2A. Preliminary assessment of the Pacific cod stock in the Aleutian Islands

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09 September, 2024

Executive summary

The following document is written in a similar style as a full stock assessment, with several omissions. The purpose is to present models for the September Plan Team meeting.

The Aleutian Islands (AI) and eastern Bering Sea (EBS) Pacific cod stocks were first managed separately in 2014. Since 2014, age-structured models have been explored in assessments but harvest specifications for Aleutian Islands (AI) Pacific cod have been based on Tier 5 methodology. This document presents two preliminary age structured models for the Aleutian Islands Pacific cod stock, as well as two Tier 5 harvest specification models.

Age structured models:

- Model 24.0: This is the base model.
- Model 24.1: This model differs from Model 24.0 by implentation of a timeblock on natural mortality from 2016 - 2024. The breakpoint between 2015 and 2016 corresponds to a shift to warmer temperatures in the Aleutian Islands during the past decade (Xiao and Ren 2022).

Tier 5 random effects model:

- Model 13.4: There has been no change to the input data for Tier 5 model; it uses existing biomass estimates from 1991 - 2022 implemented using the REMA package. The natural mortality estimate used in past models is retained for 2024. The natural mortality estimate (M = 0.34) used in past models is retained for 2024.
- Model 24.2: This is the same Tier 5 model as 13.4, except it incorporates the natural mortality estimated using M = 0.417.

Summary of changes in assessment inputs

The following substantive changes have been made to the Aleutian Islands Pacific cod age structured assessment relative to the November 2023 assessment.

Changes in the input data (age structured models)

- Realized catches for 2023, as well as a preliminary catch estimate through August 14, 2024. The current year's catch was projected to the end of the year based on the proportion caught over the past 5 years during this the period prior to August 14.
- Commercial fishery size compositions for 2023, as well as preliminary size composition from the 2024 commercial fisheries through August 14.

- No new survey data, but a survey was conducted summer 2024 that will be incorporated in the November assessment.

Changes in the input data (Tier 5 model)

- There has been no change to the input data for Tier 5 model; it uses existing biomass estimates from 1991 - 2022, and will be updated with a biomass estimate and CV from the 2024 Aleutian Islands survey for the November assessment.

Changes in the assessment methodology

- Initial F was estimated using mean catch from 1981-1990 based on the average catch from 1981-1990.
- Natural mortality was estimated externally using (http://barefootecologist.com.au/shiny_m.html) and fixed at 0.417, except in Model 24.1 after 2015 (which incorporated a time block on natural mortality).
- The timeblock on natural mortality from 2016-2024 (Model 24.1) estimated a single value.
- A Richards growth curve was estimated within the model. Previous models used the von Bertalanffy growth curve.
- Maximum age was changed from 10^+ to 13^+.
- Fishery length composition did not incorporate a plus group (max = 143 cm) whereas previous models used a plus group of 117^+ cm.
- The time of settlement was changed to indicate that larvae settle as juveniles in the same year as spawning, rather than in the following year.

Summary of Results

Model 24.1 improved the fit to the data over Model 24.0. Model 24.1 estimated a total biomass of 71,627 t, a spawning biomass of 24,383 t, and an exploitable biomass of 56,066 t for 2025. Model 24.1 ABCs were 12,089 t and 11,960 t for 2025 and 2026. Model 24.1 OFLs were 15,251 t and 15,079 t for 2025 and 2026 (Table 2A.1).

The Tier 5 ABCs and OFLs for 2025 and 2026 are the same as estimated in 2022, due to no new survey data, but a new survey datapoint will be included in the November assessment (Table 2A.2. Model 13.4 incorporates this biomass estimate directly in the calculation of reference points; therefore, the random effects model estimated an exploitable biomass of 54,166 t, which resulted in OFLs (18,416 t) and ABCs (13,812 t) for 2025 and 2026. This is comparable with the exploitable survey biomass estimated by Model 24.1 (56,066 t). The Tier 5 Model 24.2 estimated higher OFLs (22,587 t) and ABCs (16,940 t) for 2025 and 2026 due to the higher natural mortality parameter (Table 2A.2).

Overall, the age structured model 24.1 is prefered over a Tier 5 model because it incorporates a comprehensive suite of data sources (fishery and survey lengths, survey ages, maturity curve) in a likelihood framework. The random effects model simply incorporates the survey biomass indices. We recommend moving this assessment to a Tier 3 approach.

Catch of Pacific cod as of August 14, 2024 was 2,509 t. Over the past 5 years (2019 - 2023), 71% of the catch has taken place by this date. Therefore, the full year's estimate of catch in 2024 was extrapolated to be 3,533 t. This is lower than the average catch over the past five years of 13,435 t.

Responses to SSC and Plan Team Comments on Assessments in General

SSC December 2023

When estimating catch for projections, a more realistic value than maxABC should be considered, given that maxABC has not been achieved in recent years.

Authors' response

Authors plan to explore more realistic values for catch in projections.

Responses to SSC and Plan Team Comments Specific to this Assessment

Plan Team September 2023

The Plan Team favors constraining M. They recommend M with a prior based on a reasonable approach.

Authors' response

Based on this suggestion, we have incorporated an externally estimated natural mortality, M, that was based on the same methodology used to calculate M for the eastern Bering Sea Pacific cod assessment model since 2023. We used M = 0.417 for Aleutian Islands Pacific cod. This methodology is described below.

SSC December 2023

Public comment further highlighted challenges with the risk table. Elevated risk was identified but a recommended reduction from maximum ABC or rationale for no reduction was not presented for the base model. Their view was that AI cod have declined within the AI region, though they were uncertain as to the magnitude of the decline.

Authors' response

We intend to clarify any uncertainty in the 2024 assessment.

SSC December 2023

Fishery CPUE would be more appropriate to consider under fishery performance in the risk table.

Authors' response

Fishery CPUE is not indicative of abundance or stock status. Declines in CPUE may be attributed to the timing of the fishery relative to spawning season or other factors such as hyperaggregation during spawning in the trawl fishery (Rose and Kulka 1999). Standardized surveys are needed to understand whether declines in fishery CPUE are indicative of declines or increases in Aleutian Islands Pacific cod stock size.

SSC December 2023

There were three parameters for natural mortality (M) where only two were required. This is confusing and might have influenced the model results in ambiguous ways that were not fully described in the document. Standard practice would be to estimate two lognormal parameters for the two M blocks.

Authors' response

The M timeblock in Model 24.1 is now estimated using only a single parameter as suggested.

SSC December 2023

Similarly, there were three parameters estimated for time varying growth where only two were required. As a result, the SSC has the same concerns as noted in the previous bullet. In addition, the author presented a slide showing almost identical growth coefficients for time varying kappa in two periods, suggesting that time-varying growth may not be needed.

Authors' response

Time-varying growth was removed from the model based on this suggestion.

SSC December 2023

The 'q sensitivity' model, where q is calculated analytically but was almost identical to the estimated value, resulted in significant impacts on model results, indicating potential convergence issues or other inconsistencies in the model.

Authors' response

There have been numerous changes and improvements to the model since 2023. Table 1 lists eight changes and details bridging model analysis towards the final recommended model.

SSC December 2023

The increasing OFL and decreasing ABC in Model 23.2 for 2025 in the author and BSAI GPT recommended recruitment time series for projections raises concerns about the accuracy of the projections and the projection methods.

Authors' response

Noted.

SSC December 2023

When estimating catch for projections, a more realistic value than maxABC should be considered, given that maxABC has not been achieved in recent years. This problem isn't unique to AI Pacific cod (see General Stock Assessment Comments section).

Authors' response

The authors plan to explore more realistic catch values in projections.

SSC December 2023

The SSC recommends a sensitivity analysis and a possible prior on M. It is surprising that estimating M was difficult in the data-rich EBS Pacific cod assessment, but estimating M in the AI cod assessment was successful with fewer data points. The SSC encourages further collaboration among authors of the three cod assessments with regard to the treatment of M.

Authors' response

Based on further collaboration among authors of the three cod assessments with regard to the treatment of M, we have fixed the base value of M in the AI cod assessment at 0.417. A sensitivity was performed (Table 1) and results are discussed below.

SSC December 2023

The SSC recommends that the authors present a simplified version of the original September 23.0 model with minimal time varying parameters alongside a preferred model or set of models in September 2024.

Authors' response

Based on this comment, Model 24.0 is provided which represents a simplified version of the September 23.0 model.

SSC December 2023

In the ESR, the need for an indicator of winter bottom temperature during spawning was noted, possibly derived from winter fisheries data, to assess potential detrimental effects of high temperatures in the AI on spawning and egg survival.

Authors' response

The ESR group indicated that reliable bottom temperatures in the Aleutians in winter is difficult. The ROMS model does not capture the Aleutians, which would require observational data, which is infrequent and may not be properly calibrated.

For the future, the marine mammal laboratory at AFSC has placed a mooring at Unimak Pass for 3 years which could provide bottom temperature throughout the year. This data is not available currently. In addition, bottom temperatures in some regions remain relatively constant year round so that summer data could serve as a potential indicator.

SSC December 2023

Although the SSC previously recommended that AI Pacific cod be on an annual cycle, the SSC welcomes author and GPT feedback on whether moving to a biennial assessment would be beneficial to allow for more model development time, while coinciding with new AI survey data. Because 2024 will have a new survey, this consideration for a biennial cycle could begin after 2024, especially if a Tier 3 model is accepted in 2024.

Authors' response

Noted.

Data

The data used in the age structured models include fishery catch and size compositions, survey biomass and standard error, and age compositions from survey data (Table 2A.3 and Figure 2A.1). Partial catch information for 2024 was available and was extrapolated to estimate the catch for the full year. On average, 71% of the annual catch occurs by this date, as estimated by catch statistics for the past 5 full years, 2019 - 2023. The full year's estimate of catch of Pacific cod in the Aleutian Islands for 2024 was 3,533 t. Overall, catches have decreased for all gear types since 2020 (Figure 2A.2).

The data used in the Tier 5 Model included biomass estimates and associated error for the NMFS Aleutian Island research surveys, 1991-2022 (Table 2A.4).

Fishery Data

There are three predominant gear types in the Aleutian Islands Pacific cod fishery; pot, trawl, and longline, which are implemented at different times of the year (Figure 2A.3). During spawning season (January - April), mature Pacific cod aggregate for spawning at known locations. During these months, over the past 5 years (January 1, 2020 - August 14, 2024), pot and trawl gear were primarily used (26.9% trawl, 70.9% pot, 2.2% longline). After spawning, Pacific cod typically disperse for feeding (although some do not); during May through December, cod were primarily caught with trawl gear, followed by longline and pot gear (46.2% trawl, 49.9% longline, 3.9% pot). While the spawning season is approximately half the time of non-spawning (4 vs. 8 months), the majority, 63.3%, of the annual catch (during the time period January 1, 2020 - August 14, 2024) took place during spawning season. Catches have exceeded TAC harvest recommendations in five of the nine years since 2013, but have never exceeded the OFL (Table 2A.5).

CPUE aggregated over gear types for the number and weight of fish show similar trends, indicating that there has been no large shifts in the weight of individual fish (Spies et al. 2023). Recent declines in CPUE may be attributed to the timing of the fishery relative to spawning season or other factors such as hyperaggregation during spawning in the trawl fishery (Rose and Kulka 1999). Standardized surveys are needed to understand whether declines in fishery CPUE represent declines in Aleutian Islands Pacific cod stock size. Recent declines in CPUE may also be due to less effort in targeted Pacific cod fishing. The amount of targeted Pacific cod fishing has decreased since 2018, but the catch in the atka mackerel and rockfish fisheries has remained the same or increased (Figure 2A.4, Table 2A.6).

Length data taken by fishery observers is used in the model (Table 2A.3). The number of hauls from which lengths are taken are somewhat proportional to the magnitude of fishing, and the number of hauls which recorded cod lengths was highest in 2001 (Table 2A.7).

Survey Data

The National Marine Fisheries Service (NMFS) conducts biennial daytime summer trawl surveys in the Aleutian Islands. Survey biomass is estimated by extrapolating the weight from individual trawls with the measured path of the trawl area to the total area surveyed. The net used in the Aleutian Islands survey is a high-rise poly-Noreastern 4 seam bottom trawl (27.2 m headrope, 36.8 m footrope, Nichol et al. 2007). Survey biomass estimates and standard error for Pacific cod are available for the survey years 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, and 2022 (Table 2A.8). A survey is currently underway during 2024, and a survey biomass estimate will be available for the November assessment. Aleutian Islands surveys prior to 1991 were not used in the model because they were not standardized to current survey methodology; therefore, data from the 1980, 1983, and 1987 surveys were excluded. Survey data includes NMFS areas

541, 542, and 543. The Aleutian Islands bottom trawl survey does include NMFS areas 518 and 519, but these were not included in data for this model because they are not considered part of the Aleutian Islands management area.

Survey age data is available for each survey, 1991-2022. The number of cod aged from the survey has ranged between 500 and 1,200 and the number of hauls ranges from 76-173 (Table 2A.9). Length composition data from the surveys is also used in the model (Figure 2A.1). All survey data are specified in model as from July, the midpoint of NMFS surveys.

The time series of NMFS bottom trawl survey biomass is shown for Areas 541-543 (Eastern, Central, and Western AI, respectively), together with their respective coefficients of variation, in Table 2A.4. These estimates pertain to the Aleutian management area, and so are smaller than the estimates pertaining to the Aleutian survey area that were reported in BSAI Pacific cod stock assessments prior to 2013. Over the long term, the trawl survey biomass data indicate a decline, and the 2022 estimate of biomass is the lowest in the time series. The total biomass estimate for Pacific cod in the Aleutian Islands declined from over 180,000 t in 1991 to 51,539 t in the current year. Recent declines took place in the eastern Aleutians (>50% decline) and in the central Aleutians (32% decline) from the last survey in 2018 to the current survey in 2022. The western Aleutian Islands stock of Pacific cod increased from 11,425 t to 13,661 t (20% increase) between 2018 and 2022 (Figure 2A.5 and Table 2A.4).

The most recent longline survey estimate was also the lowest in the time series, but the longline survey data was not incorporated into the Tier 5 model or the age stuctured models (Table 2A.8). The longline survey was designed to target sablefish, and how well it documents the abundance of Pacific cod is uncertain.

Analytic Approach [Tier 5 model]

Model 13.4

Model 13.4 is the Tier 5 random effects model recommended by the Survey Averaging Working Group, which has been accepted by the Plan Team and SSC since the 2013 assessment for the purpose of setting AI Pacific cod harvest specifications. The Tier 5 random effects model is programmed using the ADMB software package (Fournier et al. 2012) as a "random walk" state-space model. The only parameter in Model 13.4 is the log of the log-scale process error standard deviation. When used to implement the Tier 5 harvest control rules, the Tier 5 models also require an estimate of the natural mortality rate. The Tier 5 random effects model assumes that the observation error variances are equal to the sampling variances estimated from the haul-by-haul survey data. The log-scale process errors and observations are both assumed to be normally distributed.

Recent estimates of natural mortality indicate that estimates have ranged from 0.20 to 0.96 for Pacific cod (Table 2A.10). A natural mortality estimate of 0.34 been used in the most recent Aleutian Islands Pacific cod assessment, as well as the 2022 and prior BSAI cod assessments (Thompson et al. 2018). This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006. In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for M extends from about 0.30 to 0.38. The value of 0.34 for natural mortality was used for the 2024 Tier 5 Model 13.4, as in previous years.

Under Tier 5, F_{OFL} is set equal to the natural mortality, F_{OFL} = M, and the fishing mortality rate to achieve the acceptable biological catch is 75% of M, $F_{ABC} \leq 0.75 \times$M.

Model 24.2

A new base value for natural mortality, 0.417, was introduced as a base model for age structured models. Therefore, M = 0.417 is presented as an alternative calculation for the Tier 5 reference points in Model 24.2.

Analytic Approach [Age structured models]

Stock Synthesis Version 3.30.21 was used to run the the age structured models in this assessment. Stock Synthesis requires that prior distributions and initial values be associated with all internally estimated time-invariant parameters. For age structured models presented in this assessment, all parameters were fit freely without informative priors.

The following are features of the age structured models that are consistent with the 2023 models.

- Single sex model, 1:1 male female ratio.
- Survey age and length data were input as conditional age-at-length.
- Recruitment estimated as a mean with lognormally distributed deviations.
- Maturity-at-age was estimated externally using observer data, then input into the model.
- Single-fleet fishery that combines trawl, longline, and pot fishery data, weighted by quarter, gear, and NMFS area, from 1991 - current year (through August 14).
- All parameters were constant over time except for natural mortality after 2015 in Model 24.1.
- Survey and fishery selectivity were modeled as logistic and constant over time.
- Trawl survey catchability was incorporated analytically.

Data weighting and model tuning

Survey length and age input sample sizes generated by bootstrapping the number of hauls from which length and age data were taken using the methodology of Hulson et al. (2023). Fishery length composition input sample sizes were based on the number of hauls, and scaled to the mean survey input sample size (so that the mean fishery length composition input sample size was the same as the survey mean input sample size). This did not result in a change in likelihood, but is preferred over a constant sample size approach to weighting compositional data because it considers the number of hauls in each year and therefore the varying informational content in each year. This approach is consistent among the Aleutian Islands, EBS, and GOA Pacific cod assessment models.

The parameter for variance in recruitment, sigmaR, was tuned only once at the end of the model run using a feature in SS3 that provides an estimate based on model output.

Model-based age and length composition data from survey and fishery were weighted using the methodology of Francis (2011) in an iterative process. Input sample sizes for age comps by length bin were equal to the actual number of fish aged in those categories (whole numbers). The marginal compositions were weighted using the bootstrapping method of Hulson et al (2023).

Description of Alternative Models

We present a series of models to demonstrate the importance of features implemented in 2024 models 24.0 and 24.1 (Table 2A.11). These are bridging models M24.0A tbhrough M24.0G, not intended for consideration as harvest models. Specifically these models evaluated logistic vs. dome-shaped survey selectivity, age plus group, 10^+ vs. 13^+, estimation of initial fishing mortality during the 10 years prior to the model time series (1981-1990), estimated vs. fixed natural mortality, Richards vs. von Bertalanffy growth curve, a timeblock on M during a heatwave 2016-present, and a smaller CV on growth at younger ages.

Parameters Estimated Outside the Assessment Model

Maturity

The maturity-at-length is modeled by the relationship:

$$Maturity_{length} = \frac{1}{1 + e^{-(A+Blength)}},$$

where A and B are parameters in the relationship.

A study based on a collection of 129 female fish in February, 2003, from the Unimak Pass area, NMFS area 509, found that 50% of female fish become mature at approximately 4.88 years ($L_{50\%}$) and 58.0 cm, A=-4.7143, B=0.9654 (i.e. Tables 2 and 4 in Stark 2007). This maturity ogive is used in the Bering Sea Pacific cod assessment but was not used in this assessment, because the fish in the sample were not from the Aleutian Islands.

Observers routinely collect maturity at length from Pacific cod. An alternative maturity curve was developed based on observer records of maturity from the Aleutian Islands. This parameterization is advantageous because it is based on more records that were taken from Aleutian Islands cod, and is incorporated into age-structured models presented here. Maturity was updated in 2024, resulting in the addition of 24 new visual maturity samples, which did not result in a change to the maturity curve parameters. There were 1,355 records of visual maturity data from the Aleutian Islands (see table below) during the months January – March since 2008. These were used to estimate a maturity ogive by length using the R package *sizeMat*, which estimates the length of fish at gonad maturity. Maturity was considered a binomial response varable and variables were fitted to the logistic function above for maturity, and the length at which 50% of cod are mature is $L_{50\%} = -A/B$ (Table 2A.12). This method was accepted by the Plan Team (September 2022) and SSC (October 2022). Based on this data, the maturity parameters used in the model were A = -8.143, B = 0.148, $L_{50\%}$ = 54.9 cm, and slope = -0.148. Maturity data used in the model are based on length, rather than age. An age-based histological maturity curve would be ideal and is a research priority for the model.

The maturity curve will be addressed for the November model. Reanalysis of the maturity curve with new data and filtered for stomach scan data (which can be mistaken for maturity data in OBSINT) provided 1,347 records and shifted the age at 50% maturity to 55.5 cm (Confidence intervals = 53.7 - 57.3), A = -8.589, B = 0.155.

Ageing error

After 2007, there was a shift in our understanding of the first two checks deposited at early ages in Pacific cod. Prior to 2007 they were thought to be true annuli, but subsequently determined not to be. Therefore, geing bias was not incorporated in the model, as all ages used were aged subsequent to 2007, after which time ageing methodology has been consistent and considered non-biased. Ageing error was applied to ages 2-13+. The standard deviation at the first age was 0.57 and 1.16 at the maximum age.

There were 10,134 records of aged and lengthed Pacific cod taken from NMFS research surveys between 1991 and 2022 (1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022). The maximum age observed was 13 (Table 2A.13).

Natural mortality

A natural mortality estimate of 0.34 been used in the most recent Aleutian Islands Pacific cod assessment, as well as the 2022 and prior BSAI cod assessments (Thompson et al. 2018). This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006. In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for M extends from about 0.30 to 0.38.

For the base model, natural mortality was fixed at a value calculated using standard methodology. We used the *Then_lm* method (http://barefootecologist.com.au/shiny_m.html), which is the same methodology used to calculate natural mortality, M, for the eastern Bering Sea Pacific cod assessment model. The value of M was recalculated for Aleutian Islands Pacific cod to account for different growth patterns and different maximum ages. For example, the maximum age observed in the eastern Bering Sea was 14, while the maximum age observed in the Aleutian Islands was 13. The age data used for this analysis was the same as in the assessment, from all survey years including the most recent survey in 2022 (Table 1). Based on these values, natural mortality M for Aleutian Islands Pacific cod was 0.417.

The eastern Bering Sea Pacific cod model has moved to a fixed M since 2023. Implementing a fixed value for natural mortality allows for better estimation of parameters that may be constrained by M. For EBS cod, M was calculated as 0.3866. The difference is likely due to faster growth and lower maximum age observed in Aleutian Islands Pacific cod.

Parameters Estimated Inside the Assessment Model

While describing parameter estimates, we present results from models 24.0A through 24.0G included to demonstrate the importance of features implemented in 2024 models 24.0 and 24.1 (Table 2A.11).

Growth

The Richards growth curve was used to fit growth within the models, but sensitivity to the von Bertalanffy growth curve is presented (Table 2A.11). The Richards growth curve adds an additional parameter to the logistic growth curve to account for non-symmetrical growth at early ages and maximum ages. Although the Von Bertalanffy growth curve was used in previous iterations of the age structured model, we found that the Richards growth curve improved the fit to the data. The Richards growth curve is also used in the Eastern Bering Sea and the Gulf of Alaska Pacific cod stock assessments.

The use of the Richards growth curve not only improved the fit to the growth curve but also the likelihood. The addition of the Richards growth curve (vs. von Bertalanffy in M24.0G) allows for an inflection point between younger (age 2) and older cod (age 4+) that is not available in the von Bertalanffy, and provides a better fit to the data. The addition of the full length and age composition data (present in Model 24.0A but not in Models M24.0F and M24.0G) and less uncertainty in younger ages further improved the fit to growth in Model 24.1 (Figure 2A.6).

None of these models incorporate time-varying growth because it is not justifed by size at age data. Pacific cod growth in the Aleutian Islands has not changed significantly throughout the timeseries; therefore. Timeblocks on growth were explored in 2023, but resulted in minimal changes to parameters.

Length at age

Pacific cod do not exhibit sexually dimorphic growth; males and females grow at the same rate. Therefore, the model did not distinguish between males and females. Growth is rapid at younger ages (Figure 2A.7) and was estimated within the model using the Richards growth curve as described above. Incorporating all length age and length bins were important for fitting growth.

There was no observed change in growth over time. Therefore, only constant growth was used in the age structured models. We explored fixing the length of fish (L1) at early ages (1.0 years) at external estimates, but opted for model estimation of length at L1.

Selection of maximum age

The oldest Aleutian Islands cod age observed was 13 years. The 2023 age structured models incorporated 10^+ as the maximum age, but we evaluated the use of all observed age classes. Models 24.0B and 24.0D are identical except for the plus group age. Model 24.0B incorporates 13^+ and provides a smaller total negative log likelihood than Model 2DB with age plus group 10^+. Therefore, models with the full range of observed ages, rather than a truncated age group are preferable.

Selection of maximum length

The largest cod observed in the Aleutian Islands was 143 cm, but models presented in 2023 incorporated maximum size class 117^+ cm. Model 24.0A used all size classes while Model 24.0B used the 117^+ cm plus group (Table 2A.11). The use of all size classes improved the fit to the length composition likelihood component and reduced size of the asymptotic fishery selectivity, 91 cm vs. 95 cm (Figure 2A.8). The use of a maximum size bin set at 117 cm is that the estimation of the length at the maximum age is constrained by the maximum size bin, and cod have grown as large as 143 cm. Therefore, incorporating all observed sizes improves the growth curve and informs the range of Pacific cod sizes present in the population.

CV on younger ages

Model 24.0A differs from 24.1 only in the size of the CV on growth on younger ages, and the reduction in total negative log likelihood demonstrates the improved fit to the data (Table 2A.11). This parameter applies to the CV of ages younger than the minimum age in the growth model, in this case that would apply to ages less than 1. We performed a likelihood profile over the CV on younger ages, from 0.1 to the previous value of 0.3, by increments of 0.2. Length data indicated an MLE of 0.16 while age data indicated somewhat lower, 0.14. Francis weighting provided larger weights for age data, so the global estimate was closer to 0.14. The likelihood profile indicated lower CV would be an improvement over 0.3 (Figure 2A.9).

Because likelihood may not be the best indicator of appropriate CV, we also explored the age frequency data from 1991-2022 for an indication of a CV for the CV young parameter. Because the variability at ages <1 year will be propaged to subsequent ages, we examined mean size at age and CV for ages 1-3. Age 1 (mean = 22.1 cm, CV = 1.81), Age 2 (mean = 38.3, CV = 1.54), Age 3 (mean = 48.9 cm, CV = 1.3). It was notable that the mean size at age increased with the addition of the 2022 data, suggesting that growth rate has increased in Aleutian Islands Pacific cod due to warmer ambient temperatures. With the addition of 2022 data, the age 1 mean size increased from 20.1 cm to 22.1 cm, age 2 from 36.2 cm to 38.3 cm, and age 3 from 47.8 cm to 48.9 cm.

A value of 0.16 was implemented in Models 24.0 and 24.1, lower than the previous value of 0.3. CVs lower than 0.16 did not fit the survey length frequencies well because there was some error in the sizes of age 1 and age 2 length frequency. The smaller CV at young ages improved the survey selectivity fit to observed length frequencies (Figure 2A.10).

Selectivity

Selectivity for the fishery and the survey were fit (separately) using monotonically increasing asymptotic logistic curve (Figure 2A.8). We considered dome-shaped and logistic survey selectivity as well. Dome shaped survey selectivity was explored because the survey does not collect as many large fish as the fishery. However, it did not improve the fit to the data (Models 24.0B vs. 24.0C) (Table 2A.11). Dome-shaped fishery selectivity was also examined but did not improve the fit to the data.

The fishery is modeled as a single-fleet fishery that combines trawl, longline, and pot fishery data. While these geartypes do catch different distributions of fish, past model explorations for the EBS and Aleutian Islands stock assessment models showed that there is insufficient data to merit three separate fishery selectivity curves.

Past models have explored whether a timeblock on selectivity is justified. A timeblock on selectivity during the last 4 years period of less targeted fishing did not improve the model and had insufficient data.

Initial F

The addition of initial F estimation was incorporating by providing the model with data from 1981-1990. Estimating initial F improved the fit to the data, as shown in the comparison between Model 24.0D and M24.0E (Table 2A.11). Therefore, initial fishing mortality was incorporated in Models 24.0 and 24.1.

Natural mortality

We allowed Model 24.0F to estimate natural mortality, to examine the ability of the model given the data to estimate this parameter. Model 24.0F estimated M at 0.853 and it improved the overall likelihood. However, whether there is sufficient data in the model to estimate M is uncertain. While M = 0.853 is within the range of natural mortality estimates for Pacific cod (Table 2A.10), it was outside the range of natural mortality recently calculated for Aleutian Islands Pacific cod (beteween 0.3 - 0.5). In addition, Model 24.0F provided multiple aberrant estimates, including a six-fold increase in unfished spawning biomass (Table 2A.11). Therefore, Model 24.0F supports the use of a fixed natural mortality prior to the 2016-2024 time block.

Model 24.1 used a time block which estimated natural mortality from 2016 - 2024, but it was fixed at M = 0.417 from the beginning of the time series through 2015 (Table 2A.11). The timeblock on natural mortality estimated a single value, rather than a base value with deviations. Estimating a single parameter is advantageous because it reduces the number of parameters estimated and reduces uncertainty.

Model 24.1 accounted for changing environmental conditions due to the shift in temperature through the 2016-2024 time block on natural mortality. The year 2016 was selected because this it is two years after the beginning of the documented thermal shift (Xiao and Ren 2022) (Figure 2A.11). While this thermal shift has not been documented as an ecological regime shift, it is significant and should be considered as a potential factor for changes in abundance or distribution. The time block did not start earlier because it incorporated a ~two year lag for effects of higher temperatures to be observed, the effect of cumulative stress that increased temperatures can incur (e.g. Barbeaux et al. 2018, Laurel and Rogers 2020). Pacific cod are known to respond poorly to temperatures that exceed their preferred thermal range; therefore, increased natural mortality due to the thermal shift may be the optimal model configuration. The lag also corresponded to the time required for cod to grow to a size/age at first survey selectivity. The assumption that increased natural mortality due to higher temperatures is supported by evidence in the laboratory and in situ, and includes all life stages (Laurel et al. 2008, Barbeaux et al. 2020). Accordingly, the time block on natural mortality in Model 24.1 indicated higher natural mortality which was freely esetimated and not on a bound (0.58). As of August 2024, heatwave conditions in the Aleutian Islands appear to be less extreme than in past years during all months with the exception of August in the western Aleutians, but periods of moderate heatwave conditions have occurred (Figure 2A.12). The timeblock on natural mortality in Models 24.1 and 24.0A improves the fit to survey index of abundance, particularly later years in the survey (Figure 2A.13). The survey index declined from 2018 - 2022; therefore, the spawning stock size relative to unfished is lowest for the models that include the natural mortality timeblock (Figure 2A.14).

An increase in recruitment deviations during 2015 - 2020 occurred with the natural mortality timeblock in models 24.1 and 24.0A is (Figure 2A.15). Other models accounted for the decrease in survey indices of abundance by reduced recruitment during 2010 - 2020. Presumably, the increase in recruitment in Model 24.1 was a response to the higher natural mortality. There is little evidence that Pacific cod recruitment increases during heatwave conditions. In the Gulf of Alaska, abundance declined with increasing ocean temperature during egg and larval phases, and the age-0 cod were larger (Abookire et al. 2022). The Gulf of Alaska is a broad, shallow shelf, quite different from the Aleutian Islands archipelago, a partially submerged mountain range in which cod habitat consists of narrow and steep terrain (Logerwell et al. 2005). Some life history stages of Pacific cod in the Aleutian Islands may escape warm temperatures by moving to deeper water, unlike cod in the Gulf of Alaska. Survey length compositions, which include age 1 and 2 cod, indicate that the proportion of age 1 cod decreased in 2002 and 2004 from previous years, and then increased to a stable proportion over the remainder of years through 2022 (Figure 2A.16). This is consistent with a decrease in recruitment during the early 2000s, and a subsequent increase (Figure 2A.15).

Catchability

Experiments have been performed that measure whole-gear efficiency (the proportion of fish passing between the otter doors of a bottom trawl that are subsequently captured), and these studies can inform catchability. Somerton (2004) used an 83-112 Eastern Trawl trawl net in the eastern Bering Sea and found no evidence that Pacific cod were herded into the net (Somerton et al. 2004). Another study estimated 47.3% of cod in the water column to be available to the trawl used on the eastern Bering Sea trawl survey and 91.6% are available to the trawl used on the Gulf of Alaska and Aleutian Islands surveys (Nichol et al. 2007). This study was based on results showing that 95% of cod were found within 10 m of the seafloor, based on 286 archival tagged cod off Kodiak Island in the Gulf of Alaska and off Unimak Pass in the eastern Bering Sea, Alaska (Nichol et al. 2007). More recently Rand et al. (2022) found no evidence for difference in mean size of Pacific cod caught by the survey and the fishery in the eastern Bering Sea. However, the Aleutian Islands presents a more complex environment, with rocky and steep habitat that is not consistently trawlable (Logerwell et al. 2005). It is plausible that this habitat could lead to survey catchability <1 in the Aleutian Islands.

A likelihood profile on survey catchability (q) was performed, and results are presented as the logarithm of catchability followed by the actual catchability (not logarithm) in parentheses. Log(q) was profiled from -0.8 to 0.8 (q = 0.45 to 2.22) in increments of 0.1, and showed conflict among data sources to inform catchability (Figure 2A.17). Index data suggested that survey catchability was -0.5 (q = 0.6), and recruitment suggested even lower. In contrast, F ballpark indicated higher ln(q), at 0.8 (q = 2.22). The age and length data were both close to zero, and the MLE was approximately -0.2 (q = 0.82). We estimated catchability in all models analytically, as the exploitable biomass estimated by the model divided by the survey estimate of biomass. This results in the same estimate as estimating catchability with a uniform prior, but provides a more parsimonious alternative. The calculated catchability for Model 24.0 was 2.528 and for Model 24.1 was

2.391.

Other parameters

The total likelihood and the number of parameters estimated for each model is shown in Table 2A.11.

Evaluation of Models and Associated Uncertainty

The Wald and Wolfowitz (1940) runs test was performed on Models 24.1 and 24.0, as well as the seven bridging models. This is a nonparametric hypothesis test for randomness in a sequence of data, specifically the survey abundance index. The test uses residuals from fits to abundance indices to diagnose model misspecification, using a 2-sided p-value (Carvalho et al. 2021). All models passed the runs test, providing evidence against model misspecification (Table 2A.11).

Sensitivity to Model Specification

Seven additional model runs have been provided (Models 24.0A through 24.0G) to address sensitivity of the model to model specification for the shape of the survey selectivity curve, size of the age and length plus groups, initial fishing mortality estimate, growth curve, natural mortality, and CV on growth (Table 2A.11). These sensitivites are incorporated into the sections "Parameters Estimated Outside the Assessment Model" and "Parameters Estimated Inside the Assessment Model" and are used to show sensitivity to model parameterization.

The fit to the length composition data using one step ahead (OSA) and Pearson residuals generally show no large-scale pattern of over or under-fitting. However, both residual methods indicate overestimating younger ages (~20 cm) during years 2010 through 2018. The pattern is more apparent for Model 24.0, and only visible in Model 24.1 in the Pearson residual plot (Figure 2A.18).

Likelihood Profiles on Key Parameters

Likelihood profiles have been performed on several key parameters, as described above: catchability (Figure 2A.17) and the CV on growth for younger ages (Figure 2A.9).

A likelihood profile was constructed for initial recruitment (R0) values between 10.4 and 12.0 in increments of 0.2 (Figure 2A.19). The profile suggests that the global MLE for R0 is at approximately 11.4. Index data indicates that initial recruitment is somewhat higher, while length data indicates R0 is somewhat lower. The global estimate is in the between these two and similar to the recruitment likelihood.

Convergence Status and Criteria

Convergence was determined by successful inversion of the Hessian matrix and a maximum gradient component of less than 1e-4 (this value was 1.2 e-06 for Model 24.1 and 0.0001 for Model 24.0). A jitter analysis revealed that the proposed based model (Model 24.0) and Model 24.1 are insensitive to perturbations of parameter start values on the order of 10% (Figure 2A.20 and Figure 2A.21). All parameters were estimated within their pre-specified bounds.

All model runs implemented within the jitter test had total negative log likelihood values equal to or less than the base model. Therefore, based on the jitter test, there was no evidence to reject the hypothesis that the base model successfully converged.

Retrospective analysis

A ten-year retrospective analysis was conducted by sequential removal of all data annually beginning with 2024 and ending with 2014, for Models 24.0 and 24.1 (Figure 2A.22). By age ten, a cohort of fish have reached their asymptotic length, are considered 100% mature and fully selected by the survey. For Model 24.1, the mean terminal spawning biomass estimate from each of these retrospective models was within the 95% confidence interval of the current base model for the first five years, but deviated as the number of years in the 2016-2024 timeblock was reduced. Retrospective plots for the two age structured models indicate an improved pattern for Model 24.1 over Model 24.0 (Figure 2A.22).

Hurtado-Ferro (2015) provides some guidance on the range of acceptable values for Mohn's rho. For a flatfish-like species with M = 0.2, the lower and upper bounds were given as -0.15 and 0.2. For a sardine-like species with M = 0.34, the lower and upper bounds were given to be -0.22 and 0.3. If Mohn's rho were entirely dependent on M (likely an oversimplification), then an equation for the lower and upper limits could be developed from these guidelines as follows: $Rho_{lowerbound} = -0.08 - 0.35 * M$ and $Rho_{upperbound} = 0.10 + 0.50 * M$. Using these guidelines, and noting that the base value of natural mortality for Models 24.0 and 24.1 was 0.417, lower and upper bounds would be -0.23 and 0.31. Model 24.0 produced an unacceptable Mohn's rho value, 0.471, while Model 24.1 produced a smaller retrospective pattern, 0.115 (Figure 2A.22). Given these guidelines, the Mohn's rho is not outside acceptable bounds for Model 24.1 but it is outside of acceptable values for Model 24.0 (Figure 2A.22).

Without incorporating a timeblock on natural mortality, the model cannot fit recent declines documented by the Aleutian Islands survey. For models without the natural mortality timeblock, such as Model 24.0, the retrospective patterns are outside of acceptable bounds (e.g. Mohn's rho >0.4, Figure 2A.22).

Projections and Harvest Recommendations

The Tier 3 models and projections were conducted using the Stock Synthesis program. Due to time-block on natural mortality in Model 24.1, forecasts are performed using the base value of natural mortality used in Model 24.1 from 1991-2015. As populations experience the stress of climate change, natural mortality will increase in response, as shown in Model 24.1 (Szuwalski et al. 2023). Incorporating increased natural mortality in harvest rates implies a 'double-threat', because adapting the harvest control rule to changing environmental conditions would result in both lower biomass targets and higher harvest rates (Szuwalski et al. 2023). Therefore, projections are based on the time period in which natural mortality is fixed at the base value of 0.417, and does not incorporate an increase due to climate change. While other parameters, such as recruitment, can be affected by climate change, we used recruitment and all other parameters from the entire time series in projections. In addition to simplifying assumptions in projections, this choice did not change results by a large proportion.

A Kobe plot demonstrating the stock status uncertainty over SSB/SSB_{MSY} and F/F_{MSY} indicates that the stock has shifted from $>SSB_{MSY}$ in 1991 to a lower stock status $<SSB_{MSY}$. There is currently a 97.6% probability that the stock status is between 0 and SSB_{35}, and that the fishing mortality rate is below F_{40}% (Figure 2A.23). This is consistent with other analyses: Table 2A.11 indicates that the proportion of unfished biomass is 22.3%, and fishing mortality has been low relative to management quantities (Table 2A.5, Figure 2A.2).

Tier 5 Model Results

The Tier 5 ABCs and OFLs for 2025 and 2026 for Model 13.4 are the same as estimated in 2022, due to no new survey data. The 2022 (through 2024) random effect estimates of biomass represent a 37% decline from the estimate based on the 2018 Aleutian Islands survey. Model 13.4 incorporates this biomass estimate directly in the calculation of reference points; therefore, the random effects model estimated an exploitable biomass of 54,166 t, which resulted in OFLs (18,416 t) and ABCs (13,812 t) for 2025 and 2026. Model 24.2 calculated Tier 5 ABCs and OFLs with the new estimate of natural mortality calculated using M = 0.417, which resulted in higher OFLs (22,587 t) and ABCs (16,940 t) for 2025 and 2026. We recommend the use of age structured models for reference point setting and harvest quantities.

Age Structured Model Results

The incorporation of a natural mortality time block after 2015 in Model 24.1 improved the fit to the survey index and the overall likelihood over the base Model 24.0 (Table 2A.11). Natural mortality in this timeblock was estimated at 0.579, which was higher than the natural mortality from 1991-2015, M = 0.417. AIC was lowest for Model 24.1 (Table 2A.11), indicating a better fit to the data despite the addition of an estimated timeblock parameter. Improvements in Model 24.1 over Model 24.0 are notable in the survey and length composition likelihood components, as well as the fit to the survey index and AIC (Figure 2A.24, Table 2A.11). Model 24.0 produced an unacceptable Mohn's rho value, 0.471, while Model 24.1 produced a smaller retrospective pattern, 0.115 (Figure 2A.22). Given the improvements in the model specficiation relative to fits to the data and improved assumptions, Model 24.1 would be a recommended candidate for management.

Model 24.1 differs from Model 24.0 due to the addition of a time block on natural mortality with a break in 2015, corresponding with the thermal shift in 2013/2014 with a 2-year lag (Xiao and Ren 2022). This results in the best fit to the data and the lowest AIC, and is a significant improvement over model 24.0 (Table 2A.11). Natural mortality was estimated higher in the timeblock as expected due to thermal stress 0.579, over M = 0.417. Model 24.1 improved upon Model 24.0 in several likelihood components, including survey and length compositions and survey index (Figure 2A.24, Table 2A.11). Model 24.1 also produced an acceptable retrospective pattern (Figure 2A.22) and Mohn's rho (0.115), whereas Model 24.0 did not (M24.0 Mohn's rho = 0.471). Given the improvements in the model specficiation relative to fits to the data and improved assumptions, Model 24.1 would be a recommended candidate for management.

Projections for Aleutian Islands Pacific cod 2025 through 2037 are presented for Model 24.1 for catches (Figure 2A.25) and stock status (Figure 2A.26), and for Model 24.0 for catches (Figure 2A.27) and stock status (Figure 2A.28).

November Models

We plan to present age structured models 24.0 and 24.1, and Tier 5 models 13.4 and 24.2 for the November Aleutian Islands cod assessment. As noted, we will also use a realistic catch value for projections and update the maturity curve. The new maturity curve will include observer visual maturity scans and length through September 2024, and represents 24 more records than previously used.

Acknowledgements

We thank the survey scientists and crew from National Marine Fisheries Service Aleutian Islands surveys. Thank you to Jim Ianelli for reviewing the document and SSMA/MESA for providing helpful comments.

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Tables

Table 2A.1: Summary table with a comparison of proposed 2024 Models 24.0 and 24.1. *Asterisk denotes natural mortality estimated in the timeblock 2016-2024.

	Model 24.1		Model 24.0	
Quantity	2025	2026	2025	2026
M (natural mortality rate)	0.42, 0.58*	0.42, 0.58*	0.42	0.42
Tier	3	3	3	3
Projected total (age 1+) biomass (t)	71,627	77,671	102,888	92,506
Projected female spawning biomass (t)	24,383	24,401	36,970	29,761
$B_{100\%}$	109,629	109,629	92,270	92,270
$B_{40\%}$	43,851	43,851	36,908	36,908
$B_{35\%}$	38,370	38,370	32,294	32,294
F_{OFL}	0.617	0.618	1.246	0.992
$maxF_{ABC}$	0.471	0.471	0.948	0.755
F_{ABC}	0.255	0.255	0.471	0.471
OFL	15,251	15,079	39,082	25,506
$maxABC$	12,089	11,960	31,926	20,524
ABC	12,089	11,960	31,926	20,524
Status	2023	2024	2023	2024
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Table 2A.2: Summary table with a comparison of Models 13.4 and 24.2 proposed for 2024. Model 13.4 (2023) was the tier 5 model used in 2023. M represents natural mortality rate. Note the 2024 accepted ABC and OFL were adjusted from the 2024 model values for OFL and ABC.

	Model 13.4 (2023)		Model 13.4		Model 24.2	
	As estimated or *specified last* year for:		As estimated or *recommended this* year for:		As estimated or *recommended this* year for:	
Quantity	2024	2025	2025	2026	2025	2026
M	0.34	0.34	0.34	0.34	0.417	0.417
Tier	5	5	5	5	5	5
Biomass (t)	54,165	54,165	54,166	54,166	54,166	54,166
F_{OFL}	0.34	0.34	0.34	0.34	0.417	0.417
$maxF_{ABC}$	0.255	0.255	0.255	0.255	0.313	0.313
F_{ABC}	0.255	0.255	0.255	0.255	0.313	0.313
OFL	18,416	18,416	18,416	18,416	22,587	22,587
$maxABC$	12,431	12,431	13,812	13,812	16,940	16,940
ABC	12,431	12,431	13,812	13,812	16,940	16,940
Status	2022	2023	2023	2024	2023	2024
Overfishing	No	n/a	No	n/a	No	n/a

Table 2A.3: Sources of data used in the age structured models, Model 24.0 and 24.1. *Data current through August 15, 2024.

Source	Type	Years
Fishery (Trawl, Pot, LL)	Catch biomass	1991-2024*
Fishery (Trawl, Pot, LL)	Length composition	1991-2024
AI bottom trawl survey	Biomass estimate + Length composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022
AI bottom trawl survey	Age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022

Table 2A.4: Aleutian Islands bottom trawl survey biomass estimates and standard error by NMFS area for Pacific cod, for all years used in the model.

Biomass (t)				
Year	Western	Central	Eastern	Total
1991	75,514	39,729	64,926	180,170
1994	23,797	51,538	78,081	153,416
1997	14,357	30,252	28,239	72,848
2000	43,298	36,456	47,117	126,870
2002	23,623	24,687	25,241	73,551
2004	9,637	20,731	51,851	82,219
2006	19,480	22,033	43,348	84,861
2010	21,341	11,207	23,277	55,826
2012	13,514	14,804	30,592	58,911
2014	18,088	8,488	47,032	73,608
2016	19,775	19,496	45,138	84,409
2018	11,425	20,596	49,251	81,272
2022	13,661	14,041	23,837	51,539

Proportion by area				
Year	Western	Central	Eastern	Total
1991	0.419	0.221	0.360	1
1994	0.155	0.336	0.509	1
1997	0.197	0.415	0.388	1
2000	0.341	0.287	0.371	1
2002	0.321	0.336	0.343	1
2004	0.117	0.252	0.631	1
2006	0.230	0.260	0.511	1
2010	0.382	0.201	0.417	1
2012	0.229	0.251	0.519	1
2014	0.246	0.115	0.639	1
2016	0.234	0.231	0.535	1
2018	0.141	0.253	0.606	1
2022	0.265	0.272	0.463	1

Biomass coefficient of variation				
Year	Western	Central	Eastern	Total
1991	0.092	0.112	0.370	0.141
1994	0.292	0.390	0.301	0.206
1997	0.261	0.208	0.230	0.134
2000	0.429	0.270	0.222	0.185
2002	0.245	0.264	0.329	0.164
2004	0.169	0.207	0.304	0.200
2006	0.233	0.188	0.545	0.288
2010	0.409	0.257	0.223	0.189
2012	0.264	0.203	0.241	0.148
2014	0.236	0.276	0.275	0.187
2016	0.375	0.496	0.212	0.184
2018	0.175	0.217	0.242	0.159
2022	0.202	0.159	0.227	0.126

Table 2A.5: Pacific cod catch in metric tons by year, total allowable catch (TAC), acceptable biological catch (ABC), and overfishing limit (OFL), 1991-2024. Note that specifications were combined for the Bering Sea and Aleutian Islands cod stocks through 2013 and are shown for the Aleutian Islands alone for 2013 onwards. Catch for 2024 is through August 14. ABC, OFL, and TAC for 2024 are based on last year's model output.

Year	Catch (t)	ABC	TAC	OFL
1991	9,797	229,000	229,000	-
1992	43,067	182,000	182,000	188,000
1993	34,204	164,500	164,500	192,000
1994	21,539	191,000	191,000	228,000
1995	16,534	328,000	250,000	390,000
1996	31,609	305,000	270,000	420,000
1997	25,164	306,000	270,000	418,000
1998	34,726	210,000	210,000	336,000
1999	28,130	177,000	177,000	264,000
2000	39,684	193,000	193,000	240,000
2001	34,207	188,000	188,000	248,000
2002	30,800	223,000	200,000	294,000
2003	32,456	223,000	207,500	324,000
2004	28,873	223,000	215,500	350,000
2005	22,693	206,000	206,000	365,000
2006	24,211	194,000	189,768	230,000
2007	34,354	176,000	170,720	207,000
2008	31,228	176,000	170,720	207,000
2009	28,581	182,000	176,540	212,000
2010	29,006	174,000	168,780	205,000
2011	10,888	235,000	227,950	272,000
2012	18,220	314,000	261,000	369,000
2013	13,608	307,000	260,000	359,000
2014	10,603	15,100	6,997	20,100
2015	9,216	17,600	9,422	23,400
2016	13,245	17,600	12,839	23,400
2017	15,202	21,500	15,695	28,700
2018	20,414	21,500	15,695	28,700
2019	19,200	20,600	14,214	27,400
2020	14,250	20,600	13,796	27,400
2021	12,882	20,600	13,796	27,400
2022	10,547	20,600	13,796	27,400
2023	7,312	13,812	8,425	18,416
2024	2,510	12,431	8,080	18,416

Table 2A.6: Catch of Pacific cod from 1993-2024 in non-target and targeted fisheries, as of August 14, 2024.

Year	Non-target							Target	Overall
	Atka mackerel	Flatfish	Halibut	Pollock	Rockfish	Other	Total non-target	Pacific cod	Total
1993	2,634	0	0	2	218	0	2,854	1,353	4,207
1994	6,855	3	0	11	358	0	7,244	14,295	21,539
1995	4,456	25	0	47	207	37	5,713	10,822	16,535
1996	8,675	0	0	10	394	10	9,173	22,436	31,609
1997	1,988	0	0	216	110	0	2,359	22,804	25,163
1998	3,709	19	0	1	114	33	3,891	30,836	34,727
1999	2,415	16	0	0	173	2	2,660	25,471	28,131
2000	2,088	66	0	0	115	24	2,377	37,308	39,685
2001	2,018	3	0	0	194	6	2,287	31,920	34,207
2002	1,265	2	0	0	70	4	1,433	29,369	30,802
2003	1,895	9	91	0	264	5	2,275	30,182	32,457
2004	2,109	0	91	0	132	0	2,335	26,538	28,873
2005	2,154	0	236	0	83	1	2,479	20,215	22,694
2006	1,526	29	88	0	83	2	1,741	22,470	24,211
2007	1,785	34	19	1	85	1	1,933	32,422	34,355
2008	1,005	0	86	1	220	8	1,327	29,901	31,228
2009	2,022	0	14	0	84	5	2,145	26,437	28,582
2010	1,616	13	15	377	84	0	2,116	26,890	29,006
2011	1,488	94	65	0	136	5	1,795	9,093	10,888
2012	1,265	21	26	0	115	0	1,432	16,786	18,218
2013	853	230	174	9	390	0	1,659	11,951	13,610
2014	908	141	94	0	225	0	1,369	9,233	10,602
2015	2,253	27	43	0	580	0	2,903	6,313	9,216
2016	2,495	63	61	1	544	0	3,164	10,080	13,244
2017	3,913	1	78	0	673	2	4,667	10,510	15,177
2018	3,308	5	59	2	509	0	3,901	16,514	20,415
2019	2,197	33	78	0	928	0	3,249	15,896	19,145
2020	2,176	45	74	0	770	0	3,067	11,196	14,263
2021	1,951	16	77	0	526	0	2,590	11,417	14,007
2022	0	0	0	0	0	0	0	9,209	9,209
2023	2,195	26	79	0	415	0	2,715	5,197	7,912
2024	1,763	13	3	0	82	0	1,861	650	2,511

Table 2A.7: The number of hauls in which length observations were taken for the fishery and survey length composition data, by year.

Year	number_hauls
1991	290
1992	1822
1993	828
1994	548
1995	620
1996	893
1997	440
1998	1496
1999	1626
2000	2561
2001	2967
2002	1170
2003	1220
2004	1251
2005	1076
2006	1030
2007	1411
2008	1339
2009	1207
2010	1779
2011	455
2012	612
2013	507
2014	248
2015	479
2016	406
2017	608
2018	707
2019	474
2020	443
2021	424
2022	187
2023	34
2024	3

Table 2A.8: Aleutian Islands bottom trawl biomass estimates (t) and longline survey relative population numbers and standard error for Pacific cod, for all years used in the models.

Year	Trawl Survey Biomass (t)	S.E.	Longline Survey Index	S.E.
1991	180,170	0.140		-
1992		-		-
1993		-		-
1994	153,416	0.204		-
1995		-		-
1996		-	88,627	0.113
1997	72,848	0.133		-
1998		-	131,813	0.086
1999		-		-
2000	126,870	0.183	167,593	0.099
2001		-		-
2002	73,551	0.163	84,667	0.137
2003		-		-
2004	82,219	0.198	69,171	0.148
2005		-		-
2006	84,861	0.282	102,621	0.096
2007		-		-
2008		-	77,184	0.164
2009		-		-
2010	55,826	0.187	83,973	0.132
2011		-		-
2012	58,911	0.147	82,422	0.111
2013		-		-
2014	73,608	0.185	98,559	0.200
2015		-		-
2016	84,409	0.182	129,751	0.120
2017		-		-
2018	81,272	0.158	168,708	0.141
2019		-		-
2020		-	109,521	0.086
2021		-		-
2022	51,539	0.126	63,701	0.137

Table 2A.9: Survey age composition sample size data, by year, including the number of individual fish, number of hauls, and effective sample size for each year. Effective sample sizes were generated using the methodology of Hulson et al (2023).

Year	Number of aged fish	Number of hauls	Effective sample size
1991	919	121	39
1994	1174	150	25
1997	845	99	67
2000	828	111	153
2002	1270	173	162
2004	775	107	169
2006	754	105	105
2010	673	94	156
2012	599	83	126
2014	557	76	153
2016	681	95	142
2018	575	80	197
2022	765	192	253

Table 2A.10: Estimates of natural mortality, M, for Pacific cod throughout their range. Values marked with asterisks * have been used in stock assessments.

Region	Reference Author	Year	M estimate
EBS*	Low	1974	0.375
EBS	Wespestad et al.	1982	0.700
EBS	Bakkala and Wespestad	1985	0.450
EBS	Thompson and Shimada	1990	0.290
EBS	Thompson and Methot	1993	0.370
EBS*	Shimada and Kimura	1994	0.960
EBS*	Shi et al.	2007	0.450
EBS	Thompson et al.	2007	0.340
EBS	Thompson	2016	0.360
GOA	Thompson and Zenger	1993	0.270
GOA	Thompson and Zenger	1995	0.500
GOA	Thompson et al.	2007	0.380
GOA*	Barbeaux et al.	2016	0.470
BC*	Ketchen	1964	0.595
BC*	Fournier	1983	0.650
Korea*	Jung et al.	2009	0.820
Japan*	Ueda et al.	2004	0.200

Table 2A.11: Comparison of likelihoods and model parameters among Models 24.0, 24.1, and seven bridging models, M24.0A, M24.0B, M24.0C, M24.0D, M24.0E, M24.0F, and M24.0G. Upper portion describes the features in each mode, with X demarcating features in the 2024 model and 0 representing alternative features or features found in the 2023 model. The likelihood components, derived quantities, and parameter estimates for each model are shown below Results.

Features	M24.1	M24.0	M24_0A	M24_0B	M24_0C	M24_0D	M24_0E	M24_0F	M24_0G
2024 Params (X)/Alt. Params (0)									
Max length 143/Max length 117+	X	X	X	0	0	0	0	0	0
M timeblock 2016-2024/ None	X	0	X	0	0	0	0	0	0
smaller CV young growth/ CV=0.3	X	X	0	0	0	0	0	0	0
logistic survey/dome survey	X	X	X	X	0	X	X	X	X
Max age 13/Max age 10+	X	X	X	X	X	0	0	0	0
InitF/no InitF	X	X	X	X	X	X	0	0	0
M fixed/M estimated	X	X	X	X	X	X	X	0	0
Richards Growth/ von B growth	X	X	X	X	X	X	X	X	0
Results									
Label	M24_1	M24_0	M24_0A	M24_0B	M24_0C	M24_0D	M24_0E	M24_0F	M24_0G
TOTAL_like	474.770	515.367	733.187	696.616	727.079	735.480	743.955	628.110	902.625
Survey_like	-8.281	-4.043	-12.415	-3.829	-6.708	-3.308	-3.280	-9.997	-8.507
Length_comp_like	127.206	122.324	136.964	162.235	146.185	184.074	184.217	161.732	154.364
Age_comp_like	355.671	395.501	609.959	537.925	589.337	550.428	554.867	470.414	753.548
Recruitment_like_thousands	-1.171	0.225	-2.696	-1.209	-3.887	2.610	6.445	1.961	-1.182
Forecast_Recruitment_like	0.036	0.060	0.015	0.030	0.016	0.073	0.084	0.087	0.069
Recr_Virgin_millions	87.177	73.347	94.990	79.246	102.465	66.416	73.947	985.317	609.908
SR_BH_steep	1	1	1	1	1	1	1	1	1
Natural mortality	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.741	0.674
NatM_BLK2repl_2016	0.579	-	0.604	-	-	-	-	-	-
SmryBio_unfished	268,675	226,176	278,043	235,989	312,252	238,226	265,181	511,834	425,054
SSB_Virgin_thousand_mt	219.259	184.541	232.091	197.524	263.108	201.028	223.764	321.335	265.358
SSB_2024_thousand_mt	49.215	64.959	54.053	87.169	139.403	76.539	76.212	172.101	155.144
Bratio_2024	0.224	0.352	0.233	0.441	0.530	0.381	0.341	0.536	0.585
SPRratio_2024	0.149	0.173	0.120	0.115	0.075	0.125	0.125	0.031	0.031
Ret_Catch_MSY	33,966	28,671	39,351	33,647	42,657	34,416	38,303	121,098	120,801
SR_LN(R0)	11.376	11.203	11.462	11.280	11.537	11.104	11.211	13.801	13.321
Survey catchability (q)	0.872	0.928	0.769	0.743	0.597	0.857	0.854	0.368	0.406
Size_DblN_peak_FshComb(1)	101.979	103.989	90.127	94.813	85.362	91.730	91.675	97.635	115.995
Size_DblN_top_logit_FshComb(1)	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000
Size_DblN_ascend_se_FshComb(1)	6.658	6.719	6.378	6.554	6.252	6.441	6.440	6.445	6.818
Size_DblN_peak_Srv(2)	69.435	68.774	64.198	62.791	60.635	63.928	63.905	70.589	76.957
Size_DblN_ascend_se_Srv(2)	6.500	6.539	6.267	6.289	6.160	6.350	6.351	6.297	6.641
Number of parameters	73	72	73	72	73	69	68	69	68
AIC	1095.54	1174.734	1612.374	1537.232	1600.158	1608.96	1623.91	1394.22	1941.25
SS3 diags Runs test	passed	passed	passed	passed	passed	passed	passed	passed	passed

Table 2A.12: Maturity at age ogives based on histological data (Stark 2007) and observer maturity at length data (visual observation) from 2008-2021 (1331 records), and updated for this assessment with data from 2008-2024 (1355 records). Observer-based maturity curves were used in age structured models.

Age	Stark 2007	Observer 2021	Observer 2024
1	0.023	0.007	0.007
2	0.058	0.073	0.073
3	0.140	0.338	0.338
4	0.299	0.667	0.667
5	0.528	0.861	0.861
6	0.746	0.945	0.945
7	0.885	0.977	0.977
8	0.953	0.990	0.990
9	0.982	0.995	0.995
10	0.993	0.998	0.998

Table 2A.13: Number of Pacific cod observed in otolith collections by age and year.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1991	23	230	168	238	156	52	22	19	5	5	1	0	0
1994	84	133	182	164	201	154	136	81	25	11	3	0	0
1997	56	139	104	157	138	96	64	49	25	11	3	2	1
2000	23	78	120	189	182	101	86	31	10	8	0	0	0
2002	80	173	267	231	179	166	96	35	21	14	8	0	0
2004	15	60	109	179	194	114	44	33	18	9	0	0	0
2006	61	35	132	133	170	127	56	18	9	10	3	0	0
2010	4	77	129	174	191	46	26	9	11	4	1	1	0
2012	49	56	61	134	152	89	38	11	4	4	1	0	0
2014	41	99	87	97	90	82	38	12	7	2	1	0	1
2016	42	107	145	147	104	56	50	20	8	1	1	0	0
2018	7	37	34	116	78	23	7	1	1	0	0	0	0
2022	14	55	211	238	125	67	32	8	5	0	0	0	0

Table 2A.14: Summary of 1994-2024 catches (t) of Pacific cod in the AI, by NMFS statistical area (area breakdowns not available prior to 1994). Catches for 2024 are through August 14.

Year	Total Catch			Proportions		
	Western	Central	Eastern	Western	Central	Eastern
1994	2,059	7,441	12,039	0.096	0.345	0.559
1995	1,713	5,086	9,735	0.104	0.308	0.589
1996	4,023	4,509	23,077	0.127	0.143	0.730
1997	894	4,440	19,830	0.036	0.176	0.788
1998	3,487	9,299	21,940	0.100	0.268	0.632
1999	2,322	5,276	20,532	0.083	0.188	0.730
2000	9,073	8,799	21,812	0.229	0.222	0.550
2001	12,767	7,358	14,082	0.373	0.215	0.412
2002	2,259	7,133	21,408	0.073	0.232	0.695
2003	2,997	6,707	22,752	0.092	0.207	0.701
2004	3,649	6,833	18,391	0.126	0.237	0.637
2005	4,239	3,582	14,873	0.187	0.158	0.655
2006	4,570	4,675	14,967	0.189	0.193	0.618
2007	4,974	4,692	24,689	0.145	0.137	0.719
2008	7,319	5,555	18,355	0.234	0.178	0.588
2009	7,929	6,899	13,754	0.277	0.241	0.481
2010	8,213	6,292	14,501	0.283	0.217	0.500
2011	24	1,770	9,095	0.002	0.163	0.835
2012	29	2,816	15,374	0.002	0.155	0.844
2013	47	2,884	10,682	0.003	0.212	0.785
2014	29	1,039	9,514	0.003	0.098	0.899
2015	3,170	2,364	3,676	0.344	0.257	0.399
2016	2,550	1,607	9,074	0.193	0.121	0.686
2017	3,371	3,768	8,031	0.222	0.248	0.529
2018	2,694	4,065	13,655	0.132	0.199	0.669
2019	1,340	5,298	12,507	0.070	0.277	0.653
2020	1,972	5,131	7,161	0.138	0.360	0.502
2021	1,715	3,791	8,502	0.122	0.271	0.607
2022	1,237	3,016	7,599	0.104	0.254	0.641
2023	589	2,004	5,317	0.074	0.253	0.672
2024	443	654	1,413	0.177	0.261	0.563

Table 2A.15: Discards (t) and discard rates for Pacific cod caught in the Aleutian Islands, for the period 1993 - August 14, 2024. Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998.

Year	Discards (t)	Total catch (t)	Proportion discarded
1993	1,508	4,208	0.358
1994	3,484	21,539	0.162
1995	3,180	16,534	0.192
1996	3,137	31,609	0.099
1997	2,107	25,164	0.084
1998	638	34,726	0.018
1999	514	28,130	0.018
2000	692	39,685	0.017
2001	471	34,207	0.014
2002	734	30,801	0.024
2003	332	32,457	0.010
2004	317	28,873	0.011
2005	489	22,694	0.022
2006	310	24,211	0.013
2007	554	34,355	0.016
2008	204	31,229	0.007
2009	208	28,582	0.007
2010	203	29,006	0.007
2011	91	10,889	0.008
2012	70	18,220	0.004
2013	253	13,612	0.019
2014	122	10,583	0.012
2015	95	9,210	0.010
2016	104	13,232	0.008
2017	150	15,170	0.010
2018	273	20,414	0.013
2019	151	19,145	0.008
2020	142	14,264	0.010
2021	179	14,008	0.013
2022	156	11,852	0.013
2023	169	7,911	0.021
2024	35	2,510	0.014

Table 2A.16: Summary of catches of Pacific cod (t) in the Aleutian Islands by gear type. All catches include discards. Domestic annual catch by gear is not available prior to 1988.

Year	Foreign			Joint Venture	Domestic			Total
	Trawl	Longline	Total	Trawl	Trawl	Longline and pot	Total	
1981	2,680	235	2,915	1,749	-	-	2,770	7,434
1982	1,520	476	1,996	4,280	-	-	2,121	8,397
1983	1,869	402	2,271	4,700	-	-	1,459	8,430
1984	473	804	1,277	6,390	-	-	314	7,981
1985	10	829	839	5,638	-	-	460	6,937
1986	5	0	5	6,115	-	-	786	6,906
1987	0	0	0	10,435	-	-	2,772	13,207
1988	0	0	0	3,300	1,698	167	1,865	5,165
1989	0	0	0	6	4,233	303	4,536	4,542
1990	0	0	0	0	6,932	609	7,541	7,541

Table 2A.17: Federal and state fishery Pacific cod catch in metric tons by year, 1991-2024. To avoid confidentiality problems, federal longline and pot catches have been combined. “Other” gear types include gill net and jig. Catches for 2024 are through August 14. The state fishery catch is included in the total, and broken out as a separate column from 2006 onward.

Year	Trawl	Longline+Pot	Other	Total	State
1991	3,414	6,383	0	9,797	0
1992	14,558	28,425	83	43,067	0
1993	17,311	16,860	32	34,204	0
1994	14,382	7,156	0	21,539	0
1995	10,574	5,959	0	16,534	0
1996	21,178	10,429	0	31,609	0
1997	17,349	7,725	88	25,164	0
1998	20,530	14,195	0	34,726	0
1999	16,437	11,624	68	28,130	0
2000	20,361	19,289	32	39,684	0
2001	15,826	18,361	19	34,207	0
2002	27,929	2,871	0	30,800	0
2003	31,478	978	0	32,456	0
2004	25,770	3,102	0	28,873	0
2005	19,613	3,067	12	22,693	0
2006	20,062	4,141	7	24,211	3,720
2007	28,631	5,716	6	34,354	4,140
2008	21,826	9,193	208	31,228	4,266
2009	20,821	7,739	20	28,581	2,039
2010	18,872	10,133	0	29,006	3,966
2011	9,382	1,506	0	10,888	265
2012	12,138	6,059	21	18,219	5,209
2013	8,122	5,489	0	13,612	4,793
2014	6,765	3,817	0	10,583	4,450
2015	6,129	3,080	0	9,209	161
2016	11,535	1,696	0	13,231	882
2017	8,536	6,633	0	15,170	2,946
2018	10,118	10,239	55	20,414	5,695
2019	10,293	8,710	140	19,144	6,168
2020	4,319	9,939	5	14,264	6,777
2021	3,463	10,544	0	14,007	6,710
2022	3,649	8,202	0	11,851	5,402
2023	3,728	4,182	0	7,910	4,511
2024	1,999	510	0	2,509	0

Table 2A.18: Catch of Pacific cod in the Aleutian Islands by foreign, domestic, and joint venture fisheries, 1964-1980. Note that joint venture fisheries did not commence until 1981, and domestic catch information is not available prior to 1988.

Year	Foreign	Joint Venture	Domestic	Total
1964	241	0	0	241
1965	451	0	0	451
1966	154	0	0	154
1967	293	0	0	293
1968	289	0	0	289
1969	220	0	0	220
1970	283	0	0	283
1971	2,078	0	0	2,078
1972	435	0	0	435
1973	977	0	0	977
1974	1,379	0	0	1,379
1975	2,838	0	0	2,838
1976	4,190	0	0	4,190
1977	3,262	0	0	3,262
1978	3,295	0	0	3,295
1979	5,593	0	0	5,593
1980	5,788	0	0	5,788

Figures

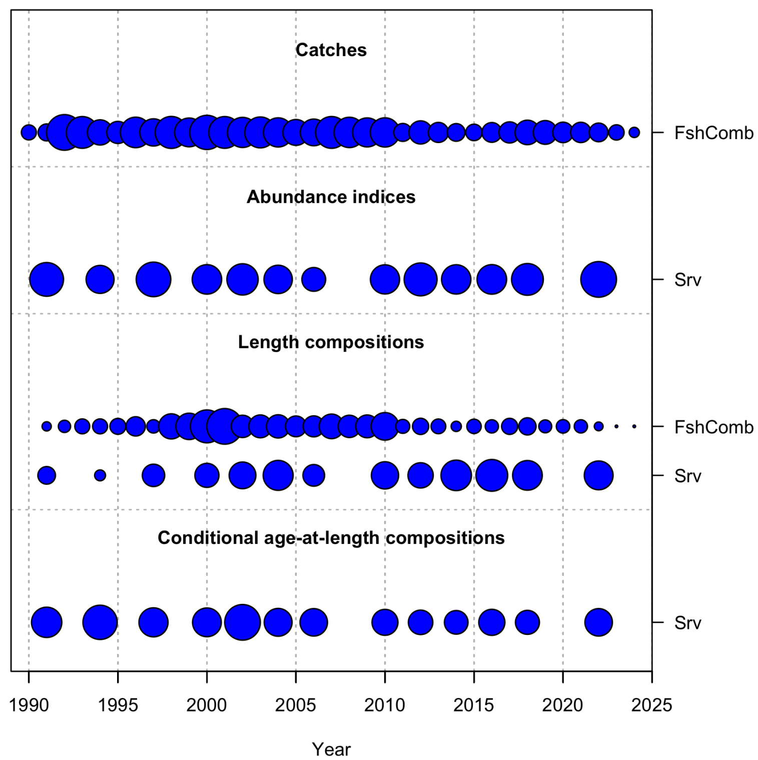

Figure 2A.1: Data sources and relative weight used in Models 24.0 and 24.1.

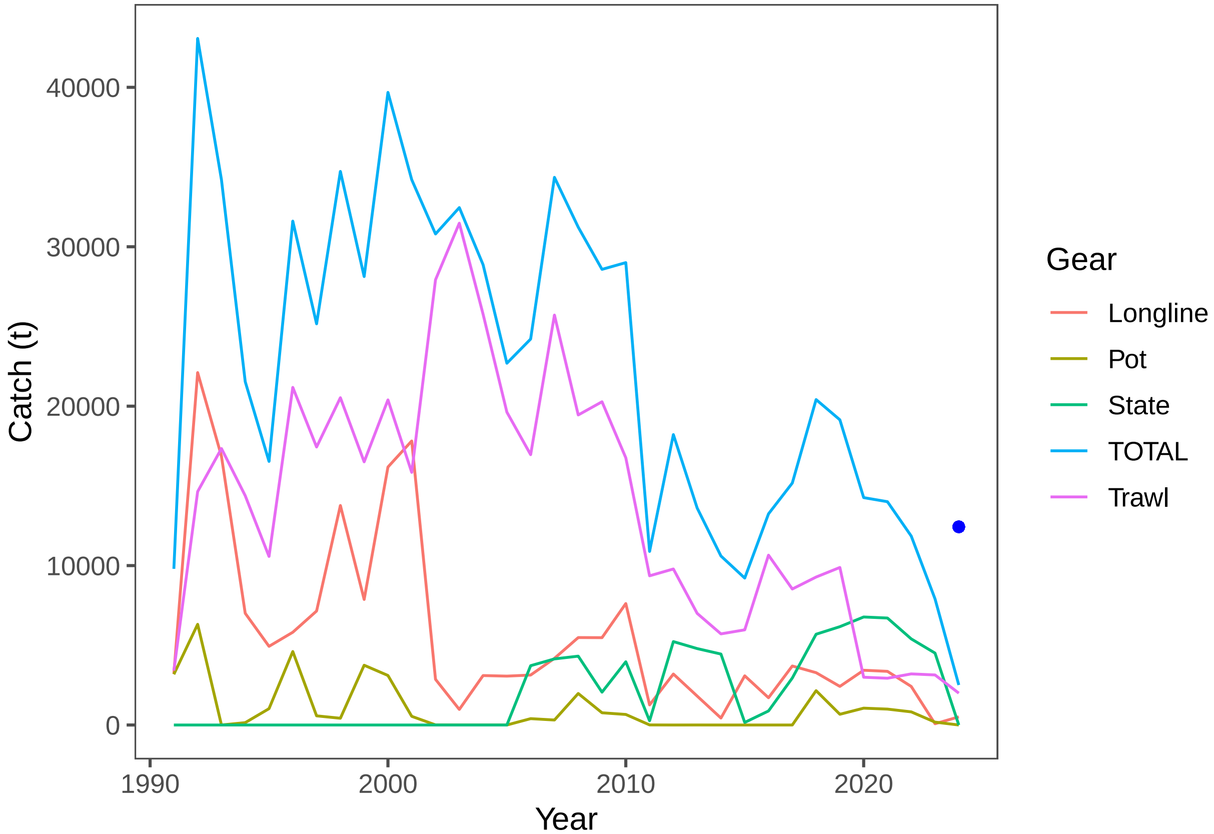

Figure 2A.2: Aleutian Islands Pacific cod catch history, with federal catches by gear type, from 1991-2024 (through August 14). The blue dot represents the ABC for 2024.

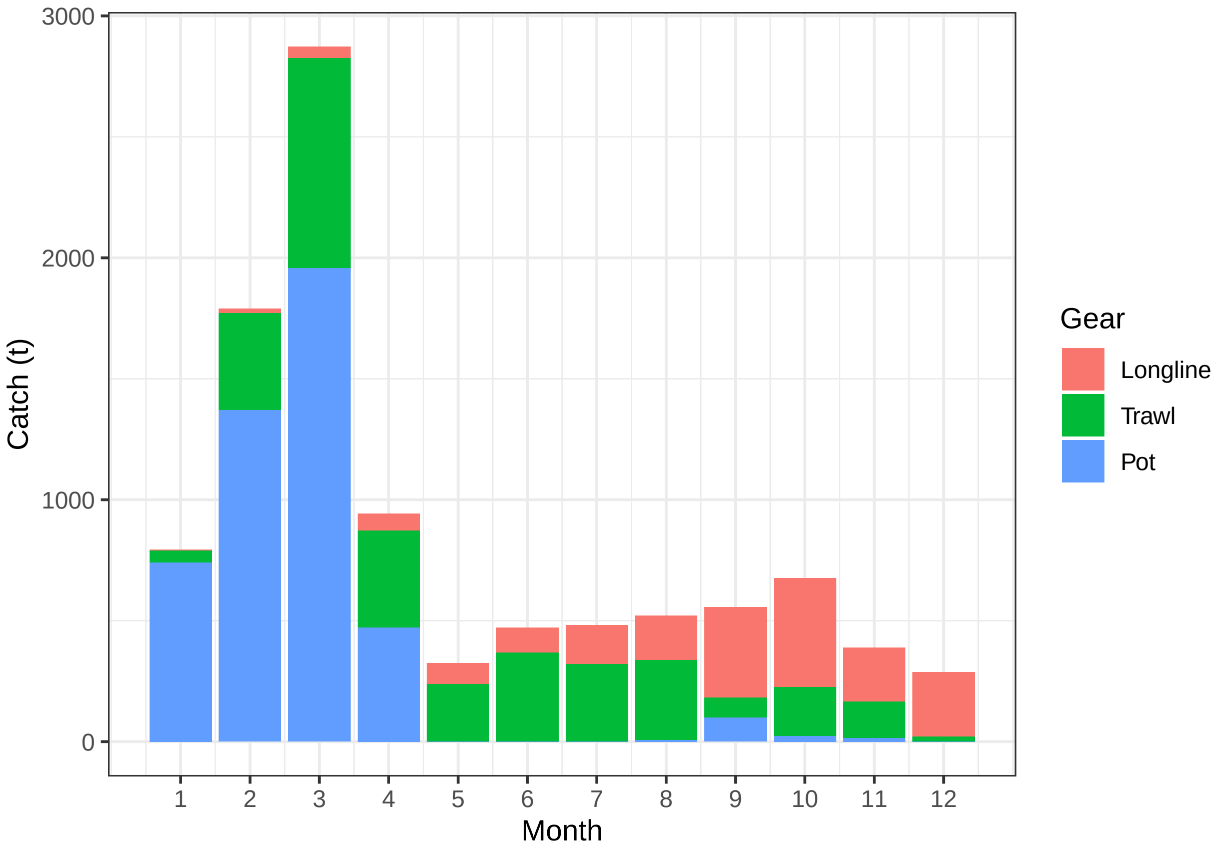

Figure 2A.3: Aleutian Islands Pacific cod average catch (t) by month per year and gear from January 1, 2020 - August 14, 2024.

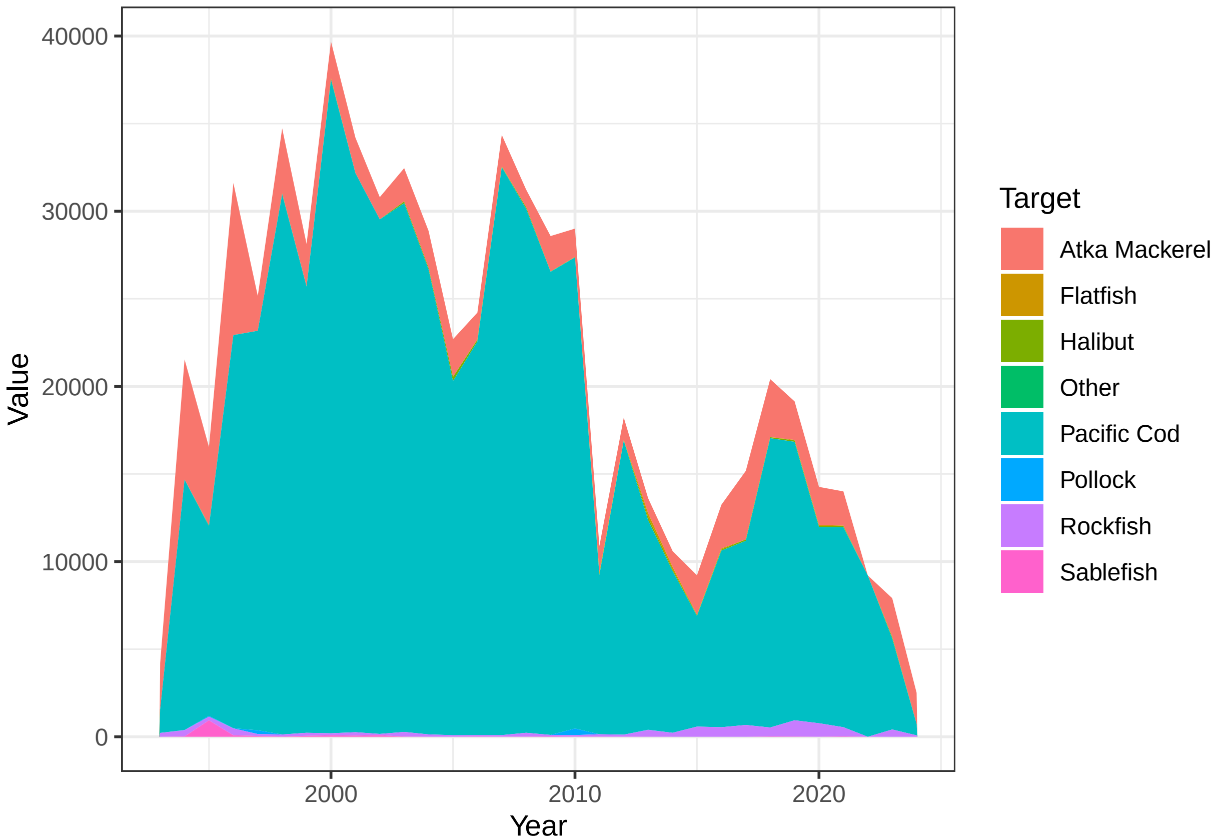

Figure 2A.4: Proportion of Pacific cod caught in targeted fisheries in the Aleutian Islands (541, 542, and 543) from 1991 through August 14, 2024.

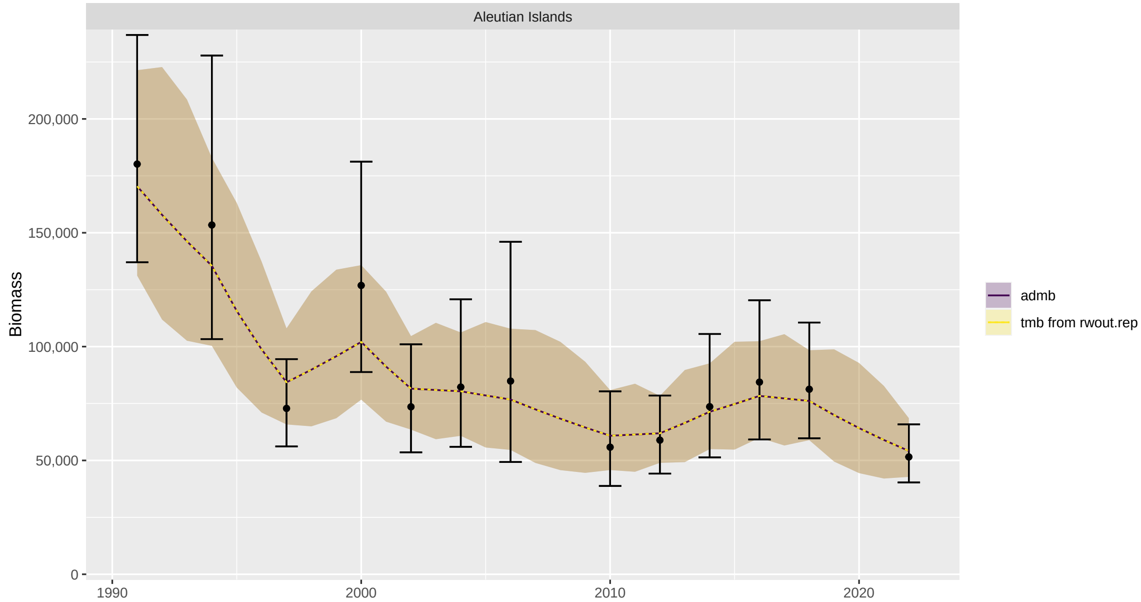

Figure 2A.5: Survey index of biomass and Tier 5 fit using a random effects model.

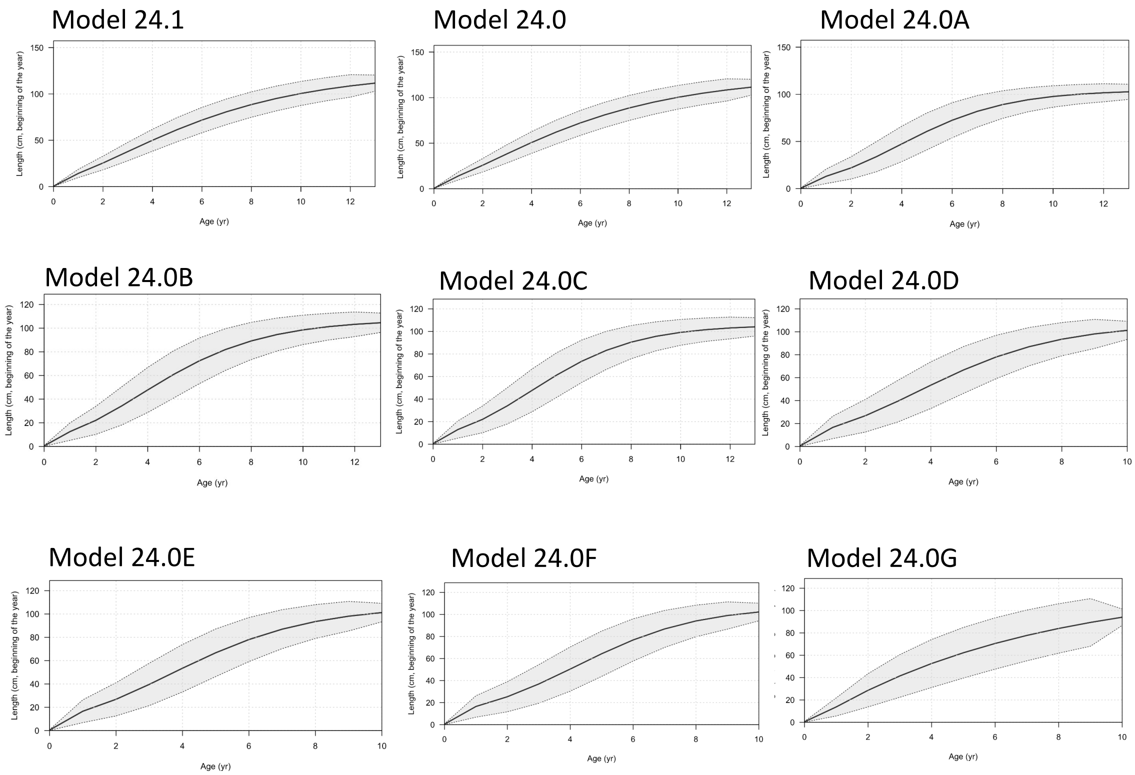

Figure 2A.6: Growth curves for Models 24.1, 24.0A, 24.0FB, 24.0C, 24.0D, 24.0E, 24.0F, and 24.0G. Model 24.0G used the von Bertalanffy growth curve, but all others used the Richards growth curve. Model 24.0A used the full length and age composition data, but Models 24.0F and 24.0G used maximum age 10+ and maximum length 117. Model 24.1 further improved the fit through reduced CV on younger ages.

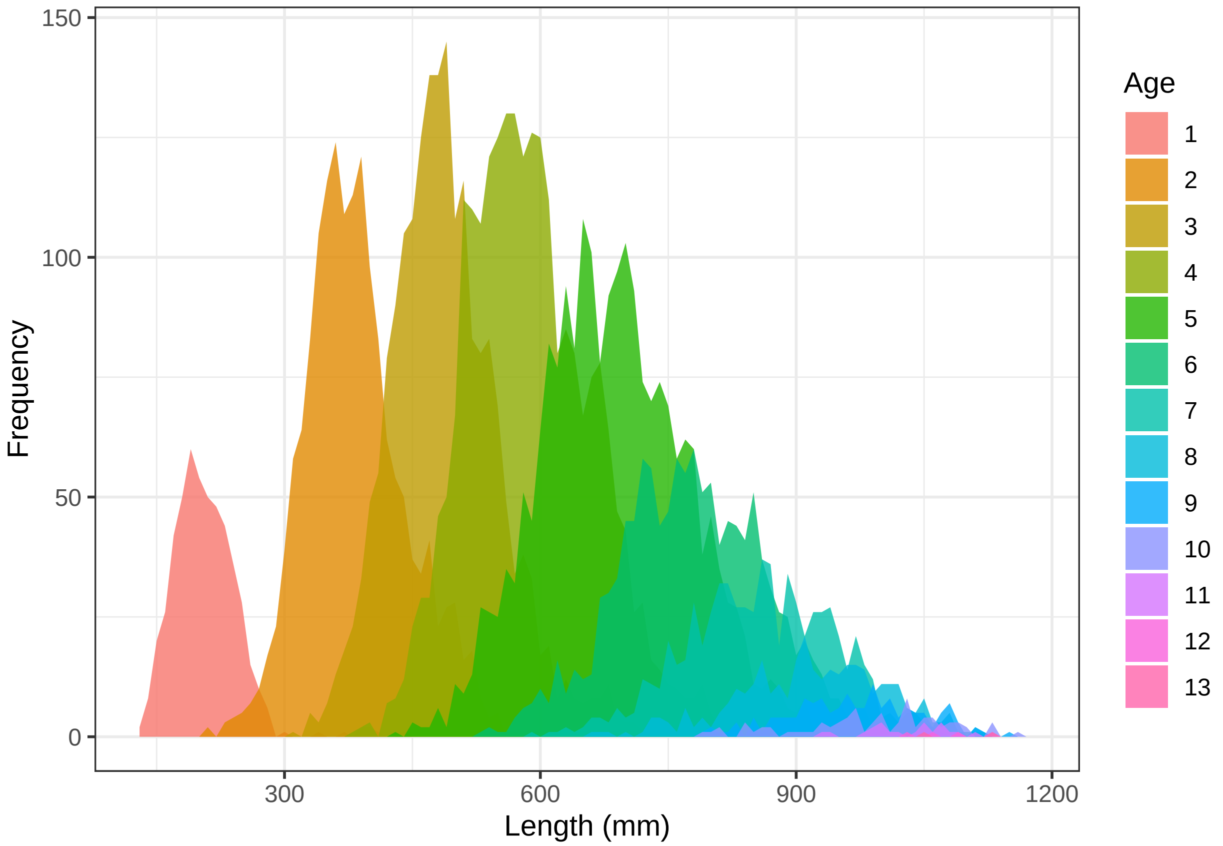

Figure 2A.7: Length frequency by age of cod collected from surveys 1991-2022.

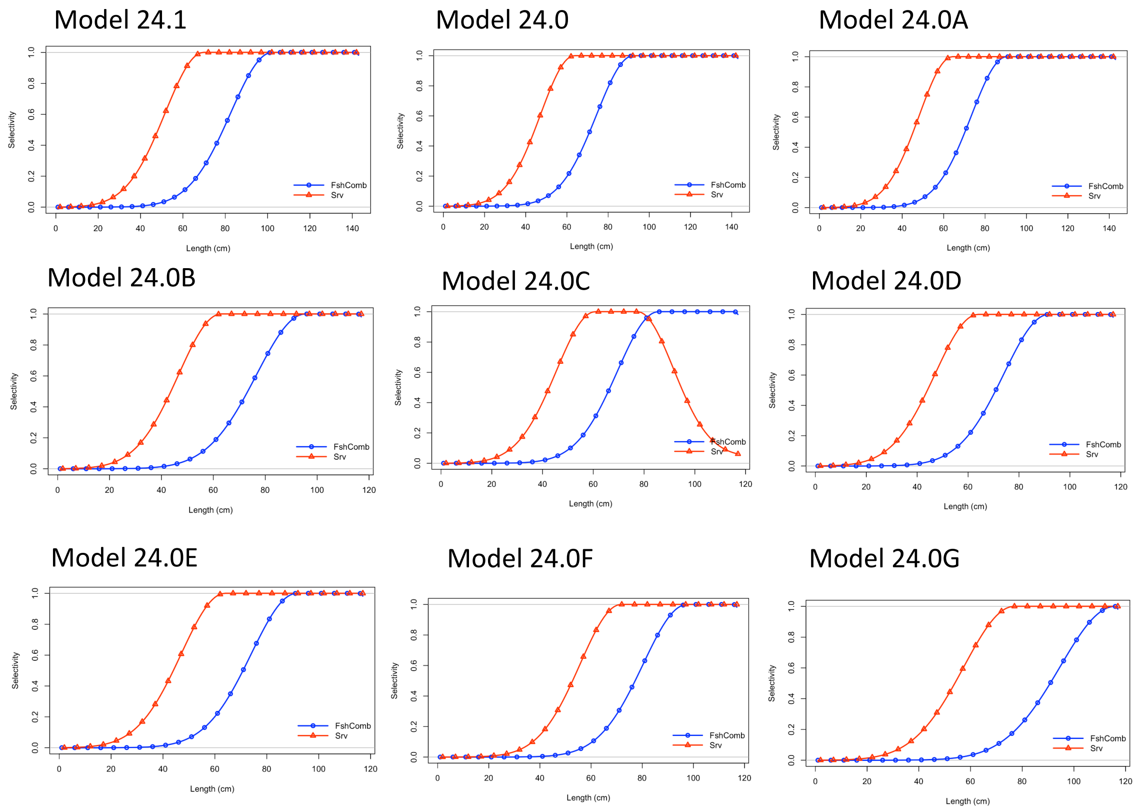

Figure 2A.8: Survey and fishery selectivity curves for Models 24.1, 24.0A, 24.0FB, 24.0C, 24.0D, 24.0E, 24.0F, and 24.0G. Model 24.0G used the von Bertalanffy growth curve, but all others used the Richards growth curve. Model 24.0A used the full length and age composition data, but Models 24.0F and 24.0G used maximum age 10+ and maximum length 117+ cm.

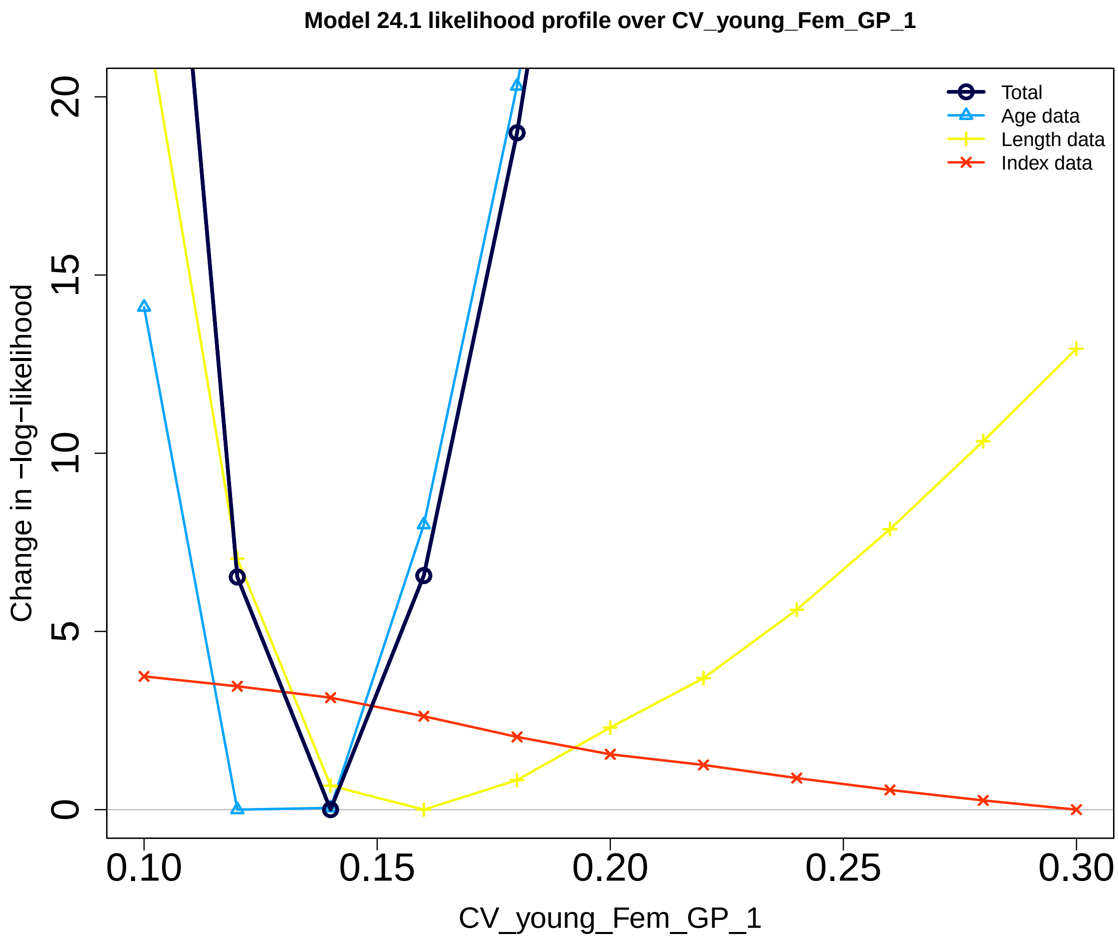

Figure 2A.9: Likelihood profile over the coefficient of variation (CV) over growth curve younger ages.

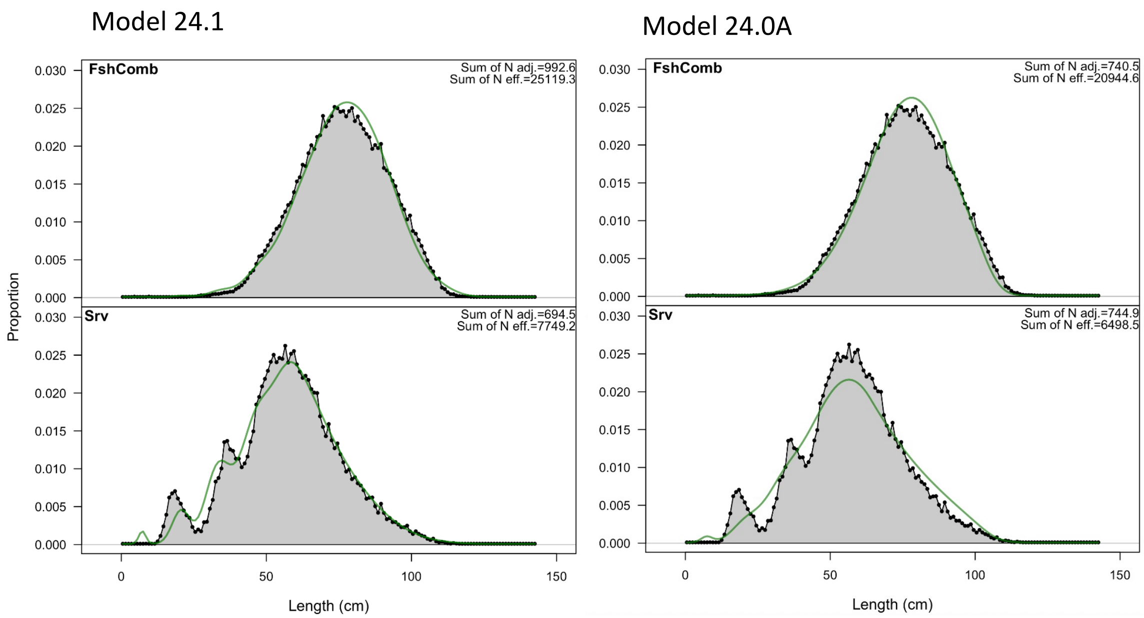

Figure 2A.10: Model fit to observed length frequencies for survey and fishery data, Model 24.1 (left) and 24.0A (right).

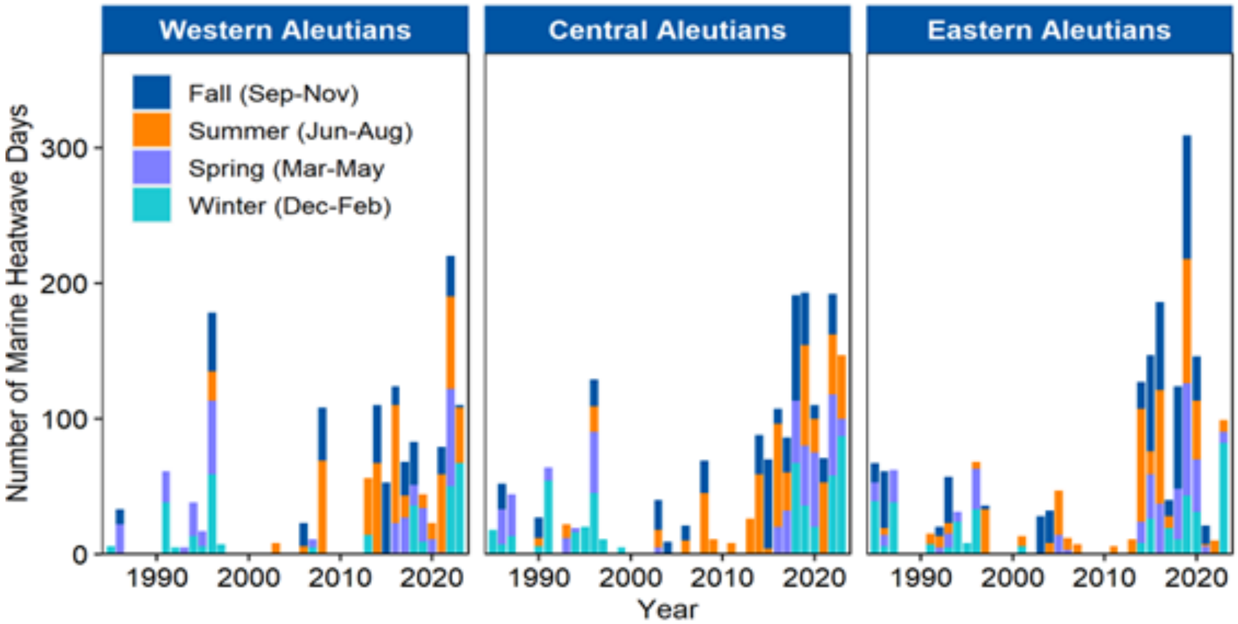

Figure 2A.11: The number of days under heatwave conditions for the western, central, and eastern Aleutian Islands, 1982 - 2023.

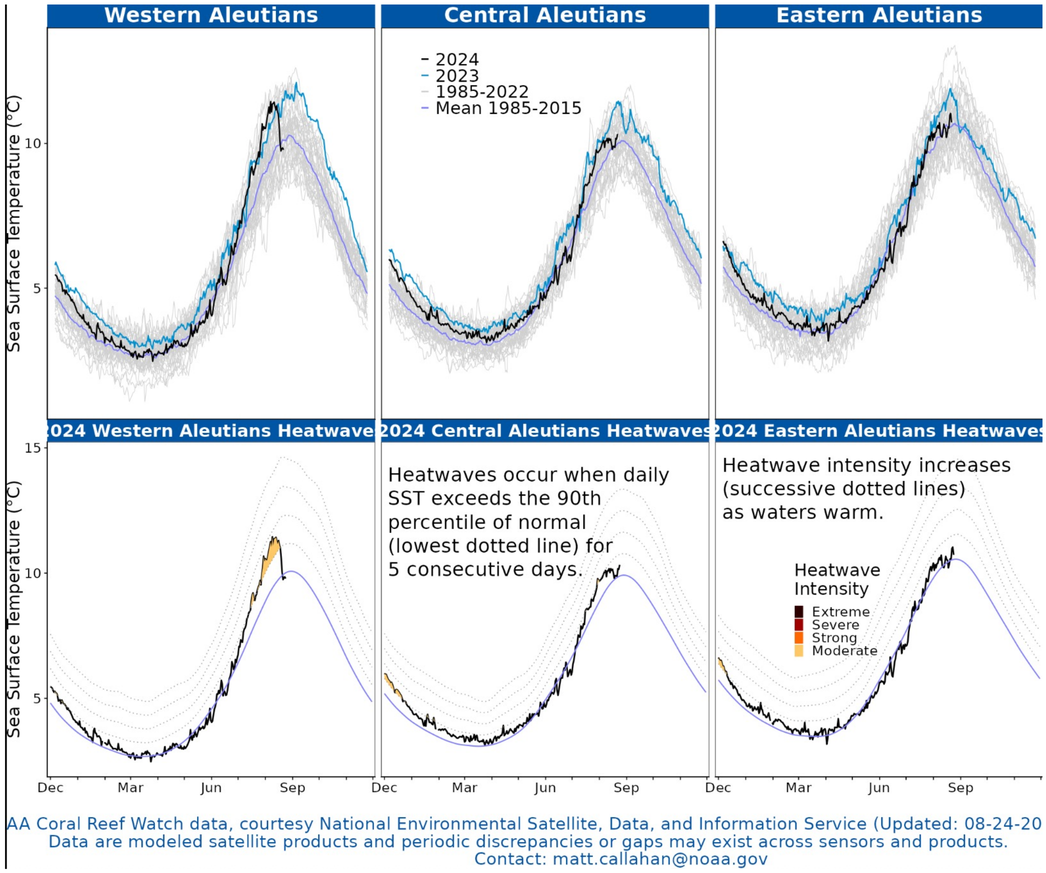

Figure 2A.12: Aleutian Islands mean sea surface temperature for the western, central, and eastern region, 2024 compared with 2023 and previous years. In 2024 there were several short periods considered heatwave conditions in the Aleutian Islands, but less than in previous years.

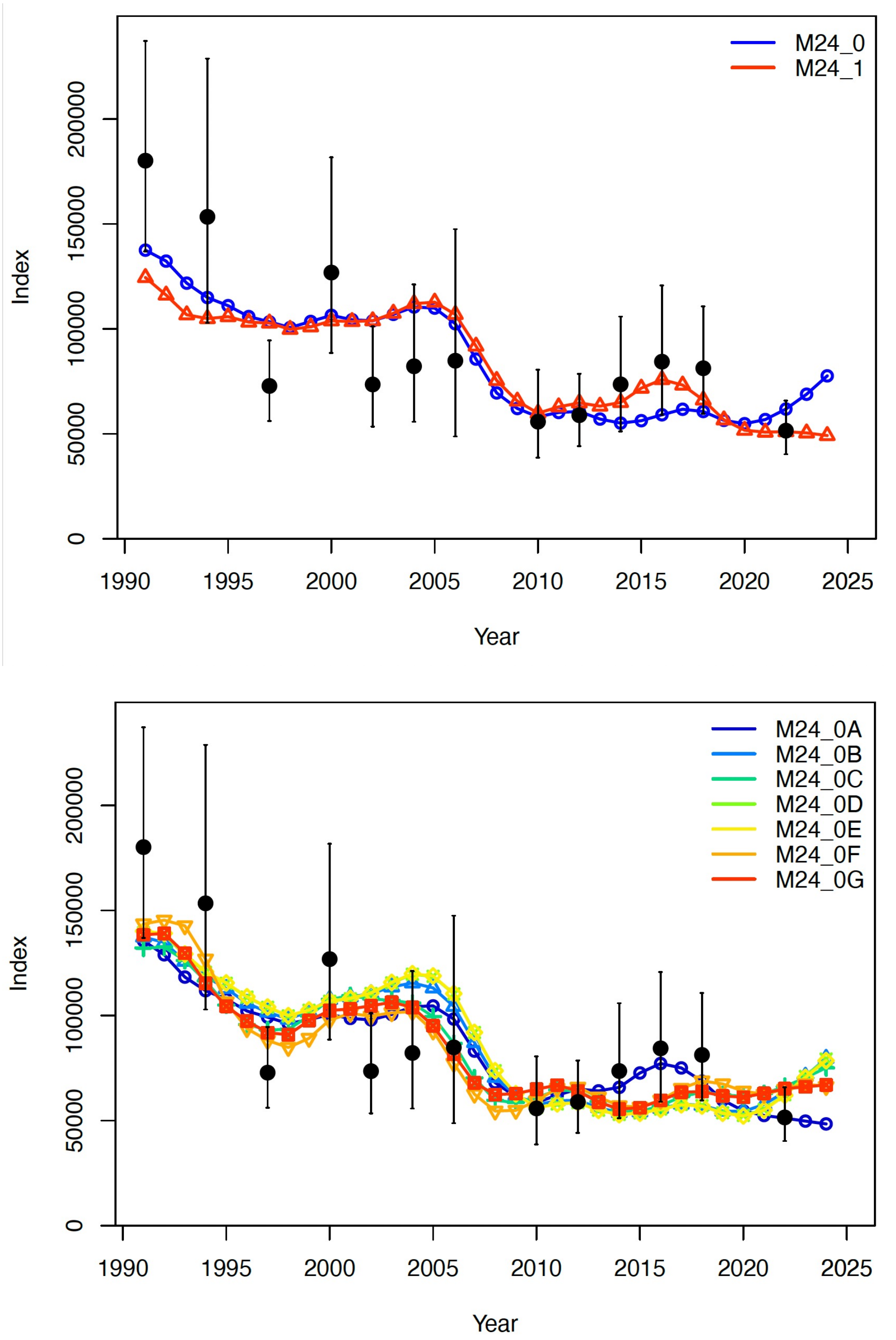

Figure 2A.13: Model fit to survey index for all Models 24.0, 24.1 (upper panel), and seven bridging models, M24.0A, M24.0B, M24.0C, M24.0D, M24.0E, M24.0F, and M24.0G (lower panel).

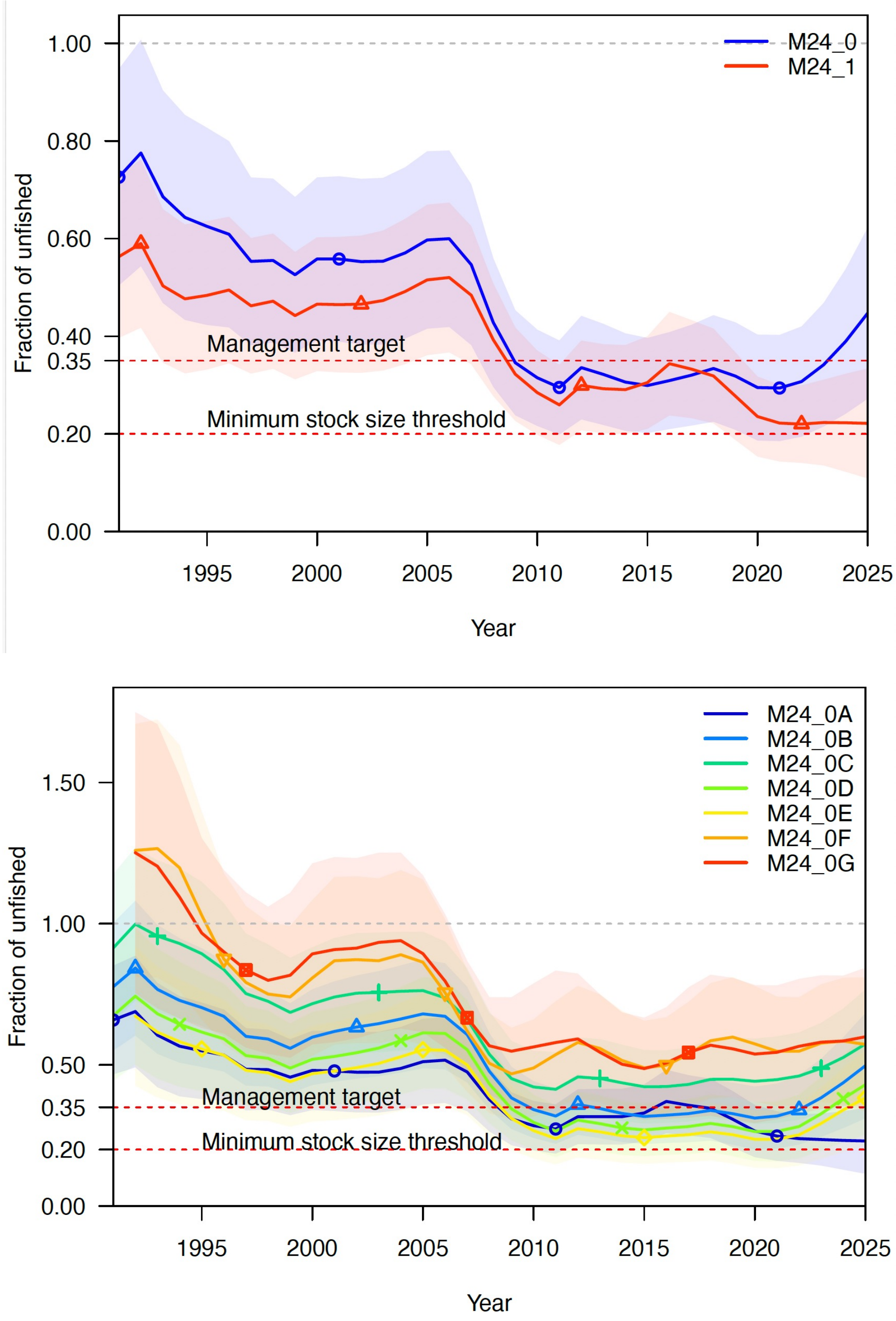

Figure 2A.14: Spawning biomass relative to unfished for all Models 24.0, 24.1 (upper panel), and seven bridging models, M24.0A, M24.0B, M24.0C, M24.0D, M24.0E, M24.0F, and M24.0G (lower panel).

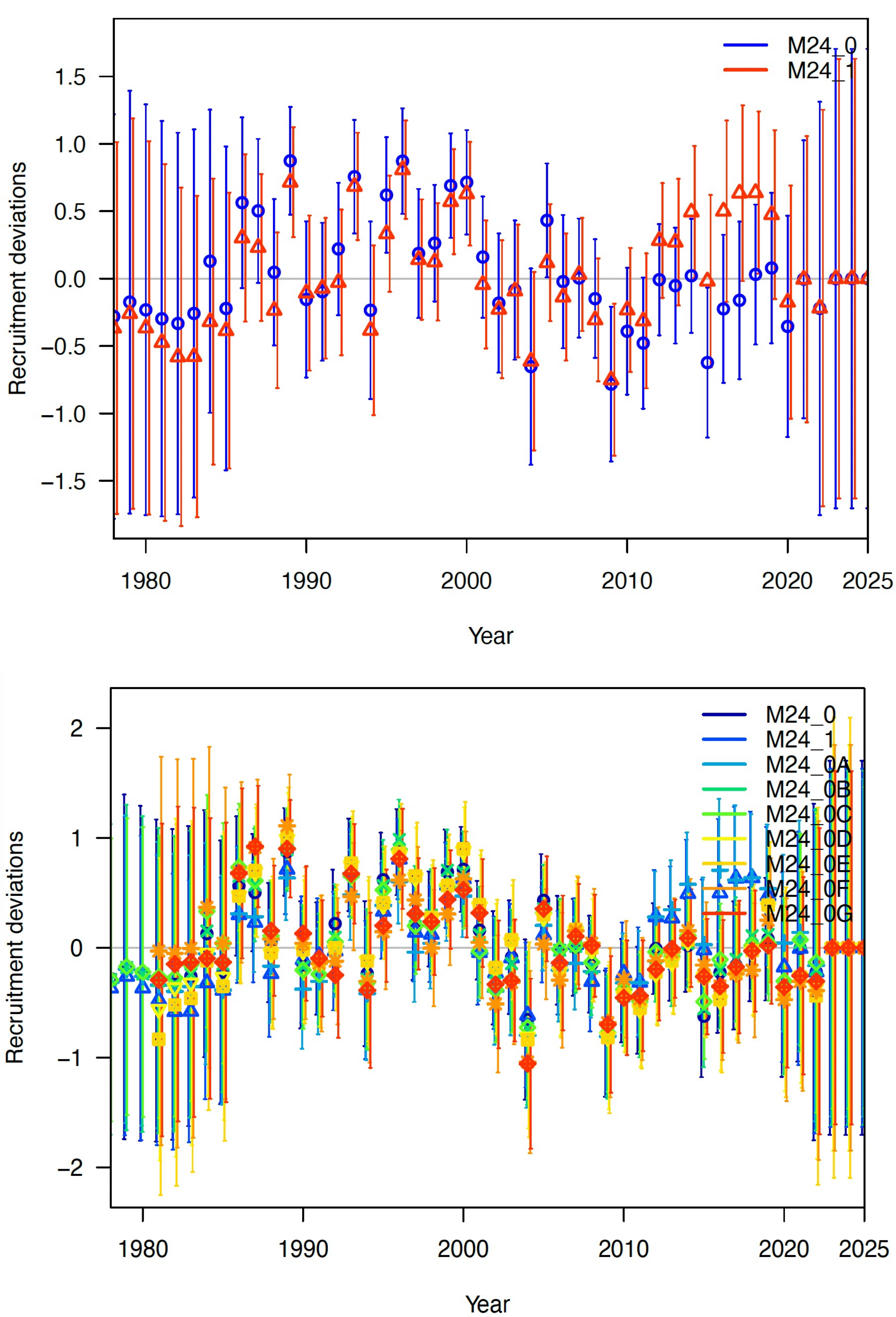

Figure 2A.15: Recruitment estimates for all Models 24.0, 24.1 (upper panel), and seven bridging models, M24.0A, M24.0B, M24.0C, M24.0D, M24.0E, M24.0F, and M24.0G (lower panel).

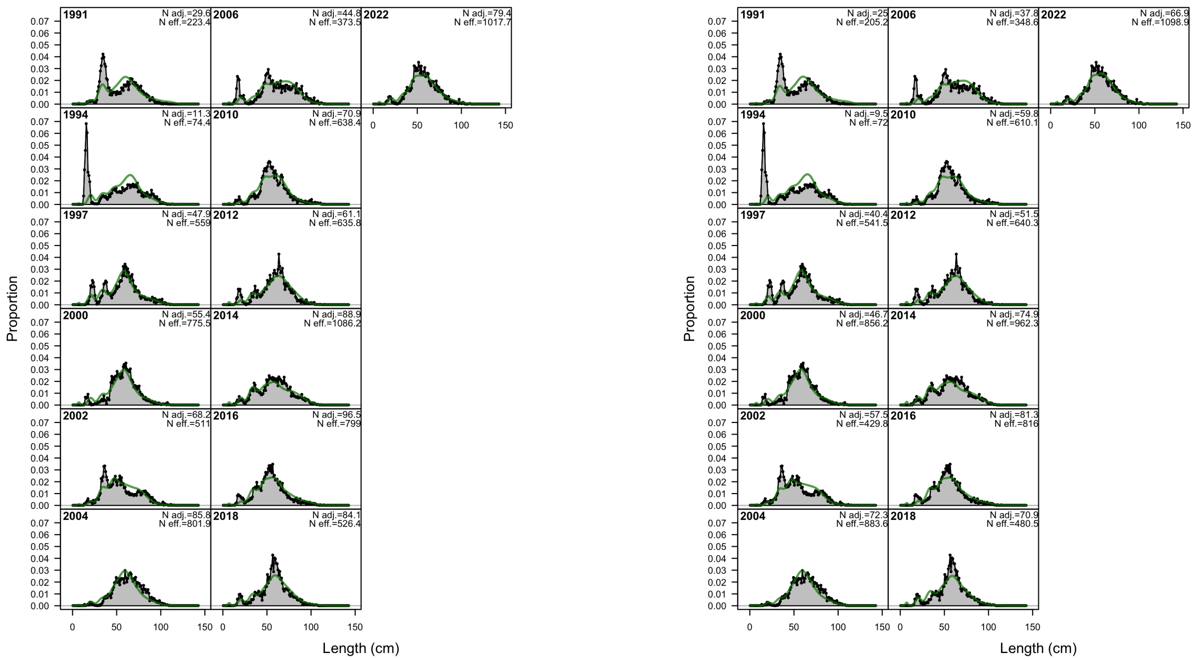

Figure 2A.16: Survey length composition and fit to the length composition, Model 24.0 (left panel) and Model 24.1 (right panel).

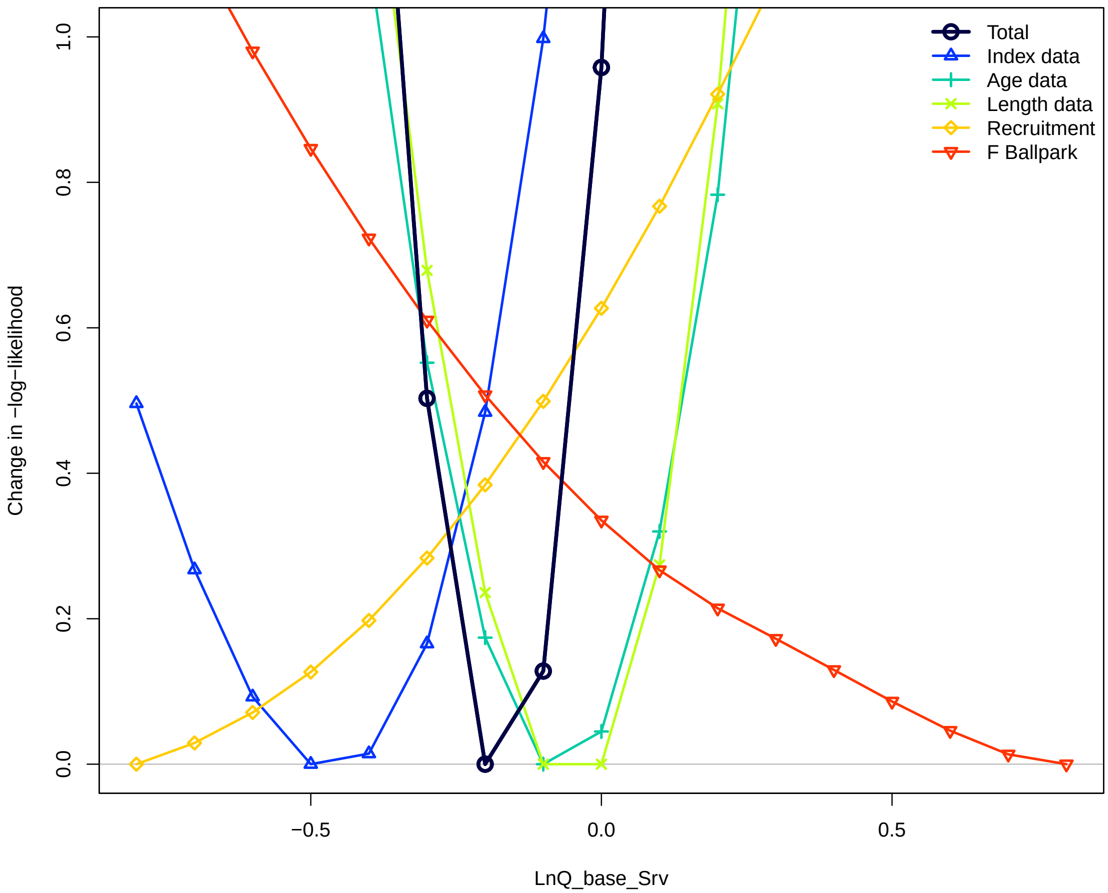

Figure 2A.17: Likelihood profile over the log of catchability (q), from -0.8 to 0.8 in increments of 0.1.

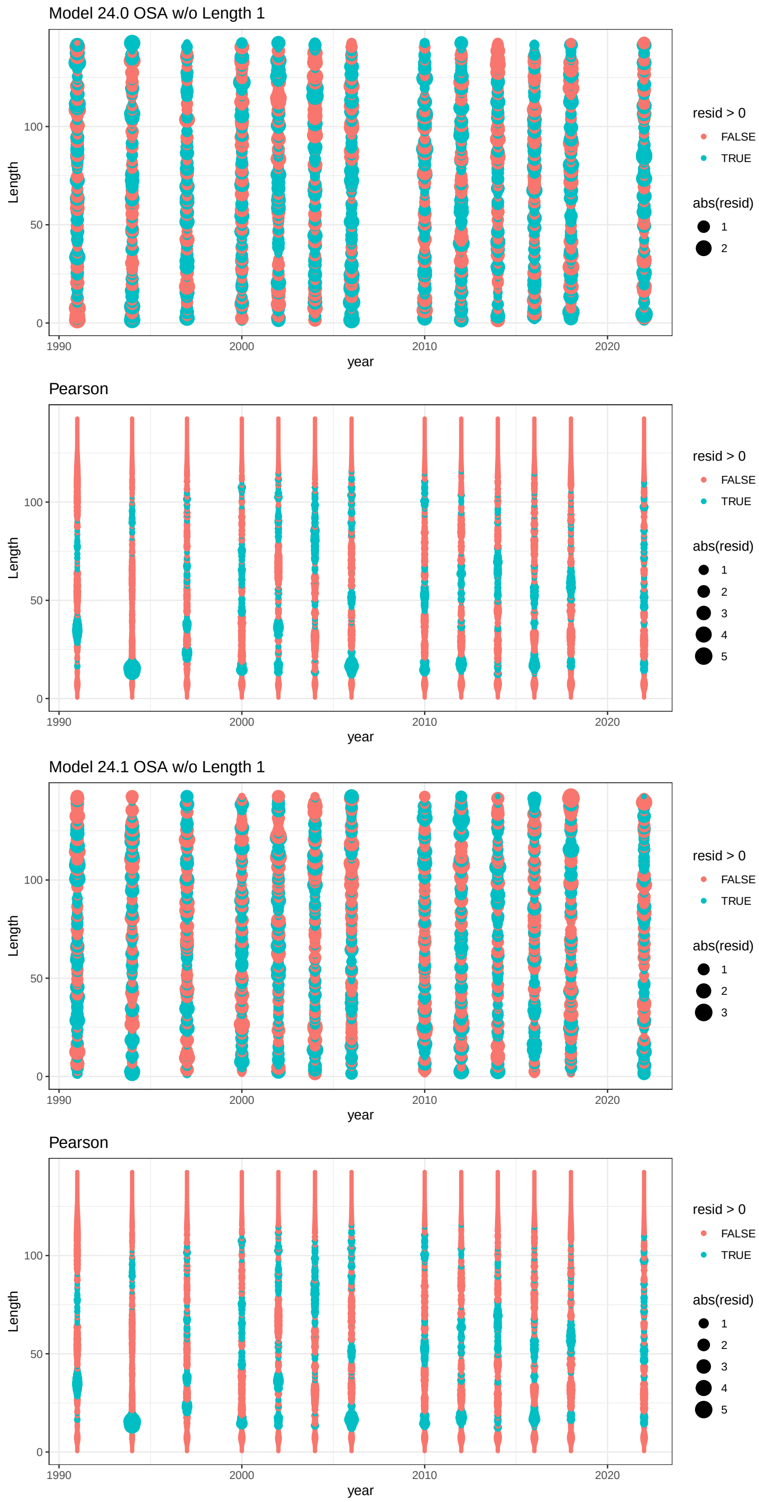

Figure 2A.18: One step ahead (OSA) and Pearson residuals for Model 24.0 (upper panel) and Model 24.1 (lower panel).

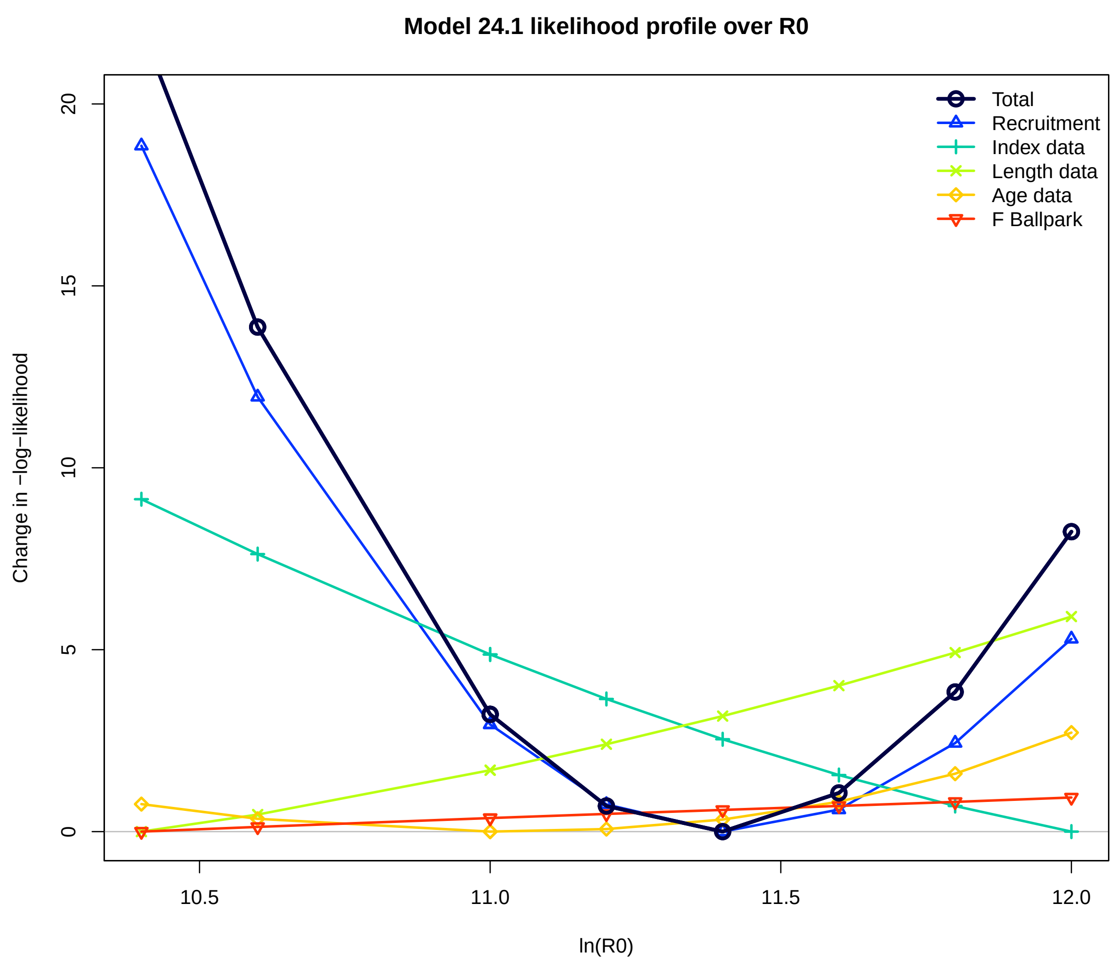

Figure 2A.19: Likelihood profile over initial recruitment, R0, from 10.4 to 12.

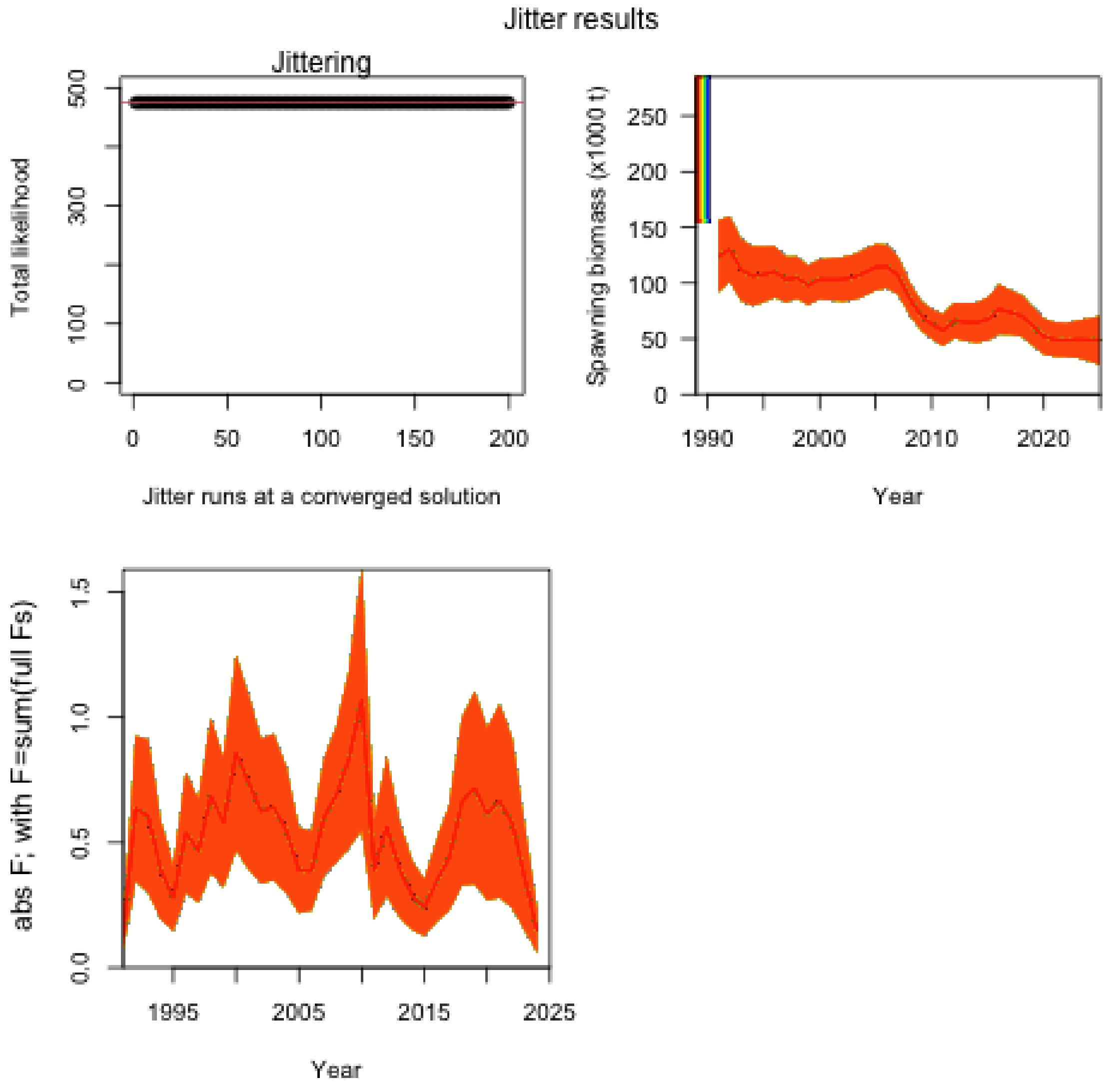

Figure 2A.20: The Model 24.1 jitter diagnostic for global convergence conducted on the Aleutian Islands Pacific cod assessment model 24.1. In the upper left panel, solid black circles represent the total likelihood obtained from 200 jittered model runs and the red horizontal dashed line represents the total likelihood value from the base-case model. The upper right panel is the spawning stock biomass (SSB) from jittered model runs. The lower panel shows the estimate of absolute fishing mortality, F, with F=sum(full Fs).

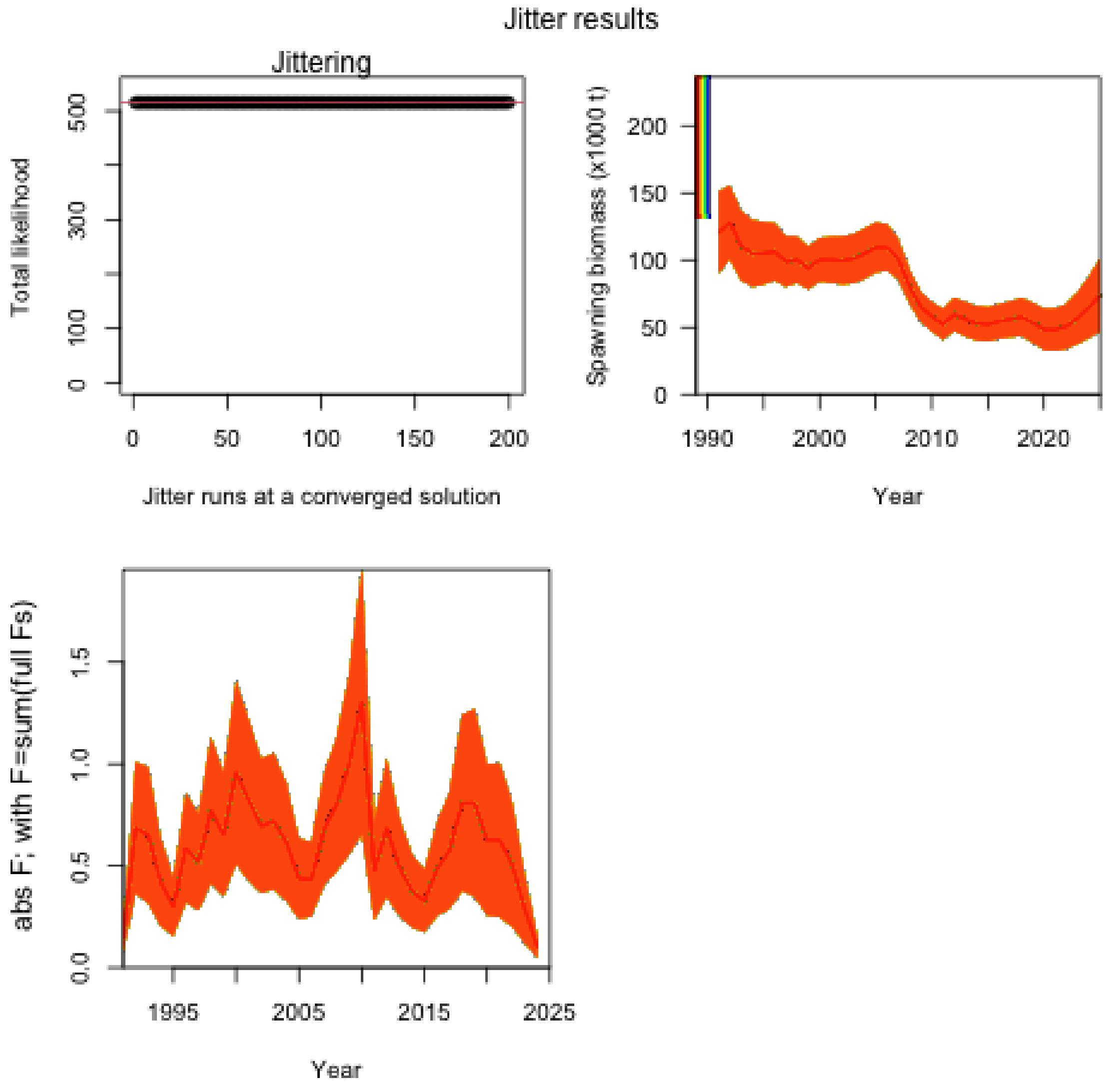

Figure 2A.21: The Model 24.0 jitter diagnostic for global convergence conducted on the Aleutian Islands Pacific cod assessment model 24.1. In the upper left panel, solid black circles represent the total likelihood obtained from 200 jittered model runs and the red horizontal dashed line represents the total likelihood value from the base-case model. The upper right panel is the spawning stock biomass (SSB) from jittered model runs. The lower panel shows the estimate of absolute fishing mortality, F, with F=sum(full Fs).

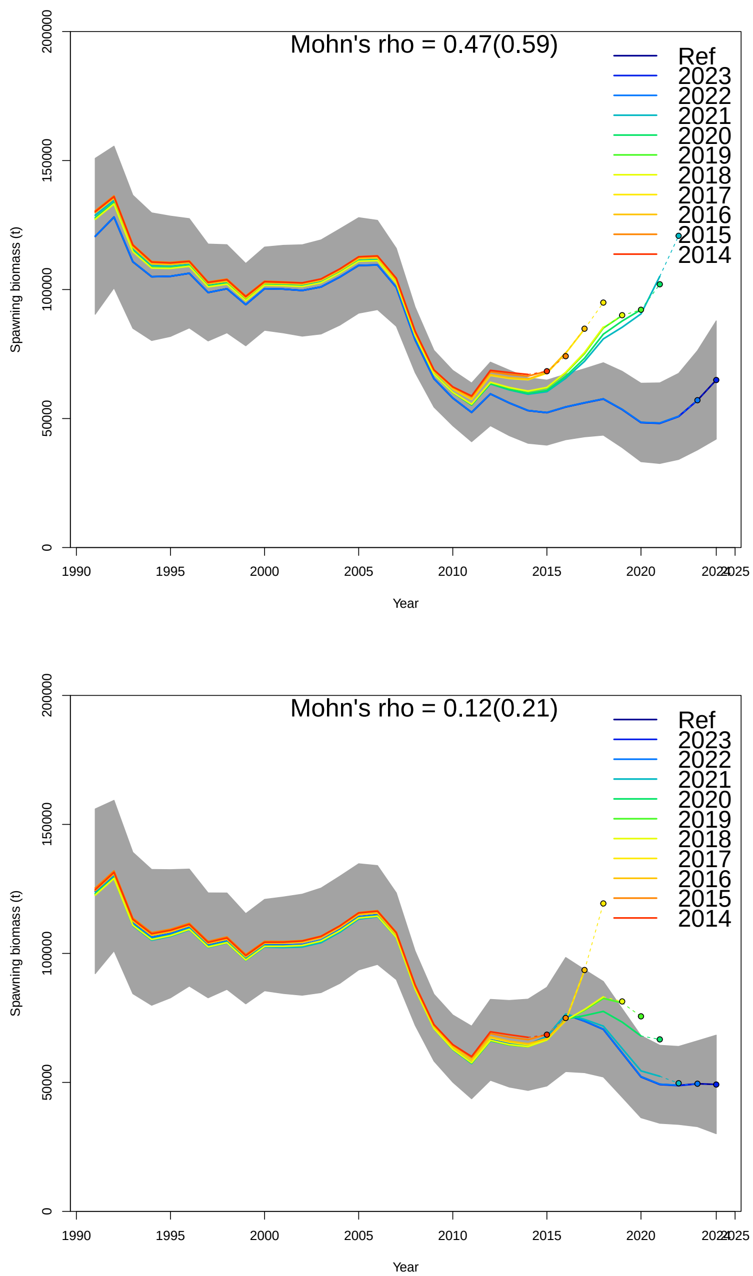

Figure 2A.22: Retrospective plot of spawning biomass, Model 24.0 (upper panel), and Model 24.1 (lower panel). Mohn's rho is presented for each retrospective, followed by the forecasted estimate of rho in parentheses. The shaded area represents the 95% confidence interval around the mean of the base year (full time series).

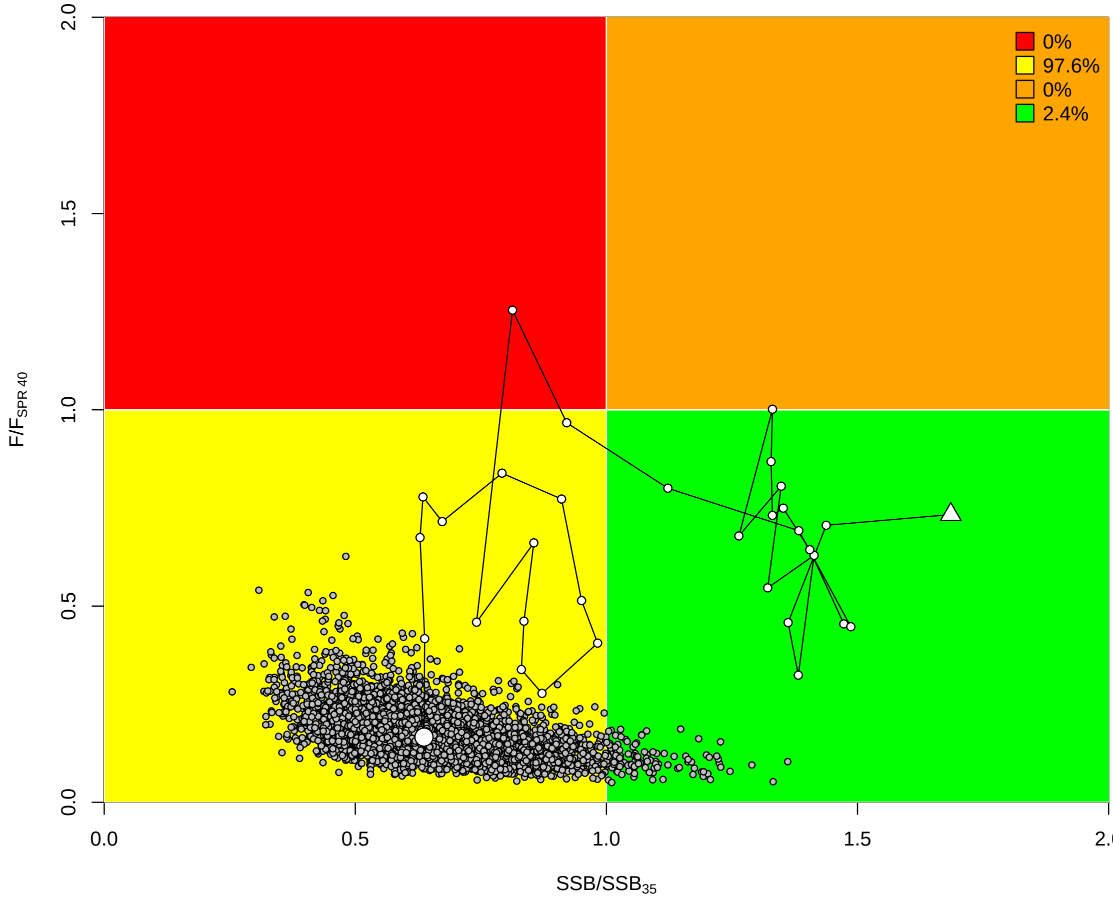

Figure 2A.23: A Kobe plot demonstrating the stock status uncertainty over SSB/SSBmsy and F/Fmsy, indicates a 97.6% probability that the stock status is between SSB8% and SSB35%, and that the fishing mortality rate is below F40%. The triangle represents the first year (1991) and the large circle the final year (2024). Grey dots provide uncertainty among Model 24.1 runs for the stock status in the final year.

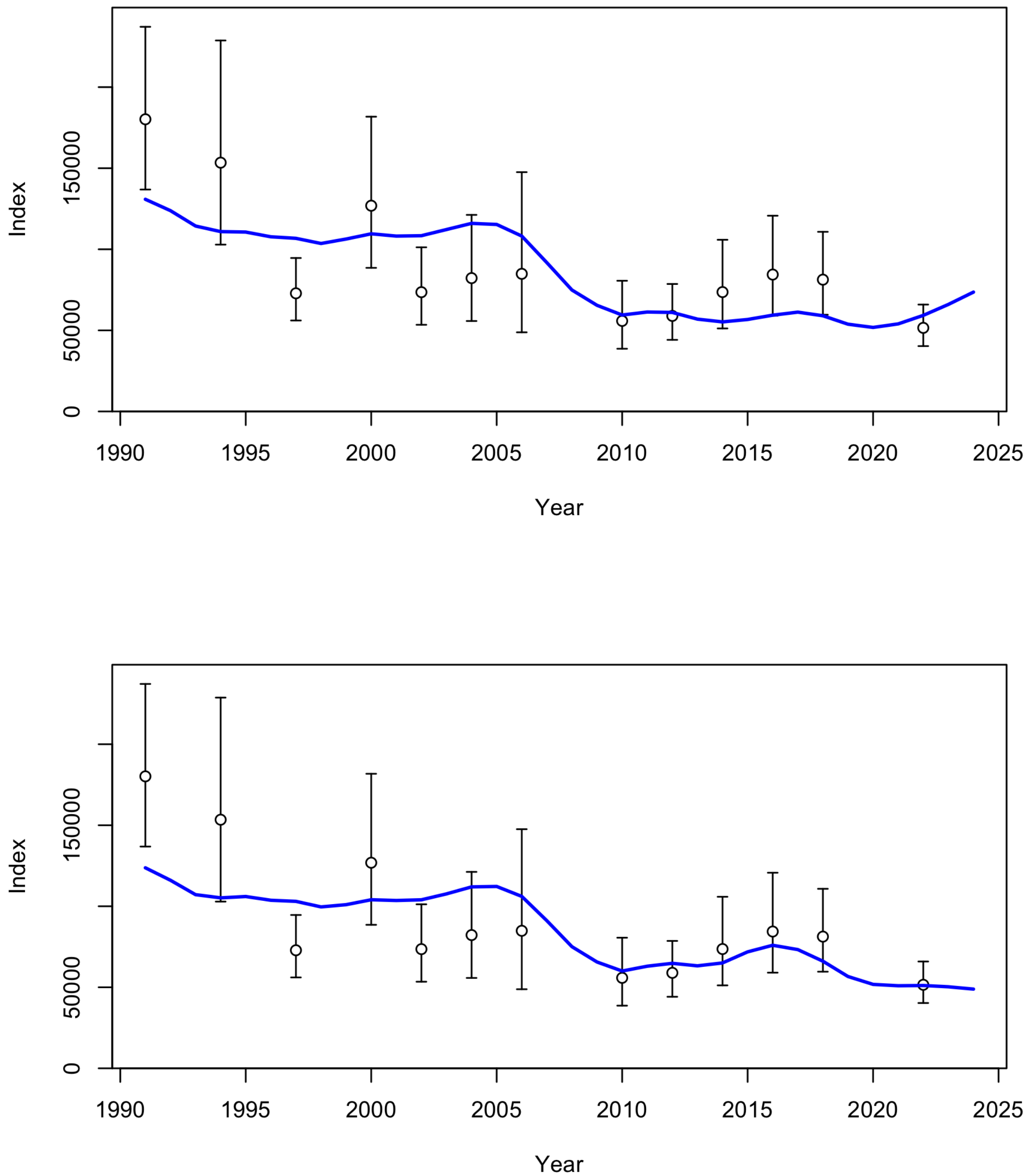

Figure 2A.24: Model 24.0 (upper panel) and Model 24.1 (lower panel) fit to survey index, 1991 - 2024.

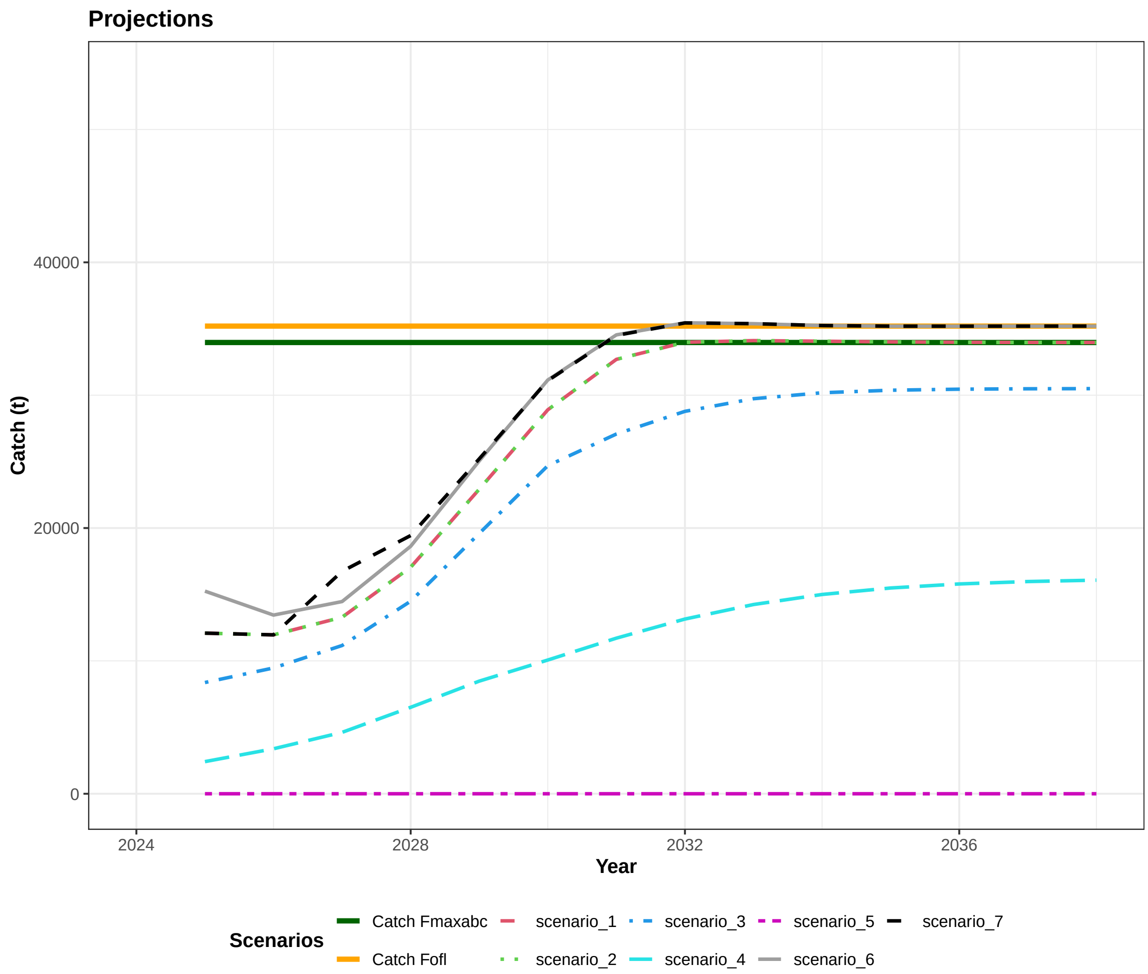

Figure 2A.25: Catch under seven NPFMC projection scenarios for Model 24.1.

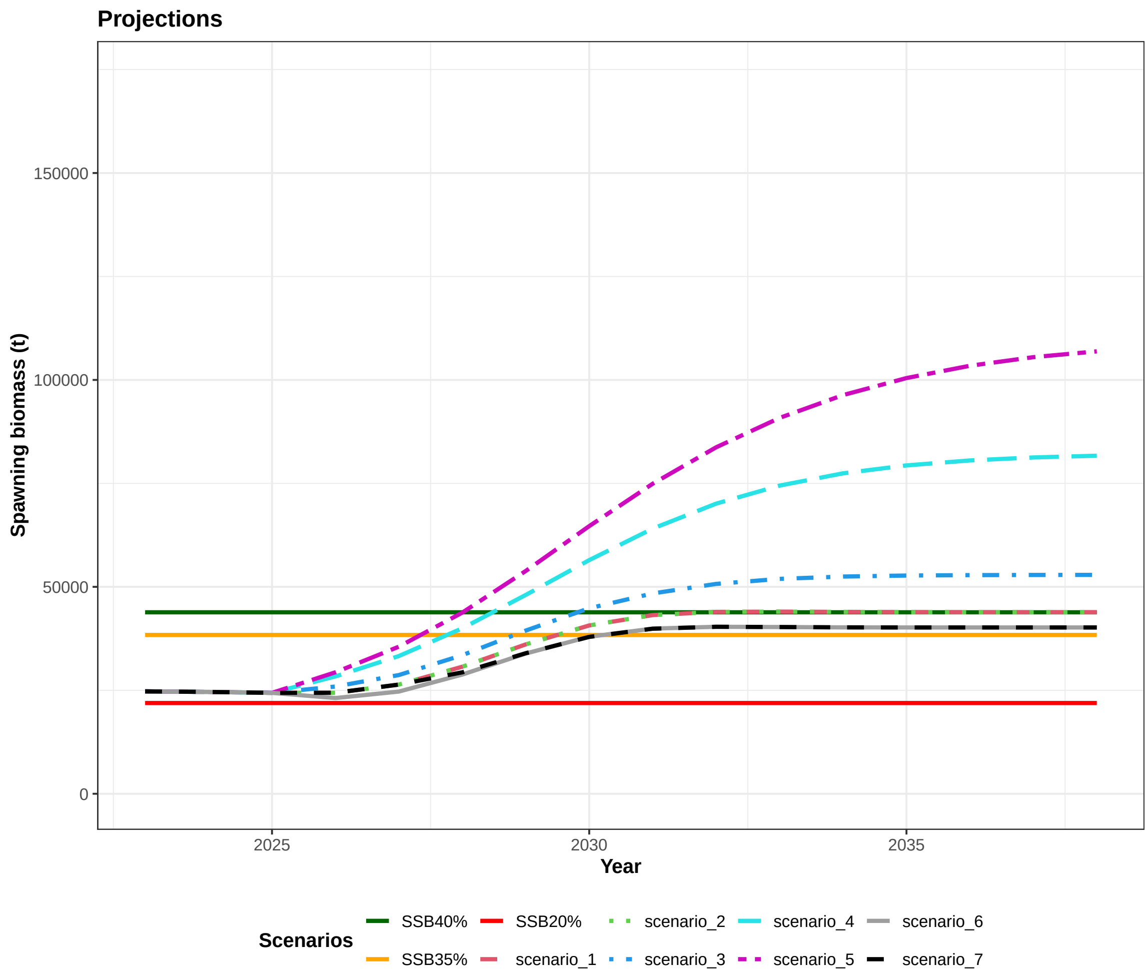

Figure 2A.26: Projected spawning stock biomass under seven NPFMC projection scenarios for Model 24.1.

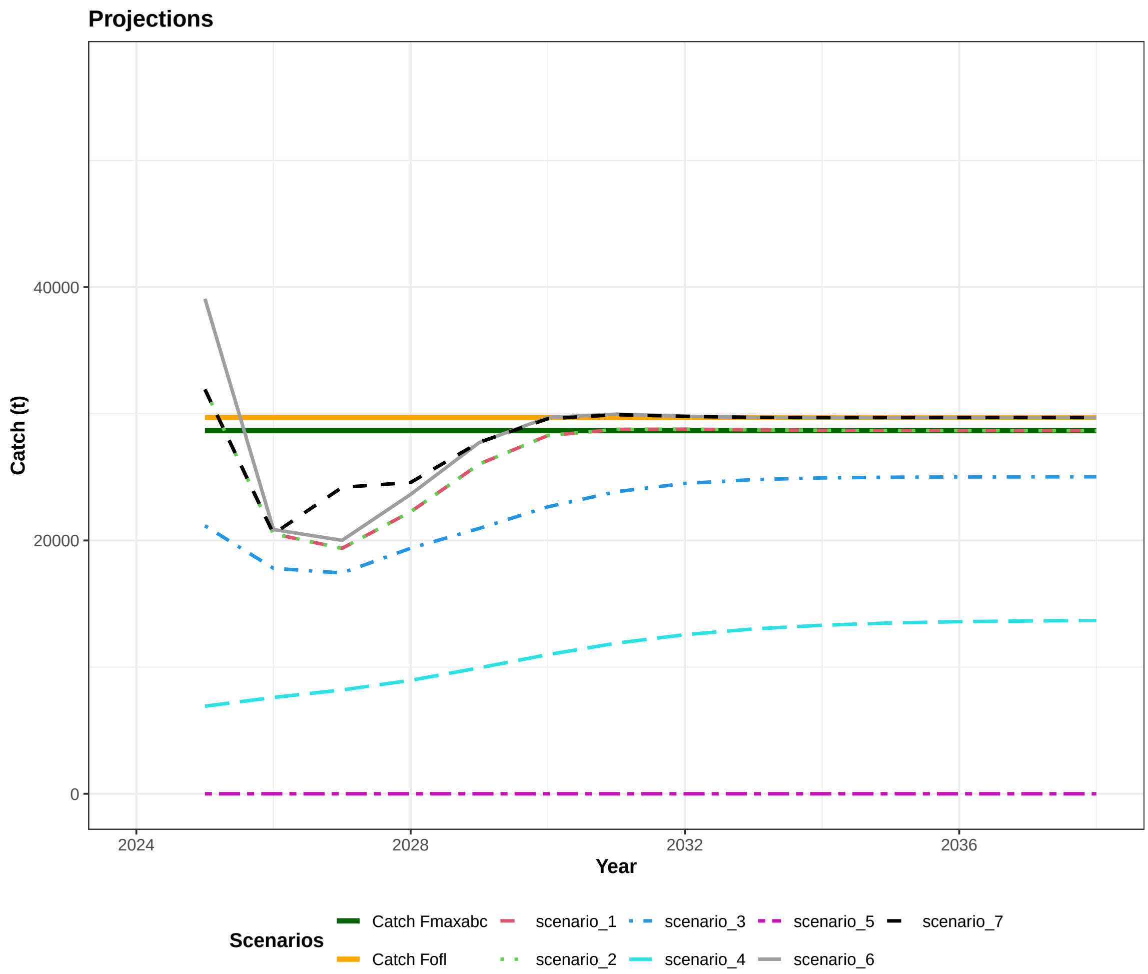

Figure 2A.27: Catch under seven NPFMC projection scenarios for Model 24.0.

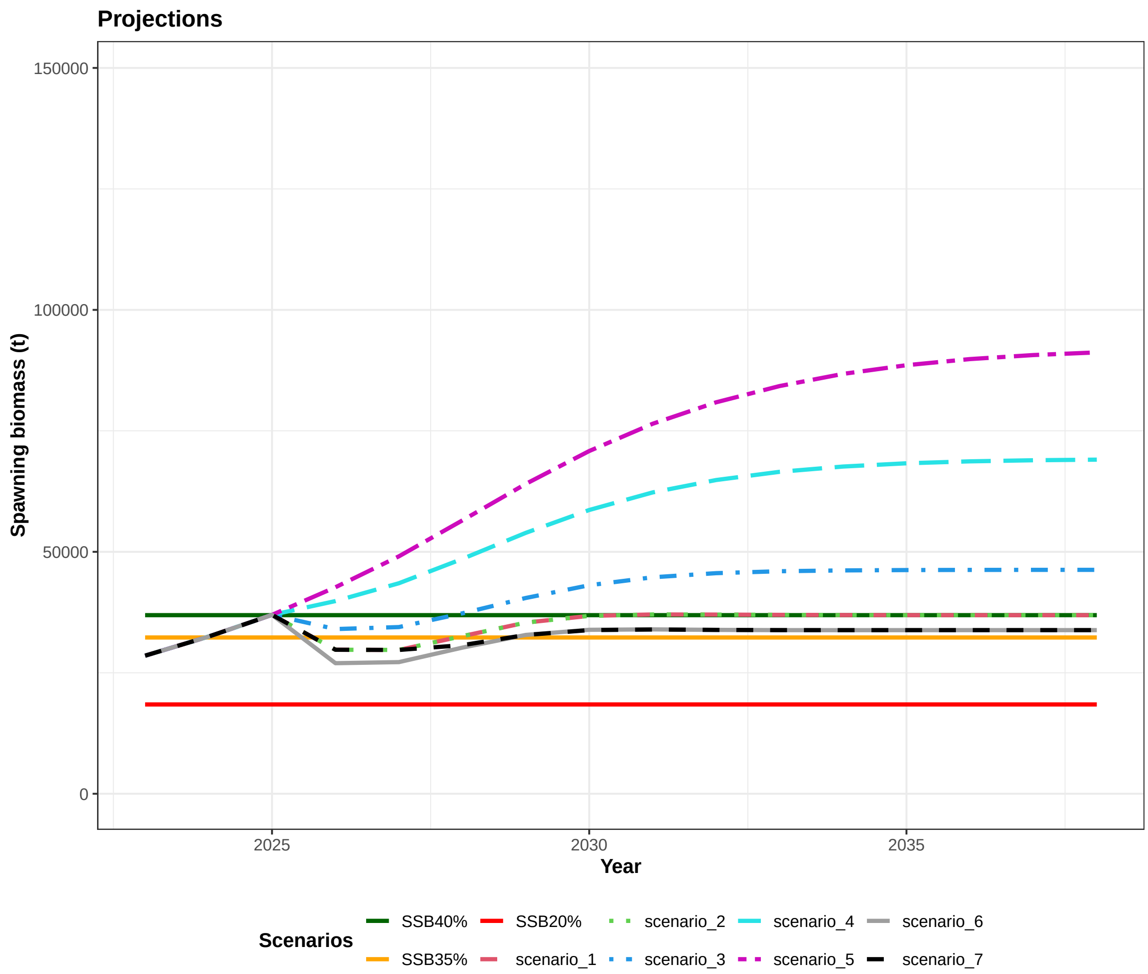

Figure 2A.28: Projected spawning stock biomass under seven NPFMC projection scenarios for Model 24.0.