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: 2022 total catch was updated and catch at age added. The 2023 TAC was used for catch in 2023.
2. Shelikof Strait acoustic survey: 2023 biomass index and age composition.
3. NMFS bottom trawl survey: 2023 index and length compositions
4. Summer acoustic survey: 2023 index and length compositions
5. ADF&G crab/groundfish trawl survey: 2023 biomass index

Changes in assessment methodology

This year there was no change in model structure, but there was a transition to a new modeling platform named Template Model Builder (TMB; (Kristensen *et al.* 2016)). A bridging analysis showed that the former 19.1a ADMB model and TMB model were equivalent, with differences of less than 0.02% in estimates and uncertainty of SSB and recruitment. Given a change in modeling platform the previous model 19.1a was renamed to 23.0. Moving to TMB allows for more flexibility in modeling process errors due to its ability to efficiently apply the Laplace approximation to get the marginal likelihood in complex, non-linear hierarchical models. We explored a suite of alternative fisheries selectivity models (Appendix 1F) but did not bring them forward for consideration this year. The advantages of this flexibility will be explored in depth in future years, but the focus this year was to transition the assessment to the new platform.

Summary of Results

The base model projection of female spawning biomass in 2024 is 274,141 t, which is 54.3% of unfished spawning biomass (based on average post-1977 recruitment) and above B40% (202,000 t), thereby placing GOA pollock in sub-tier "a" of Tier 3. New surveys in 2023 include the winter Shelikof Strait acoustic survey, summer acoustic survey, summer NMFS bottom trawl survey, and the ADF&G bottom trawl survey. These surveys showed somewhat divergent trends, with large increases in the summer NMFS bottom trawl (79.4%) and summer acoustic (71.7%) from 2021, but decreases in the winter acoustic (-29.2%) and ADF&G bottom trawl survey from 2022. Together the new data led to a increased spawning population relative to the prediction from last year.

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. We identified some aspects of the stock with elevated concerns about the stock assessment, there were none for population dynamics, environment/ecosystem, or fisheries performance categories. We therefore recommend no reduction from maximum permissible ABC.

The recommended 2024 ABC for pollock in the Gulf of Alaska west of 140° W lon. (W/C/WYK regions) is 232,543 t, which is an increase of 56.1% from the 2023 ABC. The recommended 2025 ABC is 157,687 t. The OFL in 2024 is 269,916 t, and the OFL in 2025 if the ABC is taken in 2024 is 182,891 t. These calculations are based on a projected 2023 catch of 145,215 t and the ABC for years 2024 and 2025. The estimated scale of the stock increased about 40% compared to previous years, driven by new data, particularly the new high biomass indices from summer surveys.

For pollock in southeast Alaska (Southeast Outside region, east of 140° W lon.), the ABC recommendation for both 2024 and 2025 is 9,749 t (see Appendix 1B) and the OFL recommendation for both 2024 and 2025 is 12,998 t. These recommendations are based on a Tier 5 assessment using the projected biomass in 2024 and 2025 from a random effects model fit to the 1990-2023 bottom trawl survey biomass estimates of the assessment area.

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

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity/Status	2023	2024	2024*	2025*
M (natural mortality)	0.300	0.300	0.300	0.300
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	1,137,330	850,404	1,154,403	1,430,029
Projected female spawning biomass (t)	204,554	188,277	274,141	227,091
$B_{100\%}$	469,000	469,000	505,000	505,000
$B_{40\%}$	188,000	188,000	202,000	202,000
$B_{35\%}$	164,000	164,000	177,000	177,000
F_{OFL}	0.304	0.302	0.307	0.307
maxF_{ABC}	0.257	0.257	0.260	0.260
F_{ABC}	0.257	0.257	0.260	0.260
OFL (t)	173,470	186,101	**269,916**	182,891
*max*ABC (t)	148,937	161,080	232,543	157,687
ABC (t)	148,937	161,080	**232,543**	157,687
	As determined *last* year for:		As determined *this* year for:	
Status	2022	2023	2023	2024
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 145,215 t for 2023 and estimates of maxximum permissible ABC for 2024 and 2025.

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

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity/Status	2023	2024	2024	2025
M (natural mortality)	0.30	0.30	0.30	0.30
Tier	5	5	5	5

Quantity/Status	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2023	2024	2024	2025
Biomass (t)	50,505	50,505	43,328	43,328
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	12,998	12,998
*max*ABC (t)	11,363	11,363	9,749	9,749
ABC (t)	11,363	11,363	9,749	9,749
	As determined *last* year for:		As determined *this* year for:	
Status	2022	2023	2023	2024
Overfishing	No	n/a	No	n/a

Area Allocation of Harvest

The following table shows the recommended ABC apportionment for 2024 and 2025. 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)
2024	610	6,611	40,793
	620	86,461	24,406
	630	16,901	44,773
	640	6,785	
2025	610	4,483	27,662
	620	58,629	16,550
	630	11,460	30,361
	640	4,601	

Responses to SSC and Plan Team Comments on Assessments in General

Responses to SSC and Plan Team Comments Specific to this Assessment

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

An extensive analysis of non-parametric and parametric fisheries selectivities was undertaken in 2023 (Appendix 1F). These models showed promise for improving residual patterns, but had some lingering estimation and stability issues that need to be more thoroughly addressed. This will be done next year.

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 2023, 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 constraint (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 but still under scientific review and thus not adopted this year. We anticipate having something formal to present in 2024.

In October 2023 the SSC supported *the GOA GPT recommendation that additional examinations are necessary to determine best method(s) for projecting near term trends when time-varying and auto-correlated selectivities are used in assessments.*

We examined this in Appendix 1F and found that using model predictions from non-parametric selectivity modules (2D and 3D AR(1)) generally outperformed the status quo of using an average of the most recent 4 years with data. The non-parametric functions led to improved retrospective patterns, but also lower predictive error (RMSE) in a retrospective analysis when predicting a single year out and comparing it to estimates with the data in the subsequent year. Non-parametric modules are not feasible to fit in a robust way in ADMB models, and so the new 23.0 TMB pollock model provides an important research tool to explore issues with time-variation and projections. We anticipate further research along these lines in 2024.

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 inter-annual 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 (Figs. 1.2 and 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 2018 and 2022, on average about 95% 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 had trended upwards since 2018, but has fallen in the last 2 years. The most common recent non-target species are squid, miscellaneous fish, smelt, capelin, and grenadier (Table 1.2). Bycatch estimates for prohibited species over the period 2018-2022 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 and was 13,130 in 2022.

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 compositions, NMFS summer bottom trawl survey estimates of biomass and age and length compositions, 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	1970-2023
Fishery	Age composition	1970-2022
Shelikof Strait acoustic survey	Biomass	1992-2023
Shelikof Strait acoustic survey	Age composition	1992-2023
Summer acoustic survey	Biomass	2013-2023, biennially
Summer acoustic survey	Age composition	2013-2021, biennially
NMFS bottom trawl survey	Area-swept biomass	1990-2023, biennially
NMFS bottom trawl survey	Age composition	1990-2021, biennially
ADF&G trawl survey	Delta-GLM index	1988-2023
ADF&G trawl survey	Age composition	2000-2022, 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 2022 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	0	296	296	266
	No. lengths	0	3,485	1,232	828
	Catch (t)	138	49,005	8,260	9,197
2nd half (C and D seasons)	No. ages	298	297	297	0
	No. lengths	3,673	2,204	2,350	0
	Catch (t)	23,476	20,336	22,286	0

The dominant cohort in the 2023 expected age composition data was 2018 with 27%, followed by 2017 with 21%. The 2012 is in the plus group and only accounts for about 6% of expected catch this year. Fishery catch at age in 1975-2022 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 18th comprehensive bottom trawl survey since 1984 during the summer of 2023 (Fig. 1.6). The 2023 gulfwide biomass estimate of pollock was 921,886 t, which is an increase of 74.3% from the 2021 estimate, which itself was a 72.2% increase from 2019, a sharp increase after the low in 2019. The biomass estimate for the portion of the Gulf of Alaska west of 140º W long. used in the assessment model is 887,602 t. The coefficient of variation (CV) of this estimate was 0.13, which is below the average of 0.197 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 2023 ages were not yet available (Table 1.9), so instead 2023 length compositions were used (Fig. 1.7).

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 2023 are presented in a NMFS processed report (McKelvey *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 2023 biomass estimate for Shelikof Strait in 2023 for all fish is 258,829 t, which is a 29% percent decrease from the 2022 estimate (Fig. 1.8). This estimate accounts for trawl selectivity by scaling up the number of retained pollock by selectivity curves estimated with pocket nets attached to the midwater trawl used to sample echosign, continuing an approach that was started in the 2018 assessment. Winter 2023 pre-spawning pollock surveys were also conducted in the Shumagin Islands area, Chirikof shelf break, Marmot Bay, Pavlov Bay, and Morzhovoi Bay. This contrasts with 2022 where to travel, vessel, and staffing constraints stemming from protocols required to mitigate the COVID-19 pandemic, only Shelikof was completed. Further information can be found in McKelvey *et al.* (in prep.).

Age Composition

Estimates of numbers at age from the Shelikof Strait acoustic survey (Table 1.10, Fig. 1.9) were obtained using an age-length key compiled from random otolith samples and applied to weighted length frequency samples. Sample sizes for ages and lengths are given in Table 1.11. Estimates of age composition in Shelikof Strait in 2023 indicate reduced, but persistent dominance of the 2012 year class, and a mode of age 4-6 fish, 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 was addressed further in the risk table in the 2022 assessment (Monnahan *et al.* (2022)).

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 to account for the timing of the survey relative to spawning 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

Six complete acoustic surveys, in 2013, 2015, 2017, 2019, 2021 and 2023, 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.; McGowan *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 2023 biomass estimate for summer acoustic survey is 740,417 t, which is a 71.7% percent increase from the 2021 estimate (Table 1.7). Age compositions were not yet ready and so length compositions were used instead (@ref(fig:summer_at_lcomps). 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).

In 2023 an issue with vessel noise was identified and required a minor change in the way the data were processed. The processing methods used in the survey assume that noise is negligible. However, in 2023 there was concern that this was no longer the case due to recent changes in vessel noise (sonar self-noise at 38 kHz at survey speed was ~10 dB or ten-fold higher than in 2022). The effects of noise are depth and density-dependent and are difficult to predict. Signal-to-noise thresholding and noise correction (De Robertis and Higginbottom 2007) was used to exclude pollock backscatter from areas influenced by noise (i.e. all areas with a signal-to-noise threshold of <6 dB were removed from the estimate). This revised processing resulted in total pollock biomass that was 0.19% less than for uncorrected data, confirming that noise had only a minor impact on the biomass estimate. Further details can be found in McGowan *et al.* (in prep.).

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. 1.10). 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. 1.10). 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 2023 area-swept biomass estimate for pollock for the ADF&G crab/groundfish survey was 56,611 t, a decrease of 22.5%% from the 2022 biomass estimate (Table 1.7). The 2023 pollock estimate for this survey is approximately 63% of the long-term average.

Biomass Estimates

A delta GLM model was applied to the ADF&G tow by tow data for 1988-2023 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. 1.11). 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 = 584; Table 1.12, Fig. 1.12). 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 the 1960s 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 the indices are not directly comparable due to selectivity differences and the considerable variability in each survey time series, a fairly clear downward trend is evident to 2000, followed by a stable, though variable, trend to 2008, followed by a strong increase to 2013 (Fig. 1.13). From 2016 to 2019 there was a strong divergence among the trends, but the relative abundance came back into reasonable alignment from 2020-2023 with the exception of the large estimate of the NMFS bottom trawl survey in 2023.

Indices derived from fisheries catch data were also evaluated for trends in biological characteristics (Fig. 1.14). The percent of females in the catch shows some variability and generally is close to 50-50, but has been low since 2015. Evaluation of sex ratios by season indicated that this decrease was mostly due a low percentage of females during the A and B seasons (now the A season) prior to spawning. However the sex ratio during the C and D (now the B season) 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. 1.14). In 2021 the age diversity returned to near the long-term average and remains there through 2023.

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. It is unclear whether these changes are a result of density dependence or environmental forcing. Previous assessments examined this cohort in more depth, but its impact on the fishery is diminishing and is not a focus here.

Analytical approach

General Model Structure

An age-structured model covering the period from 1970 to 2023 (54 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 penalties, 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 (1970-2023)	Log-normal	CV = 0.05, 2023 catch is projected
Fishery age comp. (1975-2022)	Multinomial	Initial sample size: 200 or the number of tows/deliveries if less than 200
Shelikof acoustic survey biomass (1992-2023)	Log-normal	CV = 0.20
Shelikof acoustic survey age comp. (1992-2023)	Multinomial	Initial sample size = 60
Shelikof acoustic survey age-1 and age-2 indices (1994-2023)	Log-normal	Tuned CVs = 0.45 and 0.55
Summer acoustic survey biomass (2013-2023)	Log-normal	CV = 0.25
Summer acoustic survey age comp. (2013-2021)	Multinomial	Initial sample size = 10
NMFS bottom trawl survey biom. (1990-2023)	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

Likelihood component	Statistical model for error	Variance assumption
ADF&G trawl survey index (1989-2023)	Log-normal	Survey-specific CV from delta GLM model rescaled so mean is 0.25=0.20-0.35
ADF&G survey age comp. (2000-2022)	Multinomial	Initial sample size = 30
Recruit process error (1970-2023)	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 a state-space research version of the model. This change had a relatively small impact on the estimated recruits and management reference points.

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 judgment as a constraint on potential values (Fig. 1.15). Catchability coefficients for other surveys were estimated as free parameters. The age-1 and age-2 winter acoustic survey indices are numerical abundance estimates, and were modeled using independently estimated catchability coefficients (i.e., no selectivity is estimated).

A vessel comparison (VC) experiment was conducted in March 2007 during the Shelikof Strait acoustic survey. The VC experiment involved the R/V Miller Freeman (MF, the survey vessel used to conduct Shelikof Strait surveys since the mid-1980s), and the R/V Oscar Dyson (OD), a noise-reduced survey vessel designed to conduct surveys that have traditionally been done with the R/V Miller Freeman. The vessel comparison experiment was designed to collect data either with the two vessels running beside one another at a distance of 0.7 nmi, or with one vessel following nearly directly behind the other at a distance of about 1 nmi. The methods were similar to those used during the 2006 Bering Sea VC experiment (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. 1.16). Somewhat surprisingly, the theoretical/empirical estimates were similar, on average, to predation model estimates. To obtain an age-specific natural mortality schedule for use in the stock assessment, we used an ensemble approach and averaged the results for all methods. Then we used the method recommended by Clay Porch in Brodziak *et al.* (2011) to rescale the age-specific values so that the average for range of ages equals a specified value. Age-specific values were rescaled so that a natural mortality for fish greater than or equal to age 5, the age at 50% maturity, was equal to 0.3, the value of natural mortality used in previous pollock assessments.

Maturity at age

Maturity stages for female pollock describe a continuous process of ovarian development between immature and post-spawning. For the purposes of estimating a maturity vector (the proportion of an age group that has been or will be reproductively active during the year) for stock assessment, all fish greater than or equal to a particular maturity stage are assumed to be mature, while those less than that stage are assumed to be immature. Maturity stages in which ovarian development had progressed to the point where ova were distinctly visible were assumed to be mature (i.e., stage 3 in the 5-stage pollock maturity scale). Maturity stages are qualitative rather than quantitative, so there is subjectivity in assigning stages, and a potential for different technicians to apply criteria differently (Neidetcher et al. 2014). Because the link between pre-spawning maturity stages and eventual reproductive activity later in the season is not well established, the division between mature and immature stages is problematic. Changes in the timing of spawning could also affect maturity at age estimates. Merati (1993) compared visual maturity stages with ovary histology and a blood assay for vitellogenin and found general consistency between the different approaches. Merati (1993) noted that ovaries classified as late developing stage (i.e., immature) may contain yolked eggs, but it was unclear whether these fish would have spawned later in the year. The average sample size of female pollock maturity stage data per year since 2000 from winter acoustic surveys in the Gulf of Alaska is 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. 1.17 and 1.18). 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. 1.19). 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. 1.20). For pollock greater than age 6, weight-at-age nearly doubled by 2012 compared to 1983-1990. However, weight at age trended strongly downward from 2012 to 2020, with some rebound in the last couple of years. Further analyses are needed to evaluate whether these changes are a density-dependent response to declining pollock abundance, or whether they are environmentally forced. Changes in weight-at-age have important 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 2023 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 1975-2022. 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 (1981-2023) 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 2022 fishery weight at age with the data now available indicate that the model overestimated weights slightly (Fig. 1.21). In this assessment, RE model estimates of weight at age are used for the fishery in `r year` and for yield projections and harvest recommendations.

Correa *et al.* (2023) details an exploratory and promising approach using a state-space model to estimate the WAA within the assessment model and this will be explored further in future years.

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 Template Model Builder [TMB; Kristensen *et al.* (2016)], a modeling platform based strongly on AD Model Builder (Fournier *et al.* 2012) but which contains improved functionality for estimating non-linear hierarchical models. 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. Like AD Model Builder, TMB includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest, and has state of the art Bayesian integration capabilities (Monnahan and Kristensen 2018).

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

Population process modeled	Number of parameters	Estimation details
Mean recruitment	1	Estimated in log space
Recruitment deviations	Years 1970-2023 = 54	Estimated as log deviances from the log mean with all years constrained by random deviation process error of 1.3.
Natural mortality	Age-specific= 10	Not currently estimated in the model
Fishing mortality	Years 1970-2023 = 54	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) = 108	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) = 108	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	123 estimated parameters + 216 process errors = 339	
need to fix this		

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 1.22 shows the changes in estimated spawning biomass as the updated catch projections, catch at age, and surveys were added sequentially. This year, additions changed both the trend and scale of the stock. In particular adding the NMFS BT index and lengths, the Shelikof index and ages, and summer acoustic index all substantially increased the estimate of stock size. Such changes are not typical, but given the large increases in survey indices it is not entirely surprising that recent trends shifted upward. Likewise, a change in scale is expected given the known sensitivity for this model to changes in data and model assumptions (as explored more thoroughly in e.g., Monnahan *et al.* (2021)) and the Plan Team presentations in 2022 (link to pdf).

The intent of this year's assessment was to migrate to the new TMB modeling framework without considering any changes to the model structure. Conversion requires a substantial effort not only in rewriting the C++ model, but also the workflow for processing model inputs and results. After adding new data to model 23.0, a final turning step was done using the Francis (2011) approach which reweighted all composition components, including the summer acoustic age composition for the second time, resulting in the only downward estimate of SSB in the model results (Fig. 1.22).

Model evaluation

The fit of model 23.0 to age composition data was evaluated using plots of observed and predicted age composition and residual plots. Figure 1.23 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, and is close to 0.5 in 2023. Catchability for the NMFS bottom trawl and summer acoustic surveys were similar (0.80 and 0.70 respectively), while the age-1 and age-2 Shelikof survey catchabilities were 0.22 and 0.26, respectively, reflecting the fact that the survey does not target these immature ages.

One-step-ahead (OSA) residuals are used this year to assess fits to composition data (Trijoulet *et al.* 2023). Plots show the fit to fishery age composition (Figs. 1.24, 1.25), Shelikof Strait acoustic survey age composition (Figs. 1.26,1.27), NMFS trawl survey age composition (Fig. 1.28), ADF&G trawl survey age composition (Fig. 1.29) and the summer acoustic survey (Fig. 1.30). Model fits to fishery age composition data are adequate in most years, though the very strong 2012 year class shows up as a positive residual in 2016-2023 due to stronger than expected abundance in the age composition. Previous assessments had strong patterns of negative residuals for older ages, but it is clear now using OSA residuals that these were not real and instead an artifact of Pearson residuals being wrong. In contrast, the pattern of negative residuals for age 4 and positive for age 3 persists with OSA residuals, suggesting these are real. More complicated selectivity forms were able to eliminate this pattern (Appendix 1F). The NMFS bottom trawl survey has relatively good residuals, even for the most recent years where there is a misfit in the index. The ADF&G compositions overall do not fit well, exhibiting strong patterns of positive residuals after 2000. The two acoustic surveys had no apparent issues fitting to the data. Overall there were no major issues in fitting the age composition data and the issues highlighted here are considered minor.

In recent assessments there was apparent conflict and uncertainty in the data about the size of the 2018 cohort. The new estimate of the initial cohort size is about 8 billion fish, larger than average (Table 1.19), an increase from 5.4 billion in the previous assessment. This appears to confirm that this cohort was relatively large and for unknown reasons was not apparent in previous years of data.

Model fits to survey biomass estimates are reasonably good for all surveys except the period 2015-2019 and now in 2023 with poor fits to the 2023 Shelikof and NMFS bottom trawl surveys (Fig. 1.31). The lack of fit in the NMFS bottom trawl survey from 2015 to 2023 is a major concern and discussed in the context of the risk table below. 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 with a few exceptions (Fig. 1.32).

Time series results

Parameter estimates and model output are presented in a series of tables and figures. Estimated survey and fishery selectivity for different periods are given in Table 1.20 (see also Figs. 1.33 and 1.34. Table 1.21 gives the estimated population numbers at age for the years 1970-2023. Table 1.19 gives the estimated time series of age 3+ population biomass, age-1 recruitment, status, and harvest rate (catch/3+ biomass) for 1977-2023 (see also Fig. 1.35). 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 103% of the proxy for unfished stock size (B100% = mean 1978- 2022 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 35% of unfished stock size. Over the years 2009-2013 stock size showed a strong upward trend, increasing from 45% to 88% of unfished stock size, but declined to 65% 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 68% in 2023. Figure 1.36 shows the historical pattern of exploitation of the stock both as a time series of SPR and fishing mortality compared to the current estimates of biomass and fishing mortality reference points. Except from the mid-1970s to mid-1980s fishing mortalities 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 1999-2023 indicates the current estimated trend in spawning biomass for 1990-2023 is consistent with previous estimates (Table 1.24 and Fig. 1.37). All time series show a similar pattern of decreasing spawning biomass in the 1990s, a period of greater stability in 2000s, followed by an increase starting in 2008. The estimated 2023 age composition from the current assessment was very similar to the projected 2023 age composition from the 2022 assessment (Fig. 1.38). Generally, the two models agree except for the age 1 recruits, where the 2022 model assumed average recruitment, but the 2023 model 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 1.39 shows a retrospective plot with data sequentially removed back to 2016. The range of errors in the estimates of spawning biomass (if the current assessment is accepted as truth) is -37.7% to -24.8%, but usually the errors are much smaller (median absolute error is -33%). There is a relatively large negative retrospective pattern in the assessment (i.e., the model consistently underestimates SSB), and the revised Mohn's ρ (Mohn 1999) across all seven peels for terminal spawning biomass is -0.308. This is considered a significant ρ based on a bootstrapping analysis done on the 2022 assessment which found that by chance ρ would be between -0.21 and 0.29 (Bryan and Monnahan in prep), and is worse than in recent years. Trends in estimates of cohort sizes is also given in Fig. 1.40.

Stock productivity

Recruitment of GOA pollock is more variable (CV = 1.3 over 1978-2022) 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. 1.35). 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. 1.41). 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 and 2023 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 1.35).

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 1978-2022 age-1 recruitment (6.297 billion), which is 2.6% 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- `r year`) was used with mean spawning weight at age from the Shelikof Strait acoustic surveys in 2019-2023 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 from 2020 to 2023 (Fig. 1.20). 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 2019 - 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
0.0%	0.000	6,295	2,014	505	0	0.0%
19.0%	0.263	6,295	1,186	202	225	19.0%

FSPR rate	Fishing mortality	Avg. Recr. (Million)	Total 3+ biomass (kt)	SSB (kt)	Catch (kt)	Harvest fraction
22.0%	0.311	6,295	1,113	177	245	22.0%

2024 acceptable biological catch (ABC)

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 84.7% of the OFL harvest rate. Projections for 2024 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, which was updated in 2023 to reflect only three levels of concern:

	Assessment-related considerations	***Population dynamics considerations***	***Environmental/ecosystem considerations***	***Fishery Performance***
Level 1: No Concern	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: 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 3: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

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

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to

simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations

Several important assessment considerations arose in 2023. The new abundance indices had conflict, with two going up and two going down. The two surveys which cover the whole extent of the Gulf were both up more than 70% from two years ago, while the two with more limited spatial coverage were down from 2022. Not surprisingly the model was not able to fit these data points, and in particular the NMFS bottom trawl index has not fit well since 2015 (Fig. 1.31).

The Shelikof abundance estimate is unexpectedly low and comprised predominantly of pollock greater than 40 cm, but also coincides with increased estimates of biomass in outlying areas, like the Chirikof shelf break and Shumagin islands, relative to recent years (Fig. 1.8). However, biomass estimates in the outlying areas are not abnormally high compared to historical surveys and the Shelikof estimate still constitutes the largest winter spawning area by far. This low Shelikof estimate is thus not well explained by spatial shifts. A mismatch between spawn timing and survey timing is another reasonable hypothesis, as the two were linked statistically via a relationship with catchability as was presented to the Groundfish Plan Team in September 2022. However, the covariate values in 2023 would suggest only moderately lower catchability and likely also not explain the poor fit to the new data point. In the end, the fit is poor but not unprecedented with this stock, and the previous few years have fit very well. We therefore believe there is no reason for a substantial concern.

In contrast the NMFS bottom trawl survey has fit poorly for the last 5 biennial surveys (since 2015). The expected trend is the opposite of the observed trend. The consistency of this misfit is a larger concern, particularly because the prior on catchability for this index is an important contributor to estimating the scale of the stock. We therefore consider this an elevated stock assessment concern.

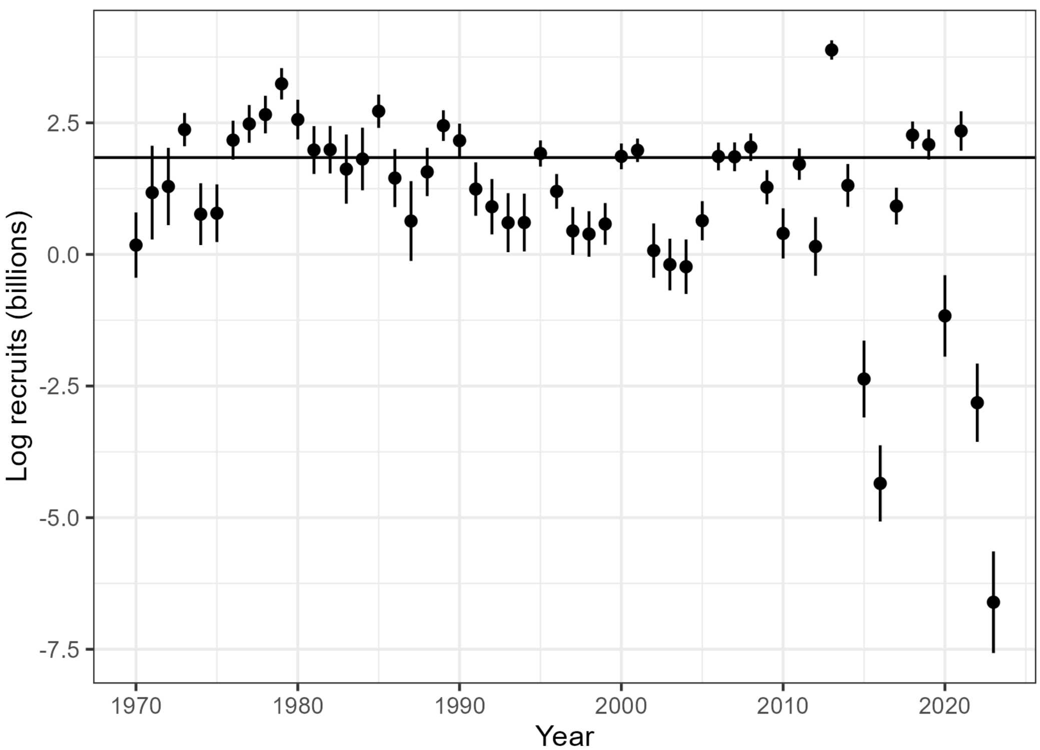
Finally, we highlight the poor retrospective pattern estimated this year. The estimated $\rho = -0.308$ is considered significant, with substantial and consistent increases of estimated SSB as data are added to the model. We hypothesized that the inflexible time-varying catchability for the winter Shelikof survey, coupled with the notably low estimate in 2023, could exaggerate this retrospective pattern. To test this hypothesis we estimated the process error for the random walk (assumed to be 0.05 in the base model) to allow it increased flexibility. This type of estimation is possible because model 23.0 is in TMB. The estimated value of the process error was 0.36, a substantial increase as expected, but the retrospective pattern was actually worse and decreased to -0.40 (results not shown). It thus appears that this retrospective pattern is not driven by an inadequately flexible catchability for the Shelikof survey. Further explorations of causes and reasonable solutions to minimize this significant retrospective pattern will be done, but for now we highlight it as a stock assessment concern.

Between the poor model fits and significant retrospective pattern we assign level 2: major concerns with assessment considerations.

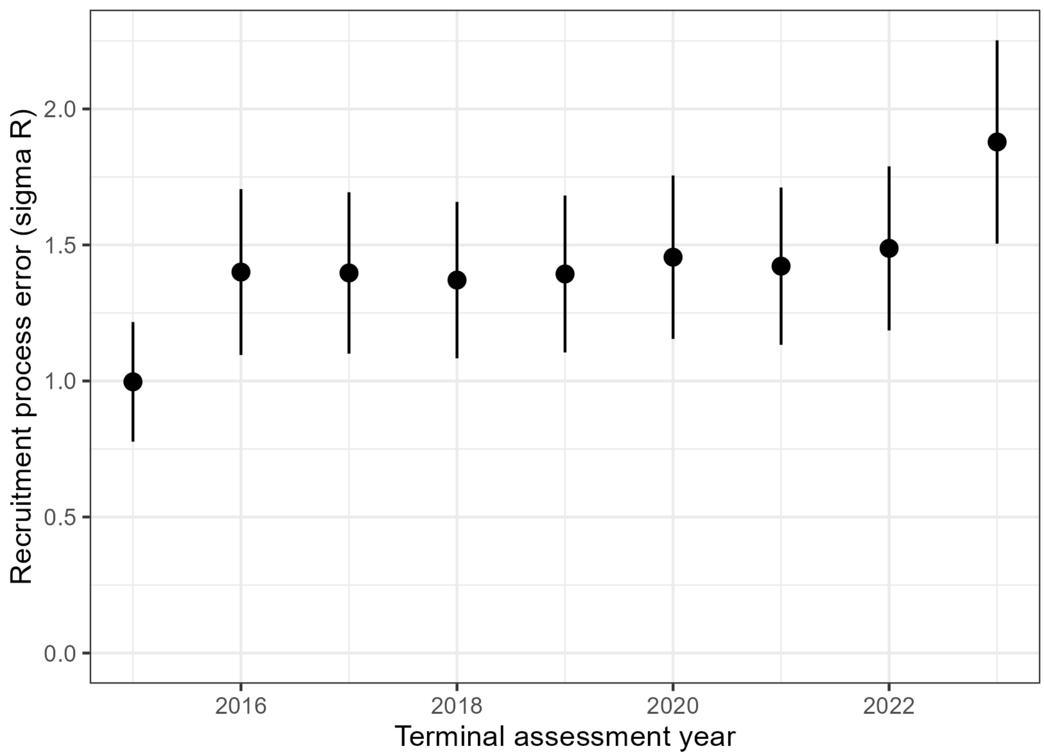
Population dynamics considerations

The large 2012 year class has had a strong impact on the recent pollock population, from a steep decline in age diversity (Fig. 1.14) to abnormal growth and maturation (but not mortality as previously suspected), which had led to an increase in concern. The estimated size of this cohort has increased substantially over the last few years, including a 9.2% and 9.9% increase in 2022 and 2023 with additional data, an increase of almost 10 billion fish from 2020 to 2023. For context, this increase alone would be considered a large cohort, and only magnifies the large impact it has on the population dynamics over the last 10 years. However, the 2012 year class, now in the 10+ age 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 1.35), resulting in a return to normal age diversity and population dynamics.

A new phenomenon emerged in the last handful of years that is worth highlighting. Many of the estimates of recent cohort sizes are abnormally small compared to previous estimates as seen in the following figure.



These recruits have implications for σ_R. We used TMB's ability to estimate process errors during a retrospective peel to test how sensitive the quantity is to these cohorts (below). We found a big increase from 2015 to 2016, and again from 2022 to 2023. This demonstrates that these small cohorts have a strong influence on the perception of the variation in recruitment. A value of σ_R closer to 1.8 is estimated by the model using data through 2023, but $\sigma_R = 1.3$ is assumed in the model this year. Future work will be done to further corroborate the small cohorts and explore whether recruitment variation should be updated. For now we consider 1.3 a more reasonable value.



These vanishingly small cohorts are clear aberrations and violate the statistical assumption of the assessment, namely that log-recruitment is normally distributed. They also are consistently estimated (Fig. 140) and corroborated by larval surveys. In other words, the estimates appear justified by the data. Whether this shift is caused by environmental forcing or other factors is unclear. However, from a population dynamics perspective, which considers recruitment in natural space, the effects are expected to be minimal. This is because the cohorts are not expected to contribute to the spawning stock whether they are very small or exceptionally small. It is the large cohorts that drive the population dynamics in the end. So while we highlight these abnormal recruitment failures, we do not believe it rises to the level of a major concern. We therefore give a level 1: no concern to population dynamics considerations.

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 2023 ocean temperatures are all within known optimal ranges for pollock life history stages (Feb-May 150-300m: spawning 1-7°C, Mar-Apr 0-200m: egg 5-6°C, Apr-Jul surface: larva 3-7°C, as referenced in the ESP, Appendix 1A). Western GOA temperatures at depth on the shelf were approximately average. Surface waters were approximately average/ cooler than average in the winter, spring, and fall with warmer waters in the summer (Satellite: Lemagie and Callahan (2023); Appendix 1A: Callahan, Seward Line: Danielson and Hopcroft (2023), NOAA bottom trawl: O'Leary (2023), Shelikof: Axler and Rogers (2023)). The central GOA experienced below average marine heatwave events this year, a decrease from last year (Appendix 1A: Barbeaux). The mean direction of the spring wind was southwest down Shelikof Strait suggesting retention in suitable larval habitat but sustained April offshore gap winds near Kodiak may have altered advective patterns (Appendix 1A:

Rogers). Over the western and central GOA, spring chlorophyll-a concentrations were below average and the peak spring bloom was considerably late (Satellite, Appendix 1A: Callahan). Upcoming 2024 winter and spring surface temperatures are predicted to be warmer than average, in alignment with El Niño conditions, potentially impacting larval pollock survival (depending on intensity and duration of the warming event).

Prey: Zooplankton biomass were below average to average on the GOA shelf in the spring and summer. Zooplankton biomass in the WGOA progressed from below average in the spring (lower small and calanoid copepod biomass and higher euphausiid biomass) to improved conditions in the summer (above average biomass of large calanoid copepods and euphausiids, but continued lower small copepod biomass; Appendix 1A: Rogers, Shelikof St., and Seward Line, Hopcroft (2023)). Summer planktivorous foraging conditions were somewhat improved with above average large calanoid copepod and euphausiid biomass, but continued lower small copepod biomass (Shelikof, Kimmel *et al.* (2023)). Planktivorous seabird reproductive success, an indicator of zooplankton availability and nutritional quality, was approximately average just south of Kodiak (Chowiet Island), and in the central GOA (Middleton Island) (Drummond *et al.* (2023), Whelan *et al.* (2023), Appendix 1A). Adult and juvenile fish conditions were below average (Bottom trawl survey, O'Leary (2023); winter acoustic survey, Appendix 1A: Monnahan). Percent euphausiids in the diet of juveniles was slightly above average (Appendix 1A: Aydin). Catches of larval and YOY pollock in spring and summer surveys were low (Shelikof St, Rogers and Porter (2023), Appendix 1A: Rogers, Kodiak beach seine survey, Appendix 1A: Laurel), suggesting less productive feeding conditions in the nearshore for larval pollock.

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, P. halibut, and arrowtooth flounder biomass have remained relatively low (Hulson *et al.* (2023), Whorton (2023), Appendix 1A: Shotwell). The sablefish population has had multiple large age classes since 2016, potentially adding predation pressure to pollock prior to moving to adult slope habitat (sablefish assessment, Goethel *et al.* (2023), Appendix 1A). Western GOA Steller sea lions were not reassessed in 2023 but remain lower than previous biomass peaks (Sweeney and Gelatt (2023)). Potential competitors include large returns of pink salmon (Whitehouse (2023), Vulstek and Russell (2023)), a relatively large population of Pacific ocean perch (Assessment Hulson *et al.* (2022), Appendix 1A), large year classes of juvenile sablefish (Assessment, Goethel *et al.* (2023), Appendix 1A).

<u>Fishery performance</u>

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.

<u>Summary and ABC recommendation</u>

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 2: Major concern	Level 1: No concern	Level 1: No concern	Level 1: No concern

Given the overall lack of elevated scores in the risk table, the author's recommended ABC is based on the maximum permissible ABC, resulting in a 2024 ABC of 232,543 t, which is a `r pct.abc.changeF`from the 2023 ABC. The author's recommended 2025 ABC is 157,687 t. The OFL in `r year+1` is 269,916 t, and the OFL in 2025 if the 2024 ABC is taken in 2024 is 182,891 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 TMB (Monnahan and Kristensen 2018). Analysis of the posterior samples indicates that probability of the stock dropping below B20% will be negligible through 2028, conditional upon the model specified here (Fig. 1.42).

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 2023 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2024 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2023. 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 2023 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 2024, 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 2023 and 2024, *F* is set equal to a constant fraction of $maxF_{ABC}$, where this fraction is equal to the ratio of the realized catches in 2020- 2022 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 2019-2023 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 2023 or 2) above 1/2 of its MSY level in 2023 and above its MSY level in 2032 under this scenario, then the stock is not overfished.
- Scenario 7: In 2024 and 2025, 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 2025 or 2) above 1/2 of its MSY level in 2025 and expected to be above its MSY level in 2034 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 2027 under full exploitation scenarios, but will stay stable under the F=0 and other low exploitation scenarios (Fig. 1.43). We project catches to increase through 2025, 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 (2022) is 132,698 t, which is less than the 2022 OFL of 173,470 t. Therefore, the stock is not subject to overfishing. The fishing mortality that would have produced a catch in 2022 equal to the 2022 OFL is 0.239.

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 274,141 t in 2023 (see Table 1.25), which is above B35% (177,000 t). Therefore, GOA pollock is not currently overfished.

Under scenario 7, projected mean spawning biomass in 2025 is 227,091 t, which is above B35% (177,000 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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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

Year	Foreign	Joint Venture	Domestic	Total	ABC/TAC
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
2022			132,698	132,698	129,754
Average (1977-2022)				109,328	125,497

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	2018	2019	2020	2021	2022
Pollock	155,002.1	117,649.7	105,943.5	98,863.3	130,667.5
Pacific Cod	846.8	811.3	1,039.3	2,917.4	3,479.0
Arrowtooth Flounder	2,670.4	2,019.6	2,417.1	810.1	771.2
Pacific Ocean Perch	1,629.5	1,083.5	1,131.0	778.6	2,251.7
Sablefish	360.0	409.2	794.7	57.7	85.4
GOA Shallow Water Flatfish	393.3	263.2	151.3	197.4	179.1
Flathead Sole	322.8	197.2	227.1	109.1	70.2
Shark	78.8	59.1	100.4	83.7	83.0
GOA Rex Sole	138.9	89.7	100.4	51.2	15.8
GOA Skate, Big	110.5	66.5	78.3	53.4	57.6
Rougheye Rockfish	9.7	41.6	31.6	40.6	90.5
Atka Mackerel	64.4	122.4	0.2	4.1	0.6
Shortraker Rockfish	0.5	8.4	29.5	30.8	121.6
GOA Dusky Rockfish	43.2	16.4	24.6	37.5	47.4
GOA Skate, Longnose	44.6	20.7	22.4	14.9	18.2
Sculpin	18.4	10.2	45.0		
Northern Rockfish	59.4	7.2	0.9	1.9	1.2
GOA Deep Water Flatfish	5.6	12.7	12.1	0.9	0.2
Other Rockfish	1.6	4.6	0.2	1.4	18.4
BSAI Skate and GOA Skate, Other	5.0	3.5	4.1	3.6	3.8
Octopus	6.4	8.3	4.4	0.3	0.1
Squid	9.5				
GOA Thornyhead Rockfish	2.6	0.2	0.5	2.3	1.9
Percent non-pollock	0.0	0.0	0.1	0.0	0.1
Non target species/species group	2,018.0	2,019.0	2,020.0	2,021.0	2,022.0
Squid		47.5	371.7	242.7	2,232.4
Misc fish	55.9	87.8	115.1	61.4	65.9
Smelt (Family Osmeridae)				240.5	93.2
Capelin	77.0	80.6	54.0		
Grenadier - Rattail Grenadier Unidentified	25.5	37.7	38.6	46.7	58.8
Other osmerids	24.4	47.0	6.6	89.2	1.3
Scypho jellies	12.8	121.4	5.5	9.9	3.4
Giant Grenadier	3.1	9.3	11.3	9.6	29.5
Sea star	45.0	2.5	3.3	0.9	0.3
Eulachon	8.7	7.6	22.3		
Sculpin				9.5	16.1
Bivalves		0.6			
Pacific Sand lance				0.1	
Hermit crab unidentified				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	2018	2019	2020	2021	2022
Bairdi Tanner Crab (nos.)	6,832	41,889	19,003	1,791	744
Blue King Crab (nos.)	0	0	0	0	0
Chinook Salmon (nos.)	14,846	20,992	10,978	10,497	13,130
Golden (Brown) King Crab (nos.)	1	0	2	0	0
Halibut (t)	341	274	136	106	79
Herring (t)	42	64	60	16	83
Non-Chinook Salmon (nos.)	8,308	5,063	2,152	1,123	1,031
Opilio Tanner (Snow) Crab (nos.)	0	0	0	0	0
Red King Crab (nos.)	0	0	5	3	0

Table 1.4. Catch (retained and discarded) of walleye pollock (t) by management area in the Gulf of Alaska compiled by the Alaska Regional Office.

Year	Utilization	Shumagin 610	Chirikof 620	Kodiak 630	West Yakutat 640	Prince William Sound 649 (state waters)	Southeast and East Yakutat 650 & 659	Total	Percent discard
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	
2022	Retained	23,282	69,048	30,007	6,402	2,801	0	131,539	
	Discarded	332	293	494	38	1	1	1,159	0.87%
	Total	23,614	69,341	30,501	6,441	2,802	1	132,699	
Average (2012-2022)		27,424	64,791	37,565	3,143	2,842	2	123,706	

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
2022	0.03	5.95	13.61	51.88	49.82	6.57	1.44	3.00	9.14	15.67	3.91	1.12	0.33	0.00	0.00	162.47

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

Year	Aged Males	Aged Females	Aged Total	Lenghted Males	Lengthed Females	Lengthed Total
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
2022	936	1,684	2,620	6,975	6,794	13,769

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

Year	Shelikof Strait acoustic survey	Summer gulfwide acoustic survey	NMFS bottom trawl west of 140W	Shelikof Strait egg production	ADFG crab/groundfish survey
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
2023	258,829	740,417	887,602		56,611

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
2023	526	434	0.13				10,248	11,794	22,042

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

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
2023	0.1	1.4	8.1	41.6	106.8	34.7	5.6	1.2	3.6	23.5	46.5	10.0	4.2	0.4	0.5	288.1

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
2023	27	0	0.05	259	312	2	573	358	408	3,767	4,533

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
2022	0.000	0.007	0.143	0.287	0.216	0.093	0.047	0.056	0.049	0.076	0.017	0.008	0.000	0.000	0.002	593

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
2023	0.001	0.015	0.151	0.670	0.959	0.996	1.000	1.000	1.000	1.000	573
Average											
All years	0.000	0.015	0.063	0.290	0.624	0.866	0.943	0.980	0.990	0.994	
2013-2023	0.000	0.037	0.128	0.402	0.762	0.938	0.986	0.996	0.999	1.000	
2017-2023	0.000	0.055	0.180	0.458	0.775	0.942	0.985	0.996	0.999	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
2022	0.114	0.321	0.609	0.699	0.779	0.973	0.919	1.143	1.077	1.094

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

Year	1	2	3	4	5	6	7	8	9	10
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
2023	0.009	0.189	0.348	0.646	0.722	0.884	1.180	1.250	1.283	1.276

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. 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.

	2023 assessment						2022 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	743	138	27%	11,931	118,092	16%	761	141	12,184	16%
1978	968	126	25%	14,244	95,408	10%	994	130	14,532	10%
1979	1,362	135	27%	25,554	106,161	8%	1,397	138	26,005	8%
1980	1,821	189	37%	12,958	115,158	6%	1,866	192	13,166	6%
1981	2,847	209	41%	7,264	147,818	5%	2,910	212	7,372	5%
1982	2,968	340	67%	7,307	169,045	6%	3,032	344	7,376	6%
1983	2,703	471	93%	5,056	215,625	8%	2,762	478	5,129	8%
1984	2,405	520	103%	6,125	307,541	13%	2,456	530	6,122	13%
1985	1,947	472	93%	15,187	286,900	15%	1,993	483	15,108	14%
1986	1,648	428	85%	4,265	86,910	5%	1,685	439	4,289	5%
1987	2,007	402	80%	1,885	68,070	3%	2,034	412	1,890	3%
1988	1,899	407	81%	4,792	63,391	3%	1,922	416	4,887	3%
1989	1,682	425	84%	11,548	75,585	4%	1,701	430	11,439	4%
1990	1,547	436	86%	8,685	88,269	6%	1,566	442	8,504	6%
1991	1,859	430	85%	3,461	100,488	5%	1,870	434	3,341	5%
1992	1,949	393	78%	2,475	90,858	5%	1,947	394	2,396	5%
1993	1,847	426	84%	1,827	108,909	6%	1,834	425	1,749	6%
1994	1,571	502	99%	1,833	107,335	7%	1,555	498	1,783	7%
1995	1,292	420	83%	6,803	72,618	6%	1,274	415	6,691	6%
1996	1,093	389	77%	3,311	51,263	5%	1,074	382	3,187	5%
1997	1,109	346	68%	1,563	90,130	8%	1,089	339	1,517	8%
1998	1,070	270	53%	1,474	125,460	12%	1,046	263	1,452	12%
1999	804	253	50%	1,784	95,638	12%	783	244	1,780	12%
2000	717	241	48%	6,438	73,080	10%	695	232	6,425	11%
2001	686	226	45%	7,229	72,077	11%	666	217	7,006	11%
2002	861	191	38%	1,076	51,934	6%	844	183	1,041	6%
2003	1,085	177	35%	825	50,684	5%	1,058	170	796	5%
2004	911	194	38%	792	63,844	7%	887	186	767	7%
2005	765	235	47%	1,896	80,978	11%	742	226	1,848	11%
2006	655	253	50%	6,429	71,976	11%	634	243	6,092	11%
2007	614	225	45%	6,387	52,714	9%	592	216	5,923	9%
2008	865	226	45%	7,668	52,584	6%	827	216	7,061	6%
2009	1,255	227	45%	3,586	44,247	4%	1,186	215	3,224	4%
2010	1,495	317	63%	1,491	76,748	5%	1,398	298	1,311	5%
2011	1,445	377	75%	5,557	81,503	6%	1,339	349	5,118	6%
2012	1,364	407	81%	1,164	103,954	8%	1,251	373	932	8%
2013	1,399	445	88%	48,590	96,363	7%	1,274	404	44,193	8%
2014	1,122	349	69%	3,709	142,640	13%	1,009	311	2,840	14%
2015	2,964	331	66%	94	167,549	6%	2,676	290	71	6%
2016	3,048	358	71%	13	177,129	6%	2,708	310	10	7%
2017	2,279	485	96%	2,504	186,155	8%	2,001	421	2,078	9%
2018	1,586	476	94%	9,644	158,070	10%	1,370	408	7,727	12%
2019	1,200	388	77%	8,060	120,243	10%	1,013	326	5,450	12%
2020	1,351	292	58%	311	107,471	8%	1,100	238	197	10%
2021	1,500	320	63%	10,430	101,160	7%	1,137	252	10,296	9%
2022	1,154	323	64%	60	132,698	11%	850	243	65	16%
2023	1,430	342	68%	1	145,215	10%				

Table 1.20. 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 (2017-2022)	Shelikof acoustic survey	Summer acoustic survey	Bottom trawl survey	ADF&G bottom trawl
1	0.001	0.004	0.002	0.009	0.003	0.221	1.000	0.131	0.004
2	0.011	0.027	0.012	0.064	0.037	0.261	1.000	0.223	0.022
3	0.119	0.177	0.075	0.339	0.297	1.000	0.998	0.353	0.110
4	0.615	0.622	0.344	0.791	0.822	1.000	0.994	0.511	0.406
5	0.950	0.927	0.775	0.969	0.982	1.000	0.975	0.668	0.791
6	0.997	0.992	0.964	0.997	0.999	0.999	0.909	0.798	0.954
7	1.000	1.000	1.000	1.000	1.000	0.996	0.718	0.890	0.991
8	0.989	0.990	0.995	0.990	0.989	0.974	0.392	0.948	0.998
9	0.872	0.873	0.878	0.872	0.872	0.848	0.141	0.981	1.000
10	0.357	0.357	0.359	0.357	0.357	0.456	0.040	1.000	1.000

Table 1.21. 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	1,194	297	184	127	90	67	50	37	28	83
1971	3,235	297	149	113	86	62	48	35	27	82
1972	3,634	806	149	92	76	59	44	34	25	80
1973	10,706	905	403	90	56	45	36	27	21	72
1974	2,148	2,666	452	241	52	31	25	20	15	61
1975	2,187	535	1,332	268	134	27	16	13	11	49
1976	8,767	545	268	802	161	77	16	9	8	40
1977	11,931	2,183	272	160	460	87	42	9	5	32
1978	14,244	2,971	1,091	162	89	233	45	22	5	24
1979	25,554	3,547	1,484	647	90	46	124	24	12	18
1980	12,958	6,363	1,773	887	378	50	26	71	14	20
1981	7,264	3,227	3,185	1,076	550	224	31	16	44	23
1982	7,307	1,809	1,616	1,938	682	340	142	19	10	45
1983	5,056	1,820	905	979	1,234	432	222	93	13	39
1984	6,125	1,259	908	541	606	758	274	141	60	36
1985	15,187	1,524	627	536	323	353	456	165	86	63
1986	4,265	3,780	760	373	317	180	201	258	95	94
1987	1,885	1,062	1,891	463	244	208	122	136	177	134
1988	4,792	470	532	1,159	308	163	144	84	95	224
1989	11,548	1,193	235	326	775	208	114	101	60	233
1990	8,685	2,876	598	144	217	515	143	78	70	211
1991	3,461	2,163	1,441	368	97	144	350	97	54	202
1992	2,475	862	1,084	886	246	63	94	228	63	180
1993	1,827	616	432	666	591	159	41	61	149	171
1994	1,833	455	309	265	442	381	104	27	40	222
1995	6,803	456	228	189	176	286	250	68	18	186
1996	3,311	1,694	229	140	127	117	195	170	47	147
1997	1,563	825	849	141	95	86	81	134	118	140
1998	1,474	389	413	520	92	60	54	51	86	177
1999	1,784	367	194	249	323	53	34	31	29	170
2000	6,438	444	183	118	157	190	31	20	18	135
2001	7,229	1,603	222	112	76	97	119	19	12	107
2002	1,076	1,799	799	133	70	46	61	74	12	83
2003	825	268	896	478	84	44	30	40	49	68

Year	1	2	3	4	5	6	7	8	9	10
2004	792	205	133	536	307	55	30	20	27	84
2005	1,896	197	102	79	339	198	37	20	14	79
2006	6,429	471	97	59	48	210	127	24	13	66
2007	6,387	1,598	233	57	36	30	136	82	15	55
2008	7,668	1,588	793	138	36	23	20	91	56	51
2009	3,586	1,908	792	474	89	24	16	14	63	76
2010	1,491	893	953	479	313	60	17	11	10	101
2011	5,557	371	446	572	310	207	41	11	8	81
2012	1,164	1,383	185	268	370	204	142	28	8	64
2013	48,590	290	692	112	172	239	137	95	19	52
2014	3,709	12,101	145	422	72	112	161	92	65	51
2015	94	924	6,059	88	261	43	69	99	58	77
2016	13	23	462	3,660	54	154	26	42	61	91
2017	2,504	3	12	280	2,315	34	101	17	28	106
2018	9,644	624	2	7	176	1,454	22	65	11	95
2019	8,060	2,401	312	1	4	109	936	14	43	75
2020	311	2,007	1,198	185	1	3	70	600	9	82
2021	10,430	77	999	703	114	0	2	46	394	65
2022	60	2,596	39	593	439	72	0	1	30	316
2023	1	15	1,294	23	353	263	45	0	1	241
Average	6,059	1,514	760	447	284	174	109	70	46	103

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	1,194	0.32	652	2,187	122	0.32	66	224
1971	3,235	0.45	1,385	7,557	116	0.33	62	217
1972	3,634	0.37	1,787	7,390	107	0.34	56	205
1973	10,706	0.16	7,820	14,656	90	0.37	45	183
1974	2,148	0.30	1,209	3,818	83	0.33	44	156
1975	2,187	0.28	1,278	3,744	90	0.24	57	144
1976	8,767	0.19	6,083	12,635	122	0.17	87	171
1977	11,931	0.18	8,366	17,017	138	0.18	98	194
1978	14,244	0.18	9,999	20,290	126	0.21	84	189
1979	25,554	0.15	18,997	34,374	135	0.21	89	204
1980	12,958	0.19	8,921	18,823	189	0.20	129	277
1981	7,264	0.23	4,638	11,378	209	0.18	147	297
1982	7,307	0.23	4,684	11,400	340	0.16	248	466
1983	5,056	0.34	2,667	9,583	471	0.16	348	638
1984	6,125	0.30	3,426	10,953	520	0.16	378	715
1985	15,187	0.16	11,087	20,801	472	0.18	331	672
1986	4,265	0.28	2,485	7,322	428	0.20	292	627
1987	1,885	0.39	907	3,918	402	0.19	279	578
1988	4,792	0.23	3,047	7,537	407	0.17	291	569
1989	11,548	0.15	8,641	15,431	425	0.15	319	564
1990	8,685	0.17	6,298	11,977	436	0.14	332	573
1991	3,461	0.26	2,101	5,704	430	0.14	327	565
1992	2,475	0.27	1,476	4,148	393	0.14	301	512
1993	1,827	0.29	1,055	3,164	426	0.13	334	545
1994	1,833	0.28	1,069	3,142	502	0.12	397	636
1995	6,803	0.13	5,314	8,710	420	0.12	331	532
1996	3,311	0.17	2,385	4,597	389	0.12	307	492
1997	1,563	0.23	999	2,447	346	0.12	272	440
1998	1,474	0.22	962	2,259	270	0.13	209	348
1999	1,784	0.20	1,204	2,644	253	0.13	194	328
2000	6,438	0.12	5,048	8,211	241	0.14	184	315
2001	7,229	0.11	5,791	9,023	226	0.15	170	301
2002	1,076	0.26	648	1,786	191	0.15	142	257
2003	825	0.25	509	1,338	177	0.15	133	237
2004	792	0.26	476	1,317	194	0.13	151	250
2005	1,896	0.19	1,311	2,741	235	0.13	182	303
2006	6,429	0.13	4,941	8,366	253	0.14	193	330
2007	6,387	0.14	4,865	8,384	225	0.15	169	300
2008	7,668	0.13	5,909	9,950	226	0.15	169	304
2009	3,586	0.17	2,599	4,946	227	0.15	171	302
2010	1,491	0.24	932	2,384	317	0.13	245	411
2011	5,557	0.15	4,129	7,477	377	0.13	294	483
2012	1,164	0.28	674	2,009	407	0.13	317	522
2013	48,590	0.09	40,454	58,362	445	0.13	343	577
2014	3,709	0.21	2,481	5,546	349	0.14	266	457
2015	94	0.37	46	190	331	0.15	250	440
2016	13	0.37	6	26	358	0.12	281	456
2017	2,504	0.18	1,770	3,542	485	0.12	383	614
2018	9,644	0.13	7,451	12,483	476	0.13	370	611
2019	8,060	0.15	6,070	10,703	388	0.14	295	511
2020	311	0.39	148	656	292	0.15	216	395
2021	10,430	0.19	7,193	15,124	320	0.16	236	433
2022	60	0.38	29	123	323	0.15	241	434
2023	1	0.49	1	3	342	0.15	254	462

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. 2019-2023)	Spawning WAA (Avg. 2019-2023)	Population WAA (Avg. 2017, 2019, 2021)	Fishery WAA (Est. 2023 from RE model)	Proportion mature females (Avg. 1983-2023)
1	1.39	0.004	0.010	0.040	0.167	0.000
2	0.69	0.040	0.113	0.204	0.390	0.015
3	0.48	0.320	0.286	0.502	0.632	0.063
4	0.37	0.840	0.498	0.630	0.952	0.290
5	0.34	0.985	0.626	0.741	1.013	0.624
6	0.30	1.000	0.804	0.860	1.068	0.866
7	0.30	1.000	0.889	0.971	1.194	0.943
8	0.29	0.989	1.008	1.092	1.290	0.980
9	0.28	0.872	1.013	1.152	1.339	0.990
10+	0.29	0.357	1.072	1.456	1.291	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
2022	AD Model Builder	Amend. 56 Tier 3	188,000
2023	Template Model Builder	Amend. 56 Tier 3	202,000

Table 1.25. Projections of GOA pollock spawning biomass, full recruitment fishing mortality, and catch for 2023 - 2036 under different harvest policies (columns). For these projections, fishery weight at age was assumed to be equal to the estimated weight at age in 2023 for the RE model. All projections begin with initial age composition in 2023 using the base run model with a projected 2023 catch of 145,215 t. The values for B100%, B40%, and B35% are 505,000 t, 202,000 t, 177,000 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
2023	293,675	293,675	293,675	293,675	293,675	293,675	293,675
2024	274,141	274,141	279,186	282,703	286,045	272,029	274,141
2025	227,091	227,091	252,893	272,442	292,286	217,023	227,091
2026	180,024	180,024	218,034	250,203	285,175	166,535	178,829
2027	151,890	151,997	187,884	224,148	266,033	140,382	147,036
2028	156,257	157,200	189,199	229,411	277,724	144,585	148,566
2029	174,975	176,902	206,316	250,778	305,141	160,531	162,733
2030	194,454	197,172	227,501	278,907	342,332	176,233	177,480
2031	211,764	215,200	249,593	309,291	382,504	190,182	190,880
2032	215,293	219,998	257,448	324,777	407,261	191,372	191,772
2033	218,138	223,373	263,797	337,945	429,242	192,914	193,145
2034	219,649	224,353	267,299	345,692	442,652	194,040	194,176
2035	222,020	226,540	272,481	355,200	457,825	195,743	195,822
2036	220,012	224,031	271,914	357,105	463,130	193,477	193,524
Fishing mortality							
Year	Max FABC	Author's recommended F	Average F	F75%	F=0	FOFL	Max FABC for two years, then FOFL
2023	0.17	0.17	0.17	0.17	0.17	0.17	0.17
2024	0.26	0.26	0.15	0.07	0.00	0.31	0.26
2025	0.26	0.26	0.15	0.07	0.00	0.31	0.26
2026	0.23	0.23	0.15	0.07	0.00	0.25	0.27
2027	0.17	0.17	0.15	0.07	0.00	0.19	0.20
2028	0.12	0.12	0.15	0.07	0.00	0.17	0.18
2029	0.11	0.11	0.15	0.07	0.00	0.17	0.18
2030	0.12	0.12	0.15	0.06	0.00	0.18	0.18
2031	0.13	0.13	0.15	0.06	0.00	0.18	0.18
2032	0.14	0.14	0.15	0.06	0.00	0.18	0.18
2033	0.14	0.14	0.15	0.06	0.00	0.19	0.19
2034	0.14	0.14	0.15	0.06	0.00	0.19	0.19
2035	0.14	0.14	0.15	0.06	0.00	0.19	0.19
2036	0.14	0.14	0.15	0.06	0.00	0.19	0.19
Catch (t)							
Year	Max FABC	Author's recommended F	Average F	F75%	F=0	FOFL	Max FABC for two years, then FOFL
2023	145,215	145,215	145,215	145,215	145,215	145,215	145,215
2024	232,543	232,543	138,674	69,211	0	269,916	232,543
2025	157,687	157,687	103,543	55,243	0	175,757	157,687
2026	113,803	113,774	86,493	47,958	0	117,702	132,031
2027	122,764	117,623	99,978	55,089	0	132,273	138,195
2028	135,561	131,812	113,212	62,238	0	156,706	159,486
2029	161,526	155,034	132,022	72,656	0	189,288	190,600
2030	182,755	179,463	141,262	76,267	0	209,047	209,440
2031	194,145	183,227	150,843	81,560	0	218,899	219,045
2032	188,578	185,643	149,355	81,648	0	209,111	209,182
2033	198,780	196,041	154,517	84,484	0	220,168	220,194
2034	201,241	198,473	156,419	85,954	0	222,541	222,555
2035	196,063	194,222	153,062	84,397	0	217,338	217,346
2036	194,826	192,460	151,932	84,102	0	216,153	216,158

Figures

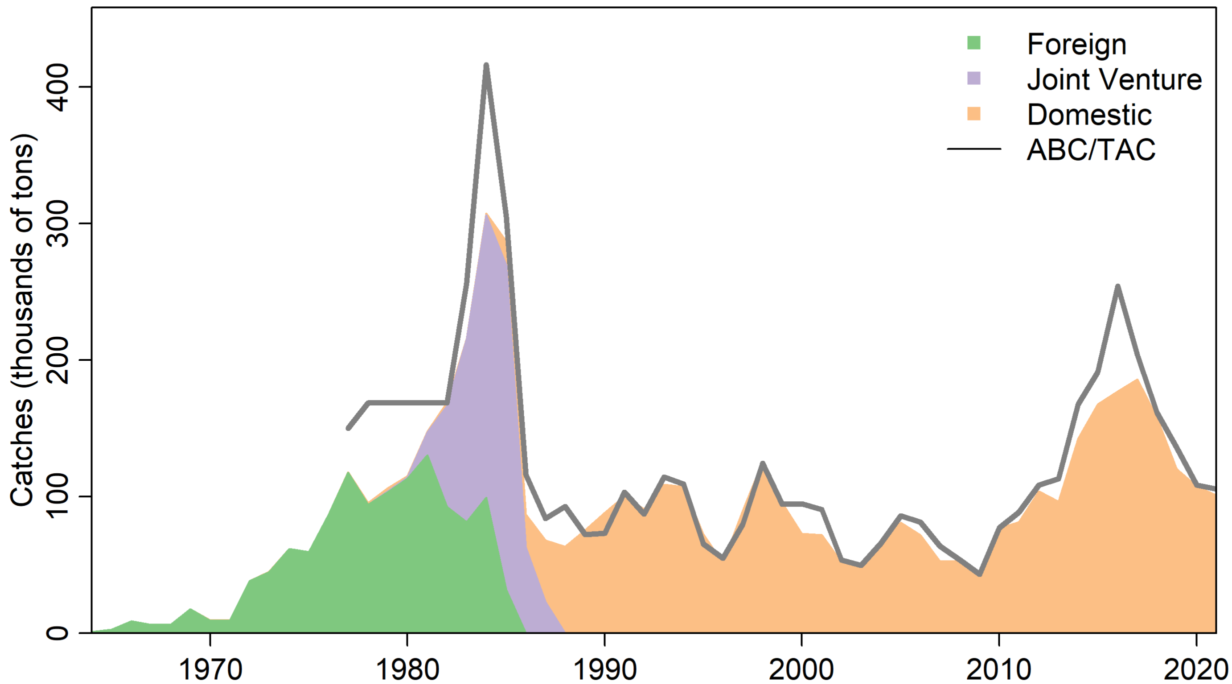


Figure 1.1. Overview of historical catches by source compared to the ABC/TAC

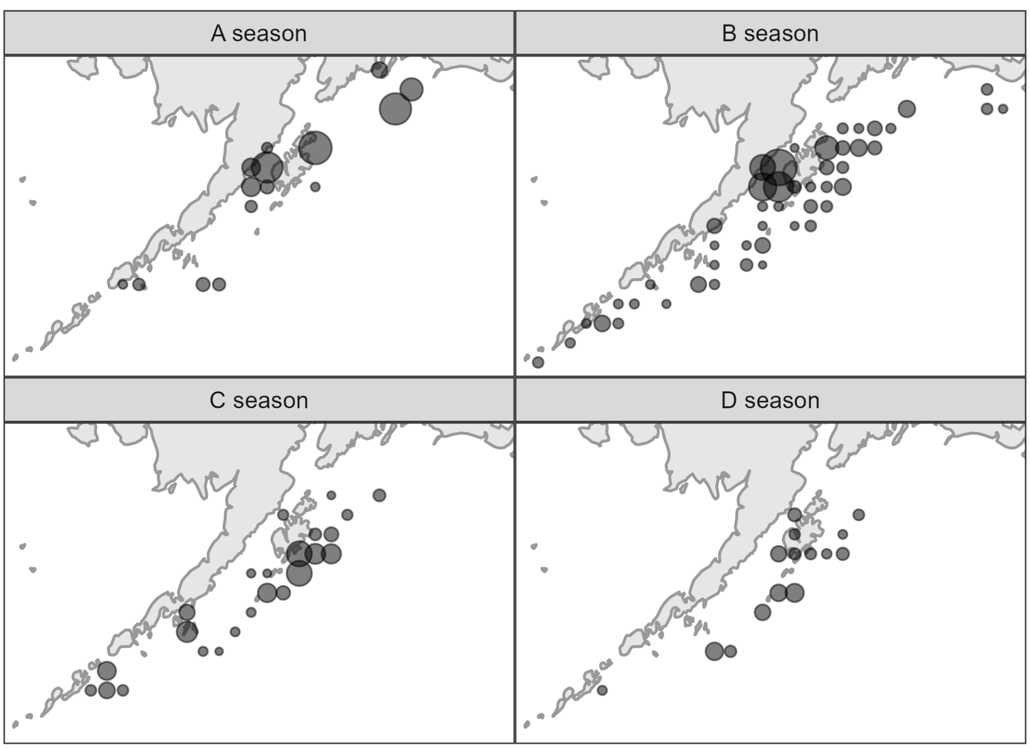


Figure 1.2. Distribution of pollock catch in the 2022 fishery shown for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul

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.

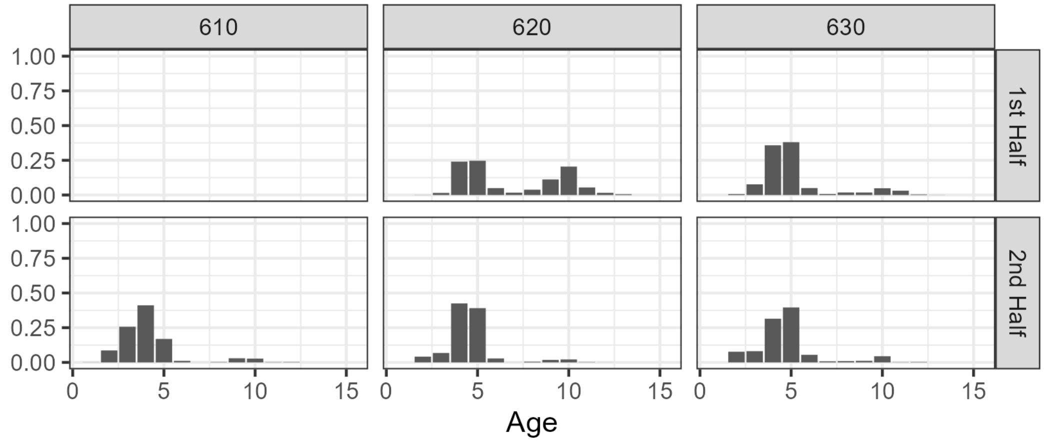


Figure 1.3. Distribution of pollock catch in the 2020 fishery shown for 1/2 degree latitude by 1 degree longitude blocks by season in the Gulf of Alaska as determined by fishery observer-recorded haul retrieval locations. Blocks with less than 1.0 t of pollock catch are not shown. The area of the circle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

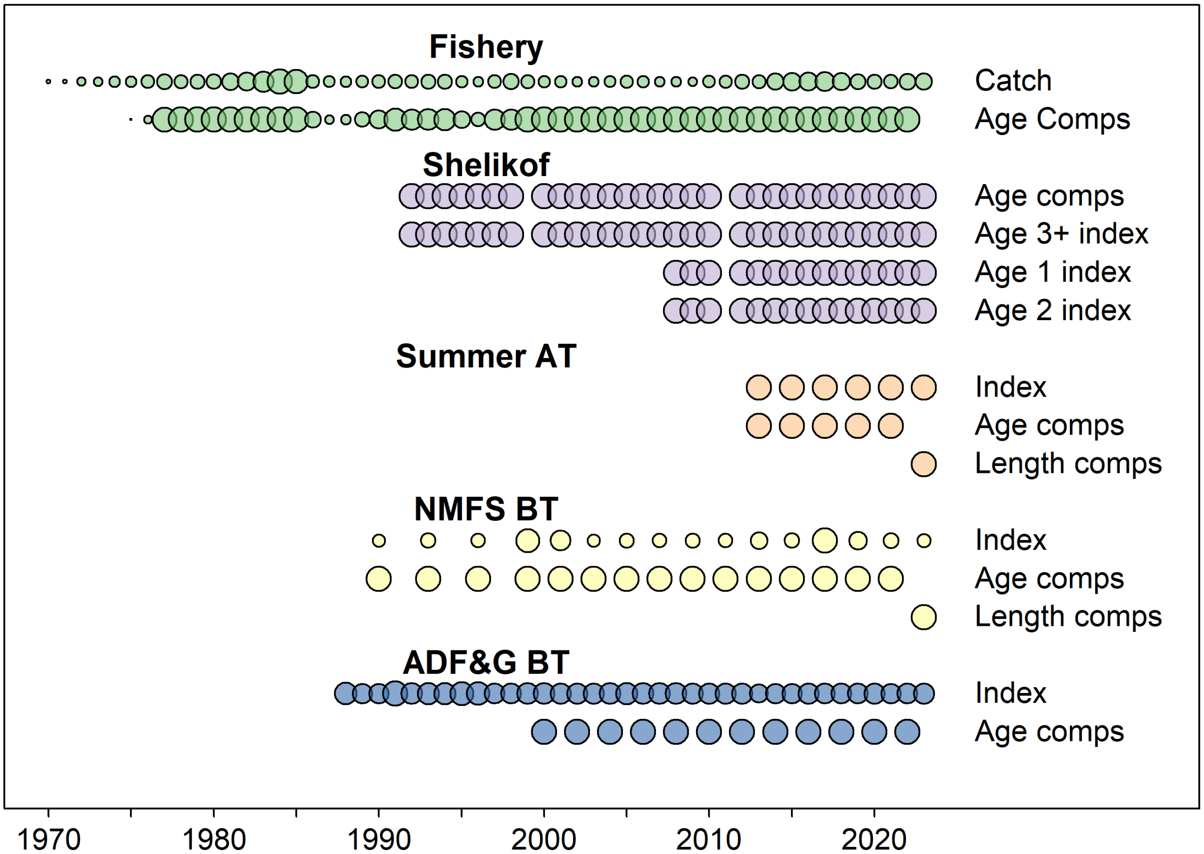


Figure 1.4. Overview of data sources and their relative weights. Circle sizes are relative to catches or data information for surveys within a row. Length compositions are only used in years without age compositions.

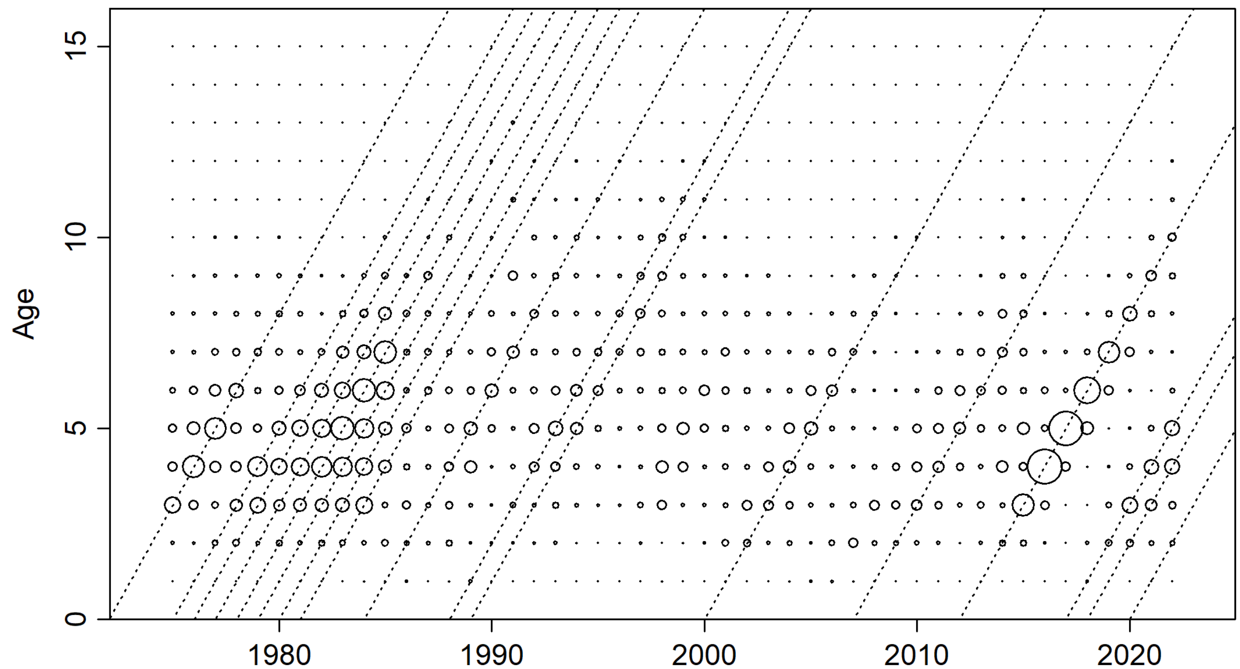


Figure 1.5. GOA pollock fishery age composition (1975- 2022).The area of the circle is proportional to the catch. Diagonal lines show strong year classes.

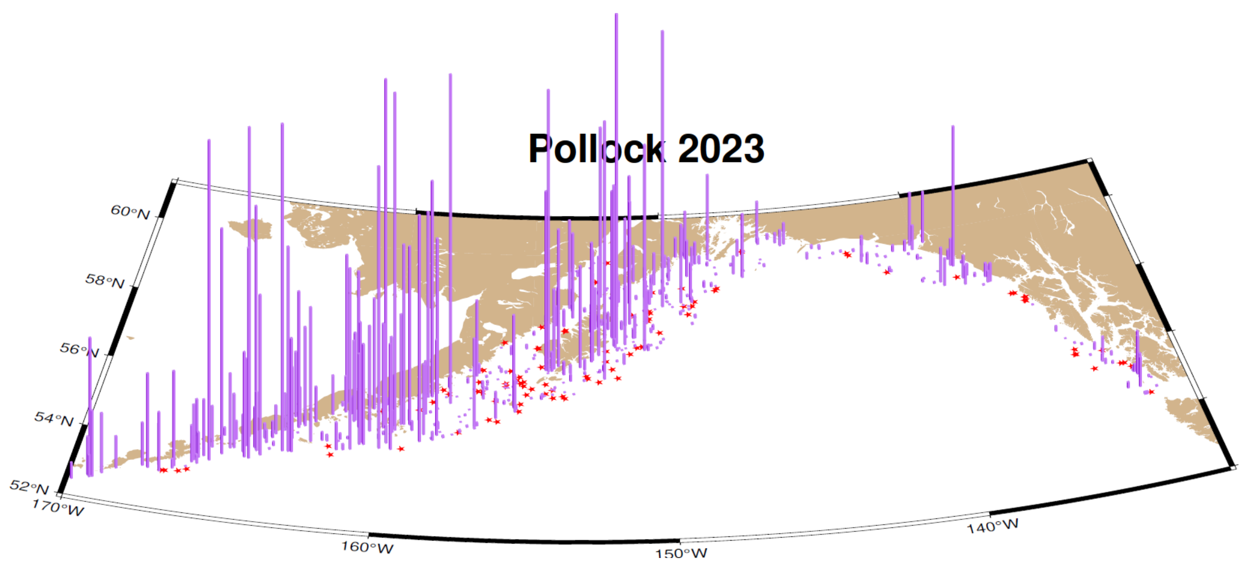


Figure 1.6. Pollock catch per unit effort (CPUE) for the 2023 NMFS bottom trawl survey in the Gulf of Alaska (heights of purple bars). Red stars indicate hauls with no pollock catch.

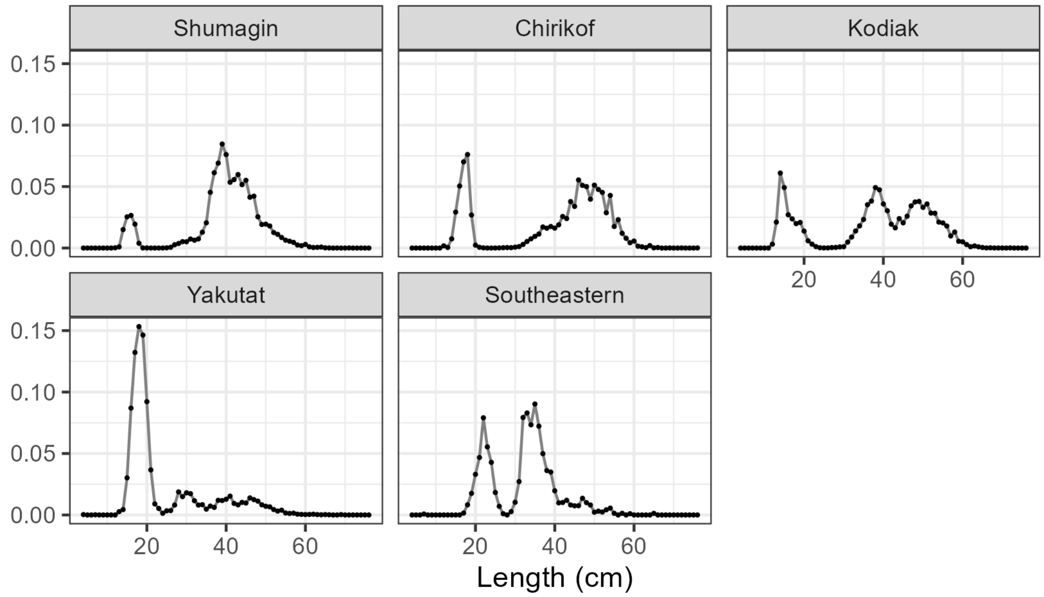


Figure 1.7. Length composition of pollock by statistical area for the 2023 NMFS bottom trawl survey.

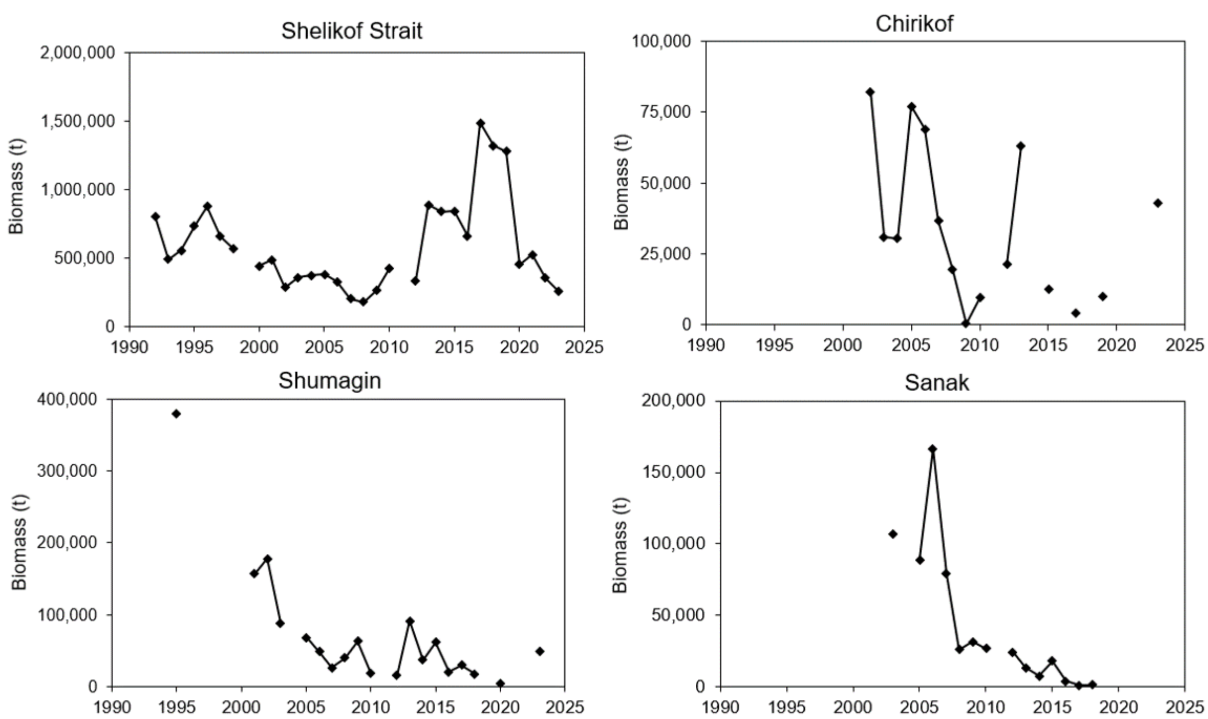


Figure 1.8. Biomass trends from winter acoustic surveys of pre-spawning aggregations of pollock in the GOA.

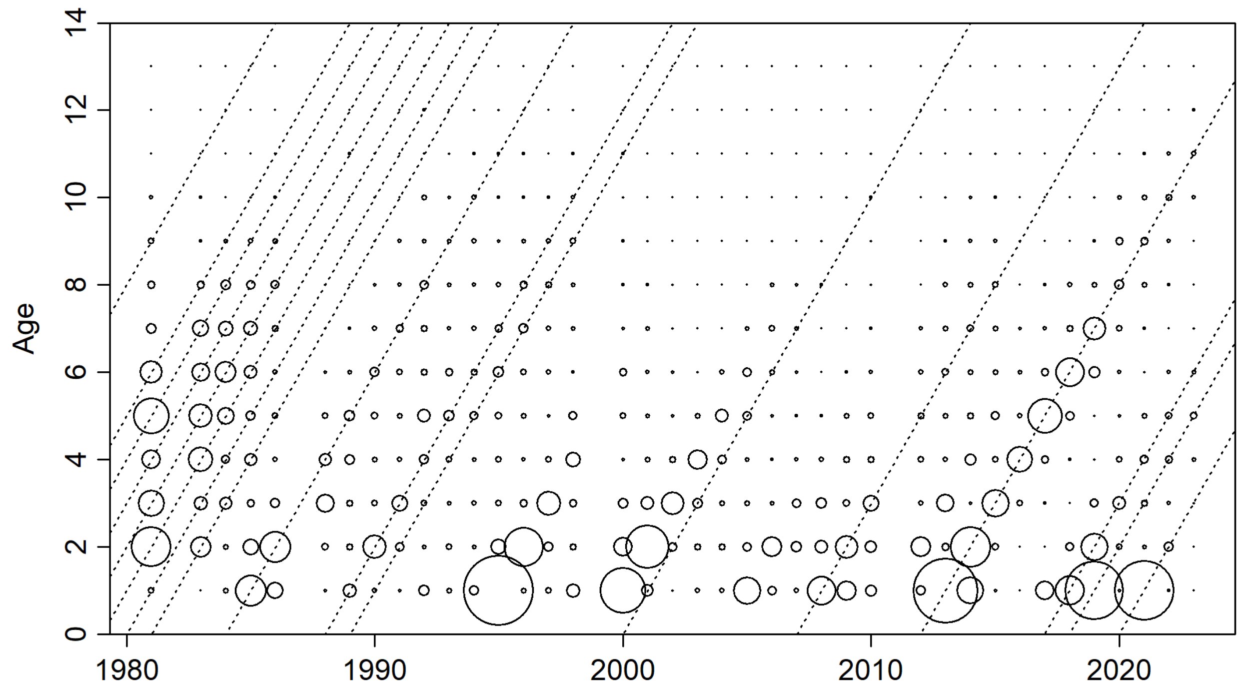


Figure 1.9. Estimated abundance at age in the Shelikof Strait acoustic survey (1981-2023 except 1982, 1987, 1999, and 2011). The area of the circle is proportional to the estimated abundance.

Figure 1.10. Tow locations for the 2023 ADF&G crab/groundfish trawl survey.

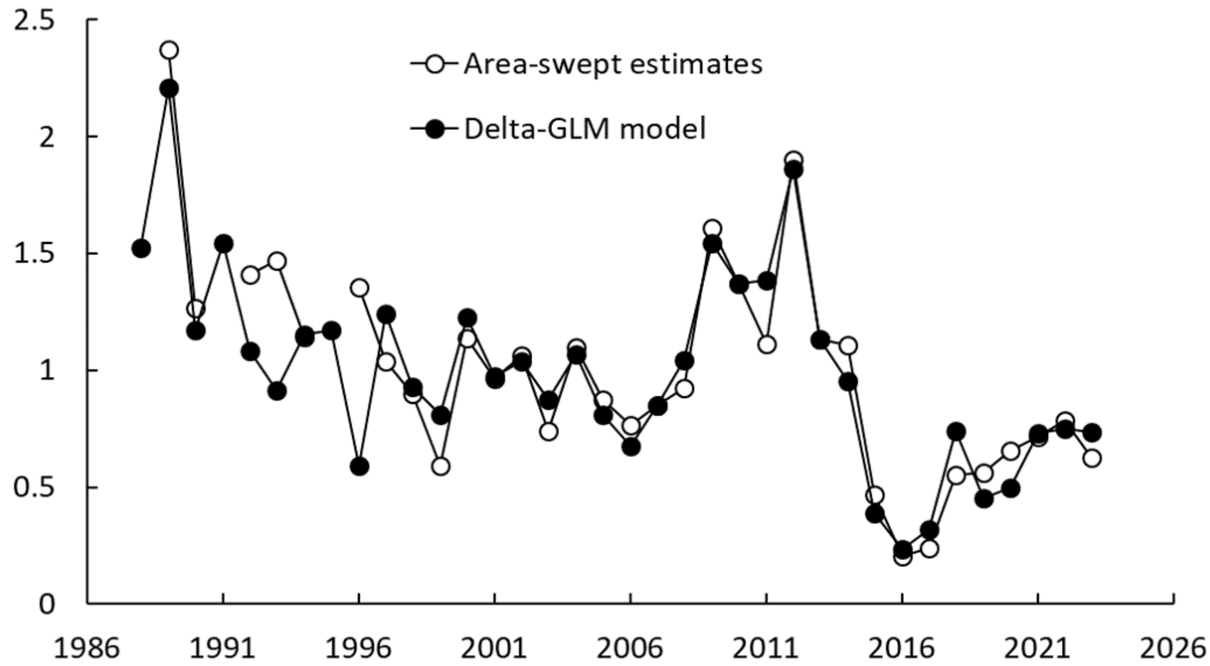


Figure 1.11. Comparison of ADF&G crab/groundfish trawl area-swept indices with year indices for a delta GLM model with a gamma error assumption for the positive observations. Both time series have been scaled by the mean for the time series.

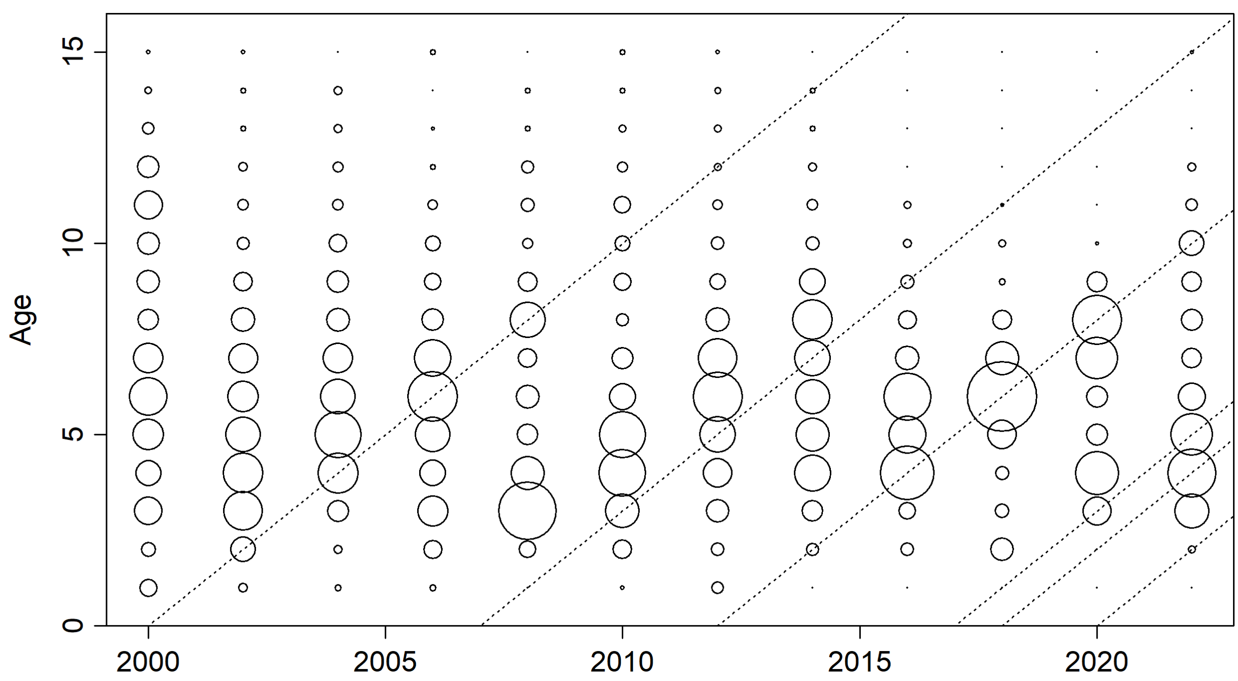


Figure 1.12. Estimated proportions at age in the ADF&G crab/groundfish survey (2000-2022). The area of the circle is proportional to the estimated abundance.

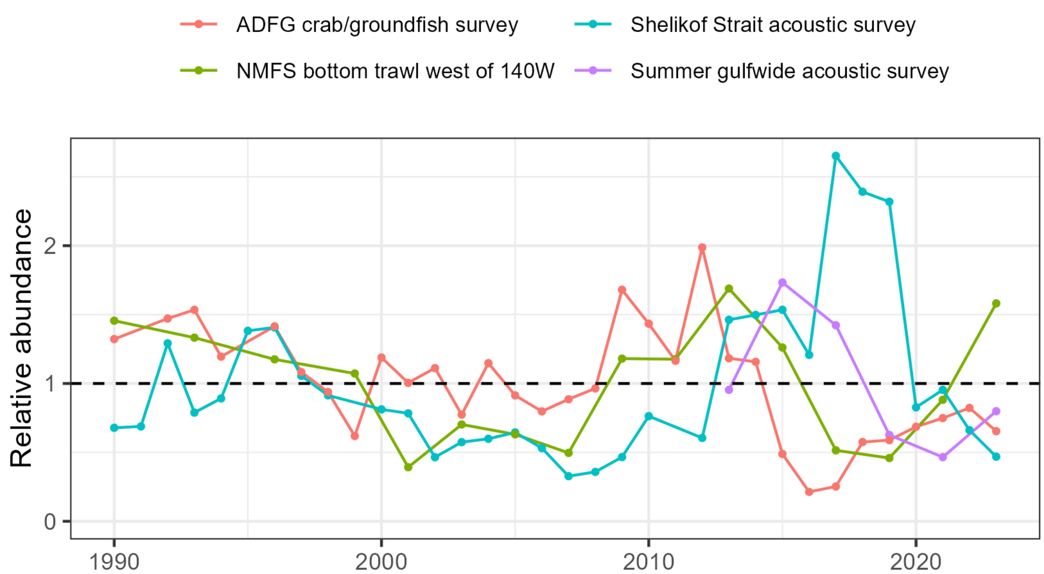


Figure 1.13. Relative trends in pollock biomass since 1990 for the Shelikof Strait acoustic survey, the NMFS bottom trawl survey, and the ADF&G crab/groundfish trawl survey. Each survey biomass estimate is standardized to the average since 1990. Shelikof Strait acoustic surveys prior to 2008 were re-scaled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

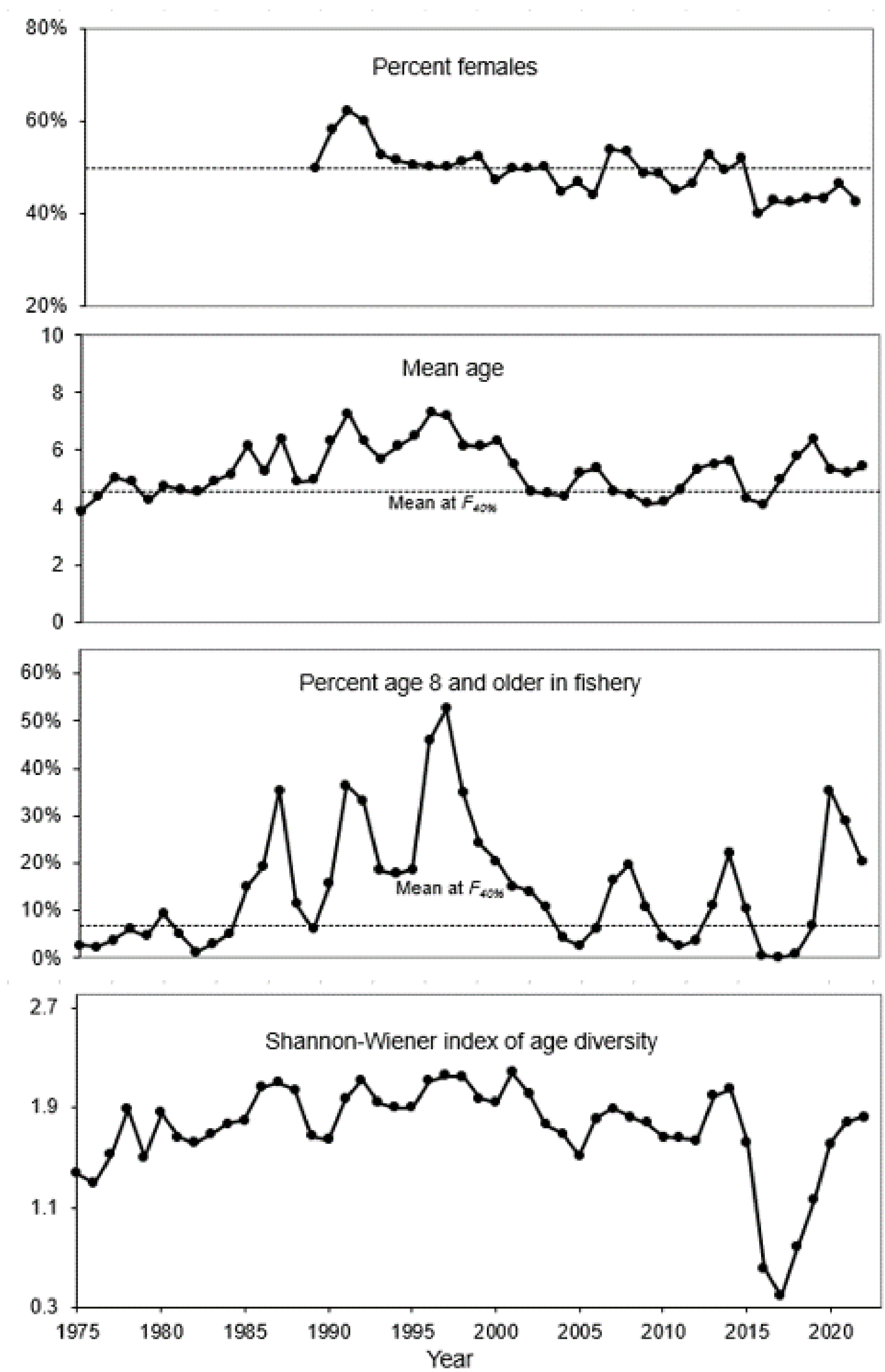


Figure 1.14. GOA pollock fishery catch characteristics.

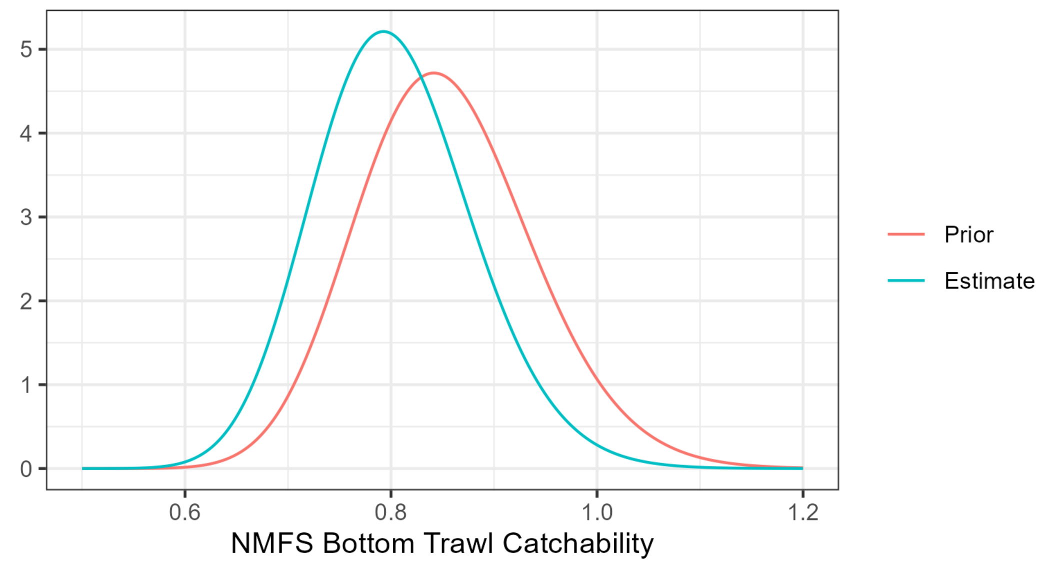


Figure 1.15. Prior on bottom trawl catchability used in the base model, and the estimate and uncertainty from the base model.

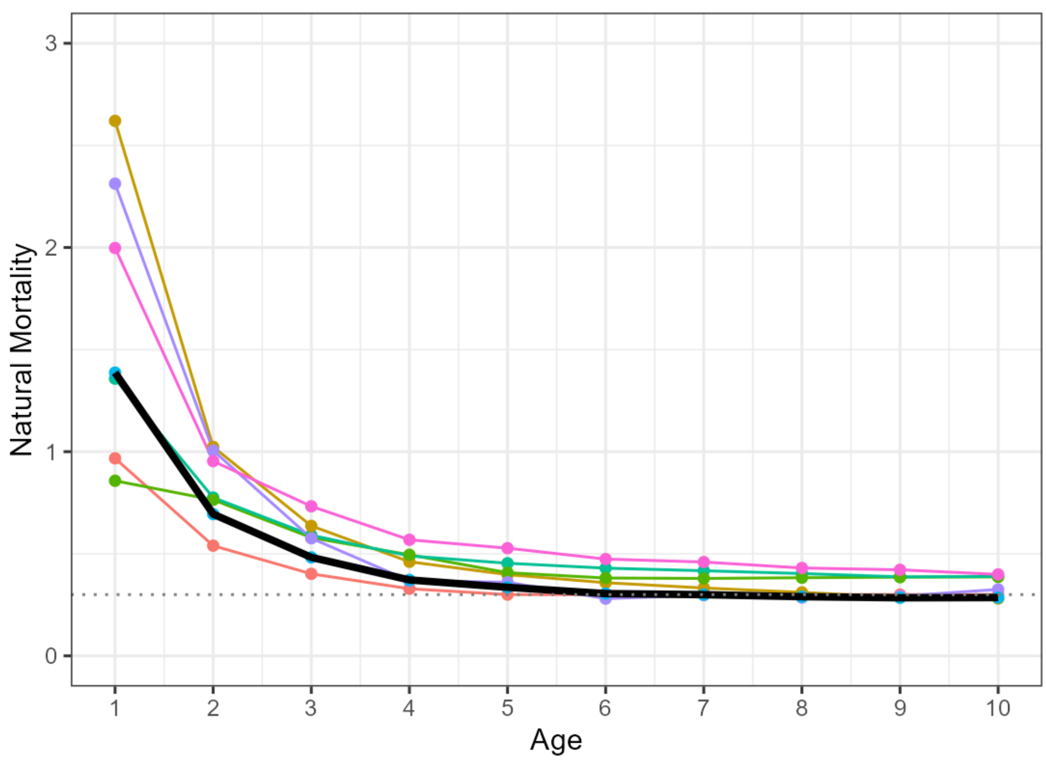


Figure 1.16. Alternative estimates of age-specific natural mortality. The scaled average was used in the stock assessment model. See table 1.14 for more information

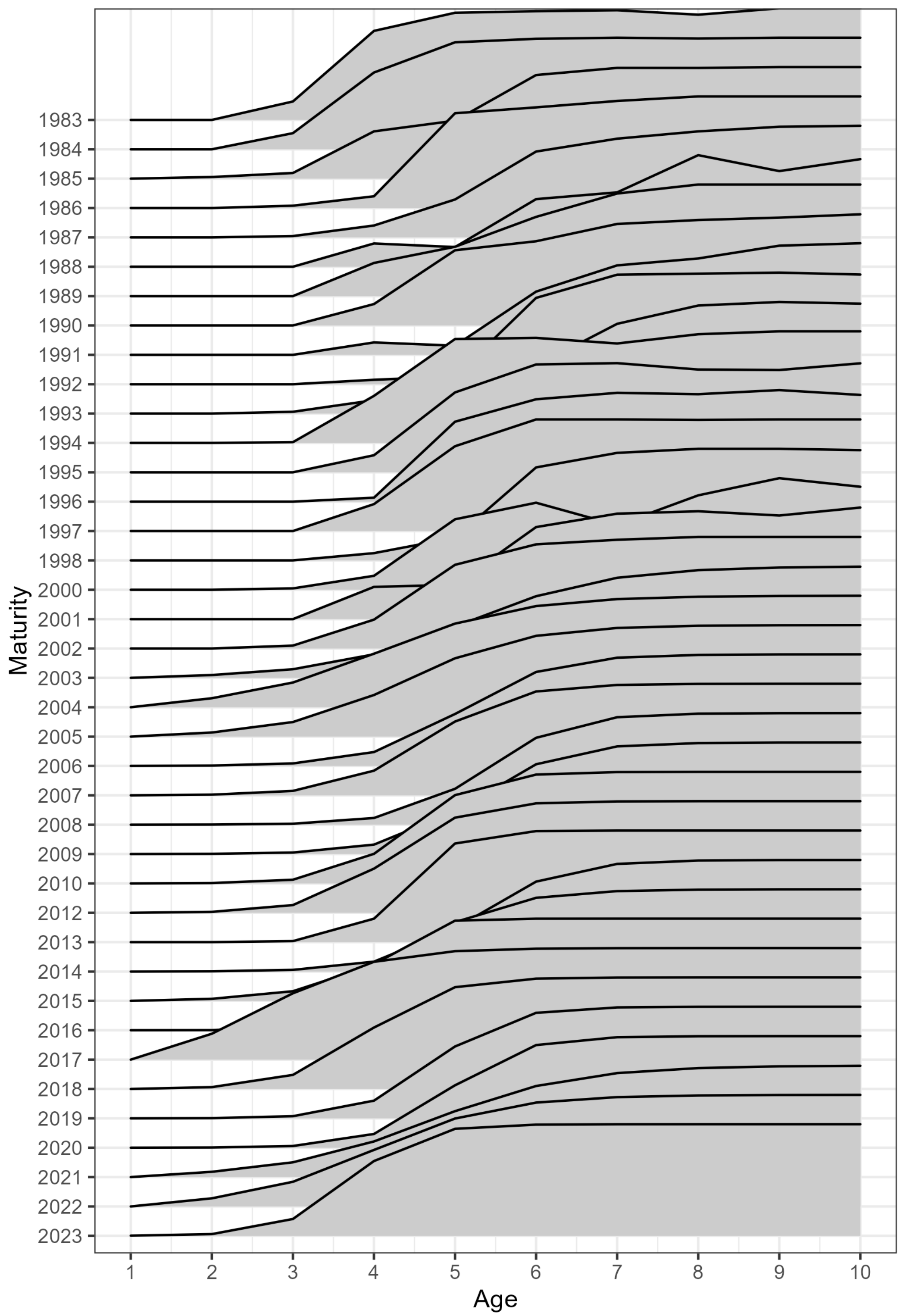


Figure 1.17. Estimates of the proportion mature at age from weighted visual maturity data collected on winter acoustic surveys in the Gulf of Alaska for all years. Maturity for age-1 fish is assumed to be zero.

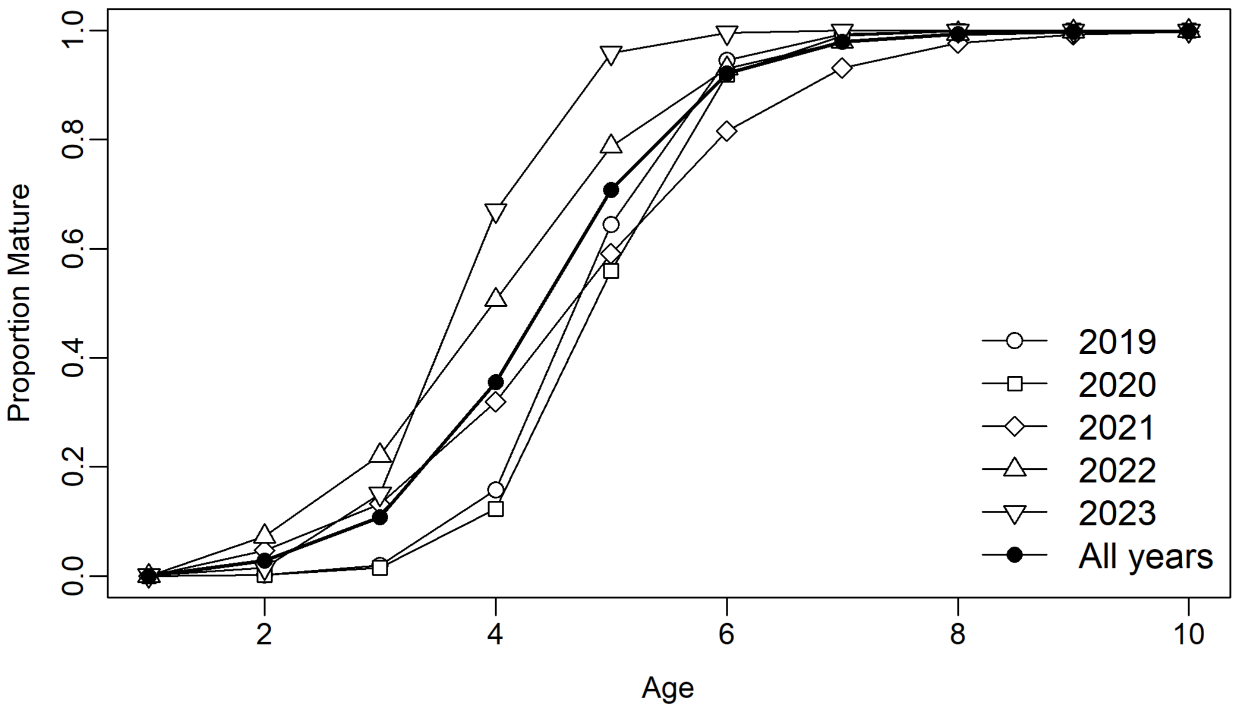


Figure 1.18. Estimates of the proportion mature at age from weighted visual maturity data collected during 2019-2023 winter acoustic surveys in the Gulf of Alaska and long-term average proportion mature at age (1983-2023). Maturity for age-1 fish is assumed to be zero.

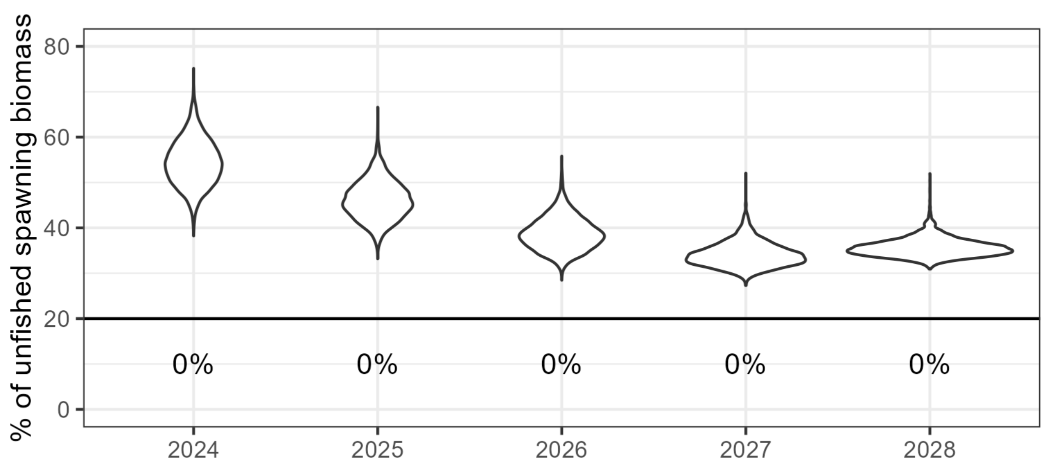


Figure 1.19. Age at 50% mature (top) and length at 50% mature (bottom) from annual logistic regressions for female pollock from winter acoustic survey data in the Gulf of Alaska. Estimates since 2003 are weighted by local abundance.

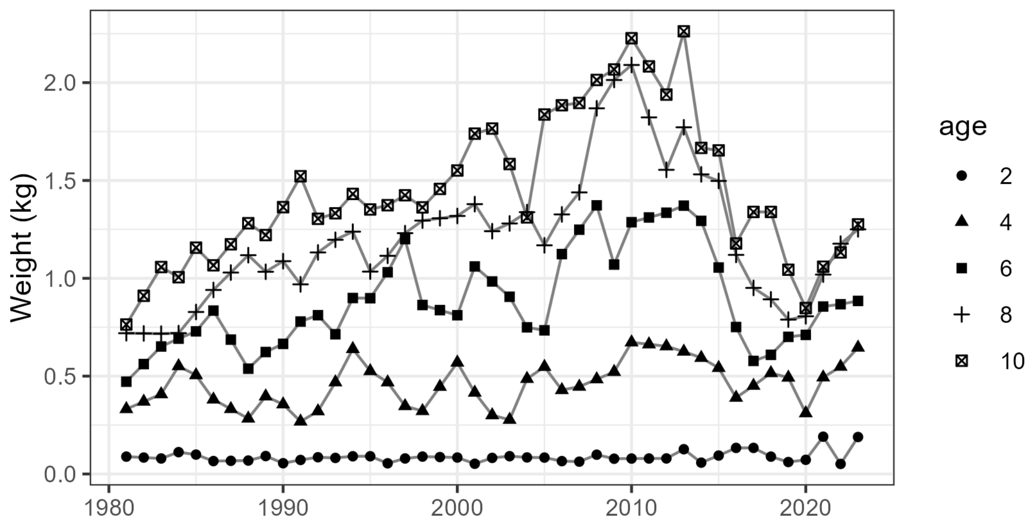


Figure 1.20. Estimated weight at age of GOA pollock (ages 2, 4, 6, 8, and 10) from Shelikof Strait acoustic surveys used in the assessment model. In 1999 and 2011, when the acoustic survey was not conducted, weights-at-age were interpolated from surveys in adjacent years.

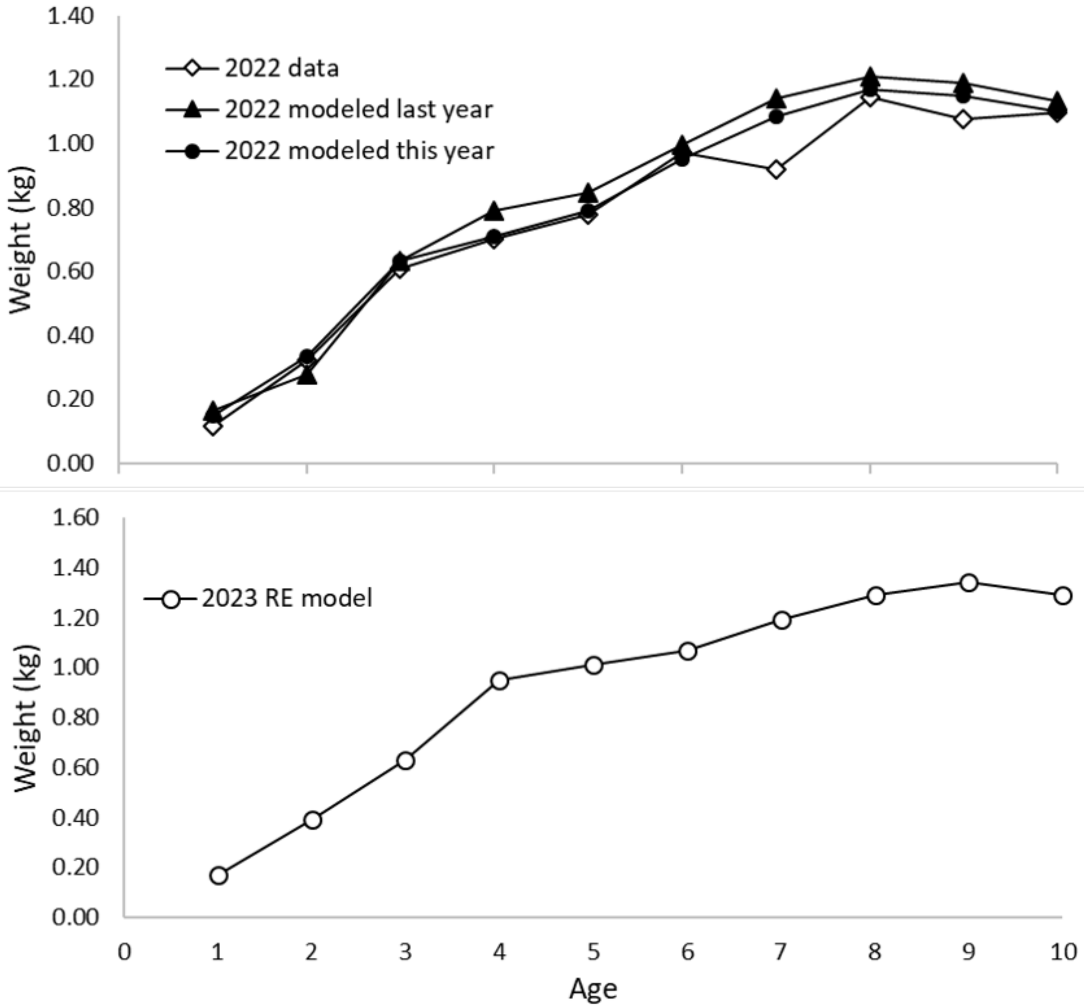


Figure 1.21. Comparison of fishery weight at age for 2022 with estimates from the random effects model last year and this year' assessment (top panel). Random effects model estimates for 2023 used in the assessment model and for yield projections (bottom panel).

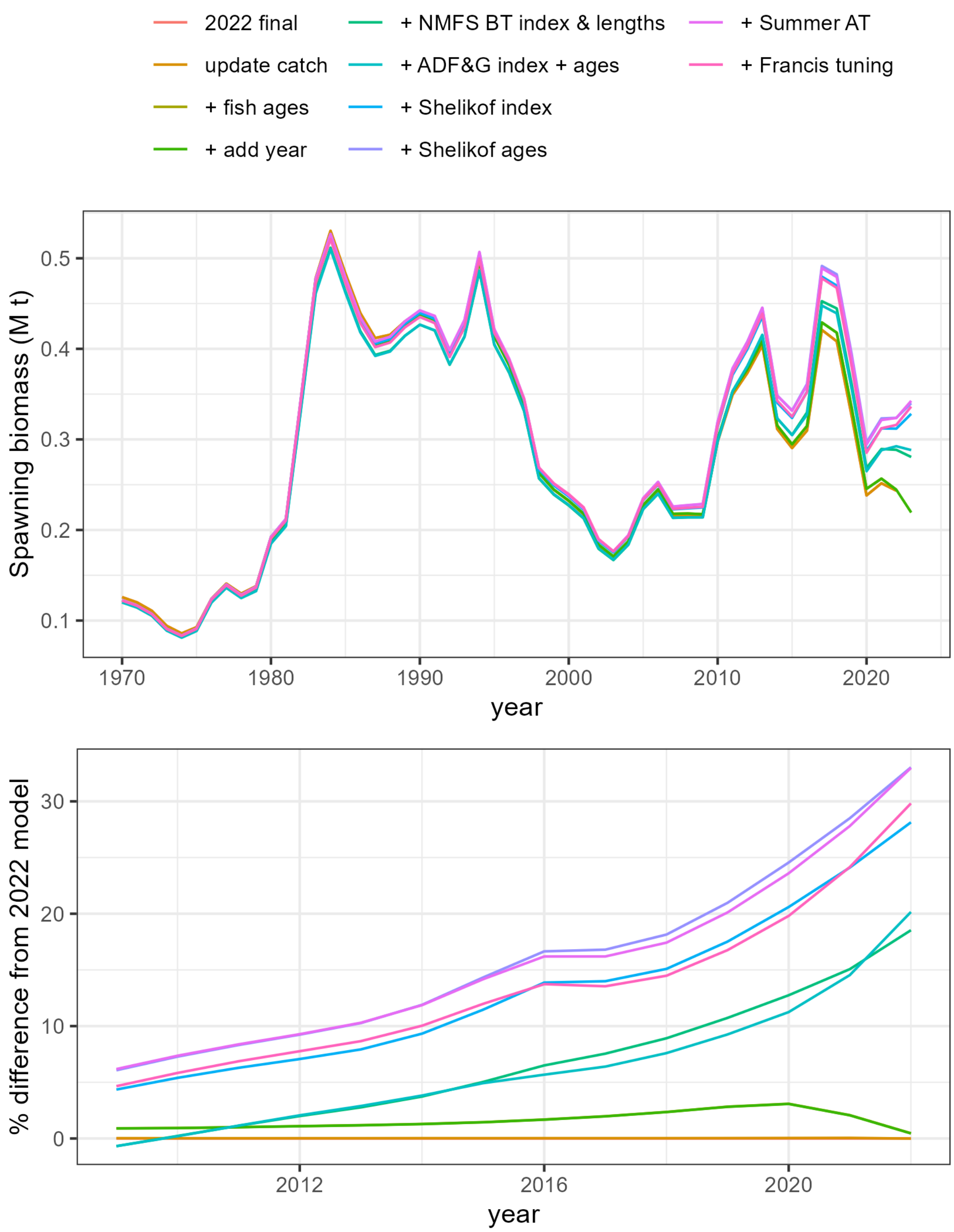


Figure 1.22. Changes in estimated spawning biomass as new data were added successively to last year's base model, ordered by row in the legend at the top. The lower panel shows recent years with an expanded scale to highlight differences.

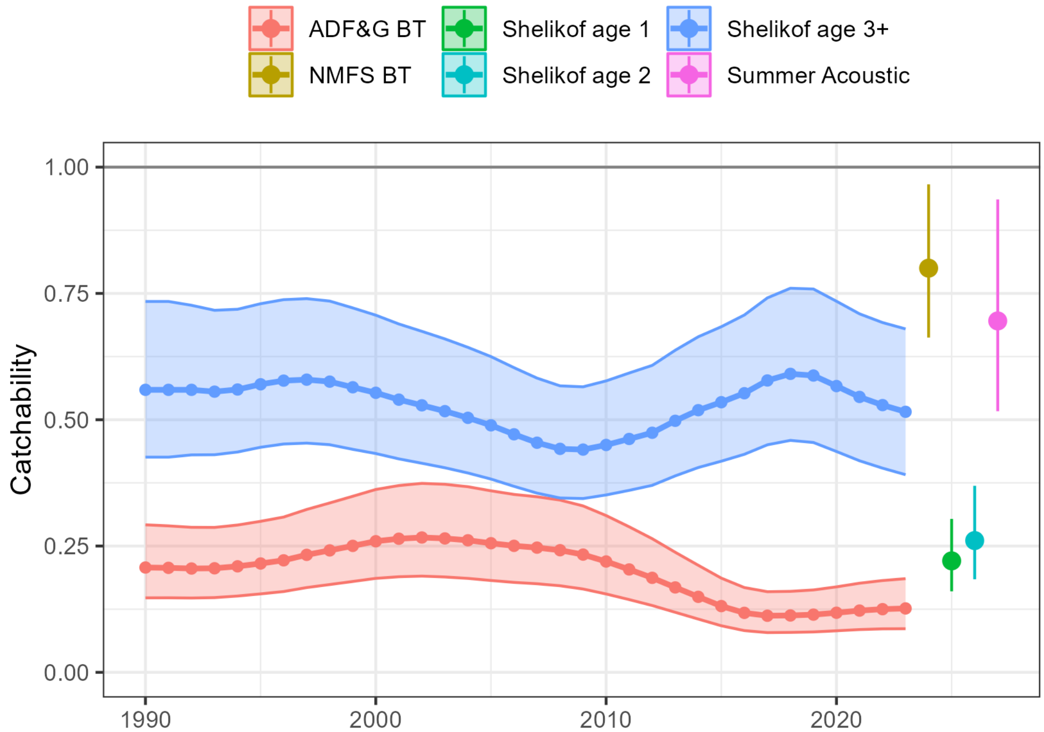


Figure 1.23. Time-varying catchability for the Shelikof Strait acoustic survey (Survey 1), the ADF&G crab/groundfish trawl survey (Survey 3), and constant catchability for the NMFS bottom trawl (Survey 2) and the age-1 and age-2 Shelikof indices (Surveys 4 and 5; representing selectivity), and for the summer NMFS acoustic survey (Survey 6), for model 19.1a. Ribbons and lines represent the 95% CI

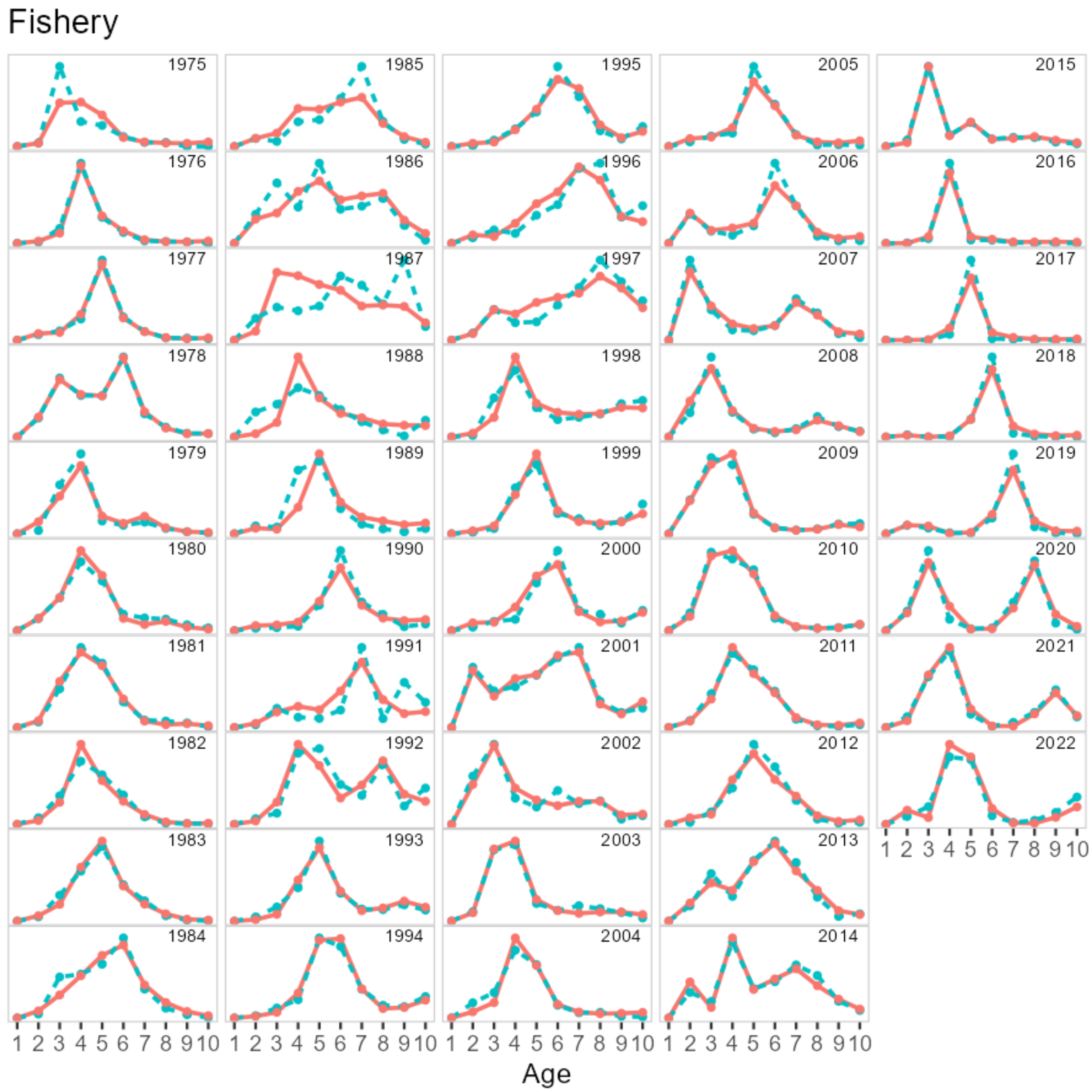


Figure 1.24. Observed and predicted fishery age composition for GOA pollock from the base model. Dashed blue lines are observations and solid red lines are model expectations.

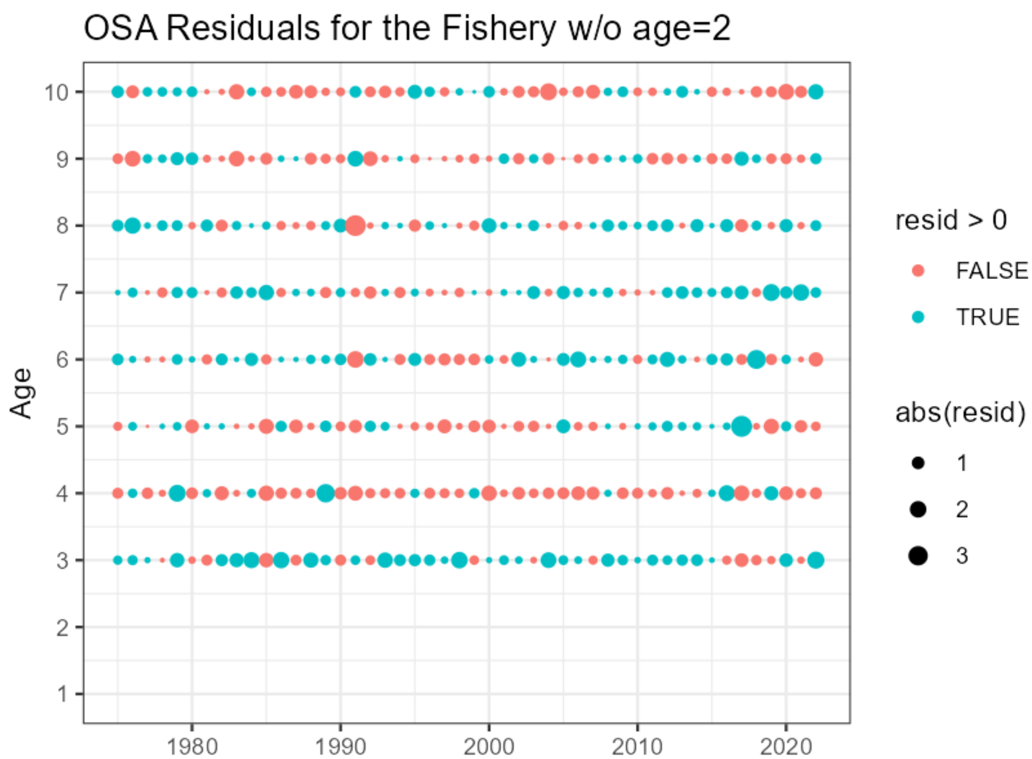


Figure 1.25. OSA residuals for fishery age compositions. Age 1 is combined with age 2 due to lack of data. OSA residuals will be distributed iid standard normal, within and among years, under a correctly specified model and assuming that the first bin fits perfectly. When the absolute residuals are larger than 3 or there are clear correlations or other patterns across ages/years, then the assumption is likely violated and interpreted as model misfit. See (Trijoulet *et al.* 2023) for more information.

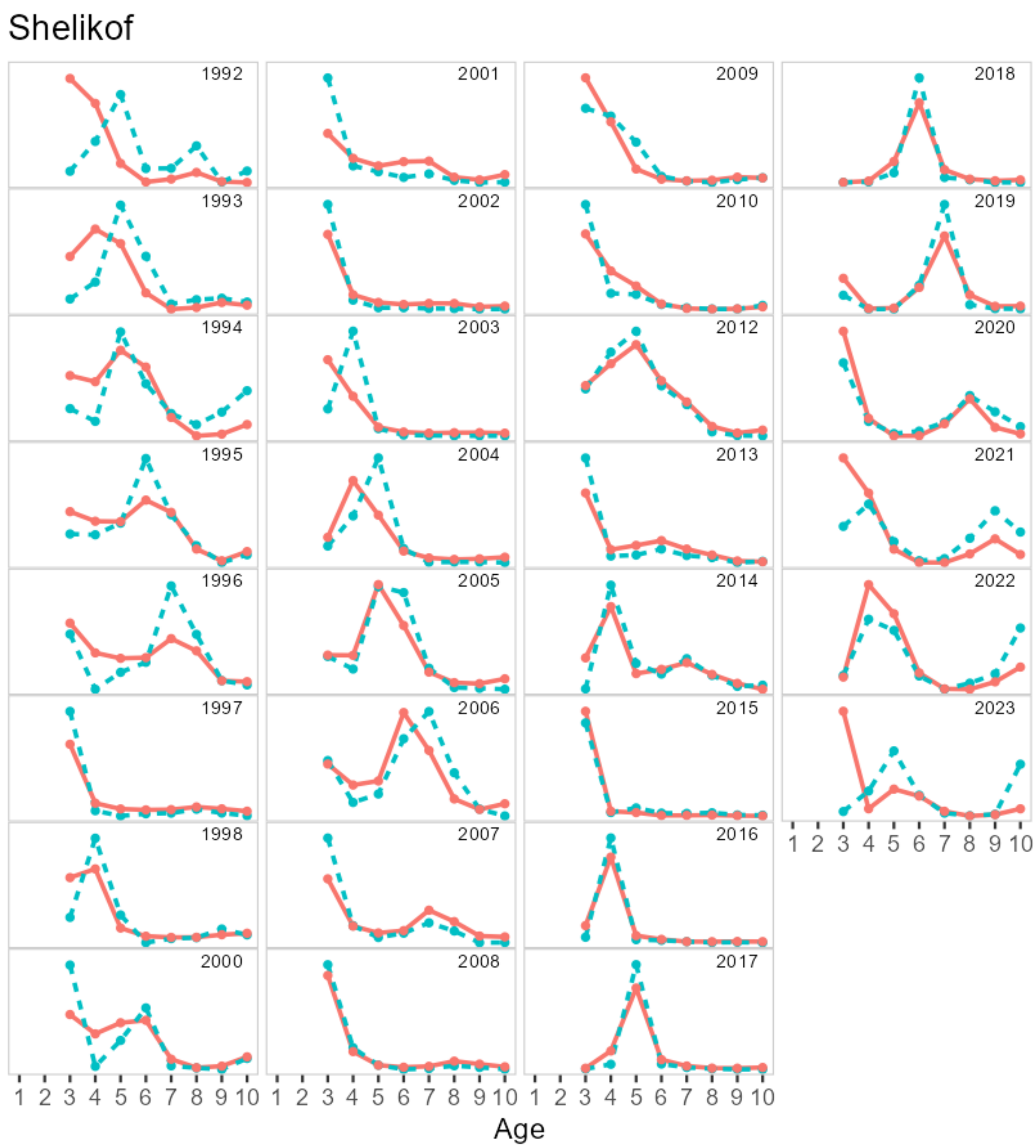


Figure 1.26. Observed and predicted Shelikof Strait acoustic survey age composition for GOA pollock from the base model. Dashed blue lines are observations and solid red lines are model expectations. Age 1 and 2 fish are modeled separately and excluded.

Figure 1.27. OSA residuals for Shelikof Strait acoustic survey age composition. Ages 1 and 2 are modeled separately and left off here. See caption for figure 1.25 for interpretation of these residuals.

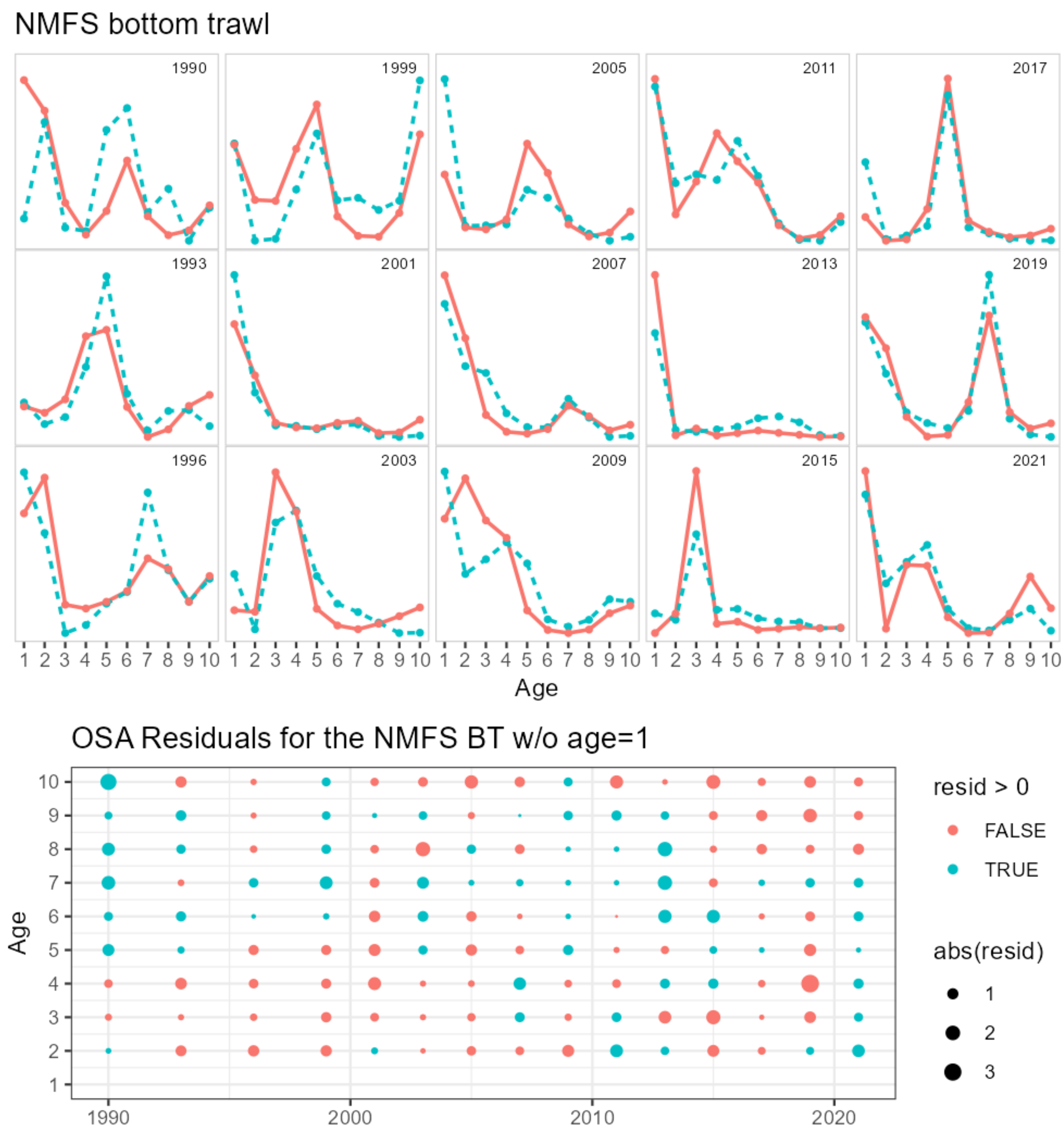


Figure 1.28. Observed and predicted NMFS bottom trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. OSA residuals for NMFS bottom trawl survey (bottom). See caption for figure 1.25 for interpretation of these residuals..

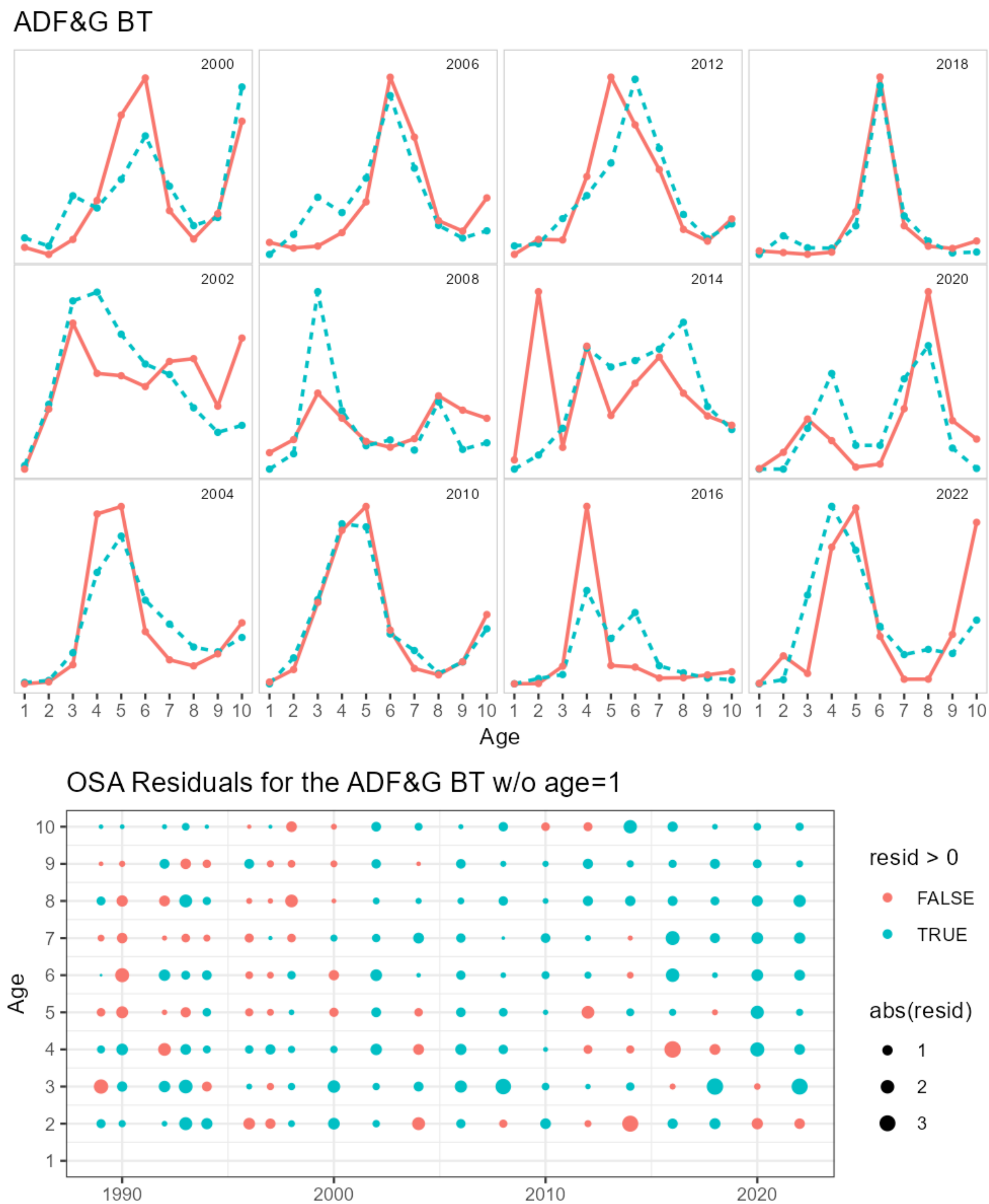


Figure 1.29. Observed and predicted ADF&G bottom trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. OSA residuals for ADF&G bottom trawl survey (bottom). See caption for figure 1.25 for interpretation of these residuals.

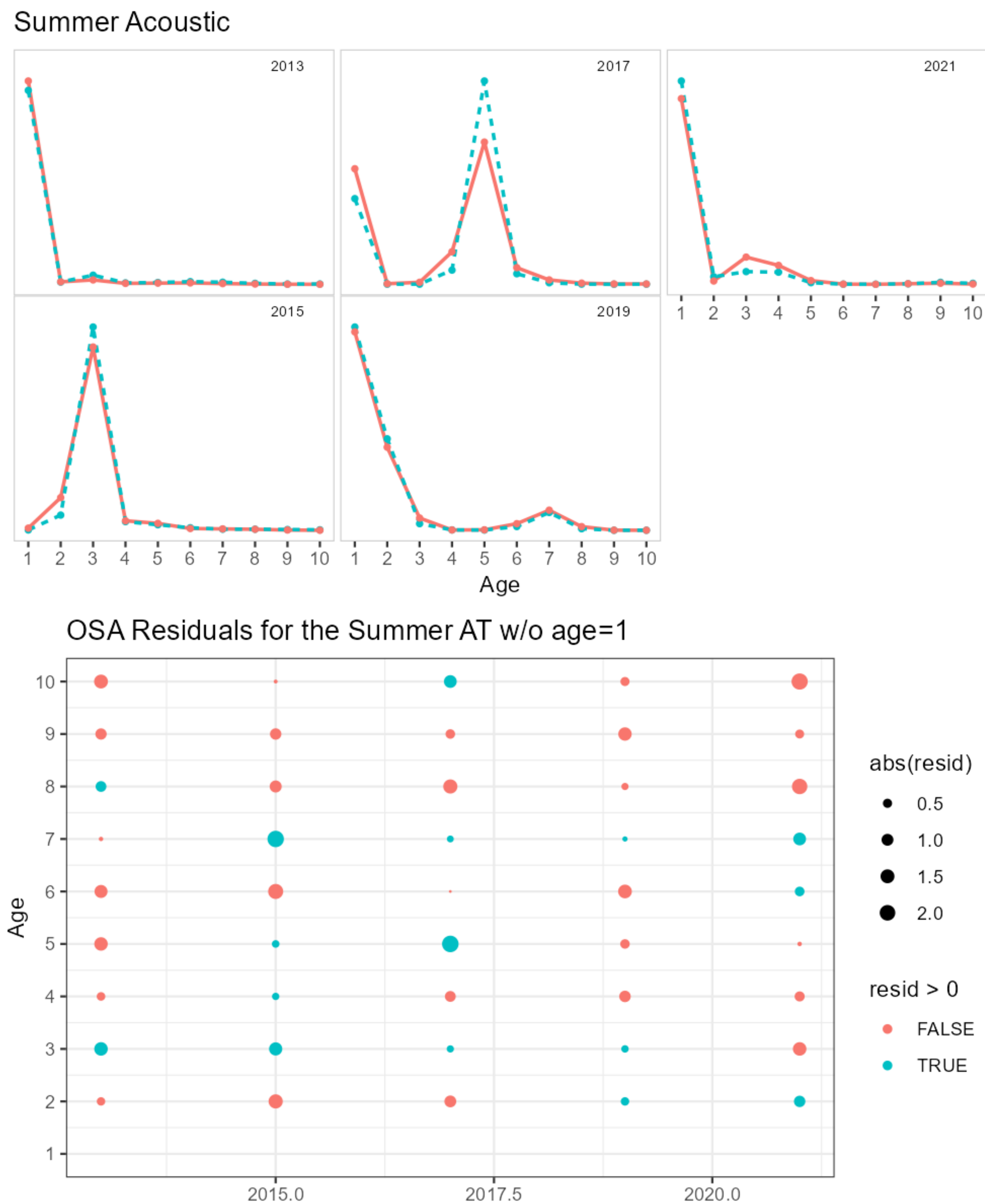


Figure 1.30. Observed and predicted summer acoustic trawl age composition for GOA pollock from the base model (top). Dashed blue lines are observations and solid red lines are model expectations. OSA residuals for the summer acoustic trawl survey (bottom). See caption for figure 1.25 for interpretation of these residuals.

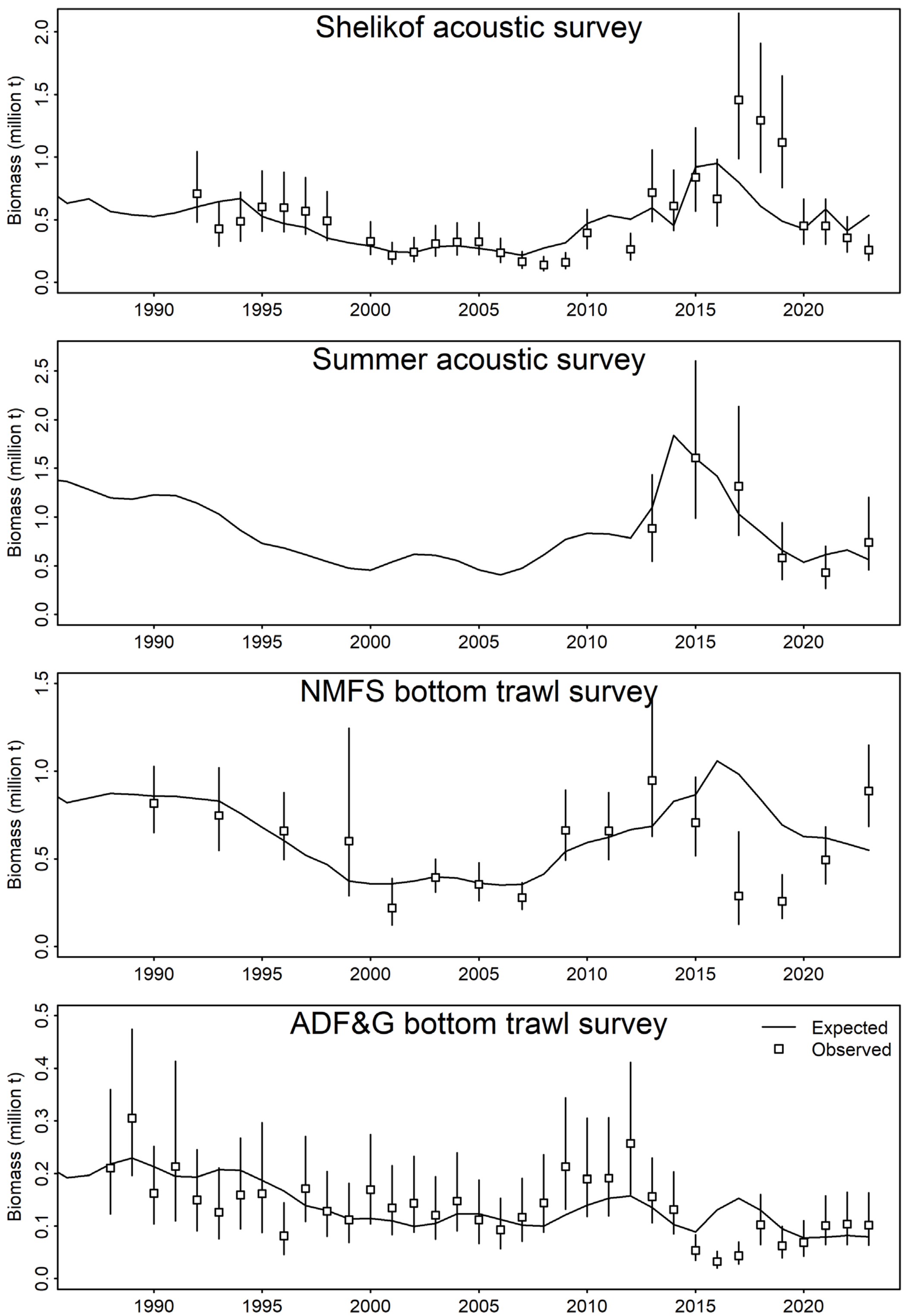


Figure 1.31. Model predicted (line) and observed survey biomass (points and 95% confidence intervals) for the four surveys. The Shelikof survey is only for ages 3+.

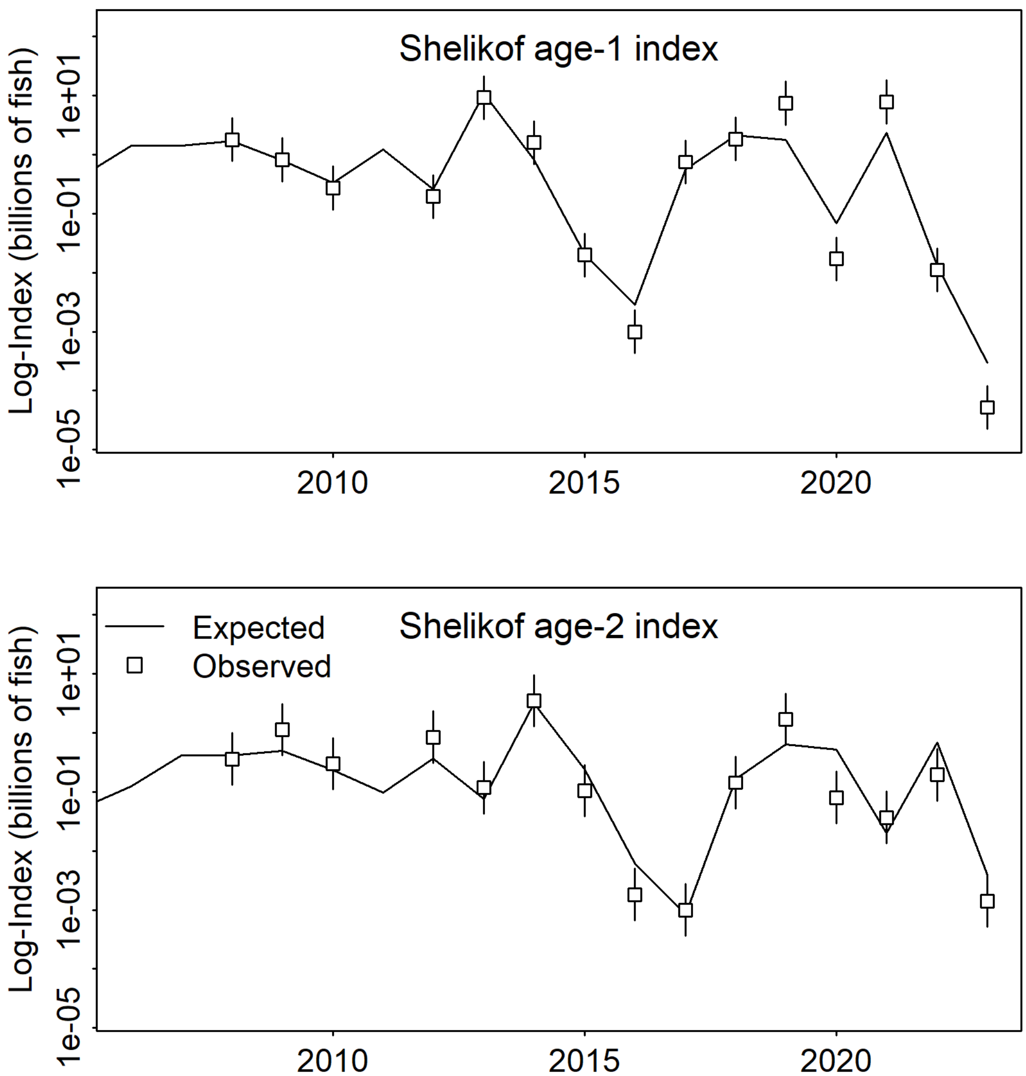


Figure 1.32. Model predicted (line) and observed survey biomass (points and 95% confidence intervals) for the age 1 and age 2 winter Shelikof surveys.

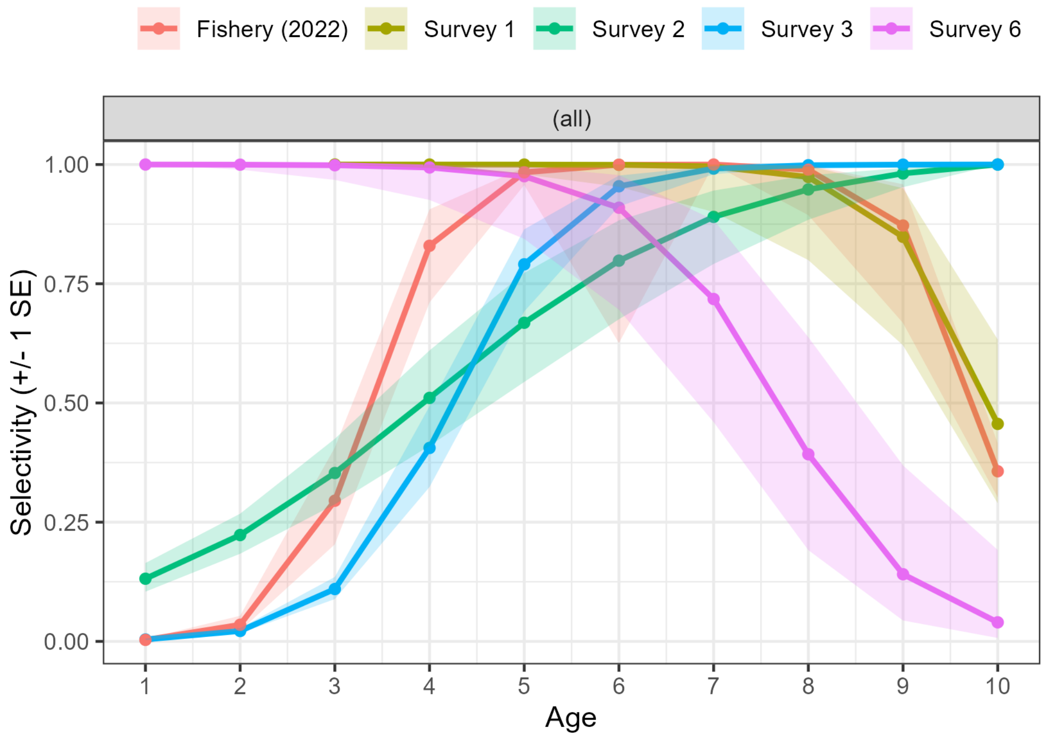


Figure 1.33. Estimated selectivity at age (lines) and uncertainty (+/- 1 SE; ribbons) for the fishery and surveys. Uncertainty calculations are done in logit space then converted and hence are asymmetric.

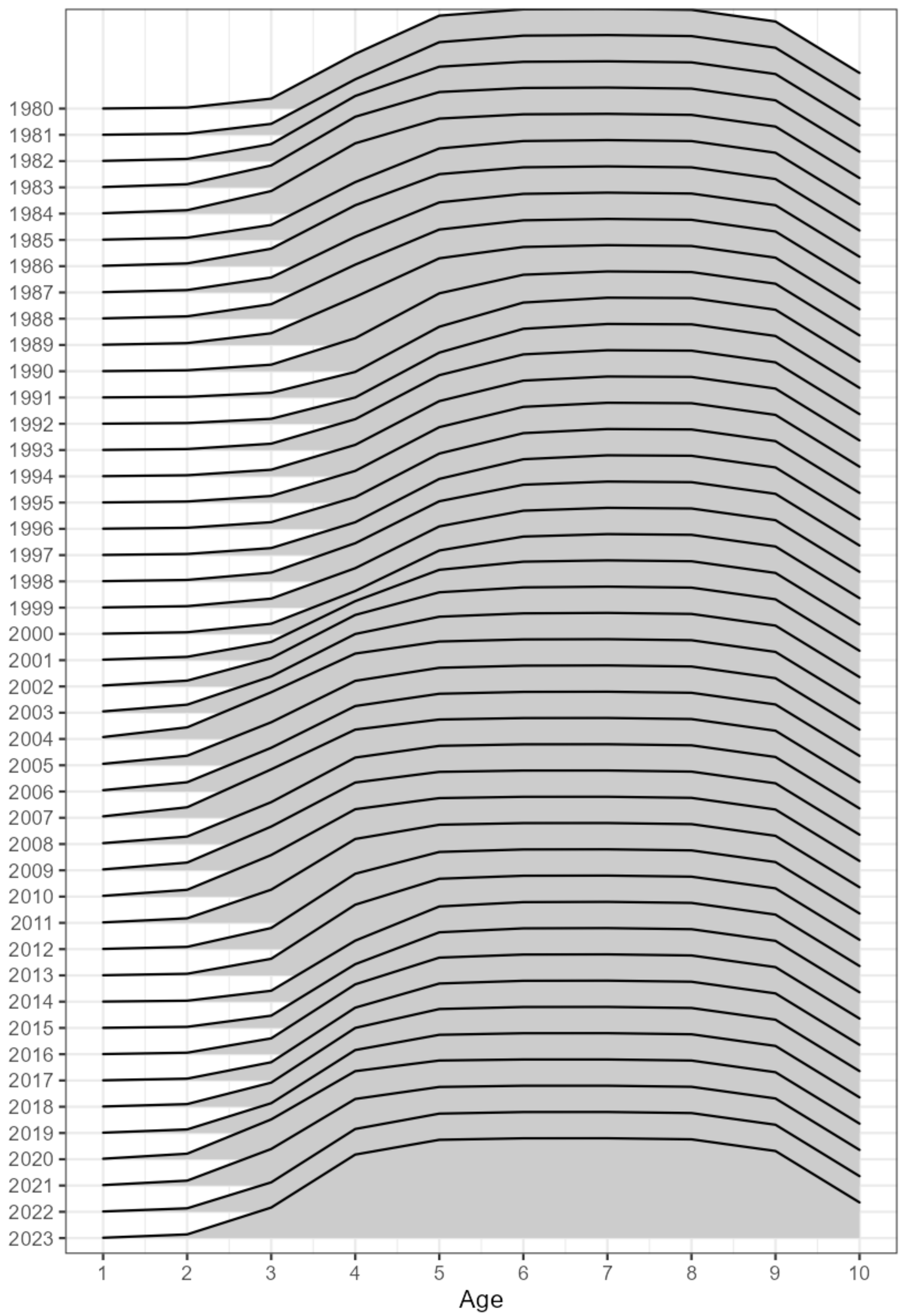


Figure 1.34. Estimates of time-varying double-logistic fishery selectivity for GOA pollock for the base model. The selectivity is scaled so the maximum in each year is 1.0.

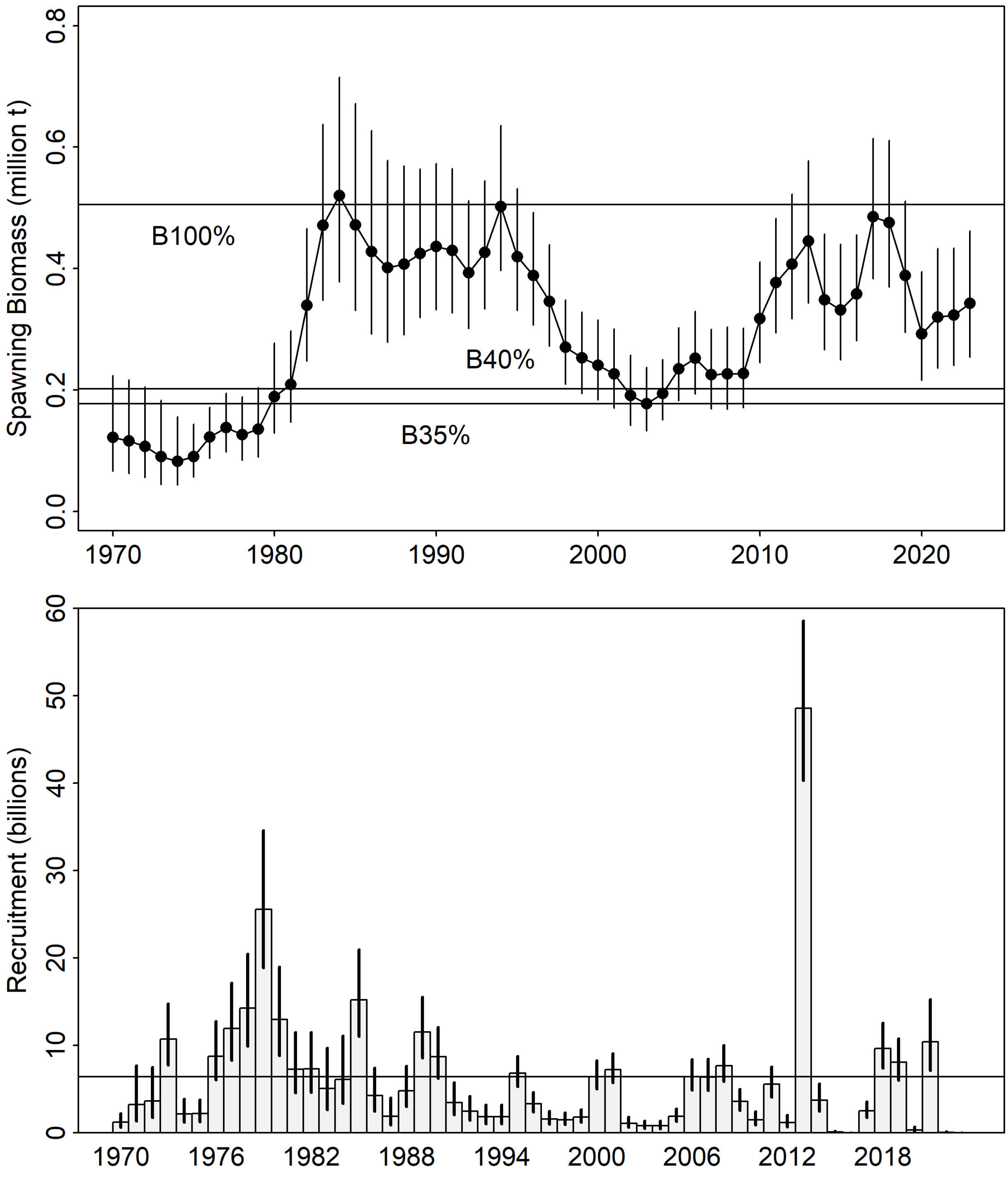


Figure 1.35. Estimated time series of GOA pollock spawning biomass (top) and age 1 recruitment (bottom) for the base model, with horizontal line at the average from 1978-2022. Vertical bars represent two standard deviations. The B35% and B40% lines represent the current estimate of these benchmarks.

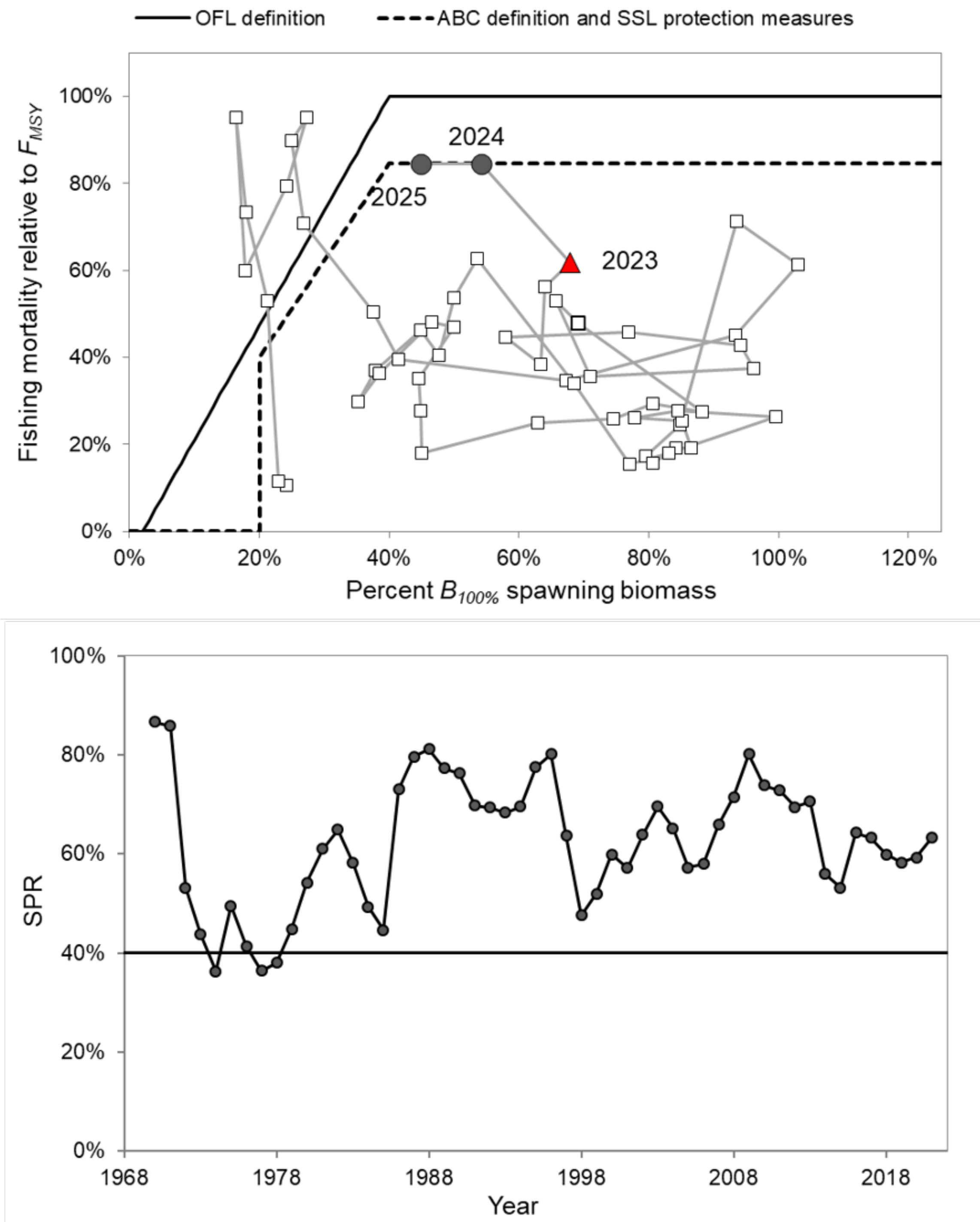


Figure 1.36. Annual fishing mortality as measured in percentage of unfished spawning biomass per recruit (top). GOA pollock spawning biomass relative to the unfished level and fishing mortality relative to FMSY (bottom). The ratio of fishing mortality to FMSY is calculated using the estimated selectivity pattern in that year. Estimates of B100% spawning biomass are based on current estimates of maturity at age, weight at age, and mean recruitment. Because these estimates change as new data become available, this figure can only be used in a general way to evaluate management performance relative to biomass and fishing mortality reference levels.

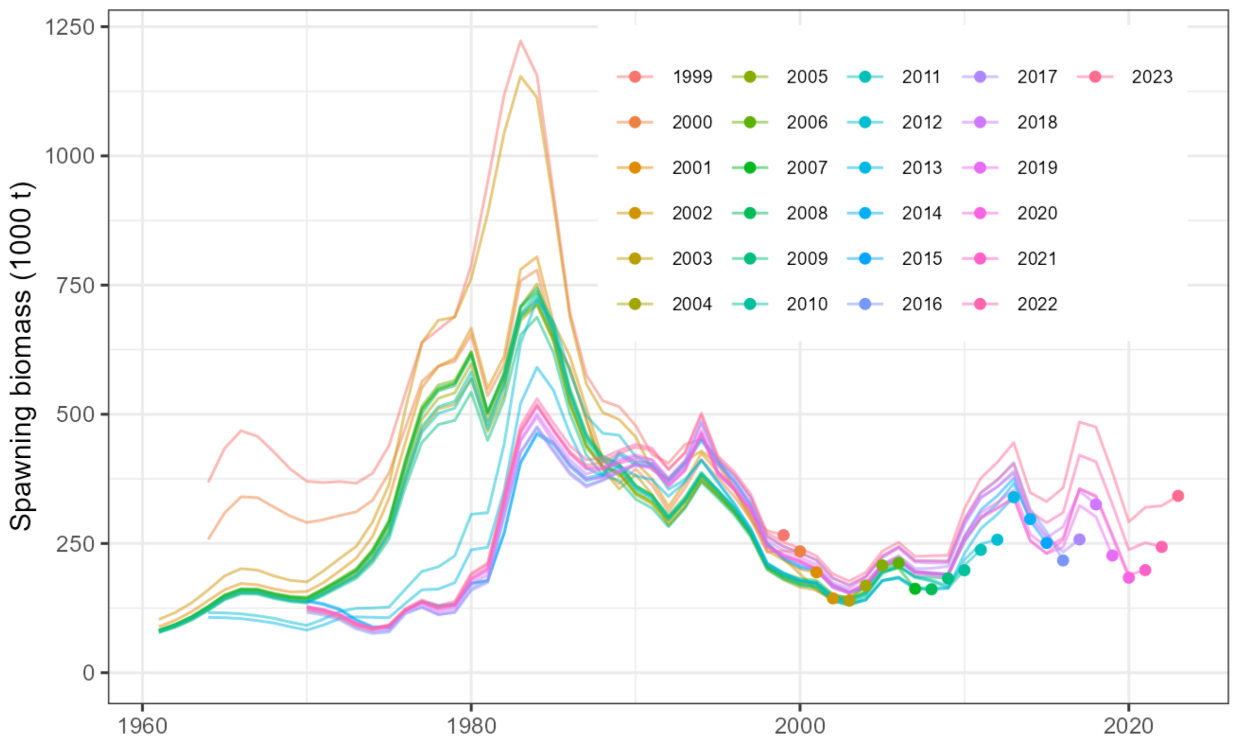


Figure 1.37. Estimated female spawning biomass for historical stock assessments conducted between 1999-2023. Lines reprsent the estimate in the assessment year and point is the terminal estimate in that year.

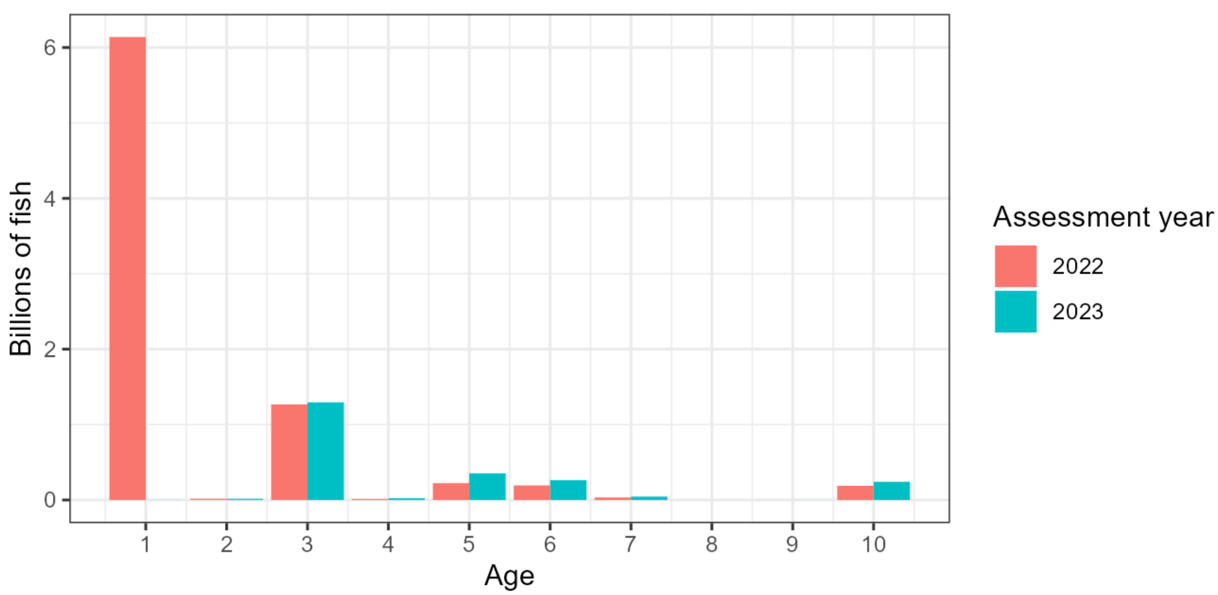


Figure 1.38. The estimated age composition in 2023 from the 2022 and 2023 assessments. The age-1 recruits have no information in the 2021 assessment and so are the average and hence not comparable

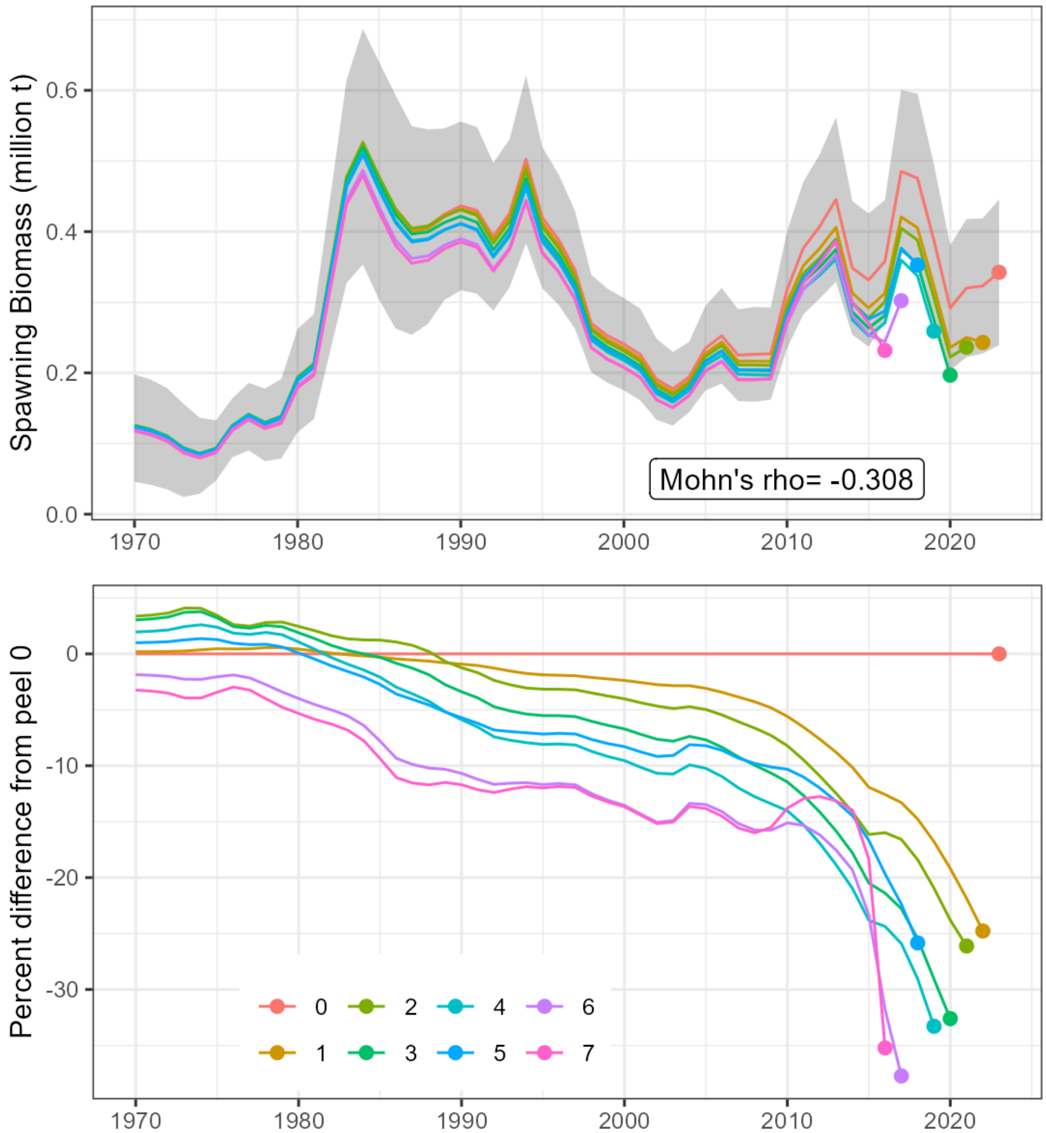


Figure 1.39. Retrospective plot of spawning biomass for models ending in years 2013-2022 for the 2023 base model. The revised Mohn's rho (Mohn 1999) for ending year spawning biomass is -0.081.

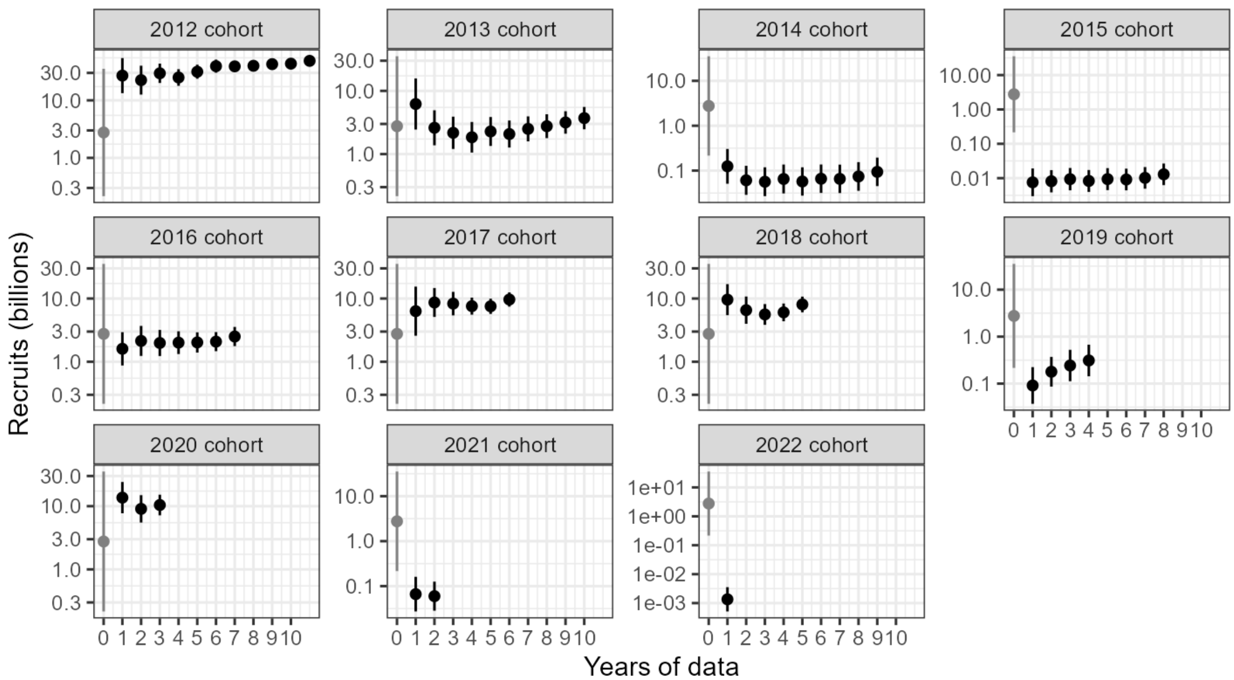


Figure 1.40. Estimates of cohort size (points) and uncertainty (95% confidence intervals) as years of data are added to the model from the retrospective analysis

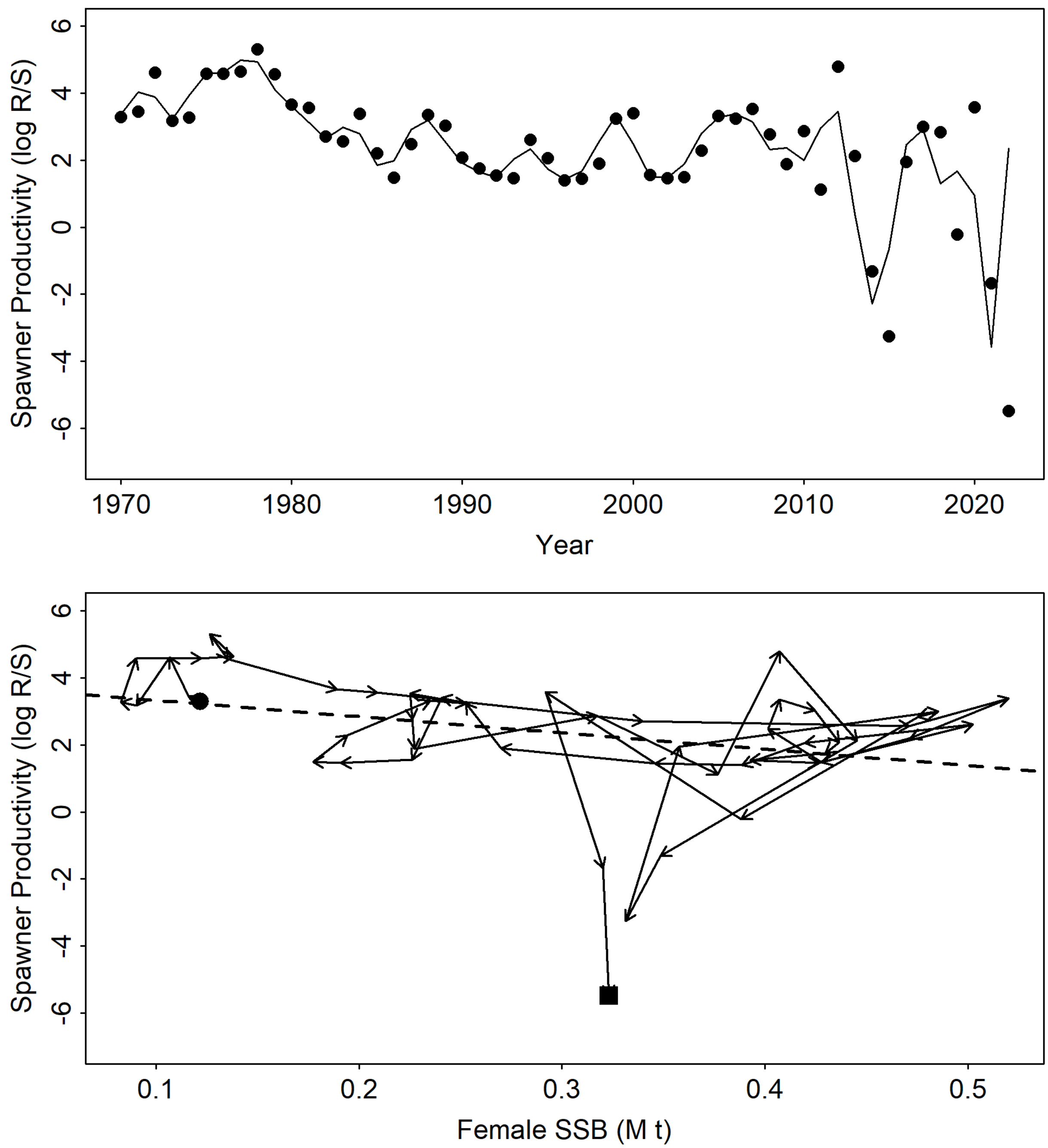


Figure 1.41. GOA pollock spawner productivity, log(R/S), in 1970-2019 (top). A five-year running average is also shown. Spawner productivity in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass.

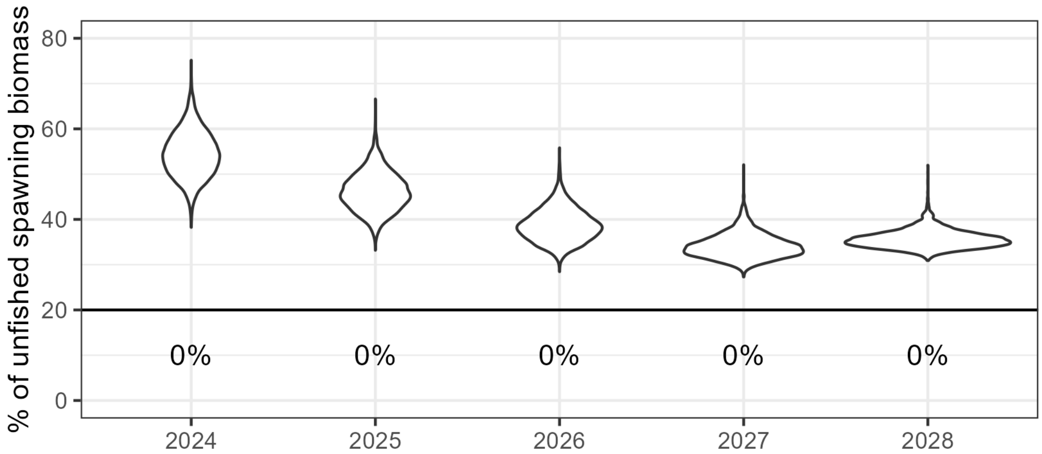


Figure 1.42. Uncertainty in spawning biomass in 2024-2028 based on a posterior samples from MCMC from the joint likelihood for the base model where catch is set to the maximum permissible FABC. Shown are the percentage below the horizontal line at 20% for each year.

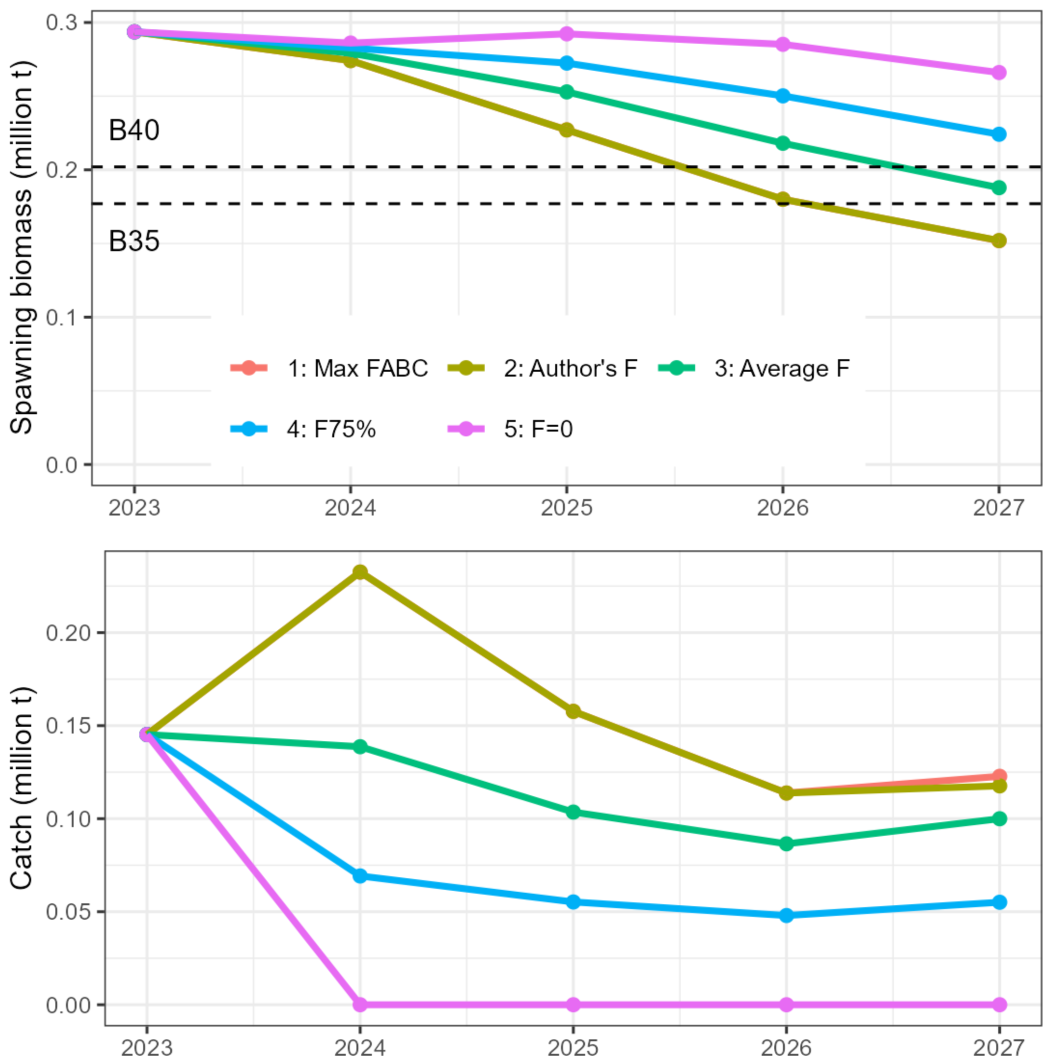


Figure 1.43. Projected mean spawning biomass and catches in 2022-2026 under different harvest rates.

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

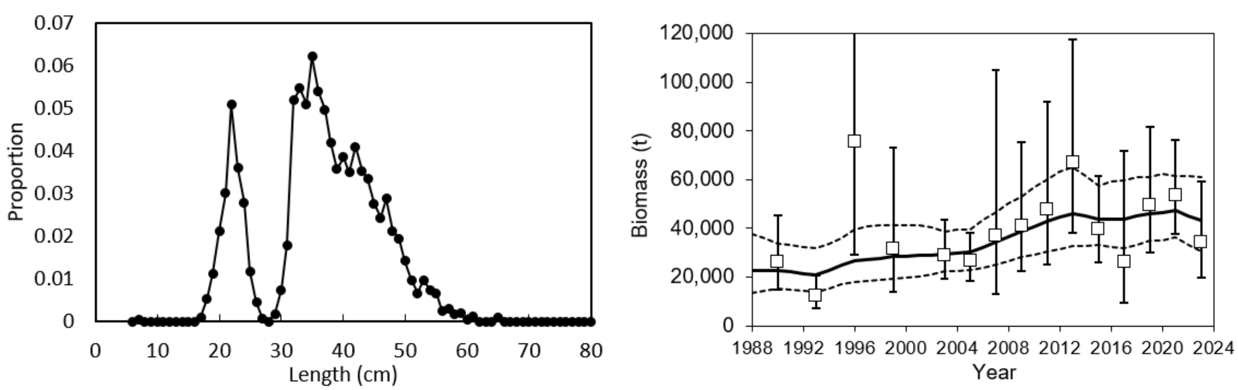
Appendix 1.A is available at this external link: https://apps-afsc.fisheries.noaa.gov/Plan_Team/2023/GOApollock_appA.pdf

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 2023 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 length composition in the 2023 bottom trawl survey showed a dominant mode at 20 cm about from 30 to 60 cm (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 2012 (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. B.1). There is a gradual increase in biomass since 2005, but confidence intervals are large. A random effects model was fit to the 1990-2023 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 (43,328 t). **The new model estimate results in a 2024 ABC of 9,749 t (43,328 t * 0.75 M), and a 2024 OFL of 12,998 t (43,328 t * M). The same ABC and OFL is recommended for 2025.**



Appendix figure 1B.1. Pollock length composition in 2023 (left) and biomass trend in southeast Alaska from a random effects model fit to NMFS bottom trawl surveys in 1990-2023 (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 40.79% which may reflect sampling variability, or interannual variation in spawning location. After rescaling, the resulting average biomass distribution was 6.01%, 87.07%, and 6.92% in areas 610, 620, and 630 (Appendix table 1D.1). In comparison to last year, the percentage in area 610 is 3.6 percentage points higher, -4.7 percentage points lower in area 620, and 1.2 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, 6.0%; 620, 70.2%; 630, 23.8%. 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, 36.0%; 620, 21.5%; 630, 39.5%; 640, 3.0%.

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 (3.0%) 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	2020	929,397	456,457	49.1%	0.0%	93.9%	6.1%
Shelikof	2021	1,176,770	457,659	38.9%	0.0%	97.1%	2.9%
Shelikof	2022	1,079,230	365,307	33.8%	0.0%	97.7%	2.3%
Shelikof	2023	1,193,130	258,829	21.7%	0.0%	98.3%	1.7%
Shelikof			Average	35.9%	0.0%	96.7%	3.3%
			% of total biomass		0.0%	34.7%	1.2%
Chirikof	2015	1,879,720	12,705	0.7%	0.0%	70.2%	29.8%
Chirikof	2017	1,463,410	2,485	0.2%	0.0%	26.3%	73.7%
Chirikof	2019	1,006,640	9,907	1.0%	0.0%	0.4%	99.6%
Chirikof	2023	1,193,130	42,804	3.6%	0.0%	36.4%	63.6%
Chirikof			Average	1.4%	0.0%	33.3%	66.7%
			% of total biomass		0.0%	0.5%	0.9%
Marmot	2018	1,143,920	12,905	1.1%	0.0%	0.0%	100.0%
Marmot	2019	1,006,640	5,407	0.5%	0.0%	0.0%	100.0%
Marmot	2021	1,176,770	6,128	0.5%	0.0%	0.0%	100.0%
Marmot	2023	1,193,130	9,653	0.8%	0.0%	0.0%	100.0%
Marmot			Average	0.7%	0.0%	0.0%	100.0%
			% of total biomass		0.0%	0.0%	0.7%
Shumagin	2017	1,463,410	29,753	2.0%	84.3%	15.7%	0.0%
Shumagin	2018	1,143,920	7,777	0.7%	95.0%	5.0%	0.0%
Shumagin	2020	929,397	4,637	0.5%	47.4%	52.6%	0.0%
Shumagin	2023	1,193,130	48,820	4.1%	96.9%	3.1%	0.0%
Shumagin			Average	1.8%	80.9%	19.1%	0.0%
			% of total biomass		1.5%	0.3%	0.0%
Sanak	2015	1,879,720	17,905	1.0%	100.0%	0.0%	0.0%
Sanak	2016	1,784,520	3,571	0.2%	100.0%	0.0%	0.0%
Sanak	2017	1,463,410	831	0.1%	100.0%	0.0%	0.0%
Sanak	2018	1,143,920		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	2016	1,784,520	11,459	0.6%	100.0%	0.0%	0.0%
Mozhovoi	2017	1,463,410	3,924	0.3%	100.0%	0.0%	0.0%
Mozhovoi	2018	1,143,920	3,759	0.3%	100.0%	0.0%	0.0%
Mozhovoi	2023	1,193,130	4,028	0.3%	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	1,784,520	2,140	0.1%	100.0%	0.0%	0.0%
Pavlof	2017	1,463,410	2,092	0.1%	100.0%	0.0%	0.0%
Pavlof	2018	1,143,920	4,413	0.4%	100.0%	0.0%	0.0%
Pavlof	2023	1,193,130	5,529	0.5%	100.0%	0.0%	0.0%
Pavlof			Average	0.3%	100.0%	0.0%	0.0%
			% of total biomass		0.3%	0.0%	0.0%
Total				40.79%	2.45%	35.52%	2.82%
Rescaled total				100.00%	6.01%	87.07%	6.92%

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*
2019	119,502	201,711	207,058	43,204
2021	78,468	131,625	197,118	23,937
2023	121,402	152,672	454,642	11,701
		Percent		
	Area 610	*Area 620*	*Area 630*	*Area 640*
2019	20.9%	35.3%	36.2%	7.6%
2021	18.2%	30.5%	45.7%	5.6%
2023	16.4%	20.6%	61.4%	1.6%
		Bottom trawl estimates		
		Biomass (t)		
Year	*Area 610*	*Area 620*	*Area 630*	*Area 640*
2019	119,312	36,450	90,921	10,921
2021	252,827	113,737	108,813	19,367
2023	480,242	159,889	225,582	21,889
		Percent		
	Area 610	*Area 620*	*Area 630*	*Area 640*
2019	46.3%	14.1%	35.3%	4.2%
2021	51.1%	23.0%	22.0%	3.9%
2023	54.1%	18.0%	25.4%	2.5%

Options for allocation

Option 5: Weighted average of acoustic plus bottom trawl biomass (2017-2023)

	Area 610	*Area 620*	*Area 630*	*Area 640*
	472,568	282,732	518,677	39,299
	35.98%	21.53%	39.49%	2.99%

Appendix table 1D.3. Calculation of 2023 Seasonal and Area TAC Allowances for the W/C/WYK region.

Proposed 2024 ABC for W/C/WYK (t):			**232,543**

Winter biomass distribution			
Area	610	620	630
Percent	6.0%	87.1%	6.9%

Summer biomass distribution				
Area	610	620	630	640
Percent	36.0%	21.5%	39.5%	3.0%

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

PWS percent	2.5%	GHL (t)	5,814
Federal percent	97.5%	Federal TAC	226,729

2) Use summer biomass distribution for the 640 allowance:

640 percent	3.0%	640 TAC (t)	6,785
610-630 percent	97.0%	610-630 TAC (	219,945

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%	54,986
A2 season	25%	54,986
B1 & B2 seasons	50%	109,972

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	6.0%	3,305	6.0%	3,305
620	70.2%	38,585	87.1%	47,876
630	23.8%	13,096	6.9%	3,805

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

	B1 & B2 season	
Area	Percent	TAC (t)
610	37.1%	40,793
620	22.2%	24,406
630	40.7%	44,773

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	6,611	40,793	2.9%	18.0%
620	86,461	24,406	38.1%	10.8%
630	16,901	44,773	7.5%	19.7%
640	6,785		3.0%	

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	70.32
2022	44.24	0.05	13.19

Exploring non-parametric and semi-parametric selectivity using 2d and 3d AR(1) smoothers

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2023-10-17

Executive Summary

Fishery age composition residuals have suggested misfit for this model for several decades, and has been a point of concern for the PT and SSC. More flexible configurations for fishery selectivity need to be explored. Facilitation of a new suite of more flexible non-parametric and semi-parametric selectivities in a more rigorous statistical framework requires moving away from ADMB and toward its replacement TMB. We thus ported model 19.1a (the 2022 final model) to TMB and demonstrate nearly identical estimates. We call the TMB version of 19.1a model 23.0 to reflect the change in software framework. We then used model 23.0 to explore a suite of fisheries selectivities which vary in their flexibility and where that flexibility is permitted. We conclude that two non-parametric models would make for an improved fisheries selectivity formulation based on analyzing OSA residuals, AIC model selection, and reduction in retrospective bias. The models are 23.0a which uses a 2D AR(1) model, and 23.0b which uses a so-called 3D AR(1) process that parses age, year, and cohort correlations from the data. These models are not expected to greatly impact management advice, but we believe their improved performance and projection capabilities make for a better stock assessment moving forward.

Proposed models

Model 23.0: Bridging from ADMB to Template Model Builder

Template Model Builder [TMB; Kristensen et al. (2016)] is a software platform designed to estimate complex, non-linear hierarchical models. Its primary feature is the ability to efficiently apply the Laplace approximation to the marginal likelihood, so that process errors can be estimated using standard numerical optimization (Skaug and Fournier 2006). It is widely seen as the successor to ADMB, which has limited Laplace approximation capabilities and thus a penalized maximum likelihood approach is generally taken (i.e., process errors fixed and random effects estimated as fixed effects). Despite this important advantage, there have been relatively few implementations for stock assessments in the North Pacific. TMB is used more widely in other areas, such as WHAM (Stock and Miller 2021) on the US East Coast, and SAM (Nielsen and Berg 2014) in Europe. A WHAM version of the GOA pollock assessment was presented to the Plan Team in 2022, but there are advantages to using a bespoke model like the ADMB version developed by Martin Dorn and used for decades. Here we present a direct port of the 2022 accepted ADMB model 19.1a to TMB. Due to a change in software we name this model 23.0, although our initial goal is to match model 19.1a as close as possible.

We therefore converted the bespoke ADMB model to TMB. There are a few important differences between ADMB and TMB in terms of syntax and functionality relevant to stock assessments. TMB has no native phased estimation capabilities (although there is an R function that serves a similar purpose) so all parameters are estimated simultaneously starting from their initial values. We used the 19.1a MLE estimates as initial values in model 23 and were able to obtain the same model predictions, and when optimized from there the same standard errors (uncertainties) for parameters and derived quantities (Fig. 1). TMB does not have an equivalent to ADMB's "dev_vector" parameter class which penalizes a vector to have a mean of zero. Model 19.1a uses this feature by estimating a single mean in addition to the vector. When converting to a standard unpenalized vector, a degree of freedom is lost. The means are thus fixed at arbitrary values and mathematically the two become equivalent.

Figure 1: Results of bridging the ADMB 19.1a model to TMB model 23.0. Shown are estimates and standard errors (SE) for two key outputs, annual recruitment (in billions) and spawning stock biomass (SSB; in M t). The differences, calculated as (TMB-ADMB)/ADMB are very small, typically less than 0.02%, and presumably due to differences in the optimizer and precision of data inputs.

Non-parametric and semi-parametric fisheries selectivity

This stock has had persistent residual patterns in the fishery age composition data for many years, particularly for age 4 and 5 (Fig. 2). This has been a concern of the PT for many years. For instance

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.

In 2022 several ad hoc approaches were explored which demonstrated that a more flexible fisheries selectivity form could reduce the residual patterns. However, these approaches were difficult to justify and relied on arbitrarily setting likelihood penalties of time-varying selectivity curves. Instead it would be ideal to explore more flexible selectivity options based on published literature, and estimate the amount of flexibility from the data. We therefore use model 23.0 to explore alternative selectivity parameterizations. First, we review three important classes of hierarchical modeling approaches that can be used for selectivity: parametric, non-parametric, and semi-parametric functions.

Parametric models

Parametric selectivity curves are mathematical functions that have typically 2-4 parameters that define a specific form or shape (often asymptotic or dome shaped). Some common functions selected for parametric selectivity are: double normal, logistic, and double logistic. The pollock model has used double logistic

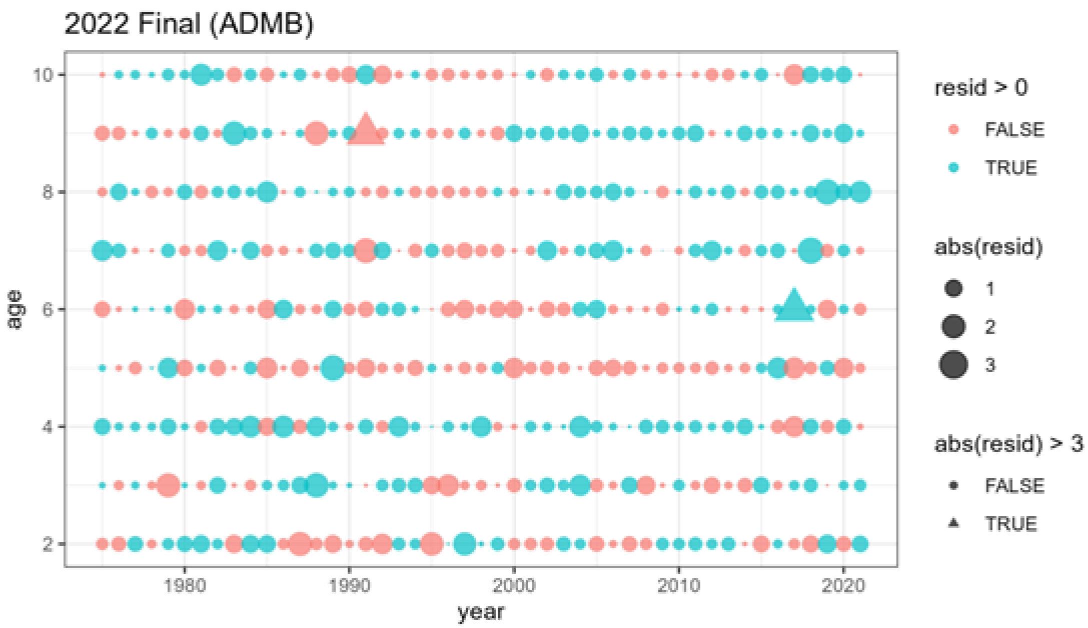

Figure 2: OSA residuals (leaving out age 1) for the 2022 accepted model. Persistent patterns in age 4, 5, and 9 fish have been a point of concern.

historically. They are usually selected based on hypothesized interactions between fishing/survey gear and the stock. That interaction accounts for "availability (i.e., the probability that a fish of a specific age or size is in the same vicinity at the same time as gear deployment) and contact (or gear) selectivity (i.e., the relative probability that a fish of specific age or size is caught given it is available to the gear" (Privitera-Johnson, Methot, and Punt 2022).

A common way to incorporate time variation in parametric models is to let the parameters vary over time, penalized as a random walk or AR(1) process. This is the current situation for model 19.1a, and historical models, where the ascending inflection point and slope parameters are time-varying. Arbitrary penalties are used in a penalized maximum likelihood context. With TMB, the variances are now estimable.

Non-parametric models

Non-parametric selectivity functions are functions that estimate parameters for each age or age by year to flexibly estimate the shape based on available data. Non-parametric models penalize large fluctuations between ages and/or years because it is unlikely that the availability or contact selectivity has large shifts between ages and/or years. For example, the Woods Hole Assessment Model (WHAM) can estimate age-specific parameters with additional yearly variation penalized by a year and age 2D-AR1 function (Stock and Miller 2021). Similarly, the stock assessment model (SAM) can estimate year and age specific selectivity that follows a random walk with multivariate normal increments that can include multiple correlation parameterizations (Nielsen and Berg 2014).

Recently Cheng et al. (2023) introduced a computationally efficient form of the 2D AR(1) process that parses variation by age, year and cohort. They provide a "marginal variance" and "conditional variance" version of this approach, which differ in how the covariance matrix is calculated. A priori the marginal variance option seems a better fit, but both are explored. The main potential advantage of this "3D" approach over the 2D one is that if there is cohort targeting by the fishery then this signal could be detected and propagated into projected selectivity, thus improving near-term estimates of SPR and management reference points.

In our non-parametric models, we estimate a mean selectivity at each age (ages 1-10), with deviations around those means allowing for flexibility. These deviations can be configured to correlate by age, year, or age and year (2D), or age, year and cohort (3D). The variances and correlations associated with these AR(1) models are estimable by TMB simultaneously with the rest of the assessment, hence uncertainty is appropriately propagated through the model.

Semi-parametric models

Semi-parametric selectivity functions are an intermediate between non-parametric and parametric models. The key difference is that a constant parametric form is estimated, and then the predicted selectivity at each age is scaled based on an exponentiated random effect deviation. Xu et al. (2019) develop a semi-parametric curve that combines the parametric logistic function with 2D-AR1 age and year specific nonparametric deviations. We extend this approach for the double logistic used for pollock. The configuration and estimation of the non-parametric component is the same.

Model set explored

Since model 23 is in TMB it is now possible to explore a large suite of new flexible selectivity forms. We wanted to explore how internally estimating time-varying fisheries selectivity would behave and compare to model 19.1a generally, so we selected a fairly large set of models (Table 1).

The selectivity equation details are given below.

- Mod 0: Parametric double logistic
  - $Sel_{age} = f_1(age)$
  - $f_1(age) = 1/(1 + exp(-slp_1 * (age - inf_1)) * (1 - 1/(1 + exp(-slp_2 * (age - inf_2)))$
- Mod 1: Parametric double logistic w/ random effects on ascending parameters
  - $Sel_{(age,y)} = f_1(age)$ as above but:
  - $slp_{1,y} = slpdev_{1,y}$
  - $inf_{1,y} = inf_dev_{1,y}$
  - $slpdev_y - slpdev_{y-1} \sim N(0, \sigma)$
  - $infdev_y - infdev_{y-1} \sim N(0, 4 * \sigma)$
- Mod 2: Semi-parametric double logistic * AR(1) by age
  - $Sel_{age} = f_1(age) * exp(dev_{age})$
  - $dev_{age} \sim MVN(0, \Sigma_a)$
- Mod 3: Semi-parametric double logistic * AR(1) by year
  - $Sel_{age,y} = f_1(age) * exp(dev_y)$
  - $dev_y \sim MVN(0, \Sigma_y)$
- Mod 4: Semi-parametric double logistic * 2D-AR(1) by age, year
  - $Sel_{age,y} = f_1(age) * exp(dev_{age,y})$
  - $dev_{age,y} \sim MVN(0, \Sigma_{age,y})$
- Mod 5: Non-parametric by age
  - $Sel_{age} = f_2(age)$
  - $f_2(age) = 1/(1 + exp(-(par_{age}))$
- Mod 6: Non-parametric AR(1) by year
  - $Sel_{age,y} = 1/(1 + exp(-(selpar_{age} + dev_y))$
  - $dev_y \sim MVN(0, \Sigma_y)$
- Mod 7: Non-parametric 2D AR(1) age, year

  - $Sel_{age,y} = 1/(1 + exp(-(selpar_{age} + dev_{age,y}))$
  - $dev_{age,y} \sim MVN(0, \Sigma_{age,y})$

- Mod 8: 3D AR(1) by a, y, and cohort using conditional variance
  - $Sel_{age,y} = 1/(1 + exp(-(selpar_{age} + dev_{age,y}))$
  - $dev_{age,y} \sim MVN(0, \Sigma_{age,cohort,y})$
- Mod 9: 3D AR(1) by a, y, and cohort using marginal variance
  - $Sel_{age,y} = 1/(1 + exp(-(selpar_{age} + dev_{age,y}))$
  - $dev_{age,y} \sim MVN(0, \Sigma_{age,cohort,y})$

where $selpar_{age}$ are age-specific parameters for the non-parametric selectivity curve, $dev_{age,y}$ are the random deviates for the non-parametric selectivity that are multivariate normal with covariance Σ.

Table 1: Fisheries selectivity models considered and fit.

Model	Type	Fixed (k) and random (p) effects associated with fisheries selectivity
Constant	Parametric double logistic	Initial and final inflection ages and slopes (k=4), no random effects (p=0). Used as a baseline without any time-variation.
ParDevs	Parametric double logistic with random walk on initial slope and inflection point	Initial and final inflection ages and slopes, plus one process error (k=5), two annual vectors of RE (p=116). This is the same as 19.1a except the process error is estimated
Log-AR1-Age	Semiparametric double logistic with random effects by age	Initial and final inflection ages and slopes, plus process error and AR1 correlation (k=6), one annual vectors of RE (p=10)
Log-AR1-Year	Semiparametric double logistic with random effects by year	Initial and final inflection ages and slopes, plus process error and AR1 correlation (k=6), one annual vector of RE (p=58)
Log-2D-AR1	Semiparametric double logistic with random effects by age and year	Initial and final inflection ages and slopes, plus process error and two AR1 correlations (k=7), matrix of RE (p=580)
Age-specific	Nonparametric age-specific fixed effects for selectivity at age. No time-variation	Mean selectivity at age, (k=10) and no random effects (p=0)
AR1-Year	Nonparametric with random effects by year	Mean selectivity at age, process error and correlation (k=12) and annual random effects (p=58)
2D-AR1	Nonparametric with random effects by age and year	Mean selectivity at age, process error and two correlations (k=13) and matrix of random effects (p=580)
3D-AR1cond	Nonparametric with random effects by age and year, using partial correlations for age, year, and cohort. Conditional variation formulation	Mean selectivity at age, process error and three partial correlations (k=14) and matrix of random effects (p=580)
3D-AR1mar	Nonparametric with random effects by age and year, using partial correlations for age, year, and cohort. Marginal variation formulation.	Mean selectivity at age, process error and three partial correlations (k=14) and matrix of random effects (p=580)

Selecting and validating flexible selectivity forms

Below we fit the alternative selectivity options (Table 1) to explore model behavior and help understand the level of complexity and flexibility needed to appropriately model fisheries selectivity. We use three primary tools to compare and contrast these models. First, we use one-step-ahead (OSA) residuals which are an improved tool over the ubiquitous Pearson residuals (Trijoulet et al. 2023). These residuals are expected to be standard normal under a correctly-specified model. We focus on visual inspection via bubble plots for non-random patterns by age, year, or cohort, as is common for Pearson residuals, instead of relying on statistical tests of normality or other properties. In particular for this example we focus on residuals for ages 3-5 which have been identified as problematic previously.

Second, we use marginal AIC for model selection. Model selection is not routinely used for stock assessment models because of the challenges associated with interpreting selection criteria when fitting to different types of data whose weights are often tuned and the use of penalized maximum likelihood (Maunder and Punt 2013; Punt, Hurtado-Ferro, and Whitten 2014). An added complication with the hierarchical models investigated here is that the penalty for the number of effective parameters does not include the random effects. Conditional AIC accounts for this but is not available at the moment. So, while the interpretation of differences in AIC is not as straightforward as in other statistical contexts, AIC still provides some important insight into the performance of the different models examined here.

Finally, we are interested in the ability of the model to estimate selectivity in the current year and near-term projections when no age data are available to inform selectivity. In previous models a 4-year average prior to the terminal year of the assessment was used, but this ignores signals of annual and cohort trends in the data. We compare these approaches using retrospective projections of age-specific selectivity and spawning stock biomass for each model. Specifically, consecutive years of data were removed, the model was refit, selectivity was projected forward one year. Projected age-specific selectivity in year y from a model fit using data until year $y-1$ was compared to estimated age-specific selectivity in year y from a model fit using data until year y using average relative error and mean squared error:

$$RE_{age} = \sum_{p}^{N_p} \left(Sel_{M(y-p),age,y-p+1} - Sel_{M(y),age,y-p+1} \right) / Sel_{M(y),age,y-p+1} / N_p$$

$$MSE_{age} = \sum_{p}^{N_p} \left(Sel_{M(y-p),age,y-p+1} - Sel_{M(y),age,y-p+1} \right)^2 / N_p$$

where RE_{age} and MSE_{age} are the relative error and mean squared error, respectively, for projected selectivity-at-age (Table 1), $Sel_{M(y-p),age,y-p+1}$ is the one-year projected selectivity from a model fit using data until year $y-p$ ($M(y-p)$), $Sel_{M(y),age,y-p+1}$ is the estimated selectivity from model fit using all available data until year y ($M(y)$),and N_p is the number of retrospective peels ($N_p = 7$). Note, that Francis weights were not updated for each retrospective peel. The above metrics were also calculated where projected selectivity $Sel_{M(y-p),age,y-p+1}$ was replaced with the average age-specific selectivity from the last five years, as is currently done for setting reference points. RE_{age} is referred to as Mohn's Rho, and was also calculated for spawning stock biomass across peels for each model.

Results

Model fits

Many models listed in Table 1 had poor performance (discussed more below) or do not have substantial flexibility to address the initial problem (Table 2). Additionally, model 9: 3D-AR1 with marginal variance did not converge. These models are ignored for clarity, and we focus on what we consider the most promising two new models: 2D-AR1 and 3D-AR1cond, and include ParDev (which is similar to accepted model 19.1a),

Table 2: Comparison of selectivity models for the 2022 assessment model. Models selected for comparison are highlighted in grey. NLL=negative log likelihood, Fsh = fishery age composition; K=number of fixed effects; dAIC=delta AIC.

Model	Total NLL	Fsh NLL	K	dAIC	2023 SSB	B0	B40	2023 OFL	2023 ABC
19.1 ADMB	NA	NA	NA	NA	204,554	469,000	188,000	173,470	148,937
0: Constant	573.3	228.6	182	112.3	219,996	468,000	187,000	196,809	168,216
1: ParDevs	514.5	125.5	185	0.8	226,254	487,000	195,000	193,353	166,533
2: Log-AR1-Age	561.1	211.8	188	100.0	220,416	473,000	189,000	205,025	175,152
3: Log-AR1-Yr	564.0	221.5	188	105.8	222,619	477,000	191,000	197,323	168,703
4: Log-2D-AR1	552.7	148.3	189	85.1	222,904	473,000	189,000	198,753	170,541
5: Age-specific	530.8	209.9	192	47.4	218,010	470,000	188,000	208,421	177,853
6: AR1-Yr	534.5	160.5	194	58.7	212,670	464,000	186,000	206,054	175,905
7: 2D-AR1	509.4	113.6	195	10.6	226,073	480,000	192,000	194,805	167,410
8: 3D-AR1 cond	503.1	115.7	196	0.0	225,539	473,000	189,000	194,824	167,577

and the Constant model as a baseline. Model 8: 3D-AR1 with conditional variance resulted in the lowest AIC followed by model 1: ParDevs (Table 2).

The estimated AR(1) parameters for the 2D-AR1 model are 0.869 (95% CI of 0.738-0.937) for the correlation by age and 0.628 (0.339-0.809) for the correlation by year, both positive and strongly statistically significant. The estimated process error was 0.259 (0.175-0.384). For the 3D-AR1 model the estimated **partial** correlations were 0.71 (0.566-0.868) for age, -0.076 (-0.597-0.455) for year, and 0.400 (-0.254-1.053) for cohort. Thus, the year correlation is not significant, the cohort one positive but not significant, and the age correlation highly significant. Finally, the estimated process error for the 3D-AR1 model was 0.277 (0.197-0.389) which was similar in magnitude and uncertainty as in the 2D model.

Spawning stock biomass (SSB) was relatively similar among the new TMB models, particularly in later years (Fig. 3) with a projected SSB of between 212 and 226 kt in 2023 (Table 2). However, the TMB models all had a higher 2023 SSB than 19.1a (Table 2) and lower uncertainty (Fig. 3). It is unclear why this is but is likely a configuration issue that can be resolved with more time. The TMB models differ in their calculation of ABC because rather than use the average fishery selectivity from the last five years of the assessment, they use predicted selectivity in 2023.

The estimated annual selectivity at age also had the same general patterns, but with some important differences. All models estimated selectivity at ages 6-8 near 1 (Fig. 4 & Fig. 5). All models also estimated selectivity at age 2 to be near zero except for a period of about 2000-2010. For age 3, all models generally agreed and there appear to be meaningful annual changes, for example in 2008 selectivity was nearly 0.5, but dropped to around 0.2 by 2015.

Key differences among models are concentrated in ages 4 and 5. As noted previously, these are the two ages with poor residuals for the ParDev approach. The largest differences were starting in 2000, with the two nonparametric models estimated lower age-4 selectivity (Fig. 5). Age 5 selectivity was always estimated over 0.75 but again there are some differences annually. Overall, all three models estimated distinct patterns of age 4 and 5 selectivity. This is somewhat surprising given the similarity of the 2D and 3D AR(1) approaches. Differences in estimates in projected years are also meaningful, but described separately below.

Model selection and validation

OSA residuals for the Constant model show clear patterns and unexpectedly large OSA residuals (Fig. 6). This justifies more flexible selectivity forms. The ParDevs model shows much improvement, but still has lingering patterns in ages 4, 5, and 9, despite having a similar AIC value. The two non-parametric models eliminated the previous issues, and have no lingering age or year patterns. There does appear to be a lingering cohort pattern for the 2012 year class (diagonal positive residuals).

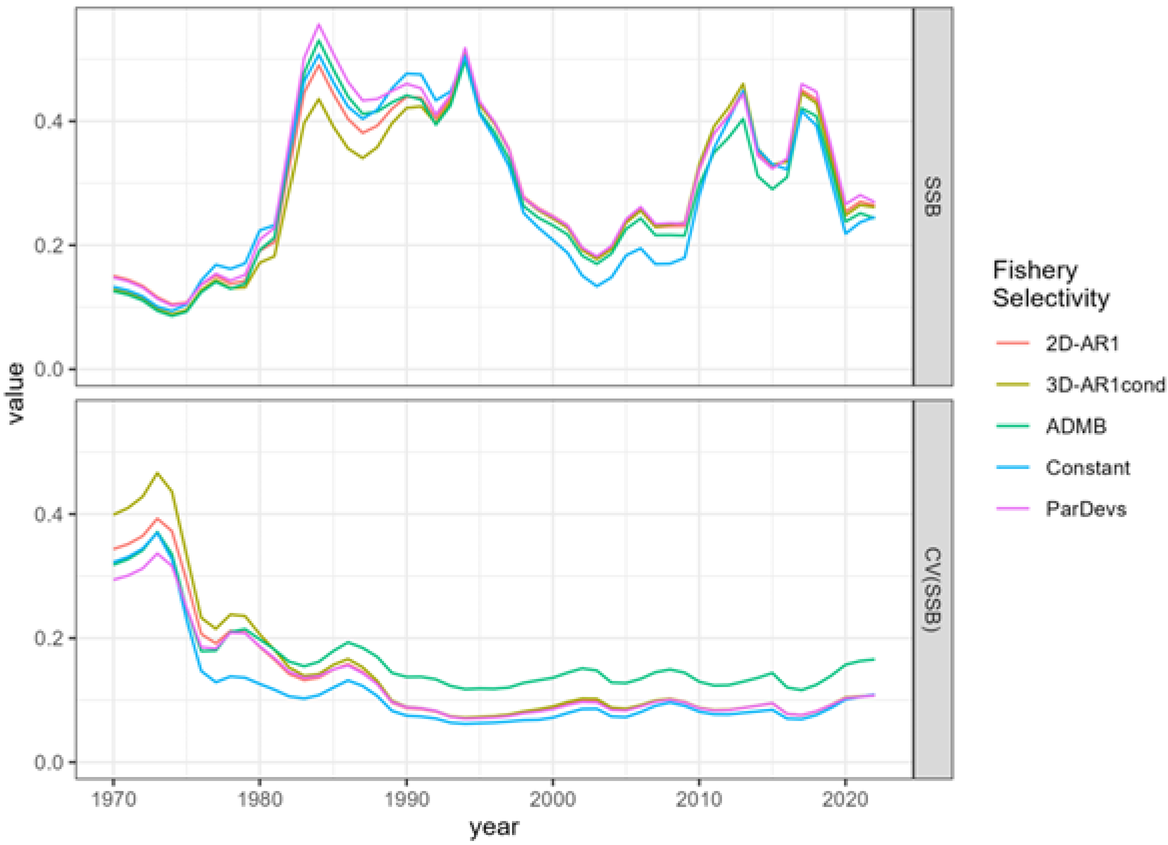

Figure 3: Resulting spawning stock biomass (SSB, M t) estimates and CV (panels) among the candidate models and the 2022 accepted model 19.1a ("ADMB"). It is currently unclear why the CV is so much lower for the TMB models.

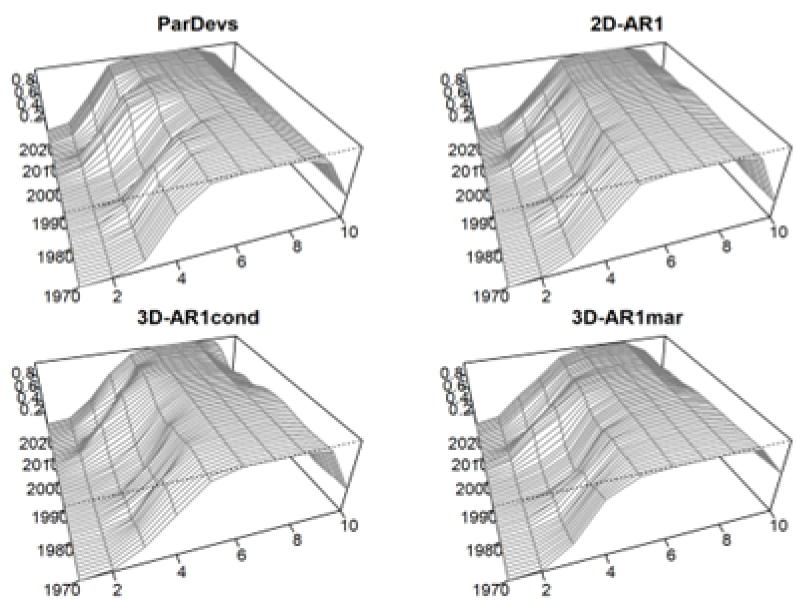

Figure 4: Perspective plots of estimated fisheries selectivity for candidate models.

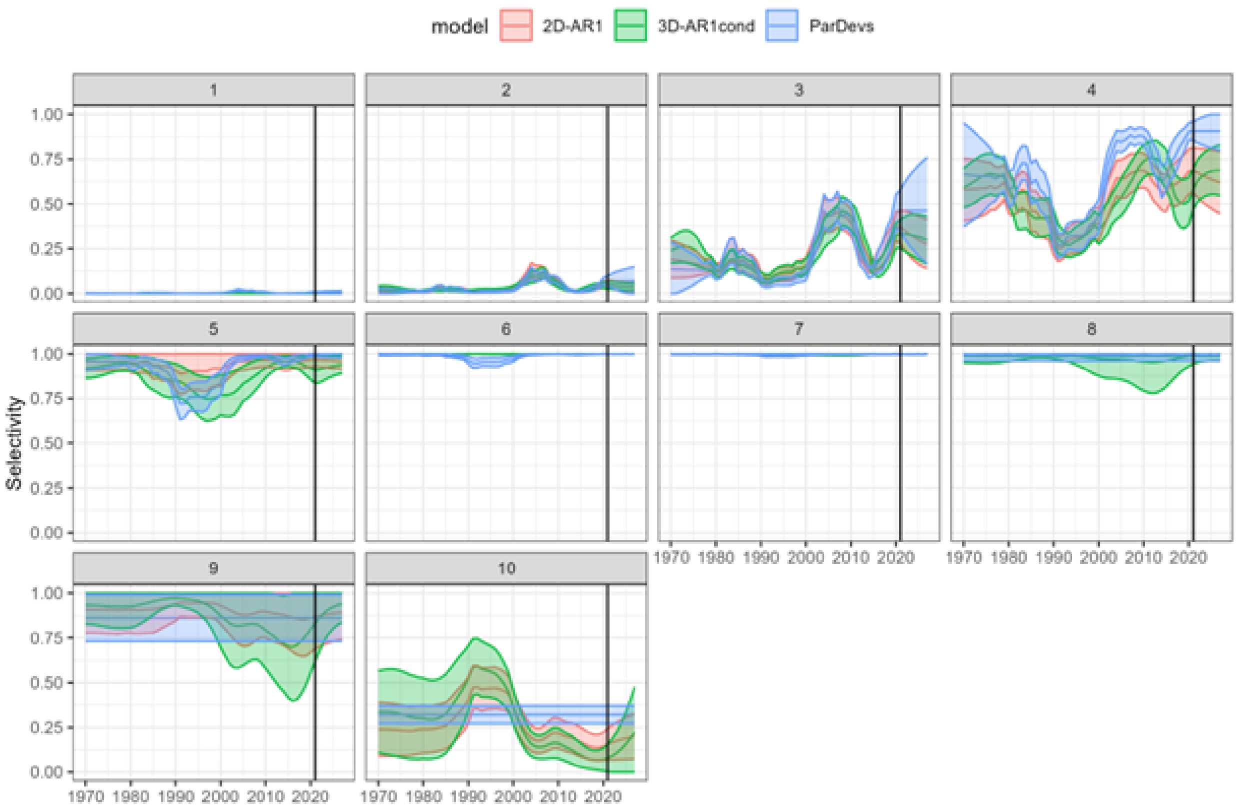

Figure 5: Annual estimates of selectivity at age (panels) with uncertainty (ribbons, +/- 1 SE) for candidate models. The last year with fishery age composition is 2021 and denoted with a vertical line.

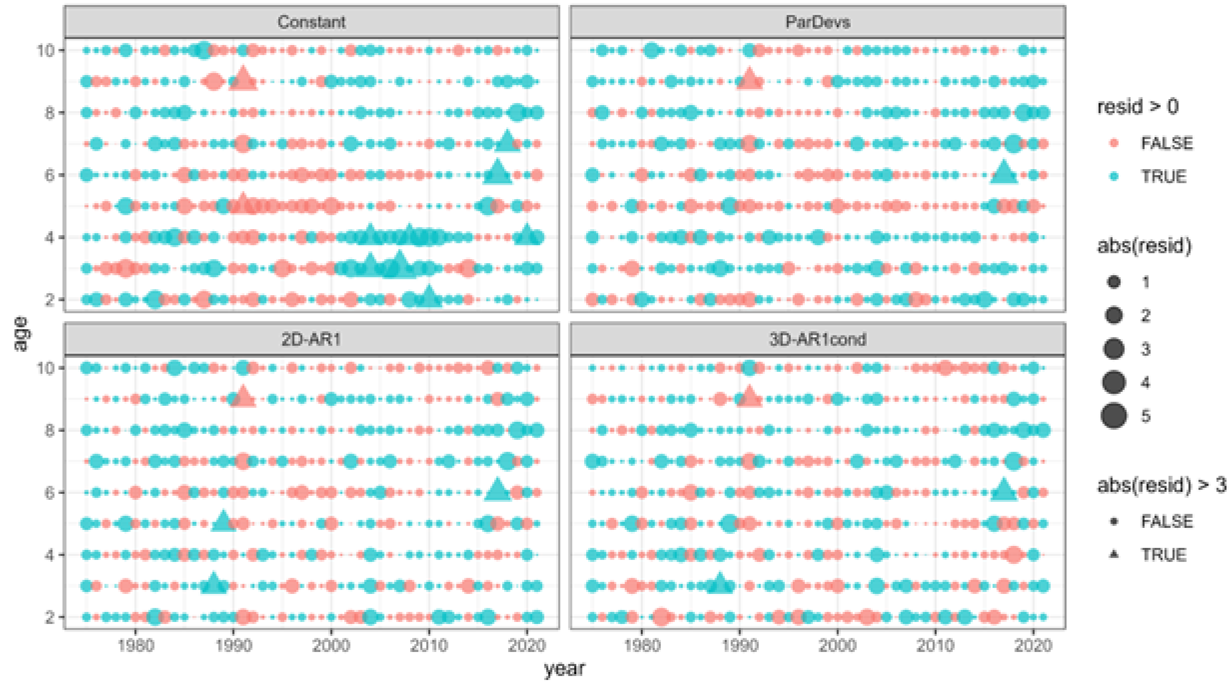

Figure 6: OSA residuals for the three candidate models compared to a model with time-invariant selectivity (Constant). Residuals are expected to have a standard normal distribution, so residuals larger than 3 are highlighted as a different shape.

One important property of OSA residuals is that they are expected to have a standard normal distribution. Standard QQ plots (Fig. 7) show that the unexpectedly large residuals using the Constant model are eliminated by the three time-varying selectivity models. However, there still seem to be some distributional issues remaining, although we judge this to be of minor concern. We do note that the QQ plots for the two non-parametric models appear slightly better than the ParDevs approach currently used in 19.1a.

Projection performance

Fisheries selectivity for the current assessment year has no fisheries age composition data and so needs to be extrapolated by the assessment model. Further, reference point and ABC calculations rely on estimates of selectivity in the following year. These projected selectivities are expected to vary among models. The ParDevs model which has a random walk on parameters will have the same prediction as the last year with data, but increasing uncertainty with further extrapolation into the future (Fig. 8). The two AR(1) models will converge toward their stationary means, but the addition of the cohort effect for the 3D method will affect the estimates and transitory behavior toward the mean. For many ages there is little meaningful difference. The age with the most divergence among models is age 4, where selectivity is 0.91 for the ParDevs, 0.68 for the 2D-AR1 model, and 0.63 for the 3D-AR1 model. Interestingly the selectivity is increasing for the 2D model and decreasing for the 3D model for this age. We hypothesize this is caused by a cohort effect, although it is not strictly statistically significant.

There are thus important differences, especially in younger ages, for the predicted selectivity at the two important extrapolated years (Fig. 9).

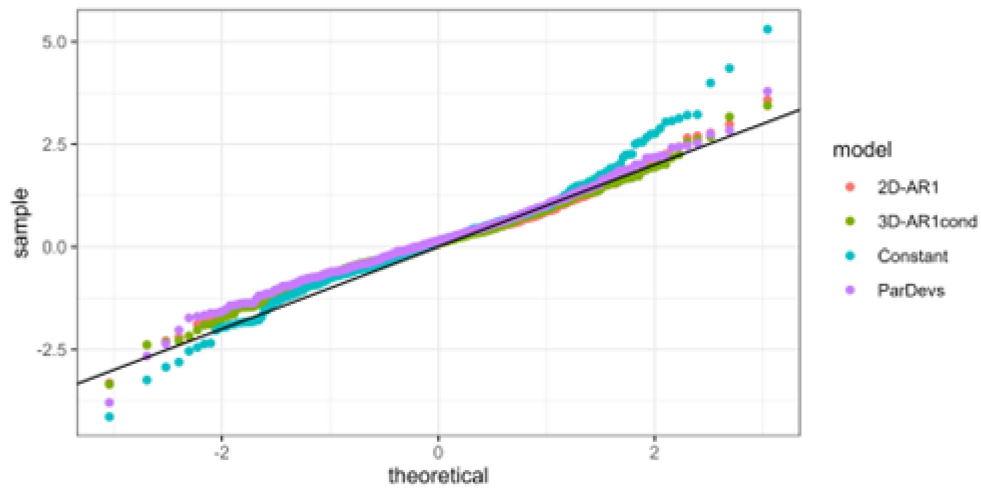

Figure 7: Quantile-quantile plots of candidate models OSA residuals, which are expected to be standard normal and thus fall on the black line. Deviation from that implies model misfit.

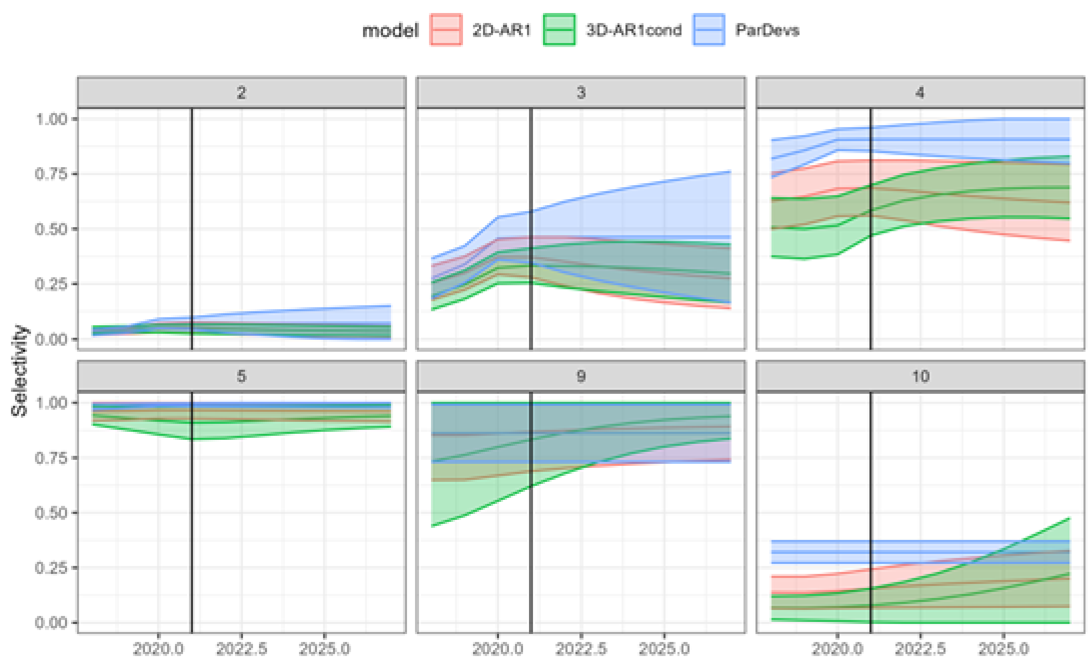

Figure 8: Behavior of the selectivity modules when projecting past the last year with fishery age comp data (2021; vertical line). Annual estimates of selectivity at age (panels) with uncertainty (ribbons, +/- 1 SE) for candidate models. Ages 1, 6,7 and 8 are left off for visual clarity as they are nearly constant at 0 or 1 (see Fig. 5). The ParDev model is a random walk so its projections are constant with increasing uncertainty. The 2D-AR1 model reverts back to its stationary mean. The 3D-AR1 model accounts for cohort effects and thus behaves slightly differently from the 2D version.

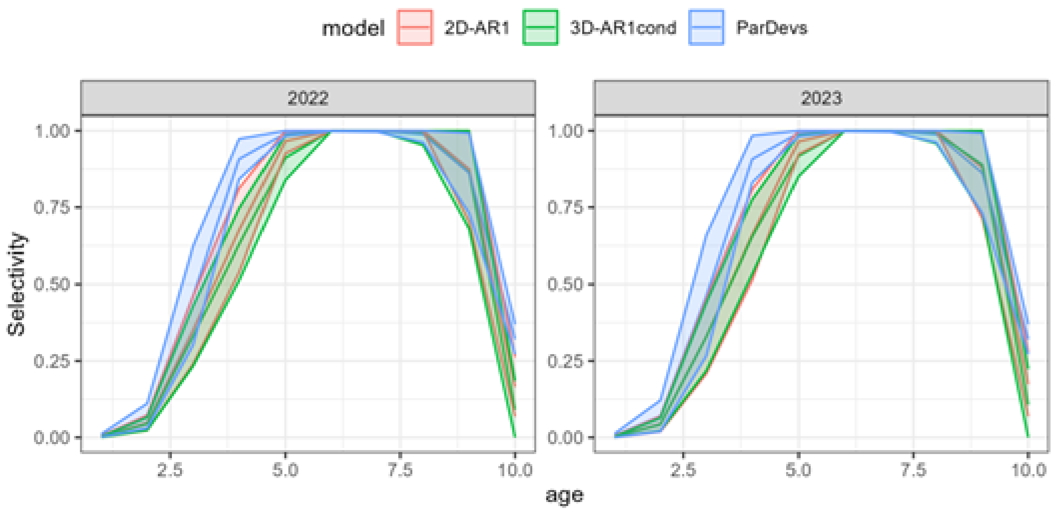

Figure 9: Estimated selectivity with uncertainty (+/- 1 SE) for the three models in the two important projection years.

Table 3: Retrospective metrics for age-specific selectivity

Model	Metric	Selectivity	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Combined
mod1	MSE	Average	0.0005	0.0175	0.0132	0.0002	0.0000	0e+00	0.000	0.0015	0.0009	0.0022
mod1	MSE	Projected	0.0005	0.0174	0.0105	0.0002	0.0000	0e+00	0.000	0.0015	0.0009	0.0021
mod1	RE	Average	-0.2145	-0.2321	-0.0980	-0.0123	-0.0012	-4e-04	-0.003	-0.0223	-0.0678	-0.0415
mod1	RE	Projected	-0.0425	-0.1115	-0.0601	-0.0079	-0.0008	-4e-04	-0.003	-0.0223	-0.0678	-0.0165
mod7	MSE	Average	0.0002	0.0130	0.0048	0.0002	0.0000	0e+00	0.000	0.0033	0.0201	0.0033
mod7	MSE	Projected	0.0001	0.0114	0.0056	0.0002	0.0000	0e+00	0.000	0.0026	0.0165	0.0028
mod7	RE	Average	-0.1707	-0.2464	-0.0816	-0.0083	0.0000	0e+00	0.000	-0.0257	-0.2567	-0.0617
mod7	RE	Projected	-0.1112	-0.2287	-0.0863	-0.0085	0.0000	0e+00	0.000	-0.0182	-0.2042	-0.0513
mod8	MSE	Average	0.0003	0.0151	0.0242	0.0015	0.0000	0e+00	0.000	0.0157	0.0733	0.0108
mod8	MSE	Projected	0.0002	0.0119	0.0104	0.0004	0.0000	0e+00	0.000	0.0039	0.0603	0.0073
mod8	RE	Average	-0.2107	-0.3241	0.0393	0.0374	0.0000	0e+00	0.000	-0.1142	-0.4495	-0.0792
mod8	RE	Projected	-0.1525	-0.2893	-0.0369	0.0132	0.0000	0e+00	0.000	-0.0474	-0.2882	-0.0608

Retrospective performance

Overall, the 3D-AR1 model had the lowest retrospective bias in spawning stock biomass (Fig. 10 & Fig. 11 & Fig. 12). When evaluating retrospective bias of age-specific selectivity, using the projected selectivity generally outperforms using the average selectivity from the 4 years prior to the terminal year of the assessment for models 1, 7, and 8 (Table 3). However, age-specific retrospective bias varied across selectivity functions. For example, projected selectivity from Model 8 had lower mean squared error for ages 2-4 than projected selectivity from Model 1, but much higher mean squared error for 6+.

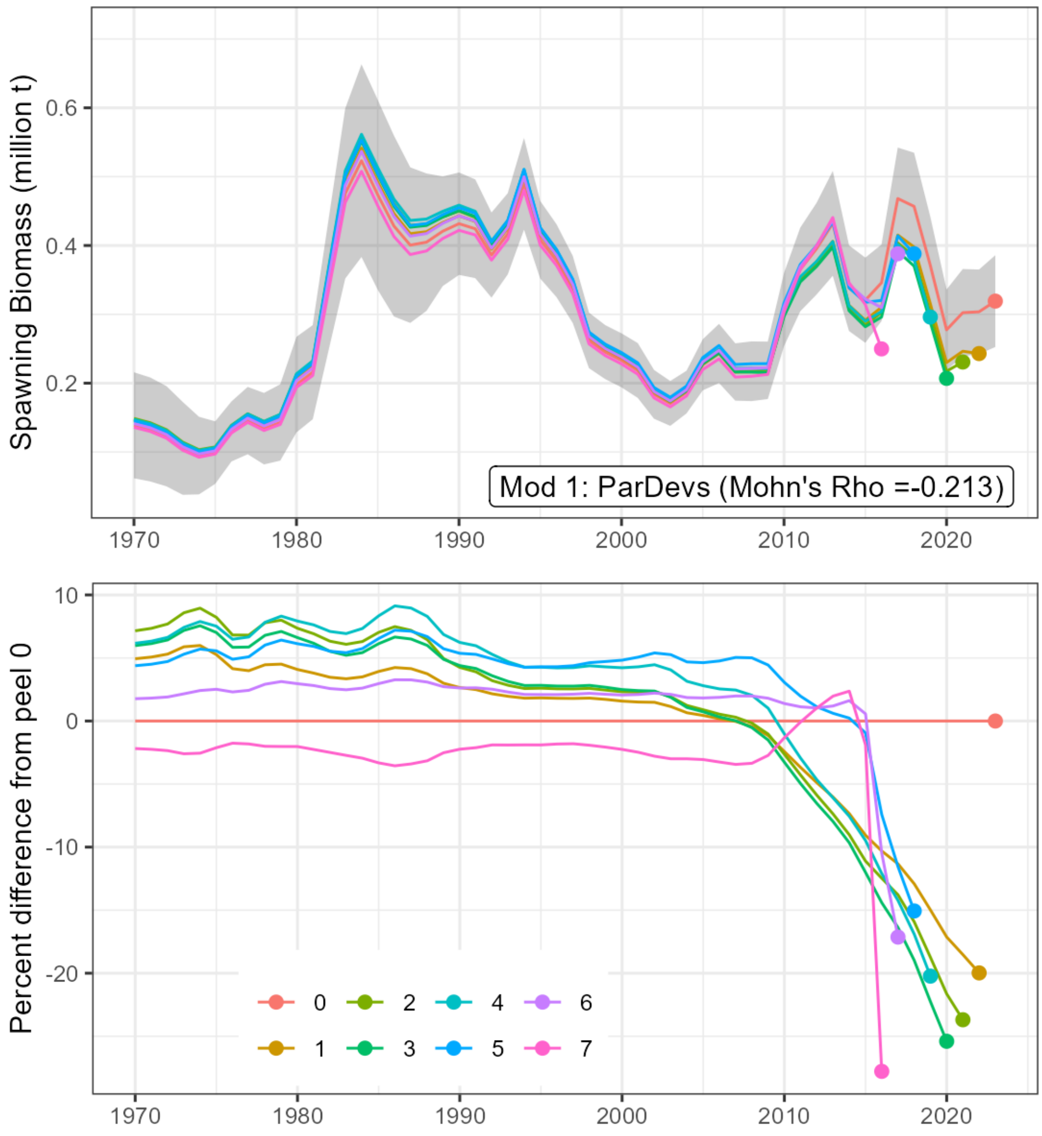

Figure 10: Retrospective spawning stock biomass for model 1 (parDevs) with n = 7 peels

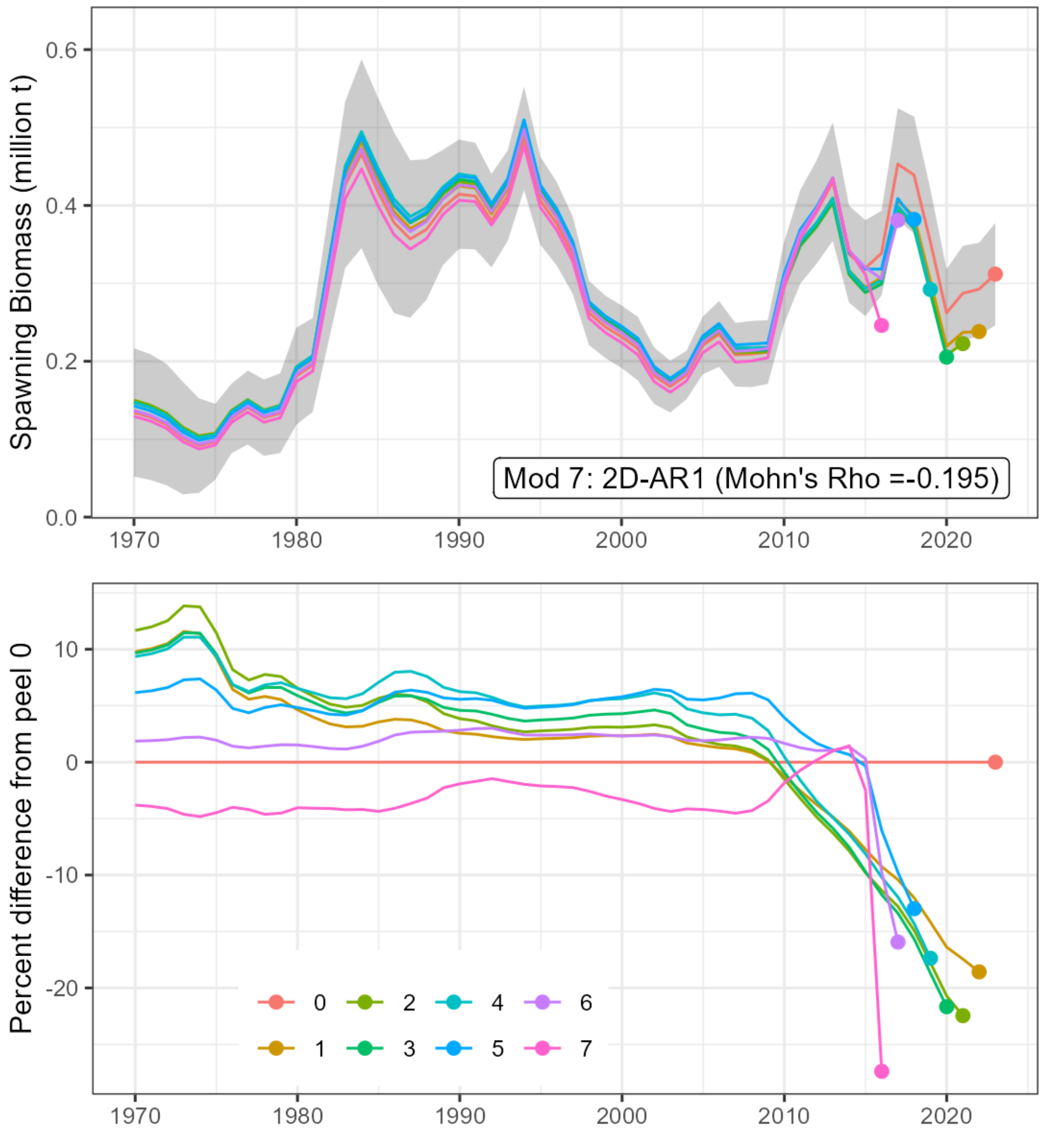

Figure 11: Retrospective spawning stock biomass for model 7 (2D AR1) with n = 7 peels

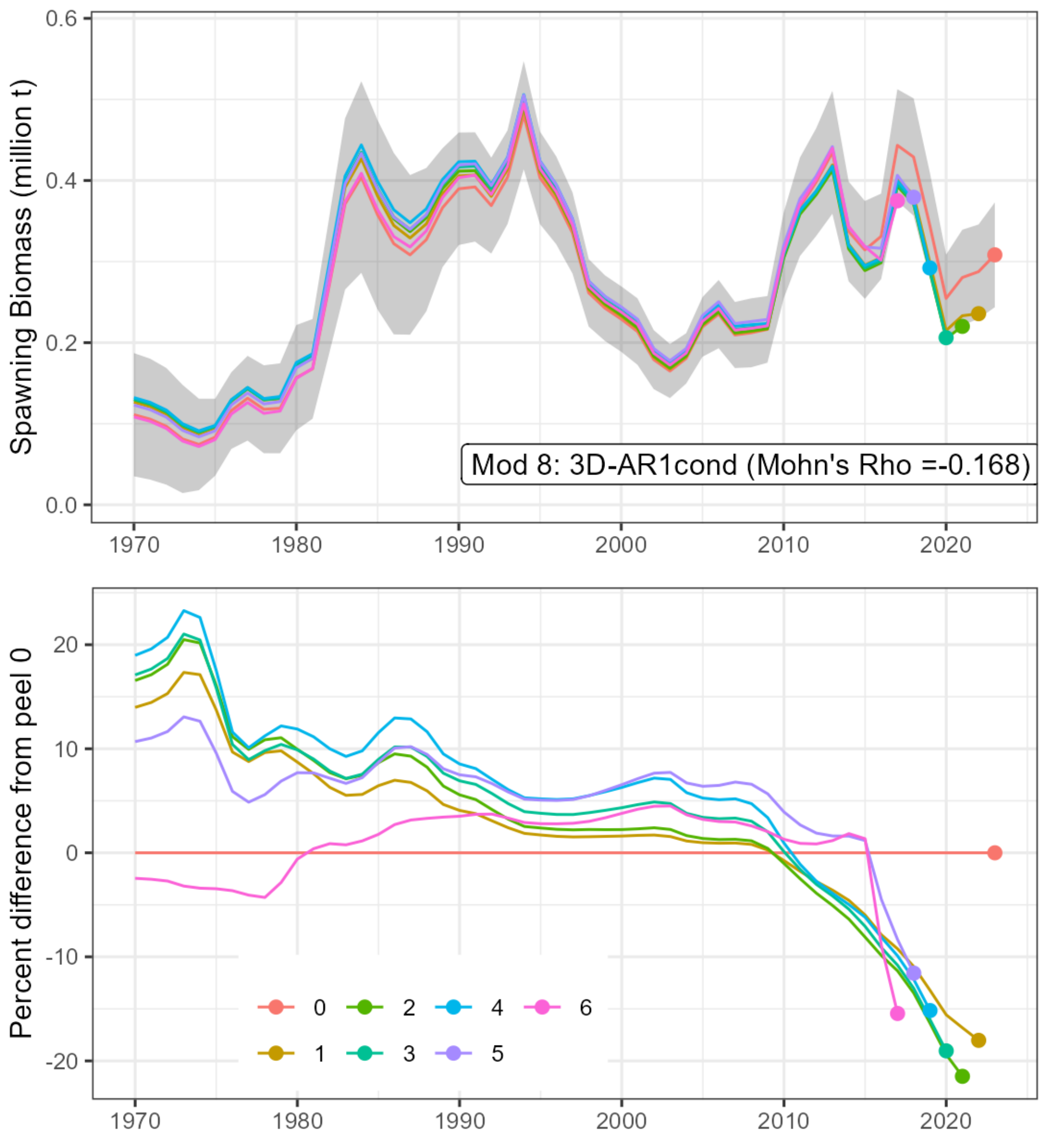

Figure 12: Retrospective spawning stock biomass for model 8 (3D AR1) with n = 7 peels

Conclusions

Moving from ADMB to TMB has a few minor disadvantages which are clearly outweighed by the advantage of being able to estimate hierarchical models in a statistically defensible way. Hierarchical or "state space" models are now considered "best practices" for stock assessment (Punt 2023) and TMB is the best available tool to accommodate that framework. We were able to bridge from the ADMB model 19.1a to within a very small degree of error. **As such we recommend retiring the ADMB model and proceeding with model 23 in TMB for use moving forward.** This modeling framework will allow for important future extensions beyond fisheries selectivity as well (e.g., maturity and weight at age smoothing internally).

It is also clear that fisheries selectivity varies over time and that the current approach of random walk parameter deviations (ParDev model) is insufficiently flexible for some ages, as determined by residual patterns. The semi-parametric models explored here did not perform well, for reasons that are not completely clear at the moment. But two of the non-parametric models were very promising and had improved residual patterns and retrospective performance. The 3D model had the lowest AIC and Mohn's Rho, with the 2D model about 10 units worse. We believe both non-parametric models would make for improved fits and projected selectivities for use in calculating management quantities. The major disadvantage of the non-parametric models is that they are about 10 times slower to fit than the parametric version with annual deviates (ParDevs), going from 4 to 40 minutes to optimize and do the delta method calculations.

Estimating non-parametric components within an assessment takes care, as putting flexibility in the wrong component can lead to poor management advice (Szuwalski, Ianelli, and Punt 2018; Fisch et al. 2023). We feel confident that selectivity does vary through time, and that the forms examined here do a good job at capturing this change. The new forms also did not lead to major changes in status, trend, or reference points among different selectivity options, but there is a remaining discrepancy when compared to 19.1a that we need to investigate and resolve. Overall, we conclude that either non-parametric option would make for an improved model, with the 3D version fitting slightly better and having a cohort effect, but being more difficult to estimate.

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