

# 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:

<b>Data</b>	<b>Source</b>	<b>Type</b>	<b>Years</b>
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  $SD = \sqrt{\ln \left( 1 + (\sqrt{\sigma^2}/x)^2 \right)}$  where  $\sigma^2$  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 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 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 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 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 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 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 6). The overall negative log-likelihood in model 2019.1c decreased compared to model 2019.1b (Table 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 5). The overall negative log-likelihood of model 2019.1d was smaller than model 2019.1c (Table 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 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 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 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 5). Visually, the fit to the bottom trawl survey is similar between models 2019.1d and 2019.1e (top panel Figure 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 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 9) and resulted in similar fits to data (Table 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 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 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 7 and illustrated in Figure 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 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

- Barbeaux, S. J., K. Aydin, B. Fissel, K. Holsman, B. Laurel, W. Palsson, L. Rogers, K. Shotwell, Q. Yang, and S. Zador. 2019. Assessment of the Pacific cod 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
- 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 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. 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 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 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 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 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 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

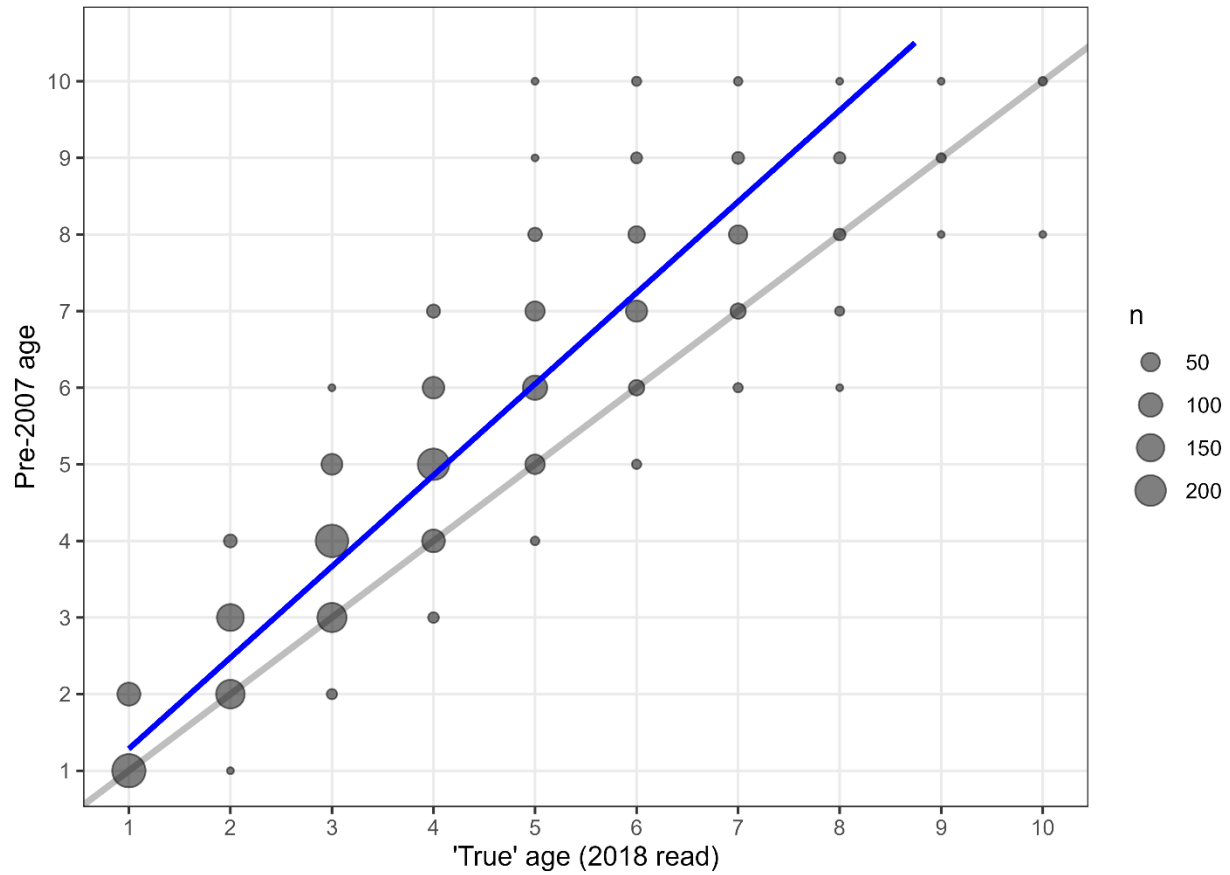


Figure 1. AgeingError R-package fit (blue line) to 2018 ageing compared to pre-2007 ageing (bubbles, with size indicating the number of times the particular age in 2018 matched the age pre-2007; grey line is 1-1 and shown for reference).

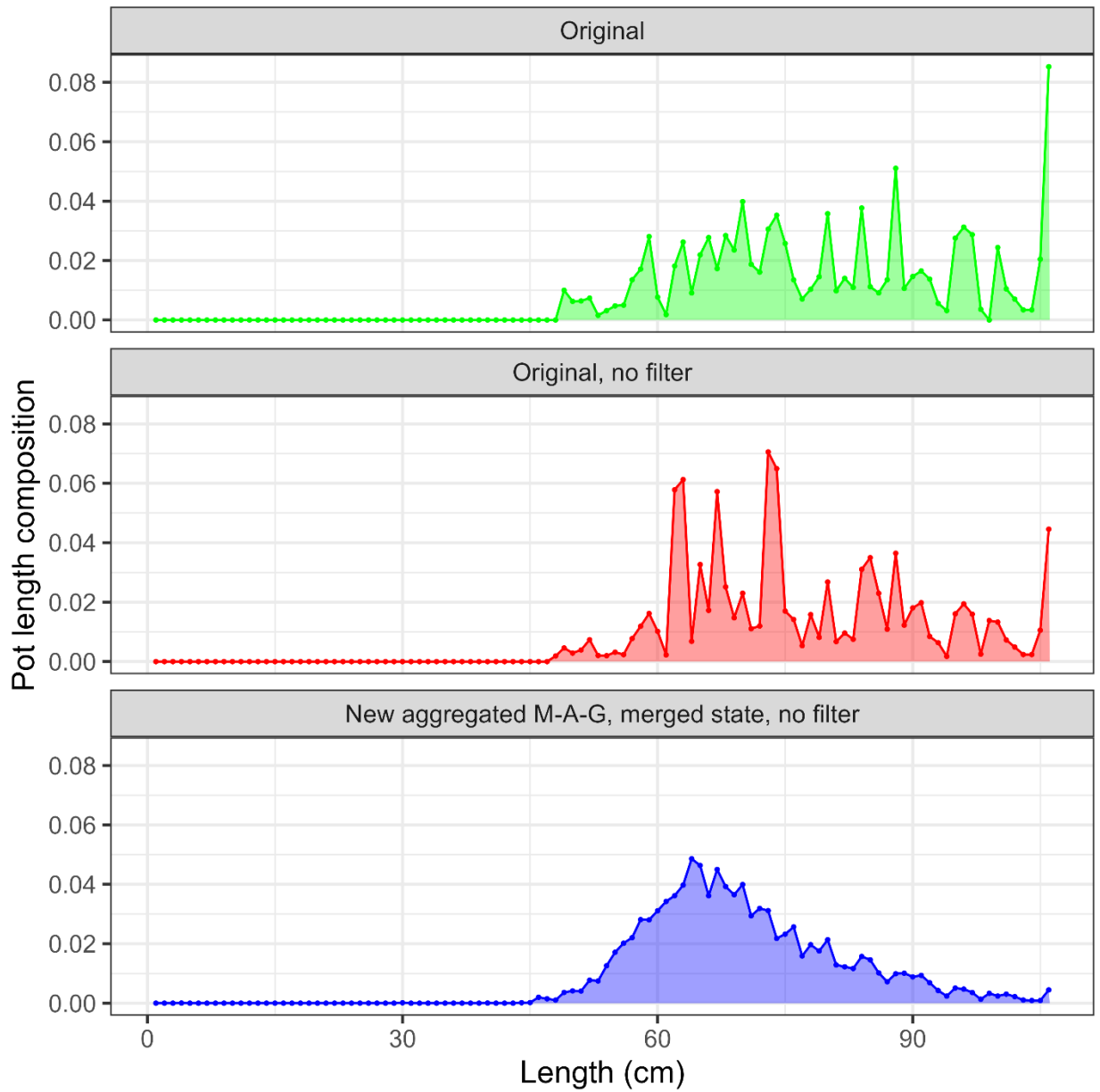


Figure 2. 2020 Pot fishery length composition following the original method for filtering and using ADF&G length frequency data (top panel), after removing the greater than 10 lengths per haul filter (middle panel), and after removing the greater than 10 lengths per haul filter and merging ADF&G length frequency data with federal data (bottom panel).

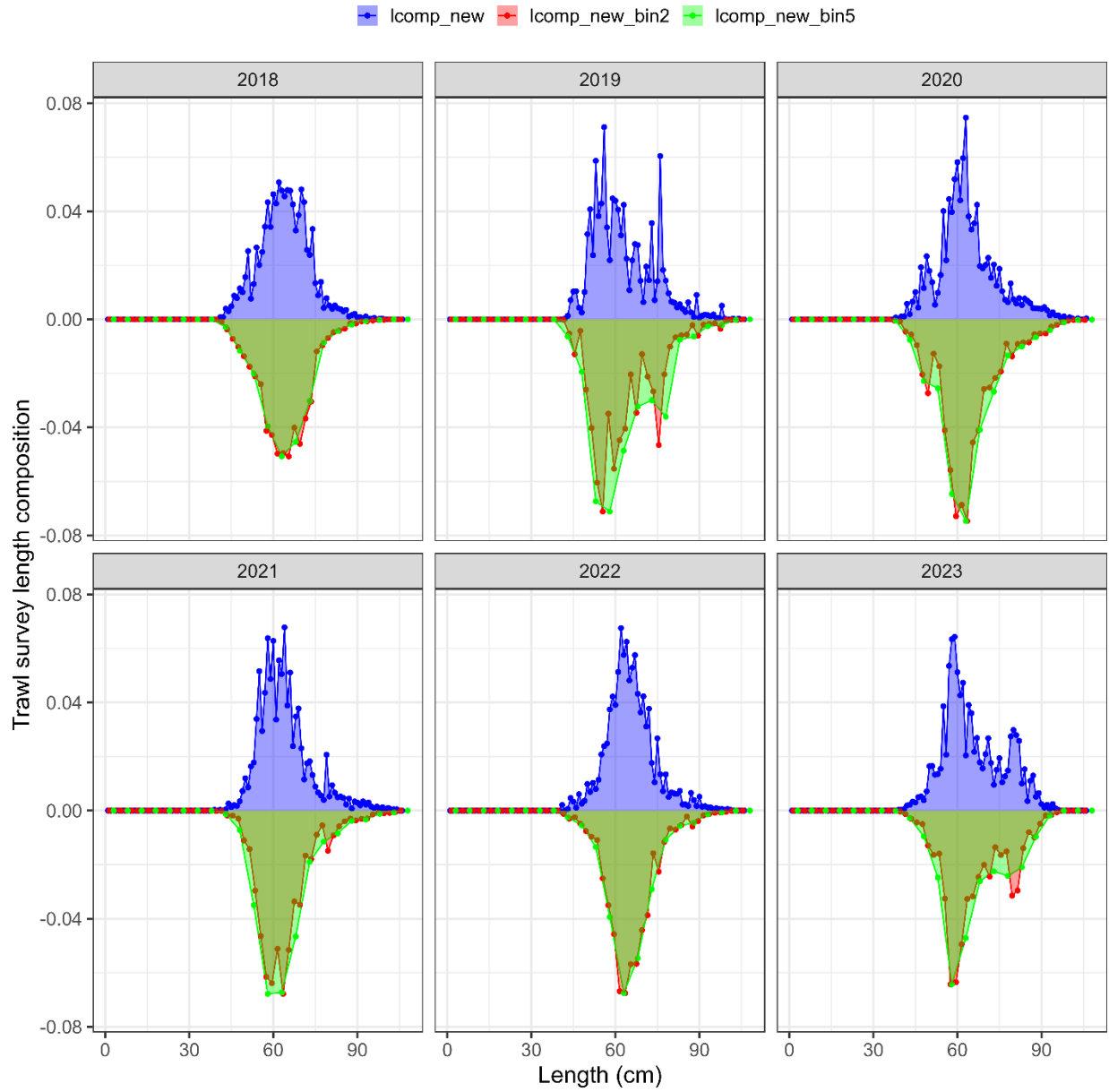


Figure 3. Recent bottom trawl survey length composition computed for 1 cm (lcomp\_new shown in blue), 2 cm (lcomp\_new\_bin2 shown in red), and 5cm (lcomp\_new-bin5 shown in green) length bins.

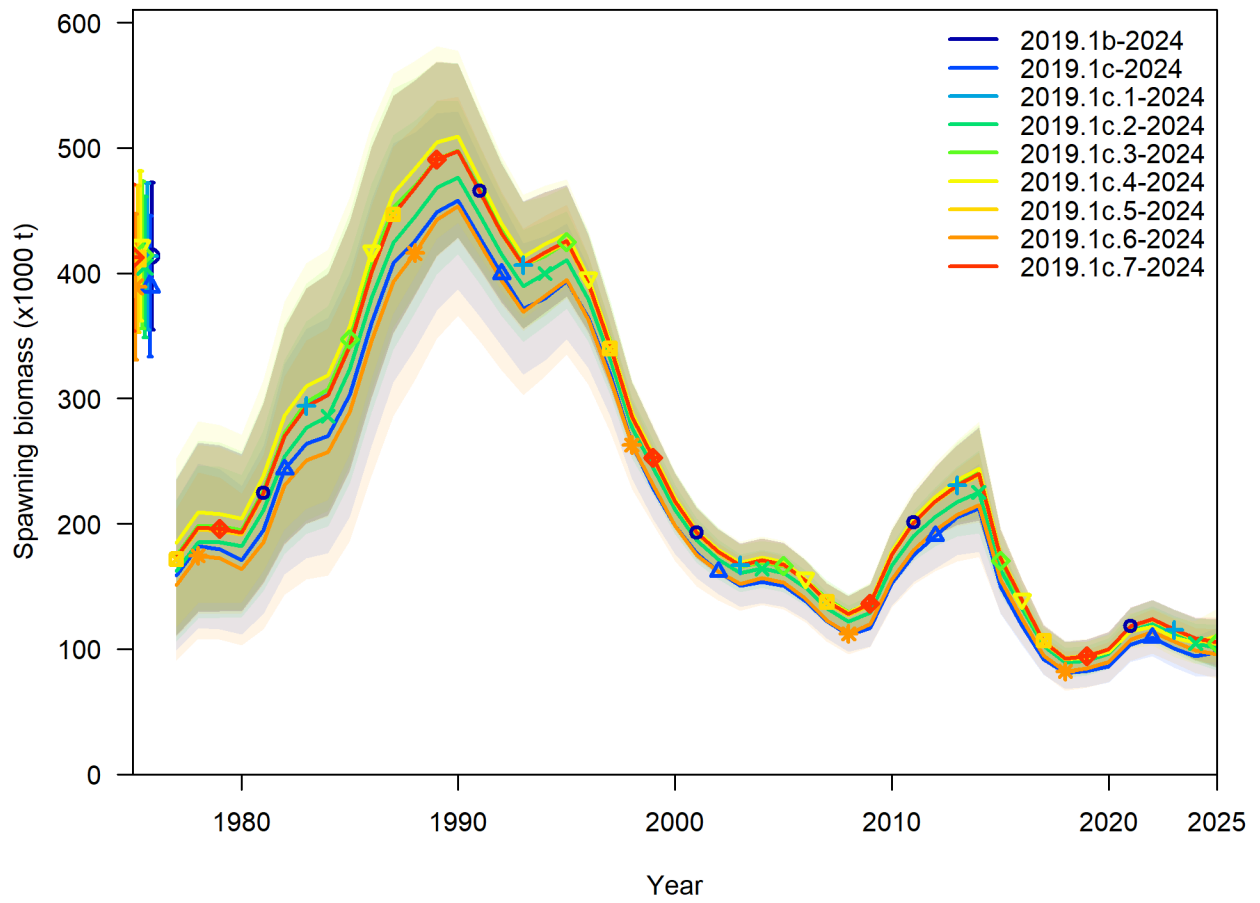


Figure 4. Estimated spawning biomass for the models considered in 2019.1c as compared to the 2023 assessment (2019.1b-2023) and the 2023 assessment with updated data (2019.1b-2024).

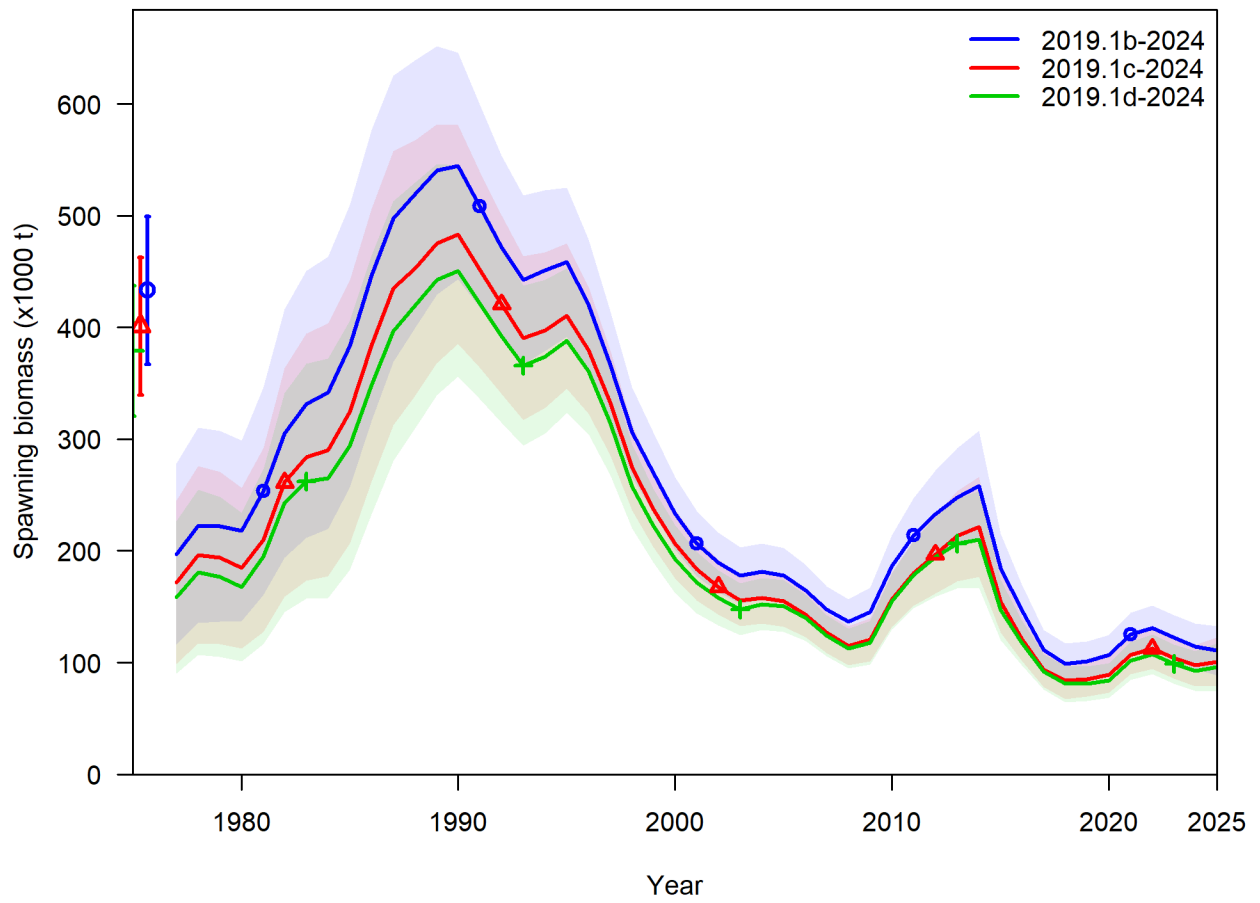


Figure 5. Estimated spawning biomass from models 2019.1b, 2019.1c, and 2019.1d.

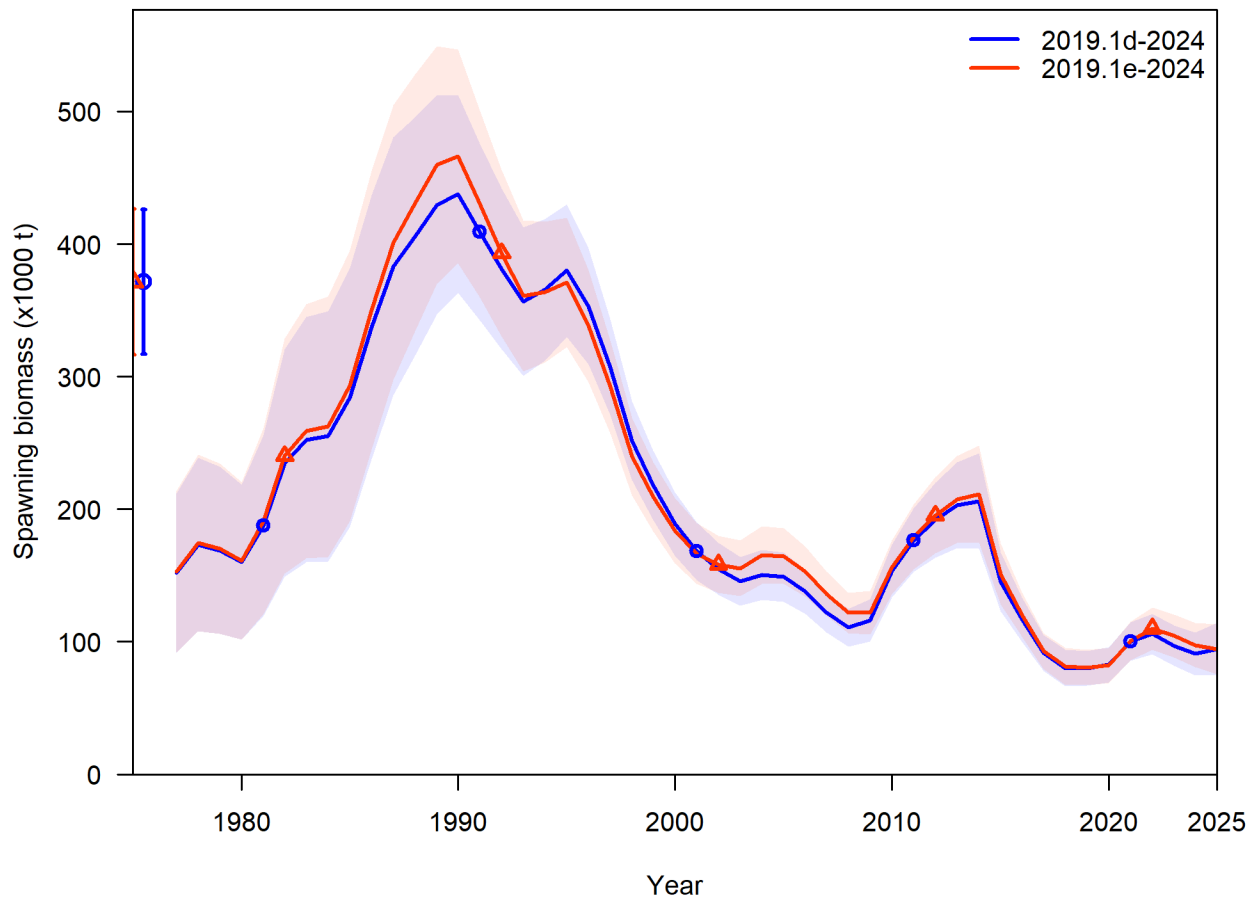


Figure 6. Estimated spawning biomass from models 2019.1d and 2019.1e.



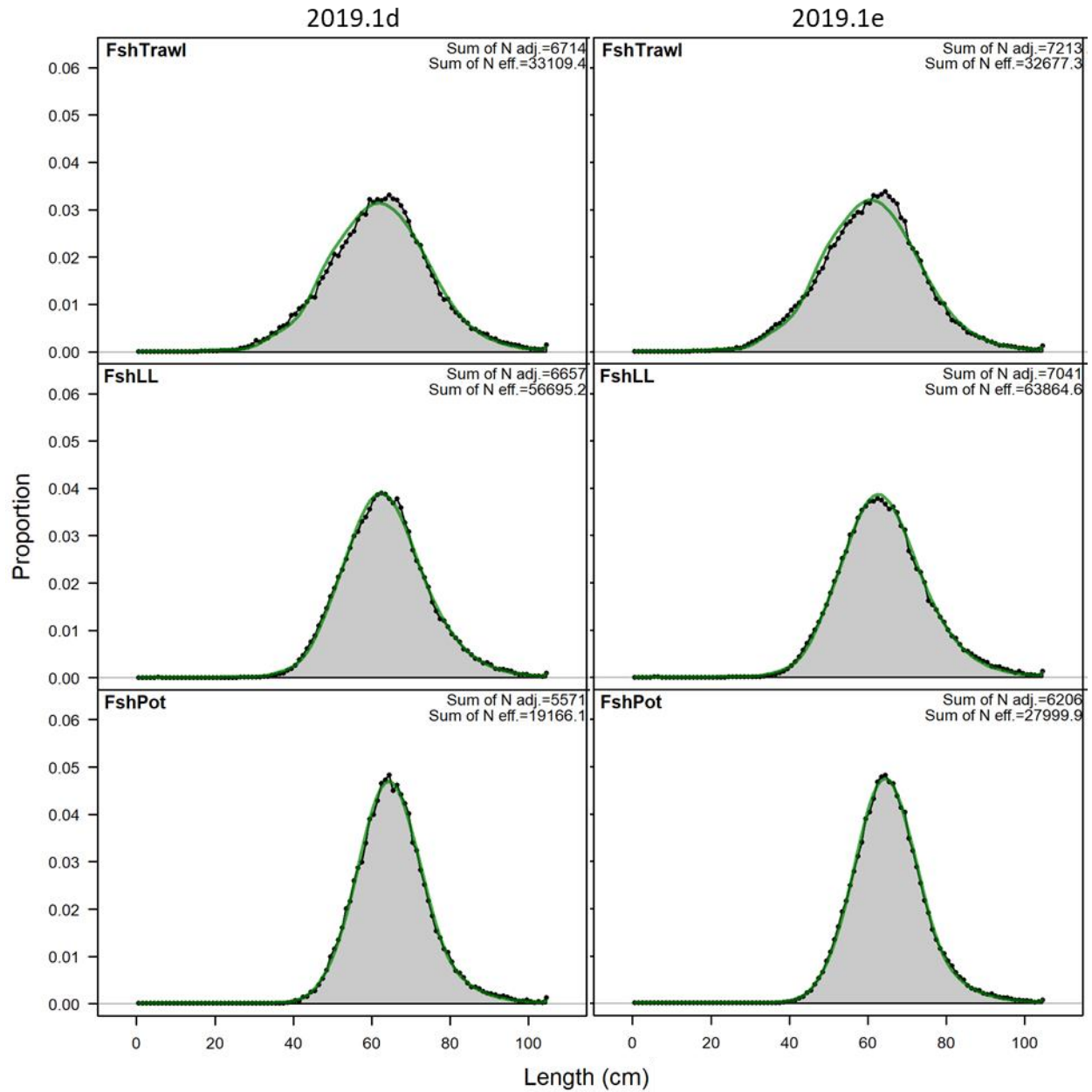


Figure 7. Aggregated fishery length composition fits for model 2019.1d (left panels) and 2019.1e (right panels).

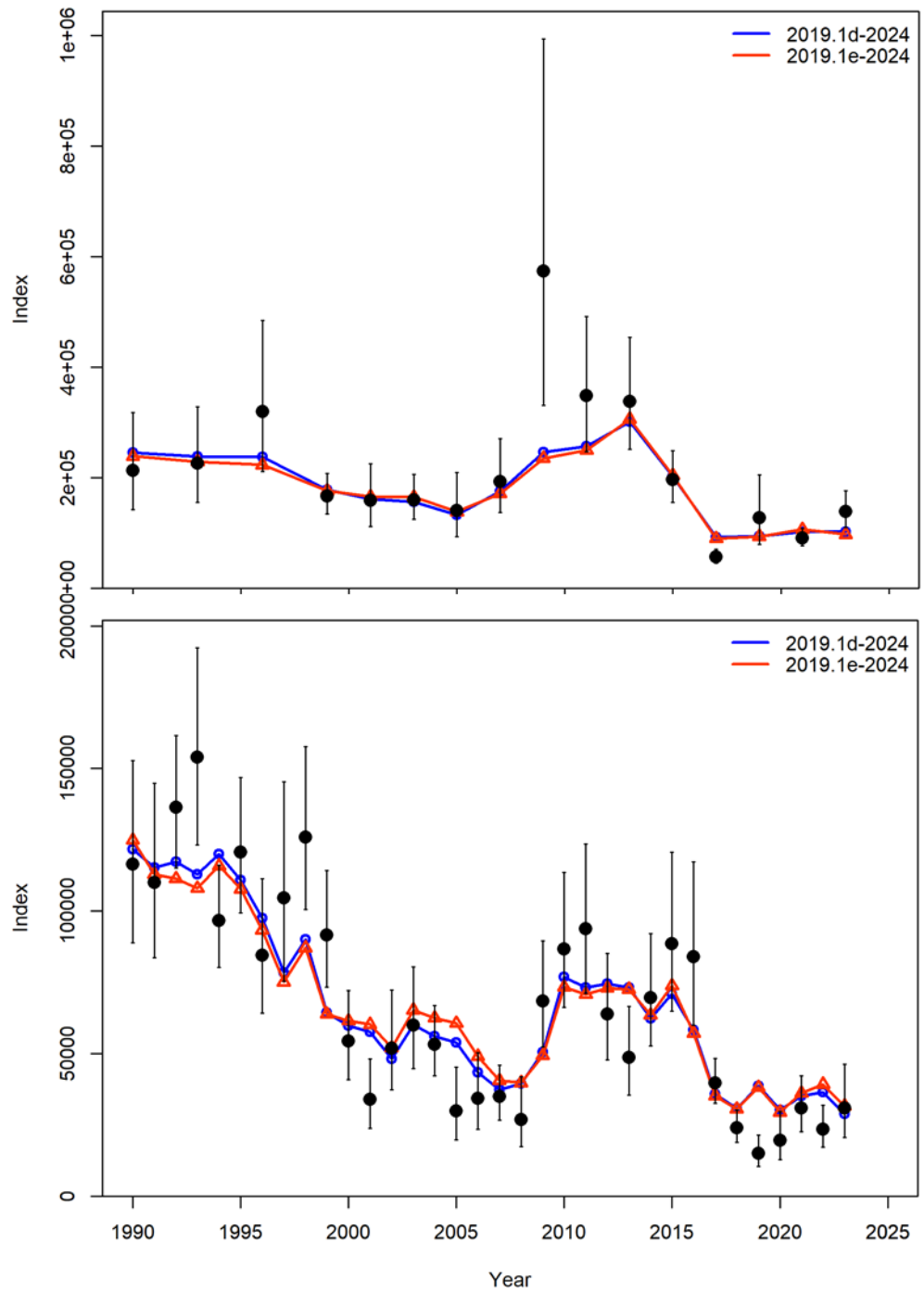


Figure 8. Model 2019.1d and 2019.1e fit to the bottom trawl survey numbers (top panel) and longline survey RPN (bottom panel).

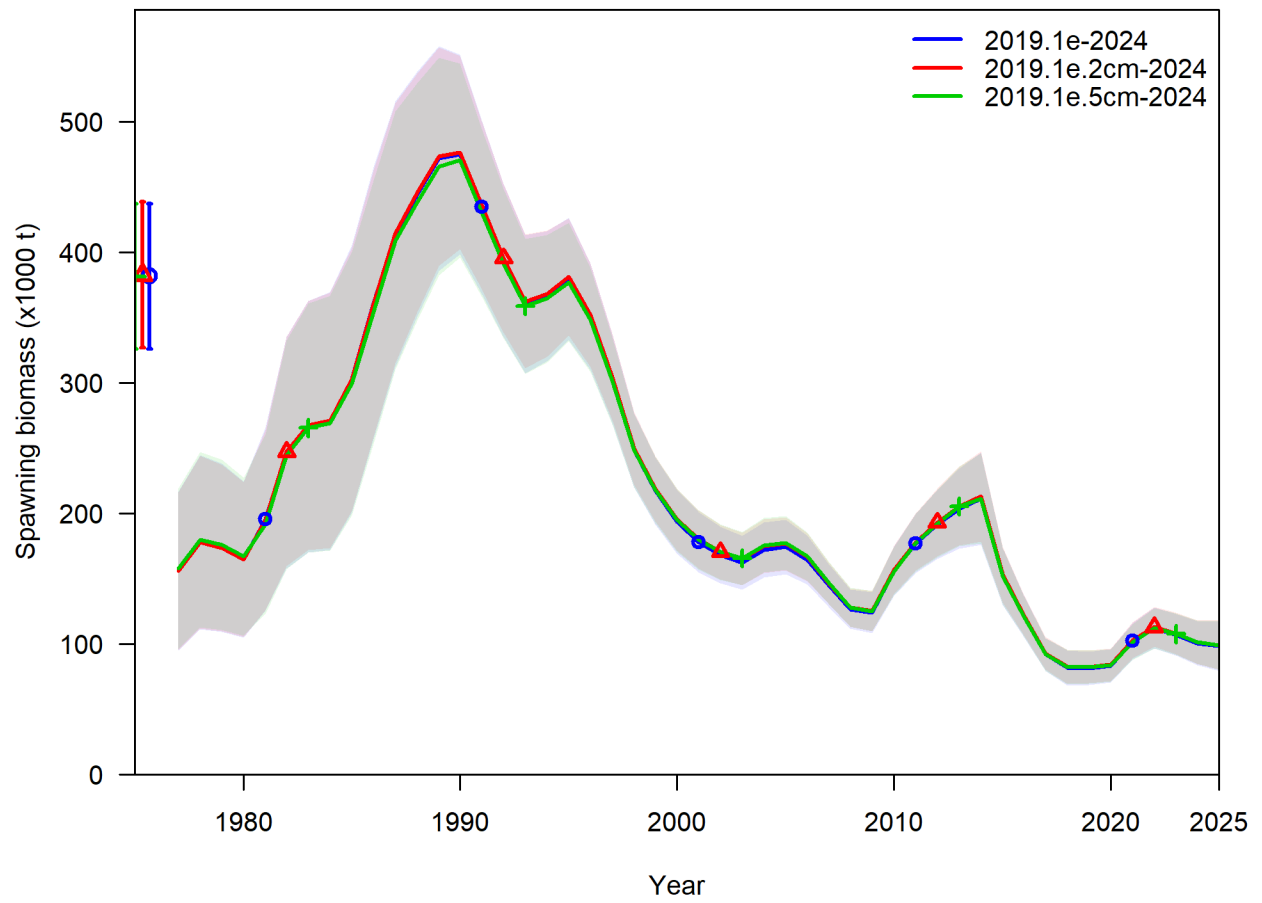


Figure 9. Estimated spawning biomass from models 2019.1e, 2019.1e.2cm, and 2019.1e.5cm.

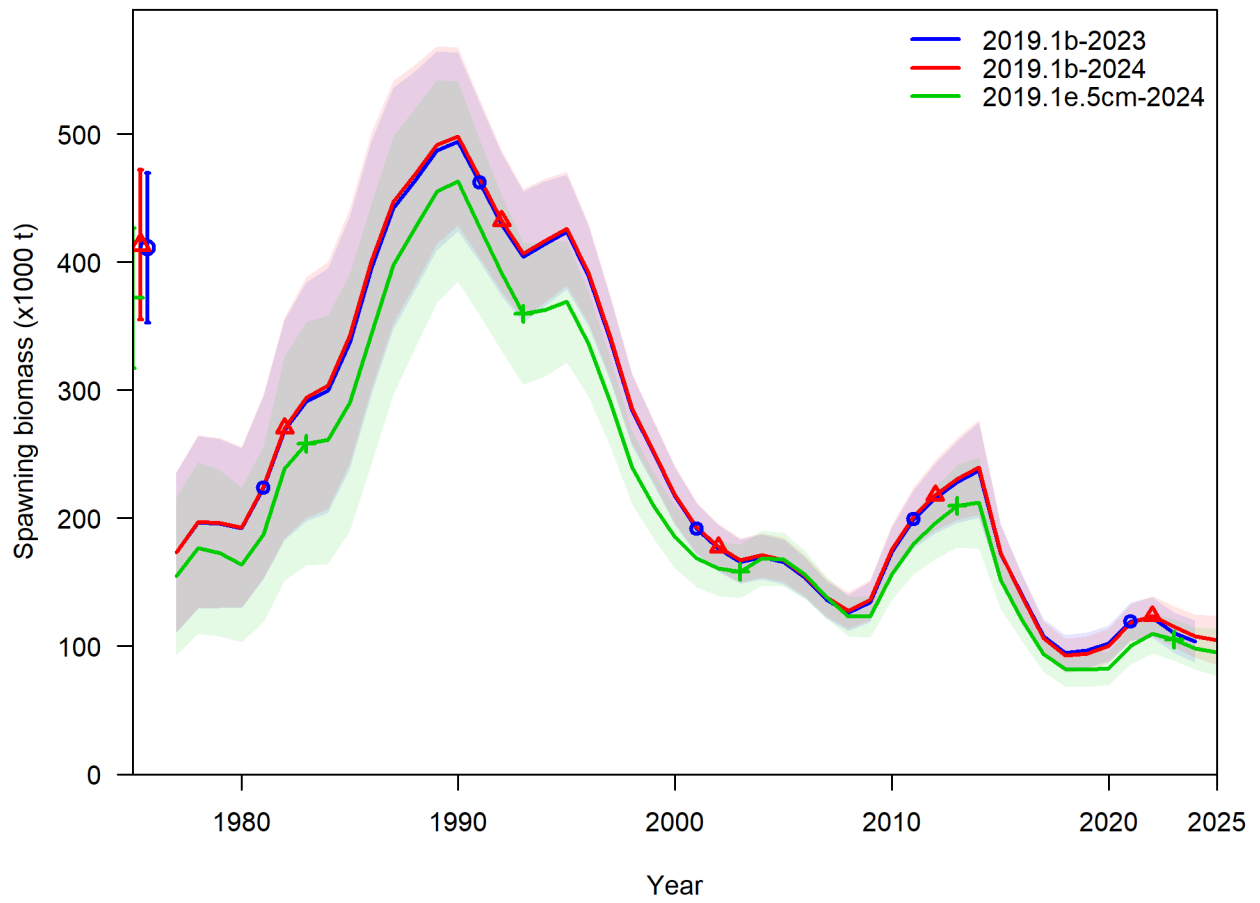


Figure 10. Estimated spawning biomass from the 2023 assessment model 2019.1b, model 2019.1b with updated data through 2024, and the recommended model 2019.1e.5cm.

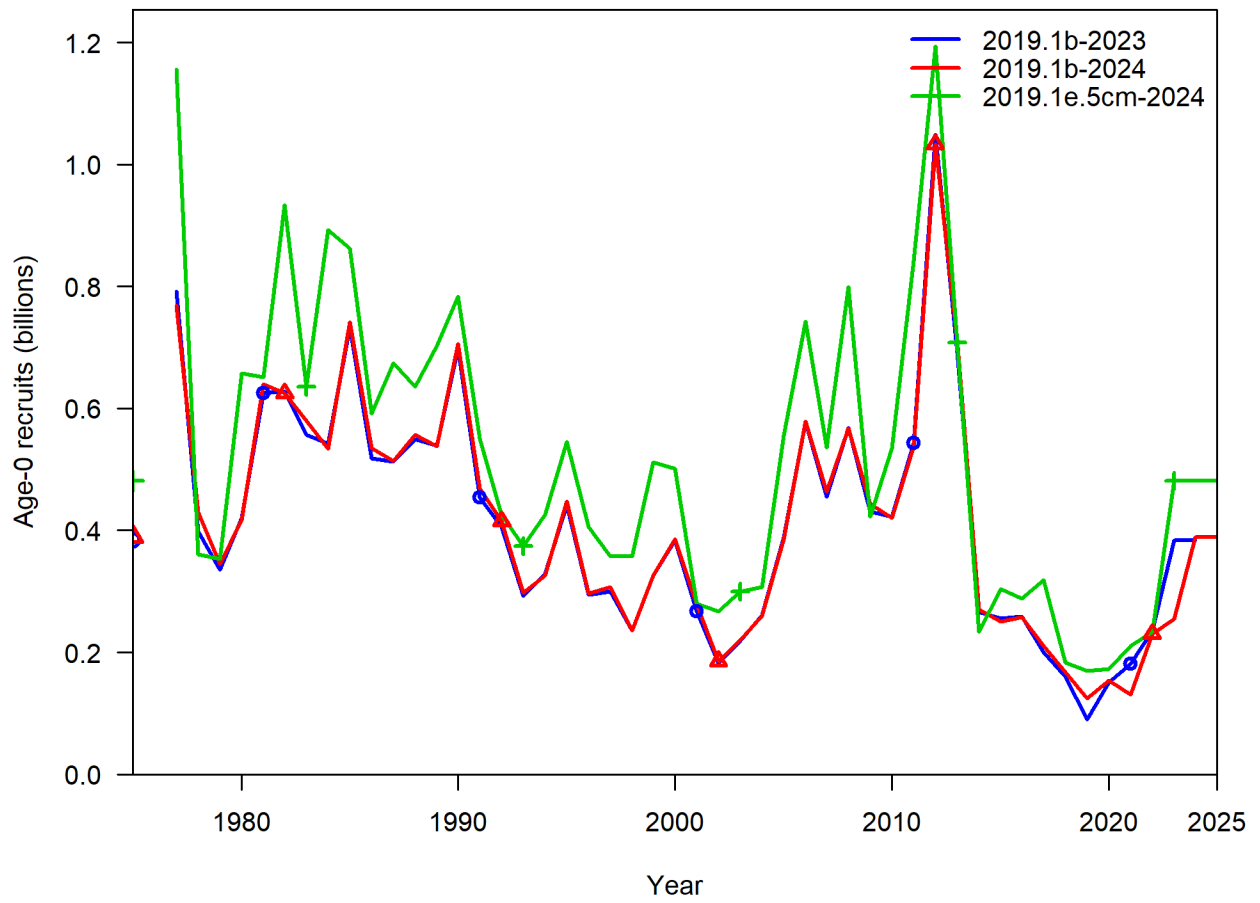


Figure 11. Estimated recruitment from the 2023 assessment model 2019.1b, model 2019.1b with updated data through 2024, and the recommended model 2019.1e.5cm.

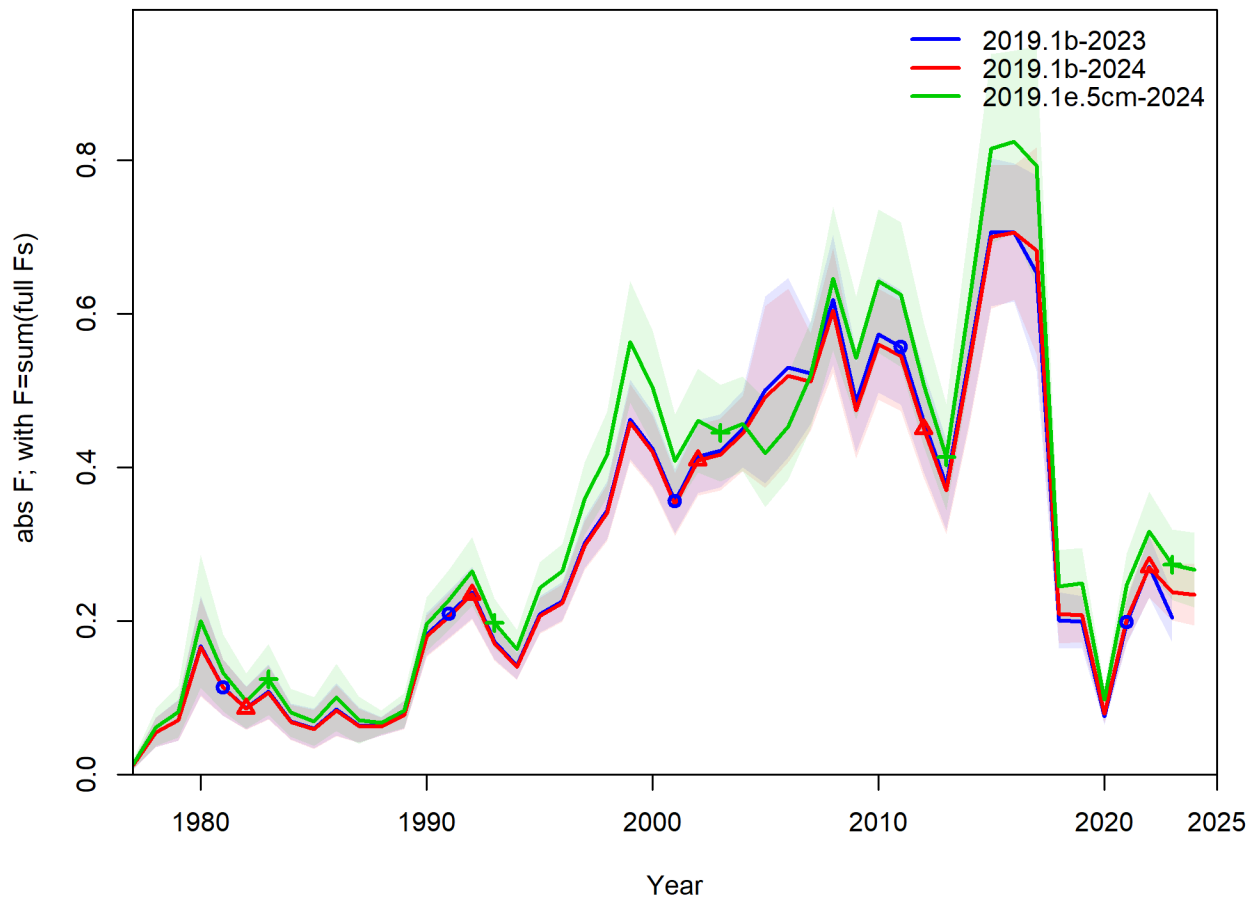


Figure 12. Estimated fishing mortality from the 2023 assessment model 2019.1b, model 2019.1b with updated data through 2024, and the recommended model 2019.1e.5cm.

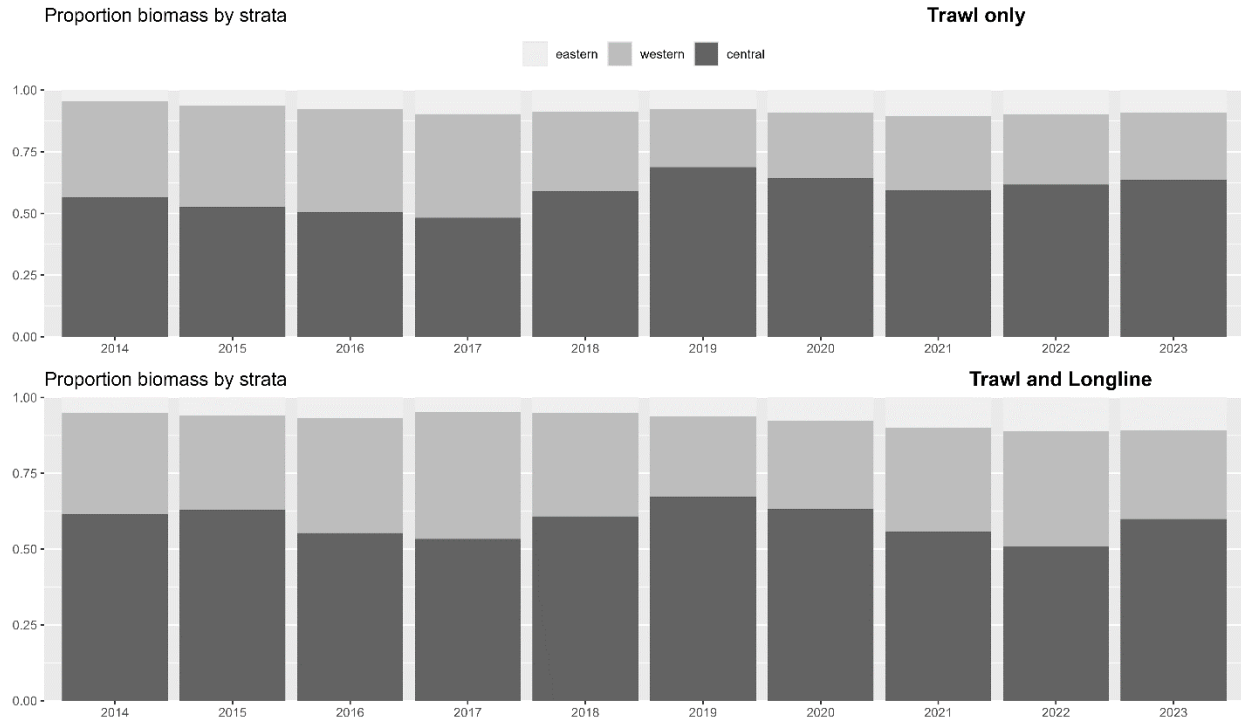


Figure 13. Comparison of apportionment from the REMA model using on the AFSC bottom trawl survey (top panel), and using both the AFSC bottom trawl survey and longline survey (bottom panel).

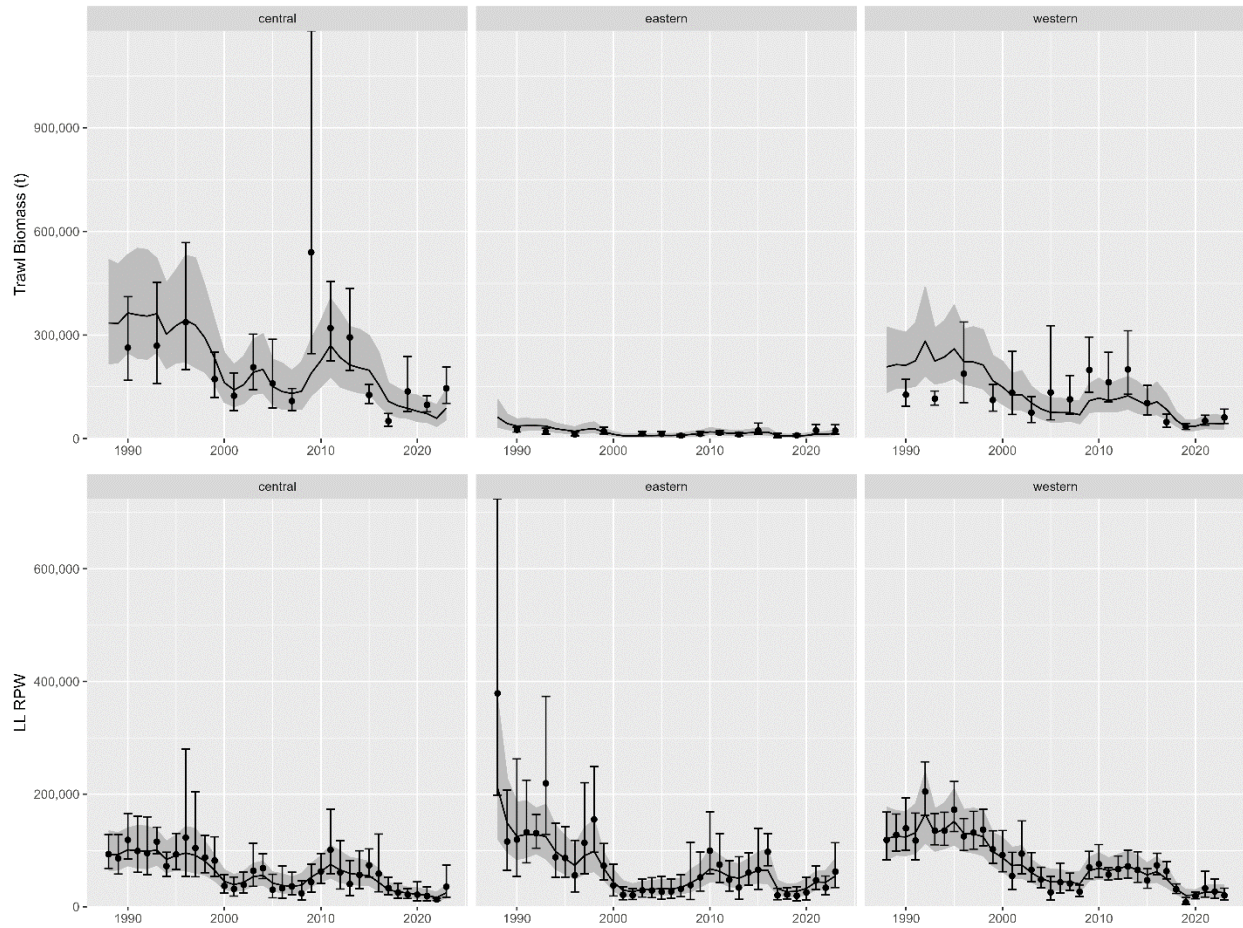


Figure 14. Example REMA model fit to both the AFSC bottom trawl survey (top panel) and longline survey (bottom panel).