II. 132: 162-193.

Doyle, M.J., S.L. Strom, K.O. Coyle, A.J. Hermann, C. Ladd, A.C. Matarese, S.K. Shotwell, and R.R. Hopcroft. Early life history phenology among Gulf of Alaska fish species: Strategies, synchronies, and sensitivities. 2019. Deep Sea Research Part II: Topical Studies in Oceanography 165 (2019): 41-73.

Fissel, B., M. Dalton, B. Garber-Yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, C. Seung, K. Sparks, M. Szymkowiak, and S. Wise. 2021. Economic status of the groundfish fisheries off Alaska, 2019. *In* Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Gaichas, S., K. Aydin, and R.C. Francis. 2015. Wasp waist or beer belly? Modeling food web structure and energetic control in Alaskan marine ecosystems, with implications for fishing and environmental forcing. Progress in Oceanography. 138(A): 1-17.

Goethel, D.R., D.H., Hanselman, C.J. Rodgveller, K.B. Echave, B.C. Williams, S.K. Shotwell, J. Sullivan, P.F. Hulson, P.W. Malecha, K.A. Siwicke, and C.R. Lunsford. 2021. Assessment of the Sablefish stock in Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Heintz, R.A., Siddon, E.C., Farley, E.V. Jr., and Napp, J.M. 2013. Correlation between recruitment and fall condition of age-0 pollock (*Theragra chalcogramma*) from the eastern Bering Sea under varying climate conditions. Deep-Sea Res. II 94: 150-156.

Hinckley, S. 1990. Variation in egg size of walleye pollock *Theragra chalcogramm*a with a preliminary examination of the effect of egg size on larval size. Fish. Bull. US, 88, 471-483.

Hulson, P.J.F., C.R. Lunsford, B. Fissel, and D. Jones. 2021. Assessment of the Pacific ocean perch stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Mngt. Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Kendall Jr., A.W., L.S. Incze, P.B. Ortner, S.R. Cummings and P.K. Brown. 1994. The vertical distribution of eggs and larvae of walleye pollock, *Theragra chalcogramma*, in Shelikof Strait, Gulf of Alaska. Fishery Bulletin, 92: 540-554. Appendix Table 1A.2a reference #10.

Kendall, A. W., Clarke, M. E., Yoklavich, M. M., and Boehlert, G. W. 1987. Distribution, feeding, and growth of larval walleye pollock, *Theragra chalcogramma*, from Shelikof Strait, Gulf of Alaska. Fishery Bulletin, 85: 499-521.

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

Murphy, J., W. Strasburger, A. Piston, S. Heinl, J. Moss, E. Fergusson, and A. Gray. 2021. Juvenile Salmon Abundance in Icy Strait, Southeast Alaska. *In* Ferriss, B., and Zador, S., 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

O'Leary, C., Laman, N., Rohan, S. 2021. Gulf of Alaska groundfish condition. *In* Ferriss, B., and Zador, S., 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Rogers, L.A., & Dougherty, A.B. 2019. Effects of climate and demography on reproductive phenology of a harvested marine fish population. Global Change Biology, 25(2), 708-720.

Shaul, L.D., G.T. Ruggerone, and J.T. Priest. 2021. Maturing Coho Salmon Weight as an Indicator of Offshore Prey Status in the Gulf of Alaska. *In* Ferriss, B., and Zador, S., 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Shotwell, S.K., K., Blackhart, C. Cunningham, E. Fedewa, D., Hanselman, K., Aydin, M., Doyle, B., Fissel, P., Lynch, O. Ormseth, P., Spencer, S., Zador. *In Review*. Introducing the Ecosystem and Socioeconomic Profile, a proving ground for next generation stock assessments.

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

Shotwell, S.K., M. Dorn, A. Deary, B. Fissel, L. Rogers, and S. Zador. 2020. Ecosystem and socioeconomic profile of the walleye pollock stock in the Gulf of Alaska. Appendix 1A In Dorn, M.W., A.L. Deary, B.E. Fissel, D.T. Jones, M. Levine, A.L. McCarthy, W.A. Palsson, L.A. Rogers, S.A. Shotwell, K.A. Spalinger, K. Williams, and S.G. Zador. 2020. Assessment of the Walleye

Pollock stock in the Gulf of Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501. Pp. 104-135.

Shotwell, K., I. Spies, J.N. Ianelli, K. Aydin, B. Fissel, D.H Hanselman, W. Palsson, K. Siwicke, and E. Yasumiishi. 2021. Assessment of the arrowtooth flounder stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Mngt. Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Siddon, E.C., Heintz, R.A., and Mueter, F.J. 2013. Conceptual model of energy allocation in walleye Pollock (*Theragra chalcogramma*) from age-0 to age-1 in the southeastern Bering Sea. Deep Sea Res. II 94: 140-149.

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

Strasburger, W.W., Hillgruber, N., Pinchuk, A.I. and Mueter, F.J., 2014. Feeding ecology of age-0 walleye pollock (*Gadus chalcogrammus*) and Pacific cod (Gadus macrocephalus) in the southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography, 109, pp.172-180.

Whitehouse, A. and K. Aydin. 2021. Foraging guild biomass-Gulf of Alaska. *In* Ferriss, B. and Zador, S., 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Wilson, M.T., Mier, K.L., and Jump, C.M. 2013. Effect of region on the food-related benefits to age-0 walleye pollock (*Theragra chalcogramma*) in association with midwater habitat characteristics in the Gulf of Alaska. ICES J. Mar. Sci. 70(7): 1396–1407. doi:10.1093/icesjms/fst138.Yang, M. S., and Nelson, M. W. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996.

Wilson, M.T. and Laman, N., 2021. Interannual variation in the coastal distribution of a juvenile gadid in the northeast Pacific Ocean: The relevance of wind and effect on recruitment. Fisheries Oceanography, 30(1), pp.3-22.

Wise, S., K. Sparks, and J. Lee. 2021. Annual Community Engagement and Participation Overview. Report from the Economic and Social Sciences Program of the Alaska Fisheries Science Center. 57 pp.

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

Tables

Table 1A.1a Pollock in the Gulf of Alaska ex-vessel market data. Total and retained catch (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), the Central Gulf's share of value, and number of trawl vessels; 2012-2016 average, and 2017-2021.

	2012-2016 Average	2017	2018	2019	2020	2021
Total catch K mt	137.52	186.2	158.1	120.2	107.5	101.2
Retained catch K mt	135.88	184.33	155.88	118.89	106.63	99.5
Ex-vessel value M $	$37.76	$35.25	$42.25	$36.12	$27.8	$27.32
Ex-vessel price lb $	$0.13	$0.09	$0.12	$0.14	$0.12	$0.12
Central Gulf share of catch	76.74%	72.26%	75.97%	73.99%	75.31%	76.62%
Vessels #	69.4	65	71	62	61	59

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

Table 1A.1b. Pollock in the Gulf of Alaska first-wholesale market data. First-wholesale production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut, fillet, surimi, and roe production volume (thousand metric tons), price (US$ per pound), and value share; 2012-2016 average, and 2017-2021.

	2012-2016 Average	2017	2018	2019	2020	2021
All Products volume K mt	53.46	78.06	69.06	51.09	39.95	31.64
All Products value M $	$99.56	$96.68	$104.92	$85.87	$70.47	$68.63
All Products price lb $	$0.84	$0.56	$0.69	$0.76	$0.8	$0.98
Head & Gut volume K mt	25.62	37.39	39.83	28.41	22.62	14.02
Head & Gut value share	33.37%	31.1%	34.5%	37.95%	36.82%	21.02%
Head & Gut price lb $	$0.59	$0.36	$0.41	$0.52	$0.52	$0.47
Fillets volume K mt	8.66	15.72	13.08	8.8	7.84	8.65
Fillets value share	26.32%	36.18%	32.01%	31.34%	34.05%	42.92%
Fillets price lb $	$1.37	$1.01	$1.16	$1.39	$1.39	$1.54
Surimi volume K mt	11.78	10.61	9.77	6.95	5.43	5.93
Surimi value share	25.72%	18.32%	19.76%	19.28%	18.15%	24.4%
Surimi price lb $	$0.99	$0.76	$0.96	$1.08	$1.07	$1.28
Roe volume K mt	2.21	1.09	2.39	1.89	1.55	1.03
Roe value share	10.39%	4.47%	9.21%	6.87%	5.34%	6.19%
Roe price lb $	$2.12	$1.8	$1.83	$1.42	$1.1	$1.88

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

Table 1A.1c. Pollock U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, Russian share of global production, U.S. export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound), the share of U.S. export volume and value with Japan, China and Germany, the share of U.S. export volume and value of meats (including H&G and fillets), surimi and roe2012-2016 average, and 2017-2021.

	2012-2016 Average	2017	2018	2019	2020	2021
Global Pollock Catch K mt	3322.75	3488.64	3395.72	3494.66	3544.03	-
U.S. Share of Global Catch	43%	44%	45%	44%	42%	-
Russian Share of global catch	49%	50%	49%	50%	52%	-
GOA share of global	4.14%	5.34%	4.66%	3.44%	3.03%	-
Export volume K mt	365.51	397.91	415.21	380.06	323.49	311.58
Export value M US$	$1003.39	$1007.49	$1129.14	$1119.9	$941.88	$899.3
Export price lb US$	$1.25	$1.15	$1.23	$1.34	$1.32	$1.31
Import value M US$	$133.29	$74.98	$78.05	$123.17	$99.84	$96.07
Net Exports	$870.1	$932.51	$1051.09	$996.73	$842.04	$803.23
Japan volume share	21.84%	21.68%	21.87%	22.85%	19.33%	21.02%
Japan value share	21.39%	22.86%	25.6%	23.88%	20.17%	21.1%
China volume share	13.09%	14.83%	13.64%	10.14%	9.68%	6.77%
China value share	10.67%	12.55%	9.88%	6.69%	6.45%	5.3%
Europe* volume share	37.13%	32.5%	32.93%	35.15%	36.98%	32.68%
Europe* value share	37.39%	32.72%	33.35%	36.86%	39.42%	36.3%
Meat Volume Share	50.24%	48.81%	49.91%	47.07%	45.77%	41.11%
Meat Value share	48.13%	46.57%	44.64%	44.34%	44.02%	40.79%
Surimi Volume Share	45%	46.55%	44.76%	45.82%	46.96%	53.8%
Surimi Value share	38.95%	42.34%	42.36%	42.58%	42.22%	49.39%
Roe Volume Share	4.76%	4.64%	5.33%	7.11%	7.27%	5.09%
Roe Value share	12.92%	11.09%	13%	13.09%	13.77%	9.82%

Notes: Exports are from the US and are note specific to the GOA region. Aggregate exports may not fully account for all pollock exports as products such as meal, minced fish and other ancillary product may be coded as generic fish type for export purposes.
Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

Table 1A.2a. 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 the stock (blue or italicized text = good conditions for the stock, 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	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Physical	Annual Heatwave GOA Model	neutral	**high**	neutral	neutral	neutral
	Spring Temperature Surface WCGOA Satellite	neutral	**high**	neutral	neutral	neutral
	Summer Temperature Bottom GOA Survey	NA	**high**	NA	neutral	NA
	Spring Wind Direction Kodiak Buoy	NA	neutral	neutral	neutral	neutral
Lower Trophic	Spring Chlorophylla Biomass WCGOA Satellite	**low**	**low**	neutral	neutral	neutral
	Spring Chlorophylla Peak WCGOA Satellite	**low**	*high*	**low**	neutral	neutral
	Spring Small Copepod Abundance Shelikof Survey	NA	*high*	NA	neutral	NA
	Summer Large Copepod Abundance Shelikof Survey	NA	neutral	NA	NA	NA
	Summer Euphausiid Abundance Kodiak Survey	NA	neutral	NA	NA	NA
	Annual Auklet Reproductive Success Chowiet Survey	**low**	neutral	NA	neutral	neutral
	Spring Pollock CPUE Larvae Shelikof Survey	NA	neutral	NA	neutral	NA
	Summer Pollock CPUE YOY Shelikof Survey	NA	neutral	NA	NA	NA
	Summer Pollock Condition YOY Shelikof Survey	NA	**low**	NA	NA	NA
	Summer Pollock CPUE YOY Nearshore Kodiak Survey	*high*	neutral	neutral	*high*	neutral

Category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
	Annual Pollock Relative Biomass Aiktak Survey	neutral	neutral	NA	NA	NA
Upper Trophic	Summer Pollock MT Consumed Age1 GOA Model	NA	neutral	NA	neutral	NA
	Summer Pollock Euphausiid Diet Juvenile GOA Survey	NA	*high*	NA	neutral	NA
	Fall Pollock Condition Adult GOA Fishery	neutral	neutral	neutral	neutral	NA
	Winter Pollock Condition Adult GOA Survey	**low**	neutral	neutral	neutral	**low**
	Summer Pollock Center Gravity Northeast WCGOA Model	NA	neutral	NA	neutral	NA
	Summer Pollock Area Occupied WCGOA Model	NA	neutral	NA	neutral	NA
	Annual Arrowtooth Biomass GOA Model	neutral	neutral	*low*	*low*	NA
	Annual Pacific Ocean Perch Biomass GOA Model	**high**	**high**	**high**	**high**	NA
	Annual Sablefish Biomass GOA Model	neutral	neutral	neutral	neutral	NA
	Annual Steller Sea Lion Adult GOA Survey	neutral	neutral	neutral	neutral	NA

Table 1A.2b: 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). A gray fill and text = “NA” will appear if there were no data for that year.

Category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Fishery Performance	Winter Spring Pollock CPUE Adult GOA Fishery	high	high	neutral	high	neutral
	Summer Fall Pollock CPUE Adult GOA Fishery	neutral	neutral	neutral	neutral	NA
Economic	Annual Pollock Real Ex-vessel Price Fishery	neutral	neutral	neutral	neutral	NA
	Winter Spring Pollock Roe Per Unit Catch Fishery	neutral	neutral	neutral	low	neutral
Community	Annual Pollock RQ Harvesting Revenue Kodiak Fishery	high	high	NA	NA	NA
	Annual Pollock RQ Processing Revenue Kodiak Fishery	high	high	NA	NA	NA
	Annual Pollock RQ Harvesting Revenue Small Communities GOA Fishery	low	low	NA	NA	NA
	Annual Pollock RQ Processing Revenue Small Communities GOA Fishery	neutral	neutral	NA	NA	NA

Figures

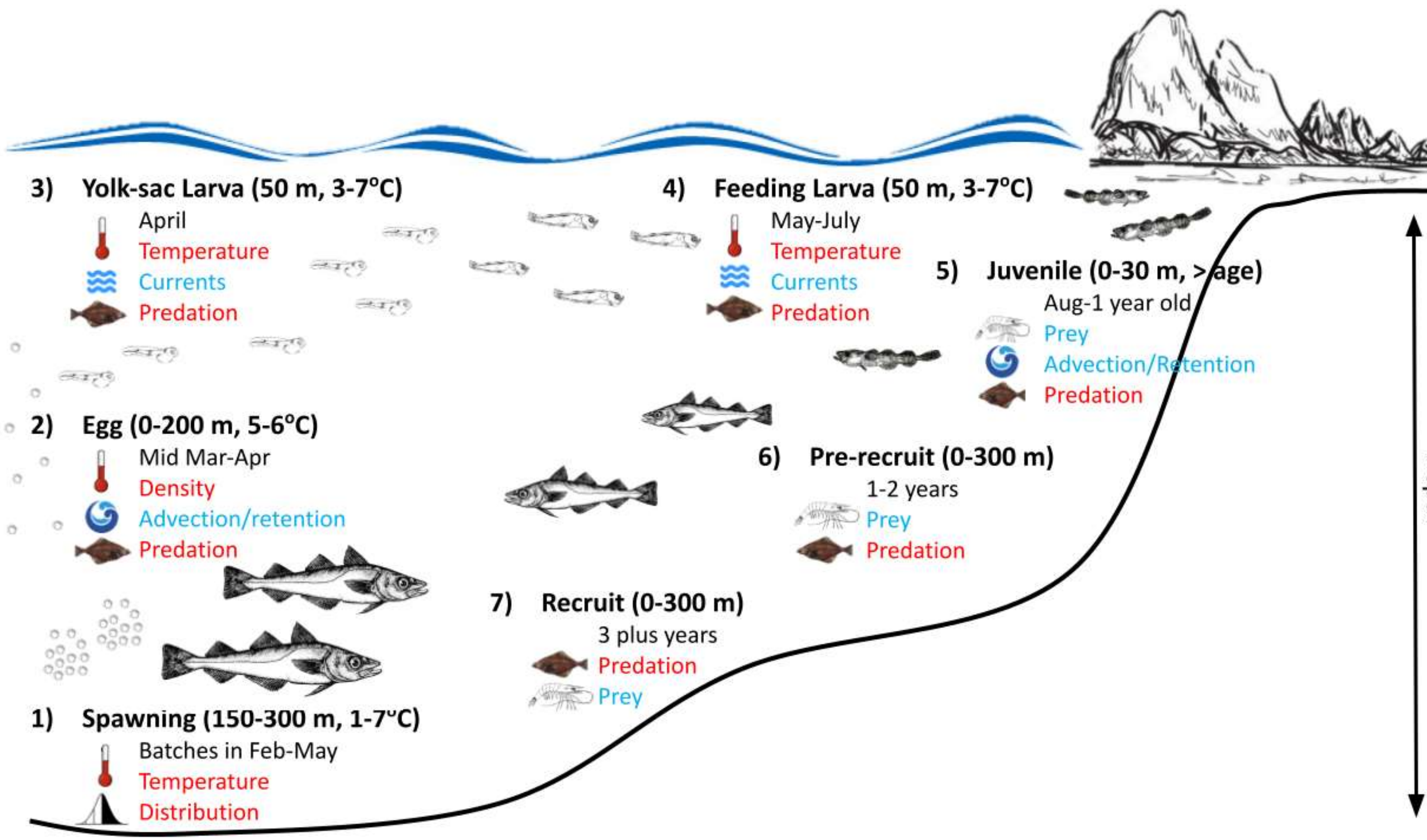


Figure 1A.1: Life history conceptual model for GOA pollock summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text indicates increases in the process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

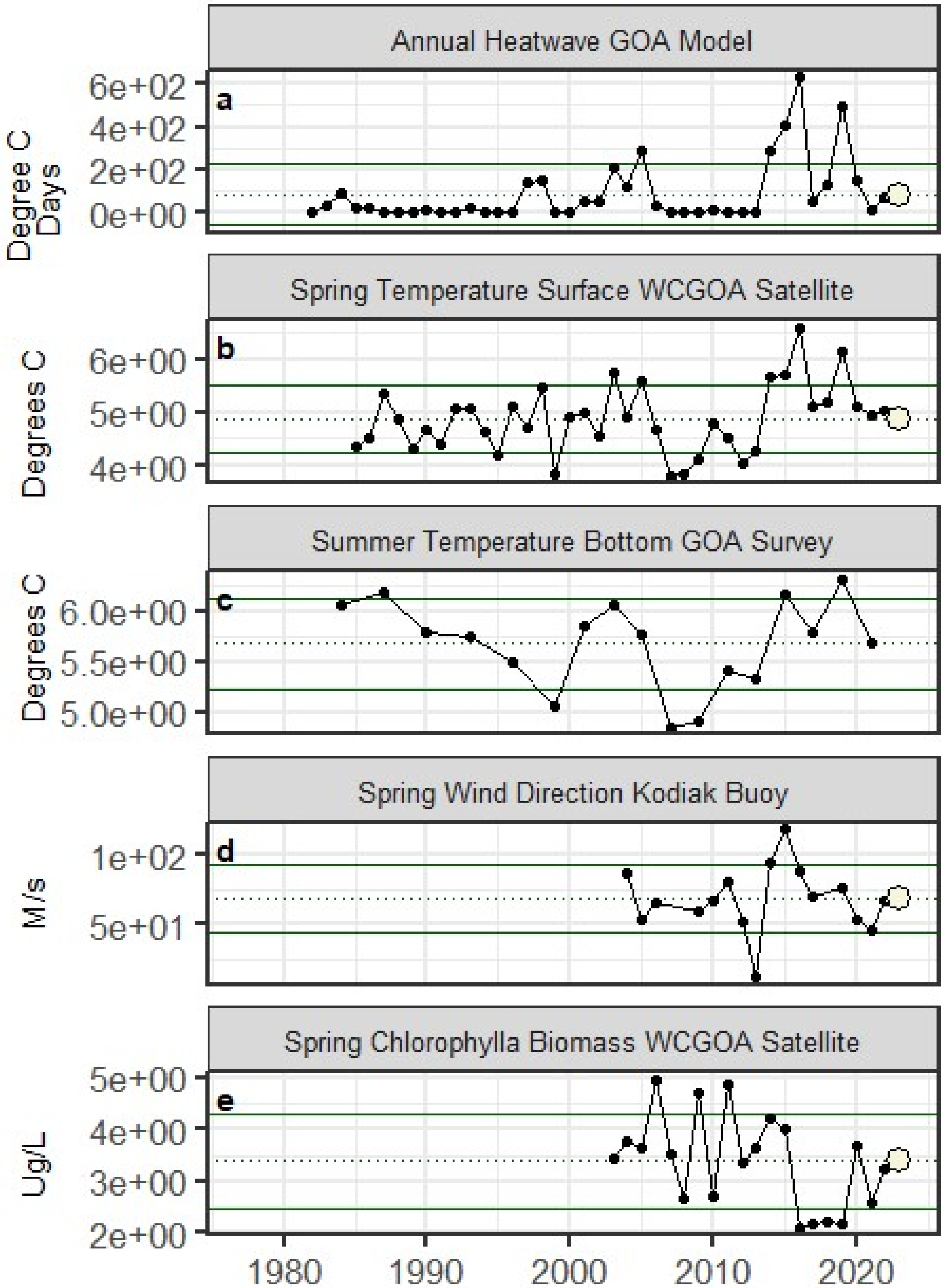


Figure 1A.2a. Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock with blue for good conditions, red for poor conditions, and a white circle is neutral).

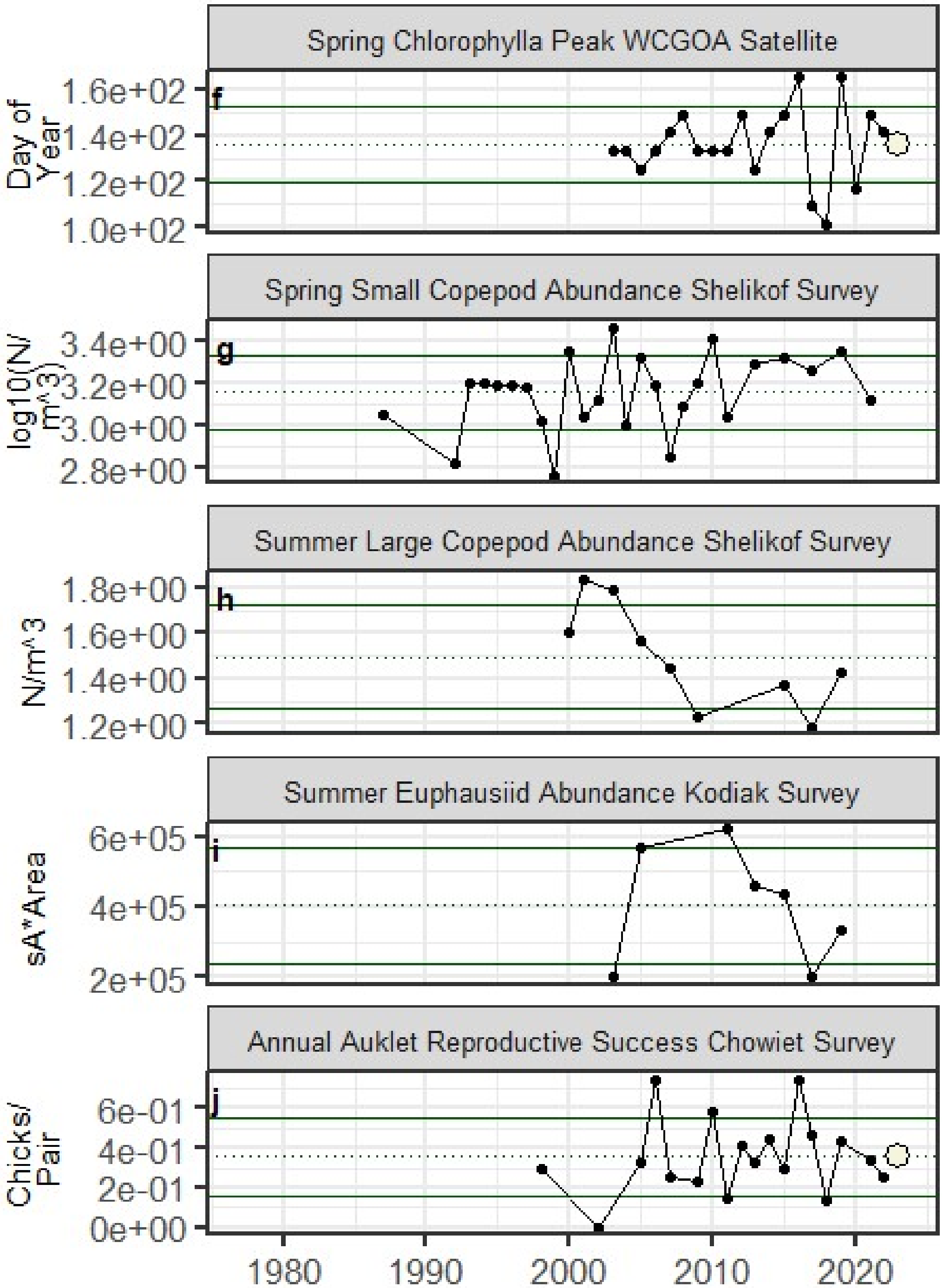


Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock with blue for good conditions, red for poor conditions, and a white circle is neutral).

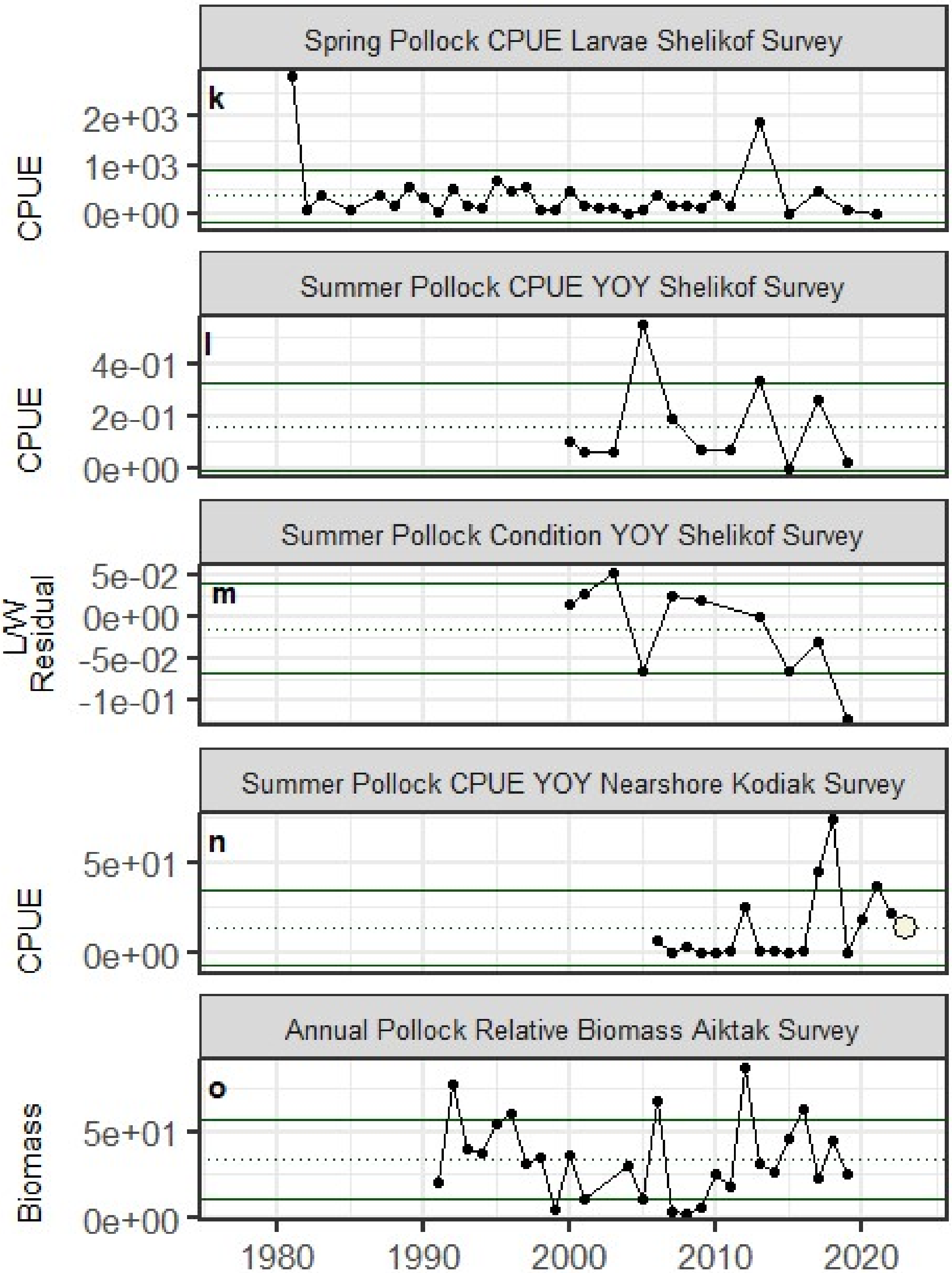


Figure 1A.2a (cont). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock with blue for good conditions, red for poor conditions, and a white circle is neutral).

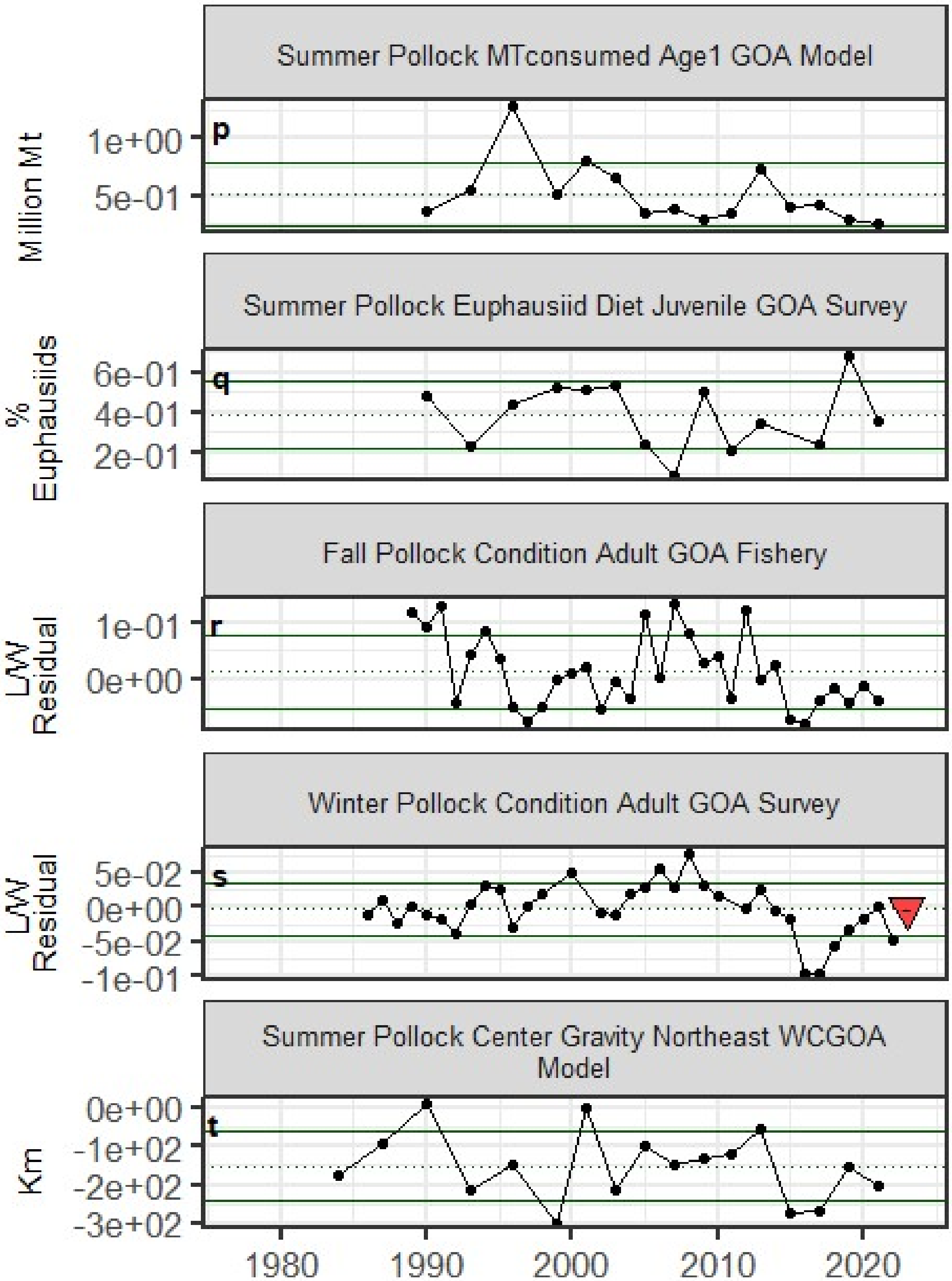


Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock with blue for good conditions, red for poor conditions, and a white circle is neutral).

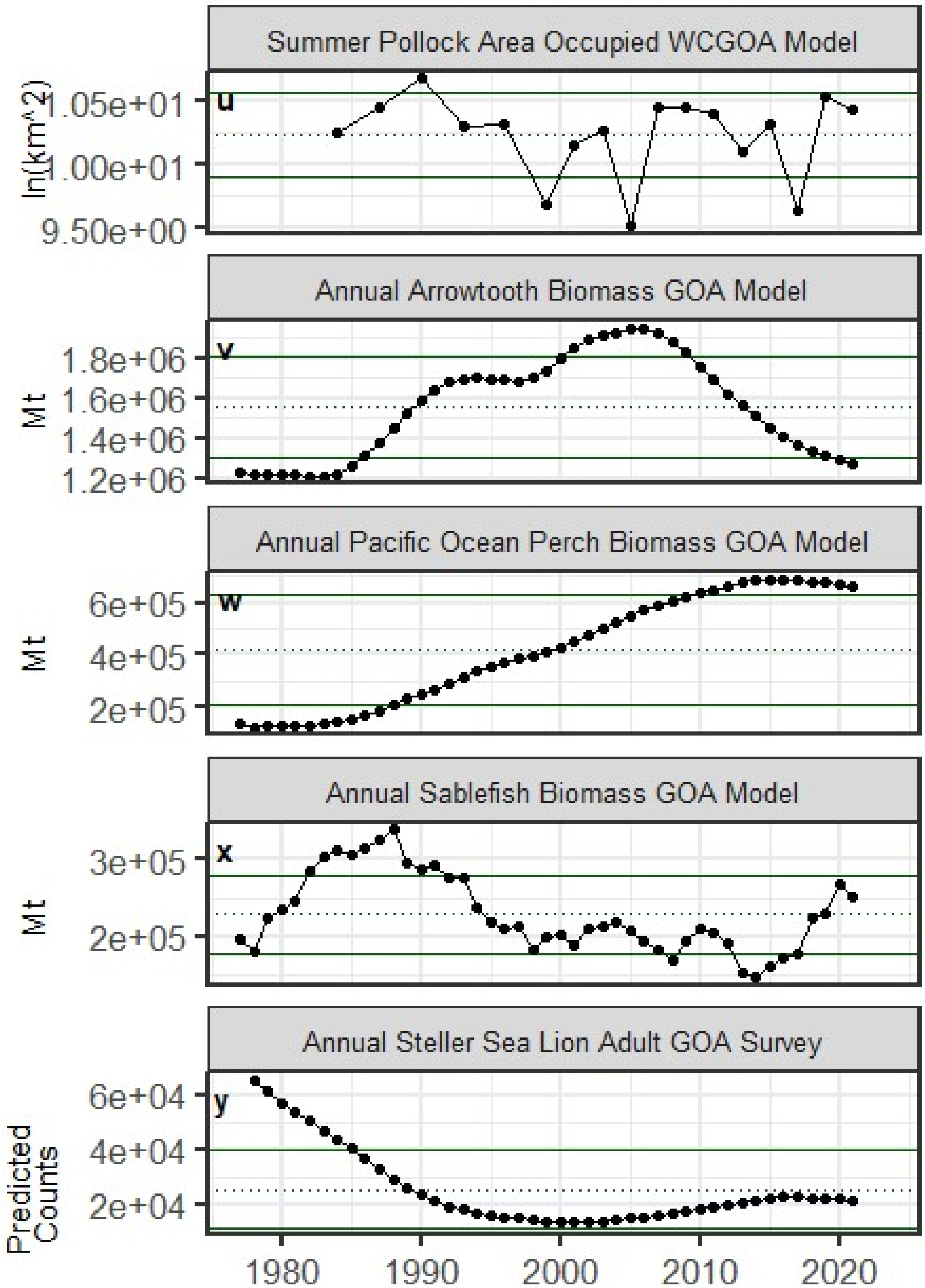


Figure 1A.2a (cont.). Selected ecosystem indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock with blue for good conditions, red for poor conditions, and a white circle is neutral).

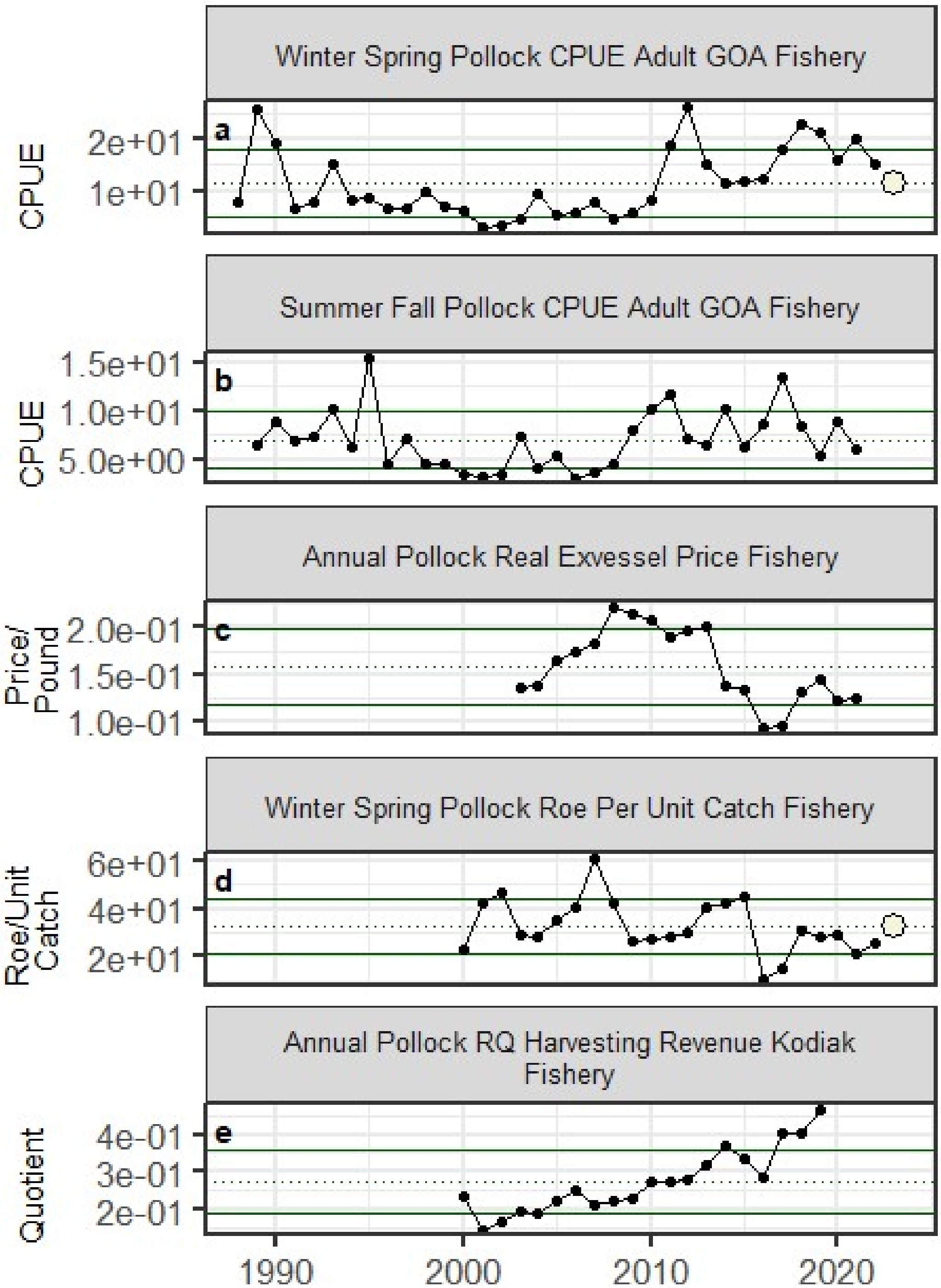


Figure 1A.2b. Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color only designates above (blue) or below (red) one standard deviation of the time series mean, no implied relationship with the stock).

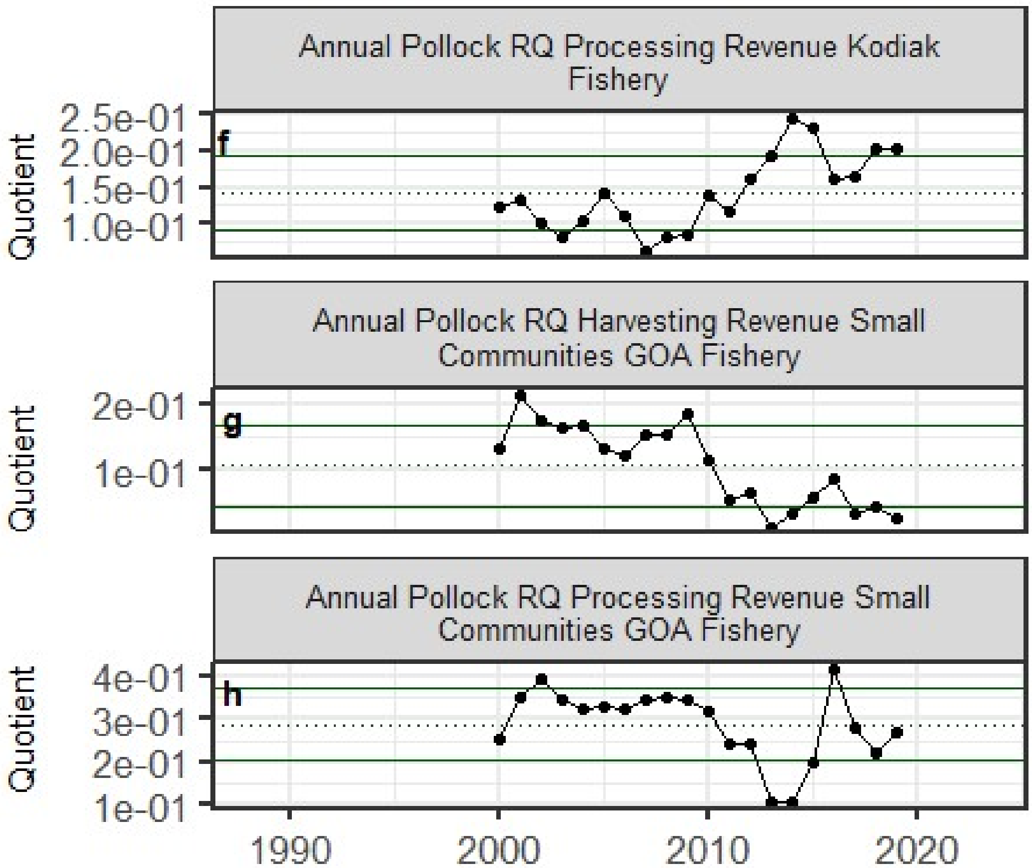


Figure 1A.2b (cont.). Selected socioeconomic indicators for GOA pollock with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color only designates above (blue) or below (red) one standard deviation of the time series mean, no implied relationship with the stock).

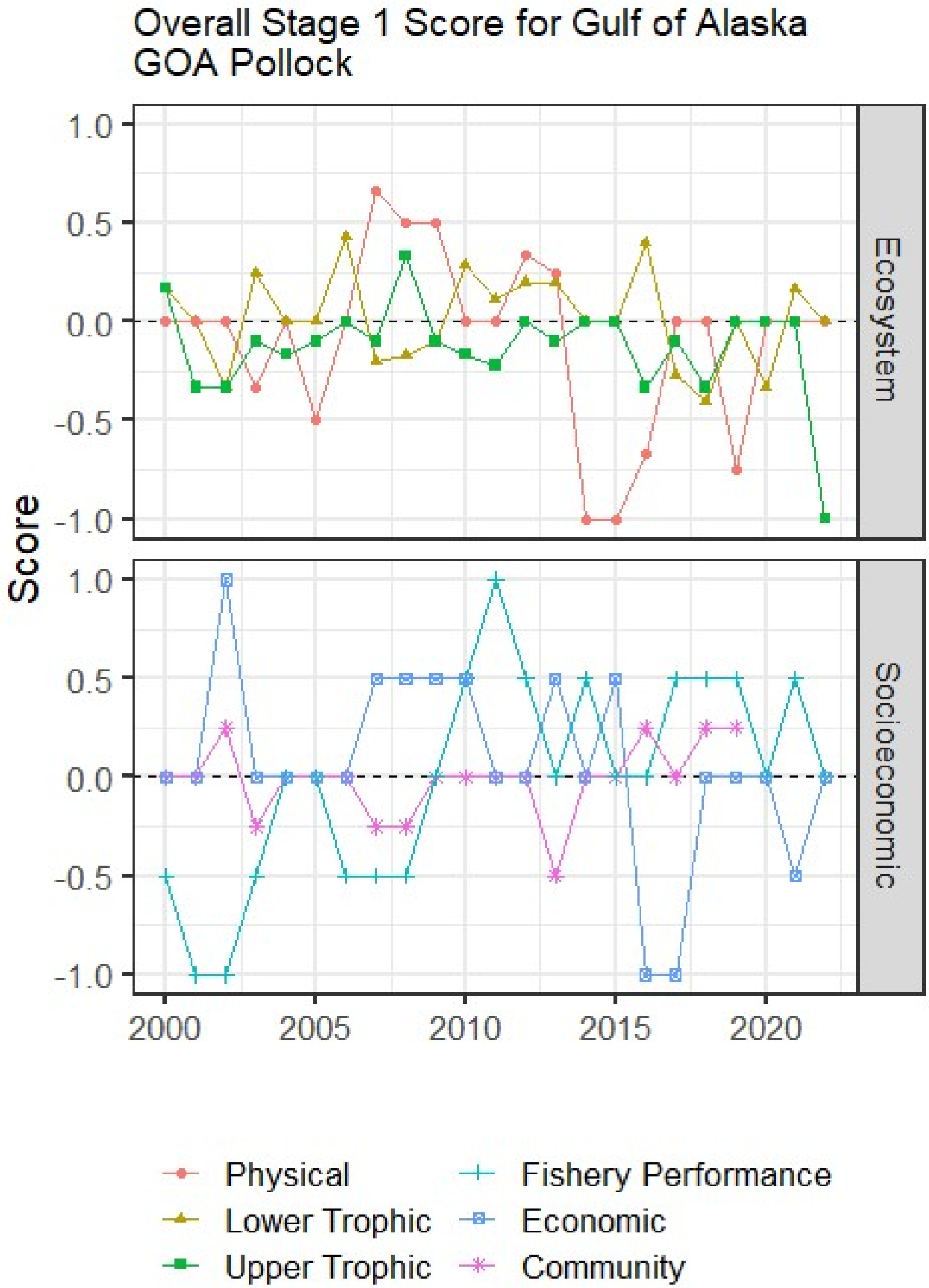


Figure 1A.3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.

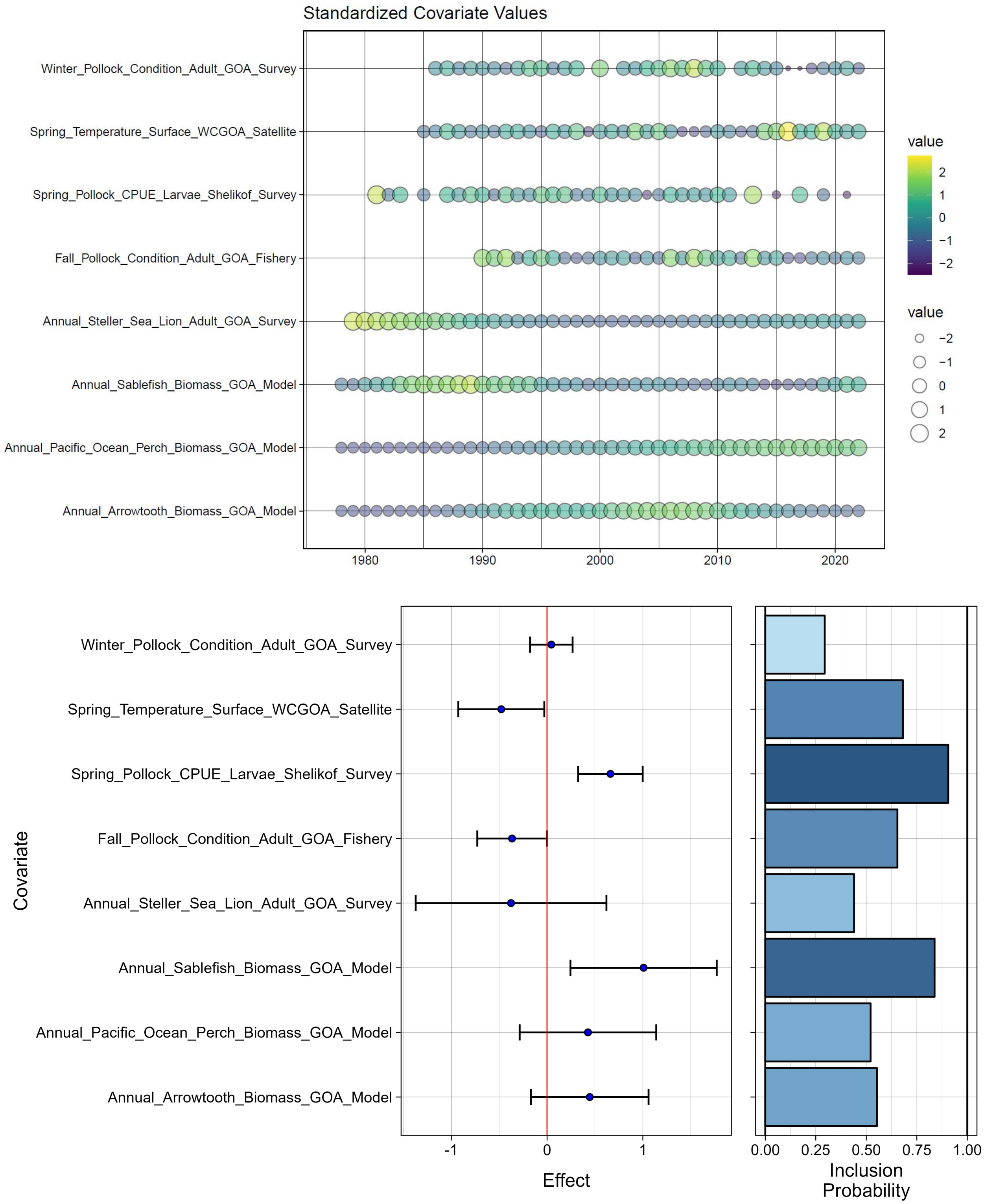


Figure 1A.4: Bayesian adaptive sampling output showing (top graph) standardized covariates and (bottom graph) the mean relationship and uncertainty (95% confidence intervals) with log GOA pollock recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom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

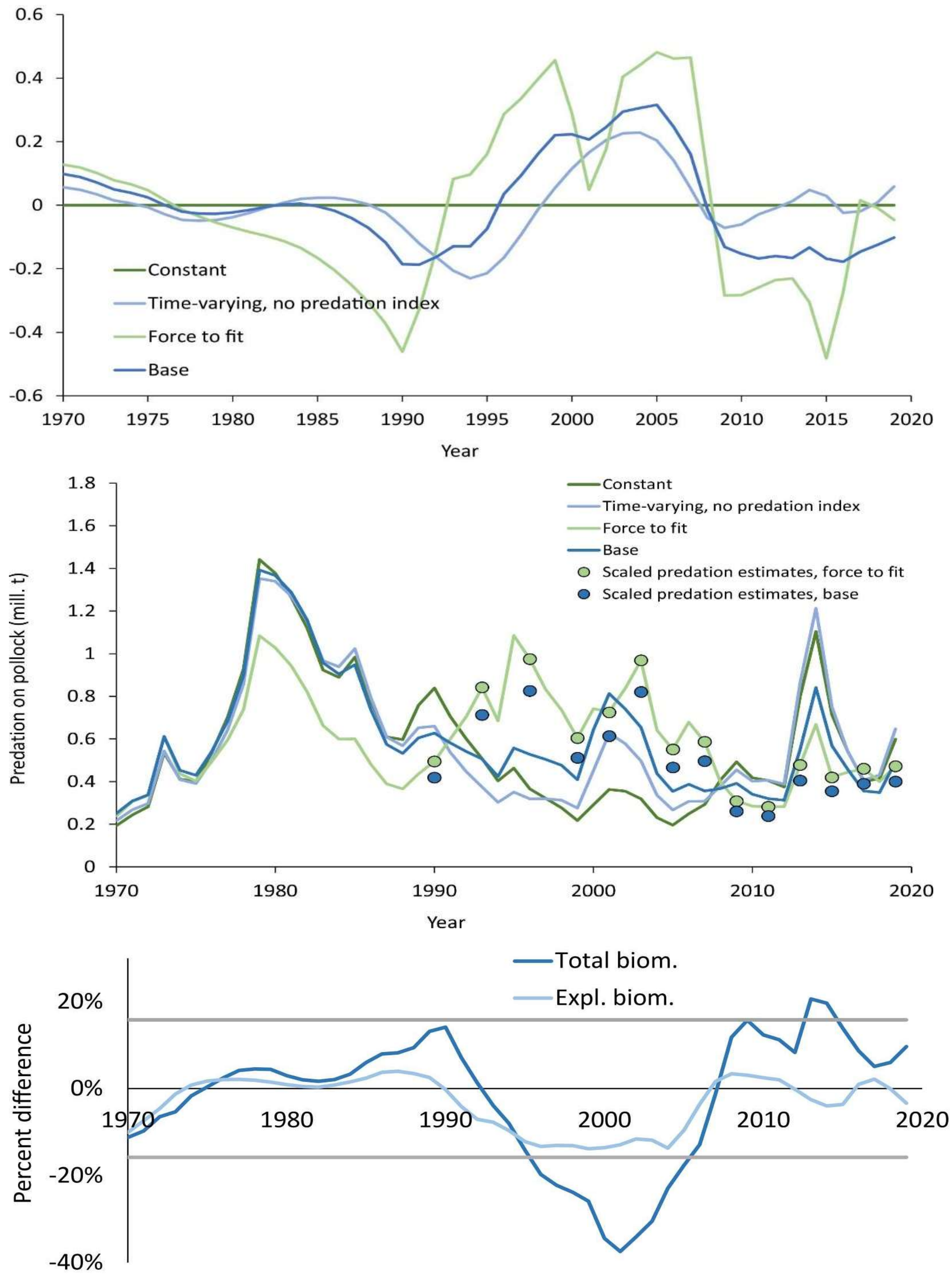


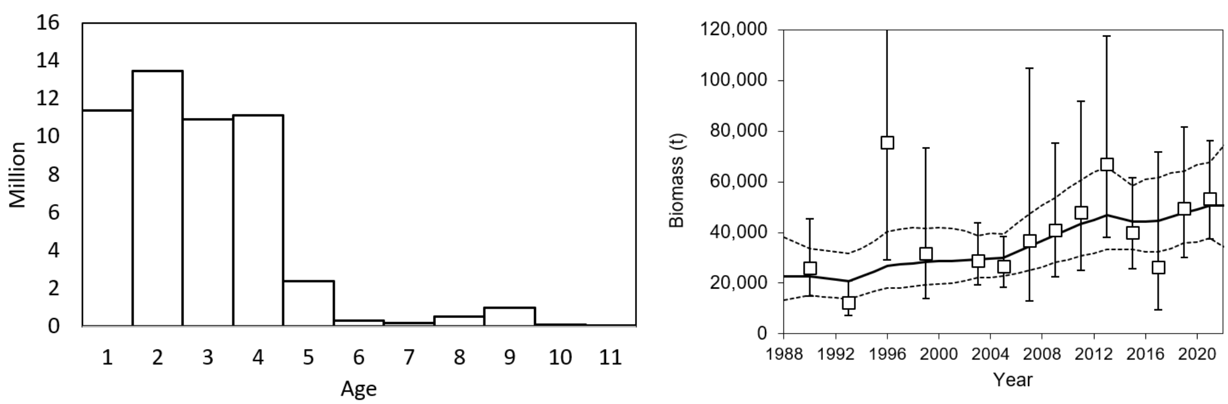
Figure 1A.5: From Dorn and Barnes, 2022. Results from a research model for GOA pollock that included time-varying predation mortality. Top panel is the estimated annual log-scale deviation in predation mortality, while the second panel shows model-estimated predation in biomass for models with and without 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 gray lines 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 2021 NMFS 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 2021 bottom trawl survey showed ages 1-4 dominated, plus a mode of age-9 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 in 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). **No new index data was available in 2022, so model fits are the same as last year. This results in a 2023 ABC of 11,363 t (50,500 t * 0.75 M), and a 2023 OFL of 15,150 t (50,500 t * M). The same ABC and OFL is recommended for 2024.**



Appendix figure 1B.1. Pollock age composition in 2021 (left) and biomass trend in southeast Alaska from a random effects model fit to NMFS bottom trawl surveys in 1990-2021 (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 age 2+ biomass estimate	Percent	Percent by management area Area 610	Area 620	Area 630
Shelikof	2019	840,403	1,219,160	145.1%	0.0%	93.9%	6.1%
Shelikof	2020	738,628	456,457	61.8%	0.0%	97.1%	2.9%
Shelikof	2021	895,106	457,659	51.1%	0.0%	97.7%	2.3%
Shelikof	2022	821,649	365,307	44.5%	0.0%	98.3%	1.7%
Shelikof			Average	75.6%	0.0%	96.7%	3.3%
			% of total biomass		0.0%	73.1%	2.5%
Chirikof	2013	1,174,910	63,224	5.4%	0.0%	70.2%	29.8%
Chirikof	2015	1,676,750	12,705	0.8%	0.0%	26.3%	73.7%
Chirikof	2017	1,280,210	2,485	0.2%	0.0%	0.4%	99.6%
Chirikof	2019	840,403	9,907	1.2%	0.0%	36.4%	63.6%
Chirikof			Average	1.9%	0.0%	33.3%	66.7%
			% of total biomass		0.0%	0.6%	1.3%
Marmot	2017	1,280,210	13,129	1.0%	0.0%	0.0%	100.0%
Marmot	2018	982,229	12,905	1.3%	0.0%	0.0%	100.0%
Marmot	2019	840,403	5,407	0.6%	0.0%	0.0%	100.0%
Marmot	2021	895,106	6,128	0.7%	0.0%	0.0%	100.0%
Marmot			Average	0.9%	0.0%	0.0%	100.0%
			% of total biomass		0.0%	0.0%	0.9%
Shumagin	2016	1,580,850	20,392	1.3%	84.3%	15.7%	0.0%
Shumagin	2017	1,280,210	29,753	2.3%	95.0%	5.0%	0.0%
Shumagin	2018	982,229	7,777	0.8%	47.4%	52.6%	0.0%
Shumagin	2020	738,628	4,637	0.6%	96.9%	3.1%	0.0%
Shumagin			Average	1.3%	80.9%	19.1%	0.0%
			% of total biomass		1.0%	0.2%	0.0%
Sanak	2015	1,676,750	17,905	1.1%	100.0%	0.0%	0.0%
Sanak	2016	1,580,850	3,571	0.2%	100.0%	0.0%	0.0%
Sanak	2017	1,280,210	831	0.1%	100.0%	0.0%	0.0%
Sanak	2018	982,229		0.0%	100.0%	0.0%	0.0%
Sanak			Average	0.3%	100.0%	0.0%	0.0%
			% of total biomass		0.3%	0.0%	0.0%
Mozhovoi	2013	1,174,910	600	0.1%	100.0%	0.0%	0.0%
Mozhovoi	2016	1,580,850	11,459	0.7%	100.0%	0.0%	0.0%
Mozhovoi	2017	1,280,210	3,924	0.3%	100.0%	0.0%	0.0%
Mozhovoi	2018	982,229	3,759	0.4%	100.0%	0.0%	0.0%
Mozhovoi			Average	0.4%	100.0%	0.0%	0.0%
			% of total biomass		0.4%	0.0%	0.0%
Pavlof	2016	1,580,850	2,140	0.1%	100.0%	0.0%	0.0%
Pavlof	2017	1,280,210	2,092	0.2%	100.0%	0.0%	0.0%
Pavlof	2018	982,229	4,413	0.4%	100.0%	0.0%	0.0%
Pavlof			Average	0.2%	100.0%	0.0%	0.0%
			% of total biomass		0.2%	0.0%	0.0%
Total				80.62%	1.97%	74.01%	4.64%
Rescaled total				100.00%	2.45%	91.80%	5.75%

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	31.0%	25.7%	37.8%	5.5%
2019	20.9%	35.3%	36.2%	7.6%
2021	18.2%	30.5%	45.7%	5.6%
		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	74.3%	8.2%	15.2%	2.4%
2019	46.3%	14.1%	35.3%	4.2%
2021	51.1%	23.0%	22.0%	3.9%

Options for allocation

Option 5: Weighted average of acoustic plus bottom trawl biomass (2017-2021)

	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 2023 Seasonal and Area TAC Allowances for the W/C/WYK region.

Proposed 2023 ABC for W/C/WYK (t):			**148,937**

Winter biomass distribution			
Area	610	620	630
Percent	2.4%	91.8%	5.7%

Summer biomass distribution				
Area	610	620	630	640
Percent	34.8%	26.1%	33.9%	5.2%

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

PWS percent	2.5%	GHL (t)	3,723
Federal percent	97.5%	Federal TAC	145,214

2) Use summer biomass distribution for the 640 allowance:

640 percent	5.2%	640 TAC (t)	7,523
610-630 percent	94.8%	610-630 TAC (t	137,691

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

TAC (t)	Percent	TAC (t)
A1 season	25%	34,423
A2 season	25%	34,423
B1 & B2 seasons	50%	68,846

4) For the A1 season, the TAC allocation in 630 is based on an average of winter and summer distributions. For the A2 season, the allocation of TAC is based on the winter biomass distribution.

	A1 season		A2 season	
Area	Percent	TAC (t)	Percent	TAC (t)
610	2.4%	843	2.4%	843
620	76.8%	26,439	91.8%	31,601
630	20.7%	7,142	5.7%	1,979

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

	B1 & B2 season	
Area	Percent	TAC (t)
610	36.7%	25,272
620	27.5%	18,965
630	35.7%	24,608

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

	TAC (t)		Percent	
Area	Season A	Season B	Season A	Season B
610	1,685	25,272	1.2%	17.4%
620	58,039	18,965	40.0%	13.1%
630	9,121	24,608	6.3%	16.9%
640	7,523		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.

Year	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
2021	41.61	0.19	31.99

Appendix 1F: State-space Modeling of the Walleye Pollock Stock in the Gulf of Alaska

Giancarlo M. Correa

Introduction

State-space models is a group of stock assessment models that separate and estimate both process error in the population dynamics and observation error in the data [@aeberhard_review_2018]. These models are especially useful when stochastic processes affect the temporal dynamics of a stock. Historically, this temporal variability has been ignored or modeled by using penalized deviations; however, the penalty terms that drive the degree of variability are normally fixed or iteratively tuned, methods that are highly subjective (e.g. @methot_adjusting_2011). In state-space models, the penalty terms are estimated as variance parameters constraining random effects and maximizing the marginal likelihood [@aeberhard_review_2018, @stock_woods_2021]. These methods are computationally demanding; however, the development of Template Model Builder (TMB, @kristensen_tmb_2016) has allowed a wider use of state-space models by performing an efficient Laplace approximation.

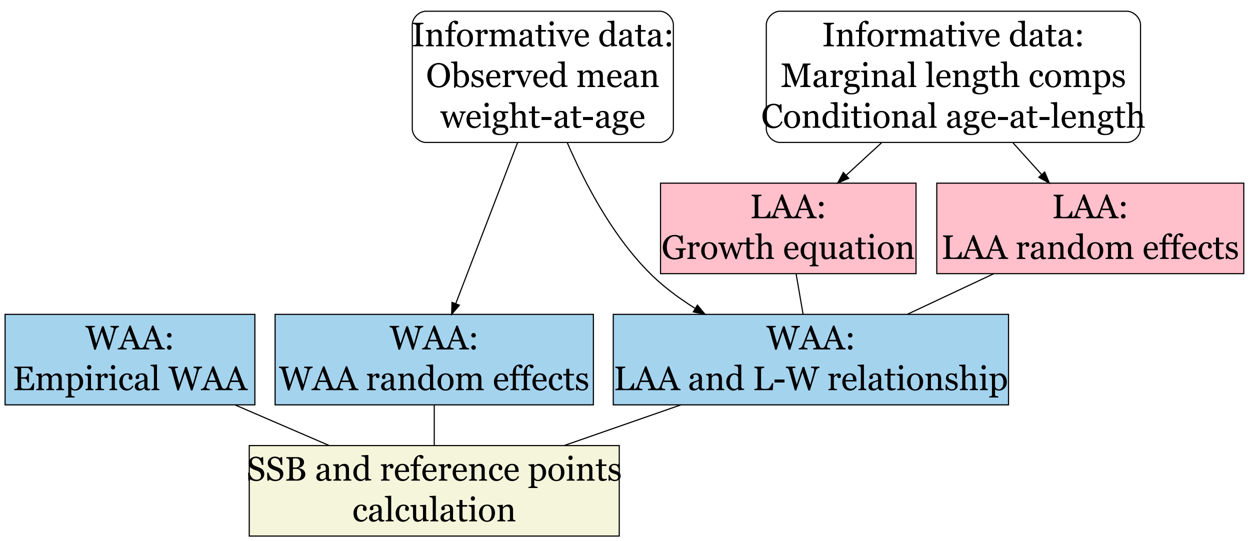


Figure 1: Growth variability can be accounted for by modeling changes in mean length-at-age (LAA) or mean weight-at-age (WAA). Distinct sources of informative data can now be used.

The Woods Hole Assessment Model (WHAM) is a fully state-space age-structured assessment model written in TMB [@stock_implementing_2021, @stock_woods_2021]. WHAM implements random effects on inter-annual transitions in numbers at age (NAA), natural mortality, selectivity, and catchability. We can also incorporate environmental covariates, which are treated as observations with error. We can link any environmental covariate to recruitment, natural mortality, and catchability, so we can implement a mechanistic approach to model temporal variations in biological and fishery parameters. WHAM has been applied to several stocks on the U.S. East Coast and has shown to be a promising platform to account for stochastic processes in a population. However, WHAM still needs to incorporate more features (e.g. internal modeling of growth, spatial structure) required for several stocks worldwide.

The use of state-space models on the U.S. West Coast and Alaska is rare while models that use penalized deviations to account for temporal variability in biological processes are still dominant (e.g. Stock Synthesis).

The reason is that most state-space models are relatively new and only allow the incorporation of age information and cannot model growth internally, essential features for stocks in these regions. For this reason, a recent project has worked on expanding the current features of WHAM, allowing the incorporation of new data inputs such as marginal length compositions, conditional age-at-length, as well as the internal modeling of somatic growth through different strategies (Figure 1). These new features have been applied to the walleye pollock in the Gulf of Alaska (GOA), and we present some preliminary results in this section.

Walleye pollock growth variability

Length observations in survey data display a substantial variability in length-at-age from 1986 to 2021 (Figure 2). We observe a increase in length-at-age until 2010-2015, and then a decrease during the last years. Currently, we are exploring distinct environmental covariates that could cause the observed growth variability and could then be included in our assessment models.

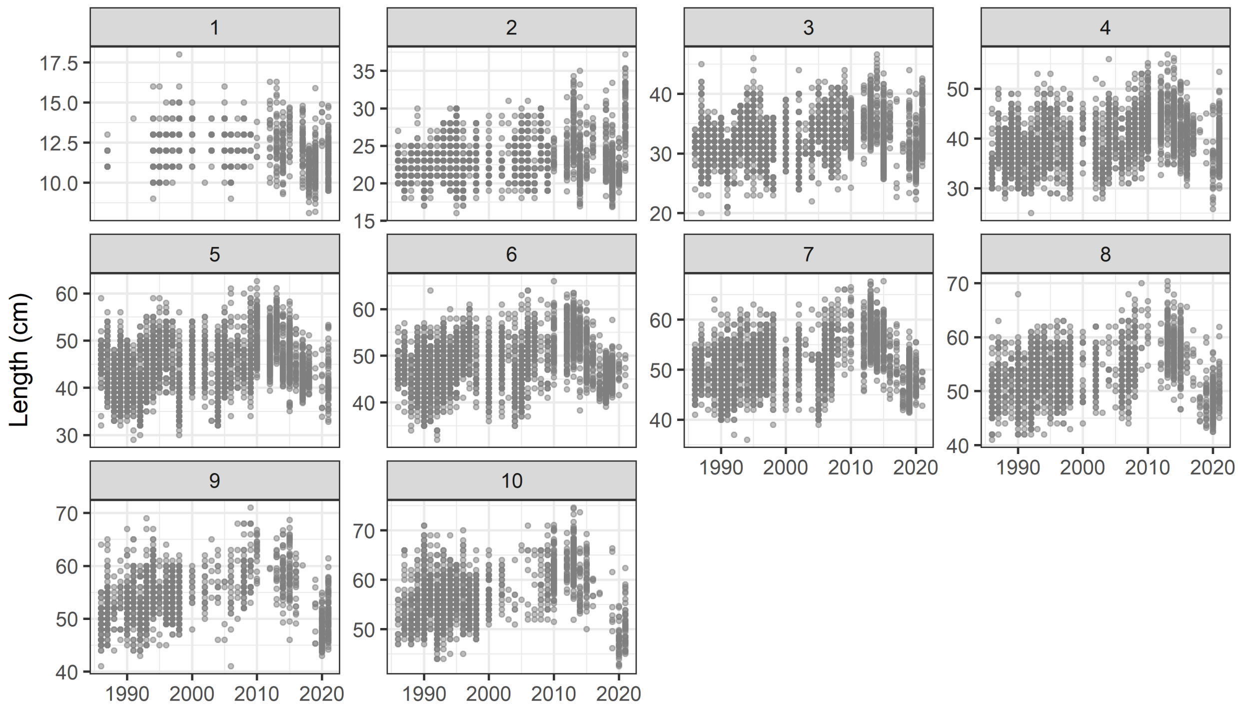


Figure 2: Length-at-age observations per age (panels) in the Shelikof survey.

Assessment models

Our first step was to implement an assessment model in WHAM as similar as possible to the official model in ADMB. Figure 3 displays our starting model in WHAM, which includes empirical weight-at-age information to account for growth variability over time. As we observe, temporal trends of spawning biomass (SSB) estimates between the ADMB and WHAM model are similar and there are only small differences in some years. Also, we note that the uncertainty in SSB is larger for the WHAM model.

Once we obtained our WHAM starting mode, we then implemented a set of models that accounted for growth variability using different strategies now available in WHAM. The only data input relevant for growth modeling included in these models was observed mean weight-at-age (Shelikof survey). Observation error was calculated from the data and incorporated in our models. Model description is shown in Table 1.

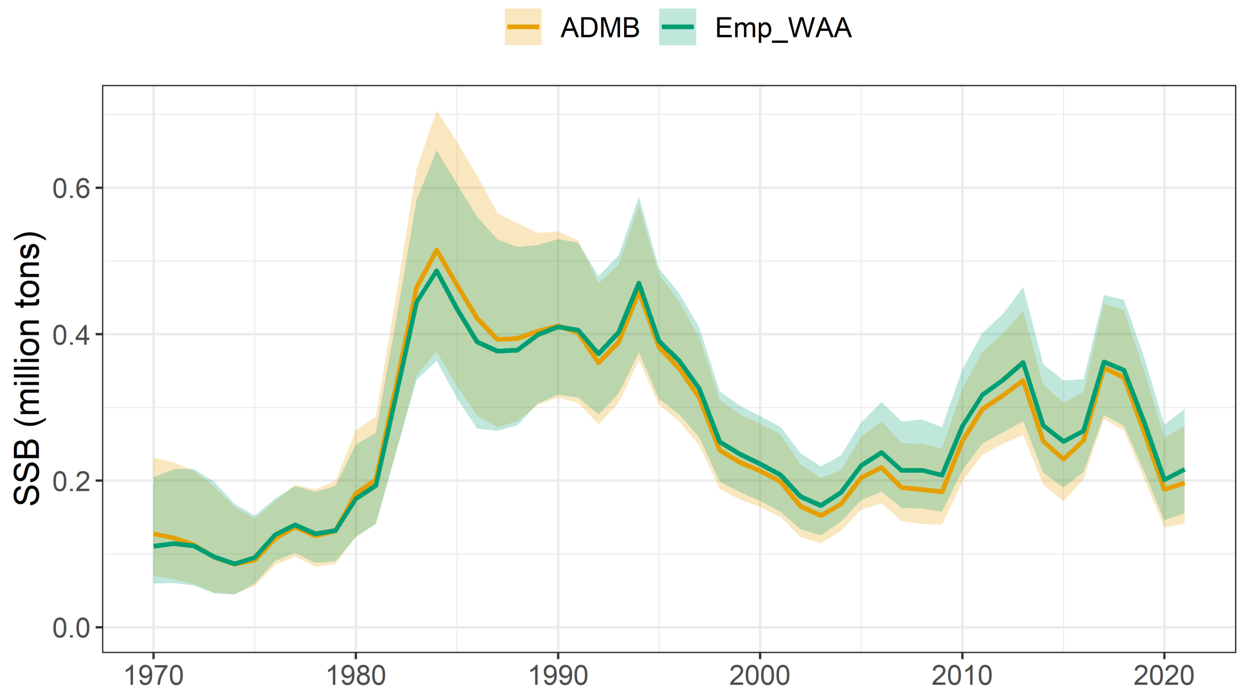
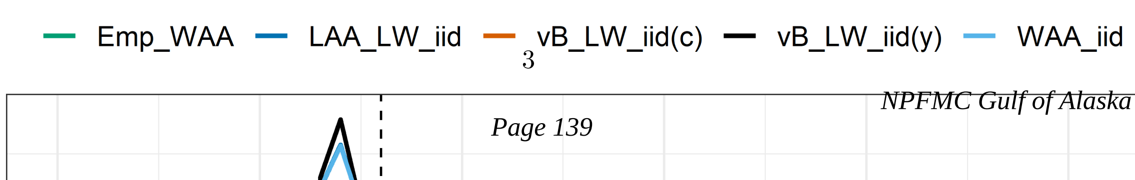


Figure 3: Spawning biomass (SSB) estimates for the ADMB and the starting WHAM model (EmpWAA). Both include empirical weight-at-age to account for growth variability.

Table 1: Models in WHAM and description.

Model name	Model description
Emp_WAA	Uses empirical weight-at-age matrices for the fishery and the Shelikof survey, which are assumed to be known perfectly.
LAA_LW_iid	Predicts random effects on mean length-at-age. Random effects vary over year and ages and are independent (iid). Uses a length-weight relationship (fixed parameters) to predict mean weight-at-age, which are then fitted to observed mean weight-at-age data (Shelikof survey).
$vB\_LW\_iid(c)$	Predicts random effects on the growth coefficient (K) and asymptotic length (L_∞). Random effects vary over cohorts and are independent ($iid(c)$). Uses a length-weight relationship (fixed parameters) to predict mean weight-at-age, which are then fitted to observed mean weight-at-age data (Shelikof survey).
$vB\_LW\_iid(y)$	Predicts random effects on the growth coefficient (K) and asymptotic length (L_∞). Random effects vary over years and are independent ($iid(y)$). Uses a length-weight relationship (fixed parameters) to predict mean weight-at-age, which are then fitted to observed mean weight-at-age data (Shelikof survey).
WAA_iid	Predicts random effects on mean weight-at-age. Random effects vary over year and ages and are independent (iid). Variation in mean length-at-age is not modeled. Predicted mean weight-at-age is then fitted to observed mean weight-at-age data (Shelikof survey).



We observed that temporal trends in mean SSB estimates were similar among all models (Figure 4). The largest differences were observed before 1995, probably because the mean values of weight-at-age assumed for the early period are larger for the models that did not incorporate empirical weight-at-age.

We also compared the coefficient of variation (CV) of SSB estimates over year, and observed that the model that included empirical weight-at-age produced the lowest CV for most years (Figure 5). The model that used von Bertalanffy function to calculate mean length-at-age (parametric approach) led to the largest CV, especially before 1995.

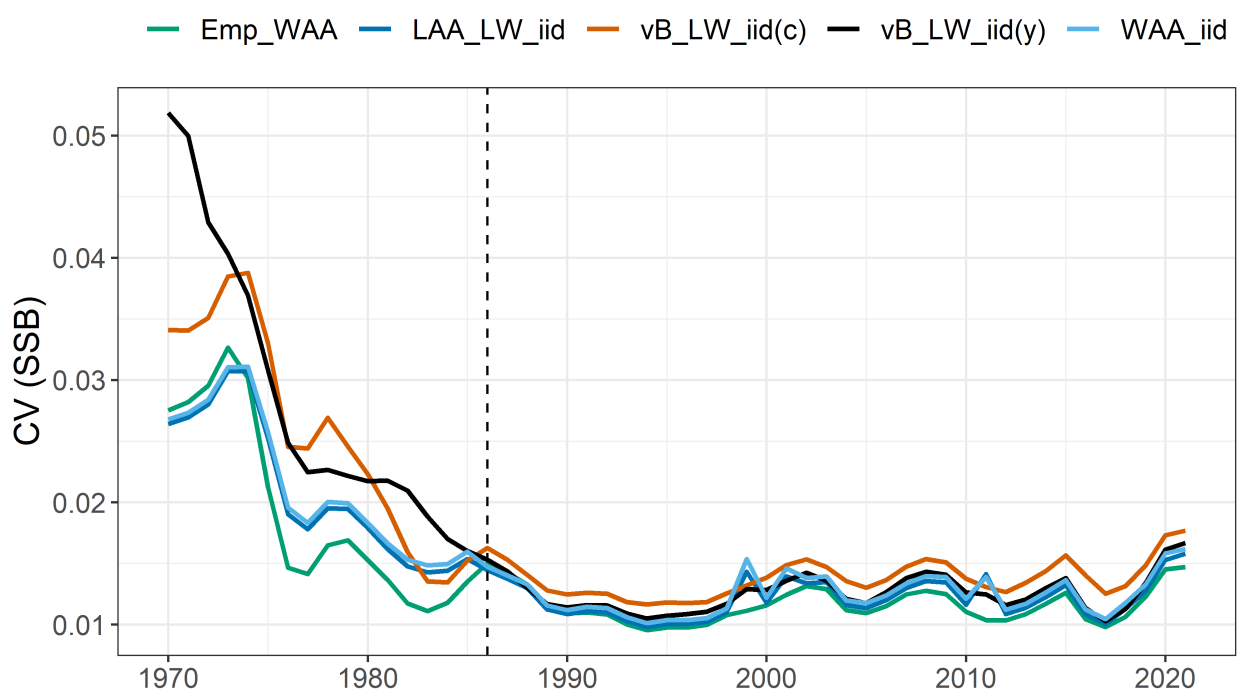


Figure 5: Coefficient of variation (CV) of spawning biomass (SSB) over years per model.The vertical dashed line represents the year when mean weight-at-age information becomes available.

For models that used the parametric approach, we observed that the growth coefficient K and asymptotic length L_∞ had a negative correlation (Figure 6). However, the parameter triggering the increase in length-at-age observed during 2000-2015 was K for the model with cohort effect $vB\_LW\_iid(c)$ but L_∞ for the model with year effect $vB\_LW\_iid(y)$.

We compared the mean length-at-age estimates (January 1st) with survey data ($\sim$ March 1st, not included in the model) (Figure 7) and observed that models closely match the patterns observed in the data. The models with the smaller residuals were those that predicted random effects on mean length-at-age (LAA_LW_iid) and weight-at-age (WAA_iid).

We use AIC to compare the performance of these models 2. The best model was LAA_LW_iid (predicted random effects on mean length-at-age, non-parametric approach), while the worst models were those that implemented the parametric approach to model growth ($vB\_LW\_iid(y)$ and $vB\_LW\_iid(c)$).

Table 2: Marginal AIC for models using the same data.

Model name	(Marginal) AIC	Δ AIC
LAA_LW_iid	816.7	0
$vB\_LW\_iid(y)$	4036.6	3219.9

Model name	(Marginal) AIC	Δ AIC
$vB\_LW\_iid(c)$	4761.9	3945.2
WAA_iid	1177.2	360.5

Discussion

In this section, we successfully implemented the official assessment model of the walleye pollock in the GOA (implemented in ADMB) in a state-space assessment model (WHAM). WHAM produces very similar results as the ADMB model. We also implemented several models in WHAM that accounted for somatic growth variability. We observed that all models gave quite similar results due to all of them use the same source of informative data (empirical or observed mean-weight-at-age). In future models, we will use other data sources to inform growth variability (e.g. marginal length compositions or conditional age-at-length).

References

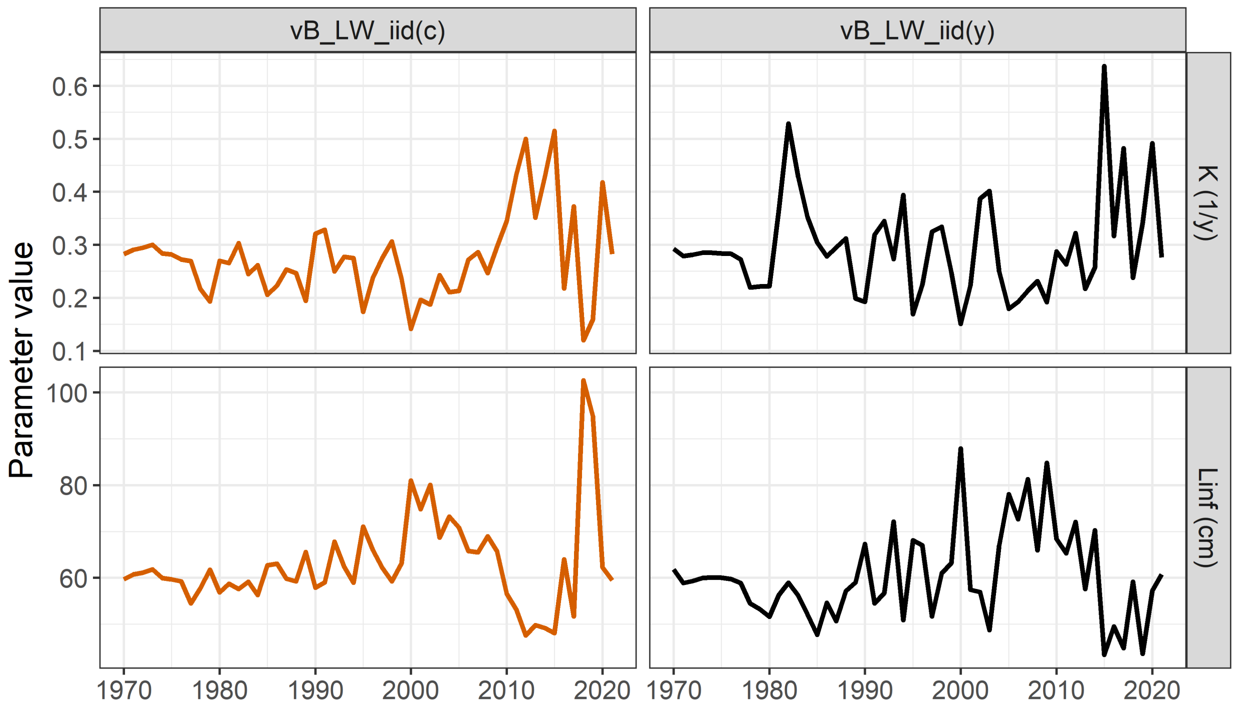


Figure 6: Time variability in growth parameteres estimated by models that used a von Bertalanffy equation.

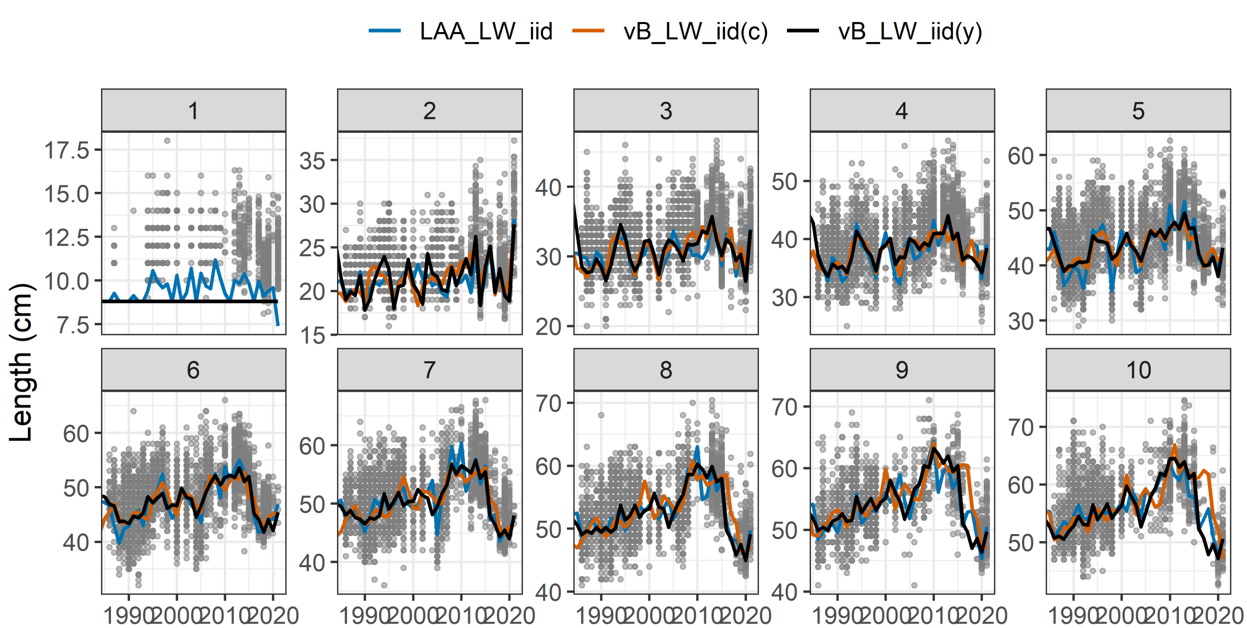


Figure 7: Length-at-age observations per age (panels) in the Shelikof survey and estimation of mean length-at-age.