2. Assessment of the Pacific Cod Stock in the Eastern Bering Sea

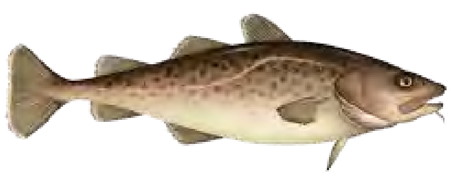
Steven J. Barbeaux, Lewis Barnett, Pete Hulson, Julie Nielsen, S. Kalei Shotwell, Elizabeth Siddon, and Ingrid Spies

Alaska Fisheries Science Center, National Marine Fisheries Service

National Oceanic and Atmospheric Administration

7600 Sand Point Way NE., Seattle, WA 98115-6349

November 16, 2024



With contributions from:

Kerim Aydin, Asia Beder, Mathew Callahan, Bridget Ferriss, Kirstin Holsman, Beth Matta, Susanne McDermott, Jens Nielsen, Jordan Watson, and Stephani Zador

This report may be cited as:

Barbeaux, S. J., Barnett, L., Hulson, P., Nielsen, J., Shotwell, S. K., Siddon, E., and Spies, I. 2024. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1-150. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501

Additional content links:

- 2024 EBS Pacific Cod Page (.html)
- Appendix 2.1: September Documentation (.pdf)
- Appendix 2.2: Eastern Bering Sea Report Card (.pdf) - Attached
- Appendix 2.3: 2024 Models Stock Synthesis Files (.zip)
- Appendix 2.4: All Models Data and Results (.xlsx)

EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the eastern Bering Sea (EBS) Pacific cod stock assessment.

Changes in the Input Data

- Catches for 1991-2024 were updated, and a preliminary total catch estimate for 2024 was incorporated. All fishery data used in the models were retrieved on October 3, 2024.
- Commercial fishery size compositions for 1991-2024 were updated, and a preliminary size composition from the 2024 commercial fishery was incorporated.
- The VAST approach for the AFSC Bering Sea (EBS+NBS) bottom trawl index was updated for 2024.
- The size composition from the 2024 EBS+NBS survey was incorporated
- The VAST approach was used to estimate the age compositions from the combined EBS+NBS survey time series through 2023.
- Aging error matrix was updated using the AgingError R library and 2000-2023 age data
- Aging bias was updated for 2000-2007 using data from otoliths read first in 2004 and then again in 2018 using the new methodology.
- Ages from otoliths read prior to 2000 were excluded from the model based on recommendations from the Age and Growth laboratory.

Changes in the Assessment Methodology

The model presented and accepted for use in 2023 (Model 23.1.0.d) was re-run with the updated data as parameterized in last year's assessment, removal of ages from otoliths read from 1994-1999, inclusion of length composition data from 1994-1999, annually varying growth limited to 2000 through 2024, updated aging error and aging bias matrix, and retuned for sigmas and variance adjustment factors. In addition, four alternative models were developed from those described in the September update (Appendix 2.1). The following additional model configurations are considered in this document:

- Model 24.0
    - Model 23.1.0.d with 5 cm length bins
- Model 24.1
    - Model 24.0 with splined aging error, and growth with a random walk on K, instead of the Richard's ρ parameter
- Model 24.2
    - Model 24.1 with non-time varying survey selectivity
- Model 24.3
    - Model 24.2 with all annually varying sigma values and variance adjustment factors retuned.

Summary of Results

Model 24.1 and Model 24.3 have very similar diagnostics, with little discernable differences in overall fits. There are tradeoffs between Model 24.1 and 24.3 in model performance that makes it difficult to choose one over the other. Both models fit the survey index well, Model 24.3 has a marginally better fit to that data component when considering likelihood, and both models fit the age and length composition data well, however Model 24.1 fits the survey length composition data better. Both models performed equally well with the fishery lengths and survey age composition data. Although the point estimate management advice (i.e. ABCs and OFLs) for the two models differ, the uncertainty around these estimates in both models show the confidence bounds overlapping making them statistically indistinguishable.

In consideration of overall model performance and consistency in management advice with last year's, the authors recommend using Model 24.1 for setting management advice for 2025. However, the authors will include results from Model 24.3 in the following discussion to allow the Plan Team and SSC ample opportunity to consider the advice from the alternate model.

The principal results from alternative **Model 24.1** are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities as specified last year by the SSC:

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2024	2025	2025*	2026*
M (natural mortality rate)	0.386	0.386	0.386	0.386
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	808,203	787,837	769,813	762,206
Projected female spawning biomass	223,107	211,131	215,747	206,498
$B_{100\%}$	567,465		561,915	
$B_{40\%}$	226,986		224,767	
$B_{35\%}$	198,612		196,671	
F_{OFL}	0.46	0.43	0.43	0.41
$maxF_{ABC}$	0.37	0.35	0.35	0.33
F_{ABC}	0.37	0.35	0.35	0.33
OFL (t)	200,995	180,798	183,509	169,243
maxABC (t)	167,952	150,876	153,617	141,520
ABC (t)	167,952	150,876	153,617	141,520
	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 assumed catches of 165,659 t, and 153,617 t in 2024 and 2025, respectively.

The principal results from alternative **Model 24.3** are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities as specified last year by the SSC:

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2024	2025	2025*	2026*
M (natural mortality rate)	0.386	0.386	0.386	0.386
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	808,203	787,837	680,076	710,201
Projected female spawning biomass	223,107	211,131	186,337	187,854
$B_{100\%}$	567,465		552,100	
$B_{40\%}$	226,986		220,840	
$B_{35\%}$	198,612		193,235	
F_{OFL}	0.46	0.43	0.37	0.37
$maxF_{ABC}$	0.37	0.35	0.30	0.30
F_{ABC}	0.37	0.35	0.30	0.30
OFL (t)	200,995	180,798	139,917	143,191
maxABC (t)	167,952	150,876	116,770	119,491
ABC (t)	167,952	150,876	116,770	119,491
Status	As determined *last* year for:		As determined *this* year for:	
	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 assumed catches of 165,659 t, and 116,770 t in 2024 and 2025, respectively.

Note that the recommended 2025 and 2026 F_{ABC} and ABC values listed above may be subject to modification following consideration by the Plan Team and SSC. The summarized results of the risk analysis (see subsection in the "Harvest Recommendations" section) are shown below:

Assessment-related considerations	*Population dynamics considerations*	*Ecosystem considerations*	*Fishery-informed stock considerations*
Level 1: No Concern	Level 1: No Concern	**Level 2: Increased Concern**	Level 1: No Concern

Under the author's recommended model, a specific reduction from maximum ABC was not considered. In the event that the 2025 F_{ABC} or ABC values are changed from those shown above, projected 2026 values of other non-constant quantities would need to change in response and would be reflected in the harvest specification tables.

Responses to SSC and Plan Team Comments

December 2023 SSC

Continued consideration of the need for incorporating time-varying survey selectivity, relative to a static selectivity function, given what appear to be relatively small changes across the timeseries.

Model 24.3 includes fixed survey selectivity as per the SSC recommendation.

The SSC reiterates its recommendation for this assessment to incorporate marginal fishery age composition data and fixing the pre-2007 aging bias to Model 22.2 values, which should help estimate fishery selectivity

The authors considered using marginal fishery ages in the model, but determined that it would be somewhat premature to move in this direction at this time considering that how to properly construct and weight this type of data is currently an active area of research. Brett Stacy, a post-doc with Andre Punt at UW, is expected to produce an R library to construct fishery marginal length and age compositions with bootstrapped input sample size. This work should conclude next year. The new aging bias is based on a re-aging experiment where otoliths initially read in 2004 were read again in 2018 and bias estimates between the two time periods calculated external to the model. This has been incorporated in all models presented this year.

Continued exploration of directly fitting conditional age-at-length data within the assessment to inform age structure alongside temporal variation in growth, as opposed to marginal age compositions.

We presented several models in September that had fishery and survey conditional age-at-length data included. There were some data conflict issues that remained unresolved and it was the opinion of the authors and the Plan Team that these models were not ready for management at this time.

Given the clear demonstration following 2019 that the spatial distribution of the EBS Pacific cod stock is related to temperature, the SSC recommends exploration of whether the relationship between prevailing temperature conditions and survey catchability may be informative for this assessment.

This is an active area of research with a post-doc, Krista Oke with Brand Harris at APU, evaluating connections among environmental conditions and catchability, selectivity, growth, natural mortality, and recruitment.

The SSC highlights the potential value in updating maturity estimates at age, given the last estimates appear to be from 2007 and that changes in maturity schedule may have occurred coinciding with the observation of increasing growth since the mid-2000s.

The authors agree that an update for maturity is long overdue, some preliminary evaluations of the maturity scan data provided by at-sea observers show the potential for substantial annual variability in maturity. Validating these data should be a priority and is an ongoing area of research.

The SSC noted that the prior on natural mortality is based on a maximum age of 14 derived from data collected since 2008 and looks forward to additional biological and/or historical information supporting this maximum age.

The age and growth lab is currently understaffed and are only able to keep up with their current workload. Having older collections aged is still a priority for the authors and they hope that the new Fourier transform near-infrared spectroscopy (FT-NIRS) will help lighten the work load and make time for these older otoliths to be aged.

Related to this, the SSC recommends including in the next assessment a likelihood profile on M that covers an extended range of values, at least encompassing values used in recent assessments.

See below, a likelihood profile on M is provided for all models considered.

The SSC supports the efforts to collect and integrate data from the state waters fishery as they represent an appreciable fraction of the catch and are therefore important to inform the size structure of the fishery mortality in the stock assessment.

This year will be the second year that length and weight data were collected from the Area O state fishery by ADF&G and provided to the authors to include in the assessment. An analysis of these data are provided in the document.

Given continued interest in connectivity among the three Alaska FMP cod stocks, the SSC requests a conceptual discussion of how the three cod stock assessments might be restructured in light of recent genetic and tagging information, including considerations of distinct genetic types in the Northern Bering Sea and in Southeast Alaska.

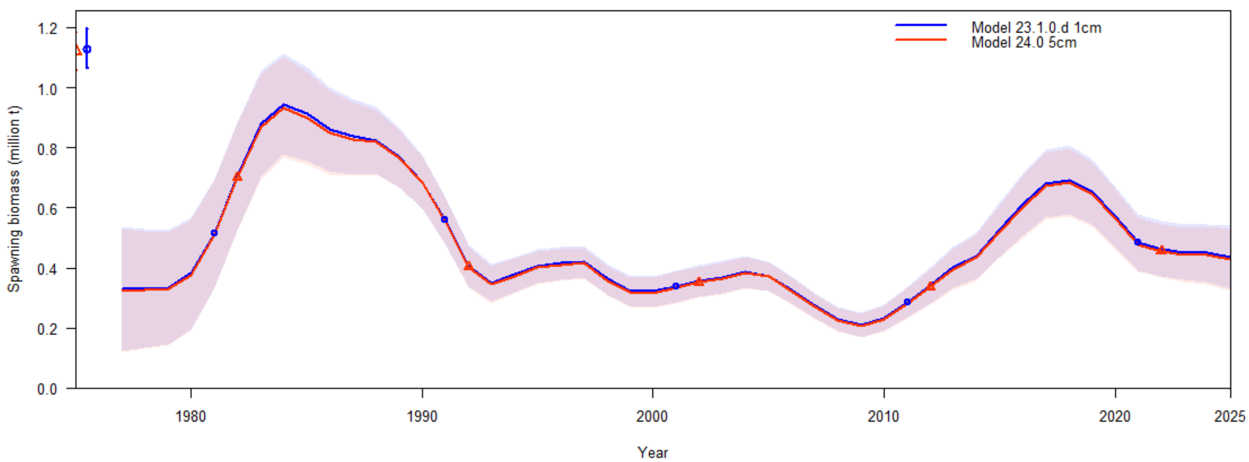
The Pacific cod team continues to work together on the individual stock assessments. In addition, tagging and genetic studies are ongoing. A brief discussion of their results are provided in the introduction of this document.

All three of the Pacific cod stock assessment authors have been working together closely this year and although a more spatially comprehensive assessment model is being considered it is not yet in production. Analysis of the PSAT and genetics data collected over the last few years will better inform our choices on model development and we await the results of that research.

<u>September 2024 Plan Team</u>

The Team recommended the author consider the effect of the increase in length bins on spawning biomass and derived management quantities and pointed to Monnahan et al. (2016) as a helpful reference on the topic.

There is little impact on estimated spawning biomass when changing bin sizes from 1 cm to 5 cm. Model 23.1.0.d is the tuned version of last year’s model with this year’s data, Model 24.0 is Model 23.1.0.d with 5cm size bins and retuned due to the changes in bin sizes and therefore input sample sizes. The figure below shows difference in spawning biomass from Model 23.1.0.d with 1cm bins and Model 24.0, the same model retuned with 5 cm bins. Table 2.16 has the results for these two models. The differences are minimal and explainable due to differences in model tuning and input sample sizes. These differences will be further explored in the document.



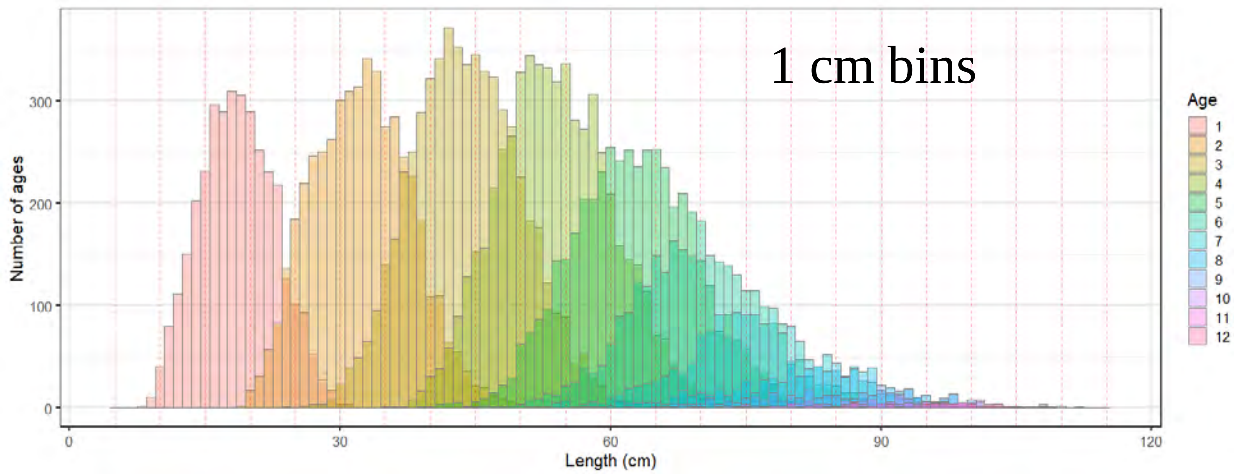
The Team recommended continued development of models using conditional age-at-length and suggested the author consider an empirical weight-at-age approach or a time-varying length-weight relationship in future years.

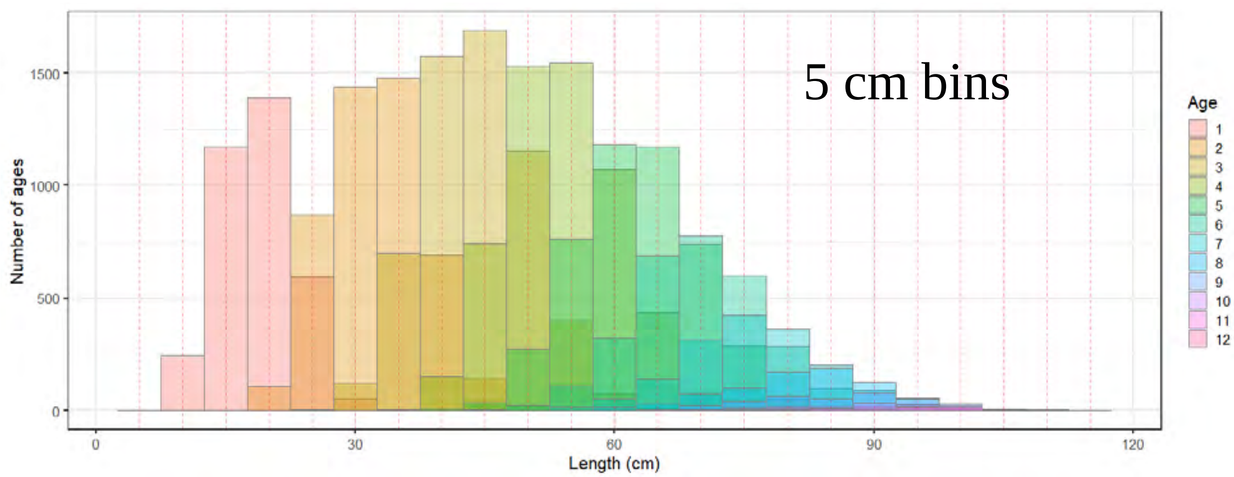
Empirical weight-at-age models will be explored next year. The biggest hurdle with EWAA approach is dealing with aging bias in constructing the EWAA matrix.

October 2024 SSC

The SSC concurs with this and recommends that the authors explore finer bin structure closer to inflection points of key processes such as selectivity and maturity, and areas of the growth curve where cod are growing quickly, rather than using 5 cm uniformly across the length range.

Given the short time period between the October meeting and when the final assessment is due at the end of October, there is not enough time to create and evaluate multiple models with differing size bins. Cod growth is very quick for the majority of their lives, growing more than 20 cm in the first year, then ~10 cm per year afterwards up to age 6. The histograms below show all length-at-age date for 2000-2023. For age 1 fish the 5 cm bins allow for at least 4 length bins with increasing number of bins at older ages. The authors demonstrated in September the lack of impact for 1 cm, 3 cm and 5 cm bins on model results. In this document Model 23.1.0.d and Model 24.0 only differ by bin size and retuning, differences in results are evaluated in the document.





At the authors' discretion, the SSC recommends a model similar to 23.1.0.d with static survey selectivity, linear aging error and an attempt to fit marginal fishery ages rather than conditional length-at-age.

The authors considered using marginal fishery ages in the model, but determined that it would be somewhat premature to move in this direction at this time considering that how to properly construct and weight this type of data is currently an active area of research. Brett Stacy, a post-doc with Andre Punt at UW, is expected to produce an R library to construct fishery marginal length and age compositions with bootstrapped input sample sizes. This work should conclude next year.

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, ranging from Santa Monica Bay, California, northward along the North American coast; across the Gulf of Alaska and Bering Sea north to Norton Sound; and southward along the Asian coast from the Gulf of Anadyr to the northern Yellow Sea; and occurring at depths from shoreline to 500 m (Ketchen 1961, Bakkala et al. 1984). The southern limit of the species distribution is about 34° N latitude, with a northern limit of about 65° N latitude (Lauth 2011). Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area.

Low-coverage whole-genome sequencing analysis (lcWGS) of 429 samples of Pacific cod from known spawning regions during spawning season indicates population structure similar to what was previously known, but with finer resolution and greater power owing to the larger number of markers. Using 1,922,927 polymorphic SNPs (Figure 2.1), the pattern of population structure mostly resembles isolation-by-distance (IBD), in which samples from proximate spawning areas are more genetically similar than samples from more distant areas. Isolation-by-distance was observed from western Gulf of Alaska (Kodiak and the Shumagin Islands) through Unimak Pass and the eastern Aleutian Islands. Previous studies have reported an isolation-by-distance pattern in Pacific cod using microsatellite markers (Cunningham et al. 2009 and Spies 2012) and reduced-representation sequencing (Drinan et al. 2018). Within the isolation-by-distance pattern, there were some distinct breaks in the population structure. The most significant genetic break occurs between western and eastern Gulf of Alaska (GOA) spawning samples (Figure 2.1), and was supported by previous research that highlighted the zona pellucida gene region (Spies et al. 2019). Notably, there was not a significant break in genetic structure between the eastern Bering Sea (Unimak) and the western Gulf of Alaska (Shumagins and Kodiak).

A new finding from the lcWGS data was the identification of a new genetic group in the Bering Sea represented by samples from Russia along the western Bering Sea shelf. We refer to this as a northern Bering Sea 'type'. In addition, a subset of samples collected from Pervenets Canyon in the eastern Bering Sea appeared genetically similar to the western Bering Sea shelf group (Figure 2.1 bottom right where light blue points, Pervenets Canyon, mix with dark blue points, Russia). The majority of samples from the eastern Bering Sea were genetically more similar to Aleutian Islands and western Gulf of Alaska samples which was a significant deviation from the isolation-by-distance pattern found with the rest of the samples (Figure 2.1 center where light blue points mix with green squares, Aleutian Islands, and pink circles, western Gulf of Alaska). This result suggests an unresolved combination of isolation-by-distance and a strong genetic break with the northern Bering Sea type. More specifically, at neutral markers Aleutian Island populations seem to follow the subtle IBD pattern documented throughout much of the western GOA. However, Aleutian Island populations are highly diverged at a few genomic regions that we believe are adaptively significant (Spies et al. 2022). These adaptive differences provide further support for the Aleutian Island management unit that was established as distinct from the Bering Sea in 2013. Overall, the presence of a distinct northern Bering Sea type, a distinct eastern Gulf of Alaska type, and a mixed eastern Bering Sea/western Gulf of Alaska stock indicate that there may be opportunities to restructure management units for Pacific cod in those regions. More research is needed to fully understand how the types of cod are distributed during non-spawning seasons.

Recent satellite tagging research on Pacific cod (S. McDermott, P.I.) indicates seasonal connectivity between the western GOA, EBS, northern Bering Sea (NBS), Russia (western Bering Sea), and Chukchi Sea (CS) but little movement between the central GOA and western GOA or between the AI and other regions. Pacific cod tagging research was initiated in 2019 and consists of an inter-agency collaboration between NOAA scientists and the Aleutians East Borough, the Freezer Longline Coalition (FLC), the Native Village of Savoonga, Norton Sound Economic Development Corporation (NSEDC), and Pacific Cod Harvesters. Satellite tags record depth, temperature, light intensity, and acceleration while tagged fish are at liberty. The tags are programmed to "pop up" from the fish at a specific time and provide a fishery-independent recovery location when they reach the surface and begin to transmit archived data to the Argos satellite network. Movement paths between the release and recovery locations can be reconstructed based on the archived data using a hidden Markov model for geolocation (Nielsen et al. 2023). To date, 316 archival satellite tags have been deployed on Pacific cod in Alaskan waters (Figure 2.2). Satellite tags were released in the winter (February-April) to characterize movement from winter spawning to summer foraging areas. Tags were also released during the summer (June-August) to characterize movement during summer foraging, migration to winter spawning locations, and annual movement patterns. From 2019 to 2022, tags were released in the AI, NBS, EBS, and western GOA regions. Beginning in 2023, GOA tag releases were expanded into the central GOA to assess seasonal movement within the GOA. In the winter of 2024, 56 satellite tags were released in the western and central GOA during a chartered tagging cruise. In addition, deployment of satellite tags (n=10) in winter was expanded into the EBS for the first time by FLC collaborators aboard a FLC vessel. During the summer of 2024, 20 satellite tags were deployed in the western GOA, 6 tags were deployed in the EBS from the annual AFSC bottom trawl survey, and 4 satellite tags were deployed in the NBS near St. Lawrence Island in a cooperative study with the NSEDC and the native village of Savoonga. As of October 2024, 25 satellite-tagged fish are still at liberty with pop-up dates programmed for the summer of 2025.

Results from tag pop-up locations and reconstructed movement paths obtained to date suggest that substantial seasonal connectivity exists between the western GOA and regions in the Bering Sea (EBS, NBS, and Russian waters). Across four years of winter releases in the western GOA (2021 – 2024), approximately 50% of satellite-tagged fish moved to summer foraging locations in the Bering Sea each year. Tagged fish in these regions generally moved northward from winter spawning to summer foraging locations (Figure 2.3 A) and southward from summer foraging to winter spawning locations (Figure 2.3 B). Winter sea ice likely influences the timing and extent of seasonal movements in the NBS, as tagged fish leave the region prior to sea ice coverage. No tagged fish have been observed to remain alive in ice-covered areas of the NBS through the winter. Some reconstructed pathways from summer-release satellite tags deployed for a full year demonstrate seasonal connectivity between the Bering Sea and the western GOA, where fish returned to summer foraging areas in the Bering Sea after moving to western GOA during the spawning period (Figure 2.3 C). No satellite-tagged fish from the central GOA or the AI have moved to the Bering Sea so far (Figure 2.3 A). Partial migration (i.e., only part of the population migrates) is apparent in our data, as some tagged fish in the AI, GOA, and EBS do not undertake large seasonal movements. Research is underway to evaluate whether genetic, physical, or environmental factors are related to migration characteristics and the proportion of fish that undertake migrations each year.

Additional information on the biology of Pacific cod, including early life history, can be found in the Ecosystem and Socioeconomic Profile (Appendix 2.2).

FISHERY

Description of the modern directed fishery

During the early 1960s, a Japanese longline fishery harvested EBS Pacific cod for the frozen fish market. Beginning in 1964, the Japanese trawl fishery for walleye pollock (*Gadus chalcogrammus*) expanded and cod became an important bycatch species and an occasional target species when high concentrations were detected during pollock operations. By the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod had consistently been in the 30,000 to 70,000 t range for a full decade. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the EBS. The foreign and joint venture sectors dominated catches through 1988, but by 1989 the domestic sector was dominant and by 1991 the foreign and joint venture sectors had been displaced entirely.

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components (although catches by jig gear are very small in comparison to the other three main gear types, with an average annual catch of less than 200 t since 1991). The breakdown of catch by gear during the most recent complete five-year period (2019-2023) is as follows: longline gear accounted for an average of 47% of the catch, trawl gear accounted for an average of 32%, and pot gear accounted for an average of 23%.

In the EBS, Pacific cod are caught throughout much of the continental shelf, with National Marine Fisheries Service (NMFS) statistical areas 509, 513, 514, 517, 519, 521, and 524 each accounting for at least 5% of the total catch over the most recent 5-year period (2019-2023). In that time period Pacific cod catch from areas 521 (29%) and 509 (21%) have made up over 50% of the total eastern Bering Sea catch.

Catches of Pacific cod taken in the EBS for the periods 1964-1980, 1981-1990, and 1991-2024 are shown in Table 2.1, Table 2.2, and Table 2.3Table 2.3, respectively; and the time series for the overall fishery (1977-2024) and by gear type (1991-2024) are shown in Figure 2.4.

Annual cumulative catch for 2019 through 2024 are shown in Figure 2.5. The start of fishing in the trawl sector in 2024 was later than 2019-2021, but at a similar time as the 2022 and 2023 fisheries. Catch rate (tons per week) in the trawl sector in 2024 appears to have been slower than in 2023 a first, but sped up by week 10. The longline sector catch rates in 2024 remained stable throughout the year unlike 2019 and 2020 when rates dipped in the summer months. The pot sector catch rates in 2024 were slow in the starting weeks than the previous four years but like 2023 continued to week 15, unlike previous years which tended to taper off earlier. As in previous years in 2024 the pot sector halted fishing in April, but unlike previous years it appears the Fall fishery has been rather anemic, with very little catch in August through October.

Maps of fishing effort for 2022 through 2024 by fishing sector (Figure 2.6) and for all gear types (Figure 2.7) indicate a dramatic shift away from the north beginning in 2020 and 2021 (Barbeaux et al. 2023) and continuing through 2024 for the trawl and longline sectors. In 2021 through 2024 there were few longline sets north of St. Lawrence Island and in 2022 through 2024 there were few longline sets north of St. Mathews Island. So far in 2023 and 2024 observed and reportable pot cod fishery was restricted to along the north side of the Alaska Peninsula and Aleutian Islands and in the southern side of St. George Island in the Pribilof Islands. Figure 2.8 shows the distribution of observed hauls by latitude and bottom depth by gear type. The largest latitudinal shift in fishing distribution is observed in the longline fishery. Here we see a slight southward shift in 2008-2013, then a shift northward peaking in 2019 through 2021, then a southward shift in the 2022 through 2024 observations. The trawl and pot fisheries also show a northward shift, the trawl fishery in 2019 and the pot fishery in 2020 and 2021, although much more subtle than for the longline fishery. The raw CPUE indices based on the method presented by Thompson et al. 2021 (Figure 2.9) show a rather flat CPUE by number trend from 2015 to 2022, then a sharp drop in 2023 and then increase in 2024 mostly driven by the pot fishery. However, the CPUE by weight shows an increasing trend from 2014-2020, an overall decreasing trend in 2021-2023, then a sharp increase in 2024. By gear the pot fishery shows an increase in CPUE in both number and weight in 2024 while the other two gear types examined show drops (Figure 2.10).

Catches of Pacific cod taken from the portion of the western Bering Sea under Russian jurisdiction during 2001 through 2021 are summarized in Table 2.4. For 2001-2008 the data were retrieved from Lajus et al. (2019). For 2009-2021 catch data from Russian Ministry of Fisheries annual reports are available for 2009-2021, РОССИЙСКАЯ ФЕДЕРАЦИЯ: СВЕДЕНИЯ ОБ УЛОВЕ РЫБЫ И ДОБЫЧЕ ДРУГИХ ВОДНЫХ БИОРЕСУРСОВ (translation: RUSSIAN FEDERATION: INFORMATION ABOUT THE CATCH OF FISH AND THE EXTRACTION OF OTHER WATER BIORESOURCES). The Russian Federation website where these reports were hosted was no longer active as of March 2022 and future availability of these data is questionable.

Discards

The catches shown in Table 2.1 and Table 2.2 include estimated discards. Proportion retained of Pacific cod in the EBS Pacific cod fisheries are shown for each year 1991-2024 in Table 2.3. Amendment 49, which mandated increased retention and utilization of Pacific cod, was implemented in 1998. From 1991-1997, discard rates in the Pacific cod fishery averaged about 14%. Since then, they have averaged about 2% overall. There was an increase in 2021 in the discard of Pacific cod in the trawl fisheries up to 5% from 1% in 2019. However, discard rates in the trawl fisheries have once again dropped to 2% in 2022 and 1% in 2023 and 2024.

Management History

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2.5. Note that, prior to 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2.3 which pertains to the EBS only.

From 1980 through 2024 TAC averaged about 85% of ABC (ABC was not specified prior to 1980), and from 1980 through 2024, commercial catch averaged about 82% of TAC. In 8 of these 45 years, TAC equaled ABC exactly, and in 17 of these 45 years, catch exceeded TAC. However, in 10 of those overages TAC was reduced by various proportions to account for a small, state-managed fishery inside state of Alaska waters (such reductions have been made in all years since 2006; see text table below for recent formulae); thus, while the combined Federal and State catch exceeded the Federal TAC in 2006-2010 and 2016-2023 by up to 10%, the overall target catch (Federal TAC plus State GHL) was *not* exceeded.

An OFL has been specified since 1992. In 1992 catch exceeded OFL by 10%, however the OFL has not been exceeded since.

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. Assessments conducted prior to 1985 consisted of simple projections of current survey numbers at age. In 1985, the assessment was expanded to consider all survey numbers at age from 1979-1985. From 1985-1991, the assessment was conducted using a bespoke separable age-structured model. In 1992, the assessment was conducted using the Stock Synthesis modeling software (Methot 1986, 1990) with age-based data. All assessments from 1993 through 2003 continued to use the Stock Synthesis modeling software, but with length-based data. Age data based on a revised ageing protocol were added to the model in the 2004 assessment. At about that time, a major upgrade in the Stock Synthesis architecture resulted in a substantially new product, at that time labeled "SS2" (Methot 2005). The assessment was migrated to SS2 in 2005. Changes to model structure were made annually through 2011, then the base model remained constant through 2015, and new base models were adopted in 2016, 2018, 2019, and 2020 (see Appendix 2.3 of Thompson et al. 2021). In 2021 a model ensemble approach was adopted and used through 2022 (Barbeaux et al. 2022). The model ensemble approach was discarded in 2023 and a new base model accepted (Barbeaux et al. 2023).

Beginning with the 2014 fishery, the Board of Fisheries for the State of Alaska has established guideline harvest levels (GHLs) in State waters between 164° and 167° west longitude in the EBS subarea (these have supplemented GHLs that had been set aside for the Aleutian Islands subarea since 2006). The table below shows the formulas that have been used to set the State GHL for the EBS (including the formula anticipated for setting the 2025 GHL):

Year	Formula
2014	0.030 × (EBS ABC +AI ABC)
2015	0.030 × (EBS ABC +AI ABC)
2016	0.064 × EBS ABC
2017	0.064 × EBS ABC
2018	0.064 × EBS ABC
2019	0.084 × EBS ABC
2020	0.090 × EBS ABC
2021	0.100 × EBS ABC
2022	0.110 × EBS ABC
2023	0.120 × EBS ABC
2024	0.120 × EBS ABC
2025	0.130 × EBS ABC

For 2020 through 2024 the Board of Fisheries established an additional GHL of 100,000 lbs. (45.4 t) for vessels using jig gear within State waters (https://www.adfg.alaska.gov/FedAidPDFs/RIR.4K.2023.12.pdf).

Table 2.6 lists all implemented amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly.

In addition to those, the following rulemaking became effective for 2021 on permit requirements:

https://www.federalregister.gov/documents/2020/12/03/2020-26593/fisheries-of-the-exclusive-economic-zone-off-alaska-pacific-cod-in-the-bering-sea-and-aleutian. In this rule, NMFS modified Federal permit conditions and imposed participation requirements for certain federally permitted vessels when fishing for Pacific cod in State of Alaska waters (state waters) adjacent to the Exclusive Economic Zone (EEZ) of the Bering Sea and Aleutian Islands (BSAI). The state waters portion of the Pacific cod fishery that runs concurrent with the Federal Pacific cod fishery is commonly known as the State's parallel fishery. The "parallel fisheries" in this preamble refer to the State waters Pacific cod parallel fisheries in the State of Alaska Bering Sea-Aleutian Islands Area, which presently is in the Dutch Harbor Subdistrict of the Bering Sea and within the Aleutian Islands Subdistrict of the Aleutian Islands, respectively. This rule prohibits (1) a hook-and-line, pot, or trawl gear vessel named on a Federal Fisheries Permit (FFP) or License Limitation Program (LLP) license from being used to catch and retain BSAI Pacific cod in State of Alaska (State) waters adjacent to the BSAI during the State's parallel Pacific cod fishery unless the vessel is named on an FFP and LLP license that have the required endorsements; (2) a hook-and-line, pot, or trawl gear vessel named on an FFP or LLP license from catching and retaining Pacific cod in state waters adjacent to the BSAI EEZ during the State's parallel fishery when NMFS has closed the EEZ to directed fishing for Pacific cod by the sector to which the vessel belongs; (3) the holder of an FFP with certain endorsements from modifying those endorsements during the effective period of the FFP; and (4) the reissuance of a surrendered FFP with certain endorsements for the remainder of the three-year term, or cycle, of FFPs.

In four consecutive year 2020-2023 the Bering Sea non-CDQ Pacific cod directed fishing closed for all non-CDQ sectors. The non-CDQ sectors have BSAI allocations and there was less fishing in the Aleutian Islands until after the Bering Sea non-CDQ sectors closed. Directed fishing for the Pacific cod non-CDQ sectors closed in 2020 on November 18, in 2021 on September 17, in 2022 on October 7, and in 2023 on October 16. The closures were to prevent exceeding the non-CDQ allocation of the total allowable catch of Pacific cod in the Bering Sea subarea of the BSAI. After the closures there was still fishing by the CDQ groups and incidental catch of Pacific cod in other targets. It appears thus far 2024 had remained open through October 13.

DATA

The first two subsections below describe fishery and survey data that are used in the current stock assessment models. The third subsection describes data that are not used in the current stock assessment models, but that may help to provide some context for the data that are used.

The following table summarizes the sources, types, and years of data included in the data file for at least one of the stock assessment models:

Source	Type	Years
Fishery	Catch biomass	1977-2024
Fishery	Catch size composition	1977-2024
Fishery	Catch per unit effort (VAST)	1996-2024
EBS+NBS trawl survey	Survey numerical abundance (VAST)	1982-2019, 2021-2024
EBS+NBS trawl survey	Survey age composition (VAST)	2000-2019, 2021-2023
EBS and GOA trawl survey	Aging bias 2004 and 2018 reads	2003
EBS and GOA trawl survey	Aging error – in year rereads	2000-2019, 2021-2023

All data used in the 2024 models are provided in zip files in the following appendices:

- Appendix 2.3 2024 Models Stock Synthesis files.zip (0.3MB)
    - https://afsc-assessments.github.io/EBS_PCOD/2024_ASSESSMENT/NOVEMBER_MODELS/APPENDICES/APPENDIX_2.3_2024_MODELS.zip
- Appendix 2.4 Data and results for all models.xlsx (2.6 MB)
    - https://afsc-assessments.github.io/EBS_PCOD/2024_ASSESSMENT/NOVEMBER_MODELS/APPENDICES/Appendix_2.4_Data_and_results.xlsx

Fishery Data Used in the Models

Catch Biomass

Catch estimates for the period 1977-2024 are shown in Table 2.1, Table 2.2, Table 2.3, and Table 2.5. However, the estimate for 2024 used in the model is complete only through October 3. The 2024 year-end catch in the model was set at the 5-year average proportion of the ABC that was harvested (98.6% or 165,659 t).

The catches shown in Table 2.1, Table 2.2, Table 2.3, and Table 2.5 consist of “official” data from the NMFS Alaska Region. However, other removals of Pacific cod are known to have occurred over the years, including removals due to subsistence fishing, sport fishing, scientific research, and fisheries managed under other FMPs. Estimates of such other removals are shown in Table 2.7 .

The catch estimates for the years 1977-1980 shown in Table 2.1 may or may not include discards.

Size Composition

Figure 2.11 shows the fishery size compositions from 1977 through 3 October 2024, which are parsed into 1 cm or 5 cm bins for use in the assessment models. The size composition were computed by using haul/vessel/month/gear/area catch proportions to create a weighted average for each year's record as described in Appendix 2.1 of Barbeaux et al. (2023). with a minimum sample size of 30 fish for any month/gear/area combination. The total number of Pacific cod measured in the fishery 1977-2024 are provided in Table 2.8.

The length distributions are generally unimodal, with a few years bimodal when larger than average year classes were encountered Figure 2.11. The peaks of the length composition in the fishery tends to be between 50 and 70 cm. The size of fish in the fishery has remained relatively stable over time, however the mean length in the fishery tends to decrease somewhat when there are large new recruitments then slowly increase as these fish age and grow (Figure 2.12). From 1977 through 1991 there was an increasing trend in mean length with the greatest mean length in 1991. There were also fewer data for this time period leading to higher uncertainty in the estimated distribution. In 1992 with the advancement of the domestic observer program and increased sampling uncertainty in the distributions was lower. For this period (1991-2024) the highest mean length occurred in 2021 following a period of low recruitment in 2014-2017. On average Pacific cod continued decrease in average size from 2021 to 2023 in part due to the influx of the 2018-year class. 2024 mean size in the fishery remained stable. It should be noted that the fishery length composition is made up of data from several gear types (trawl, longline, and pot) and the individual selectivity of these gear likely differs (Table 2.3 and Figure 2.8).

The nominal sample sizes (number of sampled hauls) for the size compositions and input sample sizes are shown in Table 2.9.

Survey Data Used in the Models

Overview of Survey Areas and Frequency

The areas covered by the eastern Bering Sea (EBS) shelf and northern Bering Sea (NBS) bottom trawl surveys are shown in Figure 2.13. Prior to 2020, in the EBS, strata 10-62 had been surveyed annually since 1982 and strata 82 and 90 had been surveyed annually since 1987. However, the EBS bottom trawl survey was cancelled in 2020 due to the COVID-19 pandemic. In the NBS, strata 70, 71, and 81 in the NBS were surveyed fully in 2010, 2017, 2019, 2021, 2022, and 2023. Less extensive surveys of the NBS were conducted in 1982, 1985, 1988, 1991, and 2018. The NBS was also scheduled to be surveyed in 2020, but, like the EBS survey, the 2020 NBS survey was cancelled due to the COVID-19 pandemic. The NBS was not surveyed in 2024.

VAST Estimates of Abundance from the EBS Shelf and NBS Bottom Trawl Surveys

The software versions of dependent programs used to generate model-based estimates were equivalent or later than these minimum standards:

- R (4.0.2)
- MKL libraries via Microsoft R Open (4.0.2)

- INLA (21.11.22)
- Matrix (1.4-0)
- TMB (1.7.22)
- VAST (3.9.0)
- cpp VAST_v13_1_0
- FishStatsUtils (2.10.0)
- DHARMa (0.4.5)

Model-based abundance index methods

For model-based indices in the Bering Sea, we fitted observations of numerical abundance per unit area from all grid cells and corner stations in the 83-112 bottom trawl survey of the EBS, 1982-2022, including exploratory northern extension samples in 2001, 2005, and 2006, as well as 83-112 samples available in the NBS in 1982, 1985, 1988, 1991, 2010, and 2017-2021. NBS samples collected prior to 2010 and in 2018 did not follow the 20 nautical mile sampling grid that was used in 2010, 2017, 2019, and 2021 to 2023 surveys. Assimilating these data therefore required extrapolating into unsampled areas. This extrapolation was facilitated by including a spatially varying response to cold-pool extent (Thorson 2019a). This spatially varying response was estimated for both linear predictors of the delta-model, and detailed comparison of results for EBS pollock has shown that it has a small but notable effect on these indices and resulting stock assessment outputs (O'Leary et al. 2020). All models were fitted in the VAST R package (Thorson and Barnett 2017; Thorson 2019b). The cold pool extent index was used as a covariate in the model and was computed within the coldpool R package (https://github.com/afsc-gap-products/coldpool; Rohan et al., 2022a).

We used a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution to model positive catch rates. We extrapolated population density to the entire EBS and NBS in each year, using AFSC GAP-vetted extrapolation grids within FishStatsUtils (https://github.com/James-Thorson-NOAA/FishStatsUtils). These extrapolation grids are defined using 3,705 m (2 nmi) × 3,705 m (2 nmi) cells; this results in 36,690 extrapolation-grid cells for the eastern Bering Sea and 15,079 in the northern Bering Sea. We used bilinear interpolation to interpolate densities from 750 "knots" to these extrapolation grid cells; knots were approximately evenly distributed over space, in proportion to the dimensions of the extrapolation grid. We estimated geometric anisotropy (how spatial autocorrelation declines with differing rates over distance in some cardinal directions than others), and included a spatial and spatio-temporal term for both linear predictors. To facilitate interpolation of density between unsampled years, we specified that the spatio-temporal fields were structured over time as an AR(1) process (where the magnitude of autocorrelation was estimated as a fixed effect for each linear predictor). We do not include any temporal correlation for intercepts, which we treated as fixed effects for each linear predictor and year. Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen 2016).

We checked model fits for convergence by confirming that (1) the derivative of the marginal likelihood with respect to each fixed effect was sufficiently small (less than ~ 0.001) and (2) that the Hessian matrix was positive definite. We then checked for evidence of model fit by computing Dunn-Smyth randomized quantile residuals (Dunn and Smyth 1996) and visualizing these using a quantile-quantile plot within the DHARMa R package. We also evaluated the distribution of these residuals over space in each year, and inspected them for evidence of residual spatio-temporal patterns.

The resulting set of estimates is shown in Table 2.10, together with their respective log-scale standard deviations (“Sigma”), and compared with those used in the 2023 assessment in Figure 2.16 (R^2 = 0.999). The VAST population abundance estimates closely resemble the design-based estimates (Table 2.10 and Figure 2.15 ; R^2 = 0.928), however the variance of the VAST estimates are on average 44% lower than the design-based estimates.

The VAST estimates of abundance show that population numbers were at an all-time high in 2014 at 1,230×10^6 fish. Abundance dropped rapidly through 2017 down to 519×10^6 fish before rebounding to 761×10^6 fish in 2019. Abundance once again dropped in 2021 to 605×10^6 fish and continued to drop to 552×10^6 fish in 2022, a drop of 9% from 2021 and a drop of 55% since the 2014 high. The 2023 estimate was a 12% increase over 2022 with a total number of 620×10^6 fish. However 2024 dropped 19% from the 2023 estimate to 501×10^6, the lowest abundance since 2008 and the 5th lowest since 1990. Maps of log population density are shown in Figure 2.17 and in Figure 2.18 VAST derived estimates of centers of gravity of abundance, abundance by region (NBS and EBS) and effective area occupied. The most apparent shift in these distributional metrics is the move northward in the center of gravity between 2010 and 2017 and a shifting southward after 2019. With this change we observed a larger proportion of the stock residing in the NBS and a reversal of that trend starting in 2021 and continuing through 2024. These distributional trends are consistent with the observed warming trend and decreasing cold pool extent through the 2010s and a return to near average conditions since 2021.

Size Composition

Design-based estimates of the size compositions (in 1-cm bins) from the combined EBS and NBS bottom trawl surveys for the years 1982-2023 are shown in Figure 2.19 (VAST estimates of size composition are not available, so design-based estimates were used for all models). The number of lengths measured and otoliths collected and aged are provided in Table 2.9. Sample sizes for the survey size and age composition data, in units of sampled hauls, are shown in Table 2.8. The survey size composition mean length are shown in Figure 2.21.

The survey size composition distributions are multi-model, unlike the fisheries size composition distributions. Smaller fish (< 40cm) are captured by the survey and individual cohorts can be observed in the data. Particularly large cohorts (e.g. 2006, 2008, 2013, and 2018) reduce the mean length, while strings of poor recruitment (2014-2017) do the opposite. The size compositions from 2012-2014 show clear indications of incoming year classes that are larger than the long-term mean, the 2015-2017 size compositions indicate a string of poor recruitments. In 2019, 2021, 2022, and 2023 bottom trawl survey size composition distributions revealed a strong 2018-year class, with a strong mode in the 40-50 cm range in 2021 and 50-60 cm mode in 2022 through 2024. In 2023 there were new modes for the 2021 and 2022-year classes at 30-40 cm and 15-20 cm. These continued through 2024 with the addition of a smaller 2023-year class mode at 15-20 cm

VAST age composition

For model-based estimation of age compositions in the Bering Sea, observations of numerical abundance-at-age were fit at each sampling location. This was made possible by applying a year-specific, region-specific (EBS and NBS) age-length key to records of numerical abundance and length-composition. In subcategories (combinations of year, length, age, sex) that contained insufficient data, age composition was computed from length composition given a globally pooled age-length key. These estimates were computed in the VAST R package, assuming a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma distribution to model positive catch rates. Density covariates were not included in estimation of age composition for consistency with models used in the previous assessment, and due to computational limitations. The same extrapolation grid was used as implemented for abundance indices, but here the spatial and spatiotemporal fields were modeled with a mesh with coarser spatial resolution than the index model, here using 50 "knots". This reduction in the spatial resolution of the model, relative to that used abundance indices, was necessary due to the increased computational load of fitting multiple age categories and using epsilon bias-correction. The same diagnostics were used to check convergence and model fit as those used for abundance indices. Both the VAST bottom trawl index and age composition estimates were calculated using code in the AFSC GAP *model-based indices* GitHub repository (https://github.com/afsc-gap-products/model-based-indices). Design-based estimates of bottom trawl products were calculated using code in the *gapindex* R package (https://github.com/afsc-gap-products/gapindex).

Updated VAST age compositions from the combined EBS and NBS surveys for 1994-2024 are shown in Figure 2.20. The age-length keys used to produce these estimates include newly read samples from the 2023 survey. Sample sizes for the survey age composition data, in units of read otoliths, are shown in Table 2.8 (but note that the sample sizes actually specified in the models are in units of sampled hauls (Table 2.9)). The mean age over time for the VAST-derived survey age composition is shown in Figure 2.21. The age composition matches the same patterns as observed in the size composition data, verifying that the 2018-year class continues to be a large portion of the population continuing into 2022. However, the 2023 age composition data show large numbers of 1 to 3-year olds (2020- through 2022-year classes). These nascent cohorts now make up a much larger proportion of the population and as a result, the mode of available ages has broadened with the 2018-year class dropping in dominance.

Aging bias and aging error

The aging error used in the 2023 accepted model (Model 23.1.0.d) was based on a linear vector from age 1 to age 20 for data collected from 1990 – 2018 using the method devised by Punt et al. (2008). For this year the data were updated to include only data aged 2000 to 2023 (Figure 2. 26). In addition, discussions with the AFSC Age and Growth Laboratory indicate that ages read prior to 2000 were likely not consistent with those read using current best practices and should not be used (Beth Matta, pers. comm.). From 2000 to 2023 the Age and Growth Laboratory at the AFSC conducted a total of 17,477 paired otolith readings for Pacific cod. Meaning the otoliths from each of these Pacific cod were assessed by two different age readers allowing an assessment of reader agreement. Using these paired tests two different aging error matrixes were estimated using the AgeingError R library 2.0.2 (Punt et al. 2024, https://pfmc-assessments.github.io/AgeingError/); a linear model and a nonlinear spline model. The linear model fit a single coefficient of variation parameter for all ages for the nonlinear aging error model a spline (option 5) with five knots at 2, 4, 6, 8, and 10 was used. For both configurations because there were few ages older than 12 in the database, 12 was used as a plus group and aging error for ages 12-20 were set at the age 12 value. In both configurations the estimated standard deviation at age increased for all ages compared to the aging error vector applied last year (Table 2.12, Table 2.13, and Figure 2. 26).

Between 2008 and 2012 the age and growth laboratory changed aging criteria in response to stable oxygen isotope chronologies (Kastelle et al. 2017) showing an overall over-aging of Pacific cod at the AFSC. To compare pre-2008 and current aging practices otoliths from 2,057 Pacific cod that had been read initially in 2004 were reread in 2018 (Figure 2. 27). AgeingError R library 2.0.2 (Punt et al. 2024, https://pfmc-assessments.github.io/AgeingError/) was used to estimate an aging bias between these two reads. In the analysis the 2018 reads were assumed to be unbiased and it was assumed that the expected age was a linear function of the its true age having a constant coefficient of variation. The bias observed in the 2004 reads was higher than what had been previously estimated within the stock assessment model (Table 2.12, Table 2.13, and Figure 2. 27).

Data Provided for Context Only

Design-Based Index Estimates from the EBS Shelf and NBS Bottom Trawl Surveys

The design-based area-swept estimates for population abundance (numbers of fish) are given in Table 2.10 and the biomass in Table 2.11. The population numbers for 2024 (463×10^6) decreased from 2023 (607×10^6) after an uptick from 2022 (511×10^6), continuing the overall decline since 2019 (731×10^6) and landing at less than half the number observed in 2014 ($1{,}134\times10^6$). Despite an increase in the eastern Bering Sea from 647×10^3 t in 2022 to 663×10^3 t in 2023, a continuation of the trend since 2018, there was an overall decline in biomass Bering Sea-wide (Table 2.11) as biomass in the NBS dropped from 153×10^3 t in 2022 to 108×10^3 t in 2023, an overall drop of 25×10^3 t or -30%. For the EBS shelf 2024 continued to decline to 636×10^3. The distribution of cod on the EBS shelf for 2022 through 2024 from the survey are provided in Figure 2.14 and population numbers with confidence intervals in Figure 2.15. The distribution of the survey shows a continued shift southward and towards the shelf edge. For 2016-2023 the inshore distribution of Pacific cod south of Nunivak Islands observed in 2010-2015 was at much lower abundance. This shift from the NBS is a continuation of a trend since 2019 when the overall proportion of the Bering Sea Pacific cod biomass in the NBS was 41% now down to only 14% in 2023.

AFSC Longline Survey

The AFSC longline survey was not conducted in 2024, trend discussed here are through 2023. The domestic longline survey began biennial sampling of the eastern BS in 1997 (Rutecki *et al.* 1997). Figure 2.22 shows the locations of the Bering Sea stations sampled by the AFSC longline survey. A Relative Population Number (RPN) index of Pacific cod abundance for the 1997 through 2023 Eastern Bering Sea survey area is available from this survey (Table 2.11 and Figure 2.23). Details about these data and a description of the methods for the AFSC sablefish longline survey can be found in Hanselman *et al.* (2016) and Echave *et al.* (2012). The 2023 estimate at 73,821 is a 31% decrease from the 2021 estimate of 108,312 and 22% lower than the previous all-time low 2019 index value of 94,496. The 2023 index value was the lowest in the time series. 2023 index was 63% lower than the 1997 highest value and 46% below the series mean of 136,739. The index has been below the long-term average since 2017.

ADFG port sampling

Starting in 2023 Alaska Department of Fish and Game (ADF&G) began collecting biological data from landed Pacific cod caught in the Dutch Harbor Subdistrict (DHS) state waters Pacific cod fishery. As of 13 October 2024, this fishery harvested 91% of its allocated GHL of 20,154 t. In February through April 2023 ADF&G port samplers measured 1,099 Pacific cod for length and weighed 790 individual Pacific cod from 11 deliveries by 5 pot fishing vessels participating in this fishery. In February through April 2024 ADF&G port samplers measured 1,314 Pacific cod for length and weighed 755 individual Pacific cod from 13 deliveries by 7 pot fishing vessels participating in this fishery.

In both years on average the DHS pot fishery caught smaller fish than the federal parallel pot fishery conducted in the same time period with a higher proportion of small fish (< 70 cm) and lower proportion of large fish (>75cm) (Figure 2.24 and Figure 2.25). It should be noted that the weight at length were similar between Pacific cod from the federal and DHS fisheries. Although these data are not being used in the stock assessment model for this year, they are being considered for operational use in the near future.

ANALYTIC APPROACH

General Model Structure

Although Pacific cod in the EBS and AI were managed on a BSAI-wide basis through 2013, the stock assessment model has always been configured for the EBS stock only. Since 1992, the assessment model has always been developed under some version of the Stock Synthesis modeling framework (technical details given in Methot and Wetzel 2013 and in the Stock Synthesis Virtual Lab). Beginning with the 2005 assessment, the EBS Pacific cod models have all used versions of Stock Synthesis based on the ADMB software package (Fournier et al. 2012). A history of previous model structures, including all Stock Synthesis-based models that have been fully vetted since 2005, is given in Appendix 2.3 of Thompson et al. (2021). Female spawning stock biomass from the accepted models from 1999 to present is provided in Figure 2.28.

Stock Synthesis V3.30.21.00 was used to run all of the models in this final assessment. The user manual is available at https://nmfs-ost.github.io/ss3-doc/SS330_User_Manual_release.html.

Parameter Estimation

Stock Synthesis requires that prior distributions be associated with all internally estimated time-invariant parameters and the base values of all internally estimated time-varying parameters. For the models presented in this assessment, uniform prior distributions were used for estimation of all such parameters, with bounds set at values sufficiently extreme that they were non-constraining. To simplify terminology, such parameters will be referred to here as being "freely estimated."

On the other hand, for each parameter that varies randomly on an annual basis, Stock Synthesis estimates a vector of annual deviations that are either added to, or multiplied by, the base value of the parameter. In the case of log recruitment, the deviations are constrained by a $N(0,\sigma^2)$ distribution. The deviations in every other vector are constrained by a $N(0,1)$ distribution, and then the vector is multiplied by a σ term specific to that vector. In 2024 for all the models in the assessment, each σ was tuned iteratively as follows:

- For the vector of deviations associated with log-scale recruitment, σ was tuned to match the square root of the variance of the estimates plus the sum of the estimates' variances (Methot and Taylor 2011).
- For all other vectors of deviations, σ was tuned to set the variance of the estimates plus the sum of the estimates' variances equal to unity.

For 2024 all the models except Model 24.2 were retuned as described above for σ_R and the σ terms on the annual deviates for growth and selectivity parameters.

All models were run using the "-hess_step" option in ADMB. As an additional check on convergence, the final versions of all the 2024 models successfully passed a "jitter" test of 50 runs with the jitter rate set at 0.1. The models all of the tuned models performed well with models 23.1.d, Model 24.0, Model 24.1, and Model 24.3 converging at the MLE 78%, 86%, 84%, and 76% of the runs and no runs converging at a negative log likelihood lower than the accepted MLE. Model 24.2 which was not tuned only converged at the MLE in 32% of the runs.

Description of Models

Names of Models

Beginning with the final 2015 assessment (Thompson 2015), model numbering has followed the protocol given by Option A in the SAFE chapter guidelines. Names of all final models adopted between the 2005 assessment (when an ADMB-based version of Stock Synthesis was first used) and the 2015 assessment were translated according to that protocol in Table 2.11 of the 2015 assessment. The goal of the protocol is to make it easy to distinguish between major and minor changes in models and to identify the years in which major model changes were introduced. Names of models constituting *minor* changes from the original form of the current base model get linked to the name of that model (e.g., Model 19.12a, is a minor modification of Model 19.12, which was the base model adopted at the conclusion of the 2019 assessment cycle), while names of models constituting *major* changes get linked to the year that they are introduced (e.g., when Model 19.12 was adopted at the conclusion of the 2019 assessment cycle, it constituted a major change from the previous base model (Model 16.6i).

For 2022 as the lead authorship changed and the method used to pull and process the data were substantially changed from previous years the ensemble of models were renamed to be 22.X series. All new models presented this year are major changes and will be numbered as a 24.X series based on those models explored in September (Appendix 2.1).

Model description

For this year we are presenting last year's model (Model 23.1.0.d) with updated data and a set of four individual models (24.X series) based on the Plan Team and SSC recommendations from September 2024 described in Appendix 2.1.

Models	**Size bins**	**Annually varying growth Parameters**	**Aging error model**	**Survey selectivity with annually varying ascending width parameter?**
M 23.1.0.d	1cm	$L_{1.5}$, Richard's ρ	Linear	Yes
M24.0	5cm	$L_{1.5}$, Richard's ρ	Linear	Yes
M24.1	5cm	$L_{1.5}$, Richard's K	Spline	Yes
M24.2	5cm	$L_{1.5}$, Richard's K	Spline	No
M24.3	5cm	$L_{1.5}$, Richard's K	Spline	No

The Model 23.1.0.d is the model used for management in 2023 with 1 cm size bins, random walks on $L_{1.5}$ and Richard's ρ, linear aging error and survey selectivity with annually varying ascending width parameter. For the fishery data there are two active selectivity parameters fit separately for early and late fishery data with 1977-1989 and 1990-2024 time blocks. For all of the alternative models the general parameterization of selectivity remained the same as Model 23.1.0.d with a six parameter double normal with all but two parameters fixed. The four new 2024 models presented for consideration this year are based on Model 23.1.0.d and their development is described in Appendix 2.1. All of the alternative models have length bins at 5 cm, this was also explored in the September document (Appendix 2.1).

It has been long understood that environment, particularly temperature, is influential in the growth of Gadus species (Taylor 1958) and annual variability in growth should be expected. Growth in Pacific cod specifically has been found to be rather elastic and dependent on environmental conditions, particularly for young fish (Laurel et al. 2008). To consider this elasticity, we included annually varying growth in all of our models. All the models have a random walk on the $L_{1.5}$ growth parameter. Model 23.1.0.d and Model 24.0 have a random walk on the Richard's ρ parameter, while Model 24.1, Model 24.2, and Model 24.3 have a random walk on the Richard's K parameter. This change from an annually varying Richard's ρ to Richard's K was based on the sensitivity analysis provided in the September document (Appendix 2.1). In addition, Models 24.1, 24.2, and 24.3 use a splined aging error instead of the linear aging error used in Model 23.1.0.d and 24.0. Model 24.2 is Model 24.1 without annually varying survey selectivity on the ascending width as in previous models.

For the annually varying parameters (e.g. σ_R, $\sigma L_{1.5}$, σ_ρ ,σ_K, and survey selectivity σ) in our models the σ's were tuned iteratively to set the variance of the estimates plus the sum of the estimates' variances equal to unity. Table 2.19 provides a list of the σ values for each set of annually varying parameters. The size and age composition data sets were fit as simple multinomial distributions and data weights iteratively adjusted with a Francis reweighting scheme TA1.8 (Francis, 2011) using variance adjustment factors to tune the input sample sizes as implemented in the R4SS R library (Taylor et al. 2021). Model 24.0 and Model 24.1 were tuned to the same variance adjustment factors and Model 24.2 was left at those factors to demonstrate how sensitive the models are to tuning. Model 24.3 is a tuned version of Model 24.2, with both sigmas and variance adjustment factors tuned iteratively.

It must be emphasized that Model 24.2 is not considered a viable model for management because it was not tuned. Model 24.2 and Model 24.3 have the same data and parameterizations with the only differences between the two models being the tuning of the sigmas and variance adjustment factors. Model 24.2 is provided to show the sensitivity of models to tuning.

Parameters Estimated Outside the Assessment Model

Weight at Length

Using the functional form weight = $\alpha \times \text{length}^\beta$, where weight is measured in kg and length is measured in cm, the long-term base values for the parameters were estimated this year (using fishery data from 1974 through 2021) as α = 5.40706E-06 (mean-unbiased) and β = 3.19601.

Maturity

A detailed history and evaluation of parameter values used to describe the maturity schedule for BSAI Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). A length-based maturity schedule was used for many years. The parameter values used for the length-based maturity schedule in the 2005 and 2006 assessments were set on the basis of a study by Stark (2007) at the following values: length at 50% maturity = 58 cm and slope of linearized logistic equation = –0.132. However, in 2007, changes in Stock Synthesis allowed for use of either a length-based or an age-based maturity schedule. Beginning with the 2007 assessment, the accepted model has used an age-based schedule with intercept = 4.88 years and slope = –0.965 (Stark 2007). The use of an age-based rather than a length-based schedule followed a recommendation from the maturity study's author (James Stark, AFSC, *pers. commun.*), and the age-based parameters were retained through the 2018 assessment. However, because all assessments since 2009 have estimated some amount of ageing bias, all models beginning with the 2019 assessment have returned to using the length-based schedule.

Stock-Recruitment "Steepness"

Following the standard Tier 3 approach, all models assume that there is no relationship between stock and recruitment, so the "steepness" parameter is set at 1.0 in each.

Natural Mortality

The parameter M representing adult natural mortality is difficult to estimate in many stock assessment models. When total removals are fitted and information exists to estimate the fishing mortality rate, estimates of M are typically correlated with estimates of survey catchability, q, such that including a Bayesian prior on M can provide information about population scale and resulting catch limits.

Substantial empirical and theoretical evidence suggests that natural mortality is lower for large bodied individuals (Andersen, 2019). Asymptotic body length L_inf is negatively correlated with the von Bertalanffy growth parameter k, such that these two growth parameters are sometimes used to predict M (Hoenig, 1983). In fact, the ratio M/k has erroneously been called a "life-history invariant" (Roff, 1984), despite theory suggesting that higher M/k is associated with lower L_mat/L_inf (Beverton & Holt, 1959). In particular, some taxa evolve behavioral and morphological defenses against predators (e.g., spines) that which likely contribute to a lower M/k than otherwise expected (Thorson et al., 2014). These antipredator defenses may in some cases be evolutionarily conserved, such that a lower-than-expected M/k for a related taxa will be informative when predicting the value of M from k for a given species. This intuition gives rise to taxonomic-nested linear mixed models or phylogenetic trait imputation, which have been used to impute missing values for natural mortality (Thorson et al., 2017), recruitment density dependence (Thorson, 2020), or other behavioral and ecological traits (Thorson et al., 2023, Thorson 2024).

As an alternative to estimating natural mortality from growth parameters, researchers have also compiled estimates of longevity from aged specimens, and research suggests that longevity-based predictions of natural mortality rate are more precise than growth-based estimates (Hamel & Cope, 2022; Then et al., 2015). Longevity can be recorded either as the maximum aged specimen, or the average of the five maximum ages (Sullivan et al., 2022). However, developing separate estimators using longevity and growth parameters then results in multiple estimators for a given species (Sullivan et al., 2022), which presents a challenge in either selecting a single estimator or weighting alternative estimators within an ensemble (Cope & Hamel, 2022).

As alternative to developing separate models using growth or longevity information, recent research has developed phylogenetic structural equation models, which can explicitly represent the dependency among multivariate trait data (Thorson et al., 2023; van der Bijl, 2018; von Hardenberg & Gonzalez-Voyer, 2013). In particular, a user-friendly R-package phylosem can impute missing trait values jointly with estimating complex dependencies among traits (Thorson & van der Bijl, 2023). Research confirms that phylosem exactly replicates results from simpler models including structural equation models, phylogenetic linear models, and phylogenetic trait imputation (Thorson & van der Bijl, In review).

For this assessment a phylogenetic structural equation model (PSEM) was fit to a high-quality database of independent estimates of natural mortality (Then et al., 2015). A PSEM was specifically used that specifies three linear associations log(L_inf)→log(t_max), log(k)→log(t_max), and t_max→log(M). A jackknife experiment confirms that this PSEM can explain nearly 50% additional variance relative to a conventional linear model when using growth parameters to predict natural mortality rate, while also providing a simple method to include both growth and longevity information in a single natural mortality estimator (Thorson, 2023). We then use either the maximum specimen age, or the average of the maximum ages to predict natural mortality rate for Pacific cod in the eastern Bering Sea since 2008. Both longevity metrics result in the same value t_max=14 years, and this results in a predicted value M=0.3866 and log standard deviation of 0.4. A natural mortality of M=0.3866 was specified in all Models.

Parameters Estimated Inside the Assessment Models

Except for the addition of some annual deviations necessitated by extending the terminal year through 2024 the parameters estimated by the assessment models are enumerated in Table 2.14. For all parameters estimated within individual Stock Synthesis runs, the estimator used was the minimum negative log likelihood.

In addition to the above, the full set of fishing mortality rates was also estimated internally, but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) exactly as functions of other model parameters, because Stock Synthesis assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data. An option does exist in Stock Synthesis for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzel 2013).

Objective Function Components

All models in this assessment include likelihood components for catch, initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition, recruitment, initial recruitment, “softbounds” (analogous to a very weak prior distribution designed to keep parameters from hitting bounds), and parameter deviations.

In Stock Synthesis, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in previous assessments, all likelihood components were given an emphasis of 1.0 here.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year and fleet (fishery or survey). In the parameter estimation process, Stock Synthesis weights a given size composition observation according to the emphasis associated with the respective likelihood component and the sample size specified (and perhaps adjusted by a multiplier) for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which Stock Synthesis was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. Over the years, assessments of EBS Pacific cod have used a variety of approaches to specify multinomial sample sizes that are roughly consistent with this recommendation (summarized most recently by Thompson and Thorson 2019).

Model input sample size

Hulson et al. (2023) found that there was not a consistent approach to setting input sample sizes for composition data in assessment models at the Alaska Fisheries Science Center. They proposed a unifying bootstrap approach that would evaluate the variance and autocorrelation within the survey composition data collections to appropriately calculate annual input sample sizes. Using a bootstrap approach (Hulson et al. 2023) for calculating input sample size for the survey length and age composition data resulted in an on average smaller age composition sample size of 157 and a much larger on average input sample size of for the size composition data of 710 (Table 2.8). A bootstrap approach is not yet available for the fishery composition data and therefore for the fishery size composition data input sample size the annual number of hauls sampled standardized to the mean survey size composition input sample size were used so that both means were equal for the two size composition data sets. As in previous years it was assumed that the raw numbers of hauls were far too high as they numbered in the tens of thousands for some year, far higher than the survey input sample size.

The 2024 models were iteratively tuned using method TA1.8 proposed by Francis (2011). This method evaluates the variability in the size and age composition data through the annual mean length or age and adjusts the input sample size so that the fit of the mean size or age is meant to fit within the uncertainty intervals at a rate consistent with the variability expected based on the adjusted sample sizes. In all models this meant a reduction in the sample sizes (Table 2.15).

Use of Survey Relative Abundance Data in Parameter Estimation

For each index, each year's abundance estimate was assumed to be drawn from a lognormal distribution specific to that year. The point estimates and lognormal "sigma" terms are shown in Table 2.10.

Use of Recruitment Deviation "Data" in Parameter Estimation

The likelihood component for recruitment is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment deviation plays the role of the datum in a normal distribution with mean zero and specified standard deviation; but, of course, the deviations are parameters, not data.

RESULTS

Model Evaluation

Individual Model Goodness of Fit

Table 2.14 and Table 2.15 show the objective function value for each data component in each model along with the number of parameters in each model. With few exceptions, objective function values are not truly comparable across models, and attempts to apply information-theoretic statistics such as the Akaike information criterion may be misleading, because

- The total parameter counts overestimate the number of "effective" parameters, as these counts include parameters with prior distributions and constrained deviations.
- The models sometimes use different data files (e.g., Model 23.1.0.d and the 24.x series use different data files, as the first has 1cm bins and the rest use 5cm bins.
- The data are weighted differently among models, due to tuning of the "sigma" terms for devs and the variance adjustment factors.
- The models may have different aging error assumed, e.g. linear vs splined.

However, within a model set, e.g. Model 24.1 and Model 24.2, data and tuning remain the same and therefore comparisons can be made (Figure 2.29). For all models the likelihoods by data component and fleet are provided in Table 2.16.

The RMSSRs for the index data and the correlations between model estimates and the index data are shown for all models below:

	M23.1.0.d	M24.0	M24.1	M24.2	M24.3
RMSSR	0.98	0.98	0.98	0.98	0.98
Correlation	0.84	0.85	0.84	0.83	0.86

Ideally, RMSSR values should equal 1.0. All models evaluated performed about equally in this respect. Fits to the bottom trawl survey abundance data are shown for all models in Figure 2.30. Individual model diagnostics and residuals for the index fits can be found in the r4ss library (Taylor et al. 2021) output provided on the AFSC-assessments public github repository:

- Model 23.1.0.d
- Model 24.0
- Model 24.1
- Model 24.2
- Model 24.3

Effective sample sizes implied by the models' fits to the size composition and age composition data are compared with the corresponding input sample sizes in Table 2.17.

Individual figures for selectivities for each model can be found here:

- Model 23.1.0.d Selectivity
- Model 24.0 Selectivity
- Model 24.1 Selectivity
- Model 24.2 Selectivity
- Model 24.3 Selectivity

All the models have fishery selectivities that are near indistinguishable (Figure 2.32, Figure 2.33, and Figure 2.34). The change from annually varying to fixed survey selectivity and tuning results in a knife-edge selectivity curve in Model 24.3 differing substantially from previous models. Changes in the annually varying selectivity among Model 23.1.0.d, Model 24.0, and Model 24.2 have slight deviations from one another, particularly for 2020-2023, but overall remain consistent (Figure 2.34).

Size composition: McAllister-Ianelli ratios (Ratio) are provided in Table 2.17. By this measure Model 23.1.0.d appears *overfit* for all length data using this measure. Models 24.0, 24.1, and 24.2, and 24.3 appear well fit to the fishery length data, while only Model 24.0 is fit appropriately to the survey length data, while Models 24.1 and 24.2 being underfit.

Fits to the mean length are shown for all models for both series in Figure 2.31.

Model fits to the size composition data and Pearson residuals can be found in the r4ss library (Taylor et al. 2021) output provided on the AFSC-assessments public github repository:

- Model 23.1.0.d size composition fits
- Model 24.0 size composition fits
- Model 24.1 size composition fits
- Model 24.2 size composition fits
- Model 24.3 size composition fits

One-step-ahead (OSA) residuals, QQ_plots, SDNRs, and composite fits for all models for both fishery and survey marginal length composition data can be found in this link.

Pearson residuals for Model 23.1.0.d, 24.0, 24.1 and 24.2 fit to the length composition models are nearly indistinguishable. OSAs show all models are similar and indicate relatively good fits to the data with a few large consistent residuals between 25 cm and 35 cm in all models. In Model 24.3 where survey selectivity is knife edge and static we see large Pearson and OSA residuals at the smallest (5 cm) size bins in the fit to the survey size composition data (Figure 2.35).

Age composition: By the McAllister-Ianelli ratio measure, the age composition data were *under*fit by all of the models with the worse underfitting by Model 23.1.0.d and best by Model 24.1 (Table 2.17).

Fits to the mean age are shown for all models for both series in Figure 2.36. Model fits to the age composition data and residuals can be found in the r4ss library (Taylor et al. 2021) output provided on the AFSC-assessments public github repository:

- Model 23.1.0.d age composition fits
- Model 24.0 age composition fits
- Model 24.1 age composition fits
- Model 24.2 age composition fits
- Model 24.3 age composition fits

One-step-ahead (OSA) residuals, QQ_plots, SDNRs, and composite fits for all models for the survey marginal age composition data can be found in this link.

Carvalho et al. (2021) Model Diagnostics from ss3diags R Library (Winker et al. 2022)

Mean absolute scaled error (MASE): The MASE diagnostic builds on the principle of evaluating the prediction skill of a model relative to a naïve baseline prediction. A prediction is said to have 'skill' if it improves the model forecast compared to the baseline. MASE uses as a baseline the 'persistence algorithm' that takes the observation at the previous time step to predict the expected outcome at the next time step as a random walk of naïve in-sample predictions. The MASE score scales the mean absolute error (MAE) of forecasts to MAE of a naïve in-sample prediction. A MASE score > 1 indicates that the average model forecasts are worse than a random walk. Conversely, a MASE score of 0.5 indicates that the model forecasts twice as accurately as a naïve baseline prediction; thus, the model has prediction skill. The MASE for each data component and model are provided in Table 2.18. All models examined performed better than a random walk for all data components with all MASE values being similar across all models. Although Model 24.3 had the overall best fit to the bottom trawl survey it performed the worst in the MASE diagnostic suggesting a possible overfit compared to the other models. Similarly Model 24.3 had the highest, and therefore worst MASE statistic for the survey length composition fit as well. The MASE for the fishery marginal length composition data were nearly identical across all models. For all of the data components the differences in MASE score among all the models are rather slight. MASE plots from the ss3diags library (Winker et al. 2022) analysis as described in Carvalho et al. (2021) are available on the AFSC-assessment github repository and linked here:

- Model 23.1.0.d diagnostics
- Model 24.0 diagnostics
- Model 24.1 diagnostics
- Model 24.2 diagnostics
- Model 24.3 diagnostics

Retrospective Performance

Retrospective analyses were conducted for all models. Mohn's ρ values (Mohn 1999) for all individual models and ensembles are provided in Table 2.20 and shown in Figure 2.37 and Figure 2.38. For all models the spawning stock biomass retrospective analysis have negatively values of ρ within their respective acceptable ranges as suggested by Hurtado-Ferro et al. (2015). Values fishing mortality are also provided. However acceptable ranges for these have yet to be determined. The spawning stock biomass retrospective plots for were produced using ss3diags library (Winker et al. 2022) and shown in Figure 2.37 and Figure 2.38.

Parameter Estimates

All parameter estimates with their standard deviations are provided in an Excel file as Appendix 2.4. Individual figures for these parameters for each model can be found here:

- Model 23.1.0.d parameter plots
- Model 24.0 parameter plots
- Model 24.1 parameter plots
- Model 24.2 parameter plots
- Model 24.3 parameter plots

Table 2.21 and Table 2.22 provide the estimates and standard deviations for the parameter estimates for all models and here we provide distribution plots of all parameters for all models.

Changes in parameters estimates for shift from 1 cm to 5 cm size bins

Model 23.1.0.d and Model 24.0 have the same parameterization with the only differences being a change from 1 cm to 5 cm bins, updating the input sample sizes to match the size bins, and retuning the variance adjustment factors using the Francis method. Overall the parameter estimates from the two models are nearly the same, all estimates are well within the uncertainty bounds from each model. A direct comparison of parameter estimates and their standard deviations and can be found in Table 2.21 and Table 2.22. Here we can see small shifts in the point estimates of the growth parameters; a 1.8% shift in the K parameter, 0.9% change in both $L_{1.5}$ and Richards ρ, and a 0.4% shift in L_{20}. In addition, there is a 4.3% change in the width of the ascending slope of the survey selectivity, 2.4% change in initial F, 1.6% change in survey catchability, and 0.1% change in $\ln(R_0)$. The sum of these small shifts in parameter fits resulted in a 0.8% change in unfished spawning biomass from 567,265 t to 562,365 t. both with have a CV of 0.03, a 3% change in $F_{40\%}$ from 0.364 to 0.365 both with a CV of 0.02, and max ABC for 2025 from 156,032 t to 151,060 t both with a CV of 0.22. The changes in point estimates of the parameters and derived quantities are well within model uncertainty bounds.

Changes in parameters estimates from Model 24.0 to 24.1

Model 24.1 differs from Model 24.0 by having annually varying parameter on the K growth parameter and having splined aging error matrix instead of the linear model. These changes improved the fit to the marginal age composition data by 4.3 likelihood and overall fit by 3.7 likelihood as there was a small degradation in fit to the survey index and marginal length composition data. Except for the annual deviations in K instead of on Richards ρ, model parameters remained very similar with little change. The base K parameter changed by 4.5% from 0.110 to 0.115 and was the largest change in parameters between the two models. The devs on $L_{1.5}$ between the two models were highly correlated with an $R^2 = 0.99$. The Richards ρ deviations in Model 24.0 and the K deviations in Model 24.1 were also highly correlated with $R^2 = 0.85$. The changes show up as small deviations in growth over time (Figure 2.39 and Figure 2.40). The unfished female spawning biomass between the two models only differed by 0.08%

from 562,365 t to 561,915 t both with CV=3.2%. $F_{40\%}$ changed by 0.5% from 0.365 to 0.363 with a cy of 1.9% for Model 24.0 and 1.8% for Model 24.1. Max ABC for 2025 changed by 1.7% from 151,060 t to 153,617 t with a CV = 22% for Model 24.0 and 23% for Model 24.1.

Changes in parameters estimates from Model 24.1 to 24.3 with mention of Model 24.2

Model 24.3 has static survey selectivity while model 24.1 has an annually varying ascending slope. Model 24.3 variance adjustment factors were retuned and therefore likelihoods for length and age compositions are not comparable. Model 24.2 is Model 24.3, but with Model 24.1 variance adjustment factors. Model 24.1 and Model 24.2 don't differ substantially, standard parameters are mostly within error bounds. However, annual deviations on $L_{1.5}$ and K in Model 24.2 differ substantially from Model 24.1 as do some of the recruitment deviations. In Model 24.2 the 2020 recruitment deviation was estimated to be 128% higher than in Model 24.1 and positive, where in Model 24.1 it was a negative deviation. This increase in the 2020 recruitment results in an overall increase in the estimated 2024 abundance compared to Model 24.3 and a worse fit to the 2024 bottom trawl survey index. The untuned model 24.2 has a degradation in fit to all data components compared to Model 24.1, however there was a reduction in 43 fewer restricted dev. parameters. If we were to apply AIC and treat these 43 pseudo-parameters as true parameters AIC would suggest Model 24.2 to be more parsimonious. However, this would be a misapplication of AIC.

Once tuned, all of the Model 24.3 growth parameters changed substantially with smaller younger fish, fitting a smaller $L_{1.5}$ at 12.08 versus 13.85 in Model 24.1, while fish were larger at older ages with L_{20} at 114.73 versus 112.26 in Model 24.1. Richards ρ is larger in Model 24.3 than in 24.1 and K is smaller. These changes in growth parameters show up in model results as substantial changes in growth between the two models (Figure 2.39 and Figure 2.40). There is also a substantial change in the deviations on $L_{1.5}$ and K in Model 24.3 resulting in a particularly large proportional differences in the size of young fish (age 1 and 2) in 2023 and 2024 compared to Model 24.1 (Figure 2.40). These changes in growth are paired with a change in survey selectivity. The peak selectivity in Model 24.3 was notably smaller at 14.09 cm than in Model 24.1 which is at 22.45 cm and the width of the ascending slope is also reduced from a log value of 3.99 in Model 24.1 to -3.52 in Model 24.3 making survey selectivity in Model 24.3 knife edge at 22.45 cm (Figure 2.32). In Model 24.3 the uncertainty of the ascending slope width parameter was very large with a standard deviation on the parameter of 97.9, or a CV 2,781% potentially indicating a model misspecification. The trade-offs in Model 24.3 were larger residuals within the first size class in the survey marginal age composition data and larger residuals on the 2024 survey marginal length composition data, but a closer fit to the 2024 bottom trawl survey index value. This fit was achieved by reducing the 2020 recruitment deviation by 140.9% compared to that estimated in Model 24.1. In addition, the bottom trawl survey catchability increased from 0.987 in Model 24.1 to 1.001 in Model 24.3, reducing the overall biomass estimates by on average 3%, but with the 2025 female spawning biomass differing by -13.3% and 2026 female spawning biomass differing by -9.0% between the two models. Sigma R in Model 24.1was lower at 0.6646 compared to 0.6908 in Model 24.3 (Table 2.19). The R_0 between the two models differed by -2.4%, but the average recruit difference was only 0.6%. Overall the fit to the data and parameter estimates are very similar between the two models, however Model 24.1 puts the status of the stock in 2025 at $B_{38\%}$ while model 24.3 has the stock at $B_{34\%}$. The difference in status and slightly lower overall estimated spawning biomass when applied to the sloping control rule with its ratcheting down of F_{ABC} below $B_{40\%}$ would result in a substantial divergence in management advice for this stock in 2025 and 2026 from Model 24.1. The advice from Model 24.3 would amount to a 24.0% reduction (-36,847 t) in the 2025 maximum ABC from that of Model 24.1. It should be noted that the uncertainty around the 2025 maximum ABC is high in both these models with a CV of 22% and 23% resulting in considerable overlap in both their distributions.

Likelihood profiles

Likelihood profiles were run for all models (except Model 24.2) for survey catchability (Figure 2.41), natural mortality (Figure 2.42), and sigma R (Figure 2.43). The similarity of profiles among models reinforces the idea that all four of these models are not substantially different in model configuration. The profiles for natural mortality and sigma R appear to have their negative log likelihood minimums at or very near where the parameters are fixed at in the management models. That all of these models appear to have smooth likelihood profiles around the MLEs suggest well fit models. In all of the profiles for all models there is some disagreement between the age and length composition data. For bottom trawl catchability the length composition data suggests a much lower catchability while the index and age data suggest a much higher catchability in all models. For all models the balance point between these three data types places catchability near 1.0 ± 0.02. The most influential data component is the index itself followed by the length composition data and then the age composition data. Likelihood profiles over natural mortality show that the initial equilibrium recruitment is the most influential, followed by order of importance length data, index data, recruitment, and finally age data. In the likelihood profile the initial recruitment and length data pulls natural mortality to higher values while index, recruitment, and age composition data pull natural mortality to lower values in all models profiled. Sigma R profiles are very similar across models, again with different data components pulling the value in different directions, the length composition data are the most influential followed by recruitment, parameter deviations for those with annually varying selectivity, then nearly equally either age or index data. Here length composition data and parameter deviations pull sigma R to higher values while the index and age data pull it to smaller values. The models are consistent, except Model 24.3 suggesting a smaller sigma R than the other models profiled.

Derived Quantities

Table 2.23 and Table 2.24 contain selected management reference points for the models explored this year. Static quantities include $B_{100\%}$, $B_{40\%}$, $B_{35\%}$, $F_{40\%}$, and $F_{35\%}$. Quantities shown for each of the first two projection years (2025 and 2026) consist of female spawning biomass, relative spawning biomass, the probability that the ratio of spawning biomass to $B_{100\%}$ will fall below 0.2, maxFABC, maxABC, catch, FOFL, OFL, and the probability that maxABC exceeds the true-but-unknown OFL. A more complete listing of derived quantities for all the models considered this year is provided in an excel worksheet as Appendix 2.4.

The values of 2025 female spawning biomass, relative spawning biomass, maximum F_{ABC}, and maximum ABC projected shown in Table 2.23 and Table 2.24 don't differ markedly from last year's projections of those same quantities from last year's Model 23.1.0.d and this year's Model 24.1 (Figure 2.44). Model 24.3 however recommends a substantial change in maximum ABC and maximum F_{ABC}. The change in maximum ABC from last year's Model 23.1.0.d to Model 24.3 is primarily due to a 14.6% reduction in estimated 2025 spawning stock biomass and reduction of the status of the stock from $B_{37\%}$ to $B_{34\%}$. This resulted in a reduction of maximum F_{ABC} from 0.35 to 0.30, a 13.7% reduction in F causing a 22.6% reduction in maximum ABC from 151 kt to 117 kt as the status of the stock drops on the steep slope of the control rule.

Difference between last year's Model 23.1.0.d, this year's Model 23.1.0.d, Model 24.1, and Model 24.3 are shown below:

Year	Quantity	Last Year	Model 23.1.0.d	Change	Model 24.1	Change	Model 23.1.0.d vs. 24.1
Unfished female spawning biomass		567,465	567,265	-0.04%	561,915	-1.0%	-0.9%
2025	Female spawning biomass	211,131	218,076	3.3%	215,747	2.2%	-1.1%
2025	Relative spawning biomass	0.370	0.384	3.8%	0.384	3.8%	0.0%
2025	maxF_{ABC}	0.350	0.349	-0.3%	0.34	-2.9%	-2.6%
2025	maxABC	150,876	156,032	3.4%	153,617	1.8%	-1.5%

Year	Quantity	Last Year	Model 23.1.0.d	Change	Model 24.3	Change	Model 23.1.0.d vs. 24.3
Unfished female spawning biomass		567,465	567,265	-0.04%	552,100	-2.7%	-2.7%
2025	Female spawning biomass	211,131	218,076	3.3%	186,337	-11.7%	-14.6%
2025	Relative spawning biomass	0.370	0.384	3.8%	0.338	-8.7%	-12.0%
2025	maxF_{ABC}	0.350	0.349	-0.3%	0.302	-13.7%	-13.5%
2025	maxABC	150,876	156,032	3.4%	116,770	-22.6%	-25.2%

Choice of model

All of the models considered this year are not substantially different. Models 23.1.0.d, Model 24.0, and Model 24.1 all have similar results and provides similar management advice. The model fits to the available data for all three of these models is nearly identical with Model 24.1 having a slightly better overall fit (-3.7LL) with an improvement to the survey marginal age composition data (-4.3LL) over Model 24.0. Mohn's ρ and predictive retrospective values for spawning stock biomass and F, and MASE values for the index and length and age composition components for these three models were also nearly identical within ±0.02 for all tests (Table 2.18 and Table 2.20). All three of the models performed well in the jitter tests with the majority of models consistently converging at the MLE and none converging at likelihoods lower than the final MLE. Choosing among these three models comes down to the small difference in likelihood and the preference of the author to move to a 5cm length bin for future model development. As such among these three models the authors would recommend moving to Model 24.1.

Model 24.2 was not tuned and is not in consideration for management so will not be discussed further.

Model 24.3 for the most part performed as well as, or in some instances better than, Model 24.1 with 43 fewer pseudo-parameters (constrained annual deviations on a selectivity parameter). Note that due to Francis method retuning of the variance adjustment factors direct comparisons of likelihoods of the size and age composition fits are not reliable gauges of goodness of fit between Model 24.3 and 24.1.

Model 24.3 fits the bottom trawl index more closely than Model 24.1 with a lower negative loglikelihood of -3.54LL for that data component. However, the MASE value for the index increased by 0.06 in Model 24.3 versus Model 24.1 pointing to a marginally better performance by Model 24.1 in that regard. The Model 24.3 estimate for the survey selectivity log of the ascending slope parameter was -3.52 making the selectivity ‘knife’s edge’ (Figure 2.32) and the estimate was highly uncertain with a CV of 2,781%. This combined with static survey selectivity lead to a worse fit to the survey length composition in Model 24.3 with larger Pearson’s and outlier (> 3) OSA residuals in the first length category.

Model 24.3 achieves the better fit to the survey index in two ways; it estimates fewer of the 2020 cohort with a lower recruitment deviation leading to a worse fit to the 2024 survey size composition, and it estimates the younger fish to be smaller in general and even more so for 2024 (Figure 2.39 and Figure 2.40). Although the Model 24.3 survey length composition data MASE value was substantially better than a random walk, it was 0.12 worse than Model 24.1 suggesting marginally better performance in this respect by Model 24.1.

There are tradeoffs between Model 24.1 and 24.3 in model performance that makes it difficult to choose one over the other. Both models fit the survey index well, Model 24.3 has a marginally better fit to that data component when considering likelihood, and both models fit the age and length composition data well, however Model 24.1 fits the survey length composition data better. The MASE values are very similar and point to two well performing models, however Model 24.1 performs slightly better in this regard for both the survey index and survey length composition. Both models performed equally well with the fishery lengths and survey age composition data. Although the point estimate management advice (i.e. ABCs and OFLs) for the two models differ, the uncertainty around these estimates in both models show the confidence bounds overlapping making them statistically indistinguishable.

In consideration of overall model performance and consistency in management advice with last year’s, the authors recommend using Model 24.1 for setting management advice for 2025. However, the authors will include results from Model 24.3 in the following discussion to allow the Plan Team and SSC ample opportunity to consider the advice from the alternate model. The authors will also provide projection results from a scenario considering the possibility of the stock’s dynamics following Model 24.3, but management advice following that from Model 24.1 and ramifications of that mismatch.

Time Series Results

The biomass estimates presented here will be defined in two ways: 1) age 0+ biomass, consisting of the biomass of all fish aged 0 years or greater in January of a given year; and 2) spawning biomass, consisting of the biomass of all spawning females in January of a given year. The recruitment estimates presented here will be defined as numbers of age 0 fish in a given year.

Results tables including estimated time series, numbers at age and length, and selectivity from all models and ensembles are provided in Excel tables in Appendix 2.4.

For all of the following values the results are from Model 24.1, but have Model 24.3 results included in brackets [ ] where they differ.

Table 2.25 and Table 2.26 provides the time series of female spawning biomass (t) since 1977 as estimated using last year's Model 23.1.0.d, that model with new data, and all of the new models. The estimated spawning biomass time series are accompanied by their respective standard deviations. Figure 2.45 shows the time series of female spawning biomass for Model 24.1 and 24.3 with distributions generated from the inverted hessian point estimates. Figure 2.46 shows a time series of the ratio of the spawning stock biomass to unfished spawning biomass for Model 24.1 and 24.3. For both models the spawning stock biomass was highest in the 1980s dropping through the 1990s and into the 2000s with the lowest spawning biomass in 2009, which reached a low of between $B_{19\%}$ [$B_{18\%}$]. With the large 2006, 2008, 2010, 2011, and 2013-year classes the stock rebounded to $B_{60\%}$ [$B_{59\%}$] by 2018 to a female spawning biomass of 339 kt [324 kt]. The stock has been declining since and is estimated to be at $B_{40\%}$ [$B_{37\%}$] in 2024 at 223 kt [204 kt] and is projected to be at 216 kt [186 kt] in 2025, status decreasing slightly to $B_{38\%}$ [$B_{34\%}$]. The two models have very similar trends in spawning stock biomass throughout most of the time series, however they diverge in the last 3 years with a steeper decline in Model 24.3.

Table 2.27 and Table 2.28 provides the time series of age 0+ biomass since 1978 as estimated using last year's Model 23.1.0.d, that model with new data, and all of the new models considered this year. The age 0+ biomass follows a similar trend to the spawning biomass with peak biomass estimated greater than 900,000 t from 1980 [1981]-1990 with the highest biomass in 1983 at 1,423 kt [1,377 kt]. After the peak in 1983 the age 0+ biomass trended downward with occasional peaks down to a low of 489 kt [460 kt], a 66% [67%] drop from the 1983 peak in 2008. The age 0+ biomass rose again to a peak of 1,250 kt [1,200 kt] in 2016 (89% [87%] of the peak 1983 biomass) before dropping to 794 kt [719 kt] in 2024. The 2025 0+ biomass is expected to decrease 3% [5%] from 2024 and continue to drop through 2027 as the lower 2019 and near average 2021-2022 year classes take precedence in the population and the 2018 cohort continues to fade.

Table 2.29 and Table 2.30 provides the time series of recruitment (1000s of fish) for the years since 1978 as estimated in last year's Model 23.1.0.d, that model with new data, and all of the new models considered this year. The estimated time series are accompanied by their respective standard deviations. Figure 2.47 shows the time series of age-0 recruitment (1000s of fish) distributions for Model 24.1 and 24.3. For the time series as a whole, the 2008 and 2013 cohorts are currently estimated to be the largest. Other recent year classes that exceed the time series average by at least 50% are the 2006, 2010, 2011, and 2018 cohorts. In last year's assessment, the 2018-year class ranked 11th in the time series, with an estimated size of 962 $\times 10^6$ fish. In this year's assessment, the 2018 year class ranked 7th [8th] in the time series, and the estimated size increased to 1,039 $\times 10^6$ [963 $\times 10^6$] fish. Although the confirmed strength of the 2018-year class is a positive sign, it should also be noted that eight of the last ten cohorts have been below average, including four of the bottom ten in the overall time series. By way of context, there has been one previous seven-year string in which six cohorts have been below average, and three previous nine-year strings in which seven cohorts have been below average.

Table 2.31 and Table 2.32 provides the time series of instantaneous apical fishing for the years since 1977 as estimated in last year's Model 23.1.0.d, that model with new data, and all of the new models considered this year. The estimated time series are accompanied by their respective standard deviations. Figure 2.48 shows time series of instantaneous apical fishing annual for Model 24.1 and 24.3. Fishing mortality increased throughout the 1980s and into the 1990's with an initial high peak in 1997 at 0.559 [0.578]. This then drops to 0.407 [0.425] in 2001 before rising again up to a maximum of 0.667 [0.705] in 2011 and dropping down to a new low of 0.255 [0.273] in 2021. There was an increase in fishing mortality in 2022 to 0.318 [0.344] and for 2024 fishing mortality is expected to reach 0.360 [0.409] by the end of the year. In both models the years 1992, 1994 through 2000, and 2002 through 2014 had estimated fishing mortality values exceeding the $F_{35\%}$ of 0.44.

Figure 2.52 and Figure 2.53 plots the estimated/projected trajectory of relative fishing mortality ($F/F_{35\%}$) and relative female spawning biomass ($B/B_{35\%}$) from 1977 through 2026 based on apical fishing mortality, overlaid with the current harvest control rules. Models prior to 2016 featured dome-shaped survey selectivity, while models since 2016 have forced survey selectivity to be asymptotic, which changed the appearance of the trajectory considerably, so that, in hindsight, the stock was being subjected to fishing mortality rates in excess of the retroactively calculated F_{OFL} values (but not the official F_{OFL} values that were calculated at the time) in all years from the early 1990s through 2017.

Figure 2.49 illustrates the numbers of age by cohort for Model 24.1 for 2010 through 2025. Here the large 2011 and 2013 cohorts can be observed peaking and then fading in prominence in the population by 2017 and then the 2018-year class in pink fading out by 2025. Figure 2.50 shows biomass at age by cohort for Model 24.1. Here we see the prominence of the 2006 and 2008-year classes in 2011-2014, then the 2011 and 2013-year classes taking prominence in 2015 through 2020, with the 2018 cohort at age 3 showing dominance for the remainder of the series. In 2025 for Model 24.1 the contribution of the 2018-year class to the total population biomass at age 8 was estimated to be about equal to the contribution from the 2021 cohort at age 5. Figure 2.51 shows the catch in tons at age by cohort for 2010-2025 from Model 24.1. Here we see the contribution to the catch of certain cohorts to mirror their contribution to overall biomass seen in the previous figure. However, there are some key differences where cohorts contribute less to the overall catch tonnage as they age past age 8 than they contribute to the population biomass.

In 2023 the SSC asked for a figure depicting either raw catch by spawning biomass or the time series of catch over total biomass. These are provided in Figure 2.54 for Model 24.1 and Model 24.3. These show the same basic trend as the phase-plane plot described earlier with peak catches in the late 1990s and then again in 2011 through 2016. At its peak the fishery was taking a ~30% of the biomass. Since 2018 the fishery has been taking less than 20% of the total biomass.

Harvest Recommendations

Results presented in this section pertain to Model 24.1 and Model 24.3 only, however results for any one specific model are available.

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the EBS have generally been managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) Stock status: $B/B_{40\%} > 1$

$F_{OFL} = F_{35\%}$

$F_{ABC} \leq F_{40\%}$

3b) Stock status: $0.05 < B/B_{40\%} \leq 1$

$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

3c) Stock status: $B/B_{40\%} \leq 0.05$

$F_{OFL} = 0$

$F_{ABC} = 0$

For Model 24.1 the estimate of $F_{35\%}$ is 0.444; and the estimate of $F_{40\%}$ is 0.363 (Table 2.24).The estimate of $B_{100\%}$ from Model 24.1 is 561,915 t. The distributions of $B_{100\%}$ for each model are shown in Figure 2.55; the estimate of $B_{40\%}$ from Model 24.1 is 224,767 t; and $B_{35\%}$ is 196,671 t (Table 2.24).

For Model 24.3 the estimate of $F_{35\%}$ is 0.442; and the estimate of $F_{40\%}$ is 0.361 (Table 2.24).The estimate of $B_{100\%}$ from Model 24.3 is 552,100 t. The distribution of $B_{100\%}$ each model are shown in Figure 2.55; the estimate of $B_{40\%}$ from Model 24.3 is 220,840 t; and $B_{35\%}$ is 193,235 t (Table 2.24).

Means and standard deviations of the ABC and OFL distributions for 2025 and 2026 are shown for Model 24.1 and Model 24.3 in Table 2.24, and the distribution for the maxABCs are shown in Figure 2.58.

Specification of OFL and Maximum Permissible ABC

For Model 24.1 given the assumptions of Scenario 2 (below), female spawning biomass for 2025 is estimated to be 215,747 t; and female spawning biomass for 2026 is estimated to drop to 206,498 t (Table 2.35).

For Model 24.3 given the assumptions of Scenario 2 (below), female spawning biomass for 2025 is estimated to be 186,337 t; and female spawning biomass for 2026 is estimated to increase to 187,854 t (Table 2.36).

Under both models female spawning biomass for 2025 and 2026 is projected to be below $B_{40\%}$, thereby placing Pacific cod in Tier 3b for both 2025 and 2026. Given this, the estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2025 and 2026 are as follows (from Table 2.24):

Model 24.1

Year	F_{OFL}	maxF_{ABC}	OFL (t)	maxABC (t)
2025	0.425	0.348	183,509	153,617
2026	0.406	0.332	169,243	141,520

Model 24.3

Year	F_{OFL}	maxF_{ABC}	OFL (t)	maxABC (t)
2025	0.369	0.302	139,917	116,770
2026	0.372	0.304	143,191	119,491

The age 0+ biomass projections for 2025 and 2026 from Model 24.1 are 769,813 t and 762,206 t, respectively (Table 2.27), and from Model 24.3 are 680,076 t and 710,201 t (Table 2.28).

Standard Harvest Scenarios, Projection Methodology, and Projection Results

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). Prior to the 2018 assessment, the standard harvest scenarios were made using the AFSC's "Proj" program. Beginning with the 2018 assessment, however, the projections have been made within Stock Synthesis. Point estimates of all time-varying parameters used in the projections are set at their respective time series means, except for annual deviations governing length at age of year classes currently in the population, as these propagate into the future. Year-end catch for 2024 was estimated to be 165,659 t, equal to the proportion of end of year catch to ABC for the previous five years times the 2024 ABC. In the event that catch is likely to be less than the recommended ABC in either of the first two projection years, Scenario 2 must be conducted, using the best estimates of catch in those two years (otherwise, Scenario 2 can be omitted if the author's recommended ABCs for the next two years are equal to the maximum permissible ABCs). The following relationship between ABC and catch was described under "Management History" in the "Fishery" section: For ABC≥198,000 t, catch = 89,000 t + 0.55×ABC; for ABC<198,000 t, catch = ABC. Because the recommended ABCs for both of the first two projection years are less than 198,000 t, no adjustment is necessary.

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.

Five of the seven standard scenarios are sometimes 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 TACs for 2025 and 2026, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

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

Scenario 2: In all future years, *F* is set equal to a constant fraction ("author's F") of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2025 recommended in the assessment to the *max* F_{ABC} for 2025, and where catches for 2025 and 2026 are estimated at their most likely values given the 2025 and 2026 recommended ABCs under this scenario. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment; also, catch tends not to equal ABC exactly.)

Scenario 3: 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 4: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

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 follow (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 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 overfished.)

Scenario 7: In 2025 and 2026, *F* is set equal to *max* F_{ABC}, and in all subsequent years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2026 or 2) above 1/2 of its MSY level in 2025 and expected to be above its MSY level in 2036 under this scenario, then the stock is not approaching an overfished condition.)

Projections (means and standard deviations) of female spawning biomass (B), full selection fishing mortality (F), and catch (C) corresponding to the standard scenarios are shown for the updated Model 23.1.0.d in Table 2.33, for Model 24.0 in Table 2.34, for Model 24.1 in Table 2.35 and for Model 24.3 in Table 2.36. Female spawning stock biomass trajectories for all scenarios for Model 24.1 are presented in Figure 2.58 and for Model 24.3 in Figure 2.59.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2025, it does not provide the best estimate of OFL for 2026, because the mean 2026 catch under Scenario 6 is predicated on the 2025 catch being equal to the 2025 OFL, whereas the actual 2025 catch will likely be less than the 2025 OFL. Table 2.24 contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Risk Table and ABC Recommendation

Risk Table Levels of Concern				
	Assessment-related considerations	*Population dynamics considerations*	*Ecosystem considerations*	*Fishery-informed stock considerations*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are typical for the stock and recent trends are within normal range.	No apparent ecosystem concerns related to biological status (e.g., environment, prey, competition, predation), or minor concerns with uncertain impacts on the stock.	No apparent concer ns related to biological status (e.g., stock abundance, distribution, fish condition), or few minor concerns with uncertain impacts on the stock.
Level 2: Increased concern	Substantially increased assessment uncertainty/ unresolved issues, such as residual patterns and substantial retrospective patterns, especially positive ones.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are unusual; trends increasing or decreasing faster than has been seen recently, or patterns are atypical.	Indicator(s) with adverse signals related to biological status (e.g., environment, prey, competition, predation).	Several indicators with adverse signals related to biological status (e.g., stock abundance, distribution, fish condition).
Level 3: Extreme Concern	Severe assessment problems; very poor fits to important data; high level of uncertainty; very strong retrospective patterns, especially positive ones.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are extremely unusual; very rapid changes in trends, or highly atypical patterns compared to previous patterns.	Indicator(s) showing a combined frequency (low/high) and magnitude(low/high) to cause severe 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) that are likely to impact the stock.	Multiple indicators with strong adverse signals related to biological status (e.g., stock abundance, distribution, fish condition), a) across different sectors, and/or b) different gear types.

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, ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. "Assessment-related 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. "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-informed stock considerations —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."

Development of the risk table in this assessment follows the approach described by Thompson (2021), which is an explicit attempt to view the risk table in the context of the probability that ABC exceeds the true-but-unknown OFL. The approach partitions this probability into internal and external components. The internal probability is routinely computed from the stock assessment model; for example Table 2.37 indicates that if the 2025 catch were to equal the 2025 maxABC, the internal probability for Model 24.1 that catch exceeds the 2025 OFL is approximately 19.6% (see the line in the table labeled "$\Pr(\text{Catch}_{2025}>\text{OFL}_{2025})$"). The external probability cannot be computed from the stock assessment model, because it involves factors that are external to the stock assessment model, and hence is evaluated using the risk table.

<u>Assessment-related considerations</u>

Recognizing the SSC's recommendation that, "Risk scores should be specific to a given stock or stock complex", the assessment considerations will be limited to a comparison of the present assessment with previous assessments of the same stock. As a point of departure, the assessment considerations category was assigned a risk level of 1 in each of the four previous assessments.

The range expansion of the stock into the NBS made assessment modeling more difficult for a few years for a two main reasons: 1) the design-based methods for calculating the index did not allow for accurate or unbiased extrapolation into the newly surveyed area for historic data and 2) it was uncertain whether the expansion was a range extension or the discovery of a new population. However, with the development of the VAST method (Thorson and Barnett 2017), it has become possible to treat the combined EBS and NBS surveys in a coherent fashion, eliminating the need to treat those surveys separately, either with or without explicit movement between areas. Spatial distribution concerns have now shifted to some extent toward movement between American and Russian jurisdictions and the western Gulf of Alaska. Although harvests in Russian waters have the potential to impact harvests in American waters if there is significant mixing between the two areas, the best available data suggest that recent (2021) harvest rates in Russian waters have not been particularly high (Table 2.4). Note that this concern is somewhat heighten as data on the Russian fishery are no longer available. There is likely a need to spatially restructure the stock assessment for the Gulf of Alaska and Bering Sea and current tagging projects described in the introduction will help inform this effort.

Another issue that is apparent this year is the conflict in data components as modeled. There is a substantial difference in management advice between Model 24.1 and Model 24.3 despite the models being very similar. The two models have differences in which data component is less well fit. Model 24.3 fits the survey index better and Model 24.1 fits the survey size composition data better. Table 2.37 considers the possibility that stock dynamics are better represented by one model, but management advice is used from the other. The difference between Model 24.1 and 24.3 in probable catch in 2025 and 2026 would be 36,847 t and 22,029 t.

If Model 24.3 represented the true dynamics of the stock and Model 24.1 was used for management, the stock would be fished in 2025 at an F of 0.410 and in 2026 at 0.392. This fishing rate would drive the stock down to $B_{32\%}$ in 2026 and 2027 instead of the expected status of $B_{34\%}$ and $B_{35\%}$ (Figure 2.60 and Figure 2.61). This mismatch would increase the probability of the stock being below $B_{20\%}$ in 2026 and 2027 from < 0.01% to 3% in both years and increase the probability of the catch exceeding the true OFL from 18.4% in 2025 and 9.1% in 2026 to 67.1% and 68.0%.

If the opposite were true and Model 24.1 better represented the stock dynamics but the fishery was managed under Model 24.3 the forgone catch for 2025 and 2026 combined would be 58,876 t. The status of the stock would be expected to increase to $B_{44\%}$ in 2025 and $B_{45\%}$ in 2026 with the probability of being below $B_{20\%}$ remaining at <0.01%. The probability of catch exceeding the true OFL would decrease from 19.6% in 2025 and 9.1% in 2026 to 5.1% and 5.5%.

Despite this uncertainty and slight increase in risk while managing the stock under Model 24.1, the assessment considerations were once again rated as level 1 (No Concern) as this concern is not considerably elevated above previous concerns.

Population dynamics considerations

Population dynamics considerations were assigned a risk level of 1 in each of the three previous assessments.

As noted above under “Time Series Results,” eight out of the ten most recent (2013-2022) cohorts are estimated to have been below average. Although strings of poor recruitment is unprecedented, they are at least somewhat concerning, as they may be harbingers of a long-term change in mean recruitment. While the time series of recruitment estimates are already part of the stock assessment model, and therefore should not be considered as a reason for a risk table adjustment, the possibility of a long-term change in mean recruitment is not part of the stock assessment model.

The estimate of age 0+ biomass for 2025 is only 0.44 standard deviations or -13% removed from the pre-2025 time series mean, and the estimate of female spawning biomass for 2025 is only 0.72 standard deviations or 11% removed from the pre-2025 time series mean. The estimated rate of change in age 0+ biomass from 2025 to 2026 is -2%. The estimated rate of change in female spawning biomass from 2024 to 2025 is -3%. None of this suggests that abundance is “increasing or decreasing faster than has been seen recently”.

Population dynamics considerations were once again rated as level 1 (No Concern).

Ecosystem considerations

Appendix 2.2 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 Eastern Bering Sea Ecosystem Status Report (ESR; Siddon 2024). The text below summarizes ecosystem information related to EBS Pacific cod provided from both the ESP and ESR.

Environmental processes:

The eastern Bering Sea (EBS) experienced a prolonged period of above-average thermal conditions from 2014 through 2021. Since 2021, and continuing from August 2023–August 2024, thermal conditions in the EBS have been close to historical baselines of many metrics. There have been no sustained marine heatwaves over the southeastern or northern Bering Sea shelves since January 2021 (Callahan and Lemagie 2024), and observed (Rohan and Barnett, 2024) and modeled (Kearney 2024, Appendix 2.2: Kearney) bottom temperatures were mostly near-normal over the past year. Sea surface temperatures (SSTs) and bottom temperatures were near the long-term means in all regions by summer 2024. The spring to summer sea surface temperature (SST) when larval Pacific cod are transiting to nearshore in their pelagic phase decreased further to below average for 2024 (see Appendix 2.2: Callahan). Notable deviations include (i) warm SSTs in the outer domain from fall 2023 through spring 2024 and (ii) unusually warm bottom temperatures in the northern outer domain since spring 2024 that may indicate an intrusion of shelf water (Callahan et al., 2024).

Atmospheric conditions are one of the primary drivers that impact the oceanographic setting in the EBS. Both the North Pacific Index (NPI) and Aleutian Low Index (ALI) provide complementary views of the atmospheric pressure system in the North Pacific. During winter 2023-2024, the NPI was average (Siddon 2024, Appendix 2.2: Siddon) and the strength and location of the Aleutian Low Pressure System were both near climatological averages (Overland and Wang, 2024). Thus, despite delayed formation of sea ice in fall 2023 (Thoman 2024), cold winds from the Arctic helped advance sea ice to near-normal extent by mid-winter. Near-normal sea ice extent and thickness (Thoman 2024b, 2024c) may have contributed to a cold pool (<2°C water) of average spatial extent (Siddon 2024), though the footprint of the coldest waters (<0°C) in 2024 was 75% smaller than in 2023 (Rohan and Barnett, 2024b). While the cold pool is included as a covariate of the spatiotemporal estimates of biomass used in the main stock assessment model, the dynamics are an important consideration and relevant to understanding the overall health of the EBS ecosystem.

December 2023 had significant along-shelf winds (to the southeast) that could have driven offshore Ekman transport. Weaker, but more sustained winds that also favored offshore transport occurred from March to May 2024 (Hennon 2024). Beginning in May and continuing through summer 2024, persistent storms resulted in a deeper mixed layer, which entrained deeper, cooler water, such that SSTs remained cooler through at least August 2024 (Stabeno 2024).

For projections into 2025, the National Multi-Model Ensemble (NMME) predicts that SSTs over the EBS are expected to be near normal (anomalies within <0.5°C of the 1982–2010 baseline) (Lemagie 2024). With the expected transition to La Niña, cooler conditions in the EBS may follow. Relatively cool SSTs may contribute to earlier formation of sea ice than has been observed over the last several years (Thoman 2024b). The ice advance season (Dec-Feb) increased slightly but remains below the time series mean and is similar in extent to 2020, while the ice extent during the retreat season (MAM) has increased steadily since 2020 and is now at the long-term average (Appendix 2.2: Wang). The spatial estimates for Pacific cod population based on the VAST model shifted further west and more spread out from last year (Appendix 2.2 Barnett).

Metrics of ocean acidification include Ωarag and pH. Ωarag is important for shell formation in Pacific cod prey items like pteropods. Summer 2024 bottom water Ωarag conditions were similar to 2023; the most corrosive bottom waters were found in slope waters and over the northwest shelf (Pilcher et al. 2024).

Prey:

The Rapid Zooplankton Assessment in the southeastern Bering Sea (SEBS) in spring noted moderate abundance of small copepods, but low abundance of large copepods along the middle shelf (higher in the outer shelf) and near-zero abundance of euphausiids in the RZA, which is typical for the spring. In summer, small copepods remained abundant throughout the region. Large copepods remained in low abundance while euphausiids increased, especially towards the northern portion of the SEBS. In fall, both small and large copepods as well as euphausiids were in low abundance, but increased towards the north. In the northern Bering Sea (NBS) in fall, small copepods had moderate and consistent abundances throughout the sampling grid, large copepods were patchy with the highest values north and south of St. Lawrence Island, and euphausiids were very low (Kimmel et al. 2024).

The biomass of motile epifauna measured over the SEBS shelf increased from 2023 to 2024 and remains above the long term mean. Trends in motile epifauna biomass indicate benthic productivity, although individual species and/or taxa may reflect varying time scales of productivity. Collectively, brittle stars, sea stars, and other echinoderms have accounted for more than 50% of the biomass in this guild. The biomass index sharply increased for tanner crabs and snow crabs, while king crabs remain below their long term mean (Siddon 2024; Richar 2024). Pacific cod (all sizes) condition (as measured by length-weight residuals) decreased from 2022 through 2024 over the southeastern shelf with negative anomalies across all strata. Over the northern shelf, condition has increased from 2022 through 2024 driven by positive condition anomalies in strata 70 (inner/middle domain south of St. Lawrence Island) (Prohaska et al. 2024). Juvenile Pacific cod (<580 mm) condition in 2024 decreased to below average, similar to 2015, while adult Pacific cod remained below average, similar to last year (Appendix 2.2: Rohan). Annual ration from the CEATTLE model has started to decrease from higher levels in 2021 and 2022 (Appendix 2.2: Holsman)

Competitors:

Competitors of Pacific cod prey resources include arrowtooth flounder, pollock, and sablefish. Arrowtooth flounder biomass has been increasing steadily since 2000 and remains at a high level above the long term mean in recent years (see Appendix 2.2: Shotwell). In the SEBS, the biomass of apex predators, which includes arrowtooth flounder, in 2024 was nearly equal to their value in 2023 and remains just below the long term mean of that guild (partially off-set by a decrease of Pacific cod by 5.5%). Within that guild, arrowtooth flounder increased 26% from 2023 to 2024 (Siddon 2024). Arrowtooth flounder may compete with adult Pacific cod for benthic prey resources, like amphipods. Pollock biomass in the EBS increased substantially from 2023 to 2024 (78% increase of pollock in the pelagic forager guild; Siddon 2024), largely as a result of the 2018 year class, and may compete with juvenile and adult Pacific cod for prey resources. The impacts of recent large year classes of sablefish to the EBS ecosystem (as prey, predators, and competitors) remains largely unknown at this time. The large 2019 and possibly 2022 year class of sablefish (Goethel et al. 2023, Shotwell and Dame, 2024) may compete with Pacific cod for prey resources as juveniles, but may also be prey for larger, adult Pacific cod.

Predators:

The biomass of jellyfish over the southeastern shelf in 2024 remained low (Yasumiishi et al. 2024) to average (Buser 2024) while biomass remained high in the NBS (Yasumiishi et al. 2024). Biomass consumed of Pacific cod by all predators in the CEATTLE model has recently increased above the long term mean (Appendix 2.2: Holsman). Pacific cod are cannibalistic and rates of cannibalism might be expected to increase as the abundance of older, larger fish increases concurrently with increases in juvenile abundance. That said, the spatial extent of the population shifted more west and spread out in 2024, which may affect the spatial overlap of adult and juvenile Pacific cod and subsequent rates of cannibalism. Other predators of Pacific cod include northern fur seals, Steller sea lions, various whale species, and tufted puffin, but unfortunately, no direct measurements of population trends for these species are available.

Summary for *Environmental/Ecosystem considerations*:

- Environment: The EBS shelf experienced oceanographic conditions that were largely average based on historical time series of multiple metrics over the past year (August 2023 - August 2024).
- Prey: Trends of prey for Pacific cod are mixed, with prey conditions over the southern EBS shelf being potentially more limiting while prey conditions over the NBS shelf appear sufficient. The condition of Pacific cod continued to decrease over the southern shelf from 2022 to 2024 and increase over the northern shelf from from 2021 to 2023. The majority of the Pacific cod biomass has remained over the SEBS in recent years.
- Competitors: Trends in competitors of Pacific cod increased substantially from 2023 to 2024, including large relative increases in arrowtooth flounder and pollock, potentially reflecting greater competitive pressure for prey resources, especially over the SEBS where the majority of the Pacific cod biomass has been in recent years.
- Predators: The multispecies CEATTLE model indicates above average predation pressure on Pacific cod; rates of cannibalism may be mitigated by spatial distribution and overlap between juvenile and adult Pacific cod.

Together, the most recent data available suggest an ecosystem risk Level 2 “Increased concern”. Indicators with adverse signals for Pacific cod were identified in the areas of prey, competition, and predation.

Fishery-informed stock considerations

Fishery-informed stock considerations were assigned a risk level of 1 in each of the three previous assessments. Figure 2.9 shows simple annual averages of catch (in weight and number) per unit effort for all gears. CPUE by number has been relatively stable over the previous 11 years and CPUE by weight although dropping in the previous three years increased in 2024. This increase was due to increases in CPUE in the pot fishery while the CPUE in the longline fishery has decreased (Figure 2.10). This in part may be due to the redistribution of fish more to the south making cod more available to pot catcher vessels fishing from Dutch Harbor (Figure 2.5). Catch rates for the longline and trawl fisheries appear to mirror the most recent three years, however catch rates in the pot fishery appears to have been lagging in the beginning of the season and has been slow to take off again after the usual summer hiatus (Figure 2.6).

Fishery performance considerations were once again rated as level 1 (No Concern).

Summary and ABC Recommendation

The risk levels assigned to the four categories are summarized below:

Assessment-related considerations	*Population dynamics considerations*	*Ecosystem considerations*	*Fishery -informed stock considerations*
Level 1: No Concern	Level 1: No Concern	**Level 2: Increased Concern**	Level 1: No Concern

A score of level 2 in the Ecosystem considerations suggests there could be justification for setting ABC at a lower value than maximum. The authors do not have a recommendation for reduction in ABC from maximum.

Status Determination

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?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2023) is 143,533 t. This is less than the 2023 OFL of 172,495 t. Therefore, the EBS Pacific cod stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2024:

a. If spawning biomass for 2024 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2024 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2024 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 2.35 and Table 2.36). If the mean spawning biomass for 2034 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 2.35 and Table 2.36):

a. If the mean spawning biomass for 2025 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2025 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2025 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2036. If the mean spawning biomass for 2035 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Table 2.34, the stock is not overfished and is not approaching an overfished condition.

To fulfill reporting requirements for the Species Information System, Model 24.1 was used to reverse-engineer the fishing mortality rate corresponding to the specified OFL for the last year with complete data (2023). The reverse-engineered F_{OFL} value (*RE* F_{OFL}) for Model 24.1 is 0.376629.

ECOSYSTEM CONSIDERATIONS

Ecosystem considerations are addressed in Appendix 2.2 and in the Ecosystem Status Report. Bycatch of prohibited species in the targeted Bering Sea Pacific cod fisheries is provided in Table 2.38, total groundfish catch in the targeted Bering Sea Pacific cod fisheries is provided in Table 2.39, and total catch of non-targeted species, including birds, in the targeted Bering Sea Pacific cod fisheries is provided in Table 2.40.

DATA GAPS AND RESEARCH PRIORITIES

Significant improvements in the quality of this assessment could be made if future research were directed toward closing certain data gaps. At this point, the most critical needs pertain to the effects of the large and potentially unprecedented movements of Pacific cod between the major subregions of the Bering Sea (eastern, northern, and western) and western Gulf of Alaska that appear to have taken place in the last few years and potentially redefining the spatial structure of these stocks. The incongruity between our current management spatial structure and the spatial structure of the Gulf of Alaska and Bering Sea Pacific cod populations is likely adversely impacting our modeling efforts and rectifying this incongruity should be a high priority. Towards this effort research should continue to focus on: 1) understanding the factors determining Pacific cod movements, 2) understanding whether/how these movements change over time, 3) obtaining accurate estimates of these movements, 4) understanding the extent to which reciprocal movements occur, and 5) understanding the spawning contributions fish in each subregion to the overall stock. To these ends continued surveying of the NBS is strongly encouraged, as are genetic analyses and tagging studies. Ageing also continues to be an issue, as the assessment models consistently estimate a positive ageing bias particularly for 2008 through 2013 as methods changed. Maturity is also an important factor that needs to be better understood. Currently the model employs a static relationship developed from data prior to 2007. Another need is development of methods to quantify input sample sizes based on the among-sample variance in compositional measurements, using bootstrapping or model-based methods for fisheries composition data. Longer-term biological research needs include improved understanding of: 1) the ecology of Pacific cod in the EBS, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 3) ecology of species that interact with Pacific cod, including estimation of interaction strengths, biomass, carrying capacity, and resilience.

ACKNOWLEDGMENTS

Data or other information new to this year's assessment: John Brogan, Beth Matta, Irina Benson, Derek Chamberlin, Todd TenBrink and Jon Short provided age data. Ian Taylor and Rick Methot answered technical questions about Stock Synthesis. Jim Ianelli and Cole Monahan provided invaluable expertise on my many stock assessment questions. Biological data from the Dutch Harbor subdistrict Pacific cod fishery were provided by Ethan Nichols and Asia Beder of the Alaska Department of Fish and Game. Ongoing contributions: Numerous AFSC personnel and countless fishery observers collected nearly all of the raw data that were used in this assessment.

Reviewers: Melissa Haltuch and the BSAI GPT provided reviews of this assessment.

REFERENCES

Andersen. (2019). Fish Ecology, Evolution, and Exploitation. Princeton University Press. https://press.princeton.edu/books/hardcover/9780691176550/fish-ecology-evolution-and-exploitationBakkala, R. G., S. Westrheim, S. Mishima, C. Zhang, E. Brown. 1984. Distribution of Pacific cod (*Gadus macrocephalus*) in the North Pacific Ocean. *International North Pacific Fisheries Commission Bulletin* 42:111-115.

Barbeaux, S. J., Barnett, L., Hall, M., Hulson, P., Nielsen, J., Shotwell, S. K., Siddon, E., Spies, I. and Thorson, J. 2023. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1-128. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501 https://apps-afsc.fisheries.noaa.gov/Plan_Team/2023/EBSpcod.pdf

Barbeaux, S. J., Barnett, L.,Connor, J., Nielsen, J., Shotwell, S. K., Siddon, E., and Spies, I. 2022. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1-177. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501 https://apps-afsc.fisheries.noaa.gov/Plan_Team/2022/EBSpcod.pdf

Beverton, R., & Holt, S. 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. In G. E. W. Wolstenholme & M. O'Conner (Eds.), Ciba Foundation Symposium-The Lifespan of Animals (Colloquia on Ageing) (pp. 142–177). J. and A. Churchil Ltd.

Buser, T., and S. Rohan. 2024. Eastern Bering Sea – Jellyfishes. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Callahan, M., and E. Lemagie. 2024. Bering Sea SST anomalies. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and

Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Callahan, M., K. Kearney, and E. Lemagie. 2024. Bering Sea SST and Bottom Temperature Trends. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Carvalho, F., Winker, H., Courtney, D., Kapur, M., Kell, L., Cardinale, M., Schirripa, M., Kitakado, T., Yemane, D., Piner, K.R. and Maunder, M.N., 2021. A cookbook for using model diagnostics in integrated stock assessments. Fisheries Research, 240, p.105959. https://doi.org/10.1016/j.fishres.2021.105959

Cunningham, K. M., M. F. Canino, I. B. Spies, and L. Hauser. 2009. Genetic isolation by distance and localized fjord population structure in Pacific cod (*Gadus macrocephalus*): limited effective dispersal in the northeastern Pacific Ocean. *Can. J. Fish. Aquat. Sci.* 66:153-166.

Drinan, D.P., Gruenthal, K.M., Canino, M.F., Lowry, D., Fisher, M.C. and Hauser, L., 2018. Population assignment and local adaptation along an isolation-by-distance gradient in Pacific cod (Gadus macrocephalus). Evolutionary Applications, 11(8), pp.1448-1464.

Dunn, P. K., and G. K. Smyth. 1996. Randomized quantile residuals. *Journal of Computational and Graphical Statistics* 5:236–244. https://doi.org/10.2307/1390802

Echave, K.B., Hanselman, D.H., Adkison, M.D., Sigler, M.F. 2012. Inter-decadal changes in sablefish, Anoplopoma fimbria, growth in the northeast Pacific Ocean. Fish. Bull. 210: 361-374

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. *Can. J. Fish. Aquat. Sci.* 38:1195-1207.

Fournier, D. A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimization Methods and Software* 27:233-249.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138. https://doi.org/10.1139/f2011-025.

Goethel, D.R., Cheng, M.L.H., Echave, K.B., Marsh, C., Rodgveller, C.J., Shotwell, K., and Siwicke, K. 2023. Assessment of the sablefish stock in Alaska. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/library/safe-reports/.

Goethel, D.R., C.J. Rodgveller, K.B. Echave, S.K. Shotwell, K.A. Siwicke, D. Hanselman, P.W. Malecha, M. Cheng, M. Williams, K. Omori, and C.R. Lunsford. 2022. Assessment of the Sablefish Stock in Alaska. Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Hamel, O. S., & Cope, J. M. (2022). Development and considerations for application of a longevity-based prior for the natural mortality rate. Fisheries Research, 256, 106477. https://doi.org/10.1016/j.fishres.2022.106477

Hanselman, D.H., C.R. Lunsford, C.J. Rodgveller, and M.J. Peterson. 2016. Assessment of the sablefish stock in Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 325-488.

Hartig, F. 2021. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.4.0. http://florianhartig.github.io/DHARMa/

Hennon, T. 2024. Winds at the Shelf Break. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Hoenig, J. M. (1983). Empirical use of longevity data to estimate mortality rates. Fishery Bulletin, 82(4), 898–903.

Hulson, P-J. F., B. C. Williams, M. R. Siskey, M. D. Bryan, and J. Conner. 2023. Bottom trawl survey age and length composition input sample sizes for stocks assessed with statistical catch-at-age assessment models at the Alaska Fisheries Science Center. U.S. Dep. Commer., NOAA Tech. Memo.NMFS-AFSC-470, 38 p.

Hurtado-Ferro, F., C. S. Szuwalski, J. L. Valero, S. C. Anderson, C. J. Cunningham, K. F. Johnson, R. Licandeo, C. R. McGilliard, C. C. Monnahan, M. L. Muradian, K. Ono, K. A. Vert-Pre, A. R. Whitten, and A. E. Punt. 2015. Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. *ICES Journal of Marine Science* 72:99-110.

Kearney, K. 2024. Cold Pool Extent - ROMS. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Ketchen, K. S. 1961. Observations on the ecology of the Pacific cod (*Gadus macrocephalus*) in Canadian waters. *Journal of the Fisheries Research Board of Canada* 18:513-558.

Kimmel, D., K. Axler, D. Crouser, H.W. Fennie, A. Godersky, J. Lamb, J. Murphy, S. Porter, and B. Snyder. 2024. Current and Historical Trends for Zooplankton in the Bering Sea. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Kimmel, D., D. Cooper, B. Cormack, C. Harpold, J. Murphy, M. Paquin, C. Pinger, B. Snyder, and R. Suryan. 2023. Current and Historical Trends for Zooplankton in theBering Sea. In: E.C. Siddon, 2023. Ecosystem Status Report 2023: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Lajus, D., D. Safronova, A. Orlov, R. Blyth-Skyrme. 2019. MSC Sustainable Fisheries Certification: Western Bering Sea Pacific cod and Pacific halibut longline public consulation daft report August 2019- Longline Fishery Association. Available: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi1o9rm9_n6AhXGAzQIHQepCMIQFnoECA0QAQ&url=https%3A%2F%2Fcert.msc.org%2FFileLoader%2FFileLinkDownload.asmx%2FGetFile%3FencryptedKey%3D5%2BaQWGafENpJsbrQJIuAHpK7FtP2%2Fpf5dstuEq9Xzuj0fxGRpDdhLxCN5SMRJezL&usg=AOvVaw2m88GDi48wq5AZym46MUxh

Lauth, R. R. 2011. Results of the 2010 eastern and northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC- 227, 256 p. Available: https://repository.library.noaa.gov/view/noaa/3852

Lemagie, E. 2024. Seasonal Projections from the National Multi-Model Ensemble (NMME). In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501

McAllister M. K., and J. N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 54:284-300.

Methot, R. D. 1986. Synthetic estimates of historical abundance and mortality for northern anchovy, *Engraulis mordax*. NMFS, Southwest Fish. Cent., Admin. Rep. LJ 86-29, La Jolla, CA.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. *Int. N. Pac. Fish. Comm. Bull.* 50:259-277.

Methot, R. D. 2005. Technical description of the Stock Synthesis II Assessment Program. Unpubl. manuscr. National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097. 54 p.

Methot, R. D., and I. G. Taylor. 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* 68:1744-1760.

Methot, R. D., and C. R. Wetzel. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* 142:86-99.

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

Nielsen, J.K., Bryan, D.R., Rand, K.M., Arostegui, M.C., Braun, C.D., Galuardi, B., and McDermott, S.F. 2023. Geolocation of a demersal fish (Pacific cod) in a high-latitude island chain (Aleutian Islands, Alaska). Anim. Biotelem. 11(1): 29. doi:10.1186/s40317-023-00340-3.

Nielsen, J.M., M.W. Callahan, L. Eisner, J. Watson, J.C. Gann, C.W. Mordy, S.W. Bell, and P. Stabeno. 2023. Spring Satellite Chlorophyll-a Concentrations in the Eastern Bering Sea. In: E.C. Siddon, 2023. Ecosystem Status Report 2023: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

O'Leary, C.A., Thorson, J.T., Ianelli, J.N. and Kotwicki, S., 2020. Adapting to climate-driven distribution shifts using model-based indices and age composition from multiple surveys in the walleye pollock (Gadus chalcogrammus) stock assessment. Fisheries Oceanography, 29(6), pp.541-557.

Overland, J. and M. Wang. 2024. Wintertime Aleutian Low Index. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Pilcher, D., J. Cross, N. Monacci, E. Kennedy, E. Siddon, and W.C. Long. 2024. Ocean Acidification. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Prohaska, B., R. Howard, and S. Rohan. 2024. Eastern and Northern Bering Sea Groundfish Condition. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Prohaska, B. and S. Rohan. 2023. Eastern and Northern Bering Sea Groundfish Condition. In: E.C. Siddon, 2023. Ecosystem Status Report 2023: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

Richar, J. 2024. Eastern Bering Sea Commercial Crab Stock Biomass Indices. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Roff, D. A. (1984). The evolution of life history parameters in teleosts. Canadian Journal of Fisheries and Aquatic Sciences, 41(6), 989–1000.

Rohan, S., and L. Barnett. 2024. Summer Temperatures. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Rohan, S., and L. Barnett. 2024b. Cold Pool Extent - AFSC Bottom Trawl Survey. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Rohan, S.K., Barnett L.A.K., and Charriere, N. 2022A. Evaluating approaches to estimating mean temperatures and cold pool area from AFSC bottom trawl surveys of the eastern Bering Sea. U.S. Dep. Commer., NOAA Tech. Mem. NMFS-AFSC-456, 42 p.

Rohan, S., B. Prohaska, and C. O'Leary. 2022B. Eastern and Northern Bering Sea Groundfish Condition. In Siddon, E.C., 2022. Ecosystem Status Report 2022: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Rutecki, T. L., and Varosi, E. R. 1997. Distribution, age, and growth of juvenile sablefish, Anoplopoma fimbria, in southeast Alaska. U.S. Dep. Commer., NOAA Technical Report NMFS, vol. 130, pp. 45– 54.

Savage, K. 2020. 2019-2020 Gray Whale Unusual Mortality Event. In Siddon, E.C., 2020. Ecosystem Status Report 2020: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Shimada, A. M., and D. K. Kimura. 1994. Seasonal movements of Pacific cod (*Gadus macrocephalus*) in the eastern Bering Sea and adjacent waters based on tag-recapture data. U.S. Natl. Mar. Fish. Serv., *Fish. Bull.* 92:800-816.

Shotwell, S.K., and Dame, R. 2024. Appendix 3C. Ecosystem and Socioeconomic Profile of the Sablefish stock in Alaska - Report Card. In: Goethel, D.R., and Cheng, M.L.H. 2024. Assessment of the Sablefish stock in Alaska. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/library/safe-reports/.

Siddon, E.C., 2023. Ecosystem Status Report 2023: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Siddon, E.C., 2023b. Eastern Bering Sea 2023 Report Card. In: E.C. Siddon, 2023. Ecosystem Status Report 2023: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

Siddon, E. 2024. Southeastern Bering Sea Report Card. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Spies, I. 2012. Landscape genetics reveals population subdivision in Bering Sea and Aleutian Islands Pacific cod. *Transactions of the American Fisheries Society* 141:1557-1573.

Spies, I., K. M. Gruenthal, D. P. Drinan, A. B. Hollowed, D. E. Stevenson, C. M. Tarpey, L. Hauser. 2019. Genetic evidence of a northward range expansion in the eastern Bering Sea stock of Pacific cod. *Evolutionary Applications* 0:000-000. https://doi.org/10.1111/eva.12874

Spies, I., Tarpey, C., Kristiansen, T., Fisher, M., Rohan, S., Hauser, L. 2022. Genomic differentiation in Pacific cod using Pool-Seq. Evolutionary Applications. doi: 10.1111/eva.13488.

Stabeno, P. 2024. Mixed Layer Depth at Mooring M2. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Stark, J. W. 2007. Geographic and seasonal variations in maturation and growth of female Pacific cod (*Gadus macrocephalus*) in the Gulf of Alaska and Bering Sea. Fish. Bull. 105:396-407.

Sullivan, J. Y., C. A. Tribuzio, and K. B. Echave. 2022. A review of available life history data and updated estimates of natural mortality for several rockfish species In Alaska. U.S. Dep. Commer.,NOAA Tech. Memo. NMFS-AFSC-443, 45 p

Taylor, C.C. 1958. Cod Growth and Temperature, ICES Journal of Marine Science, 23(3). pp366–370, https://doi.org/10.1093/icesjms/23.3.366

Taylor, I.G., Doering, K.L., Johnson, K.F., Wetzel, C.R., Stewart, I.J., 2021. Beyond visualizing catch-at-age models: Lessons learned from the r4ss package about software to support stock assessments. Fisheries Research, 239:105924 https://doi.org/10.1016/j.fishres.2021.105924

Then, A. Y., Hoenig, J. M., Hall, N. G., Hewitt, D. A., & Handling editor: Ernesto Jardim. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72(1), 82–92. https://doi.org/10.1093/icesjms/fsu136

Thoman, R., 2024. Early Season Ice Extent. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Thoman, R. 2024b. Bering Sea Daily Ice Extent. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Thoman, R. 2024c. Sea Ice Thickness. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Thompson, G. G. 2015. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 251-470. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G. 2021. Frameworks for addressing scientific uncertainty: A joint probability approach for linking the risk table to ABC reductions. In Scientific and Statistical Committee (editor), SSC Workshop on Risk Tables for ABC Advice to Council (Appendix A to the June 2021 SSC minutes, https://meetings.npfmc.org/CommentReview/DownloadFile?p=d168987e-21c8-4c54-b981-15fb9f0a77db.pdf&fileName=SSC%20FINAL%20Report%20June%202021.pdf), Discussion 8 (p. 61-65, also Figures 6-9 on p. 80-82).

Thompson, G. G., S. Barbeaux, J. Conner, B. Fissel, T. Hurst, B. Laurel, C. O'Leary, L. Rogers, S. K. Shotwell, E. Siddon, I. Spies, J. Thorson, and A. Tyrell. 2021. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1-344. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501. https://apps-afsc.fisheries.noaa.gov/refm/docs/2021/EBSpcod.pdf

Thompson, G. G., J. Conner, S. K. Shotwell, B. Fissel, T. Hurst, B. Laurel, L. Rogers, and E. Siddon. 2020. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1-344. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501. https://apps-afsc.fisheries.noaa.gov/refm/docs/2020/EBSpcod.pdf

Thompson, G. G., and M. W. Dorn. 2005. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 219-330. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and R. R. Lauth. 2012. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian

Islands regions, p. 245-544. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thompson, G. G., and J. T. Thorson. 2019. Assessment of the Pacific cod stock in the Eastern Bering Sea. *In* Plan Team for the Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1-271. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Thorson, J.T., 2024. Trees for fishes: The neglected role for phylogenetic comparative methods in fisheries science. Fish and Fisheries, 25(1), pp.168-179.

Thorson, J. T. 2020. Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model. Fish and Fisheries, 21(2), 237–251. https://doi.org/10.1111/faf.12427

Thorson, J. T., Maureaud, A. A., Frelat, R., Mérigot, B., Bigman, J. S., Friedman, S. T., Palomares, M. L. D., Pinsky, M. L., Price, S. A., & Wainwright, P. (2023). Identifying direct and indirect associations among traits by merging phylogenetic comparative methods and structural equation models. Methods in Ecology and Evolution, 14(5), 1259–1275. https://doi.org/10.1111/2041-210X.14076

Thorson, J. T., Munch, S. B., Cope, J. M., & Gao, J. 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications, 27(8), 2262–2276. https://doi.org/10.1002/eap.1606

Thorson, J.T., 2018. Three problems with the conventional delta-model for biomass sampling data, and a computationally efficient alternative. Canadian Journal of Fisheries and Aquatic Sciences. 75(9): 1369-1382. https://doi.org/10.1139/cjfas-2017-0266

Thorson, J. T., 2019a. Measuring the impact of oceanographic indices on species distribution shifts: The spatially varying effect of cold-pool extent in the eastern Bering Sea. Limnology and Oceanography, 64(6), pp.2632-2645.

Thorson, J.T., 2019b. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. Fish. Res. 210, 143–161. https://doi.org/10.1016/j.fishres.2018.10.013

Thorson, J. T., and L. A. K. Barnett. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. *ICES Journal of Marine Science* 74:1311-1321. https://doi.org/10.1093/icesjms/fsw193

Thorson, J. T., K. F. Johnson, R. D. Methot, and I. G. Taylor. 2017. Model-based estimates of effective sample size in stock assessment models using the Dirichlet-multinomial distribution. *Fisheries Research* 192:84-93.

Thorson, J. T., and K. Kristensen. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. *Fisheries Research* 175:66–74. https://doi.org/10.1016/j.fishres.2015.11.016

Thorson, J. T., A. O. Shelton, E. J. Ward, and H. J. Skaug. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES Journal Marine Science* 72:1297-1310.

Thorson, J. T., & van der Bijl, W. 2023. phylosem: A fast and simple R package for phylogenetic inference and trait imputation using phylogenetic structural equation models. Journal of Evolutionary Biology. 36:10 1357-1364. https://doi.org/10.1111/jeb.14234

van der Bijl, W. 2018. phylopath: Easy phylogenetic path analysis in R. PeerJ, 6, e4718. https://doi.org/10.7717/peerj.4718

von Hardenberg, A., & Gonzalez-Voyer, A. 2013. Disentangling evolutionary cause-effect relationships with phylogenetic confirmatory path analysis. Evolution; International Journal of Organic Evolution, 67(2), 378–387. https://doi.org/10.1111/j.1558-5646.2012.01790.x

Winker, H., F. Carvalho, M. Cardinale and L. Kell. 2022. ss3diags R package version 1.0.8.

Yasumiishi, E., A. Andrews, J. Murphy, and A. Dimond. 2024. Jellyfish from Surface Trawl Surveys, 2004–2024. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock

Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Yasumiishi, E., A. Andrews, J. Murphy, A. Dimond, and E. Farley. 2023. Trends in the Biomass of Jellyfish in the South- and Northeastern Bering Sea During Late-Summer Surface Trawl Surveys, 2004–2023. In: E.C. Siddon, 2023. Ecosystem Status Report 2023: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

TABLES

Table 2.1. Summary of 1964-1980 catches (t) of Pacific cod in the eastern Bering Sea by fleet sector. "For." = foreign, "JV" = joint venture processing, "Dom." = domestic annual processing. Catches by gear are not available for these years. Catches may not always include discards.

Year	For.	JV	Dom.	Total
1964	13,408	0	0	13,408
1965	14,719	0	0	14,719
1966	18,200	0	0	18,200
1967	32,064	0	0	32,064
1968	57,902	0	0	57,902
1969	50,351	0	0	50,351
1970	70,094	0	0	70,094
1971	43,054	0	0	43,054
1972	42,905	0	0	42,905
1973	53,386	0	0	53,386
1974	62,462	0	0	62,462
1975	51,551	0	0	51,551
1976	50,481	0	0	50,481
1977	33,335	0	0	33,335
1978	42,512	0	31	42,543
1979	32,981	0	780	33,761
1980	35,058	8,370	2,433	45,861

Table 2.2. Summary of 1981-1990 catches (t) of Pacific cod in the eastern Bering Sea by fleet sector, and gear type. All catches include discards. “LLine” = longline, “Subt.” = sector subtotal. Breakdown of domestic annual processing by gear is not available prior to 1988.

	Foreign			Joint Venture		Domestic Annual Processing				
Year	**Trawl**	**LLine**	**Subt.**	**Trawl**	**Subt.**	**Trawl**	**LLine**	**Pot**	**Subt.**	**Total**
1981	30,347	5,851	36,198	7,410	7,410	n/a	n/a	n/a	12,899	56,507
1982	23,037	3,142	26,179	9,312	9,312	n/a	n/a	n/a	25,613	61,104
1983	32,790	6,445	39,235	9,662	9,662	n/a	n/a	n/a	45,904	94,801
1984	30,592	26,642	57,234	24,382	24,382	n/a	n/a	n/a	43,487	125,103
1985	19,596	36,742	56,338	35,634	35,634	n/a	n/a	n/a	51,475	143,447
1986	13,292	26,563	39,855	57,827	57,827	n/a	n/a	n/a	37,923	135,605
1987	7,718	47,028	54,746	47,722	47,722	n/a	n/a	n/a	47,435	149,903
1988	0	0	0	106,592	106,592	93,706	2,474	299	96,479	203,071
1989	0	0	0	44,612	44,612	119,631	13,935	145	133,711	178,323
1990	0	0	0	8,078	8,078	115,493	47,114	1,382	163,989	172,067

Table 2.3. Summary of 1991-2023 catches (t) and percent retained (%) of Pacific cod in the EBS by gear type. Catches for 2024 are through October 3.

	Catch (t)					Percent retained (%)			
Year	**Longline**	**Pot**	**Trawl**	**Other**	**Total**	**Longline**	**Pot**	**Trawl**	**Other**
1991	77,506	3,342	129,394	0	210,242	98	100	88	0
1992	79,404	7,510	77,291	1	164,206	98	99	72	100
1993	49,297	2,094	81,793	2	133,186	95	99	65	100
1994	78,557	8,036	84,934	730	172,257	96	98	69	100
1995	97,664	19,277	110,954	600	228,495	96	99	68	100
1996	88,881	28,003	91,912	266	209,062	97	99	76	100
1997	117,010	21,490	93,924	171	232,595	97	100	82	96
1998	84,328	13,229	60,775	193	158,525	97	100	98	100
1999	81,470	12,397	51,897	100	145,864	98	100	97	100
2000	81,643	15,849	53,847	39	151,378	97	100	98	100
2001	90,365	16,472	35,649	53	142,539	98	100	98	100
2002	100,272	15,050	51,064	165	166,551	98	99	97	100
2003	108,670	19,936	46,673	155	175,434	98	99	98	100
2004	108,474	17,242	57,793	231	183,740	98	100	99	100
2005	113,127	17,096	52,600	104	182,927	98	100	99	100
2006	96,567	18,960	53,213	83	168,823	98	100	98	100
2007	77,136	17,237	45,672	82	140,127	98	100	99	100
2008	88,918	17,367	33,490	20	139,795	98	99	99	100
2009	96,595	13,611	36,954	12	147,172	98	100	99	100
2010	81,616	19,678	41,201	344	142,839	98	100	97	100
2011	116,762	27,995	63,926	506	209,189	98	100	99	100
2012	128,300	28,725	75,505	86	232,616	99	100	99	100
2013	124,814	30,249	81,614	14	236,691	97	100	98	100
2014	127,256	39,196	72,261	2	238,715	98	100	99	100
2015	128,191	37,937	66,665	28	232,821	98	100	99	100
2016	127,917	47,078	72,574	48	247,617	98	100	99	100
2017	122,774	46,182	68,876	13	237,845	98	100	99	100
2018	100,209	39,684	59,958	0	199,851	98	100	99	0
2019	88,780	41,056	49,018	49	178,903	98	100	99	100
2020	72,088	32,967	50,564	38	155,657	98	100	98	100
2021	57,256	25,693	38,765	20	121,734	98	100	95	100
2022	69,408	36,841	42,536	28	148,813	98	100	98	100
2023	66,815	34,916	41,780	22	143,533	98	100	99	100
2024*	57,296	29,186	40,597	18	127,097	98	100	99	100

Table 2.4. Pacific cod catch in the western Bering Sea Russian EEZ for 2001-2021. 2001-2008 from Lajus et al. (2019). 2009-2021 catch data from from Russian Ministry of Fisheries annual reports, РОССИЙСКАЯ ФЕДЕРАЦИЯ: СВЕДЕНИЯ ОБ УЛОВЕ РЫБЫ И ДОБЫЧЕ ДРУГИХ ВОДНЫХ БИОРЕСУРСОВ (translation: RUSSIAN FEDERATION: INFORMATION ABOUT THE CATCH OF FISH AND THE EXTRACTION OF OTHER WATER BIORESOURCES) for 2009 through 2021. The Russian Federation website where these reports were hosted was no long active as of March 2022, future availability of these data is questionable.

Year	Catch(t)	Year	Catch(t)
2001	13,300	2012	15,397
2002	12,600	2013	18,065
2003	18,900	2014	23,068
2004	22,200	2015	19,799
2005	14,900	2016	21,420
2006	14,600	2017	31,664
2007	13,700	2018	45,793
2008	15,100	2019	NA
2009	11,124	2020	92,680
2010	16,252	2021	85,364
2011	16,260		

Table 2.5. History of BSAI (1977-2013) and EBS (2014-2024) Pacific cod catch, TAC, Alaska State GHL (2016-2024), ABC, and OFL (t). Catch for 2024 is through October 3. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the EBS catches from Table 2.3 for the period 1977-2013. Source for historical specifications: NPFMC staff.

Year	Catch	TAC	ABC	OFL	Year	Catch	TAC	GHL	ABC	OFL
1977	35,597	58,000			2002	197,356	200,000		223,000	294,000
1978	45,838	70,500			2003	207,900	207,500		223,000	324,000
1979	39,354	70,500			2004	212,621	215,500		223,000	350,000
1980	51,649	70,500	148,000		2005	205,633	206,000		206,000	265,000
1981	63,941	78,700	160,000		2006	193,029	189,768		194,000	230,000
1982	69,501	78,700	168,000		2007	174,484	170,720		176,000	207,000
1983	103,231	120,000	298,000		2008	171,030	170,720		176,000	207,000
1984	133,084	210,000	291,000		2009	175,756	176,540		182,000	212,000
1985	150,384	220,000	347,000		2010	171,850	168,780		174,000	205,000
1986	142,511	229,000	249,000		2011	220,089	227,950		235,000	272,000
1987	163,110	280,000	400,000		2012	250,840	261,000		314,000	369,000
1988	208,236	200,000	385,300		2013	250,301	260,000		307,000	359,000
1989	182,865	230,681	370,600		2014	238,715	246,897		255,000	299,000
1990	179,608	227,000	417,000		2015	232,821	240,000		255,000	346,000
1991	220,038	229,000	229,000		2016	247,617	238,680	16,320	255,000	390,000
1992	207,278	182,000	182,000	188,000	2017	237,845	223,704	15,296	239,000	284,000
1993	167,391	164,500	164,500	192,000	2018	199,851	188,136	12,864	201,000	238,000
1994	193,802	191,000	191,000	228,000	2019	178,903	166,475	15,204	181,000	216,000
1995	245,033	250,000	328,000	390,000	2020	155,657	141,799	14,074	155,873	191,386
1996	240,676	270,000	305,000	420,000	2021	121,734	111,380	12,426	123,805	147,949
1997	257,765	270,000	306,000	418,000	2022	148,813	136,466	16,917	153,383	183,012
1998	193,256	210,000	210,000	336,000	2023	143,533	127,409	17,425	144,834	172,495
1999	173,998	177,000	177,000	264,000	2024	127,097	147,753	20,154	167,952	200,995
2000	191,060	193,000	193,000	240,000						
2001	176,749	188,000	188,000	248,000						

Table 2.6. Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP, except that Amendment 113, which is listed in Appendix A of the FMP, is omitted here, due to the fact that the final rule implementing that amendment was vacated by the U.S. District Court for the District of Columbia on March 21, 2019).

Amendment 2, implemented January 12, 1982:

For Pacific cod, decreased maximum sustainable yield to 55,000 t from 58,700 t, increased equilibrium yield to 160,000 t from 58,700 t, increased acceptable biological catch to 160,000 t from 58,700 t, increased optimum yield to 78,700 t from 58,700 t, increased reserves to 3,935 t from 2,935 t, increased domestic annual processing (DAP) to 26,000 t from 7,000 t, and increased DAH to 43,265 t from 24,265 t.

Amendment 4, implemented May 9, 1983, supersedes Amendment 2:

For Pacific Cod, increased equilibrium yield and acceptable biological catch to 168,000 t from 160,000 t, increased optimum yield to 120,000 t from 78,700 t, increased reserves to 6,000 t from 3,935 t, and increased TALFF to 70,735 t from 31,500 t.

Amendment 10, implemented March 16, 1987:

Established Bycatch Limitation Zones for domestic and foreign fisheries for yellowfin sole and other flatfish (including rock sole); an area closed to all trawling within Zone 1; red king crab, C. bairdi Tanner crab, and Pacific halibut PSC limits for DAH yellowfin sole and other flatfish fisheries; a C. bairdi PSC limit for foreign fisheries; and a red king crab PSC limit and scientific data collection requirement for U.S. vessels fishing for Pacific cod in Zone 1 waters shallower than 25 fathoms.

Amendment 24, implemented February 28, 1994, and effective through December 31, 1996:

1. Established the following gear allocations of BSAI Pacific cod TAC as follows: 2 percent to vessels using jig gear; 44.1 percent to vessels using hook-and-line or pot gear, and 53.9 percent to vessels using trawl gear.
2. Authorized the seasonal apportionment of the amount of Pacific cod allocated to gear groups. Criteria for seasonal apportionments and the seasons authorized to receive separate apportionments will be set forth in regulations.

Amendment 46, implemented January 1, 1997, superseded Amendment 24:

Replaced the three year Pacific cod allocation established with Amendment 24, with the following gear allocations in BSAI Pacific cod: 2 percent to vessels using jig gear; 51 percent to vessels using hook-and-line or pot gear; and 47 percent to vessels using trawl gear. The trawl apportionment will be divided 50 percent to catcher vessels and 50 percent to catcher processors. These allocations as well as the seasonal apportionment authority established in Amendment 24 will remain in effect until amended.

Amendment 49, implemented January 3, 1998:

Implemented an Increased Retention/Increased Utilization Program for pollock and Pacific cod beginning January 1, 1998 and rock sole and yellowfin sole beginning January 1, 2003.

Amendment 64, implemented September 1, 2000, revised Amendment 46:

Allocated the Pacific cod Total Allowable Catch to the jig gear (2 percent), fixed gear (51 percent), and trawl gear (47 percent) sectors.

Amendment 67, implemented May 15, 2002, revised Amendment 39:

Established participation and harvest requirements to qualify for a BSAI Pacific cod fishery endorsement for fixed gear vessels.

Amendment 77, implemented January 1, 2004, revised Amendment 64:

Implemented a Pacific cod fixed gear allocation between hook and line catcher processors (80%), hook and line catcher vessels (0.3%), pot catcher processors (3.3%), pot catcher vessels (15%), and catcher vessels (pot or hook and line) less than 60 feet (1.4%).

(Continued on next page.)

Table 2.6. (Cont.) Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP).

Amendment 85, partially implemented March 5, 2007, superseded Amendments 46 and 77:
Implemented a gear allocation among all non-CDQ fishery sectors participating in the directed fishery for Pacific cod. After deduction of the CDQ allocation, the Pacific cod TAC is apportioned to vessels using jig gear (1.4 percent); catcher processors using trawl gear listed in Section 208(e)(1)-(20) of the AFA (2.3 percent); catcher processors using trawl gear as defined in Section 219(a)(7) of the Consolidated Appropriations Act, 2005 (Public Law 108-447) (13.4 percent); catcher vessels using trawl gear (22.1 percent); catcher processors using hook-and-line gear (48.7 percent); catcher vessels ≥60’ LOA using hook-and-line gear (0.2 percent); catcher processors using pot gear (1.5 percent); catcher vessels ≥60’ LOA using pot gear (8.4 percent); and catcher vessels <60’ LOA that use either hook-and-line gear or pot gear (2.0 percent).

Amendment 99, implemented January 6, 2014 (effective February 6, 2014):
Allows holders of license limitation program (LLP) licenses endorsed to catch and process Pacific cod in the Bering Sea/Aleutian Islands hook-and-line fisheries to use their LLP license on larger newly built or existing vessels by:
1. Increasing the maximum vessel length limits of the LLP license, and
2. Waiving vessel length, weight, and horsepower limits of the American Fisheries Act.

Amendment 103, implemented November 14, 2014:
Revise the Pribilof Islands Habitat Conservation Zone to close to fishing for Pacific cod with pot gear (in addition to the closure to all trawling).

Amendment 109, implemented May 4, 2016:
Revised provisions regarding the Western Alaska CDQ Program to update information and to facilitate increased participation in the groundfish CDQ fisheries (primarily Pacific cod) by:
1. Exempting CDQ group-authorized catcher vessels greater than 32 ft LOA and less than or equal to 46 ft LOA using hook-and-line gear from License Limitation Program license requirements while groundfish CDQ fishing,
2. Modifying observer coverage category language to allow for the placement of catcher vessels less than or equal to 46 ft LOA using hook-and-line gear into the partial observer coverage category while groundfish CDQ fishing, and
3. Updating CDQ community population information, and making other miscellaneous editorial revisions to CDQ Program-related text in the FMP.

Amendment 120, implemented December 20, 2019:
1. Limits the number of catcher/processors (C/Ps) eligible to operate as motherships receiving and processing Pacific cod from catcher vessels (CVs) directed fishing in the BSAI non-Community Development Quota Program Pacific cod trawl fishery.
2. Prohibits replaced Amendment 80 C/Ps from receiving and processing Pacific cod harvested and delivered by CVs directed fishing for Pacific cod in the BSAI and GOA.

Amendment 122, implemented August 8, 2023
1. Establishes the Pacific Cod Trawl Cooperative Program (PCTC Program or Program), a limited access privilege program (LAPP) to harvest Pacific cod in the BSAI trawl catcher vessel (CV) sector.

Table 2.7 Non-commercial catch of Pacific cod (kg) in the Bering Sea 2012-2021.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Grand Total
AFSC Annual Longline Survey	27,179		32,797		26,260		29,028		26,629		141,893
Aleutian Island Bottom Trawl Survey		2,167		1,940		2,814				2,522	9,443
Bait for Crab Fishery	1,383,450	1,750,993	2,013,221	1,424,231	864,191	885,990	864,204	1,323,011	957,800	181,944	11,649,035
Bering Sea Acoustic Survey											0
BS Bottom Trawl Survey											0
BS Slope Survey				874							874
Blue King Crab Pot Survey						3,438				4,581	8,019
Bristol Bay Red King Crab Tagging								729			729
BSAI Trawl Salmon Excluder Device EFP 2018-03-02									2,041		2,041
Eastern Bering Sea Bottom Trawl Survey	33,345	38,500	39,268	35,590	24,072	18,859	18,544		22,500	24,334	255,012
EBS Walleye Pollock Acoustic-Trawl Survey						342				12	354
Gulf of Alaska Bottom Trawl Survey	0		134				22				156
IPHC Annual Longline Survey	28,887	52,417	58,812	47,227	36,527	33,603	46,065		26,513	32,881	362,932
Large-Mesh Trawl Survey	573	1,041	1,137	830	1,007	467	285		373	934	6,647
NBS Bottom Trawl Survey					8,800	6,394	11,535		7,616	4,987	39,332
Pollock EFP 11-01											0
Pribilof Island Tanner Tagging							66				66
Pribilof Islands Crab Survey				4,557							4,557
Sport Fishery				1,630	1,844	3,712		902			8,088
St. Matthews Crab Survey					5,415						5,418
Summer EBS Survey with Russia											0
Grand Total	1,473,435	1,845,118	2,145,369	1,516,880	968,117	955,620	969,750	1,324,642	1,043,473	252,195	12,494,599

Table 2.8. Number of hauls sampled and input composition sample sizes (survey includes EBS and NBS; units = hauls). * as of October 3, 2024

Year	Survey hauls	Fishery hauls	Fishery input	Year	Survey hauls	Fishery hauls	Fishery input
1977		92	6	2002	364	11,607	751
1978		147	10	2003	363	14,477	936
1979		181	12	2004	361	12,144	785
1980		187	12	2005	360	11,641	753
1981		212	14	2006	354	9,078	587
1982	313	106	7	2007	368	7,119	460
1983	255	393	25	2008	338	8,429	545
1984	264	471	30	2009	360	7,465	483
1985	345	710	46	2010	405	6,652	430
1986	349	725	47	2011	368	8,739	565
1987	339	1,328	86	2012	356	9,342	604
1988	339	1,353	88	2013	354	11,094	718
1989	293	626	40	2014	373	12,129	784
1990	329	643	42	2015	354	11,200	724
1991	313	5,267	341	2016	376	9,498	614
1992	332	5,195	336	2017	481	8,317	538
1993	363	3,080	199	2018	364	6,390	413
1994	364	4,839	313	2019	479	4,605	298
1995	347	5,258	340	2020		3,526	228
1996	359	6,797	440	2021	476	2,894	187
1997	369	7,216	467	2022	481	3,902	252
1998	362	6,898	446	2023	438	3,793	245
1999	336	9,171	593	2024*	335	3,114	201
2000	355	9,966	645				
2001	366	10,581	684				

Table 2.9. Number of otoliths and fish measured for length from the bottom trawl survey and fishery. 1cm and 5cm for the survey are the bootstrap based input sample sizes used in the 1cm length binned and 5cm length binned models. * as of October 3, 2024

Fishery				Survey					Fishery				Survey				
		Length			Length		Age				Length			Length		Age	
Year	**#Hauls**	**1cm**	**5cm**	**#Hauls**	**1cm**	**5cm**	**1cm**	**5cm**	**Year**	**#Hauls**	**1cm**	**5cm**	**#Hauls**	**1cm**	**5cm**	**1cm**	**5cm**
1977	92	6	6						2002	11,607	751	751	402	2,136	909	162	162
1978	147	10	10						2003	14,477	936	936	363	1,011	425	255	206
1979	181	12	12						2004	12,144	785	785	422	1,918	801	198	155
1980	187	12	12						2005	11,641	753	753	360	1,142	335	166	150
1981	212	14	14						2006	9,078	587	587	354	2,563	1,048	417	328
1982	106	7	7	313	2,415	1,170			2007	7,119	460	460	368	278	118	57	60
1983	393	25	25	255	1,153	322			2008	8,429	545	545	381	1,756	583	82	85
1984	471	30	30	264	2,484	972			2009	7,465	483	483	360	922	275	152	138
1985	710	46	46	369	863	223			2010	6,652	430	430	451	1,188	373	49	48
1986	725	47	47	349	2,016	706			2011	8,739	565	565	368	1,357	432	54	50
1987	1,328	86	86	339	2,092	1,150			2012	9,342	604	604	400	859	263	61	53
1988	1,353	88	88	370	1,597	1,117			2013	11,094	718	718	354	870	236	72	67
1989	626	40	40	293	1,187	806			2014	12,129	784	784	373	1,063	298	141	133
1990	643	42	42	329	1,206	547			2015	11,200	724	724	354	2,116	785	87	81
1991	5,267	341	341	330	1,178	420			2016	9,498	614	614	412	3,109	1,235	158	154
1992	5,195	336	336	332	802	254			2017	8,317	538	538	481	3,918	1,722	153	145
1993	3,080	199	199	363	787	349			2018	6,390	413	413	364	2,955	1,420	130	119
1994	4,839	313	313	364	1,296	511			2019	4,605	298	298	479	1,741	635	193	152
1995	5,258	340	340	347	1,942	909			2020	3,526	228	228	*NA*	*NA*	*NA*	*NA*	*NA*
1996	6,797	440	440	359	1,413	549			2021	2,894	187	187	476	3,973	1,558	180	196
1997	7,216	467	467	369	1,371	652			2022	3,902	252	252	481	2,978	1,062	183	171
1998	6,898	446	446	362	2,143	1,037			2023	3,793	245	245	438	2,181	717	210	171
1999	9,171	593	593	336	2,053	863			**2024***	3,114	201	201	335	2,556	1,027		
2000	9,966	645	645	355	1,373	501	169	124									
2001	10,581	684	684	366	1,754	515	225	167									

Table 2.10. VAST estimates of bottom trawl survey population estimates including estimates from 2023 and designed-based bottom trawl survey population abundance estimates in number of fish. Note that the design-based estimates are not used in any assessment model.

	VAST				Design-based	
Year	**2023 Survey Population**	**Survey sigma**	**2024 Survey population**	**Survey sigma**	**Survey population**	**Survey sigma**
1982	716,238,486	0.058	715,517,329	0.057	584,527,764	0.065
1983	872,881,656	0.068	873,613,312	0.068	755,141,713	0.107
1984	707,235,961	0.052	706,333,724	0.052	653,144,367	0.073
1985	898,449,665	0.047	901,208,370	0.046	844,157,635	0.135
1986	886,272,919	0.048	885,008,114	0.048	840,829,831	0.100
1987	826,673,977	0.058	825,641,077	0.057	698,609,301	0.064
1988	546,198,585	0.044	546,100,589	0.044	512,360,646	0.070
1989	359,056,286	0.057	359,172,791	0.057	301,283,393	0.066
1990	472,952,956	0.052	472,140,589	0.051	439,009,229	0.084
1991	513,960,581	0.052	513,627,319	0.052	498,850,467	0.103
1992	558,740,796	0.057	558,055,506	0.057	587,304,178	0.117
1993	828,537,387	0.057	828,771,804	0.057	817,857,217	0.122
1994	1,175,872,285	0.050	1,174,742,378	0.049	1,260,690,444	0.122
1995	722,563,373	0.049	722,059,064	0.048	764,228,128	0.099
1996	612,476,384	0.060	613,005,030	0.060	615,809,467	0.143
1997	522,126,209	0.056	523,442,900	0.056	494,486,664	0.143
1998	617,988,136	0.071	619,556,656	0.071	524,149,999	0.090
1999	524,847,498	0.055	527,894,428	0.055	542,810,224	0.100
2000	518,365,580	0.056	518,416,637	0.056	489,723,432	0.090
2001	1,009,265,997	0.055	1,009,879,503	0.055	977,116,907	0.094
2002	630,299,339	0.070	631,717,077	0.071	545,304,209	0.099
2003	624,762,160	0.079	625,925,880	0.079	517,535,040	0.120
2004	491,606,853	0.081	492,384,586	0.081	405,251,778	0.085
2005	503,860,346	0.071	503,964,618	0.071	465,249,132	0.137
2006	440,865,680	0.046	440,786,736	0.046	407,949,964	0.059
2007	596,262,820	0.051	596,072,936	0.051	758,497,684	0.261
2008	484,296,412	0.051	483,587,514	0.051	494,359,349	0.101
2009	714,651,282	0.046	713,922,932	0.046	724,773,833	0.087
2010	751,996,509	0.049	752,482,556	0.049	908,910,263	0.130
2011	862,113,812	0.048	862,076,821	0.048	847,967,419	0.094
2012	1,052,650,749	0.059	1,053,714,988	0.059	996,959,219	0.092
2013	760,050,533	0.056	768,343,917	0.056	764,239,273	0.165
2014	1,229,682,439	0.068	1,230,165,174	0.068	1,134,482,396	0.127
2015	1,083,380,793	0.067	1,081,398,929	0.066	989,903,732	0.115
2016	941,158,208	0.094	941,485,483	0.094	662,134,412	0.093
2017	519,281,137	0.044	519,064,849	0.044	500,634,049	0.073
2018	527,053,290	0.063	527,814,198	0.063	249,081,430	0.071
2019	761,533,036	0.051	761,370,473	0.051	730,701,588	0.092
2021	605,259,773	0.055	607,307,846	0.056	551,453,353	0.072
2022	551,869,130	0.048	552,637,226	0.048	511,194,737	0.064
2023	620,421,592	0.047	620,365,123	0.046	607,932,837	0.073
2024			501,465,762	0.054	436,530,028	0.071

Table 2.11. Designed-based biomass estimate for the AFSC bottom trawl survey 1987-2024 and relative population number (RPN) estimates for the AFSC longline survey Bering Sea region 1997-2024. Note that these are not used in any assessment model.

	EBS		NBS		Total		AFSC Longline	
Year	**Biomass (t)**	**CV**	**Biomass (t)**	**CV**	**Biomass (t)**	**CV**	**RPN**	**CV**
1982	1,013,625	0.073			1,013,625	0.073		
1983	1,189,533	0.102			1,189,533	0.102		
1984	1,014,756	0.062			1,014,756	0.062		
1985	1,001,620	0.056			1,001,620	0.056		
1986	1,118,640	0.062			1,118,640	0.062		
1987	1,064,504	0.060			1,064,504	0.060		
1988	975,197	0.079			975,197	0.079		
1989	866,777	0.072			866,777	0.072		
1990	727,806	0.072			727,806	0.072		
1991	530,731	0.073			530,731	0.073		
1992	539,064	0.083			539,064	0.083		
1993	670,773	0.080			670,773	0.080		
1994	1,379,428	0.179			1,379,428	0.179		
1995	1,010,002	0.091			1,010,002	0.091		
1996	910,374	0.096			910,374	0.096		
1997	627,118	0.109			627,118	0.109	204,250	0.099
1998	551,408	0.078			551,408	0.078		
1999	618,730	0.091			618,730	0.091	139,390	0.105
2000	537,449	0.080			537,449	0.080		
2001	827,408	0.088			827,408	0.088	168,872	0.135
2002	597,450	0.106			597,450	0.106		
2003	625,549	0.099			625,549	0.099	203,096	0.124
2004	578,018	0.058			578,018	0.058		
2005	638,154	0.068			638,154	0.068	109,534	0.210
2006	543,533	0.053			543,533	0.053		
2007	450,305	0.078			450,305	0.078	119,105	0.139
2008	427,423	0.065			427,423	0.065		
2009	430,461	0.082			430,461	0.082	95,553	0.222
2010	872,777	0.118	29,126	0.226	901,904	0.114		
2011	913,952	0.073			913,952	0.073	143,786	0.182
2012	899,909	0.113			899,909	0.113		
2013	813,804	0.092			813,804	0.092	171,225	0.245
2014	1,098,193	0.140			1,098,193	0.140		
2015	1,111,980	0.135			1,111,980	0.135	157,996	0.193
2016	986,239	0.078			986,239	0.078		
2017	644,508	0.078	287,551	0.127	932,060	0.066	124,913	0.147
2018	507,316	0.058			507,316	0.058		
2019	517,141	0.044	365,005	0.147	882,146	0.066	94,496	0.141
2020								
2021	616,380	0.049	227,582	0.178	843,962	0.060	108,312	0.216
2022	647,400	0.065	153,735	0.130	801,135	0.058		
2023	663,075	0.056	108,346	0.146	771,421	0.053	73,822	0.181
2024	635,840	0.057			635,840	0.057		

Table 2.12. Aging error and aging bias for Model 23.1.0.d and 24.0 with linear aging error.

Expected Age	1977-2007		2008-2024	
	Observed Age	Stdev	Observed Age	Stdev
0.5	0.595	0.113	0.5	0.113
1.5	1.786	0.113	1.5	0.113
2.5	2.977	0.226	2.5	0.226
3.5	4.167	0.340	3.5	0.340
4.5	5.358	0.453	4.5	0.453
5.5	6.549	0.566	5.5	0.566
6.5	7.739	0.679	6.5	0.679
7.5	8.930	0.793	7.5	0.793
8.5	10.121	0.906	8.5	0.906
9.5	11.312	1.019	9.5	1.019
10.5	12.502	1.132	10.5	1.132
11.5	13.693	1.245	11.5	1.245
12.5	14.884	1.359	12.5	1.359
13.5	16.074	1.472	13.5	1.472
14.5	17.265	1.585	14.5	1.585
15.5	18.456	1.698	15.5	1.698
16.5	19.646	1.812	16.5	1.812
17.5	20.837	1.925	17.5	1.925
18.5	22.028	2.038	18.5	2.038
19.5	23.218	2.151	19.5	2.151
20.5	24.409	2.264	20.5	2.264

Table 2.13. Aging error and aging bias for Model 24.1, Model 24.2, and Model 24.3 with splined aging error.

Expected Age	1977-2007 Observed Age	Stdev	2008-2024 Observed Age	Stdev
0.5	0.595	0.180	0.5	0.180
1.5	1.786	0.180	1.5	0.180
2.5	2.977	0.301	2.5	0.301
3.5	4.167	0.381	3.5	0.381
4.5	5.358	0.439	4.5	0.439
5.5	6.549	0.492	5.5	0.492
6.5	7.739	0.563	6.5	0.563
7.5	8.930	0.670	7.5	0.670
8.5	10.121	0.815	8.5	0.815
9.5	11.312	0.993	9.5	0.993
10.5	12.502	1.204	10.5	1.204
11.5	13.693	1.325	11.5	1.325
12.5	14.884	1.445	12.5	1.445
13.5	16.074	1.565	13.5	1.565
14.5	17.265	1.686	14.5	1.686
15.5	18.456	1.806	15.5	1.806
16.5	19.646	1.927	16.5	1.927
17.5	20.837	2.047	17.5	2.047
18.5	22.028	2.168	18.5	2.168
19.5	23.218	2.288	19.5	2.288
20.5	24.409	2.408	20.5	2.408

Table 2.14 Parameter counts in the models.

Model	Model 23.1.0.d	Model 24.0	Model 24.1	Model 24.2	Model 24.3
Early recruitment deviations	20	20	20	20	20
Main recruitment deviations	46	46	46	46	46
Length at age 1.5 deviations	25	25	25	25	25
Richard's Rho deviations	25	25			
K deviations			25	25	25
Selectivity (survey) deviations	43	43	43		
Annual deviations	159	159	159	116	116
Growth	4	4	4	4	4
Stock-recruitment	2	2	2	2	2
Initial fishing mortality	1	1	1	1	1
Log catchability (survey)	2	2	2	2	2
Selectivity (fishery)	4	4	4	4	4
Selectivity (survey)	2	2	2	2	2
TRUE parameters	15	15	15	15	15
Total parameters	174	174	174	131	131

Table 2.15. Objective function values (negative log likelihood) and parameter counts as well as selected results for 2024 proposed models.

Label	Model.23.1.0.d	Model 24.0	Model 24.1	Model 24.2	Model 24.3
# parameters	174	174	174	131	131
TOTAL like	347.664	250.559	246.832	259.777	235.788
Survey like	-59.0241	-59.3939	-59.0658	-56.6235	-60.9809
Length comp like	317.474	222.537	222.633	236.33	214.803
Age comp like	64.544	61.7063	57.439	58.4723	60.9784
Francis TA1.8 Variance adjustment factors					
Fishery length	0.420	0.428	0.428	0.428	0.445
Survey length	0.083	0.194	0.194	0.194	0.135
Survey age	0.502	0.454	0.454	0.454	0.604
Jitter % success	78%	86%	84%	32%	70%
Index RMSE	0.146	0.145	0.146	0.155	0.140
SDNR					
Survey Age	0.93	0.93	0.93	0.93	0.93
Survey Length	0.99	0.94	0.96	0.96	1.00
Fishery Length	1.09	1.08	1.08	1.07	1.08
LN(R_0)	13.3606	13.3448	13.3409	13.3543	13.3169
σ_R	0.6908	0.6908	0.6908	0.6908	0.6646
Natural mortality (M)	0.387	0.387	0.387	0.387	0.387
L_{20}	112.781	113.276	112.26	112.517	114.732
$L_{1.5}$	13.988	13.869	13.851	13.761	12.077
VonBert K	1.494	1.507	1.486	1.503	1.552
Bratio 2023	0.398	0.395	0.398	0.416	0.376
SPRratio 2023	0.540	0.545	0.542	0.527	0.564
Q Bottom trawl survey	0.970	0.985	0.987	0.970	1.008
Q sd ajustment	0.093	0.092	0.093	0.102	0.087
$B_{100\%}$ (10^6 t)	567,265	562,365	561,915	565,875	552,100
$F_{35\%}$	0.364	0.365	0.363	0.364	0.361
maxABC 2025	156,032	151,060	153,617	172,866	116,770
maxABC 2026	144,010	140,989	141,520	160,276	119,491

Jitter % success = percent of 50 jitter runs at 0.1 jitter that successfully converged at the MLE.
RMSSR = Root of the mean squared standardized residual (>1 = underfit, <1 overfit)
LN(R_0) = the natural log of the equilibrium virgin recruits at age-0
$B_{100\%}$ = equilibrium unfished female spawning biomass
$F_{40\%}$ = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
maxABC = maximum permissible ABC under Tier 3

Table 2.16.Likelihoods by fleet for all models.

Label	All	fishery	survey	Model
Age_like	64.544	0	64.544	Model 23.1.0.d 1cm
Age_like	61.706	0	61.706	Model 24.0
Age_like	57.439	0	57.439	Model 24.1
Age_like	5.847e+01	0.000e+00	58.472	Model 24.2
Age_like	6.098e+01	0.000e+00	60.978	Model 24.3
Catch_like	7.141e-11	7.141e-11	0	Model 23.1.0.d 1cm
Catch_like	9.319e-11	9.319e-11	0	Model 24.0
Catch_like	6.862e-11	6.862e-11	0	Model 24.1
Catch_like	5.153e-11	5.153e-11	0	Model 24.2
Catch_like	1.61068e-10	1.61068e-10	0	Model 24.3
Init_equ_like	0.0001627	0.0001627	0	Model 23.1.0.d 1cm
Init_equ_like	0.000171724	0.000171724	0	Model 24.0
Init_equ_like	0.000171388	0.000171388	0	Model 24.1
Init_equ_like	0.000160892	0.000160892	0	Model 24.2
Init_equ_like	0.000150797	0.000150797	0	Model 24.3
Length_like	317.474	156.793	160.680	Model 23.1.0.d 1cm
Length_like	222.537	119.666	102.871	Model 24.0
Length_like	222.633	119.365	103.269	Model 24.1
Length_like	236.33	119.964	116.367	Model 24.2
Length_like	214.803	123.735	91.068	Model 24.3
Surv_like	-59.024	0	-59.024	Model 23.1.0.d 1cm
Surv_like	-59.394	0	-59.394	Model 24.0
Surv_like	-59.066	0	-59.066	Model 24.1
Surv_like	-56.624	0	-56.624	Model 24.2
Surv_like	-60.981	0	-60.981	Model 24.3

Table 2.17. Fits to size composition and age composition data with (Nave) adjusted average input sample size, the (Har. Mean EffN) harmonic mean of the effective sample size, and the ratio of the two.

Model	Data	Nave	Har. Mean Effn	Ratio
Model 23.1.0.d	Fishery Length	152.107	594.409	3.908
Model 24.0	Fishery Length	154.982	157.493	1.016
Model 24.1	Fishery Length	154.982	157.306	1.015
Model 24.2	Fishery Length	154.982	157.771	1.018
Model 24.3	Fishery Length	160.939	160.496	0.997
Model 23.1.0.d	Survey Length	133.232	511.003	3.835
Model 24.0	Survey Length	138.364	141.602	1.023
Model 24.1	Survey Length	138.364	141.252	1.021
Model 24.2	Survey Length	138.364	124.933	0.903
Model 24.3	Survey Length	96.732	126.182	1.304
Model 23.1.0.d	Survey Age	135.435	47.742	0.353
Model 24.0	Survey Age	70.087	47.142	0.673
Model 24.1	Survey Age	70.087	52.406	0.748
Model 24.2	Survey Age	70.087	50.132	0.715
Model 24.3	Survey Age	93.284	65.148	0.698

Table 2.18.Mean absolute scaled error (MASE) values for model data components for all models and versions. Values greater than 1.0 indicated prediction fits worse than a random walk.

	Index	Lengths		Age
Model		Fishery	Survey	Survey
Model 23.1.0.d	0.47	0.15	0.31	0.14
Model 24.0	0.45	0.16	0.32	0.15
Model 24.1	0.47	0.15	0.32	0.14
Model 24.2	0.48	0.15	0.42	0.15
Model 24.3	0.53	0.15	0.44	0.14

Table 2.19.“Sigma” terms for vectors of annual random deviations other than those associated with catchability.Deviations are ~normal(0,σ^2) for ln(Recruits), ~normal(0,1) for others.

	Model 23.1.0.d			Model 24.0			Model 24.1			Model 24.2			Model 24.3		
Parameter	**var_dev**	**ave_var**	**sigma**	**var_dev**	**ave_var**	**sigma**	**var_dev**	**ave_var**	**sigma**	**var_dev**	**ave_var**	**sigma**	**var_dev**	**ave_var**	**sigma**
ln(R)	0.4243	0.0344	0.6908	0.4403	0.0353	0.6908	0.4453	0.0359	0.6908	0.4517	0.0349	0.6908	0.4077	0.0339	0.6646
$L_{1.5}$	0.3759	0.6153	0.2903	0.3483	0.6363	0.2903	0.3836	0.6323	0.2903	0.5276	0.5694	0.2903	0.6798	0.3206	0.2855
Richard’s Rho	0.2489	0.7124	0.0624	0.2437	0.7088	0.0624									
Richard’s K							0.2037	0.8025	0.0624	0.2240	0.8048	0.0624	0.1631	0.8269	0.0511
Sur. Sel. Asc.	0.3349	0.6503	0.2338	0.3968	0.7283	0.2338	0.4015	0.7315	0.2338						

Table 2.20.Retrospective Mohn’s rho values for spawning stock biomass (SSB) and full selection fishing mortality (F) for all models.

2023 Models	Model 23.1.0.d	Model 24.0	Model 24.1	Model 24.2	Model 24.3
SSBMohn’s	-0.10	-0.11	-0.10	-0.14	-0.09
SSB Predictive	-0.15	-0.15	-0.15	-0.20	-0.14
FMohn’s	0.13	0.14	0.13	0.20	0.12
F Predictive	0.19	0.20	0.19	0.27	0.18

Table 2.21.Estimated parameter values and standard deviations for Model23.1.0.d, Model 24.0 and Model 24.1 The full list of parameters and deviations can be found in Appendix 2.4.

	Model 23.1.0.d		**Model 24.0**		**Model 24.1**	
Label	**Est.**	**Stdev.**	**Est.**	**Stdev.**	**Est.**	**Stdev.**
$L_{1.5}$	13.988	0.208	13.869	0.315	13.851	0.323
L_{20}	112.781	3.575	113.276	3.696	112.260	3.437
VonBert_K	0.112	0.013	0.110	0.014	0.115	0.013
Richards ρ	1.494	0.073	1.507	0.076	1.486	0.074
LN(R_0)	13.361	0.043	13.345	0.043	13.341	0.042
SR_regime_1976	-0.641	0.235	-0.647	0.235	-0.647	0.235
Early_InitAge_20	-0.005	0.689	-0.005	0.689	-0.005	0.689
Early_InitAge_19	-0.003	0.690	-0.003	0.690	-0.003	0.690
Early_InitAge_18	-0.005	0.689	-0.005	0.689	-0.005	0.689
Early_InitAge_17	-0.008	0.688	-0.008	0.688	-0.008	0.688
Early_InitAge_16	-0.013	0.686	-0.013	0.686	-0.013	0.686
Early_InitAge_15	-0.020	0.684	-0.020	0.684	-0.020	0.684
Early_InitAge_14	-0.032	0.680	-0.032	0.680	-0.031	0.680
Early_InitAge_13	-0.049	0.675	-0.049	0.675	-0.048	0.675
Early_InitAge_12	-0.074	0.667	-0.074	0.667	-0.073	0.667
Early_InitAge_11	-0.109	0.657	-0.110	0.657	-0.109	0.657
Early_InitAge_10	-0.157	0.644	-0.157	0.644	-0.156	0.644
Early_InitAge_9	-0.216	0.629	-0.216	0.629	-0.215	0.629
Early_InitAge_8	-0.281	0.614	-0.282	0.614	-0.281	0.614
Early_InitAge_7	-0.342	0.600	-0.342	0.600	-0.341	0.600
Early_InitAge_6	-0.372	0.591	-0.371	0.591	-0.372	0.591
Early_InitAge_5	-0.327	0.592	-0.324	0.593	-0.325	0.593
Early_InitAge_4	-0.155	0.603	-0.148	0.605	-0.149	0.604
Early_InitAge_3	0.060	0.598	0.065	0.601	0.064	0.599
Early_InitAge_2	-0.003	0.607	0.003	0.607	-0.001	0.606
Early_InitAge_1	0.104	0.654	0.080	0.654	0.079	0.652
InitF	0.085	0.028	0.087	0.029	0.087	0.029
Ln (Q_{BT})	-0.031	0.057	-0.015	0.056	-0.013	0.056
Q_{BT} extra SD	0.093	0.019	0.092	0.019	0.093	0.019
Fishery peak selectivity 1990-2024	74.633	0.935	74.737	0.947	74.624	0.938
Fishery ascending slope width 1990-2024	5.964	0.041	5.968	0.042	5.965	0.042
Fishery peak selectivity 1977-1989	74.555	5.604	74.940	5.710	74.691	5.668
Fishery ascending slope width 1977-1989	6.448	0.265	6.465	0.268	6.456	0.268
Survey peak selectivity	22.143	0.600	22.554	1.099	22.450	1.117
Survey ascending slope width	3.852	0.136	4.016	0.251	3.993	0.256

Table 2.22.Estimated parameter values and standard deviations for Model23.1.0.d, Model 24.2, and Model 24.3 The full list of parameters and deviations can be found in Appendix 2.4.

	Model 24.2			Model 24.3
Label	**Est.**	**Stdev.**	**Est.**	**Stdev.**
$L_{1.5}$	13.761	0.379	12.077	0.148
L_{20}	112.517	3.481	114.732	3.995
VonBert_K	0.112	0.013	0.106	0.014
Richards ρ	1.503	0.073	1.552	0.071
$LN(R_0)$	13.354	0.043	13.317	0.038
SR_regime_1976	-0.630	0.235	-0.582	0.233
Early_InitAge_20	-0.006	0.689	-0.005	0.663
Early_InitAge_19	-0.003	0.690	-0.003	0.664
Early_InitAge_18	-0.005	0.689	-0.005	0.663
Early_InitAge_17	-0.008	0.688	-0.008	0.662
Early_InitAge_16	-0.013	0.686	-0.012	0.661
Early_InitAge_15	-0.021	0.684	-0.019	0.658
Early_InitAge_14	-0.032	0.680	-0.029	0.655
Early_InitAge_13	-0.049	0.675	-0.045	0.650
Early_InitAge_12	-0.074	0.667	-0.068	0.644
Early_InitAge_11	-0.110	0.657	-0.101	0.634
Early_InitAge_10	-0.158	0.644	-0.145	0.623
Early_InitAge_9	-0.217	0.629	-0.200	0.609
Early_InitAge_8	-0.282	0.613	-0.261	0.595
Early_InitAge_7	-0.342	0.600	-0.318	0.582
Early_InitAge_6	-0.371	0.592	-0.346	0.574
Early_InitAge_5	-0.322	0.594	-0.299	0.576
Early_InitAge_4	-0.145	0.605	-0.126	0.586
Early_InitAge_3	0.067	0.601	0.073	0.580
Early_InitAge_2	0.010	0.609	-0.010	0.586
Early_InitAge_1	0.116	0.660	0.088	0.626
InitF	0.084	0.028	0.082	0.027
Ln (Q_{BT})	-0.030	0.057	0.008	0.051
Q_{BT} extra SD	0.102	0.020	0.087	0.018
Fishery peak selectivity 1990-2024	74.655	0.939	74.932	0.955
Fishery ascending slope width 1990-2024	5.966	0.042	5.979	0.041
Fishery peak selectivity 1977-1989	74.787	5.705	74.515	5.681
Fishery ascending slope width 1977-1989	6.461	0.269	6.465	0.269
Survey peak selectivity	21.507	1.157	14.088	3.782
Survey ascending slope width	3.716	0.288	-3.527	97.922

Table 2.23. Management reference point for Model 23.1.0.d in 2023, this year's Model 23.1.0.d in 2024, Model 24.0, and Model 24.1.

	Last Year Est.	Model 23.1.0.d Est.	Model 23.1.0.d cv	Model 24.0 Est.	Model 24.0 cv	Model 24.1 Est.	Model 24.1 cv
$B_{100\%}$	567,465	567,265	0.032	562,365	0.032	561,915	0.032
$B_{40\%}$	226,986	226,906	0.032	224,945	0.032	224,767	0.032
$B_{35\%}$	198,613	198,543	0.032	196,827	0.032	196,671	0.032
$F_{40\%}$	0.379	0.364	0.019	0.365	0.019	0.363	0.018
$F_{35\%}$	0.465	0.446	0.024	0.447	0.025	0.444	0.024
2025 Female spawning biomass	211,131	218,076	0.124	213,439	0.125	215,747	0.127
2025 Relative spawning biomass	0.37	0.384	0.041	0.380	0.041	0.384	0.042
2025 Pr(B/B100%<0.2)	< 0.001	< 0.001		< 0.001		< 0.001	
2025 $maxF_{ABC}$	0.35	0.349	0.043	0.345	0.043	0.348	0.044
2025 maxABC	150,876	156,032	0.219	151,060	0.221	153,617	0.225
2025 Catch	150,876	156,032	0.219	151,060	0.221	153,617	0.225
2025 F_{OFL}	0.43	0.427	0.124	0.423	0.125	0.425	0.127
2025 OFL	180,798	186,462	0.217	180,601	0.219	183,509	0.223
2025 Pr(max(ABC>truOFL)	0.020	0.183		0.187		0.192	
2026 Female spawning biomass		209,148	0.086	205,830	0.086	206,498	0.087
2026 Relative spawning biomass		0.369	0.025	0.366	0.025	0.367	0.026
2026 Pr(B/B100%<0.2)		< 0.001		< 0.001		< 0.001	
2026 $maxF_{ABC}$		0.334	0.028	0.332	0.028	0.332	0.028
2026 maxABC		144,010	0.146	140,989	0.147	141,520	0.147
2026 Catch		144,010	0.146	140,989	0.147	141,520	0.147
2026 F_{OFL}		0.409	0.134	0.407	0.135	0.406	0.136
2026 OFL		172,261	0.237	168,705	0.237	169,243	0.240
2026 Pr(max(ABC>truOFL)		0.087		0.089		0.093	

Legend:
$B_{100\%}$ = equilibrium unfished female spawning biomass
$B_{40\%}$ = 40% of B100% (the inflection point of the harvest control rules in Tier 3)
$B_{35\%}$ = 35% of B100% (the BMSY proxy for Tier 3)
$F_{40\%}$ = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
$F_{35\%}$ = fishing mortality that reduces equilibrium spawning per recruit to 35% of unfished
Relative spawning biomass = ratio of female spawning biomass to $B_{100\%}$
Pr($B/B_{100\%}$<0.2) = probability that relative spawning biomass is less than 0.2
$maxF_{ABC}$ = maximum permissible ABC fishing mortality rate under Tier 3
maxABC = maximum permissible ABC under Tier 3
Catch = estimated catch conditional on ABC=maxABC
F_{OFL} = OFL fishing mortality rate under Tier 3
OFL = OFL under Tier 3
Pr(maxABC>truOFL) = probability that maxABC is greater than the "true" OFL

Table 2.24.Management reference point for Model 23.1.0.d in 2023, Model 24.1, and Model 24.3.

	Last Year Est.	Model 24.1 Est.	Model 24.1 cv	Model 24.3 Est.	Model 24.3 cv
$B_{100\%}$	567,465	561,915	0.032	552,100	0.029
$B_{40\%}$	226,986	224,767	0.032	220,840	0.029
$B_{35\%}$	198,613	196,671	0.032	193,235	0.029
$F_{40\%}$	0.379	0.363	0.018	0.361	0.019
$F_{35\%}$	0.465	0.444	0.024	0.442	0.024
2025 Female spawning biomass	211,131	215,747	0.127	186,337	0.125
2025 Relative spawning biomass	0.37	0.384	0.042	0.338	0.037
2025 Pr(B/B100%<0.2)	< 0.001	< 0.001		< 0.001	
2025 maxF_{ABC}	0.35	0.348	0.044	0.302	0.037
2025 maxABC	150,876	153,617	0.225	116,770	0.223
2025 Catch	150,876	153,617	0.225	116,770	0.223
2025 F_{OFL}	0.43	0.425	0.127	0.369	0.125
2025 OFL	180,798	183,509	0.223	139,917	0.221
2025 Pr(max(ABC>truOFL)	0.020	0.192		0.184	
2026 Female spawning biomass		206,498	0.087	187,854	0.087
2026 Relative spawning biomass		0.367	0.026	0.340	0.024
2026 Pr(B/B100%<0.2)		< 0.001		< 0.001	
2026 maxF_{ABC}		0.332	0.028	0.304	0.026
2026 maxABC		141,520	0.147	119,491	0.149
2026 Catch		141,520	0.147	119,491	0.149
2026 F_{OFL}		0.406	0.136	0.372	0.135
2026 OFL		169,243	0.240	143,191	0.227
2026 Pr(max(ABC>truOFL)		0.093		0.093	

Legend:
$B_{100\%}$ = equilibrium unfished female spawning biomass
$B_{40\%}$ = 40% of B100% (the inflection point of the harvest control rules in Tier 3)
$B_{35\%}$ = 35% of B100% (the BMSY proxy for Tier 3)
$F_{40\%}$ = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
$F_{35\%}$ = fishing mortality that reduces equilibrium spawning per recruit to 35% of unfished
Relative spawning biomass = ratio of female spawning biomass to $B_{100\%}$
Pr($B/B_{100\%}$<0.2) = probability that relative spawning biomass is less than 0.2
maxF_{ABC} = maximum permissible ABC fishing mortality rate under Tier 3
maxABC = maximum permissible ABC under Tier 3
Catch = estimated catch conditional on ABC=maxABC
F_{OFL} = OFL fishing mortality rate under Tier 3
OFL = OFL under Tier 3
Pr(maxABC>truOFL) = probability that maxABC is greater than the "true" OFL

Table 2.25.Female spawning biomass (t) time series comparison for Model 23.1.0.d in 2023 (last Year Est.), this year's Model 23.1.0.d in 2024, and Model 24.0. 2025 values based on 2024 total catch of 165,659t

		Model 23.1.0.d		Model 24.0	
Year	**Last Year Est.**	**Est.**	**Stdev.**	**Est.**	**Stdev.**
1978	120,404	165,991	71,298	162,988	70,242
1979	122,464	168,090	69,043	165,200	68,095
1980	149,229	190,833	67,338	188,141	66,434
1981	228,665	257,826	65,183	255,833	64,337
1982	335,736	352,521	64,853	350,361	64,108
1983	428,454	439,046	63,774	435,070	63,144
1984	465,465	472,651	60,852	466,421	60,346
1985	448,278	456,011	56,219	448,970	55,698
1986	417,396	430,656	50,528	424,952	49,793
1987	400,785	418,469	45,038	414,422	44,108
1988	393,564	411,910	39,952	409,106	38,991
1989	367,874	384,457	35,538	382,887	34,732
1990	328,005	342,855	31,895	341,820	31,386
1991	273,319	280,354	28,425	278,786	28,153
1992	197,646	203,719	25,128	201,195	24,935
1993	165,454	175,431	22,626	172,515	22,426
1994	189,727	189,119	21,089	186,449	20,818
1995	215,388	203,348	20,114	200,846	19,766
1996	221,131	208,069	19,347	205,449	18,947
1997	217,428	210,698	19,039	207,937	18,605
1998	188,128	181,424	18,558	178,646	18,098
1999	168,406	162,336	18,270	159,606	17,798
2000	165,975	160,865	18,637	158,085	18,170
2001	178,348	169,948	18,959	167,048	18,537
2002	192,341	178,553	19,282	175,743	18,888
2003	202,885	184,756	19,744	182,242	19,410
2004	210,084	193,897	18,779	191,865	18,505
2005	200,995	186,819	17,614	185,105	17,360
2006	174,916	163,753	16,440	162,339	16,199
2007	142,957	136,737	15,229	135,410	14,987
2008	116,100	115,022	14,251	113,576	14,028
2009	103,150	105,534	14,608	103,749	14,373
2010	109,328	116,758	15,541	115,075	15,314
2011	129,255	143,535	18,439	141,591	18,172
2012	151,206	170,574	21,367	168,225	21,073
2013	184,946	200,427	24,259	197,311	23,878
2014	202,036	220,434	28,008	217,094	27,578
2015	255,266	263,139	32,129	259,564	31,653
2016	300,939	305,675	37,373	301,484	36,818
2017	335,350	340,486	40,672	335,707	40,066
2018	334,920	346,635	41,205	341,972	40,597
2019	317,676	327,393	39,451	323,061	38,828
2020	275,236	285,052	36,306	281,188	35,678
2021	232,544	242,603	33,515	238,776	32,881
2022	220,241	231,997	32,793	228,117	32,170
2023	213,565	225,886	33,478	222,180	32,884
2024	223,107	224,653	35,183	220,977	34,593
2025		218,076	38,188	213,439	37,581

Table 2.26.Female spawning biomass (t) time series comparison for Model 23.1.0.d in 2023 (last Year Est.), Model 24.1, and Model 24.3. 2025 values based on 2024 total catch of 165,659t

		Model 24.1		Model 24.3				Model 24.1		Model 24.3	
Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.	Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.
1978	120,404	162,729	70,178	176,291	75,762	2003	202,885	176,986	20,272	171,588	17,770
1979	122,464	164,870	68,001	178,364	73,716	2004	210,084	189,332	19,883	182,961	17,493
1980	149,229	187,478	66,329	198,161	71,863	2005	200,995	185,113	18,724	178,852	16,532
1981	228,665	254,730	64,202	257,835	68,771	2006	174,916	164,242	17,541	158,158	15,439
1982	335,736	349,230	63,959	344,050	67,070	2007	142,957	138,233	16,128	131,954	14,262
1983	428,454	434,432	63,014	423,531	64,867	2008	116,100	115,774	14,749	110,500	13,166
1984	465,465	466,329	60,246	452,543	61,216	2009	103,150	105,743	15,179	100,452	13,431
1985	448,278	448,974	55,620	434,703	55,836	2010	109,328	117,979	16,128	112,012	14,315
1986	417,396	424,979	49,721	412,485	49,181	2011	129,255	144,385	19,234	137,639	16,878
1987	400,785	414,607	44,030	404,826	43,012	2012	151,206	170,052	21,996	163,139	19,349
1988	393,564	409,506	38,911	400,467	37,593	2013	184,946	197,630	24,426	190,045	21,662
1989	367,874	383,607	34,650	373,991	33,119	2014	202,036	214,952	27,951	207,104	24,577
1990	328,005	342,722	31,306	333,097	29,727	2015	255,266	257,384	32,019	245,921	28,053
1991	273,319	279,578	28,083	270,852	26,534	2016	300,939	300,444	37,606	286,697	32,584
1992	197,646	201,690	24,870	193,982	23,348	2017	335,350	333,897	40,997	318,597	35,580
1993	165,454	172,879	22,348	166,049	20,943	2018	334,920	338,807	41,330	324,159	36,101
1994	189,727	186,920	20,720	180,987	19,623	2019	317,676	319,867	39,488	305,173	34,652
1995	215,388	201,360	19,652	196,312	18,757	2020	275,236	279,597	36,264	265,111	31,942
1996	221,131	205,969	18,835	201,377	17,900	2021	232,544	237,994	33,504	224,229	29,420
1997	217,428	208,618	18,538	203,722	17,466	2022	220,241	228,861	32,877	214,211	28,837
1998	188,128	179,370	18,122	173,954	16,804	2023	213,565	223,838	33,644	207,322	29,609
1999	168,406	160,356	17,945	154,576	16,353	2024	223,107	223,289	35,481	203,532	31,252
2000	165,975	158,937	18,524	152,137	16,551	2025		215,747	38,841	186,337	32,860
2001	178,348	163,818	18,885	158,062	16,812						
2002	192,341	170,769	19,257	165,484	17,157						

Table 2.27. Total biomass (t) time series comparison for Model 23.1.0.d in 2023 (Last Year Est.), this year's Model 23.1.0.d in 2024, and Model 24.0. 2025 values based on 2024 total catch of 165,659t

	Model 23.1.0.d		Model 24.0		Model 23.1.0.d		Model 24.0
Year	Last Year Est.	Est.	Est.	Year	Last Year Est.	Est.	Est.
1978	424,461	550,282	540,099	2003	838,594	758,441	749,945
1979	568,732	655,838	645,696	2004	796,080	732,029	725,350
1980	870,422	909,972	900,733	2005	714,486	661,502	655,494
1981	1,167,200	1,192,160	1,179,430	2006	613,232	573,115	567,394
1982	1,371,820	1,387,590	1,369,160	2007	515,138	496,234	490,762
1983	1,430,170	1,448,190	1,425,760	2008	478,564	488,525	482,451
1984	1,413,420	1,431,710	1,409,970	2009	516,621	544,238	535,836
1985	1,376,670	1,410,450	1,393,330	2010	601,334	636,989	627,933
1986	1,343,430	1,378,320	1,363,930	2011	715,247	774,572	764,406
1987	1,344,880	1,380,590	1,369,930	2012	773,752	846,214	834,331
1988	1,285,410	1,323,240	1,316,600	2013	882,016	944,966	929,918
1989	1,108,380	1,149,090	1,143,080	2014	992,445	1,049,020	1,033,590
1990	919,309	958,850	951,246	2015	1,182,710	1,185,160	1,168,740
1991	794,807	816,098	806,536	2016	1,252,430	1,271,800	1,254,900
1992	695,827	726,438	716,065	2017	1,213,480	1,243,690	1,227,440
1993	714,779	736,082	726,026	2018	1,081,690	1,122,320	1,107,920
1994	849,281	810,303	799,665	2019	964,696	983,014	968,792
1995	945,821	871,297	860,603	2020	867,430	877,304	862,534
1996	905,215	830,130	819,924	2021	813,563	837,339	824,443
1997	805,012	749,380	739,562	2022	799,431	829,640	817,069
1998	689,174	650,029	639,970	2023	779,534	807,840	794,611
1999	674,645	656,580	645,918	2024	808,260	804,068	789,814
2000	708,060	671,559	660,998	2025		782,614	766,747
2001	744,843	680,977	670,307				
2002	810,688	729,587	719,625				

Table 2.28. Total biomass (t) time series comparison for Model 23.1.0.d in 2023 (Last Year Est.), Model 24.1, and Model 24.3. 2025 values based on 2024 total catch of 165,659t.

Year	Last Year Est.	Model 24.1 Est.	Model 24.3 Est.
1978	424,461	538,029	570,287
1979	568,732	641,556	654,216
1980	870,422	894,031	881,064
1981	1,167,200	1,172,510	1,142,010
1982	1,371,820	1,364,130	1,323,330
1983	1,430,170	1,422,940	1,377,310
1984	1,413,420	1,407,740	1,359,110
1985	1,376,670	1,391,310	1,350,250
1986	1,343,430	1,362,170	1,324,920
1987	1,344,880	1,368,740	1,331,910
1988	1,285,410	1,316,640	1,282,180
1989	1,108,380	1,144,130	1,113,020
1990	919,309	952,551	923,713
1991	794,807	807,173	778,552
1992	695,827	715,824	689,328
1993	714,779	725,679	701,808
1994	849,281	799,235	776,179
1995	945,821	860,331	839,651
1996	905,215	820,331	800,222
1997	805,012	740,745	720,224
1998	689,174	641,160	617,217
1999	674,645	647,151	620,178
2000	708,060	661,682	636,271
2001	744,843	658,067	637,495
2002	810,688	700,162	681,099
2003	838,594	731,054	711,181
2004	796,080	715,842	694,565
2005	714,486	654,071	633,293
2006	613,232	570,105	549,428
2007	515,138	495,134	470,952
2008	478,564	489,042	460,645
2009	516,621	543,541	513,507
2010	601,334	638,865	604,791
2011	715,247	776,908	744,473
2012	773,752	839,599	803,634
2013	882,016	928,490	889,483
2014	992,445	1,025,390	986,262
2015	1,182,710	1,156,620	1,106,640
2016	1,252,430	1,250,360	1,200,300
2017	1,213,480	1,220,490	1,170,550
2018	1,081,690	1,099,300	1,055,010
2019	964,696	959,813	916,467
2020	867,430	855,929	809,380
2021	813,563	820,876	772,337
2022	799,431	817,870	764,923
2023	779,534	798,720	733,608
2024	808,260	794,604	718,697
2025		769,813	680,076

Table 2.29. Age 0 recruitment (1000x of fish) time series comparison for Model 23.1.0.d in 2023 (Last Year Est.), this year's Model 23.1.0.d in 2024, and Model 24.0.

		Model 23.1.0.d		Model 24.0	
Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.
1978	666,598	1,005,390	472,766	968,276	458,312
1979	1,160,220	982,446	243,700	941,562	232,550
1980	159,614	249,826	77,006	244,828	72,202
1981	207,882	236,934	55,838	235,576	60,022
1982	1,277,270	1,341,750	127,772	1,366,430	135,586
1983	343,818	303,002	78,016	280,252	87,952
1984	1,212,850	1,218,170	115,174	1,206,910	116,822
1985	523,497	478,916	71,390	504,718	69,086
1986	214,907	278,068	49,398	256,276	41,584
1987	55,641	97,798	29,624	83,914	23,604
1988	349,525	342,990	54,592	337,950	53,536
1989	754,746	815,342	92,726	802,208	96,934
1990	659,356	744,006	93,162	749,982	99,438
1991	605,839	463,598	82,720	448,674	86,082
1992	1,311,820	1,142,840	97,406	1,127,890	97,732
1993	546,338	360,670	60,970	365,562	60,962
1994	349,344	301,424	47,772	294,586	47,970
1995	307,284	263,606	45,560	264,642	45,964
1996	982,733	955,230	81,664	930,404	79,946
1997	411,720	424,290	55,638	429,142	56,014
1998	377,025	321,116	52,498	316,940	51,658
1999	1,005,280	745,128	75,754	736,010	73,190
2000	659,934	691,694	66,946	687,130	65,408
2001	339,282	323,094	46,862	327,258	45,952

		Model 23.1.0.d		Model 24.0	
Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.
2002	382,162	370,938	45,956	368,924	44,572
2003	354,230	319,878	42,474	314,618	41,324
2004	259,790	273,704	39,252	273,442	38,322
2005	452,881	440,262	63,408	445,994	64,464
2006	763,306	933,032	95,504	916,342	96,298
2007	426,903	389,806	78,392	379,802	78,004
2008	1,386,370	1,554,170	146,732	1,537,170	146,864
2009	329,010	289,488	100,720	292,472	102,130
2010	935,671	987,372	132,994	969,864	132,764
2011	1,153,180	1,359,690	162,762	1,333,680	162,752
2012	985,325	705,064	124,718	703,956	126,264
2013	1,375,760	1,504,940	135,954	1,489,460	135,862
2014	304,359	274,996	67,100	277,510	68,432
2015	362,098	422,232	65,506	417,470	65,148
2016	252,121	247,918	52,500	243,504	51,428
2017	394,254	263,956	60,846	242,680	56,540
2018	962,390	1,050,520	117,740	1,050,060	116,836
2019	282,001	262,854	56,724	265,740	58,662
2020	420,541	474,678	70,330	460,920	69,170
2021	526,789	564,534	88,498	551,056	85,660
2022	661,439	420,396	76,200	420,486	75,890
2023	661,439	629,438	28,612	622,386	28,172
2024		629,438	28,612	622,386	28,172

Table 2.30. Age 0 recruitment (1,000× of fish) time series for Model 23.1.0.d in 2023 (Last Year Est.), Model 24.1 and Model 24.3.

		Model 24.1		Model 24.3	
Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.
1978	666,598	966,864	451,878	1,012,390	476,154
1979	1,160,220	946,676	230,100	883,500	240,078
1980	159,614	244,192	71,754	243,804	75,854
1981	207,882	235,902	59,964	257,394	65,824
1982	1,277,270	1,362,430	134,868	1,345,360	139,024
1983	343,818	280,710	87,812	335,944	89,162
1984	1,212,850	1,205,500	116,420	1,108,590	117,086
1985	523,497	506,122	68,870	519,550	74,786
1986	214,907	256,970	41,532	244,502	43,760
1987	55,641	84,264	23,656	100,238	27,760
1988	349,525	338,132	53,330	323,822	51,030
1989	754,746	799,804	96,222	813,196	95,118
1990	659,356	748,590	98,872	723,920	98,632
1991	605,839	448,812	85,626	482,434	89,424
1992	1,311,820	1,125,110	96,970	1,093,160	97,660
1993	546,338	366,594	60,766	354,714	63,424
1994	349,344	295,502	47,856	282,124	47,598
1995	307,284	268,510	46,058	298,086	46,532
1996	982,733	926,422	79,190	857,992	70,212
1997	411,720	433,580	54,766	456,496	52,114
1998	377,025	307,692	50,662	305,380	44,638
1999	1,005,280	716,788	71,430	733,622	62,406
2000	659,934	686,868	63,776	654,124	55,392
2001	339,282	311,904	45,000	320,388	40,996
2002	382,162	367,992	43,938	350,510	38,440
2003	354,230	320,784	41,816	313,844	37,354
2004	259,790	255,660	37,824	247,512	33,324
2005	452,881	451,604	63,008	400,698	51,660
2006	763,306	945,580	97,548	928,564	85,584
2007	426,903	357,018	79,082	359,134	72,040
2008	1,386,370	1,553,390	147,648	1,490,430	133,292
2009	329,010	301,630	106,428	328,228	101,742
2010	935,671	970,076	134,520	951,106	121,688
2011	1,153,180	1,347,100	157,008	1,297,380	136,058
2012	985,325	676,196	126,232	690,064	113,016
2013	1,375,760	1,495,550	136,594	1,443,680	121,780
2014	304,359	266,890	69,798	263,420	61,680
2015	362,098	429,674	67,710	424,906	60,468
2016	252,121	239,158	52,818	225,326	46,270
2017	394,254	234,880	56,860	238,820	52,646
2018	962,390	1,039,390	116,464	963,000	100,214
2019	282,001	265,938	61,398	264,298	53,544
2020	420,541	477,720	73,260	449,296	63,472
2021	526,789	578,324	90,604	544,048	81,586
2022	661,439	399,306	73,416	404,180	71,492
2023	661,439	621,430	27,664	606,480	24,416
2024		621,430	27,664	606,480	24,416

Table 2.31. Instantaneous apical fishing mortality comparison for Model 23.1.0.d in 2023 (Last Year Est.), this year's Model 23.1.0.d in 2024, and Model 24.0. 2024 F based on catch of 165,659t.

		Model 23.1.0.d		Model 24.0				Model 23.1.0.d		Model 24.0	
Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.	Year	Last Year Est.	Est.	Stdev.	Est.	Stdev.
1977	0.126	0.088	0.028	0.09	0.03	2002	0.413	0.392	0.036	0.398	0.038
1978	0.16	0.11	0.034	0.114	0.036	2003	0.414	0.446	0.04	0.454	0.042
1979	0.114	0.082	0.024	0.084	0.024	2004	0.426	0.448	0.04	0.454	0.04
1980	0.083	0.066	0.016	0.066	0.016	2005	0.462	0.456	0.038	0.462	0.038
1981	0.088	0.076	0.016	0.076	0.016	2006	0.509	0.492	0.04	0.498	0.04
1982	0.07	0.064	0.01	0.064	0.012	2007	0.522	0.534	0.046	0.54	0.046
1983	0.094	0.086	0.012	0.088	0.012	2008	0.64	0.534	0.05	0.542	0.052
1984	0.123	0.116	0.014	0.118	0.014	2009	0.715	0.634	0.068	0.646	0.07
1985	0.151	0.142	0.016	0.144	0.016	2010	0.611	0.676	0.078	0.69	0.08
1986	0.152	0.138	0.016	0.142	0.016	2011	0.762	0.552	0.062	0.562	0.064
1987	0.172	0.156	0.018	0.158	0.018	2012	0.685	0.668	0.074	0.68	0.074
1988	0.241	0.218	0.024	0.22	0.024	2013	0.602	0.612	0.066	0.622	0.066
1989	0.231	0.212	0.022	0.212	0.022	2014	0.525	0.548	0.058	0.558	0.06
1990	0.268	0.258	0.02	0.26	0.02	2015	0.41	0.486	0.052	0.496	0.052
1991	0.431	0.418	0.036	0.422	0.036	2016	0.374	0.396	0.04	0.404	0.042
1992	0.455	0.434	0.044	0.442	0.044	2017	0.334	0.366	0.036	0.372	0.038
1993	0.382	0.364	0.036	0.372	0.038	2018	0.286	0.324	0.032	0.33	0.032
1994	0.422	0.428	0.038	0.436	0.04	2019	0.283	0.274	0.026	0.28	0.026
1995	0.514	0.54	0.046	0.548	0.046	2020	0.294	0.272	0.026	0.276	0.026
1996	0.46	0.474	0.038	0.482	0.04	2021	0.265	0.282	0.028	0.286	0.028
1997	0.544	0.554	0.046	0.564	0.046	2022	0.335	0.25	0.026	0.256	0.028
1998	0.424	0.44	0.038	0.448	0.04	2023	0.316	0.314	0.034	0.32	0.036
1999	0.432	0.446	0.042	0.454	0.044	2024		0.306	0.036	0.31	0.036
2000	0.435	0.446	0.042	0.454	0.044						
2001	0.373	0.088	0.028	0.09	0.03						

Table 2.32. Instantaneous apical fishing mortality comparison for Model 23.1.0.d in 2023 (Last Year Est.), Model 24.,1 and Model 24.3. 2024 F based on catch of 165,659t.

		Model 24.1		Model 24.3	
Year	**Last Year Est.**	**Est.**	**Stdev.**	**Est.**	**Stdev.**
1977	0.126	0.09	0.028	0.082	0.026
1978	0.16	0.112	0.036	0.104	0.032
1979	0.114	0.084	0.024	0.078	0.022
1980	0.083	0.066	0.016	0.064	0.016
1981	0.088	0.076	0.016	0.076	0.016
1982	0.07	0.064	0.01	0.066	0.012
1983	0.094	0.088	0.012	0.09	0.014
1984	0.123	0.118	0.014	0.122	0.016
1985	0.151	0.144	0.016	0.148	0.018
1986	0.152	0.14	0.016	0.144	0.016
1987	0.172	0.158	0.018	0.16	0.018
1988	0.241	0.22	0.024	0.224	0.024
1989	0.231	0.212	0.022	0.216	0.022
1990	0.268	0.258	0.02	0.268	0.02
1991	0.431	0.42	0.036	0.438	0.036
1992	0.455	0.44	0.044	0.462	0.046
1993	0.382	0.37	0.036	0.386	0.038
1994	0.422	0.432	0.038	0.45	0.04
1995	0.514	0.544	0.046	0.562	0.048
1996	0.46	0.478	0.038	0.492	0.04
1997	0.544	0.56	0.046	0.578	0.046
1998	0.424	0.444	0.038	0.462	0.04
1999	0.432	0.45	0.042	0.472	0.044
2000	0.435	0.456	0.044	0.478	0.044
2001	0.373	0.09	0.028	0.082	0.026
2002	0.413	0.406	0.038	0.424	0.038
2003	0.414	0.464	0.044	0.484	0.044
2004	0.426	0.462	0.042	0.482	0.042
2005	0.462	0.462	0.04	0.482	0.04
2006	0.509	0.492	0.042	0.514	0.042
2007	0.522	0.53	0.048	0.556	0.048
2008	0.64	0.53	0.052	0.558	0.052
2009	0.715	0.632	0.068	0.668	0.07
2010	0.611	0.672	0.078	0.714	0.08
2011	0.762	0.546	0.062	0.58	0.062
2012	0.685	0.666	0.074	0.706	0.074
2013	0.602	0.614	0.066	0.646	0.066
2014	0.525	0.558	0.06	0.586	0.06
2015	0.41	0.498	0.052	0.524	0.052
2016	0.374	0.404	0.042	0.426	0.042
2017	0.334	0.374	0.038	0.394	0.038
2018	0.286	0.33	0.032	0.348	0.032
2019	0.283	0.28	0.026	0.296	0.026
2020	0.294	0.278	0.026	0.294	0.026
2021	0.265	0.286	0.03	0.304	0.03
2022	0.335	0.256	0.028	0.274	0.028
2023	0.316	0.318	0.036	0.344	0.036
2024		0.306	0.036	0.336	0.038

Table 2.33. Standard harvest scenarios Model 23.1.0.d.

Female Spawning Biomass							
Yr	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
2024	224,653	224,653	224,653	224,653	224,653	224,653	224,653
2025	218,076	218,076	218,076	218,076	218,076	218,076	218,076
2026	209,148	209,148	217,506	220,596	259,858	199,501	209,148
2027	205,925	205,925	218,359	223,359	300,462	192,629	205,925
2028	210,979	210,979	225,321	231,143	342,135	196,561	202,282
2029	219,535	219,535	236,220	241,967	383,392	204,588	206,472
2030	226,301	226,301	246,790	252,490	421,242	210,724	210,991
2031	229,839	229,839	254,902	260,624	453,707	213,634	213,458
2032	231,771	231,771	260,381	266,168	480,194	214,482	214,309
2033	232,770	232,770	263,818	269,682	501,035	214,517	214,430
2034	233,265	233,265	265,876	271,809	517,015	214,382	214,353
2035	233,506	233,506	267,071	273,057	529,015	214,281	214,278
2036	233,622	233,622	267,749	273,774	537,890	214,236	214,239
Full selection F							
2024	0.358	0.358	0.358	0.358	0.358	0.358	0.358
2025	0.349	0.349	0.285	0.262	0	0.427	0.349
2026	0.334	0.334	0.285	0.265	0	0.389	0.334
2027	0.329	0.329	0.285	0.268	0	0.375	0.402
2028	0.337	0.337	0.285	0.273	0	0.383	0.395
2029	0.352	0.352	0.285	0.273	0	0.399	0.403
2030	0.363	0.363	0.285	0.273	0	0.412	0.413
2031	0.364	0.364	0.285	0.273	0	0.418	0.418
2032	0.364	0.364	0.285	0.273	0	0.420	0.420
2033	0.364	0.364	0.285	0.273	0	0.420	0.420
2034	0.364	0.364	0.285	0.273	0	0.420	0.420
2035	0.364	0.364	0.285	0.273	0	0.419	0.419
2036	0.364	0.364	0.285	0.273	0	0.419	0.419
Catch (t)							
2024	165,659	165,659	165,659	165,659	165,659	165,659	165,659
2025	156,032	156,032	129,885	120,264	0	186,462	156,032
2026	144,010	144,010	129,182	122,505	0	158,060	144,010
2027	141,377	141,377	130,721	126,348	0	150,118	169,263
2028	150,126	150,126	136,246	133,955	0	158,544	166,565
2029	162,880	162,880	143,219	140,590	0	172,123	174,623
2030	172,479	172,479	149,169	146,283	0	181,904	182,107
2031	175,141	175,141	153,359	150,326	0	186,276	185,918
2032	176,241	176,241	156,030	152,927	0	187,401	187,110
2033	176,778	176,778	157,639	154,511	0	187,343	187,208
2034	177,036	177,036	158,576	155,444	0	187,090	187,051
2035	177,160	177,160	159,110	155,981	0	186,926	186,924
2036	177,220	177,220	159,409	156,285	0	186,859	186,865

Table 2.34. Standard harvest scenarios for Model 24.0

Female spawning biomass (t)							
Yr	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
2024	220,977	220,977	220,977	220,977	220,977	220,977	220,977
2025	213,439	213,439	213,439	213,439	213,439	213,439	213,439
2026	205,830	205,830	212,880	216,937	254,971	196,452	205,829
2027	203,807	203,807	214,302	220,846	295,904	190,781	203,807
2028	209,603	209,603	221,880	229,455	338,154	195,373	200,984
2029	218,367	218,367	233,102	240,650	379,938	203,521	205,361
2030	225,057	225,057	243,735	251,287	418,179	209,536	209,791
2031	228,497	228,497	251,786	259,416	450,913	212,315	212,141
2032	230,477	230,477	257,173	264,924	477,584	213,093	212,923
2033	231,517	231,517	260,526	268,400	498,552	213,104	213,019
2034	232,042	232,042	262,521	270,499	514,615	212,966	212,939
2035	232,302	232,302	263,672	271,728	526,680	212,868	212,865
2036	232,430	232,430	264,322	272,433	535,600	212,826	212,829
Full selection F							
2024	0.366	0.366	0.366	0.366	0.366	0.366	0.366
2025	0.345	0.345	0.290	0.259	0	0.423	0.345
2026	0.332	0.332	0.290	0.263	0	0.387	0.332
2027	0.329	0.329	0.290	0.268	0	0.375	0.403
2028	0.339	0.339	0.290	0.274	0	0.385	0.397
2029	0.354	0.354	0.290	0.274	0	0.402	0.406
2030	0.365	0.365	0.290	0.274	0	0.415	0.415
2031	0.365	0.365	0.290	0.274	0	0.420	0.420
2032	0.365	0.365	0.290	0.274	0	0.422	0.422
2033	0.365	0.365	0.290	0.274	0	0.422	0.422
2034	0.365	0.365	0.290	0.274	0	0.422	0.422
2035	0.365	0.365	0.290	0.274	0	0.422	0.422
2036	0.365	0.365	0.290	0.274	0	0.421	0.421
Catch (t)							
2024	165,659	165,659	165,659	165,659	165,659	165,659	165,659
2025	151,060	151,060	129,019	116,395	0	180,601	151,060
2026	140,989	140,989	128,454	119,752	0	154,959	140,989
2027	139,977	139,977	130,442	124,864	0	148,852	167,625
2028	149,646	149,646	136,375	133,176	0	158,189	166,085
2029	162,637	162,637	143,570	139,948	0	171,906	174,355
2030	172,036	172,036	149,600	145,664	0	181,483	181,673
2031	174,187	174,187	153,803	149,691	0	185,651	185,296
2032	175,323	175,323	156,460	152,271	0	186,672	186,387
2033	175,889	175,889	158,051	153,838	0	186,581	186,450
2034	176,167	176,167	158,973	154,759	0	186,326	186,289
2035	176,304	176,304	159,494	155,289	0	186,167	186,166
2036	176,371	176,371	159,785	155,588	0	186,104	186,110

Table 2.35. Standard harvest scenarios for Model 24.1

Female spawning biomass (t)							
Yr	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
2024	223,289	223,289	223,289	223,289	223,289	223,289	223,289
2025	215,747	215,747	215,747	215,747	215,747	215,747	215,747
2026	206,498	206,498	214,100	217,840	256,749	196,957	206,498
2027	204,037	204,037	215,067	221,260	297,451	190,926	204,038
2028	209,904	209,904	222,580	229,870	339,709	195,649	201,276
2029	218,736	218,736	233,790	241,219	381,555	203,880	205,711
2030	225,396	225,396	244,368	251,931	419,823	209,859	210,103
2031	228,890	228,890	252,344	260,080	452,532	212,577	212,397
2032	230,902	230,902	257,666	265,585	479,140	213,317	213,146
2033	231,963	231,963	260,973	269,054	500,025	213,315	213,230
2034	232,502	232,502	262,939	271,147	516,000	213,175	213,148
2035	232,771	232,771	264,072	272,372	527,980	213,078	213,075
2036	232,904	232,904	264,711	273,074	536,825	213,038	213,041
Full selection F							
2024	0.360	0.360	0.360	0.360	0.360	0.360	0.360
2025	0.348	0.348	0.289	0.261	0	0.425	0.348
2026	0.332	0.332	0.289	0.263	0	0.386	0.332
2027	0.328	0.328	0.289	0.268	0	0.374	0.401
2028	0.338	0.338	0.289	0.272	0	0.384	0.395
2029	0.353	0.353	0.289	0.272	0	0.401	0.405
2030	0.363	0.363	0.289	0.272	0	0.413	0.414
2031	0.363	0.363	0.289	0.272	0	0.419	0.418
2032	0.363	0.363	0.289	0.272	0	0.420	0.420
2033	0.363	0.363	0.289	0.272	0	0.420	0.420
2034	0.363	0.363	0.289	0.272	0	0.420	0.420
2035	0.363	0.363	0.289	0.272	0	0.420	0.420
2036	0.363	0.363	0.289	0.272	0	0.420	0.420
Catch (t)							
2024	165,659	165,659	165,659	165,659	165,659	165,659	165,659
2025	153,617	153,617	129,984	118,414	0	183,509	153,617
2026	141,520	141,520	128,918	120,412	0	155,279	141,520
2027	140,135	140,135	130,800	125,153	0	148,876	167,733
2028	149,985	149,985	136,769	133,205	0	158,494	166,395
2029	163,069	163,069	143,954	140,044	0	172,324	174,751
2030	172,030	172,030	149,930	145,765	0	181,816	181,986
2031	174,199	174,199	154,074	149,775	0	185,871	185,507
2032	175,347	175,347	156,686	152,337	0	186,828	186,542
2033	175,923	175,923	158,248	153,891	0	186,717	186,587
2034	176,208	176,208	159,152	154,804	0	186,461	186,425
2035	176,349	176,349	159,663	155,329	0	186,305	186,304
2036	176,418	176,418	159,947	155,625	0	186,244	186,251

Table 2.36. Standard harvest scenarios for Model 24.3

Female spawning biomass (t)							
Yr	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
2024	203,532	203,532	203,532	203,532	203,532	203,532	203,532
2025	186,337	186,337	186,337	186,337	186,337	186,337	186,337
2026	187,854	187,854	186,926	196,603	226,070	180,440	187,855
2027	194,380	194,380	193,058	208,713	269,191	183,286	194,380
2028	205,437	205,437	205,148	223,268	315,225	192,471	197,454
2029	215,890	215,890	218,774	236,660	360,502	201,658	203,332
2030	222,417	222,417	230,129	247,918	401,404	207,160	207,411
2031	225,634	225,634	238,106	255,992	436,028	209,313	209,171
2032	227,355	227,355	243,180	261,270	464,009	209,759	209,612
2033	228,212	228,212	246,220	264,533	485,884	209,661	209,586
2034	228,627	228,627	247,971	266,478	502,575	209,510	209,486
2035	228,826	228,826	248,954	267,608	515,070	209,424	209,420
2036	228,921	228,921	249,494	268,253	524,295	209,392	209,394
Full selection F							
2024	0.409	0.409	0.409	0.409	0.409	0.409	0.409
2025	0.302	0.302	0.310	0.226	0	0.369	0.302
2026	0.304	0.304	0.310	0.239	0	0.357	0.304
2027	0.315	0.315	0.310	0.255	0	0.363	0.386
2028	0.334	0.334	0.310	0.271	0	0.382	0.392
2029	0.352	0.352	0.310	0.271	0	0.401	0.405
2030	0.361	0.361	0.310	0.271	0	0.413	0.413
2031	0.361	0.361	0.310	0.271	0	0.417	0.417
2032	0.361	0.361	0.310	0.271	0	0.418	0.418
2033	0.361	0.361	0.310	0.271	0	0.418	0.418
2034	0.361	0.361	0.310	0.271	0	0.418	0.418
2035	0.361	0.361	0.310	0.271	0	0.418	0.418
2036	0.361	0.361	0.310	0.271	0	0.418	0.418
Catch (t)							
2024	165,659	165,659	165,659	165,659	165,659	165,659	165,659
2025	116,770	116,770	119,658	89,682	0	139,917	116,770
2026	119,491	119,491	120,962	99,956	0	133,006	119,491
2027	129,425	129,425	126,601	113,392	0	139,486	155,067
2028	145,289	145,289	135,455	128,691	0	154,890	161,865
2029	159,936	159,936	144,123	136,143	0	169,538	171,769
2030	167,711	167,711	150,673	141,856	0	177,973	178,181
2031	169,589	169,589	154,969	145,693	0	181,054	180,760
2032	170,522	170,522	157,574	148,089	0	181,553	181,308
2033	170,967	170,967	159,084	149,524	0	181,314	181,199
2034	171,178	171,178	159,934	150,361	0	181,055	181,020
2035	171,279	171,279	160,403	150,840	0	180,919	180,917
2036	171,327	171,327	160,658	151,110	0	180,874	180,879

Table 2.37. Management scenarios and probabilities derived from inverted hessian and assumption normal distribution.

Value	Model 24.1	Model 24.3	Model 24.3 w/ Model 24.1 Catch	Model 24.1 w/ Model 24.3 Catch
$Catch_{2025}$	153,617 t	116,770 t	153,617 t	116,770 t
$Catch_{2026}$	141,520 t	119,491 t	141,520 t	119,491 t
$Catch_{2025}$-$maxABC_{2025}$	0	0	+36,847 t	-36,847 t
$Catch_{2026}$-$maxABC_{2026}$	0	0	+22,029 t	-22,029 t
$Bratio_{2026}$	0.367	0.340	0.319	0.444
$Bratio_{2027}$	0.363	0.352	0.320	0.452
F_{2025}	0.348	0.302	0.410	0.257
F_{2026}	0.332	0.304	0.392	0.261
$F_{2025}/F_{35\%}$	0.783	0.679	0.929	0.578
$F_{2026}/F_{35\%}$	0.747	0.685	0.887	0.587
$Pr(B_{2026}<B_{20\%})$	<0.01%	<0.01%	3.2%	<0.01%
$Pr(B_{2027}<B_{20\%})$	<0.01%	<0.01%	3.1%	<0.01%
$Pr(Catch_{2025}>OFL_{2025})$	19.6%	18.4%	67.1%	5.1%
$Pr(Catch_{2026}>OFL_{2026})$	9.1%	9.3%	68.0%	5.5%

Table 2.38. Bycatch of prohibited species in the Pacific cod target fishery 2020-2024. All values but halibut are in numbers, halibut values are in tons.

	2020	2021	2022	2023	2024
Bairdi Tanner Crab (#)	80,987	35,819	110,092	73,766	36,823
Blue King Crab (#)	1,573	360	4,563	1,144	778
Chinook Salmon (#)	235	147	269	1,212	953
Golden (Brown) King Crab (#)	2,332	17,369	2,858	2,483	155
Halibut (t)	229.8	146.5	348.4	348.9	286.0
Herring (#)	0	1	0	1	0
Non-Chinook Salmon (#)	115	83	100	69	105
Opilio Tanner (Snow) Crab (#)	147,399	73,701	67,081	54,831	36,389
Red King Crab (#)	21,417	282,146	147,545	91,807	25,925

Table 2.39 Catch of groundfish in the targeted Bering Sea Pacific cod fisheries. Catch of <0.1t is not included in table

Species	2020	2021	2022	2023	2024
Bering flounder	0.0	0.1		0.0	
cod, Pacific (gray)	128,363.4	99,971.6	129,890.7	125,125.4	115,769.4
flounder, Alaska plaice	32.2	6.2	9.7	8.6	14.3
flounder, arrowtooth	364.9	195.1	391.9	599.5	966.7
flounder, general	2.1	0.8	15.4	7.6	0.0
flounder, starry	73.5	64.6	33.8	186.5	81.6
greenling, atka mackerel	14.3	72.6	67.9	9.0	11.2
groundfish, general	107.1	139.1	337.0	51.5	17.9
halibut, Pacific	18.6	1.3	0.6	1.8	0.0
Kamchatka flounder	49.9	40.0	47.7	63.5	52.8
octopus, North Pacific	443.4	109.5	149.6	101.8	207.0
Pacific sleeper shark	18.2	16.6	20.0	12.6	11.0
perch, Pacific ocean	13.0	4.6	2.8	1.8	1.3
pollock, walleye	5,512.2	4,316.1	6,260.6	7,181.4	5,405.9
rockfish, black	0.4	0.1	0.9	1.5	0.8
rockfish, dusky	9.8	14.0	13.0	11.0	14.6
rockfish, harlequin	0.0	0.0	0.0		
rockfish, northern	20.2	30.2	23.5	25.2	27.6
rockfish, other	31.2	6.5	8.5	15.2	17.5
rockfish, rougheye	1.9	1.4	3.6	3.8	3.2
rockfish, shortraker	5.3	6.1	2.0	2.7	2.2
rockfish, silvergray					0.1
rockfish, thornyhead (idiots)	3.5	0.7	0.3	0.2	1.5
rockfish, widow				0.1	0.0
rockfish, yelloweye (red snapper)	0.0		0.1	0.0	0.1
rockfish, yellowtail	0.0			0.2	
sablefish (blackcod)	133.9	152.3	186.2	126.9	170.4
sculpin	2029				
shark, other	1.3	0.4	1.0		0.1
shark, salmon	0.1	9.6	3.0	2.4	1.1
shark, spiny dogfish	0.7	0.6	0.9	3.6	2.1
skate, Alaskan	707.9	599.6	9,768.8	9,578.2	9,159.4
skate, Aleutian	27.2	13.2	485.5	1,121.9	413.0
skate, big	5.4	13.2	49.6	135.2	168.2
skate, longnose	0.7			0.4	2.4
skate, other	12,362.7	11,740.7	12,474.8	10,107.8	10,035.1
skate, Whiteblotched	2.6	1.6	102.5	166.0	78.0
sole, butter	45.0	23.5	45.1	149.3	125.9
sole, dover			1.8	1.5	0.0
sole, English	1.4	0.8	1.2	33.3	0.1
sole, flathead	585.6	318.9	536.7	552.9	595.1
sole, rex	10.5	5.3	18.2	25.1	22.5
sole, rock	410.4	357.4	661.6	1,313.9	1,454.4
sole, sand			0.1	1.1	6.3
sole, yellowfin	814.9	719.1	810.2	432.1	512.1
turbot, Greenland	63.0	9.4	12.5	27.9	10.2
Total	**152,288.1**	**118,963.3**	**162,439.5**	**157,190.6**	**145,363.0**

Table 2.40 Catch of non-target species in the targeted Bering Sea Pacific cod fisheries. Catch of <0.1t is not included in table. All species except birds in tons, birds are in number and not included in the bottom total weight.

Species	2020	2021	2022	2023	2024
Birds (#)	3,048	2,011	3,264	2,611	3,562
Benthic urochordata	13.4	0.4	0.6	3.6	14.5
Bivalves	4.2	0.9	5.4	4.2	5.2
Brittle star unidentified	0.6	0.1	0.1	0.4	0.2
Corals Bryozoans - Corals Bryozoans Unidentified	4.3	1.5	3.0	0.9	2.6
Eelpouts	6.3	6.5	0.3	0.5	1.2
Giant Grenadier	156.5	12.4	9.2	2.8	1.4
Greenlings	1.0	0.4	0.4	1.3	0.4
Grenadier - Rattail Grenadier Unidentified	3.2	0.5	0.0		0.2
Hermit crab unidentified	1.0	3.0	1.5	1.1	0.5
Invertebrate unidentified	3.2	0.9	4.8	10.3	1.9
Misc crabs	7.6	4.4	16.5	20.0	0.7
Misc crustaceans	2.0	0.0	0.0	1.5	0.9
Misc fish	17.4	13.8	25.4	45.6	38.2
Misc inverts (worms etc)	0.0	0.0	0.0	0.0	0.1
Pacific Hake			0.5		
Pacific Sandfish		0.0	0.0		0.1
Polychaete unidentified	0.6	0.1	0.0	0.0	0.0
Saffron Cod	0.1	0.3	0.7	0.2	0.4
Sculpin		2,274.0	2,477.6	2,058.6	1,910.8
Scypho jellies	25.7	64.2	97.1	98.9	107.7
Sea anemone unidentified	48.7	21.6	63.6	64.0	115.2
Sea pens whips	15.6	5.3	33.8	19.4	36.9
Sea star	230.6	185.0	472.4	333.0	299.6
Snails	37.9	55.3	34.0	35.7	37.6
Sponge unidentified	2.3	0.3	1.6	0.7	1.7
Squid	0.0	0.0	3.6	0.0	0.0
State-managed Rockfish	1.0	0.2	0.1	0.1	0.0
urchins dollars cucumbers	0.7	0.3	1.5	2.5	4.3
Total	**583.9**	**2,651.4**	**3,253.6**	**2,705.3**	**2,582.2**

FIGURES

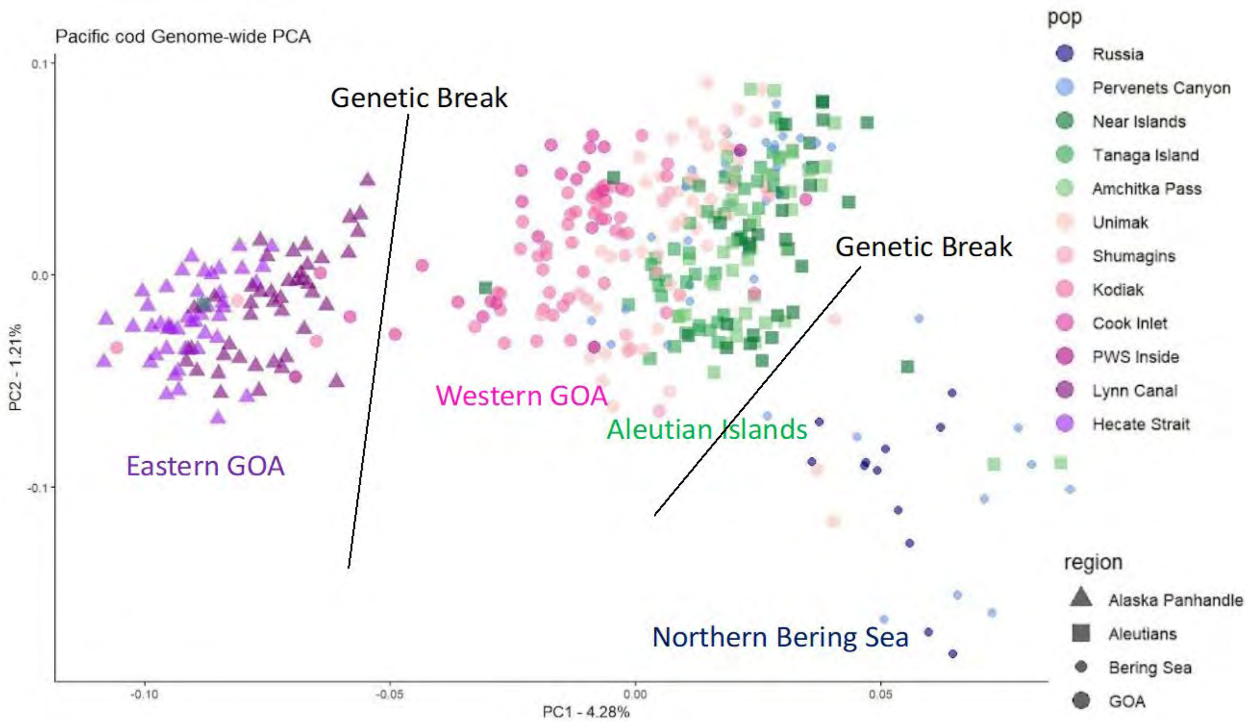


Figure 2.1. Principal components analysis of 1,922,927 polymorphic SNPs from the lcWGS dataset.

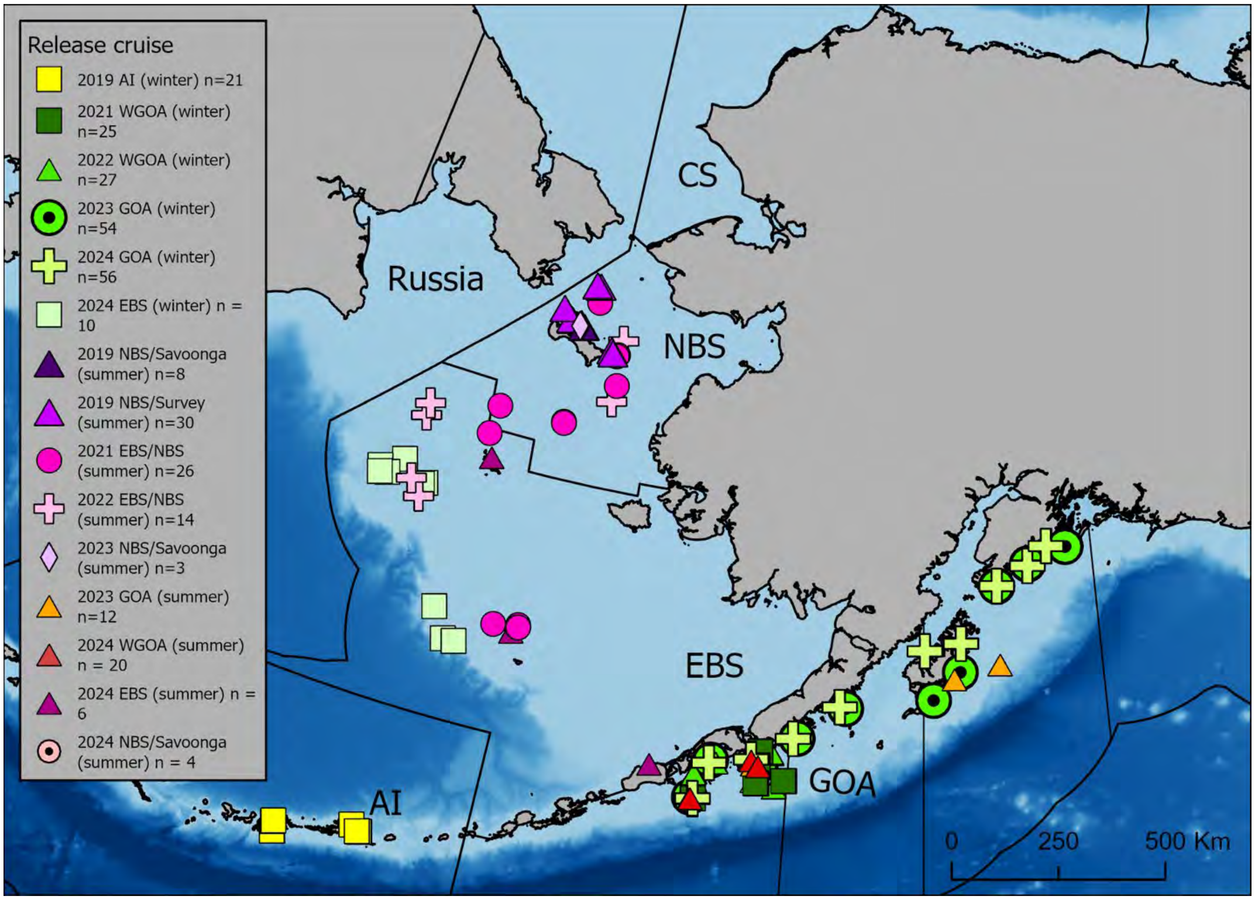


Figure 2.2. Pacific cod satellite tag release locations in the Aleutian Islands (AI), eastern Bering Sea (EBS), northern Bering Sea (NBS), Chukchi Sea (CS), and Gulf of Alaska (GOA). Releases occurred in the winter (n = 193) to characterize movement from winter spawning to summer foraging areas and in the summer (n=133) to characterize seasonal and annual movement from summer foraging areas.

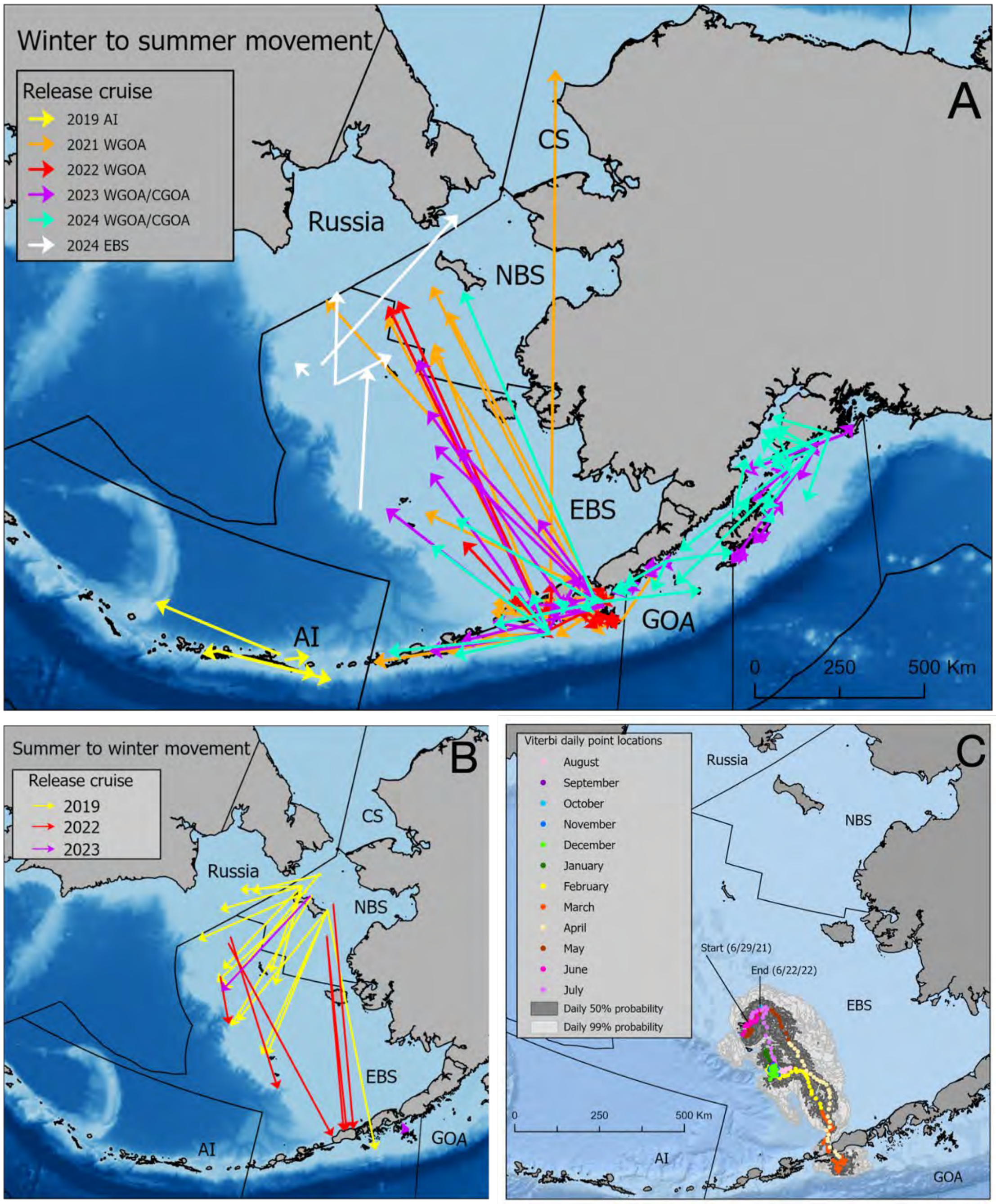


Figure 2.3. Seasonal movement of satellite-tagged Pacific cod A) from winter to summer (pop-up locations for tags that reported May or later), B) from summer to winter (pop-up locations from January through March), and C) an example of an annual movement pattern provided by the geolocation model for a single tagged fish, where a pathway was reconstructed based on satellite tag data. Points indicate estimated daily point locations and polygons indicate the daily 50% and 99% uncertainty in location probability.

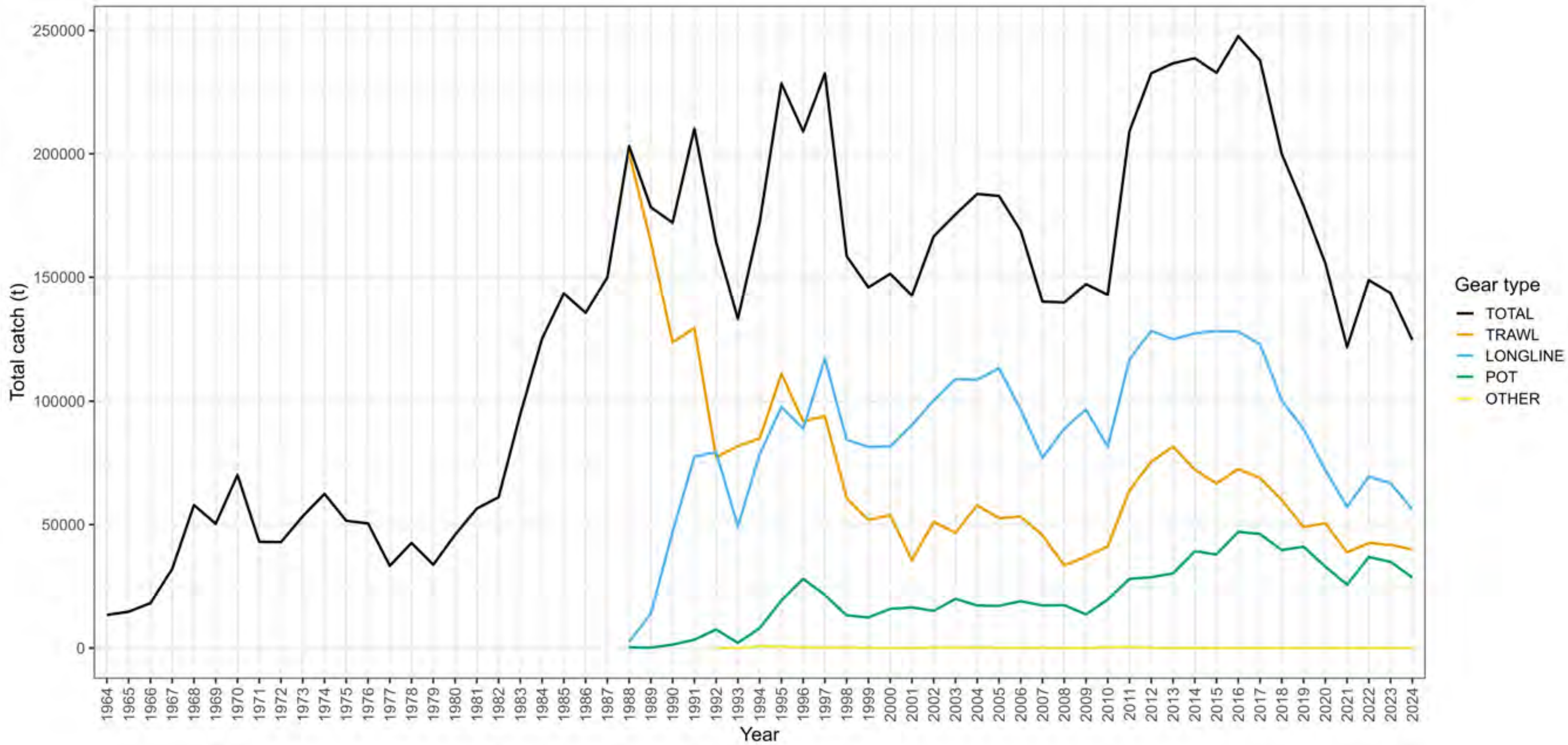


Figure 2.4. Total catch and catch by gear type. Catch for 2024 is through October 3.

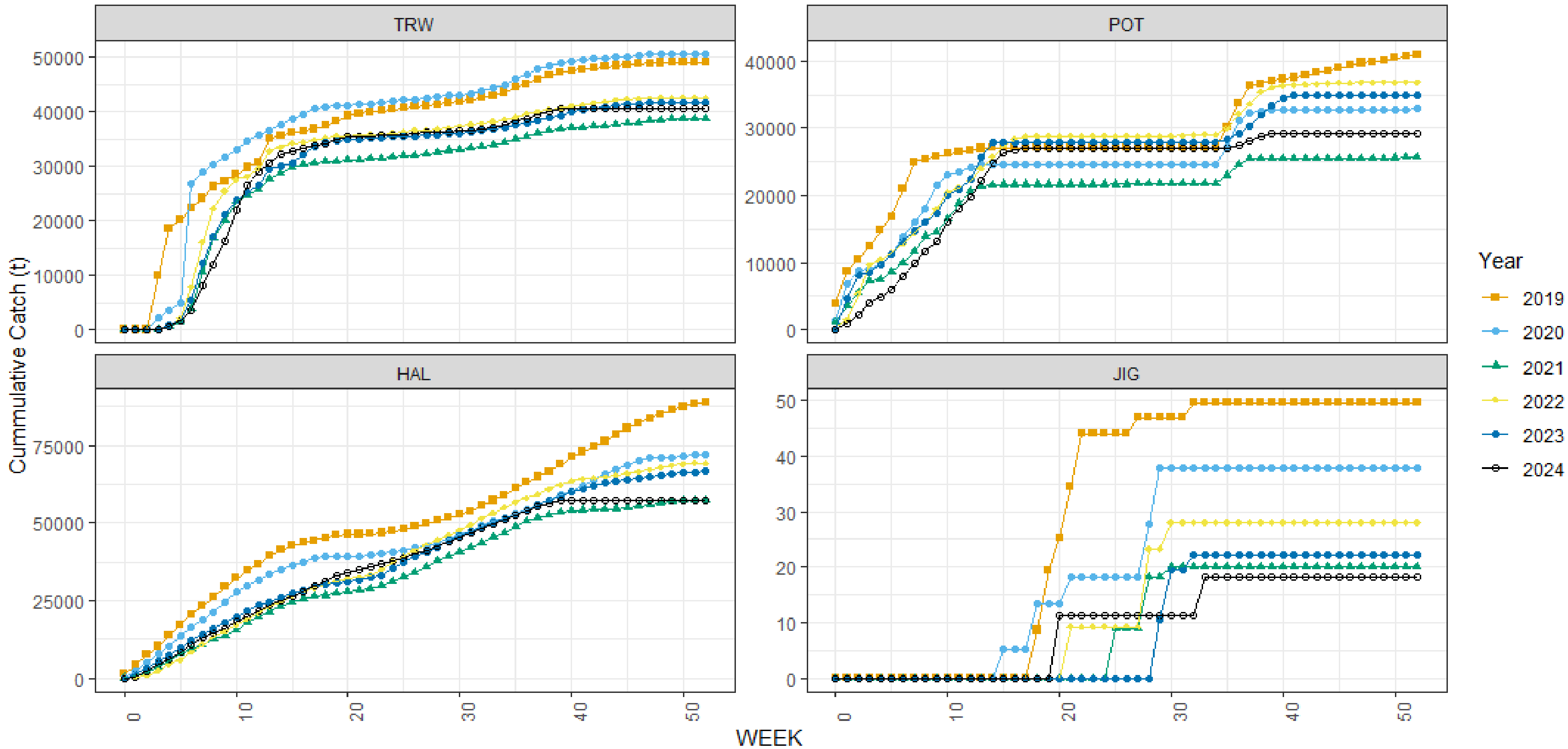


Figure 2.5. Cumulative Pacific cod catch by gear type for 2019-2024. Data for 2024 are current through October 8.

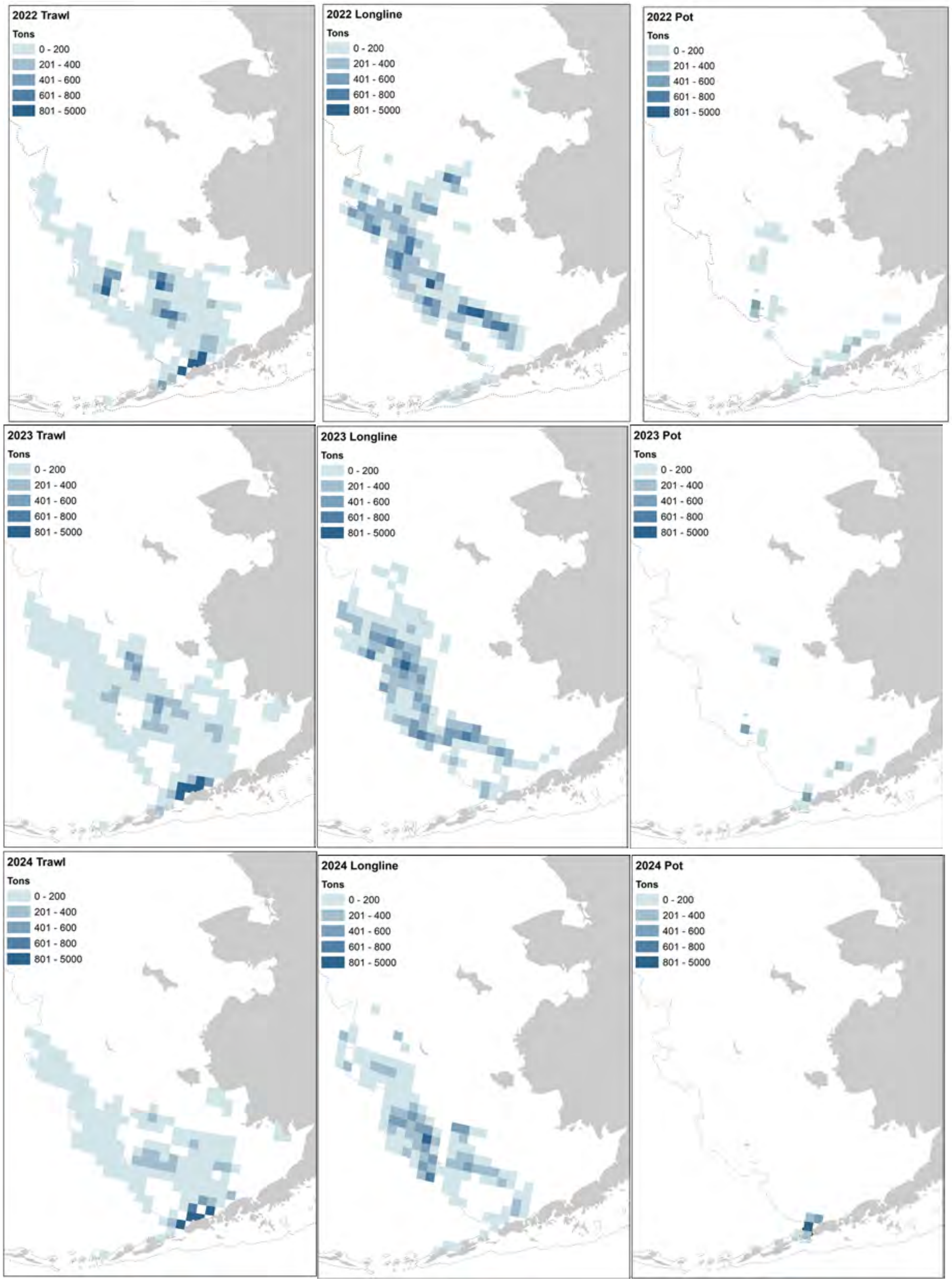


Figure 2.6. Observed catch by gear type for 2022-2024. Data are aggregated by bottom trawl survey grid cells (20nm^2) and all cells with fewer than 3 vessels fishing have been removed. Data for 2024 are through October 8. Bathymetry line (dotted gray) shown is at 200 m.

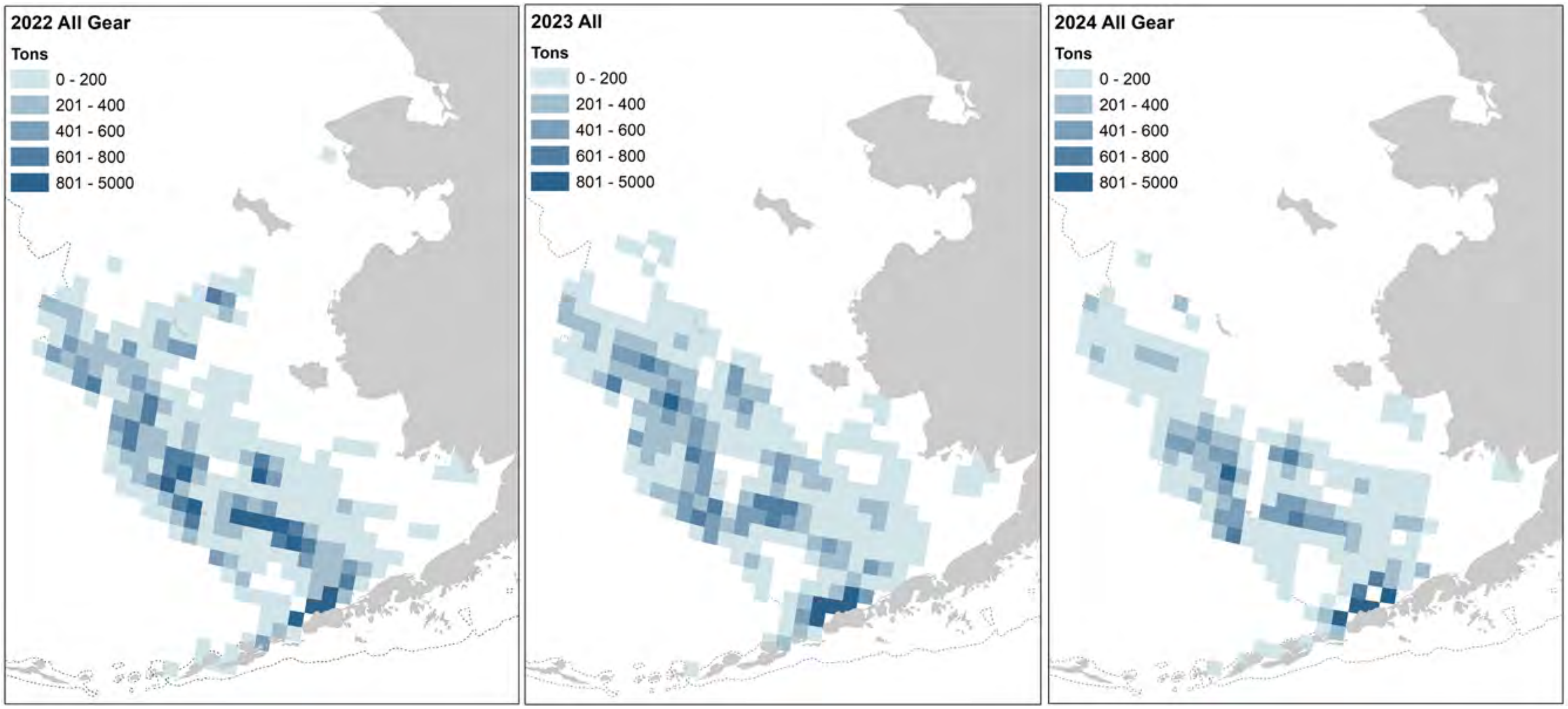


Figure 2.7. Total observed catch for 2022-2024. Data are aggregated by bottom trawl survey grid cells (20nm^2) and all cells with fewer than 3 vessels fishing have been removed. Data for 2024 are through October 8. Bathymetry line (dotted gray) shown is at 200 m.

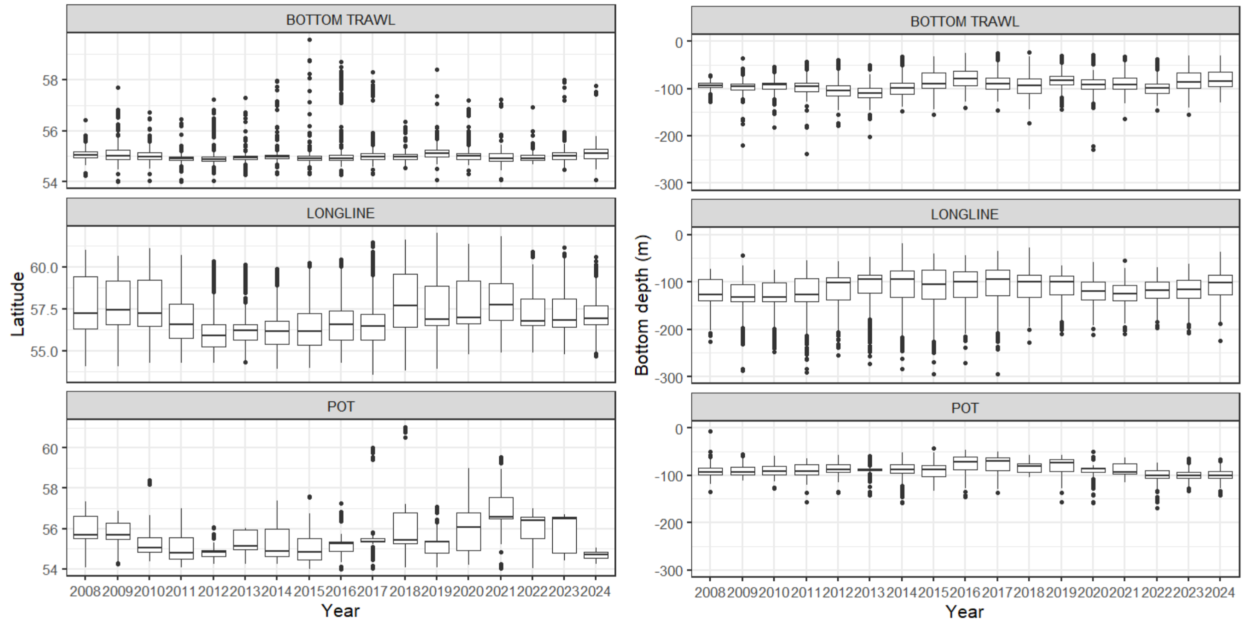


Figure 2.8. Distribution of Pacific cod hauls or sets by gear type for 2008-2024 for January-March by (left) Latitude and (right) bottom depth in meters. All data pulled October 3, 2024.

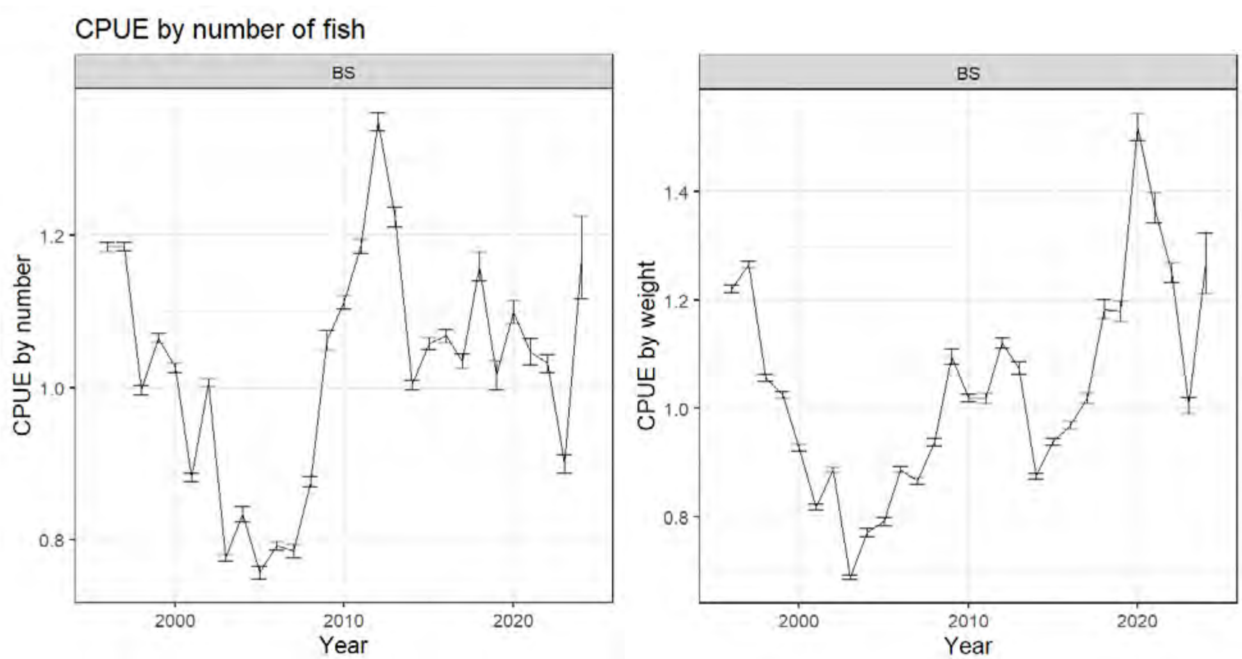


Figure 2.9. Thompson et al. (2021) combined fishery CPUE index estimates for 1996-2024 by (left) number and (right) weight of fish. All data pulled October 3, 2024.

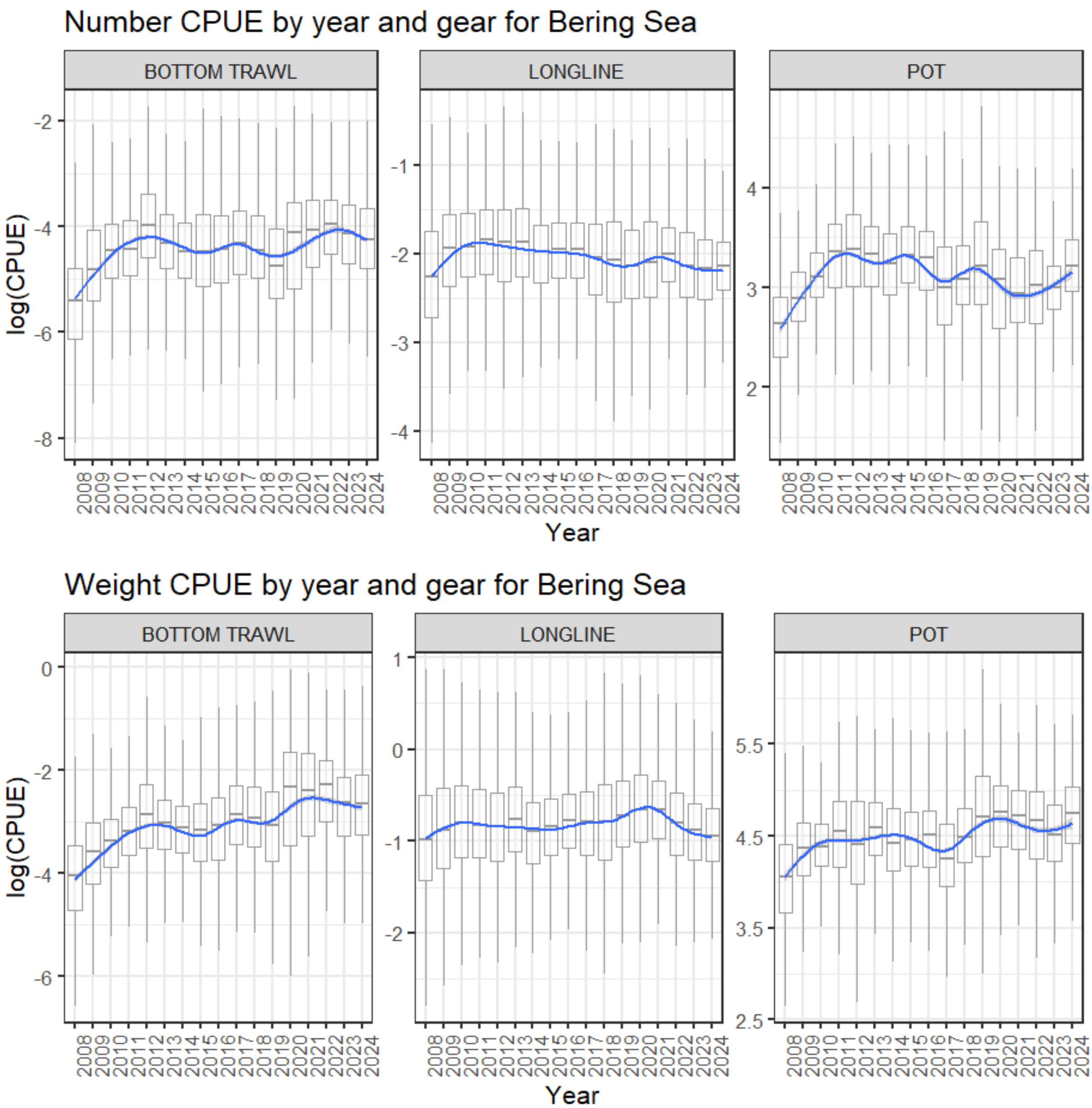


Figure 2.10. Raw and **not** standardized fishery catch per unit effort (CPUE) estimates for 2008-2024 by (top) number and (bottom) weight of fish by gear type. For numbers CPUE is log number of cod per minute, for longline it is log number of cod per hood and for pot log number of cod per pot. For weight CPUE bottom trawl is log tons per minute, longline is log kg per hook, and pot is log kg per pot. All data pulled October 3, 2024.

1 cm length bins

5 cm length bins

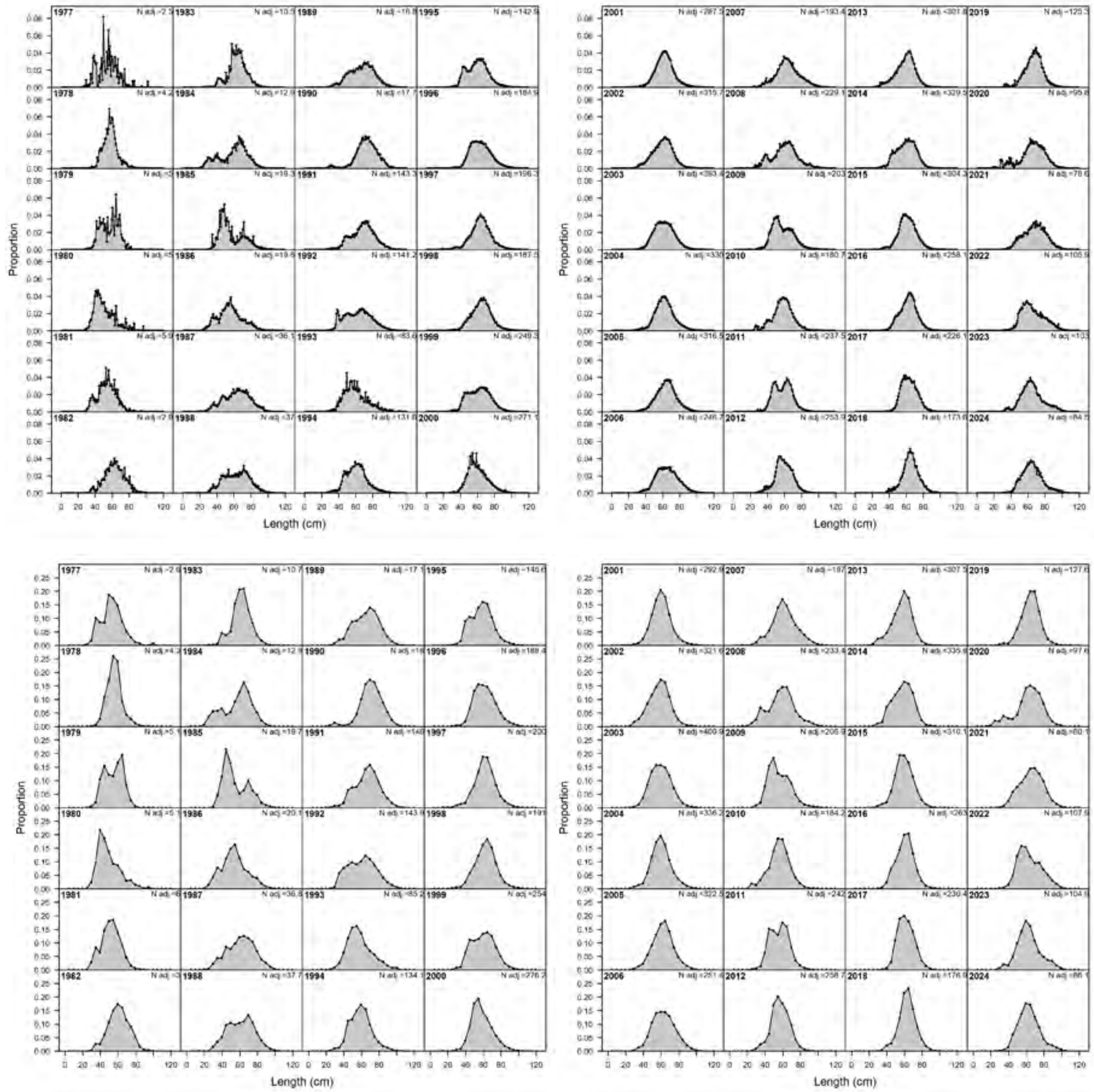


Figure 2.11. Combined fishery length composition distributions by year in (top) 1 cm bins and (bottom) 5 cm bins. Data queried October 3, 2024.

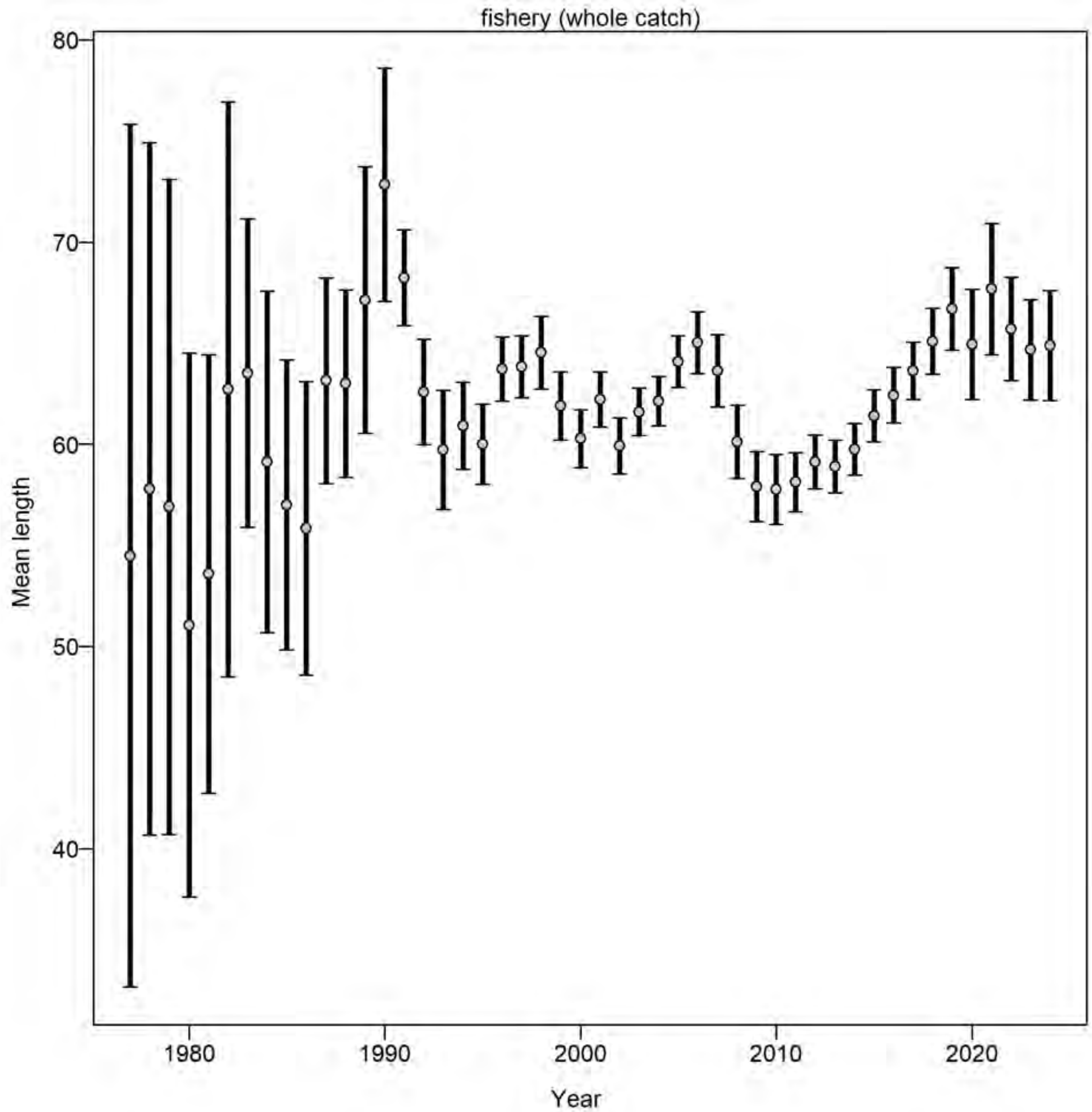


Figure 2.12. Combined fishery mean length (cm) by year.

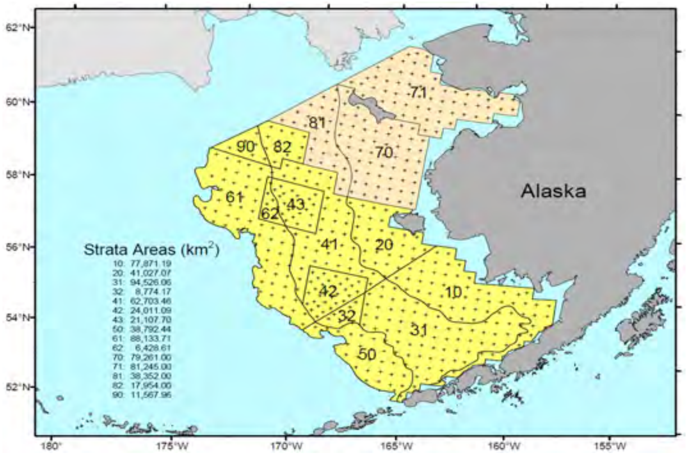


Figure 2.13. AFSC bottom trawl survey strata where crosses represent station locations.

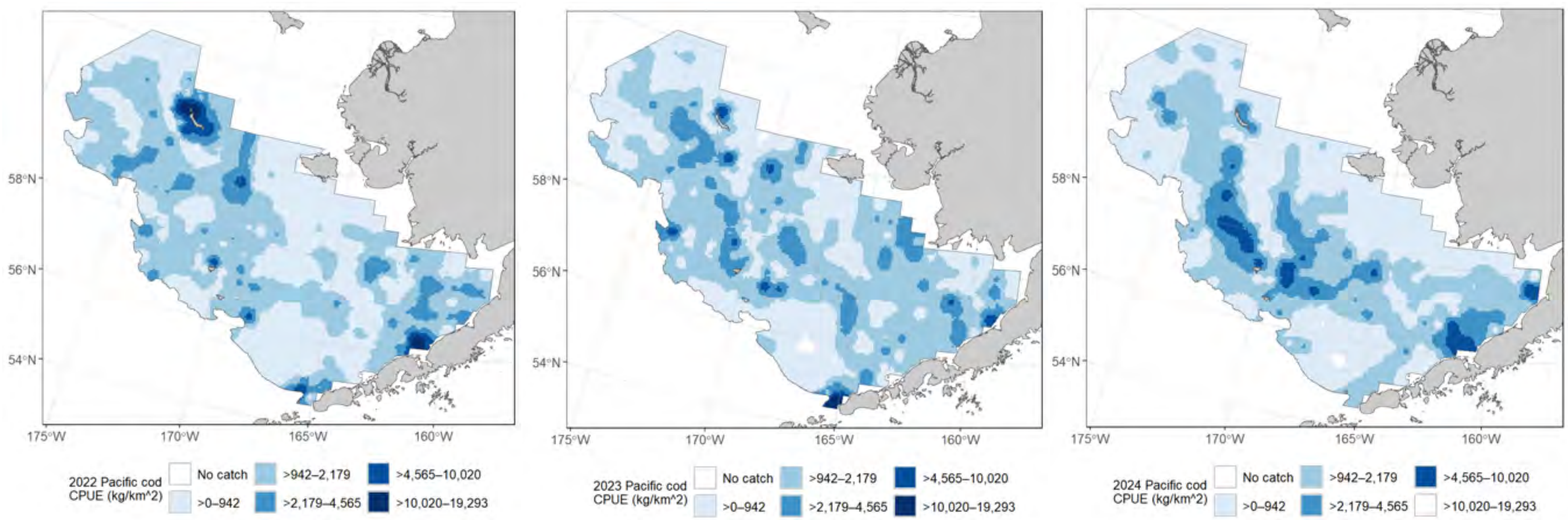


Figure 2.14. AFSC bottom trawl survey Pacific cod catch per unit effort for 2022-2024 (from left to right).

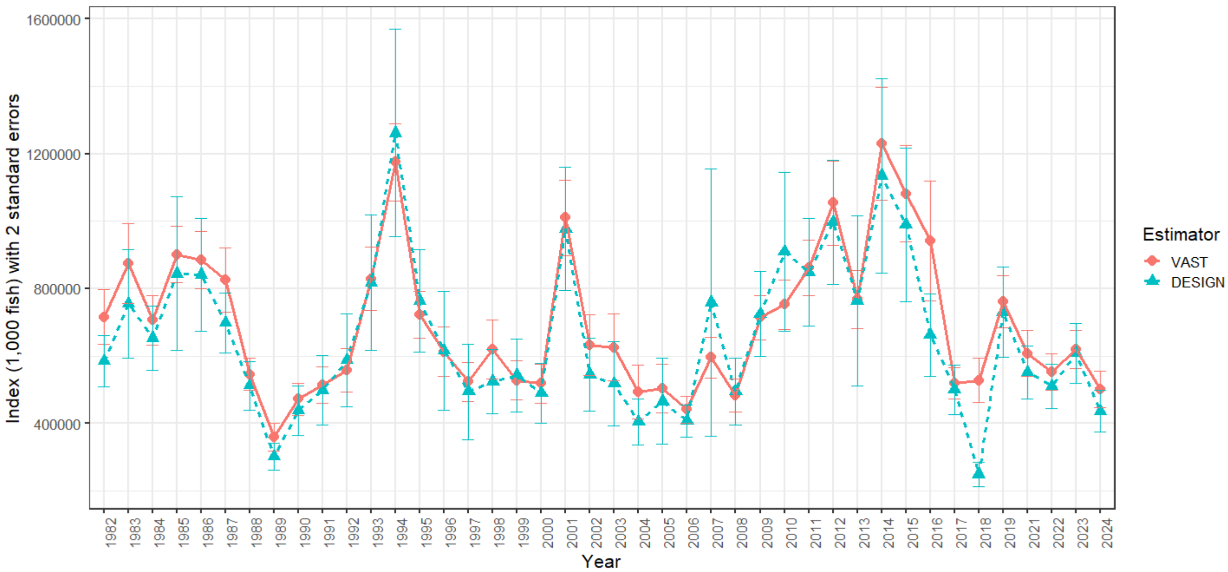


Figure 2.15. Pacific cod abundance estimates (1000s of fish) for design-based and 2024 VAST Bottom trawl survey time series.

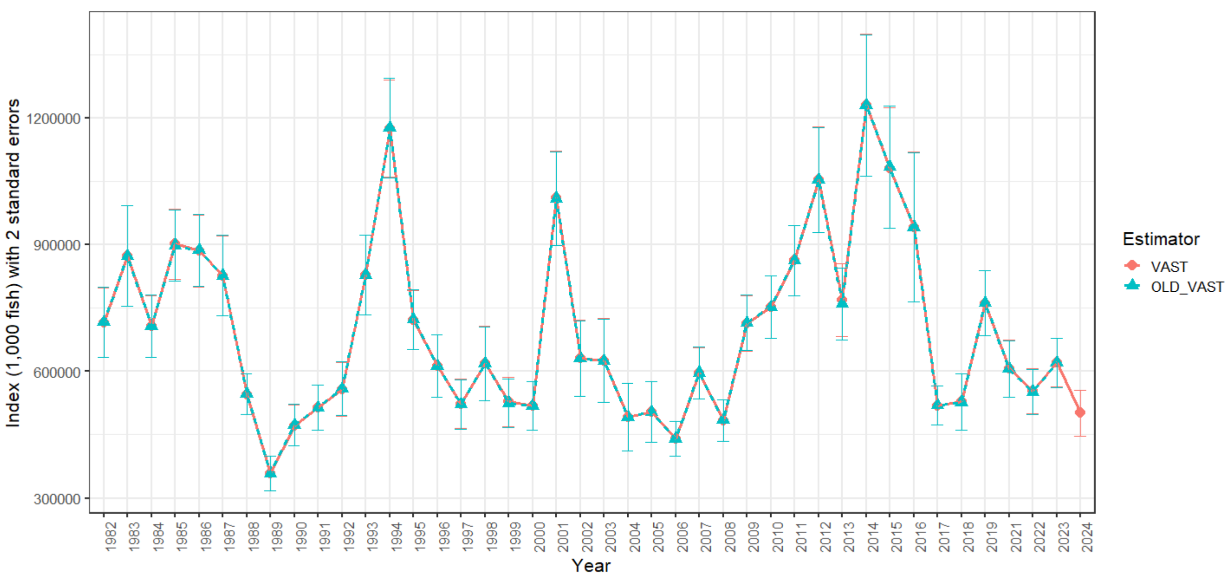


Figure 2.16. The 2023 (OLD_VAST) and 2024 (VAST) Bering Sea bottom trawl survey Pacific cod abundance (1000s of fish) estimates with confidence intervals (2 standard errors).

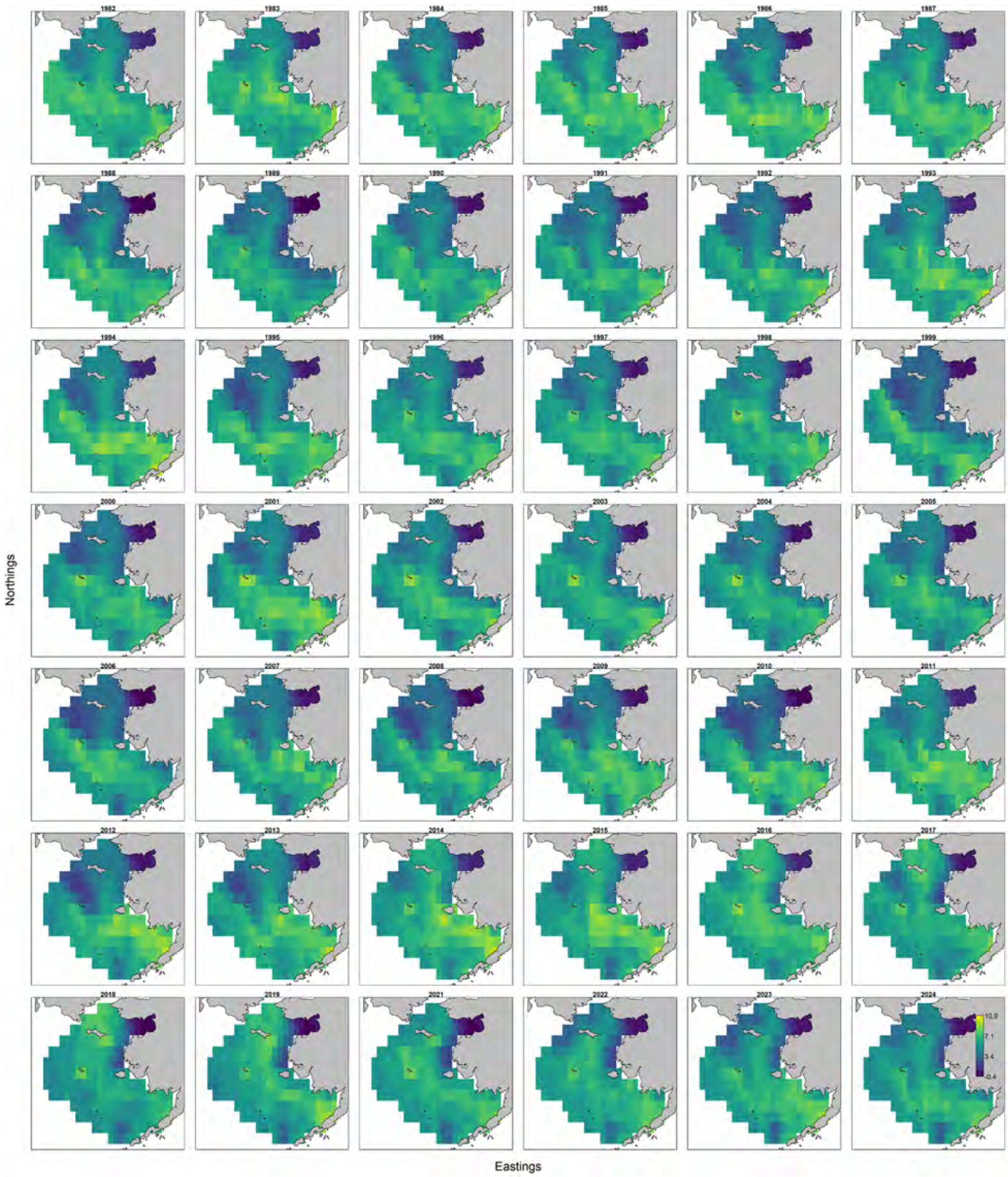


Figure 2.17. Bering Sea shelf bottom trawl survey Pacific cod abundance log density maps by year from 2023 VAST.

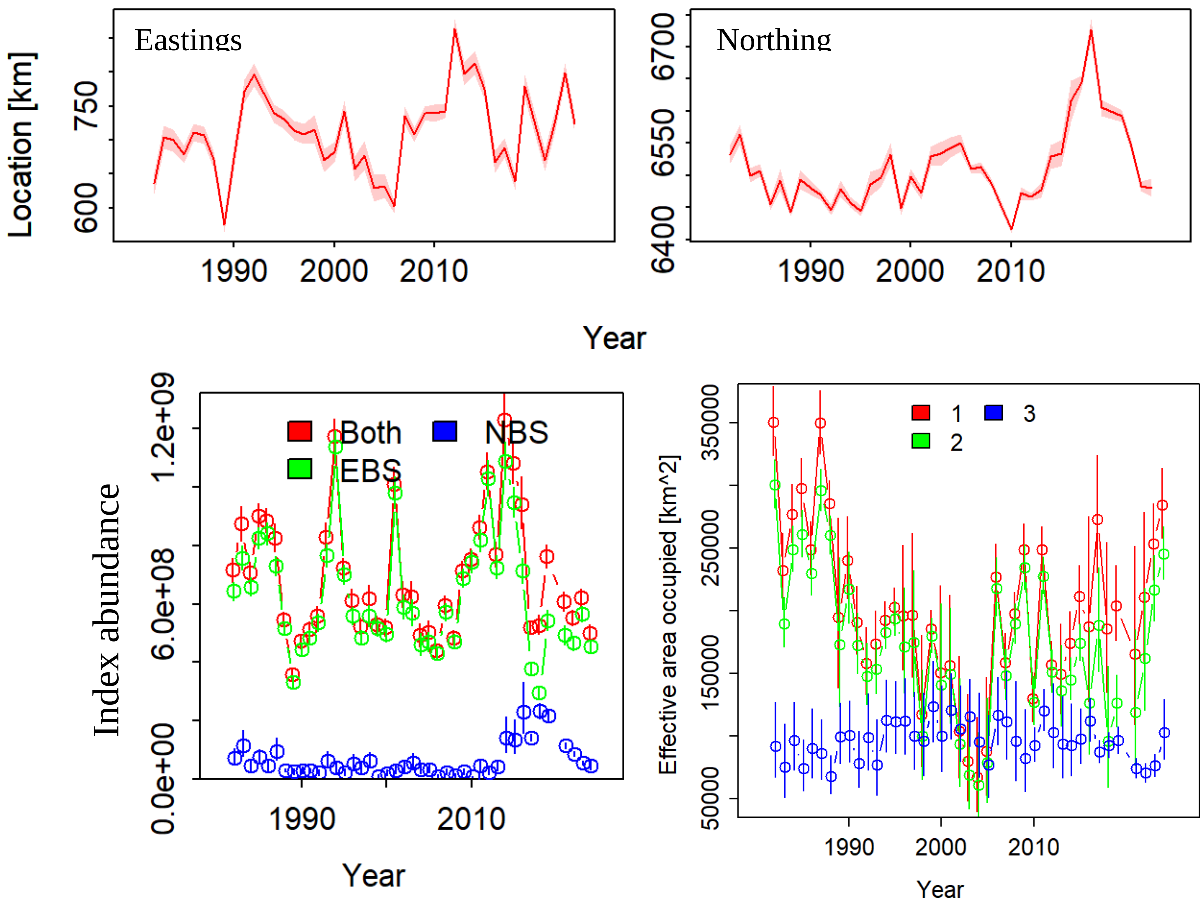


Figure 2.18. Bering Sea shelf bottom trawl survey index center of gravity (top left) eastings, (top right) northings, (bottom left) abundance index by area, and (bottom right) effective area occupied 1982-2024 for Pacific cod from 2024 VAST.

1 cm length bins

5 cm length bins

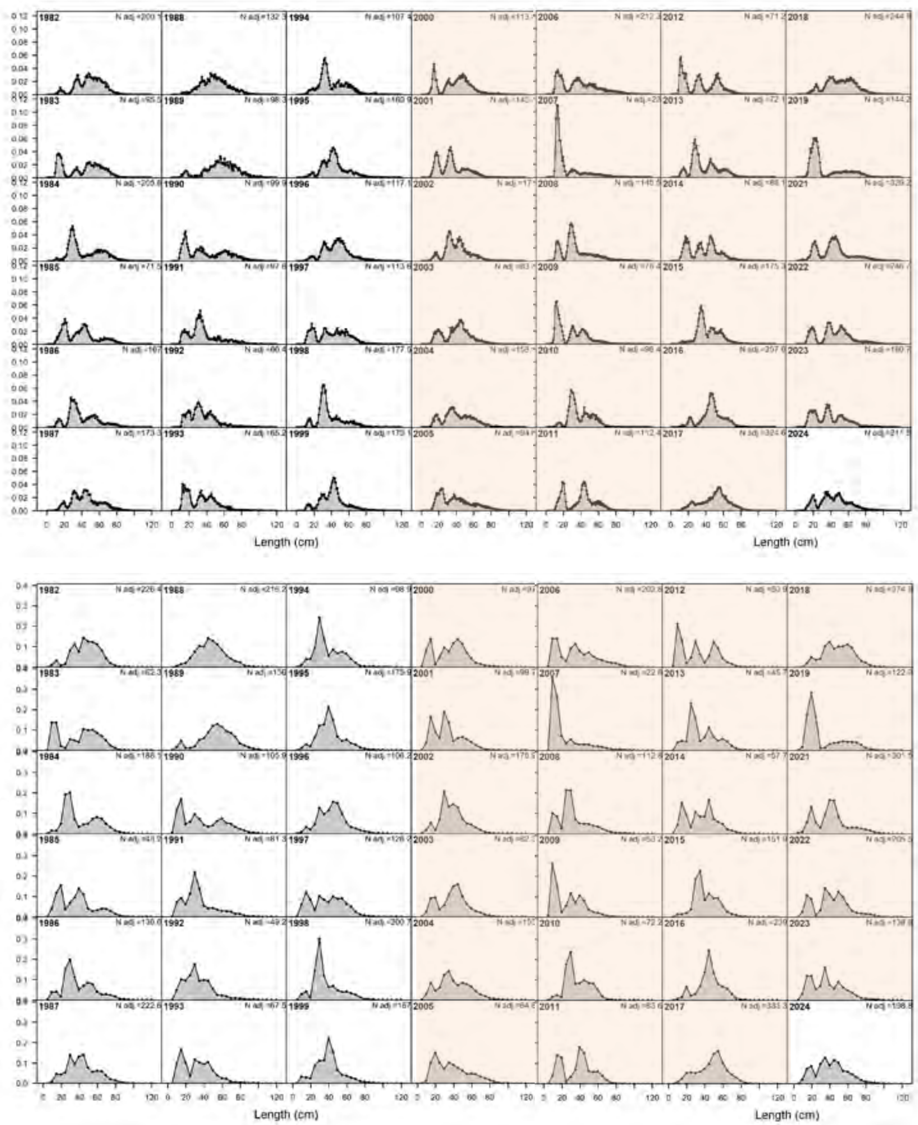


Figure 2.19. Bottom trawl survey length composition distributions by year for (top) 1cm bins and (bottom) 5cm bins. Colored years indicate length composition data not used in the models as age composition was available.

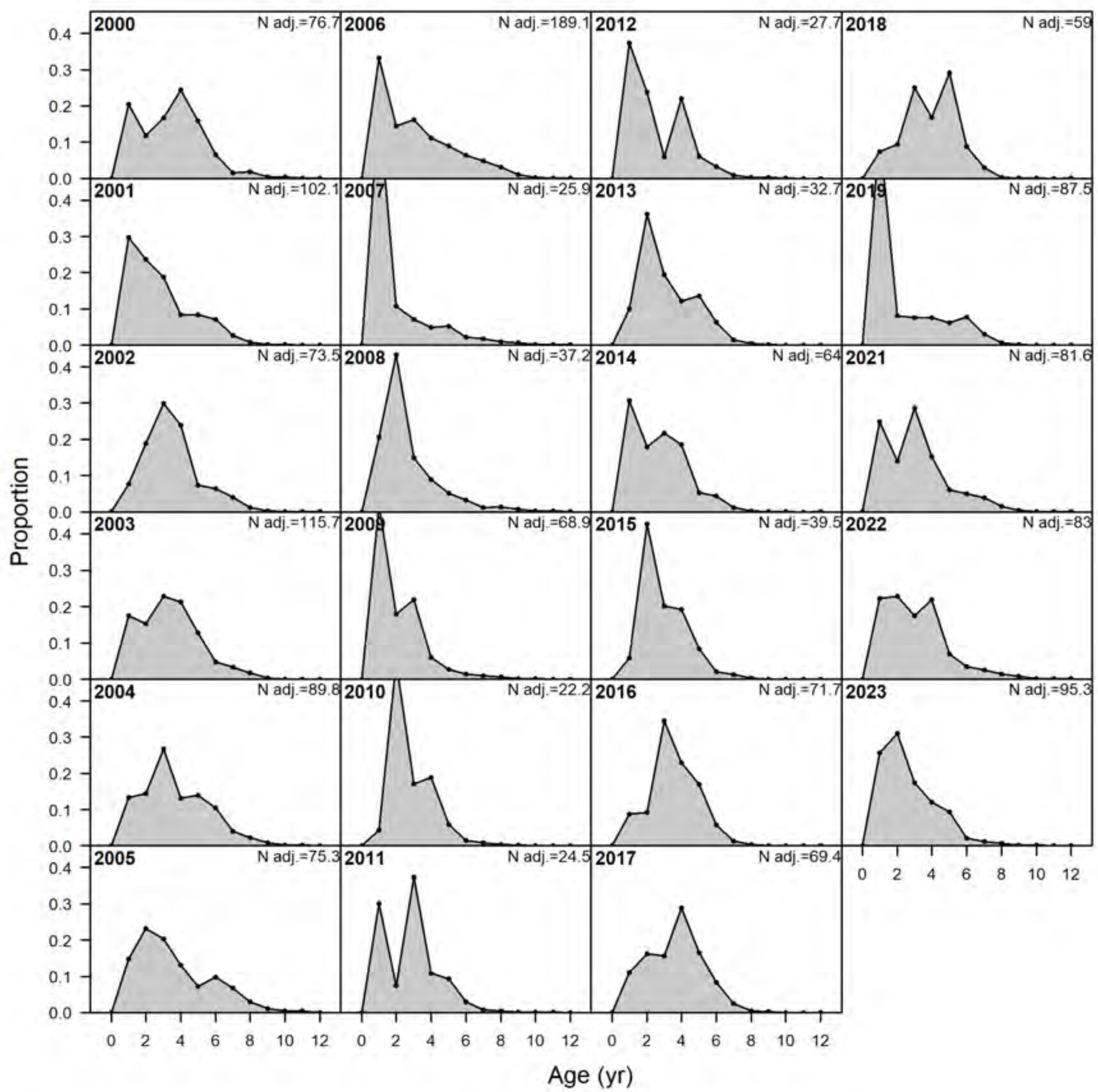


Figure 2.20. Bottom trawl survey age composition distributions by year.

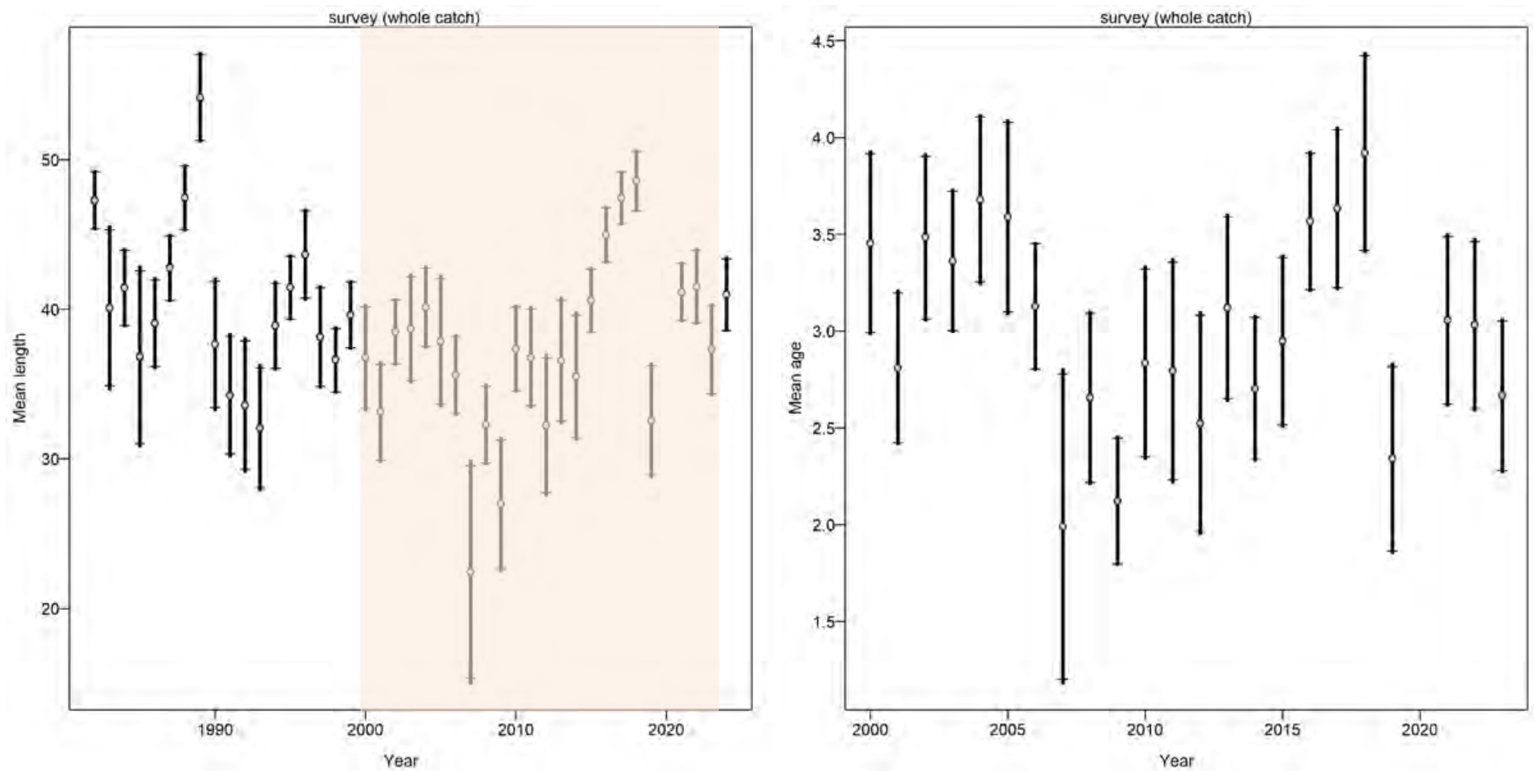


Figure 2.21. AFSC bottom trawl survey (left) mean length (cm) and (right) mean age by year. Colored block in the length composition indicates times when age composition data are available.

Figure 2.22. Locations of AFSC longline survey stations in the EBS region.

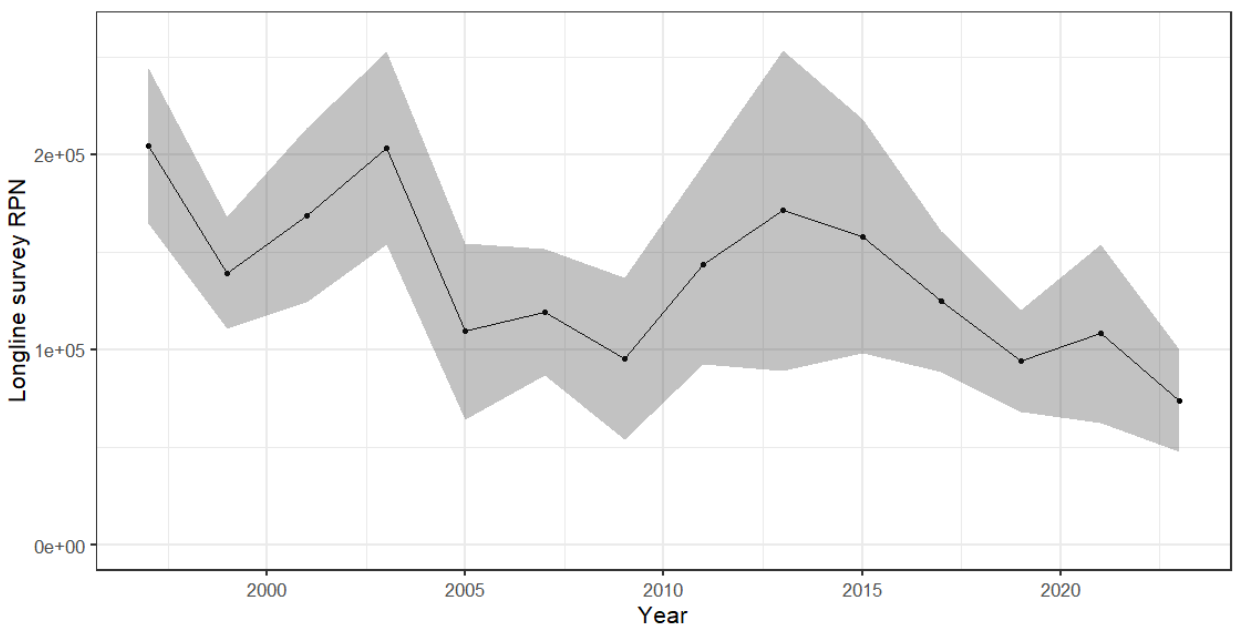


Figure 2.23. AFSC longline survey relative population numbers (RPN) for EBS region.

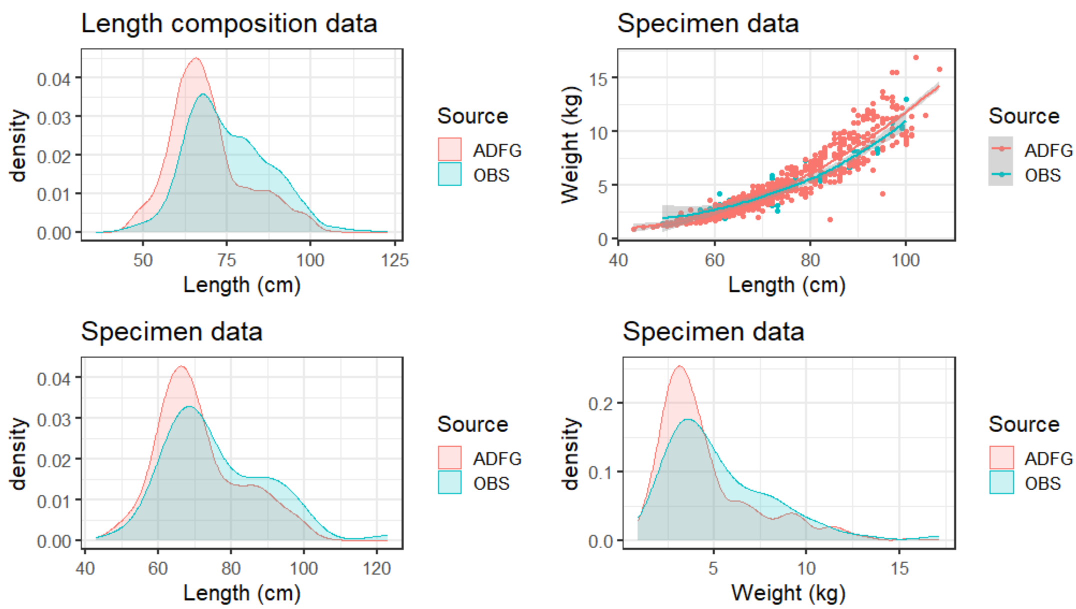


Figure 2.24 Pacific cod size and weight distribution comparisons for samples collected in the Dutch Harbor Subdistrict (DHS) pot fishery and Federal Bering Sea pot fisheries in the first trimester of 2023. All of the samples collected in the federal fishery were from NMFS Area 517. (Top left) length composition data, and (top left, bottom) length and weight from individually weighed specimen collections.

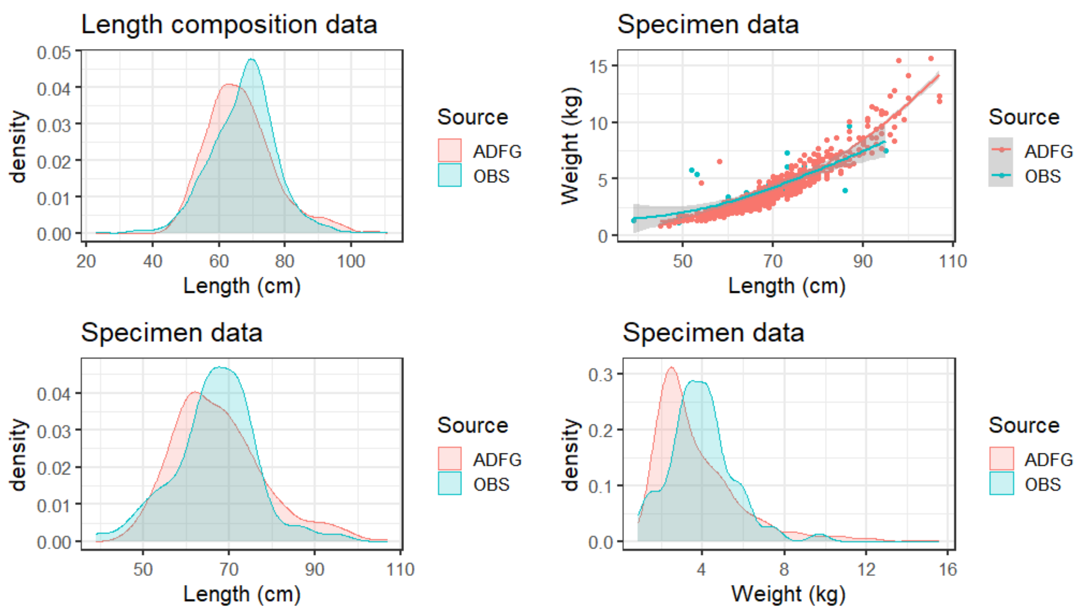


Figure 2.25 Pacific cod size and weight distribution comparisons for samples collected in the Dutch Harbor Subdistrict (DHS) pot fishery and Federal Bering Sea pot fisheries in the first trimester of 2024. All of the samples collected in the federal fishery were from NMFS Area 517. (Top left) length composition data, and (top left, bottom) length and weight from individually weighed specimen collections.

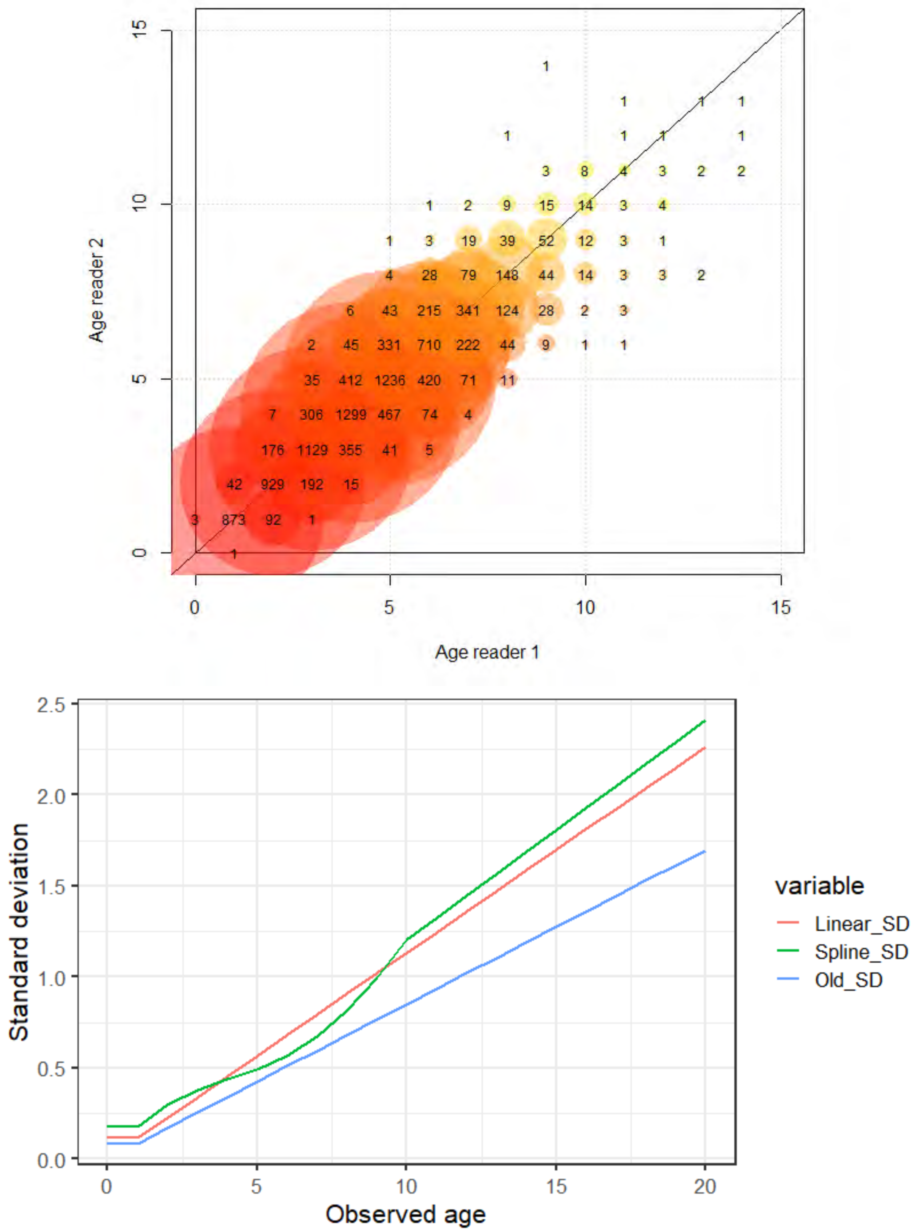
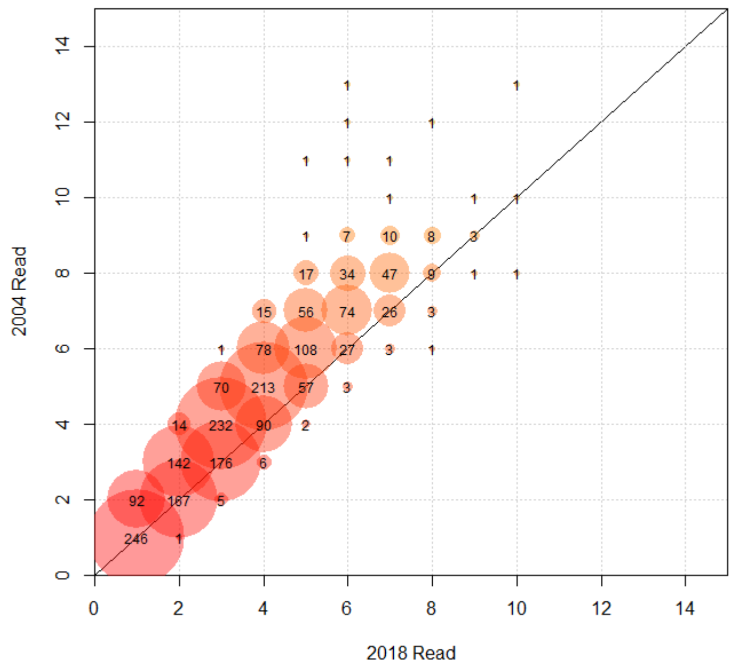


Figure 2.26 (Top) Results from paired age reader testing for Pacific cod with the number of otoliths read at each age by paired readers and (bottom) aging error standard deviation for (Linear_SD) linear and (Spline_SD) spline model from 2000-2023 age testing data and (old_SD) the aging error used in the 2023 model.



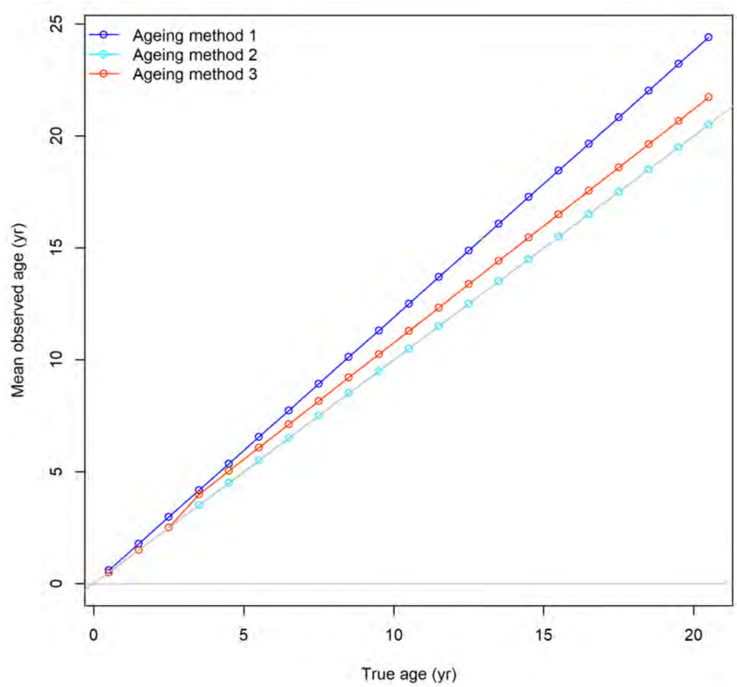


Figure 2.27 (top) distribution of age data read in 2004 (reader 1) and 2018 (reader 2)used to compute aging bias for pre-2008 age data and (bottom) aging bias (dark blue; method 1) calculated from these data, (red line; method 3) used in last year's model, and (light blue; method 2) no bias used for ages collected after 2008 and the 1:1 line.

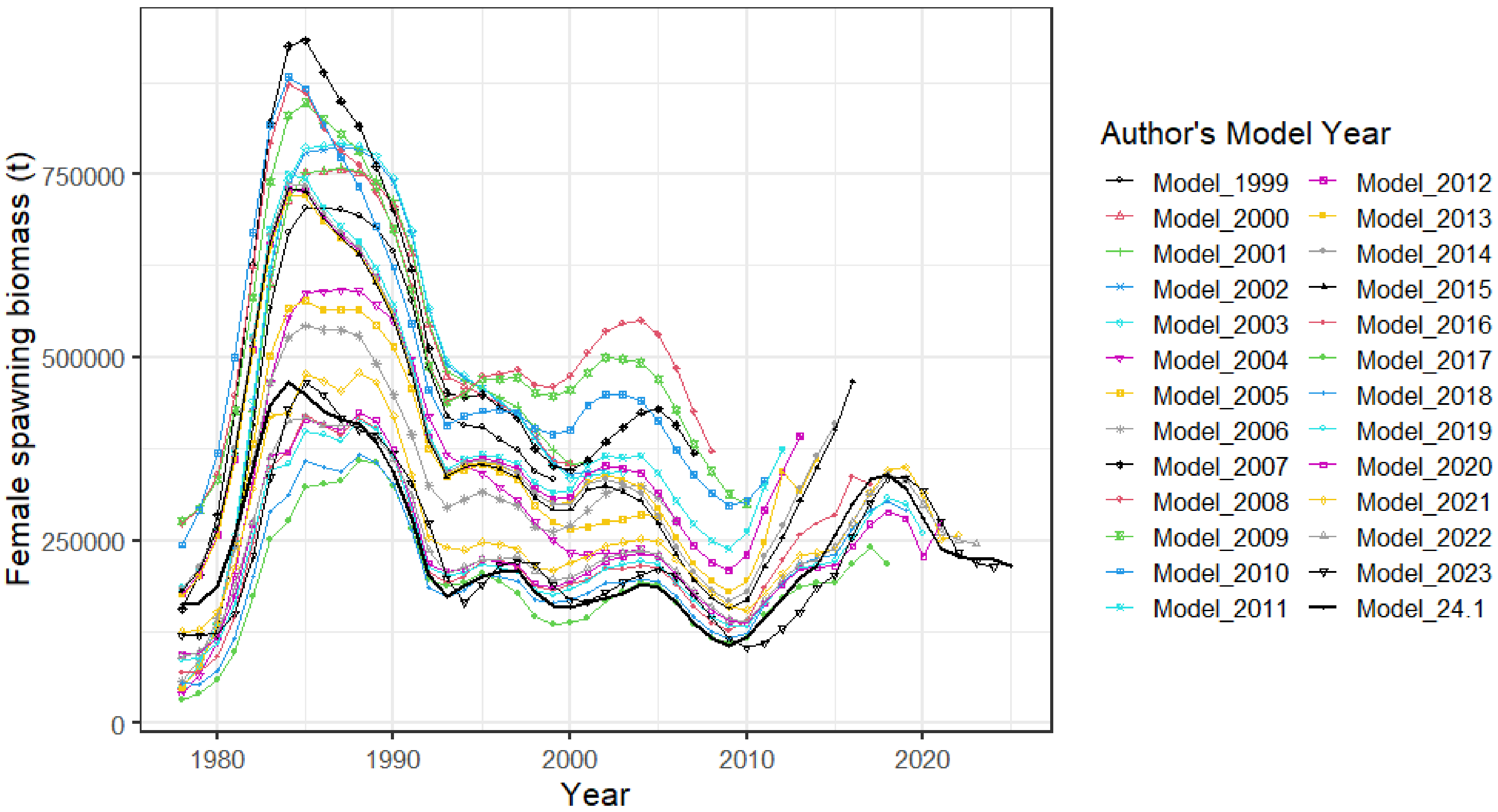


Figure 2.28. History of model estimated female spawning biomass from 1999-2024 accepted models and the 2024 Model 24.1.

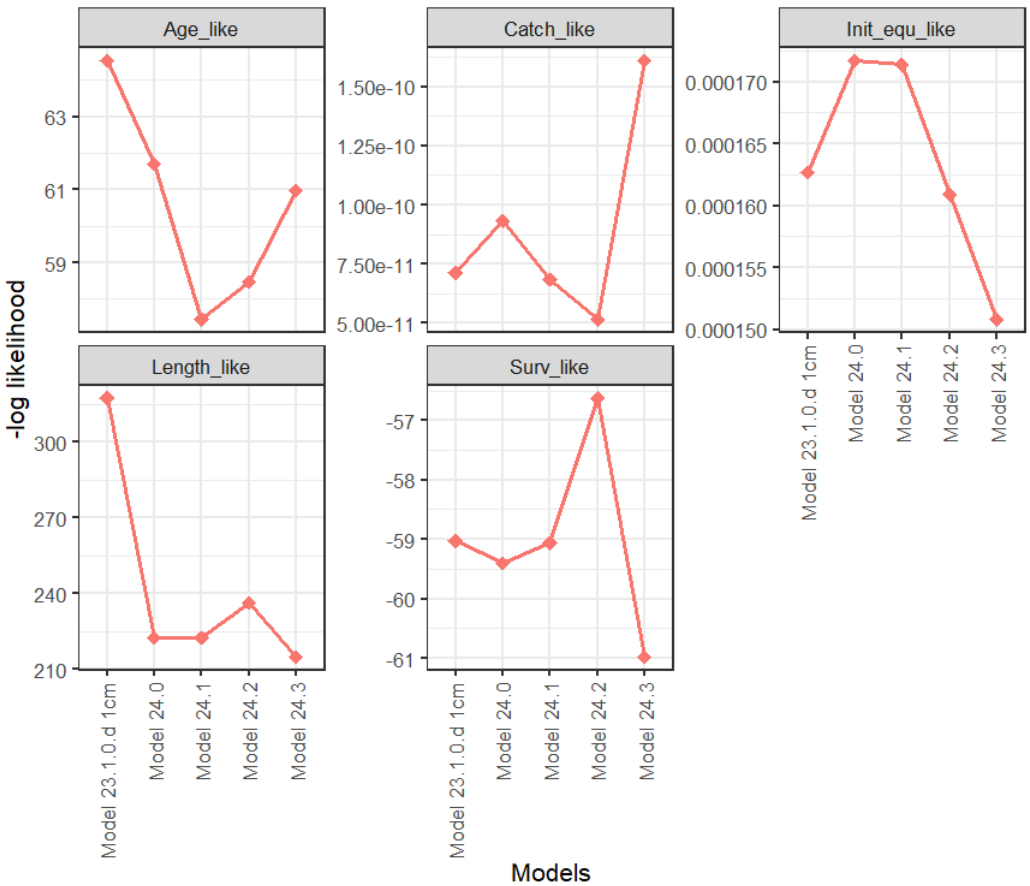


Figure 2.29. Objective function by likelihood component and total for all models. Note that the age and length composition likelihoods are not comparable between Model 23.1.0.d and Model 24.3.0 and the rest due to differences in tuning of variance adjustment factors.

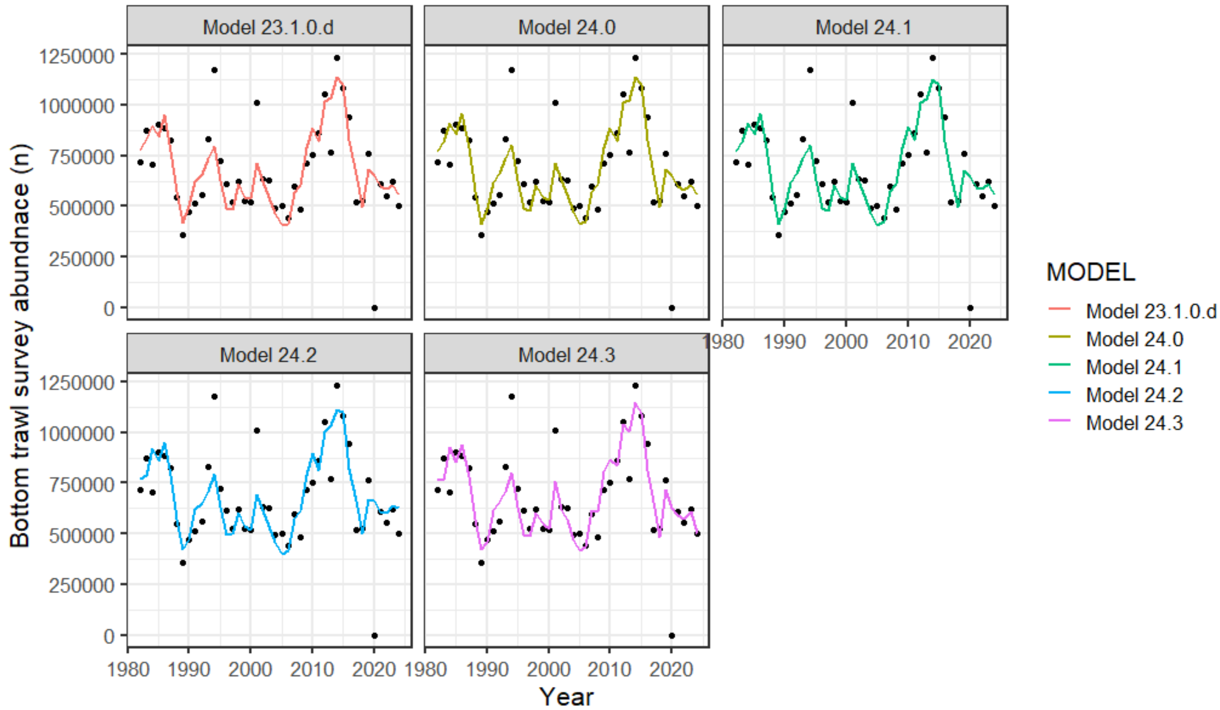


Figure 2.30. Fits to the bottom trawl survey data (population numbers) for all models. Black dots are the observed values.

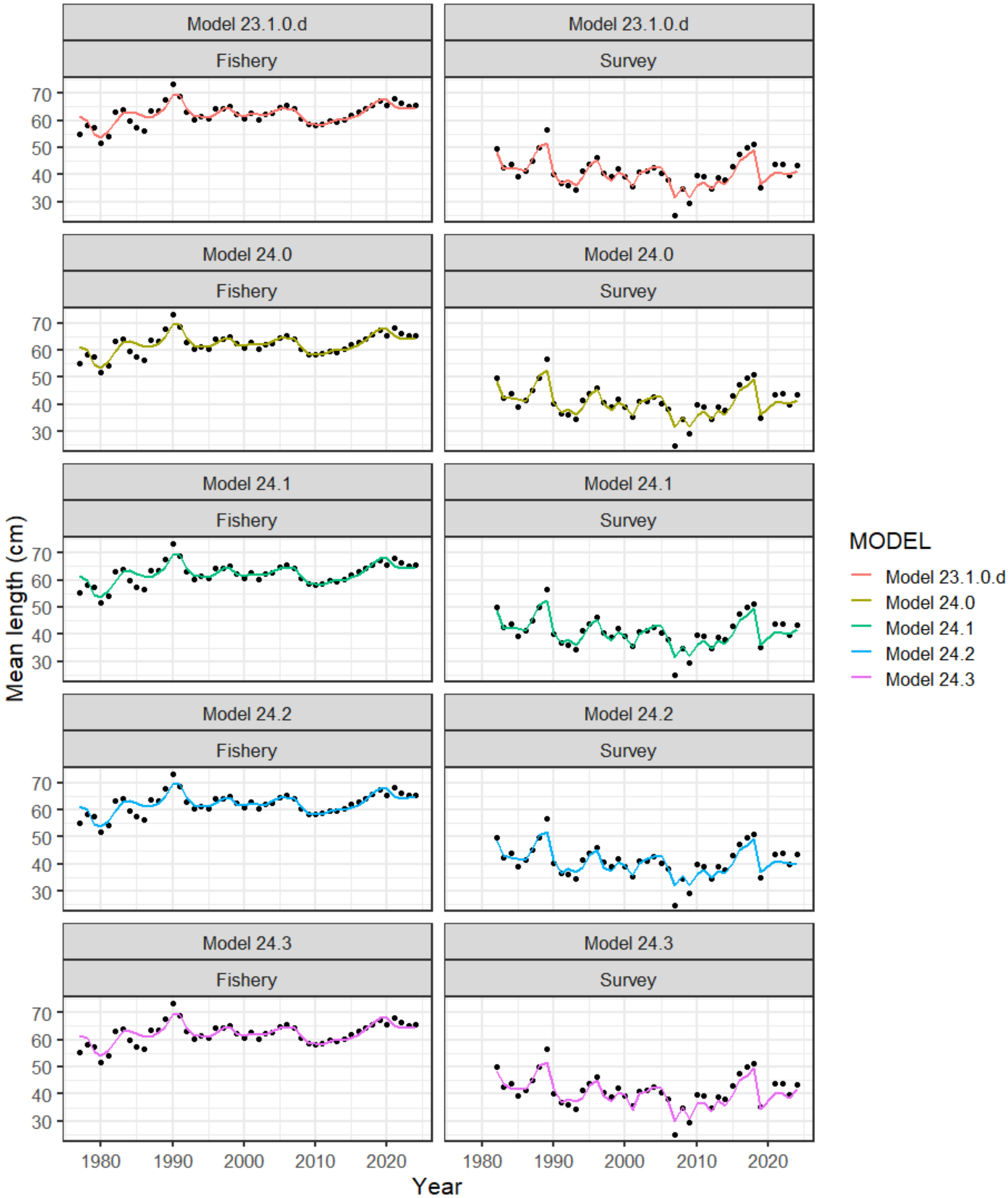


Figure 2.31. Mean length and fits to mean length by model for all models. Black dots are the observed values.

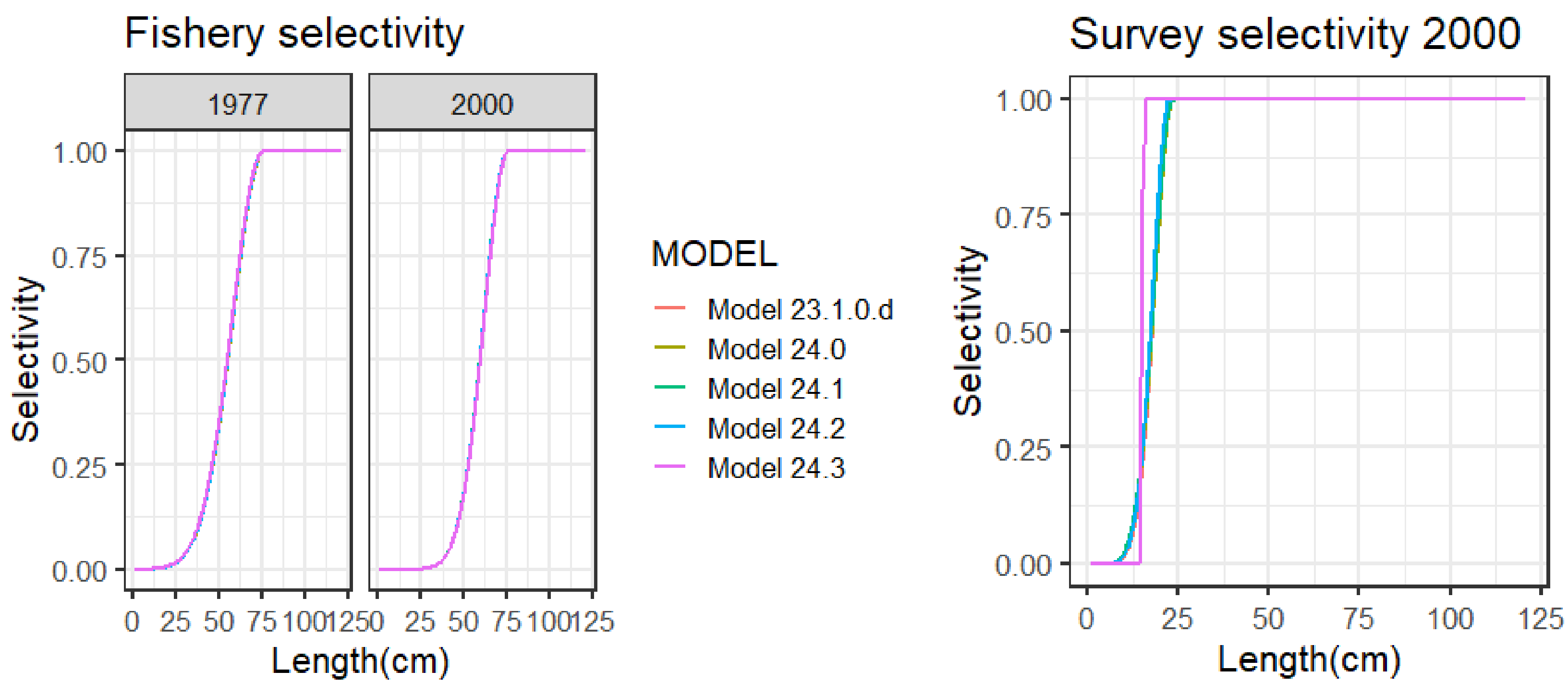


Figure 2.32. Basic shapes for fishery and survey selectivities for all models. Note that for all the models with time varying selectivities although the parameters change slightly the basic shape remains the same over time.

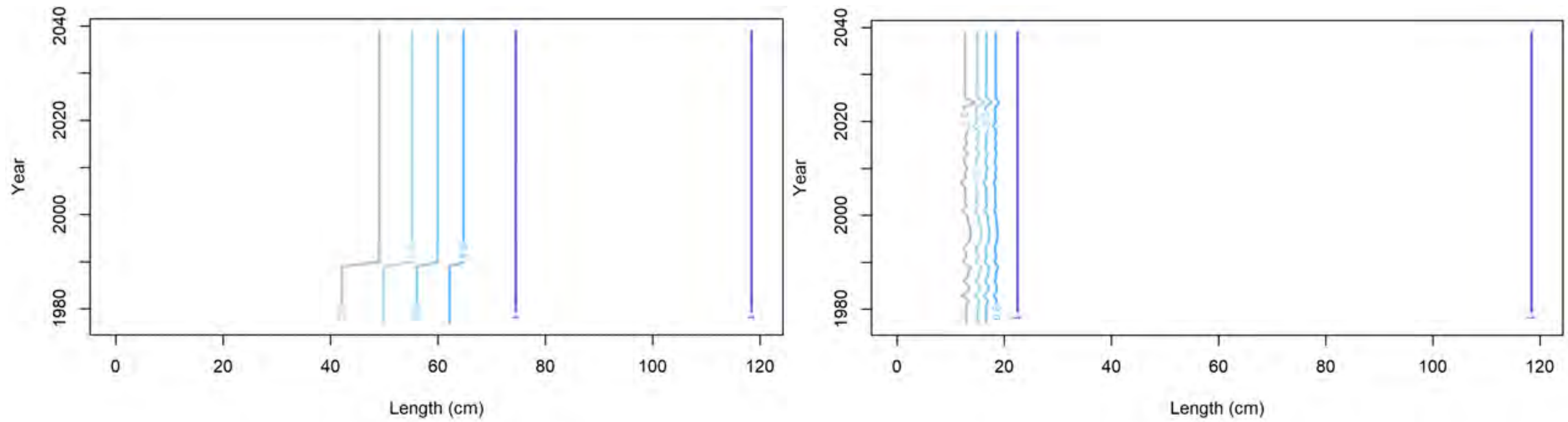


Figure 2.33 Time varying selectivity for Model 23.1.0.d showing blocks for the (left) fishery selectivity and (right) annual deviations in the survey selectivity.

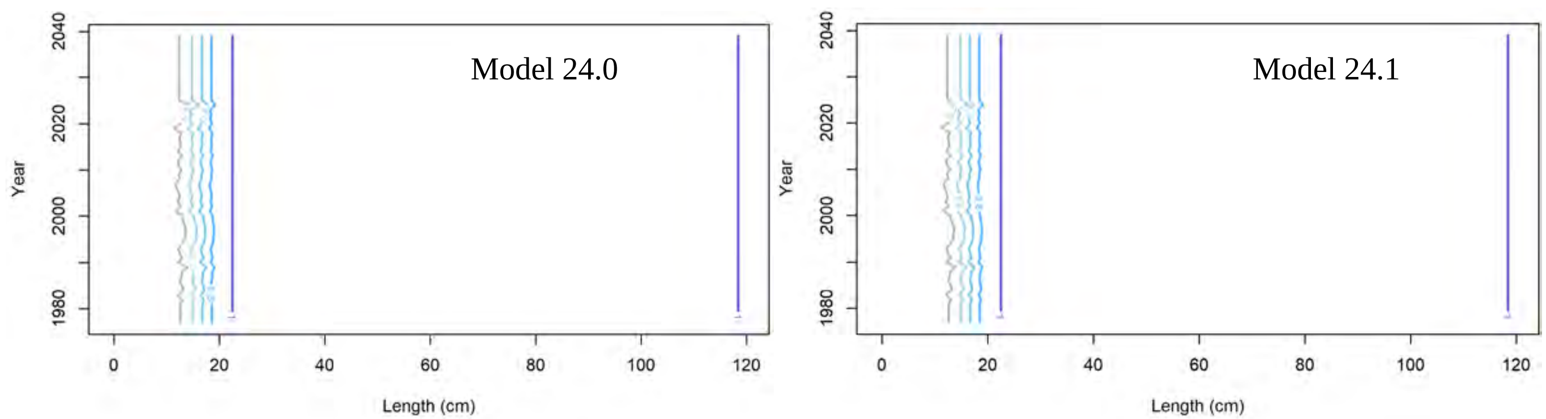


Figure 2.34 Time survey varying selectivity for (left) Model 24.0 and (right) Model 24.1.

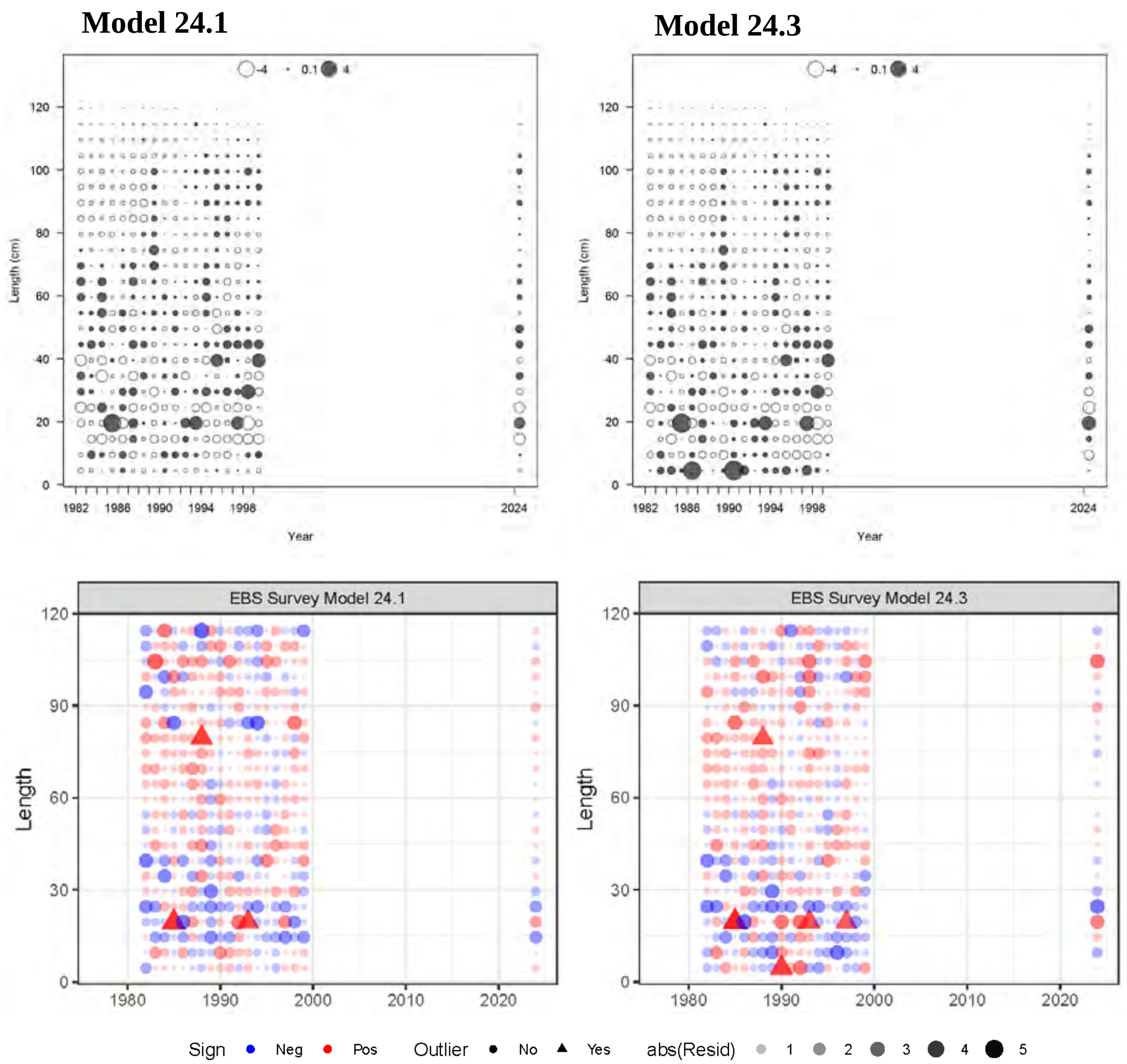


Figure 2.35. (Top) Pearson residuals and (bottom) One-step-ahead (OSA) residuals from survey length composition data for (left) Model 24.1 and (right) Model 24.3. Triangles in the OSA plots are values > 3.

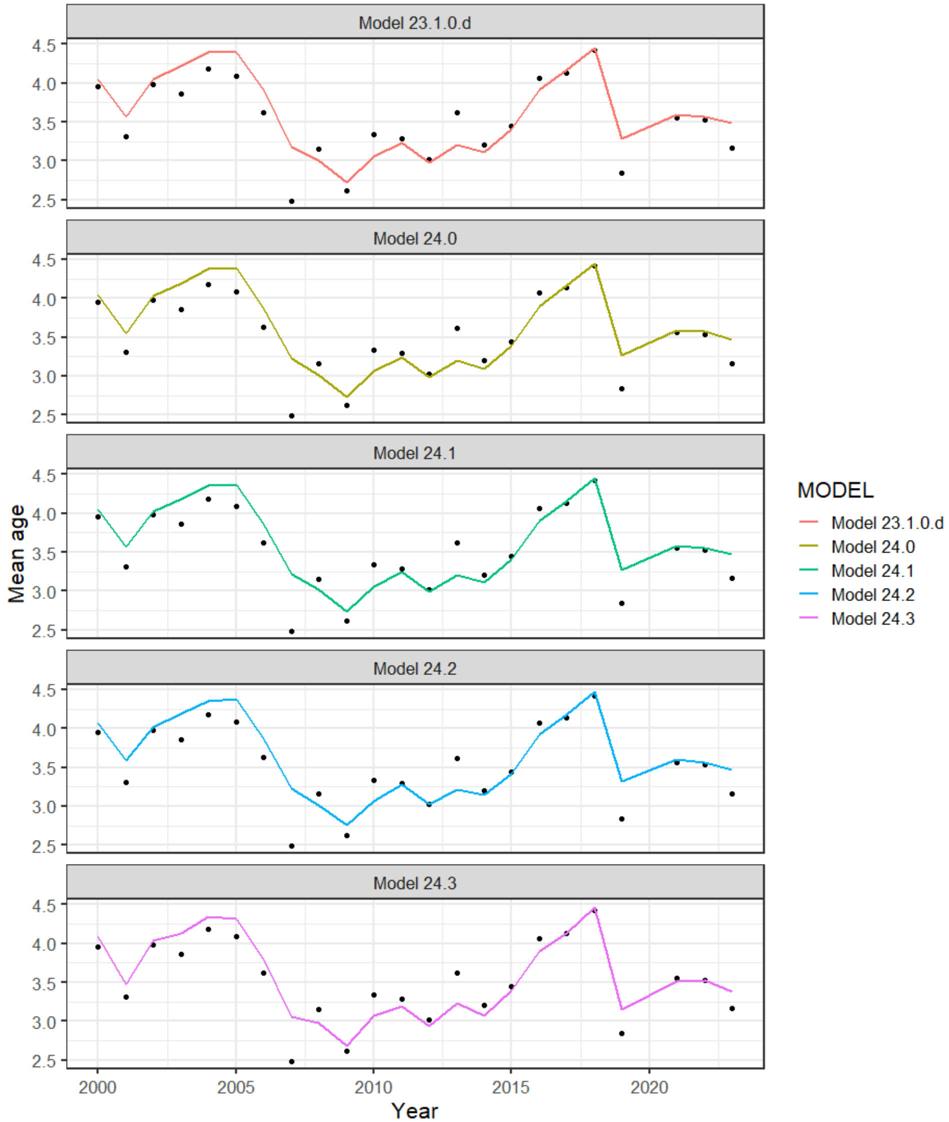


Figure 2.36. Mean age and fits to mean age by model for all models. Black dots are the observed values.

Model 23.1.0.d

Model 24.0

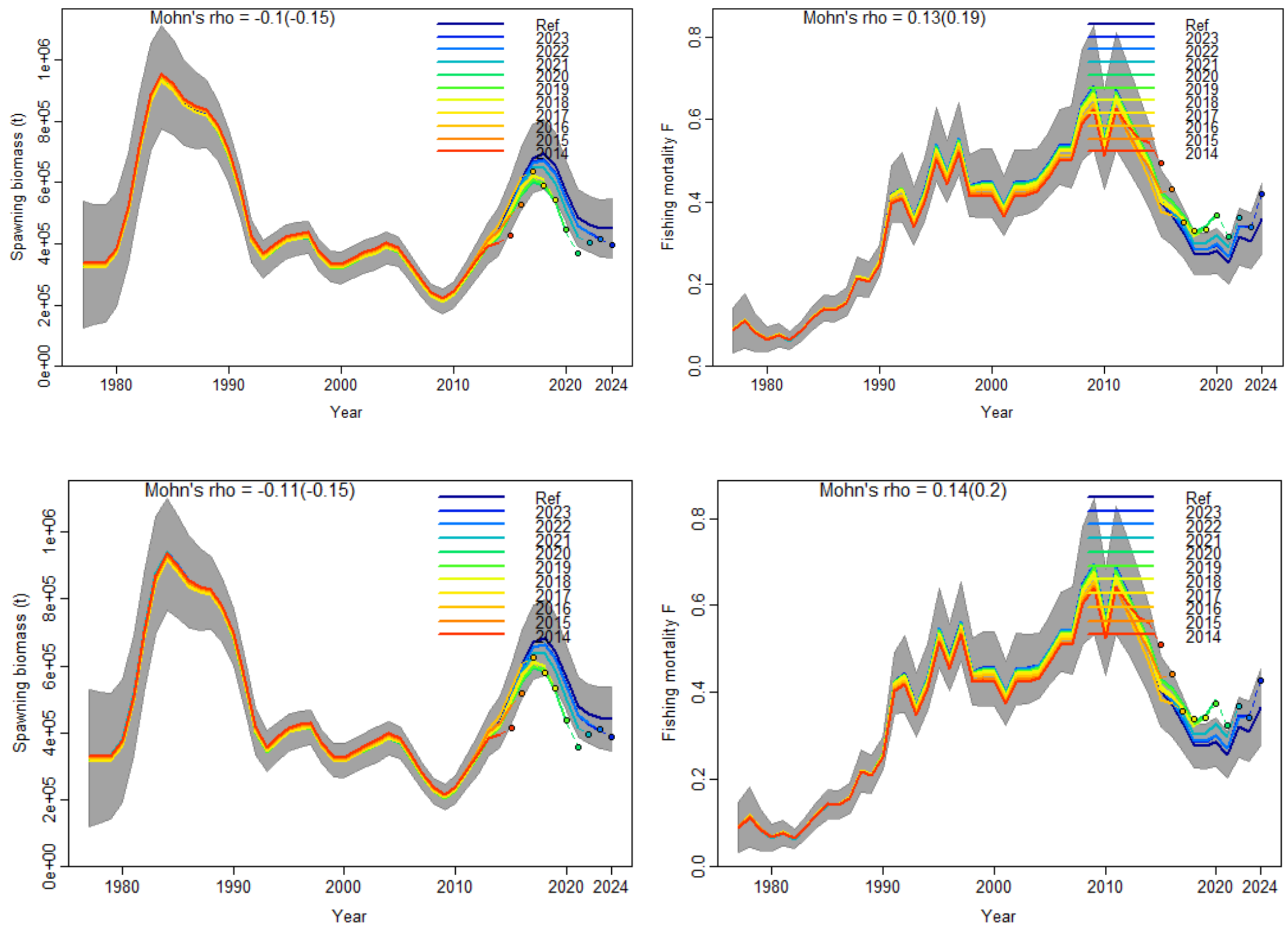


Figure 2.37. Retrospective plots of (left) spawning stock biomass and (right) fishing mortality including the Mohn's rho and in parenthesis the Predictive rho values. Plots from the ss3diags R library (Winker et al. 2022) and described in Carvalho et al. (2021).

Model 24.1

Model 24.3

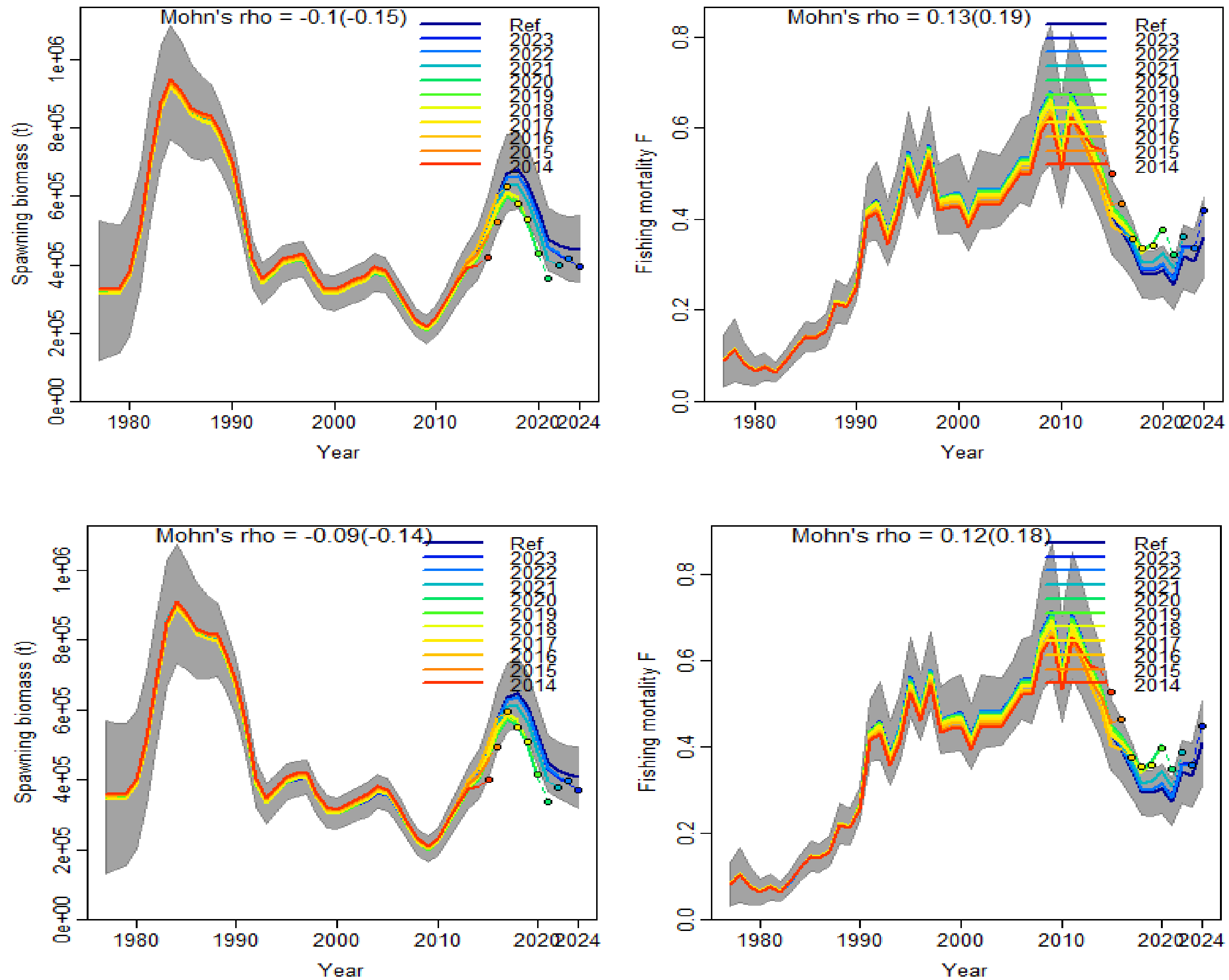


Figure 2.38. Retrospective plots of (left) spawning stock biomass and (right) fishing mortality including the Mohn's rho and in parenthesis the Predictive rho values. Plots from the ss3diags R library (Winker et al. 2022) and described in Carvalho et al. (2021).

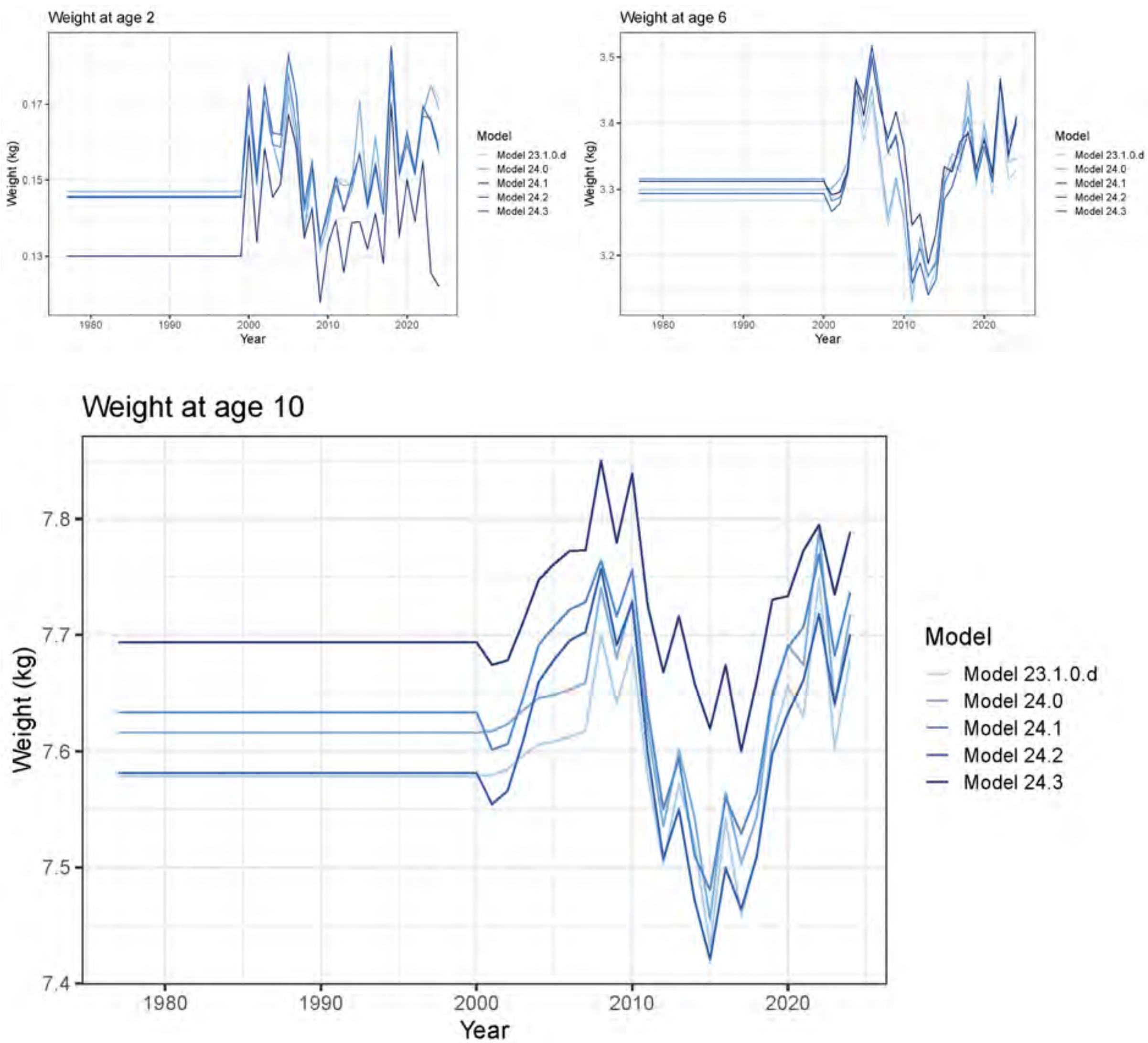


Figure 2.39 Model weight at age (kg) at age 2, age 6, and age 10.

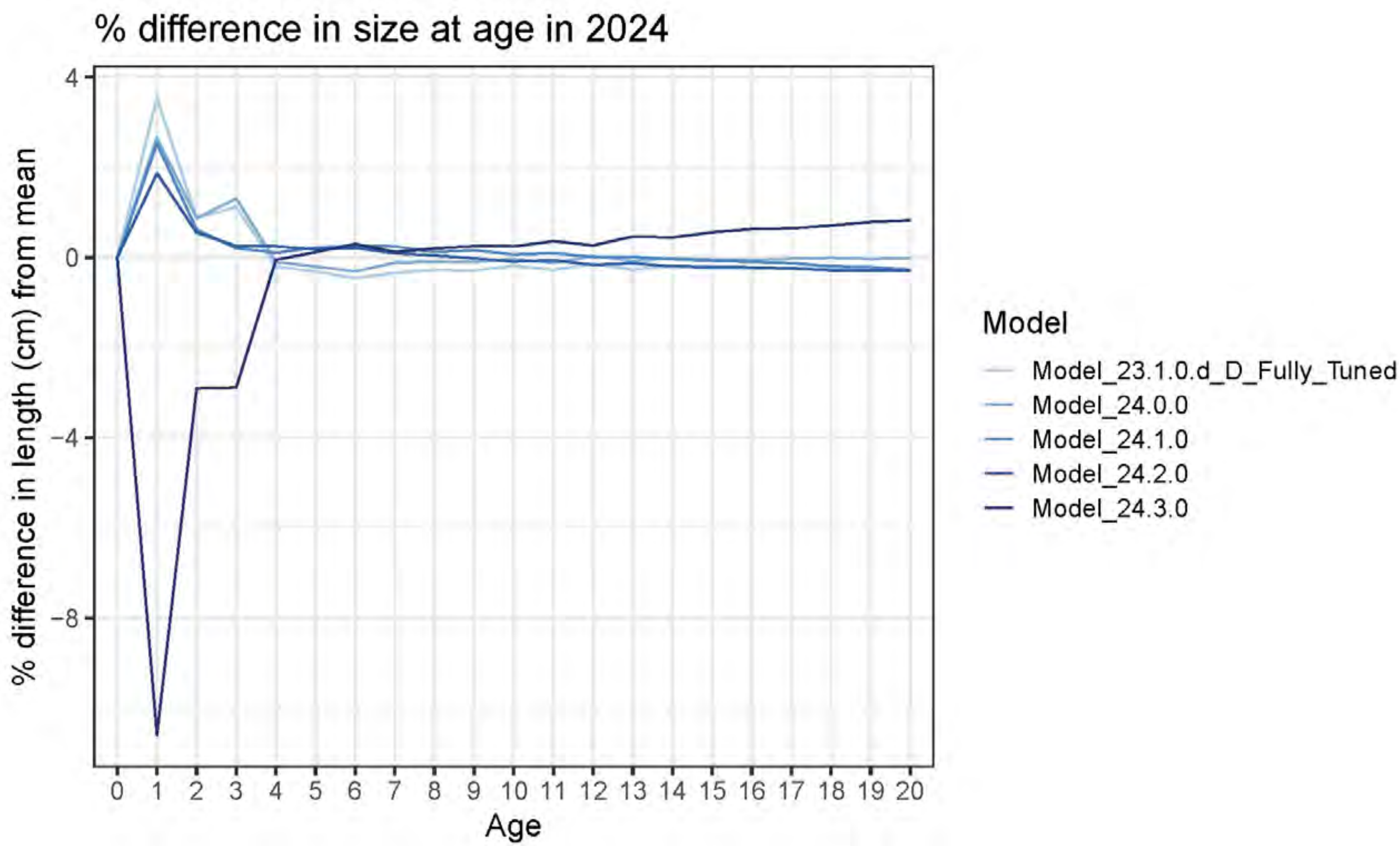


Figure 2.40 Difference in length from the mean of the modes at age in 2024.

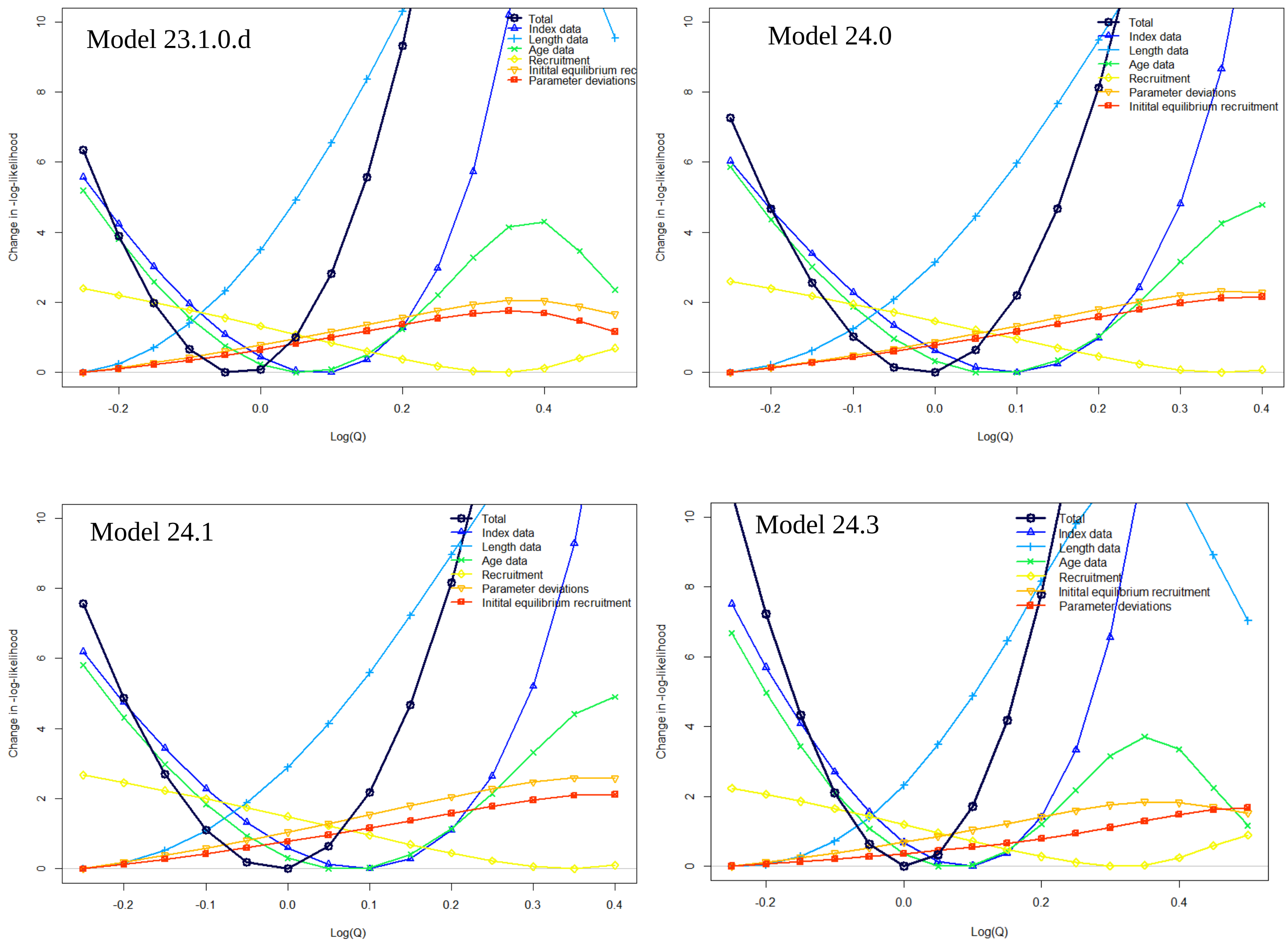


Figure 2.41. Likelihood profiles over survey catchability by model component for (top left) Model 23.1.0.d, (top right) Model 24.2.0, (bottom left) Model 24.1, and (bottom right) Model 24.3.

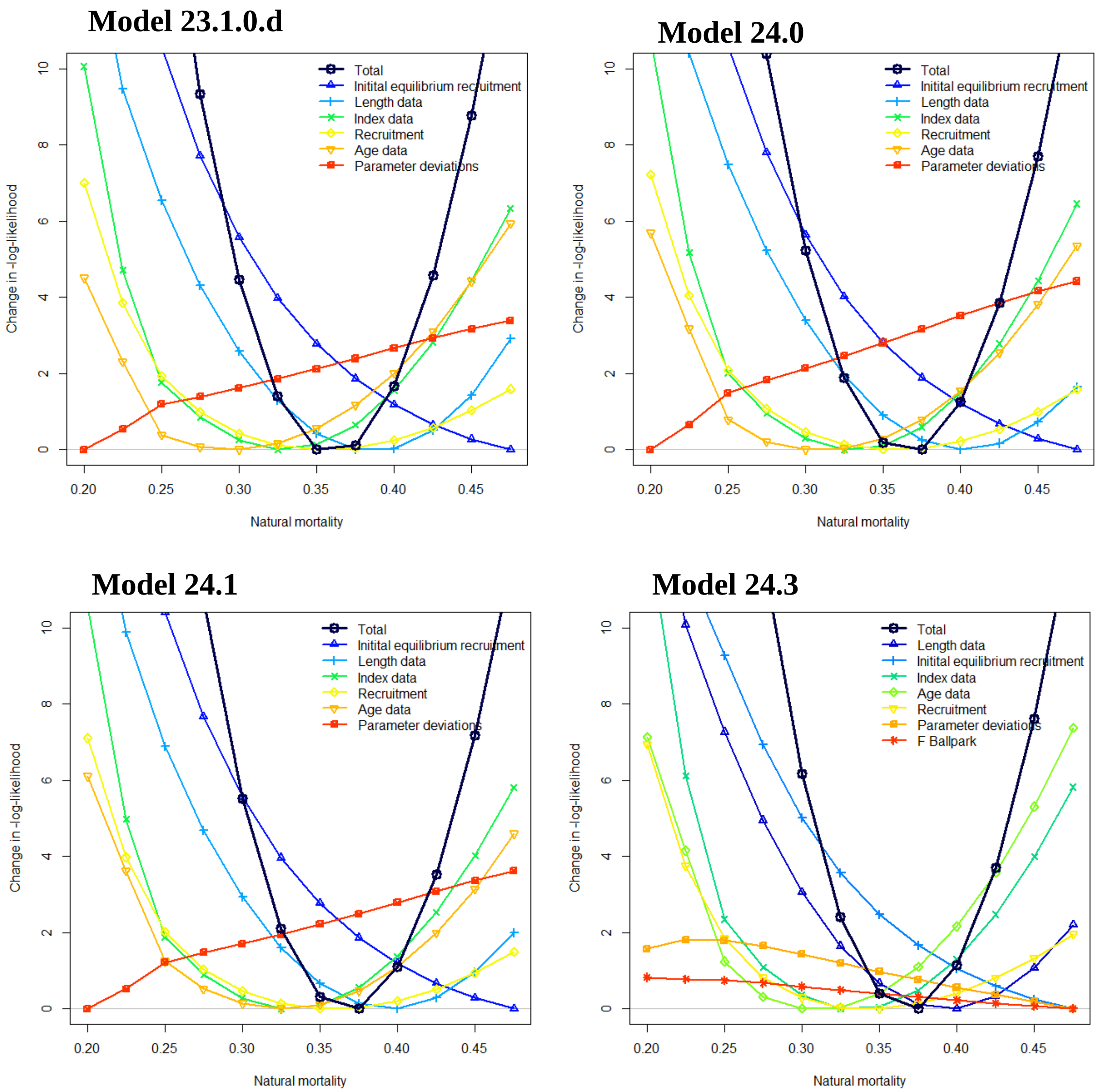


Figure 2.42. Likelihood profile over natural mortality for Model 23.1.0.d, Model 24.0, Model 24.1, and Model 24.3.

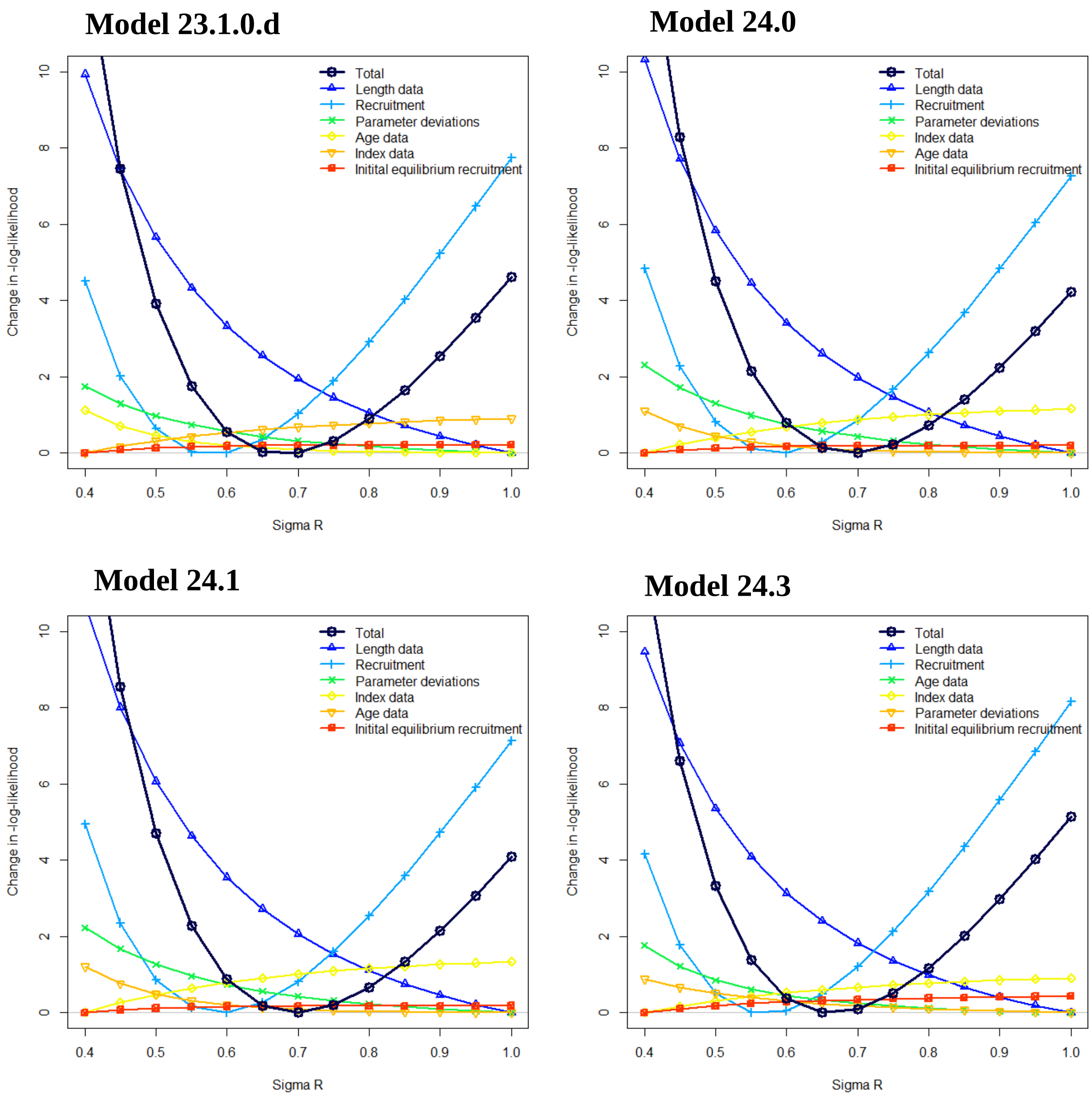


Figure 2.43. Likelihood profile over sigma R for Model 23.1.0.d, Model 24.0, Model 24.1, and Model 24.3.

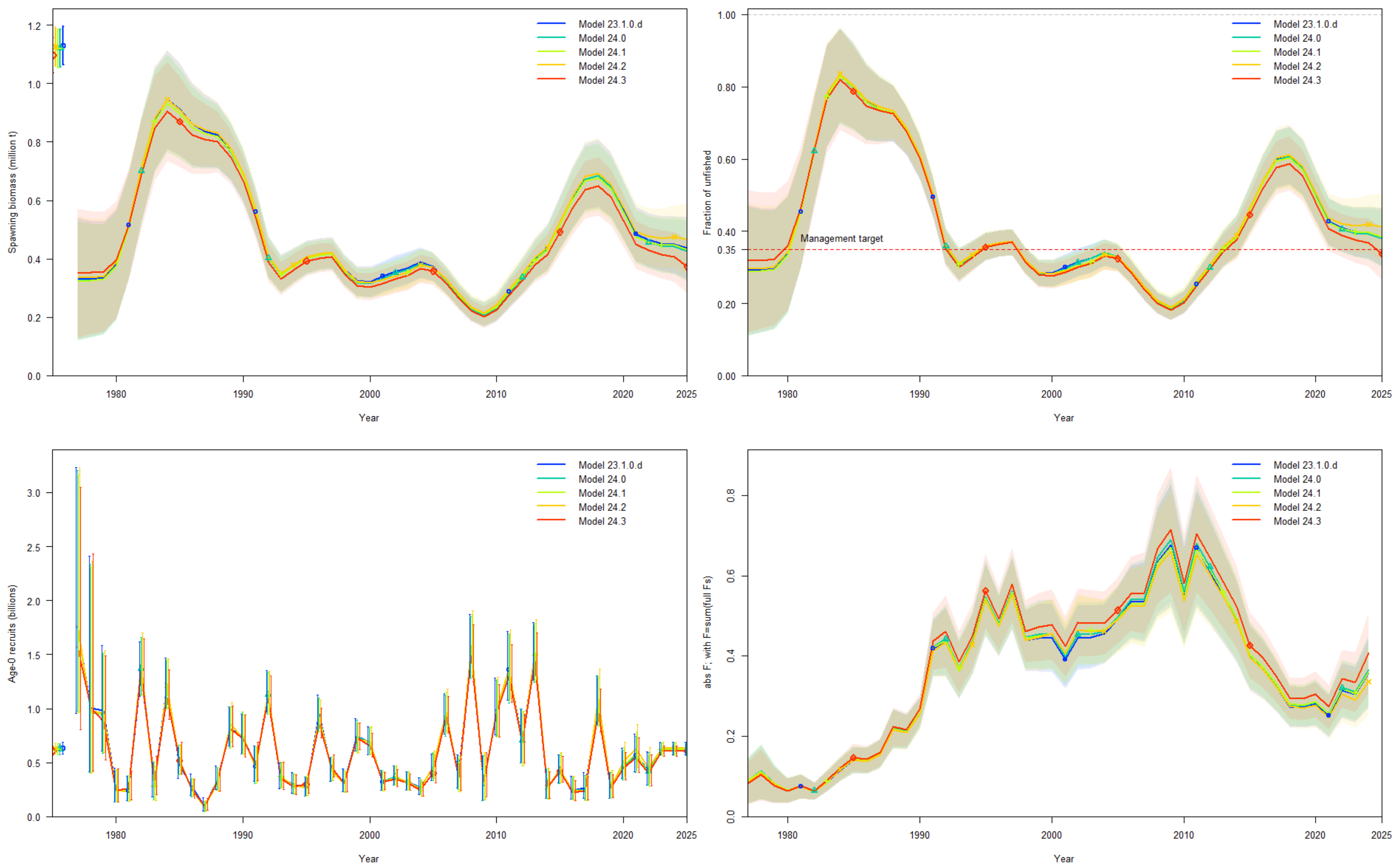


Figure 2.44. (Top left) Total spawning biomass (t), (top right) spawning biomass/unfished biomass, (bottom left) Age-0 recruits, and (bottom right) F (sum of the apical fishing mortality) for the (yellow, dashed) 2022 ensemble and (blue solid) Model 23.1.0.d.

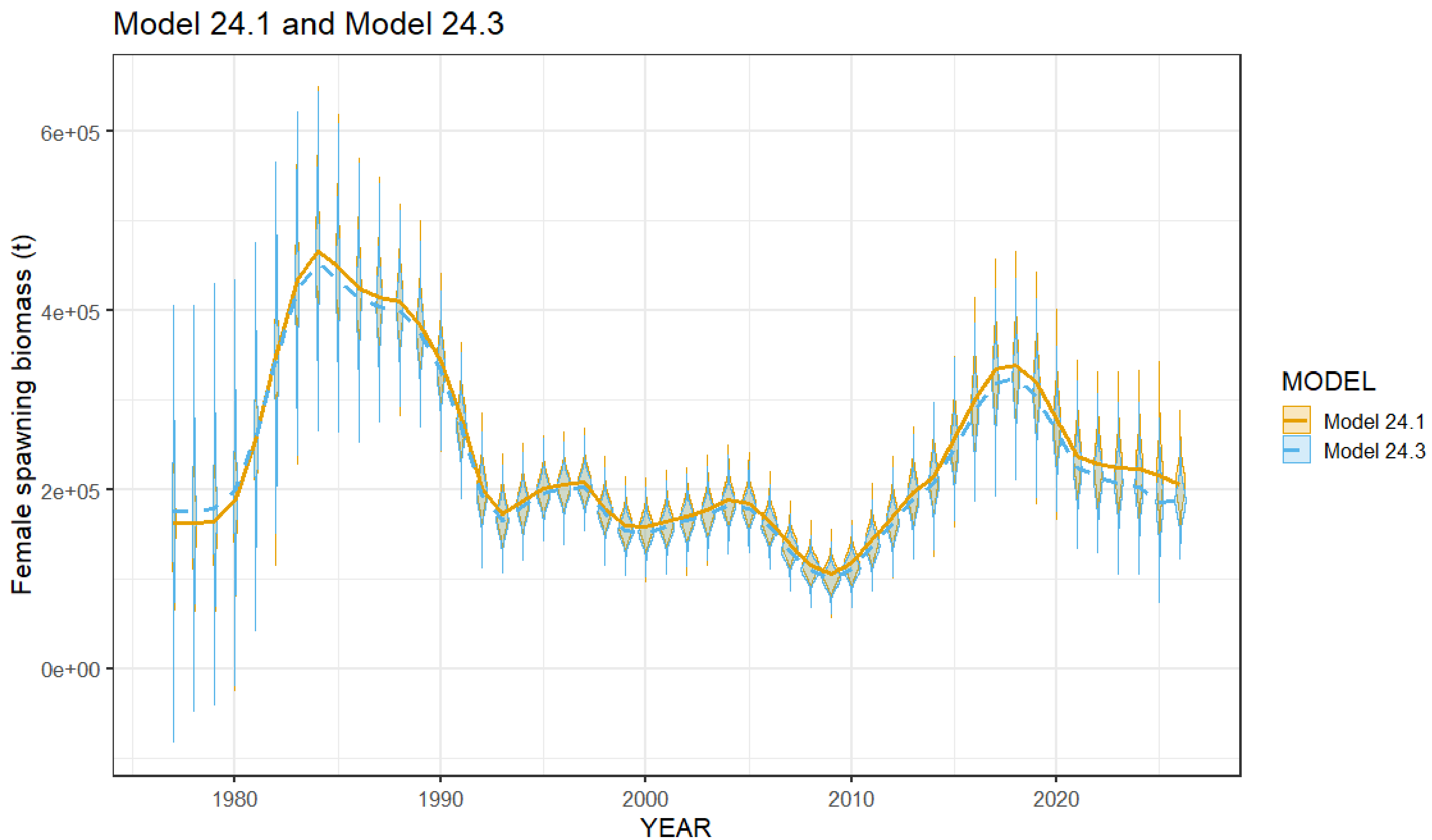


Figure 2.45. Female spawning biomass (t) for Model 24.1 and 24.3.

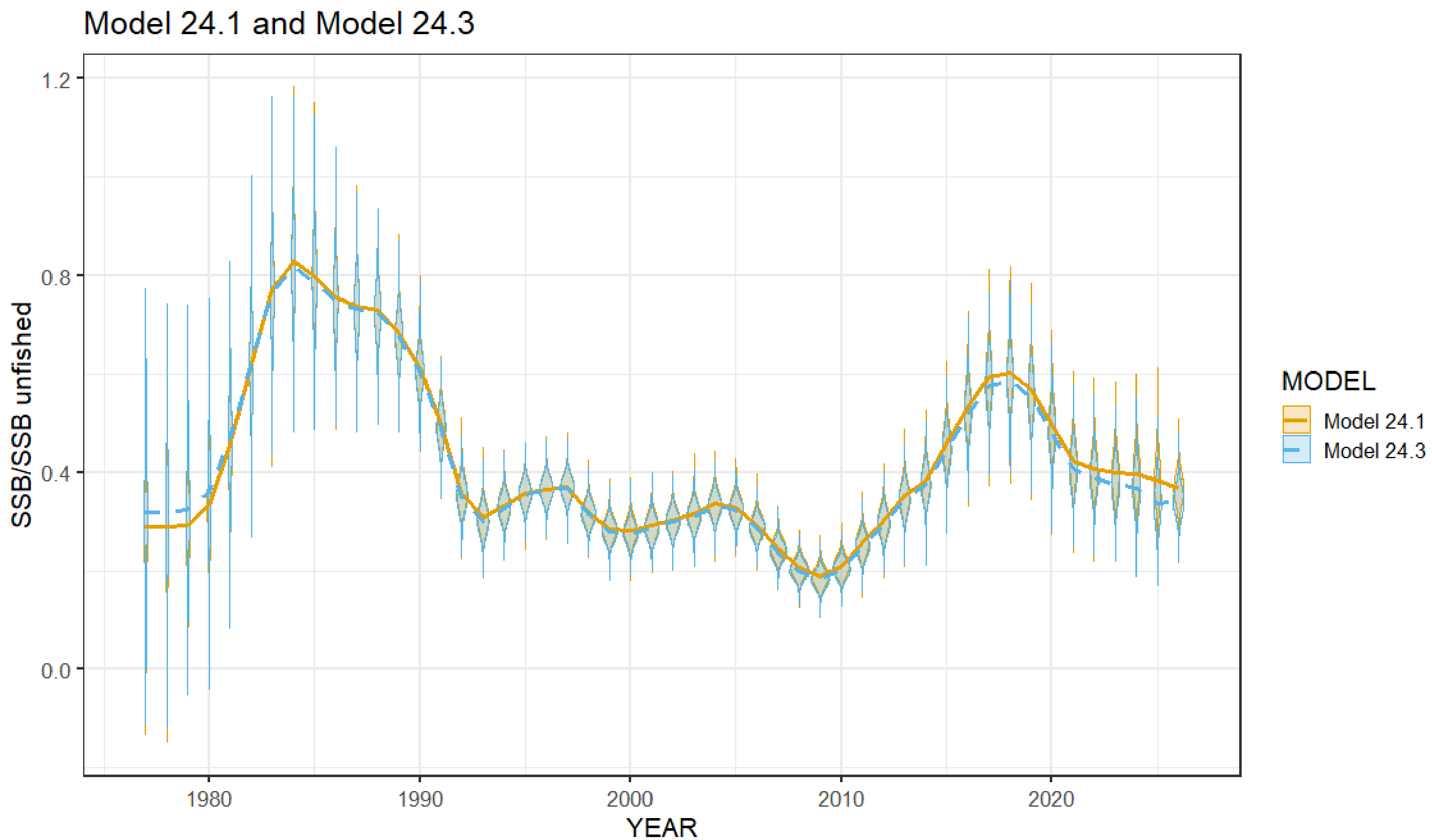


Figure 2.46. Ratio of spawning stock biomass to unfished spawning biomass Model 24.1 and 24.3

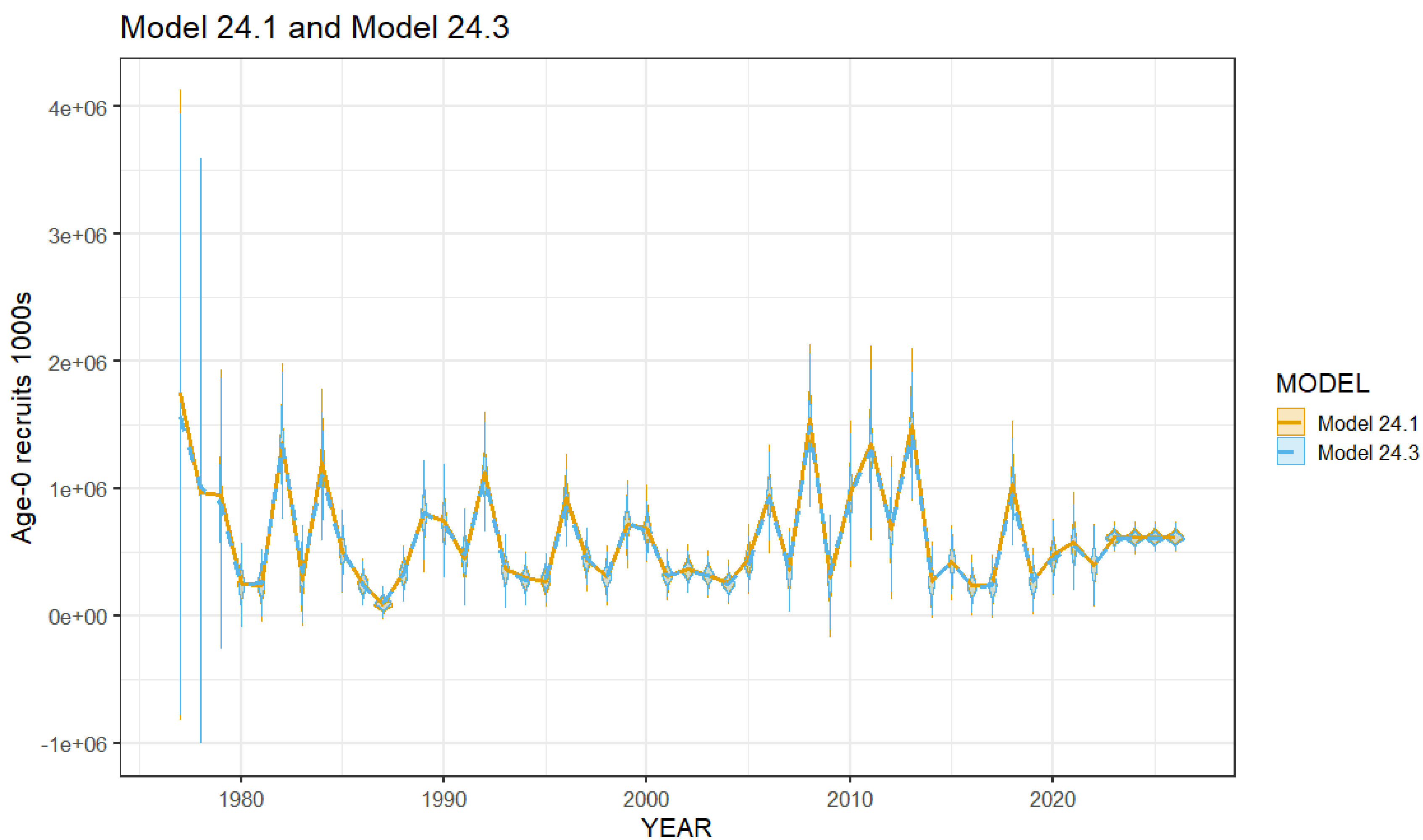


Figure 2.47. Recruitment (1,000s at age-0) for Model 24.1 and 24.3

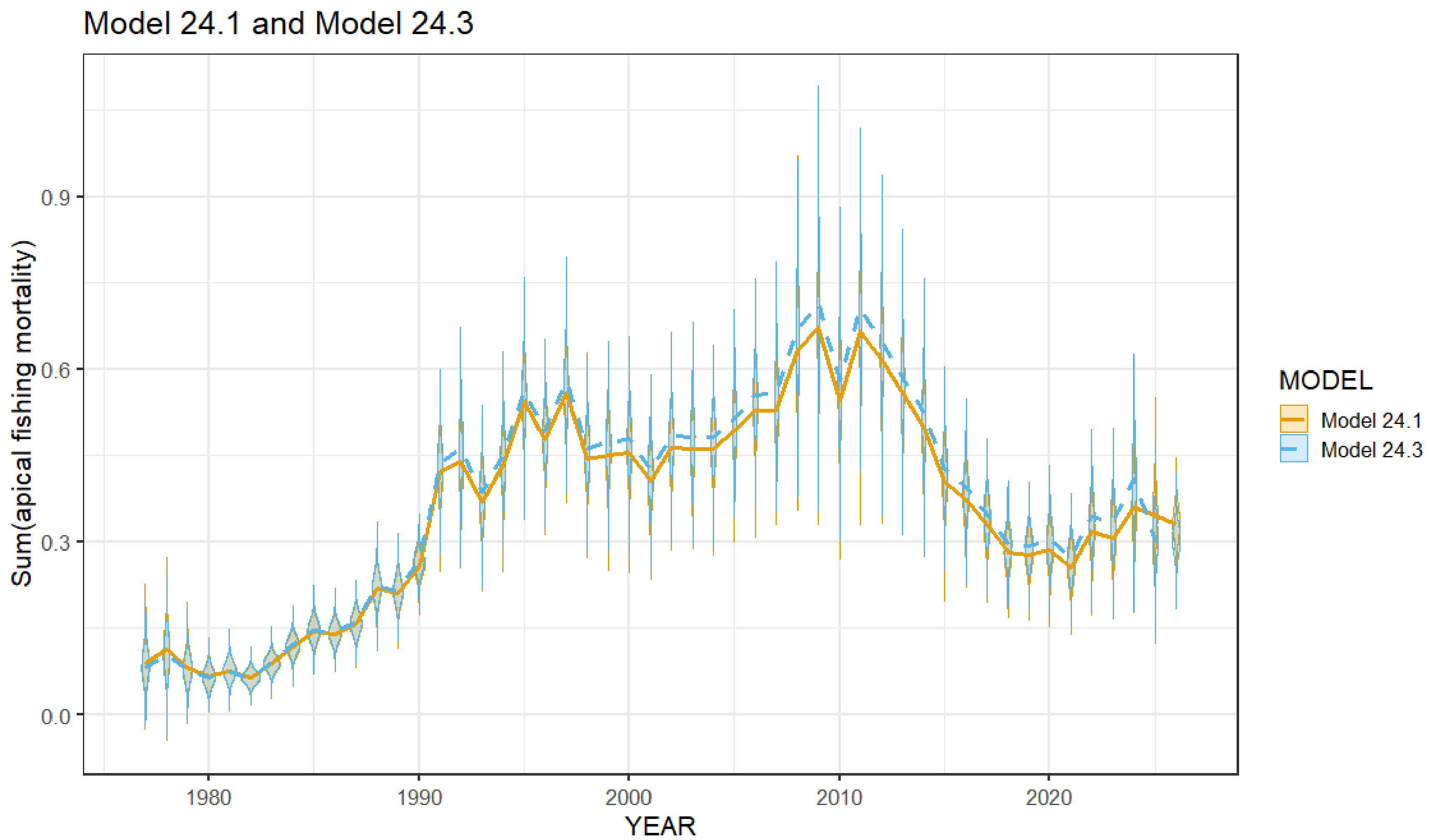


Figure 2.48. Instantaneous apical fishing mortality (F) for Model 24.1 and 24.3.

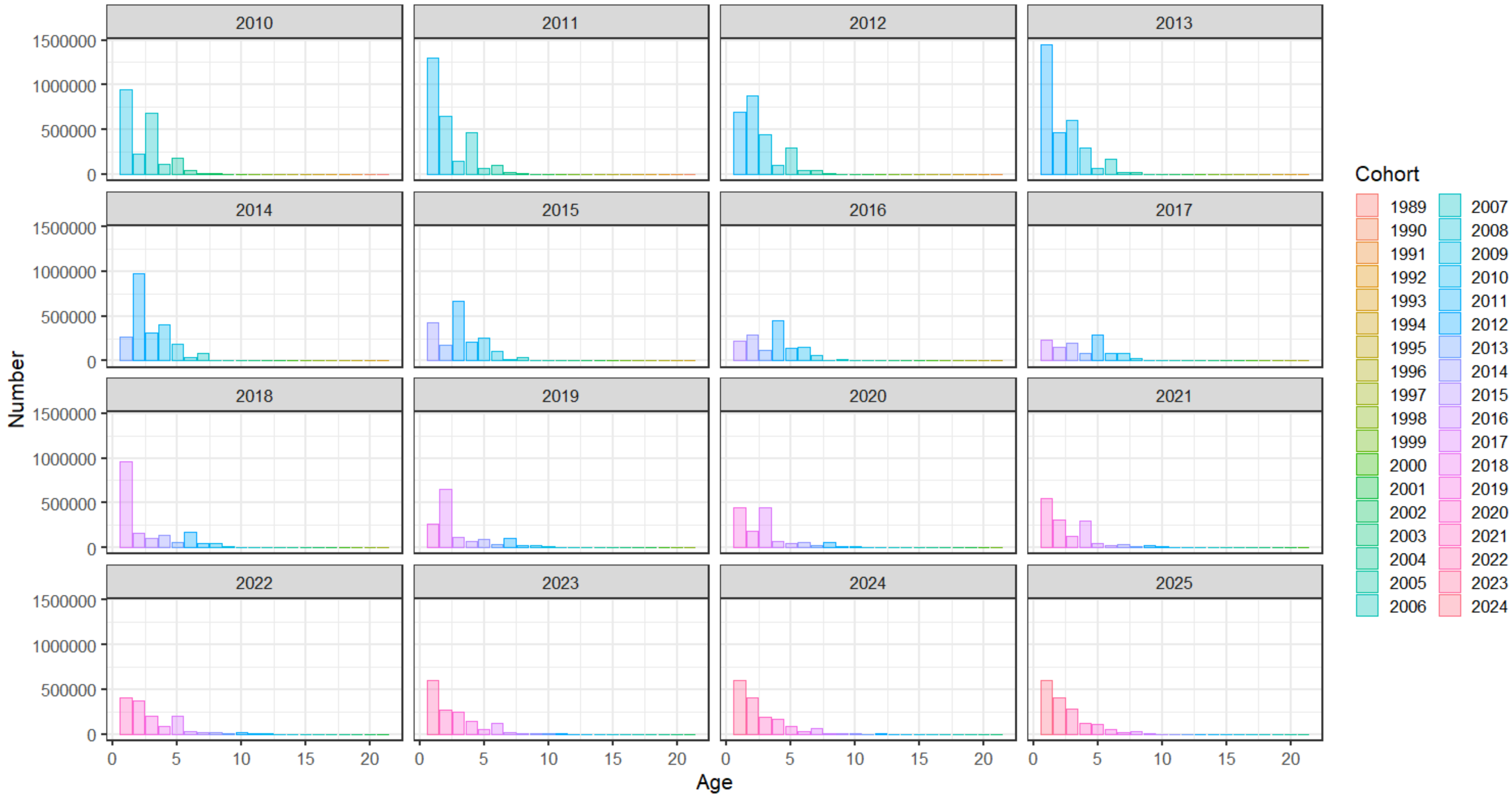


Figure 2.49. Numbers at age 2010-2025 from Model 24.1 by cohort.

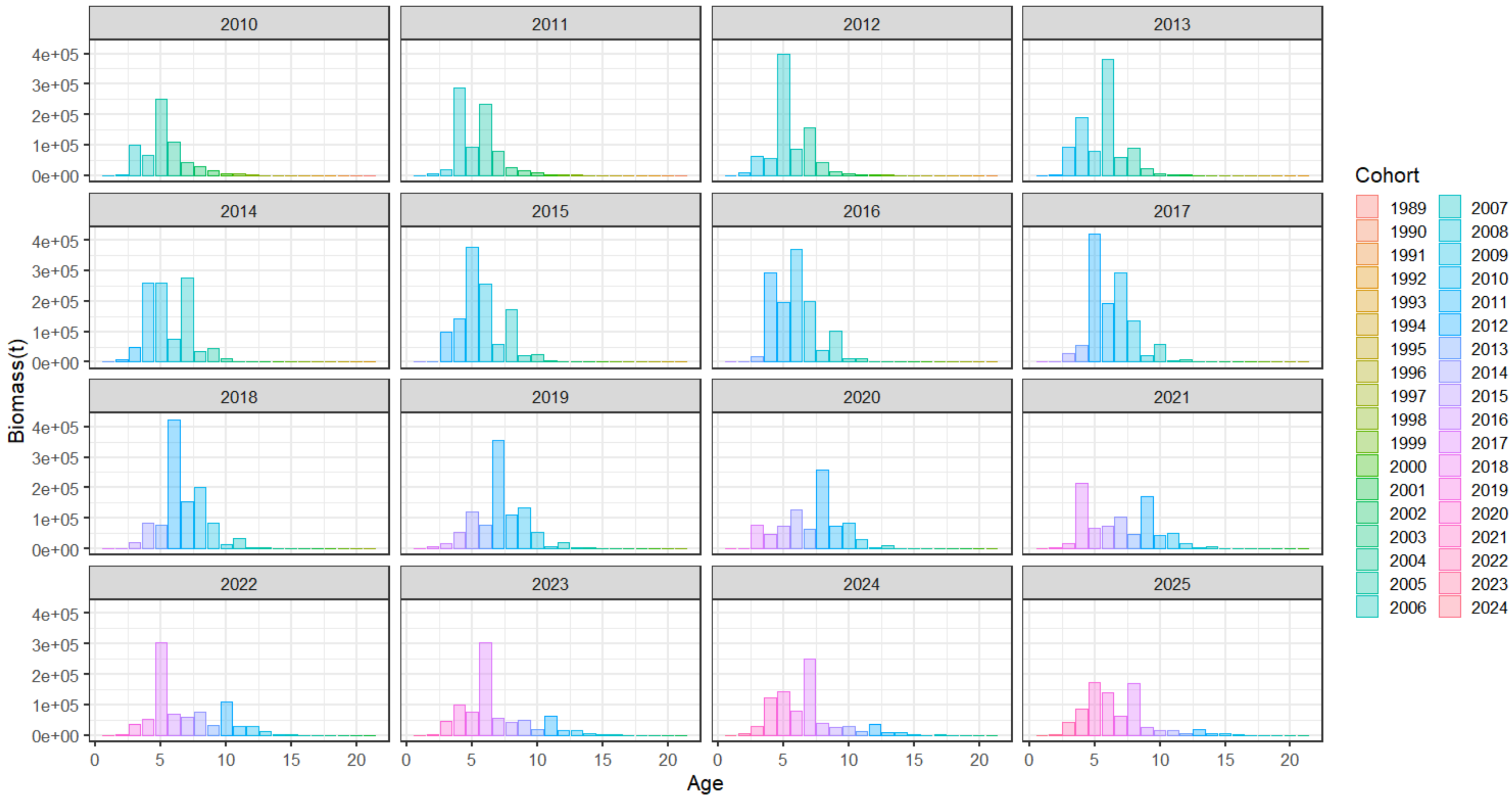


Figure 2.50. Biomass at age 2010-2025 from Model 24.1 by cohort.

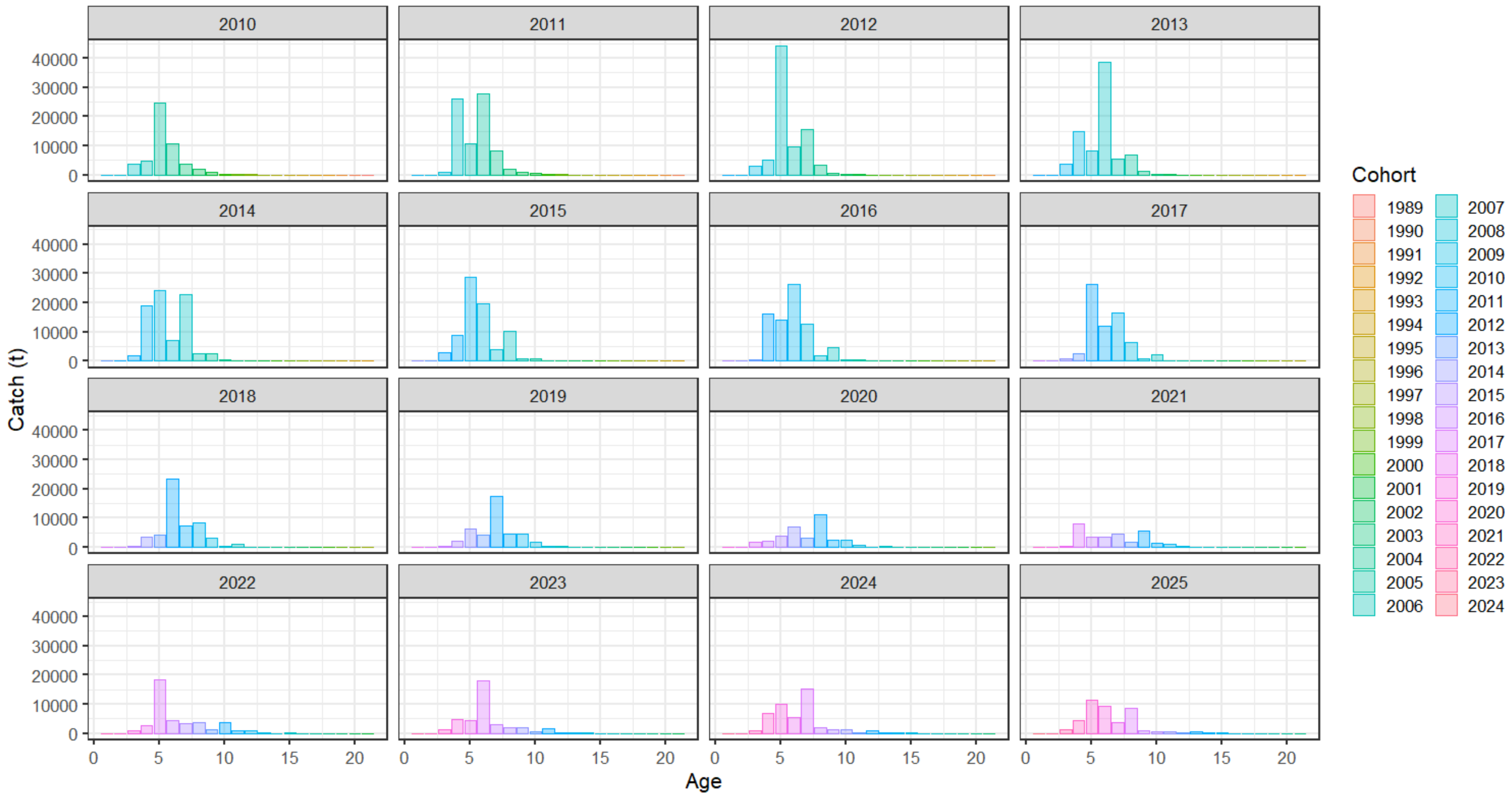


Figure 2.51. Catch in tons at age 2010-2025 from Model 24.1 by cohort.

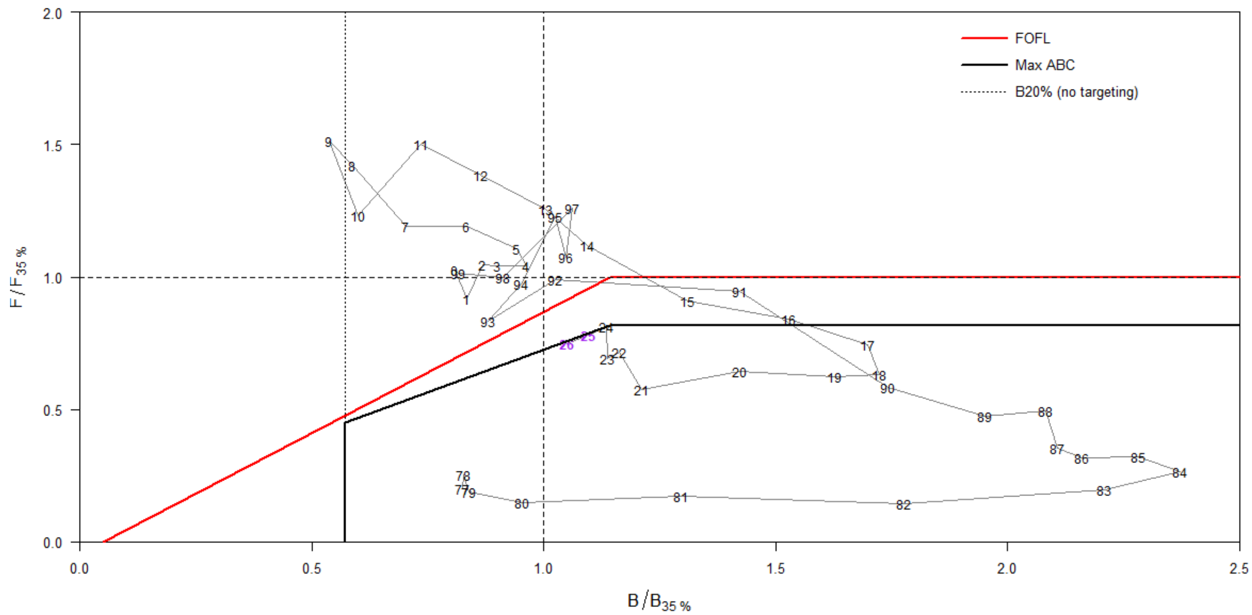


Figure 2.52. Phase plane plot for Model 24.1.

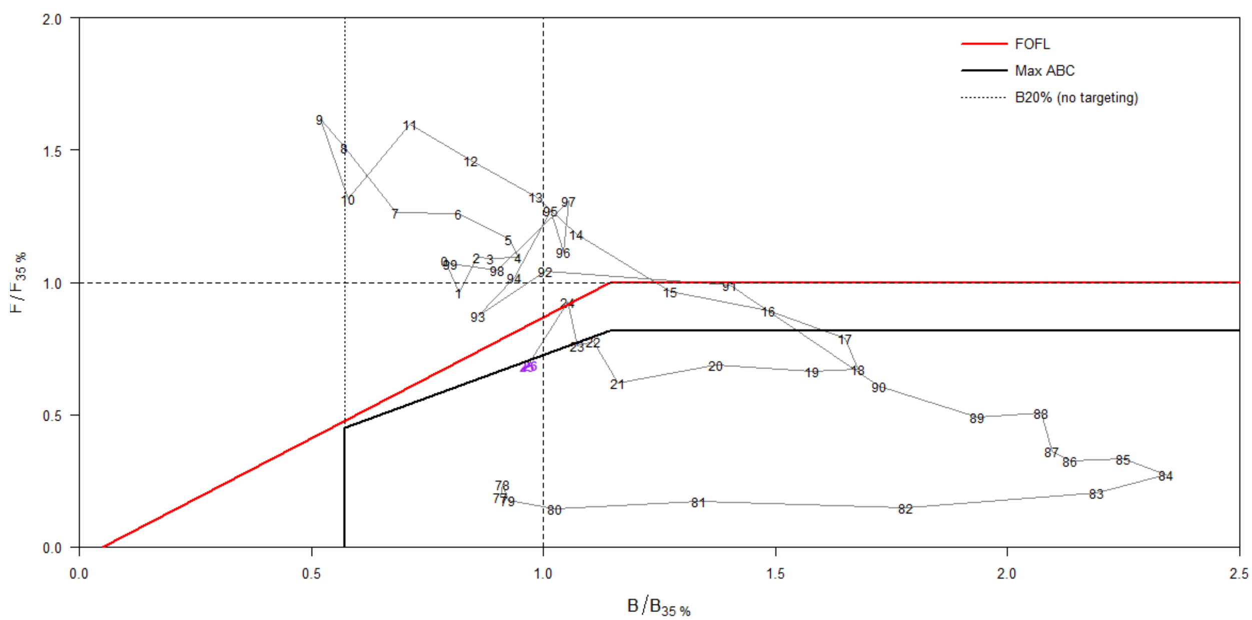


Figure 2.53. Phase plane plot for Model 24.3.

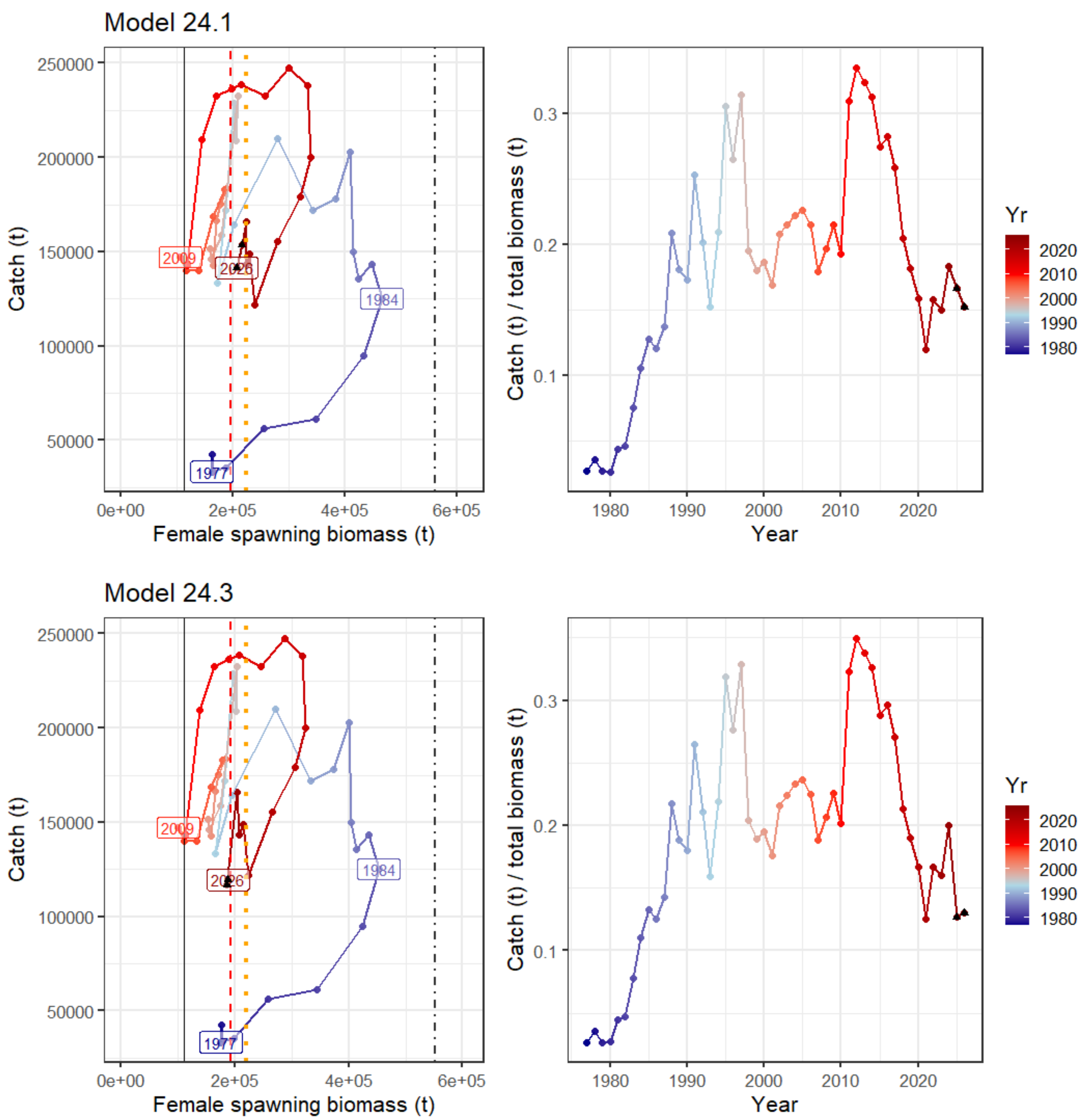


Figure 2.54 Plots of (left) catch (t) by spawning biomass (t) and (left) catch/total biomass for the Model 24.1 and Model 24.3 with (black line) $B_{20\%}$, (red dashed line) $B_{35\%}$, (orange dotted line) $B_{40\%}$, and (grey dash-dot line) $B_{100\%}$ for all years. Black triangles are projections for 2025 and 2026.

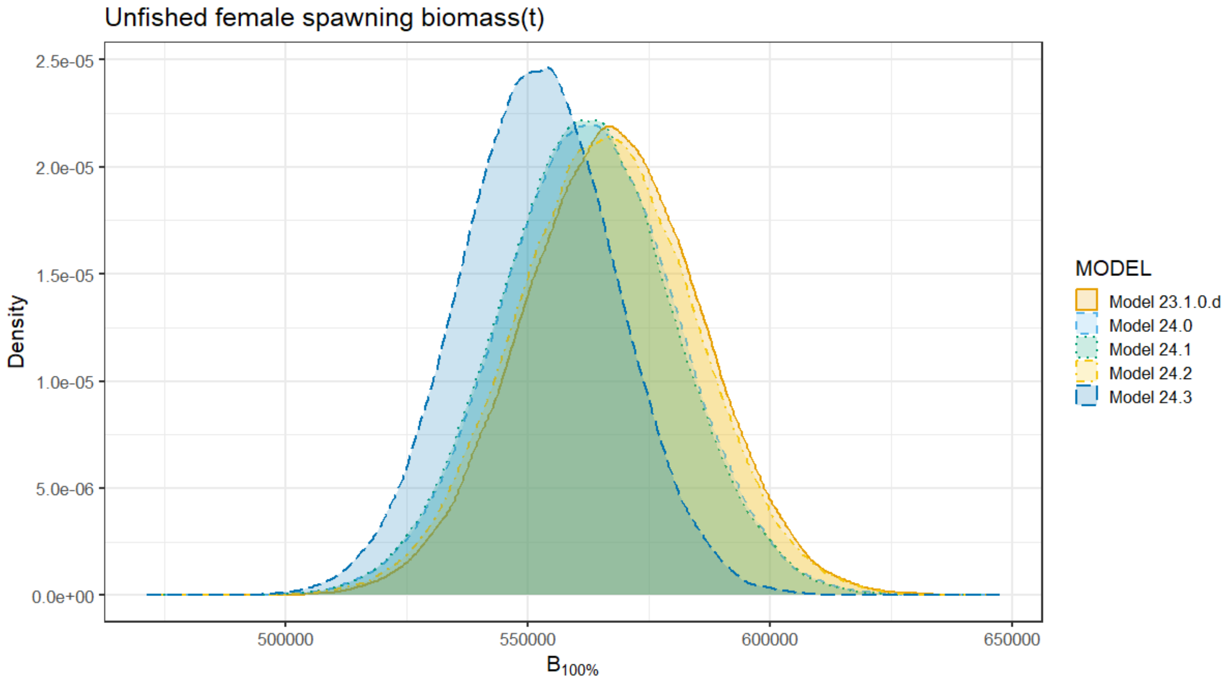


Figure 2.55. Distribution of female unfished spawning biomass ($SSB_{100\%}$) for all models.

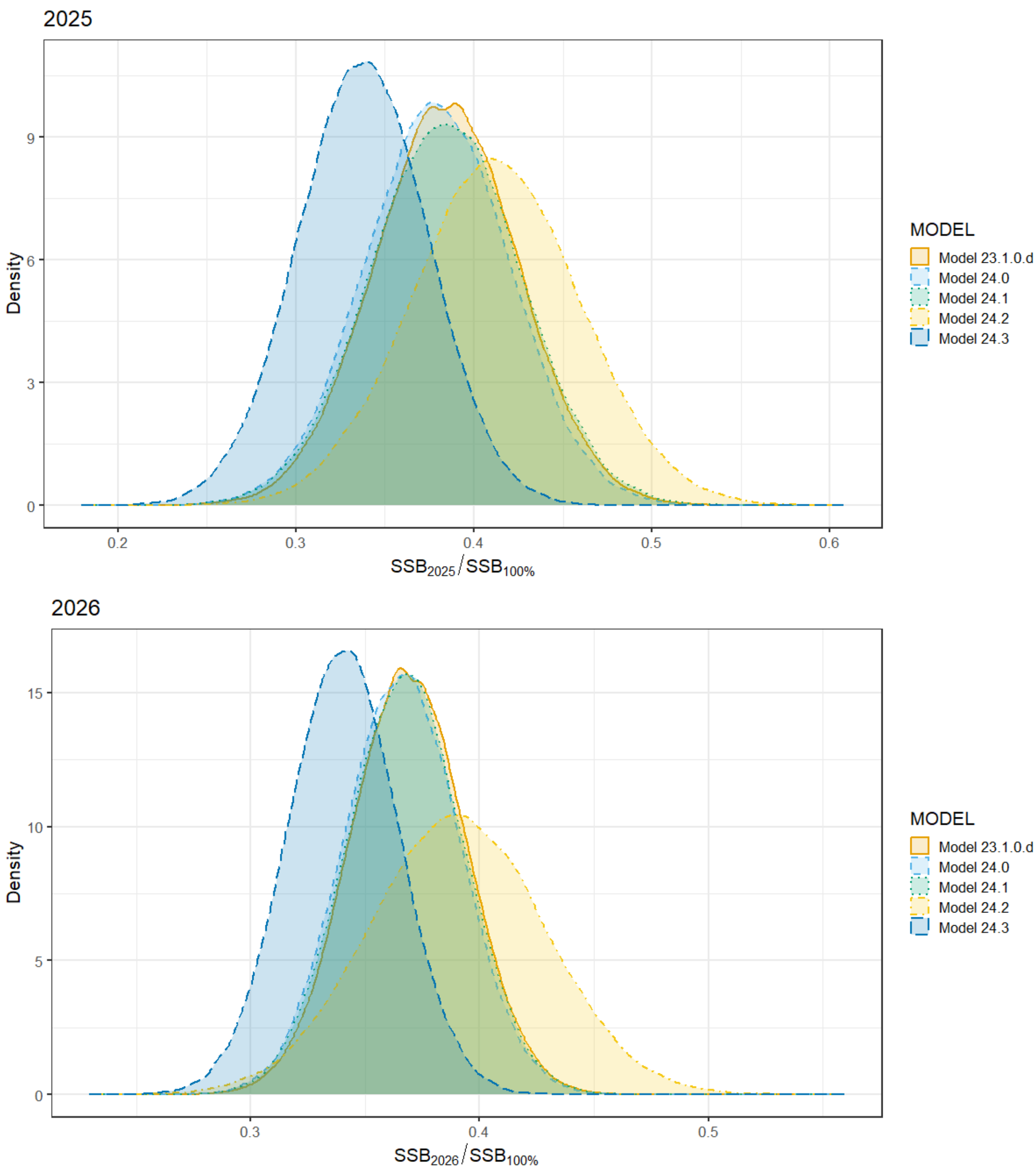


Figure 2.56. Ratio of spawning stock biomass to unfished spawning biomass distributions for (top) 2025 and (bottom) 2026 for all models.

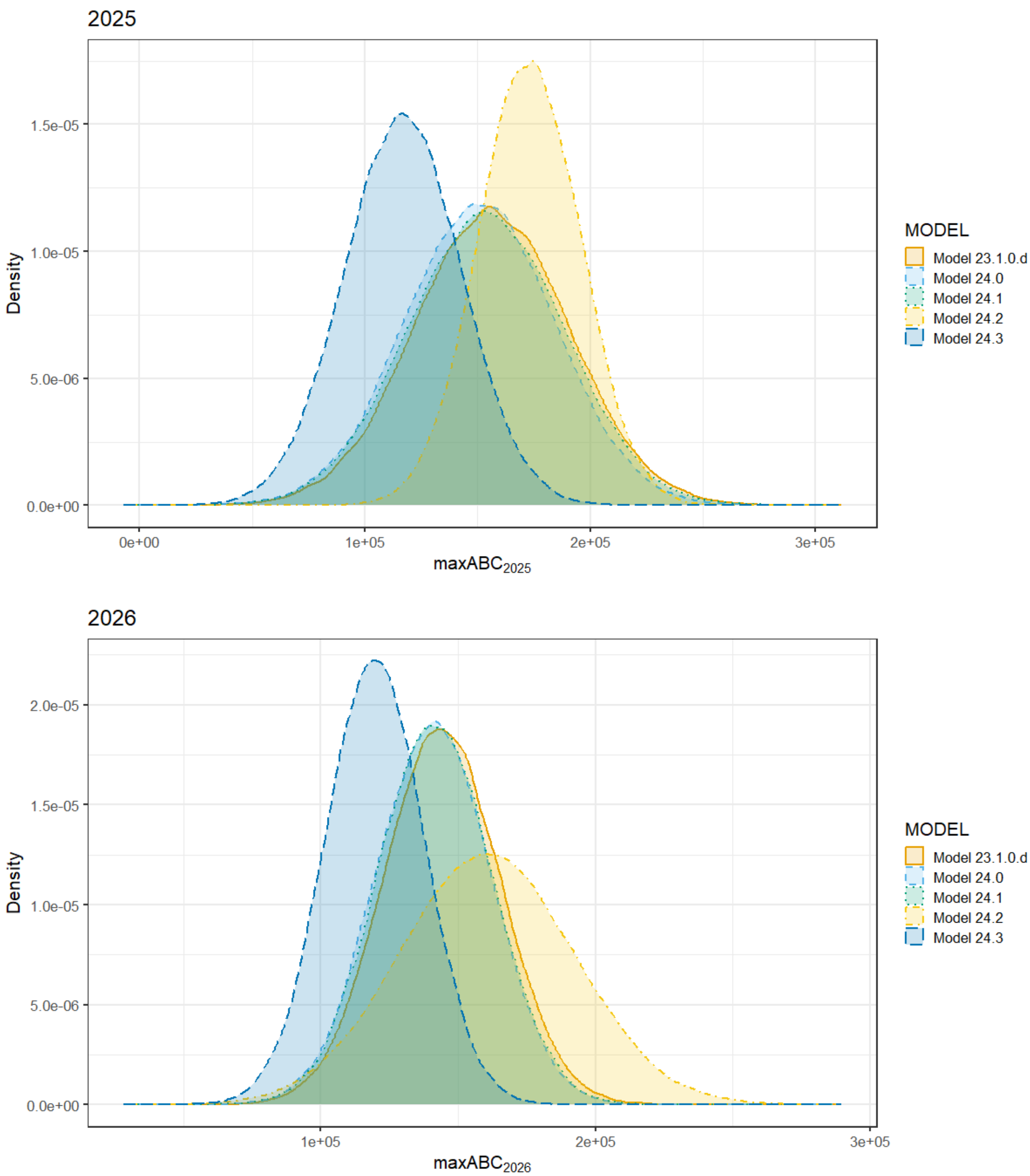


Figure 2.57. Forecasted maximum ABC for (top) 2025 and (bottom) 2026 for all models.

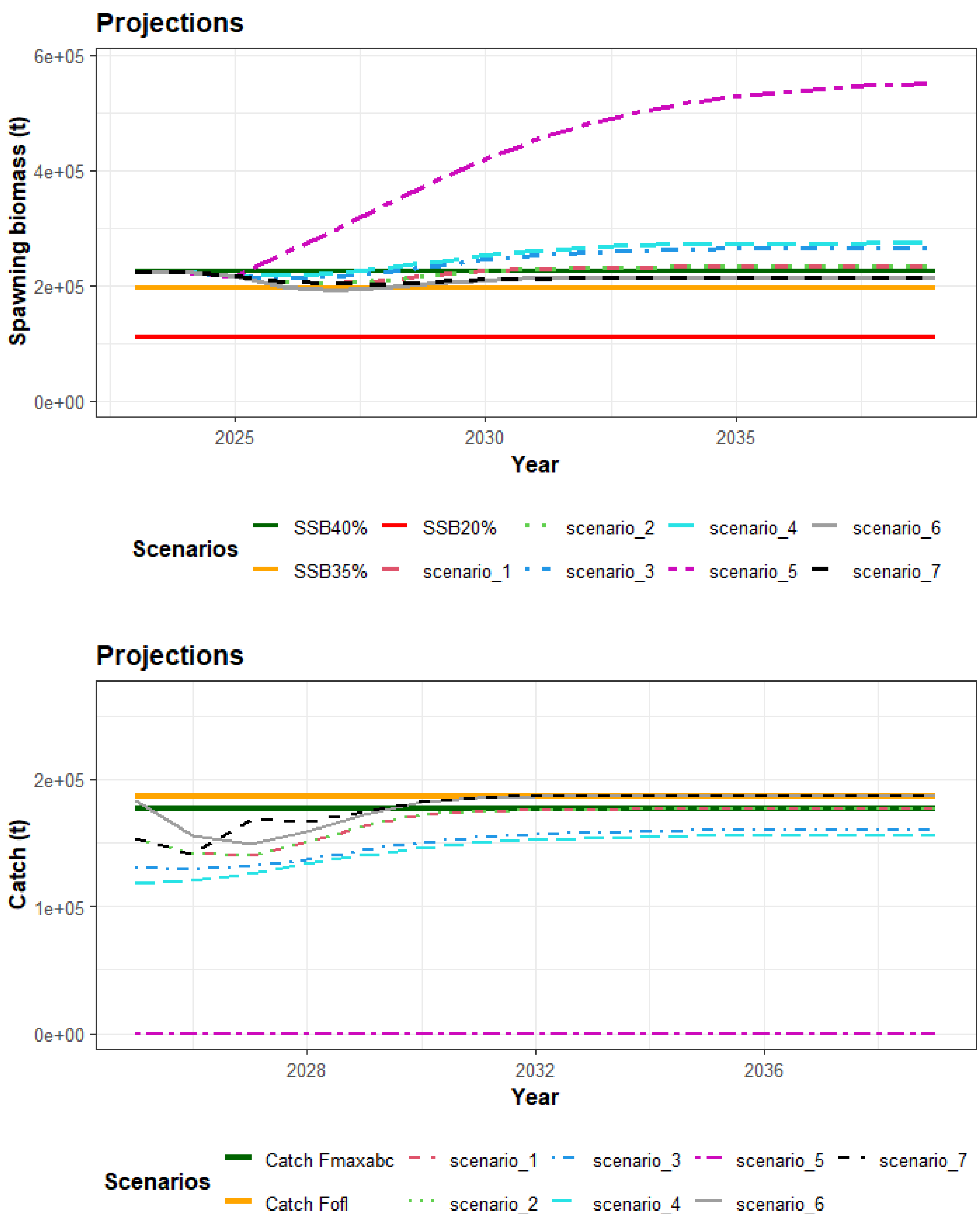


Figure 2.58. (Top) Female spawning biomass (t) and (bottom) projected catch (t) for the seven North Pacific projection scenarios from Model 24.1.

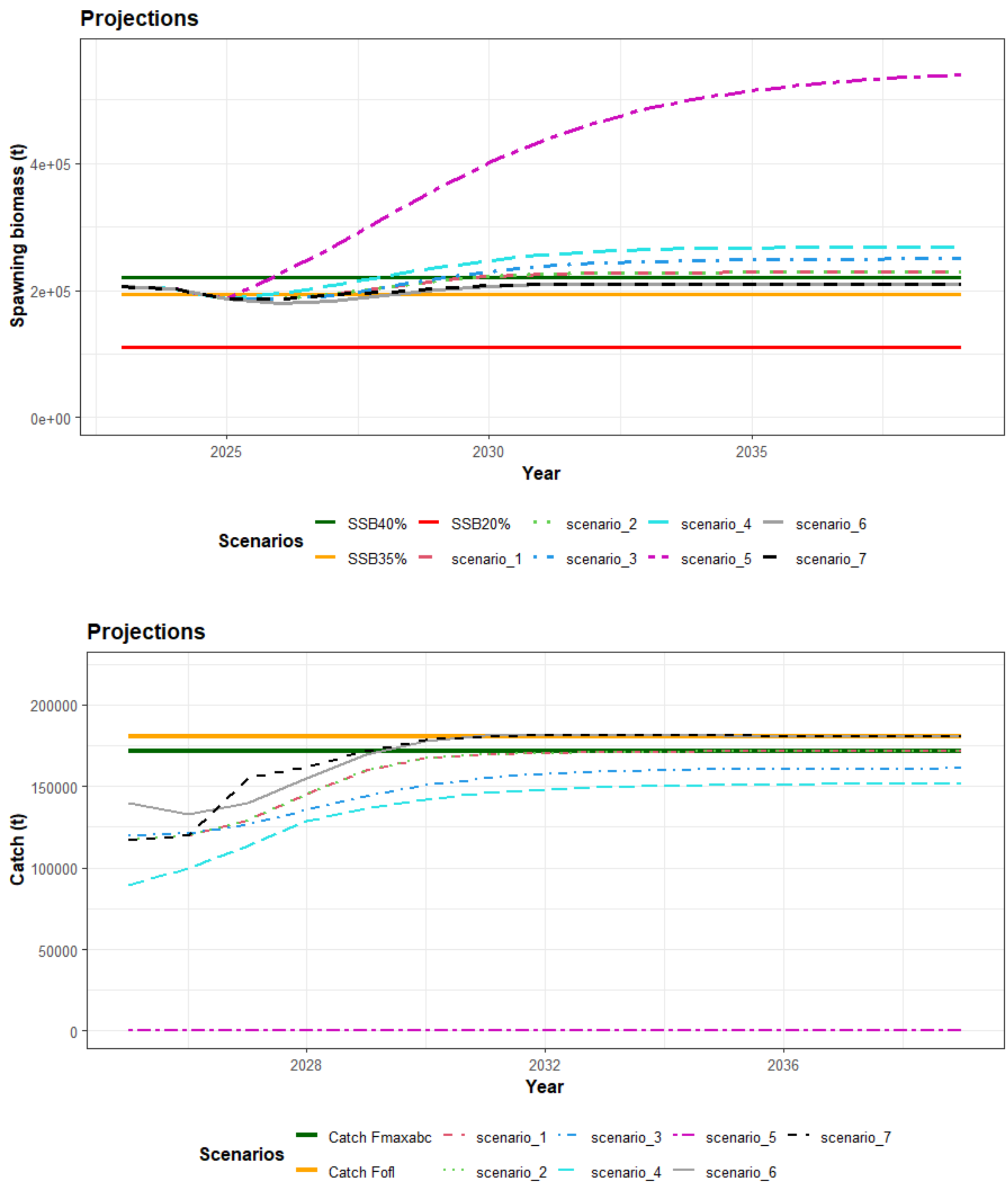


Figure 2.59. (Top) Female spawning biomass (t) and (bottom) projected catch (t) for the seven North Pacific projection scenarios from Model 24.3.

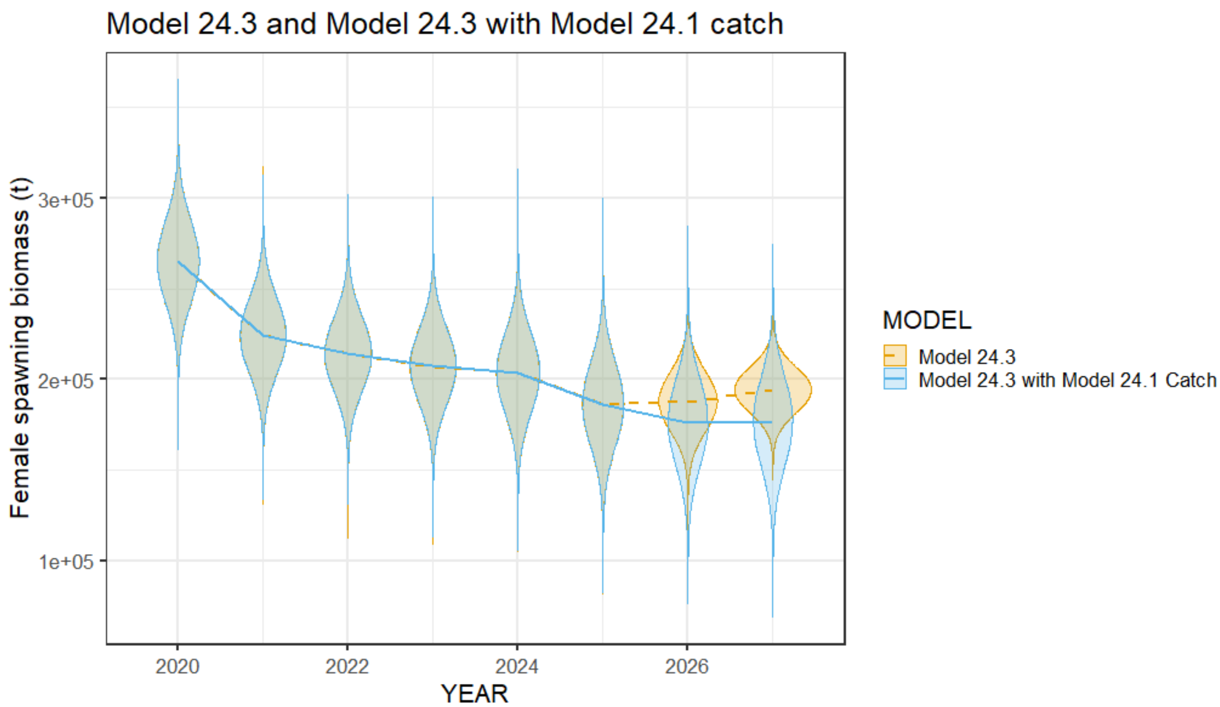


Figure 2.60. (Top) Female spawning biomass (t) and (bottom) biomass ratio for Model 24.3 with 2025 and 2026 catches at Model 24.3 maximum ABCs and Model 24.3 with 2025 and 2026 catches at the maximum ABCs from Model 24.1 for 2020-2027.

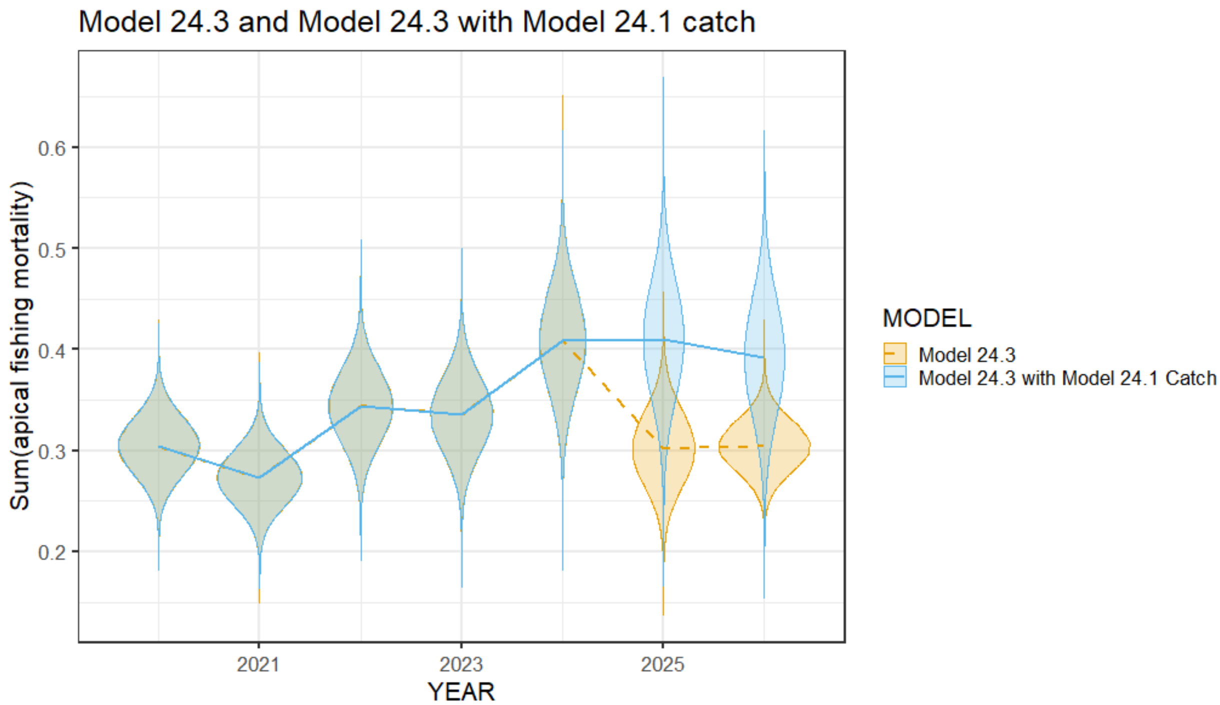


Figure 2.61.Sum apical fishing mortality for Model 24.3 with 2025 and 2026 catches at Model 24.3 maximum ABCs and Model 24.3 with 2025 and 2026 catches at the maximum ABCs from Model 24.1 for 2020-2027.