Chapter 2: Assessment of the Pacific cod stock in the Gulf of Alaska

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November 2024

This report may be cited as: Hulson, P.-J. F., S. J. Barbeaux, B. Ferriss, K. Echave, J. Nielsen, S. McDermott, B. Laurel, A. Abookire, I. Spies, and S. K. Shotwell. 2024. Assessment of the Pacific cod stock in the Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/library/safe-reports/.

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Executive Summary

Pacific cod in the Gulf of Alaska are assessed on an annual stock assessment schedule to coincide with the availability of new survey data. We use a statistical age-structured model as the primary assessment tool for Gulf of Alaska Pacific cod which qualifies as a Tier 3 stock. This assessment consists of a population model, which uses survey and fishery data to generate a historical time series of population estimates, and a projection model, which uses results from the population model to predict future population estimates and recommended harvest levels. All data and results (including model input files and plots), as well as documents and presentations pertaining to this assessment can be found at this link and by following the QR code provided in the title page of this document.

Summary of Changes in Assessment Inputs

Relative to last year's assessment, the following changes have been made in the current assessment:

Changes in the input data

1. Federal and state catch data for 2023 were updated and preliminary federal and state catch data for 2024 were included;
2. Commercial federal and state fishery size composition data for 2023 were updated, and preliminary commercial federal and state fishery size composition data for 2024 were included;
3. AFSC bottom trawl survey and commercial federal conditional age-at-length data for 2023 were included;
4. The input data file changes described in Appendix 2.2 were included;
5. Ageing error was updated with data through 2023 and pre-2007 ageing bias was updated and fixed, rather than estimated;
6. A new method for computing commercial fishery length composition that merges federal and state length observations was incorporated;
7. The length bins for length composition and conditional age-at-length were changed from 1 cm to 5 cm.

Changes in the methodology

The model used for 2024 is largely the same in terms of methodology as last year's accepted model (Model 19.1b). However, given the large number of input data changes that are incorporated into the recommended model for the current assessment we rename this model as Model 24.0. There were no other model changes made in this year's assessment.

Summary of Results

Model 24.0 indicates that the stock remains at low levels but is above $B_{20\%}$; for 2025 the stock is estimated to be at $B_{28.7\%}$, less than $B_{40\%}$, placing it in sub-tier "b" of Tier 3. For the 2025 fishery, we recommend the maximum allowable ABC of 32,141 t. This ABC is less than 1% different from the 2024 ABC of 32,272 t. The 2025 ABC is 14% larger than the 2025 ABC projected in last year's assessment. The corresponding reference values are summarized in the following table, with the recommended ABC and OFL values in bold. The stock is not being subject to overfishing, is not currently overfished, nor is it approaching a condition of being overfished.

Quantity	As estimated or *specified last* year for: 2024	2025	As estimated or *specified this* year for: 2025	2026
M (natural mortality rate)	0.46*	0.46*	0.49*	0.49*
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	184,242	202,618	177,497	200,521
Female spawning biomass (t)				
Projected	51,959	47,698	46,920	44,674
$B_{100\%}$	175,187	175,187	163,585	163,585
$B_{40\%}$	70,075	70,075	65,434	65,434
$B_{35\%}$	61,315	61,315	57,255	57,255
F_{OFL}	0.52	0.48	0.57	0.51
$maxF_{ABC}$	0.42	0.38	0.46	0.43
F_{ABC}	0.42	0.38	0.46	0.43
OFL (t)	38,712	33,970	**38,688**	33,099
maxABC (t)	32,272	28,184	32,141	30,193
ABC (t)	32,272	28,184	**32,141**	30,193
Status	As determined *last* year for: 2022	2023	As determined *this* year for: 2023	2024
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

**Base natural mortality M varies between 0.49 and 0.82*
*** Assumed 2024 catch to be the 2024 ABC. For 2026 projections the 2025 catch was assumed to be at the projected ABC.*

Area apportionment

Using the random effects model (as applied within the *rema* R-package, Sullivan *et al.* 2022) with the trawl survey biomass estimates through 2023, the area-apportioned ABCs are:

	Western	Central	Eastern	Total
Area apportionment	27.10%	63.80%	9.10%	100%
2025 ABC	8,710	20,506	2,925	32,141
2026 ABC	8,182	19,263	2,748	30,193

Responses to SSC and Plan Team Comments on Assessments in General

"The SSC requests that when Bayesian model output is reported, basic convergence diagnostics are also presented." (SSC, Dec 2023)

In Figure 2.37 we report ESS and Rhat values, as well as plot the mixing of the chains used in MCMC analysis.

Combined recommendations on the risk table:

"*The SSC continues to support a three-category risk table with categories normal, increased, and extreme, and requests that the category descriptions be revised to cover the range covered by the original table.*"

"*The SSC reiterates that only fishery performance indicators that provide some inference regarding biological status of the stock should be used.*"

"*The SSC recommends that the risk tables consider potential future risks when these can be anticipated.*"

"*When risk scores are reported, the SSC requests that a brief justification for each score be provided, even when that score indicates no elevated risk.*"

The three category risk table template, as well as the other suggestions provided by the SSC are adhered to in the 'Risk Table and ABC Recommendation' of this assessment.

"*The Team recommended as a best practice that appendices be linked in the front of the document (as with the sablefish assessment) to allow for an easier review of the appendices.*" (Plan Team, November 2023)

All appendices are included at the end of this document. If appendices are not included in this document the link is provided under the appendix title.

Responses to SSC and Plan Team Comments Specific to this Assessment

"The SSC appreciates the preliminary evaluation of conditional age-at-length patterns and recommends further evaluation of growth-related issues, including updating the length-weight relationship with more recent data, evaluating if there have been significant growth changes, and examining empirical weight at age. The SSC encourages consistency with EBS and AI cod assessments in approaches to these and other issues, where possible." (SSC, Dec 2022)

"The Team recommended that the data for length-weight relationships be reevaluated and examined for sensitivity to the trends over time and areas." (Plan Team, Nov 2022)

"The Team recommended the authors look at the model-predicted mean weight-at-age (by gear type), and compare to the observed weight-at-age data to see if there are discernible spatial or temporal patterns that the model is missing." (Plan Team, Nov 2022)

"The Team recommended that an evaluation comparing how growth changes may affect the residuals be pursued. The Team also recommended the author investigate whether size-based selectivity affects the patterns observed." (Plan Team, Nov 2022)

We respond to these combined SSC and Plan Team comments as they relate to the same topic. We have obtained funding to hire a post doc that is investigating environmental links within this stock assessment, with growth being one of the important model estimates that will be investigated. Part of this work will include evaluation of growth changes over time and space, and the consistency of the GOA cod assessment with the EBS and AI cod assessments. As a precursor to this work, preliminary results investigating environmental links with growth were presented at the September 2022 Plan Team meeting, with indications that growth estimation within the assessment can be greatly improved through such environmental linkages. We will continue to include these comments in the SAFE until this work is completed and presented to the Plan Team and SSC.

"Based on recent tagging and genetic studies, the SSC encourages further exploration of fish movement as a potential major cause of population changes. Movement should be considered in concert with high natural mortality events for future models, and specifically consideration should be given to an Alaska-wide stock or GOA/EBS model." (SSC, Dec 2022)

We have recently obtained funding to pursue investigations into movement and developing a stock assessment model that takes into account exchange between the western GOA and EBS. We look forward to updating the SSC on this work in years to come and we will continue to include this comments in the SAFE until this work is completed and presented to the Plan Team and SSC.

"The SSC reiterates its encouragement for the authors to consider whether information from the IPHC setline survey and NMFS longline survey, alongside the NMFS bottom trawl survey, may provide a superior basis for apportionment recommendations, perhaps through the use of an integrated spatiotemporal model or a multi-survey random effects model." (SSC, Dec 2023)

Analysis of including the AFSC longline survey index to apportionment was presented at the September 2024 Plan Team meeting and included in Appendix 2.2 (the presentation can be found at this link). The recommendation is to continue to develop the *rema* model framework in order to allow for an environmental link to be considered with the scaling coefficient between the AFSC bottom trawl and longline surveys. We will continue to monitor development of spatiotemporal models used for apportionment.

"The SSC requests the authors evaluate the utility of the 14 forecast recruitment deviations. It is not clear where they are used in the document and whether they affect the estimation of other parameters." (SSC, Dec 2023)

These forecast recruitments have been turned off in the author's recommended model, and they had no effect on the estimation of other parameters (see Appendix 2.2 for impacts of turning these parameters off).

"The Team recommended the author only bring forward their preferred model as "2024" in November, in addition to the base model used in the previous assessment." (Plan Team, Sept 2024)

Model 24.0 has been brought forward as the recommended model for the 2024 assessment.

"The Team recommended using Akaike Information Criterion (AIC) to inform selection of the aging error model." (Plan Team, Sept 2024)

AIC was used to select the linear method for ageing error, as this method was preferred over the spline model option.

"The Team also noted that weight-at-age is produced as a standard output of this model (as it is needed to fit the catch biomass), and recommended comparing the model-estimated weight-at-age to empirical data on weight-at-age." (Plan Team, Sept 2024)

We have included the fit to empirical length-weight data (Fig. 2.16) and both empirical length-at-age and empirical weight-at-age (Fig. 2.29) in this year's assessment.

"The SSC requests a thorough revaluation of the current modeling approach for survey selectivity and catchability, including alternatives to the current selectivity blocks in the trawl survey, and alternatives to a strongly dome-shaped selectivity in the longline survey, and whether selectivity rather than catchability is more appropriately modeled with a time-varying temperature covariate." (SSC, Dec 2023)

In the presentation to the Plan Team at the September 2024 meeting (link to presentation provided in a previous response) we showed (1) that the dome-shaped longline survey selectivity to the longline survey was potentially supported by depth ranges occupied by larger fish (also shown in Fig. 2.13), (2) dome-shaped longline survey selectivity was strongly preferred by AIC comparison, (3) there was slight model improvement when combining the environmental link for both longline survey catchability and selectivity, but that the resulting model estimates were not significantly different, and (4) upon fixing the trawl survey selectivity to be asymptotic and time-invariant large implications on management quantities resulted. The history of the Pacific cod assessment in the GOA is one of continual reevaluation of catchability and selectivity, both of which have had large impacts on model and subsequent management quantity estimates (for example, see bottom panel of Fig 2.20). We plan to take a measured approach in reevaluation of catchability and selectivity and we are currently developing methods to support the proper evaluation of selectivity and catchability (in particular, in determining the input sample size for the composition data that informs estimates of selectivity). When these developments and the analysis has been conducted, we will present the results to the Plan Team and SSC with our recommendations.

"The Team recommended that sufficient samples be processed and analyzed so that the resulting data can be used in the assessment." (Plan Team, Nov 2023)

"The SSC supports the GOA GPT recommendation to work up the backlog of maturity data, and further to evaluate trends in maturity, as well as relationships between growth and maturity." (SSC, Dec 2023)

We address both of these comments, as they pertain to the same topic. To date, there has been no updated maturity data shared with the author to inform this assessment.

Introduction

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over Gulf of Alaska (GOA), as well as the eastern Bering Sea (EBS) and the Aleutian Islands (AI) area. The Aleut word for Pacific cod, *atxidax*, literally translates to "the fish that stops" (Betts *et al.* 2011). Recoveries from archeological middens on Sanak Island in the western GOA show a long history (at least 6,000 years) of exploitation. Over this period, the archeological record reveals fluctuations in Pacific cod size distribution, which Betts *et al.* (2011) tie to changes in abundance due to climate variability (Fig. 2.1). Over this long period colder climate conditions appear to have consistently led to higher abundance with more small/young cod in the population and warmer conditions to lower abundance with fewer small/young cod in the population. Recent comparisons of Pacific cod length distributions extrapolated from bones retrieved from middens and those from the modern domestic fishery show a cline in size from larger fish in the west to smaller fish in the southeastern GOA that has been consistent for over 6,000 years (West *et al.* 2020).

Conventional tagging studies (e.g., Shimada and Kimura 1994) have found that Pacific cod migrate both within and between the EBS, AI, and GOA outside of their winter (January – April) spawning season. In 2021, a cooperative tagging study between the Alaska Fisheries Science Center (AFSC) and the Aleutians East Borough (AEB) was initiated to examine the seasonal movements of Pacific cod captured in the western GOA during the winter spawning season using pop-up satellite tags. Pop-up satellite tags are designed to release from the fish after a predetermined deployment time (e.g., 180 days) and transmit archived data to satellites after floating to the surface, whereas conventional tags require a platform of recovery such as a fishery. Pathways between release and pop-up locations can be reconstructed from archived depth, temperature, and light data recorded by the tags using a hidden Markov model. Satellite tags were released on Pacific cod in the western GOA in March 2021 and April 2022 to improve understanding of seasonal connectivity between winter spawning locations of Pacific cod in the western GOA and foraging locations in GOA and EBS during summer months when AFSC bottom- trawl surveys are conducted. In 2023 and 2024, the study was expanded to the central GOA to improve understanding of seasonal migration patterns for western and central GOA fish. During the expanded winter study, satellite tags were deployed at 10 release locations ranging from Sanak Island western GOA to the entrance of Prince William Sound in the centralGOA. Winter release tags were programmed to popup after either 6 months (80% of tags) or 15 months (20% of tags). In 2023 and 2024, satellite tags were also released during the summer in the western and central GOA to better understand annual movement patterns and movement from summer foraging to winter spawning areas. Summer release tags were programmed to pop up after 12 months. To date, 194 satellite tags have been deployed in the GOA from 2021 to 2024 (Figure 2.2A). In the western GOA, 92 satellite tags were released on the winter cruise and 30 satellite tags were released during the summer. In the central GOA, 70 satellite tags were released on the winter cruise and 2 satellite tags were released during the summer. Pop-up locations for satellite tags deployed in the GOA to date (Figure 2.2B) indicate that seasonal connectivity exists between the western GOA (Shumagin Islands and westward), EBS, northern Bering Sea, western Bering Sea (Russia), and Chukchi Sea. Approximately 50% of cod tagged in the western GOA during the winter moved to summer foraging locations in the Bering Sea across all four years of tagging. However, fish tagged in the central GOA have not been observed to move into the EBS or AI. Within the central GOA, some tagged fish displayed considerable movement but largely remained within management areas. Partial migration (i.e., only part of the population undertakes seasonal migration) was evident in reconstructed pathways, as some fish remained in the vicinity of their release location year-round. Analyses to quantify and characterize movement between management areas within the GOA and between the GOA and the Bering Sea are on-going. Additional satellite and conventional tag releases in the GOA are planned for March 2025.

Recent research funded by the Pacific States Cod Disaster Fund includes evidence for distinct genetic differences among some juveniles found in the western GOA, which may be the result of differential spawn timing. In addition, we found mixing between eastern GOA and western GOA juvenile cod, indicating transport not only by the prevailing currents moving eastern GOA cod westward, but also eddies that likely move western GOA cod eastward (S. Schaal pers. comm.). The fate of juvenile cod transported long distances is unknown; however, it is unlikely they remain and successfully spawn in a new location because of the large genetic differentiation observed between eastern and western GOA spawning cod populations. Several transcriptomics experiments on age-0 and juvenile cod investigated mechanisms of mortality under increased temperatures and co-occurring acidification (S. Spencer pers. comm.). Results indicated a heightened immune response paired with lipid dysregulation under warming-associated mortality. Acidification slowed/impaired digestion, which may also contribute to larval condition. Finally, investigations are underway to evaluate whether there is a genetic difference between cod tagged in the western GOA that migrate into the EBS during summer months vs. those that remain stationary (L. Timm pers. comm.).

Although there appears to be some genetic differentiation within the GOA management area and some cross migration between the western GOA and EBS that may vary seasonally, the Pacific cod stock in the GOA region is currently managed as a single stock. Further work is needed to understand the genetic stock structure of cod in the GOA and its relationship with the EBS stock of cod during spawning and feeding periods.

A detailed account of Pacific cod life history, environmental drivers, economic and social indicators can be found in the GOA Pacific cod ecosystem and socioeconomic processes (ESP) in the 2021 assessment (Barbeaux *et al.* 2021).

Fishery

Fishery history and management measures

For a full description of the fishery history and management measures see Hulson *et al.* 2022. Here we summarize this section and refer to the relevant Tables and Figures. Catches of Pacific cod since 1991 by gear type and jurisdiction are shown in Table 2.1; catches prior to that are listed in Thompson *et al.* (2011). Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components; Figure 2.3 shows landings by gear since 1977. The history of Total Allowable Catch (TAC), Acceptable Biological Catch (ABC), Overfishing Level (OFL), and State of Alaska Guideline Harvest Levels (GHL) are summarized since 1991 and compared with the time series of aggregate commercial catches in Table 2.2 (data prior to 1991 are shown in Hulson *et al.* 2022). The complete history of allocation (in percentage terms) by regulatory area within the GOA is shown in Table 2.3. Catch reported in Tables 2.1 and 2.2 include discarded Pacific cod, estimated retained and discarded amounts are shown in Table 2.4.

Recent fishery performance

Data for managing the GOA groundfish fisheries are collected in multiple ways. The primary source of catch composition data in the federally managed fisheries for Pacific cod are collected by on-board observers (Faunce *et al.* 2017). The Alaska Department of Fish and Game (ADFG) sample individual deliveries for state managed fisheries (Nichols *et al.* 2015). Overall catch delivered is reported through a (historically) paper and electronic catch reporting system. Total catch is estimated through a blend of catch reporting, observer, and electronic monitoring data (Cahalan *et al.* 2014).

The distribution of directed cod fishing is distinct to gear type. Figure 2.4 shows the recent distribution of catch since 2015 for the three major gear types. Figure 2.5 shows the distribution of observed catch for the most recent year of catch data (2024) for the three major gear types, as well as the distinction between observed and electronic monitored catch.

In 2015 combined state and federal catch was 79,480 t (23% below the ABC), while in 2016 combined catch was 64,054 t (35% below the ABC) and in 2017 catch was 48,727 t (45% below the ABC) (Table 2.2). The ABC was substantially reduced for 2018 to 18,000 t from 88,342 t in 2017, an 81% reduction. This was a 65% reduction from the realized 2017 catch. In 2018 the total catch was 15,150 t. For 2019 the ABC was set below the maximum ABC at 17,000 t and combined fishery caught 15,715 t which was 91% of the ABC.

In 2020 the spawning stock biomass was projected to have dropped below 20% of the unfished spawning biomass ($B_{20\%}$) and the federal Pacific cod fishery in the GOA was closed by regulation to directed Pacific cod fishing. $B_{20\%}$ is a minimum spawning stock size threshold instituted to help ensure adequate forage for the endangered western stock of Steller sea lions. The State of Alaska directed Pacific cod fishery remained open and Pacific cod bycatch in other federally managed groundfish fisheries was allowed. The Pacific cod ABC for 2020 was set to 14,621 t, but the combined TAC and State of Alaska groundfish harvest level (GHL) was reduced to account for additional uncertainty. The State of Alaska managed fisheries are allocated 26.7% of the GOA Pacific cod ABC. The federal Pacific cod TAC was reduced by 40% from the maximum of 10,719 t as a further level of precaution to 6,431 t. ADF&G also reduced their maximum prescribed harvest limit of 3,902 t by 35% to 2,537 t. This resulted in a total combined federal TAC and State of Alaska GHL of 8,968 t or 61% of the maximum ABC. In 2020 a total combined catch of 6,842 t was harvested (Table 2.1), the state having taken 2,799 t (91% of the GHL) and federal fisheries haven taken 4,043 t (61% of the federal TAC). The catch in the federal fisheries were split primarily between the arrowtooth flounder (1,237 t), walleye pollock (1,040 t), and shallow water flatfish fisheries (938 t). In 2021 the stock was projected to be above $B_{20\%}$ and the federal fishery was once again allowed to open.

In 2024 the federal TAC was set at 23,766 t and state GHL set at 8,506 t (Table 2.2). As of October 17, 2024 a total of 23,171 t (72% of the ABC) have been harvested (Table 2.1). State fisheries have harvested 6,311 t (74% of the GHL) and federal fisheries 16,860 t (71% of the TAC). In 2024 38% of the Pacific cod catch was by trawl, 32% by pot gear, and 28% by longline, while jig and other gear harvested 2% (Table 2.1).

The largest component of incidental catch of other targeted groundfish species in the GOA Pacific cod fisheries by weight are skate species in combination followed by walleye pollock, arrowtooth flounder, sablefish, and octopus (Table 2.5). Shallow-water flatfish, sharks (predominantly spiny dogfish), and demersal shelf rockfish also make up a major component of the bycatch in these fisheries. The largest component of prohibited species catch is Bairdi tanner crab, followed by halibut and Golden king crab (Table 2.6). Incidental catch of non-target species in the GOA Pacific cod fishery are listed in Table 2.7.

Trawl

The distribution of catch from the trawl fishery since 2015 shows it has been widely distributed across the central and western GOA (Fig. 2.4) with the highest concentration of catch coming from southeast of Kodiak Island in the central GOA and around the Shumigan Islands in the western GOA. In 2016 trawl fishing in the western GOA shifted away from the Shumigan Islands further to the west around Sanak Island and near the Alaska Peninsula, this shift continued through 2017. Trawl fishing in 2018 for the A-season had a similar pattern as 2017 with large catches from around Sanak Island, but some increased effort on Portlock Bank to the southeast of Kodiak Island. There was substantially less catch and observed effort in 2018 and 2019 than previous years. Although the 2020 directed federal Pacific cod fishery was closed, there were observations of Pacific cod catch in other fisheries; these observations primarily surrounded Kodiak Island from the pollock and shallow water flatfish fisheries. In 2024, there were observed catches in the western GOA, but trawl catch of Pacific cod was primarily centered around Kodiak Island (Fig. 2.5).

The trawl fishery generally catches a larger size range of fish than seen in longline and pot gear, with fish as small as 10 cm appearing in the observed length composition samples (Fig. 2.6). Vessel participation in the trawl fishery has generally increased since the directed fishery was closed in 2020 (Fig 2.7). Trawl catch has been consistent in the western and central GOA since 2021 (Fig. 2.8). (Fig 2.8). Due to bycatch in other fisheries trawl catch of Pacific cod in 2020 remained above 3,000 t despite the closure of the federal directed fishery.

Longline

Since 2015 the longline fishery has primarily occurred on the border of the central and western GOA management areas, in deeper waters south of the Shumagin Islands, and South of Unimak Island to the western edge of the western GOA management area shelf. In 2024 observers and electronic monitoring show a large portion of the longline catch coming from near the Shumagin Islands in the western GOA, and the southern edge of Kodiak Island and the southern edge of the Seward Peninsula in the central GOA (Fig. 2.5). In recent years, the size of Pacific cod caught in the longline fishery has ranged from 50 cm to 75 cm (Fig. 2.6). Declines in vessel participation in this fishery were seen from 2018 to 2020 (Fig. 2.7). This trend has reversed since the fishery closure in 2020: the number of vessels participating in the Pacific cod longline fishery in the central GOA increased from 3 in 2020 to greater than 30 since 2021. In both the central and western GOA, catch in 2024 was similar to 2022 (Fig. 2.8).

CPUE figures were produced for the longline fisheries in the GOA in previous assessments (Barbeaux *et al.* 2021). However, the consistency of the data are in question because of electronic monitoring reducing the available data and changes in observer coverage. It should be noted that CPUE is not available from the EM monitored vessels as number of hooks retrieved and soak time are not recorded. Thus, we do not present CPUE in this assessment but will continue to monitor developments in estimating CPUE.

Pot

The pot fishery started in the early 1990s (Table 2.1 and Fig. 2.3) and is predominately pursued using smaller catcher vessels. In the State of Alaska managed fishery an average of 84% of the state catch comes from pot fishing vessels. Pot fishing occurs close to the major ports of Kodiak, Sand Point and on either side of the Kenai Peninsula (Fig. 2.4). In 2017, the observer coverage rate of pot fishing vessels was greatly reduced from 14% to ~4%, which impacted our ability to adequately identify the spatial distribution of the pot fishery. From the data collected there appears to have been less fishing to the southwest of Kodiak Island in 2017, however this may be due to low observer coverage. In 2018 - 2020, there were few observed hauls throughout the GOA due to the lower TAC, low fishing levels, and the 2020 directed federal fishery closure. In 2024 the majority of catch from the pot fishery was centered around Kodiak and the Shumagin Islands (Fig. 2.5).

The pot fishery generally catches fish greater than 50 cm (Fig. 2.6) and that are, on average, larger than fish seen in the trawl and longline fisheries. Since 2004, the majority of vessels targeting GOA Pacific cod are in the pot fleet (Fig. 2.7). In 2020 pot fishing was greatly reduced, with just 15 vessels in the central GOA and 19 in the western GOA, compared to 27 and 33 the previous year. By 2022 the number of participating vessels increased again to pre-closure levels, with 41 vessels in the western GOA and 31 in the central GOA. The majority of catch taken by the pot fishery in the western and central GOA occurs prior to March. 2024 catch levels were similar to 2022 (Fig. 2.8).

Like the longline fishery CPUE figures were produced for the pot fisheries in the GOA in previous assessments (Barbeaux *et al.* 2021), but similar consistency issues with the data exists. It should be noted that there were no data available for CPUE calculations in 2020 nor any CPUE data available for the western GOA in 2021.

Other gear types, non-directed, and non-commercial catch

There is a small jig fishery for Pacific cod in the GOA, which is primarily a state managed fishery with no observer data documenting distribution. This fishery has taken on average 2,400 t per year. In 2017 through 2020 the jig fishery remained low with catch at less than 500 t for all regions (Table 2.1). Since 2017, the number of jig vessels participating in the GOA Pacific cod fishery has ranged from 27 to 65 vessels (Fig. 2.7). The majority of catch from jig vessels comes from the central GOA, where the 2024 catch was the largest since 2020 (Fig. 2.8).

Pacific cod are also caught as bycatch in other commercial fisheries. Although historically the shallow water flatfish fishery caught the most Pacific cod, since 2020, the greatest sources of Pacific cod bycatch have been the bottom walleye pollock, halibut, arrowtooth flounder, and rockfish fisheries (Table 2.8).

Non-commercial catch of Pacific cod in the GOA is relatively small at less than 400 t; data are available through 2023 (Table 2.9). The largest component of this catch comes from the recreational fishery, generally taking approximately one-third to one-half of the non-commercial catch. The IPHC Annual Longline survey also takes between one-third and one half of the non-commercial catch.

Other fishery related indices for stock health

Indices of fishery CPUE can be informative to the health of a stock, however CPUE in directed fisheries can be hyper-stable with CPUE remaining high even at low abundance (Walters 2003). This phenomenon is believed to have contributed to the decline of the Northern Atlantic cod (*Gadus morhua*) on the eastern coast of Canada (Rose and Kulka 1999). Instead of showing directed CPUE, the non-targeted catch of Pacific cod in other directed fisheries is examined as an indicator of population trends. We examine two disparate fisheries to evaluate trends in incidental catch of Pacific cod: the pelagic walleye pollock fishery and the bottom trawl shallow water flatfish fishery. The occurrence of Pacific cod in the pelagic pollock fishery appears to be an index of abundance that is particularly sensitive to 2 year old Pacific cod, which are thought to be more pelagic. As an index of recruitment abundance, we track the incidence of occurrence as proportion of hauls with cod in the central GOA pollock A season. The shallow water flatfish fishery tracks a larger portion of the adult population of Pacific cod. As an index of the adult population abundance we track the catch rates in tons of Pacific cod per ton of all species caught in the shallow water flatfish fishery. For the walleye pollock fishery in the central GOA, abundance of small cod in pelagic trawls was larger in 2022 and 2024 as compared to 2021 and 2023 (Fig. 2.9). The catch of Pacific cod in the shallow water flatfish fisheries has seen an increasing trend since the time series low in 2017.The 2024 value is the largest in the recent time series and only smaller than the 2014 value since 2008 (Fig. 2.9). It should be noted that none of these indices are controlled for gear, vessel, effort, or fishing practice changes.

Data

This section describes data used in the current assessment. It does not attempt to summarize all available data pertaining to Pacific cod in the GOA. All data used for Model 24.0 are provided in Stock Synthesis (SS3) data files as well as in spreadsheet format can be found at the link provided in the *Executive Summary* section of this document.

The following table and Figure 2.10 presents the data included in this assessment (the years shown in bold font are those that are new to this assessment).

Data	Source	Type	Years
Federal and state fishery catch, by gear type (trawl, pot, and longline)	AKFIN	Metric tons	1977 – **2024**
Federal and state fishery catch-at-length, by gear type	AKFIN, ADF&G	Frequency observed at length (in cm)	1977 – **2024**
GOA NMFS bottom trawl survey abundance	AKFIN	Total numbers	1990 – 2023
AFSC Sablefish Longline survey Pacific cod Relative Population Numbers	AKFIN	RPN	1990 – 2023
GOA NMFS bottom trawl survey length composition	AKFIN	Number at length (in cm)	1990 – 2023
GOA NMFS bottom trawl survey conditional age-at-length	AKFIN	Proportion age at length	1990 – **2023**
AFSC Sablefish Longline survey Pacific Cod length composition	AKFIN	RPN at length (in cm)	1990 – 2023
Federal fishery conditional age-at-length	AKFIN	proportion age at length	2007 – **2023**
CFSR bottom temperature indices	National Center for Atmospheric Research	temperature anomaly at mean depth for P. cod size bins	1979 – **2024**

Fishery:

Catch Biomass

Catches for the period 1991-2024 are shown for the three main gear types in Table 2.1, with the catches for 2024 presented through October 17, 2024. For the assessment model the Oct-Dec catch was assumed to reach the full Total Allowable Catch (TAC) and state Guideline Harvest Level (GHL). Three fishery fleets were modeled (by gear categories); trawl (all trawl types), longline (longline and jig) and pot.

Length Composition

Fishery length compositions are presently available by gear for at least one gear type in every year from 1977 through October of 2024. There are two methods employed within the GOA Pacific cod assessment to compute fishery length composition which are based upon different types of data available prior to 1991 and after 1991. Specifically, prior to 1991 there is no Catch Accounting System (CAS) derived total catch weight, and the foreign length frequency data is not associated with NMFS management areas.

For length composition data prior to 1991, the fishery haul-level length composition data were available from both the foreign and domestic fisheries. The method to compute gear-specific length composition data prior to 1991 were based on weighting the haul-level length frequency samples by the extrapolated number of fish in each haul as follows:

$$p_{l,g,y<1991} = \sum_h \frac{n_{l,g,h,y}}{\sum_l n_{l,g,h,y}} N_{h,g,y} \Big/ \sum_h N_{h,g,y}$$

where p is the proportion of fish at length l for gear type g in year y, n is the number of fish measured in haul h at length l from gear type g, and year y and N is the total extrapolated number of fish in haul h for gear type g, and year y.

In previous assessments the post-1991 gear-specific length composition was computed by weighting the federal haul-level length frequency observations by weekly catch totals provided by CAS within a NMFS management area. Hauls were removed from the length frequency data if there were less than 10 lengths sampled in a haul. These gear- and area-specific weekly weighted length compositions were then expanded to the trimester-level. ADF&G port-sampled length frequency collections have also been collected and available to the GOA Pacific cod assessment since 1997. ADF&G gear-specific length composition data was computed to the trimester- and area-level by weighting the length frequencies at the trimester- and area-level by the federal catch. If there were federal data missing at the trimester- and area-level then the expanded ADF&G length composition was used, otherwise only the expanded federal length composition was used.

In the current assessment we employ a method to expand gear-specific fishery length composition that (1) aggregates and weights length frequency data at the monthly rather than weekly level, (2) removes the 10 lengths measured per haul filter, and (3) merges the ADF&G length frequency data (see Tables 2.2.1 and 2.2.2 in Appendix 2.2 regarding the amount of data filtered and ADF&G data employed in the previous method). Length composition in the current assessment is computed as follows:

$$p_{l,g,y\geq 1991} = \sum_{m,a} \left(\left(\frac{n_{l,g,m,a,y}}{\sum_l n_{l,g,m,a,y}} N_{g,m,a,y} \Big/ \sum_{g,m,a} N_{y,m,a,g} \right) \left(\frac{W_{g,m,a,y}}{\sum_{g,m,a} W_{g,m,a,y}} \right) \right)$$

where p is the proportion of fish at length l for gear type g in year y, n is the total number of federal and ADF&G fish measured at length l in gear type g, month m, NMFS area a, and year y and N is the total extrapolated number of fish from federal hauls in gear type g, month m, NMFS area a, and year y. The W terms come from the CAS database and represent total weight (in kg) from gear type g, month m, NMFS area a, and year y. The current method to expand fishery length composition by simplifying the expansion method to weight length frequencies at the monthly rather than weekly level, removing the haul filter, and merging state data reduces variability in the resulting length composition data (see Fig. 2.2.2 in Appendix 2.2 using 2020 Pot fishery length composition as an example) and is consistent with the way catch is treated in the assessment, as both the federal and ADF&G total catch for each fleet are combined within the catch time series

Age composition

Otoliths for fishery age composition have been collected since 1982. In 2017, the Age and Growth laboratory made a concerted effort to begin aging these data. These data have been processed in two ways, the first was to develop an age and gear specific age-length key which was then used in conjunction with the length composition data described above to create age composition distributions. The age data was also used to develop an annual conditional length-at-age matrix for each fishery.

Surveys:

Bottom trawl survey

The AFSC has been conducting standardized bottom trawl surveys for groundfish and crab in the GOA since 1984. For a description of the historical survey see Hulson *et al.* (2022). Here we focus on recent survey trends and results.

The 2023 survey was conducted with two chartered vessels that accomplished 526 stations following the protocols of Stauffer (2004) and von Szalay and Raring (2018). While the GOA Bottom Trawl Survey optimally employs three chartered vessels and targets 825 stations, the reduced 2023 survey likely captured the trend and magnitude of the cod abundance in the GOA. The 2023 survey covered all strata; regions, and shelf, gully, and upper slope habitats to 700 m. The coefficient of variation of the population numbers estimate was 12.1% and was lower than the historical average of 17%. The 2023 survey design was comparable to the 2013, 2017, 2019, and 2021 surveys that were also conducted with two vessels and achieved 547, 534, 541, and 539 stations, respectively.

The spatial distribution of Pacific cod in the trawl survey is highly variable (Fig. 2.11) with inconsistent peaks in catch. The 2019 survey showed an increase in cod east of Kodiak Island on Portlock Bank and south of Marmot Island in the central GOA, but fewer cod in the eastern and western GOA. The distribution of cod in the 2021 survey is comparable to the 2019 survey except the peaks in CPUE east of Kodiak were not observed and more cod were encountered to the west of Kodiak Island and in the western GOA near the Shumagin Islands. In the 2023 survey cod abundance increased in the western and central GOA, with sporadic catches in the eastern GOA.

<u>Biomass and abundance estimates</u>

The Pacific cod biomass estimates from the bottom trawl survey are highly variable between survey years (Table 2.10). For example, biomass estimates dropped by 48% between the 1996 and 1999, but subsequent estimates were similar through 2005. The 2009 survey estimate spiked at 2 times the 2006 estimate, but was uncertain (CV = 30.3%). Subsequent surveys showed a decline through 2017 with a slight uptick in 2019, a drop in 2021, and another uptick in 2023. The 2017 estimates for abundance and biomass were the lowest in the time series (a 71% drop in abundance and 58% drop in biomass compared to the 2015 estimate). Although the 2019 survey resulted in a 126% increase in abundance from 2017, the estimate remained historically low at 58% of the time series mean. The 2021 survey abundance estimate was the second lowest in the time series, next only to the 2017 estimate. The 2023 abundance estimate was 53% larger than the 2021 estimate and the 2023 biomass estimate was 33% larger than the 2021 estimate.

Length Composition

The bottom trawl survey encounters fish as small as 5 cm and generally tracks large year-classes as they grow (e.g., the 1996, 2005-2008, and 2012 year-classes). The mean length in the trawl survey was generally larger from 1990-2005 except for the 1997 and 2001 surveys as compared to recent surveys (Fig 2.6). The decline in mean length in 2007 and 2009 were apparently due to the large incoming 2005-2008 year-classes. The mean length in the survey increased in the 2011-2017 survey then dropped again in 2019, increased again in 2021, but then dropped again in 2023. The average length of fish for 2007-2023 remains below the 1984-2005 overall average.

Age Composition

Otoliths for bottom trawl survey age composition are collected in each survey and are used as conditional age-at-length data within the GOA Pacific cod assessment.

AFSC longline survey

The AFSC longline survey has been conducted annually since 1988. This survey samples the continental slope and major gullies in the GOA, providing data to calculate relative abundance in this area (Rutecki et al. 2016, Siwicke and Malecha 2024). The survey is primarily directed at sablefish, but also catches considerable numbers of Pacific cod. The order in which areas are surveyed was changed in 1998 to reduce interactions between survey sampling and short, intense fisheries. Before 1998, the order was AI and/or EBS, western Gulf, central Gulf, eastern Gulf. Starting in 1998, the eastern Gulf area was surveyed before the central Gulf area.

Pacific cod catch in the longline survey primarily occur in the western and central GOA (Fig. 2.12), with inconsistent peaks in catch. The location of 2023 survey catches were similar to the 2022 survey, with consistent increases in catch in the western GOA in 2023 compared to 2022.

Factors affecting availability to the longline survey

Yang *et al.* 2019 showed that GOA Pacific cod exhibit a depth relationship with temperature, in which Pacific cod move to deeper depths in warmer years and shallower depths in colder years. We display this relationship for different size classes using area-weighted observed bottom temperaturesand CPUE weighted depth of Pacific cod in the AFSC bottom trawl survey (Figure 2.13). The general trend for each size class is a shallower depth distribution during colder than average years, and a deeper depth distribution in warmer than average years. Within Figure 2.13 we include the depth strata of the AFSC longline survey (solid horizontal lines) with text that indicate the proportion of hachis (i.e., longline skates) that are deployed by the longline survey in these depth strata to display the overlap of GOA Pacific cod depth distribution with the longline survey. We note that availability to the longline survey in colder than average years may be less than in warmer than average years. We also note the limited depth range of fish larger than 81 cm as compared to fish smaller than 81 cm. While the depth distribution of larger fish displays the same relationship with temperature as smaller fish, larger fish are not present in as deep of depths as the smaller fish, even in warmer than average years.

Abundance index

A Relative Population Number (RPN) index of Pacific cod abundance and length compositions for 1990 through 2023 is available from this survey (Table 2.10). Details about these data and a description of the methods for the AFSC longline survey can be found in Echave *et al.* (2012). This RPN index follows the trend observed in the bottom trawl survey for 1990 through 2018 with a decline in abundance from 1990 through 2008 and a sharp increase (154%) in 2009, and then continued increase through 2011 with the maturation of the large 2005-2008 year-classes. In 2012-2013 there appears a decline in the abundance index concurrent with a drop in overall shelf temperature, potentially due to changes in availability of Pacific cod in these years as the population moved to shallower areas (for example, as shown in Fig 2.13). In 2014-2016 the index increases but this may reflect increased availability with warmer conditions. The index showed a sharp drop (53%) in abundance from 2016 to 2017, again (40%) from 2017 to 2018, and yet again (37%) from 2018 to 2019. The 2019 estimate was 83% lower than the 2015 abundance estimate. The 2020 RPN showed a 30% increase from 2019, but the 2020 RPN remains the second lowest estimate of the time series. The increasing trend observed in 2020 continued in 2021 with a 58% increase, but then decreased again in 2022 by 24%. The 2023 RPN increased 32% compared to the 2022 RPN.

Length composition

Unlike the bottom trawl survey, the longline survey encounters few small fish (Fig 2.6). The size composition data show consistent and steep unimodal distributions with a stepped decreasing trend in mean size between 1990 and 2015 and then a generally increasing mean size from 2015-2023 (Fig. 2.3.8 and 2.3.9). This matches the trend observed in all three fisheries. Changes in mean size appear consistent with changing availability in the survey due to bottom temperatures and changes in the overall population with large year classes. A larger number of smaller fish are encountered during this survey in warm years vs. cold years. There is a sharp decline in mean size in 2009 when the large 2005 year-class would be becoming available to this survey. The even steeper decline in average length in 2015 was encountered in the second warmest year on record for the time series. In 2019 a more severe drop in average length was anticipated due to the increased temperatures on the shelf and an increase in abundance due to increased availability. That we observed neither of these anticipated outcomes portends that either very few small fish were available in the population, or a change in behavior. There is a sharp decline in length composition from 60 cm to 80 cm, with few fish larger than 80 cm captured in the AFSC longline survey, which could be due to different depth distribution of larger fish compared to smaller and the overlap with the depths sampled by the longline survey (Fig. 2.13).

Laurel and Litzow age-0 index

Beach seine sampling of age-0 cod was conducted at two Kodiak Island bays during 2006-2024 and an expanded survey was conducted since 2018 at 13 additional bays on Kodiak Island, the Alaska Peninsula, and the Shumagin Islands. Sampling occurred during July and August (days of year 184-240), within two hours of a minus tide at the long-term Kodiak sites, and within two hours of a low tide at the expanded survey sites. At all sites, a 36 m long, negatively buoyant beach seine was deployed from a boat and pulled to shore by two people standing a fixed distance apart on shore. Wings on the seine (13 mm mesh) were 1 m deep at the ends and 2.25 m in the middle with a 5 mm delta mesh cod end bag. The seine wings were attached to 25 m ropes for deployment and retrieval from shore. The seine was set parallel to the beach and ~ 25 m, making the effective sampling area ~ 900 m^2 of bottom habitat.

A model-based index of annual CPUE for age-0 cod was used to resolve inter-annual differences in sampling across different bays and different days of the year. Specifically, a Bayesian zero-inflated negative binomial (ZINB) model was used invoking year as a categorical variable, day of year as a continuous variable, and site nested within bay as a group-level (random) effect. The day of year effect was modeled with thin plate regression splines to account for non-linear changes in abundance through the season and the number of basis functions was limited to 3 to avoid over-fitting data. This model was fit using Stan 2.21.0, R 4.0.2 and the *brms* package (Carpenter *et al.* 2017, Bürkner 2017, R Core Team 2022). The beach seine age-0 CPUE index showed the large 2012 year class and subsequent drop in CPUE for 2013-2016, and alternating small recruitment in 2019, 2021, and 2023 with larger recruitment in 2017, 2018, 2020, and 2022 (Fig. 2.9). Age-0 recruitment estimated in 2024 was slightly larger than 2023, and not as large as 2022.

Alaska Department of Fish and Game bottom trawl survey

The Alaska Department of Fish and Game (ADFG) has conducted bottom trawl surveys of nearshore areas of the GOA since 1987. Although these surveys are designed to monitor population trends of Tanner crab and red king crab, Pacific cod and other fish are also sampled. Standardized survey methods using a 400-mesh eastern trawl were employed from 1987 to the present. The survey is designed to sample at fixed stations from mostly nearshore areas from Kodiak Island to Unimak Pass, and does not cover the entire shelf area. The average number of tows completed during the survey is 360. On average, 89% of these tows contain Pacific cod. Details of the ADFG trawl gear and sampling procedures are in Spalinger (2006).

To develop an index from these data, a simple delta GLM model was applied. Data were filtered to exclude missing latitude and longitudes and missing depths. This model is separated into two components: one that tracks presence-absence observations and a second that models factors affecting positive observations. For both components, a fixed-effects model was selected and includes year, geographic area, and depth as factors. Strata were defined according to ADFG district (Kodiak, Chignik, South Peninsula) and depth (< 30 fathoms, 30-70 fathoms, > 70 fathoms). The error assumption of presence-absence observations was assumed to be binomial but alternative error assumptions were evaluated for the positive observations (lognormal versus gamma). The AIC statistic indicated the lognormal distribution was more appropriate than the gamma. Comparison of delta GLM indices with the area-swept estimates indicated similar trends. Variances were based on a bootstrap procedure, and CVs for the annual index values ranged from 0.06 to 0.14. These values underestimate uncertainty relative to population trends since the area covered by the survey is a small percentage of the GOA shelf area where Pacific cod have been observed.

The ADFG survey index follows the trends observed in both the AFSC bottom trawl survey and longline survey indices, with a drop in abundance between 1998 and 1999 (-45%) and relatively low abundance throughout the 2000s (Fig. 2.9). This survey differs from other indices as the estimates only increased in 2012 (an 89% increase from 2011), and then dropped off steadily afterwards to a record low in 2016 and second lowest in 2017. Alternating increases and decreases in the index resulted in 2018-2019 and 2020-2021. Since 2021 the index has consistently increased, with a 29% increase in 2023 compared to 2022, and a 9% increase in 2024 compared to 2023. Length composition data from this survey show wide multi-modal length distributions are common with modes of age-0 fish at times available at near 10 cm, however the 2019 through 2021 surveys have no fish smaller than 22 cm, while there were some fish smaller than 22 cm that occurred in the 2022, 2023, and 2024 surveys.

Environmental indices

CFSR bottom temperature indices

The Climate Forecast System Reanalysis (CFSR) is the latest version of the National Centers for Environmental Prediction (NCEP) climate reanalysis. The oceanic component of CFSR includes the Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 4 (MOM4) with iterative sea-ice (Saha *et al.* 2010). It uses 40 levels in the vertical with a 10-meter resolution from surface down to about 262 meters. The zonal resolution is 0.5° and a meridional resolution of 0.25° between 10°S and 10°N, gradually increasing through the tropics until becoming fixed at 0.5° poleward of 30°S and 30°N.

To make the index, the CFSR reanalysis grid points were co-located with the AFSC bottom trawl survey stations. The co-located CFSR oceanic temperature profiles were then linearly interpolated to obtain the temperatures at the depths centers of gravity for 0-20 cm Pacific cod as determined from the AFSC bottom trawl survey. All co-located grid points were then averaged to get the time series of CFSR temperatures over the period of 1979-2024. The temperature anomalies based on the CFSR index used in Model 24.0 is shown in Figure 2.14.

Analytic Approach

General Model Structure

The assessment model used for GOA Pacific cod is a single sex, age-based model with length-based selectivity. This model has data from three fisheries (longline, pot, and combined trawl fisheries) with a single season and two survey indices (post-1990 AFSC bottom trawl survey and the AFSC longline survey indices). Length composition data were available for all three fisheries and both survey indices. Conditional age-at-length data were available for the three fisheries and AFSC bottom trawl survey. To see the history of models used in this assessment refer to A'mar and Palsson (2015). The model for this year was run in SS3 version 3.30.22.1 (Methot and Wetzell 2013).

The SS3 control and forecast files for this year's model can be found at the link provided in the *Executive Summary* section of this document.

Parameters Estimated Outside the Assessment Model

Ageing error

Within the GOA Pacific cod assessment model, ageing error is applied using paired reader-tester data (Fig. 2.15). In the current assessment we update the ageing error parameters with data through 2023 (we also start ageing error at age-1 rather than age-3 as in previous assessments). We update these parameters after pooling the reader-tester data for the GOA and EBS in order to leverage the larger number of samples available within both regions. Using the R-package AgeingError (Punt *et al.* 2008), we found that there was minimal difference between the parameters estimated for each region separately, and each region combined. We use the linear method for estimating ageing error, as this was the preferred method using AIC comparison with the AgeingError R package. The ageing error parameters estimated outside the model are shown in Table 2.11.

Ageing Bias

Kastelle *et al.* (2017) stated that one of the specific reasons for their study was to investigate the apparent mismatch between the mean length-at-age (from growth-zone based ages) and length-frequency modal sizes in the BSAI Pacific cod stock assessments, and to evaluate whether age determination bias could account for the mismatch. Based on improvements in estimating mean length-at-age, Kastelle *et al.* (2017) suggested that using an ageing bias correction should prove beneficial for rectifying discrepancies between mean length-at-age estimates and length-frequency modes in Pacific cod assessment models. To investigate ageing bias the otoliths used in Stark (2007) were reread using the most recent methods and reading criteria (Fig. 2.15). In the current assessment we used the reread data to estimate ageing bias with the AgeingError R package and fix the ageing error bias parameters (rather than estimate them internally within the assessment as has been done in previous assessment models) for the minimum and maximum ages in the model. The ageing bias parameters estimated outside the model are shown in Table 2.11.

Weight-at-Length

Weight-at-length was estimated outside the model with the following relationship:

$$W = \alpha L^{\beta}$$

where W is weight (in kg), L is length (in cm), α is the weight-length coefficient, and β is the weight-length exponent. Parameters for the relationship between length and weight were estimated outside the model using GOA bottom trawl survey data through 2023 (n = 10,411, Fig. 2.16). In the current assessment we also include length-weight data collected during the age-0 beach seine survey (n = 821), as fish at these lengths are not captured within the AFSC bottom trawl survey. Weight-at-length parameters estimated outside the model are shown in Table 2.11.

Maturity

The length at 50% maturity was last updated in the 2018 assessment (Barbeaux *et al.* 2018) and was estimated using the *gonad_mature* function in the sizeMat R package (Torrejon-Magallanes 2017). Data used to estimate length-at-maturity include observer scans up to 2018. The maturity parameters estimated outside the model are shown in Table 2.11.

Parameters Estimated Inside the Assessment Model

Parameters estimated conditionally (i.e., within individual SS3 runs, based on the data and the parameters estimated independently) in the model include parameters that estimate recruitment and initial abundance, growth, natural mortality, survey catchability, and survey and fishery selectivity parameters (Table 2.12).

Natural Mortality

For a description of the development of the priors used in this assessment for natural mortality rate *M* see Hulson *et al.* (2022). A lognormal prior on *M* of -0.81 (μ=0.44) with a standard deviation of 0.41 is used in this assessment. In Model 24.0 *M* was estimated for two time blocks, 2014-2016 and all other years, as a single non-varying parameter for all ages for each block. In 2017 it was hypothesized that due to the drop in all available survey indices between 2013 and 2017 that there was an increase in *M* during the height of the 2014-2016 marine heatwave.

Growth

For Model 24.0 length-at-age, L_a, was modeled with a three parameter von Bertalanffy growth model with parameters L_1, the length at age-0, L_∞, the maximum asymptotic length, and *k*, the growth rate, as:

$$L_a = L_\infty - (L_1 - L_\infty)e^{ka}$$

where *a* was age.

The initial values and 'priors' for the three von Bertalanffy growth parameters were based on a nonlinear least squares regression of the 2007-2015 AFSC GOA bottom trawl survey length-at-age data. The *nls* function from the nlstools package in R (Baty *et al.* 2015) was used to provide prior and initial values. Variance of the parameters were determined through bootstrap of the model with 1,000 iterations. We recognized that these 'priors' are not true priors as they are drawn from the data used in the model, but were necessary in setting structure within the model while allowing some flexibility in the model fitting which we think is a compromise to fixing parameters. Previous modeling effort using uninformative priors on these three parameters has led to model convergence at unreasonable values or non-convergence. Two parameters describing the SD in length-at-age for the minimum age (age-0) and the maximum age (age-10) were estimated in the model with uninformative priors.

Recruitment

In Model 24.0 recruitment by year, R_y, were modeled as:

$R_y = (R_0 e^{\vartheta})e^{-0.5 b_y \sigma_R^2 + \tilde{R}_y}$, if $y \geq 1977 \rightarrow \vartheta = 0$, where $\tilde{R}_y = N(0;\ \sigma_R^2)$,

R_0 was the unfished equilibrium recruitment, $\tilde{R}_y$ was the lognormal recruitment deviation for year *y*, σ_R^2 was the standard deviation among recruitment deviations in log space and was fixed at 0.44, and b_y was a bias adjustment fraction applied during year-*y* (Methot and Taylor 2011). To account for an environmental regime change in 1977 (Anderson and Piatt 1999) the parameter ϑ was fit for recruitment allowing for a change in R_0 prior to the regime change in 1977. Projections in the base model post-2024 assumed average recruitment for 1977-2022 of R_y.

Survey and Fishery selectivity

The same functional form to define the fishery selectivity schedules in previous year's assessments was used this year for both the fishery and survey. This functional form, the double normal, is constructed from two underlying and rescaled normal distributions, with a horizontal line segment joining the two peaks. This form uses the following six parameters (selectivity parameters are referenced by these numbers in several of the tables in this assessment):

1. Beginning of peak region (where the curve first reaches a value of 1.0)
2. Width of peak region (where the curve first departs from a value of 1.0)
3. Ascending "width" (equal to twice the variance of the underlying normal distribution)
4. Descending width
5. Initial selectivity (at minimum length/age)
6. Final selectivity (at maximum length/age)

All but the "beginning of peak region" parameter are transformed: The widths are log-transformed and the other parameters are logit-transformed.

The following table provides the time varying selectivity components for Model 24.0:

Component	Temporal Blocks/Devs
Longline Fishery	Annually variable 1978-1989
Trawl Fishery	Blocks – 1990-2004, 2005-2006, 2007-2016, 2017-Present
Pot Fishery	Blocks – 1977-2012 and 2013-Present
Bottom trawl survey	Blocks – 1990-1995, 1996-2006, 2007-Present

In this year's model both fishery and survey selectivities were length-based. Uniform prior distributions were used for all selectivity parameters, except for *dev* vectors in models with annually varying selectivities which were constrained by input standard deviations ("sigma") of 0.2.

In the recent time blocks the AFSC bottom trawl survey is constrained to have an asymptotic selectivity, whereas the AFSC longline survey is allowed to be dome-shaped. Asymptotic selectivity is reasonable for the AFSC bottom trawl survey given that the survey covers the range of Pacific cod depth and spatial distribution in the GOA. Dome-shaped selectivity is allowed for the AFSC longline survey because the depth distribution of larger cod (>81 cm) do not overlap with the longline survey depth distribution as significantly as for cod smaller than 80 cm, regardless of the average bottom temperature (Fig. 2.13).

Fishing mortality

In Model 24.0 the full set of year- and gear-specific fishing mortality rates were also estimated conditionally, but not in the same sense as the selectivity parameters. The fishing mortality rates are determined computationally rather than estimated statistically because this assessment 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.

Catchability

In Model 24.0 catchability for the AFSC bottom trawl survey was fit with a non-informative prior. An ecosystem-linked covariate on AFSC longline survey catchability has been in use since 2017 (Barbeaux *et al.* 2016) due to the relationship between depth and bottom temperature of Pacific cod (Fig. 2.13) and will continue to be used in all of the models presented. Annual catchability, Q_y, was modeled using a multiplicative link as:

$$log(Q_y) = log(\bar{Q})e^{\tau f_{Jy}},$$

where $\bar{Q}$ was the mean catchability for the AFSC longline survey, τ was the ecosystem link parameter fit with an uninformative prior, and f_{Jy} was the June CFSR bottom temperature anomaly in the central GOA in year y (Fig. 2.14).

Likelihood Components

The model includes likelihood components for trawl survey relative abundance, fishery and survey size composition, fishery and survey conditional age-at-length, recruitment, parameter deviations, and "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and initial (equilibrium) catch.

Use of Composition Data in Parameter Estimation

Length and conditional age-at-length composition data were assumed to be drawn from a multinomial distribution specific to a particular year and gear within the year. In the parameter estimation process, the assessment weights a given length composition observation according to the emphasis associated with the respective likelihood component and the input sample size specified. As was done in previous assessments, we set input sample sizes for the fishery length composition at the number of hauls sampled or 200 whichever is least, and for the surveys the length composition input sample sizes were set at 100. For fishery and survey conditional age-at-length the input sample sizes were set at the number of age samples per length bin multiplied by 0.14.

Description of Alternative Models

The alternative models evaluated in this year's assessment are described in Appendix 2.2 and were presented at the September 2024 Plan Team and October 2024 SSC meetings. The model alternatives that will be presented and compared in the current assessment include:

- Model 19.1b-23: the 2023 accepted model;
- Model 19.1b: the 2023 accepted model with updated data through 2024;
- Model 19.1c: include necessary corrections to model input data files to Model 19.1b (these are described in Appendix 2.2)
- Model 19.1d: Model 19.1c with updated reader-tester data used to estimate ageing error parameters through 2023, start ageing error at age-1 rather than age-3, estimate aging bias with reread 2007 age data, and fix these bias parameters in the model rather than estimate (as described in the 'Ageing error' and 'Ageing bias' sections above);
- Model 19.1e: Model 19.1d with new method to compute fishery length composition (as described in the 'Length Composition' section within the 'Fishery' section above)
- Model 24.0: Model 19.1e with length bins set at 5 cm rather than 1 cm.

Results

Model Evaluation

Model evaluation criteria included changes to the negative-log likelihood, model adherence to biological principles and assumptions, the relative sizes of the negative-log likelihood components, how well the model fits to the survey indices, the survey and fishery length composition, and conditional age-at-length data, reasonable curves for fishery and survey selectivity, retrospective pattern, and model behavior during sensitivity analyses.

Across the alternative models considered estimates of spawning biomass and age-0 recruitment were generally similar (Fig. 2.17); this same result held for key parameter estimates (Fig. 2.18). The largest shift in estimates of spawning biomass, recruitment, and key parameters occurred between Model 19.1b and 19.1c, specifically, when the month of AFSC bottom trawl survey condition age-at-length was changed from January to July (see Appendix 2.2 for more details and results among the changes made within Model 19.1c). An improvement to model fit for all data integrated within the assessment occurred when ageing error and ageing bias was updated in Model 19.1d as compared to 19.1b and 19.1c, as indicated by decreases for all negative log-likelihood components (Table 2.13). Implementing the new method to compute fishery length comps in Model 19.1e resulted in similar data fits and model estimates as Model 19.1d. Extending length bins from 1 cm to 5 cm in Model 24.0 resulted in nearly identical estimates of spawning biomass, age-0 recruitment, and key parameters as Model 19.1e. Further, estimates of current year selectivity was indistinguishable between Model 24.0 and 19.1e (Fig. 2.19). The ratio of input sample size (ISS, used in the multinomial likelihood for length composition and condition age-at-length) to effective sample size (ESS, as a measure of model fit to compositional data) gives an indication of how well the model produces uncertainty in predicted composition data that matches in input uncertainty defined in the observed composition data. All the alternative models with 1 cm length bins have an average ratio of ISS to ESS of less than 0.4 (Table 2.13), indicating that the ESS in composition data is twice as large as what the ISS would indicate. Applying 5 cm length bins in Model 24.0 results in a ratio of ISS to ESS that is closer to 1 than any of the other alternative models considered (Table 2.13). We recommend Model 24.0 for the following reasons:

1. It makes necessary corrections to input data files,
2. Updates to ageing error and ageing bias produces improved model fits,
3. The new method to compute fishery length composition by expanding from the month level and merging ADF&G length frequency data serves to reduce noise in the fishery length composition data,
4. Increasing the length bin size from 1 cm to 5 cm results in a more efficient model (reducing run time by nearly 50%) and improves the ratio of ISS to ESS.

For Model 24.0 the likelihoods appear well defined with the gradient of the objective function at less than $1e^{-5}$ (the final gradient was $6.57e^{-6}$). Convergence of Model 24.0 was further examined by “jittering” starting parameters by a factor of 5% over 50 runs to evaluate if models had converged to local minima. Jitter analysis revealed that Model 24.0 was insensitive to perturbations of parameter start values on the order of 5% with a total of 44 of the 50 jitter runs converged and 78% of the converged models resulting in estimates at the lowest MLE from the accepted models.

To evaluate stability and performance of the recommended Model 24.0 we performed several sensitivity analyses including:

1. Retrospective analysis,
2. Leave-one-out analysis,
3. Add-one-in analysis,
4. Longline survey environmental link analysis, and,
5. Key parameter profiles.

Two types of retrospective analyses are evaluated. The first is a ‘data retrospective’, in which data is sequentially removed from the author’s recommended model going back 10 years from the current year. The second is a ‘model retrospective’ in which accepted assessment model estimates of spawning biomass are compared going back to the 2003 assessment. The results of the data retrospective analysis revealed a small, and negative, retrospective pattern as data was removed from Model 24.0 (top panel Fig. 2.20). The negative retrospective pattern is a result of increases in the estimates of spawning biomass as data were sequentially added over time. Since the 2016 stock assessment the accepted models have been consistent in estimated spawning biomass and well within the 95% confidence intervals estimated in Model 24.0 (bottom panel Fig. 2.20), although, prior to 2016 there has been variability in estimated spawning biomass from the accepted model for GOA Pacific cod.

Leave-one-out analysis was performed by removing a single year’s worth of data from the model sequentially going back 10 years from the current year. This is distinct from the retrospective analysis in that only a single year of data is removed from the model in the leave-one-out analysis, as compared to all the years after a certain year being removed as in the retrospective analysis. Leave-one-out analysis allows evaluation of the model's sensitivity to a specific year's data. We examined the behavior of the model and the effects of removing the data on key parameter estimates (*M*, and *q*), and derived quantities ($F_{40\%}$, unfished spawning biomass, forecast spawning biomass, and ABC). For this analysis we focused on the difference between the full model and the model with data left out, i.e. was there a direction of change when data were removed from the complete model, and the variability of the variance estimates as data were removed. Model 24.0 resulted in relatively low differences across all examined parameters and derived quantities (Fig. 2.21). A notable difference was observed in the forecasted ABC and spawning biomass when removing data in 2023. Model 24.0 estimated a smaller forecasted ABC and spawning biomass when the 2023 data was removed from the model, although, this is not surprising given that both sources of survey index data increased in 2023 compared to previous years.

Add-one-in analysis was performed by adding in each new source of data to the current assessment (as compared to the data available for the previous years' assessment) one at a time to evaluate the author's recommended model's sensitivity to each new source of data. Similar to the leave-one-out analysis, we examined the behavior of the model and the effects of adding the data on key parameter estimates and derived quantities as compared to the full model. In general, the model estimates of key parameters and quantities is robust to each new source of data (Fig. 2.22). A notable result is that the addition of the AFSC bottom trawl survey and trawl fishery conditional age-at-length data served to increase the forecasted ABC more than any of the other datasets.

In order to evaluate the robustness of the environmental link with the longline survey catchability parameter we performed two tests. First, we removed the environmental link and ran the model using only the mean longline survey catchability parameter. Second, we generated 50 iterations of 'white noise' (with N(0,1)) and used this in place of the CFSR index and fit the model (Fig. 2.23). We compared Model 24.0 with these two tests using Akaike Information Criterion (AIC, Burnham and Anderson 2002). The AIC value from the model that did not include the CFSR index was 20 larger than the AIC value from Model 24.0. On average, the AIC value from the 50 model runs with white noise in place of the CFSR index was 7.3 larger than the AIC of Model 24.0 (where 45 of the 50 runs resulted in an AIC value for Model 24.0 that was smaller than a model using white noise). Given the results of these two tests, Model 24.0 using the CFSR index for the longline survey catchability parameter is preferred and continues to be recommended.

Negative log-likelihood profiles were conducted for several key parameters estimated in Model 24.0 (Fig. 2.24). Theses profiles were conducted by setting a parameter at a range of values, running the model, and storing the negative log-likelihood value. This type of analysis allows for evaluation of the influence of a model parameter's value on the fit to the data sources used within the assessment. Across a number of the key parameters investigated, the profile for the length composition and conditional age-at-length data were inversely related. For example, as the negative log-likelihood for the length composition would decrease the negative log-likelihood for the conditional age-at-length would increase. This inverse relationship suggests a possible data conflict between these sources.

Overall, Model 24.0 results in reasonable fits to the data, estimates biologically plausible parameters with reasonable amounts of uncertainty (Table 2.14), and produces consistent patterns in abundance compared to previous assessments. Model 24.0 fits the AFSC bottom trawl and longline survey indices reasonably well (Fig. 2.25), although, positive residuals have persisted in the fit to the longline survey since 2018. Fits to the length composition data for the years in which the data are available are shown in Appendix

2.3 (Figures 2.3.1 to 2.3.9). The aggregated fit from Model 24.0 to the fishery length composition data and one-step-ahead residuals do not indicate any serious model misspecification, although, there are a few outlier residuals that result in the fit to each fleet (Fig. 2.26). Model 24.0 fits well to the survey length composition data in aggregate, while there are some outliers present in the one-step ahead residuals (Fig. 2.27). The Pearson residuals that resulted from Model 24.0 across the length composition data fit do not indicate alarming patterns across time or length (Fig. 2.28). Model 24.0 fits to the available conditional age-at-length are shown for the years in which data are available in Appendix 2.3 (Figures 2.3.10 to 2.3.27). While there are many processes that conditional age-at-length inform within an assessment model, a primary process that is informed is the estimation of growth. In general, Model 24.0 fits AFSC bottom trawl survey length and weight observations well (Fig. 2.29). The estimated current year selectivity (Fig 2.19) and time-dependent selectivity (Fig. 2.30) estimated by Model 24.0 are consistent with previous assessment results.

Overall, Model 24.0 yields reasonable results and we continue to use it to recommend the 2025 ABC and OFL.

Time Series Results

Definitions

The biomass estimates presented here will be defined in two ways: 1) total biomass was defined as age 0+ biomass, consisting of the biomass of all fish aged 0 years or greater in a given year; and 2) spawning biomass was defined as the biomass of all spawning females in a given year. The recruitment estimates presented here are defined as numbers of age-0 fish in a given year; actual recruitment to fishery and survey depends on selectivity curves as estimated (noting that there are no indices involving age-0 Pacific cod). All results presented are from Model 24.0, additional results (including standard SS3 plots and estimated numbers at age and length) can be found at the link provided in the *Executive Summary* section of this document

Biomass

Total biomass estimates show a long decline from their peak in 1988 (Table 2.15 and Fig. 2.31) to a low in 2006 and then an increase to another peak in 2014, after which there was a sharp decline through 2018 followed by a slight increase through 2024 and is forecasted to increase through 2029. Spawning biomass (Table 2.15 and Fig. 2.31) shows a similar trend of decline since the late 1980s with a peak in 1989 to a low in 2008. There was then a short increase in spawning biomass coincident with the maturation of the 2005-2008 year classes through 2014, after which the decline continued to lowest level in 2019 and 2020. The spawning biomass then slightly increased in 2021 and 2022 and is projected to slightly decrease through 2026 and then increase through 2029.

Recruitment and Numbers-at-Age

The recruitment predictions in Model 24.0 (Table 2.16 and Fig. 2.32) show above average recruitment for most of the 1980s, below average recruitment from the mid-1990s to mid-2000s, above average recruitment from the mid-2000s to 2013, and below average recruitment since. Numbers-at-age, with the mean age, are shown in Figure 2.33. Overall, the model estimates a decrease in the mean age since 2019.

Fishing Mortality

Fishing mortality appears to have increased steadily with the decline in abundance from 1990 through a peak in 2008 with continued high fishing mortality through 2017 (Table 2.17 and Fig. 2.34). 2017 had the highest total exploitation rate of the time series. The period between 1990 and 2008 saw both a decline in recruitment paired with increases in catch. The period of increasing fishing mortality was mainly attributed to the rise in the pot fishery, which also shows the largest increase in continuous F (Fig. 2.34). In 2018 through 2020 there was a sharp decrease in fishing mortality coincident with the drastic cuts in ABC and closure of the federal directed fishery in 2020. In 2021 with the reopening of the federal fishery mortality once again increased, but remained lower than observed in the previous decade prior to 2017. In retrospect the phase plane plots (Fig. 2.35) show that F was estimated to have been above the ABC control rule advised levels from 2015 to 2017 and biomass has been below $B_{35\%}$ since 2017, and projected to continue to be below through 2026. It should be noted that this plot shows what the current model predicts, not what the past assessments had estimated.

Uncertainty Results

MCMC were conducted with the R package *adnuts* (Monnahan and Kristensen 2018, Monnahan *et al.* 2020). 2,500,000 MCMC iterations were thinned to every 2000th iteration and the first half of the iterations were removed to account for the burn-in period. The MCMC chains for these parameters appear well mixed, with a minimum ESS of 311 and maximum Rhat of 1.03 for these key parameters (Fig. 2.36) and the MCMC histograms are well defined and bracket the MLE estimates (Fig. 2.37).

Harvest Recommendations

Amendment 56 Reference Points

Amendment 56 to the GOA 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 GOA 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: $B/B_{40\%} \leq 0.05$

$F_{OFL} = 0$

$F_{ABC} = 0$

Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. These reference points are estimated as follows, based on this year's model, Model 24.0:

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
Spawning biomass:	57,255 t	65,434 t	163,585 t

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. For this assessment, the apportionment was based on this year's model's estimates of fishing mortality by gear for the five most recent complete years of data.

Specification of OFL and Maximum Permissible ABC

For Model 24.0 spawning biomass for 2025 is estimated by this year's model to be 49,605 t at spawning. This is below the $B_{40\%}$ value of 65,218 t, thereby placing Pacific cod in sub-tier "b" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2025 and 2026 as follows (2026 values are predicated on the assumption of the full TAC and GHL being taken in 2024 and that the 2025 catch will be at maximum ABC in the projection):

Units	Year	Overfishing Level (OFL)	Maximum Permissible ABC
Harvest amount	2025	38,688	32,141
Harvest amount	2026	33,099	30,193
Fishing mortality rate	2025	0.57	0.46
Fishing mortality rate	2026	0.51	0.43

The age 0+ biomass projections for 2025 and 2026 from this year's model are 180,671 t and 199,305 t, respectively.

Risk Table and ABC Recommendation

Assessment-related considerations.

The GOA Pacific cod assessment does not show a strong retrospective pattern in recent estimates of spawning biomass, either in the data retrospective or in the model retrospective across recent assessments (Fig. 2.20). The retrospective pattern in spawning biomass in the current assessment is negative, which means that as years of data were added to the model the estimates of spawning biomass increase. All in all, Model 24.0 is responding appropriately to observed data sources. An additional assessment concern, as it relates to projecting biomass and management quantities, is that the projection model uses mean recruitment from 1977 – 2022 to project biomass into future years. However, Model 24.0 continues to estimate below average recruitment since 2014. Therefore, given these recent low recruitment estimates it is likely that the forecasted spawning biomass is overly optimistic. However, the effect on the two-year projections to result in ABC and OFL recommendations is not largely impacted by this recruitment assumption, as the year classes that are assumed to be at mean recruitment aren't contributing much to the overall level of spawning biomass in the short term. For the reasons that Model 24.0 is fitting the available data reasonably well, does not have a concerning retrospective pattern, and the mean recruitment assumption in the projections does not have a large impact on short term ABC and OFL recommendations, we rate the assessment considerations category at level 1, with typical to moderately increased uncertainty.

Population dynamics considerations

Female spawning biomass is estimated to decrease over the next 2 years, then increase in the medium-term once the projected year classes (i.e., based on mean recruitment since 1977) begin contributing to the SSB (Fig. 2.31). To reiterate, mean recruitment levels have not been estimated in the model since 2014 so the increase in the medium term is likely overly optimistic. Auxiliary information on recruitment from non-target fishery sources and the beach seine survey of age-0 fish surveys suggest a very weak 2019 year class, a strong 2020 year class, and above average 2017, 2018, and 2022 year classes. How these indices relate to overall recruitment into the fishery and population is currently unknown, as they have yet to materialize in the estimates of recent recruitment in the assessment. However, in the observations of length composition (and age composition) from the AFSC bottom trawl survey these stronger year classes are present, but not estimated well by the model. While the 2023 observations of population scale from both the fitted data sources (bottom trawl survey and longline survey) and the monitored data sources (ADFG trawl survey) indicate an increase in abundance compared to 2022, this increase has yet to translate to a recovery of the cod stock in the GOA to historical levels. Because of the persistent low levels of observed and estimated abundance we continue to rate the population dynamics considerations category at level 2, increased concern.

Ecosystem considerations

The most recent data available suggest an ecosystem risk level 1 – no apparent ecosystem concerns. The 2023/2024 El Niño event had moderate impacts in the GOA, bringing warmer waters to the surface in winter and at depth in the winter and spring, but not exceeding known thermal thresholds for cod or elevating adult metabolic demands. Spawning conditions were average to slightly below average based on heatwave and habitat suitability with average cross-shelf transport to nursery habitat. Prey availability for larval/juvenile cod (zooplankton) was average to above average (increased euphausiids), while prey availability for adult cod was mixed but less well-monitored (e.g., declining Tanner crab biomass). Adult ration current year projection remains below average. There is no expected change in cod predation (moderate), but biomass consumed projections were higher than in 2023. Competition for zooplankton may be reduced due to low returns of pink salmon. Upcoming 2025 winter and spring surface temperatures are predicted to be cooler than average, in alignment with weak La Niña conditions, allowing more dissipation of heat at depth. An extended written description of these Ecosystem Considerations can be found in Appendix 4 of the Gulf of Alaska Ecosystem Status Report (Ferriss 2024). Appendix 2.1 provides a detailed look at environmental/ecosystem considerations specific to this stock within the ecosystem and socioeconomic profile. Broad-scale information on environmental and ecosystem considerations are provided by the Gulf of Alaska Ecosystem Status Report.

Fishery-informed stock considerations

Where data were available catch-per-unit effort measures in the GOA fisheries showed mixed signals. It should be noted that catch levels and fishery participation have been low over the past 4 years in comparison with previous years. Bycatch in other fisheries still remain low compared to fisheries prior to the 2014-2016 marine heatwave, with the exception of the shallow water flatfish fishery, within which Pacific cod catch has increased. We consider the concern level to be 1 – no apparent concerns.

Summary and ABC recommendation

These results are summarized in the table below:

Assessment-related considerations	*Population dynamics considerations*	*Ecosystem considerations*	*Fishery Performance considerations related to health of the stock*
Level 1: Normal	Level 2: Increased concerns	Level 1: Normal	Level 1: Normal

From 2008-2017 the GOA Plan Team and SSC recommended setting the ABC at the maximum permissible level under Tier 3. For 2018 through 2019 an ABC was recommended below the maximum ABC in an attempt to ensure the 2019 and 2020 SSB would remain above $B_{20\%}$. For 2020 although the ABC was set at the maximum the stock was below $B_{20\%}$ and because of the rules in place to protect forage for Steller sea lions the directed federal fishery was be required to remain closed. However, for added precaution both the federal TAC and state GHL were reduced. Biological reference points from GOA Pacific cod SAFE documents for years 2002 – 2025 are provided in Table 2.18. While the largest score of the risk table is level 2, we do not recommend that ABC be set below the maximum permissible.

For 2025 the spawning stock biomass is projected to be above $B_{20\%}$, and despite a drop in spawning biomass in 2026 is projected to remain above $B_{20\%}$ in 2026.

Area Allocation of Harvests

Using the *rema* R package with the AFSC bottom trawl survey biomass through 2023 (Fig. 2.38), the area-apportioned ABCs for the two-year projections of Model 24.0 would be:

	Western	Central	Eastern	Total
Area apportionment	27.10%	63.80%	9.10%	100%
2025 ABC	8,710	20,506	2,925	32,141
2026 ABC	8,182	19,263	2,748	30,193

Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Year-end catch for 2024 was set equal to the 2024 ABC. 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.

Selectivity used in the projections was the mean selectivity since 2000, recruitment was based on average recruitment from 1977-2022 and growth and mortality were as estimated in 2024.

Five of the seven standard scenarios support the alternative harvest strategies analyzed in the Alaska Groundfish Harvest Specifications Final Environmental Impact Statement. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2025, 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 the author's recommend level, max ABC.

Scenario 3: In all future years, *F* is set equal to the 2020-2024 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, *F* is set equal to the $F_{75\%}$. (Rationale: This scenario was developed by the NMFS Regional Office based on public feedback on alternatives.

Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA′s requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above half of its B_{MSY} level in 2024 and above its B_{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 2026 and expected to be above its MSY level in 2036 under this scenario, then the stock is not approaching an overfished condition.)

Scenarios 1 through 7 were projected 15 years from 2024 in Model 24.0 (Table 2.19). Scenarios 3, 4, and 5 (no fishing) project the stock to be below $B_{35\%}$ until 2027, scenarios 1, 2, 6, and 7 have the stock below $B_{35\%}$ until 2028. Fishing at the maximum permissible rate indicate that the spawning stock will be below $B_{35\%}$ in 2025 through 2027 due to poor recruitment and high mortality in 2015-2017. Under an assumption of environmental conditions at the 1977-2022 mean, the stock recovers above $B_{35\%}$ by 2027.

Our projection model run under these conditions indicates that for Scenario 6, the GOA Pacific cod stock although below $B_{35\%}$ in 2024 at 52,034 t will be above its MSY value in 2034 at 74,698 t and therefore would not be classified as overfished.

Projections 7 with fishing at the OFL after 2025 results in an expected spawning biomass of 74,739 t by 2036 and would therefore not be approaching an overfished condition.

Under Scenarios 6 and 7 for Model 24.0 the GOA Pacific cod stock would not currently be considered overfished, nor would it be approaching an overfished status. The 2023 OFL given Model 24.0 would have produced a sum of apical F of 0.36 in 2023.

Ecosystem Considerations

An Ecosystem and Socioeconomic Profile has been provided in Appendix 2.1.

Data Gaps and Research Priorities

Research is needed around three linked themes:

1) **Better understanding of the effects of warming temperatures on Pacific cod ecology and population dynamics**, with a focus on indices and parameters to improve the stock assessment (e.g. mortality, growth, maturity),

2) **Expanded early life history work** (spawning, larval, age-0) to focus on spatial-temporal variation in stock reproductive output, survival processes, and how these vary with changes in climate, and

3) **Resolving stock spatial structure, migration patterns, and connectivity** based on tagging and new genetics/genomics approaches. Research that covers a wide range of methods, including understanding early life history, satellite tagging, modelling, genetics, surveys, and maturity are needed.

Specific project to support these research themes:

Growth and survival of young cod

Continuation of age-0 juvenile surveys across the western and central GOA will generate better estimates of growth and survival for juvenile cod in the stock assessment model. Expanding the temporal scale of Kodiak surveys would help identify the timing of settlement to nearshore habitat, validate a spatial-temporal spawning model and understand overwintering ecology/survival. Larger projects (3-5 years) would include linking observations of spawning - larvae - juvenile surveys to identify climate-driven reproductive output.

Tagging to determine cod movement

Pop-up satellite tags in GOA recording temperature and depth (modeled location) combined with bioenergetics models could be used to ascertain movement, growth, and spawn timing. Tagging is also useful for improving age estimation for cod, which is critical for successful stock assessment models. In addition it is apparent from the most recent satellite tagging efforts that at least the western GOA Pacific cod population is highly connected with the Bering Sea and Chukchi Sea.

Improved stock assessment modeling

In connection with the pop-up tag study, there is a need to develop a multi-area assessment model for the BSAI and GOA. The further development of the ecosystem-linked GOA models is also needed to evaluate impacts of climate change and appropriate management strategies in a warming planet.

Survey

Research on seasonal migration of Pacific cod and impacts of annual variability in migration on the standard survey estimates would improve our understanding of how climate variability and survey timing impact survey estimates. One way to accomplish this would be to increase bottom trawl survey effort outside of the standard summer survey. To understand seasonal migration and interannual variability in Pacific cod migration would require several, 5 or more, years of survey effort in the spring, but could include a much smaller spatial area limited to the central and eastern GOA in waters < 200 m. Besides increasing funding for surveys, there would need to be additional survey staff needed to conduct this work as there is currently a shortage of trained personnel for current survey efforts.

Genetics

Genetics studies are needed to improve understanding of stock structure, which will improve our ability to realistically model stock size. Genetics studies will also allow us to identify the spawning stock origin of different components of the population, to track movement of cod from winter to summer, and to inform selectivity and stock size relative to summer surveys. All of these insights are critical to inform better understanding of stock structure, which will improve management.

Maturity

The stock assessment critically needs better estimates of size- and age-at-maturity and how these parameters are affected by temperature. Since 2006, there has been an ~200% increase in average individual mass of age-0 juveniles observed in August (Laurel *et al.* 2023). These changes in body size adhere to the 'temperature size rule' for fish, which are predicted to lead to initially larger body size for early stages, but ultimately result in earlier maturity, smaller body sizes and lower productivity as adults (Atkinson 1994). Such changes in maturity schedules, size-at-age and spawning response to temperature (e.g., skip spawning) need to be further studied for Pacific cod in the GOA.

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Tables

Table 2.1. Catch (t) for 1991 through 2024 by jurisdiction and gear type (as of 2024-10-17)

	Federal					State				
Year	**Trawl**	**Long-line**	**Pot**	**Other**	**Subtot**	**Long-line**	**Pot**	**Other**	**Subtot**	**Total**
1991	58,092	7,630	10,464	115	76,301	-	-	-	-	76,301
1992	54,593	15,675	10,154	325	80,747	-	-	-	-	80,747
1993	37,806	8,963	9,708	11	56,488	-	-	-	-	56,488
1994	31,447	6,778	9,161	100	47,486	-	-	-	-	47,486
1995	41,875	10,978	16,055	77	68,985	-	-	-	-	68,985
1996	45,990	10,196	12,040	53	68,279	-	-	-	-	68,279
1997	48,406	10,978	9,065	26	68,475	-	7,368	1,327	8,695	77,170
1998	41,570	10,012	10,510	29	62,121	-	9,183	1,320	10,503	72,624
1999	37,167	12,363	19,015	70	68,615	-	12,410	1,518	13,928	82,543
2000	25,443	11,660	17,351	54	54,508	-	10,399	1,644	12,043	66,551
2001	24,383	9,910	7,171	155	41,619	-	7,829	2,083	9,912	51,531
2002	19,810	14,666	7,694	176	42,346	-	10,578	1,714	12,292	54,638
2003	18,884	9,525	12,765	161	41,335	62	7,943	3,242	11,247	52,582
2004	17,513	10,326	14,966	400	43,205	51	10,602	2,765	13,418	56,623
2005	14,549	5,732	14,749	203	35,233	26	9,653	2,673	12,352	47,585
2006	13,132	10,244	14,540	118	38,034	55	9,146	662	9,863	47,897
2007	14,775	11,539	13,573	44	39,931	270	11,378	682	12,330	52,261
2008	20,293	12,106	11,229	63	43,691	317	13,438	1,568	15,323	59,014
2009	13,976	13,968	11,951	206	40,101	676	9,919	2,500	13,095	53,196
2010	22,035	16,538	20,116	429	59,118	826	14,604	4,045	19,475	78,593
2011	16,456	16,622	29,233	722	63,033	1,033	16,675	4,627	22,335	85,368
2012	20,084	14,467	21,238	722	56,511	866	15,940	4,613	21,419	77,930
2013	21,706	12,836	17,011	476	52,029	1,088	14,156	1,303	16,547	68,576
2014	26,917	14,735	19,957	1,046	62,655	1,007	18,445	2,838	22,290	84,945
2015	22,268	13,047	20,653	408	56,376	577	19,719	2,808	23,104	79,480
2016	15,217	8,123	19,248	346	42,934	803	18,609	1,708	21,120	64,054
2017	13,041	8,965	13,426	67	35,499	155	13,011	62	13,228	48,727
2018	3,818	3,033	4,013	121	10,985	310	3,660	195	4,165	15,150
2019	4,535	2,763	3,732	178	11,208	358	3,820	329	4,507	15,715
2020	3,427	586	30	-	4,043	529	1,779	491	2,799	6,842
2021	5,986	3,834	3,427	52	13,299	558	4,230	1,085	5,873	19,172
2022	8,207	5,775	4,912	3	18,897	372	5,658	994	7,024	25,921
2023	6,473	5,177	4,069	378	16,097	563	3,653	1,412	5,628	21,725
2024	6,399	4,754	5,388	319	16,860	528	4,293	1,490	6,311	23,171

Table 2.2. History of Pacific cod catch (t, includes catch from State waters), Federal TAC (does not include State guideline harvest level, GHL), ABC, OFL and State of Alaska GHL (1997-Present) since 1991. Catch for 2024 is current through 2024-10-17 and includes catch from State of Alaska fisheries. See Hulson et al. 2022 (Table 2.2) for catch history prior to 1991.

Year	Catch	TAC	ABC	OFL	GHL
1991	76,301	77,900	77,900	-	-
1992	80,747	63,500	63,500	87,600	-
1993	56,488	56,700	56,700	78,100	-
1994	47,486	50,400	50,400	71,100	-
1995	68,985	69,200	69,200	126,000	-
1996	68,279	65,000	65,000	88,000	-
1997	77,170	69,115	81,500	180,000	12,385
1998	72,624	66,060	77,900	141,000	11,840
1999	82,543	67,835	84,400	134,000	16,565
2000	66,551	59,800	76,400	102,000	17,685
2001	51,531	52,110	67,800	91,200	15,690
2002	54,638	44,230	57,600	77,100	13,370
2003	52,582	40,540	52,800	70,100	12,260
2004	56,623	48,033	62,810	102,000	14,777
2005	47,585	44,433	58,100	86,200	13,667
2006	47,897	52,264	68,859	95,500	16,595
2007	52,261	52,264	68,859	97,600	16,595
2008	59,014	50,269	66,493	88,660	16,224
2009	53,196	41,807	55,300	66,600	13,493
2010	78,593	59,563	79,100	94,100	19,537
2011	85,368	65,100	86,800	102,600	21,700
2012	77,930	65,700	87,600	104,000	21,900
2013	68,576	60,600	80,800	97,200	20,200
2014	84,945	64,738	88,500	107,300	23,762
2015	79,480	75,202	102,850	140,300	27,648
2016	64,054	71,925	98,600	116,700	26,675
2017	48,727	64,442	88,342	105,378	23,900
2018	15,150	13,096	18,000	23,565	4,904
2019	15,715	12,368	17,000	23,669	4,632
2020	6,842	6,431	14,621	17,794	2,537
2021	19,172	17,321	23,627	28,977	6,306
2022	25,921	24,111	32,811	39,555	8,700
2023	21,725	18,103	24,634	29,737	6,531
2024	23,171	23,766	32,272	38,712	8,506

Table 2.3. History of GOA Pacific cod allocations by regulatory area (in percent) for 1991-2024, and proposed for 2025 (in parentheses). See Barbeaux *et al.* (2018) for 1977-1990.

Year(s)	Western	Central	Eastern
1991	33	62	5
1992	37	61	2
1993-1994	33	62	5
1995-1996	29	66	5
1997-1999	35	63	2
2000-2001	36	57	7
2002	39	55	6
2002	38	56	6
2003	39	55	6
2003	38	56	6
2004	36	57	7
2004	35.3	56.5	8.2
2005	36	57	7
2005	35.3	56.5	8.2
2006	39	55	6
2006	38.54	54.35	7.11
2007	39	55	6
2007	38.54	54.35	7.11
2008	39	57	4
2008	38.69	56.55	4.76
2009	39	57	4
2009	38.69	56.55	4.76
2010	35	62	3
2010	34.86	61.75	3.39
2011	35	62	3
2011	35	62	3
2012	35	62	3
2012	32	65	3
2013	38	60	3
2014	37	60	3
2015	38	60	3
2016	41	50	9
2017	41	50	9
2018	44.9	45.1	10
2019	44.9	45.1	10
2020	33.8	57.8	8.4
2021	33.8	57.8	8.4
2022	30.3	60.2	9.5
2023	30.3	60.2	9.5
2024	27.1	63.8	9.1
2025	*27.1*	*63.8*	*9.1*

Table 2.4. Estimated retained and discarded GOA Pacific cod (t, as of 2024-10-17)

Year	Discarded	Retained	Grand Total
1991	1,427	74,873	76,300
1992	3,920	76,827	80,747
1993	5,886	50,602	56,488
1994	3,122	44,363	47,485
1995	3,546	65,439	68,985
1996	7,555	60,725	68,280
1997	4,828	72,342	77,170
1998	1,732	70,893	72,625
1999	1,645	80,898	82,543
2000	1,378	65,174	66,552
2001	1,904	49,627	51,531
2002	3,715	50,923	54,638
2003	2,485	50,097	52,582
2004	1,268	55,355	56,623
2005	1,043	46,541	47,584
2006	1,852	46,045	47,897
2007	1,448	50,813	52,261
2008	3,307	55,707	59,014
2009	3,944	49,252	53,196
2010	3,097	75,496	78,593
2011	2,178	83,189	85,367
2012	949	76,981	77,930
2013	4,560	64,016	68,576
2014	5,302	79,643	84,945
2015	1,723	77,758	79,481
2016	868	63,187	64,055
2017	711	48,016	48,727
2018	604	14,546	15,150
2019	1,194	14,522	15,716
2020	1,748	5,094	6,842
2021	1,404	17,769	19,173
2022	1,677	24,245	25,922
2023	1,873	19,852	21,725
2024	2,026	21,145	23,171

Table 2.5. Weight of groundfish bycatch (t, by assessed stock), discarded (D) and retained (R), for 2020 – 2024 for GOA Pacific cod as target species (as of 2024-10-17).

	2020		2021		2022		2023		2024	
Stock	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**
Arrowtooth flounder	50.4	0.3	147.5	2	82.8	14.3	81	0.6	90.7	0.8
Atka mackerel	-	-	2.9	0	0.5	-	0.1	-	0.1	-
Deep-water flatfish	0.2	-	1.2	-	2.4	-	7.2	-	0.3	0.1
Demersal shelf rockfish	0.1	0.6	9.4	12.3	9.2	8.4	30.4	30.6	12.6	14.8
Dusky rockfish	-	0.8	2.5	2.3	2.4	1.9	1.2	1.7	1.3	3.1
Flathead sole	0.1	-	18.1	2.8	7.5	1.3	10.7	0.3	38.7	0.3
Northern rockfish	-	-	3.4	1	0.4	0.8	2.6	0.2	0.8	0.1
Octopus	0	12	14.4	23.3	49.5	60.2	72.2	41.2	37	66
Other rockfish	0.4	0.1	7.4	0.4	45.4	1.2	18	0.7	1.9	0.3
Pacific Ocean perch	0	7.8	0.2	1.5	0.8	6.2	0	-	1.1	0.1
Rex sole	0.1	-	1.6	0	8.6	0.2	7.8	-	3	-
Rougheye and Blackspotted rockfish	0.1	0.2	2.4	0.8	0.3	0.3	0.7	0.8	0.9	0.1
Sablefish	5.5	24.4	64.1	64.5	104.5	17	42.5	34.9	23.1	0.4
Shallow-water flatfish	0.1	0	18.7	0.6	31.7	100.2	22.2	1.4	89.6	72.8
Shortraker rockfish	0.1	0	4.6	0.4	1.3	0.6	1.5	0.1	0.1	-
Skarks	14.5	0.3	162.2	0	68.2	0.2	71.6	-	13	0.2
Skates	12.1	4.2	508.4	106.6	692.5	217.8	660.3	188.3	326.2	137.7
Thornyheads	0	-	0.4	0.6	1.6	2.7	6.7	0.4	1.7	-
Walleye pollock	11.4	4.4	271.9	21.8	132.1	50.4	68.6	36	4.4	59.2
Total	99	55.5	1252	253.7	1260.5	492.9	1127.4	360.8	656.7	359.1

Table 2.6. Prohibited species catch (t for halibut and herring, counts for crab and salmon) for 2020 – 2024 for GOA Pacific cod as target species (as of 2024-10-17).

Species	2020	2021	2022	2023	2024
Bairdi Tanner Crab	166	30,372	24,691	27,117	10,771
Blue King Crab	0	0	0	0	0
Chinook Salmon	0	3,827	0	857	9
Golden (Brown) King Crab	19	26	16	81	280
Halibut	19	599	353	409	317
Herring	0	0	0	0	0
Non-Chinook Salmon	0	0	0	0	8
Opilio Tanner (Snow) Crab	9	0	0	0	0
Red King Crab	0	10	0	0	0

Table 2.7. Incidental catch (t or birds by number) of non-target species groups by GOA Pacific cod fisheries (as of 2023-10-20). 0.00 indicates ≤0.005 tons, a blank indicates no catch or confidential data.

Species Group	2020	2021	2022	2023	2024
Benthic urochordata	-	-	0	0.01	0.05
Birds - Gull	-	7.73	36.27	44.92	-
Birds - Northern Fulmar	-	21.27	224.79	17.92	-
Birds - Unidentified	-	9.33	-	404.15	-
Birds - Unidentified Albatross	-	-	11.04	-	-
Bivalves	-	0	0.63	0.01	0.22
Brittle star unidentified	-	-	0.02	0.01	0.01
Corals Bryozoans - Corals Bryozoans Unidentified	0.18	0.08	0.07	0.58	0.01
Eelpouts	-	-	0.02	0.08	0.05
Giant Grenadier	-	79.55	48.08	43.61	-
Greenlings	-	0.45	0.29	0.35	0.28
Grenadier - Rattail Grenadier Unidentified	-	0.12	0.07	0	0.04
Hermit crab unidentified	-	0.01	0.08	0.04	0.03
Invertebrate unidentified	0.11	0.01	0.75	1.85	0.02
Misc crabs	-	0.14	0.05	4.17	0.21
Misc crustaceans	-	-	0	0	0.04
Misc fish	7.71	33.35	34.69	23.38	99.79
Sculpin	-	119.66	175.62	123.35	49.15
Scypho jellies	0.02	0.19	0.03	0.07	0.52
Sea anemone unidentified	0	1.09	1.1	1.67	2.32
Sea pens whips	-	0.04	1.43	0.14	0.52
Sea star	1.66	18.44	22.45	30.36	50.11
Snails	0.06	0.27	2.19	3.62	0.52
Sponge unidentified	-	0.05	1.11	0.69	1.15
State-managed Rockfish	-	2.24	2.31	1.89	0.3
urchins dollars cucumbers	-	0.03	0.64	0.2	0.61

Table 2.8. Pacific cod catch (t) by trip target in Gulf of Alaska groundfish fisheries (as of 2024-10-17).

Trip Target	2020	2021	2022	2023	2024	Average
Pacific Cod	2,678	14,345	20,006	15,216	19,959	14,441
Pollock - bottom	899	2,841	3,355	3,769	362	2,245
Halibut	717	560	1,076	1,372	1,499	1,045
Arrowtooth Flounder	1,237	379	415	514	646	638
Rockfish	170	660	670	448	352	460
Shallow Water Flatfish - GOA	938	254	222	137	150	340
Pollock - midwater	141	74	121	209	163	141
Sablefish	49	58	34	30	40	42
Rex Sole - GOA	14	-	22	-	-	18
Flathead Sole	-	3	-	-	-	3
Grand Total	6,843	19,174	25,921	21,726	23,171	19,367
Non-Pacific cod trip target total	4,165	4,829	5,915	6,510	3,212	4,926

Table 2.9. Noncommercial fishery catch (t); total source amounts less than 10 kg were omitted (as of 2024-10-17)

Source	**2019**	**2020**	**2021**	**2022**	**2023**
AFSC Annual Longline Survey	5.5	10.2	13.1	14.7	15.3
GOA Shelf and Slope Walleye Pollock Acoustic-Trawl Survey	-	-	0.1	-	-
Gulf of Alaska Bottom Trawl Survey	7.8	-	7.9	-	10
IPHC Annual Longline Survey	105	30	75.3	34.8	79.4
Large-Mesh Trawl Survey	7.3	7.9	5	6.2	8
Small-Mesh Trawl Survey	0.3	0.7	0.1	0.1	0.1
Sport Fishery	78.6	70.1	182.4	168.1	284.8
Summer Acoustic-Trawl Survey of Walleye Pollock in the Gulf of Alaska	0.1	-	-	-	-
Total	204.6	118.9	283.9	223.9	397.6

Table 2.10. GOA AFSC Longline survey estimated Relative Population Numbers (RPNs), and bottom trawl survey estimated biomass (t) and numbers of fish ('Abundance', in 1000s) shown along with coefficients of variation (in parentheses).

Year	RPN	Biomass (t)	Abundance
1990	116,434 (13.9%)	416,788 (15.3%)	212,436 (20.7%)
1991	110,061 (14.1%)	-	-
1992	136,383 (8.7%)	-	-
1993	153,950 (11.4%)	405,782 (18.1%)	225,779 (19.3%)
1994	96,563 (9.4%)	-	-
1995	120,710 (10%)	-	-
1996	84,535 (14.1%)	538,153 (20%)	319,416 (21.5%)
1997	104,647 (16.9%)	-	-
1998	125,877 (11.5%)	-	-
1999	91,480 (11.3%)	306,413 (12.6%)	166,639 (11.2%)
2000	54,316 (14.5%)	-	-
2001	33,841 (18.1%)	257,614 (20.4%)	158,424 (18%)
2002	51,903 (17%)	-	-
2003	59,952 (15%)	297,402 (15%)	159,749 (12.9%)
2004	53,109 (11.8%)	-	-
2005	29,864 (21.4%)	308,175 (26.2%)	139,895 (20.8%)
2006	34,316 (19.7%)	-	-
2007	34,994 (14%)	232,035 (13.9%)	192,306 (17.5%)
2008	26,881 (22.8%)	-	-
2009	68,395 (13.8%)	752,651 (30.3%)	573,603 (28.6%)
2010	86,725 (13.8%)	-	-
2011	93,743 (14.1%)	500,975 (13.6%)	348,035 (17.7%)
2012	63,768 (14.8%)	-	-
2013	48,553 (16.2%)	506,362 (14.8%)	337,992 (15.2%)
2014	69,665 (14.3%)	-	-
2015	88,482 (15.9%)	253,932 (10.5%)	196,555 (12%)
2016	83,887 (17.2%)	-	-
2017	39,575 (10.1%)	107,324 (12.8%)	56,199 (11.7%)
2018	23,857 (12.1%)	-	-
2019	14,933 (18.5%)	181,581 (21.8%)	127,118 (24.7%)
2020	19,459 (21.8%)	-	-
2021	30,830 (16.2%)	174,414 (8.8%)	90,914 (8.7%)
2022	23,393 (15.9%)	-	-
2023	30,802 (20.9%)	231,185 (12.6%)	138,683 (12.1%)

Table 2.11. Values for parameters estimated outside the GOA Pacific cod assessment model.

Parameter	Value
Ageing error SD at age-0	0.11
Ageing error SD at age-10	1.13
Ageing bias at age-0	1.31
Ageing bias at age-10	2.17
Weight-length coefficient	3.40E-06
Weight-length exponent	3.27
Length at 50% maturity	53.7
Slope of maturity	-0.27

Table 2.12. Number of parameters (categorized by parameter type) for the author's recommended model.

	Parameter	Number
Recruitment/Initial abundance		--
	Early Init Devs	10
	Early Rec Dev	1
	Main Rec Dev	47
	log(mean recruitment)	1
	1976 R reg.	1
Biology		--
	Growth (LVB)	5
	Natural Mortality	2
Catchability/Selectivity		--
	Survey catchability (trawl)	1
	Survey catchability (longline)	2
	Trawl survey selex	16
	Longline survey selex	5
	Trawl fishery selex	19
	Trawl fishery selex devs	39
	Longline fishery selex	15
	Longline fishery selex devs	24
	Pot fishery selex	8
	Total	196

Table 2.13. Comparison among alternative models negative log-likelihoods and mean ratios of input sample size (ISS) to effective sample size (ESS) for composition data (individual components within the component-type, i.e., 'Length composition', are shown in italics).

Component	19.1b-23	19.1b	19.1c	19.1d	19.1e	24.0
Total negative log-likelihood	2930.97	3079.77	2919.92	2835.91	2838.29	2069.52
Survey indices	-3.32	-5.35	-10.25	-11.72	-2.11	-0.56
Bottom trawl survey index	*-5.58*	*-6.41*	*-8.5*	*-8.87*	*-6.43*	*-6.28*
Longline survey index	*2.26*	*1.06*	*-1.76*	*-2.84*	*4.32*	*5.72*
Length composition	1817.93	1852.35	1707.83	1699.21	1691.55	1341.35
Trawl fishery length composition	*578.07*	*604.67*	*526.48*	*521.45*	*534.29*	*435.34*
Longline fishery length composition	*330.22*	*340.08*	*320.17*	*324.87*	*349.05*	*259.49*
Pot fishery length composition	*453.49*	*453.37*	*420.07*	*424.38*	*370.5*	*311.15*
Bottom trawl survey length composition	*189.42*	*186.43*	*192.64*	*179.44*	*184.5*	*157.12*
Longline survey length composition	*266.73*	*267.81*	*248.47*	*249.07*	*253.21*	*178.25*
Conditional age-at-length	1101.99	1227.04	1215.75	1142.22	1142.58	721.69
Trawl fishery CAAL	*156.73*	*190.28*	*212.84*	*200.5*	*197.52*	*122.29*
Longline fishery CAAL	*246.39*	*262.61*	*244.52*	*225.12*	*227.75*	*127.02*
Pot fishery CAAL	*192.5*	*200.1*	*189.53*	*178.19*	*179.75*	*98.15*
Bottom trawl survey CAAL	*506.37*	*574.04*	*568.86*	*538.41*	*537.57*	*374.24*
Parameter deviations and priors	13.74	5.72	6.57	6.18	6.25	7.03
Recruitment deviations	*3.16*	*-5*	*-3.62*	*-4.09*	*-3.94*	*-2.62*
Initial Regime (InitEQ_Regime)	*3.09*	*3.07*	*2.72*	*2.85*	*2.83*	*2.75*
Parameter priors	*1*	*1.15*	*1.33*	*1.31*	*1.28*	*1.17*
Selectivity deviations	*6.5*	*6.49*	*6.15*	*6.11*	*6.07*	*5.74*
Length composition mean ISS/ESS	0.35	0.35	0.33	0.33	0.33	1.41
Trawl fishery	*0.35*	*0.37*	*0.33*	*0.33*	*0.33*	*1.43*
Longline fishery	*0.26*	*0.26*	*0.25*	*0.25*	*0.26*	*1.04*
Pot fishery	*0.5*	*0.48*	*0.46*	*0.47*	*0.45*	*2.06*
Bottom trawl survey	*0.32*	*0.31*	*0.31*	*0.3*	*0.31*	*1.18*
Longline survey	*0.35*	*0.35*	*0.32*	*0.32*	*0.33*	*1.31*
Conditional age-at-length mean ISS/ESS	0.35	0.37	0.29	0.32	0.32	0.83
Trawl fishery	*0.42*	*0.42*	*0.28*	*0.29*	*0.27*	*0.6*
Longline fishery	*0.4*	*0.41*	*0.27*	*0.27*	*0.28*	*0.66*
Pot fishery	*0.3*	*0.32*	*0.23*	*0.23*	*0.24*	*0.48*
Bottom trawl survey	*0.32*	*0.34*	*0.33*	*0.4*	*0.4*	*1.28*

Table 2.14. Key parameter estimates with standard deviations (SD) estimated from the author's recommended model.

Name		Value	SD
Biology		--	--
	Beginning of year length at age-1 (cm)	17.43	0.314
	Beginning of year length at age-10 (cm)	99.46	0.015
	Growth rate	0.19	0.002
	SD in length-at-age for age-1	4.01	0.187
	SD in length-at-age for age-10	8.99	0.345
	Natural mortality (2014-2016)	0.82	0.053
	Natural mortality (all years)	0.49	0.023
Recruitment/Abundance		--	--
	log(mean recruitment)	13.09	0.213
	1976 Regime adjustment	-0.68	0.19
Survey catchability		--	--
	Bottom trawl survey	1.28	0.125
	Longline survey	1.16	0.108
	Longline survey environmental coefficient	0.94	0.411

Table 2.15. Estimated female spawning biomass (t), standard deviation in spawning biomass (SD), and total biomass (t, age 0+) from the 2023 accepted assessment (denoted as 'Previous') and the author's recommended model (denoted as 'Current').

Year	Previous Sp.Bio	Previous SD[Sp.Bio]	Previous Tot.Bio.	Current Sp.Bio	Current SD[Sp.Bio]	Current Tot.Bio.
1977	86,688	15,935	272,441	82,030	18,624	263,078
1978	98,380	17,214	289,235	93,526	20,289	274,934
1979	97,764	16,847	330,096	91,392	19,576	306,236
1980	96,006	15,934	386,068	86,468	18,181	367,433
1981	111,789	18,228	418,191	100,306	21,344	404,096
1982	134,330	21,932	443,790	128,098	27,305	429,094
1983	145,538	23,772	485,373	138,760	29,352	464,679
1984	149,802	24,401	530,505	140,462	29,869	506,907
1985	168,636	25,105	587,423	156,013	31,122	571,308
1986	197,792	25,243	647,087	185,062	32,452	643,066
1987	220,914	24,054	698,761	213,389	33,340	705,665
1988	231,754	21,809	724,226	228,887	32,111	733,973
1989	243,438	19,800	733,137	243,403	30,496	738,995
1990	246,919	17,780	724,593	246,430	27,784	722,469
1991	230,939	15,820	694,233	227,089	24,492	680,037
1992	214,700	14,233	673,111	207,464	21,875	646,435
1993	201,964	13,093	647,461	190,501	19,878	613,356
1994	207,132	12,396	630,312	191,073	18,675	593,657
1995	211,697	11,446	601,250	193,714	17,173	562,274
1996	194,439	9,959	541,257	176,600	14,814	500,923
1997	169,657	8,367	489,569	152,166	12,234	448,772
1998	142,072	7,078	436,698	125,266	10,174	401,629
1999	125,720	6,289	391,753	109,867	9,138	365,436
2000	108,573	5,720	340,653	96,878	8,662	324,871
2001	95,796	5,163	311,814	88,328	8,115	306,187
2002	88,198	4,683	307,313	84,006	7,558	310,405
2003	82,954	4,429	300,217	82,664	7,400	311,203
2004	84,857	4,465	286,487	88,050	7,629	302,383
2005	82,850	4,406	263,066	87,817	7,438	280,139
2006	76,512	4,062	251,563	81,816	6,620	264,404
2007	68,076	3,711	258,308	72,894	5,786	261,734
2008	63,092	3,638	288,235	65,126	5,343	282,345
2009	67,152	3,999	329,541	64,976	5,702	320,013
2010	86,782	4,889	382,329	82,099	7,028	370,972
2011	99,472	5,860	404,507	94,676	8,458	394,847
2012	107,730	6,958	411,061	103,497	9,906	399,102
2013	114,120	8,126	433,983	110,310	11,073	414,288
2014	118,695	9,489	500,671	111,288	11,831	463,262
2015	86,062	5,895	394,061	79,084	7,540	362,383
2016	70,066	4,279	277,065	62,598	5,599	255,983
2017	53,898	3,435	177,128	48,276	4,390	161,564
2018	47,454	3,547	156,630	42,448	4,549	137,613
2019	48,468	3,492	168,218	41,786	4,293	146,791
2020	51,108	3,576	176,942	41,907	4,216	159,919
2021	59,590	3,794	186,120	50,256	4,537	178,117
2022	61,228	3,989	180,883	55,452	4,940	180,403
2023	55,170	4,034	173,300	54,246	5,070	174,394
2024	51,959	4,225	184,242	52,034	5,160	174,445
2025	-	-	-	46,920	5,643	177,497

Table 2.16. Age-0 recruitment (millions) and standard deviation of age-0 recruits by year from the 2023 accepted assessment (denoted as 'Previous') and the author's recommended model (denoted as 'Current'). Highlighted are the 1977 and 2012 year classes.

Year	Previous Recruitment	Previous SD[Rec]	Current Recruitment	Current SD[Rec]
1977	0.79	0.18	1.18	0.36
1978	0.4	0.11	0.39	0.14
1979	0.34	0.09	0.37	0.13
1980	0.42	0.11	0.65	0.21
1981	0.62	0.14	0.7	0.23
1982	0.63	0.15	0.94	0.3
1983	0.56	0.16	0.68	0.27
1984	0.54	0.15	0.9	0.3
1985	0.73	0.15	0.88	0.25
1986	0.52	0.11	0.61	0.17
1987	0.51	0.09	0.66	0.16
1988	0.55	0.09	0.66	0.16
1989	0.54	0.09	0.69	0.16
1990	0.7	0.11	0.78	0.17
1991	0.45	0.08	0.57	0.13
1992	0.41	0.07	0.43	0.1
1993	0.29	0.05	0.36	0.08
1994	0.33	0.05	0.42	0.09
1995	0.44	0.06	0.54	0.11
1996	0.29	0.04	0.4	0.08
1997	0.3	0.04	0.36	0.07
1998	0.24	0.03	0.34	0.07
1999	0.33	0.04	0.51	0.1
2000	0.38	0.05	0.5	0.1
2001	0.27	0.04	0.3	0.06
2002	0.18	0.03	0.26	0.05
2003	0.22	0.03	0.3	0.06
2004	0.26	0.03	0.3	0.06
2005	0.39	0.05	0.54	0.1
2006	0.58	0.07	0.74	0.13
2007	0.45	0.06	0.54	0.1
2008	0.57	0.07	0.79	0.15
2009	0.43	0.06	0.43	0.09
2010	0.42	0.06	0.52	0.11
2011	0.54	0.09	0.81	0.17
2012	1.05	0.17	1.18	0.27
2013	0.69	0.13	0.72	0.19
2014	0.27	0.06	0.24	0.07
2015	0.26	0.05	0.28	0.07
2016	0.26	0.04	0.28	0.06
2017	0.2	0.03	0.3	0.06
2018	0.16	0.02	0.21	0.04
2019	0.09	0.02	0.18	0.04
2020	0.15	0.03	0.19	0.04
2021	0.18	0.04	0.22	0.05
2022	0.24	0.06	0.21	0.07
2023	0.38	0.18	0.41	0.19
2024	-	-	0.49	0.24
Mean 1977 - (Final year - 2)	0.42		0.52	

Table 2.17. Estimated fishing mortality in terms of apical F and total exploitation for the author's recommended model.

Year	Sum Apical F	SD[F]	Total Exploitation
1977	0.012	0.003	0.009
1978	0.058	0.013	0.044
1979	0.077	0.018	0.049
1980	0.191	0.046	0.096
1981	0.123	0.027	0.089
1982	0.09	0.019	0.069
1983	0.115	0.025	0.079
1984	0.075	0.016	0.047
1985	0.064	0.016	0.025
1986	0.094	0.022	0.039
1987	0.066	0.016	0.047
1988	0.063	0.009	0.046
1989	0.078	0.012	0.059
1990	0.182	0.021	0.1
1991	0.212	0.024	0.112
1992	0.247	0.027	0.125
1993	0.185	0.019	0.092
1994	0.154	0.015	0.08
1995	0.23	0.021	0.123
1996	0.25	0.022	0.136
1997	0.34	0.029	0.172
1998	0.395	0.034	0.181
1999	0.534	0.048	0.226
2000	0.477	0.046	0.205
2001	0.386	0.037	0.168
2002	0.436	0.041	0.176
2003	0.421	0.039	0.169
2004	0.432	0.038	0.187
2005	0.394	0.04	0.17
2006	0.425	0.04	0.181
2007	0.487	0.041	0.2
2008	0.602	0.055	0.209
2009	0.506	0.047	0.166
2010	0.6	0.056	0.212
2011	0.584	0.057	0.216
2012	0.473	0.048	0.195
2013	0.388	0.041	0.166
2014	0.574	0.06	0.183
2015	0.771	0.074	0.219
2016	0.783	0.071	0.25
2017	0.737	0.08	0.302
2018	0.229	0.026	0.11
2019	0.237	0.025	0.107
2020	0.095	0.009	0.043
2021	0.24	0.022	0.108
2022	0.305	0.028	0.144
2023	0.256	0.025	0.125
2024	0.416	0.045	0.185

Table 2.18. Biological reference points from GOA Pacific cod SAFE documents for years 2002 – 2024, and recommended for 2025 from the author's recommended model (in italics).

Year	$SB_{100\%}$	$SB_{40\%}$	$F_{40\%}$	OFL_{y+1}	$maxABC_{y+1}$
2002	212,000	85,000	0.41	82,000	57,600
2003	226,000	90,300	0.35	88,300	52,800
2004	222,000	88,900	0.34	103,000	62,810
2005	211,000	84,400	0.31	91,700	58,100
2006	329,000	132,000	0.56	165,000	68,859
2007	259,000	103,000	0.46	136,000	68,859
2008	302,000	121,000	0.49	108,000	66,493
2009	255,500	102,200	0.52	88,000	55,300
2010	291,500	116,600	0.49	117,600	79,100
2011	256,300	102,500	0.42	124,100	86,800
2012	261,000	104,000	0.44	121,000	87,600
2013	234,800	93,900	0.49	111,000	80,800
2014	227,800	91,100	0.54	120,100	88,500
2015	316,500	126,600	0.5	155,400	102,850
2016	325,200	130,000	0.41	116,700	98,600
2017	196,776	78,711	0.53	105,378	88,342
2018	168,583	67,433	0.34	23,565	19,401
2019	172,240	68,896	0.29	23,669	19,665
2020	187,780	75,112	0.22	17,794	14,621
2021	180,111	72,045	0.33	28,977	23,627
2022	165,508	66,203	0.5	39,555	32,811
2023	167,414	66,966	0.41	29,737	24,634
2024	175,187	70,075	0.42	38,712	32,272
2025	*163,585*	*65,434*	*0.46*	*38,688*	*32,141*

Table 2.19. Results for the projection scenarios from the author's recommended model. Catch in tons, fishing mortality (F), and Female spawning stock biomass (SSB) in tons for the 7 standard projection scenarios.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Catch	-	-	-	-	-	-	-
2024	32,272	32,272	32,272	32,272	32,272	32,272	32,272
2025	32,141	32,141	17,068	24,894	0	38,688	32,141
2026	30,193	30,193	18,559	25,910	0	33,099	30,193
2027	39,135	39,135	22,193	34,345	0	42,529	47,236
2028	59,122	59,122	28,182	51,305	0	64,447	65,766
2029	71,693	71,693	34,726	59,975	0	81,372	81,288
2030	77,378	77,378	40,106	66,388	0	85,646	85,547
2031	80,257	80,257	43,764	70,070	0	87,493	87,442
2032	81,475	81,475	45,973	71,878	0	88,136	88,115
2033	81,994	81,994	47,328	72,767	0	88,370	88,361
2034	82,197	82,197	48,086	73,169	0	88,448	88,444
2035	82,275	82,275	48,495	73,347	0	88,474	88,473
2036	82,302	82,302	48,700	73,418	0	88,482	88,481
2037	82,312	82,312	48,803	73,446	0	88,484	88,484
F	-	-	-	-	-	-	-
2024	0.42	0.42	0.42	0.42	0.42	0.42	0.42
2025	0.46	0.46	0.23	0.34	0	0.57	0.46
2026	0.43	0.43	0.23	0.34	0	0.51	0.43
2027	0.49	0.49	0.23	0.4	0	0.57	0.61
2028	0.61	0.61	0.23	0.49	0	0.72	0.73
2029	0.65	0.65	0.23	0.49	0	0.81	0.81
2030	0.65	0.65	0.23	0.49	0	0.81	0.81
2031	0.65	0.65	0.23	0.49	0	0.81	0.81
2032	0.65	0.65	0.23	0.49	0	0.81	0.81
2033	0.65	0.65	0.23	0.49	0	0.81	0.81
2034	0.65	0.65	0.23	0.49	0	0.81	0.81
2035	0.65	0.65	0.23	0.49	0	0.81	0.81
2036	0.65	0.65	0.23	0.49	0	0.81	0.81
2037	0.65	0.65	0.23	0.49	0	0.81	0.81
SSB	-	-	-	-	-	-	-
2024	52,034	52,034	52,034	52,034	52,034	52,034	52,034
2025	46,920	46,920	46,920	46,920	46,920	46,920	46,920
2026	44,674	44,674	50,121	47,277	56,435	42,351	44,674
2027	50,138	50,138	58,758	53,782	70,845	47,229	50,138
2028	61,936	61,936	74,590	66,425	92,276	58,532	59,276
2029	72,038	72,038	92,772	78,210	117,044	67,594	67,574
2030	78,526	78,526	108,404	87,525	140,496	71,714	71,633
2031	82,012	82,012	119,484	93,154	159,756	73,627	73,578
2032	83,558	83,558	126,438	96,043	174,087	74,330	74,308
2033	84,258	84,258	130,941	97,548	185,302	74,604	74,595
2034	84,540	84,540	133,526	98,248	192,983	74,698	74,694
2035	84,651	84,651	134,940	98,564	197,984	74,730	74,729
2036	84,689	84,689	135,652	98,690	201,034	74,740	74,739
2037	84,702	84,702	136,008	98,741	202,897	74,742	74,742

Figures

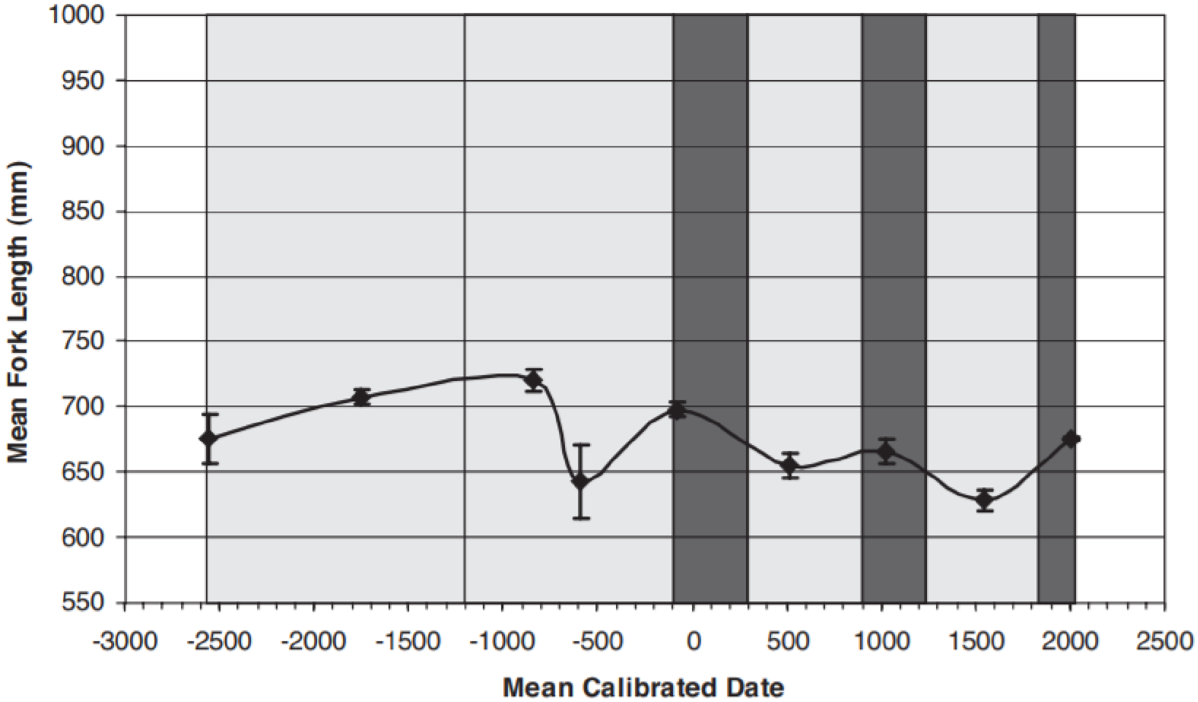

Figure 2.1. GOA Pacific cod mean lengths with climate reconstruction. The shaded boxes represent periods of significant changes in air temperature, sea surface temperature, storminess, and ocean circulation that drive ocean productivity. The lightly shaded boxes represent periods of cooler and stormier environments, which are generally more productive, while the darkly shaded boxes represent warmer and generally less productive environments. Dates are presented as calibrated means; (From Betts *et al.* 2011; Figure 11.4).

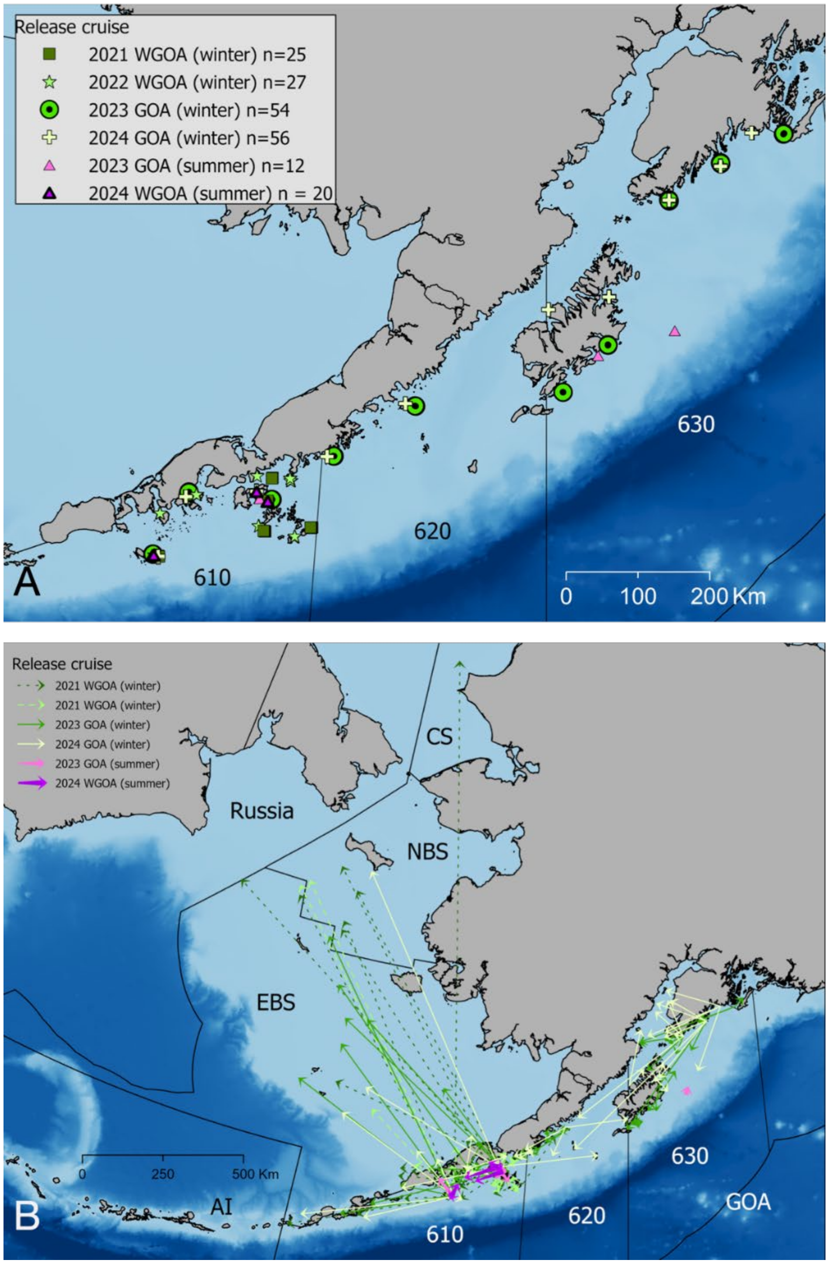

Figure 2.2 Pacific cod satellite tag A) release locations in Gulf of Alaska (GOA) management areas 610, 620, and 630 from 2021 – 2024 and B) pop-up locations from GOA satellite tag releases by region (AI = Aleutian Islands, EBS = Eastern Bering Sea, NBS = Northern Bering Sea, CS = Chukchi Sea).

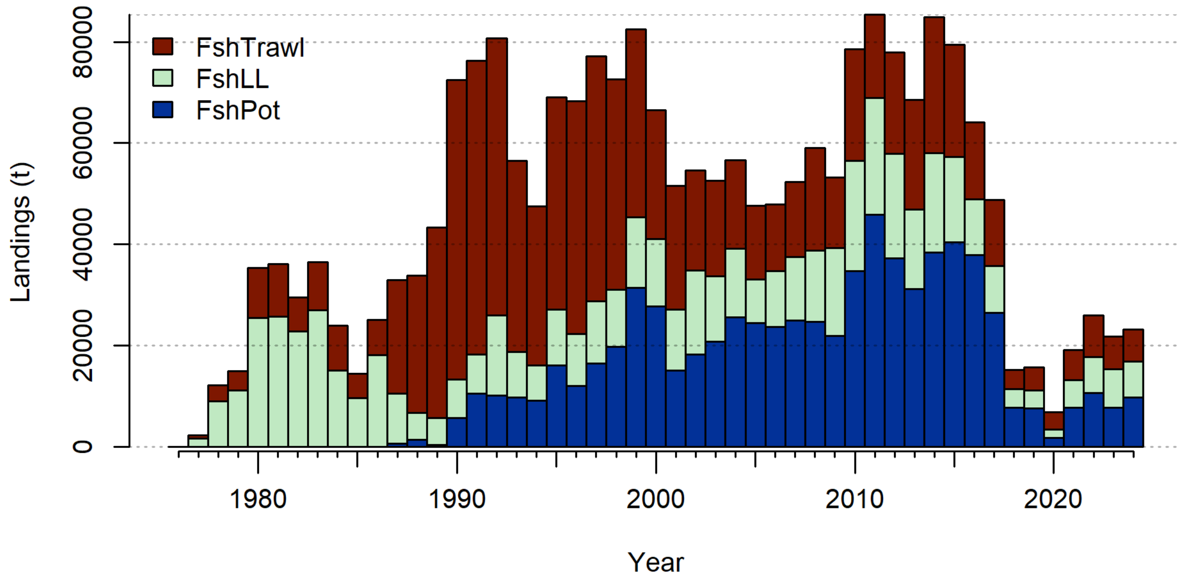

Figure 2.3. Commercial catch (mt) of Pacific cod in the GOA in trawl (FshTrawl), longline (FshLL), and pot (FshPot) gear from 1977-2024. Note that 2024 catch was through October 17.

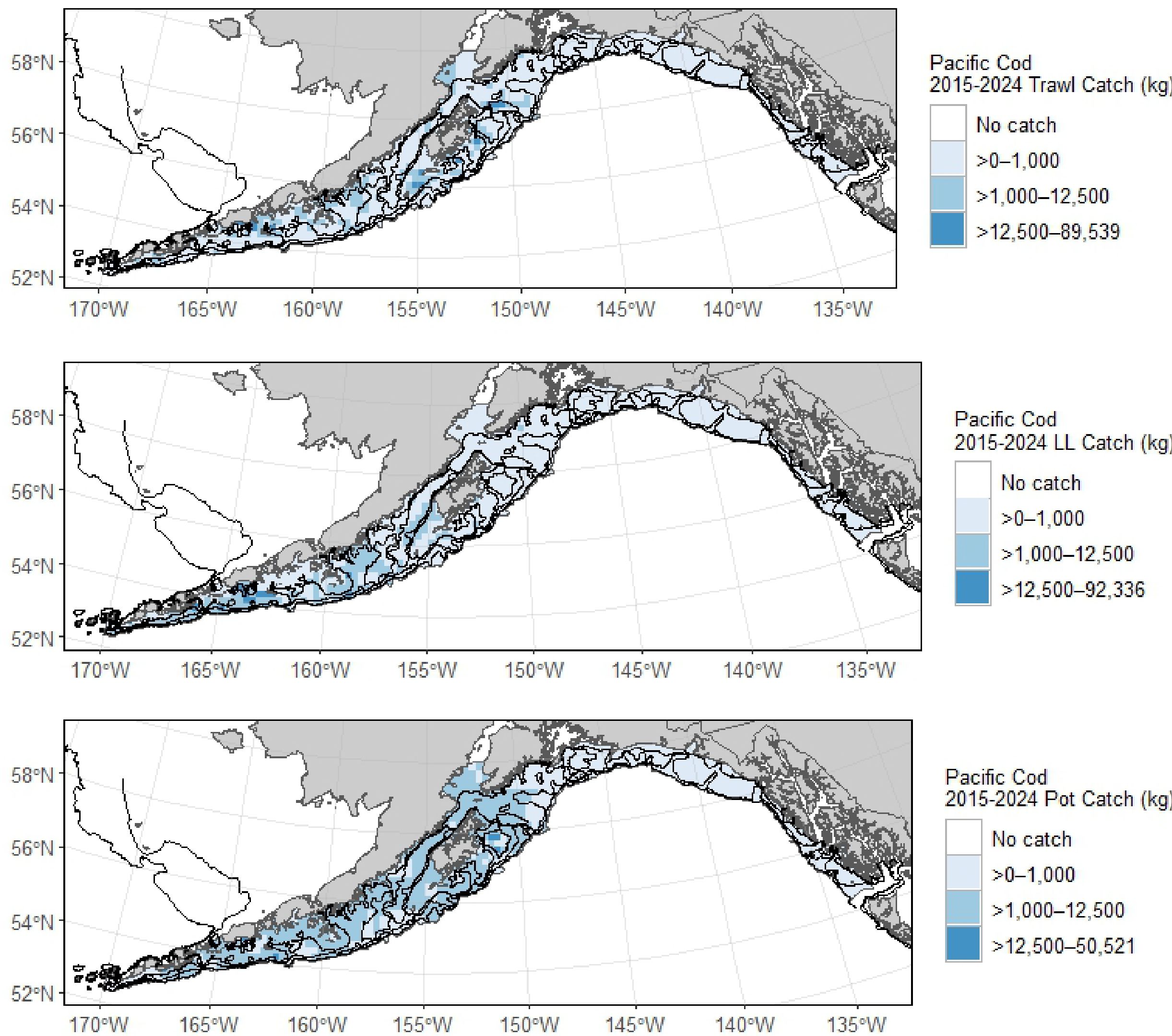

Figure 2.4. Commercial catch of Pacific cod in the GOA by 20km^2 grid for 2015-2024.

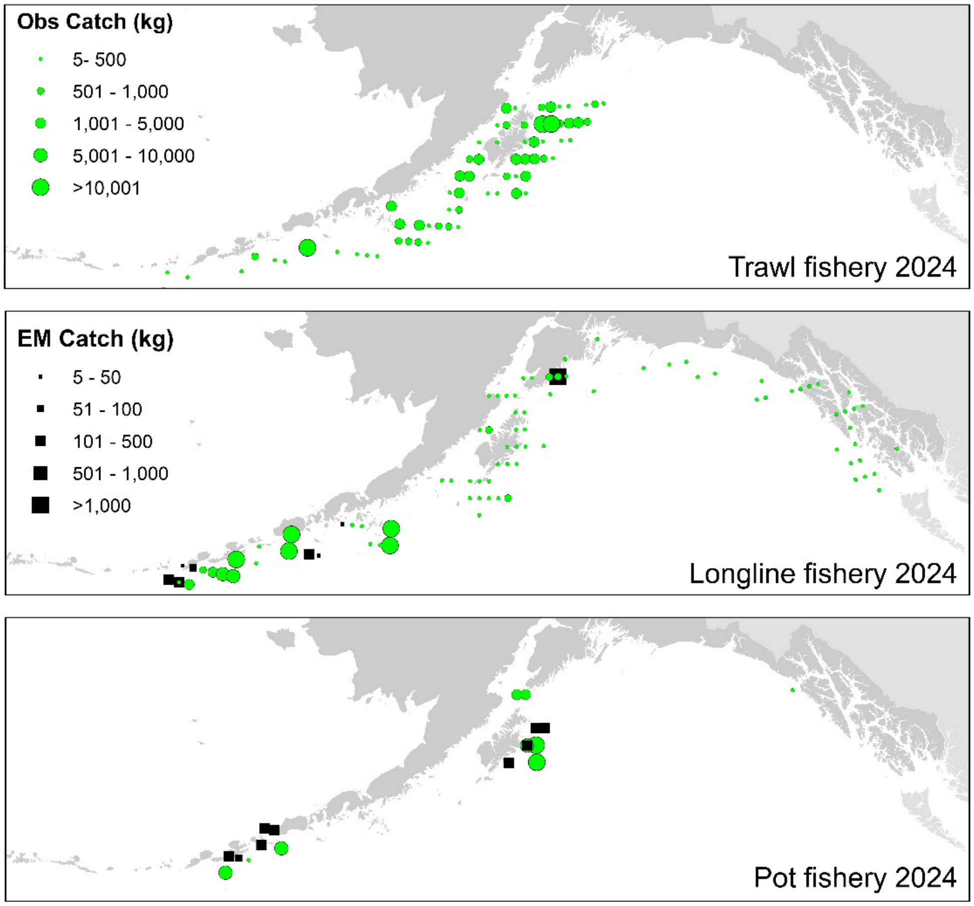

Figure 2.5. Observed (Obs) and electronic monitored (EM) commercial catch of Pacific cod in the GOA by 20 km^2 grid for 2023. These data include bycatch Pacific cod, but do not include trawl EM data as locations are not yet available.

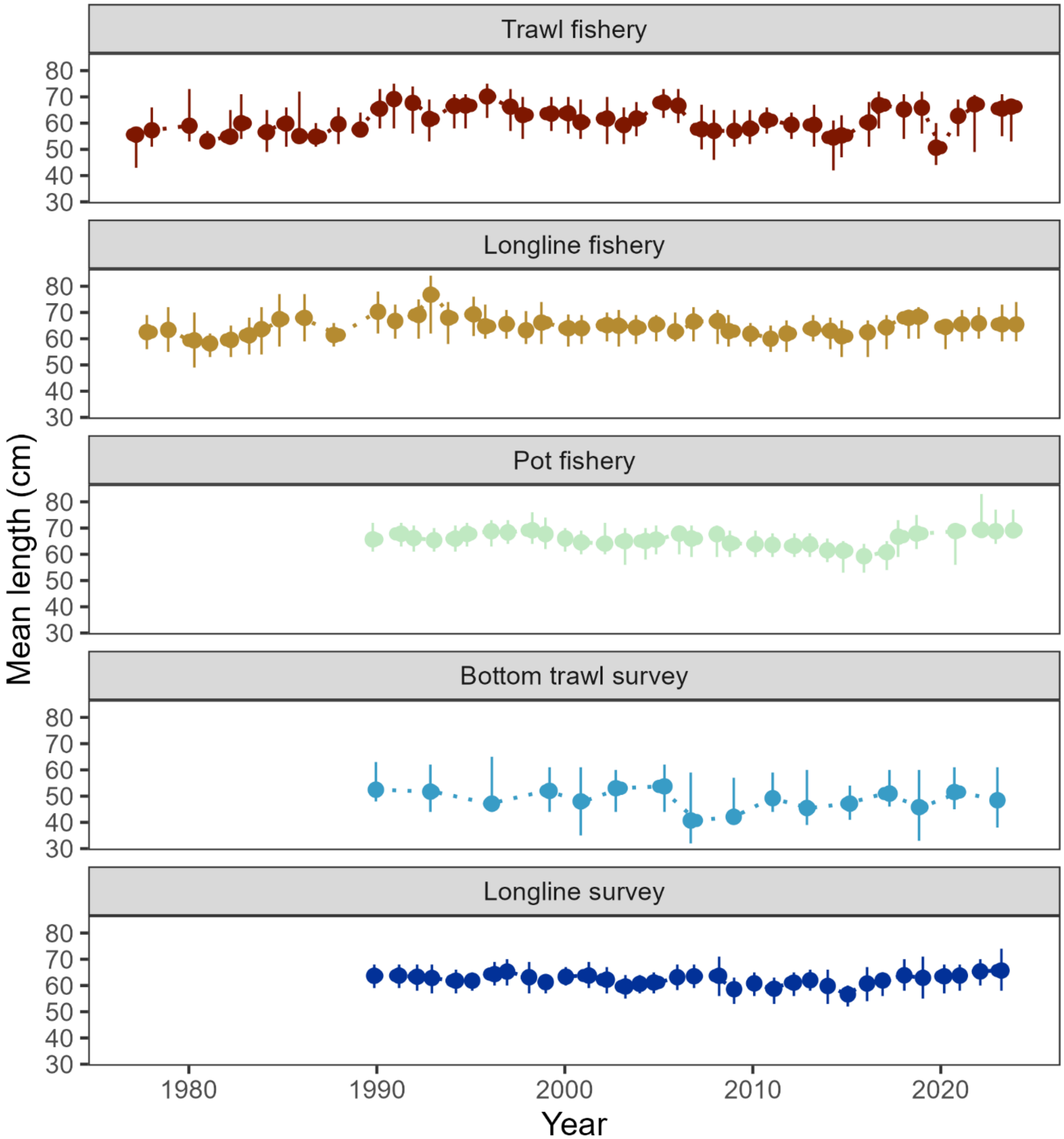

Figure 2.6. Mean length (in cm) observed in the fisheries and surveys used in the GOA Pacific cod assessment (with inter-quartile range in observed length included).

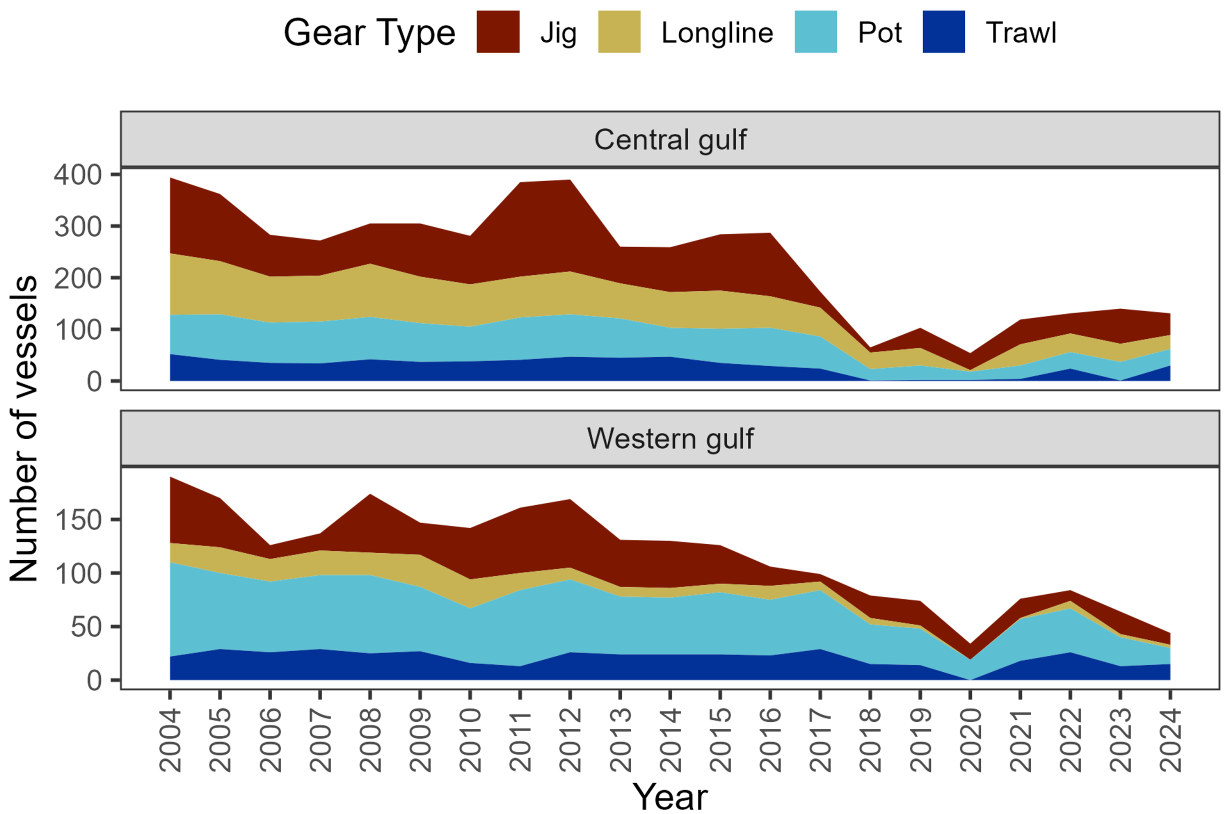

Figure 2.7. Vessel participation in the directed cod fishery by year, GOA sub-region, and gear type.

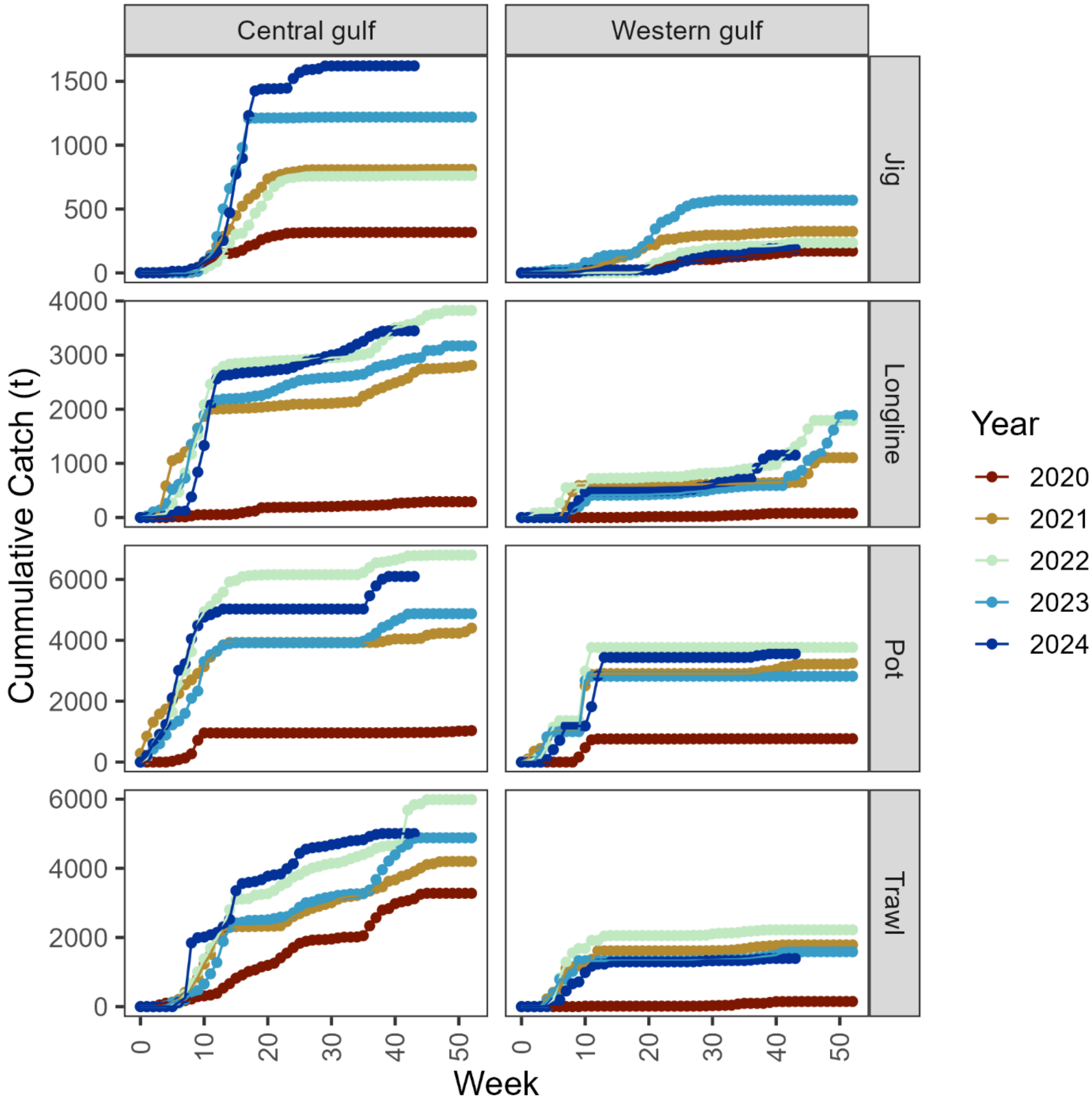

Figure 2.8. Cumulative catch week of the year for 2020-2024 by GOA sub-area and fleet (2024 catch through week 43).

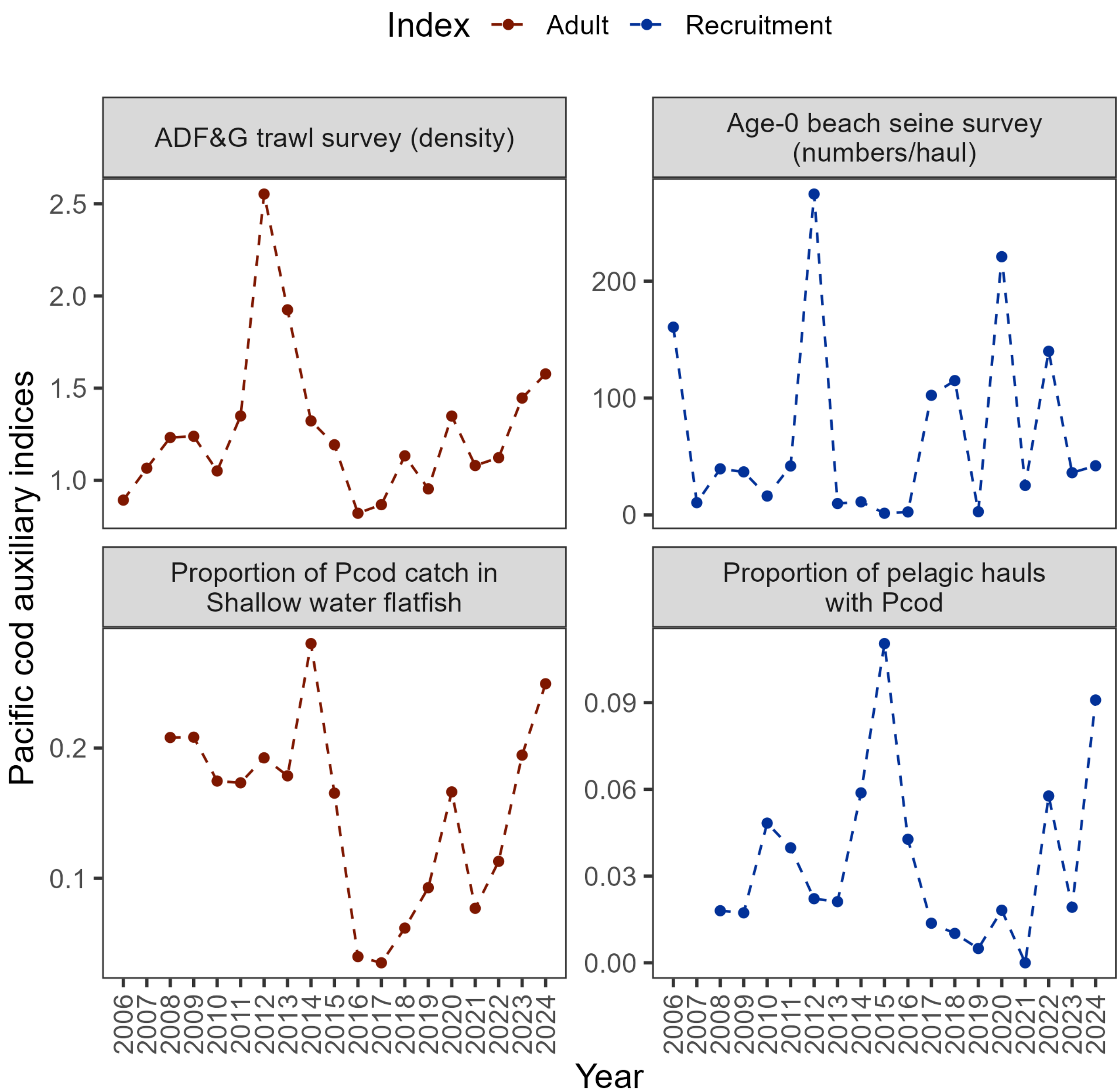

Figure 2.9. Auxiliary indices for GOA Pacific cod adult and recruitment abundance. ADFG bottom trawl survey delta-glm density (top left panel) and proportion of Pacific cod bycatch in the GOA shallow water flatfish fishery (bottom left panel) representing indices for adult abundance, and age-0 beach seine survey numbers per haul (top right panel) and proportion of pelagic trawls in the Central GOA A Season (January-April) walleye pollock fishery with Pacific cod present (bottom right panel) representing indices for recruitment.

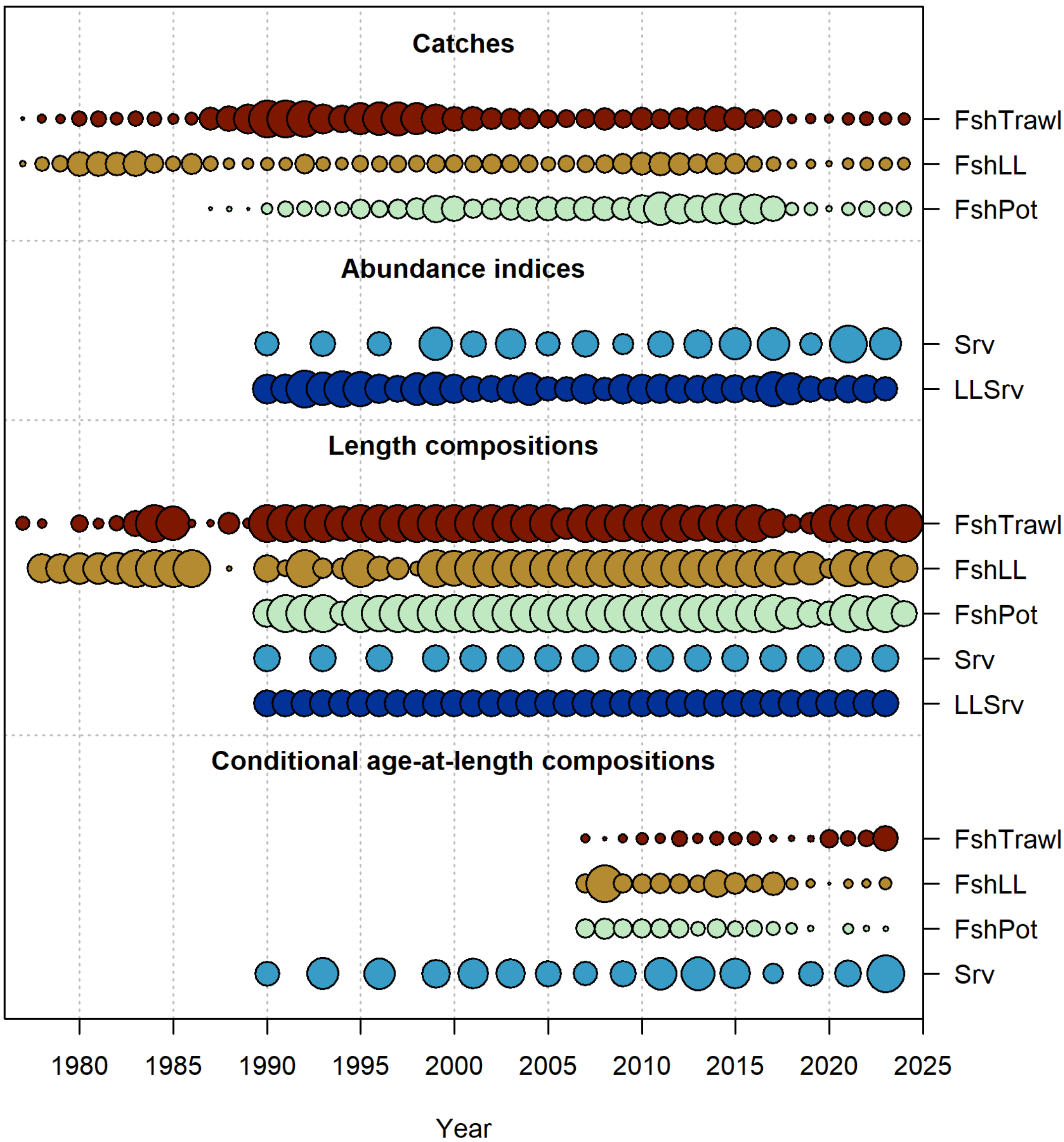

Figure 2.10. Data fit in the author's recommended model. Circles are proportional to total catch for catches, precision for indices and input sample size for compositions and length-at-age observations. Data source include fishery data from trawl (FshTrawl), longline (FshLL), and pot (FshPot) fisheries. Survey data include the AFSC longline (LLSrv) and bottom trawl (Srv) surveys. Note that since the circles are scaled relative to maximum within each type, the plots of scaling across dataset types should not be compared.

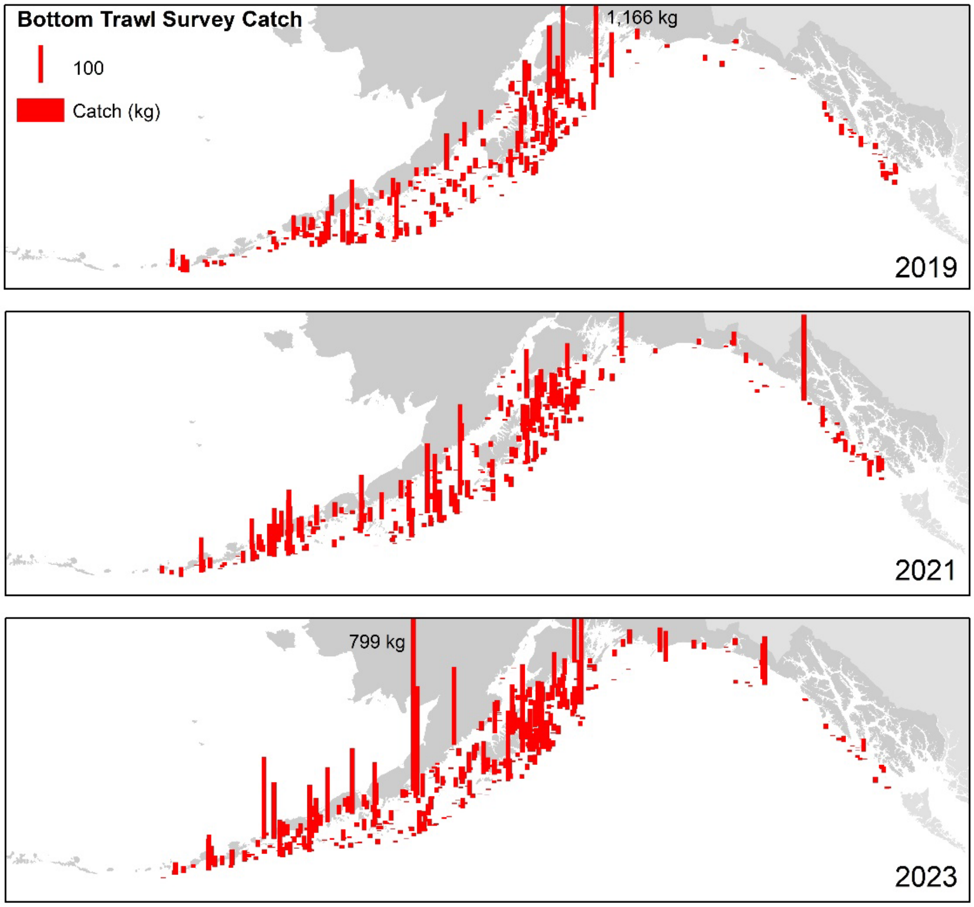

Figure 2.111. Distribution of AFSC bottom trawl survey catch (kg) of Pacific cod for 2019-2023.

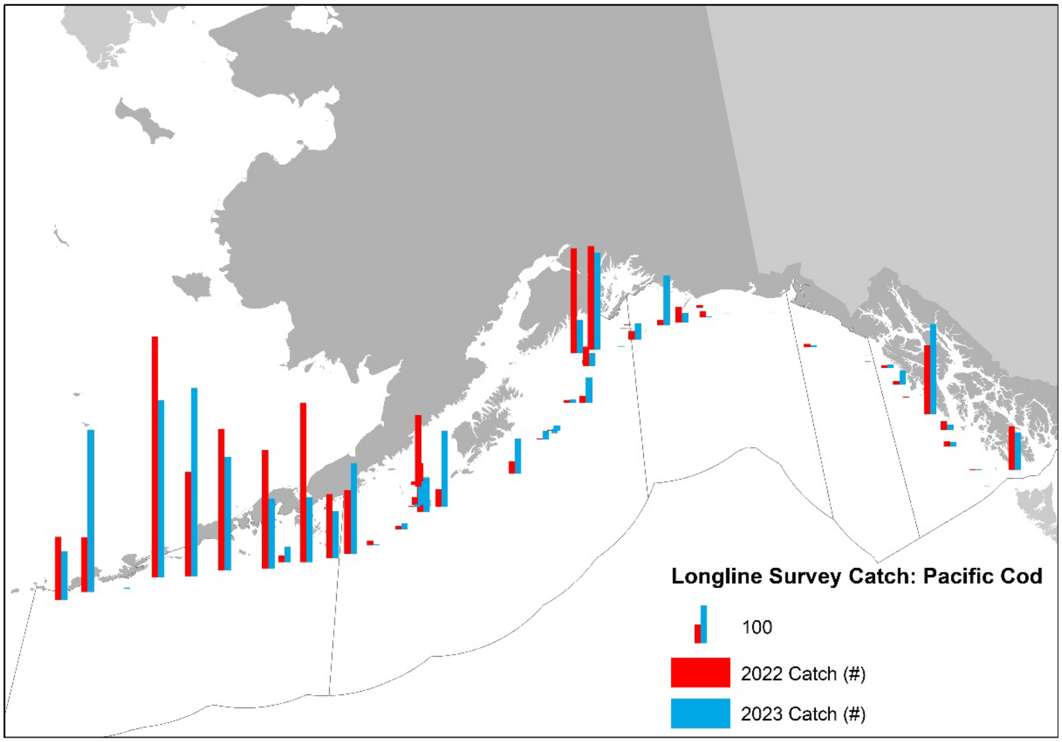

Figure 2.12. Distribution of AFSC longline survey catch (numbers) of Pacific cod in 2022 and 2023.

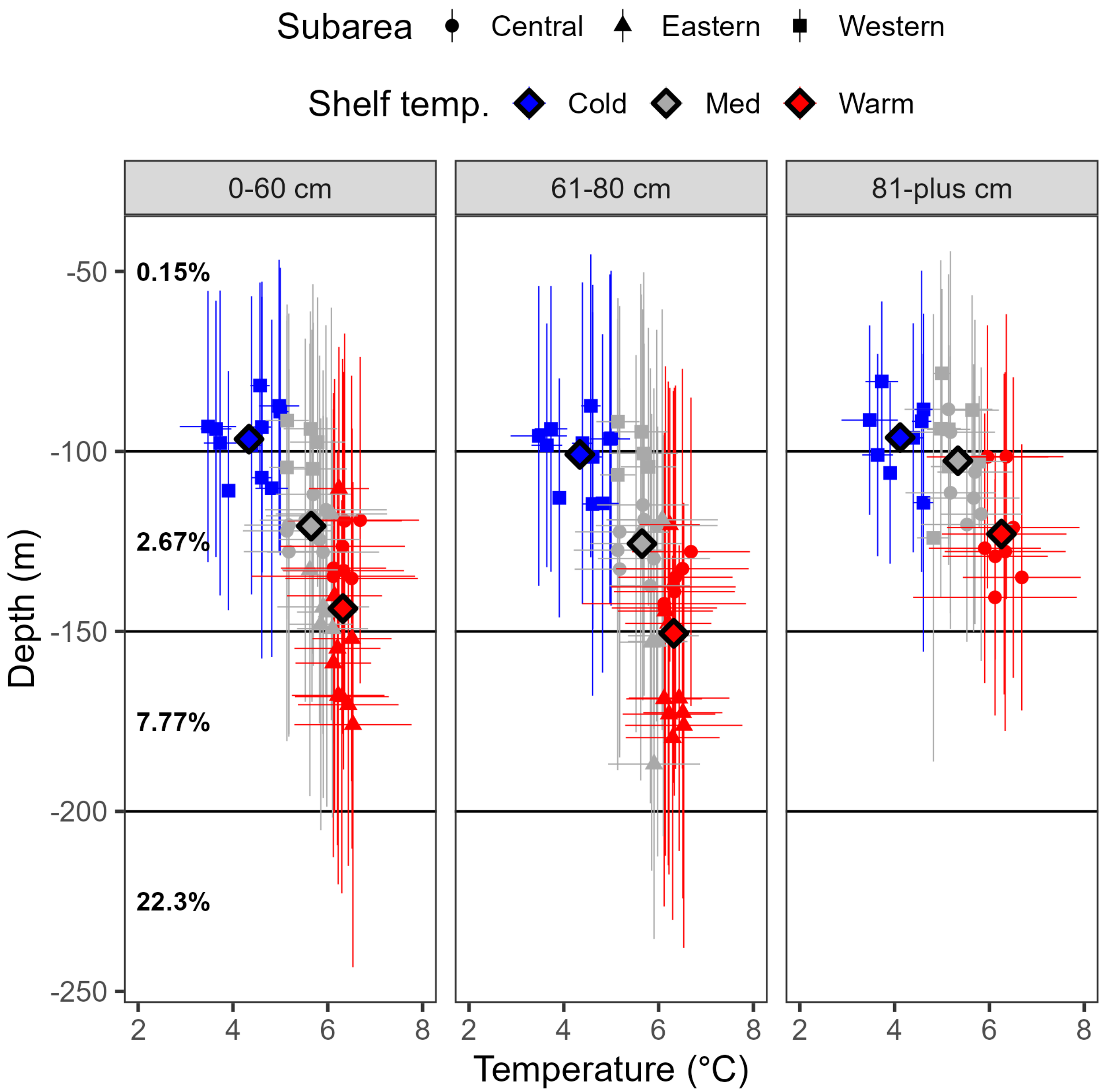

Figure 2.13. Area-weighted observed bottom temperature compared to CPUE-weighted depth of Pacific cod from the AFSC bottom trawl survey for different size classes. 'Cold', 'Med', and 'Warm' temperatures are defined as 33% percentiles of observed area-weighted bottom depths. Horizontal black lines indicate the depth strata for the AFSC longline survey that overlap with GOA Pacific cod depth distribution, and bold black text is the proportion of hatchis deployed by the AFSC longline survey in these depth strata.

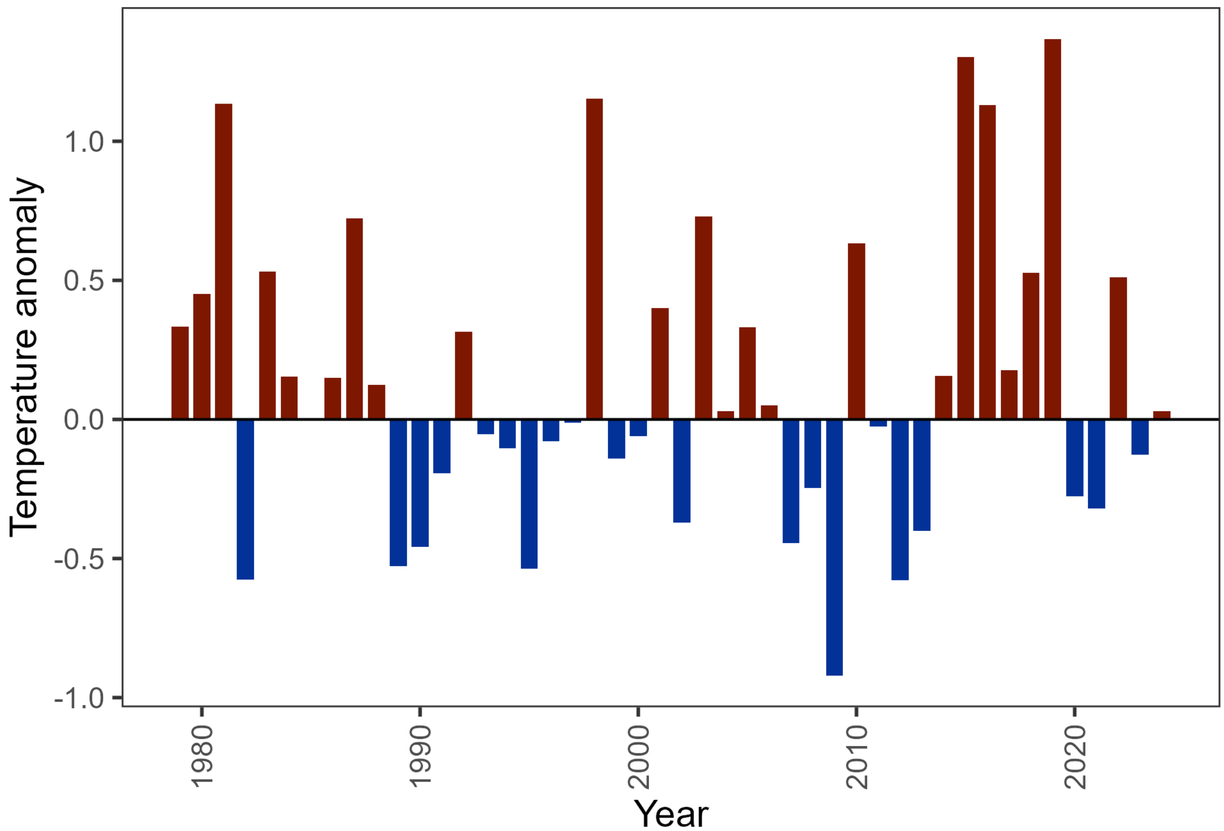

Figure 2.14. Climate Forcast System Reanalysis (CFSR) central GOA bottom temperatures anomailies at the AFSC bottom trawl survey mean depths for 0-20 cm Pacific cod in June used as a covariate to the AFSC longline survey catchability.

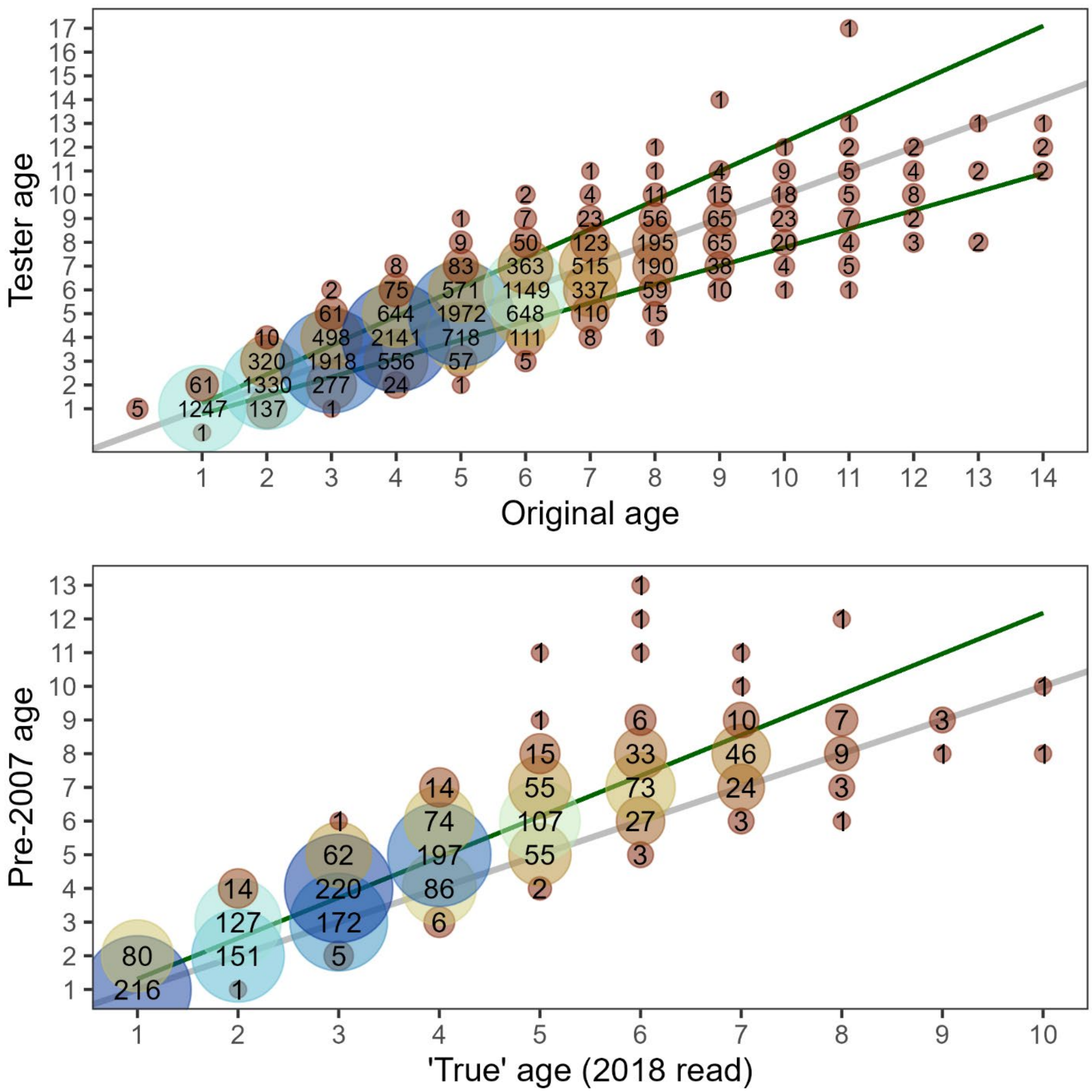

Figure 2.15. Reader-tester paired ageing data used to estimate ageing error (top panel) and otoliths read originally in 2007 that were reread in 2018 used to estimate ageing bias (bottom panel). Estimates of uncertainty in age reading (95% confidence intervals) and bias in ageing as estimated by the AgeingError R package are shown with green lines in each panel, one-to-one reference is shown by the grey line in each panel.

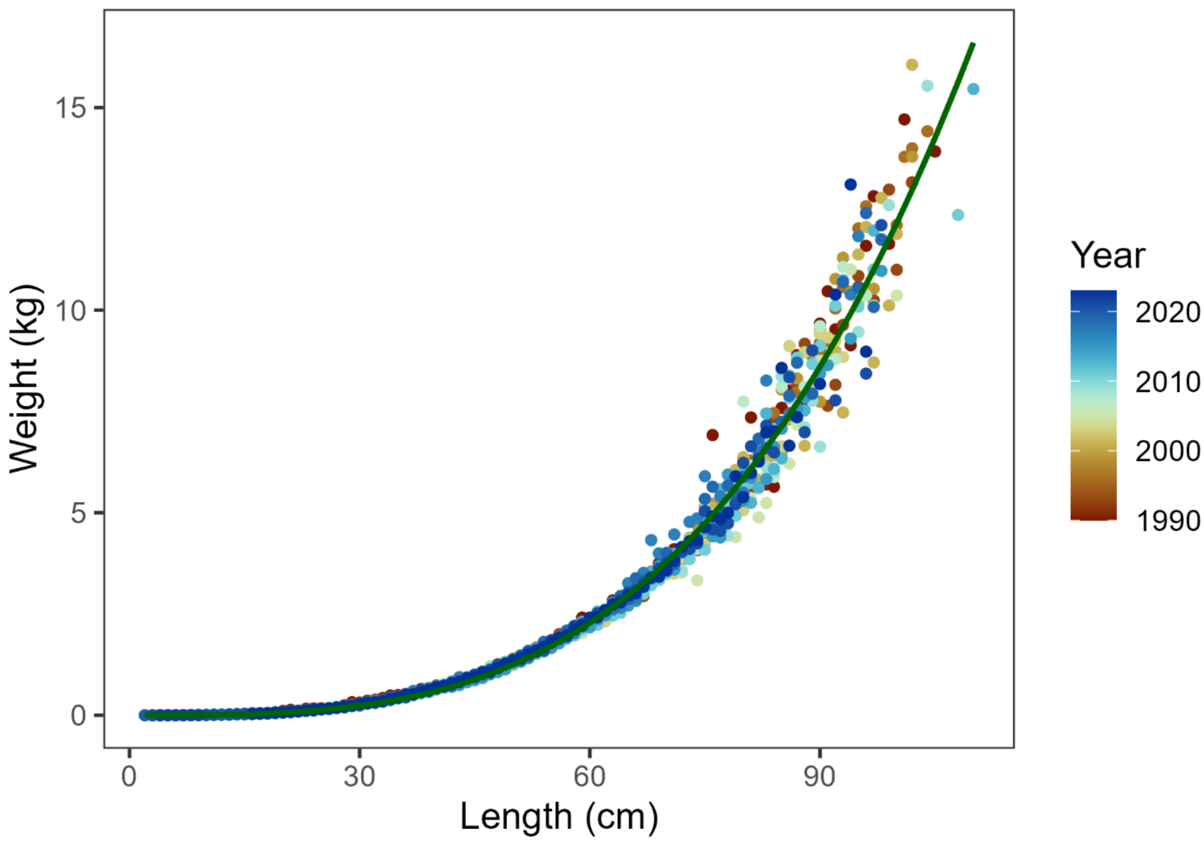

Figure 2.16. AFSC bottom trawl survey and age-0 beach seine survey observed weight-at-length (points) and fit used in the recommended assessment shown with the solid green line.

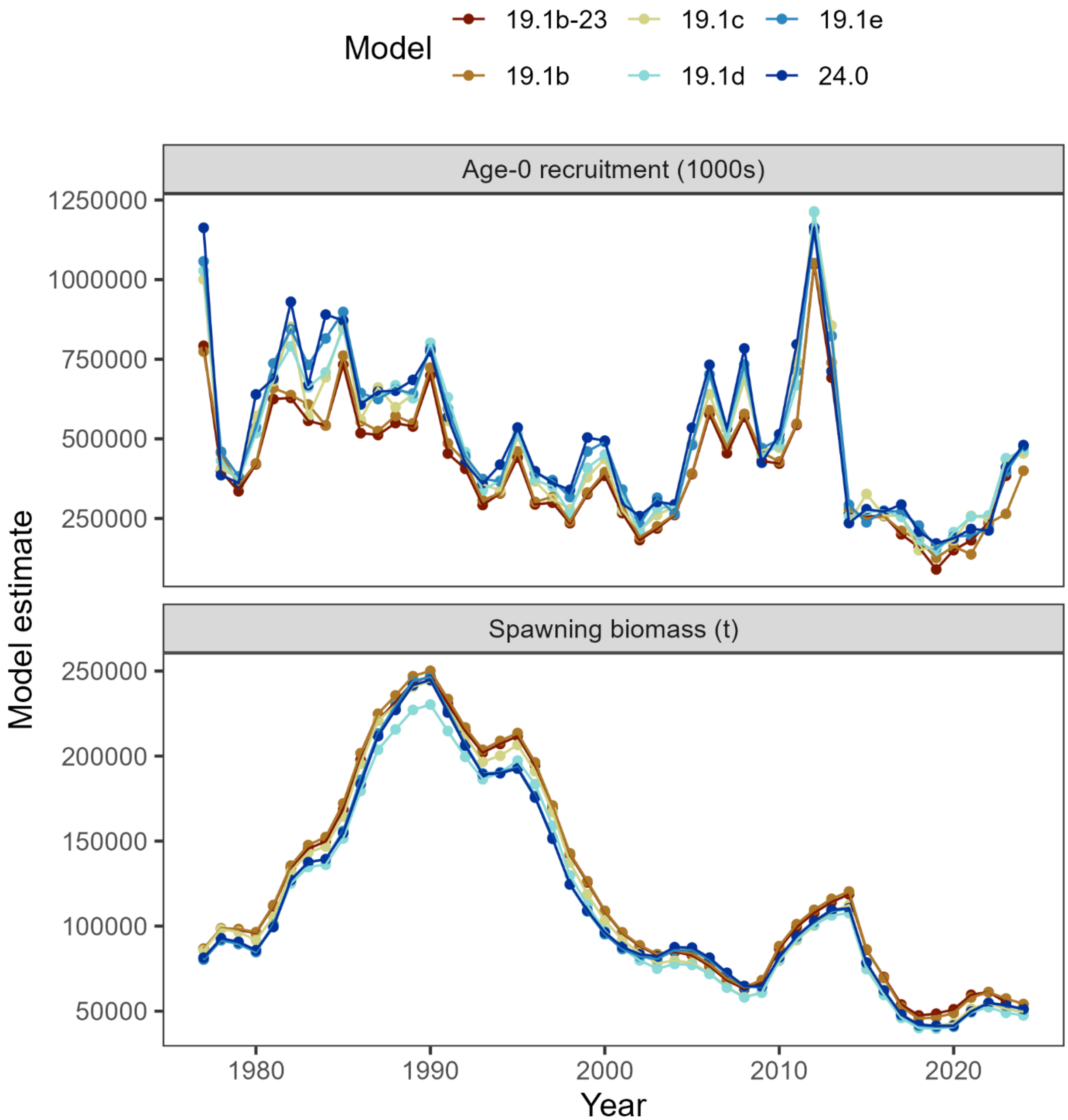

Figure 2.17. Comparison among alternative model estimates of age-0 recruitment (top panel) and spawning biomass (bottom panel).

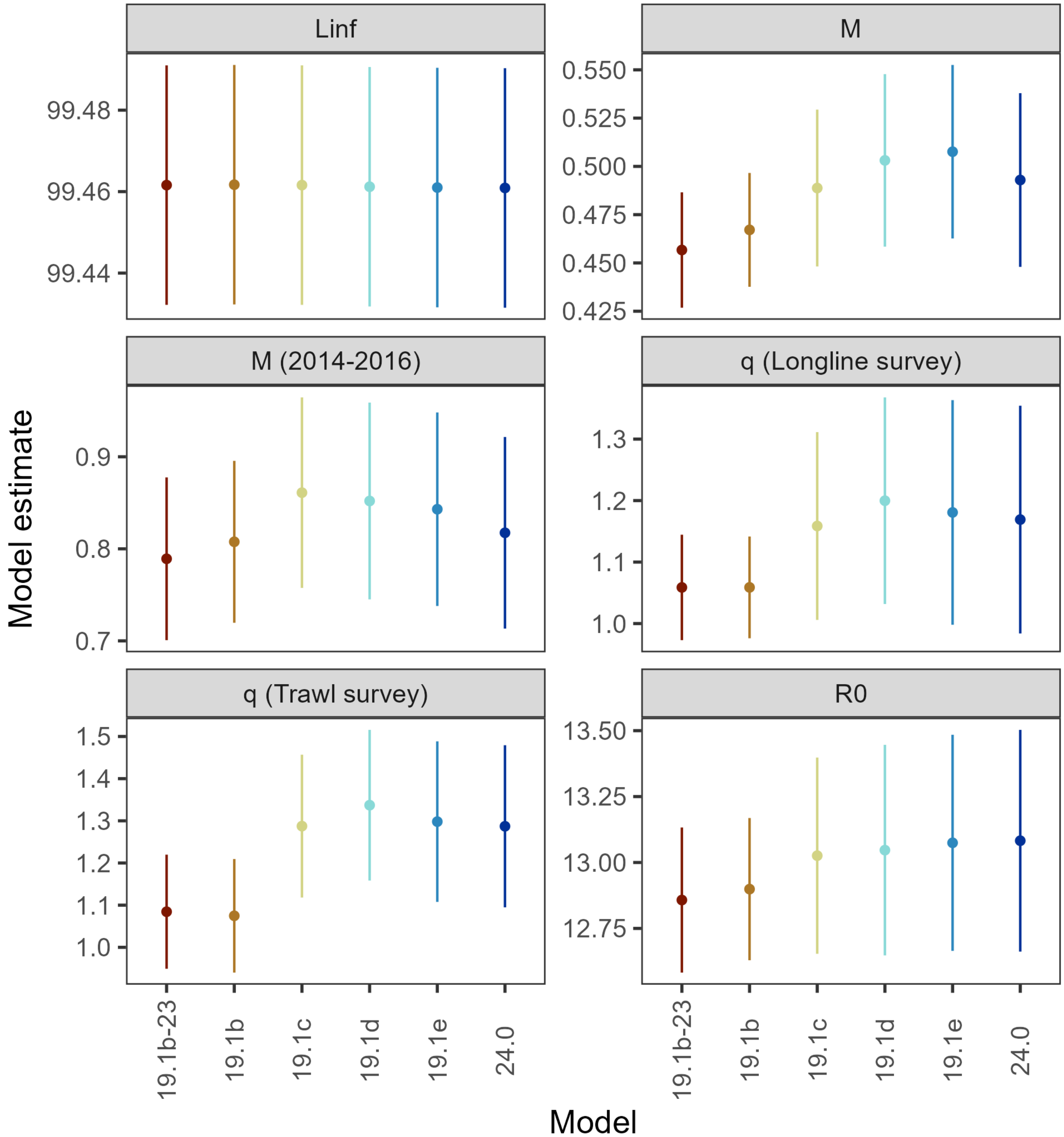

Figure 2.18. Comparison among alternative models of key parameter estimates with 95% confidence intervals.

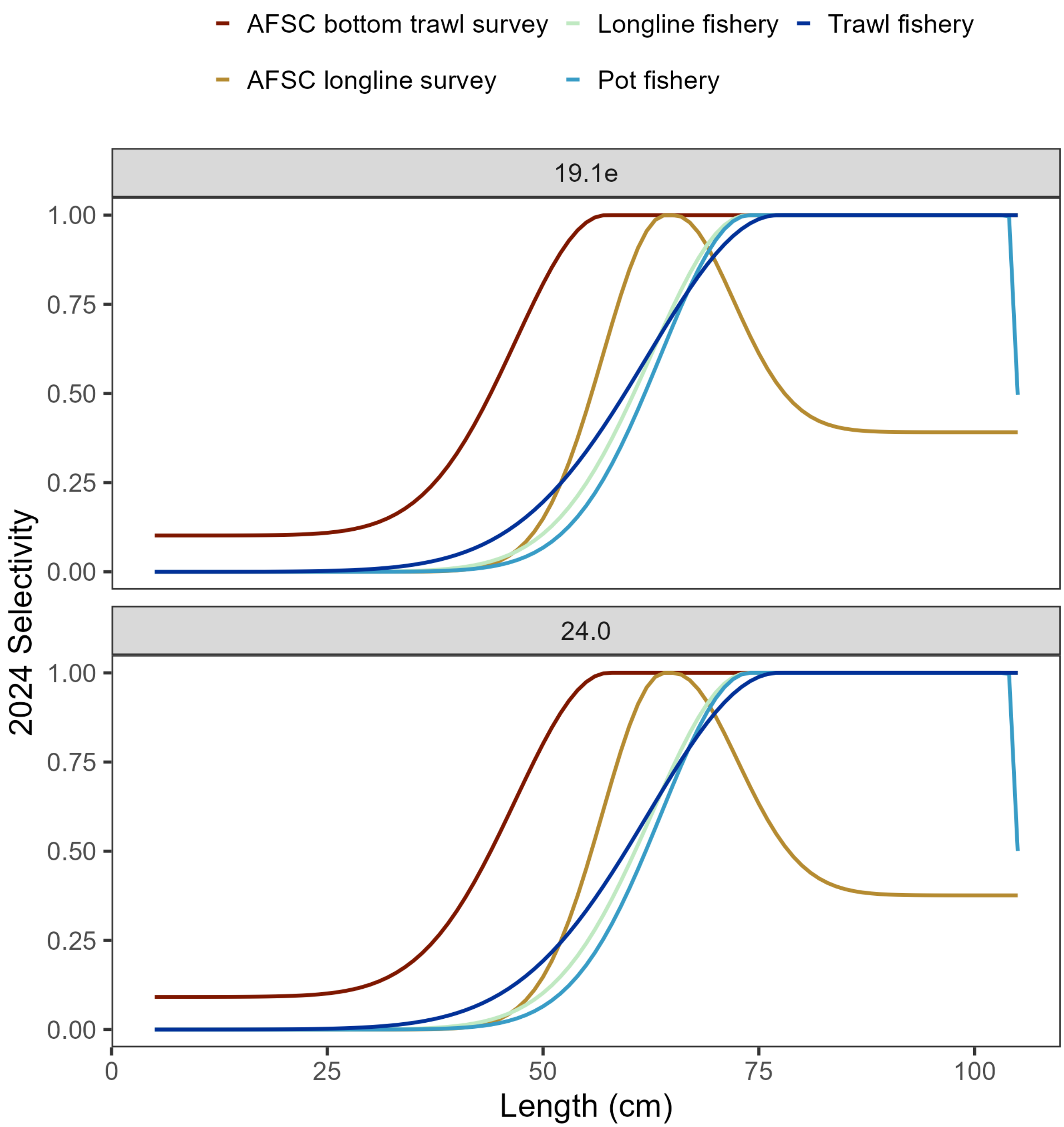

Figure 2.19. Comparison among alternative models estimates of current year selectivity with 1 cm length bins (19.1e) and 5 cm length bins (24.0).

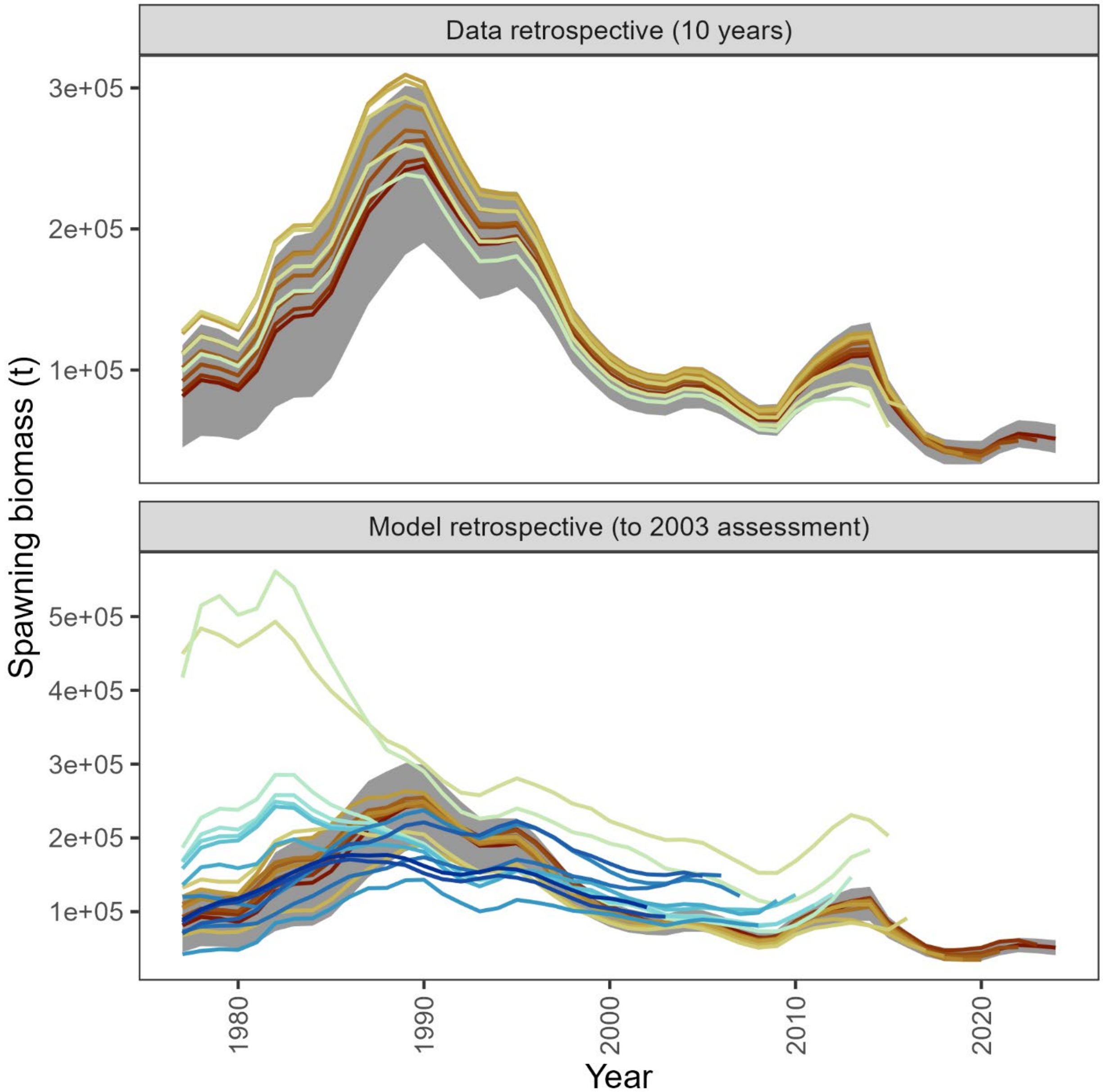

Figure 2.20. Retrospective analysis of spawning biomass upon removing data from the author's recommended model (top panel) and in comparison to previously accepted models (bottom panel). The shaded region is the 95% confidence intervals from the author's recommended model.

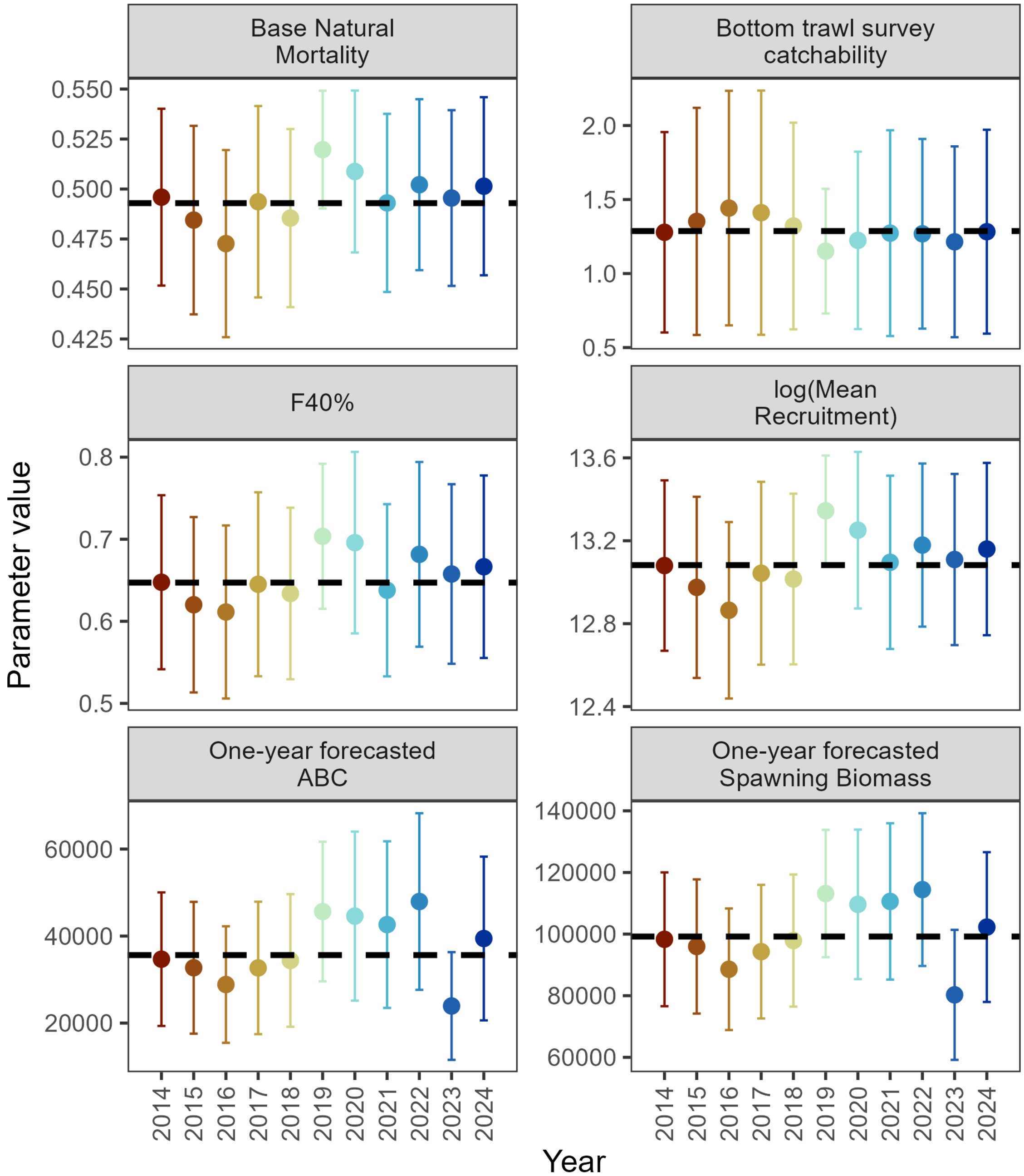

Figure 2.21. Leave-one-out analysis showing parameters and derived quantities as one year of data were removed from the model fit of the author's recommended model. The horizontal dashed line denotes the author's recommended model's estimate.

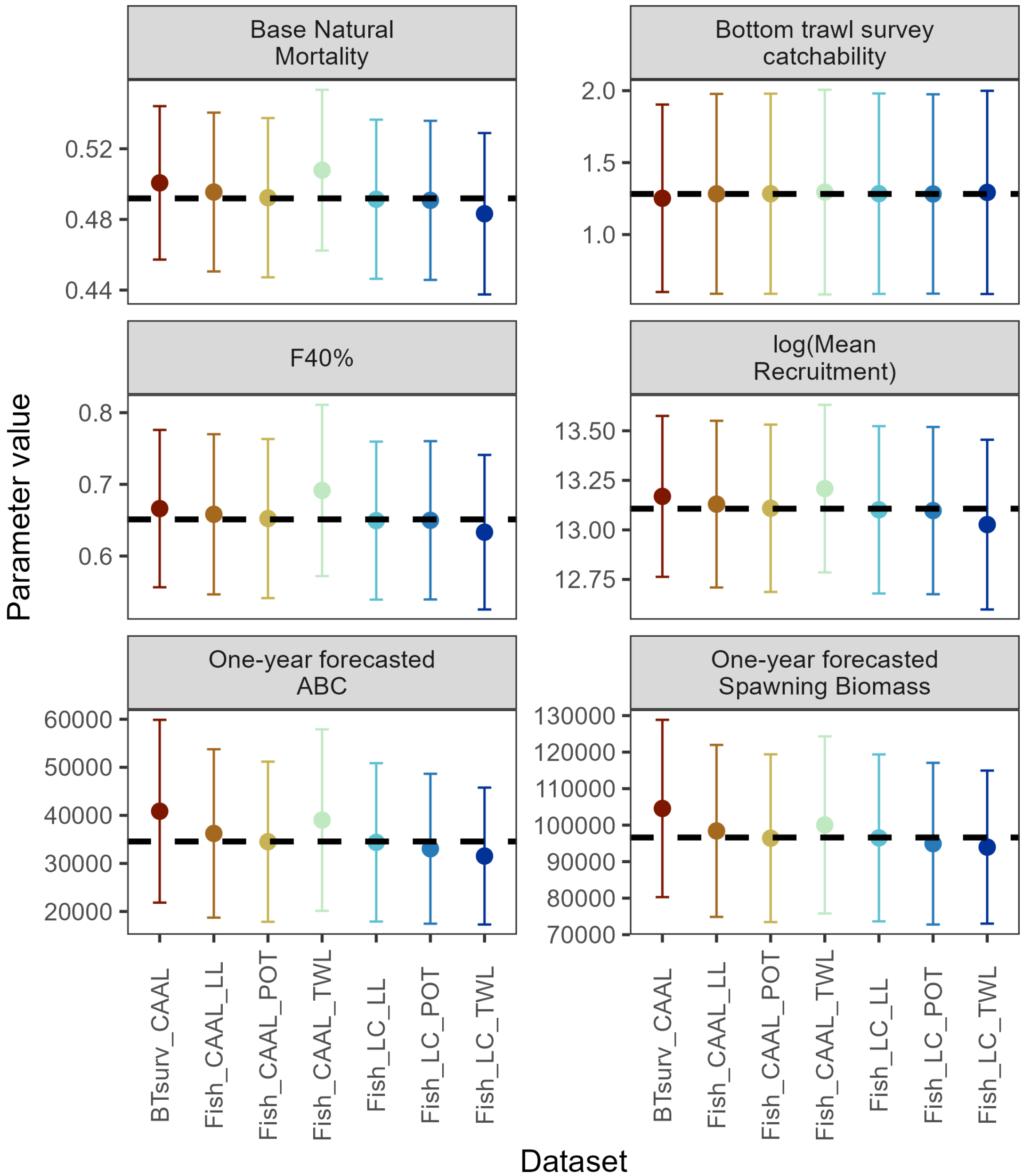

Figure 2.22. Add-one-in analysis showing parameters and derived quantities as each data source were added to the author's recommended model. CAAL denotes conditional age-at-length data, LC denotes length comp data, and Indx denotes index data from the bottom trawl survey (BTsurv), longline survey (LLsurv) and fisheries (denoted with gear type). The horizontal dashed line denotes the author's recommended model's estimate with only catch data updated.

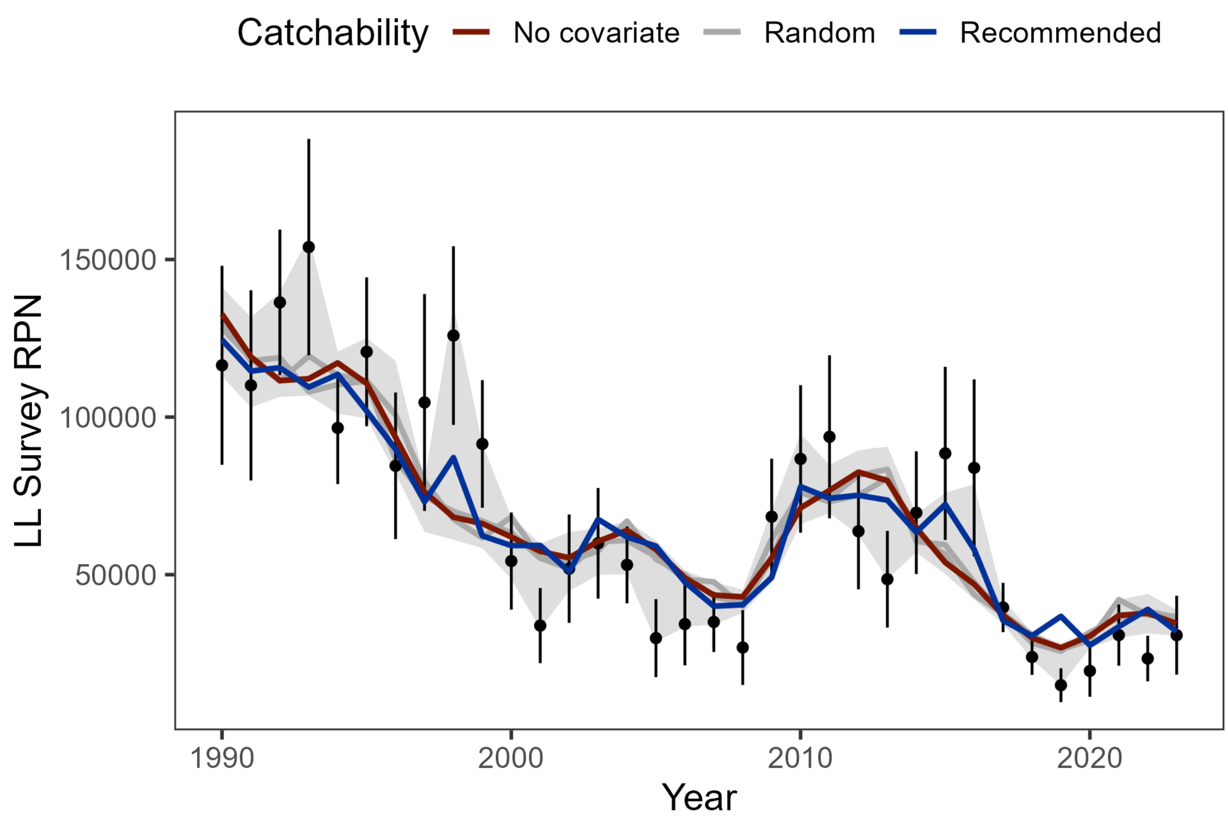

Figure 2.23. AFSC longline survey catchability environmental link analysis where 'No covariate' is the author's recommended model with the environmental link parameter turned off, 'Random' is when white-noise was generated and used in place of the CFSR index (two random draws are shown in grey as an example, and the range of model fits with random white noise is shown in the grey shaded region), and 'Recommended' is the author's recommended model using the CFSR index as a link to survey catchability.

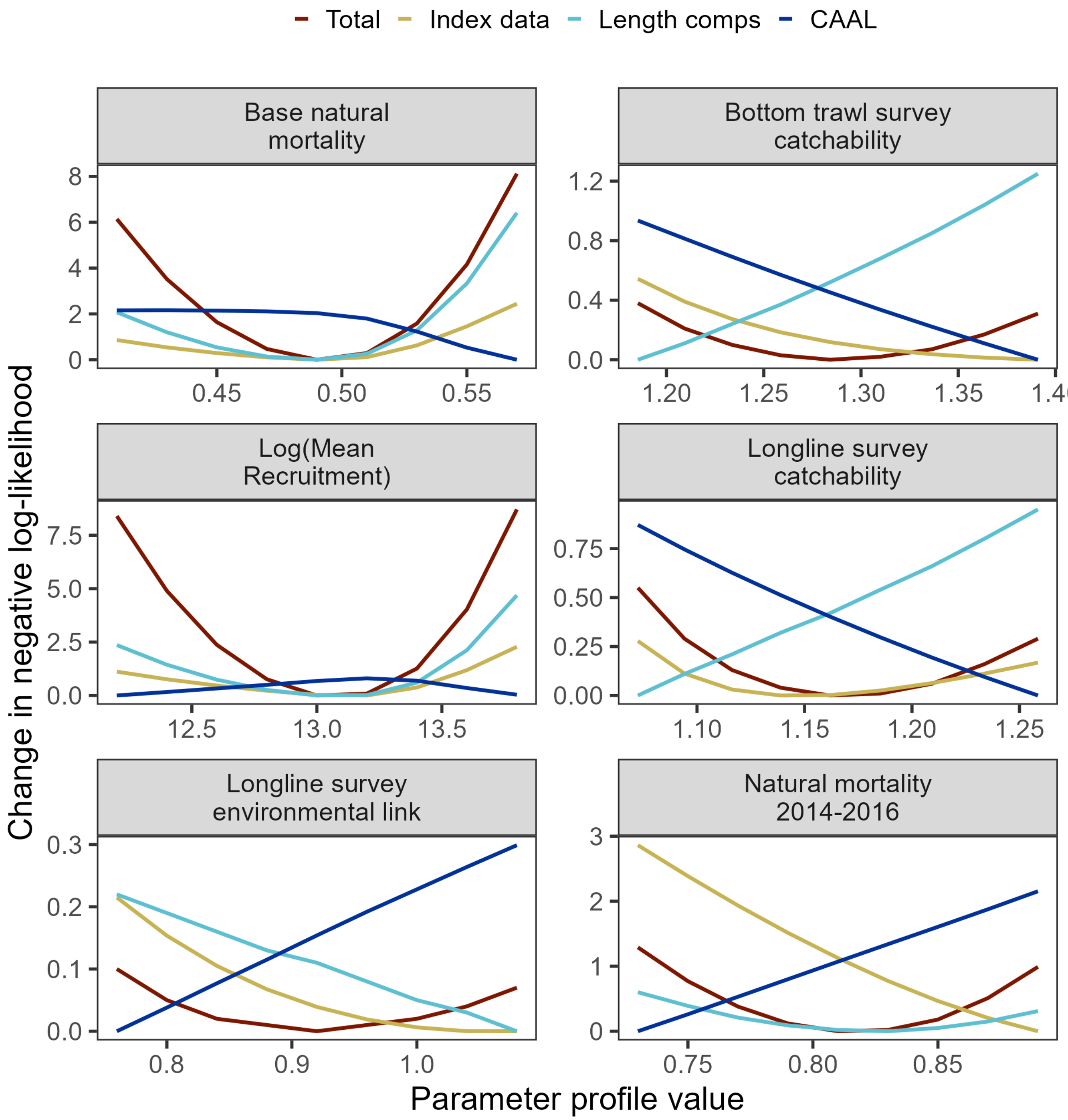

Figure 2.24. Negative log-likelihood profiles for key parameters estimates in the author's recommended model.

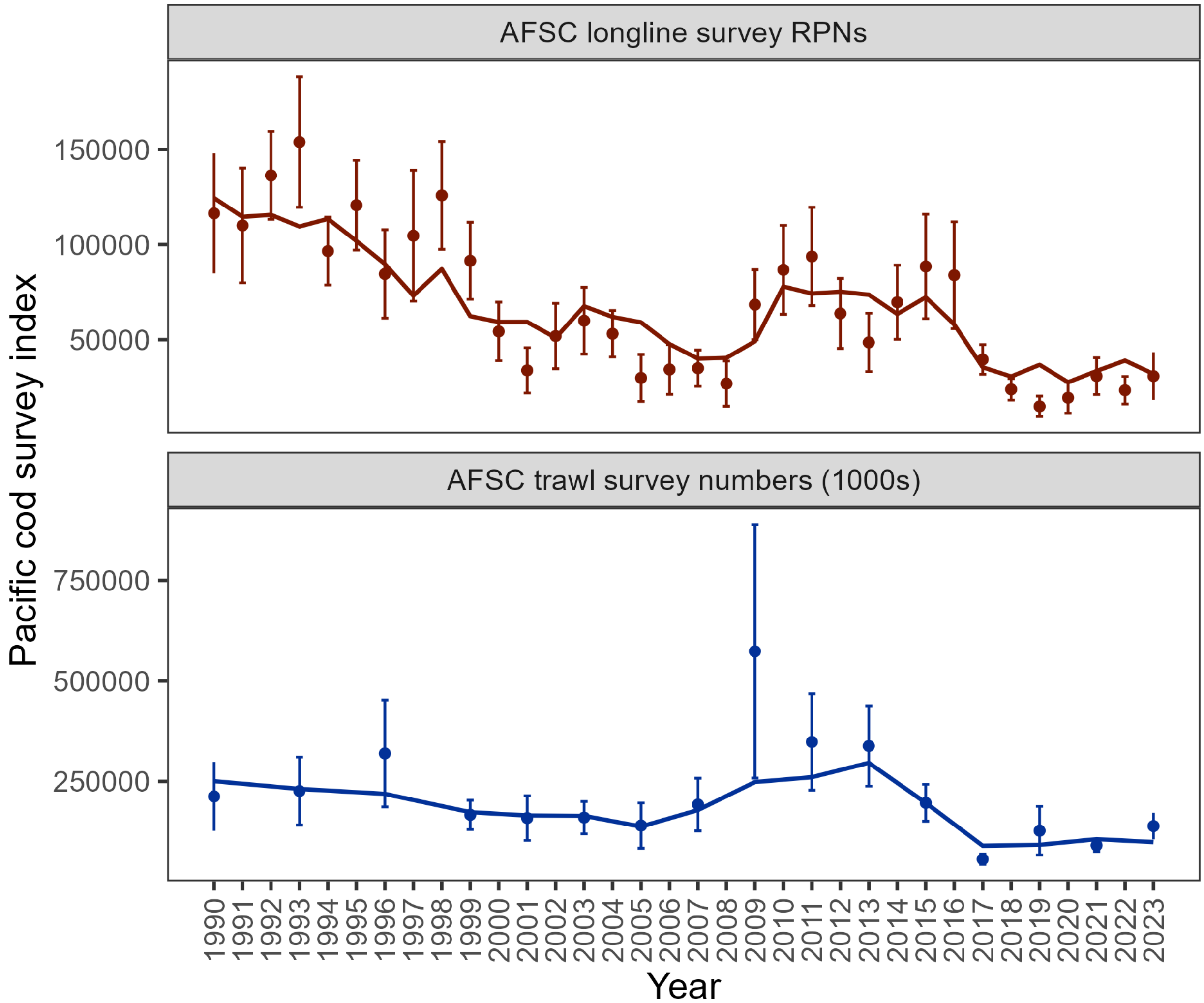

Figure 2.25. Population indices fit by the assessment model, including AFSC longline survey relative population numbers (RPN – top panel) and AFSC bottom trawl survey abundance (numbers – bottom panel). Model fit is shown as a solid line and observed data is shown as points (with error bars indicating the 95% confidence intervals).

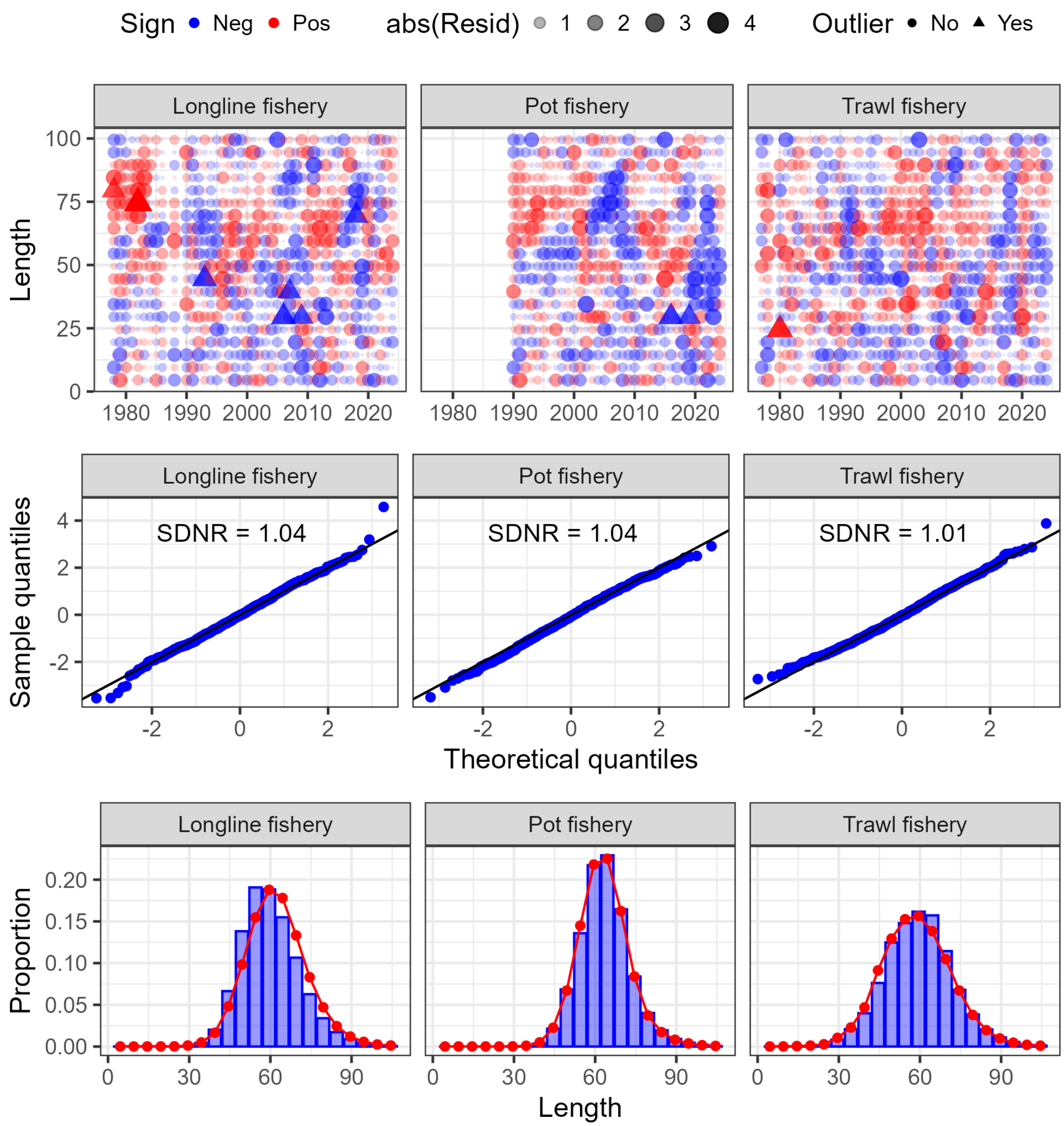

Figure 2.26. One-step ahead residuals (top panels), theoretical versus sample quantiles (middle panels), and aggregated model fit (bottom panels) for the fishery length composition data (fleets shown across the columns) fit in the author's recommended model.

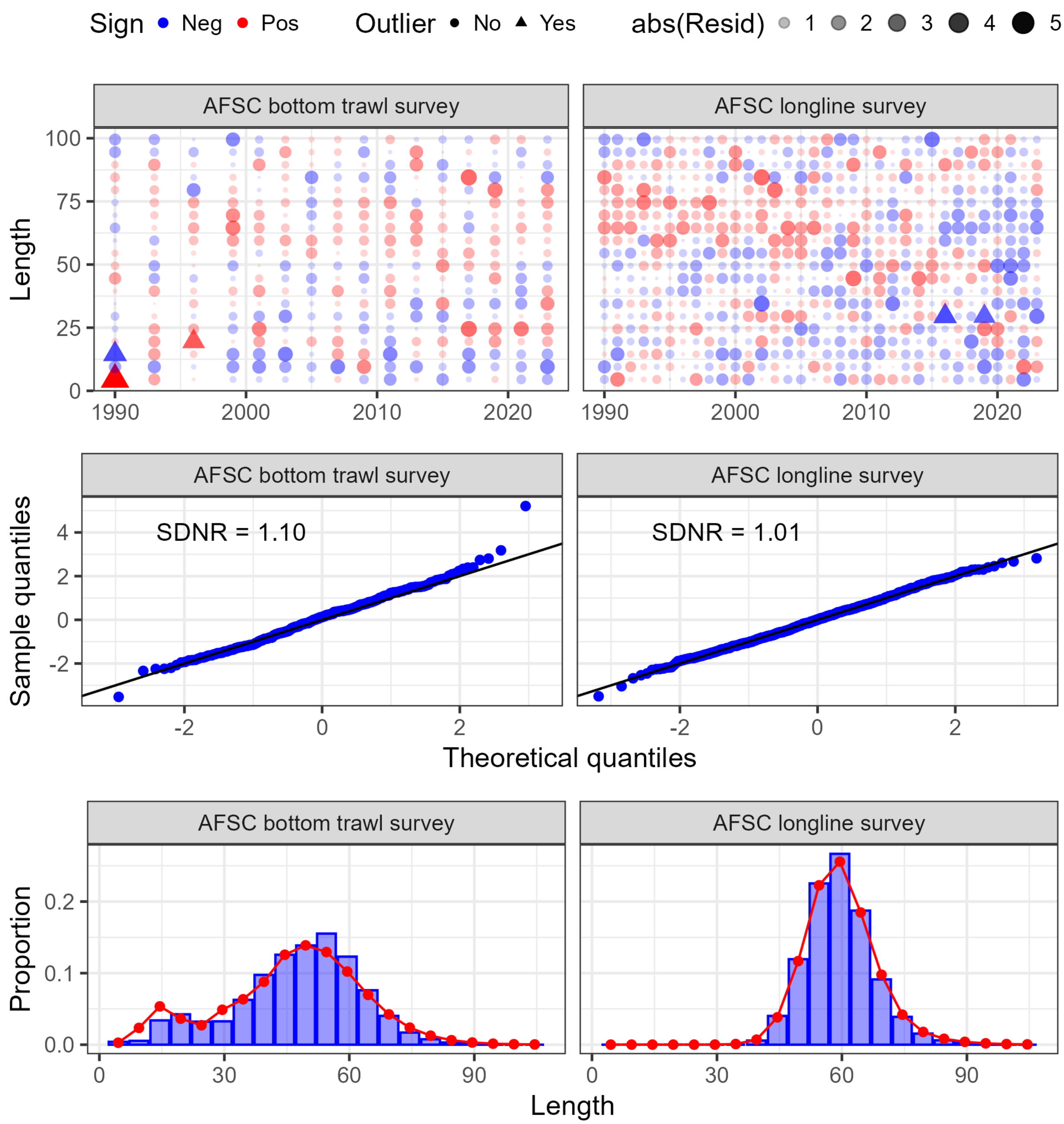

Figure 2.27. One-step ahead residuals (top panels), theoretical versus sample quantiles (middle panels), and aggregated model fit (bottom panels) for the survey length composition data (surveys shown across the columns) fit in the author's recommended model.

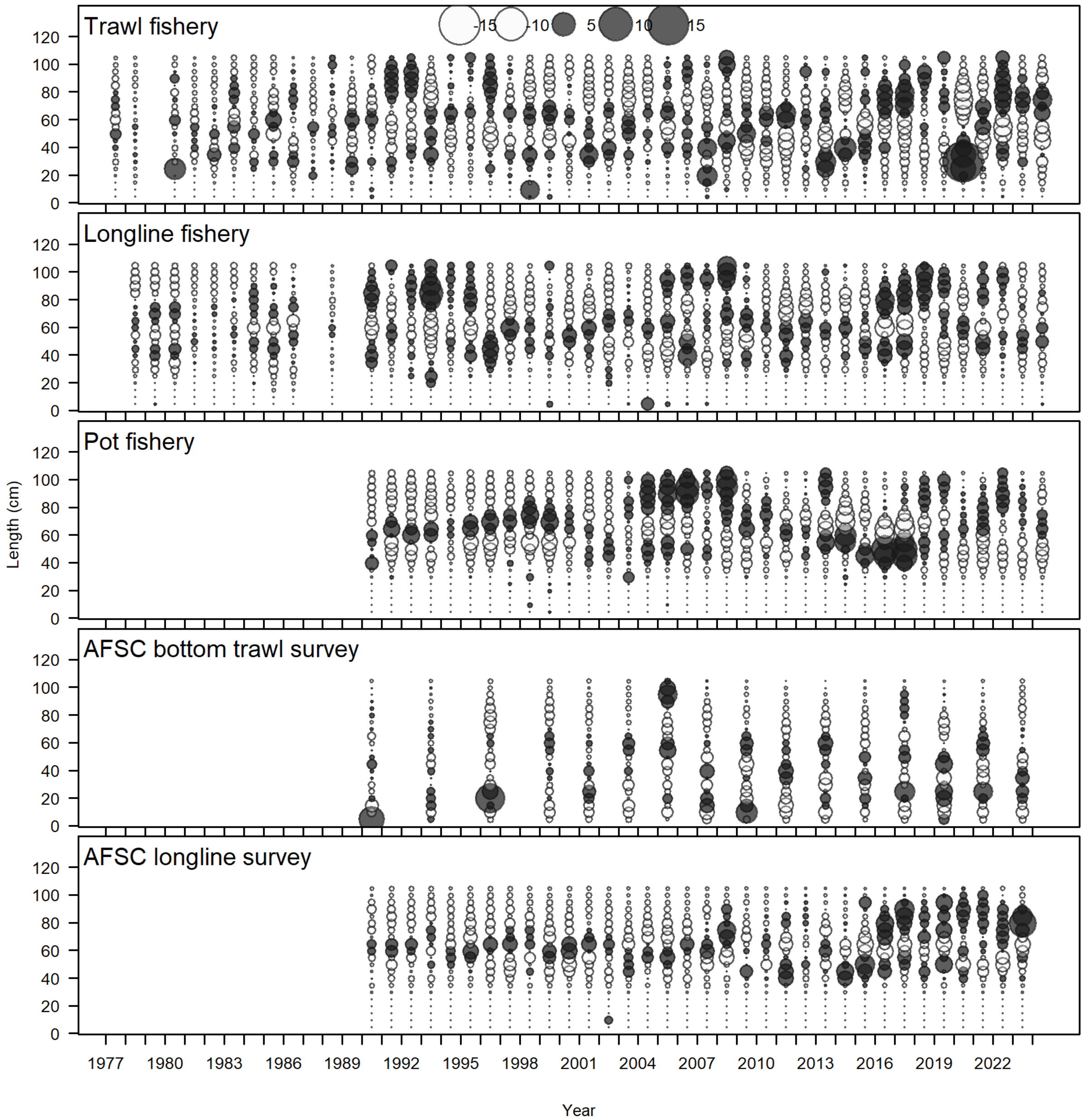

Figure 2.28. Pearson residuals for the fishery and survey length composition data fit in the author's recommended model.

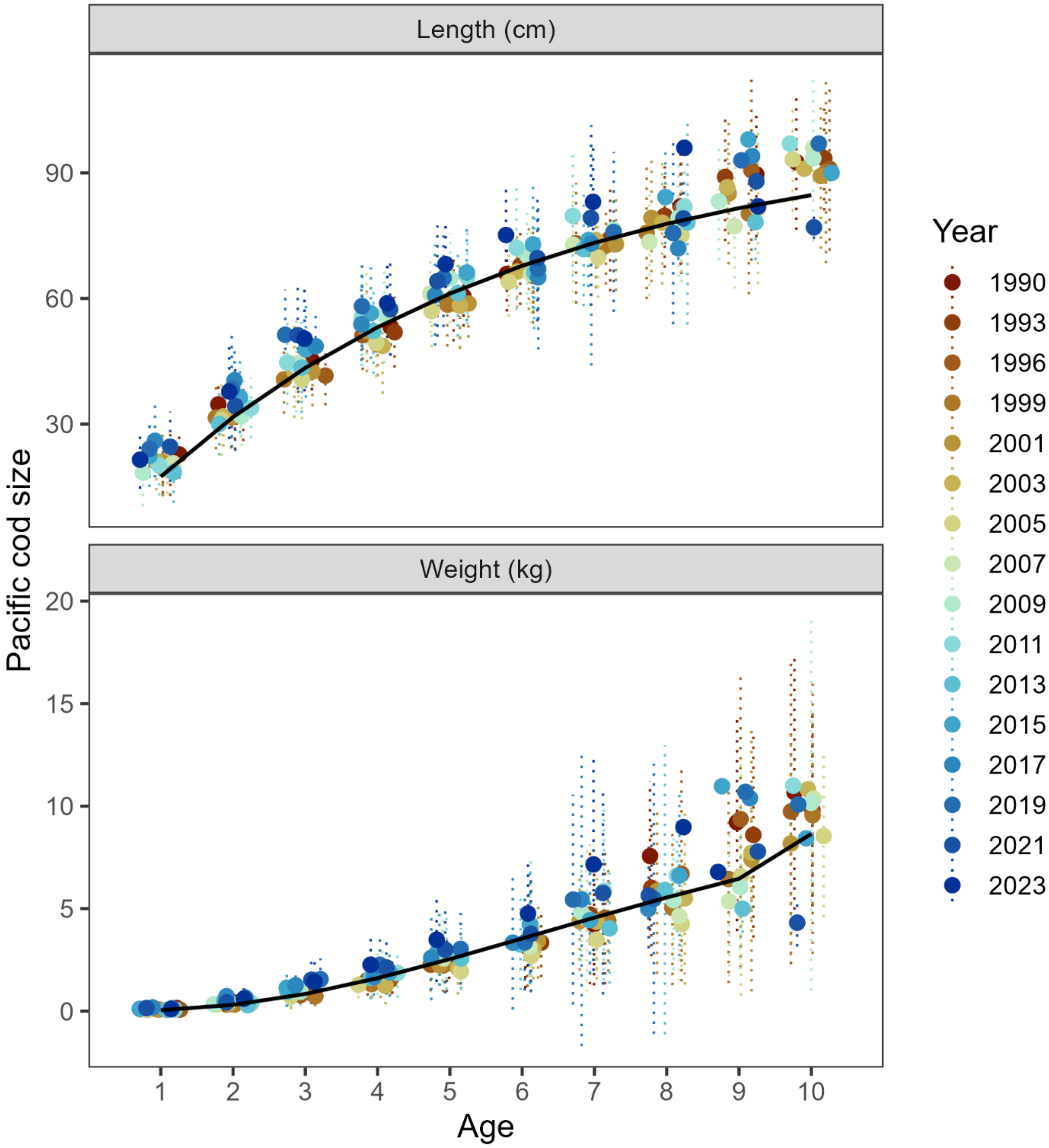

Figure 2.29. Author recommended model fit (solid line) to AFSC bottom trawl survey observed mean length-at-age (top panel) and weight-at-age (bottom panel) across the years of the survey (ranges shown are the 95% confidence interval in the yearly mean length or weight).

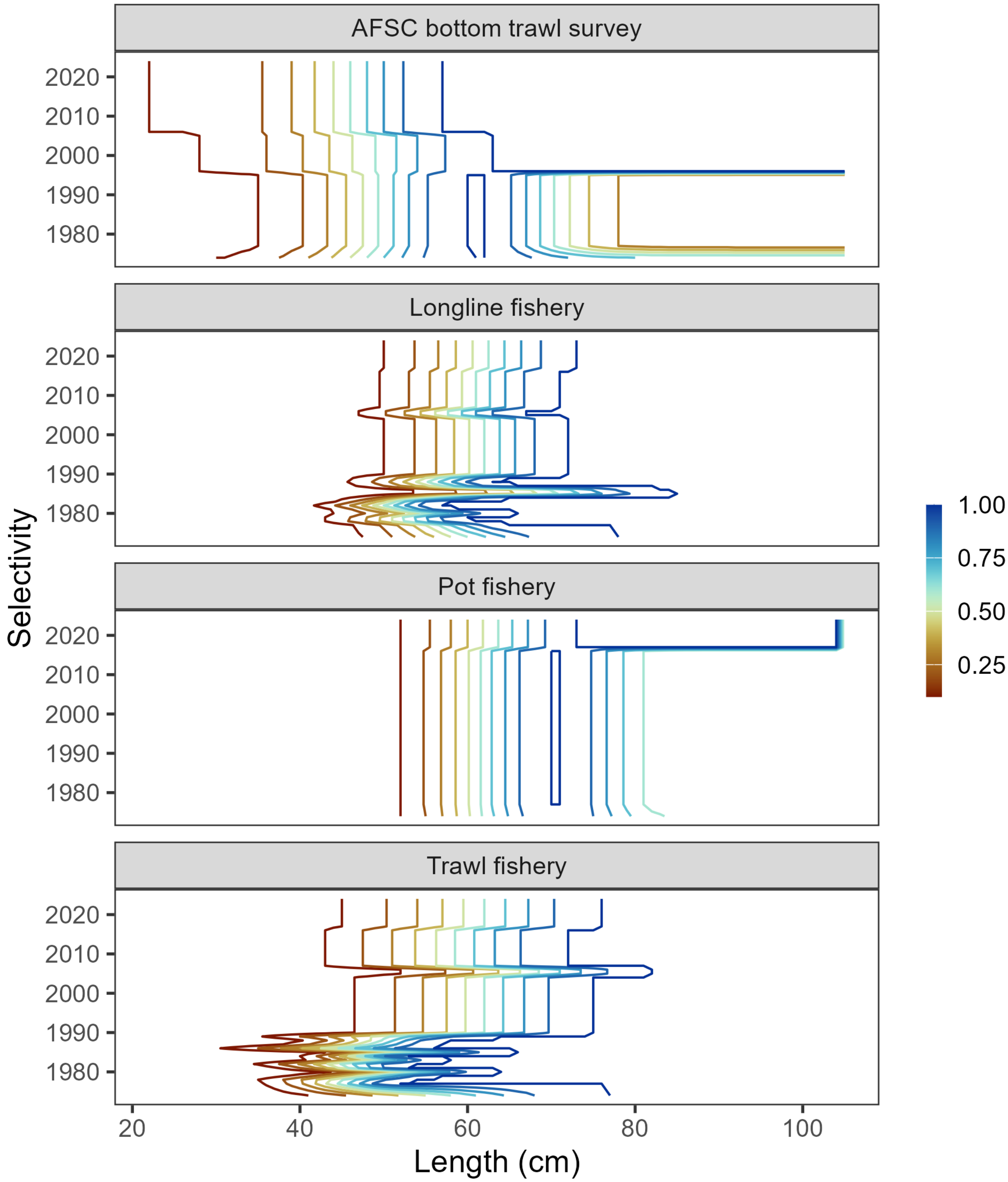

Figure 2.30. Estimated selectivity from the author recommended model across time.

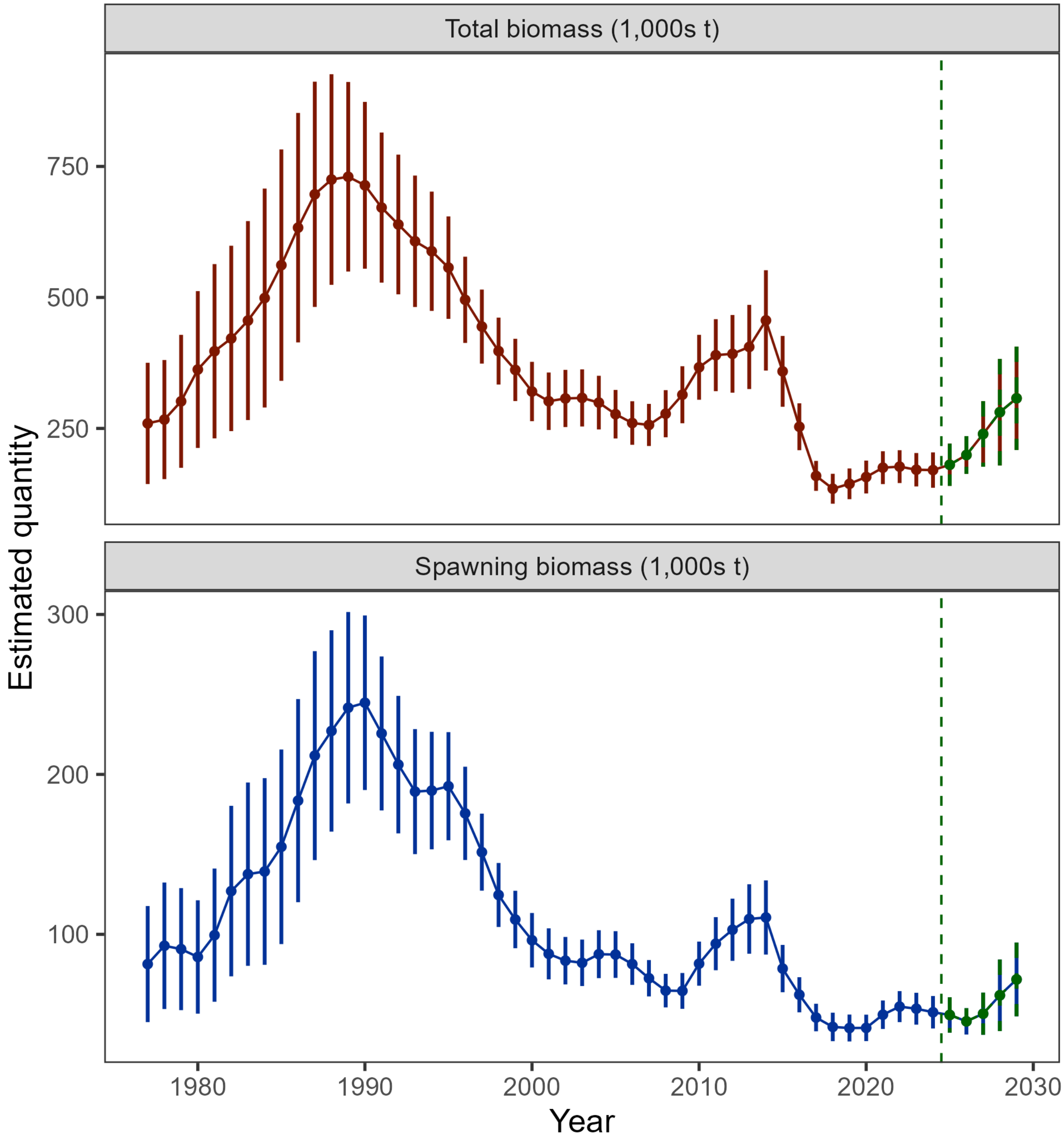

Figure 2.31. Estimated total biomass (top panel) and spawning biomass (bottom panel) from the author's recommended model with 95% confidence intervals. The five-year forecasted biomass values are denoted in green shading and with the vertical dashed line in each plot.

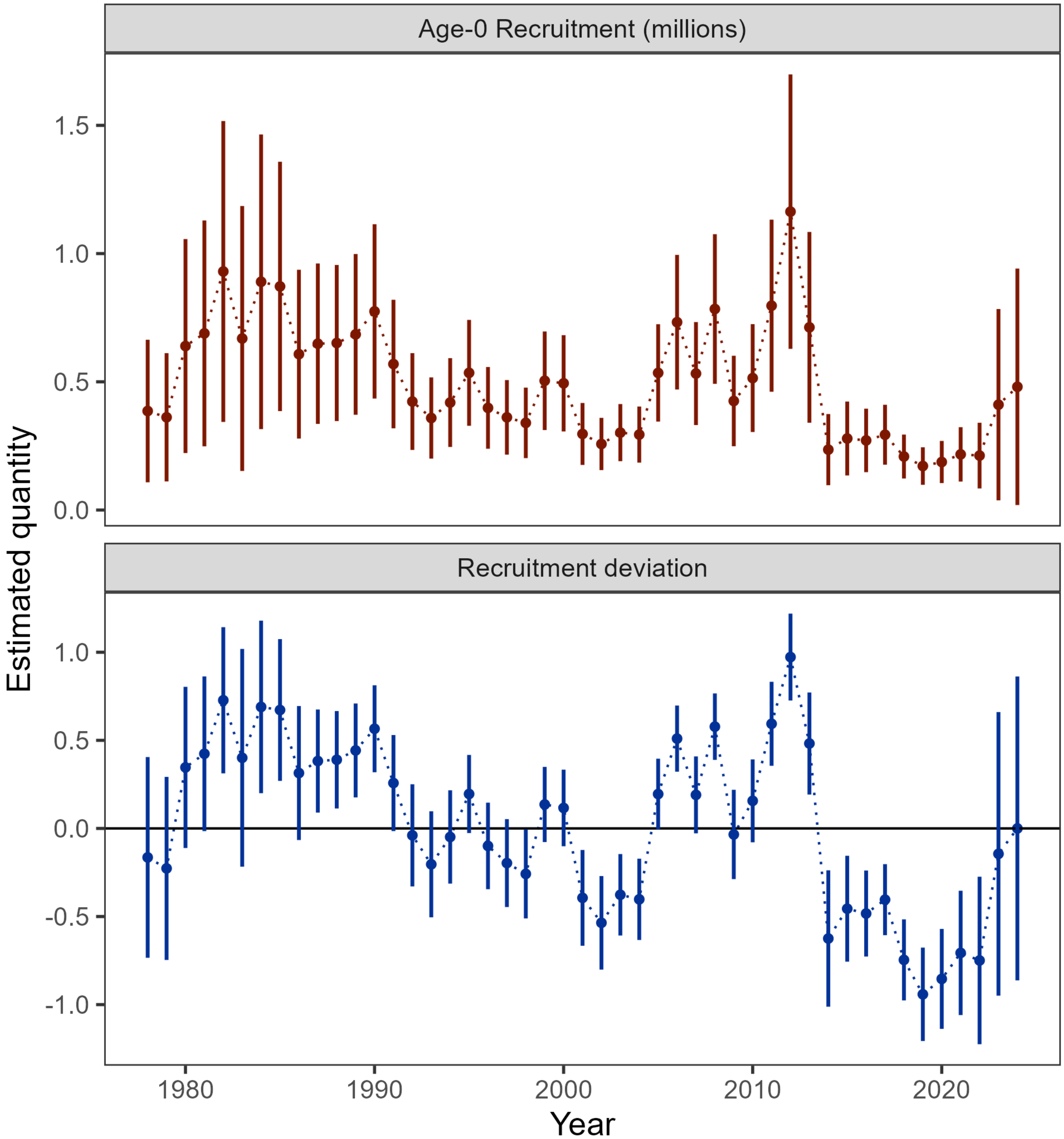

Figure 2.32. Age-0 recruitment (top panel) and log recruitment deviations (bottom panel) with 95% confidence intervals from the author's recommended model.

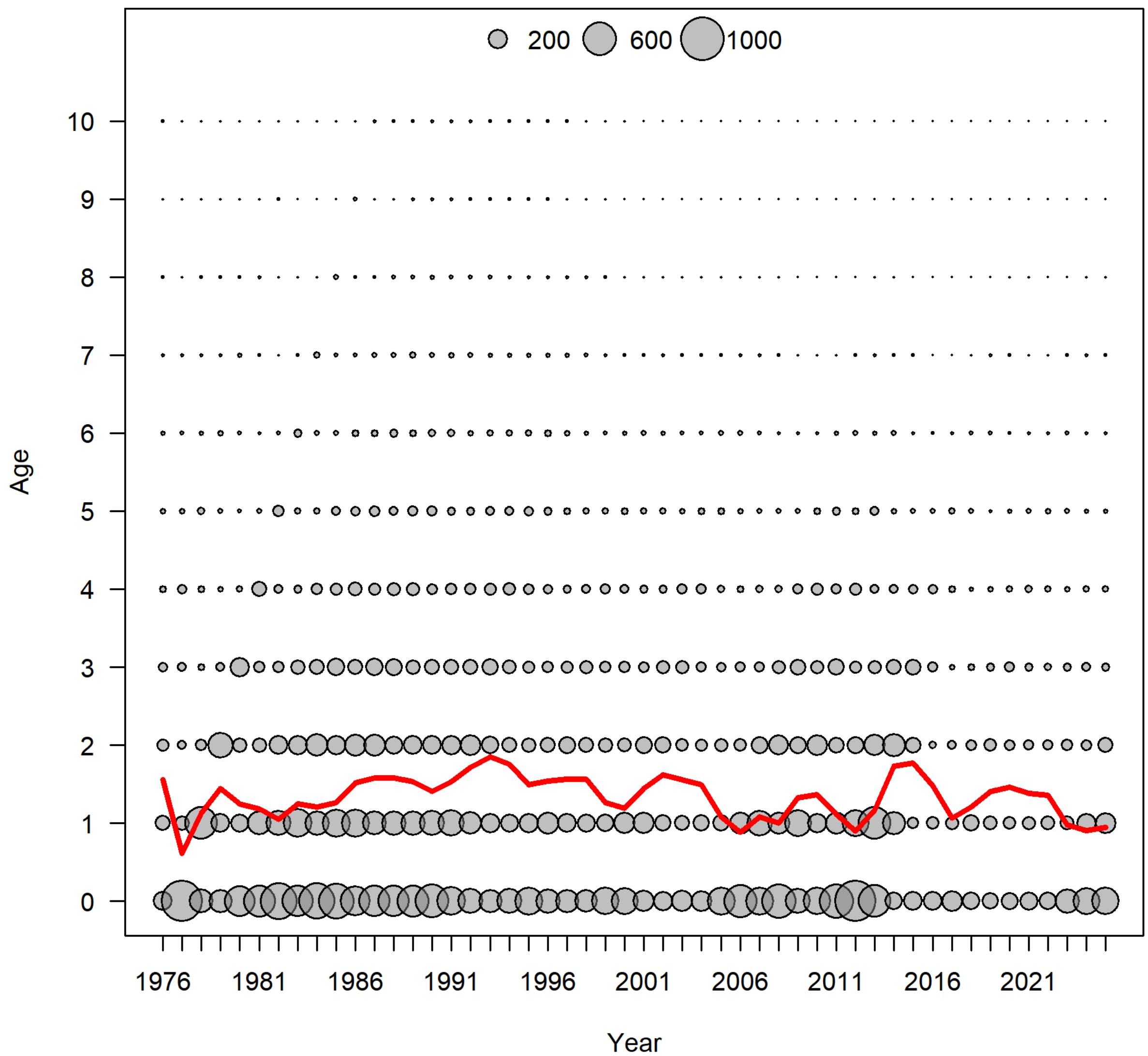

Figure 2.33. Predictions of middle of the year number at age with mean age (red line) from the author's recommended model.

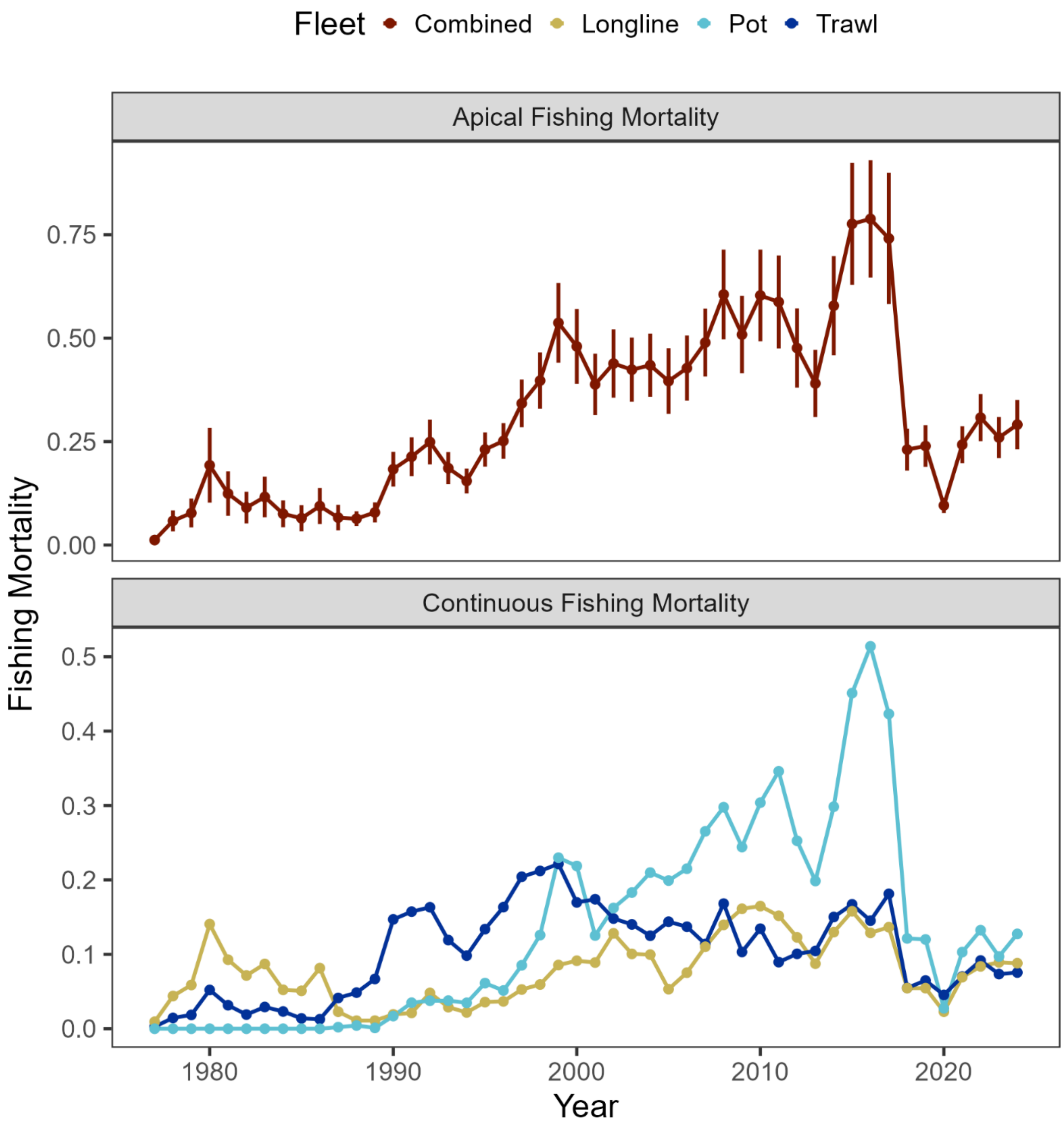

Figure 2.34. Sum of apical fishing mortality (top) and continuos fishing mortality by fisheries (bottom) from the author's recommended model.

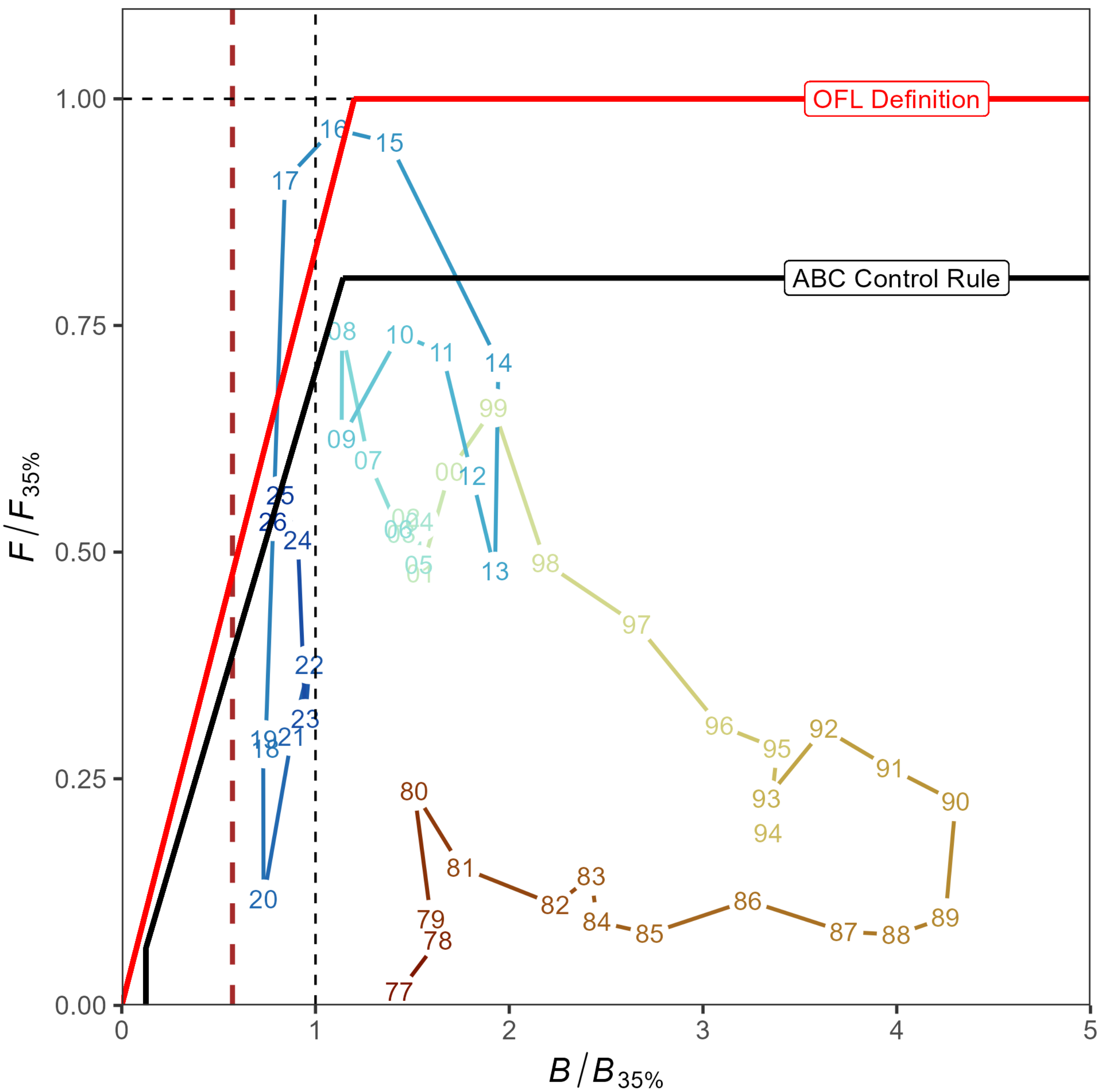

Figure 2.35. Ratio of historical $F/F_{35\%}$ versus female spawning biomass relative to $B_{35\%}$ for GOA pacific cod, 1977-2026 from the author's recommended model. The Fs presented are the sum of the full Fs across fleets. Dashed vertical red line is at $B_{20\%}$, Steller sea lion closure rule for GOA Pacific cod.

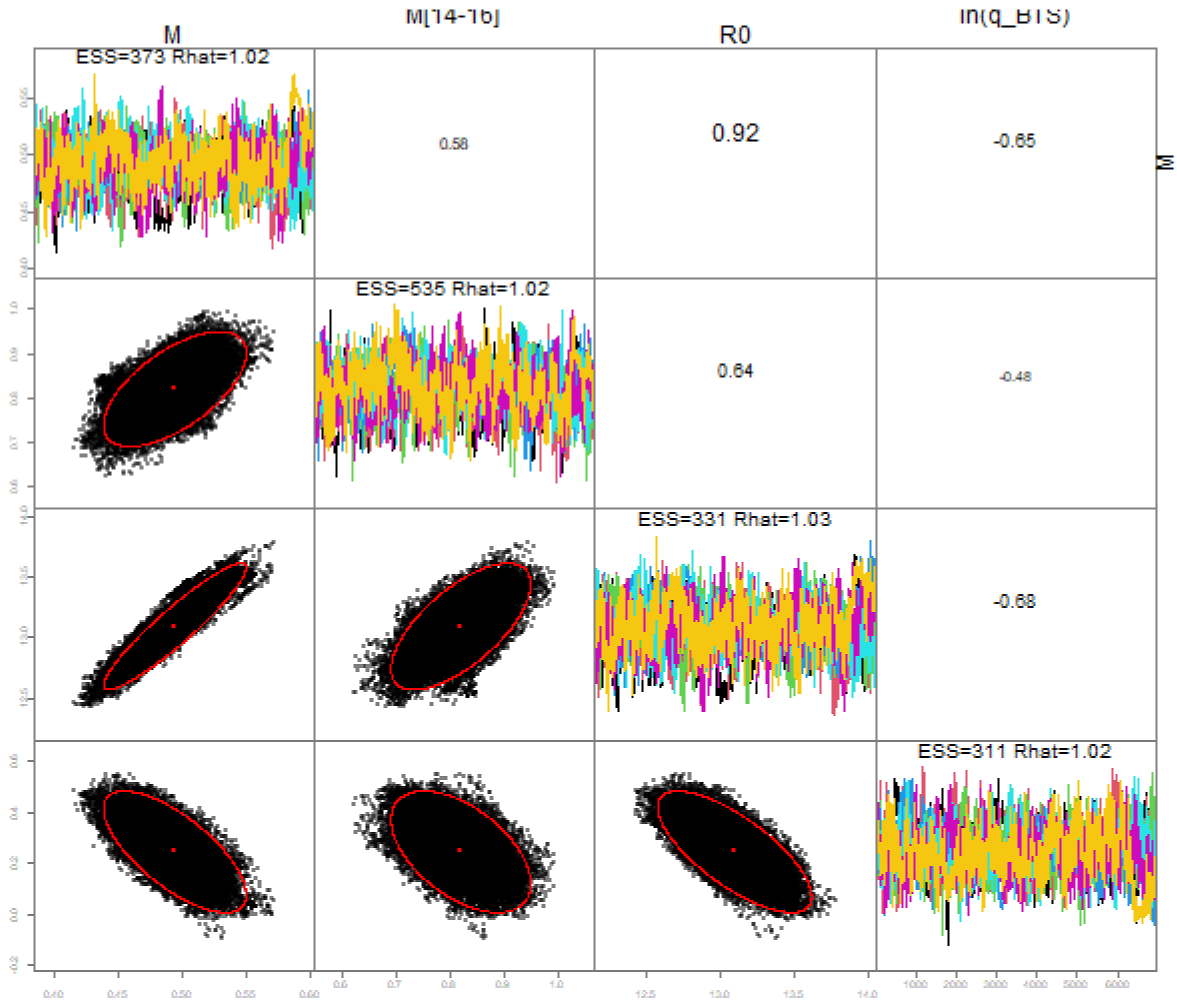

Figure 2.36. MCMC pairs plot of key model parameters, with diagnostics shown in the diagonal and parameter correlations shown in the top right.

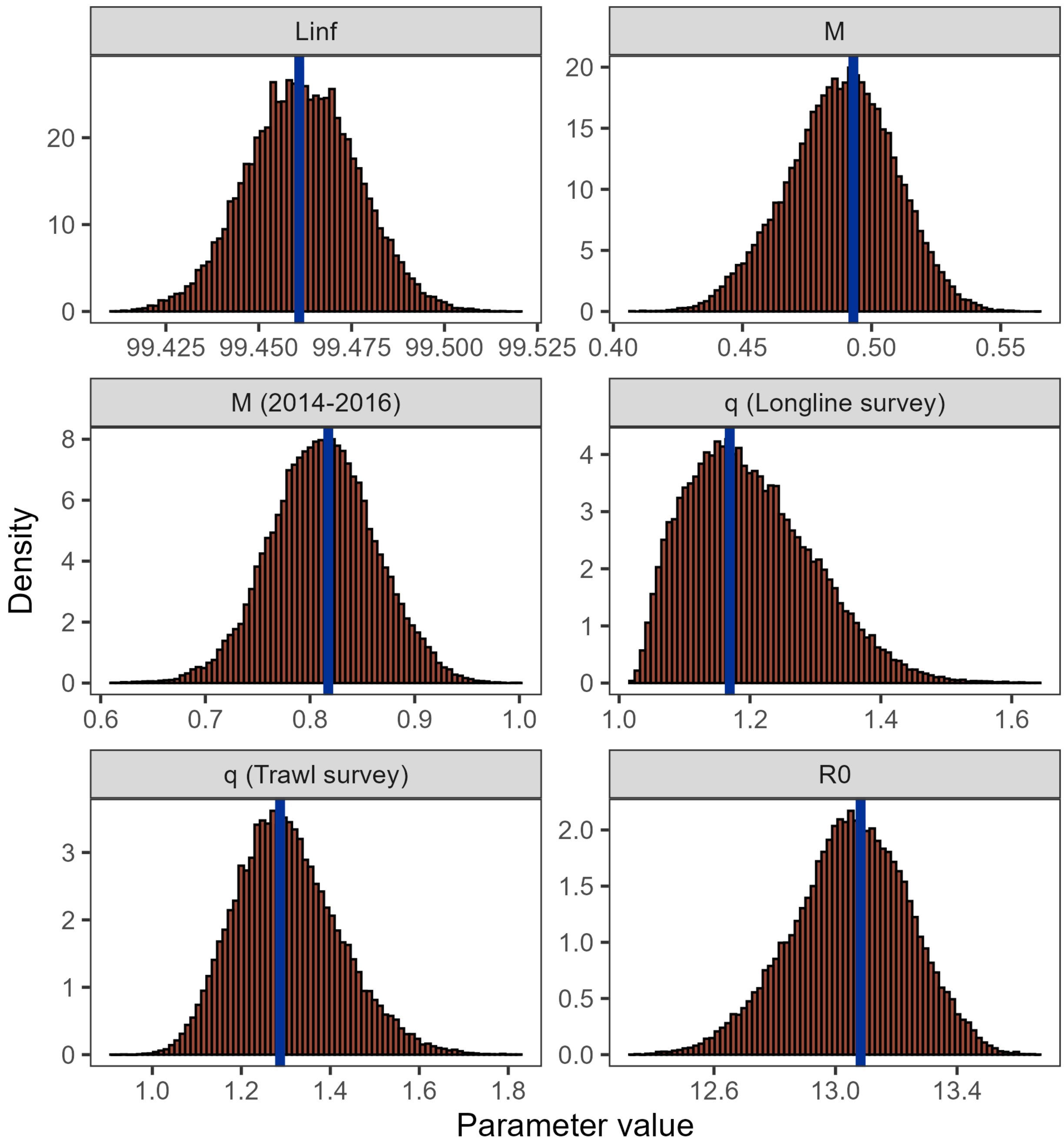

Figure 2.37. Histograms of MCMC draws for key parameters from the author's recommended model compared to MLE estimate (vertical line).

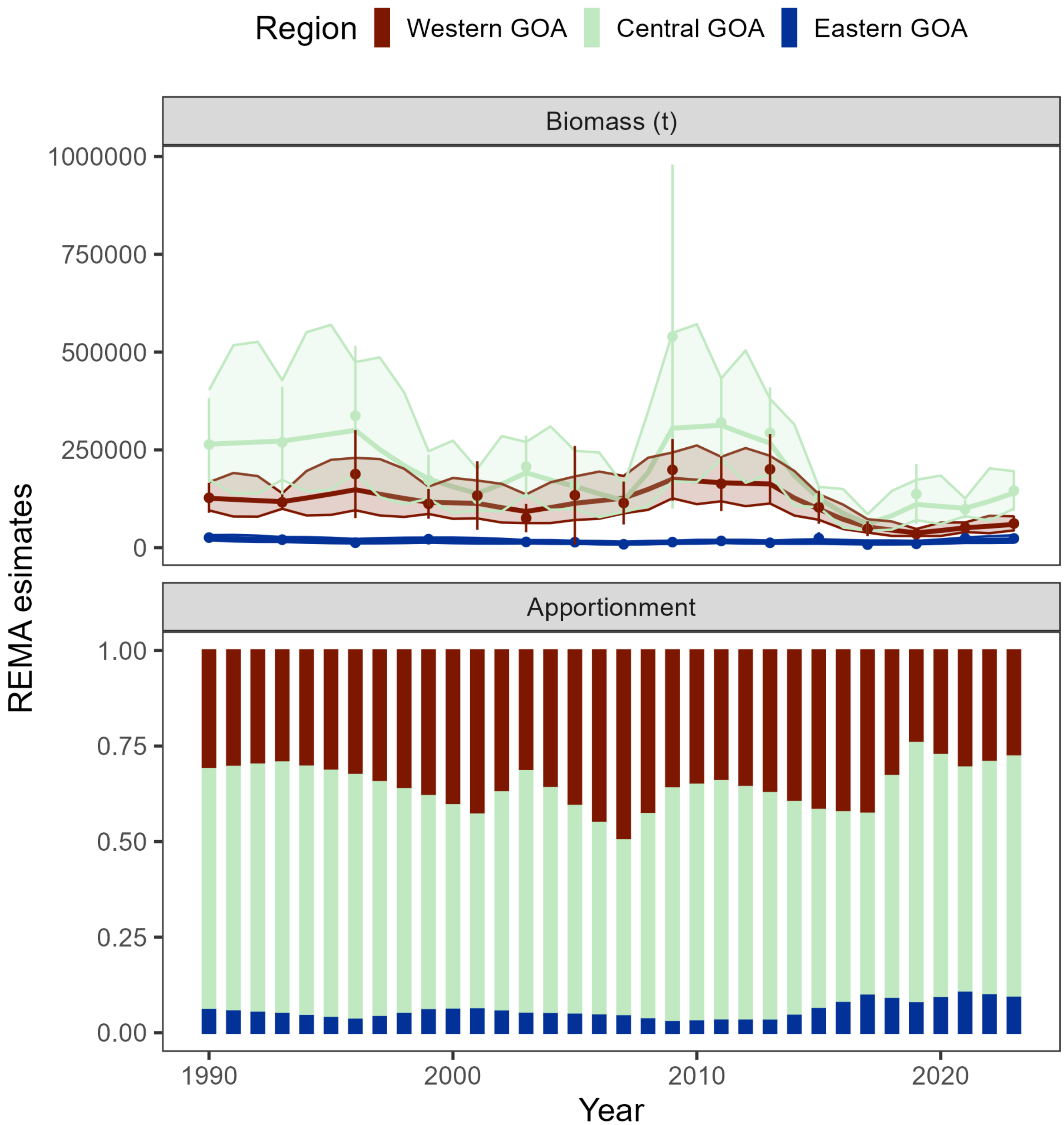

Figure 2.38. REMA results as fit to the AFSC bottom trawl survey by area (top panel) used for apportionment (bottom panel).

Appendix 2.1 Ecosystem and Socioeconomic Profile of the Pacific cod stock in the Gulf of Alaska - Report Card

The ESP can be found at this link.

Appendix 2.2 Summary of the 2024 Recommended Model Alternatives for Gulf of Alaska Pacific cod

Pete Hulson, Steve Barbeaux, and Ingrid Spies

Executive Summary

The explored model alternatives for the 2024 assessment of Gulf of Alaska (GOA) Pacific cod involve changes to input data. The changes implemented in the model alternatives include correcting errors in data input files, improving model consistency with other AFSC cod assessments, updating important data input parameters, simplifying fishery length composition expansion methods, and improving model efficiency. Ultimately, the models we recommend for consideration at the November Groundfish Plan Team result in improvements as compared to the accepted model in 2023 (model 2019.1b).

Including the AFSC longline survey within the REMA model for apportionment was also explored, the results of which are presented here. We recommend development of the REMA model to include an environmental link with the scaling parameters and further development of environmental indices for each sub-region within the GOA prior to integration of the AFSC longline survey within the REMA model. We make this recommendation to avoid introducing unnecessary variability in the apportionment estimates among sub-regions that may be reduced once these developments are completed.

Data

An advancement made in this year's GOA cod assessment included re-development of the R-programming code used to query and construct data files used in the model. The historical code was refactored for clarity, to align with ongoing efforts to streamline this assessment's code base, to include documentation that describes the important steps in calculations, and to integrate with current efforts to develop R-packages for data querying, specifically to integrate with the afscdata R-package. Part of this re-development involved transitioning the querying of data tables housed in both the AFSC and AK Fisheries Information Network (AKFIN) databases to only querying data from the AKFIN database.

It is normally the case that the models presented at the September Groundfish Plan Team meeting only use data through the last full assessment. However, because of the differences in data sources used in the re-developed R-scripts, to follow this guideline additional functionality would have needed to be developed in order to filter data to match exactly with what was used in the 2023 assessment. This additional functionality development was not undertaken for two primary reasons: (1) it did not seem a reasonable use of time to develop code that would only be used for this single assessment cycle, and (2) there were no surveys conducted in the GOA in 2024, thus, the model will not be updated with any population index data and the only data updated thus far in 2024 was fishery catch and length composition. For these reasons, the model alternatives presented here include updated data through the beginning of September 2024. As will be done in the November SAFE document, in the following table we highlight the data that has been added since the last full assessment and included in the model alternatives presented here in bold font:

Data	Source	Type	Years
Federal and state fishery catch, by gear type (trawl, longline, and pot)	AKFIN	Metric tons	1977 – **2024**
Federal and state fishery catch-at-length, by gear type	AKFIN, ADF&G	Frequency observed at length (in cm)	1977 – **2024**
GOA NMFS bottom trawl survey numbers	AKFIN	Total numbers	1990 – 2023
AFSC Sablefish Longline survey Pacific cod Relative Population Numbers	AKFIN	RPN	1990 – 2023
GOA NMFS bottom trawl survey length composition	AKFIN	Number at length (in cm)	1990 – 2023
GOA NMFS bottom trawl survey conditional age-at-length	AKFIN	Proportion age at length	1990 – 2021
AFSC Sablefish Longline survey Pacific Cod length composition	AKFIN	RPN at length (in cm)	1990 – 2023
Federal fishery conditional age-at-length	AKFIN	proportion age at length	2007 – 2022

Analytic Approach

The base model used in this analysis is the accepted model from the 2023 assessment cycle (model 2019.1b). Model 19.1b is a single sex, age-based model with length-based selectivity and is optimized with the Stock Synthesis software (Methot and Wetzell 2013).

Description of Alternative Models

2019.1c

There are seven proposed changes to model input data files that culminate in model scenario 2019.1c. While these changes are all incorporated in model 2019.1c we also applied these changes one-by-one in order to evaluate the impact of each. Individually, these changes are:

1. 2019.1c.1: when fitting a log-normal population index the log-scale standard deviation (SD) is computed as $SD = \sqrt{\ln\left(1 + \left(\sqrt{\sigma^2}/x\right)^2\right)}$ where σ^2 is the variance, and x is the population index value. This method had been applied in the GOA cod model for the AFSC bottom trawl survey index, but had not been applied to the AFSC longline survey index. Model 2019.1c.1 applies this method to the AFSC longline survey RPN index.
2. 2019.1c.2: in the computation of the AFSC longline survey length composition, the lengths were inadvertently set to 1 cm larger. For example, the RPN of fish at 50 cm became the RPN of fish at 51 cm. Model 2019.1c.2 assigns the correct length when computing the AFSC longline survey length composition.
3. 2019.1c.3: in the data file the month for the longline survey length composition had been set at 1 (January) when it should have been 7 (July). Model 2019.1c.3 sets the month for the AFSC longline survey length composition at 7.
4. 2019.1c.4: the fishery length composition input sample size has historically been set at the number of hauls sampled, with a maximum of 200. However, in the computation of fishery length

composition, hauls with less than 10 observations were removed, but this filtering was not reflected in the input sample size. Model 2019.1c.4 sets the fishery length composition at the number of hauls actually used in the computation of length composition, with a maximum of 200.

5. 2019.1c.5: the plus length bin for the length composition data had been set at 116 cm, but since 1977 less than 2% of the years had a proportion of greater than 0.01 with a plus length bin of 104 cm. Model 2019.1c.5 sets the plus length bin at 104 cm.
6. 2019.1c.6: in the data file the month for the AFSC bottom trawl survey conditional age-at-length data was set at 1 (January), when it should have been set at 7 (July). Model 2019.1c.6 sets the month for the AFSC bottom trawl survey conditional age-at-length data at 7.
7. 2019.1c.7: in the assessment, the phase for the forecast recruitment parameters was set at a value which enabled the estimation of these parameters, whereas, in the Eastern Bering Sea (EBS) cod assessment these parameters are turned off. Model 2019.1c.7 turns off the forecast recruitment parameters.

2019.1d

Within the GOA cod assessment model, ageing error is applied using paired reader-tester data. In model 2019.1d we propose to build upon model 2019.1c and update the ageing error parameters with data through 2023. In addition, we propose to update these parameters after pooling the reader-tester data for the GOA and EBS in order to leverage the larger number of samples available within both regions. Using the linear ageing error method within the R-package AgeingError (Punt et al. 2008), we found that there was minimal difference between the parameters estimated for each region separately, and each region combined. The estimated ageing error SD for age-1 was 0.11 regardless of how the data was pooled, and for age-10 (the plus age in the GOA assessment) was 1.09 for the GOA, 1.14 for the EBS, and 1.13 for combined regions. Thus, in model 2019.1d we apply these updated ageing error parameters starting at age-1 with an SD of 0.11 and ending at age-10 with an SD of 1.13 while using a linear relationship between. We note that besides updating the ageing error SD parameters, a difference in this approach with model 2019.1b accepted in 2023 is that ageing error started at age-3, whereas in 2019.1d we start ageing error at age-1.

Because bias was discovered in the age reading for cod prior to 2007 (Barbeaux et al. 2019), model 2019.1b estimated two parameters to apply bias in the ageing error for any age data fit prior to 2007 (a parameter for the bias starting at age-3 and the bias for the final age in the model, age-10, with a linear trend between these ages). In 2018, a set of specimen data (n = 2,056) that was originally aged in 2004 was re-read by age readers in the AFSC Age and Growth Program. Using this data within the AgeingError R-package we estimated the bias in the pre-2007 data (Figure 2.2.1). In model 2019.1d, rather than estimate bias, we fix the bias parameters based on the results from the AgeingError model fit to these re-read data, where the bias was 0.24 for age-1 and 2.00 for age-10, with a linear relationship defined in the model between these two ages.

2019.1e

As has been noted since the 2022 assessment, fishery length composition (specifically for the pot fleet) has become increasingly variable. Within model 2019.1e we propose changes to the methods used to compute fishery length composition that aid in reducing this variability.

In the expansion of fishery length frequency observations to annual fishery length composition for each fleet fit in the cod assessment model (trawl, longline, and pot fisheries), hauls have been removed that sampled less than 10 fish. Prior to around 2015, this represented a small proportion of hauls, particularly for the longline and trawl fleets (Table 2.2.1). However, since 2015 the numbers of hauls that sampled less than 10 fish per haul has increased. For example, since 2020 around 70% of the hauls sampled in the trawl fleet had less than 10 length frequencies observed per haul.

Length frequencies are also collected from State fisheries managed by the Alaska Department of Fish and Game (ADF&G) and have been integrated within the GOA cod assessment. The use of ADF&G length frequency data occurs when there is federal data missing at a month-area-gear level. It is important to note that ADF&G length frequency data is not used if there is federal data within a month-area-gear, regardless of the quantity of federal length frequency data compared to the quantity of ADF&G length frequency data.

In model 2019.1e we use model 2019.1d and include two changes to how fishery length frequency data is handled. First, we eliminate the filter that removes hauls that sampled less than 10 lengths and use all length frequency data available. Second, rather than 'fill-in' missing federal length frequency data with ADF&G data we merge the ADF&G data with the federal data so that all length frequency data from both sources can be used in the expansion of length composition data fit in the GOA cod assessment. This recommendation is consistent with the way catch is treated in the model, both the federal and ADF&G total catch for each fleet are combined within the catch time series. In order to merge the ADF&G data, we also transition the fishery length composition expansion from weighting by catch at the week-area-gear level to weighting by catch at the month-area-gear level. In general, these two changes help to smooth out much of the variability in the fishery length composition data (2020 pot fishery length composition shown in Figure 2.2.2 as an example).

2019.1e.2cm and 2019.1e.5bm

Two additional models were considered as a subset of model 2019.1e to evaluate model performance and sensitivity to the bin size within the length composition and conditional age-at-length data. The first additional model, 2019.1e.2cm evaluates using 2 cm bins, and the second, 2019.1e.5cm, evaluates using 5 cm bins. Using recent bottom trawl survey length compositions as an example, increasing the bin size serves to smooth the length composition while retaining important signal within the data (Figure 2.2.3).

Description of Alternative Apportionment

There are a handful of assessments conducted at AFSC that utilize both the AFSC bottom trawl survey biomass and longline survey Relative Population Weight (RPW) indices within the REMA model (e.g., Shortraker rockfish, Echave et al., 2023). Further, it has been a longstanding request by the SSC that the AFSC longline survey be considered for apportionment within the GOA cod assessment. Here, we compare the current method of apportionment using the AFSC bottom trawl survey biomass only with apportionment after integrating the AFSC bottom trawl survey biomass and longline survey RPW within the REMA model.

Results

Model 2019.1c – input data changes

The majority of the input data changes made within model 2019.1c resulted in minor changes to assessment estimates (estimates of spawning biomass shown as an example in Table 2.2.3). Only three input data changes resulted in an absolute average percent difference in estimates of spawning biomass that was greater than 1%: 2019.1c.2 in which the length bin was corrected for the longline survey length composition; 2019.1c.4 in which the input sample size for fishery length composition data was set at the number of hauls actually used to compute length composition, and 2019.1c.6 in which the month for bottom trawl survey conditional age-at-length was changed from 1 (January) to 7 (July). The largest of these was from model 2019.1c.6, which resulted in a 10% decrease in spawning biomass estimates on average. Combining all of these changes within model 2019.1c resulted in a decrease in the estimated spawning biomass across the time series of the model (Figure 2.2.4). This decrease coincided with an increase in the bottom trawl catchability parameter to 1.19 in 2019.1c compared to 1.07 in 2019.1b (other key parameter estimates are shown in Table 2.2.6). The overall negative log-likelihood in model 2019.1c decreased compared to model 2019.1b (Table 2.2.4), due primarily to a decrease in the length composition component, which decreased as the input sample size decreased to reflect the number of hauls from which samples were used in the fishery length composition expansion.

Model 2019.1d – updating ageing error

Updating ageing error and bias parameters in model 2019.1d resulted in a slight decrease in estimated spawning biomass compared to model 2019.1c (Figure 2.2.5). The overall negative log-likelihood of model 2019.1d was smaller than model 2019.1c (Table 2.2.4), indicating that updating ageing error and bias parameters improved model fit. The largest decrease in negative log-likelihood occurred for the conditional age-at-length data component, although there was a decrease in the negative log-likelihood for each data component of the model. Compared to model 2019.1b and 2019.1c the AFSC bottom trawl catchability parameter estimate in model 2019.1d increased (other key parameter estimates are shown in Table 2.2.6).

Model 2019.1e – fishery length composition

Removing the filter and merging ADF&G length frequency data when expanding the fishery length composition data resulted in an increase in estimated spawning biomass in model 2019.1e compared to model 2019.1d (Figure 2.2.6). Model 2019.1e fit to fishery length composition improved for the longline and pot fishery compared to model 2019.1d, but slightly degraded for the trawl fishery (as illustrated by the aggregated fit in Figure 2.2.7). While the fit to the fishery length composition improved in general, it was at the expense of fit to the survey indices, particularly the longline survey (Table 2.2.5). Visually, the fit to the bottom trawl survey is similar between models 2019.1d and 2019.1e (top panel Figure 2.2.8). The fit to the longline survey results in the largest difference between 2019.1d and 2019.1e in the mid-2000s (bottom panel Figure 2.2.8), although the fit since 2010 has been similar between these two models.

Applying the 2 cm and 5 cm bins within model 2019.1e resulted in models that estimated similar trends and magnitudes in spawning biomass (Figure 2.2.9) and resulted in similar fits to data (Table 2.2.5).

Recommended model 2019.1e.5cm/2024.0

We recommend that model 2019.1e.5cm be pursued for consideration at the November Plan Team meeting as an alternative model to the accepted model 2019.1b. This model represents a number of improvements to the 2023 assessment model that include correcting errors in data input files, improving model consistency with other AFSC cod assessments, updating important data input parameters, simplifying fishery length composition expansion methods, and improving model efficiency through extending the bins for length composition data. Ultimately, the model estimates a shift in spawning biomass to smaller values (Figure 2.2.10). However, model 2019.1e.5cm is consistent with model 2019.1b by the end of the model’s time series. We note that there are a number of important changes in parameter estimates that occur in model 2019.1e.5c compared to model 2019.1b (Table 2.2.6 and Figures 11 and 12); these changes primarily occurred due to model change 2019.1c.6, in which the month for the bottom trawl survey conditional age-at-length was corrected to July rather than January as opposed to model changes that updated ageing error and changed how fishery length composition was expanded. Because of these changes in parameter estimates and the number of improvements made to the input data sources for the model, we recommend consideration of a model renumbering to 2024.0 for this model.

Alternative apportionment investigation

We used the REMA model to estimate alternative apportionment by integrating the AFSC longline survey RPW index with the AFSC bottom trawl survey biomass index. We followed a factorial design consisting of combinations that varied the number of process error parameters (either a single parameter or a parameter by sub-region), the number of scaling parameters (either a single parameter or a parameter by sub-region), and parameters to estimate additional uncertainty applied to the bottom trawl and longline survey indices (either one or both). AIC comparison across these combinations resulted in four models that were not statistically different with difference in AIC values less than 1. Changing how process error was estimated and estimating additional uncertainty for either of the surveys did not result in different AIC values. We compare across these four models to illustrate the differences in apportionment with the current convention of only using the bottom trawl survey.

Over the last 5 years of surveys (from 2019 – 2023), the variability in apportionment for the each of the GOA sub-regions has been larger when using both the trawl and longline surveys as compared to using only the trawl survey (Table 2.2.7 and illustrated in Figure 2.2.13). The coefficient of variation (CV) in apportionment estimates over the most recent 5 years is, on average, about 70% larger when using both surveys as compared to only the trawl survey. Compared to the apportionment that was used in the 2023 assessment, using both the longline and trawl survey results in a larger apportionment to the Eastern and Western GOA and smaller apportionment to the Central GOA as compared to using the trawl survey data only. This change in apportionment and variability is primarily due to differences in the relative biomass and RPW that is estimated within each of the sub-regions for each survey (illustrated in Figure 2.2.14). Particularly for the Eastern GOA, the AFSC longline survey estimates relatively larger RPW than the trawl survey estimates biomass.

Within the GOA cod assessment, there remains an environmental link between bottom temperature and AFSC longline survey catchability. However, the environmental index used for this link does not yet have a sub-region component. Further, the REMA model does not have the functionality to include an environmental link; in this case we propose developing a link with the scaling parameter that would mimic the link used in the main assessment. While increased variability in itself is not a reason to reject using the REMA model with indices from both surveys, we hypothesize that including an environmental link within the REMA model may serve to dampen some of the variability that results when using the AFSC longline survey as an additional index. Further, while there is some shift in apportionment when using the multi-index REMA model, the results are not substantially different than using the AFSC bottom trawl survey on its own. For these reasons, we recommend to continue using only the AFSC bottom trawl survey for apportionment in the GOA cod assessment until (1) functionality in the REMA model is developed to accommodate an environmental link with the scaling parameters, and (2) environmental indices that can be linked to the AFSC longline survey are developed at the sub-region scale.

Literature Cited

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Echave, K. B., K. A. Siwicke, J. Sullivan, and B. Ferriss, 2023. Assessment of the Shortraker Rockfish stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501

Punt, A.E., Smith, D.C., KrusicGolub, K., Robertson, S., 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Can. J. Fish. Aquat. Sci. 65 (9), 1991–2005.

Tables

Table 2.2.1. Percent of hauls within fishery length frequency data that sampled less than 10 lengths per haul.

	Longline	Pot	Trawl
1991-2012	2%	4%	3%
2013	12%	12%	2%
2014	6%	14%	5%
2015	5%	8%	4%
2016	13%	10%	4%
2017	12%	12%	20%
2018	23%	6%	6%
2019	22%	10%	6%
2020	60%	--	79%
2021	20%	14%	72%
2022	6%	30%	76%
2023	34%	36%	68%

Table 2.2.2. Percent of ADF&G length frequency data used to compute fishery length compositions in the GOA cod assessment.

	Longline	Pot	Trawl
1997-2016	35%	19%	38%
2017	33%	0%	--
2018	40%	33%	--
2019	40%	50%	--
2020	100%	100%	--
2021	67%	67%	--
2022	60%	0%	--
2023	50%	100%	--

Table 2.2.3. Average percent difference in estimated spawning biomass (SSB) from models considered within model 2019.1c compared to the base model 2019.1b.

Model	% difference in SSB
2019.1c	-10.5%
2019.1c.1	-0.1%
2019.1c.2	-4.5%
2019.1c.3	0.2%
2019.1c.4	1.6%
2019.1c.5	-0.3%
2019.1c.6	-10.6%
2019.1c.7	0.0%

Table 2.2.4. Likelihood components from model 2019.1b (both from the 2023 assessment and with data updated through September 2024), 2019.1c, and 2019.1d.

Likelihood component		2019.1b-23	2019.1b-24	2019.1c	2019.1d
TOTAL		2930.97	3050.99	2805.81	2727.26
Catch		1.089E-12	1.206E-12	5.98E-12	3.99E-12
Survey		-3.32	-3.78	-6.80	-8.03
	Srv	-5.58	-5.82	-6.98	-7.19
	LLSrv	2.26	2.04	0.18	-0.84
Length composition		1817.93	1868.43	1704.53	1697.31
Conditional age-at-length		1101.99	1180.16	1100.23	1030.48
Recruitment		3.16	-4.86	-2.55	-2.96
InitEQ_Regime		3.09	3.10	3.16	3.25
Forecast_Recruitment		0.61	0.41	0.00	0.00
Parm_priors		1.00	1.02	1.14	1.15
Parm_softbounds		0.01	0.01	0.01	0.01
Parm_devs		6.50	6.50	6.08	6.04

Table 2.2.5. Likelihood components from model 2019.1d, 2019.1e, 2019.1e.2cm, and 2019.1e.5cm.

Likelihood component		2019.1d	2019.1e	2019.1e.2cm	2019.1e.5cm
TOTAL		2727.26	2715.8	2342.31	1974.01
Catch		3.99E-12	2.44E-12	1.98E-12	1.91E-12
Survey		-8.03	0.63	1.46	2.16
	Srv	-7.19	-5.23	-5.08	-5.17
	LLSrv	-0.84	5.86	6.54	7.33
Length composition		1697.31	1676.90	1507.59	1330.40
Conditional age-at-length		1030.48	1030.97	825.75	633.31
Recruitment		-2.96	-3.03	-2.74	-1.62
InitEQ_Regime		3.25	3.17	3.18	3.02
Forecast_Recruitment		0.00	0.00	0.00	0.00
Parm_priors		1.15	1.16	1.13	1.08
Parm_softbounds		0.01	0.01	0.01	0.01
Parm_devs		6.04	6.00	5.92	5.65

Table 2.2.6. Key parameter estimates from model 2019.1b (both from the 2023 assessment and with data updated through September 2024) and models 2019.1c, 2019.1d, and 2019.1e.5cm.

Parameter	2019.1b-23	2019.1b-24	2019.1c	2019.1d	2019.1e.5cm
NatM	0.46	0.46	0.47	0.48	0.48
NatM: 14-16	0.79	0.80	0.82	0.82	0.80
lnR	12.86	12.87	12.99	13.03	13.08
q_twl	1.08	1.07	1.19	1.23	1.19
q_ll	1.06	1.06	1.08	1.11	1.09
q_llenv	1.42	1.46	1.28	1.14	1.28

Table 2.2.7. Apportionment estimates for 2023 with coefficient of variation (CV) since 2019 from the REMA model when using only the AFSC bottom trawl survey compared to variants using both the AFSC bottom trawl survey and longline survey.

Model	Western	CV[W]	Central	CV[C]	Eastern	CV[E]
pcod trawl survey	27.1%	8.9%	63.8%	5.4%	9.1%	11.3%
pcod multi survey, extra ll cv; pe1q3	27.6%	11.3%	62.8%	7.4%	9.5%	16.9%
pcod multi survey, extra twl cv; pe1q3	28.9%	20.7%	59.7%	14.8%	11.4%	25.8%
pcod multi survey, extra twl & ll cv; pe1q3	29.1%	15.1%	60.0%	10.9%	10.9%	23.3%
pcod multi survey, extra ll cv; pe3q3	27.5%	10.9%	62.7%	7.4%	9.8%	18.8%

Figures

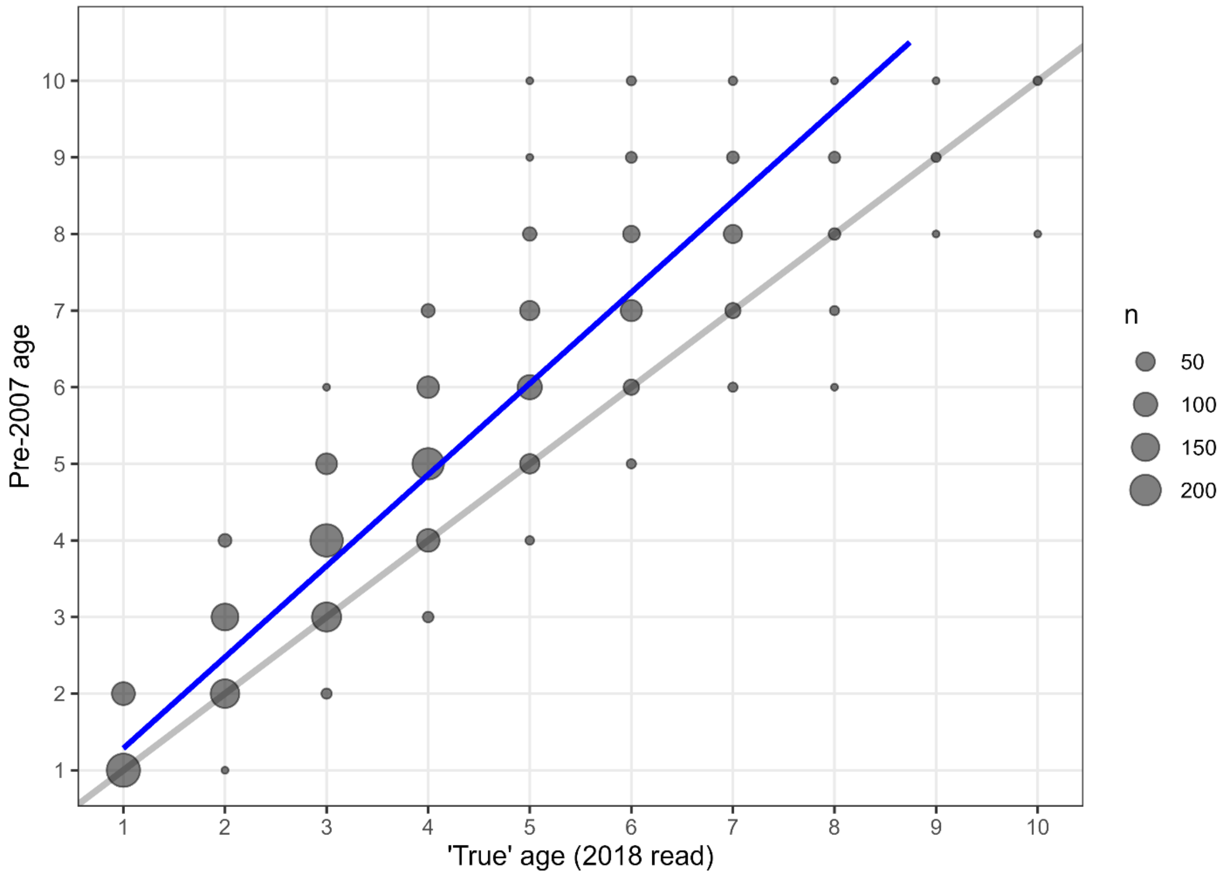

Figure 2.2.1. AgeingError R-package fit (blue line) to 2018 ageing compared to pre-2007 ageing (bubbles, with size indicating the number of times the particular age in 2018 matched the age pre-2007; grey line is 1-1 and shown for reference).

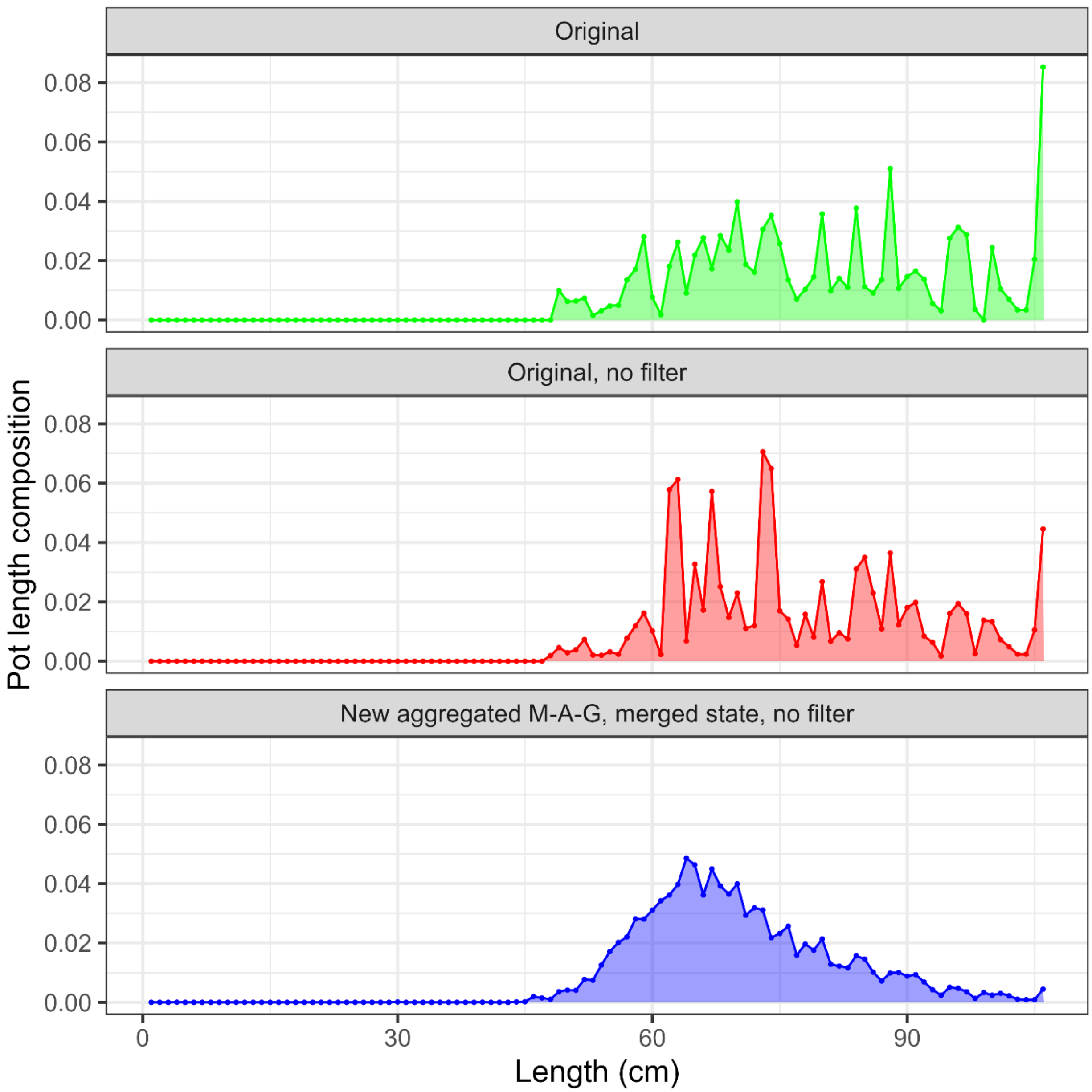

Figure 2.2.2. 2020 Pot fishery length composition following the original method for filtering and using ADF&G length frequency data (top panel), after removing the greater than 10 lengths per haul filter (middle panel), and after removing the greater than 10 lengths per haul filter and merging ADF&G length frequency data with federal data (bottom panel).

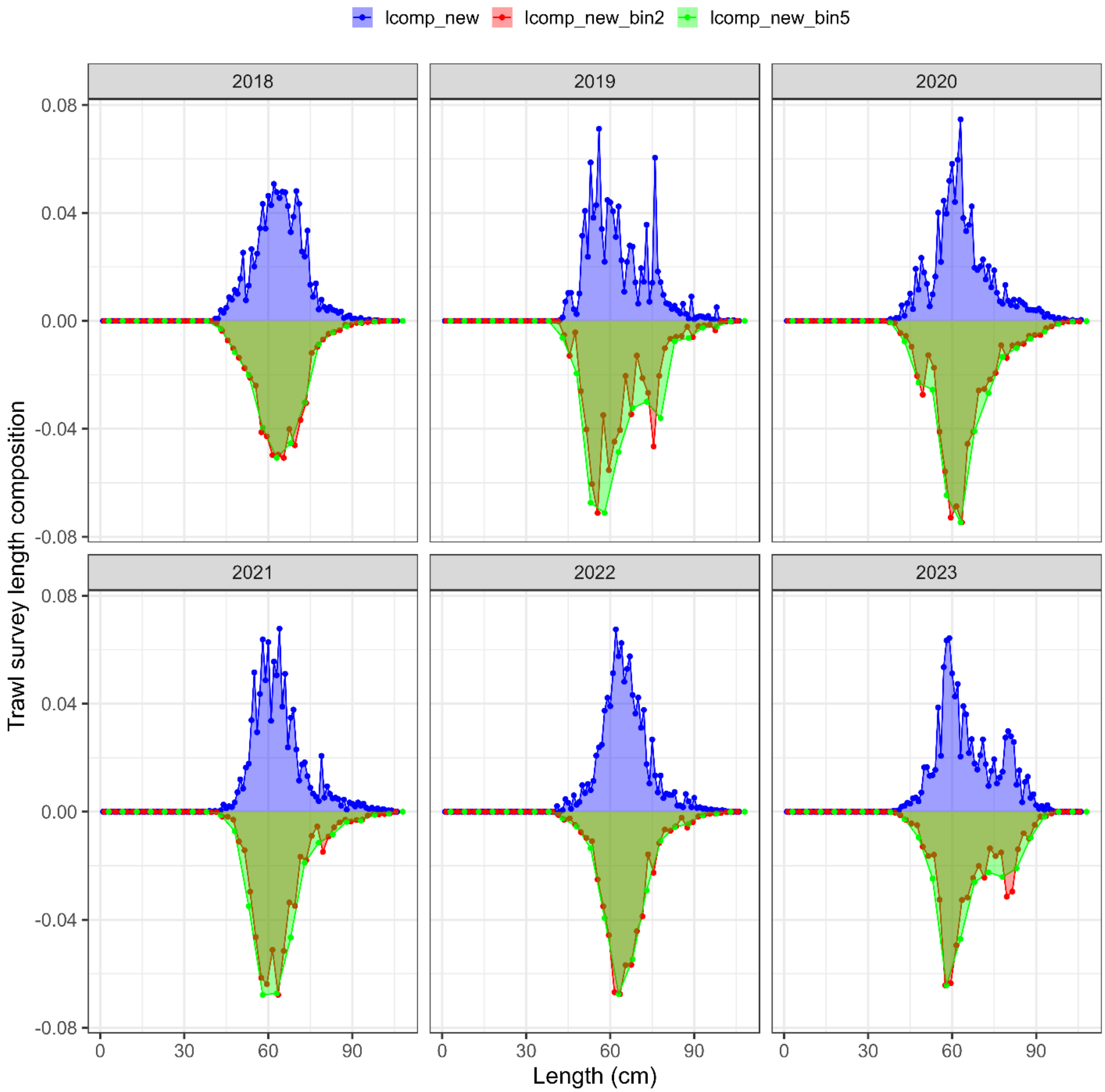

Figure 2.2.3. Recent bottom trawl survey length composition computed for 1 cm (lcomp_new shown in blue), 2 cm (lcomp_new_bin2 shown in red), and 5cm (lcomp_new-bin5 shown in green) length bins.

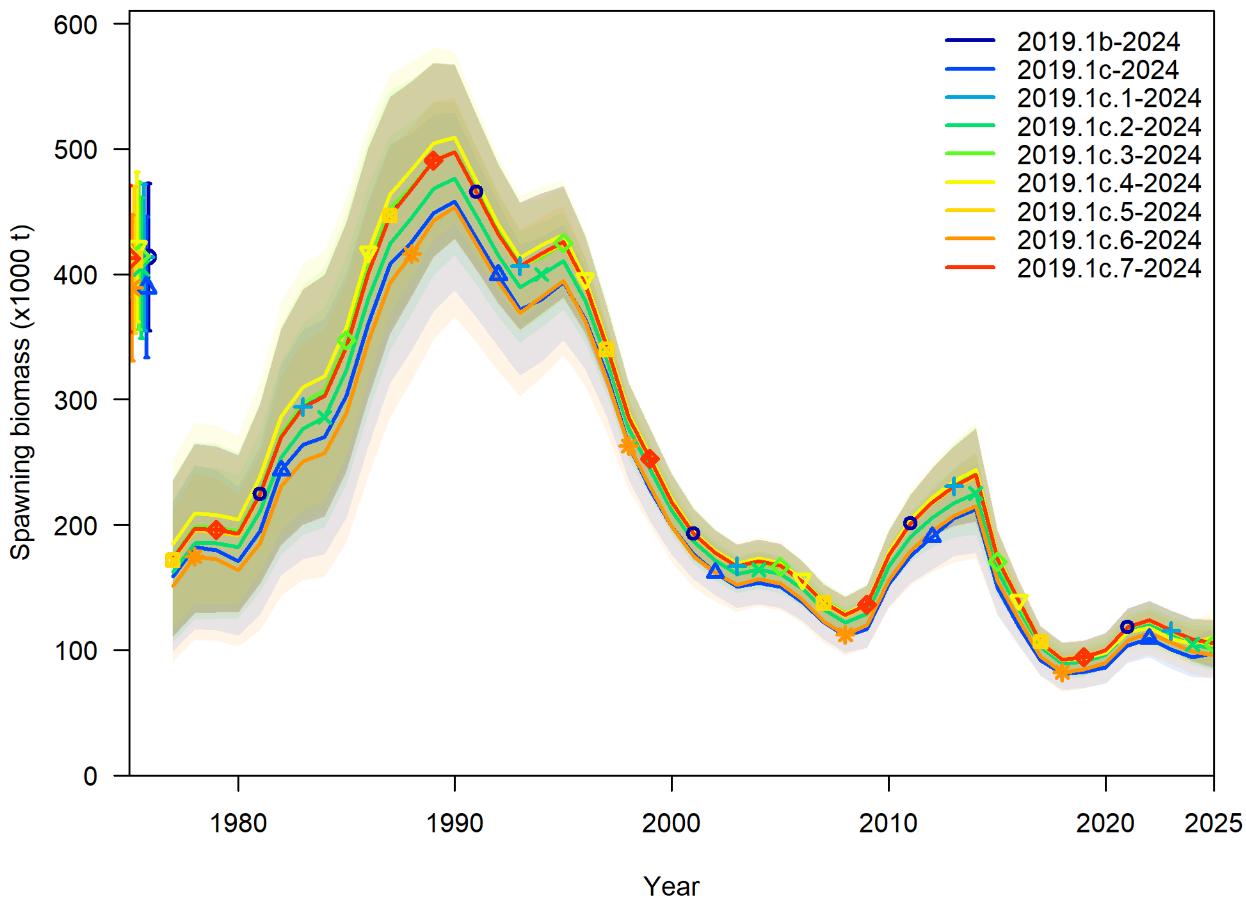

Figure 2.2.4. Estimated spawning biomass for the models considered in 2019.1c as compared to the 2023 assessment (2019.1b-2023) and the 2023 assessment with updated data (2019.1b-2024).

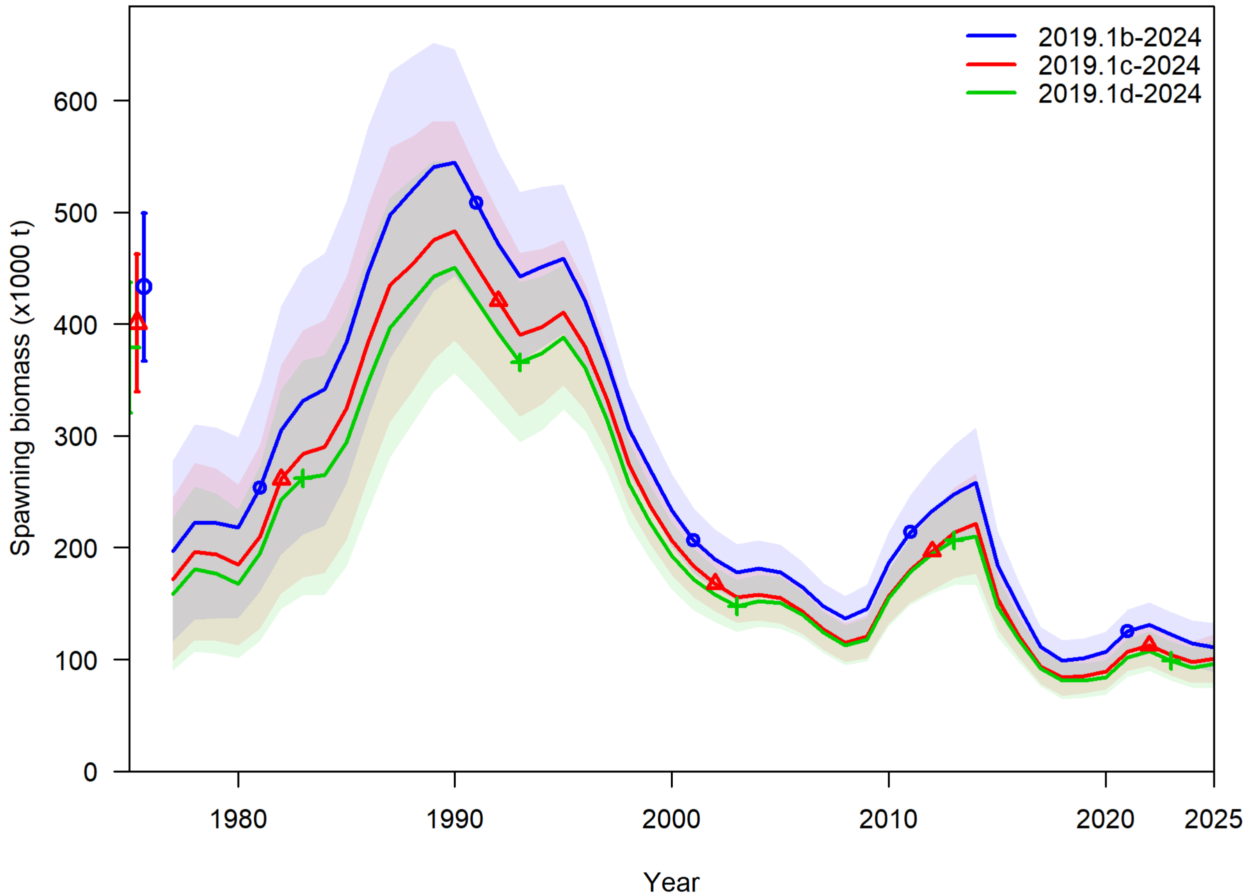

Figure 2.2.5. Estimated spawning biomass from models 2019.1b, 2019.1c, and 2019.1d.

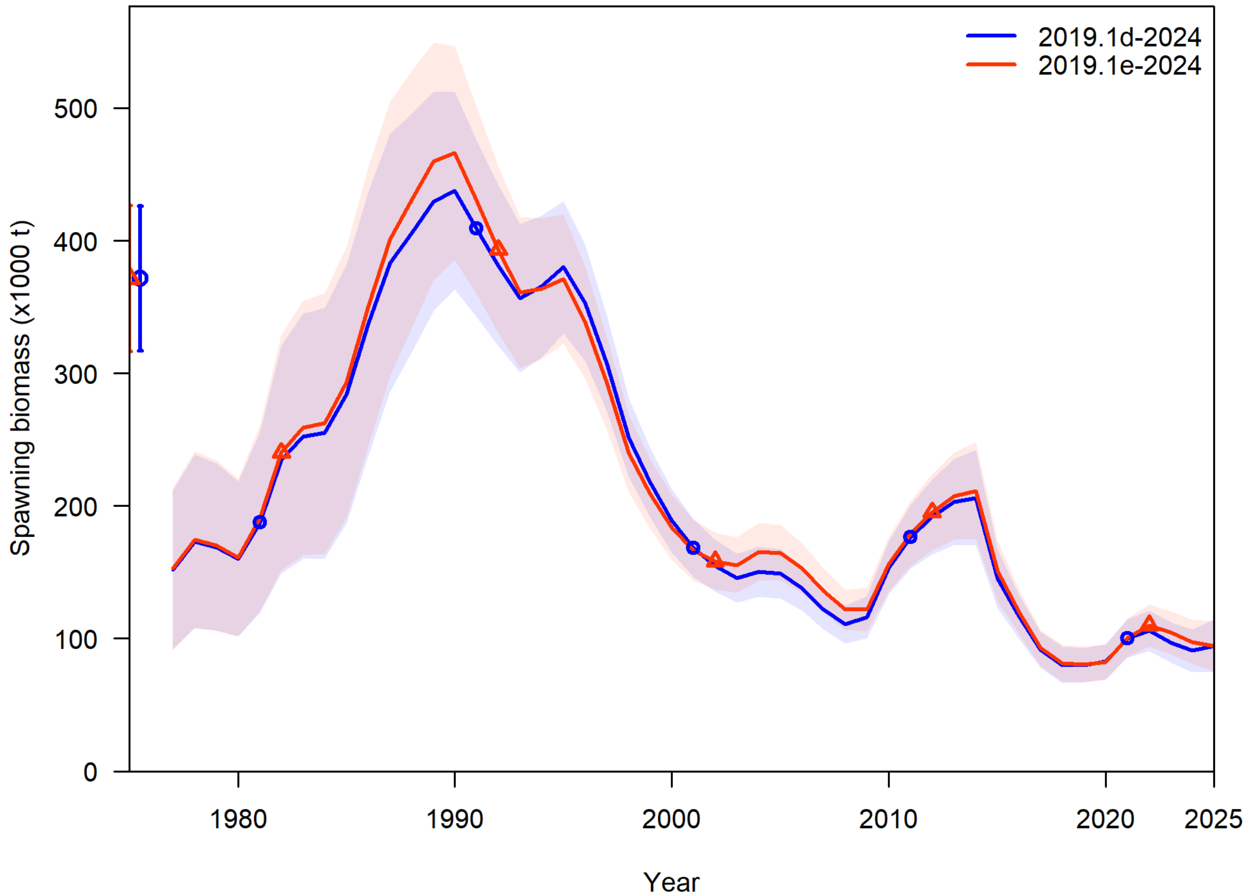

Figure 2.2.6. Estimated spawning biomass from models 2019.1d and 2019.1e.

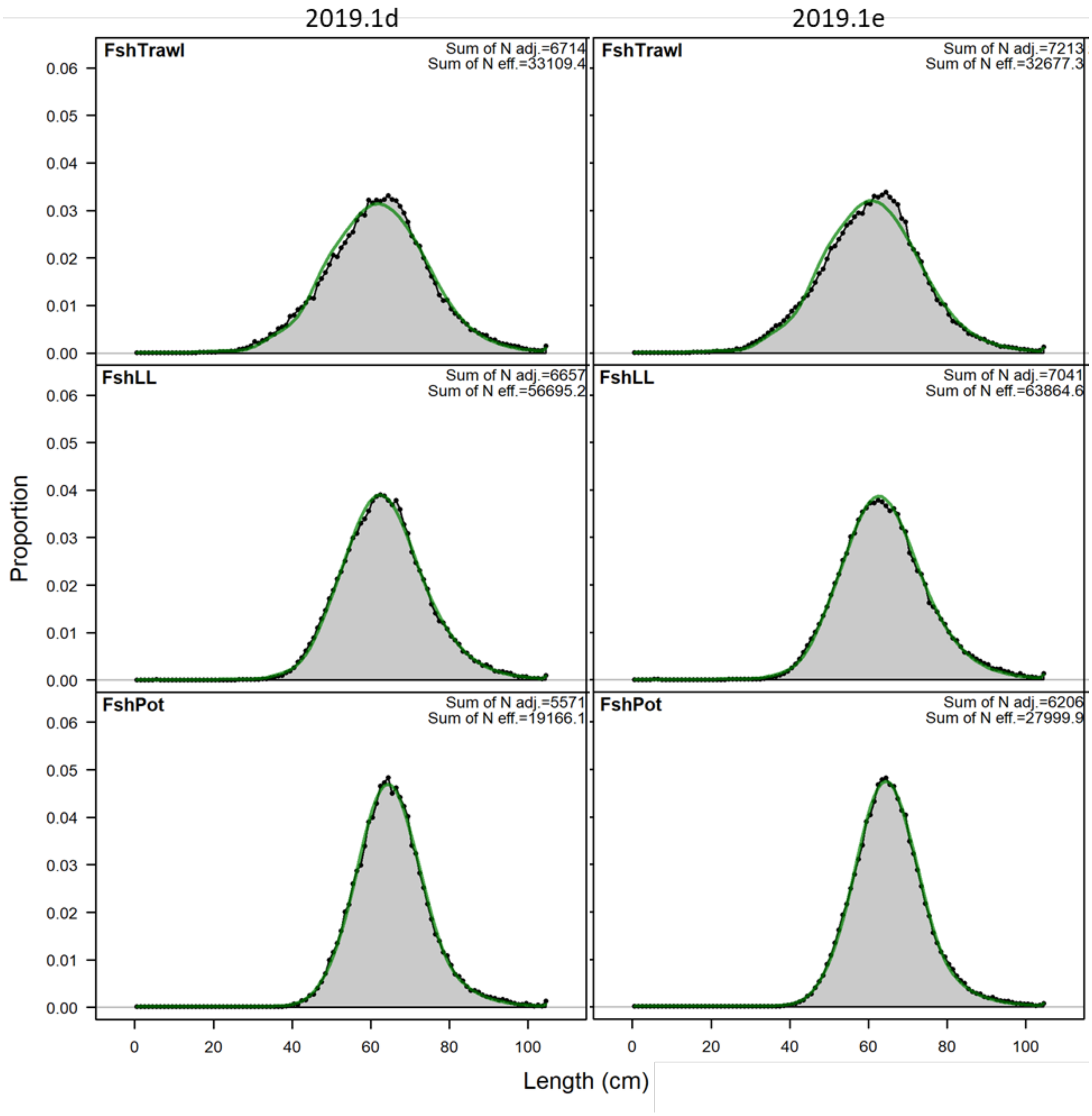

Figure 2.2.7. Aggregated fishery length composition fits for model 2019.1d (left panels) and 2019.1e (right panels).

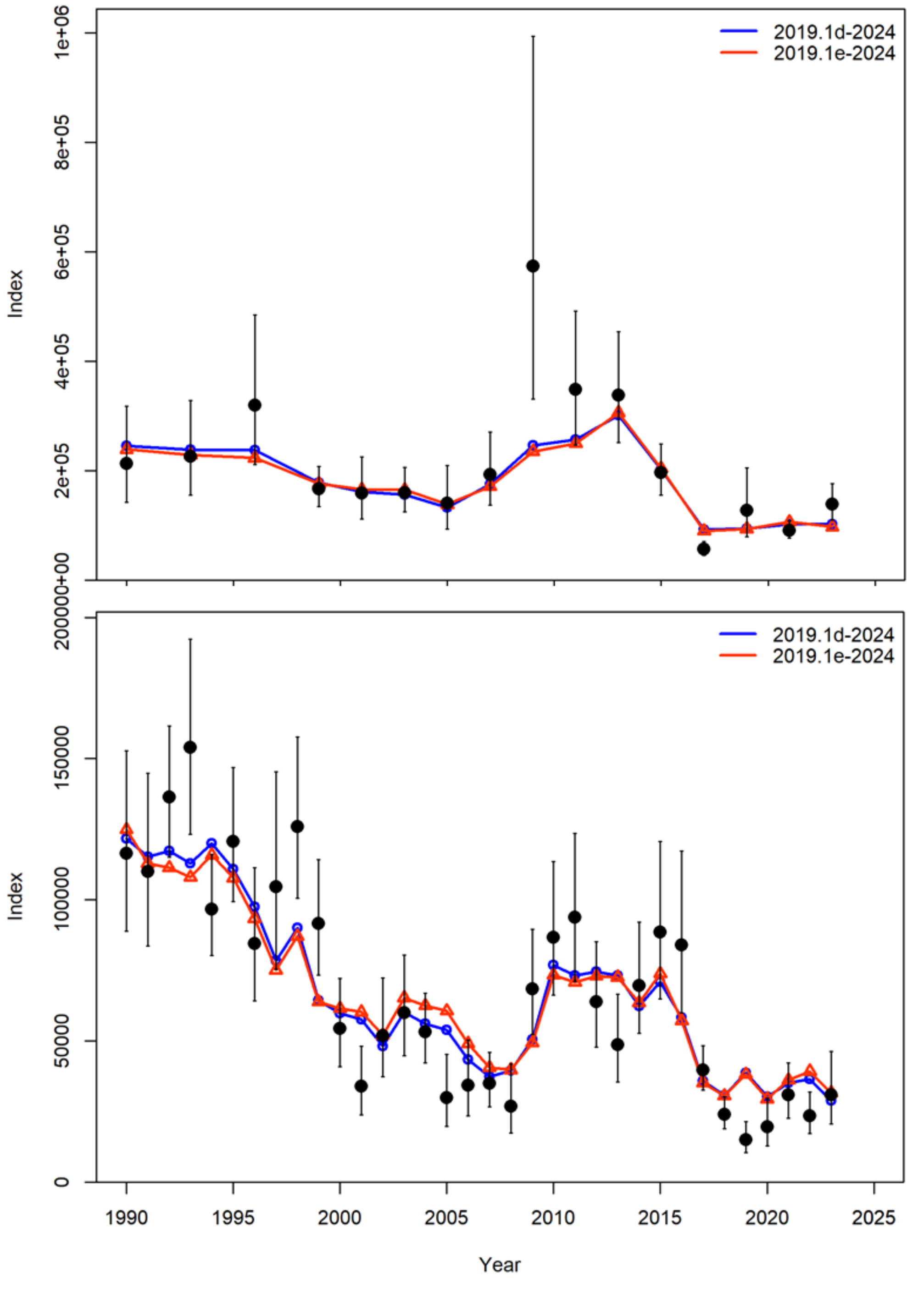

Figure 2.2.8. Model 2019.1d and 2019.1e fit to the bottom trawl survey numbers (top panel) and longline survey RPN (bottom panel).

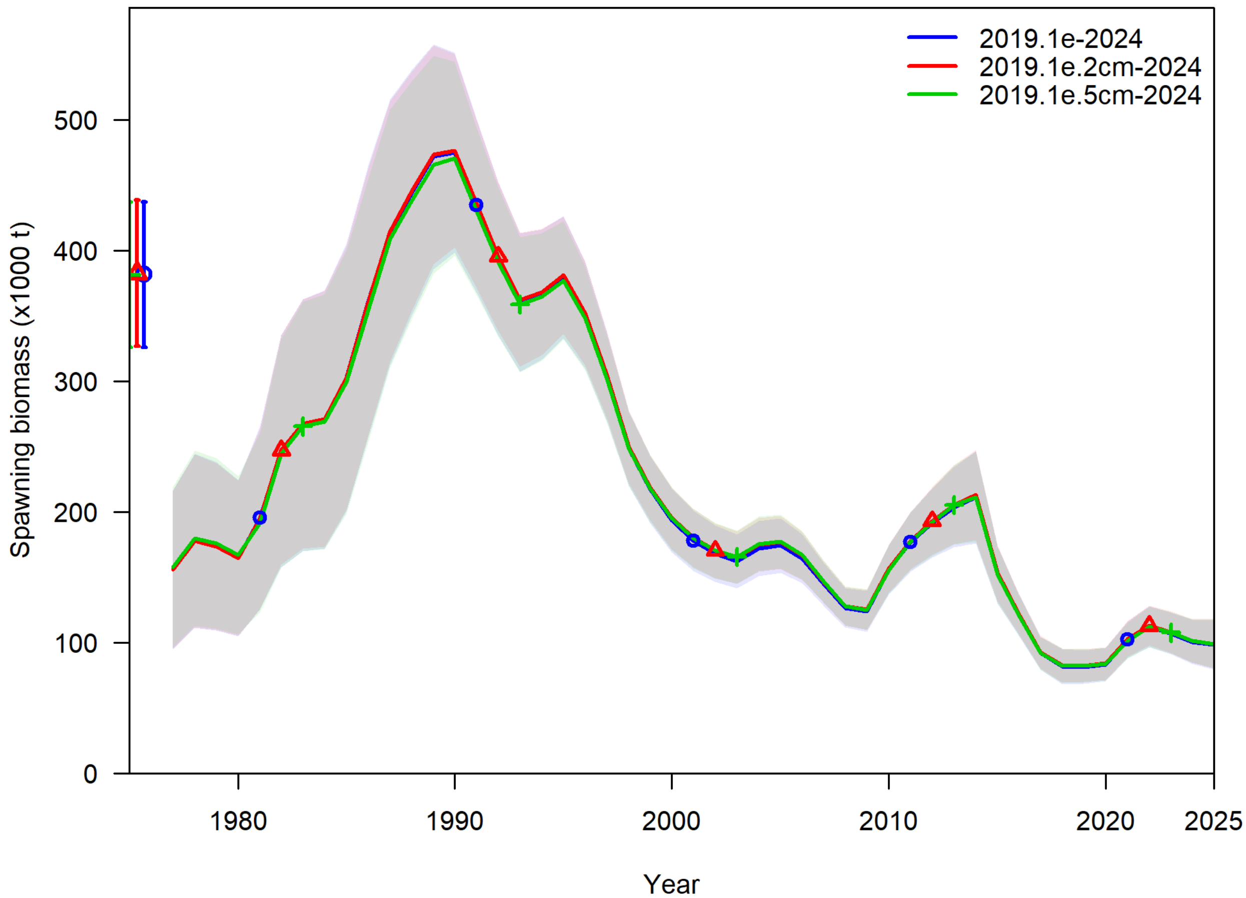

Figure 2.2.9. Estimated spawning biomass from models 2019.1e, 2019.1e.2cm, and 2019.1e.5cm.

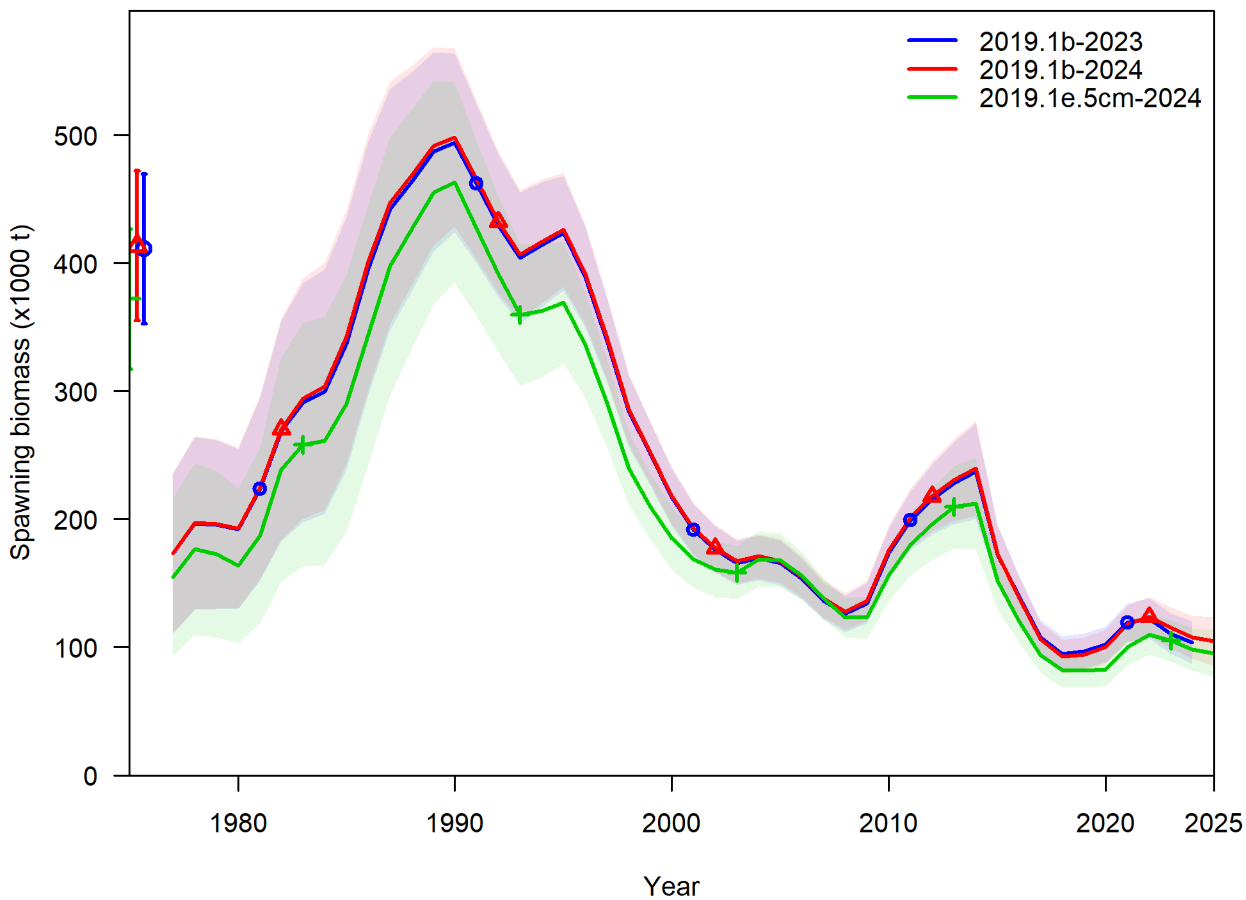

Figure 2.2.10. Estimated spawning biomass from the 2023 assessment model 2019.1b, model 2019.1b with updated data through 2024, and the recommended model 2019.1e.5cm.

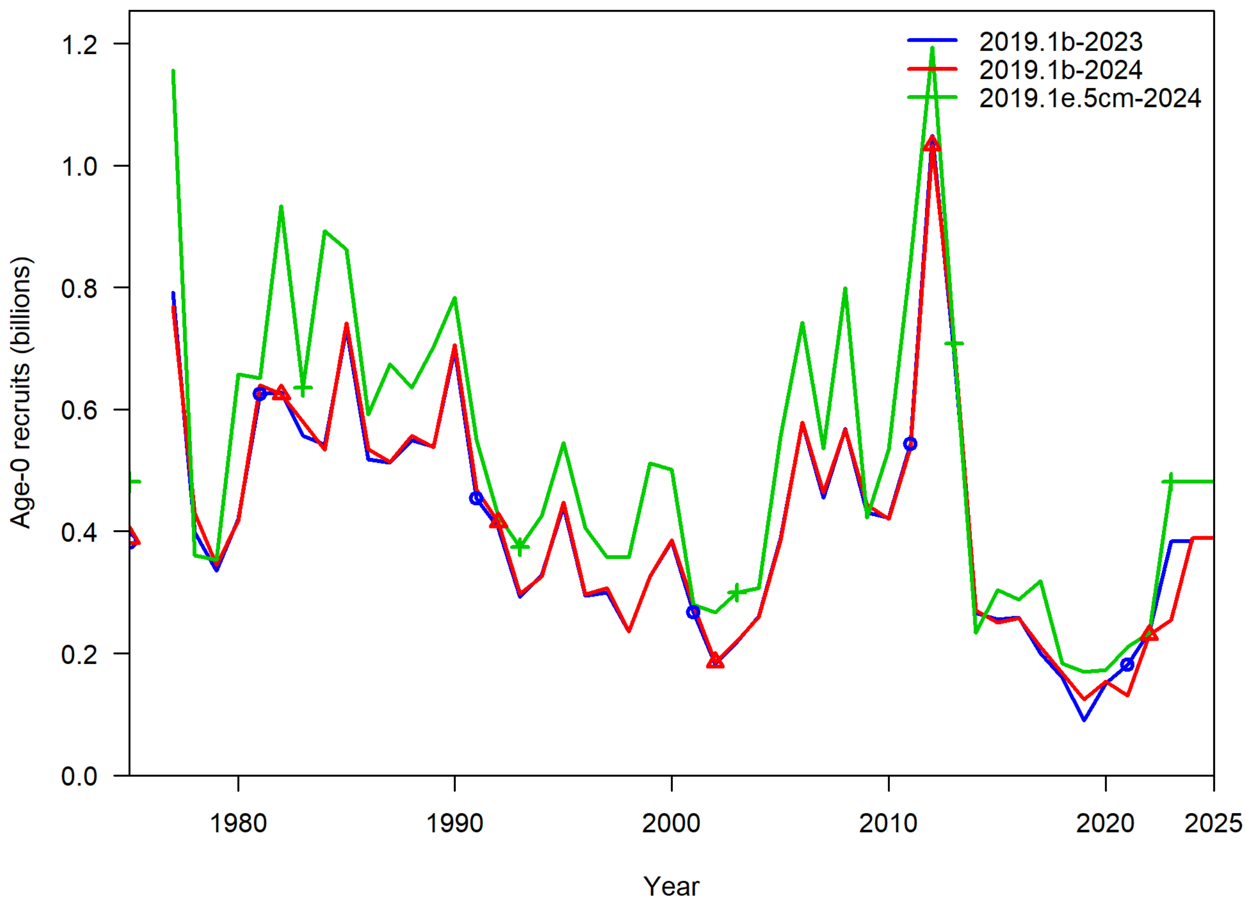

Figure 2.2.11. Estimated recruitment from the 2023 assessment model 2019.1b, model 2019.1b with updated data through 2024, and the recommended model 2019.1e.5cm.

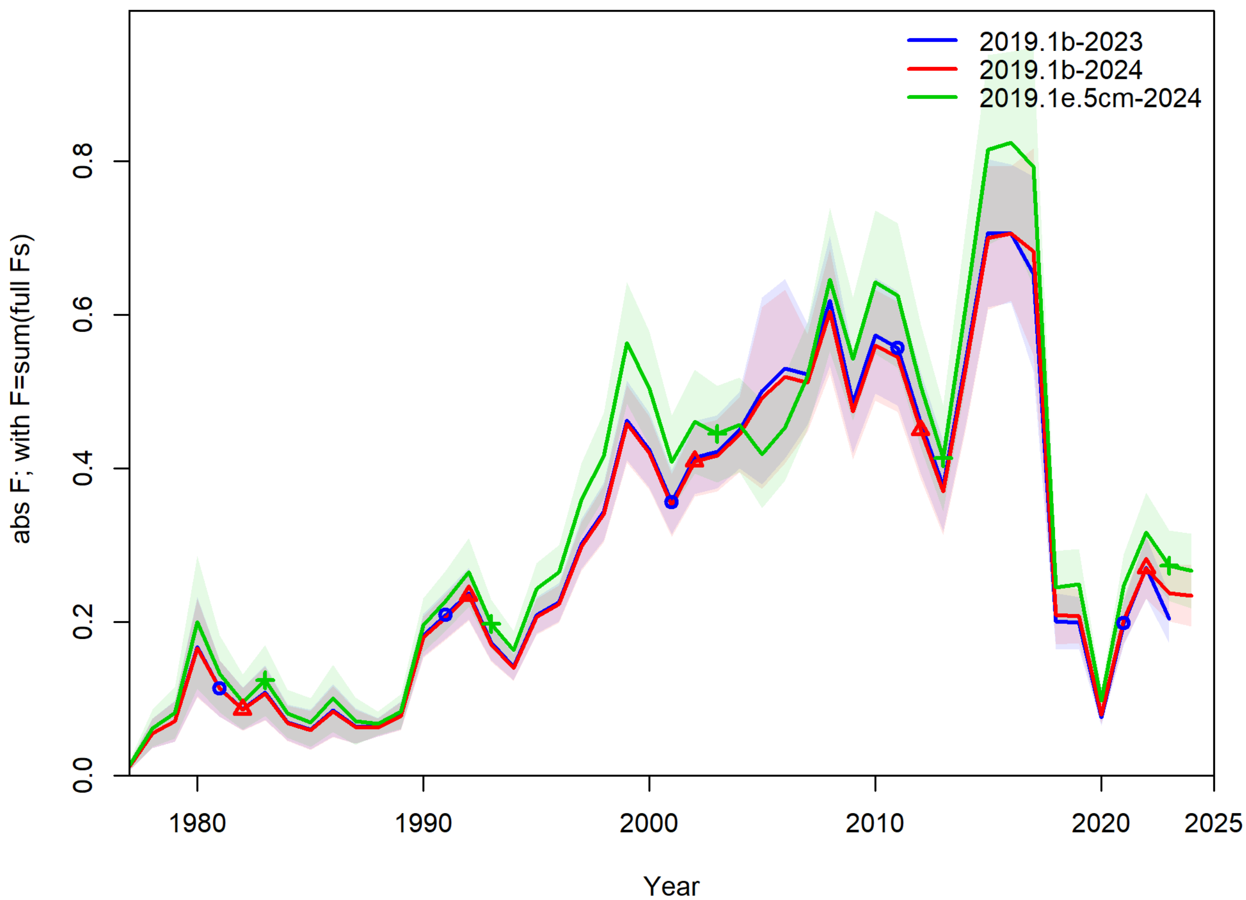

Figure 2.2.12. Estimated fishing mortality from the 2023 assessment model 2019.1b, model 2019.1b with updated data through 2024, and the recommended model 2019.1e.5cm.

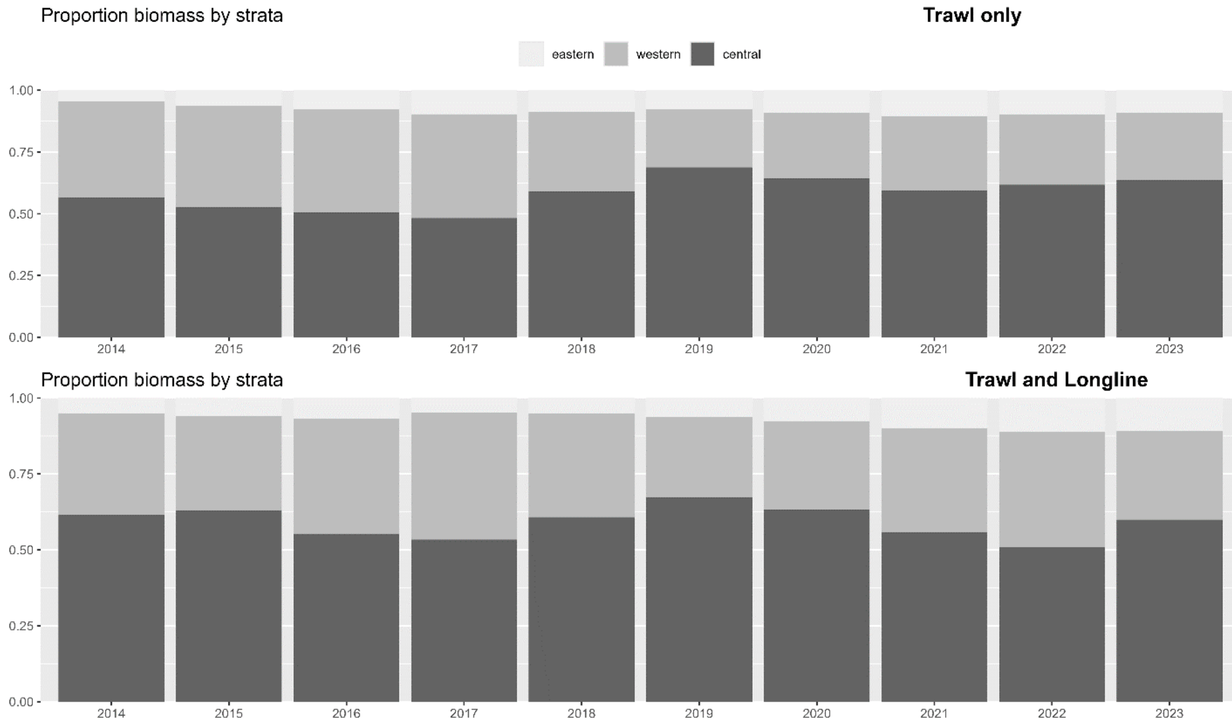

Figure 2.2.13. Comparison of apportionment from the REMA model using on the AFSC bottom trawl survey (top panel), and using both the AFSC bottom trawl survey and longline survey (bottom panel).

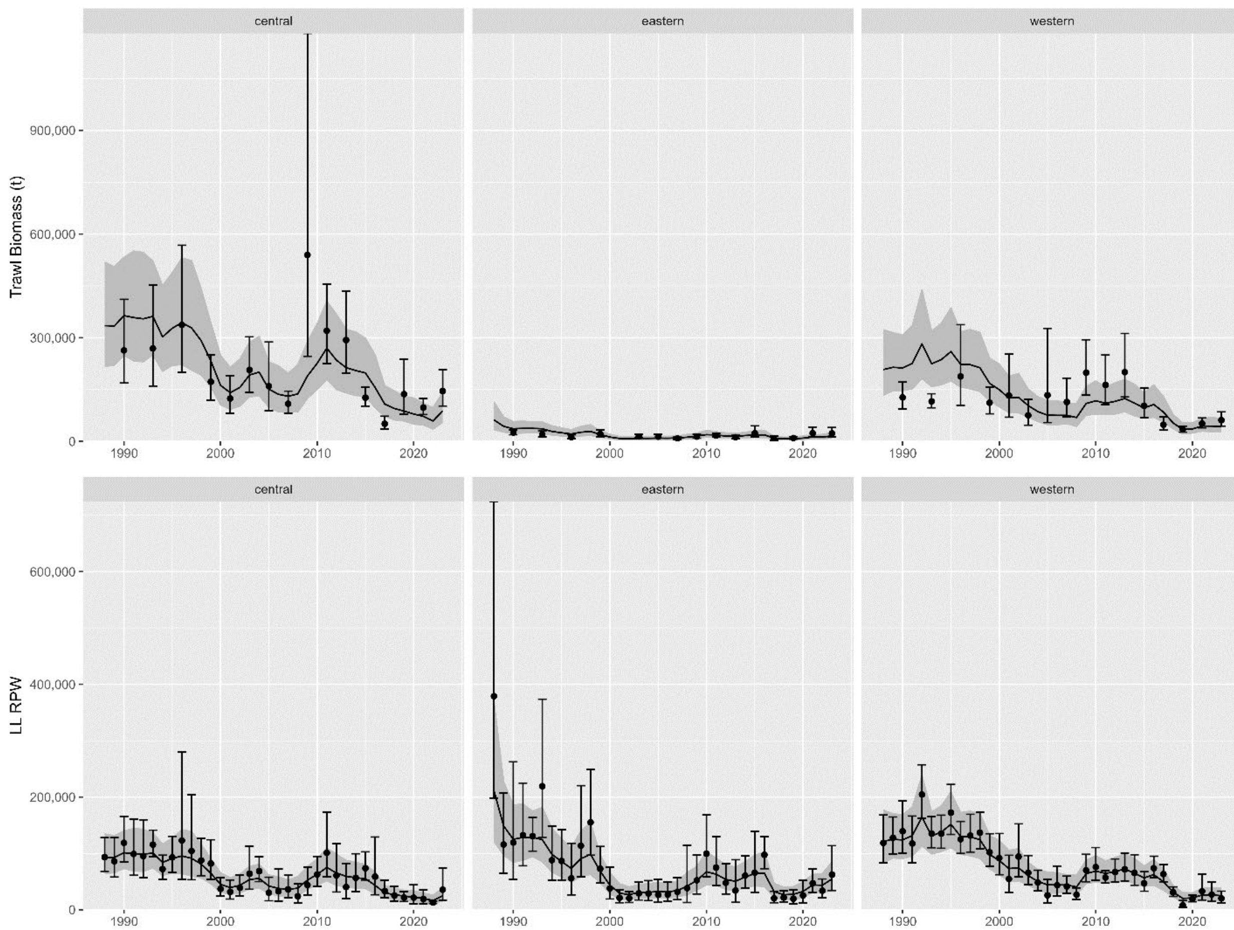

Figure 2.2.14. Example REMA model fit to both the AFSC bottom trawl survey (top panel) and longline survey (bottom panel).

Appendix 2.3 Recommended model fits to compositional data

Introduction

Contained within this appendix are the figures that show the author's recommended model fit to length composition and conditional age-at-length composition.

Figures

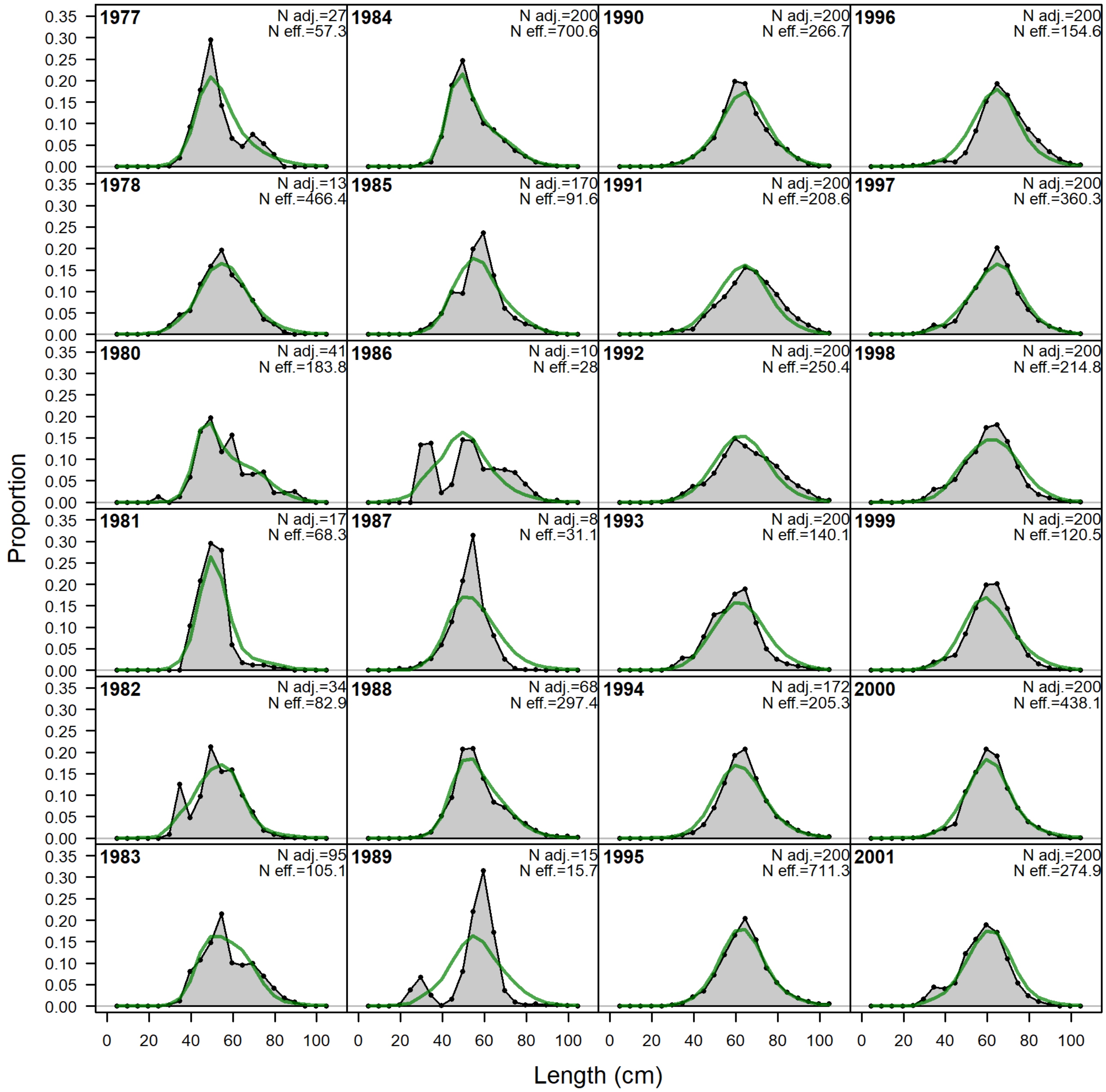

Figure 2.3.1. Recommended model fits to trawl fishery length composition (black points with grey shading show observed values, green line is model fit).

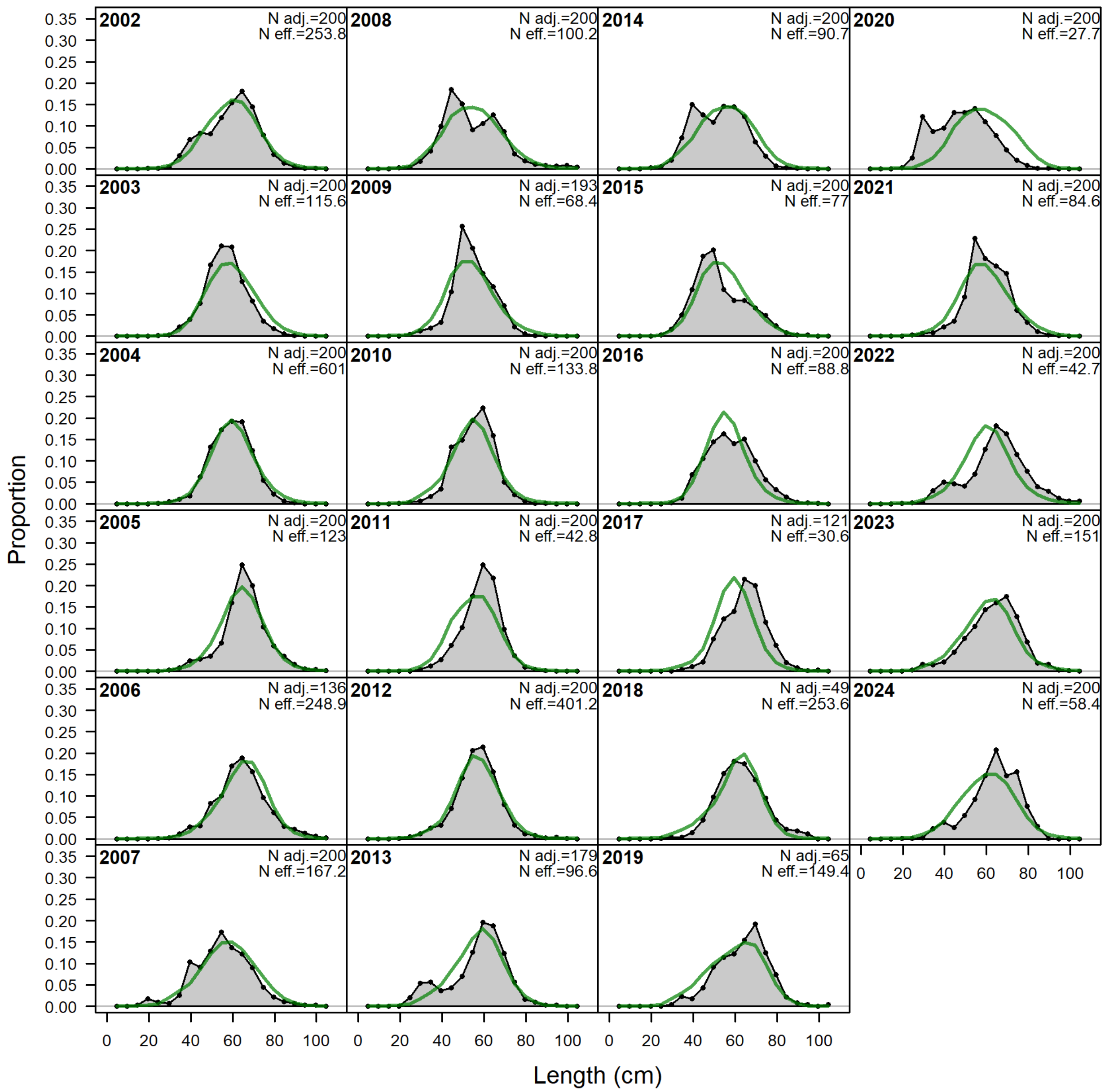

Figure 2.3.2. Recommended model fits to trawl fishery length composition (cont.).

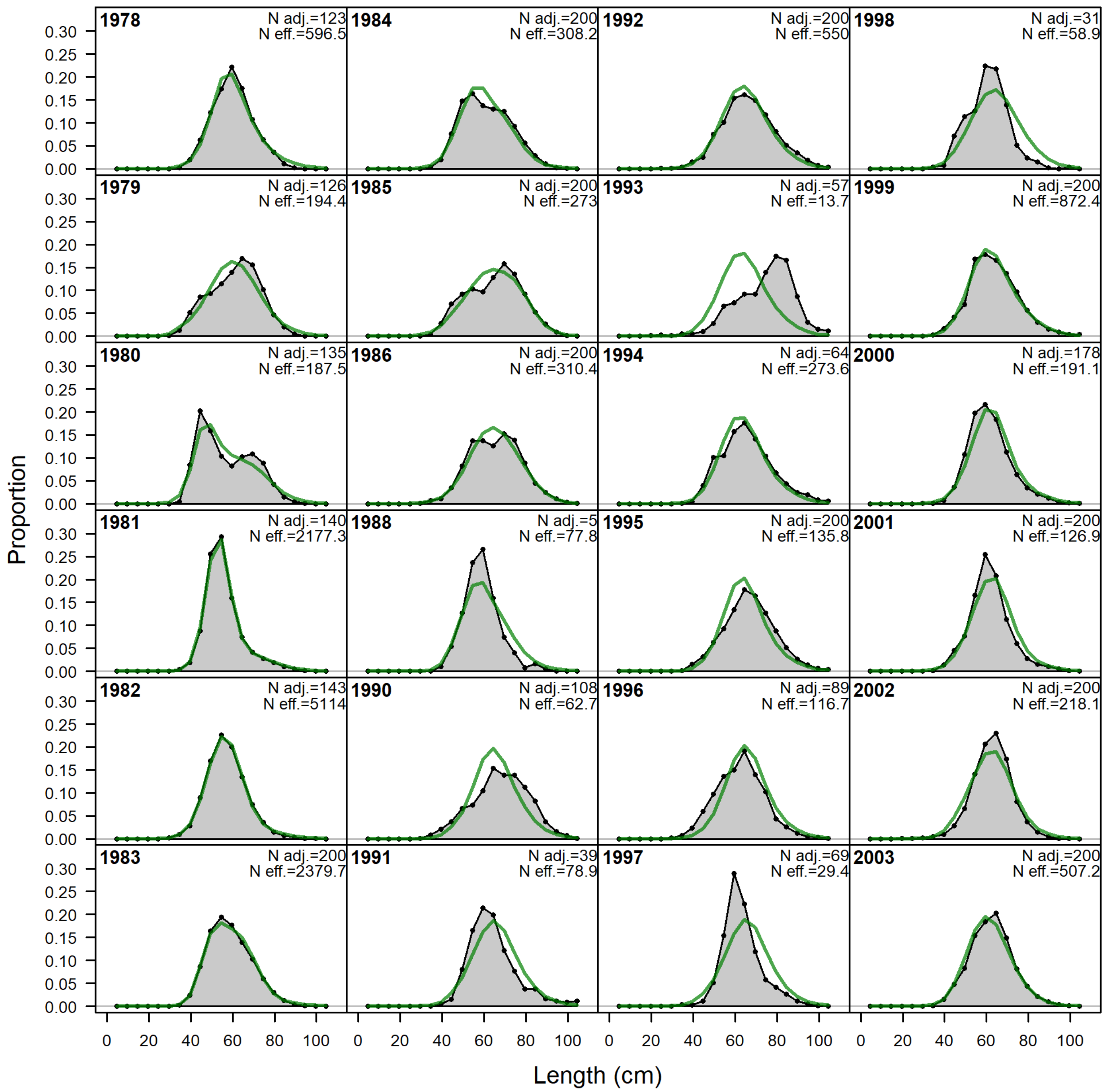

Figure 2.3.3. Recommended model fits to longline fishery length composition (black points with grey shading show observed values, green line is model fit).

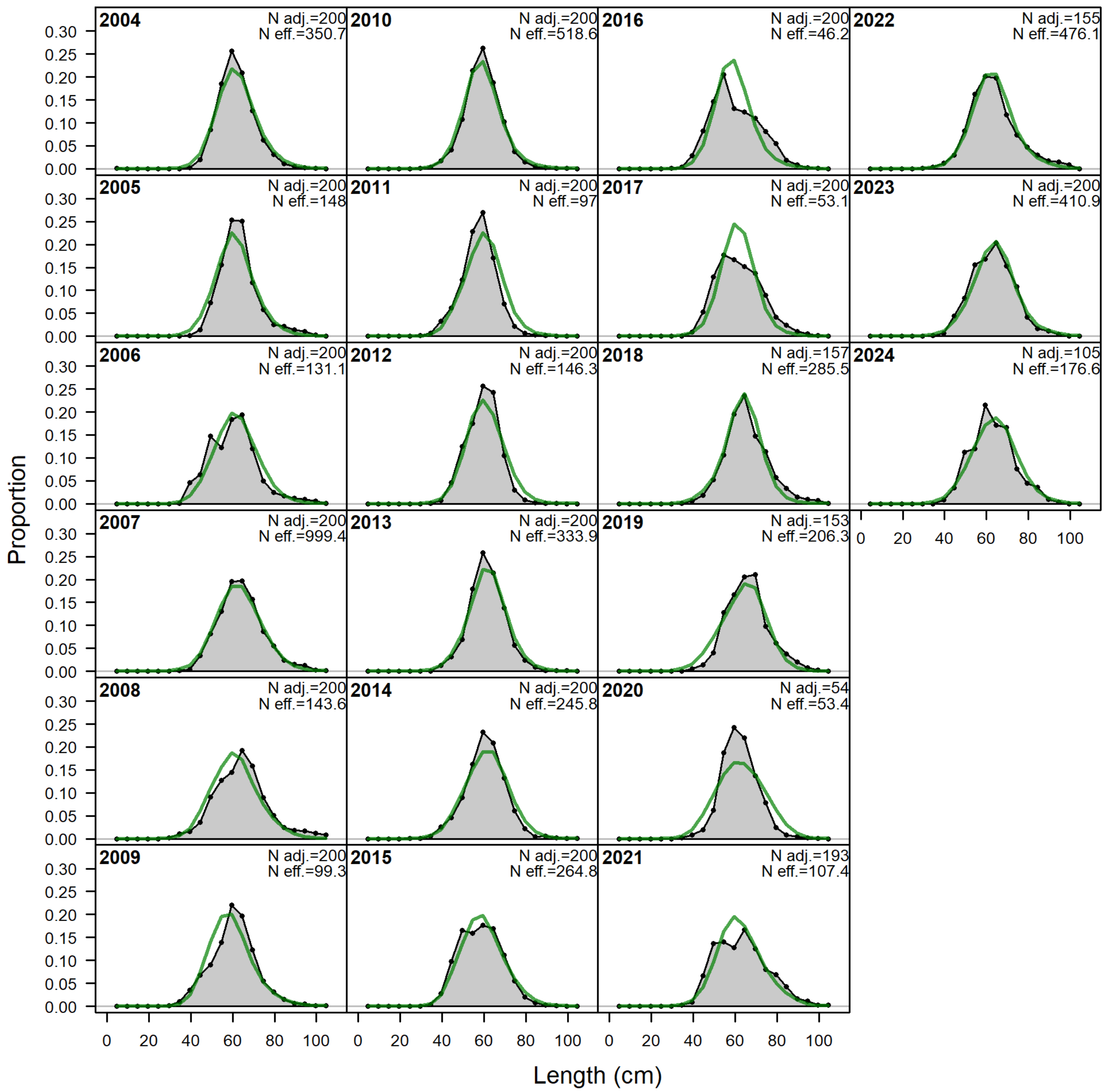

Figure 2.3.4. Recommended model fits to longline fishery length composition (cont.).

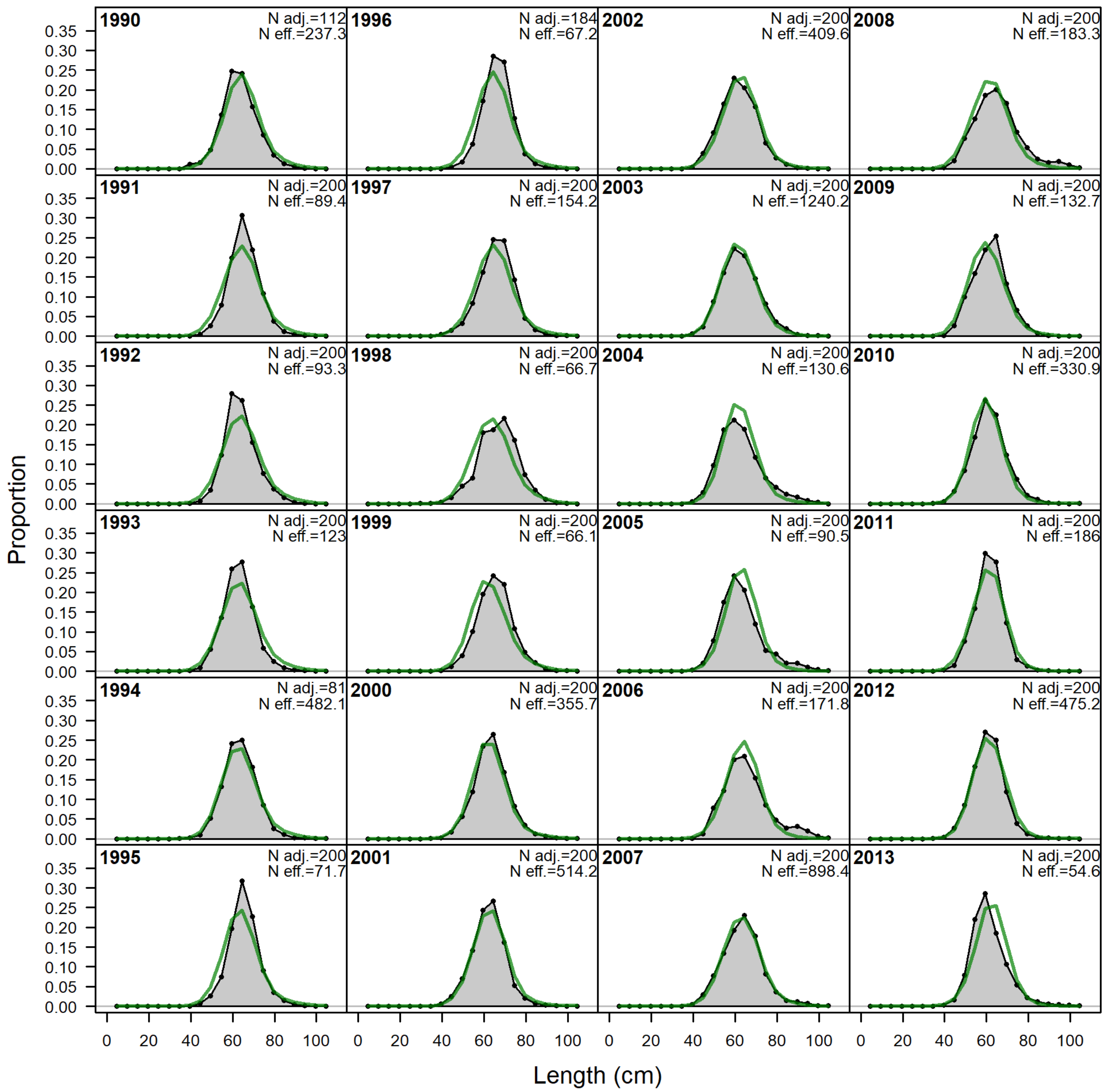

Figure 2.3.5. Recommended model fits to pot fishery length composition (black points with grey shading show observed values, green line is model fit).

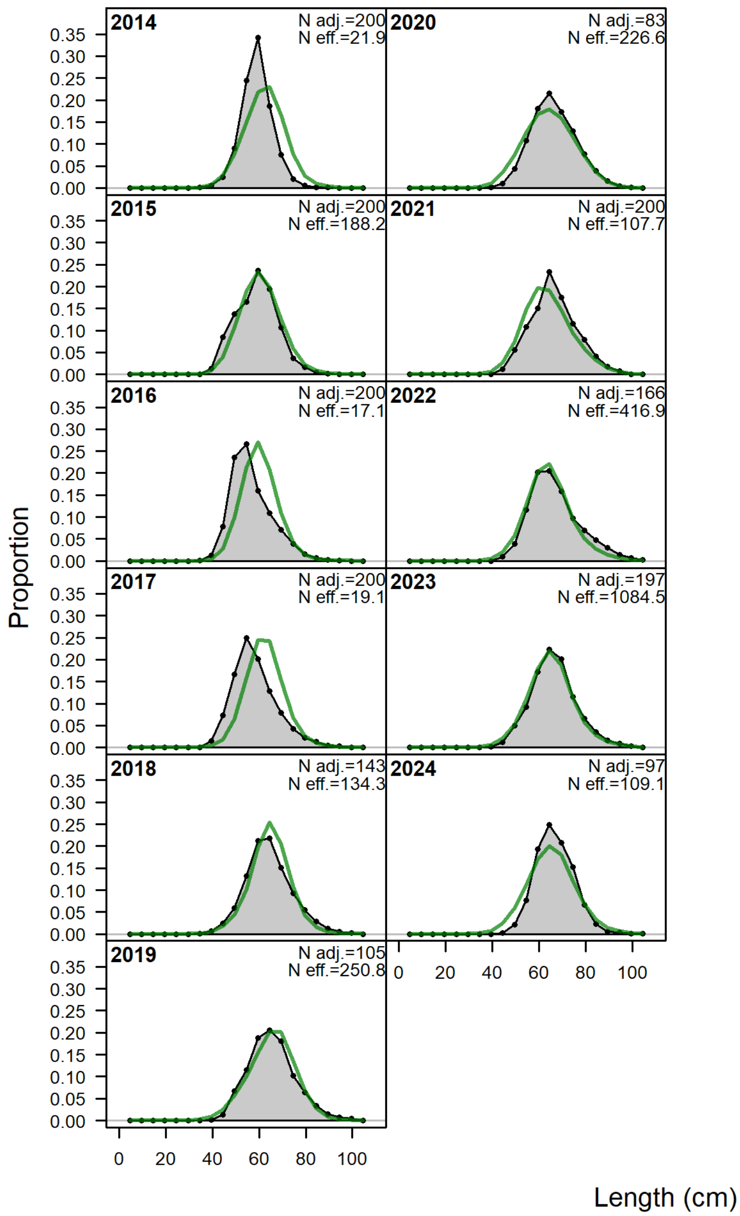

Figure 2.3.6. Recommended model fits to pot fishery length composition (cont.).

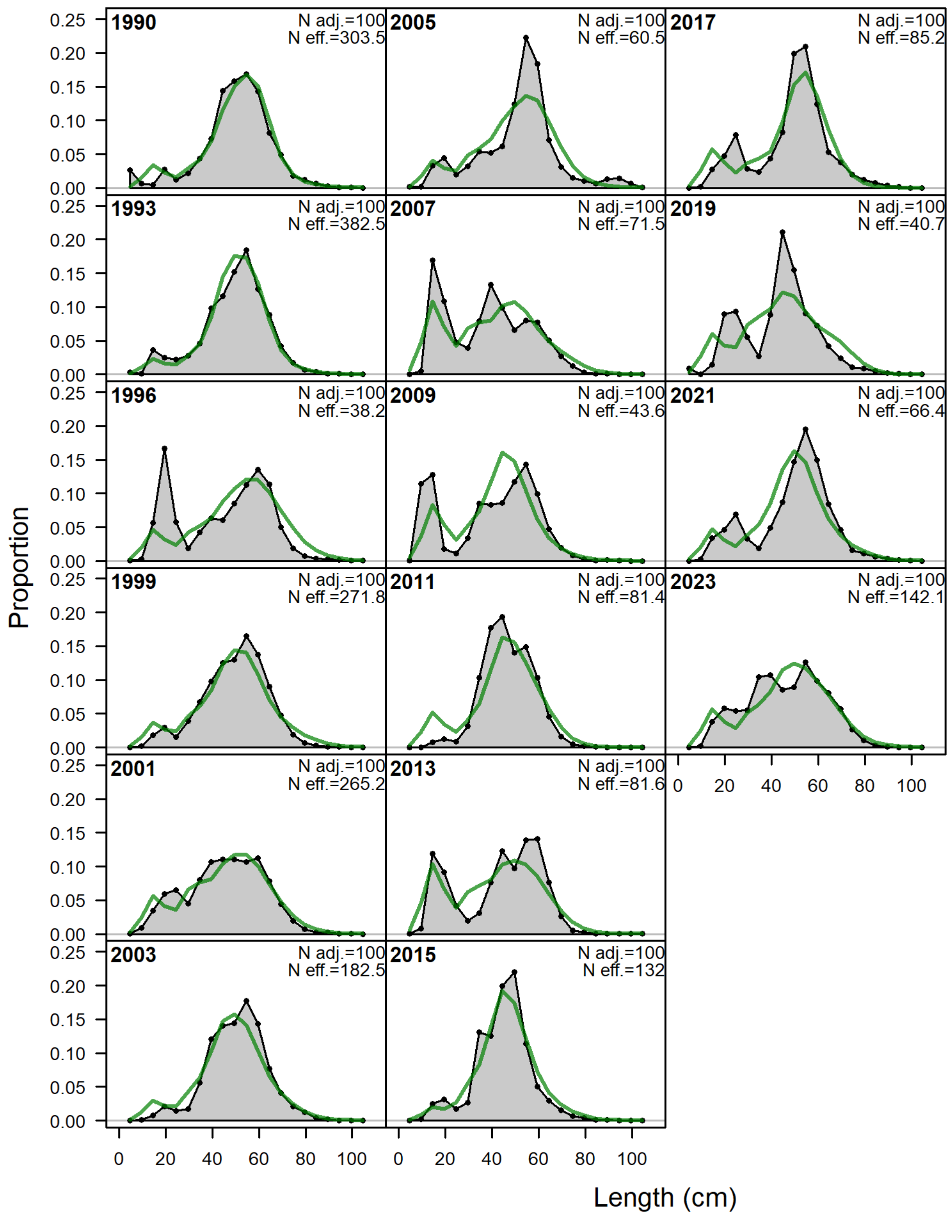

Figure 2.3.7. Recommended model fits to AFSC bottom trawl survey length composition (black points with grey shading show observed values, green line is model fit).

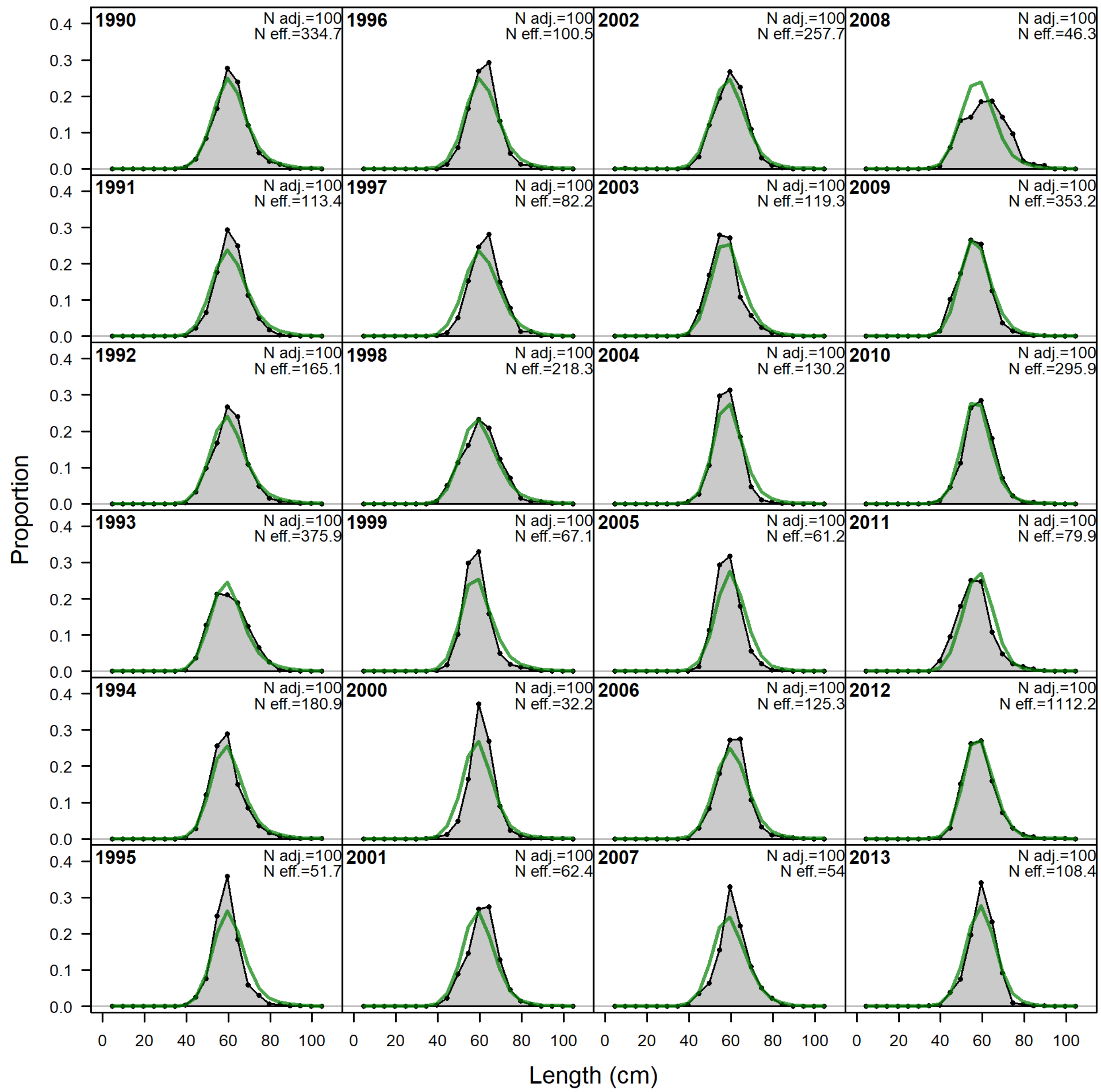

Figure 2.3.8. Recommended model fits to AFSC longline survey length composition (black points with grey shading show observed values, green line is model fit).

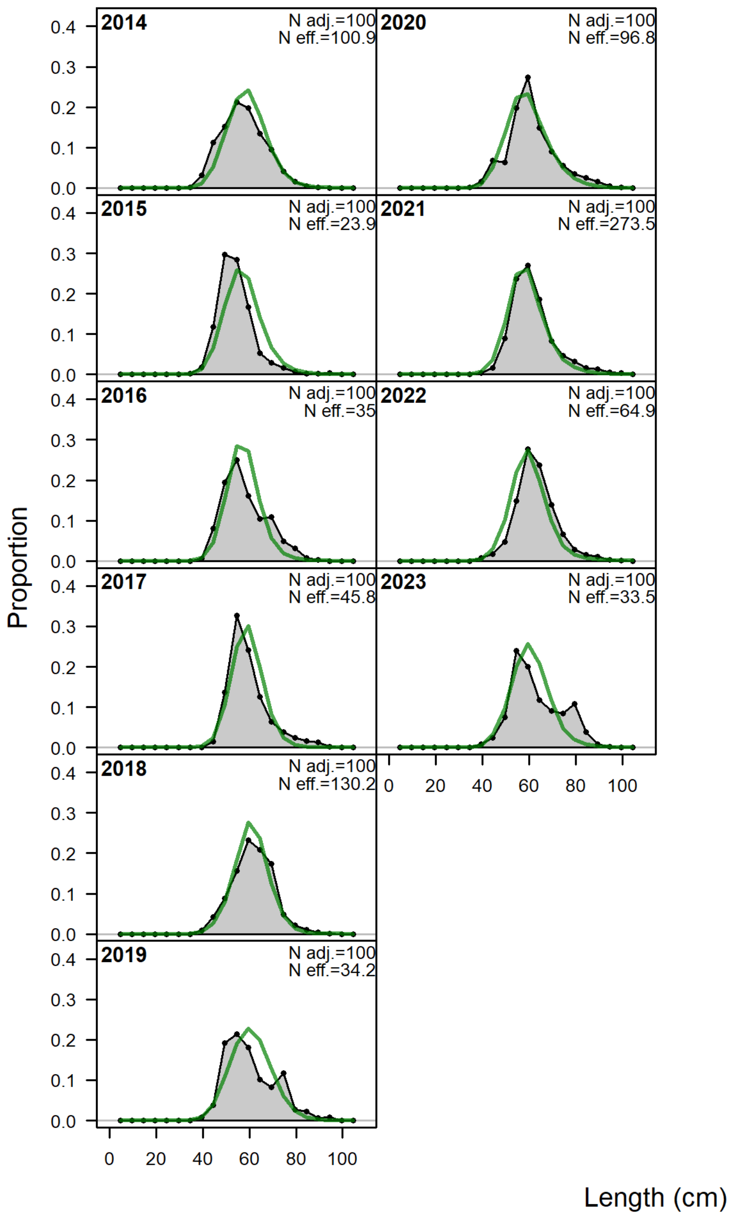

Figure 2.3.9. Recommended model fits to AFSC longline survey length composition (cont.).

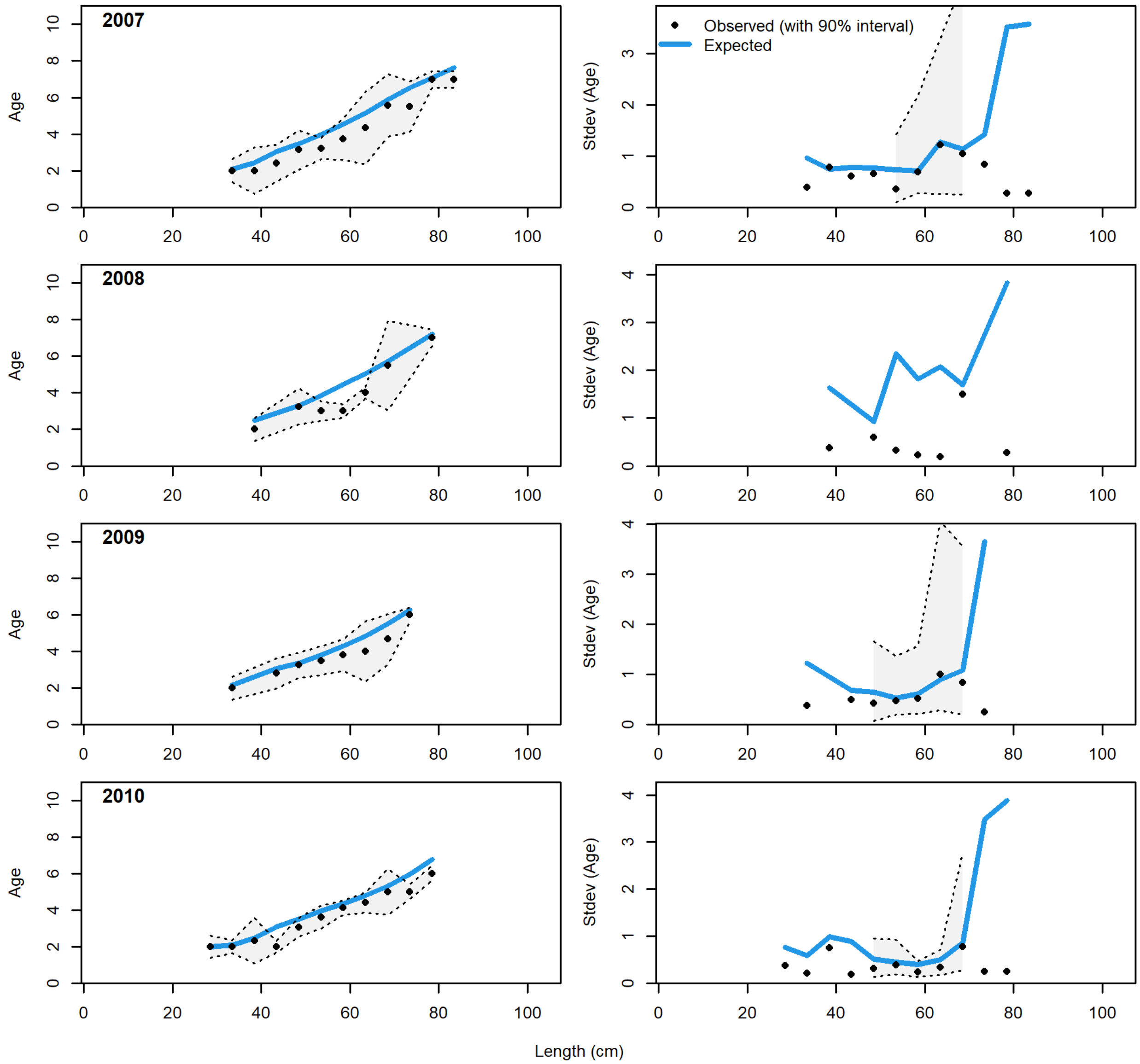

Figure 2.3.10. Recommended model fits to trawl fishery condition age-at-length (black dots with grey shading outlined with dashed line are observed values, blue line is model fit).

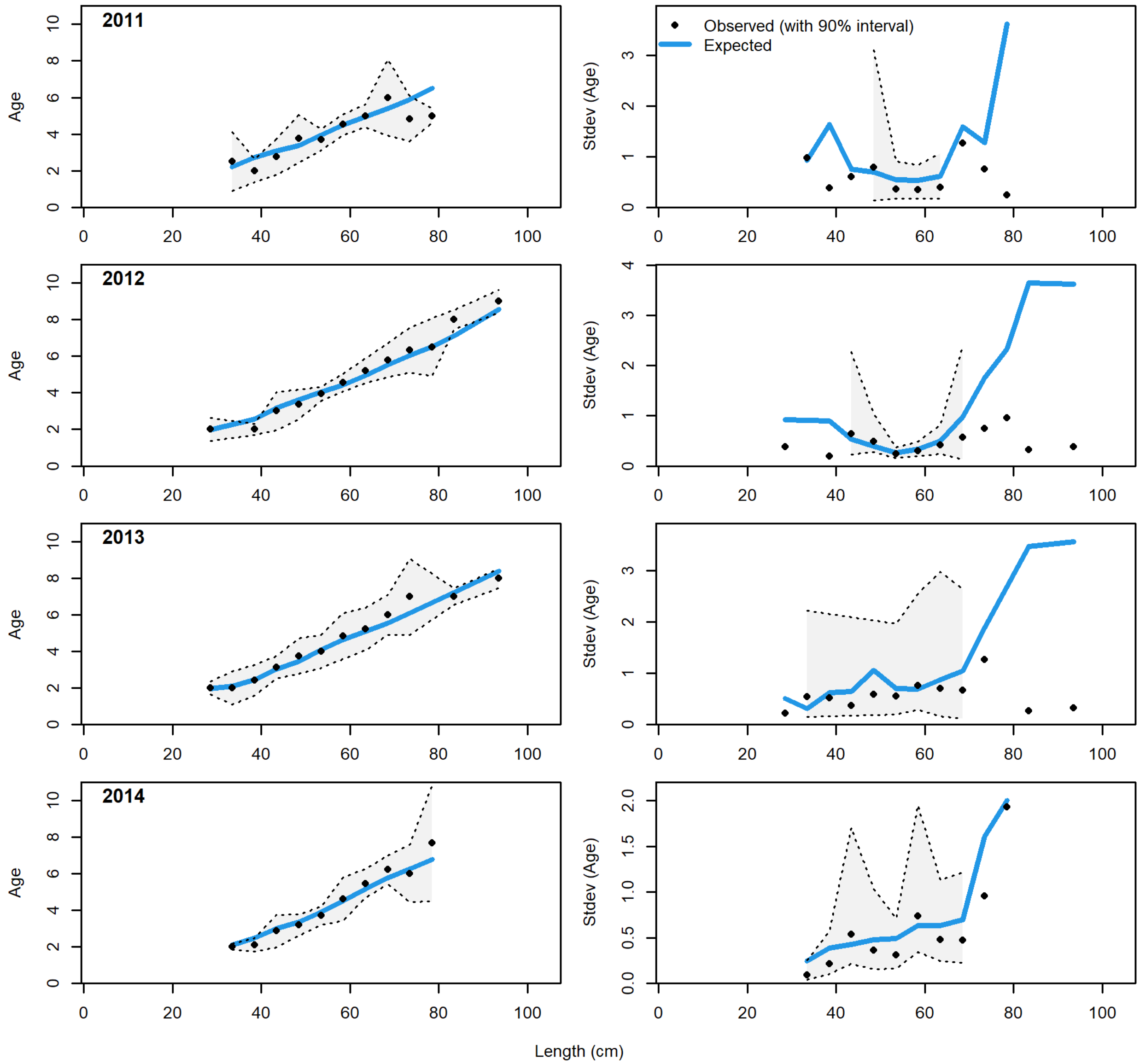

Figure 2.3.11. Recommended model fits to trawl fishery condition age-at-length (cont.).

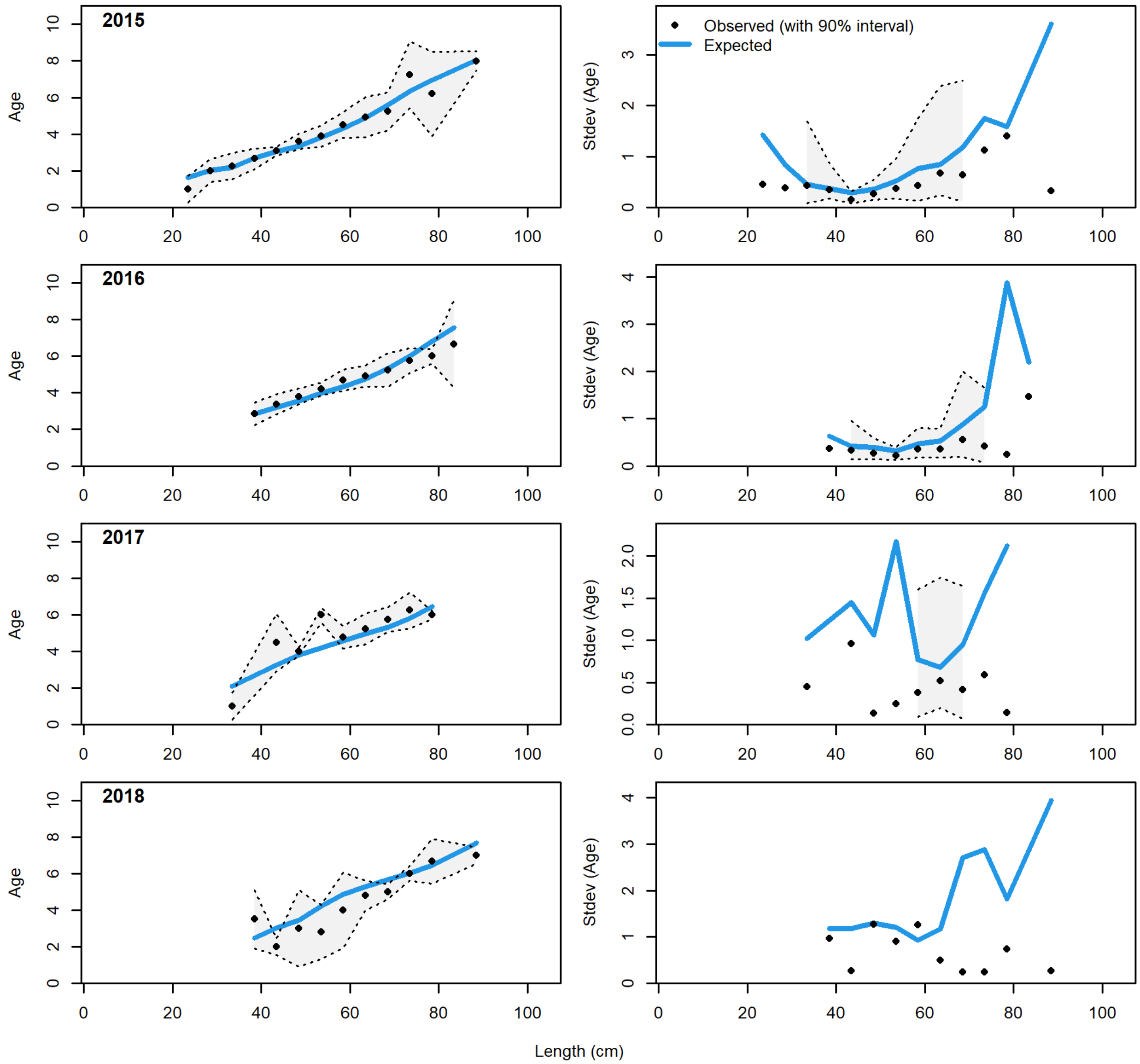

Figure 2.3.12. Recommended model fits to trawl fishery condition age-at-length (cont.).

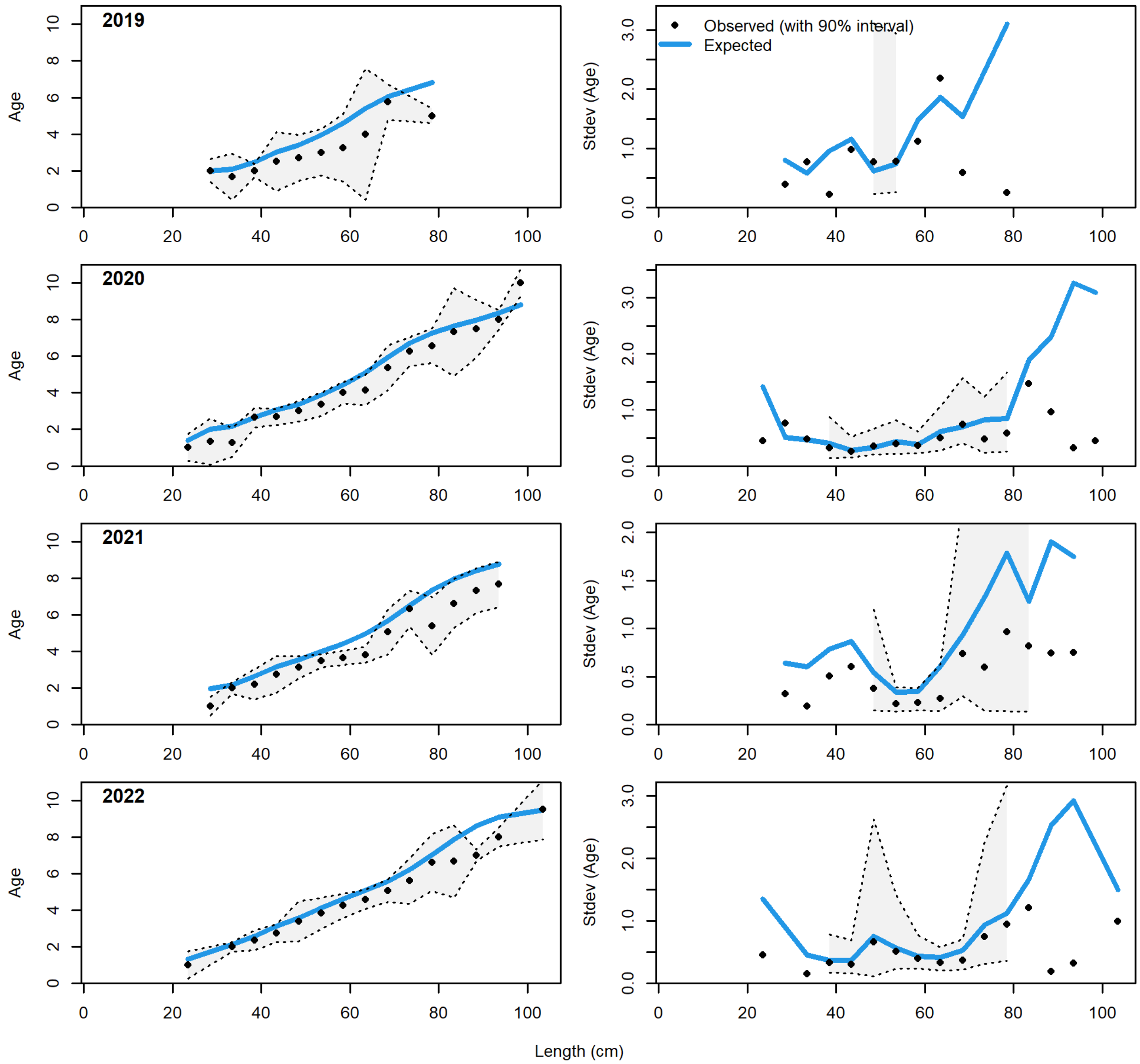

Figure 2.3.13. Recommended model fits to trawl fishery condition age-at-length (cont.).

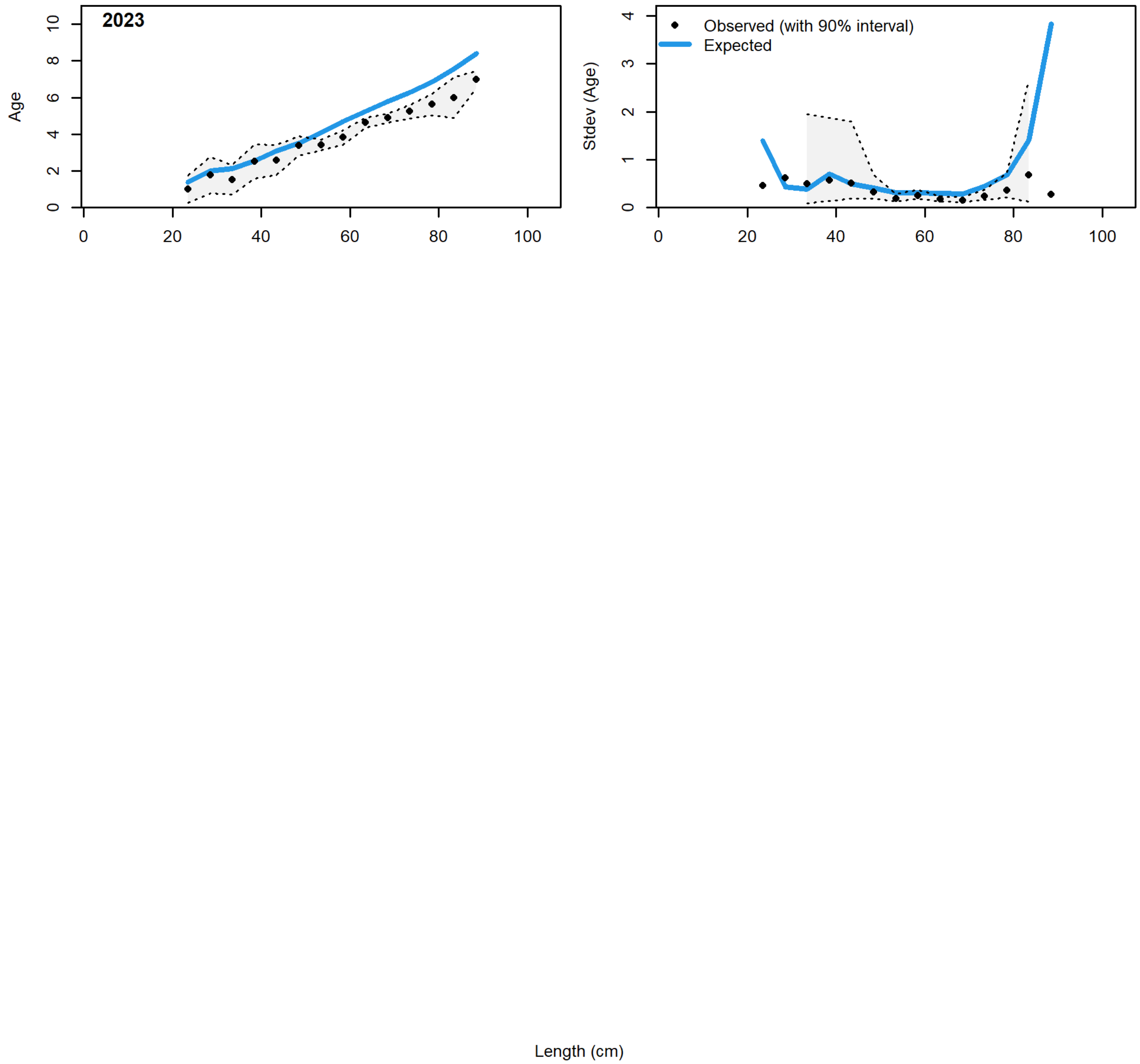

Figure 2.3.14. Recommended model fits to trawl fishery condition age-at-length (cont.).

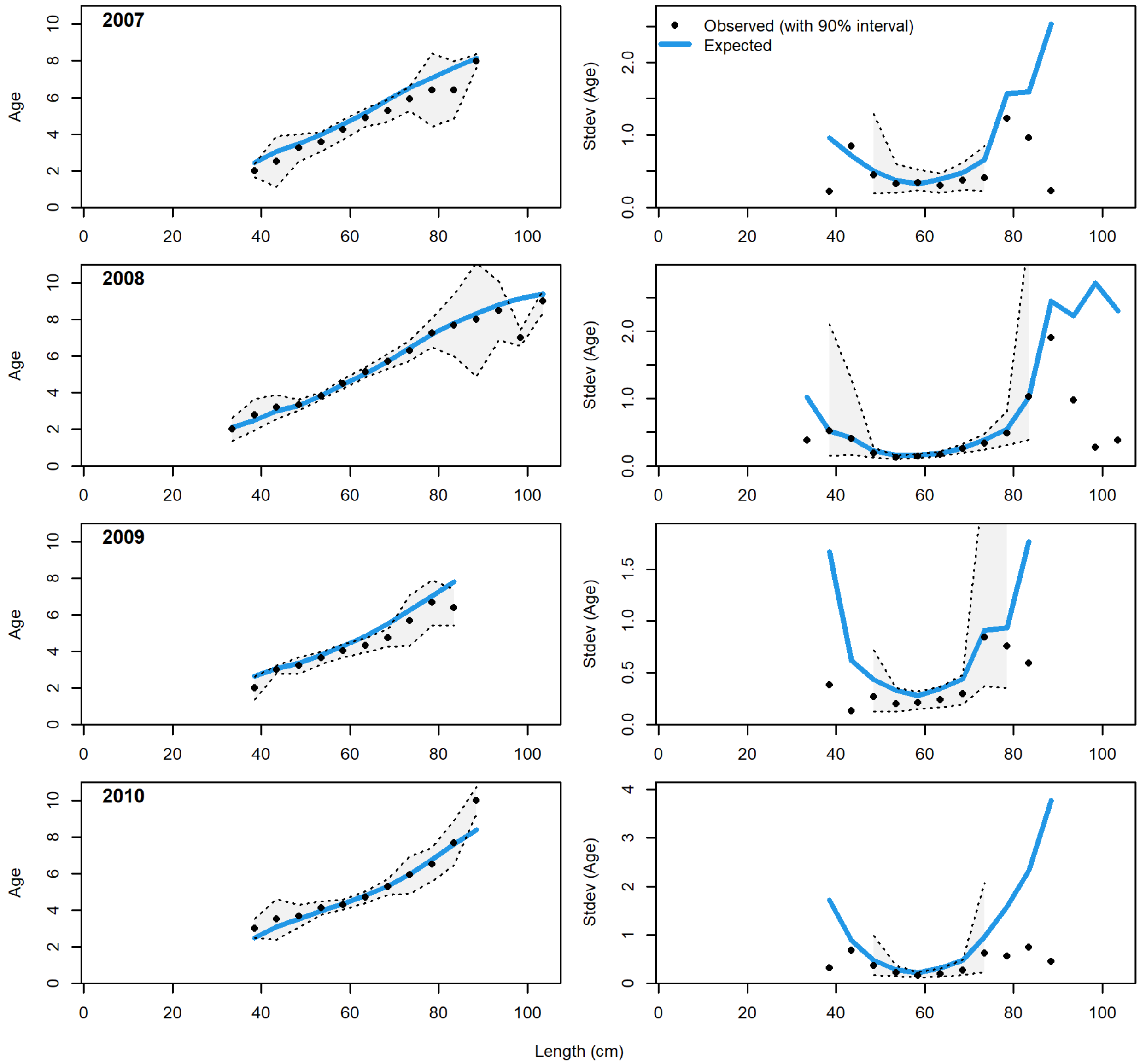

Figure 2.3.15. Recommended model fits to longline fishery condition age-at-length (black dots with grey shading outlined with dashed line are observed values, blue line is model fit).

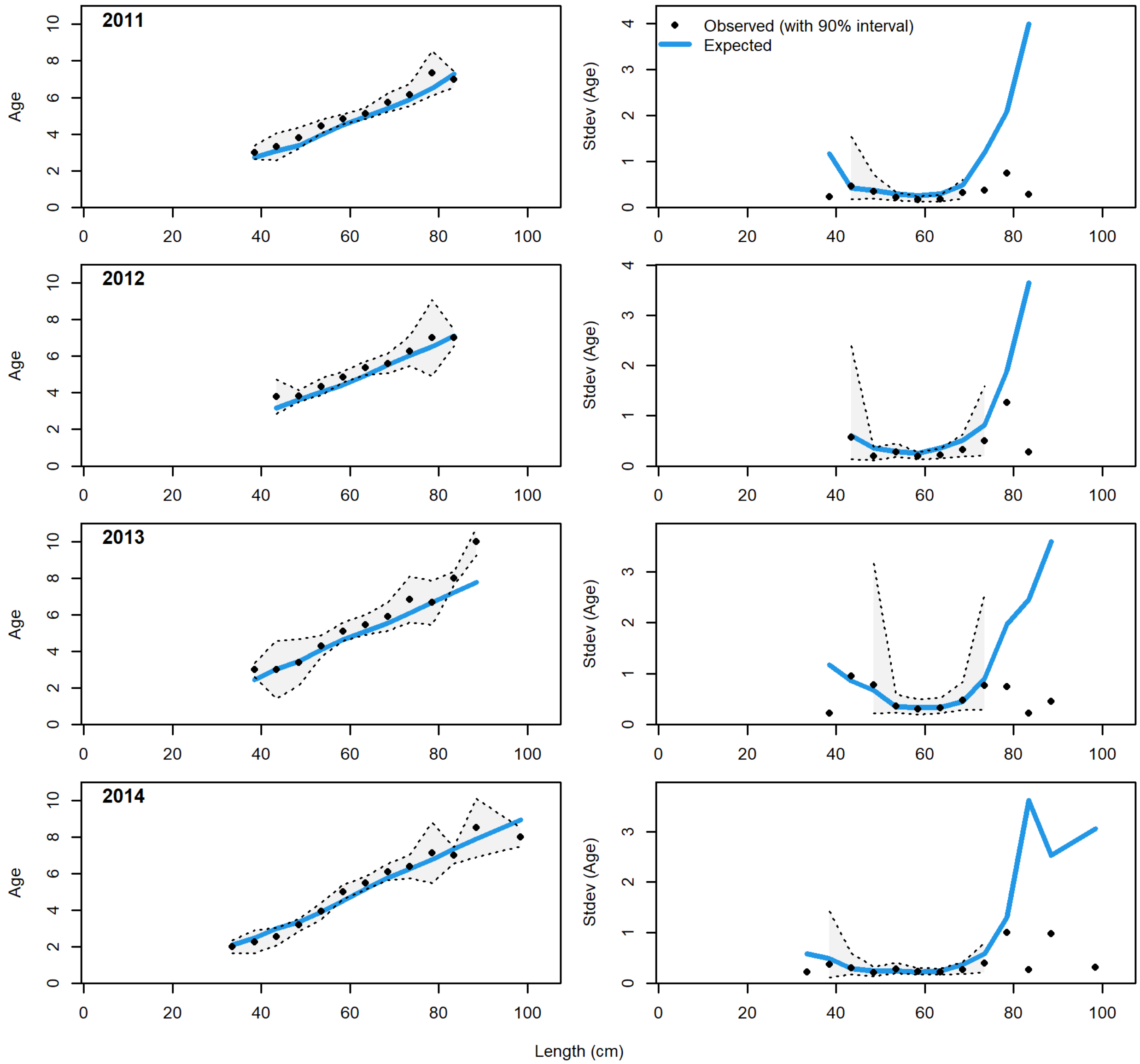

Figure 2.3.16. Recommended model fits to longline fishery condition age-at-length (cont.).

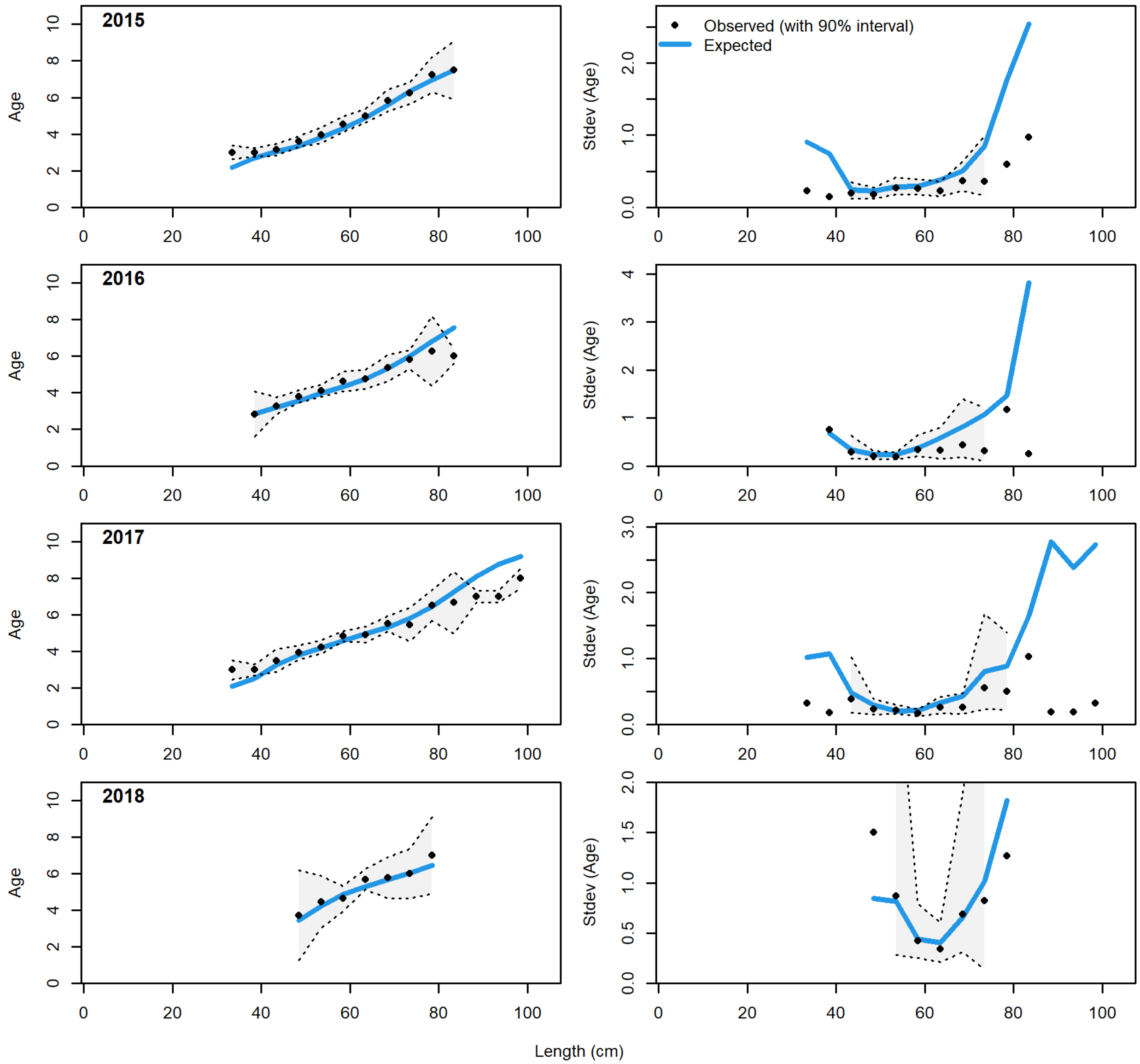

Figure 2.3.17. Recommended model fits to longline fishery condition age-at-length (cont.).

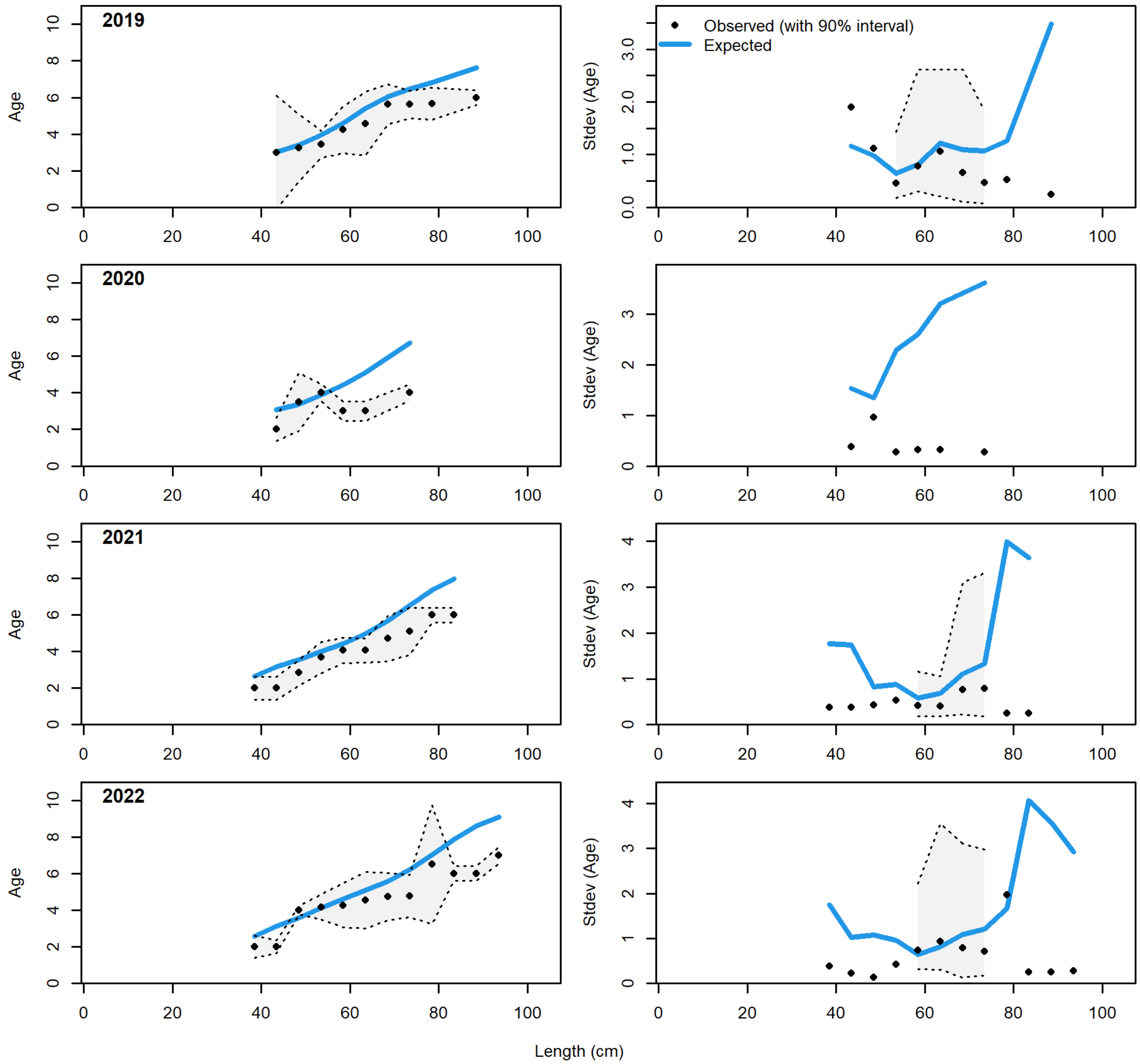

Figure 2.3.18. Recommended model fits to longline fishery condition age-at-length (cont.).

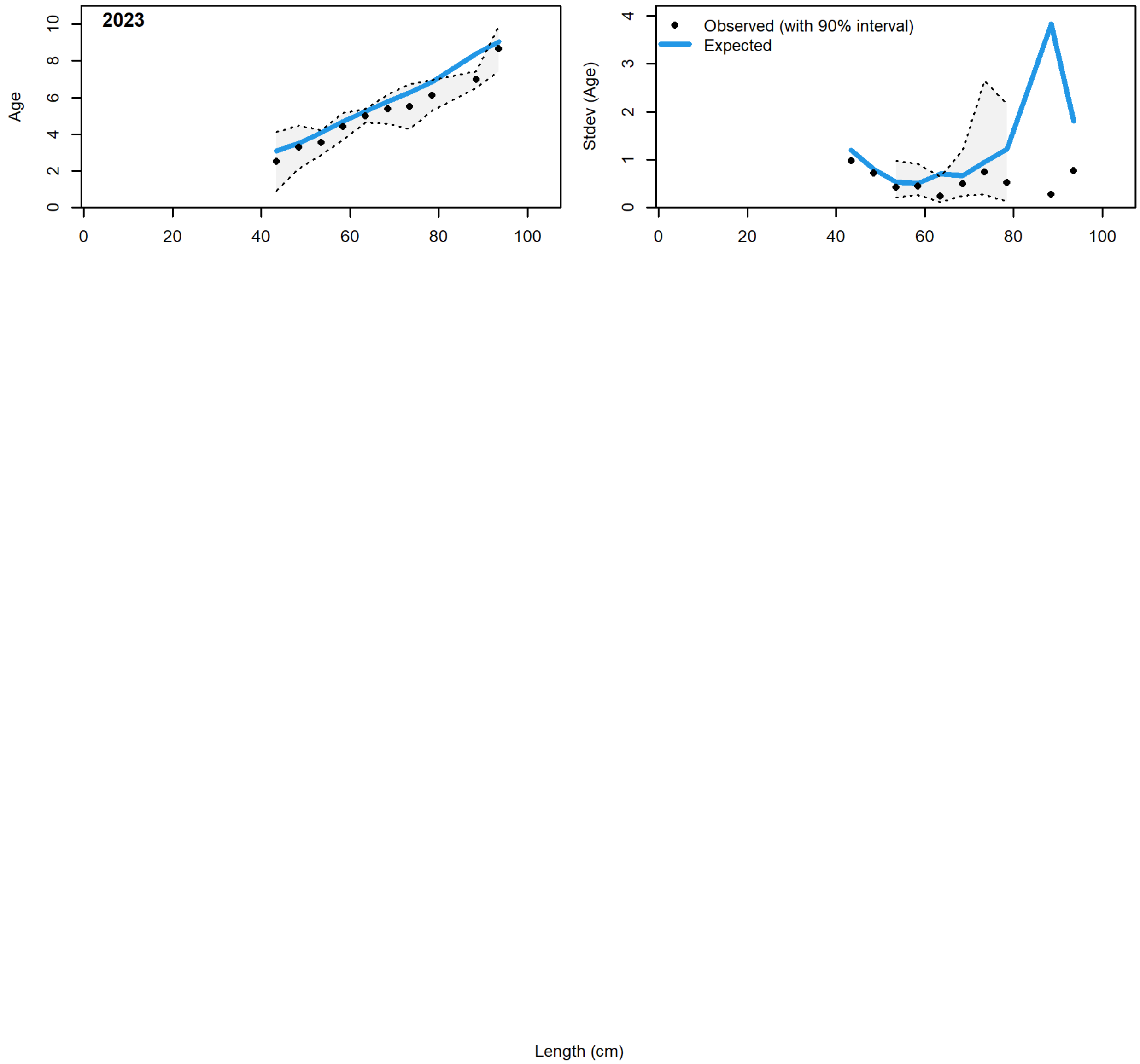

Figure 2.3.18. Recommended model fits to longline fishery condition age-at-length (cont.).

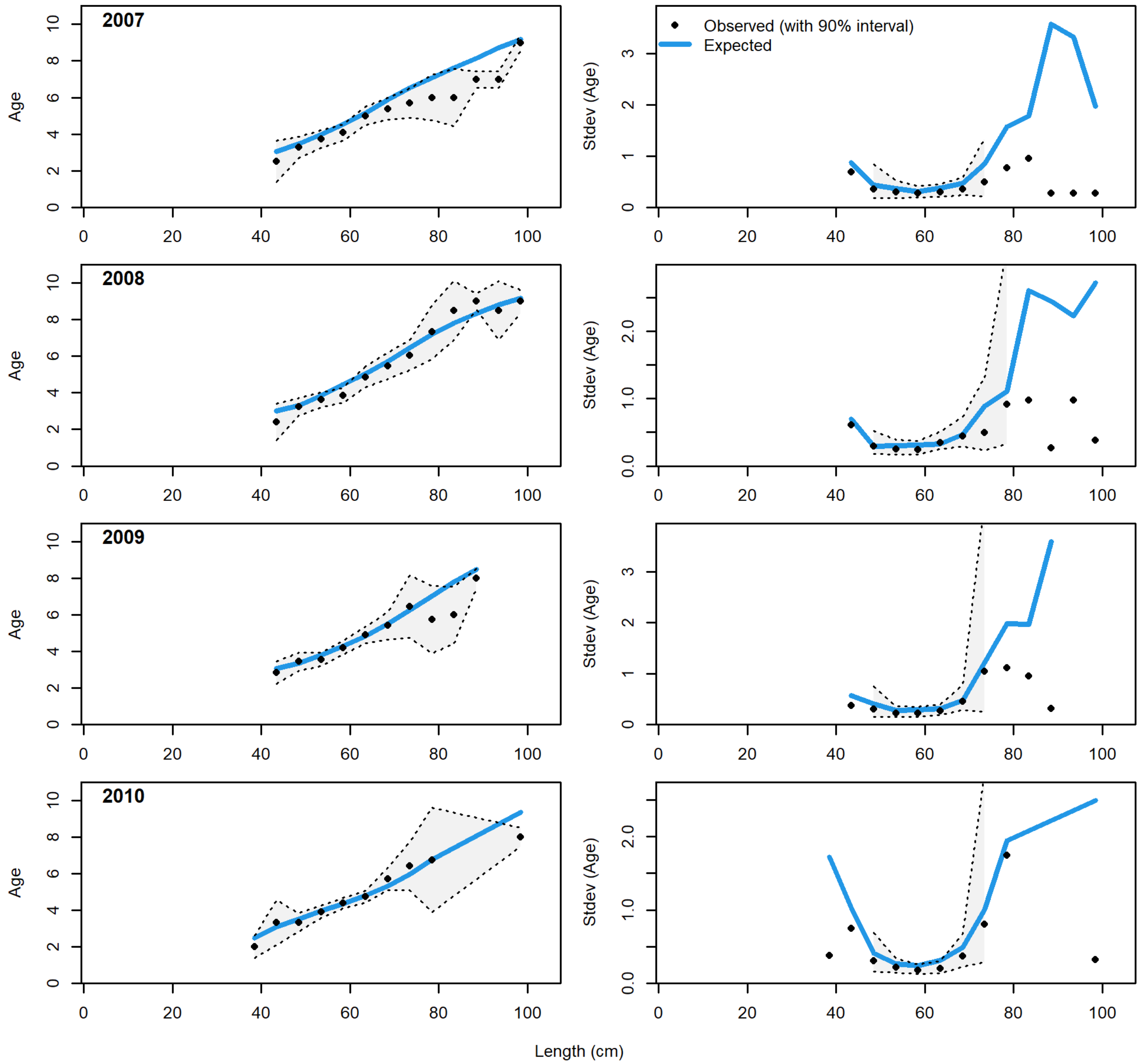

Figure 2.3.19. Recommended model fits to pot fishery condition age-at-length (black dots with grey shading outlined with dashed line are observed values, blue line is model fit).

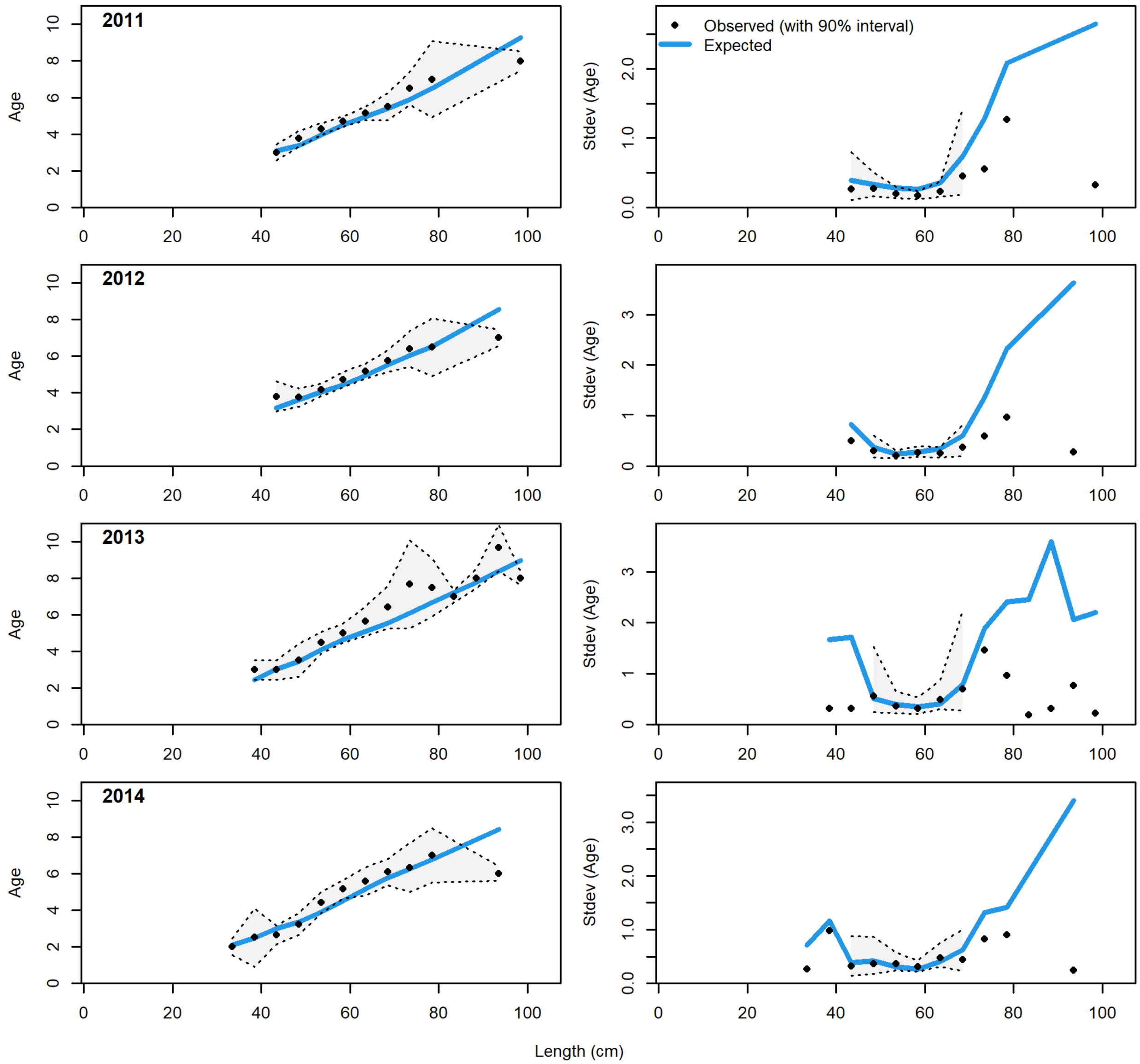

Figure 2.3.20. Recommended model fits to pot fishery condition age-at-length (cont.).

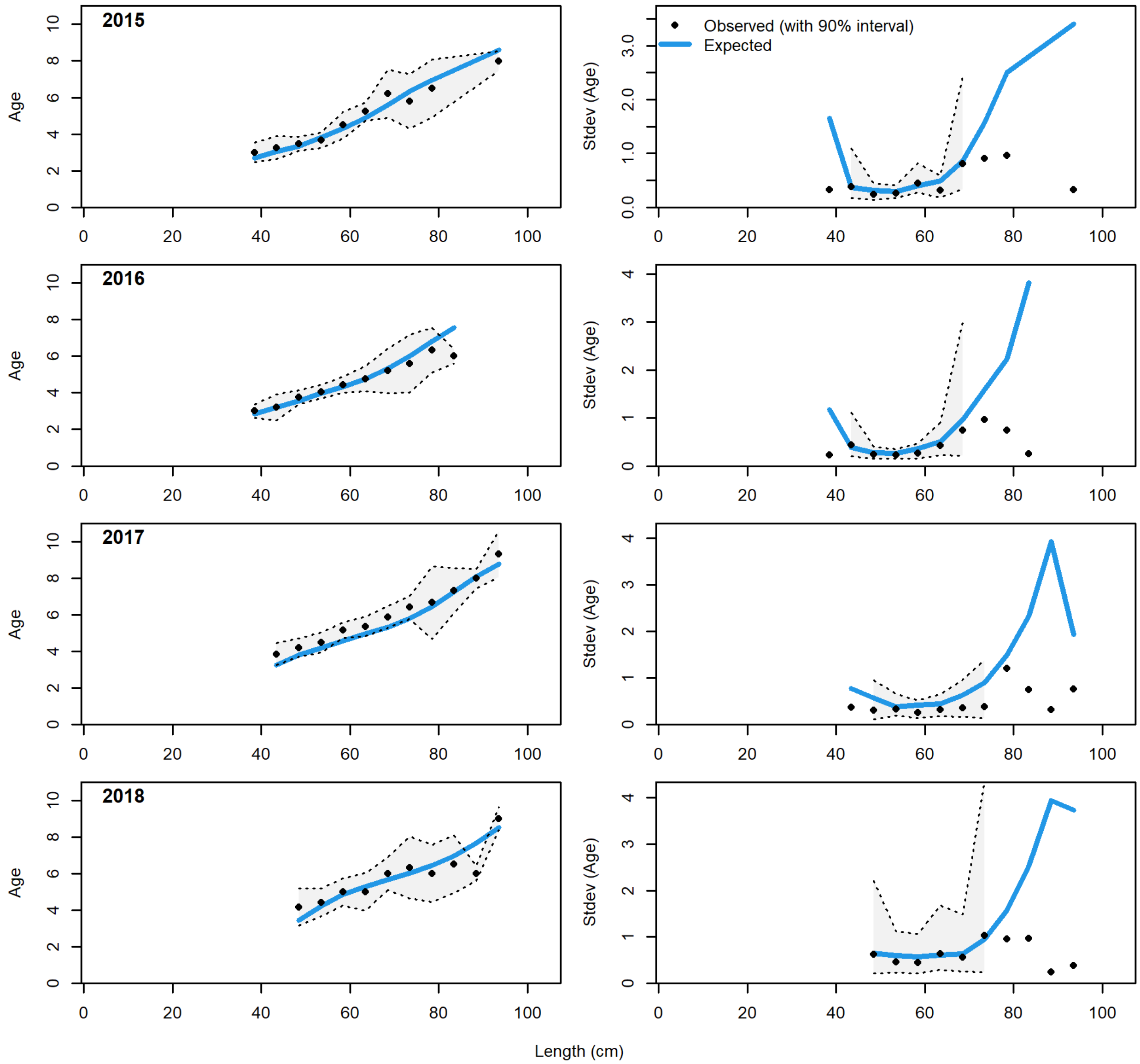

Figure 2.3.21. Recommended model fits to pot fishery condition age-at-length (cont.).

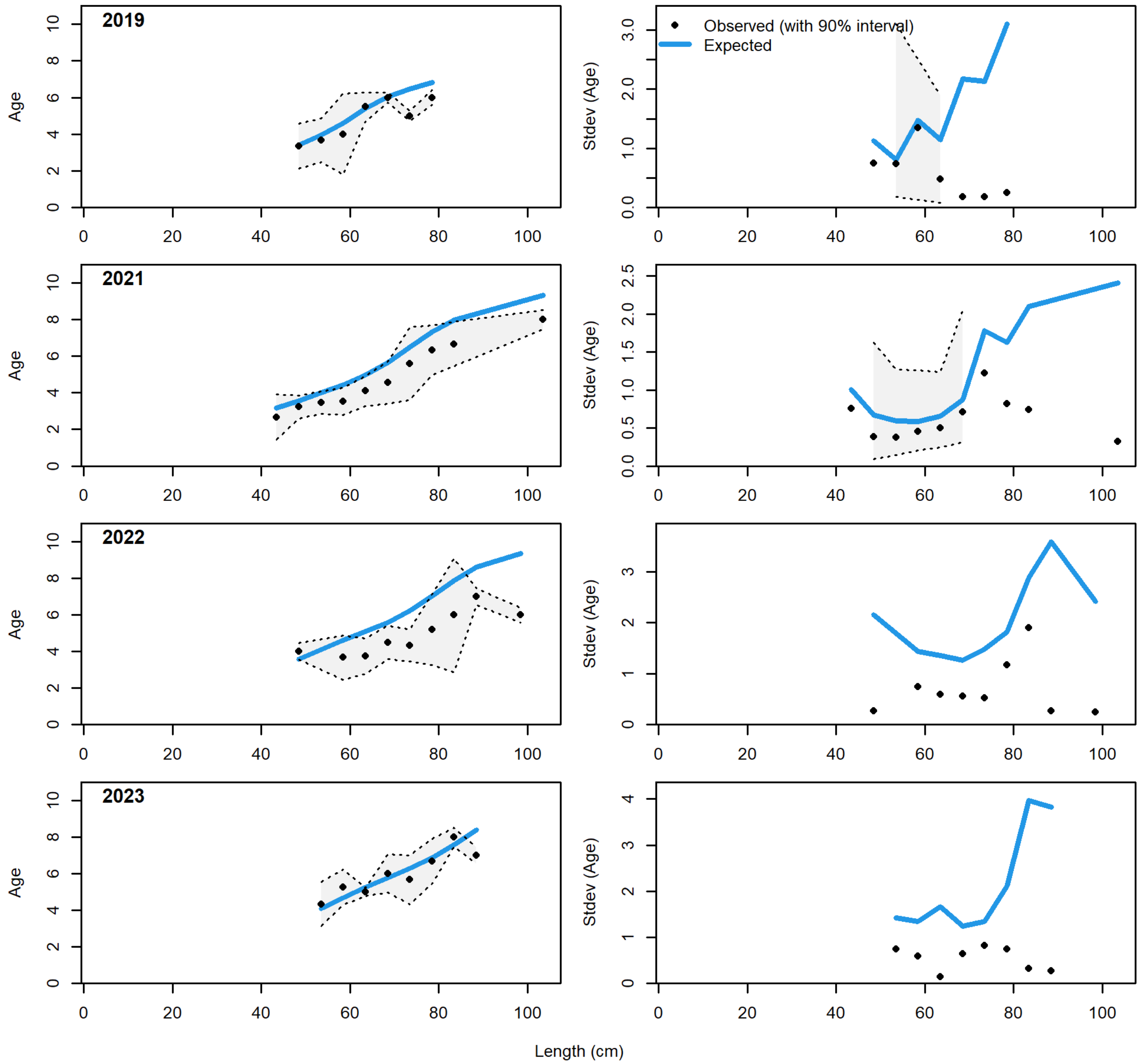

Figure 2.3.23. Recommended model fits to pot fishery condition age-at-length (cont.).

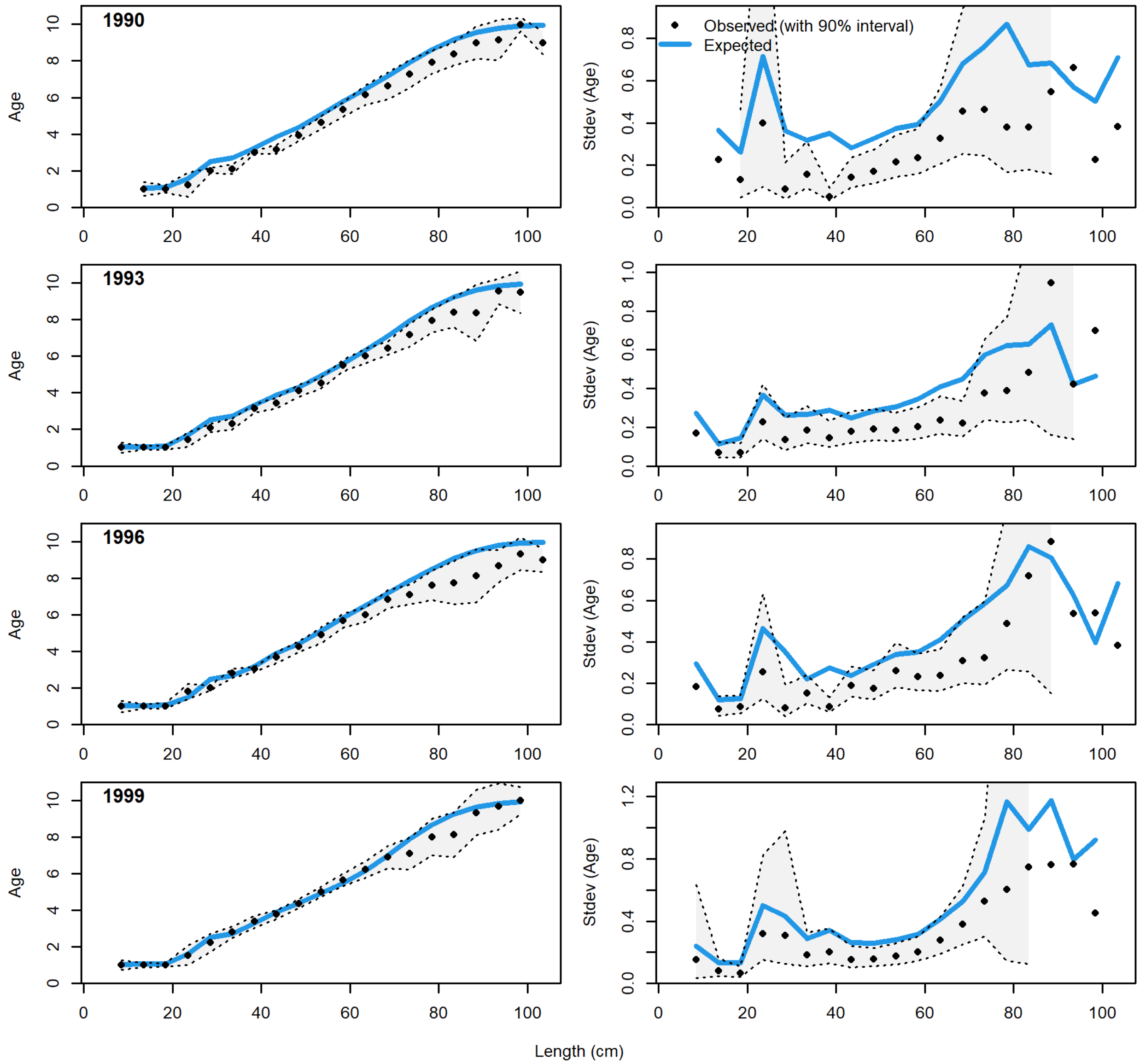

Figure 2.3.24. Recommended model fits to AFSC bottom trawl survey condition age-at-length (black dots with grey shading outlined with dashed line are observed values, blue line is model fit).

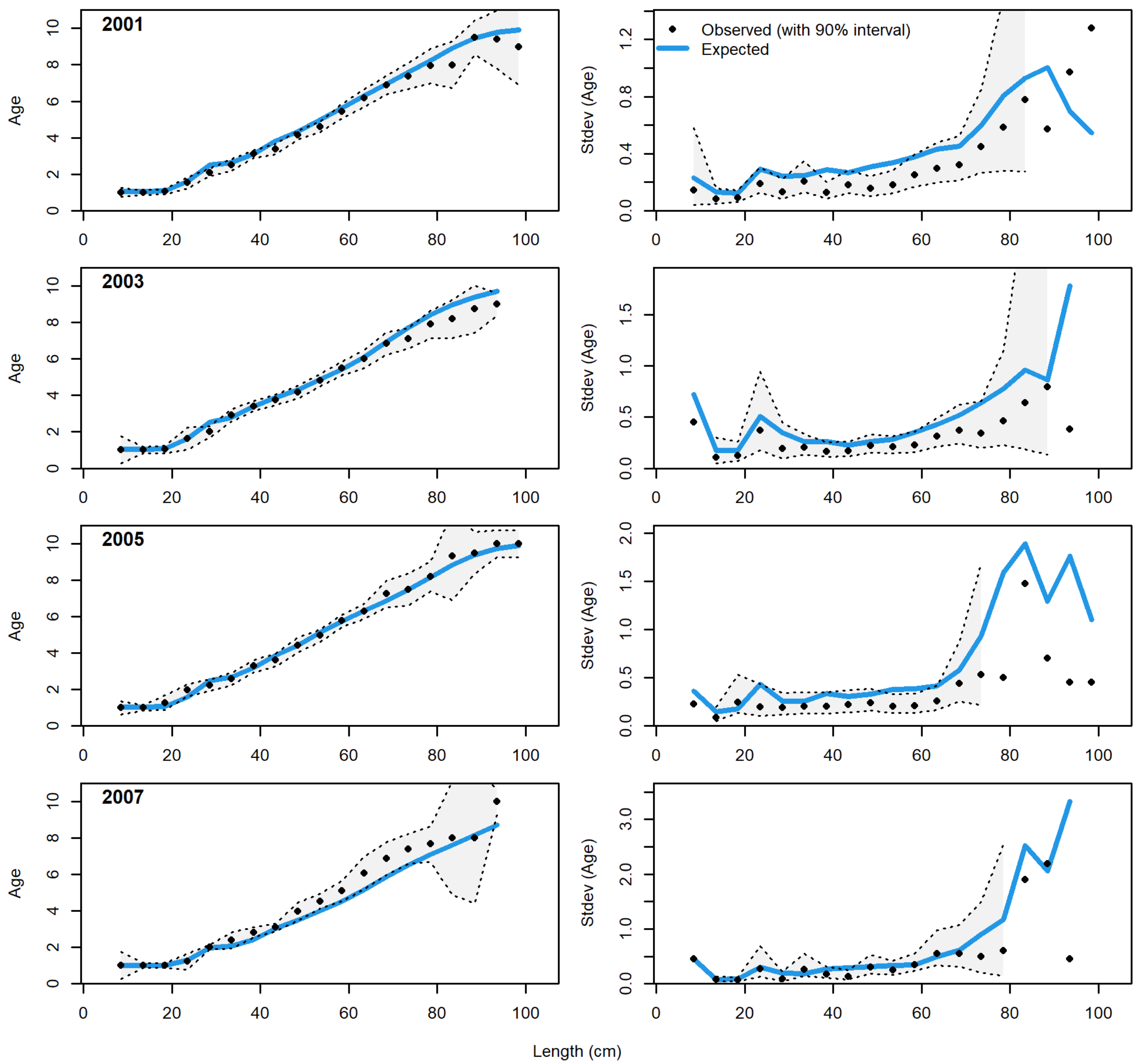

Figure 2.3.25. Recommended model fits to AFSC bottom trawl survey condition age-at-length (cont.).

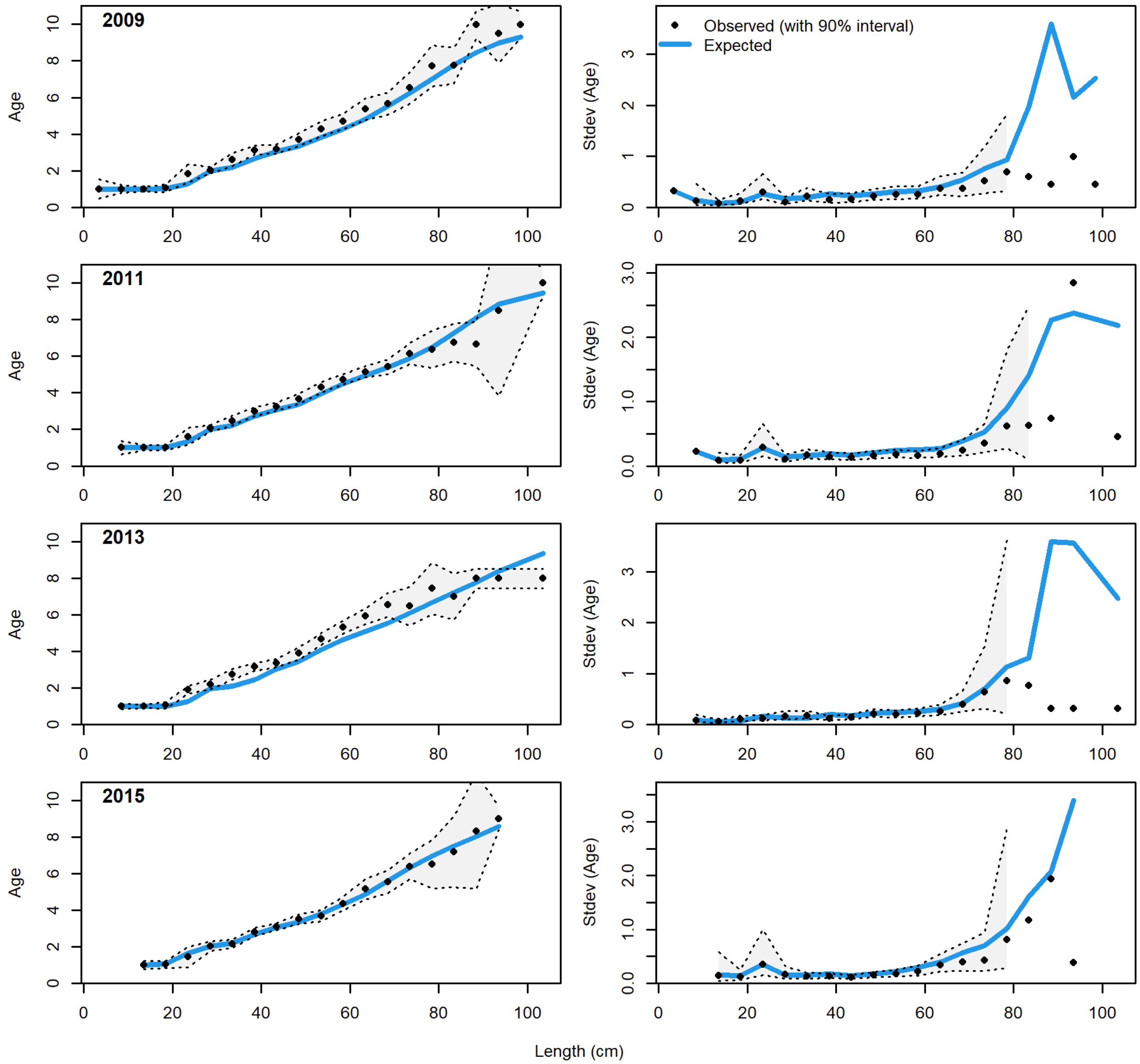

Figure 2.3.26. Recommended model fits to AFSC bottom trawl survey condition age-at-length (cont.).

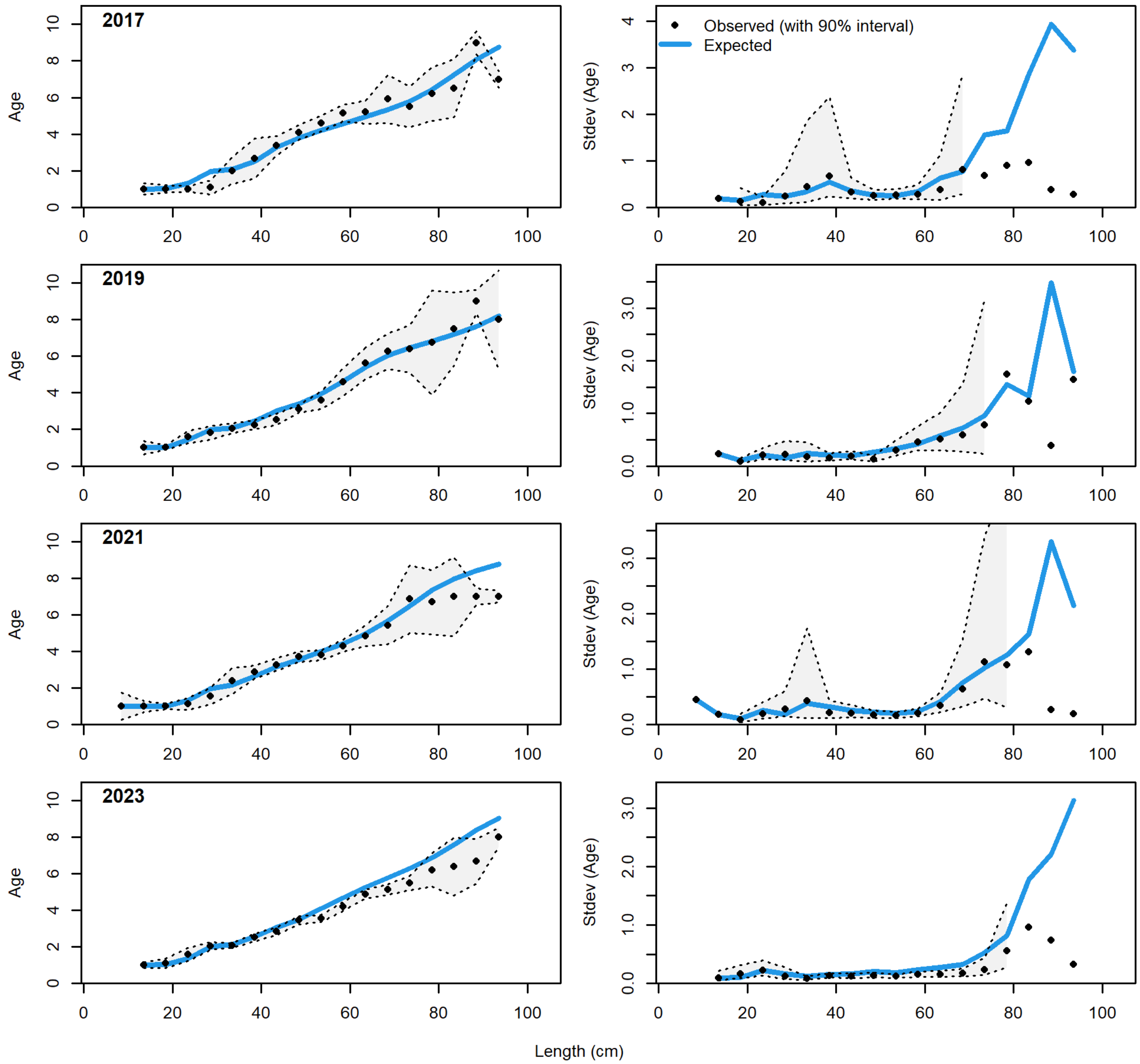

Figure 2.3.27. Recommended model fits to AFSC bottom trawl survey condition age-at-length (cont.).