Agenda Item G.2
Attachment 3 (***Electronic Only***)
September 2023

# Status of Rex Sole (*Glyptocephalus zachirus*) along the U.S. West Coast in 2023

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# Contents

# Executive summary

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## Stock

This assessment applies to Rex Sole (*Glyptocephalus zachirus*) off the West Coast of the United States from the U.S.-Canada border to the U.S.-Mexico border using data through 2022. Rex Sole are modeled in this assessment as a single stock due to the lack of biological and genetic data supporting the presence of multiple stocks. Rex Sole have a wide depth distribution. They are most commonly found in waters up to 500 m but range down to more than 1100 m. This assessment applies to their full depth range.

## Catches

Catch data exists for Rex Sole starting in 1916. Catches were highest in the period from about 1950-1990, and have been relatively stable but slightly declining in the last 20 years (Figure i). Recent landings (since 1981) were provided by Pacific Fisheries Information Network (PacFIN). Landings are nearly entirely from the commercial bottom trawl fishery. The fleet structure included two fleets (Table i) to incorporate the availability of reliable discard data starting in 2002 with the advent of the West Coast Groundfish Observer Program (WCGOP): one historical coastwide fishery (removals 1916-2001) and one current coastwide fishery (catch and discards modeled separately for 2002-2022).

**Table i:** Recent landings by fleet, total landings summed across fleets, and the total mortality including discards.

| Year | FISHERY current (mt) | FISHERY historical (mt) | Total Landings (mt) | Total Dead (mt) |
|---|---|---|---|---|
| 2013 | 514.80 | 0 | 514.80 | 622.67 |
| 2014 | 418.17 | 0 | 418.17 | 530.65 |
| 2015 | 537.78 | 0 | 537.78 | 720.39 |
| 2016 | 613.84 | 0 | 613.84 | 809.01 |
| 2017 | 556.85 | 0 | 556.85 | 773.47 |
| 2018 | 476.57 | 0 | 476.57 | 638.00 |
| 2019 | 369.56 | 0 | 369.56 | 509.48 |
| 2020 | 320.63 | 0 | 320.63 | 419.33 |
| 2021 | 283.45 | 0 | 283.45 | 411.83 |
| 2022 | 307.33 | 0 | 307.33 | 445.15 |

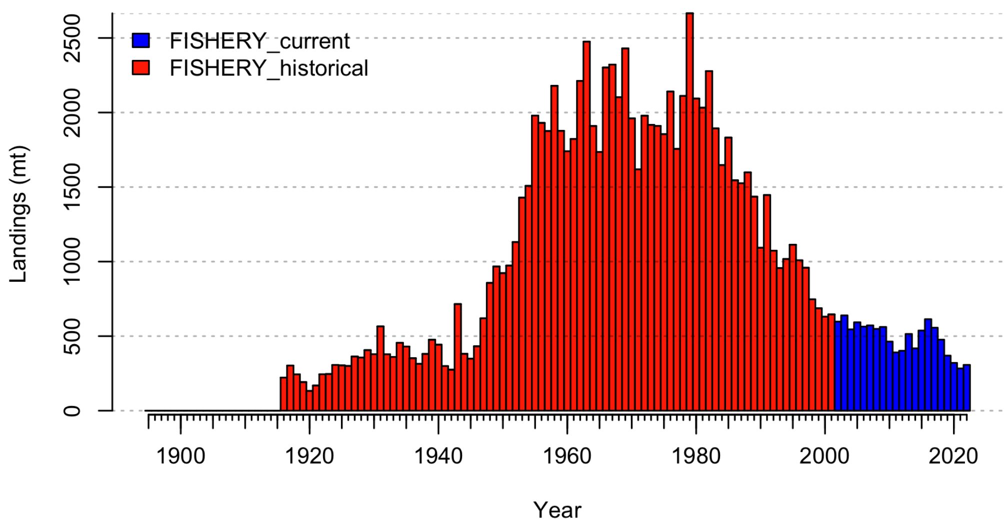


**Figure i:** Total landings removal for the 2 fleets. The historical fishery fleet landings (1916-2001, red) include both retained and estimated discarded fish (total dead catch). Estimated time-varying discarded rates in the historical fishery were based on the previous assessment and Pikitch et al. (1988). The current fishery fleet (2002-2022, blue) reports landings only (retained fish) with discards estimated in the model.

## Data and assessment

This stock assessment for Rex Sole off the West Coast of the United States uses the stock assessment framework Stock Synthesis (SS3; (Methot and Wetzel 2013)) version 3.30.21. The previous assessment of Rex Sole was conducted in 2013 and estimated the stock to be increasing with a stock status determination of 80 percent of virgin (or unfished) spawning biomass in 2013 (Cope et al. 2015). During the development of this assessment, many model specifications were changed from the last assessment model, most notably the inclusion of length compositions from both fishery-dependent and fishery-independent sources, the inclusion of conditional age-at-length (CAAL) data from the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS), the modeling of discards separately from landings starting in 2002, and updating all biological parameters. The model time domain is 1916 to 2022, with a 12-year forecast beginning in 2023.

All the data sources included in the base model for Rex Sole have been re-evaluated for this assessment, including improvements in the data and associated analyses. For the catch data, this assessment included a newly available catch reconstruction for Washington landings from 1948-1980 and an updated catch reconstruction from Oregon for 1929-1980. Age data from the WCGBTS were included as CAAL data. Maturity and fecundity parameters were updated to West Coast-specific parameter values (Hosie and Horton 1977), rather than using parameter values from studies conducted in Alaska, as was done in the last stock assessment. The indices of abundance were calculated using Species Distribution Models with Template Model Builder (`sdmTMB`) (Anderson et al. 2022), a newly developed geostatistical method.

The definition of fishing fleets changed in this assessment relative to the 2013 assessment. Two fishing fleets are now defined in the model: one historical coastwide fishery (removals 1916-2001) and one current coastwide fishery (catch and discards modeled separately for 2002-2022). This change was made to facilitate the inclusion of discard data from the WCGOP, which began collecting data in 2002.

This assessment integrates data and information from multiple sources into one modeling framework. Specifically, the assessment uses landings data and discard estimates; survey indices of abundance; length composition data from fishery landings, fishery discards, and the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) and WCGBTS; CAAL data from the WCGBTS, and information on weight-at-length from the WCGBTS. The base model was tuned to account for the weighting of composition data as well as the specification of recruitment variance and recruitment bias adjustments. The derived outputs of the model include estimates of recruitment at equilibrium spawning biomass ($R_0$), annual recruitment deviations, length-based selectivity of the fisheries (sex-specific) and surveys (non-sex-specific), estimated sex-specific growth curves, retention for the current fishery fleet, the time series of spawning biomass, age and size structure, and current and projected stock status.

Multiple sources of uncertainty are modeled explicitly, including parameter uncertainty using prior distributions, observational uncertainty through standard deviations of survey estimates, and model uncertainty through comprehensive sensitivity analyses to data source and model structural assumptions. A base model was selected that best fit the observed data while balancing the desire to capture the central tendency across those sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model misspecification.

## Stock biomass and dynamics

The stock spawning output is currently trending upwards (Figure ii), and the 2023 spawning output relative to unfished equilibrium spawning output is above the target of 25 percent of unfished spawning output (Table ii (0.76), Figure iii). The uncertainty around the stock status and scale in 2023 estimate a 95% asymptotic confidence interval of 0.67-0.85 for stock status and 692 - 1133 million eggs for spawning output.

**Table ii:** Estimated recent trend in spawning output and the fraction unfished and the 95 percent intervals.

| Year | Spawning Output (eggs) | Lower Interval (eggs) | Upper Interval (eggs) | Fraction Unfished | Lower Interval | Upper Interval |
|---|---|---|---|---|---|---|
| 2013 | 637390000 | 479224630 | 795555370 | 0.53 | 0.46 | 0.60 |
| 2014 | 687399000 | 517131245 | 857666755 | 0.57 | 0.50 | 0.65 |
| 2015 | 742168000 | 559667914 | 924668086 | 0.62 | 0.54 | 0.70 |
| 2016 | 784763000 | 591003312 | 978522688 | 0.65 | 0.57 | 0.74 |
| 2017 | 819703000 | 615457113 | 1023948887 | 0.68 | 0.59 | 0.77 |
| 2018 | 846911000 | 634446984 | 1059375016 | 0.71 | 0.61 | 0.80 |
| 2019 | 869378000 | 651369246 | 1087386754 | 0.73 | 0.63 | 0.82 |
| 2020 | 887881000 | 666781383 | 1108980617 | 0.74 | 0.64 | 0.84 |
| 2021 | 901312000 | 679302960 | 1123321040 | 0.75 | 0.66 | 0.85 |
| 2022 | 909284000 | 687615993 | 1130952007 | 0.76 | 0.66 | 0.85 |
| 2023 | 912716000 | 692053455 | 1133378545 | 0.76 | 0.67 | 0.85 |

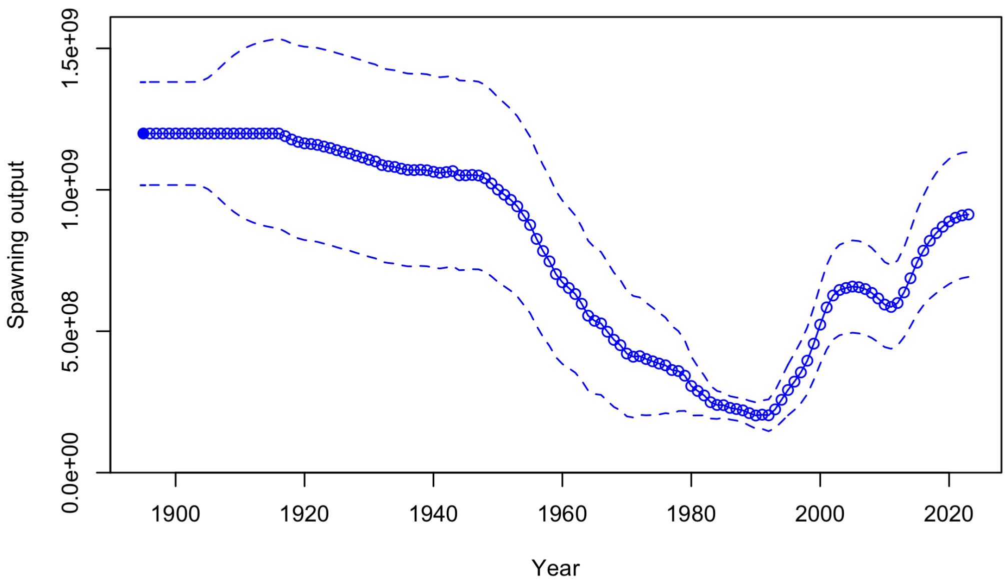


**Figure ii:** Estimated time series of spawning output.

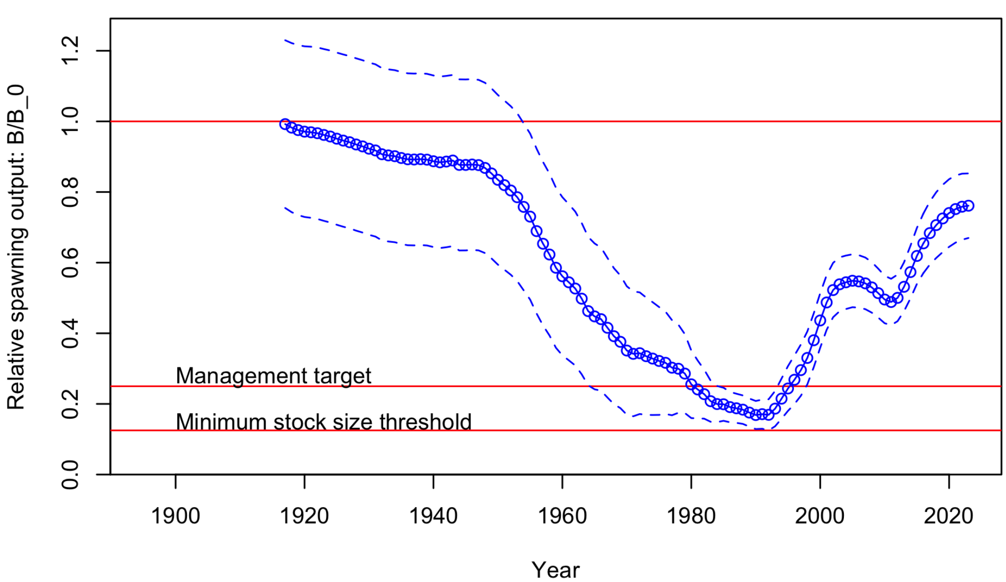


**Figure iii:** Estimated time series of spawning output, relative to unfished equilibrium.

## Recruitment

Rex Sole appear to have moderate variability in recruitment (Figure iv, Table iii). 2021-2023 were not included in the main recruitment deviations and are instead termed late recruitment deviations that are not constrained to sum to zero (Figure v).

**Table iii:** Estimated recent trend in recruitment and recruitment deviations and the 95 percent intervals.

| Year | Recruitment (1,000s) | Lower Interval (1,000s) | Upper Interval (1,000s) | Recruitment Deviations | Lower Interval | Upper Interval |
|---|---|---|---|---|---|---|
| 2013 | 100549.0 | 76545.50 | 132079.63 | 0.61 | 0.42 | 0.79 |
| 2014 | 42805.7 | 30103.53 | 60867.55 | -0.26 | -0.55 | 0.03 |
| 2015 | 59163.6 | 42059.05 | 83224.22 | 0.05 | -0.23 | 0.33 |
| 2016 | 67444.1 | 45484.69 | 100005.22 | 0.17 | -0.18 | 0.52 |
| 2017 | 41706.7 | 21842.71 | 79635.19 | -0.31 | -0.95 | 0.32 |
| 2018 | 64498.0 | 34147.30 | 121824.91 | 0.10 | -0.53 | 0.72 |
| 2019 | 53606.6 | 25198.33 | 114041.99 | -0.12 | -0.88 | 0.64 |
| 2020 | 59397.1 | 26025.24 | 135561.31 | -0.05 | -0.89 | 0.79 |
| 2021 | 63114.4 | 24790.01 | 160686.80 | 0.01 | -0.97 | 0.98 |
| 2022 | 62659.5 | 24528.07 | 160070.20 | 0.00 | -0.98 | 0.98 |
| 2023 | 62691.8 | 24541.35 | 160148.55 | 0.00 | -0.98 | 0.98 |

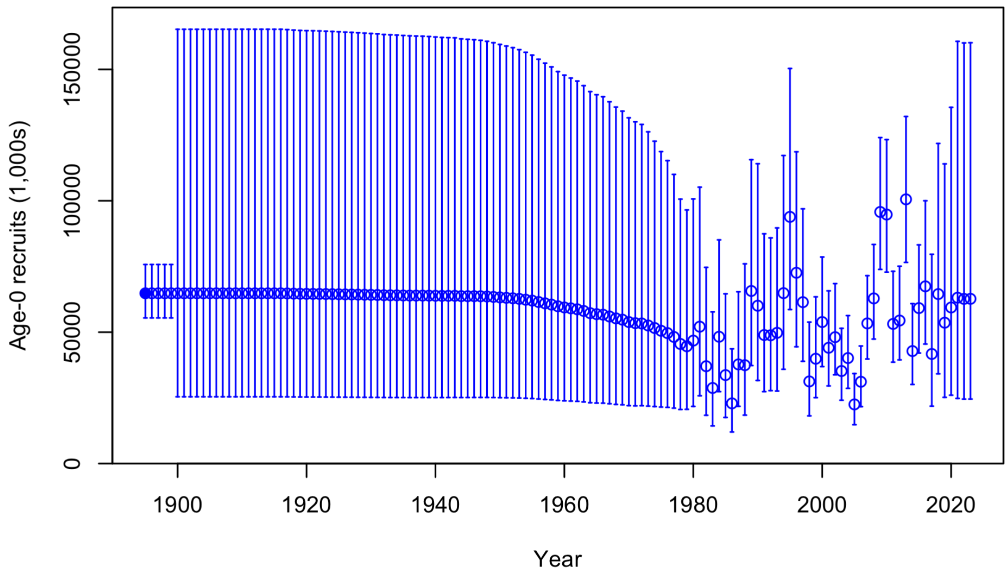


**Figure iv:** Estimated time series of age-0 recruits (1000s).

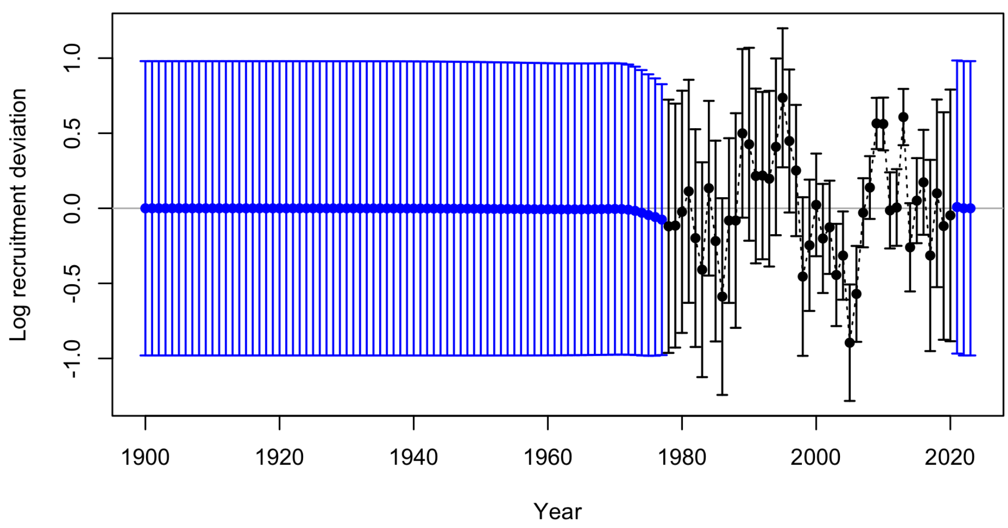


**Figure v:** Estimated time series of recruitment deviations.

## Exploitation status

The harvest rate was estimated to have been above the target proxy harvest rate for much of the 1980s and early 1990s, but below the target rate for the last 25 years (Figure vi), and well below the target rate for the last ten years (Table iv). The spawning output relative to unfished equilibrium in 2023 is estimated to be at 0.76 of unfished spawning output, which is well above the target.

**Table iv:** Estimated recent trend in relative fishing intensity, exploitation rate, and the 95 percent intervals. The spawning potential ratio (SPR) is utilized in the calculation as (1-SPR)/(1-SPR30%).

| Year | (1-SPR)/(1-SPR30%) | Lower Interval | Upper Interval | Exploitation Rate | Lower Interval | Upper Interval |
|---|---|---|---|---|---|---|
| 2013 | 0.351 | 0.278 | 0.424 | 0.100 | 0.061 | 0.139 |
| 2014 | 0.296 | 0.232 | 0.360 | 0.080 | 0.049 | 0.112 |
| 2015 | 0.357 | 0.284 | 0.430 | 0.102 | 0.062 | 0.142 |
| 2016 | 0.374 | 0.298 | 0.450 | 0.108 | 0.066 | 0.151 |
| 2017 | 0.349 | 0.276 | 0.422 | 0.099 | 0.060 | 0.138 |
| 2018 | 0.291 | 0.227 | 0.354 | 0.079 | 0.048 | 0.109 |
| 2019 | 0.234 | 0.181 | 0.288 | 0.061 | 0.037 | 0.084 |
| 2020 | 0.194 | 0.148 | 0.239 | 0.048 | 0.030 | 0.067 |
| 2021 | 0.187 | 0.144 | 0.231 | 0.047 | 0.029 | 0.065 |
| 2022 | 0.198 | 0.153 | 0.244 | 0.050 | 0.031 | 0.069 |

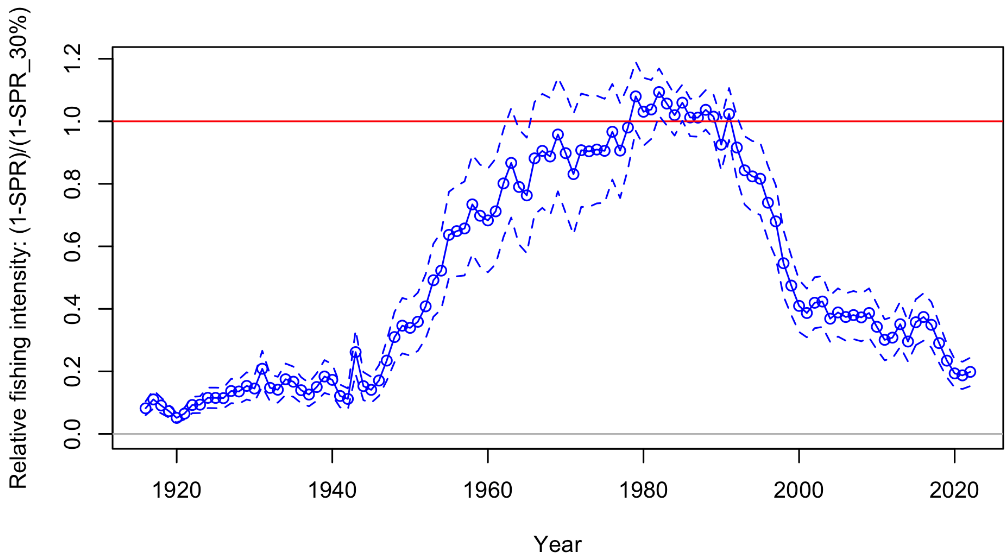


**Figure vi:** Estimated recent trend in relative fishing intensity and the 95 percent intervals. The spawning potential ratio (SPR) is utilized in the calculation as (1-SPR)/(1-SPR30%). The red horizontal line at 1.0 indicates fishing intensity equal to the target and values above this reflect harvest in excess of the proxy harvest rate.

## Reference points

The relative biomass compared to the ratio of the estimated SPR to the management target (SPR 30%) across all model years is shown in Figure vii where warmer colors (red) represent early years and colder colors (blue) represent recent years. Fishing intensity was estimated to be above the target for the 1980s and early 1990s, but the recent 25 years of fishing intensity below target levels led to the stock returning to be above the target.

**Table v:** Summary of reference points and management quantities for the base model.

| | Estimate | Lower Interval | Upper Interval |
|---|---|---|---|
| Unfished spawning output (millions) | 1199 | 1011 | 1387 |
| Unfished Age 0+ Biomass (mt) | 30007 | 25380 | 34635 |
| Unfished Recruitment (R0) | 64798 | 54653 | 74944 |
| Spawning Output (2023) (millions) | 913 | 692 | 1133 |
| Fraction Unfished (2023) | 0.761 | 0.67 | 0.853 |
| Reference Points Based SB25% | - | - | - |
| Proxy Spawning Output (millions) SB25% | 300 | 253 | 347 |
| SPR Resulting in SB25% | 0.33 | 0.33 | 0.33 |
| Exploitation Rate Resulting in SB25% | 0.573 | 0.381 | 0.764 |
| Yield with SPR Based On SB25% (mt) | 1680 | 1419 | 1942 |
| Reference Points Based on SPR Proxy for MSY | - | - | - |
| Proxy Spawning Output (millions) (SPR30) | 259 | 218 | 300 |
| SPR30 | 0.3 | - | - |
| Exploitation Rate Corresponding to SPR30 | 0.651 | 0.432 | 0.869 |
| Yield with SPR30 at SB SPR (mt) | 1658 | 1400 | 1916 |
| Reference Points Based on Estimated MSY Values | - | - | - |
| Spawning Output (millions) at MSY (SB MSY) | 321 | 270 | 371 |
| SPR MSY | 0.346 | 0.34 | 0.352 |
| Exploitation Rate Corresponding to SPR MSY | 0.537 | 0.363 | 0.712 |
| MSY (mt) | 1683 | 1421 | 1945 |

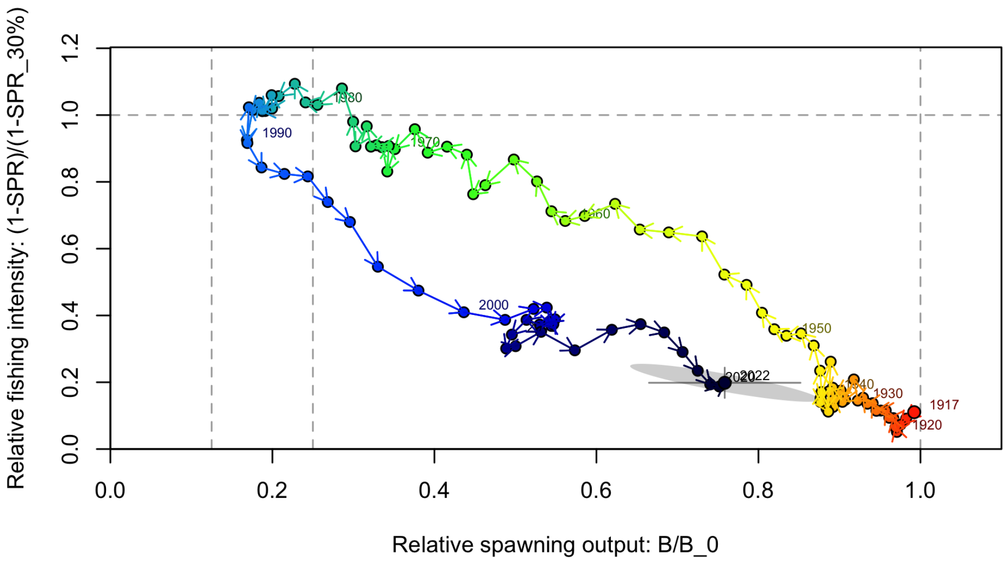


**Figure vii:** Phase plot of biomass ratio vs. spawning potential ratio (SPR). Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95 percent intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlation between the two quantities.

## Management performance

In the last ten years, landings and estimated total mortality have been well below the overfishing limit (OFL) and Acceptable Biological Catch (ABC) (Table vi). This comparison is made more complicated by the inclusion of Rex Sole in the "Other Flatfish" stock complex and the lack of Rex Sole-specific quantities for all years, but an extrapolation of the proportion of Rex Sole to the "Total Flatfish" values for the years for which a Rex Sole-specific value does not exist indicates that exploitation has remained consistently below the annual catch limit (ACL). Total mortality has been less than 25% of ACL for the past six years.

**Table vi:** Recent trend in commercial landings (mt) relative to the management guidelines. Estimated total mortality reflects the commercial landings plus the model-estimated discarded biomass. As OFL and ACL values specific to Rex Sole were not available for all years, OFL and ACL values are provided for both Rex Sole and the "Other Flatfish" stock complex, which Rex Sole is a part of. Estimated total mortality is not available for 2022 because complete discard information was not available for this year at the time of the assessment.

| | Other Flatfish | | Rex Sole | | | |
|---|---|---|---|---|---|---|
| Year | OFL | ACL | OFL | ACL | Total Landings | Estimated Total Mortality |
| 2011 | - | 4884 | - | - | 391 | 466 |
| 2012 | - | 4884 | - | - | 402 | 485 |
| 2013 | - | 4884 | - | - | 515 | 603 |
| 2014 | - | 4884 | - | - | 418 | 507 |
| 2015 | - | 8620 | - | - | 538 | 674 |
| 2016 | - | 7496 | - | - | 614 | 762 |
| 2017 | 11165 | 8510 | 5476 | 4562 | 557 | 713 |
| 2018 | 9690 | 7281 | 4001 | 3333 | 477 | 597 |
| 2019 | 8750 | 6498 | 3061 | 2550 | 370 | 471 |
| 2020 | 8202 | 6041 | 2513 | 2093 | 321 | 396 |
| 2021 | 7714 | 4802 | 2026 | 1377 | 283 | 372 |
| 2022 | 7808 | 4838 | 2120 | 1414 | 307 | - |

## Unresolved problems and major uncertainties

The higher than expected estimate of catchability ($Q$) for the WCGBTS remains a major unresolved issue for this assessment. The value estimated in the base model is 3.97; recent estimates of catchability for the WCGBTS for other flatfish on the West Coast are between 1 and 3 (Wetzel 2019; Wetzel and Berger 2021). This is in line with a study of the gear used by this survey by Bryan et al. (2014), which showed that flatfish like Rex Sole exhibited herding behavior when encountering the gear deployed by the WCGBTS. Bryan et al. (2014) estimated that values of $Q$ between 1 and 3 could be expected for flatfish caught by the WCGBTS, given that the distance between the trawl doors is about three times the distance between the leading edge of the wings. The high value estimated is supported by the likelihood profile (Figure 64) and notably, some older assessments for similar flatfishes have even higher estimated values of $Q$ for this survey; see the assessment Pacific sanddab (*Citharichthys sordidus*) on the West Coast in 2013 (He et al. 2013). Survey catchability for Rex Sole, assessed for the Gulf of Alaska in 2021 was estimated at 1.17 using a normal prior (~N(1.2, 0.175)) and based on herding studies for Rex Sole (McGilliard and Palsson 2021).

The length-age relationship for Rex Sole on the U.S. West Coast is highly uncertain. The growth curve estimated within the model (Figure 17) was considerably different than the growth curve estimated external to the model, which estimated a much larger $L_{infinity}$ for both sexes. However, because of the known effect that the biased sampling of smaller and larger individuals used to construct this growth curve has on these estimates (Perreault et al. 2020), the externally estimated growth curve was not used for this model. Moreover, most of the age composition data was only collected during 2017-2019. More unbiased age data collected for this stock would refine the estimates of growth.

The biological parameters used in this assessment represent a considerable source of uncertainty in the assessment that is explored through sensitivity analyses. Except for the age-length relationship which was estimated in the model using CAAL data, all biological parameters were fixed. The parameter values for maturity- and fecundity-at-length relationships were both from Hosie and Horton (1977). The maturity parameters were based on macroscopic maturity identification and the study reported a length at 50% maturity, but without a statistical fit to the data. Because of this, the slope of the logistic maturity-at-length curve was assumed to be the same as for fish in the Gulf of Alaska (Abookire 2006), used in the 2013 assessment. Furthermore, macroscopic maturity determination may have have limited accuracy, as shown for other West Coast groundfishes (Min et al. 2022). Histological analysis of Rex Sole ovaries collected in good numbers by the WCGBTS would provide a much needed update to maturity-at-length information. The fecundity-at-length relationship was based on a limited sample size of 13 fish, with only two fish greater than 40 cm. The fecundity parameters would also benefit from more samples and greater spatial coverage. Additionally, the value of natural mortality is very uncertain and the likelihood profile (Figure 62) favored a lower value of $M$, but the base model was unstable when $M$ was estimated rather than fixed. Moreover, this assessment fixed steepness at 0.7, as this value led to the most stable models during the model development process. This assessment explored fixing steepness to 0.8, the median of current accepted prior for steepness of U.S. West Coast flatfish, but the improvements to data fits were insignificant. Further examination and exploration of steepness is warranted in future assessments.

## Decision table and projections

The forecast of stock abundance and yield was developed using the base model. The total catch projections for 2023 and 2024 were based on the maximum total dead mortality from the years 2020-2022, as provided by the Groundfish Management Team (GMT). The exploitation rate for 2025 and beyond is based on an SPR of 30 percent and the 25:5 harvest control rule (Table vii).

Two alternative catch scenarios are included in the decision table (Table viii). These catch scenarios were estimated using the default harvest control rule for Rex Sole (P* of 0.4 and $\sigma_y$ of 1.0) as well as an alternative scenario with P* of 0.45 and $\sigma_y$ of 1.0. Full attainment ABC = ACL was assumed in both runs.The axis of uncertainty in the decision table explores the uncertainty in female natural mortality. Uncertainty in the forecasts is based upon the uncertainty around the 2023 OFL, with a search was conducted across values of female natural mortality to determine the values that would correspond to the 12.5% and 87.5% percentiles of the normal distribution given the maximum likelihood estimate and the asymptotic uncertainty the 2023 OFL estimate. The female natural mortality values that corresponded with the lower and upper quantiles were 0.175 $yr^{-1}$ and 0.210 $yr^{-1}$.

**Table vii:** Projections of potential OFLs (mt), ABCs (mt), estimated spawning output, and fraction unfished.

| Year | Predicted OFL (mt) | ABC Catch (mt) | Age 0+ Biomass (mt) | Spawning Output | Fraction Unfished |
|---|---|---|---|---|---|
| 2023 | 5173.06 | 447.17 | 24276.9 | 912716000 | 0.76 |
| 2024 | 5188.27 | 447.17 | 24412.1 | 915434000 | 0.76 |
| 2025 | 5205.59 | 4549.68 | 24578.2 | 919551000 | 0.77 |
| 2026 | 4299.66 | 3719.21 | 21379.7 | 759249000 | 0.63 |
| 2027 | 3678.62 | 3152.58 | 19224.6 | 645197000 | 0.54 |
| 2028 | 3260.91 | 2768.52 | 17773.2 | 565092000 | 0.47 |
| 2029 | 2984.23 | 2509.73 | 16781.5 | 509628000 | 0.43 |
| 2030 | 2801.39 | 2333.56 | 16079.1 | 471396000 | 0.39 |
| 2031 | 2678.03 | 2212.06 | 15554.6 | 444694000 | 0.37 |
| 2032 | 2590.04 | 2118.65 | 15138.6 | 425381000 | 0.35 |
| 2033 | 2523.30 | 2043.88 | 14796.8 | 410958000 | 0.34 |
| 2034 | 2469.55 | 1983.05 | 14510.3 | 399845000 | 0.33 |

**Table viii:** Decision table summary of 10 year projections beginning in 2025 for alternative states of nature based on an axis of uncertainty about female natural mortality for the base model. Columns range over low, mid, and high states of nature and rows show two catch scenarios of full ACL attainment for 12 years at P* values of 0.4 and 0.45 for 2025-2034.

| | | M = 0.175 | | M = 0.186 | | M = 0.210 | |
|---|---|---|---|---|---|---|---|
| Year | Catch | Spawning Output (millions) | Fraction unfished | Spawning Output (millions) | Fraction unfished | Spawning Output (millions) | Fraction unfished |
| **ACL P* = 0.4** | | | | | | | |
| 2023 | 447 | 792 | 0.669 | 913 | 0.761 | 1054 | 0.886 |
| 2024 | 447 | 801 | 0.676 | 915 | 0.764 | 1046 | 0.879 |
| 2025 | 3967 | 811 | 0.685 | 920 | 0.767 | 1039 | 0.873 |
| 2026 | 3310 | 671 | 0.566 | 783 | 0.653 | 909 | 0.764 |
| 2027 | 2850 | 570 | 0.481 | 684 | 0.570 | 815 | 0.685 |
| 2028 | 2527 | 497 | 0.420 | 613 | 0.511 | 749 | 0.629 |
| 2029 | 2305 | 446 | 0.377 | 563 | 0.470 | 702 | 0.590 |
| 2030 | 2147 | 411 | 0.347 | 528 | 0.441 | 670 | 0.564 |
| 2031 | 2032 | 386 | 0.326 | 504 | 0.421 | 649 | 0.545 |
| 2032 | 1942 | 367 | 0.310 | 487 | 0.407 | 634 | 0.533 |
| 2033 | 1869 | 354 | 0.299 | 475 | 0.396 | 623 | 0.524 |
| 2034 | 1810 | 343 | 0.290 | 467 | 0.389 | 617 | 0.519 |
| **ACL P* = 0.45** | | | | | | | |
| 2023 | 447 | 792 | 0.669 | 913 | 0.761 | 1054 | 0.886 |
| 2024 | 447 | 801 | 0.676 | 915 | 0.764 | 1046 | 0.879 |
| 2025 | 4550 | 811 | 0.685 | 920 | 0.767 | 1039 | 0.873 |
| 2026 | 3719 | 646 | 0.545 | 759 | 0.633 | 888 | 0.747 |
| 2027 | 3153 | 529 | 0.446 | 645 | 0.538 | 781 | 0.657 |
| 2028 | 2769 | 447 | 0.377 | 565 | 0.471 | 707 | 0.594 |
| 2029 | 2510 | 390 | 0.329 | 510 | 0.425 | 655 | 0.551 |
| 2030 | 2334 | 351 | 0.296 | 471 | 0.393 | 620 | 0.522 |
| 2031 | 2212 | 323 | 0.273 | 445 | 0.371 | 597 | 0.502 |
| 2032 | 2119 | 302 | 0.255 | 425 | 0.355 | 580 | 0.488 |
| 2033 | 2044 | 285 | 0.241 | 411 | 0.343 | 568 | 0.478 |
| 2034 | 1983 | 271 | 0.229 | 400 | 0.333 | 560 | 0.471 |

## Scientific uncertainty

The estimated uncertainty in the base model around the 2023 spawning output is $\sigma = 0.123$ and the uncertainty in the base model around the 2023 OFL is $\sigma = 0.124$.

## Research and data needs

Progress on a number of research topics and data issues would substantially improve the ability of this assessment to reliably and precisely model Rex Sole population dynamics in the future:

1. Continued research on the uncertainty in the catch histories of all groundfishes. Catch is a critical component of these and all stock assessments, especially when attempting to define population scale. Historical reconstructions were updated for California, Oregon, and Washington for this assessment. Some Washington catch locations were only reported as the U.S.-Canada border; future assessments should confirm the amount of catch removals that strictly belong to U.S. waters.

2. Estimating catchability for the WCGBTS remains a major challenge for this assessment. Further understanding of reasonable or probable catchability ($Q$) values will enhance the interpretation of scale, a generally weakly informed output of data moderate assessments. It may be possible to inform a prior on $Q$ based on estimates of $Q$ from other data-rich assessments or research studies.

3. Further information on historical discards would be beneficial for future Rex Sole assessments. Limited historical discard data prior to 2002 (rate and length compositions) led to unstable models when assuming a single fishery fleet.

4. Updated biological research of Rex Sole specifically along the U.S. West Coast is critically needed. This assessment improved the assumptions of growth, maturity and fecundity parameters for U.S. West Coast Rex Sole since the previous assessment. The length-age relationship for Rex Sole remains highly uncertain, as the length-stratified sampling used to select otoliths for aging preferentially sampled smaller males and larger females. Though this bias was partially accounted for with internally estimated growth curves, more unbiased age data would greatly improve this assessment. Furthermore, the maturity and fecundity assumptions are based on a single study from the 1960s and 1970s, which had limited spatial coverage (Oregon only) and a small sample size for the fecundity-at-length relationship (Hosie and Horton 1977). Updated maturity information using updated histological methods could be obtained by processing gonads from the WCGBTS. Gonads are collected in good numbers on the WCGBTS, but none have been processed for maturity. Additionally, further exploration of steepness values would be worthwhile.

# 1 Introduction

## 1.1 Basic Information

This assessment reports the status of Rex Sole (*Glyptocephalus zachirus*) off the U.S. West coast using data through 2022. Within the assessment area the resource is treated as a single stock due to the lack of biological and genetic data supporting the presence of multiple stocks. This is a data-moderate assessment based upon catch, age (although very limited), length, and index data. Rex Sole is a medium sized, moderately long-lived (estimated to 29 years) right-eyed flatfish ranging widely in distribution from central Baja California to the Aleutian Islands. They are common in a large part of their recorded range, from southern California to the Aleutian Islands. Rex Sole have a wide depth distribution, as they are most commonly found in waters up to 500 m but range down to more than 1100 m.

## 1.2 Life History

Rex Sole feed on benthic infaunal and epifaunal invertebrates, such as amphipods, polychaetes, and ophiuroids (Kravitz et al. 1977). Rex Sole exhibit changes in diet with size, as small (< 150 mm standard length) Rex Sole have been found to feed primarily on amphipods and other crustaceans, while large (150 mm - 450 mm standard length) Rex Sole feed primarily on polychaetes (Pearcy and Hancock 1978). Seasonal differences in the diet of Rex Sole have also been observed, with Euphausiids principally consumed only in summer, while Cumaceans and *Oikopleura* were much more common prey during the winter (Pearcy and Hancock 1978). Rex Sole are consumed by other flatfishes, rockfishes, salmon, sharks, skates, sea birds, seals, and sea lions (Love 1996).

Spawning off northern Oregon has been recorded from January through June, with a peak in March - April (Hosie and Horton 1977). However, the spawning period appears to vary spatially and/or temporally for Rex Sole, based on studies from other areas and in other years that found spawning periods of January - April and January - August (Hosie and Horton 1977). Length at 50% maturity in Oregon is about 24 cm for females and 16 cm for males (Hosie and Horton 1977). The pelagic phase of Rex Sole lasts about a year (Pearcy et al. 1977), and young of the year (YOY) Rex Sole recruit to soft seafloors after reaching lengths between about 40 mm and 89 mm (Love 1996). Rex Sole show a preference for muddy-sand bottom, but also are found on both sand and mud bottoms (Hosie 1976), and appear to exhibit some ontogenetic movement, as juveniles tend to be found shallower than adults (Love 1996).

## 1.3 Historical and Current Fishery Information

Rex Sole have been a reasonably popular commercial species (Love 1996), commonly caught in the bottom trawl fisheries. Rex Sole have been caught in the commercial trawl fishery since the late 19th century, marketed as both fresh fish and, historically, as mink food. In Oregon, Rex Sole have been important in the trawl fishery since it began in the 1930s, with it being the fourth most important commercial flatfish by weight in the 1970s (Hosie 1976). Targeting for Rex Sole in commercial fisheries has varied over the years, with major removals occurring in the mid-20th century to provide feed for mink farms. They have not been targeted heavily in the last few decades, thus their vulnerability to overfishing is believed to be low (V = 1.28) (Cope et al. 2015).

## 1.4 Summary of Management History and Performance

Rex Sole are managed on the U.S. West Coast through the Pacific Coast Groundfish Fishery Management Plan (FMP), which was implemented in 1982. As most catches of Rex Sole are made incidentally to other groundfish species and full attainment of the catch values is not achieved, Rex Sole management has historically been linked to the management of co-occurring limiting species such as Yellowtail rockfish (*Sebastes flavidus*) and English sole (*Parophrys vetulus*) (Cope et al. 2015).

The introduction of the individual fishing quota (IFQ) fishery in 2011 created an allocation system of quota pounds to vessels participating in the catch share program for species in the groundfish Fishery Management Plan. Overall, Rex Sole removals have been well below the annual catch limits (ACLs, Table 3).

## 1.5 Fisheries off Canada and Alaska

Rex Sole occur along the entire coast of British Columbia (BC) and are primarily taken by the commercial mixed-species groundfish bottom trawl fishery (Anderson et al. 2021). This fishery implemented 100% at-sea observer coverage and 100% dockside monitoring in 1996, but catches prior to 1996 are highly uncertain (Anderson et al. 2021). As there is no directed fishery or assigned quota for Rex Sole, they have never been formally assessed in BC. However, a recent analysis indicated that the West Coast Vancouver Island Rex Sole stock (groundfish management area 3CD) is at around 0.5 of unfished levels (Anderson et al. 2021).

Rex Sole in Alaska are managed as two stocks, a Gulf of Alaska (GOA) stock and as part of the "Other Flatfish" stock complex in the Bering Sea and Aleutian Islands (BSAI). Rex Sole in the Gulf of Alaska are caught in a directed fishery using bottom trawl gear (McGilliard and Palsson 2021). Catch data exist for GOA Rex Sole starting in 1982, with total catch peaking at 5,874 tons in 1996. The five-year average catch of GOA Rex Sole from 2016-2020 was 1,567 tons, and fishery catches from 2010-2021 did not exceed 40% of the total allowable catch (TAC) (McGilliard and Palsson 2021). The GOA Rex Sole stock was estimated to be very close to $B_{100}$ in 2021. BSAI Rex Sole represent one of the three species that comprise most of the biomass and catch of the BSAI Other Flatfish complex (Monahan 2020). Catch data on BSAI Rex Sole are available since 1995, with catches peaking at 2,000 tons in 2005.

# 2 Data

Data comprise the foundational components of stock assessment models. The decision to include or exclude particular data sources in an assessment model depends on many factors. These factors often include, but are not limited to, the way in which data were collected (e.g., measurement method and consistency); the spatial and temporal coverage of the data; the quantity of data available per desired sampling unit; the representativeness of the data to inform the modeled processes of importance; timing of when the data were provided; limitations imposed by the Terms of Reference; and the presence of an avenue for the inclusion of the data in the assessment model. Attributes associated with a data source can change through time, as can the applicability of the data source when different modeling approaches are explored (e.g., stock structure or time-varying processes). Therefore, the specific data sources included or excluded from this assessment should not necessarily constrain the selection of data sources applicable to future stock assessments for Rex Sole. Even if a data source is not directly used in the stock assessment, it can provide valuable insights into biology, fishery behavior, or localized dynamics.

Data from a wide range of programs were available for possible inclusion in the current assessment model. Descriptions of each data source included in the model (Figure 1) and sources that were explored but not included in the base model are provided below. Data that were excluded from the base model were explicitly explored during the development of this stock assessment or have not changed since their past exploration in a previous Rex Sole stock assessment. In some cases, the inclusion of excluded data sources were explored through sensitivity analyses (see Section 3).

## 2.1 Fishery-Dependent Data

Fishery removals were divided between 2 temporally distinct fleets: 1) the 1916-2001 fleet and 2) the 2002-2022 fleet. The historical fishery fleet landings (1916-2001) include both retained and estimated discarded fish (total dead catch). Estimated time-varying discarded rates in the historical fishery were based on the previous assessment and Pikitch et al. (1988). The current fishery fleet (2002-2022) reports landings only (retained fish) with discards estimated in the model (Figure 2 and Table 2). This historical and current fishery fleet structure is split in a similar fashion as the Longnose Skate 2019 assessment's fishery fleet (Gertseva et al. 2019).

### 2.1.1 Recent commercial landings

#### 2.1.1.1 PacFIN

Commercial data were downloaded from the PacFIN database on March 3, 2023, and provided landings for Washington, Oregon, and California from 1981-2022. The 2017 catch data from California was incorrectly input into PacFIN and therefore the catch data for this year was instead pulled from CalCOM database for the California Cooperative Survey (CalCOM). PacFIN staff are aware of this issue, but this issue was not addressed by the time of this report's publication.

#### 2.1.1.2 North Pacific Database Program (NORPAC)

NORPAC provides estimated Rex Sole bycatch by the at-sea whiting fishery from 1991-2022. The at-sea whiting fishery occurs mostly in Washington and Oregon. Since a very small amount of bycatch is caught in California by a few vessels, this catch cannot be reported at only the California level for confidentiality reasons. For this reason, the small amount of bycatch from California was aggregated with Oregon's.

### 2.1.2 Historical Reconstruction

#### 2.1.2.1 Washington

Washington reconstruction landings from 1948-1980 were provided by the Washington Department of Fish and Wildlife (WDFW). This data was not available to the 2013 Rex Sole assessment. A portion of Rex Sole catch landed in Washington was caught in Canadian waters. Since there is no information to attribute a proportion of this catch to U.S. waters, 50% of the U.S.-Canada catch was assumed to be from U.S. waters.

#### 2.1.2.2 Oregon

The catch reconstruction for Oregon landings from 1929-1980 were provided by Oregon Department of Fish and Wildlife (ODFW). Landings were estimated by different gear type, but ultimately this data was aggregated into a single gear type for this assessment. ODFW updated the catch with minor changes since the 2013 Rex Sole assessment.

#### 2.1.2.3 California

California historical landings from 1931-1968 were obtained from the database maintained by Southwest Fisheries Science Center (SWFSC) Fisheries Ecology Division for commercial groundfish landings. Ralston et al. (2010) describes how the reconstruction was conducted. California Department of Fish and Wildlife (CDFW) has not updated their reconstruction since the 2013 Rex Sole assessment.

##### 2.1.2.3.1 California Department of Fish and Game Bulletin

California commercial landings of Rex Sole from 1916-1930 were estimated from total sole landings by Bureau of Commercial Fisheries (1949). From 1916-1930, approximately 5.1% of of California's total sole landings are assumed to be Rex Sole; this proportion was assumed constant over this time period to obtain Rex Sole landings per year.

##### 2.1.2.3.2 CalCOM

CalCOM data from 1969-1980 was used to estimate total California commercial catch. CalCOM expands landings from fish tickets and then expands again by year to estimate total catch volume by species. A discussion of the reliability of CalCOM estimates can be found in Ralston et al. (2010).

### 2.1.3 Treatment of historical and recent commercial landings data

Commercial landings were summed for each year across all above listed sources to obtain the total coastwide retained catch. Note that in Table 2, separate landings and estimated discards are provided for the historical fleet, but these are aggregated in the model, whereas for the current fleet, landings are given in Table 2 while discards are estimated in the model. Historical discards were estimated from historical landings with the time-varying discard rate from 1916 to 2001. The historical time-varying discard rate was based on the previous assessment and Pikitch et al. (1988). This fleet structure was motivated by the limited availability of historical discard length compositions, which is discussed more in the following section. Landings by source are reported in Appendix B, Table 15.

### 2.1.4 Discard data

Data on Rex Sole discards for the current coastwide Rex Sole fishery (2002-2022) come from observations from the WCGOP. The historical fishery (1916-2001) was represented as total removals (landings and discards). For the historical fishery, the same assumptions were made for discard rates as in the 2013 Rex Sole assessment: a discard rate (discard catch/retained catch) of 50% was assumed for years before 1950; discard rates from a study conducted by Pikitch et al. (1988) were used for 1985-1986; and values between 1950 and 1985, and between 1986 and 2002, were obtained by linear interpolation. There is a precedent set by the Longnose Skate assessment of 2019 which also split their fishery fleet into historical and current fleets for similar reasons on discard data availability (Gertseva et al. 2019).

#### 2.1.4.1 WCGOP

The WCGOP, run by the Northwest Fisheries Science Center (NWFSC), has been monitoring discard observations since 2002. The IFQ program, implemented in 2011, increased observer coverage rates to nearly 100 percent for all the limited entry trawl vessels in the program, and discard rates declined compared to pre-2011 rates. Discard rates were obtained for both the catch share and the non-catch share sector for Rex Sole. Total discard rates of combined catch share and non-catch share sectors are provided (Figure 3). After the establishment of the catch-share program, discard rates from non-participating vessels were high (close to 1), but their catch of Rex Sole was low and these rates had a relatively low impact on the value of the post-2011 rates. A single discard rate was calculated by weighting discard rates based on the commercial landings by each sector (from the Groundfish Expanded Mortality Multi-Year (GEMM) data). Coefficients of variation were calculated for the non-catch share sector and pre-catch share years by bootstrapping vessels within ports because the observer program randomly chooses vessels within ports to be observed. The coefficient of variation of discarding in the catch share fleet, given nearly 100% observer coverage, was considered low and a value of 0.01 was assumed. Because the catch share fleet had much larger removals than the non-catch share after 2011, the confidence intervals for the mean values after 2011 were considered low and assumed to be 0.01. Discard mean individual body weight and length composition data were obtained from the WCGOP data and used in this assessment (Figure 4 and Figure 5).

#### 2.1.4.2 Pikitch et al. (1988)

Pikitch et al. (1988) collected trawl discards from 1985 to 1987. The northern and southern boundaries of the study were 48°42’ N and 42°60’ N, respectively. This area falls primarily within the Columbia International North Pacific Fishery Commission (INPFC) area (Pikitch et al. 1988; Rogers and Pikitch 1992). Participation in the study was voluntary and included vessels using bottom, midwater, and shrimp trawl gears. Observers of normal fishing operations on commercial vessels collected the data, estimated the total weight of the catch by tow, and recorded the weight of species retained and discarded in the sample. Results of the Pikitch data were obtained from John Wallace (personal communication, NWFSC, NOAA) in the form of ratios of discard weight to retained weight of Rex Sole.

### 2.1.5 Fishery length compositions

Commercial fishery length-frequency distributions for Rex Sole were obtained from the PacFIN Biological Data System (BDS). Due to variations in sampling effort and because the number of fish sampled by port samplers is not proportional to the amount of landed catch in each trip, the observed length data were expanded using the following algorithm using the `PacFIN.Utilities` (Johnson and Wetzel 2023) package in R:

1. Length data were acquired at the trip level by sex, year and state.
2. The raw numbers in each trip were scaled by a per-trip expansion factor calculated by dividing the total weight of trip landings by the total weight of the species sampled.
3. A per-year, per-state expansion factor was computed by dividing the total weight of state landings by the total weight of the species sampled for length in the state.
4. The per-trip expanded numbers were multiplied by the per-state expansion factor and summed to provide the coast-wide length-frequency distributions by year.

Length compositions were available for the retained portion of the catch from 1975, 1982, and 2001-2021. Length compositions were available for the discarded portion of the catch from 2010-2021. However, the length compositions for the retained catch were dropped for 1975, 1982, 2001, and 2002 due to small sample sizes (effective sample size under 15).

Input sample sizes ($N_{input}$) for fishery length frequency distributions by year were calculated as a function of the number of trips and number of fish via the Stewart Method (Ian J. Stewart, International Pacific Halibut Commission (IPHC), personal communication):

$$N_{input} = N_{trips} + 0.138 N_{fish} \qquad \text{when } \frac{N_{fish}}{N_{trips}} < 44 \tag{1}$$

$$N_{input} = 7.06 N_{trips} \qquad \text{when } \frac{N_{fish}}{N_{trips}} \geq 44 \tag{2}$$

The method is based on analysis of the input and model-derived effective sample sizes from U.S. West Coast groundfish stock assessments. A piece-wise linear regression was used to estimate the increase in effective sample size per sample based on fish-per-sample and the maximum effective sample size for large numbers of individual fish.

## 2.2 Fishery-Independent Data

### 2.2.1 Descriptions of Surveys used in this Assessment

#### 2.2.1.1 NWFSC West Coast Groundfish Bottom Trawl Survey

The WCGBTS, which began in 2003, is the longest time series of fishery-independent data included in this assessment and the most recent. The WCGBTS is based on a random-grid design, covering the coastal waters from a depth of 55-1,280 m (Bradburn et al. 2011) (Figure 6). This design generally uses four industry-chartered vessels per year assigned to a roughly equal number of randomly selected grid cells and divided into two 'passes' of the coast. Two vessels fish from north to south during each pass between late May and early October. This design therefore incorporates both vessel-to-vessel differences in catchability, variance associated with selecting a relatively small number (approximately 700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian borders, and towing only a small section of the selected cells.

The following data inputs used to fit the base model were generated from WCGBTS data: an index of relative abundance (Table 4; Figures 7, 8), length-composition distributions (Table 5; Figure 9), and conditional age-at-length (CAAL) data (Table 6; Figure 10). See Section 2.2.3 and 2.2.4.

#### 2.2.1.2 AFSC/NWFSC West Coast Triennial Shelf Survey

The Triennial Survey was first conducted by the Alaska Fisheries Science Center (AFSC) in 1977, and the survey continued until 2004 (Weinberg et al. 2002). In 2004, the survey was conducted by the NWFSC Fishery Resource and Monitoring Division (FRAM). Its basic design was a series of equally-spaced east-to-west transects across the continental shelf from which searches for tows in a specific depth range were initiated. The survey design changed slightly over time. In general, all of the surveys were conducted in the mid summer through early fall. The 1977 survey was conducted from early July through late September. The surveys from 1980 through 1989 were conducted from mid-July to late September. The 1992 survey was conducted from mid July through early October. The 1995 survey was conducted from early June through late August. The 1998 survey was conducted from early June through early August. Finally, the 2001 and 2004 surveys were conducted from May to July.

Haul depths ranged from 91 - 457 m during the 1977 survey with no hauls shallower than 91 m. Due to haul performance issues and truncated sampling with respect to depth, the data from 1977 were omitted from this analysis. Haul depth and southern extent of the survey varied from 1980-2004, with a minimum depth of 55 m for all years (Figure 11).

The data inputs generated from the Triennial survey were an index of relative abundance (Table 7; Figure 12) and length-composition distributions. For the calculation of length compositions, due to the changes in survey timing, the triennial survey was split into early (1980-1992) and late (1995-2004) survey time series (Tables 8 & 9; Figure 14 & Figure 15; See Section 2.2.3 and 2.2.4.). The index of abundance was estimated by fitting density data from the AFSC to a spatio-temporal delta model implemented as an R package, sdmTMB (Anderson et al. 2022), described above for the WCGBTS (Figure 13). Although the triennial index was calculated as a single time-series, this survey is treated as two surveys in the model to account for changes in length composition samples due to the aforementioned changes in survey coverage (Figure 12).

### 2.2.2 Unused fishery-independent data

#### 2.2.2.1 AFSC Slope Survey

The AFSC Slope Survey (Slope Survey) operated during the months of October to November aboard the R/V *Miller Freeman*. Partial survey coverage of the U.S. West Coast occurred during the years 1988-1996 and complete coverage (north of 34°30'S Lat.) during the years 1997 and 1999-2001. Typically, only these four years that are seen as complete surveys are included in assessments.

This survey was considered, but the same decision was reached as in the last assessment (Cope et al. 2015) to exclude this survey because either the frequency of occurrence was too low or the resultant index was deemed insufficiently informative.

#### 2.2.2.2 NWFSC Slope Survey

The NWFSC also operated a Slope Survey during the years 1998-2002. However, this data was not included in this assessment because either the frequency of occurrence was too low or the resultant index was deemed insufficiently informative.

### 2.2.3 Survey indices of abundance

Geostatistical models of biomass density were fit to survey data using Template Model Builder (TMB) (Kristensen et al. 2016) via the R package `sdmTMB` (Anderson et al. 2022). These models can account for latent spatial factors with a constant spatial Gaussian random field and spatiotemporal deviations to evolve as a random walk Guassian random field (Thorson et al. 2015). Tweedie, delta-binomial, delta-gamma, and mixture distributions, which allow for extreme catch events, were investigated. Results are shown only for the distribution that led to the best model diagnostics, e.g., similar distributions of theoretical normal quantiles and model quantiles, high precision, lack of extreme predictions that are incompatible with the life history, and low Akaike information criterion (AIC) (Figures 7, 8, 12, and 13). Indices from this best model were predicted using a grid based on available survey locations. Code to reproduce the analysis is available at https://github.com/kellijohnson-NOAA/indexwc (Johnson et al. 2023).

#### 2.2.3.1 WCGBTS

As Rex Sole were encountered up to nearly 1,000 m, neither the data nor the prediction grid were truncated and instead encompassed the full range of 55-1,280 meters. This decision was made because by including the deeper depths in the model, edge effects were minimized. Furthermore, the model did not predict appreciable numbers of Rex Sole in the depths outside of which they were encountered. WCGBTS design and description is detailed in Keller et al. (2017).

The model used a delta model with a Gamma distribution for the catch-rate component. A logit-link was used for encounter probability and a log-link for positive catch rates. The response variable was catch (mt) with an offset of area ($km^2$) to account for differences in effort. Fixed effects were estimated for each year. Additionally, survey pass was included as a covariate. Vessel-year effects, which have traditionally been included in index standardization for this survey, were not included as the estimated variance for the random effect was close to zero. Vessel-year effects were more prominent when models did not include spatial effects and were included for each unique combination of vessel and year in the data to account for the random selection of commercial vessels used during sampling (Helser et al. 2004; Thorson and Ward 2014).

Spatial and spatiotemporal variation was included in the encounter probability model and spatial variation was included in the positive catch rate model. The variance of the spatiotemporal effect was estimated to be less than 0.01 for the positive catch rate model and was therefore not included in the final model. Spatial variation was approximated using 500 knots, where more knots led to non-estimable standard errors because the positive encounters are too sparse to support the dense spatiotemporal structure.

#### 2.2.3.2 Triennial Survey

As Rex Sole were encountered throughout the full depth range of the survey, neither the data nor the prediction grid were truncated and instead encompassed the full range of 55-500 meters.

Data were modeled using a delta model with a lognormal distribution for the catch-rate component. A logit-link was used for encounter probability and a log-link for positive catch rates. The response variable was catch (mt) with an offset of area ($km^2$) to account for differences in effort. Fixed effects were estimated for each year. No other covariates were modelled. Vessel-year effects, which have traditionally been included in index standardization for this survey, were not included as the estimated variance for the random effect was close to zero. Vessel-year effects were more prominent when models did not include spatial effects and were included for each unique combination of vessel and year in the data to account for the random selection of commercial vessels used during sampling (Helser et al. 2004; Thorson and Ward 2014).

Spatial and spatiotemporal variation was included in the encounter probability model and spatial variation was included in the positive catch rate model. The variance of the spatiotemporal effect was estimated to be less than 0.01 for the positive catch rate model and was therefore not included in the final model. Spatial variation was approximated using 500 knots, where more knots led to non-estimable standard errors because the positive encounters are too sparse to support the dense spatiotemporal structure.

### 2.2.4 Survey length- and age-composition data

#### 2.2.4.1 NWFSC West Coast Groundfish Bottom Trawl Survey lengths

Length bins from 2 to 60 cm in 2 cm increments were used to summarize the length frequency of the WCGBTS catches in each year (Figure 9). These length compositions were expanded to account for subsampling within tows, with further expansion based upon the stratification. There were six strata used for the expansion, based on stratification by depth (55 - 183 m, 183 - 549 m, and 549 - 1280 m) and latitude (32°N - 34.5°N and 34.5°N - 49°N). Length compositions were separated into males and females, with unsexed fish distributed between males and females assuming a 50:50 sex ratio.

#### 2.2.4.2 NWFSC West Coast Groundfish Bottom Trawl Survey ages

Age data collected by the WCGBTS were incorporated in the assessment model as CAAL data, which avoids double use of fish with length and an age observation by explicitly stating the length associated with each aged fish. Although the sample size was relatively small (620 aged fish), they were included in the model because when the length-age relationship was estimated externally and parameters fixed in the model to these externally-estimated values, the model was unstable. This is likely due to the fact that the externally estimated growth curve based on these ages was biased due to the length-stratified sampling design used to collect these ages which may have preferentially sampled large and small fish (Perreault et al. 2020).

#### 2.2.4.3 AFSC/NWFSC West Coast Triennial Shelf Survey lengths

The same length bins (2 to 60 cm in 2 cm increments) were used to summarize the length frequency of the Triennial Survey survey catches. The stratifications for length data expansions differed between the two time periods. In the early time period (1980-1992), there were two coastwide strata, one from 55 m - 183 m and one from 183 m - 500 m (Figure 14). In the late time period (1995 - 2004), there were three coastwide strata: 55 m - 183 m, 183 m - 350 m, and 350 m - 500 m (Figure 15).

There are no Rex Sole age data from the Triennial Survey.

## 2.3 Biological Data

### 2.3.1 Growth (Length-at-Age)

The 2013 assessment used published length-at-age parameters of Gulf of Alaska (GOA) Rex Sole (Abookire 2006) because no age information was available for West Coast Rex Sole at the time. In this assessment, sex-specific length-at-age relationships were internally estimated for Rex Sole using newly available age information from fish collected by the WCGBTS from 2007 to 2019. Rex Sole otoliths from the survey were aged by Nikki Paige (Pacific States Marine Fisheries Commission, PSMFC) and Tyler Johnson (PSMFC) as part of the NWFSC: Cooperative Ageing Project.

Rex Sole are moderately difficult to age due to the presence of check marks or "false years", which sometimes appear in the early years when fish are growing most rapidly (Tyler Johnson, PSMFC, pers. comm.). There were a total of 620 ages from 350 females, 231 males and 39 unsexed fish. The maximum sized fish in the age dataset was 47 cm. The oldest age was a 33 year old male (not the maximum sized). All unsexed fish were small in size (range 7 cm to 18 cm) and young (0 to 2 years). Therefore, unsexed fish were randomly assigned male or female based on an assumed 50:50 sex ratio to include these fish in the growth analysis. WCGBTS age data were collected by a length-stratified sampling design which may have preferentially sampled large and small fish (Perreault et al. 2020). Larger females and smaller males tended to be selected for aging relative to the overall length distribution of Rex Sole caught by the WCGBTS (Figure 16). To alleviate some of this bias, the current assessment model internally estimated dimorphic growth parameters with the CAAL compositions.

CAAL observations were fit internally in the assessment model using the von Bertalanffy growth function. Figure 17 shows age-at-length data and fits to the WCGBTS data for males and females. Fits to the updated length-at-age data for West Coast Rex Sole were visually compared to the growth parameters assumed in the 2013 assessment (GOA fish), which showed that West Coast Rex Sole are smaller than GOA Rex Sole. Updated growth parameters of the Schnute parameterization of the von Bertalanffy growth function (VBGF) were estimated internally at the following values using the reference ages of $a1$ = 1 and $a2$ = 20 years:

Females: $L_{a1}$ = 9.73 cm; $L_{a2}$ = 33.74 cm; $k$ = 0.247 per year

Males: $L_{a1}$ = 13.59 cm; $L_{a2}$ = 32.09 cm; $k$ = 0.224 per year

The corresponding VBGF parameters are:

Females: $t_0$ = -0.368; $L_{inf}$ = 33.97 cm; $k$ = 0.247 per year

Males: $t_0$ = -1.433; $L_{inf}$ = 32.36 cm; $k$ = 0.224 per year

### 2.3.2 Maturity

No maturity information for West Coast Rex Sole was available for the 2013 assessment. The 2013 assessment used parameters of a maturity-at-length logistic regression estimated for Rex Sole collected in the GOA (Abookire 2006), where length at 50% maturity was 35 cm. Because West Coast Rex Sole grow differently and are smaller than Rex Sole in the GOA, this suggested that length-at-maturity was also likely to be different between the two regions and needed to be updated for the 2023 assessment.

Gonads of Rex Sole are routinely collected in the WCGBTS, but none were analyzed for maturity for the 2023 assessment. To update maturity information relevant to West Coast Rex Sole, the 2023 assessment used macroscopic maturity information from a study of females collected from 1969 to 1973 off Oregon (Hosie and Horton 1977). This study found that no females matured until 19 cm, 50% of females were mature at 24 cm, and 100% were mature at 30 cm (N = 453). Maturity information in Hosie and Horton (1977) suggests that West Coast Rex Sole mature at smaller lengths compared to fish in the GOA. A logistic regression was not fit to the data in Hosie and Horton (1977) and raw data was not published. Therefore, the 2023 assessment assumed an $L_{50}$ of 24 cm in Hosie and Horton (1977) and used the same slope ($b$ = -0.392) of the logistic regression fit to maturity-at-length information for GOA fish (Abookire 2006) and used in the 2013 assessment. Maturity-at-length in the 2023 assessment was modeled as:

$$Prob(mat) = \frac{1}{1 + e^{(a+bL)}} \tag{3}$$

where the probability of being mature is a logistic function of length ($L$) in centimeters, $b$ is the slope set to $b$ = -0.392 and $a$ is solved for from the relationship of $L_{50}$ = -$a/b$. The updated maturity curve is compared to parameters used in the 2013 assessment (from GOA fish) in Figure 18.

The maturity-at-length relationship is uncertain for Rex Sole owing to a lack of updated biological data for West Coast fish. A query to the ODFW, the affiliation of the authors of the Hosie and Horton (1977) study, found that the original datasheets from that study are archived at ODFW. A future request could be made to recover and digitize the raw data from the original datasheets but this was not possible for the 2023 assessment. Alternatively, it is recommended that ovary samples from the WCGBTS be processed for maturity information for the next assessment cycle.

### 2.3.3 Fecundity

The 2013 assessment did not model a length-fecundity relationship and assumed spawning output was proportional to spawning biomass. The 2023 assessment assumes a fecundity-at-length relationship based on fecundity information of Oregon Rex Sole (Hosie and Horton 1977). Fecundity in this assessment is modeled as a power function of length:

$$F = 9.07e^{-3}L^{4.227} \tag{4}$$

where $F$ is fecundity in number of eggs per female and $L$ is length in cm, with parameter values from Hosie and Horton (1977). The Hosie and Horton (1977) study estimated the fecundity of 13 females collected from waters off Oregon. Only two females were greater than 40 cm. The limited fecundity information from Hosie and Horton (1977) suggests that fecundity increases at a faster rate with length than body weight with length. This means that larger females likely have greater relative fecundity compared to small females (i.e., produce more eggs per kg of body weight) and violates the assumption that spawning output is proportional to spawning biomass.

In general, reproductive information is lacking for West Coast flatfish and the sample size informing the length-fecundity relationship is small. However, the fecundity exponent for Rex Sole of $b = 4.227$ (Hosie and Horton 1977) is similar to the length-fecundity exponent for West Coast Petrale Sole (*Eopsetta jordani*) of $b = 4.55$ (95% CI 3.97 to 5.13, $n = 70$) (Lefebvre et al. 2019). This further justifies the use of fecundity information in the assessment, as Petrale Sole is another West Coast flatfish species with a similar reproductive strategy. Future assessments of Rex Sole would benefit from updated fecundity information and a better understanding of the reproductive strategy, such as whether this species is a determinate or indeterminate batch spawner.

### 2.3.4 Sex Ratio

No information on the sex ratio at birth was available so the sex ratio of female to male fish at recruitment was assumed to be 50:50. The sex ratio from the WCGBTS generally hovered around 50:50 (Figure 19), with deviations from this ratio explained by the dimorphic growth exhibited by this species. Only 0.28% of fish from all of the surveys were unsexed.

### 2.3.5 Length-Weight Relationship

As was done in the 2013 assessment, this assessment calculated the length-weight relationship for females and males separately (Figure 20). The length-weight relationships used in this assessment were estimated externally using updated information from the WCGBTS, which included the years 2007 to 2022 (no survey in 2020). The updated information included 6748 females and 4512 males. There were 73 small, unsexed fish excluded from the model. Weight was modeled as a power function of length:

$$W = aL^b \tag{5}$$

where weight ($W$) is measured in grams and length ($L$) in centimeters. The $a$ and $b$ parameters come from a linear, log-space regression with a bias correction ($\sigma^2/2$) to report the mean intercept ($a$). The sex-specific parameters estimated for the 2023 assessment were:

Females: $a = 3.21\text{x}10^{-06}$ ; $b = 3.20$
Males: $a = 3.01\text{x}10^{-06}$ ; $b = 3.22$

### 2.3.6 Natural Mortality

Natural mortality ($M$) is a parameter that is highly uncertain. Currently, there are no published estimates of natural mortality for Rex Sole, aside from what was estimated in the 2013 assessment. The 2013 assessment estimated natural mortality at 0.199 $yr^{-1}$ for both males and females (Cope et al. 2015). Estimating $M$ in the 2023 assessment was attempted but resulted in model instability. Therefore, the 2023 assessment fixed both female and male natural mortality at 0.186 $yr^{-1}$, which was the median value of a prior on $M$ based on an assumed maximum age of 29 years Hamel and Cope (2022).

The current method for developing a prior on natural mortality for West Coast groundfish stock assessments is based on Hamel (2015) and updated by Hamel and Cope (2022). This method combines meta-analytic approaches relating the natural mortality rate to other life-history parameters to develop a general prior on $M$ for many fish species. This approach modifies work done by Then et al. (2015) who estimated $M$ and recommended $M$ estimates based on maximum age alone. Hamel and Cope (2022) re-evaluated the data used by Then et al. (2015) by fitting the one-parameter$A_{max}$ model under a log-log transformation as was done in Hamel (2015). The methods for the prior in Hamel and Cope (2022) also reduced the variance around the estimate. The equation for the point estimate (i.e., the median in real space) for $M$, based on Hamel and Cope (2022) is:

$$M = \frac{5.4}{A_{max}} \tag{6}$$

where $A_{max}$ is the maximum age of the focal species. The prior is defined as a lognormal distribution with mean $\ln(5.4/A_{max})$ and standard deviation in log-space of 0.31 (Hamel 2015; Hamel and Cope 2022).

The maximum age of Rex Sole assumed in the 2013 assessment was 29 years (Love 1996). This assumption was not changed in the 2023 assessment. However, the updated age information for the 2023 assessment from the WCGBTS found one male with an estimated age of 33 years old that was captured in 2017. The majority of Rex Sole captured by the WCGBTS from 2007 to 2019 were less than 23 years old (99% of aged specimens), and no other specimens were aged to be older than 26 years. It is unclear if the one male aged at 33 years is an outlier or a true age, in which case $M$ may be lower than assumed in this assessment based on the longevity-based methods for a prior on $M$.

There was little support from WCGBTS data for sex-specific differences in maximum age. However, sex-specific differences in $M$ were explored in the 2023 assessment through sensitivity analyses. As noted, Rex Sole are moderately difficult to age (Tyler Johnson, PSMFC, pers. comm.) and age data are subject to ageing error in both precision and accuracy. This could impact the estimate of longevity and therefore the prior on $M$ and should be a focus of future research.

# 3 Assessment Model

## 3.1 Summary of Previous Assessments and Reviews

Rex Sole was last assessed in 2013 (Cope et al. 2015). That assessment used extended Simple Stock Synthesis (exSSS), a data-moderate assessment method, and incorporated removals (landings and discards not distinguished) and indices of abundance from fishery-independent trawl surveys. The assessment fixed most life history parameters, but did estimate male and female natural mortality ($M_f = 0.2$, $M_m = 0.19$). The 2013 assessment estimated the stock to be at approximately 80% of virgin biomass.

### 3.1.1 Response to the 2013 STAR Panel and SSC Recommendations

The 2013 STAR Panel reviewed eight data-moderate stocks (brown, China, copper, sharpchin, stripetail, and yellowtail rockfishes and English and rex soles) simultaneously. As such, some of the recommendations from the last STAR panel, particularly those pertaining to nearshore rockfishes, are not relevant to Rex Sole.

*Data input recommendations*

**Recommendation:** The Panel strongly emphasizes the value of conducting a data workshop during which catches, indices, biology, and other data inputs are reviewed.

**Response:** Rex Sole was one of the species reviewed at the Pre-Assessment Workshop on May 20th, 2023. All data, including catches, discards, indices, and biology were reviewed.

**Recommendation:** Consider developing GLMM models in which latitude and depth are treated as continuous covariates rather than as factors.

**Response:** `sdmTMB` (Anderson et al. 2022) was used to develop the survey indices in this model. Latitude and longitude were incorporated into the model using spatial and spatiotemporal effects approximated as Gaussian Markov random fields. These random fields account for the fact that some samples are closer together in space than others and therefore should share more information relative to samples that occur further apart from one another.

Depth was investigated as a fixed effect but proved to be difficult to estimate given the small number of positive tows at deep depths. Results from models with the effect of depth estimated using splines predicted large quantities of Rex Sole in California compared to models without depth. Further work is needed on including the effect of depth when it is not linear or a simple polynomial, especially when the effects are different for the presence/absence and catch rate models given that the framework must either use splines for both or none at this point in time.

**Recommendation:** The historical CPFV drift-specific data should be keypunched, which should allow the algorithm for developing CPFV-based data indices to be improved.

**Response:** The Observer-based Recreational CPUEs from commercial passenger fishing vessel (CPFV) were not applied to Rex Sole in the 2013 assessment.

**Recommendation:** Habitat maps should be developed so that structural rather than true zeros are designated using data which are independent from the data used to determine the indices.

**Response:** The presence/absence of Rex Sole was used to inform the prediction grid for the development of the indices. The spatial footprint of the prediction grid was restricted to the minimum and maximum latitude and longitude values where Rex Sole were sampled, and Rex Sole were found to nearly the deepest depths of the WCGBTS, leading the STAT to decide to retain all depths sampled by the surveys. However, more work needs to be done on using covariates linked with life-history characteristics to further limit the extent of the prediction grid based on biology rather than presence/absence.

**Recommendation:** Revisit the approach used to select among error models and whether to include extraordinary catch events components when conducting the GLMM analyses.

**Response:** The error model selected was based on model diagnostics, e.g., similar distributions of theoretical normal quantiles and model quantiles, high precision, lack of extreme predictions that are incompatible with the life history, and low AIC. Mixture distributions, which allow for extreme catch events, were investigated when developing the indices for this assessment, but were ultimately not selected because the standard errors were inestimable and the resulting indices from error distributions that do not account for extreme events did not show biologically impossible changes in abundance due to large catch events.

**Recommendation:** Consider including a vessel factor (as a random effect) when developing indices for the Triennial survey.

**Response:** Vessel and/or vessel-year effects were not investigated for any of the fishery-independent surveys given that spatiotemporal models were used and vessel effects tend to be estimated close to zero for these models, making the model unstable due to the lack of parsimony.

**Recommendation:** Splitting the triennial survey into early and late periods became established practice without looking at the issue comprehensively or considering the loss of information from breaking a time series. A comprehensive evaluation of the issues and trade-offs is still needed.

**Response:** Given that spatiotemporal models were used to estimate the index of abundance for the Triennial survey (Anderson et al. 2022), the change in the spatial footprint of the survey is accounted for and thus separating the index into two time periods is not necessary from an overall spatial coverage standpoint. But, future research should investigate using spatiotemporal models to also expand the composition data such that length samples could also be used from the entire time series instead of only being able to use the composition data from years where the entire spatial footprint was sampled to estimate selectivity.

**Recommendation:** Consistent residual patterns in NWFSC surveys for a number of assessments suggests there may be some unknown factor affecting survey catchability, or that some factor is affecting the productivity of multiple stocks in the same way.

**Response:** Residual patterns for the fit to the WCGBTS index are still a major issue, and are discussed in the Unresolved Problems and Major Uncertainties as well as Research and Data Needs sections in this document.

## 3.2 Model Structure and Assumptions

### 3.2.1 Modeling Platform

The assessment was conducted using Stock Synthesis version 3.30.21 (Methot and Wetzel 2013). The 2013 Rex Sole assessment used extended Simple Stock Synthesis (exSSS), which utilized the flexibility of Stock Synthesis to model the stock using catches and indices of abundance. The version of Stock Synthesis in exSSS from the 2013 assessment was version 3.24. Model bridging was performed between both versions of Stock Synthesis and discussed below. The R package r4ss, version 1.48.1 (Taylor et al. 2021), along with R version 4.1.2 (R Core Team 2022) were used to investigate and plot model fits.

### 3.2.2 Model Changes from the Last Assessment

The 2013 assessment model was restructured to include data and information that have since become available. The most notable changes include: (1) adding length composition data for surveys, fishery, and discards; (2) updating most of the biological parameters; (3) internally estimating growth parameters with CAAL data; and (4) estimating discard rates for the current fishery. In addition, data sources were extended to include the period 2013-2022. The main changes of the 2023 model from the 2013 model are listed below:

1. Updating biological parameters (fecundity, maturity, length-weight)
2. Internally estimating growth parameters
3. Including length composition data
4. Including CAAL data
5. Two-fleet structure (historical 1916-2001 vs. current 2002-2022)
6. Including mean body weight of discarded fish for current fishery
7. Estimating discard rates for current fishery
8. Sex-specific fishery selectivity (male selectivity as offset from female)
9. Dropping WCGBTS extra standard deviation (see text below)
10. Fixing steepness of stock-recruit relationship (see text below)
11. Estimating recruitment deviations
12. Fixing natural mortality ($M$)
13. Data weighting
14. Block design for current fishery retention

Since the model had difficulty fitting to the WCGBTS index, WCGBTS extra standard deviation was removed. Steepness was fixed at 0.7, as this value led to the most stable models during the model development process.

### 3.2.3 Bridging Analysis

#### 3.2.3.1 SS version bridging from 3.24 to 3.30

The exploration of models began by bridging from Stock Synthesis version 3.24, which was used in the last assessment, to version 3.30.21. This bridging produced no discernible differences in scale or status.

#### 3.2.3.2 Model and Data bridging

The model structure changed substantially from the 2013 assessment. The main steps of bridging from the 2013 model are listed below and shown in Figure 21. Individual steps of the model bridging are not always expected to improve model fits nor convergence, rather several model components had to be updated simultaneously. Some of these steps (e.g., updating biological parameters), were broken into dedicated sensitivity analyses to explore the response of the model to smaller changes. Starting from the 2013 model, the bridging steps that were taken were:

1. Updated the historical fishery removals (to 2013)
2. Extended fishery removals to 2022
3. Updated historical survey indices with geostatistical indices (to 2013)
4. Extended WCGBTS index to 2022
5. Added survey length compositions
6. Added discard rates, length compositions, and mean weights for the current fishery
7. Freed recruitment deviations and fixed steepness
8. Updated the biological parameters
9. Included CAAL from the WCGBTS, with growth estimated internally

The steps that appeared to have the greatest effects on model fits were including length and age composition data and updating the biological parameters (Figures 21, 22). Notably, several of the steps presented here were performed with two alternative ways of treating catchability ($Q$) for the WCGBTS: analytically solved for (or "float"), or fixed. The effects of different treatments of WCGBTS $Q$ were substantial and were explored with a sensitivity analysis (see section below).

### 3.2.4 Model Parameters

The base model has a total of 174 estimated parameters (Table 10) that can be grouped into the following categories:

- 10 growth parameters, with the following five parameters estimated for both sexes:
  - $L_{a1}$
  - $L_{a2}$
  - $k$
  - CV for young fish
  - CV for old fish
- 136 recruitment parameters:

  - the log of the initial recruitment ($ln(R_0)$)
  - 123 recruitment deviation parameters covering the range 1900-2022, with 1978-2020 representing the "main" period modeled as a zero-centered deviation vector
  - 12 forecast recruitment parameters, for 2023-2034

- 2 extra standard deviation parameters for indices (Triennial early and Triennial late)
- 11 retention parameters (one for each of the 11 years from 2011-2021)
- 15 selectivity parameters (7 for the 2002-2022 fishery fleet and 8 for the three survey fleets)

All life history parameters except growth are fixed to values described in the Biology section (2.3). Sensitivity scenarios and likelihood profiles were used to explore uncertainty in the values of the natural mortality and growth parameters. Estimating natural mortality was explored, with the prior assumed to be lognormal with a standard deviation of 0.31 (Hamel 2015; Hamel and Cope 2022). The exploration of model sensitivity to the growth parameters $La_1$ and $La_2$ was conducted by increasing or decreasing the value of these parameters by 10%.

#### 3.2.5 Key Assumptions and Structural Choices

Model development began using a "data moderate" category 2 approach, which according to the Terms of Reference relies on catch histories, length compositions, and fishery-independent indices of abundance as data inputs. However, including the limited WCGBTS age data as CAAL compositions allowed for more accurate estimation of growth parameters and uncertainty around them within the model (rather than fixing them to values estimated outside of the model), improved the model fits to abundance indices and length composition data, and allowed for more reasonable estimation of other model parameters, including those defining selectivity curves and catchability. Based on these factors, the STAT and STAR Panel agreed to include this data source in the model as well.

This assessment model assumes two removal fleets: one historical coastwide fishery (removals 1916-2001) and one current coastwide fishery (catch and discards modeled separately for 2002-2022). The Triennial Survey and WCGBTS survey are included as the fishery-independent measures of abundance trends. Selectivities for the fishery and survey fleets are all fixed to be asymptotic. Selectivity for the historical fishery is assumed to mirror the selectivity of the current fishery. Life history parameters are sex-specific, with one growth type, and assumed stationary. Asymptotic retention is assumed for the current fishery, with the time-varying asymptote parameter of the retention curve allowed to change annually for 2011-2022 to improve model fit to discard rates. Recruitment assumes a Beverton-Holt stock-recruit relationship and recruitment deviations are estimated.

### 3.2.6 Data Weighting

The base assessment model estimates additional variance on the early and late Triennial Survey data to allow the model to balance model fit to the data while acknowledging that variances may be underestimated in index standardization. No additional variance was estimated for the WCGBTS. The input CVs for the surveys ranged from 5% to 10% (see Table 4 and Table 7). A sensitivity was run with additional variance estimated for the WCGBTS.

Initial sample sizes for the survey length compositions were based on Stewart and Hamel (2014). The Francis method (Francis and Hilborn 2011) was used to balance the data inputs and likelihood components. The Francis method treats mean length as an index, with effective sample size defining the variance around the mean. If the variability around the mean does not encompass model predictions, the length data should be down-weighted until predictions fit within the intervals. This method accounts for correlation in the data (i.e., the multinomial distribution), but can be sensitive to years that are outliers, as the amount of down-weighting is applied to all years within a data source, and not year-specific. A sensitivity was performed with another data-weighting treatment, the Dirichlet-Multinomial approach (Thorson et al. 2017).

## 3.3 Model Selection and Evaluation

The base assessment model for Rex Sole was developed to balance parsimony and realism, and the goal was to estimate a spawning output trajectory and relative stock status for the population of Rex Sole in federal waters off the West Coast. The model contains many assumptions to achieve parsimony and uses different data types and sources to estimate reality. A series of investigative model runs were conducted to achieve the final base model. These include considerations of model structure, data and parameter treatment, estimation phasing, and jittered starting values to achieve a converged and balanced model that provides sensible parameter estimates and derived quantities.

## 3.4 Base Model Results

### 3.4.1 Parameter Estimates

Estimated parameter values are provided in Table 10. $ln(R_0)$ was estimated to be 11.079. Selectivity curves for the two Triennial Survey fleets, the WCGBTS fleet, and the two fishery fleets (where selectivity was estimated for the 2002-2022 fleet and mirrored for the 1916-2001 fleet) are shown in Figure 23. The selectivity for all fleets was fixed to be asymptotic. The fishery selectivity reaches a maximum selectivity for females at 45 cm and for males at 31 cm.

Fishery selectivity is allowed to vary by sex, to improve fits to observed length composition data. The selectivity for the WCGBTS reaches maximum selectivity at 28 cm (selectivity was not estimated separately for both sexes). The retention curves for the 2002-2022 fishery fleet are shown for females in Figure 24 and for males in Figure 25.

### 3.4.2 Fits to the Data

The fit to the Triennial survey (split into early and late due to the fleet structure within the model), improves during the later period of the index. There is a slight trend of underestimation in the final years of the early Triennial period, but no consistent trend in over- and underestimation for the fit to the late Triennial period (Figure 26 and 27). For the WCGBTS, the fit follows the general trend of increases and decreases in the index, meeting the last point in 2022 (Figure 28).

Fits to the length data were examined based on the Pearson residuals-at-length, the annual mean lengths, and aggregated length composition data for the commercial and fishery-independent fleets. Annual length composition fits are shown in Appendix A. Pearson residuals for the length composition of the early Triennial survey do not show a consistent trend (Figure 29), but the residuals for the late Triennial increase for median-sized male fish, where the model assumed fewer males were expected than observed (Figure 30). For the WCGBTS, the residuals are also largest for median-sized male fish, but there is less of a consistent trend than the late Triennial period (Figure 31).

For the early Triennial, the fit to the mean survey lengths is good for all years except for 1986, which is underestimated (Figure 32). The fit to the mean survey lengths for the late Triennial is more variable (Figure 33). The first year is underestimated and the final year is overestimated. For the WCGBTS, the fit generally follows the trend of mean lengths, although some years (particularly 2003, 2005, and 2019) are not fit well (Figure 34). The final two years of the WCGBTS are slightly overestimated. The discrepancy in observed versus expected lengths, outside of the sensitivity of Pearson residuals to small sample sizes, could be due to sex-misidentification.

For the fishery, the largest residuals are with males slightly smaller than the median size (Figure 35). Fits to the mean fishery lengths show a relatively stable mean length index, with a slight increase in size in the most recent years (Figure 36). This increase was well fit, despite the rigid nature (e.g., few estimated parameters) of the model. Fits to WCGOP discard lengths showed some degree of underestimation of the length of the smallest discarded fish (Figure 39). This was in part because of a relatively high proportion of 8-12 cm fish in some years of the discard length data (Figure 67).

The observed WCGOP discard rates for the current coastwide fishery were fit using time blocks for years 2011-2021 (Figure 37). WCGOP discard rates observations have small CV values after 2011 because observer coverage on vessels participating in the catch share program is near 100%. Therefore, time blocks were set up to allow for temporal variability of the asymptote parameter of the retention curve for years 2011-2021 to improve model fit. Observed discard rates were lower than average in 2008 and the model overestimated discards for that year. The fit to mean body weights from discard data were generally within the CV of the observations, except in the first years of data (2002-2003) where the model underestimated mean weights (Figure 38).

The CAAL data included in the model was small, representing only 620 ages. As such, the Pearson residuals for the CAAL compositions have strong patterns (Figure 40 and Figure 41). The model tends to underestimate the lengths of the older fish. The model fits to the mean age by year are good (Figure 42), with no consistent trend of over- or underestimation. Fits to CAAL data would likely be improved with the addition of more age data.

#### 3.4.3 Population Trajectory

The predicted spawning output is given in Table 1 and plotted in Figure 43. The time series of spawning output shows a moderate decline until around 1950, a period of steep decline until 1990, and a subsequent increase (although non-monotonic) that is particularly steep in recent years. The total biomass shows a similar trajectory across the modeled years (Figure 44).

The 2022 spawning output relative to unfished equilibrium spawning output is above the target of 25 percent of unfished spawning output (0.76, Figure 45). Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning output is greater in the first half of the time series, but is limited in the last 40 years.

The stock-recruit curve is shown in Figure 46. The estimated annual recruitment is shown in Figure 47.

### 3.5 Model Diagnostics

#### 3.5.1 Convergence

Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. Starting parameters were jittered by 10% for 50 iterations. Though negative log-likelihood values were found, these values were within 0.001 of the base model's and thus not significantly better (Table 13 and Figure 66). Moreover, these differences are mostly attributed to annual recruitment deviation estimates. Jitter results confirm that the base model represents the best fit to the data. There were no difficulties in inverting the Hessian to obtain estimates of variability, although much of the early model investigation was done without attempting to estimate a Hessian.

### 3.5.2 Sensitivity Analyses

We performed a number of sensitivity analyses on the base assessment model to evaluate the base model's response to change in key parameters and model components.

- Selectivity and catchability
  - Estimating $Q$ for WCGBTS
  - Fixing $Q$ at the prior mean used in AFSC Rex Sole assessment
  - Dome-shaped fishery selectivity
- Biology from 2013 model
  - Weight-length relationship
  - Fecundity and maturity
  - Growth
  - Estimating $M$ for males and females (2013 $M$)
  - Estimating $M$ for males only
- Data weighting
  - Tuning sample sizes with Dirichlet-Multinomial method
  - Tuning sample sizes with McAllister-Ianelli method
  - Adding extra SD to the WCGBTS index
- Stock-recruit
  - Estimating steepness
- Historical catch and discards
  - Increase (50%) in historical discards
  - Decrease (50%) in historical discards

For table and plot readability, sensitivity analyses are divided into biological sensitivities and combined catchability, discard, and selectivity sensitivities. Likelihood values and estimates of key parameters from each sensitivity are shown in Table 11 and Table 12. Plots of the estimated time-series of spawning biomass and relative spawning biomass are shown in Figures 48, 49, 50, and 51.

Sensitivity analyses to the treatment of selectivity and catchability had significant effects on the population trajectory (Figure 49). In particular, fixing $Q$ at the mean prior value used for the AFSC survey (1.2, compared to the value analytically solved for in the base model of 3.97) produced a much higher stock size and current status.

Sensitivities to 2013 assumptions of the biological parameters revealed that the model became unstable when the Von Bertalanffy growth function parameters were reverted to 2013 values (Figure 48). Estimating male $M$ led to a higher current stock status than in the base model (Figure 50). Male $M$ was estimated at 0.147, which is lower than the base model's fixed value of 0.186. Using the 2013 configuration for fecundity led to a lower population trajectory and stock scale (Figure 48 and Figure 50).

The two sensitivities exploring alternative data weighting approaches were compared to the base model which used the Francis method. The Dirichlet-Multinomial method led to similar estimates to the base model (Figure 49). However, the McAllister-Ianelli method made the model unstable and led to an unreasonable relative spawning biomass (Figure 52). Both the Francis and Dirichlet-Multinomial data weighting methods give commercial fishery length compositions the lowest weight, early Triennial Survey the highest weight, and late Triennial survey and WCGBTS survey relatively moderate weights. Adding extra standard deviation to the WCGBTS index led to lower spawning biomass (Figure 49) and poor fits to the WCGBTS index.

Estimating steepness in the 2023 base model resulted in an small change in the current stock status, but little difference in stock scale. Steepness was fixed to 0.7 in the 2023 model. The sensitivity of allowing the model to estimate steepness resulted in a value for steepness of 0.809 (Figure 50).

Sensitivities to increasing or decreasing the assumed discard rates for the historical fishery (-50% and +50% of the rate used in the 2013 assessment) had limited effects on biomass trajectories and model fit (Figure 49), indicating that maintaining this assumption in the 2023 assessment is adequate.

### 3.5.3 Retrospective Analysis

A five-year retrospective analysis was conducted by running the model and sequentially removing one year of data. Retrospective spawning output estimates were generally within the confidence intervals of the reference model (Figure 53), which also led to consistent estimates of stock status among the retrospective scenarios, with no strong pattern until the removal of a significant amount of the age data in year 5 (Figure 54).

### 3.5.4 Likelihood Profiles

Likelihood profiles were conducted for $ln(R_0)$, steepness ($h$), male and female natural mortality ($M$) with male $M$ as an offset of female $M$, and catchability ($Q$) for the WCGBTS survey. Likelihood profiles fix the featured parameter(s) at a specific value across a range of values and estimate the remaining parameters. A likelihood profile offers insight into information on a given parameter or parameter pairing, while providing an additional way to describe uncertainty in the parameter by identifying the range of parameters within 1.92 likelihood units of the reference model.

The $ln(R_0)$ profile shows strong evidence for the maximum likelihood value of 11.1 (Figure 58). Population size increases as $ln(R_0)$ increases. Recruitment data had the largest impact on $ln(R_0)$ (Figure 59).

For steepness, the negative log-likelihood supported values between 0.70 - 0.90 (Figure 60). Likelihood components are similar across these values (Figure 61). Estimating $h$ within the model led to a value of 0.809 (described above). More research into the biology of Rex Sole could better inform steepness.

The natural mortality profile for females (Figure 62) suggests a value that is biologically unrealistic for flatfish (minimum negative log-likelihood occurs at value of 0.07 for $M$). In this profile, male natural mortality was set as an offset of female natural mortality, with the offset parameter fixed at 0 (thus keeping it the same value as female natural mortality). Length and age data have the largest impact on the total likelihood for these profiles, particularly those from the WCGBTS (Figure 61). A sensitivity was done to estimate the male natural mortality while fixing female natural mortality (described above). As is the case for many stocks, $M$ represents a major source of uncertainty for Rex Sole.

The WCGBTS catchability profile recommends a $ln(Q)$ value around 1.38. This results in a $Q$ value of 3.97, which is higher than is expected based on the gear used by the survey (Bryan et al. 2014). Rex Sole, like other flatfish, are known to exhibit herding behavior in response to bottom trawl gear (McGilliard and Palsson 2021). Rex Sole assessments from the AFSC have used a normal prior with a mean of 1.2 (McGilliard and Palsson 2021). The $Q$ likelihood is strongly impacted by the length compositions from the fishery, the age data from WCGBTS, and recruitment data.

#### 3.5.5 Unresolved Problems and Major Uncertainties

The estimation of catchability ($Q$) for the WCGBTS remains a major unresolved issue for this assessment. The value that was achieved by estimating $Q$ during model development was 3.97, which is somewhat higher than expected. Estimates for other flatfish on the West Coast are between 1 and 3 (Wetzel 2019; Wetzel and Berger 2021). Catchability for Rex Sole, when assessed for the Gulf of Alaska in 2021, was estimated at 1.17 using a normal prior (~N(1.2, 0.175)) based on herding studies for Rex Sole (McGilliard and Palsson 2021). The high value estimated in model development was supported by the likelihood profile (Figure 64).

Fixing catchability for the WCGBTS deteriorated the fit to the index of abundance. Both of these issues may be connected to the depth at which Rex Sole are found. The shallowest depth for the survey is 55m. Given that Rex Sole were encountered generally at the lower bound of the survey depth (Figure 55), it is possible that a sizeable portion of the population is located shallower. Additionally, density estimates are expanded to rocky and high-relief areas where surveys cannot trawl and flatfish are generally found at lower densities.

Updated biological research of Rex Sole specifically along the U.S. West Coast is critically needed. The length-age relationship for Rex Sole remains highly uncertain, as the length-stratified sampling preferentially sampled smaller males and larger females. Though this bias was partially accounted for by internally estimated growth curves, more unbiased age data would greatly improve this assessment. The biological parameters, except growth, used in this assessment were all fixed rather than estimated and represent a considerable source of uncertainty that is explored in the sensitivity analyses. In the case of fecundity and maturity, the parameter values were both from Hosie and Horton (1977). The maturity parameters were estimated outside of the model based on macroscopic maturity assignments, which have been shown to have limited accuracy for similar West Coast groundfishes (Min et al. 2022). Histological analysis of Rex Sole ovaries collected by the WCGBTS would provide updated maturity estimates. The estimates of fecundity were based on a limited sample size of 13 fish, with only two fish greater than 40 cm. Additionally, the value of natural mortality is very uncertain, but the base model was unstable when $M$ was estimated rather than fixed. Furthermore, exploring steepness values closer to the U.S West Coast flatfish's accepted median prior of 0.8 is worthwhile.

# 4 Management

## 4.1 Reference Points

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model (2022). Sustainable total yields (landings plus discards) were 1,658 mt when using an SPR 30% reference harvest rate and with a 95% confidence interval of 1,400 - 1,916 mt based on estimates of uncertainty. The spawning biomass equivalent to 25% of the unfished spawning output (SB25%) was 300 million eggs.

The spawning output relative to unfished equilibrium in 2023 is estimated to be above the management target of 25 percent of unfished spawning output (76%, Figure 45). The fishing intensity, $1 - \text{SPR}$, has been below the harvest rate limit (1 - SPR30%) in the last 25 years (Figure 57).

Table 14 shows the full suite of estimated reference points for the base model and Figure 56 shows the equilibrium curve based on the fixed steepness value of 0.7 from the base model.

## 4.2 Harvest Projections and Decision Tables

The forecast of stock abundance and yield was developed using the base model. The total catch projections for 2023 and 2024 were based on the maximum total dead mortality from the years 2020-2022, as provided by the GMT. The exploitation rate for 2025 and beyond is based on an SPR of 30 percent and the 25:5 harvest control rule, with two alternative catch scenarios. The catch scenarios were estimated using the default harvest control rule for Rex Sole (P* of 0.4 and $\sigma_y$ of 1.0) as well as an alternative scenario with P* of 0.45 and $\sigma_y$ of 1.0. Full attainment ABC = ACL was assumed under both runs.

The axis of uncertainty in the decision table explores the uncertainty in female natural mortality. Uncertainty in the forecasts is based upon the uncertainty around the 2023 OFL, with a search was conducted across values of female natural mortality to determine the values that would correspond to the 12.5% and 87.5% percentiles of the normal distribution given the maximum likelihood estimate and the asymptotic uncertainty the 2023 OFL estimate. The female natural mortality values that corresponded with the lower and upper quantiles were 0.175 yr-1 and 0.210 yr-1.

## 4.3 Evaluation of Scientific Uncertainty

The estimated uncertainty in the base model around the 2024 spawning output is $\sigma = 0.123$ and the uncertainty in the base model around the 2024 OFL is $\sigma = 0.124$. The estimated model uncertainty was less than the category 2 groundfish data moderate assessment default value of $\sigma = 1.0$, which is not surprising given the fixed parameters in the assessment model.

## 4.4 Research and Data Needs

### 4.4.1 Items Identified in the Last Assessment

The 2013 data-moderate groundfish assessment that included Rex Sole enumerated the following relevant research and data needs:

1. Continued research on the uncertainty in the catch histories of all groundfishes. Catch is a critical component of these and all stock assessments, especially when attempting to define population scale. Reconstructions of historical catches are still needed for certain areas, time periods, and fisheries. Currently, reconstructed catches are available for California's commercial and recreational fisheries extending back to 1916 and 1928. Oregon has completed a reconstruction for its commercial catch since 1876 (V. Gertseva, NMFS; personal communication), but recreational catch prior to 1980

is assumed to be zero in this analysis. Recreational catch in Washington was reconstructed to 1975 for these assessments, and interpolated back to 1960. A thorough reconstruction of historical commercial catches (prior to 1981) is urgently needed for Washington. Estimates of uncertainty in historical catch reconstructions are needed for all states. Reconstructed catches tend to be most precise for common species, and progressively less precise as species become uncommon. Because data-poor and data-moderate assessments focus on the less common species, quantification of the precision of catch reconstructions is especially important to these assessments.

(a) Progress: Washington historical reconstructions were provided by WDFW and included in this current assessment. Since some catch location was only reported as the U.S.-Canada border, future assessments should confirm the amount of catch removals that strictly belong to U.S. waters. ODFW also provided updated historical reconstructions for this assessment. Recreational catch is still assumed to be zero for both Oregon and Washington reconstructions. California reconstructions remain unchanged since the previous previous assessment.

2. Further consideration as to when it is appropriate to split or maintain the full time series for the Triennial survey. While this proved of little sensitivity in these examples, it could be important in some instances.

(a) Progress: Due to the recently developed geostatistical method used in this assessment (Anderson et al. 2022), this assessment does not split the Triennial survey when estimating an index of abundance. However, this survey is split into an early and late period for the calculation of length compositions, given the differences in depth range between the early and late Triennial survey.

3. The NWFSC slope survey showed poor behavior or limited information for all stocks. Understanding why this may be (including the residual patterns) will help diagnose its use as a data input for catch and index only models.

(a) Progress: This assessment did not include the NWFSC slope survey because the frequency of occurrence was too low and the resultant index was deemed insufficiently informative.

4. Further understanding of reasonable or probable catchability ($Q$) values will enhance the interpretation of scale, a generally weakly informed output of these catch and index-only models that are dependent on trawl surveys. We already have an extensive collection of estimated $Q$ values from data-rich assessments, assuring feasibility.

(a) Progress: Estimating catchability for the WCGBTS remains a major challenge for this assessment. See the Model Diagnostics section for more information.

### 4.4.2 Current Research and Data Needs Identified

There are many areas of research that could be improved to benefit the understanding and assessment of Rex Sole. Below are issues that are considered of importance.

1. Limited historical discard data (rate and length compositions) led to unstable models when assuming a single fishery fleet. This was circumvented by splitting the fleet into historical and current fleets, and hard wiring the discard into the historical fleet to avoid estimating discard rates prior to 2002. Further information on historical discards would be beneficial for future Rex Sole assessments.
2. Updated biological research of Rex Sole specifically along the U.S. West Coast is instrumental to improving future assessments for this stock. This assessment used improved estimates of growth, maturity, and fecundity parameters for U.S. West Coast Rex Sole compared to the last assessment. However, the maturity and fecundity assumptions are based on a single study from the 1960s and 1970s, which had limited spatial coverage (Oregon only) and a small sample size for the length-fecundity relationship (Hosie and Horton 1977). Gonads are collected in good numbers from the WCGBTS, but none have been processed for maturity. Furthermore, growth was estimated internally in the model based on limited age data, as the externally estimated growth curve was believed to be biased towards estimating higher values of $L_{infinity}$ for both sexes due to the length-stratified sampling used to construct the growth curve. More unbiased age data for Rex Sole would greatly improve future assessments.
3. Catchability is an ongoing concern and major source of uncertainty in the model. See #4 in the previous list.

# 5 Acknowledgments

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## 7 Tables

Table 1: Time-series of population estimates from the base model

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 1896 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64798.5 | 0.000 | 0.0000000 | 0.0000 |
| 1897 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64798.5 | 0.000 | 0.0000000 | 0.0000 |
| 1898 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64798.5 | 0.000 | 0.0000000 | 0.0000 |
| 1899 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64798.5 | 0.000 | 0.0000000 | 0.0000 |
| 1900 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64798.0 | 0.000 | 0.0000000 | 0.0000 |
| 1901 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64797.9 | 0.000 | 0.0000000 | 0.0000 |
| 1902 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64797.9 | 0.000 | 0.0000000 | 0.0000 |
| 1903 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64797.8 | 0.000 | 0.0000000 | 0.0000 |
| 1904 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64797.7 | 0.000 | 0.0000000 | 0.0000 |
| 1905 | 30007.30 | 1199 | 30007.30 | 1.0000000 | 64797.5 | 0.000 | 0.0000000 | 0.0000 |
| 1906 | 30007.20 | 1199 | 30007.20 | 1.0000000 | 64797.4 | 0.000 | NA | 0.0000 |
| 1907 | 30007.20 | 1199 | 30007.20 | 1.0000000 | 64797.2 | 0.000 | NA | 0.0000 |
| 1908 | 30007.20 | 1199 | 30007.20 | 0.9999917 | 64797.0 | 0.000 | NA | 0.0000 |
| 1909 | 30007.10 | 1199 | 30007.10 | 0.9999917 | 64796.8 | 0.000 | NA | 0.0000 |
| 1910 | 30007.10 | 1199 | 30007.10 | 0.9999917 | 64796.6 | 0.000 | NA | 0.0000 |
| 1911 | 30007.00 | 1199 | 30007.00 | 0.9999917 | 64796.3 | 0.000 | NA | 0.0000 |
| 1912 | 30007.00 | 1199 | 30007.00 | 0.9999917 | 64796.0 | 0.000 | NA | 0.0000 |
| 1913 | 30006.90 | 1199 | 30006.90 | 0.9999917 | 64795.6 | 0.000 | NA | 0.0000 |
| 1914 | 30006.80 | 1199 | 30006.80 | 0.9999833 | 64795.2 | 0.000 | NA | 0.0000 |
| 1915 | 30006.80 | 1199 | 30006.80 | 0.9999833 | 64794.8 | 0.000 | NA | 0.0000 |
| 1916 | 30006.70 | 1199 | 30006.70 | 0.9999833 | 64794.3 | 222.300 | 0.0819354 | 0.0074 |
| 1917 | 29822.30 | 1190 | 29822.30 | 0.9922435 | 64739.6 | 302.800 | 0.1104320 | 0.0102 |
| 1918 | 29592.40 | 1178 | 29592.40 | 0.9823268 | 64668.5 | 243.950 | 0.0910310 | 0.0082 |

**Table 1:** Time-series of population estimates from the base model *(continued)*

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 1919 | 29438.70 | 1169 | 29438.70 | 0.9753376 | 64617.4 | 191.800 | 0.0729321 | 0.0065 |
| 1920 | 29347.40 | 1164 | 29347.40 | 0.9709255 | 64584.5 | 132.600 | 0.0513477 | 0.0045 |
| 1921 | 29317.30 | 1162 | 29317.30 | 0.9691741 | 64570.7 | 169.000 | 0.0649867 | 0.0058 |
| 1922 | 29261.60 | 1159 | 29261.60 | 0.9665051 | 64550.1 | 244.400 | 0.0925722 | 0.0084 |
| 1923 | 29150.30 | 1153 | 29150.30 | 0.9615927 | 64512.5 | 245.900 | 0.0935557 | 0.0084 |
| 1924 | 29050.70 | 1148 | 29050.70 | 0.9571222 | 64477.8 | 306.600 | 0.1155150 | 0.0106 |
| 1925 | 28912.80 | 1140 | 28912.80 | 0.9510254 | 64430.3 | 304.000 | 0.1152860 | 0.0105 |
| 1926 | 28793.20 | 1134 | 28793.20 | 0.9456292 | 64387.5 | 300.100 | 0.1145090 | 0.0104 |
| 1927 | 28691.30 | 1128 | 28691.30 | 0.9409503 | 64349.6 | 363.600 | 0.1373190 | 0.0127 |
| 1928 | 28549.20 | 1121 | 28549.20 | 0.9346200 | 64298.2 | 356.700 | 0.1357630 | 0.0125 |
| 1929 | 28429.50 | 1114 | 28429.50 | 0.9291904 | 64253.0 | 406.200 | 0.1536360 | 0.0143 |
| 1930 | 28283.20 | 1106 | 28283.20 | 0.9226516 | 64198.3 | 379.001 | 0.1451830 | 0.0134 |
| 1931 | 28176.60 | 1100 | 28176.60 | 0.9177391 | 64155.7 | 565.451 | 0.2084580 | 0.0201 |
| 1932 | 27928.30 | 1087 | 27928.30 | 0.9069634 | 64064.3 | 378.667 | 0.1473370 | 0.0136 |
| 1933 | 27863.20 | 1083 | 27863.20 | 0.9036356 | 64032.9 | 360.634 | 0.1413740 | 0.0129 |
| 1934 | 27821.50 | 1081 | 27821.50 | 0.9014420 | 64010.3 | 455.475 | 0.1749160 | 0.0164 |
| 1935 | 27706.50 | 1075 | 27706.50 | 0.8963628 | 63962.7 | 430.156 | 0.1670190 | 0.0155 |
| 1936 | 27625.30 | 1070 | 27625.30 | 0.8926763 | 63926.1 | 352.238 | 0.1398640 | 0.0128 |
| 1937 | 27617.70 | 1070 | 27617.70 | 0.8920925 | 63914.9 | 314.182 | 0.1259780 | 0.0114 |
| 1938 | 27642.70 | 1071 | 27642.70 | 0.8930016 | 63915.6 | 380.800 | 0.1500670 | 0.0138 |
| 1939 | 27609.30 | 1069 | 27609.30 | 0.8916255 | 63896.2 | 476.126 | 0.1836480 | 0.0172 |
| 1940 | 27500.10 | 1064 | 27500.10 | 0.8870883 | 63848.8 | 443.002 | 0.1730160 | 0.0161 |
| 1941 | 27429.80 | 1060 | 27429.80 | 0.8840357 | 63813.0 | 299.348 | 0.1214670 | 0.0109 |

**Table 1:** Time-series of population estimates from the base model *(continued)*

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 1942 | 27486.10 | 1063 | 27486.10 | 0.8862209 | 63821.1 | 275.099 | 0.1120350 | 0.0100 |
| 1943 | 27556.30 | 1066 | 27556.30 | 0.8891650 | 63834.7 | 715.134 | 0.2616180 | 0.0260 |
| 1944 | 27253.70 | 1051 | 27253.70 | 0.8767629 | 63715.1 | 381.636 | 0.1528970 | 0.0140 |
| 1945 | 27259.50 | 1051 | 27259.50 | 0.8766879 | 63700.6 | 349.215 | 0.1410280 | 0.0128 |
| 1946 | 27292.00 | 1053 | 27292.00 | 0.8778555 | 63695.8 | 432.279 | 0.1708260 | 0.0158 |
| 1947 | 27251.90 | 1051 | 27251.90 | 0.8761791 | 63665.1 | 619.771 | 0.2346380 | 0.0227 |
| 1948 | 27060.20 | 1041 | 27060.20 | 0.8682057 | 63577.9 | 857.294 | 0.3098800 | 0.0317 |
| 1949 | 26692.30 | 1022 | 26692.30 | 0.8526593 | 63420.0 | 967.461 | 0.3462790 | 0.0362 |
| 1950 | 26273.50 | 1001 | 26273.50 | 0.8345357 | 63232.5 | 922.755 | 0.3392710 | 0.0351 |
| 1951 | 25938.40 | 983 | 25938.40 | 0.8195356 | 63068.3 | 973.309 | 0.3587680 | 0.0375 |
| 1952 | 25599.70 | 964 | 25599.70 | 0.8043236 | 62896.6 | 1131.260 | 0.4081290 | 0.0442 |
| 1953 | 25168.10 | 942 | 25168.10 | 0.7852876 | 62678.9 | 1429.310 | 0.4916180 | 0.0568 |
| 1954 | 24537.20 | 909 | 24537.20 | 0.7579204 | 62359.9 | 1508.000 | 0.5223890 | 0.0615 |
| 1955 | 23908.70 | 876 | 23908.70 | 0.7303122 | 62018.6 | 1979.530 | 0.6367830 | 0.0828 |
| 1956 | 22958.10 | 826 | 22958.10 | 0.6893202 | 61483.0 | 1930.420 | 0.6487130 | 0.0841 |
| 1957 | 22146.50 | 784 | 22146.50 | 0.6535359 | 60969.0 | 1875.820 | 0.6572640 | 0.0847 |
| 1958 | 21462.80 | 747 | 21462.80 | 0.6230094 | 60490.9 | 2179.070 | 0.7342270 | 0.1015 |
| 1959 | 20596.50 | 702 | 20596.50 | 0.5855453 | 59856.4 | 1877.250 | 0.6979490 | 0.0911 |
| 1960 | 20059.00 | 673 | 20059.00 | 0.5614450 | 59407.1 | 1740.130 | 0.6829760 | 0.0868 |
| 1961 | 19680.50 | 653 | 19680.50 | 0.5444291 | 59068.1 | 1822.660 | 0.7119690 | 0.0926 |
| 1962 | 19261.90 | 631 | 19261.90 | 0.5266791 | 58700.6 | 2212.140 | 0.8013190 | 0.1148 |
| 1963 | 18552.30 | 597 | 18552.30 | 0.4979933 | 58076.5 | 2475.260 | 0.8669700 | 0.1334 |
| 1964 | 17680.00 | 555 | 17680.00 | 0.4628229 | 57236.0 | 1909.720 | 0.7900570 | 0.1080 |

**Table 1:** Time-series of population estimates from the base model *(continued)*

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 1965 | 17337.80 | 537 | 17337.80 | 0.4478486 | 56851.7 | 1735.670 | 0.7630400 | 0.1001 |
| 1966 | 17158.00 | 528 | 17158.00 | 0.4399978 | 56651.6 | 2302.010 | 0.8815470 | 0.1342 |
| 1967 | 16516.90 | 498 | 16516.90 | 0.4155498 | 55973.5 | 2321.510 | 0.9054400 | 0.1406 |
| 1968 | 15898.80 | 470 | 15898.80 | 0.3917030 | 55257.9 | 2102.840 | 0.8874610 | 0.1323 |
| 1969 | 15496.20 | 451 | 15496.20 | 0.3758071 | 54753.8 | 2430.250 | 0.9577510 | 0.1568 |
| 1970 | 14844.20 | 421 | 14844.20 | 0.3511272 | 53856.7 | 1961.000 | 0.8981180 | 0.1321 |
| 1971 | 14610.00 | 410 | 14610.00 | 0.3417985 | 53433.1 | 1619.100 | 0.8310500 | 0.1108 |
| 1972 | 14656.90 | 412 | 14656.90 | 0.3436075 | 53309.0 | 1978.700 | 0.9074910 | 0.1350 |
| 1973 | 14388.80 | 402 | 14388.80 | 0.3351012 | 52541.3 | 1917.140 | 0.9039400 | 0.1332 |
| 1974 | 14169.70 | 394 | 14169.70 | 0.3283539 | 51588.4 | 1910.230 | 0.9096700 | 0.1348 |
| 1975 | 13948.70 | 386 | 13948.70 | 0.3216557 | 50529.4 | 1855.020 | 0.9055380 | 0.1330 |
| 1976 | 13760.10 | 379 | 13760.10 | 0.3164330 | 49645.8 | 2140.800 | 0.9665500 | 0.1556 |
| 1977 | 13317.90 | 363 | 13317.90 | 0.3025813 | 48180.6 | 1756.010 | 0.9063060 | 0.1319 |
| 1978 | 13181.90 | 359 | 13181.90 | 0.2996105 | 45505.0 | 2111.290 | 0.9802540 | 0.1602 |
| 1979 | 12713.70 | 343 | 12713.70 | 0.2858656 | 44638.0 | 2665.600 | 1.0797400 | 0.2097 |
| 1980 | 11762.50 | 306 | 11762.50 | 0.2554900 | 46792.3 | 2093.670 | 1.0305500 | 0.1780 |
| 1981 | 11299.00 | 289 | 11299.00 | 0.2408886 | 52089.9 | 2032.510 | 1.0379200 | 0.1799 |
| 1982 | 10932.60 | 273 | 10932.60 | 0.2276491 | 37041.3 | 2277.950 | 1.0935900 | 0.2084 |
| 1983 | 10376.70 | 249 | 10376.70 | 0.2077223 | 28758.9 | 1893.560 | 1.0568100 | 0.1825 |
| 1984 | 10029.30 | 239 | 10029.30 | 0.1996072 | 48260.5 | 1647.490 | 1.0196100 | 0.1643 |
| 1985 | 9814.02 | 239 | 9814.02 | 0.1990183 | 33666.0 | 1831.930 | 1.0596800 | 0.1867 |
| 1986 | 9432.13 | 229 | 9432.13 | 0.1910525 | 22905.4 | 1545.540 | 1.0122600 | 0.1639 |
| 1987 | 9160.79 | 225 | 9160.79 | 0.1876271 | 37734.3 | 1525.490 | 1.0117700 | 0.1665 |

**Table 1:** Time-series of population estimates from the base model *(continued)*

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 1988 | 8809.39 | 220 | 8809.39 | 0.1837055 | 37427.7 | 1598.480 | 1.0367600 | 0.1815 |
| 1989 | 8417.48 | 210 | 8417.48 | 0.1755111 | 65678.5 | 1435.640 | 1.0148800 | 0.1706 |
| 1990 | 8345.05 | 202 | 8345.05 | 0.1685769 | 60067.1 | 1092.820 | 0.9252690 | 0.1310 |
| 1991 | 8882.81 | 205 | 8882.81 | 0.1709622 | 48913.0 | 1446.410 | 1.0233500 | 0.1628 |
| 1992 | 9317.59 | 203 | 9317.59 | 0.1691190 | 48815.2 | 1073.470 | 0.9162410 | 0.1152 |
| 1993 | 10121.60 | 224 | 10121.60 | 0.1865954 | 49749.2 | 957.018 | 0.8431520 | 0.0946 |
| 1994 | 11000.80 | 258 | 11000.80 | 0.2148800 | 64854.8 | 1017.390 | 0.8237840 | 0.0925 |
| 1995 | 11839.60 | 292 | 11839.60 | 0.2437026 | 93877.7 | 1113.330 | 0.8163040 | 0.0940 |
| 1996 | 12822.00 | 322 | 12822.00 | 0.2683609 | 72606.7 | 1008.910 | 0.7396550 | 0.0787 |
| 1997 | 14160.50 | 355 | 14160.50 | 0.2956955 | 61412.7 | 958.890 | 0.6798710 | 0.0677 |
| 1998 | 15564.20 | 396 | 15564.20 | 0.3302029 | 31255.7 | 746.962 | 0.5460160 | 0.0480 |
| 1999 | 16873.10 | 456 | 16873.10 | 0.3802867 | 39885.8 | 687.164 | 0.4744810 | 0.0407 |
| 2000 | 17756.10 | 523 | 17756.10 | 0.4362914 | 53852.9 | 630.554 | 0.4095860 | 0.0355 |
| 2001 | 18339.40 | 584 | 18339.40 | 0.4872476 | 44062.4 | 645.928 | 0.3868060 | 0.0352 |
| 2002 | 18664.70 | 626 | 18664.70 | 0.5223922 | 48101.8 | 774.275 | 0.4195950 | 0.0415 |
| 2003 | 18689.50 | 646 | 18689.50 | 0.5386984 | 35215.9 | 815.546 | 0.4235420 | 0.0436 |
| 2004 | 18528.40 | 653 | 18528.40 | 0.5444040 | 40145.9 | 689.718 | 0.3686200 | 0.0372 |
| 2005 | 18316.10 | 658 | 18316.10 | 0.5487352 | 22505.0 | 745.750 | 0.3886020 | 0.0407 |
| 2006 | 17880.90 | 656 | 17880.90 | 0.5468252 | 31130.7 | 705.822 | 0.3740370 | 0.0395 |
| 2007 | 17287.90 | 649 | 17287.90 | 0.5413823 | 53335.1 | 712.347 | 0.3802180 | 0.0412 |
| 2008 | 16712.80 | 635 | 16712.80 | 0.5299727 | 62848.0 | 679.089 | 0.3727640 | 0.0406 |
| 2009 | 16420.80 | 616 | 16420.80 | 0.5136957 | 95740.8 | 693.402 | 0.3868330 | 0.0422 |
| 2010 | 16610.90 | 594 | 16610.90 | 0.4955938 | 94766.2 | 575.631 | 0.3426520 | 0.0347 |

**Table 1:** Time-series of population estimates from the base model *(continued)*

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 2011 | 17545.00 | 586 | 17545.00 | 0.4885887 | 53137.5 | 484.161 | 0.3009760 | 0.0276 |
| 2012 | 18867.30 | 600 | 18867.30 | 0.5002377 | 54429.4 | 506.799 | 0.3080100 | 0.0269 |
| 2013 | 20087.40 | 637 | 20087.40 | 0.5316058 | 100549.0 | 622.668 | 0.3509850 | 0.0310 |
| 2014 | 21231.40 | 687 | 21231.40 | 0.5733150 | 42805.7 | 530.647 | 0.2955880 | 0.0250 |
| 2015 | 22404.60 | 742 | 22404.60 | 0.6189943 | 59163.6 | 720.389 | 0.3571870 | 0.0322 |
| 2016 | 23080.40 | 785 | 23080.40 | 0.6545201 | 67444.1 | 809.008 | 0.3740920 | 0.0351 |
| 2017 | 23504.40 | 820 | 23504.40 | 0.6836612 | 41706.7 | 773.473 | 0.3490790 | 0.0329 |
| 2018 | 23729.10 | 847 | 23729.10 | 0.7063537 | 64498.0 | 638.000 | 0.2905830 | 0.0269 |
| 2019 | 23844.00 | 869 | 23844.00 | 0.7250920 | 53606.6 | 509.475 | 0.2344690 | 0.0214 |
| 2020 | 23971.40 | 888 | 23971.40 | 0.7405241 | 59397.1 | 419.328 | 0.1936460 | 0.0175 |
| 2021 | 24075.70 | 901 | 24075.70 | 0.7517260 | 63114.4 | 411.834 | 0.1872980 | 0.0171 |
| 2022 | 24176.00 | 909 | 24176.00 | 0.7583750 | 62659.5 | 445.148 | 0.1984310 | 0.0184 |
| 2023 | 24276.90 | 913 | 24276.90 | 0.7612374 | 62691.8 | 447.169 | 0.1982070 | 0.0184 |
| 2024 | 24412.10 | 915 | 24412.10 | 0.7635043 | 62717.1 | 447.169 | 0.1975860 | 0.0183 |
| 2025 | 24578.20 | 920 | 24578.20 | 0.7669380 | 62755.3 | 4549.685 | 0.9479200 | 0.1851 |
| 2026 | 21379.70 | 759 | 21379.70 | 0.6332405 | 61012.4 | 3719.204 | 0.9440980 | 0.1740 |
| 2027 | 19224.60 | 645 | 19224.60 | 0.5381171 | 59341.3 | 3152.573 | 0.9407480 | 0.1640 |
| 2028 | 17773.20 | 565 | 17773.20 | 0.4713067 | 57846.1 | 2768.513 | 0.9373840 | 0.1558 |
| 2029 | 16781.50 | 510 | 16781.50 | 0.4250477 | 56596.1 | 2509.733 | 0.9339670 | 0.1496 |
| 2030 | 16079.10 | 471 | 16079.10 | 0.3931609 | 55603.2 | 2333.562 | 0.9304680 | 0.1451 |
| 2031 | 15554.60 | 445 | 15554.60 | 0.3708905 | 54833.3 | 2212.052 | 0.9273450 | 0.1422 |
| 2032 | 15138.60 | 425 | 15138.60 | 0.3547828 | 54231.4 | 2118.652 | 0.9236630 | 0.1400 |
| 2033 | 14796.80 | 411 | 14796.80 | 0.3427535 | 53754.6 | 2043.872 | 0.9198980 | 0.1381 |

**Table 1:** Time-series of population estimates from the base model *(continued)*

| Year | Total Biomass (mt) | Spawning Output (millions of eggs) | Total Age 0+ Biomass | Fraction Unfished | Age 0 Recruits | Total mortality (mt) | (1-SPR)/(1-SPR30%) | Exploitation Rate |
|---|---|---|---|---|---|---|---|---|
| 2034 | 14510.30 | 400 | 14510.30 | 0.3334848 | 53369.9 | 1983.052 | 0.9165490 | 0.1367 |

**Table 2:** Total landings for the 2 fleets. Note that for the historical fishery fleet (1916-2001), retained and discarded catch are aggregated in the model, whereas the landings for the current fishery fleet (2002-2022) represent only landings, with discards estimated in the model.

| Year | FISHERY_current (Landings) | FISHERY_historical (Retained) | FISHERY_historical (Discards) |
|---|---|---|---|
| 1916 | 0.0 | 148.2 | 74.1 |
| 1917 | 0.0 | 201.9 | 100.9 |
| 1918 | 0.0 | 162.6 | 81.4 |
| 1919 | 0.0 | 127.9 | 63.9 |
| 1920 | 0.0 | 88.4 | 44.2 |
| 1921 | 0.0 | 112.7 | 56.3 |
| 1922 | 0.0 | 162.9 | 81.5 |
| 1923 | 0.0 | 163.9 | 82.0 |
| 1924 | 0.0 | 204.4 | 102.2 |
| 1925 | 0.0 | 202.7 | 101.3 |
| 1926 | 0.0 | 200.1 | 100.0 |
| 1927 | 0.0 | 242.4 | 121.2 |
| 1928 | 0.0 | 237.8 | 118.9 |
| 1929 | 0.0 | 270.8 | 135.4 |
| 1930 | 0.0 | 252.7 | 126.3 |
| 1931 | 0.0 | 377.0 | 188.5 |
| 1932 | 0.0 | 252.5 | 126.2 |
| 1933 | 0.0 | 240.4 | 120.2 |
| 1934 | 0.0 | 303.7 | 151.8 |
| 1935 | 0.0 | 286.7 | 143.4 |
| 1936 | 0.0 | 234.8 | 117.4 |
| 1937 | 0.0 | 209.5 | 104.7 |
| 1938 | 0.0 | 253.9 | 126.9 |
| 1939 | 0.0 | 317.4 | 158.7 |
| 1940 | 0.0 | 295.3 | 147.7 |
| 1941 | 0.0 | 199.6 | 99.8 |
| 1942 | 0.0 | 183.4 | 91.7 |
| 1943 | 0.0 | 476.8 | 238.4 |
| 1944 | 0.0 | 254.4 | 127.2 |
| 1945 | 0.0 | 232.8 | 116.4 |
| 1946 | 0.0 | 288.2 | 144.1 |
| 1947 | 0.0 | 413.1 | 206.6 |
| 1948 | 0.0 | 571.5 | 285.8 |
| 1949 | 0.0 | 645.0 | 322.5 |
| 1950 | 0.0 | 615.2 | 307.6 |
| 1951 | 0.0 | 651.5 | 321.8 |

**Table 2:** Total landings for the 2 fleets. Note that for the historical fishery fleet (1916-2001), retained and discarded catch are aggregated in the model, whereas the landings for the current fishery fleet (2002-2022) represent only landings, with discards estimated in the model. *(continued)*

| Year | FISH-ERY_current (Landings) | FISH-ERY_historical (Retained) | FISH-ERY_historical (Discards) |
|---|---|---|---|
| 1952 | 0.0 | 760.3 | 370.9 |
| 1953 | 0.0 | 964.7 | 464.6 |
| 1954 | 0.0 | 1022.0 | 486.0 |
| 1955 | 0.0 | 1347.2 | 632.4 |
| 1956 | 0.0 | 1612.8 | 747.2 |
| 1957 | 0.0 | 1466.8 | 670.6 |
| 1958 | 0.0 | 1507.2 | 679.9 |
| 1959 | 0.0 | 1407.0 | 626.0 |
| 1960 | 0.0 | 1339.4 | 587.8 |
| 1961 | 0.0 | 1397.3 | 604.6 |
| 1962 | 0.0 | 1606.6 | 685.3 |
| 1963 | 0.0 | 1771.2 | 744.7 |
| 1964 | 0.0 | 1350.3 | 559.4 |
| 1965 | 0.0 | 1325.8 | 541.1 |
| 1966 | 0.0 | 1641.8 | 660.2 |
| 1967 | 0.0 | 1663.0 | 658.5 |
| 1968 | 0.0 | 1513.0 | 589.8 |
| 1969 | 0.0 | 1756.3 | 674.0 |
| 1970 | 0.0 | 1429.6 | 539.8 |
| 1971 | 0.0 | 1180.5 | 438.6 |
| 1972 | 0.0 | 1491.8 | 545.1 |
| 1973 | 0.0 | 1495.2 | 537.2 |
| 1974 | 0.0 | 1584.0 | 559.3 |
| 1975 | 0.0 | 1538.6 | 533.8 |
| 1976 | 0.0 | 1756.5 | 598.8 |
| 1977 | 0.0 | 1483.0 | 496.5 |
| 1978 | 0.0 | 1811.2 | 595.2 |
| 1979 | 0.0 | 2421.6 | 781.1 |
| 1980 | 0.0 | 1763.4 | 558.0 |
| 1981 | 0.0 | 1551.2 | 481.3 |
| 1982 | 0.0 | 1746.7 | 531.3 |
| 1983 | 0.0 | 1458.8 | 434.8 |
| 1984 | 0.0 | 1275.2 | 372.3 |
| 1985 | 0.0 | 1424.7 | 407.2 |
| 1986 | 0.0 | 1207.8 | 337.8 |
| 1987 | 0.0 | 1200.2 | 325.2 |

**Table 2:** Total landings for the 2 fleets. Note that for the historical fishery fleet (1916-2001), retained and discarded catch are aggregated in the model, whereas the landings for the current fishery fleet (2002-2022) represent only landings, with discards estimated in the model. *(continued)*

| Year | FISHERY_current (Landings) | FISHERY_historical (Retained) | FISHERY_historical (Discards) |
|---|---|---|---|
| 1988 | 0.0 | 1266.5 | 332.0 |
| 1989 | 0.0 | 1145.4 | 290.2 |
| 1990 | 0.0 | 878.0 | 214.8 |
| 1991 | 0.0 | 1170.3 | 276.1 |
| 1992 | 0.0 | 874.8 | 198.7 |
| 1993 | 0.0 | 785.5 | 171.6 |
| 1994 | 0.0 | 841.1 | 176.3 |
| 1995 | 0.0 | 927.1 | 186.3 |
| 1996 | 0.0 | 846.3 | 162.6 |
| 1997 | 0.0 | 810.3 | 148.6 |
| 1998 | 0.0 | 635.9 | 111.0 |
| 1999 | 0.0 | 589.5 | 97.7 |
| 2000 | 0.0 | 544.9 | 85.6 |
| 2001 | 0.0 | 562.4 | 83.5 |
| 2002 | 597.6 | 0.0 | 0.0 |
| 2003 | 639.3 | 0.0 | 0.0 |
| 2004 | 545.5 | 0.0 | 0.0 |
| 2005 | 593.0 | 0.0 | 0.0 |
| 2006 | 564.0 | 0.0 | 0.0 |
| 2007 | 572.3 | 0.0 | 0.0 |
| 2008 | 548.7 | 0.0 | 0.0 |
| 2009 | 561.8 | 0.0 | 0.0 |
| 2010 | 463.8 | 0.0 | 0.0 |
| 2011 | 390.9 | 0.0 | 0.0 |
| 2012 | 402.0 | 0.0 | 0.0 |
| 2013 | 514.8 | 0.0 | 0.0 |
| 2014 | 418.2 | 0.0 | 0.0 |
| 2015 | 537.8 | 0.0 | 0.0 |
| 2016 | 613.8 | 0.0 | 0.0 |
| 2017 | 556.8 | 0.0 | 0.0 |
| 2018 | 476.6 | 0.0 | 0.0 |
| 2019 | 369.6 | 0.0 | 0.0 |
| 2020 | 320.6 | 0.0 | 0.0 |
| 2021 | 283.4 | 0.0 | 0.0 |
| 2022 | 307.3 | 0.0 | 0.0 |

**Table 3:** Recent trend in commercial landings (mt) relative to the management guidelines. Estimated total catch reflects the commercial landings plus the model estimated discarded catch. As OFL and ACL values specific to Rex Sole were not available for all years, OFL and ACL values are provided for both Rex Sole and the "Other Flatfish" stock complex, which Rex Sole is a part of. Estimated total mortality not available for 2022 because complete discard information was not available for this year at the time of the assessment.

| | Other Flatfish | | Rex Sole | | | |
|---|---|---|---|---|---|---|
| Year | OFL | ACL | OFL | ACL | Total Landings | Estimated Total Mortality |
| 2011 | - | 4884 | - | - | 391 | 466 |
| 2012 | - | 4884 | - | - | 402 | 485 |
| 2013 | - | 4884 | - | - | 515 | 603 |
| 2014 | - | 4884 | - | - | 418 | 507 |
| 2015 | - | 8620 | - | - | 538 | 674 |
| 2016 | - | 7496 | - | - | 614 | 762 |
| 2017 | 11165 | 8510 | 5476 | 4562 | 557 | 713 |
| 2018 | 9690 | 7281 | 4001 | 3333 | 477 | 597 |
| 2019 | 8750 | 6498 | 3061 | 2550 | 370 | 471 |
| 2020 | 8202 | 6041 | 2513 | 2093 | 321 | 396 |
| 2021 | 7714 | 4802 | 2026 | 1377 | 283 | 372 |
| 2022 | 7808 | 4838 | 2120 | 1414 | 307 | - |

**Table 4:** Model-based (sdmTMB) index of abundance for the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

| Year | Index | SE |
|---|---|---|
| 2003 | 65105 | 0.069 |
| 2004 | 68312 | 0.071 |
| 2005 | 66240 | 0.061 |
| 2006 | 58558 | 0.063 |
| 2007 | 57164 | 0.060 |
| 2008 | 40462 | 0.061 |
| 2009 | 36916 | 0.059 |
| 2010 | 39236 | 0.058 |
| 2011 | 43665 | 0.059 |
| 2012 | 48219 | 0.056 |
| 2013 | 58097 | 0.069 |
| 2014 | 62578 | 0.058 |
| 2015 | 72238 | 0.058 |
| 2016 | 78079 | 0.056 |
| 2017 | 79754 | 0.058 |

**Table 4:** Model-based (sdmTMB) index of abundance for the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS). *(continued)*

| Year | Index | SE |
|---|---|---|
| 2018 | 82001 | 0.057 |
| 2019 | 72797 | 0.082 |
| 2021 | 68204 | 0.059 |
| 2022 | 74300 | 0.062 |

**Table 5:** Summary of the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) length samples.

| Year | Tows | All Fish | Sexed Fish | Unsexed Fish | Model Input Sample Size |
|---|---|---|---|---|---|
| 2003 | 171 | 10843 | 10843 | 0 | 528 |
| 2004 | 305 | 13932 | 13884 | 48 | 942 |
| 2005 | 425 | 16007 | 15980 | 27 | 1313 |
| 2006 | 396 | 11580 | 11580 | 0 | 1223 |
| 2007 | 423 | 9621 | 9608 | 13 | 1307 |
| 2008 | 399 | 7227 | 7166 | 61 | 1232 |
| 2009 | 395 | 4114 | 4088 | 26 | 1220 |
| 2010 | 442 | 2658 | 2611 | 47 | 1365 |
| 2011 | 424 | 6988 | 6921 | 67 | 1310 |
| 2012 | 432 | 7426 | 7399 | 27 | 1334 |
| 2013 | 305 | 5729 | 5720 | 9 | 942 |
| 2014 | 432 | 8682 | 8667 | 15 | 1334 |
| 2015 | 418 | 8517 | 8500 | 17 | 1291 |
| 2016 | 426 | 8667 | 8643 | 24 | 1316 |
| 2017 | 427 | 5231 | 5203 | 28 | 1319 |
| 2018 | 431 | 4831 | 4822 | 9 | 1331 |
| 2019 | 210 | 2424 | 2423 | 1 | 648 |
| 2021 | 420 | 4097 | 4087 | 10 | 1297 |
| 2022 | 390 | 3991 | 3984 | 7 | 1205 |

**Table 6:** Summary of the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) age samples.

| Year | Tows | All Fish | Sexed Fish | Unsexed Fish | Model Input Sample Size |
|---|---|---|---|---|---|
| 2007 | 7 | 7 | 7 | 0 | 7 |
| 2008 | 17 | 20 | 16 | 4 | 20 |
| 2009 | 19 | 23 | 19 | 4 | 23 |
| 2010 | 30 | 37 | 28 | 9 | 37 |
| 2011 | 35 | 45 | 40 | 5 | 45 |
| 2012 | 23 | 27 | 22 | 5 | 27 |
| 2013 | 10 | 10 | 9 | 1 | 10 |
| 2014 | 7 | 8 | 7 | 1 | 8 |
| 2015 | 5 | 5 | 5 | 0 | 5 |
| 2016 | 9 | 9 | 8 | 1 | 9 |
| 2017 | 145 | 167 | 160 | 7 | 167 |
| 2018 | 151 | 175 | 174 | 1 | 175 |
| 2019 | 79 | 87 | 86 | 1 | 87 |

**Table 7:** Model-based (sdmTMB) index of abundance for the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

| Year | Index | SE |
|---|---|---|
| 1980 | 7047 | 0.102 |
| 1983 | 14732 | 0.083 |
| 1986 | 20251 | 0.088 |
| 1989 | 21157 | 0.084 |
| 1992 | 18061 | 0.074 |
| 1995 | 24880 | 0.068 |
| 1998 | 38079 | 0.066 |
| 2001 | 44842 | 0.064 |
| 2004 | 79609 | 0.072 |

**Table 8:** Summary of the Early AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) length samples.

| Year | Tows | All Fish | Sexed Fish | Unsexed Fish | Model Input Sample Size |
|---|---|---|---|---|---|
| 1980 | 12 | 786 | 786 | 0 | 37 |

**Table 8:** Summary of the Early AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) length samples. *(continued)*

| Year | Tows | All Fish | Sexed Fish | Unsexed Fish | Model Input Sample Size |
|---|---|---|---|---|---|
| 1983 | 14 | 1937 | 1910 | 27 | 43 |
| 1986 | 83 | 5778 | 5775 | 3 | 256 |
| 1989 | 327 | 23799 | 23781 | 18 | 1010 |
| 1992 | 254 | 15343 | 15212 | 131 | 784 |

**Table 9:** Summary of the Late AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) length samples.

| Year | Tows | All Fish | Sexed Fish | Unsexed Fish | Model Input Sample Size |
|---|---|---|---|---|---|
| 1995 | 303 | 24270 | 24115 | 155 | 936 |
| 1998 | 366 | 32750 | 32746 | 4 | 1130 |
| 2001 | 452 | 37570 | 37463 | 107 | 1396 |
| 2004 | 365 | 34584 | 34582 | 2 | 1127 |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model.

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| NatM_uniform_Fem_GP_1 | 0.186 | -2 | (0.001, 2) | - | - | lognormal(-1.681,0.31) |
| L_at_Amin_Fem_GP_1 | 9.735 | 2 | (1, 26.898) | OK | 0.317 | - |
| L_at_Amax_Fem_GP_1 | 33.743 | 4 | (1, 83.64) | OK | 0.291 | - |
| VonBert_K_Fem_GP_1 | 0.247 | 4 | (0.05, 0.776) | OK | 0.01 | - |
| CV_young_Fem_GP_1 | 0.200 | 3 | (0.05, 0.2) | HI | 0 | - |
| CV_old_Fem_GP_1 | 0.088 | 3 | (0.05, 0.2) | OK | 0.005 | - |
| Wtlen_1_Fem_GP_1 | 0.000 | -3 | (-3, 3) | - | - | - |
| Wtlen_2_Fem_GP_1 | 3.204 | -3 | (-3, 4) | - | - | - |
| Mat50%_Fem_GP_1 | 24.000 | -3 | (1, 50) | - | - | - |
| Mat_slope_Fem_GP_1 | -0.392 | -3 | (-30, 3) | - | - | - |
| Eggs_scalar_Fem_GP_1 | 0.009 | -3 | (-3, 3) | - | - | - |
| Eggs_exp_len_Fem_GP_1 | 4.227 | -3 | (-3, 5) | - | - | - |
| NatM_uniform_Mal_GP_1 | 0.186 | -2 | (0.001, 2) | - | - | lognormal(-1.681,0.31) |
| L_at_Amin_Mal_GP_1 | 13.588 | 2 | (1, 26.898) | OK | 0.383 | - |
| L_at_Amax_Mal_GP_1 | 32.092 | 4 | (1, 83.64) | OK | 0.37 | - |
| VonBert_K_Mal_GP_1 | 0.224 | 4 | (0.05, 0.776) | OK | 0.014 | - |
| CV_young_Mal_GP_1 | 0.114 | 3 | (0.05, 0.2) | OK | 0.011 | - |
| CV_old_Mal_GP_1 | 0.088 | 3 | (0.05, 0.2) | OK | 0.005 | - |
| Wtlen_1_Mal_GP_1 | 0.000 | -3 | (-3, 3) | - | - | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| Wtlen_2_Mal_GP_1 | 3.218 | -3 | (-3, 4) | - | - | - |
| CohortGrowDev | 1.000 | -1 | (0.1, 10) | - | - | - |
| FracFemale_GP_1 | 0.500 | -99 | (0, 1) | - | - | - |
| SR_LN(R0) | 11.079 | 1 | (1, 31) | OK | 0.08 | - |
| SR_BH_steep | 0.700 | -3 | (0.25, 0.99) | - | - | normal(0.8,0.093) |
| SR_sigmaR | 0.500 | -4 | (0, 2) | - | - | - |
| SR_regime | 0.000 | -4 | (-5, 5) | - | - | - |
| SR_autocorr | 0.000 | -99 | (0, 0) | - | - | - |
| Early_RecrDev_1900 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1901 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1902 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1903 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1904 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1905 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1906 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1907 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1908 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1909 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1910 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1911 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1912 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1913 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1914 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1915 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1916 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1917 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| Early_RecrDev_1918 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1919 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1920 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1921 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1922 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1923 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1924 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1925 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1926 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1927 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1928 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1929 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1930 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1931 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1932 | 0.000 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1933 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1934 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1935 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1936 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1937 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1938 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1939 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1940 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1941 | -0.001 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1942 | -0.002 | 4 | (-5, 5) | - | 0.5 | - |
| Early_RecrDev_1943 | -0.002 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1944 | -0.002 | 4 | (-5, 5) | - | 0.499 | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| Early_RecrDev_1945 | -0.002 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1946 | -0.002 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1947 | -0.003 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1948 | -0.003 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1949 | -0.003 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1950 | -0.003 | 4 | (-5, 5) | - | 0.499 | - |
| Early_RecrDev_1951 | -0.004 | 4 | (-5, 5) | - | 0.498 | - |
| Early_RecrDev_1952 | -0.004 | 4 | (-5, 5) | - | 0.498 | - |
| Early_RecrDev_1953 | -0.004 | 4 | (-5, 5) | - | 0.498 | - |
| Early_RecrDev_1954 | -0.005 | 4 | (-5, 5) | - | 0.498 | - |
| Early_RecrDev_1955 | -0.005 | 4 | (-5, 5) | - | 0.498 | - |
| Early_RecrDev_1956 | -0.005 | 4 | (-5, 5) | - | 0.497 | - |
| Early_RecrDev_1957 | -0.006 | 4 | (-5, 5) | - | 0.497 | - |
| Early_RecrDev_1958 | -0.006 | 4 | (-5, 5) | - | 0.497 | - |
| Early_RecrDev_1959 | -0.006 | 4 | (-5, 5) | - | 0.497 | - |
| Early_RecrDev_1960 | -0.006 | 4 | (-5, 5) | - | 0.496 | - |
| Early_RecrDev_1961 | -0.007 | 4 | (-5, 5) | - | 0.496 | - |
| Early_RecrDev_1962 | -0.007 | 4 | (-5, 5) | - | 0.496 | - |
| Early_RecrDev_1963 | -0.007 | 4 | (-5, 5) | - | 0.496 | - |
| Early_RecrDev_1964 | -0.007 | 4 | (-5, 5) | - | 0.496 | - |
| Early_RecrDev_1965 | -0.007 | 4 | (-5, 5) | - | 0.496 | - |
| Early_RecrDev_1966 | -0.007 | 4 | (-5, 5) | - | 0.495 | - |
| Early_RecrDev_1967 | -0.006 | 4 | (-5, 5) | - | 0.495 | - |
| Early_RecrDev_1968 | -0.005 | 4 | (-5, 5) | - | 0.495 | - |
| Early_RecrDev_1969 | -0.005 | 4 | (-5, 5) | - | 0.495 | - |
| Early_RecrDev_1970 | -0.004 | 4 | (-5, 5) | - | 0.495 | - |
| Early_RecrDev_1971 | -0.005 | 4 | (-5, 5) | - | 0.495 | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| Early_RecrDev_1972 | -0.009 | 4 | (-5, 5) | - | 0.493 | - |
| Early_RecrDev_1973 | -0.017 | 4 | (-5, 5) | - | 0.49 | - |
| Early_RecrDev_1974 | -0.030 | 4 | (-5, 5) | - | 0.485 | - |
| Early_RecrDev_1975 | -0.045 | 4 | (-5, 5) | - | 0.478 | - |
| Early_RecrDev_1976 | -0.058 | 4 | (-5, 5) | - | 0.471 | - |
| Early_RecrDev_1977 | -0.076 | 4 | (-5, 5) | - | 0.46 | - |
| Main_RecrDev_1978 | -0.120 | 5 | (-5, 5) | - | 0.43 | - |
| Main_RecrDev_1979 | -0.115 | 5 | (-5, 5) | - | 0.414 | - |
| Main_RecrDev_1980 | -0.023 | 5 | (-5, 5) | - | 0.411 | - |
| Main_RecrDev_1981 | 0.113 | 5 | (-5, 5) | - | 0.379 | - |
| Main_RecrDev_1982 | -0.199 | 5 | (-5, 5) | - | 0.37 | - |
| Main_RecrDev_1983 | -0.409 | 5 | (-5, 5) | - | 0.365 | - |
| Main_RecrDev_1984 | 0.134 | 5 | (-5, 5) | - | 0.297 | - |
| Main_RecrDev_1985 | -0.218 | 5 | (-5, 5) | - | 0.341 | - |
| Main_RecrDev_1986 | -0.588 | 5 | (-5, 5) | - | 0.334 | - |
| Main_RecrDev_1987 | -0.082 | 5 | (-5, 5) | - | 0.28 | - |
| Main_RecrDev_1988 | -0.081 | 5 | (-5, 5) | - | 0.365 | - |
| Main_RecrDev_1989 | 0.499 | 5 | (-5, 5) | - | 0.286 | - |
| Main_RecrDev_1990 | 0.426 | 5 | (-5, 5) | - | 0.328 | - |
| Main_RecrDev_1991 | 0.215 | 5 | (-5, 5) | - | 0.297 | - |
| Main_RecrDev_1992 | 0.218 | 5 | (-5, 5) | - | 0.284 | - |
| Main_RecrDev_1993 | 0.197 | 5 | (-5, 5) | - | 0.298 | - |
| Main_RecrDev_1994 | 0.409 | 5 | (-5, 5) | - | 0.3 | - |
| Main_RecrDev_1995 | 0.736 | 5 | (-5, 5) | - | 0.236 | - |
| Main_RecrDev_1996 | 0.448 | 5 | (-5, 5) | - | 0.243 | - |
| Main_RecrDev_1997 | 0.252 | 5 | (-5, 5) | - | 0.223 | - |
| Main_RecrDev_1998 | -0.454 | 5 | (-5, 5) | - | 0.269 | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| Main_RecrDev_1999 | -0.246 | 5 | (-5, 5) | - | 0.223 | - |
| Main_RecrDev_2000 | 0.023 | 5 | (-5, 5) | - | 0.174 | - |
| Main_RecrDev_2001 | -0.201 | 5 | (-5, 5) | - | 0.185 | - |
| Main_RecrDev_2002 | -0.127 | 5 | (-5, 5) | - | 0.158 | - |
| Main_RecrDev_2003 | -0.444 | 5 | (-5, 5) | - | 0.174 | - |
| Main_RecrDev_2004 | -0.315 | 5 | (-5, 5) | - | 0.15 | - |
| Main_RecrDev_2005 | -0.895 | 5 | (-5, 5) | - | 0.198 | - |
| Main_RecrDev_2006 | -0.570 | 5 | (-5, 5) | - | 0.163 | - |
| Main_RecrDev_2007 | -0.030 | 5 | (-5, 5) | - | 0.117 | - |
| Main_RecrDev_2008 | 0.138 | 5 | (-5, 5) | - | 0.107 | - |
| Main_RecrDev_2009 | 0.565 | 5 | (-5, 5) | - | 0.087 | - |
| Main_RecrDev_2010 | 0.562 | 5 | (-5, 5) | - | 0.09 | - |
| Main_RecrDev_2011 | -0.014 | 5 | (-5, 5) | - | 0.129 | - |
| Main_RecrDev_2012 | 0.005 | 5 | (-5, 5) | - | 0.13 | - |
| Main_RecrDev_2013 | 0.608 | 5 | (-5, 5) | - | 0.096 | - |
| Main_RecrDev_2014 | -0.260 | 5 | (-5, 5) | - | 0.15 | - |
| Main_RecrDev_2015 | 0.051 | 5 | (-5, 5) | - | 0.144 | - |
| Main_RecrDev_2016 | 0.173 | 5 | (-5, 5) | - | 0.178 | - |
| Main_RecrDev_2017 | -0.314 | 5 | (-5, 5) | - | 0.325 | - |
| Main_RecrDev_2018 | 0.100 | 5 | (-5, 5) | - | 0.319 | - |
| Main_RecrDev_2019 | -0.118 | 5 | (-5, 5) | - | 0.387 | - |
| Main_RecrDev_2020 | -0.047 | 5 | (-5, 5) | - | 0.427 | - |
| Late_RecrDev_2021 | 0.008 | 7 | (-5, 5) | - | 0.498 | - |
| Late_RecrDev_2022 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2023 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2024 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2025 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| ForeRecr_2026 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2027 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2028 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2029 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2030 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2031 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2032 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2033 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| ForeRecr_2034 | 0.000 | 7 | (-5, 5) | - | 0.5 | - |
| LnQ_base_SURVEY1(3) | 0.820 | -1 | (-5, 5) | - | - | - |
| Q_extraSD_SURVEY1(3) | 0.421 | 1 | (0.01, 0.5) | OK | 0.172 | - |
| LnQ_base_SURVEY2(4) | 1.219 | -1 | (-5, 5) | - | - | - |
| Q_extraSD_SURVEY2(4) | 0.162 | 1 | (0.01, 0.5) | OK | 0.087 | - |
| LnQ_base_SURVEY3(5) | 1.378 | -1 | (-5, 5) | - | - | - |
| Size_DblN_peak_FISHERY_current(1) | 47.305 | 5 | (10, 58) | OK | 2.617 | - |
| Size_DblN_top_logit_FISHERY_current(1) | -15.000 | -4 | (-15, 7) | - | - | - |
| Size_DblN_ascend_se_FISHERY_current(1) | 5.767 | 5 | (-5, 10) | OK | 0.138 | - |
| Size_DblN_descend_se_FISHERY_current(1) | 15.000 | -5 | (-5, 10) | - | - | - |
| Size_DblN_start_logit_FISHERY_current(1) | -999.000 | -99 | (-999, 15) | - | - | - |
| Size_DblN_end_logit_FISHERY_current(1) | -999.000 | -5 | (-999, 15) | - | - | - |
| Retain_L_infl_FISHERY_current(1) | 26.900 | 3 | (5, 70) | OK | 0.203 | - |
| Retain_L_width_FISHERY_current(1) | 1.539 | 3 | (0.1, 40) | OK | 0.14 | - |
| Retain_L_asymptote_logit_FISHERY_current(1) | 2.457 | 3 | (-10, 10) | OK | 0.18 | - |
| Retain_L_maleoffset_FISHERY_current(1) | 0.000 | -4 | (-3, 3) | - | - | - |
| SzSel_Male_Peak_FISHERY_current(1) | -12.192 | 6 | (-20, 20) | OK | 1.693 | - |
| SzSel_Male_Ascend_FISHERY_current(1) | -2.265 | 4 | (-5, 5) | OK | 0.249 | - |
| SzSel_Male_Descend_FISHERY_current(1) | 0.000 | -4 | (-10, 10) | - | - | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| SzSel_Male_Final_FISHERY_current(1) | 0.000 | -6 | (-20, 10) | - | - | - |
| SzSel_Male_Scale_FISHERY_current(1) | 1.000 | -5 | (0.01, 1) | - | - | - |
| Size_DblN_peak_SURVEY1(3) | 26.974 | 4 | (10, 58) | OK | 0.42 | - |
| Size_DblN_top_logit_SURVEY1(3) | -1.707 | 5 | (-15, 7) | OK | 157.428 | - |
| Size_DblN_ascend_se_SURVEY1(3) | 3.061 | 4 | (-5, 10) | OK | 0.119 | - |
| Size_DblN_descend_se_SURVEY1(3) | 15.000 | -5 | (-5, 10) | - | - | - |
| Size_DblN_start_logit_SURVEY1(3) | -999.000 | -99 | (-999, 15) | - | - | - |
| Size_DblN_end_logit_SURVEY1(3) | -999.000 | -5 | (-10, 15) | - | - | - |
| Size_DblN_peak_SURVEY2(4) | 26.154 | 4 | (10, 58) | OK | 0.845 | - |
| Size_DblN_top_logit_SURVEY2(4) | 4.000 | 5 | (-7, 15) | OK | 245.964 | - |
| Size_DblN_ascend_se_SURVEY2(4) | 3.290 | 4 | (-5, 10) | OK | 0.239 | - |
| Size_DblN_descend_se_SURVEY2(4) | 15.000 | -5 | (-5, 15) | - | - | - |
| Size_DblN_start_logit_SURVEY2(4) | -999.000 | -99 | (-999, 15) | - | - | - |
| Size_DblN_end_logit_SURVEY2(4) | -999.000 | -5 | (-10, 15) | - | - | - |
| Size_DblN_peak_SURVEY3(5) | 28.807 | 4 | (10, 58) | OK | 0.367 | - |
| Size_DblN_top_logit_SURVEY3(5) | 15.000 | -4 | (-7, 15) | - | - | - |
| Size_DblN_ascend_se_SURVEY3(5) | 3.496 | 4 | (-5, 10) | OK | 0.083 | - |
| Size_DblN_descend_se_SURVEY3(5) | 15.000 | -5 | (-5, 15) | - | - | - |
| Size_DblN_start_logit_SURVEY3(5) | -999.000 | -99 | (-999, 15) | - | - | - |
| Size_DblN_end_logit_SURVEY3(5) | -999.000 | -5 | (-999, 15) | - | - | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2011 | 2.710 | 3 | (-10, 10) | OK | 0.076 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2012 | 2.792 | 3 | (-10, 10) | OK | 0.068 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2013 | 9.893 | 3 | (-10, 10) | HI | 3.211 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2014 | 3.088 | 3 | (-10, 10) | OK | 0.097 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2015 | 2.201 | 3 | (-10, 10) | OK | 0.058 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2016 | 2.295 | 3 | (-10, 10) | OK | 0.071 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2017 | 1.770 | 3 | (-10, 10) | OK | 0.05 | - |

**Table 10:** Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

| Label | Value | Phase | Bounds | Status | SD | Prior |
|---|---|---|---|---|---|---|
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2018 | 1.975 | 3 | (-10, 10) | OK | 0.059 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2019 | 1.699 | 3 | (-10, 10) | OK | 0.048 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2020 | 2.036 | 3 | (-10, 10) | OK | 0.062 | - |
| Retain_L_asymptote_logit_FISHERY_current(1)_BLK1repl_2021 | 1.337 | 3 | (-10, 10) | OK | 0.038 | - |

**Table 11:** Summary of biological sensitivities on the base model.

| Label | base model | estimate male M | 2013 fe-cundity | 2013 growth | 2013 M | 2013 WL | estimate h |
|---|---|---|---|---|---|---|---|
| TOTAL_like | 897.00 | 830.00 | 899.00 | 4.16e+03 | 829.00 | 898.00 | 896.00 |
| Survey_like | 0.84 | 1.34 | 1.00 | -1.98 | 2.25 | 0.00 | 0.59 |
| Length_comp_like | 261.00 | 207.00 | 261.00 | 1.49e+03 | 206.00 | 262.00 | 261.00 |
| Age_comp_like | 780.00 | 766.00 | 780.00 | 2.63e+03 | 765.00 | 780.00 | 780.00 |
| Parm_priors_like | 0.58 | 0.86 | 0.58 | 0.58 | 1.23 | 0.58 | 0.00 |
| Recr_Virgin_millions | 64.80 | 57.70 | 71.60 | 32.40 | 47.20 | 66.40 | 59.20 |
| SR_LN(R0) | 11.10 | 11.00 | 11.20 | 10.40 | 10.80 | 11.10 | 11.00 |
| SR_BH_steep | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.81 |
| NatM_uniform_Fem_GP_1 | 0.19 | 0.19 | 0.19 | 0.19 | 0.17 | 0.19 | 0.19 |
| NatM_uniform_Mal_GP_1 | 0.19 | 0.15 | 0.19 | 0.19 | 0.13 | 0.19 | 0.19 |
| L_at_Amax_Fem_GP_1 | 33.70 | 33.40 | 33.70 | 41.80 | 33.20 | 33.70 | 33.70 |
| L_at_Amax_Mal_GP_1 | 32.10 | 31.60 | 32.10 | 41.80 | 31.50 | 32.10 | 32.10 |
| VonBert_K_Fem_GP_1 | 0.25 | 0.28 | 0.25 | 0.39 | 0.28 | 0.25 | 0.25 |
| VonBert_K_Mal_GP_1 | 0.22 | 0.22 | 0.22 | 0.39 | 0.22 | 0.22 | 0.22 |
| SSB_Virgin_thousand_mt | 1.20e+06 | 1.12e+06 | 3.86 | 2.87e+06 | 1.12e+06 | 1.23e+06 | 1.10e+06 |
| Bratio_2021 | 0.75 | 0.82 | 0.59 | 0.03 | 0.75 | 0.75 | 0.83 |
| SPRratio_2020 | 0.19 | 0.16 | 0.26 | 1.13 | 0.18 | 0.19 | 0.19 |

**Table 12:** Summary of catchability, discard, and selectivity sensitivities on the base model.

| Label | Base model | Fishery selex dome | DM weights | MI weights | WCGBTS extra SD | Estimate WCGBTS Q | Fix WCGBTS Q at AFSC val | Increase historical discards | Decrease historical discards |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL_like | 897.00 | 897.00 | 4.21e+03 | 729.00 | 851.00 | 897.00 | 934.00 | 897.00 | 898.00 |
| Survey_like | 0.84 | 0.84 | 36.70 | 7.61 | -25.30 | 0.84 | 0.95 | 0.91 | 0.79 |
| Length_comp_like | 261.00 | 261.00 | 3.71e+03 | 535.00 | 244.00 | 261.00 | 266.00 | 261.00 | 261.00 |
| Age_comp_like | 780.00 | 780.00 | 552.00 | 311.00 | 776.00 | 780.00 | 785.00 | 780.00 | 781.00 |
| Parm_priors_like | 0.58 | 0.58 | 12.70 | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 |
| Recr_Virgin_millions | 64.80 | 64.80 | 63.90 | 1.12e+10 | 61.00 | 64.80 | 144.00 | 70.50 | 59.40 |
| SR_LN(R0) | 11.10 | 11.10 | 11.10 | 30.00 | 11.00 | 11.10 | 11.90 | 11.20 | 11.00 |
| SR_BH_steep | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| NatM_uniform_Fem_GP_1 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 |
| NatM_uniform_Mal_GP_1 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 |
| L_at_Amax_Fem_GP_1 | 33.70 | 33.70 | 34.00 | 32.10 | 33.60 | 33.70 | 33.10 | 33.70 | 33.80 |
| L_at_Amax_Mal_GP_1 | 32.10 | 32.10 | 32.60 | 30.00 | 32.20 | 32.10 | 31.60 | 32.00 | 32.20 |
| VonBert_K_Fem_GP_1 | 0.25 | 0.25 | 0.27 | 0.29 | 0.25 | 0.25 | 0.26 | 0.25 | 0.24 |
| VonBert_K_Mal_GP_1 | 0.22 | 0.22 | 0.22 | 0.38 | 0.22 | 0.22 | 0.24 | 0.23 | 0.22 |
| SSB_Virgin_thousand_mt | 1.20e+06 | 1.20e+06 | 1.24e+06 | 1.78e+14 | 1.13e+06 | 1.20e+06 | 2.58e+06 | 1.30e+06 | 1.10e+06 |
| Bratio_2021 | 0.75 | 0.75 | 0.77 | 1.31 | 0.66 | 0.75 | 1.09 | 0.77 | 0.74 |
| SPRratio_2020 | 0.19 | 0.19 | 0.18 | 0.00 | 0.23 | 0.19 | 0.07 | 0.18 | 0.21 |

**Table 13:** Results of 50 jitters from base model.

| Status | Jitter.0.1 |
|---|---|
| Returned to base case | 9 |
| Found local minimum | 37 |
| Likelihood Diff <0.5 | 46 |
| Marginally better solution | 37 |
| Gradient > 1 | 0 |
| Total | 50 |

**Table 14:** Summary of reference points and management quantities for the base model.

| | Estimate | Lower Interval | Upper Interval |
|---|---|---|---|
| Unfished spawning output (millions) | 1199 | 1011 | 1387 |
| Unfished Age 0+ Biomass (mt) | 30007 | 25380 | 34635 |
| Unfished Recruitment (R0) | 64798 | 54653 | 74944 |
| Spawning Output (2023) (millions) | 913 | 692 | 1133 |
| Fraction Unfished (2023) | 0.761 | 0.67 | 0.853 |
| Reference Points Based SB25% | - | - | - |
| Proxy Spawning Output (millions) SB25% | 300 | 253 | 347 |
| SPR Resulting in SB25% | 0.33 | 0.33 | 0.33 |
| Exploitation Rate Resulting in SB25% | 0.573 | 0.381 | 0.764 |
| Yield with SPR Based On SB25% (mt) | 1680 | 1419 | 1942 |
| Reference Points Based on SPR Proxy for MSY | - | - | - |
| Proxy Spawning Output (millions) (SPR30) | 259 | 218 | 300 |
| SPR30 | 0.3 | - | - |
| Exploitation Rate Corresponding to SPR30 | 0.651 | 0.432 | 0.869 |
| Yield with SPR30 at SB SPR (mt) | 1658 | 1400 | 1916 |
| Reference Points Based on Estimated MSY Values | - | - | - |
| Spawning Output (millions) at MSY (SB MSY) | 321 | 270 | 371 |
| SPR MSY | 0.346 | 0.34 | 0.352 |
| Exploitation Rate Corresponding to SPR MSY | 0.537 | 0.363 | 0.712 |
| MSY (mt) | 1683 | 1421 | 1945 |

# 8 Figures

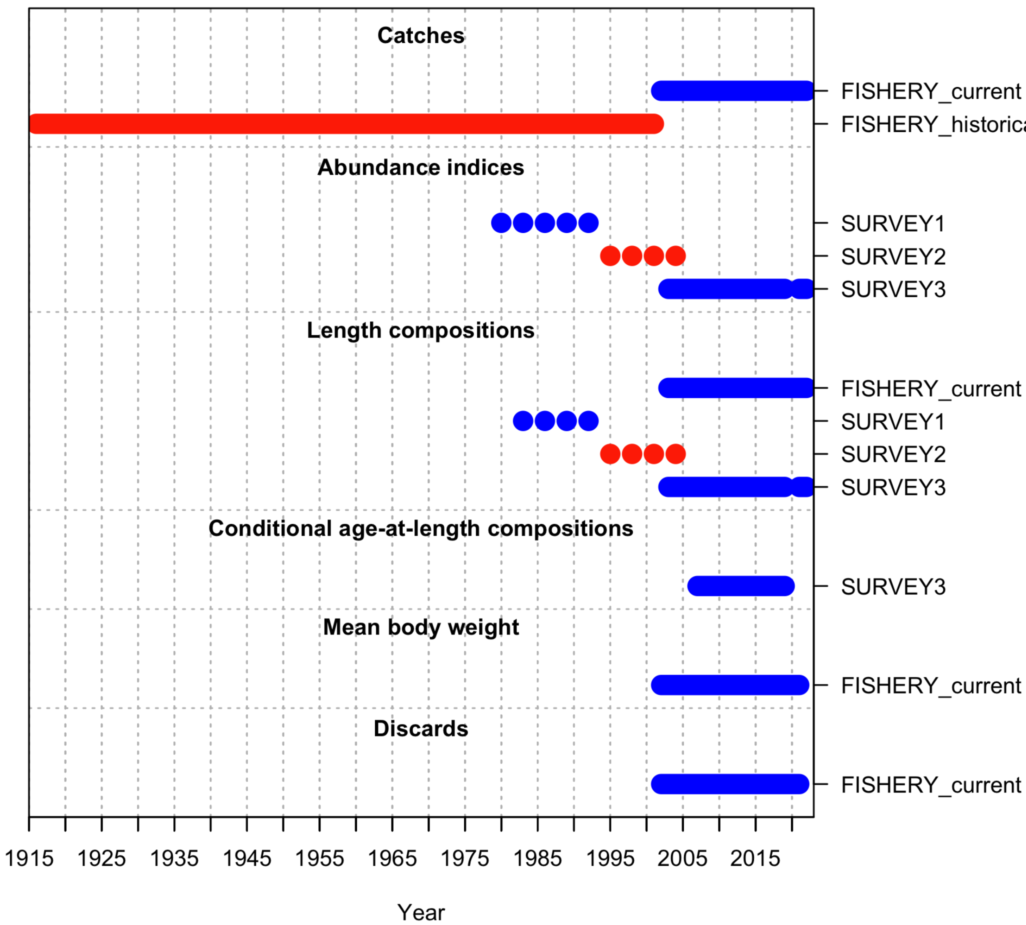


**Figure 1:** Summary of data sources used in the base model.

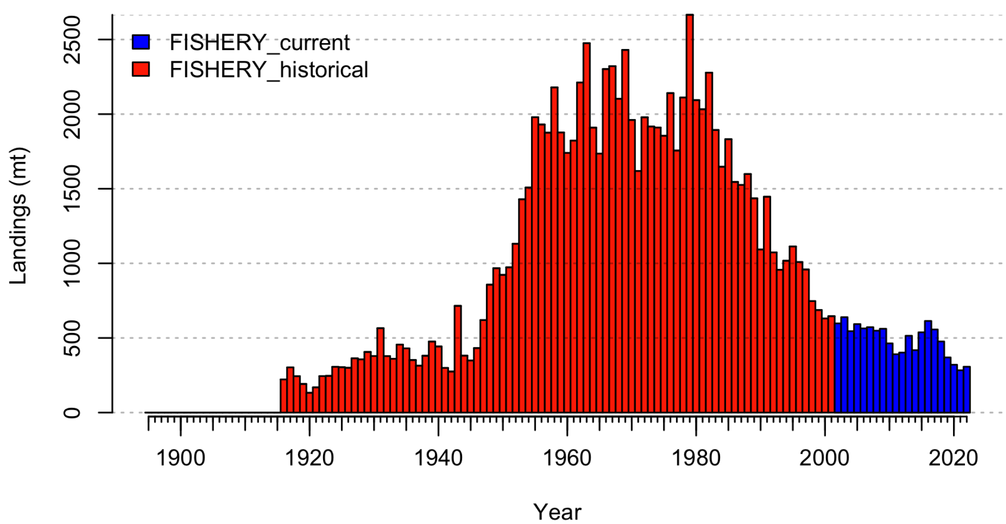


**Figure 2:** Total landings removal for the 2 fleets. The historical fishery fleet landings (1916-2001, red) include both retained and discarded fish (total dead catch). The current fishery fleet (2002-2022, blue) reports landings only (retained fish) with discards estimated in the model.

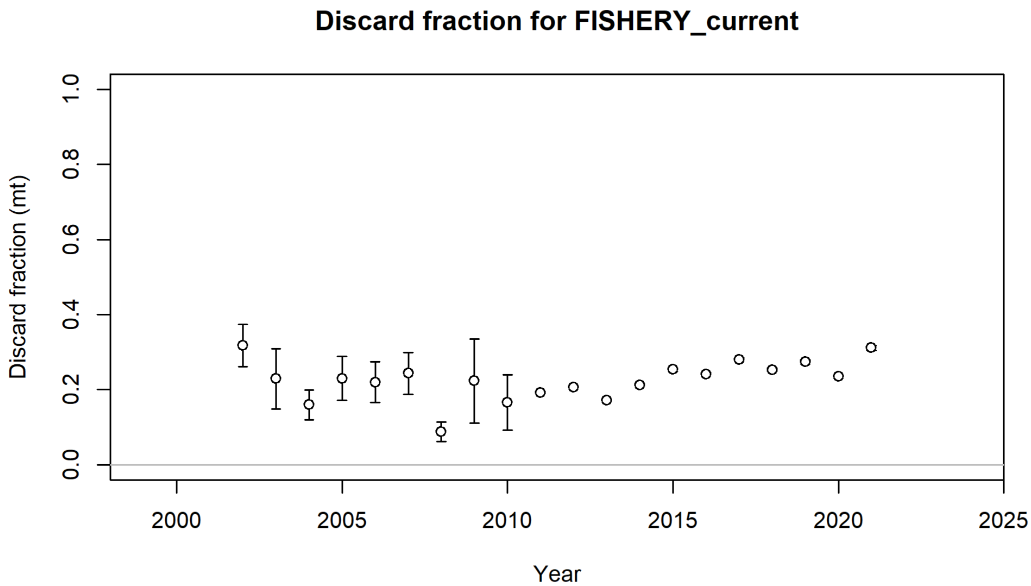


**Figure 3:** Coastwide current fishery discard rates for Rex Sole.

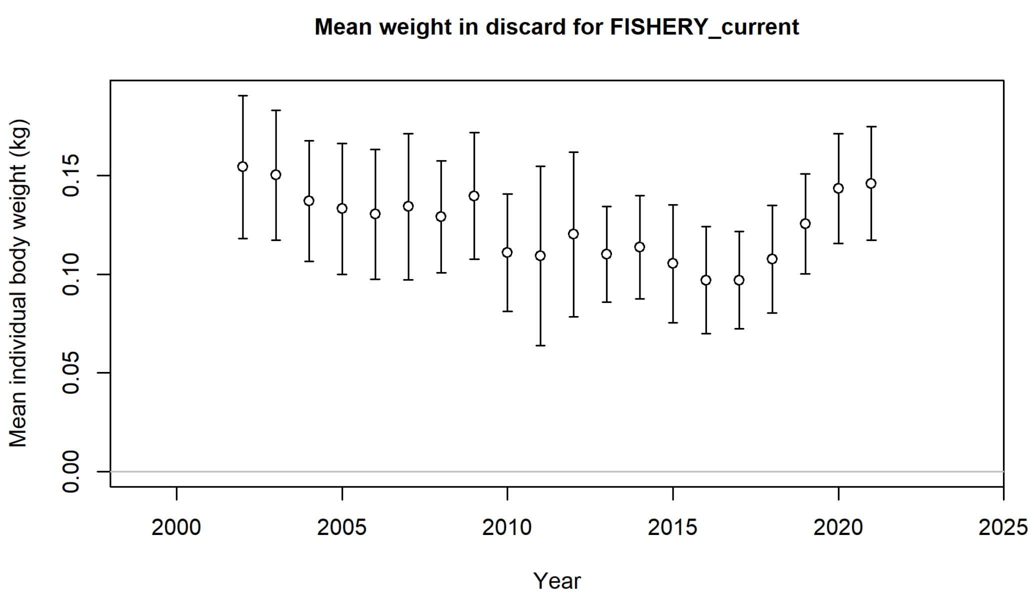


**Figure 4:** Coastwide current fishery mean body weights of discarded fish for Rex Sole.

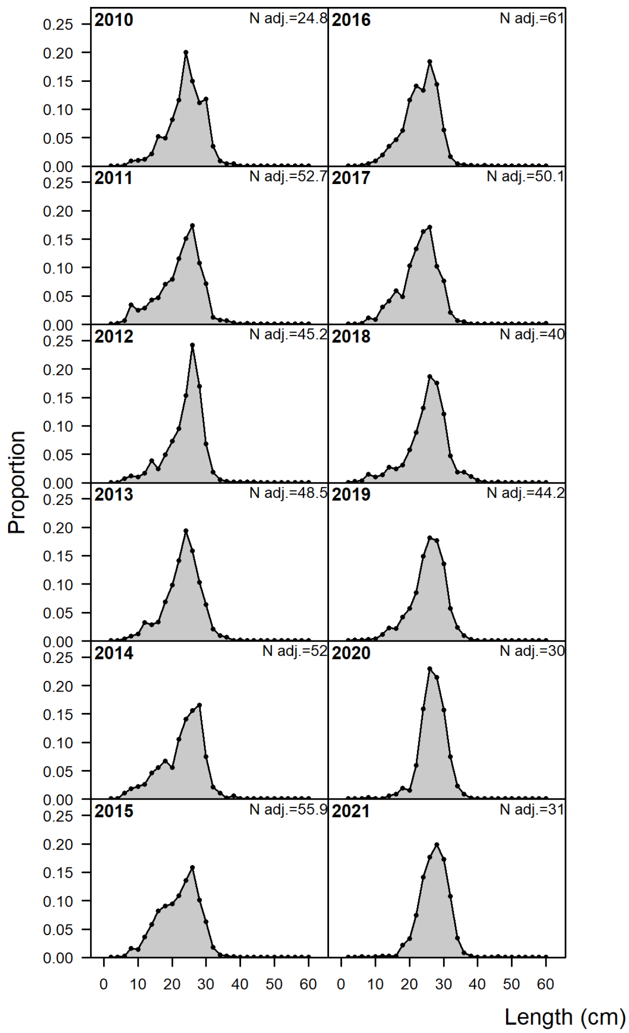


**Figure 5:** Coastwide current fishery length compositions of discarded fish for Rex Sole (unsexed).

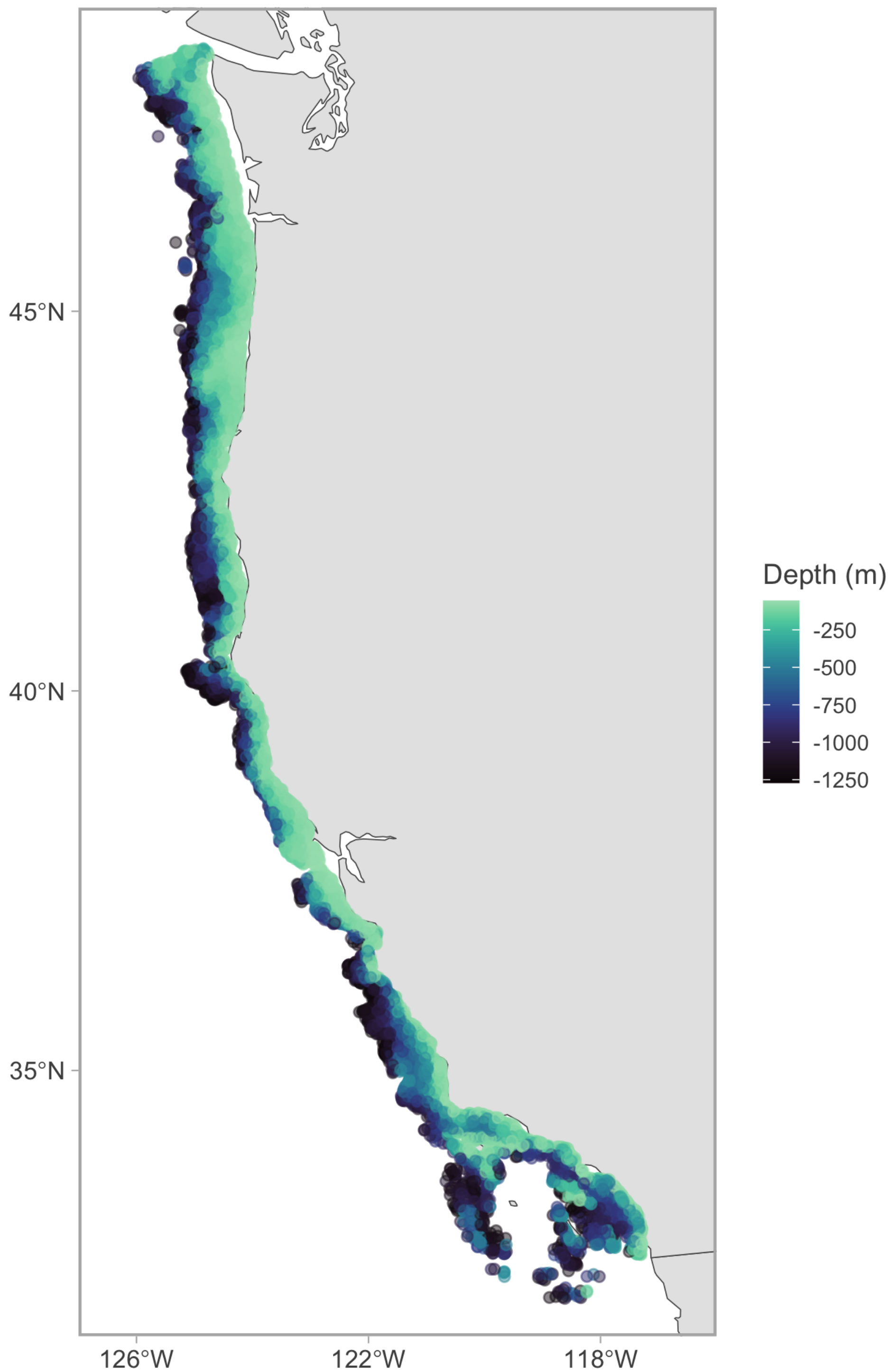


**Figure 6:** Sampling locations and depth for all years of the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

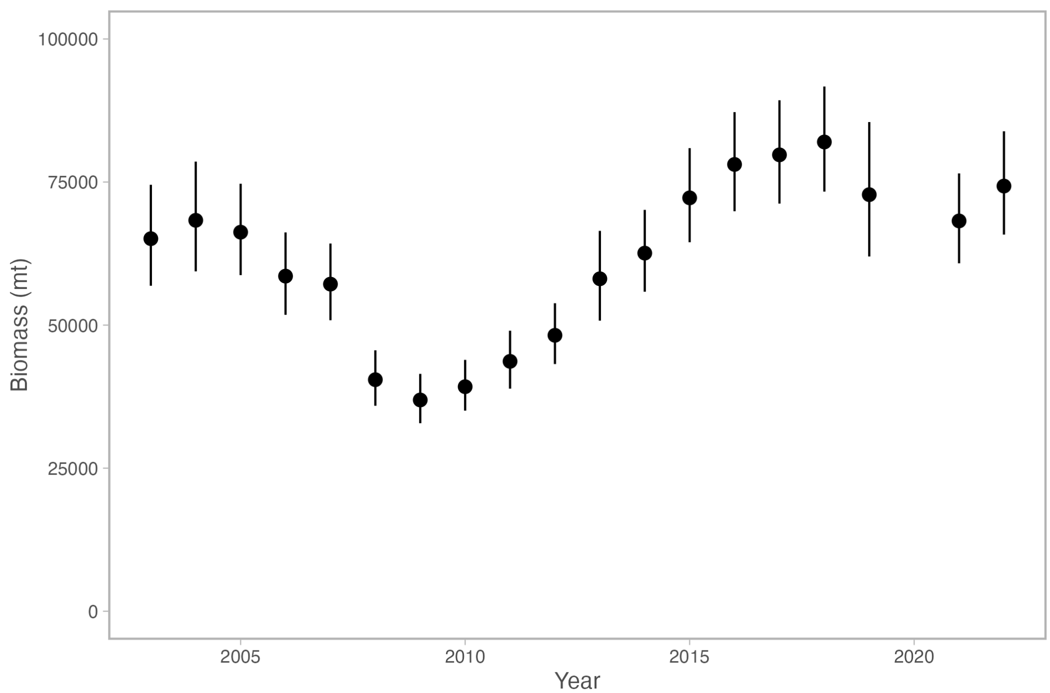


**Figure 7:** Model-based (sdmTMB) index of abundance for the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

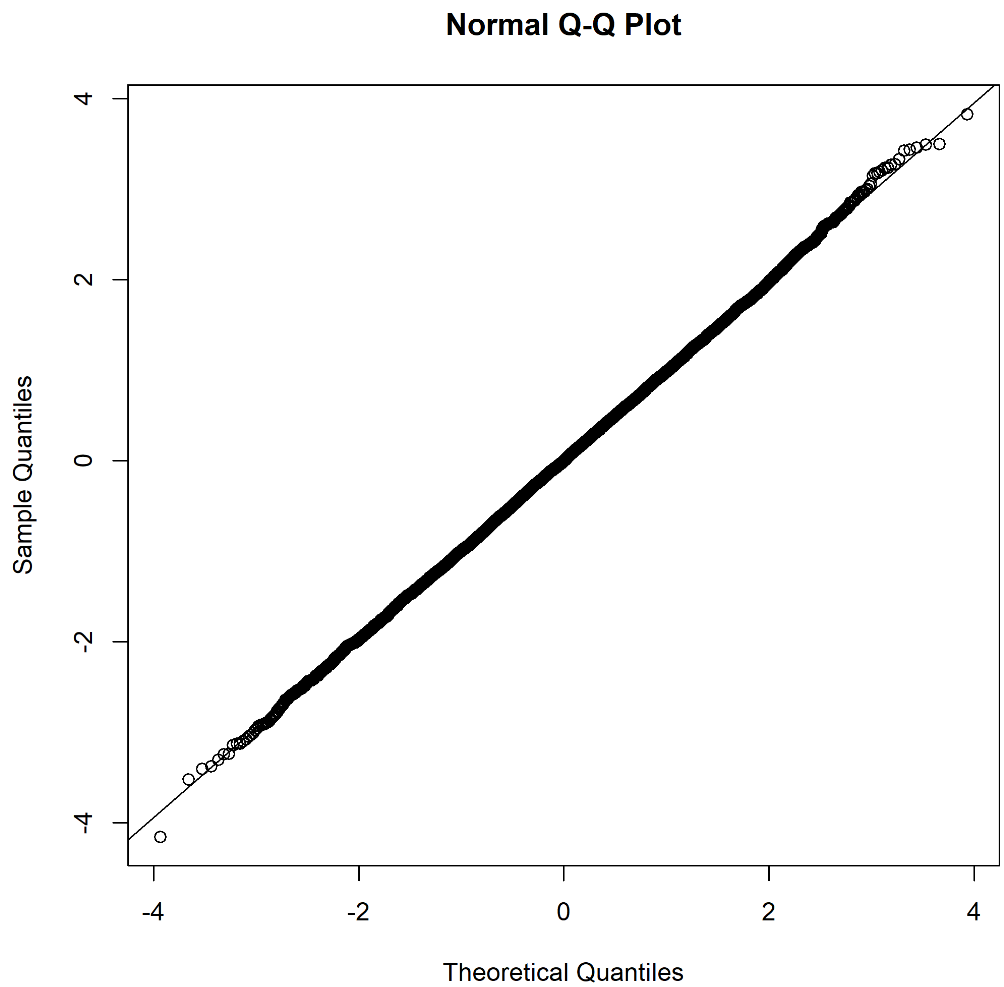


**Figure 8:** QQ plot for the NWFSC West Coast Groundfish Bottom Trawl Survey (WCG-BTS).

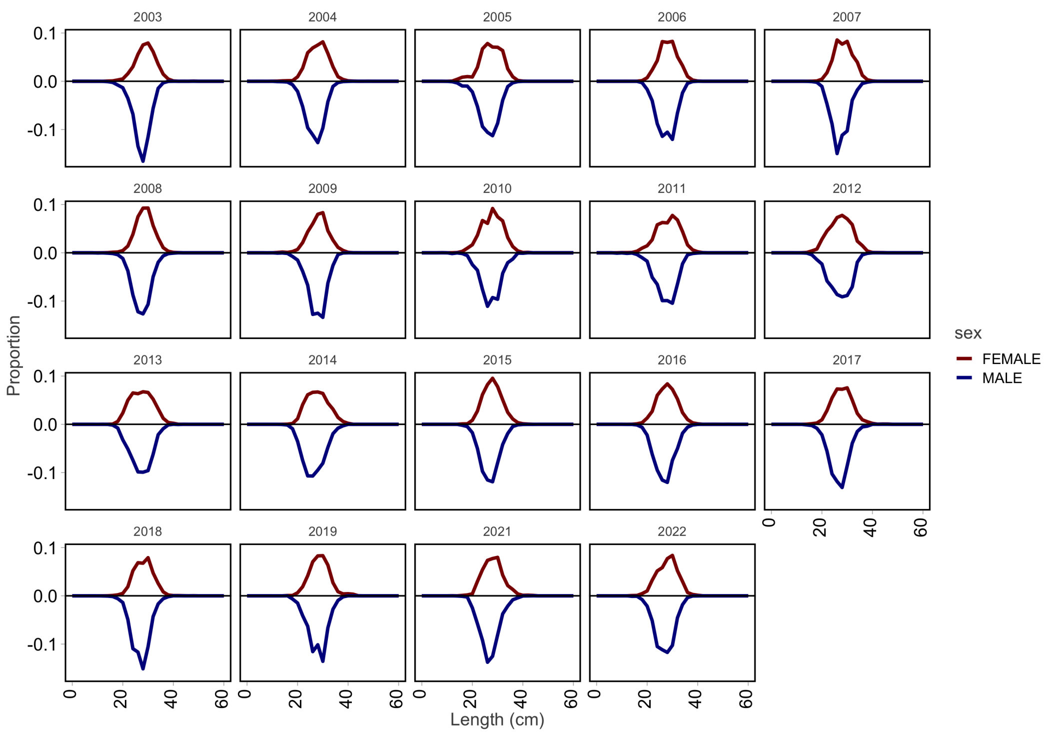


**Figure 9:** Length-composition of males and females for the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS).

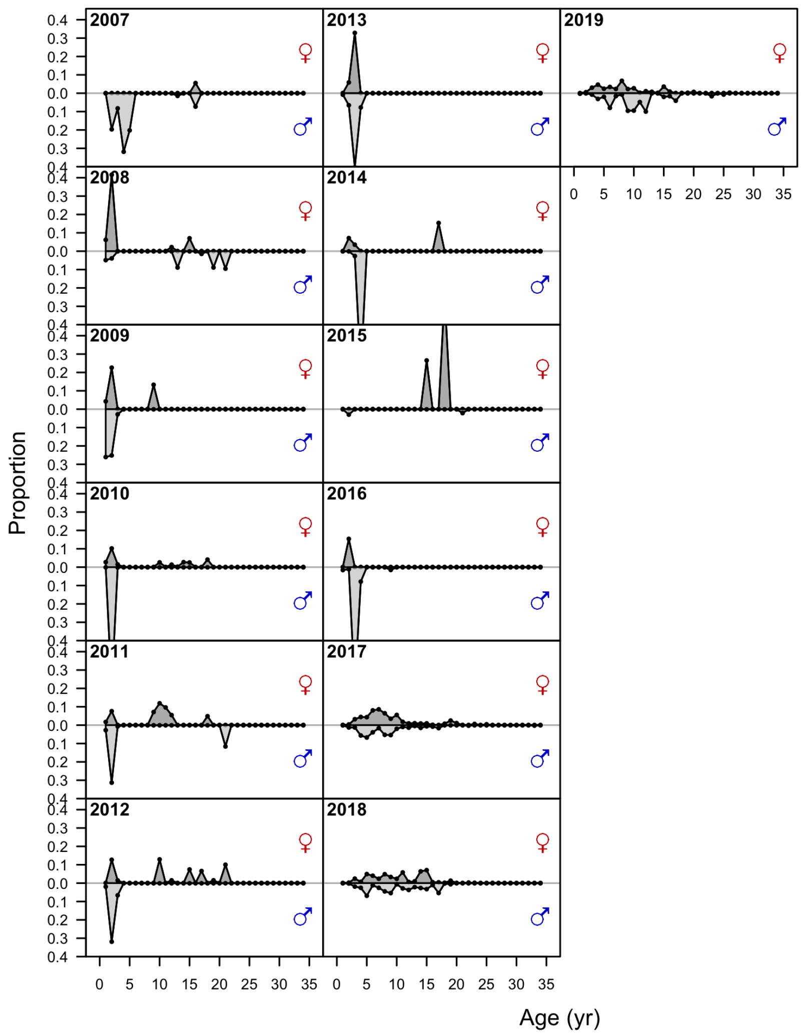


**Figure 10:** Age composition data for males and females for the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS). Rex Sole were not randomly sampled for aging prior to 2017.

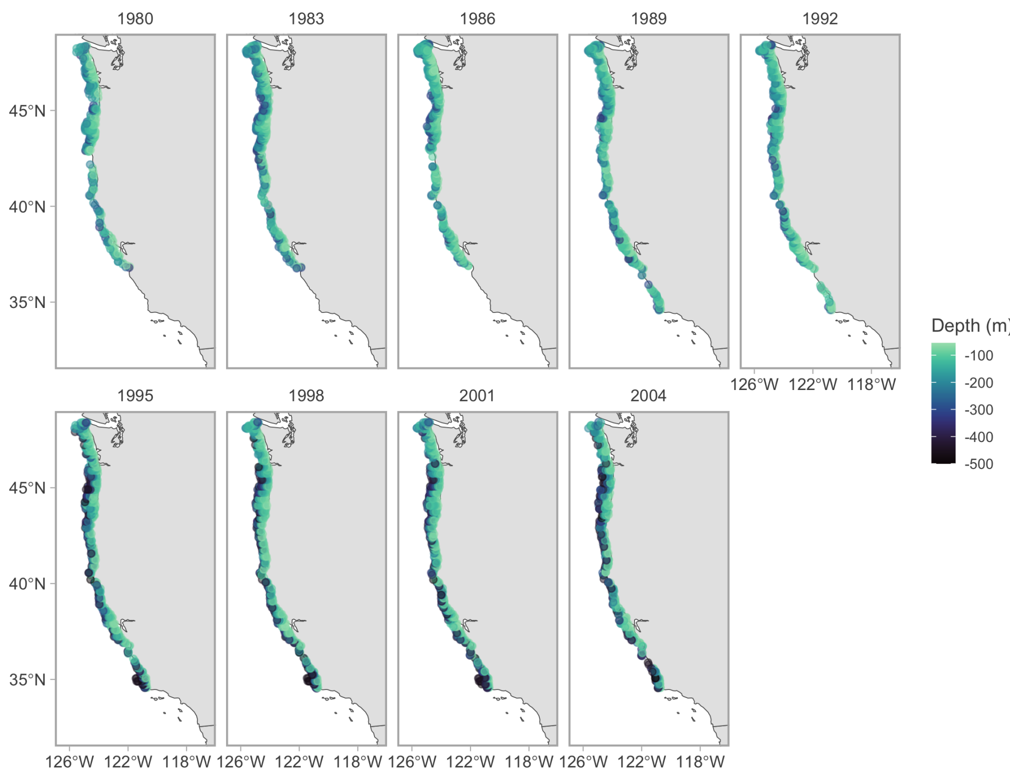


**Figure 11:** Sampling locations and depth for all years of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey), split between the Early and Late periods used for the length composition calculation.

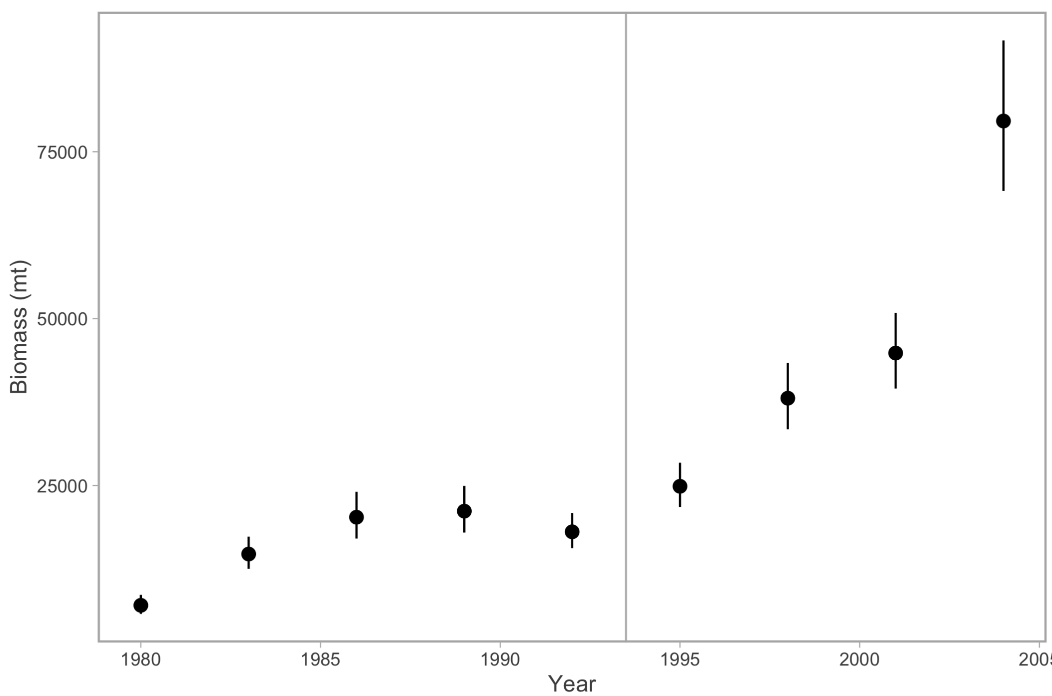


**Figure 12:** Model-based (sdmTMB) index of abundance for the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey). While the index was calculated as a single time-series, the vertical line represents the split between Early and Late Triennial periods used for the length composition calculation.

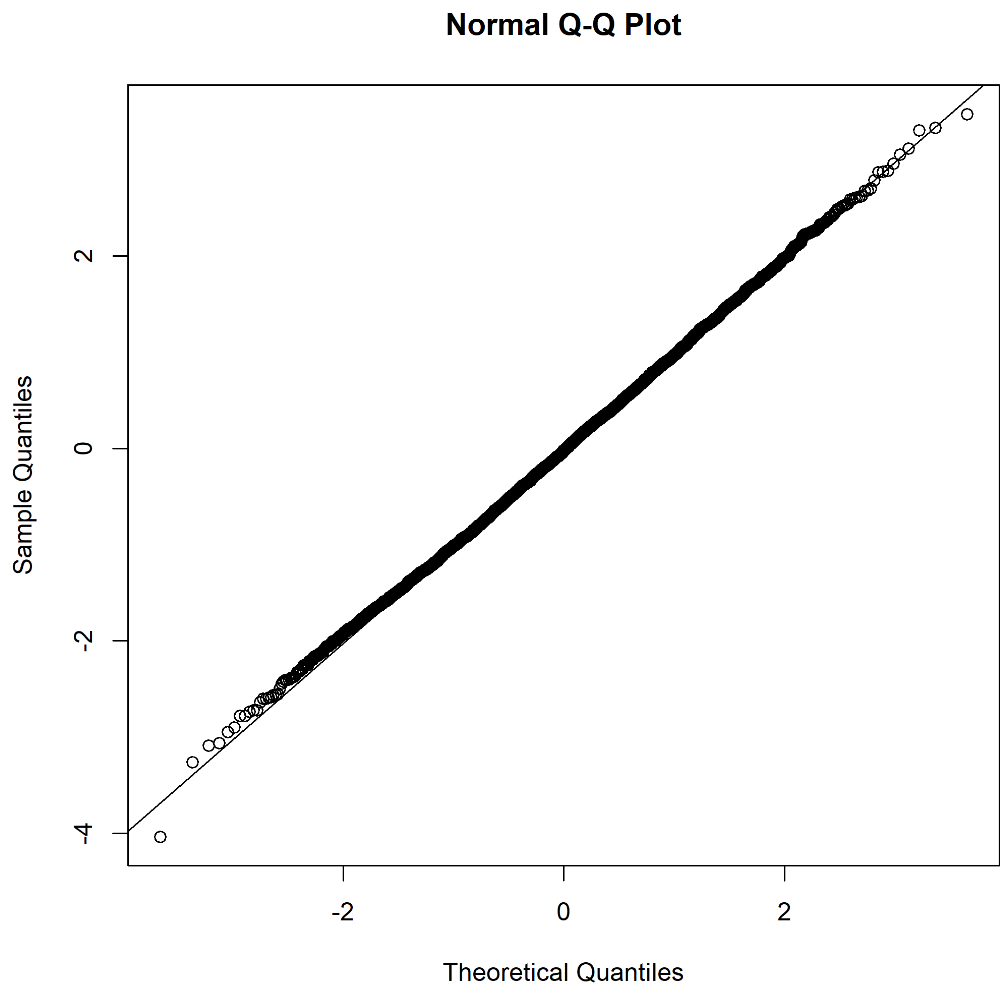


**Figure 13:** QQ plot for the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

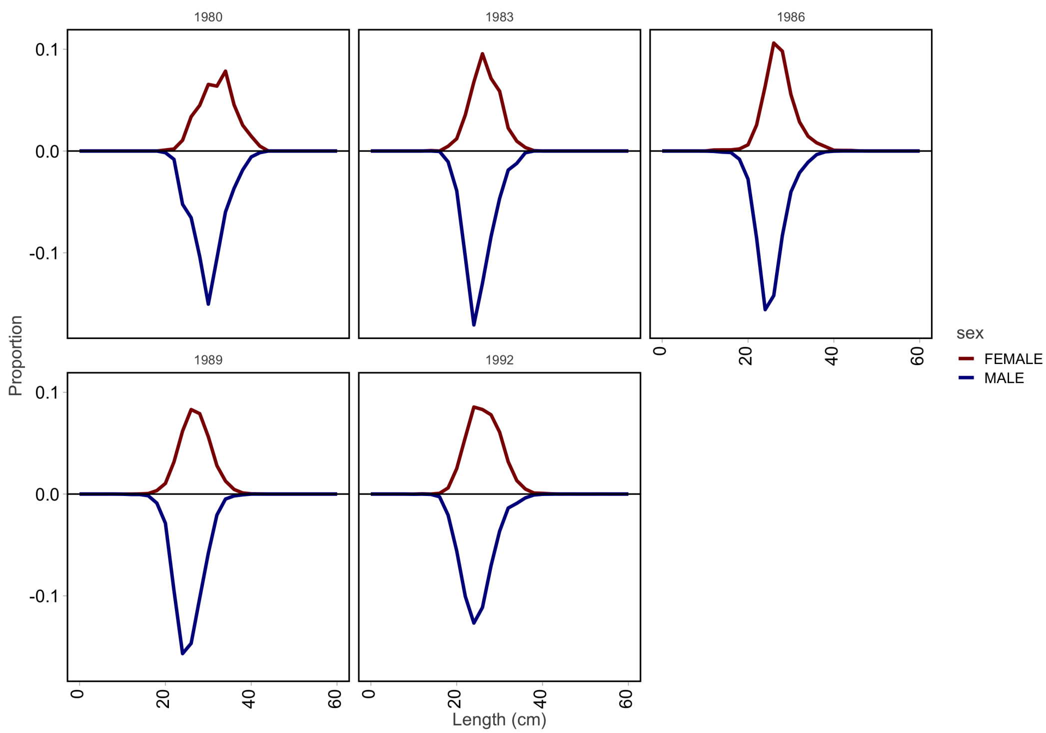


**Figure 14:** Length-composition of males and females for the Early AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

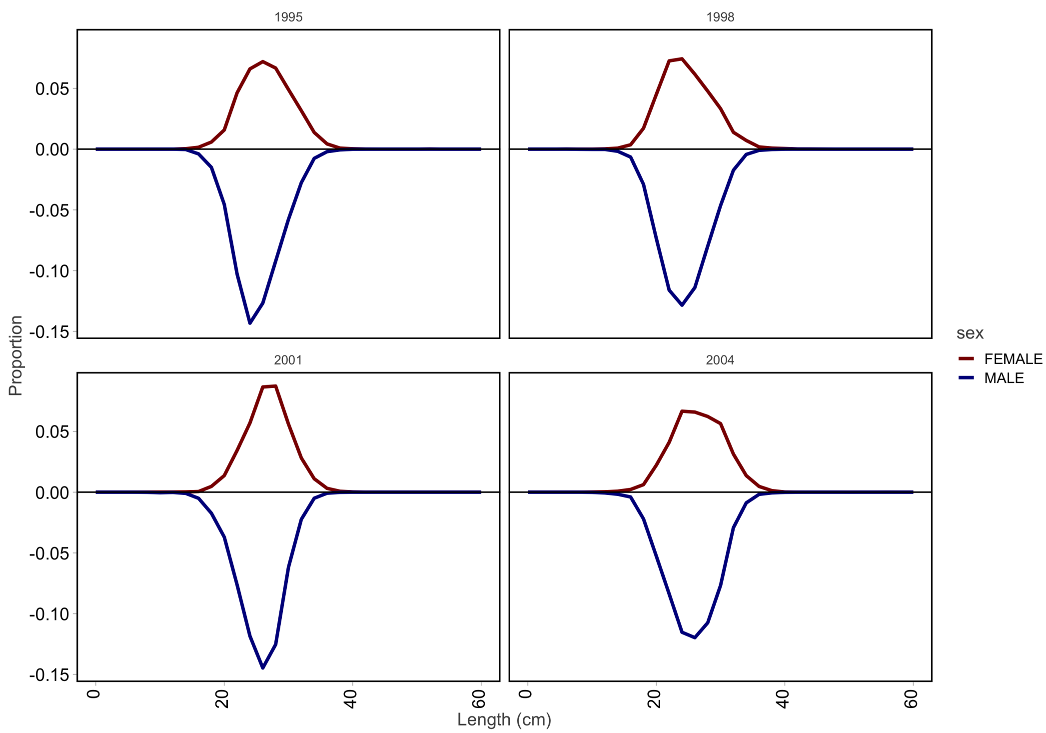


**Figure 15:** Length-composition of males and females for the Late AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey).

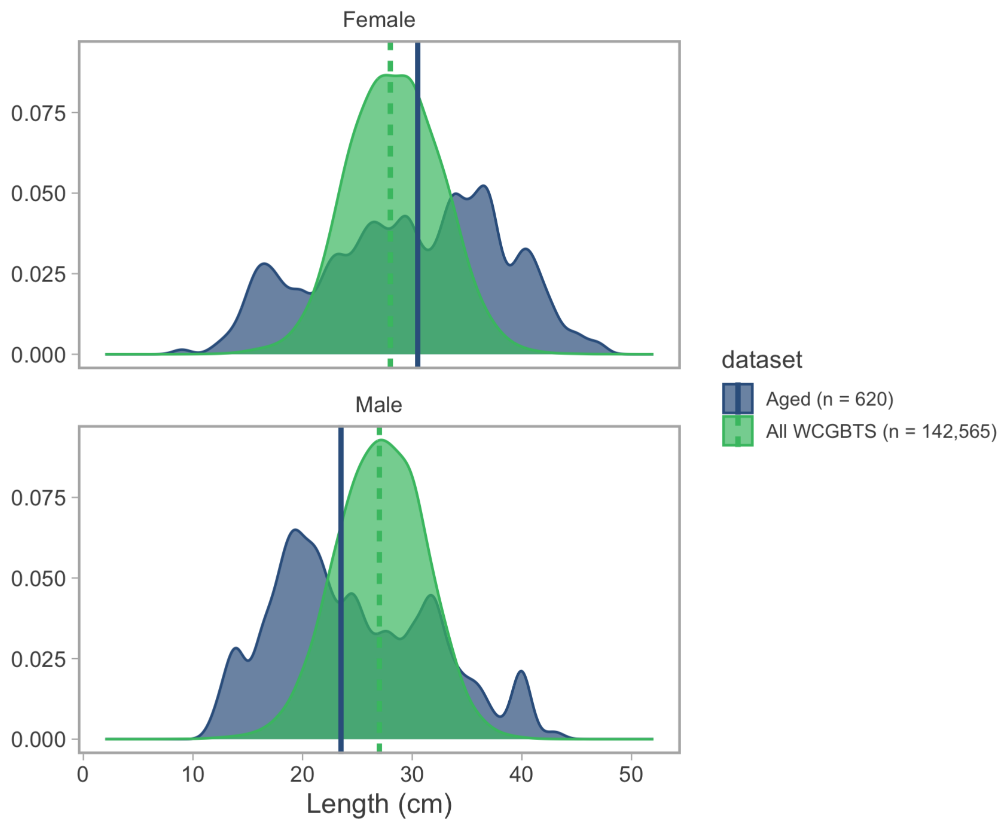


**Figure 16:** Proportion of measured lengths for all WCGBTS Rex Sole (green, n = 142,565) and for the subset of fish selected for aging (blue, n = 620). Vertical lines represent the median length for each dataset and sex.

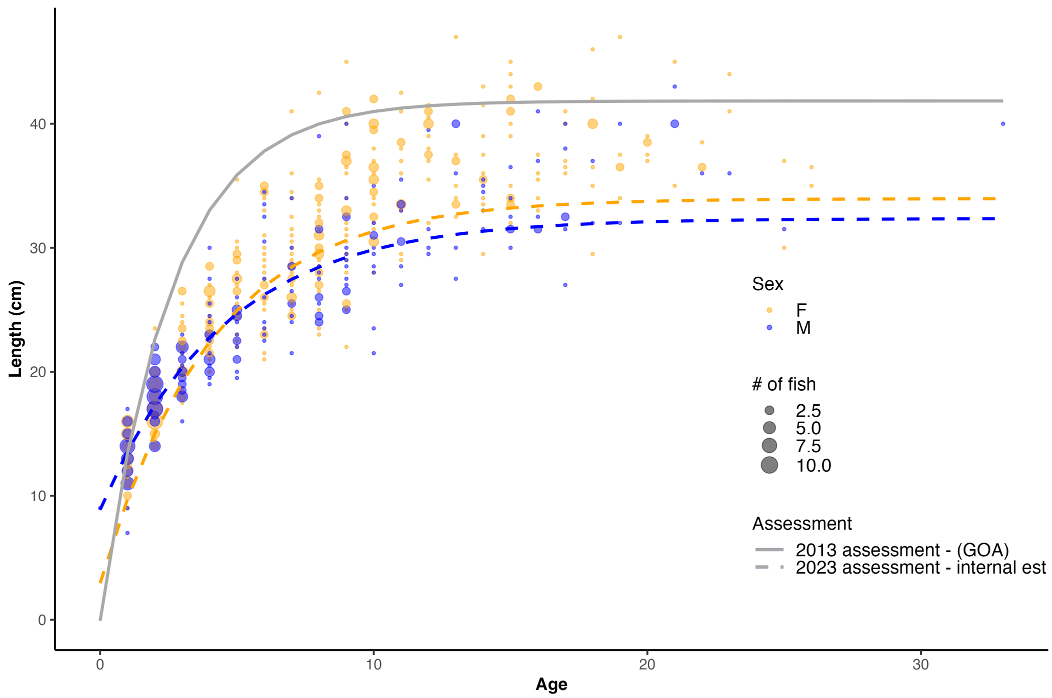


**Figure 17:** Sex-specific growth curves were fit internally in the assessment model using data from the WCGBTS. Length-at-age information for West Coast Rex Sole (WCGBTS) are compared to the growth parameters assumed in the 2013 assesment that used fixed parameters of Gulf of Alaska (GOA) Rex Sole due to a lack of age data for West Coast fish in 2013. Updated growth information used in the 2023 assessment show that West Coast Rex Sole are smaller than fish in the GOA and exhibit dimorphic growth.

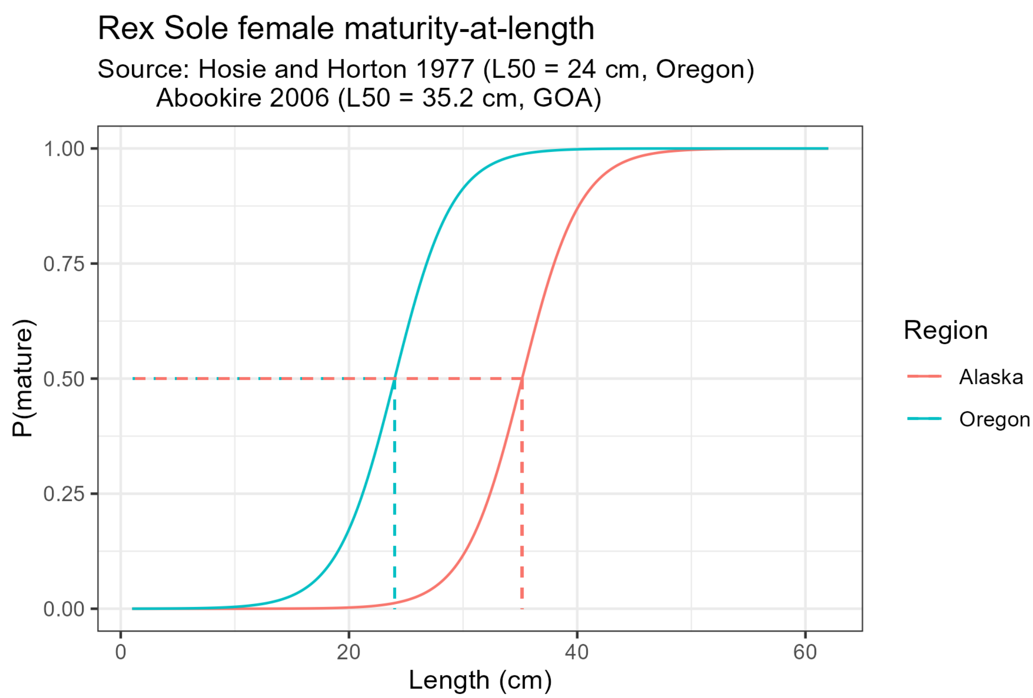


**Figure 18:** Maturity-at-length for the 2023 assessment based on $L_{50}$ of Oregon Rex Sole (Hosie and Horton 1977) and assuming a same slope as the 2013 assessment, which used maturity-at-length information from Gulf of Alaska (GOA) fish (Abookire 2006).

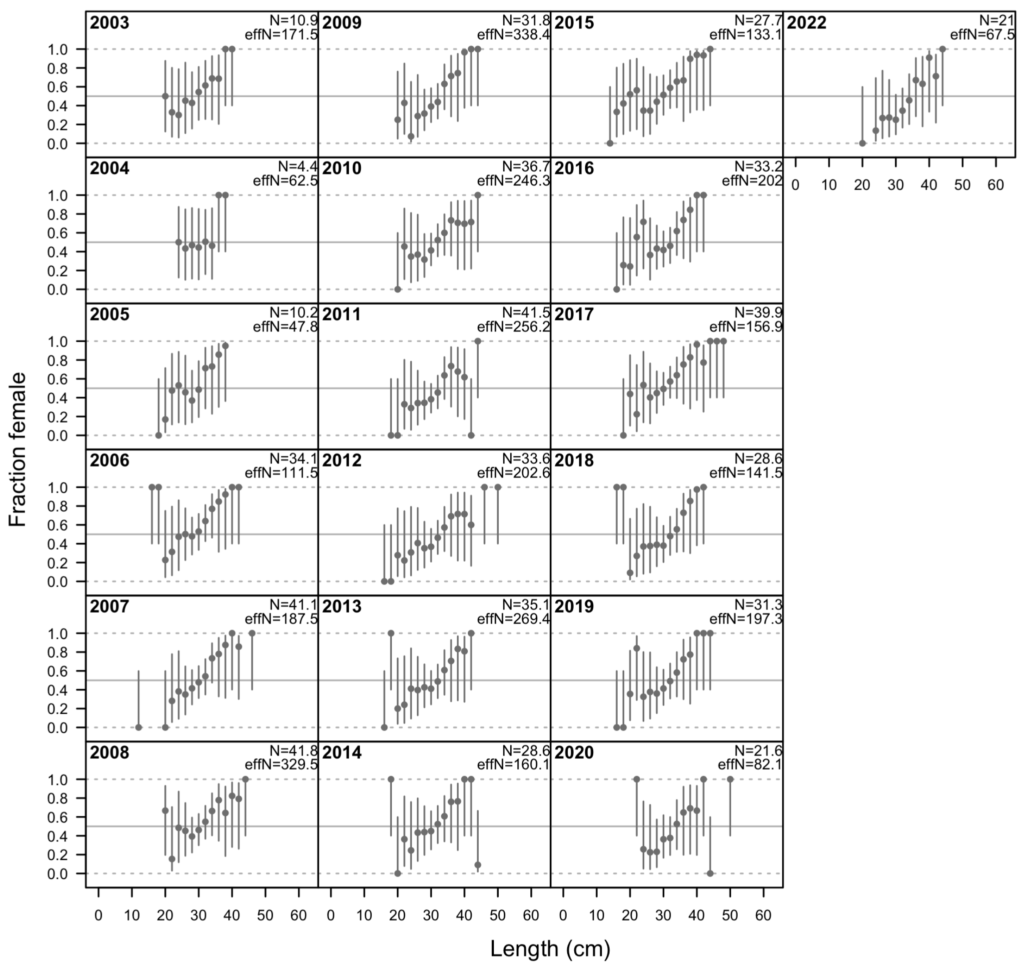


**Figure 19:** Sex ratio for the WCGBTS.

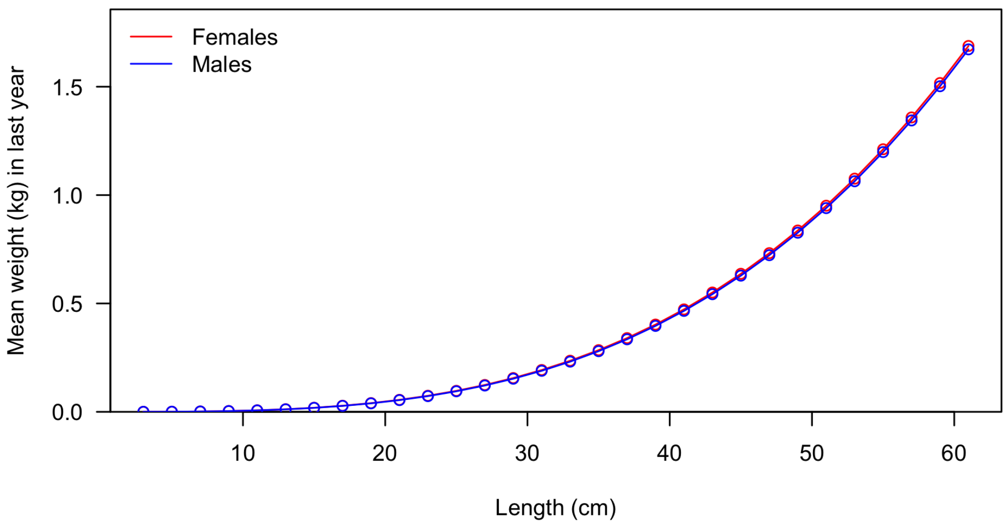


**Figure 20:** Weight-length relationship estimated using data from the WCGBTS.

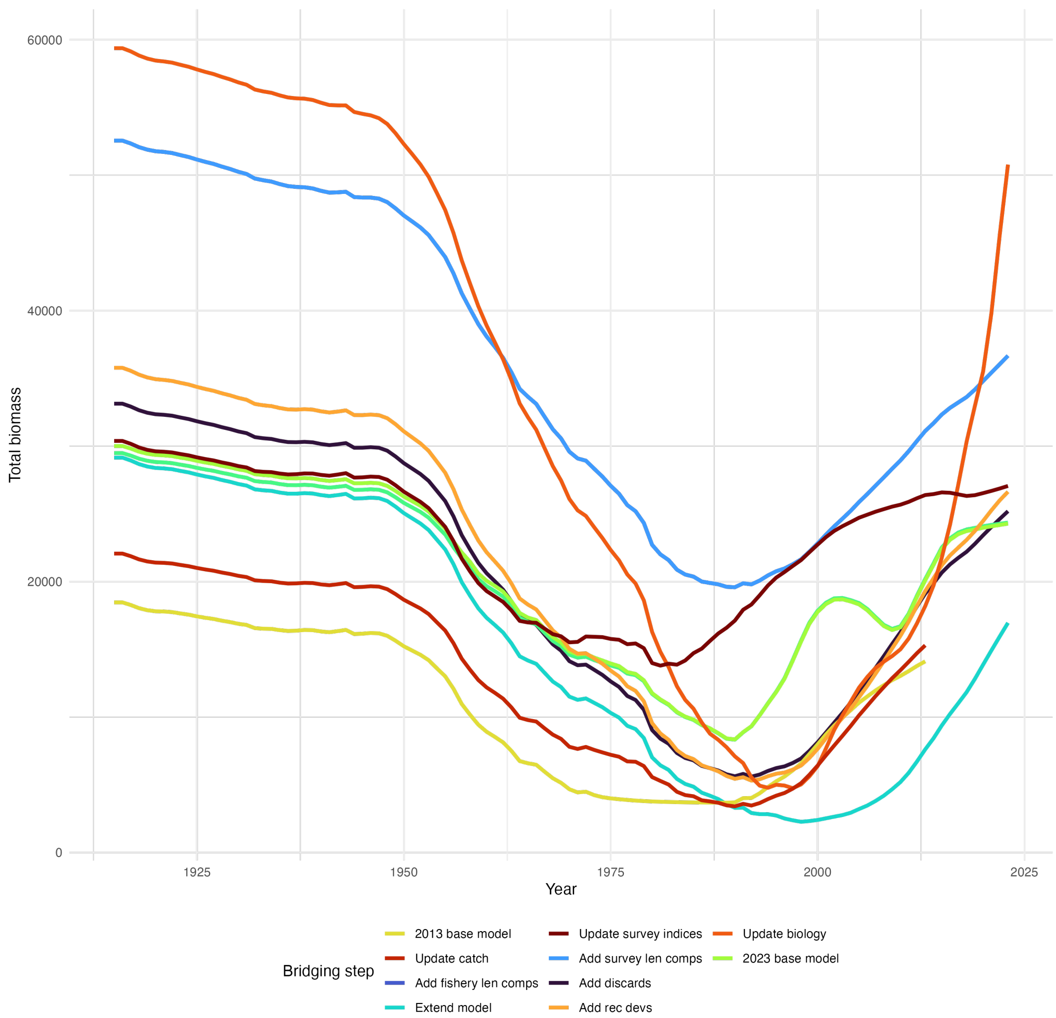


**Figure 21:** Estimated total biomass trajectories for key steps of model bridging.

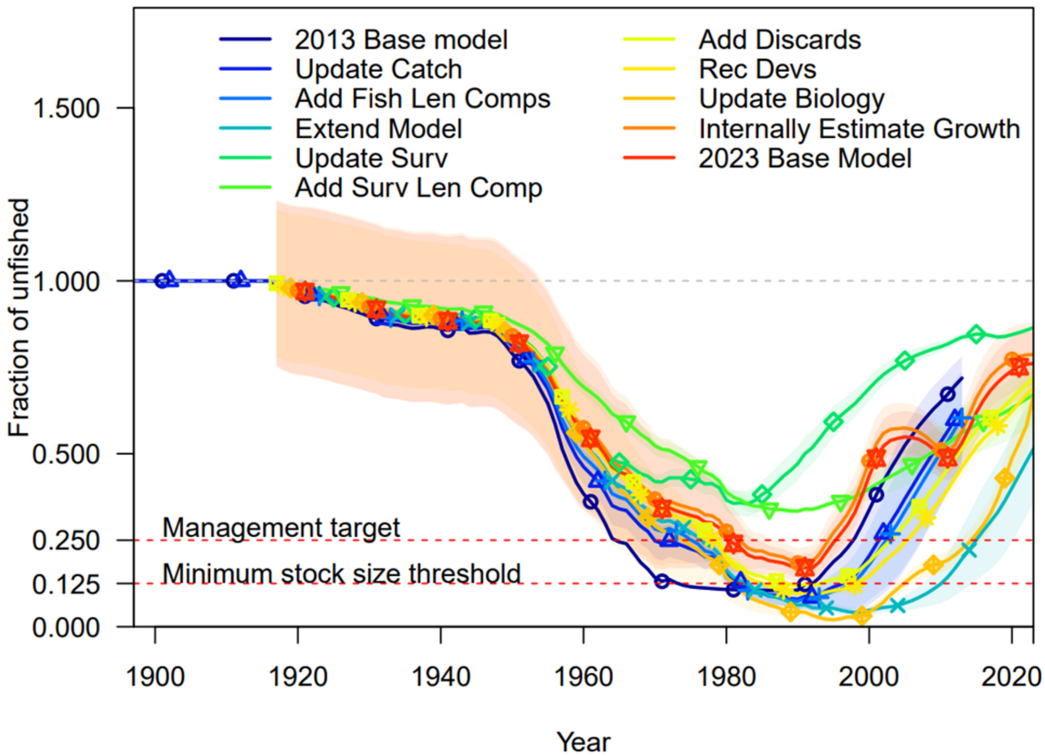


**Figure 22:** Estimated biomass ratio trajectories for key steps of model bridging.

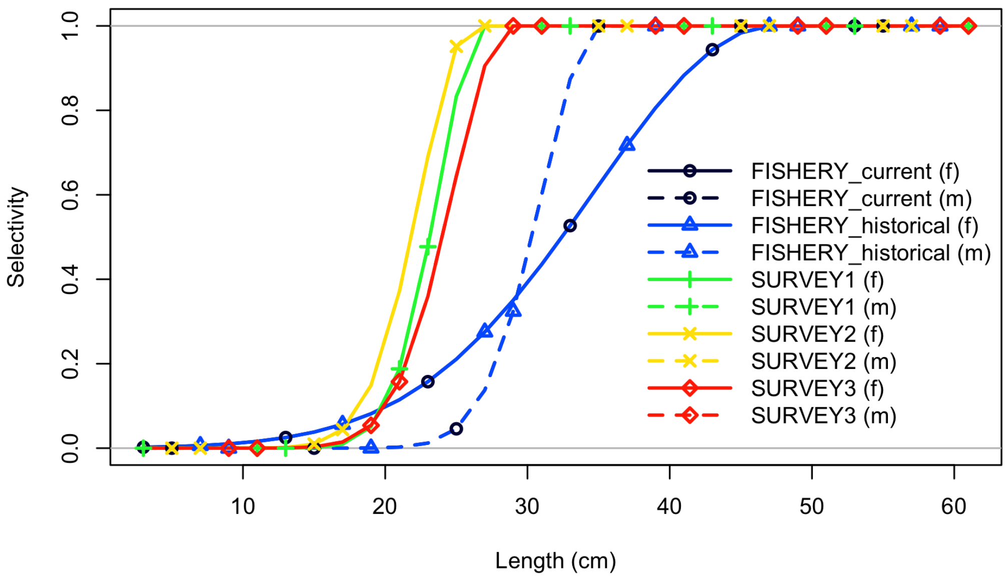


**Figure 23:** Estimated selectivity curves for the surveys and fishery fleets.

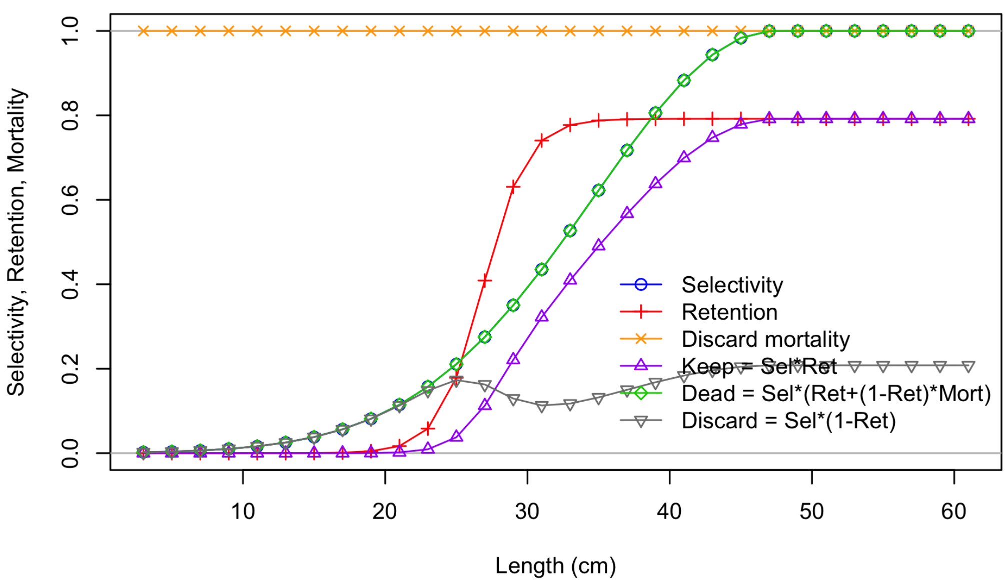


**Figure 24:** Selectivity, retention, and discard rates by length for females in the 2002-2022 fishery fleet.

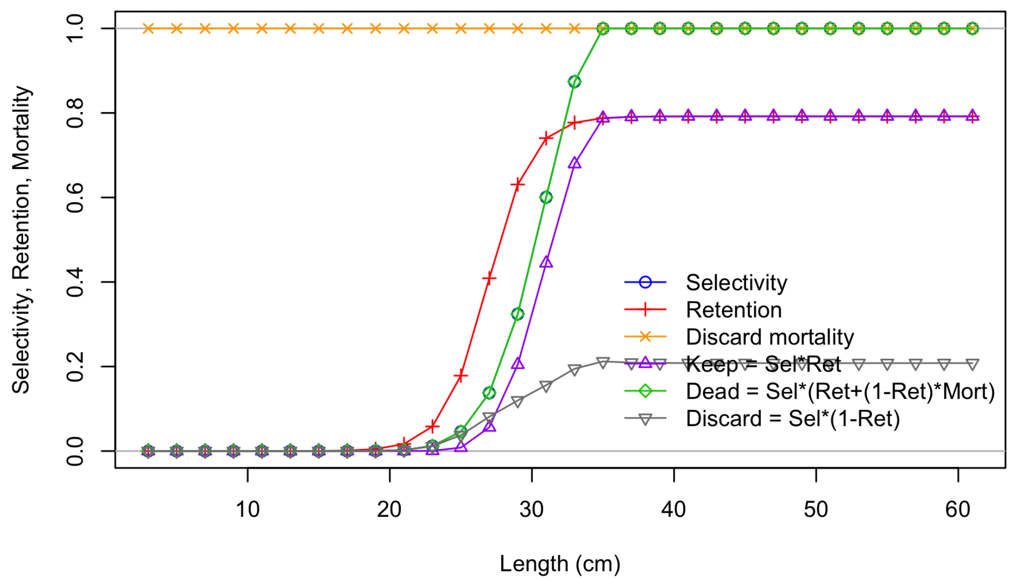


**Figure 25:** Selectivity, retention, and discard rates by length for males in the 2002-2022 fishery fleet.

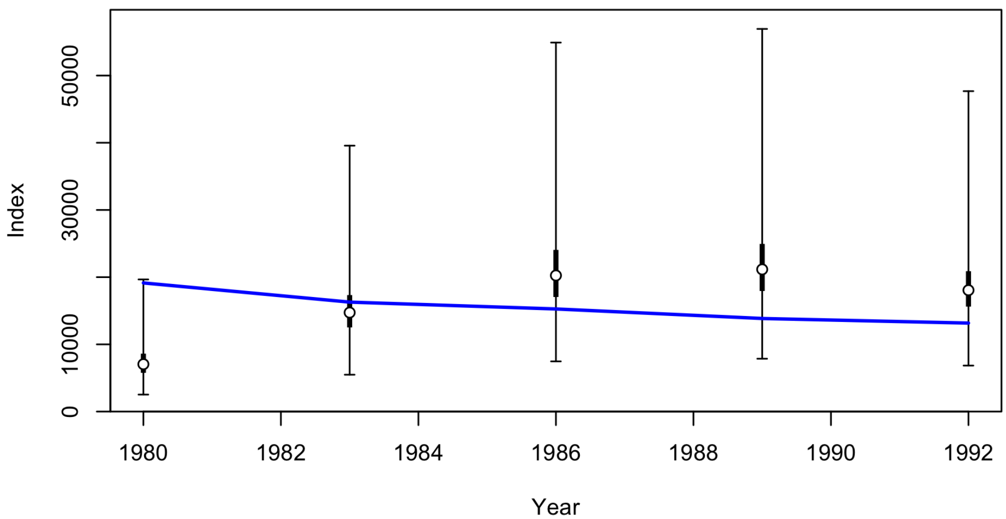


**Figure 26:** Fit to index data for the early period of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey). Lines indicate 95% uncertainty interval around index values. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty.

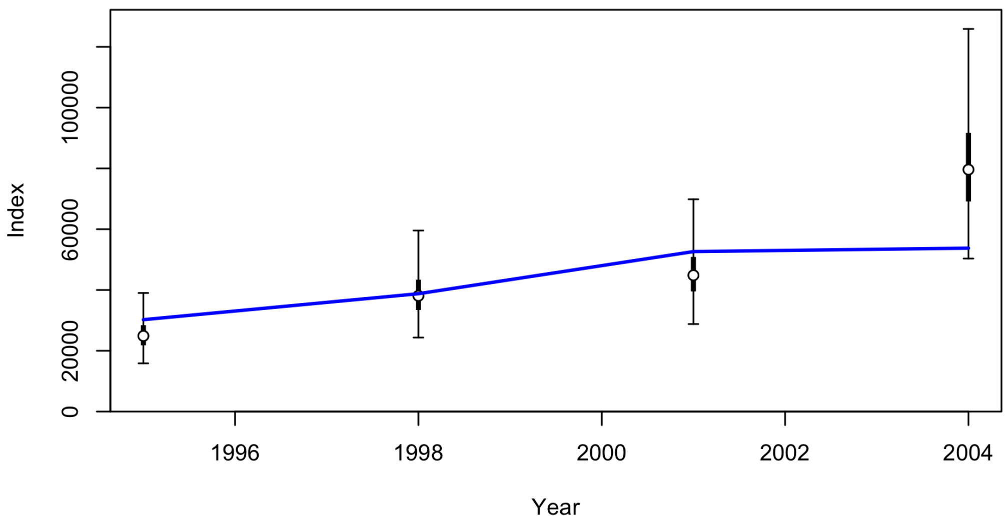


**Figure 27:** Fit to index data for the late period of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey). Lines indicate 95% uncertainty interval around index values. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty.

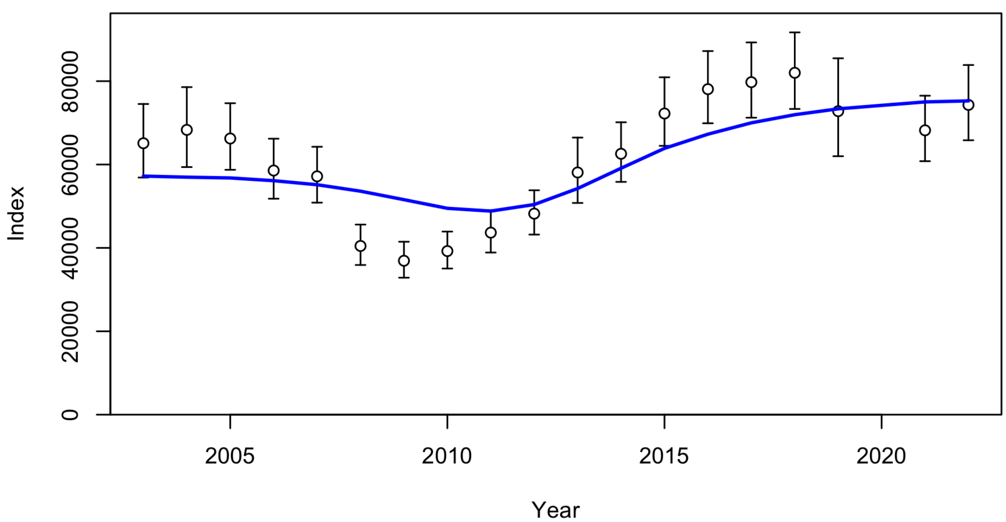


**Figure 28:** Fit to index data for the late period of the West Coast Groundfish Bottom Trawl Survey (WCGBTS). Lines indicate 95% uncertainty interval around index values.

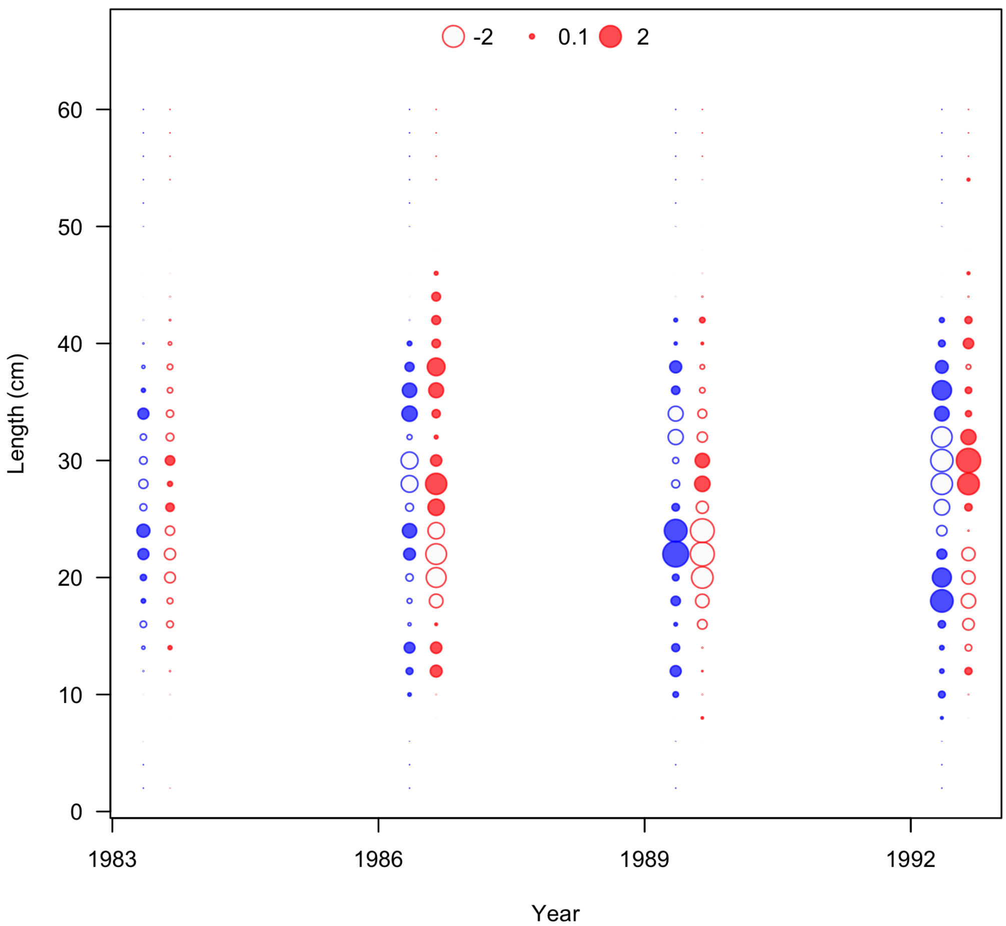


**Figure 29:** Pearson residuals for length composition from the early period of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) for males (blue) and females (red). Closed bubbles are positive residuals and open bubles are negative residuals.

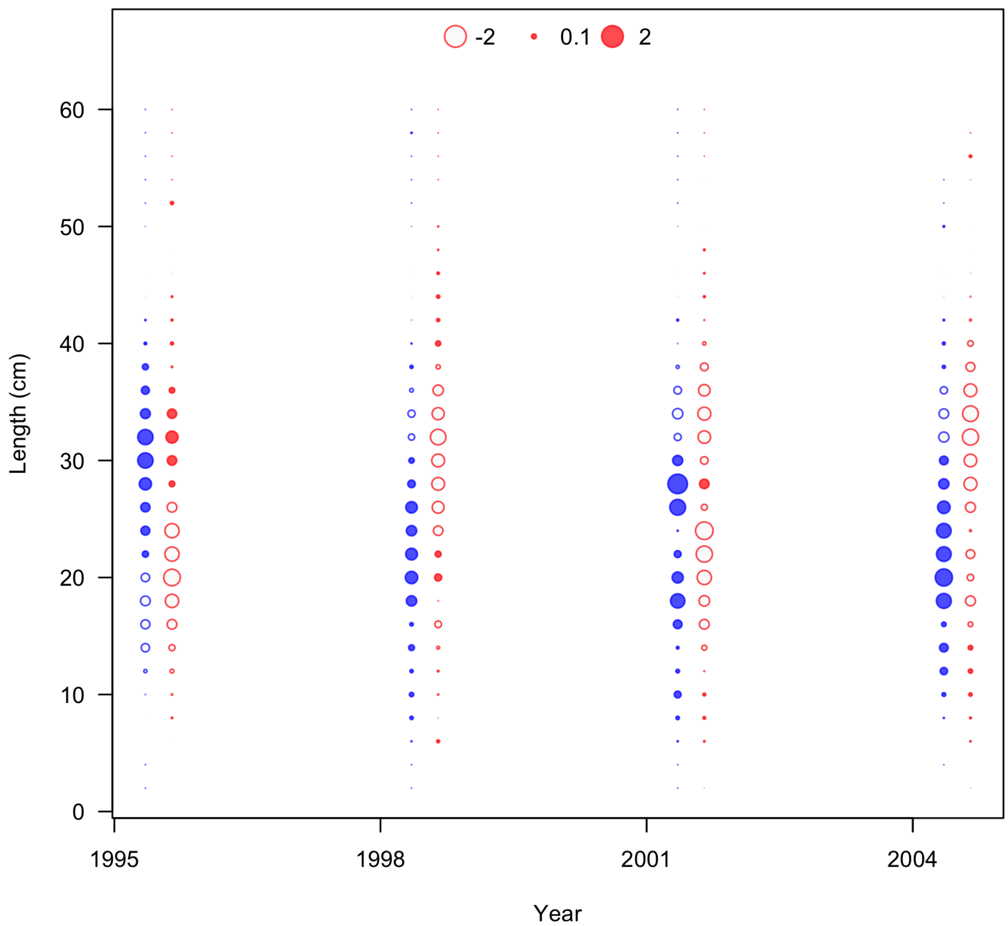


**Figure 30:** Pearson residuals for length composition from the late period of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) for males (blue) and females (red). Closed bubbles are positive residuals and open bubles are negative residuals.

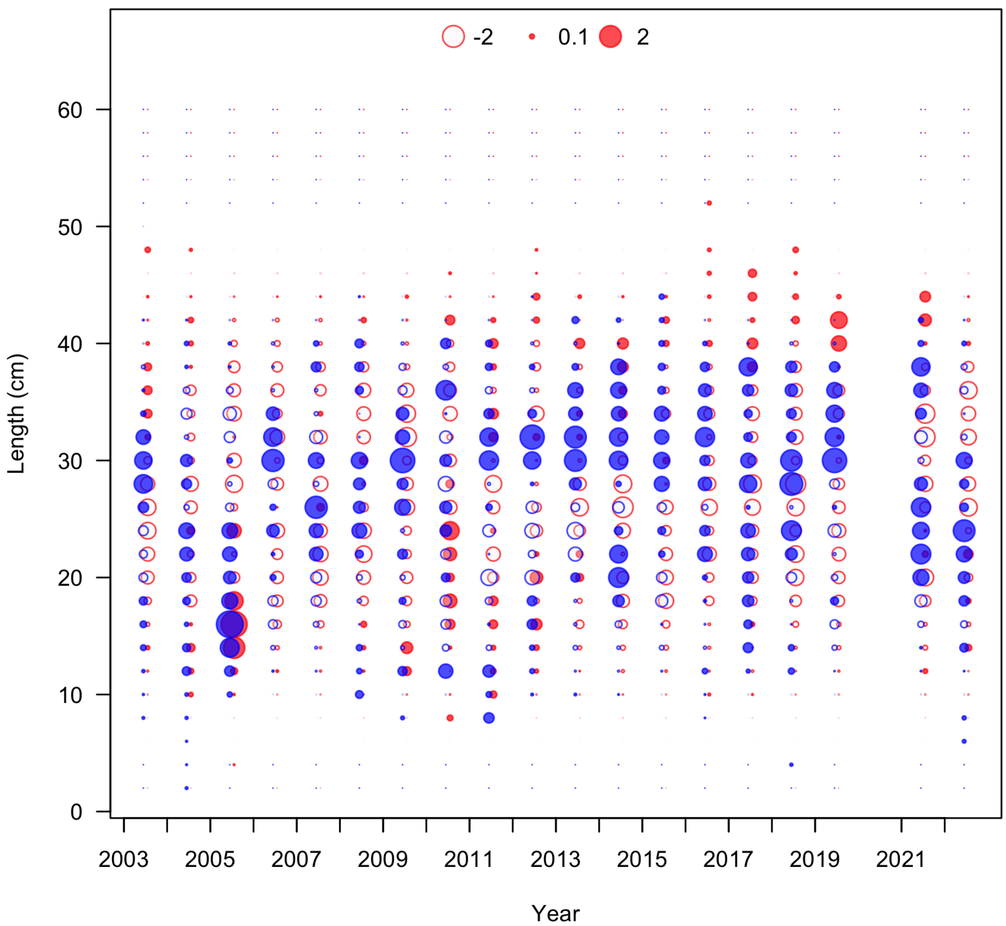


**Figure 31:** Pearson residuals for length composition from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) for males (blue) and females (red). Closed bubbles are positive residuals and open bubles are negative residuals.

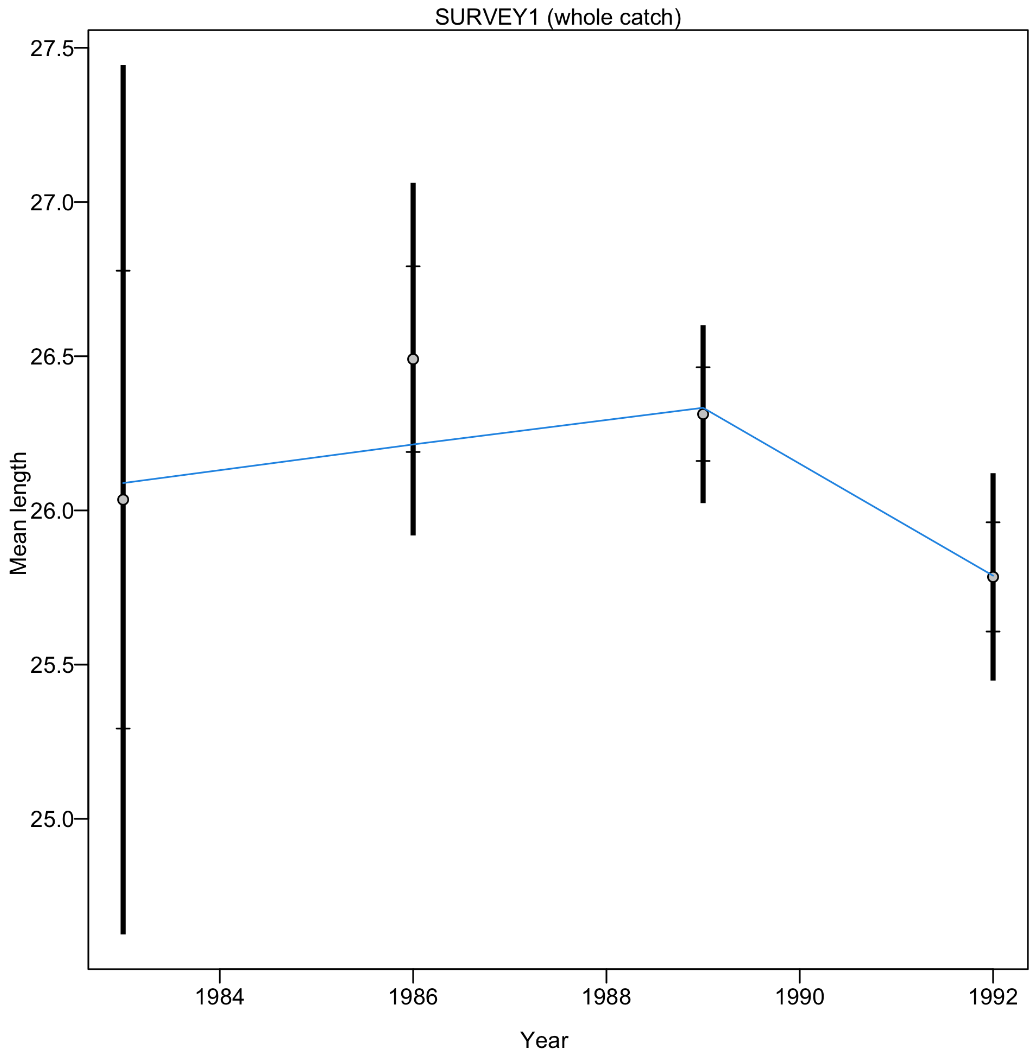


**Figure 32:** Fit to mean length from the early period of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) with 95% confidence intervals.

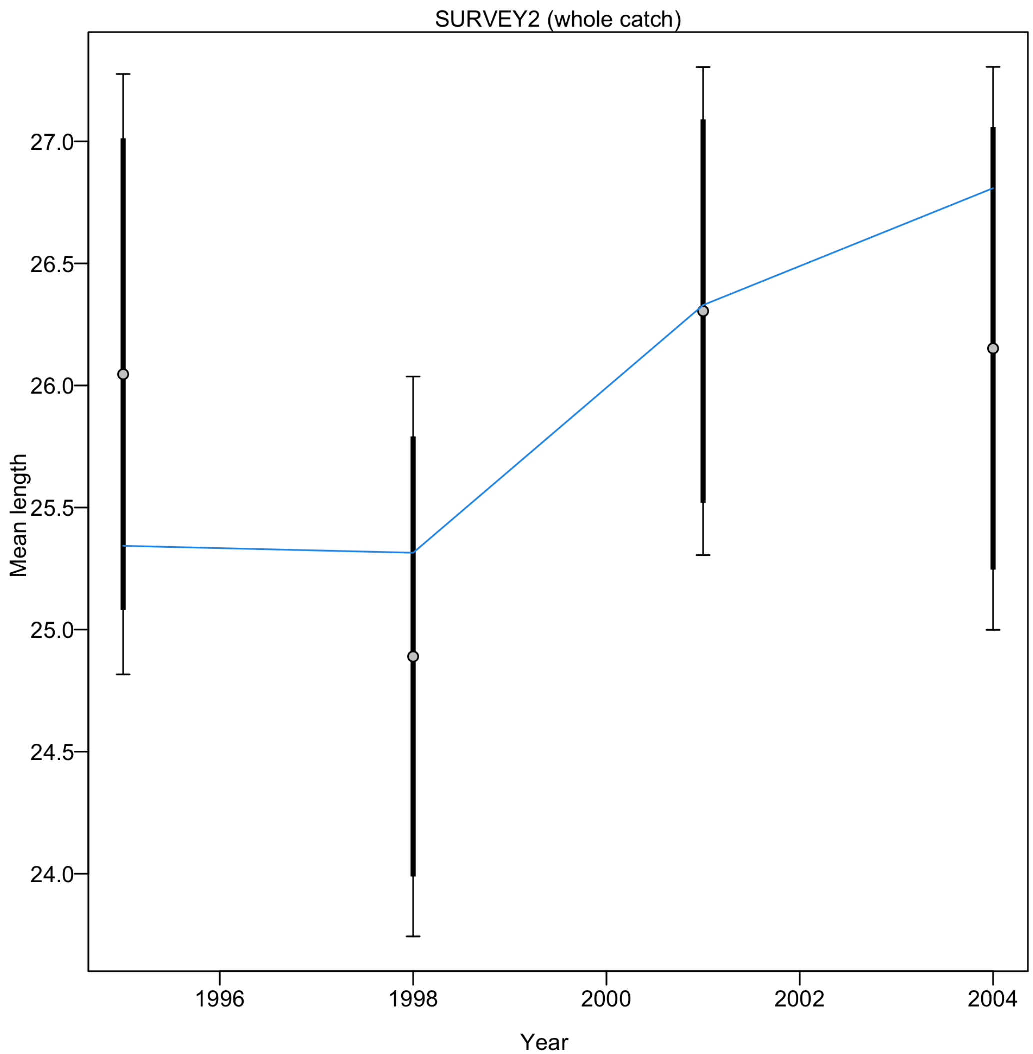


**Figure 33:** Fit to mean length from the late period of the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) with 95% confidence intervals.

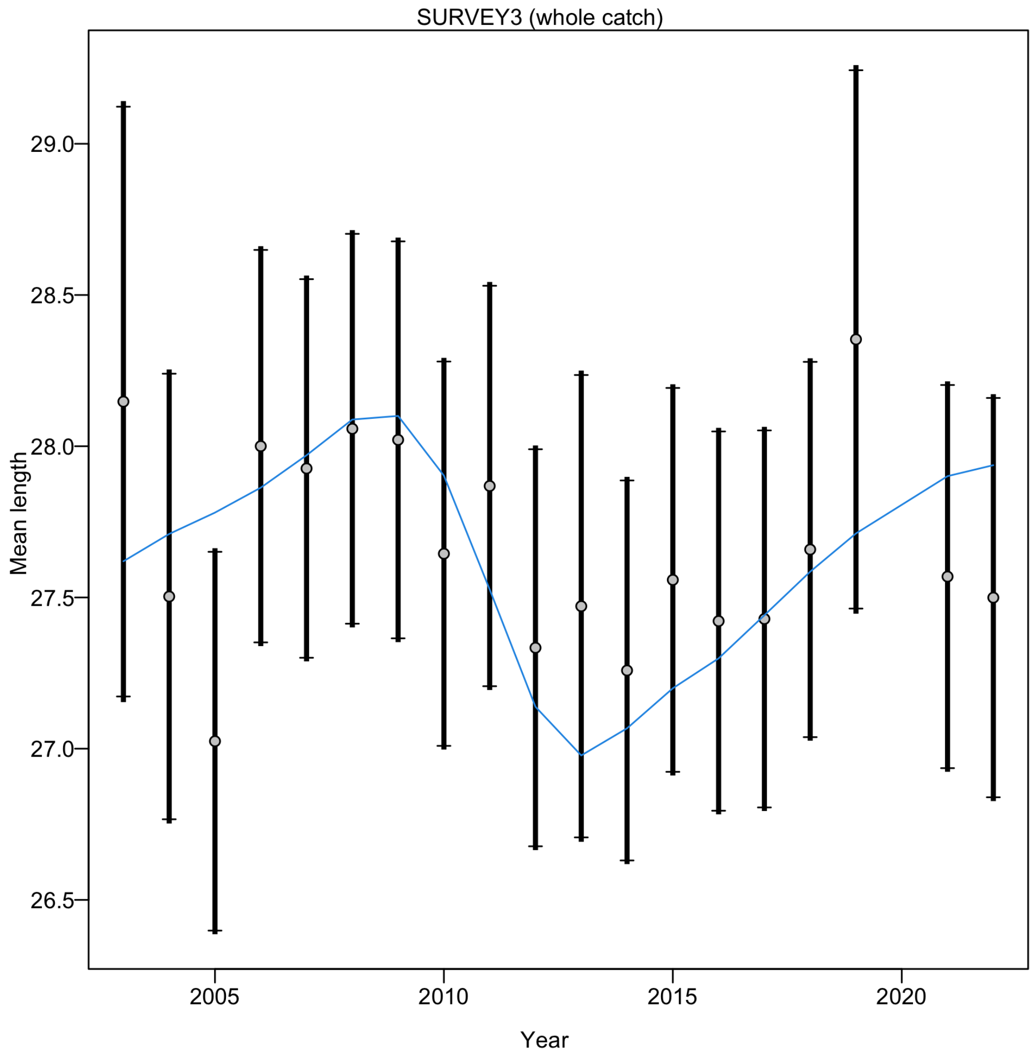


**Figure 34:** Fit to mean length from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) with 95% confidence intervals.

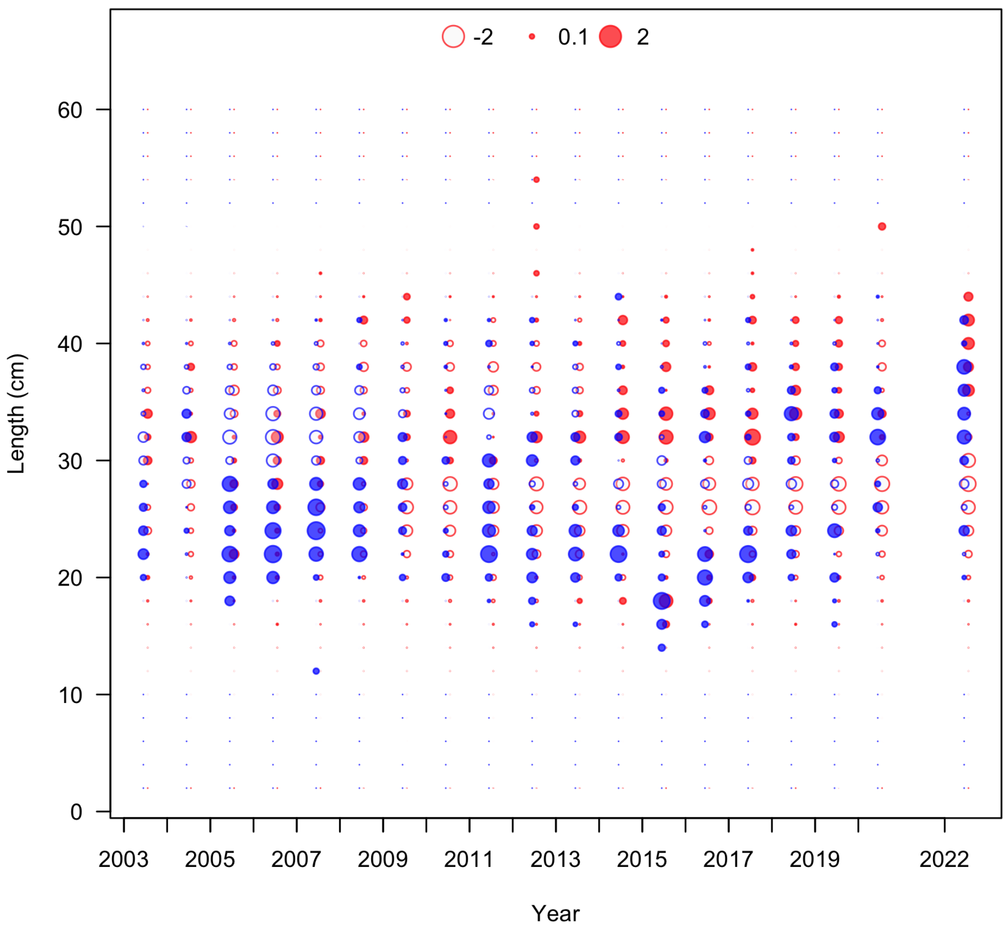


**Figure 35:** Pearson residuals for length composition from the fishery (after 2003) for males (blue) and females (red). Closed bubbles are positive residuals and open bubles are negative residuals.

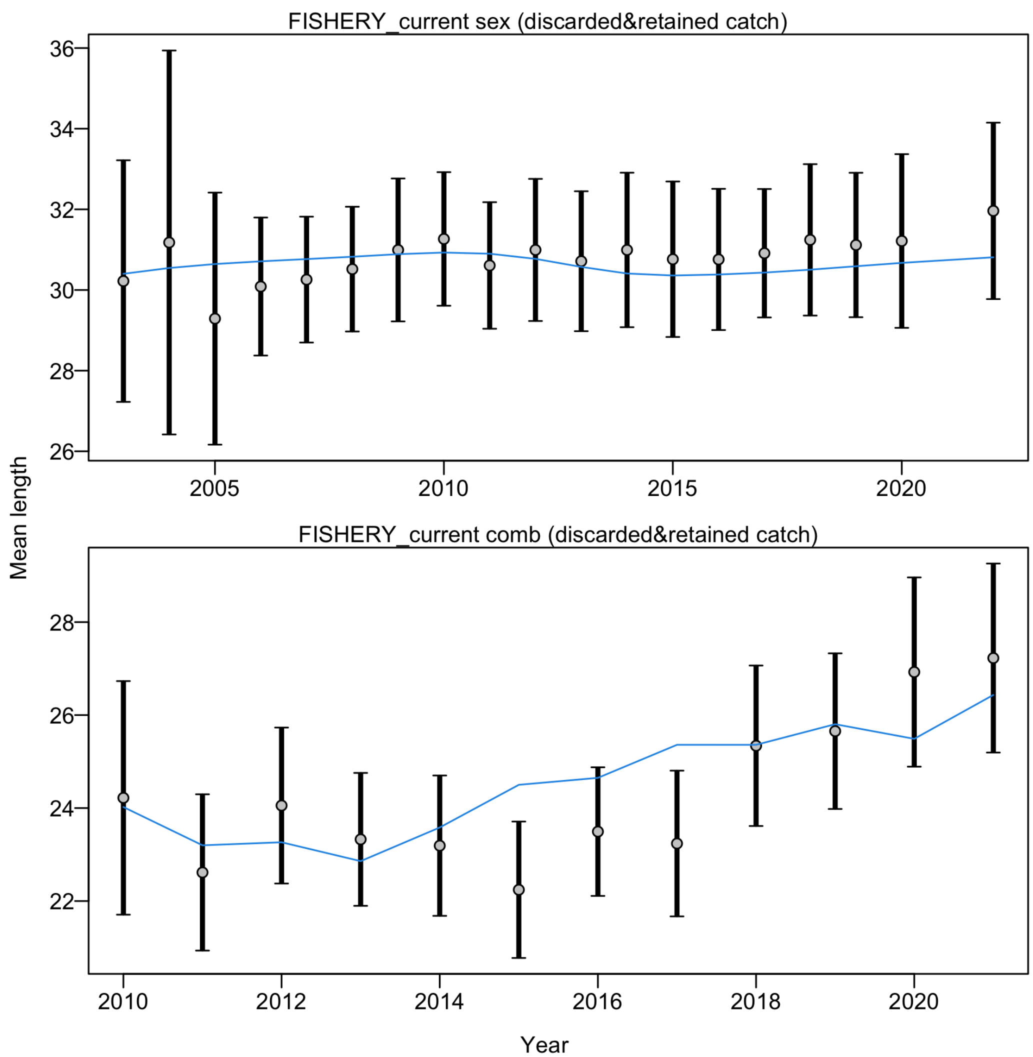


**Figure 36:** Fit to mean length from the fishery with 95% confidence intervals.

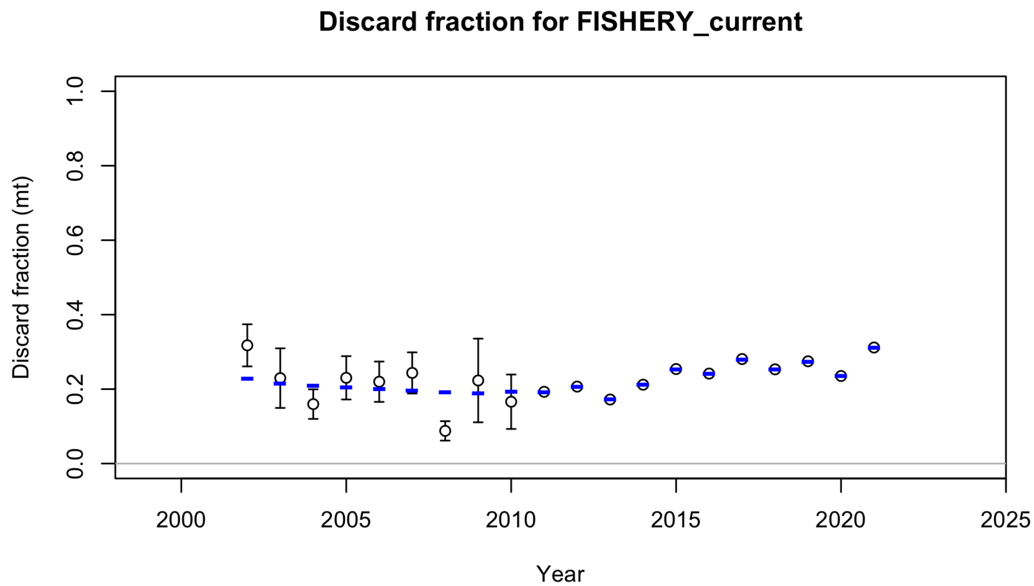


**Figure 37:** Fit to the discard rates for the current fleet for Rex Sole.

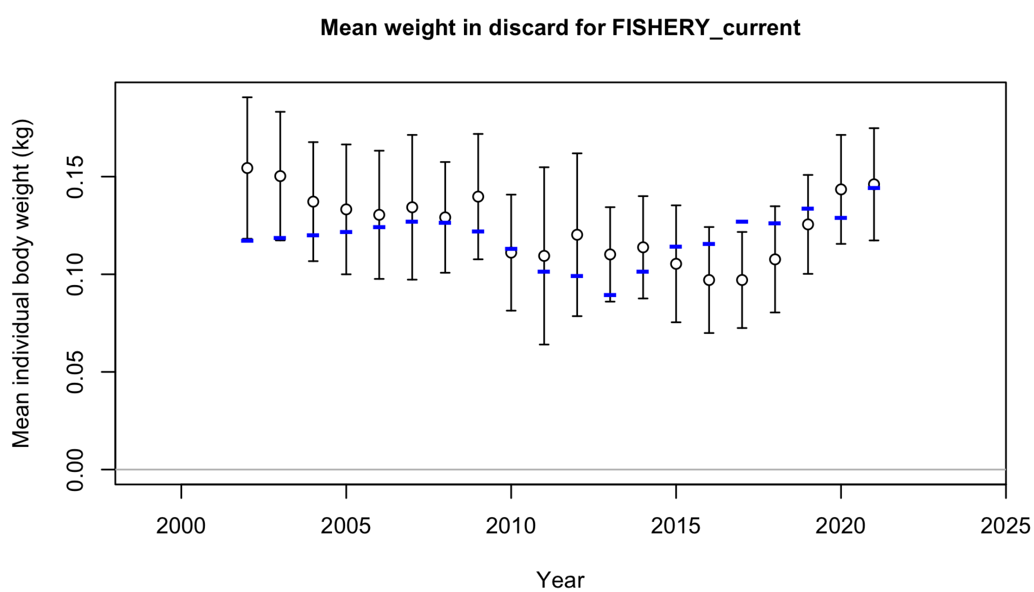


**Figure 38:** Fit to mean body weights of discarded fish for the current fishery in Rex Sole.

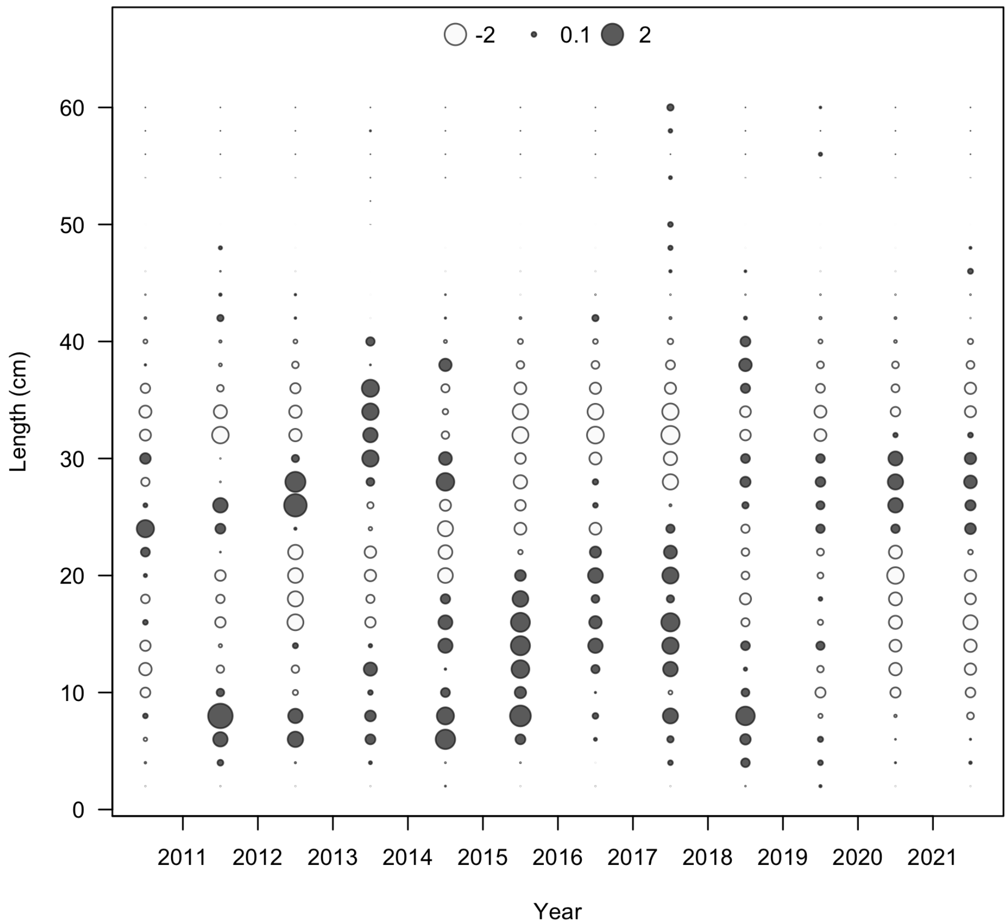


**Figure 39:** Pearson residuals, discard, current fishery (max=7.8). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

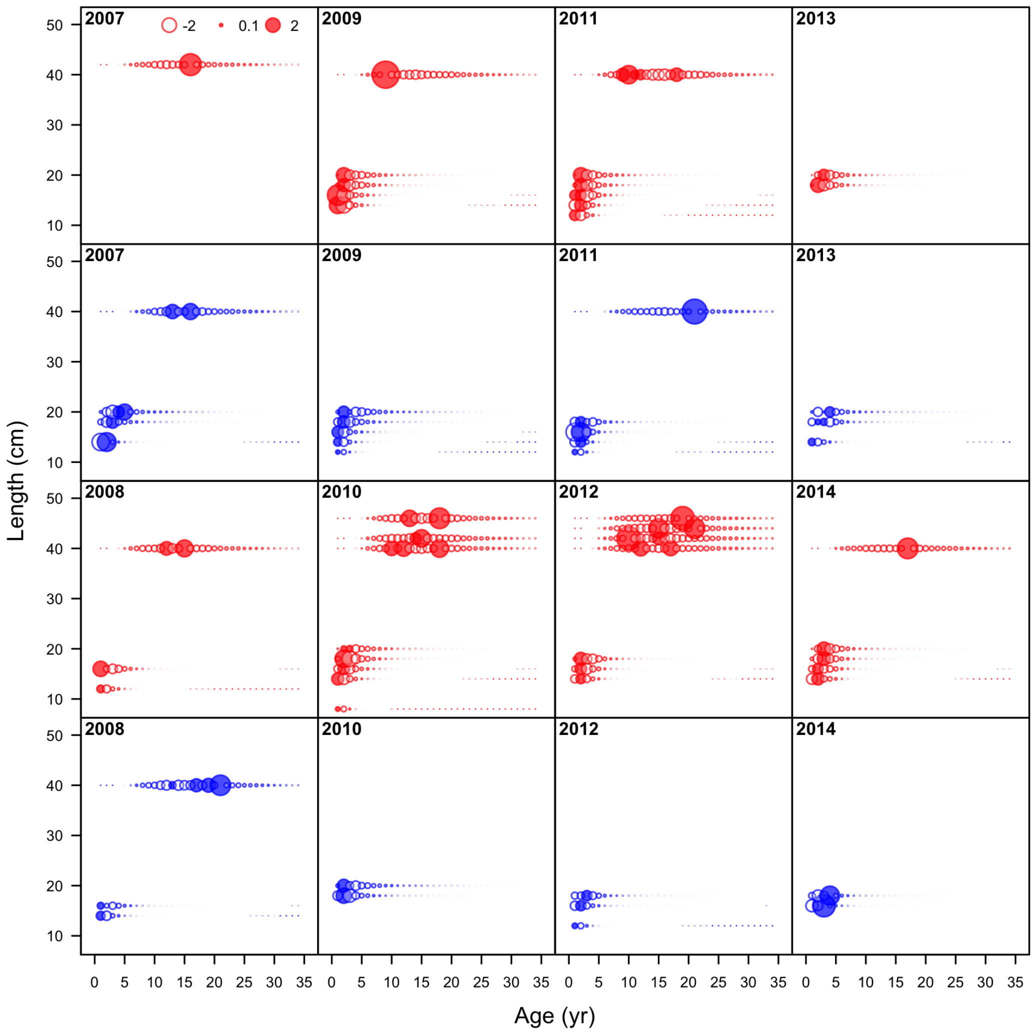


**Figure 40:** Pearson residuals for conditional age-at-length data from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) for males (blue) and females (red) in the years 2007 to 2014 (max = 29.58). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

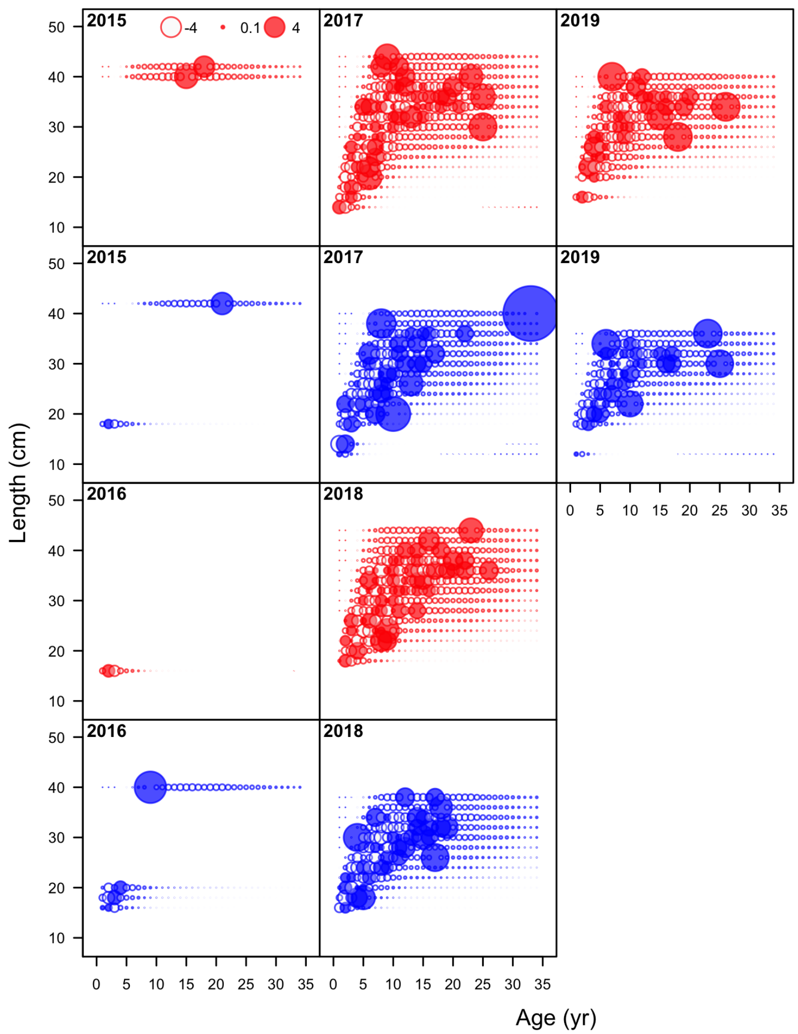


**Figure 41:** Pearson residuals for conditional age-at-length data from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) for males (blue) and females (red) in the years 2015 to 2019 (max = 29.58). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

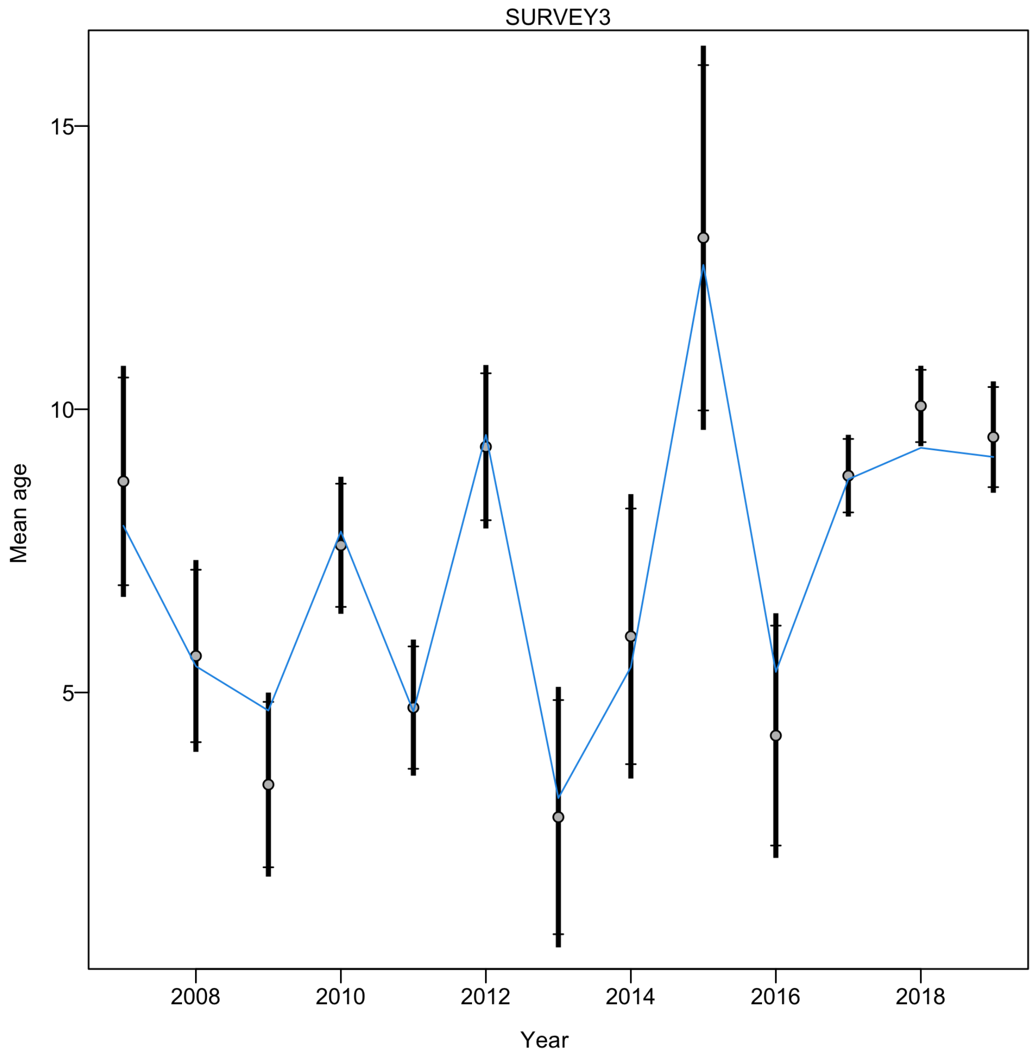


**Figure 42:** Fit to the mean age from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) with 95% confidence intervals.

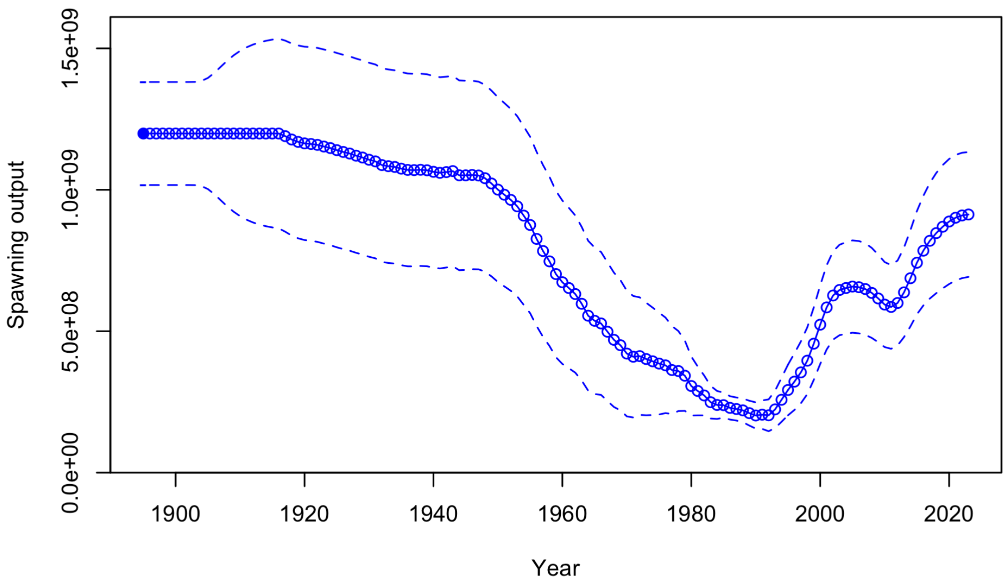


**Figure 43:** Estimated time series of spawning output.

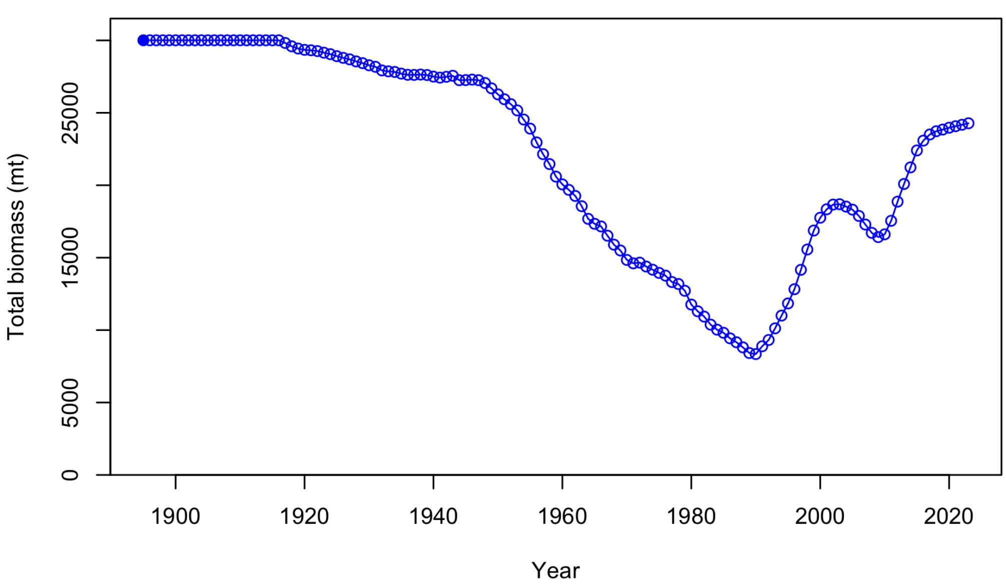


**Figure 44:** Estimated time series of total biomass (mt).

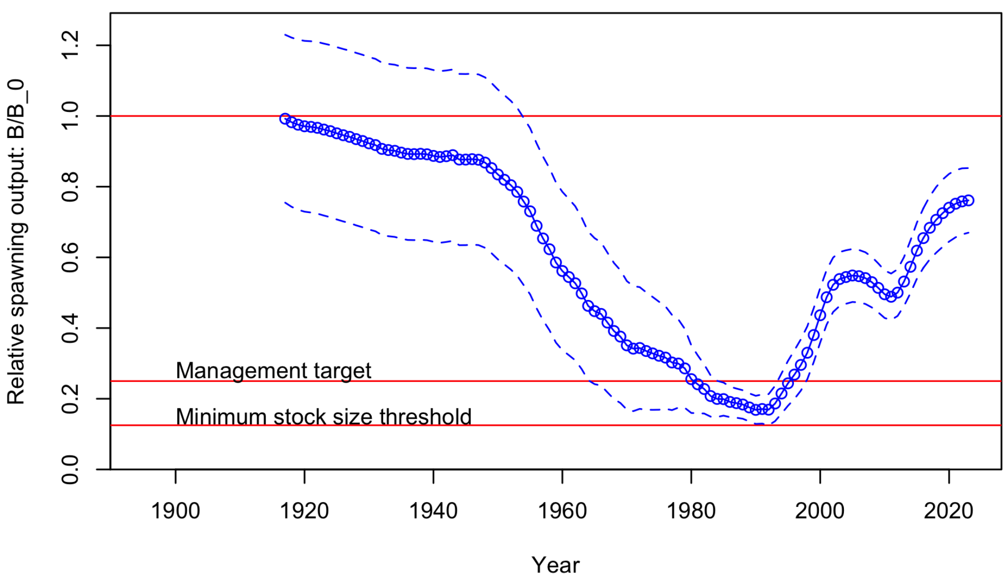


**Figure 45:** Estimated time series of spawning output, relative to unfished equilibrium.

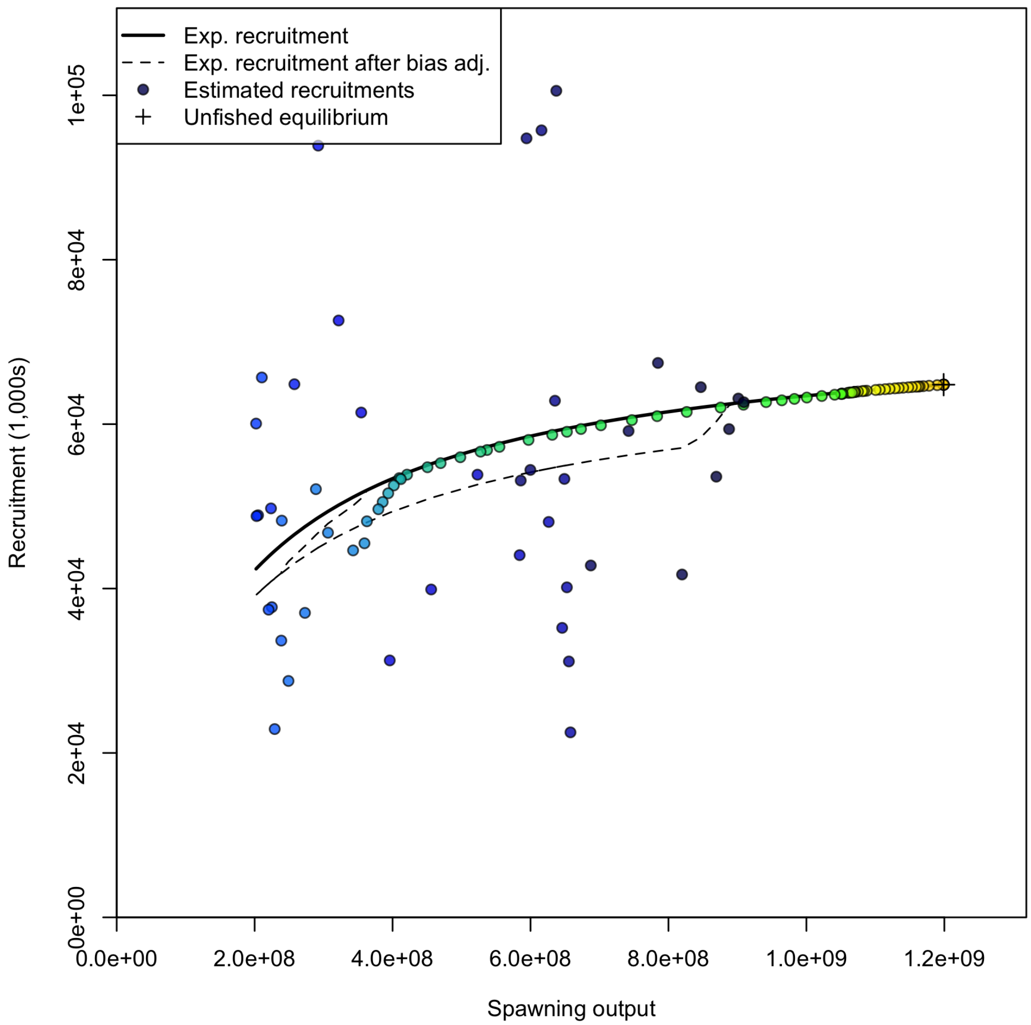


**Figure 46:** Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

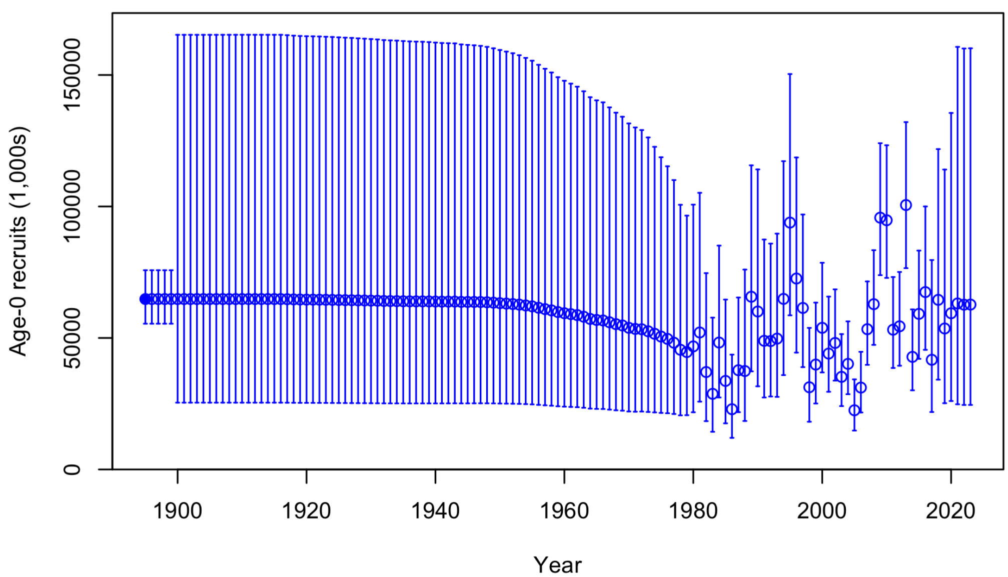


**Figure 47:** Estimated time series of age-0 recruits (1000s).

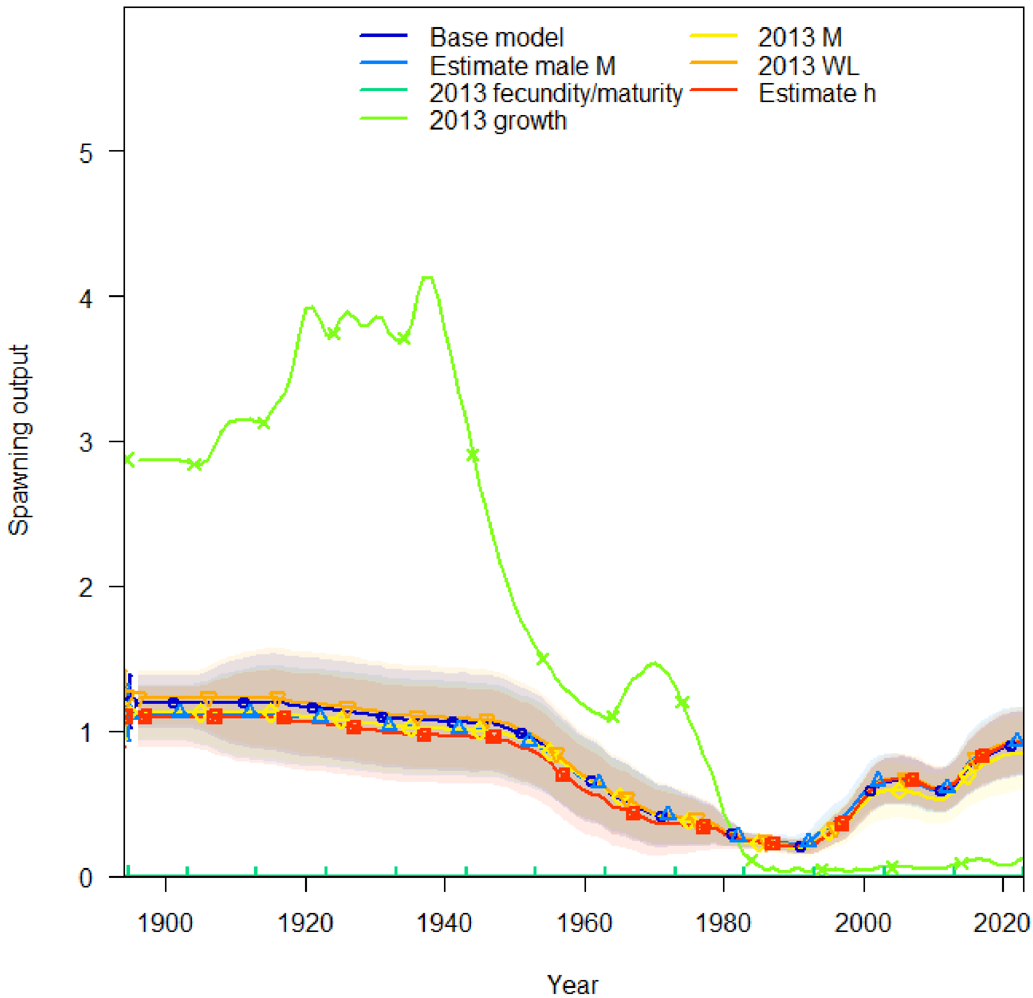


**Figure 48:** Estimated spawning biomass for the base model and selected biological sensitivity analyses.

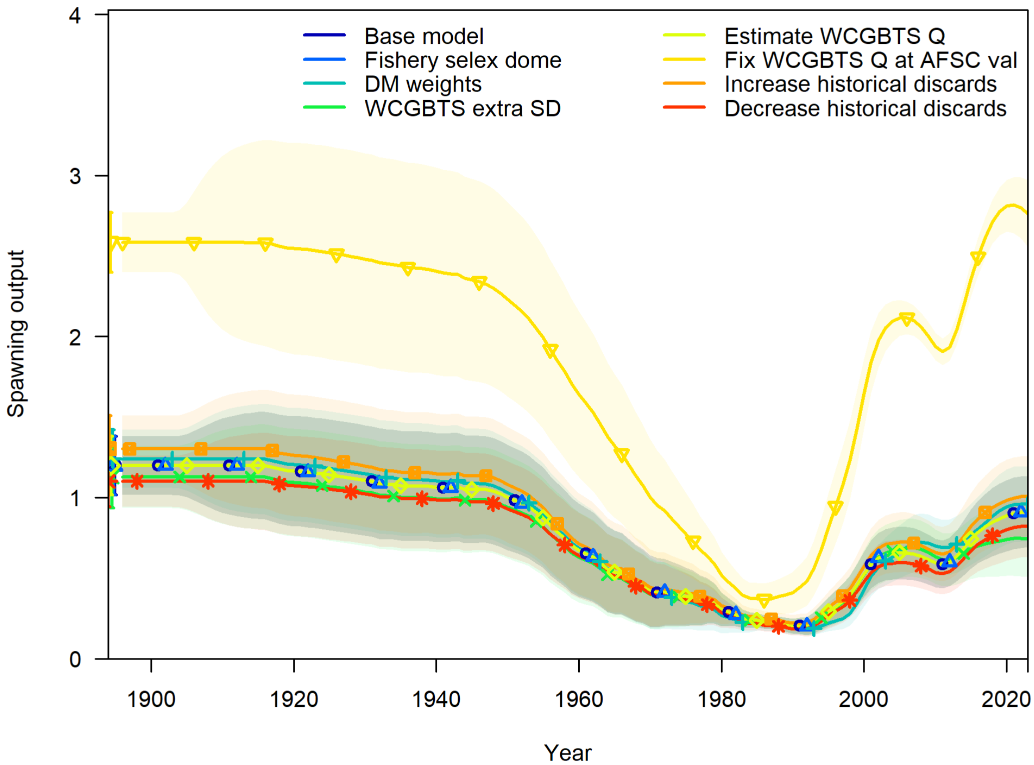


**Figure 49:** Estimated spawning biomass for the base model and each catchability, discard, and selectivity sensitivity analysis.

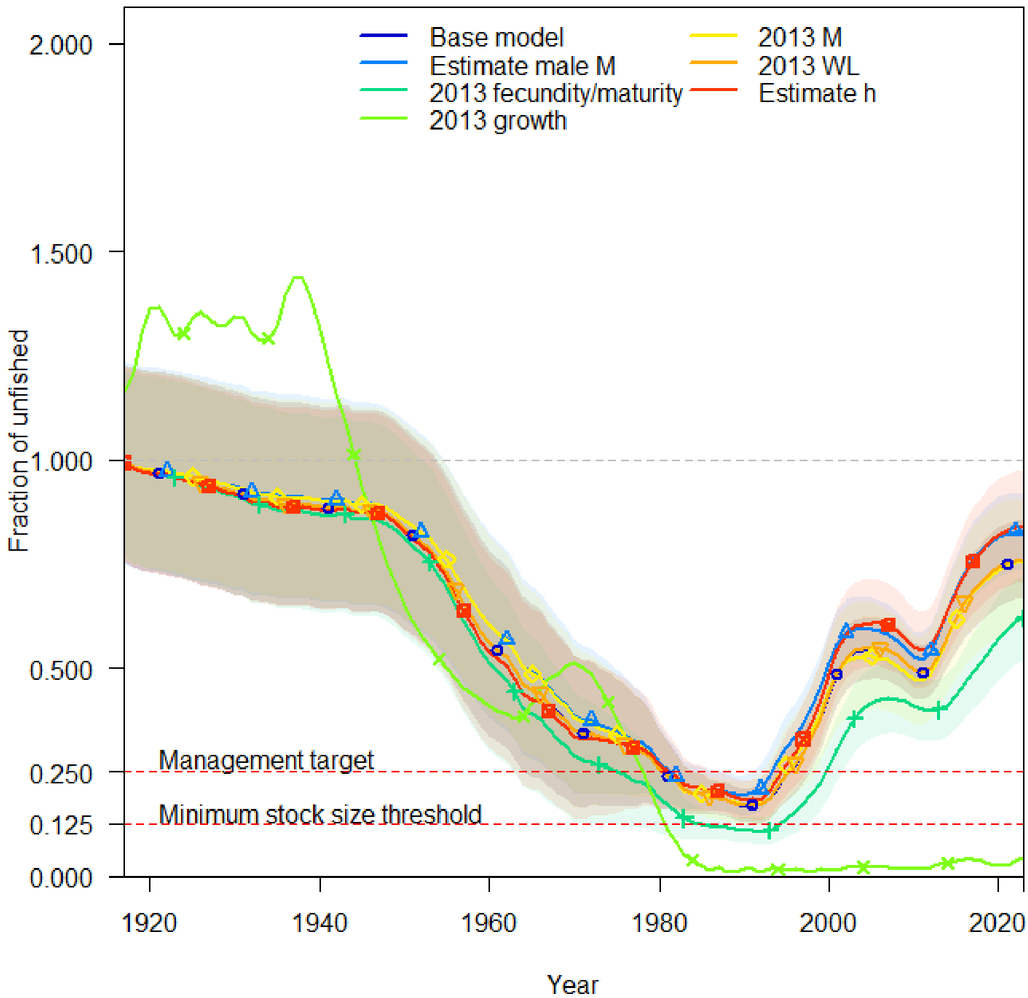


**Figure 50:** Estimated relative spawning biomass for the base model and selected biological sensitivity analyses.

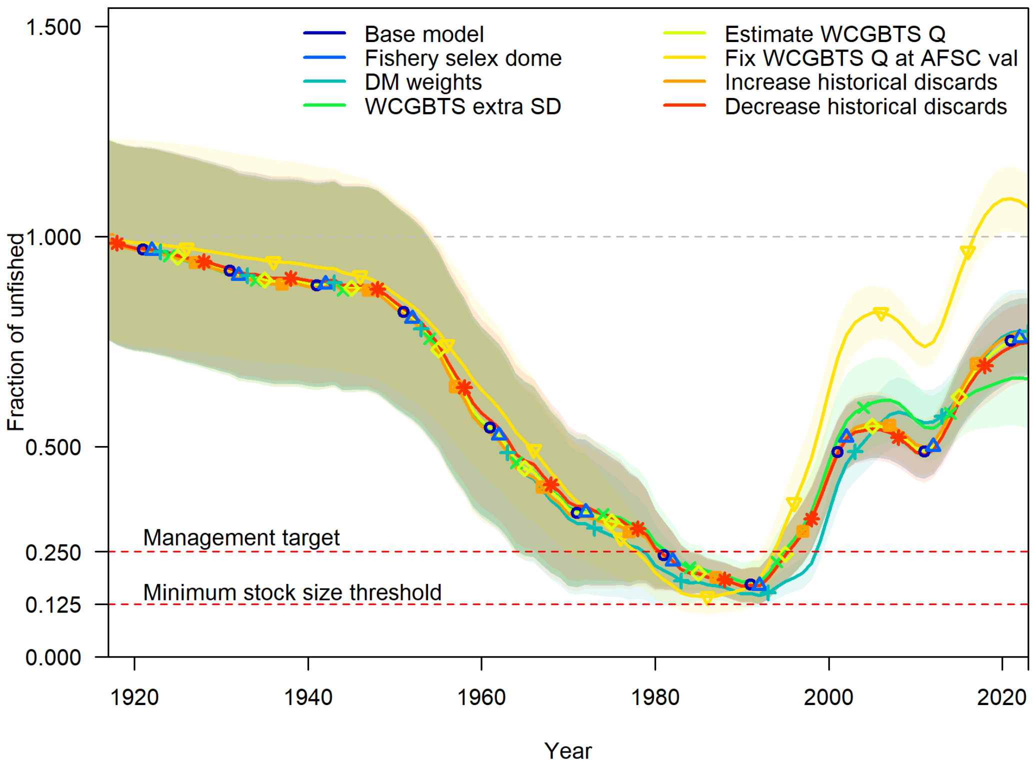


**Figure 51:** Estimated relative spawning biomass for the base model and each catchability, discard, and selectivity sensitivity analysis.

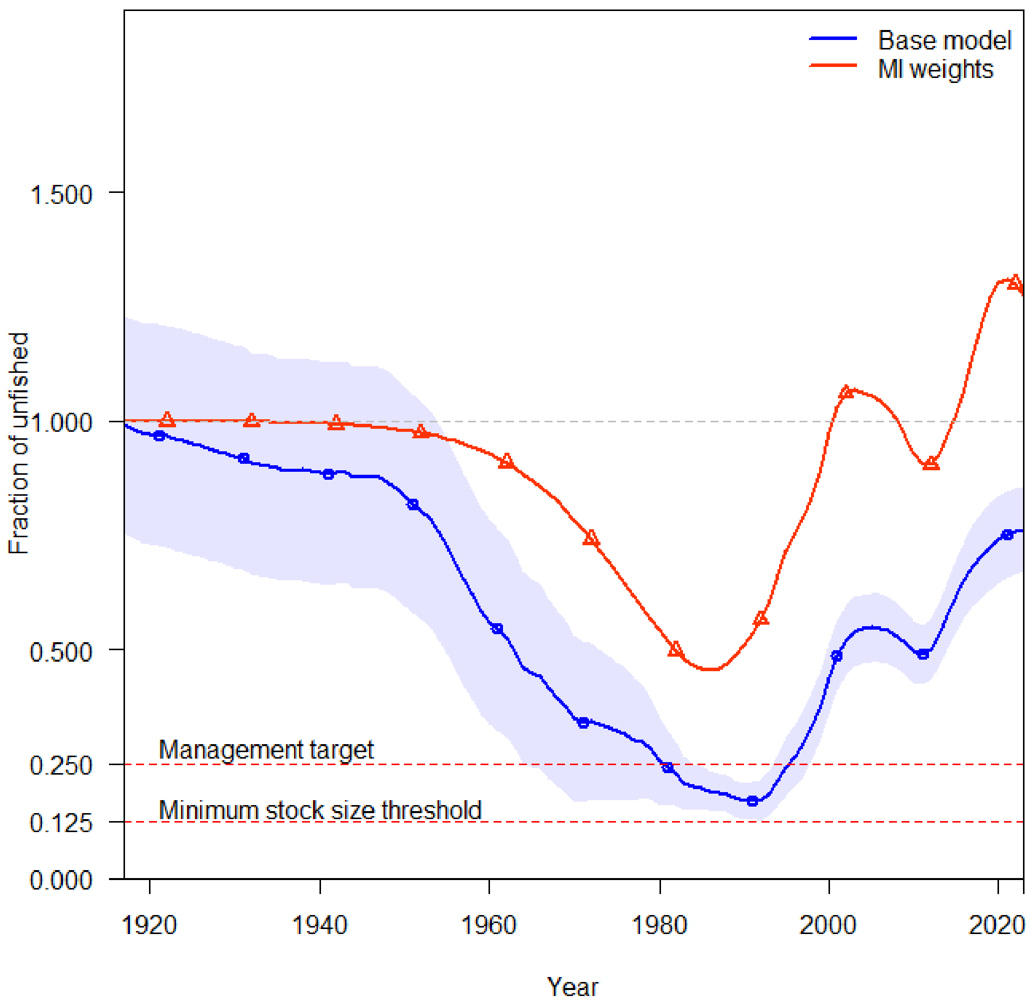


**Figure 52:** Estimated relative spawning biomass for the base model, with Francis weighting, and a sensitivity to McAllister-Ianelli weighting.

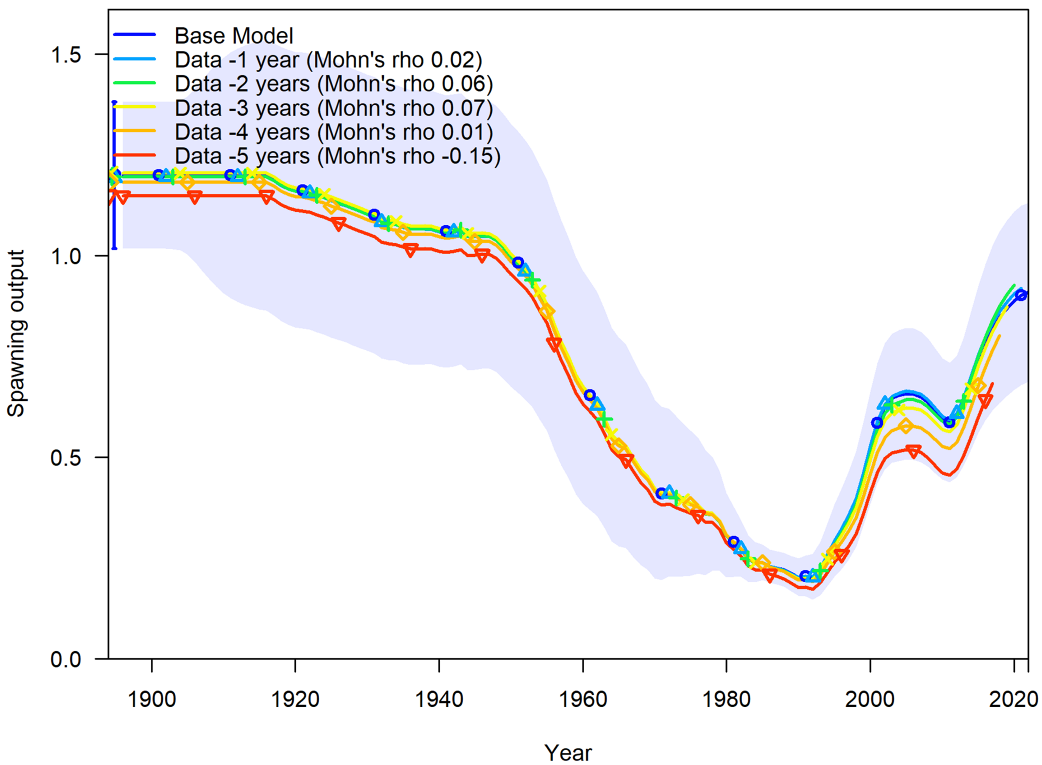


**Figure 53:** Change in the estimate of spawning output when the 5 most recent years of data are removed sequentially.

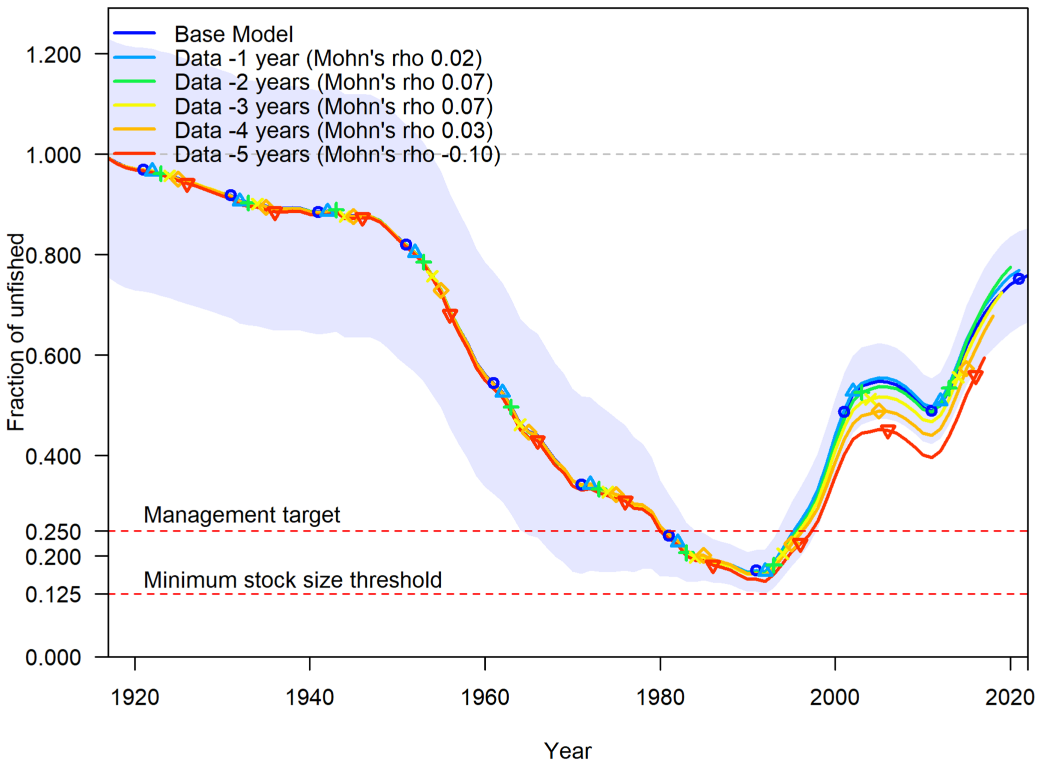


**Figure 54:** Change in the estimate of fraction unfished when the 5 most recent years of data are removed sequentially.

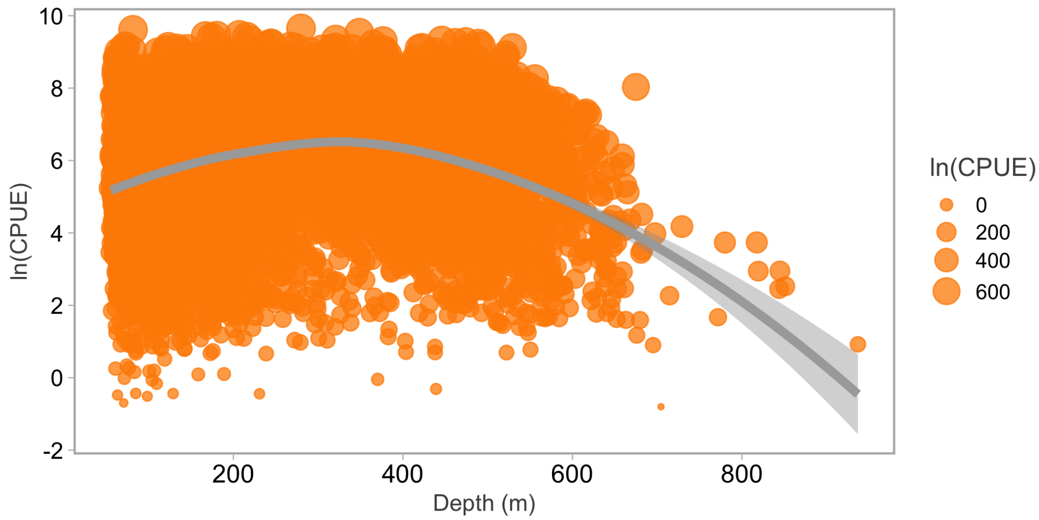


**Figure 55:** Log of catch per unit effort (CPUE) by depth for the West Coast Groundfish Bottom Trawl Survey (WCGBTS).

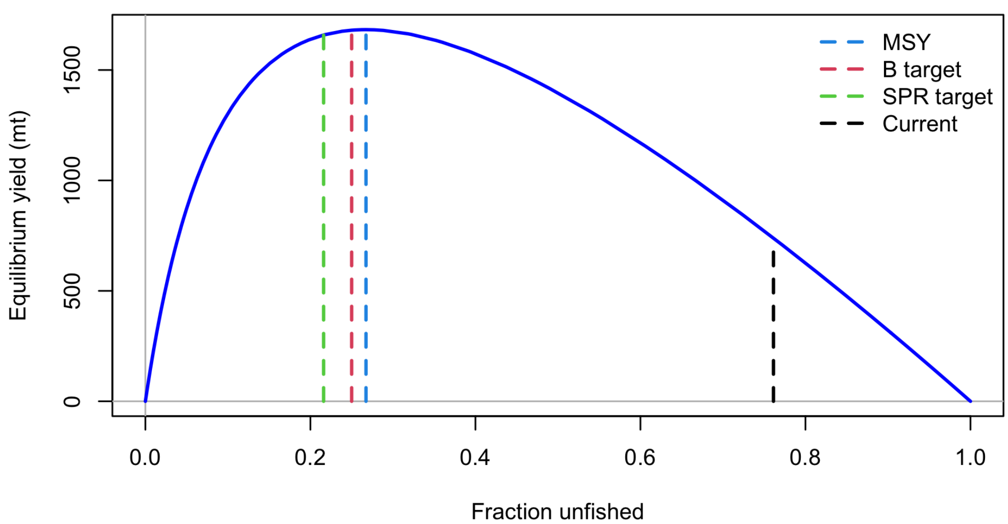


**Figure 56:** Equilibrium yield curve for the base case model. Values are based on the 2022 fishery selectivity and with steepness fixed at 0.7.

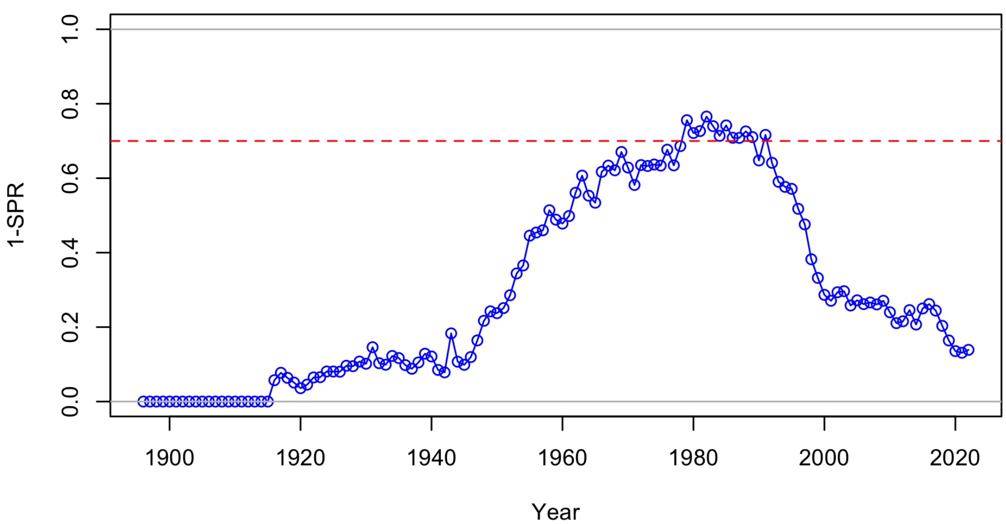


**Figure 57:** Estimated 1 - relative spawning ratio (SPR) by year.

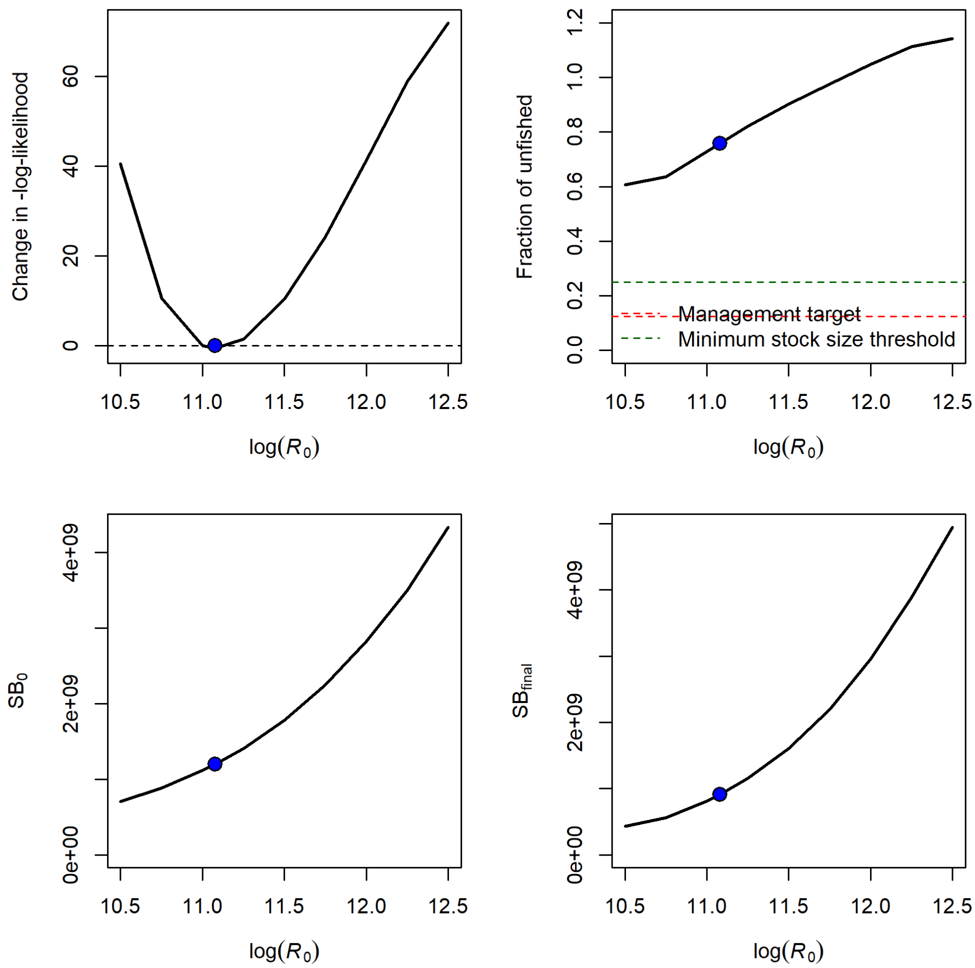


**Figure 58:** $ln(R_0)$ likelihood profiles (change in the negative log-likelihood across a range of $ln(R_0)$ values) and derived quantities.

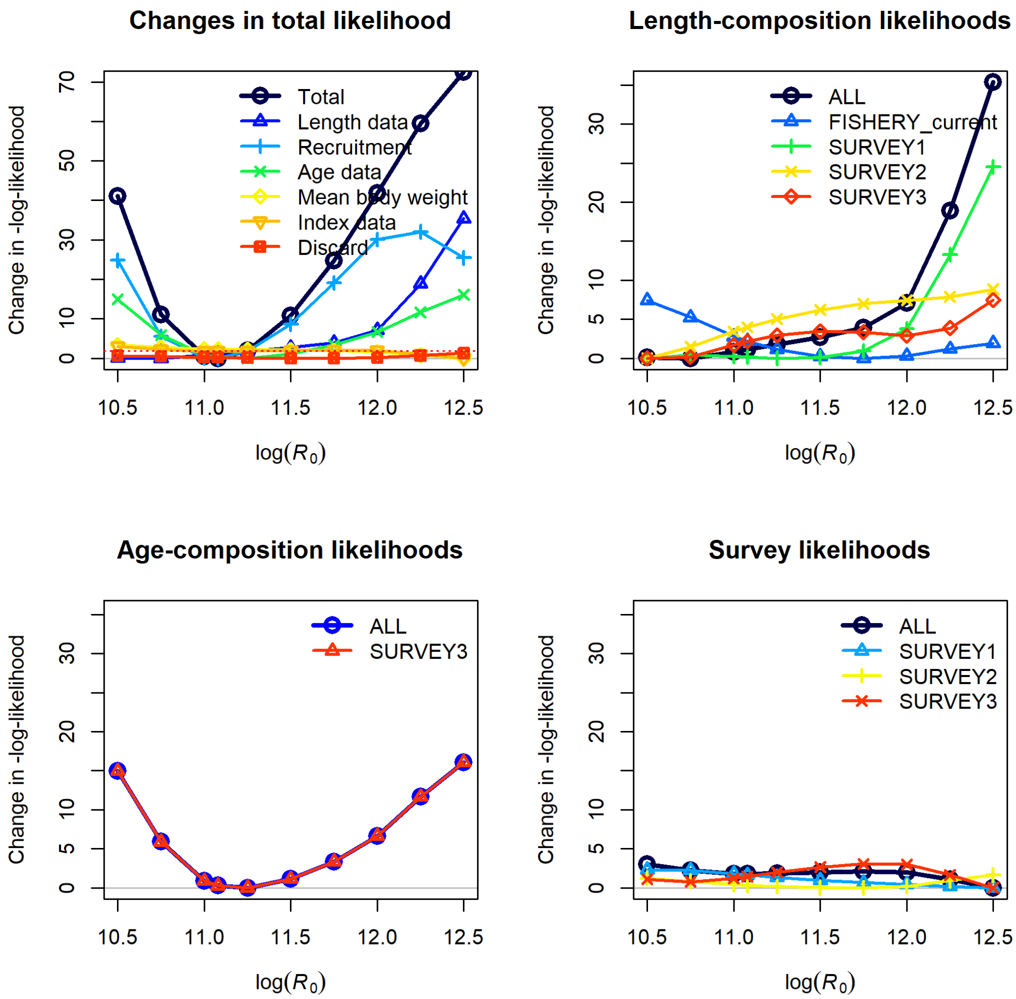


**Figure 59:** $ln(R_0)$ likelihood component contributions.

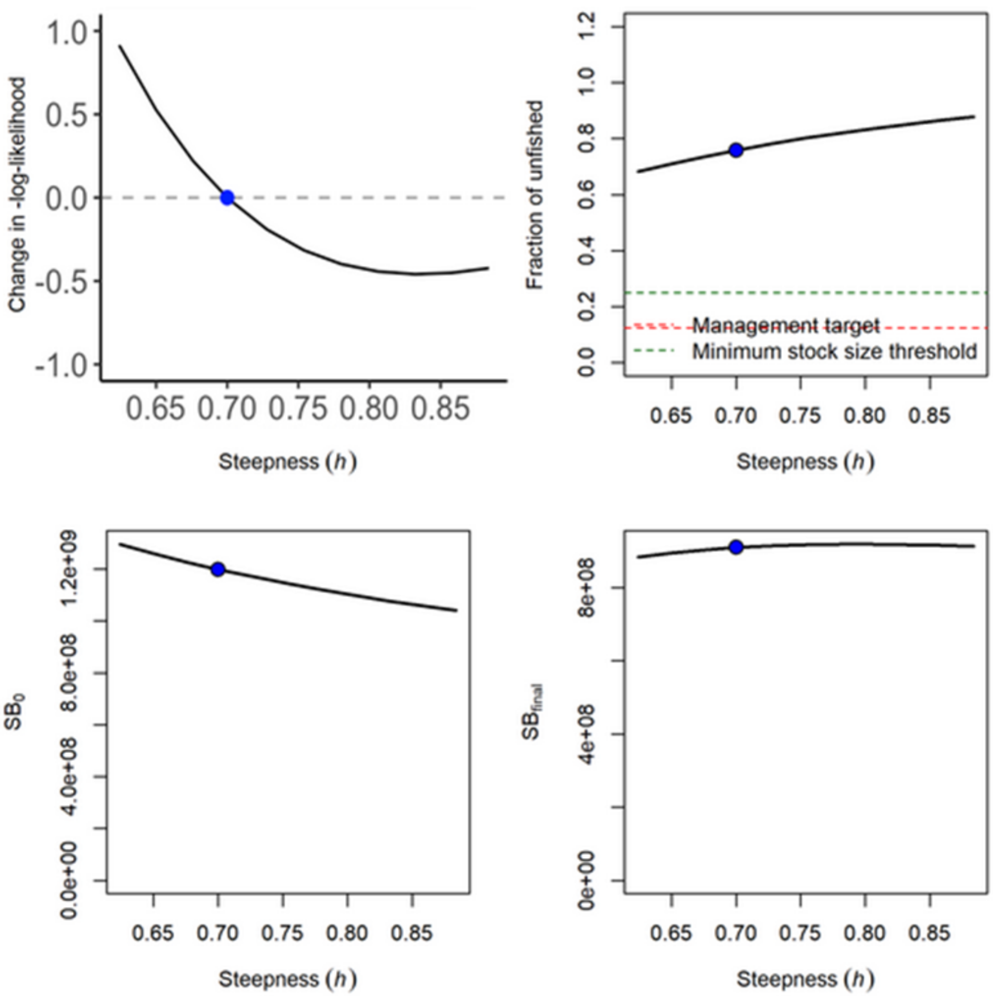


**Figure 60:** Steepness likelihood profiles (change in the negative log-likelihood across a range of steepness values) and derived quantities.

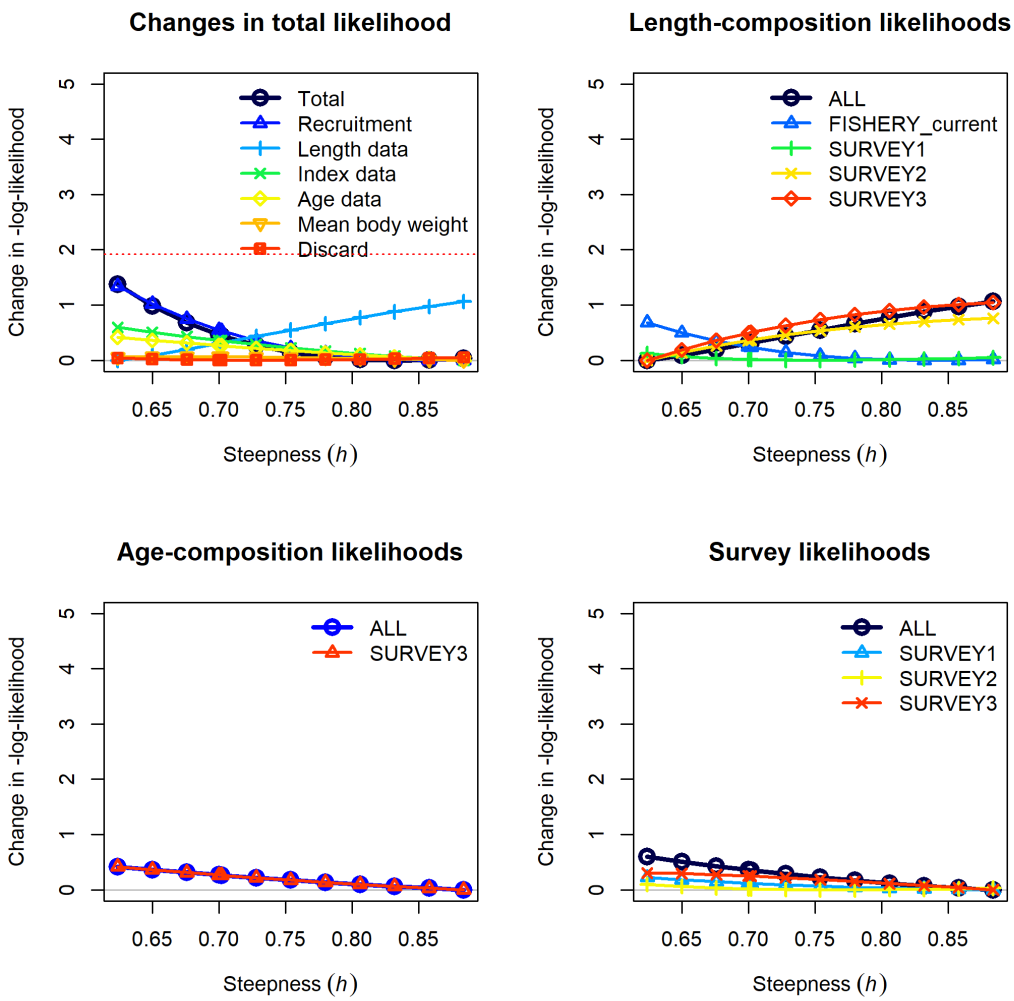


**Figure 61:** Steepness likelihood component contributions.

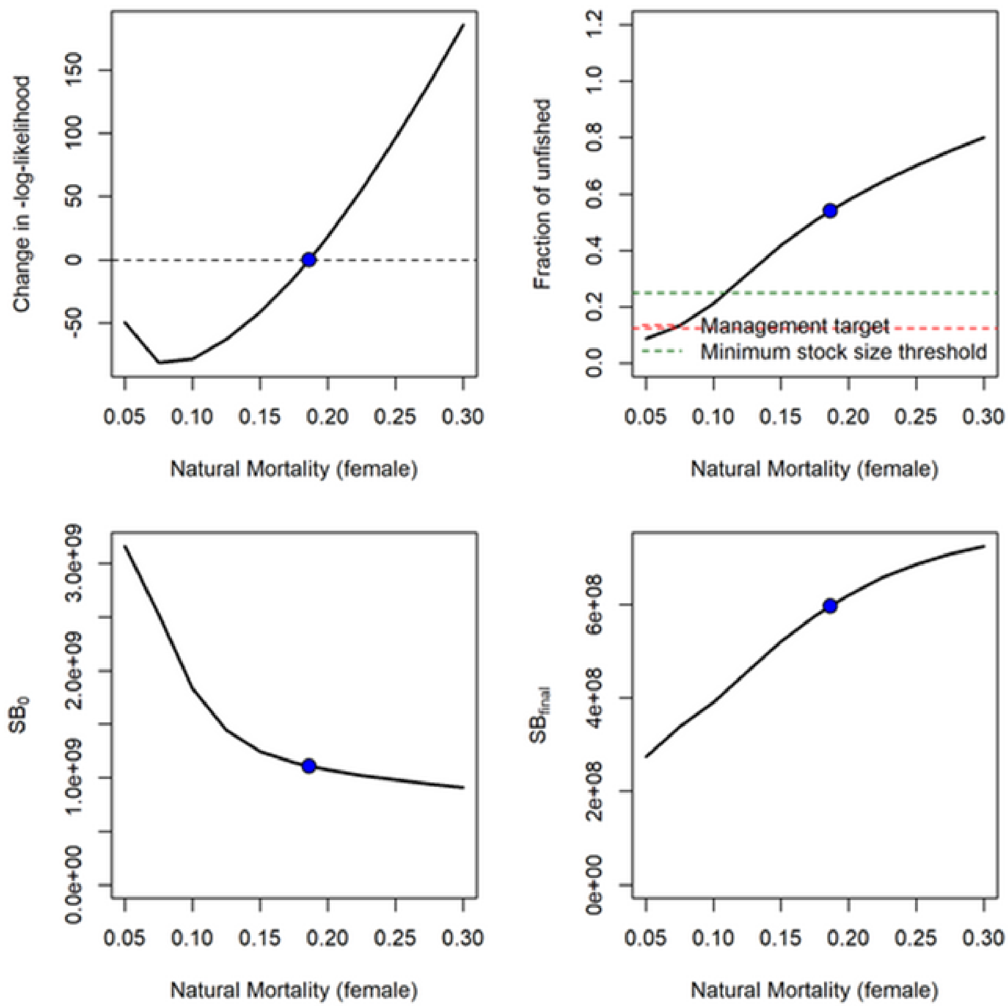


**Figure 62:** Female *M* likelihood profiles (change in the negative log-likelihood across a range of natural mortality values) and derived quantities.

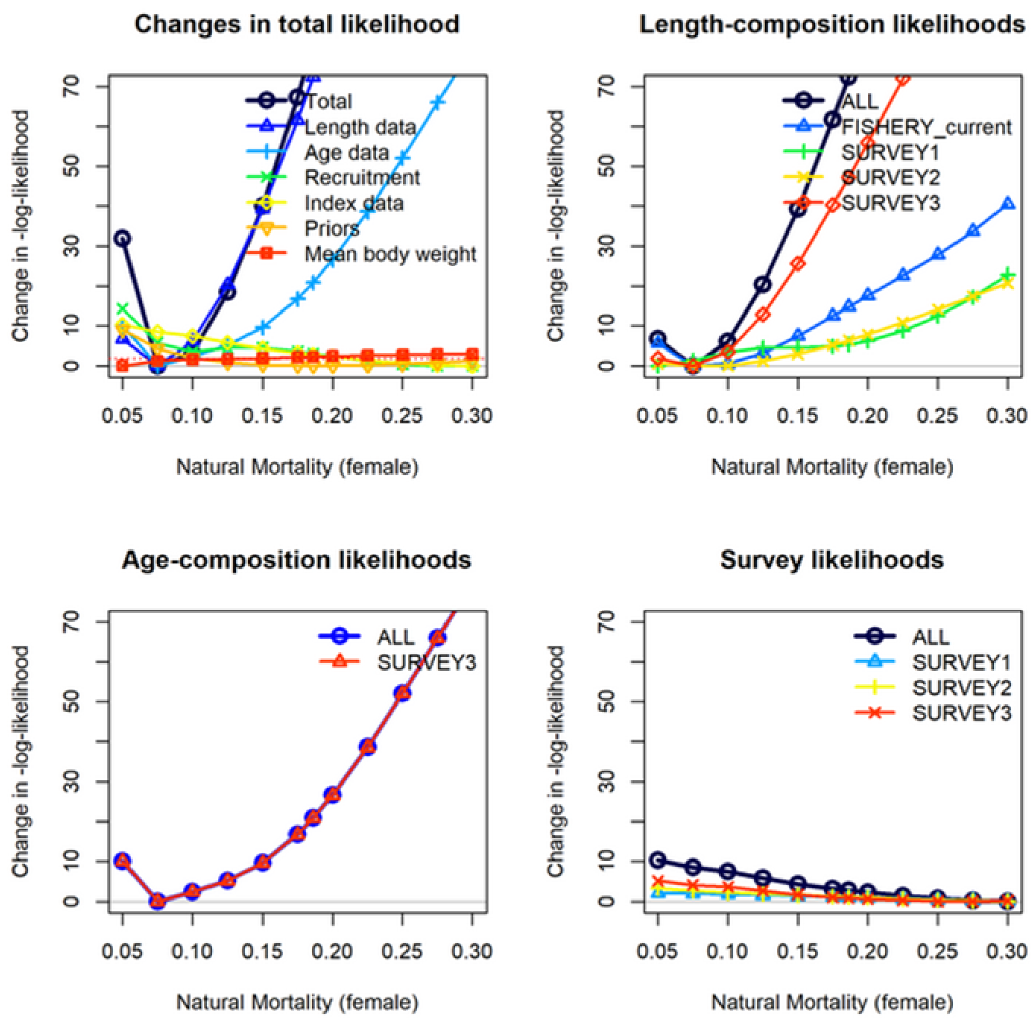


**Figure 63:** Female $M$ likelihood component contributions.

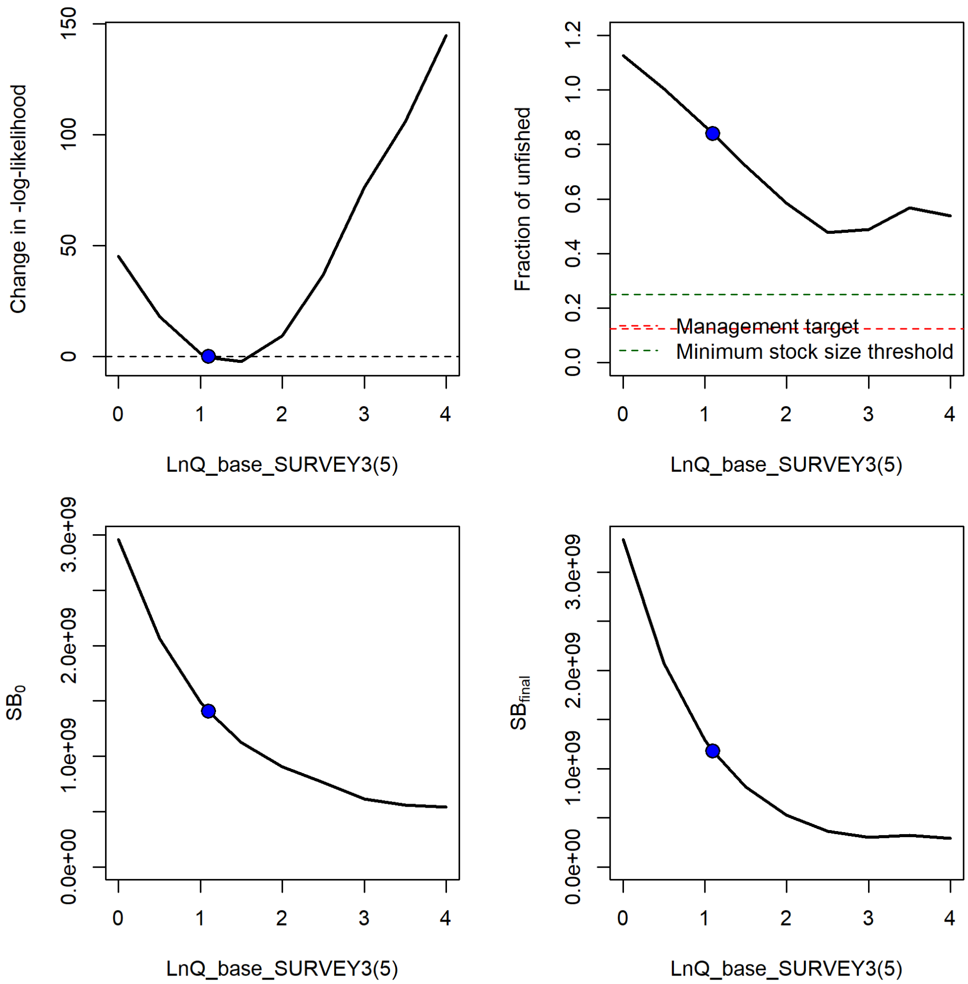


**Figure 64:** WCGBTS $Q$ likelihood profiles (change in the negative log-likelihood across a range of $Q$ values) and derived quantities.

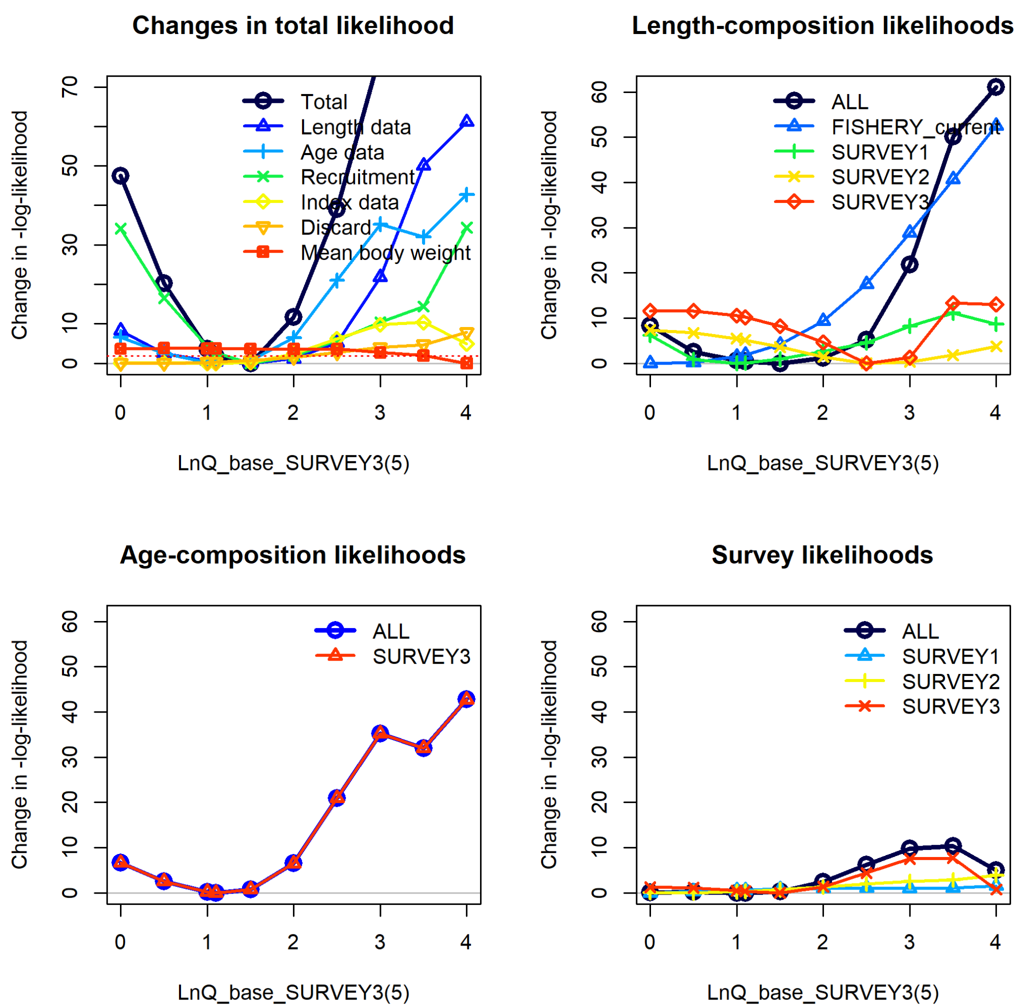


**Figure 65:** $Q$ likelihood component contributions.

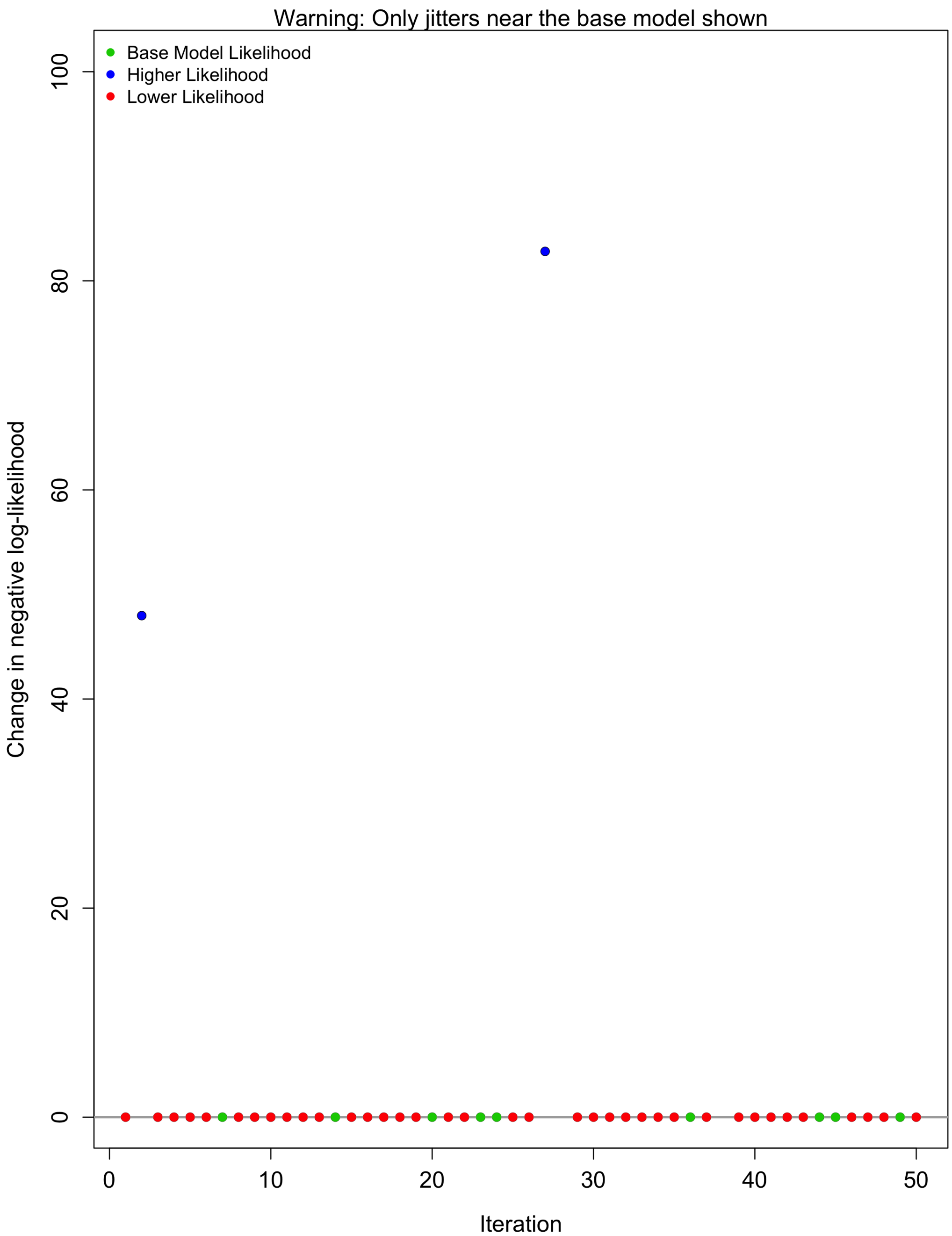


**Figure 66:** Change of negative log-likelihood for 50 iterations with 10% jitter.

# 9 Appendix A

## 9.1 Detailed fits to length composition data

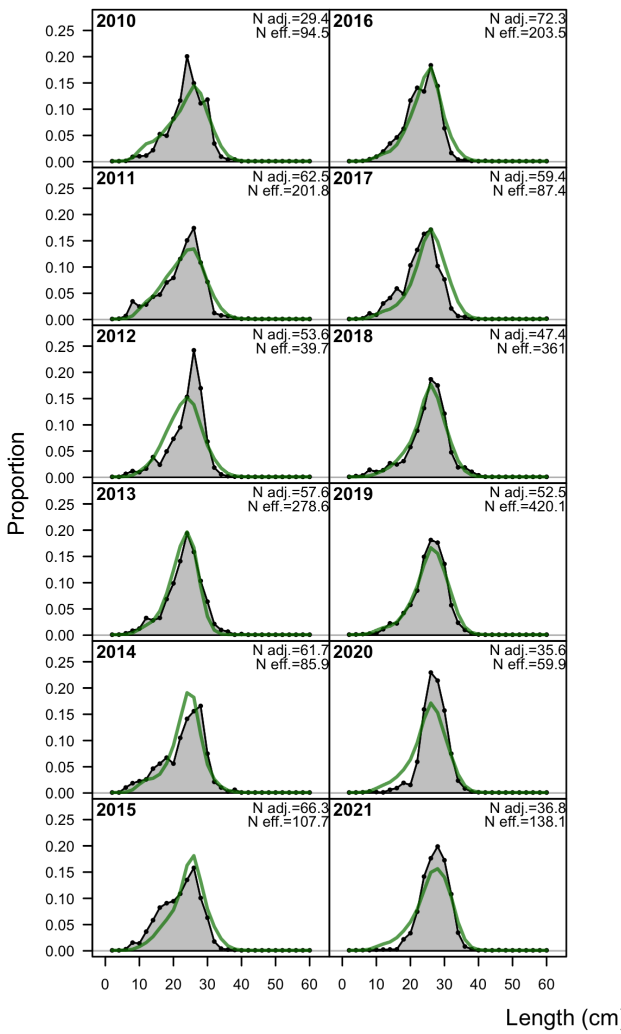


**Figure 67:** Length comps, discard, current fishery (2002-2022). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

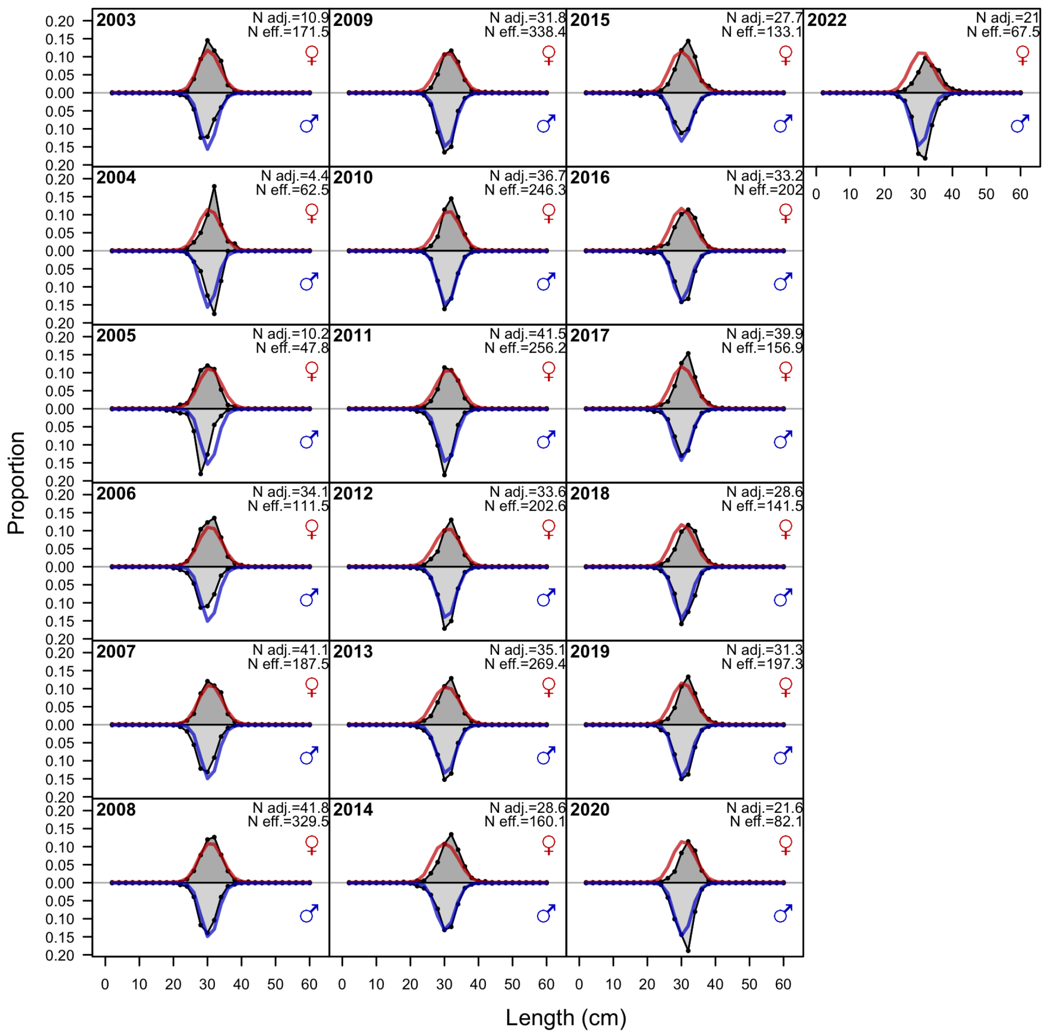


**Figure 68:** Length comps, retained, current fishery (2002-2022). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

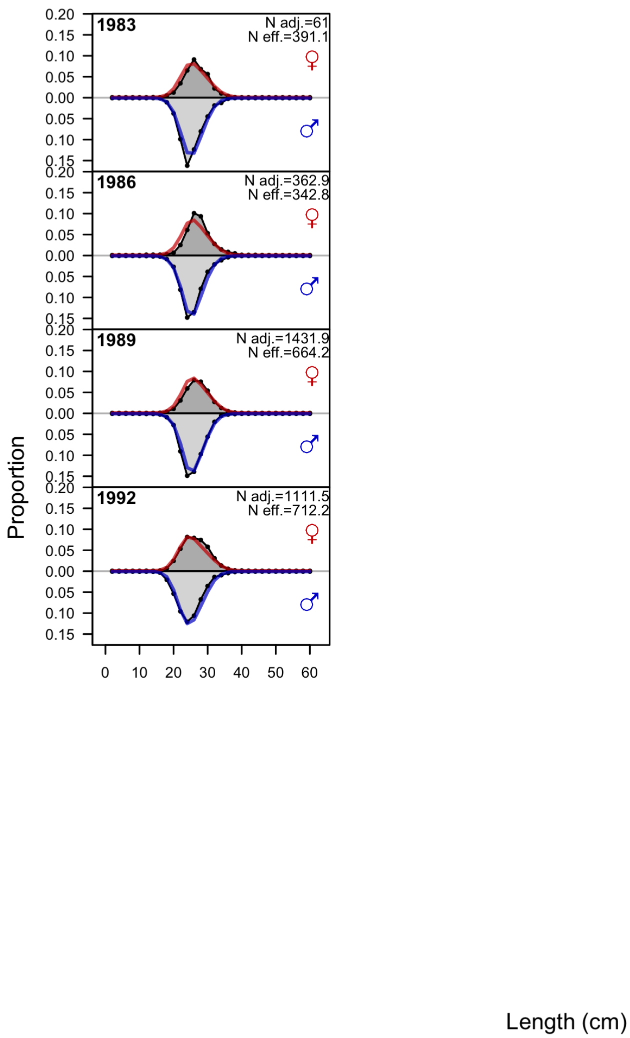


**Figure 69:** Length comps, early Triennial survey. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

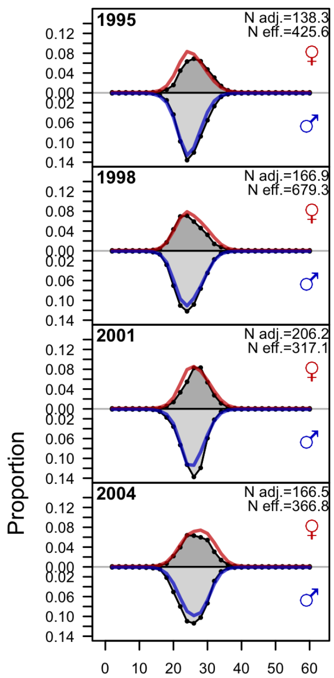


**Figure 70:** Length comps, late Triennial survey. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

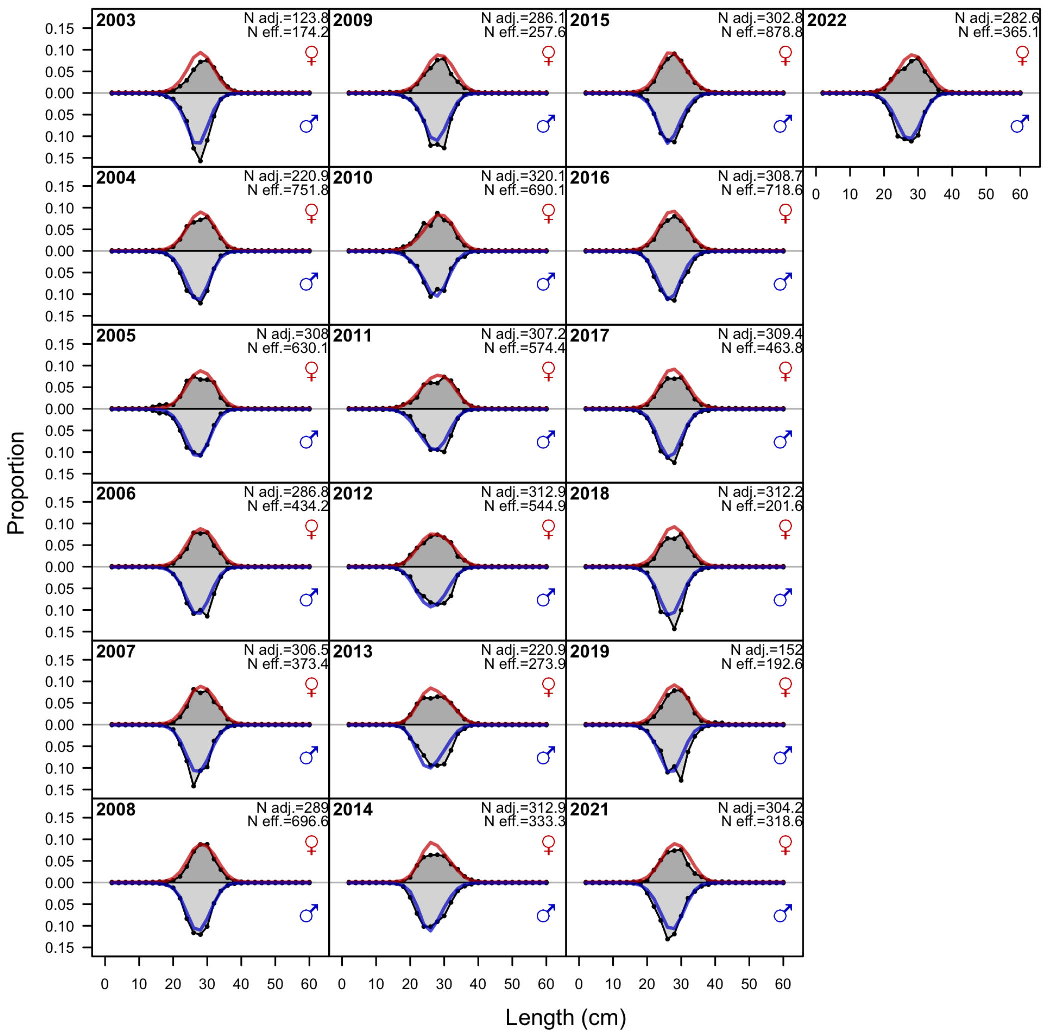


**Figure 71:** Length comps, WCGBTS. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

# 10 Appendix B

## 10.1 Landings by Data Source

**Table 15:** Landings (mt) from each data source for the modeled years. Historical discards are calculated using the previous assessment's time-varying discard rate assumption.

| Year | CDFG.Bulletin.74 | CA.Recon | CALCOM | OR.Recon | WA.Recon | PacFIN | NORPAC | Hist.Discard |
|---|---|---|---|---|---|---|---|---|
| 1916 | 148.2 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 74.10 |
| 1917 | 201.9 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.90 |
| 1918 | 162.6 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 81.35 |
| 1919 | 127.9 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 63.90 |
| 1920 | 88.4 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 44.20 |
| 1921 | 112.7 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 56.30 |
| 1922 | 162.9 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 81.50 |
| 1923 | 163.9 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 82.00 |
| 1924 | 204.4 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 102.20 |
| 1925 | 202.7 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 101.30 |
| 1926 | 200.1 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1927 | 242.4 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 121.20 |
| 1928 | 237.8 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 118.90 |
| 1929 | 270.8 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 135.40 |
| 1930 | 252.7 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 126.30 |
| 1931 | 0.0 | 377.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 188.45 |
| 1932 | 0.0 | 252.0 | 0.0 | 0.48 | 0.00 | 0.00 | 0.00 | 126.19 |
| 1933 | 0.0 | 240.2 | 0.0 | 0.22 | 0.00 | 0.00 | 0.00 | 120.21 |
| 1934 | 0.0 | 303.6 | 0.0 | 0.08 | 0.00 | 0.00 | 0.00 | 151.79 |
| 1935 | 0.0 | 286.5 | 0.0 | 0.24 | 0.00 | 0.00 | 0.00 | 143.42 |
| 1936 | 0.0 | 233.9 | 0.0 | 0.92 | 0.00 | 0.00 | 0.00 | 117.41 |
| 1937 | 0.0 | 204.8 | 0.0 | 4.69 | 0.00 | 0.00 | 0.00 | 104.69 |
| 1938 | 0.0 | 253.8 | 0.0 | 0.10 | 0.00 | 0.00 | 0.00 | 126.90 |
| 1939 | 0.0 | 302.8 | 0.0 | 14.58 | 0.00 | 0.00 | 0.00 | 158.74 |
| 1940 | 0.0 | 269.1 | 0.0 | 26.20 | 0.00 | 0.00 | 0.00 | 147.70 |
| 1941 | 0.0 | 168.3 | 0.0 | 31.26 | 0.00 | 0.00 | 0.00 | 99.78 |
| 1942 | 0.0 | 175.8 | 0.0 | 7.57 | 0.00 | 0.00 | 0.00 | 91.73 |
| 1943 | 0.0 | 224.8 | 0.0 | 251.96 | 0.00 | 0.00 | 0.00 | 238.38 |
| 1944 | 0.0 | 187.5 | 0.0 | 66.92 | 0.00 | 0.00 | 0.00 | 127.21 |
| 1945 | 0.0 | 200.6 | 0.0 | 32.21 | 0.00 | 0.00 | 0.00 | 116.41 |
| 1946 | 0.0 | 258.7 | 0.0 | 29.52 | 0.00 | 0.00 | 0.00 | 144.06 |
| 1947 | 0.0 | 382.4 | 0.0 | 30.75 | 0.00 | 0.00 | 0.00 | 206.62 |
| 1948 | 0.0 | 403.2 | 0.0 | 164.87 | 3.43 | 0.00 | 0.00 | 285.80 |
| 1949 | 0.0 | 438.2 | 0.0 | 206.77 | 0.00 | 0.00 | 0.00 | 322.49 |

**Table 15:** Landings (mt) from each data source for the modeled years. Historical discards are calculated using the previous assessment's time-varying discard rate assumption. *(continued)*

| Year | CDFG.Bulletin.74 | CA.Recon | CALCOM | OR.Recon | WA.Recon | PacFIN | NORPAC | Hist.Discard |
|---|---|---|---|---|---|---|---|---|
| 1950 | 0.0 | 464.1 | 0.0 | 151.10 | 0.00 | 0.00 | 0.00 | 307.55 |
| 1951 | 0.0 | 454.0 | 0.0 | 197.51 | 0.00 | 0.00 | 0.00 | 321.80 |
| 1952 | 0.0 | 531.5 | 0.0 | 228.84 | 0.00 | 0.00 | 0.00 | 370.92 |
| 1953 | 0.0 | 456.7 | 0.0 | 507.98 | 0.00 | 0.00 | 0.00 | 464.64 |
| 1954 | 0.0 | 514.8 | 0.0 | 507.20 | 0.00 | 0.00 | 0.00 | 486.00 |
| 1955 | 0.0 | 485.0 | 0.0 | 862.15 | 0.00 | 0.00 | 0.00 | 632.38 |
| 1956 | 0.0 | 514.9 | 0.0 | 804.33 | 0.00 | 0.00 | 0.00 | 611.19 |
| 1957 | 0.0 | 556.9 | 0.0 | 730.39 | 0.00 | 0.00 | 0.00 | 588.53 |
| 1958 | 0.0 | 626.7 | 0.0 | 874.46 | 0.52 | 0.00 | 0.00 | 677.38 |
| 1959 | 0.0 | 632.7 | 0.0 | 666.47 | 0.04 | 0.00 | 0.00 | 578.04 |
| 1960 | 0.0 | 489.3 | 0.0 | 720.06 | 0.06 | 0.00 | 0.00 | 530.71 |
| 1961 | 0.0 | 526.8 | 0.0 | 745.40 | 0.00 | 0.00 | 0.00 | 550.47 |
| 1962 | 0.0 | 626.4 | 0.0 | 918.46 | 5.84 | 0.00 | 0.00 | 661.43 |
| 1963 | 0.0 | 696.6 | 0.0 | 1028.28 | 17.76 | 0.00 | 0.00 | 732.63 |
| 1964 | 0.0 | 632.4 | 0.0 | 686.97 | 30.94 | 0.00 | 0.00 | 559.41 |
| 1965 | 0.0 | 671.3 | 0.0 | 514.66 | 46.61 | 0.00 | 0.00 | 503.11 |
| 1966 | 0.0 | 729.7 | 0.0 | 873.14 | 38.98 | 0.00 | 0.00 | 660.19 |
| 1967 | 0.0 | 794.0 | 0.0 | 810.66 | 58.36 | 0.00 | 0.00 | 658.49 |
| 1968 | 0.0 | 861.7 | 0.0 | 642.73 | 8.56 | 0.00 | 0.00 | 589.85 |
| 1969 | 0.0 | 0.0 | 1024.6 | 726.02 | 5.66 | 0.00 | 0.00 | 673.98 |
| 1970 | 0.0 | 0.0 | 789.9 | 621.71 | 11.89 | 0.00 | 0.00 | 537.49 |
| 1971 | 0.0 | 0.0 | 643.9 | 510.13 | 26.51 | 0.00 | 0.00 | 438.56 |
| 1972 | 0.0 | 0.0 | 753.7 | 649.58 | 45.92 | 0.00 | 0.00 | 529.51 |
| 1973 | 0.0 | 0.0 | 718.8 | 615.11 | 76.54 | 0.00 | 0.00 | 506.70 |
| 1974 | 0.0 | 0.0 | 626.7 | 621.61 | 163.44 | 0.00 | 0.00 | 498.48 |
| 1975 | 0.0 | 0.0 | 746.8 | 494.50 | 135.88 | 0.00 | 0.00 | 477.84 |
| 1976 | 0.0 | 0.0 | 913.0 | 512.27 | 171.27 | 0.00 | 0.00 | 544.26 |
| 1977 | 0.0 | 0.0 | 702.2 | 452.22 | 161.17 | 0.00 | 0.00 | 440.42 |
| 1978 | 0.0 | 0.0 | 697.6 | 653.79 | 237.68 | 0.00 | 0.00 | 522.22 |
| 1979 | 0.0 | 0.0 | 868.5 | 746.52 | 400.48 | 0.00 | 0.00 | 650.09 |
| 1980 | 0.0 | 0.0 | 861.6 | 541.43 | 187.39 | 0.00 | 0.00 | 503.26 |
| 1981 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1551.20 | 0.00 | 481.31 |
| 1982 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1746.66 | 0.00 | 531.29 |
| 1983 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1458.78 | 0.00 | 434.78 |
| 1984 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1275.24 | 0.00 | 372.25 |
| 1985 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1424.70 | 0.00 | 407.23 |
| 1986 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1207.76 | 0.00 | 337.77 |
| 1987 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1200.24 | 0.00 | 325.25 |
| 1988 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1266.45 | 0.00 | 332.03 |

**Table 15:** Landings (mt) from each data source for the modeled years. Historical discards are calculated using the previous assessment's time-varying discard rate assumption. *(continued)*

| Year | CDFG.Bulletin.74 | CA.Recon | CALCOM | OR.Recon | WA.Recon | PacFIN | NORPAC | Hist.Discard |
|---|---|---|---|---|---|---|---|---|
| 1989 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1145.43 | 0.00 | 290.22 |
| 1990 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 878.03 | 0.00 | 214.79 |
| 1991 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 1170.28 | 0.00 | 276.13 |
| 1992 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 874.76 | 0.00 | 198.71 |
| 1993 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 785.46 | 0.00 | 171.56 |
| 1994 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 841.10 | 0.00 | 176.29 |
| 1995 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 927.07 | 0.00 | 186.26 |
| 1996 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 846.34 | 0.00 | 162.57 |
| 1997 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 810.30 | 0.00 | 148.59 |
| 1998 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 635.92 | 0.00 | 111.04 |
| 1999 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 589.45 | 0.00 | 97.71 |
| 2000 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 544.93 | 0.00 | 85.62 |
| 2001 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 562.44 | 0.00 | 83.49 |
| 2002 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 597.65 | 0.00 | 0.00 |
| 2003 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 639.35 | 0.00 | 0.00 |
| 2004 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 545.46 | 0.00 | 0.00 |
| 2005 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 593.03 | 0.00 | 0.00 |
| 2006 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 563.97 | 0.00 | 0.00 |
| 2007 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 572.28 | 0.00 | 0.00 |
| 2008 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 548.75 | 0.00 | 0.00 |
| 2009 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 561.80 | 0.00 | 0.00 |
| 2010 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 463.81 | 0.00 | 0.00 |
| 2011 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 390.91 | 0.00 | 0.00 |
| 2012 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 399.13 | 2.91 | 0.00 |
| 2013 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 502.71 | 12.08 | 0.00 |
| 2014 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 409.98 | 8.19 | 0.00 |
| 2015 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 531.56 | 6.22 | 0.00 |
| 2016 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 611.01 | 2.83 | 0.00 |
| 2017 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 548.40 | 8.45 | 0.00 |
| 2018 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 445.85 | 30.72 | 0.00 |
| 2019 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 336.39 | 33.17 | 0.00 |
| 2020 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 317.62 | 3.01 | 0.00 |
| 2021 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 272.55 | 10.89 | 0.00 |
| 2022 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 259.84 | 47.49 | 0.00 |