

Status of sablefish (*Anoplopoma fimbria*) along the U.S. West Coast in 2023

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Contents

Executive Summary	i
Stock	i
Landings and Catches	i
Data and Assessment	ii
Stock Biomass and Dynamics	iii
Recruitment	vi
Exploitation Status	ix
Ecosystem Considerations	xi
Reference Points	xi
Management Performance	xv
Unresolved Problems and Major Uncertainties	xv
Decision Table and Projections	xvi
Scientific Uncertainty	xvii
Research and Data Needs	xvii
1 Introduction	1
1.1 Basic Information	1
1.2 Life History	1
1.3 Ecosystem Considerations	2
1.4 Historical and Current Fishery Information	2
1.5 Summary of Management History and Performance	2
1.6 Foreign Fisheries	2
2 Data	3
2.1 Fishery-Dependent Data	3
2.1.1 Commercial Landings	3
2.1.2 Commercial Discard	4
2.2 Fishery-Independent Data	5
2.2.1 Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey	5
2.2.2 Environmental Indices	6
2.3 Biological Data	6
3 Assessment Model	6
3.1 Summary of Previous Assessments and Reviews	6
3.2 Model Structure and Assumptions	6
3.2.1 Description of New Modeling Approaches	6
3.2.2 Modeling Platform and Structure	6
3.2.3 Model Changes from the Last Assessment	7
3.2.4 Key Assumptions and Structural Choices	8
3.2.5 Priors	8
3.2.6 Data Weighting	8
3.2.7 Model Parameters	9
3.3 Base Model Results	10
3.3.1 Base Model Selection	10

3.3.2	Parameter Estimates	10
3.3.3	Fits to the Data	12
3.3.4	Population Trajectory	13
3.4	Model Diagnostics	13
3.4.1	Convergence	13
3.4.2	Sensitivity Analyses	14
3.4.3	Retrospective Analysis	15
3.4.4	Historical Analysis	16
3.4.5	Likelihood Profiles	16
4	Management	17
4.1	Reference Points	17
4.2	Unresolved Problems and Major Uncertainties	17
4.3	Harvest Projections and Decision Tables	18
4.4	Evaluation of Scientific Uncertainty	18
4.5	Regional Management Considerations	18
4.6	Research and Data Needs	19
5	Acknowledgments	19
6	References	20
7	Tables	23
7.1	Data	23
7.2	Model Results	30
7.2.1	Estimated Parameters	30
7.2.2	Sensitivity and Retrospective Analyses	42
7.3	Reference Points and Projections	47
8	Figures	50
8.1	Data	50
8.1.1	Summary	50
8.1.2	Fishery-Dependent Data	51
8.1.3	Fishery-Independent Data	58
8.2	Model Results	70
8.2.1	Bridging	70
8.2.2	Estimated Biology	79
8.2.3	Estimated Selectivity	83
8.2.4	Estimated Recruitment	89
8.2.5	Estimated Time Series	93
8.2.6	Fits to Data	97
8.2.7	Sensitivity and Retrospectives Analyses	120
8.2.8	Likelihood Profiles	136
8.3	Reference Points and Projections	148

Executive Summary

Stock

This assessment update reports the status of sablefish (*Anoplopoma fimbria*) off the U.S. West Coast using data through 2022. The resource is modeled as a single stock; however, sablefish disperse to and from offshore seamounts, along the coastal waters of the U.S. West Coast, Canada, and Alaska and across the Aleutian Islands to the Western Pacific. This potential movement is not explicitly accounted for in this analysis.

Landings and Catches

The earliest landings of sablefish off the U.S. West Coast used within in this assessment begin in 1890. The landings began to slowly increase starting in the 1910s and continued at a roughly constant level until the 1960s where landings sharply increased (Figure i). After peaking in the late 1970s, catches slowly decreased until the 2000s when catches generally stabilized roughly between 4,000–6,000 mt. Since the 2019 benchmark assessment (Haltuch et al. 2019), fishery landings have been divided among coastwide fixed-gear and trawl fleets (see Table i for the most recent ten years). Annual discard mortality by fleet is estimated within the model and informed by data from the West Coast Groundfish Observer Program and other historical discarding studies. This internal estimation can result in model estimates of catches (landings plus discards) that differ between stock assessments, even when the input landings remain unchanged, due to changes in fixed and estimated parameter values, priors, or parameterizations.

The landings in this assessment update were minimally revised and corrected from those used in the 2019 benchmark and the 2021 update assessments. First, landings from the ‘Oregon Coast’ International North Pacific Fishery Commission area, i.e., between 42.000–46.267°N. latitude, are no longer excluded from the total landings. Second, landings from 1977–1982 in the catch reporting area that includes both U.S. and Canadian waters are now assigned 50–50% to each country rather than 100% to the U.S. Third, a time series of sablefish catches from the At-Sea Pacific Hake fishery since 1990 are now included in the trawl fleet. Previous assessments have included bycatch of sablefish from the shoreside fleet but these at-sea catches were previously only included as a sensitivity.

Table i: Landings (mt) by fleet and the summed coastwide total landings and estimated total catch.

Year	Fixed Gear Landings	Trawl Landings	Total Landings	Total Catch
2013	2,726.91	1,426.08	4,152.99	4,220.25
2014	3,119.44	1,323.02	4,442.46	4,525.20
2015	3,671.89	1,510.69	5,182.58	5,266.98
2016	3,919.57	1,516.67	5,436.24	5,537.02
2017	3,864.59	1,827.76	5,692.35	5,814.87
2018	3,749.87	1,622.34	5,372.21	5,469.99
2019	3,668.05	1,710.35	5,378.40	5,575.29
2020	2,831.94	1,122.63	3,954.57	4,095.54
2021	3,205.24	1,708.05	4,913.29	5,217.28
2022	3,965.85	2,405.70	6,371.55	6,913.62

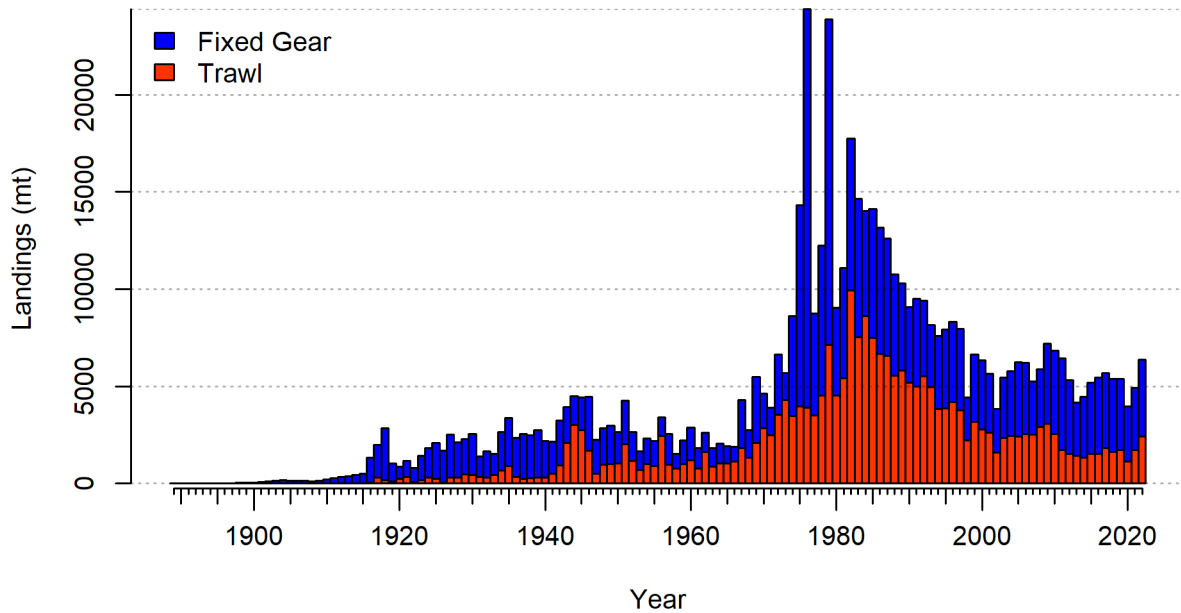


Figure i: Landings by year from the fixed-gear (blue) and trawl (red) fleets.

Data and Assessment

The last benchmark stock assessment for sablefish took place during 2019 (Haltuch et al. 2019) and was followed by an update assessment in 2021 (Kapur et al. 2021). This assessment update uses the stock assessment framework Stock Synthesis (SS3) version 3.30.21.00. Primary data sources include fishery landings, length compositions from discarded fish and the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey, and age compositions from the retained catch and fishery-independent data sources. The fishery landings were re-evaluated for this assessment update and extended through 2022. No new age readings were conducted for the fishery collections. Data on the discarded rates and mean observed individual body weight of the discarded catch were updated and new values were included in this analysis. Though, only the two most recently available years, 2020–2021, of discard rates were updated and the rest remained at the values used in the 2021 update assessment. The relative index of abundance estimated using data from the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey, which samples depths from 55–1,280 m, represents the primary source of information on the stock’s trend and was updated and re-analyzed to include the most recent data, including length- and conditional-age-at-length composition data, covering the period 2003–2022. Other, discontinued, survey indices contribute information on trend and sablefish demographics. Historical surveys include the Northwest Fisheries Science Center Slope Survey conducted from 1998–2002, Alaska Fisheries Science Center Slope Survey conducted from 1984–2001, and Alaska Fisheries Science Center/Northwest Fisheries Science Center West Coast Triennial Shelf Survey

conducted from 1980–2004. Data from the historical surveys were not re-evaluated for this assessment update. Additionally, an environmental time-series of sea level was used as an index of recruitment in the base model; this time-series was updated and re-analyzed using the latest tide-gauge data.

All externally estimated model parameters, weight-length relationship, maturity schedule, and fecundity relationships, remained unchanged from the 2019 benchmark assessment. As in previous assessments, growth and natural mortality were estimated using sex-specific relationships. Uncertainty in recruitment was included by estimating a full time-series of deviations from the stock-recruitment curve. The ‘one-way-trip’ nature of the time-series does not facilitate estimation of the steepness parameter (h) of the stock-recruitment relationship. Therefore, h was fixed at 0.7, similar to values used for other groundfish stock assessments.

Stock Biomass and Dynamics

During the first half of the 20th century it is estimated that sablefish were exploited at relatively modest levels. Modest catches continued until the 1960s, along with a higher frequency of above average, but uncertain, estimates of recruitment through the 1970s, which led to a sharp increase in the spawning biomass during the mid-1950s to mid-1970s (Figure ii). Subsequently, spawning biomass is estimated to have declined between the mid-1970s and the early 2010s, with the largest harvests occurring during the 1970s followed by harvests that were, on average, higher than pre-1970s harvest through the early 2000s. In recent years, the spawning biomass is estimated to be increasing due to strong recruitment events in 2008, 2013, 2016, 2020, and 2021 (Table ii). Although the relative trend in spawning biomass is robust to uncertainty in the leading model parameters, the productivity of the stock is uncertain due to confounding of natural mortality, absolute stock size, and productivity. The estimates of uncertainty around the point estimate of stock size in 2023 are large, suggesting that the spawning biomass could range from just under 49,643 mt to 185,395 mt.

The estimated trajectory of relative stock biomass (Figure ii) across the times series is highly variable, with the population increasing to near unfished levels in the 1970s; declining to near the target relative biomass of 40% around 2000; and then increasing at the end of the modeled period (Table ii and Figure iii). The estimated fraction unfished in 2023 from the base model is 63.0% (95% confidence interval 42.4%–83.6%) increasing from the estimated fraction unfished in 2021 of 58% (Kapur et al. 2021).

Table ii: Estimated recent trend in spawning biomass and the fraction unfished and the 95 percent intervals for the base model.

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2013	81,988.9	32,289.3	131,688.5	0.440	0.289	0.591
2014	82,768.8	32,925.9	132,611.7	0.444	0.293	0.595
2015	82,489.8	32,955.8	132,023.8	0.442	0.292	0.592
2016	81,830.7	32,591.5	131,069.9	0.439	0.289	0.588
2017	82,908.1	32,989.6	132,826.6	0.444	0.292	0.597
2018	84,803.5	33,803.9	135,803.1	0.455	0.299	0.610
2019	89,431.6	35,948.5	142,914.7	0.479	0.316	0.643
2020	98,233.0	40,133.2	156,332.8	0.527	0.349	0.704
2021	106,760.0	44,563.1	168,956.9	0.572	0.384	0.761
2022	110,930.0	46,717.3	175,142.7	0.595	0.400	0.789
2023	117,519.0	49,642.5	185,395.5	0.630	0.424	0.836

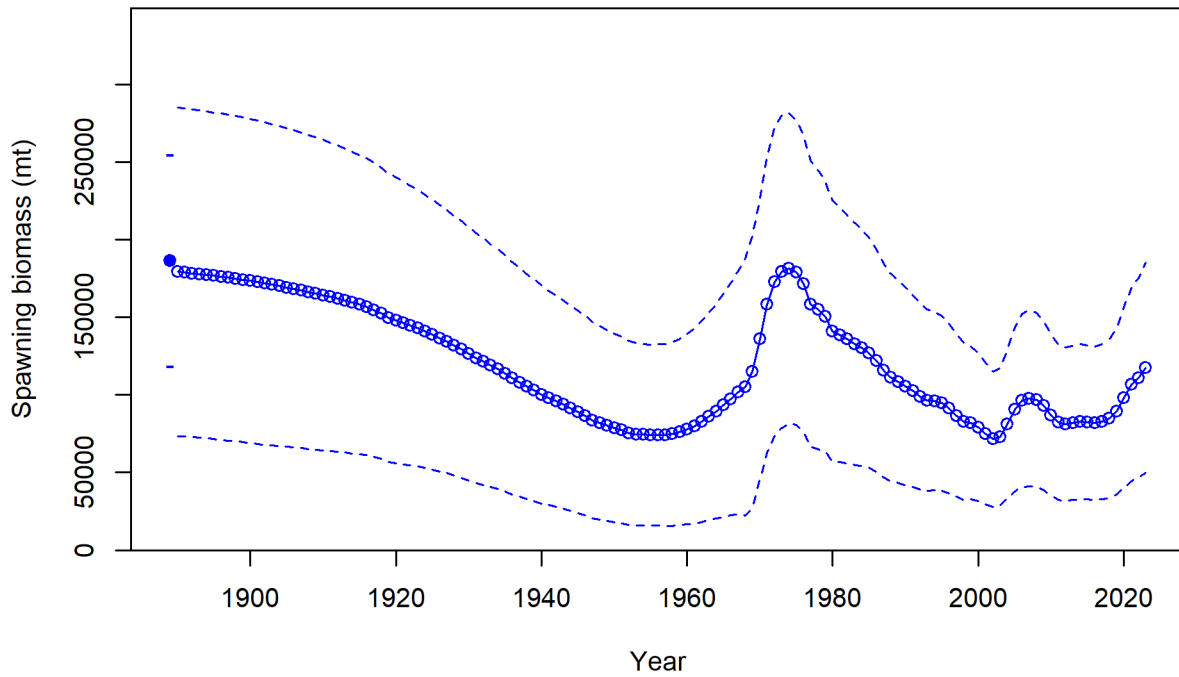


Figure ii: Estimated time series of spawning biomass (circles and line: median; light broken lines: 95 percent intervals) for the base model.

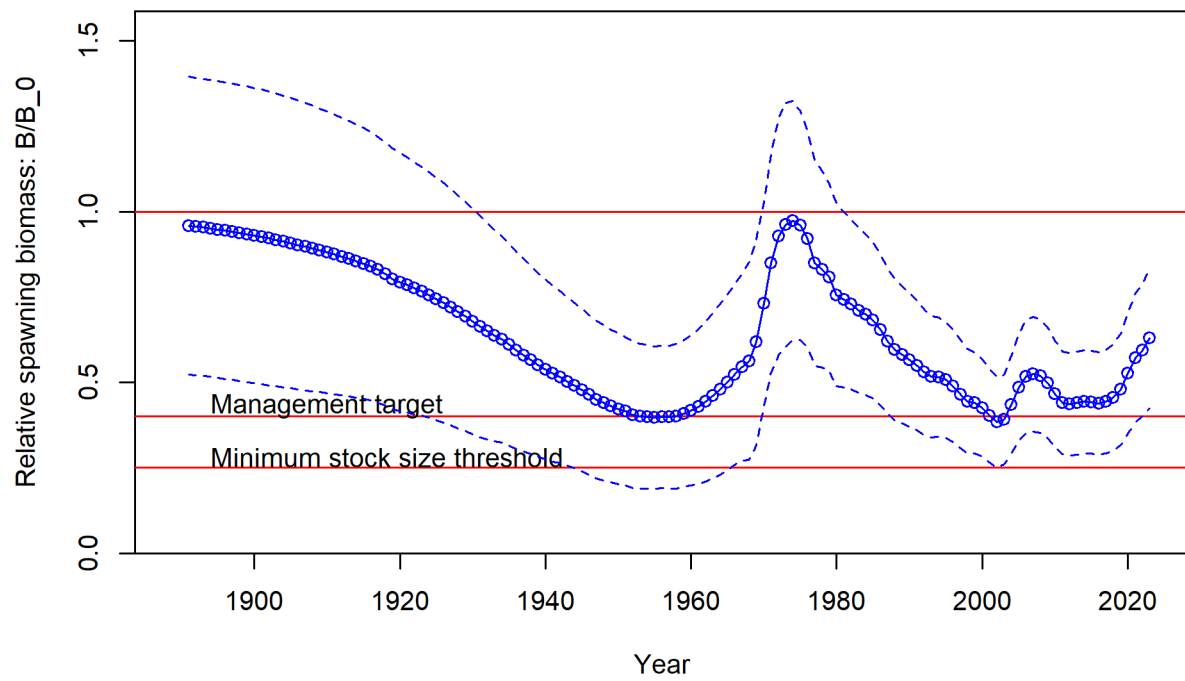


Figure iii: Estimated time series of fraction of unfished spawning biomass (circles and line: median; light broken lines: 95 percent intervals) for the base model.

Recruitment

Sablefish recruitment is estimated to have been quite variable with large amounts of uncertainty in individual recruitment events. A period of generally negative recruitment was followed by a single large recruitment event in the early-1960s. This large event was followed by a period of 10 or so years of average recruitment and another large recruitment event in the late-1970s. These two large events combined with a period of more slightly positive recruitments than what was estimated for pre-1960 contributed heavily to the large increase in stock biomass that subsequently declined throughout much of the 1970s forward. Less frequent large recruitments during the mid-1980s through 1990 slowed the rate of stock decline, with another series of large recruitments during 1999–2001 leading to a leveling off in the stock decline. The above-average cohorts from 2008, 2013, 2015, 2016, 2020, and 2021 are contributing to an increasing spawning stock size (Table iii and Figures iv and v). The large recruitment events in 2020 and 2021 are estimated to be greater than any other recruitment across the modeled period (Table iii and Figure v).

Table iii: Estimated recent trend in recruitment (1,000s) and recruitment deviations and their 95 percent intervals for the base model.

Year	Recruitment (1,000s)	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2013	37,796.8	21,711.8	65,798.2	1.700	1.500	1.900
2014	7,268.4	3,612.7	14,623.0	0.053	-0.441	0.547
2015	27,643.7	15,611.4	48,949.6	1.400	1.100	1.700
2016	66,059.4	37,936.7	115,029.6	2.300	2.000	2.500
2017	13,137.7	6,584.6	26,212.5	0.645	0.172	1.100
2018	3,955.7	1,547.0	10,114.4	-0.561	-1.393	0.272
2019	13,835.9	6,433.0	29,757.9	0.681	0.080	1.300
2020	154,839.0	82,091.7	292,052.8	3.100	2.700	3.400
2021	208,277.0	98,698.5	439,513.4	2.900	2.400	3.400
2022	9,122.3	1,396.4	59,593.2	-0.687	-2.975	1.600
2023	18,302.3	2,302.0	145,516.7	0.000	-2.744	2.700

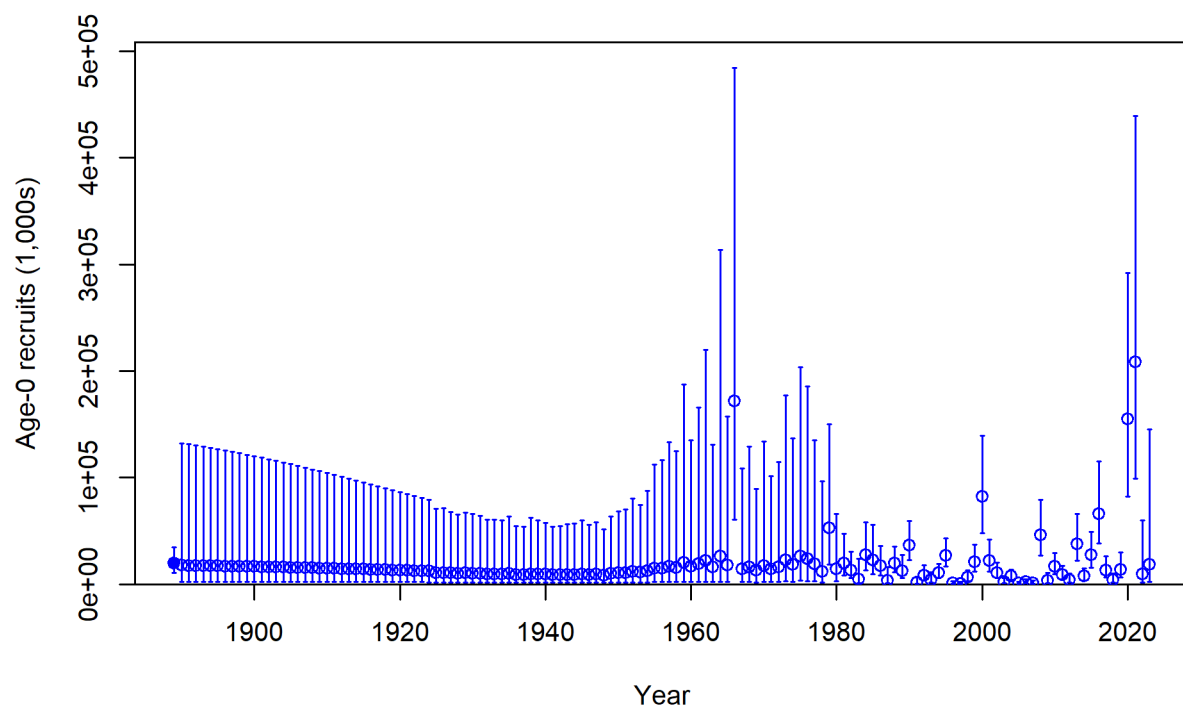


Figure iv: Estimated time series of age-0 recruits (1,000s) for the base model with 95 percent intervals.

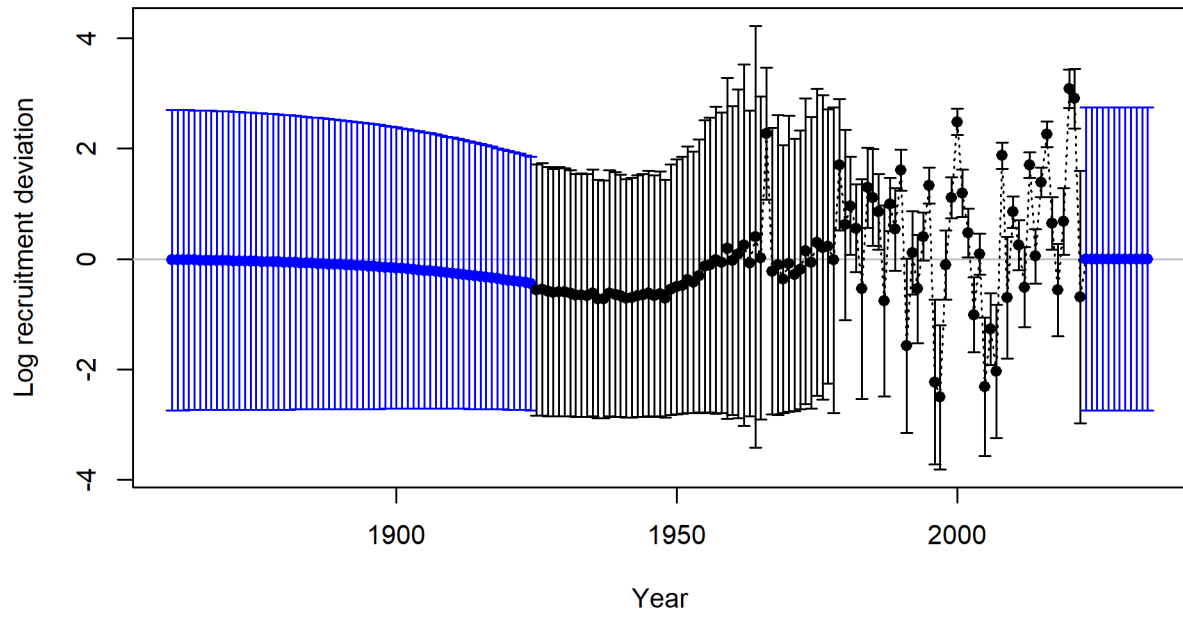


Figure v: Estimated time series of recruitment deviations with their 95 percent intervals. The early and recent blue dots are recruitment deviations that are not part of the main period.

Exploitation Status

Fishing intensity has been at or below the current management target of 1.0 since the mid-1980s and declining in the last ten years (Table iv; Figure vi). Here, fishing intensity is reported as a the ratio of one minus the spawning potential ratio to one minus the SPR target of 45%, $\frac{1-SPR}{1-SPR_{45\%}}$. The occurrence of overexploitation relative to the proxy occurs at all fishing intensity values larger than 1.0. Estimated exploitation for the most recent year was on par with estimates from 2015–2019 but greater than the previous two years (Table iv).

Table iv: Estimated recent trend in $\frac{1-SPR}{1-SPR_{45\%}}$, where SPR is the spawning potential ratio and $SPR_{45\%}$ is the SPR management target; the exploitation rate; and their 95 percent intervals for the base model.

Year	$\frac{1-SPR}{1-SPR_{45}}$	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2013	0.591	0.286	0.895	0.018	0.008	0.029
2014	0.598	0.289	0.907	0.019	0.008	0.031
2015	0.679	0.345	1.000	0.023	0.010	0.036
2016	0.717	0.374	1.100	0.025	0.011	0.040
2017	0.660	0.337	0.984	0.024	0.010	0.038
2018	0.629	0.315	0.943	0.023	0.010	0.036
2019	0.565	0.272	0.857	0.022	0.010	0.035
2020	0.368	0.159	0.576	0.014	0.006	0.021
2021	0.435	0.197	0.673	0.017	0.008	0.027
2022	0.531	0.257	0.806	0.023	0.010	0.036

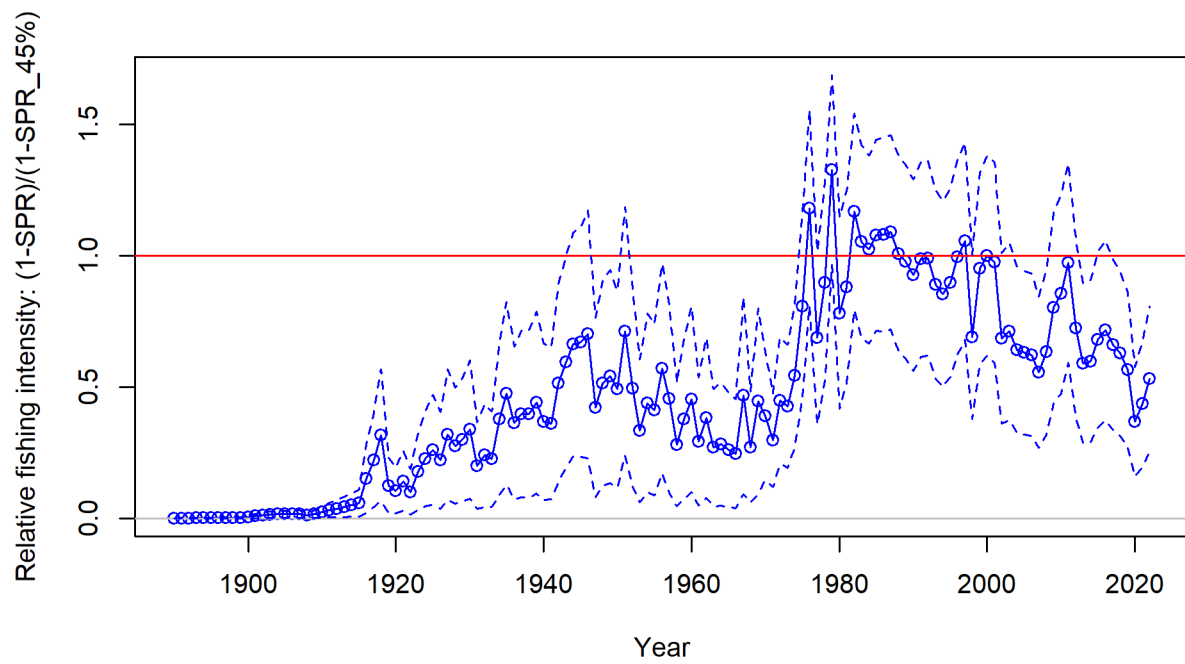


Figure vi: Time series of spawning potential ratio ratio: $\frac{1-SPR}{1-SPR_{45\%}}$.

Ecosystem Considerations

The climate vulnerability analysis (McClure et al. 2023) suggests that processes affecting sablefish recruitment are sensitive to climatic and, therefore, oceanic drivers. Given high climate vulnerability, changes in the abundance, productivity, and spatial distribution of sablefish are likely, and these changes are likely to impact fishing fleets and communities because of the high value of this fishery. The climate vulnerability analysis also suggests that sablefish are likely to shift their distribution in response to climate variability. Strong coastwide recruitment appears to be associated with good recruitment north of Cape Mendocino ($\sim 40^\circ\text{N}$), which itself is correlated with transport and temperature in the northern portion ($40^\circ\text{--}48^\circ\text{N}$) of the U.S. West Coast, specifically with the northern transport of yolk-sac larvae (Tolimieri et al. 2018). A re-analysis of the relationship between sea level and recruitment found that variation around the stock-recruitment curve was negatively correlated with sea level north of Cape Mendocino. Reliable sea-level data are available back to 1925, which predates the availability of composition data and thus may allow for better hindcasting of the stock dynamics relative to a model without the time series. Furthermore, information on current and future recruitment can be informed by the time series, leading to more robust estimates of estimates of uncertainty in management quantities.

The sablefish stock has experienced latitudinal shifts in the center of the distribution of stock biomass along the U.S. West Coast Coast, which has affected fishing opportunities to individual ports (Selden et al. 2019). The population centroid shifted to the north from 1980–1992 then south by 2013. More recently, the distribution of stock biomass shifted north, illustrated by an increase in trawl survey biomass in the north, but not as far north as in the 1990s.

Whale entanglements with pot gear has the potential to limit effort in the pot-gear sectors due to protections for marine mammals. The estimated fleet-wide entanglements were consistently above the 5-year running average threshold during 2002 to 2017 in the combined Limited Entry sablefish and Open Access Fixed Gear pot sectors (Hanson et al. 2019). This result was largely due to the Open Access Fixed Gear pot sector, which had entanglements consistently above the 5-year running average threshold, while entanglements in the Limited Entry sablefish pot sector were consistently below the threshold.

Reference Points

The estimated 2023 spawning biomass relative to unfished equilibrium spawning biomass is 63%, well above the management target of 40% of unfished spawning biomass. The fishing intensity has been at or below the $\text{SPR}_{45\%}$ since the mid 1980s and declining in the last ten years (Figure vii). The relative spawning biomass compared to fishing intensity across almost all model years was above the thresholds in both directions (Figure vii). All reference points were calculated based on a steepness value fixed at 0.7 and the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2022 (Table v). Sustainable total yield, landings plus discards, using $\text{SPR}_{45\%}$ is 9,641.13 mt. The spawning biomass equivalent to 40% of the unfished spawning biomass ($\text{SB}_{40\%}$) calculated using $\text{SPR}_{45\%}$ was 74,613.6 mt.

Table v: Summary of reference points and management quantities, including estimates of the 95 percent intervals for the model area.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	186,534.00	118,407.81	254,660.19
Unfished Age 4+ Biomass (mt)	458,971.00	280,172.31	637,769.69
Unfished Recruitment (R_0)	19,453.90	7,838.53	31,069.27
Spawning Biomass (mt) (2023)	117,519.00	49,642.51	185,395.49
Fraction Unfished (2023)	0.63	0.42	0.84
Reference Points Based $SB_{40\%}$	NA	NA	NA
Proxy Spawning Biomass (mt) $SB_{40\%}$	74,613.60	47,363.04	101,864.16
SPR Resulting in $SB_{40\%}$	0.46	0.46	0.46
Exploitation Rate Resulting in $SB_{40\%}$	0.04	0.04	0.05
Yield with SPR Based On $SB_{40\%}$ (mt)	9,477.83	4,432.47	14,523.19
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Biomass (mt) ($SPR_{45\%}$)	71,629.00	45,468.58	97,789.42
$SPR_{45\%}$	0.45	NA	NA
Exploitation Rate Corresponding to $SPR_{45\%}$	0.04	0.04	0.05
Yield with $SPR_{45\%}$ at SB SPR (mt)	9,641.13	4,509.22	14,773.04
Reference Points Based on Estimated MSY	NA	NA	NA
Spawning Biomass (mt) at MSY (SB MSY)	45,903.50	29,025.25	62,781.75
SPR MSY	0.33	0.32	0.33
Exploitation Rate Corresponding to SPR MSY	0.07	0.06	0.08
MSY (mt)	10,431.20	4,881.90	15,980.50

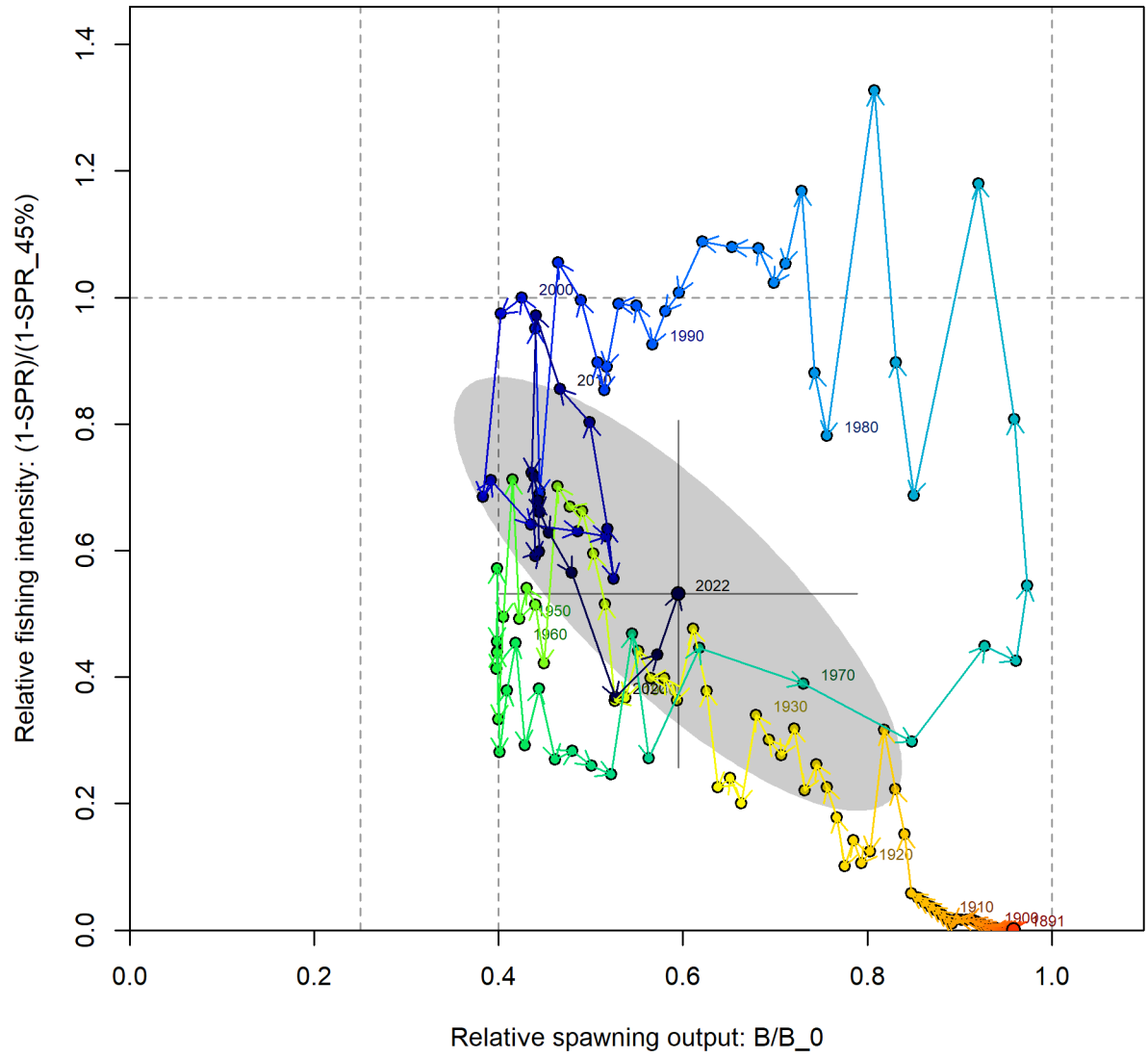


Figure vii: Phase plot of biomass ratio vs. spawning potential ratio (SPR) ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Warmer colors (red) represent early years and colder colors (blue) represent recent years. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension.

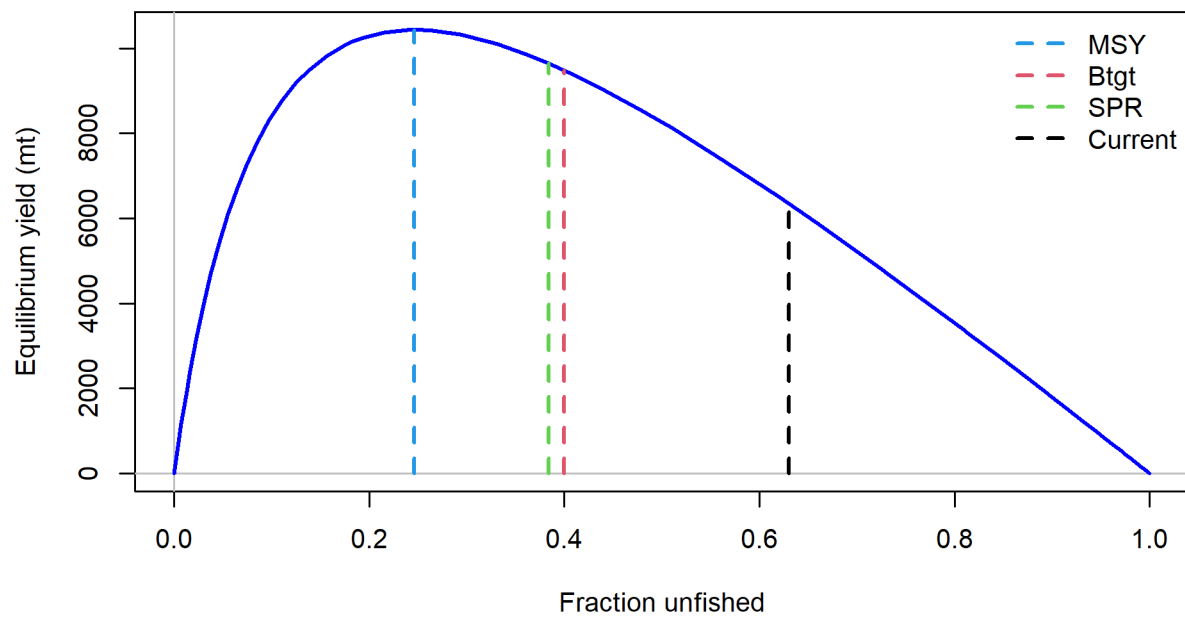


Figure viii: Yield curve with reference points.

Management Performance

Sablefish management includes a rich history of seasons, size-limits, trip-limits, and a complex permit system. Managers divide coastwide yield targets among the fleets, fishery sectors (including both limited entry and open access), as well as north and south of 36° N. latitude. In the most recent decade catches have been well below the overfishing limit (OFL) and annual catch limit (ACL) with attainment ranging between 53–83% attainment of the ACL (Table vi). Attainment by the fishery was lowest in 2020 and highest in 2022.

Table vi: The overfishing limit (OFL; mt), annual catch limit (ACL; mt), landings (mt), and estimated catch (mt) between for the most recent ten years.

Year	OFL	ACL	Landings	Catch
2013	6,621	5,451	4,152.99	4,220.25
2014	7,158	5,909	4,442.46	4,525.20
2015	7,857	6,512	5,182.58	5,266.98
2016	8,526	7,121	5,436.24	5,537.02
2017	8,050	7,196	5,692.35	5,814.87
2018	8,239	7,419	5,372.21	5,469.99
2019	8,489	7,596	5,378.40	5,575.29
2020	8,648	7,755	3,954.57	4,095.54
2021	9,402	8,791	4,913.29	5,217.28
2022	9,005	8,375	6,371.55	6,913.62

Unresolved Problems and Major Uncertainties

This assessment update estimates very large recruitment events occurring near the end of the modeled period in 2020 and 2021. Anecdotal information from the fishery of high bycatch of small sablefish starting in the summer of 2021 indicated that there was likely a strong cohort entering the population and this is supported by the data collected by the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey in both 2021 and 2022. However, since these young fish have only been observed in two years by the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey there is more uncertainty around the strength of these year classes than cohorts that have been better observed that will hopefully be resolved with future subsequent observations by the survey and the fishery.

The data available for sablefish off the U.S. West Coast are not informative with respect to absolute stock size and productivity. This could be, in part, due to the largely one-way-trip nature of the historical series (i.e., a slow and steady decline in spawning biomass) that has only recently stabilized and increased, which can be consistent with a larger less productive stock, a smaller more productive stock, or many combinations in between. While the historical catches provide some information about the minimum stock size necessary to remove the catches from the population, there is limited information in the data regarding the upper limit of the stock size. The above factors are also confounded by movement of sablefish between the region included in this assessment and regions to the north. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in many parameters can result in different estimates of management reference points. However, because several leading model parameters, such as natural mortality, selectivity, and historical recruitments, are estimated within the stock assessment model, the uncertainty about these estimates remains large and typically overlapped among the investigated models. The uncertainty will remain

until a more informative time-series, better quality demographic and biological information are accumulated, or a range-wide analysis is completed for sablefish.

Uncertainty in the current ageing methods (both bias and imprecision), as well as relatively sparse fishery sampling, result in age data that are potentially variable. Furthermore, because sablefish grow rapidly, nearing asymptotic length in their first decade of life, length data is not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that the stock trajectory (via shifts in recruitment strength) is closely linked to productivity regimes in the California Current. Studies of oceanographic drivers of sablefish recruitment explain between 25 percent and just over 50 percent of the sablefish recruitment variability, depending upon the oceanographic covariates evaluated. Uncertainty in future environmental conditions and changes in the timing, dynamics, and productivity of the California Current ecosystem via climate change or cycles similar to the historical period should be considered a significant source of uncertainty in all projections of stock status. The ongoing Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey is a fairly precise relative index of abundance over a broad demographic component of the stock but it does not survey the entire stock as sablefish reside in waters deeper than 1,280 m, the survey limit, and to the north. Therefore, a portion of the stock is unobserved. This index has the potential to inform future stock assessments about the scale of the population relative to catches being removed; however, such information will require contrast in the observed survey trend.

Decision Table and Projections

The projection of stock biomass, status, and harvest limits was developed using the base model. The total catches in 2023 and 2024 were set at 9,118 and 8,359 mt, respectively, based on recommendations from the Groundfish Management Team. The ABC values were estimated using a category 1 time-varying σ_y starting at 0.50 combined with a P* value of 0.45. The catches during the projection period, 2025–2034, were set equal to the year-specific Acceptable Biological Catch (Table vii). The spawning biomass and fraction unfished increase sharply during the projection due to the estimated large recruitments in 2020 and 2021 maturing and entering the spawning population, resulting in future overfishing limits and Acceptable Biological Catches that are substantially higher than those set for 2023–2024.

Table vii: The adopted OFL (mt), ACL (mt), and assumed removals (mt) in 2023-24 and the projected OFL (mt), ABC (mt), spawning biomass, and fraction unfished for 2025-2034. The projected ABCs are calculated using a P* of 0.45 and category 1 time-varying sigma.

Year	Adopted OFL	Adopted ACL	Assumed Removals	OFL	ABC	Spawning Biomass	Fraction Unfished
2023	11,577	10,824	9,118	-	-	117,519	0.630
2024	10,670	9,923	8,359	-	-	141,875	0.761
2025	-	-	-	39,085	36,545	183,592	0.984
2026	-	-	-	37,310	34,699	207,142	1.110
2027	-	-	-	34,160	31,632	214,059	1.148
2028	-	-	-	29,701	27,385	210,719	1.130
2029	-	-	-	25,318	23,217	203,091	1.089
2030	-	-	-	21,812	19,914	194,403	1.042
2031	-	-	-	19,380	17,616	185,924	0.997
2032	-	-	-	17,843	16,130	177,993	0.954

Table vii: The adopted OFL (mt), ACL (mt), and assumed removals (mt) in 2023-24 and the projected OFL (mt), ABC (mt), spawning biomass, and fraction unfished for 2025-2034. The projected ABCs are calculated using a P* of 0.45 and category 1 time-varying sigma. (*continued*)

Year	Adopted OFL	Adopted ACL	Assumed Removals	OFL	ABC	Spawning Biomass	Fraction Unfished
2033	-	-	-	16,898	15,208	170,621	0.915
2034	-	-	-	16,281	14,587	163,747	0.878

Scientific Uncertainty

The model estimated uncertainty around the 2023 spawning biomass for the model is $\sigma = 0.29$. The uncertainty around the OFL in 2023 is $\sigma = 0.32$. Each of these are likely underestimates of overall uncertainty due to the necessity to fix several key population dynamics parameters (e.g., steepness, recruitment variance) and also because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

Research and Data Needs

Please refer to the 2019 benchmark assessment for a detailed list of research and data needs for sablefish (Haltuch et al. 2019).

1 Introduction

1.1 Basic Information

Sablefish (*Anoplopoma fimbria*, or ‘black cod’) are distributed in the Northeastern Pacific Ocean from the southern tip of Baja California northward to the North-Central Bering Sea and in the Northwestern Pacific Ocean from Kamchatka southward to the northeastern coast of Japan (Hart 1973; Eschmeyer and Herald 1983). Despite their vast range, U.S. West Coast sablefish are modeled as a single population. Thus, this assessment does not explicitly account for movement between offshore sea mounts (Shaw and Parks 1997; Morita et al. 2012; Hanselman et al. 2015), to regions to the north of the U.S. West Coast, or to the Western Pacific (Fujioka et al. 1988; Heifetz and Fujioka 1991; Hanselman et al. 2015). To the modelers’ knowledge there is no information regarding sablefish from the Pacific Coast of Mexico.

Previous analyses suggest the existence of several stocks of sablefish in the Eastern Pacific Ocean that are largely delineated by management boundaries (Schirripa 2007). More recent genetic analyses found that sablefish in the Northeastern Pacific Ocean are a single panmictic population (Jasonowicz et al. 2017). Additional support for a panmictic population stems from tag recoveries that show sablefish move between the regions currently used for management (Hanselman et al. 2015; Sogard and Berkeley 2017). Analyses of length-at-age data has found spatial variation in von Bertalanffy growth parameters across the Northeastern Pacific Ocean (McDevitt 1987; Echave et al. 2012; Head et al. 2014; Gertseva et al. 2017; Kapur et al. 2020). While geographic break points at approximately 36°N. latitude, between Point Conception and Monterey, California at the start of the Southern California Bight, and 50°N. latitude, where the North Pacific Current bifurcates, suggest zones of growth variation, generally with increasing maximum body size and decreasing growth rates with increasing latitude, they do not indicate regions with separate populations.

Smaller sablefish are generally found in shallower waters but the demographics appears to be fully mixed (adult and juvenile) near the shelf–slope break (i.e., 100–300 m). Beyond the shelf–slope break, the adult population is dominated by older individuals (Methot 1994) and younger fish become increasingly rare. Fish in the deepest areas sampled tend to be the oldest individuals but not the largest individuals, suggesting that age rather than size dictates depth distribution. However, the interaction between environmental conditions and seasonal movements that produce an increase in age with depth are largely unknown. The population is distributed beyond the greatest depth sampled by any of the surveys and beyond the deepest commercial fishing areas. Research in these deeper habitats occupied by sablefish is potentially difficult because they extend across the boundary of the exclusive economic zone and sea mounts and ridges around the Pacific. There are relatively fewer sablefish in the Puget Sound and the Strait of Georgia than in coastal U.S. waters. Therefore, connectivity among these areas and the open coast is likely of less importance to this assessment than movement along the coast.

1.2 Life History

Tolimieri et al. (2018) provide a thorough review of the literature on spawning and early life history of sablefish in the U.S. West Coast. Briefly, sablefish off the U.S. West Coast exhibit a protracted spawning period from December through March, with peak in February (Guzmán et al. 2017). This winter-time spawning may result in reduced availability to the commercial fishery during the winter months. Spawning occurs along the continental shelf–slope break in waters deeper than 300 m. Eggs (~ 2.1 mm in diameter) are buoyant and rise in the water column before hatching and sinking to deeper waters. Pelagic juveniles are

present in off-shore surface waters and settle to the benthos as age-0 recruits during the late summer to fall, with most newly settled fish at depths of less than 250 m.

Sablefish reach full size and maturity in their first decade of life, reaching nearly asymptotic size and beginning to mature after 5–7 years. Female sablefish generally reach larger sizes than males. However, the sex ratio tends to be skewed toward males at the oldest ages implying a lower natural mortality rate for males relative to females. The oldest sablefish on record was captured in 2006 off Washington and aged (with observation error) at 102 years. This female was only 68 cm long, nowhere near the longest individual (117 cm).

Adult sablefish are fast swimming and capable of feeding on a diverse array of prey species including fishes, cephalopods, and crustaceans (Low et al. 1976). The cohabitation of adult and juvenile sablefish may result in some cannibalism, and large changes in predator biomass (such as the recent rebuilding of lingcod, *Ophiodon elongatus*) could have a feedback on juvenile survival and, therefore, stock productivity.

Range-wide investigations of sablefish growth suggest that growth varies across the Northeastern Pacific, with a generally increasing cline in length-at-age data with latitude (McDevitt 1987; Echave et al. 2012; Gertseva et al. 2017; Kapur et al. 2020). Break points in growth have been identified at around 50°N. latitude (approximately the northern end of Vancouver Island, Canada), where north of this breakpoint female asymptotic-length estimates were consistently over 70 cm and south of this breakpoint female asymptotic-length estimates were below 66 cm (Kapur et al. 2021). A second break point was identified at 36°N. latitude (approximately Monterey, California), where asymptotic size for females and males to the south were 60.43 cm and 55.00 cm, respectively (Kapur et al. 2020). Note that this information was not included in the 2019 benchmark assessment nor this update, as the data to construct a spatially-structured model and account for movement between areas north and south of 36°N. latitude are not available. Instead, coastwide, sex-specific growth parameters were estimated for females and males, as it was done in 2019 benchmark assessment.

1.3 Ecosystem Considerations

A detailed summary of social–ecological system (SES) analyses, the Climate Vulnerability Assessment, and environmental drivers of sablefish recruitment is available in the 2019 benchmark assessment report (Haltuch et al. 2019).

1.4 Historical and Current Fishery Information

This section is not required for an update assessment, please see the last benchmark assessment (Haltuch et al. 2019) for more information.

1.5 Summary of Management History and Performance

This section is not required for an update assessment, please see the last benchmark assessment (Haltuch et al. 2019) for more information.

1.6 Foreign Fisheries

This section is not required for an update assessment, please see the last benchmark assessment (Haltuch et al. 2019) for more information.

2 Data

All data incorporated within this assessment update, which followed a more limited data updating approach compared to typical update assessments, are shown in Figure 1. This update was added to the 2023 assessment workload in April 23, 2023 with the agreement that the assessment adhere to a more limited approach to updating data compared to a typical assessment update. The following data sources were updated for this assessment update:

1. The work to add recent commercial to the model for 2021–2022 identified three issues in the landings data in the 2021 assessment update which likely extended to previous assessments. Select landings from the Pacific Fisheries Information Network (PacFIN) for sablefish were omitted for the 2019 benchmark and 2021 update assessments. These landings have been added to this update assessment (see section *recommercial-landings* for additional information). Second, landings from 1977–1982 in the catch reporting area that includes both U.S. and Canadian waters were assigned 50–50% to each country rather than 100% to the U.S. as previous assessments had assumed. Finally, it appears that previous assessments failed to include bycatch from the at-sea fishery in the base-model landings. The annual bycatch of sablefish by the at-sea fishery of sablefish is typically relatively low but after there have been sharp increases following years of large recruitment events (e.g., 304 mt in 2022).
2. The discard mean weights and length compositions from discarded fish observed by the West Coast Groundfish Observer Program (WCGOP) were updated and the new values for 2020 and 2021 were added to the model. Discard rates from 2020–2021 were added to the model.
3. The relative index of abundance, length composition, and conditional-age-at-length data from the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey (WCGBTS) were updated and extended through 2022.
4. The environmental index data to inform estimation of recruitment were updated and extended through 2022.

All other data sources used in the sablefish assessment were retained in the same form as included in the 2021 assessment update.

2.1 Fishery-Dependent Data

2.1.1 Commercial Landings

Historical commercial landings prior to 1970, 1986, and 1980 for Washington, Oregon, and California, respectively, remained unchanged from the 2019 benchmark assessment. Landings data were pulled from PacFIN (17 July 2023) and re-evaluated in this assessment update.

Changes to recent landings from PacFIN include typical updates to historical data given standard updates to fish-ticket data that normally results in changes of just a few mt per year. Additional changes to the data were made because of two changes in the methods used to extract the data. First, landings from the ‘Oregon Coast’ International North Pacific Fishery Commission (INPFC) area, i.e., between 42.000–46.267°N. latitude, are no longer excluded from the total landings. These landings occurred between 1980–2011 and sum to

approximately 4,060 mt. Annual summaries are not possible given the confidentiality of the data. Second, landings from 1977–1982 in the catch reporting area that includes both U.S. and Canadian waters are now assigned 50–50% to each country rather than 100% to the U.S. Specific differences are not reported here given it is unclear if their sums are confidential. Both of these changes were approved by state representatives prior to their use in this assessment.

This assessment update also pulled bycatch of sablefish by the At-Sea Pacific Hake (*Merluccius productus*) fishery since 1990 from the Alaska Fisheries Science Center (AFSC) North Pacific Database Program (NORPAC) database (27 July 2023). These data were not included in the landings data used in the 2019 benchmark and 2021 update assessments. Across most years the bycatch of sablefish in the At-Sea Pacific Hake fishery is relatively low, particularly compared to the landings data from other groundfish sectors contained in PacFIN. However, there have been select years where the bycatch of sablefish in this fishery has been higher than average, which seem to correspond to one or two year after strong recruitment events for sablefish (e.g., bycatch of 153 mt and 116 mt in 2017 and 2018, respectively). The bycatch of sablefish in this fishery in 2022 of 304 mt was greater than any other year in the time series (1990–2022). These data were added to landings for the trawl fleet in the model and were included in the model bridging to better understand the impact of adding these removals to the model. The full time series, i.e., back to 1978, was not available for this assessment update. Future assessments will want to include the full time series.

2.1.2 Commercial Discard

The WCGOP estimates of commercial discards and biological data from 2020 and 2021 were added to the assessment update model. The assessment update for sablefish conducted in 2021 experienced challenges where 2019 discard data appeared to depart in the frequency of sablefish being discarded and the size of discarded fish requiring the assessment update to add a new retention block for the trawl and fixed gear fleets for 2019 and 2020. Including the most recent WCGOP data in this assessment update allowed for these data to better inform the estimation of recent discarding practices which may be changing due to large recent recruitment events.

The discard rates in the trawl fleet are similar in 2020 and 2021 but are increased compared to the 2019 rates (Figure 4). The increased observed discard rate in the trawl fleet aligns with reports from the fishery of increased encounters with young small fish in recent years. The discard rates of the fixed gear fleet in 2020 and 2021 were similar or slightly greater than the observed 2019 rates but 2020 and 2021 had larger uncertainty (Figure 3). The discard rate data were assumed to be normally distributed and fit by year in the model. Rates prior to 2020 were not updated and remain the same as what was used to fit the 2021 assessment update.

The mean body weight of discarded fish by the fixed gear fleet are similar in 2022 and 2021 to those observed in 2019 (Figure 5). The mean body of discarded fish by the trawl fleet declined by year since 2019 with increased variability in the body weights of discarded fish in the final year of data (Figure 6).

The observed length distribution of fish discarded by the fixed-gear fleet in 2020 and 2021 ranged between 40–60 cm, peaking around 50–55 cm (Figure 7). In contrast, the discarded length by the trawl fleet were generally smaller ranging between 20–55 cm (Figure 8).

2.2 Fishery-Independent Data

Multiple fishery-independent surveys are incorporated in the assessment of sablefish off the U.S. West Coast. The biological data and relative indices of abundance from the Alaska Fisheries Science Center/Northwest Fisheries Science Center West Coast Triennial Shelf Survey (Triennial Survey), Alaska Fisheries Science Center Slope Survey (Slope Survey), and Northwest Fisheries Science Center Slope Survey (NWFSC Slope Survey) were not re-evaluated for this assessment update. See Haltuch et al. (2019) and Kapur et al. (2021) for details on these data and how they were processed for inclusion within this assessment.

2.2.1 Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey

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). 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 to early October. There were only two vessels used in 2019 and three in 2013, with one of the three that year unable to complete its survey pass due to a government shutdown. No survey occurred in 2020 due to Coronavirus disease (COVID-19). This design therefore incorporates both vessel-to-vessel differences in catchability, as well as 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.

Sablefish are observed across the full sampling depth range of the WCGBTS (Figure 9) and across all latitudes off the West Coast (Figure 10). The WCGBTS across most years has 400 or more positive tows for sablefish each year (Table 3). A coastwide relative index of abundance was estimated for sablefish using the species distribution modeling platform sdmTMB (Anderson et al. 2022). A delta model with a gamma error distribution was selected over the lognormal distribution based on the quantile-quantile plots (Figure 11). This was the same error distribution selected by the 2019 benchmark assessment and the 2021 assessment update. The relative index of abundance for sablefish decreased to the lowest levels between 2008–2010, began to slowly increase between 2011–2019, and then sharply increased in the final two years of the time series, 2021–2022, to the highest levels observed by the WCGBTS (Figure 12).

Length and age samples collected annually by the WCGBTS were processed using 2 cm length bins between 18 to 90 cm and age bins between 0 to 50. The age data were input as conditional-age-at-length data to inform the estimation of growth within the model. The length compositions were expanded to the tow level and strata level (Table 2). The same stratification was used for their expansion as was used in the 2019 benchmark assessment and 2021 assessment update.

The 2021 and 2022 annual length compositions for fish less than 30 cm indicate potentially multiple above average recruitments entering the population (Figure 19). The age data in 2021 also shows above average observations of age-0 and age-1 fish with these same cohorts also being observed in 2022 (Figure 14). The size-at-age of age-0 and age-1 fish by pass of the WCGBTS were examined to better understand how the sizes of young fish in 2021 and 2022 compare to other years in the time series (Figure 13). Across all years, age-0 fish are observed more frequently during the second pass of the survey compared to the first pass with age-0 fish generally being less than 30 cm. The size of age-1 fish generally range between 30–45 cm with sizes increasing between pass 1 to pass 2. The distribution of age-1 sizes observed in 2021 and 2022 is more

variable compared to most other years in the time series. Additionally, the distribution of sizes in age-1 fish varied between 2021 and 2022 with observed age-1 fish being slightly smaller by pass in 2022 compared to 2021 (Figure 13).

2.2.2 Environmental Indices

Research and assessments during recent decades have examined the relationship between sea level, measured via tide gauges, and sablefish recruitment (Haltuch et al. 2019). Changes in sea level serve as a proxy for large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport. A re-analysis of the relationship between sea level and recruitment was conducted for this assessment that included all available tide-gauge data available for the U.S. West Coast through 2022, using the same approach as in the 2019 benchmark assessment (Figure 20).

2.3 Biological Data

A number of biological parameters were estimated outside the 2019 assessment model (weight-length relationship, the maturity schedule, and fecundity relationships). These values are treated as fixed in that model and this assessment update, and therefore, uncertainty reported for the stock assessment results does not include any uncertainty associated with these quantities.

3 Assessment Model

3.1 Summary of Previous Assessments and Reviews

History of Modeling Approaches

This section is not required for an update assessment.

Responses to Most Recent Previous STAR panel and SSC Recommendations

This section is not required for an update assessment.

Responses to Groundfish Subcommittee Recommendations

This section is not required in a draft update assessment undergoing review. Point by point responses will be added after receiving the recommendations.

3.2 Model Structure and Assumptions

3.2.1 Description of New Modeling Approaches

This section is not required for an update assessment.

3.2.2 Modeling Platform and Structure

The assessment was conducted using SS3 version 3.30.21.00 developed by Dr. Richard Methot at the National Oceanic & Atmospheric Administration (NOAA), Northwest Fisheries Science Center (NWFSC) (Methot

and Wetzel 2013). This most recent version was used because it included improvements and corrections not available in the previously used version of SS3, i.e., version 3.30.16.00. Bridging between the previous and current base models is discussed in Section 3.2.3. The R package `r4ss`, version 1.48.1, was used to investigate and plot model fits.

3.2.3 Model Changes from the Last Assessment

A brief list of changes that were made to the model configuration compared to the previous assessment (Kapur et al. 2021) are listed below.

- **Data**

- The landings time series was both corrected (i.e., inclusion of Oregon Coast INPFC area data, exclusion of Canadian landings, and inclusion of bycatch of sablefish in the At-Sea Pacific Hake fishery since 1990) and updated from the previous assessment. See Section 2 for more details on each of these changes. None of the changes in the catch time series led to changes in the fit to the WCGBTS index (Figure 21). Corrections to the historical time series led to a slight increase in R_0 and thus also the remainder of the time series in spawning biomass (Figure 22) but not changes fraction unfished (Figure 23).
- The index for the WCGBTS was updated with the most recent data using `sdmtmb` (Figure 24). Updating the index led to changes in R_0 but little change in recent biomass (Figures 25–26), and thus, the recent population status is at a lower fraction of unfished than the previous base model.
- Updating and including recent compositional information from the fishery discarded lengths, survey lengths, and survey ages led to noticeable changes in the model output but should be looked at in aggregate after the model was re-tuned with these data rather than as individual changes to the base model (Figures 24–26).
- The survey length-composition data were input as either sexed or unsexed fish rather than assigning a sex to unsexed fish based on the observed sex ratio as was done in the past, which led to an increase in R_0 (Figures 25–26) and the trend in abundance from the WCGBTS index (Figure 24).
- The index for the environmental linkage was updated, which resulted in very little changes to the model output (Figures 24–26).
- Information on mean body weight of the discarded fish were updated and data from the most recent years were included (Figures 27–29).
- Information on discard rates from the most recent years were included and the input variance for these two most recent years in the trawl fleet was set to 0.05 (Figures 27–29).

- **Fleet structure**

- Essentially, no changes were made to the fleet structure used in the model. Benign remnants of the pot fleet, which was removed in 2019, were removed from the model files.

- **Biology**

- No changes were made to the biological parameterization of the model.

- **Recruitment**

- The bias adjustment ramp was updated to end with the last year of catches and begin to ramp down towards zero two years prior. Other parameters in the ramp were left as they were specified

in the 2019 assessment. Note that the traditional method for estimating these parameters, which occurs external to the model, can often lead to the ramp starting years before composition data are available because of the inclusion of the environmental index.

- **Selectivity and retention**

- The ascending inflection for size-based retention within the fixed-gear fleet in the 2019 time block was fixed at the lower bound of 10 given that it was consistently estimated at this lower bound during the bridging analysis (Figures 27–29).
- The descending width for age-based selectivity within the trawl fleet in the 2011 time block was fixed at the upper bound of 10 given that it was consistently estimated at this upper bound during the bridging analysis (Figures 27–29).

- **Software and workflow**

- Use a newer version of SS3, version 3.30.21.00.
- Use previously updated versions of numerous R packages related to processing input and output files for the assessment, including *nufscDiag*, *sa4ss*, *r4ss*, and *PacFIN.Utilities*.
- Created *sablefish*, an R package stored on GitHub, to provide a transparent and reproducible system for processing the data, modifying the model files, and writing these reports.

3.2.4 Key Assumptions and Structural Choices

With the exceptions noted in Section 3.2.3, the general model specifications were retained from the previous assessment to conform to the Terms of Reference (ToR) for an update assessment. The assessment is sex-specific, including the estimation of separate growth curves and natural mortality parameters for males and females. The sex ratio at birth is assumed to be 50:50. Female spawning biomass is used in calculating stock status. The model starts at equilibrium, assuming an unfished initial age structure in 1889. The internal population dynamics include ages 0–70, where age 70 is the plus group. The data use a plus-group age of 50 because there is little growth occurring at the model plus-group age and very few observations.

The following likelihood components are included in this model: catch, indices, discard, mean body weight, length composition, age composition, recruitment, and parameter priors (Table 5). See the SS3 technical documentation for details on each component (Methot and Wetzel 2013).

3.2.5 Priors

The prior distributions for natural mortality (M) by sex remain the same as what was assumed in the 2019 benchmark assessment and were based on the Hamel (2015) and Hamel and Cope (2022) meta-analytic approach with an assumed maximum age of 102 years for females and 98 for males. The priors assumed a log normal distribution with a median of 0.053 and 0.055 yr^{-1} and a standard error of 0.438 and 0.438 for females and males, respectively.

3.2.6 Data Weighting

Length data from the WCGBTS and fishery discards, conditional age-at-length compositions from the WCGBTS, and marginal age compositions from the fishery fleets and other surveys were fit and appropriately weighted using an iterative approach. The Francis method (Table 6), which is based on equation TA1.8 in

Francis (Francis 2011), was used with three iterations to tune the length and age data simultaneously. It was assumed for age-at-length data that each age was a random sample within the length bin and the model started with a sample size equal to the number of fish in that length bin. A sensitivity is included to examine the differences when data weighting of the composition data used the McAllister–Ianelli (McAllister and Ianelli 1997) method, which is based on the harmonic mean.

Extra variability parameters were estimated and added to the input variance for the indices of abundance for three surveys in the model, Triennial Survey both early and late, NWFSC Slope Survey, and Slope Survey as well as the environmental index. Estimating additional variance for the WCGBTS was explored and determined to be different than zero but was not included in the base model because it previously had not been included. Instead, estimating this additional variance was explored as a sensitivity.

Added variances for discard rates and mean body weights were set using values calculated iteratively using the root mean square error (RMSE) of differences between input and estimated values derived from SS3. Variances were parameterized in terms of standard deviation and coefficient of variation, respectively.

3.2.7 Model Parameters

There were 235 estimated parameters in the base model. These included one parameter for R_0 ; 10 parameters for growth; 2 parameters for sex-specific natural mortality; 4 parameters for extra variability for the survey indices; 45 parameters for age-based selectivity, length-based retention, and time blocking of the fleets and the surveys; 163 recruitment deviations (including 30 pre-model deviations); and 10 forecast recruitment deviations which were fixed at 0 (Table 4).

The stock-recruitment relationship follows a Beverton–Holt parameterization with steepness fixed at 0.70 due to the largely one-way trip nature of the time series during the period with good data collections and the high degree of confounding between equilibrium recruitment, M , and h . Likelihood profiles for h in past sablefish assessments suggest that there is little information in the data to determine h . The use of a fixed value underestimates the uncertainty in MSY and equilibrium yield. However, the importance of this reduced uncertainty is somewhat reduced because both F and SB_{proxy} are used for management rather than MSY .

The standard deviation of recruitment deviates remained fixed at 1.4 and was not iteratively tuned when running the model. Model results suggest that recruitment may be more variable but since 2019 the value has not been allowed to be higher than 1.4.

Maturity-at-length and length-weight parameters also remained fixed at the values that were externally estimated in 2019 and used in the 2019 benchmark assessment (Haltuch et al. 2019) (Figures 30 and 31). The fecundity relationship was not updated here or in 2019 and is assumed equal to female weight-at-length.

Selectivity curves remained dome shaped for all fleets within the model. The dome-shaped curves are appropriate given that older sablefish are often found in deeper waters and may move into areas that limit their availability to fishing gear. The descending limb of dome-shaped age selectivity in the fixed gear fleet remained fixed at the value used in the 2019 benchmark assessment, which was based on the results of likelihood profiles (Haltuch et al. 2019).

3.3 Base Model Results

3.3.1 Base Model Selection

Sources of structural uncertainty in this assessment remain largely the same as the previous assessment because this is an update rather than a benchmark assessment. Model selection processes were limited to fixing the two parameters related to selectivity and retention that were consistently estimated at their bounds during the bridging analysis (see Section 3.2.3).

In reality, un-modeled spatiotemporal variation in M , growth, and movement because of predation, availability of food resources, or environmental factors may, to an unknown degree, impact sablefish and the perception of the stock size and status. Potential shifts in spatial distribution in response to changes in density outside the waters of the California Current or climate impacts could substantially reduce our ability to model and predict current and future trends. However, this degree of complexity is beyond the information content of the currently available data but efforts to synthesize existing data for Northeast Pacific sablefish with the aim of stock-wide modeling are underway. Until then, residual patterns in the length data may be present due to un-modeled time-varying processes.

3.3.2 Parameter Estimates

Estimates of key parameters include female $M = 0.071 \text{ yr}^{-1}$, male $M = 0.059 \text{ yr}^{-1}$, and $R_0 = 9.876$ (Table 4). Females were estimated as growing larger than males with female length-at-age 30 (the second reference age) equal to 61.1 cm compared to 56.1 cm for males (Figure 32) with each sex having relatively similar growth rates (0.367 yr^{-1} for females compared to 0.381 yr^{-1} for males).

Age-based selectivity was estimated as dome shaped for all fishery and survey fleets in the model. The model estimated sex-specific selectivity for the fixed-gear fleet with a higher selectivity on female fish compared to male sablefish. The age of peak female selectivity for the for the fixed-gear fleet was fixed at 5 for the historical period between 1890–1996 but varied with time, decreasing in 1997 to 3, increasing in 2003 to 5, and decreasing in 2011 to 3. The peak of the fixed-gear female selectivity curve was the furthest to the right (selectivity peaking at older ages) of all the estimated curves in the model (Figure 33), which is not surprising given that only 21 age-1 fish and zero age-0 fish have been aged from samples taken from this fleet. This assessment update added recent WCGOP data between 2020–2021 (discard rates, mean weights, and lengths) to better inform the final retention time period between 2019–2022. During model bridging the retention curve for the fixed-gear fleet estimated the peak size at the lower bound of 10 cm, a size where there is little to no selectivity, and it was decided to fix this parameter at the previous estimate of 31.4. The fixed-gear retention curve in the final time block, 2019–2022, estimated a decreased proportion (< 1.0) of retained fish across all sizes relative to the previous time block between 2011–2019 (Figures 34–36).

Selectivity for the trawl fleet was estimated as a single curve, rather than sex-specific, with four fixed parameters, one estimated time-invariant parameter, and one time-varying parameter. The width of the descending limb, which is time-varying, has been fixed for the early period since the 2019 model but this assessment also fixed the parameter at the upper bound of 8.7 in the terminal block because it was consistently estimated at the bound during the bridging analyses. The trawl fleet selects the largest range of sablefish by age compared to all other fleets in the model. The initial age of peak selectivity for the for the trawl fleet was fixed at 1 across the time series with the model estimating changes in the descending limb of the selectivity

curve to select a increasing proportion of older fish across time blocks: 1890–1981, 1982–2002 , 2003–2010, and 2011–2022. The retention curve shifted rightward in the final time block (2019–2022), only retaining fish at larger sizes relative to the previous time block between 2011–2018 (Figures 34, 37, and 38).

The Triennial Survey was estimated to select the least amount of older fish, descending to a near-zero selectivity at about the same age, age 4–5, as the peak in the fixed-gear fleet (Figure 33). Sex-specific selectivity was estimated for the Triennial Survey, with males selected at 84 percent of females at age zero and 0 percent of females at the maximum age (Figure 33). Although, female selectivity at approximately 5 years and older is small in its own right.

The time- and sex-invariant selectivities for the slope surveys are similar to their previous estimates, with the NWFSC Slope Survey selecting more older fish than any other survey and the Slope Survey selecting fish at a younger age than the NWFSC Slope Survey (Figure 33). Sablefish abundance is correlated with temperature and depth, and thus, the higher selectivities of the slope surveys may be a combination of availability and gear selectivity rather than just gear selectivity alone. The width of the descending limb for both slope surveys was poorly estimated, reflected in the high estimates of uncertainty for these parameters.

The WCGBTS was estimated to select fish at the youngest age (peak selectivity at age 0.11) and a similar amount of older fish as the Slope Survey (Figure 33). The higher selection of young fish in the WCGBTS compared to the current fleets increases the potential for the WCGBTS to provide information about strong year classes sooner than the fisheries.

A number of issues were noticed when reviewing the estimation of selectivity and retention in this assessment update. Across all fleets, there were a number of selectivity parameters that were estimated with high uncertainty that may indicate a lack of information in the data to estimate these parameters. This assessment was also required to fixed several selectivity parameters that were estimated at parameter bounds. These general behaviors were also encountered in the 2019 assessment resulting in a number of selectivity parameters being fixed during model development due to poor estimation behavior at that time. These issues in totality indicate that selectivity may be overparameterized. The next benchmark assessments should explore simplifying selectivity as well as alternative parameterization. To better understand the impact of estimating poorly informed selectivity parameters, a sensitivity is included in Section 3.4.2 that fixes selectivity parameters with high uncertainty at their estimates but the model results are largely the same.

Estimates of catchability for the trawl surveys ranged from 0.46–1.32 with the Triennial Survey having the highest catchability across surveys. However, the catchability for this survey was estimated to have decreased in 1995 to 0.85. The input data for all historical surveys were not altered for this assessment and it could be that the estimates of abundance for the Triennial Survey are inflated relative to its footprint if the survey was projected to the entire California Current rather than just outside its spatial footprint. The environmental survey had the highest estimate of additional variance needed to fit the data of all the indices used in the model (Table 4). A sensitivity is included (see Section 3.4.2) where the added variance for the WCGBTS was turned on, in which it was estimated to be non-zero, unlike in 2019 and 2021, which allowed to model to not fit the final two survey data points (2021 and 2022) that have sharply increased compared to the 2019 data point.

Estimated annual recruitment (Table 4; Figure 39) was highest in the following ten years shown in descending order of the estimates: 2020, 2021, 2000, 1966, 2016, 2008, 1979, 2013, 1990, and 2015. The estimated

recruitment deviations in 2020 and 2021 are the largest in the time series. These estimates are informed by the WCGBTS 2021-2022 data that had sharp increases in the number of age-0 and age-1 fish being observed. Additionally, the fishery has reported encountering large numbers of small sablefish in the last couple of years. While there seems to be strong information that there may be multiple strong recruitments in recent years additional observations of these fish as they mature and enter the fishery will better inform the magnitude of these recruitments. The third largest estimated recruitment deviation in time series occurred in the mid-1960s. The exact year of this large recruitment is uncertain with the model estimating it to have occurred in a slightly different years with changes to the model parameterization (switching between 1964-1966). The smallest ten recruitment events, which are harder to estimate than large events, occurred in the following years in ascending order: 1997, 2005, 1996, 2007, 1991, 2006, 2003, 1987, 1937, and 1936. The bias adjustment ramp was left the same as the previous assessment except for extending the right limb by two years (Figure 41). The suggested ramp is based on the environmental time series being informative about recruitment where we chose to retain the setting from previous assessments that implement the ramp with the onset of biological age samples rather than the start of the environmental time series. Recruitment is estimated based on the spawner-recruit curve in the forecast period but estimated up to the terminal year of data used to fit the model (Figure 42).

3.3.3 Fits to the Data

Fits to the environmental time series were noisy, as they have been in previous assessments. The estimated index is essentially a flat line until the most recent years, where there are sharp increases followed by a prompt return to zero (Figure 47). The estimated added standard deviation was 0.949305, and thus, the environmental time series provided limited information regarding historical recruitment during model periods without other data. In 2019, this added variance parameter was estimated at 0.73 suggesting that the environmental index has lost some prediction power since the last benchmark assessment.

Fits to the historical surveys were similar to the last assessment update and the last benchmark assessment. The Triennial Survey data showed an increasing trend in the 2000s, though the model failed to fit the high estimates of abundance in the early 2000s and is even below the lower limit of the estimated added variance (48). Fits to the Slope Survey suggest a slight decreasing trend during the late 1990s followed by a small increase into the early 2000s (Figure 49). There was no estimated trend in the NWFSC Slope Survey, as might be expected for such short time series (Figure 50).

The base model fit the trend (decline, then stabilization, and increase) in the WCGBTS well until the two most recent years of the survey (Figure 51). The recent estimates were below the data providing some justification for estimating an additional variance parameter (see Section 3.4.2).

Of all the length data used to fit the model, the model fit the discard lengths from the fixed-gear fishery the best (Figure 52). The model appears to have done a particularly poor job fitting the large numbers of small, i.e., 20–30 cm, fish in the WCGBTS but it is important to remember that the distribution of observed unsexed fish will almost always be truncated to small lengths because larger fish will appear in the sexed distributions. Thus, small fish will almost always be underfit relative to the data for unsexed fish (Figure 53). In some years, the fits to the sexed data from the WCGBTS were quite good (Figure 53) and match the bimodal distribution of lengths (e.g., 2015 and 2021) found in the data (Figure 19). Other years, (e.g., 2022) the underfitting of the small, unsexed fish was also seen in the sexed fish.

For the discarded lengths, the model fit the discard lengths from the trawl fleet less well than the discard lengths from the fixed-gear fleet (Figures 54–55). Large residuals were only seen for the fixed-gear lengths from years prior to 2007 (Figure 54), where similar magnitudes of underfitting the data are present for the trawl fleet for almost all recent years since 2014 (Figure 55). The expected distribution of discarded lengths from the trawl fishery was shifted to the left of the observed lengths for the recent years, a pattern largely not seen in years prior to 2014. The previous assessment update had similar fits to the annual discard lengths for both fleets (2004–2019; Kapur et al. 2021).

Underfitting of some young ages and overfitting of very old males was common in all fleets and surveys except the Slope Survey (Figure 56). This same patterns were present in the 2021 assessment update (Kapur et al. 2021) but the latter pattern was not present in the 2019 benchmark assessment (Haltuch et al. 2019). The largest residuals in the marginal age compositions were seen in the fits to the age data from the Triennial Survey (Figures 57–60). This was the one fleet where the Francis data weighting method also wanted to substantially upweight the age data (increase weight by a factor of 10), well beyond the input sample size, but the weight for these data was capped at 1.0, equal to the number of ages. The data for the slope surveys are limited given the short time series; never the less, patterns in these residuals were limited. Conditional age-at-length data from the WCGBTS were fit particularly well for lengths less than 60 cm (Figures 61–65), noting that 60 cm is approaching the estimated female maximum length. The expected mean age-at-length generally matched the observed mean at-length for sizes less than 60 cm and 20 years or less across all years. The expected mean age-at-length was generally split the observed data points for older larger fish starting in 2009 but for earlier years in the data, 2003–2008, the expected size-at-age was generally higher than the observations. The standard deviation around growth for sablefish is largest for smaller younger fish and larger older fish compared to intermediate sizes and ages. Marginal ages for the WCGBTS were included in the model but not used for fitting strictly to see how they would have been fit (Figure 60).

3.3.4 Population Trajectory

Spawning biomass, the proxy for spawning output, is estimated to have declined from an unfished equilibrium of 186,534 to approximately 79,000 mt in the 1950s (Table 7 and Figure 45). Biomass quickly turned around, increasing to unfished equilibrium by the mid-1970s, only to come right back down again to the management target in the early-2000s. Since then, several strong recruitment events (2008, 2013, 2016) have led to sharp increases in the spawning biomass, though the biomass remains far from unfished levels at the end of time series (Figure 46). Total biomass largely follows the same trajectory as spawning biomass across the majority of the time series with a distinct departure in the most recent years with total biomass sharply increasing based on the estimates of the 2020 and 2021 recruitments (Figure 43).

3.4 Model Diagnostics

3.4.1 Convergence

Proper convergence was evaluated 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 using the jitter function built into Stock Synthesis, using a jitter input of 0.05. This was repeated 100 times with 16 out of 100 runs returning to the base model likelihood. A better, lower negative log-likelihood, model fit was not found. Through the jittering and the likelihood profiles, we are confident that the base model,

as presented, represents the best fit to the data given the assumptions made. There were no difficulties in inverting the Hessian to obtain estimates of variability.

During the process of jittering the model starting parameter values it was noted that often 1 or more selectivity parameters were estimated on their bounds. The estimated measures of uncertainty for eight parameters, primarily selectivity parameters, were excessively large with standard deviations for these parameters in the hundreds, if not thousands suggesting that they were poorly informed. We chose to leave their parameterization as is but we do show a sensitivity where all of these parameters were fixed at their estimated values to characterize changes the amount of uncertainty in derived quantities when they were not estimated compared to the base model where they were estimated (see Section 3.4.2 and Figure 81).

3.4.2 Sensitivity Analyses

Several sensitivity analyses were conducted to examine the relative influence of specific changes to data inputs and structural model assumptions to further address uncertainty associated with the base model estimates and derived management quantities. The first group of sensitivity analyses include changes to the data or model assumptions that should be addressed in the next benchmark assessment but led to almost no changes compared to the current base model. The second group of sensitivity analyses includes models with changed assumptions that did lead to differences compared to the base model. The third group of sensitivity analyses mainly includes sensitivities required by the ToR.

The environmental index used in the base model is the result of a dynamic factor analysis implemented using a multivariate autoregressive state space model, the same model that was used for the 2019 assessment (Haltuch et al. 2019). In 2021, the dynamic factor analysis showed some instability and a similar but Bayesian analysis was investigated that proved to be more robust. The Bayesian output was also updated this year and included as a sensitivity. The results are largely the same (Figures 72–73), as was expected.

Estimates of parameter uncertainty for some selectivity parameters in the base model are high. It was hoped that fixing the the parameters that control the difference in male and female selectivity for the trawl fleet and the Triennial Survey at age zero to zero rather than estimating them would decrease the high estimated uncertainty in other parameters but this was not the case. The uncertainties for the problematic parameters were still high but the resulting time series are the same (Figures 72–73). Fixing these two selectivity parameters at zero is justified because one would not expect the selectivity of age-0 fish to be different between males and females and there are very few age-0 fish caught in the trawl fleet and the Triennial Survey to inform the differences between male and female selectivity at age zero even if there was one. We tried to estimate the two retention parameters that were fixed at their bounds in the bridging analysis to see if tuning the model facilitated estimating them. Both parameters still went to their bounds when estimated. The results from the run with the parameters estimated is nearly the same as the results from the base model but it is poor practice to use results from a model run with parameters on the bound because estimates variance can be suspect when a parameter is on the bound. Thus, we choose to keep them fixed in the base model.

Recent best practices suggest that we should not be constraining recruitment deviations in the main period to sum to zero. Estimated recruitment deviations for a given model can be seen as a sample from a theoretical distribution rather than a census. Thus, we would never expect a sample of a deviation vector to sum to

zero so we turned the sum to zero constraint off as a sensitivity. Most of the differences between this model and the base model occur in the historical time period when there is little information about recruitment (Figures 74–77), which is a reflection of the change in R_0 (Table 9) rather than a change in specific estimates of recruitment.

Estimating an additional variance for the WCGBTS led to the model not fitting the most recent survey year nearly as well as any other sensitivity or the base model and thus the upward trend at the end of the time series became less pronounced (Figure 75). The estimate of the time series of spawning biomass was larger for this model than the base model because all of the large recruitment events except for the most recent one were estimated to have been larger than what the base model estimated them at. This also led to increasing in other quantities relevant to management like yield at spawning potential ratio (SPR) (Table 9).

Tuning the model using the harmonic-mean method versus the Francis method led to a significant change in the weight applied to the Triennial Survey ages. In the base model, the Francis tuning wanted to upweight these data relative to the other data sets but the multiplier was capped at 1.0. With the harmonic-mean method, the multiplier was less than 0.1. As a result, the Triennial Survey index was fit better and the WCGBTS was fit less well compared to the base model. The estimated trajectories of spawning biomass are similar between the two models from the early 1980s going forward (Figure 80) but the sensitivity has a lower estimate of R_0 and smaller estimates of early recruitment.

Estimating a single M instead of sex-specific M resulted in lower M than either sex-specific estimate of 0.053. In the base model, M was estimated at $0.071yr^{-1}$ for females and $0.059yr^{-1}$ for males. This is the same result as the 2021 update assessment. The estimate of unfished spawning biomass, while within the uncertainty bounds of the current base model, was below the base model estimate. Estimating a single M reduced the size of large recruitment events and suggested that the population was just barely above $B_{40\%}$ in 2021 (Figures 80–81).

Fitting to the marginal rather than conditional ages for all years from the WCGBTS led to a much higher estimate of R_0 compared to the base model (Table 10), though still within the range of uncertainty characterized by the base model (Figure 80). This was the only sensitivity that led to estimates of the 2022 survey index for the WCGBTS within the input uncertainty.

Implementing asymptotic age-based selectivity for the WCGBTS reduced R_0 and also reduced the absolute size of large recruitment events (Figure 80). This model had a higher overall log-likelihood than the base model and did a poorer job of fitting the length compositions from that survey, particularly in the most recent years (Table 10).

3.4.3 Retrospective Analysis

A retrospective analysis was conducted by running the base model with data removed for the past 5 years (Table 11). All retrospective model runs fell within the uncertainty estimates from the base model. There was limited evidence of a retrospective pattern in estimates of spawning biomass (Figure 82) and stock status (Figure 83). The retrospective pattern in stock status is largely driven by the relative amount of data available to inform the estimates of some of the largest recruitment events observed for sablefish. The estimated likelihood components and select parameter estimates are shown in Table 12.

3.4.4 Historical Analysis

Estimates of the current spawning biomass (Figure 84) and fraction unfished (Figure 85) were consistent with prior stock assessments, particularly from the 1980s forward, the period of time with good data for sablefish. Estimates of recent spawning biomass are greater for this update and the 2019 update compared to the three previous models, all of which estimate a lower spawning biomass than what is currently estimated due to the recent large recruitment events. The historical models, i.e., models ran prior the last benchmark assessment, differ from more recent models that use a larger age group for the maximum age in the data bins. The largest differences between the models with respect to estimates of fraction unfished occur in the 1960s and the 1980s, where this assessment aligns with recent models in the 1960s and older models in the 1980s, highlighting the uncertainty in the magnitude of the large recruitment event in the early 1960s. See Figure 83 in Haltuch et al. (2019) for comparisons to older assessments of sablefish, i.e., back to 2005.

3.4.5 Likelihood Profiles

Likelihood profiles were conducted for sex-specific M , h , R_0 and values separately. These likelihood profiles were conducted by fixing the parameter at specific values and estimated the remaining parameters based on the fixed parameter value. The priors for all parameters, including the parameter being profiled, were included in every likelihood model. For example, including the prior on M across the profiled values of M provides information on the likelihood contribution of that prior as if it were estimated in the model.

The profile over female M suggested the negative log-likelihood was minimized at the same value estimated in the base model, 0.071 yr^{-1} (Figure 88). This minimization occurs at the crosshair of information present in the age versus recruitment data. Though, the differences in the negative log likelihood were less than two for a range of values between $0.06\text{--}0.09 \text{ yr}^{-1}$, similar to the 2019 benchmark assessment (Haltuch et al. 2019). This is not a trivial parameter range and the assessment results vary considerably among these values in absolute scale (Figures 86–87). Only the lowest investigated value, which was less than 0.06 yr^{-1} , led to the population going below the minimum stock size threshold (Figure 87) yet no investigated value for male M led to the population going below this threshold (Figure 90). Male M is inherently smaller than female M though and the same range was used for both investigations rather than a relative range. The results would have probably been more similar should a relative range been used.

Similar likelihoods were found for R_0 over the values $9.4\text{--}10.4$, values which led to a broad range of stock sizes (Figures 91–90). For all explored values, the population was estimated to currently be well above the management target and only having been below the minimum size threshold in the late 1950s.

In the base model, h is fixed at 0.7 , making it an important profile to evaluate as its uncertainty is not explicitly included in the results of the base model. In 2011, the maximum likelihood estimate for h was 0.2 , which implies zero surplus production, which is biologically implausible. Profile results indicate essentially equal support in the data over a broad range of explored values (Figure 94). Most of the values included in the profile led to similar trajectories of spawning biomass (Figure 92).

4 Management

4.1 Reference Points

The estimated 2023 spawning biomass relative to unfished equilibrium spawning biomass is 63%, well above the management target of 40% of unfished spawning biomass. The fishing intensity has been at or below the current management harvest rate limit (SPR; $SPR_{45\%}$) since the mid 1980s and declining in the last ten years (Figure 98). The interaction between the relative biomass compared to the ratio of the estimated SPR to the management target ($SPR_{45\%}$) indicates that the stock has remained within management targets and is likely to do so within the current year as well (Figure 99). The current estimate of fraction unfished is larger than maximum sustainable yield (*MSY*), SPR target, and relative target biomass reference points (Figure 100) based on a steepness value fixed at 0.7.

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2022 (Table 14). Sustainable total yield, landings plus discards, using an $SPR_{45\%}$ is 9,641.13 mt. The spawning biomass equivalent to 40% of the unfished spawning biomass ($SB_{40\%}$) calculated using the SPR target ($SPR_{45\%}$) was 74,613.6 mt.

4.2 Unresolved Problems and Major Uncertainties

This assessment update estimates very large recruitment events occurring near the end of the modeled period in 2020 and 2021. Anecdotal information from the fishery of high bycatch of small sablefish starting in the summer of 2021 indicated that there was likely a strong cohort entering the population and this is supported by the data collected by the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey in both 2021 and 2022. However, since these young fish have only been observed in two years by the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey there is more uncertainty around the strength of these year classes than cohorts that have been better observed that will hopefully be resolved with future subsequent observations by the survey and the fishery.

The data available for sablefish off the U.S. West Coast are not informative with respect to absolute stock size and productivity. This could be, in part, due to the largely one-way-trip nature of the historical series (i.e., a slow and steady decline in spawning biomass) that has only recently stabilized and increased, which can be consistent with a larger less productive stock, a smaller more productive stock, or many combinations in between. While the historical catches provide some information about the minimum stock size necessary to remove the catches from the population, there is limited information in the data regarding the upper limit of the stock size. The above factors are also confounded by movement of sablefish between the region included in this assessment and regions to the north. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in many parameters can result in different estimates of management reference points. However, because several leading model parameters, such as natural mortality, selectivity, and historical recruitments, are estimated within the stock assessment model, the uncertainty about these estimates remains large and typically overlapped among the investigated models. The uncertainty will remain until a more informative time-series, better quality demographic and biological information are accumulated, or a range-wide analysis is completed for sablefish.

Uncertainty in the current ageing methods (both bias and imprecision), as well as relatively sparse fishery sampling, result in age data that are potentially variable. Furthermore, because sablefish grow rapidly,

nearing asymptotic length in their first decade of life, length data is not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that the stock trajectory (via shifts in recruitment strength) is closely linked to productivity regimes in the California Current. Studies of oceanographic drivers of sablefish recruitment explain between 25 percent and just over 50 percent of the sablefish recruitment variability, depending upon the oceanographic covariates evaluated. Uncertainty in future environmental conditions and changes in the timing, dynamics, and productivity of the California Current ecosystem via climate change or cycles similar to the historical period should be considered a significant source of uncertainty in all projections of stock status. The ongoing Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey is a fairly precise relative index of abundance over a broad demographic component of the stock but it does not survey the entire stock as sablefish reside in waters deeper than 1,280 m, the survey limit, and to the north. Therefore, a portion of the stock is unobserved. This index has the potential to inform future stock assessments about the scale of the population relative to catches being removed; however, such information will require contrast in the observed survey trend.

4.3 Harvest Projections and Decision Tables

The projection of stock biomass, status, and harvest limits was developed using the base model. The total catches in 2023 and 2024 were set at 9,118 and 8,359 mt, respectively, based on recommendations from the Groundfish Management Team (GMT). The ABC values were estimated using a category 1 time-varying σ_y starting at 0.50 combined with a P* value of 0.45. The catches during the projection period, 2025 - 2034 were set equal to the year-specific ABC (Table 13). The spawning biomass and fraction unfished increase sharply during the projection due to the estimated large recruitments in 2020 and 2021 maturing and entering the spawning population, resulting in future OFLs and ABCs that are substantially higher than those set for 2023–24.

4.4 Evaluation of Scientific Uncertainty

The model estimated uncertainty around the 2023 spawning biomass for the model is $\sigma = 0.29$. The uncertainty around the OFL in 2023 is $\sigma = 0.32$. Each of these are likely underestimates of overall uncertainty due to the necessity to fix several key population dynamics parameters (e.g., steepness, recruitment variance) and also because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

4.5 Regional Management Considerations

Sablefish is currently modeled as a coastwide stock with corresponding coastwide OFL, ABC, and ACL values. The coastwide ACL is then apportioned into two area-specific ACLs north and south of 36° N. latitude. In the 2019 the PFMC adopted a methodology to split the ACL using a five-year rolling average biomass estimate by area from the WCGBTS (November 2019 PFMC Meeting Decision Document). This historical management line corresponds with a recent data-driven analysis of sablefish growth that suggests a difference in growth rates north and south of 36° N latitude (Kapur et al. 2020). The estimates represent the relative distribution of the sablefish population observed by the survey, not the entire population. Additionally, it is likely that fish from more northerly regions are migrating into U.S. West Coast waters (pers. comm., L. Rogers), which may bias the survey estimates of the distribution of fish in each region. Thus, these results should be interpreted with caution.

The estimated proportion of the observed biomass by the WCGBTS between the years of 2017–2022 (no survey was conducted in 2020) is 21.5% south of 36° N. latitude and 78.5% north of 36° N. latitude. In contrast, the estimates in 2019 using data between 2014–2018 was 21.6% in the south and 78.4% in the north.

4.6 Research and Data Needs

Please refer to the 2019 benchmark assessment for a detailed list of research and data needs for sablefish (Haltuch et al. 2019).

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7 Tables

7.1 Data

Table 1: Landings (mt) by fleet and the summed coastwide total landings.

Year	Fixed Gear	Trawl	Total Landings
1890	2.1	0.0	2.1
1891	6.1	0.0	6.1
1892	6.8	0.0	6.8
1893	10.1	0.0	10.1
1894	12.2	0.0	12.2
1895	16.6	0.0	16.6
1896	18.7	0.0	18.7
1897	20.7	0.0	20.7
1898	22.7	0.0	22.7
1899	24.8	0.0	24.8
1900	49.9	0.0	49.9
1901	76.3	1.4	77.7
1902	102.7	2.8	105.5
1903	129.1	4.1	133.2
1904	155.5	5.5	161.0
1905	138.1	6.9	145.0
1906	135.2	8.3	143.5
1907	142.0	9.6	151.6
1908	85.8	11.0	96.8
1909	141.1	12.4	153.4
1910	196.3	13.7	210.0
1911	251.6	15.1	266.6
1912	306.8	16.4	323.3
1913	362.1	17.8	379.9
1914	417.4	19.1	436.5
1915	472.5	20.1	492.6
1916	1,287.9	26.3	1,314.2
1917	1,694.9	286.4	1,981.3
1918	2,683.8	157.0	2,840.8
1919	919.1	105.4	1,024.5
1920	627.0	245.8	872.8
1921	846.4	321.9	1,168.3
1922	711.2	84.5	795.8
1923	1,259.0	169.4	1,428.5
1924	1,535.0	293.8	1,828.7
1925	1,869.4	227.4	2,096.8
1926	1,639.2	55.3	1,694.5

Table 1: Landings (mt) by fleet and the summed coastwide total landings. (*continued*)

Year	Fixed Gear	Trawl	Total Landings
1927	2,206.0	312.4	2,518.4
1928	1,820.9	288.6	2,109.6
1929	1,814.8	468.4	2,283.2
1930	2,096.5	445.8	2,542.3
1931	1,066.8	330.4	1,397.2
1932	1,345.2	303.3	1,648.5
1933	1,094.1	428.7	1,522.8
1934	1,958.0	681.4	2,639.4
1935	2,481.5	901.5	3,383.0
1936	2,015.3	337.0	2,352.3
1937	2,296.6	231.5	2,528.1
1938	2,217.1	258.0	2,475.1
1939	2,448.2	295.4	2,743.6
1940	1,878.0	301.4	2,179.5
1941	1,652.4	487.7	2,140.1
1942	2,293.4	935.4	3,228.8
1943	1,838.2	2,084.6	3,922.8
1944	1,485.6	2,998.9	4,484.5
1945	1,691.0	2,726.1	4,417.1
1946	2,782.5	1,672.3	4,454.9
1947	1,716.5	516.3	2,232.8
1948	1,886.9	945.6	2,832.5
1949	1,986.5	983.1	2,969.6
1950	1,623.7	1,016.5	2,640.2
1951	2,253.0	2,011.8	4,264.8
1952	1,477.8	1,163.2	2,641.0
1953	965.2	691.6	1,656.8
1954	1,323.3	997.1	2,320.4
1955	1,289.1	898.3	2,187.4
1956	970.9	2,434.9	3,405.8
1957	1,599.3	951.7	2,551.0
1958	764.1	768.1	1,532.2
1959	1,234.5	984.4	2,218.9
1960	1,675.4	1,191.9	2,867.3
1961	1,055.5	756.0	1,811.5
1962	1,010.2	1,616.6	2,626.8
1963	949.0	869.4	1,818.4
1964	1,008.8	1,037.8	2,046.5
1965	909.9	1,023.6	1,933.5
1966	740.2	1,132.5	1,872.7
1967	2,459.8	1,819.1	4,278.9

Table 1: Landings (mt) by fleet and the summed coastwide total landings. (*continued*)

Year	Fixed Gear	Trawl	Total Landings
1968	1,421.1	1,313.9	2,735.0
1969	3,410.9	2,068.0	5,478.9
1970	1,765.9	2,839.9	4,605.8
1971	1,407.3	2,479.8	3,887.0
1972	3,082.1	3,538.5	6,620.7
1973	1,396.6	4,275.5	5,672.1
1974	5,122.5	3,478.1	8,600.5
1975	10,333.7	3,966.0	14,299.7
1976	20,506.8	3,888.0	24,394.8
1977	5,243.5	3,497.8	8,741.4
1978	7,708.8	4,532.1	12,240.9
1979	16,772.0	7,116.3	23,888.3
1980	4,537.3	4,506.9	9,044.3
1981	5,695.5	5,399.0	11,094.5
1982	7,789.4	9,944.0	17,733.3
1983	7,118.2	7,533.5	14,651.7
1984	5,402.6	8,612.5	14,015.0
1985	6,632.3	7,500.0	14,132.3
1986	6,478.4	6,672.0	13,150.3
1987	6,050.3	6,551.1	12,601.4
1988	5,201.0	5,542.7	10,743.7
1989	4,477.6	5,806.9	10,284.4
1990	3,869.3	5,196.8	9,066.1
1991	4,514.3	4,999.8	9,514.1
1992	3,896.1	5,504.0	9,400.1
1993	3,185.6	4,965.8	8,151.4
1994	3,746.1	3,832.8	7,578.9
1995	4,057.0	3,864.8	7,921.8
1996	4,112.9	4,208.2	8,321.0
1997	4,170.9	3,773.1	7,944.0
1998	2,206.4	2,205.2	4,411.6
1999	3,474.9	3,169.0	6,643.9
2000	3,567.3	2,759.6	6,326.9
2001	3,034.1	2,623.6	5,657.8
2002	2,220.5	1,599.5	3,819.9
2003	3,105.1	2,331.9	5,437.0
2004	3,336.5	2,448.3	5,784.8
2005	3,803.8	2,419.6	6,223.5
2006	3,656.7	2,544.7	6,201.4
2007	2,750.1	2,497.9	5,248.0
2008	2,976.2	2,898.1	5,874.4

Table 1: Landings (mt) by fleet and the summed coastwide total landings. (*continued*)

Year	Fixed Gear	Trawl	Total Landings
2009	4,135.8	3,062.8	7,198.6
2010	4,291.6	2,552.8	6,844.4
2011	4,690.0	1,735.9	6,425.9
2012	3,772.3	1,532.2	5,304.5
2013	2,726.9	1,426.1	4,153.0
2014	3,119.4	1,323.0	4,442.5
2015	3,671.9	1,510.7	5,182.6
2016	3,919.6	1,516.7	5,436.2
2017	3,864.6	1,827.8	5,692.4
2018	3,749.9	1,622.3	5,372.2
2019	3,668.1	1,710.3	5,378.4
2020	2,831.9	1,122.6	3,954.6
2021	3,205.2	1,708.0	4,913.3
2022	3,965.8	2,405.7	6,371.5
2023	6,140.7	2,519.3	8,660.1
2024	5,621.8	2,405.9	8,027.7
2025	27,922.7	7,334.9	35,257.6
2026	26,306.2	7,244.4	33,550.6
2027	23,620.2	6,996.8	30,617.0
2028	19,832.4	6,689.3	26,521.7
2029	16,121.6	6,372.4	22,494.0
2030	13,215.4	6,082.7	19,298.1
2031	11,255.0	5,817.0	17,072.0
2032	10,063.9	5,566.5	15,630.4
2033	9,394.4	5,340.5	14,734.9
2034	9,000.1	5,130.3	14,130.4

Table 2: The stratification used to estimate design-based indices of abundance and to expand the survey composition data. Depths are in m, locations are in decimal degrees, and area is in km².

Shallow Depth	Deep Depth	South Latitude	North Latitude	Area (km ²)
55	183	32.0	34.5	5812.339
183	549	32.0	34.5	9955.261
549	900	32.0	34.5	15683.986
900	1280	32.0	34.5	15788.733
55	183	34.5	40.5	10687.856
183	549	34.5	40.5	6951.654
549	900	34.5	40.5	7801.300
900	1280	34.5	40.5	8058.580
55	183	40.5	45.0	11255.125
183	549	40.5	45.0	6210.903
549	900	40.5	45.0	5264.062
900	1280	40.5	45.0	5303.944
55	183	45.0	49.0	11787.265
183	549	45.0	49.0	5828.867
549	900	45.0	49.0	4023.608
900	1280	45.0	49.0	3954.627

Table 3: The total number of ‘positive’ tows, the ‘proportion’ of tows that were positive and the number fish that were lengthed and/or aged by survey and year.

Survey	Year	Positive	Proportion	Lengthed	Aged
Slope Survey	1984	89	0.96	6,126	832
Slope Survey	1988	57	1.00	5,579	0
Slope Survey	1989	46	1.00	3,297	420
Slope Survey	1990	102	1.00	3,623	0
Slope Survey	1991	89	0.99	3,357	473
Slope Survey	1992	77	0.99	2,826	0
Slope Survey	1993	123	0.98	3,607	0
Slope Survey	1995	103	0.97	3,698	811
Slope Survey	1996	204	1.00	5,406	1,271
Slope Survey	1997	176	0.97	6,671	1,485
Slope Survey	1999	193	0.97	5,005	492
Slope Survey	2000	206	1.00	6,452	1,665
Slope Survey	2001	206	1.00	6,392	484
WCGBTS	2003	422	0.78	5,799	1,389
WCGBTS	2004	331	0.70	4,540	1,086
WCGBTS	2005	447	0.70	5,567	1,575
WCGBTS	2006	399	0.62	4,833	1,363
WCGBTS	2007	429	0.62	4,470	1,259
WCGBTS	2008	420	0.62	3,973	1,190
WCGBTS	2009	419	0.62	3,688	1,181
WCGBTS	2010	457	0.64	4,232	1,271
WCGBTS	2011	456	0.66	4,674	1,193
WCGBTS	2012	428	0.61	4,381	1,091
WCGBTS	2013	307	0.65	3,280	992
WCGBTS	2014	461	0.68	4,319	1,200
WCGBTS	2015	420	0.63	4,910	1,197
WCGBTS	2016	439	0.63	4,544	1,213
WCGBTS	2017	459	0.65	4,883	1,219
WCGBTS	2018	435	0.62	4,785	1,482
WCGBTS	2019	226	0.65	2,226	874
WCGBTS	2021	518	0.76	6,281	2,162
WCGBTS	2022	465	0.73	6,184	1,659
NWFSC Shelf Survey	2001	34	0.48	NA	NA
NWFSC Slope Survey	1998	200	0.66	1,991	676
NWFSC Slope Survey	1999	293	0.90	3,036	478
NWFSC Slope Survey	2000	299	0.91	3,226	753
NWFSC Slope Survey	2001	306	0.92	2,942	617
NWFSC Slope Survey	2002	383	0.90	4,135	1,631
Triennial Survey	1980	186	0.62	1,944	0

Table 3: The total number of ‘positive’ tows, the ‘proportion’ of tows that were positive and the number fish that were lengthed and/or aged by survey and year. (*continued*)

Survey	Year	Positive	Proportion	Lengthed	Aged
Triennial Survey	1983	337	0.70	6,682	915
Triennial Survey	1986	372	0.77	5,588	68
Triennial Survey	1989	314	0.71	5,751	490
Triennial Survey	1992	284	0.67	7,491	550
Triennial Survey	1995	338	0.77	8,550	363
Triennial Survey	1998	268	0.57	8,179	432
Triennial Survey	2001	371	0.80	14,032	435
Triennial Survey	2004	296	0.77	10,042	490

7.2 Model Results

7.2.1 Estimated Parameters

Table 4: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model.

Label	Value	SD	Phase	Prior	Min.	Max.	Status
<i>M</i> (female)	0.071	0.01	3	lnN(0.053, 0.438)	0.010	0.110	OK
L-at-Amin (female)	25.262	0.50	2	-	22.000	35.000	OK
L-at-Amax (female)	61.130	0.67	2	-	60.000	70.000	OK
VonBert_K (female)	0.367	0.02	2	-	0.150	0.550	OK
CV_young (female)	0.058	0.01	2	-	0.001	0.150	OK
CV_old (female)	0.103	0.00	2	-	0.010	0.300	OK
Wtlen_1 (female)	0.000	-	-50	Normal	0.000	1.000	-
Wtlen_2 (female)	3.273	-	-50	Normal	0.000	4.000	-
Mat50Mat_slope (female)	-0.421	-	-50	Normal	-3.000	3.000	-
Eggs/kg_inter (female)	1.000	-	-50	Normal	-3.000	3.000	-
Eggs/kg_slope_wt (female)	0.000	-	-50	Normal	-3.000	3.000	-
<i>M</i> (male)	0.059	0.01	3	lnN(0.055, 0.438)	0.010	0.110	OK
L-at-Amin (male)	26.621	0.61	2	-	15.000	35.000	OK
L-at-Amax (male)	56.111	0.38	2	-	50.000	60.000	OK
VonBert_K (male)	0.381	0.02	2	-	0.200	0.550	OK
CV_young (male)	0.070	0.01	2	-	0.001	0.150	OK
CV_old (male)	0.078	0.00	2	-	0.010	0.300	OK
Wtlen_1 (male)	0.000	-	-50	Normal	0.000	1.000	-
Wtlen_2 (male)	3.270	-	-50	Normal	0.000	4.000	-
CohortGrowDev	1.000	-	-1	-	0.100	10.000	-
FracFemale	0.500	-	-99	-	0.000	1.000	-
SR_LN(R0)	9.876	0.30	1	-	8.000	12.000	OK
SR_BH_steep	0.700	-	-7	beta(0.600, 0.223)	0.200	1.000	-
SR_sigmaR	1.400	-	-50	-	0.200	1.500	-
SR_regime	0.000	-	-50	-	-1.000	1.000	-
SR_autocorr	0.000	-	-50	-	-1.000	1.000	-
Early age 30	-0.017	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Early age 29	-0.018	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Early age 28	-0.019	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Early age 27	-0.020	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Early age 26	-0.021	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Early age 25	-0.023	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 24	-0.024	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 23	-0.026	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 22	-0.028	1.38	3	N(0.000 1.400)	-4.000	4.000	-

Early age 21	-0.029	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 20	-0.031	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 19	-0.033	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 18	-0.035	1.38	3	N(0.000 1.400)	-4.000	4.000	-
Early age 17	-0.038	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Early age 16	-0.040	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Early age 15	-0.043	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Early age 14	-0.046	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Early age 13	-0.049	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Early age 12	-0.052	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Early age 11	-0.055	1.36	3	N(0.000 1.400)	-4.000	4.000	-
Early age 10	-0.058	1.36	3	N(0.000 1.400)	-4.000	4.000	-
Early age 9	-0.062	1.36	3	N(0.000 1.400)	-4.000	4.000	-
Early age 8	-0.066	1.36	3	N(0.000 1.400)	-4.000	4.000	-
Early age 7	-0.070	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Early age 6	-0.074	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Early age 5	-0.078	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Early age 4	-0.083	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Early age 3	-0.087	1.34	3	N(0.000 1.400)	-4.000	4.000	-
Early age 2	-0.092	1.34	3	N(0.000 1.400)	-4.000	4.000	-
Early age 1	-0.096	1.34	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1890	-0.101	1.34	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1891	-0.106	1.33	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1892	-0.112	1.33	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1893	-0.117	1.33	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1894	-0.123	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1895	-0.129	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1896	-0.136	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1897	-0.143	1.31	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1898	-0.150	1.31	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1899	-0.157	1.30	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1900	-0.164	1.30	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1901	-0.172	1.30	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1902	-0.181	1.29	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1903	-0.189	1.29	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1904	-0.198	1.28	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1905	-0.207	1.28	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1906	-0.217	1.27	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1907	-0.227	1.27	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1908	-0.237	1.26	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1909	-0.247	1.26	3	N(0.000 1.400)	-4.000	4.000	-

Early_RecrDev_1910	-0.258	1.25	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1911	-0.269	1.25	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1912	-0.280	1.24	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1913	-0.292	1.24	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1914	-0.305	1.23	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1915	-0.317	1.22	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1916	-0.330	1.22	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1917	-0.344	1.21	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1918	-0.357	1.21	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1919	-0.370	1.20	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1920	-0.384	1.20	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1921	-0.398	1.19	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1922	-0.413	1.18	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1923	-0.427	1.18	3	N(0.000 1.400)	-4.000	4.000	-
Early_RecrDev_1924	-0.443	1.17	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1925	-0.559	1.16	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1926	-0.552	1.17	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1927	-0.588	1.15	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1928	-0.610	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1929	-0.591	1.15	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1930	-0.600	1.15	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1931	-0.618	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1932	-0.660	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1933	-0.656	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1934	-0.663	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1935	-0.616	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1936	-0.724	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1937	-0.726	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1938	-0.623	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1939	-0.641	1.13	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1940	-0.666	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1941	-0.712	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1942	-0.701	1.11	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1943	-0.668	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1944	-0.659	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1945	-0.620	1.13	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1946	-0.669	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1947	-0.627	1.13	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1948	-0.716	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1949	-0.554	1.16	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1950	-0.499	1.18	3	N(0.000 1.400)	-4.000	4.000	-

Main_RecrDev_1951	-0.475	1.19	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1952	-0.375	1.23	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1953	-0.427	1.21	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1954	-0.307	1.26	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1955	-0.137	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1956	-0.109	1.36	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1957	-0.020	1.42	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1958	-0.068	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1959	0.191	1.58	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1960	-0.028	1.42	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1961	0.094	1.52	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1962	0.253	1.67	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1963	-0.077	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1964	0.401	1.95	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1965	0.019	1.50	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1966	2.270	0.61	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1967	-0.224	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1968	-0.111	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1969	-0.364	1.24	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1970	-0.091	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1971	-0.286	1.26	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1972	-0.195	1.29	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1973	0.143	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1974	-0.066	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1975	0.302	1.42	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1976	0.207	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1977	0.230	1.27	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1978	-0.017	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1979	1.706	0.61	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1980	0.617	0.88	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1981	0.962	0.45	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1982	0.557	0.40	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1983	-0.541	1.02	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1984	1.291	0.37	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1985	1.115	0.45	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1986	0.855	0.35	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1987	-0.758	0.88	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1988	0.993	0.25	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1989	0.536	0.38	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1990	1.615	0.19	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1991	-1.571	0.80	3	N(0.000 1.400)	-4.000	4.000	-

Main_RecrDev_1992	0.110	0.38	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1993	-0.541	0.50	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1994	0.405	0.22	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1995	1.330	0.16	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1996	-2.231	0.76	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1997	-2.505	0.67	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1998	-0.108	0.32	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_1999	1.105	0.19	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2000	2.483	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2001	1.192	0.22	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2002	0.470	0.22	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2003	-1.010	0.34	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2004	0.089	0.19	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2005	-2.315	0.64	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2006	-1.266	0.33	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2007	-2.036	0.62	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2008	1.873	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2009	-0.701	0.56	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2010	0.851	0.15	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2011	0.254	0.23	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2012	-0.512	0.37	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2013	1.704	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2014	0.053	0.25	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2015	1.389	0.14	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2016	2.262	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2017	0.645	0.24	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2018	-0.561	0.42	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2019	0.681	0.31	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2020	3.078	0.18	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2021	2.904	0.27	3	N(0.000 1.400)	-4.000	4.000	-
Main_RecrDev_2022	-0.687	1.17	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2023	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2024	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2025	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2026	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2027	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2028	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2029	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2030	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2031	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2032	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-

ForeRecr_2033	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
ForeRecr_2034	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Q_ENV	0.060	0.03	1	-	-15.000	15.000	OK
Q_extraSD_ENV	0.949	0.07	2	-	0.100	1.300	OK
LnQ_AKSHLF	0.277	0.28	1	-	-15.000	15.000	OK
Q_extraSD_AKSHLF	0.170	0.07	2	-	0.025	1.300	OK
LnQ_AKSLP	-0.423	-	-1	-	-15.000	5.000	-
Q_extraSD_AKSLP	0.033	0.04	2	-	0.001	0.700	OK
LnQ_NWSLP	-0.782	-	-1	-	-15.000	15.000	-
Q_extraSD_NWSLP	0.164	0.08	2	-	0.001	0.800	OK
LnQ_NWCBO	-0.595	-	-1	-	-15.000	15.000	-
Q_extraSD_NWCBO	0.000	-	-2	-	0.001	0.400	-
LnQ_AKSHLF_1995	-0.160	0.29	2	-	-15.000	15.000	OK
Ret_L_infl_FIX	41.000	-	-5	-	10.000	60.000	-
Ret_L_width_FIX	6.005	-	-5	-	0.100	20.000	-
Ret_L_asymptote_FIX	10.000	-	-5	-	-10.000	10.000	-
Ret_L_maleoffset_FIX	0.000	-	-50	-	-10.000	10.000	-
Disc_L_infl_FIX	28.000	-	-50	-	8.000	70.000	-
Disc_L_width_FIX	0.010	-	-50	-	0.001	2.000	-
Disc_L_level_old_FIX	0.200	-	-50	-	0.010	0.800	-
Disc_L_male_offset_FIX	0.000	-	-50	-	-10.000	10.000	-
Ret_L_infl_TWL	41.000	-	-5	-	15.000	55.000	-
Ret_L_width_TWL	2.898	-	-5	-	0.100	20.000	-
Ret_L_asymptote_TWL	10.000	-	-5	-	-10.000	10.000	-
Ret_L_maleoffset_TWL	0.000	-	-50	-	-10.000	10.000	-
Disc_L_infl_TWL	28.000	-	-50	-	8.000	70.000	-
Disc_L_width_TWL	0.010	-	-50	-	0.001	2.000	-
Disc_L_level_old_TWL	0.500	-	-50	-	0.100	0.800	-
Disc_L_male_offset_TWL	0.000	-	-50	-	-10.000	10.000	-
Age_peak_FIX	5.000	-	-4	-	2.000	20.000	-
Age_top_FIX	-4.000	-	-4	-	-20.000	5.000	-
Age_ascend_FIX	0.158	0.73	4	-	-15.000	10.000	OK
Age_descend_FIX	2.735	0.36	4	-	-10.000	10.000	OK
Age_start_FIX	-5.000	-	-4	-	-5.000	5.000	-
Age_end_FIX	-1.500	-	-4	-	-5.000	5.000	-
Age_1MaleDogleg_FIX	0.000	-	-4	-	-15.000	15.000	-
Age_1MaleatZero_FIX	0.057	58093.90	4	-	-15.000	15.000	OK
Age_1MaleatDogleg_FIX	-0.881	0.12	4	-	-15.000	15.000	OK
Age_1MaleatMaxage_FIX	-1.094	0.49	4	-	-15.000	15.000	OK
Age_peak_TWL	1.000	-	-4	-	0.010	20.000	-
Age_top_TWL	-4.000	-	-4	-	-20.000	5.000	-

Age_ascend_TWL	-2.424	4421.94	4	-	-20.000	10.000	OK
Age_descend_TWL	-9.000	-	-4	-	-10.000	10.000	-
Age_start_TWL	-4.027	-	-4	-	-5.000	5.000	-
Age_end_TWL	-1.495	0.17	4	-	-5.000	5.000	OK
Age_peak_AKSHLF	1.000	-	-4	-	1.000	12.000	-
Age_top_AKSHLF	-4.000	-	-4	-	-5.000	5.000	-
Age_ascend_AKSHLF	-9.729	1690.89	4	-	-10.000	10.000	OK
Age_descend_AKSHLF	-1.019	0.41	4	-	-10.000	10.000	OK
Age_start_AKSHLF	-2.500	-	-4	-	-10.000	5.000	-
Age_end_AKSHLF	-3.782	0.50	4	-	-10.000	5.000	OK
Age_4MaleDogleg_AKSHLF	0.000	-	-4	-	-15.000	15.000	-
Age_4MaleatZero_AKSHLF	-0.544	58018.30	4	-	-15.000	15.000	OK
Age_4MaleatDogleg_AKSHLF	-0.177	0.13	4	-	-15.000	15.000	OK
Age_4MaleatMaxage_AKSHLF	-6.000	2.41	4	-	-15.000	15.000	OK
Age_peak_AKSLP	1.439	0.54	4	-	1.000	12.000	OK
Age_top_AKSLP	-4.000	-	-4	-	-20.000	5.000	-
Age_ascend_AKSLP	-4.000	-	-4	-	-10.000	10.000	-
Age_descend_AKSLP	-5.964	57854.70	4	-	-20.000	10.000	OK
Age_start_AKSLP	-1.338	-	-4	-	-5.000	5.000	-
Age_end_AKSLP	-0.557	0.39	4	-	-5.000	5.000	OK
Age_peak_NWSLP	3.578	1.23	4	-	1.000	12.000	OK
Age_top_NWSLP	-4.000	-	-4	-	-5.000	5.000	-
Age_ascend_NWSLP	1.453	1.23	4	-	-10.000	10.000	OK
Age_descend_NWSLP	-14.479	60168.60	4	-	-20.000	50.000	OK
Age_start_NWSLP	-4.565	-	-4	-	-5.000	5.000	-
Age_end_NWSLP	0.267	0.66	4	-	-5.000	5.000	OK
Age_peak_NWCBO	0.107	0.03	4	-	0.010	5.000	OK
Age_top_NWCBO	-4.000	-	-4	-	-20.000	5.000	-
Age_ascend_NWCBO	-8.447	55027.70	4	-	-20.000	10.000	OK
Age_descend_NWCBO	3.352	0.18	4	-	-10.000	10.000	OK
Age_start_NWCBO	-4.000	-	-4	-	-5.000	5.000	-
Age_end_NWCBO	-0.320	-	-4	-	-5.000	5.000	-
Ret_L_infl_FIX_1942	25.000	-	-5	-	25.000	60.000	-
Ret_L_infl_FIX_1947	38.960	-	-5	-	25.000	60.000	-
Ret_L_infl_FIX_1997	39.341	2.30	5	-	25.000	60.000	OK
Ret_L_infl_FIX_2011	40.923	0.78	5	-	25.000	60.000	OK
Ret_L_infl_FIX_2019	31.359	-	-5	-	10.000	60.000	-
Ret_L_asymptote_FIX_1942	10.000	-	-5	-	-10.000	10.000	-
Ret_L_asymptote_FIX_1947	10.000	-	-5	-	-10.000	10.000	-
Ret_L_asymptote_FIX_1997	2.463	0.31	5	-	-10.000	10.000	OK
Ret_L_asymptote_FIX_2011	4.008	-	-5	-	-10.000	10.000	-

Ret_L_asymptote_FIX_2019	1.852	0.12	5	-	-10.000	10.000	OK
Ret_L_infl_TWL_1942	25.000	-	-5	-	15.000	55.000	-
Ret_L_infl_TWL_1947	45.929	-	-5	-	15.000	55.000	-
Ret_L_infl_TWL_1982	47.391	0.51	5	-	15.000	55.000	OK
Ret_L_infl_TWL_2011	33.392	0.24	5	-	15.000	55.000	OK
Ret_L_infl_TWL_2019	42.474	0.62	5	-	15.000	55.000	OK
Ret_L_asymptote_TWL_1942	10.000	-	-5	-	-10.000	10.000	-
Ret_L_asymptote_TWL_1947	10.000	-	-5	-	-10.000	10.000	-
Ret_L_asymptote_TWL_1982	3.750	0.44	5	-	-10.000	10.000	OK
Ret_L_asymptote_TWL_2011	10.000	-	-5	-	-10.000	10.000	-
Ret_L_asymptote_TWL_2019	6.039	3.34	5	-	-10.000	10.000	OK
Age_peak_FIX_1997	3.196	0.35	4	-	2.000	20.000	OK
Age_peak_FIX_2003	4.978	0.98	4	-	2.000	20.000	OK
Age_peak_FIX_2011	3.064	0.02	4	-	2.000	20.000	OK
Age_ascend_FIX_1997	-1.240	-	-4	-	-10.000	20.000	-
Age_ascend_FIX_2003	1.816	0.77	4	-	-10.000	20.000	OK
Age_ascend_FIX_2011	-8.447	1685.04	4	-	-10.000	20.000	OK
Age_descend_TWL_1982	2.040	0.46	4	-	-10.000	10.000	OK
Age_descend_TWL_2003	6.801	0.43	4	-	-10.000	10.000	OK
Age_descend_TWL_2011	8.737	-	-4	-	-10.000	10.000	-
Age_descend_AKSHLF_1995	3.185	0.18	4	-	-10.000	10.000	OK

Table 5: Likelihood components by source.

Label	Total
Total	2495.96
Catch	0.00
Equilibrium catch	0.00
Indices	-4.67
Discard	-110.42
Mean body weight	-25.78
Length composition	180.61
Age composition	2415.89
Recruitment	40.08
Initial equilibrium regime	0.00
Forecast recruitment	0.00
Parameter priors	0.25
Parameter deviations	0.00
Crash penalty	0.00

Table 6: Data weightings applied to length and age compositions according to the ‘Francis’ method.

Type	Fleet	Francis
Length	fixed-gear fleet	0.11
Length	trawl fleet	0.06
Length	WCGBTS	0.02
Age	fixed-gear fleet	0.11
Age	trawl fleet	0.20
Age	Triennial Survey	1.00
Age	Slope Survey	0.08
Age	NWFSC Slope Survey	0.11
Age	WCGBTS	0.15

Table 7: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass Age 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR45%)	Exploitation Rate
1890	468356	179356	441037	0.962	17510	2	0.000	0.000
1891	467055	178887	439881	0.959	17414	6	0.001	0.000
1892	465680	178397	438677	0.956	17315	7	0.001	0.000
1893	464234	177885	437425	0.954	17211	10	0.001	0.000
1894	462717	177343	436059	0.951	17104	12	0.001	0.000
1895	461130	176770	434630	0.948	16992	17	0.002	0.000
1896	459474	176166	433137	0.944	16876	19	0.002	0.000
1897	457750	175534	431583	0.941	16756	21	0.002	0.000
1898	455959	174876	429967	0.938	16632	23	0.002	0.000
1899	454100	174191	428290	0.934	16504	25	0.003	0.000
1900	452171	173481	426550	0.930	16371	51	0.005	0.000
1901	450148	172730	424722	0.926	16234	79	0.008	0.000
1902	448026	171938	422803	0.922	16092	107	0.011	0.000
1903	445807	171104	420791	0.917	15946	135	0.014	0.000
1904	443487	170227	418688	0.913	15796	164	0.018	0.000
1905	441067	169308	416490	0.908	15641	147	0.016	0.000
1906	438589	168373	414242	0.903	15482	146	0.016	0.000
1907	436037	167411	411925	0.897	15319	154	0.017	0.000
1908	433399	166417	409530	0.892	15153	99	0.011	0.000
1909	430737	165427	407116	0.887	14984	156	0.017	0.000
1910	427937	164375	404571	0.881	14813	214	0.024	0.001
1911	425002	163260	401893	0.875	14640	271	0.030	0.001
1912	421932	162083	399086	0.869	14462	329	0.037	0.001

Table 7: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass Age 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR45%)	Exploitation Rate
1913	418732	160845	396152	0.862	14279	386	0.044	0.001
1914	415404	159546	393095	0.855	14089	444	0.051	0.001
1915	411947	158189	389918	0.848	13896	500	0.058	0.001
1916	408364	156775	386623	0.840	13703	1334	0.151	0.003
1917	403903	154867	382458	0.830	13502	2021	0.223	0.005
1918	398722	152615	377617	0.818	13301	2888	0.316	0.008
1919	392678	149827	371876	0.803	13096	1043	0.124	0.003
1920	388452	148074	367942	0.794	12894	895	0.106	0.002
1921	384339	146455	364157	0.785	12690	1197	0.141	0.003
1922	379883	144686	360035	0.776	12490	810	0.101	0.002
1923	375771	143067	356204	0.767	12287	1455	0.178	0.004
1924	370991	141098	351731	0.756	12079	1866	0.226	0.005
1925	365780	138921	346856	0.745	10725	2135	0.262	0.006
1926	360003	136571	341685	0.732	10780	1721	0.221	0.005
1927	354402	134417	336903	0.721	10377	2565	0.318	0.008
1928	347718	131817	331346	0.707	10120	2150	0.276	0.006
1929	341250	129324	325125	0.693	10284	2332	0.301	0.007
1930	334562	126656	318859	0.679	10160	2594	0.340	0.008
1931	327669	123750	312117	0.663	9942	1429	0.201	0.005
1932	322015	121436	306443	0.651	9511	1682	0.240	0.005
1933	316142	119005	300875	0.638	9518	1559	0.226	0.005
1934	310458	116737	295595	0.626	9425	2700	0.378	0.009
1935	303743	113935	289271	0.611	9831	3463	0.476	0.012
1936	296546	110779	282065	0.594	8787	2398	0.364	0.009
1937	290483	108118	276066	0.580	8730	2573	0.398	0.009
1938	284341	105435	270120	0.565	9640	2520	0.398	0.009
1939	278594	102917	264958	0.552	9428	2794	0.442	0.011
1940	272919	100314	258917	0.538	9155	2223	0.367	0.009
1941	268098	98099	253592	0.526	8703	2190	0.362	0.009
1942	263449	96109	249389	0.515	8767	3232	0.515	0.013
1943	257847	93808	244325	0.503	9021	3927	0.595	0.016
1944	251695	91483	238692	0.490	9056	4489	0.663	0.019
1945	245127	89051	232244	0.477	9366	4422	0.669	0.019
1946	238899	86551	225811	0.464	8871	4460	0.701	0.020
1947	232896	83796	219537	0.449	9189	2314	0.422	0.011
1948	229489	82083	215701	0.440	8366	2971	0.514	0.014
1949	225632	80352	212161	0.431	9789	3113	0.540	0.015
1950	222124	78747	208518	0.422	10305	2789	0.492	0.013
1951	219536	77468	205691	0.415	10512	4564	0.712	0.022

Table 7: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass Age 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR45%)	Exploitation Rate
1952	215801	75589	200771	0.405	11548	2823	0.494	0.014
1953	214583	74611	198747	0.400	10938	1771	0.333	0.009
1954	214976	74361	198439	0.399	12320	2488	0.439	0.013
1955	215427	74136	198088	0.397	14593	2344	0.413	0.012
1956	217213	74272	199047	0.398	15010	3833	0.571	0.019
1957	218648	74305	198525	0.398	16407	2742	0.455	0.014
1958	222439	74780	199916	0.401	15669	1687	0.281	0.008
1959	228192	76288	204574	0.409	20390	2421	0.378	0.012
1960	234990	78047	209526	0.418	16466	3129	0.454	0.015
1961	241588	79984	215317	0.429	18707	1976	0.292	0.009
1962	250042	82855	221605	0.444	22095	2954	0.382	0.013
1963	258759	85996	231371	0.461	16003	2009	0.269	0.009
1964	267916	89592	238578	0.480	26045	2259	0.283	0.009
1965	278581	93355	247230	0.500	17917	2153	0.260	0.009
1966	288991	97427	259009	0.522	171566	2114	0.246	0.008
1967	337652	101648	265388	0.545	14273	5365	0.468	0.020
1968	382626	105031	277821	0.563	16070	3293	0.271	0.012
1969	424256	115199	285072	0.618	12680	5928	0.446	0.021
1970	451538	136276	429322	0.731	17093	5003	0.389	0.012
1971	468861	158257	446152	0.848	14335	4201	0.298	0.009
1972	477574	173034	455857	0.928	15873	7054	0.449	0.015
1973	476981	179363	453148	0.962	22352	6157	0.426	0.014
1974	474591	181565	450495	0.973	18160	9080	0.544	0.020
1975	467359	178922	439871	0.959	26191	14916	0.807	0.034
1976	455553	171681	423493	0.920	23712	25167	1.180	0.059
1977	435003	158590	402583	0.850	19138	9349	0.686	0.023
1978	430407	154973	394550	0.831	11862	13003	0.898	0.033
1979	420135	150630	390376	0.808	52753	24987	1.327	0.064
1980	406150	141039	373497	0.756	14008	10016	0.781	0.027
1981	405986	138606	367593	0.743	19738	12213	0.880	0.033
1982	403222	135938	353978	0.729	13122	19723	1.168	0.056
1983	389970	132643	367178	0.711	4365	15970	1.053	0.043
1984	375275	130340	353918	0.699	27184	15221	1.023	0.043
1985	362677	127173	344488	0.682	22705	15366	1.077	0.045
1986	351388	121887	329098	0.653	17405	14513	1.080	0.044
1987	341645	115865	307131	0.621	3441	13987	1.089	0.046
1988	329282	111116	304031	0.596	19680	11695	1.007	0.038
1989	319796	108383	300911	0.581	12409	11244	0.979	0.037
1990	310026	105701	294601	0.567	36326	9957	0.925	0.034

Table 7: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass Age 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR45%)	Exploitation Rate
1991	307229	102480	277958	0.549	1494	10682	0.986	0.038
1992	300900	98899	273598	0.530	7970	10542	0.990	0.039
1993	292727	96535	264507	0.518	4140	8946	0.890	0.034
1994	282851	96049	276745	0.515	10649	8089	0.853	0.029
1995	272831	94623	262343	0.507	26787	8445	0.898	0.032
1996	266425	91296	251295	0.489	756	9173	0.995	0.037
1997	257381	86722	236266	0.465	569	8768	1.055	0.037
1998	246281	82964	226912	0.445	6188	4772	0.690	0.021
1999	237784	82064	235370	0.440	20770	7096	0.951	0.030
2000	229996	79308	221149	0.425	81833	6900	0.999	0.031
2001	241640	75124	205934	0.403	22222	6995	0.974	0.034
2002	257742	71472	195940	0.383	10676	4623	0.685	0.024
2003	274888	73061	201215	0.392	2441	5945	0.711	0.030
2004	284157	81159	261563	0.435	7506	6193	0.641	0.024
2005	287079	90612	275941	0.486	693	6572	0.630	0.024
2006	282848	96357	276973	0.517	2004	6505	0.622	0.023
2007	273794	97831	267315	0.524	930	5487	0.555	0.021
2008	262133	96692	260322	0.518	46301	6124	0.634	0.024
2009	259051	92970	245303	0.498	3501	7623	0.803	0.031
2010	254387	86995	228985	0.466	16321	7265	0.855	0.032
2011	252403	82231	212107	0.441	8875	6536	0.972	0.031
2012	250354	81264	237052	0.436	4117	5407	0.723	0.023
2013	247007	81989	229095	0.440	37797	4220	0.591	0.018
2014	250796	82769	232378	0.444	7268	4525	0.598	0.019
2015	253317	82490	228814	0.442	27644	5267	0.679	0.023
2016	258813	81831	219535	0.439	66059	5537	0.717	0.025
2017	276921	82908	240366	0.444	13138	5815	0.660	0.024
2018	294259	84804	236010	0.455	3956	5470	0.629	0.023
2019	306847	89432	249320	0.479	13836	5575	0.565	0.022
2020	314733	98233	299188	0.527	154839	4096	0.368	0.014
2021	355705	106760	306069	0.572	208277	5217	0.435	0.017
2022	443477	110930	299848	0.595	9122	6914	0.531	0.023
2023	525277	117519	298212	0.630	18302	9118	0.624	0.031
2024	591216	141875	424483	0.761	18819	8359	0.398	0.020
2025	636828	183592	615645	0.984	19421	36545	0.959	0.059
2026	634109	207142	605691	1.110	19664	34699	0.956	0.057
2027	617911	214059	588802	1.148	19726	31632	0.954	0.054
2028	595310	210719	565615	1.130	19696	27385	0.951	0.048
2029	571577	203091	541675	1.089	19625	23217	0.948	0.043

Table 7: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass Age 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR45%)	Exploitation Rate
2030	549200	194403	519282	1.042	19539	19914	0.946	0.038
2031	528818	185924	498979	0.997	19447	17616	0.943	0.035
2032	510285	177993	480566	0.954	19354	16130	0.940	0.034
2033	493279	170621	463694	0.915	19262	15208	0.937	0.033
2034	477514	163747	448067	0.878	19168	14587	0.935	0.033

7.2.2 Sensitivity and Retrospective Analyses

Table 8: The total and likelihood contribution by data type and parameter estimates for the sensitivity group 1.

Likelihood or Parameter	Base Model	Bayesian Index	Estimate Parameters Fixed In Bridging	Fix Male P2Parameters	Fix Parameters With High Variance
Total Likelihood	2495.96	2495.53	2495.40	2495.96	2495.96
Survey Likelihood	-4.67	-4.83	-5.13	-4.67	-4.67
Discard Likelihood	-110.42	-110.42	-110.39	-110.42	-110.42
Length Likelihood	180.61	180.61	179.95	180.61	180.61
Age Likelihood	2415.89	2415.56	2416.45	2415.89	2415.89
Rec. Likelihood	40.08	40.13	39.95	40.08	40.08
Forecast Rec. Likelihood	0.00	0.00	0.00	0.00	0.00
Prior Likelihood	0.25	0.26	0.26	0.25	0.25
Parameter Devs. Likelihood	0.00	0.00	0.00	0.00	0.00
R_0	9.88	9.89	9.89	9.88	9.88
SB ₀ S	186.53	187.51	186.57	186.53	186.54
SB 2023	117.52	119.65	117.04	117.52	117.53
Fraction Unfished 2023	0.63	0.64	0.63	0.63	0.63
Yield at SPR	9641.13	9764.24	9706.90	9641.13	9641.81
h	0.70	0.70	0.70	0.70	0.70
M (female)	0.07	0.07	0.07	0.07	0.07
Lmin (female)	25.26	25.26	25.27	25.26	25.26
Lmax (female)	61.13	61.14	61.09	61.13	61.13
k (female)	0.37	0.37	0.37	0.37	0.37
CV _{young} (female)	0.06	0.06	0.06	0.06	0.06

Table 8: The total and likelihood contribution by data type and parameter estimates for the sensitivity group 1. (*continued*)

Likelihood or Parameter	Base Model	Bayesian Index	Estimate Parameters Fixed In Bridging	Fix Male P2Parameters	Fix Parameters With High Variance
CV_{old} (female)	0.10	0.10	0.10	0.10	0.10
M (male)	0.06	0.06	0.06	0.06	0.06
Lmin (male)	26.62	26.62	26.62	26.62	26.62
Lmax (male)	56.11	56.11	56.10	56.11	56.11
k (male)	0.38	0.38	0.38	0.38	0.38
CV_{young} (male)	0.07	0.07	0.07	0.07	0.07
CV_{old} (male)	0.08	0.08	0.08	0.08	0.08

Table 9: The total and likelihood contribution by data type and parameter estimates for the sensitivity group 2.

Likelihood or Parameter	Base Model	Asymptotic Selectivity For Latest Survey	Non Centered Recruitment Deviations	Turn On Added Variance For Recent Survey
Total Likelihood	2495.96	2543.44	2495.65	2483.35
Survey Likelihood	-4.67	12.86	-4.57	6.45
Discard Likelihood	-110.42	-109.09	-110.38	-106.18
Length Likelihood	180.61	194.99	180.53	179.05
Age Likelihood	2415.89	2428.89	2415.20	2395.24
Rec. Likelihood	40.08	41.77	40.44	36.49
Forecast Rec. Likelihood	0.00	0.00	0.00	0.00
Prior Likelihood	0.25	0.16	0.21	0.34
Parameter Devs. Likelihood	0.00	0.00	0.00	0.00
R_0	9.88	9.48	9.70	9.97
SB_0S	186.53	156.82	161.46	202.04
SB 2023	117.52	68.54	112.56	129.99
Fraction Unfished 2023	0.63	0.44	0.70	0.64
Yield at SPR	9641.13	6960.51	8149.84	10674.40
h	0.70	0.70	0.70	0.70
M (female)	0.07	0.07	0.07	0.07
Lmin (female)	25.26	25.38	25.26	25.24

Table 9: The total and likelihood contribution by data type and parameter estimates for the sensitivity group 2. (*continued*)

Likelihood or Parameter	Base Model	Asymptotic Selectivity For Latest Survey	Non Centered Recruitment Deviations	Turn On Added Variance For Recent Survey
Lmax (female)	61.13	62.73	61.13	61.74
k (female)	0.37	0.34	0.37	0.36
CV_{young} (female)	0.06	0.06	0.06	0.06
CV_{old} (female)	0.10	0.11	0.10	0.10
M (male)	0.06	0.06	0.06	0.06
Lmin (male)	26.62	26.58	26.62	26.35
Lmax (male)	56.11	57.11	56.11	56.34
k (male)	0.38	0.37	0.38	0.38
CV_{young} (male)	0.07	0.07	0.07	0.08
CV_{old} (male)	0.08	0.08	0.08	0.08

Table 10: The total and likelihood contribution by data type and parameter estimates for the sensitivity group 3.

Likelihood or Parameter	Base Model	Single Natural Mortality	Tune With Harmonic Mean	Use Marginal Ages
Total Likelihood	2495.96	2501.46	3649.36	1228.79
Survey Likelihood	-4.67	-5.19	-7.67	-13.39
Discard Likelihood	-110.42	-108.95	-78.77	-108.55
Length Likelihood	180.61	180.67	157.95	181.03
Age Likelihood	2415.89	2414.85	3564.58	1165.05
Rec. Likelihood	40.08	45.63	41.41	39.10
Forecast Rec. Likelihood	0.00	0.00	0.00	0.00
Prior Likelihood	0.25	0.01	0.26	1.03
Parameter Devs. Likelihood	0.00	0.00	0.00	0.00
R_0	9.88	9.36	9.88	10.35
SB_0S	186.53	168.25	184.34	241.44
SB 2023	117.52	77.64	125.59	148.76
Fraction Unfished 2023	0.63	0.46	0.68	0.62
Yield at SPR	9641.13	6137.99	9544.94	14901.60
h	0.70	0.70	0.70	0.70
M (female)	0.07	0.05	0.07	0.09

Table 10: The total and likelihood contribution by data type and parameter estimates for the sensitivity group 3. (*continued*)

Likelihood or Parameter	Base Model	Single Natural Mortality	Tune With Harmonic Mean	Use Marginal Ages
Lmin (female)	25.26	25.27	25.53	26.81
Lmax (female)	61.13	61.14	61.13	62.91
k (female)	0.37	0.37	0.36	0.34
CV_{young} (female)	0.06	0.06	0.05	0.11
CV_{old} (female)	0.10	0.10	0.10	0.09
M (male)	0.06	0.00	0.06	0.08
Lmin (male)	26.62	26.62	27.05	31.88
Lmax (male)	56.11	55.95	56.16	57.75
k (male)	0.38	0.38	0.37	0.31
CV_{young} (male)	0.07	0.07	0.07	0.10
CV_{old} (male)	0.08	0.08	0.08	0.06

Table 11: The average relative bias of retrospective estimates (Mohn’s rho; Mohn, 1999) given the removal of five years of data for fishing intensity (F), fraction unfished (Figure 83), recruitment, and spawning stock biomass (SSB ; Figure 82). Columns are derivations of Mohn’s rho used by the Alaska Fisheries Science Center (AFSC), suggested by Hurtado-Ferro et al. (2015), and used by the Northeast Fisheries Science Center (NEFSC).

Quantity	AFSC	Mohn	NEFSC
F	0.111	0.556	-0.126
SSB	-0.071	-0.356	0.356
Fraction unfished	-0.032	-0.161	0.591
Recruitment	-0.156	-0.781	0.406

Table 12: The total and likelihood contribution by data type and parameter estimates for the base model and the retrospective data peels.

Likelihood or Parameter	Base Model	Retro -1	Retro -2	Retro -3	Retro -4	Retro -5
Total Likelihood	2495.96	2355.94	2203.06	2187.87	2088.54	1948.51
Survey Likelihood	-4.67	-3.26	-8.11	-8.04	-6.63	-5.61
Discard Likelihood	-110.42	-111.24	-111.79	-106.96	-102.56	-101.29
Length Likelihood	180.61	163.04	146.97	143.81	141.28	127.93
Age Likelihood	2415.89	2298.23	2167.99	2148.22	2042.56	1913.70
Rec. Likelihood	40.08	37.16	34.16	34.01	34.46	34.47
Forecast Rec. Likelihood	0.00	0.00	0.00	0.00	0.00	0.00
Prior Likelihood	0.25	0.32	0.51	0.49	0.44	0.45
Parameter Devs. Likelihood	0.00	0.00	0.00	0.00	0.00	0.00
R_0	9.88	9.92	9.93	9.91	9.84	9.78
SB ₀ S	186534.00	187302.00	182359.00	179923.00	175605.00	168848.00
SB 2023	117519.00	119022.00	104441.00	104848.00	102410.00	92331.60
Fraction Unfished 2023	0.63	0.64	0.57	0.58	0.58	0.55
Yield at SPR	9641.13	10023.50	10069.20	9891.91	9396.78	8949.35
h	0.70	0.70	0.70	0.70	0.70	0.70
M (female)	0.07	0.07	0.08	0.08	0.08	0.08
Lmin (female)	25.26	25.68	25.67	25.64	25.60	25.41
Lmax (female)	61.13	61.29	62.02	62.05	62.40	62.59
k (female)	0.37	0.37	0.35	0.35	0.35	0.36
CV _{young} (female)	0.06	0.06	0.06	0.06	0.06	0.06
CV _{old} (female)	0.10	0.10	0.11	0.11	0.11	0.10
M (male)	0.06	0.06	0.07	0.06	0.06	0.06
Lmin (male)	26.62	26.98	27.20	27.23	27.17	26.90
Lmax (male)	56.11	56.23	56.56	56.59	56.65	56.68
k (male)	0.38	0.38	0.37	0.37	0.37	0.38
CV _{young} (male)	0.07	0.07	0.07	0.07	0.07	0.07
CV _{old} (male)	0.08	0.08	0.08	0.08	0.08	0.07

7.3 Reference Points and Projections

Table 13: The adopted OFL (mt), ACL (mt), and assumed removals (mt) in 2023-24 and the projected OFL (mt), ABC (mt), spawning biomass, and fraction unfished for 2025-2034. The projected ABCs are calculated using a P^* of 0.45 and category 1 time-varying sigma.

Year	Adopted OFL	Adopted ACL	Assumed Removals	OFL	ABC	Spawning Biomass	Fraction Unfished
2023	11,577	10,824	9,118	-	-	117,519	0.630
2024	10,670	9,923	8,359	-	-	141,875	0.761
2025	-	-	-	39,085	36,545	183,592	0.984
2026	-	-	-	37,310	34,699	207,142	1.110
2027	-	-	-	34,160	31,632	214,059	1.148
2028	-	-	-	29,701	27,385	210,719	1.130
2029	-	-	-	25,318	23,217	203,091	1.089
2030	-	-	-	21,812	19,914	194,403	1.042
2031	-	-	-	19,380	17,616	185,924	0.997
2032	-	-	-	17,843	16,130	177,993	0.954
2033	-	-	-	16,898	15,208	170,621	0.915
2034	-	-	-	16,281	14,587	163,747	0.878

Table 14: Summary of reference points and management quantities, including estimates of the 95 percent intervals for the model area.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	186,534.00	118,407.81	254,660.19
Unfished Age 4+ Biomass (mt)	458,971.00	280,172.31	637,769.69
Unfished Recruitment (R_0)	19,453.90	7,838.53	31,069.27
Spawning Biomass (mt) (2023)	117,519.00	49,642.51	185,395.49
Fraction Unfished (2023)	0.63	0.42	0.84
Reference Points Based $SB_{40\%}$	NA	NA	NA
Proxy Spawning Biomass (mt) $SB_{40\%}$	74,613.60	47,363.04	101,864.16
SPR Resulting in $SB_{40\%}$	0.46	0.46	0.46
Exploitation Rate Resulting in $SB_{40\%}$	0.04	0.04	0.05
Yield with SPR Based On $SB_{40\%}$ (mt)	9,477.83	4,432.47	14,523.19
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Biomass (mt) ($SPR_{45\%}$)	71,629.00	45,468.58	97,789.42
$SPR_{45\%}$	0.45	NA	NA
Exploitation Rate Corresponding to $SPR_{45\%}$	0.04	0.04	0.05
Yield with $SPR_{45\%}$ at SB SPR (mt)	9,641.13	4,509.22	14,773.04
Reference Points Based on Estimated MSY	NA	NA	NA
Spawning Biomass (mt) at MSY (SB MSY)	45,903.50	29,025.25	62,781.75
SPR MSY	0.33	0.32	0.33

Table 14: Summary of reference points and management quantities, including estimates of the 95 percent intervals for the model area. (*continued*)

	Estimate	Lower Interval	Upper Interval
Exploitation Rate Corresponding to SPR MSY	0.07	0.06	0.08
MSY (mt)	10,431.20	4,881.90	15,980.50

8 Figures

8.1 Data

8.1.1 Summary

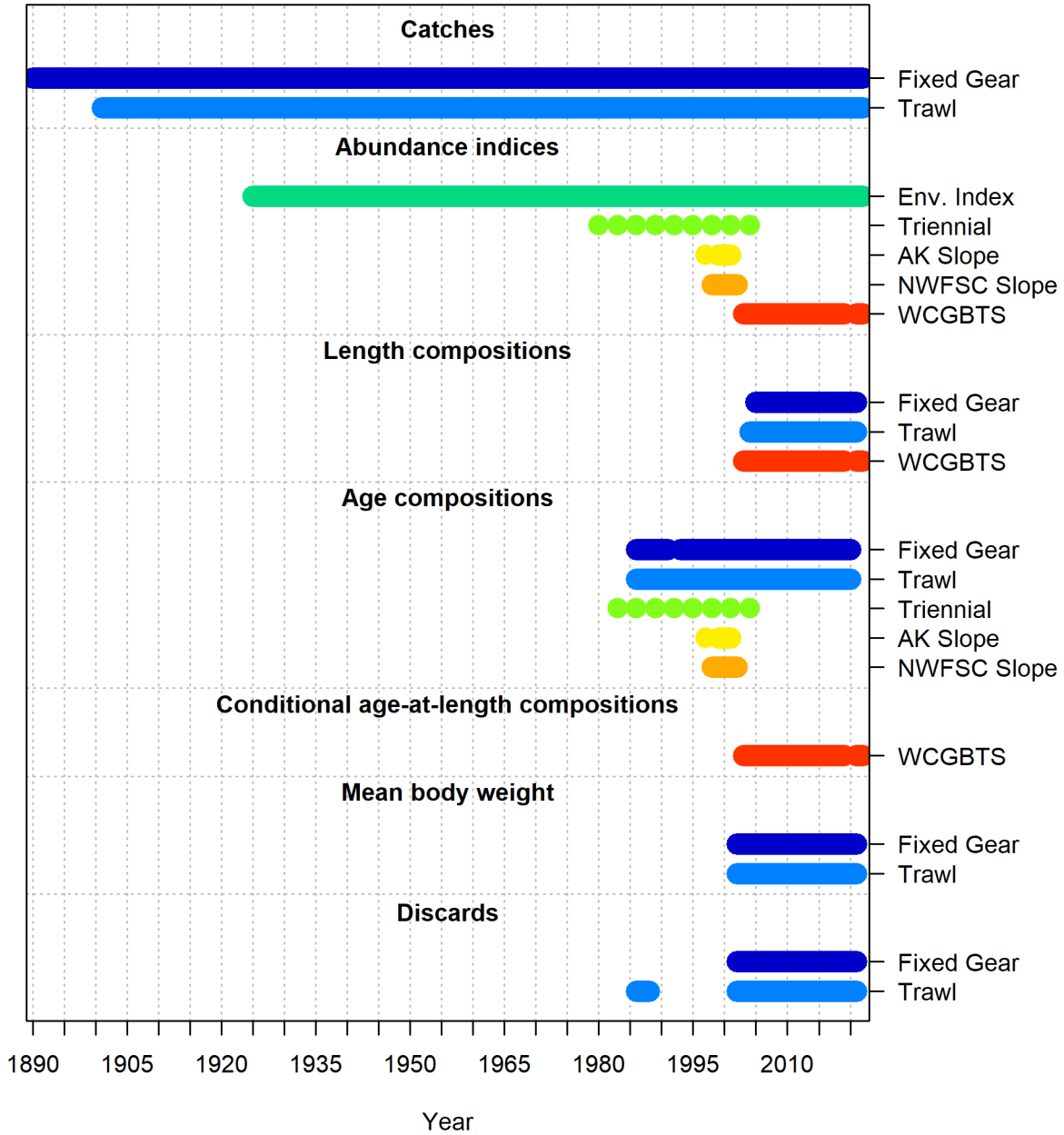


Figure 1: Summary of data sources used in the base model.

8.1.2 Fishery-Dependent Data

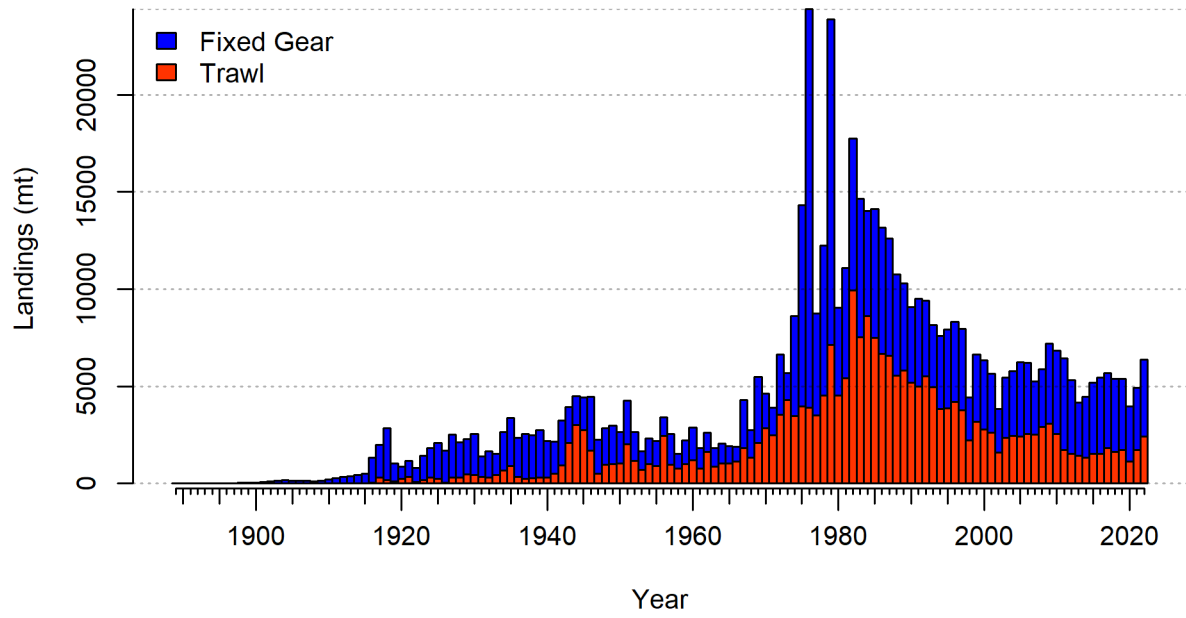


Figure 2: Landings (mt) by year from the fixed gear (blue) and trawl (red) fleets.

Discard fraction for Fixed Gear

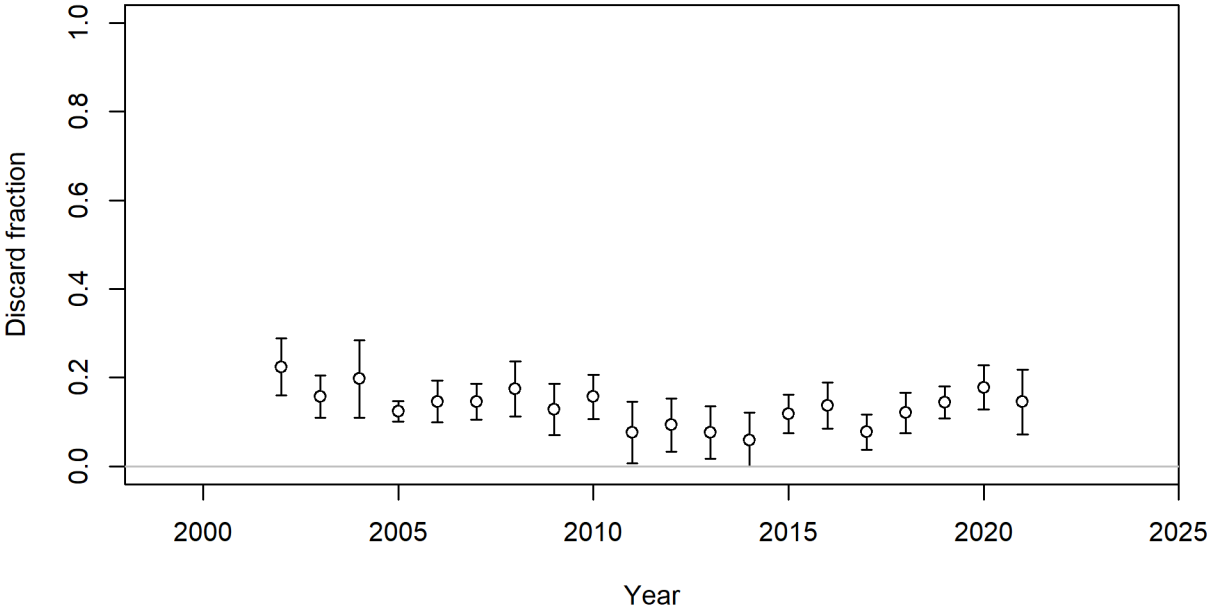


Figure 3: Annual West Coast Groundfish Observer Program discard rates for the fixed-gear fleet from the discarded catch.

Discard fraction for Trawl

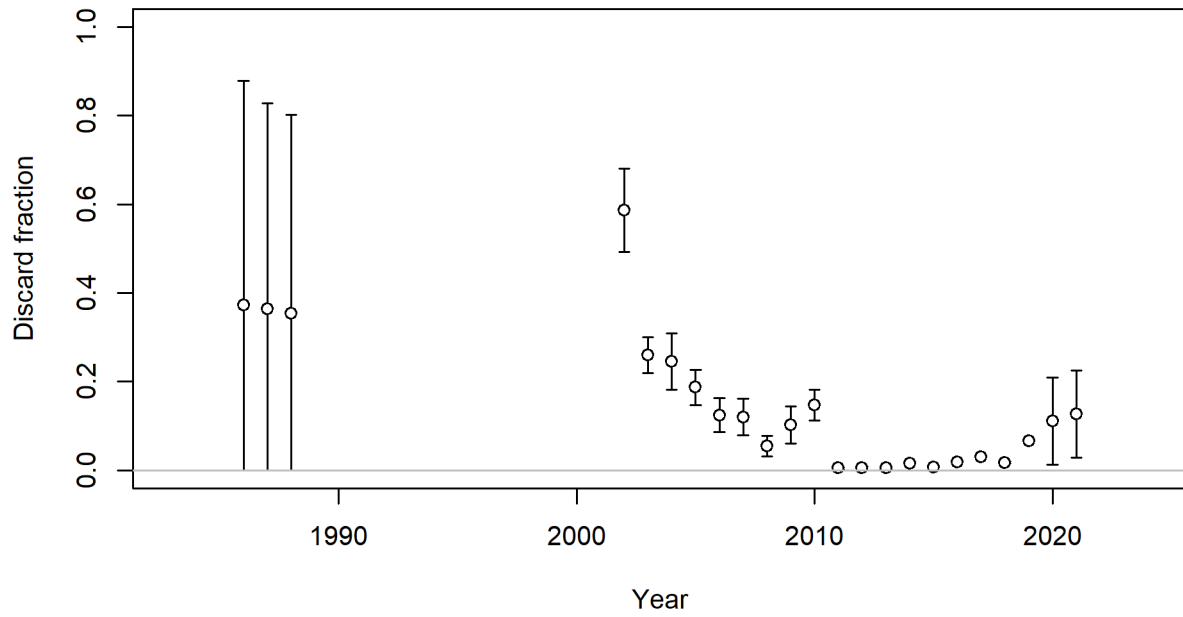


Figure 4: Annual West Coast Groundfish Observer Program discard rates for the trawl fleet from the discarded catch.

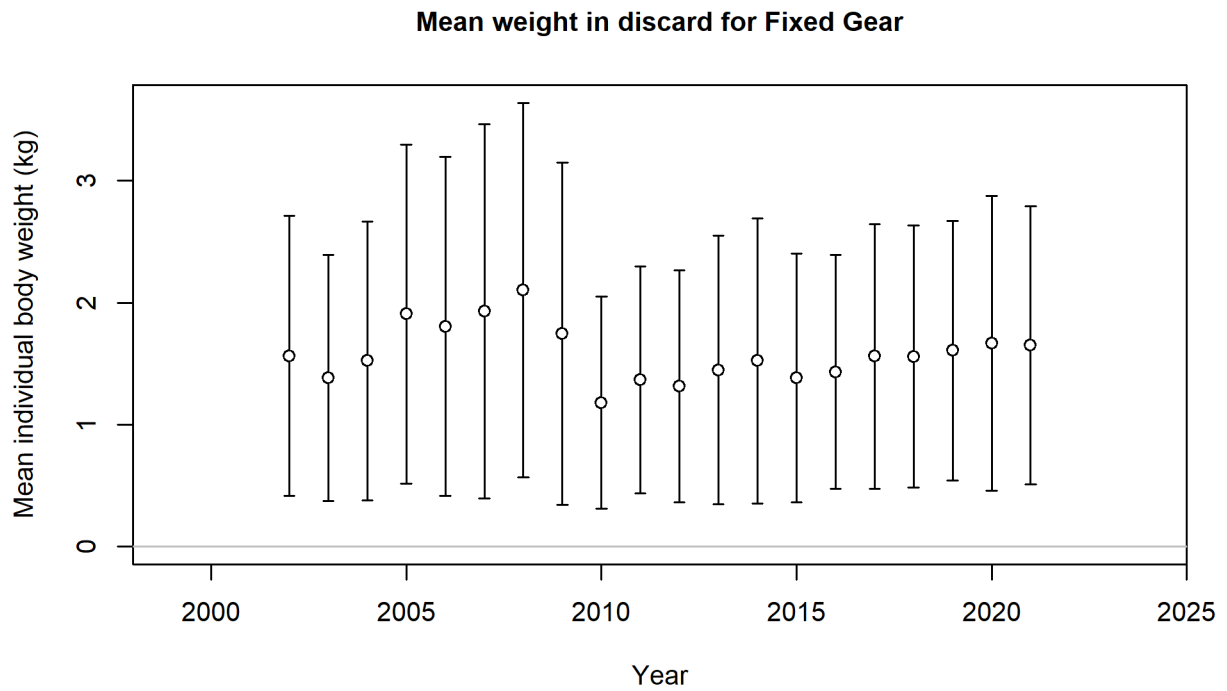


Figure 5: Annual West Coast Groundfish Observer Program mean weights (kg) for the fixed-gear fleet from the discarded catch.

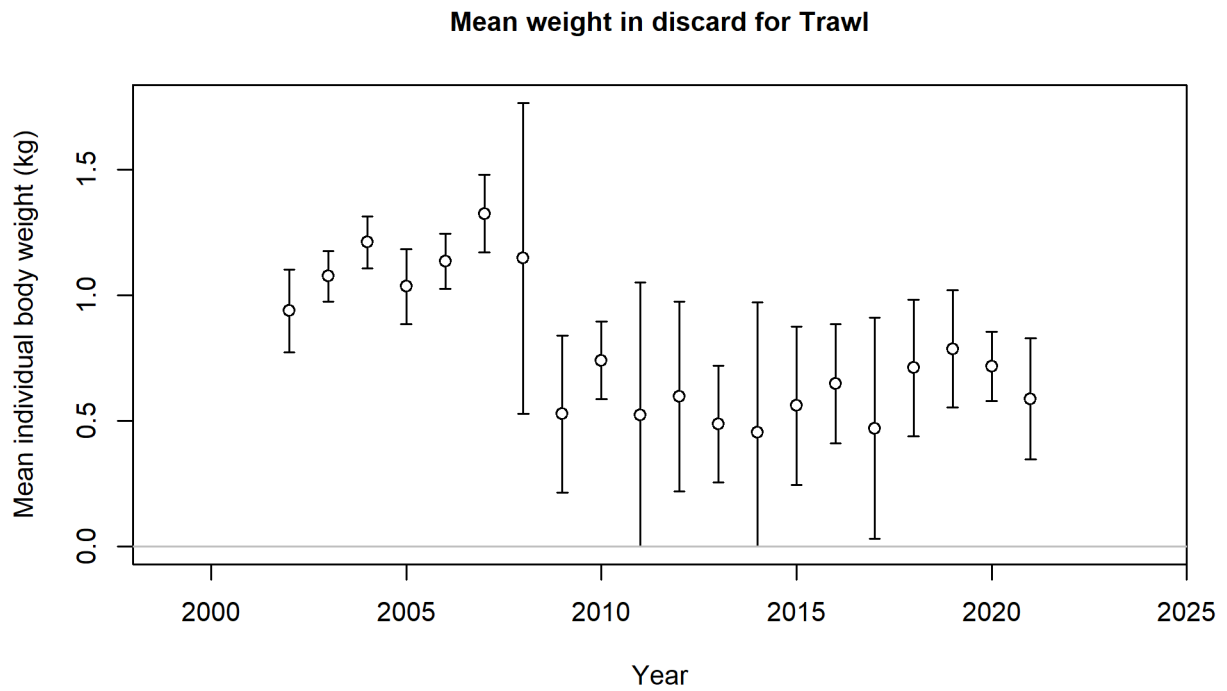


Figure 6: Annual West Coast Groundfish Observer Program mean weights (kg) for the trawl fleet from the discarded catch.

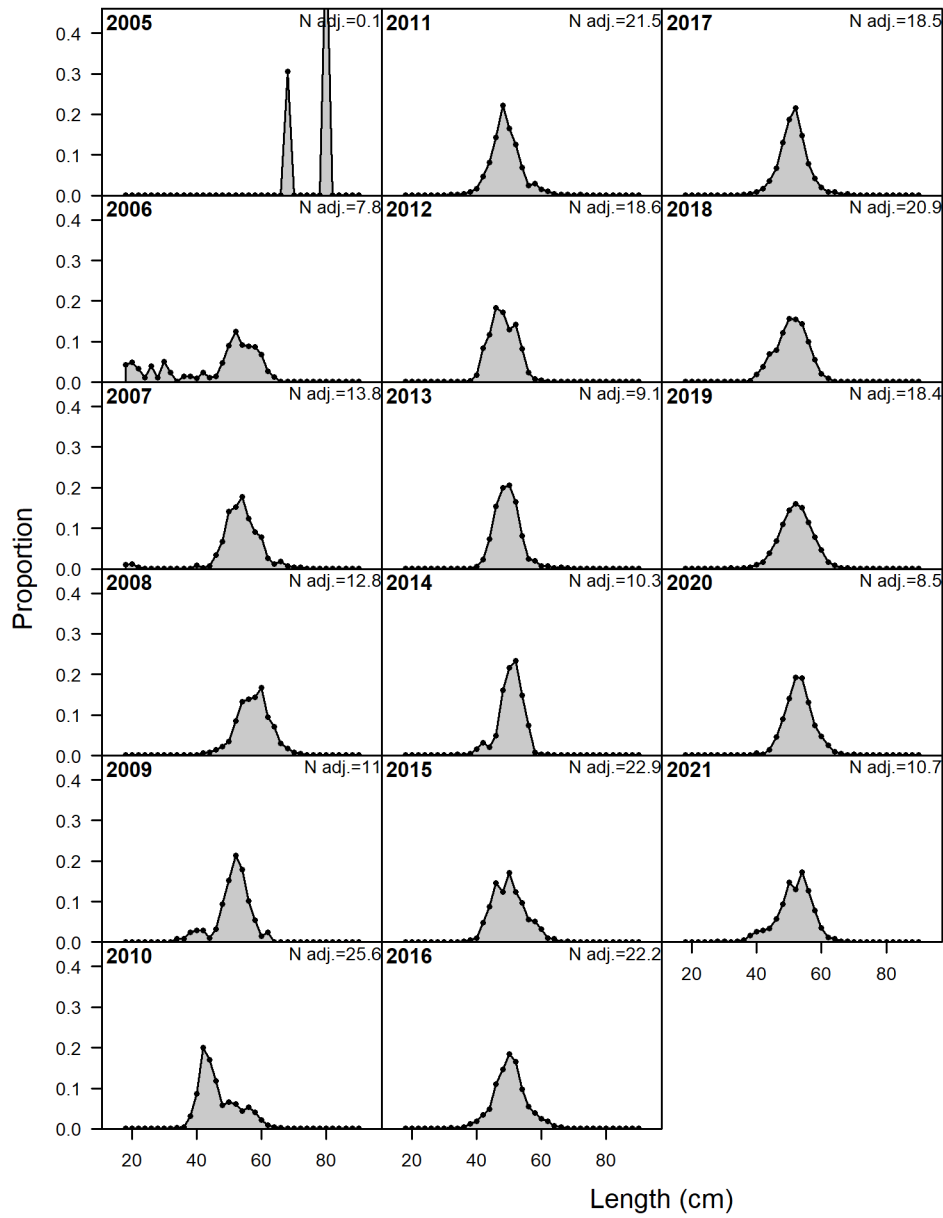


Figure 7: Annual length-composition data for the fixed-gear fleet from the discarded catch.

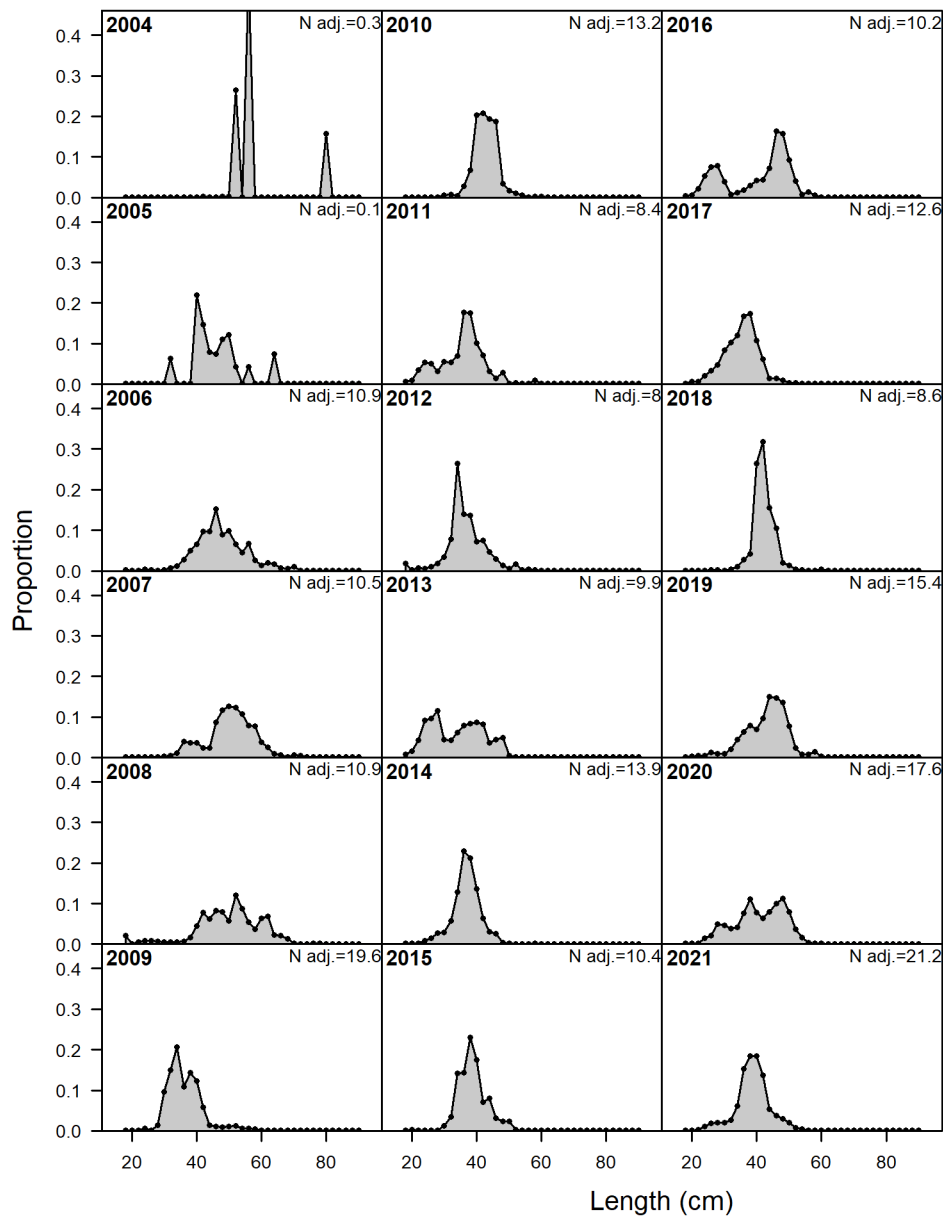


Figure 8: Annual length-composition data for the trawl fleet from the discarded catch.

8.1.3 Fishery-Independent Data

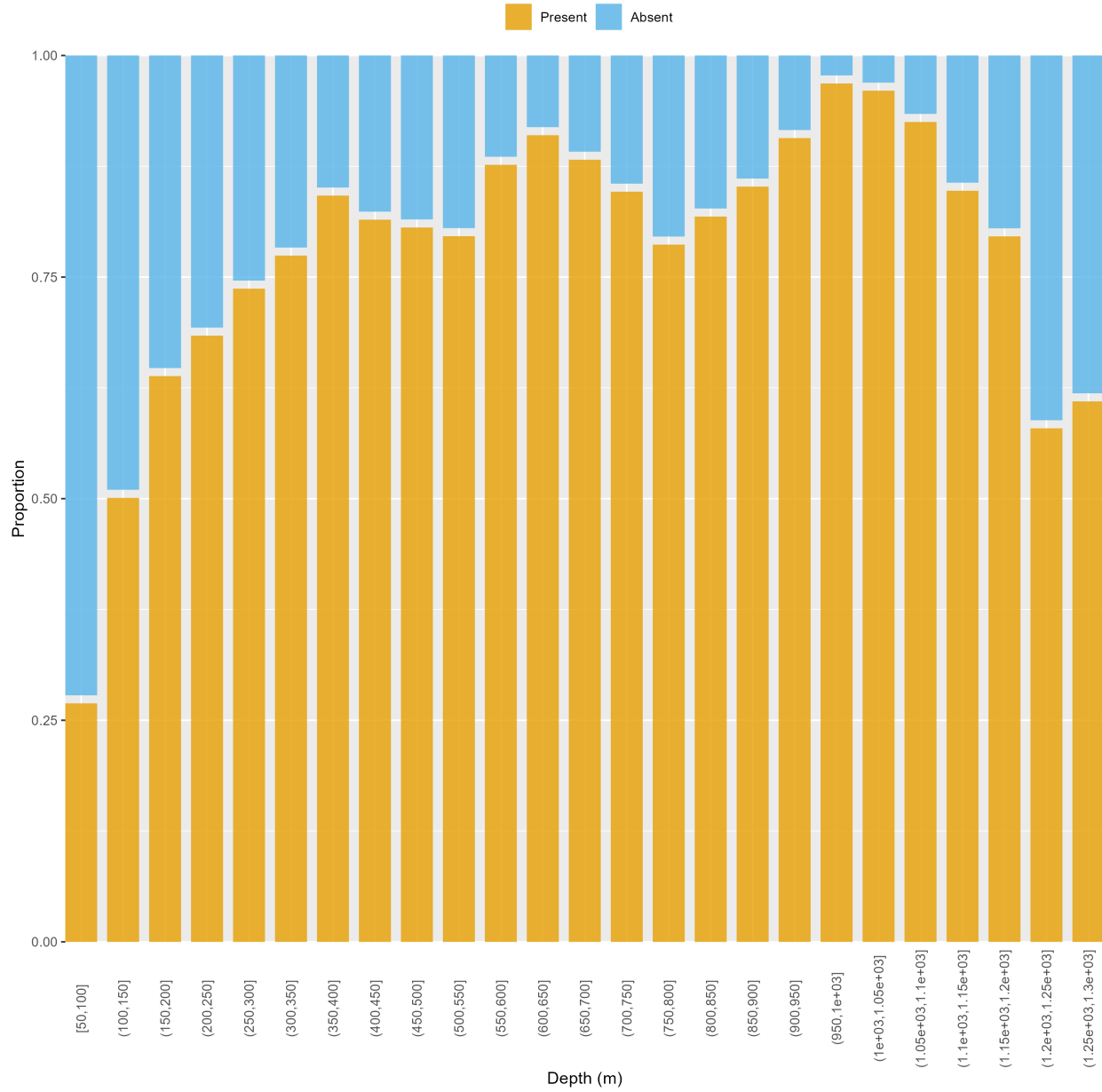


Figure 9: The proportion of tows that observe sablefish out of all tows performed within a given range of depths (m) sampled for the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey.

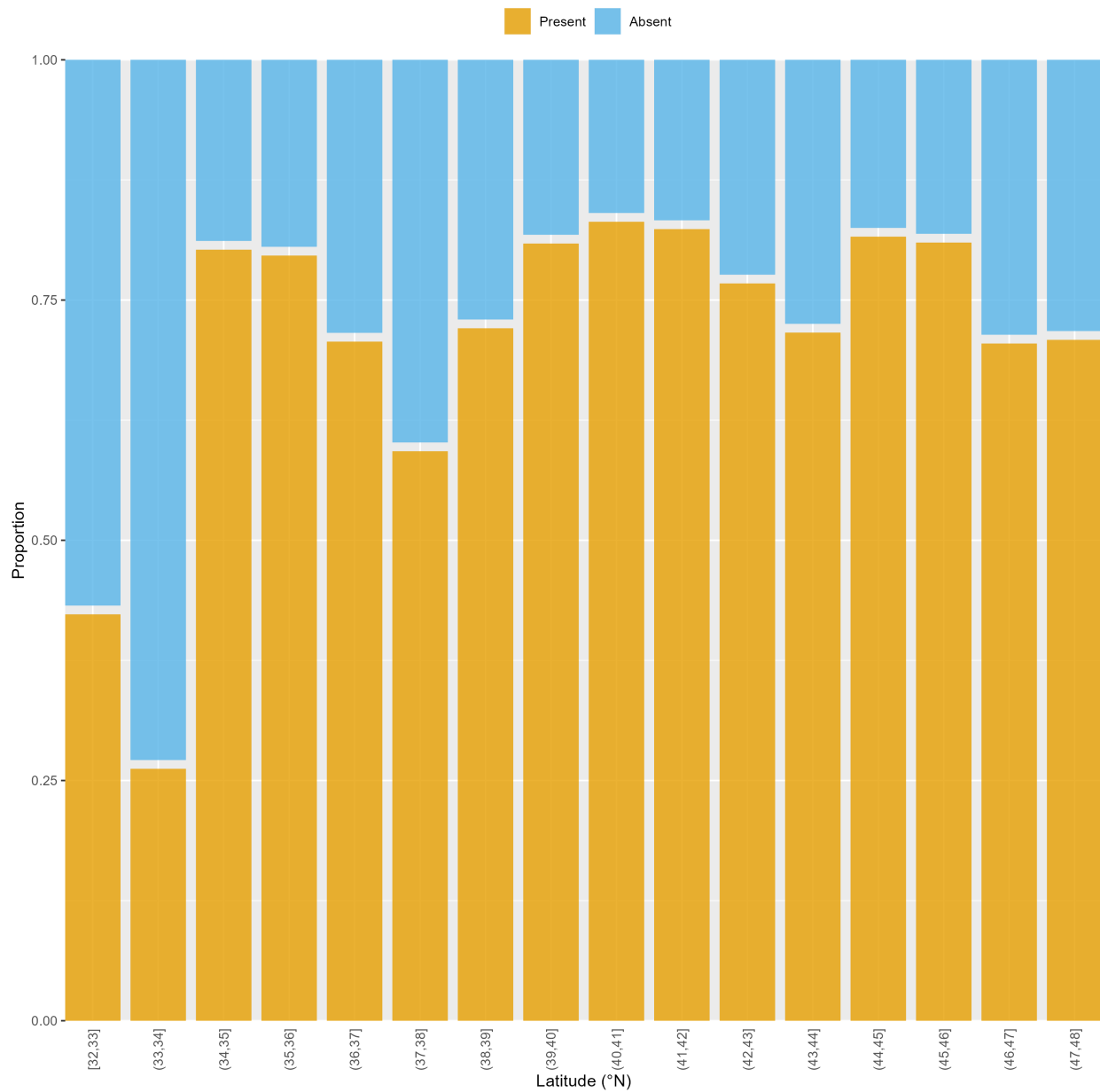


Figure 10: The proportion of tows that observe sablefish out of all tows performed within a given range of latitudes (decimal degrees) in the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey.

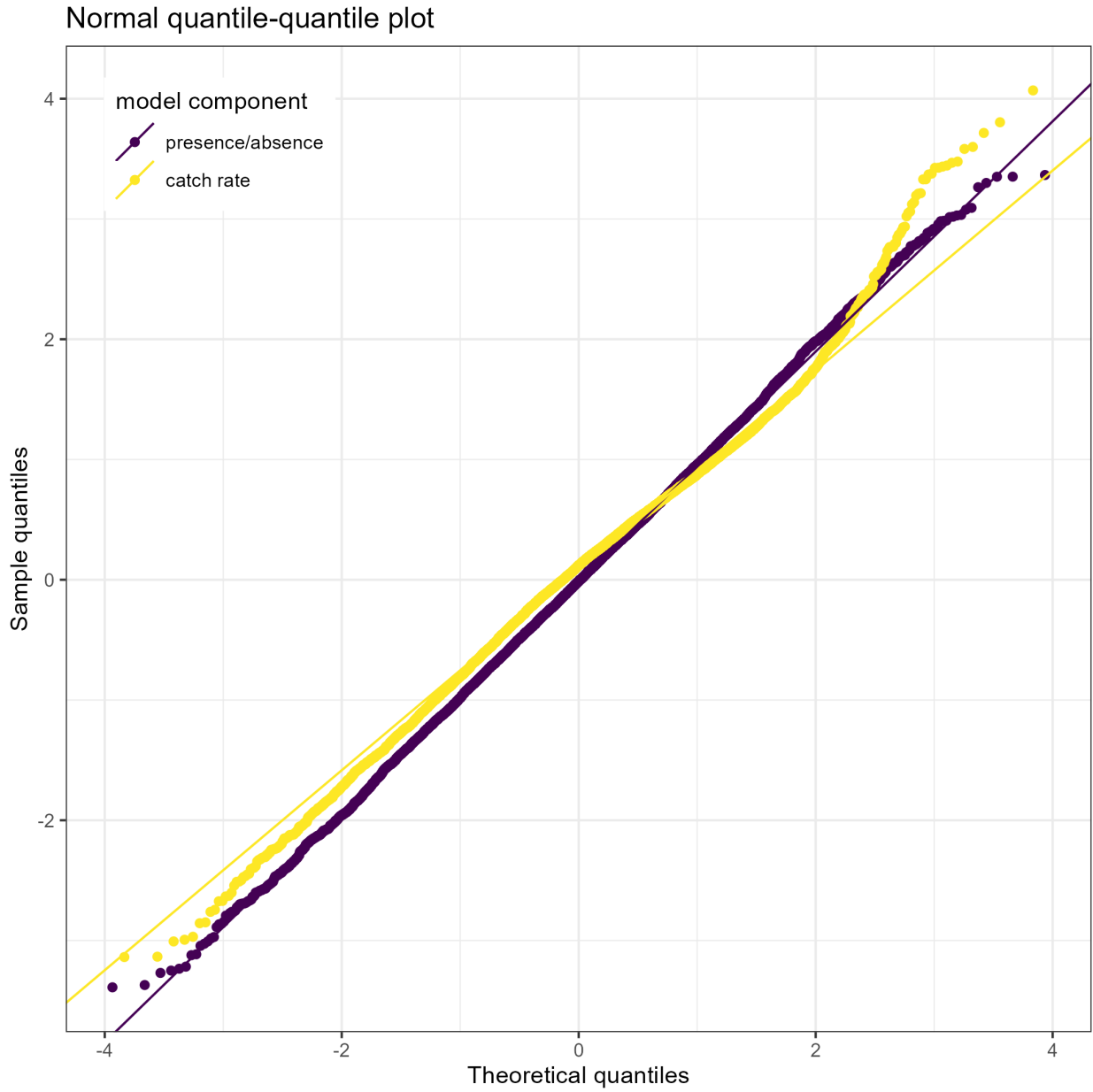


Figure 11: Quantile-quantile plot for the presence/absence (purple) and rate (yellow) components of a delta model fit to abundance data from the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey where the rate component assumed a gamma distribution.

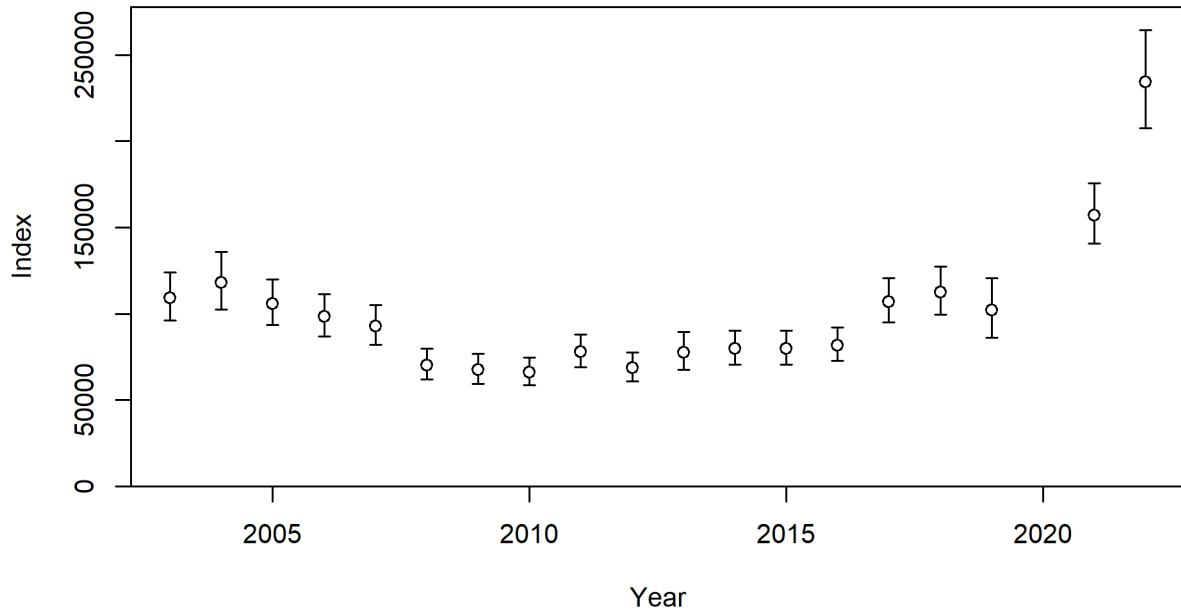


Figure 12: Annual relative index of abundance for the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey.

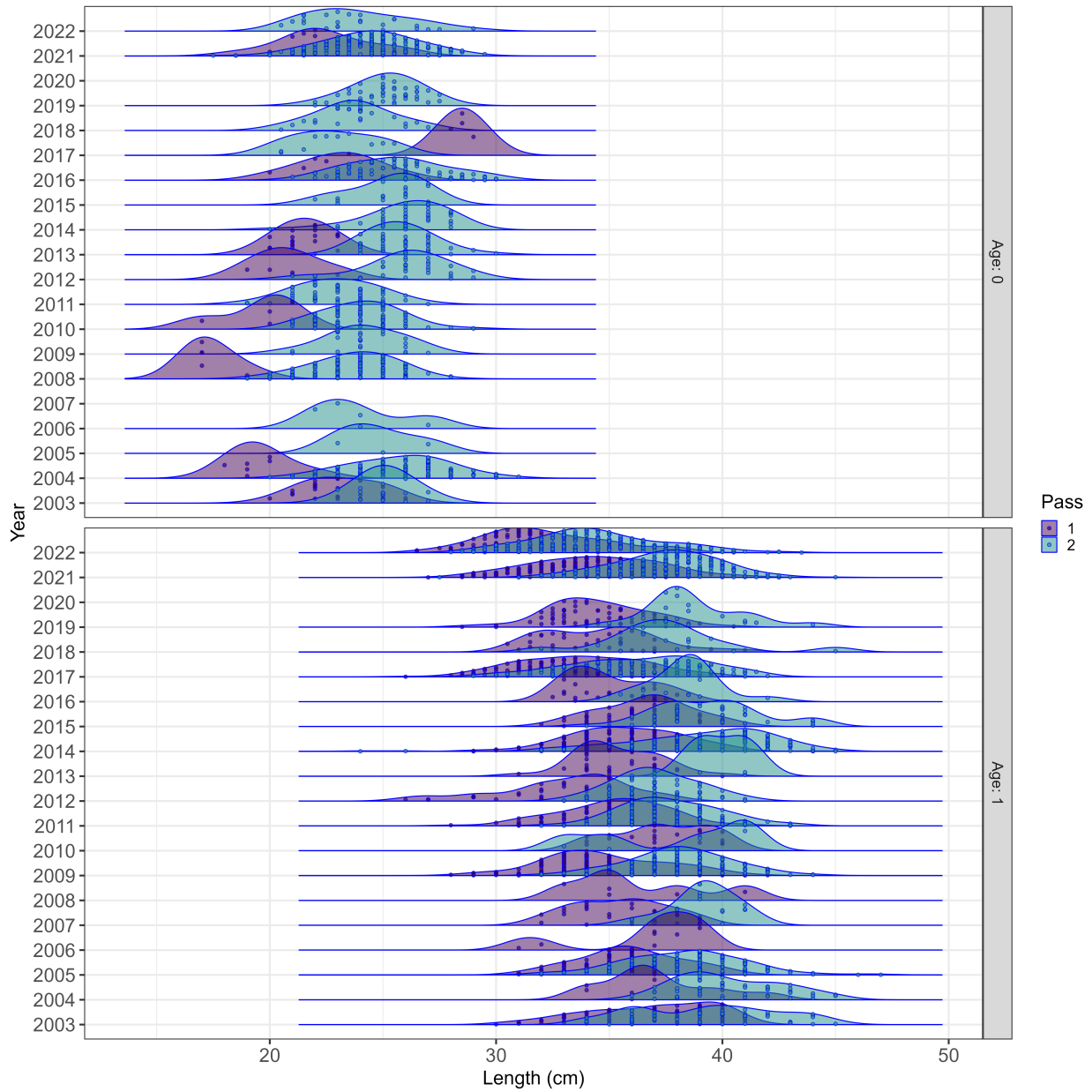


Figure 13: The length distribution of age-0 (upper panel) and age-1 (lower panel) fish by survey pass (colors) across years sampled by the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey. Blue dots indicate the lengths observed for each age and by pass.

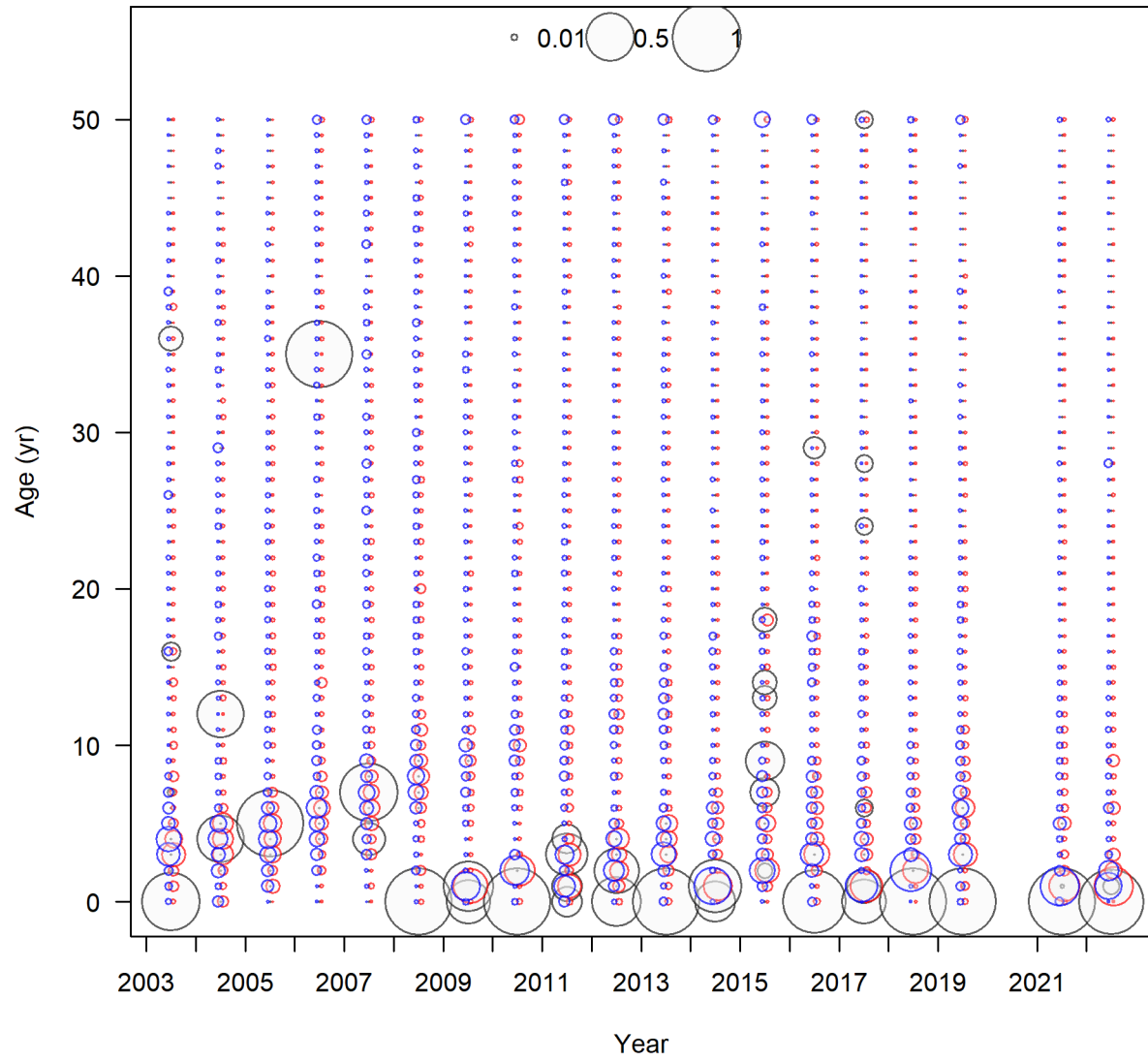


Figure 14: Annual female, male, and unsexed (red, blue, and black, respectively) age-composition data that were excluded from the model fitting process for the WCGBTS from the whole catch.

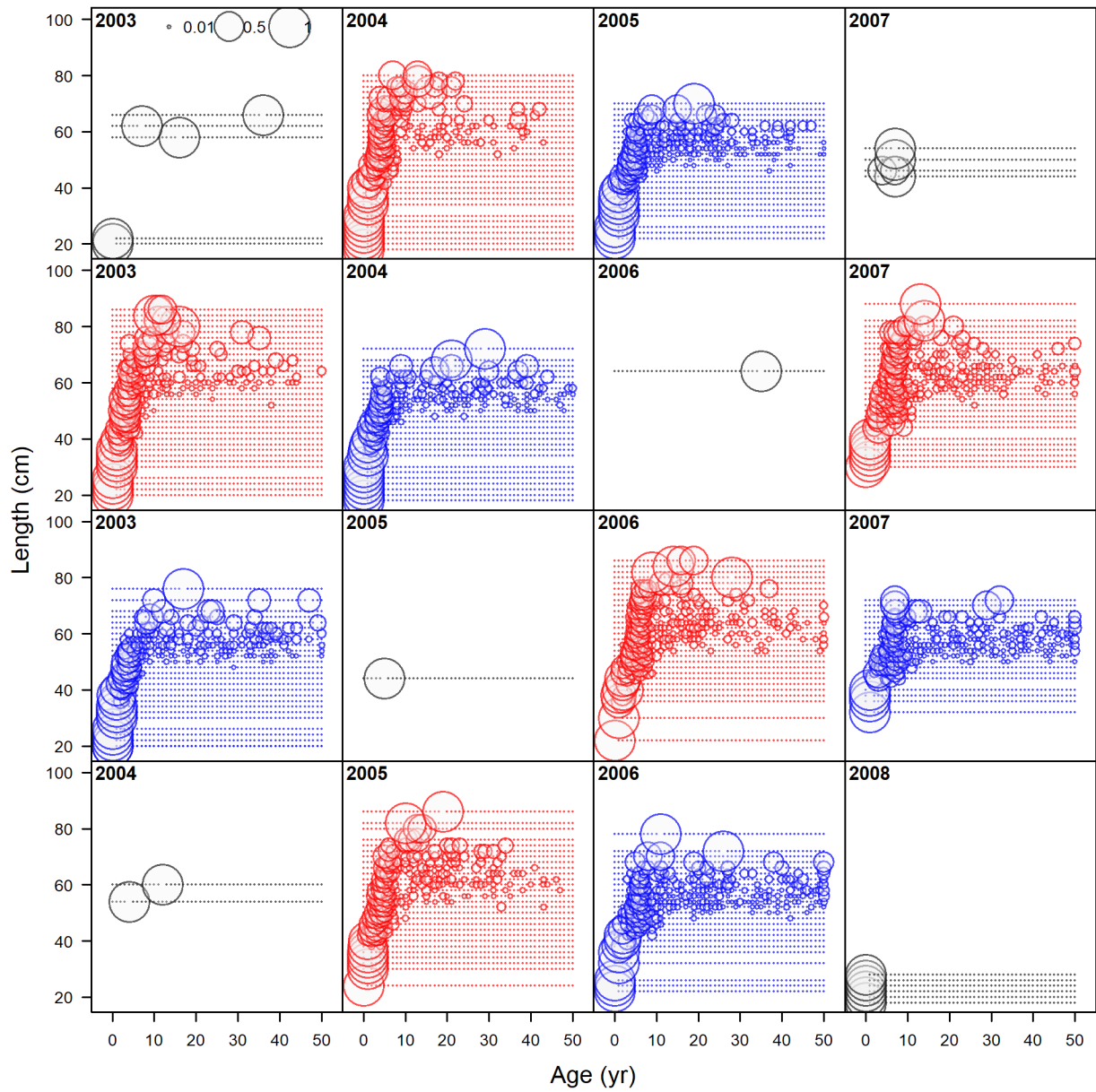


Figure 15: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGBTS from the whole catch.

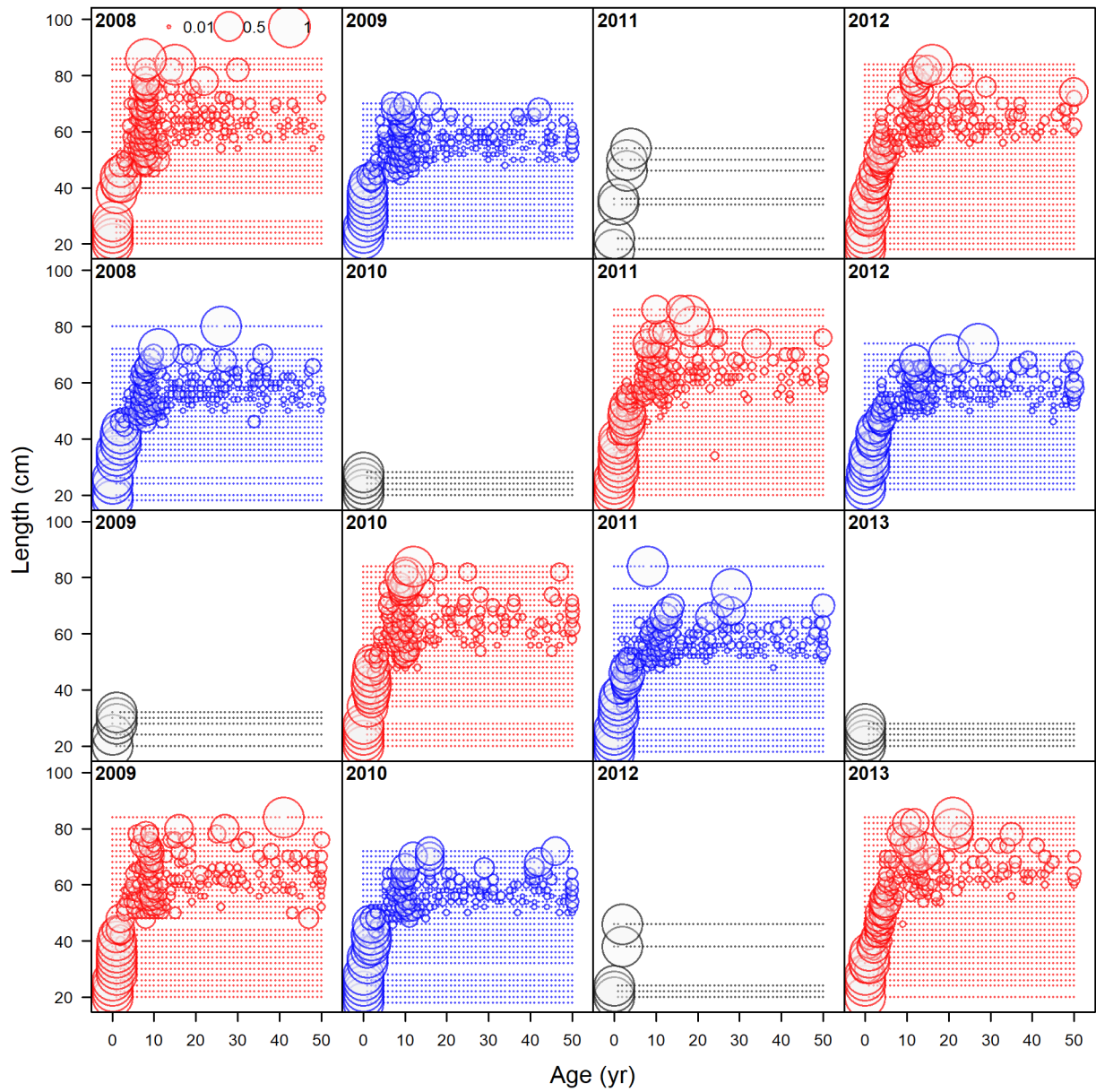


Figure 16: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGTBS from the whole catch. Continued from Figure 15.

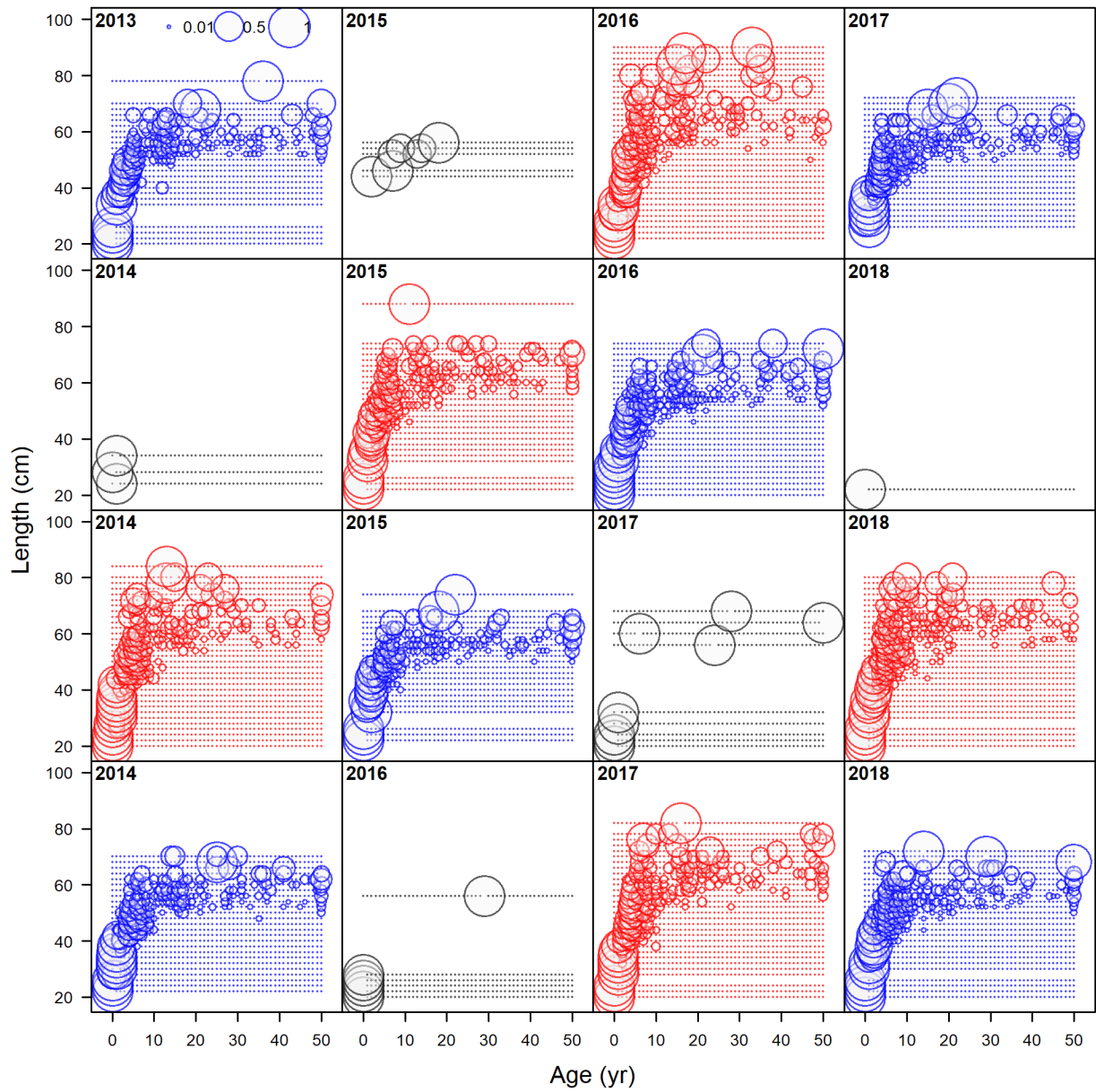


Figure 17: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGBTS from the whole catch. Continued from Figure 16.

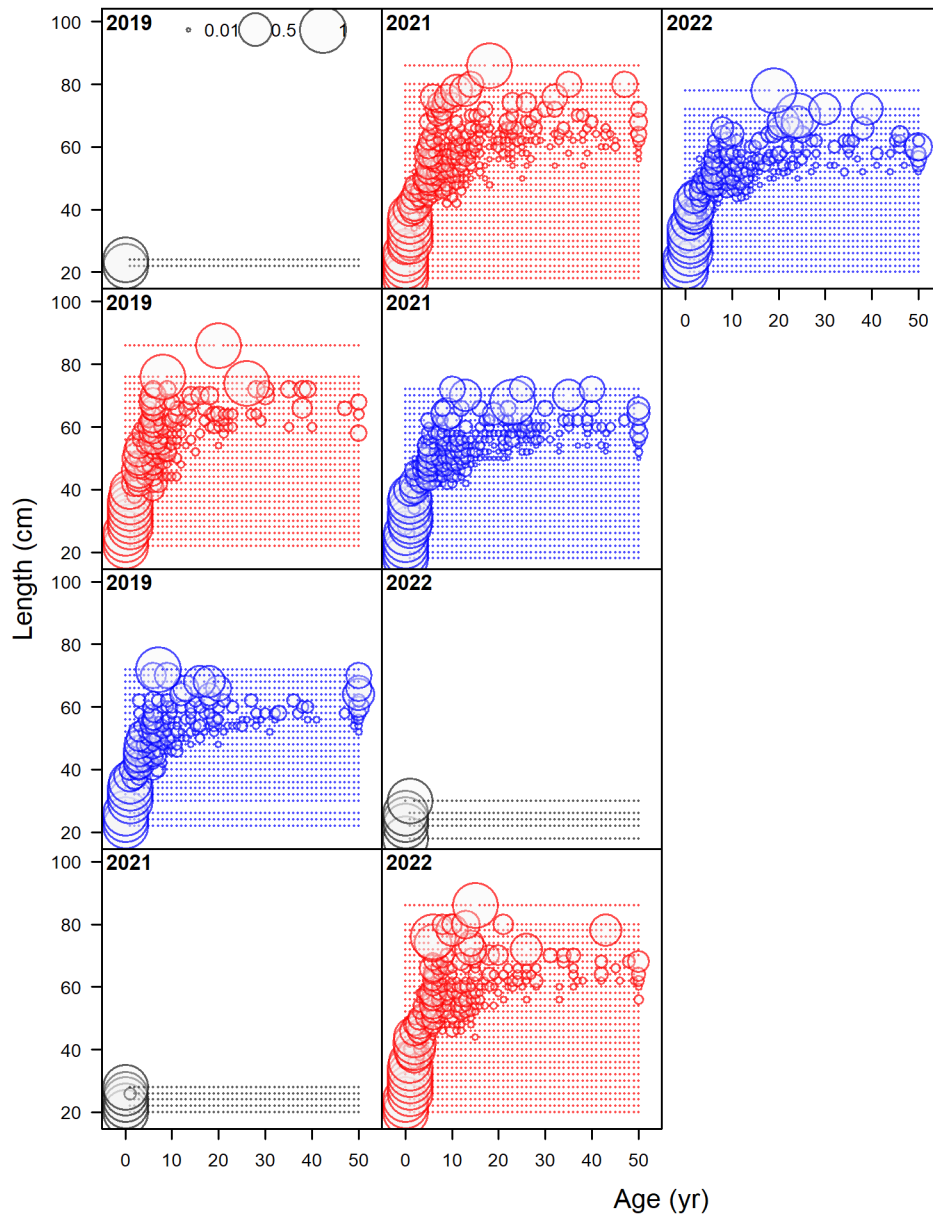


Figure 18: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCG BTS from the whole catch. Continued from Figure 17.

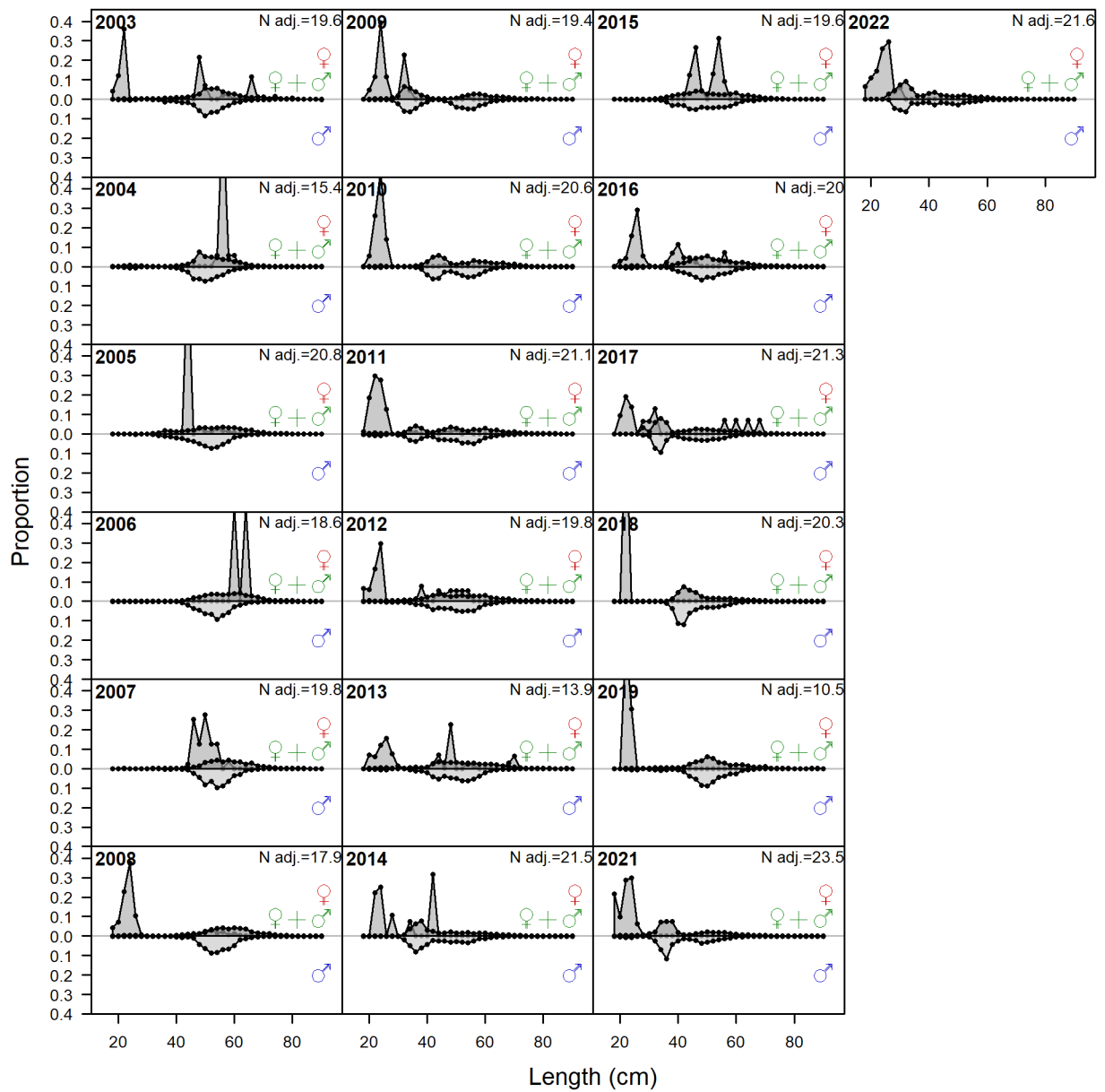


Figure 19: Annual length-composition data for the WCGBTS from the whole catch.

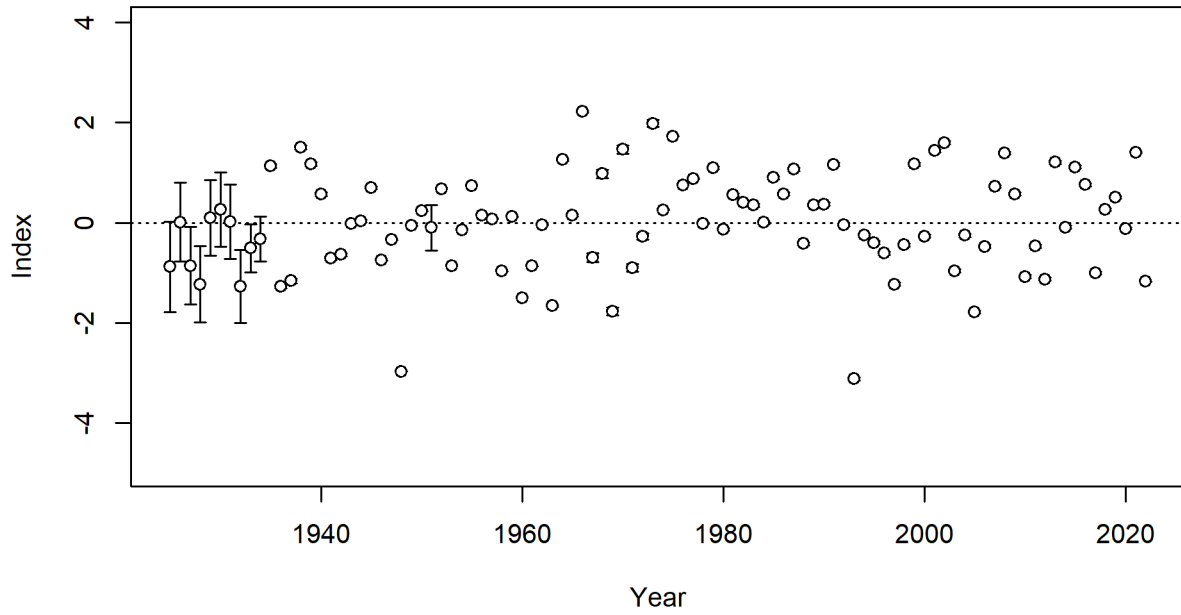


Figure 20: Annual relative index of abundance for the environmental index.

8.2 Model Results

8.2.1 Bridging

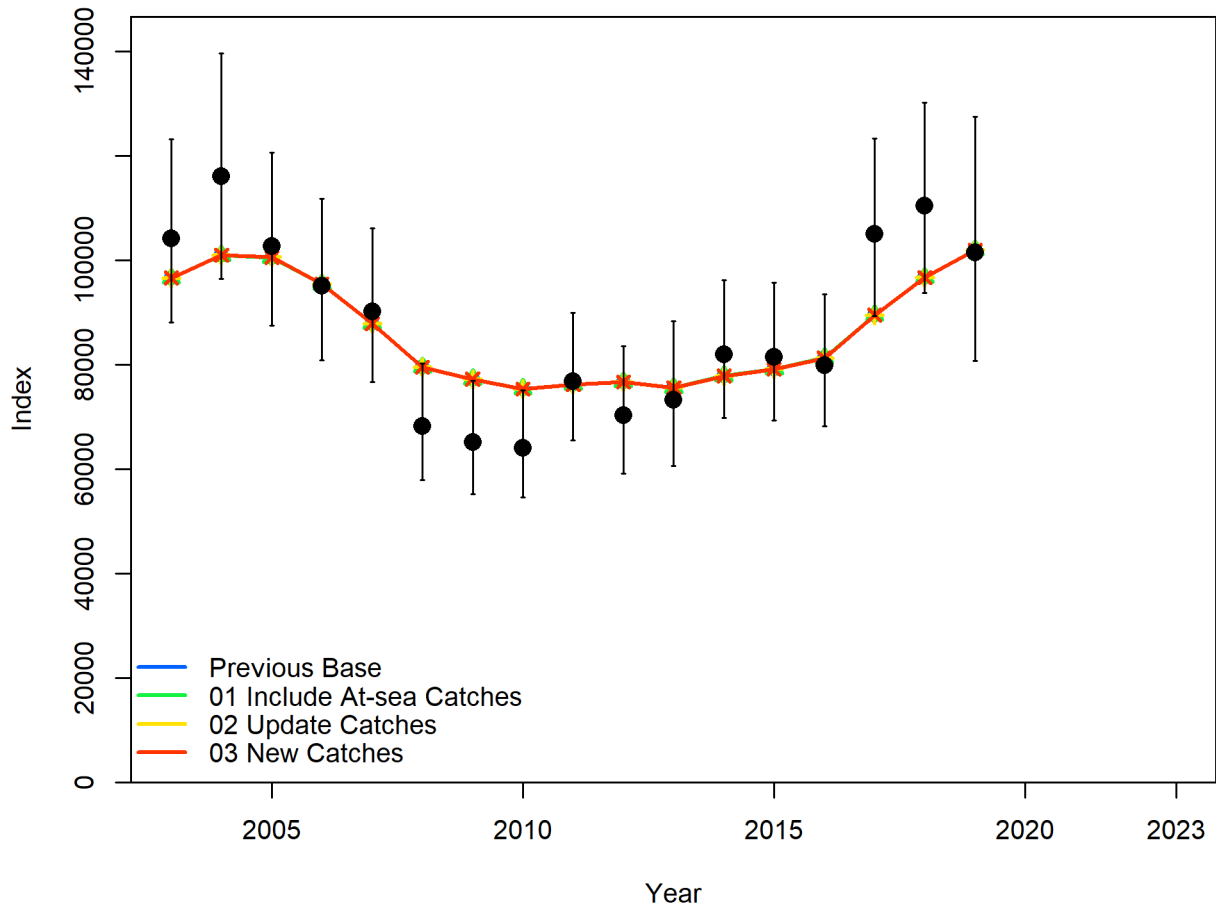


Figure 21: Recent survey across several steps towards creating the base model from the previous assessment model.



Figure 22: Spawning biomass across several steps towards creating the base model from the previous assessment model.

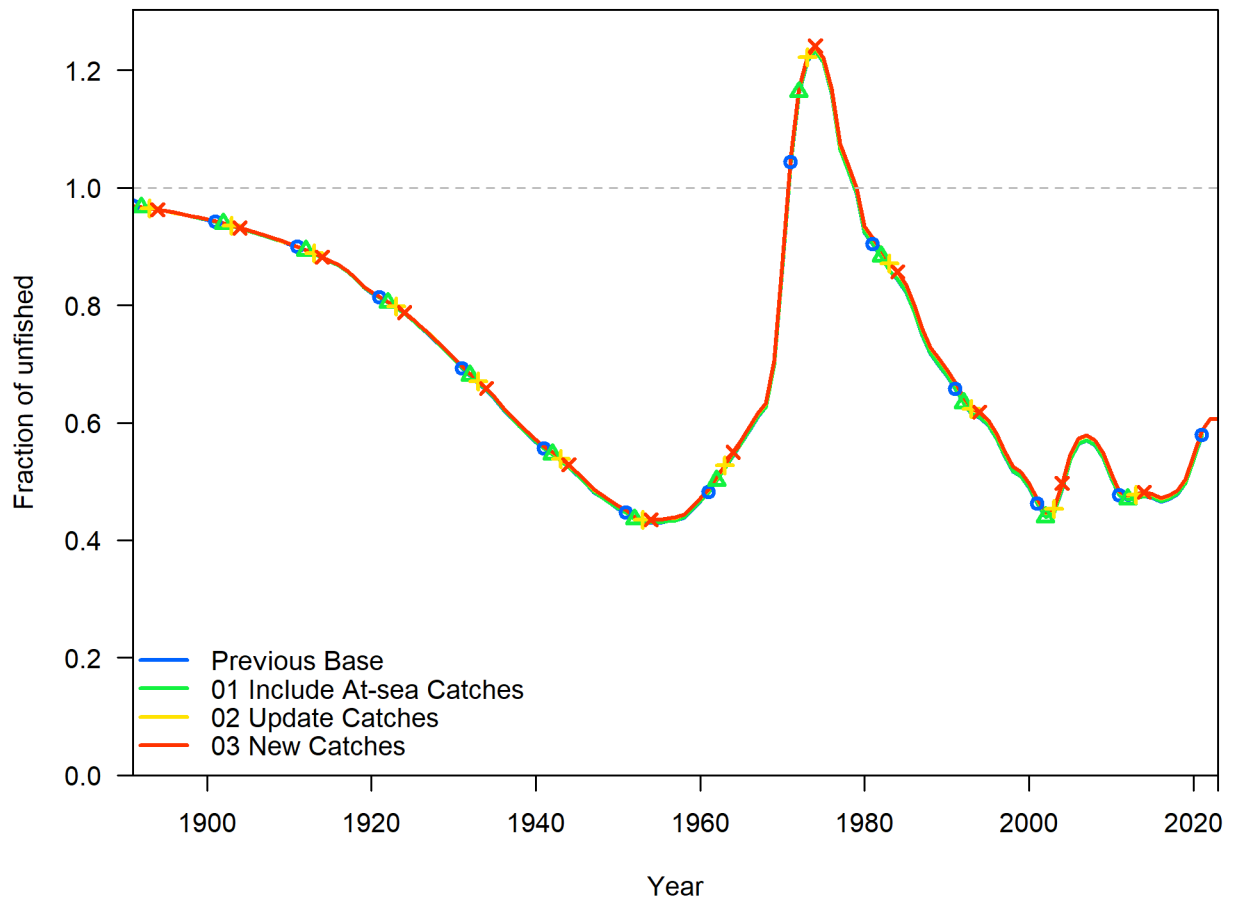


Figure 23: Fraction unfished across several steps towards creating the base model from the previous assessment model.

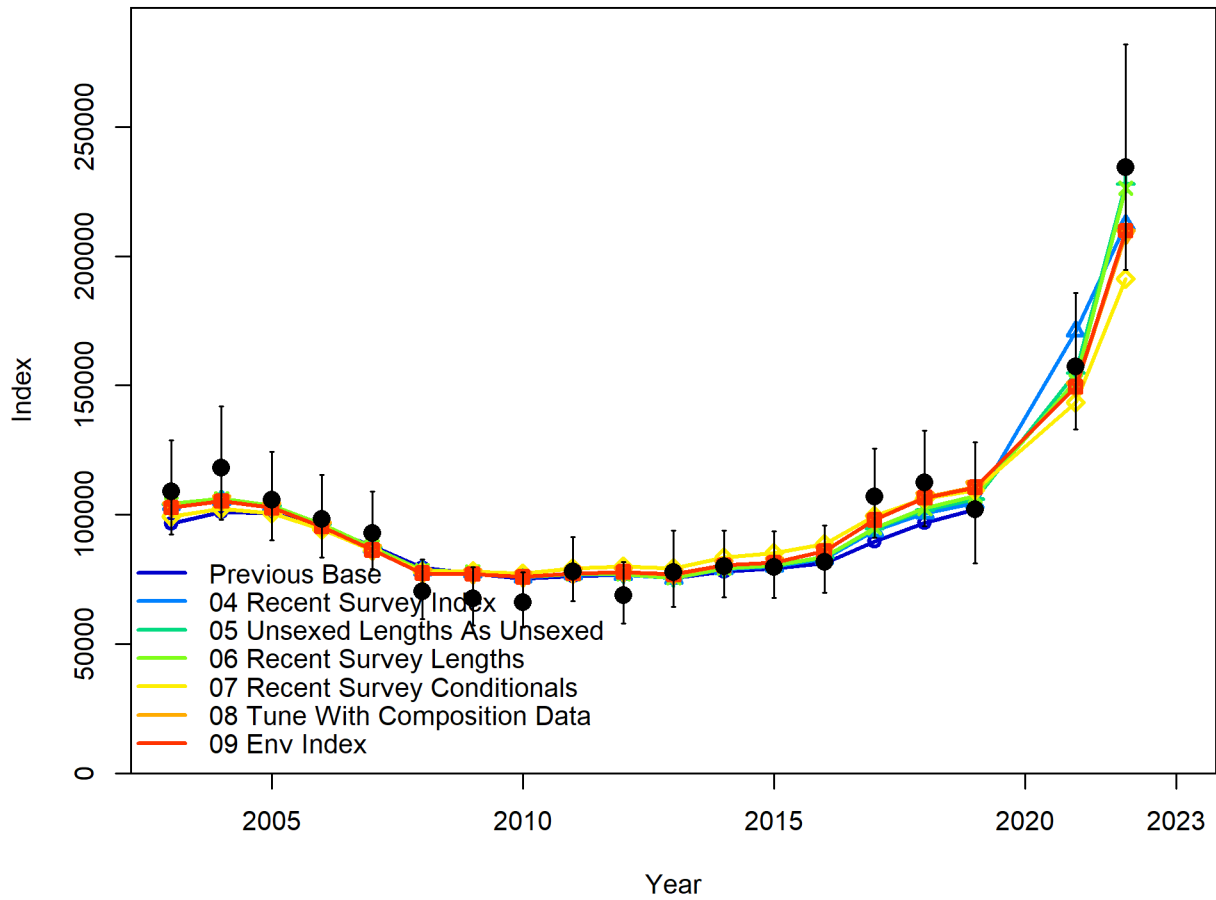


Figure 24: Recent survey across several steps towards creating the base model from the previous assessment model.

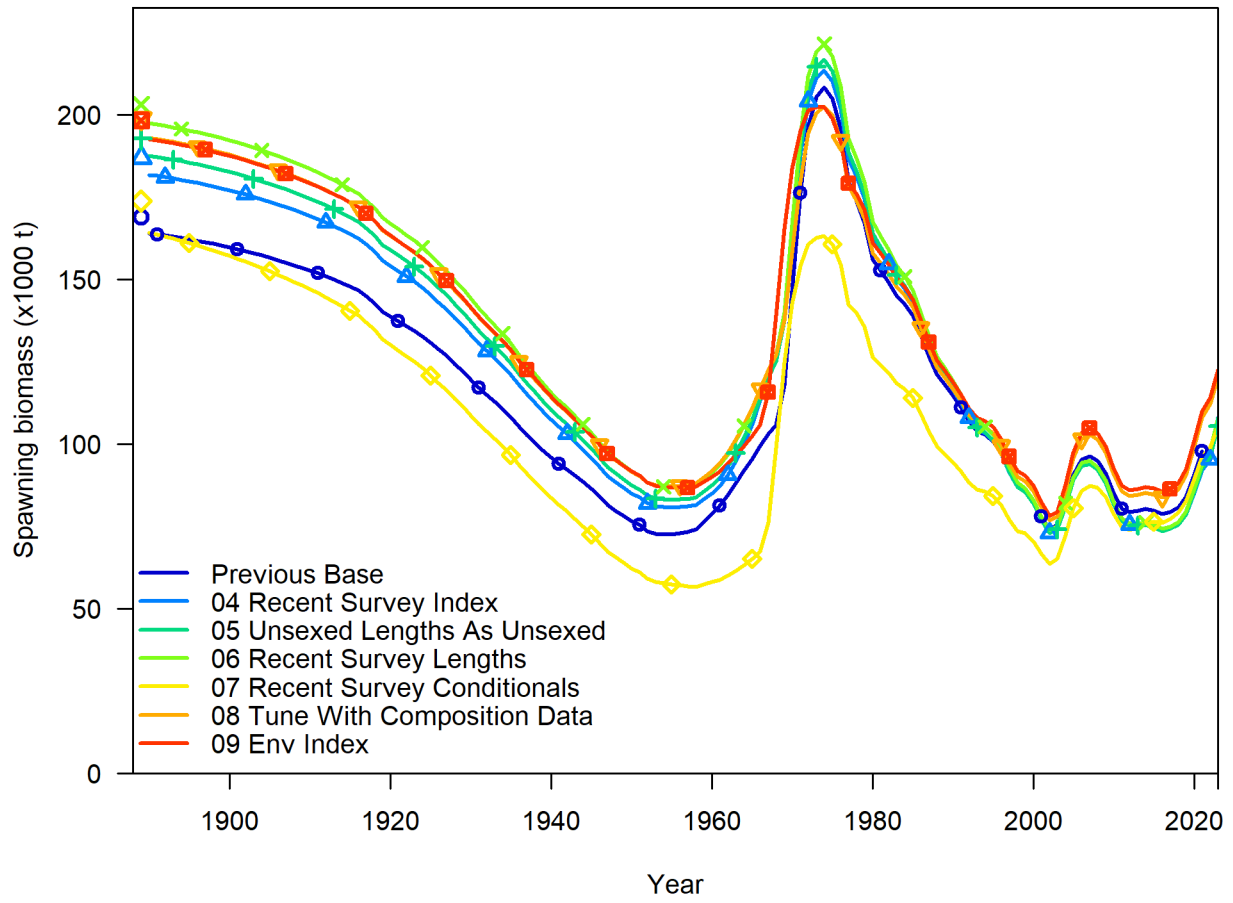


Figure 25: Spawning biomass across several steps towards creating the base model from the previous assessment model.

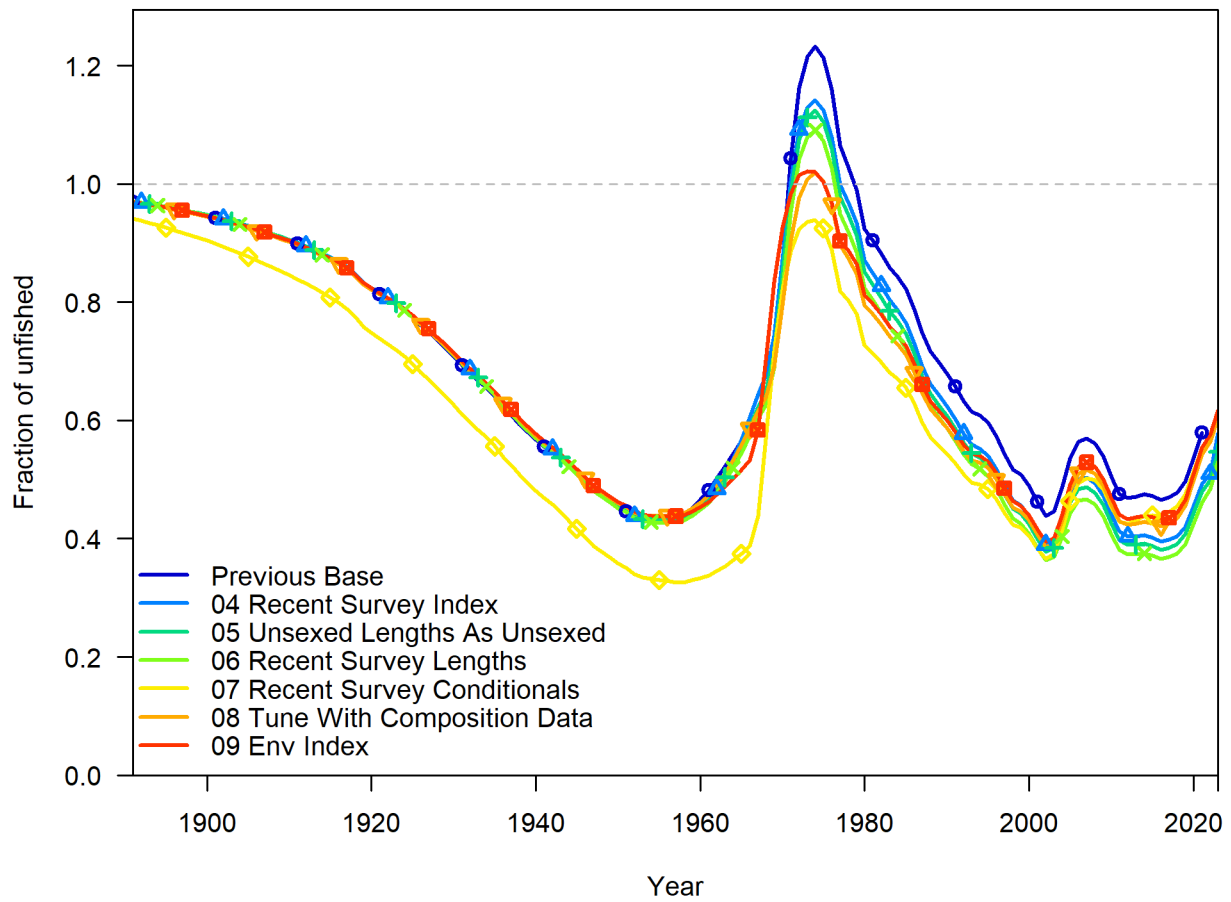


Figure 26: Fraction unfinished across several steps towards creating the base model from the previous assessment model.

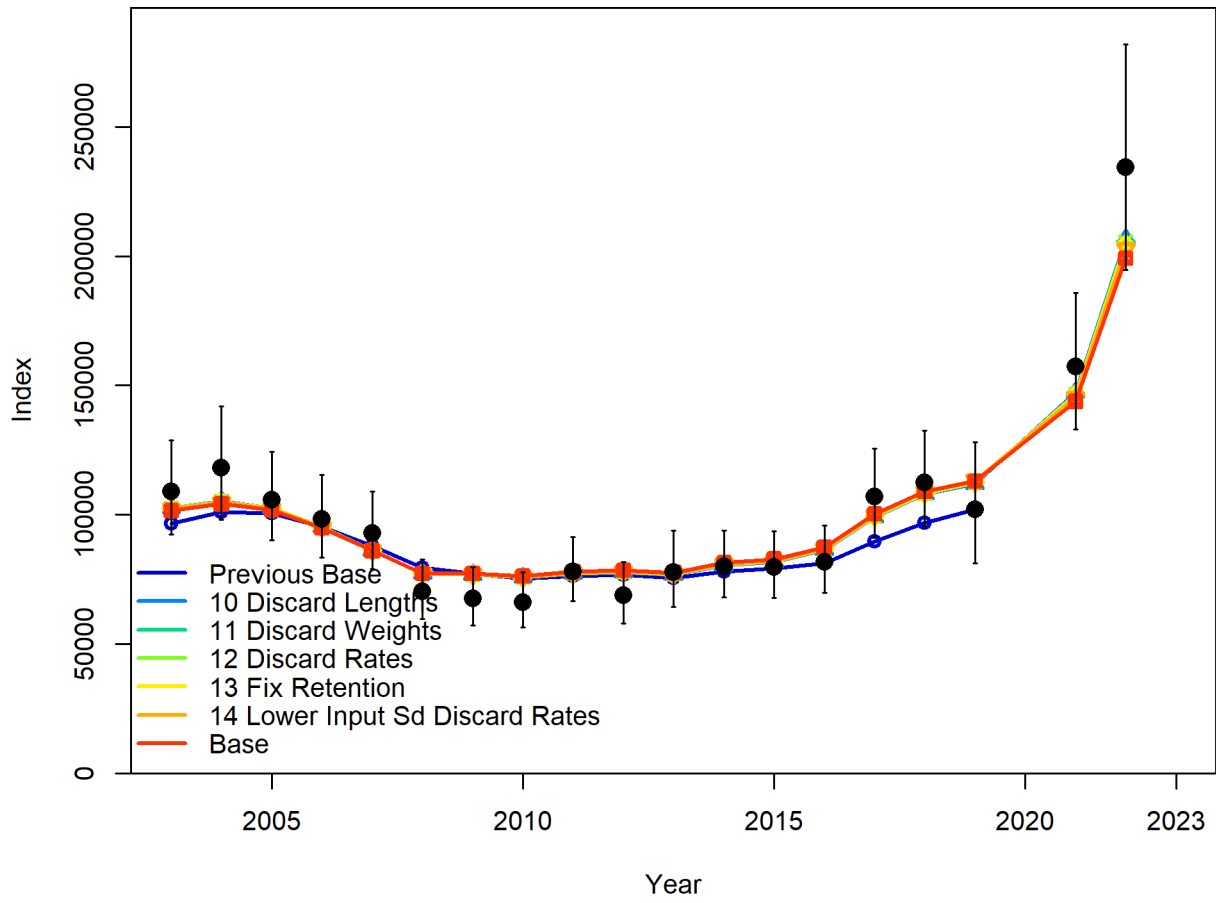


Figure 27: Recent survey across several steps towards creating the base model from the previous assessment model.

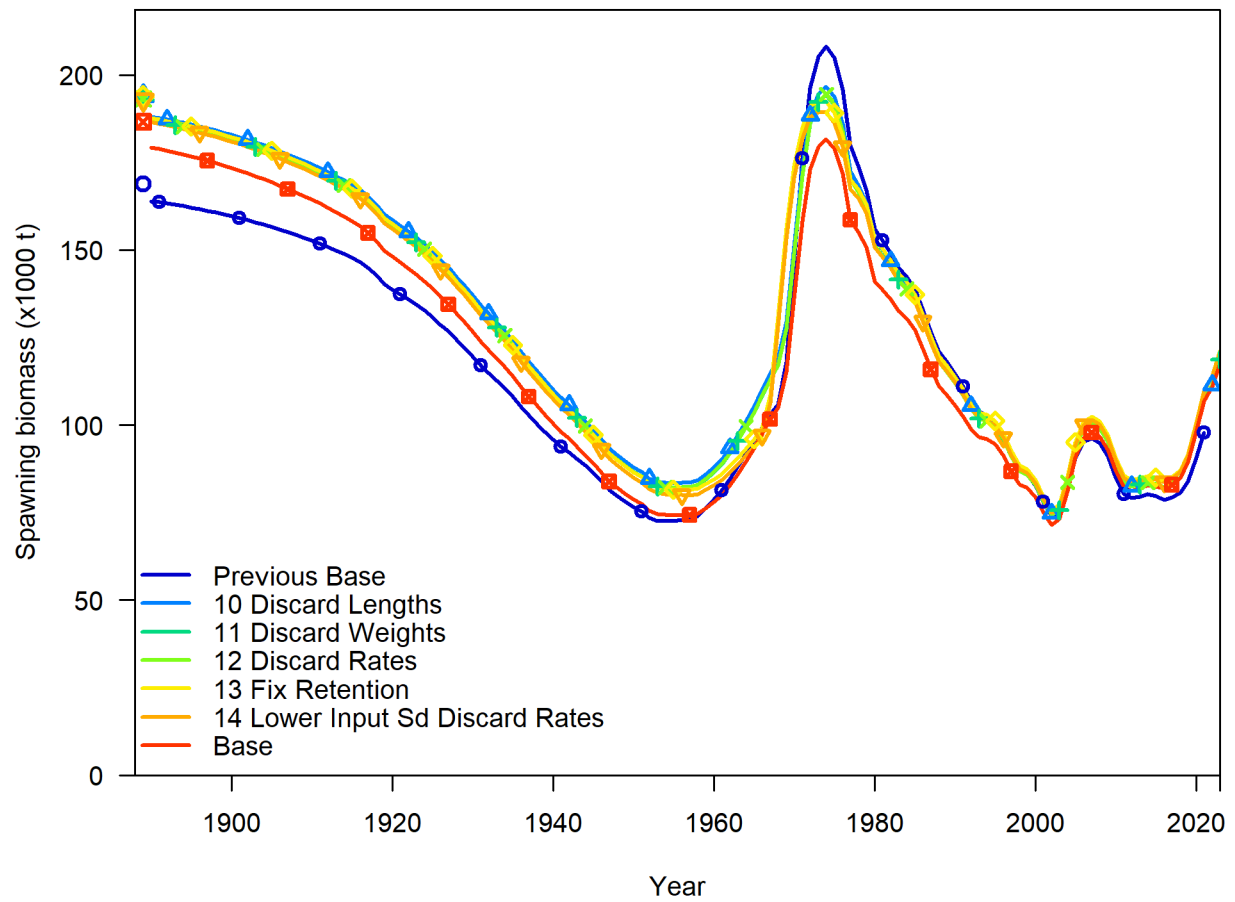


Figure 28: Spawning biomass across several steps towards creating the base model from the previous assessment model.

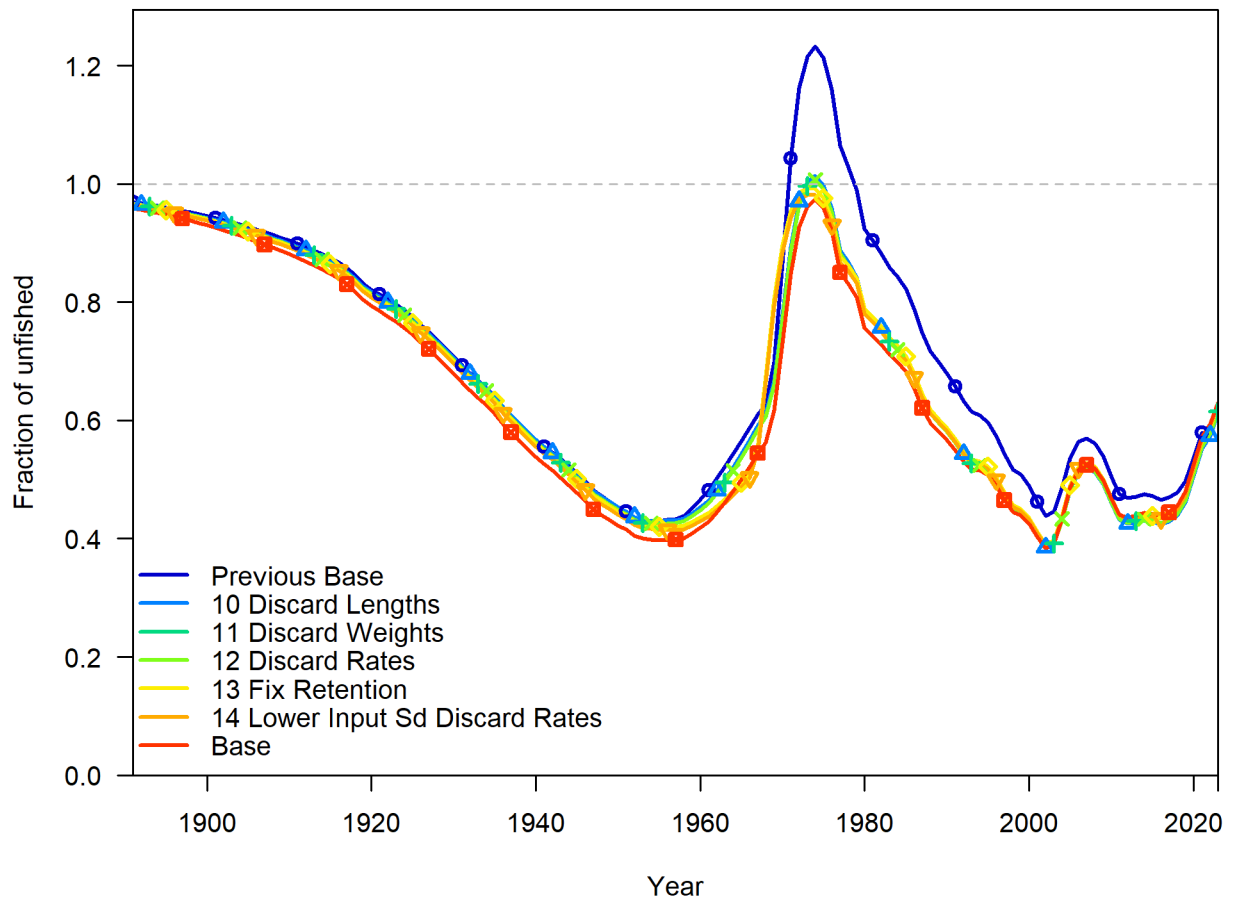


Figure 29: Fraction unfinished across several steps towards creating the base model from the previous assessment model.

8.2.2 Estimated Biology

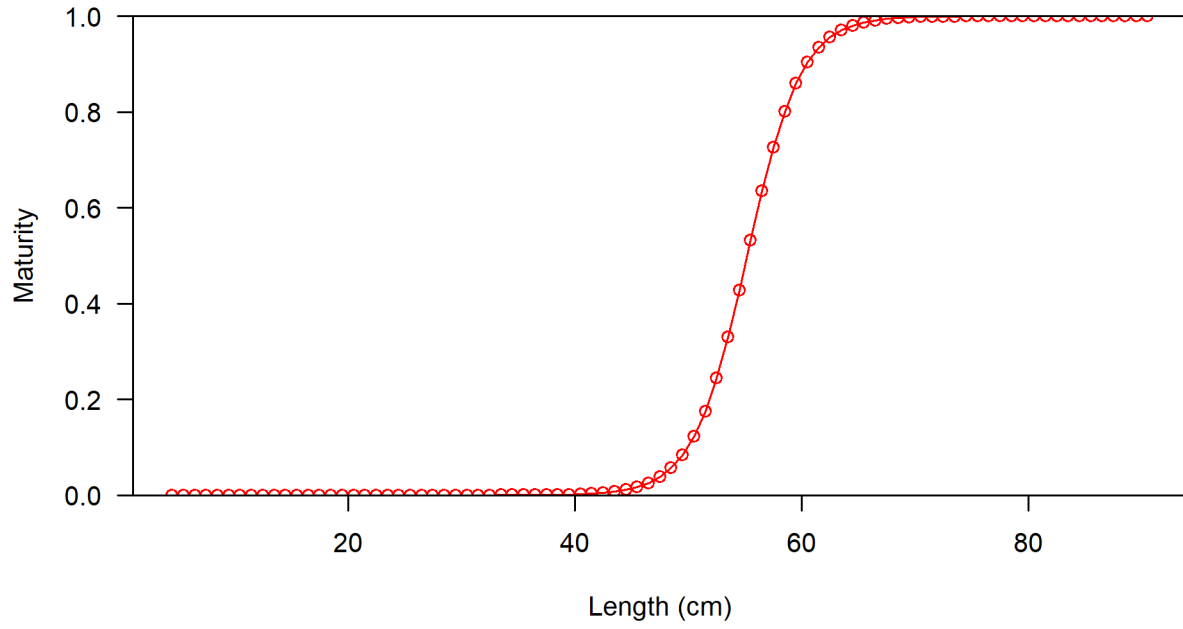


Figure 30: Maturity at length.

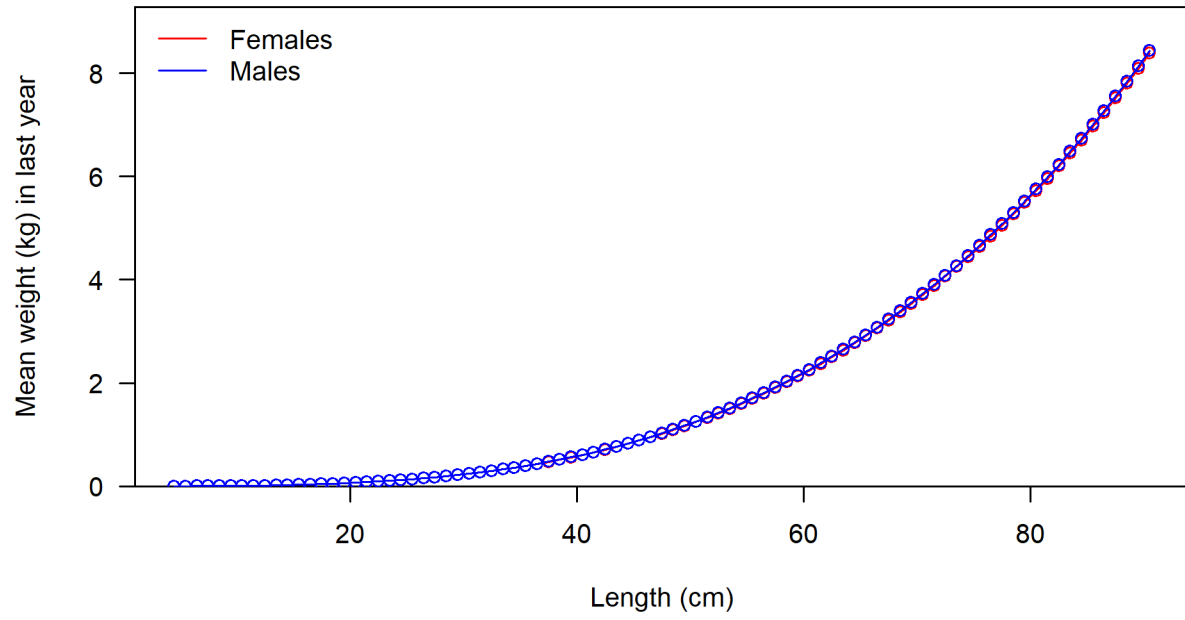


Figure 31: Weight-length relationship.

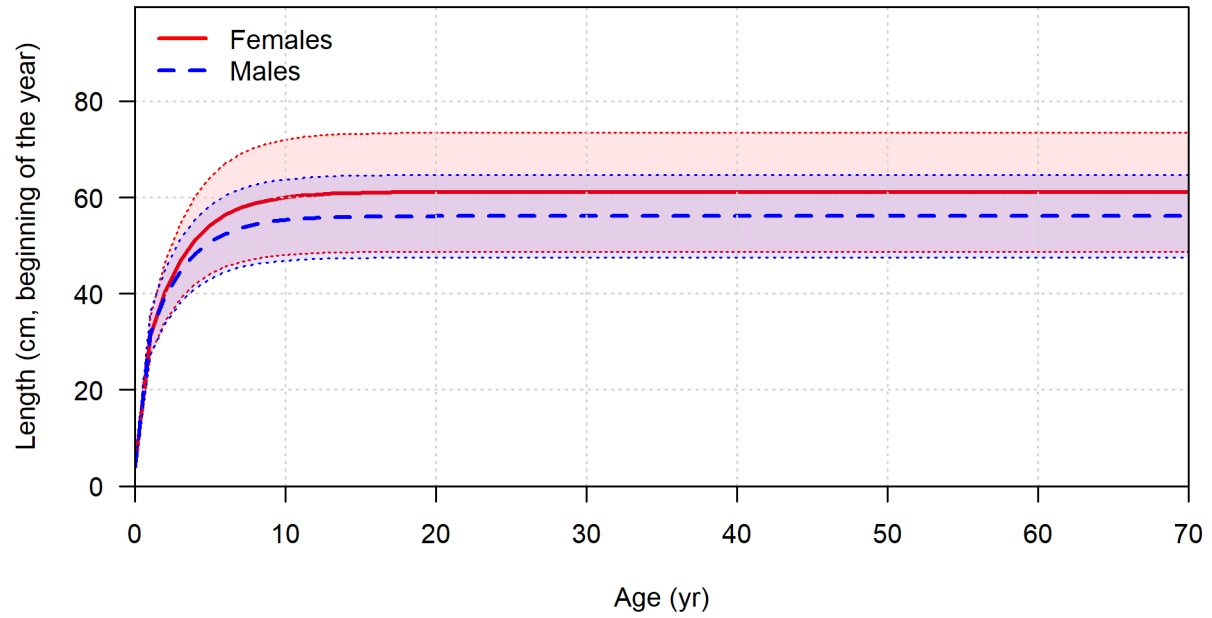


Figure 32: Length at age in the beginning of the year in the ending year of the model. Shaded area indicates 95% distribution of length at age around estimated growth curve.

8.2.3 Estimated Selectivity

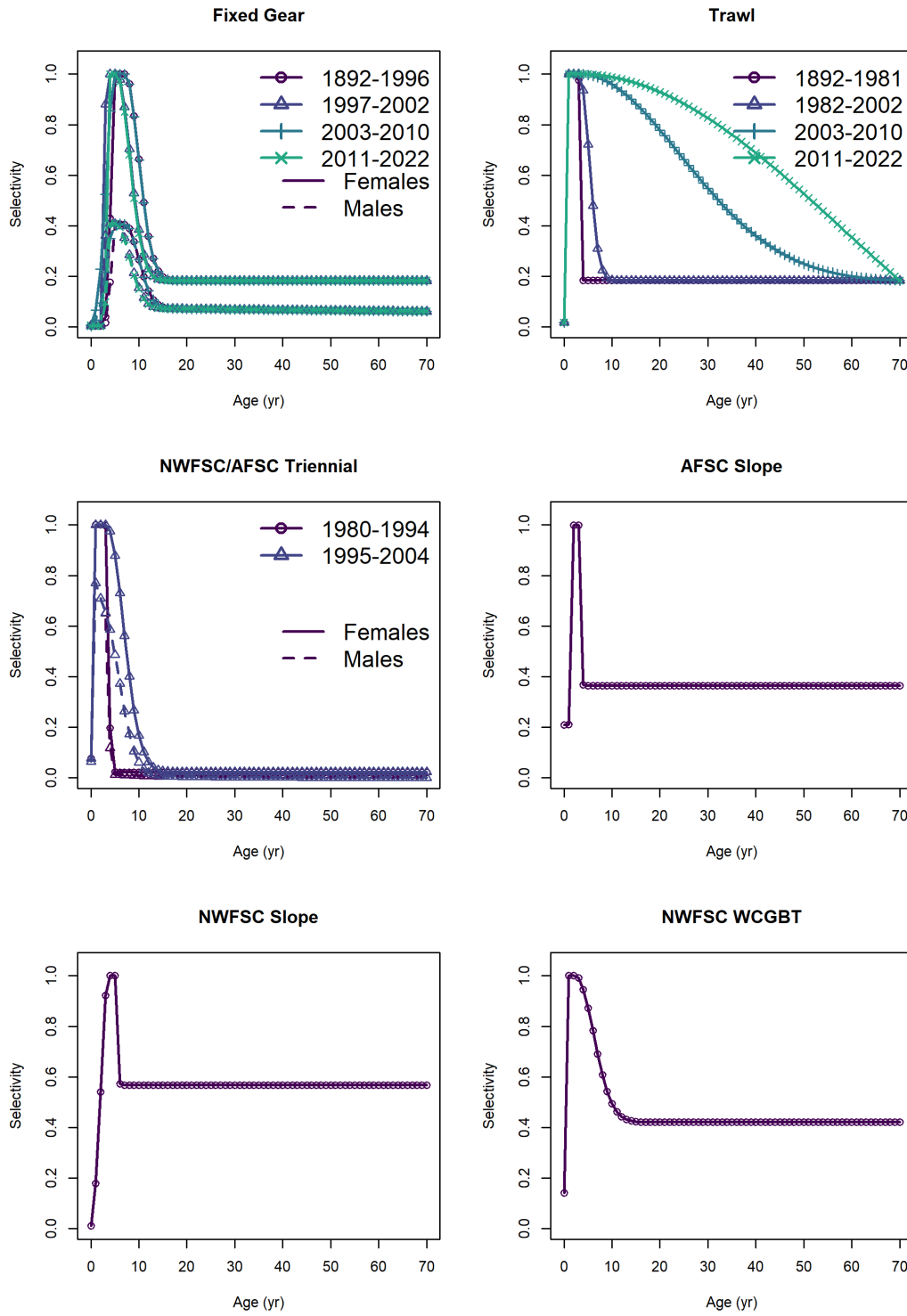


Figure 33: Fleet-specific estimated selectivity at age by time block. Solid lines are female-specific and dashed lines are male-specific selectivities.

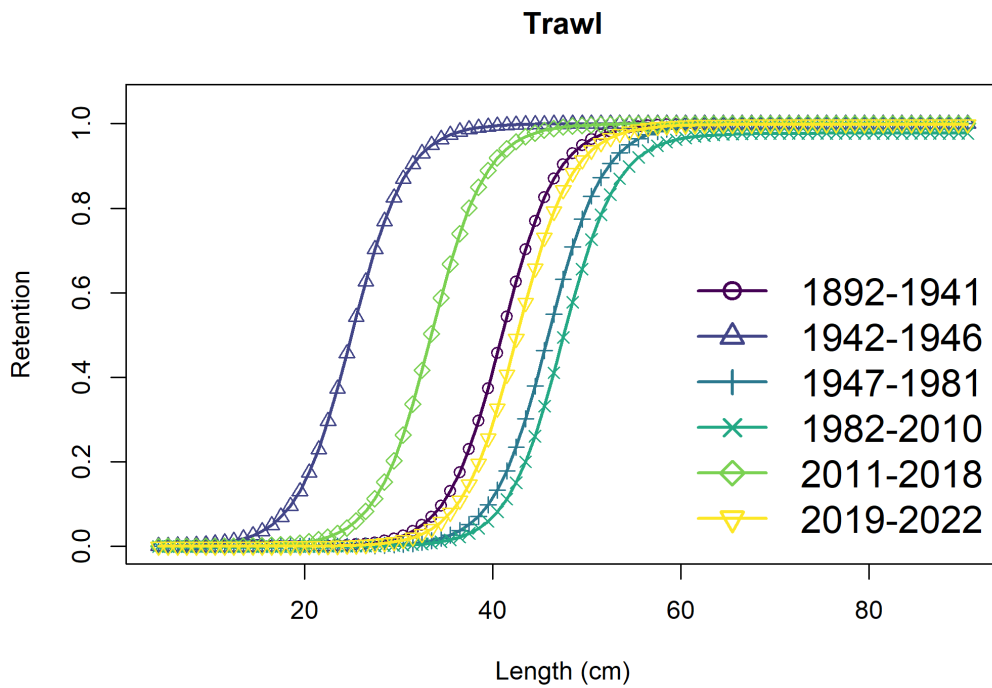
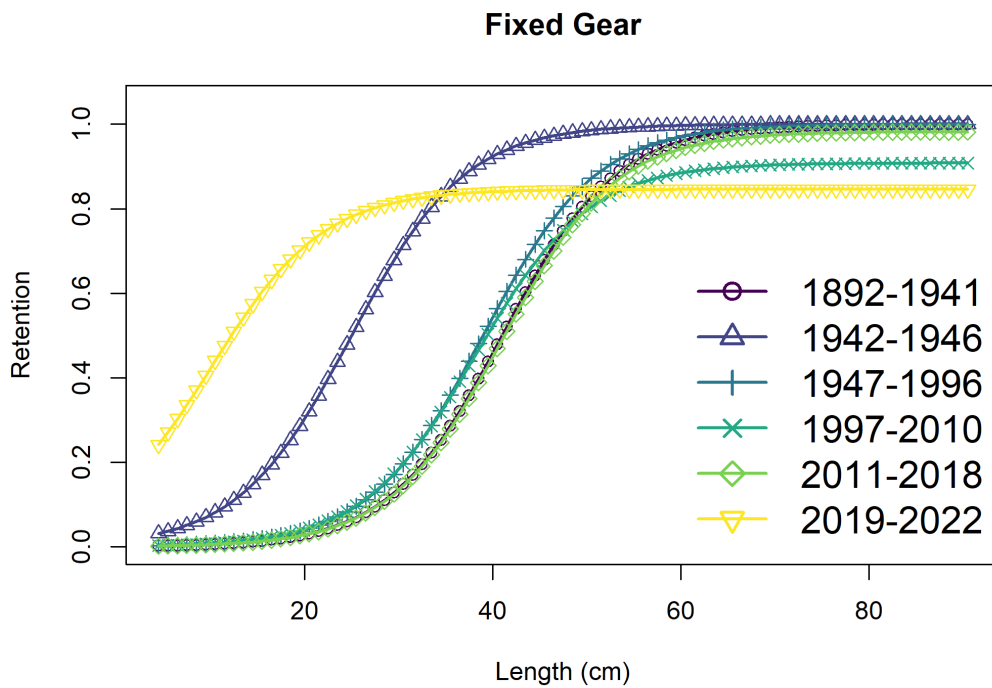


Figure 34: Fleet-specific estimated retention by time block.

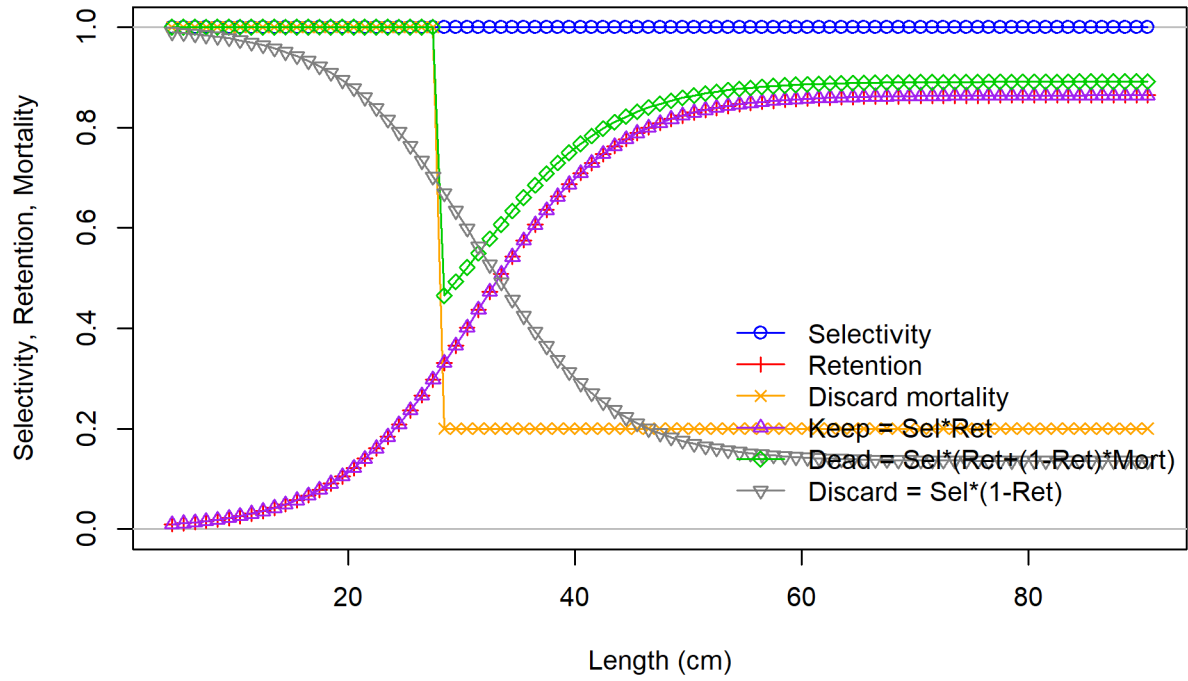


Figure 35: Estimated retention and discard mortality for females for the fixed-gear fleet.

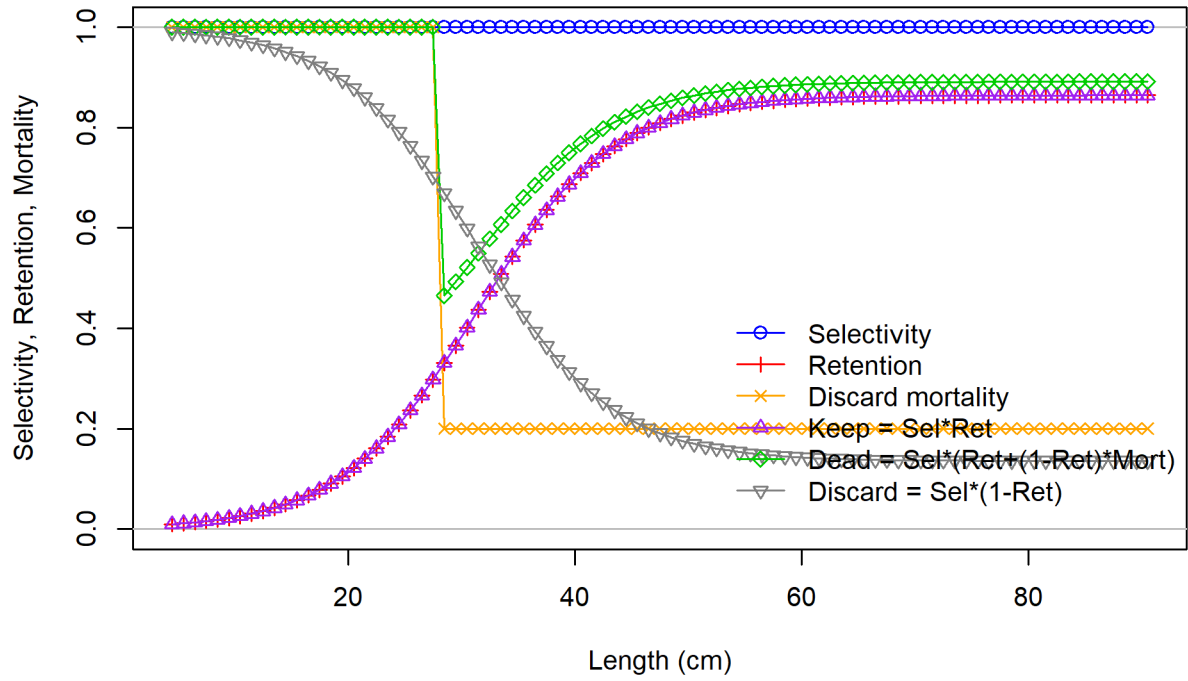


Figure 36: Estimated retention and discard mortality for males for the fixed-gear fleet.

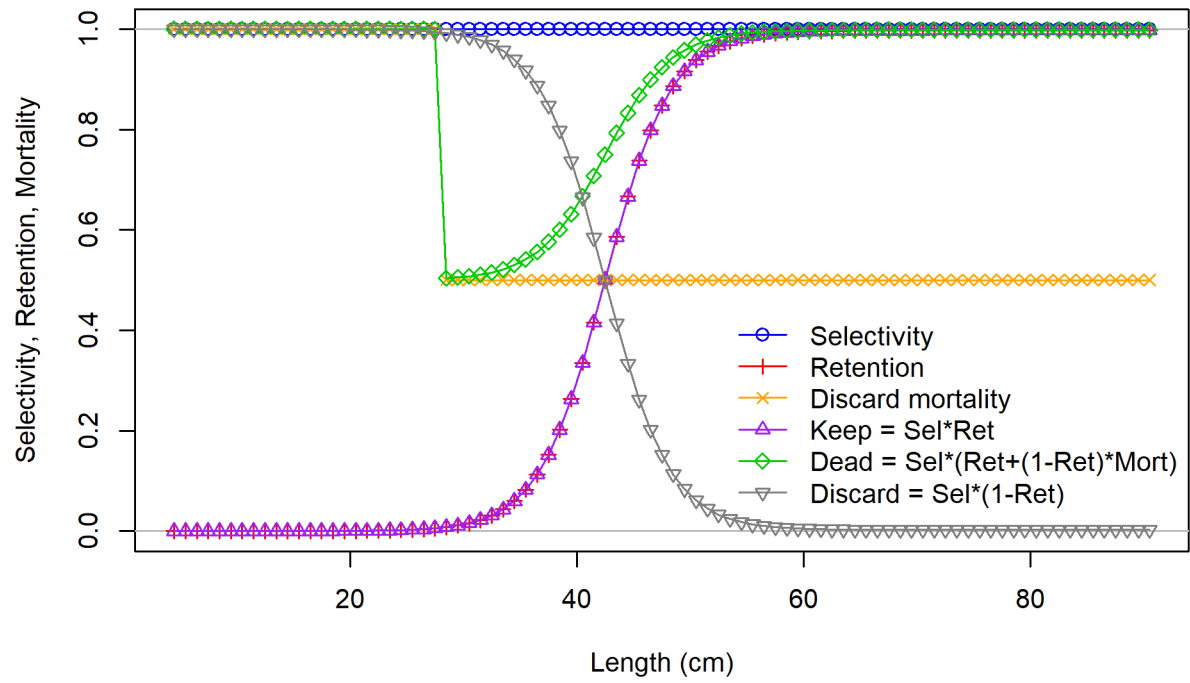


Figure 37: Estimated retention and discard mortality for females for the trawl fleet.

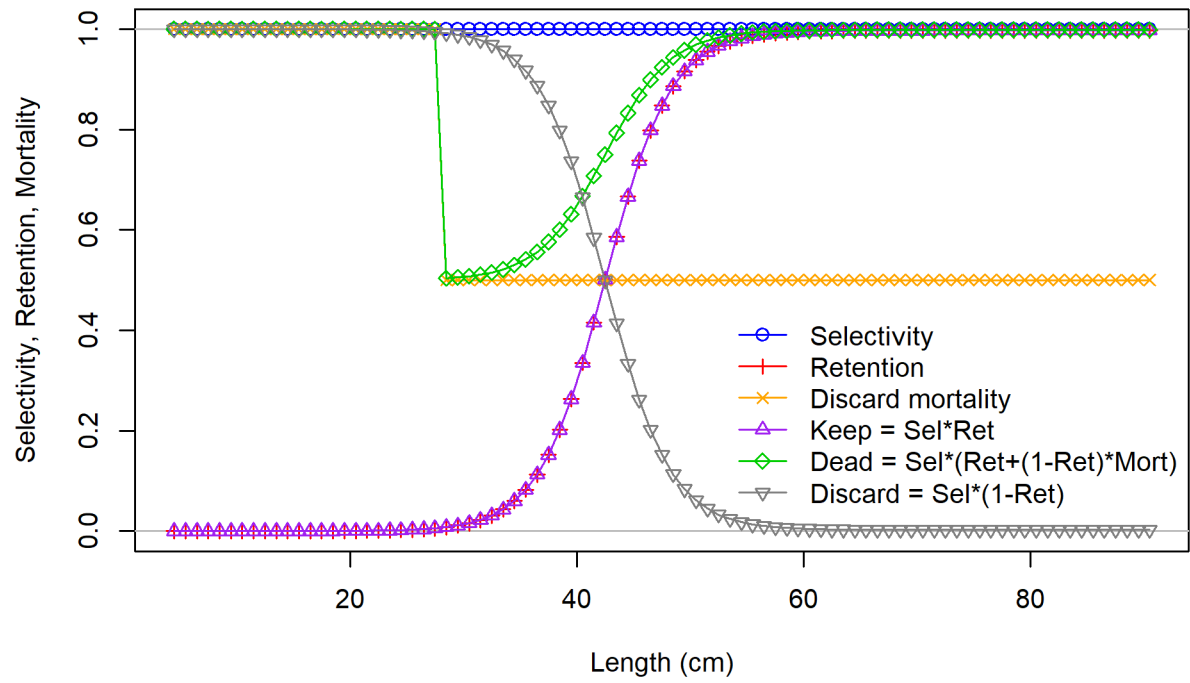


Figure 38: Estimated retention and discard mortality for males for the trawl fleet.

8.2.4 Estimated Recruitment

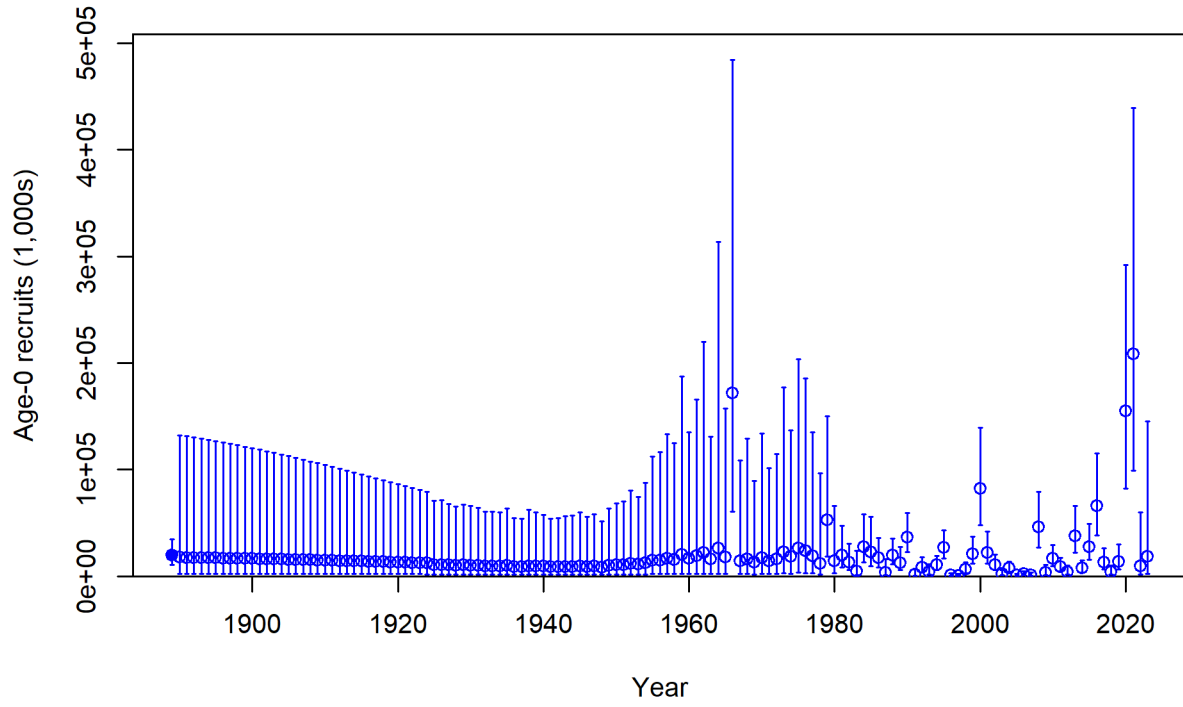


Figure 39: Estimated time series of age-0 recruits (1000s).

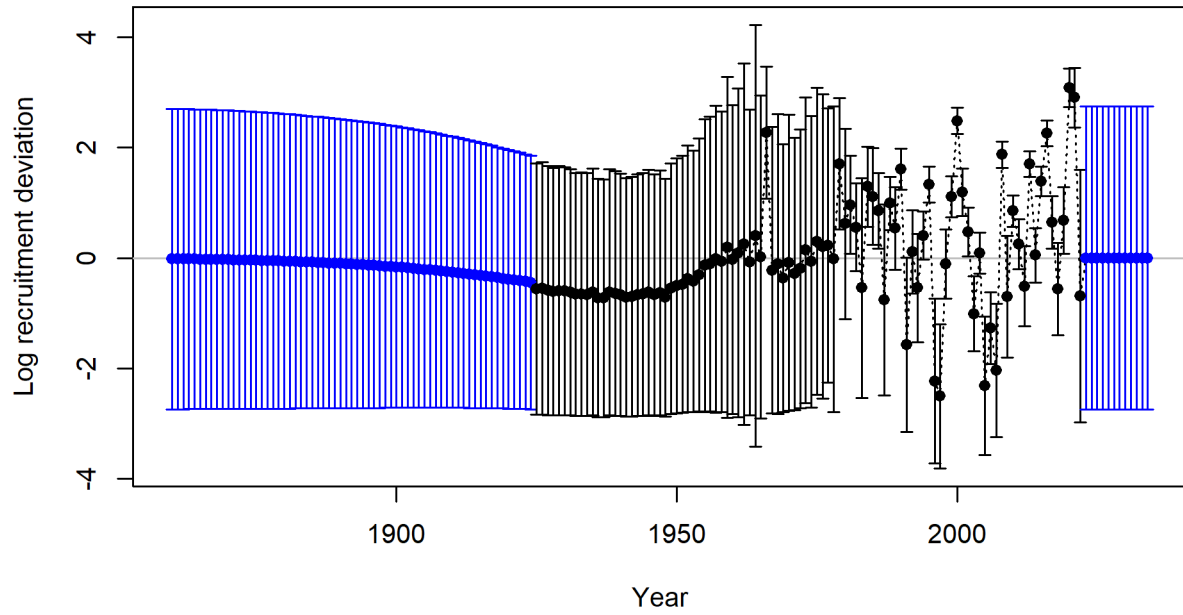


Figure 40: Estimated time series of recruitment deviations.

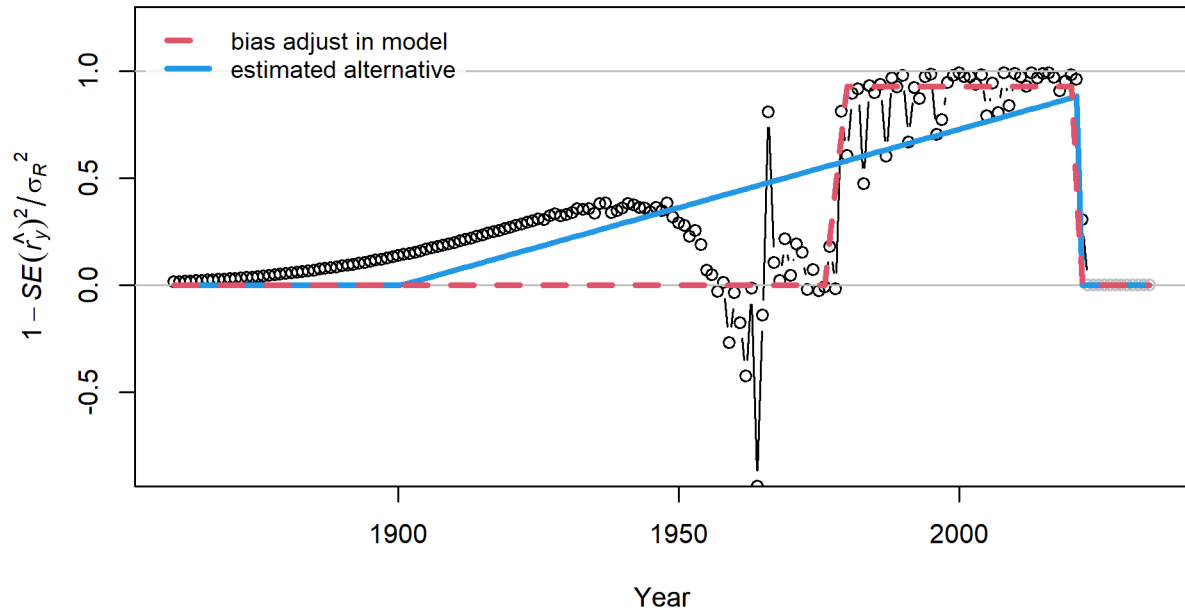


Figure 41: Points are transformed variances. Red line shows current settings for bias adjustment specified in the control file. Blue line shows least squares estimate of alternative bias adjustment relationship for recruitment deviations (which may or may not be an improvement).

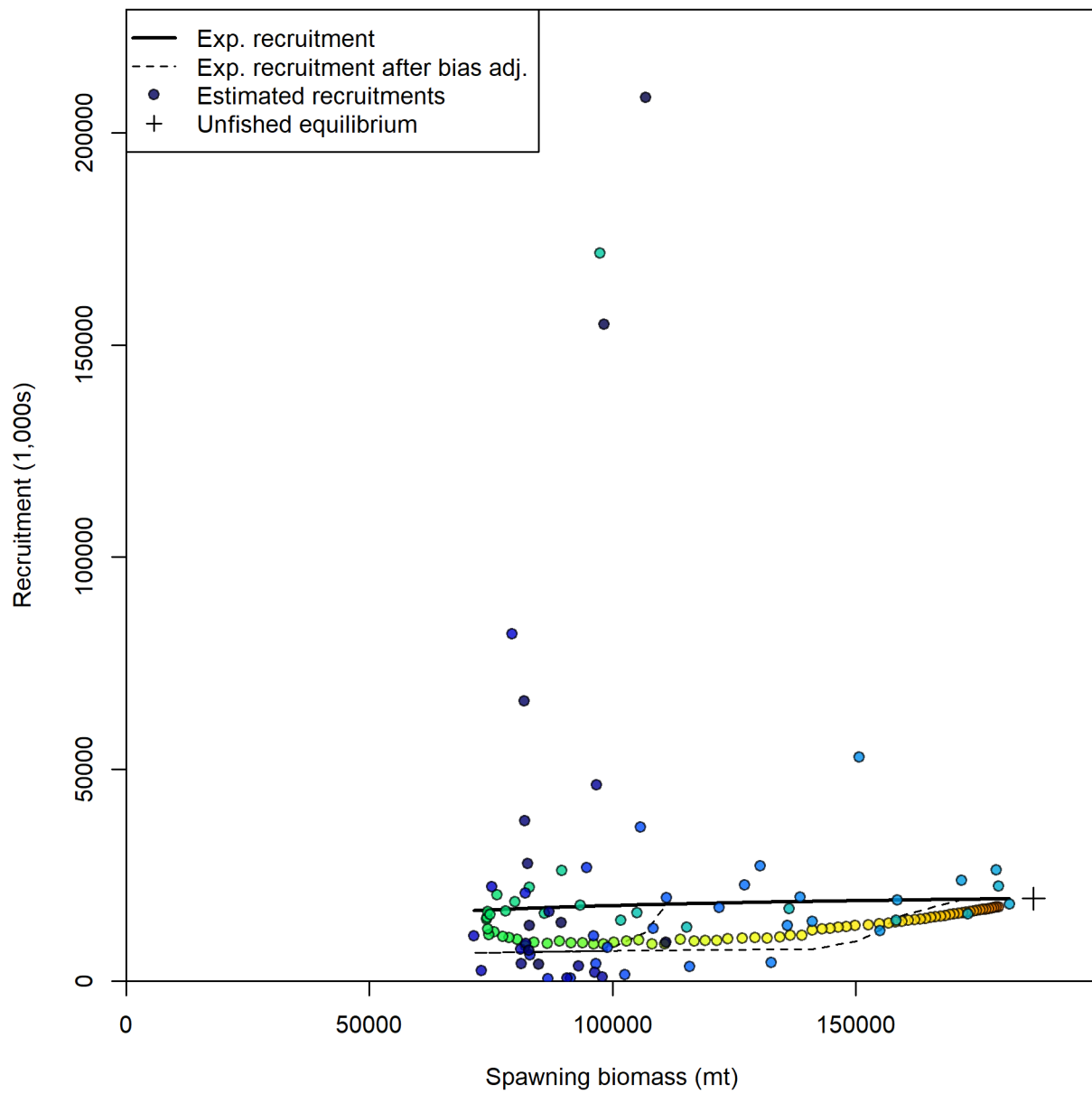


Figure 42: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in later years.

8.2.5 Estimated Time Series

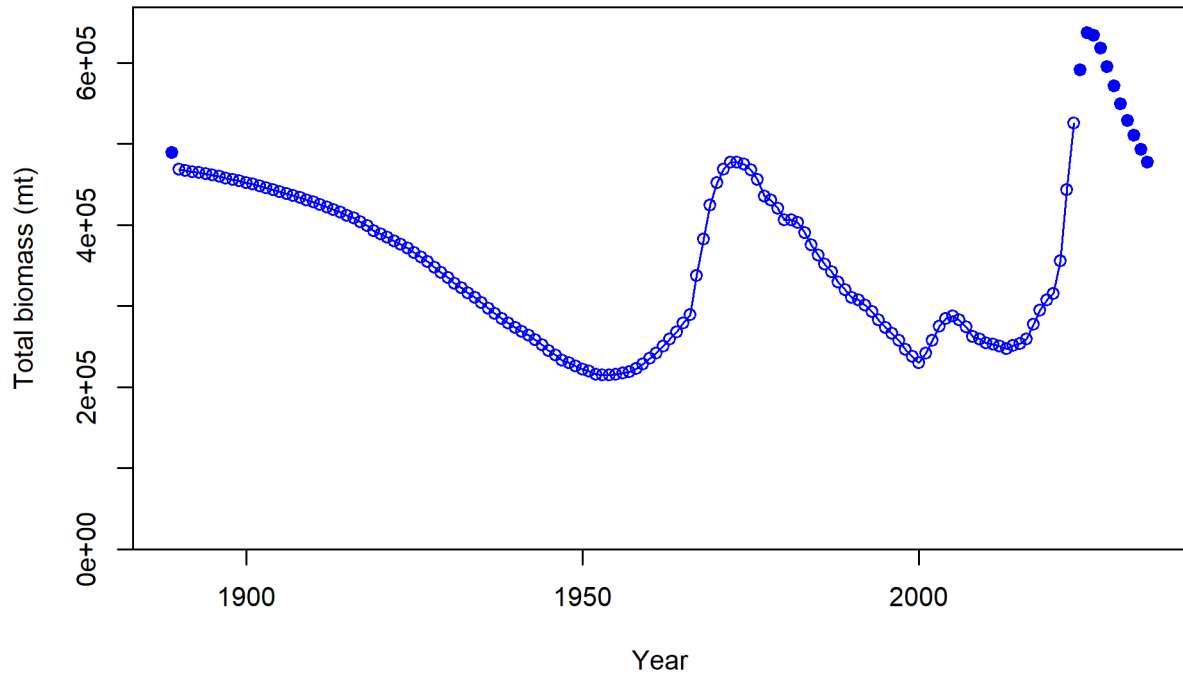


Figure 43: Estimated time series of total biomass.

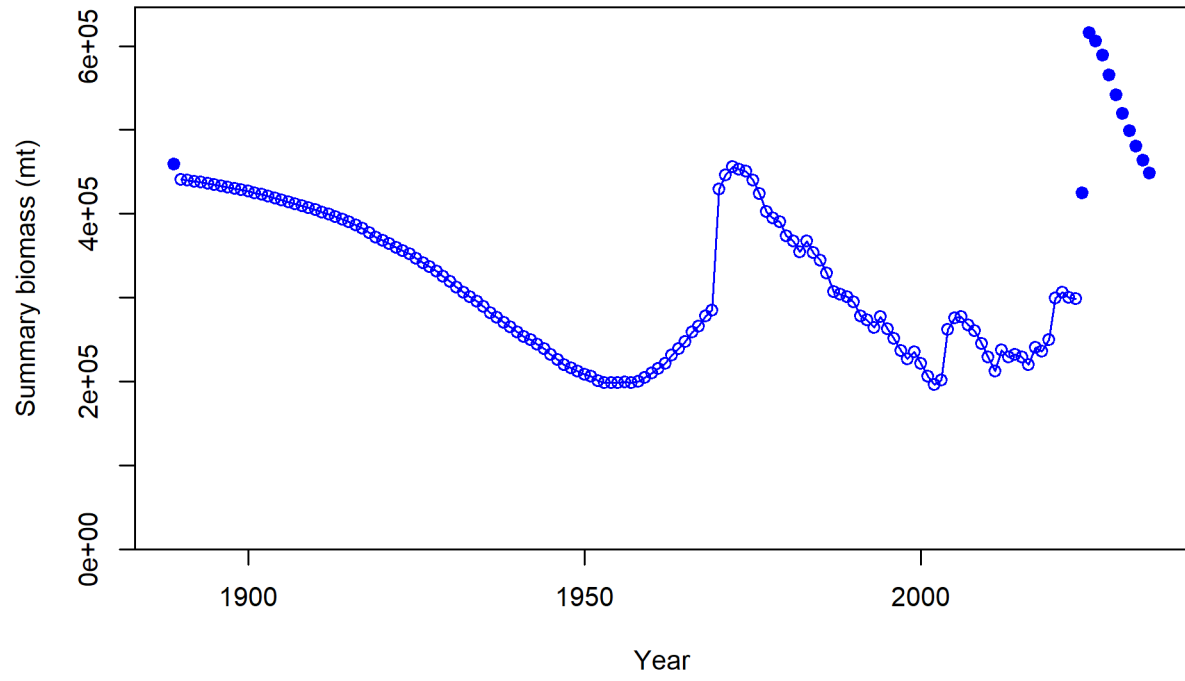


Figure 44: Estimated time series of summary biomass.

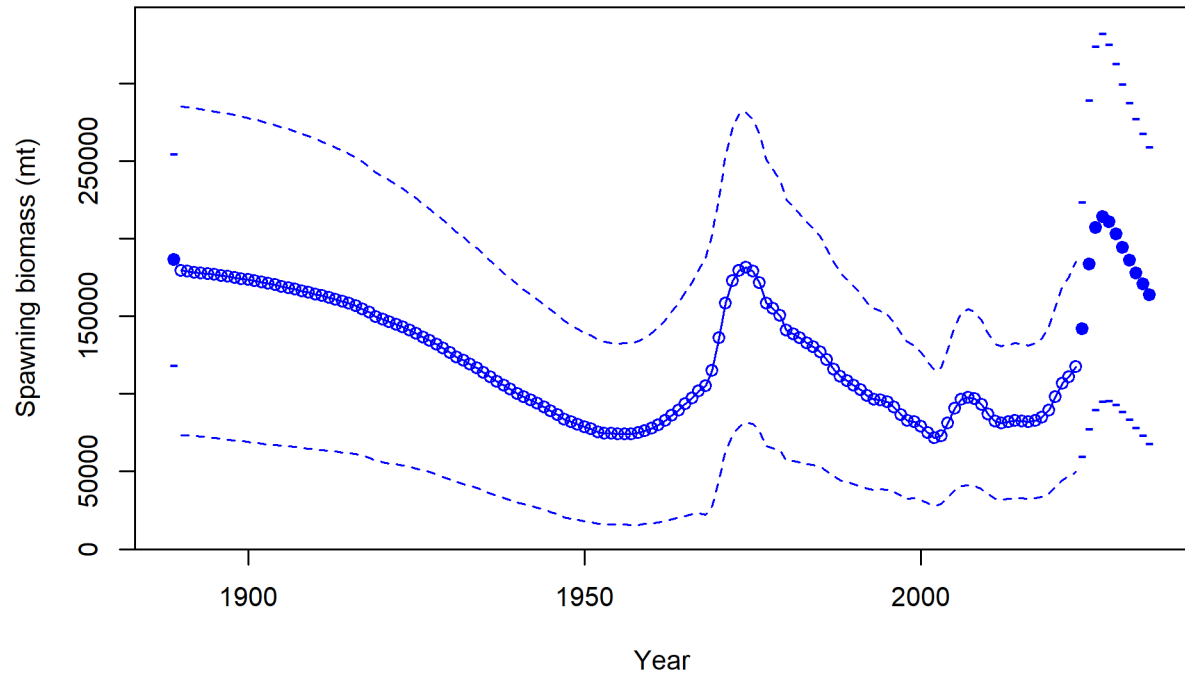


Figure 45: Estimated time series of spawning biomass (mt) with forecast with 95 asymptotic intervals forecast.

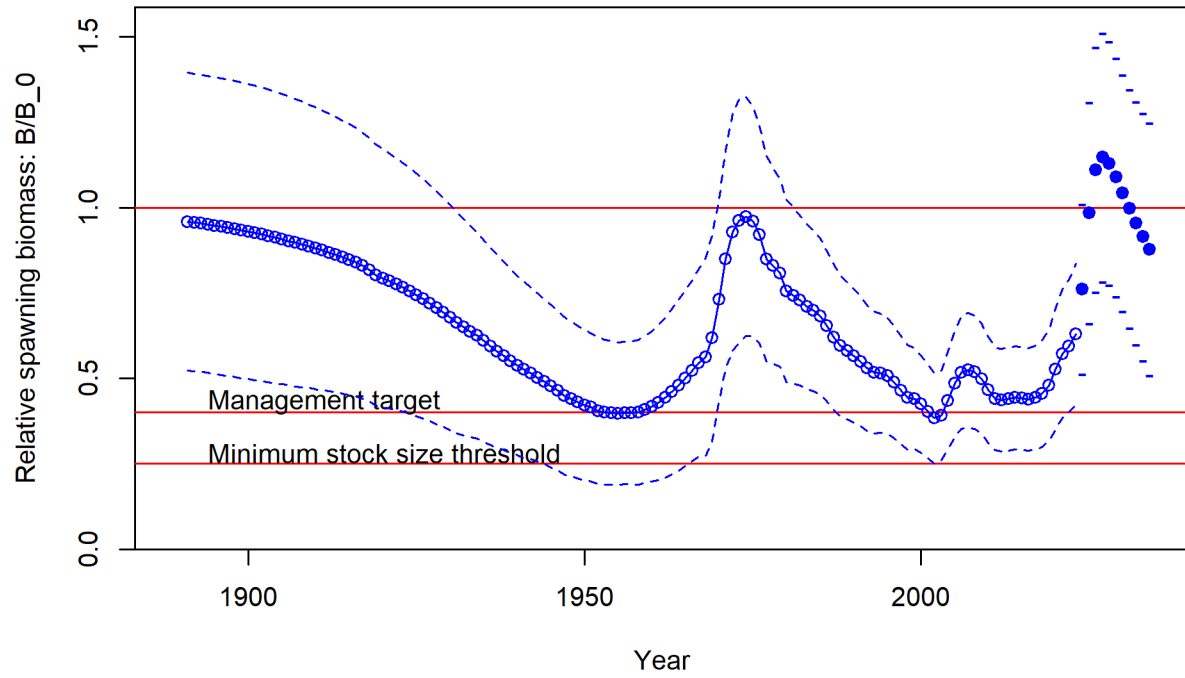


Figure 46: Estimated time series of relative spawning biomass forecast.

8.2.6 Fits to Data

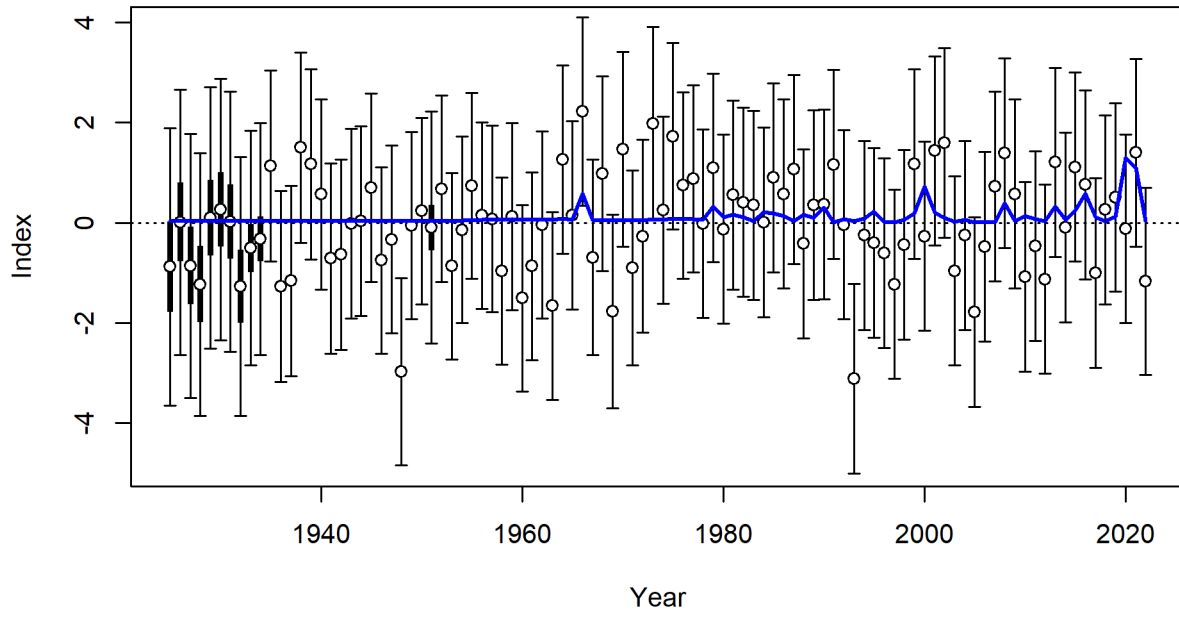


Figure 47: Fit to the environmental survey.

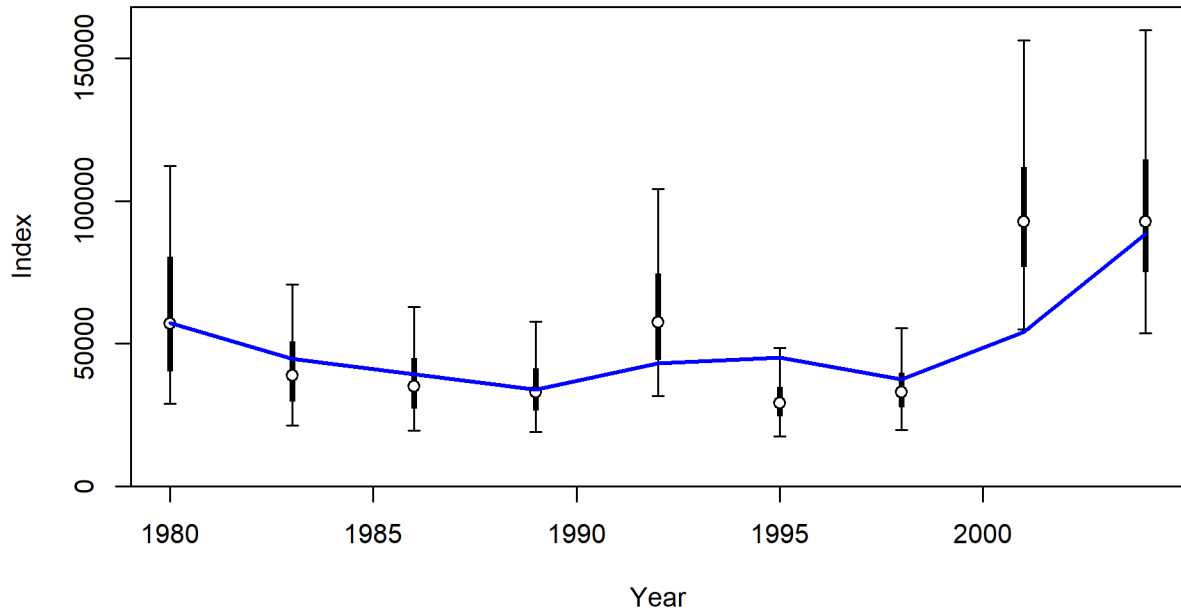


Figure 48: Fit to the Triennial Survey.

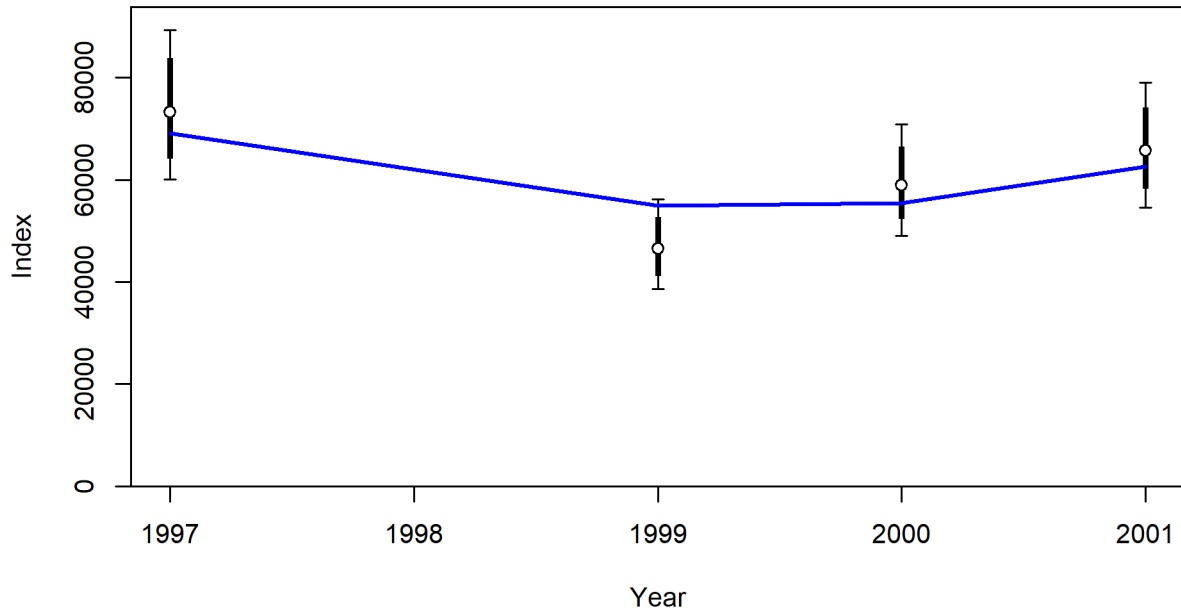


Figure 49: Fit to the Slope Survey.

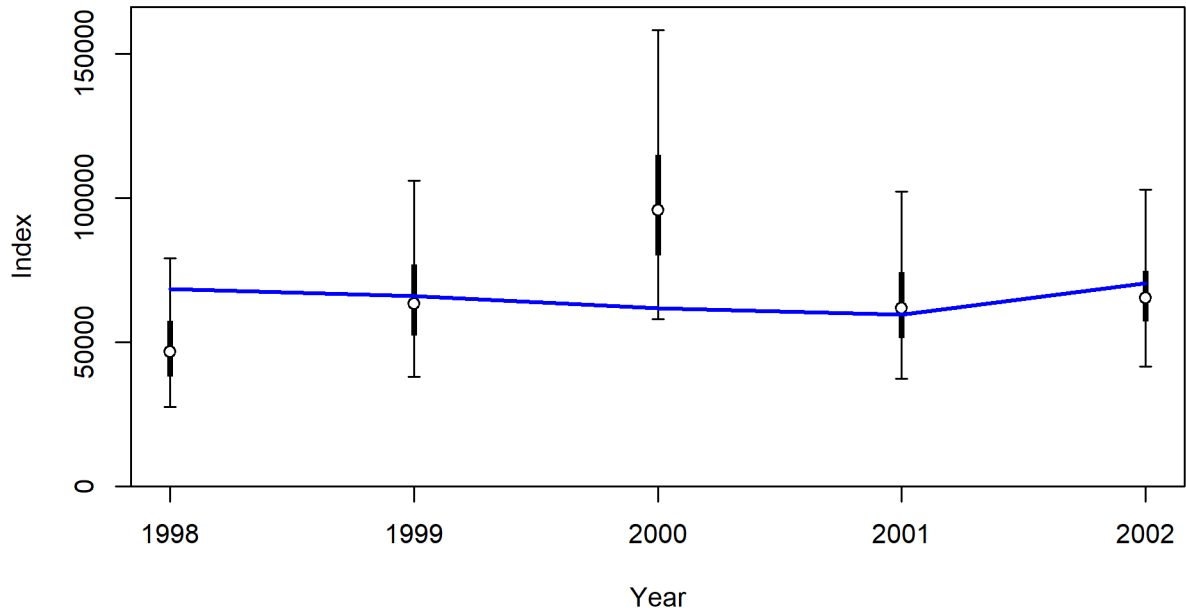


Figure 50: Fit to the NWFSC Slope Survey.

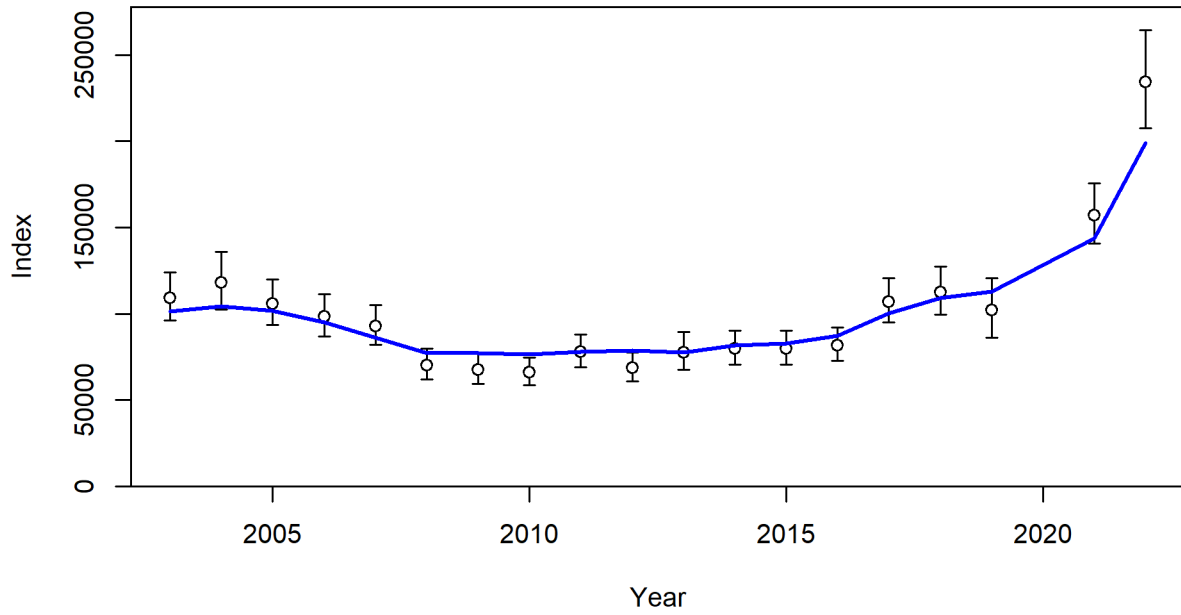


Figure 51: Fit to the WCGBTS.

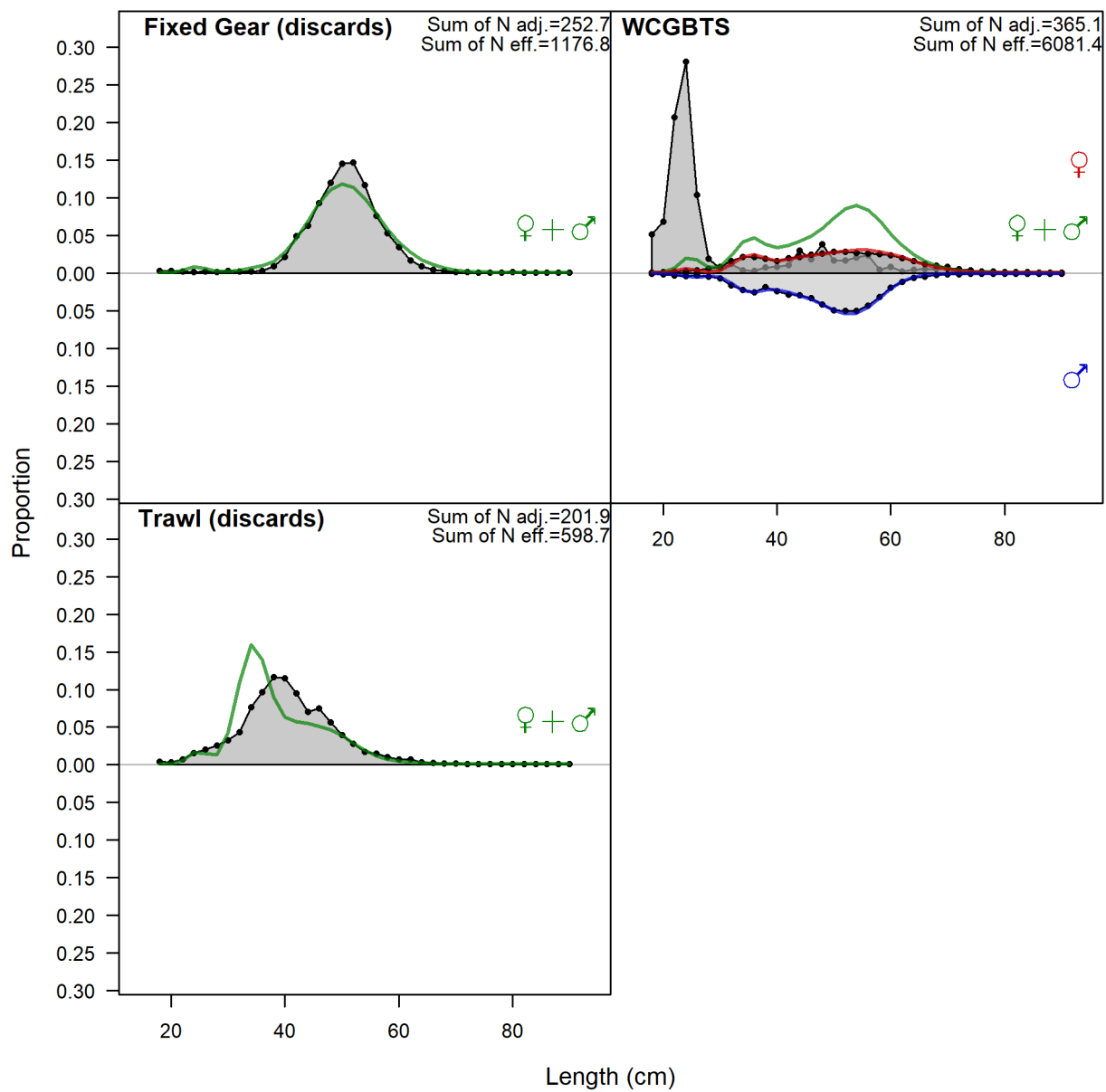


Figure 52: Length composition aggregated across years by fleet with the model estimated fit to the data by sex (green unsexed, red female, and blue male).

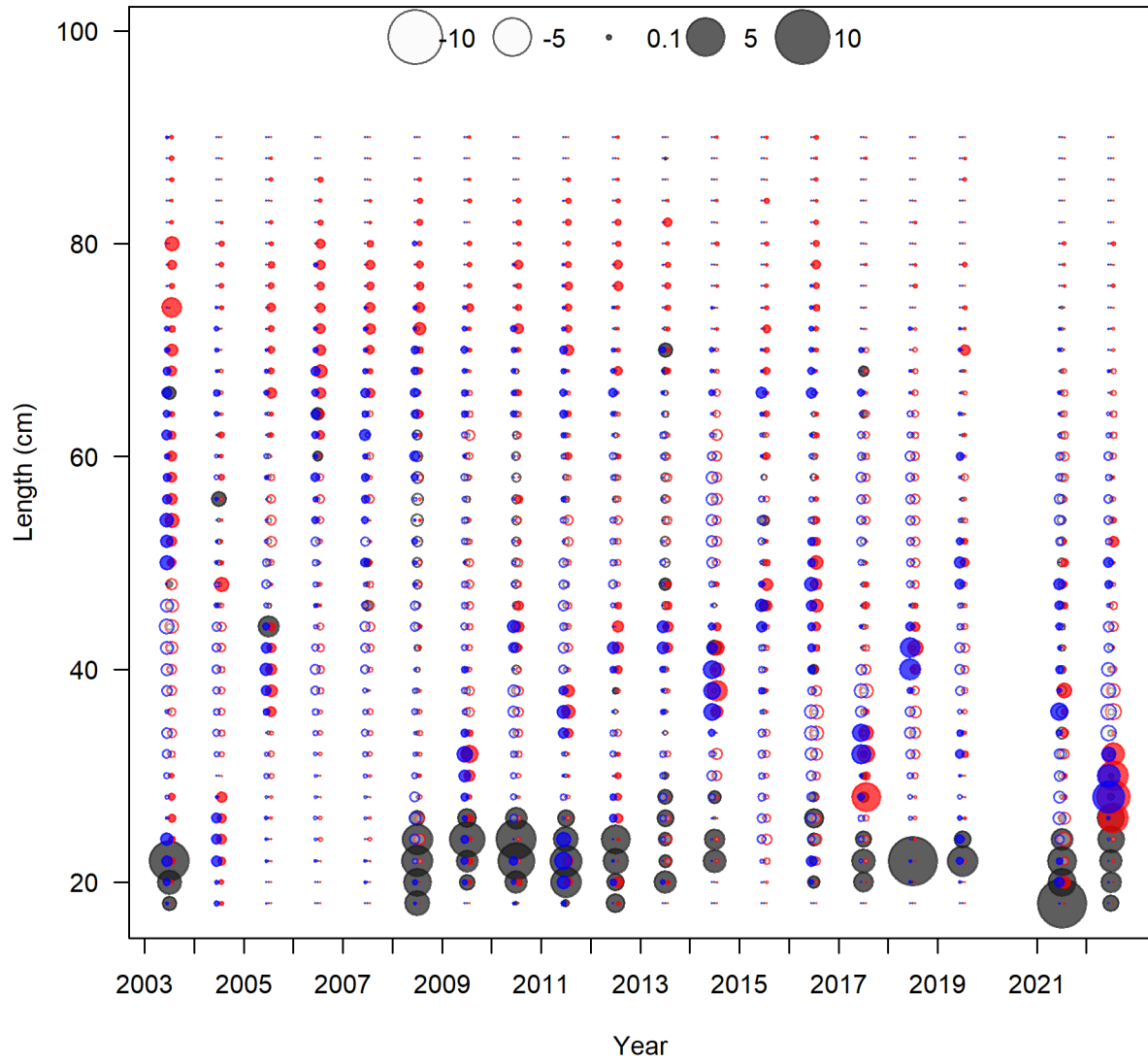


Figure 53: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of length-composition data for the WCGBTS from the whole catch.

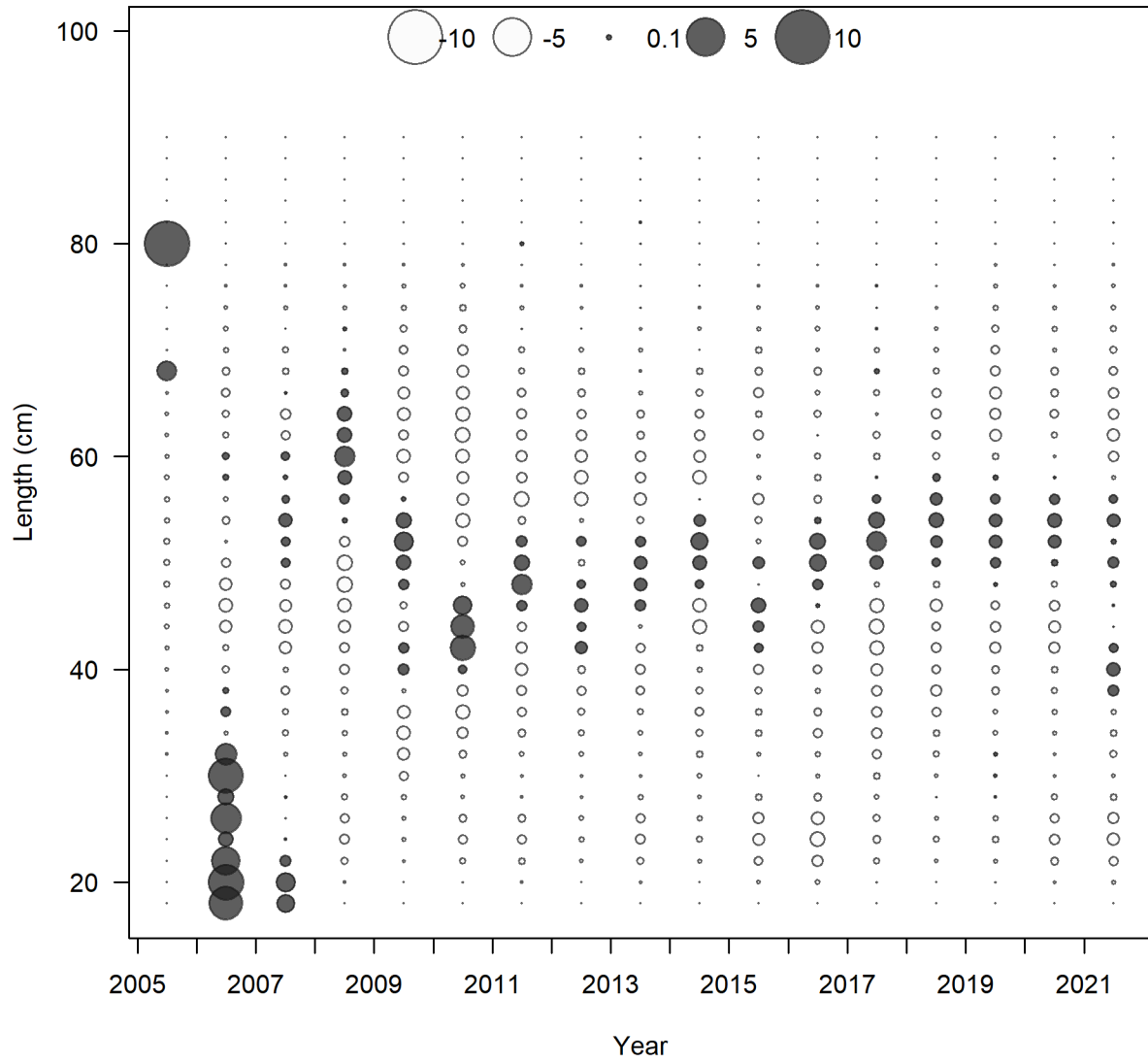


Figure 54: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of length-composition data for the fixed-gear fleet from the discarded catch.

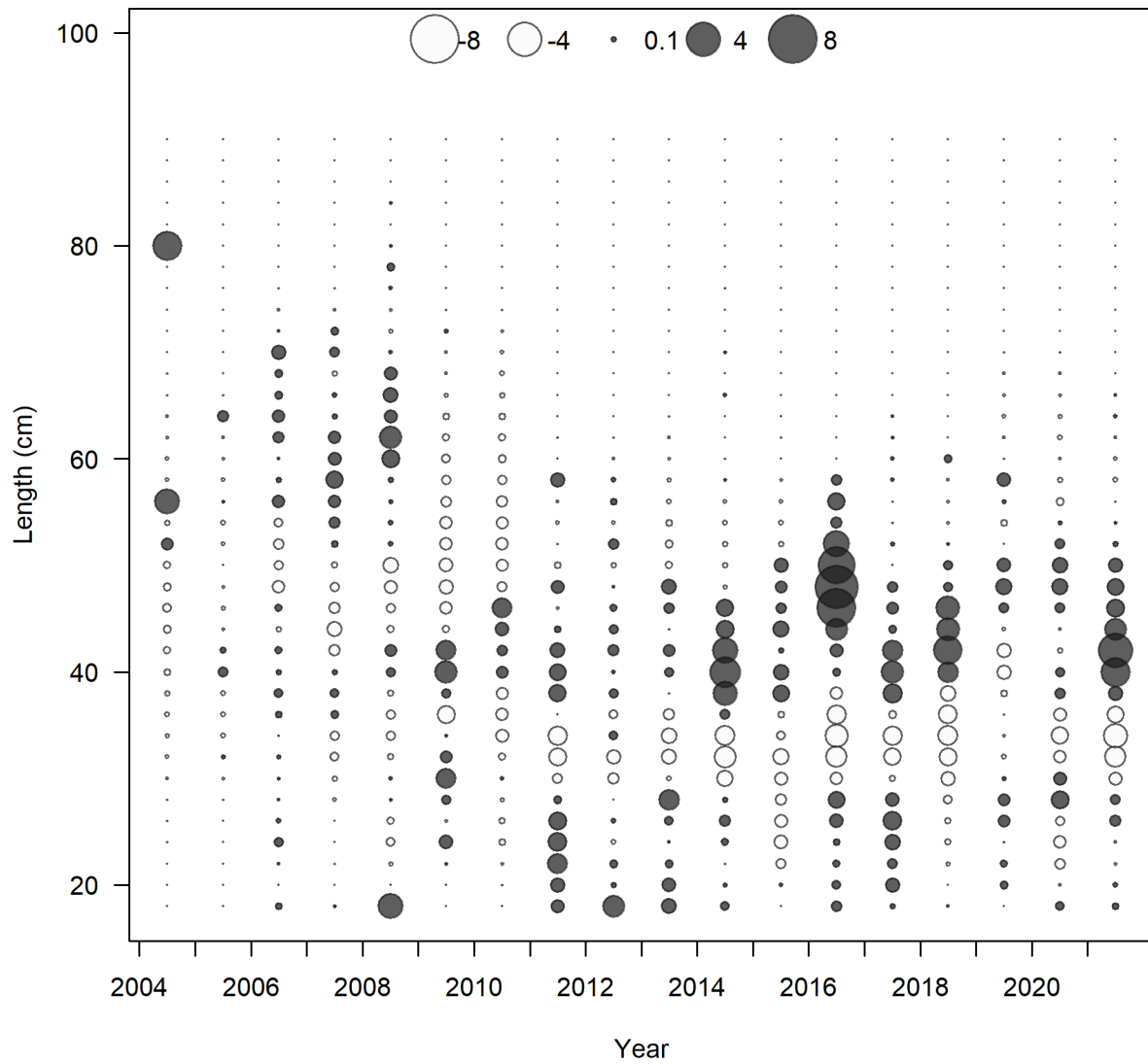


Figure 55: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of length-composition data for the trawl fleet from the discarded catch.

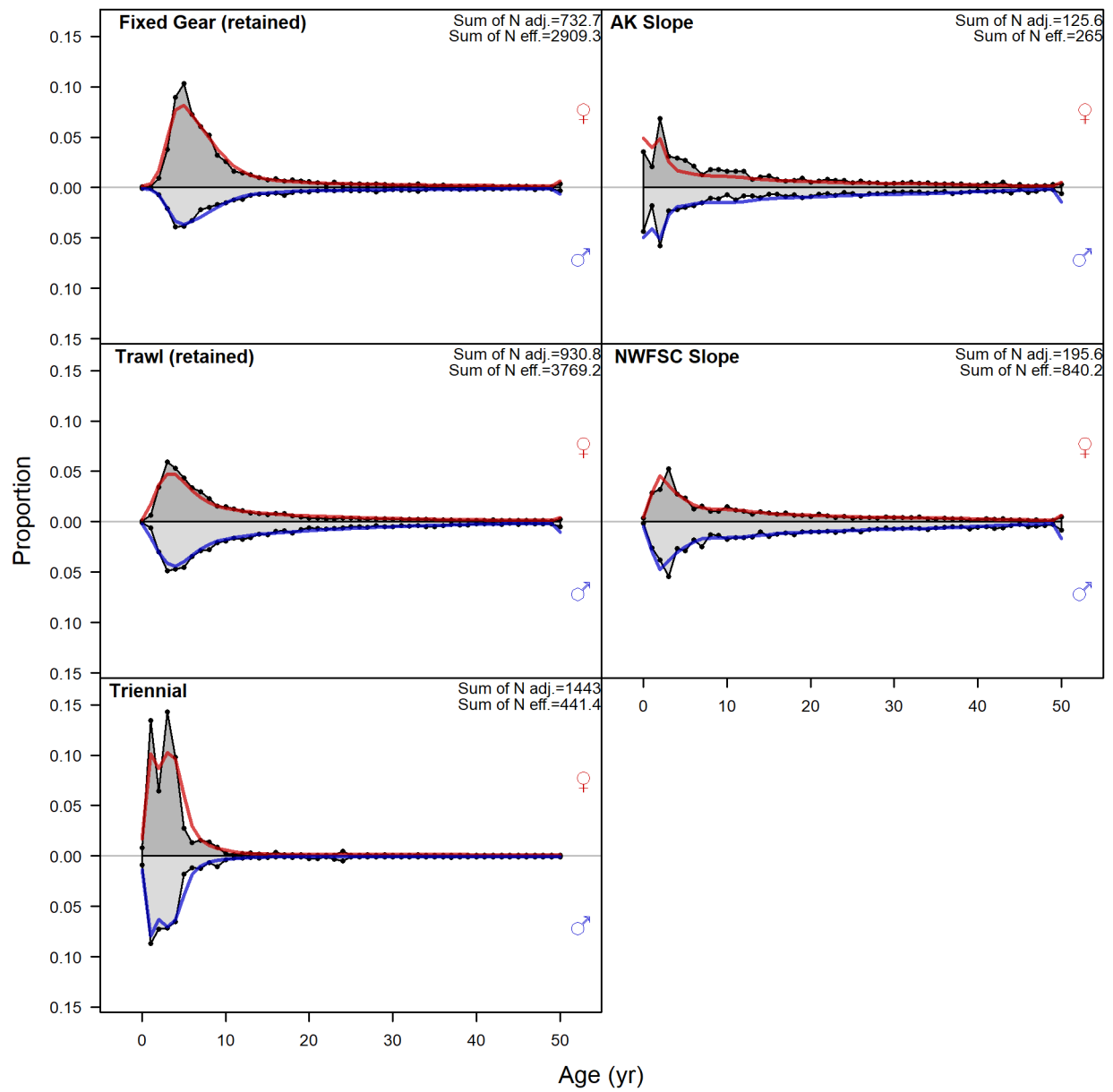


Figure 56: Length composition aggregated across years by fleet with the model estimated fit to the data by sex (green unsexed, red female, and blue male).

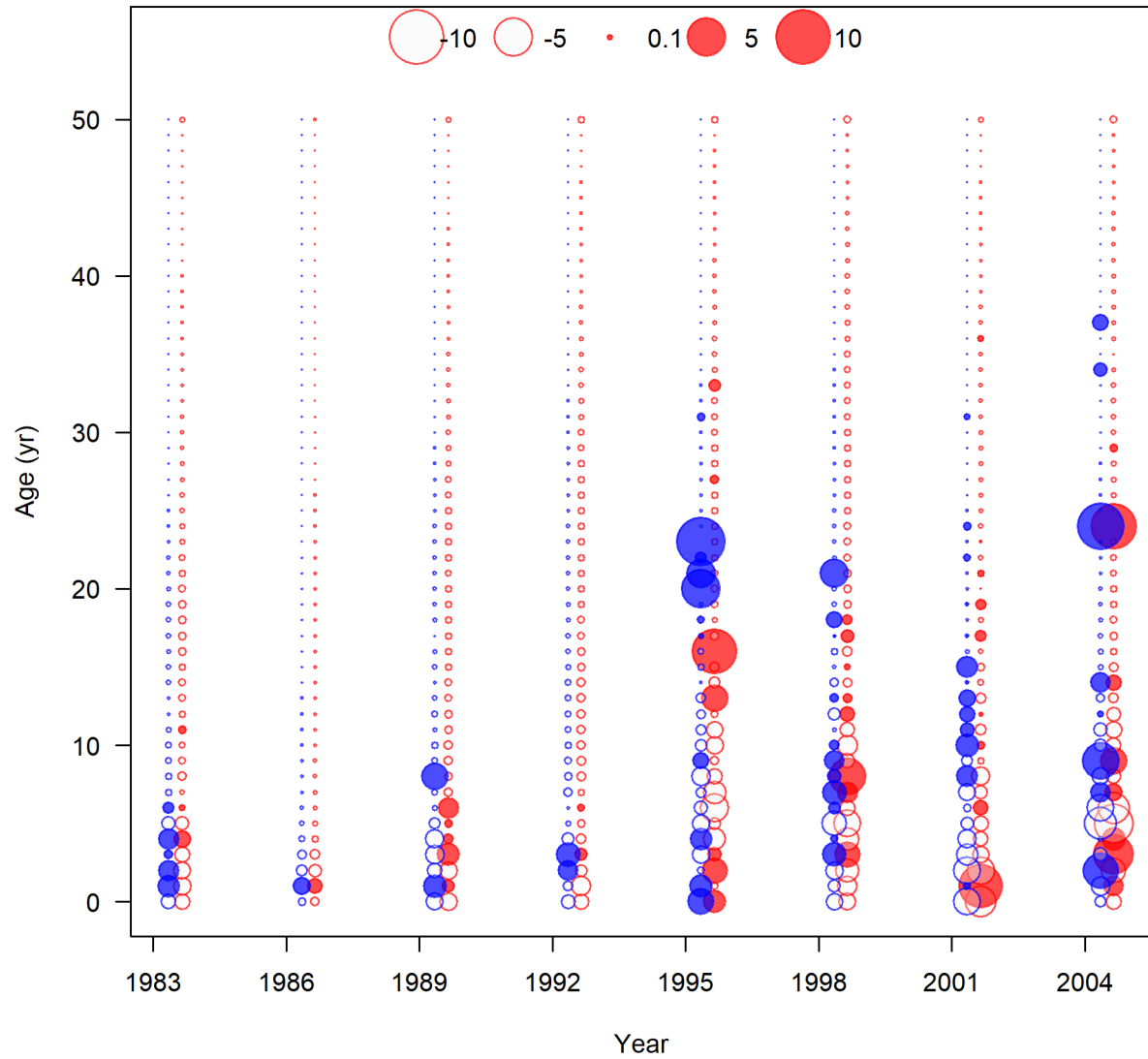


Figure 57: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the Triennial Survey from the whole catch.

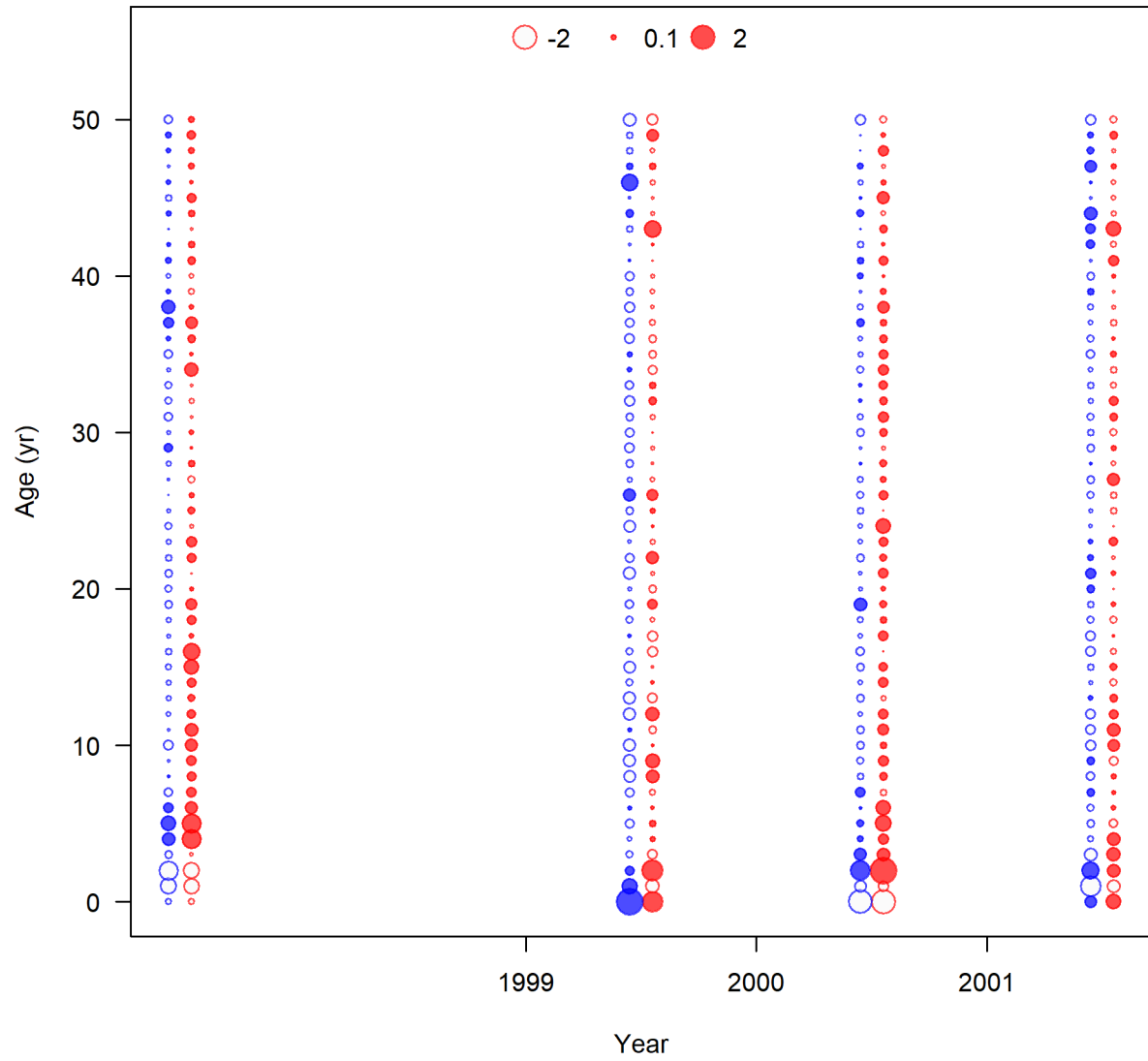


Figure 58: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the Slope Survey from the whole catch.

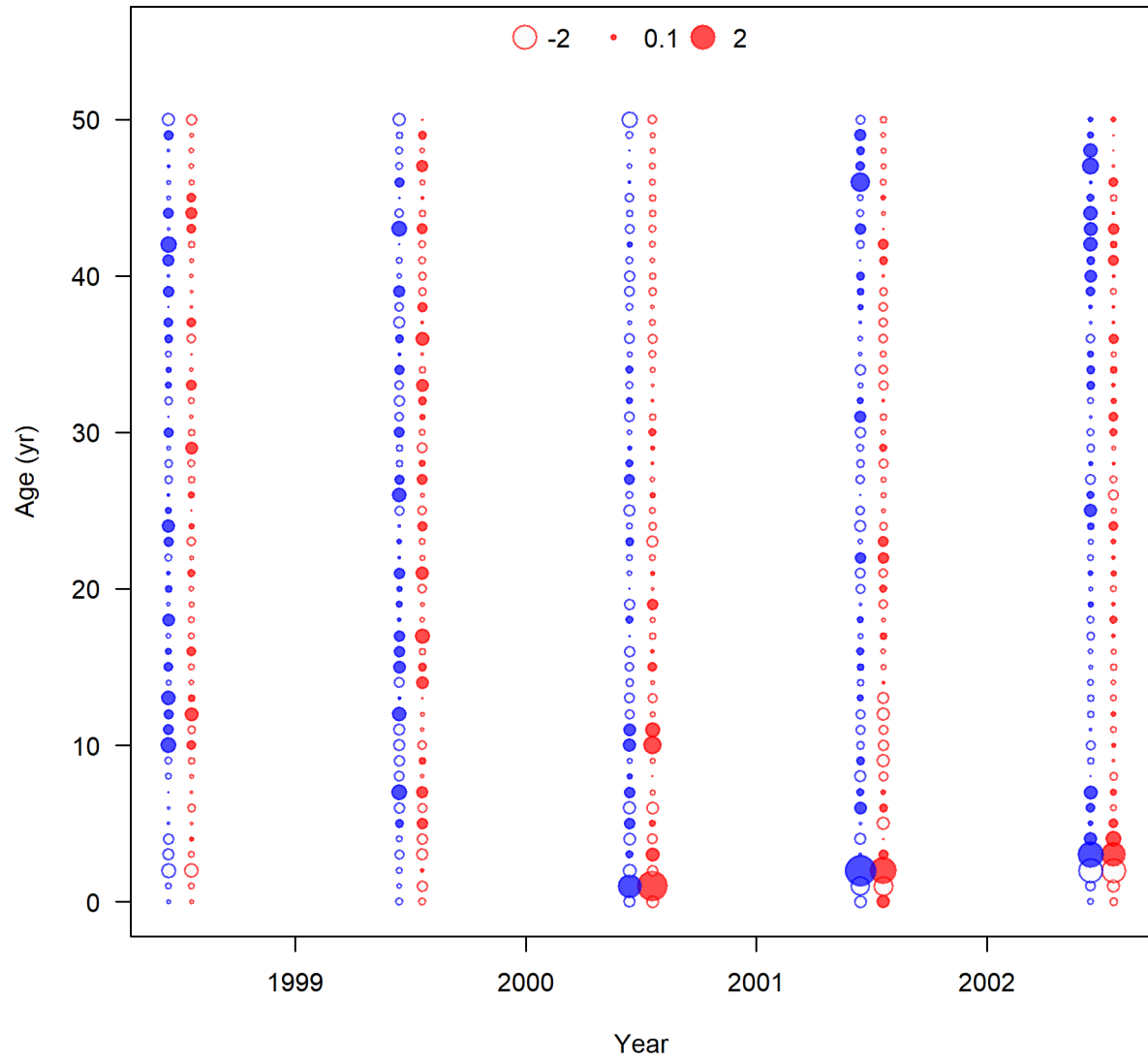


Figure 59: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the NWFSC Slope Survey from the whole catch.

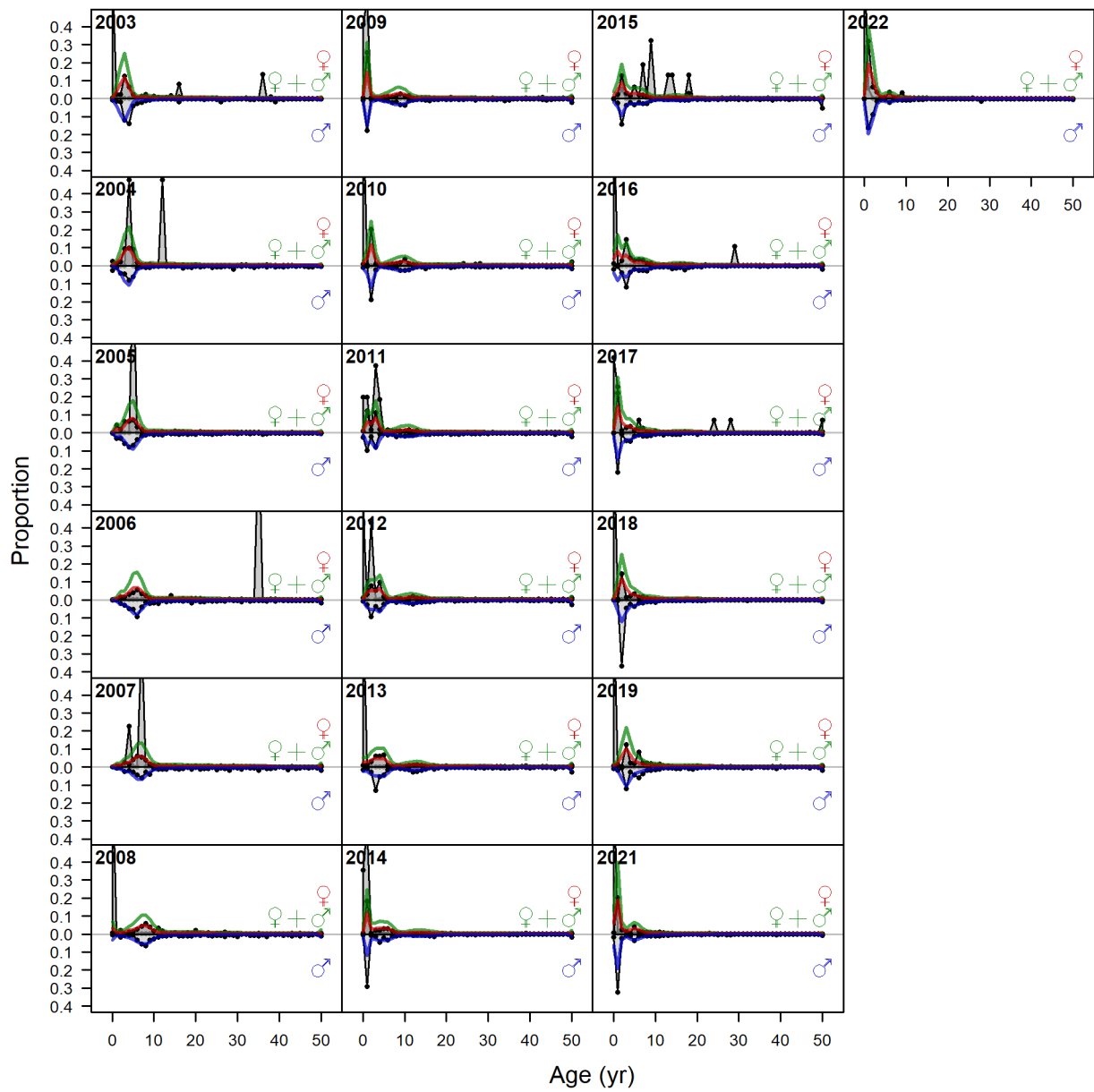


Figure 60: Fits to the annual female, male, and unsexed (red, blue, and green, respectively) age-composition data that were excluded from the model fitting process for the WCGBTS from the whole catch.

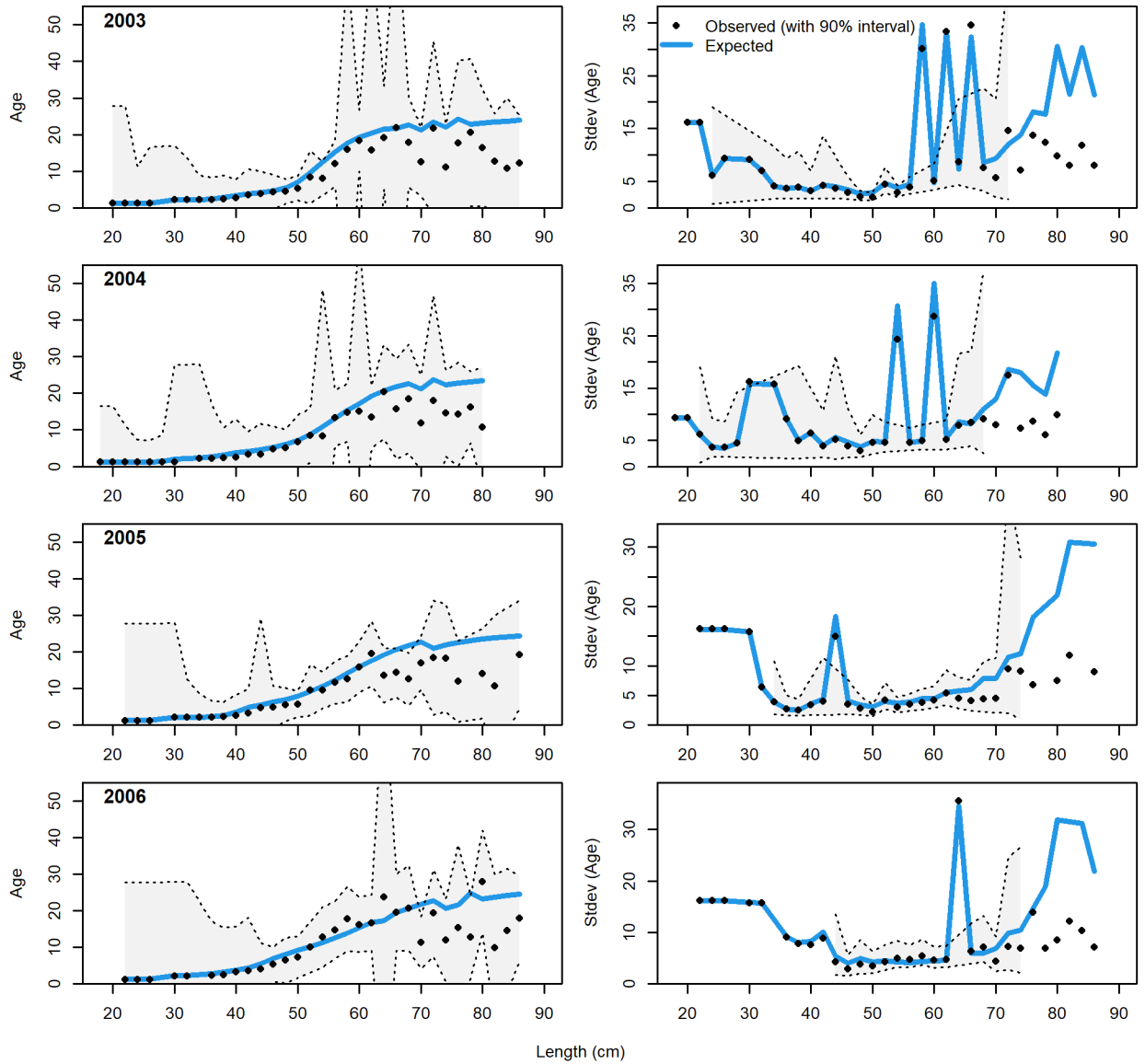


Figure 61: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch.

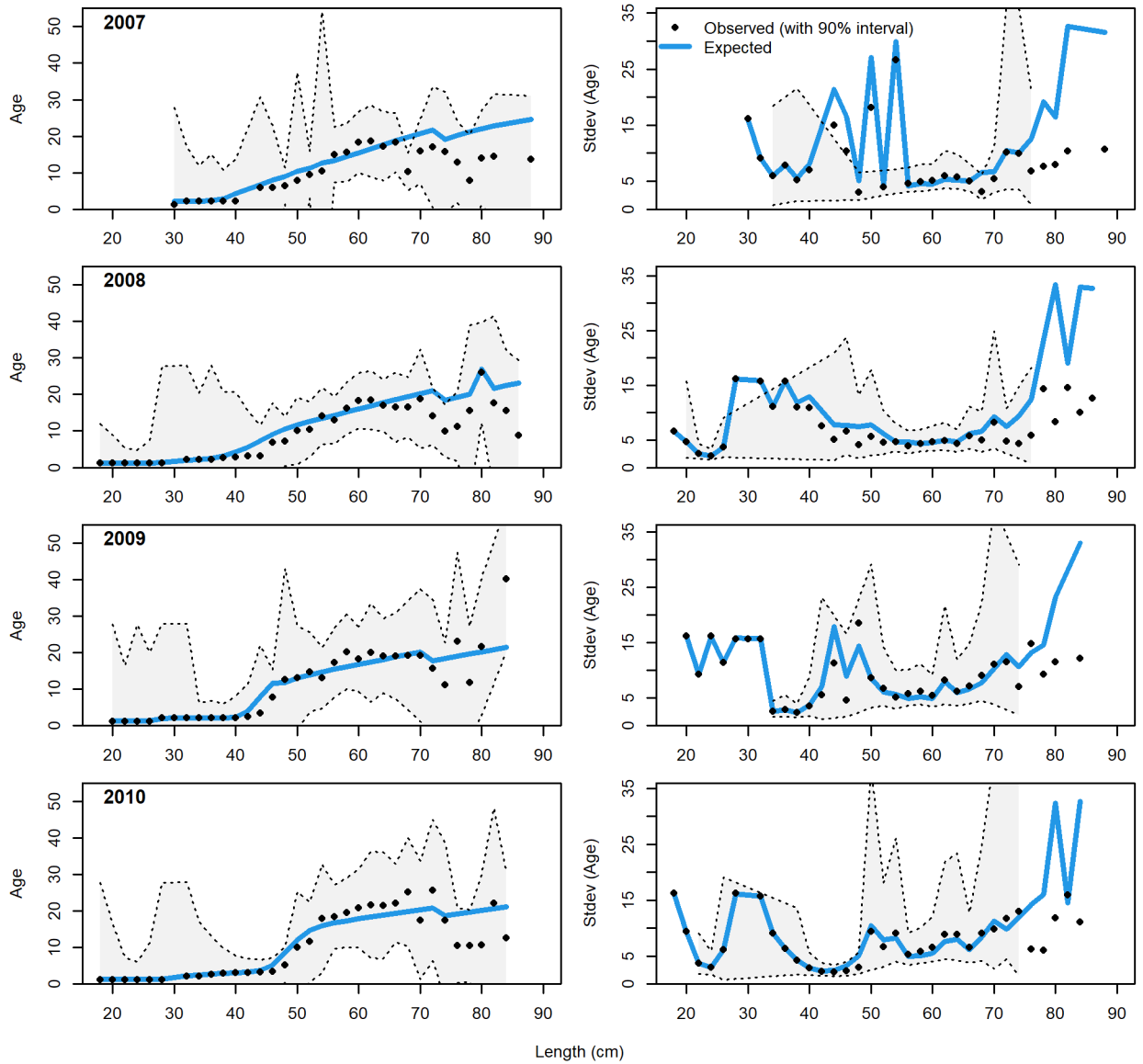


Figure 62: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued from Figure 61.

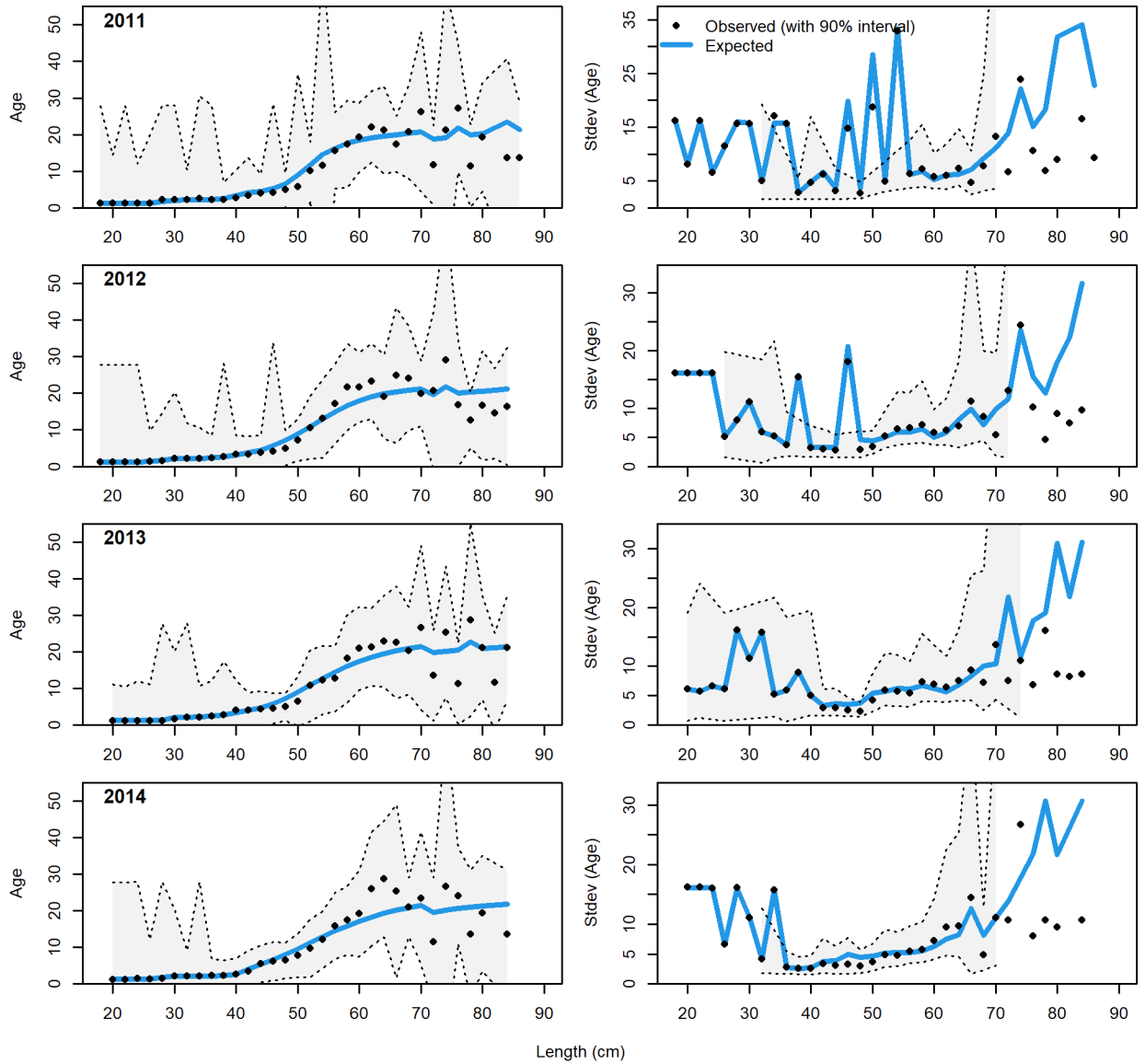


Figure 63: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued from Figure 62.

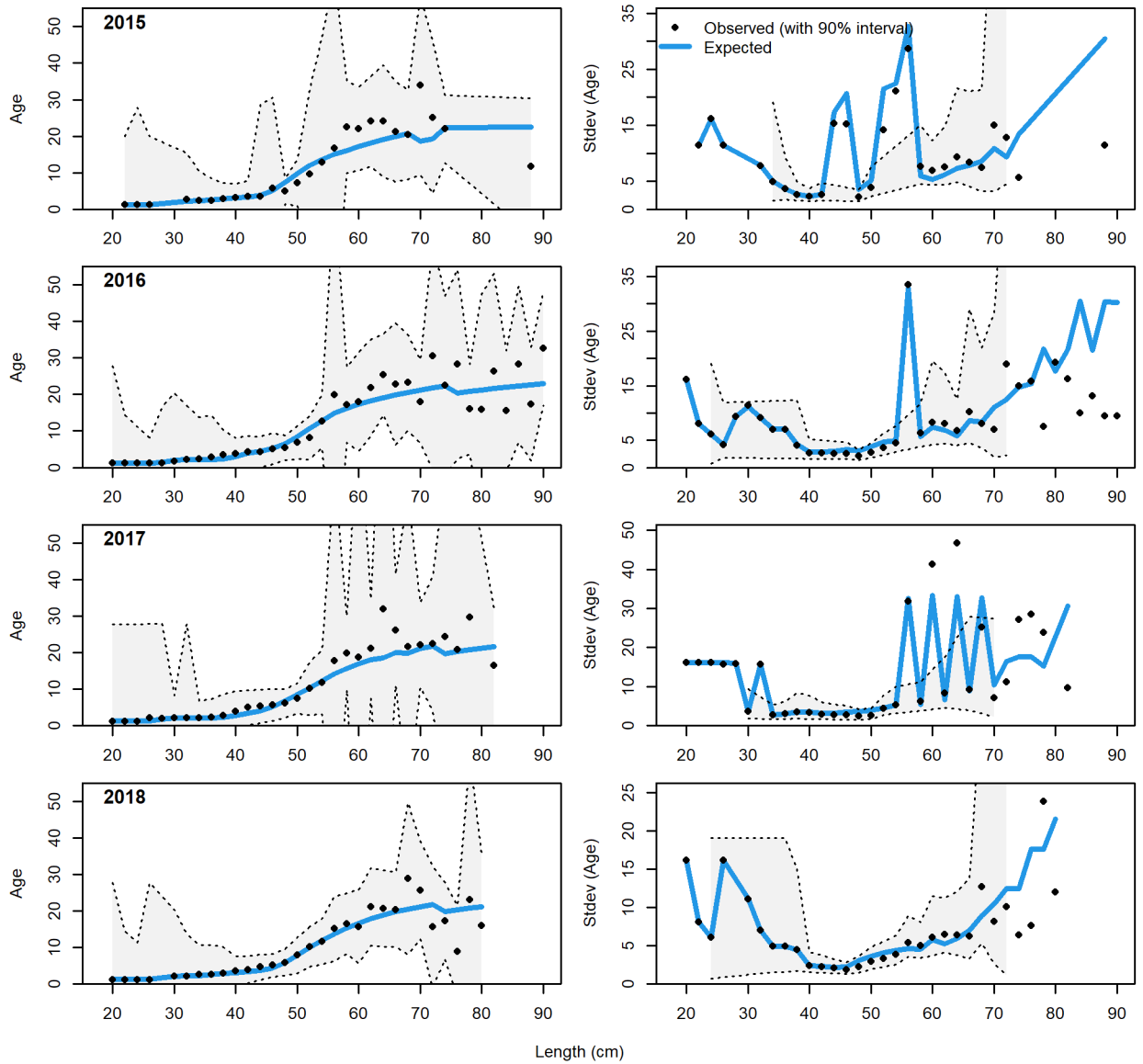


Figure 64: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued from Figure 63.

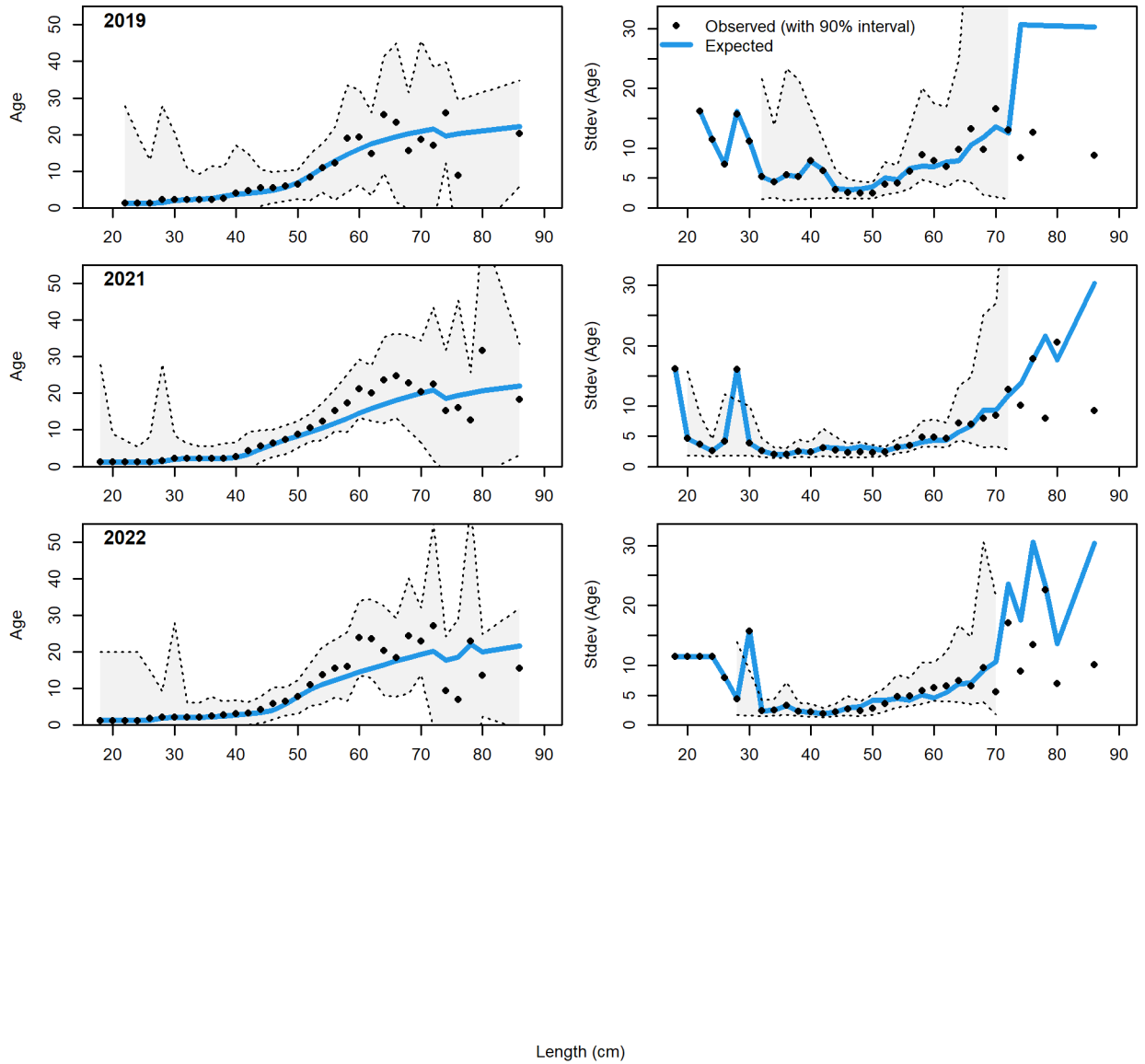


Figure 65: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued from Figure 64.

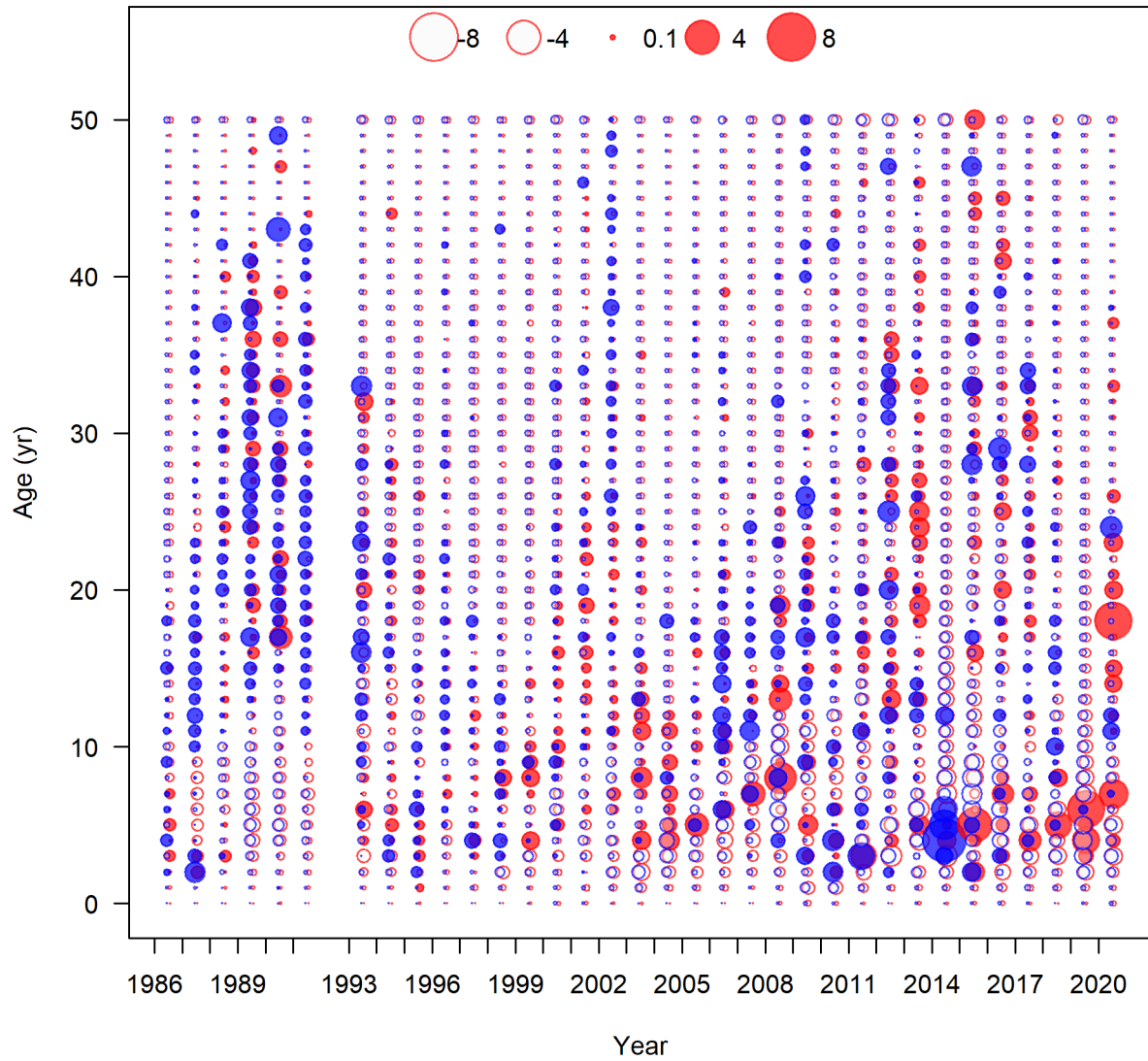


Figure 66: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the fixed-gear fleet from the retained catch.

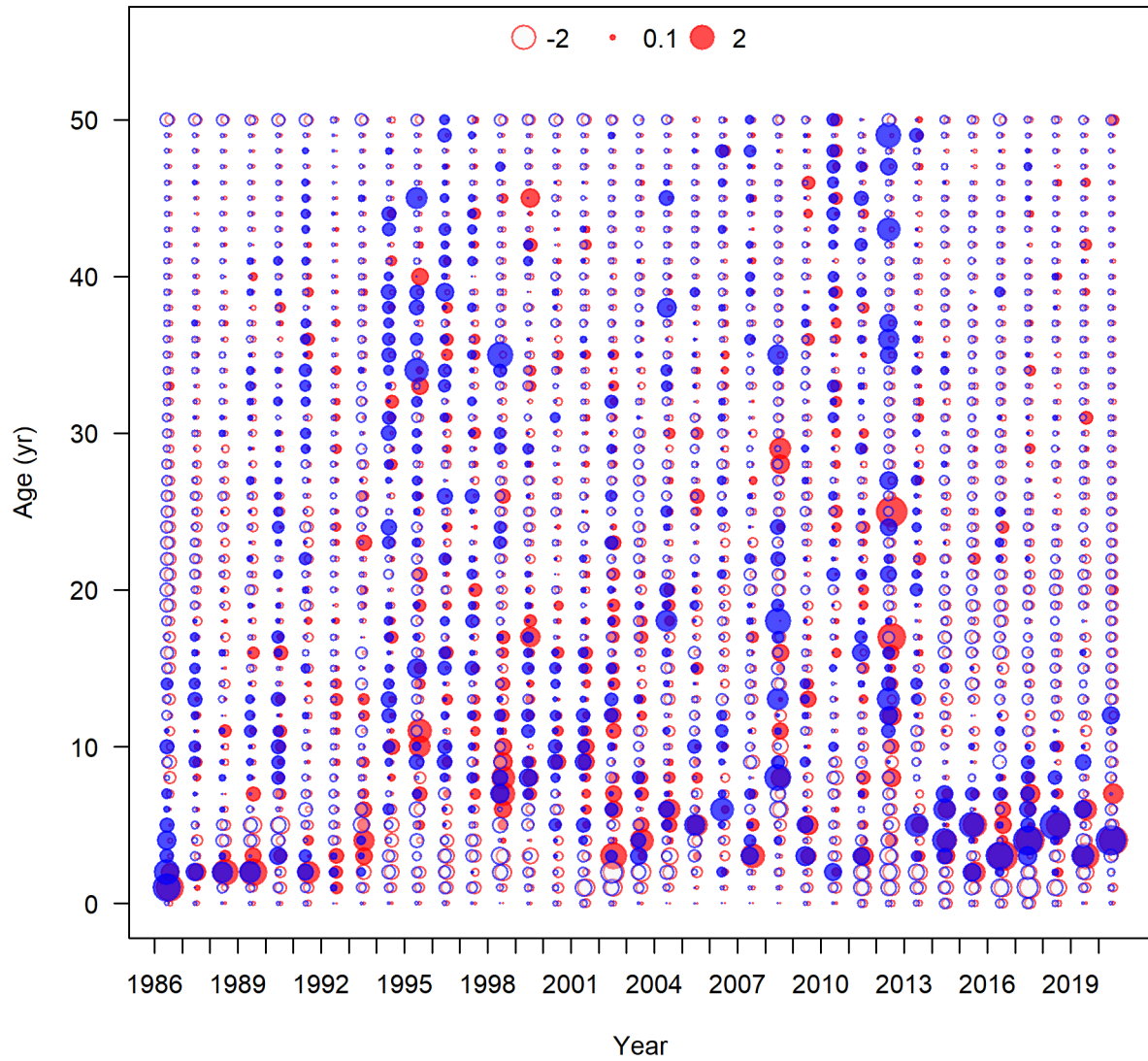


Figure 67: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the trawl fleet from the retained catch.

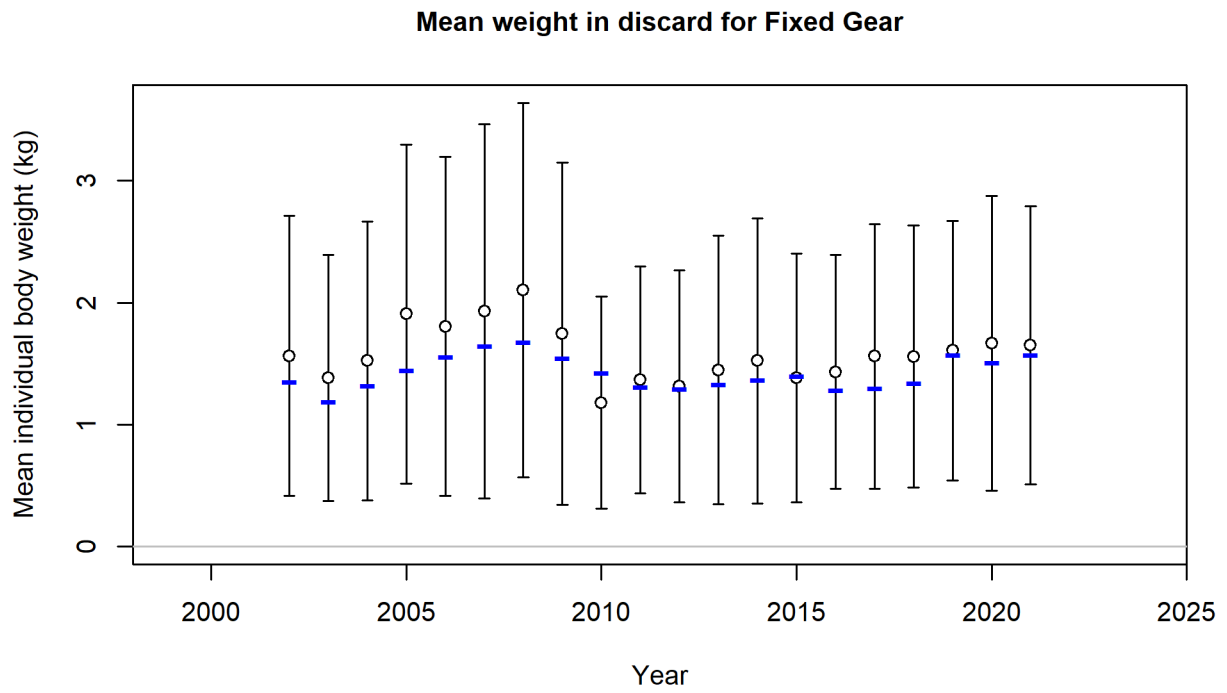


Figure 68: Fits to the mean body weight (kg) data for the fixed-gear fleet from the discarded catch.

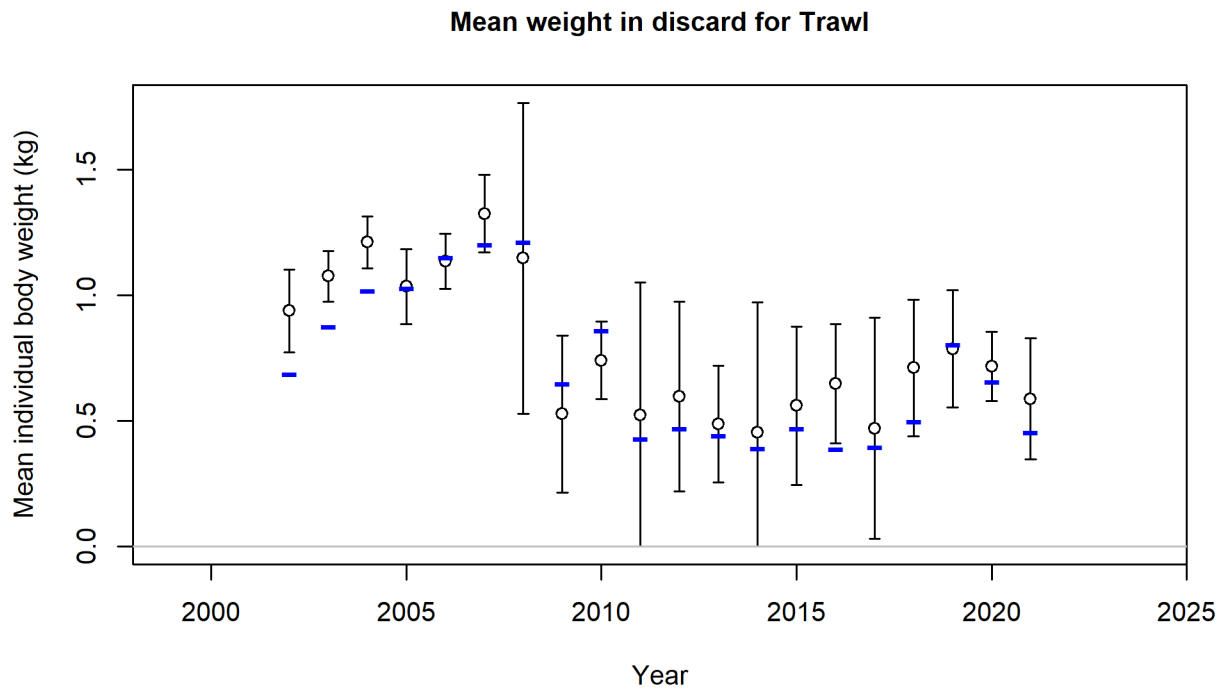


Figure 69: Fits to the mean body weight (kg) data for the trawl fleet from the discarded catch.

8.2.7 Sensitivity and Retrospectives Analyses



Figure 70: Annual recruitment deviations across a range of sensitivity analyses and the base model.

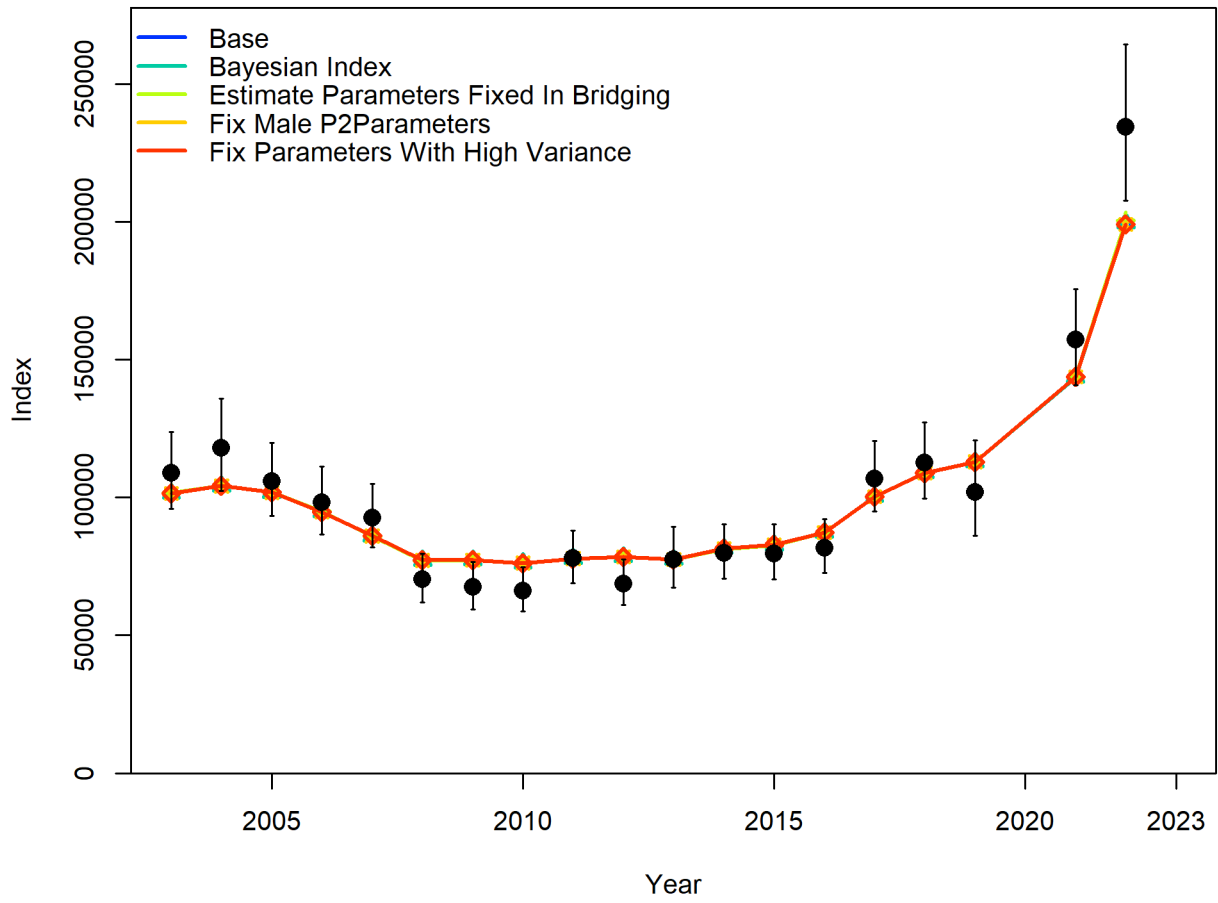


Figure 71: Recent survey index across a range of sensitivity analyses and the base model.

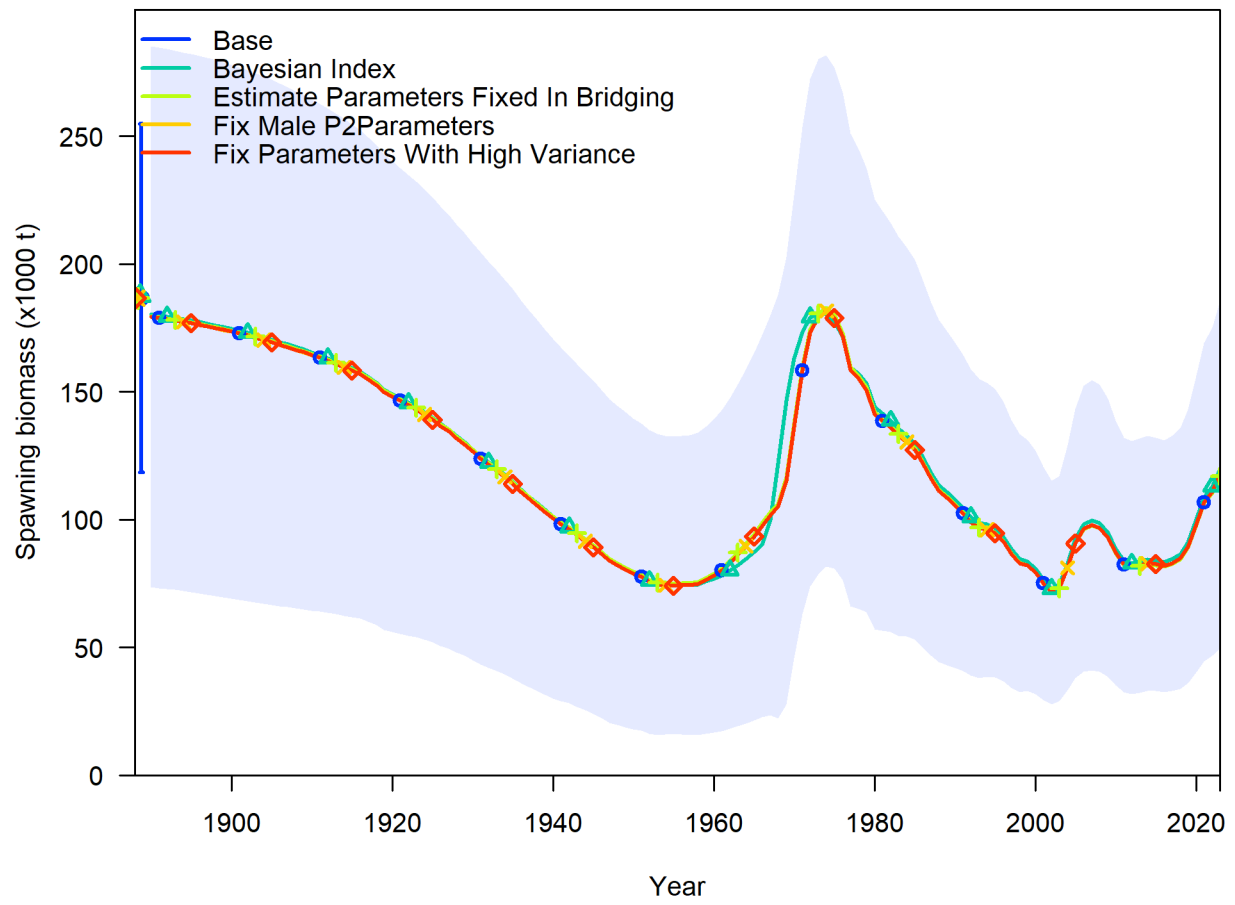


Figure 72: Spawning biomass across a range of sensitivity analyses and the base model.

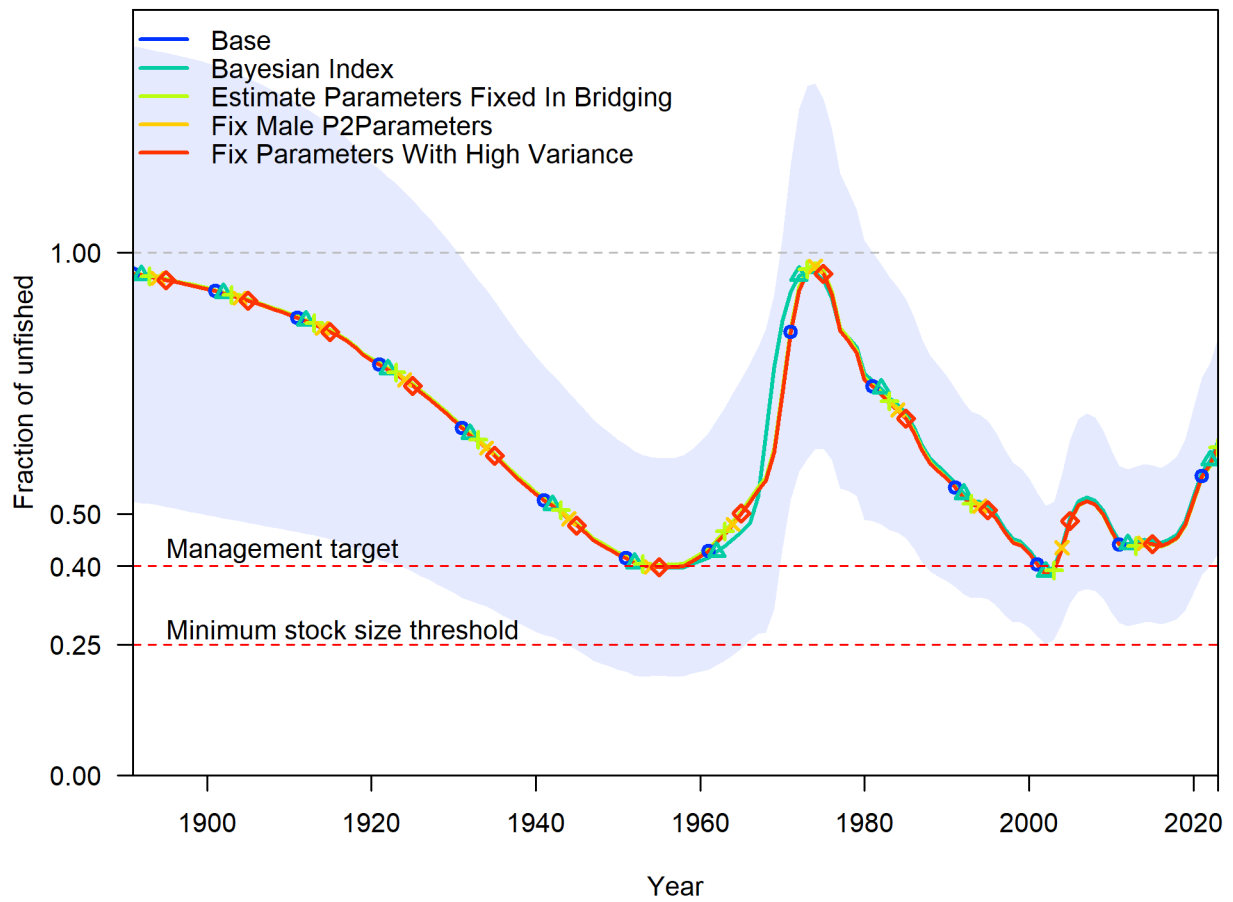


Figure 73: Fraction unfished across a range of sensitivity analyses and the base model.

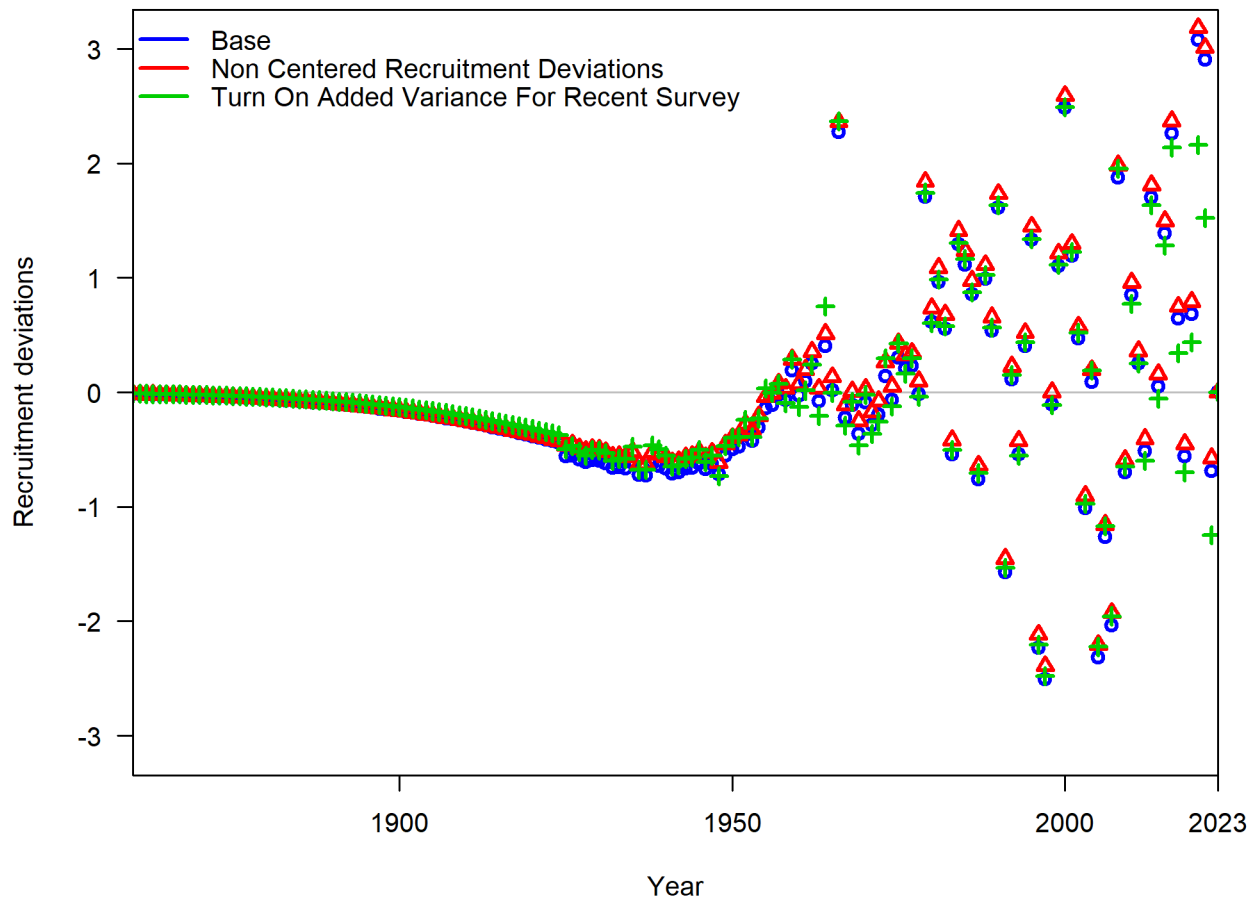


Figure 74: Annual recruitment deviations across a range of sensitivity analyses and the base model.

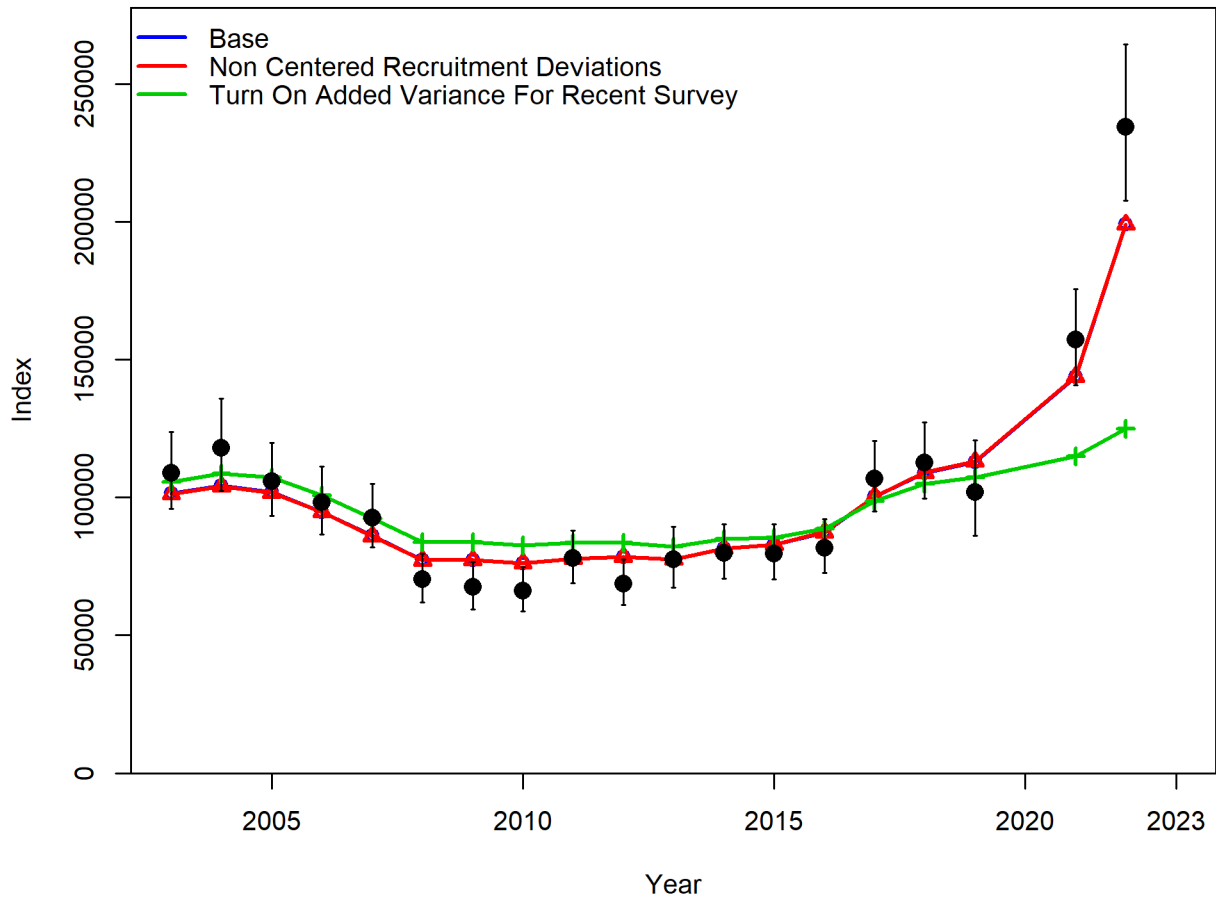


Figure 75: Recent survey index across a range of sensitivity analyses and the base model.

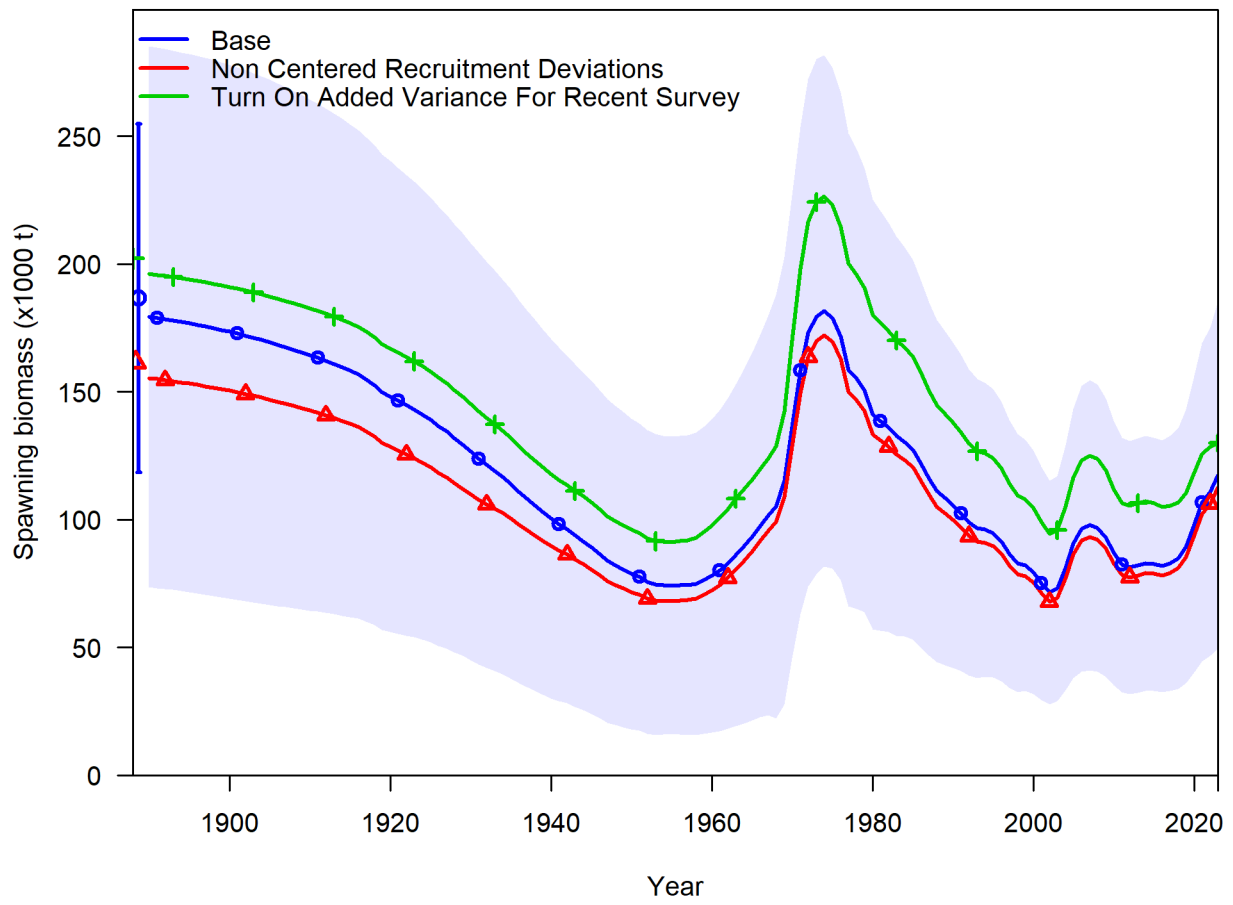


Figure 76: Spawning biomass across a range of sensitivity analyses and the base model.

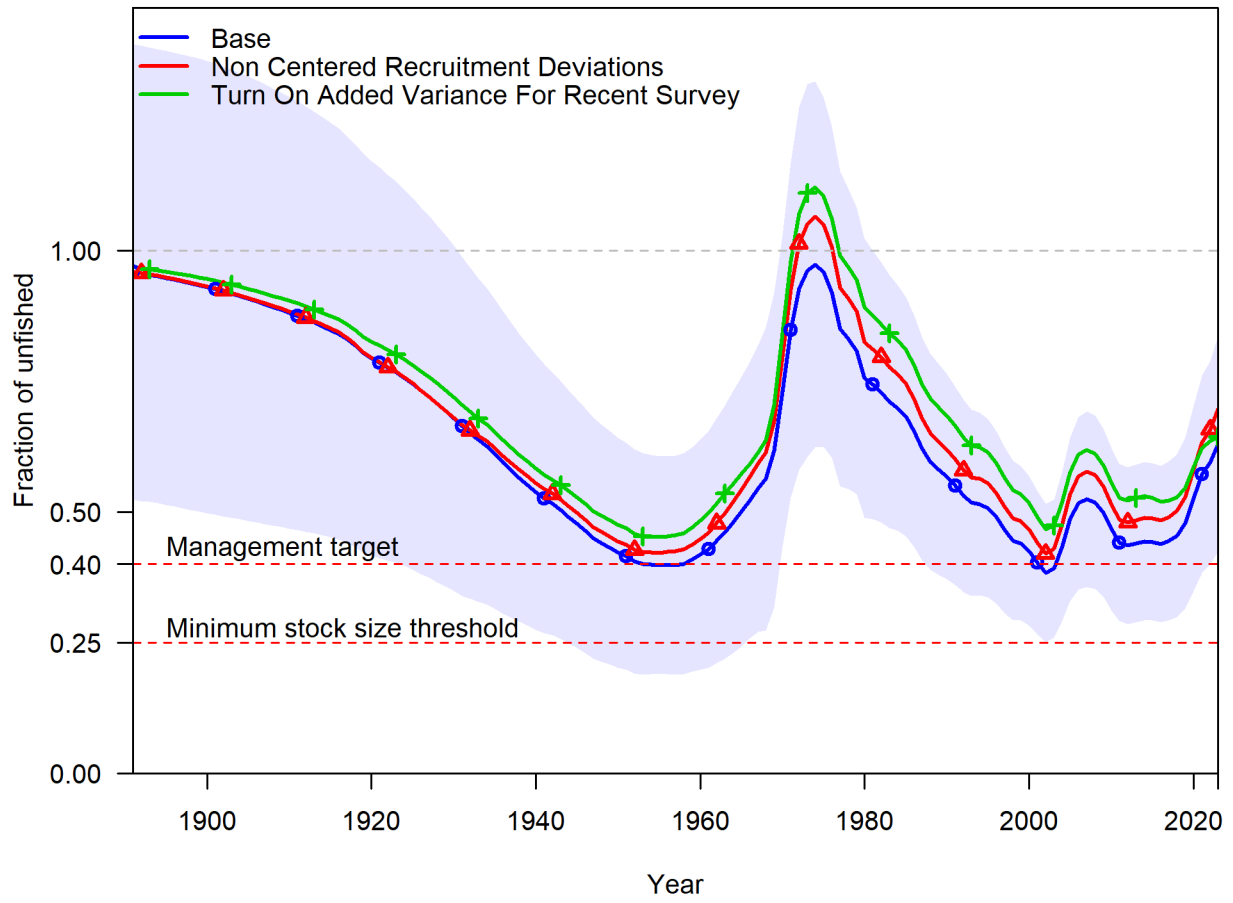


Figure 77: Fraction unfished across a range of sensitivity analyses and the base model.

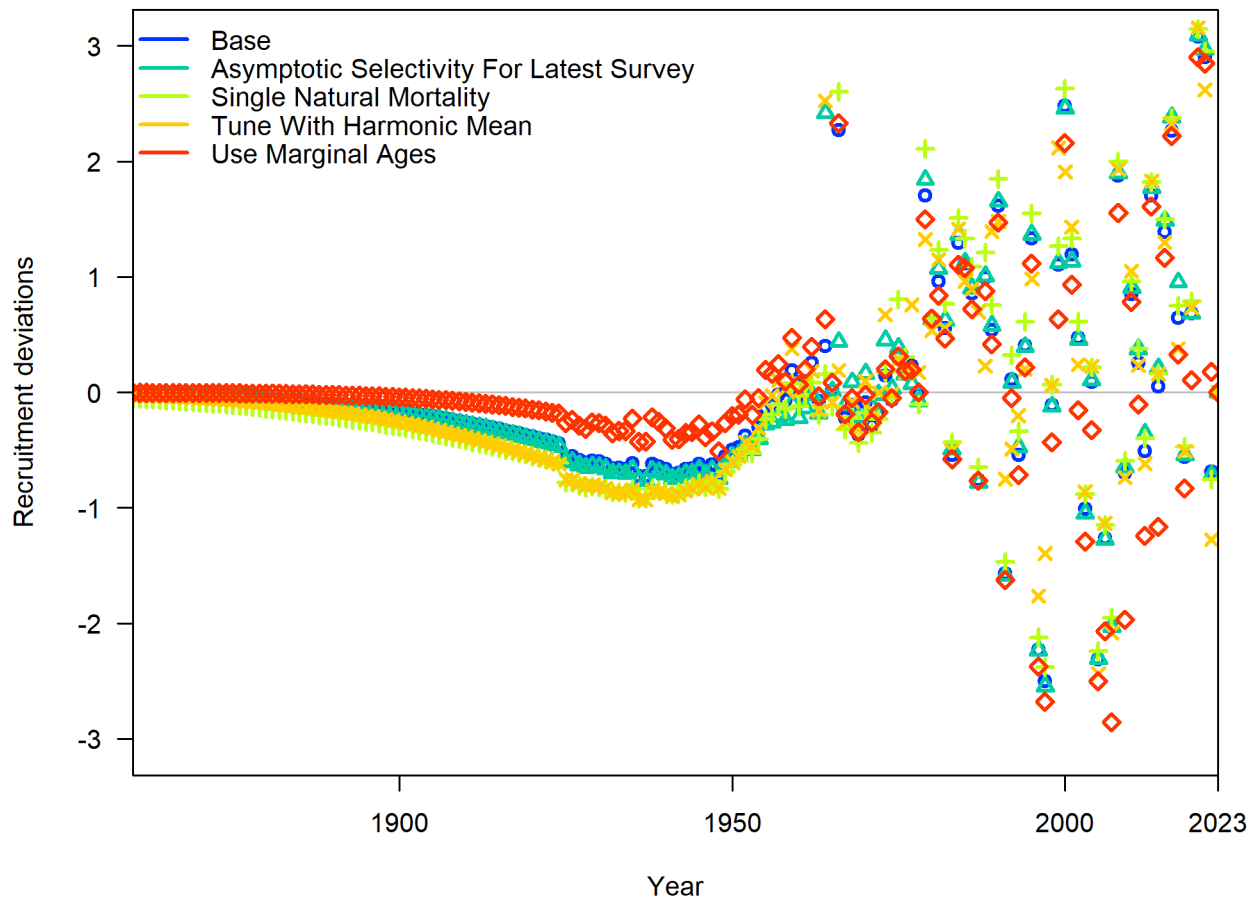


Figure 78: Annual recruitment deviations across a range of sensitivity analyses and the base model.

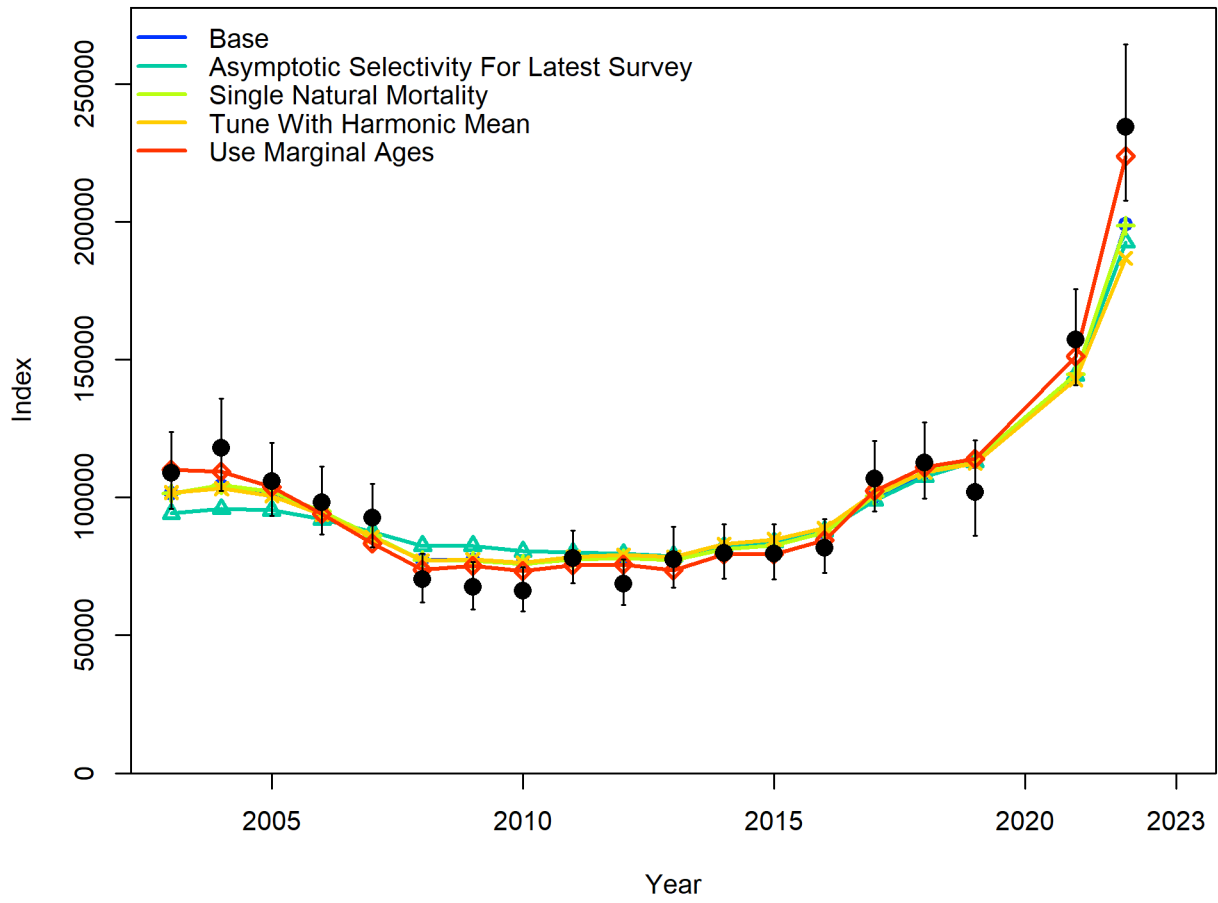


Figure 79: Recent survey index across a range of sensitivity analyses and the base model.

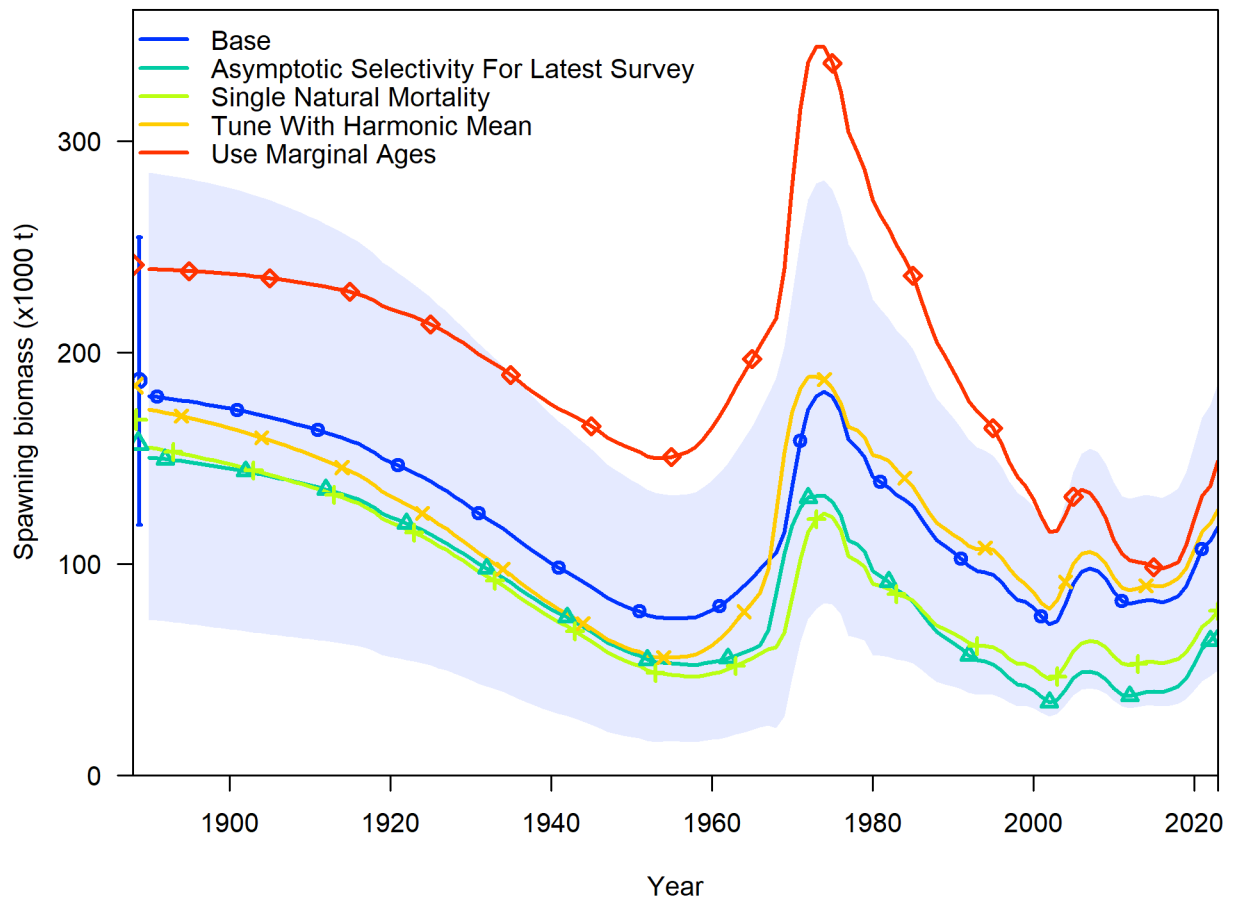


Figure 80: Spawning biomass across a range of sensitivity analyses and the base model.

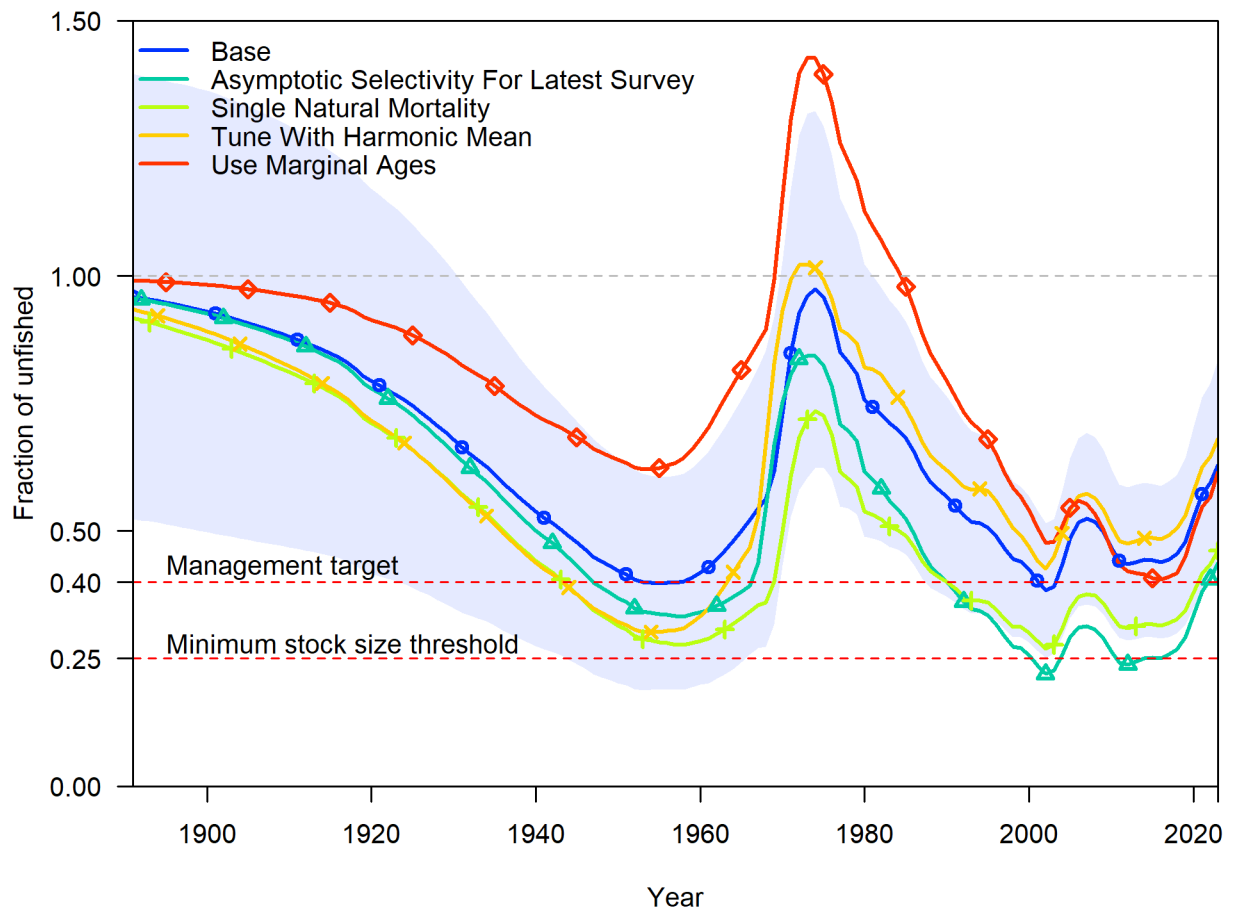


Figure 81: Fraction unfished across a range of sensitivity analyses and the base model.

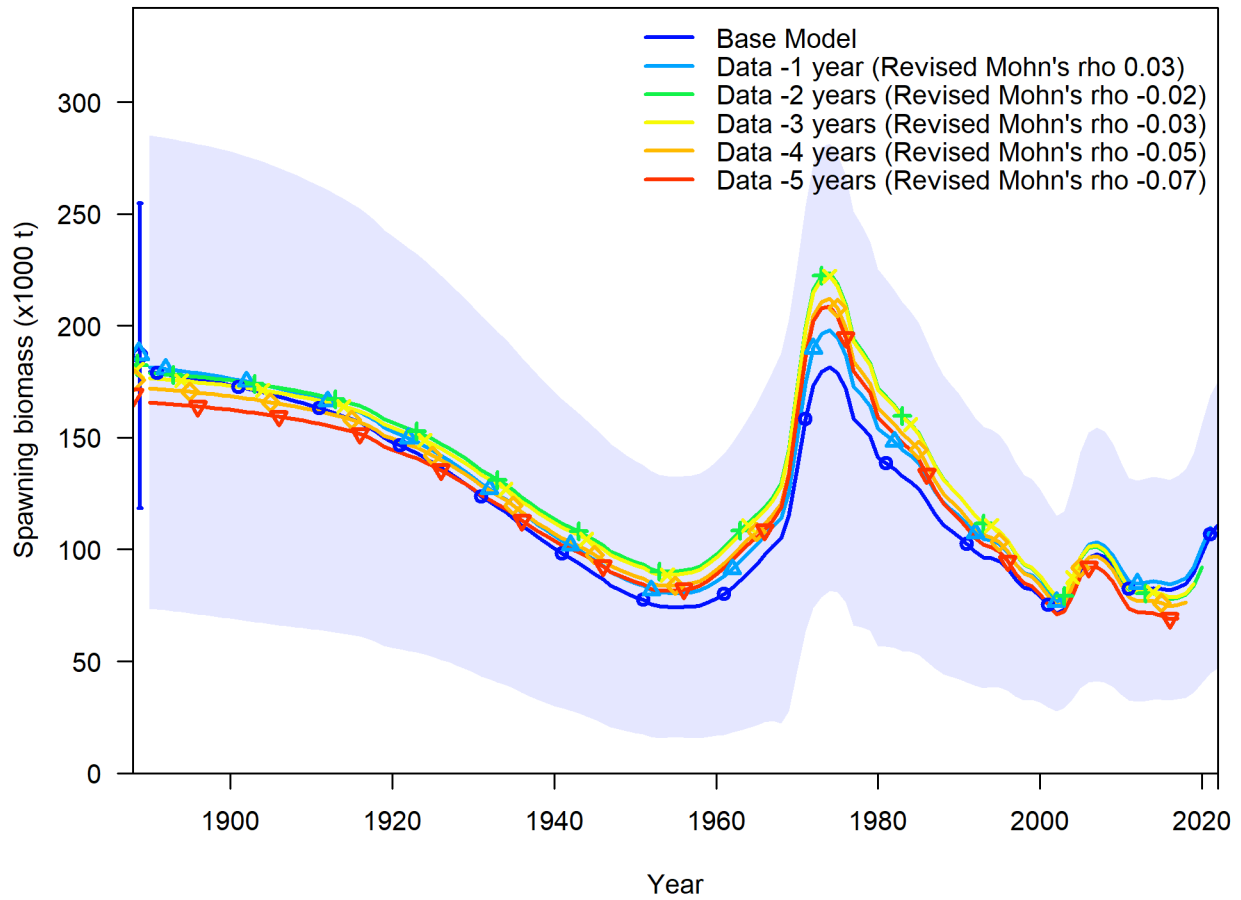


Figure 82: Retrospective patterns for spawning stock biomass (*SSB*) when up to five years of data were removed from the base model. Mohn's rho (Mohn, 1999) values were recalculated for each peel given the removal of another year of data. See Table 11 for other derivations of Mohn's rho.

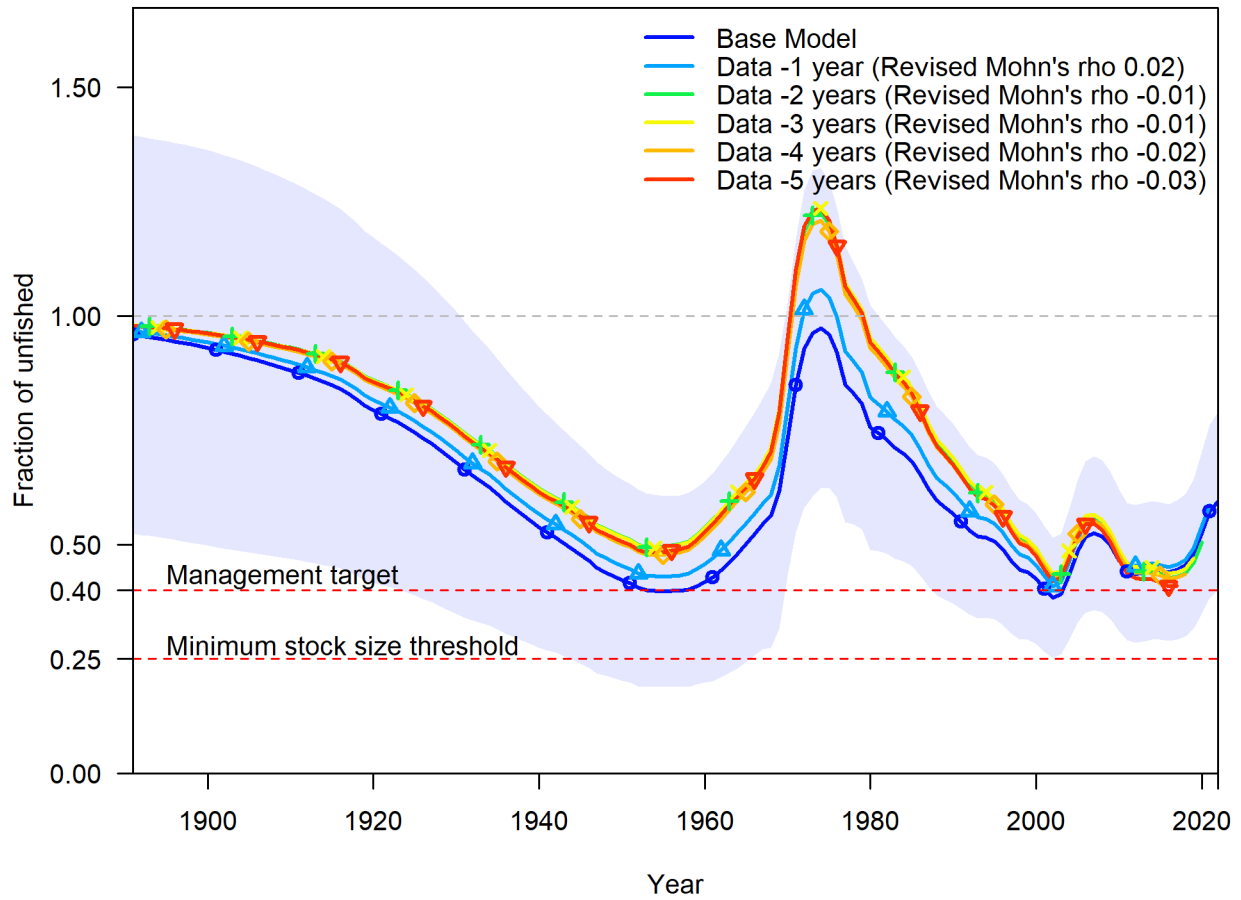


Figure 83: Retrospective patterns for fraction unfished when up to five years of data were removed from the base model. Mohn's rho (Mohn, 1999) values were recalculated for each peel given the removal of another year of data. See Table 11 for other derivations of Mohn's rho.

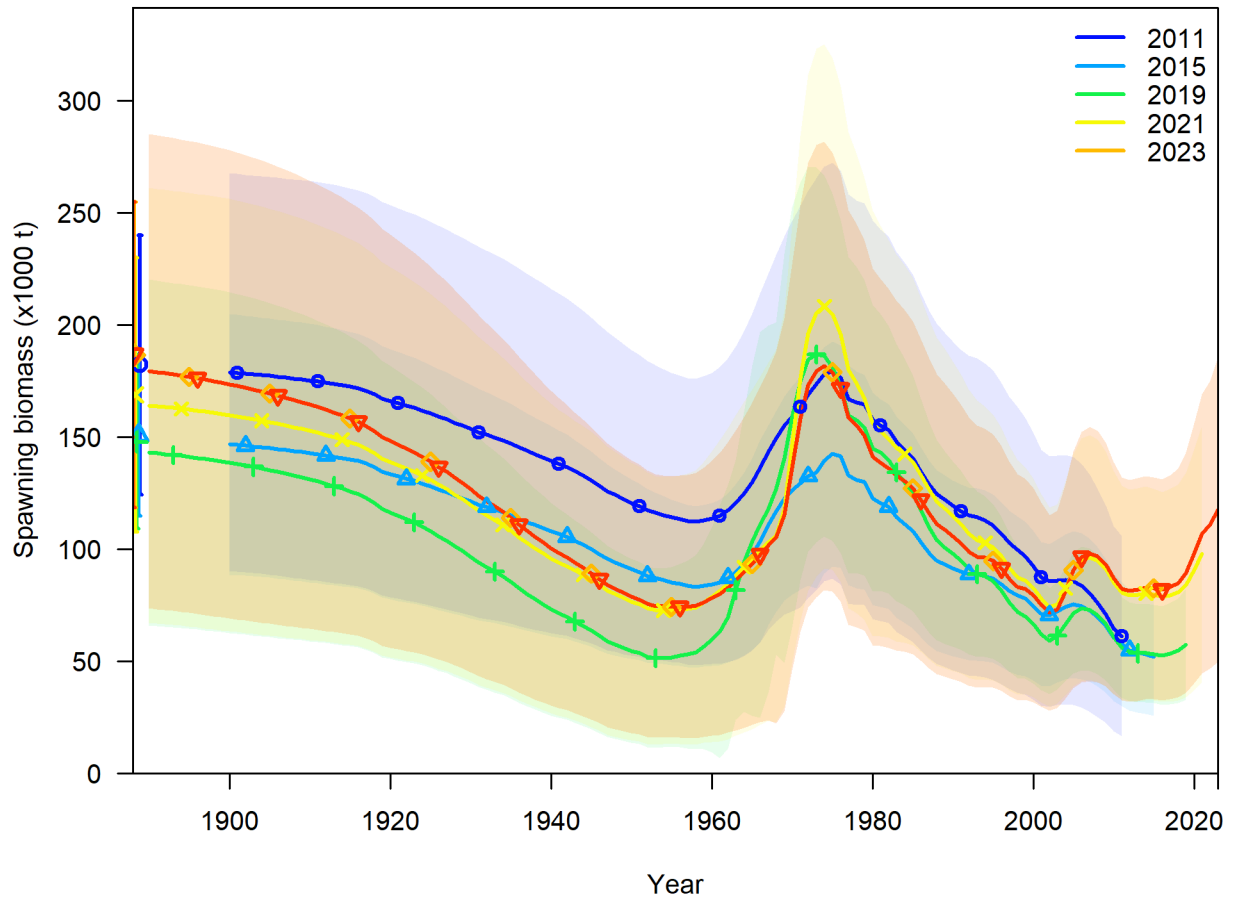


Figure 84: Comparisons of spawning biomass (mt) between the current assessment and recent benchmark and update assessments since 2011.

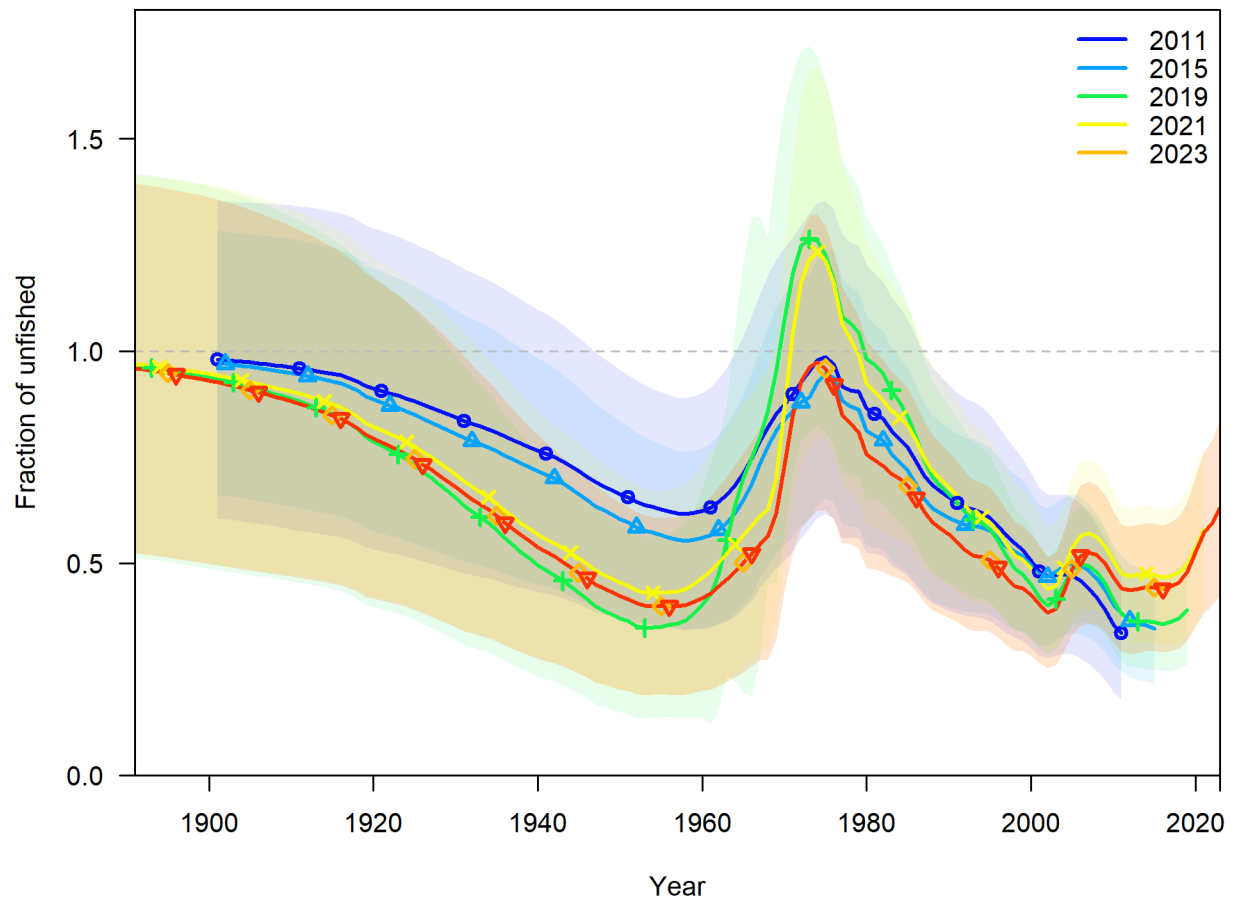


Figure 85: Comparisons of fraction unfinished between the current assessment and recent benchmark and update assessments since 2011.

8.2.8 Likelihood Profiles

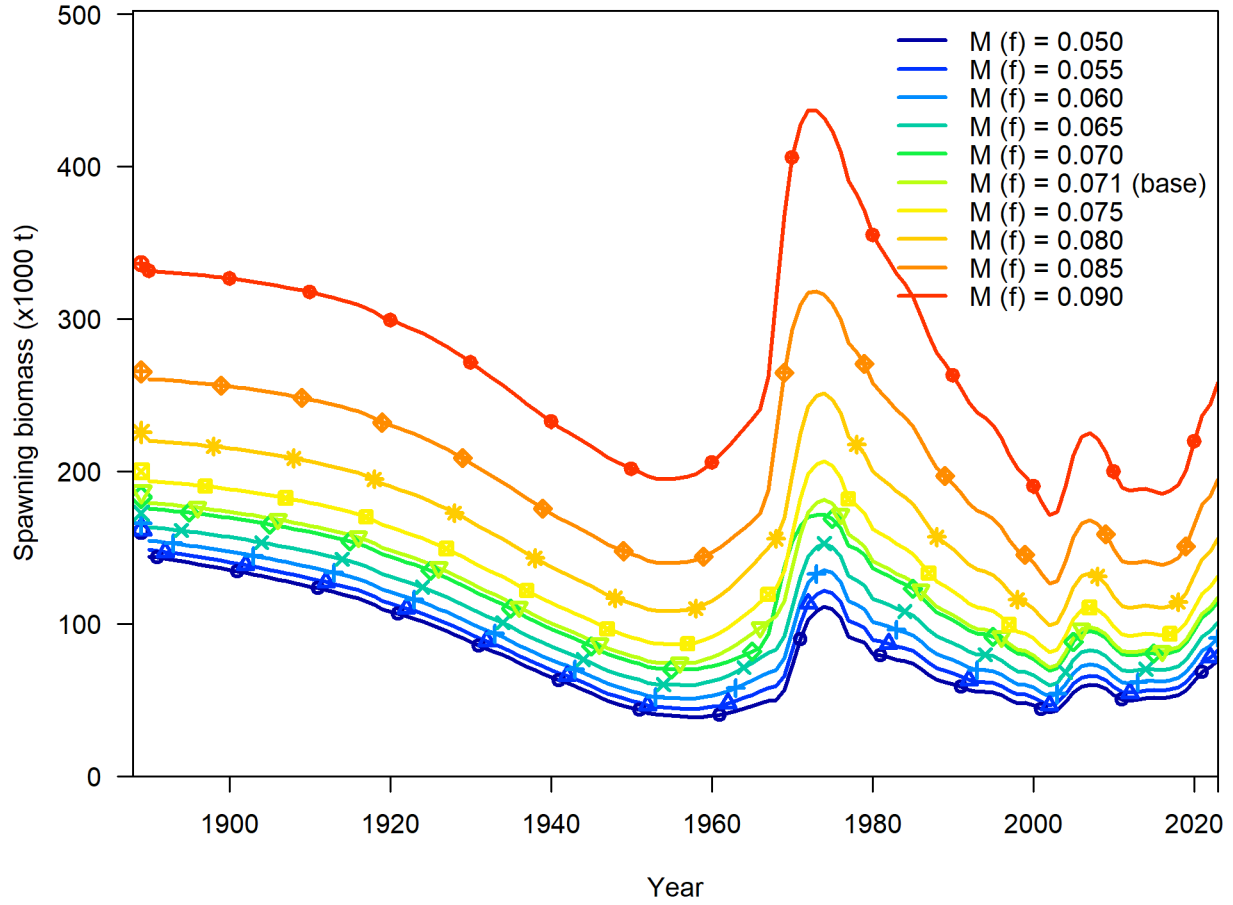


Figure 86: Change in the spawning biomass across a range of female natural mortality values.

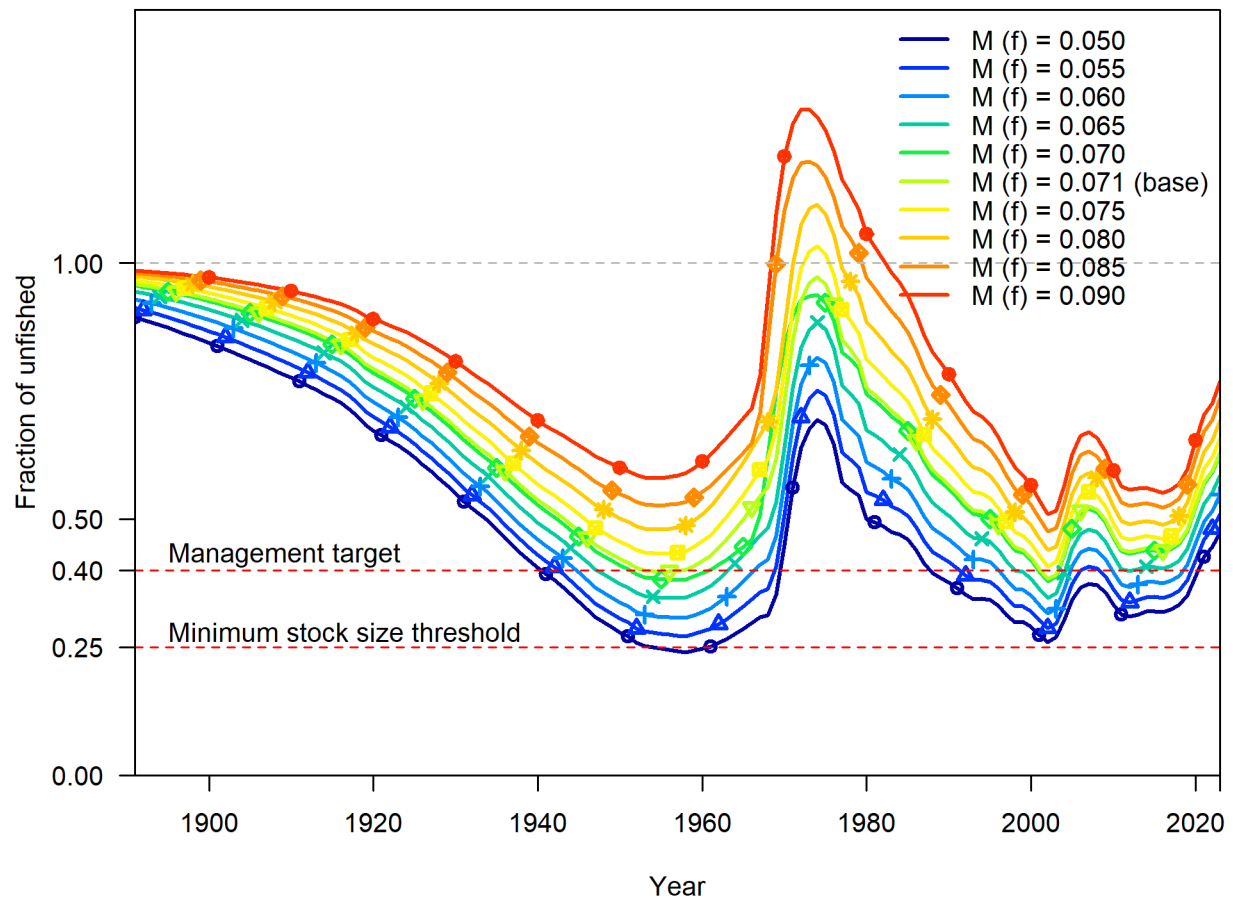


Figure 87: Change in the fraction unfished across a range of female natural mortality values.

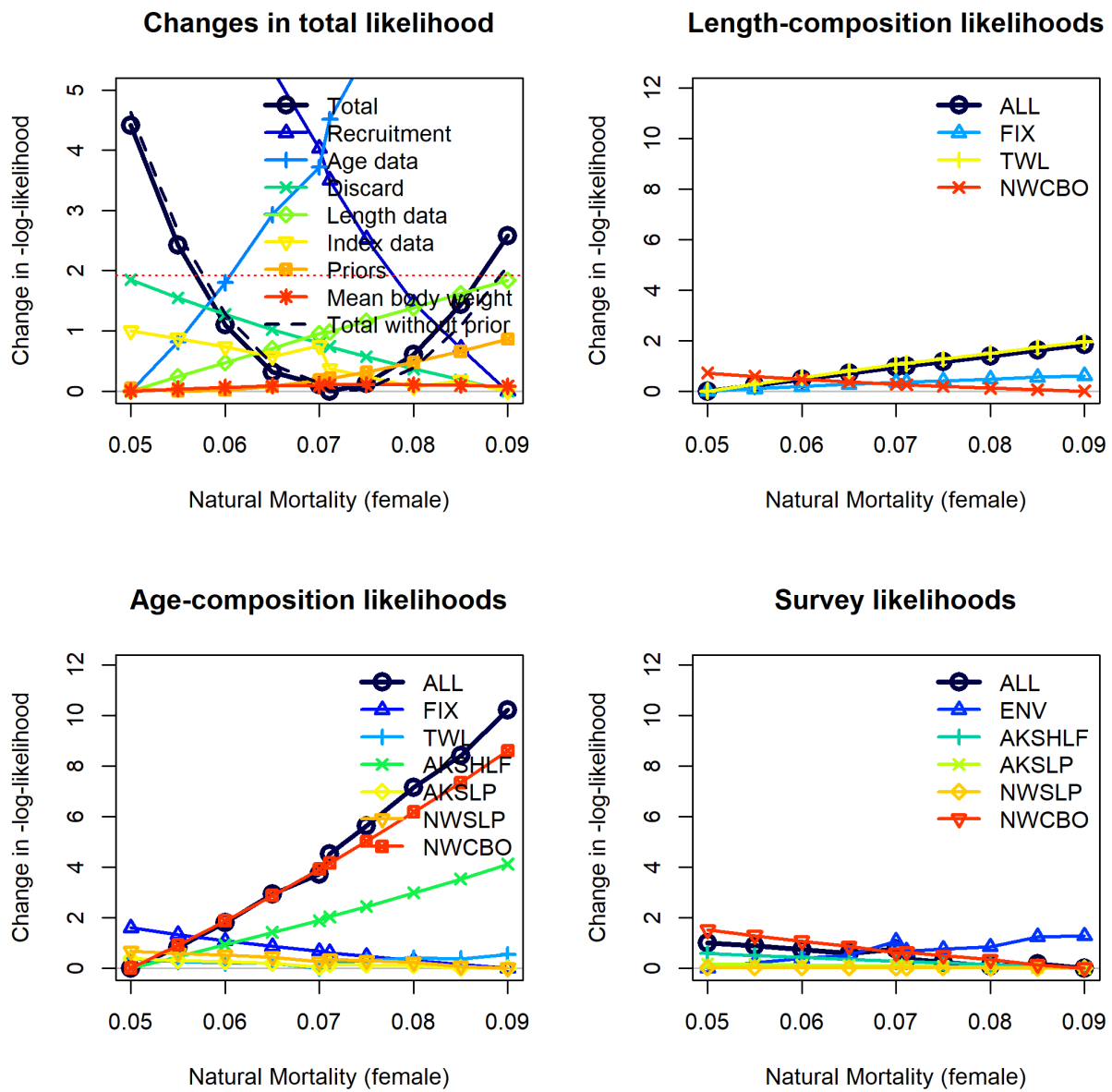


Figure 88: Change in the negative log-likelihood across a range of female natural mortality values.

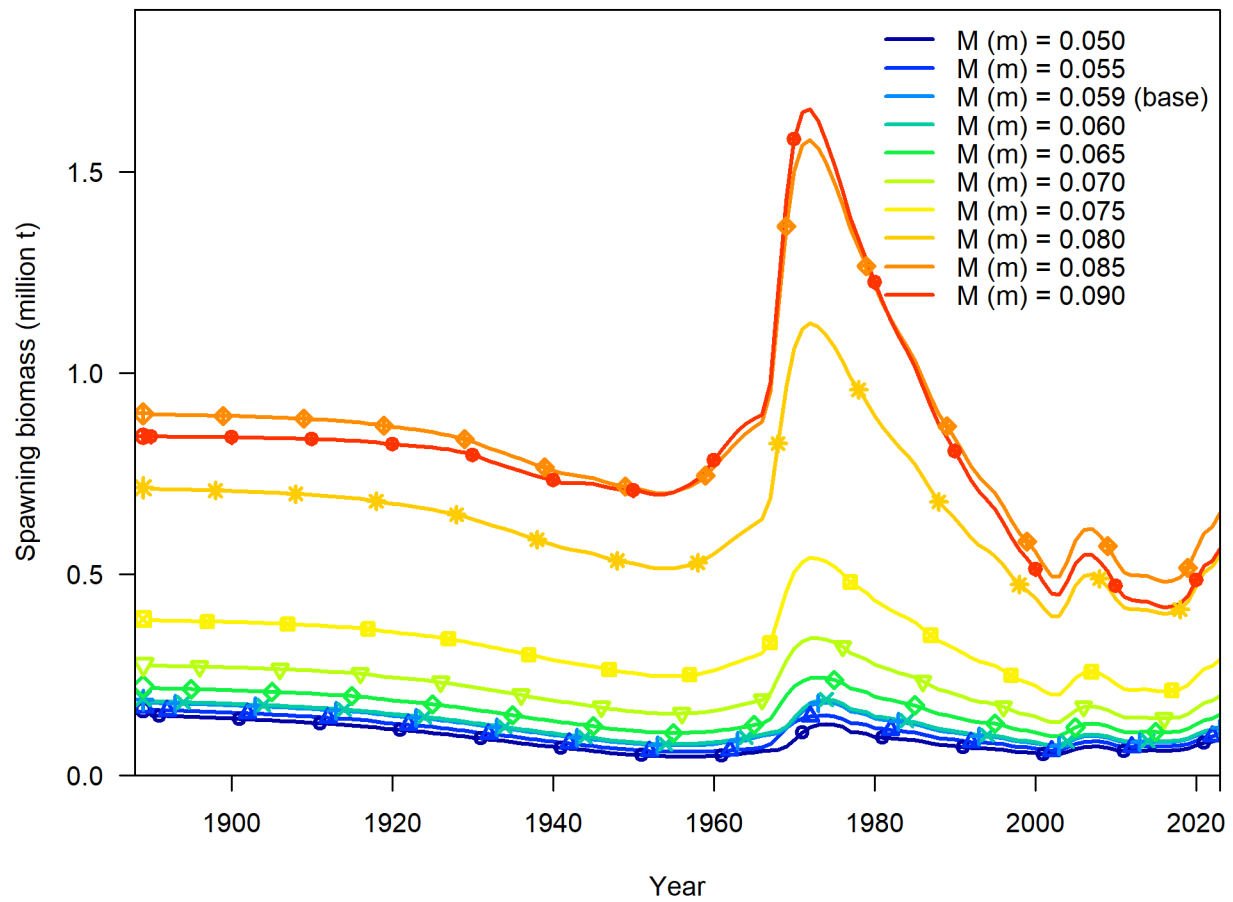


Figure 89: Change in the spawning biomass across a range of male natural mortality values.

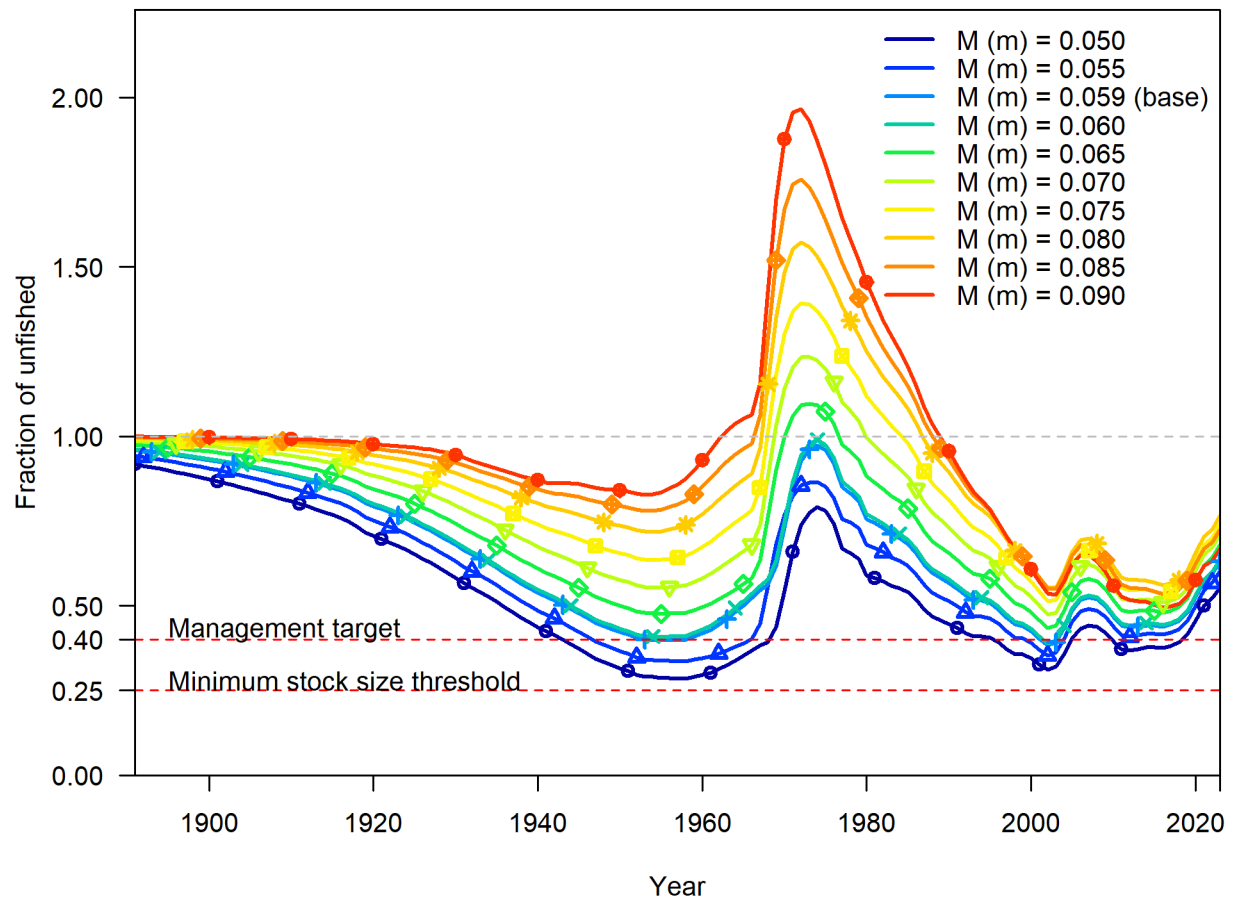


Figure 90: Change in the fraction unfished across a range of male natural mortality values.

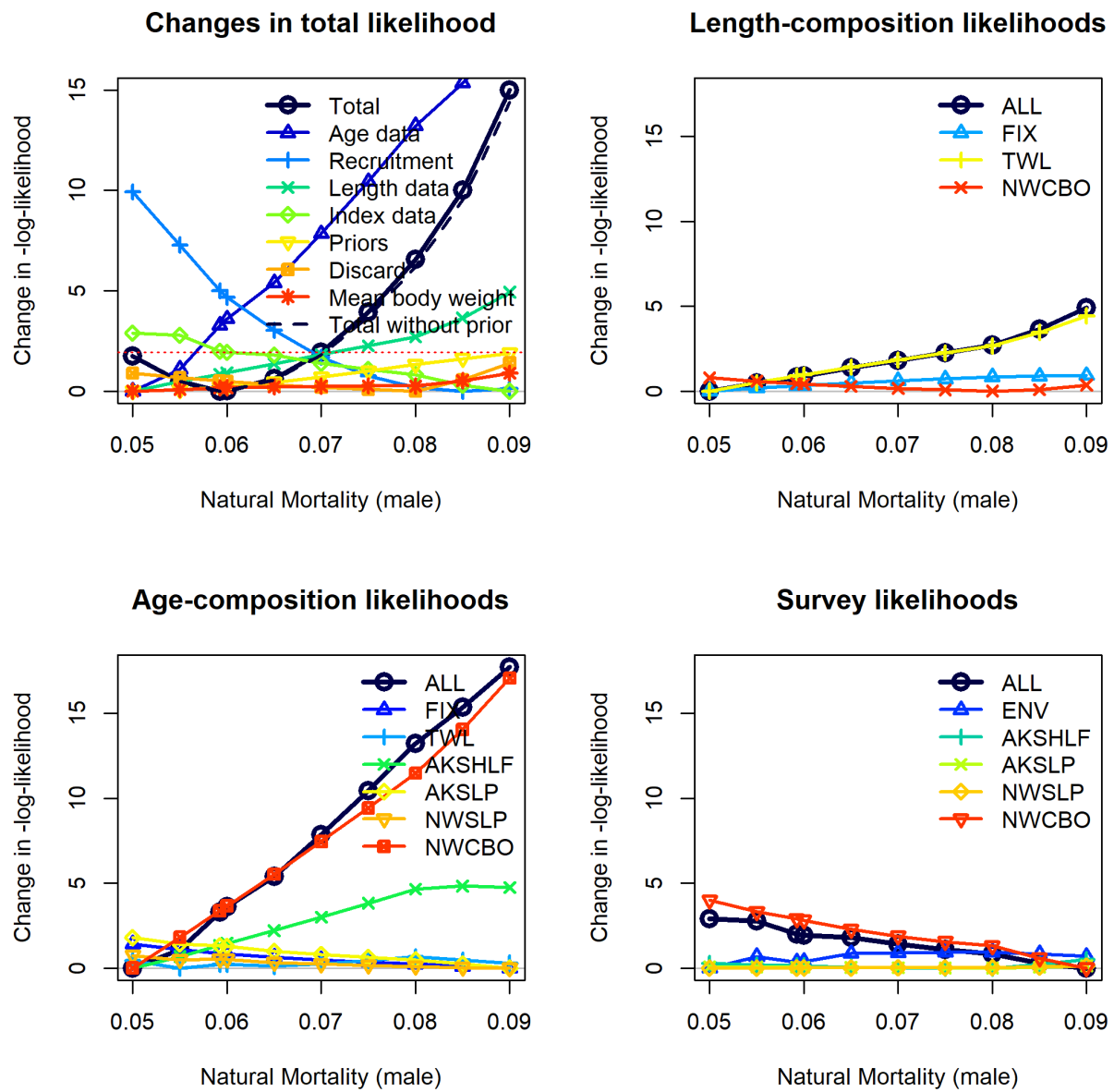


Figure 91: Change in the negative log-likelihood across a range of male natural mortality values.

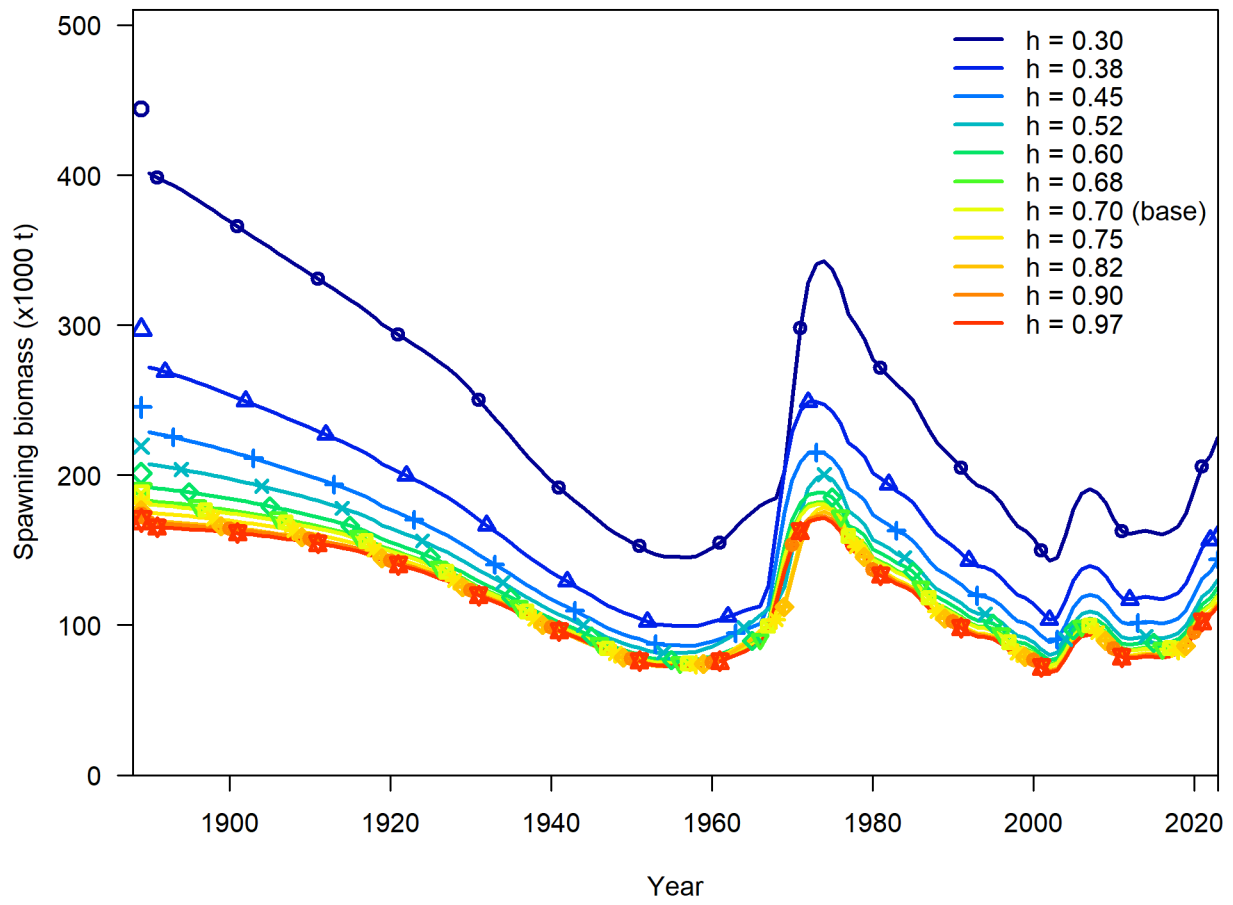


Figure 92: Change in the spawning biomass across a range of steepness values.

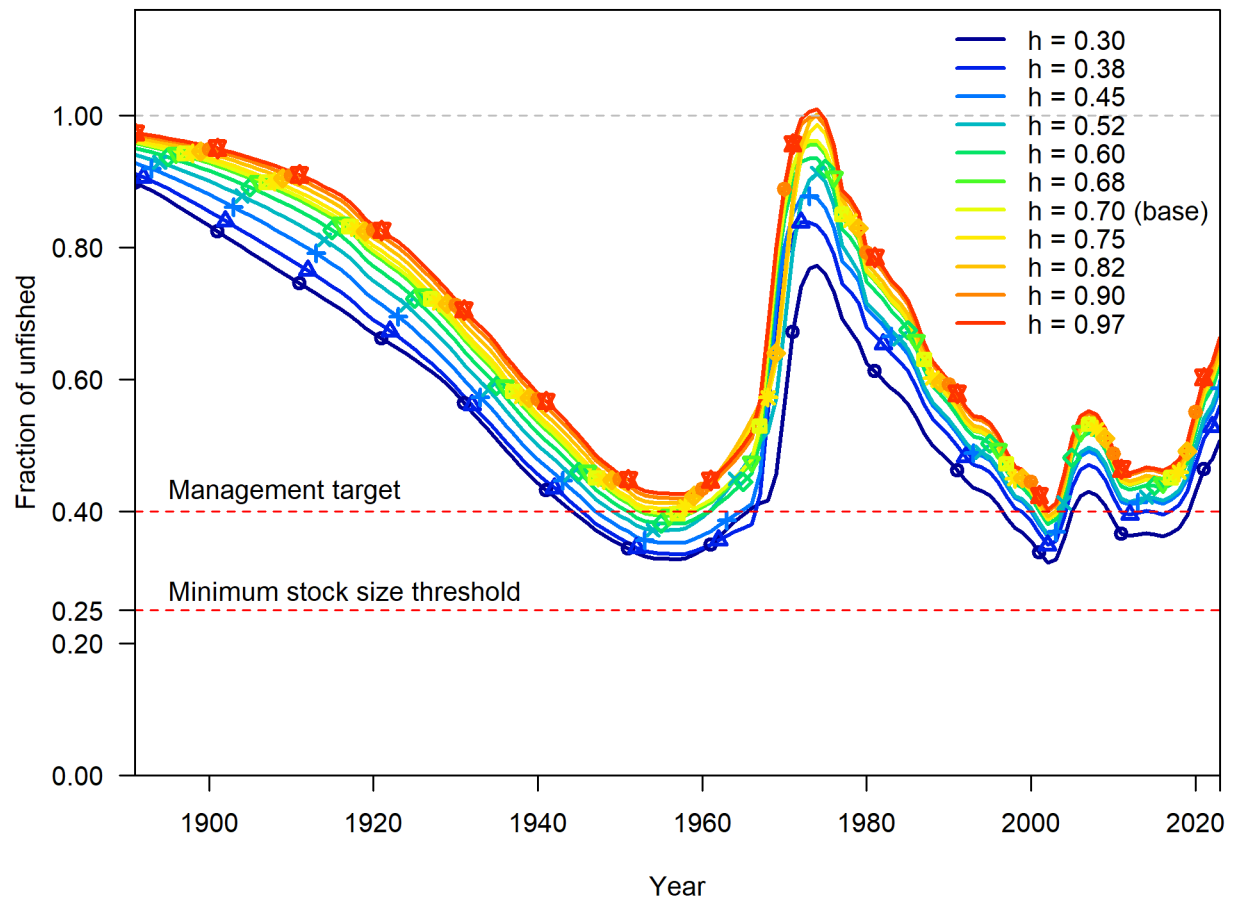


Figure 93: Change in the fraction unfished across a range of steepness values.

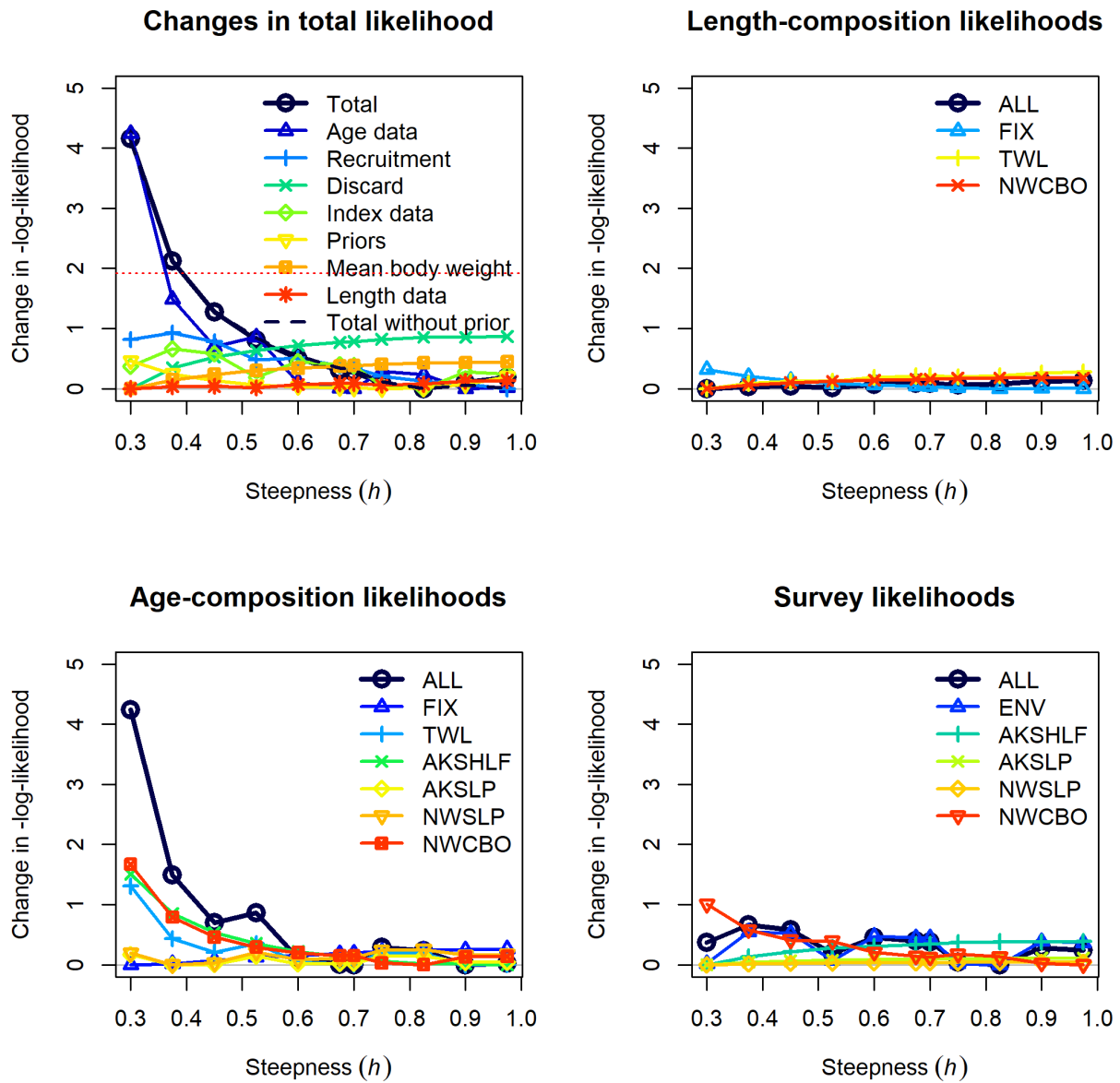


Figure 94: Change in the negative log-likelihood across a range of steepness values.

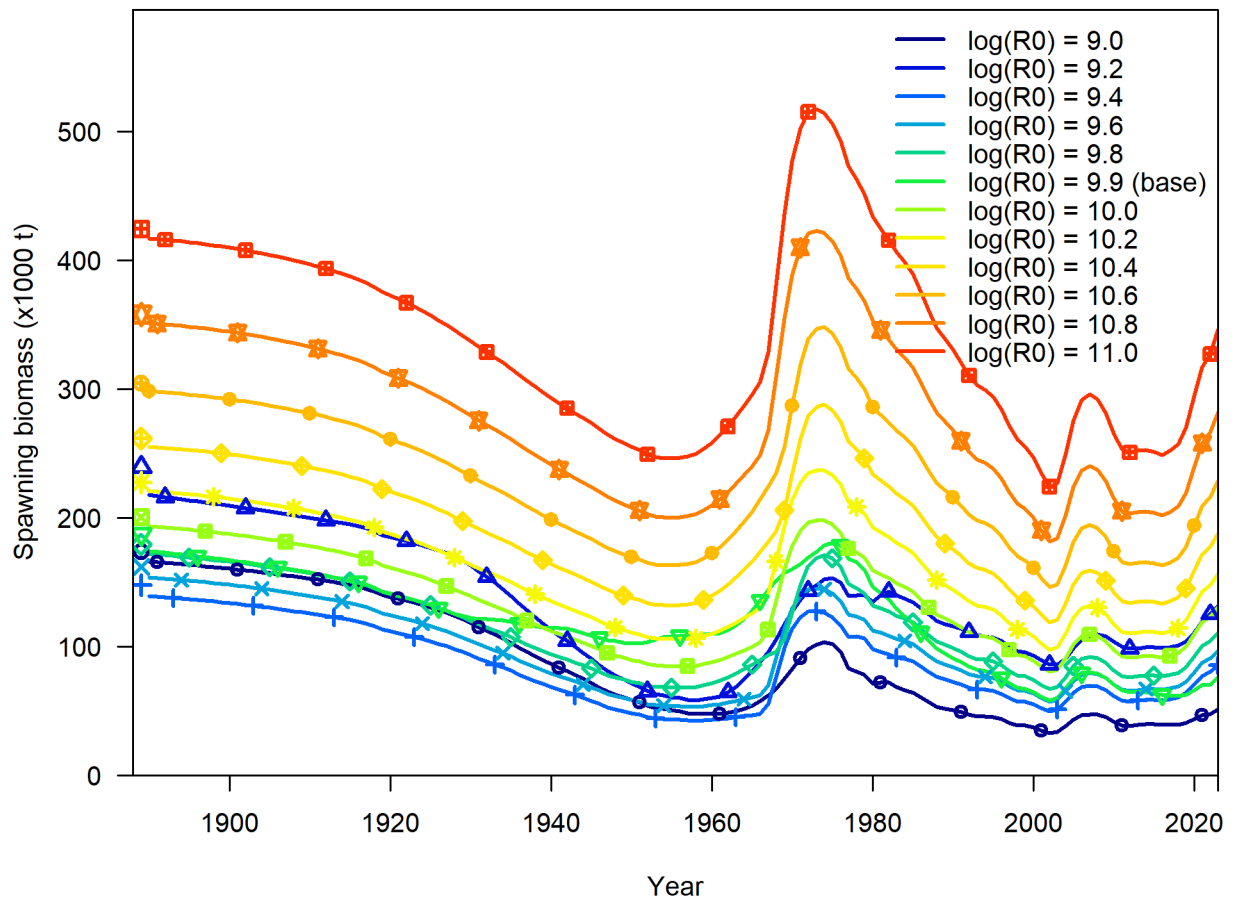


Figure 95: Change in the spawning biomass across a range of natural log of unfished recruitment values.

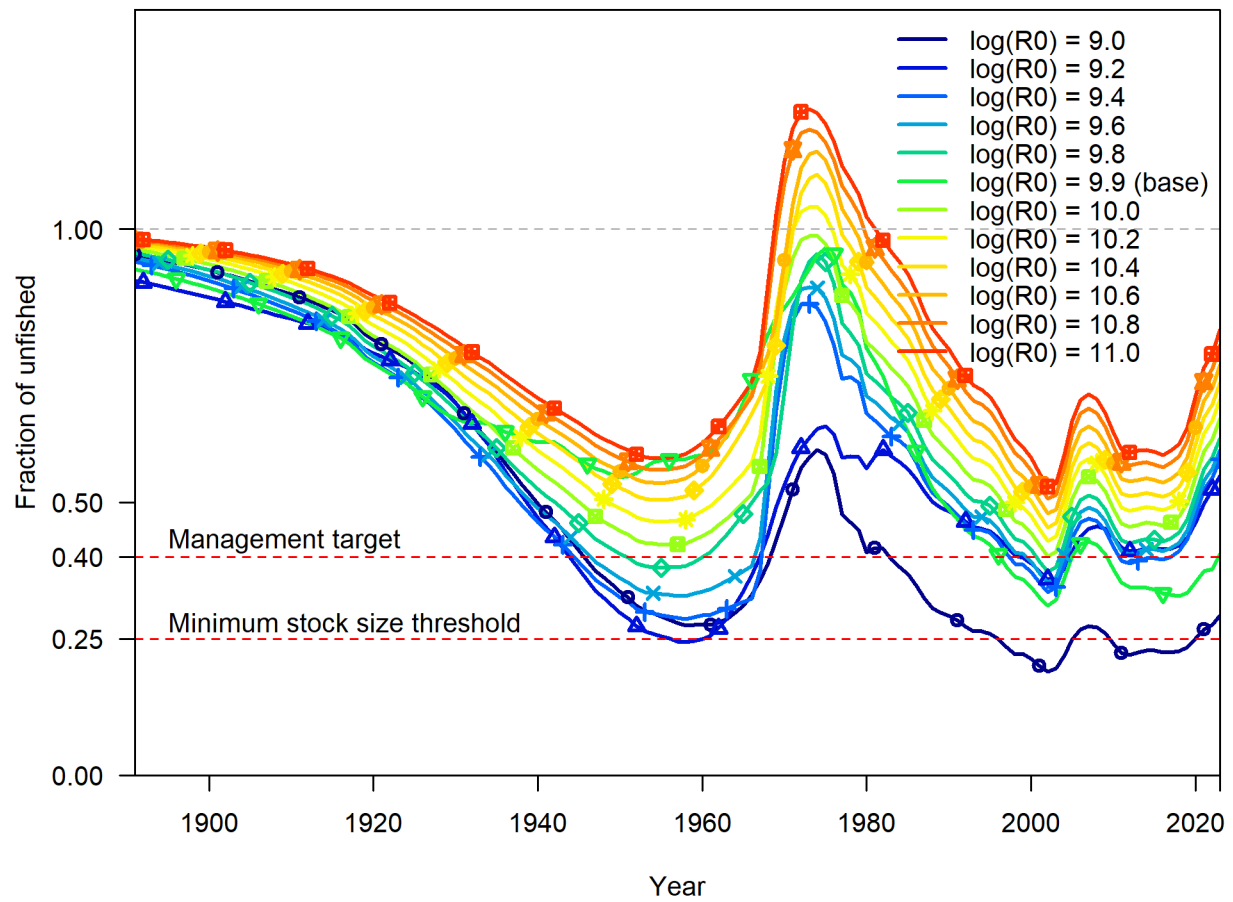


Figure 96: Change in the fraction unfished across a range of natural log of unfished recruitment values.

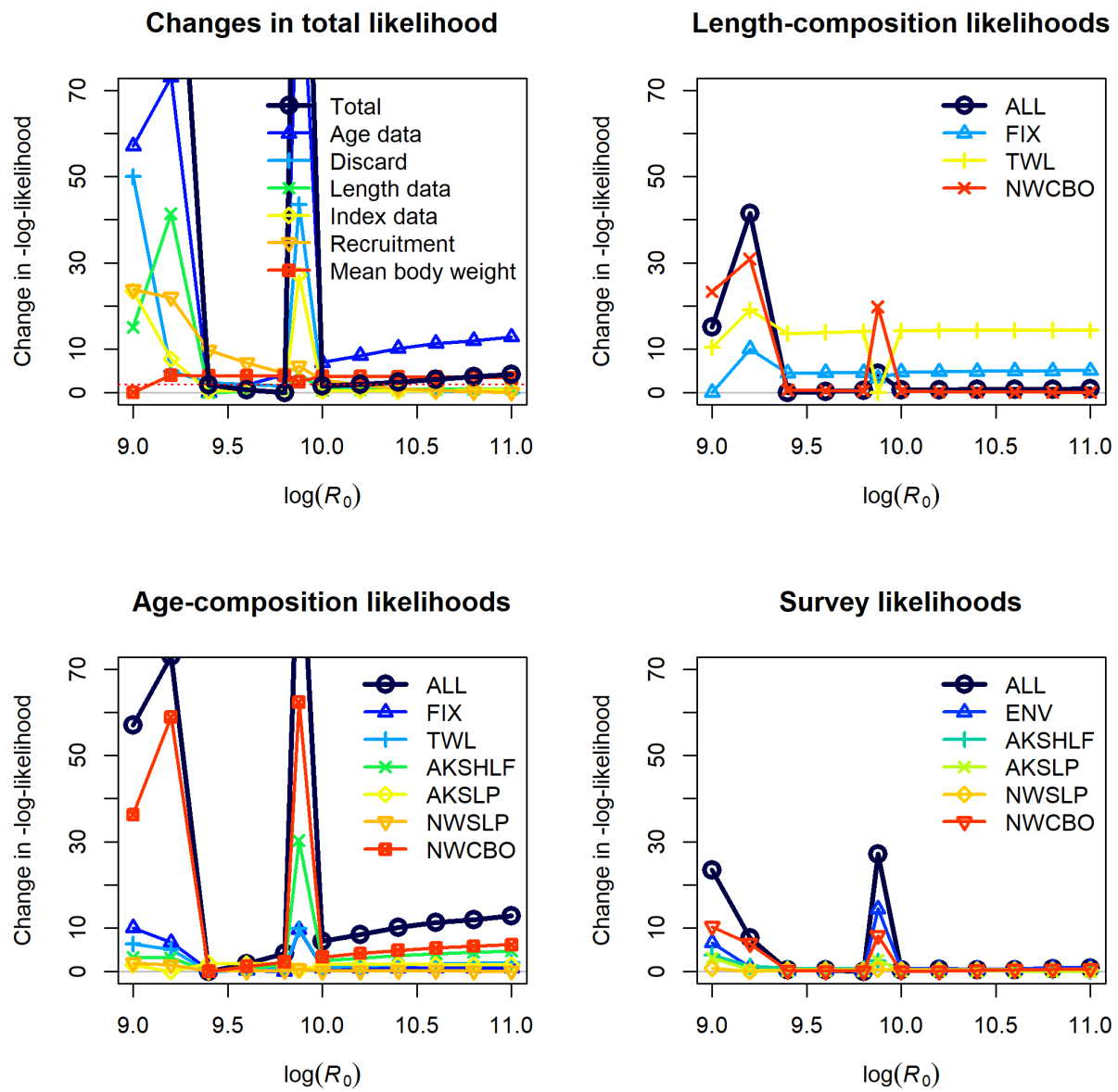


Figure 97: Change in the negative log-likelihood across a range of natural log of unfished recruitment values.

8.3 Reference Points and Projections

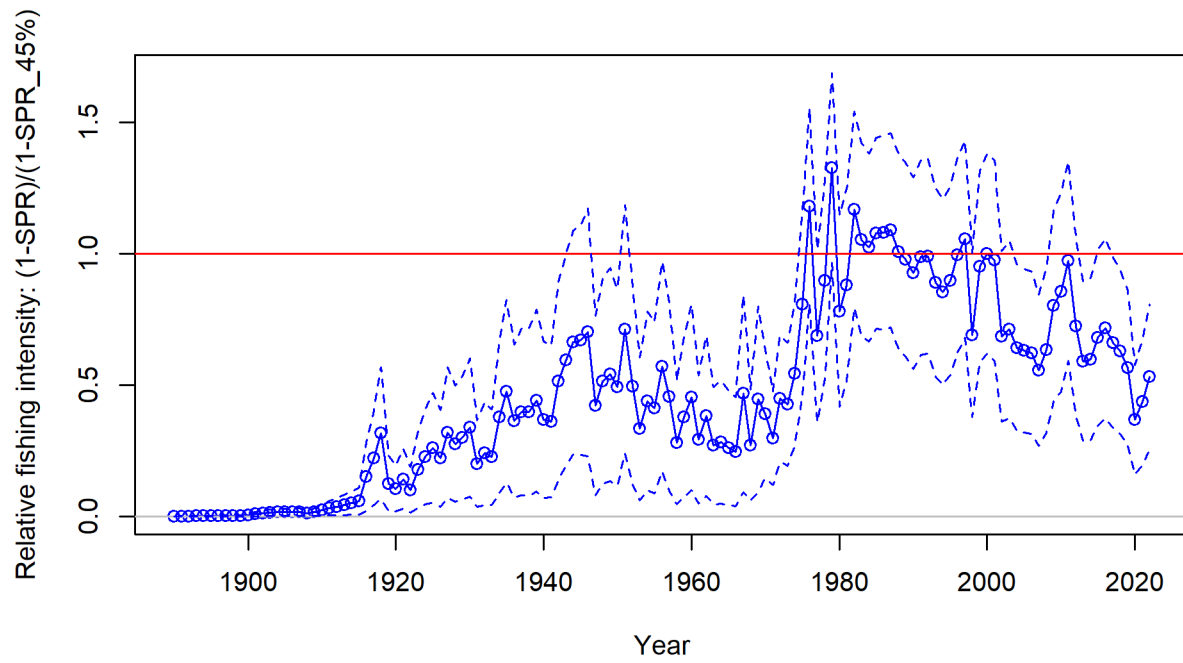


Figure 98: Time series of spawning potential ratio (SPR) ratio: $(1-SPR)/(1-SPR_{45\%})$.

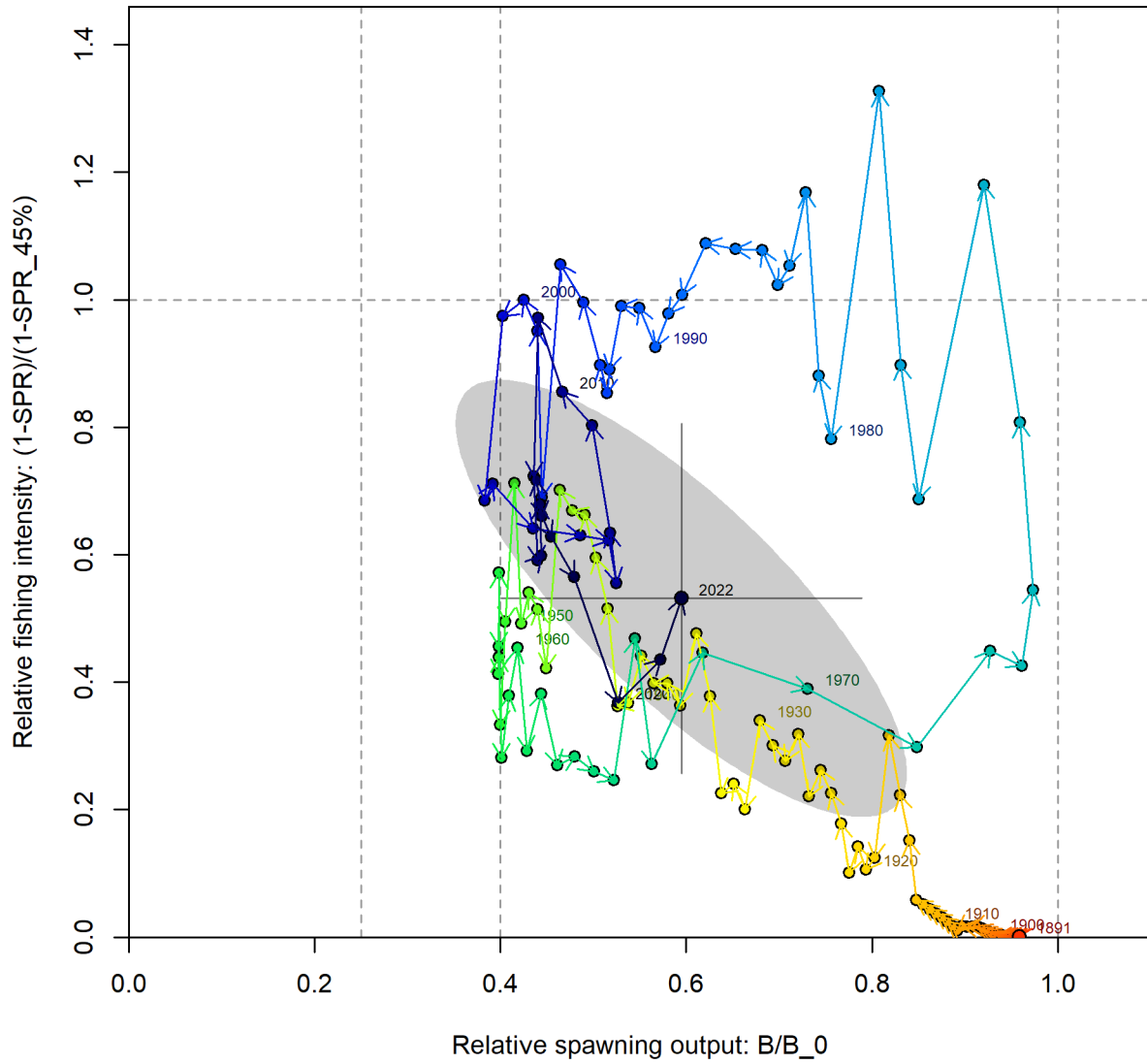


Figure 99: Phase plot of biomass ratio vs. SPR ratio. Each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Warmer colors (red) represent early years and colder colors (blue) represent recent years. Lines through the final point show 95 percent intervals based on the asymptotic uncertainty for each dimension.

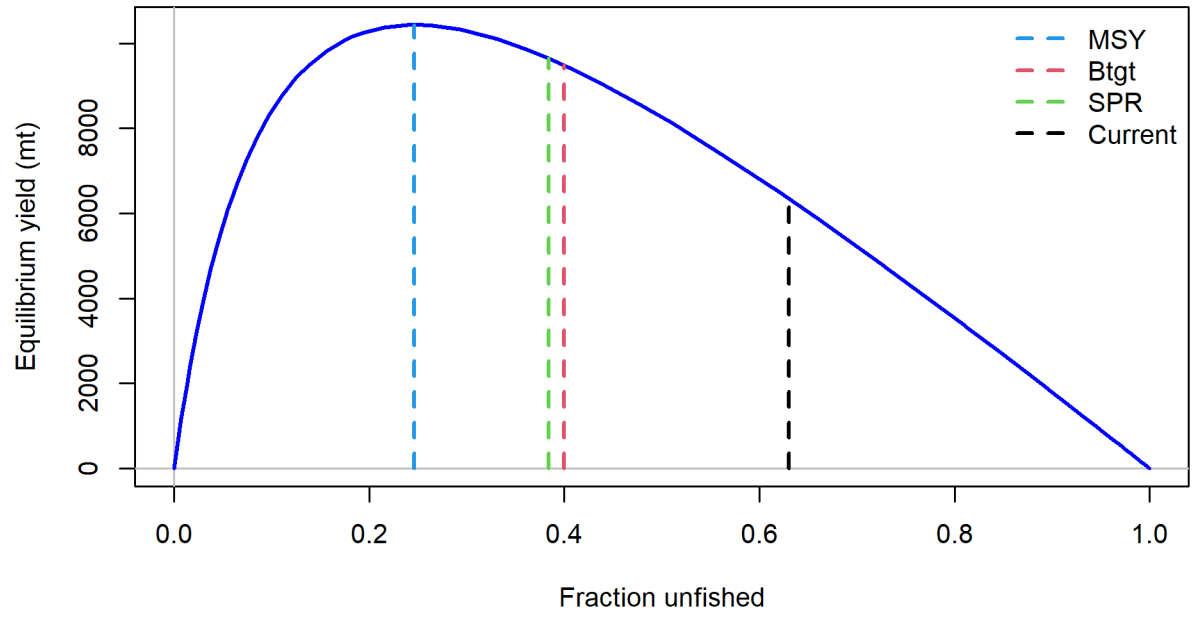


Figure 100: Yield curve with reference points.