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

by

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Executive Summary

Stock

This update assessment reports the status of sablefish (*Anoplopoma fimbria*) off the coast U.S. West Coast using data through 2022. The resource is modeled as a single population; 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 and 6,000 mt. Since the 2019 benchmark assessment (Haltuch et al. 2019), 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 that differ between stock assessments, even when the input landings remain unchanged, due to changes in parameters, priors, or parameterizations.

The landings in this update assessment 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, 1977–1982 landings from the catch reporting area that includes both U.S. and Canadian waters are now assigned equally to each country rather than 100% to the U.S. Third, a time series of sablefish catches from the Pacific Hake (*Merluccius productus*) At-Sea 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: Recent landings by fleet, total landings summed across fleets, and the total dead catch including discards for the model area.

Year	Fixed Gear (mt)	Trawl (mt)	Total Landings (mt)	Total Dead (mt)
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
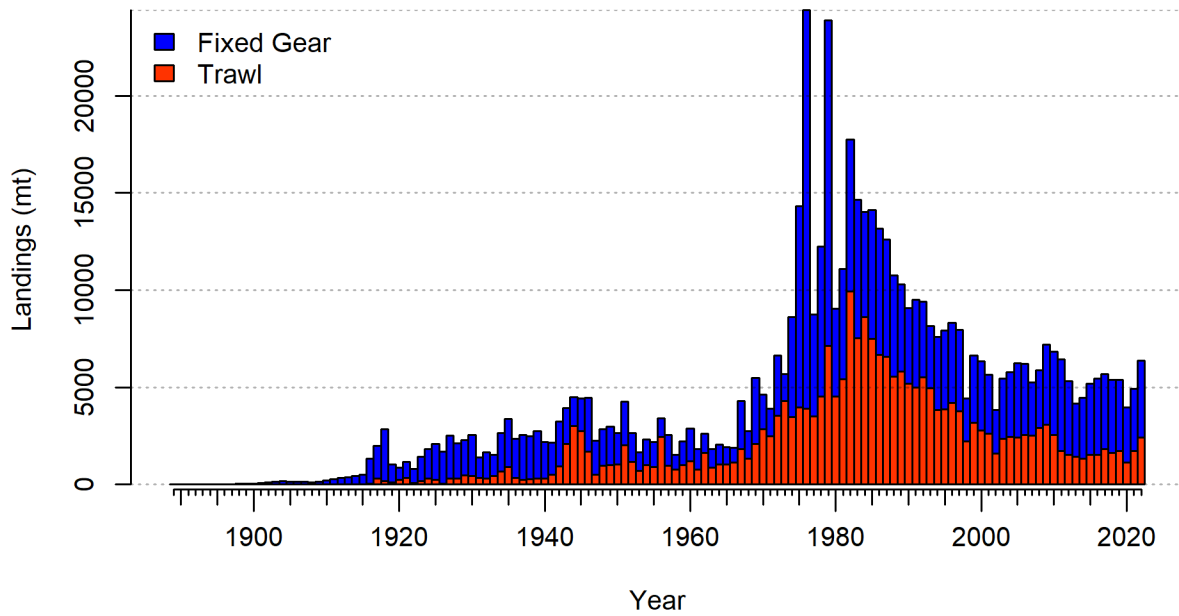
Figure i: Yearly landings (mt) for the fixed-gear (blue) and trawl (red) fleets.

Data and Assessment

The last benchmark stock assessment for sablefish took place in 2019 (Haltuch et al. 2019) and was followed by an update in 2021 (Kapur et al. 2021). This update assessment 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 update assessment and extended through 2022. No new age readings were conducted for the fishery collections. Data on discard rates and mean observed individual body weight of the discarded catch were updated, while 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 (Kapur et al. 2021). The relative index of abundance estimated using data from the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey, which samples depths between 55 and 1,280 m, represents the primary source of information regarding population trends and was updated and re-analyzed to include the most recent data. Length-composition and conditional age-at-length data were also updated for this survey to include the most recent data. Other, discontinued, survey indices also contribute information on trend and demographics. Historical surveys include the 1998–2002 Northwest Fisheries Science Center Slope Survey, 1984–2001 Alaska Fisheries Science Center Slope Survey, and 1980–2004 Alaska Fisheries Science Center/Northwest Fisheries Science Center West Coast Triennial Shelf Survey. Data from the historical surveys were not re-evaluated for this update assessment. Additionally, an environmental time-series of sea level informs 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 steepness (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 spawning biomass 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 spawning 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% interval 42.4%–83.6%) increasing from the 2021 (Kapur et al. 2021) estimate of 2021 fraction unfished of 58%.

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

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2013	81,988.90	32,289.31	131,688.49	0.44	0.29	0.59
2014	82,768.80	32,925.94	132,611.66	0.44	0.29	0.59
2015	82,489.80	32,955.83	132,023.77	0.44	0.29	0.59
2016	81,830.70	32,591.50	131,069.90	0.44	0.29	0.59
2017	82,908.10	32,989.58	132,826.62	0.44	0.29	0.60
2018	84,803.50	33,803.87	135,803.13	0.45	0.30	0.61
2019	89,431.60	35,948.49	142,914.71	0.48	0.32	0.64
2020	98,233.00	40,133.20	156,332.80	0.53	0.35	0.70
2021	106,760.00	44,563.09	168,956.91	0.57	0.38	0.76
2022	110,930.00	46,717.27	175,142.73	0.59	0.40	0.79
2023	117,519.00	49,642.51	185,395.49	0.63	0.42	0.84
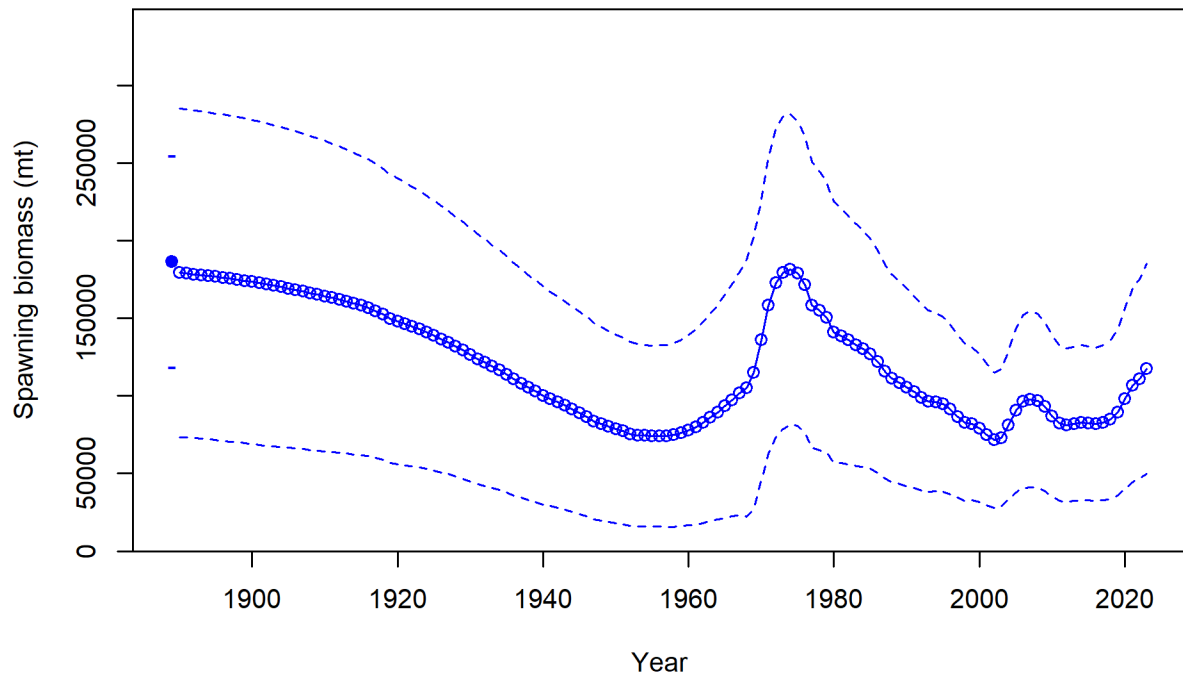
Figure ii: Estimated time series of spawning biomass (open circles) and 95% intervals (broken lines). Spawning biomass prior to the first modelled year (filled circle) and its 95% intervals (horizontal lines) are also shown.
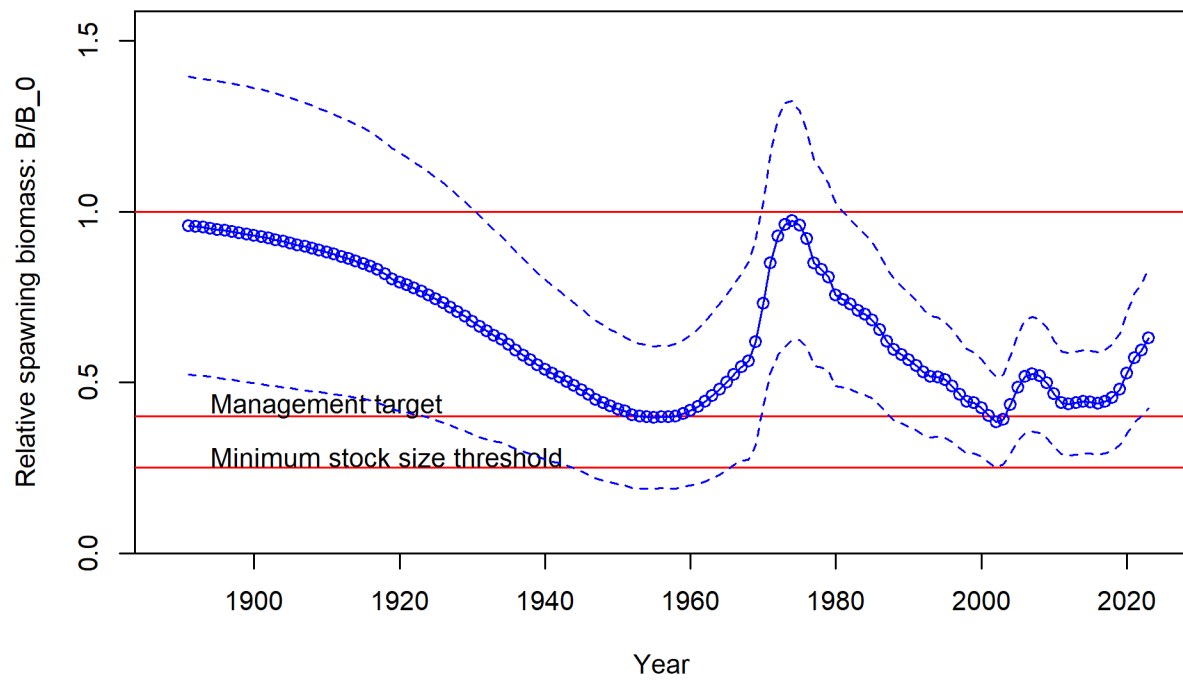
Figure iii: Estimated time series of fraction unfished in terms of spawning biomass (circles and line) and 95% intervals (broken lines). Horizontal, red lines at 1.0, the management target, and the minimum threshold are shown for reference.

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 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 biomass that subsequently declined throughout much of the 1970s. Some slightly large recruitments during the mid-1980s through 1990 slowed the rate of decline, with the 1999–2001 large recruitments leading to a leveling off in the decline. The above-average cohorts from 2008, 2013, 2015, 2016, 2020, and 2021 are contributing to the current increasing trend in spawning biomass (Table iii and Figure iv). The large recruitment events in 2020 and 2021 are estimated to be two of the three largest recruitment events in the modeled period (Figure iv).

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

Year	Recruit-ment (1,000s)	Lower Interval	Upper Interval	Recruit-ment Deviations	Lower Interval	Upper Interval
2013	37,796.80	21,711.81	65,798.20	1.704	1.47	1.93
2014	7,268.36	3,612.75	14,622.97	0.053	-0.44	0.55
2015	27,643.70	15,611.43	48,949.64	1.389	1.12	1.66
2016	66,059.40	37,936.71	115,029.59	2.262	2.03	2.49
2017	13,137.70	6,584.62	26,212.48	0.645	0.17	1.12
2018	3,955.65	1,547.01	10,114.44	-0.561	-1.39	0.27
2019	13,835.90	6,433.00	29,757.85	0.681	0.08	1.28
2020	154,839.00	82,091.73	292,052.75	3.078	2.73	3.43
2021	208,277.00	98,698.48	439,513.44	2.904	2.37	3.44
2022	9,122.34	1,396.42	59,593.20	-0.687	-2.97	1.60
2023	18,302.30	2,301.96	145,516.68	0.000	-2.74	2.74
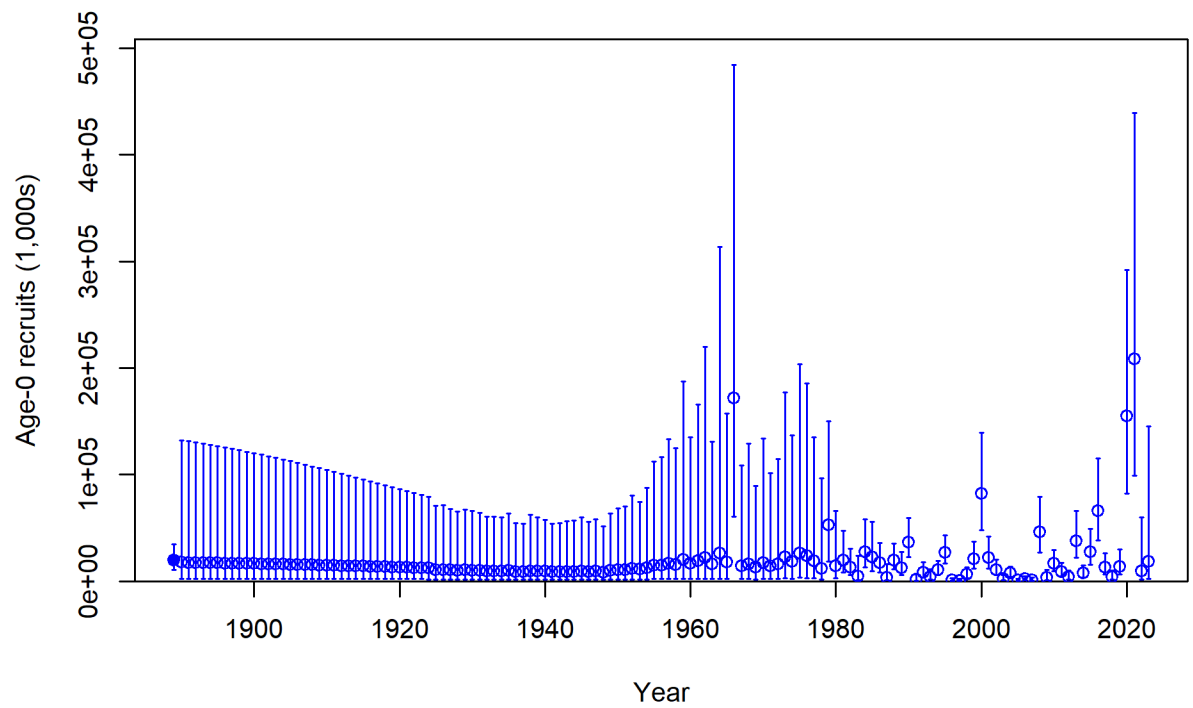
Figure iv: Estimated time series of age-0 recruits (1,000s; open circles) and 95% intervals (whiskers). The number of recruits in the year prior to the first modelled year (filled circle) is also shown.

Exploitation Status

Fishing intensity has been at or below the current management target of 1.0 and, on average, declining since 1988 (Table iv; Figure v). Here, fishing intensity is reported as a the ratio of one minus the spawning potential ratio to one minus the SPR target of 45%, $\frac{1-SPR}{1-SPR_{45\%}}$. Estimated exploitation for the most recent year was on par with 2015–2019 estimates 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 and the exploitation rate. Lower and upper values represent 95% intervals of the estimates.

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
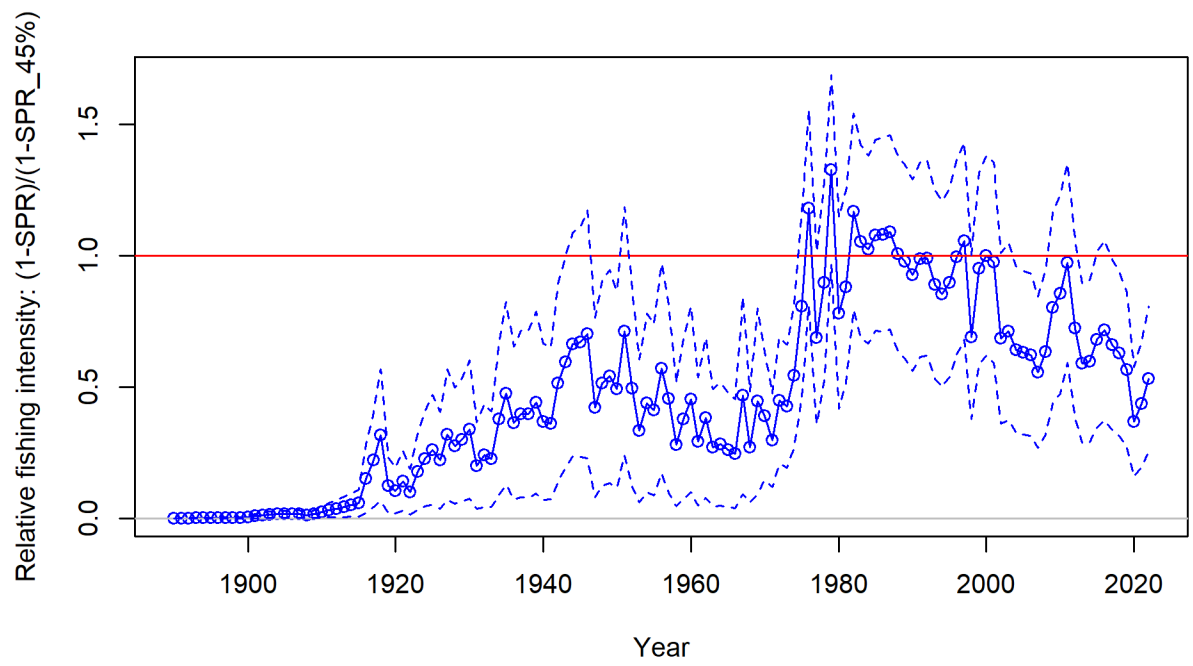
Figure v: Time series of relative fishing using $\frac{1-SPR}{1-SPR_{45\%}}$, where SPR is the spawning potential ratio and 45% is the target.

Ecosystem Considerations

The climate vulnerability analysis for the California Current (McClure et al. 2023) suggests that processes affecting sablefish recruitment are sensitive to climatic and, therefore, oceanic drivers. Given the high climate vulnerability of sablefish, changes in their abundance, productivity, and spatial distribution are likely, and these changes are likely to impact fishing fleets and communities because of the high value of this fishery. Strong coastwide recruitment appears to be associated with good recruitment north of Cape Mendocino ($\sim 40°$N), which itself is correlated with transport and temperature in the northern portion (40°–48°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.

Sablefish population has experienced latitudinal shifts in the center of their distribution along the U.S. West Coast, which has affected fishing opportunities to individual ports (Selden et al. 2019). The population centroid shifted to the north between 1980 and 1992, then south by 2013. More recently, the distribution of 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. Estimated fleet-wide entanglements were consistently above the 5-year running-average threshold in the 2002–2017 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 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 spawning biomass is 63%, well above the management target of 40%. 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 $SPR_{45\%}$ is 9,641.13 mt. The spawning biomass equivalent to 40% of the unfished spawning biomass ($SB_{40\%}$) calculated using $SPR_{45\%}$ 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.

Reference Points	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	186,534.000	118,407.808	254,660.192
Unfished Age 4+ Biomass (mt)	458,971.000	280,172.306	637,769.694
Unfished Recruitment (R_0)	19,453.900	7,838.526	31,069.274
2023 Spawning Biomass (mt)	117,519.000	49,642.507	185,395.493
2023 Fraction Unfished	0.630	0.424	0.836
Reference Points Based $SB_{40\%}$	NA	NA	NA
Proxy Spawning Biomass (mt) $SB_{40\%}$	74,613.600	47,363.045	101,864.155
SPR Resulting in $SB_{40\%}$	0.464	0.464	0.464
Exploitation Rate Resulting in $SB_{40\%}$	0.043	0.035	0.050
Yield with SPR Based On $SB_{40\%}$ (mt)	9,477.830	4,432.471	14,523.189
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Biomass (mt) ($SPR_{45\%}$)	71,629.000	45,468.577	97,789.423
$SPR_{45\%}$	0.450	NA	NA
Exploitation Rate Corresponding to $SPR_{45\%}$	0.045	0.037	0.053
Yield with $SPR_{45\%}$ at SB SPR (mt)	9,641.130	4,509.219	14,773.041
Reference Points Based on Estimated MSY	NA	NA	NA
Spawning Biomass (mt) at MSY (SB MSY)	45,903.500	29,025.251	62,781.749
SPR MSY	0.327	0.324	0.330
Exploitation Rate Corresponding to SPR MSY	0.069	0.057	0.082
MSY (mt)	10,431.200	4,881.895	15,980.505

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	7,116	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 update assessment 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, because 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 year classes that have been observed more, a problem 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, be 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 these 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 M, selectivity, and historical recruitments, are estimated within the 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, which is dominated by shifts in recruitment strength, is closely linked to productivity regimes in

the California Current. Studies of oceanographic drivers of sablefish recruitment explain between 25% and just over 50% 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 as 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 and to the north of the survey extent. 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 2023 update assessment for sablefish off the U.S. West Coast was assigned a category 1 determination by the Scientific and Statistical Committee to the PFMC. 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 Catchs that are substantially higher than those set for 2023–2024.

Table vii: The adopted 2023–24 overfishing limit (OFL; mt), annual catch limit (; mt), and assumed removals (mt) and the projected OFL (mt), Acceptable Biological Catch (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 Re-movals	OFL	ABC	Spawn-ing Biomass	Fraction Unfished
2023	11,577.00	10,824.00	9,118.00	NA	NA	117,519.00	0.63
2024	10,670.00	9,923.00	8,359.00	NA	NA	141,875.00	0.76
2025	NA	NA	NA	39,085.30	36,544.69	183,592.00	0.98
2026	NA	NA	NA	37,310.40	34,698.66	207,142.00	1.11
2027	NA	NA	NA	34,160.00	31,632.18	214,059.00	1.15
2028	NA	NA	NA	29,701.30	27,384.65	210,719.00	1.13
2029	NA	NA	NA	25,318.50	23,217.10	203,091.00	1.09
2030	NA	NA	NA	21,811.90	19,914.27	194,403.00	1.04
2031	NA	NA	NA	19,379.70	17,616.13	185,924.00	1.00
2032	NA	NA	NA	17,842.70	16,129.76	177,993.00	0.95
2033	NA	NA	NA	16,898.00	15,208.22	170,621.00	0.91
2034	NA	NA	NA	16,280.60	14,587.40	163,747.00	0.88

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).

Table viii: Decision table with projections of spawning biomass (SB; mt) and fraction unfished (SB / unfished SB) based on harvest control rules (HCRs; rows) and states of nature (columns). Annual catch limits (ACLs; mt) for each HCR were defined using an estimate of uncertainty (i.e., P^*). Italics indicate years were the full catch could not be removed from the low state of nature because of insufficient biomass. Catches are total dead biomass, i.e., dead discard plus catch. Low (columns 4–5) and high (columns 8–9) states of nature are based on the terminal SB $\pm$ 1.15 of the base model (columns 6–7) SB standard deviation and the resulting unfished recruitment was used for the projections. Results are conditioned on the first two years of catches, provided by the GMT, being achieved exactly. The alternative catch stream is based on P^* of 0.40, where the agreed-upon buffer level is $P^* = 0.45$.

HCR	Year	Catch	SB	SB/SB$_0$	SB	SB/SB$_0$	SB	SB/SB$_0$
P*0.45	2023	9,118	81,817	0.558	117,519	0.630	166,569	0.699
	2024	8,359	98,275	0.670	141,875	0.761	201,559	0.846
	2025	36,545	126,884	0.865	183,592	0.984	260,780	1.095
	2026	34,699	139,748	0.953	207,142	1.110	299,826	1.258
	2027	31,632	140,726	0.959	214,059	1.148	316,170	1.327
	2028	27,385	134,879	0.919	210,719	1.130	317,238	1.331
	2029	23,217	126,680	0.864	203,091	1.089	310,681	1.304
	2030	19,914	118,407	0.807	194,403	1.042	301,045	1.264
	2031	17,616	110,823	0.755	185,924	0.997	290,498	1.219
	2032	16,130	104,008	0.709	177,993	0.954	279,948	1.175
	2033	15,208	97,837	0.667	170,621	0.915	269,750	1.132
	2034	14,587	92,167	0.628	163,747	0.878	260,043	1.091
P*0.40	2023	9,118	81,817	0.558	117,519	0.630	166,569	0.699
	2024	8,359	98,275	0.670	141,875	0.761	201,559	0.846
	2025	34,121	126,884	0.865	183,592	0.984	260,780	1.095
	2026	32,403	140,789	0.960	208,215	1.116	300,856	1.263
	2027	29,541	142,970	0.975	216,375	1.160	318,395	1.336
	2028	25,560	138,237	0.942	214,180	1.148	320,570	1.345
	2029	21,658	130,948	0.893	207,470	1.112	314,913	1.322
	2030	18,524	123,368	0.841	199,462	1.069	305,950	1.284
	2031	16,328	116,321	0.793	191,492	1.027	295,908	1.242
	2032	14,929	109,939	0.749	183,955	0.986	285,747	1.199
	2033	14,023	104,121	0.710	176,892	0.948	275,849	1.158
	2034	13,283	98,767	0.673	170,287	0.913	266,400	1.118

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 populations 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 have 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 a 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 ($\sim$ 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

Only data sources (Figure 1) with recently collected information were updated within this update assessment, which followed a more limited approach to updating data compared to a typical update assessment as agreed upon by the Pacific Fishery Management Council (PFMC) on 23 April 2023. Therefore, only the following data sources were updated for this update assessment:

1. The adding of recent 2021–2022 commercial landings to the model identified three issues in the landings data for the 2021 update assessment, which likely extended to previous assessments as well. First, select landings from Pacific Fisheries Information Network (PacFIN) were omitted. These landings have been added to this update assessment (see section refcommercial-landings for additional information). Second, landings from 1977–1982 in the catch reporting area that includes both U.S. and Canadian waters are now assigned 50–50% to the respective countries rather than 100% to the U.S.A. Finally, previous assessments failed to include bycatch of sablefish from the Pacific Hake (*Merluccius productus*) At-Sea Fishery in the base model. Annual bycatch of sablefish is typically low but can experience sharp increases following years with large recruitment events (e.g., 304 mt in 2022).

2. The discard mean weights and length compositions from discarded fish observed by 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 to 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 update assessment.

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 for this update assessment.

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 1980–2011 landings sum to approximately 4,060 mt. Second, 1977–1982 landings from 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. waters. More specific information for both of these changes is not reported here given confidentiality rules. Both of these changes were approved by state representatives prior to their use in this assessment.

This update assessment also includes data on bycatch of sablefish by the Pacific Hake At-Sea 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 used in the 2019 benchmark and 2021 update assessments. Across most years the bycatch of sablefish in the Pacific Hake At-Sea 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 seems to correspond to one or two year after strong sablefish recruitment events (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 trawl landings during the bridging process. The full time series, i.e., back to 1978, was not available for this update assessment. Future assessments will want to include the full time series.

2.1.2 Commercial Discard

WCGOP estimates of commercial discards and biological data from 2020 and 2021 were added to the update assessment model. The 2021 update assessment process experienced challenges while adding the 2019 discard data, which appeared to depart in the frequency of sablefish being discarded and the size of discarded fish, requiring a new retention block for the trawl and fixed-gear fleets for 2019 and 2020. Including the most recent WCGOP data in this update assessment 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 between 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 for this update assessment.

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 weight of discarded fish by the trawl fleet has been declining annually 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 cm and 60 cm, peaking around 50–55 cm (Figure 7). In contrast, the lengths discarded by the trawl fleet were generally smaller (e.g., 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

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Center Slope Survey (Slope Survey), and Northwest Fisheries Science Center Slope Survey (NWFSC Slope Survey) were not re-evaluated for this update assessment. See Haltuch et al. (2019) and Kapur et al. (2021) for details on these data and how the were processed.

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 between 55 m and 1,280 m in depth (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 and early October. Only two vessels were used in 2019 and three in 2013, with one of the three in 2019 unable to complete its pass due to a government shutdown. No survey occurred in 2020 due to Coronavirus disease (COVID-19). The design 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 Canadian borders. Note that the Survey is not permitted to access the Cowcod Conservation Areas (CCAs) in Southern California.

Sablefish are observed across the full range of depths (Figure 9) and latitudes (Figure 10) sampled by the WCGBTS. Across most years, there are at least 400 annual positive tows of sablefish (see Supplementary csv files for sample sizes). A coastwide relative index of abundance was estimated for sablefish using the Species Distribution Modeling platform written in Template Model Builder (TMB) (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 and 2021 update assessments. The relative index of abundance for sablefish decreased to the lowest levels between 2008 and 2010, begun to slowly increase between 2011 and 2019, and then sharply increased from 2021 to 2022 to the highest estimated for the time series (Figure 12).

Length and age samples collected annually during the WCGBTS were processed using 2 cm length bins between 18 cm and 90 cm and age bins between 0 and 50 years. The length compositions were expanded to the tow level and strata level (see Supplementary csv files for strata specifications). The same stratification was used for their expansion as was used in the 2019 benchmark and 2021 update assessments. The age data were included as conditional-age-at-length data to better inform the internal estimation of growth than can be done using marginal age data. Input sample sizes for the conditional-age-at-length data were the annual number of fish sampled for both age and length.

The 2021 and 2022 length compositions for fish less than 30 cm indicate potentially multiple above average recruitments entering the population (Figure 19). The 2021–2022 age data also indicate above average observations of fish from the 2021 and 2020 cohorts (Figure 14). Across all years, age-0 fish were observed more frequently during the second pass of the survey compared to the first pass, with age-0 fish generally measuring less than 30 cm (Figure 13). The size of age-1 fish generally ranged between 30 cm and 45 cm, with sizes increasing from pass 1 to pass 2. The distribution of age-1 fish size observed in 2021 and 2022 was more variable compared to most other years. Additionally, the distribution of sizes in age-1 fish varied between 2021 and 2022, with age-1 fish being slightly smaller by pass in 2022 compared to 2021.

2.2.2 Environmental Indices

Research and assessments of sablefish during recent decades have examined the relationship between sea level, measured via tide gauges, and 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 used in the 2019 assessment (Figure 20).

2.3 Biological Data

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

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

The Groundfish Subcommittee recommended that "research around density dependent growth be prioritized'', which was outside of the scope of this update assessment and will thus need to be a priority between now and the next benchmark assessment, particularly for years with large recruitment events.

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 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 model is discussed in Section 3.2.3. The R package r4ss, version 1.49.1, 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 Pacific Hake At-Sea 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 WCGBTS relative index of abundance 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 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 updated versions of numerous R packages related to processing input and output files for the assessment, including *nwfscDiag*, *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 model is sex-specific, including the estimation of sex-specific growth curves and natural mortality parameters. 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 beginning of the plus group. The data use a plus-group age of 50 years because there is little growth occurring at the model plus-group age and very few observations.

3.2.5 Priors

The prior distributions for sex-specific natural mortality (M) remained 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 years for males. The priors were followed 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 (see equation TA1.8 in Francis 2011) was used with three iterations to tune the length and age data simultaneously (Table 3). For conditional-age-at-length data, it was assumed that each age was a random sample within the length bin, and thus, the model started with a sample size equal to the number of fish in that length bin. A sensitivity is included to examine differences in parameter estimates when data weighting was implemented using the McAllister–Ianelli method (McAllister and Ianelli 1997), which is based on the harmonic mean.

Additional variance was estimated and added to the input variance for the following three relative indices of abundance: 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 in a sensitivity and

determined to be different than zero but was not included in the base model because it was not included in the last full assessment.

Added variances for discard rates and mean body weights were iteratively calculated using the root mean square error (RMSE) of differences between input and estimated values derived from SS3. These 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 M; 4 parameters for the extra variability of survey indices; 45 parameters for age-based selectivity and length-based retention; 163 recruitment deviations (including 30 pre-model deviations); and 10 forecast recruitment deviations, which were fixed at 0 (Table 2).

The stock-recruitment relationship follows a Beverton–Holt parameterization with steepness (h) fixed at 0.70 due to the largely one-way trip nature of the time series during the period with good data collection 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 under estimates the uncertainty in MSY and equilibrium yield. However, the importance of this reduced uncertainty is somewhat reduced because both and 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. Model results suggest that recruitment may be more variable but since the 2019 assessment the input value for this parameter has not changed.

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 to be 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 assessment 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 stock size and status. Potential shifts in the spatial distribution of sablefish 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 $M = 0.071$ yr^{-1}, male $M = 0.059$ yr^{-1}, and $R_0 = 9.876$ (Table 2). Females were estimated to grow 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). Yet, the sexes were estimated to have 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. Sex-specific selectivity for the fixed-gear fleet was estimated to be higher for female fish compared to male fish. 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 female selectivity curve for the fixed-gear fleet was further to the right than all other estimated selectivity peaks (Figure 33) indicating that this fleet selected older females compared to the other fleets. This was not surprising given that only 21 fish ages 0–1 were identified in samples taken from the fixed-gear fleet.

This update assessment added recent, 2020–2021, WCGOP data (discard rates, mean weights, and lengths) to better inform 2019–2022 retention. 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 2019–2022 fixed-gear retention curve suggests that a decreased proportion (< 1.0) of fish were retained across all sizes relative to the previous 2011–2019 time block (Figures 34–36).

A single, rather than sex-specific, selectivity curve was estimated for the trawl fleet with four fixed parameters, one estimated time-invariant parameter, and one time-varying parameter. The trawl fleet selects the largest range of ages compared to all other fleets in the model. The initial age of peak selectivity for the for the trawl fleet was fixed at 1.0. The time-varying width of the descending limb has been fixed for the early period (1890–1981) since the 2019 model. This update assessment also fixed it at the upper bound (8.7) in the terminal time block (2011–2022) because it was consistently estimated at the bound during the bridging analyses. As time progressed in the model period, the estimate of the descending limb of the selectivity curve increased across time blocks indicating the selection of an increasing proportion of older fish with time. The retention curve shifted rightward in the final time block (2019–2022) compared to the previous time block (2011–2018) (Figures 34, 37, and 38).

Selectivity for the Triennial Survey indicates that this survey selected the least amount of older fish relative to the other surveys and fleets, descending to a near-zero selectivity at about the same age, age 4–5, as the

peak in the fixed-gear fleet (Figure 33). Selectivity was sex-specific for this survey, with male selectivity being 84 percent of female selectivity at age zero and 0 percent of female selectivity at the maximum age (Figure 33). Although, female selectivity at approximately 5 years and older was small in its own right.

The time- and sex-invariant selectivities for the slope surveys were similar to estimates from previous models, 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 the youngest fish of all the fleets and surveys (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 update assessment. 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. During this assessment, some of these difficult to estimate parameters were fixed a their bounds. These general behaviors were also encountered in the 2019 assessment and resulted in a number of selectivity parameters being fixed during model development due to poor estimation behavior at that time. These issues indicate that selectivity may be overparameterized. The next benchmark assessment should explore simplifying selectivity as well as explore alternative parameterizations. 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 to fit the model (Table 2). 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. In this sensitivity, the added variance allowed to model to not fit the final two survey data points (2021 and 2022) that show a sharp increase relative to the 2019 data point.

Annual recruitment deviations (Table 2; Figure 39) was estimated to be the highest in the following ten years: 2020, 2021, 2000, 1966, 2016, 2008, 1979, 2013, 1990, and 2015, in order from largest to smallest. 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 fourth largest estimated recruitment deviation in

time series occurred in the mid-1960s. The exact year of this large recruitment is uncertain with the year of occurrence tending to shift to any year between 1964 and 1966 depending on the parameterization of the model. The smallest ten recruitment events, which are harder to estimate than large events, occurred in the following years: 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 up to the terminal year of the model because the survey selects such young fish and is based on the spawner–recruit curve in the forecast period (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. 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. 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 (Figure 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 decline, subsequent stabilization, and terminal 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), though this was not included in the base model.

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 fits to the discarded lengths from the trawl fleet were not as good as they were for the fixed-gear fleet (Figures 54–55). Where, large residuals were only present in the fits to the discarded fixed-gear lengths in 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 2021 update assessment (Kapur et al. 2021) had similar fits to the annual discarded lengths for both fleets.

Some of the worst fits to the length data were for the large numbers of small, i.e., 20–30 cm, fish in the WCGBTS (Figure 53). These small, unsexed fish are almost always under fit relative to larger, unsexed fish because larger fish have a higher tendency of being sexed and thus the distribution of the sampled, unsexed fish will not represent the true population. 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.

Underfitting of some younger ages and overfitting of very old males was common in all fleets and surveys except the Slope Survey (Figure 56). These same patterns were present in the 2021 update assessment (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 Francis data weighting suggested substantially increasing the weight of these age data 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 and no stark patterns were detected in the residuals. 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 maximum length for females. The expected mean age-at-length generally matched the observed mean age-at-length for sizes less than 60 cm and ages less than 20 years across all years. The expected mean age-at-length, in general, split the observed data points for older, larger fish starting in 2009 but for earlier years, 2003–2008, the expected mean age-at-length was generally higher than the observations. The standard deviation around growth was largest at the ranges of the observed ages/lengths. Marginal ages for the WCGBTS were included in the model but were not included in the likelihood (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 4 and Figure 45). Biomass quickly turned around, increasing to unfished equilibrium by the mid-1970s, only to come down again to the management target in the early-2000s. Since then, several strong recruitment events (2008, 2013, and 2016) have led to sharp increases in spawning biomass, though spawning 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 large estimated sizes of the 2020 and 2021 recruitment deviations (Figure 43).

3.4 Model Diagnostics

3.4.1 Convergence

Model 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 starting parameter values it was noted that often one 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 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 the 2021 analysis, the dynamic factor analysis showed some instability and a similar 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 expected.

Estimates of uncertainty for some selectivity parameters in the base model were high. It was hoped that fixing 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 6) rather than a change in specific estimates of recruitment.

Estimating additional variance for the WCGBTS led to the model not fitting the most recent survey year nearly as well as the base model and thus the upward trend at the end of the time series became less

pronounced (Figure 75). The estimates of spawning biomass were larger for this sensitivity than the base model because all of the large recruitment events, except for the most recent one, were estimated at higher values than what were estimated in the base model. This also led to increases in other quantities relevant to management (Table 6) like yield at spawning potential ratio (SPR).

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, Francis tuning led to larger weights for 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 harmonic-mean method led to a lower estimate of R_0 and smaller estimates of early recruitment compared to the base model.

Estimating a single M instead of sex-specific M resulted in a lower estimate ($M = 0.053$ yr^{-1}) than estimates of either female or male M from the base model (0.071 yr^{-1} and 0.059 yr^{-1}, respectively). This is the same result as the 2021 update assessment (Kapur et al. 2021). 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 higher estimate of R_0 compared to the base model (Table 7), 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 7).

3.4.3 Retrospective Analysis

A retrospective analysis was conducted by running the base model with data removed for the past 5 years. All retrospective model runs fell within the uncertainty estimates from the base model (Table 8). 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.

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. These larger estimates of spawning biomass are primarily due to the large estimates of recruitment for the recent

years in the recent models. 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. Estimates from this update assessment of fraction unfished align with estimates from recent models for years in the 1960s and older models for years 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. These likelihood profiles were conducted by fixing the parameter of interest at specific values and estimating the remaining parameters based on the fixed parameter value. The priors for all parameters, including the parameter being profiled, were included in every likelihood calculation. 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 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 0.06–0.09 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). No investigated value included in the profile over male M led to the population going below this threshold (Figure 90). Male M was inherently smaller than female M but the same range was used for both investigations rather than a relative range. The results would have probably been more similar if a relative range had been used.

Similar likelihoods were found for R_0 values between 9.4 and 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 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 and 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$_{45\%}$) since the mid 1980s and has been declining in the last ten years (Figure 98). The interaction between the relative biomass and 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

the maximum sustainable yield (MSY), SPR target, and relative target biomass reference points (Figure 100) based on $h = 0.7$.

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2022 (Table 10). The estimated sustainable total yield inclusive of both landings and discards was 9,641.13 mt according to $SPR_{45\%}$. The spawning biomass equivalent to 40% of 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 update assessment 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, because 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 year classes that have been observed more, a problem 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, be 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 these 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 M, selectivity, and historical recruitments, are estimated within the 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, which is dominated by shifts in recruitment strength, is closely linked to productivity regimes in the California Current. Studies of oceanographic drivers of sablefish recruitment explain between 25% and just over 50% 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 as 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 and to the north of the survey extent. 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 2023 update assessment for sablefish off the U.S. West Coast was assigned a category 1 determination by the Scientific and Statistical Committee (SSC) to the PFMC. 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 Acceptable Biological Catch (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 ABCs (Table 9). 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 2023–2024.

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 overfishing limit (OFL), ABC, and annual catch limit (ACL) values. The coastwide ACL is then apportioned into two area-specific ACLs north and south of 36° N. latitude. For the 2019 assessment, 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 2017–2022 observed biomass by the WCGBTS is 21.5% south of 36° N. latitude and 78.5% north of 36° N. latitude. In contrast, the estimates from the 2019 analysis using 2014–2018 data 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 summed coastwide total landings up to 2022 followed by their respective projections up to 2034.

Year	Fixed-Gear Fleet	Trawl Fleet	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 summed coastwide total landings up to 2022 followed by their respective projections up to 2034. (*continued*)

Year	Fixed-Gear Fleet	Trawl Fleet	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

Table 1: Landings (mt) by fleet and summed coastwide total landings up to 2022 followed by their respective projections up to 2034. (*continued*)

Year	Fixed-Gear Fleet	Trawl Fleet	Total Landings
1967	2,459.8	1,819.1	4,278.9
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

Table 1: Landings (mt) by fleet and summed coastwide total landings up to 2022 followed by their respective projections up to 2034. (*continued*)

Year	Fixed-Gear Fleet	Trawl Fleet	Total Landings
2007	2,750.1	2,497.9	5,248.0
2008	2,976.2	2,898.1	5,874.4
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

7.2 Model Results

7.2.1 Estimated Parameters

Table 2: 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
M (female)	0.071	0.01	3	lnN(0.053, 0.438)	0.010	0.110	OK
Length-at-age min (female)	25.262	0.50	2	-	22.000	35.000	OK
Length-at-age max (female)	61.130	0.67	2	-	60.000	70.000	OK
von Bertalanffy K (female)	0.367	0.02	2	-	0.150	0.550	OK
Growth CV young (female)	0.058	0.01	2	-	0.001	0.150	OK
Growth CV old (female)	0.103	0.00	2	-	0.010	0.300	OK
Weight-length 1 (female)	0.000	-	-50	Normal	0.000	1.000	-
Weight-length 2 (female)	3.273	-	-50	Normal	0.000	4.000	-
Maturity at 50% (female)	55.190	-	-50	Normal	53.000	59.000	-
Maturity slope (female)	-0.421	-	-50	Normal	-3.000	3.000	-
Eggs/kg intercept (female)	1.000	-	-50	Normal	-3.000	3.000	-
Eggs/kg slope wt (female)	0.000	-	-50	Normal	-3.000	3.000	-
M (male)	0.059	0.01	3	lnN(0.055, 0.438)	0.010	0.110	OK
Length-at-age min (male)	26.621	0.61	2	-	15.000	35.000	OK
Length-at-age max (male)	56.111	0.38	2	-	50.000	60.000	OK
von Bertalanffy K (male)	0.381	0.02	2	-	0.200	0.550	OK
Growth CV young (male)	0.070	0.01	2	-	0.001	0.150	OK
Growth CV old (male)	0.078	0.00	2	-	0.010	0.300	OK
Weight-length 1 (male)	0.000	-	-50	Normal	0.000	1.000	-
Weight-length 2 (male)	3.270	-	-50	Normal	0.000	4.000	-
Frac. female	0.500	-	-99	-	0.000	1.000	-
$ln(R_0)$	9.876	0.30	1	-	8.000	12.000	OK
h	0.700	-	-7	beta(0.600, 0.223)	0.200	1.000	-
σR	1.400	-	-50	-	0.200	1.500	-
Stock–recr. ρ_1	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	-

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued)*

Label	Value	SD	Phase	Prior	Min.	Max.	Status
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 Recr. Dev. 1890	-0.101	1.34	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1891	-0.106	1.33	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1892	-0.112	1.33	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1893	-0.117	1.33	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1894	-0.123	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1895	-0.129	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1896	-0.136	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1897	-0.143	1.31	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1898	-0.150	1.31	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1899	-0.157	1.30	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1900	-0.164	1.30	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1901	-0.172	1.30	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1902	-0.181	1.29	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1903	-0.189	1.29	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1904	-0.198	1.28	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1905	-0.207	1.28	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1906	-0.217	1.27	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1907	-0.227	1.27	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1908	-0.237	1.26	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1909	-0.247	1.26	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1910	-0.258	1.25	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1911	-0.269	1.25	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1912	-0.280	1.24	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1913	-0.292	1.24	3	N(0.000 1.400)	-4.000	4.000	-

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued)*

Label	Value	SD	Phase	Prior	Min.	Max.	Status
Early Recr. Dev. 1914	-0.305	1.23	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1915	-0.317	1.22	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1916	-0.330	1.22	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1917	-0.344	1.21	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1918	-0.357	1.21	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1919	-0.370	1.20	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1920	-0.384	1.20	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1921	-0.398	1.19	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1922	-0.413	1.18	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1923	-0.427	1.18	3	N(0.000 1.400)	-4.000	4.000	-
Early Recr. Dev. 1924	-0.443	1.17	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1925	-0.559	1.16	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1926	-0.552	1.17	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1927	-0.588	1.15	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1928	-0.610	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1929	-0.591	1.15	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1930	-0.600	1.15	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1931	-0.618	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1932	-0.660	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1933	-0.656	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1934	-0.663	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1935	-0.616	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1936	-0.724	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1937	-0.726	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1938	-0.623	1.14	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1939	-0.641	1.13	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1940	-0.666	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1941	-0.712	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1942	-0.701	1.11	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1943	-0.668	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1944	-0.659	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1945	-0.620	1.13	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1946	-0.669	1.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1947	-0.627	1.13	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1948	-0.716	1.10	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1949	-0.554	1.16	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1950	-0.499	1.18	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1951	-0.475	1.19	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1952	-0.375	1.23	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1953	-0.427	1.21	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1954	-0.307	1.26	3	N(0.000 1.400)	-4.000	4.000	-

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued*)

Label	Value	SD	Phase	Prior	Min.	Max.	Status
Main Recr. Dev. 1955	-0.137	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1956	-0.109	1.36	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1957	-0.020	1.42	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1958	-0.068	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1959	0.191	1.58	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1960	-0.028	1.42	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1961	0.094	1.52	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1962	0.253	1.67	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1963	-0.077	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1964	0.401	1.95	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1965	0.019	1.50	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1966	2.270	0.61	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1967	-0.224	1.32	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1968	-0.111	1.39	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1969	-0.364	1.24	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1970	-0.091	1.37	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1971	-0.286	1.26	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1972	-0.195	1.29	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1973	0.143	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1974	-0.066	1.35	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1975	0.302	1.42	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1976	0.207	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1977	0.230	1.27	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1978	-0.017	1.41	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1979	1.706	0.61	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1980	0.617	0.88	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1981	0.962	0.45	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1982	0.557	0.40	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1983	-0.541	1.02	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1984	1.291	0.37	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1985	1.115	0.45	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1986	0.855	0.35	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1987	-0.758	0.88	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1988	0.993	0.25	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1989	0.536	0.38	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1990	1.615	0.19	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1991	-1.571	0.80	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1992	0.110	0.38	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1993	-0.541	0.50	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1994	0.405	0.22	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1995	1.330	0.16	3	N(0.000 1.400)	-4.000	4.000	-

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued*)

Label	Value	SD	Phase	Prior	Min.	Max.	Status
Main Recr. Dev. 1996	-2.231	0.76	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1997	-2.505	0.67	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1998	-0.108	0.32	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 1999	1.105	0.19	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2000	2.483	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2001	1.192	0.22	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2002	0.470	0.22	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2003	-1.010	0.34	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2004	0.089	0.19	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2005	-2.315	0.64	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2006	-1.266	0.33	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2007	-2.036	0.62	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2008	1.873	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2009	-0.701	0.56	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2010	0.851	0.15	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2011	0.254	0.23	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2012	-0.512	0.37	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2013	1.704	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2014	0.053	0.25	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2015	1.389	0.14	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2016	2.262	0.12	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2017	0.645	0.24	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2018	-0.561	0.42	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2019	0.681	0.31	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2020	3.078	0.18	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2021	2.904	0.27	3	N(0.000 1.400)	-4.000	4.000	-
Main Recr. Dev. 2022	-0.687	1.17	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2023	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2024	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2025	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2026	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2027	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2028	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2029	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2030	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2031	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2032	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2033	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Forecast Recr. Dev. 2034	0.000	1.40	3	N(0.000 1.400)	-4.000	4.000	-
Q Env. Index	0.060	0.03	1	-	-15.000	15.000	OK
Q extra SD Env. Index	0.949	0.07	2	-	0.100	1.300	OK

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued*)

Label	Value	SD	Phase	Prior		Min.	Max.	Status
ln(Q) Triennial	0.277	0.28	1		-	-15.000	15.000	OK
Q extra SD Triennial	0.170	0.07	2		-	0.025	1.300	OK
ln(Q) AK Slope	-0.423	-	-1		-	-15.000	5.000	-
Q extra SD AK Slope	0.033	0.04	2		-	0.001	0.700	OK
ln(Q) NWFSC Slope	-0.782	-	-1		-	-15.000	15.000	-
Q extra SD NWFSC Slope	0.164	0.08	2		-	0.001	0.800	OK
ln(Q) WCGBTS	-0.595	-	-1		-	-15.000	15.000	-
Q extra SD WCGBTS	0.000	-	-2		-	0.001	0.400	-
ln(Q) Triennial 1995	-0.160	0.29	2		-	-15.000	15.000	OK
Retain L infl Fixed Gear	41.000	-	-5		-	10.000	60.000	-
Retain L width Fixed Gear	6.005	-	-5		-	0.100	20.000	-
Retain L asymptote Fixed Gear	10.000	-	-5		-	-10.000	10.000	-
Retain L male offset Fixed Gear	0.000	-	-50		-	-10.000	10.000	-
Disc L infl Fixed Gear	28.000	-	-50		-	8.000	70.000	-
Disc L width Fixed Gear	0.010	-	-50		-	0.001	2.000	-
Disc L level old Fixed Gear	0.200	-	-50		-	0.010	0.800	-
Disc L male offset Fixed Gear	0.000	-	-50		-	-10.000	10.000	-
Retain L infl Trawl	41.000	-	-5		-	15.000	55.000	-
Retain L width Trawl	2.898	-	-5		-	0.100	20.000	-
Retain L asymptote Trawl	10.000	-	-5		-	-10.000	10.000	-
Retain L male offset Trawl	0.000	-	-50		-	-10.000	10.000	-
Disc L infl Trawl	28.000	-	-50		-	8.000	70.000	-
Disc L width Trawl	0.010	-	-50		-	0.001	2.000	-
Disc L level old Trawl	0.500	-	-50		-	0.100	0.800	-
Disc L male offset Trawl	0.000	-	-50		-	-10.000	10.000	-
Age peak Fixed Gear	5.000	-	-4		-	2.000	20.000	-
Age top Fixed Gear	-4.000	-	-4		-	-20.000	5.000	-
Age ascend Fixed Gear	0.158	0.73	4		-	-15.000	10.000	OK
Age descend Fixed Gear	2.735	0.36	4		-	-10.000	10.000	OK
Age start Fixed Gear	-5.000	-	-4		-	-5.000	5.000	-
Age end Fixed Gear	-1.500	-	-4		-	-5.000	5.000	-
Age 1 male Dogleg FIX	0.000	-	-4		-	-15.000	15.000	-
Age 1 male at 0 FIX	0.057	58093.90	4		-	-15.000	15.000	OK
Age 1 male at dogleg FIX	-0.881	0.12	4		-	-15.000	15.000	OK
Age 1 male at max. age FIX	-1.094	0.49	4		-	-15.000	15.000	OK
Age peak Trawl	1.000	-	-4		-	0.010	20.000	-
Age top Trawl	-4.000	-	-4		-	-20.000	5.000	-
Age ascend Trawl	-2.424	4421.94	4		-	-20.000	10.000	OK
Age descend Trawl	-9.000	-	-4		-	-10.000	10.000	-
Age start Trawl	-4.027	-	-4		-	-5.000	5.000	-
Age end Trawl	-1.495	0.17	4		-	-5.000	5.000	OK

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued*)

Label	Value	SD	Phase	Prior		Min.	Max.	Status
Age peak Triennial	1.000	-	-4		-	1.000	12.000	-
Age top Triennial	-4.000	-	-4		-	-5.000	5.000	-
Age ascend Triennial	-9.729	1690.89	4		-	-10.000	10.000	OK
Age descend Triennial	-1.019	0.41	4		-	-10.000	10.000	OK
Age start Triennial	-2.500	-	-4		-	-10.000	5.000	-
Age end Triennial	-3.782	0.50	4		-	-10.000	5.000	OK
Age 4 male Dogleg AKSHLF	0.000	-	-4		-	-15.000	15.000	-
Age 4 male at 0 AKSHLF	-0.544	58018.30	4		-	-15.000	15.000	OK
Age 4 male at dogleg AKSHLF	-0.177	0.13	4		-	-15.000	15.000	OK
Age 4 male at max. age AKSHLF	-6.000	2.41	4		-	-15.000	15.000	OK
Age peak AK Slope	1.439	0.54	4		-	1.000	12.000	OK
Age top AK Slope	-4.000	-	-4		-	-20.000	5.000	-
Age ascend AK Slope	-4.000	-	-4		-	-10.000	10.000	-
Age descend AK Slope	-5.964	57854.70	4		-	-20.000	10.000	OK
Age start AK Slope	-1.338	-	-4		-	-5.000	5.000	-
Age end AK Slope	-0.557	0.39	4		-	-5.000	5.000	OK
Age peak NWFSC Slope	3.578	1.23	4		-	1.000	12.000	OK
Age top NWFSC Slope	-4.000	-	-4		-	-5.000	5.000	-
Age ascend NWFSC Slope	1.453	1.23	4		-	-10.000	10.000	OK
Age descend NWFSC Slope	-14.479	60168.60	4		-	-20.000	50.000	OK
Age start NWFSC Slope	-4.565	-	-4		-	-5.000	5.000	-
Age end NWFSC Slope	0.267	0.66	4		-	-5.000	5.000	OK
Age peak WCGBTS	0.107	0.03	4		-	0.010	5.000	OK
Age top WCGBTS	-4.000	-	-4		-	-20.000	5.000	-
Age ascend WCGBTS	-8.447	55027.70	4		-	-20.000	10.000	OK
Age descend WCGBTS	3.352	0.18	4		-	-10.000	10.000	OK
Age start WCGBTS	-4.000	-	-4		-	-5.000	5.000	-
Age end WCGBTS	-0.320	-	-4		-	-5.000	5.000	-
Retain L infl Fixed Gear 1942	25.000	-	-5		-	25.000	60.000	-
Retain L infl Fixed Gear 1947	38.960	-	-5		-	25.000	60.000	-
Retain L infl Fixed Gear 1997	39.341	2.30	5		-	25.000	60.000	OK
Retain L infl Fixed Gear 2011	40.923	0.78	5		-	25.000	60.000	OK
Retain L infl Fixed Gear 2019	31.359	-	-5		-	10.000	60.000	-
Retain L asymptote Fixed Gear 1942	10.000	-	-5		-	-10.000	10.000	-
Retain L asymptote Fixed Gear 1947	10.000	-	-5		-	-10.000	10.000	-
Retain L asymptote Fixed Gear 1997	2.463	0.31	5		-	-10.000	10.000	OK
Retain L asymptote Fixed Gear 2011	4.008	-	-5		-	-10.000	10.000	-
Retain L asymptote Fixed Gear 2019	1.852	0.12	5		-	-10.000	10.000	OK
Retain L infl Trawl 1942	25.000	-	-5		-	15.000	55.000	-
Retain L infl Trawl 1947	45.929	-	-5		-	15.000	55.000	-

Table 2: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. (*continued*)

Label	Value	SD	Phase	Prior		Min.	Max.	Status
Retain L infl Trawl 1982	47.391	0.51	5		-	15.000	55.000	OK
Retain L infl Trawl 2011	33.392	0.24	5		-	15.000	55.000	OK
Retain L infl Trawl 2019	42.474	0.62	5		-	15.000	55.000	OK
Retain L asymptote Trawl 1942	10.000	-	-5		-	-10.000	10.000	-
Retain L asymptote Trawl 1947	10.000	-	-5		-	-10.000	10.000	-
Retain L asymptote Trawl 1982	3.750	0.44	5		-	-10.000	10.000	OK
Retain L asymptote Trawl 2011	10.000	-	-5		-	-10.000	10.000	-
Retain L asymptote Trawl 2019	6.039	3.34	5		-	-10.000	10.000	OK
Age peak Fixed Gear 1997	3.196	0.35	4		-	2.000	20.000	OK
Age peak Fixed Gear 2003	4.978	0.98	4		-	2.000	20.000	OK
Age peak Fixed Gear 2011	3.064	0.02	4		-	2.000	20.000	OK
Age ascend Fixed Gear 1997	-1.240	-	-4		-	-10.000	20.000	-
Age ascend Fixed Gear 2003	1.816	0.77	4		-	-10.000	20.000	OK
Age ascend Fixed Gear 2011	-8.447	1685.04	4		-	-10.000	20.000	OK
Age descend Trawl 1982	2.040	0.46	4		-	-10.000	10.000	OK
Age descend Trawl 2003	6.801	0.43	4		-	-10.000	10.000	OK
Age descend Trawl 2011	8.737	-	-4		-	-10.000	10.000	-
Age descend Triennial 1995	3.185	0.18	4		-	-10.000	10.000	OK

Table 3: 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 4: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawn-ing Biomass (mt)	Total Biomass Age 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortal-ity (mt)	(1-SPR)/(1-SPR45%)	Exploita-tion Rate
1890	468,356.00	179,356.00	441,037.00	0.96	17,510.00	2.00	0.000	0.000
1891	467,055.00	178,887.00	439,881.00	0.96	17,414.00	6.00	0.001	0.000
1892	465,680.00	178,397.00	438,677.00	0.96	17,315.00	7.00	0.001	0.000
1893	464,234.00	177,885.00	437,425.00	0.95	17,211.00	10.00	0.001	0.000
1894	462,717.00	177,343.00	436,059.00	0.95	17,104.00	12.00	0.001	0.000
1895	461,130.00	176,770.00	434,630.00	0.95	16,992.00	17.00	0.002	0.000
1896	459,474.00	176,166.00	433,137.00	0.94	16,876.00	19.00	0.002	0.000
1897	457,750.00	175,534.00	431,583.00	0.94	16,756.00	21.00	0.002	0.000
1898	455,959.00	174,876.00	429,967.00	0.94	16,632.00	23.00	0.002	0.000
1899	454,100.00	174,191.00	428,290.00	0.93	16,504.00	25.00	0.003	0.000
1900	452,171.00	173,481.00	426,550.00	0.93	16,371.00	51.00	0.005	0.000
1901	450,148.00	172,730.00	424,722.00	0.93	16,234.00	79.00	0.008	0.000
1902	448,026.00	171,938.00	422,803.00	0.92	16,092.00	107.00	0.011	0.000
1903	445,807.00	171,104.00	420,791.00	0.92	15,946.00	135.00	0.014	0.000
1904	443,487.00	170,227.00	418,688.00	0.91	15,796.00	164.00	0.018	0.000
1905	441,067.00	169,308.00	416,490.00	0.91	15,641.00	147.00	0.016	0.000
1906	438,589.00	168,373.00	414,242.00	0.90	15,482.00	146.00	0.016	0.000
1907	436,037.00	167,411.00	411,925.00	0.90	15,319.00	154.00	0.017	0.000
1908	433,399.00	166,417.00	409,530.00	0.89	15,153.00	99.00	0.011	0.000
1909	430,737.00	165,427.00	407,116.00	0.89	14,984.00	156.00	0.017	0.000
1910	427,937.00	164,375.00	404,571.00	0.88	14,813.00	214.00	0.024	0.001
1911	425,002.00	163,260.00	401,893.00	0.88	14,640.00	271.00	0.030	0.001
1912	421,932.00	162,083.00	399,086.00	0.87	14,462.00	329.00	0.037	0.001
1913	418,732.00	160,845.00	396,152.00	0.86	14,279.00	386.00	0.044	0.001
1914	415,404.00	159,546.00	393,095.00	0.85	14,089.00	444.00	0.051	0.001
1915	411,947.00	158,189.00	389,918.00	0.85	13,896.00	500.00	0.058	0.001
1916	408,364.00	156,775.00	386,623.00	0.84	13,703.00	1,334.00	0.151	0.003
1917	403,903.00	154,867.00	382,458.00	0.83	13,502.00	2,021.00	0.223	0.005
1918	398,722.00	152,615.00	377,617.00	0.82	13,301.00	2,888.00	0.316	0.008
1919	392,678.00	149,827.00	371,876.00	0.80	13,096.00	1,043.00	0.124	0.003
1920	388,452.00	148,074.00	367,942.00	0.79	12,894.00	895.00	0.106	0.002
1921	384,339.00	146,455.00	364,157.00	0.78	12,690.00	1,197.00	0.141	0.003
1922	379,883.00	144,686.00	360,035.00	0.78	12,490.00	810.00	0.101	0.002
1923	375,771.00	143,067.00	356,204.00	0.77	12,287.00	1,455.00	0.178	0.004
1924	370,991.00	141,098.00	351,731.00	0.76	12,079.00	1,866.00	0.226	0.005
1925	365,780.00	138,921.00	346,856.00	0.74	10,725.00	2,135.00	0.262	0.006
1926	360,003.00	136,571.00	341,685.00	0.73	10,780.00	1,721.00	0.221	0.005
1927	354,402.00	134,417.00	336,903.00	0.72	10,377.00	2,565.00	0.318	0.008

Table 4: 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
1928	347,718.00	131,817.00	331,346.00	0.71	10,120.00	2,150.00	0.276	0.006
1929	341,250.00	129,324.00	325,125.00	0.69	10,284.00	2,332.00	0.301	0.007
1930	334,562.00	126,656.00	318,859.00	0.68	10,160.00	2,594.00	0.340	0.008
1931	327,669.00	123,750.00	312,117.00	0.66	9,942.00	1,429.00	0.201	0.005
1932	322,015.00	121,436.00	306,443.00	0.65	9,511.00	1,682.00	0.240	0.005
1933	316,142.00	119,005.00	300,875.00	0.64	9,518.00	1,559.00	0.226	0.005
1934	310,458.00	116,737.00	295,595.00	0.63	9,425.00	2,700.00	0.378	0.009
1935	303,743.00	113,935.00	289,271.00	0.61	9,831.00	3,463.00	0.476	0.012
1936	296,546.00	110,779.00	282,065.00	0.59	8,787.00	2,398.00	0.364	0.009
1937	290,483.00	108,118.00	276,066.00	0.58	8,730.00	2,573.00	0.398	0.009
1938	284,341.00	105,435.00	270,120.00	0.56	9,640.00	2,520.00	0.398	0.009
1939	278,594.00	102,917.00	264,958.00	0.55	9,428.00	2,794.00	0.442	0.011
1940	272,919.00	100,314.00	258,917.00	0.54	9,155.00	2,223.00	0.367	0.009
1941	268,098.00	98,099.00	253,592.00	0.53	8,703.00	2,190.00	0.362	0.009
1942	263,449.00	96,109.00	249,389.00	0.52	8,767.00	3,232.00	0.515	0.013
1943	257,847.00	93,808.00	244,325.00	0.50	9,021.00	3,927.00	0.595	0.016
1944	251,695.00	91,483.00	238,692.00	0.49	9,056.00	4,489.00	0.663	0.019
1945	245,127.00	89,051.00	232,244.00	0.48	9,366.00	4,422.00	0.669	0.019
1946	238,899.00	86,551.00	225,811.00	0.46	8,871.00	4,460.00	0.701	0.020
1947	232,896.00	83,796.00	219,537.00	0.45	9,189.00	2,314.00	0.422	0.011
1948	229,489.00	82,083.00	215,701.00	0.44	8,366.00	2,971.00	0.514	0.014
1949	225,632.00	80,352.00	212,161.00	0.43	9,789.00	3,113.00	0.540	0.015
1950	222,124.00	78,747.00	208,518.00	0.42	10,305.00	2,789.00	0.492	0.013
1951	219,536.00	77,468.00	205,691.00	0.41	10,512.00	4,564.00	0.712	0.022
1952	215,801.00	75,589.00	200,771.00	0.40	11,548.00	2,823.00	0.494	0.014
1953	214,583.00	74,611.00	198,747.00	0.40	10,938.00	1,771.00	0.333	0.009
1954	214,976.00	74,361.00	198,439.00	0.40	12,320.00	2,488.00	0.439	0.013
1955	215,427.00	74,136.00	198,088.00	0.40	14,593.00	2,344.00	0.413	0.012
1956	217,213.00	74,272.00	199,047.00	0.40	15,010.00	3,833.00	0.571	0.019
1957	218,648.00	74,305.00	198,525.00	0.40	16,407.00	2,742.00	0.455	0.014
1958	222,439.00	74,780.00	199,916.00	0.40	15,669.00	1,687.00	0.281	0.008
1959	228,192.00	76,288.00	204,574.00	0.41	20,390.00	2,421.00	0.378	0.012
1960	234,990.00	78,047.00	209,526.00	0.42	16,466.00	3,129.00	0.454	0.015
1961	241,588.00	79,984.00	215,317.00	0.43	18,707.00	1,976.00	0.292	0.009
1962	250,042.00	82,855.00	221,605.00	0.44	22,095.00	2,954.00	0.382	0.013
1963	258,759.00	85,996.00	231,371.00	0.46	16,003.00	2,009.00	0.269	0.009
1964	267,916.00	89,592.00	238,578.00	0.48	26,045.00	2,259.00	0.283	0.009
1965	278,581.00	93,355.00	247,230.00	0.50	17,917.00	2,153.00	0.260	0.009
1966	288,991.00	97,427.00	259,009.00	0.52	171,566.00	2,114.00	0.246	0.008

Table 4: 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
1967	337,652.00	101,648.00	265,388.00	0.54	14,273.00	5,365.00	0.468	0.020
1968	382,626.00	105,031.00	277,821.00	0.56	16,070.00	3,293.00	0.271	0.012
1969	424,256.00	115,199.00	285,072.00	0.62	12,680.00	5,928.00	0.446	0.021
1970	451,538.00	136,276.00	429,322.00	0.73	17,093.00	5,003.00	0.389	0.012
1971	468,861.00	158,257.00	446,152.00	0.85	14,335.00	4,201.00	0.298	0.009
1972	477,574.00	173,034.00	455,857.00	0.93	15,873.00	7,054.00	0.449	0.015
1973	476,981.00	179,363.00	453,148.00	0.96	22,352.00	6,157.00	0.426	0.014
1974	474,591.00	181,565.00	450,495.00	0.97	18,160.00	9,080.00	0.544	0.020
1975	467,359.00	178,922.00	439,871.00	0.96	26,191.00	14,916.00	0.807	0.034
1976	455,553.00	171,681.00	423,493.00	0.92	23,712.00	25,167.00	1.180	0.059
1977	435,003.00	158,590.00	402,583.00	0.85	19,138.00	9,349.00	0.686	0.023
1978	430,407.00	154,973.00	394,550.00	0.83	11,862.00	13,003.00	0.898	0.033
1979	420,135.00	150,630.00	390,376.00	0.81	52,753.00	24,987.00	1.327	0.064
1980	406,150.00	141,039.00	373,497.00	0.76	14,008.00	10,016.00	0.781	0.027
1981	405,986.00	138,606.00	367,593.00	0.74	19,738.00	12,213.00	0.880	0.033
1982	403,222.00	135,938.00	353,978.00	0.73	13,122.00	19,723.00	1.168	0.056
1983	389,970.00	132,643.00	367,178.00	0.71	4,365.00	15,970.00	1.053	0.043
1984	375,275.00	130,340.00	353,918.00	0.70	27,184.00	15,221.00	1.023	0.043
1985	362,677.00	127,173.00	344,488.00	0.68	22,705.00	15,366.00	1.077	0.045
1986	351,388.00	121,887.00	329,098.00	0.65	17,405.00	14,513.00	1.080	0.044
1987	341,645.00	115,865.00	307,131.00	0.62	3,441.00	13,987.00	1.089	0.046
1988	329,282.00	111,116.00	304,031.00	0.60	19,680.00	11,695.00	1.007	0.038
1989	319,796.00	108,383.00	300,911.00	0.58	12,409.00	11,244.00	0.979	0.037
1990	310,026.00	105,701.00	294,601.00	0.57	36,326.00	9,957.00	0.925	0.034
1991	307,229.00	102,480.00	277,958.00	0.55	1,494.00	10,682.00	0.986	0.038
1992	300,900.00	98,899.00	273,598.00	0.53	7,970.00	10,542.00	0.990	0.039
1993	292,727.00	96,535.00	264,507.00	0.52	4,140.00	8,946.00	0.890	0.034
1994	282,851.00	96,049.00	276,745.00	0.52	10,649.00	8,089.00	0.853	0.029
1995	272,831.00	94,623.00	262,343.00	0.51	26,787.00	8,445.00	0.898	0.032
1996	266,425.00	91,296.00	251,295.00	0.49	756.00	9,173.00	0.995	0.037
1997	257,381.00	86,722.00	236,266.00	0.46	569.00	8,768.00	1.055	0.037
1998	246,281.00	82,964.00	226,912.00	0.44	6,188.00	4,772.00	0.690	0.021
1999	237,784.00	82,064.00	235,370.00	0.44	20,770.00	7,096.00	0.951	0.030
2000	229,996.00	79,308.00	221,149.00	0.42	81,833.00	6,900.00	0.999	0.031
2001	241,640.00	75,124.00	205,934.00	0.40	22,222.00	6,995.00	0.974	0.034
2002	257,742.00	71,472.00	195,940.00	0.38	10,676.00	4,623.00	0.685	0.024
2003	274,888.00	73,061.00	201,215.00	0.39	2,441.00	5,945.00	0.711	0.030
2004	284,157.00	81,159.00	261,563.00	0.43	7,506.00	6,193.00	0.641	0.024
2005	287,079.00	90,612.00	275,941.00	0.49	693.00	6,572.00	0.630	0.024

Table 4: 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
2006	282,848.00	96,357.00	276,973.00	0.52	2,004.00	6,505.00	0.622	0.023
2007	273,794.00	97,831.00	267,315.00	0.52	930.00	5,487.00	0.555	0.021
2008	262,133.00	96,692.00	260,322.00	0.52	46,301.00	6,124.00	0.634	0.024
2009	259,051.00	92,970.00	245,303.00	0.50	3,501.00	7,623.00	0.803	0.031
2010	254,387.00	86,995.00	228,985.00	0.47	16,321.00	7,265.00	0.855	0.032
2011	252,403.00	82,231.00	212,107.00	0.44	8,875.00	6,536.00	0.972	0.031
2012	250,354.00	81,264.00	237,052.00	0.44	4,117.00	5,407.00	0.723	0.023
2013	247,007.00	81,989.00	229,095.00	0.44	37,797.00	4,220.00	0.591	0.018
2014	250,796.00	82,769.00	232,378.00	0.44	7,268.00	4,525.00	0.598	0.019
2015	253,317.00	82,490.00	228,814.00	0.44	27,644.00	5,267.00	0.679	0.023
2016	258,813.00	81,831.00	219,535.00	0.44	66,059.00	5,537.00	0.717	0.025
2017	276,921.00	82,908.00	240,366.00	0.44	13,138.00	5,815.00	0.660	0.024
2018	294,259.00	84,804.00	236,010.00	0.46	3,956.00	5,470.00	0.629	0.023
2019	306,847.00	89,432.00	249,320.00	0.48	13,836.00	5,575.00	0.565	0.022
2020	314,733.00	98,233.00	299,188.00	0.53	154,839.00	4,096.00	0.368	0.014
2021	355,705.00	106,760.00	306,069.00	0.57	208,277.00	5,217.00	0.435	0.017
2022	443,477.00	110,930.00	299,848.00	0.59	9,122.00	6,914.00	0.531	0.023
2023	525,277.00	117,519.00	298,212.00	0.63	18,302.00	9,118.00	0.624	0.031
2024	591,216.00	141,875.00	424,483.00	0.76	18,819.00	8,359.00	0.398	0.020
2025	636,828.00	183,592.00	615,645.00	0.98	19,421.00	36,545.00	0.959	0.059
2026	634,109.00	207,142.00	605,691.00	1.11	19,664.00	34,699.00	0.956	0.057
2027	617,911.00	214,059.00	588,802.00	1.15	19,726.00	31,632.00	0.954	0.054
2028	595,310.00	210,719.00	565,615.00	1.13	19,696.00	27,385.00	0.951	0.048
2029	571,577.00	203,091.00	541,675.00	1.09	19,625.00	23,217.00	0.948	0.043
2030	549,200.00	194,403.00	519,282.00	1.04	19,539.00	19,914.00	0.946	0.038
2031	528,818.00	185,924.00	498,979.00	1.00	19,447.00	17,616.00	0.943	0.035
2032	510,285.00	177,993.00	480,566.00	0.95	19,354.00	16,130.00	0.940	0.034
2033	493,279.00	170,621.00	463,694.00	0.92	19,262.00	15,208.00	0.937	0.033
2034	477,514.00	163,747.00	448,067.00	0.88	19,168.00	14,587.00	0.935	0.033

7.2.2 Sensitivity and Retrospective Analyses

Table 5: 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	2,495.96	2,495.53	2,495.40	2,495.96	2,495.96
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	2,415.89	2,415.56	2,416.45	2,415.89	2,415.89
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_0S	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	9,641.13	9,764.24	9,706.90	9,641.13	9,641.81
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
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 6: 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	2,495.96	2,543.44	2,495.65	2,483.35
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	2,415.89	2,428.89	2,415.20	2,395.24
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	9,641.13	6,960.51	8,149.84	10,674.40
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
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 7: 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	2,495.96	2,501.46	3,649.36	1,228.79
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	2,415.89	2,414.85	3,564.58	1,165.05
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	9,641.13	6,137.99	9,544.94	14,901.60
h	0.70	0.70	0.70	0.70
M (female)	0.07	0.05	0.07	0.09
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 8: 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	2,495.96	2,355.94	2,203.06	2,187.87	2,088.54	1,948.51
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	2,415.89	2,298.23	2,167.99	2,148.22	2,042.56	1,913.70
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_0S	186,534.00	187,302.00	182,359.00	179,923.00	175,605.00	168,848.00
SB 2023	117,519.00	119,022.00	104,441.00	104,848.00	102,410.00	92,331.60
Fraction Unfished 2023	0.63	0.64	0.57	0.58	0.58	0.55
Yield at SPR	9,641.13	10,023.50	10,069.20	9,891.91	9,396.78	8,949.35
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 9: The adopted 2023–24 overfishing limit (OFL; mt), annual catch limit (; mt), and assumed removals (mt) and the projected OFL (mt), Acceptable Biological Catch (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	11,577.00	10,824.00	9,118.00	NA	NA	117,519.00	0.63
2024	10,670.00	9,923.00	8,359.00	NA	NA	141,875.00	0.76
2025	NA	NA	NA	39,085.30	36,544.69	183,592.00	0.98
2026	NA	NA	NA	37,310.40	34,698.66	207,142.00	1.11
2027	NA	NA	NA	34,160.00	31,632.18	214,059.00	1.15
2028	NA	NA	NA	29,701.30	27,384.65	210,719.00	1.13
2029	NA	NA	NA	25,318.50	23,217.10	203,091.00	1.09
2030	NA	NA	NA	21,811.90	19,914.27	194,403.00	1.04
2031	NA	NA	NA	19,379.70	17,616.13	185,924.00	1.00
2032	NA	NA	NA	17,842.70	16,129.76	177,993.00	0.95
2033	NA	NA	NA	16,898.00	15,208.22	170,621.00	0.91
2034	NA	NA	NA	16,280.60	14,587.40	163,747.00	0.88

Table 10: Summary of reference points and management quantities, including estimates of the 95 percent intervals for the model area.

Reference Points	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	186,534.000	118,407.808	254,660.192
Unfished Age 4+ Biomass (mt)	458,971.000	280,172.306	637,769.694
Unfished Recruitment (R_0)	19,453.900	7,838.526	31,069.274
2023 Spawning Biomass (mt)	117,519.000	49,642.507	185,395.493
2023 Fraction Unfished	0.630	0.424	0.836
Reference Points Based $SB_{40\%}$	NA	NA	NA
Proxy Spawning Biomass (mt) $SB_{40\%}$	74,613.600	47,363.045	101,864.155
SPR Resulting in $SB_{40\%}$	0.464	0.464	0.464
Exploitation Rate Resulting in $SB_{40\%}$	0.043	0.035	0.050
Yield with SPR Based On $SB_{40\%}$ (mt)	9,477.830	4,432.471	14,523.189
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Biomass (mt) ($SPR_{45\%}$)	71,629.000	45,468.577	97,789.423
$SPR_{45\%}$	0.450	NA	NA
Exploitation Rate Corresponding to $SPR_{45\%}$	0.045	0.037	0.053
Yield with $SPR_{45\%}$ at SB SPR (mt)	9,641.130	4,509.219	14,773.041
Reference Points Based on Estimated MSY	NA	NA	NA
Spawning Biomass (mt) at MSY (SB MSY)	45,903.500	29,025.251	62,781.749
SPR MSY	0.327	0.324	0.330
Exploitation Rate Corresponding to SPR MSY	0.069	0.057	0.082
MSY (mt)	10,431.200	4,881.895	15,980.505

Table 11: Decision table with projections of spawning biomass (SB; mt) and fraction unfished (SB / unfished SB) based on harvest control rules (HCRs; rows) and states of nature (columns). Annual catch limits (ACLs; mt) for each HCR were defined using an estimate of uncertainty (i.e., P^*). Italics indicate years were the full catch could not be removed from the low state of nature because of insufficient biomass. Catches are total dead biomass, i.e., dead discard plus catch. Low (columns 4–5) and high (columns 8–9) states of nature are based on the terminal SB $\pm$ 1.15 of the base model (columns 6–7) SB standard deviation and the resulting unfished recruitment was used for the projections. Results are conditioned on the first two years of catches, provided by the GMT, being achieved exactly. The alternative catch stream is based on P^* of 0.40, where the agreed-upon buffer level is $P^* = 0.45$.

HCR	Year	Catch	SB	SB/SB$_0$	SB	SB/SB$_0$	SB	SB/SB$_0$
P*0.45	2023	9,118	81,817	0.558	117,519	0.630	166,569	0.699
	2024	8,359	98,275	0.670	141,875	0.761	201,559	0.846
	2025	36,545	126,884	0.865	183,592	0.984	260,780	1.095
	2026	34,699	139,748	0.953	207,142	1.110	299,826	1.258
	2027	31,632	140,726	0.959	214,059	1.148	316,170	1.327
	2028	27,385	134,879	0.919	210,719	1.130	317,238	1.331
	2029	23,217	126,680	0.864	203,091	1.089	310,681	1.304
	2030	19,914	118,407	0.807	194,403	1.042	301,045	1.264
	2031	17,616	110,823	0.755	185,924	0.997	290,498	1.219
	2032	16,130	104,008	0.709	177,993	0.954	279,948	1.175
	2033	15,208	97,837	0.667	170,621	0.915	269,750	1.132
	2034	14,587	92,167	0.628	163,747	0.878	260,043	1.091
P*0.40	2023	9,118	81,817	0.558	117,519	0.630	166,569	0.699
	2024	8,359	98,275	0.670	141,875	0.761	201,559	0.846
	2025	34,121	126,884	0.865	183,592	0.984	260,780	1.095
	2026	32,403	140,789	0.960	208,215	1.116	300,856	1.263
	2027	29,541	142,970	0.975	216,375	1.160	318,395	1.336
	2028	25,560	138,237	0.942	214,180	1.148	320,570	1.345
	2029	21,658	130,948	0.893	207,470	1.112	314,913	1.322
	2030	18,524	123,368	0.841	199,462	1.069	305,950	1.284
	2031	16,328	116,321	0.793	191,492	1.027	295,908	1.242
	2032	14,929	109,939	0.749	183,955	0.986	285,747	1.199
	2033	14,023	104,121	0.710	176,892	0.948	275,849	1.158
	2034	13,283	98,767	0.673	170,287	0.913	266,400	1.118

8 Figures

8.1 Data

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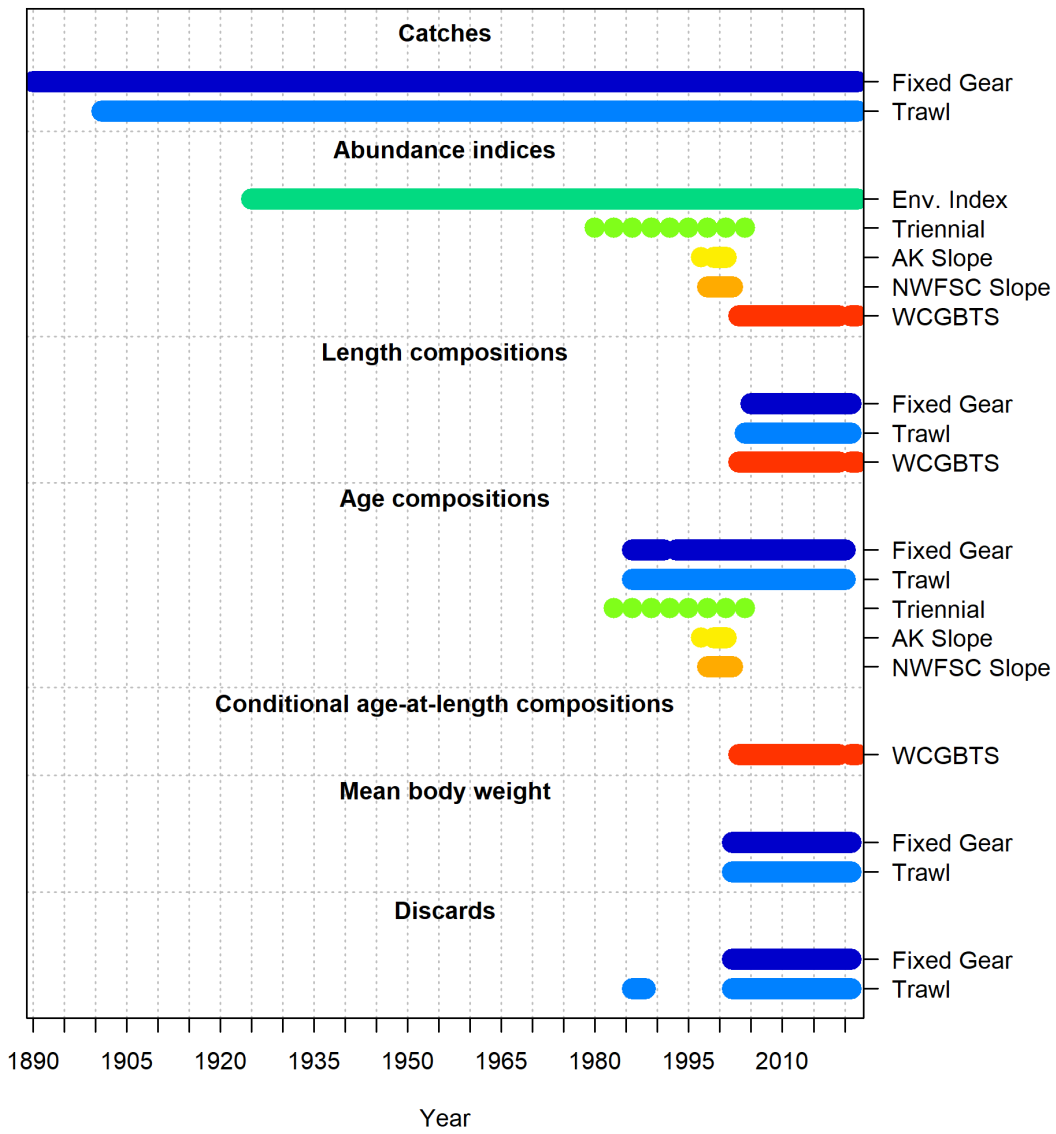
Figure 1: Summary of data sources used in the base model.

8.1.2 Fishery-Dependent Data
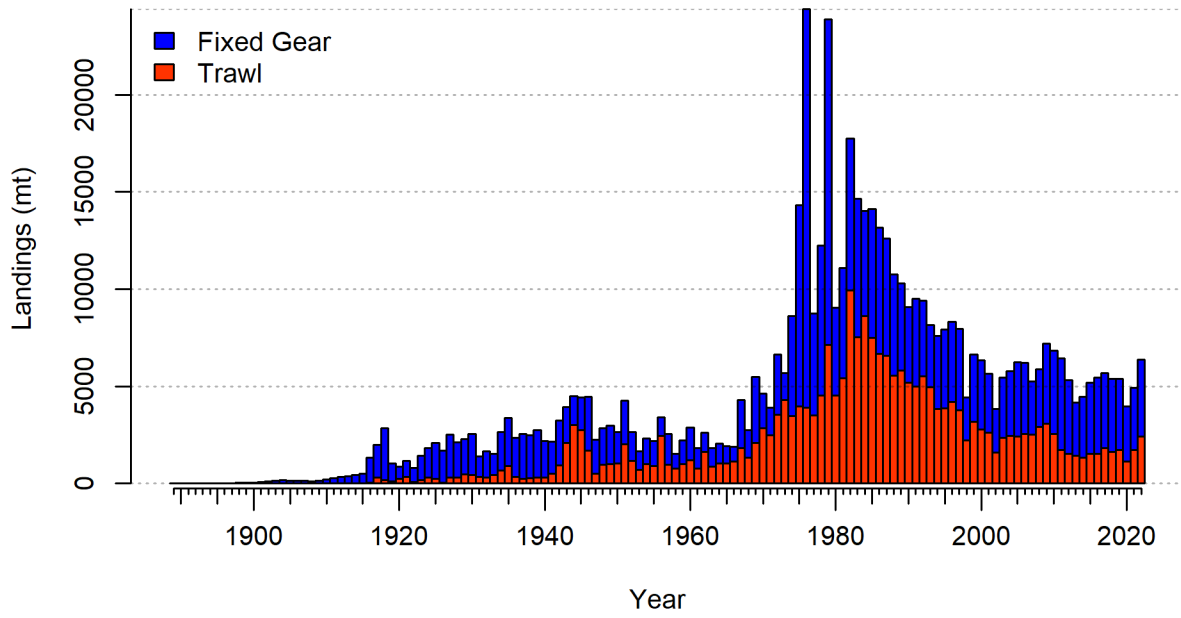
Figure 2: Landings (mt) by year from the fixed gear (blue) and trawl (red) fleets.

Discard fraction for Fixed Gear
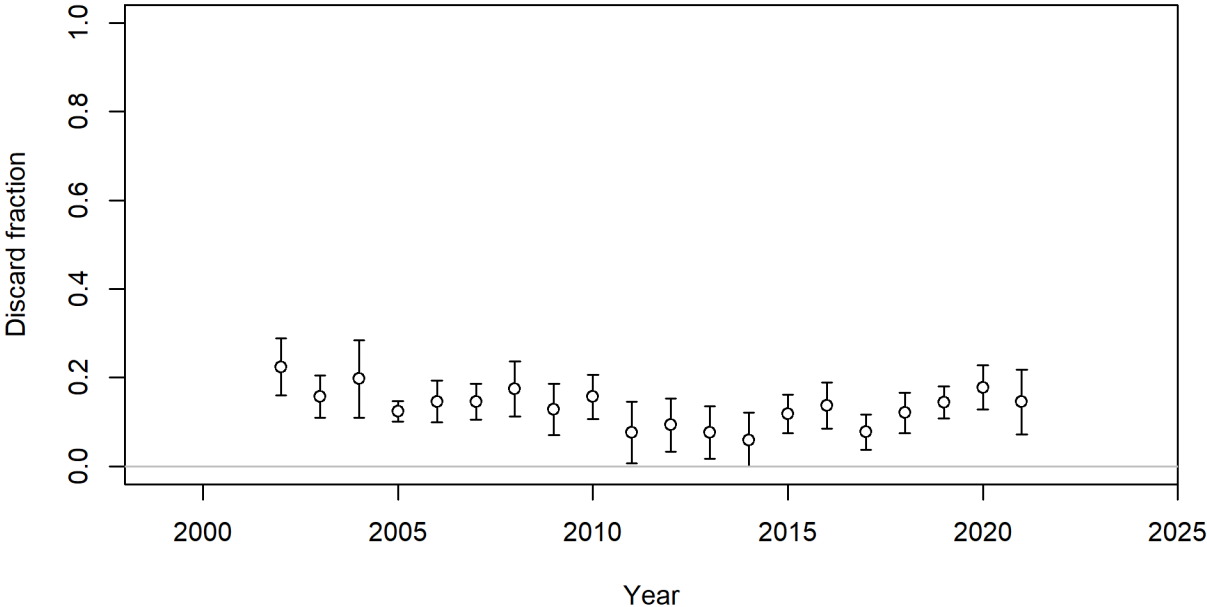
Figure 3: Annual West Coast Groundfish Observer Program discard rates for the fixed-gear fleet from the discarded catch.
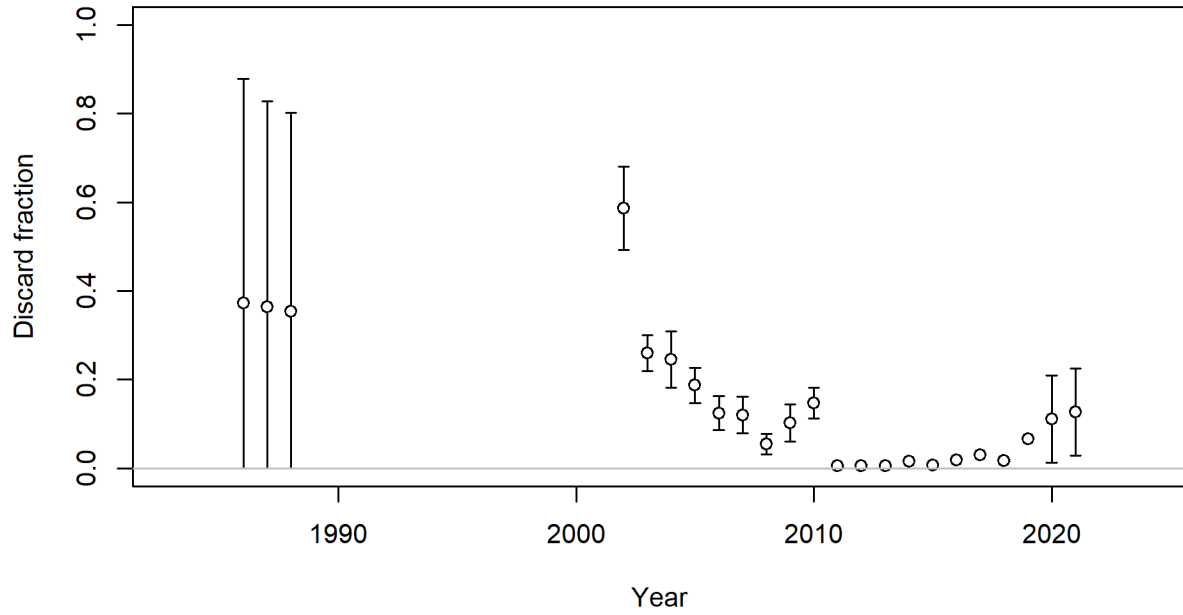
Figure 4: Annual West Coast Groundfish Observer Program discard rates for the trawl fleet from the discarded catch.
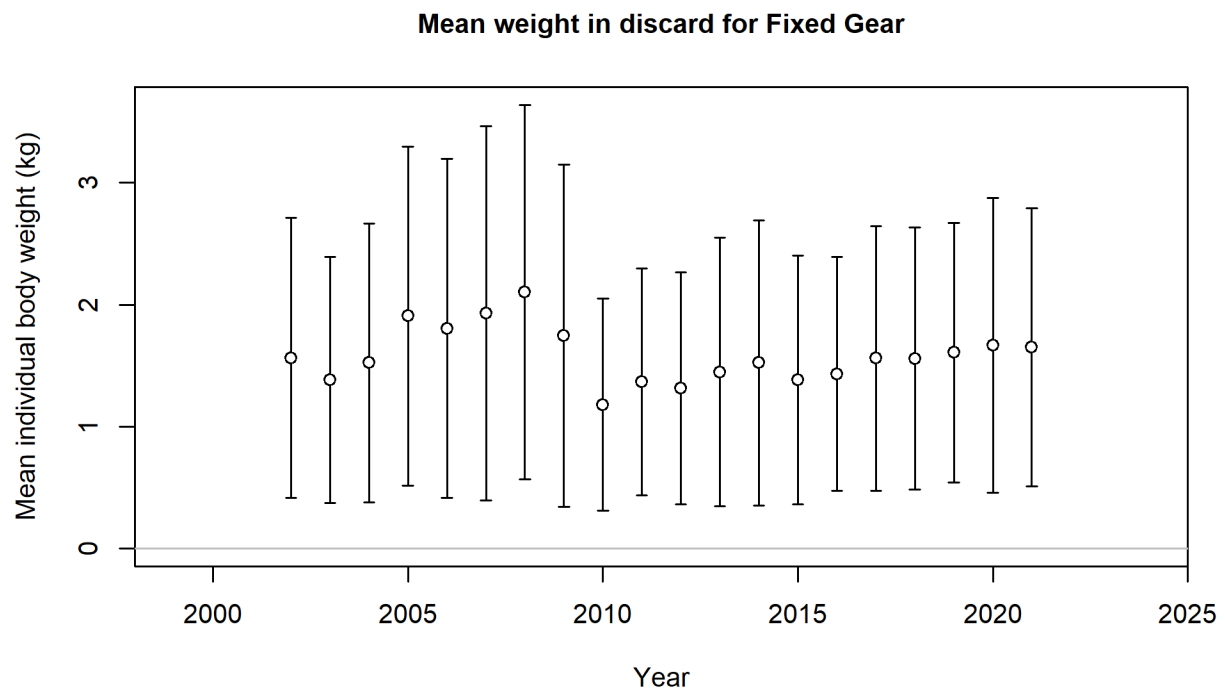
Figure 5: Annual West Coast Groundfish Observer Program mean weights (kg) for the fixed-gear fleet from the discarded catch.
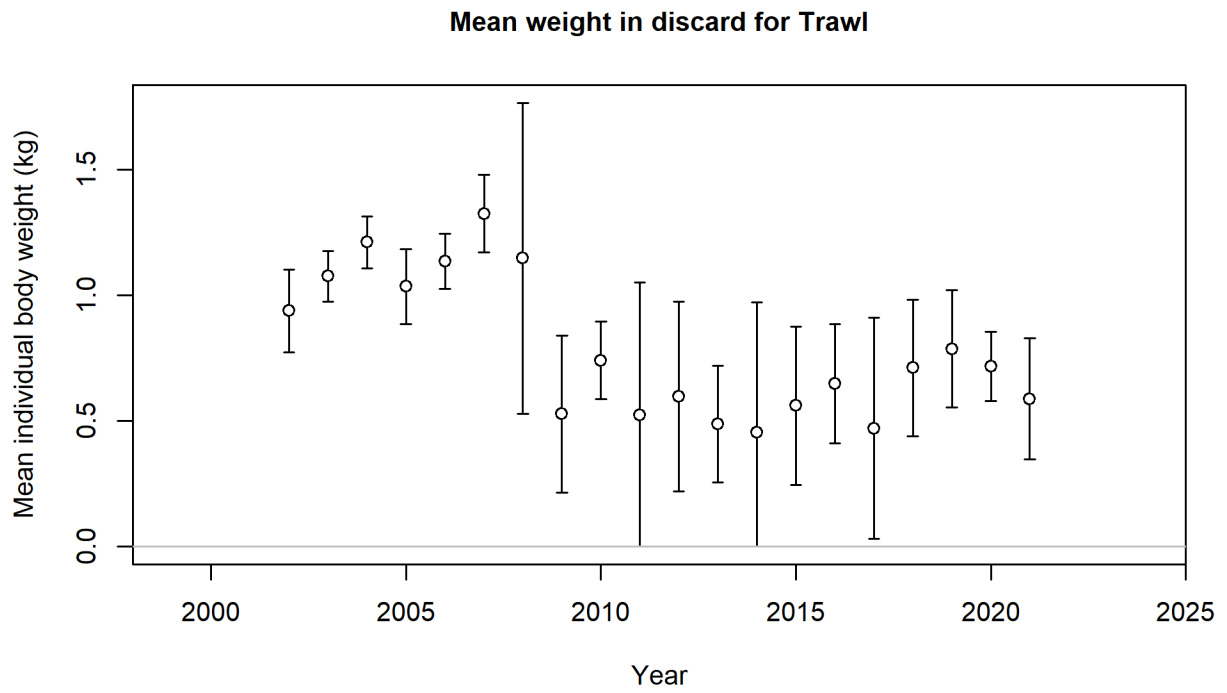
Figure 6: Annual West Coast Groundfish Observer Program mean weights (kg) for the trawl fleet from the discarded catch.
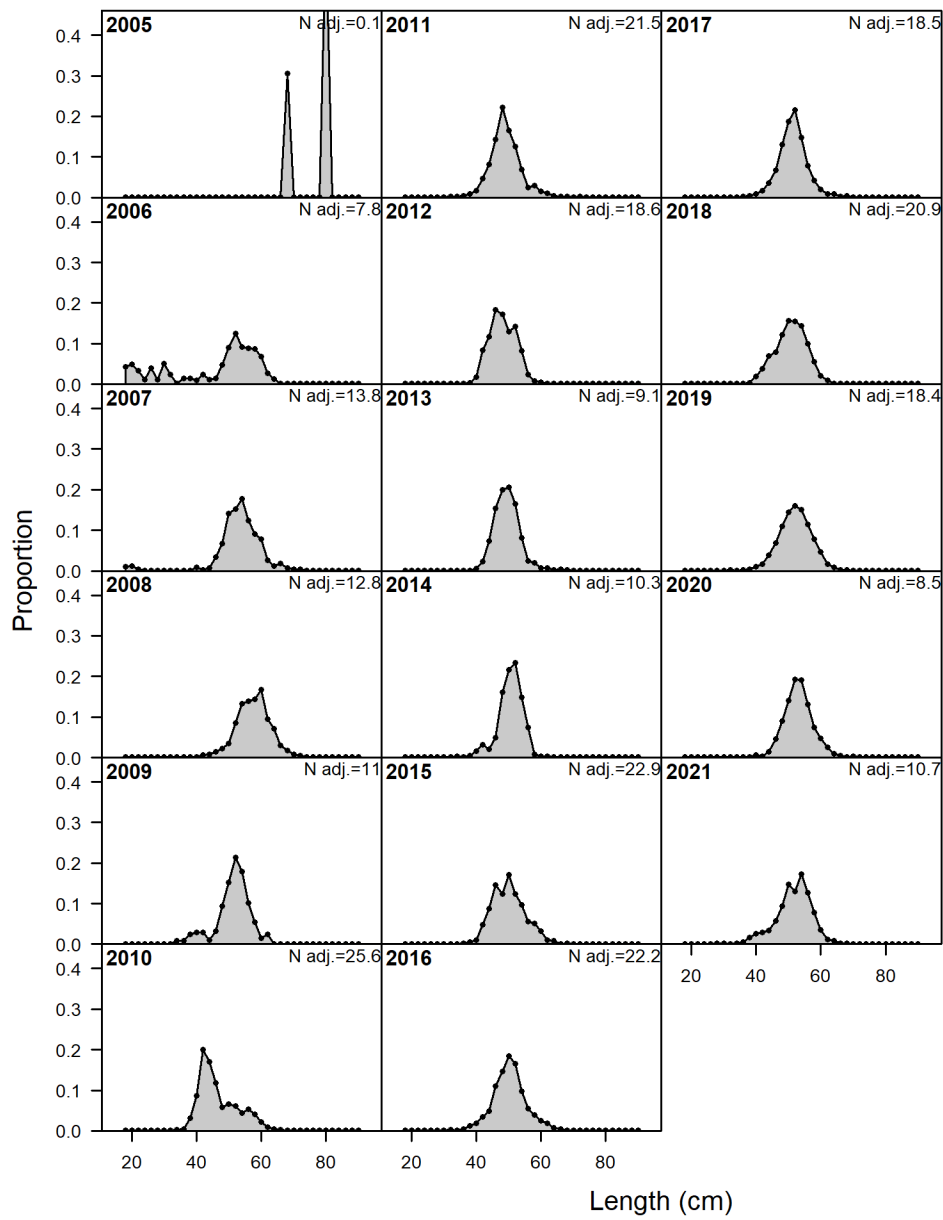
Figure 7: Annual length-composition data for the fixed-gear fleet from the discarded catch.
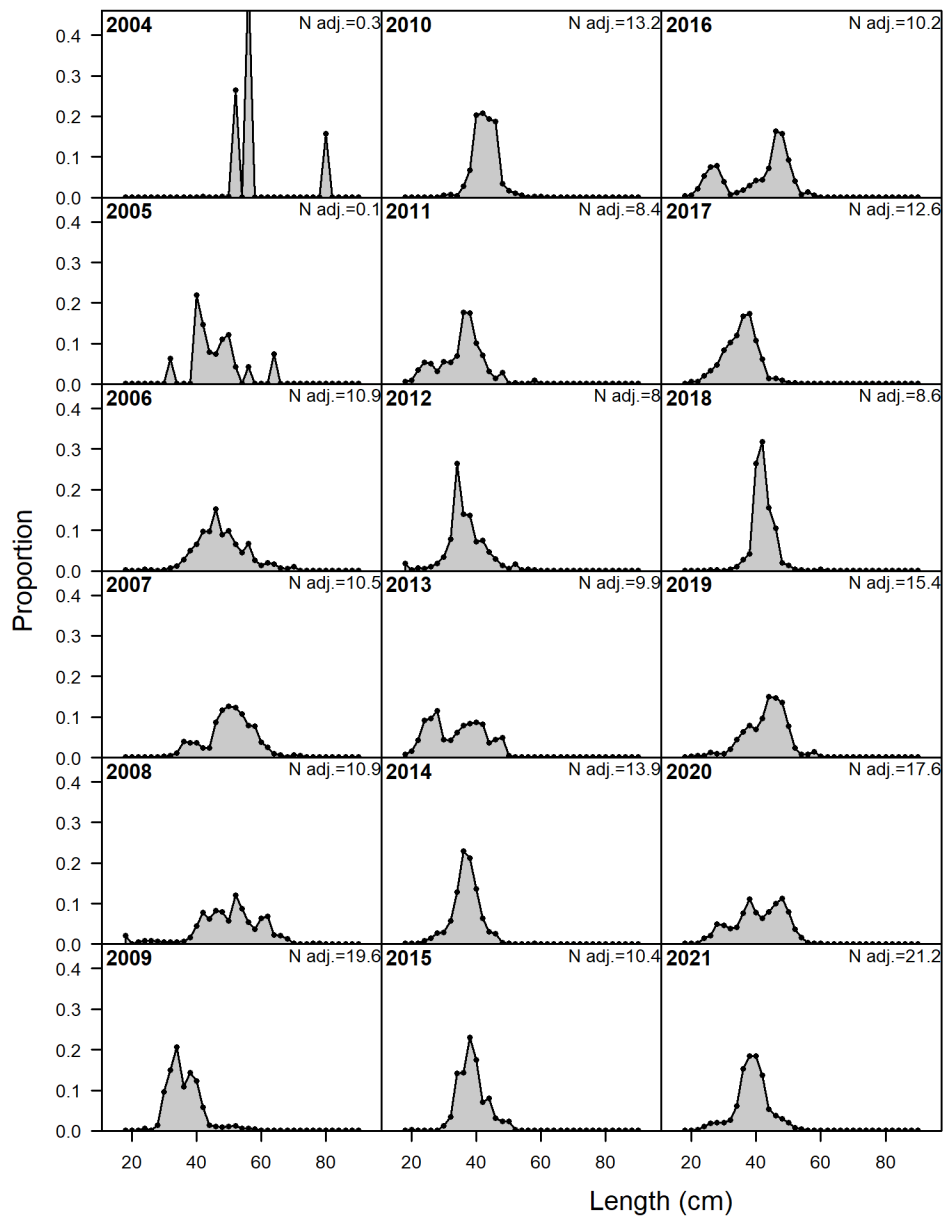
Figure 8: Annual length-composition data for the trawl fleet from the discarded catch.

8.1.3 Fishery-Independent Data
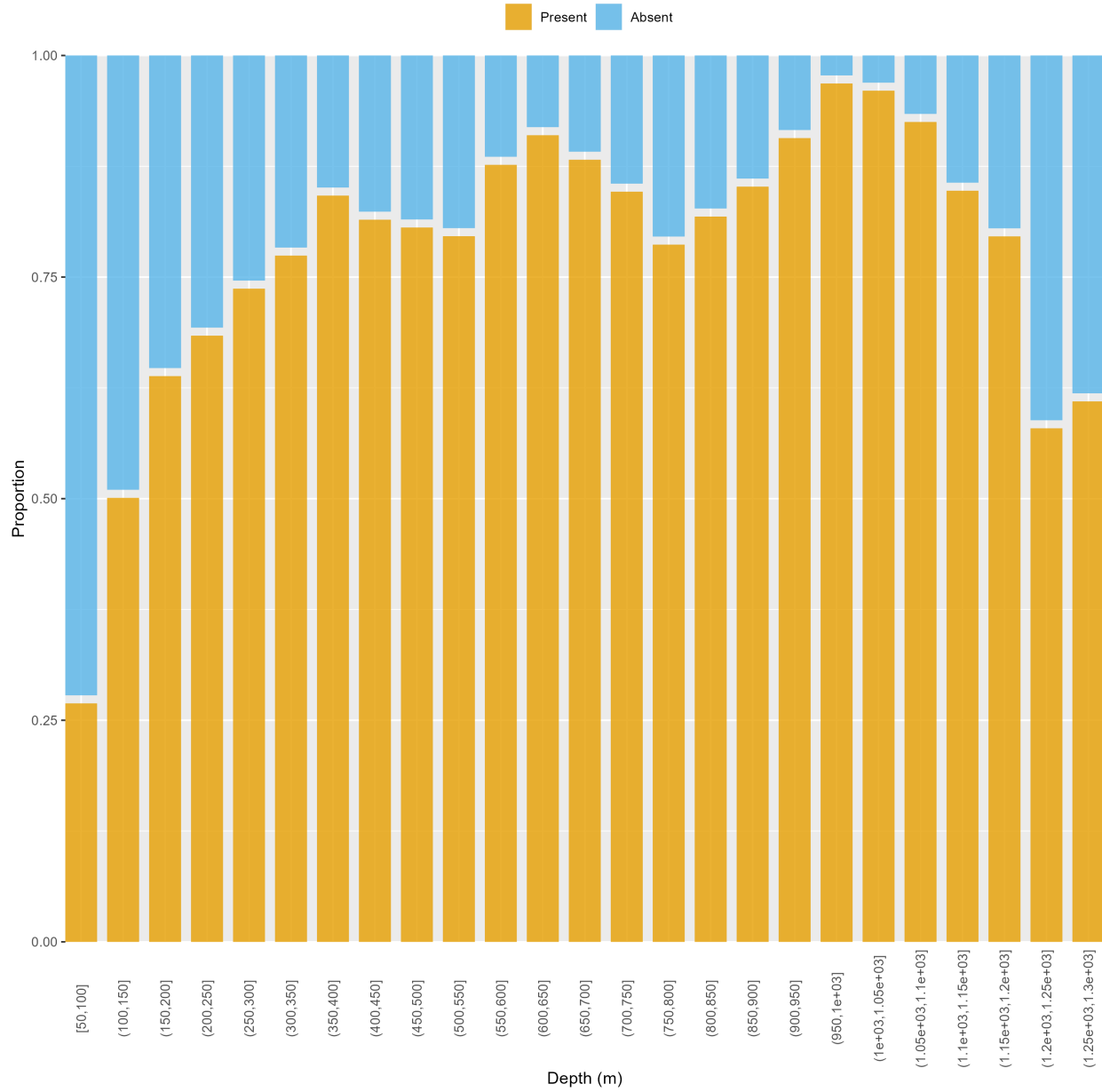
Figure 9: The proportion of tows that observe sablefish out of all tows performed within a given range of depths m sampled for the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey.
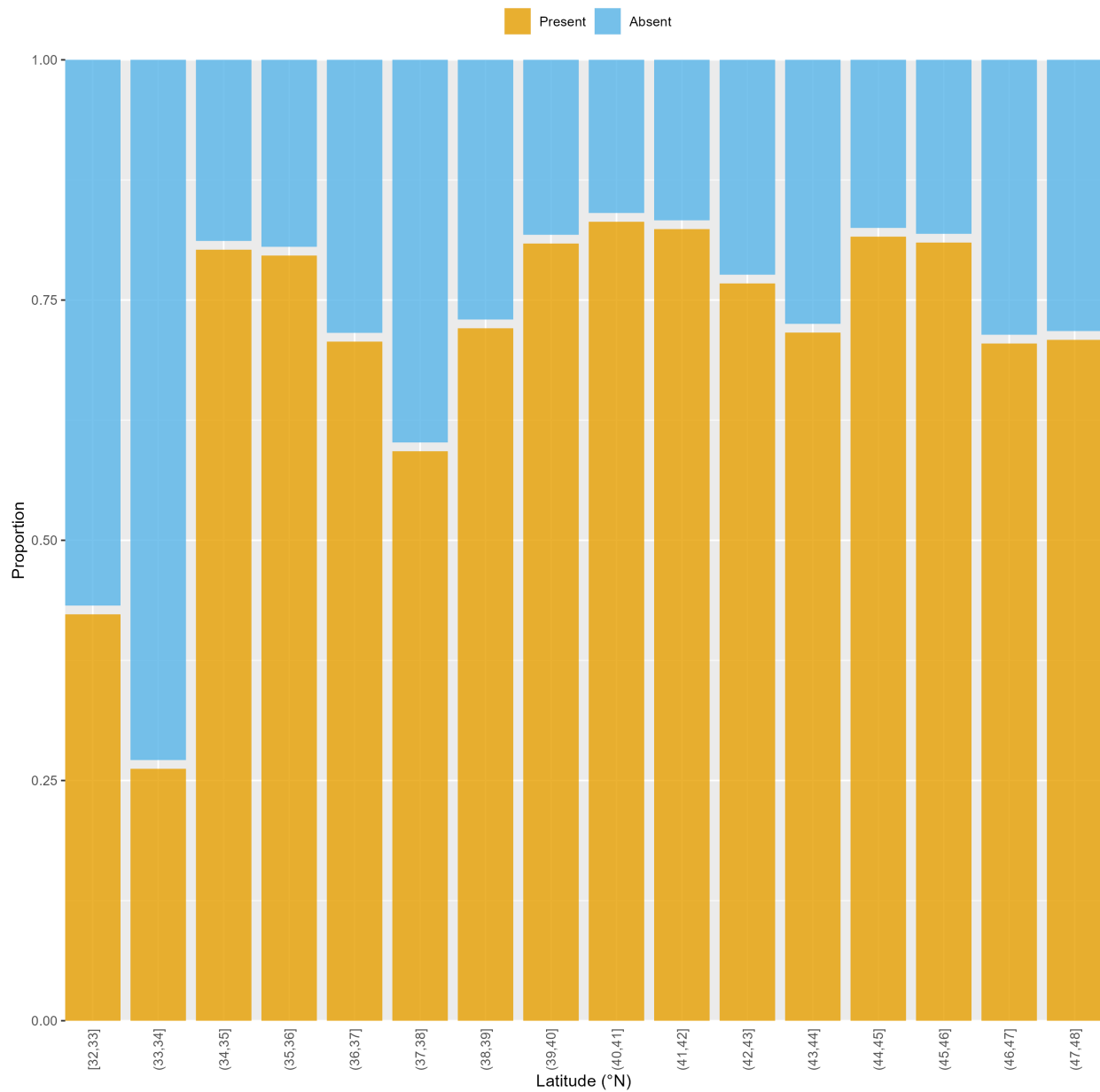
Figure 10: The proportion of tows that observe sablefish out of all tows performed within a given range of latitudes (decimal degrees) in the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey.
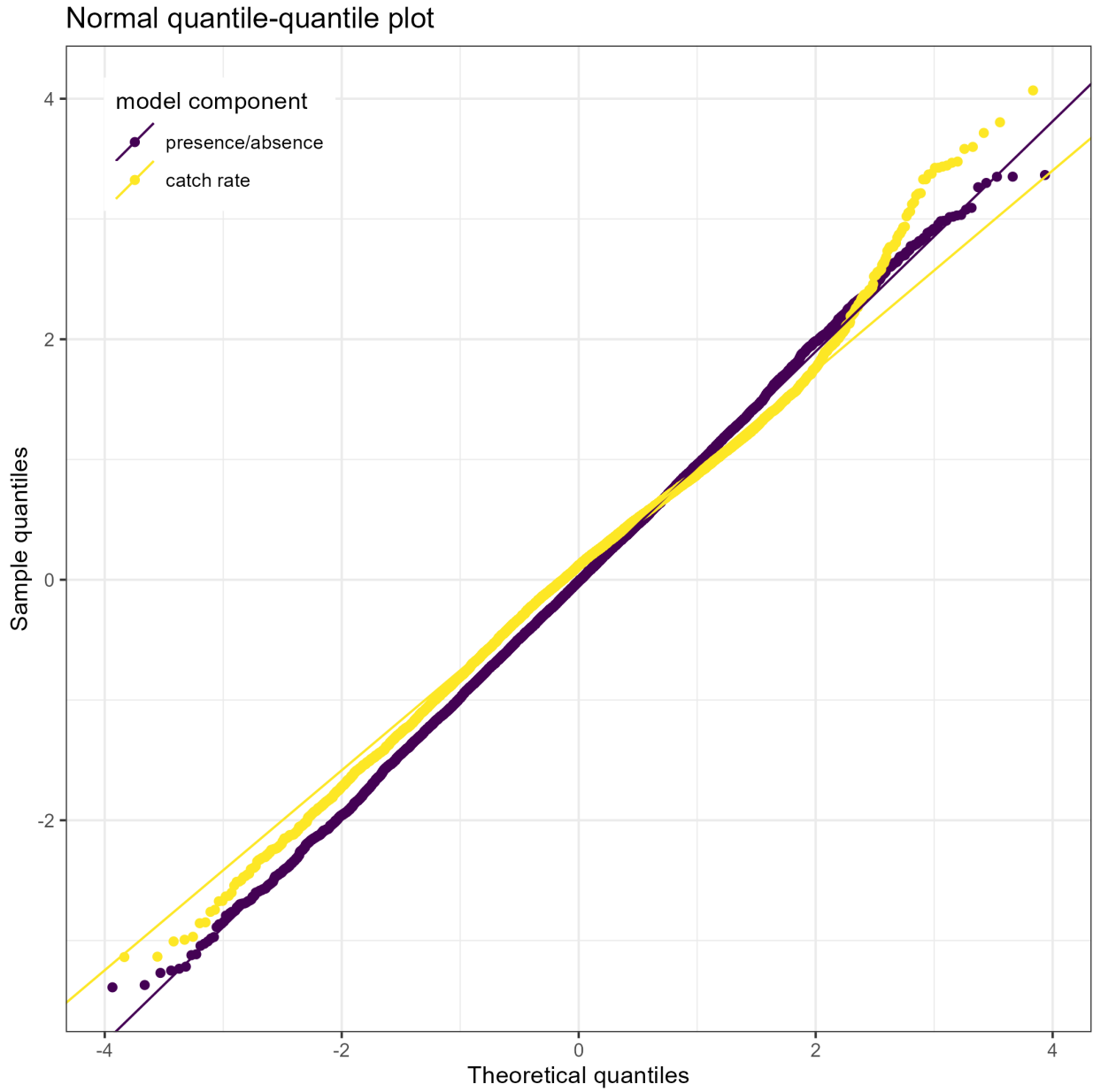
Figure 11: Quantile-quantile plot for the presence/absence (purple) and rate (yellow) components of a delta model fit to abundance data from the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey where the rate component assumed a gamma distribution.
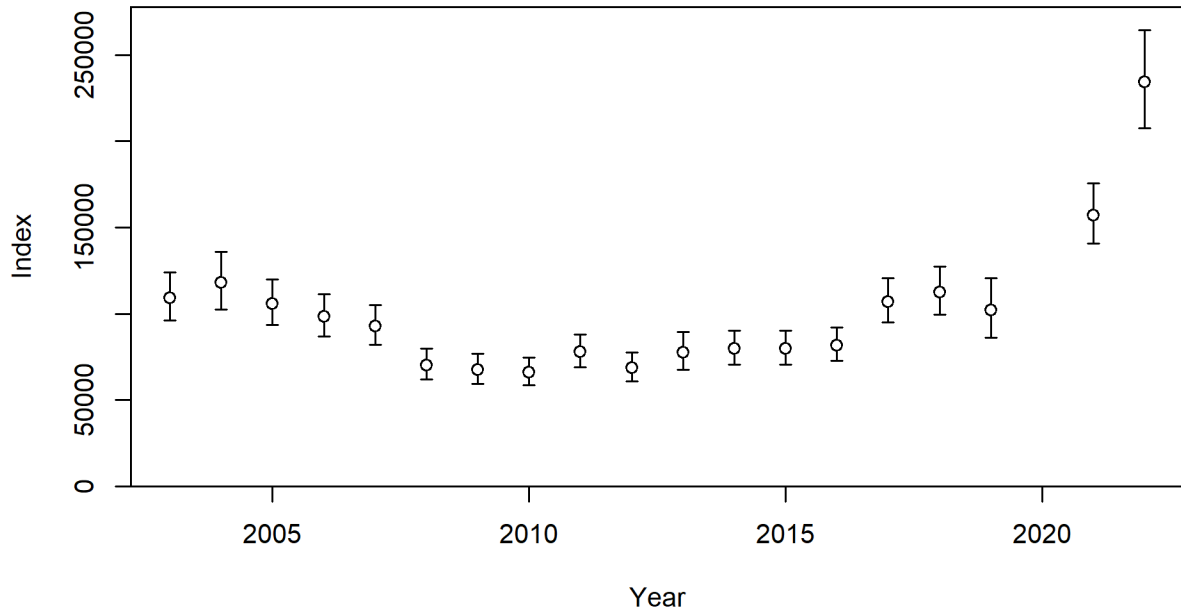
Figure 12: Annual relative index of abundance for the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey.
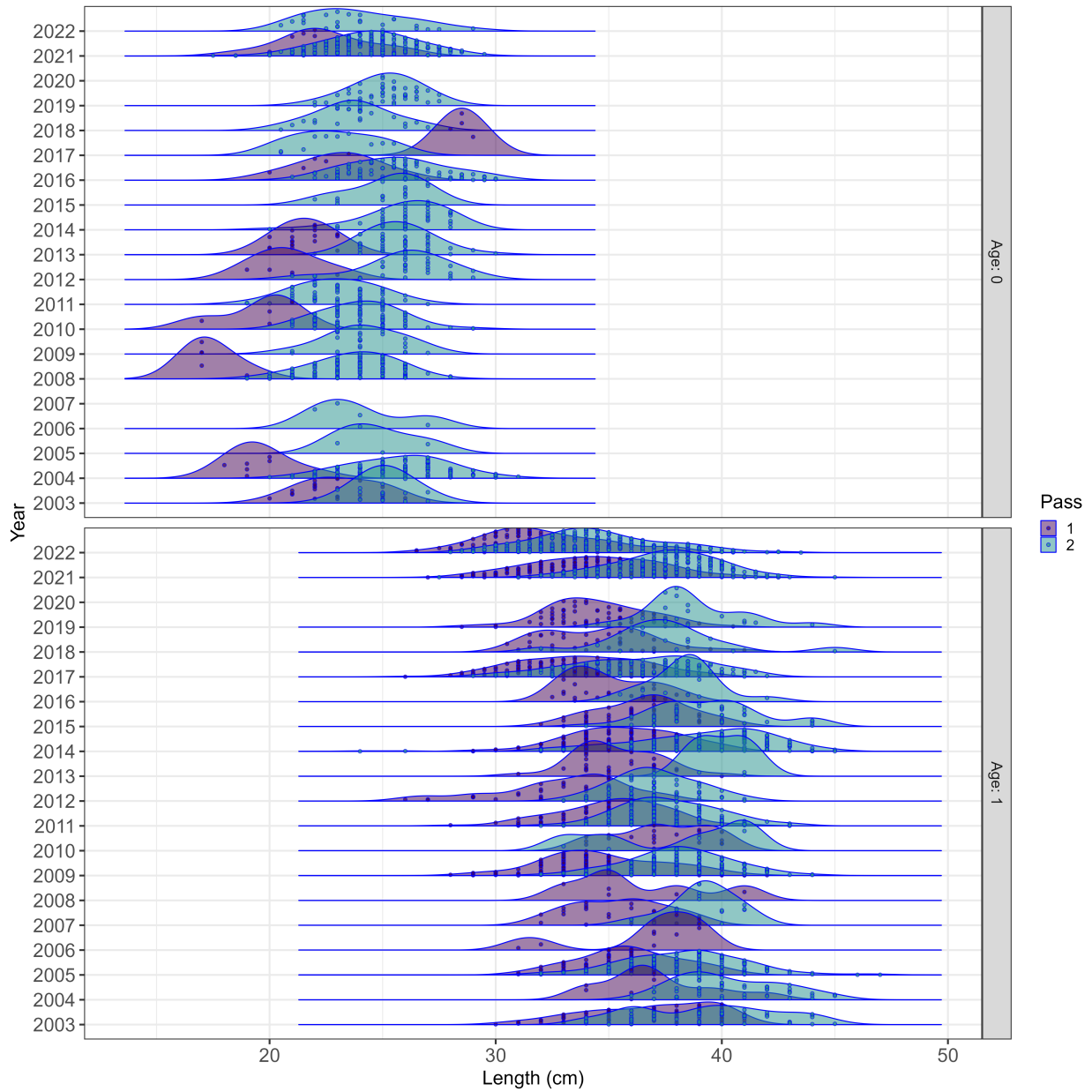
Figure 13: The length distribution of age-0 (upper panel) and age-1 (lower panel) fish by survey pass (colors) across years sampled by the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey. Blue dots indicate the lengths observed for each age and by pass.
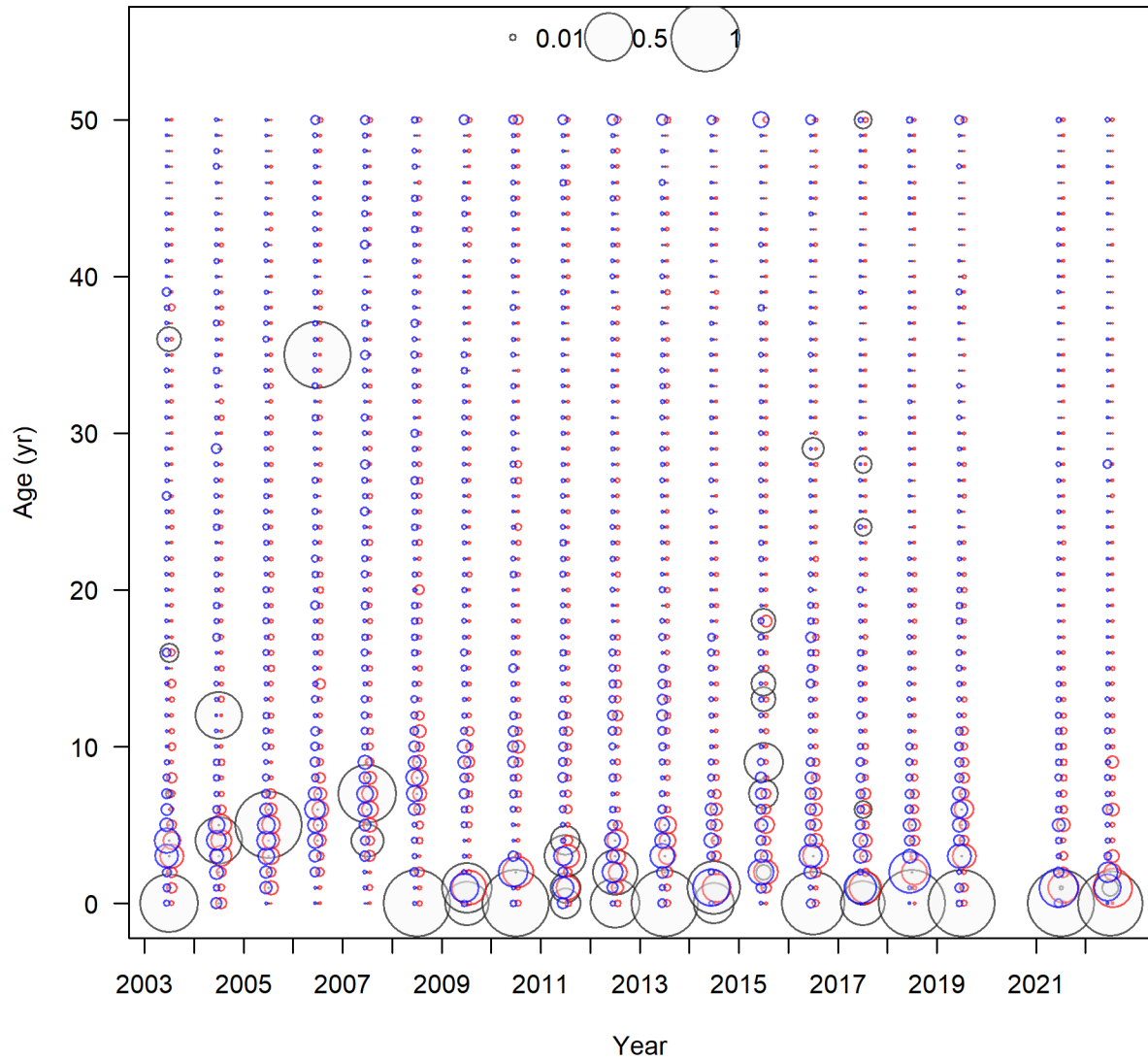
Figure 14: Annual female, male, and unsexed (red, blue, and black, respectively) age-composition data that were excluded from the model fitting process for the WCGBTS from the whole catch.
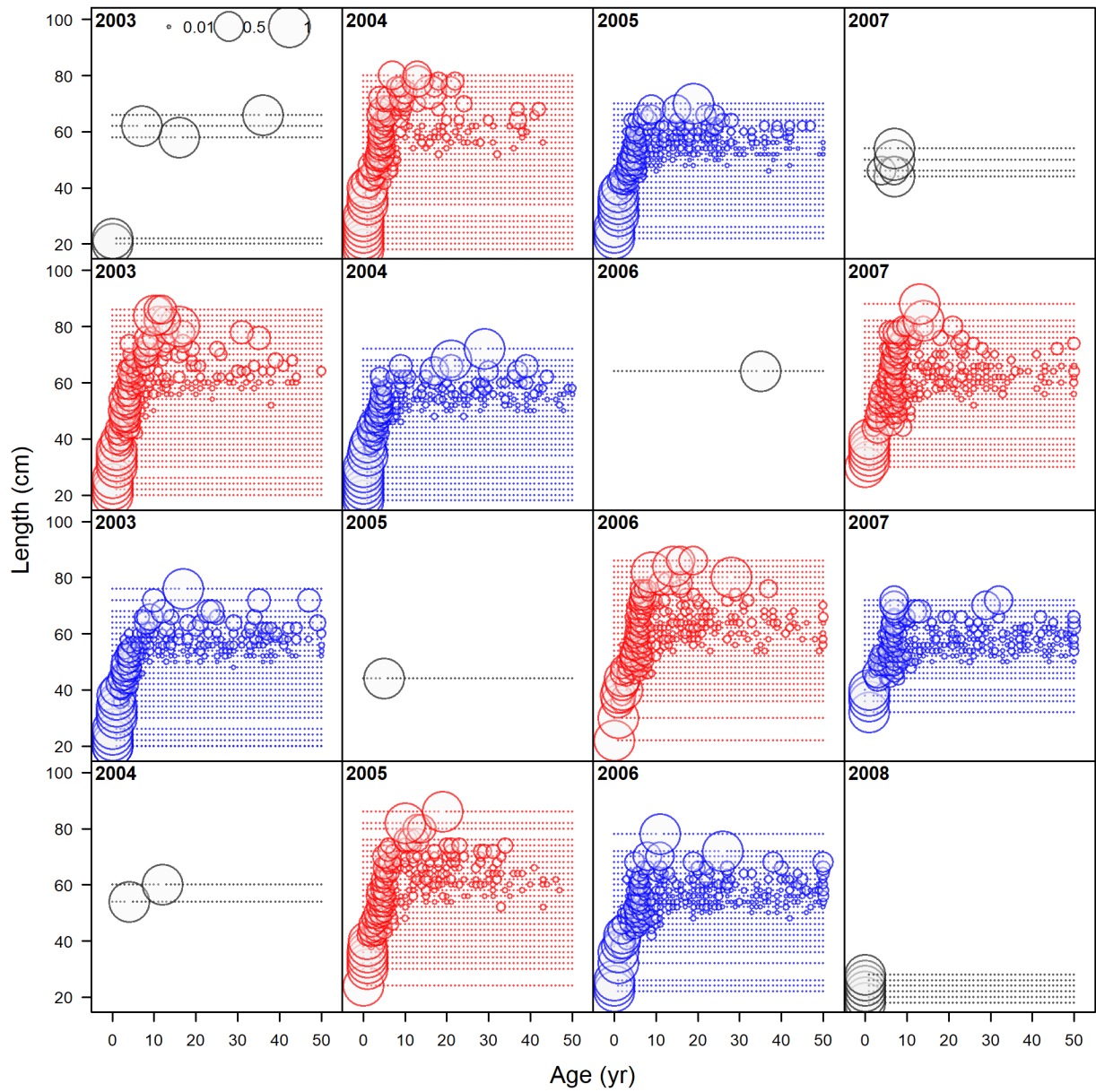
Figure 15: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGBTS from the whole catch.

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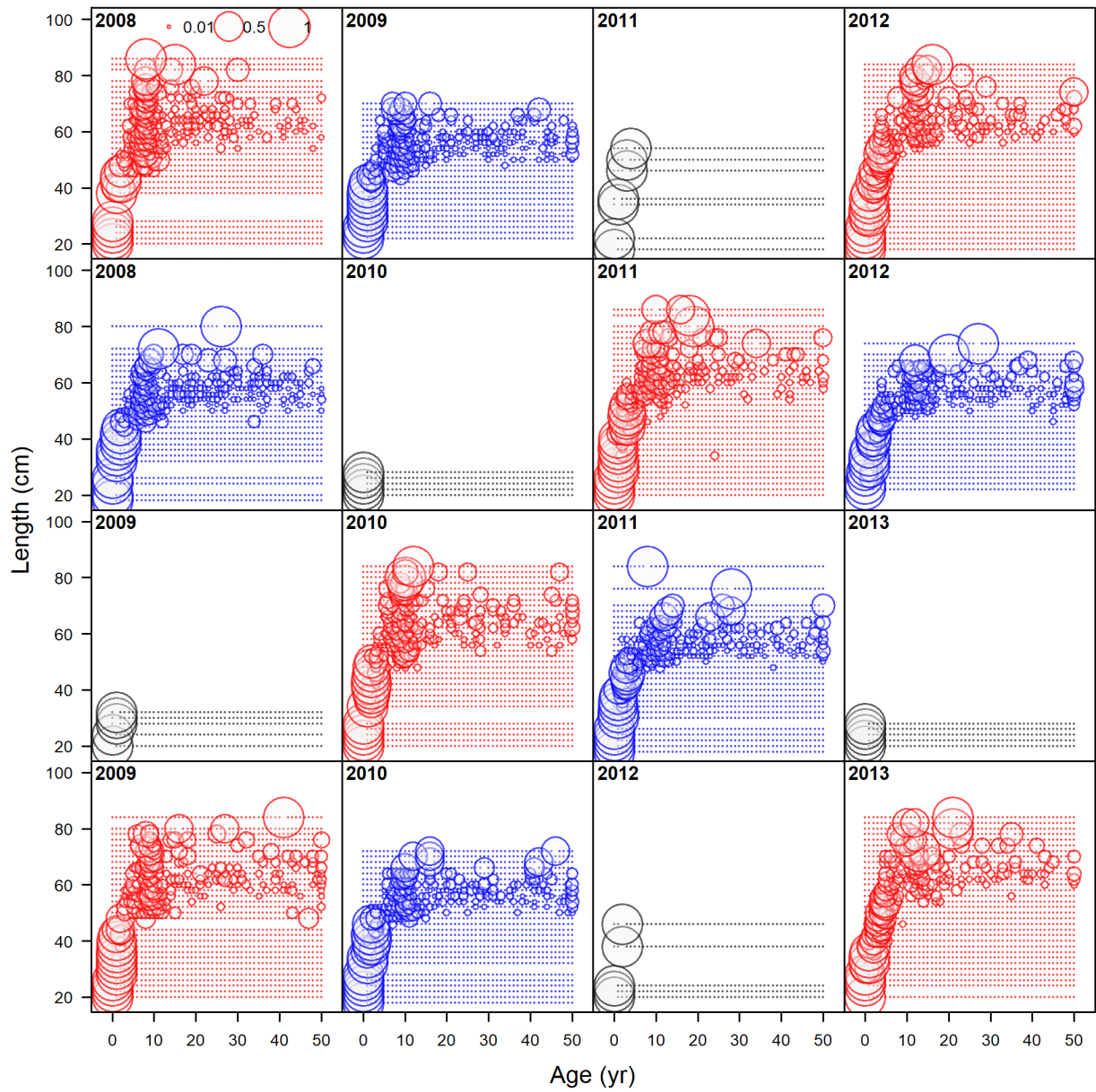
Figure 16: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGBTS from the whole catch. Continued.
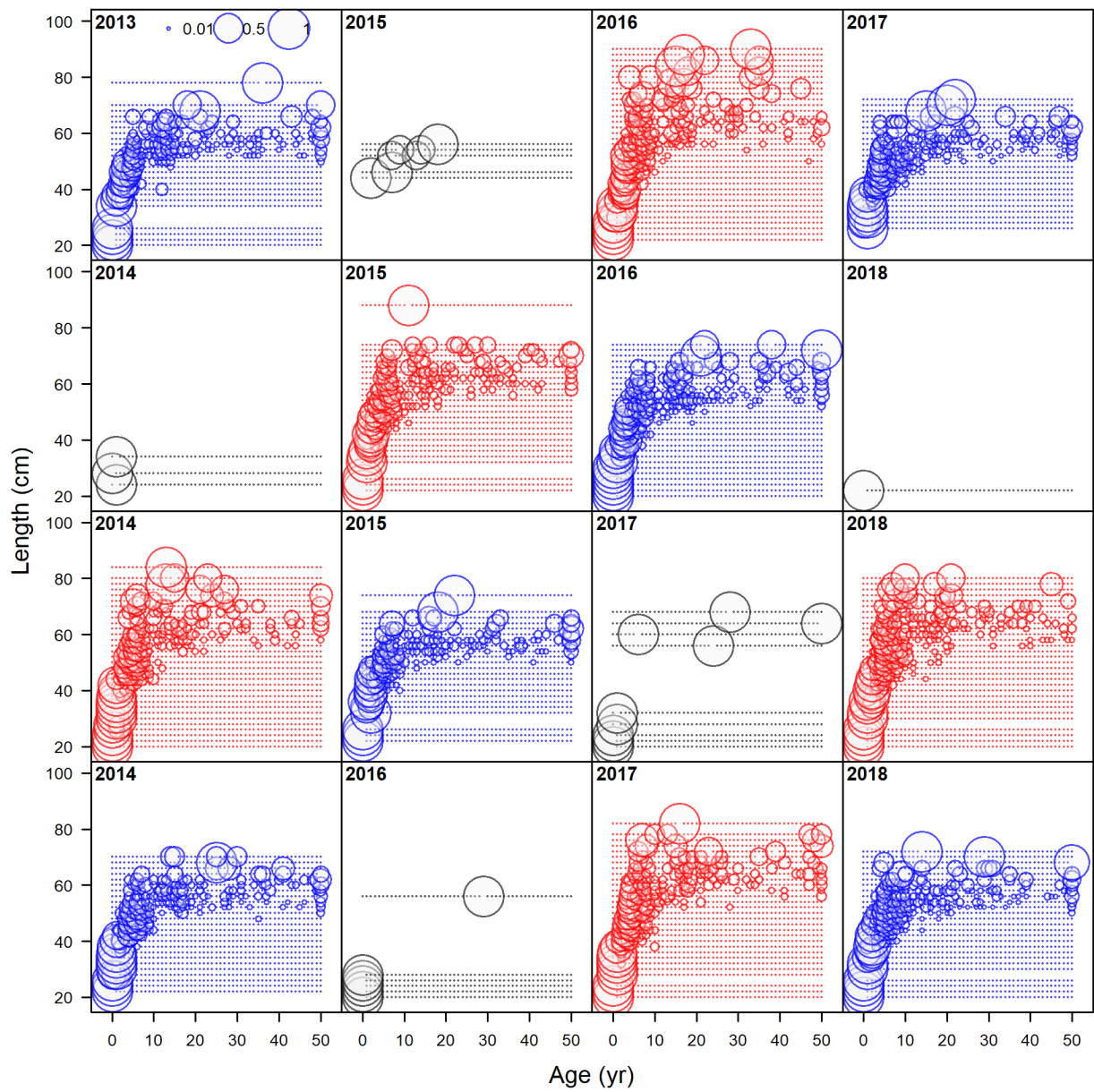
Figure 17: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGBTS from the whole catch. Continued.
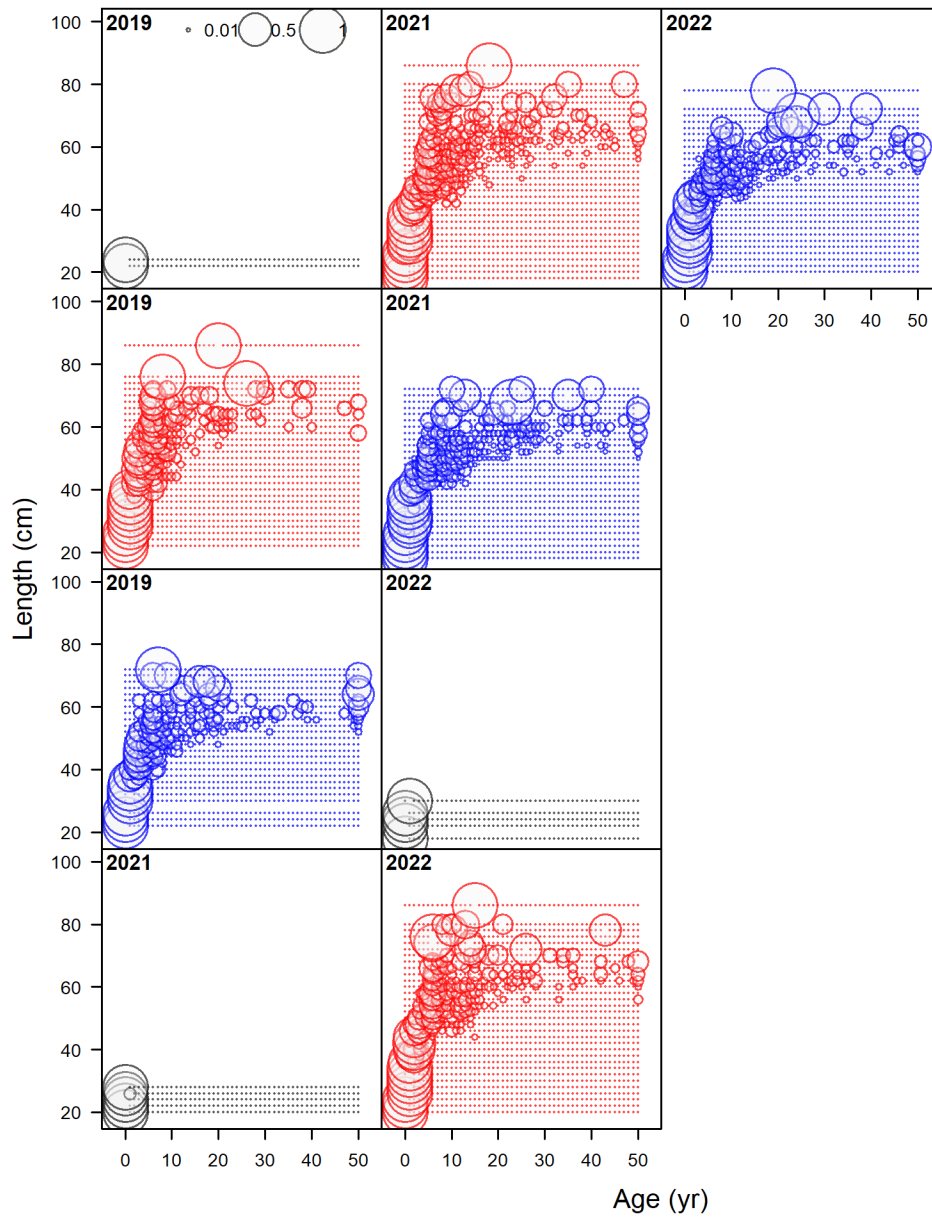
Figure 18: Annual female, male, and unsexed (red, blue, and black, respectively) conditional age-at-length data for the WCGBTS from the whole catch. Continued.
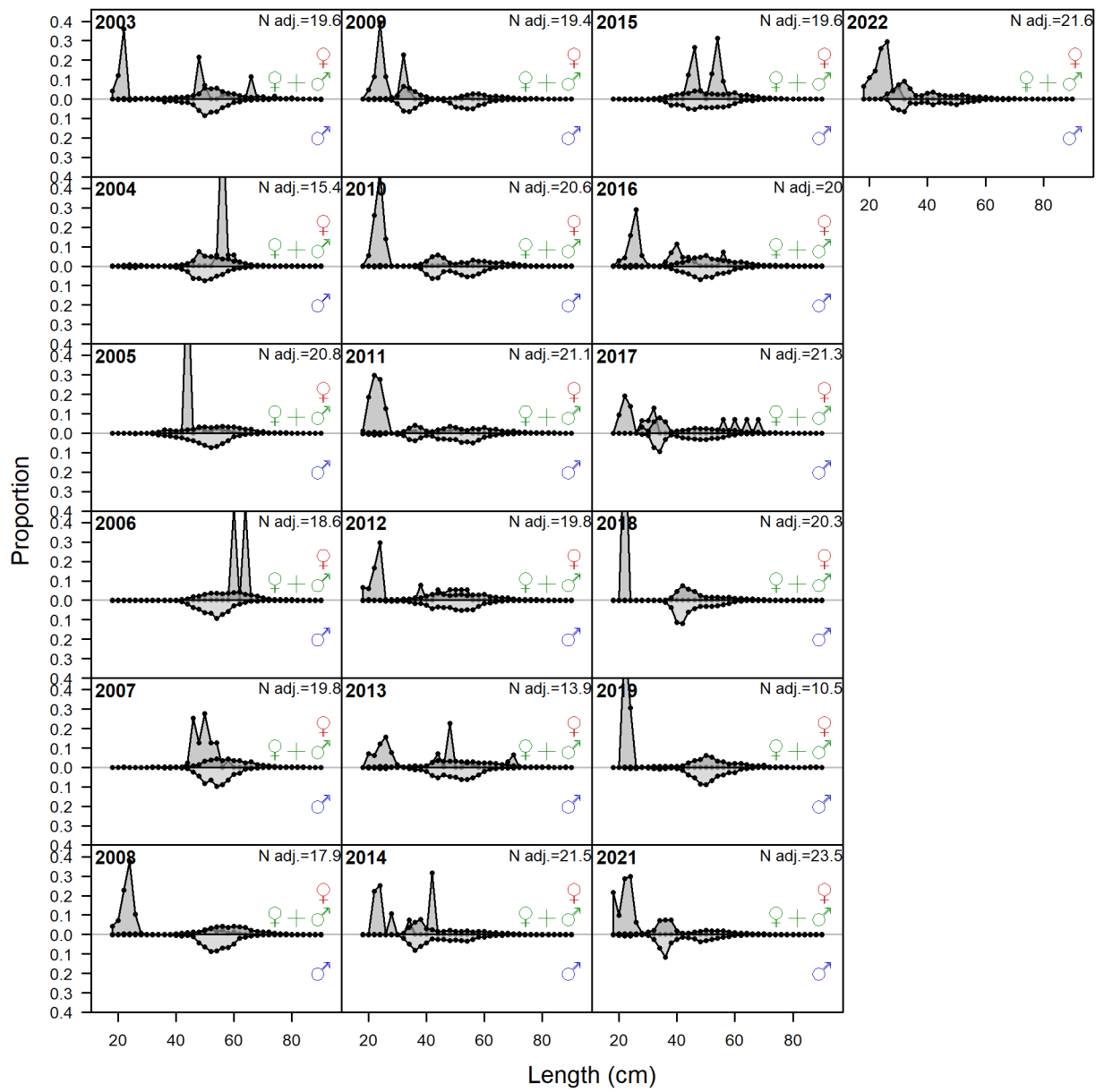
Figure 19: Annual length-composition data for the WCGBTS from the whole catch.
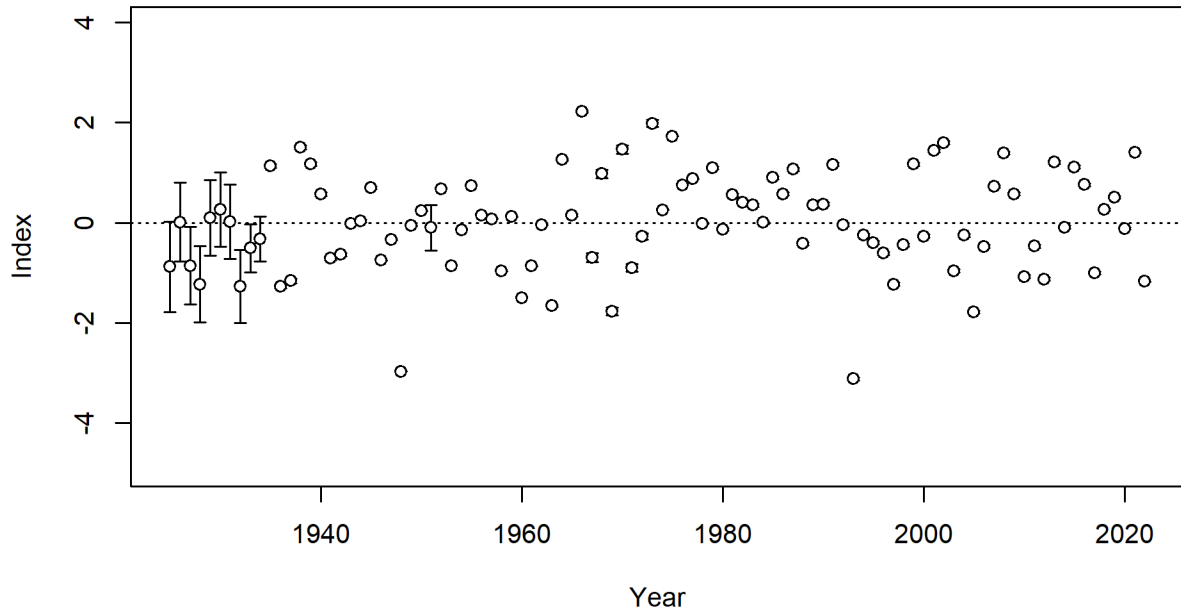
Figure 20: Annual relative index of abundance for the environmental index.

8.2 Model Results

8.2.1 Bridging
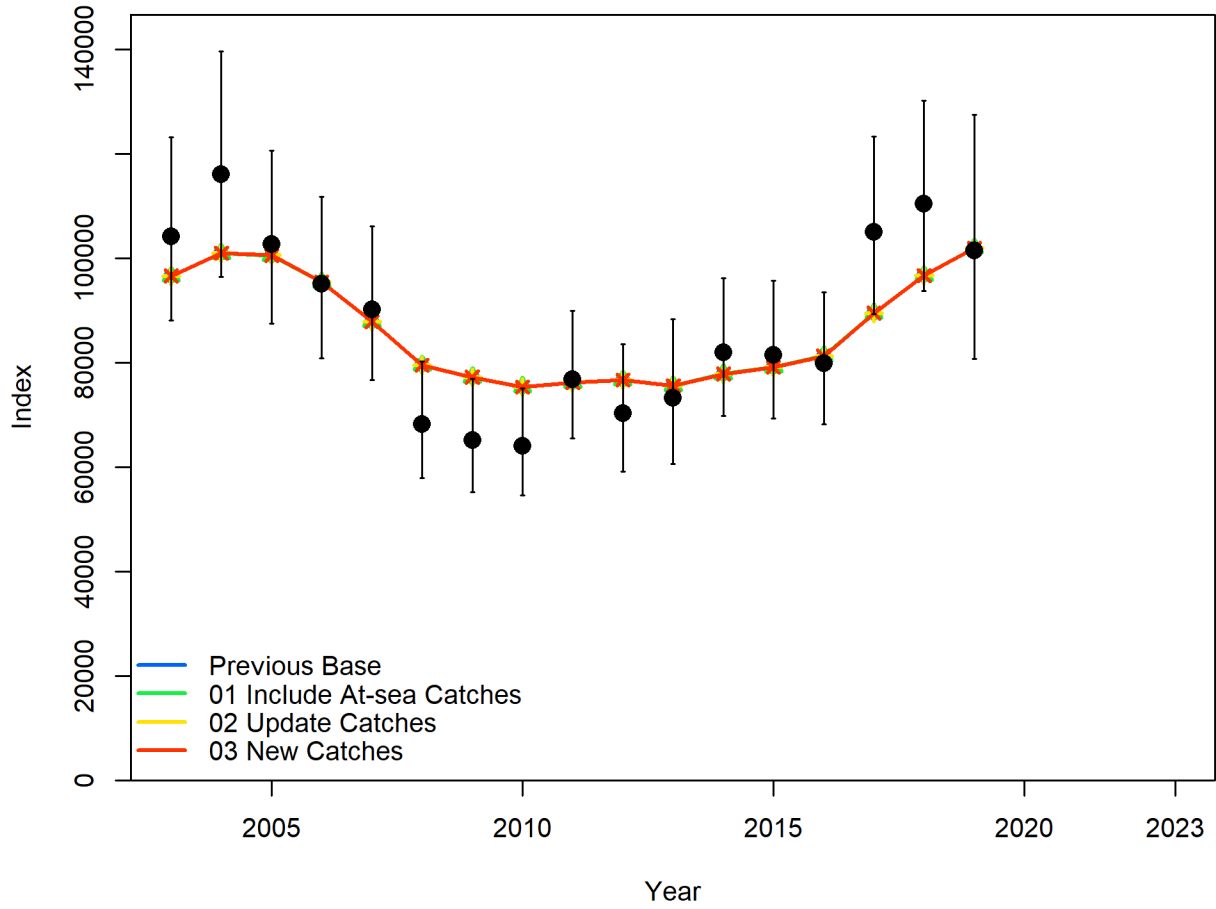
Figure 21: Recent survey across several steps towards creating the base model from the previous assessment model.
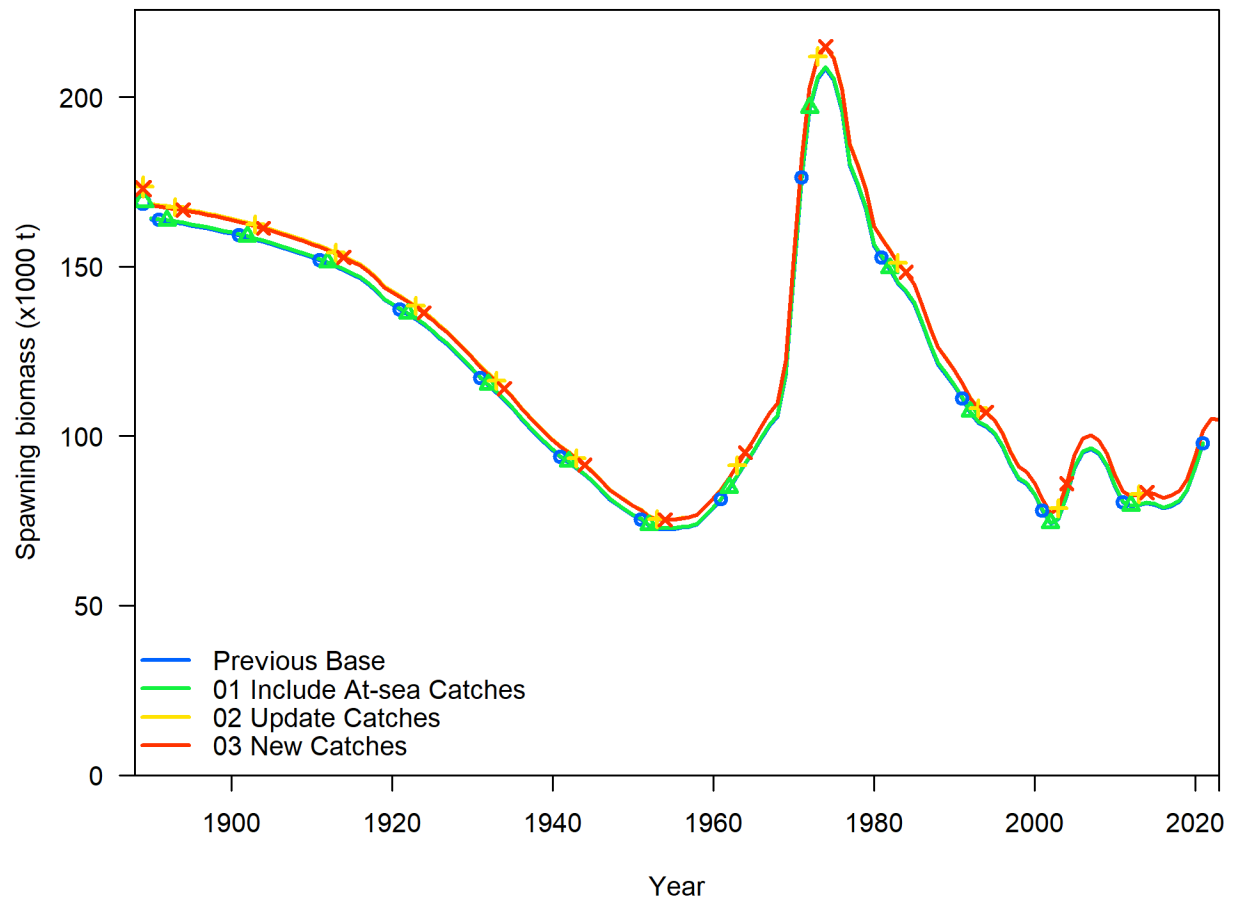
Figure 22: Spawning biomass across several steps towards creating the base model from the previous assessment model.
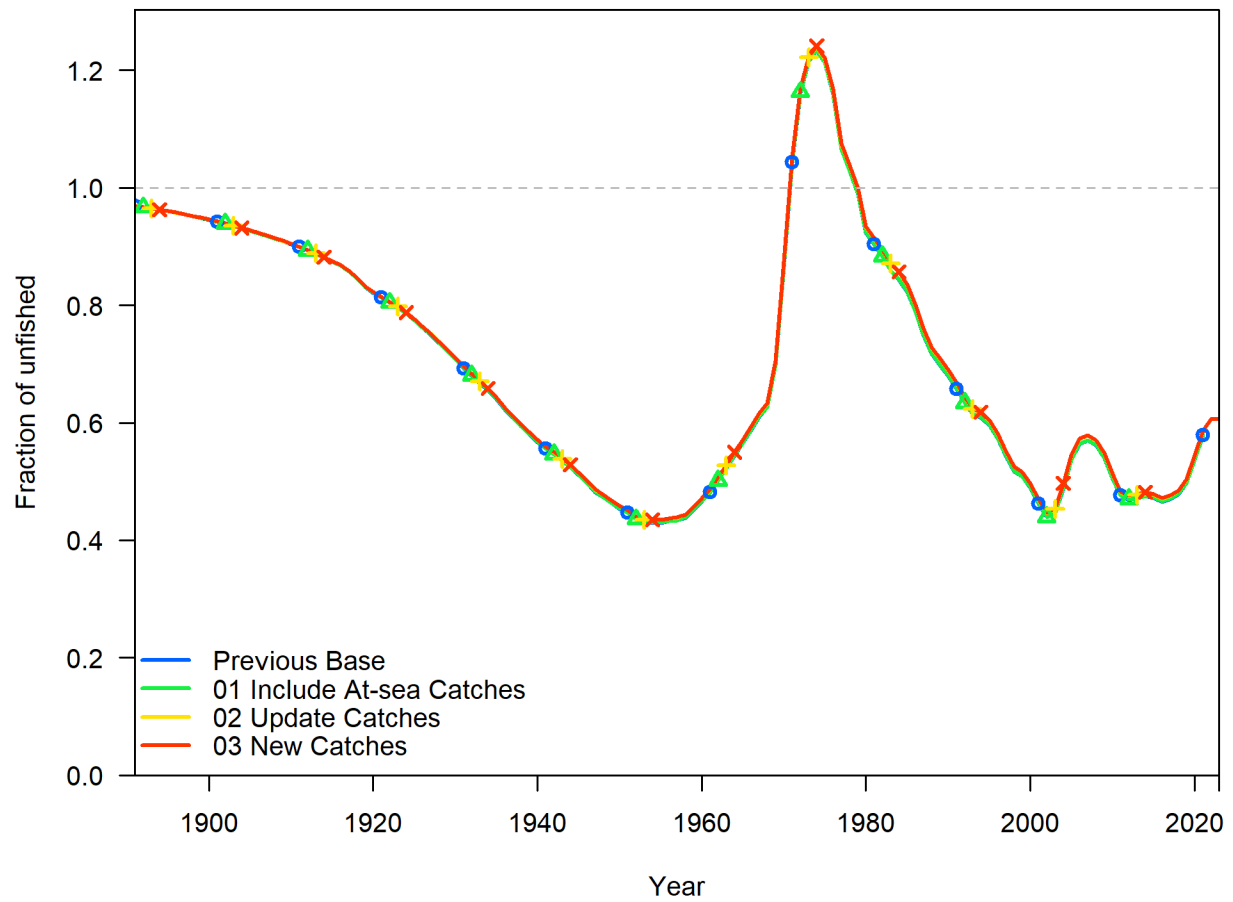
Figure 23: Fraction unfished across several steps towards creating the base model from the previous assessment model.
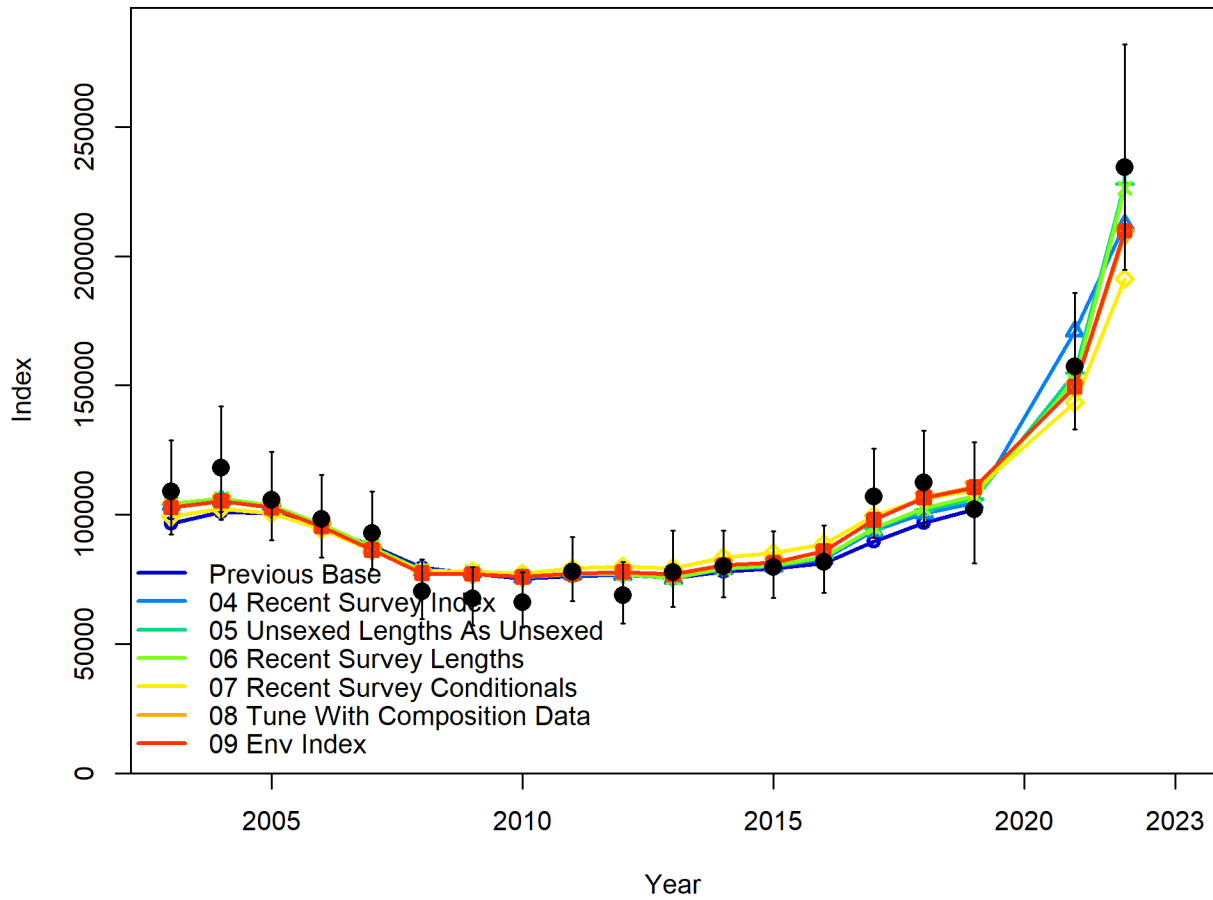
Figure 24: Recent survey across several steps towards creating the base model from the previous assessment model.
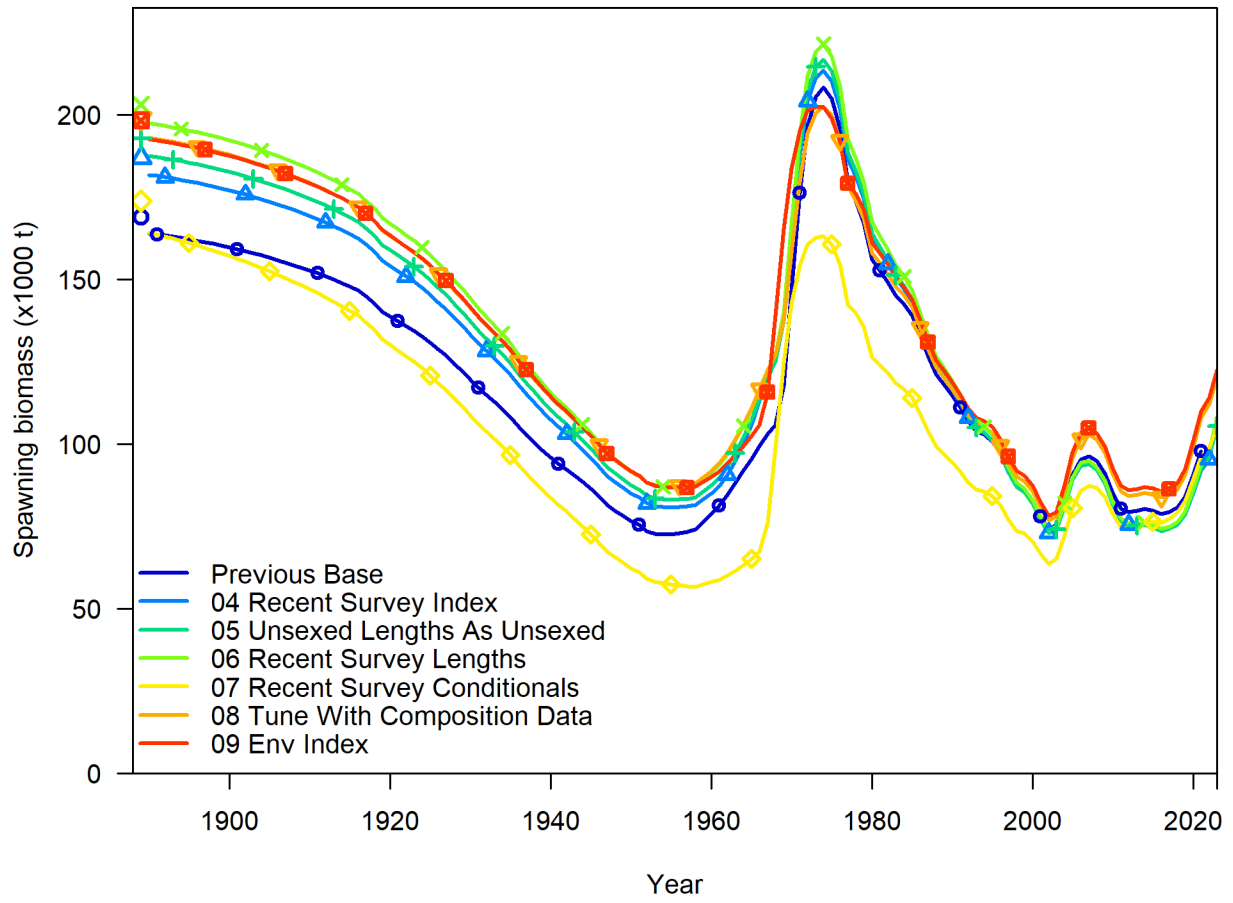
Figure 25: Spawning biomass across several steps towards creating the base model from the previous assessment model.
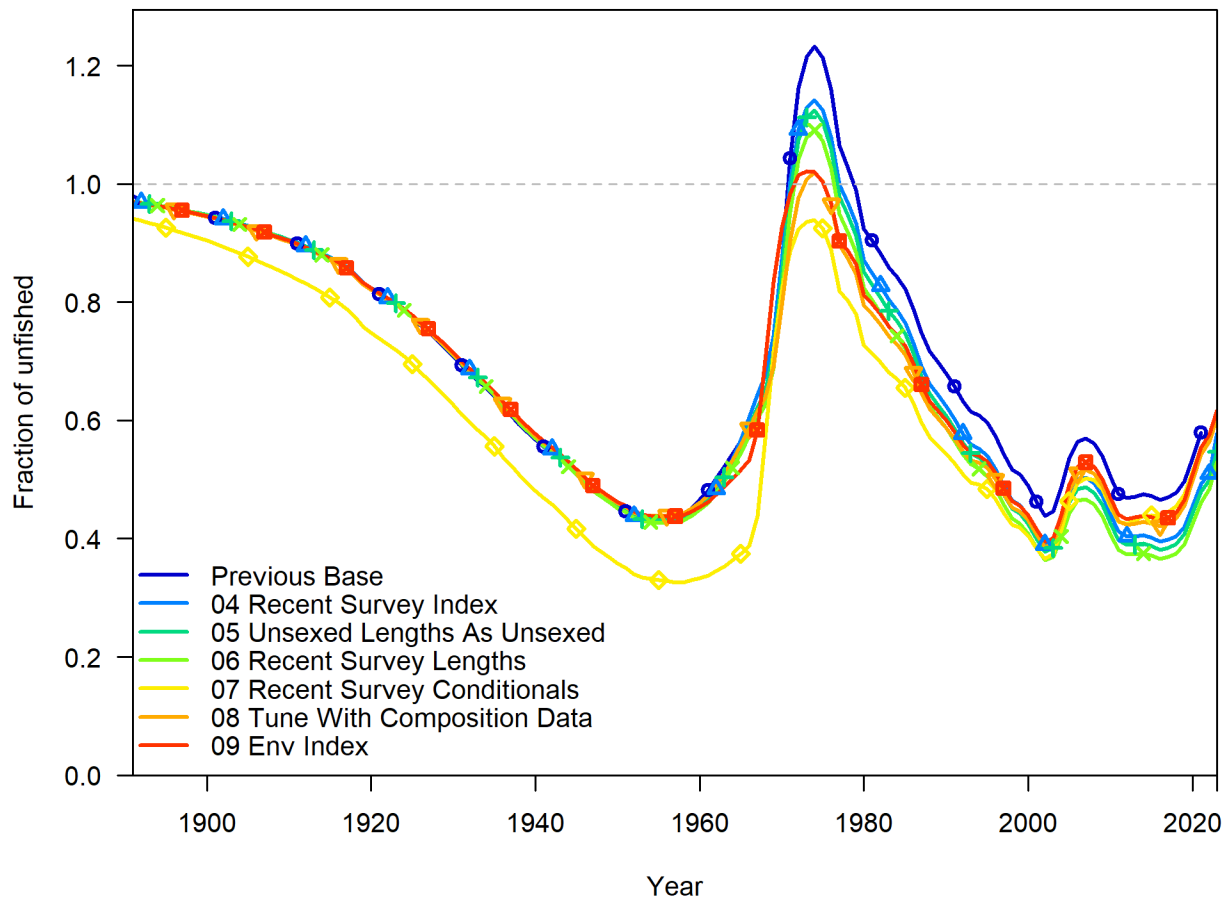
Figure 26: Fraction unfished across several steps towards creating the base model from the previous assessment model.
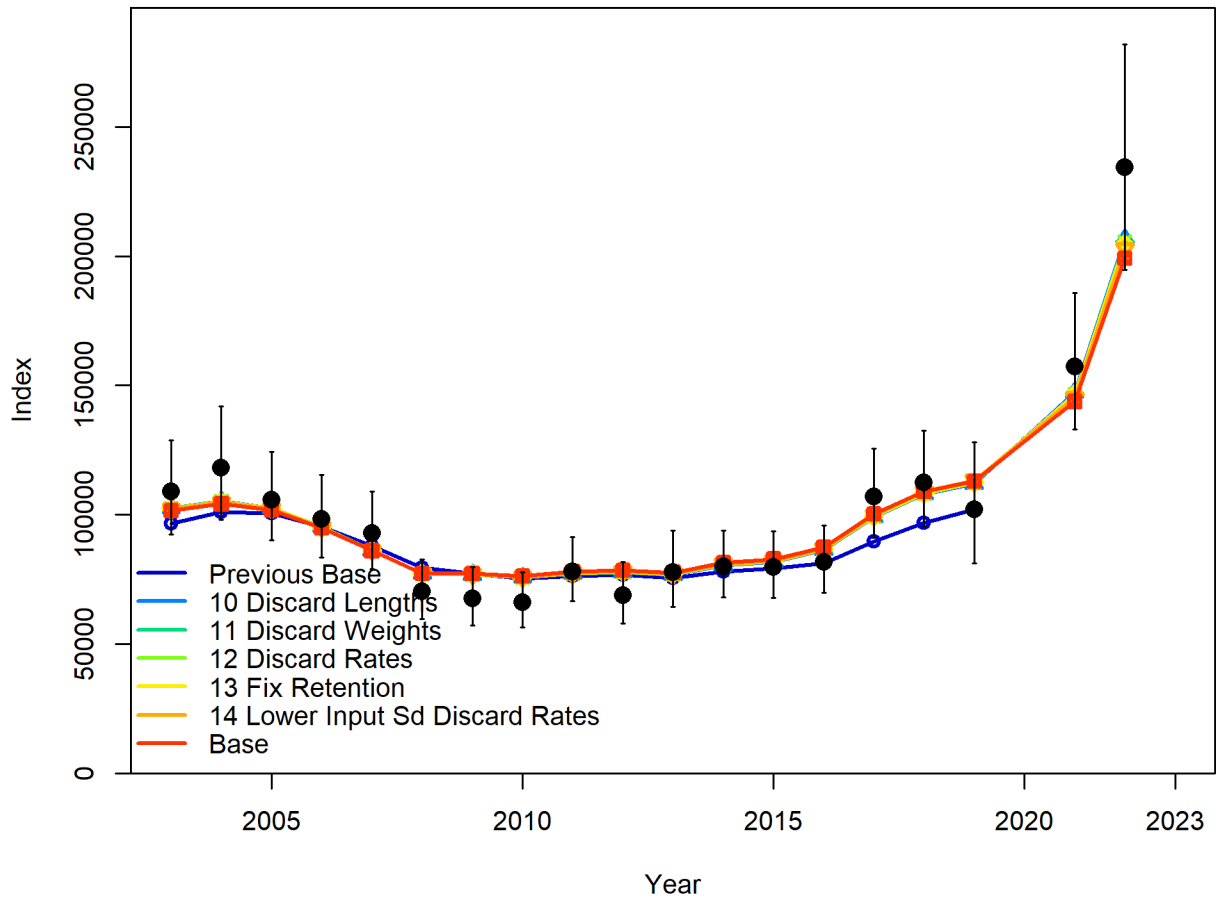
Figure 27: Recent survey across several steps towards creating the base model from the previous assessment model.
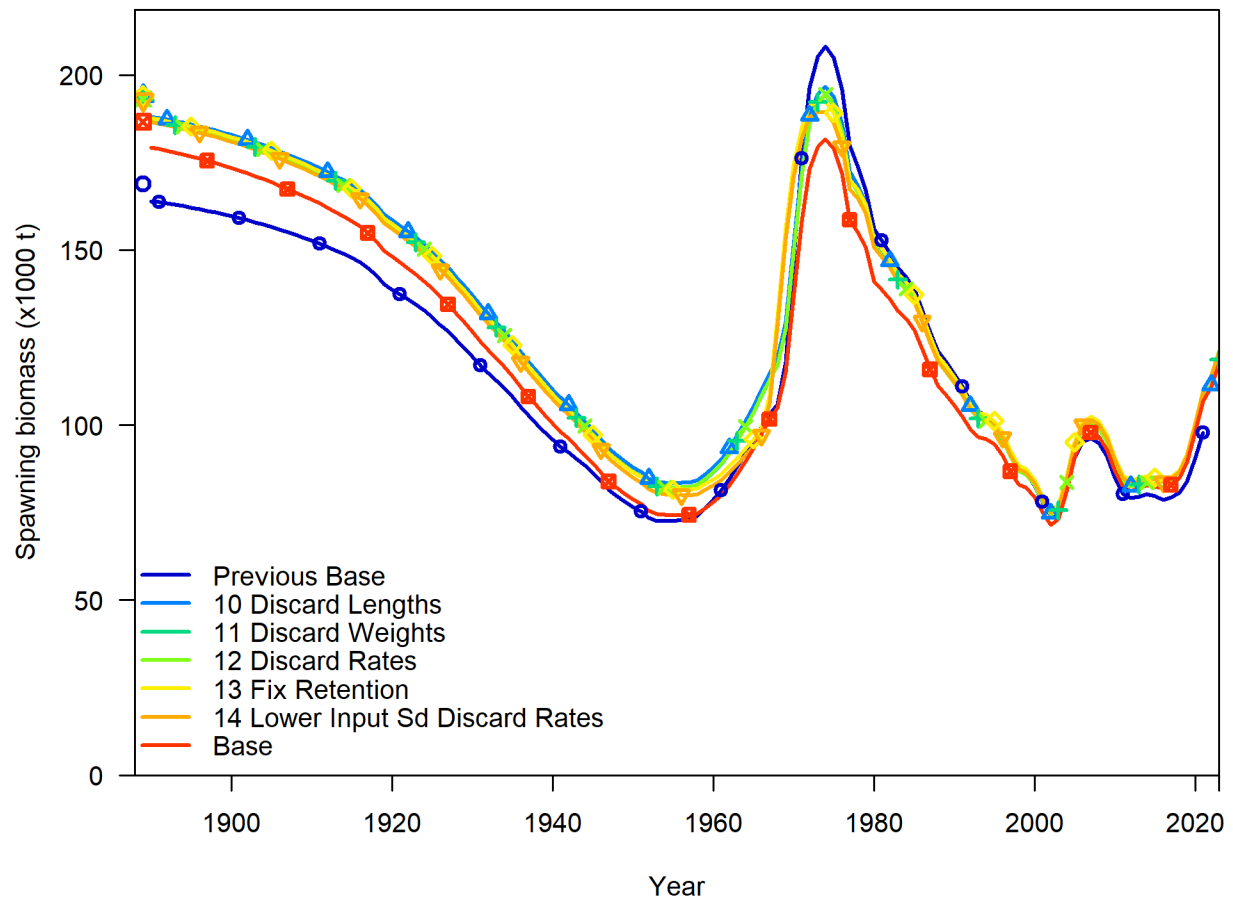
Figure 28: Spawning biomass across several steps towards creating the base model from the previous assessment model.
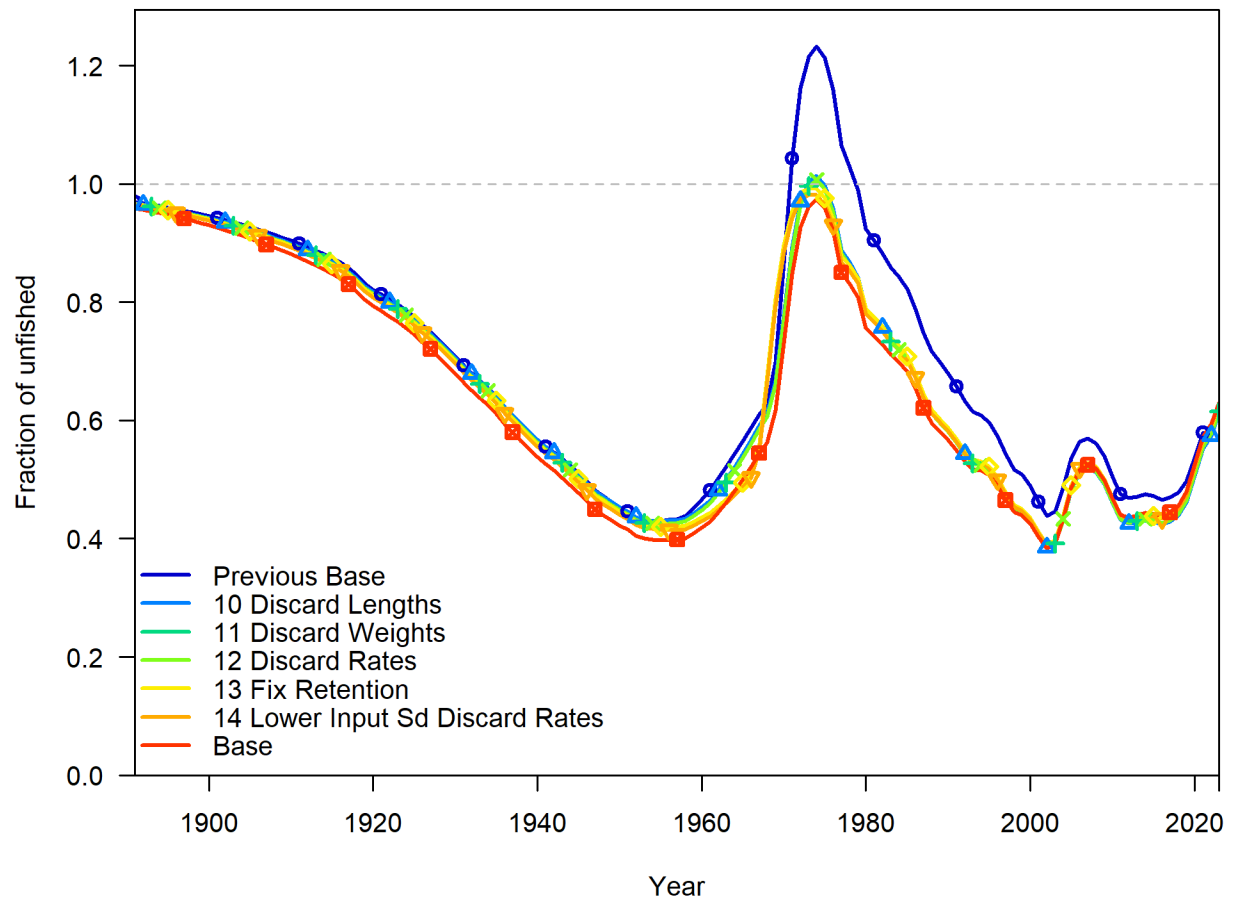
Figure 29: Fraction unfished across several steps towards creating the base model from the previous assessment model.

8.2.2 Estimated Biology
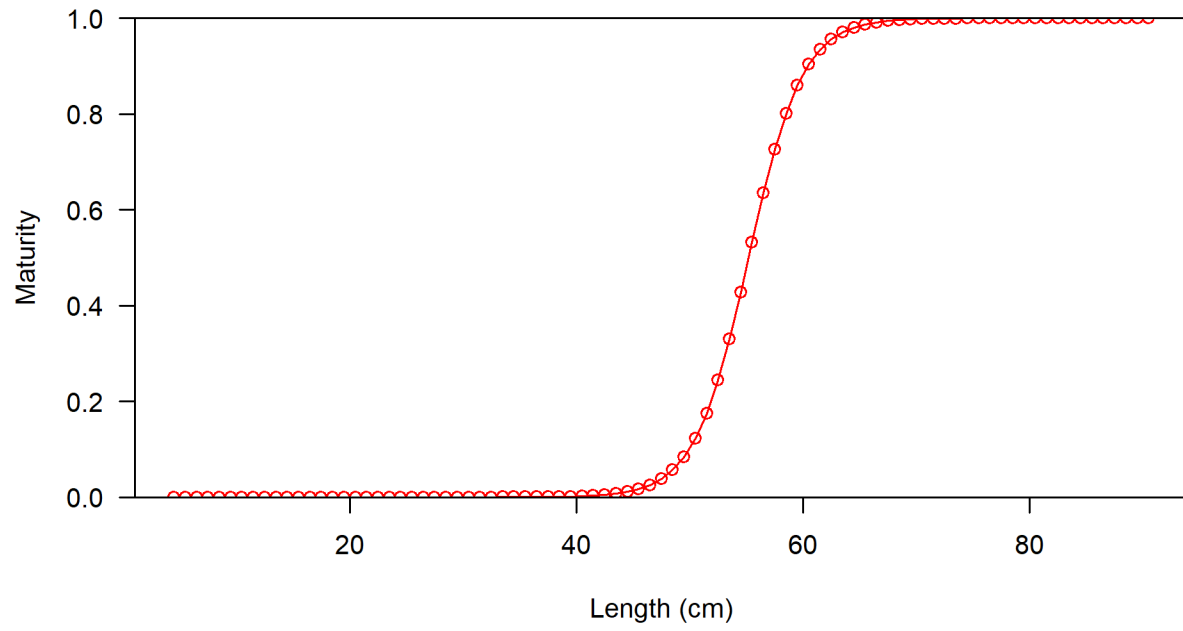
Figure 30: Maturity at length.
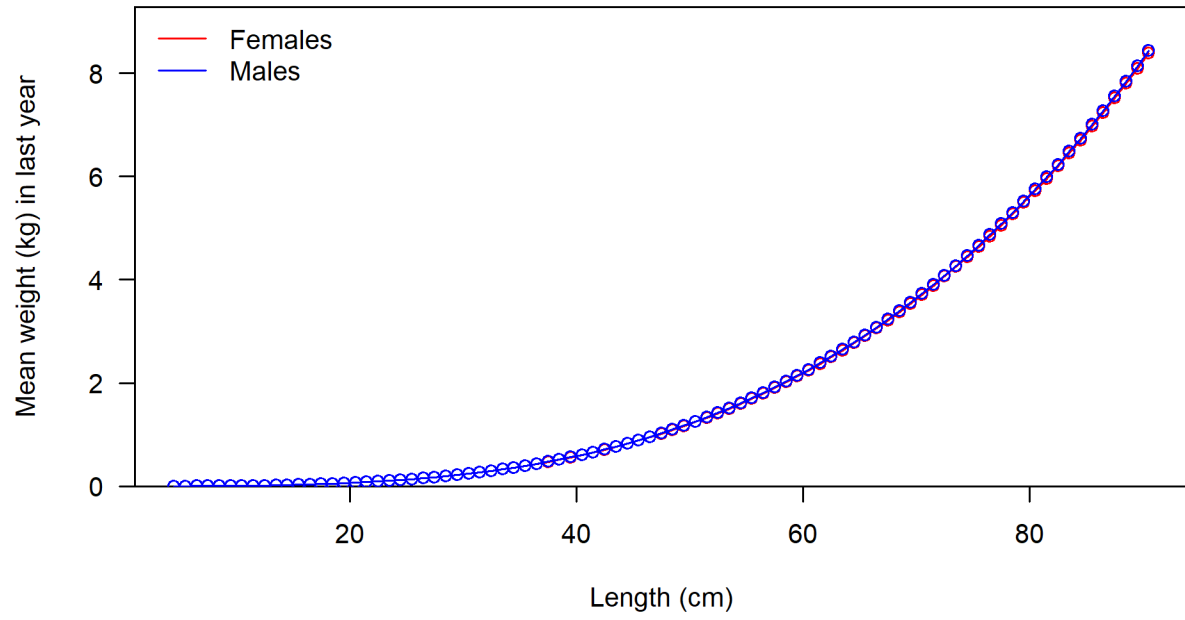
Figure 31: Weight-length relationship.
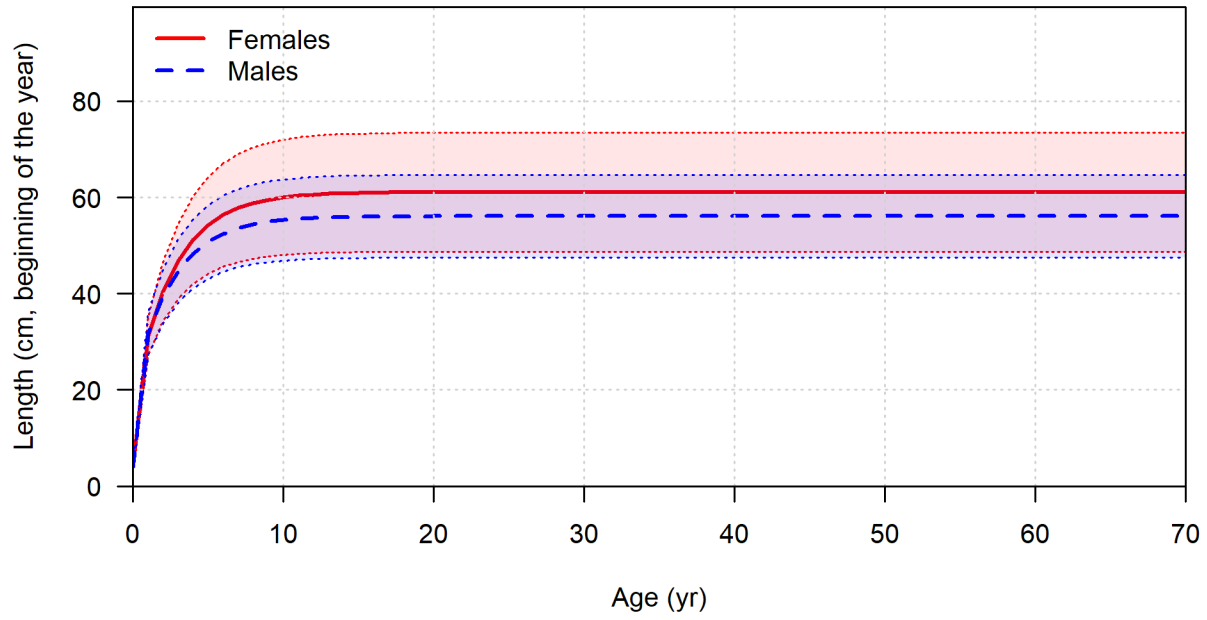
Figure 32: Length at age in the beginning of the year in the ending year of the model. Shaded area indicates 95% distribution of length at age around estimated growth curve.

8.2.3 Estimated Selectivity
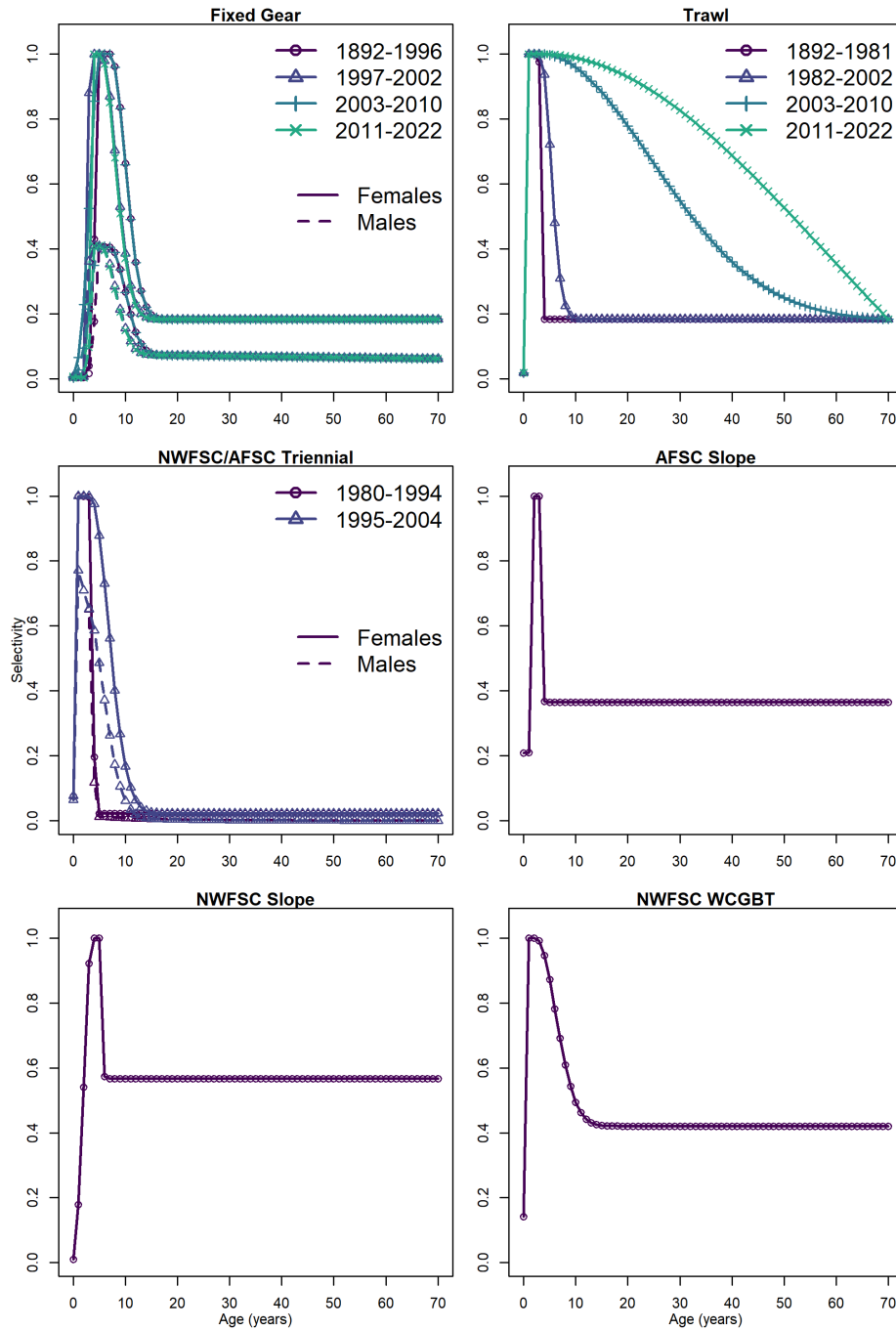
Figure 33: Estimated selectivity at age by fleet, time block, and sex (female = solid; male = dashed).
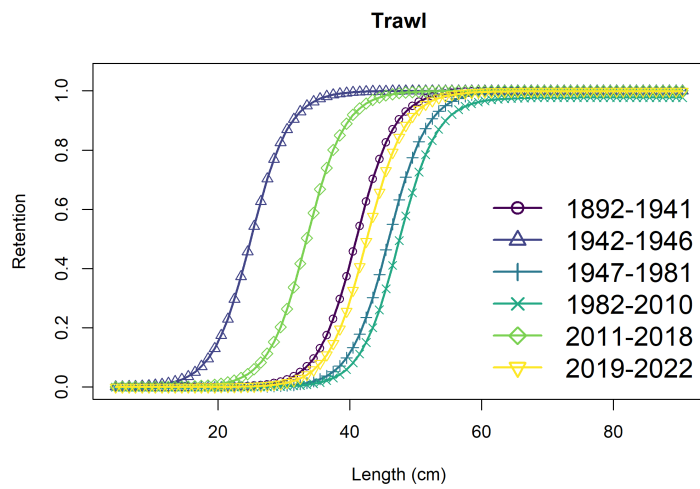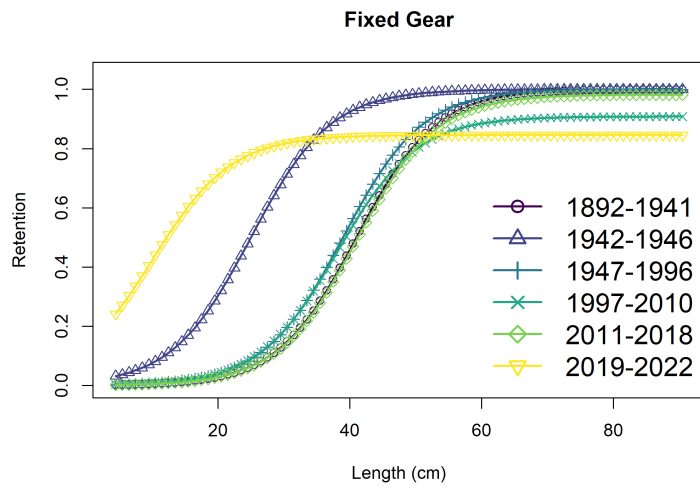
Figure 34: Fleet-specific estimated retention by time block.
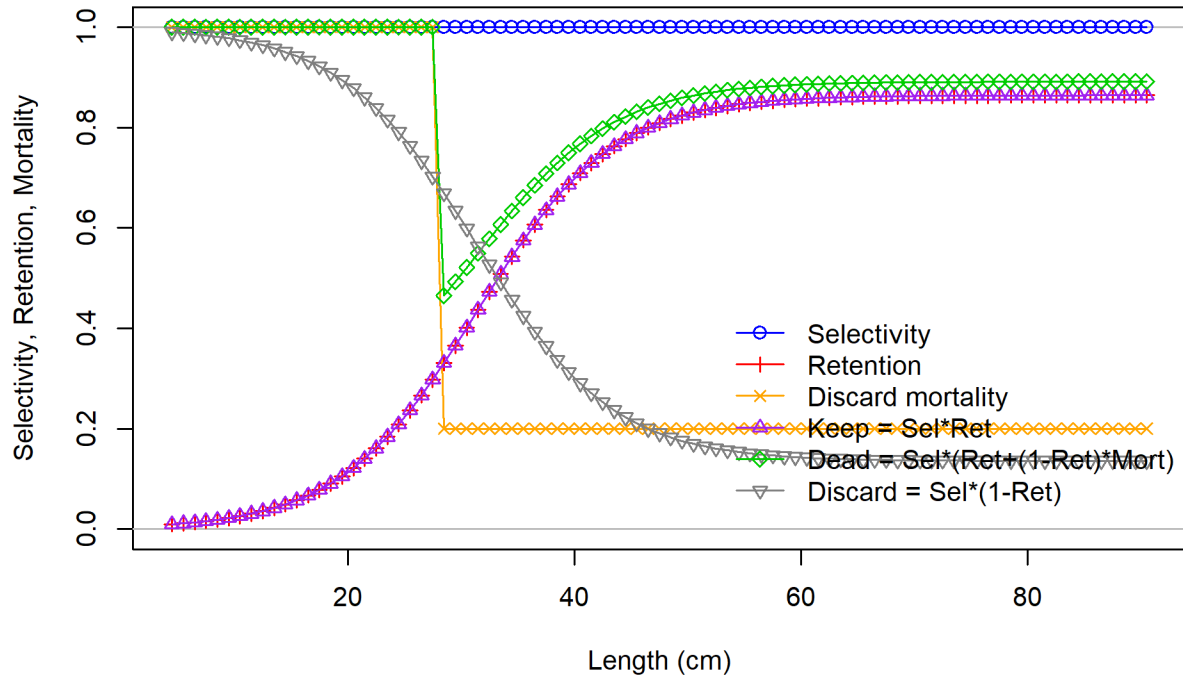
Figure 35: Estimated retention and discard mortality for females for the fixed-gear fleet.
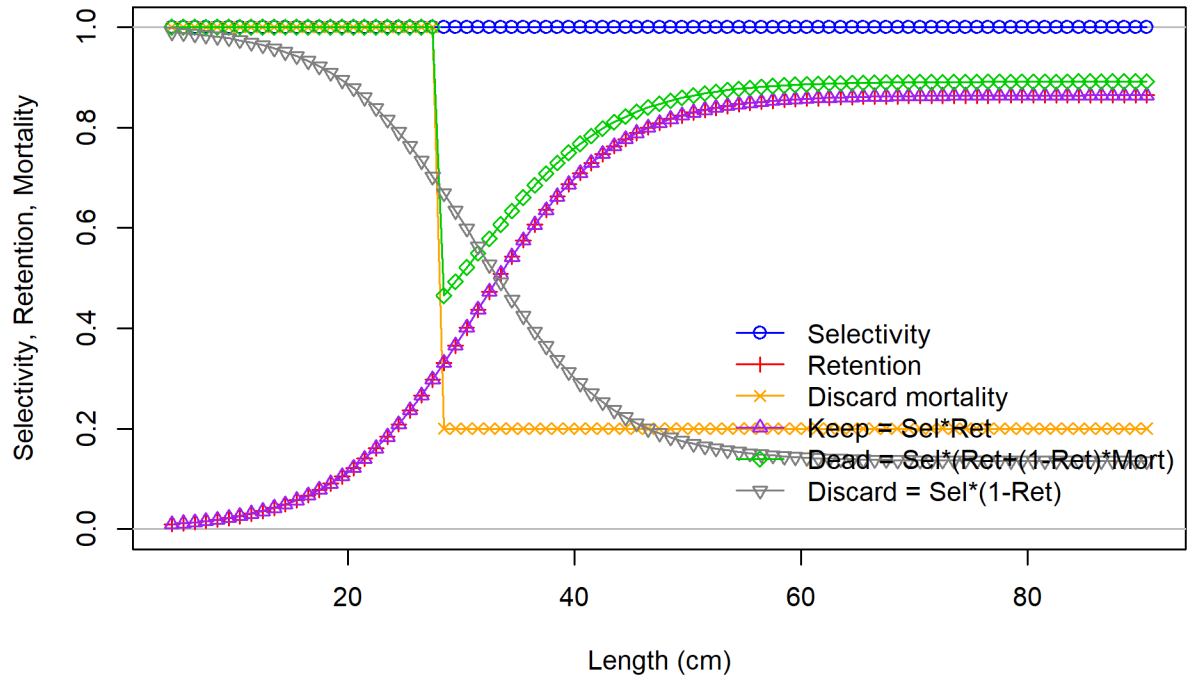
Figure 36: Estimated retention and discard mortality for males for the fixed-gear fleet.
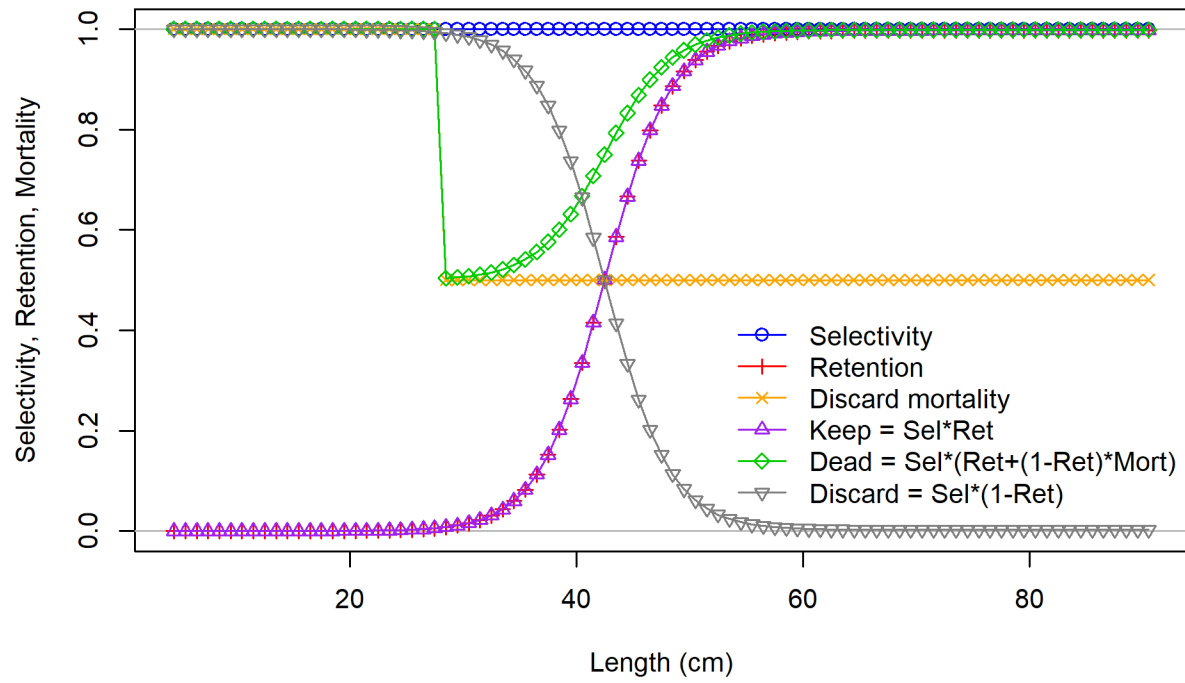
Figure 37: Estimated retention and discard mortality for females for the trawl fleet.
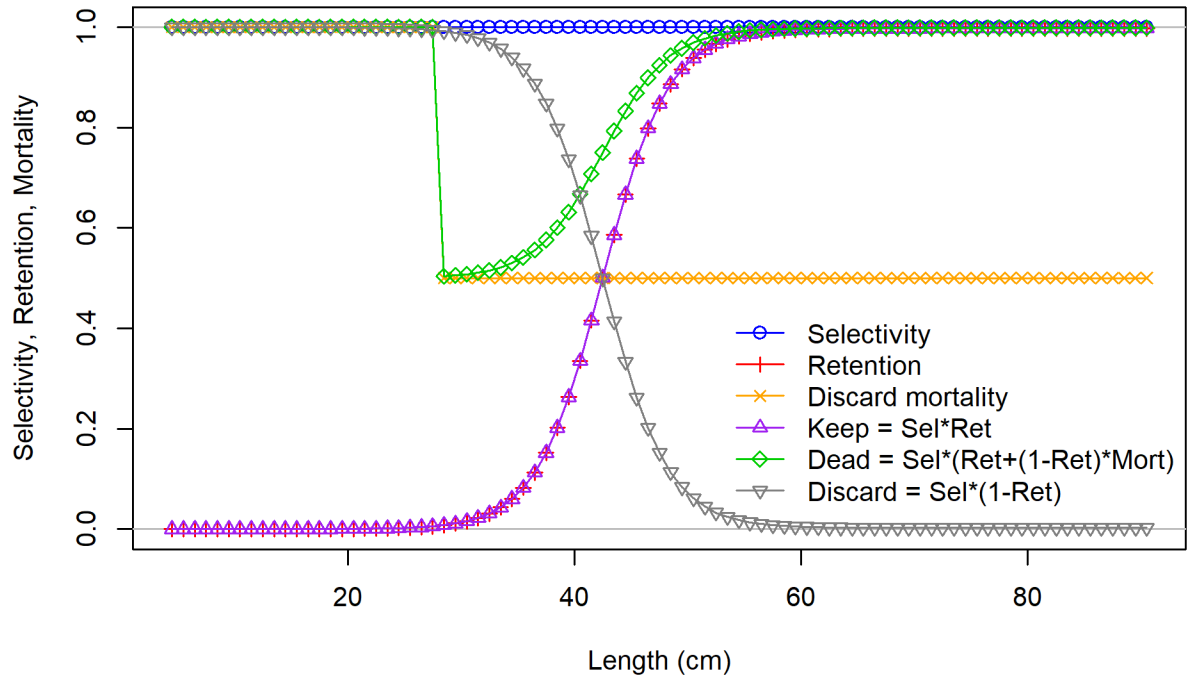
Figure 38: Estimated retention and discard mortality for males for the trawl fleet.

8.2.4 Estimated Recruitment
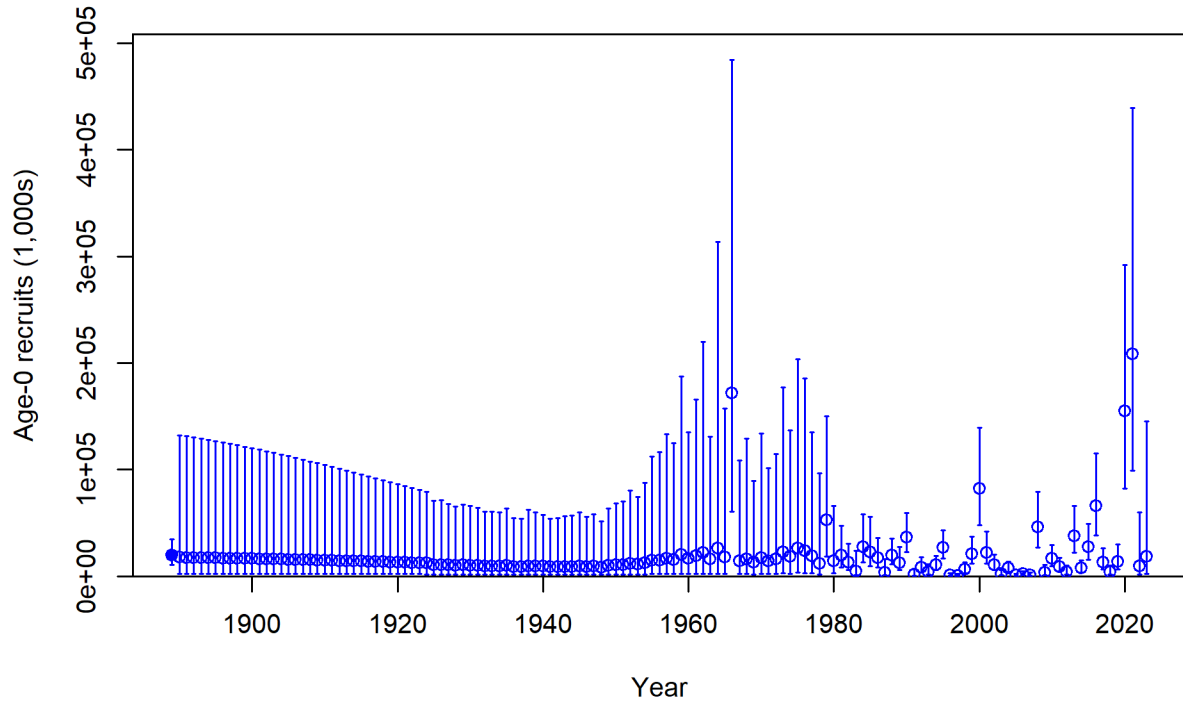
Figure 39: Estimated time series of age-0 recruits (1000s).
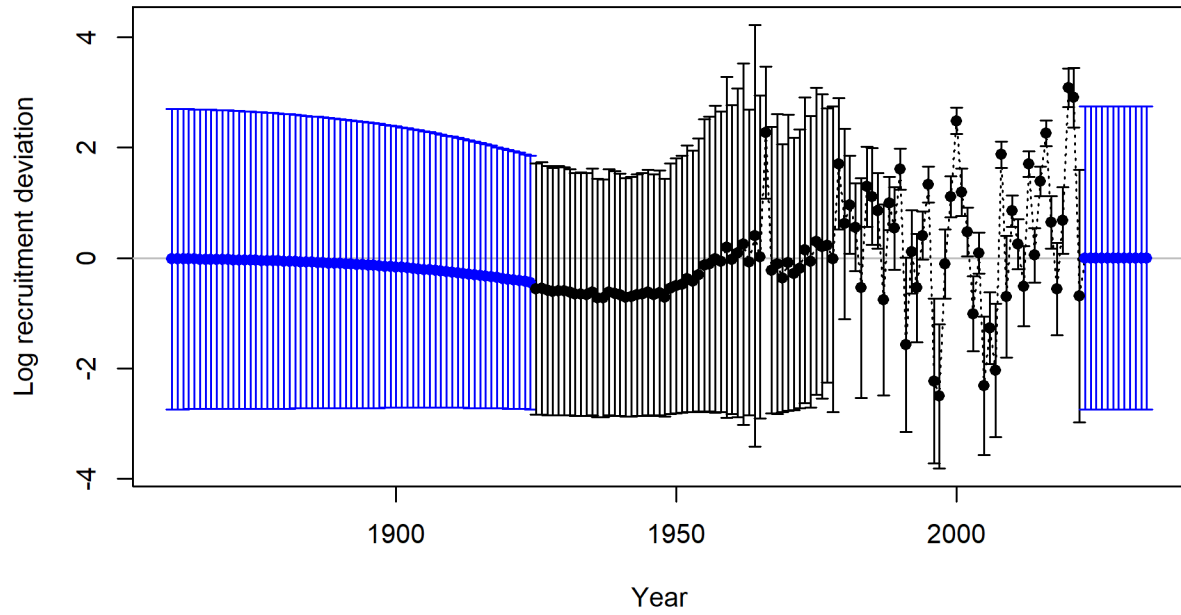
Figure 40: Estimated time series of recruitment deviations.
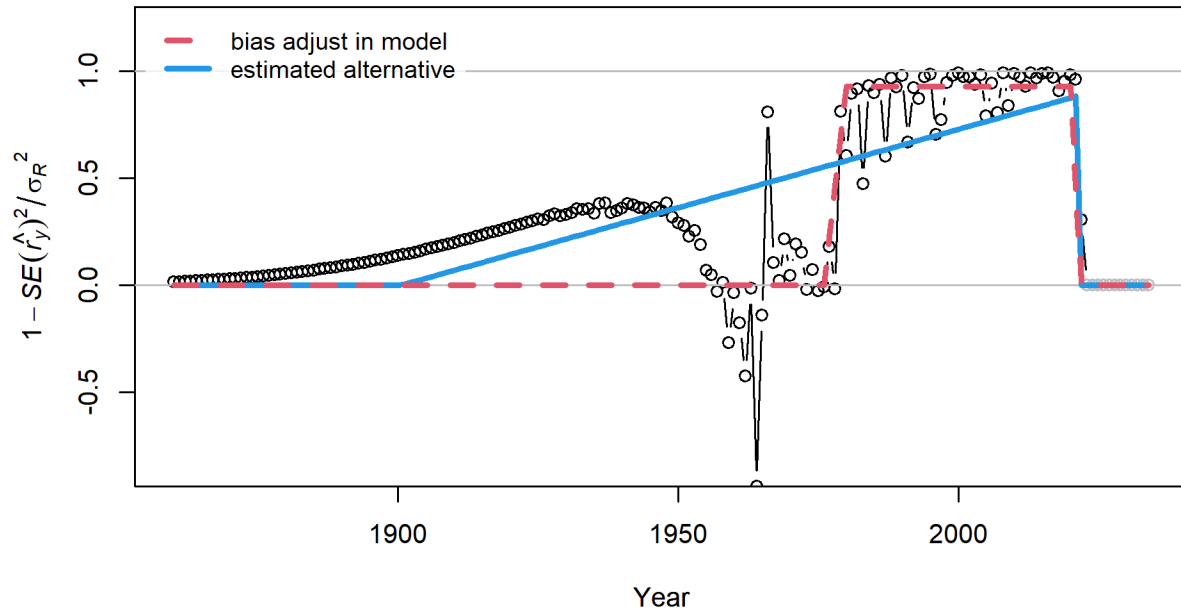
Figure 41: Points are transformed variances. Red line shows current settings for bias adjustment specified in the control file. Blue line shows least squares estimate of alternative bias adjustment relationship for recruitment deviations (which may or may not be an improvement).
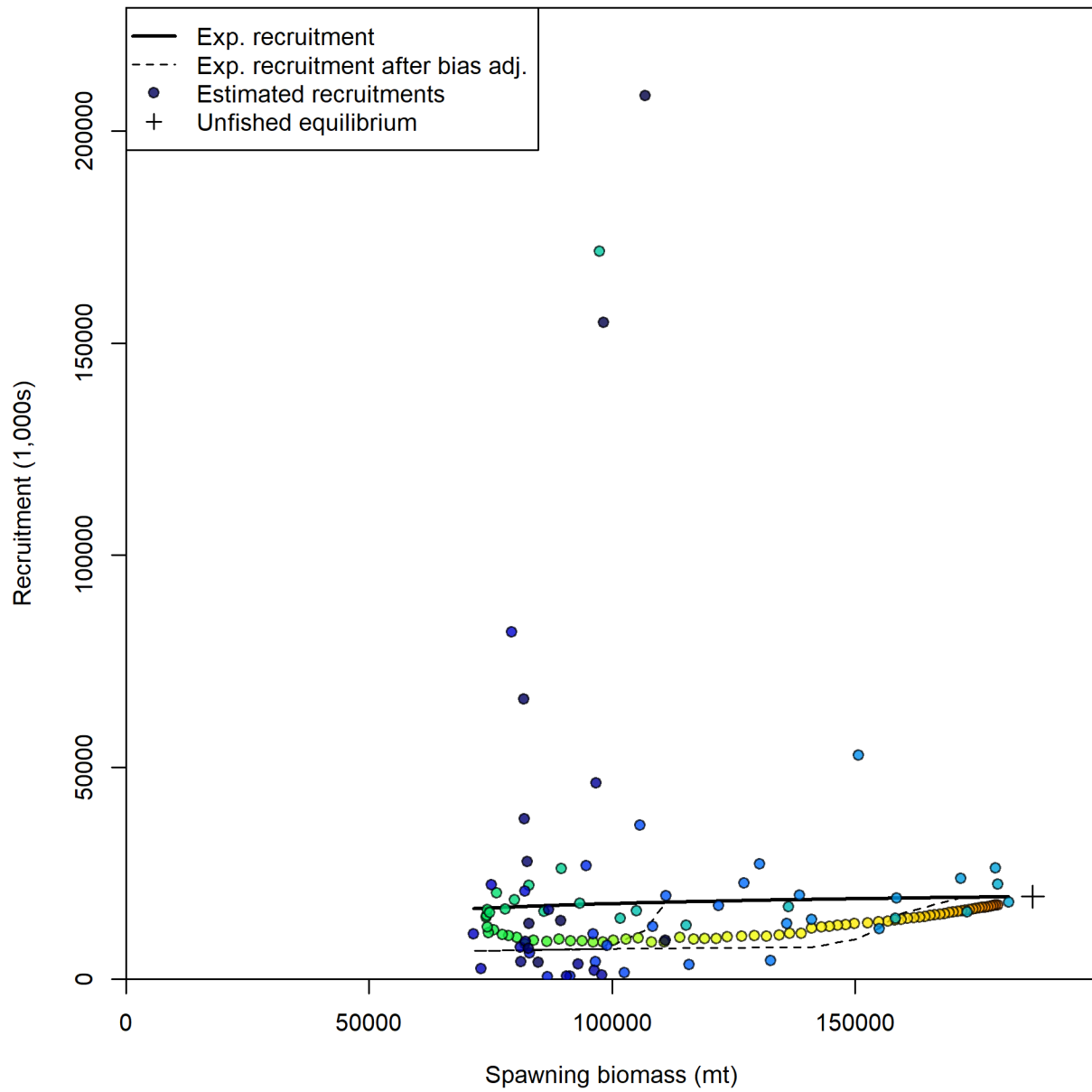
Figure 42: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in later years.

8.2.5 Estimated Time Series
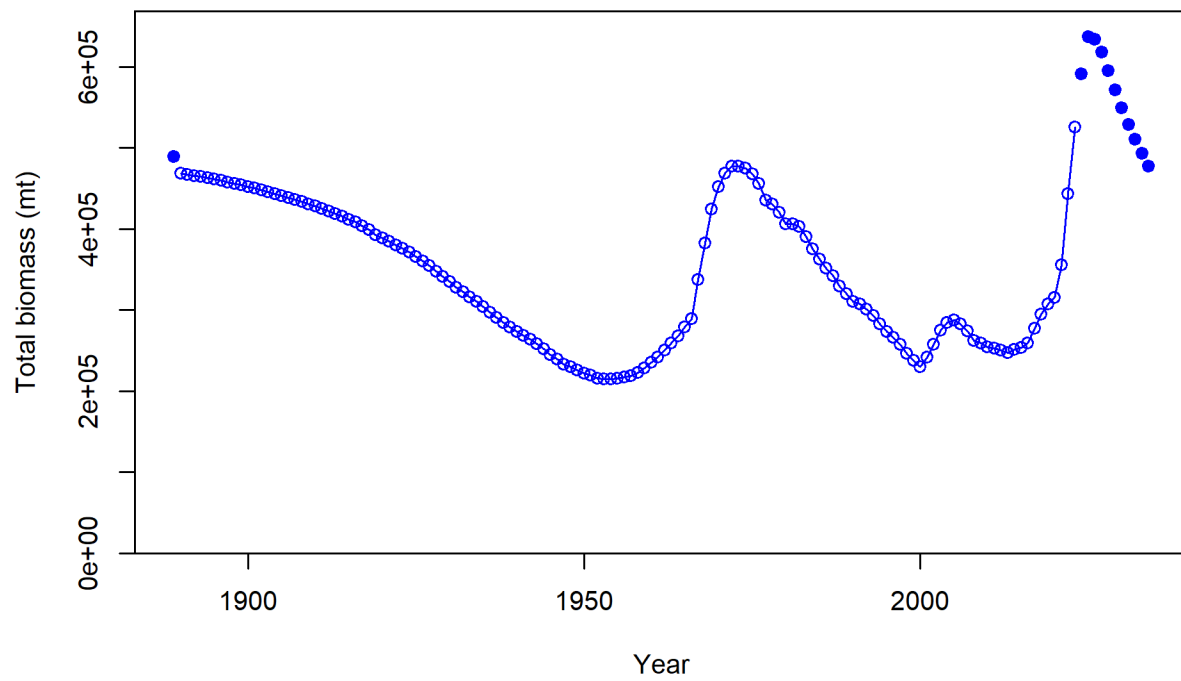
Figure 43: Estimated time series of total biomass.
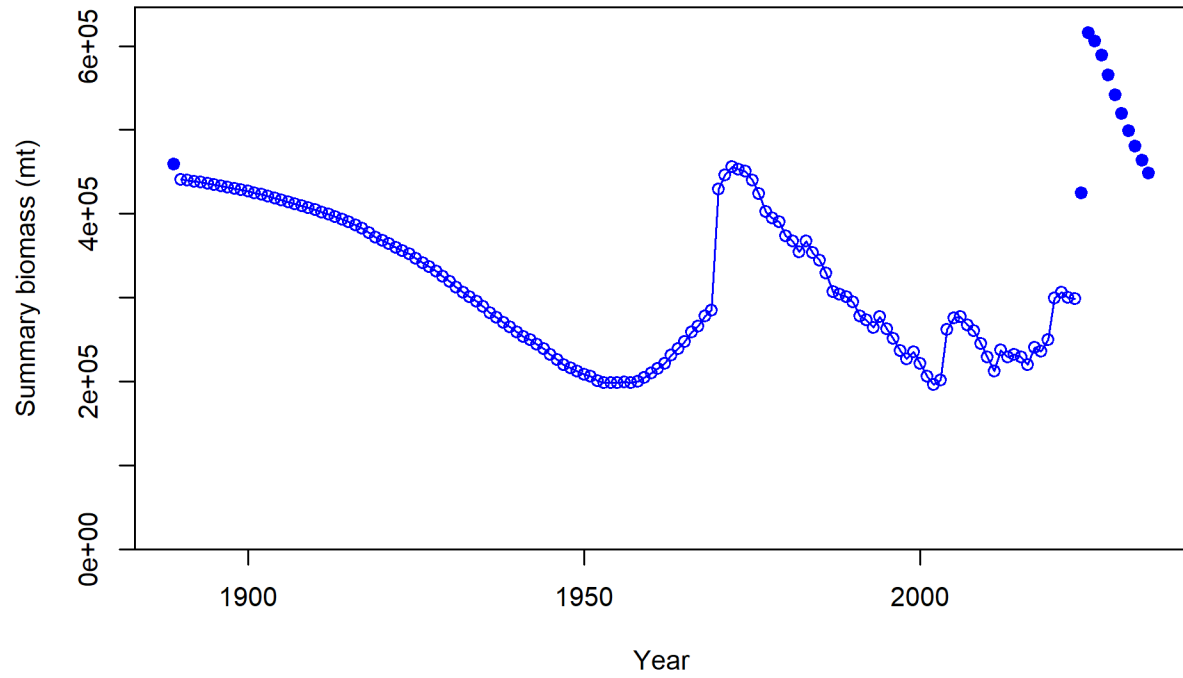
Figure 44: Estimated time series of summary biomass.
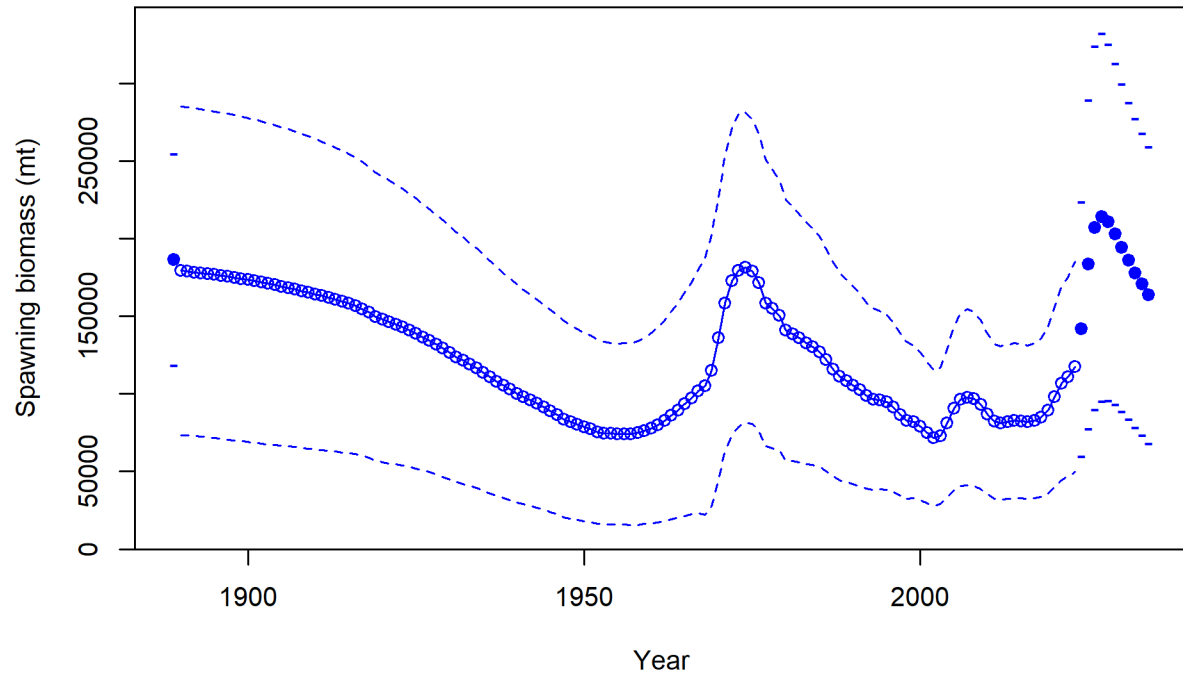
Figure 45: Estimated time series of spawning biomass (mt) with forecast with 95 asymptotic intervals forecast.
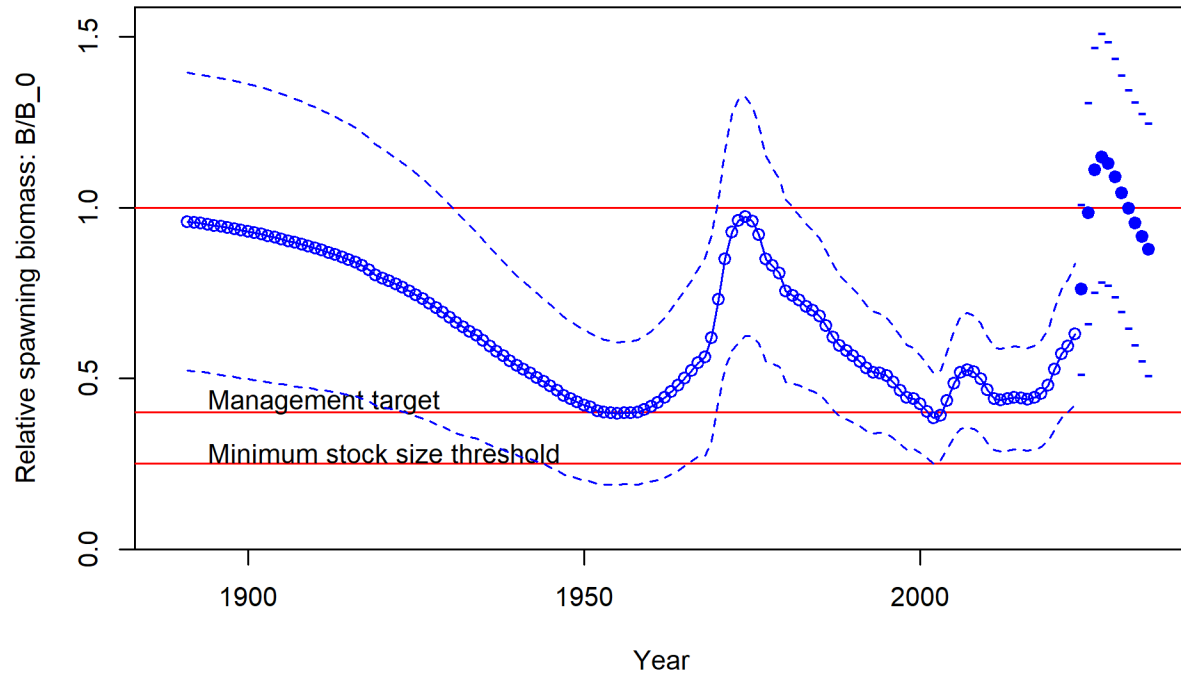
Figure 46: Estimated time series of relative spawning biomass forecast.

8.2.6 Fits to Data
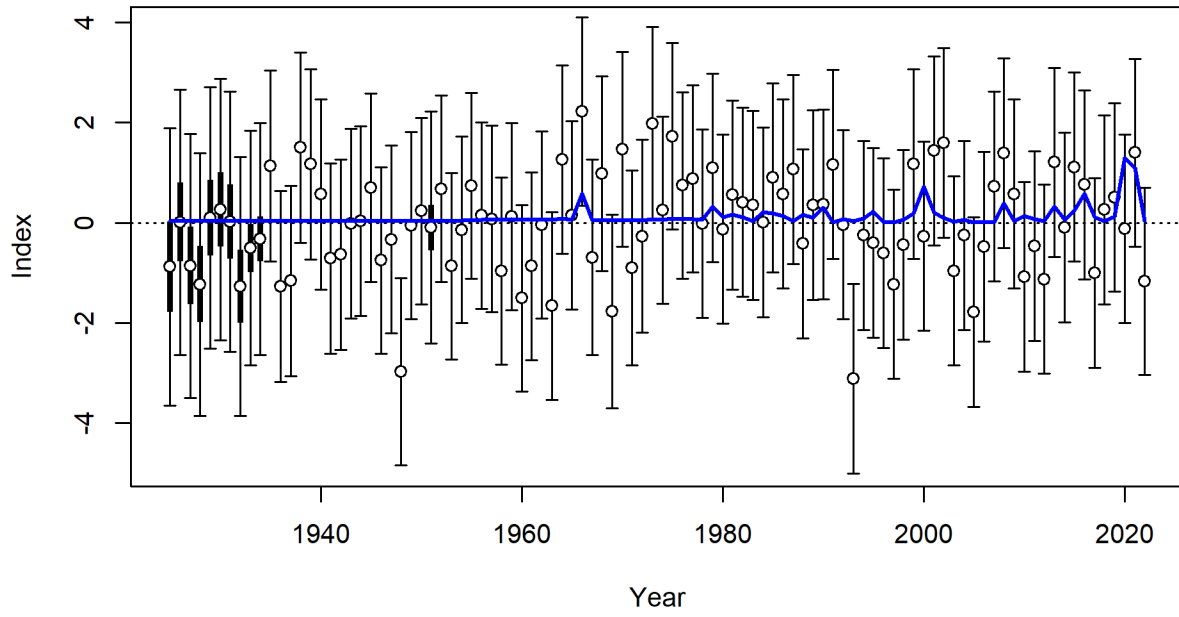
Figure 47: Fit to the environmental survey.
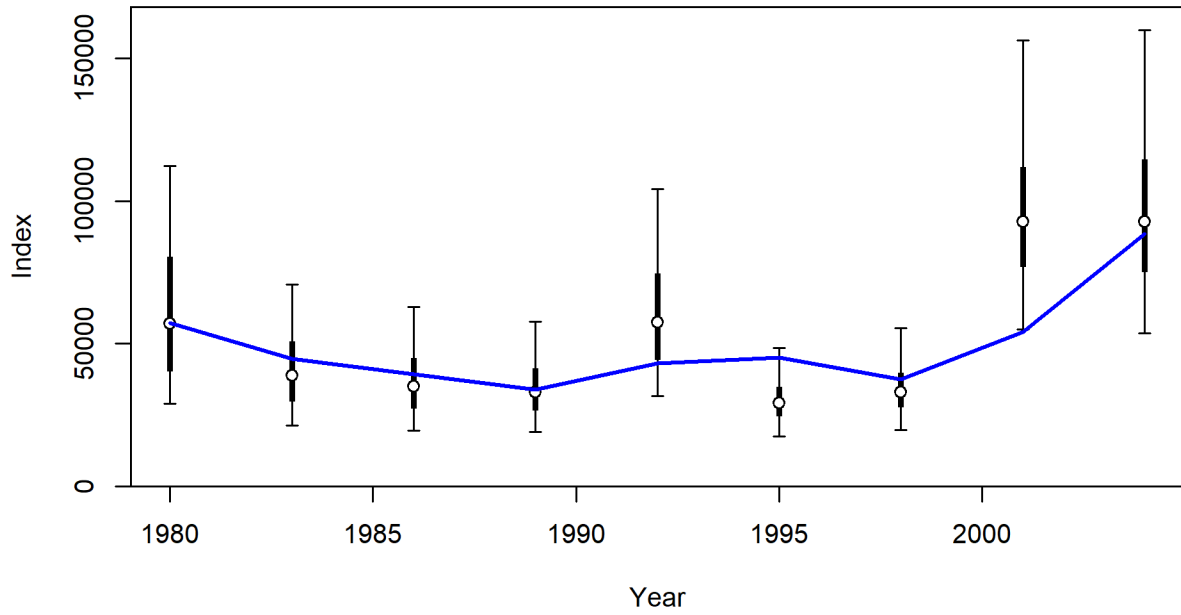
Figure 48: Fit to the Triennial Survey.
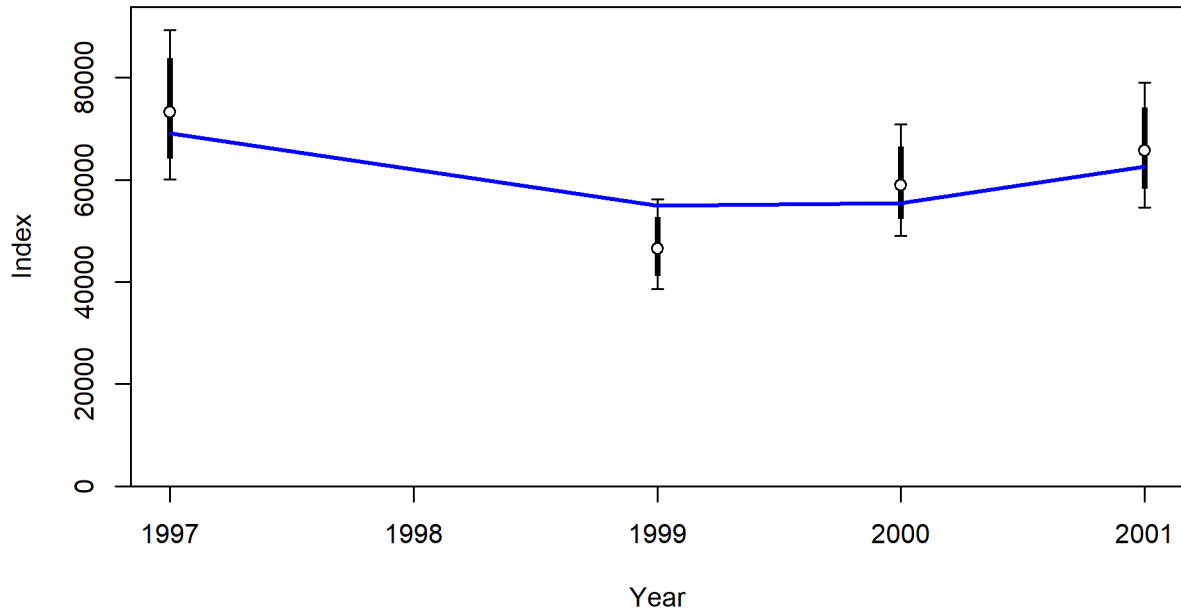
Figure 49: Fit to the Slope Survey.
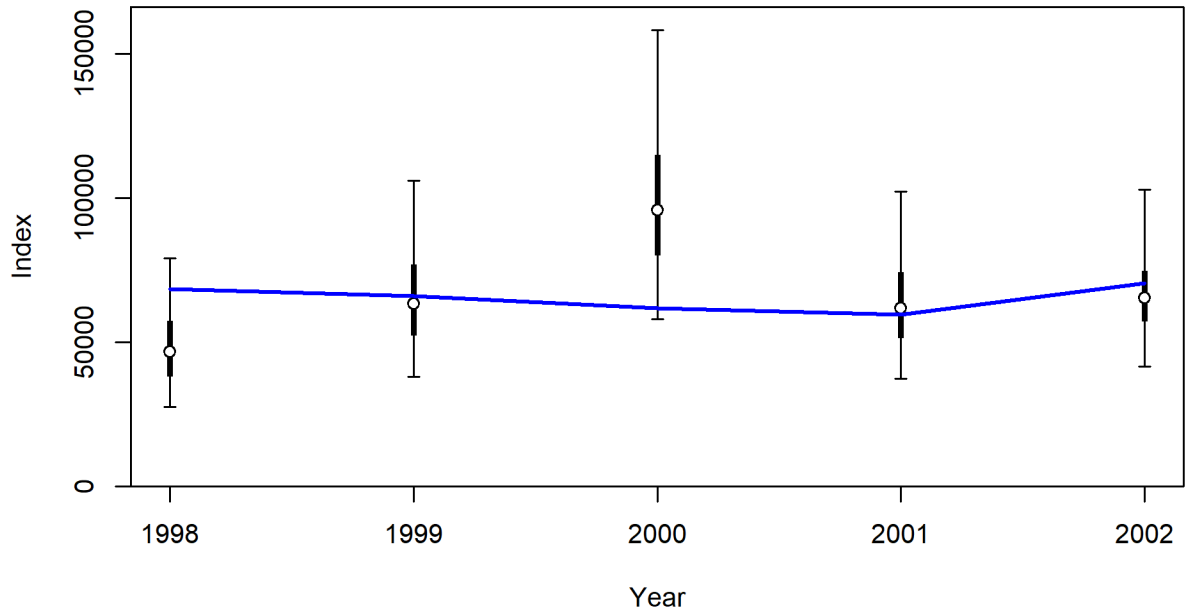
Figure 50: Fit to the NWFSC Slope Survey.
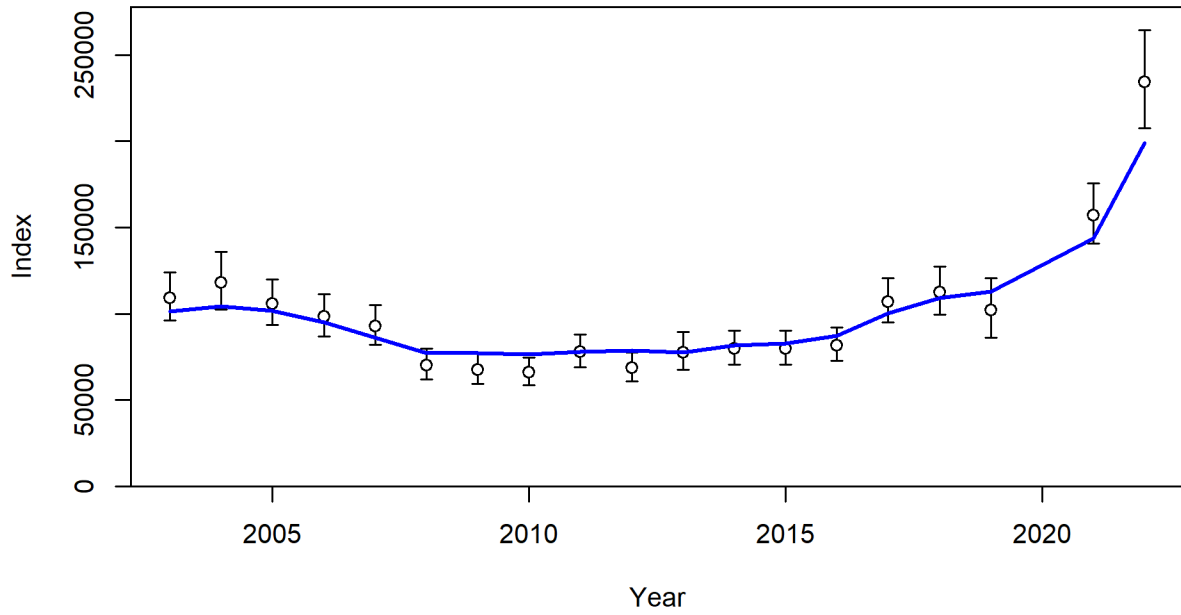
Figure 51: Fit to the WCGBTS.
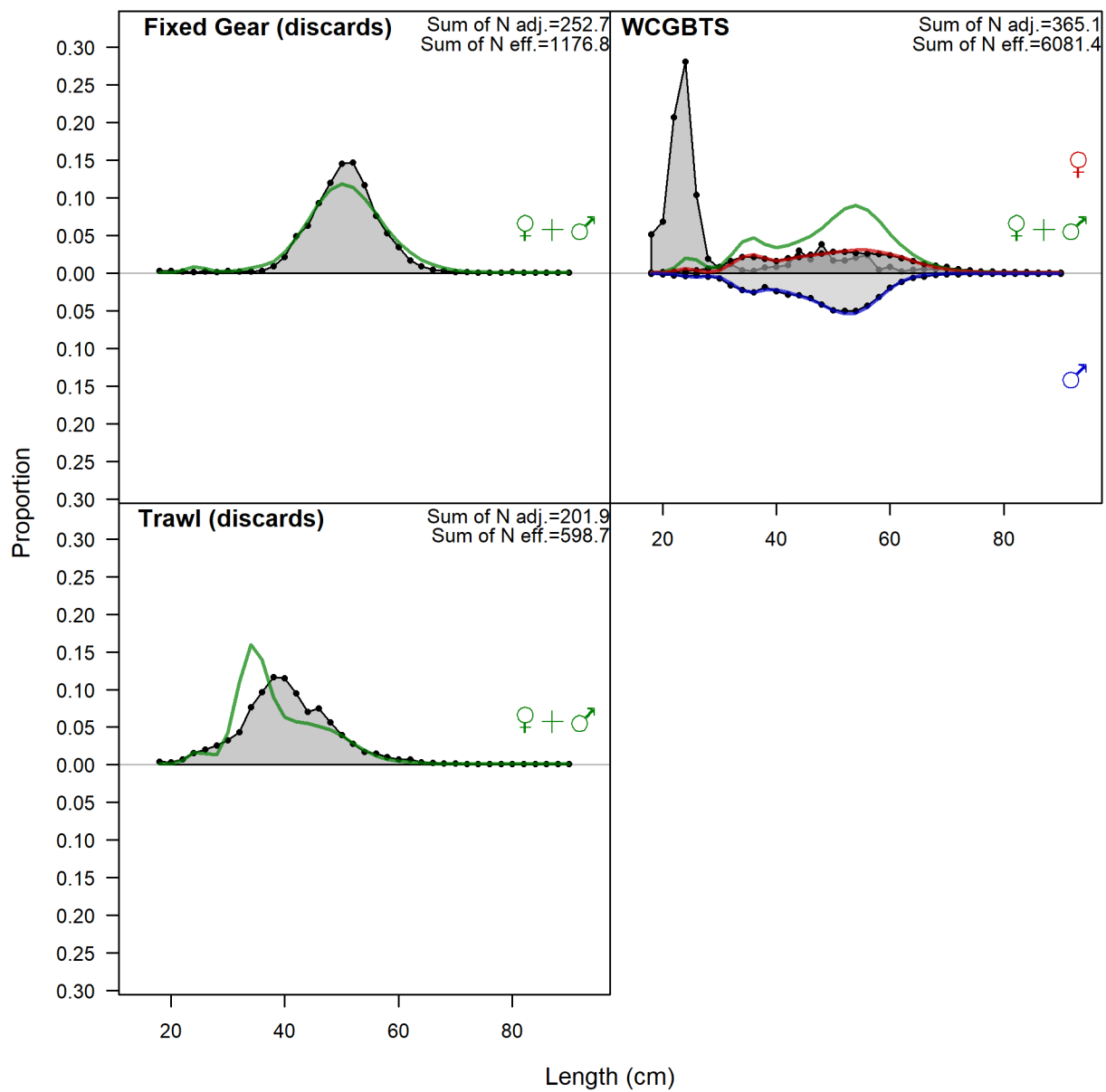
Figure 52: Length composition aggregated across years by fleet with the model estimated fit to the data by sex (green unsexed, red female, and blue male).
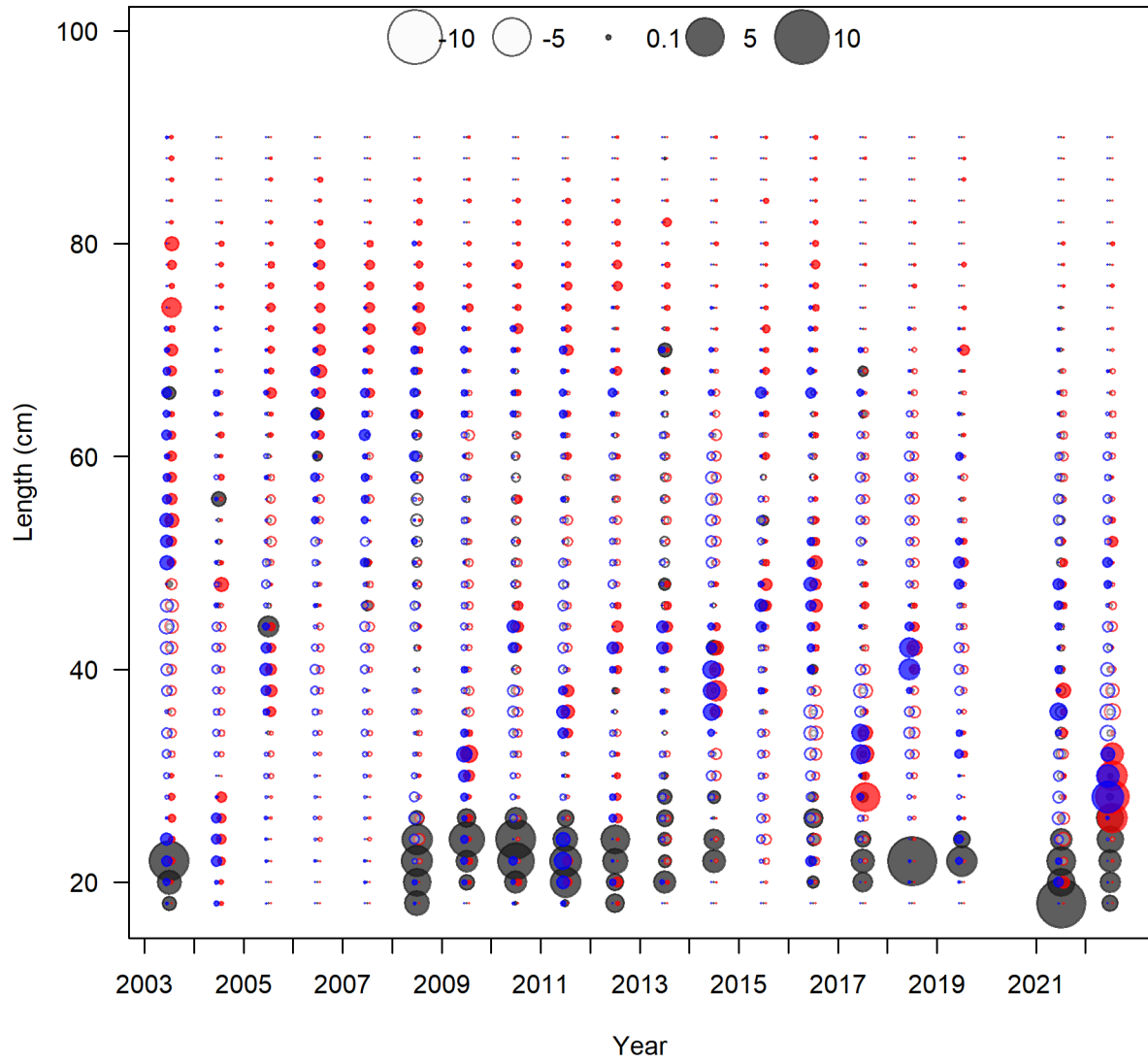
Figure 53: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of length-composition data for the WCGBTS from the whole catch.
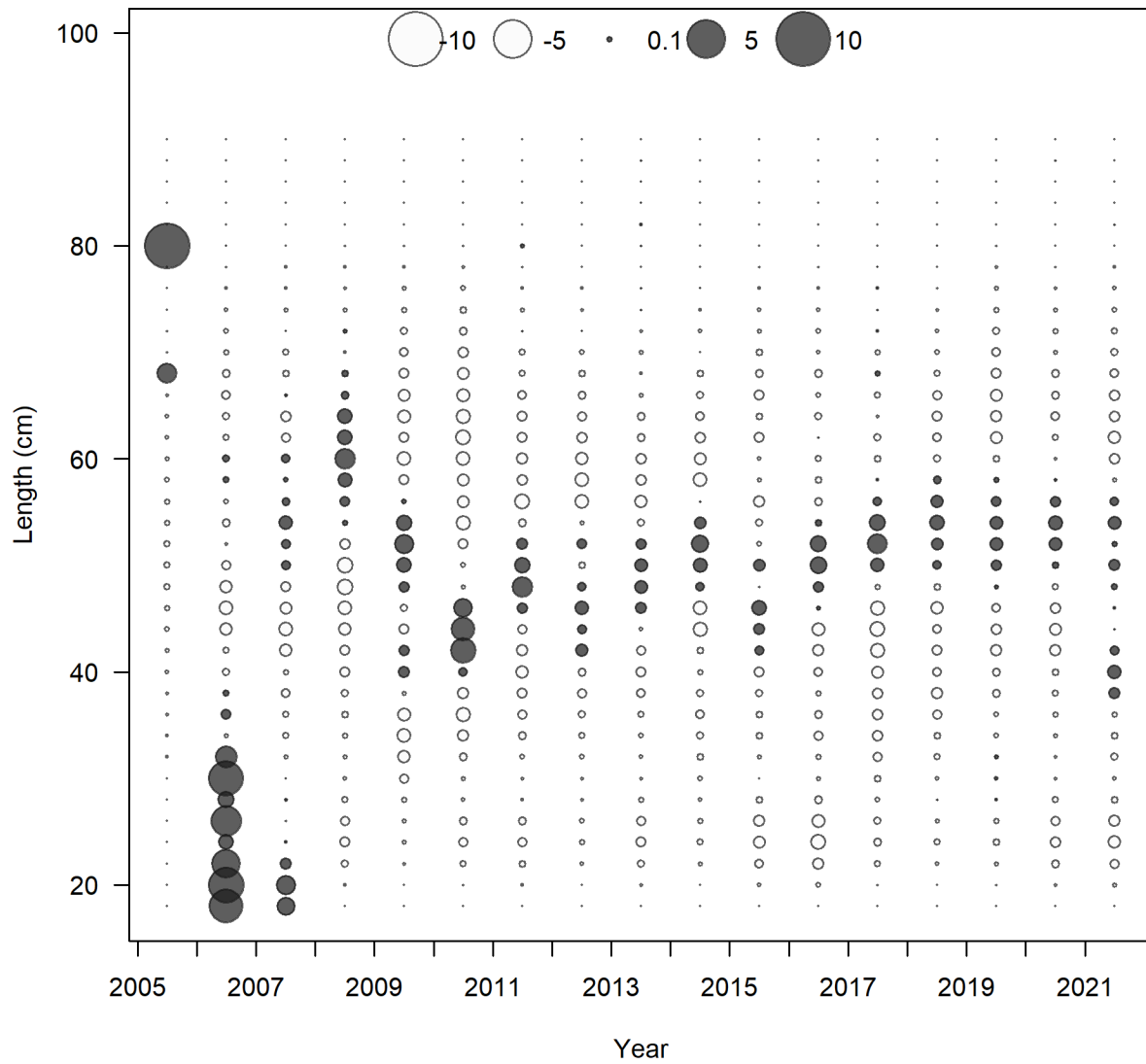
Figure 54: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of length-composition data for the fixed-gear fleet from the discarded catch.
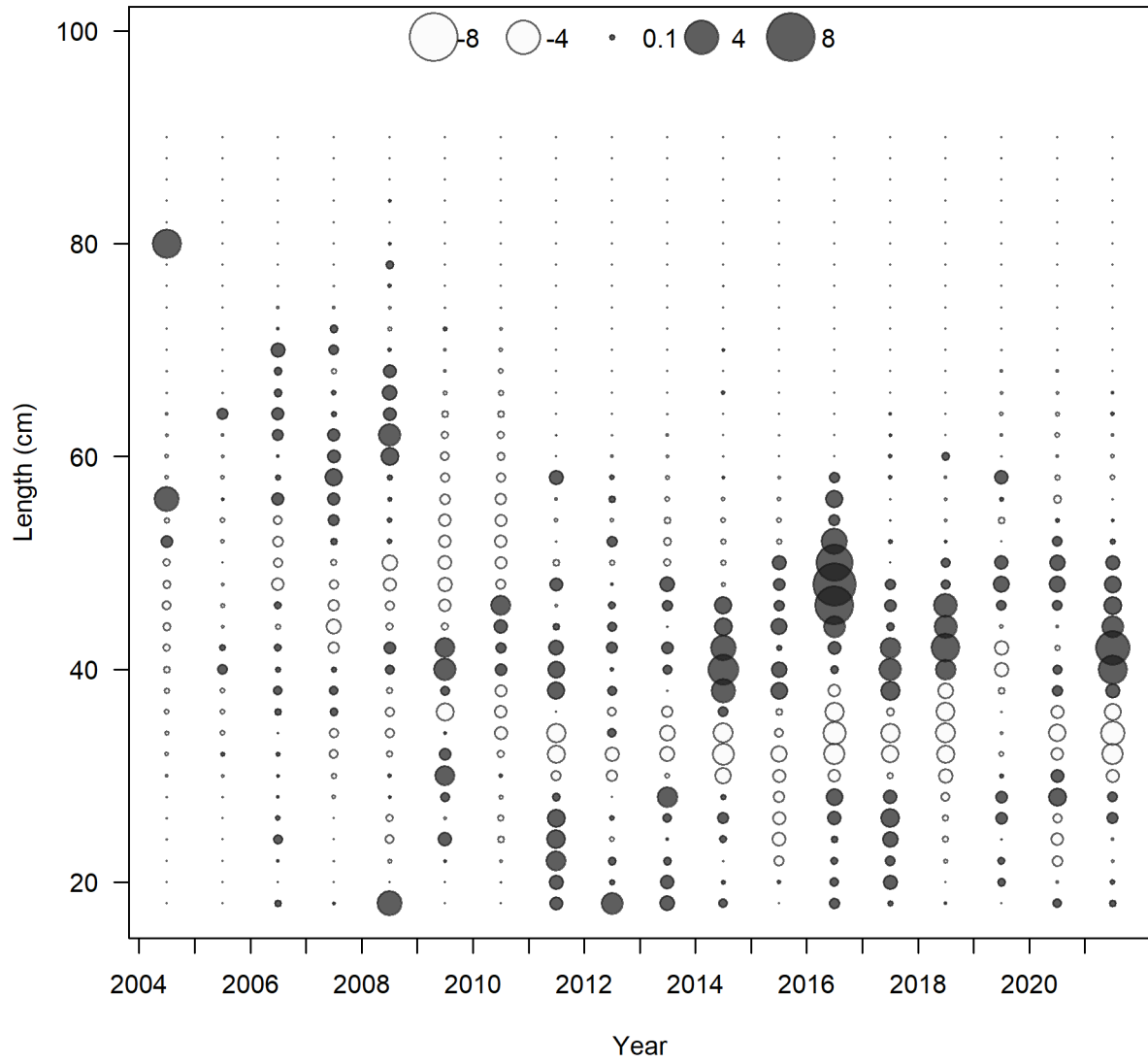
Figure 55: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of length-composition data for the trawl fleet from the discarded catch.
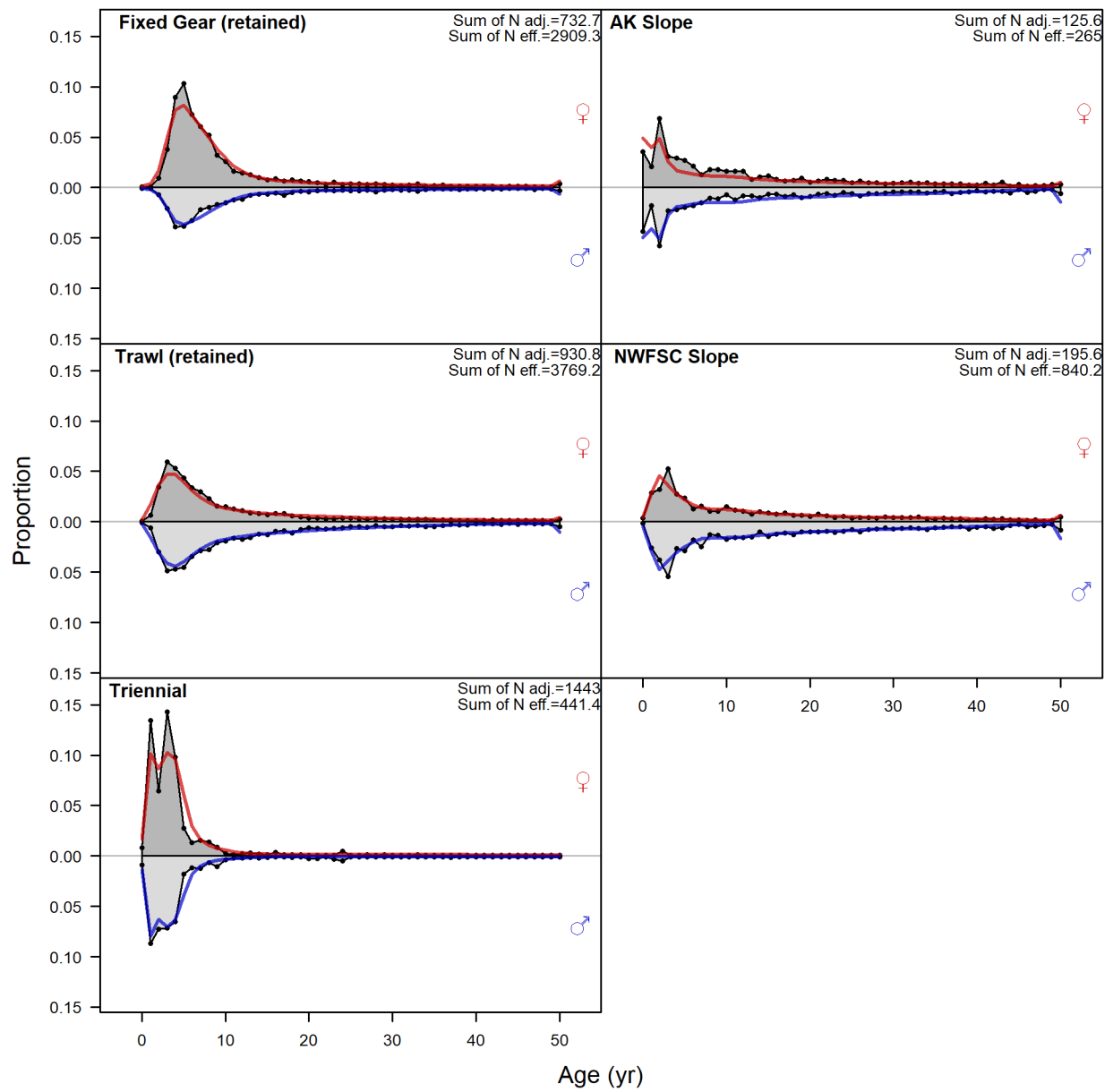
Figure 56: Age composition aggregated across years by fleet with the model estimated fit to the data by sex (green unsexed, red female, and blue male).
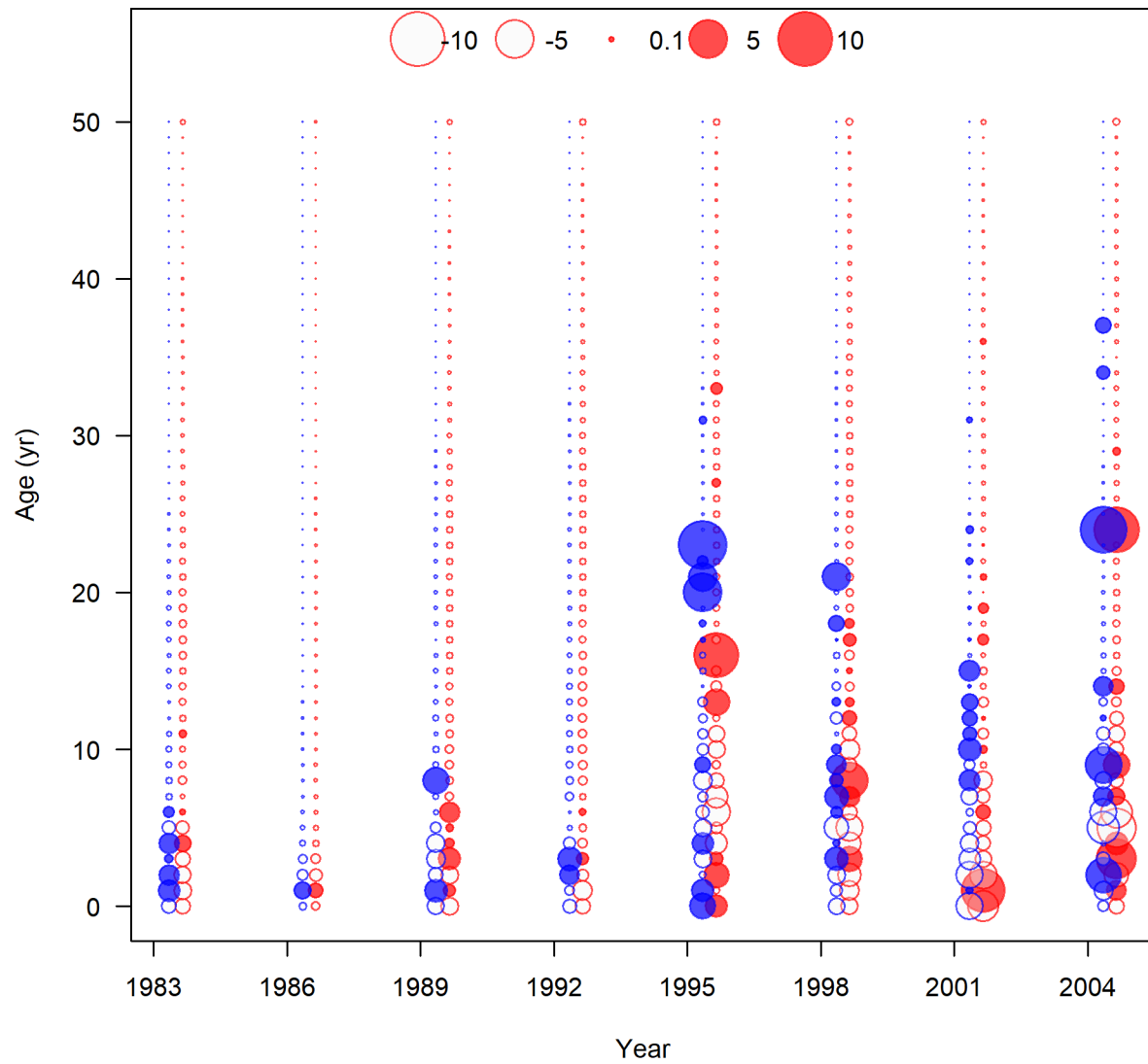
Figure 57: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the Triennial Survey from the whole catch.
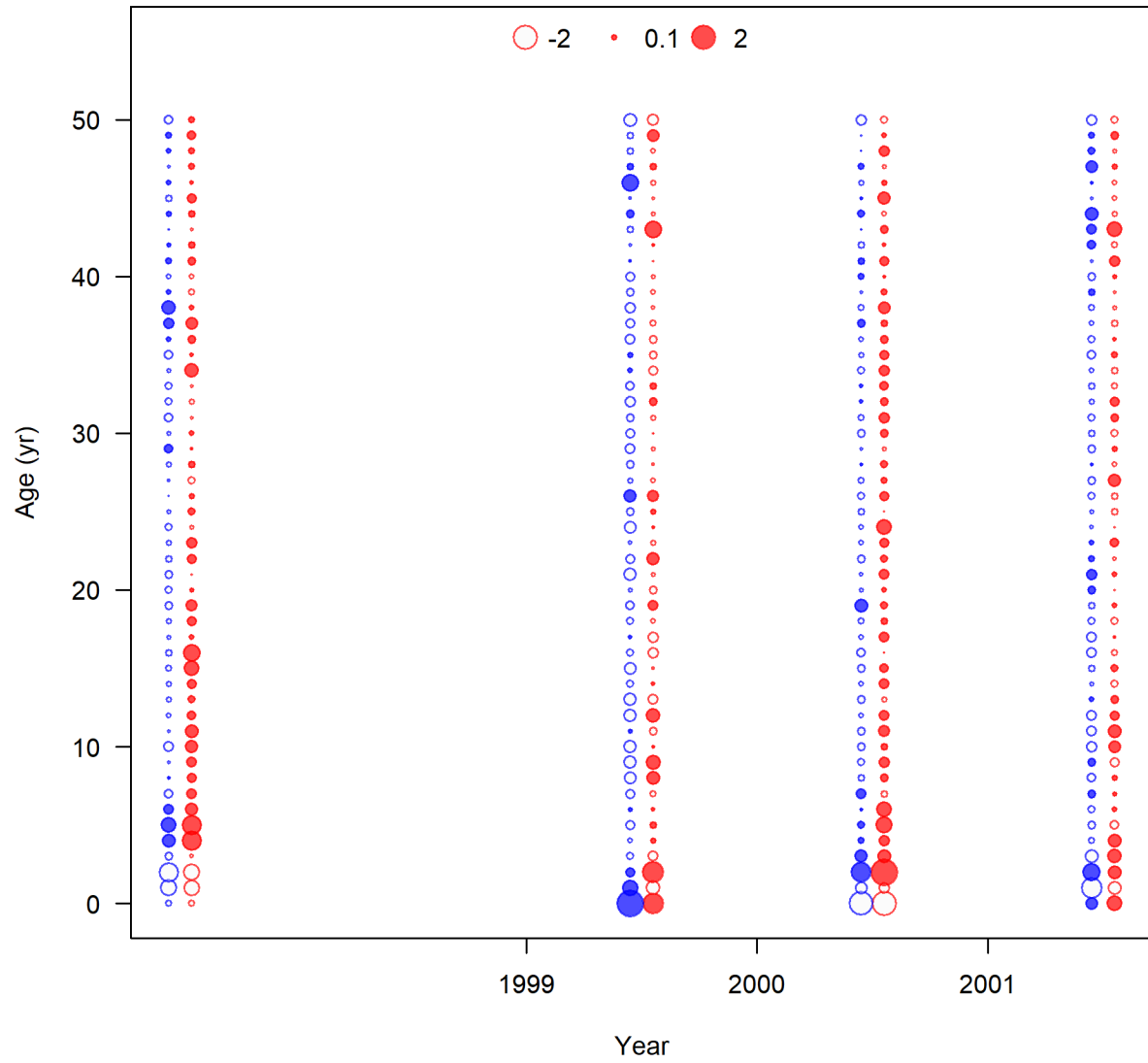
Figure 58: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the Slope Survey from the whole catch.
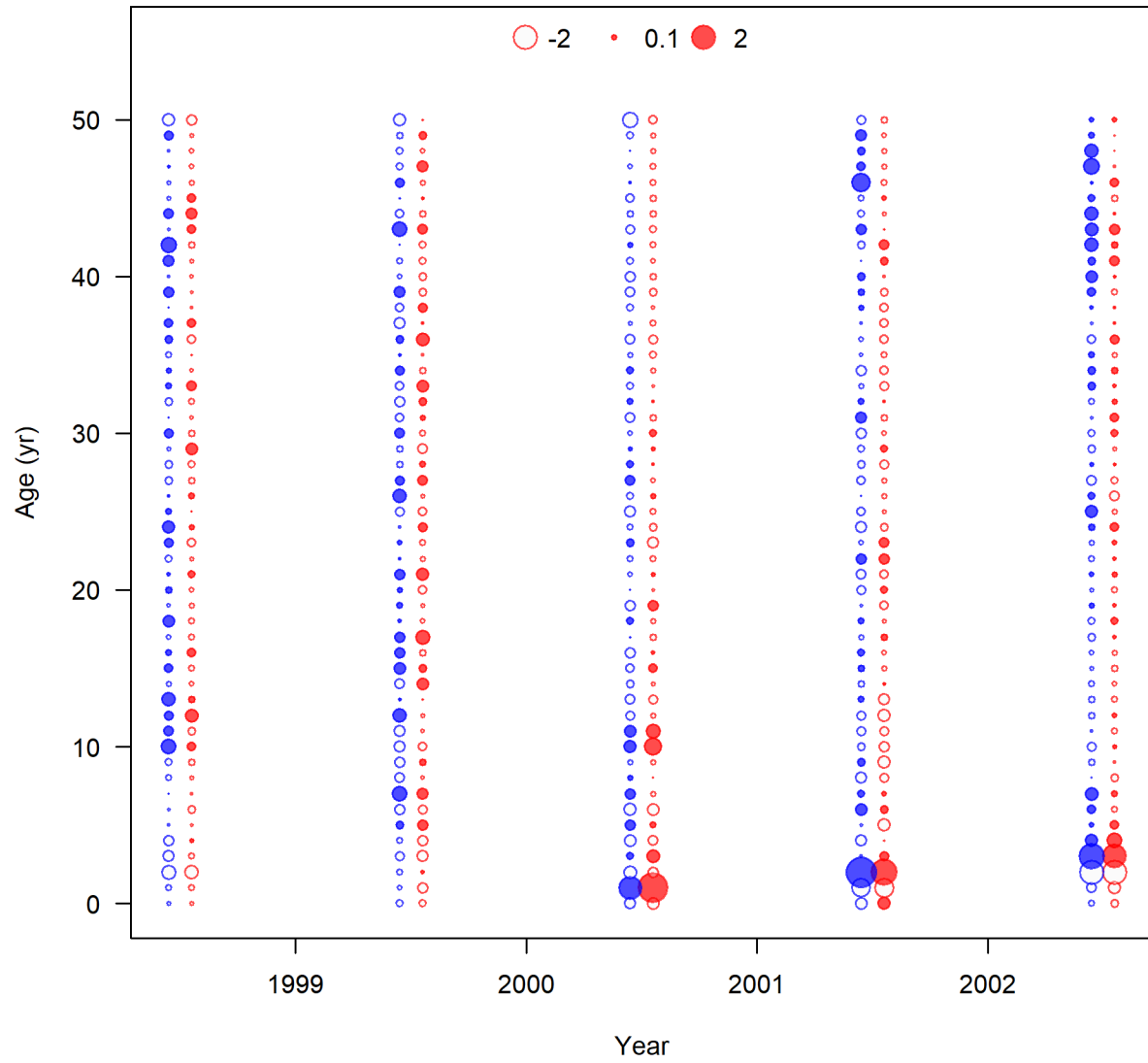
Figure 59: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the NWFSC Slope Survey from the whole catch.
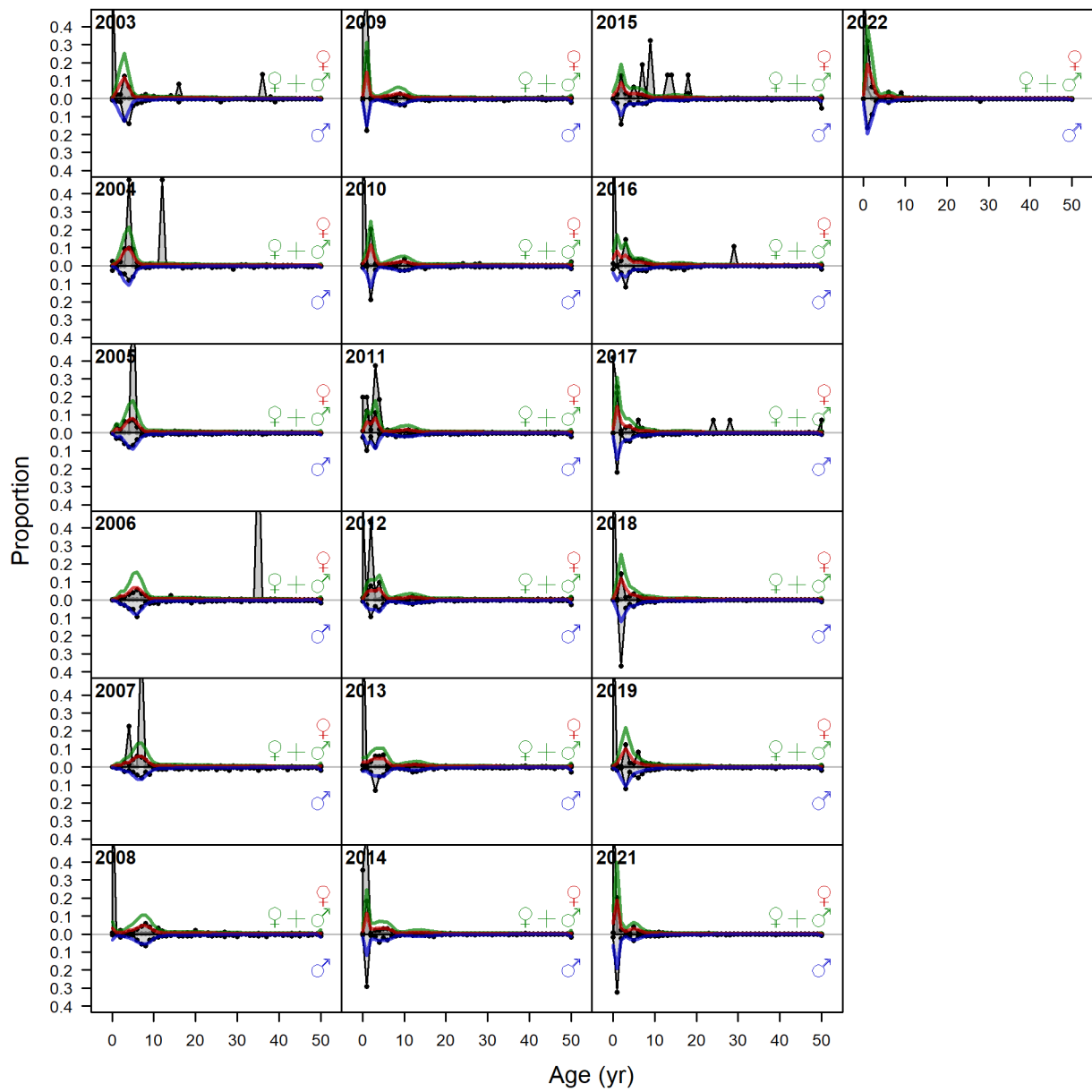
Figure 60: Fits to the annual female, male, and unsexed (red, blue, and green, respectively) age-composition data that were excluded from the model fitting process for the WCGBTS from the whole catch.
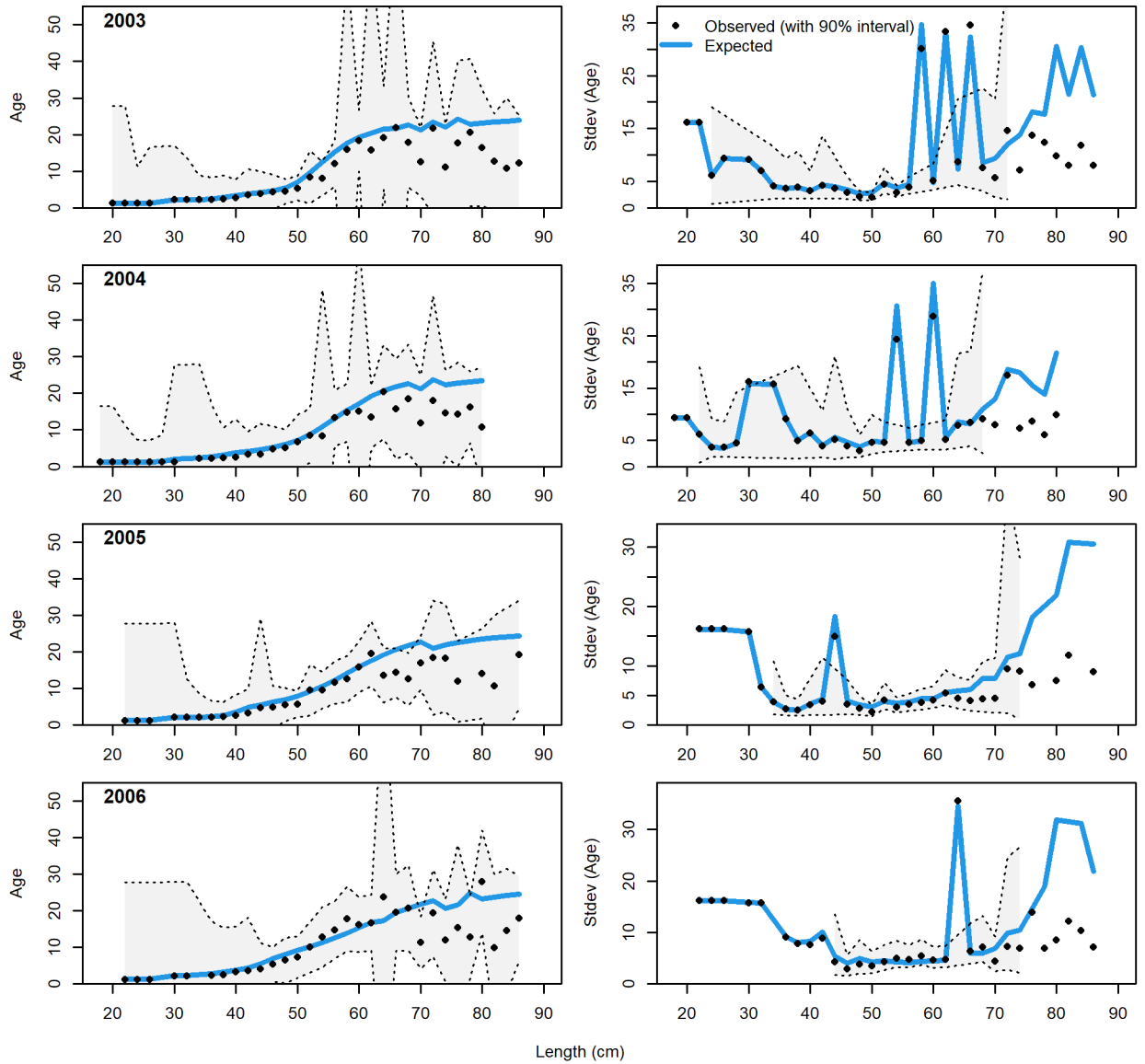
Figure 61: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch.

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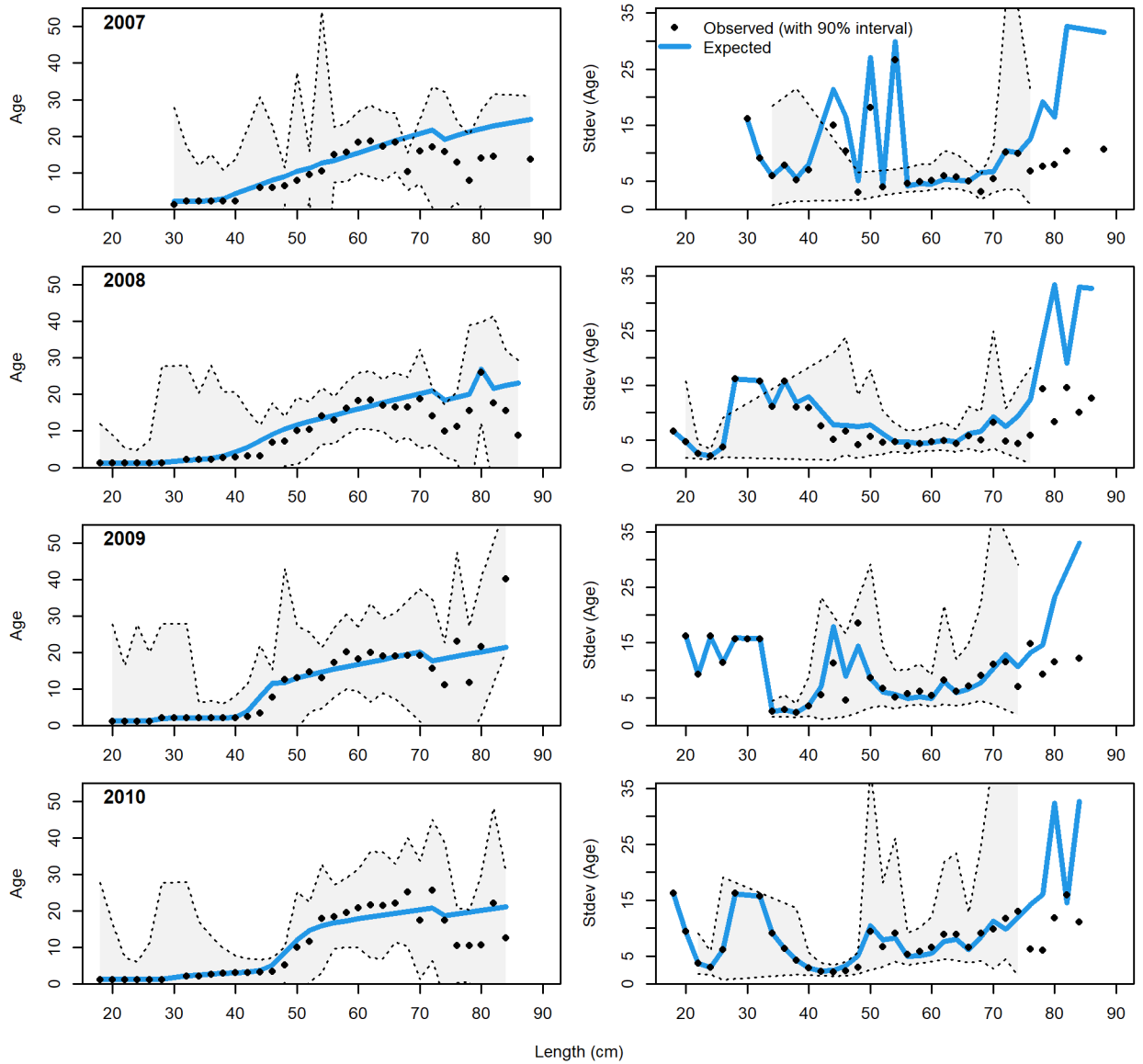
Figure 62: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued.
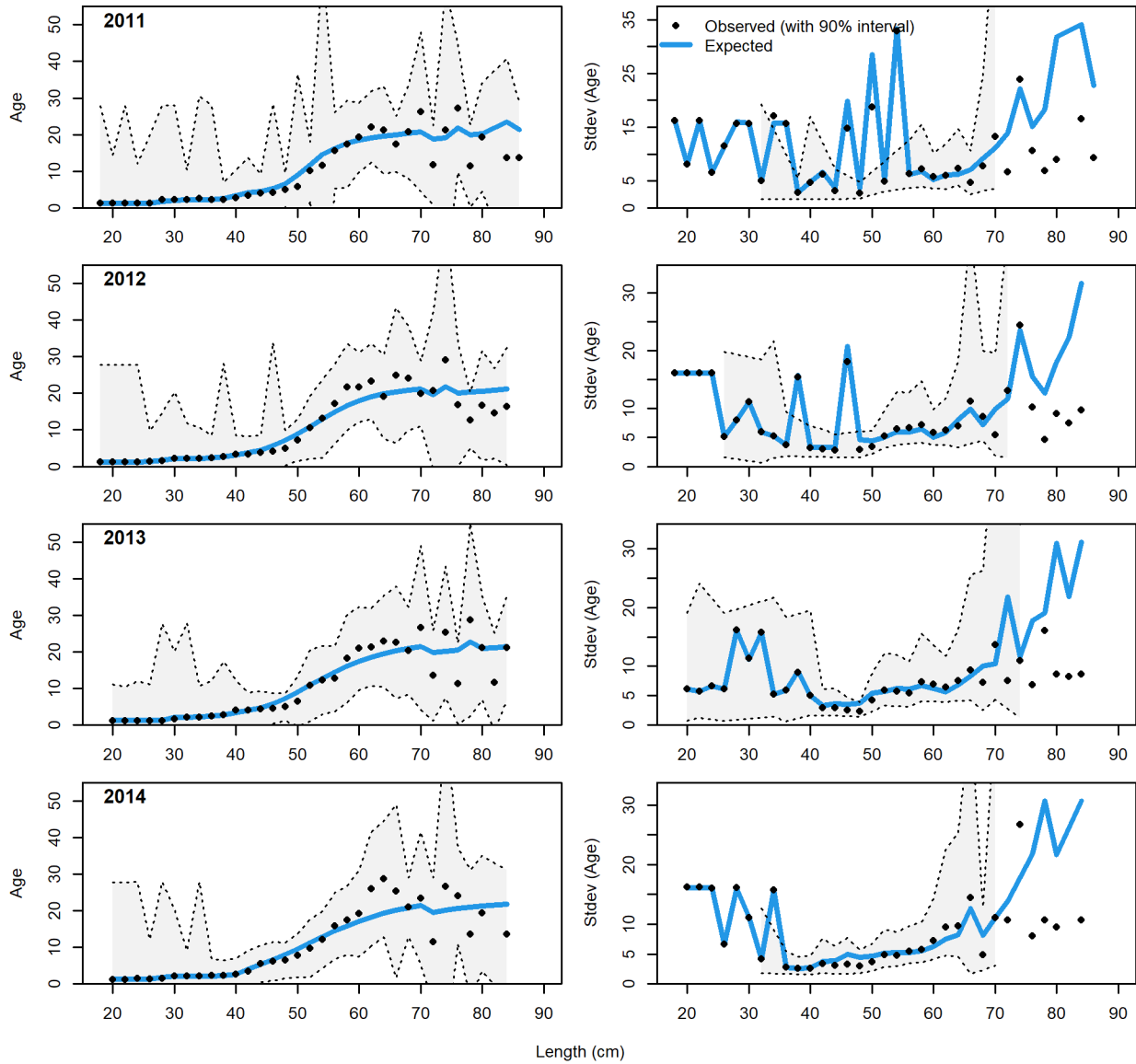
Figure 63: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued.
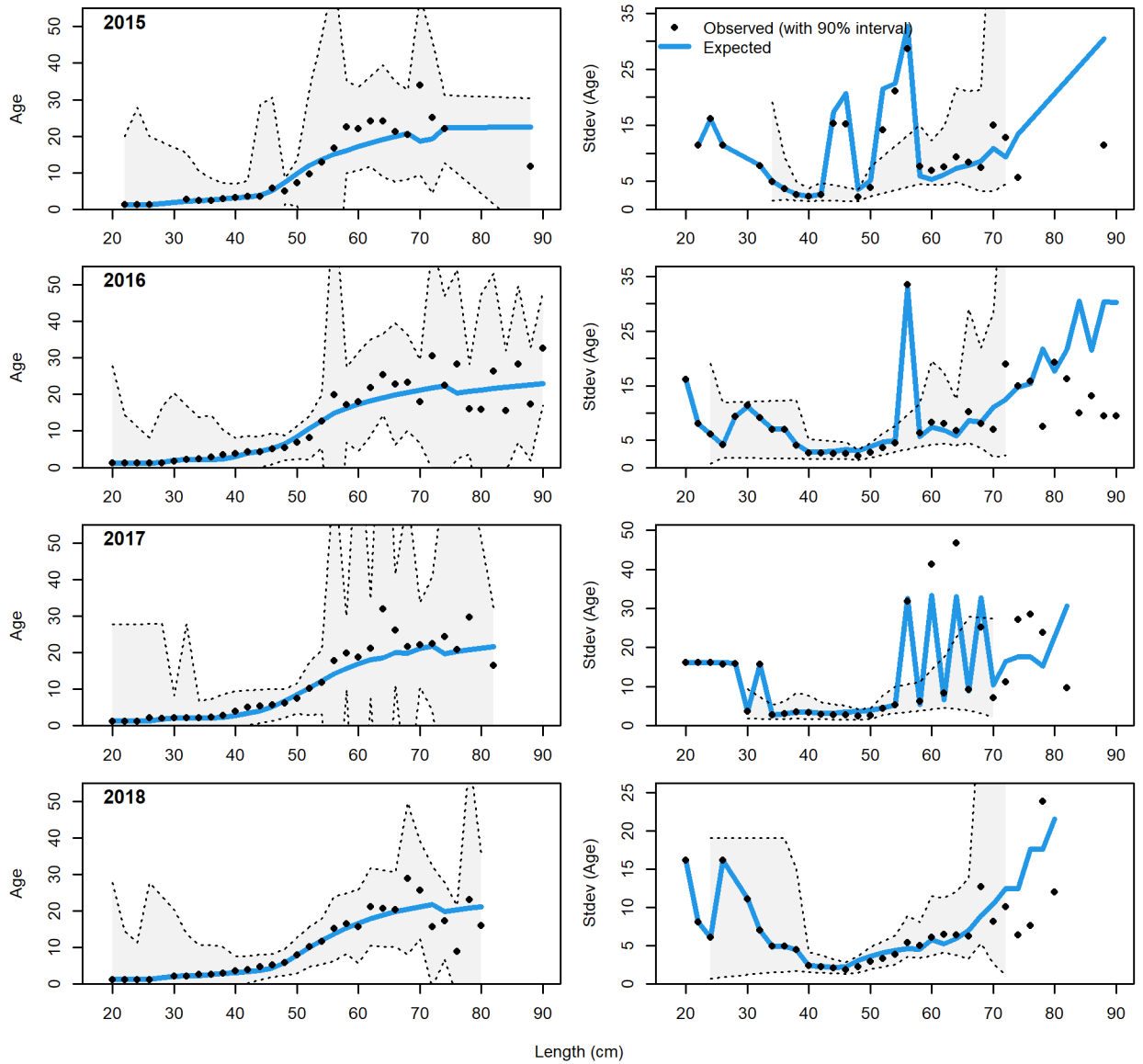
Figure 64: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued.
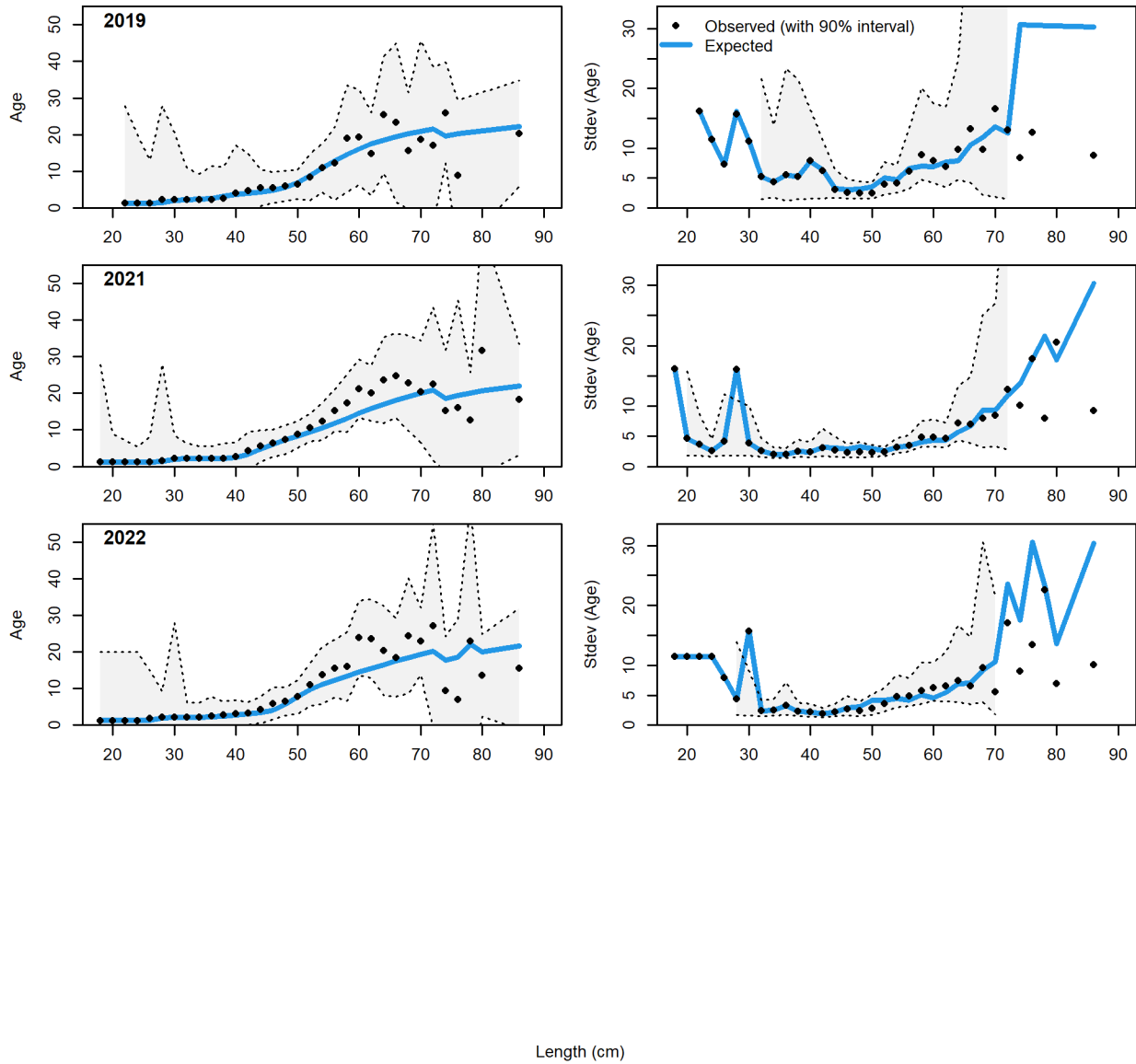
Figure 65: Year-specific conditional age-at-length data with 1.64 standard errors of the mean (left) and standard deviation (Stdev) at age with 90 percent interval from a chi-square distribution for the standard deviation of mean age (right) from the WCGBTS from the whole catch. Continued.

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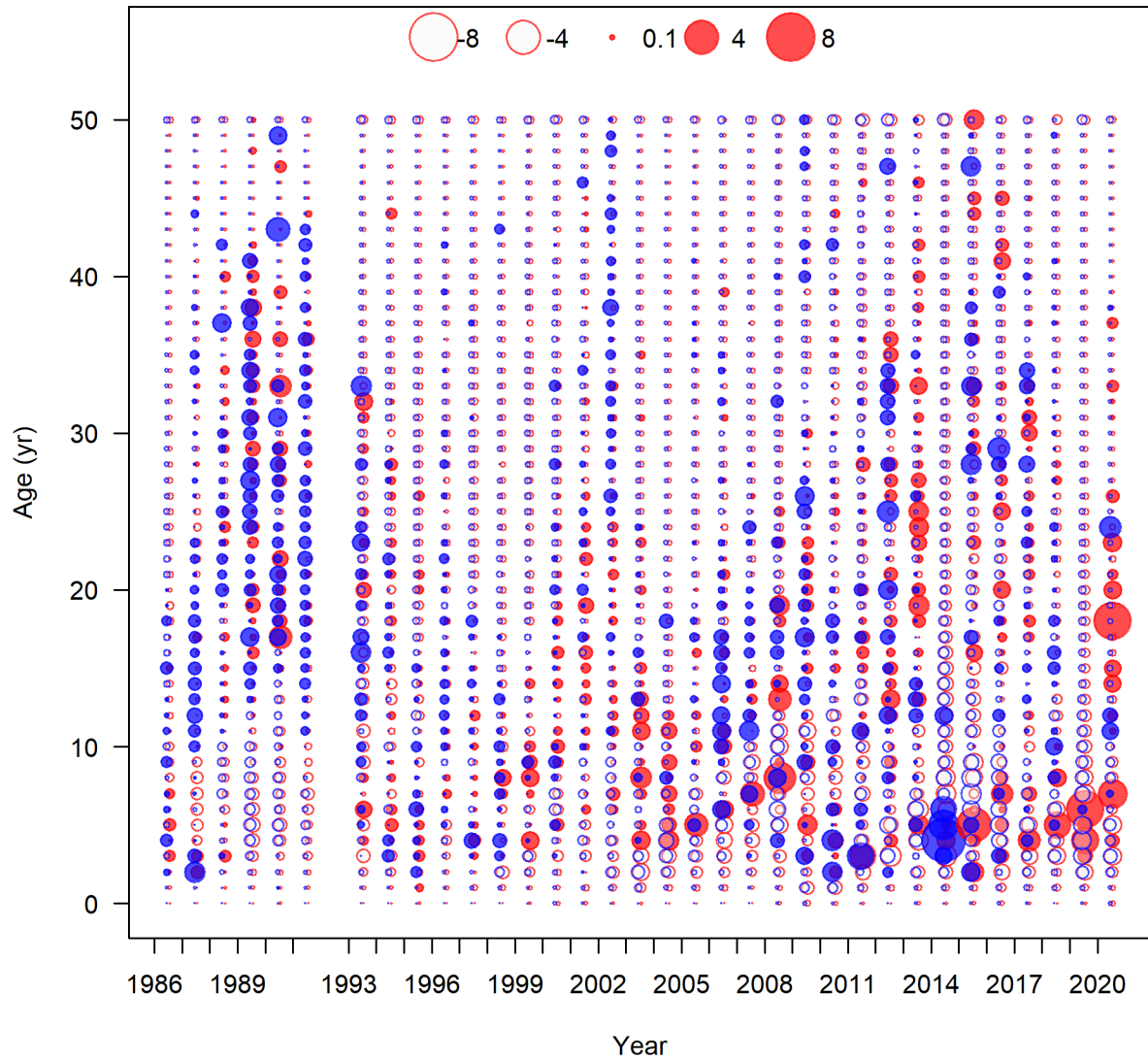
Figure 66: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the fixed-gear fleet from the retained catch.
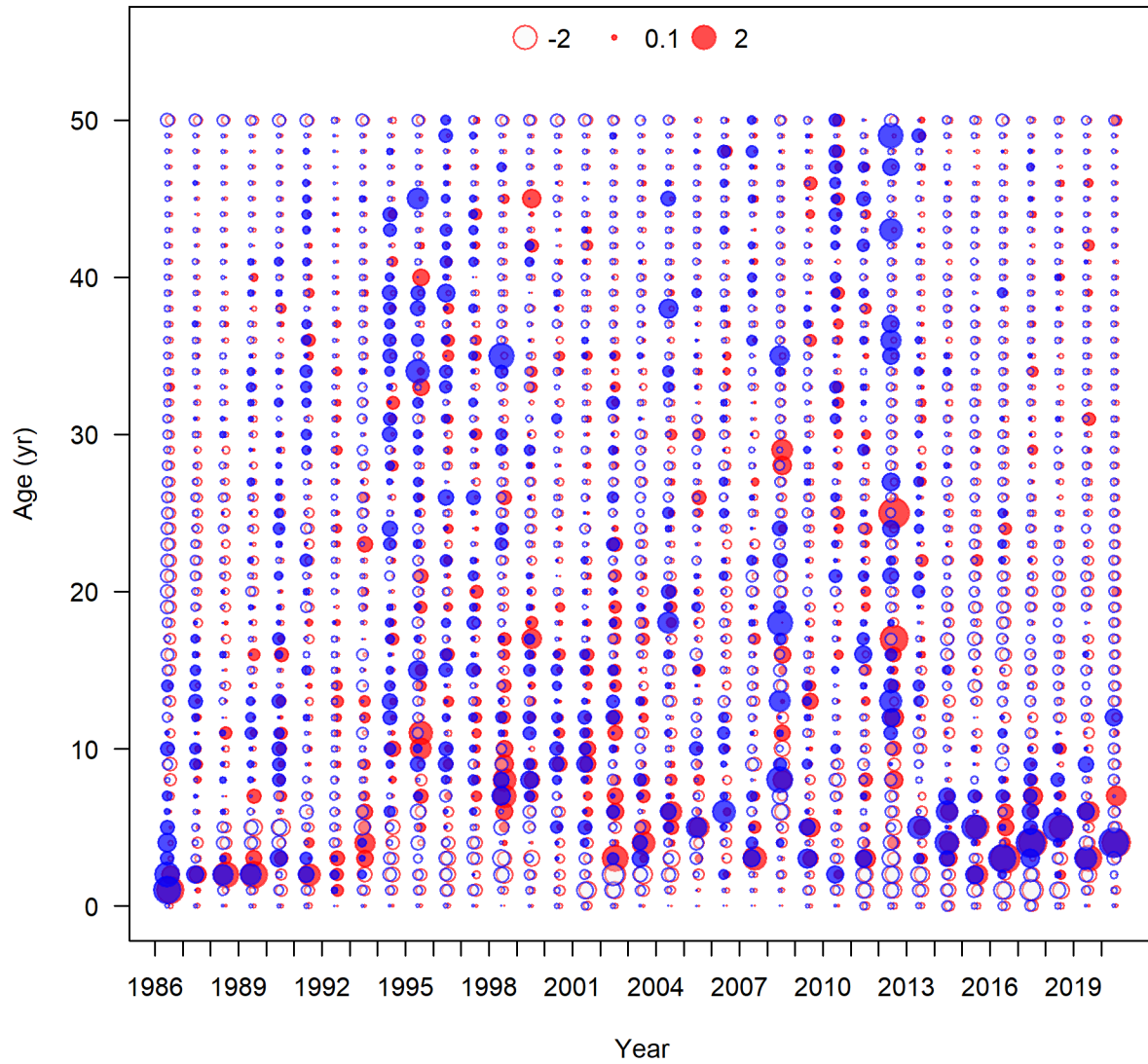
Figure 67: Pearson residuals, where closed and open bubbles indicate the observed value was greater or less than the expected, respectively, of age-composition data for the trawl fleet from the retained catch.
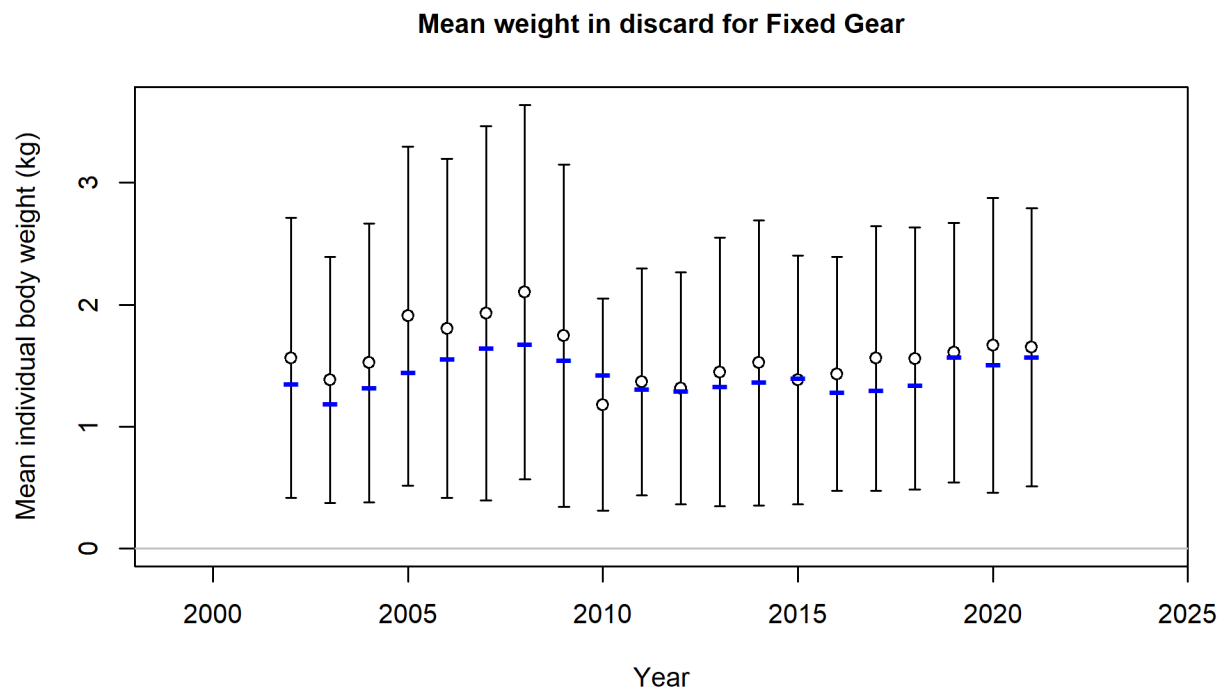
Figure 68: Fits to the mean body weight (kg) data for the fixed-gear fleet from the discarded catch.
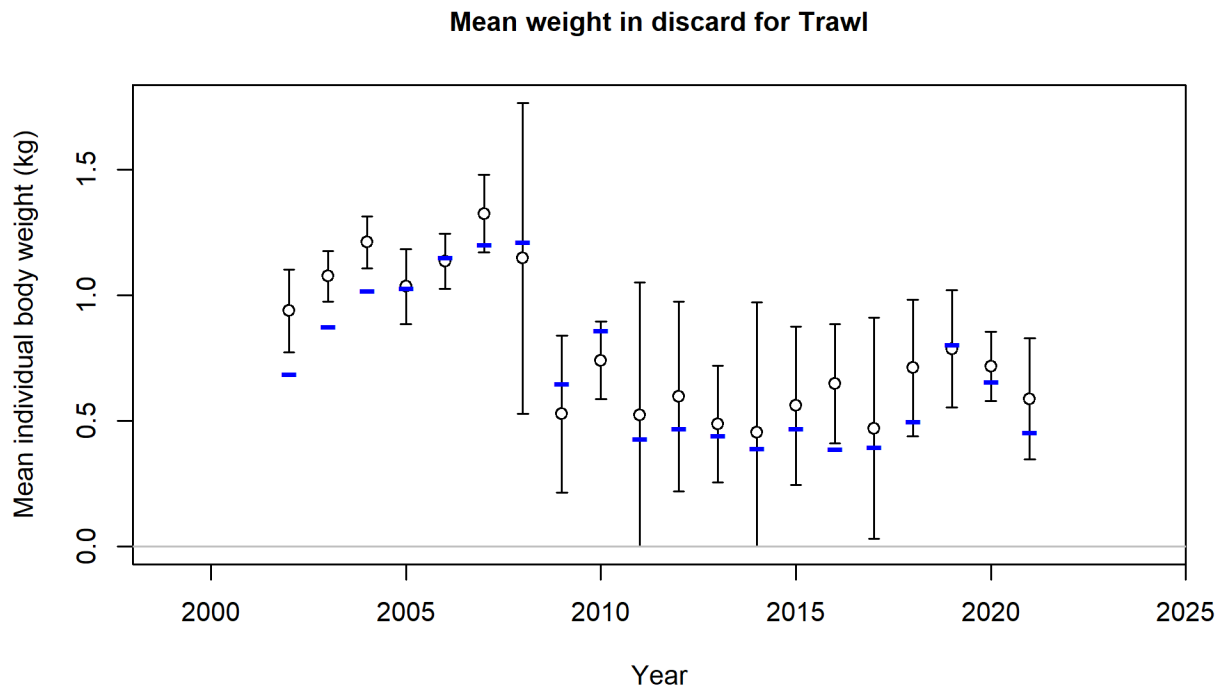
Figure 69: Fits to the mean body weight (kg) data for the trawl fleet from the discarded catch.

8.2.7 Sensitivity and Retrospectives Analyses
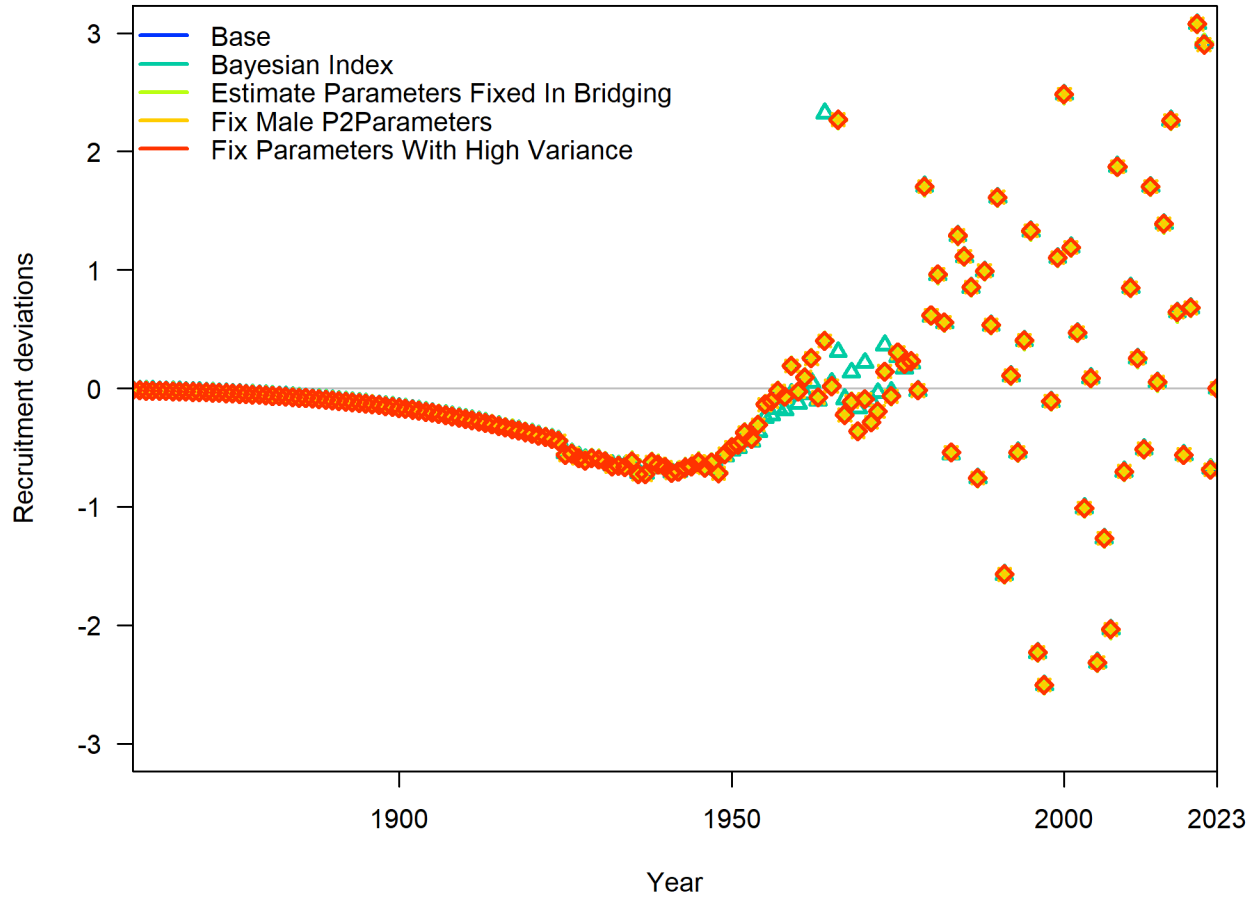
Figure 70: Annual recruitment deviations across a range of sensitivity analyses and the base model.
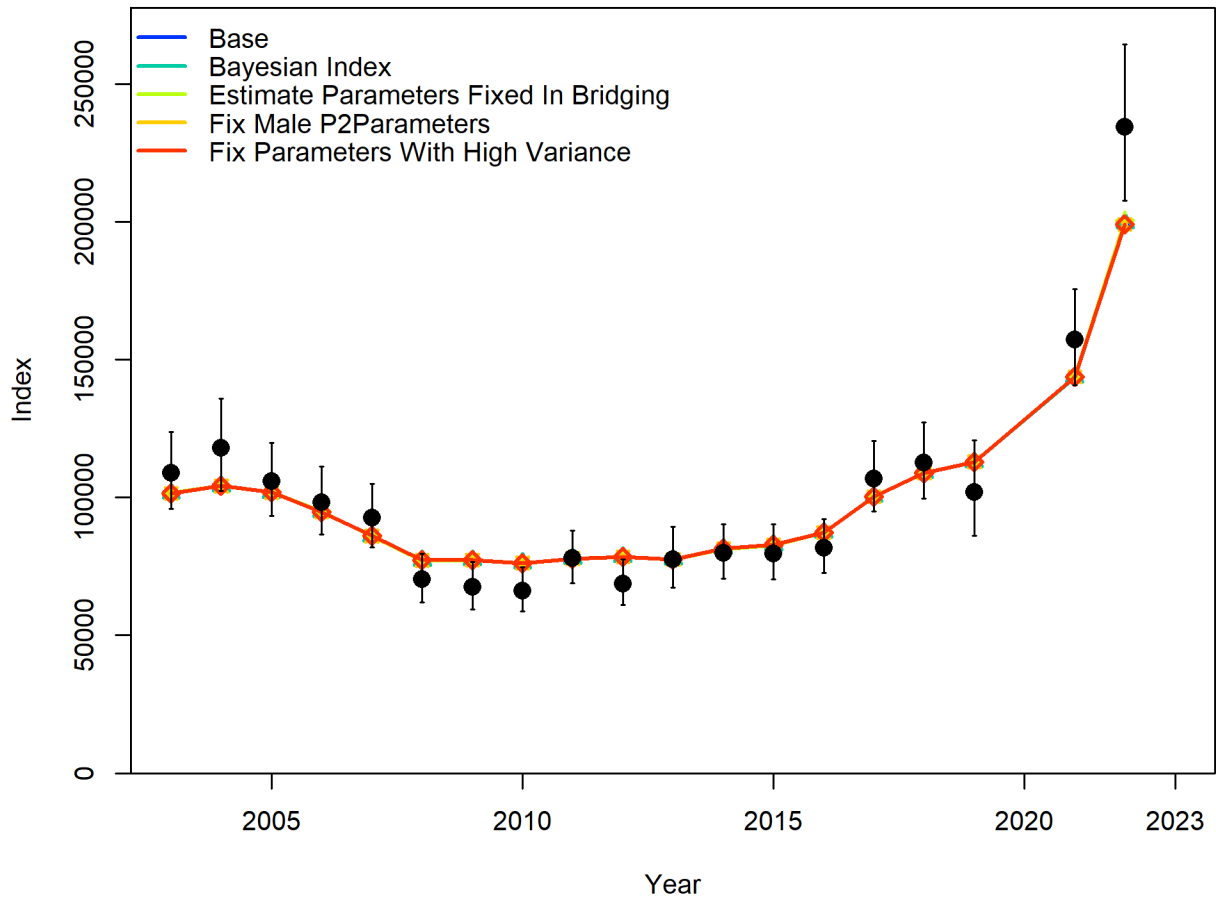
Figure 71: Recent survey index across a range of sensitivity analyses and the base model.
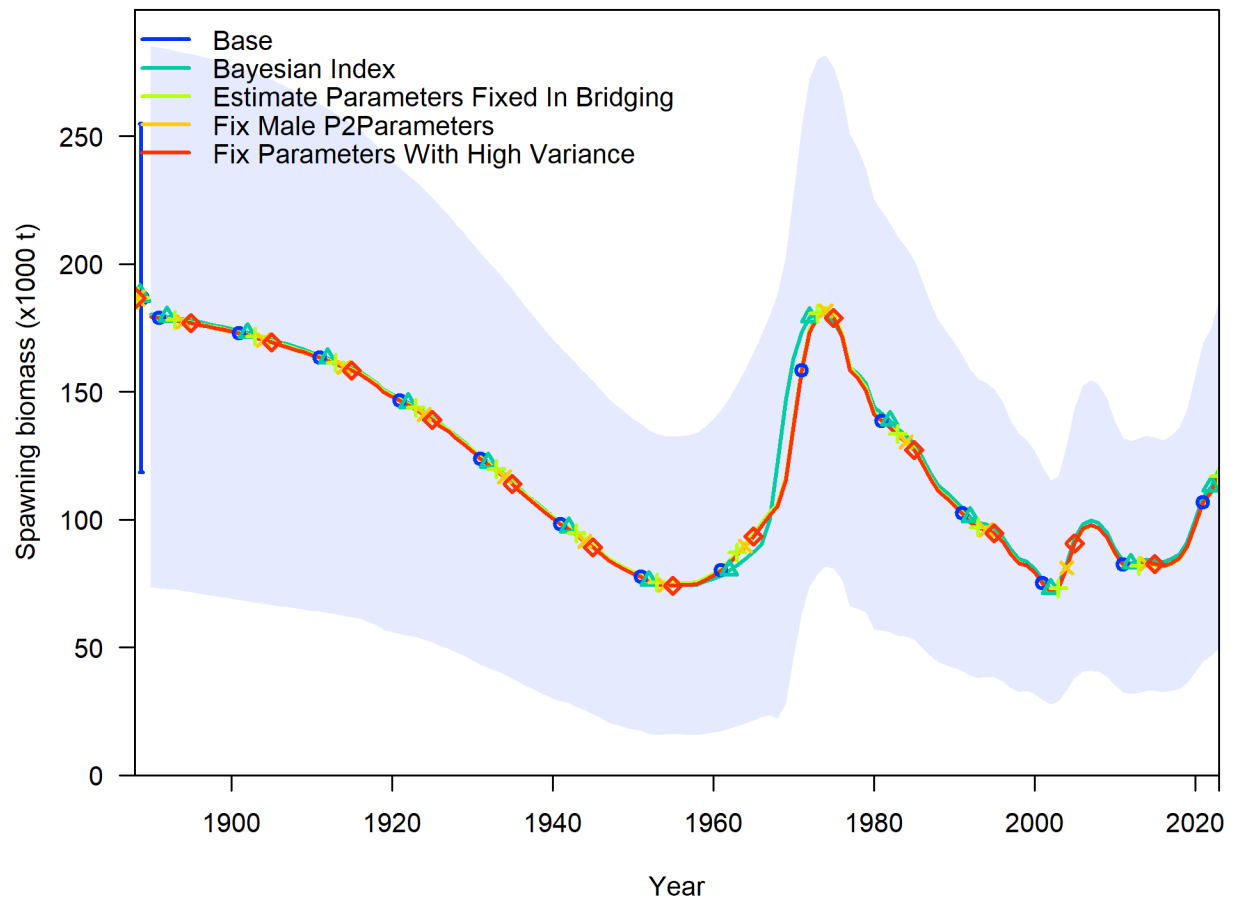
Figure 72: Spawning biomass across a range of sensitivity analyses and the base model.
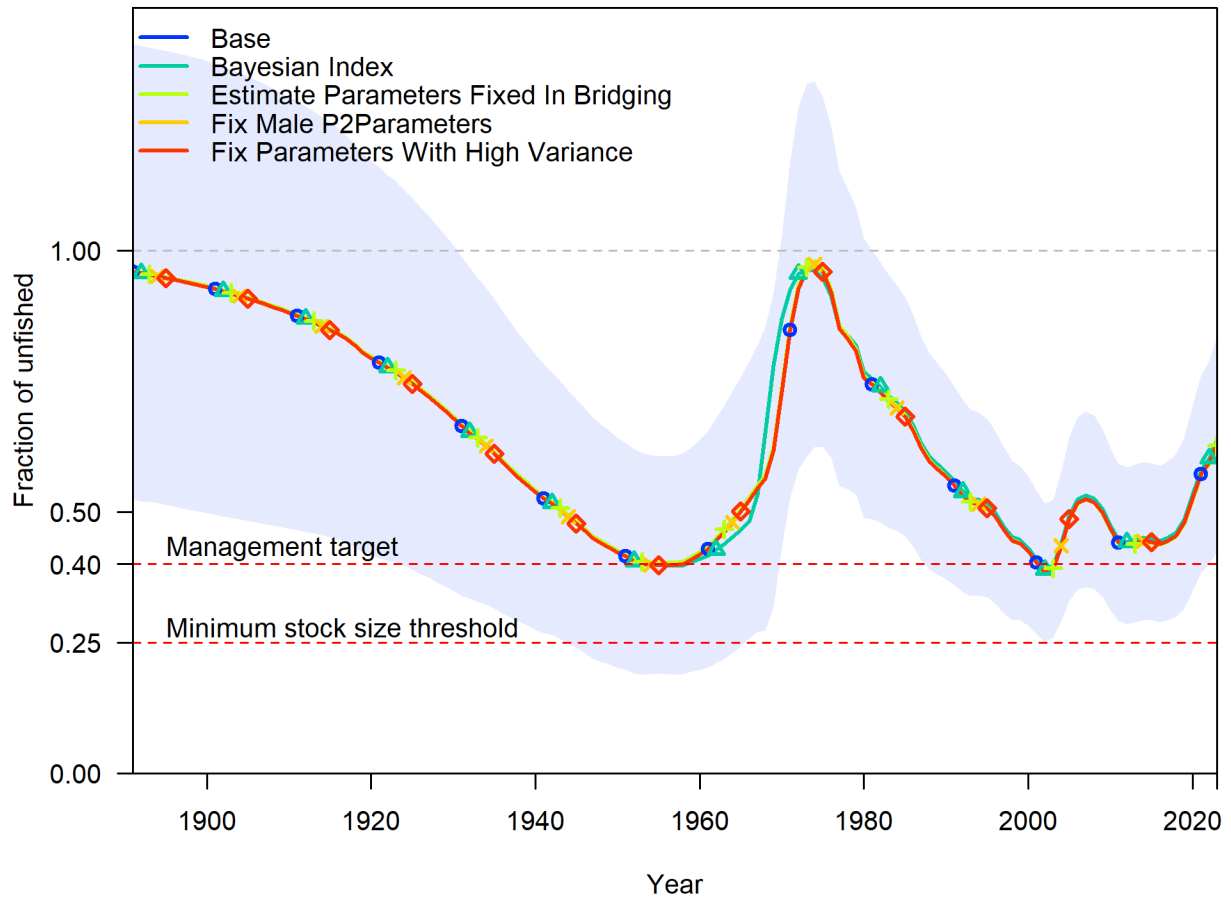
Figure 73: Fraction unfished across a range of sensitivity analyses and the base model.
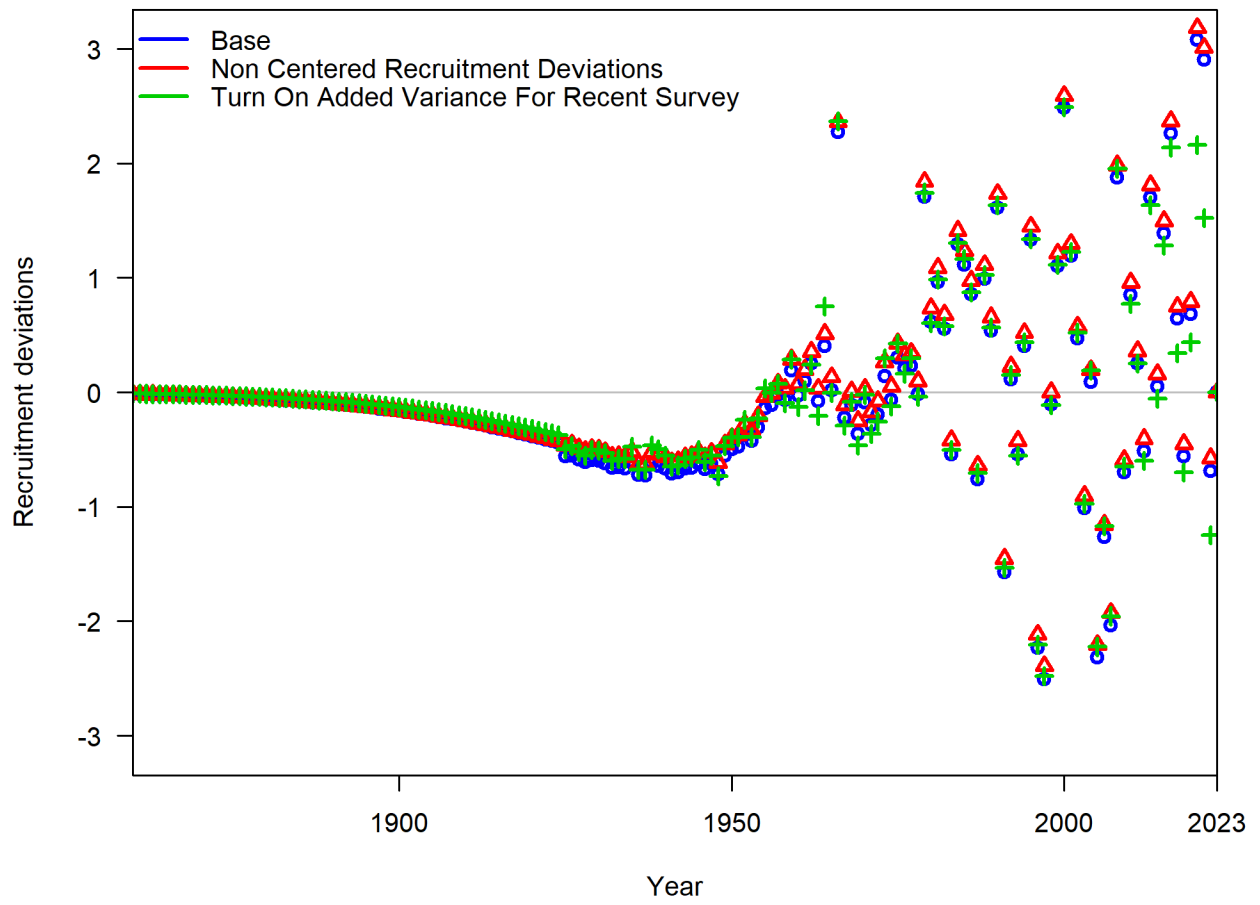
Figure 74: Annual recruitment deviations across a range of sensitivity analyses and the base model.

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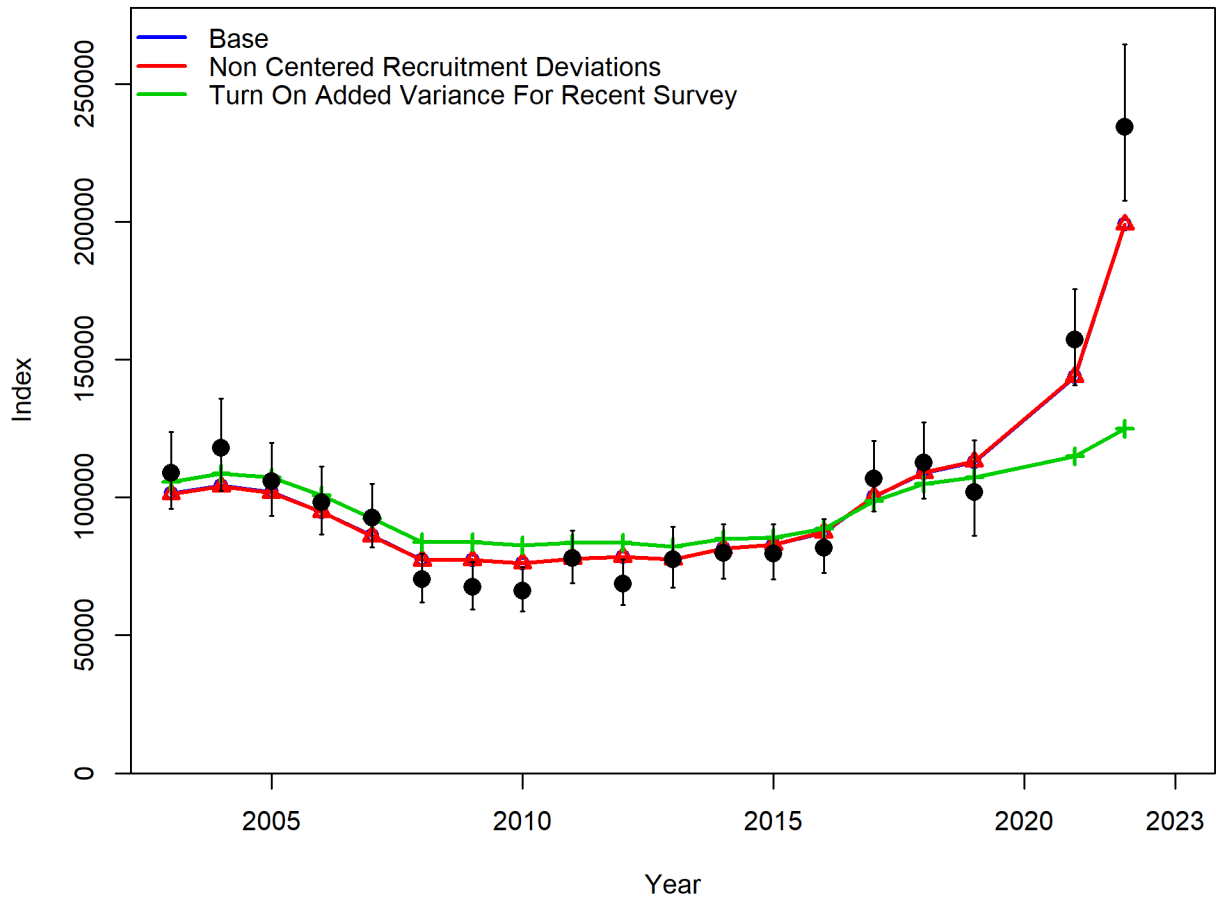
Figure 75: Recent survey index across a range of sensitivity analyses and the base model.
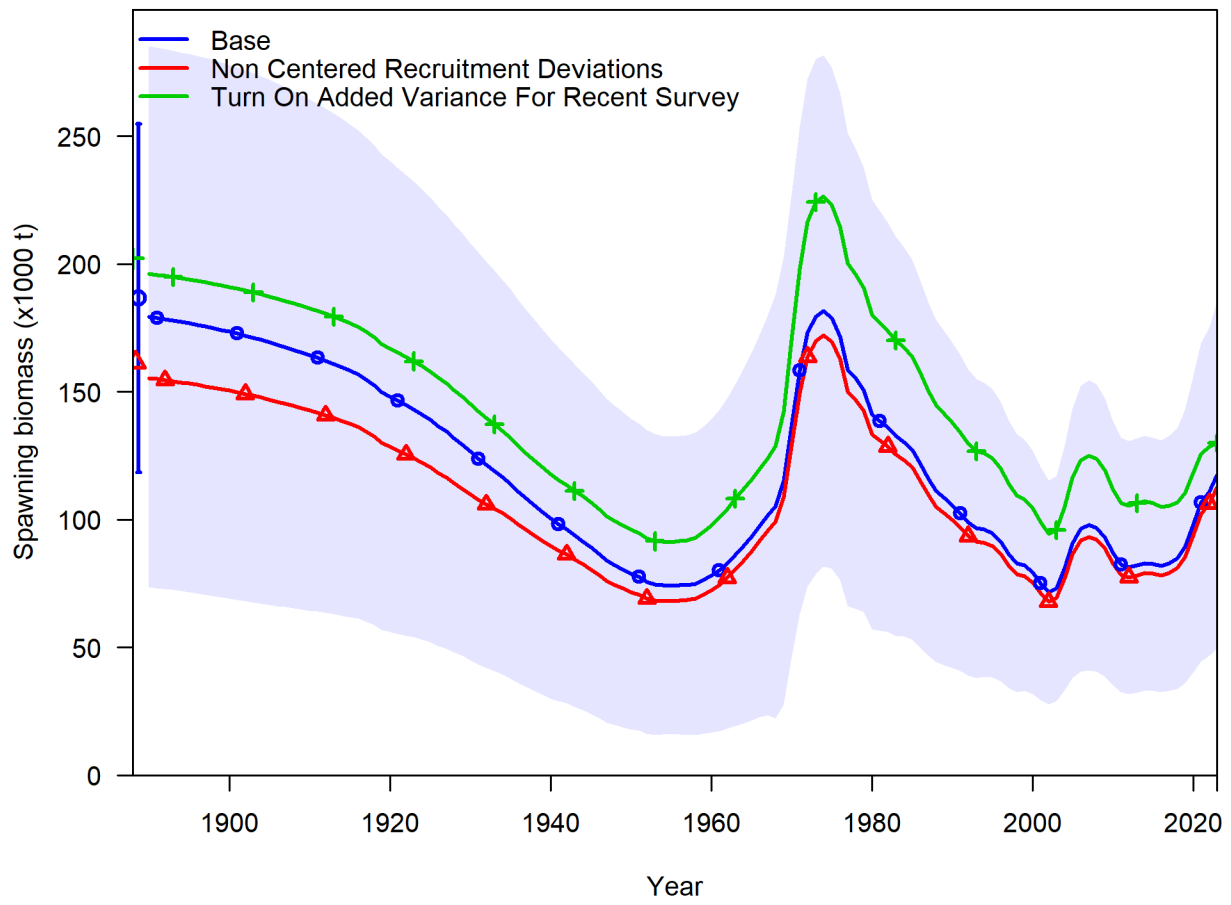
Figure 76: Spawning biomass across a range of sensitivity analyses and the base model.
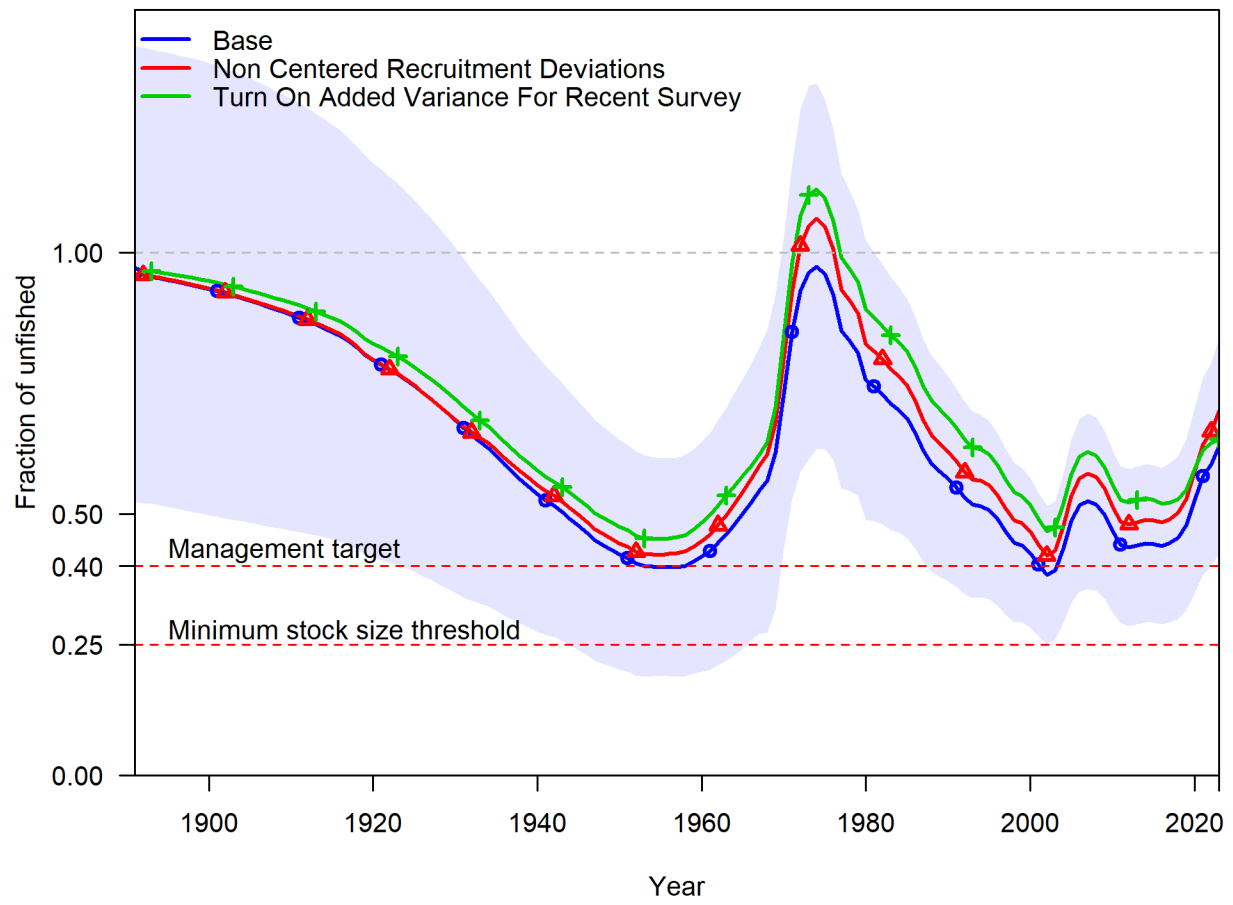
Figure 77: Fraction unfished across a range of sensitivity analyses and the base model.
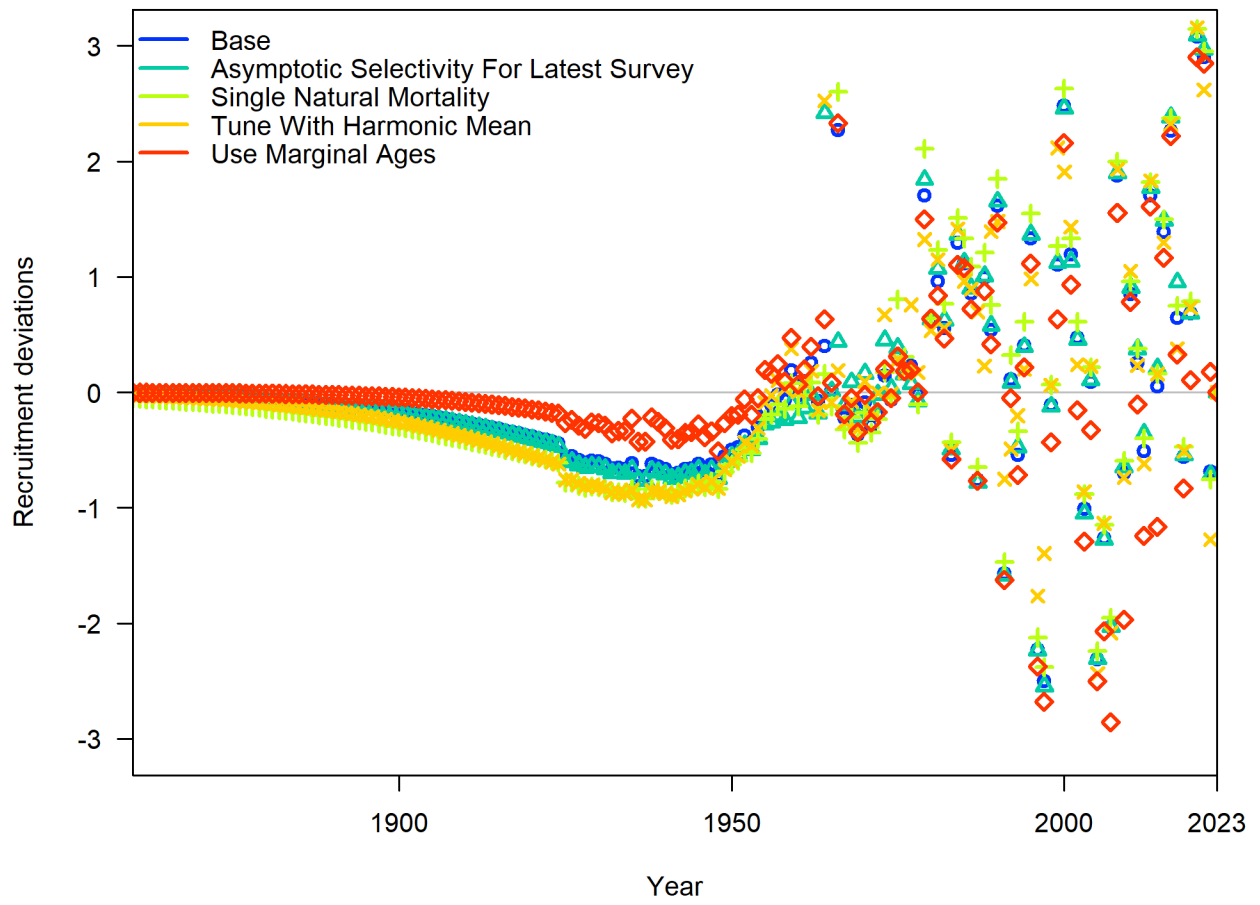
Figure 78: Annual recruitment deviations across a range of sensitivity analyses and the base model.
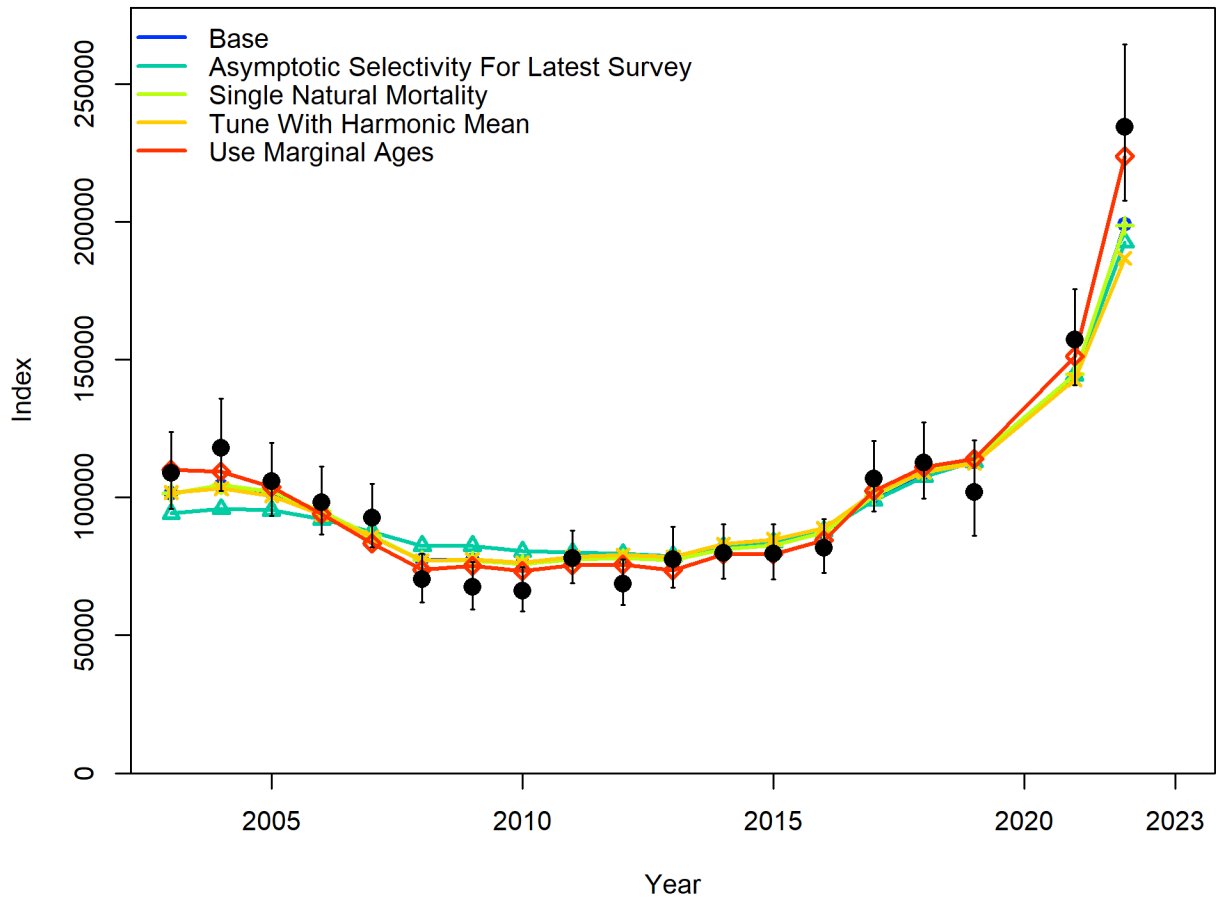
Figure 79: Recent survey index across a range of sensitivity analyses and the base model.
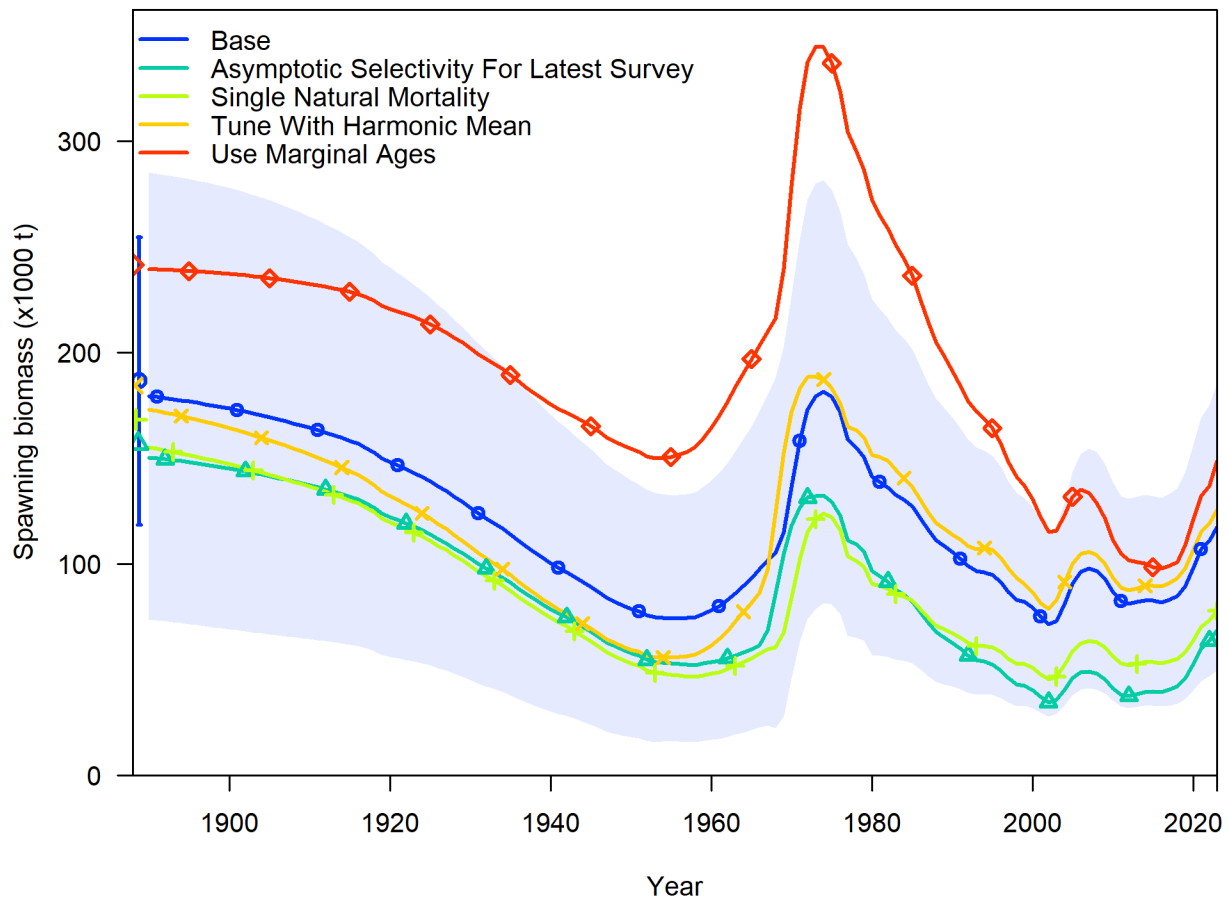
Figure 80: Spawning biomass across a range of sensitivity analyses and the base model.
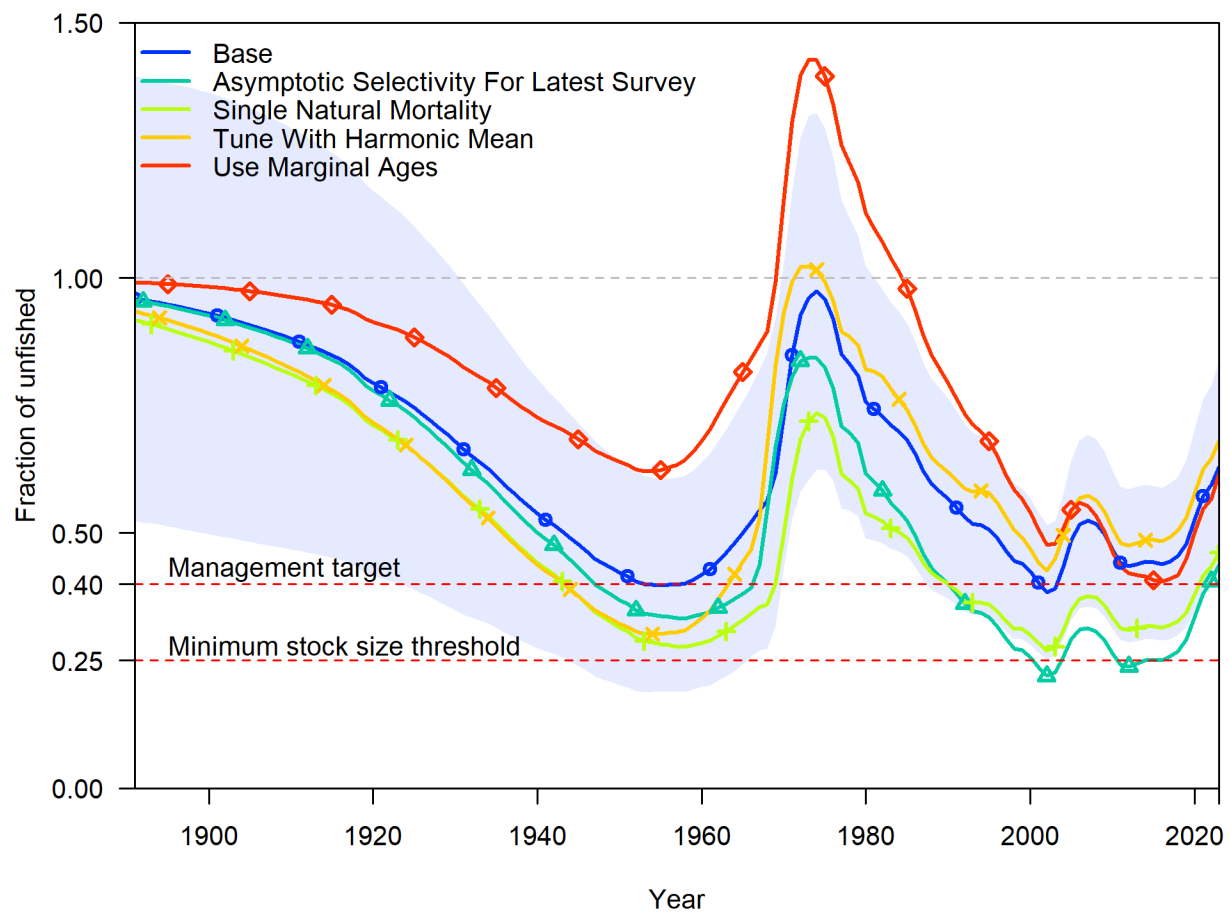
Figure 81: Fraction unfished across a range of sensitivity analyses and the base model.
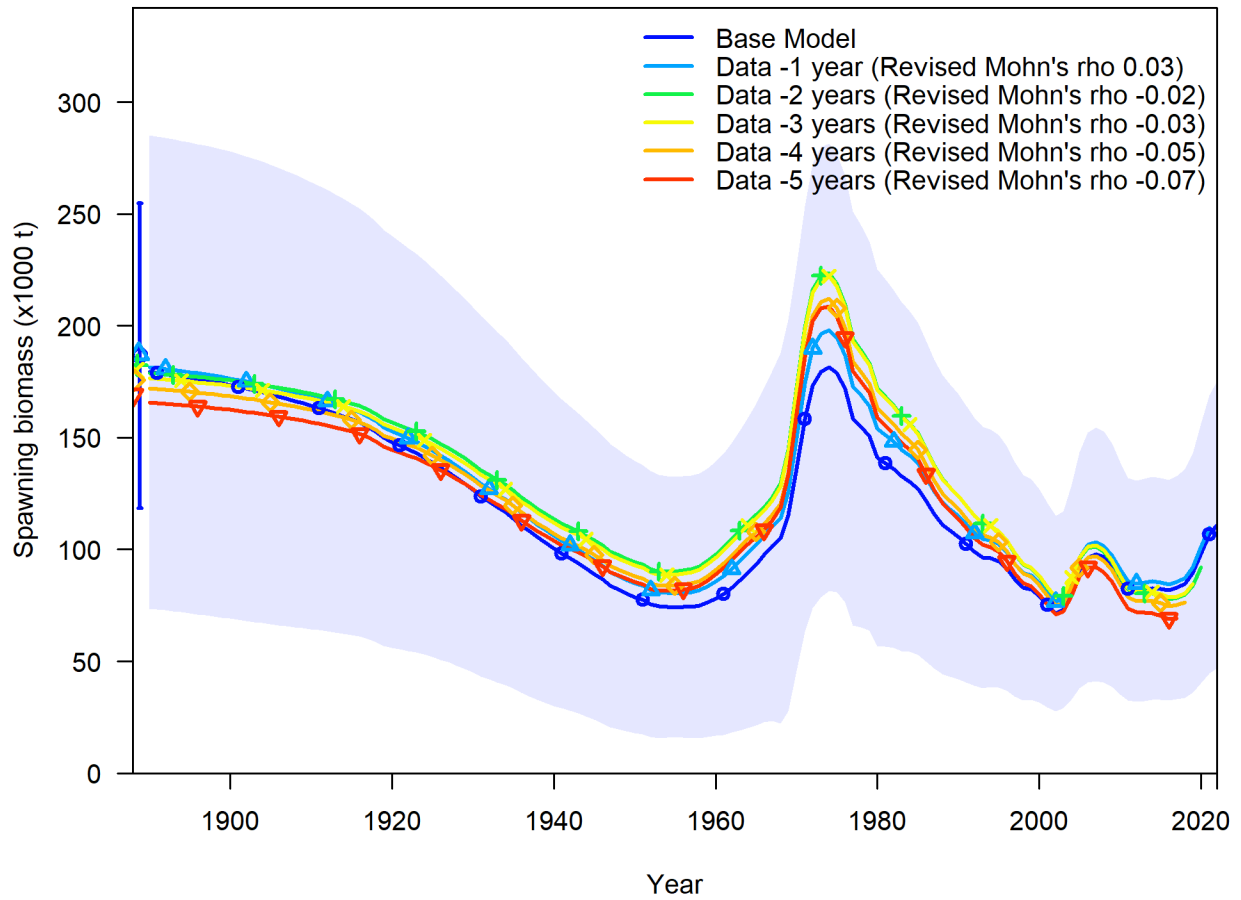
Figure 82: Retrospective patterns for spawning stock biomass (*SSB*) when up to five years of data were removed from the base model. Mohn's rho (Mohn, 1999) values were recalculated for each peel given the removal of another year of data.
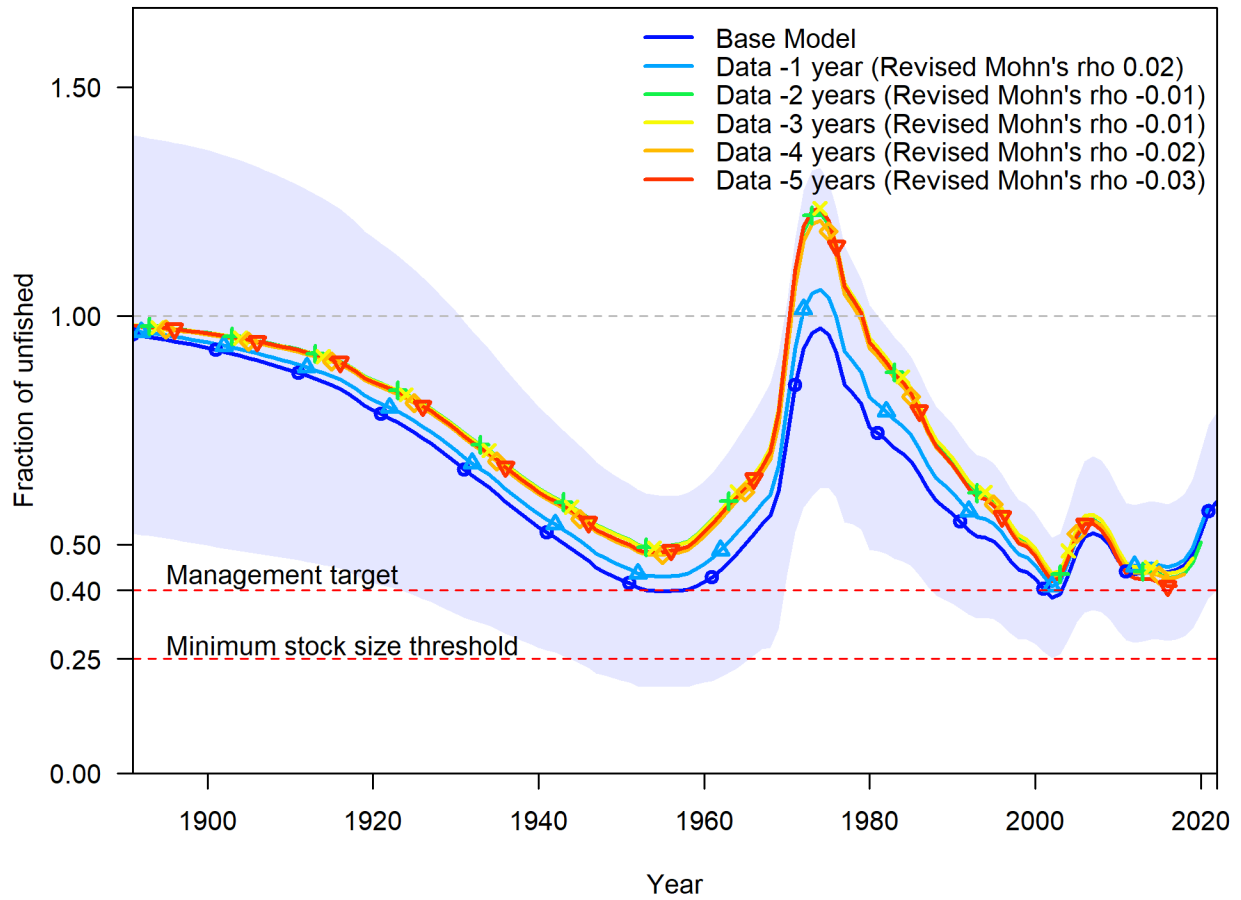
Figure 83: Retrospective patterns for fraction unfished when up to five years of data were removed from the base model. Mohn's rho (Mohn, 1999) values were recalculated for each peel given the removal of another year of data.

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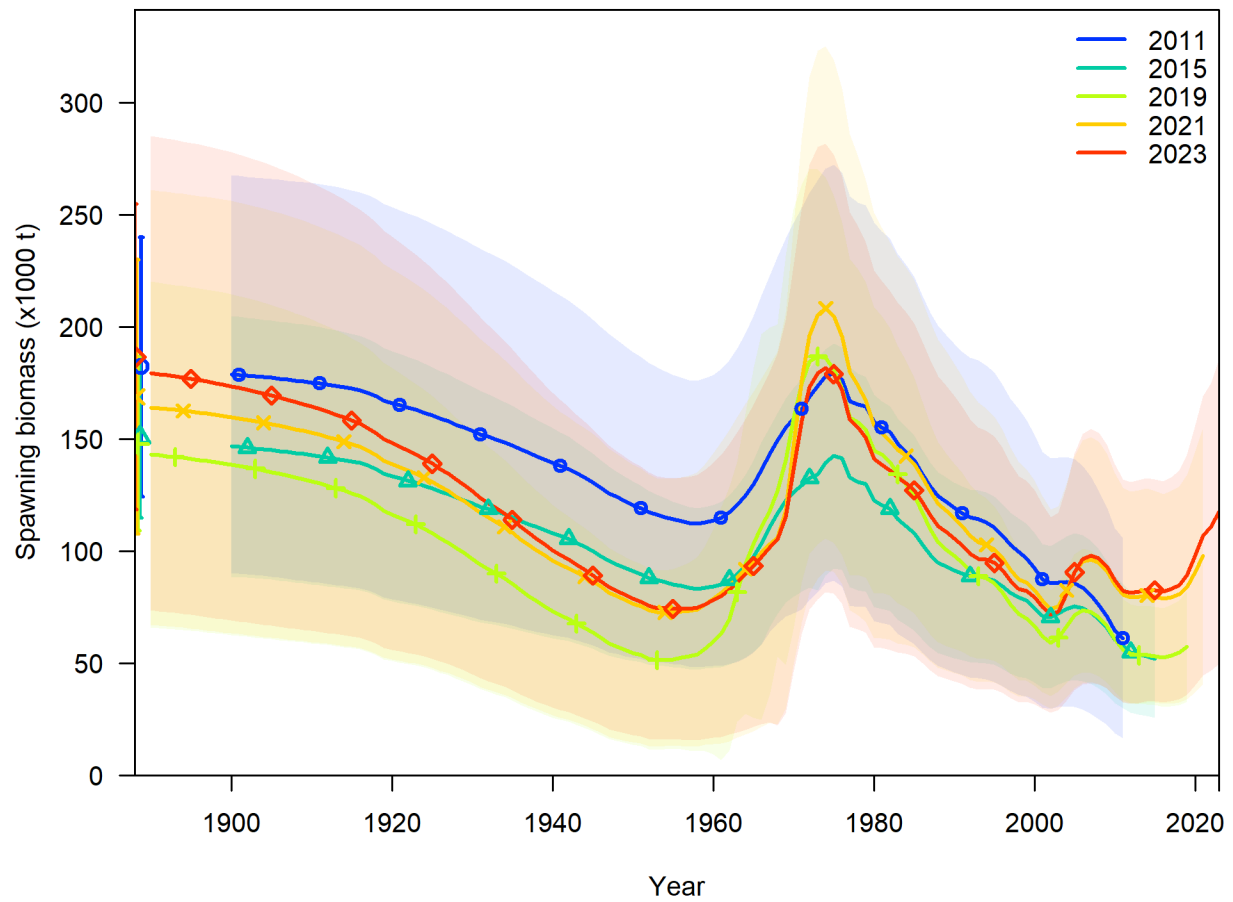
Figure 84: Comparisons of spawning biomass (mt) between the current assessment and recent benchmark and update assessments since 2011.
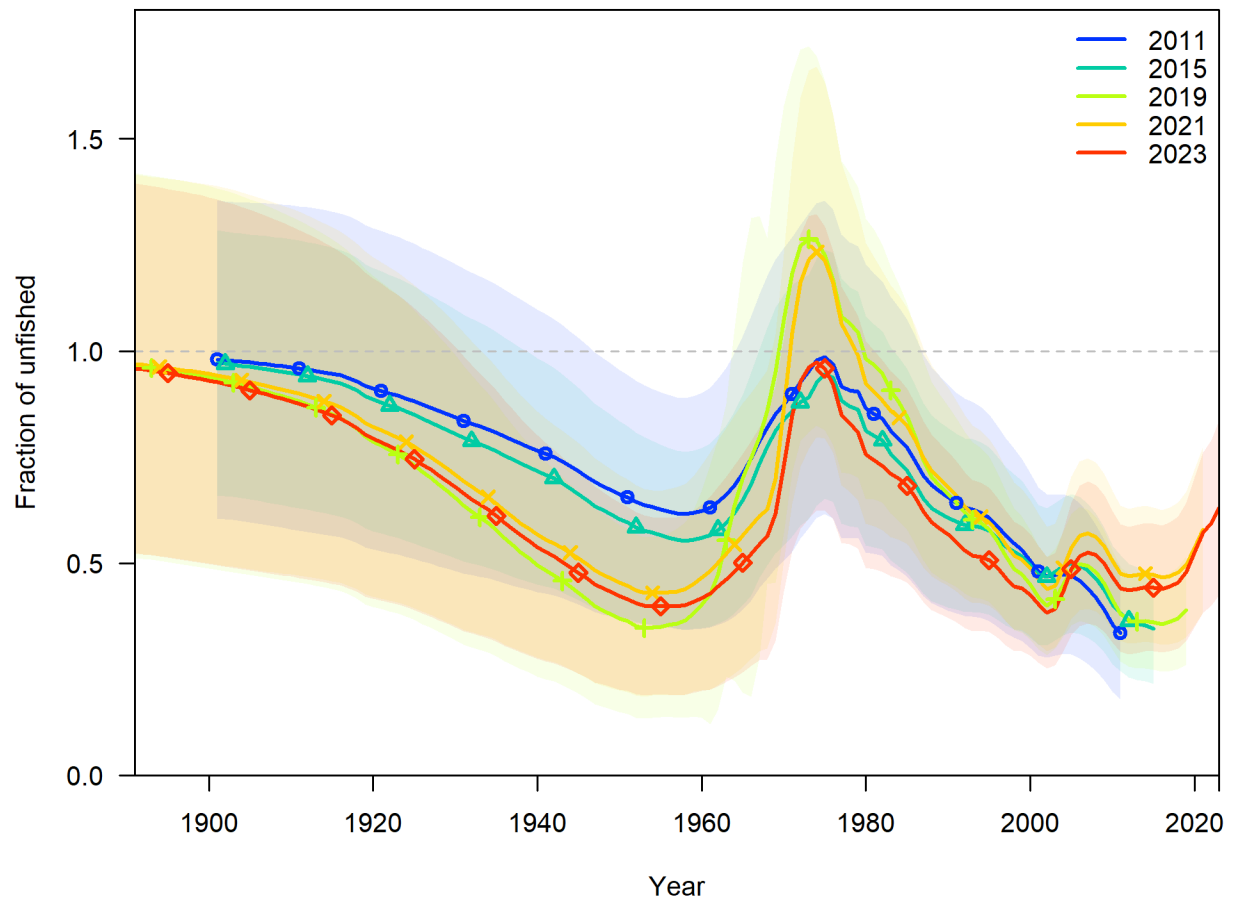
Figure 85: Comparisons of fraction unfished between the current assessment and recent benchmark and update assessments since 2011.

8.2.8 Likelihood Profiles
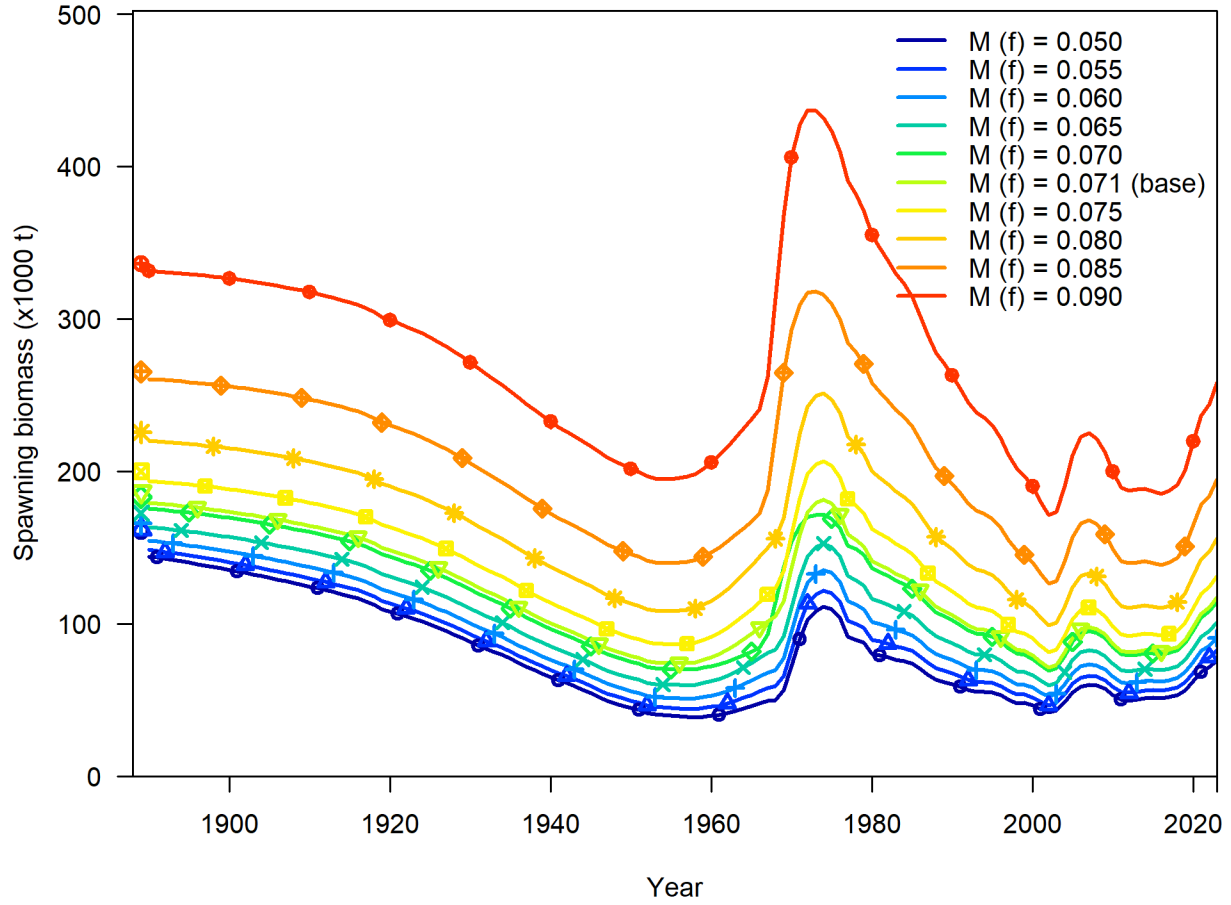
Figure 86: Change in the spawning biomass across a range of female natural mortality values. .
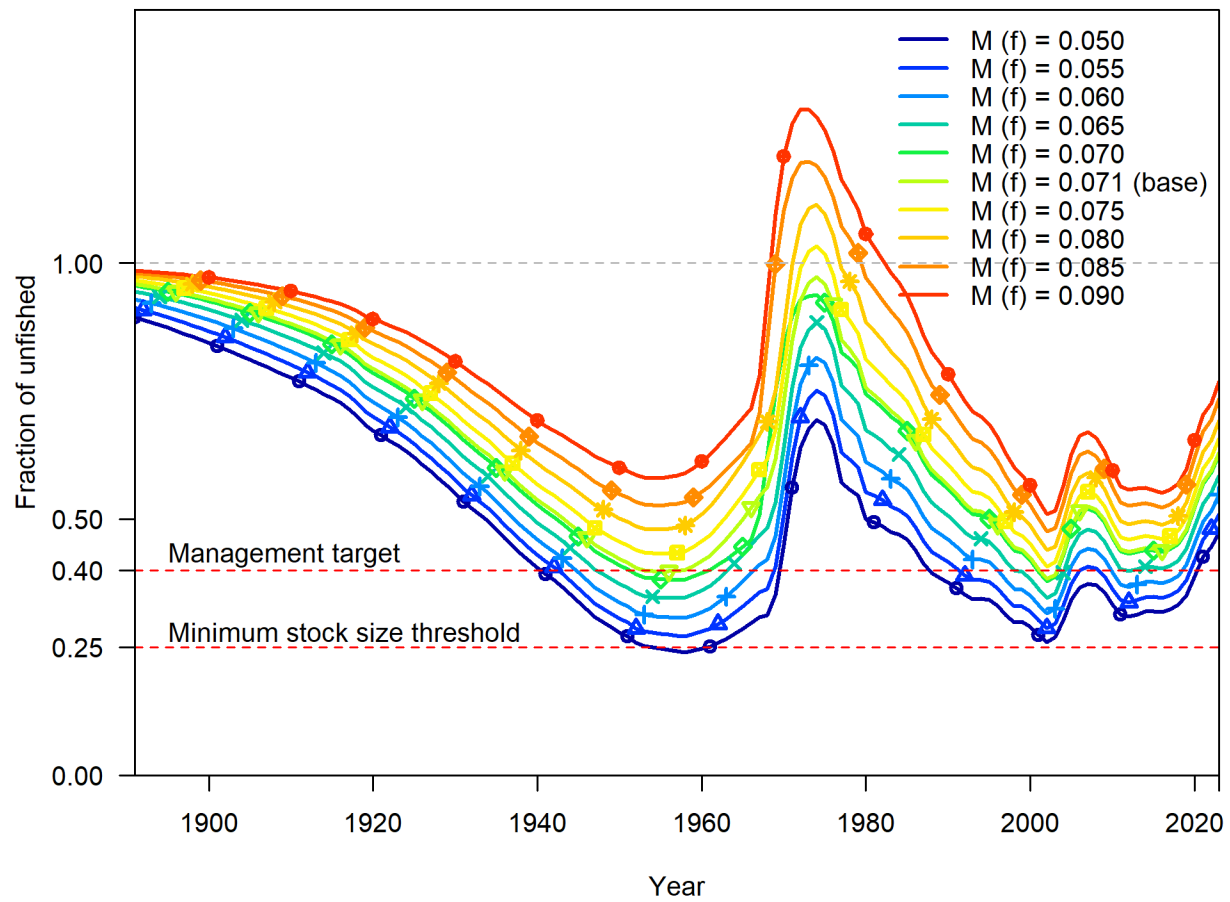
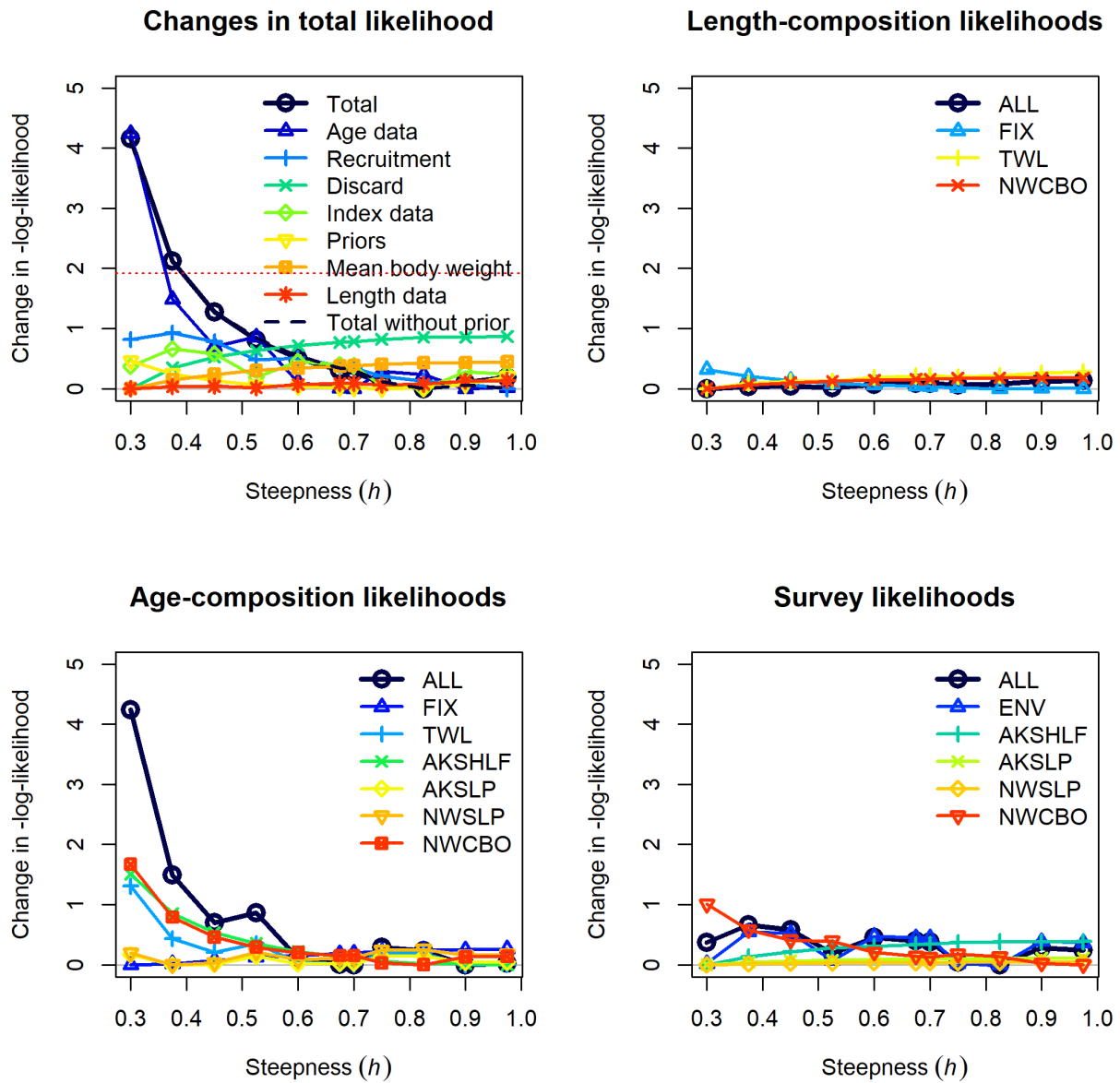**Figure 87:** Change in the fraction unfished across a range of female natural mortality values. .
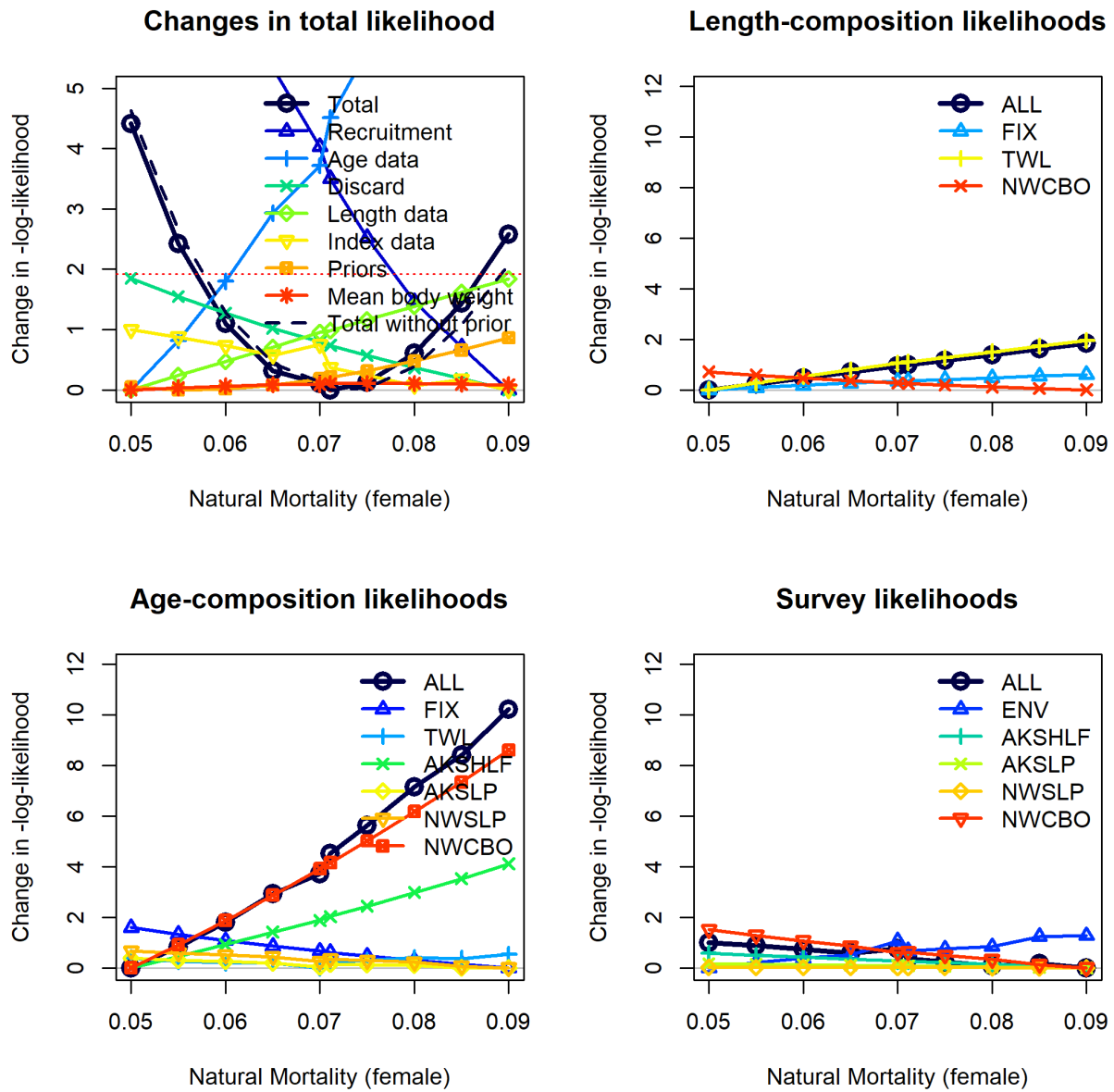
Figure 88: Change in the negative log-likelihood across a range of female natural mortality values. Fixed Gear = FIX, Trawl = TWL, Env. Index = ENV, Triennial = AKSHLF, AK Slope = AKSLP, NWFSC Slope = NWSLP, and WCGBTS = NWCBO.
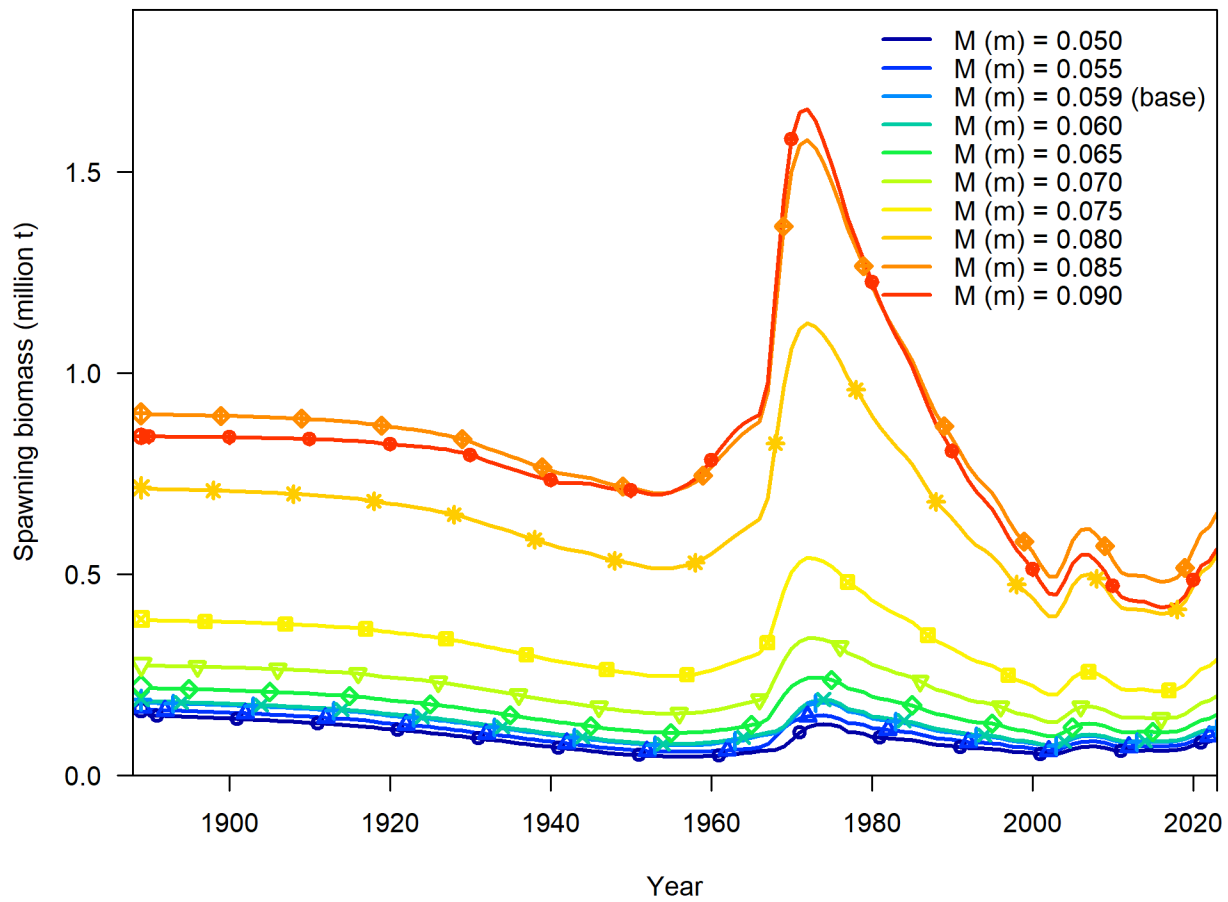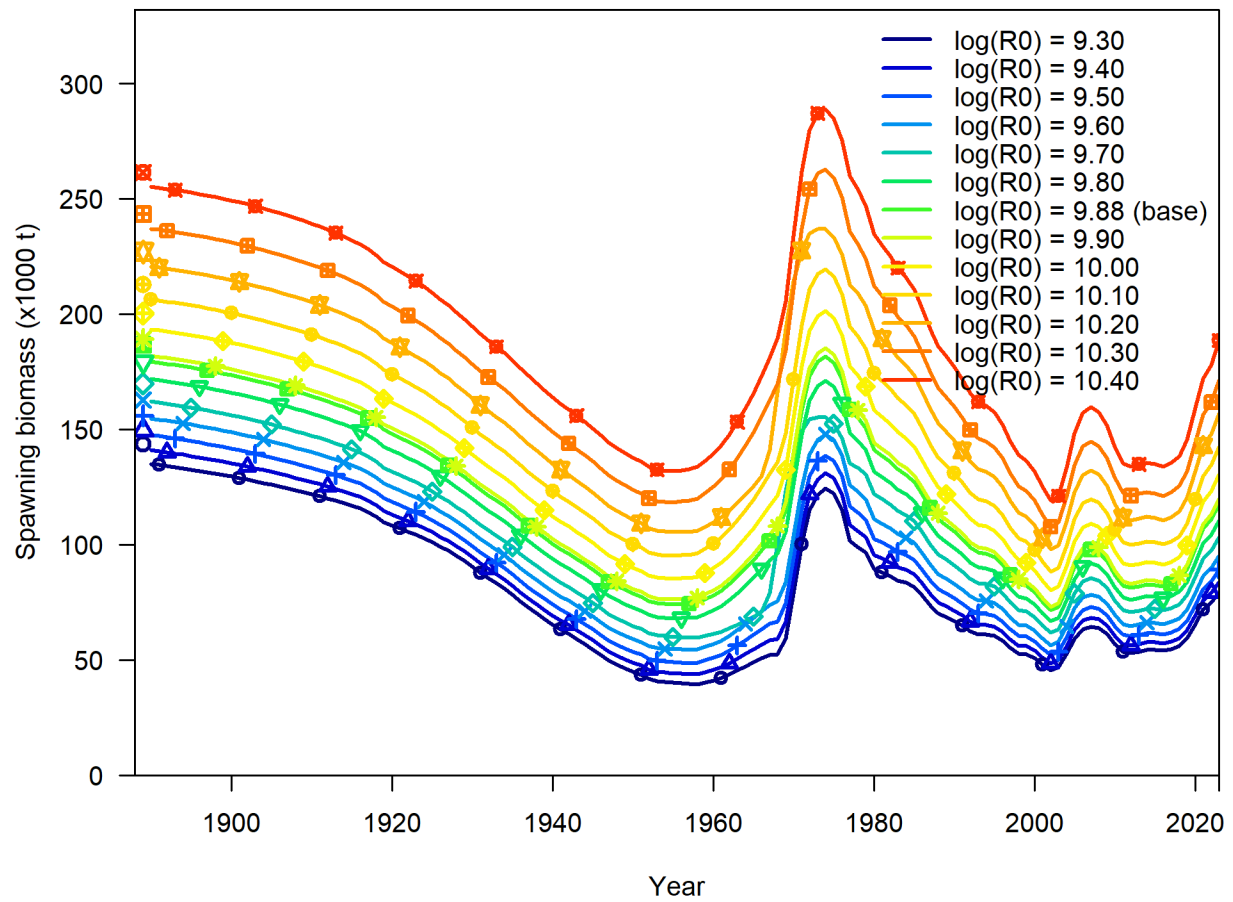
Figure 89: Change in the spawning biomass across a range of male natural mortality values. .
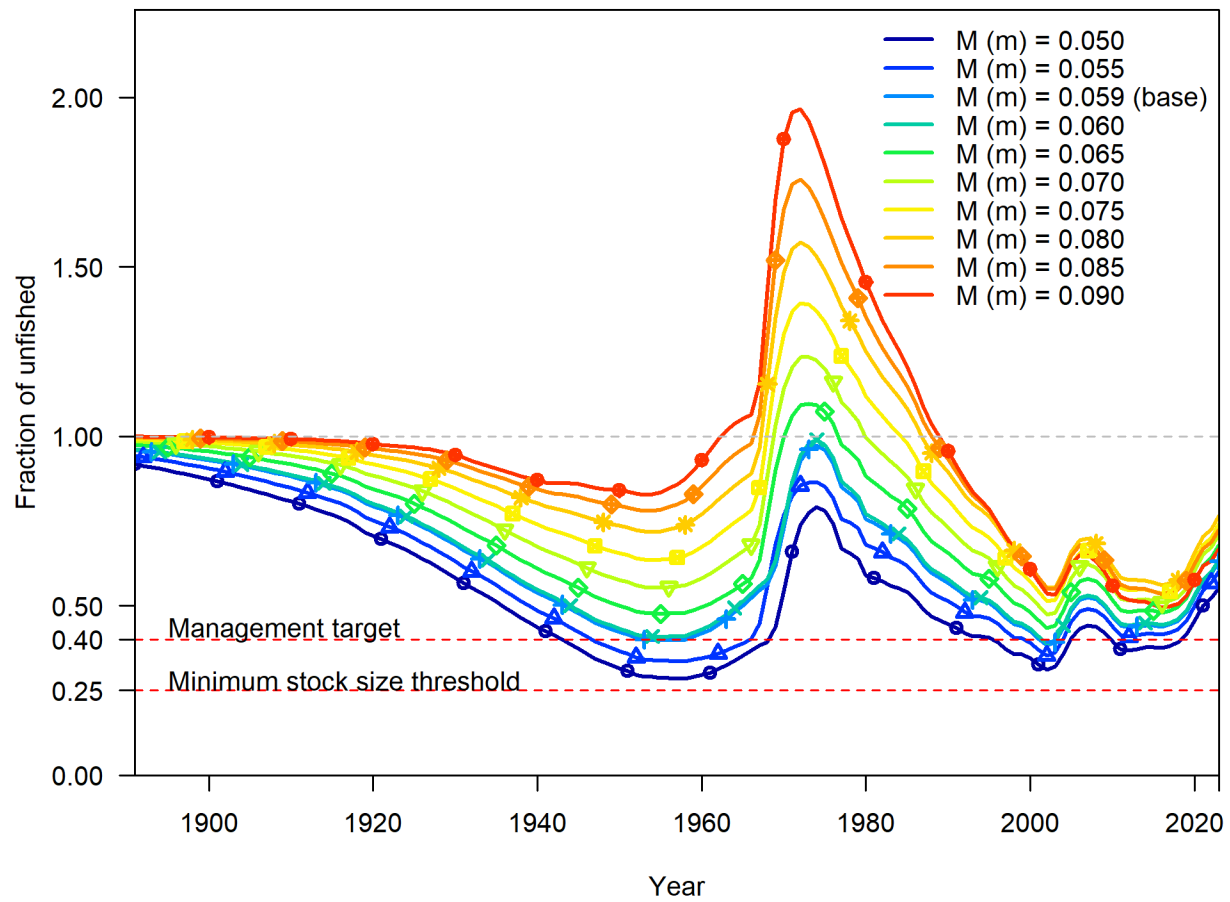
Figure 90: Change in the fraction unfished across a range of male natural mortality values. .
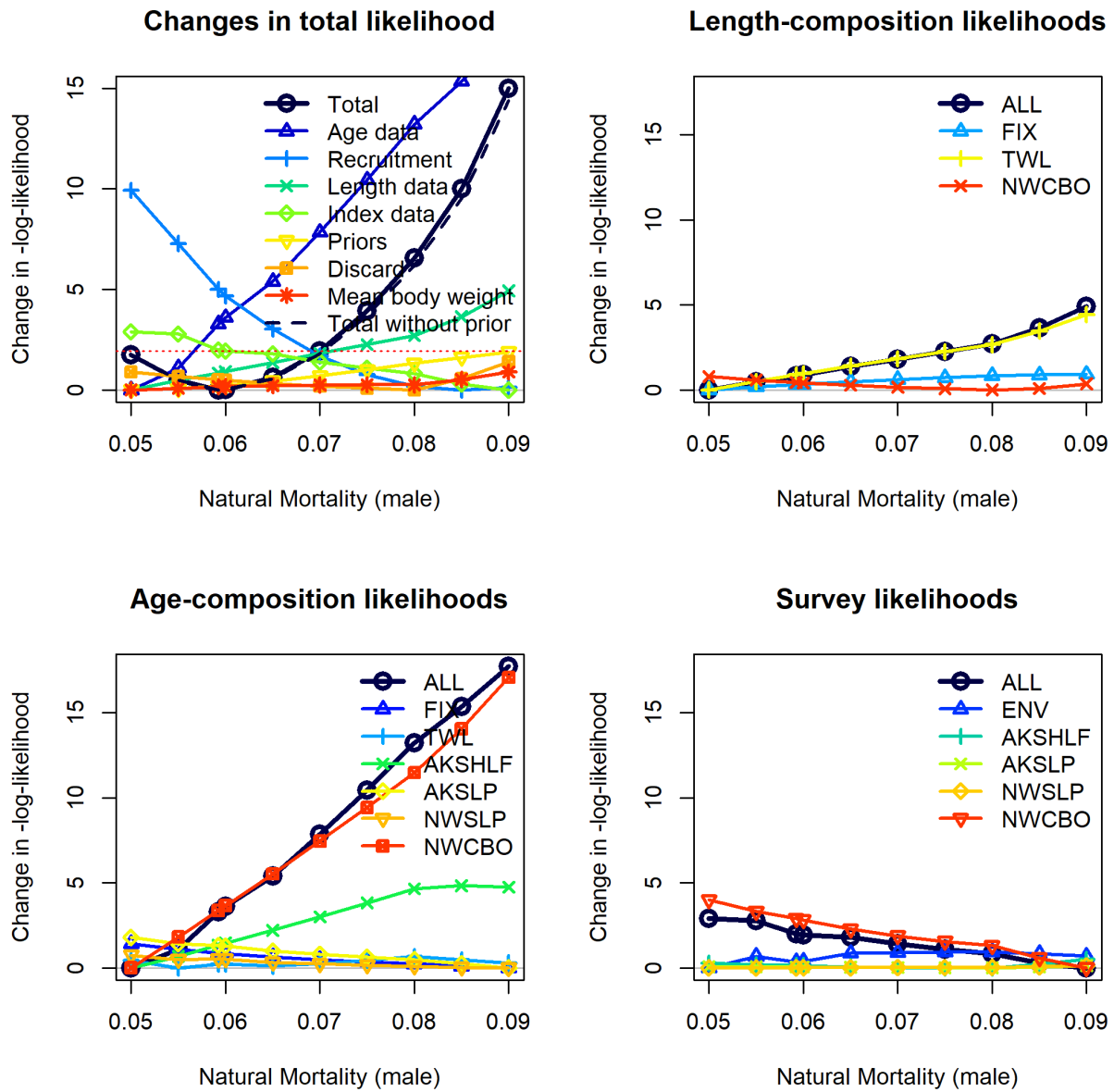
Figure 91: Change in the negative log-likelihood across a range of male natural mortality values. Fixed Gear = FIX, Trawl = TWL, Env. Index = ENV, Triennial = AKSHLF, AK Slope = AKSLP, NWFSC Slope = NWSLP, and WCGBTS = NWCBO.
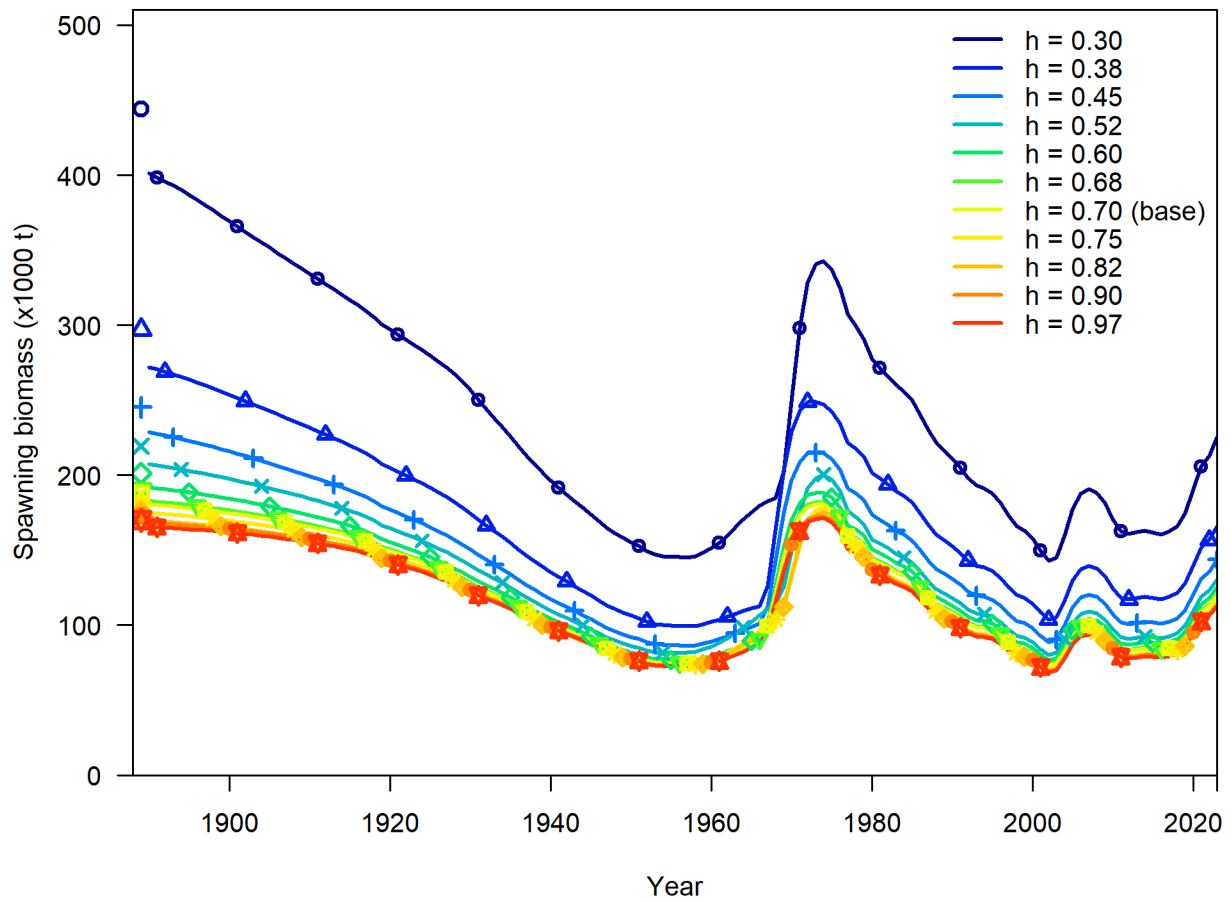
Figure 92: Change in the spawning biomass across a range of steepness values. .
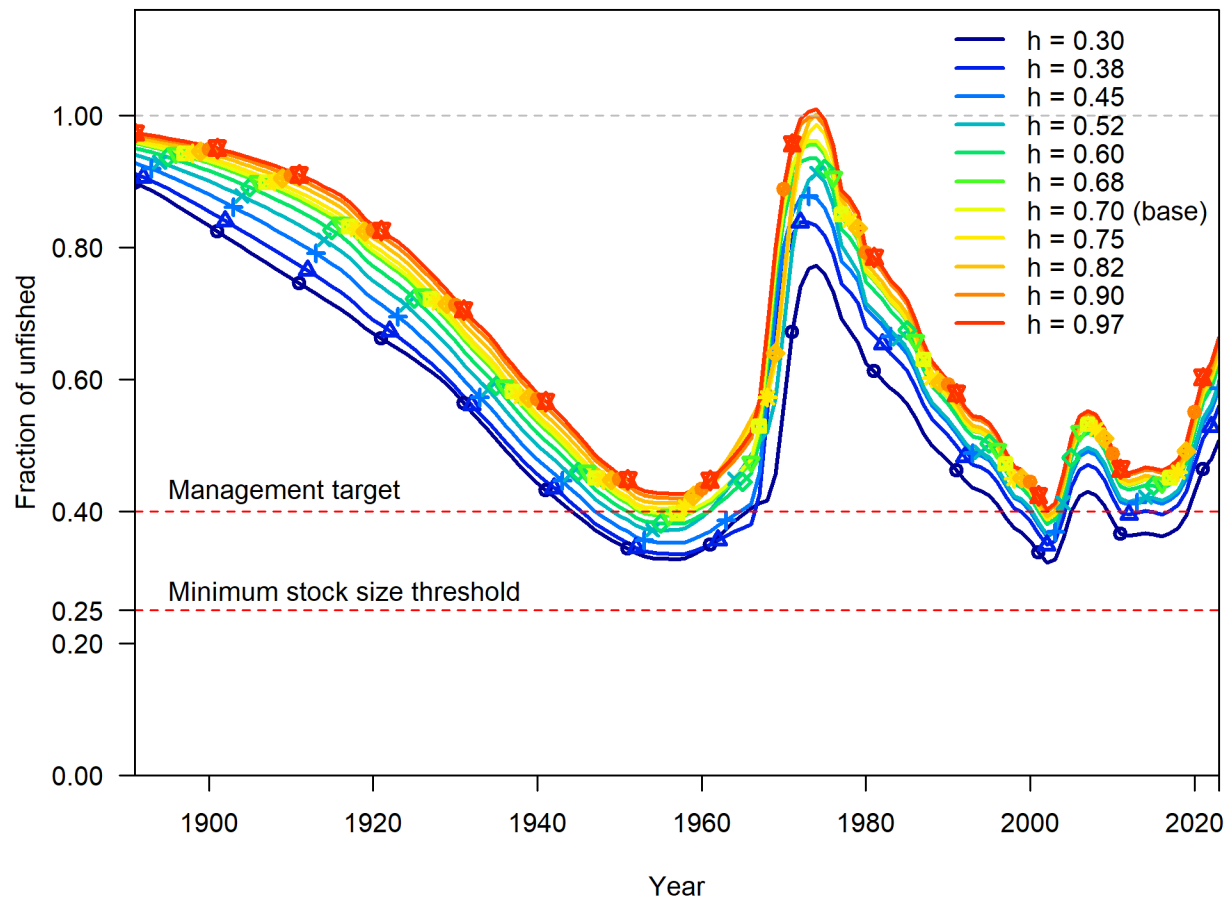
Figure 93: Change in the fraction unfished across a range of steepness values. .

Figure 94: Change in the negative log-likelihood across a range of steepness values. Fixed Gear = FIX, Trawl = TWL, Env. Index = ENV, Triennial = AKSHLF, AK Slope = AKSLP, NWFSC Slope = NWSLP, and WCGBTS = NWCBO.

**Figure 95:** Change in the spawning biomass across a range of natural log of unfished recruitment values. .
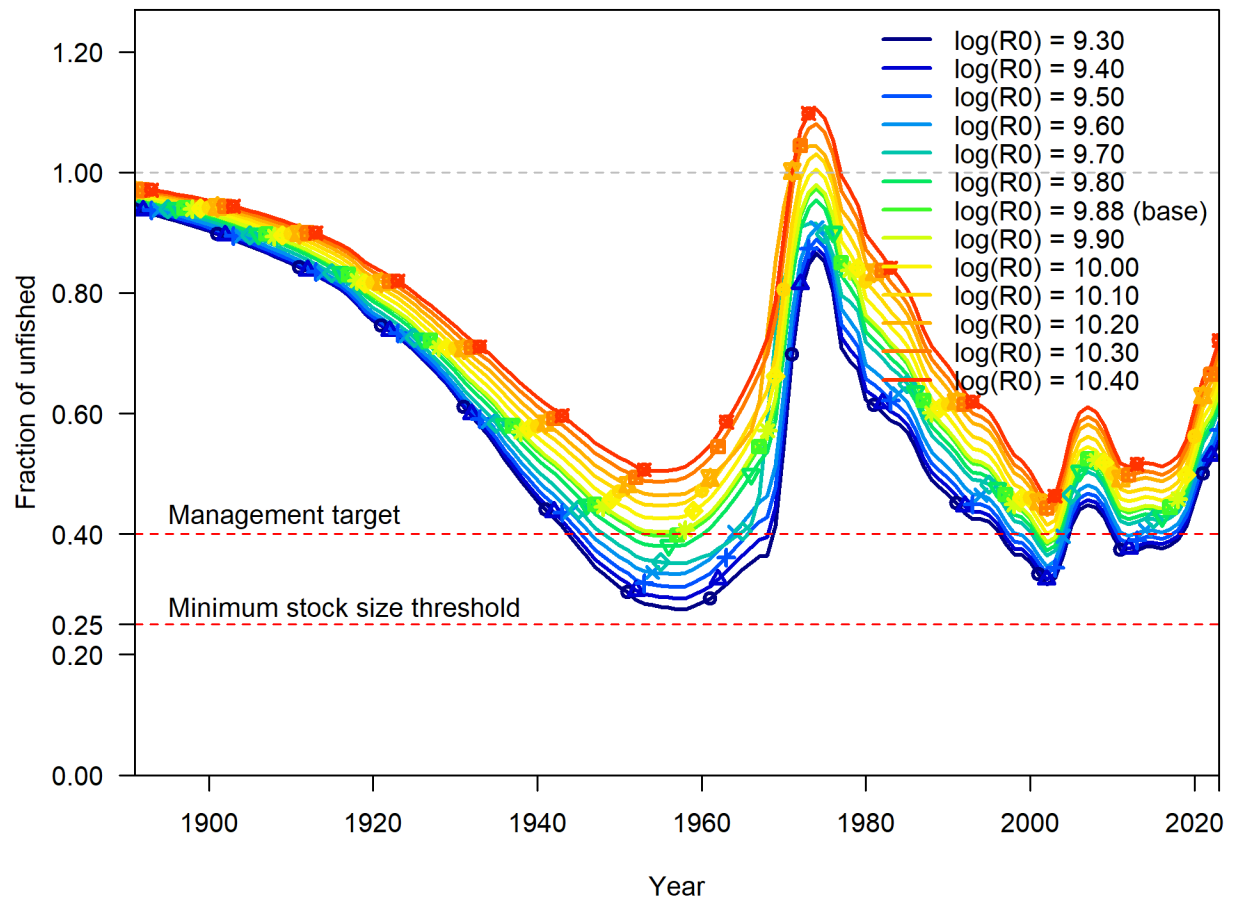
Figure 96: Change in the fraction unfished across a range of natural log of unfished recruitment values. .
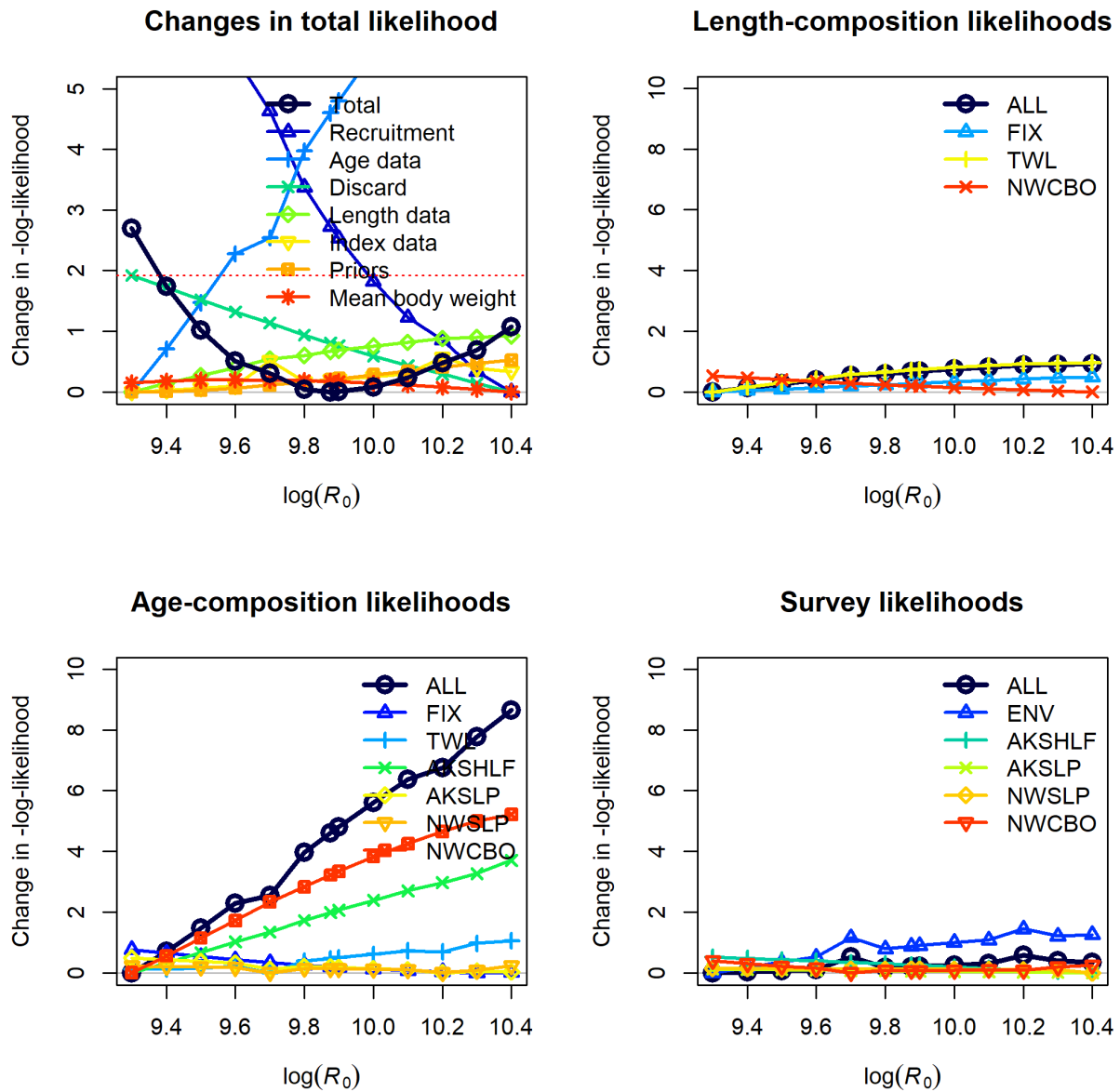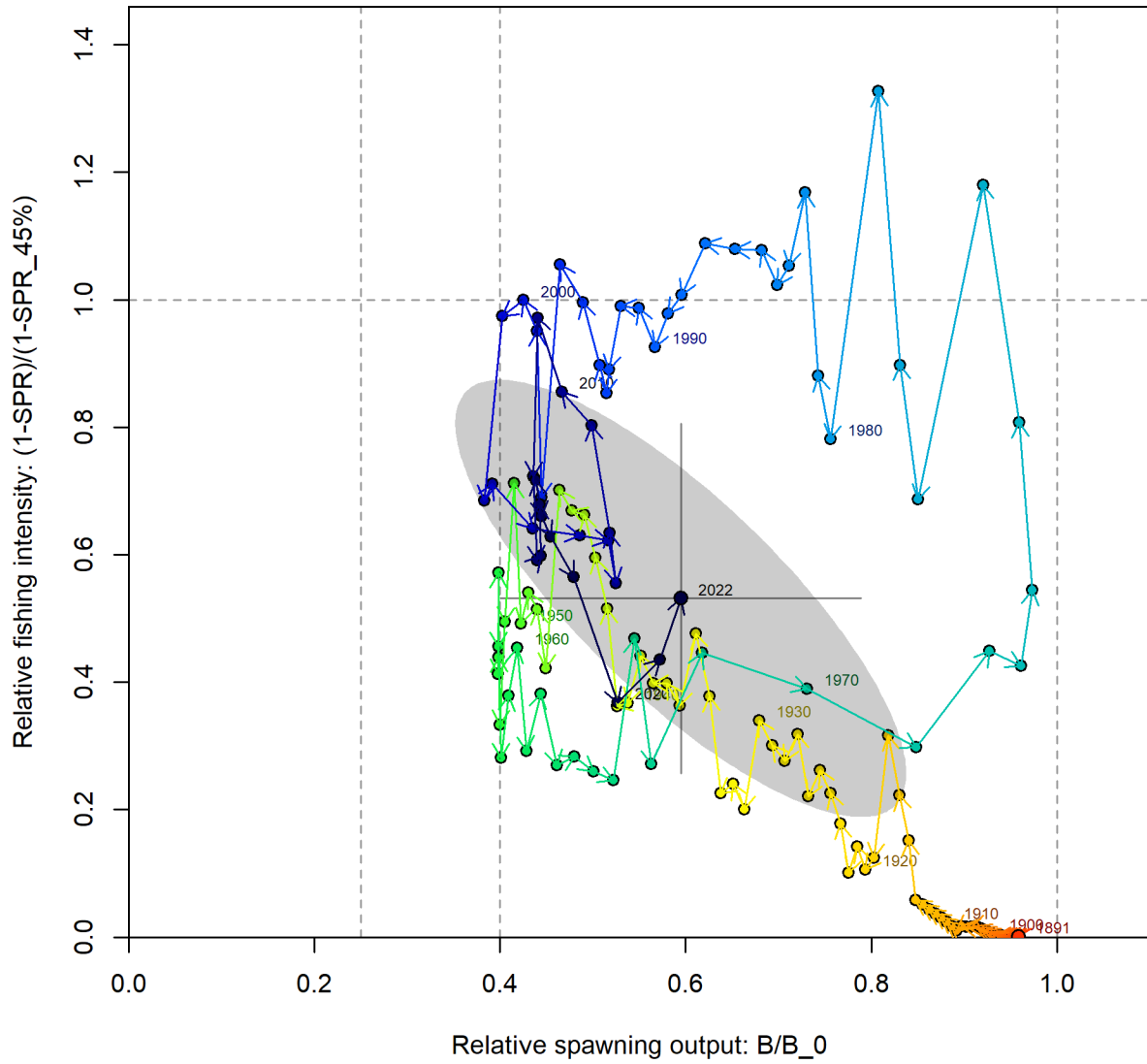
Figure 97: Change in the negative log-likelihood across a range of natural log of unfished recruitment values. Fixed Gear = FIX, Trawl = TWL, Env. Index = ENV, Triennial = AKSHLF, AK Slope = AKSLP, NWFSC Slope = NWSLP, and WCGBTS = NWCBO.

8.3 Reference Points and Projections
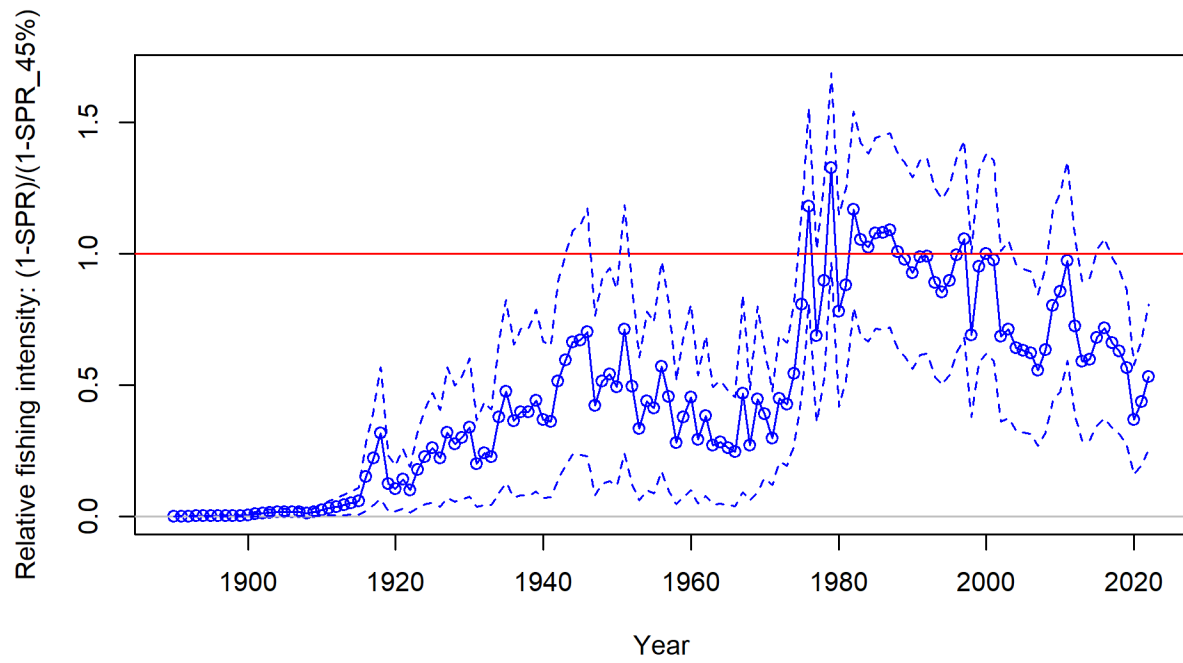
Figure 98: Time series of fishing intensity which is $\frac{1-SPR}{1-SPR_{45\%}}$ where SPR is spawning potential ratio.

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.
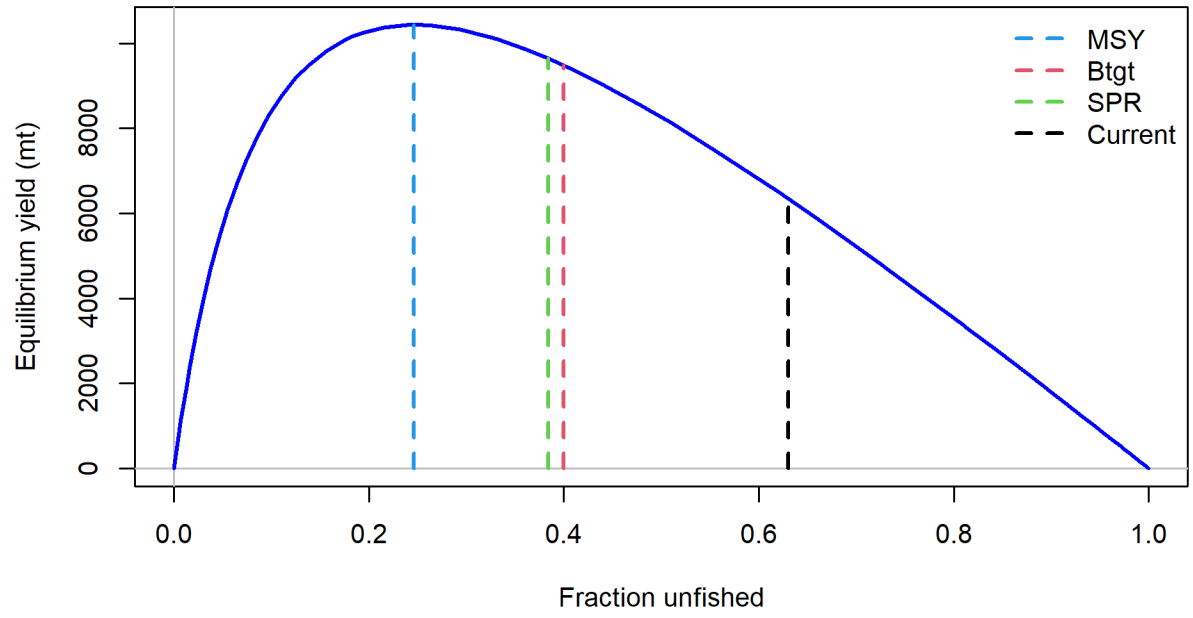
Figure 100: Yield curve with reference points.