Status of Canary Rockfish (*Sebastes pinniger*) along the U.S. West Coast in 2023

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One-page summary

- This assessment reports the status of canary rockfish (*Sebastes pinniger*) off the U.S. West Coast using data through 2022.
- Canary rockfish is a long-lived shelf rockfish caught primarily north of Point Conception in commercial trawl, commercial non-trawl, and recreational fisheries.
- The most recent full stock assessment was conducted in 2015. Catch-only projections were conducted in 2017, 2019, and 2021.
- Canary rockfish have an unusual pattern in sex ratio, where the percent of fish that are female decreases rapidly starting around age 20. The cause for this pattern is unknown and could be because females experience higher mortality rates, move into habitat inaccessible to fishing gear, some combination of the two, or something different altogether.
- The major changes to this assessment compared to the previous benchmark assessment are:
  - Data were reanalyzed and extended to 2022.
  - This model estimates separate female and male natural mortality rates that are constant across ages, and separate selectivity by sex for larger fish. This is in contrast to the 2015 model, which estimated separate natural mortality only for older females, and assumed the same selectivity between sexes.
  - This model estimates coastwide recruitment deviations. The 2015 assessment estimated additional spatial recruitment deviations by state.
  - This model estimates separate selectivity curves for fishing fleets by state. The 2015 model assumed selectivity was the same along the coast.
  - The method for weighting data from different sources has been aligned with current standard practices.
- The model estimates recovery from the population's low abundance in 1995 to be slower than was estimated in the 2015 assessment, but more similar to estimates from earlier assessments. The change from the 2015 model is primarily due to different assumptions regarding natural mortality and current data weighting practices on the updated data.
- Current depletion (spawning output relative to unfished spawning output) in 2023 is 0.351, and is in the "precautionary zone" between the target of 0.4 and the limit of 0.25.
- The estimate of recent fishing intensity (measured as 1-spawning potential ratio) in 2022 is 0.469, and is close to the reference point of 0.5.

Executive summary

Stock

This assessment reports the status of canary rockfish (*Sebastes pinniger*) off the U.S. West Coast using data through 2022. The stock of canary rockfish was modeled as a single coastwide population. While canary rockfish are modeled as a single population, spatial aspects are addressed through geographic separation of data sources/fleets where possible. There is currently no genetic evidence suggesting distinct biological stocks of canary rockfish off the U.S. West Coast. This assessment does not account for populations located in Canadian or Mexican waters and assumes that these northern and southern populations do not contribute to nor take from the population being assessed here.

Catches

Canary rockfish is caught in both commercial and recreational fisheries off the U.S. West Coast, with the majority of catches coming from commercial sources (Figure i). The rockfish fishery off the U.S. West Coast developed off California late in the 19th century and was catching an average of almost 2,500 metric tons per year over the period 1916-1940 (with an increase in catches in 1916, during World War I). To the north, the rockfish fishery developed slowly and became established during the early 1940s, when the United States became involved in World War II and wartime shortages of red meat created an increased demand for other sources of protein. Catches of canary rockfish increased considerably during this period. Canary rockfish catches dropped somewhat following the war, and were generally stable from the 1950s to the 1960s. In 1977, when the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) was enacted, the large foreign-dominated rockfish fishery that had developed since the late 1960s had its catches eliminated, and the domestic trawl fishery subsequently increased its catches. The trawl fishery reached a peak for canary rockfish in the early 1980s (1982: 5,155 mt) and subsequently decreased after the establishment of strict management restrictions starting in the mid-1990s. The decrease in the trawl fishery allowed the recreational and non-trawl fisheries to take a larger proportion of total catch of canary rockfish beginning in the 2000s. Following the removal of the overfished designation in 2015, catches of canary rockfish increased considerably, though to levels well below those seen during much of the period of industrial fishing. Today, most catch of canary rockfish still occurs in the trawl fishery (particularly in a growing midwater trawl fleet), though there is a sizable recreational component of landings as well (Table i).

Table i: Summary of total removals (mt) by fleet (TWL = trawl, NTWL = non-trawl, Rec = recreational, ASHOP = at-sea hake) over the last ten years. Removals from the foreign and CA ASHOP fleets are not shown because they did not have removals within the last ten years. Dead discards are included with landings for each fleet, so total removals and total dead catch are equivalent.

Year	CA TWL	OR TWL	WA TWL	CA NTWL	OR NTWL	WA NTWL	CA Rec	OR Rec	WA Rec	OR ASHOP	WA ASHOP	Total Dead
2013	1.5	6.1	4.6	6.4	2.8	3.3	14.8	4.0	1.0	0.1	0.6	45.0
2014	2.0	10.3	2.2	4.4	1.8	6.0	22.4	3.0	1.4	0.4	0.3	54.1
2015	7.0	41.1	4.0	5.2	3.2	9.6	26.9	14.3	2.2	0.1	0.1	113.7
2016	2.8	17.0	5.0	3.1	6.7	5.1	23.7	9.8	1.9	0.2	0.3	75.6
2017	75.3	148.1	37.3	7.2	5.7	3.3	83.4	28.2	4.6	1.8	4.8	399.7
2018	139.7	173.9	156.3	7.5	4.4	2.2	61.8	43.6	3.9	3.0	2.5	598.7
2019	176.2	194.5	65.4	10.6	6.2	1.7	71.4	38.7	11.9	0.7	4.3	581.8
2020	73.7	186.6	78.9	18.6	7.5	3.0	76.7	60.6	7.3	0.2	0.7	513.7
2021	78.5	223.5	73.6	25.6	6.6	1.4	73.0	38.6	32.2	3.2	2.7	558.7
2022	90.1	315.3	102.4	22.5	11.0	0.9	62.6	55.6	34.2	4.2	1.5	700.4

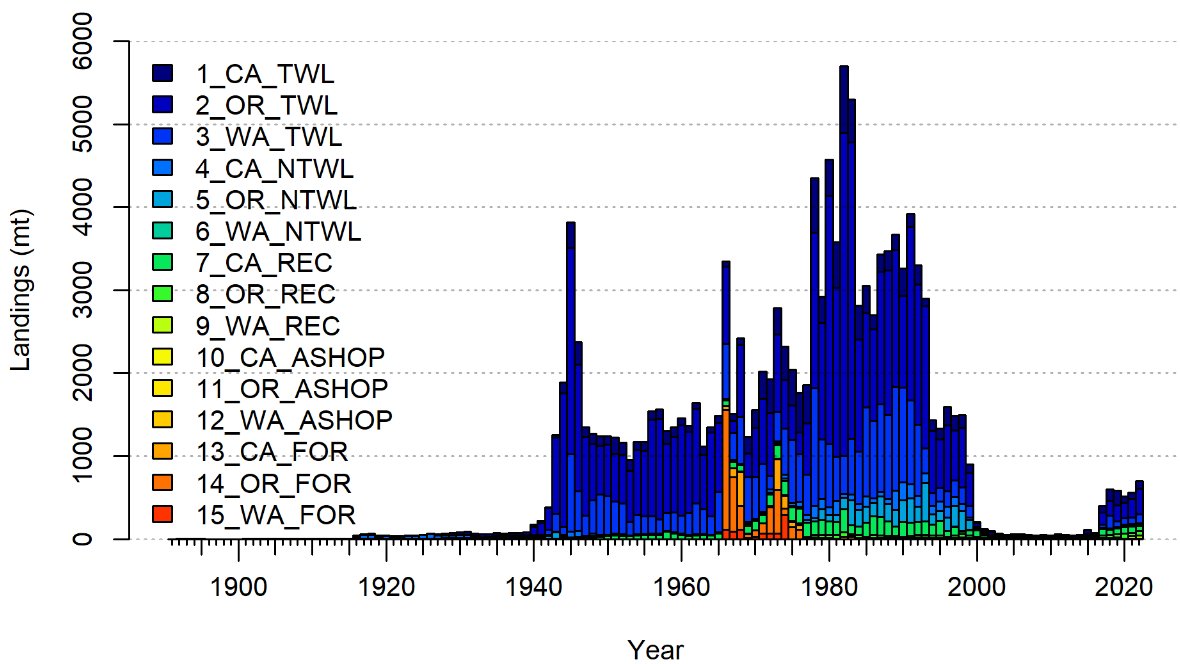

Figure i: Total removals of canary rockfish over full assessment period by fleet (TWL = trawl, NTWL = non-trawl, Rec = recreational, ASHOP = at-sea hake, FOR = foreign).

Data and assessment

Canary rockfish was most recently assessed in 2015 using an age-structured population model that allowed for spatial differences in recruitment deviations and depletion by state. The current assessment uses an areas-as-fleets approach to account for different sizes and ages of fish available in each state, but returns to a coastwide population model configuration.

This assessment uses the stock assessment framework Stock Synthesis (SS3; version 3.30.21). The assessment model is a two-sex age-structured model operating on an annual time step covering the period 1892 to 2022, with a twelve-year projection, and assumes an unfished population prior to 1892. Population dynamics are modeled for ages 1 through 35, with age 1 including dynamics for age 0, and age 35 being the accumulator age. The model also allows for differences in selectivity between sexes.

This assessment includes updated total removals (dead discards plus landings) from five fleets (commercial trawl, non-trawl, foreign, at-sea hake, and recreational), each of which is divided across three states; fishery-independent indices from the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS), AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey), and a pre-recruit survey; and age and length data from the fishery and the WCGBTS and Triennial Survey. It extends all of these data sets from the previous assessment through 2022, and also includes any updates to previously used data.

Growth is assumed to follow the von Bertalanffy growth model, and the assessment explicitly estimates all parameters describing somatic growth. Recruitment dynamics are assumed to follow the Beverton-Holt stock-recruit function, and recruitment deviations are estimated. In addition, this assessment includes a maturity curve based on newly analyzed ovaries; updated biological relationships for fecundity, steepness, and mortality; and new assumptions on the modeling of natural mortality.

Model uncertainty is explicitly included in this assessment by parameter estimation uncertainty. Model specification uncertainty is explored through sensitivity analyses addressing alternative input assumptions such as data treatment and weighting, and treatment of life history parameters, selectivity, and recruitment. Base models were selected that best fit the observed data while balancing the desire to capture the central tendency across sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model mis-specification.

Stock biomass and dynamics

The base model estimate of spawning output in millions of eggs is estimated to be 8009. It declined to a minimum of 487 million eggs in 1995. Since 1995 the stock is estimated to have recovered at a positive but recently slowing rate to a recent peak of 2809 million eggs in 2023. In terms of spawning output relative to unfished levels, the minimum was 0.061, also reached in 1995, and the current 2023 estimate is 0.351 (Table ii, Figures ii and iii).

Table ii: Spawning output (millions of eggs) and fraction of unfished spawning output for the last ten years. Upper and lower confidence intervals are 2.5 percent and 97.5 percent, respectively.

Year	Spawning Output	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2013	2136.39	1586.79	2685.99	0.27	0.21	0.32
2014	2262.34	1685.71	2838.97	0.28	0.22	0.34
2015	2386.05	1783.11	2988.99	0.30	0.24	0.36
2016	2497.02	1869.79	3124.25	0.31	0.25	0.38
2017	2603.03	1953.69	3252.37	0.33	0.26	0.39
2018	2674.36	2004.74	3343.98	0.33	0.27	0.40
2019	2715.07	2026.70	3403.44	0.34	0.27	0.41
2020	2749.66	2043.61	3455.71	0.34	0.27	0.41
2021	2784.46	2061.05	3507.87	0.35	0.28	0.42
2022	2808.02	2067.01	3549.03	0.35	0.28	0.42
2023	2808.87	2050.19	3567.55	0.35	0.28	0.42

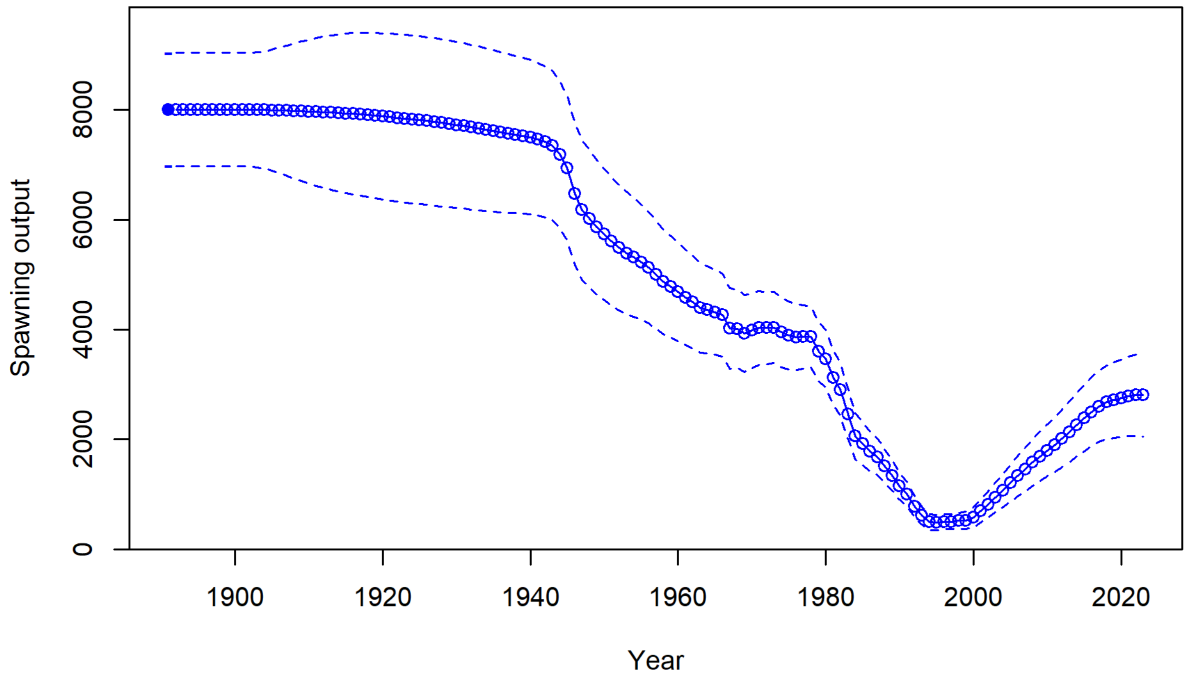

Figure ii: Estimate of spawning output (millions of eggs) over full assessment period. Dashed lines cover 95 percent confidence interval.

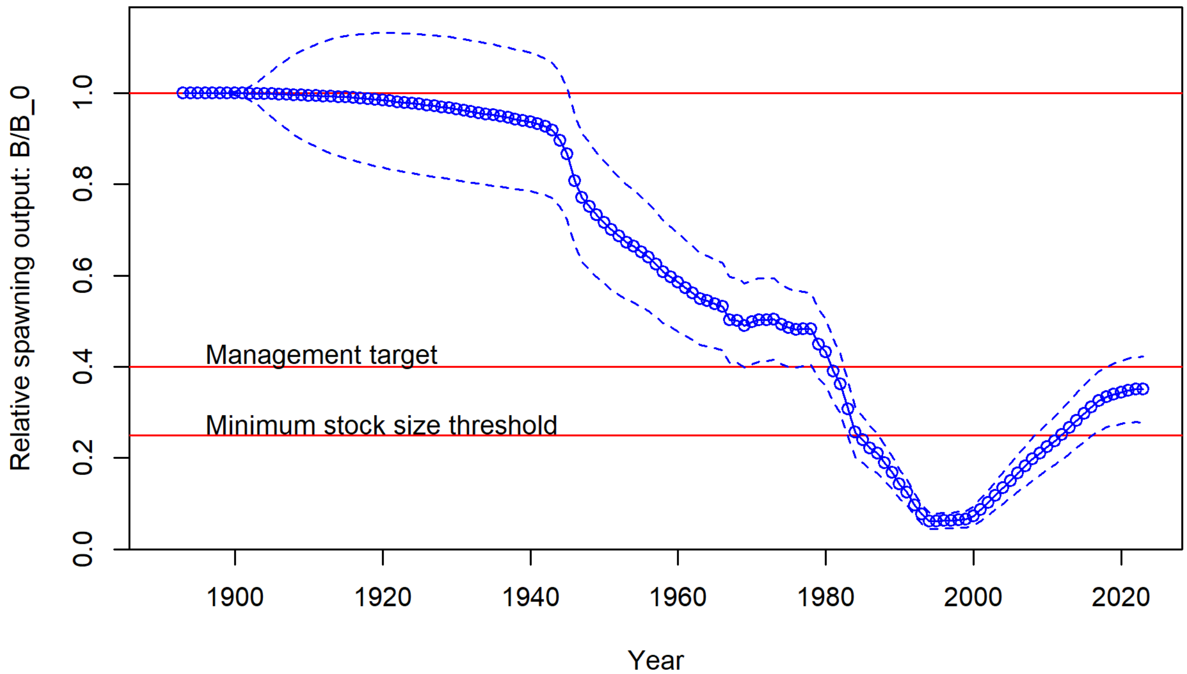

Figure iii: Estimate of spawning output relative to unfished over full assessment period. Dashed lines cover 95 percent confidence interval.

Recruitment

Recruitment dynamics (Table iii, Figures iv and v) are assumed to follow a Beverton-Holt stock-recruit function and the steepness parameter was fixed at the value of 0.72, which is the mean of steepness prior probability distribution. The level of virgin recruitment ($\ln(R_0)$) is estimated to inform the magnitude of the initial stock size. Annual recruitment is treated as stochastic with 'main' recruitment deviations estimated for 1960–2022 and 'early' deviations for 1892–1959.

The recruitment time series is punctuated by a large recruitment event in 1968, following by a generally declining trend until the 2000s where recruitment varies around a relatively stable average. Among recent years, large events occurred in 2003, 2007, 2013, and 2021–2022, as well as in 2023 where recruitment was pulled from the stock-recruit curve. The 1968 recruitment was estimated at about 6 million age-0 recruits while the latter six were around 3 million. Recent (since 2000) recruitment has averaged around 2.1 million recruits. Recruitment follows a cyclical pattern since 2000 but has more often had deviations below the average (negative recruitment deviations) than above the average.

Table iii: Estimates of recruitment (1000s of fish) and recruitment deviations over last ten years with 95 percent confidence interval

Year	Recruitment	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2013	2880.70	2141.07	3875.83	0.08	-0.14	0.30
2014	1538.69	1074.34	2203.74	-0.56	-0.86	-0.26
2015	1506.96	1039.05	2185.58	-0.60	-0.91	-0.28
2016	1943.69	1358.40	2781.17	-0.35	-0.65	-0.06
2017	973.78	618.12	1534.08	-1.06	-1.46	-0.65
2018	926.82	549.61	1562.91	-1.11	-1.60	-0.62
2019	1812.21	914.58	3590.84	-0.44	-1.12	0.23
2020	2234.81	914.62	5460.59	-0.24	-1.16	0.69
2021	3199.87	1408.69	7268.58	0.07	-0.77	0.91
2022	2825.14	1114.56	7161.05	-0.11	-1.08	0.86
2023	3149.97	1237.02	8021.15	0.00	-0.98	0.98

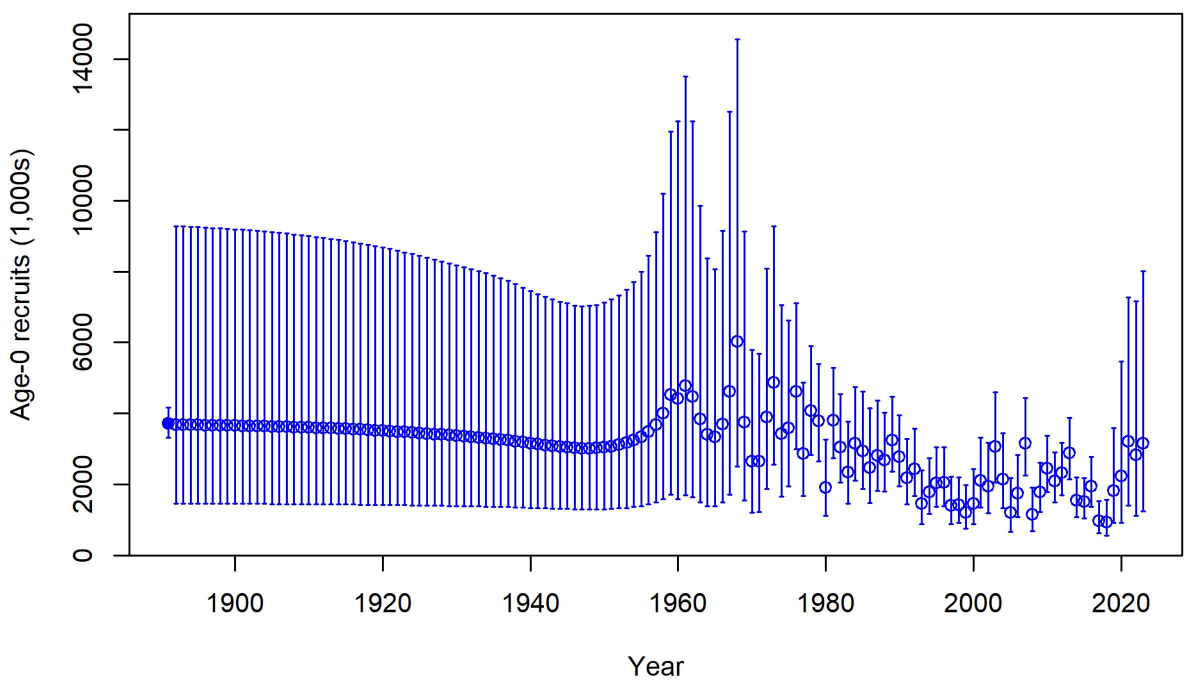

Figure iv: Estimate of age-0 recruitment (1000s of fish) over full assessment period. Bars represent 95 percent confidence intervals.

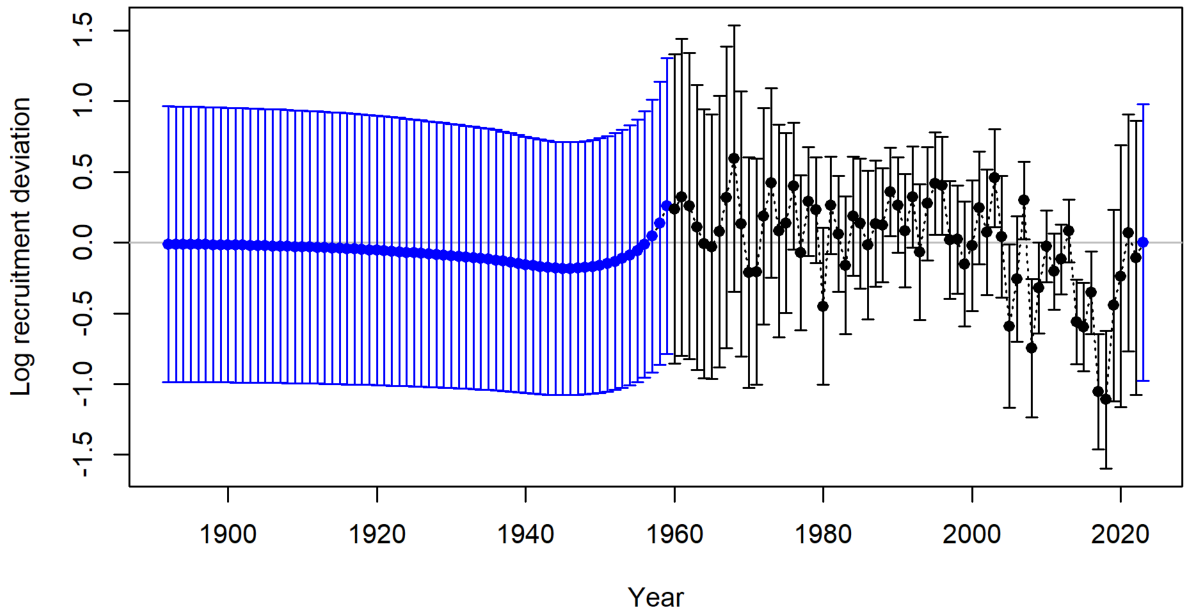

Figure v: Estimate of multiplicative devations from stock-recruit relationship (recruitment deviations) over full assessment period. Bars represent 95 percent confidence intervals. Blue points are early and forecast recruitment deviations, while black points are for the main period.

Exploitation status

There are two measures of exploitation status (Table iv). The target harvest rate is determined by 1-SPR or "fishing intensity." SPR is the spawning potential ratio, or percent of unfished spawning output that would result at equilibrium from fishing at a given rate. Because the target is based on 1-SPR, a value of 0 means no fishing is occurring (at equilibrium, unfished spawning output would result from fishing at the current rate), and a value of 1 means at equilibrium all spawning fish would be killed before spawning, and the population would collapse. The second measure is the exploitation rate, or total dead catch divided by total age 5+ biomass.

Fishing intensity rose from zero to consistently near the target starting around 1950, and then rose from the target starting in the 1970s towards 1.0 (Figure vi). Intensity remained slightly below 1.0 from 1980 to the mid-1990s as the population rapidly depleted. Exploitation rates dropped dramatically in 2000 with the overfished designation, and the population has been slowly increasing since. Exploitation rates rose again in 2017 and are currently close to target levels. Spawning output remains slightly below the target, indicating additional yield may be possible if the population further increases.

Table iv: Estimates of 1-SPR (spawning potentital ratio) and exploitation rate over last ten years with 95 percent confidence interval.

Year	1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2013	0.05	0.04	0.06	0.00	0.00	0.00
2014	0.06	0.04	0.07	0.00	0.00	0.00
2015	0.11	0.08	0.13	0.00	0.00	0.01
2016	0.07	0.06	0.09	0.00	0.00	0.00
2017	0.29	0.23	0.34	0.01	0.01	0.02
2018	0.39	0.31	0.46	0.02	0.02	0.03
2019	0.38	0.31	0.46	0.02	0.02	0.03
2020	0.36	0.29	0.44	0.02	0.01	0.02
2021	0.39	0.31	0.47	0.02	0.01	0.02
2022	0.47	0.38	0.56	0.03	0.02	0.03

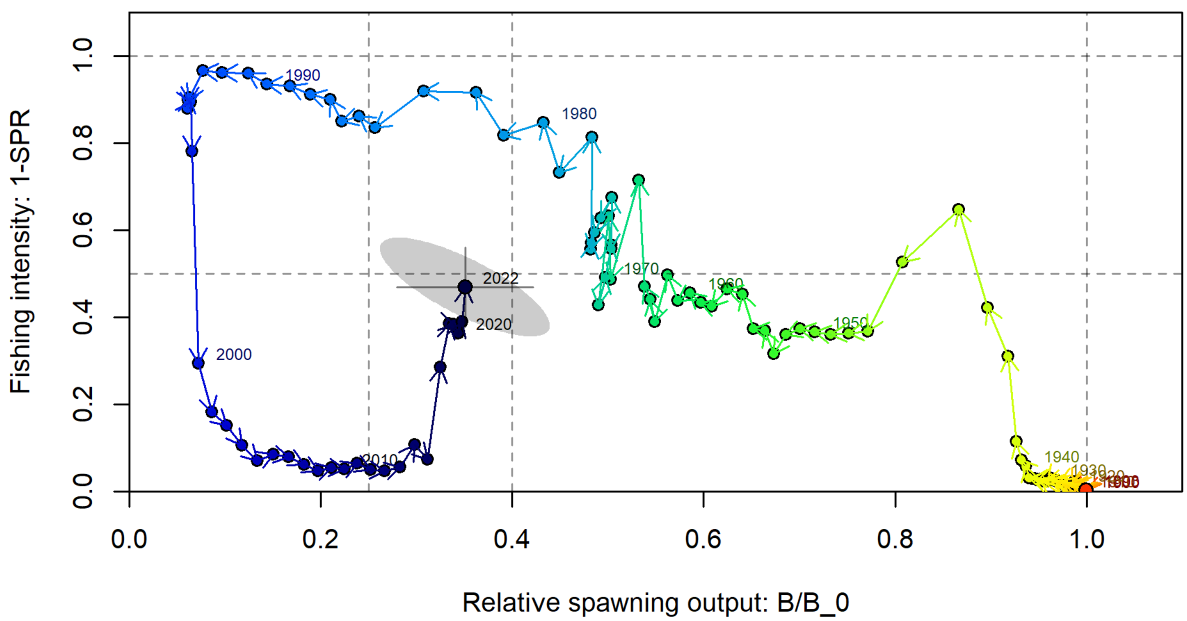

Figure vi: Estimates of 1-SPR (spawning potential ratio, i.e., fishing intensity) versus spawning output relative to unfished level for full time series. Vertical dashed lines are at 0.25 (limit), 0.4 (target), and 1 (unfished level). Horizontal dashed lines are at 0.5 (target) and 1 (population cannot persist in equilibrium). Arrows point in chronological direction with red to yellow colors representing years early in the assessment period and dark blue representing present-day. Gray oval is 95 percent confidence ellipse for joint distribution of depletion and fishing intensity in terminal model year (2022), with solid gray vertical and horizontal lines representing 95 percent confidence interval of each quantity individually.

Ecosystem considerations

Although ecosystem factors have not been explicitly modeled in this assessment, there are several important aspects of the recent California current ecosystem that appear to warrant consideration. Lingcod (*Ophiodon elongatus*), a potentially important predator of small canary rockfish, have increased over the last two decades. To the extent that the component of natural mortality of canary rockfish added by predation from lingcod and other predators has been increasing over recent years, recruitment may be underestimated. This effect could also lead to longer than predicted recovery times for canary rockfish. Conversely, Pacific salmon are known to consume young canary rockfish, and their populations have generally declined in recent years. Canary rockfish recruitment, growth, and condition have all been found to be associated with the Pacific Decadal Oscillation (PDO), as well as other basin-scale indices. However, relationships between productivity of fish populations with non-mechanistic basin-scale indicators such as the PDO have been degrading in recent years due to climate change, so these relationships may not be reliable predictors moving forward. According to a recent California Current climate vulnerability analysis that ranked species on a scale of low, moderate, high, and very high, canary rockfish have high exposure and high sensitivity to climate change, similar to most rockfish. The prevalence of a strong 1999 year-class for many west coast groundfish species suggest that environmentally driven recruitment variation may be correlated among species with relatively diverse life-history strategies. Much research is currently underway to explore these phenomena, and it appears likely that more explicit exploration of ecosystem processes and influences may be able to be incorporated into management both within and outside of future canary rockfish stock assessments.

Reference points

The management target for canary rockfish is 40% of unfished spawning output, or SO40%. This is associated with an annual exploitation rate of 0.0325 yr^{-1} (95% confidence interval, 0.0314-0.0336) and yield of 1152 mt (1018-1286). The target fishing intensity is SPR=0.5, which leads to an equilibrium spawning output of 3573 million eggs (3121-4025). Table v contains a full list of model estimates and 95% confidence intervals of target spawning output, target 1-SPR, target exploitation rate, and target yield for targets based on spawning depletion (SO40%), 1-SPR (SPR50), and the model estimate of MSY (maximum sustainable yield), as well as key population quantities at unfished levels and their current values.

Table v: Summary of reference points and management quantities, including estimates of 95 percent confidence intervals

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output (millions of eggs)	8008.63	6996.09	9021.17
Unfished Age 5+ Biomass (mt)	75272.70	67024.76	83520.64
Unfished Recruitment (R0)	3716.87	3296.97	4136.77
Spawning Output (millions of eggs) (2023)	2808.87	2050.19	3567.55
Fraction Unfished (2023)	0.35	0.28	0.42
Reference Points Based SO40%			
Proxy Spawning Output (millions of eggs) SO40%	3203.45	2798.43	3608.47
SPR Resulting in SO40%	0.46	0.46	0.46
Exploitation Rate Resulting in SO40%	0.03	0.03	0.03
Yield with SPR Based On SO40% (mt)	1151.99	1018.02	1285.96
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (millions of eggs) (SPR50)	3573.08	3121.33	4024.83
SPR50	0.50		
Exploitation Rate Corresponding to SPR50	0.03	0.03	0.03
Yield with SPR50 at SO SPR (mt)	1093.67	966.45	1220.89
Reference Points Based on Estimated MSY Values			
Spawning Output (millions of eggs) at MSY (SO MSY)	2063.47	1797.25	2329.69
SPR MSY	0.33	0.33	0.33
Exploitation Rate Corresponding to SPR MSY	0.05	0.05	0.05
MSY (mt)	1246.13	1101.31	1390.95

Management performance

Total mortality of canary rockfish is generally well below the annual catch limit (Table vi). However, for catch limits in 2013–2016 the stock was in an overfished designation. During that time, attainment averaged around 60%. In 2015 the full annual catch limit (ACL) was nearly achieved (93% attainment). Beginning in 2017, the ACL increased more than tenfold with the lifting of the overfished designation. Since that time, catches have increased and attainment has averaged around 40%.

Table vi: The OFL (overfishing limit), ABC (allowable biological catch), ACL (annual catch limit), and total mortality (landings + dead discards), all in units of metric tons

Year	OFL	ABC	ACL	Total Mortality
2013	752	719	116	45.00
2014	741	709	119	54.09
2015	733	701	122	113.69
2016	729	697	125	75.61
2017	1793	1714	1714	399.66
2018	1596	1526	1526	598.69
2019	1517	1450	1450	581.78
2020	1431	1368	1368	513.68
2021	1459	1338	1338	558.68
2022	1432	1307	1307	700.36

Unresolved problems and major uncertainties

The major uncertainty in this assessment is treatment of natural mortality. This issue has been a long-standing uncertainty for canary rockfish assessments, and remains so. This uncertainty arises from observations in survey and fishery data that age-based sex-ratios are male skewed starting around age 20. This could be explained by females being less susceptible to capture, or to fewer females in the population, or to some combination of both. No refugia for old females has been found thus far suggesting mortality may be a more probable culprit, however sex ratios within Oregon fishery data have been nearer to equal in the last decade. Regardless, there is uncertainty on how best to model this dynamic.

The choice of how to model natural mortality matters. Assuming fixed sex-specific age-invariant natural mortality results in a more pessimistic outlook because natural mortality for females is fixed at the lower prior (0.0643) value. If natural mortality is age-dependent, female natural mortality is estimated to be higher at older ages, and the magnitude of the value increases with the age at which the break in natural mortality occurs. A higher natural mortality estimate results in a more optimistic population trajectory that increases dramatically in the 2000s from low abundance in the late 1990s. Modeling selectivity as sex-dependent, as in the base model, reflects a middle ground in the estimate of natural mortality, in that age-invariant estimates between males and females differ by 20 percent (with females higher), while avoiding the less common biological assumption that natural mortality increases with age. However, applying sex-dependent selectivity results in larger females having greater selectivity values than males, which would seem to be opposite to treatments in past assessments for explaining the male-skewed sex ratio due to older females being less susceptible to capture. Assuming no sex-dependent selectivity results in a worse fitting model, and also has a different population outlook in that natural mortality for females is estimated lower than the prior estimate (0.055) while high recruitment in recent years results in a greater population increase than would be expected under such a low natural mortality estimate under average recruitment deviations.

A challenge with the current base model is that it is highly parameterized with many correlations between parameters above 0.8, including some parameters with correlations as high as 0.97. Earlier versions of the model suggested a flat likelihood surface. Although the current base model is more stable due to simplifications to the Washington recreational and Oregon non-trawl selectivity blocks, the number of selectivity parameters and correlations among them indicate additional simplification may be warranted. Simplifying the number of selectivity parameters by reducing the number of time-varying blocks degrades model fit by a large degree and does not appear to be a solution for reducing model complexity. Modeling selectivity as a three parameter double-normal reduces correlation in parameters compared to a four parameter formulation, however modeling sex-dependent selectivity reintroduces a fourth selectivity parameter. Alternative forms for modeling selectivity and continued explorations into ways to model processes that lead to high male sex ratios in older ages may help reduce parameter correlations, and limit concerns about potential over-parameterization.

Decision table and projections

The 2023 stock assessment for canary rockfish off the U.S. West Coast was assigned a category 1 determination by the Scientific and Statistical Committee to the Pacific Fishery Management Council (PFMC). A ten-year projection of the base model with catches equal to the estimated ACL based on the category 1 time-varying σ (0.5) with either $P^* = 0.45$ or $P^* = 0.40$ (i.e., termed the "buffer") for years 2025-2034 is shown in Tables vii–viii. The removals in 2023 and 2024 were set equal to the recommended fleet-specific values as provided by the Groundfish Management Team (GMT). At the end of the projection period, 2034, the projected ACL removals for the default harvest control rule ($P^* = 0.45$) result in spawning output relative to unfished to be 33.1 percent.

The axis of uncertainty in the decision table is based on the uncertainty around natural mortality. Alternative structural assumptions around natural mortality were used to identify the low and high states of nature, where the base model is assigned a 50 percent probability of being the true state of nature and both the low and high states of nature are assigned a 25 percent probability. The alternative states of nature were based on the M ramp (high state) and single M (low state) sensitivity runs. The proposed decision table assumes full ACL removal during the projection period under alternative catch streams based on a $P^* = 0.45$ and $P^* = 0.40$ (Table ix).

Table vii: Projections of estimated OFL (mt), ABC (mt), resulting ACLs (mt) based on 40-10 rule and applied buffers with $P^* = 0.45$, and estimated spawning output in millions of eggs, and spawning output relative to unfished for 2025-2034, with assumed removals in 2023 and 2024 based on recommended values from the Groundfish Management Team.

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed removals (mt)	OFL (mt)	Buffer	ABC	ACL	Spawning Output	Fraction Unfished
2023	1413	1284	1284	863.16					2808.87	0.35
2024	1434	1296	1296	860.19					2782.56	0.35
2025					646.93	0.935	604.88	571.28	2739.40	0.34
2026					654.71	0.930	608.88	572.51	2709.94	0.34
2027					674.29	0.926	624.39	583.52	2670.26	0.33
2028					703.06	0.922	648.22	601.48	2625.73	0.33
2029					737.31	0.917	676.11	623.09	2584.62	0.32
2030					773.77	0.913	706.45	647.92	2556.58	0.32
2031					809.71	0.909	736.03	674.16	2548.98	0.32
2032					843.09	0.904	762.15	699.96	2564.13	0.32
2033					872.65	0.900	785.38	725.64	2599.27	0.32
2034					897.79	0.896	804.42	749.34	2649.08	0.33

Table viii: Projections of estimated OFL (mt), ABC (mt), resulting ACLs (mt) based on the 40-10 rule and applied buffers with $P^* = 0.40$, and estimated spawning output in millions of eggs, and spawning output relative to unfished for 2025-2034, with assumed removals in 2023 and 2024 based on recommended values from the Groundfish Management Team.

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed removals (mt)	OFL (mt)	Buffer	ABC	ACL	Spawning Output	Fraction Unfished
2023	1413	1284	1284	863.16					2808.87	0.35
2024	1434	1296	1296	860.19					2782.56	0.35
2025					646.93	0.873	564.77	533.39	2739.40	0.34
2026					656.02	0.864	566.80	533.26	2713.76	0.34
2027					677.00	0.856	579.51	542.25	2678.11	0.33
2028					707.29	0.848	599.78	557.64	2637.77	0.33
2029					743.20	0.840	624.29	576.93	2601.05	0.32
2030					781.39	0.832	650.12	598.45	2577.72	0.32
2031					819.19	0.824	675.01	621.13	2575.43	0.32
2032					854.49	0.817	698.12	644.73	2596.64	0.32
2033					885.95	0.809	716.73	666.53	2638.56	0.33
2034					913.01	0.801	731.32	686.28	2695.91	0.34

Table ix: Decision table with 10-year projections beginning in 2025 for alternative states of nature based around modeling natural mortality. 'Mgmt' refers to the two management scenarios (A) the default harvest control rule $P^* = 0.45$, and (B) harvest control rule with a lower $P^* = 0.40$. Catch (in mt) is from the projections from the base model for each management scenario, and is applied to each state of nature. Catches in 2023 and 2024 are fixed at the ACLs and have been set for that year with values provided by the GMT. The alternative states of nature ('Low', 'Base', and 'High') are provided in the columns, and assume female natural mortality is either fixed at the prior estimate (Single M; low state), estimated as age-invariant (base), or is estimated at older ages (M ramp; high state). Spawning output ('Spawn', in millions of eggs) and fraction of unfished ('Frac') is provided for each state of nature.

Mgmt	Year	Catch	Low Spawn Single M	Low Frac Single M	Base Spawn	Base Frac	High Spawn M ramp	High Frac M ramp
A	2023	863	2523.10	0.244	2808.87	0.351	3098.08	0.430
	2024	860	2494.43	0.241	2782.56	0.347	3068.81	0.426
	2025	571	2449.39	0.237	2739.40	0.342	3021.70	0.419
	2026	573	2420.81	0.234	2709.94	0.338	2986.12	0.414
	2027	584	2383.86	0.230	2670.26	0.333	2938.59	0.407
	2028	601	2343.21	0.226	2625.73	0.328	2885.43	0.400
	2029	623	2305.70	0.223	2584.62	0.323	2836.83	0.393
	2030	648	2279.22	0.220	2556.58	0.319	2804.60	0.389
	2031	674	2269.97	0.219	2548.98	0.318	2797.59	0.388
	2032	700	2280.56	0.220	2564.13	0.320	2817.93	0.391
	2033	726	2309.81	0.223	2599.27	0.325	2860.65	0.397
	2034	749	2354.31	0.227	2649.08	0.331	2917.64	0.405
B	2023	863	2523.10	0.244	2808.87	0.351	3098.08	0.430
	2024	860	2494.43	0.241	2782.56	0.347	3068.81	0.426
	2025	533	2449.39	0.237	2739.40	0.342	3021.70	0.419
	2026	533	2424.82	0.234	2713.76	0.339	2989.89	0.415
	2027	542	2392.15	0.231	2678.11	0.334	2946.34	0.409
	2028	558	2355.98	0.228	2637.77	0.329	2897.29	0.402
	2029	577	2323.21	0.224	2601.05	0.325	2853.02	0.396
	2030	598	2301.84	0.222	2577.72	0.322	2825.45	0.392
	2031	621	2298.39	0.222	2575.43	0.322	2823.73	0.392
	2032	645	2315.69	0.224	2596.64	0.324	2850.17	0.395
	2033	667	2352.54	0.227	2638.56	0.329	2899.70	0.402
	2034	686	2405.68	0.232	2695.91	0.337	2964.22	0.411

Scientific uncertainty

The model estimate of σ_{OFL}, the uncertainty around the overfishing limit, is 0.145. Given the significant structural uncertainty in the model, particularly around natural mortality, selectivity, and the processes leading to the lack of older females in the population, this is considered an underestimate. It is also lower than the default Category 1 uncertainty value of 0.5, so projections will use the default value of $\sigma_{\mathrm{OFL}} = 0.5$.

Research and data needs

We list current research recommendations and prioritize them from high to low. Lower priority needs should not not be interpreted as unimportant, but rather lower relative to other priorities listed here. The topics are further expanded upon in the full document.

1. Continued research into the mechanism leading to skewed sex ratios and empirical studies to estimate natural mortality rates. (High)
2. The WCGBTS has low encounter rates with canary rockfish in part because it has limited access to rocky habitat. We recommend exploration of non-trawl coast-wide fishery-independent indices. (Medium)
3. Similar to recommendations 1 and 2, other biological relationships can be updated to better understand dynamics for canary rockfish. Few samples of canary rockfish are available to inform estimates of fecundity. Fecundity for canary rockfish was based on a genus level relationship. (Medium)
4. This assessment model does not include any ecosystem or climate considerations, but canary rockfish are considered highly vulnerable and highly exposed to climate change. (Medium)
5. Establish a process by which research-based assessments can be done to explore differences in spatial and non-spatial modeling structure, stability, and results. (Medium)
6. Research to inform understanding of movement rates for a spatial model, as well as improve estimates of natural mortality. (Low)
7. Revision of the ageing error matrices, incorporating the new aged canary rockfish data and utilizing new analytical methods. (Low)

1 Introduction

1.1 Basic Information

Canary rockfish (*Sebastes pinniger*) are distributed in the northeastern Pacific Ocean from the western Gulf of Alaska to northern Baja California; however, the species is most abundant from British Columbia to central California (Miller and Lea 1972; Hart 1973; Love et al. 2002). Adults are primarily found along the continental shelf shallower than 300 m, although they are occasionally observed in deeper waters. Juvenile canary rockfish are found in shallow and intertidal areas (Love et al. 2002).

From 2001 to 2011, the canary rockfish stock assessment models structured the population as a single coastwide stock, but used an areas-as-fleets approach to varying degrees to account for spatial differences in sizes and ages observed in fisheries along the coast. The most recent assessment in 2015 instead modeled three distinct areas along the coast, but assumed biological relationships and fishery selectivity were constant across latitudes (Thorson and Wetzel 2016). Research since the previous assessment indicates that canary rockfish are genetically well-mixed along the U.S. west coast (Budrick 2016), that the previous assessment model had poor numerical stability, and that the spatially explicit parameters that the model attempted to estimate were not in fact identifiable (Monnahan et al. 2019).

Spatial models have commonly been utilized for populations where spatial differences in growth and/or movement exist (Punt 2019), but have also been applied for populations with regional differences in catch histories (Cope and Punt 2011). In these situations spatial models have generally performed well. However, research has also argued for parsimony (Goethel et al. 2023), and identified that there are tradeoffs in model stability (Punt 2019) and performance (Punt et al. 2015). There is limited evidence suggesting biological differences among regions and little information to inform movement dynamics for spatial models of canary rockfish. The 2015 assessment also found results from a spatial model and single-area (coastwide) model were similar (Thorson and Wetzel 2016). For these reasons, and because early attempts to maintain the spatial structure applied in the 2015 assessment to the 2023 base model indicated model instability, we return to the historical single-area (coastwide) model for this assessment with fishery selectivity generally estimated by state (Figure 1).

1.2 Life History

Canary rockfish are a medium to large-bodied rockfish and achieve a maximum size of around 70 cm. Female canary rockfish reach larger sizes than males. Canary rockfish are relatively long-lived, with a maximum observed age in the literature of 84 years. However, in both the California Current and the coastal waters off British Columbia, only males are commonly observed above the age of 50, while females tend to be rare above age 30. The degree to which this pattern reflects behavioral differences translating to reduced availability to fishery and survey fishing gear, or an increase in relative mortality for older females has been the focus of much discussion and remains unclear. A similar pattern has been observed for yellowtail rockfish (*Sebastes flavidus*) and black rockfish (*Sebastes melanops*), two closely related species (Wallace and Lai 2005; Cope et al. 2016; Rasmuson et al. 2023). Since the 2002 assessment, this pattern has been accommodated within the stock assessment model by allowing female natural mortality to increase at approximately the age of first sexual maturity, as justified by an increase in behavioral risk or physiological stress resulting from female spawning.

Adult canary rockfish primarily inhabit areas in and around rocky habitat. They form very dense schools, leading to an extremely patchy population distribution that is reflected in both fishery and survey encounter rates, and this distribution strongly affects the calculation and interpretation of population indices and age- or size-composition data. Juvenile canary rockfish are found in shallow and intertidal areas (Love et al. 2002). Canary rockfish spawn in the winter, producing pelagic larvae and juveniles that remain in the upper water column for 3-4 months (Love et al. 2002). These juveniles settle in shallow water around nearshore rocky reefs, where they may congregate for up to three years (Boehlert and Yoklavich 1984; Sampson 1996) before moving into deeper water. The mean size of individuals captured in the trawl survey shows a characteristic ontogenetic shift to deeper water with increasing body size. In addition, the age and size of canary rockfish appears to vary by latitude, with the oldest largest fish occurring in more northerly latitudes and declining southward along the coast, with some evidence of breakpoints in size occurring along central California or southern Oregon (Keller et al. 2018; Brooks 2021).

The most recent research indicates limited stock structure of canary rockfish along the U.S. west coast. Limited tagging research conducted off Oregon found that of 10 canary rockfish recovered, 2 moved between 5 and 30 km, and 5 moved more than 100 km over a period of up to several years (DeMott 1982). A single canary from that study moved 236 km to the south, and those that moved the farthest also moved to much greater depths than the shallow reefs at which they had been tagged. Another study in central and southern California tagged 13 canary rockfish but recaptured none (Hanan and Curry 2012). Early genetic research found patterns suggestive of some population structuring between the northern California/southern Oregon and northern Oregon/southern Washington, but this work was based on limited sampling and also found evidence of reduced gene flow between shallow and deeper areas (Wishard et al. 1980). Using modern population genetic methods (Gomez-Uchida et al. 2003), Budrick (2016) found little support for population structure of canary rockfish within the California Current. Supporting the genetic analysis, otolith microchemistry indicates no differentiation in natal or juvenile habitat between canary rockfish collected in Oregon and Washington waters (Gao et al. 2013).

There are few biogeographic boundaries clearly applicable to rockfish on the U.S. and Canadian west coasts. However, canary rockfish are not found in large numbers south of Point Conception. The divergence zone at the northern edge of Vancouver Island likely creates a barrier for pelagic dispersal and productivity for many species (Ware and McFarlane 1989); therefore it is the southern portion of the B.C. canary resource that is most likely to have dynamics linked to the U.S. resource. It is likely that canary rockfish cross the U.S. Canadian border as pelagic larvae, juveniles, and possibly adults making their ontogenetic shift to deeper water or moving between areas of rocky habitat.

The 2002 assessment integrated what had previously been separate north-south assessments based on the observations of highest density occurring near headlands and International North Pacific Fishery Commission (INPFC) boundaries commonly used to delineate management and assessment areas (Methot and Piner 2002). They reasoned that splitting stocks or assessments at any INPFC boundaries would divide high-density areas that most likely are biologically linked. This logic was followed in the 2005 benchmark assessment and subsequent 2007 and 2009 update assessments, separating fishing fleets geographically to account for potential spatial patterns while retaining a coast-wide assessment area. All U.S. assessments have used the U.S.-Canadian border as the northern boundary for the stock, although the basis for this choice appears to be largely based on both (1) consistency with current management needs, and (2) data availability and feasibility of expanding data from multiple jurisdictions within a single stock assessment.

1.3 Ecosystem Considerations

Canary rockfish are reported to have a diverse diet. Pelagic juveniles consume copepods, amphipods and krill, while adults consume krill and many species of small fish (Love et al. 2002). The California Current Trophic Database includes records of canary rockfish consuming amphipods, copepods, euphausiids, isopods, mysids, pandalid shrimp, myctophids, herring, and chaetognaths, as well as unidentified bony fish and crustaceans (Bizzarro et al. 2023). The degree to which variability in food supply may affect body condition, spawning success or annual growth is unknown. Young-of-the-year canary rockfish have been reported in stomachs of Chinook and coho salmon (*Oncorhynchus tshawytscha* and *Oncorhynchus kisutch*, Thayer et al. 2014; Bizzarro et al. 2023), and they are also consumed by seabirds (Warzybok et al. 2018). Although canary rockfish are difficult to identify to the species level in stomach contents, they are likely preyed upon by other large fish such as lingcod (*Ophiodon elongatus*). A 47 cm canary rockfish was once reported in the stomach of a 24 kg Lingcod off the coast of Monterey, California (Phillips 1959). According to a recent California Current climate vulnerability analysis that ranked species on a scale of low, moderate, high, and very high, canary rockfish have high exposure and high sensitivity to climate change, similar to most rockfish (McClure et al. 2023).

Although ecosystem factors have not been explicitly modeled in this assessment, there are several important aspects of the recent California current ecosystem that appear to warrant consideration. Lingcod, a potentially important predator of small canary, have rebuilt over the last two decades (Johnson et al. 2021; Taylor et al. 2021b). To the extent that the component of natural mortality of canary rockfish added by predation from Lingcod and other predators has been increasing over recent years, recruitment may be underestimated. This effect could also lead to longer than predicted recovery times for canary rockfish (Oken and Essington 2016). Conversely, Pacific salmon are known to consume young canary rockfish, and their populations have generally declined in recent years (Bizzarro et al. 2023). Canary rockfish productivity as estimated in the last assessment is significantly associated with the PDO (Mantua et al. 1997; Bell et al. 2023), and growth and condition were also found to be associated with the PDO and other basin-scale indices (Keller et al. 2018). However, relationships between productivity of fish populations with non-mechanistic basin-scale indicators such as the PDO have been degrading in recent years due to climate change (Litzow et al. 2020; Werb and Rudnick 2023), so these relationships may not be reliable predictors moving forward. In contrast to predictions from the climate vulnerability analysis, there is evidence that canary rockfish productivity has been trending upward recently (Bell et al. 2023). The prevalence of a strong 1999 year-class for many west coast groundfish species suggest that environmentally driven recruitment variation may be correlated among species with relatively diverse life-history strategies (Thorson et al. 2013; Stachura et al. 2014). Much research is currently underway to explore these phenomena, and it appears likely that more explicit exploration of ecosystem processes and influences may be able to be incorporated into management both within and outside of future canary rockfish stock assessments.

1.4 Historical and Current Fishery Information

Canary rockfish is caught in both commercial and recreational fisheries off the U.S. West Coast alongside other rockfish species, with the majority of catches for canary rockfish coming from commercial sources (Tables 1–2, and Figure 2). The rockfish fishery off the U.S. West Coast developed off California late in the 19th century and was catching an average of almost 2,500 metric tons per year across species over the period 1916-1940 (with an increase in catches in 1916, during World War I). To the north, the rockfish fishery developed slowly and became established during the early 1940s, when the United States became involved in

World War II and wartime shortages of red meat created an increased demand for other sources of protein (Harry and Morgan 1961; Alverson et al. 1964). Rockfish catches dropped somewhat following the war, and were generally stable from the 1950s to the 1960s.

Historically, the vast majority of canary rockfish off the U.S. West Coast have been harvested by commercial trawling vessels, followed by hook-and-line (primarily vertical longline), shrimp trawls, and various miscellaneous gears (e.g., nets and pots). In 1977, when the MSFCMA was enacted, the large foreign-dominated rockfish fishery that had developed since the late 1960s had its catches eliminated, and the domestic trawl fishery subsequently increased its catches. Canary rockfish were also sought by recreational anglers and considered to be a moderately important species caught in the private vessel and charter boat fisheries off Washington, Oregon, and northern California.

Inspection of the historical catch reconstructions for canary rockfish (see Section 2.2.1 for details) shows that reconstructed catches from 1892 to 2022 were highest historically in the trawl and foreign fisheries (Figure 2). The trawl (TWL) fishery was high around the end of World War II (1945: 3,724 mt), but decreased during the 1950s-1960s. A foreign fleet (FOR) operated 1966-1976, and nearly exceeded the domestic trawl landings in 1966 (TWL: 1,658 mt, FOR: 1,599 mt). The foreign fleet was replaced by the domestic bottom trawl fleet following the MSFCMA (1978 TWL: 3,945 mt). The trawl fishery reached a peak in the early 1980s (1982: 5,155 mt) and subsequently decreased after the establishment of strict management restrictions starting in the mid-1990s. The decrease in the trawl fishery allowed the recreational and non-trawl fisheries to take a larger proportion of total catch beginning in the 2000s. Following the removal of the overfished designation due to findings from the 2015 assessment (Thorson and Wetzel 2016), catches increased considerably, though to levels well below those seen during much of the period of industrial fishing. Today, most catch still occurs in the trawl fishery (particularly in a growing midwater trawl fleet), though there is a sizable recreational (REC) component of landings as well (2022 TWL: 507 mt, REC: 152 mt). Trawl catches are highest in Oregon, whereas non-trawl and recreational catches are highest in California.

1.5 Summary of Management History and Performance

The first regulations established on the canary rockfish fishery off the U.S. West Coast were implemented in 1983 as trip limits (40,000 lb. per trip) on the entire *Sebastes* complex (a market category that included all rockfish species except Pacific Ocean perch *Sebastes alutus* and widow rockfish *Sebastes entomelas*) harvested from the U.S. Vancouver and Columbia INPFC areas (Pacific Fishery Management Council 2002). Commercial vessels were not required to separate most rockfish catches into individual species, but rather, only into mixed-species categories, such as the *Sebastes* complex. Port biologists in each state routinely sample market categories (e.g., *Sebastes* complex) to determine the actual species composition of these mixed-species categories. Since 1967, various port sampling programs have been utilized by state and federal marine fishery agencies to determine the species compositions of the commercial groundfish landings off the U.S. West Coast (Sampson and Crone 1997). Stratified, multistage sampling designs are currently used in the port sampling programs for purposes of evaluating the species compositions of the total landings, as well as for obtaining biological data on individual species Pearson and Erwin (1997).

From 1983 through 1994, canary rockfish were monitored as part of the *Sebastes* complex, with various trip limits imposed over this 10-year span. In 1993 and 1994, commercial fishermen communicated that fewer canary rockfish were being caught in their rockfish tows (Pacific Fishery Management Council 2002). The

1994 canary rockfish stock assessment (Sampson and Stewart 1994) confirmed that the observed declines in the field were likely the result of a population that had not responded favorably to recent levels of fishing pressure and further recommended that the canary rockfish Acceptable Biological Catch (ABC) be reduced to allow the stock to recover. Beginning in 1995, the ABC for canary rockfish was reduced nearly 60%, to 1,250 mt. In 1995, trip limits specific to canary rockfish (cumulative monthly trip limit of 6,000 lb.) were imposed and commercial vessels were required to sort canary rockfish from other rockfishes. In 1998, catches of canary rockfish were regulated using a two-month cumulative trip limit of 40,000 lb. for the Sebastes complex, of which, no more than 15,000 lb. (38%) could be composed of canary rockfish. That is, although this species was allocated its own market category, it was still being managed as part of the mixed-species complex. The ABC was further reduced to 1,045 mt.

The two stock assessments conducted in 1999 (California and Washington-Oregon) found the stock to be depleted and an overfished determination was made in 2000. Subsequently, commercial and recreational fishing opportunities were severely restricted and removals were mainly from bycatch. Canary rockfish became a limiting species for fisheries that target other commercially important species on the continental shelf. The optimum yield (OY) in 2003 was 44 mt; which was only about 1% of the peak annual catches in the early 1980s. Management regulations were sufficiently strict to keep the catch that year to only 51 mt. During the overfished time period, the fishery was far below ABC levels. Shelf rockfish species (including canary) could no longer be retained by vessels using bottom trawl footropes with a diameter of greater than 8 inches. The use of small-footrope gear increases the risk of gear loss in rocky areas, and this restriction was intended to discourage trawlers from fishing in high-relief, rocky habitat. The impact of the change in gear regulations was reinforced through reductions in landing limits for all other shelf rockfish species.

In 2002, the trawl and non-trawl Rockfish Conservation Areas (RCAs) were implemented as depth-based closed areas to reduce bycatch of overfished rockfish species such as canary rockfish in the northern portion of the coast and bocaccio (*Sebastes paucispinis*) in the south. Specific boundaries for the trawl RCA have varied across bimonthly periods within and among years in response to changing discard rates and fishery dynamics. There was generally a dynamic pattern of the closed area extending from the shoreline (or 75 fm) out to 150 fm (274 m), 200 fm (366 m) or 250 fm (457 m). Deeper depths are generally closed in the winter months and there are a number of latitudinal differences in the extent of the current RCA; however the large majority of depths deeper than 75 fm (137 m) where canary rockfish occur were closed to all commercial on-bottom fishing for groundfish. It is possible that by closing most of the depth range of the species the RCA influenced the size range of canary rockfish available to the fishery. The PFMC eliminated the trawl RCA off of the coasts of California and Oregon in 2018, and the decision went into effect in 2020. The non-trawl RCA has also seen relaxation for some gear types over certain latitudes in recent years.

Beginning in 2005, the modified "flatfish" trawl gear was required shoreward of the RCA. This gear was found to reduce the catch-per-unit-effort of canary rockfish relative to standard commercial gear in pilot experiments (King et al. 2004). Recreational limits were also substantially reduced for more than a decade. After first reducing bag limits, starting in 2003 all three states allowed no retention of canary rockfish during recreational fishing. From 2005 to the end of the overfished designation, mortality associated with recreational fishing was primarily comprised of discard mortality from fish caught while targeting other species such as Pacific halibut (*Hippoglossus stenolepis*) or other rockfish.

A groundfish trawl rationalization program was commenced in 2010 via Amendment 20 to the Groundfish

Fisheries Management Plan. Under this program, groundfish limited entry trawl vessels making shoreside deliveries are managed primarily through a system of individual transferable or tradeable quotas (ITQs). Trawl permit holders were provided with quota share percentages of the allowable catch of major species and assemblages, based on historical fishery participation. After ACLs are set for species for a given year, the shares are used to calculate individual quotas (in weight) that represent the amount of species' catch the permitted individual (and associated vessel) are entitled to catch. Unlike previous management, which relied on limiting the landings of vessels, the new system holds individual vessels responsible for retained and discarded catch. Discard amounts are verified by 100% at-sea observation of participating vessels. Vessel accountability for discards has generally led to a reduction in fleet discards since implementation for Pacific rockfishes as a whole. A system for tracking quota balances was also created, and vessels are not allowed to fish when they have negative balances for any species/assemblage. Quota pounds have been transferable between permit holders since the program's beginning, and now the shares of most species may be sold. Accumulation of shares or pounds is subject to accumulation and usage caps. Additionally, the program provided the opportunity for trawl pounds to be fished with other gears on qualified vessels ("gear switching").

Catch accountability for motherships and associated catcher-vessels in the mothership sector for Pacific hake (*Merluccius productus*) was achieved through a system of regulated cooperatives. Pacific hake catcher-processors operated for years as a voluntary cooperative, and that arrangement was formalized by provisions of Amendment 20 (NMFS 1992). Cooperatives in both of these sectors received annual poundage allocations of hake and non-hake species, based on the entitlements of cooperative members, and these amounts are not transferable between cooperatives. There is also no provision for voluntary transfers of pounds or shares between fishery sectors. Beginning in 2020, the separate allocations for catcher-processors and motherships were combined into a single at-sea hake set-aside.

Canary rockfish was declared rebuilt following the 2015 stock assessment (Thorson and Wetzel 2016). As a result, in 2017 the ACL increased more than tenfold from 125 mt to 1714 mt (Table 3). Catches increased substantially following this relaxation, especially in the recreational fishery and in a growing midwater trawl fishery (Figure 2). Since rebuilding, total mortality (catches plus dead discards) has generally been around 40% of the ACL. Areas and depths previously restricted have since started to reopen.

1.6 Foreign and Alaska Fisheries

Canary rockfish in Canadian waters off the coast of British Columbia appear to have similar life history characteristics to those found off the U.S. West Coast. Similar to the U.S. West Coast, male age samples display a long tail past 60, but there are few females older than 40 (DFO 2023). A 2022 assessment successfully estimated both male and female natural mortality (constant across ages) as 0.065 and 0.093 yr^{-1}, respectively (DFO 2023). The canary rockfish population in Canadian waters reached a similar trough around 2000 to that observed in the U.S. (DFO 2023). Removals are dominated by the trawl fishery and by catches off the west coast of Vancouver Island (areas 3C and 3D, DFO 2023). Catches were highest (>1200 mt) in the decade from 1986-1995, and then declined and have remained relatively stable since, averaging around 800 mt since 1996, and around 540 mt during that time for the west coast of Vancouver Island (DFO 2023).

It is difficult to conclude what the current status of canary rockfish is off of Alaska. The North Pacific Fishery Management Council (NPFMC) assesses and manages canary rockfish as a minor part of an assemblage including seven species of demersal shelf rockfishes (Joy et al. 2022). The primary component of this group is yelloweye rockfish (*Sebastes ruberrimus*), although quillback (*Sebastes maliger*), copper (*Sebastes caurinus*), China (*Sebastes nebulosus*), tiger (*Sebastes nigrocinctus*) and rosethorn (*Sebastes helvomaculatus*) rockfishes are also included. No species in the assemblage are the target of a commercial fishery. Yelloweye rockfish biomass is estimated from an autoregressive random effects model applied to submersible biomass estimates (crewed 1994-2009, and remotely operated 2012-2022) and the IPHC longline survey (Joy et al. 2022). A bayesian state-space surplus production model that incorporated catches was also recently presented as a research model. Canary rockfish, in particular, is managed as Tier 6, and no direct indices of canary rockfish abundance in the Gulf of Alaska have been reported.

2 Data

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

Data from a wide range of programs were available for possible inclusion in the current assessment model. Descriptions of each data source included in the model and sources that were explored but not included in the base model are provided below. In some cases, the inclusion of excluded data sources were explored through sensitivity analyses (see Section 3.5.2).

2.1 Data Sources Used in this Assessment

This assessment updates the data that were used in the 2015 benchmark assessment and the corrections to catch applied for the 2017 catch only update, as well as utilizes additional data that were collected since the last benchmark. Fishery data sources (including length composition, age composition, and catch time series) are split among three strata to make comparisons to and explorations from the 2015 benchmark assessment more direct, whereas abundance indices and corresponding length and age compositions from the fishery-independent surveys are combined across these strata to match the population scale reflected in the model. Each data source is summarized here, and then discussed in more detail below:

1. Data regarding total removals of canary rockfish are compiled for years 1892-2022. These data are obtained from several sources:
   a. In California, landed recreational (1928–2022) and commercial (1916–2022) catches along with estimates of recreational dead discards come from multiple data sources including state reconstructions, CalCOM database for the California Cooperative Survey (CalCOM), Recreational

Fishery Information Network (RecFIN), and Pacific Fisheries Information Network (PacFIN). Historical recreational landings up to 1980 are based on those used in the previous benchmark assessment.

b. In Oregon, landed recreational and commercial (1892–2022) catches along with estimates of recreational dead discards were provided directly by Oregon Department of Fish and Wildlife (ODFW) and come from multiple data sources including state reconstructions, PacFIN, and RecFIN.
c. In Washington, landed recreational catches (1967–2022) along with estimates of recreational releases were provided directly by Washington Department of Fish and Wildlife (WDFW). Historical commercial landed catches (1935–1980) are based on those used in the previous assessment. Commercial landed catches from 1981–2022 are from PacFIN.
d. Foreign trawl fleet catches from 1966–1976 are based on Rogers (2003).
e. Total removals of canary in the at-sea hake fishery (1973–2022) were provided by the Northwest Fisheries Science Center (NWFSC) At-Sea Hake Observer Program (ASHOP).
f. Total commercial discards for recent years (2003–2021) are estimated in the annual mortality report using data from a variety of sources including the West Coast Groundfish Observer Program (WCGOP), and are publicly available.
g. Discard rates for 1981-1994 are obtained from the Pikitch study (Pikitch et al. 1988) as analyzed by J. Wallace.

2. Fishery-independent data are included from three different surveys:
    a. The Triennial Survey conducted by the Alaska Fisheries Science Center provides abundance index, length composition, and age-composition samples and was included for years 1980-2004.
    b. The WCGBTS conducted by the NWFSC provides abundance index, length composition, and age-composition samples, and was available for years 2003-2022, with the exception of 2020 due to the COVID-19 pandemic.
    c. The pre-recruit survey, which combines data collected by the Southwest Fisheries Science Center (SWFSC), NWFSC, and Pacific Whiting Conservation Cooperative provides a relative index of density for pre-recruit fish, and was included for most years from 2001-2022. Composition data are not used for this survey.

3. Fishery-dependent composition data are included from the following sources:
    a. Commercial length and age composition data were obtained from PacFIN.
    b. Recreational length and age composition data from state sampling programs or historical sampling efforts were either provided by the state agencies or were obtained from RecFIN.
    c. Length and age data for canary rockfish from the at-sea hake fishery were obtained from the NWFSC ASHOP.

4. Estimates of life history parameters are generated from various sources, and include:
    a. Updated maturity schedule from analyses based on functional age-at-maturity, which accounts for abortive maturation, wherein young spawners may have yolk present but are not yet spawning capable, and skip spawning, wherein mature individuals do not spawn in every year.
    b. Updated fecundity relationship based on a meta-analysis assuming fecundity is a power function of length.
    c. Updated prior for natural mortality rate along with updated treatment of mortality as age-invariant but sex dependent.

d. Updated prior on steepness according to best practices.
e. Updated weight-at-length relationship as estimated from the WCGBTS.
f. Estimates of ageing error for break-and-burn ages were maintained from the previous benchmark assessment.

These data sources are illustrated in Figure 3.

2.2 Fishery-Dependent Data

2.2.1 Total Removals

Removals (1892-2022) for canary rockfish were compiled from multiple data sources. This assessment includes total removals (landings plus dead discards) by state for the following fleets: trawl, non-trawl, recreational, foreign trawl, and at-sea hake. A summary of total removals are provided in Table 1 and Table 2, and Figure 2.

2.2.1.1 Commercial Landings by State

2.2.1.1.1 Washington Commercial landings data in Washington were available from 1935–2022. Historical landings (1935–1980) were retained from the last full assessment where they were assumed to be for trawl gears (Stewart 2007; Thorson and Wetzel 2016). Recent landings (1981–2022) for the trawl and non-trawl (mainly hook and line) gears were obtained from PacFIN, the central repository for West coast commercial landings (extracted on 03/23/2023, Pacific States Marine Fisheries Commission (PSMFC), Portland, Oregon). A small update to 2022 landings from PacFIN values was provided by WDFW on 06/18/2023.

2.2.1.1.2 Oregon Commercial landings data in Oregon were available from 1892–2022. Historical landings from 1892 to 1986 were provided by ODFW (Karnowski et al. 2014). Landings in 1987–1999 were compiled from a combination of PacFIN, (extracted on 03/23/2023), and a separate ODFW reconstruction that delineated canary rockfish-specific landings among unspecified species categories within PacFIN (e.g. URCK and POP1, Oregon Department of Fish and Wildlife 2017). Canary rockfish landings from this reconstruction were substituted for the URCK and POP1 landings available from PacFIN and added to PacFIN landings from other categories for a complete time series of canary rockfish during this time period. Commercial landings in 2000–2022 were available on PacFIN (extracted on 03/23/2023).

2.2.1.1.3 California Commercial landings data in California were available from 1916–2022. Historical landings from 1916 to 1980 were obtained following the process described in the southern California vermilion rockfish (*Sebastes miniatus*) assessment (see Dick et al. 2021b for complete details). Briefly, landings 1916–1968 came from a state reconstruction (Ralston et al. 2010). Landings from unknown gears in known regions were allocated proportional to landings from known gears within the same region for each year. Landings from unknown locations (Region 0) and unknown gears were allocated proportional to the landings from known gears across all known locations for each year. Landings from 1969–1980 came from CalCOM, which for 1969–1977 incorporates fish ticket data including mixed species categories for rockfish that were assigned to individual species using the earliest species composition samples (from the late 1970s and ealy

1980s). Recent (1981–2022) landings by trawl and non-trawl gears were obtained from PacFIN (extracted on 03/23/2023).

Additional catches caught off the coast of Oregon or Washington but landed in California from 1948-1968 were included, as these were not incorporated within the Ralston et al. (2010) reconstruction (E. Dick, SWFSC, personal communication, 3/16/23). These final landings are in the California landings history for consistency with treatment for other states, because historical catches landed in Oregon or Washington but caught in the other state's waters are similarly attributed to the state where they were landed.

2.2.1.2 Commercial Discards Discarding was not estimated in the model. Estimates of dead discards were combined with landed catch to provide estimates of total removals that were used as input within the assessment model. In recent years (2000–2022), estimates of dead discards were calculated from discard data, but in earlier years (before 2000), estimates of dead discards were calculated based on assumed discard ratios.

The ratio of discarded weight to landed weight (hereafter termed the "discard ratio") for the domestic trawl and non-trawl fisheries was assumed at the following values: 1% discard ratio for 1892–1980, based on the assumption that discard rates were low prior to management actions due to the high-value nature of the fishery (and consistent with the previous assessment, Thorson and Wetzel 2016); 5% discard ratio for 1981–1994 which is approximately the value calculated by J. Wallace, NMFS using data from Pikitch et al. (1988); 20% discard ratio for 1995–1999, based on the assumption that discard ratios would be higher than previous years but less than years when discard data was present due to the period of non-retention (and consistent with the previous assessment, Thorson and Wetzel 2016).

Onboard observers were deployed on fishing vessels starting in 2002 to collect data on discarding practices. Discard amounts for the domestic trawl and non-trawl fleets from 2002–2021 were determined based on WCGOP data provided in the Groundfish Expanded Mortality Multi-Year (GEMM) product, available publicly. The GEMM provides estimates of dead discards coastwide. Therefore, the total coastwide estimates of dead discards in trawl and fixed gears as provided in the GEMM were allocated by state based on the total observed landings and discards for each state as observed by WCGOP. Dead discards were added to landings to obtain total removals for 2002–2021. Total removals in 2000, 2001, and 2022 where no WCGOP data were available were calculated by applying the average discard ratios from 2002–2004 (for estimates in 2000 and 2001) and 2019–2021 (for estimates in 2022) for each gear to landings for that gear.

2.2.1.3 Recreational Landings and Discards by state

2.2.1.3.1 Washington Washington recreational landings, in number of fish retained, were provided by WDFW for 1967 and 1975–2022. Landings estimates starting in 1990 were reworked by the WDFW sport sampling unit since the previous assessment. For 1968–1974, a linear ramp between the values in 1967 and 1975 was used to approximate landings. Recreational landings were assumed to be zero prior to 1967. Documentation for landing estimates compiled for 1987–1989 could not be located by WDFW, but were used in lieu of linear interpolation between estimates in 1986 and 1990.

Discard estimates for 2002–2022, in number of fish released, were also provided by WDFW. Numbers released in specific depth categories were available from 2005–2022, and estimates of the proportion of releases that occurred using descender devices were available from 2016–2022. Released fish at unknown depths were allocated proportional to released fish at known depths in years with depth-specific values. For 2002–2004, which had no depth-specific information, the average total release mortality rate in 2005–2007 was used to calculate the number of dead discards. Depth-specific release-mortality rates were based on agreed upon values for canary rockfish for surface releases (Table 1-10, Pacific Fishery Management Council 2014) and releases with descender devices (Table 1-13, Pacific Fishery Management Council 2014). The release mortality rates using descender devices in deep waters (30+ fathoms) in Pacific Fishery Management Council Pacific Fishery Management Council (2014) were binned at a finer scale than in the provided data on descender device usage. Number of releases decreased with water depth, so the release morality in 30+ fathoms when using descender devices was assumed as the average of release mortality rates for 30–50 fathoms and 50-100 fathoms from Pacific Fishery Management Council (2014).

The total discard mortality rate (release rate multiplied by release mortality rate) for 2002 was also applied to 2000–2001 landings. All three years shared a two canary daily bag limit, and were assumed to have similar discarding practices. We assumed zero recreational releases prior to 2000 when canary rockfish was included as part of a ten rockfish daily limit, and release rates were generally low (P. Anderson, personal communication, 03/20/23).

Total removals in the Washington recreational fleet were converted from numbers to weight to maintain consistency with units from other fleets. Length data for sport catches were provided by WDFW for 1979–2022. The average length of canary rockfish by year was calculated and converted to average weight based on parameters of the length-weight relationship ($\alpha = 1.040\text{E-}05$ and $\beta = 3.084$ for length in cm and weight in kg) as used in RecFIN. In years where the number of length samples was fewer than 25, lengths were borrowed from the nearest neighboring years to calculate a three year weighted-average. A value of 25 was used because it was the 'small sample size' threshold used by Dick et al. (2021a) and had increased percent standard error compared to other sample sizes. Borrowing lengths from neighboring years was only applied from years with roughly similar fishing regulations. Thus, lengths were only calculated from neighboring years in the periods $<$1999 (canary rockfish part of group daily bag limits), 2000–2003 (canary rockfish with individual daily bag limits), 2004–2016 (period of no retention), and 2017–2022 (post non-retention). Any years without lengths were assigned the non-weighted-average length across years within a period. A non-weighted length was applied to give each year equal weight in calculating an overall average for each period.

2.2.1.3.2 Oregon Historic Ocean Boat Landings and Discards (1979–2000)

Recently, ODFW undertook an effort to comprehensively reconstruct all marine fish recreational ocean boat landings prior to 2001 (Whitman 2023, in review). Reconstructed catch estimates from the ODFW Oregon Recreational Boat Survey (ORBS) improve upon estimates from the federal Marine Recreational Fisheries Statics Survey (MRFSS), which have known biases related to effort estimation and sampling (van Voorhees et al. 2000) that resulted in catch estimates considered implausible by ODFW. However, the ORBS sample estimates are known to lack the comprehensive spatial and temporal coverage of MRFSS. Addressing this coverage issue is a major part of this reconstruction. In general, the base data and methodology for these reconstructed estimates are consistent with recent assessments for other nearshore species (Cope and Whitman 2021; Langseth et al. 2021; Taylor et al. 2021b; Wetzel et al. 2021).

Prior to 2001, ORBS monitored marine species in both multi-species categories, such as rockfish, flatfish, and other miscellaneous fishes, and individual species, such as lingcod or halibut. For this comprehensive reconstruction, four species categories were selected to reconstruct, including rockfish, lingcod, flatfish and miscellaneous, which constitute the bulk of the managed marine fish species. Canary rockfish are a component of the rockfish species category.

Category-level estimates were expanded to account for gaps in sampling coverage in two separate pathways. First, estimates from five major ports were expanded to include unsampled winter months in years lacking complete coverage. Expansions were based on available year-round sampling data and excluded years where regulations may have impacted the temporal distribution of catch. Second, all other minor port estimates were expanded to include seasonal estimates in years lacking any sampling based on the amount of minor port catch as compared to all major port estimates. A subset of landings were sampled by ORBS for species compositions within these categories. Once category-level landings were comprehensive in space and time, species compositions were applied for the three multi-species categories, including rockfish, flatfish and miscellaneous fish. Borrowing rules for species compositions were specific to the category and determined based on a series of regression tree analyses that detailed the importance of each domain (year, month, port and fishing mode) to variability in compositions.

Ocean boat estimates 1979–2000 in numbers of fish of canary rockfish from the above described methods were converted to biomass using biological samples from MRFSS (A. Whitman, ODFW, personal communication, 2023). MRFSS biological data are available 1980–1989 and 1993–2000. An annual average weight was applied to the total annual number of fish to obtain an annual biomass estimate of the landings. Several years of missing biological data (1979, 1990–1992) were filled in using neighboring years or interpolation. Landings from 1979 to 2000 averaged 29.9 mt and are of similar magnitude to the previous assessment, though landings appear to have less interannual variability than the previous assessment (Thorson and Wetzel 2016). Landings were relatively high in the first year of available data (1979) and so landings from 1972 to 1978 were initiated at zero in 1972 and linearly ramped up to the value in 1979. The provided landings do not include an estimate of discarded fish, and thus are assumed as total removals. Bag limits in the recreational fishery during this time period (prior to 2001) were generally liberal and ODFW staff recommended that no additional mortality of discarded fish be included prior to 2001.

Modern Ocean Boat Landings and Discards (2001 – 2022)

Recreational landings for ocean boat modes from 2001–2022 are available from RecFIN. Both retained and released estimates of mortality are included, though retained mortality contributes the vast majority to total mortality in years outside the overfished designation for canary rockfish. Release mortality is estimated from angler-reported release rates and the application of discard mortality rates from the PFMC (Pacific Fishery Management Council 2014). The average proportion of canary rockfish discarded averaged 4.5% in 2001–2003 and 2017–2022. During years where canary rockfish retention was prohibited, discard rates increased to 96.1% on average (2004–2016). From 2001 to 2022, total landings averaged 16.0 mt, ranging from 1.7 to 60.6 mt. In 2022, estimated ocean boat landings were 55.7 mt.

2.2.1.3.3 California Recreational landings in California were available from 1928–2022. Historical estimates of recreational landings 1928–1979 were obtained from the previous assessment (Thorson and Wetzel 2016), which were in turn were obtained from CalCOM. For years since 1979, recreational landings along with estimates of dead discards came from RecFIN via the MRFSS (1980–2003) and California Recreational

Fisheries Survey (CRFS) (2005–2022) sampling programs. Landings and dead discards were added together to obtain estimates of total removals. Discards prior to 1980 were assumed to be zero.

A number of years with missing or incomplete estimates for recreational removals were filled in. The removals in 1980 from MRFSS were not used due to survey quality problems related to 1980 being the first year of MRFSS (Karpov et al. 1995; Cope and Key 2009). Removals for this year were averaged across removals in 1979 and 1981. No or minimal party/charter (PC) estimates were available from 1993–1995, so PC mode removals for these years were calculated assuming an average ratio of private/rental (PR) to PC modes across all years with data within MRFSS and added to PR values to obtain total recreational estimates. The MRFSS sampling program did not sample from 1990–1992, and so estimates during these three years were obtained as averages from neighboring years. Estimates in 1990 were the average from 1987–1989, estimates in 1991 were the average from 1987–1989 and 1993–1995, and estimates in 1992 were the average from 1993-1995. Because of the transition from MRFSS to CRFS, no estimate was available in either database in 2004 for this assessment cycle. California Department of Fish and Wildlife (CDFW) provided a value of 10.59 mt for 2004 (J. Budrick, CDFW, personal communication, 3/20/23), based on an available previous pull of MRFSS data for the gopher rockfish (*Sebastes carnatus*) assessment. Estimates for California recreational removals from the previous canary rockfish assessment were not used because these appeared to only reflect estimates of landings, and not total removals.

CA Recreational Data Impacted by COVID-19 Pandemic

The COVID-19 pandemic impacted recreational port sampling in 2020 and 2021. No sampling occurred at all in April-June, 2020. CDFW provided proxy values for these months (M. Parker, CDFW, personal communication, 2/22/23). Total proxy values for canary rockfish weight were summed across district and added to the existing estimate for 2020 from RecFIN. In addition, California recreational total mortality estimates in the "rockfish genus" were inflated due to CRFS samplers being unable to closely examine catch and identify catch to species. This was a problem for both PR and PC modes in 2020 and primarily for the PC mode in 2021. An effort was made to allocate some of the rockfish genus mortality to other rockfish species for these modes and years (J. Coates, CDFW, personal communication, 2/10/23). An expected value of rockfish genus mortality in 2020 and 2021 was generated by mode and year according to the average proportion to the total rockfish mortality that this category represented in 2018 and 2019, when regulations were consistent with 2020 and 2021. Mortality above this expected value was attributed to the other species also based on proportions each species represented to the total from 2018 and 2019. Calculations were made by year, mode, and district. The shore-based modes were grouped in with the PR mode. Calculations were initially made in numbers of fish because rockfish genus mortality is only recorded this way. Numbers of fish by species were then converted to weight in kilograms based on average weights of fish recorded by the CRFS program by district in 2019. Total reallocated values for canary rockfish weight were summed across modes and districts and added to existing estimates for 2020 from the sum of the proxy value and RecFIN and for 2021 from RecFIN.

2.2.1.4 At Sea Hake Fishery Catches of canary rockfish are monitored aboard the vessel by observers in the ASHOP and were provided for the years 1975–2022 (V. Tuttle, NOAA, personal communication, 4/3/23). Observers use a spatial sample design, based on weight, to randomly choose a portion of the haul to sample for species composition. For the last decade, this is typically 30-50% of the total weight. The total weight of the sample is determined by all catch passing over a flow scale. All species other than hake are removed and weighed, by species, on a motion compensated flatbed scale. Observers record the weights of all non-hake species. Non-hake species total weights are expanded in the database by using the proportion of the haul sampled to the total weight of the haul. The catches of non-hake species in unsampled hauls is determined using bycatch rates determined from sampled hauls. Since 2001, more than 97% of the hauls have been observed and sampled.

Values for percentages of the catch that was retained were available in the data starting in 1997. When not provided, we assumed percent retained was 100 percent. We also assumed that any canary rockfish not retained were dead. We therefore added the retained landings to the amount of landings not retained to obtained total removals.

Total removals were partitioned to state based on latitude, with retrieved hauls from 46.25°N to 49°N assigned to Washington, 42°N to 46.25°N assigned to Oregon, and < 42°N assigned to California. Starting in 1992, processing of at-sea hake was restricted to north of 42°N (NMFS 1992). Very small catches from south of 42°N during this time were assigned to Oregon. Due to confidentiality, catches in 1975 were not reported or used within the model, and catches in 1976 were combined and assigned to Oregon.

2.2.1.5 Foreign Catches From the 1960s through the early 1970s, foreign trawling enterprises harvested considerable amounts of rockfish off Washington and Oregon, including large quantities of canary rockfish. Foreign catches of individual species were estimated by Rogers (2003) and attributed to INPFC areas from 1966-1976 for canary rockfish. INPFC areas do not coincide with the fleet areas defined in this assessment. Therefore, INPFC catches were translated to states in the following manner: catches from the US Vancouver INPFC area were designated to Washington, catches in the Columbia INPFC area were allocated to Oregon, and catches from the Eureka and Monterey INPFC areas were assigned to California. These definitions match where the majority of commercial trawl landings occur by state for each INPFC area within PacFIN.

2.2.2 Composition Data

Commercial landings of rockfish and the biological characteristics of these landings were not consistently sampled for scientific purposes until the early 1960s (Niska, 1976). Statewide sampling programs to determine species compositions of the landed catches began in the late 1960s. The first rigorous monitoring programs that included routine collection of biological data (e.g., sex, age, size, maturity states, etc.) were begun in 1980. Currently, port biologists employed by each state fishery agency (ODFW, WDFW) or PSMFC with the California Cooperative Groundfish Survey (CCGS) collect species-composition information and biological data from the landed catches of commercial vessels that have completed their fishing trips. The sampling sites are commonly processing facilities located at ports along the coasts of California, Oregon and Washington. The monitoring programs currently in place are generally based on stratified, multistage sampling designs.

Recreational landings of rockfish and the biological characteristics of these landings were not consistently sampled for scientific purposes until the late 1970s. The first rigorous monitoring programs that included routine collection of biological data (e.g., sex, age, size, maturity states, etc.) began in 1980 by the national MRFSS program under the PSMFC and by state sampling programs. State sampling programs replaced MRFSS in the 2003–2004 period to better support in season management. Currently, port biologists employed by each state fishery management agency (CDFW, ODFW, WDFW) collect catch, effort, and biological data from the landed catches of recreational vessels that have completed their fishing trips. Onboard sampling also occurs on party/charter vessels in Oregon and California.

Twenty-eight bins from 12 to 66 cm were used to summarize the length frequency distributions of fishery-dependent and fishery-independent sources of catch. The first bin includes all observations less than 12 cm and the last bin includes all fish larger than 66 cm. Thirty-five data bins from age 1 to age 35 were used to summarize the age frequency distributions of fishery-dependent sources of catch, with the last bin including all fish aged greater than 35 years and the first bin including the (very small) number of age-0 fish. Conditional age at length data was used to summarize fishery-independent sources of age data, and is described in more detailed in Section 3.3.5.3.

2.2.2.1 Commercial Trawl and Non-trawl Fisheries Length- and marginal age-frequency distributions were calculated for each commercial fleet for which observations were available. Biological length and age data were extracted from the PacFIN Biological Data System on May 8, 2023. Biological data were divided into trawl and non-trawl fleets for each state according to the fleet structure used for this assessment (see Section 3.3.5.1). Length samples were available starting in 1977 for California fleets, 1973 for Oregon fleets, and 1968 for Washington fleets. Age samples were available starting in 1980 for all states' fleets. There was a mix of biological length and age samples with and without sex information but the majority of length and nearly all age samples included information on sex, so were modelled as sex specific compositions.

During data exploration it was noted that samples previously labelled as special project samples from Oregon were appropriate to represent dynamics from the fishery. The majority of these occurred during 1973–1986, and therefore 5,859 special project samples from Oregon through 1986 were retained for composition data. Also during data exploration, there were 700 age samples from Washington without a final age determination. These represented a small proportion of samples among the years which they occurred and so were excluded.

Among age samples, 6,645 were from surface reads, starting in 1973 for Oregon and 1975 for Washington. Ages of surface reads were truncated to around 30 prior to 1980, and were more similar to break and burn reads when both were available starting in 1980. Given known biases of surface reads, and the clear truncation in years where only surface years were available, we excluded surface reads from age compositions.

For commercial trawl and nontrawl fleets, the raw observations (compiled from PacFIN) were expanded to the sample level, to allow for any fish that were not measured, then to the trip level to account for the relative size of the landing from which the sample was obtained. These expanded length and age observations were then combined within a year for each fleet.

The input sample sizes for the expanded commercial length and age data were calculated based on a combination of the number of trips or hauls and fish by year:

$$\text{Input effN} = N_{\text{trips}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{trips}} < 44$$

$$\text{Input effN} = 7.06 * N_{\text{trips}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \geq 44$$

The magnitude of sampling for each fleet and year are given in Table 4 and Table 5, which shows the different magnitudes of sampling across time and between state agencies. These tables show both the total number of fish sampled as well as the number of trips by year and state over which samples were obtained. During modeling we noticed sparse length and age composition data of unsexed fish for several years across fleets. Composition data with very few unsexed length and age samples relative to sexed samples within a year were excluded from the model.

The weighted commercial length-frequency distributions are shown in Figures 4-9. A number of important patterns are visible in the data, although the data are noisy. The trawl fleets appear to show a decline in mean length of the catch from 1978 to 1990 for California and from around 1980 to 2000 for Oregon (Figures 4 and 5), with variable length since 2000 and some increase from around 2013 for the Oregon and Washington trawl fleets (Figures 5 and 6). The length-frequency distributions from the non-trawl fleet are much more sparse compared to the trawl fleet, especially during the period of non-retention where no lengths were sampled, making it difficult to discern a pattern in the mean length landed (Figures 7-9). However, Oregon non-trawl lengths show some decline during the 1990s and Oregon and California non-trawl lengths show increases in the most recent years, though these can also be explained by changes in regulations for canary rockfish in recent years.

The weighted marginal commercial age-frequency distributions are shown in Figures 10-15. Age data for California were sparse (no data between 1987 and 2001 as well as in 2008 and 2011–2012) compared to age data from Oregon and Washington (Figure 10) but sample sizes have increased in recent years. Age compositions for the trawl fleets were generally similar, ranging from approximately 5 to 25 years, with peaks at 10 years of age for both sexes. Mean age from the Oregon trawl fleet shows a clear decline from around age 20 from the mid-1980s to around age 10 in 2000, with periods of increases each decade since 2000 (Figure 11). Washington age data show highly variable patterns that make general patterns difficult to determine (Figure 12). Age data for the non-trawl fleet for all states are sparse enough that no pattern can reliably be discerned (Figures 13–15) though the distribution of ages in Washington is shifted towards older canary rockfish compared to other states' non-trawl and trawl fisheries, possibly due to the lack of a nearshore non-trawl fishery in Washington.

2.2.2.2 At-sea hake fishery Length- and marginal age-frequency distributions were calculated for the at-sea hake fishery using data collected by the NWFSC ASHOP (extracted on 3/31/23 for lengths and 5/1/2023 for ages). Length and age observations were available starting in 2003, which was after the period that at sea processing was restricted to north of 42°N. Consequently, length and age compositions were only available for Oregon and Washington components of the at-sea hake fishery. Raw observations were aggregated within a year for each fleet, and the input sample sizes for composition data was the number of hauls.

The magnitude of sampling for the at-sea hake fishery is given in Table 6 and Table 7. These tables show both the total number of fish samples as well as the number of trips by year and state over which samples were obtained and which were used as input sample sizes. During modeling we noticed sparse length and age composition data of unsexed fish for several years across fleets. Composition data with very few unsexed length and age samples relative to sexed samples within a year were excluded from the model.

The at-sea hake fishery was comprised of similarly sized canary rockfish relative to the commercial trawl fisheries and exhibited little trend over time (Figures 16-17). Age data were also comparable to ages from the commercial trawl fisheries and show little discernible pattern over time (Figures 18-19).

2.2.2.3 Foreign fishery

No length or age data were available from foreign fleets. Selectivity of these fleets was assumed to be the same as the respective state trawl fleets.

2.2.2.4 Recreational fishery

Length- and marginal age-frequency distributions were calculated for each recreational fleet for which observations were available. Biological length and age composition data were extracted from various sources. For Washington, biological samples starting in 1979 (for lengths) were obtained from sport biodata as provided by WDFW on April 27, 2023. Age samples began in 2004. For Oregon, biological samples starting in 1980 (for lengths) were obtained from ODFW via the MRFSS and ORBS sampling programs as accessed via RecFIN on January 25, 2023 for lengths and April 28, 2023 for ages. Age samples began in 1999. For California, length samples 1980–2003 were obtained via the MRFSS sampling program as accessed via RecFIN (accessed March 30, 2023) and provided by CDFW. Length samples starting in 2003 were obtained via the CRFS sampling program as accessed via the RecFIN website (accessed April 14, 2023). Length samples collected from the Deb Wilson-Vandenberg onboard CPFV survey for 1987–1998 were also obtained from CDFW. California has no aged samples of canary rockfish available from MRFSS or CRFS sampling.

Between 1987-1989 and 1993-1998 there were recreational length data for the CPFV fleet from both MRFSS and the Deb Wilson-Vandenberg data sets. During data exploration it was determined that the lengths in MRFSS from 1997 and 1998 were also in the Deb Wilson-Vandenberg data, indicating that these data sources were duplicated for these years but also potentially other years where they overlapped. In order to avoid duplicate data, the length data from MRFSS for private/charter mode, which had far fewer length samples for the overlapping years than Deb Wilson-Vandenberg for the CPFV fleet, were removed from the data used within the model. A sensitivity was run using only the MRFSS data to test the effect of this choice (see Section 3.5.2).

Biological length data were aggregated across party/charter and private/rental mode based on similarity in the overall length distributions, and consistent with past canary rockfish assessments. There was a mix of biological length and age samples with and without sex information. The majority of length samples for Washington and Oregon, and all length samples for California did not include information on sex. The majority of age samples included information on sex, so were modeled as sex-specific age distributions. Only lengths from retained fish were used and only samples from ocean areas. In addition, ODFW provided MRFSS length samples with the addition of a column that flagged length values imputed from weights to allow for selection of directly measured values. A sensitivty to using lengths from both retained and released fish was explored and described in Section 3.5.2. Altogether there were very limited number of samples from inland/estuary areas and from which direct measurements were not available so no sensitivity of inclusion of these samples was done.

For each fleet, the raw observations were aggregated within a year. A catch-weighted approach was explored for Oregon and Washington observations from RecFIN because these states have a formalized appraoch (E.J. Dick, SWFSC, personal communication, 3/28/23) and a separate data table exists within RecFIN (J. Edwards, PSMFC, personal communication, 3/30/23) that includes the weightings. The catch-weighted distributions were very similar to the distributions based on raw observations, so raw distributions were used for simplicity.

The approach to determine the input sample sizes for the recreational length and age data varied by data source and data type. Some data sources had unique trip numbers within the data such as the Deb Wilson-Vandenberg data and the Oregon CPFV releases. Other data sources that lacked a clear trip identifier used combinations of multiple fields to attempt to estimate unique combinations that represented the number of trips sampled. In general the number of trips for both age and length composition data was estimated based on a mix of time, location, and fishery type. The number of trips for length and age compositions from Washington sport biodata was estimated using a combination of fish sample date (or sample date if blank), fish (or sample) punch card area, and fishing mode. The number of trips for length compositions from ORBS sampling was estimated using a field (ANGLER_ID) that encompasses time, area, and fishing mode. The number of trips for age composition from ORBS sampling was estimated using sampling date, sampling site (PORT_NAME), and fishing mode. The number of trips for length compositions from MRFSS sampling was estimated using year and id code, MRFSS area code and sampling location (INTSITE for California or ORBSport for Oregon), and fishery mode. The number of trips for length compositions from CRFS sampling was estimated using sampling date, sampling site (COUNTY_NUMBER), and fishing area and mode. Collectively, the estimates for the number of trips are meant to represent a reasonable starting point that generally reflects the degree of similarity of information from sampling a given number of likely similar fish within any sampling event.

The magnitude of sampling for each fleet and year is given in Table 8 and Table 9, which show the different sampling frequencies employed over different time periods and between state agencies. These tables show both the total number of fish samples as well as the number of trips by year and state over which samples were obtained and which were used as input sample sizes. During modeling we noticed sparse age composition data of unsexed fish for a few years across recreational fleets. Composition data with very few unsexed age samples relative to sexed samples within a year were excluded from the model.

The recreational length-frequency distributions are shown in Figures 20-22. All three recreational fleets appear to generally catch smaller fish relative to the commercial fleets within the same state, likely due to differences in fishing depth. Recreational lengths from California are highly variable, with sizes typically between 20-40 cm, but with sudden shifts in time (Figure 20). Recreational lengths from Oregon are less variable and typically range 25-40 cm, but had limited and variable sampling during the period of non-retention (Figure 21). In Washington, recreational lengths tend to be larger than in either California and Oregon, typically ranging from 30-45 cm (Figure 22). Length distributions for all recreational fleets showed an increase is sizes in recent years, which could be due to changes in regulations. Length distributions aggregated over all years for Oregon and Washington also showed patterns of bimodality with a peak around 35 cm and then another around 50 cm (Figure 23). This pattern was not due to combining across modes as it was present for both party/charter and private/rental modes.

The recreational marginal age-frequency distributions are shown in Figures 24-25. Recreational ages were typically younger than in commercial fisheries. Ages ranged between 5-10 years but had long tails of older fish, with a larger proportional tail of older fish observed in Washington compared to Oregon. An increase in the age of sampled catch was observed in both Washington and Oregon recreational fleets, although the few years of Washington samples makes comparisons difficult. The changes in regulations in recent years complicate whether this pattern was due to increased ages of fish in the population or changes in fishing practices.

2.3 Fishery-Independent Data

Fishery-independent data are derived from three main sampling programs: the Triennial Survey (1980-2004), the WCGBTS, and the pre-recruit survey (2001-2022). Each source of information is used to generate an index of abundance. The Triennial Survey and WCGBTS also provide age and length-composition sampling data and were extracted on May 1, 2023 and February 13, 2023, respectively.

2.3.1 West Coast Groundfish Bottom Trawl Survey

The WCGBTS is based on a random-grid design, covering the coastal waters from a depth of 55-1,280 m (Bradburn et al. 2011). This design uses four vessels per year (except in years 2004 and 2014, when only three vessels were available, and 2020 when the survey did not occur due to COVID-19), assigned to a roughly equal number of randomly selected grid cells divided into two 'passes'. Two vessels fish from north to south during each pass between late May to early October. This design therefore incorporates both vessel-to-vessel differences in catchability, as well as variance associated with selecting a relatively small number (approximately 700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian borders.

The WCGBTS encounters canary infrequently, generally in less than 10% of the total tows conducted, though this includes slope tows well beyond the depth canary inhabit (Table 10). However, when canary aggregations are encountered, catches can be as large as 4.9 mt in a single 12-15 minute tow; this equates to an average density of approximately 1 kg every 2.5 m^2 or 0.4 $kg \cdot m^{-2}$. There are 19 tows that have encountered at least 500 kg of canary, and 4 tows have encountered over 1000 kg (2088 kg in 2015, 3033 kg in 2017, 3650 kg in 2018, and 3984 kg in 2006). These large tows are located primarily off the northern Washington coast near the Canadian border, with some located off the Oregon or Northern California coasts (Figure 26) . The presence of infrequent very large tows creates a strongly right-skewed distribution of catch rates, still visible after log-transformation. These very large catches do not appear to be dominated by either very large individuals or very small individuals, indicating that these areas represent neither recruitment 'hot-spots', nor unexploited 'pockets' of very old canary rockfish.

2.3.2 Triennial Survey

Prior to the WCGBTS, the triennial shelf trawl survey conducted by NMFS starting in 1977 served as the main fishery-independent data source regarding the abundance of canary rockfish in the California Current (Dark and Wilkins 1994). The sampling methods used in the survey over the 24-year period are most recently described in Weinberg et al. (2002); the basic design was a series of equally spaced transects from which searches for tows in a specific depth range were initiated. In some parts of the coast this led to a very non-random allocation of stations with regard to the entire shelf area. In general, all of the surveys were conducted in the mid-summer through early fall: the survey in 1977 was conducted from early July through late September; the surveys from 1980 through 1989 ran from mid-July to late September; the survey in 1992 spanned from mid-July through early October; the survey in 1995 was conducted from early June to late July; the 1998 survey ran from early June through early August; and the 2001/2004 surveys were conducted in May-July. The initial year of the survey in 1977 was based on a sampling design that spanned from 50 to 260 fm (91 to 475 m) and did not come as far inshore (30 fm) as the subsequent surveys conducted on a triennial basis from 1980 to 2001.

Surveys that have extended south of Monterey have detected only very small abundances relative to the north, so changes in sampling in this area does not influence the relative index. Because of the large number of 'water hauls' eliminated in 1977, especially in the U.S. Vancouver INPFC area, and because the sampling depths were not the same as the other years, the 1977 survey year was not used in the assessment. A full description of the water haul issue can be found in Zimmerman et al. (2001).

2.3.3 Pre-recruit survey

The Fishery Ecology Division of the SWFSC has conducted a standardized pelagic juvenile trawl survey (the Rockfish Recruitment and Ecosystem Assessment Survey) during May-June every year since 1983 (Ralston et al. 2013; Sakuma et al. 2016; Field et al. 2021). A primary purpose of the survey is to estimate the abundance of pelagic juvenile rockfishes (*Sebastes spp.*) and to develop indices of year-class strength for use in groundfish stock assessments on the U. S. West Coast. This is possible because the survey samples young-of-the-year rockfish when they are ~100 days old, an ontogenetic stage that occurs after year-class strength is established, but well before cohorts recruit to commercial and recreational fisheries. This survey has encountered tremendous interannual variability in the abundance of the species that are routinely indexed, as well as high apparent synchrony in abundance among the ten most frequently encountered species (Ralston et al. 2013). Past assessments have used data from this survey to provide indices of year-class strength (as relative age-0 abundance), including the 2015 Canary rockfish assessment, and assessments for widow rockfish (Adams et al. 2019), blue/deacon rockfish (Dick et al. 2018), bocaccio (He et al. 2015), shortbelly rockfish (*Sebastes jordani*, Field et al. 2007), and chilipepper rockfish (*Sebastes goodei*, Field et al. 2015).

Historically, the survey was conducted between 36°30′N and 38°20′N latitude (the 'core area' from approximately Carmel, CA to just north of Point Reyes, CA), but starting in 2004 the spatial coverage expanded to cover from the U.S./Mexico border to Cape Mendocino. Additionally, since 2001 data are available from comparable surveys conducted by the Pacific Whiting Conservation Cooperative and the NWFSC (2001–2009) and the NWFSC "Pre-recruit" survey (2011–2022) for waters off of Oregon and Washington (Field et al. 2021). Coastwide data have revealed both spatial differences in species composition (e.g. north and south of Point Conception) and interannual shifts in the distribution of most pelagic juvenile rockfishes: The near absence of fish in the core survey area during the 2005–2007 period, which saw two of the lowest abundance levels of juvenile rockfish ever observed in the core area time series, was associated with an apparent redistribution of fish, both to the north and the south (Ralston and Stewart 2013). As the core area index seems to have failed to capture the magnitude of the 1999 year class for most stocks, the recommendations from the juvenile rockfish survey workshop held in 2005 were to use only the coastwide data (since 2001) for juvenile indices rather than the longer-term 'core area' indices unless a convincing case could be made otherwise. We used data from 2001 to 2022, the period for which we have coastwide coverage. On account of the COVID-19 pandemic, sampling in 2020 was very limited and restricted to the historical core area, so this year is excluded. In the years 2010, 2012, and 2022, sampling did not span the entire coastwide spatial domain, with data lacking from northern CA and OR. These years were not included in the model, but sensitivity of the stock assessment to inclusion of the index for these years is explored in sensitivities.

Catch per tow was adjusted to a common age of 100 days (see Ralston et al. (2013) for details) to account for interannual differences in age structure, as has been done for prior assessment indices using this dataset. Similar to the previous assessment, the data were used as an index of spawning output × exp(recruitment deviation), or recruitment before density dependence has occurred. We also explored using the data as an index of age-0 recruits, and results were identical.

2.3.4 Index standardization

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

2.3.4.1 WCGBTS The data were truncated to depths less than 275 m prior to modelling given that there were zero positive encounters in depths deeper than 275 m. The prediction grid was also truncated to only include available survey locations in depths between 55–275 m to limit extrapolating beyond the data and edge effects.

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

Spatial and spatiotemporal variation was included in the encounter probability model and spatial variation was included in the positive catch rate model. The variance of the spatiotemporal effect was estimated to be less than 0.01 for the positive catch rate model and was therefore not included in the final model. Spatial variation was approximated using 200 knots, where more knots led to non-estimable standard errors because the positive encounters are too sparse to support the dense spatiotemporal structure.

2.3.4.2 Triennial Survey The data were truncated to depths less than 366 m and latitudes north of 37°N prior to modelling to control for temporal changes in survey extent. No canary rockfish were ever encountered below 366 m and only 13 tows encountered canary rockfish south of 37°N out of 831 total tows that encountered canary. The data also excluded any tows outside of the U.S. exclusive economic zone (i.e., in Canadian waters). The prediction grid was truncated to these same extents to limit extrapolating beyond the data and edge effects.

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

Spatial and spatiotemporal variation was included in the encounter probability model and spatial variation was included in the positive catch rate model. The variance of the spatiotemporal effect was estimated to be less than 0.01 for the positive catch rate model and was therefore not included in the final model. Spatial variation was approximated using 200 knots, where more knots led to non-estimable standard errors because the positive encounters are too sparse to support the dense spatiotemporal structure.

2.3.4.3 Pre-recruit survey For the index model, we used data from 35–48.2°N latitude (just north of Point Conception to La Push, WA). Canary rockfish were never caught south of 35°N. Since catch (and sampling) varied over space and time, we modeled catch using a spatial GLM with the package `sdmTMB` (Anderson et al. 2022). The 100-day-standardized catch per tow was modeled as a function of fixed year effects along with Julian date (GAM smoother with k=4) to account for seasonality, a spatial random field, and IID spatiotemporal random fields.

We fit the model using 3 different error structures: tweedie, delta-lognormal, and delta-gamma. Dharma quantile residuals from model simulations suggested that tweedie distribution was the best fit, and so was used. The tweedie model also best reproduced the observed proportion of zeros in the data based on simulations from the fitted model. As expected, the Julian date effect showed a decline in catch towards the end of the sampling season, as juveniles begin to settle out of the water column.

For the coastwide index, predictions from the model were made for all active sample stations within the survey region, for the mean Julian date, for each year. Predictions were added together for each year to produce the index. Active stations are those regularly and consistently sampled, and are located on a semi-regular grid spanning the sampling region. Interpolating to a finer spatial grid had little impact on the resulting index.

2.3.5 Survey composition data

Biological data were extracted from the NWFSC data warehouse on February 13, 2023 for the WCGBTS and May 1, 2023 for the Triennial Survey. For the length-composition samples from the WCGBTS, data bins are populated with a modest, but consistent degree of sampling: 32-84 tows and 306-1467 fish lengths per year (Table 10). The Triennial Survey (Table 11) had both more positive tows each year (42-177) and more fish lengths per year (356-2781). Compositions and input sample sizes were calculated by standard procedures in the `nwfscSurvey` package using sample size multipliers from Stewart and Hamel (2014) for shelf rockfish ($2.43 * N_{\text{tow}}$) and the following strata separations:

- WCGBTS latitudes: 32 (Mexican border), 34.5 (change in survey design), 42 (California-Oregon border), 46 (Oregon-Washington border), 49 (Canadian border) degrees North
- WCGBTS depths: 55 (minimum survey extent), 183 (change in survey design), 350 (depth limit of canary rockfish) meters

- Triennial Survey latitudes: 37 (southernmost latitude with consistent sampling across years), 42, 46, 49 degrees (as noted above) degrees North
- Triennial Survey depths: 55 (minimum survey extent), 183 (change in survey design), 350 (depth limit of canary rockfish) meters

State strata were included to account for the fact that age and length tends to increase northward along the coast (Keller et al. 2018; Brooks 2021).

The survey length-frequency distributions are shown in Figures 27-29 and indicate the WCGBTS catches a wide range of lengths with generally little change in size over time, and that lengths in the Triennial Survey were also similar over time except smaller sizes in 1992 and larger sizes in 2004.

The conditional-age-at-length samples consist of approximately one-quarter as many fish as the samples for length (Table 10 and 11). These distributions show a tight range of ages at a given length, and show the growth trajectory of females reaching larger sizes than males for a given age (see Section 2.4). Besides the addition of recent survey years, this assessment also includes data for the first time from recently aged otoliths from the 1986 Triennial Survey. Compositions were again calculated using the `nwfscSurvey` package and the same strata as the length compositions, with input sample sizes fixed at the number of unique fish within a given length bin (Wetzel et al. 2023).

2.4 Biological Data

2.4.1 Natural Mortality

Due to an unexplained male-skewed sex ratio at older ages observed across fishery-independent and fishery-dependent data sources, canary rockfish natural mortality has been modeled in a number of ways over the years. Sampson (1996) modeled a linear ramp in female natural mortality from 0.06 yr^{-1} at age 9 to roughly 0.18 yr^{-1} at age 25, the plus group. In 1999, the ramp was adjusted to be from 0.06 at age 11 to 0.20 at age 25, and the document contains an extensive review of life history theory regarding increasing female natural mortality (Crone et al. 1999). Methot and Piner (2002) fixed male and young female natural mortality at 0.06, but estimated an offset for older females, and based the slope of increasing natural mortality on maturity, not age, resulting in a non-linear ramp by age. In 2005, that option was no longer available in stock synthesis, so the assessment approximated the 2001 pattern by using a linear ramp from age 6 to age 14, again estimating a female offset (Methot and Stewart 2005). This has been the approach for all canary rockfish assessments since 2005.

The increased ramp in natural mortality was also used in yellowtail rockfish assessments prior to 2005 with support from Tagart (1991) that the senescent mortality hypothesis fit the fishery age data well, and was a better biological explanation for the disappearance of older age females than the alternative hypothesis that the older females were not vulnerable to the fishery. The pattern of male-skewed sex ratio at older ages has been observed along the U.S. West Coast in fishery data off Oregon (Rasmuson et al. 2023), Canada (DFO 2023), and Alaska and in black rockfish in addition to canary and yellowtail rockfishes. Although it has been found in these three semi-pelagic species, the pattern has not been observed for bocaccio, chilipepper rockfish, shortbelly rockfish, or dusky rockfishes (*Sebastes ciliatus*, in Alaska), which are also semi-pelagic. However, starting in the 2010's the sex ratio has been less skewed in fishery data off Oregon (Rasmuson et al. 2023). The sex ratio has remained male-skewed within the WCGBTS in recent years.

In this assessment, we elect to model natural mortality for males and females separately as has been done in past assessments. After consultation with state biologists, we also elect to model natural mortality as age-invariant. This provides a more parsimonious approach to modeling natural mortality than using a linear ramp (as mentioned in PFMC 2023) which has been done for past assessments. Secondly, both a linear ramp and breakpoint with increasing female natural mortality at age does not align with the general life history belief that natural mortality declines with age (Lorenzen 1996). We updated the longevity-based prior for the natural mortality rate for males and females based on Hamel and Cope (2022), using a maximum age of 84 yrs, the same age used in the previous assessment (Love et al. 2002; Thorson and Wetzel 2016). This results in a lognormal prior with a log-mean of -2.74, a log-standard deviation of 0.31, and a median natural mortality of 0.0643 yr^{-1} for both sexes. As was done in the previous assessments, we fixed the male natural mortality value at the prior and estimate female natural mortality. The same maximum age for males and females was used. Estimating separate male and female natural mortality removes the need for a user-selected breakpoint or linear ramp, and has been done in the past assessments for yellowtail (Stephens and Taylor 2017) and black rockfish for Washington and California (Cope et al. 2016). Sensitivities to the choice of natural mortality structure are described in Section 3.5.2.

2.4.2 Maturity

We estimate the maturity schedule using available histological measurements from female ovaries. This includes 226 samples collected by ODFW and WDFW during winter (October–February) in 2014, 2015, and 2016; and 527 ovaries collected during the WCGBTS in 2009–2016 across a range of depths (57–222 m) and latitudes (35.7–48.3$^{\circ}N$) and 53 collected during the Hook and Line Survey between 2009–2022.

We use functional maturity rather than biological maturity as the measure of maturity in this assessment. Rockfish begin the process of maturing several years before they reach spawning potential. Thus biological maturity would indicate that yolk is present but not that the fish is spawning capable. Juveniles in abortive maturation and adults in skip spawning would be marked as biologically mature but functionally immature. Biological maturity indicates the fish was putting energy reserves toward spawning, but not necessarily spawning capable for the year; functional maturity captures the actual spawners.

We estimate maturity in this assessment using age at maturity. Not all histological samples included ages, so a total of 777 samples were used for estimating age at maturity. We assume age at maturity follows a two-parameter logistic regression model with an asymptote at 1 based on the findings of Head et al. (2016) and fits to histological samples. Parameters were fixed in the model at estimates from the logistic regression, and were $A_{50\%} = 10.87$ and slope $\alpha = -0.69$. This relationship is an improvement to the maturity curve used in the previous assessment, as it uses functional maturity instead of biological maturity. This, in addition to the use of age instead of length, eliminated the need for a third parameter in the maturity curve estimating the probability of skip spawning. Due to variation in the growth rate, a given length can represent a wide range of ages, especially at larger sizes. The new relationship results in a rightward shift in maturity and increase in maturity at older ages compared to the relationship derived within the 2015 assessment (Figure 30).

2.4.3 Fecundity

Fecundity was fixed at the parameter values from the meta-analysis in Dick et al. (2017). Existing species specific fecundity information for canary rockfish is limited and only 9 samples of canary rockfish exist within the rockfish fecundity database housed at the Southeast Fisheries Science Center (SEFSC) (S. Beyer, University of Washington, personal communication, 5/22/23). Dick et al. (2017) performed their analysis on subgenera with at least three species, which excluded canary rockfish, so the relationship in Dick et al. (2017) for general *Sebastes* species was used for this assessment. Fecundity was assumed as a power function of length, as in Dick et al. (2017), whereas the previous assessment assumed fecundity was linearly proportional to weight and used parameter estimates from Dick (2009). Although these reflect different parameterizations, they are transferrable based on the weight-length relationship. The fecundity relationship for this assessment was $7.218e - 08L^{4.04}$ in millions of eggs where L is length in cm. The new relationship results in a decrease in fecundity at larger sizes compared to the relationship used in the 2015 assessment (Figure 31).

2.4.4 Steepness

Steepness is defined as the proportion of average recruitment for an unfished population that is expected for a population with 20% of unfished spawning output. It represents a measure of compensation in the spawner-recruit relationship. It is typically difficult to estimate using data for a single population (Conn et al. 2010), which has led to a series of meta-analyses to estimate its likely value (Myers et al. 1995; Dorn 2002).

Steepness in this assessment was fixed at the prior mean value. The SSC-approved prior for steepness in 2023 assumes a beta distribution with a mean of 0.72 and standard deviation of 0.16 (PFMC 2023). The prior parameters are based on the Thorson-Dorn rockfish prior (commonly used in past West Coast rockfish assessments) which was reviewed and endorsed by the Scientific and Statistical Committee (SSC) in 2017. However, this approach was subsequently rejected for future analysis in 2019 when the new meta-analysis resulted in a mean value of approximately 0.95. In the absence of a new method for generating a prior for steepness the default approach reverts to the previously endorsed method, the 2017 value.

2.4.5 Length-Weight Relationship

The length-weight relationship for canary rockfish was estimated outside the model using available coastwide biological data collected from the WCGBTS. This included 3593 females and 4576 males. The estimated length-weight relationship for canary rockfish was $W = 1.19e - 05L^{3.09}$ for females and $W = 1.08e - 05L^{3.12}$ for males, where L is fork length in cm and W is weight in kg and is similar between sexes (Figure 32). The curve was fit as a linear model in log space and then corrected for lognormal bias. The relationship is similar to the relationship used in the previous 2015 benchmark assessment which also indicated that male and female canary rockfish have similar length-weight relationships (Figure 33).

2.4.6 Growth (Length-at-Age)

Canary rockfish display sexually dimorphic growth. Females reach larger maximum sizes than males and take longer to reach that size. Recent research also indicates that canary rockfish growth varies latitudinally (Gertseva et al. 2017; Keller et al. 2018; Brooks 2021). Using WCGBTS and Hook and Line Survey data and considering breakpoints at the biogeographic boundaries of Point Conception and Cape Mendocino, Keller et al. (2018) found growth differences that were statistically significant but inconsistent across sexes.

However, the bulk of the canary rockfish population, and particularly the bulk of older individuals needed to reliably estimate a growth curve, are found north of Cape Mendocino. More consistent with theory, Brooks (2021) found that individuals of both sexes tended to grow slower and to larger sizes farther north, with a break point estimated between Coos Bay, OR and Newport, OR based on data from samples collected in untrawlable habitat, with similar numbers coming from each major port along the coast. We explored estimating two growth curves external to the assessment model split at Coos Bay, OR, but using the more expansive WCGBTS data (1567 vs. 8424 samples; maximum age of 51 vs. 65). Results indicated that although individuals captured north of Coos Bay did grow to slightly larger sizes than those captured south of Coos Bay, particularly female individuals, the differences were biologically minor and did not warrant the additional complexity in the stock assessment model (Figure 34). Thus, growth was assumed constant across the coast, as was assumed in the 2015 benchmark assessment. Externally estimated von-Bertalanffy growth parameters for canary rockfish using WCGBTS data were as follows: $L_\infty = 57.9$ cm and $k = 0.143$ for females with length at age 1 equal to 11.38 cm, and $L_\infty = 51.3$ cm and $k = 0.175$ for males with length at age 1 equal to 11.36 cm. We therefore assume size of young males and females are identical, consistent with the assumptions in the 2015 benchmark assessment. Though the estimates differ slightly, these parameters (L_∞, k, length at age 1) are identical to those estimated internally within the stock assessment model.

2.4.7 Sex Ratio

As described in the mortality section, the observed sex ratio is skewed towards males at older ages (Figure 35). The sex ratio based on length is skewed towards females at larger sizes due to the sexually dimorphic growth (Figure 36). For young fish, there were limited sex-specific observations by length or age across data sources. The WCGBTS had the highest frequency of small fish observed. However, as revealed in the figures above, many of the small fish observed by the survey were too small for sex determination. In the absence of evidence of a differential sex ratio at birth, the sex ratio of young fish was assumed to be 1:1.

2.4.8 Ageing Precision and Bias

The ageing error matrices used in the 2015 benchmark assessment for break and burn samples were retained for this analysis. Ageing error was explored in the 2015 assessment including extensive model selection and exploration on the ageing methods to include and the appropriate ageing lab to treat as unbiased (Thorson and Wetzel 2016). An extensive description on the history of including ageing error and bias into past canary assessments was also provided in the 2015 assessment (Thorson and Wetzel 2016). Surface read ages were not included in this assessment and therefore surface read ageing error matrices from the 2015 assessment were not retained in the model.

Per the 2015 assessment, ages from the CAPS ageing laboratory were assumed unbiased, and a linear bias for break-and-burn reads from ODFW and WDFW ageing labs were estimated along with a constant coefficient of variation (CV) for imprecision for break-and-burn reads from CAPS, ODFW, and WDFW. The estimated pattern for bias and imprecision from the 2015 assessment indicates that ODFW break-and-burn reads are almost unbiased relative to CAPS break-and-burn reads, and the WDFW break-and-burn reads have a positive bias relative to CAPS break-and-burn reads (+3.76 yrs. at age 30, their Figure 38 in Thorson and Wetzel 2016).

There is little evidence to suggest ageing estimation has changed over time relative to the samples included in the previous analyses. A new TMB-based ageing error software has been developed (A. Punt, University of

Washington, personal communication, 2023) but has not yet been fully explored or documented. Therefore, revision of the ageing error matrices has been left as a research project to be completed in time for the next full assessment.

2.5 Environmental and Ecosystem Data

This assessment does not include any environmental or ecosystem data.

2.6 Data Sources Considered But Not Used

2.6.1 California Commercial Collection Report System (CCRS)

From 1977–1985, CCRS provided data on commercial passenger fishing vessels sampled at dockside. This study was very limited in spatial scale, focusing efforts on a limited portion of the species range in the Monterey Bay, California area representing only the southern end of the distribution of canary rockfish. In addition, this region is unique in providing access to deeper depths a short distance from shore along the sub-marine canyons of Monterey and Carmel Bays potentially biasing representation relative to the entire coast north of Point Conception within California where they are commonly found. Though 488 canary rockfish were sampled during the duration of the survey limited geographic representation at the southern edge of the species range and lack of representation from other ports with more distant grounds on the shelf/slope limits the utility of this data and comparability to other data sets.

2.6.2 Historical CDFW Dockside Sampling

A dockside sampling effort was undertaken by CDFW during the 1950s-1970s to collect data from the private and rental boat and party charter fleets. Data collected from 1958 to 1972 was from (Miller and Gotshall 1965) and (Miller and Geibel 1973) and efforts were made to digitize data from sample sites in the Monterey Bay Area from Ano Nuevo to Point Sur. Over the course of the survey, 1032 canary rockfish lengths were collected from party boats and 461 from private boats. The limited geographic representation at the southern edge of the species range and lack of representation from other ports with more distant grounds on the shelf/slope limits the utility of this data and comparability to other data sets.

2.6.3 California Recreational Indices

2.6.3.1 California Collaborative Fisheries Research Program (CCFRP) The CCFRP has conducted fishery-independent data collection efforts onboard commercial passenger fishing vessels both inside and outside of MPAs between 2007 and present. Aspects of canary rockfish life history make the data set less than ideal. One important consideration is the limitation of sampling to less than 150 ft to minimize barotrauma for fish released by this hook and line survey, which limits access to the primary depth distribution of adult canary rockfish. In addition, until 2017 the sampling was focused on central California. While additional data has been collected subsequently to better represent the statewide abundance of groundfish stocks, and sampling of only shallow waters could have the potential to inform year class strength, the limited depths sampled and spatial limitations early in the survey reduce the utility and representativeness of the survey for this northerly distributed stock at this time. Lastly, the high degree of vagility of canary rockfish makes accounting for MPA effects of lesser importance reducing the impetus to account for trends in closed areas for this species.

2.6.3.2 Deb Wilson-Vandenberg Index for CPFV/PC Mode

The Deb Wilson-Vandenberg data set originated from an onboard observer survey conducted by CDFW in central California from 1988–1998 and is referred to as the Deb Wilson-Vandenberg onboard observer survey (Reilly et al. 1998). The fine-scale catch and effort data allow better filtering of the data for indices to fishing stops within suitable habitat for the target species. Length data from this dataset was applied in the assessment but the representativeness as a fishery-dependent index to inform coastwide dynamics is questionable. As such, we did not pursue development of an index from this dataset.

2.6.3.3 CRFS Onboard CPFV Index

The state of California implemented a statewide onboard observer sampling program in 1999 (Monk et al. 2014). The program surveys the commercial passenger fishing vessel (CPFV) fleet fishing out of 15 coastal counties and two counties inside San Francisco Bay, representing 46 site locations. Observers collect spatially-explicit catch and release records. During an onboard observer trip the sampler rides along on the CPFV and records location-specific catch and discard information to the species level for a subset of anglers onboard the vessel. Due to similar concerns about representativeness of a coastwide index as other state specific indices of abundance, as well as concerns with shifts in fishing due to significant changes in the regulations during this time period, we did not pursue development of an index from this dataset.

2.6.4 California Remotely Operated Vehicle Survey

CDFW in collaboration with Marine Applied Research and Exploration (MARE) have been conducting remote operated vehicle (ROV) surveys along the California coast in Marine Protected Area (MPA) and reference sites adjacent to them since 2007 for the purposed of long-term monitoring of changes in size, density (fish/sq meter) and length of fish and invertebrate species along the California coast. Surveys of the entire coast have been undertaken twice, taking three years to complete each resulting in super years of 2015 (2014–2016) and 2020 (2019–2021) available for analysis. The use of this data in stock assessments was approved by the SSC for use in stock assessments after a methodology review conducted in 2019 for use as an index of abundance or absolute abundance estimate using seafloor mapping as the basis for expansion to rocky reef habitat. Ultimately, this survey was not used for this assessment due to limited temporal coverage (two three-year periods) and highly variable estimates, as well as limited representation to coastwide dynamics.

2.6.5 Washington Sport Dockside Interview Data

The WDFW provided recreational dockside fisheries data from 1981 through 2022 for consideration in this assessment. Data were collected at the trip level, with the number of landed fish and the number of anglers on each vessel being recorded. The amount of time fished by each angler was not recorded. The recreational dockside data was considered for use in this assessment, however, management measures implemented over the past several decades impeded extracting a reliable signal for use as abundance indices. In 2003, management restricted summer fishing depths to shallower than 20-fathoms in WDFW marine areas 3 and 4, and in 2006 modified this depth restriction to 30-fathoms in marine areas 2, 3, and 4. Additionally, daily rockfish limits were 15 fish from 1981-1991, 12 fish from 1992-1994 (except in area 1 where it remained at 15), 10 fish from 1995-2016, and a reduction to 7 fish from 2017-2022. The effects of these management changes to CPUE of canary rockfish could not be reconciled with changes in the abundance indices and therefore this dataset was not used in this assessment.

2.6.6 Washington Nearshore Rod-and-Reel Survey

Fishery-independent data available for this assessment came from two distinct WDFW research projects. The first was the Rockfish Tagging Program that was initiated in the early 2010s primarily off the central coast of Washington with sparse coverage in the northern and southern coast. The second data set was from the standardized Coastwide Rod-and-Reel Survey that began in 2019. The tagging program had strong focus on black rockfish and had little information for canary. The new nearshore survey was impacted by the COVID pandemic and was not completed as originally designed. Due to their short time spans and spatial coverage limited to Washington waters, these two datasets are not used in this assessment.

2.6.7 WA olympic coast YOY survey (NOAA)

Dive surveys represent a promising data source for canary rockfish as their habitat preferences for rocky untrawlable habitat means they have relatively low encounter rates by NMFS trawl surveys. However, this seven-year dataset covering juvenile rockfish habitat (2015-2022, missing 2020) contained three years without any canary observations, and only covers the northern Washington coast. Due to limited sample sizes and coverage of only a small fraction of the assessed area, this dataset was deemed insufficient for inclusion in the assessment. Future research could synthesize dive surveys from throughout the range of canary to build a more robust recruitment index post-density dependence that may be more appropriate for inclusion in an assessment.

2.6.8 Oregon Indices

Two indices of relative abundance were developed for canary rockfish in Oregon using the `sdmTMB` package, one fishery-dependent and the other fishery independent, but ultimately not included in the base model due to their limited representation of coastwide canary rockfish dynamics. Given the period of non-retention for canary rockfish, the only viable fishery-dependent index was based on onboard sampling of charter vessels that includes both retained and released fish. A second index from Oregon's marine reserve hook and line survey was also developed, but not used because of its spatial coverage limited to the state of Oregon.

2.6.9 Hook and Line Survey

This survey operates south of Point Conception, whereas canary rockfish density decreases substantially after that major biogeographic barrier. Thus, this survey does not cover the main spatial range of the stock and was not considered representative.

2.6.10 IPHC Longline Survey

Data from the IPHC longline survey data were examined for their utility in providing an index of abundance for canary rockfish. This survey caught 178 canary rockfish over 23 years, and thus was deemed insufficient for developing an index.

3 Assessment Model

3.1 History of Modeling Approaches

3.1.1 Early assessment history

The first formal assessment of the canary rockfish resource off the U.S. West Coast was done in 1984 (Golden and Demory 1984). The final results from the initial assessment in 1984 were largely based on qualitative examinations of trends in age and size distributions generated from both fishery and survey data. The 1984 research also included exploratory efforts to fit dynamic models to time series data, using tools such as Virtual Population Analysis and Stock Reduction Analysis, but due to highly variable sample data and its lack of availability in all years, results from the modeling were not considered scientifically valid. The 1984 assessment concluded that the canary rockfish resource was generally stable at that time and that the current restrictions were still reasonable.

The canary rockfish assessment conducted in 1990 was the first evaluation to incorporate separable catch-at-age analysis and in particular, the first to use the Stock Synthesis Model (Golden and Wood 1990; Methot and Wetzel 2013). All subsequent stock assessments have used the Stock Synthesis Model to evaluate the status of canary rockfish, although the model has undergone considerable development. The Columbia INPFC area was the only portion of the canary rockfish resource formally modeled in 1990. The 1990 assessment was the first to propose two broad assumptions regarding the absence of old females in the sample information relative to males: (1) the females are subject to a different rate of natural mortality than males; or (2) the females are less vulnerable to the fishing and sampling gears. Based on a $F_{35\%}$ management model, results from the 1990 assessment indicated the ABC for the canary rockfish resource in the Columbia INPFC area should be decreased by roughly 30 percent.

The assessment conducted in 1994 again utilized the age-based version of the Stock Synthesis model to evaluate the status of the canary rockfish population in the Columbia, INPFC area, as well as the U.S. Vancouver INPFC area (Sampson and Stewart 1994). The data sources in the previous assessment (1990) were updated, with the exception of the commercial trawl effort index from the fishery due to sample and estimation biases associated with logbook data. Results from the 1994 assessment clearly indicated that the current level of F exerted on the canary rockfish population exceeded $F_{20\%}$ (the overfishing threshold at that time) and thus, the researchers recommended that the ABC be reduced to allow the stock to recover (Sampson and Stewart 1994).

In 1996, the canary rockfish stock was assessed using similar methods and configurations as in 1994 (Sampson 1996). The model was largely similar to that in 1994. One difference between the 1994 and 1996 assessments was the manner in which error associated with age-composition data from the fisheries was accommodated. In the 1996 assessment, a single, percent-agreement error structure was used to describe the variability in the age-related data, whereas in 1994, an error-transition matrix was used to standardize multiple sets of age estimates generated from two age readers. Newly obtained data supported findings from the 1994 analyses and final results further indicated that the canary rockfish stock had suffered fishing in excess of $F_{20\%}$.

In 1999, two age-structured stock assessments were adopted. Williams et al. (1999) completed an assessment for the southern INPFC areas (Eureka and Monterey) and Crone et al. (1999) conducted a separate assessment for the Northern INPFC areas (Columbia and US Vancouver). Both assessments concluded that the abundance of canary rockfish was below the overfished threshold. A major source of uncertainty was the role that natural mortality and adult movements played in the relative lack of old females. The northern assessment was performed using an age-based stock synthesis model and relied on age distributions to summarize changes in the age-structure. The Southern assessment was a length-based (although still age-structured) model in AD Model Builder (ADMB). The southern assessment also tried to account for effects of sized-based removals on population growth. The subsequent rebuilding analysis relied upon recruitment information from the northern area where the larger portion of the stock occurs.

3.1.2 2002 Benchmark

The 2002 assessment unified the previous northern and southern assessments into a coast-wide model (Methot and Piner 2002). This assessment was the first to incorporate the newly available survey information from the WCGBTS. This assessment focused on the exploration of two states of nature that were considered in previous assessments: age-dependent natural mortality for females versus dome-shaped female selectivity. Together with the STAR panel, it was concluded that these need not represent discrete hypotheses and that both scenarios could be modeled simultaneously. The 2002 assessment concluded that the canary stock was still at very low levels, 8% of the estimated unexploited conditions.

3.1.3 2005 Benchmark

The 2005 assessment converted and updated the 2002 effort using Stock Synthesis 2 (Methot and Stewart 2005). The assessment reconfigured the spatial separation of fisheries to separate northern and southern California due to the north-south difference in occurrence of larger fish and the varying north-south distribution of fishery sampling. Fishery removals were divided among more fleets; separating trawl, non-trawl, and recreational fleets by state with some state/gear combinations. This assessment switched from age-based selectivity to length-based selectivity, and assumed asymptotic selectivity for males and allowed dome-shaped selectivity for females. Numerous changes to data in the model were utilized including adding ageing error bias, iterative re-weighting of data sources, dropping the trawl and recreational fishery CPUE, and fixing the parameters defining the variability in size-at-age at values estimated outside the model.

SSC review of the canary rockfish assessment concluded that the parametric variance around a single base model underestimated the overall uncertainty in the canary rockfish assessment. After considerable deliberation, the SSC and STAT concluded that the base (selectivity allowed to differ by sex) and alternate (sex invariant selectivity) models were equally likely and supported a statistically based blend of the two models as the basis for the rebuilding analysis, with both indicating low levels of depletion.

3.1.4 2007 Benchmark

The 2007 benchmark assessment proceeded by rebuilding all data streams and re-examining all assumptions regarding selectivity, growth, and mortality (Stewart 2007). The 2007 assessment updated to using a double-normal selectivity option which was simpler than the double-logistic used in the 2005 assessment by 2 parameters (6 vs. 8). The 2007 assessment incorporated substantial new assessment data as well as the addition of the at-sea hake fleet, research catches, improved ageing-error definitions and the introduction of conditional age-at-length data for survey fleets. Due to the use of conditional age data in place of marginal age-frequency distributions and mean-length at age data used in 2005, the parameters describing the distribution of length at a given age were also freely estimable. These changes had a larger effect than the selectivity parameterization, serving to increase the estimate of SB_0 and current stock size, but had little effect on relative trend over the time series. Changes to the stock-recruit relationship included fixing steepness at 0.51, estimating the full time series of recruitment deviations and adding a ramp to bias correction. The 2007 assessment also eliminated several discrete time-blocks for changes in fishery selectivity prior to recent management actions. In aggregate, these changes further scaled the estimate of the time series of spawning biomass up, but retained the relative trend. The 2007 assessment was also the first to split the triennial indces into an early and late period due to changes in the survey's timing.

The 2007 model was subsequently updated twice, in 2009 (Stewart 2009) and 2011 (Wallace and Cope 2011). The 2009 update decreased the catch time series prior to World War II, reducing the estimate of spawning biomass by an average of 14 percent (19 percent in the first 10 years of the series and 47 perecent in the last 10), and the 2011 update resulted in little additional change.

3.1.5 2015 Benchmark

The 2015 stock assessment updated data streams and biological relationships from the 2007 benchmark, and changed the modeled population structure compared to past assessments (Thorson and Wetzel 2016). The most significant change in parameters governing biological relationships was an increase in the steepness parameter from 0.511 in 2007 to 0.773 in 2015, due to updates in the Thorson-Dorn rockfish prior from past meta-analysis (Dorn 2002). Additional changes in biological relationships were in parameters governing the maturity relationship, which explicitly accounted for the presence of skip spawning, as well as updates to the fecundity relationship and the addition of a natural mortality prior. While values from the steepness prior distribution were used in assigning alternative states of nature in 2007, values of both steepness and natural mortality were used (separately) in assigning alternative states of nature in 2015.

The 2015 assessment modeled the population of canary rockfish along the U.S. West Coast across three areas by state. The spatial structure was modeled as a tool to "visualize and explore model residuals and a method to identify time-varying selectivity at the stock-wide level, rather than as a basis for spatially varying fisheries management". The spatial areas in the 2015 assessment were similar in many ways in that they shared the same growth parameters, and no movement in adults among the areas was assumed. The authors applied small movement rates (0.01 to 0.05) starting at age 3 as sensitivities and found little change in model results. The only connection modeled between the three areas therefore was apportionment of recruits from a single shared stock-recruitment relationship to each area. Sensitivity to the assumed spatial structure found that results were similar to a coast-wide representation of the population.

In addition to updates in biological parameters, and spatial changes to the population model, the 2015 stock assessment made improvements in the analysis of age-error matrices for better accounting for uncertainty and bias in age reads for canary rockfish, and significant improvements in including spatial-autocorrelation of survey data when calculating abundance indices. Analysis in ageing error bias resulted in the inclusion of surface reads from the late 1970s and early 1980s in that strong bias in surface read ages could be accounted for based on the ageing-error matrices, although the presence of surface reads was found through sensitivities to have negligible effect on model results. Improved survey index calculation is now accepted practice for U.S. West Coast assessments.

The 2015 assessment model indicated that canary rockfish was above the management target (>40 percent) for spawning output relative to unfished levels, and was subsequently used to support the declaration that the stock was rebuilt. There have been three subsequent catch-only projections of this assessment to account for actual and projected removals. They occurred in 2017 (Thorson and Wallace 2017), 2019 (Wallace 2019), and 2021 (Correa and Wetzel 2021). The 2017 catch-only projection corrected an error found during the 2017 assessment cycle in the database used to inform historical catches for the California commercial fleets prior to 1951, which were found to be about half the amount used in the 2015 assessment model. The 2021 catch-only projection corrected the catch time series in 2016–2018 that were used in the 2019 catch-only projection.

3.2 Most Recent STAR panel and SSC Recommendations

The 2015 STAR panel and SSC did not list any major deficiencies for the previous assessment. Responses to research recommendations from the 2015 STAR panel reported are below.

Recommendation: The historical catch data ultimately used in the assessment differed from that which was given in the original draft assessment presented for review at the panel. The review process would be improved by ensuring that any such issues (i.e. disagreements about the best available historical catch) are resolved well in advance of the assessment review meeting. One possible approach might be to have an earlier step in the process intended to sign-off on the input data, analogous to the way that the STAR panel signs-off on the stock assessments. Ongoing efforts to reconstruct Washington catch data, in the way that has already been done for Oregon and California, should help to resolve these issues in the medium term, but until then, there will still be a need to work with agreed, interim catch estimates for inclusion in stock assessments.

Response: Significant progress has been made to streamline the review process to reduce the number of changes to catch streams during STAR reviews. The TOR outlines the steps for finalizing catch time series by a designated data deadline, which we have done. Increased communication between the STAT, management and advisory bodies, and state agencies have resulted in changes to the catch history during model development, and as of time of writing, not during the STAR review.

Recommendation: Catch and discard history for this stock in U.S. waters is highly uncertain. While the STAT was able to construct alternative upper and lower bounds for catch using simple multipliers on certain years of historical catch, this is arbitrary. Work to assess the uncertainty related to each individual data source would allow a better investigation of the overall combined uncertainty and its effect on 10 stock assessments.

Response: This assessment includes a new reconstruction of canary rockfish landings in Oregon within unspecified PacFIN categories from 1987-1999. A formal Washington reconstruction is nearing completion, but was not yet ready for use in this assessment. Increased variation about catch time series was explored as a sensitivity.

Recommendation: Improved documentation is required to clearly outline the process used to construct the historical catch and discard time series from the various data sources. Such documentation should also include the process for construction of alternative catch histories that are used to propagate such uncertainty into the stock assessment.

Response: This assessment report has attempted to more clearly document the process used to construct the historical catch and discard time series. In addition, the use of github for this assessment means that the code used to construct the time series, and many of the decisions involved, is publicly available and the process is reproducible. Finally, the STAT has communicated repeatedly with state partners and the GMT to ensure that catch time series are appropriate, per the TOR. This communication did result in changes to the catch history during model development.

Recommendation: Additional work on the geospatial index is required to better resolve differences in abundance trends among areas.

Response: This assessment did not use a spatially stratified abundance index, although during early index development separate year by area covariates were considered for use in index development.

Recommendation: Work towards a combined US/Canadian stock assessment would greatly aid our overall understanding of stock status.

Response: Little progress has been made on a combined US/Canadian stock assessment. The STAT did obtain catches and estimated recruitment and recruitment deviations from a recent British Columbia assessment. We have conducted a sensitivity with these catches added to Washington fleets, and compared the recruitment deviations estimated within our base model and the Canadian model to look for synchrony. Other than fisheries under a binational treaty, U.S. West coast assessments use the U.S.-Canadian border as the northern limit for data to use within models.

Recommendation: If data permit, the trawl fleet should be divided into separate components so that bycatches in the shrimp and pelagic trawls are separated from catches in the main bottom trawl fleet. In the current assessment, composition data for the trawl fleet have a major influence on the estimated stock trends, so it would be desirable to use data that are more representative of the main fleet in order to improve estimated selectivity of the fleet.

Response: Due to the already complex fleet structure in this model, the shrimp and pelagic trawls were maintained within the main trawl fleet. The number of samples for the shrimp trawl gear is less than 1% of the samples compared to the trawl gear in Oregon, so is expected to have a small effect on selectivity estimates. The midwater trawl component has more samples and removals are higher in recent years (in part because midwater trawl codes were only available starting in 1979 for Oregon and in 2000 for Washington). However, selectivity blocks are imposed, and are expected to limit the effect of midwater trawl composition data on the entire trawl time series. Moreover, initial analyses indicated length and composition data from the shrimp and midwater trawl fisheries within PacFIN were comparable to other trawl gears.

Recommendation: Basic life history research may help to resolve assessment uncertainties regarding appropriate values for natural mortality and steepness, and how to best account for the apparent loss of older females in the population.

Response: This assessment includes fecundity and maturity curves based on new data made available since the last benchmark assessment. While efforts have been undertaken to understand the apparent loss of older females, this has not resulted in any clear resolution. A research study sampling in non-trawlable habitat along the U.S. West Coast found a similar lack of old females in the data (Brooks 2021). Examination of data from the Oregon trawl fleet indicates that in the decade from 2010-2020 the fraction of females in older age classes was not lower than the fraction of females in younger age classes, unlike sex ratio patterns seen in previous decades (Rasmuson et al. 2023).

3.3 Model Structure and Assumptions

3.3.1 Modeling Platform and Structure

We used Stock Synthesis version 3.30.21, compiled February 10, 2023 by Rick Methot at the National Oceanic & Atmospheric Administration (NOAA) NWFSC using the 64-bit version of ADMB 13.1 (Methot and Wetzel 2013). This most recent version includes improvements and corrections to older model versions. The previous benchmark assessment used an older version of Stock Synthesis, version 3.24V. The R package `r4ss`, version 1.48.0 (Taylor et al. 2021a), along with R version 4.2.2 (R Core Team 2022) were used to investigate and plot model fits.

3.3.2 Balance of Realism and Parsimony

The base assessment model for canary rockfish was developed to balance parsimony and realism, and the goal was to estimate a spawning output trajectory for the population of canary rockfish off the U.S. West Coast. The model contains many assumptions to achieve parsimony and uses many different sources of data to estimate reality. A series of investigative model runs were done to achieve the final base model, some of which are described as sensitivities (Section 3.5.2) and some of which are included in the bridging steps described below. Notably, we simplify the population structure of the last benchmark assessment model by assuming a single coastwide stock, yet increase spatial fleet structure by unmirroring fleet selectivities among states and allowing sex-dependent selectivity at larger sizes. We balance the increased complexity in spatial fleet structure by simplifying the selectivity parameterization and combining fleets and minimizing the use of blocks where possible, and assuming natural mortality to be age-invariant, as opposed to increasing with age for females.

3.3.3 Model Changes from the Last Assessment

The assessment model structure has been significantly altered from the 2015 benchmark stock assessment (Thorson and Wetzel 2016). The primary change affecting model results is the change in modeling of natural mortality. We model natural mortality as sex-dependent and age-invariant which offers a simplified and more biologically common approach to modeling natural mortality than an increasing linear ramp in female natural mortality. While natural mortality of females and males likely is similar at young ages, given that the fisheries and surveys do not fully select the smaller, younger fish, natural mortality at young ages does not matter as much as a reasonable cumulative natural mortality at older ages. Assumptions to this choice are tested with sensitivities and described in Section 3.5.2.

Another substantial change is in the treatment of spatial structure in the model, both in terms of population spatial structure as well as fishery fleet structure. We simplify modeling the population structure of canary rockfish along the U.S. West Coast by assuming a coastwide population, yet increase the spatial complexity of the fishery. This amounts to using an areas-as-fleets approach (Punt 2019). Although an areas-as-fleets approach does not account for potential regional differences in depletion, because catches are assumed to act over the entire modeled area, early explorations indicated instability when unmirroring fleets and updating the selectivity parameterization and blocks, thus suggesting that the data may not support realistic fleet complexity within the spatial model. Through bridging of the spatial model (described below) we show that the change in population structure does not have a large effect on model results, especially relative to changes in the modeling of natural mortality and the relative contribution of various data sources to model estimates.

By reducing complexity in the population structure of the model, we could increase the spatial complexity of the fishery. Spatial fleet dynamics allow the model structure to account for varying selectivity and historical management actions that may have impacted the fishery and the available data in specific ways. In the 2015 assessment, fleets were assumed to have the same selectivity across states. We allowed selectivity estimates to be informed by the dynamics in waters where they fish, although we have mirrored some fleets where we believe the data indicate it is appropriate to do so. We have also increased the number of selectivity blocks for the non-trawl and recreational fisheries, which is appropriate given the large changes in regulations for canary rockfish. Lastly, we have elected to include sex-dependent selectivity, which both improves fits to data and allows dynamics between male and also female natural mortality to align better with observed sex-ratios. Sensitivities to choices about selectivity are described in Section 3.5.2.

While, in general, fleet structure in the base model is more complex than in the 2015 assessment, we simplified our fleets where reasonable. We treated survey fleets as exclusively survey fleets, and did not model the small amount of catches from these surveys. It is no longer standard practice to include surveys as fishing fleets in West Coast assessments. We also removed the California at-sea hake fishery composition data, which was very sparse, and incorrectly assigned to California, and combined selectivity for the Washington and Oregon fleets, which have similar dynamics and fish across state boundaries.

Data have also been updated for this assessment. The synthesis and treatment of data has been altered for this assessment based on updated best practices and extensive work by NWFSC to document, reproduce, and standardize data processing steps, along with extensive work by staff at state agencies and PSMFC in providing consistent and accurate data in a more easily obtainable manner. Catch time series have been updated according to current best knowledge. States have updated their historical reconstructions, and past issues with catch time series mentioned in the last assessment review process and in subsequent catch-only updates have been corrected. Catch time series for the foreign fleets was also repartitioned to states in a manner more consistent with patterns observed in the domestic fishery. We assigned data from shrimp trawls as part of the trawl, where for the 2015 assessment they were included within the non-trawl fleets. Available length and age data have been processed using updated and more reproducible approaches. Substantial effort was made by the NWFSC ageing lab in providing age reads for new and previously collected canary rockfish otoliths. These allow age composition data for recreational fleets to be included as well as additional years of data for other fishery and survey fleets. Although more age data were available, we elected to remove surface age reads from the model due to known biases in addition to their removal having little effect on model results of the 2015 assessment. Sensitivities to assumptions around data choices are described in Section 3.5.2.

In addition to updated data, the process in which data contributes to the likelihood was updated. The previous assessment applied equal data weights to each fleet type across areas, and preferentially downweighted age data based on the relative sample size compared to the number of length samples by applying impact factors (i.e. lambdas) to composition data of less than one. Furthermore, the previous assessment did not apply data weighting to conditional-age-at-length data data from the surveys. In whole, these steps are not currently standard practice. For this assessment we do not adjust lambda values. Rather we allow the data weighting procedure to offset the contributions of age and length data, including conditional-age-at-length data in the data weighting, while checking that the sample sizes of composition data do not exceed the number of fish actually sampled.

Lastly, a number of changes due to updating fixed parameter estimates and prior values were made for this assessment compared to the 2015 assessment. These changes include updates to the steepness prior, natural mortality prior, the fecundity relationship, and a change in maturity from length-at-biological maturity to age-at-functional-maturity based on additional analysis of maturity samples by Melissa Head at NWFSC. Changes to biological parameters are more completely described in Section 2.4. The effect of these changes on model results is described below in the bridging analysis.

3.3.4 Bridging Analysis from the 2015 Benchmark Assessment

The exploration of models began by bridging from the 2015 benchmark assessment model to the newest version of Stock Synthesis, version 3.30.21. Using the newest Stock Synthesis version resulted in a slightly lower spawning output starting around 1995 (Figures 37 and 38) due to a higher value of catchability for the Washington late triennial survey. From there, bridging from the 2015 benchmark assessment model to the current base model followed five general steps:

1. Update data inputs to reflect best information currently available. Data was updated by source (fishery independent, fishery independent) and type (catch, compositions, indices).
2. Update life history information including natural mortality value and pattern, maturity, steepness, fecundity, and weight-length relationship.
3. Update the structure of the modeled population, going from a spatial structure for recruitment to a single-area structure for recruitment.
4. Reapply current data weighting practices.
5. Update structure of selectivity.

To arrive at a final base model additional revisions were made after these five steps to determine the best fit to the data. These include correcting an error in the generation of the triennial index of abundance, which was found late in the bridging process, adding in recent commercial age samples that were inadvertently omitted in earlier bridging steps, revisions to the fleet structure, weightings, selectivity blocks, selectivity parameterizations, and extending the period of early recruitment deviations.

A thorough description of the current base model is presented separately below. This section is intended only to more clearly identify where substantive changes were made from the previous benchmark assessment. Sensitivities to many of the components within the steps above are included in the Sensitivities (Section 3.5.2).

Changes due to updating data streams are shown in Figures 39 and 40. Updating the fishery catch and composition data increases initial spawning output and produces a steady increase in recent spawning output. Updating survey indices and composition data results in a decreasing trend in spawning output in the most recent years. Changes in life history parameter values are shown in Figures 41 and 42. Individually these changes produce different estimates for initial spawning output, but collectively offset and result in continuing the trajectory from the 2015 benchmark assessment.

Changes due to altering the structure of natural mortality are more substantial than changes to data and biology (Figures 43 and 44). Assuming age-invariant natural mortality results in a female natural mortality estimate of 0.076, which is larger at young ages but smaller at older ages than estimates using a ramp in natural mortality as applied previously. Although assuming age-invariant natural mortality results in similar recent spawning output and trajectory, doing so increases the estimate of $ln(R_0)$ and thus reduces the degree of recovery in spawning output relative to unfished, as also shown within sensitivities from the 2015 benchmark assessment. Also similar to the findings from the 2015 benchmark assessment, changing the structure of the population from spatial to non-spatial resulted in small changes in the current model (Figures 45 and 46). Updating the data weighting process to current standard weighting practices and to account for the new updated data however resulted in a decrease in the degree of recovery in spawning output relative to unfished, due in part to a reduced estimate for female natural mortality to 0.065 in the coastwide model and 0.071 in the spatial model.

Changes in how selectivity was modeled are shown in Figures 47 and 48. Allowing selectivity to be sex-dependent resulted in a large change in the degree of recovery in spawning output relative to unfished, due to an increase in the estimated value of female natural mortality. Other changes in selectivity including unmirroring fleets and using an alternative parameterization of the double normal (three parameter instead of four) resulted in small changes. Various additional changes as described above result in the final base model.

3.3.5 Key Assumptions and Structural Choices

3.3.5.1 Definition of Fleets and Areas To foster comparability between the coastwide base model and a state-stratified model more similar to the 2015 base model, we retain state-specific fleets for each fleet type from the 2015 assessment, with the exception of survey fleets which are coastwide. All fleets are ordered from south to north. That is, fleet 1 is California trawl, fleet 2 Oregon trawl, and fleet 3 Washington trawl, etc.

Fleets in the base model include:

- 1-3 Trawl – Bottom trawl gears, including shrimp trawl and mid-water trawl.
- 4-6 Non-trawl – The non-trawl fleet includes a variety of sources of directed and bycatch mortality in commercial fisheries.
- 7-9 Recreational – Including both private-rental and party-charter modes.
- 10-12 At-sea hake – The at-sea hake fleet includes both tribal and non-tribal at-sea hake fisheries.
- 13-15 Foreign – The foreign fleet operated 1966-1976, and does not include any composition data. We assume that the foreign fleets have selectivity equal to that of their respective trawl fleet.
- 28 WCGBTS

29 Triennial Survey early – because canary rockfish sampling should be minimally impacted by the changes in the triennial survey that occurred in 1995, we chose to mirror selectivity and catchability between the early (1980–1992) and late triennial (1995–2004) fleets, but maintain two fleets to explore sensitivity to this assumption.

30 Triennial Survey late

31 Pre-recruit survey

Fleets 16 through 27 were holdovers from the previous model structure and were not used.

3.3.5.2 Initialization of the Model We start the model in the first year of reconstructed catch data, 1892. The population is assumed to experience no fishing mortality prior to this year, and to start in a stable age-distribution. Early recruitment deviations are estimated starting in the first model year. Main period recruitment deviations begin in 1960 and end in 2022.

3.3.5.3 Conditional Age at Length Data Age-frequency data from the WCGBTS and Triennial Survey were compiled as conditional age-at-length distributions by sex and year. The approach consists of tabulating the sums within rows as the standard length-frequency distribution and, instead of also tabulating the sums to the age margin, the distribution of ages in each row of the age-length key is treated as a separate observation, conditioned on the row (length) from which it came.

This approach has several benefits for analysis above the standard use of marginal age compositions. First, age structures are generally collected as a subset of the fish that have been measured. If the ages are to be used to create an external age-length key to transform the lengths to ages, then the uncertainty due to sampling and missing data in the key are not included in the resulting age-compositions used in the stock assessment. The second major benefit to using conditional age-composition observations is that in addition to being able to estimate the basic growth parameters inside the assessment model, the distribution of lengths at a given age that is usually controlled by the CV of length at some young age and the CV at a much older age, are also more reliably estimated. This information could only be derived from marginal age-composition observations where very strong and well-separated cohorts existed, and that are quite accurately aged and measured; rare conditions at best. By fully estimating the growth specifications within the stock assessment model, bias due to size-based selectivity and length-stratified ageing is avoided, and known sources of variation are included when estimating growth parameters.

3.3.6 Model Parameters

3.3.6.1 Model Likelihood Components The model contains four primary likelihood components:

1. Fit to survey indices of abundance (included for fleets 28-31).
2. Fit to length composition samples (included for fleets 1-12 with the exception of fleet 10, and fleets 28-30; i.e., all fishing fleets except the foreign and California at-sea hake fleets, and the pre-recruit survey).
3. Fit to age composition samples (marginal ages are included for fisheries, i.e., fleets 1-6 and 8-9, and 11-12, and conditional age-at-length samples are included for surveys, fleets 28-30).

4. Penalties on recruitment deviations which range from 1892-2022 as well as penalties from prior likelihoods for parameters estimated with prior distributions and for uncertainty around catches.

Indices of abundance are assumed to exhibit lognormal measurement errors, where the log-standard deviation from the model used to standardize the relevant survey data is treated as an accurate estimate of measurement errors. Length, marginal age, and conditional-age-at- length samples are all assumed to follow a multinomial sampling distribution, where the sample size is fixed at the input sample size for the composition data, and where this input sample size is subsequently weighted to account for additional sources of overdispersion. Recruitment deviations are assumed to follow a lognormal distribution, where the standard deviation of this distribution is set to be 0.5. Total removals are assumed to follow a lognormal distribution with standard deviation set to 0.05. Priors for select biological parameters are described below.

3.3.6.2 Data Weighting Length and age composition data for the commercial fleets started with a sample size determined from the equation listed in Section 2.2.2.1. The exception to this was for the at-sea hake fishery where input sample sizes were based on the number of hauls. Input sample size for length and age composition data for the recreational fishery was determined based on the number of estimated trips (described in Section 2.2.2.4). Length composition data for the WCGBTS and Triennial Survey were based on input sample sizes calculated as a multiple of the number of tows (described in Section 2.3.5 and conditional-age-at-length input sample sizes were set equal to the number of ages within a given length bin.

The base model was weighted using the "Francis method", which was based on equation TA1.8 in Francis (2011), as this method accounts for correlation in the data (i.e., the multinomial distribution), and is widely used among West Coast stock assessments. This formulation looks at the mean length or age and the variance of the mean to determine if across years, model explains the variability in the data. If the variability around the mean does not encompass the model predictions, then that data source should be weighted, and typically is down-weighted. We iterated the Francis method until weights stabilized. The weighting of both the length and age composition was allowed to exceed one, and we confirmed that data sources that were upweighted did not have a weighted sample size above the number of fish sampled that would be a cause for concern. Weights for conditional-age-at-length data, which were a direct count of the number of available ages, were all less than one.

Sensitivities were performed examining the difference in the model fits and results due to weighting using the McAllister-Ianelli Harmonic Mean Weighting (McAllister and Ianelli 1997) method and are described in Section 3.5.2. Note however that this method was found to be inferior to the Francis method (Punt 2017). We also explored the Dirichlet Multinomial Weighting (Thorson et al. 2017), which is appealing because it conducts the data weighting internally by estimating one additional model parameter per data type and source and does not require additional iterations. However, Dirichlet-multinomial weighting has not been thoroughly simulation tested, and nearly all data weights for both lengths and ages were estimated close to one. This was deemed implausible and the method was not explored further.

3.3.6.3 Priors and Constraints on Parameters Priors were used for fixed parameter values for male natural mortality and steepness in the base model, as well as for the estimated parameter value for female natural mortality. Details on the choice and value of priors for these parameters are described in Section 2.4 for natural mortality and steepness and are not repeated here. We model recruitment deviations around the stock-recruit relationship which are penalized towards zero with standard deviation of $\sigma_R = 0.5$ and constrained to sum to one over the main period. For estimated parameters, we set lower and upper bounds to keep the minimization algorithms within a reasonable parameter space. We do not include any other informative priors or structural constraints on parameters.

3.3.6.4 Selectivity assumptions Length-based selectivity is allowed to be dome-shaped for all surveys and fisheries. Selectivity curves were estimated using a double-normal pattern for every fishery and survey, except where selectivity was mirrored among fleets. A double-normal selectivity pattern allows flexibility in the model to estimate either asymptotic or dome-shaped selectivity.

We specifically estimated three parameters for each selectivity curve, including:

1. Parameter 1: the minimum length at which selectivity is one (i.e. the "peak").
2. Parameter 3: the width of the ascending curve for selectivity at lengths less than the peak, which controls the slope at which selectivity approaches the peak.
3. Parameter 4: the width of the descending curve for selectivity at lengths greater than the peak, which controls the slope at which selectivity declines from the peak.

The parameter that controls the width over which selectivity is one (parameter 2) was fixed at a low value. Parameters 5 and 6 were set to have selectivity at small sizes start at zero (parameter 5 set to a low value), and allow selectivity for larger sizes to be non-zero and decay according to parameter 4 (parameter 6 set to -999). Setting parameter 6 this way simplifies the selectivity parameters and allows a single parameter to govern the dome-ness of the selectivity shape instead of two.

The foreign fishery does not have length or age composition samples available. Therefore, selectivity is mirrored to the domestic trawl fishery for each state. We also specify that commercial trawl selectivity is mirrored between Oregon and Washington due to similar composition data and the fact that many vessels cross the border while fishing and then return to home ports to land their catch. These landings and, particularly, composition data that is caught off of the coast of one state and landed in the other is difficult to disentangle. Finally, we specify that selectivity for the at-sea hake fleet is mirrored among all three states.

We additionally allow selectivity to be time-varying for the trawl, non-trawl, and recreational fleets. Time-varying selectivity in the trawl fleet was blocked at 2000 (reflecting changes in fishing behavior following the declaration of overfished status for canary rockfish in 2000), and at 2011 (reflecting a change in fishing behavior following the implementation of individual transferable quotas). Time-varying selectivity in the non-trawl fleet was limited by the sparseness of composition data between the period when canary rockfish was declared overfished and when regulations relaxed in 2017. Based on patterns in the data and discussion with state partners about regulation changes, we included selectivity blocks for the Oregon and California non-trawl fleets at 2000 and then again at 2020, to reflect the general period of relaxed regulations for the fishery initiated by the rebuilt declaration. Due to high correlation among parameters in the most recent block, selectivity for the Oregon non-trawl was mirrored between the early (< 2000) and late (> 2019) periods. The Washington non-trawl fleet had very sparse composition data until 2017, so for parsimony we did not apply any time blocking for this fleet. Regulations for the recreational fleets across the coast have been variable, based on seasonal or depth closures and bag limits. Time blocks were applied to the California recreational fleet in 2004 and again in 2017, corresponding to the imposition and lifting of the most stringent regulations. Time-blocks were applied to the Oregon recreational fleet in 2004 and again in 2015, and for the Washington recreational fleet in 2006 and again in 2021, which correspond roughly to the periods where depth restrictions were imposed (for the first block) and again lifted (for the second block). Due to high correlation among parameters in the most recent block, selectivity for the Washington recreational fleet was mirrored between the early (< 2006) and late (> 2020) periods. For each break-point change in selectivity, we re-estimate all parameters. Sensitivities to selectivity assumptions include the use of a four parameter parameterization, fixing fleets to have asymptotic selectivity, and simplified blocking (Section 3.5.2).

Early model explorations around structuring natural mortality indicated the data did not support estimating higher female natural mortality than fixed male natural mortality when natural mortality was constant across ages. This was somewhat surprising given the observed male-skewed sex-ratios at age among trawl and survey landings. There appeared to be lack of support for young females, in particular, to have higher natural mortality. When age-varying natural mortality was assumed, as done in previous stock assessments for canary rockfish, higher values for older female natural mortality were estimated. We found that by allowing sex-dependent selectivity in parameter 4, which governs how steeply selectivity declines at larger sizes, the estimate for female natural mortality increased and the fit to the data improved. Sex-dependence on other selectivity parameters was explored, but parameter 4 had the largest per-parameter improvement in likelihood, and was large enough to warrant the additional number of selectivity parameters. We therefore estimate sex-dependent selectivity in the base model, modeled as a logarithmic female offset to parameter 4 for all fleets and blocks with sex-specific composition data (i.e. all fleets and blocks except the California recreational fleet and the 2004-2014 block of the Oregon recreational fleet). Sensitivity to excluding sex-dependent selectivity is described in Section 3.5.2.

3.3.6.5 Stock Recruitment Function In this assessment $\ln(R_0)$ (the natural logarithm of unfished recruitment) was estimated, while steepness was fixed at its prior mean of 0.72. Lognormal deviations from the standard Beverton-Holt stock-recruit relationship were estimated from 1892–2022 with a fixed σ_R value of 0.5. There is limited information regarding recruitment prior to 1960 but deviations are estimated in the base model to account for uncertainty around the unfished condition to a degree consistent with estimated variability in recruitment. The early deviations are estimated from the beginning of the model period until 1960 in order to fully propagate uncertainty in recruitment and allow population age-structure to represent plausible deviations from the equilibrium at the start of composition data. Main phase recruitment deviations are estimated beginning in 1960, shortly before composition data becomes available in 1968.

3.4 Base Model Results

3.4.1 Parameter Estimates

The base model parameter estimates along with approximate asymptotic normal standard errors (SD column) are shown in Table 12. This table enumerates a total of 232 estimated parameters. These include one parameter for $\ln(R_0)$, one parameter for female natural mortality, nine parameters describing growth, one parameter for survey catchability in the Triennial Survey, one parameter for extra variability for the pre-recruit survey, 69 parameters for length-based selectivity and blocks along with 19 parameters for sex-dependent selectivity and blocks, and 131 recruitment deviations. The likelihood components from fitting the base model to data are shown in Table 13. The estimated data weights by the Francis method are shown in Table 14.

The full r4ss plotting output is available in the supplementary material on the Pacific Fishery Management Council website.

3.4.1.1 Biology Parameters The estimates of growth parameters by sex varied relative to the externally estimated parameters (Table 12). The length-at-age 1 was less than the external estimate from survey data for both sexes while the L_∞ estimates for both sexes were higher than the external estimates. The internally estimated k for females and males was less than than the values estimated externally, with the value for females being more similar. The 95% confidence interval of the internally estimated growth curves (Figure 49) contains the externally estimated curves. The coefficient of variation in growth was assumed to be function of length-at-age. Estimates for the coefficient of variation at L_∞ were slightly less than half those at length-at-age 1 for males and females. However, given the estimates for length at older and younger ages, this still results in greater variability in length at older ages.

3.4.1.2 Selectivity Estimated selectivity curves are shown in Figure 50 and 52 for females and Figures 51 and 53 for males, with selectivity parameters provided in Table 12. Nearly all fleets show a strong dome-shaped pattern with the exception of 1) selectivity for females by the Oregon and Washington trawl fleets from 2000–2011, 2) selectivity for females by the Oregon non-trawl fleet prior to 2000 and after 2019, and 3) selectivity for both sexes by the Triennial Survey. Sensitivity to allowing for one asymptotic fleet is shown in section 3.5.2.

For the trawl fleets, the length at peak selectivity is greatest prior to 2000, with the California peak at 45 cm and the mirrored Oregon and Washington peak at 50 cm. Selectivity shifts towards smaller fish in recent time periods between 0–6 cm depending on the fleet and time block. The pattern of dome-ness between time periods is stronger in California in recent years whereas for Oregon and Washington the curve tends to shift towards smaller fish, and to an asymptotic pattern for females between 2000–2011. The foreign fleets are mirrored to the trawl fleets and have the same selectivity curves.

For the non-trawl fleets, the patterns in selectivity are more variable, reflecting the sparseness of the composition data. In California, selectivity for smaller fish is greater in the non-trawl fleet than in the trawl fleet, with the period prior to 2000 peaking at the largest size of 36 cm. The range of lengths selected is more compressed but has shifted towards smaller fish by 2–3 cm in more recent years. In Oregon, prior to 2000 and after 2019, peak selectivity was 31 cm. For females, selectivity was estimated to be asymptotic during this time. From 2000–2019 peak selectivity increased slightly to 33, and also became much more domed for both sexes. The Washington non-trawl fleet has sparse data so is modeled as having constant selectivity across time, with a peak at 46 cm.

The at-sea hake fishery has mirrored selectivity across each state given the similarities in the fishery along the coast. The selectivity curve is more narrow than that for either the trawl or non-trawl fleets, with a steep increase around 40 cm and peak at 44 cm. No time-varying selectivity is applied to the at-sea hake fishery.

For the recreational fishery, the length at peak selectivity is shifted towards smaller fish compared to the commercial fleets. Selectivity increases sharply and reaches a peak of 29 cm in California, 31 cm in Oregon and 35 cm in Washington. All recreational fleets show strong dome-ness with the exception of selectivity for females in Washington before 2006 and after 2020, though this case is still not asymptotic.

The WCGBTS and Triennial Surveys are estimated to have a slowly increasing selectivity curve across a wide range of lengths; starting at very small sizes and increasing to a peak near 43–44cm. This likely reflects the spatial and bathymetric coverage and non-targeting nature of the survey design compared to the fishery. Selectivity for the WCGBTS declines for larger individuals whereas for the Triennial Survey selectivity is nearly asymptotic. No time-varying selectivity is applied for the surveys, and the Triennial Survey is mirrored across the early and late period.

For all fleets and surveys, male selectivity shows a greater dome-ness than females. This is likely compensating for a lower availability of large females given that their natural mortality estimate is higher than males. Thus, greater selectivity for females still means that large females are less commonly caught than large males due to their relatively lower occurrence in the population owing to their higher natural mortality rate. This also allows for effective fishing mortality on larger and older females to be greater than for males, such that both natural mortality and fishing mortality contribute to the smaller number of old females observed.

3.4.1.3 Catchability Catchability for surveys comparing observed to expected vulnerable biomass across all years was analytically solved for the WCGBTS and pre-recruit survey, and estimated for the Triennial Survey. The Triennial Survey was mirrored across the early and late period so catchability was equivalent. The values for catchability of the adult surveys are commensurate with surveys for a species that is partially inaccessible and caught on a subset of tows (Tables 10, 11). Catchability in regular space was calculated as 0.45 for the WCGBTS, 0.06 for the pre-recruit survey, and estimated to be 0.28 for the mirrored Triennial Survey (Table 12). Additional survey index variability for the pre-recruit survey that is process error added directly to each year's input standard deviation was estimated within the model at 0.51 Fits to adult surveys were near enough to confidence intervals of the estimates of the survey that down-weighting the survey data by estimating additional variability was not warranted.

3.4.1.4 Stock-recruit Parameters In this assessment the natural logarithm of R_0 was estimated, while steepness was fixed at its prior mean of 0.72. Lognormal deviations from the standard Beverton-Holt stock-recruit relationship were estimated from 1892–2022 with a fixed σ_R value of 0.5. There is limited information regarding recruitment prior to 1960 but deviations are estimated in the base model to account for uncertainty around the unfished condition to a degree consistent with estimated variability in recruitment. The time series of estimated recruitments and annual recruitment deviations are shown in Figures 54 and 55. The spawner-recruit curve is shown in Figure 56.

Years with the highest recruitment deviations were estimated to have occurred in the 1960s and continued through around 1990. Starting around 2005 recruitment deviations became more consistently negative and reached their nadir in 2018. Much of this period corresponds to a period of relatively sparse composition data. Deviations have increased closer to average levels since 2018 but these deviations are more uncertain given the few years available to sample these age classes. The recruitment bias adjustment applied within the model across years is shown in Figure 57. This relationship was updated during early model exploration with the final version near to the suggested alternative provided within r4ss such that it was left at the earlier values. Similarly, the value of σ_R was tuned to match the observed variation in recruitment deviations, following Methot et al. (2011), and as provided in r4ss. The tuned value was similar (0.47 for the period 1960–2022) to that already used (0.5) so the value of 0.5 was retained.

3.4.2 Fits to the Data

Fits to the data are shown based on the Pearson residuals for length and marginal age compositions, annual mean lengths and ages, and aggregated length and marginal age composition for the fishery. For the surveys, similar metrics were used; however, fits of ages are conditioned on length, and fits to the survey indices are also provided. For simplicity, within this section we refer to marginal age compositions as simply age compositions.

The aggregated fit to the length composition data by fleet is shown in Figure 58. Fits are generally consistent with observed data aggregated over all years for males, females, and combined when sex-specific data are unavailable. Fits balance the bimodal patterns for Oregon and Washington recreational data and Oregon non-trawl data, and are generally consistent for both Washington and Oregon trawl data, where selectivity was mirrored. The mode of proportion at length is generally larger for females than males in trawl gear, reflecting the dimorphic growth in canary, but are similar for other gears.

Pearson residual plots by fleet (fishery and survey) as well as mean lengths by year observed from the composition data are shown in (Figures 59–86). Yearly mean length is variable for canary rockfish, particularly for non-trawl fleets both in terms of sample sizes within and across years. However, patterns are still discernible. Patterns in length data indicate a declining trend in mean length of about 5 cm in the trawl fishery starting in the early years (1980s) when data is available. The decline is best captured in the Oregon trawl lengths, although the fit declines around 3 cm and underestimates the observed decline. The decline is also present to a lesser extent in the California and Washington trawl lengths. Fits also reveal an increase in mean length in recent years (up to 7 cm in California non-trawl data but less for other fleets), which is best captured by fits to the non-trawl and recreational fleets within the final time-varying selectivity block of each fleet. Patterns in mean length for the at-sea hake fishery and the surveys are generally uninformative.

The aggregated fit to the age composition data by fleet is shown in Figure 87. Fits are generally consistent with observed data aggregated over all years for males and females despite selectivity being based on lengths. Fits are best for the trawl fleets, and poorer for Oregon and Washington non-trawl data, which are sparse and variable. Fits do not capture the steeper decline and early long tail in the proportion of older fish in the recreational fleets. The mode of proportion at age is generally similar for females and males, in contrast to the patterns in length, especially for the trawl gear. The aggregated age compositions show that general patterns of increasing selectivity for young individuals, and declining proportion at age for old individuals, are generally captured. Summaries also exhibit the greater proportion of males in the plus-group (age 35+) than females for the trawl fleets.

Pearson residual plots by fishery fleet as well as mean age by year observed from the composition data are show in (Figures 88–107). The range of ages cover a larger range of modeled ages compared to the length samples, but patterns are comparable to those observed from the length composition fits. Patterns in age data also indicate a declining trend in mean age in the fishery starting in the early years (1980s) when data is available. The decline is best captured in the fits to the Oregon trawl ages. The mean age in the data declines from approximately a mean age of around 20 to a mean age of 11, although the fit underestimates the magnitude of decline and starts around a mean age of 16. Fits to California trawl ages also indicate a long term decline but data are sparse. Fits to Washington trawl ages are overestimated relative to observed data, but also indicate a decline in mean age, albeit from younger ages than the Oregon trawl trend. As with lengths, recreational mean ages are lower and suggest an increase in mean age in recent years. Patterns in mean length for the non-trawl and at-sea hake fleets are generally uninformative.

Pearson residuals of conditional age-at-length compositions are shown for each survey (Figures 108–111). These show variability in length at age over time, which is propagated into model uncertainty through the use of conditional-age-at-length data. Positive residuals near the lower range of the data exist for the early Triennial Survey and recent years of the WCGBTS. These suggest that older male canary rockfish at length are observed than estimated in the model for these years, which is consistent with our comparison of externally estimated growth parameters for males being near the lower uncertainty range for growth estimated internal to the model. Predictive plots, where a well-fitting model has a predicted average and standard deviation of age-at-length that is within the 95% predictive interval, are available within the r4ss documentation available online. Predictive plots for all surveys generally show fits are within the 95% predictive interval, indicating no evidence of poor fit to conditional age-at-length data. This suggests that a model with time-constant growth provides a satisfactory approximation to the process governing age and length.

Fits to indices of abundance for each survey fleet (Figures 112–115). These plots show that fits to the WCGBTS indices are generally within the 95% confidence interval bounds with the exception of 2009 and 2019. With 19 years of survey data, approximately one year is expected to fall outside of the 95% confidence interval, and two falling outside the range would not be an usual occurrence. The residuals appear randomly distributed, with no particularly long strings of positive or negative values. The survey index increases slowly, with a minor break point between a “low” state until 2013 and a “high” state thereafter. The triennial survey captures the general decline in population abundance during the 1980s and early 1990s and the beginning of rebuilding in the late 1990s and early 2000s. The model is unable to capture the sharp rise and fall at the beginning of the time series, and thus falls outside of the 95% confidence interval in 1980 and 1983. The pre-recruit survey captures high estimated recruitment events in 2013, 2016, and 2021, though the model underestimates recruitment in 2016 relative to the survey. The model falls outside of the input 95% confidence in five years (2002, 2004, 2007, 2009, and 2016), but in no years when including the extra estimated standard deviation. Sensitivity to estimation of this additional variability is included in Section 3.5.2.

3.4.3 Population Trajectory

Summary time series of population trajectories are provided in Table 15. Total mortality estimates for 2023 and 2024 were provided by the GMT. The estimated spawning output (in millions of eggs) is shown in Figure 116, total biomass in Figure 117, spawning output relative to unfished in Figure 118, and fishing intensity measured as one minus the spawning potential ratio (1-SPR) in Figure 119. Spawning output declines from the 1940s with the increase in harvest (Figure 2), stabilizes in the 1970s, and then declines to its lowest point in 1995. Spawning output stabilizes until 2000 when levels increase steadily to recent years with a slowing trend. The estimated total biomass follows the same general trend as observed in spawning output, but with a more pronounced decrease from 1980 to 1995 (Figure 117). The estimated spawning output relative to the unfished equilibrium spawning output was at its lowest (6.1 percent) in 1995 and has since increased. It is currently within the precautionary zone at 35.1 percent for 2023 (Figure 118). Population trajectories track the patterns in fishing intensity, where fishing intensity was steadily above a fishing mortality that would produce an SPR of 0.5 starting in the 1960s and lasting nearly four decades (Figure 119). Fishing intensity has been low since 2000 but has recently increased to a fishing mortality corresponding to an SPR of near 0.5.

3.5 Model Diagnostics

3.5.1 Convergence Status

The base model has a final gradient of <0.00001 and the hessian is determinant. We therefore conclude that the parameter estimates represent a global minimum. No parameters are at or within 2.5 percent of a boundary but two parameter pairs have high correlation coefficients (0.97) with four others between 0.90 and 0.95.

3.5.1.1 Evidence of Search for Global Convergence A search for global convergence was conducted multiple times during model development, and these led to the choices described within this report for developing the current model. Analyses from earlier models suggested the likelihood surface was flat around the maximum likelihood estimate, and found some improvements in the likelihood value. However, model trajectories were similar suggesting improvements in the likelihood surface did not greatly change model dynamics.

Model convergence of the current model was determined by starting the minimization process from dispersed values of the maximum likelihood parameter estimates. Starting parameters were jittered using the jitter function built into Stock Synthesis, using a jitter fraction of 0.05. This was repeated 50 times with ten runs returning to the original best likelihood value, and five runs being very close at just 0.01 likelihood units above. No jitter runs resulted in an improved likelihood value. Given that this jitter analysis did not result in a final better likelihood value, we conclude the model has obtained a global optimum, and we proceed with this model as the current base model. Profiles of key parameters (Section 3.5.4) and sensitivity runs (Section 3.5.2) also did not show evidence of instability and support the conclusion from the jitter analysis.

3.5.2 Sensitivity Analyses

The base model contains substantial uncertainty in both how data were processed, and structural assumptions made. We test senstivity to a number of these assumptions. In general, structural assumptions regarding how productive the population is and how the model handles the relative lack of old females in age composition data led to the strongest changes in model outputs (Figure 120). All sensitivities with the exception of the bomb radiocarbon age bias led to relatively similar estimates of growth parameters, indicating growth is well-estimated in the model and we do not discuss it beyond the bomb radiocarbon sensitivity (Tables 16–19). We divide the sensitivities into four groups: how data are prepared, how data are weighted, selectivity and catchability, and population productivity.

3.5.2.1 Data Choices Compiling data for the assessment model required a number of choices and assumptions. The following sensitivity models fall under data choices:

- No sparse comps: exclude all year-fleet combination of length and age composition data with input sample sizes less than five.
- Pre-recruit data: include pre-recruit survey index from 2010, 2012, and 2022 which had more limited sampling.
- Canada catch: add catches from the west coast of Vancouver Island to Washington trawl and non-trawl fleets

- Catch SE 0.1: Increase the uncertainty in input catches from 0.05 to 0.1 for years before 1980. Years before 1980 approximate the period with less extensive sampling, and where historical reconstructions are used to estimate catch. Adjusting catch standard error was done in lieu of manually changing catch streams to “low” and “high” scenarios.
- Bomb radiocarbon age error: Recent research based on radiocarbon signatures in otoliths from the atomic testing era indicates that canary rockfish ages based on otolith annuli may be biased negatively by approximately 10% from the true age (A. Stephens, NWFSC, personal communication, 4/19/23). This sensitivity assumes all readers have an additional 10% negative ageing bias from whatever bias was assumed in the base model.

Overall, decisions with respect to input data had a low impact on model outcomes (Table 16, Figures 121 and 122). Sensitivities generally led to similar current biomass levels, but varying estimates of unfished biomass, leading to somewhat different depletion estimates. Still, in all cases depletion in 2023 was within the 95% confidence interval of the base model. Models produced similar estimates of female natural mortality. The bomb radiocarbon sensitivity produced a somewhat lower estimate because the additional ageing error bias allows for more older fish in the population than the base model assumes. The bomb radiocarbon sensitivity also had a higher unfished and recent biomass (within the base model 95% confidence interval), higher depletion (within base model 95% confidence interval), and lower estimates of von Bertalanffy growth rates (slower growth) because the sensitivity increases all ages by 10%, but leaves lengths unchanged. Including Canadian catches predictably increased the population scale substantially, well outside of the 95% confidence interval. Because Canadian fishing continued during the period canary rockfish was declared overfished in the U.S., including Canadian catches also resulted in a more muted recovery and somewhat lower depletion in 2023.

3.5.2.2 Data Weighting The assessment model contains data from a variety of sources, some of which are expected to be more informative than others. Sampling units from these different data sources are not necessarily comparable (e.g., an observation from a survey index versus an observation of a fish length). Data weighting procedures are objective algorithms that can be used to assign weights to different data sources to optimize the fit of the model to the data. The following sensitivity models fall under data weighting:

- McAllister-Ianelli data weighting: Use the algorithm suggested by McAllister and Ianelli (1997) instead of Francis (2011)
- No extra SD: Do not estimate an extra standard deviation for the pre-recruit survey index. This means the pre-recruit survey cannot be down-weighted to allow for better fitting of other data sources.
- Francis Ages X10: Upweight all age composition samples 10x relative to the weight assumed in the base model
- Francis Length Weights X10: Upweight all length composition samples 10x relative to the weight assumed in the base model

The choice of data weighting algorithm and the extra standard deviation on the survey index were not influential (Table 17, Figures 123 and 124). Data weights for the McAllister-Iannelli method compared to those used in the base model indicate the McAllister-Iannelli weights the composition data less relative to the

Francis method (Table 20). Eliminating the survey extra standard deviation did result in a larger survey index negative log-likelihood (worse fit), supporting the choice of its estimation. Increasing the weight of the age data led to a lower population scale (outside of the 95% confidence interval of the base model), similar depletion in 2023, and a trajectory where the population begins declining after fishing effort increases following the lifting of the overfished designation. Increasing the weight of length composition data essentially does the opposite, increasing the unfished biomass and 2023 depletion (both outside of base model 95% confidence interval), and leading to a steep and rapid recovery of the population in recent years. While age and length composition likelihoods are not comparable among these scenarios, the survey index negative log-likelihood increases both when upweighting lengths and when upweighting ages, indicating worse fits to survey indices in both cases. Upweighting the length and age data by a factor of ten is not meant to be realistic scenarios, but rather to illustrate how different data sources influence model results. All data weighting scenarios generally produced similar estimates of female natural mortality, with the model using the McAllister-Iannelli weights estimated a slightly larger value.

3.5.2.3 Selectivity and Catchability There are numerous possible ways to parameterize selectivity in a stock assessment model, and its correct parameterization is generally a major source of structural uncertainty. Selectivity is of particular importance for canary rockfish because it is unknown whether the absence of old females in composition data is due to a lack of availability, old females are available but experience higher natural mortality rates than their male counterparts, or some combination of the two. Catchability represents the fraction of the population that is available to a survey. It can either be estimated as a model parameter with uncertainty, or analytically calculated within the model. Because the base model mirrors catchability between the early and late triennial periods, catchability for the triennial survey had to be estimated rather than calculated analytically (“floated”). The following sensitivity models fall under selectivity and catchability:

- No sex selectivity: Assume males and females have the same three-parameter double-normal selectivity curve (applies to all fleets)
- Simpler blocks: Remove all selectivity blocks for California trawl, California non-trawl, California recreational, and Oregon recreational fleets because each had relatively similar selectivity curves over time. Combine the later two periods for Oregon-Washington trawl into one block (2000-2022) due to similarities in the left hand side of their selectivity curves.
- WA NTWL asymptotic: Assume the Washington non-trawl fleet has asymptotic selectivity, applied to males and females. The base model assumes all fleets can have dome-shaped selectivity, and many do, which could lead to the presence of cryptic biomass. The Washington non-trawl fleet was deemed most likely to have asymptotic selectivity because 1) it fishes in untrawlable habitat where larger fish likely reside, 2) the average size of canary rockfish tends to increase northward along the coast, and 3) there is no nearshore component so harvest would presumably be at depths where larger individuals would be found.
- WCGBTS asymptotic: Assume the WCGBTS has asymptotic selectivity, applied to males and females. This sensitivity serves a similar purpose as the sensitivity assuming the Washington non-trawl fleet has asymptotic selectivity. The WCGBTS samples across the full range of deeper depths of canary rockfish habitat where larger individuals likely reside, as well as samples across a wide range of latitudes, and so could presumably encounter larger individuals.

- Float Q: Move all triennial data into the early triennial period and float Q (i.e., calculate it analytically).
- Unmirror tri: Estimate separate selectivity for early and late triennial. Calculate two Q values analytically, one for each period.

Eliminating sex-specific selectivity was one of the most influential sensitivities tested, across all groups of sensitivity analyses (Table 18, Figures 120 and 125–126). Eliminating sex-specific selectivity resulted in a higher unfished and recent biomass and higher depletion in 2023, both well outside the 95% confidence interval of the base model. The estimate of female natural mortality goes down substantially to a value even lower than the fixed value of males. Fits to age and length composition data deteriorate, as expected, and the survey negative log-likelihood also increases, indicating a worse fit to survey indices, particularly the WCGBTS.

Treatment of the Triennial Survey catchability value and including an asymptotic selectivity curve for the WCGBTS were not influential on model estimates, while simpler selectivity blocks, including an asymptotic selectivity curve for the Washington non-trawl fleet, and unmirroring the Triennial Survey were moderately influential (Table 18, Figures 125 and 126). The latter three scenarios resulted in higher estimates of unfished biomass. Simplifying selectivity blocking led to a more rapid recovery over the past two decades, and a 2023 depletion above the target of 40%. Unmirroring the Triennial Survey similarly resulted in a more rapid recovery compared to the base but leveled off in recent years and reached a 2023 depletion near the target of 40%. Assuming the Washington non-trawl fleet has asymptotic selectivity led to a depletion slightly lower to that estimated in the base model, and the population trend increased at a consistent rate in recent years, rather than leveling off as in the base model. Other than eliminating sex-specific selectivity, all sensitivities in this group led to similar estimates of female natural mortality. Simplified blocking and asymptotic fleets both increased the negative log-likelihood. Unmirroring the triennial, which is associated with estimating three additional parameters, only decreased the negative log-likelihood by 1 unit, supporting mirroring the two time periods. Fully combining the triennial and floating catchability does not have a comparable likelihood to the base model because the composition data for the late period were all assigned to the early period fleet, and therefore assigned a different Francis weight.

3.5.2.4 Population Productivity The base model makes a number of structural assumptions related to population productivity. These assumptions are known to be influential and drive how quickly a population will recover from an overfished state. The following sensitivity models fall under population productivity:

- Estimate h: Estimate steepness of the stock-recruit relationship
- Estimate male M: Estimate male natural mortality
- Single M: Fix female natural mortality to the median of the prior distribution, similar to males.
- M ramp: Fix female natural mortality at young ages to the median of the prior distribution, similar to males. Assume, similar to recent assessments, natural mortality increases linearly from age 6 to 14, and estimate female natural mortality for ages 14 and higher. This ramp roughly follows the maturity curve, thus presuming that higher female natural mortality rates are associated with maturation and spawning.

- M break 20: Similar to the M ramp scenario, but instead of a linear ramp in natural mortality between a younger and older age, assume a single break-point in natural mortality. For this scenario we assume a break-point of 20 (change starting at age 21) which is approximately the point at which the sex ratio begins to change in survey and fishery data.

Structural assumptions in the model that determine population productivity were strongly influential on derived model outputs (Table 19, Figures 127 and 128). The model internally estimates steepness to be 0.895. This indicates expected recruitment of the population remains high even at low spawning outputs, and led to a lower estimate of unfished biomass (within the 95% confidence interval), but a more rapid recovery in the 2000s and 2010s, leading to a depletion above the target of 40%. Female natural mortality was similar to the base model. The likelihood increased by two units despite estimating one additional parameter, indicating that the model was likely close to, but not quite at, the global optimum for this scenario.

The model internally estimated male natural mortality to be 0.0708 yr^{-1}, higher than the fixed value of 0.0643 yr^{-1} (Table 19, Figures 127 and 128). When the model freely estimated male natural mortality, the estimate of female natural mortality also increased to 0.084 yr^{-1}. This increase in natural mortality for both sexes resulted in a lower estimate of unfished biomass, but as with the estimation of steepness, a steeper increase in population size in recent years and a higher depletion in 2023 near the 40% target, though still within the base model 95% confidence interval. The negative log-likelihood decreased by only 1 unit with the flexibility of estimating an additional parameter. This decrease of less than two units supports the choice to fix male natural mortality in the base model.

Assuming that female natural mortality increases as they reach sexual maturity rather than remaining constant throughout their lives led to lower unfished biomass than the base model (within or just beyond the 95% confidence interval) and a higher depletion in 2023 (near to or above the management target; Table 19, Figures 127 and 128). The estimate of natural mortality for only old females as a ramp to age 14 was higher than the estimate of natural mortality for all females (0.0934 versus 0.0779 yr^{-1}, respectively), but lower than for only old females as a break-point at age 20 (0.171 yr^{-1}). The total likelihood was 2 units more for the ramp scenario and 26 units lower for the break-point scenario compared to the base model. Both scenarios estimate the same number of parameters as the base model. Together, this indicates some support within the data to differentiate between the two biological hypotheses of constant versus increasing natural mortality, conditional on the structure of selectivity. However, estimates for female natural mortality for the better fitting break-point model would suggest a longevity of 32 years based on the natural mortality prior, which is inconsistent with what is known about canary rockfish.

Finally, fixing female natural mortality at the median of the prior used for males resulted in a substantially higher estimate of unfished biomass (outside the 95% confidence interval of the base model) and a much more muted recovery, leading to a lower spawning output in 2023 and a significantly lower depletion (outside the base model 95% confidence interval and below the minimum stock size threshold; Figures 127 and 128). The direction of these results is expected, as the fixed rate is 20% lower than the rate estimated in the base model, indicating a less productive population.

3.5.2.5 Sensitivities Not Included in Document Using MRFSS length samples instead of those from the Deb Wilson-Vandenberg data, including lengths of released fish in California and Oregon recreational composition data, and assuming the pre-recruit survey occurs after density-dependence instead of before all had minimal impacts on model outputs. Dirichlet-multinomial data weighting, and estimating a fourth parameter of the double-normal selectivity curve for all fleets led to models that did not converge (final gradient >0.01 for Dirichlet-multinomial, gradient >100 for fourth selectivity parameter).

3.5.3 Retrospective Analysis

A five-year retrospective was done by successively removing years of data to obtain models with ending years ranging from 2017 to 2021. The retrospective analysis shows a negative retrospective bias in that initial spawning output and recent spawning output generally decline as more years of data are removed, but changes are within the uncertainty intervals of the base model (Figure 129). The largest change in scale occurs when four years of data are removed, and although the exact reason for this is unknown this peel is the first to miss the high value in the WCGBTS index and ends in the year with the lowest recruitment deviation from the base model. The magnitude of change in initial and recent spawning output is generally comparable across all peels, although recent spawning output declines slightly more for each peel and leads to slightly lower estimates of spawning output relative to unfished (Figure 130). Estimates of Mohn's ρ (Mohn 1999), which measures the magnitude of retrospective bias, are -0.42 over all years (average of -0.084 per year) for spawning output and -0.23 over all years (average of -0.046 per year) for spawning output relative to unfished. According to Hurtado-Ferro et al. (2015), Mohn's ρ values on a per-year basis of less than -0.15 are not cause for concern, but should not be taken as lack of true bias.

3.5.4 Likelihood Profiles

We use likelihood profiles to assess the support of the data for the estimation of different key parameters (steepness, average unfished recruitment, and female and male natural mortality rates). A likelihood profile over a parameter fixes that parameter to a range of values, and then freely estimates the rest of the base model at each fixed value. We separate the likelihood profile into contributions from different data sources to assess the degree to which different data sources agree or conflict.

Low values of $\ln(R_0)$ maximize the age composition likelihood, the recruitment penalties are minimized by slightly higher values of $\ln(R_0)$ than the full model estimates, and the indices support a value of $\ln(R_0)$ close to the full model estimate (Figures 131, 132). The Oregon recreational fleet most strongly drives the age composition likelihood, but age composition data from many fleets support lower population scales. The length composition data are relatively uninformative in determining population scale. The survey index likelihood is mainly informed by the early and late triennial indices, which show the most contrast over their survey period.

The likelihood profile over steepness indicates that a value higher than that fixed in the model, around 0.9, maximizes the full likelihood (Figures 133, 134). This is similar to the internally estimated value of steepness (0.895) found in section 3.5.2.4. We do not consider that to be plausible for a long-lived species such as canary rockfish and therefore fix steepness at the mean of the prior distribution for rockfishes ($h = 0.72$). The profile is most strongly informed by recruitment penalties and age data. There is some conflict between length data, which favor low steepness, and age data, which favor high steepness. There is some conflict among fleets in the length data, with some fleets supporting higher steepness and other fleets supporting lower steepness. The survey index favors steepness relatively close to the fixed value, around 0.7, and this is mainly informed by the triennial surveys.

The female natural mortality likelihood profile is most strongly driven by length data, with some influence of age data and recruitment penalties (Figures 135, 136). Survey indices contain little information to inform female natural mortality estimation. The length composition data shows a conflict between trawl gears supporting natural mortality close to the estimate, Washington non-trawl and recreational fleets supporting lower values, and the Oregon recreational fleet supporting higher values.

The likelihood profile over male natural mortality shows relatively little information from the data to support its estimation, confirming the choice to fix it to the median of the prior distribution (Figures 137, 138). The profile is minimized at a similar value (around 0.070 yr^{-1}) to the sensitivity that estimates male natural mortality (Section 3.5.2.4) and slightly higher than the fixed value in the base model of 0.0643. Unlike females, recruitment penalties are most influential on the male natural mortality profile. There is a conflict between age data, which supports lower natural mortality values, and length data, which supports higher values. Similar to females, survey indices contain very little information to estimate male natural mortality.

3.5.5 Comparison of Base Model to Previous Assessments

We plot summary biomass and recruitment from eight past benchmark and update assessments conducted for canary rockfish, starting in 1994, and compare to current estimates (Figure 139). Summary biomass is used because fecundity relationships have changed over time between biomass and egg production. Summary biomass has most often been modeled as biomass of age 5 and above canary rockfish, with the exception of the 2002 assessment, which used age 3 and above. A metric of summary biomass was not readily obtainable for the 1999 assessment, so is excluded from the figure. The plot of summary biomass indicates that the equilibrium scale of the current base model is very similar to that of the last three assessment models, and is lower than other assessment models. Summary biomass around 1990 is similar for all models produced from 1999 onward. The current base model indicates a slower rate of increase than either the 2007 or 2015 assessment models, and faster rate of increase since 1990 than the other assessment models. Age-0 recruits are estimated to be slightly higher for the current base model compared to the 2015 assessment model and similar to the 2009/2011 update assessments. Recruitment in recent years for the current base model is similar in scale and general pattern to past assessments, although the individual trajectories are variable.

3.5.6 Comparison with Similar Stocks and Species

The recent assessment for canary rockfish in Canada shows a similar decline and subsequent rebuilding of the stock in Canadian waters, where the magnitude of decline and the timing of the commencement of rebuilding are generally similar to the current assessment (DFO 2023). The Canadian assessment was a catch-at-age model and included six fishery-independent trawl survey series and a bottom trawl CPUE series. It internally estimated constant male and female natural mortality at 0.065 and 0.093 yr^{-1}, respectively, while assuming asymptotic selectivity curves. The male natural mortality is similar to this assessment, while the female rate is higher. The model penalized recruitment variability much less ($\sigma_R = 0.9$), and estimated stock-recruit steepness. Recruitment in the Canadian assessment showed a long-term increasing trend, unlike the long-term decreasing trend estimated in this assessment. This may be because the Canadian assessment assumed selectivity remained constant over time. Detrended recruitment deviations show a minor correspondence between the U.S. and Canada models (Figure 140, correlation = 0.23, two-sided 95% confidence interval -0.01- 0.45). This indicates uncertainty in estimates of year-class strength between the two models. The Alaska assessment is based upon density estimates of yelloweye rockfish from crewed or remotely operated vehicles, as well as the IPHC long-line survey, and therefore contains no information for canary rockfish (Joy et al. 2022).

3.5.7 Unresolved Problems and Major Uncertainties

The major uncertainty in this assessment is treatment of natural mortality. This issue has been a long-standing uncertainty for canary rockfish assessments, and remains so. This uncertainty arises from observations in survey and fishery data that age-based sex-ratios are male skewed starting around age 20. This could be explained by females being less susceptible to capture, or to fewer females in the population, or to some combination of both. No refugia for old females has been found thus far suggesting mortality may be a more probable culprit, however sex ratios within Oregon fishery data have been nearer to equal in the last decade. Regardless, there is uncertainty on how best to model this dynamic.

The choice of how to model natural mortality matters. Assuming fixed sex-specific age-invariant natural mortality results in a more pessimistic outlook because natural mortality for females is fixed at the lower prior (0.0643) value. If natural mortality is age-dependent, female natural mortality is estimated to be higher at older ages, and the magnitude of the value increases with the age at which the break in natural mortality occurs. A higher natural mortality estimate results in a more optimistic population trajectory that increases dramatically in the 2000s from low abundance in the late 1990s. Modeling selectivity as sex-dependent, as in the base model, reflects a middle ground in the estimate of natural mortality, in that age-invariant estimates between males and females differ by 20 percent (with females higher), while avoiding the less common biological assumption that natural mortality increases with age. However, applying sex-dependent selectivity results in larger females having greater selectivity values than males, which would seem to be opposite to treatments in past assessments for explaining the male-skewed sex ratio due to older females being less susceptible to capture. Assuming no sex-dependent selectivity results in a worse fitting model, and also has a different population outlook in that natural mortality for females is estimated lower than the prior estimate (0.055) while high recruitment in recent years results in a greater population increase than would be expected under such a low natural mortality estimate under average recruitment deviations.

A challenge with the current base model is that it is highly parameterized with many correlations between parameters above 0.8, including some parameters with correlations as high as 0.97. Earlier versions of the model suggested a flat likelihood surface. Although the current base model is more stable due to simplifications to the Washington recreational and Oregon non-trawl selectivity blocks, the number of selectivity parameters and correlations among them indicate additional simplification may be warranted. Simplifying the number of selectivity parameters by reducing the number of time-varying blocks degrades model fit by a large degree and does not appear to be a solution for reducing model complexity. Modeling selectivity as a three parameter double-normal reduces correlation in parameters compared to a four parameter formulation, however modeling sex-dependent selectivity reintroduces a fourth selectivity parameter. Alternative forms for modeling selectivity and continued explorations into ways to model processes that lead to high male sex ratios in older ages may help reduce parameter correlations, and limit concerns about potential over-parameterization.

4 Management

4.1 Reference Points

Reference points were calculated using the estimated selectivities and catch distribution among fleets in the final year of the model, 2022. Average unfished spawning output is estimated to be 8009 million eggs and unfished total summary (age 5+) biomass is estimated to be 75273 metric tons. A population at equilibrium at a target of $B_{40\%}$ is associated with a total dead catch of 1152 metric tons and spawning output of 3203 million eggs. A population at equilibrium at an SPR target of 50% is associated with a total dead catch of 1094 metric tons and spawning output of 3573 million eggs. A population at equilibrium at model-estimated maximum sustainable yield is associated with a total dead catch of 1246 metric tons and spawning output of 2063 million eggs. For a full list of reference points at the three different management targets, see Table 21.

The 2023 canary rockfish spawning output relative to unfished spawning output is within the precautionary zone at 35.1 percent (Figure 118). The fishing intensity ($1 - \text{SPR}$) has been low since 2000 but has recently increased to fishing mortality corresponding to an SPR near 0.5 (Figure 119). The yield curve indicates current yield is below MSY estimated in the model, but above an optimum yield based on both proxy targets (Figure 141).

4.2 Harvest Projections and Decision Tables

The 2023 stock assessment for canary rockfish off the U.S. West Coast was assigned a category 1 determination by the Scientific and Statistical Committee to the PFMC. A ten-year projection of the base model with total catches equal to the estimated ACL based on the category 1 time-varying σ (0.5) with either $P^* = 0.45$ or $P^* = 0.40$ (i.e., termed the "buffer") for years 2025-2034 is shown in Tables 22–23. Catches were apportioned to each fleet based on the relative fishing morality among fleets in the last four years of the model. The removals in 2023 and 2024 were set equal to the recommended fleet-specific values as provided by the GMT (W. Roberts, WDFW, personal communication, 7/6/23). The adopted OFL, ABC, and ACL values for 2024 in Tables 22–23 are from the updated values identified during the September PFMC meeting (Supplemental REVISED Attachment 1, September 2023).

At the end of the projection period, 2034, the projected ACL removals result in spawning output relative to unfished to be slightly lower than in 2025 at 33.1 percent for the default harvest control rule ($P^* = 0.45$), but starting to increase. The delayed increase in spawning output relative to unfished is due in part to the long period of negative recruitment deviations over the last decade. Projections were done assuming average recruitment, which given the age of maturity for canary rockfish take a number of years to contribute to spawning output. If projected ACL removals were applied to a model assuming lower than average recruitment during the projection period, such as during the recent period of low recruitment deviations in 2014-2019, which reflects about half as much recruitment compared to the base projections, then the spawning output relative to unfished at the end of the projection period would be 30.5 percent, and would be decreasing (Figure 142). The effect of alternative assumptions for recruitment on a 10 year projection is limited given that recruits take time before contributing to spawning output.

The axis of uncertainty in the decision table is based on the uncertainty around natural mortality. Alternative structural assumptions around natural mortality as described in (Section 3.5.2) were used to identify the low and high states of nature, where the base model is assigned a 50 percent probability of being the true state of nature and both the low and high states of nature are assigned a 25 percent probability. The alternative states of nature were based on the M ramp (high state) and single M (low state) sensitivity runs. We use alternative model configurations because we think these better capture structural uncertainties for modeling canary rockfish compared to states of nature based on percentiles from the base model, which assumes different values around a single structural choice for the model. However, the range in 2023 spawning output from the alternative states of nature is less than the range spanned by the 12.5 and 87.5 percentiles from the base model, and is nearer to the 23 and 77 percentiles. The proposed decision table assumes full ACL removal during the projection period under alternative catch streams based on a $P^* = 0.45$ and $P^* = 0.40$ (Table 24).

4.3 Evaluation of Scientific Uncertainty

The model estimated uncertainty around the 2023 spawning output for canary rockfish is $\sigma = 0.14$ and the uncertainty around the OFL was $\sigma = 0.15$. Each of these are very likely to underestimate overall uncertainty due to the necessity to fix several key population dynamics parameters (e.g., steepness, recruitment variance, natural mortality for males) and because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

Based on the considerations, explorations, and diagnostics described previously, we conclude that different treatments and assumptions regarding data preparation, data weightings, and decisions around selectivity blocks and mirroring have limited relative impact on estimates of stock status for canary rockfish compared to choices around stock productivity. Estimates of stock status are sensitive to assumptions regarding the biological parameters that govern productivity and the yield curve, especially the base natural mortality rate, the assumption that female natural mortality is age-invariant is estimated separately from males, and indirectly that male and female selectivity differs with respect to the rate of decline at larger lengths. We therefore recommend that further understanding on the appropriate forms and values of natural mortality are prioritized as a subject for future research.

4.4 Regional Management Considerations

Regional management differences exist across the U.S. West Coast based on various state-specific management measures. Spatial closures, bag limits, and depth restrictions can influence the effect of fishing on populations of a species that can vary by region. Spatial closures are expected to increase the spatial heterogeneity in abundance and size or age structure of fished stocks. This greater spatial variability can complicate the assumptions made in stock assessment models, particularly the assumption that the densities and demographic structure of assessed populations are relatively homogeneous. Although a wide range of factors above and beyond spatial management measures can also lead to violations of those assumptions, the challenge can be particularly important for longer lived populations with lower movement rates. While spatially explicit assessment models provide a means of more explicitly addressing these challenges, such models are computationally intensive, require robust data from the specific areas being modeled, and may also require detailed information regarding movement and dispersal rates (McGilliard et al. 2015; Berger et al. 2017; Cadrin 2020).

The 2015 stock assessment used a spatial population model with spatial connectivity in the apportionment of recruitment, and catches assigned to individual regions. Spatial models can provide regional estimates in spawning output and spawning output relative to unfished levels, although estimates from individual areas within spatial models can be biased even when estimates over the entire area are unbiased (Bosley et al. 2022). Regional estimates of spawning output or relative spawning output were not provided in the 2015 stock assessment report (Thorson and Wetzel 2016). The text briefly mentions that California had the largest declines in spawning output relative to unfished levels, and the model assumed recruitment was apportioned approximately as 20-50-30 for California, Oregon, and Washington. Ultimately, Thorson and Wetzel (2016) argued that a spatial approach was "a tool to visualize and explore model residuals and to be a method to identify time-varying selectivity at the stock-wide level, rather than as a basis for spatially varying fisheries management."

For this assessment, we chose to focus efforts on a coastwide model. The reasons for doing so have been described elsewhere, but briefly were based on principles of parsimony, evidence of concerns around model stability, and the similar overall results between the coastwide and spatial models in our bridging analysis as well as from Thorson and Wetzel (2016), even with low levels of movement among regions. We used an area-as-fleets approach to approximate spatial structure in exploitation, and to capture potential differences in population-structure by region within composition data. Such an approach performs well when the underlying population is uniform, but can be biased when it is not (Bosley et al. 2022). Crucially, matching movement dynamics is more important than matching spatial structure of the population (Bosley et al. 2022). The extent to which canary rockfish move remains uncertain, and thus understanding the magnitude of movement would be beneficial to understanding the benefit of various modeling structures for assessing canary rockfish. However, limited information from tagging, genetic, and otolith microchemistry analyses indicates relatively high movement rates among areas (DeMott 1982; Gao et al. 2013; Budrick 2016).

Finally, using total survey biomass for apportioning quota to regions maximizes system yield (Bosley et al. 2019). Thus, in lieu of reliable spatially explicit estimates of absolute and relative spawning output, estimates from the WCGBTS can be used to apportion catch across regions, as is already standard for U.S. West Coast assessments. Using model-based indices calculated for each state during the process of bridging from a spatial to coastwide model, over the last five years (2017-2022) 15% of the canary rockfish population has inhabited California waters, 36% Oregon, and 49% Washington.

4.5 Research and Data Needs

4.5.1 Responses to Previous Assessment Research and Data Needs

Recommendations from the 2015 benchmark assessment are listed below and are summarized for brevity. We provide our response to these below, and also provide updated research recommendations in the section that follows based on our experience this cycle.

1. A historical catch reconstruction be initiated with the intent of estimating spatial location of catches. Such a process has been initiated in other regions (e.g., the Northwest Atlantic, M. Pinsky, pers. comm.), and will be important to validate the assumptions that are necessary when developing spatial models.

Response: This assessment includes a new reconstruction of canary rockfish landings in Oregon within unspecified PacFIN categories from 1987–1999. A formal Washington reconstruction is nearing completion, but was not yet ready for use in this assessment. Some work was begun on separating canary rockfish landings in Oregon into those caught in Oregon and Washington waters while compiling data for this assessment. While logbook information may be sufficient to eventually approximate state of catch, the composition data is much more challenging to separate and could not be done within the time available. A comprehensive approach to account for trawl-caught fish across state boundaries is underway as a result of this analysis. Because this assessment model returned to a coastwide configuration, this recommendation was given lower priority.

2. We endorse a systematic (rather than ad hoc and species-specific) exploration and analysis of Canadian data sources (length and age-composition, indices of abundance, landings, and discards) for several rockfishes.

Response: Progress remains species-specific. However, progress for some groundfish species (sablefish, *Anoplopoma fimbria* and petrale sole, *Eopsetta jordani*) is occurring outside of regular regional stock assessment cycles so that it can be completed in a more intentional and less ad hoc fashion. Canary rockfish has not been prioritized for these activities by NMFS or DFO. We explored Canadian canary rockfish landings and estimates of recruitment deviations from an assessment conducted one year prior to this one.

3. We therefore recommend that future research explore methods to stitch these time series back together (i.e., using covariates and a meta-analytic information regarding the ratio of catchability in the two periods).

Response: Changes in the spatial (latitudinal and depth) extent of the triennial survey should not impact canary rockfish, which are generally not found in the areas the survey expanded into. Canary rockfish are also not known to undertake seasonal migrations, so the change in timing should similarly not be influential. Therefore, this assessment estimates the triennial index using a single spatial GLMM. Both composition data and catch data are truncated so as not to include areas of survey expansion. The index is entered into the assessment model as two different fleets to maintain the ability to test for sensitivity to combining the periods, but catchability and selectivity are mirrored between these two fleets. Thus, they are treated as a single time series with different age and length composition data weights.

4. We suggest that basic life history research be highly prioritized for future research.

Response: This assessment includes updated data and relationships on growth, condition (weight-length), fecundity, and maturity. A number of studies on canary rockfish life history and population structure have been published since the previous assessment (Budrick 2016; Keller et al. 2018; Brooks 2021). Unfortunately, these have not resulted in a better understanding of natural mortality and the apparent loss of older females. This remains a research priority. In absence of better understanding of canary rockfish natural mortality, we use natural mortality rates from a recently updated prior (Hamel and Cope 2022).

4.5.2 Current Research and Data Needs

We list current research recommendations and prioritize them from high to low. Lower priority needs should not not be interpreted as unimportant, but rather lower relative to other priorities listed here.

1. Continued research into the mechanism leading to skewed sex ratios and empirical studies to estimate natural mortality rates. This remains a critical uncertainty for canary rockfish, as well as other species of rockfish along the U.S. West Coast, but one that remains largely unknown. The rate of natural mortality as well as whether and to what extent it increases with age is a major source of uncertainty for this assessment, as it has been for past assessments. Recent evidence suggesting sex ratios are nearer unity may be informative, but further research to understand the mechanism by which this occurs would be beneficial for understand the ability of canary rockfish to recover. (High)

2. The WCGBTS has low encounter rates with canary rockfish in part because it has limited access to rocky habitat. We recommend exploration of a non-trawl coast-wide fishery-independent indices. This could mean an expansion of the Hook and Line Survey into more northern waters, or taking advantage of developments in model-based index standardization to stitch together multiple similar overlapping fishery-independent non-trawl sampling programs that have occurred over smaller spatial and temporal scales than the WCGBTS. This also has the potential to provide biological data in a variety of habitats and across latitudinal gradients which when aged using current best practices can help inform biological parameters that have been suggested by Brooks (2021) to occur above the southern range of canary rockfish but were not seen to the same extent in current WCGBTS data. (Medium)

3. Similar to recommendations 1 and 2, other biological relationships can be updated to better understand dynamics for canary rockfish. Few samples of canary rockfish are available to inform estimates of fecundity. Fecundity for canary rockfish was based on a genus level relationship from Dick et al. (2017). The resulting curve from these two relationships did not greatly differ but did result in changes in the spawning output within the bridging analysis. Greater species-specific information on canary rockfish fecundity would ensure that biological relationships better reflect individual species dynamics should they differ from other species in their genus. (Medium)

4. This assessment model does not include any ecosystem or climate considerations, but canary rockfish are considered highly vulnerable and highly exposed to climate change. To date, most research has relied on non-mechanistic basin-scale indices that may not be reliable predictors of how environmental conditions will impact productivity moving forward. In addition, the lack of correspondence between recruitment deviations estimated in this assessment and in British Columbia is concerning, as recruitment deviations are often used as response variables to understand environmental drivers of productivity. We recommend further research into environmental drivers of canary rockfish productivity to understand how future and past climate change impact both short-term and long-term changes in productivity. Doing this research in a multispecies manner across groundfish species, particularly those with similar life histories, may lead to more statistical power to gain new insight. (Medium)

5. Further exploration of differences in spatial and non-spatial modeling structure, stability, and results. The structure of canary rockfish stock assessments has varied over time. The 2015 assessment added population structure so as to more explicitly describe potential regional differences in depletion. For this assessment we return to a coastwide model for reasons explain previously. Although the 2015 model showed little difference in results between a spatial and coastwide model, which is also supported

through bridging analyses both before and after data weighting, balancing spatial explorations of differences in exploitation, movement, or biological patterns with the realities of model complexity and stability within the time frame of production stock assessments is challenging. Given that this issue could apply to other species in addition to canary rockfish we suggest the possibility of establishing a process by which research-based assessments can be done to explore these issues, similar to the research track process on the east coast of the U.S. (Medium)

6. Research to inform understanding of movement rates for a spatial model, as well as improve estimates of natural mortality. Large scale movement patterns for canary rockfish are generally unknown. However, even a small number of tagging samples collected intermittently can improve model estimates (Goethel et al. 2019). Any method that determines both the extent and direction of movement would be useful; the method need not be limited to tagging. (Low)

7. Ageing error matrices were not updated from the 2015 assessment. Revision of the ageing error matrices, incorporating the new aged canary rockfish data and utilizing new analytical methods are topics for future research. Potential bias in ageing of old canary rockfish based on bomb-radiocarbon data (A. Stephens, NWFSC, personal communication, May 2023) should also be considered in these analyses. (Low)

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7 Tables

Table 1: Total removals (mt) of canary rockfish for the trawl (TWL), non-trawl (NTWL), and recreational (Rec) fleets used in the assessment model. See text for description of sources.

Year	TWL CA	TWL OR	TWL WA	NTWL CA	NTWL OR	NTWL WA	Rec CA	Rec OR	Rec WA
1892	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0
1893	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0
1894	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0
1895	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
1896	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
1897	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
1898	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
1899	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
1900	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
1901	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
1902	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
1903	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
1904	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
1905	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
1906	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0
1907	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
1908	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0
1909	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0
1910	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0
1911	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0
1912	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0
1913	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0
1914	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0
1915	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0
1916	9.4	0.0	0.0	27.4	2.8	0.0	0.0	0.0	0.0
1917	14.4	0.0	0.0	44.3	2.9	0.0	0.0	0.0	0.0
1918	15.4	0.0	0.0	45.8	3.1	0.0	0.0	0.0	0.0
1919	11.9	0.0	0.0	26.6	3.2	0.0	0.0	0.0	0.0
1920	11.9	0.0	0.0	28.7	3.4	0.0	0.0	0.0	0.0
1921	9.3	0.0	0.0	25.7	3.5	0.0	0.0	0.0	0.0
1922	8.2	0.0	0.0	23.9	3.6	0.0	0.0	0.0	0.0
1923	9.6	0.0	0.0	28.9	3.8	0.0	0.0	0.0	0.0
1924	5.3	0.0	0.0	35.0	3.9	0.0	0.0	0.0	0.0
1925	3.6	0.0	0.0	43.0	4.1	0.0	0.0	0.0	0.0
1926	11.8	0.0	0.0	50.5	4.2	0.0	0.0	0.0	0.0
1927	15.2	0.0	0.0	40.7	4.3	0.0	0.0	0.0	0.0
1928	18.8	0.0	0.0	35.3	7.2	0.0	1.6	0.0	0.0
1929	34.4	0.0	0.0	23.9	12.3	0.0	3.2	0.0	0.0
1930	29.8	0.0	0.0	34.0	11.3	0.0	3.6	0.0	0.0
1931	41.2	0.0	0.0	33.1	9.0	0.0	4.9	0.0	0.0
1932	28.2	0.8	0.0	27.4	2.9	0.0	6.1	0.0	0.0
1933	38.4	0.5	0.0	10.9	4.7	0.0	7.3	0.0	0.0
1934	32.9	0.0	0.3	15.2	5.1	0.0	8.5	0.0	0.0

Table 1: Total removals (mt) of canary rockfish for the trawl (TWL), non-trawl (NTWL), and recreational (Rec) fleets used in the assessment model. See text for description of sources. *(continued)*

Year	TWL CA	TWL OR	TWL WA	NTWL CA	NTWL OR	NTWL WA	Rec CA	Rec OR	Rec WA
1935	33.7	0.4	2.3	23.1	4.6	0.0	9.7	0.0	0.0
1936	20.2	1.4	3.0	20.8	11.0	0.0	11.0	0.0	0.0
1937	30.7	2.8	2.7	13.2	13.1	0.0	13.0	0.0	0.0
1938	31.3	0.0	3.9	13.5	12.9	0.0	12.8	0.0	0.0
1939	41.5	4.0	4.1	12.9	7.3	0.0	11.2	0.0	0.0
1940	33.8	90.8	9.1	9.6	16.3	0.0	16.1	0.0	0.0
1941	26.8	139.7	3.4	12.3	21.8	0.0	14.8	0.0	0.0
1942	6.5	262.5	66.5	9.2	30.2	0.0	7.9	0.0	0.0
1943	32.0	917.6	214.8	7.6	74.8	0.0	7.5	0.0	0.0
1944	133.6	1610.2	89.3	28.6	19.2	0.0	6.2	0.0	0.0
1945	303.5	2484.5	935.7	69.5	12.3	0.0	8.3	0.0	0.0
1946	275.2	1529.8	471.7	71.6	15.1	0.0	14.2	0.0	0.0
1947	110.4	953.6	246.4	16.4	7.6	0.0	11.3	0.0	0.0
1948	125.7	679.5	400.1	32.0	12.5	0.0	22.7	0.0	0.0
1949	110.7	588.4	486.6	12.4	8.4	0.0	29.4	0.0	0.0
1950	99.8	616.2	467.7	10.1	7.8	0.0	35.8	0.0	0.0
1951	201.0	566.9	391.2	16.3	6.0	0.0	42.4	0.0	0.0
1952	143.5	587.2	373.1	12.3	5.7	0.0	37.0	0.0	0.0
1953	137.2	615.5	161.8	7.2	3.0	0.0	31.7	0.0	0.0
1954	98.3	781.5	232.1	17.5	3.5	0.0	39.9	0.0	0.0
1955	105.0	787.1	219.0	4.1	4.3	0.0	48.4	0.0	0.0
1956	102.5	1166.1	209.2	6.4	2.7	0.0	54.1	0.0	0.0
1957	116.0	1214.6	173.1	7.0	6.0	0.0	50.7	0.0	0.0
1958	154.2	830.1	219.1	9.1	1.2	0.0	86.3	0.0	0.0
1959	115.3	908.9	244.9	6.3	2.4	0.0	69.6	0.0	0.0
1960	88.5	1082.9	221.5	8.0	1.6	0.0	54.2	0.0	0.0
1961	69.0	982.8	262.9	6.5	4.5	0.0	38.1	0.0	0.0
1962	68.7	1148.5	366.4	9.3	4.1	0.0	46.5	0.0	0.0
1963	97.1	660.5	294.9	8.7	3.7	0.0	49.6	0.0	0.0
1964	61.4	1014.1	217.7	8.2	0.8	0.0	45.5	0.0	0.0
1965	82.5	832.2	485.2	9.1	6.2	0.0	69.4	0.0	0.0
1966	59.8	934.6	664.1	7.2	4.2	0.0	75.4	0.0	0.0
1967	82.3	152.0	324.2	7.7	11.9	0.0	79.4	0.0	0.8
1968	79.6	873.2	559.5	4.8	10.8	0.0	84.4	0.0	1.2
1969	198.2	282.5	545.4	19.0	24.0	0.0	92.3	0.0	1.5
1970	217.6	592.9	504.6	12.0	9.3	0.0	115.9	0.0	1.8
1971	329.7	776.7	578.1	21.1	19.0	0.0	101.1	0.0	2.2
1972	409.4	752.7	161.2	40.9	24.7	0.0	133.3	0.0	2.5
1973	318.2	928.1	361.2	19.6	26.3	0.0	155.2	5.1	2.8
1974	400.1	585.1	552.2	50.0	33.2	0.0	163.8	10.1	3.2
1975	435.2	415.0	759.4	36.0	17.5	0.0	158.9	15.2	3.5
1976	474.8	267.3	579.1	50.0	23.3	0.0	175.2	20.2	1.6
1977	460.4	622.3	486.0	59.5	28.7	0.0	167.5	25.3	4.0
1978	653.8	1877.7	1413.4	146.0	44.8	0.0	161.3	30.3	5.9
1979	314.6	1409.2	711.8	128.7	126.7	0.0	178.9	35.4	4.2

Table 1: Total removals (mt) of canary rockfish for the trawl (TWL), non-trawl (NTWL), and recreational (Rec) fleets used in the assessment model. See text for description of sources. *(continued)*

Year	TWL CA	TWL OR	TWL WA	NTWL CA	NTWL OR	NTWL WA	Rec CA	Rec OR	Rec WA
1980	442.7	2983.2	763.4	95.8	72.8	0.0	166.0	37.2	2.7
1981	546.8	2041.3	533.5	172.2	79.2	0.0	153.1	47.2	2.3
1982	807.1	3897.0	451.2	45.3	145.6	0.0	275.6	50.5	2.5
1983	513.1	3573.6	674.9	70.0	298.0	0.0	105.6	28.9	4.4
1984	402.0	1355.0	635.6	63.0	200.5	0.0	107.4	36.0	7.8
1985	332.4	1133.0	1076.5	117.4	199.3	0.0	163.8	19.3	3.8
1986	172.3	1099.9	932.4	58.6	158.6	0.0	226.8	38.5	6.2
1987	213.9	1597.5	1054.3	53.0	250.5	0.0	225.2	25.0	6.3
1988	231.7	1745.7	1015.6	56.5	208.3	0.0	184.2	19.5	6.1
1989	188.3	1652.4	1253.7	224.9	204.2	0.0	115.6	22.8	9.4
1990	337.9	1099.5	1140.8	216.7	268.0	0.0	175.0	14.2	8.9
1991	151.1	2095.8	1007.7	167.2	295.1	0.0	165.7	19.2	9.7
1992	233.4	1691.6	855.6	132.0	185.2	0.0	156.3	26.4	18.8
1993	93.3	1716.4	300.6	112.1	460.6	0.0	162.0	35.6	18.0
1994	124.6	754.2	155.1	97.7	120.8	0.0	133.7	28.2	10.4
1995	132.9	583.5	162.4	115.1	116.3	3.6	173.4	35.2	8.8
1996	219.0	792.8	191.4	125.7	164.2	3.5	63.1	22.0	8.5
1997	176.0	602.3	205.1	104.3	251.4	5.6	102.6	28.0	8.0
1998	159.1	713.2	204.6	81.2	246.3	6.2	26.6	42.0	13.5
1999	99.8	399.5	141.1	30.6	118.8	6.5	64.9	25.1	7.9
2000	14.8	40.6	13.0	13.5	12.5	3.8	77.1	20.8	6.2
2001	10.6	20.5	9.5	10.9	11.6	5.6	33.4	11.1	5.4
2002	16.1	29.4	23.7	0.1	0.5	4.3	6.2	9.1	2.4
2003	1.2	16.8	10.8	2.2	0.5	7.2	18.1	9.0	2.1
2004	2.4	7.6	7.8	2.4	5.9	2.2	10.6	2.2	0.9
2005	3.1	15.4	23.8	1.6	1.8	2.2	5.8	3.2	1.4
2006	9.4	16.4	9.1	2.6	2.7	1.1	14.1	1.7	0.8
2007	20.2	3.4	4.0	3.4	1.9	0.8	14.1	1.9	0.7
2008	9.9	4.6	3.2	1.2	0.9	5.4	7.6	2.5	0.6
2009	1.6	7.5	5.4	1.6	3.1	3.4	18.0	3.5	0.6
2010	0.5	4.0	6.7	5.2	1.0	4.8	15.8	4.5	1.0
2011	0.3	3.1	3.6	13.0	4.3	9.7	19.8	3.1	1.1
2012	0.6	6.7	5.0	4.2	1.9	6.1	18.2	3.0	1.0
2013	1.5	6.1	4.6	6.4	2.8	3.3	14.8	4.0	1.0
2014	2.0	10.3	2.2	4.4	1.8	6.0	22.4	3.0	1.4
2015	7.0	41.1	4.0	5.2	3.2	9.6	26.9	14.3	2.2
2016	2.8	17.0	5.0	3.1	6.7	5.1	23.7	9.8	1.9
2017	75.3	148.1	37.3	7.2	5.7	3.3	83.4	28.2	4.6
2018	139.7	173.9	156.3	7.5	4.4	2.2	61.8	43.6	3.9
2019	176.2	194.5	65.4	10.6	6.2	1.7	71.4	38.7	11.9
2020	73.7	186.6	78.9	18.6	7.5	3.0	76.7	60.6	7.3
2021	78.5	223.5	73.6	25.6	6.6	1.4	73.0	38.6	32.2
2022	90.1	315.3	101.2	22.5	11.0	0.9	62.6	55.6	34.2

Table 2: Total removals (mt) of canary rockfish for the foreign (FOR) and at-sea hake (ASHOP) fleets used in the assessment model. Removals before 1966 are zero. See text for description of sources.

Year	FOR CA	FOR OR	FOR WA	ASHOP CA	ASHOP OR	ASHOP WA
1966	41	1445	113	0.0	0.0	0.0
1967	103	658	90	0.0	0.0	0.0
1968	415	286	109	0.0	0.0	0.0
1969	5	50	12	0.0	0.0	0.0
1970	0	73	28	0.0	0.0	0.0
1971	0	118	70	0.0	0.0	0.0
1972	13	318	68	0.0	0.0	0.0
1973	372	525	68	0.0	0.0	0.0
1974	150	81	288	0.0	0.0	0.0
1975	63	141	0	0.0	0.0	0.0
1976	49	114	0	0.0	8.1	0.0
1977	0	0	0	0.0	1.5	0.0
1978	0	0	0	0.4	11.9	0.6
1979	0	0	0	0.0	11.2	0.3
1980	0	0	0	0.4	8.4	1.7
1981	0	0	0	2.8	1.5	0.3
1982	0	0	0	0.1	0.2	27.0
1983	0	0	0	0.0	2.1	26.2
1984	0	0	0	0.0	1.2	2.1
1985	0	0	0	0.0	4.6	2.8
1986	0	0	0	0.0	0.9	3.8
1987	0	0	0	0.0	2.5	6.3
1988	0	0	0	0.2	3.7	2.2
1989	0	0	0	0.3	1.6	1.0
1990	0	0	0	0.1	2.2	1.8
1991	0	0	0	0.0	2.1	1.8
1992	0	0	0	0.0	0.1	2.2
1993	0	0	0	0.0	0.2	0.7
1994	0	0	0	0.0	0.7	4.0
1995	0	0	0	0.0	0.1	0.3
1996	0	0	0	0.0	0.0	1.0
1997	0	0	0	0.0	0.5	2.7
1998	0	0	0	0.0	0.2	4.7
1999	0	0	0	0.0	0.1	6.8
2000	0	0	0	0.0	0.2	2.2
2001	0	0	0	0.0	1.0	2.9
2002	0	0	0	0.0	2.4	2.8

Table 2: Total removals (mt) of canary rockfish for the foreign (FOR) and at-sea hake (ASHOP) fleets used in the assessment model. Removals before 1966 are zero. See text for description of sources. *(continued)*

Year	FOR CA	FOR OR	FOR WA	ASHOP CA	ASHOP OR	ASHOP WA
2003	0	0	0	0.0	0.2	0.7
2004	0	0	0	0.0	4.5	0.7
2005	0	0	0	0.0	0.5	0.9
2006	0	0	0	0.0	0.4	0.6
2007	0	0	0	0.0	1.8	0.2
2008	0	0	0	0.0	0.5	3.2
2009	0	0	0	0.0	0.0	2.5
2010	0	0	0	0.0	0.0	1.1
2011	0	0	0	0.0	0.0	1.1
2012	0	0	0	0.0	0.1	0.3
2013	0	0	0	0.0	0.1	0.6
2014	0	0	0	0.0	0.4	0.3
2015	0	0	0	0.0	0.1	0.1
2016	0	0	0	0.0	0.2	0.3
2017	0	0	0	0.0	1.8	4.8
2018	0	0	0	0.0	3.0	2.5
2019	0	0	0	0.0	0.7	4.3
2020	0	0	0	0.0	0.2	0.7
2021	0	0	0	0.0	3.2	2.7
2022	0	0	0	0.0	4.2	1.5

Table 3: The OFL, ABC, ACL, and total mortality (landings + dead discards), all in units of metric tons.

Year	OFL	ABC	ACL	Total Mortality
2013	752	719	116	45.00
2014	741	709	119	54.09
2015	733	701	122	113.69
2016	729	697	125	75.61
2017	1793	1714	1714	399.66
2018	1596	1526	1526	598.69
2019	1517	1450	1450	581.78
2020	1431	1368	1368	513.68
2021	1459	1338	1338	558.68
2022	1432	1307	1307	700.36

Table 4: Summary of the number of length samples and trips for commercial trawl (TWL) and non-trawl (NTWL) fleets for California (CA), Oregon (OR), and Washington (WA).

Year	Trips TWL CA	Lengths TWL CA	Trips TWL OR	Lengths TWL OR	Trips TWL WA	Lengths TWL WA	Trips NTWL CA	Lengths NTWL CA	Trips NTWL OR	Lengths NTWL OR	Trips NTWL WA	Lengths TWL WA
1968	0	0	0	0	2	402	0	0	0	0	0	0
1969	0	0	0	0	2	718	0	0	0	0	0	0
1970	0	0	0	0	1	268	0	0	0	0	0	0
1971	0	0	0	0	8	1804	0	0	0	0	0	0
1972	0	0	0	0	2	501	0	0	0	0	0	0
1973	0	0	1	51	1	230	0	0	0	0	0	0
1974	0	0	4	370	0	0	0	0	0	0	0	0
1975	0	0	0	0	5	1244	0	0	0	0	0	0
1976	0	0	2	89	4	766	0	0	0	0	0	0
1977	25	64	8	750	2	481	0	0	0	0	0	0
1978	71	384	7	670	4	721	1	1	0	0	0	0
1979	32	170	6	600	8	800	13	49	0	0	0	0
1980	103	318	21	1034	18	1654	12	45	0	0	1	22
1981	60	192	7	603	18	1765	16	79	0	0	0	0
1982	90	437	20	1358	13	1300	10	70	0	0	0	0
1983	125	421	30	2836	17	1650	6	36	0	0	0	0
1984	82	373	21	2064	17	1550	10	33	0	0	0	0
1985	94	447	29	1891	18	1750	25	89	0	0	0	0
1986	57	396	16	1545	17	1650	29	100	0	0	0	0
1987	60	305	35	1751	25	1300	15	121	0	0	0	0
1988	52	272	23	1148	19	950	13	94	3	287	0	0
1989	45	247	23	1130	18	900	27	330	0	0	0	0
1990	49	349	22	1099	17	850	19	84	1	100	0	0
1991	36	191	22	869	22	1100	15	207	0	0	0	0
1992	29	229	34	1364	20	1000	148	1841	0	0	0	0
1993	34	252	22	1113	17	854	154	1415	0	0	0	0
1994	16	151	15	750	15	750	148	2057	0	0	0	0
1995	16	273	16	847	22	1100	83	1323	0	0	0	0
1996	24	442	19	1162	16	751	106	1390	1	37	0	0
1997	23	355	28	1545	26	870	80	1107	12	584	0	0
1998	14	210	28	1560	26	846	45	387	8	335	0	0
1999	14	305	28	1517	20	753	67	788	5	168	0	0
2000	11	87	16	496	7	229	16	148	24	176	2	3
2001	17	203	32	879	13	428	29	243	29	191	0	0
2002	15	294	58	1173	30	638	3	22	0	0	1	8
2003	5	46	35	273	21	271	1	1	0	0	0	0
2004	6	15	49	354	30	334	0	0	0	0	3	22
2005	9	67	49	350	31	413	0	0	0	0	0	0

Table 4: Summary of the number of length samples and trips for commercial trawl (TWL) and non-trawl (NTWL) fleets for California (CA), Oregon (OR), and Washington (WA). (*continued)*

Year	Trips TWL CA	Lengths TWL CA	Trips TWL OR	Lengths TWL OR	Trips TWL WA	Lengths TWL WA	Trips NTWL CA	Lengths NTWL CA	Trips NTWL OR	Lengths NTWL OR	Trips NTWL WA	Lengths TWL WA
2006	6	52	58	360	26	455	0	0	0	0	1	35
2007	9	67	45	122	44	353	0	0	0	0	2	6
2008	10	23	60	202	18	305	0	0	0	0	0	0
2009	11	100	82	487	23	401	0	0	0	0	0	0
2010	10	57	33	365	13	312	0	0	0	0	1	3
2011	4	12	45	418	20	372	0	0	0	0	0	0
2012	13	167	59	494	27	455	0	0	0	0	0	0
2013	18	310	158	1175	23	386	0	0	0	0	1	10
2014	27	202	146	1322	11	127	0	0	0	0	0	0
2015	32	426	145	1912	23	291	0	0	0	0	0	0
2016	30	361	116	1290	29	409	0	0	0	0	0	0
2017	34	827	184	2533	59	901	26	158	125	514	9	53
2018	35	612	161	1916	28	788	26	176	119	426	15	86
2019	26	635	153	1534	36	625	9	35	174	816	24	145
2020	33	721	79	848	17	251	19	251	70	292	14	119
2021	35	600	94	1210	26	555	24	472	112	299	30	200
2022	26	362	102	1365	30	664	22	314	124	430	35	221

Table 5: Summary of the number of aged samples and trips for commercial trawl (TWL) and non-trawl (NTWL) fleets for California (CA), Oregon (OR), and Washington (WA).

Year	Trips TWL CA	Ages TWL CA	Trips TWL OR	Ages TWL OR	Trips TWL WA	Ages TWL WA	Trips NTWL CA	Ages NTWL CA	Trips NTWL OR	Ages NTWL OR	Trips NTWL WA	Ages NTWL WA
1980	78	255	9	417	9	753	1	8	0	0	0	0
1981	47	161	7	428	18	1456	1	5	0	0	0	0
1982	51	210	14	457	12	1168	2	12	0	0	0	0
1983	116	396	29	2724	17	1524	2	6	0	0	0	0
1984	78	363	19	1856	17	1326	1	1	0	0	0	0
1985	76	401	24	1204	17	1647	3	29	0	0	0	0
1986	0	0	16	807	17	1501	0	0	0	0	0	0
1987	1	1	29	1448	24	1243	0	0	0	0	0	0
1988	0	0	16	459	19	948	0	0	0	0	0	0
1989	0	0	23	1055	18	887	0	0	0	0	0	0
1990	0	0	20	998	17	850	0	0	0	0	0	0
1991	0	0	22	850	20	984	0	0	0	0	0	0
1992	0	0	32	1280	20	1000	0	0	0	0	0	0
1993	0	0	22	1110	17	802	0	0	0	0	0	0
1994	0	0	4	200	15	749	0	0	0	0	0	0
1995	0	0	14	794	22	1100	0	0	0	0	0	0
1996	0	0	18	1093	15	741	0	0	0	0	0	0
1997	0	0	28	1537	17	846	0	0	1	17	0	0
1998	0	0	28	1554	17	819	0	0	4	87	0	0
1999	0	0	28	1516	15	737	0	0	0	0	0	0
2000	0	0	16	491	6	227	0	0	0	0	0	0
2001	1	28	24	733	13	425	0	0	5	39	0	0
2002	7	76	51	1008	30	634	3	22	0	0	1	8
2003	4	43	32	241	21	271	1	1	0	0	0	0
2004	5	12	47	333	29	318	0	0	0	0	3	22
2005	6	54	45	342	31	411	0	0	0	0	0	0
2006	5	32	47	240	26	453	0	0	0	0	1	35
2007	2	21	38	108	44	351	0	0	0	0	2	6
2008	0	0	58	195	18	304	0	0	0	0	0	0
2009	3	21	81	485	23	396	0	0	0	0	0	0
2010	1	5	31	340	13	307	0	0	0	0	1	3
2011	0	0	41	390	19	343	0	0	0	0	0	0
2012	0	0	58	493	27	436	0	0	0	0	0	0
2013	12	147	154	1150	22	334	0	0	0	0	1	10
2014	11	76	146	1319	6	81	0	0	0	0	0	0
2015	10	150	133	1607	22	284	0	0	0	0	0	0
2016	1	1	114	1237	29	383	0	0	0	0	0	0
2017	8	132	165	1194	59	866	0	0	6	14	8	52

Table 5: Summary of the number of aged samples and trips for commercial trawl (TWL) and non-trawl (NTWL) fleets for California (CA), Oregon (OR), and Washington (WA). (*continued)*

Year	Trips TWL CA	Ages TWL CA	Trips TWL OR	Ages TWL OR	Trips TWL WA	Ages TWL WA	Trips NTWL CA	Ages NTWL CA	Trips NTWL OR	Ages NTWL OR	Trips NTWL WA	Ages NTWL WA
2018	11	190	148	856	20	603	0	0	4	9	13	81
2019	13	306	131	708	17	268	1	6	13	32	10	40
2020	5	79	76	841	8	88	12	119	53	238	10	78
2021	12	246	74	932	15	287	14	241	10	42	16	108
2022	20	295	92	710	17	391	11	189	8	44	17	108

Table 6: Summary of the number of hauls and length samples for the at-sea hake fleets for Oregon (OR), and Washington (WA). No samples were collected in California.

Year	Hauls OR	Lengths OR	Hauls WA	Lengths WA
2003	36	46	49	119
2004	75	137	28	84
2005	94	140	86	180
2006	82	106	83	141
2007	189	428	37	68
2008	87	147	134	339
2009	5	5	132	236
2010	7	8	118	257
2011	3	3	76	202
2012	29	34	46	76
2013	19	22	45	121
2014	65	105	39	68
2015	18	23	17	34
2016	42	60	34	65
2017	223	443	229	644
2018	127	306	131	319
2019	59	114	132	339
2020	23	33	33	74
2021	143	416	28	87
2022	124	308	14	74

Table 7: Summary of the number of trips and aged samples for the at-sea hake fleets for Oregon (OR), and Washington (WA). No samples were collected in California.

Year	Hauls OR	Ages OR	Hauls WA	Ages WA
2003	33	43	49	100
2004	75	121	27	53
2005	90	122	83	143
2006	80	104	81	126
2007	175	330	33	57
2008	86	143	129	299
2009	5	5	131	227
2010	7	8	118	233
2011	3	3	75	200
2012	28	33	44	74
2013	18	21	44	88
2014	63	98	38	66
2015	17	21	15	32
2019	35	46	83	139
2020	23	32	32	60
2021	56	80	14	20

Table 8: Summary of the number of length samples and trips for recreational fleets for California (CA), Oregon (OR), and Washington (WA).

Year	Lengths CA	Trips CA	Lengths OR	Trips OR	Lengths WA	Trips WA
1979	0	0	0	0	40	4
1980	873	207	112	32	15	5
1981	429	118	77	22	45	5
1982	616	153	193	55	6	1
1983	425	140	32	15	3	1
1984	534	180	281	73	0	0
1985	1108	314	306	81	0	0
1986	1384	293	135	36	0	0
1987	618	107	203	53	1	1
1988	1283	203	348	85	0	0
1989	1775	231	150	35	0	0
1990	571	60	0	0	0	0
1991	545	65	0	0	0	0
1992	1109	164	0	0	0	0
1993	1926	357	525	123	0	0
1994	1828	280	642	129	0	0
1995	2015	273	599	106	38	15
1996	1925	237	329	77	15	7
1997	2164	227	443	110	14	6
1998	715	121	705	169	0	0
1999	981	205	1158	202	0	0
2000	386	92	732	124	0	0
2001	175	65	1201	503	0	0
2002	110	48	1693	660	198	16
2003	48	33	1881	805	229	16
2004	209	106	23	18	44	7
2005	398	167	18	11	51	8
2006	599	182	20	11	15	6
2007	348	128	9	8	10	4
2008	141	70	29	19	13	7
2009	172	75	16	9	13	7
2010	92	54	28	17	12	3
2011	205	82	47	20	11	5
2012	127	56	32	15	9	4
2013	134	60	20	12	6	3
2014	136	63	19	12	8	4
2015	163	87	2822	1053	37	7

Table 8: Summary of the number of length samples and trips for recreational fleets for California (CA), Oregon (OR), and Washington (WA). *(continued)*

Year	Lengths CA	Trips CA	Lengths OR	Trips OR	Lengths WA	Trips WA
2016	133	56	2323	943	31	14
2017	3252	667	4036	1139	1301	122
2018	2876	608	4577	1360	700	137
2019	3018	637	4490	1405	1455	232
2020	0	0	932	228	462	48
2021	2160	358	4255	1039	1219	100
2022	1841	469	3869	1057	1162	90

Table 9: Summary of the number of aged samples and trips for recreational fleets for Oregon (OR), and Washington (WA). No aged samples are available for the California recreational fleet.

Year	Ages OR	Trips OR	Ages WA	Trips WA
1999	393	37	0	0
2000	367	30	0	0
2004	0	0	40	6
2005	0	0	44	6
2006	0	0	4	2
2007	0	0	7	2
2008	0	0	9	4
2009	0	0	8	3
2010	0	0	11	2
2011	0	0	1	1
2012	0	0	7	2
2014	0	0	8	4
2015	315	129	5	3
2016	259	102	4	4
2017	238	105	1193	85
2018	192	102	285	27
2019	201	102	398	25
2020	241	88	424	31
2021	616	130	823	45
2022	449	136	938	52

Table 10: Summary of canary rockfish samples in the West Coast Groundfish Bottomtrawl Survey (WCG-BTS).

Year	N tows	N positive tows	N caught	N ages	N lengths
2003	542	50	455	262	423
2004	471	37	789	254	482
2005	637	53	850	231	530
2006	641	32	3618	247	623
2007	687	48	733	497	673
2008	679	35	830	452	792
2009	681	32	307	239	306
2010	714	51	1010	397	495
2011	695	46	786	364	573
2012	698	56	1316	596	852
2013	469	38	609	376	512
2014	682	75	2279	901	1467
2015	668	77	2530	735	1064
2016	692	80	1650	605	1055
2017	707	84	4724	528	970
2018	702	65	3273	474	719
2019	349	40	1345	359	544
2021	682	52	712	417	530
2022	632	51	1541	490	694

Table 11: Summary of canary rockfish samples in the Triennial Shelf Survey (Triennial).

Year	N tows	N positive tows	N caught	N ages	N lengths
1980	301	73	915	452	659
1983	479	177	6027	1441	2781
1986	483	169	5618	651	2544
1989	440	88	2672	307	1350
1992	421	66	530	93	361
1995	441	42	616	221	600
1998	468	82	370	195	356
2001	466	72	929	341	397
2004	383	62	443	211	412

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
NatM uniform Fem GP 1	0.078	2	(0.02, 0.2)	OK	0.002	Log Norm (-2.74, 0.31)
L at Amin Fem GP 1	8.159	3	(2, 15)	OK	0.231	None
L at Amax Fem GP 1	59.223	3	(50, 70)	OK	0.293	None
VonBert K Fem GP 1	0.139	3	(0.02, 0.21)	OK	0.002	None
CV young Fem GP 1	0.089	4	(0.02, 0.21)	OK	0.009	None
CV old Fem GP 1	0.039	4	(0.01, 0.21)	OK	0.003	None
Wtlen 1 Fem GP 1	1.19e-05	-99	(0, 0.1)	NA	NA	None
Wtlen 2 Fem GP 1	3.09	-99	(2, 4)	NA	NA	None
Mat50% Fem GP 1	10.87	-99	(9, 12)	NA	NA	None
Mat slope Fem GP 1	-0.688	-99	(-3, 3)	NA	NA	None
Eggs scalar Fem GP 1	7.218e-08	-99	(1e-10, 0.1)	NA	NA	None
Eggs exp len Fem GP 1	4.043	-99	(2, 6)	NA	NA	None
NatM uniform Mal GP 1	0.064	-99	(0.02, 0.2)	NA	NA	Log Norm (-2.74, 0.31)
L at Amin Mal GP 1	8.159	-99	(0, 15)	NA	NA	None
L at Amax Mal GP 1	53.713	3	(50, 70)	OK	0.262	None
VonBert K Mal GP 1	0.163	3	(0.02, 0.21)	OK	0.003	None
CV young Mal GP 1	0.098	4	(0.02, 0.21)	OK	0.009	None
CV old Mal GP 1	0.046	4	(0.01, 0.21)	OK	0.003	None
Wtlen 1 Mal GP 1	1.08e-05	-99	(0, 0.1)	NA	NA	None
Wtlen 2 Mal GP 1	3.118	-99	(2, 4)	NA	NA	None
CohortGrowDev	1	-99	(-1, 1)	NA	NA	None
FracFemale GP 1	0.5	-99	(1e-06, 0.999)	NA	NA	None
SR LN(R0)	8.221	1	(7, 11)	OK	0.058	None
SR BH steep	0.72	-99	(0.21, 0.99)	NA	NA	Full Beta (0.72, 0.16)
SR sigmaR	0.5	-99	(0, 2)	NA	NA	None
SR regime	0	-99	(-5, 5)	NA	NA	None
SR autocorr	0	-99	(0, 2)	NA	NA	None
Early RecrDev 1892	-0.011	5	(-5, 5)	act	0.497	None
Early RecrDev 1893	-0.011	5	(-5, 5)	act	0.497	None
Early RecrDev 1894	-0.012	5	(-5, 5)	act	0.497	None
Early RecrDev 1895	-0.013	5	(-5, 5)	act	0.497	None
Early RecrDev 1896	-0.014	5	(-5, 5)	act	0.497	None
Early RecrDev 1897	-0.015	5	(-5, 5)	act	0.496	None
Early RecrDev 1898	-0.015	5	(-5, 5)	act	0.496	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Early RecrDev 1899	-0.016	5	(-5, 5)	act	0.496	None
Early RecrDev 1900	-0.017	5	(-5, 5)	act	0.496	None
Early RecrDev 1901	-0.018	5	(-5, 5)	act	0.495	None
Early RecrDev 1902	-0.02	5	(-5, 5)	act	0.495	None
Early RecrDev 1903	-0.021	5	(-5, 5)	act	0.495	None
Early RecrDev 1904	-0.022	5	(-5, 5)	act	0.495	None
Early RecrDev 1905	-0.023	5	(-5, 5)	act	0.494	None
Early RecrDev 1906	-0.025	5	(-5, 5)	act	0.494	None
Early RecrDev 1907	-0.026	5	(-5, 5)	act	0.494	None
Early RecrDev 1908	-0.028	5	(-5, 5)	act	0.493	None
Early RecrDev 1909	-0.03	5	(-5, 5)	act	0.493	None
Early RecrDev 1910	-0.031	5	(-5, 5)	act	0.492	None
Early RecrDev 1911	-0.033	5	(-5, 5)	act	0.492	None
Early RecrDev 1912	-0.035	5	(-5, 5)	act	0.491	None
Early RecrDev 1913	-0.037	5	(-5, 5)	act	0.491	None
Early RecrDev 1914	-0.039	5	(-5, 5)	act	0.490	None
Early RecrDev 1915	-0.042	5	(-5, 5)	act	0.490	None
Early RecrDev 1916	-0.044	5	(-5, 5)	act	0.489	None
Early RecrDev 1917	-0.047	5	(-5, 5)	act	0.489	None
Early RecrDev 1918	-0.05	5	(-5, 5)	act	0.488	None
Early RecrDev 1919	-0.052	5	(-5, 5)	act	0.487	None
Early RecrDev 1920	-0.056	5	(-5, 5)	act	0.486	None
Early RecrDev 1921	-0.059	5	(-5, 5)	act	0.486	None
Early RecrDev 1922	-0.062	5	(-5, 5)	act	0.485	None
Early RecrDev 1923	-0.066	5	(-5, 5)	act	0.484	None
Early RecrDev 1924	-0.07	5	(-5, 5)	act	0.483	None
Early RecrDev 1925	-0.073	5	(-5, 5)	act	0.482	None
Early RecrDev 1926	-0.078	5	(-5, 5)	act	0.481	None
Early RecrDev 1927	-0.082	5	(-5, 5)	act	0.480	None
Early RecrDev 1928	-0.086	5	(-5, 5)	act	0.479	None
Early RecrDev 1929	-0.09	5	(-5, 5)	act	0.478	None
Early RecrDev 1930	-0.095	5	(-5, 5)	act	0.477	None
Early RecrDev 1931	-0.099	5	(-5, 5)	act	0.476	None
Early RecrDev 1932	-0.104	5	(-5, 5)	act	0.475	None
Early RecrDev 1933	-0.108	5	(-5, 5)	act	0.474	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Early RecrDev 1934	-0.113	5	(-5, 5)	act	0.473	None
Early RecrDev 1935	-0.118	5	(-5, 5)	act	0.471	None
Early RecrDev 1936	-0.125	5	(-5, 5)	act	0.470	None
Early RecrDev 1937	-0.132	5	(-5, 5)	act	0.468	None
Early RecrDev 1938	-0.139	5	(-5, 5)	act	0.467	None
Early RecrDev 1939	-0.148	5	(-5, 5)	act	0.465	None
Early RecrDev 1940	-0.157	5	(-5, 5)	act	0.463	None
Early RecrDev 1941	-0.165	5	(-5, 5)	act	0.461	None
Early RecrDev 1942	-0.172	5	(-5, 5)	act	0.459	None
Early RecrDev 1943	-0.178	5	(-5, 5)	act	0.458	None
Early RecrDev 1944	-0.183	5	(-5, 5)	act	0.457	None
Early RecrDev 1945	-0.185	5	(-5, 5)	act	0.457	None
Early RecrDev 1946	-0.184	5	(-5, 5)	act	0.457	None
Early RecrDev 1947	-0.182	5	(-5, 5)	act	0.457	None
Early RecrDev 1948	-0.178	5	(-5, 5)	act	0.457	None
Early RecrDev 1949	-0.172	5	(-5, 5)	act	0.458	None
Early RecrDev 1950	-0.162	5	(-5, 5)	act	0.459	None
Early RecrDev 1951	-0.15	5	(-5, 5)	act	0.461	None
Early RecrDev 1952	-0.134	5	(-5, 5)	act	0.463	None
Early RecrDev 1953	-0.114	5	(-5, 5)	act	0.466	None
Early RecrDev 1954	-0.09	5	(-5, 5)	act	0.469	None
Early RecrDev 1955	-0.058	5	(-5, 5)	act	0.474	None
Early RecrDev 1956	-0.014	5	(-5, 5)	act	0.481	None
Early RecrDev 1957	0.048	5	(-5, 5)	act	0.492	None
Early RecrDev 1958	0.137	5	(-5, 5)	act	0.510	None
Early RecrDev 1959	0.26	5	(-5, 5)	act	0.535	None
Main RecrDev 1960	0.238	5	(-5, 5)	act	0.558	None
Main RecrDev 1961	0.32	5	(-5, 5)	act	0.572	None
Main RecrDev 1962	0.259	5	(-5, 5)	act	0.552	None
Main RecrDev 1963	0.107	5	(-5, 5)	act	0.514	None
Main RecrDev 1964	-0.009	5	(-5, 5)	act	0.485	None
Main RecrDev 1965	-0.029	5	(-5, 5)	act	0.477	None
Main RecrDev 1966	0.077	5	(-5, 5)	act	0.490	None
Main RecrDev 1967	0.32	5	(-5, 5)	act	0.544	None
Main RecrDev 1968	0.594	5	(-5, 5)	act	0.481	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Main RecrDev 1969	0.132	5	(-5, 5)	act	0.479	None
Main RecrDev 1970	-0.212	5	(-5, 5)	act	0.416	None
Main RecrDev 1971	-0.206	5	(-5, 5)	act	0.408	None
Main RecrDev 1972	0.188	5	(-5, 5)	act	0.391	None
Main RecrDev 1973	0.422	5	(-5, 5)	act	0.343	None
Main RecrDev 1974	0.082	5	(-5, 5)	act	0.383	None
Main RecrDev 1975	0.138	5	(-5, 5)	act	0.324	None
Main RecrDev 1976	0.399	5	(-5, 5)	act	0.230	None
Main RecrDev 1977	-0.072	5	(-5, 5)	act	0.280	None
Main RecrDev 1978	0.292	5	(-5, 5)	act	0.196	None
Main RecrDev 1979	0.23	5	(-5, 5)	act	0.191	None
Main RecrDev 1980	-0.451	5	(-5, 5)	act	0.282	None
Main RecrDev 1981	0.264	5	(-5, 5)	act	0.176	None
Main RecrDev 1982	0.061	5	(-5, 5)	act	0.209	None
Main RecrDev 1983	-0.162	5	(-5, 5)	act	0.248	None
Main RecrDev 1984	0.187	5	(-5, 5)	act	0.214	None
Main RecrDev 1985	0.135	5	(-5, 5)	act	0.235	None
Main RecrDev 1986	-0.015	5	(-5, 5)	act	0.268	None
Main RecrDev 1987	0.133	5	(-5, 5)	act	0.228	None
Main RecrDev 1988	0.124	5	(-5, 5)	act	0.206	None
Main RecrDev 1989	0.359	5	(-5, 5)	act	0.160	None
Main RecrDev 1990	0.265	5	(-5, 5)	act	0.173	None
Main RecrDev 1991	0.084	5	(-5, 5)	act	0.204	None
Main RecrDev 1992	0.323	5	(-5, 5)	act	0.183	None
Main RecrDev 1993	-0.066	5	(-5, 5)	act	0.245	None
Main RecrDev 1994	0.276	5	(-5, 5)	act	0.205	None
Main RecrDev 1995	0.417	5	(-5, 5)	act	0.184	None
Main RecrDev 1996	0.402	5	(-5, 5)	act	0.177	None
Main RecrDev 1997	0.02	5	(-5, 5)	act	0.213	None
Main RecrDev 1998	0.021	5	(-5, 5)	act	0.195	None
Main RecrDev 1999	-0.152	5	(-5, 5)	act	0.226	None
Main RecrDev 2000	-0.022	5	(-5, 5)	act	0.236	None
Main RecrDev 2001	0.245	5	(-5, 5)	act	0.203	None
Main RecrDev 2002	0.072	5	(-5, 5)	act	0.227	None
Main RecrDev 2003	0.457	5	(-5, 5)	act	0.177	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Main RecrDev 2004	0.039	5	(-5, 5)	act	0.220	None
Main RecrDev 2005	-0.591	5	(-5, 5)	act	0.294	None
Main RecrDev 2006	-0.257	5	(-5, 5)	act	0.226	None
Main RecrDev 2007	0.298	5	(-5, 5)	act	0.140	None
Main RecrDev 2008	-0.747	5	(-5, 5)	act	0.249	None
Main RecrDev 2009	-0.321	5	(-5, 5)	act	0.165	None
Main RecrDev 2010	-0.026	5	(-5, 5)	act	0.129	None
Main RecrDev 2011	-0.205	5	(-5, 5)	act	0.137	None
Main RecrDev 2012	-0.119	5	(-5, 5)	act	0.127	None
Main RecrDev 2013	0.082	5	(-5, 5)	act	0.113	None
Main RecrDev 2014	-0.561	5	(-5, 5)	act	0.153	None
Main RecrDev 2015	-0.596	5	(-5, 5)	act	0.160	None
Main RecrDev 2016	-0.354	5	(-5, 5)	act	0.150	None
Main RecrDev 2017	-1.055	5	(-5, 5)	act	0.208	None
Main RecrDev 2018	-1.111	5	(-5, 5)	act	0.248	None
Main RecrDev 2019	-0.444	5	(-5, 5)	act	0.345	None
Main RecrDev 2020	-0.238	5	(-5, 5)	act	0.472	None
Main RecrDev 2021	0.068	5	(-5, 5)	act	0.428	None
Main RecrDev 2022	-0.109	5	(-5, 5)	act	0.494	None
LnQ base WCGBTS(28)	-0.788	-99	(-25, 25)	NA	NA	None
LnQ base Tri early(29)	-1.256	2	(-25, 25)	OK	0.459	None
LnQ base prerec(31)	-2.762	-99	(-25, 25)	NA	NA	None
Q extraSD prerec(31)	0.507	2	(0, 3)	OK	0.154	None
Size DblN peak CA TWL(1)	45.31	4	(13.001, 65)	OK	0.797	None
Size DblN top logit CA TWL(1)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se CA TWL(1)	4.312	5	(0, 9)	OK	0.147	None
Size DblN descend se CA TWL(1)	3.483	5	(0, 9)	OK	0.374	None
Size DblN start logit CA TWL(1)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit CA TWL(1)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend CA TWL(1)	1.398	5	(-9, 9)	OK	0.331	None
Size DblN peak OR TWL(2)	49.534	4	(13.001, 65)	OK	0.493	None
Size DblN top logit OR TWL(2)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se OR TWL(2)	4.183	5	(0, 9)	OK	0.090	None
Size DblN descend se OR TWL(2)	2.597	5	(0, 9)	OK	0.331	None
Size DblN start logit OR TWL(2)	-15	-99	(-99, 99)	NA	NA	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Size DblN end logit OR TWL(2)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend OR TWL(2)	2.235	5	(-9, 9)	OK	0.692	None
Size DblN peak CA NTWL(4)	36.145	4	(13.001, 65)	OK	1.076	None
Size DblN top logit CA NTWL(4)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se CA NTWL(4)	4.251	5	(0, 9)	OK	0.221	None
Size DblN descend se CA NTWL(4)	5.219	5	(0, 9)	OK	0.434	None
Size DblN start logit CA NTWL(4)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit CA NTWL(4)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend CA NTWL(4)	0.113	5	(-9, 9)	OK	0.711	None
Size DblN peak OR NTWL(5)	31.054	4	(13.001, 65)	OK	0.195	None
Size DblN top logit OR NTWL(5)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se OR NTWL(5)	-7.368	5	(-9, 9)	OK	25.393	None
Size DblN descend se OR NTWL(5)	6.118	5	(-9, 9)	OK	0.362	None
Size DblN start logit OR NTWL(5)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit OR NTWL(5)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend OR NTWL(5)	7.715	5	(-9, 9)	OK	27.402	None
Size DblN peak WA NTWL(6)	46.162	4	(13.001, 65)	OK	0.775	None
Size DblN top logit WA NTWL(6)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se WA NTWL(6)	3.403	5	(-9, 9)	OK	0.250	None
Size DblN descend se WA NTWL(6)	2.596	5	(-9, 9)	OK	0.389	None
Size DblN start logit WA NTWL(6)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit WA NTWL(6)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend WA NTWL(6)	2.794	5	(-9, 9)	OK	0.401	None
Size DblN peak CA REC(7)	28.823	4	(13.001, 65)	OK	0.645	None
Size DblN top logit CA REC(7)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se CA REC(7)	3.479	5	(0, 9)	OK	0.210	None
Size DblN descend se CA REC(7)	4.826	5	(0, 9)	OK	0.132	None
Size DblN start logit CA REC(7)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit CA REC(7)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend CA REC(7)	0	-99	(-9, 9)	NA	NA	None
Size DblN peak OR REC(8)	30.931	4	(13.001, 65)	OK	0.556	None
Size DblN top logit OR REC(8)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se OR REC(8)	3.129	5	(-9, 9)	OK	0.213	None
Size DblN descend se OR REC(8)	3.245	5	(-9, 9)	OK	0.293	None
Size DblN start logit OR REC(8)	-15	-99	(-99, 99)	NA	NA	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Size DblN end logit OR REC(8)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend OR REC(8)	2.303	5	(-9, 9)	OK	0.266	None
Size DblN peak WA REC(9)	34.908	4	(13.001, 65)	OK	1.542	None
Size DblN top logit WA REC(9)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se WA REC(9)	3.295	5	(-9, 9)	OK	0.595	None
Size DblN descend se WA REC(9)	5.217	5	(-9, 9)	OK	0.296	None
Size DblN start logit WA REC(9)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit WA REC(9)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend WA REC(9)	2.206	5	(-9, 9)	OK	0.786	None
Size DblN peak CA ASHOP(10)	43.5	4	(13.001, 65)	OK	0.509	None
Size DblN top logit CA ASHOP(10)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se CA ASHOP(10)	2.452	5	(0, 9)	OK	0.287	None
Size DblN descend se CA ASHOP(10)	2.89	5	(0, 9)	OK	0.233	None
Size DblN start logit CA ASHOP(10)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit CA ASHOP(10)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend CA ASHOP(10)	2.305	5	(-9, 9)	OK	0.248	None
Size DblN peak WCGBTS(28)	48.178	4	(13.001, 65)	OK	2.750	None
Size DblN top logit WCGBTS(28)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se WCGBTS(28)	7.018	5	(0, 9)	OK	1.120	None
Size DblN descend se WCGBTS(28)	2.343	5	(0, 9)	OK	1.623	None
Size DblN start logit WCGBTS(28)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit WCGBTS(28)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend WCGBTS(28)	2.412	5	(-9, 9)	OK	1.318	None
Size DblN peak Tri early(29)	61.155	4	(13.001, 65)	OK	23.316	None
Size DblN top logit Tri early(29)	-15	-99	(-99, 99)	NA	NA	None
Size DblN ascend se Tri early(29)	6.69	5	(0, 9)	OK	1.347	None
Size DblN descend se Tri early(29)	4.818	5	(0, 9)	OK	93.366	None
Size DblN start logit Tri early(29)	-15	-99	(-99, 99)	NA	NA	None
Size DblN end logit Tri early(29)	-999	-99	(-99, 99)	NA	NA	None
SzSel Fem Descend Tri early(29)	1.239	5	(-9, 9)	OK	142.117	None
Size DblN peak CA TWL(1) BLK1repl 2000	43.681	4	(13.001, 65)	OK	1.173	None
Size DblN peak CA TWL(1) BLK1repl 2011	45.075	4	(13.001, 65)	OK	0.736	None
Size DblN ascend se CA TWL(1) BLK1repl 2000	3.79	5	(0, 9)	OK	0.345	None
Size DblN ascend se CA TWL(1) BLK1repl 2011	4.293	5	(0, 9)	OK	0.186	None
Size DblN descend se CA TWL(1) BLK1repl 2000	1.719	5	(0, 9)	OK	1.130	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Size DblN descend se CA TWL(1) BLK1repl 2011	1.84	5	(0, 9)	OK	0.584	None
SzSel Fem Descend CA TWL(1) BLK1repl 2000	2.371	5	(-9, 9)	OK	0.917	None
SzSel Fem Descend CA TWL(1) BLK1repl 2011	1.886	5	(-9, 9)	OK	0.418	None
Size DblN peak OR TWL(2) BLK1repl 2000	43.403	4	(13.001, 65)	OK	0.964	None
Size DblN peak OR TWL(2) BLK1repl 2011	45.33	4	(13.001, 65)	OK	0.497	None
Size DblN ascend se OR TWL(2) BLK1repl 2000	4.246	5	(0, 9)	OK	0.203	None
Size DblN ascend se OR TWL(2) BLK1repl 2011	4.749	5	(0, 9)	OK	0.102	None
Size DblN descend se OR TWL(2) BLK1repl 2000	3.826	5	(0, 9)	OK	0.388	None
Size DblN descend se OR TWL(2) BLK1repl 2011	2.844	5	(0, 9)	OK	0.222	None
SzSel Fem Descend OR TWL(2) BLK1repl 2000	8.732	5	(-9, 9)	OK	7.550	None
SzSel Fem Descend OR TWL(2) BLK1repl 2011	1.867	5	(-9, 9)	OK	0.189	None
Size DblN peak CA NTWL(4) BLK2repl 2000	33.606	4	(13.001, 65)	OK	2.157	None
Size DblN peak CA NTWL(4) BLK2repl 2020	34.657	4	(13.001, 65)	OK	2.033	None
Size DblN ascend se CA NTWL(4) BLK2repl 2000	3.045	5	(0, 9)	OK	0.917	None
Size DblN ascend se CA NTWL(4) BLK2repl 2020	2.772	5	(0, 9)	OK	1.077	None
Size DblN descend se CA NTWL(4) BLK2repl 2000	4.319	5	(0, 9)	OK	0.756	None
Size DblN descend se CA NTWL(4) BLK2repl 2020	4.156	5	(0, 9)	OK	0.412	None
SzSel Fem Descend CA NTWL(4) BLK2repl 2000	1.087	5	(-9, 9)	OK	0.904	None
SzSel Fem Descend CA NTWL(4) BLK2repl 2020	0.911	5	(-9, 9)	OK	0.320	None
Size DblN peak OR NTWL(5) BLK6repl 2000	32.908	4	(13.001, 65)	OK	1.494	None
Size DblN ascend se OR NTWL(5) BLK6repl 2000	2.482	5	(-9, 9)	OK	0.864	None
Size DblN descend se OR NTWL(5) BLK6repl 2000	4.345	5	(-9, 9)	OK	0.361	None
SzSel Fem Descend OR NTWL(5) BLK6repl 2000	1.079	5	(-9, 9)	OK	0.361	None
Size DblN peak CA REC(7) BLK3repl 2004	30.318	4	(13.001, 65)	OK	0.824	None
Size DblN peak CA REC(7) BLK3repl 2017	32.117	4	(13.001, 65)	OK	0.634	None
Size DblN ascend se CA REC(7) BLK3repl 2004	3.336	5	(0, 9)	OK	0.297	None
Size DblN ascend se CA REC(7) BLK3repl 2017	3.306	5	(0, 9)	OK	0.252	None
Size DblN descend se CA REC(7) BLK3repl 2004	3.715	5	(0, 9)	OK	0.280	None
Size DblN descend se CA REC(7) BLK3repl 2017	4.213	5	(0, 9)	OK	0.132	None
SzSel Fem Descend CA REC(7) BLK3repl 2004	0	-99	(-9, 9)	NA	NA	None
SzSel Fem Descend CA REC(7) BLK3repl 2017	0	-99	(-9, 9)	NA	NA	None
Size DblN peak OR REC(8) BLK4repl 2004	31.698	4	(13.001, 65)	OK	1.795	None
Size DblN peak OR REC(8) BLK4repl 2015	30.915	4	(13.001, 65)	OK	0.254	None
Size DblN ascend se OR REC(8) BLK4repl 2004	2.698	5	(-9, 9)	OK	0.877	None
Size DblN ascend se OR REC(8) BLK4repl 2015	2.112	5	(-9, 9)	OK	0.162	None

Table 12: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (expected value and SD). (*continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp. Val, SD)
Size DblN descend se OR REC(8) BLK4repl 2004	4.544	5	(-9, 9)	OK	0.422	None
Size DblN descend se OR REC(8) BLK4repl 2015	4.174	5	(-9, 9)	OK	0.099	None
SzSel Fem Descend OR REC(8) BLK4repl 2004	0	-99	(-9, 9)	NA	NA	None
SzSel Fem Descend OR REC(8) BLK4repl 2015	1.112	5	(-9, 9)	OK	0.099	None
Size DblN peak WA REC(9) BLK5repl 2006	32.069	4	(13.001, 65)	OK	0.515	None
Size DblN ascend se WA REC(9) BLK5repl 2006	2.127	5	(-9, 9)	OK	0.321	None
Size DblN descend se WA REC(9) BLK5repl 2006	4.577	5	(-9, 9)	OK	0.130	None
SzSel Fem Descend WA REC(9) BLK5repl 2006	0.985	5	(-9, 9)	OK	0.143	None

Table 13: Likelihood components by source.

Data type	Total
TOTAL	3980.34
Catch	0.00
Equil catch	0.00
Survey	-9.76
Length comp	1476.95
Age comp	2524.05
Recruitment	-11.10
InitEQ Regime	0.00
Forecast Recruitment	0.00
Parm priors	0.18
Parm softbounds	0.02
Parm devs	0.00
Crash Pen	0.00

Table 14: Data weightings applied to length and age compositions according to the 'Francis' method. 'Obs.' refers to the number of unique composition vectors included in the likelihood. 'N input' and 'N adj.' refer to the sample sizes of those vectors before and after being adjusted by the weights. 'CAAL' is conditional age-at-length data. The WCGBTS and Tri age comps are conditioned on length, so there are more observations with fewer samples per observation.

Type	Fleet	Francis	Obs.	Mean N input	Mean N adj.	Sum N adj.
Length	CA_TWL	0.240	80	42.2	10.2	812.9
Length	OR_TWL	0.257	49	168.7	43.4	2127.6
Length	WA_TWL	0.199	76	63.5	12.6	959.0
Length	CA_NTWL	0.212	56	55.0	11.7	652.4
Length	OR_NTWL	0.083	14	99.9	8.3	116.5
Length	WA_NTWL	1.669	13	20.2	33.8	439.0
Length	CA_REC	0.158	42	192.8	30.5	1279.2
Length	OR_REC	0.259	51	233.5	60.4	3080.5
Length	WA_REC	0.937	50	18.8	17.6	880.1
Length	OR_ASHOP	0.190	20	72.5	13.8	276.0
Length	WA_ASHOP	0.104	20	74.5	7.7	154.9
Length	WCGBTS	0.047	19	127.3	6.0	113.3
Length	Tri_early	0.103	5	94.6	9.8	48.8
Length	Tri_late	0.047	4	149.5	7.0	28.0
Age	CA_TWL	1.254	26	41.4	51.9	1349.2
Age	OR_TWL	0.246	43	157.0	38.6	1658.7
Age	WA_TWL	0.211	63	70.0	14.8	930.6
Age	CA_NTWL	0.515	12	11.7	6.0	72.1
Age	OR_NTWL	0.701	9	19.3	13.6	122.0
Age	WA_NTWL	1.100	13	12.3	13.5	176.0
Age	OR_REC	1.488	10	95.7	142.4	1423.9
Age	WA_REC	0.818	18	16.8	13.7	247.0
Age	OR_ASHOP	0.474	16	49.6	23.5	376.0
Age	WA_ASHOP	0.106	16	62.2	6.6	105.7
CAAL	WCGBTS	0.205	812	10.4	2.1	1727.4
CAAL	Tri_early	0.119	188	13.2	1.6	294.6
CAAL	Tri_late	0.183	128	6.9	1.3	162.0

Table 15: Time series of population estimates from the base model and during the projection period. Spawning output is in millions of eggs and age-0 recruits is in numbers of 1000s. Total mortality for 2023 and 2024 is based on estimates provided by the Groundfish Management Team.

Year	Total Biomass (mt)	Spawning Output	Total Biomass 5+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1892	76700.4	8008.63	75272.7	1.00	3676.85	5.79	0.00	0.00
1893	76694.2	8007.80	75266.9	1.00	3674.38	5.79	0.00	0.00
1894	76686.7	8006.96	75261.2	1.00	3671.75	5.79	0.00	0.00
1895	76676.4	8006.13	75255.6	1.00	3668.98	1.49	0.00	0.00
1896	76666.6	8005.91	75254.5	1.00	3666.06	0.36	0.00	0.00
1897	76653.3	8005.86	75242.2	1.00	3662.98	0.37	0.00	0.00
1898	76635.2	8005.78	75225.2	1.00	3659.72	0.21	0.00	0.00
1899	76612.5	8005.67	75203.5	1.00	3656.26	0.35	0.00	0.00
1900	76584.9	8005.38	75177.2	1.00	3652.58	0.49	0.00	0.00
1901	76552.9	8004.76	75146.4	1.00	3648.68	0.64	0.00	0.00
1902	76516.8	8003.58	75111.6	1.00	3644.53	0.78	0.00	0.00
1903	76477.0	8001.64	75073.2	1.00	3640.11	0.92	0.00	0.00
1904	76433.8	7998.86	75031.4	1.00	3635.40	1.07	0.00	0.00
1905	76387.5	7995.30	74986.7	1.00	3630.40	1.21	0.00	0.00
1906	76338.2	7991.12	74939.1	1.00	3625.11	1.35	0.00	0.00
1907	76286.3	7986.45	74888.9	1.00	3619.51	1.49	0.00	0.00
1908	76231.7	7981.39	74836.3	1.00	3613.61	1.64	0.00	0.00
1909	76174.6	7976.02	74781.1	1.00	3607.39	1.78	0.00	0.00
1910	76114.9	7970.37	74723.5	1.00	3600.82	1.92	0.00	0.00
1911	76052.6	7964.47	74663.5	0.99	3593.89	2.07	0.00	0.00
1912	75987.6	7958.34	74600.9	0.99	3586.54	2.21	0.00	0.00
1913	75919.9	7951.97	74535.7	0.99	3578.74	2.35	0.00	0.00
1914	75849.3	7945.37	74467.7	0.99	3570.50	2.50	0.00	0.00
1915	75775.7	7938.52	74396.8	0.99	3561.83	2.64	0.00	0.00
1916	75698.8	7931.41	74322.9	0.99	3552.72	39.63	0.01	0.00
1917	75580.2	7921.02	74207.5	0.99	3543.01	61.62	0.02	0.00
1918	75434.9	7908.37	74065.5	0.99	3532.74	64.22	0.02	0.00
1919	75283.0	7894.87	73917.1	0.99	3521.91	41.71	0.01	0.00
1920	75151.0	7882.47	73788.8	0.98	3510.58	44.01	0.01	0.00
1921	75013.6	7869.39	73655.2	0.98	3498.63	38.49	0.01	0.00
1922	74878.8	7856.35	73524.5	0.98	3486.11	35.76	0.01	0.00
1923	74743.5	7843.15	73393.5	0.98	3473.02	42.32	0.01	0.00
1924	74597.9	7829.12	73252.5	0.98	3459.37	44.18	0.01	0.00
1925	74446.5	7814.81	73105.8	0.98	3445.23	50.73	0.02	0.00
1926	74283.9	7799.79	72948.1	0.97	3430.60	66.55	0.02	0.00
1927	74100.1	7782.91	72769.6	0.97	3415.56	60.24	0.02	0.00

Table 15: Time series of population estimates from the base model and during the projection period. Spawning output is in millions of eggs and age-0 recruits is in numbers of 1000s. Total mortality for 2023 and 2024 is based on estimates provided by the Groundfish Management Team. (*continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 5+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1928	73918.2	7765.84	72593.0	0.97	3400.25	62.82	0.02	0.00
1929	73729.0	7747.82	72409.4	0.97	3384.79	73.85	0.03	0.00
1930	73523.7	7727.59	72209.9	0.96	3369.19	78.69	0.03	0.00
1931	73308.6	7706.80	72000.7	0.96	3353.49	88.29	0.03	0.00
1932	73078.5	7684.55	71776.5	0.96	3337.65	65.43	0.02	0.00
1933	72866.6	7664.37	71570.6	0.96	3321.47	61.84	0.02	0.00
1934	72653.4	7643.46	71363.5	0.95	3304.38	62.11	0.02	0.00
1935	72434.7	7622.34	71150.9	0.95	3285.74	73.80	0.03	0.00
1936	72198.3	7599.84	70920.9	0.95	3264.66	67.37	0.03	0.00
1937	71962.8	7577.27	70692.0	0.95	3240.74	75.48	0.03	0.00
1938	71712.8	7553.02	70449.1	0.94	3214.16	74.49	0.03	0.00
1939	71457.4	7528.28	70201.6	0.94	3186.07	81.02	0.03	0.00
1940	71188.5	7502.17	69941.4	0.94	3157.26	175.63	0.06	0.00
1941	70817.4	7463.96	69580.2	0.93	3130.42	218.94	0.07	0.00
1942	70397.8	7419.77	69171.0	0.93	3106.37	382.75	0.11	0.01
1943	69811.6	7354.19	68595.3	0.92	3084.62	1254.46	0.31	0.02
1944	68355.4	7182.44	67149.5	0.90	3062.09	1887.07	0.42	0.03
1945	66296.3	6938.86	65100.1	0.87	3044.55	3813.72	0.65	0.06
1946	62360.8	6470.40	61173.6	0.81	3021.95	2377.54	0.53	0.04
1947	59987.5	6180.37	58808.8	0.77	3011.27	1345.83	0.37	0.02
1948	58735.1	6015.99	57563.8	0.75	3012.97	1272.57	0.36	0.02
1949	57607.4	5870.43	56443.1	0.73	3023.09	1235.85	0.36	0.02
1950	56563.2	5736.83	55404.6	0.72	3043.20	1237.31	0.37	0.02
1951	55561.9	5611.10	54404.6	0.70	3072.47	1223.76	0.37	0.02
1952	54614.8	5495.84	53454.7	0.69	3112.65	1158.86	0.36	0.02
1953	53776.9	5392.39	52610.0	0.67	3165.49	956.31	0.32	0.02
1954	53188.1	5316.92	52010.5	0.66	3237.33	1172.83	0.37	0.02
1955	52426.5	5221.22	51234.6	0.65	3333.99	1167.91	0.37	0.02
1956	51723.8	5130.11	50512.3	0.64	3475.14	1541.02	0.45	0.03
1957	50708.6	4999.72	49470.5	0.62	3684.83	1567.41	0.46	0.03
1958	49749.5	4870.01	48473.9	0.61	4011.11	1300.01	0.42	0.03
1959	49151.4	4780.04	47823.5	0.60	4521.91	1347.41	0.43	0.03
1960	48607.5	4687.53	47208.0	0.59	4410.93	1456.77	0.46	0.03
1961	48098.2	4586.85	46592.5	0.57	4773.41	1363.86	0.44	0.03
1962	47843.9	4502.35	46216.7	0.56	4477.21	1643.56	0.50	0.04
1963	47483.2	4395.43	45757.4	0.55	3831.55	1114.54	0.39	0.02
1964	47826.5	4360.06	46106.2	0.54	3405.22	1347.75	0.44	0.03

Table 15: Time series of population estimates from the base model and during the projection period. Spawning output is in millions of eggs and age-0 recruits is in numbers of 1000s. Total mortality for 2023 and 2024 is based on estimates provided by the Groundfish Management Team. (*continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 5+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1965	48064.2	4309.98	46336.3	0.54	3332.89	1484.61	0.47	0.03
1966	48238.3	4262.08	46661.4	0.53	3689.44	3344.32	0.71	0.07
1967	46583.6	4024.63	45178.0	0.50	4619.93	1509.30	0.49	0.03
1968	46795.0	4011.48	45445.9	0.50	6025.32	2423.54	0.63	0.05
1969	46069.1	3926.35	44663.4	0.49	3752.80	1229.95	0.43	0.03
1970	46615.5	3985.95	45002.7	0.50	2645.77	1555.20	0.49	0.03
1971	46902.2	4029.10	45051.5	0.50	2644.60	2015.93	0.57	0.04
1972	46736.7	4029.31	44891.5	0.50	3888.18	1923.69	0.56	0.04
1973	46594.5	4039.26	45319.7	0.50	4875.04	2781.47	0.67	0.06
1974	45488.5	3946.97	44391.5	0.49	3426.60	2316.58	0.63	0.05
1975	44823.1	3892.30	43554.4	0.49	3586.57	2044.69	0.59	0.05
1976	44419.8	3861.05	42837.0	0.48	4614.06	1762.76	0.56	0.04
1977	44250.4	3867.03	42632.9	0.48	2857.79	1855.26	0.57	0.04
1978	44005.3	3868.15	42624.0	0.48	4077.52	4346.23	0.81	0.10
1979	41251.4	3598.89	39790.0	0.45	3780.88	2920.97	0.73	0.07
1980	39931.1	3463.34	38429.1	0.43	1899.73	4574.38	0.85	0.12
1981	37016.1	3129.26	35744.7	0.39	3801.32	3580.22	0.82	0.10
1982	35079.7	2902.16	33666.0	0.36	3052.73	5702.23	0.92	0.17
1983	31003.8	2460.92	29799.9	0.31	2345.87	5296.95	0.92	0.18
1984	27379.9	2056.54	26368.9	0.26	3162.47	2810.74	0.84	0.11
1985	26240.3	1919.91	24951.3	0.24	2940.76	3052.85	0.86	0.12
1986	24842.5	1778.05	23760.3	0.22	2469.63	2697.99	0.85	0.11
1987	23786.2	1679.97	22768.5	0.21	2811.61	3434.39	0.90	0.15
1988	21968.8	1515.45	20830.3	0.19	2687.68	3473.78	0.91	0.17
1989	20104.2	1342.44	19042.9	0.17	3246.18	3674.14	0.93	0.19
1990	18033.2	1148.63	17032.0	0.14	2773.01	3264.91	0.94	0.19
1991	16370.0	995.56	15302.5	0.12	2170.39	3915.34	0.96	0.26
1992	14096.1	776.97	13014.5	0.10	2439.11	3301.56	0.96	0.25
1993	12431.1	613.96	11324.5	0.08	1450.25	2899.30	0.97	0.26
1994	11155.8	492.62	10208.1	0.06	1784.19	1429.43	0.90	0.14
1995	11284.7	486.75	10464.8	0.06	2039.39	1331.69	0.88	0.13
1996	11448.2	501.89	10670.6	0.06	2047.53	1591.04	0.90	0.15
1997	11292.7	501.01	10669.3	0.06	1396.86	1486.50	0.89	0.14
1998	11175.7	515.01	10462.2	0.06	1422.37	1497.75	0.89	0.14
1999	10983.0	524.95	10244.4	0.07	1210.99	900.90	0.78	0.09
2000	11315.9	578.21	10648.9	0.07	1462.74	204.75	0.29	0.02
2001	12274.5	690.08	11737.9	0.09	2114.36	122.42	0.18	0.01

Table 15: Time series of population estimates from the base model and during the projection period. Spawning output is in millions of eggs and age-0 recruits is in numbers of 1000s. Total mortality for 2023 and 2024 is based on estimates provided by the Groundfish Management Team. (*continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 5+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
2002	13257.2	813.28	12722.2	0.10	1942.67	97.05	0.15	0.01
2003	14246.1	940.18	13686.1	0.12	3066.90	68.83	0.11	0.01
2004	15237.3	1071.19	14557.9	0.13	2145.91	47.17	0.07	0.00
2005	16273.7	1203.67	15448.4	0.15	1201.48	59.78	0.09	0.00
2006	17349.2	1332.78	16475.4	0.17	1748.15	58.98	0.08	0.00
2007	18444.7	1458.49	17466.4	0.18	3152.72	52.29	0.06	0.00
2008	19502.7	1577.73	18804.3	0.20	1140.65	39.69	0.05	0.00
2009	20592.0	1689.19	19976.5	0.21	1787.84	47.31	0.05	0.00
2010	21657.6	1795.73	20845.9	0.22	2450.24	44.73	0.05	0.00
2011	22676.5	1902.95	21773.1	0.24	2086.84	59.08	0.06	0.00
2012	23649.1	2015.33	23058.2	0.25	2315.07	47.07	0.05	0.00
2013	24609.4	2136.39	23817.9	0.27	2880.70	45.00	0.05	0.00
2014	25536.2	2262.34	24648.0	0.28	1538.69	54.09	0.06	0.00
2015	26459.6	2386.05	25608.9	0.30	1506.96	113.69	0.11	0.00
2016	27306.6	2497.02	26400.0	0.31	1943.69	75.61	0.07	0.00
2017	28128.5	2603.03	27265.2	0.33	973.78	399.66	0.29	0.01
2018	28543.5	2674.36	27950.5	0.33	926.82	598.69	0.39	0.02
2019	28649.8	2715.07	28047.8	0.34	1812.21	581.78	0.38	0.02
2020	28635.9	2749.66	28043.4	0.34	2234.81	513.68	0.36	0.02
2021	28580.0	2784.46	28139.0	0.35	3199.87	558.68	0.39	0.02
2022	28397.8	2808.02	27841.7	0.35	2825.14	700.36	0.47	0.03
2023	28077.2	2808.87	27248.5	0.35	3149.97	863.16	0.57	0.03
2024	27645.4	2782.56	26634.2	0.35	3142.99	860.19	0.59	0.03
2025	27320.0	2739.40	26139.2	0.34	3131.32	571.28	0.45	0.02
2026	27430.3	2709.94	26289.2	0.34	3123.19	572.51	0.44	0.02
2027	27684.2	2670.26	26477.8	0.33	3112.03	583.52	0.44	0.02
2028	28060.1	2625.73	26857.1	0.33	3099.20	601.48	0.44	0.02
2029	28532.0	2584.62	27333.0	0.32	3087.05	623.09	0.43	0.02
2030	29073.4	2556.58	27878.1	0.32	3078.61	647.92	0.43	0.02
2031	29659.0	2548.98	28468.0	0.32	3076.30	674.16	0.43	0.02
2032	30266.7	2564.13	29080.1	0.32	3080.90	699.96	0.43	0.02
2033	30879.2	2599.27	29696.0	0.32	3091.42	725.64	0.43	0.02
2034	31482.6	2649.08	30301.0	0.33	3105.96	749.34	0.43	0.02

Table 16: Estimates of likelihood components and major model parameters for data sensitivities. Likelihood is negative log-likelihood, where a lower value would indicate better fit to data. However, because of differences in input data for these sensitivities, likelihoods are generally uncomparable among scenarios.

	Base	No sparse comps	Pre-recruit data	Canada catches	Catch SE 0.1	Bomb radiocarbon age bias
TOTAL_like	3980	3750	3985	3992	3980	4015
Survey_like	-9.76	-9.99	-8.06	-8.21	-9.75	-7.74
Length_comp_like	1477	1353	1480	1479	1477	1476
Age_comp_like	2524	2417	2525	2532	2524	2563
Parm_priors_like	0.184	0.189	0.184	0.179	0.184	0.134
Recr_Virgin_millions	3.72	3.69	3.72	4.63	3.72	3.94
SR_LN(R0)	8.22	8.21	8.22	8.44	8.22	8.28
NatM_uniform_Fem_GP_1	0.0779	0.0781	0.0779	0.0777	0.0779	0.0758
L_at_Amax_Fem_GP_1	59.2	59.2	59.2	59.3	59.2	59.3
L_at_Amax_Mal_GP_1	53.7	53.7	53.7	53.7	53.7	53.7
VonBert_K_Fem_GP_1	0.139	0.139	0.139	0.139	0.139	0.125
VonBert_K_Mal_GP_1	0.163	0.163	0.163	0.163	0.163	0.147
SSB_Virgin	8009	7908	8015	10033	8017	8417
Bratio_2023	0.351	0.344	0.35	0.313	0.351	0.414
SPRratio_2022	0.469	0.479	0.469	0.603	0.469	0.416

Table 17: Estimates of likelihood components and major model parameters for data weighting sensitivities. Likelihood is negative log-likelihood, where lower values indicate better fit to data. Because of differences in input data, likelihoods are only comparable between the base model and the 'No extra SD' model.

	Base	McAllister-Ianelli	No extra SD	Francis ages x10	Francis lengths x10
TOTAL_like	3980	5857	4002	25536	16669
Survey_like	-9.76	-8.21	4.28	5.11	-5.95
Length_comp_like	1477	2340	1481	1833	13924
Age_comp_like	2524	3537	2528	23610	2764
Parm_priors_like	0.184	0.254	0.182	0.187	0.126
Recr_Virgin_millions	3.72	3.87	3.73	2.31	4.01
SR_LN(R0)	8.22	8.26	8.22	7.75	8.3
NatM_uniform_Fem_GP_1	0.0779	0.0806	0.0779	0.078	0.0755
L_at_Amax_Fem_GP_1	59.2	59.4	59.2	60.6	58.1
L_at_Amax_Mal_GP_1	53.7	53.6	53.7	54.1	52.6
VonBert_K_Fem_GP_1	0.139	0.138	0.139	0.131	0.153
VonBert_K_Mal_GP_1	0.163	0.165	0.162	0.161	0.175
SSB_Virgin	8009	7808	8054	5249	9031
Bratio_2023	0.351	0.342	0.348	0.361	0.463
SPRratio_2022	0.469	0.451	0.471	0.873	0.31

Table 18: Estimates of likelihood components and major model parameters for selectivity sensitivities. Likelihood is negative log-likelihood, where lower values indicate better fit to data. Because of differences in input data, likelihoods for the 'Float Q' model are not comparable.

	Base	No sex selectivity	Simpler blocks	WA NTWL asymptotic	WCGBTS asymptotic	Float Q	Unmirror Tri
TOTAL_like	3980	4257	4105	4017	3984	3950	3979
Survey_like	-9.76	-2.99	-8.36	-9	-9.35	-9.66	-9.67
Length_comp_like	1477	1631	1559	1493	1479	1483	1475
Age_comp_like	2524	2641	2567	2547	2525	2487	2524
Parm_priors_like	0.184	0.124	0.185	0.141	0.184	0.182	0.195
Recr_Virgin_millions	3.72	3.95	4.1	3.93	3.73	3.7	3.87
SR_LN(R0)	8.22	8.28	8.32	8.28	8.22	8.22	8.26
NatM_uniform_Fem_GP_1	0.0779	0.0553	0.078	0.0761	0.0779	0.0779	0.0784
L_at_Amax_Fem_GP_1	59.2	61.1	59.4	58.9	59.1	59.2	59.3
L_at_Amax_Mal_GP_1	53.7	53.1	53.7	52.9	53.6	53.7	53.8
VonBert_K_Fem_GP_1	0.139	0.126	0.138	0.141	0.14	0.139	0.139
VonBert_K_Mal_GP_1	0.163	0.165	0.162	0.169	0.164	0.163	0.162
SSB_Virgin	8009	17660	8863	8769	8010	8011	8264
Bratio_2023	0.351	0.532	0.441	0.339	0.35	0.353	0.392
SPRratio_2022	0.469	0.182	0.347	0.414	0.467	0.468	0.431

Table 19: Estimates of likelihood components and major model parameters for productivity sensitivities. Likelihood is negative log-likelihood, where lower values indicate better fit to data.

	Base	Estimate h	Estimate male M	M ramp	M break 20	Single M
TOTAL_like	3980	3978	3979	3982	3954	4015
Survey_like	-9.76	-7.41	-8.98	-8.98	-8.16	-10.1
Length_comp_like	1477	1482	1475	1485	1469	1496
Age_comp_like	2524	2519	2527	2518	2504	2535
Parm_priors_like	0.184	0.164	0.404	0.709	4.94	0
Recr_Virgin_millions	3.72	3.37	4.14	3.6	3.53	3.27
SR_LN(R0)	8.22	8.12	8.33	8.19	8.17	8.09
SR_BH_steep	0.72	0.895	0.72	0.72	0.72	0.72
NatM_uniform_Fem_GP_1	0.0779	0.0775	0.084	NA	NA	0.0643
NatM_uniform_Mal_GP_1	0.0643	0.0643	0.0708	NA	NA	0.0643
NatM_break_2_Fem_GP_1	NA	NA	NA	0.0934	0.171	NA
L_at_Amax_Fem_GP_1	59.2	59.2	59.3	59.6	60.2	59.3
L_at_Amax_Mal_GP_1	53.7	53.7	53.7	53.4	53.2	53.5
VonBert_K_Fem_GP_1	0.139	0.139	0.139	0.137	0.134	0.138
VonBert_K_Mal_GP_1	0.163	0.163	0.163	0.165	0.166	0.165
SSB_Virgin	8009	7329	7645	7212	6809	10354
Bratio_2023	0.351	0.506	0.405	0.43	0.541	0.244
SPRratio_2022	0.469	0.386	0.418	0.407	0.339	0.577

Table 20: Data weightings applied to length and age compositions according to the 'Francis' and 'McAlister Ianelli' (MI) methods. 'CAAL' is conditional age-at-length data.

Type	Fleet	Francis	MI
Length	CA_TWL	0.240	0.223
Length	OR_TWL	0.257	0.658
Length	WA_TWL	0.199	0.111
Length	CA_NTWL	0.212	0.115
Length	OR_NTWL	0.083	0.367
Length	WA_NTWL	1.669	0.525
Length	CA_REC	0.158	0.517
Length	OR_REC	0.259	0.192
Length	WA_REC	0.937	0.327
Length	OR_ASHOP	0.190	0.302
Length	WA_ASHOP	0.104	0.750
Length	WCGBTS	0.047	0.506
Length	Tri_early	0.103	0.913
Length	Tri_late	0.047	0.443
Age	CA_TWL	1.254	0.205
Age	OR_TWL	0.246	0.975
Age	WA_TWL	0.211	0.395
Age	CA_NTWL	0.515	0.366
Age	OR_NTWL	0.701	0.629
Age	WA_NTWL	1.100	0.631
Age	OR_REC	1.488	0.714
Age	WA_REC	0.818	0.372
Age	OR_ASHOP	0.474	0.326
Age	WA_ASHOP	0.106	0.925
CAAL	WCGBTS	0.205	0.248
CAAL	Tri_early	0.119	0.190
CAAL	Tri_late	0.183	0.429

Table 21: Summary of reference points and management quantities, including estimates of 95 percent intervals.

Category	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output (millions of eggs)	8008.63	6996.09	9021.17
Unfished Age 5+ Biomass (mt)	75272.70	67024.76	83520.64
Unfished Recruitment (R0)	3716.87	3296.97	4136.77
Spawning Output (millions of eggs) (2023)	2808.87	2050.19	3567.55
Fraction Unfished (2023)	0.35	0.28	0.42
Reference Points Based SO40%			
Proxy Spawning Output (millions of eggs) SO40%	3203.45	2798.43	3608.47
SPR Resulting in SO40%	0.46	0.46	0.46
Exploitation Rate Resulting in SO40%	0.03	0.03	0.03
Yield with SPR Based On SO40% (mt)	1151.99	1018.02	1285.96
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (millions of eggs) (SPR50)	3573.08	3121.33	4024.83
SPR50	0.50		
Exploitation Rate Corresponding to SPR50	0.03	0.03	0.03
Yield with SPR50 at SO SPR (mt)	1093.67	966.45	1220.89
Reference Points Based on Estimated MSY Values			
Spawning Output (millions of eggs) at MSY (SO MSY)	2063.47	1797.25	2329.69
SPR MSY	0.33	0.33	0.33
Exploitation Rate Corresponding to SPR MSY	0.05	0.05	0.05
MSY (mt)	1246.13	1101.31	1390.95

Table 22: Projections of estimated OFL (mt), ABC (mt), resulting ACLs (mt) based on the 40-10 rule and applied buffers with $P^* = 0.45$, and estimated spawning output in millions of eggs, and spawning output relative to unfished for 2025-2034, with assumed removals in 2023 and 2024 based on recommended values from the Groundfish Management Team.

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed removals (mt)	OFL (mt)	Buffer	ABC	ACL	Spawning Output	Fraction Unfished
2023	1413	1284	1284	863.16					2808.87	0.35
2024	1434	1296	1296	860.19					2782.56	0.35
2025					646.93	0.935	604.88	571.28	2739.40	0.34
2026					654.71	0.930	608.88	572.51	2709.94	0.34
2027					674.29	0.926	624.39	583.52	2670.26	0.33
2028					703.06	0.922	648.22	601.48	2625.73	0.33
2029					737.31	0.917	676.11	623.09	2584.62	0.32
2030					773.77	0.913	706.45	647.92	2556.58	0.32
2031					809.71	0.909	736.03	674.16	2548.98	0.32
2032					843.09	0.904	762.15	699.96	2564.13	0.32
2033					872.65	0.900	785.38	725.64	2599.27	0.32
2034					897.79	0.896	804.42	749.34	2649.08	0.33

Table 23: Projections of estimated OFL (mt), ABC (mt), resulting ACLs (mt) based on the 40-10 rule and applied buffers with $P^* = 0.40$, and estimated spawning output in millions of eggs, and spawning output relative to unfished for 2025-2034, with assumed removals in 2023 and 2024 based on recommended values from the Groundfish Management Team.

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed removals (mt)	OFL (mt)	Buffer	ABC	ACL	Spawning Output	Fraction Unfished
2023	1413	1284	1284	863.16					2808.87	0.35
2024	1434	1296	1296	860.19					2782.56	0.35
2025					646.93	0.873	564.77	533.39	2739.40	0.34
2026					656.02	0.864	566.80	533.26	2713.76	0.34
2027					677.00	0.856	579.51	542.25	2678.11	0.33
2028					707.29	0.848	599.78	557.64	2637.77	0.33
2029					743.20	0.840	624.29	576.93	2601.05	0.32
2030					781.39	0.832	650.12	598.45	2577.72	0.32
2031					819.19	0.824	675.01	621.13	2575.43	0.32
2032					854.49	0.817	698.12	644.73	2596.64	0.32
2033					885.95	0.809	716.73	666.53	2638.56	0.33
2034					913.01	0.801	731.32	686.28	2695.91	0.34

Table 24: Decision table with 10-year projections beginning in 2025 for alternative states of nature based around modeling natural mortality. 'Mgmt' refers to the two management scenarios (A) the default harvest control rule $P^* = 0.45$, and (B) harvest control rule with a lower $P^* = 0.40$. Catch (in mt) is from the projections from the base model for each management scenario, and is applied to each state of nature. Catches in 2023 and 2024 are fixed at the ACLs and have been set for that year with values provided by the GMT. The alternative states of nature ('Low', 'Base', and 'High') are provided in the columns, and assume female natural mortality is either fixed at the prior estimate (Single M; low state), estimated as age-invariant (base), or is estimated at older ages (M ramp; high state). Spawning output ('Spawn', in millions of eggs) and fraction of unfished ('Frac') is provided for each state of nature.

Mgmt	Year	Catch	Low Spawn Single M	Low Frac Single M	Base Spawn	Base Frac	High Spawn M ramp	High Frac M ramp
A	2023	863	2523.10	0.244	2808.87	0.351	3098.08	0.430
	2024	860	2494.43	0.241	2782.56	0.347	3068.81	0.426
	2025	571	2449.39	0.237	2739.40	0.342	3021.70	0.419
	2026	573	2420.81	0.234	2709.94	0.338	2986.12	0.414
	2027	584	2383.86	0.230	2670.26	0.333	2938.59	0.407
	2028	601	2343.21	0.226	2625.73	0.328	2885.43	0.400
	2029	623	2305.70	0.223	2584.62	0.323	2836.83	0.393
	2030	648	2279.22	0.220	2556.58	0.319	2804.60	0.389
	2031	674	2269.97	0.219	2548.98	0.318	2797.59	0.388
	2032	700	2280.56	0.220	2564.13	0.320	2817.93	0.391
	2033	726	2309.81	0.223	2599.27	0.325	2860.65	0.397
	2034	749	2354.31	0.227	2649.08	0.331	2917.64	0.405
B	2023	863	2523.10	0.244	2808.87	0.351	3098.08	0.430
	2024	860	2494.43	0.241	2782.56	0.347	3068.81	0.426
	2025	533	2449.39	0.237	2739.40	0.342	3021.70	0.419
	2026	533	2424.82	0.234	2713.76	0.339	2989.89	0.415
	2027	542	2392.15	0.231	2678.11	0.334	2946.34	0.409
	2028	558	2355.98	0.228	2637.77	0.329	2897.29	0.402
	2029	577	2323.21	0.224	2601.05	0.325	2853.02	0.396
	2030	598	2301.84	0.222	2577.72	0.322	2825.45	0.392
	2031	621	2298.39	0.222	2575.43	0.322	2823.73	0.392
	2032	645	2315.69	0.224	2596.64	0.324	2850.17	0.395
	2033	667	2352.54	0.227	2638.56	0.329	2899.70	0.402
	2034	686	2405.68	0.232	2695.91	0.337	2964.22	0.411

8 Figures

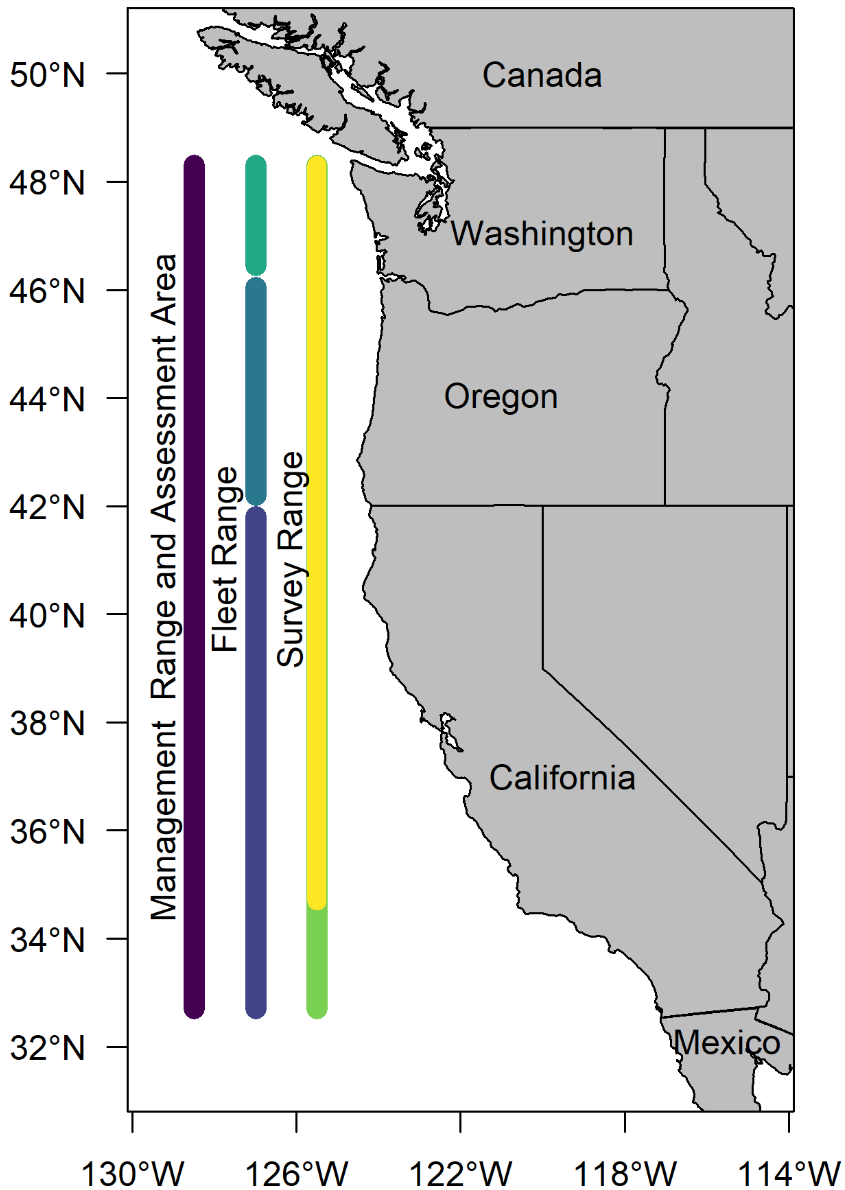

Figure 1: Map of management and the 2023 assessment area along with fleet spatial structure and survey ranges for canary rockfish off the U.S. West Coast.

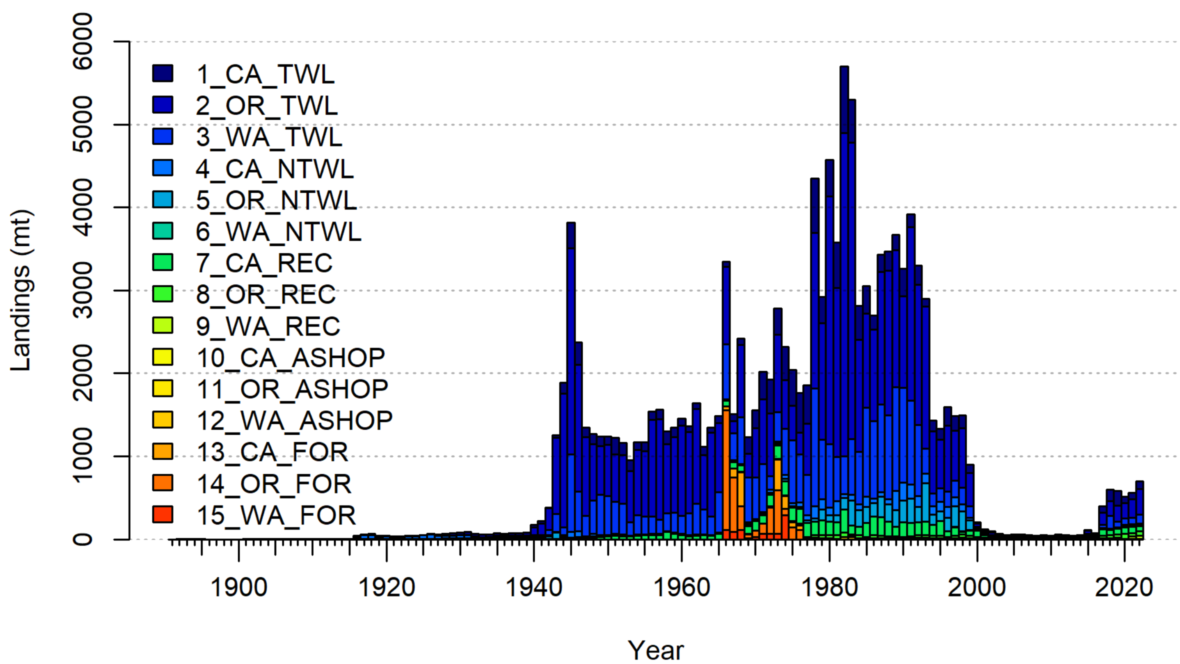

Figure 2: Total removals for canary rockfish off the U.S. West Coast from 1892-2022 by fleet (TWL = trawl, NTWL = non-trawl, Rec = recreational, ASHOP = at-sea hake, FOR = foreign).

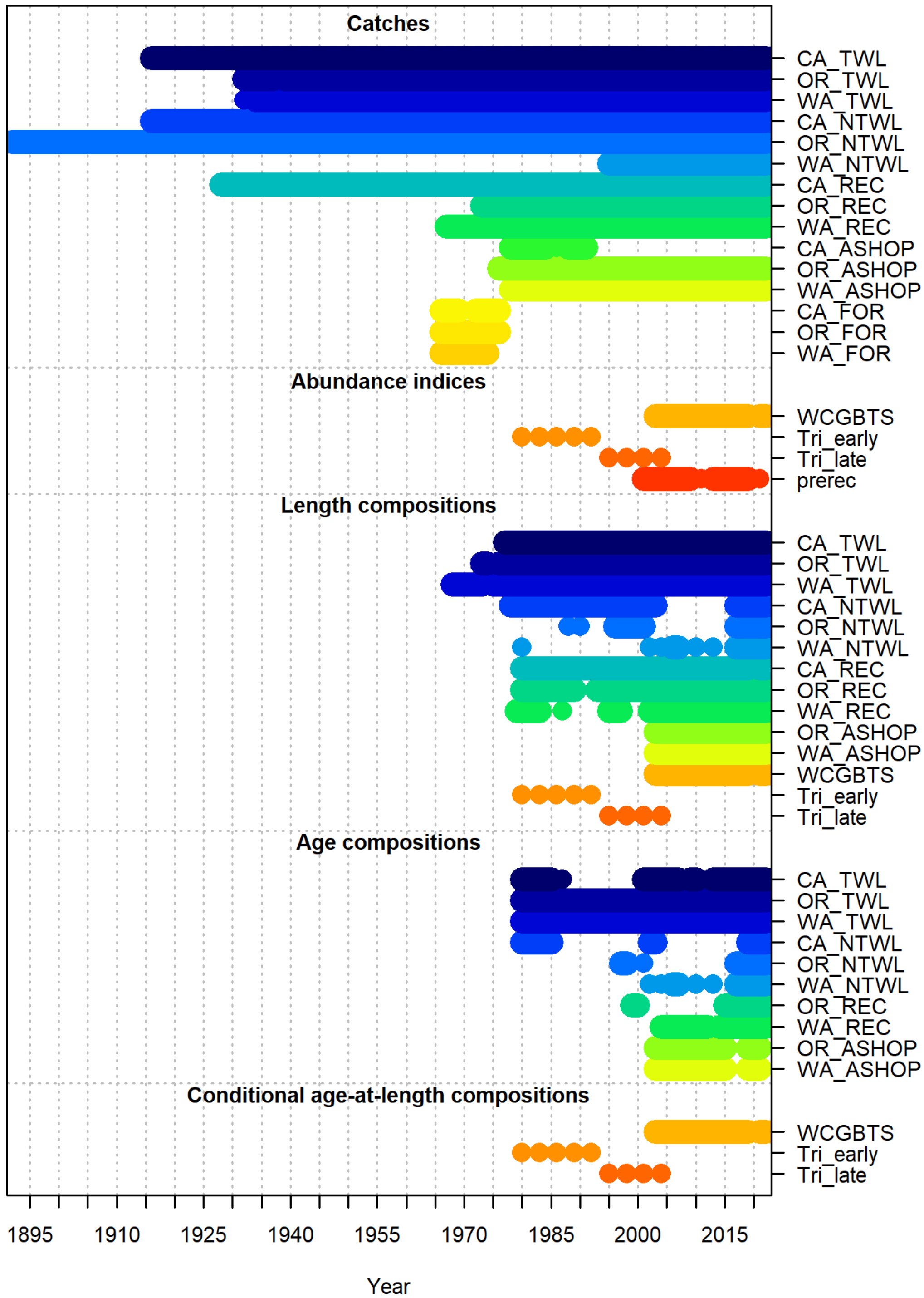

Figure 3: Illustration of types of data used for each fleet within the assessment for canary rockfish off the U.S. West Coast.

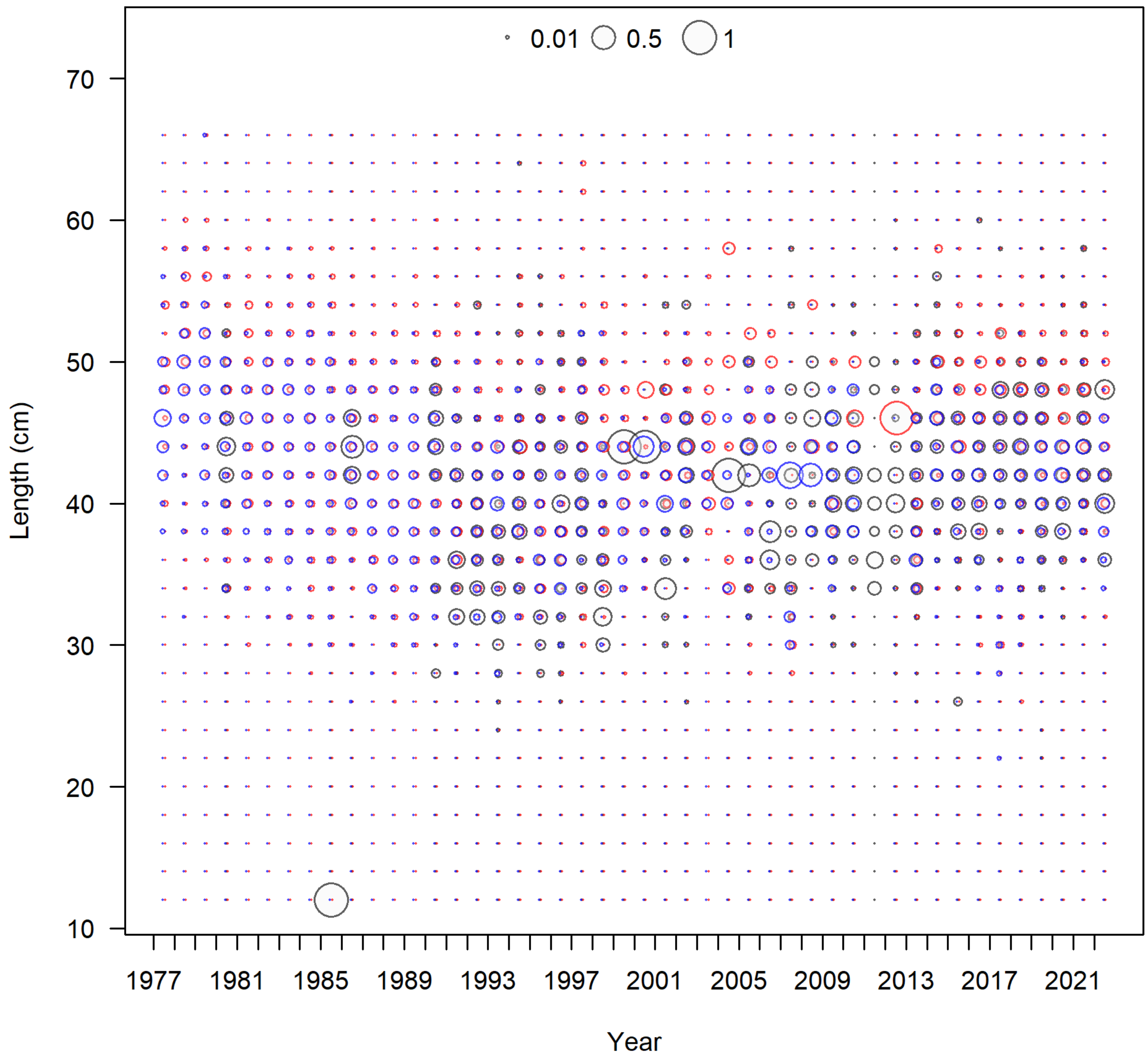

Figure 4: Length composition data for the California trawl fishery for females (red), males (blue), and unsexed (black).

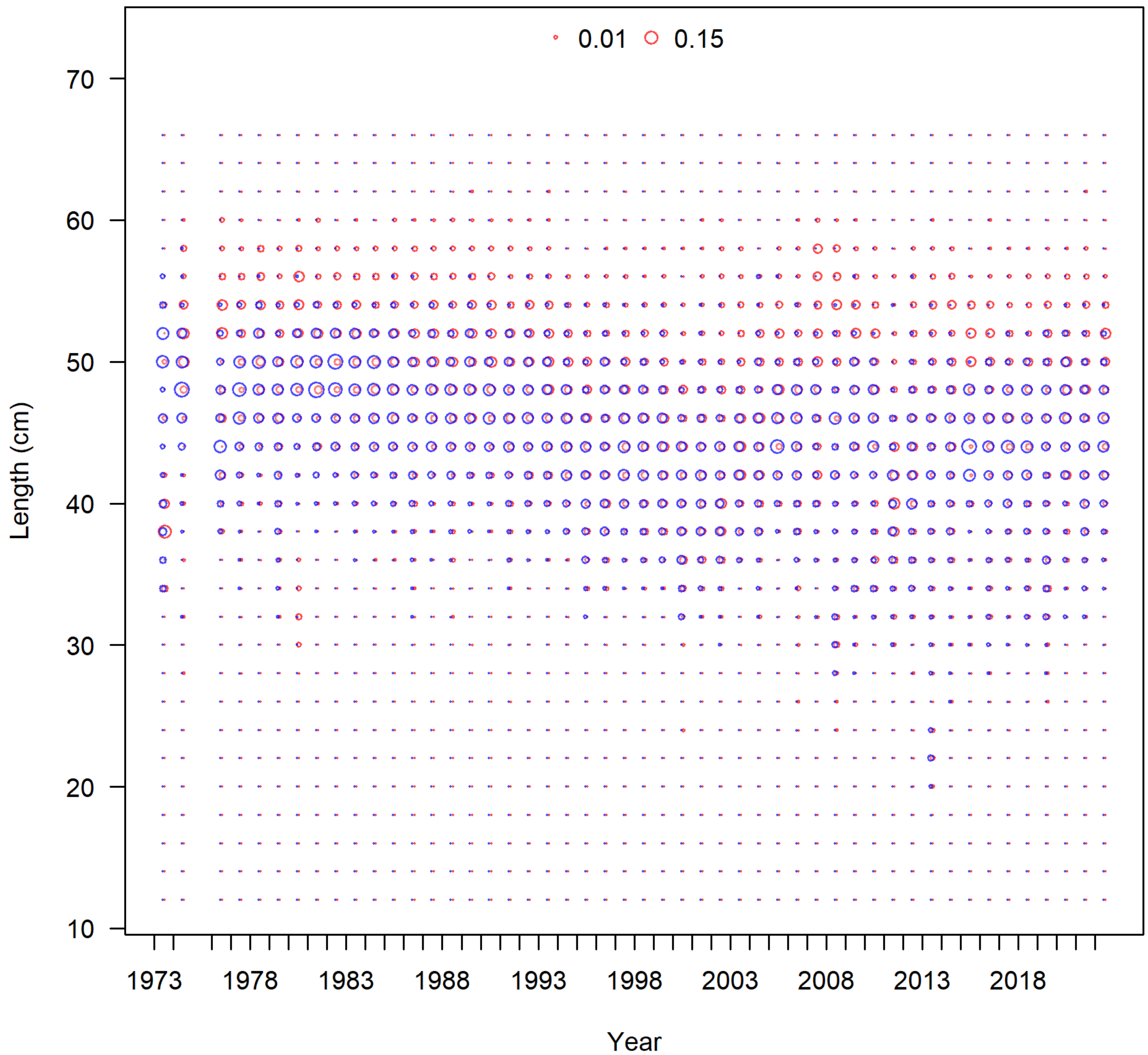

Figure 5: Length composition data for the Oregon trawl fishery for females (red) and males (blue).

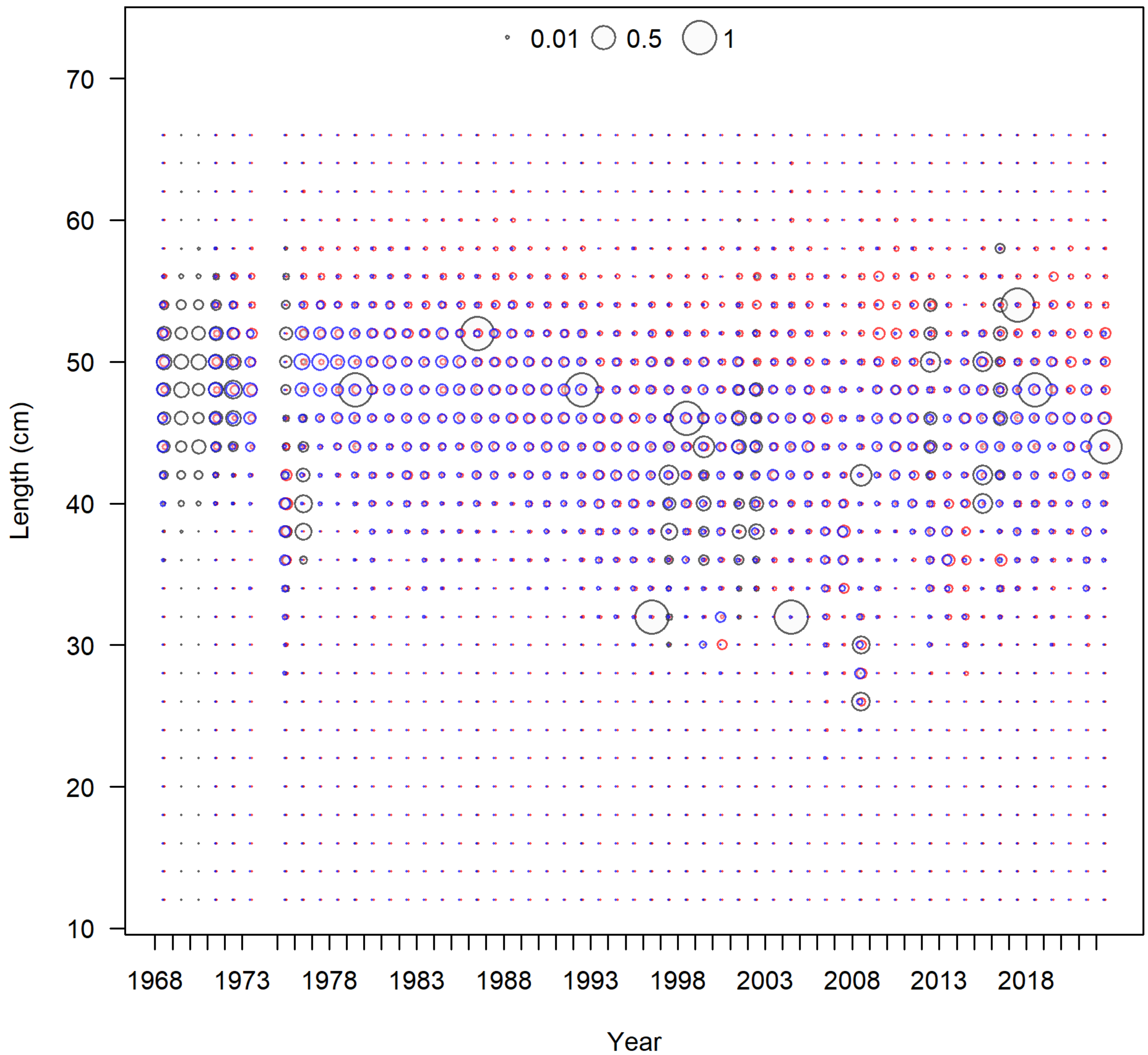

Figure 6: Length composition data for the Washington trawl fishery for females (red), males (blue), and unsexed (black).

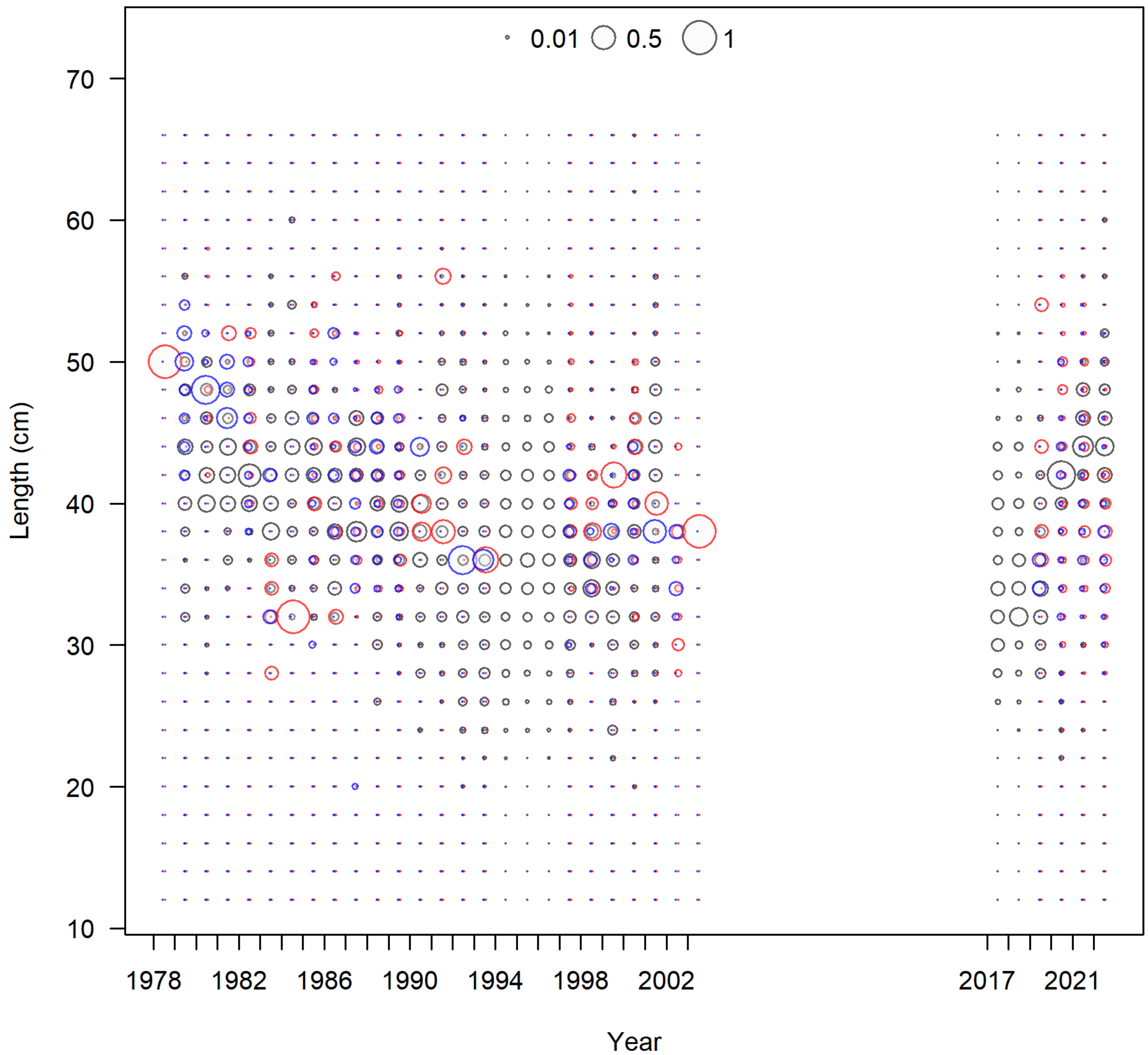

Figure 7: Length composition data for the California non-trawl fishery for females (red), males (blue), and unsexed (black).

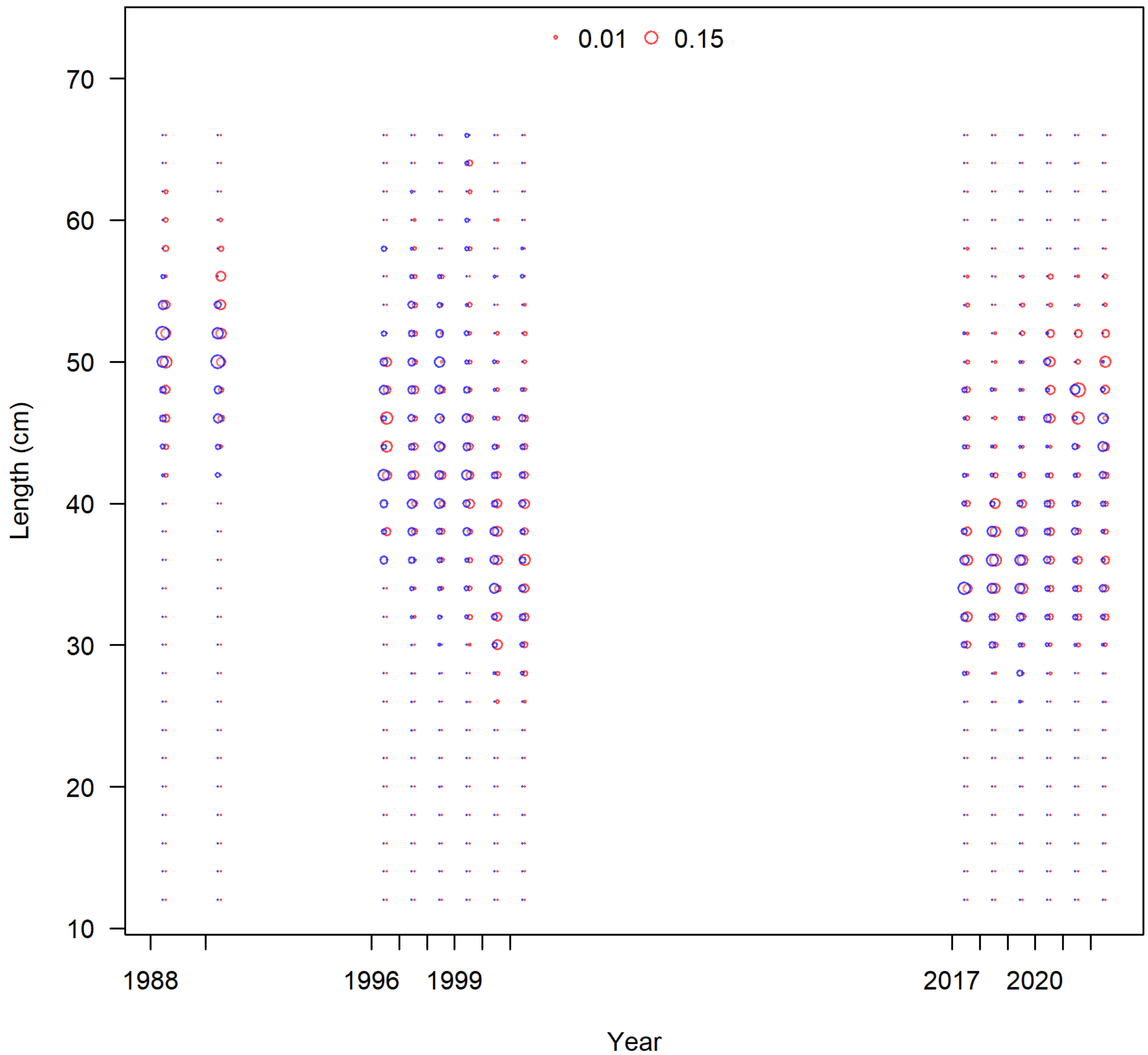

Figure 8: Length composition data for the Oregon non-trawl fishery for females (red) and males (blue).

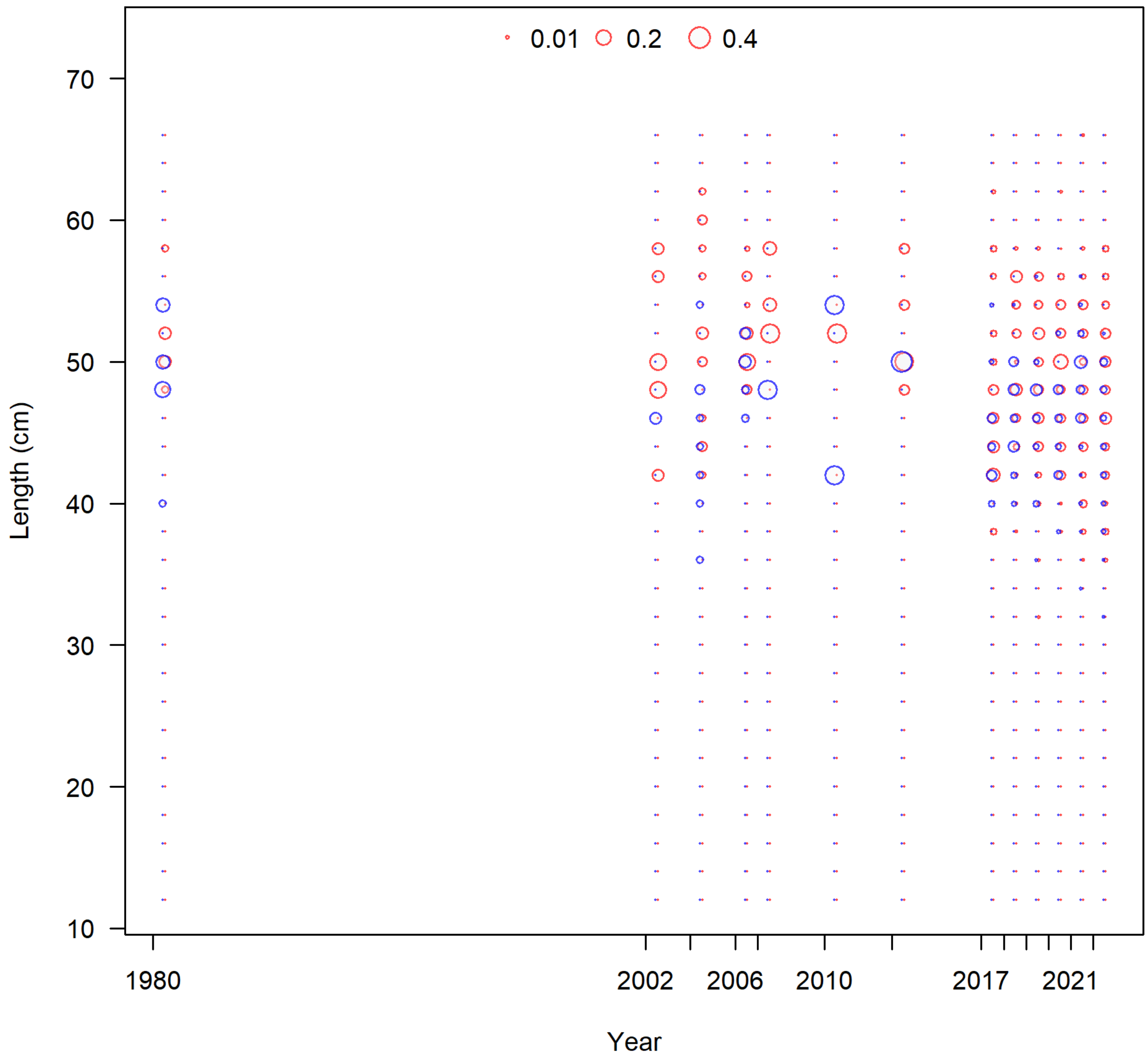

Figure 9: Length composition data for the Washington non-trawl fishery for females (red) and males (blue).

Figure 10: Age composition data for the California trawl fishery for females (red) and males (blue).

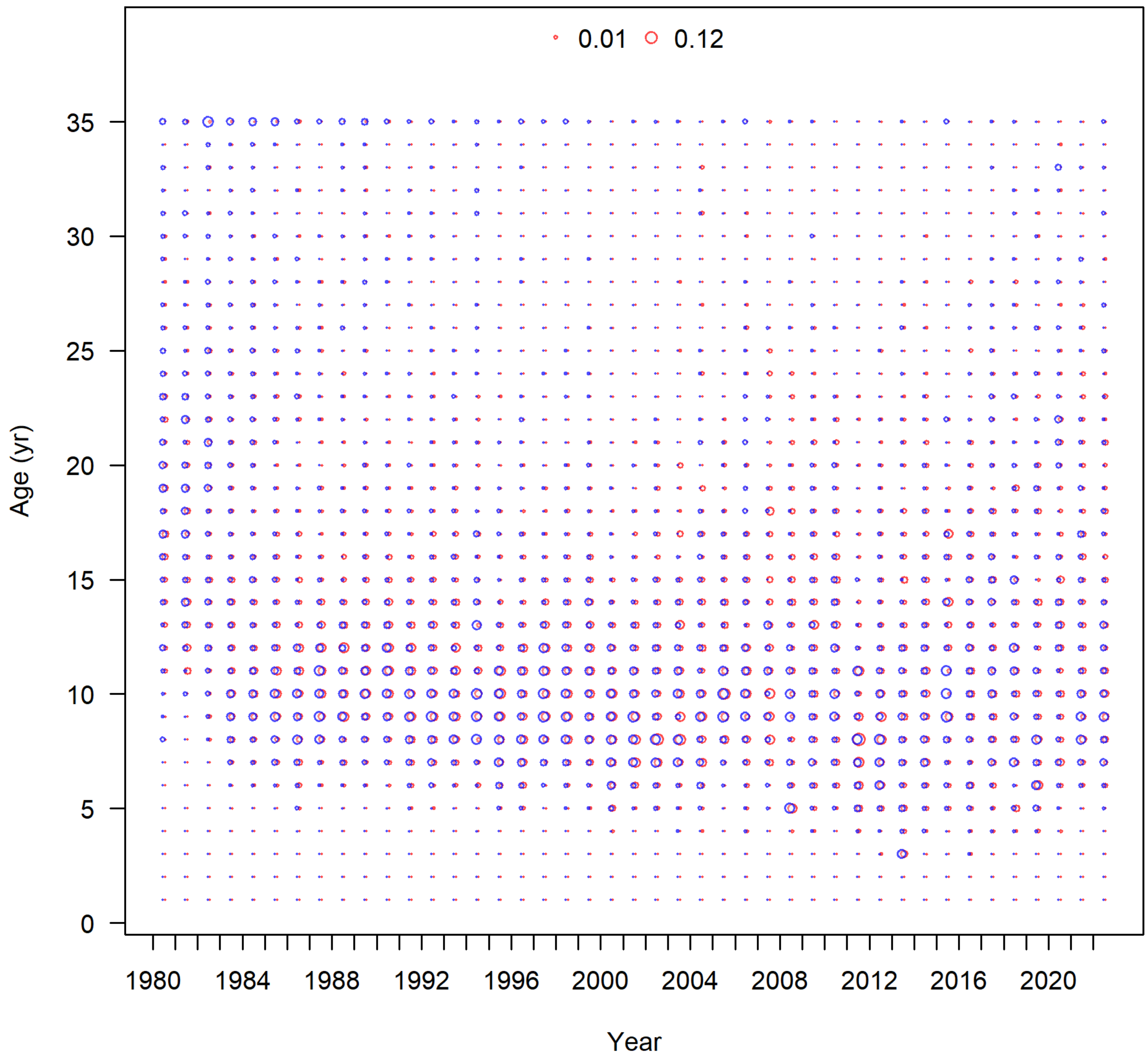

Figure 11: Age composition data for the Oregon trawl fishery for females (red) and males (blue).

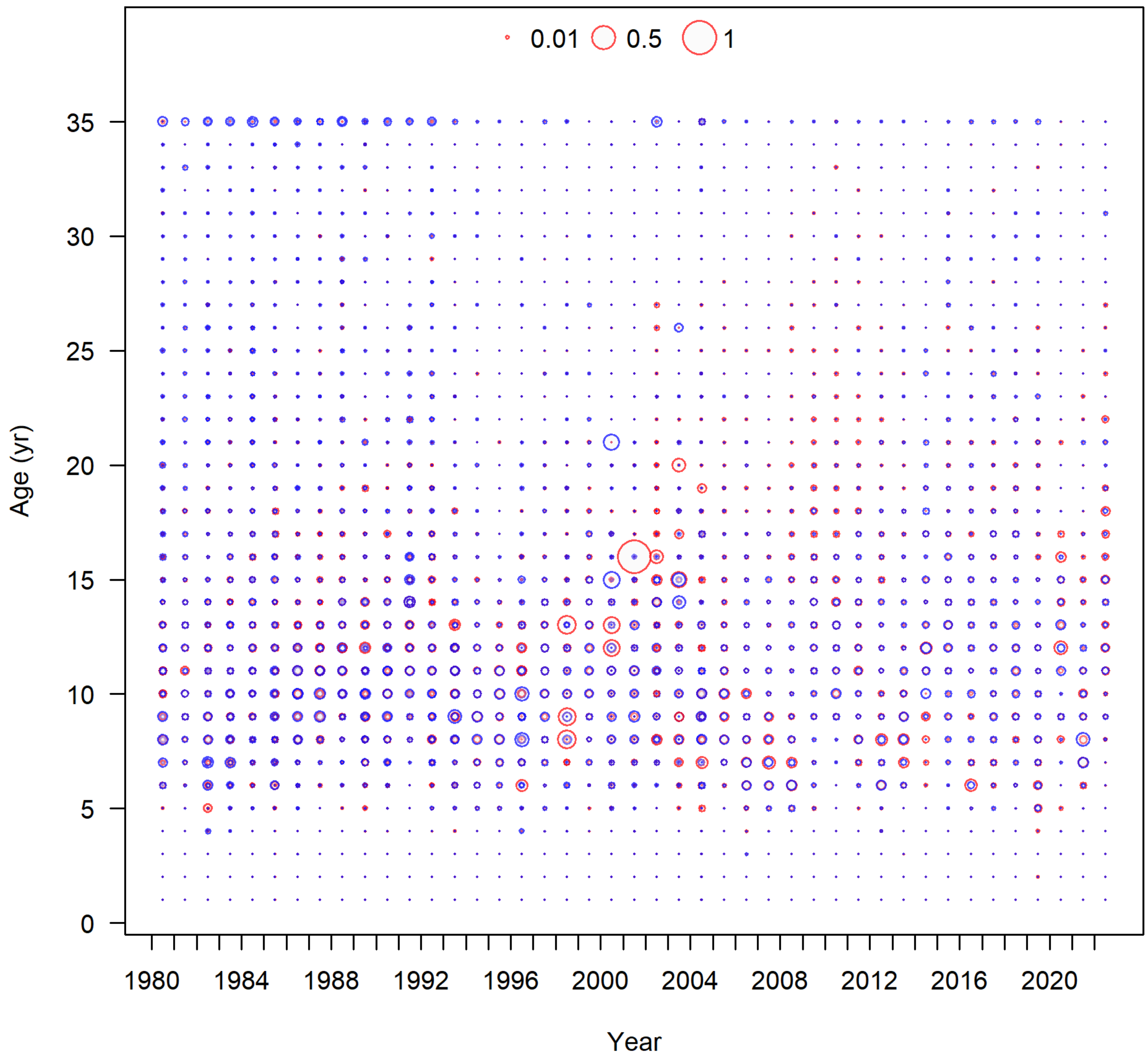

Figure 12: Age composition data for the Washington trawl fishery for females (red) and males (blue).

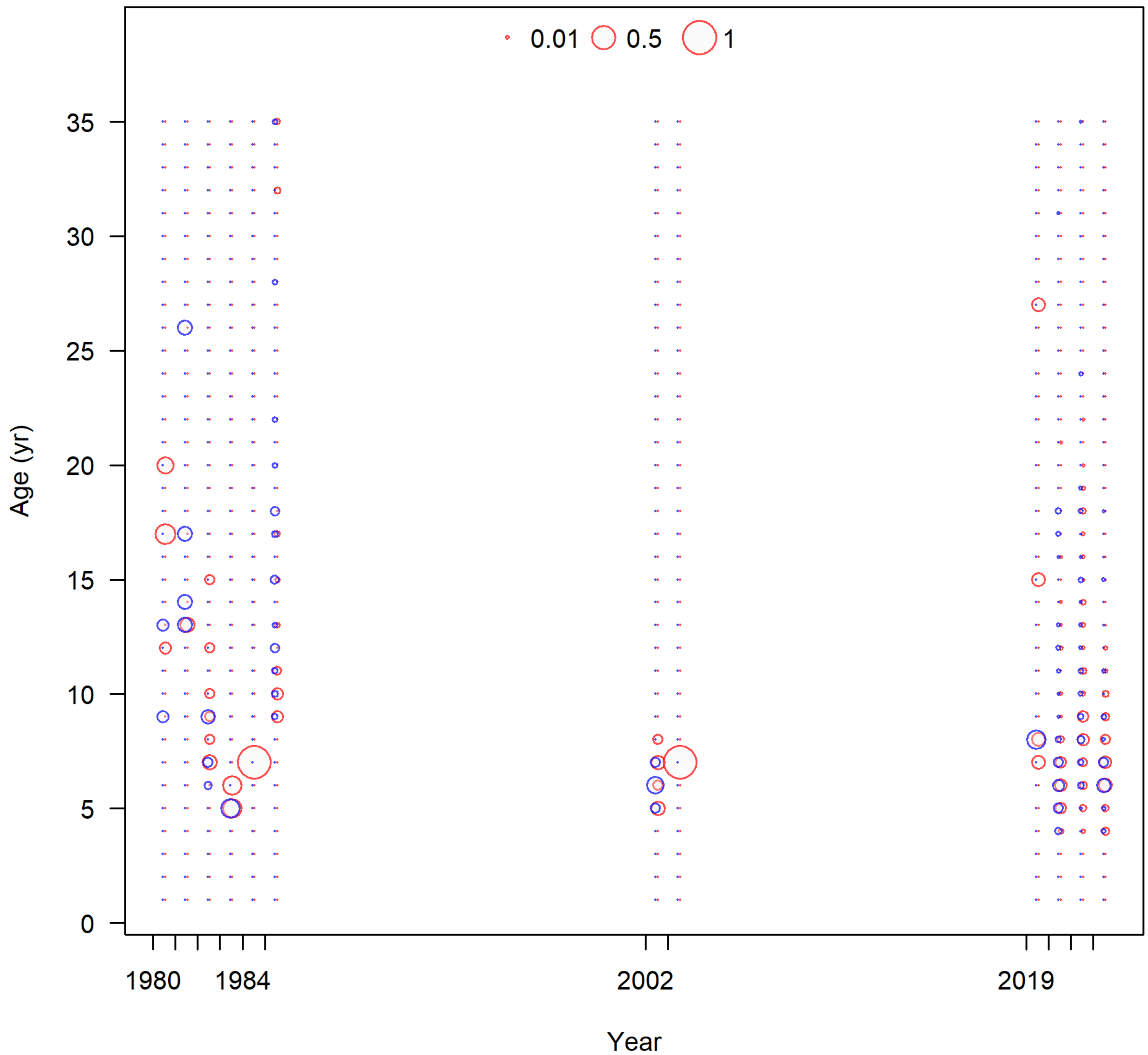

Figure 13: Age composition data for the California non-trawl fishery for females (red) and males (blue).

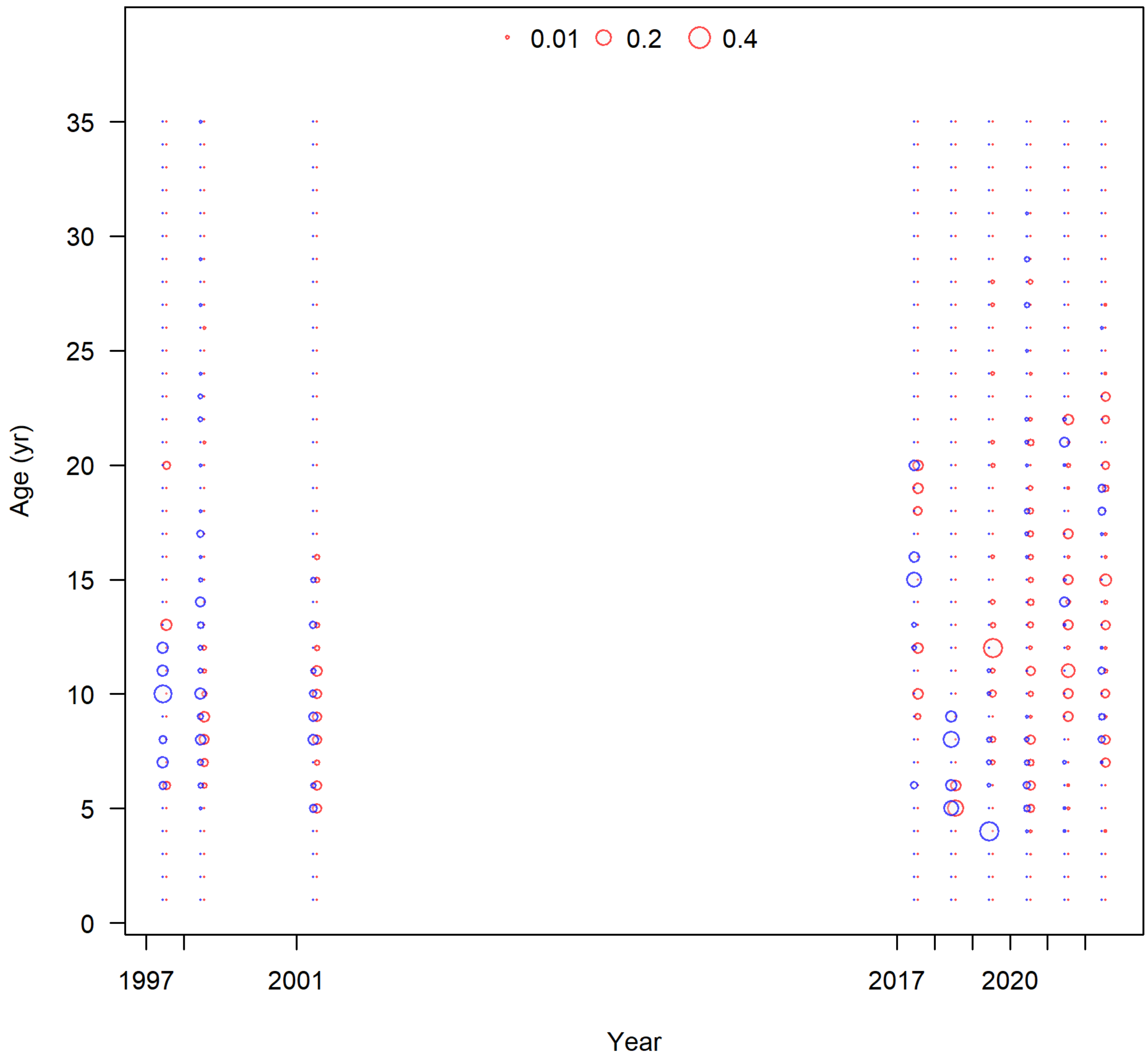

Figure 14: Age composition data for the Oregon non-trawl fishery for females (red) and males (blue).

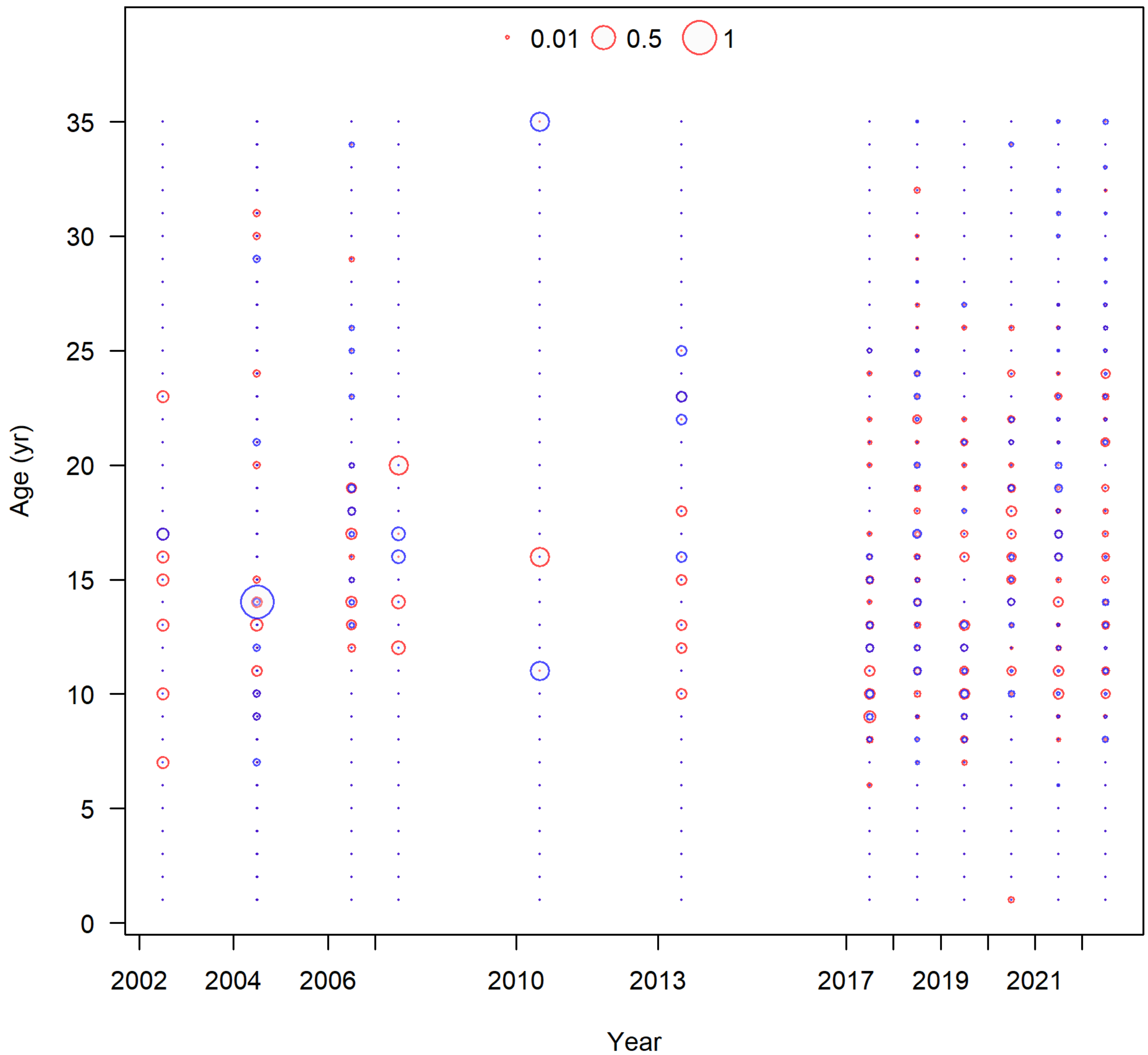

Figure 15: Age composition data for the Washington non-trawl fishery for females (red) and males (blue).

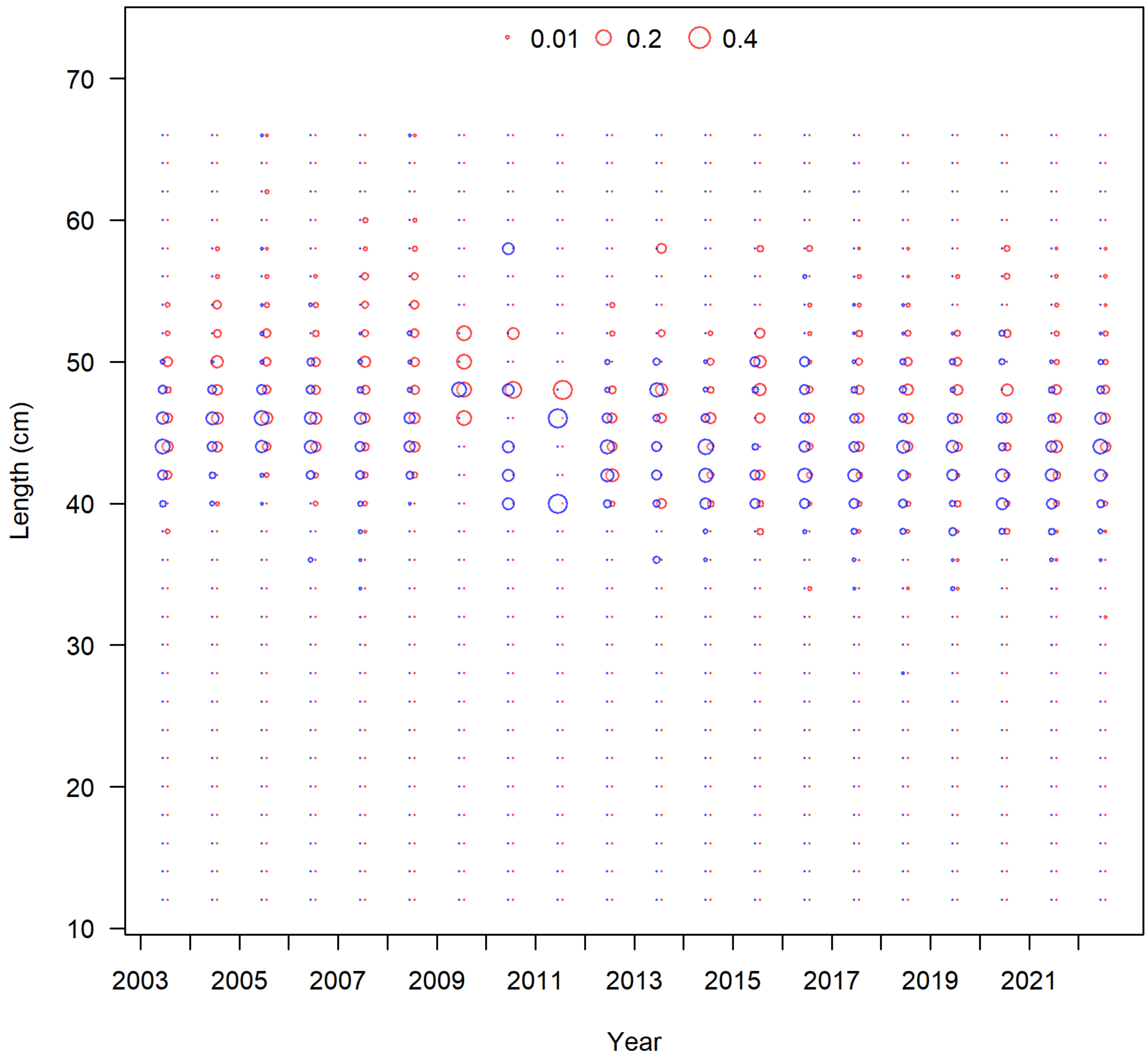

Figure 16: Length composition data for the Oregon at-sea hake fishery for females (red) and males (blue).

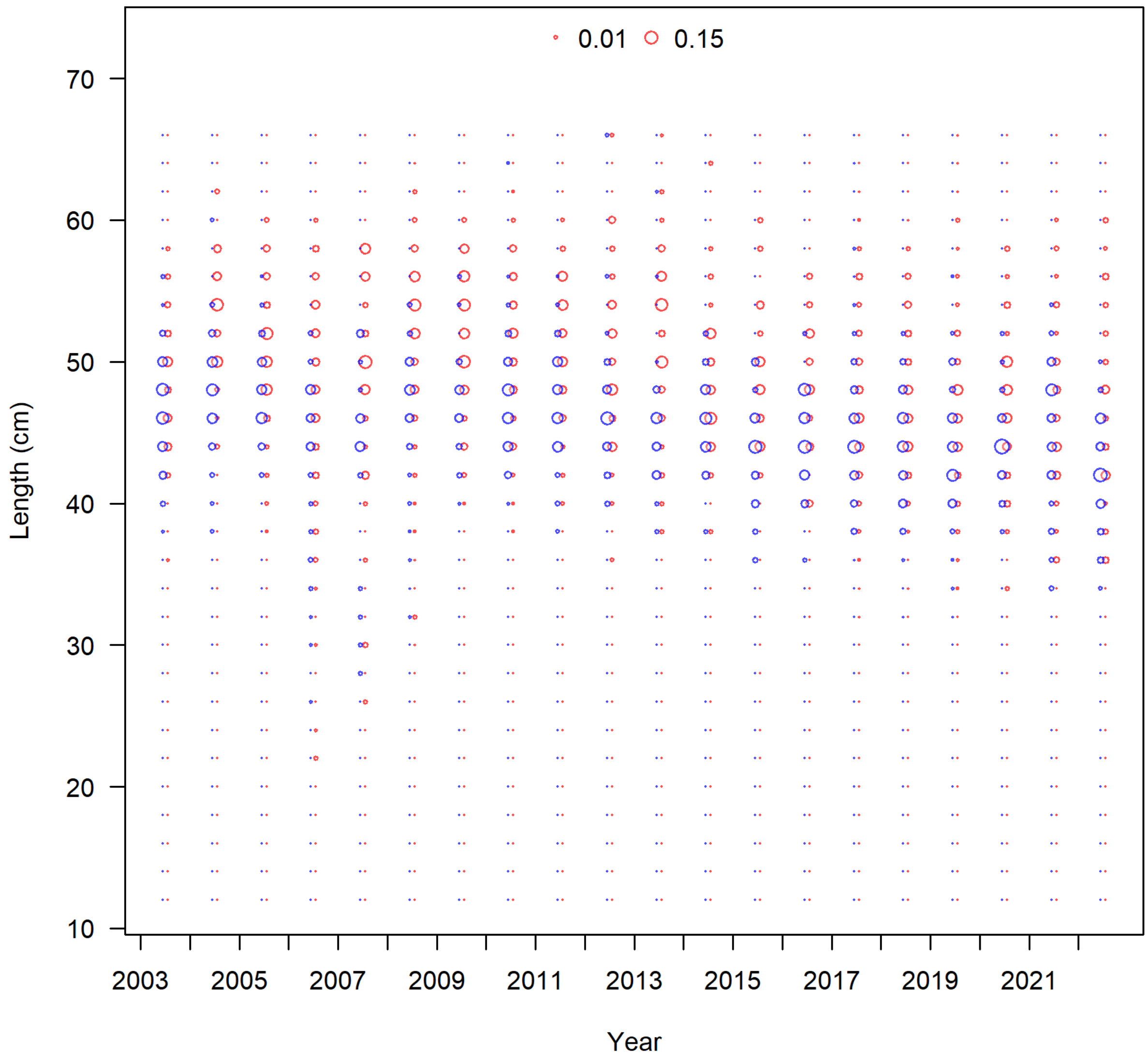

Figure 17: Length composition data for the Washington at-sea hake fishery for females (red) and males (blue).

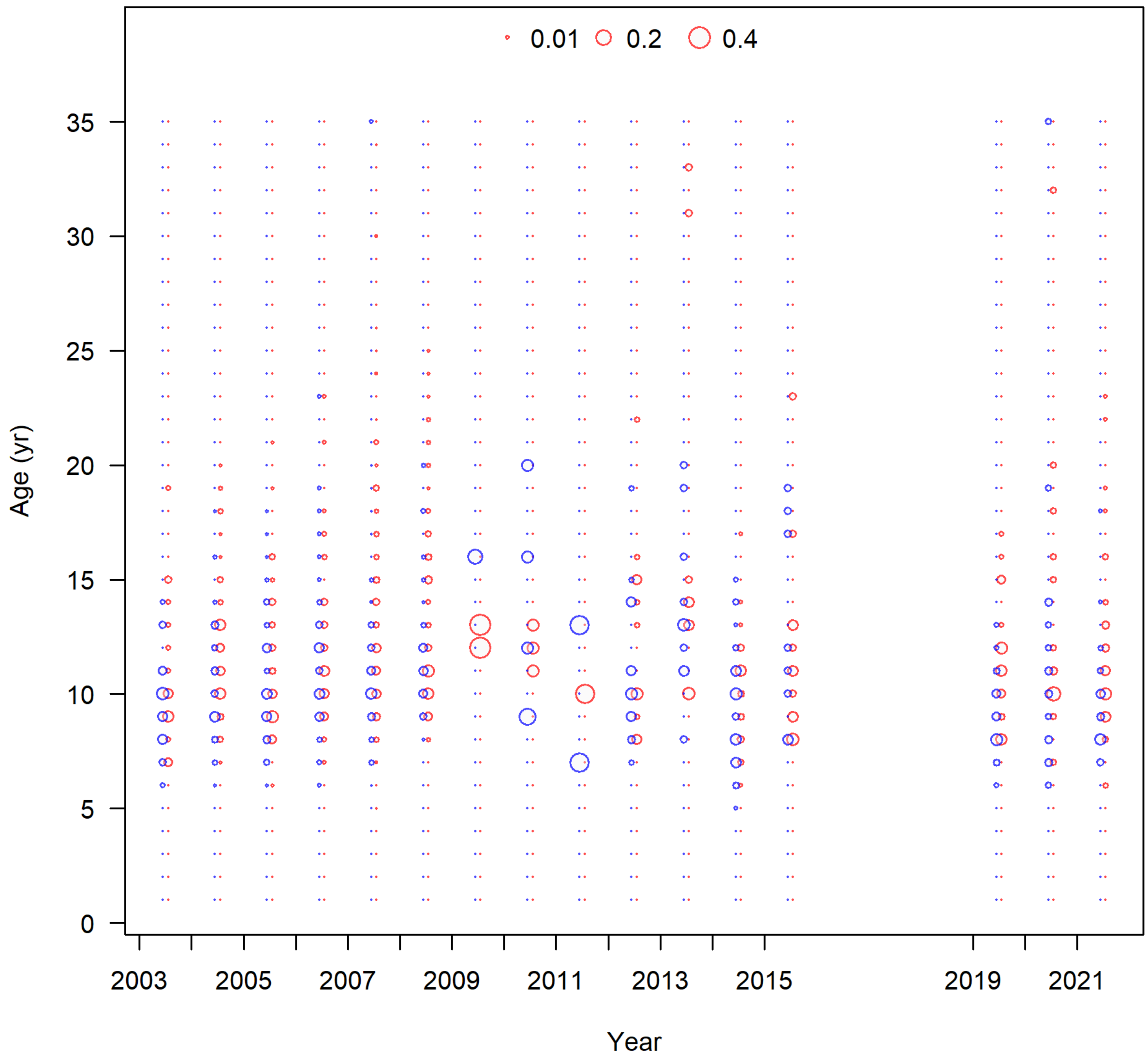

Figure 18: Age composition data for the Oregon at-sea hake fishery for females (red) and males (blue).

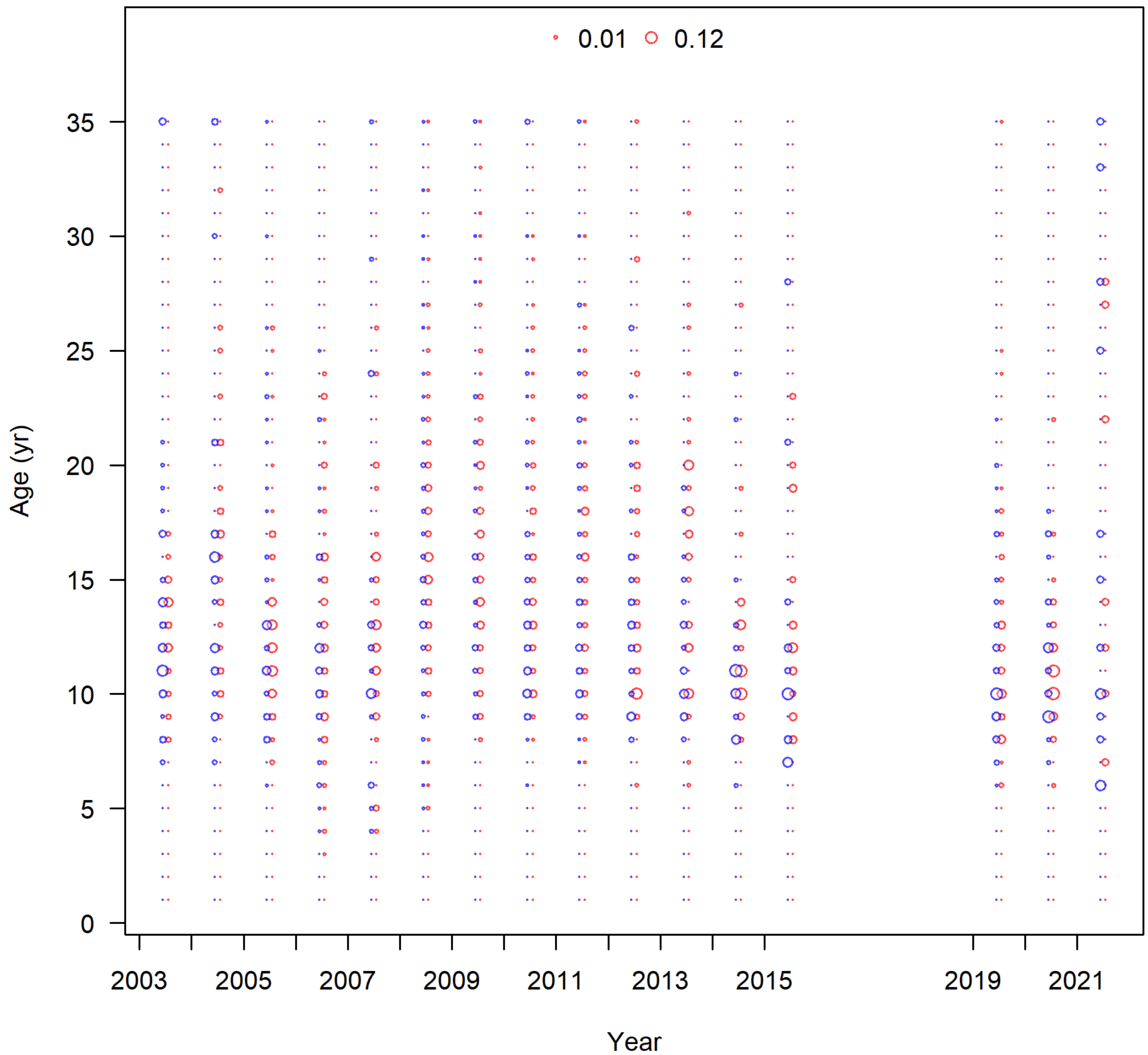

Figure 19: Age composition data for the Washington at-sea hake fishery for females (red) and males (blue).

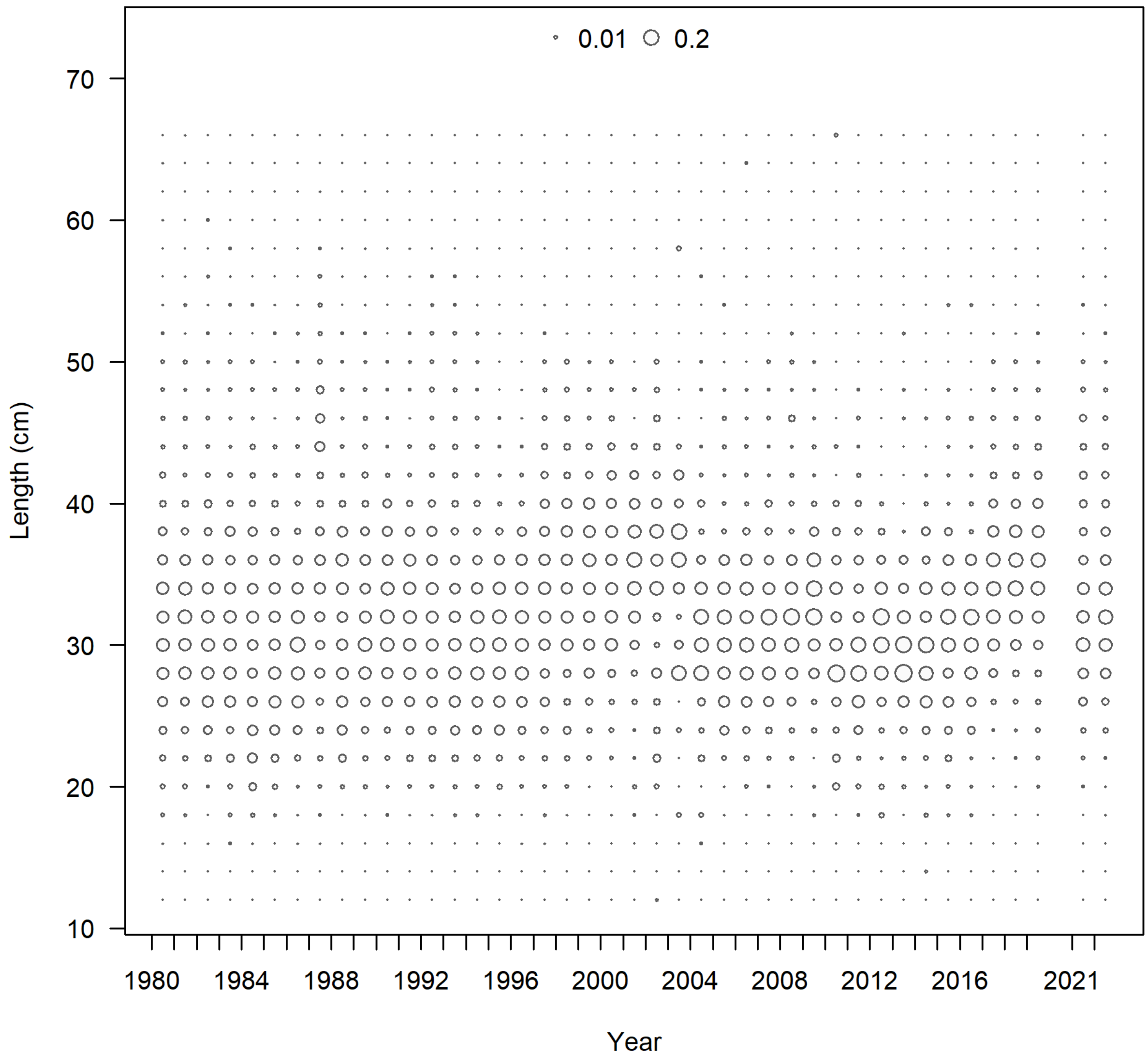

Figure 20: Length composition data for the California recreational fishery for unsexed (black).

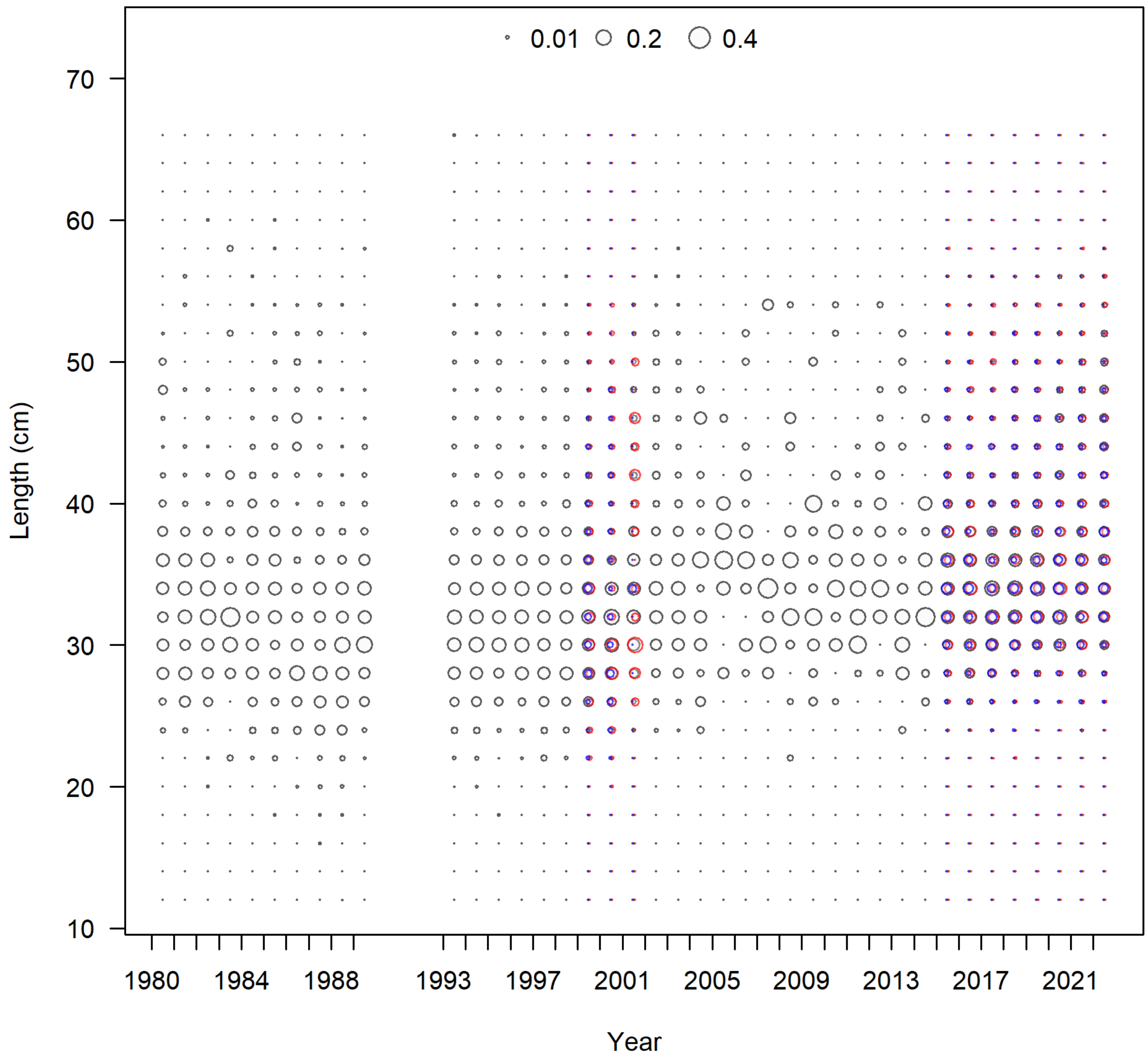

Figure 21: Length composition data for the Oregon recreational fishery for females (red), males (blue), and unsexed (black).

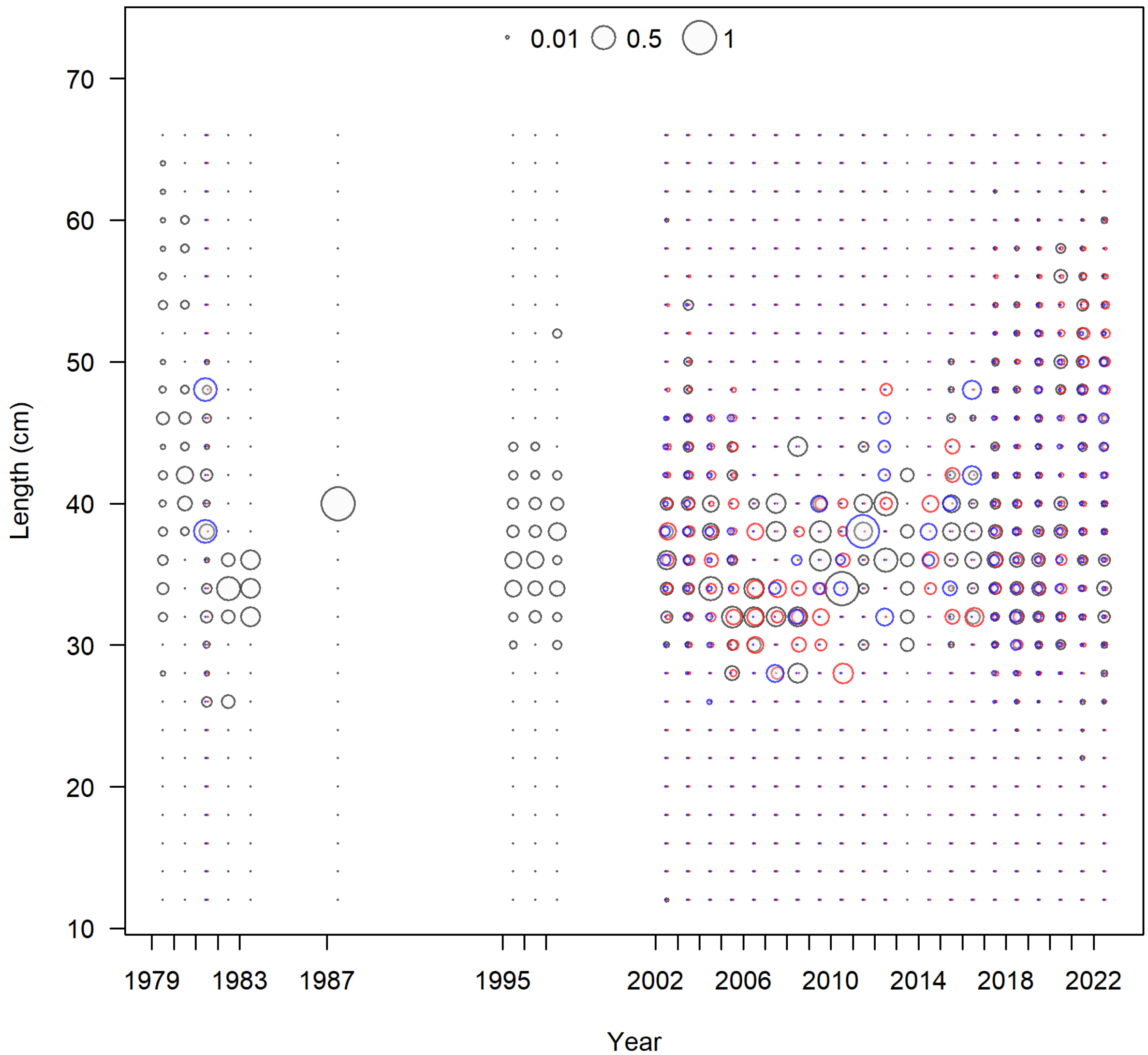

Figure 22: Length composition data for the Washington recreational fishery for females (red), males (blue), and unsexed (black).

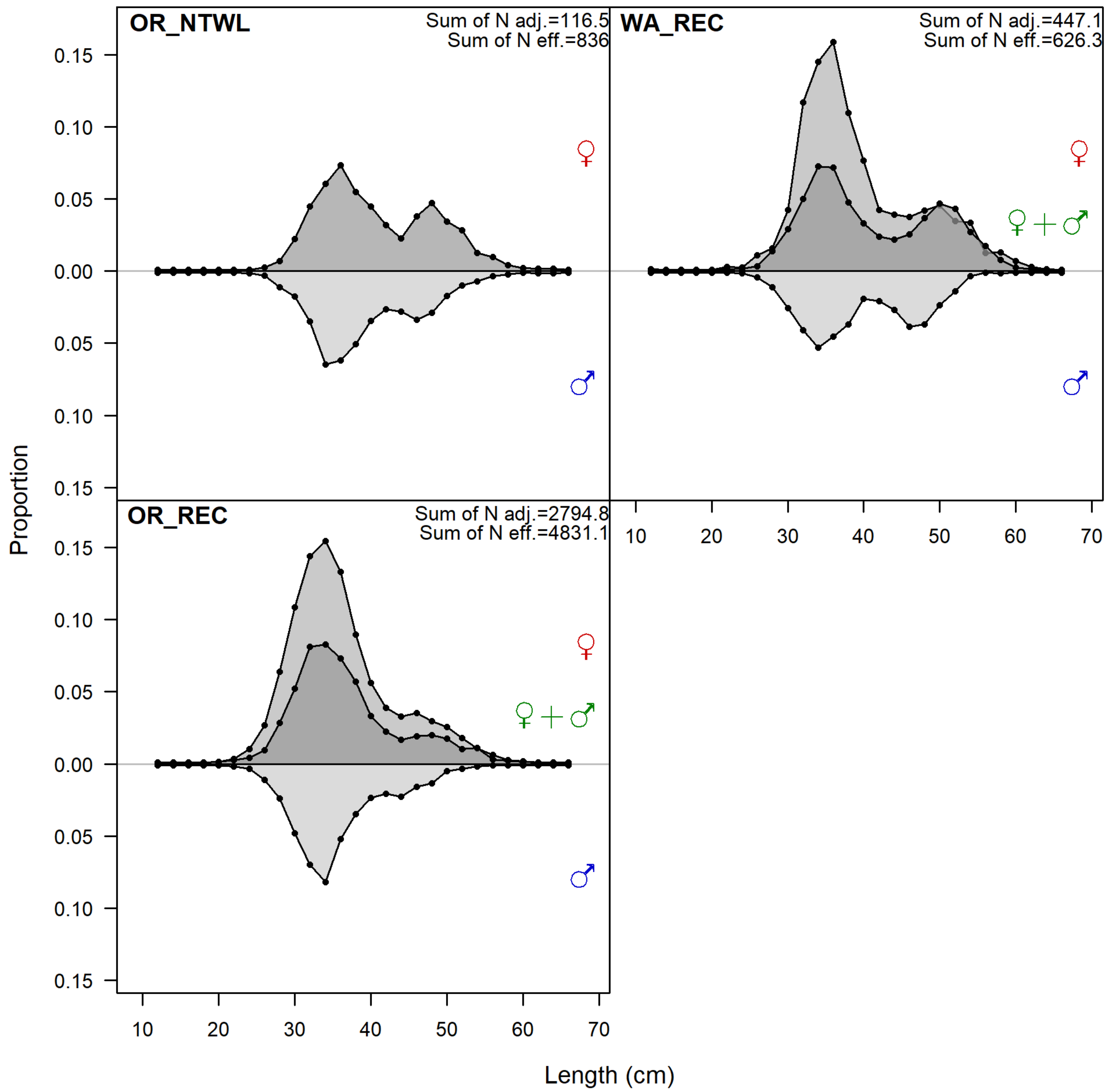

Figure 23: Aggregate length composition data for the three fisheries with bimodal patterns in length.

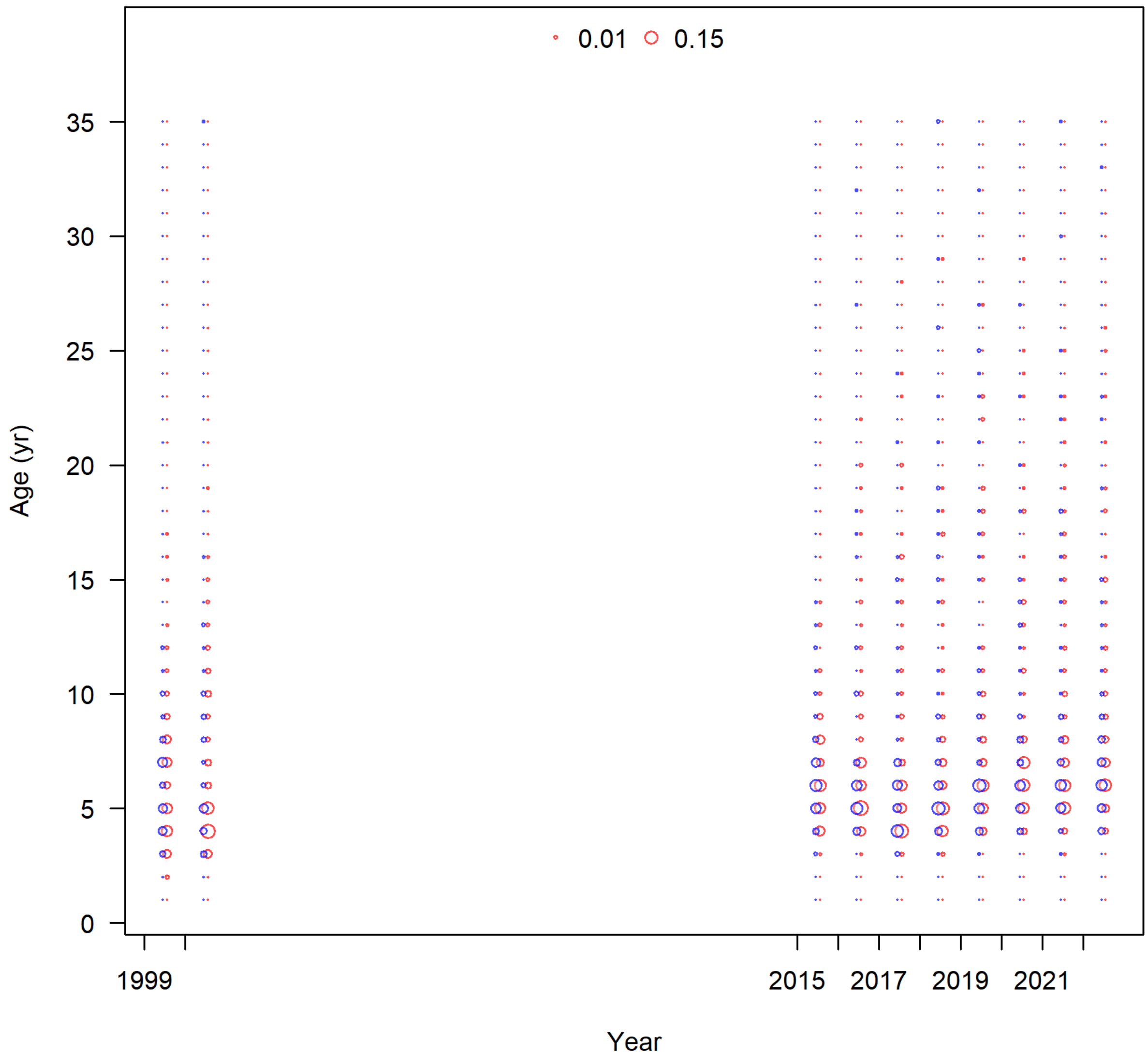

Figure 24: Age composition data for the Oregon recreational fishery for females (red) and males (blue).

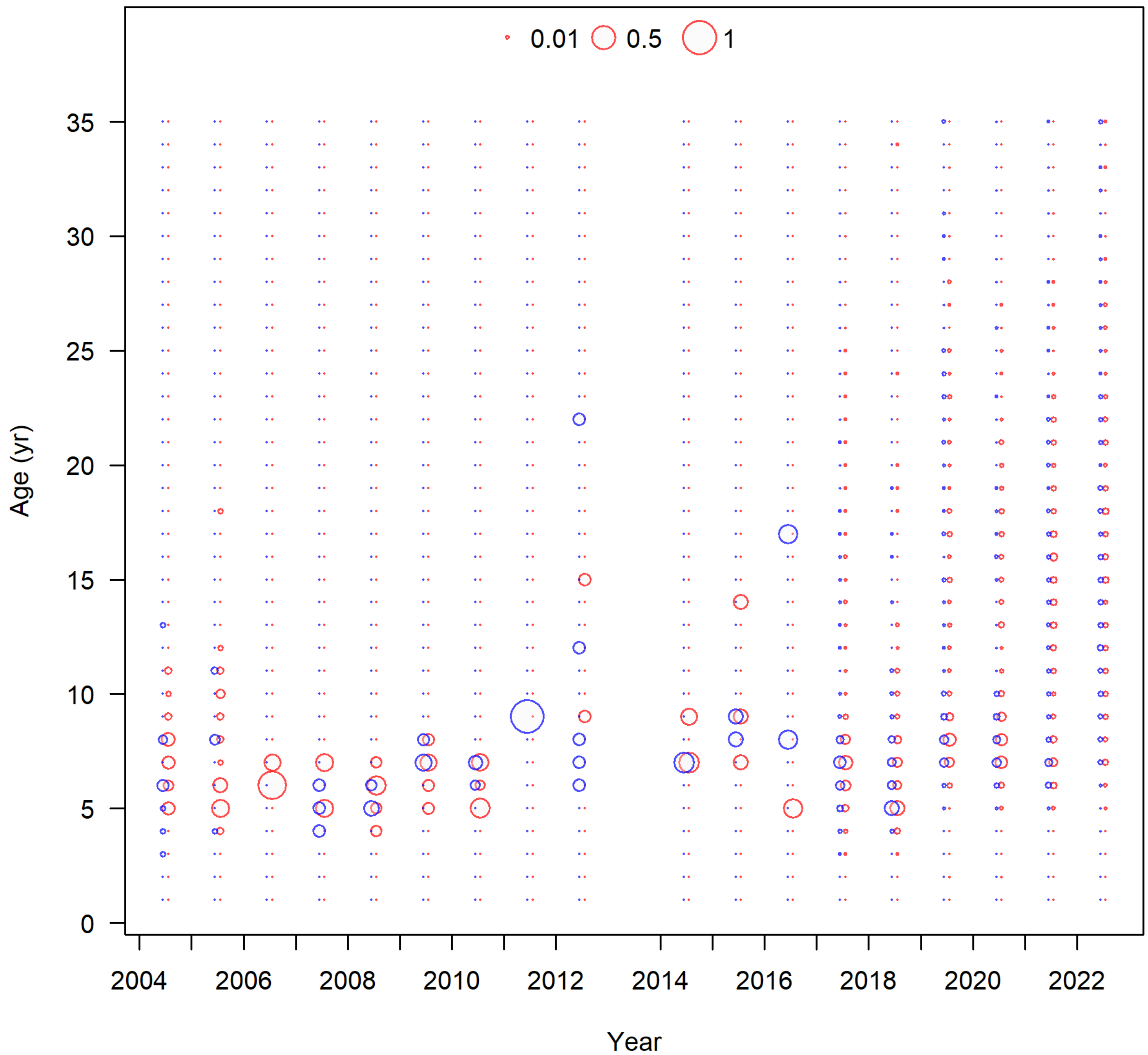

Figure 25: Age composition data for the Washington recreational fishery for females (red) and males (blue).

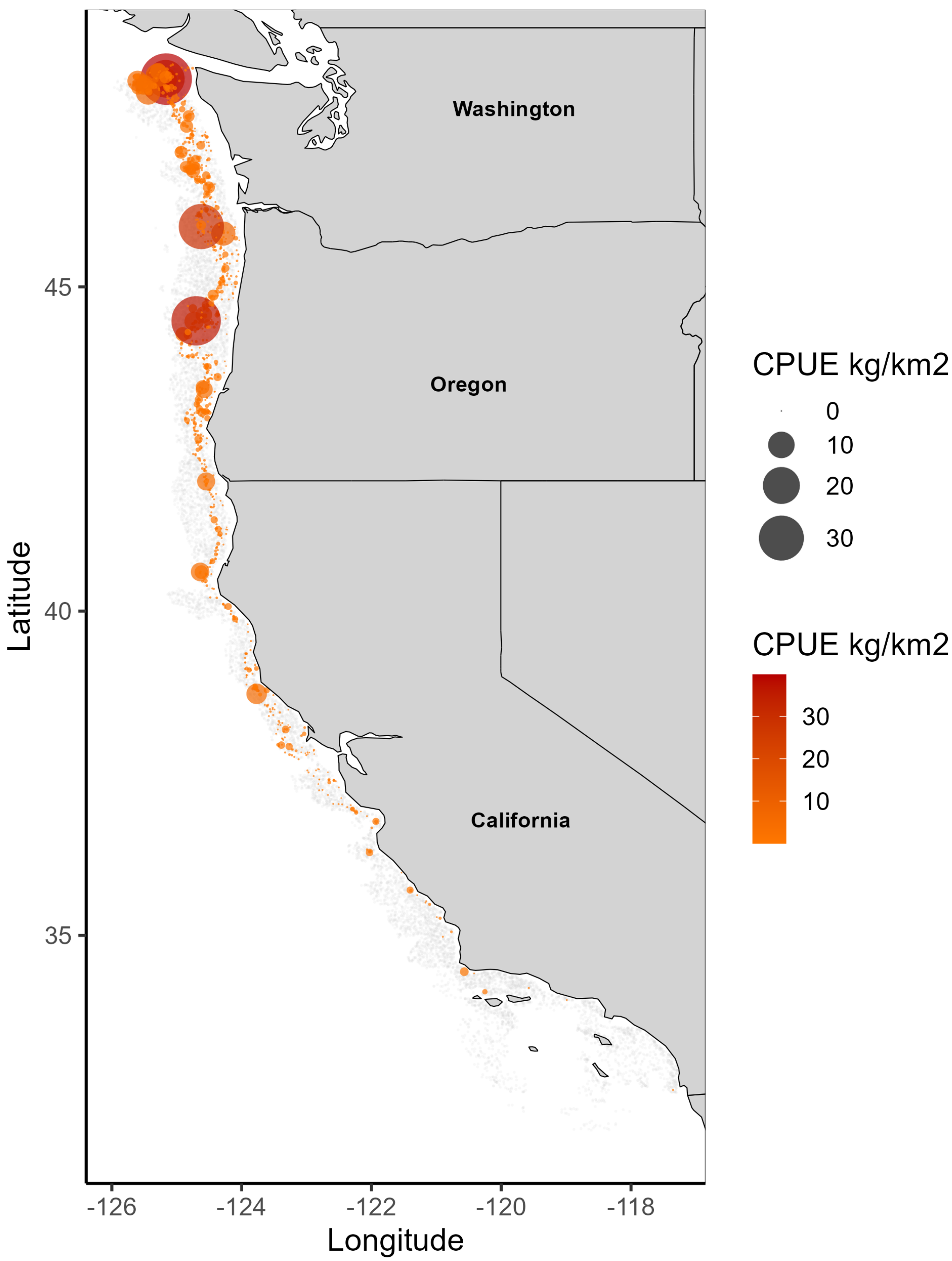

Figure 26: Map of WCGBTS stations and density of catches of canary rockfish. Faint gray dots are tows without canary rockfish. Larger redder circles indicate higher catch rates.

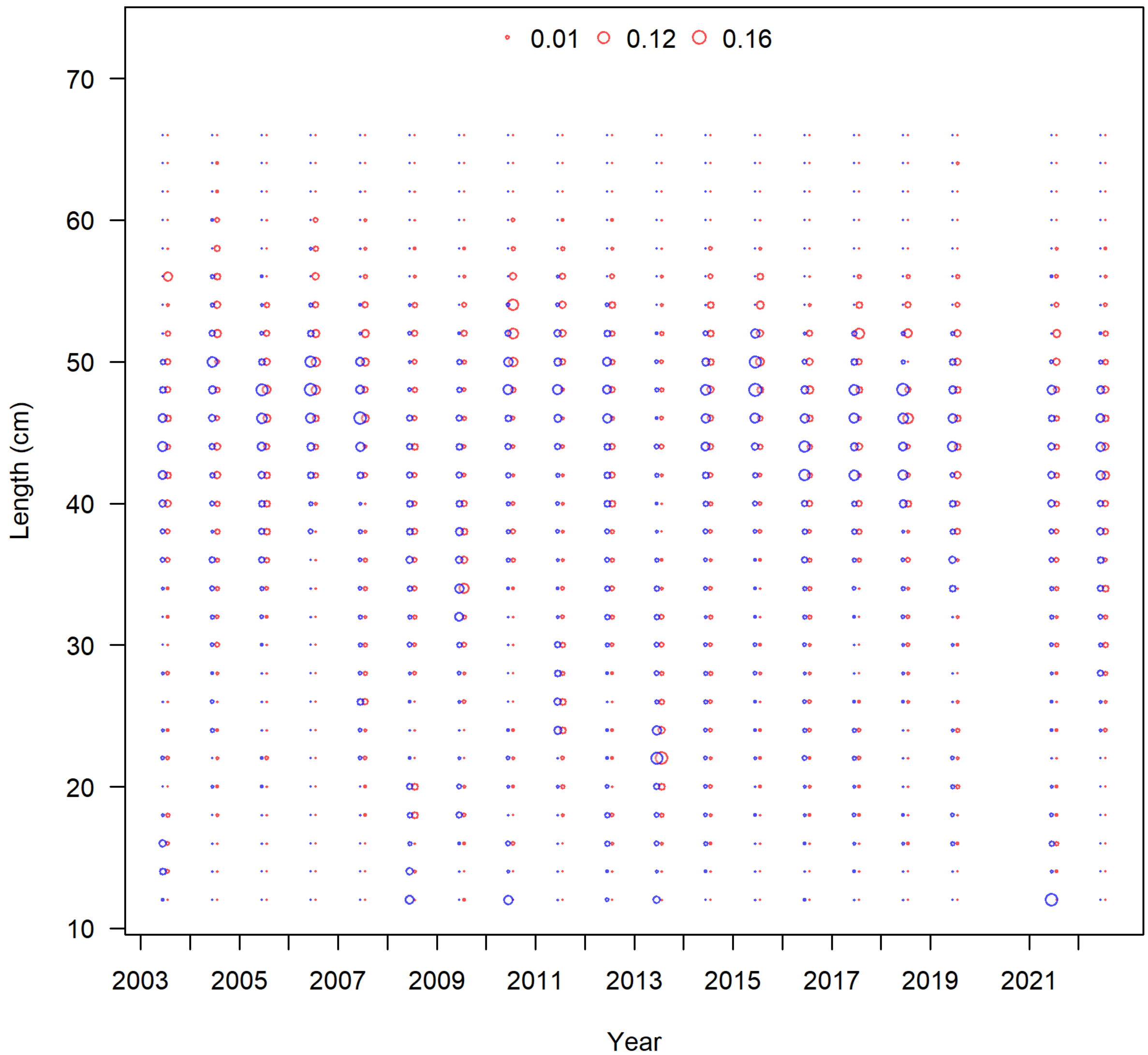

Figure 27: Length composition data for the WCGBTS for females (red) and males (blue).

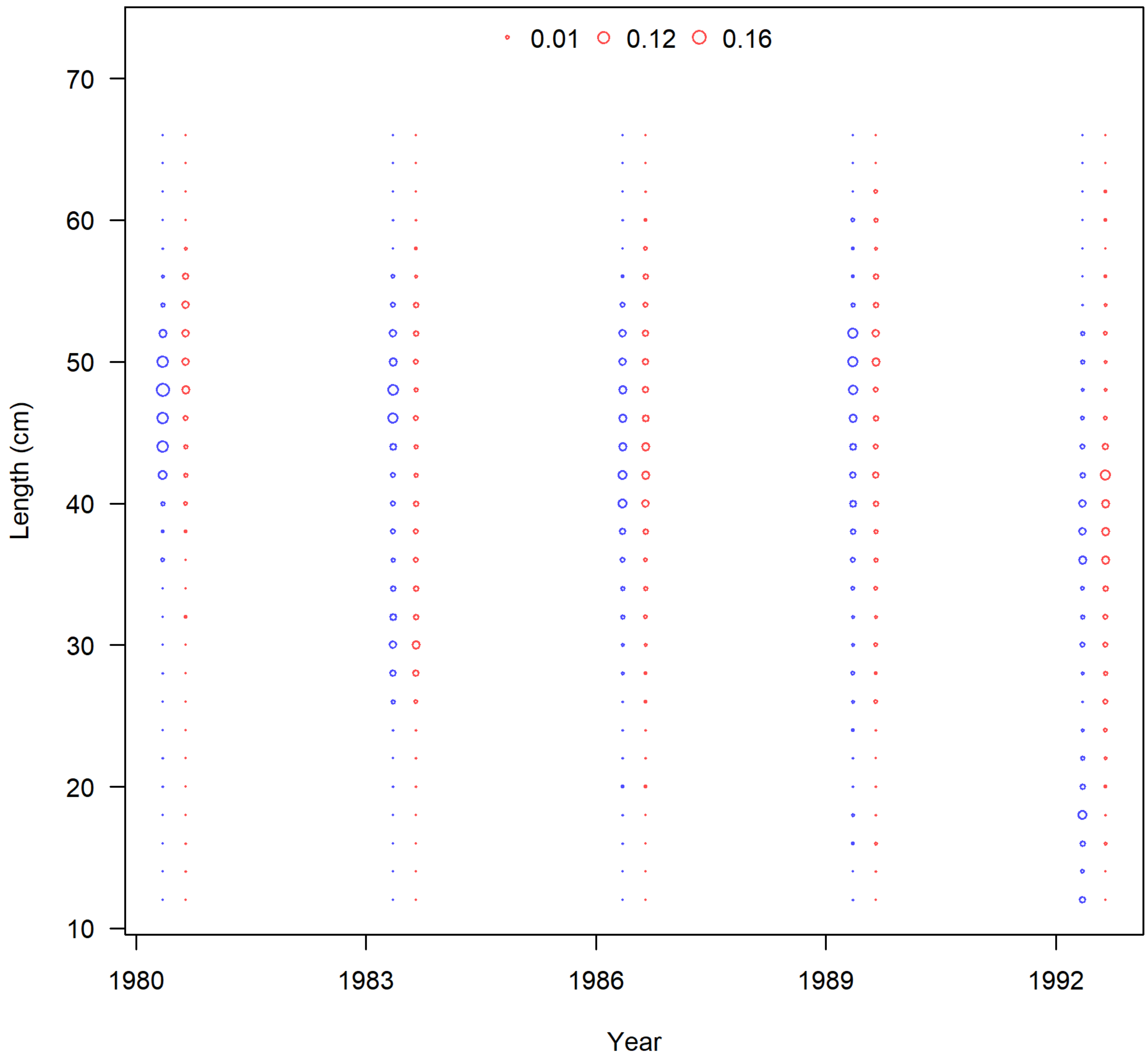

Figure 28: Length composition data for the early years of the Triennial Survey for females (red) and males (blue).

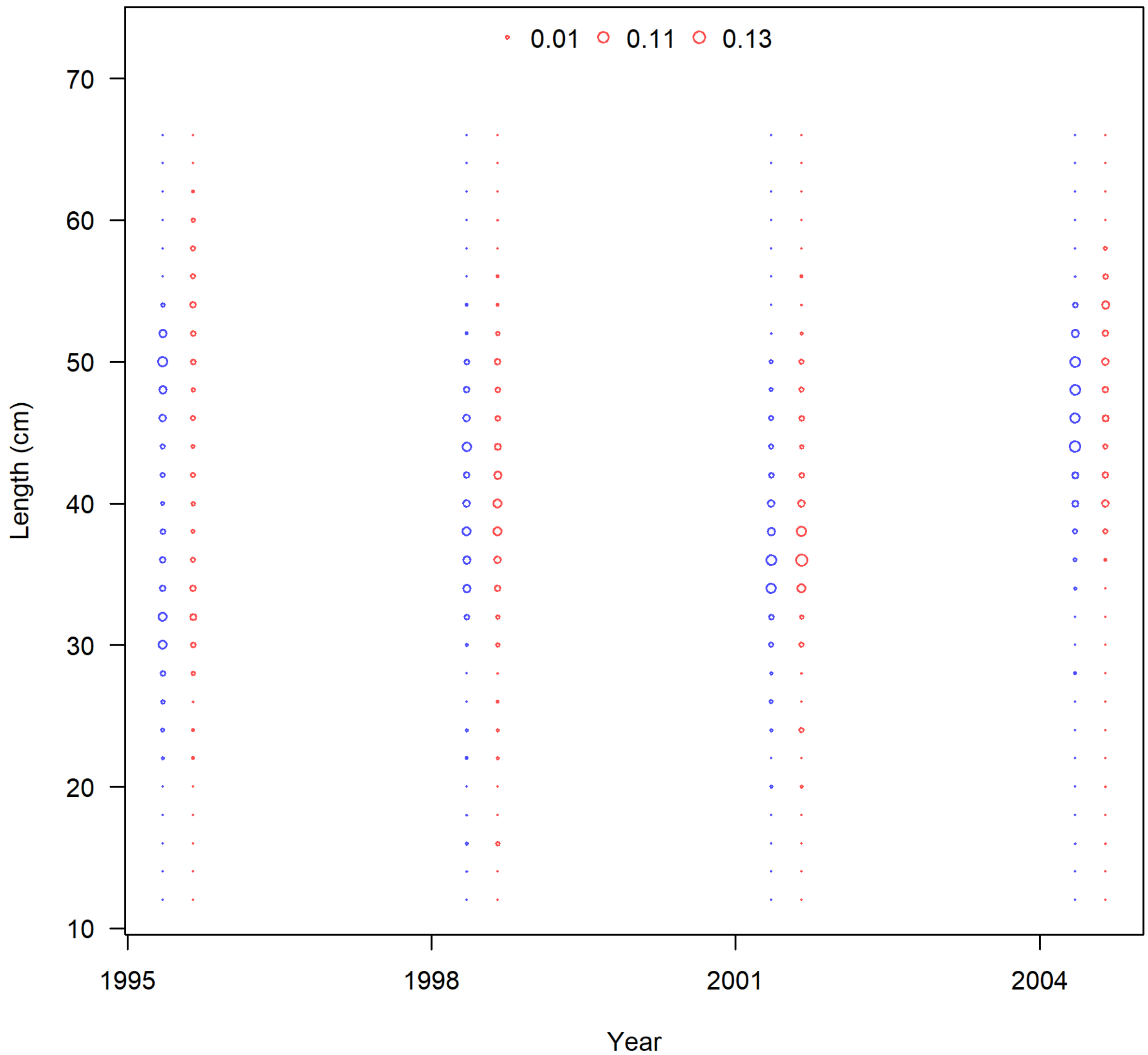

Figure 29: Length composition data for the later years of the Triennial Survey for females (red) and males (blue).

8.1 Biology

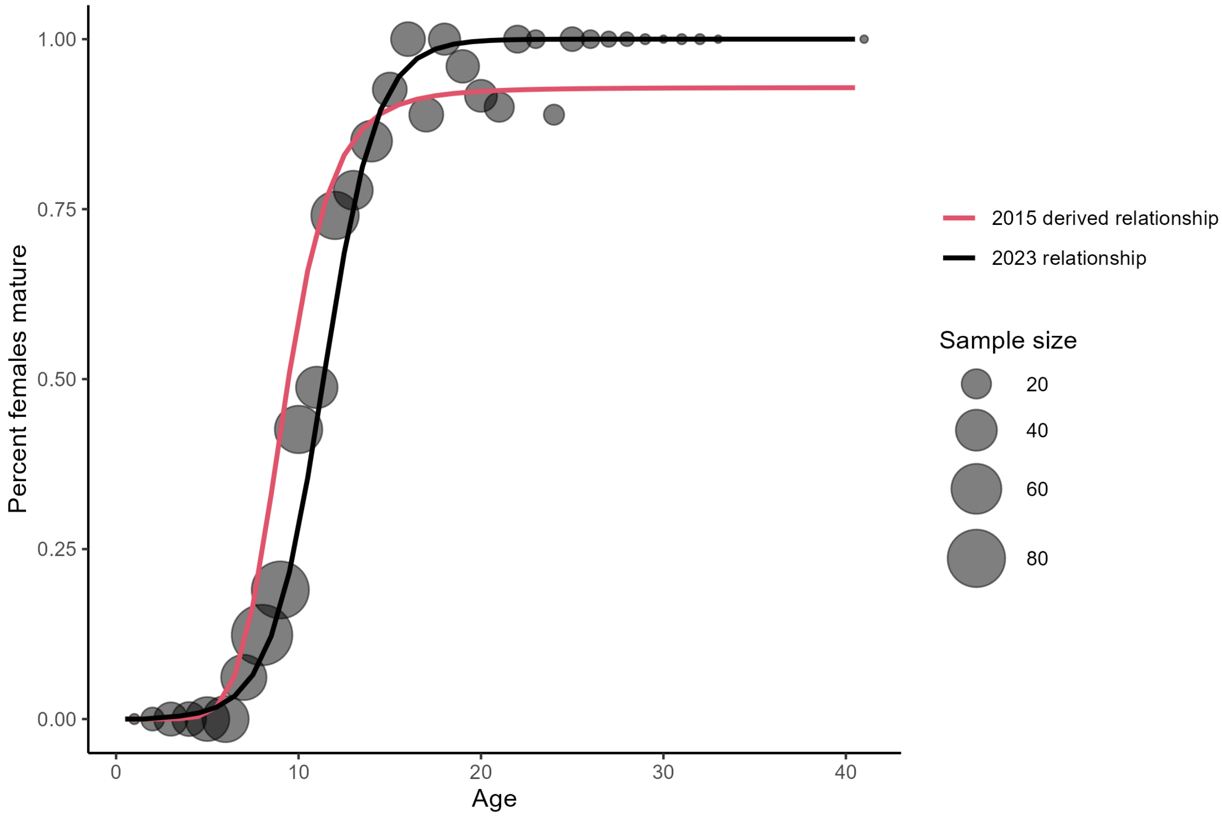

Figure 30: Maturity at age relationship used for the current assessment (black), compared to the last benchmark assessment (red). Sample sizes are shown as gray circles.

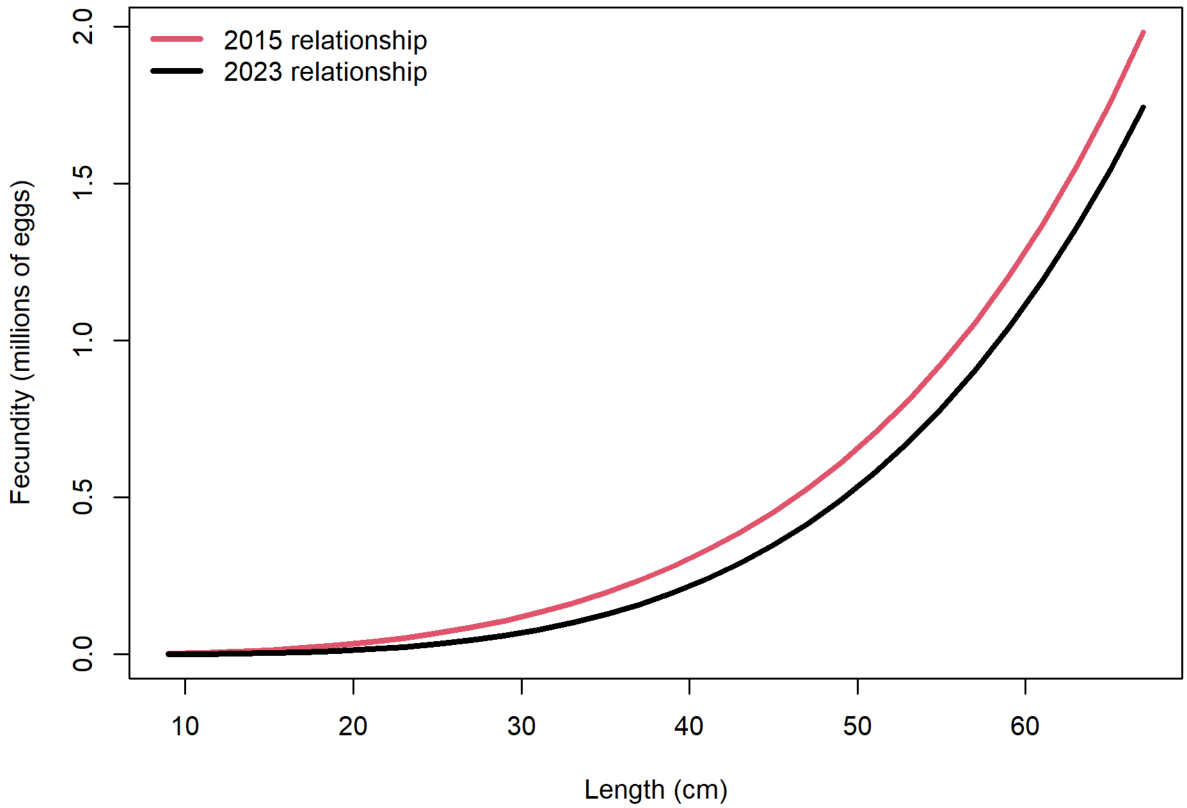

Figure 31: Fecundity at length relationship.

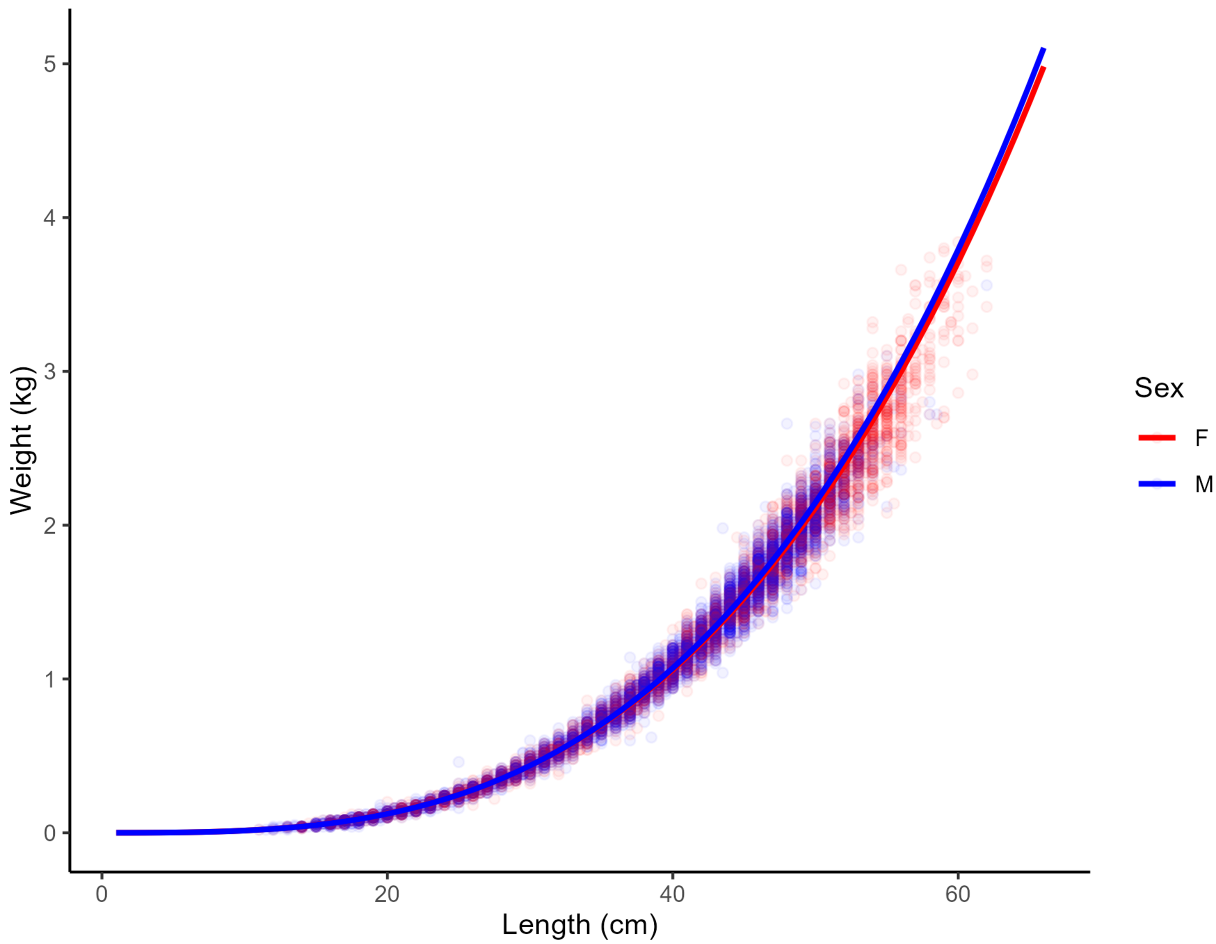

Figure 32: Weight-length relationship for male and females.

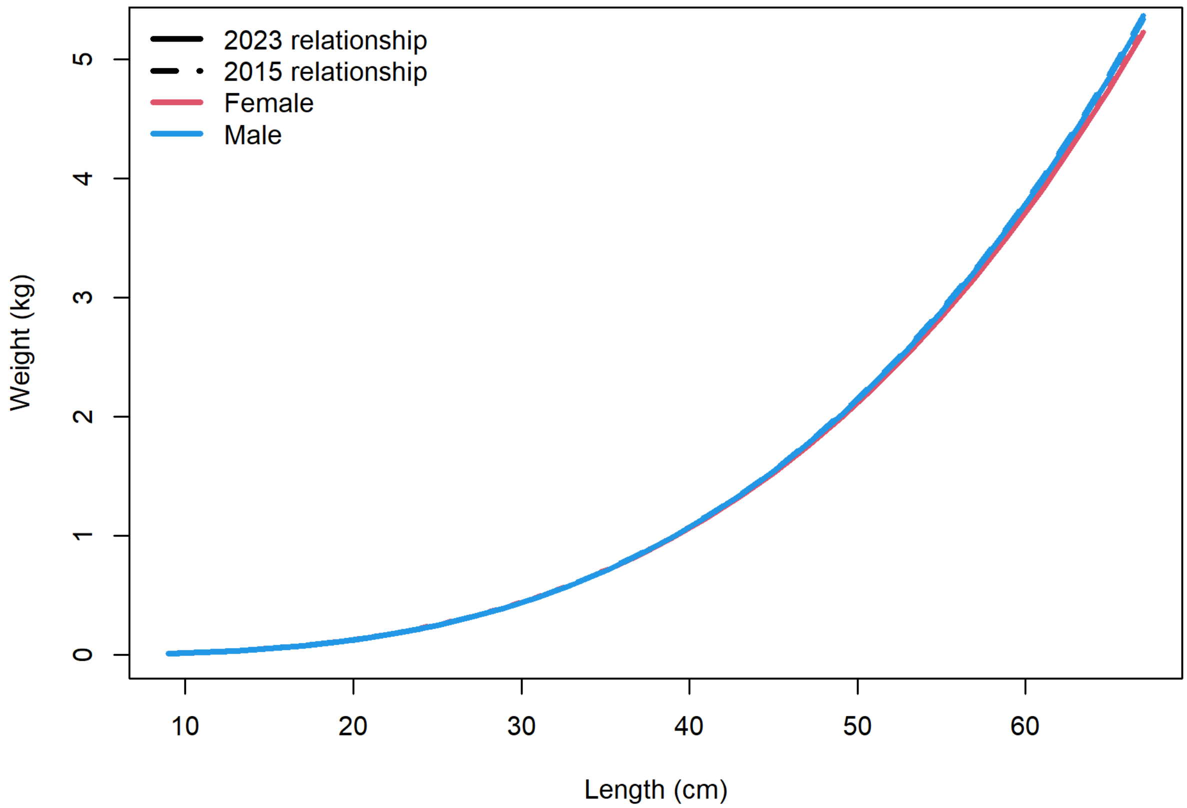

Figure 33: Weight-length comparisons for males and females with previous benchmark assessment.

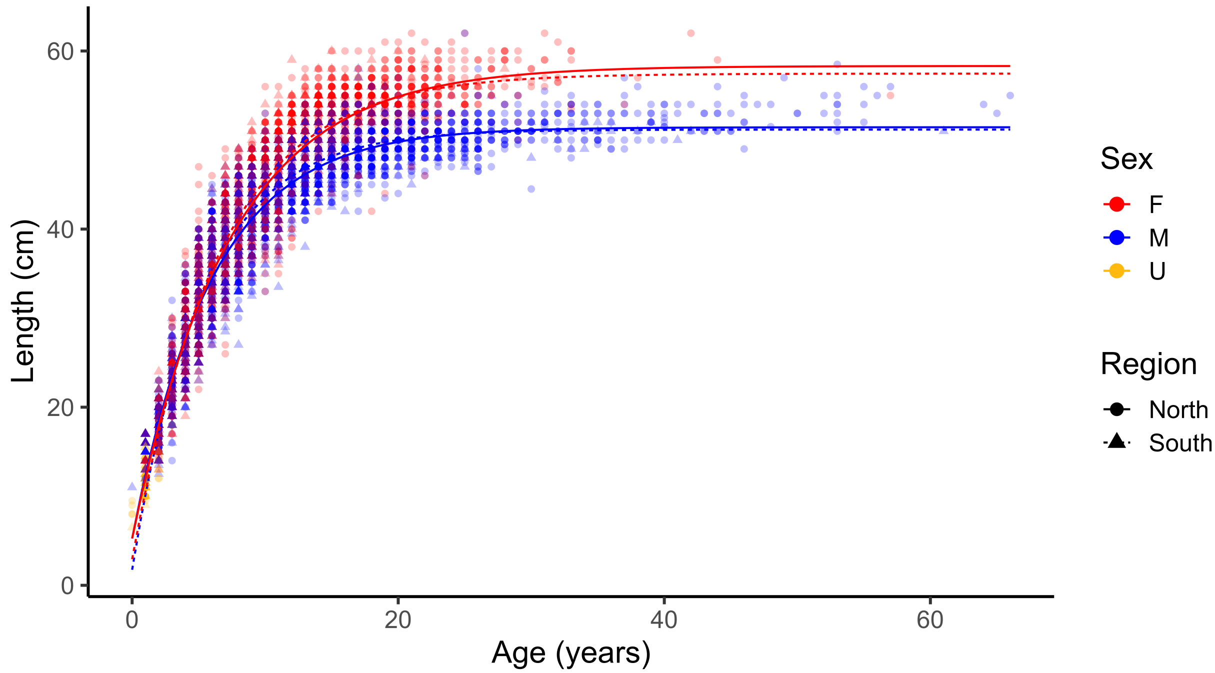

Figure 34: Externally estimated age-length relationship by Sex and latitude, where 'North' is latitudes greater than 43.3672°N (Coos Bay, OR) for females (red), males (blue), and unsexed (yellow). Note that in the base model growth is estimated internally and is assumed constant across latitudes.

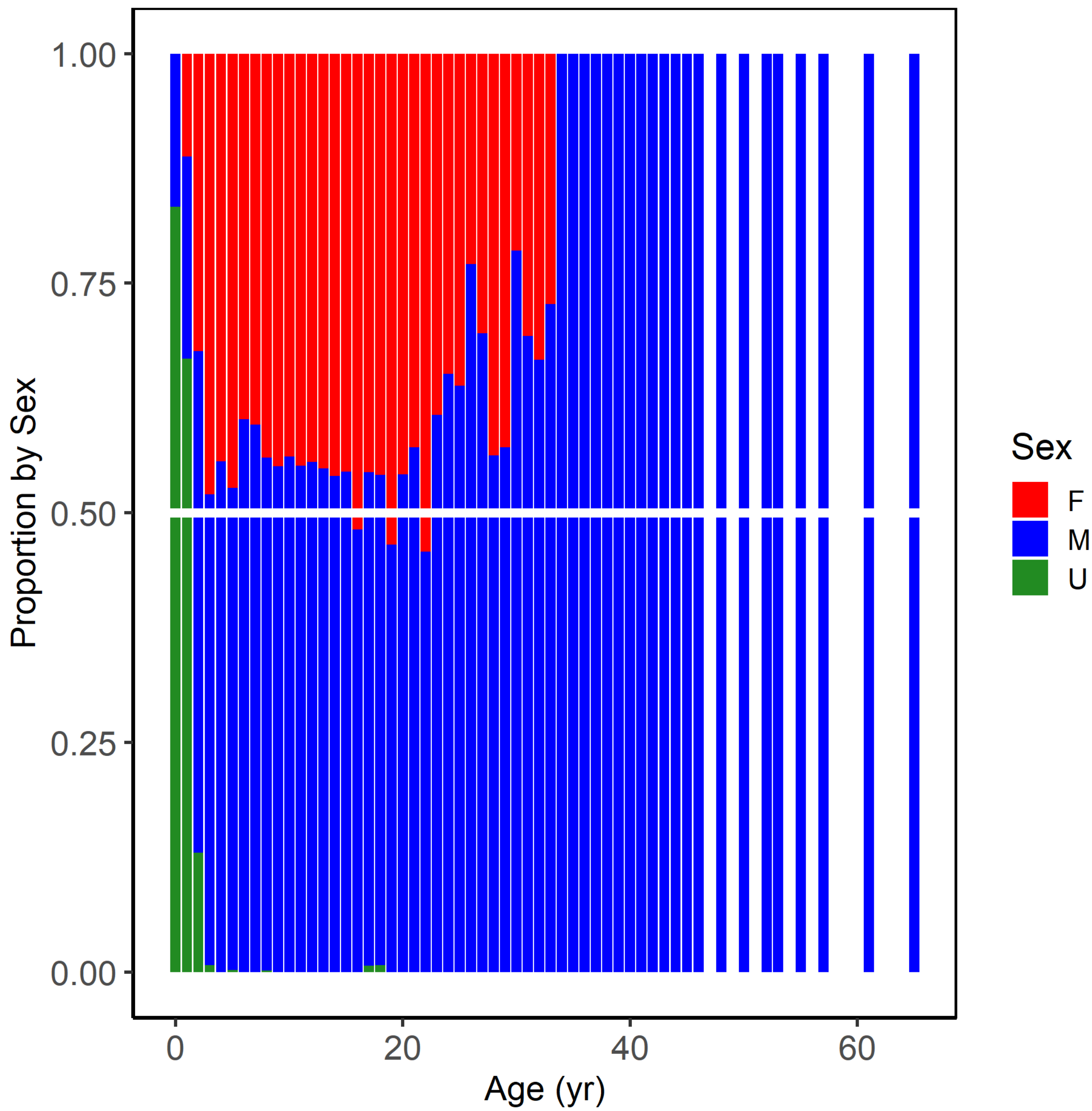

Figure 35: Sex ratio by age in the WCGBTS for females (red), males (blue) and unsexed (green).

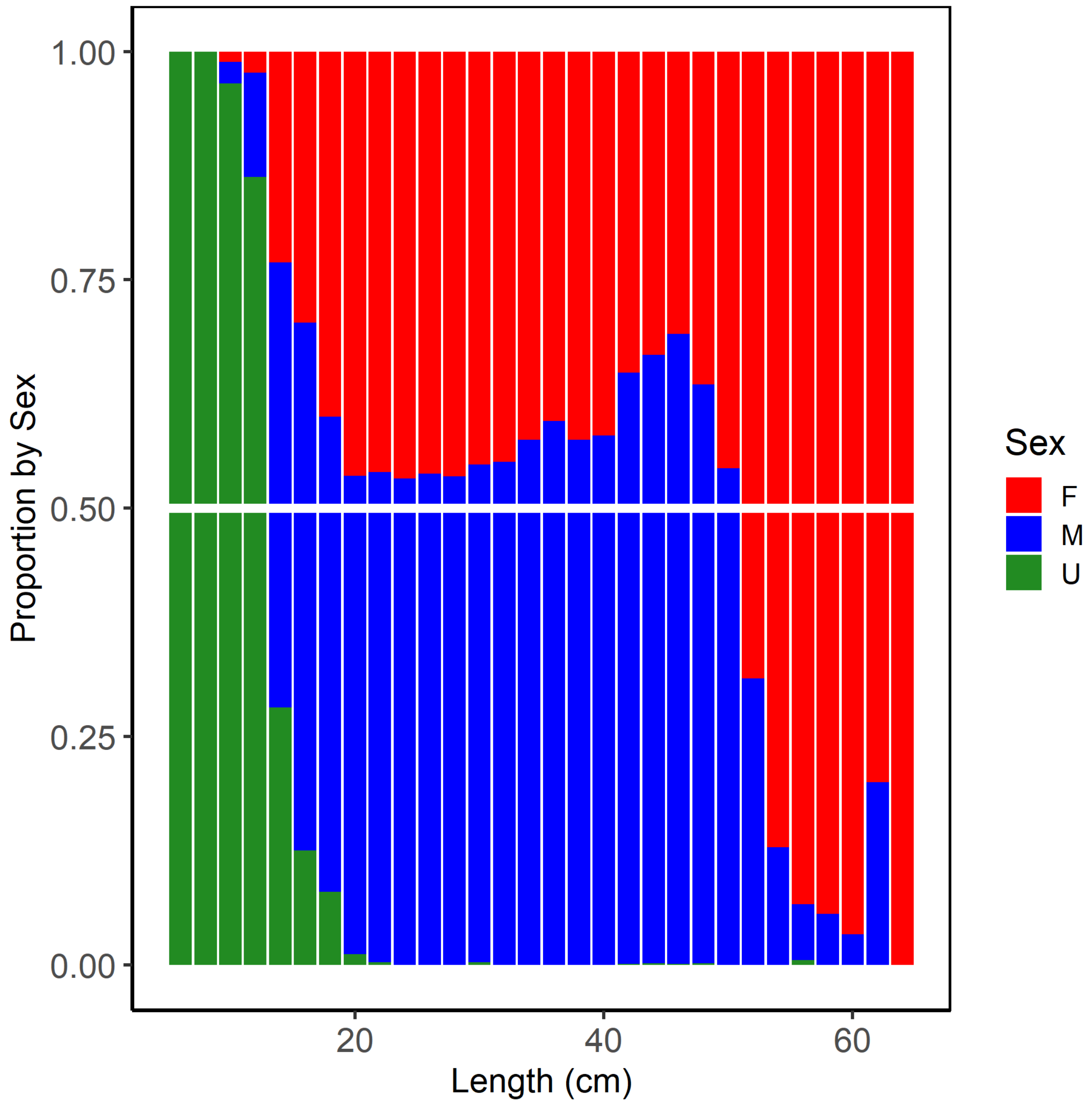

Figure 36: Sex ratio by length in the WCGBTS for females (red), males (blue) and unsexed (green).

8.2 Model bridging

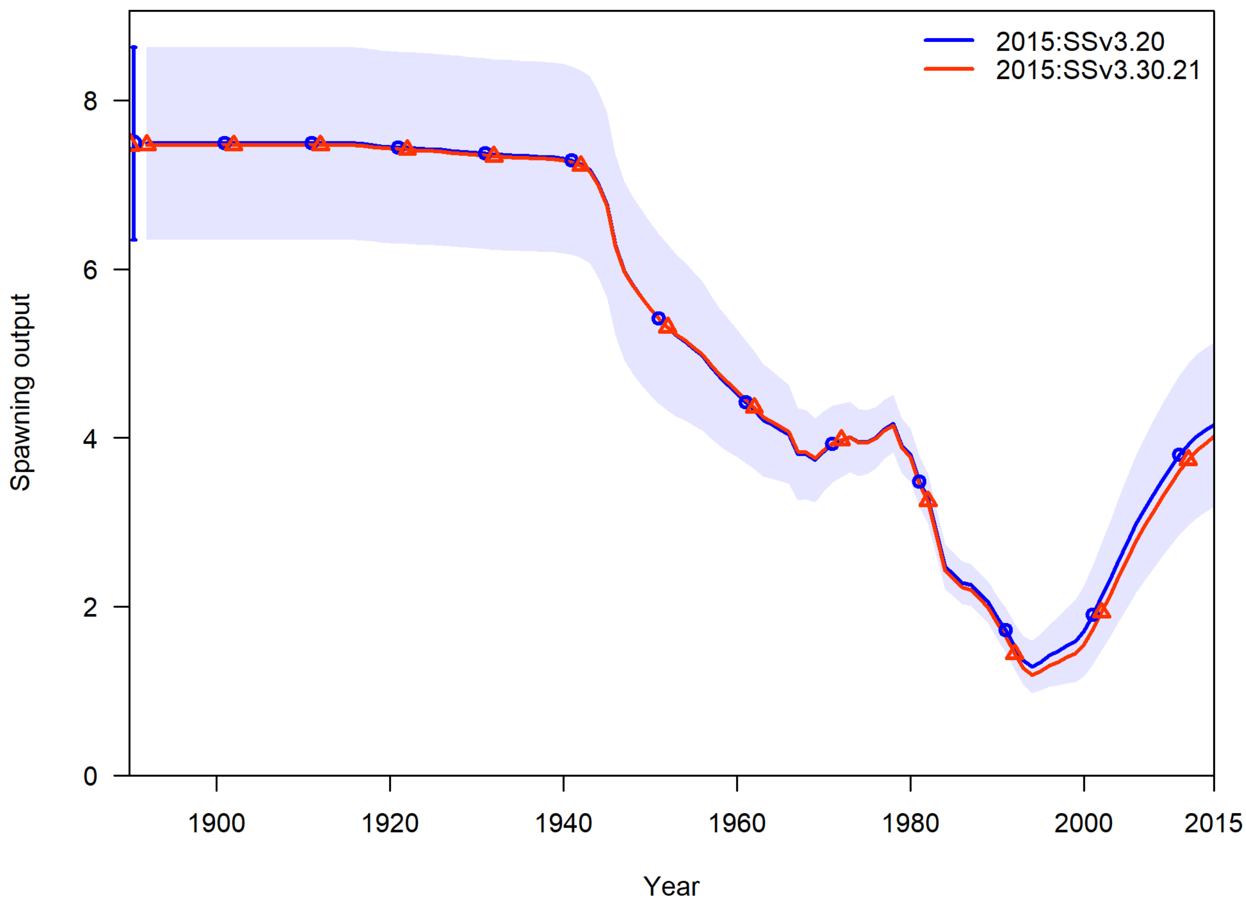

Figure 37: Model version bridge comparison of estimated spawning output of the 2015 assessment.

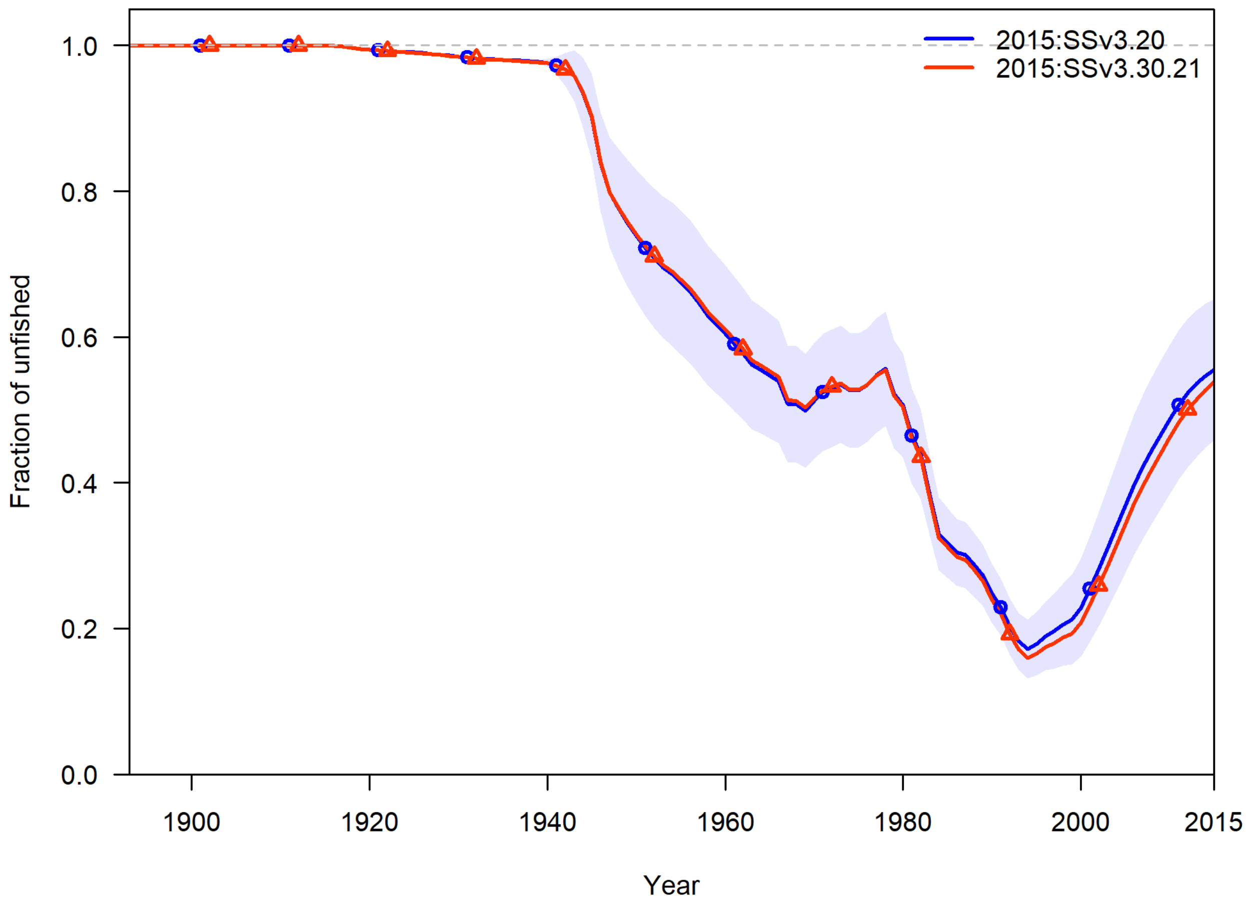

Figure 38: Model version bridge comparison of estimated spawning output relative to unfished of the 2015 assessment.

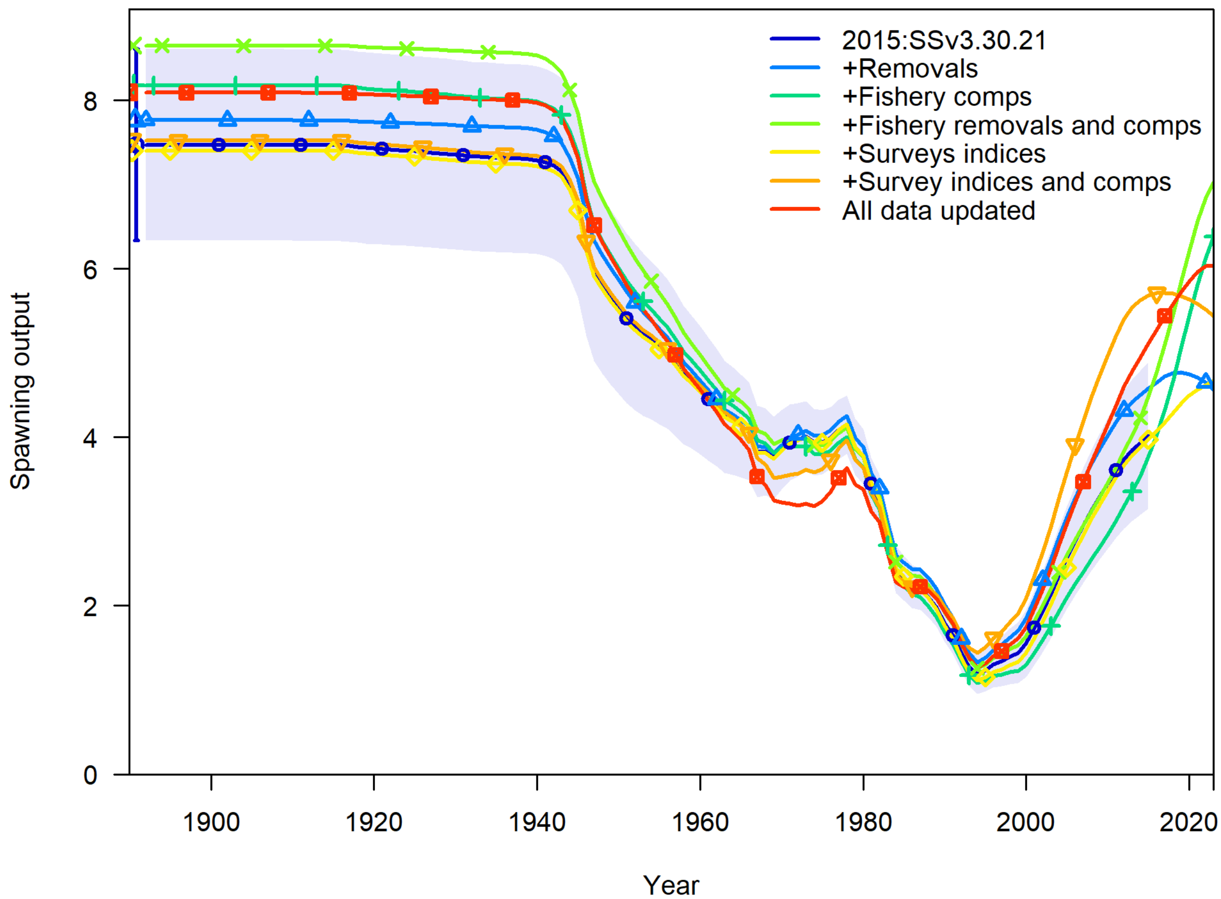

Figure 39: Data bridge comparison of estimated spawning output. Each step is done individually from the updated 2015 model except the final one (All data), which combines across steps.

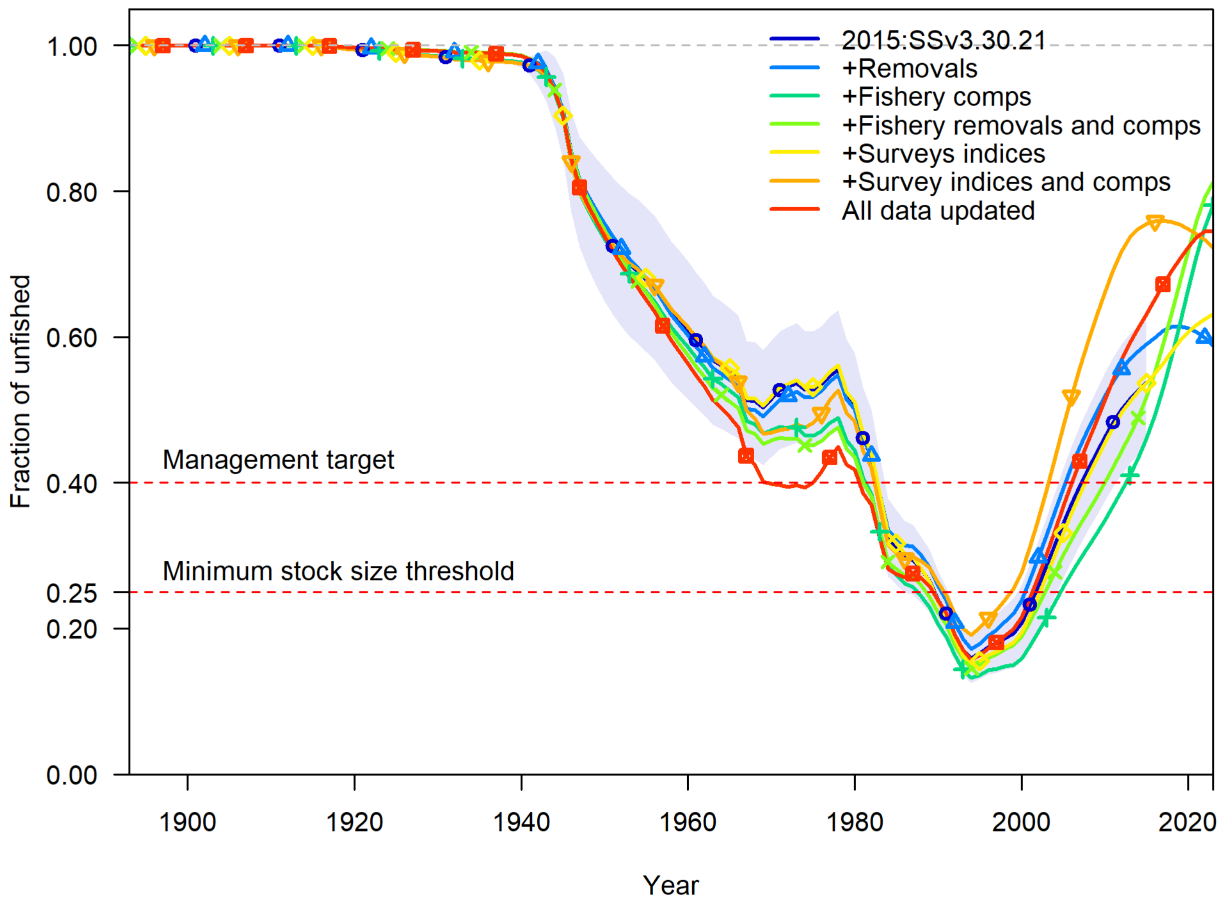

Figure 40: Data bridge comparison of estimated spawning output relative to unfished. Each step is done individually from the updated 2015 model except the final one (All data), which combines across steps.

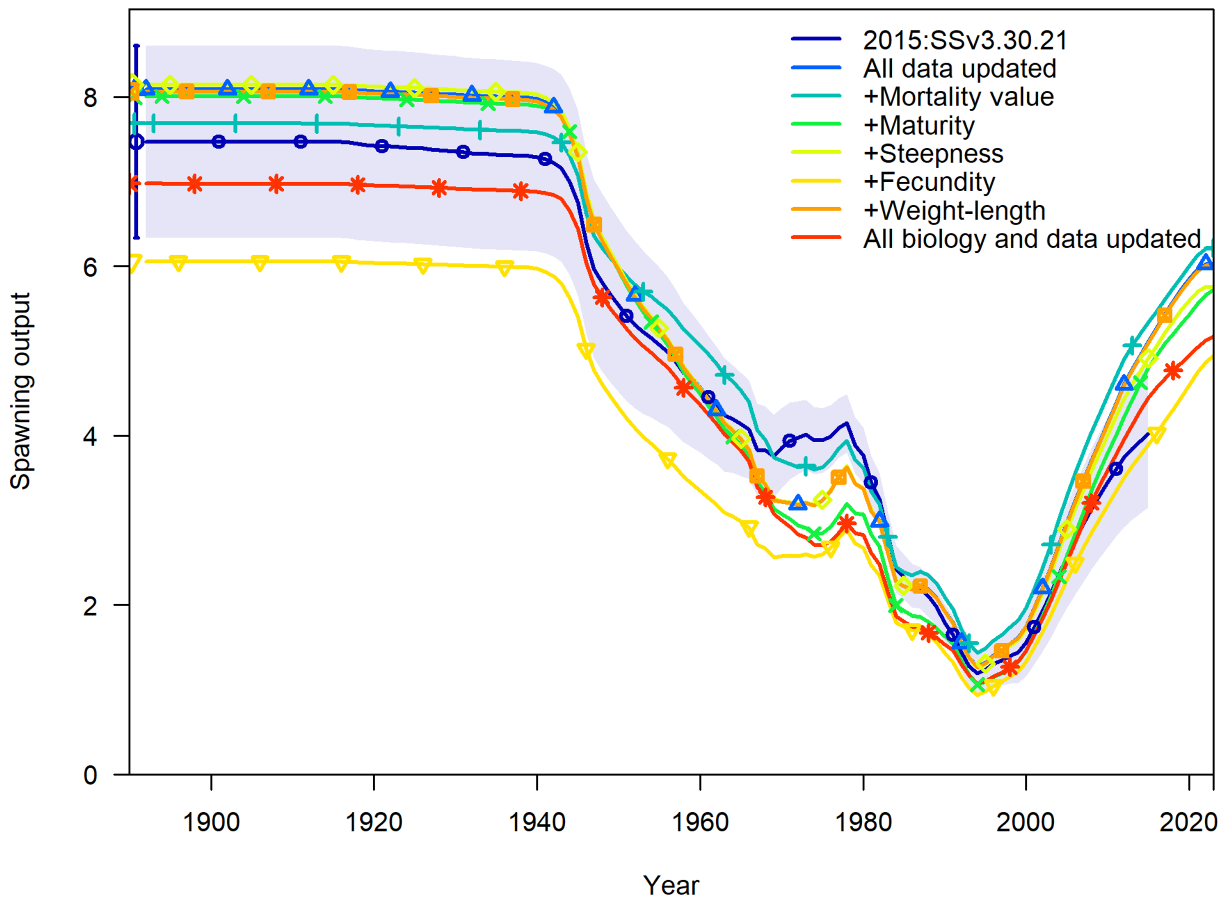

Figure 41: Life history parameters bridge comparison of estimated spawning output. Each step is done individually from the 'All data updated' model except the final one (All biology and data), which combines across steps.

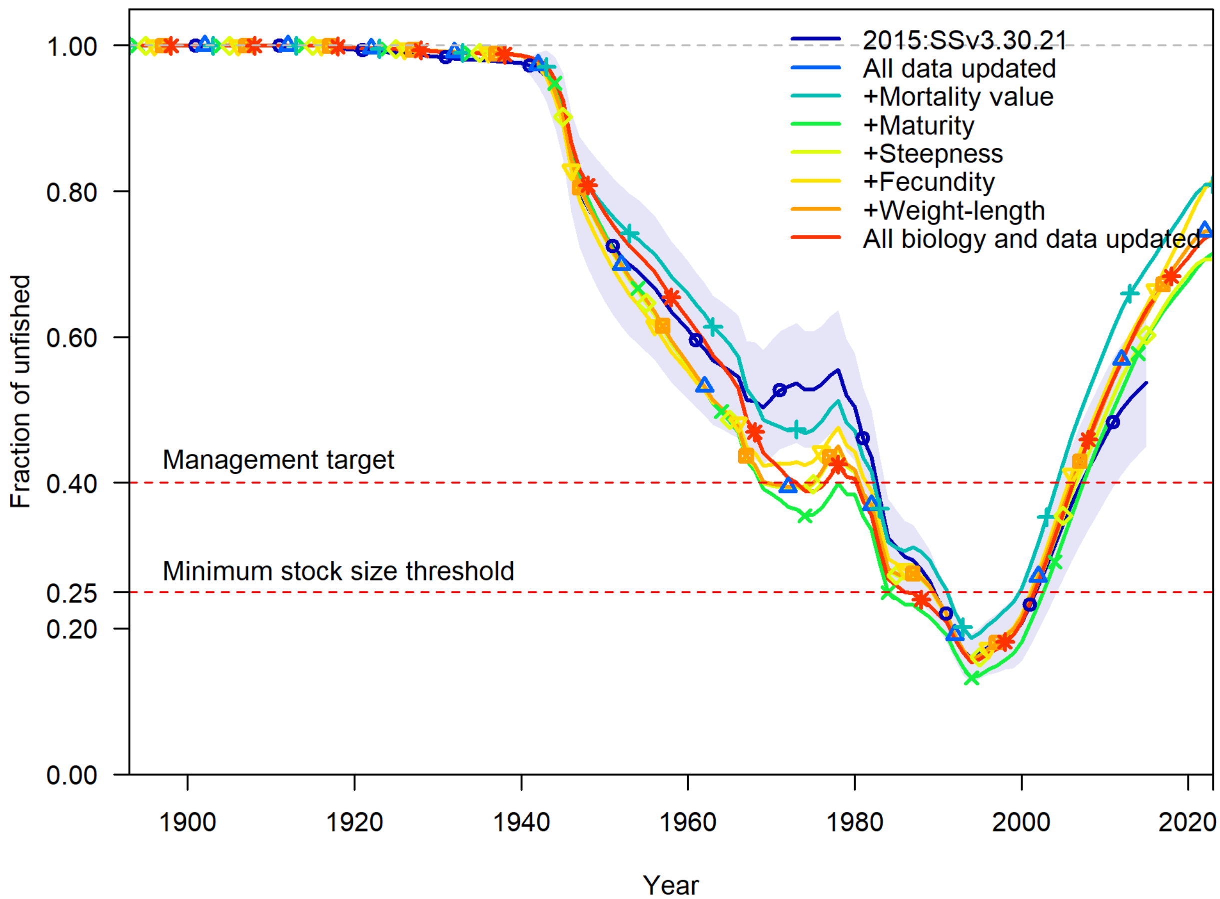

Figure 42: Life history parameters bridge comparison of estimated spawning output relative to unfished. Each step is done individually from the 'All data updated' model except the final one (All biology and data), which combines across steps.

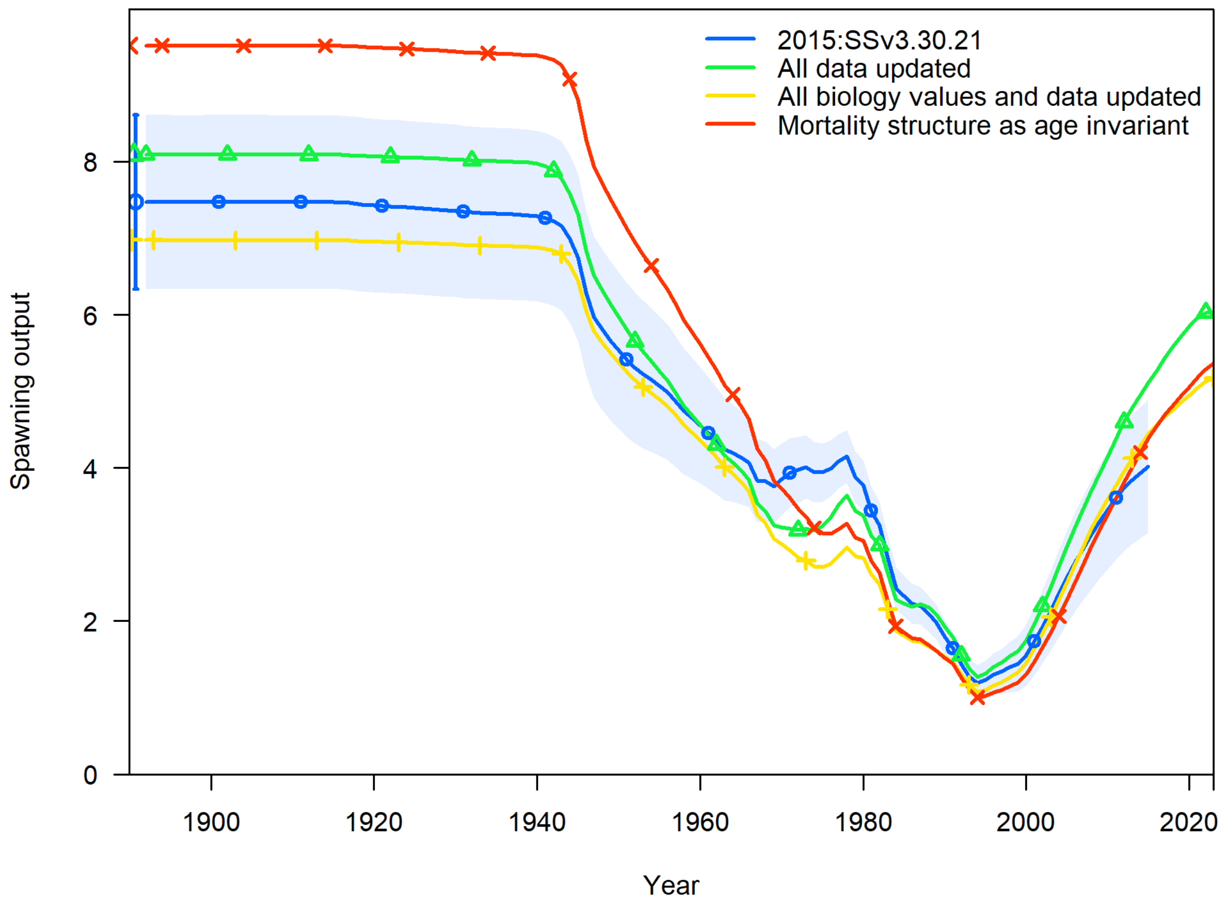

Figure 43: Bridge comparison of estimated spawning output when updating the structure of natural mortality. Each step is done cumulatively from the previous model.

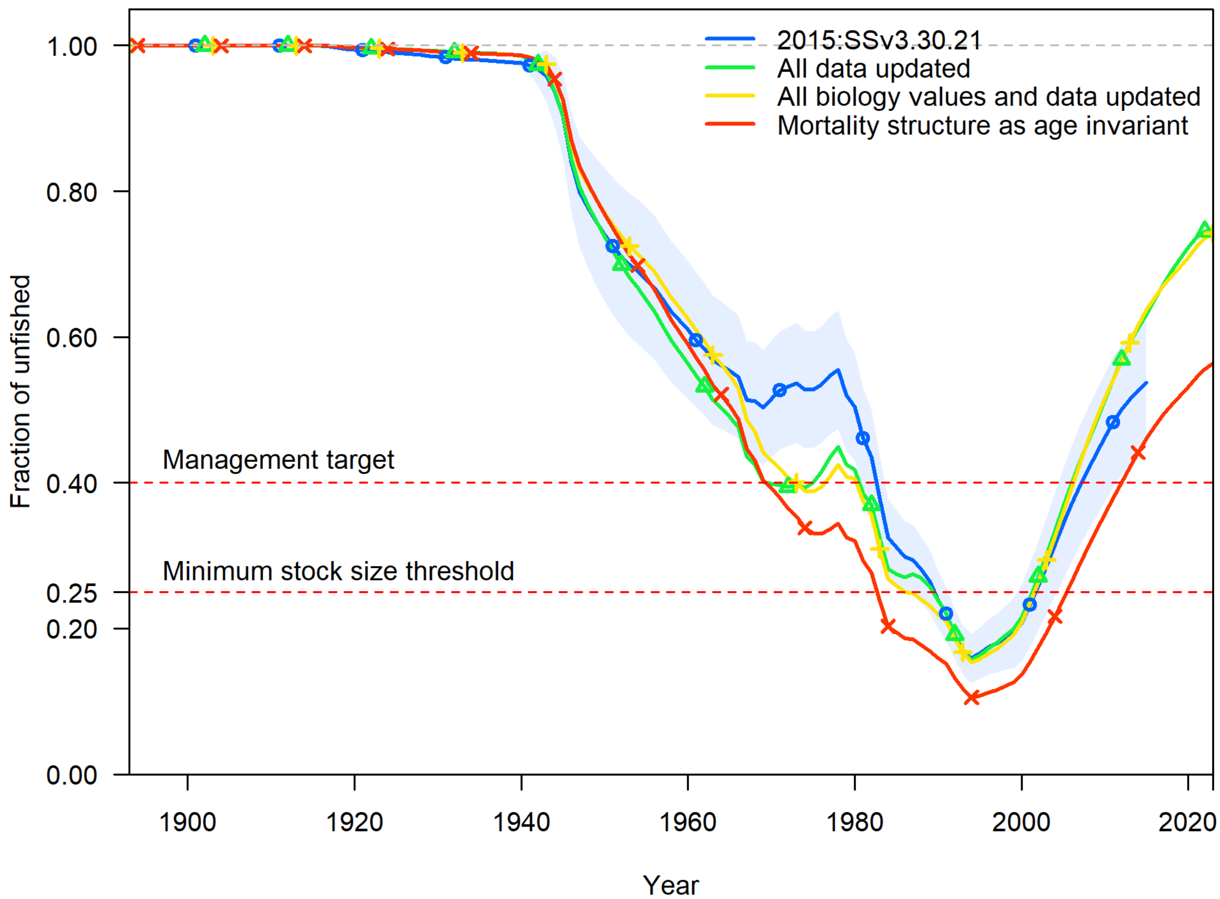

Figure 44: Bridge comparison of estimated spawning output relative to unfished when updating the structure of natural mortality. Each step is done cumulatively from the previous model.

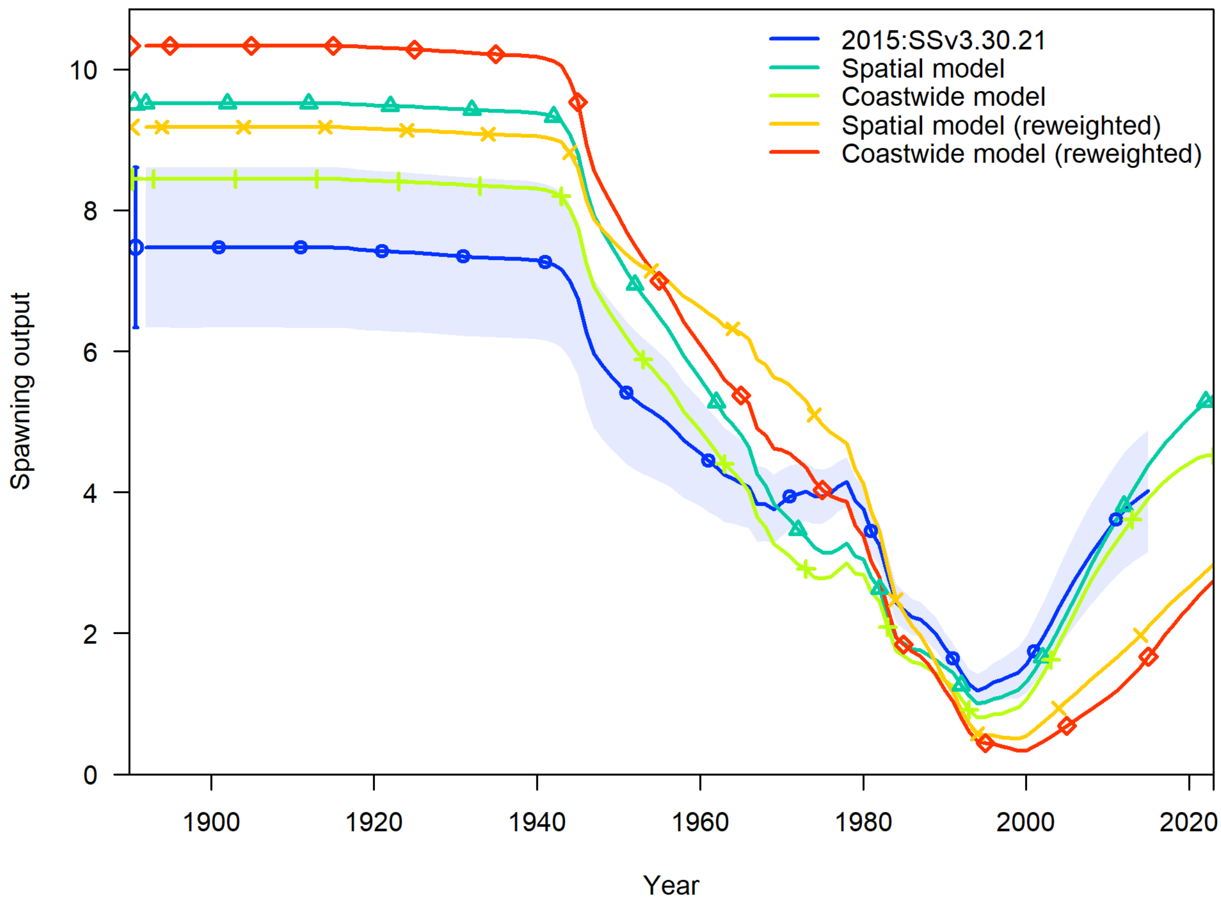

Figure 45: Spatial population structure and data reweighting bridge comparisons of estimated spawning output.

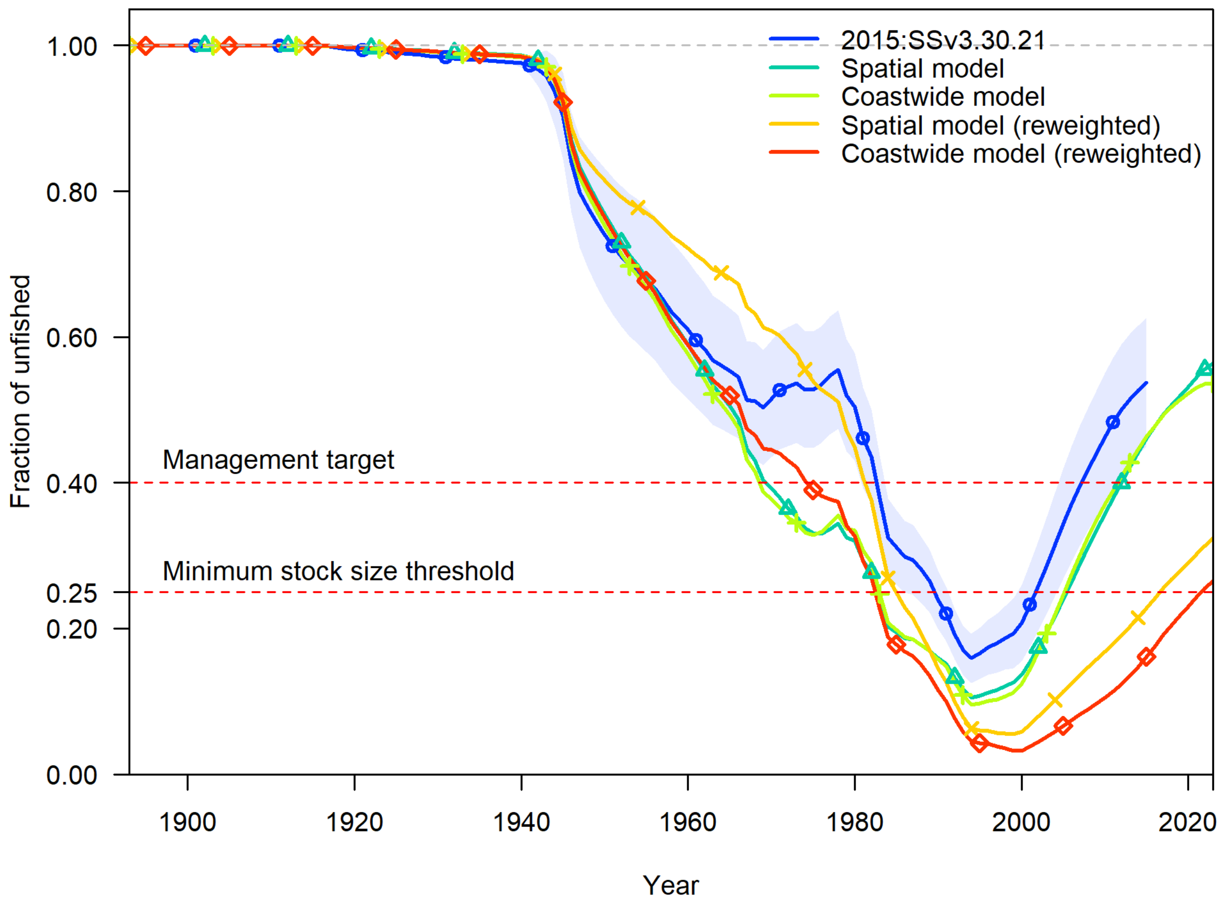

Figure 46: Spatial population structure and data reweighting bridge comparisons of estimated spawning output relative to unfished.

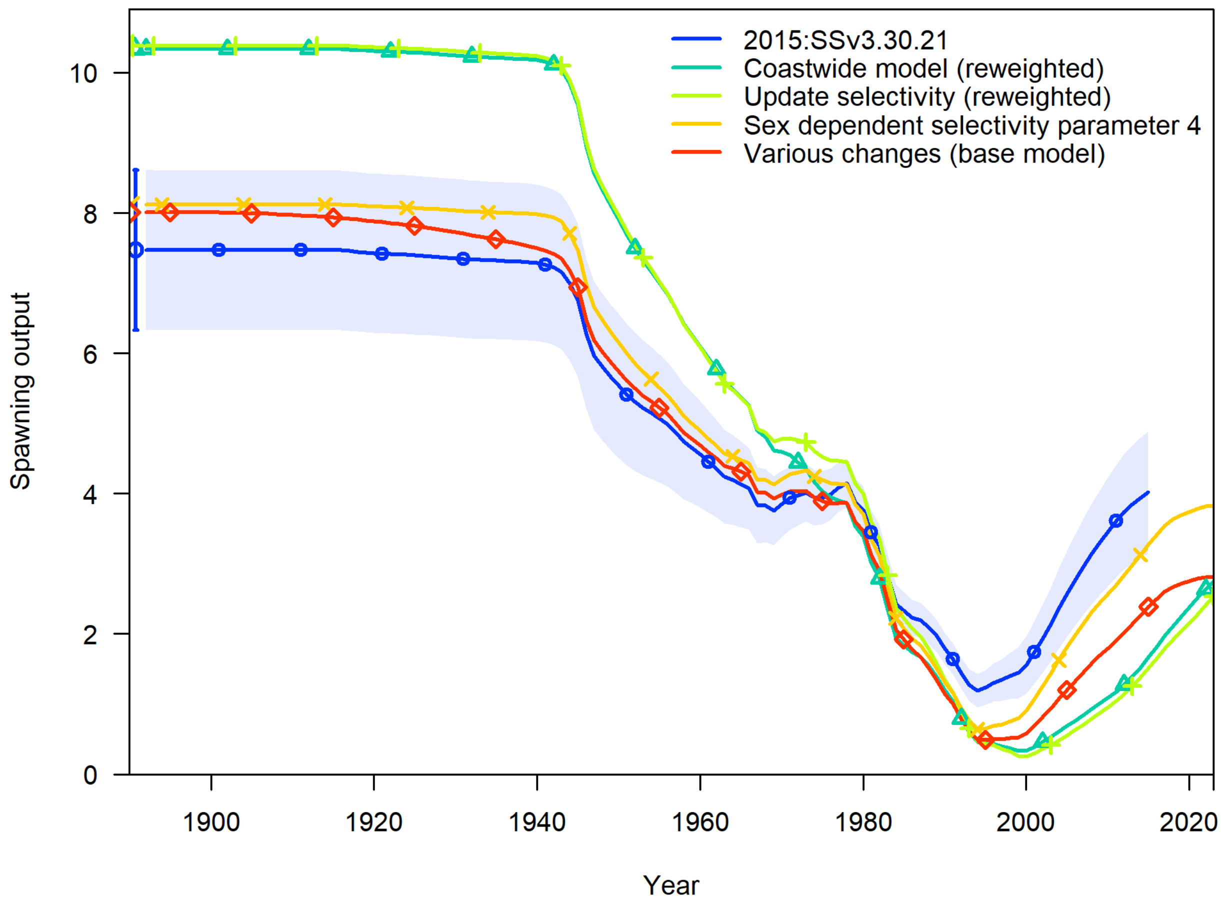

Figure 47: Selectivity bridge comparisons of estimated spawning output. Each step after the 'Coastwide model' is done cumulatively from the previous model.

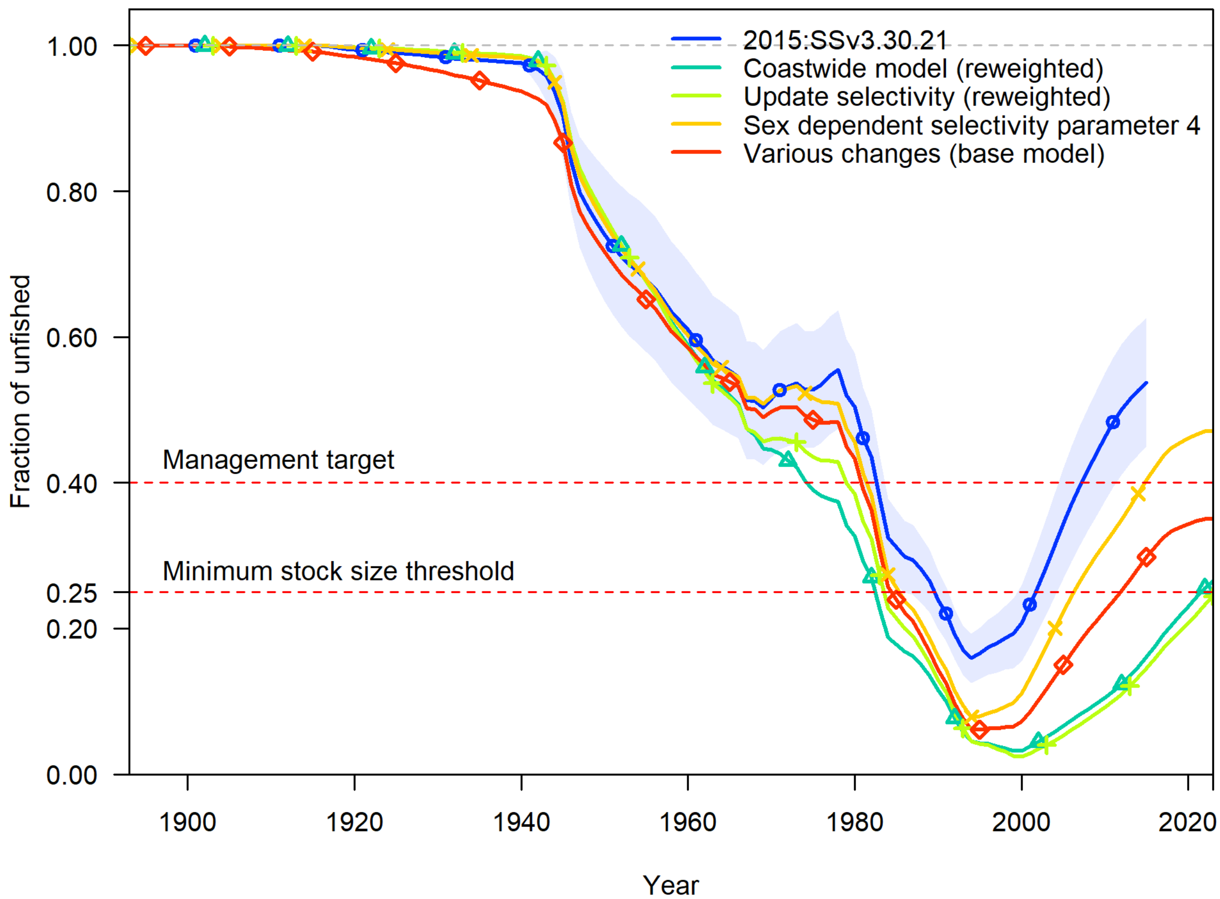

Figure 48: Selectivity bridge comparisons of estimated spawning output relative to unfished. Each step after the 'Coastwide model' is done cumulatively from the previous model.

8.3 Model results

8.3.1 Estimated growth

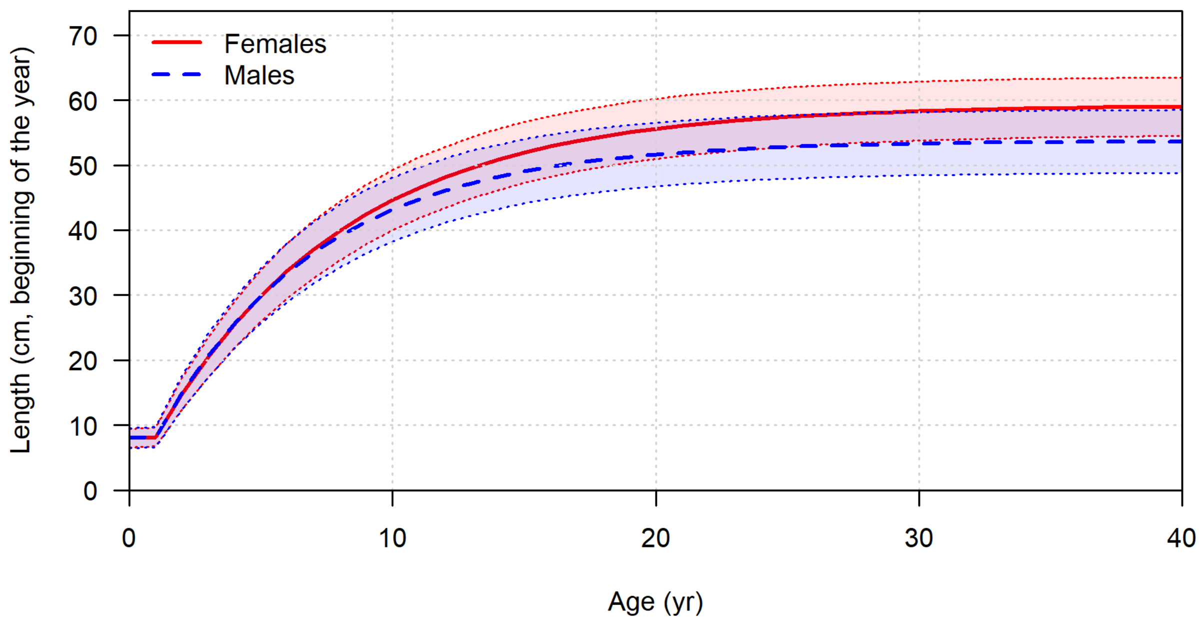

Figure 49: Model estimated length-at-age in the beginning of the year. Shaded area indicates 95 percent distribution of length-at-age around the estimated growth curve.

8.3.2 Selectivity

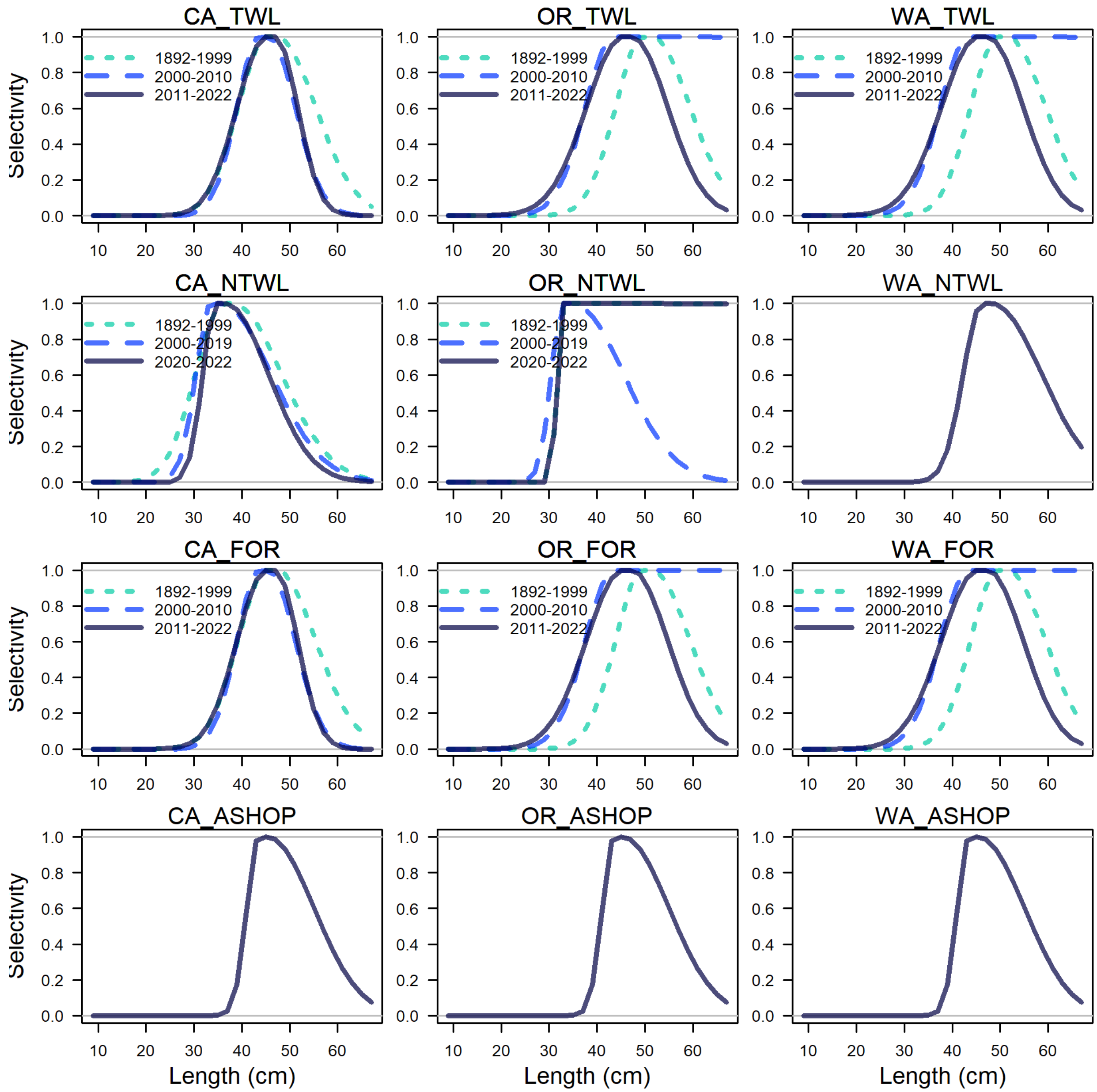

Figure 50: Selectivity curves for commercial fleets over time for females. If only one curve is included for a fleet it is applied over all years.

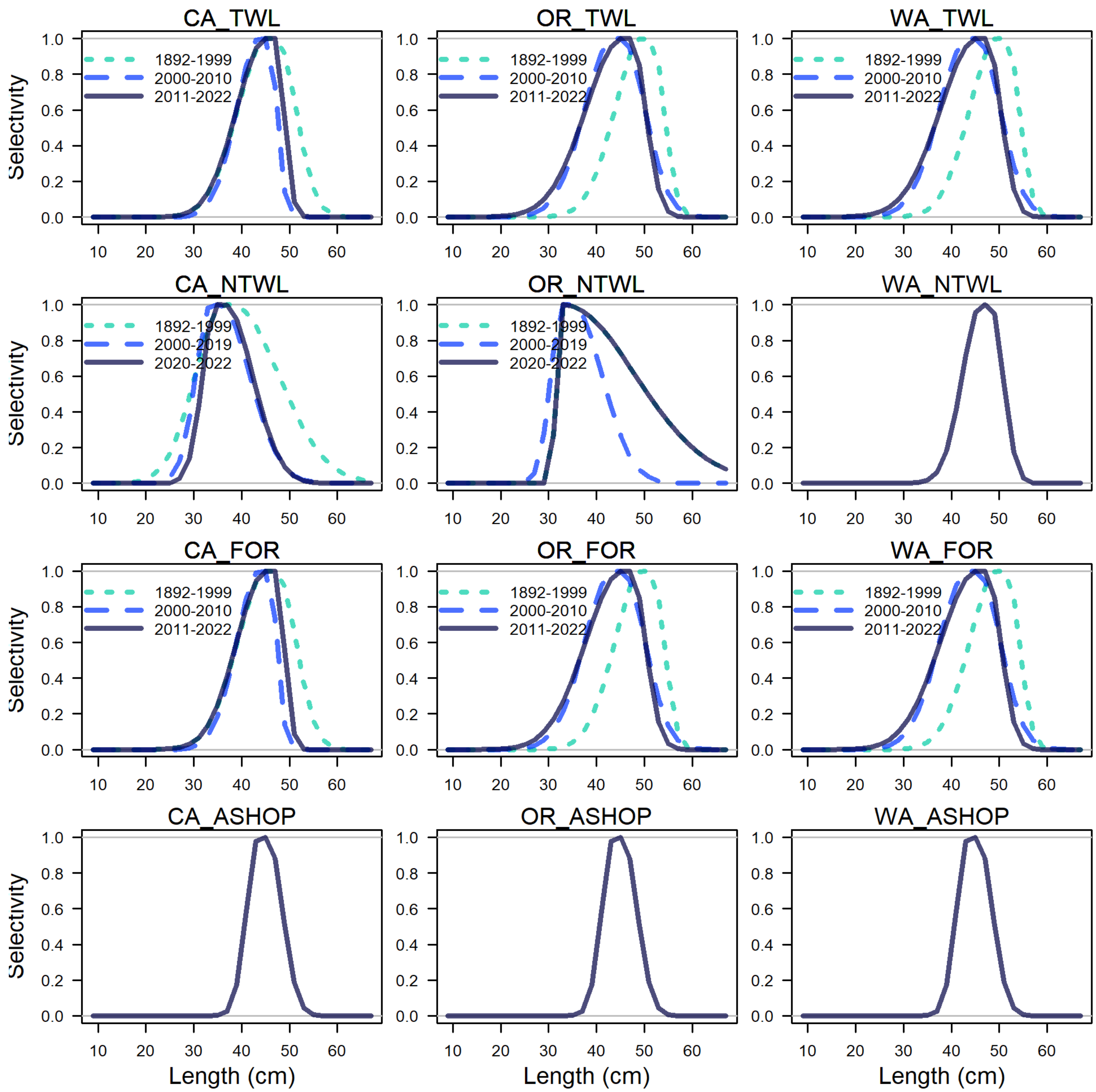

Figure 51: Selectivity curves for commercial fleets over time for males. If only one curve is included for a fleet it is applied over all years.

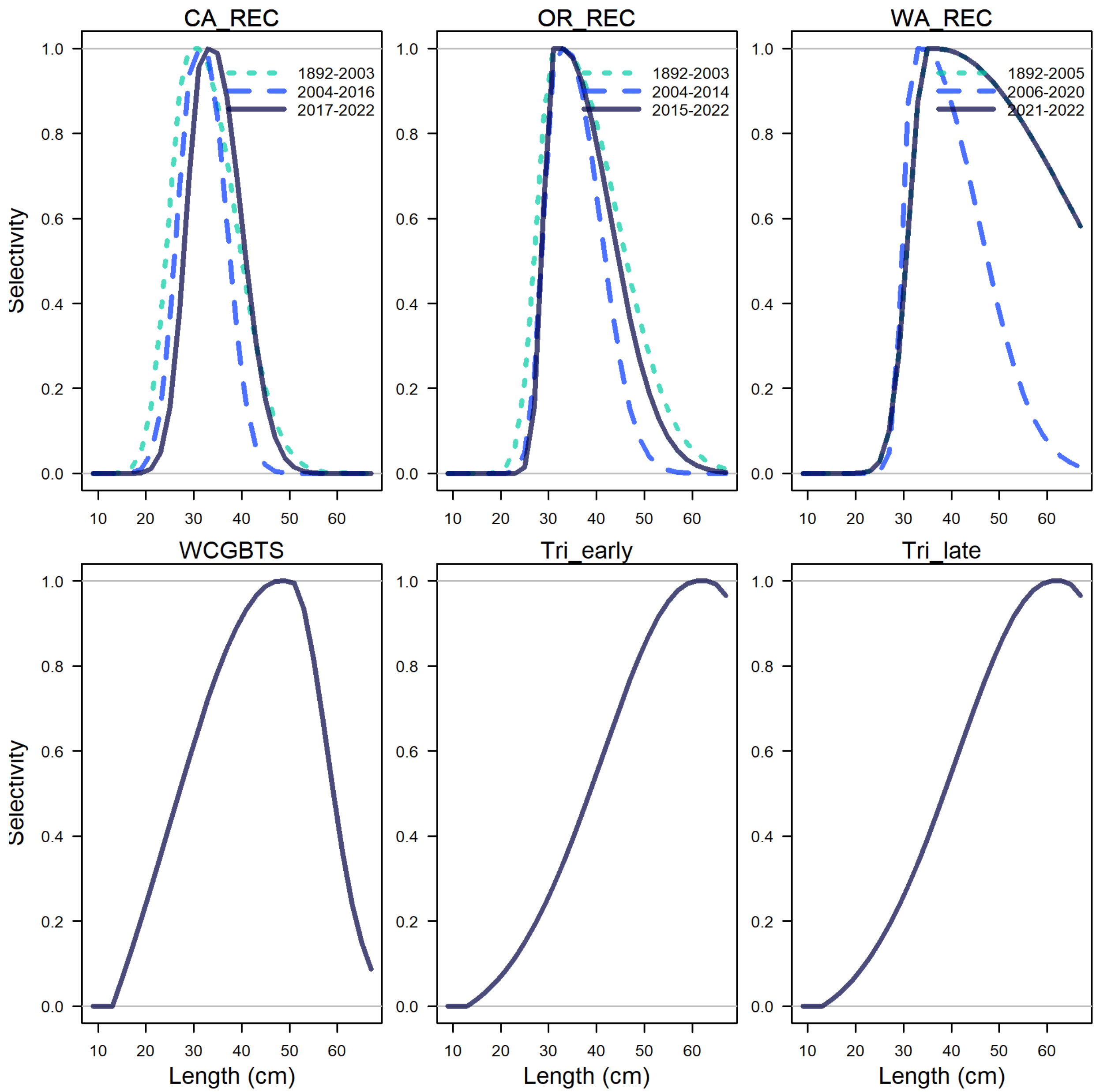

Figure 52: Selectivity curves for recreational and survey fleets over time for females. If only one curve is included for a fleet it is applied over all years.

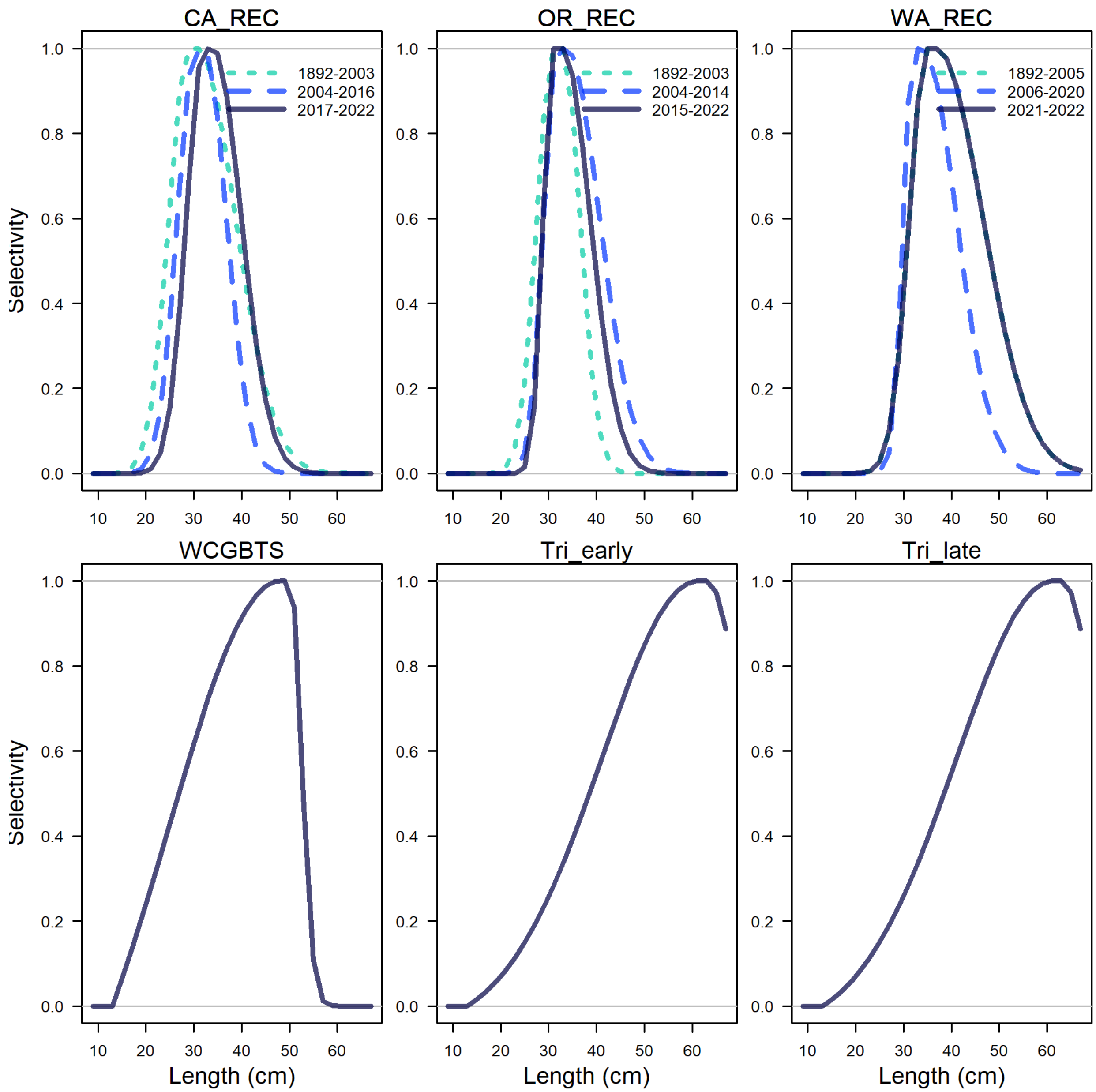

Figure 53: Selectivity curves for recreational and survey fleets over time for males. If only one curve is included for a fleet it is applied over all years.

8.3.3 Recruitment

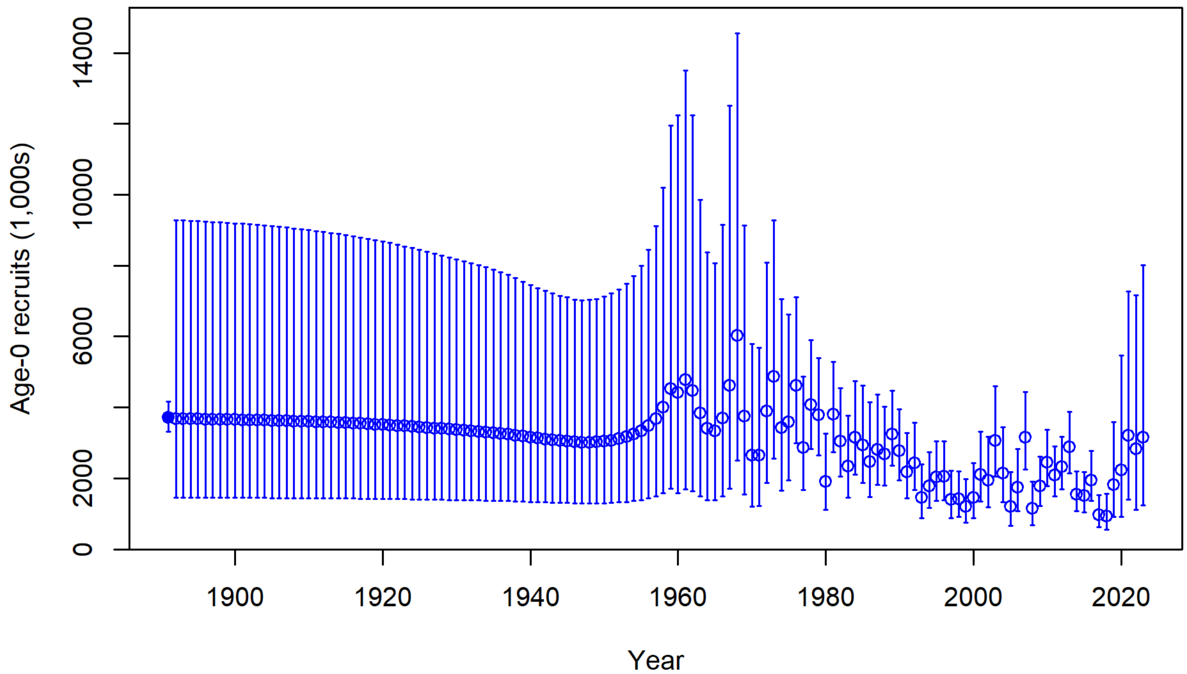

Figure 54: Estimated time series of age-0 recruits (1000s).

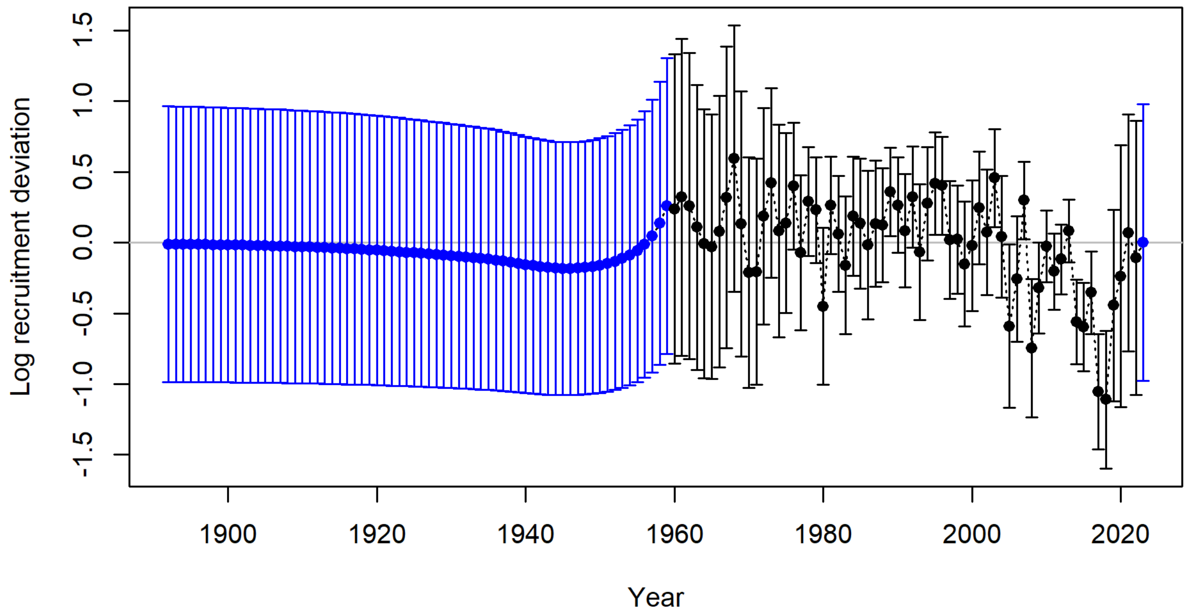

Figure 55: Estimated time series of recruitment deviations (circles) and 95 percent confidence intervals (whiskers) for the main recruitment deviations (black) and early or forecast deviations (blue).

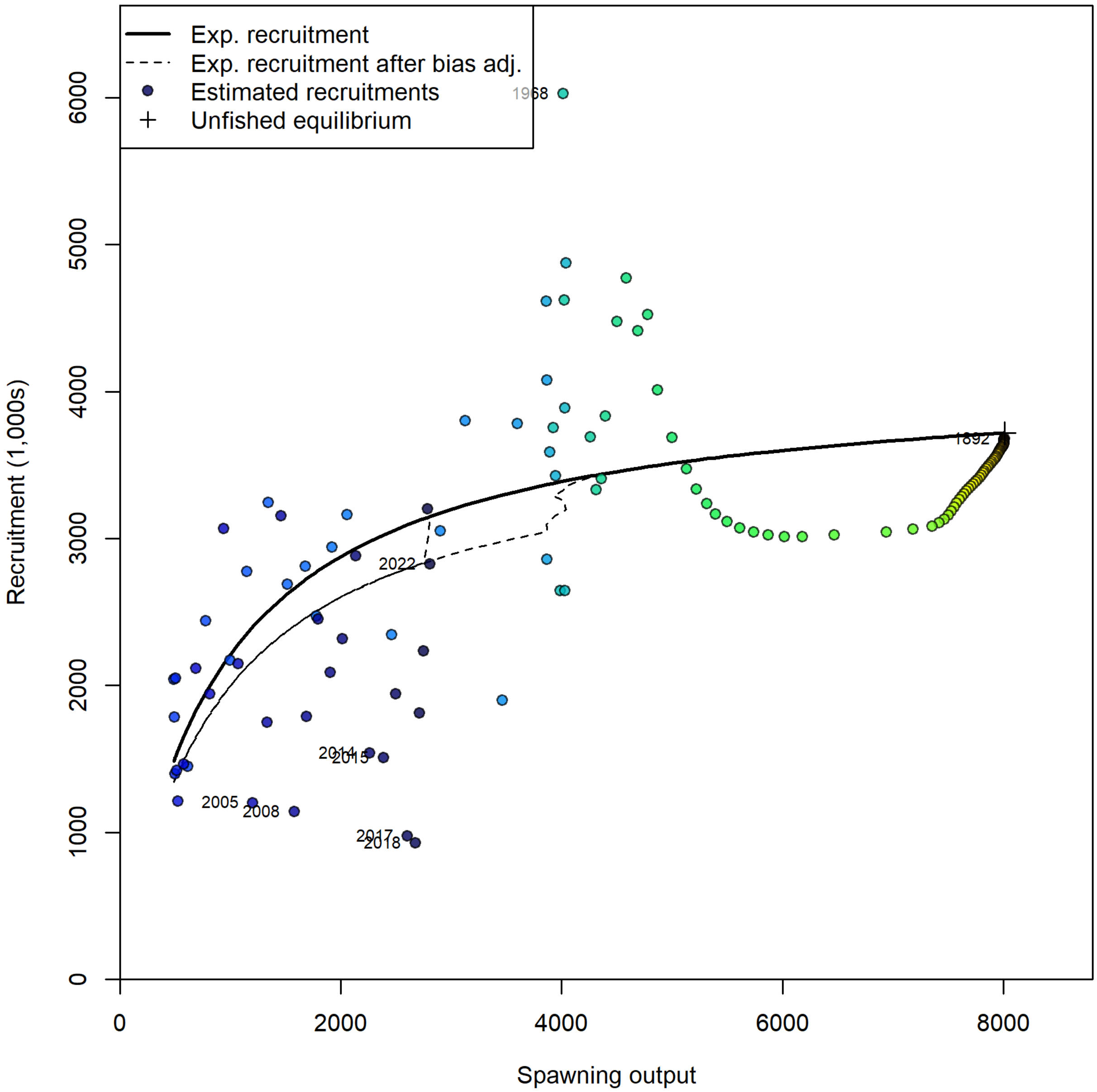

Figure 56: Stock-recruit curve with labels on first, last, and years with log-deviations greater than 0.50. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

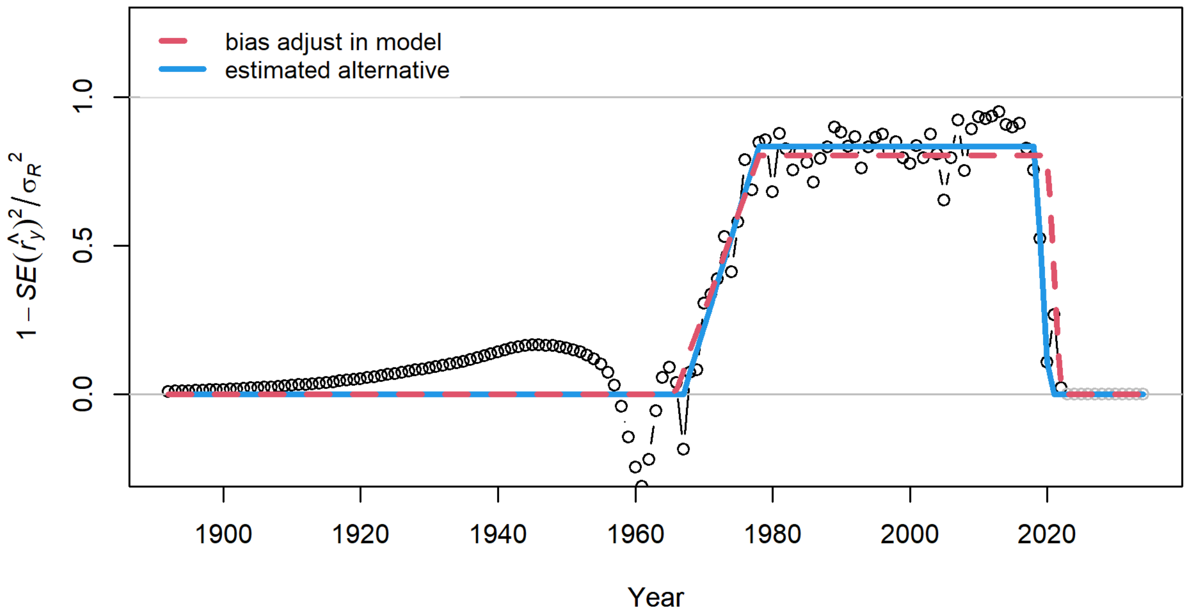

Figure 57: Points are transformed variances. Red line shows current settings for bias adjustment specified in control file. Blue line shows least squares estimate of alternative bias adjustment relationship for recruitment deviations.

8.3.4 Fits to data

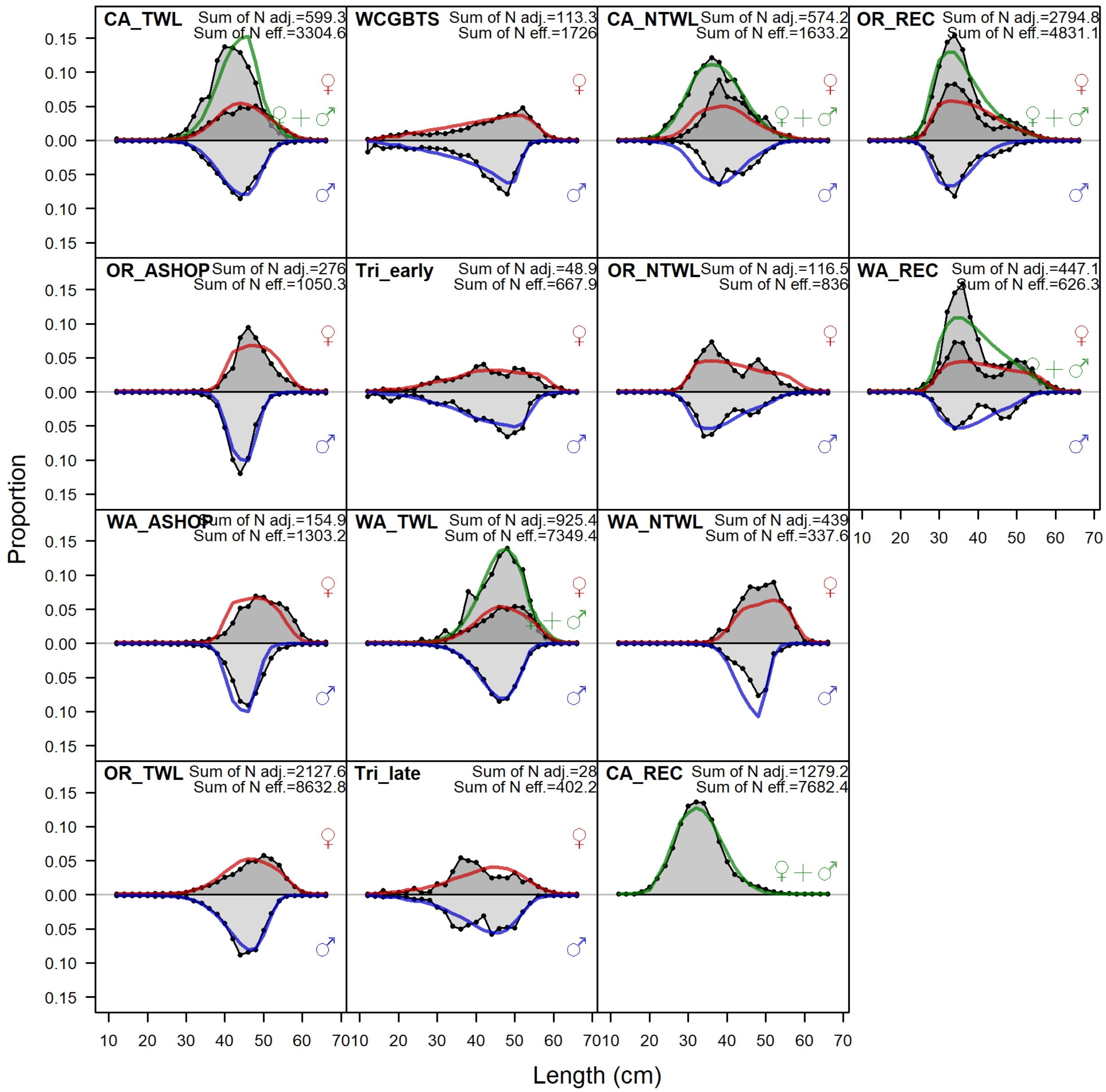

Figure 58: Length composition aggregated across years by fleet with the model estimated fit to the data by sex (green unsexed, red female, and blue male).

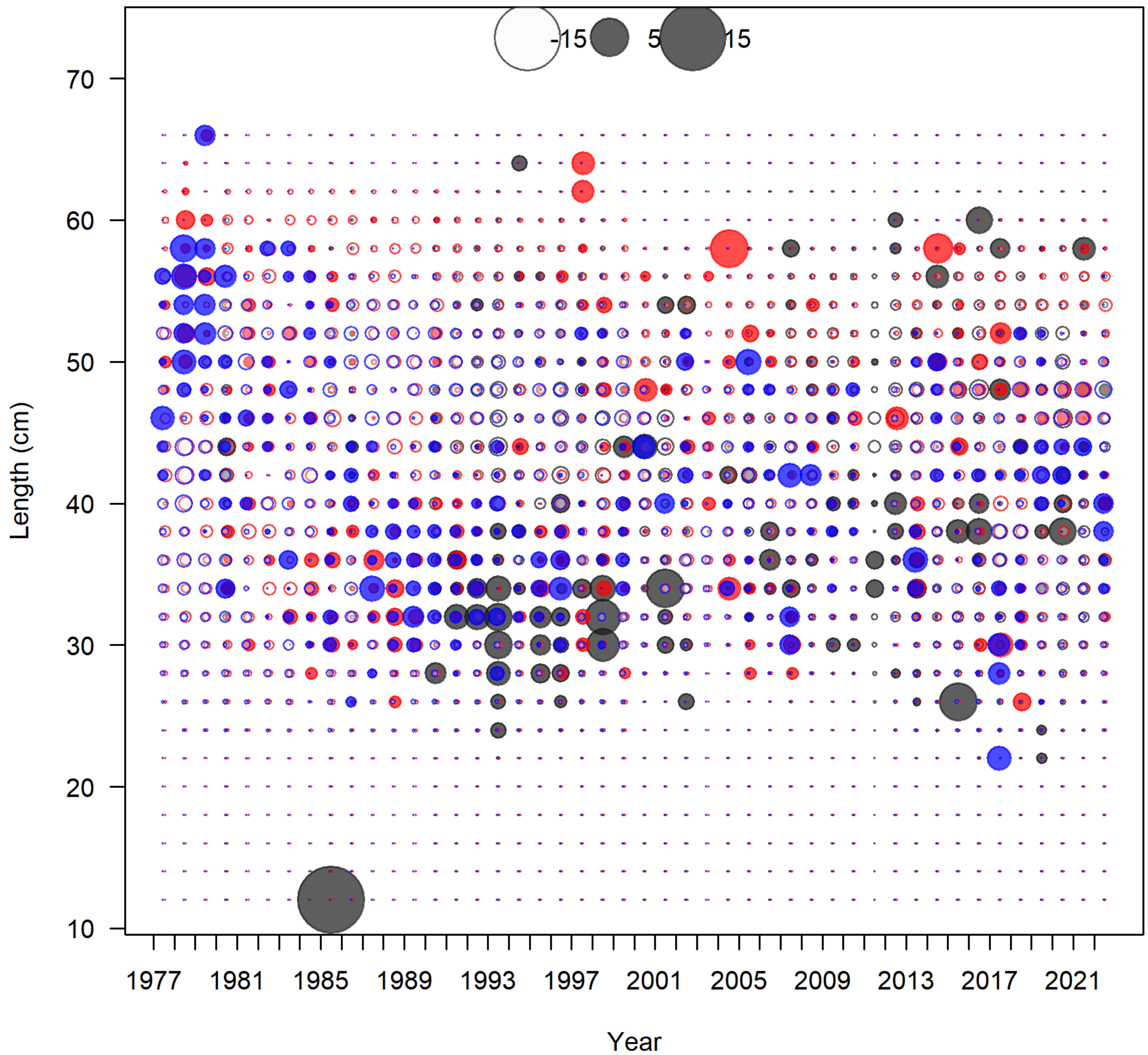

Figure 59: Pearson residuals for lengths in the California trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red), males (blue), and unsexed (black).

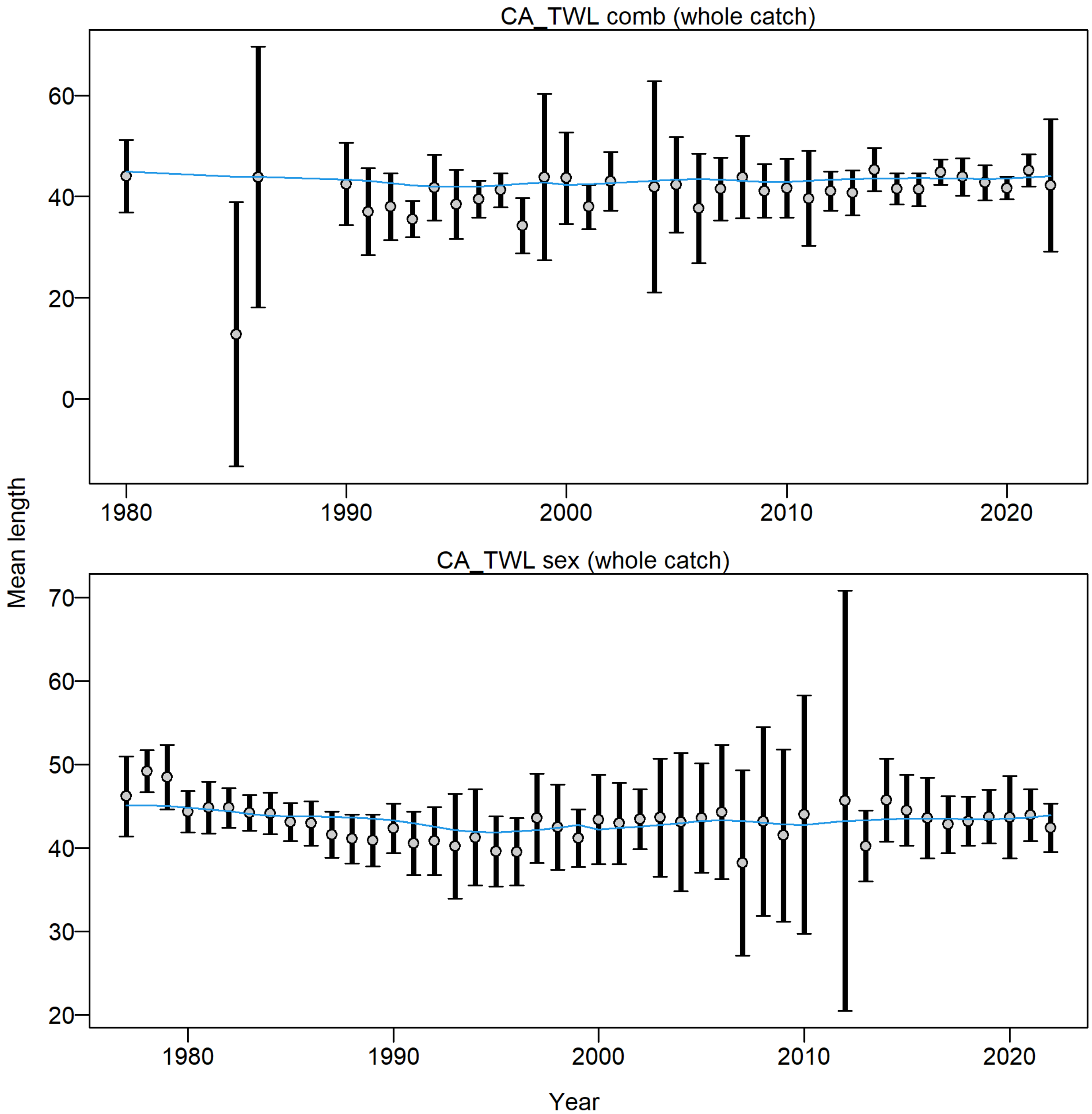

Figure 60: Mean length for the California trawl fleet with 95 percent confidence intervals based on current samples sizes for unsexed (top panel) and sexed (bottom panel) samples.

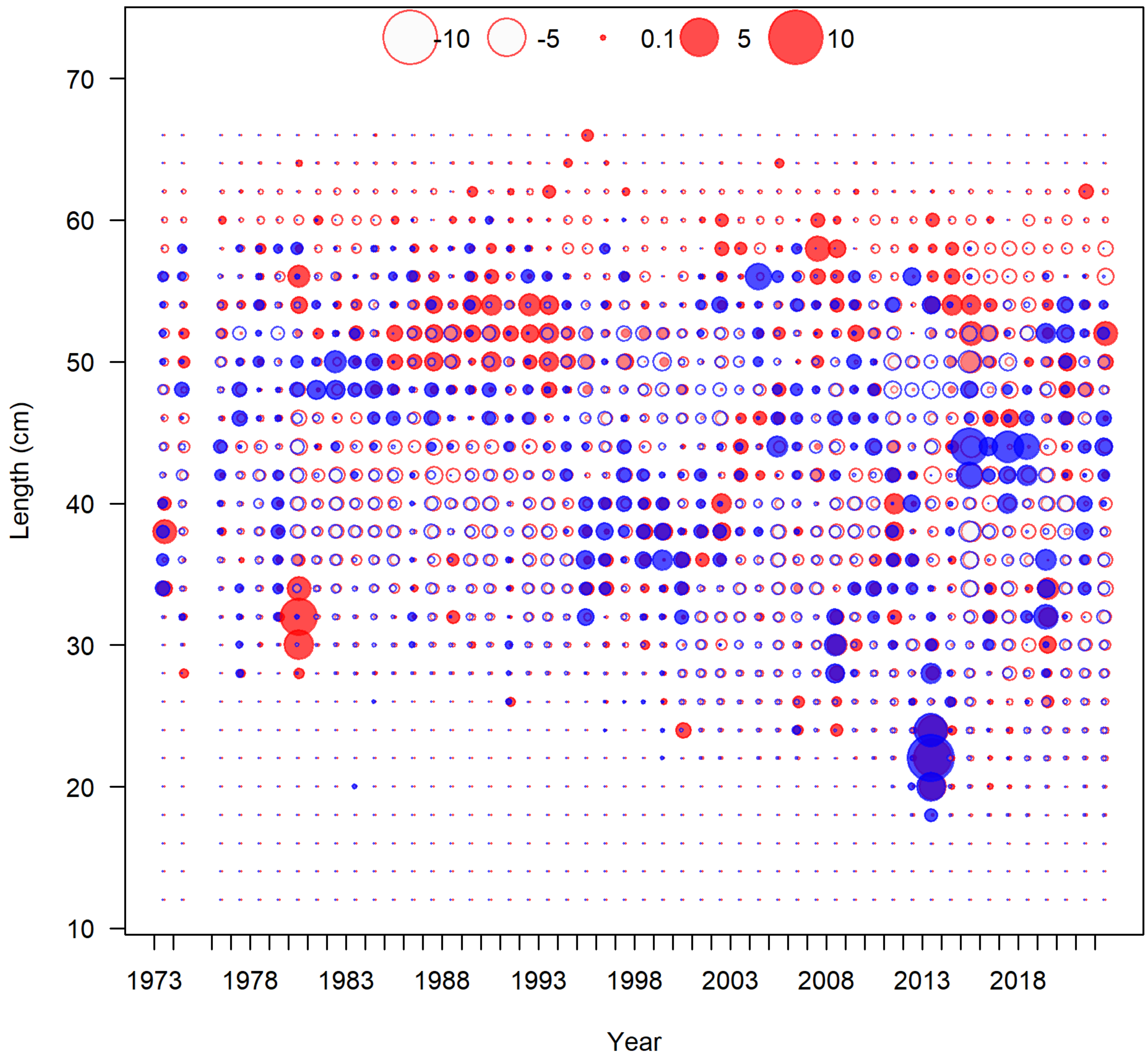

Figure 61: Pearson residuals for lengths in the Oregon trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected)for females (red) and males (blue).

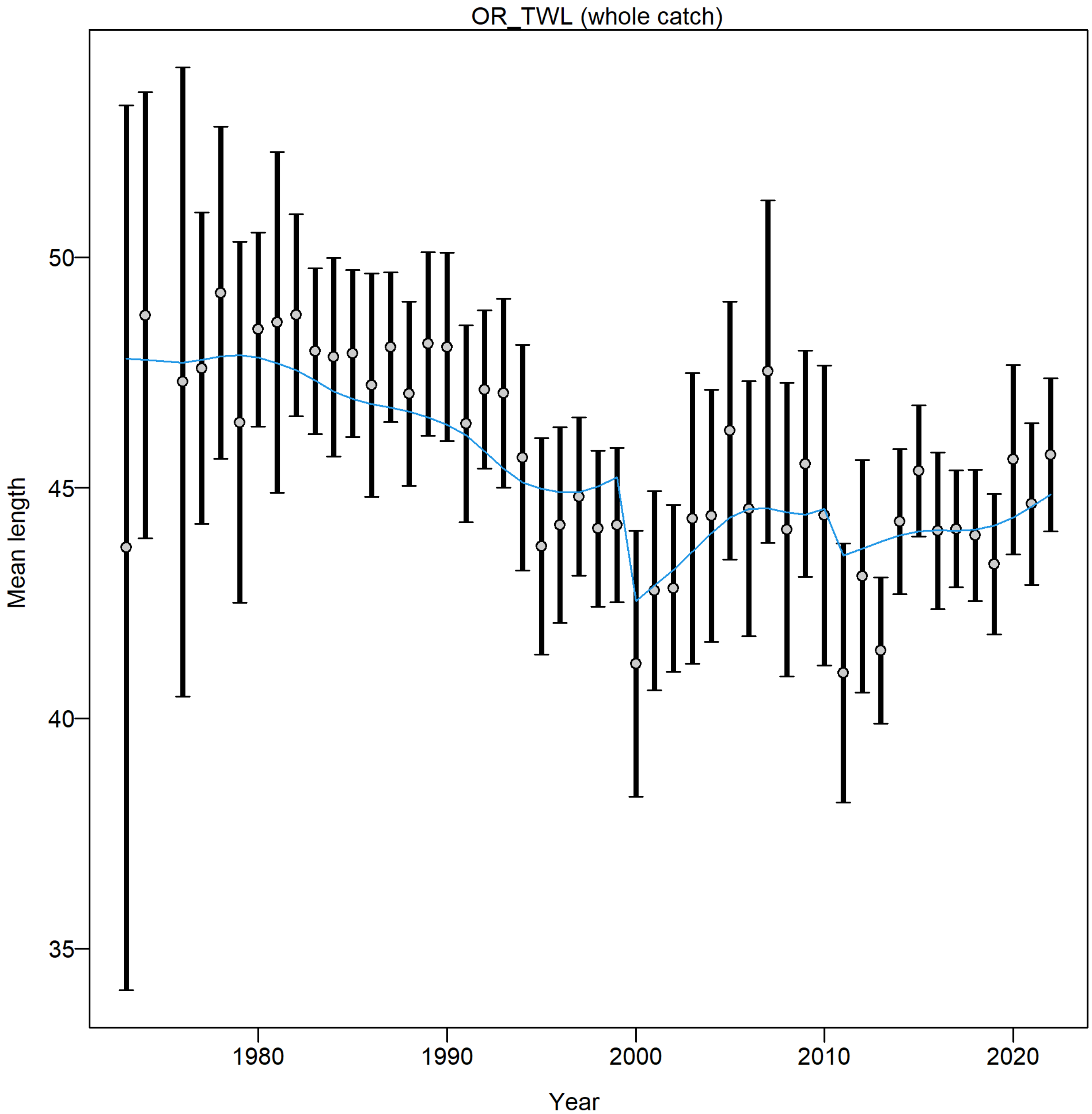

Figure 62: Mean length for the Oregon trawl fleet with 95 percent confidence intervals based on current samples sizes.

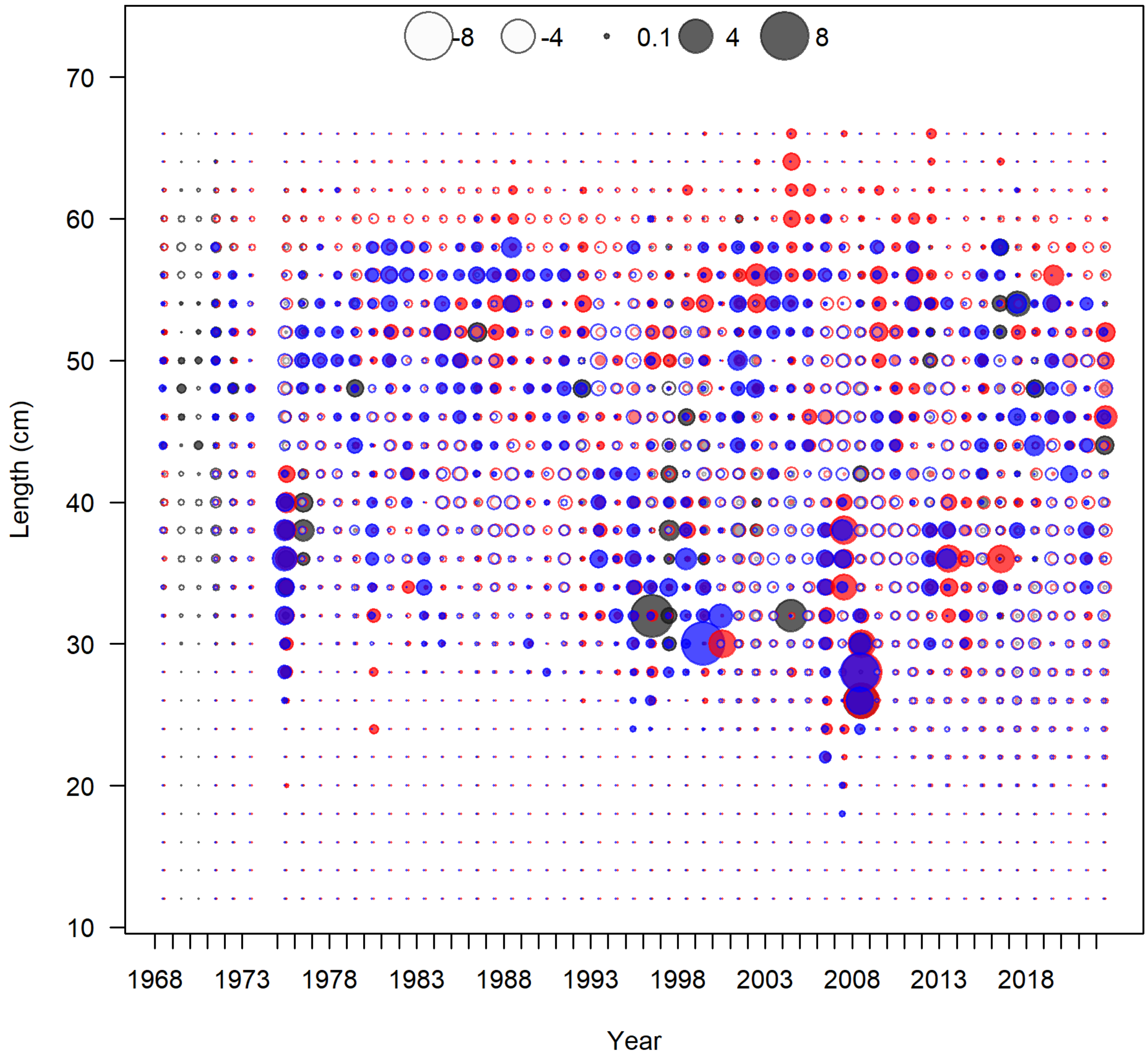

Figure 63: Pearson residuals for lengths in the Washington trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red), males (blue), and unsexed (black).

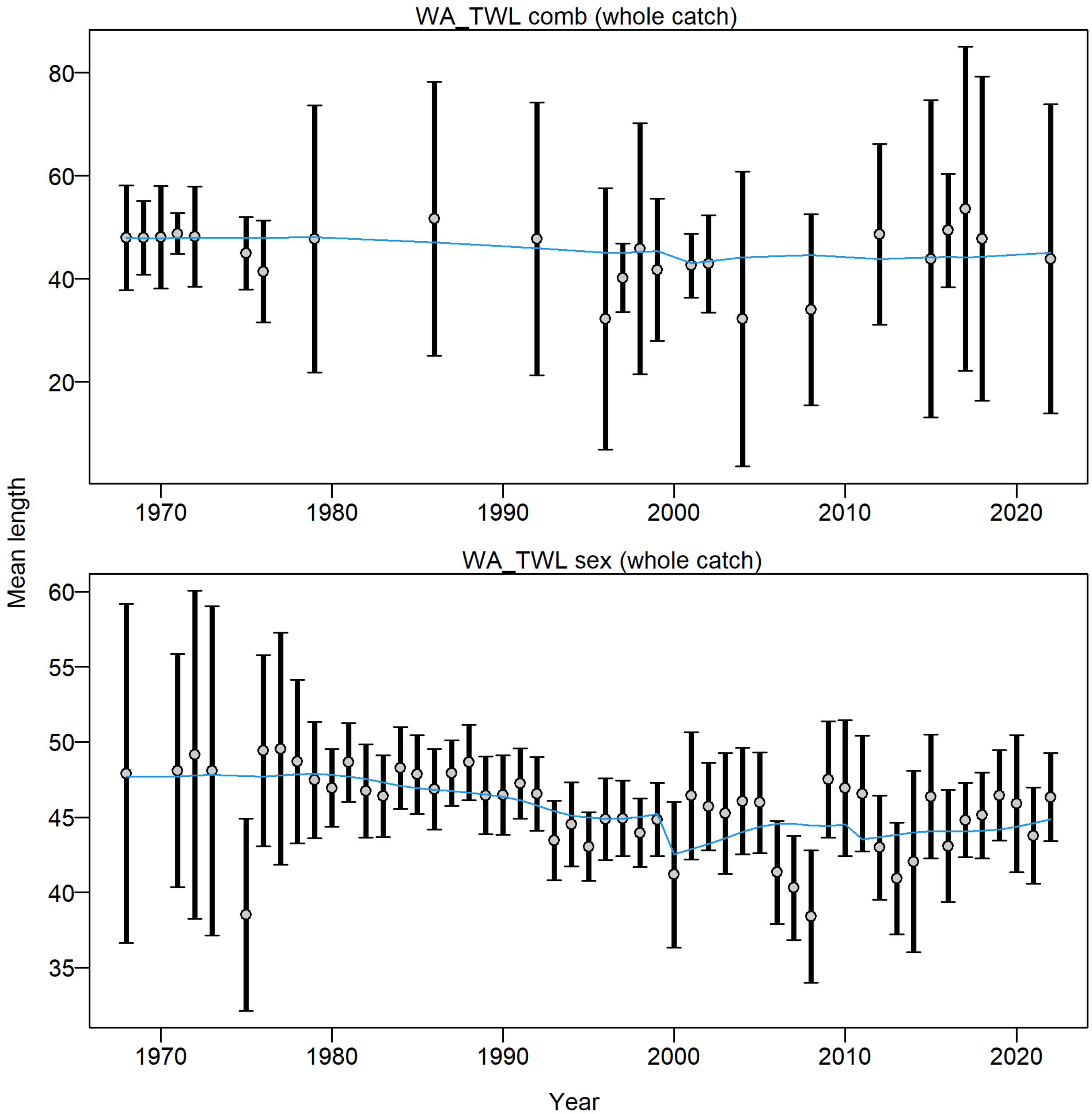

Figure 64: Mean length for the Washington trawl fleet with 95 percent confidence intervals based on current samples sizes for unsexed (top panel) and sexed (bottom panel) samples.

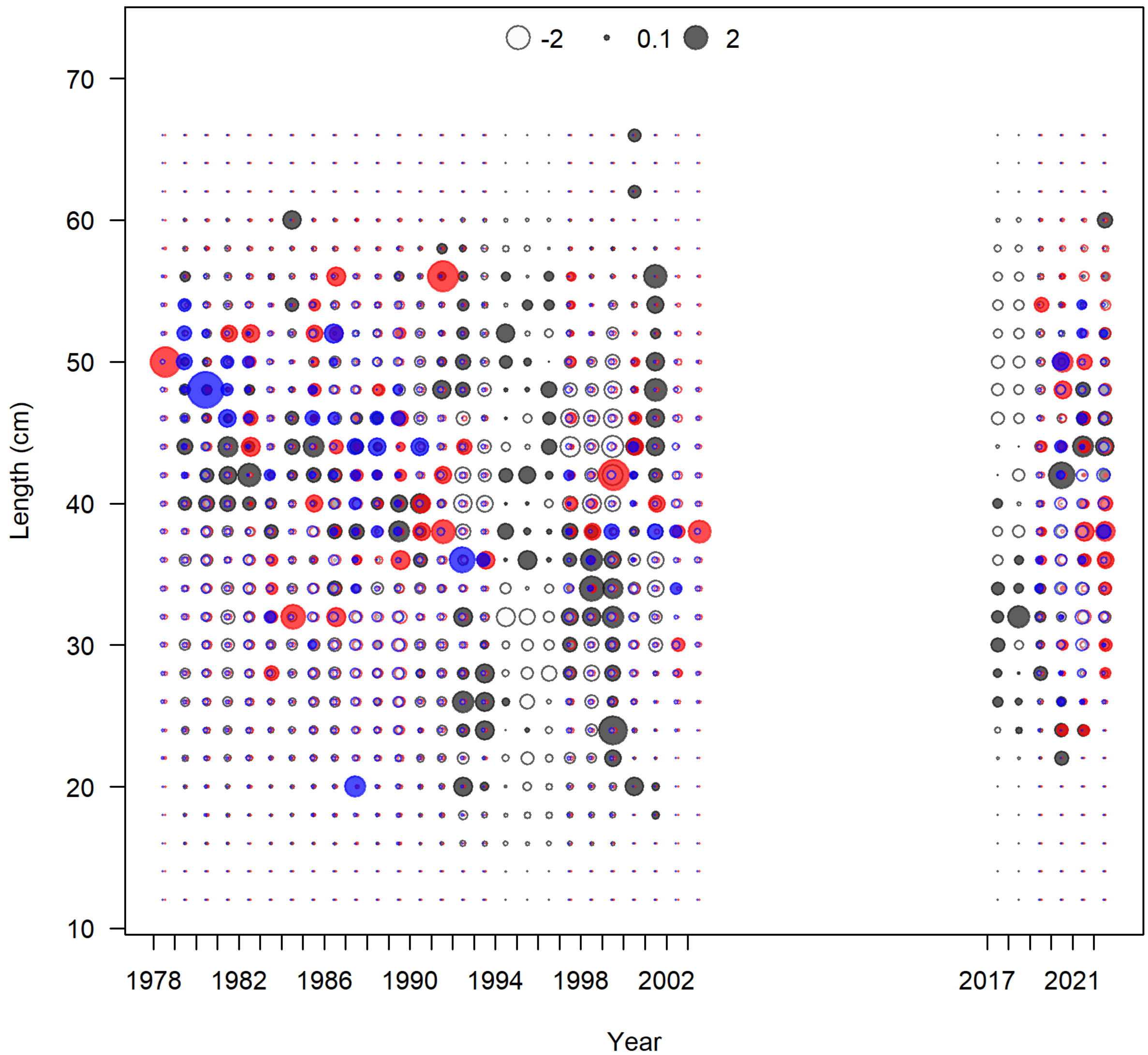

Figure 65: Pearson residuals for lengths in the California non-trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red), males (blue), and unsexed (black).

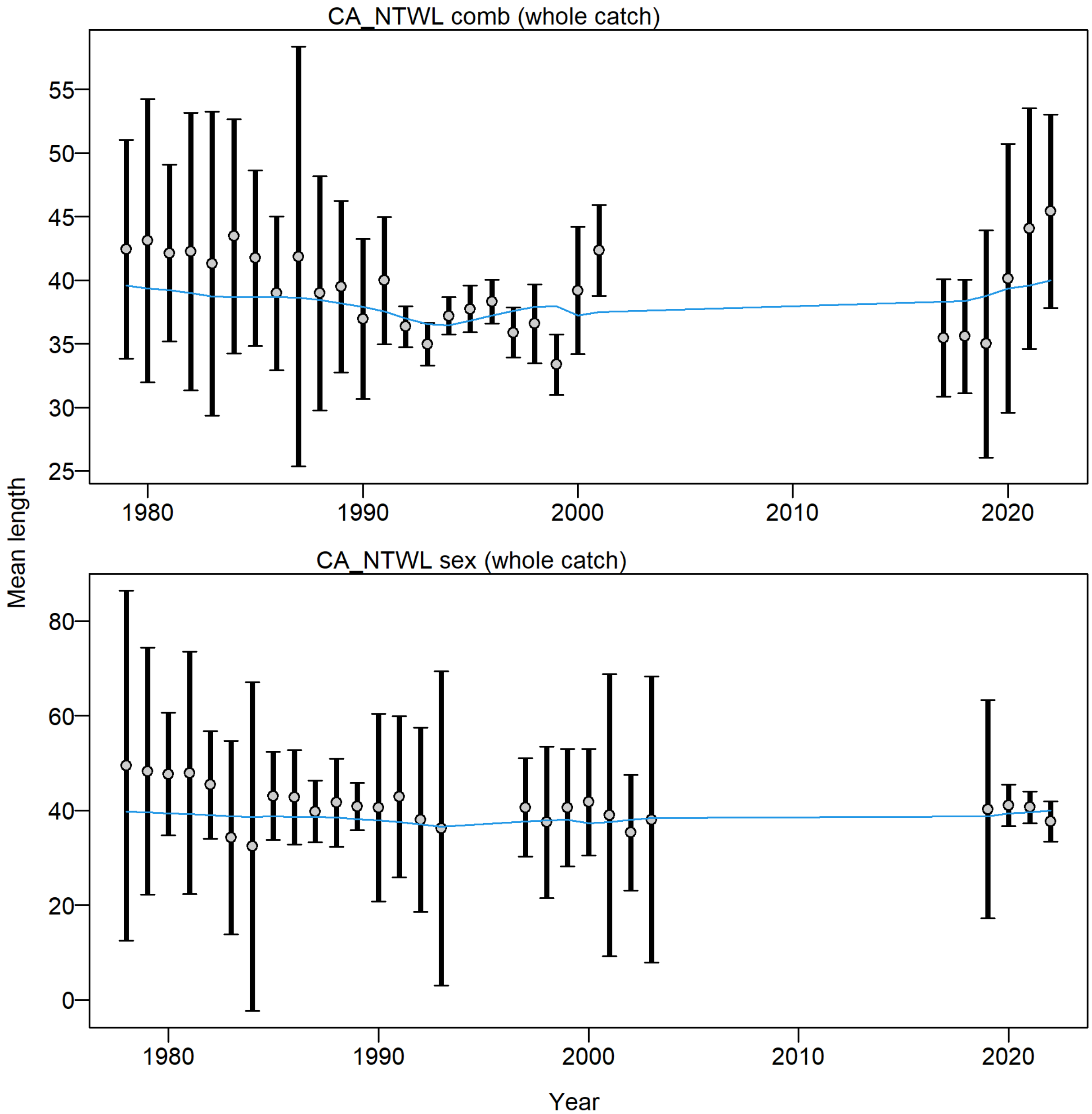

Figure 66: Mean length for the California non-trawl fleet with 95 percent confidence intervals based on current samples sizes for unsexed (top panel) and sexed (bottom panel) samples.

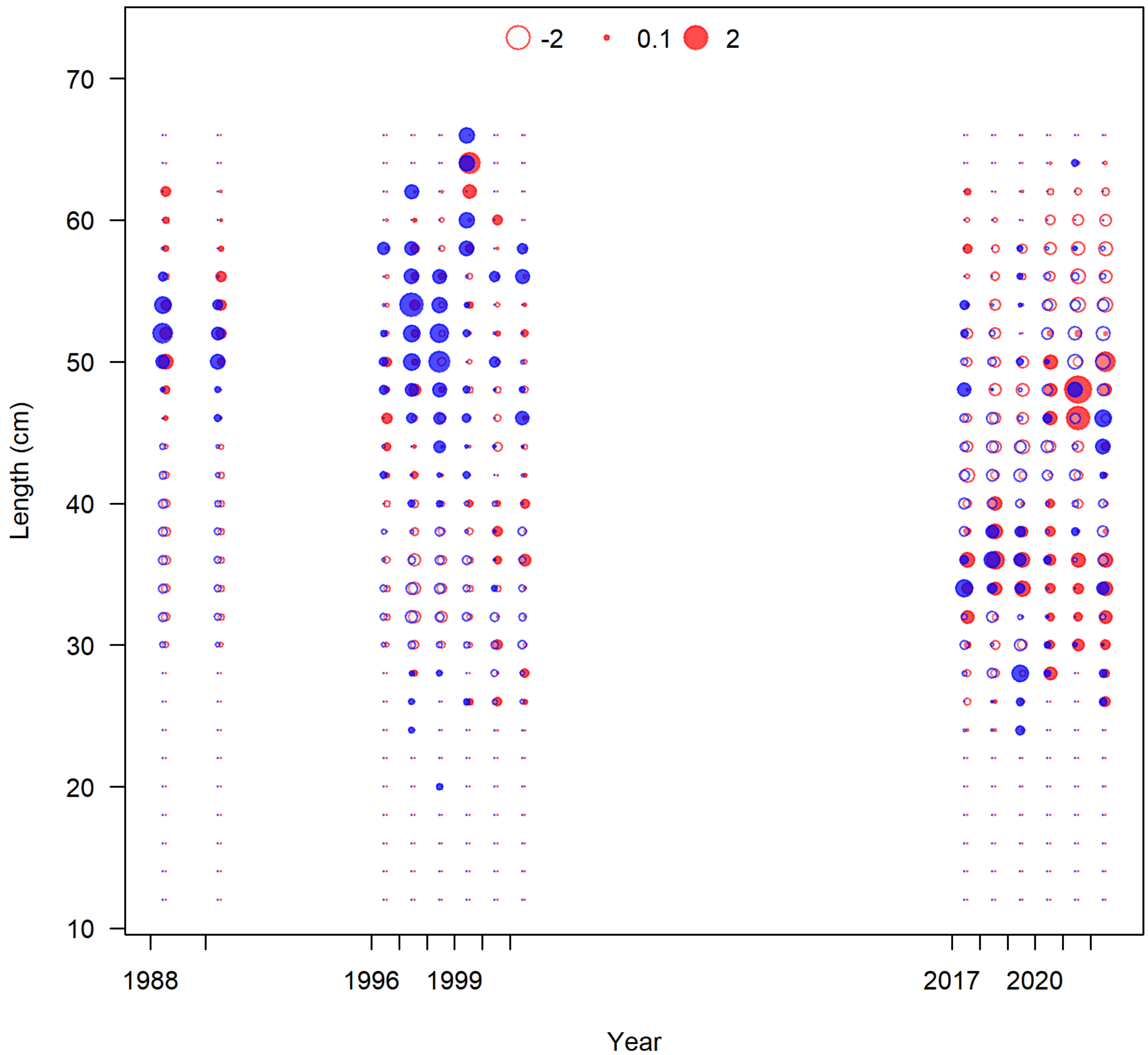

Figure 67: Pearson residuals for lengths in the Oregon non-trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red), males (blue), and unsexed (black).

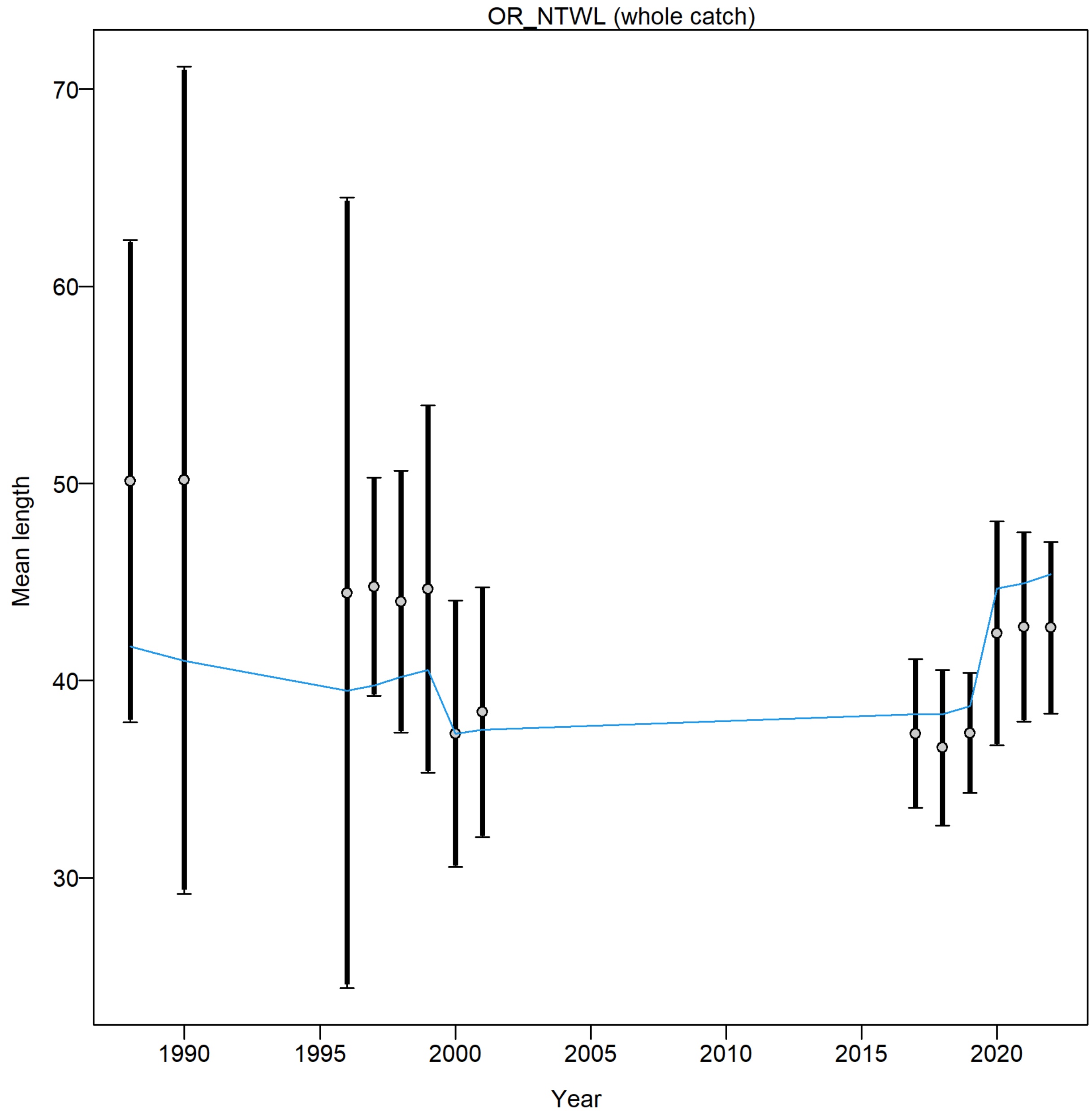

Figure 68: Mean length for the Oregon non-trawl fleet with 95 percent confidence intervals based on current samples sizes.

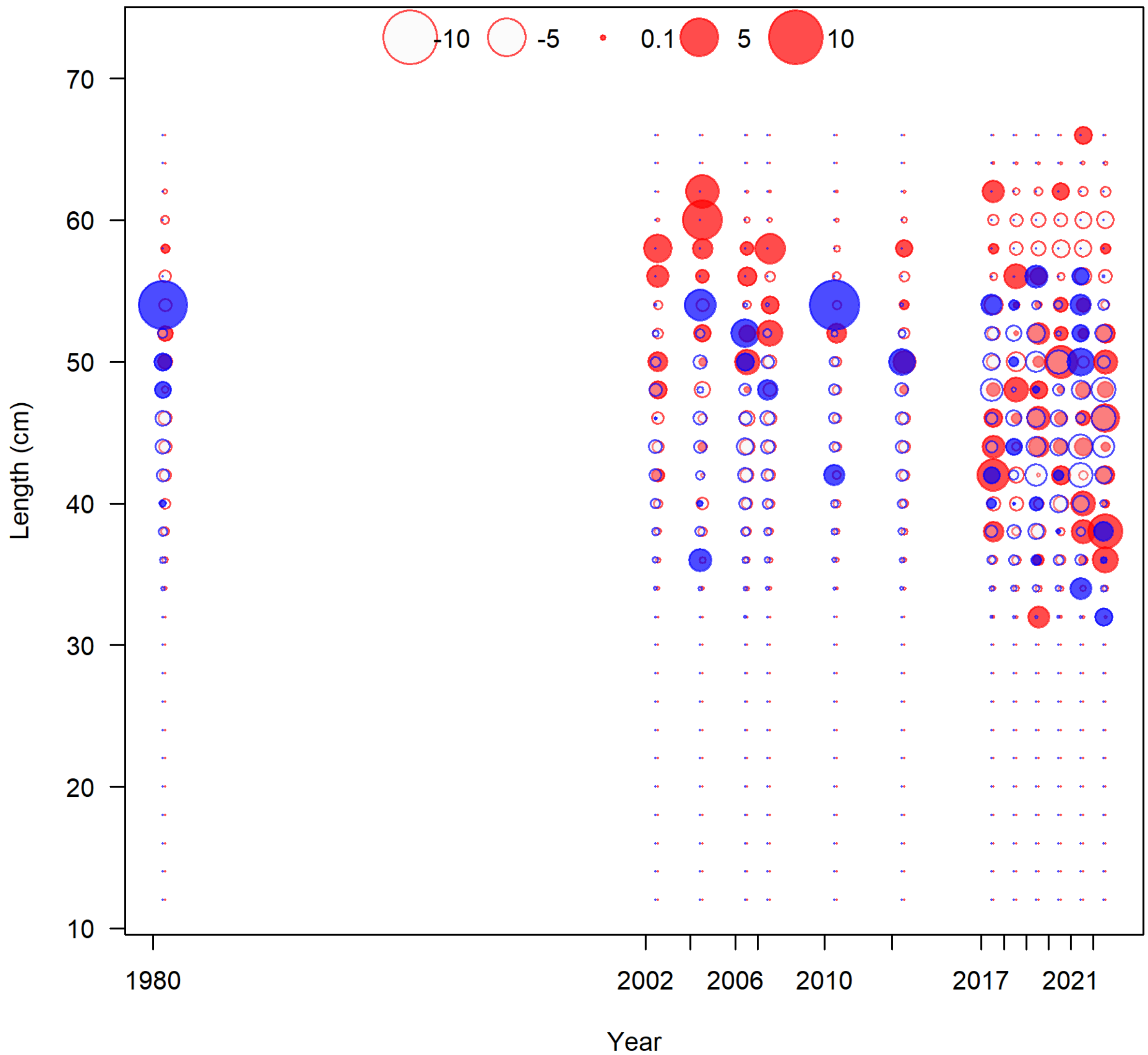

Figure 69: Pearson residuals for lengths in the Washington non-trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

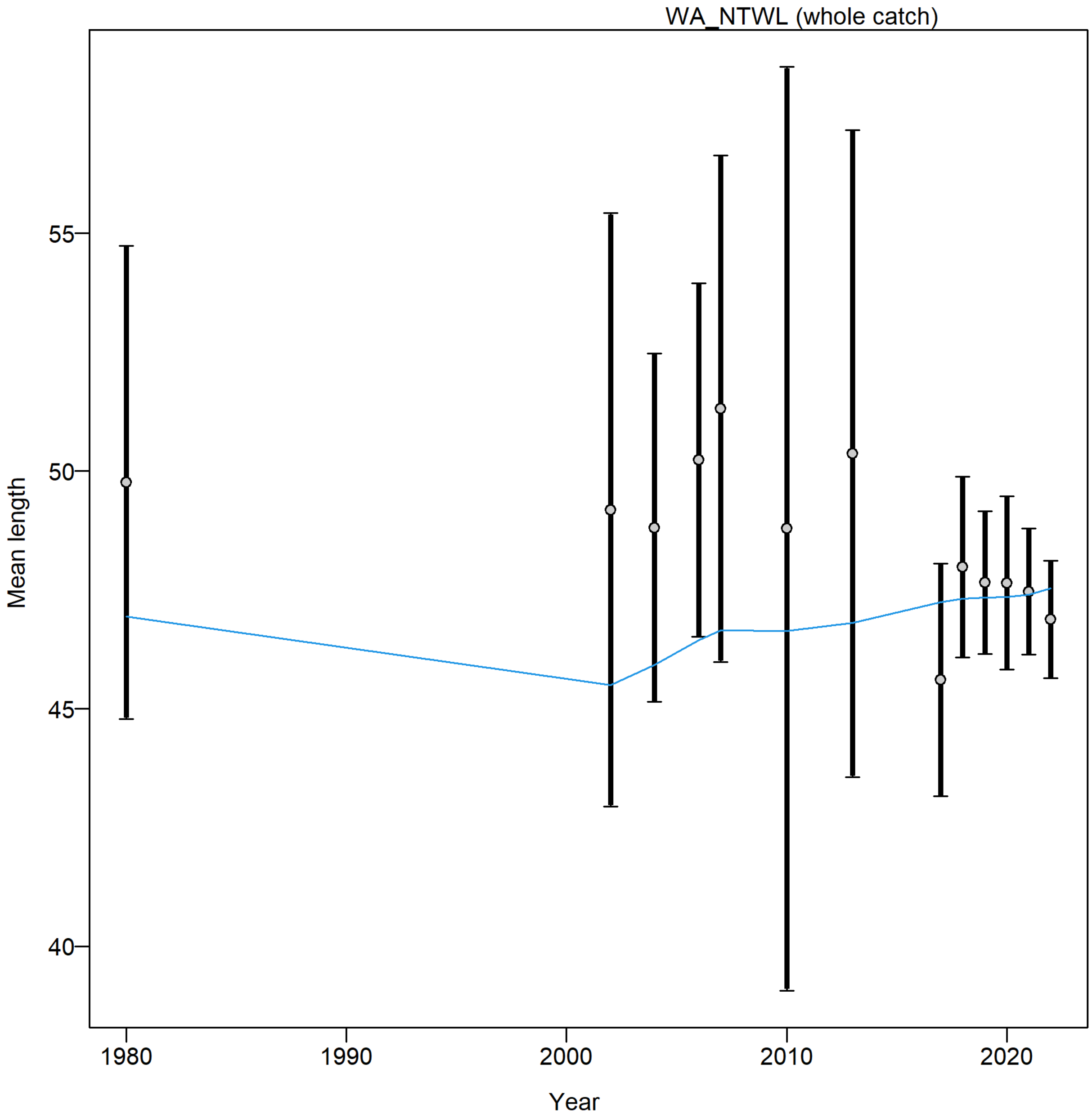

Figure 70: Mean length for the Washington non-trawl fleet with 95 percent confidence intervals based on current samples sizes.

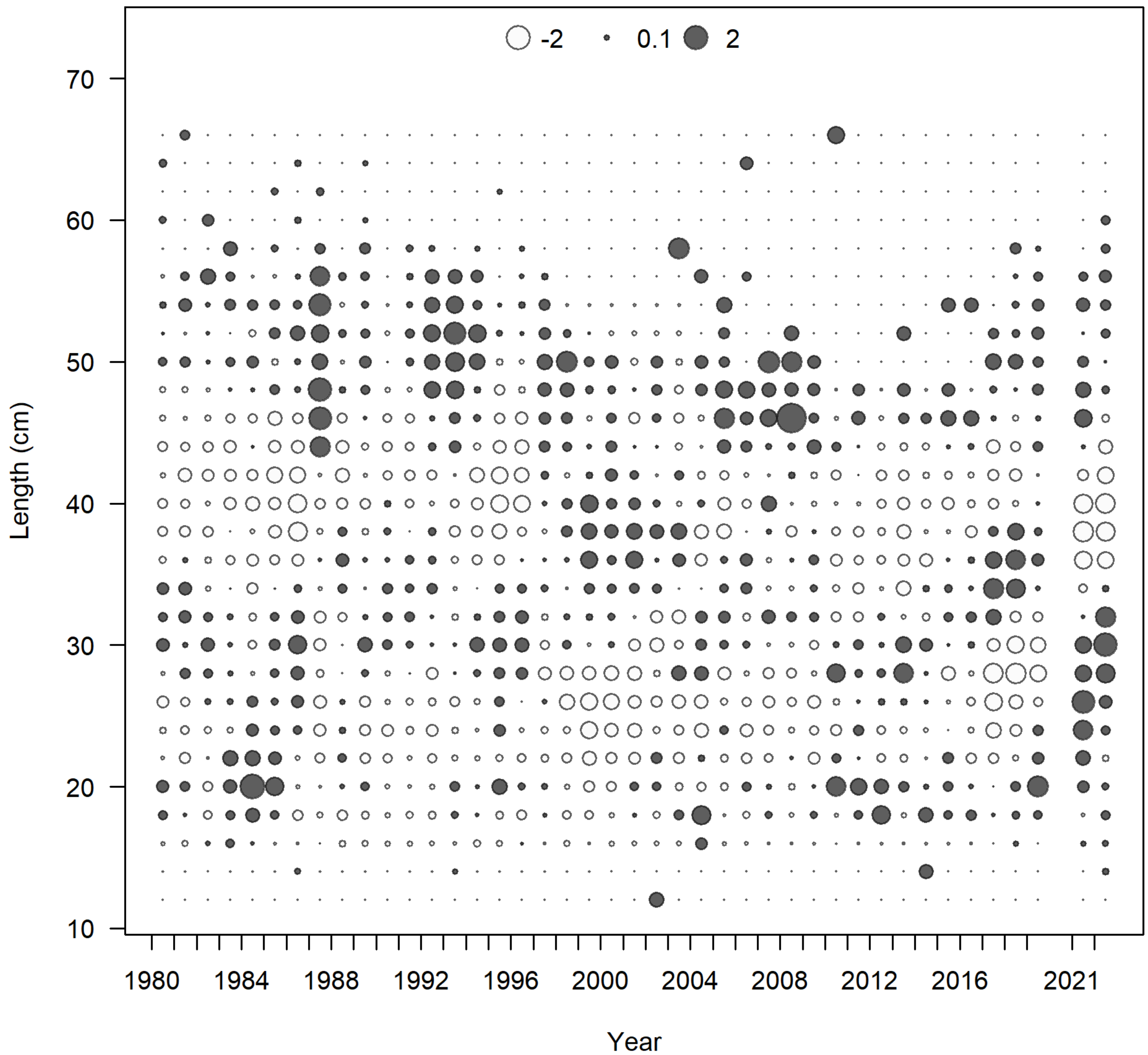

Figure 71: Pearson residuals for lengths in the California recreational fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for unsexed (black).

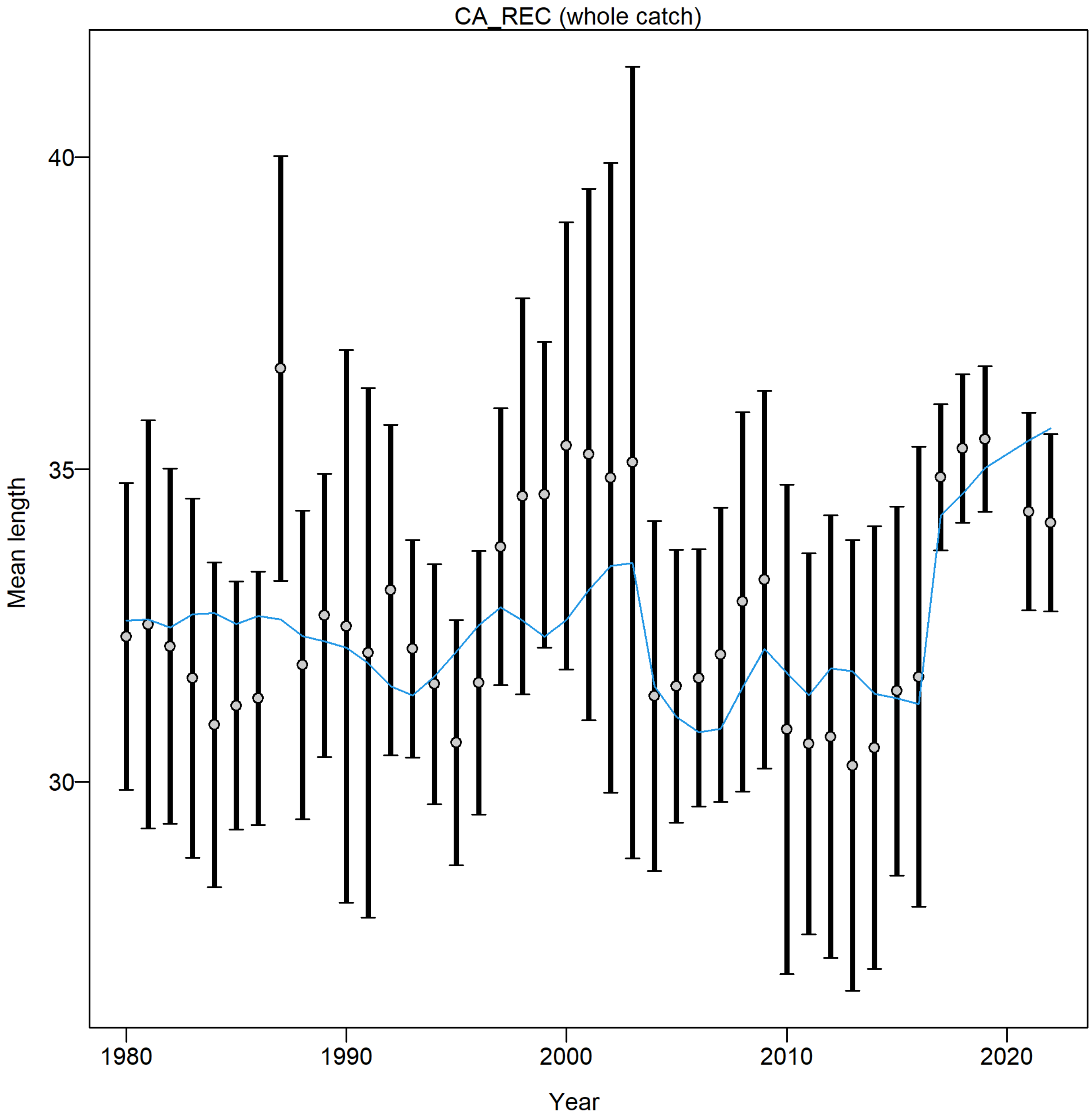

Figure 72: Mean length for the California recreational fleet with 95 percent confidence intervals based on current samples sizes.

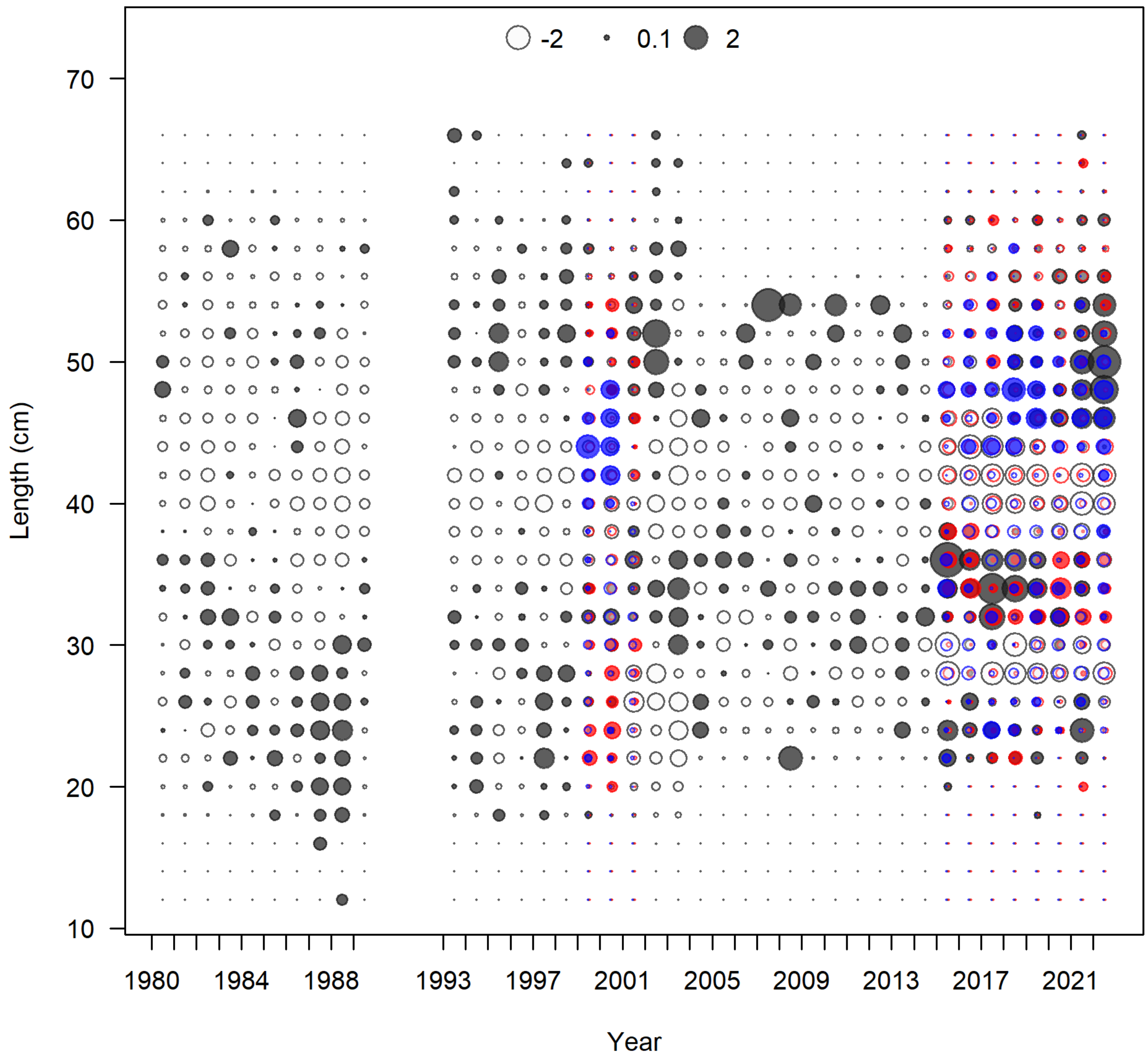

Figure 73: Pearson residuals for lengths in the Oregon recreational fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red), males (blue), and unsexed (black).

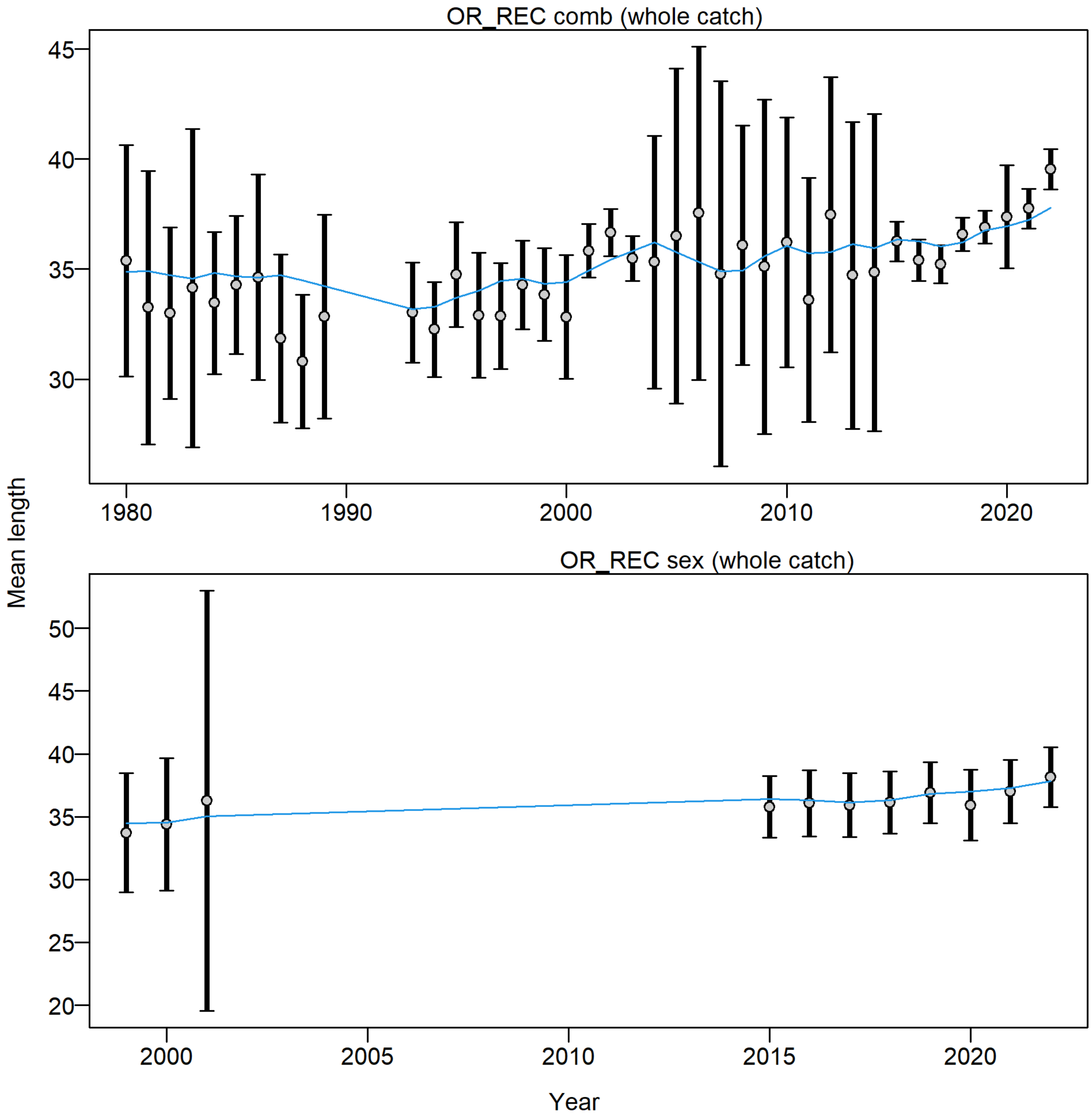

Figure 74: Mean length for the Oregon recreational fleet with 95 percent confidence intervals based on current samples sizes for unsexed (top panel) and sexed (bottom panel) samples.

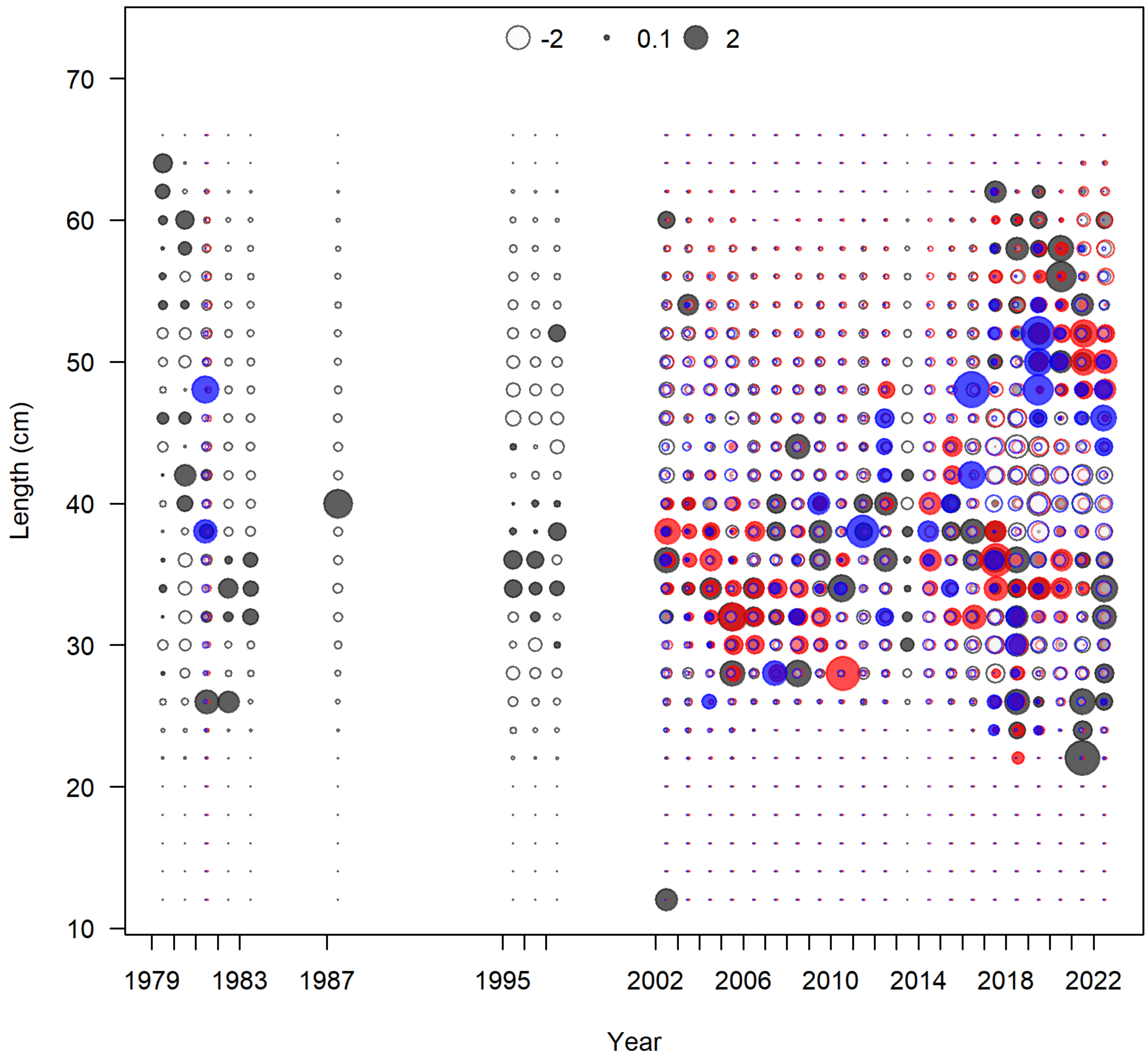

Figure 75: Pearson residuals for lengths in the Washington recreational fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red), males (blue), and unsexed (black).

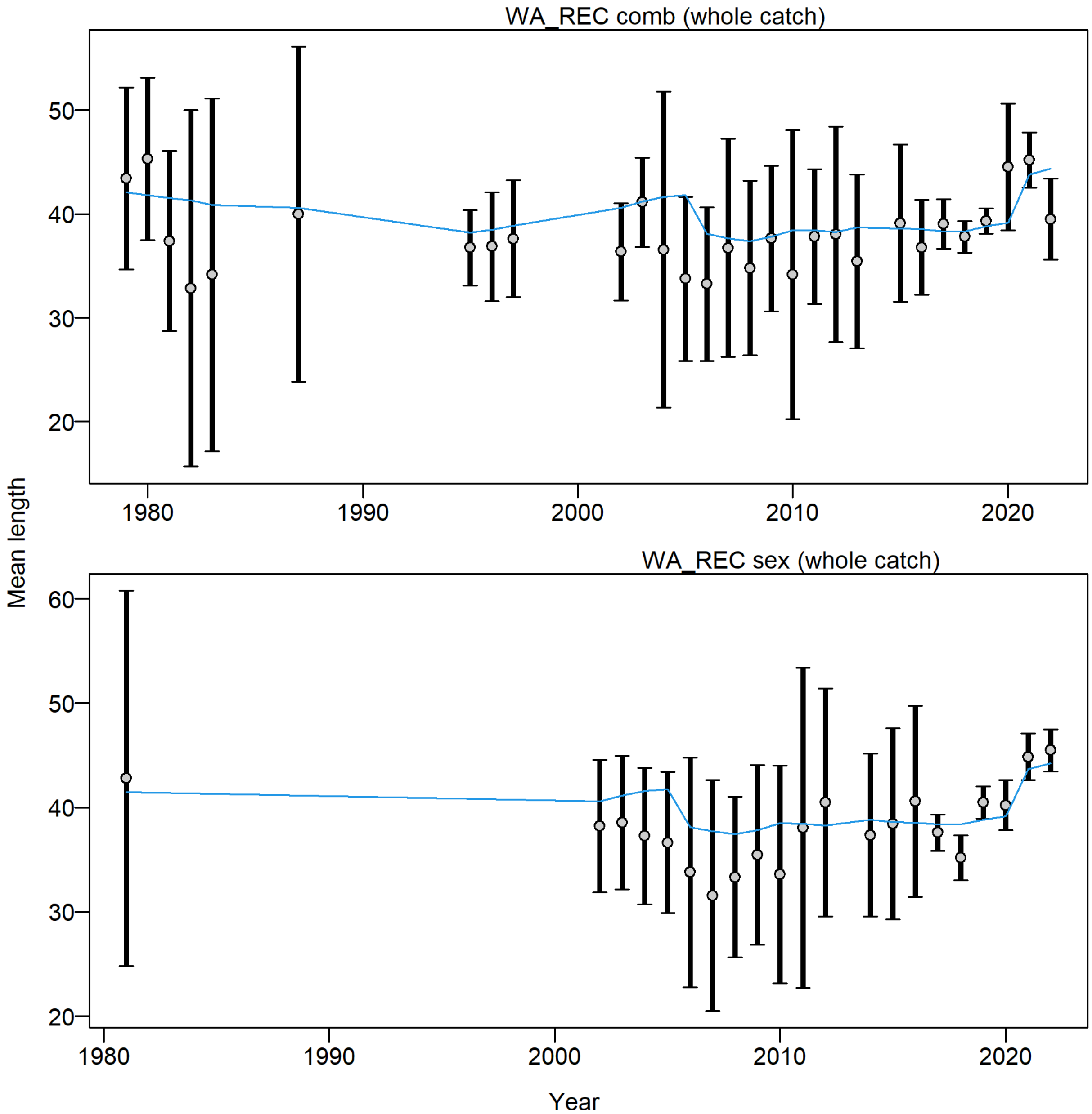

Figure 76: Mean length for the Washington recreational fleet with 95 percent confidence intervals based on current samples sizes for unsexed (top panel) and sexed (bottom panel) samples.

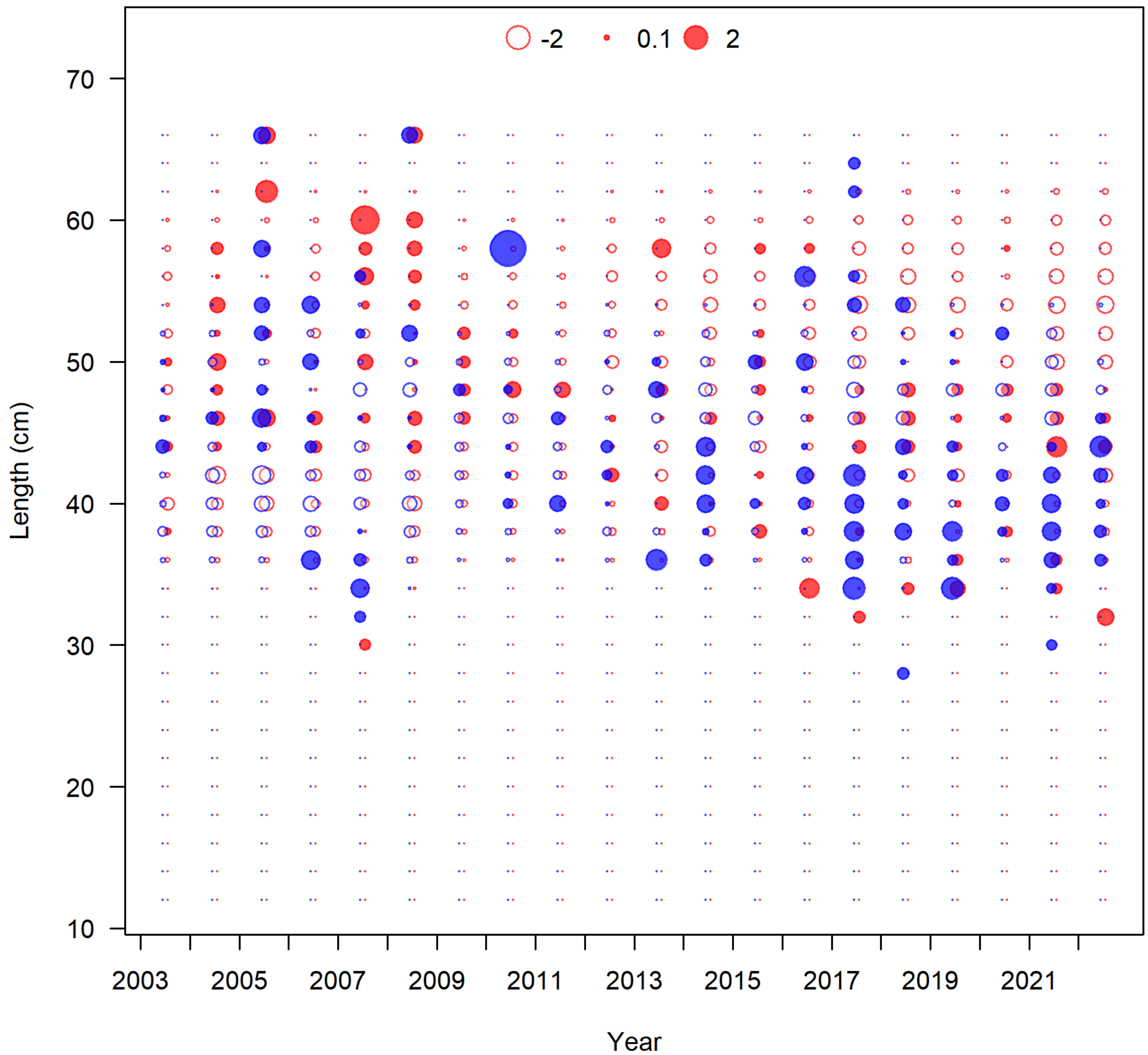

Figure 77: Pearson residuals for lengths in the Oregon at-sea hake fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

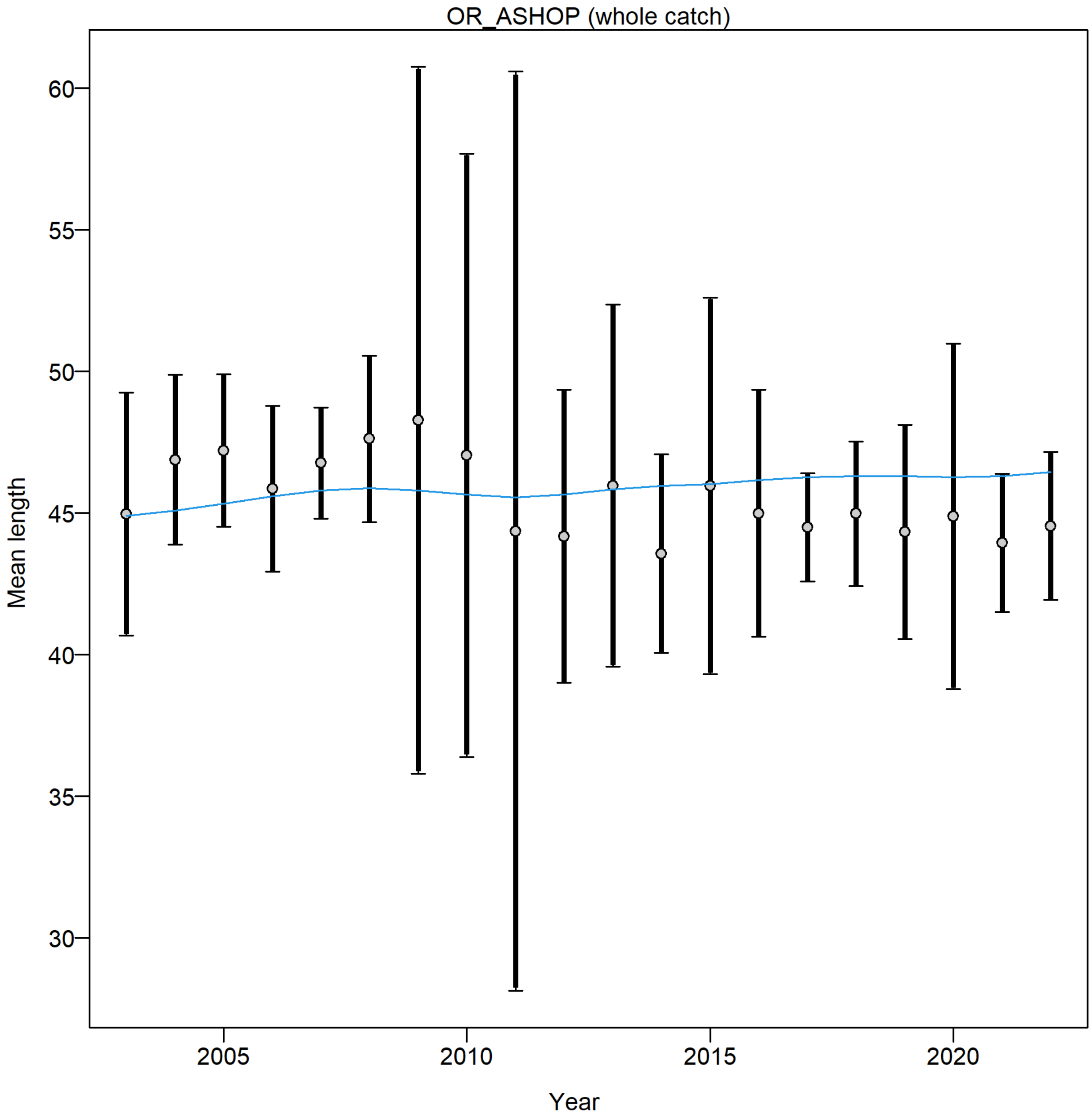

Figure 78: Mean length for the Oregon at-sea hake fleet with 95 percent confidence intervals based on current samples sizes.

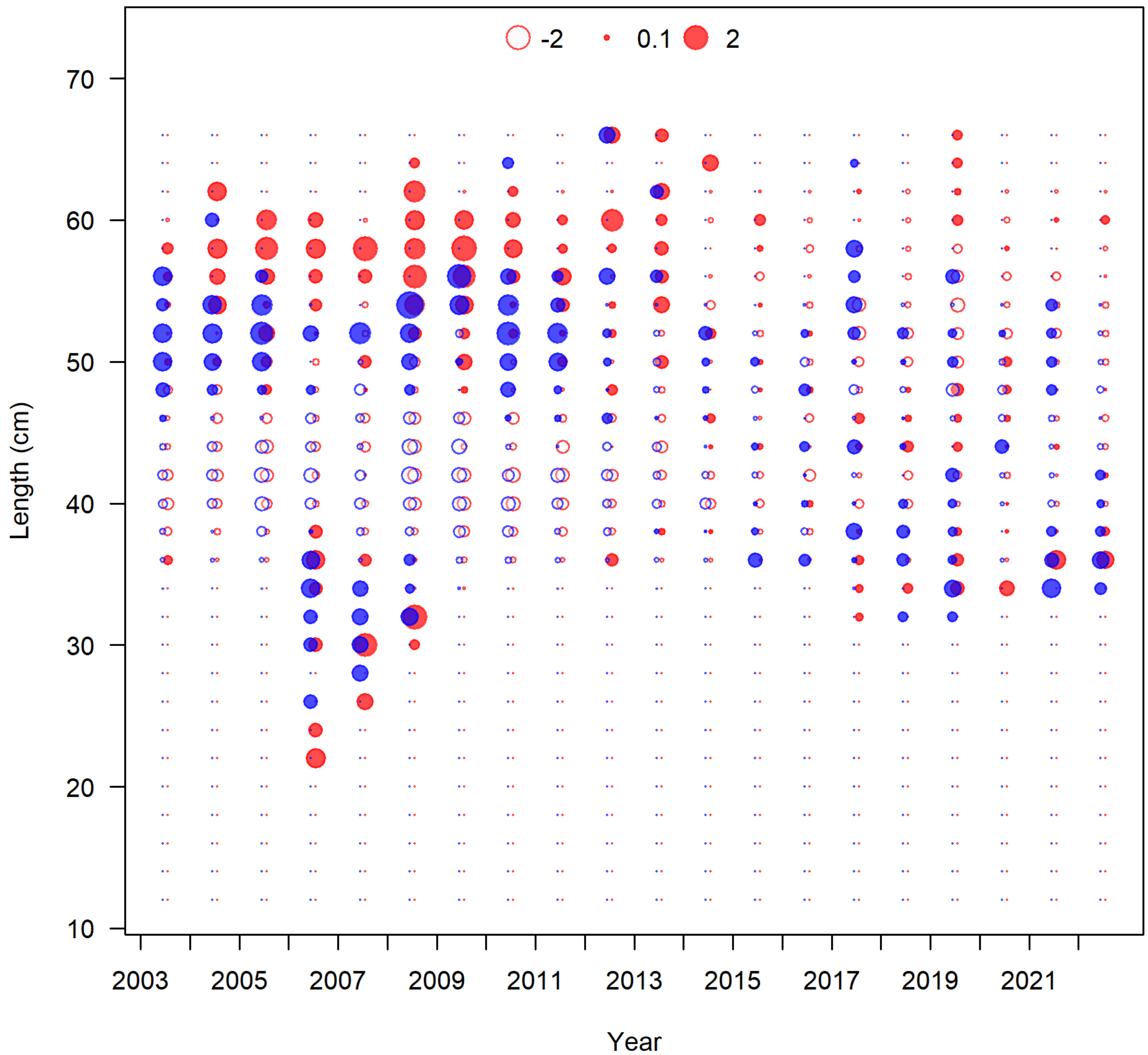

Figure 79: Pearson residuals for lengths in the Washington at-sea hake fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females(red) and males (blue).

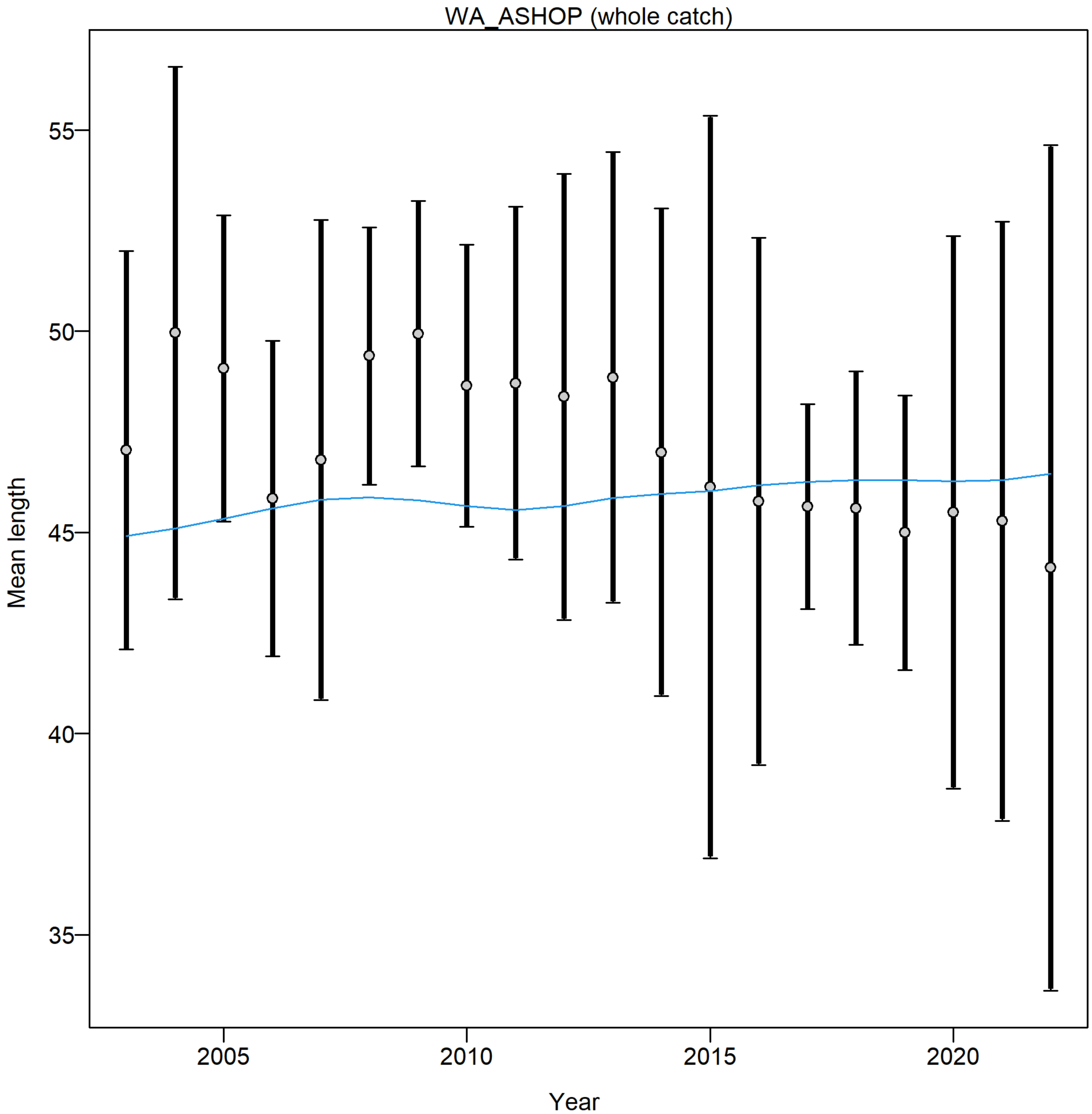

Figure 80: Mean length for the Washington at-sea hake fleet with 95 percent confidence intervals based on current samples.

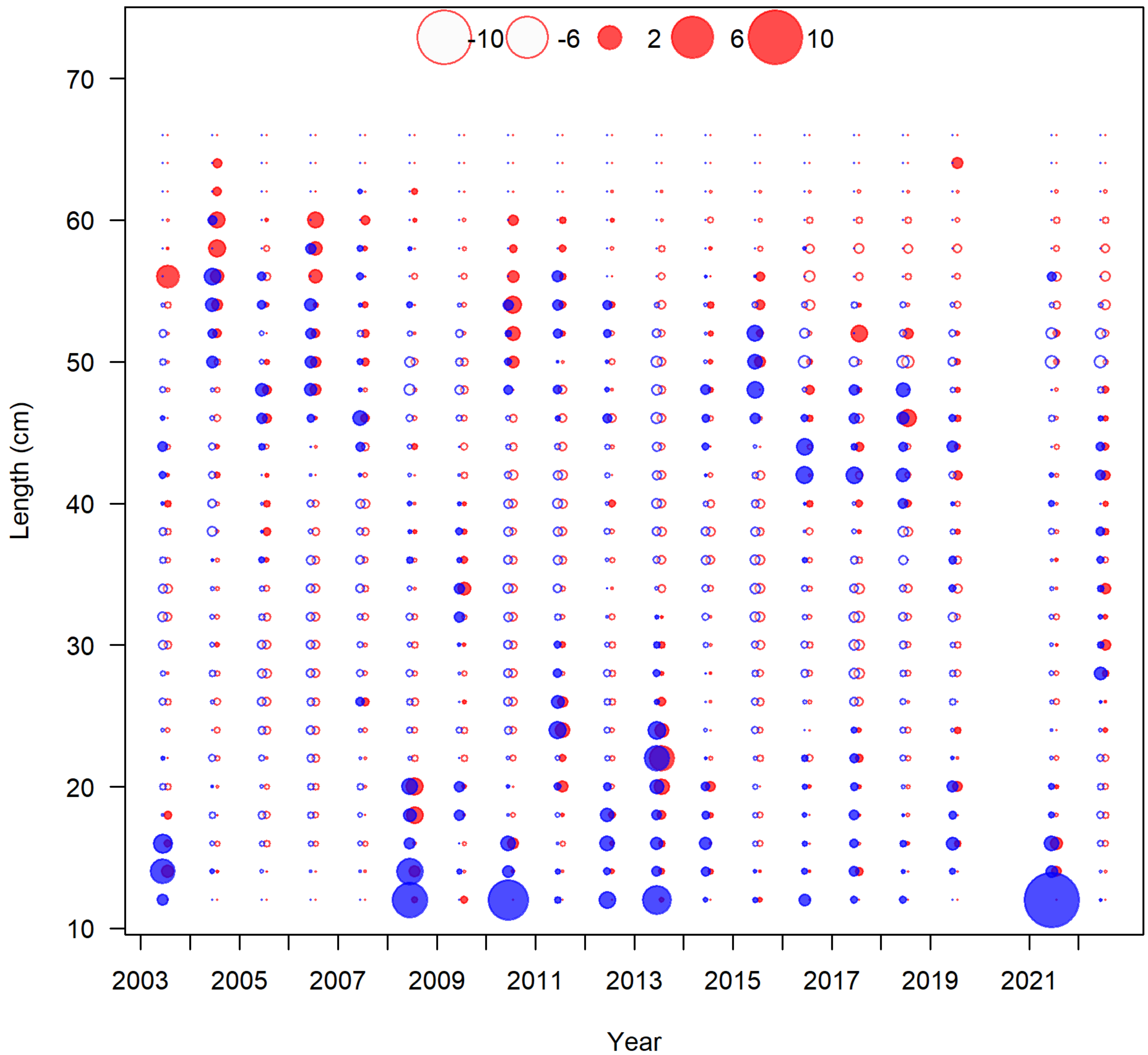

Figure 81: Pearson residuals for lengths in the West Coast Groundfish Bottomtrawl Survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

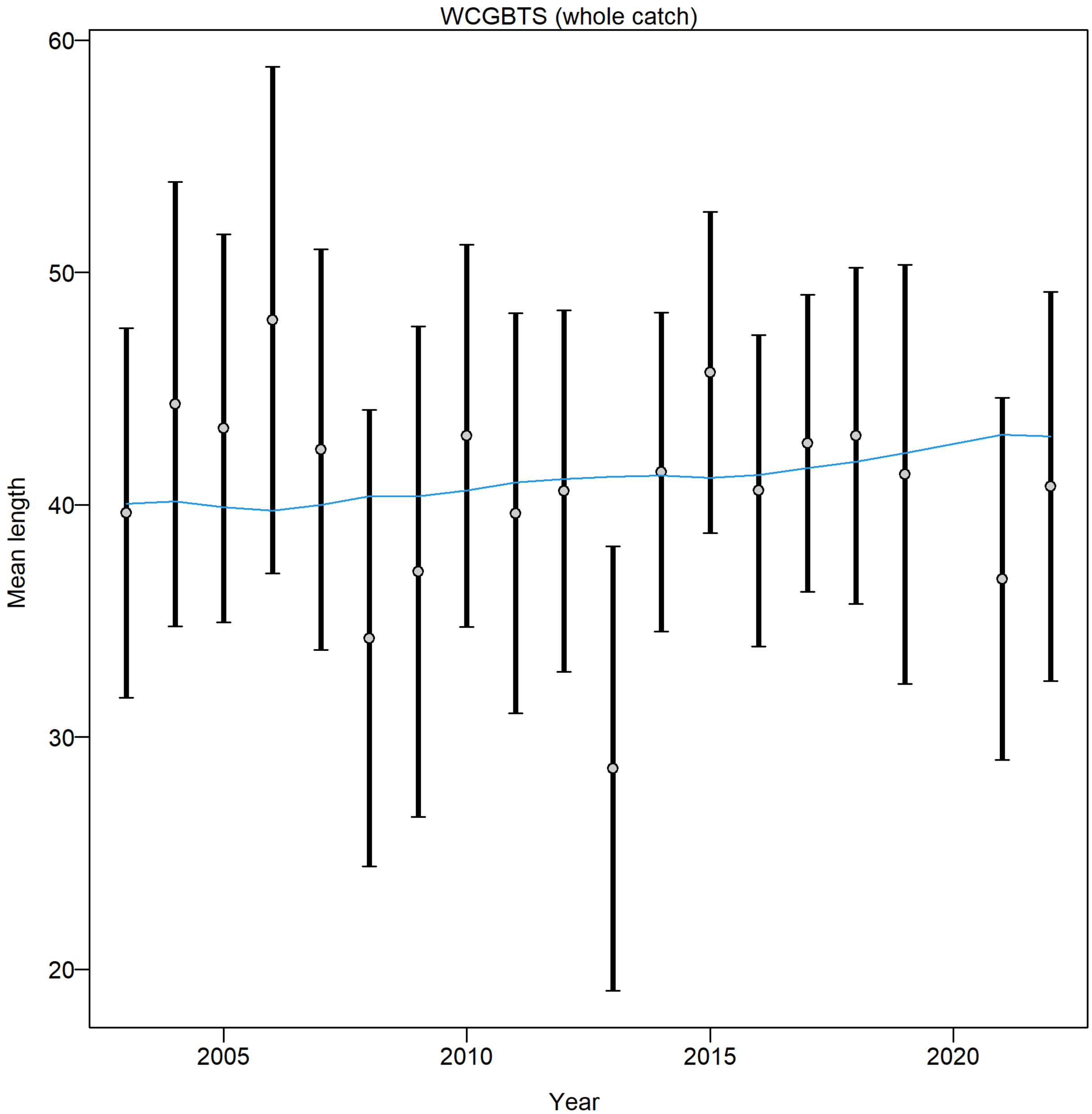

Figure 82: Mean length for the West Coast Groundfish Bottomtrawl Survey with 95 percent confidence intervals based on current samples.

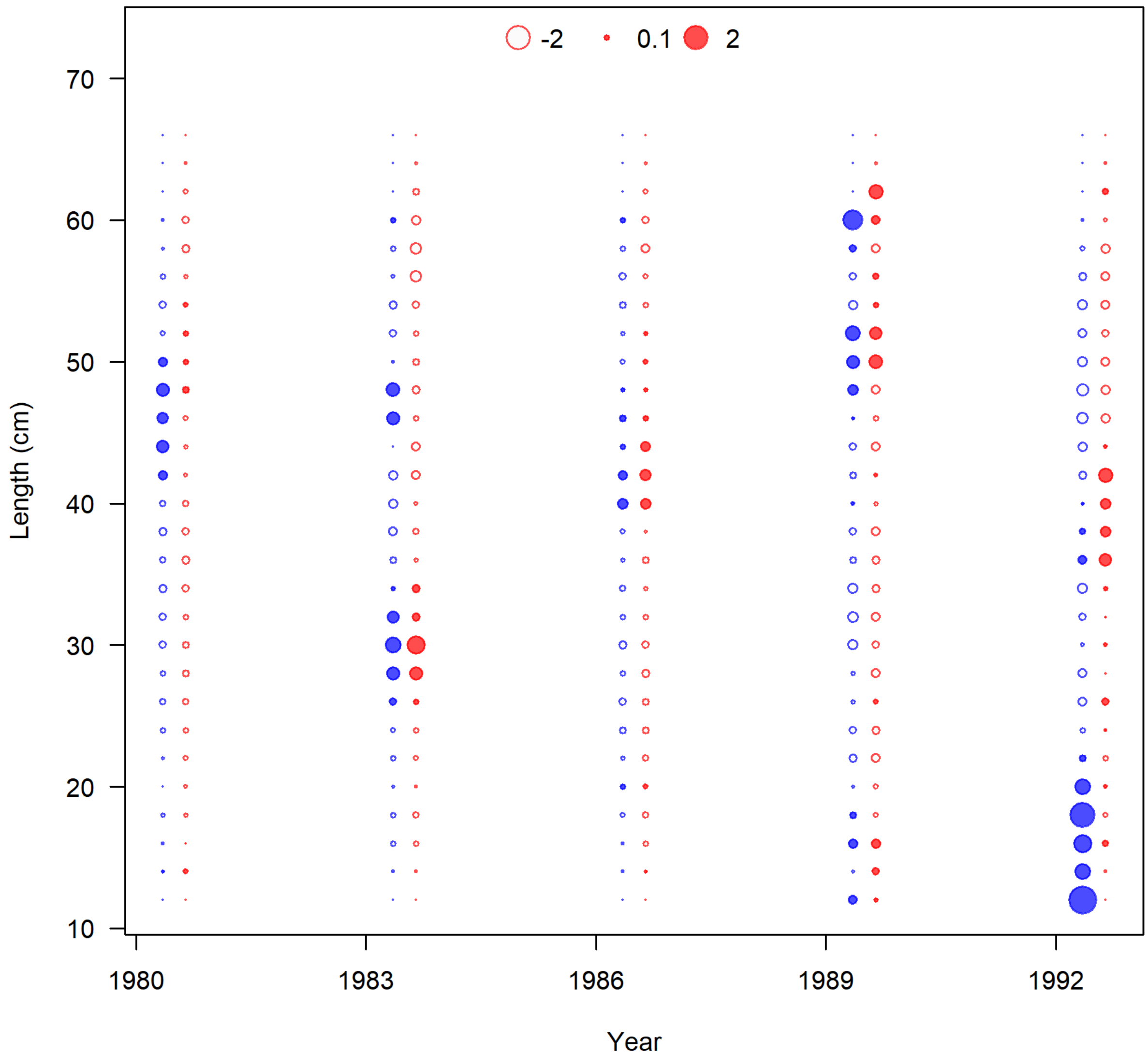

Figure 83: Pearson residuals for lengths in the early Triennial Survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

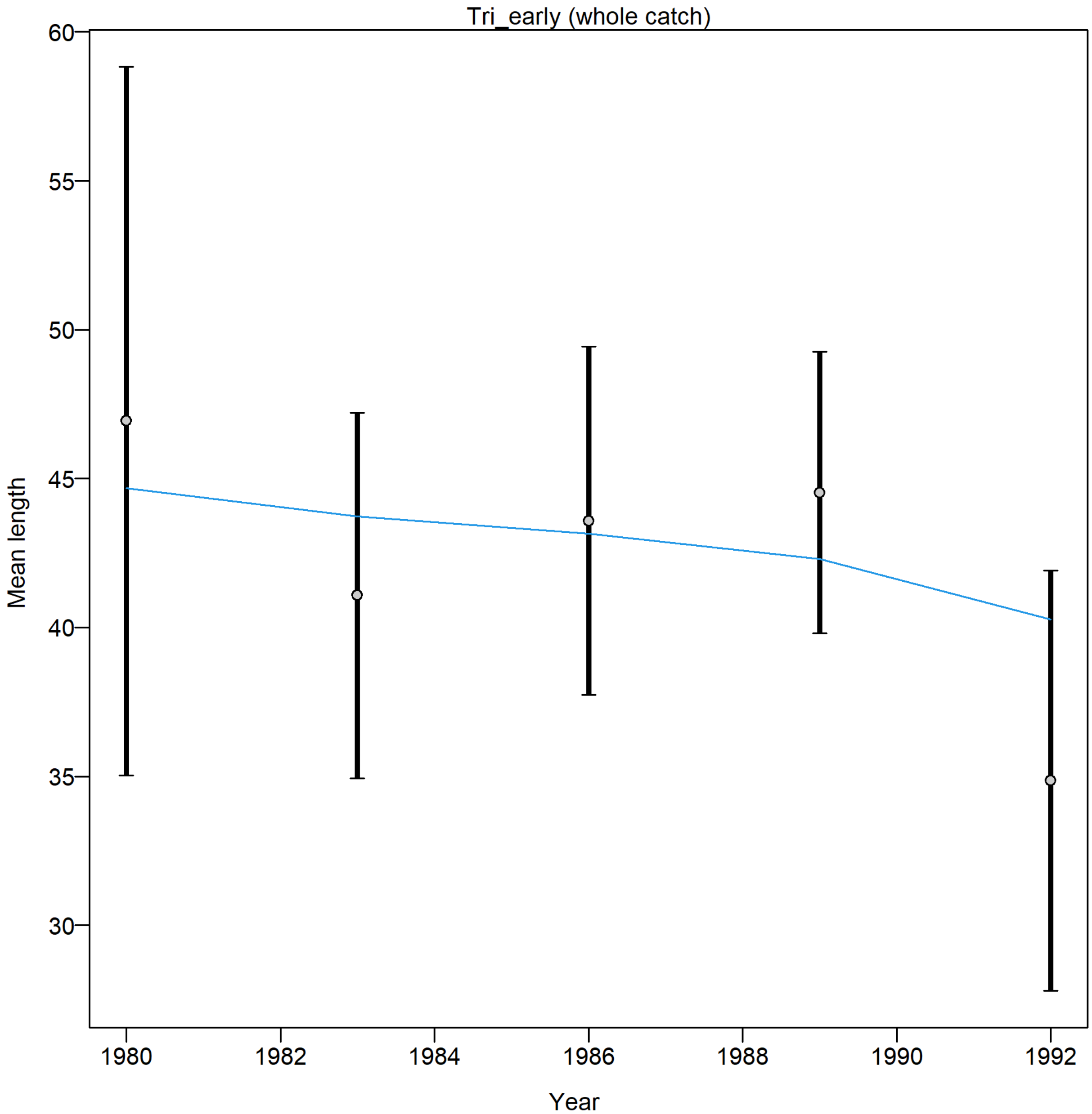

Figure 84: Mean length for the early Triennial Survey with 95 percent confidence intervals based on current samples.

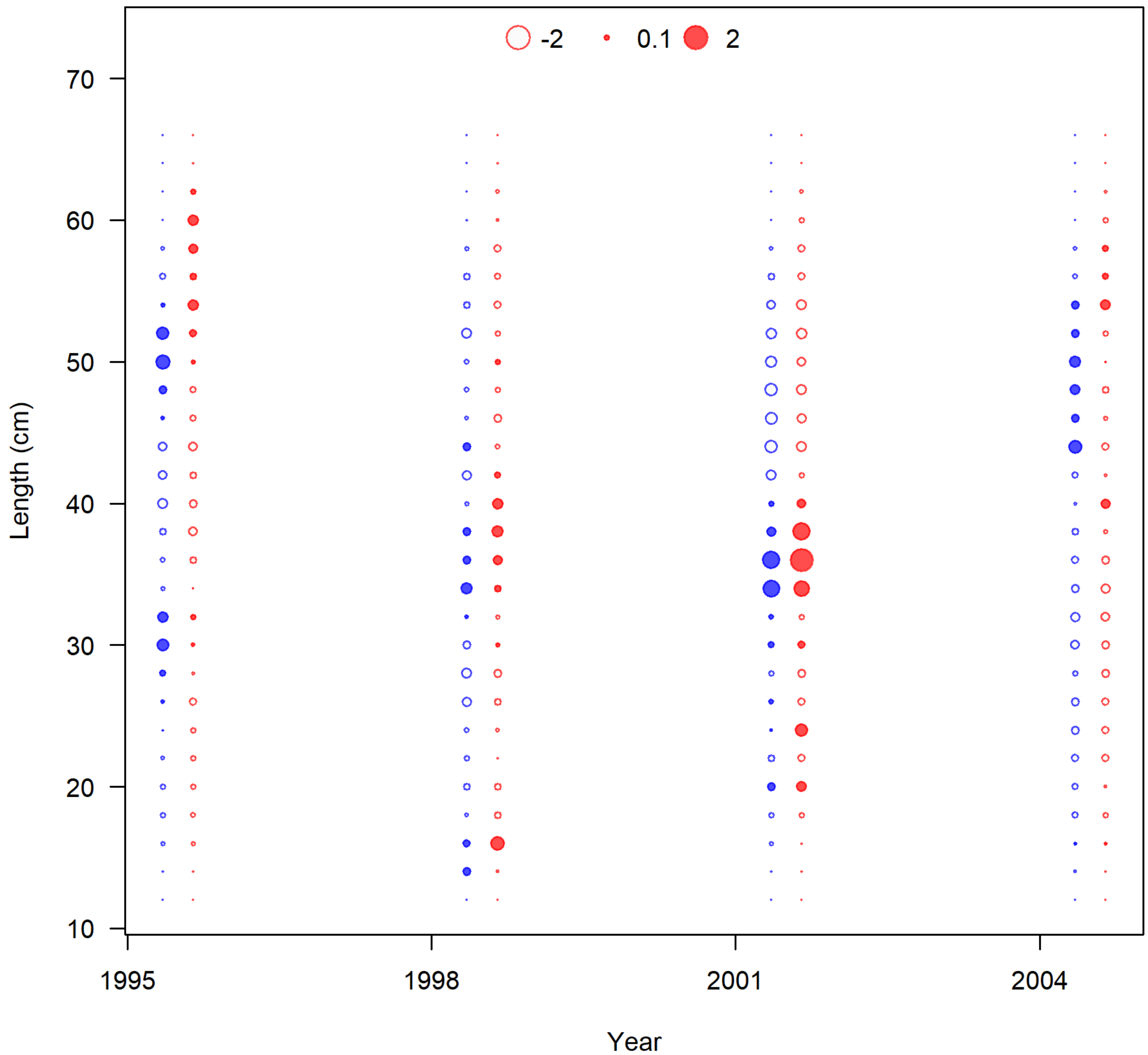

Figure 85: Pearson residuals for lengths in the late Triennial Survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

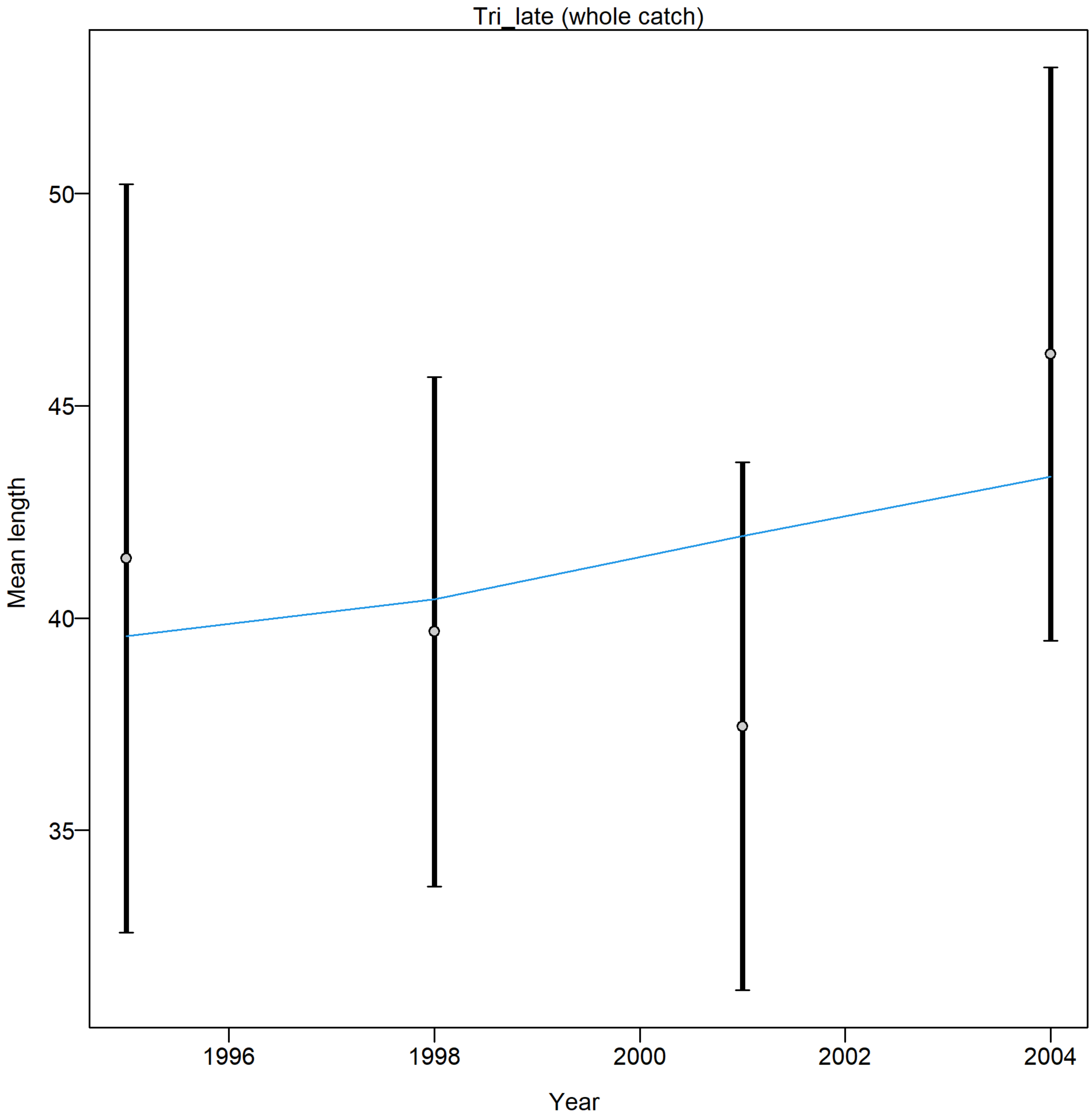

Figure 86: Mean length for the late Triennial Survey with 95 percent confidence intervals based on current samples.

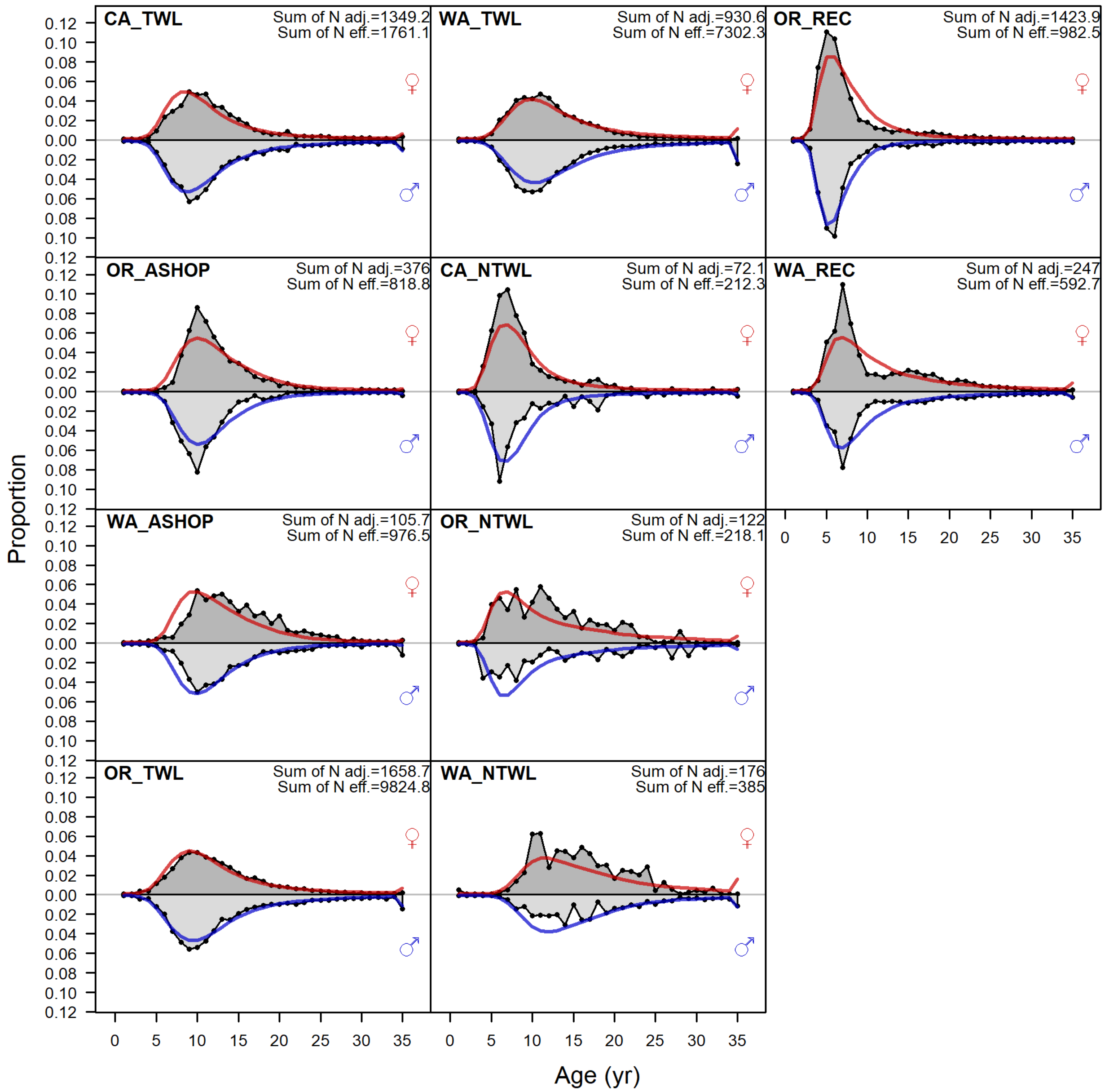

Figure 87: Age composition aggregated across years by fleet with the model estimated fit to the data by sex (red female, and blue male).

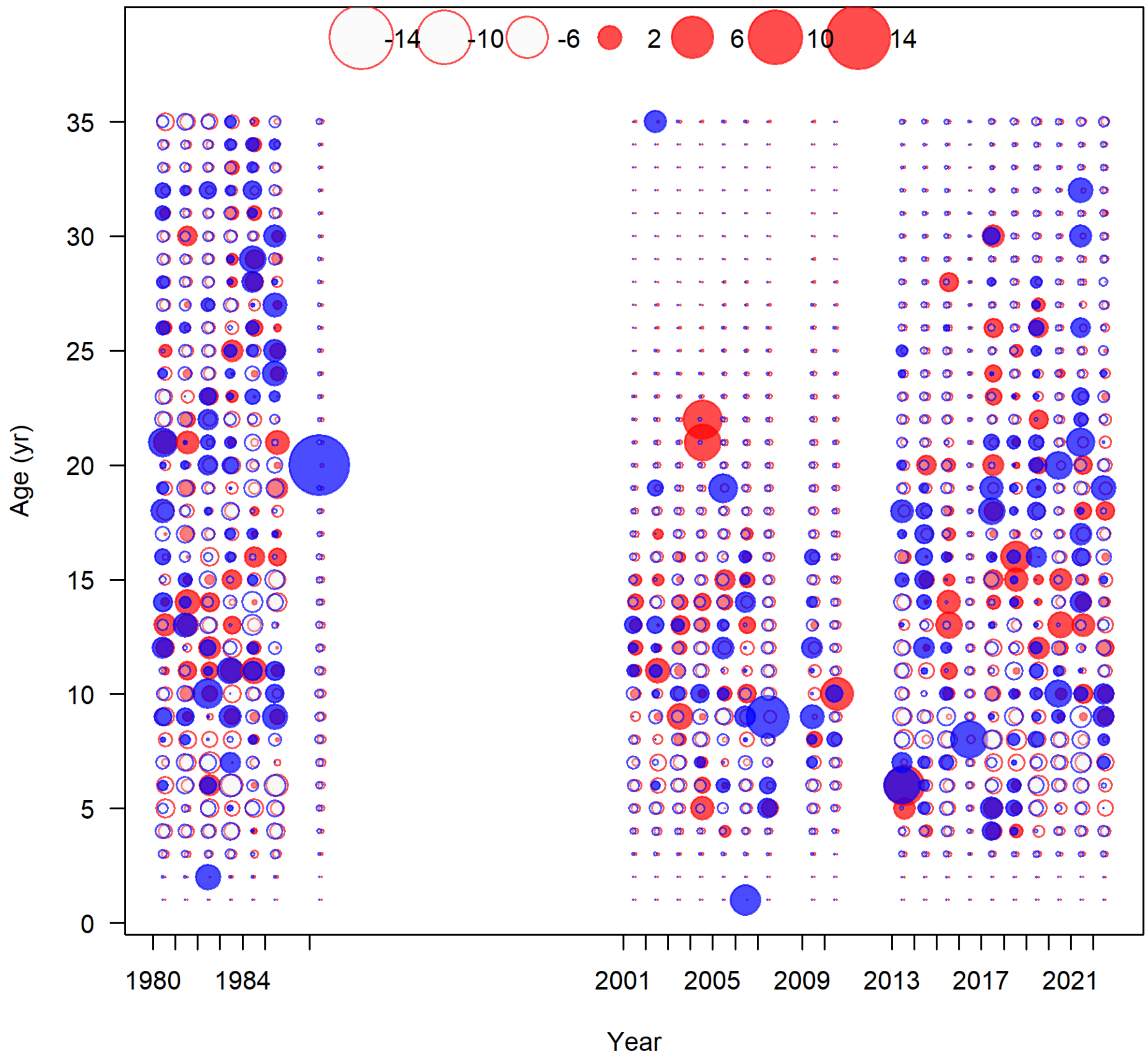

Figure 88: Pearson residuals for ages in the California trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

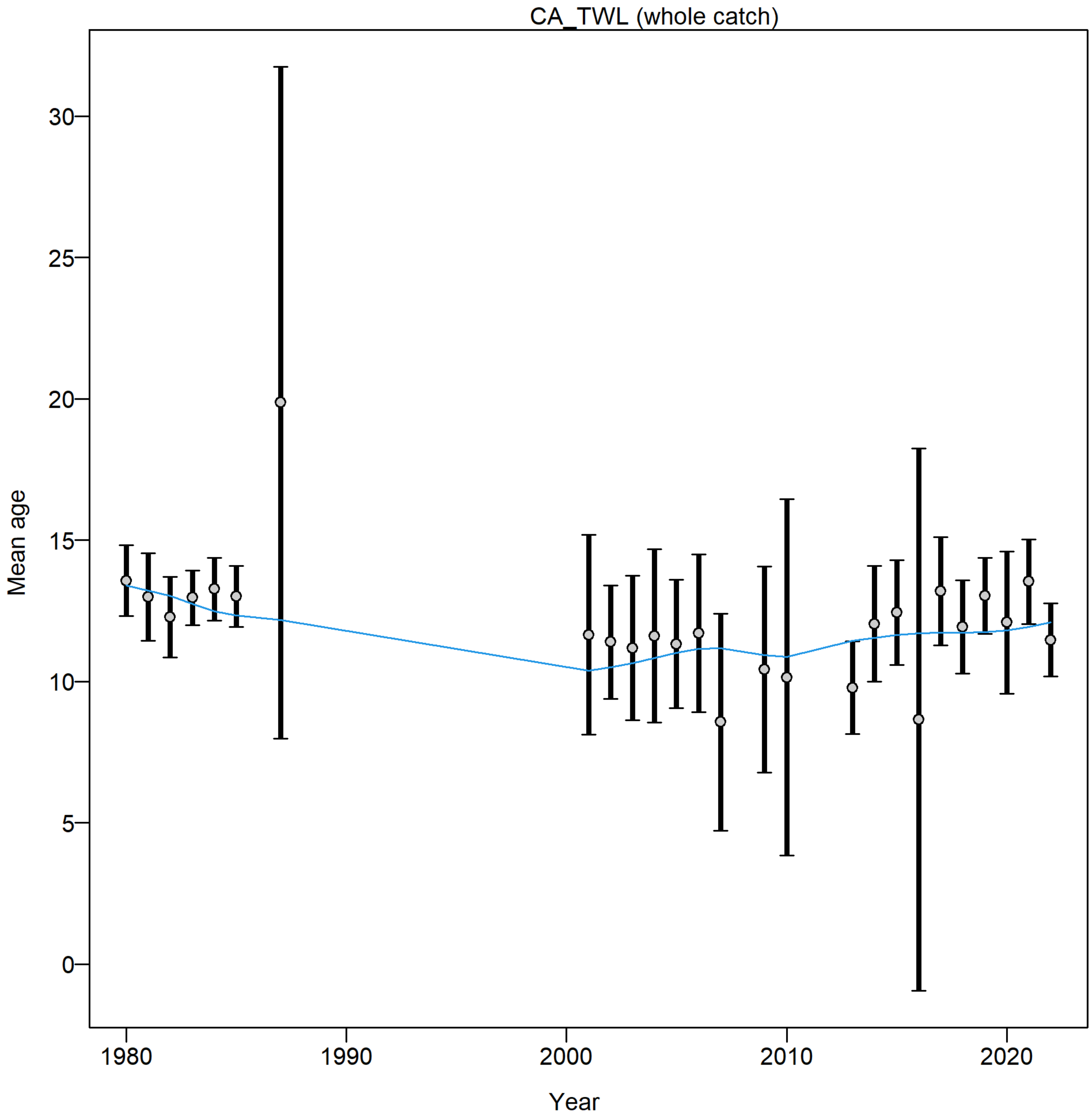

Figure 89: Mean age for the California trawl fleet with 95 percent confidence intervals based on current samples sizes.

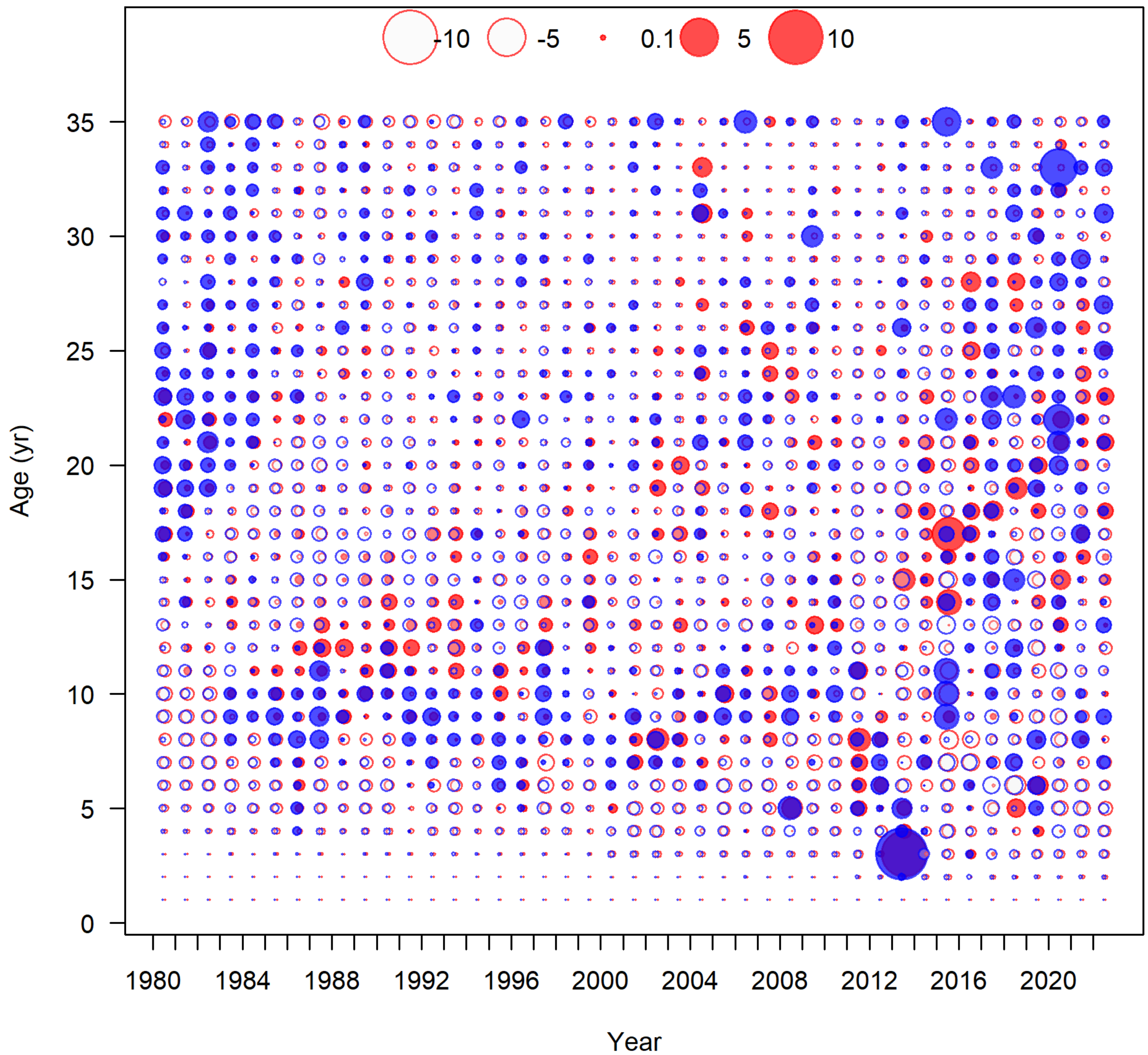

Figure 90: Pearson residuals for ages in the Oregon trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

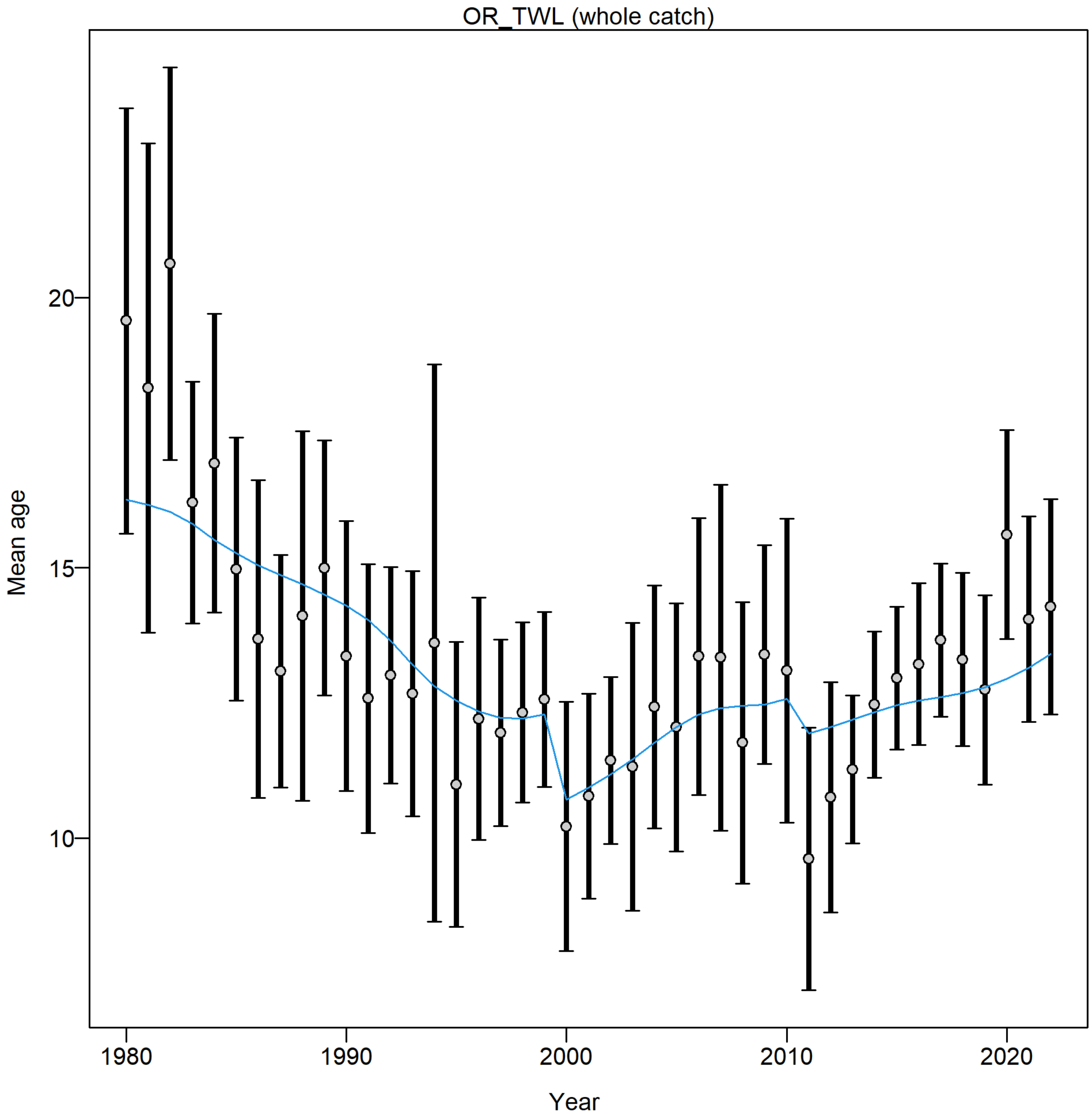

Figure 91: Mean age for the Oregon trawl fleet with 95 percent confidence intervals based on current samples sizes.

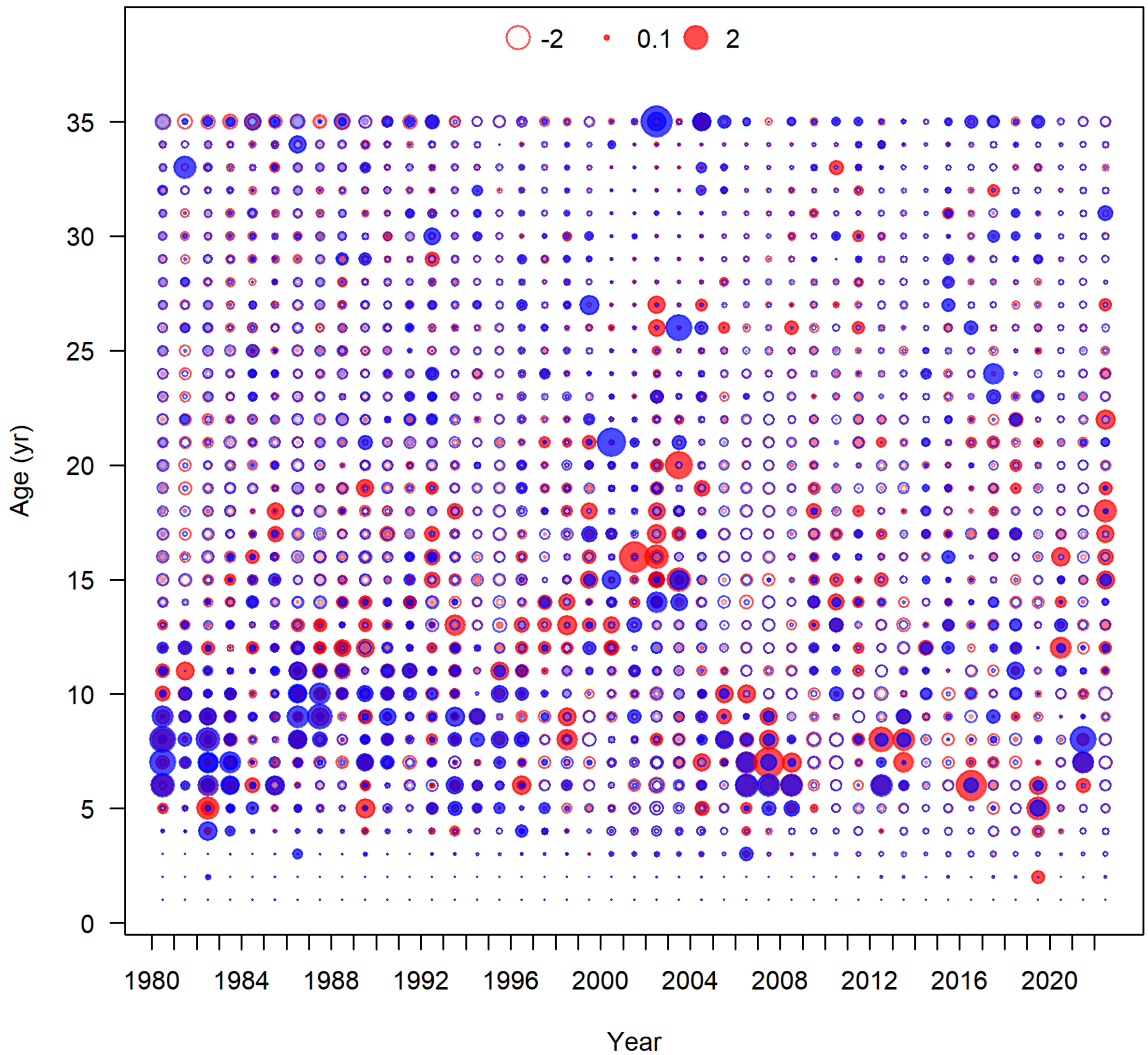

Figure 92: Pearson residuals for ages in the Washington trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

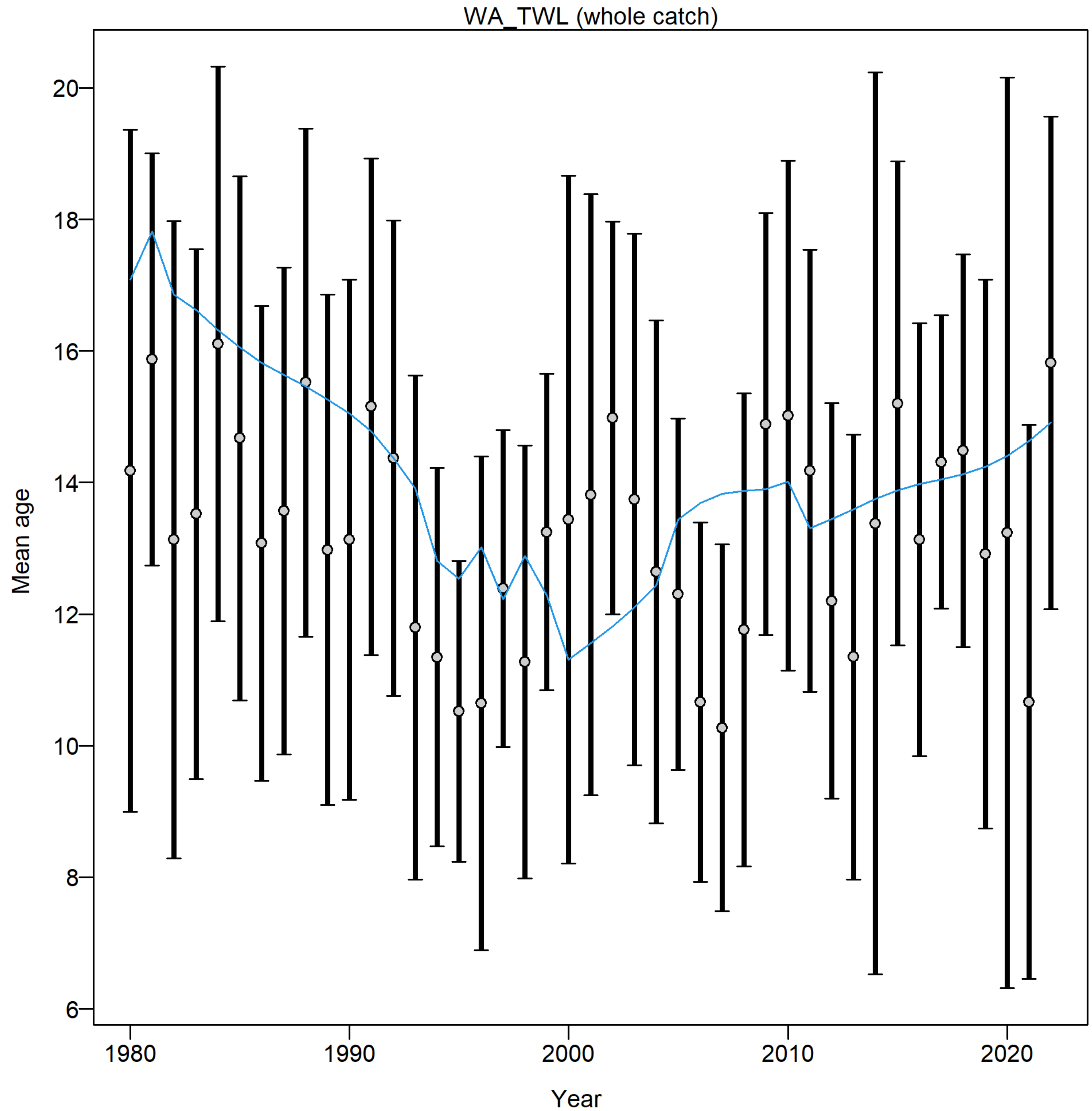

Figure 93: Mean age for the Washington trawl fleet with 95 percent confidence intervals based on current samples sizes.

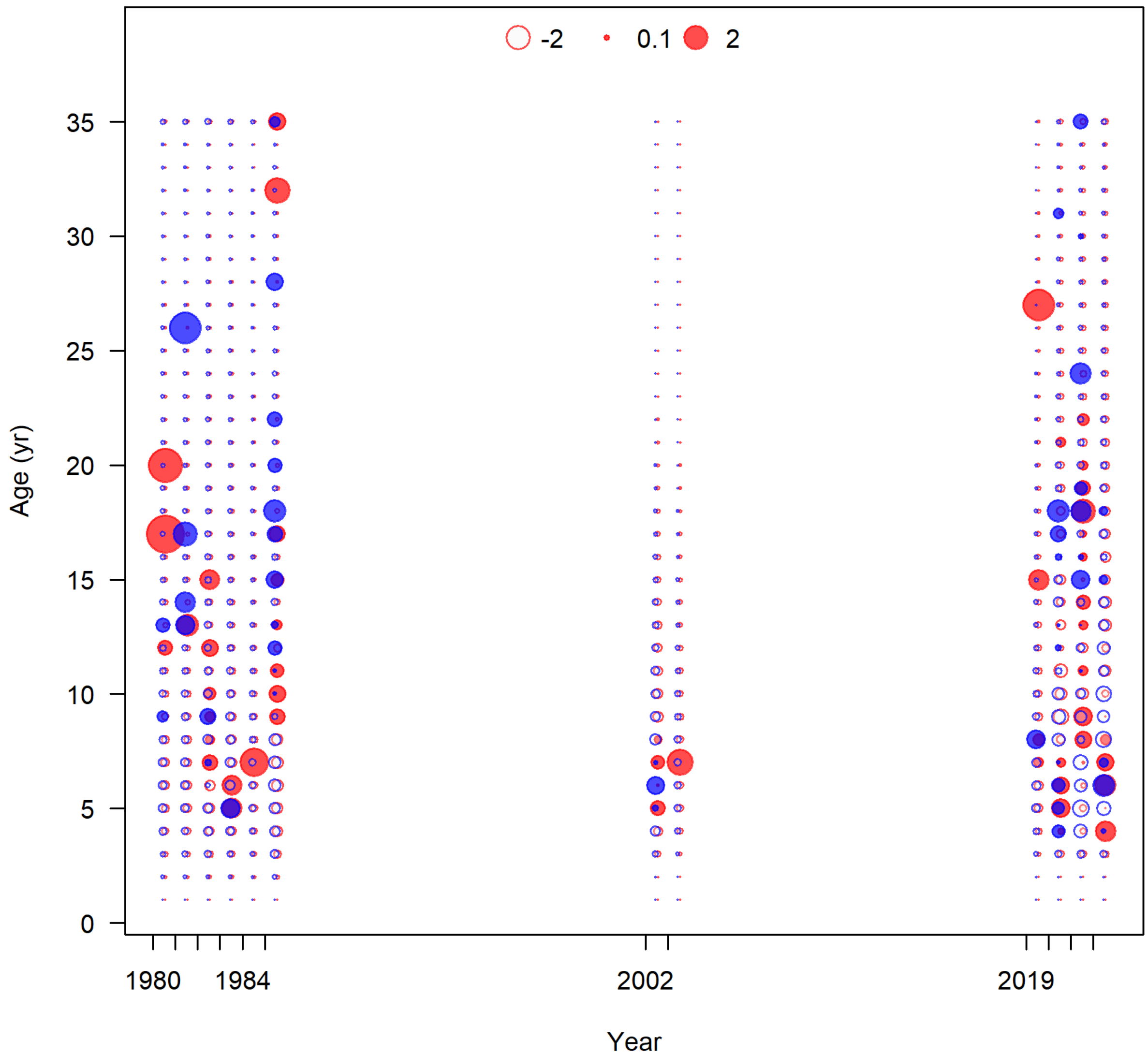

Figure 94: Pearson residuals for ages in the California non-trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

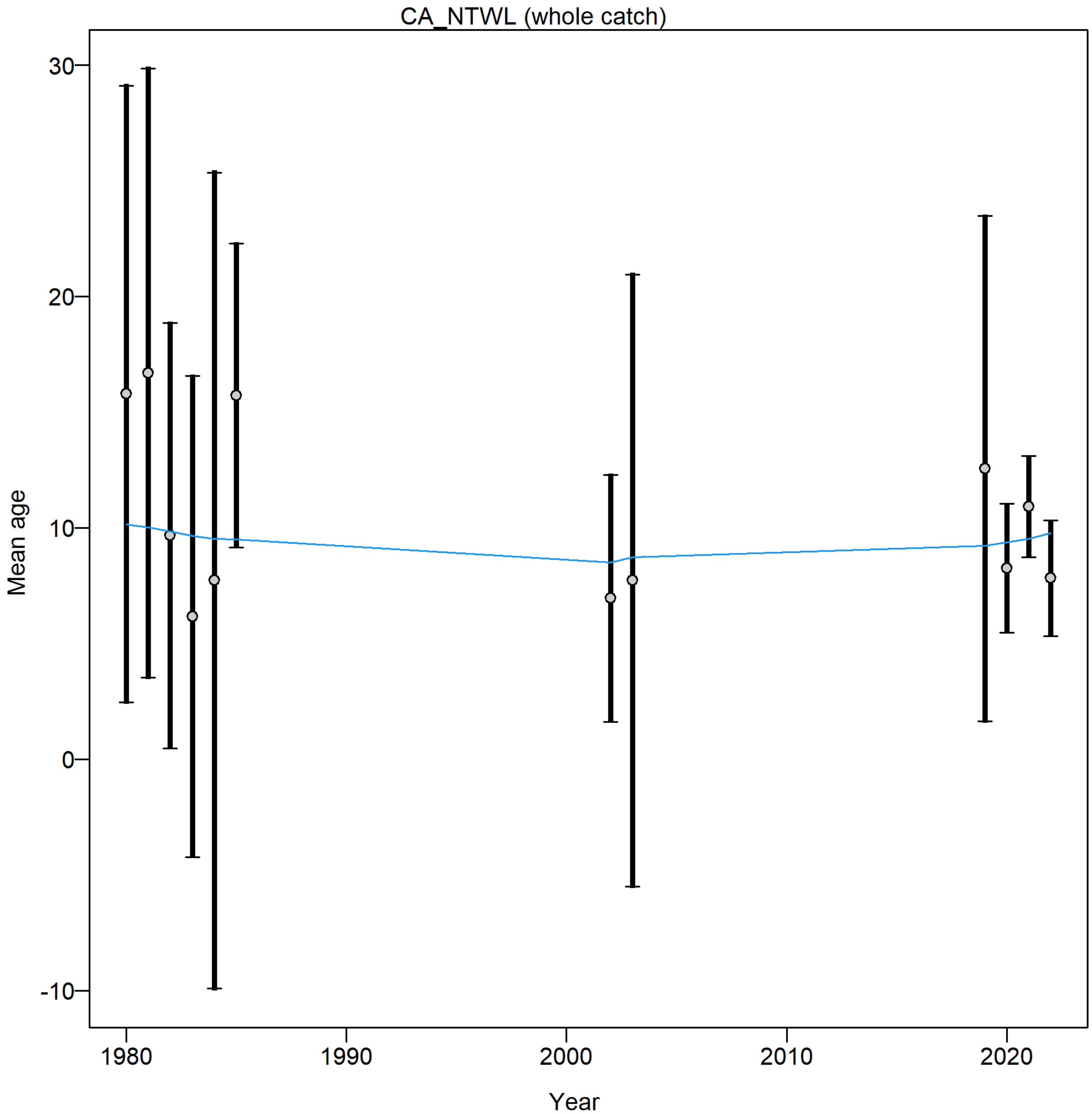

Figure 95: Mean age for the California non-trawl fleet with 95 percent confidence intervals based on current samples sizes.

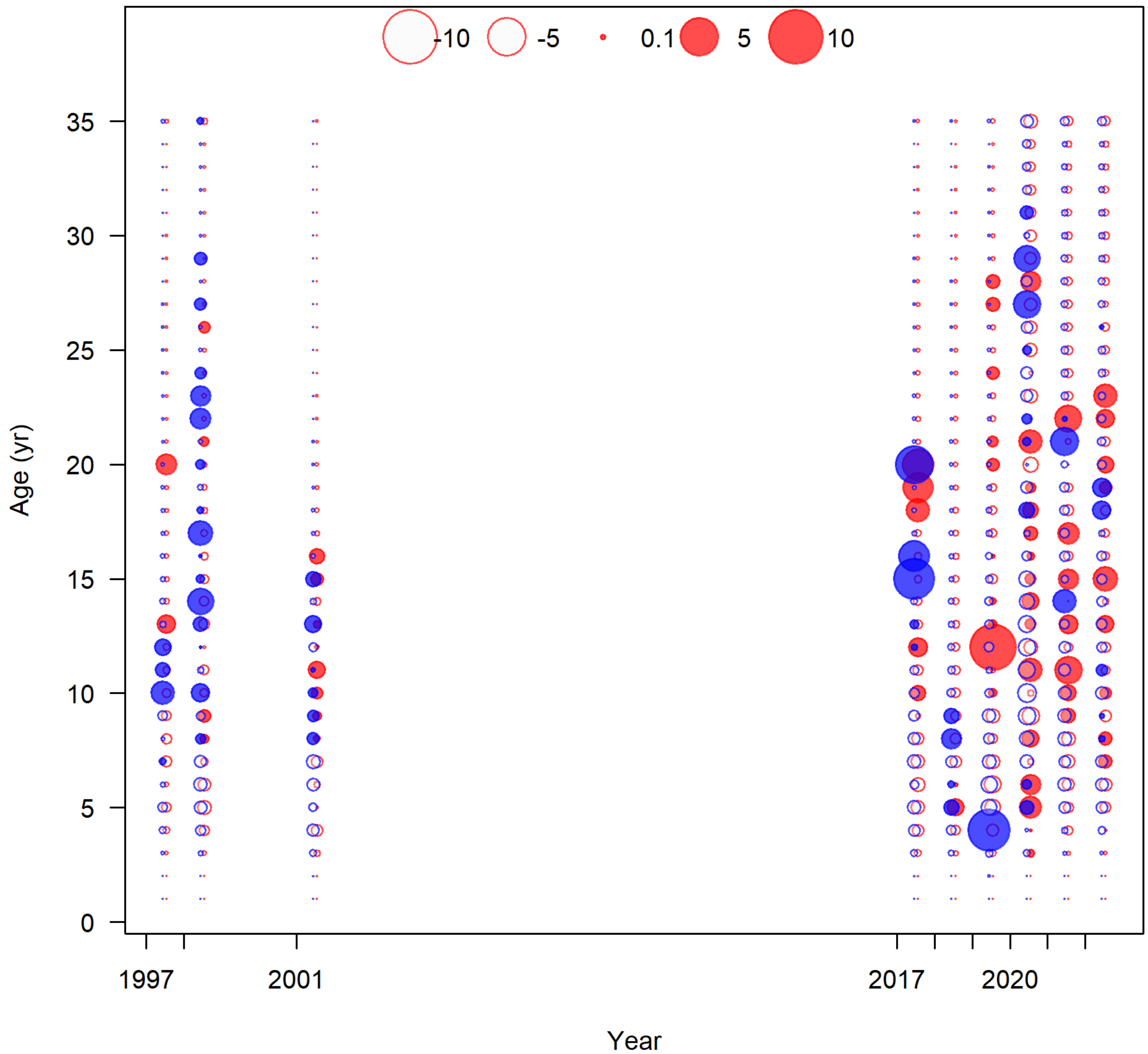

Figure 96: Pearson residuals for ages in the Oregon non-trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

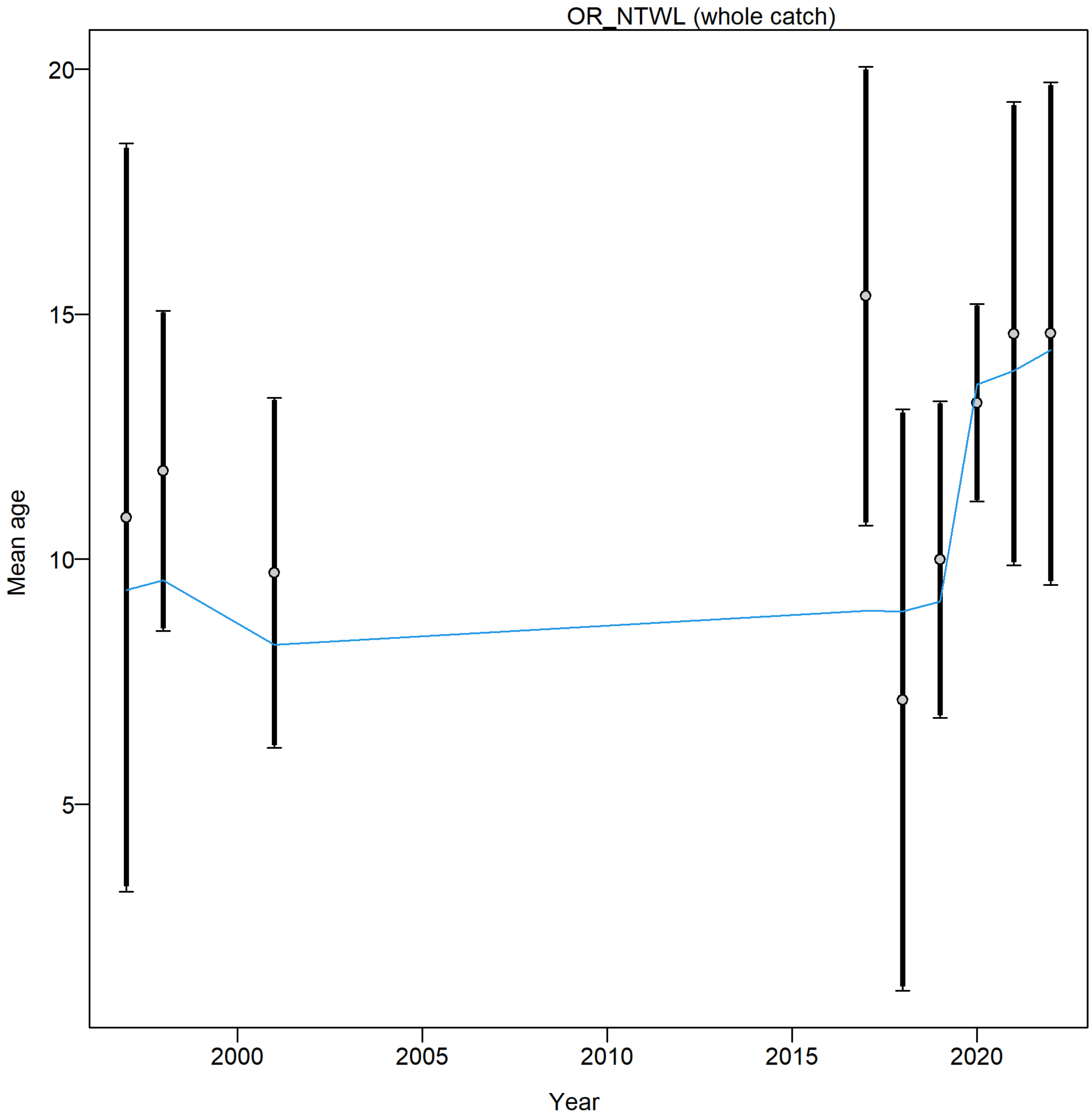

Figure 97: Mean age for the Oregon non-trawl fleet with 95 percent confidence intervals based on current samples sizes.

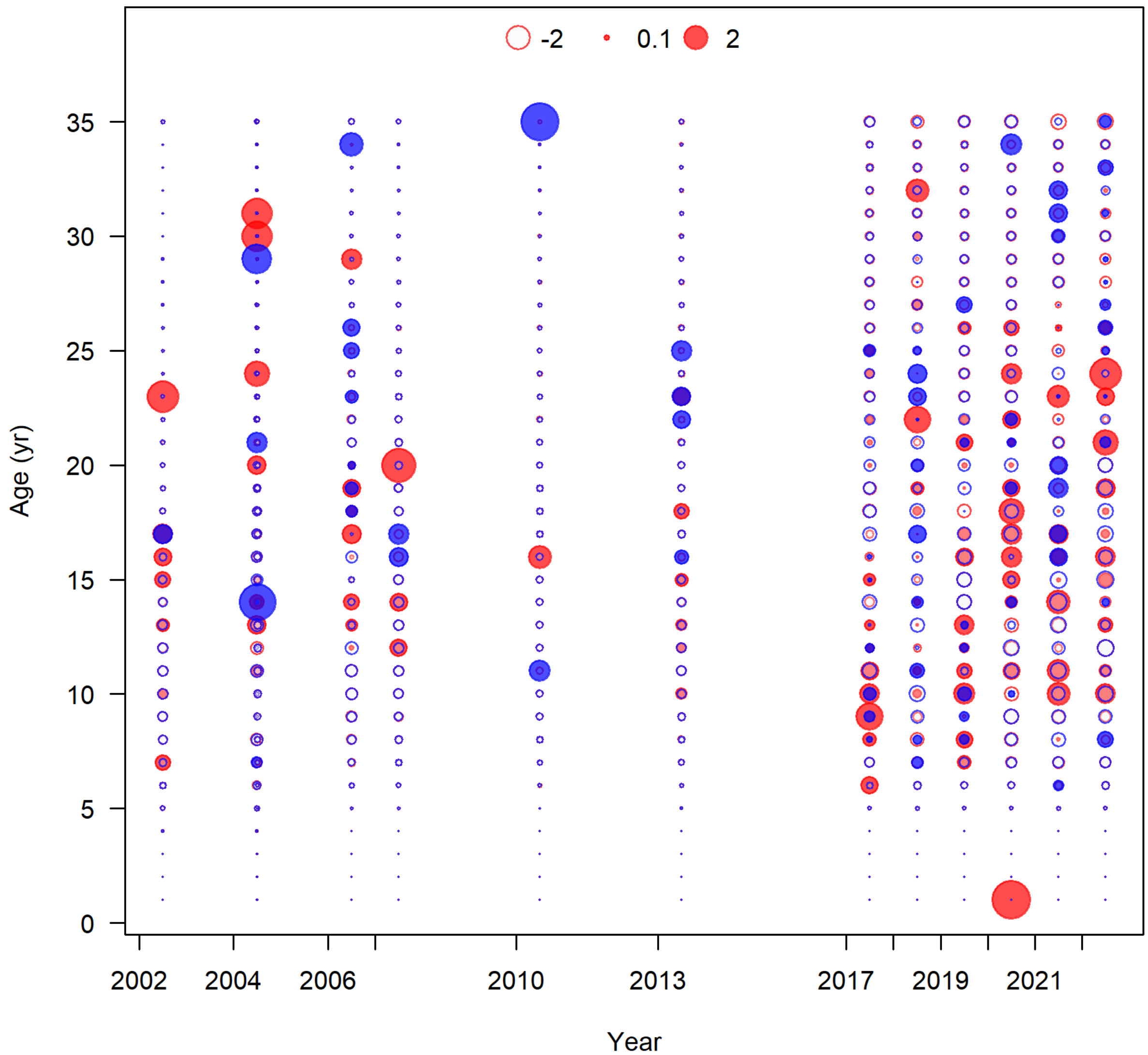

Figure 98: Pearson residuals for ages in the Washington non-trawl fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

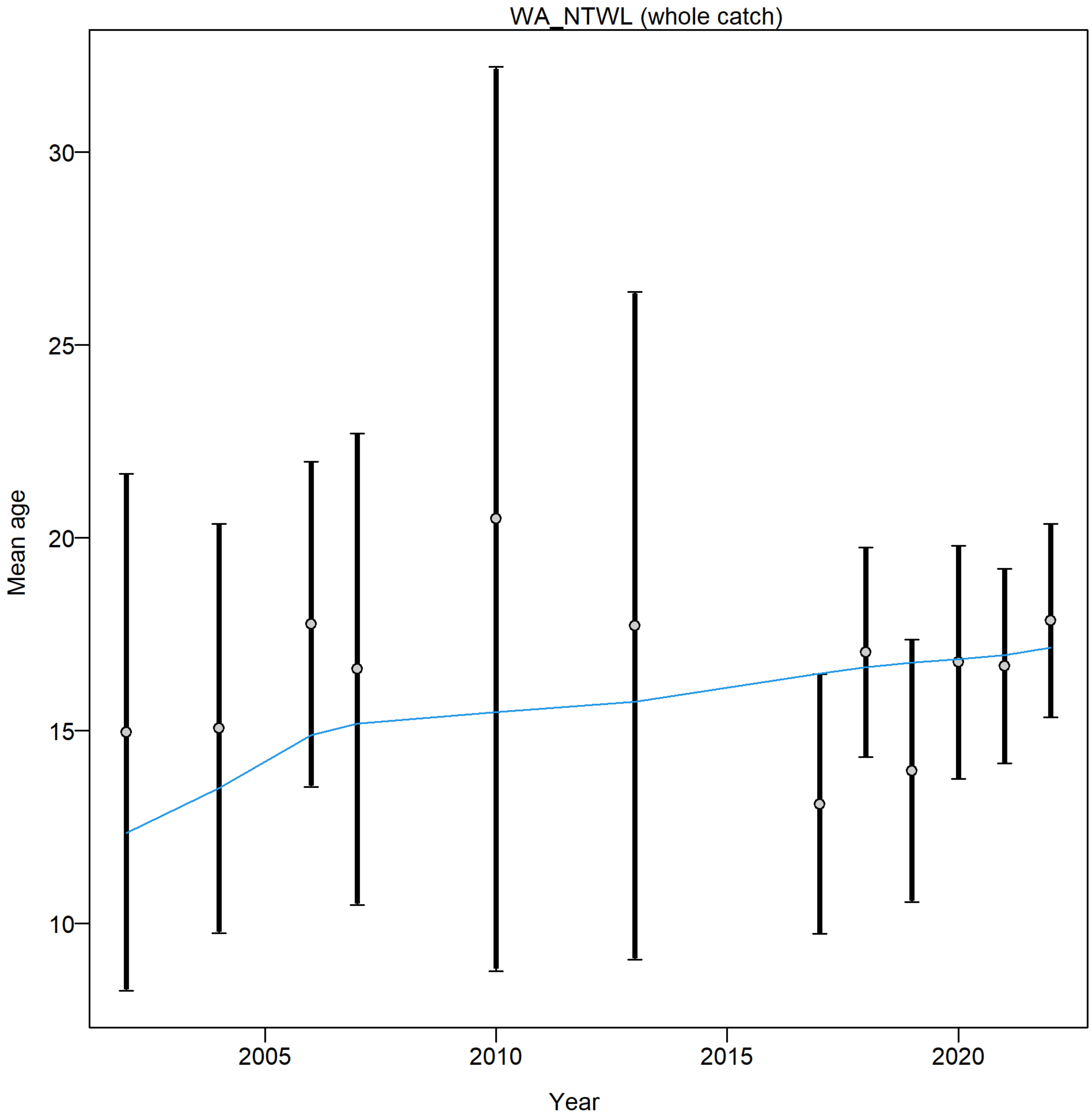

Figure 99: Mean age for the Washington non-trawl fleet with 95 percent confidence intervals based on current samples sizes.

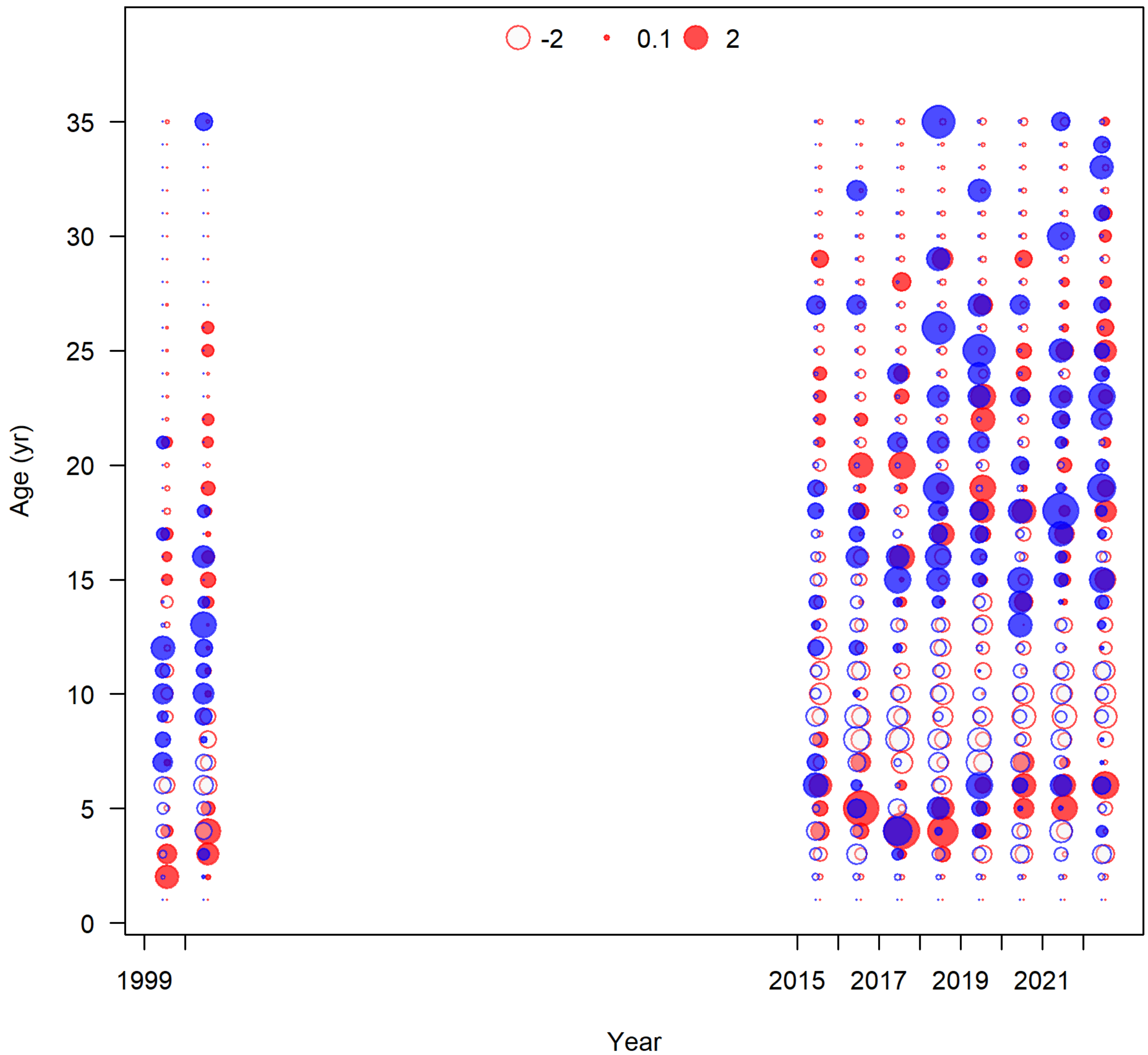

Figure 100: Pearson residuals for ages in the Oregon recreational fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

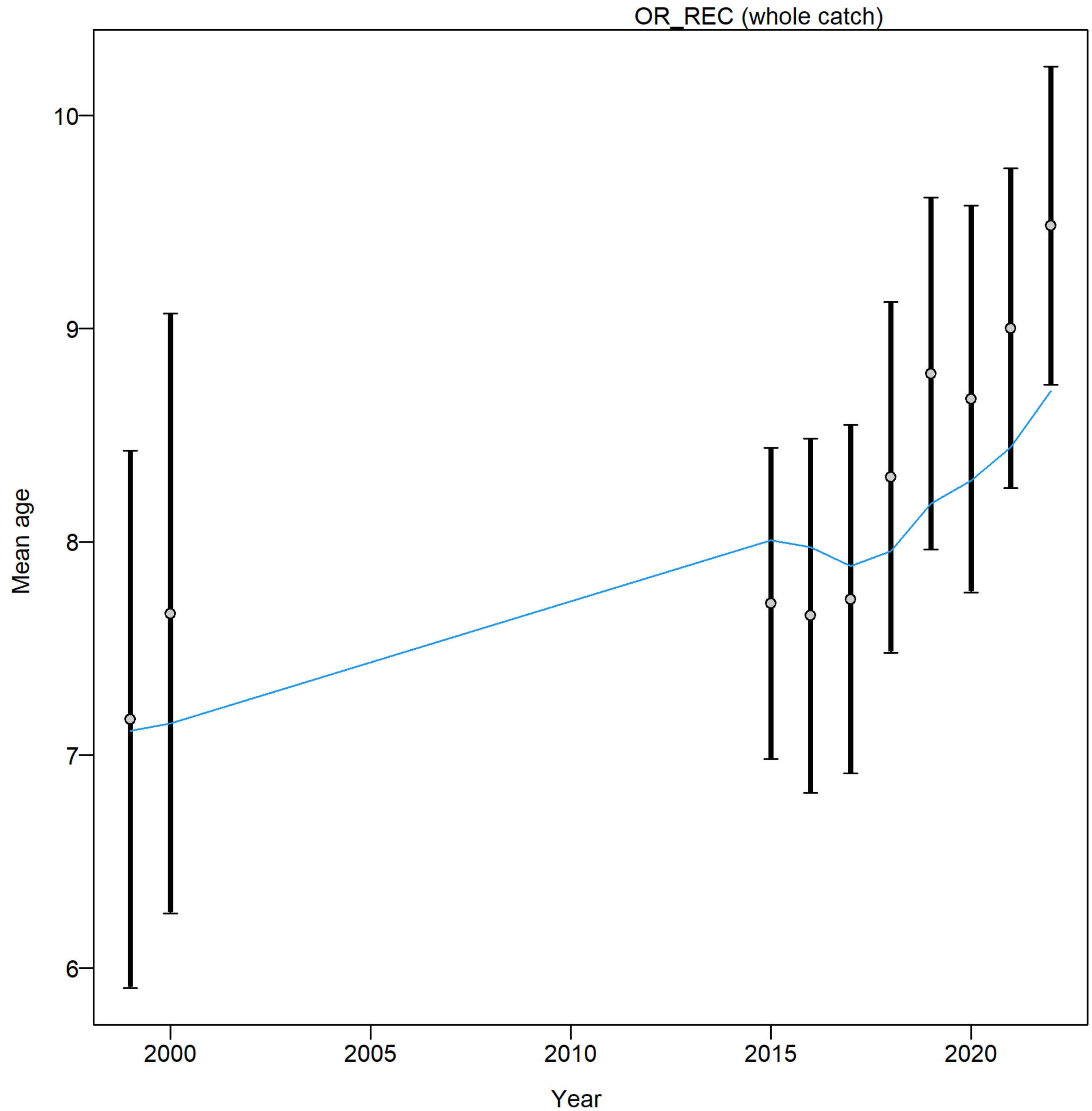

Figure 101: Mean age for the Oregon recreational fleet with 95 percent confidence intervals based on current samples sizes.

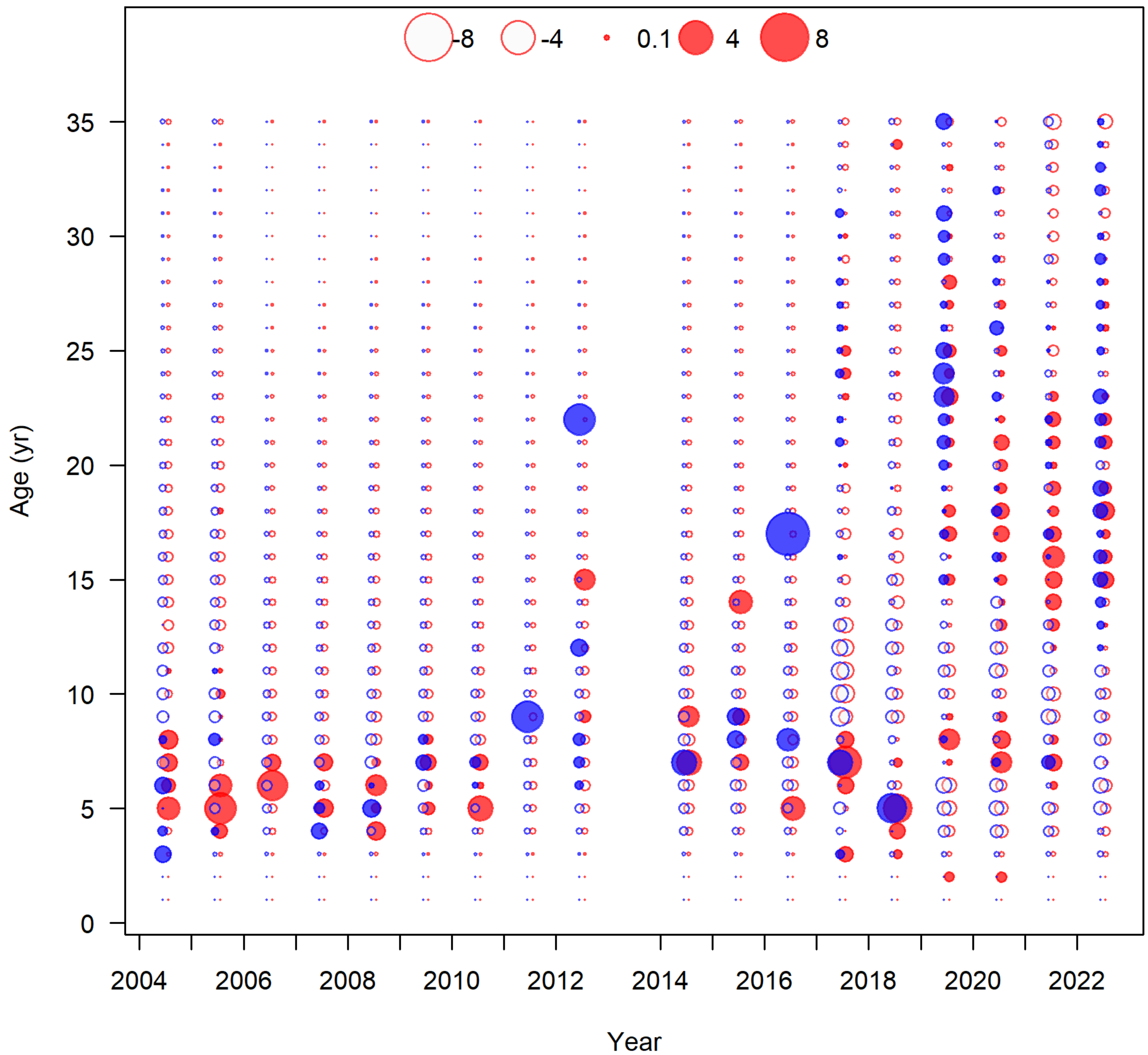

Figure 102: Pearson residuals for ages in the Washington recreational fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

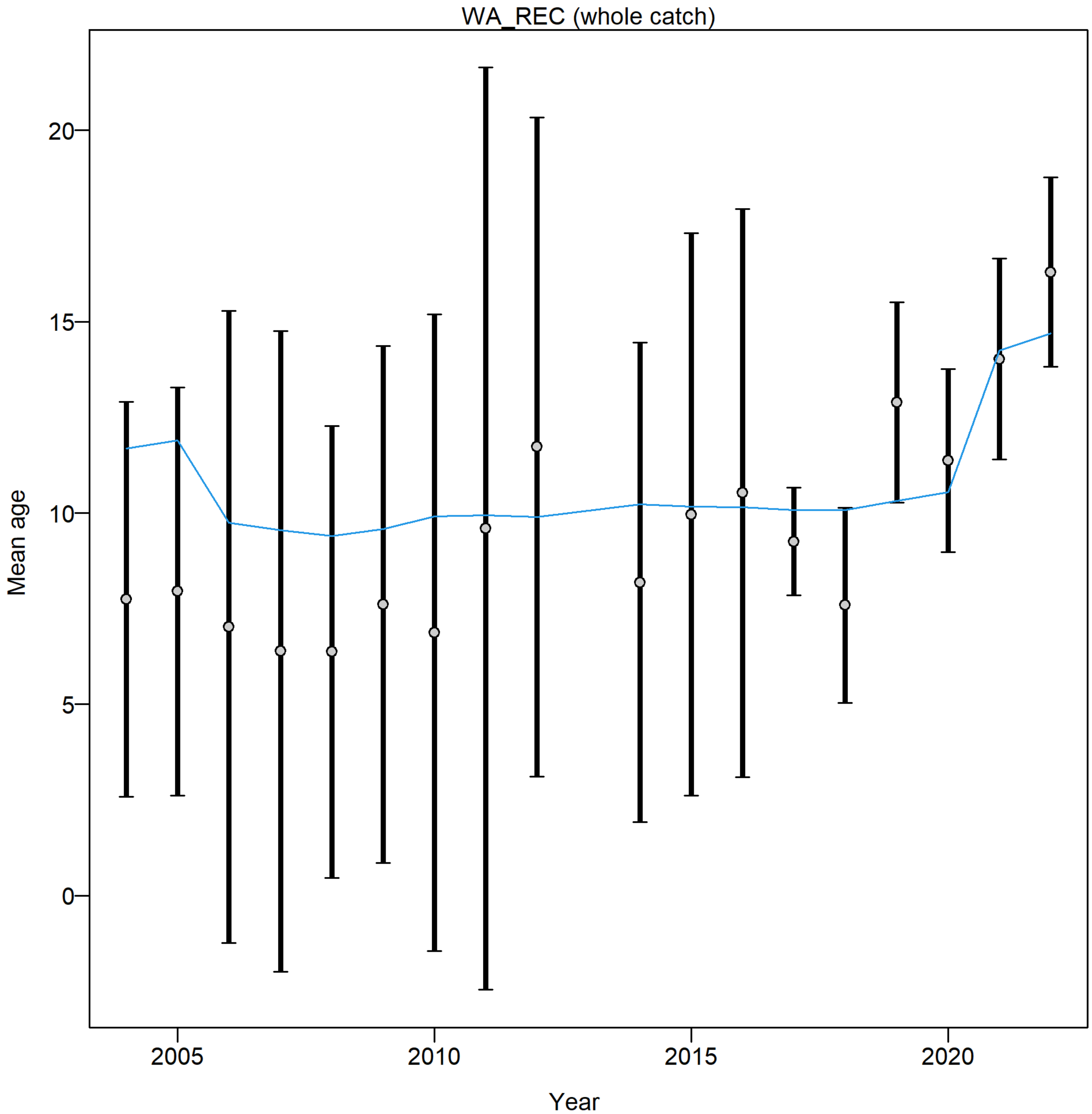

Figure 103: Mean age for the Washington recreational fleet with 95 percent confidence intervals based on current samples sizes.

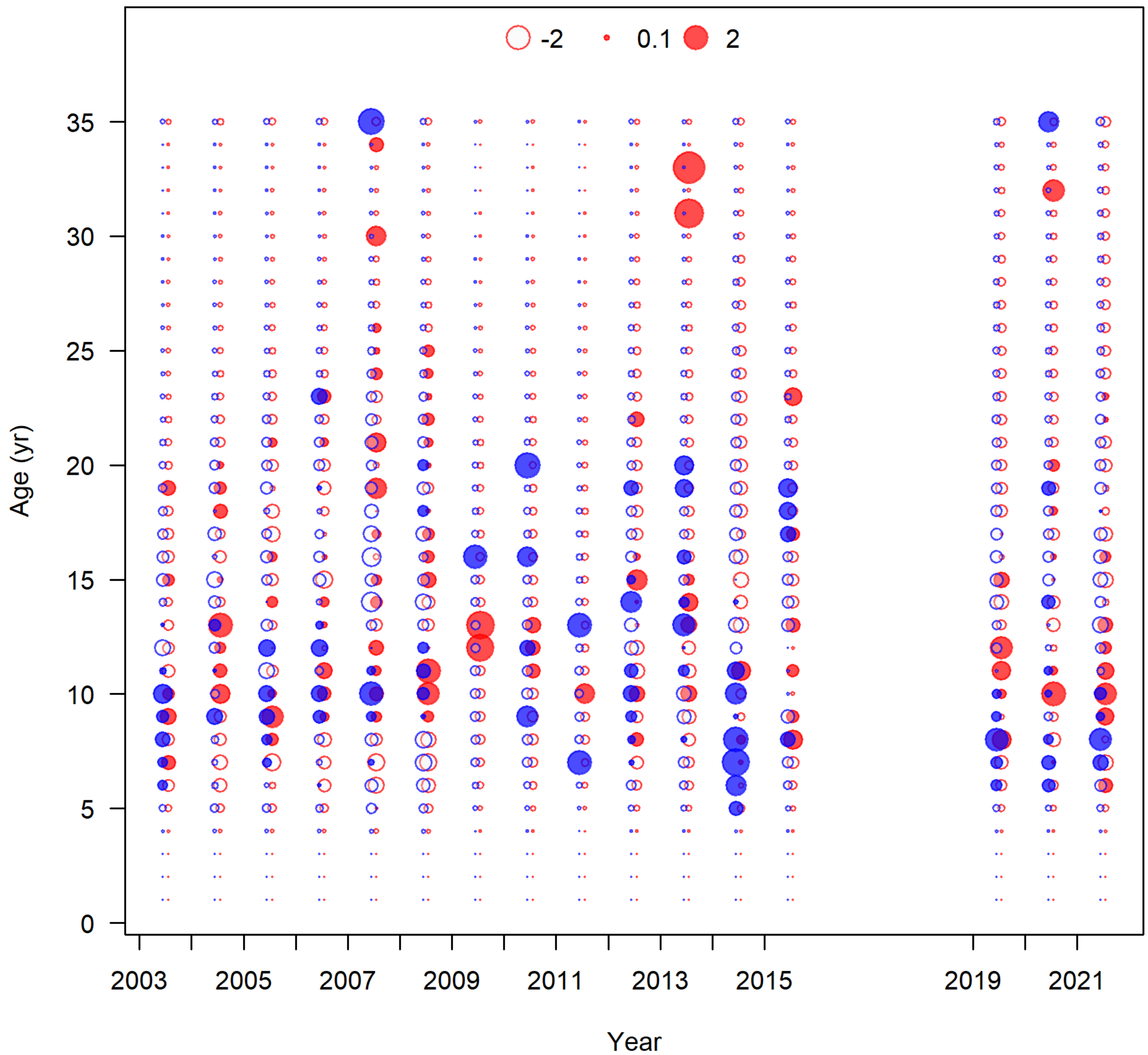

Figure 104: Pearson residuals for ages in the Oregon at-sea hake fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

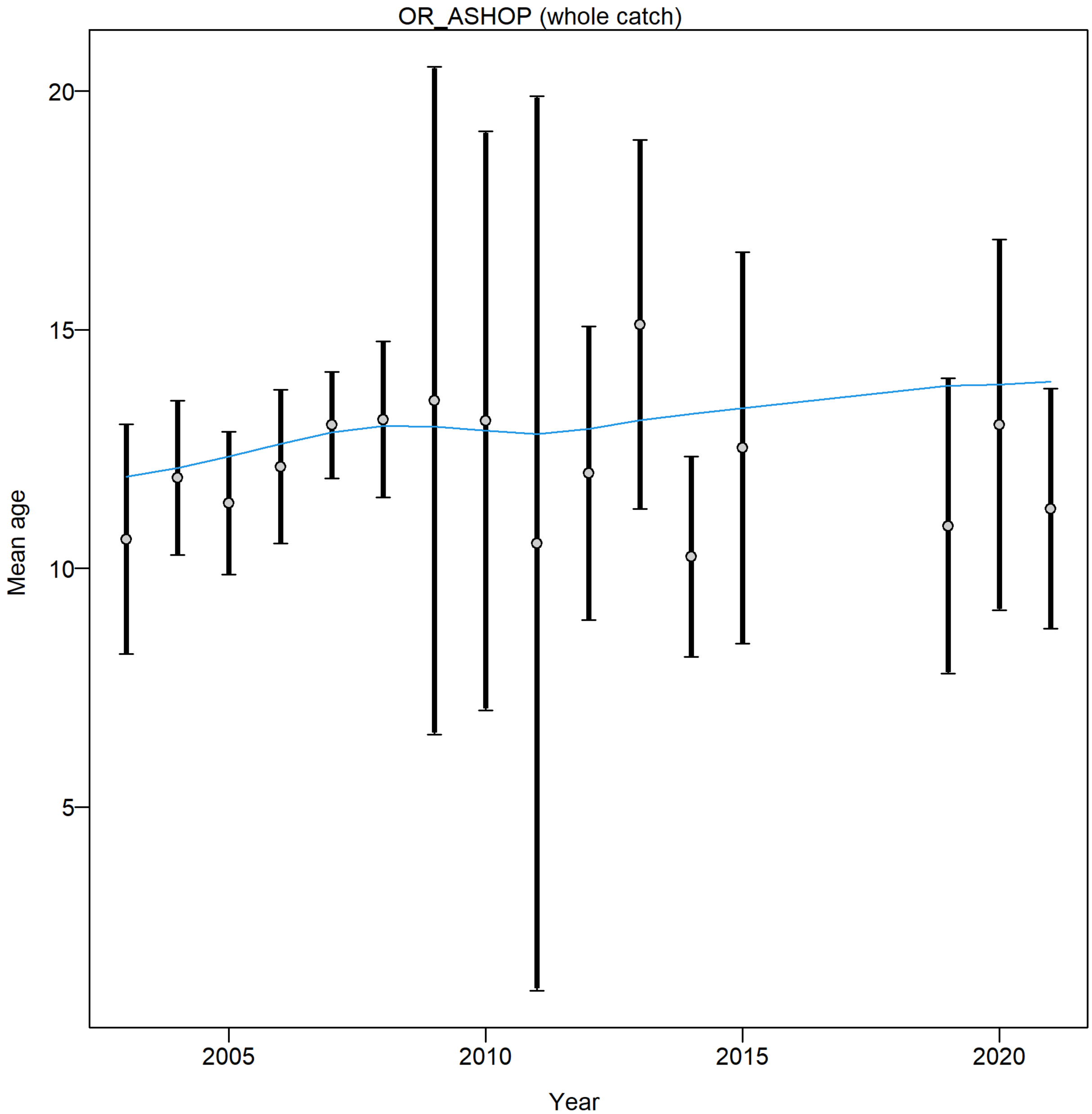

Figure 105: Mean age for the Oregon at-sea hake fleet with 95 percent confidence intervals based on current samples sizes.

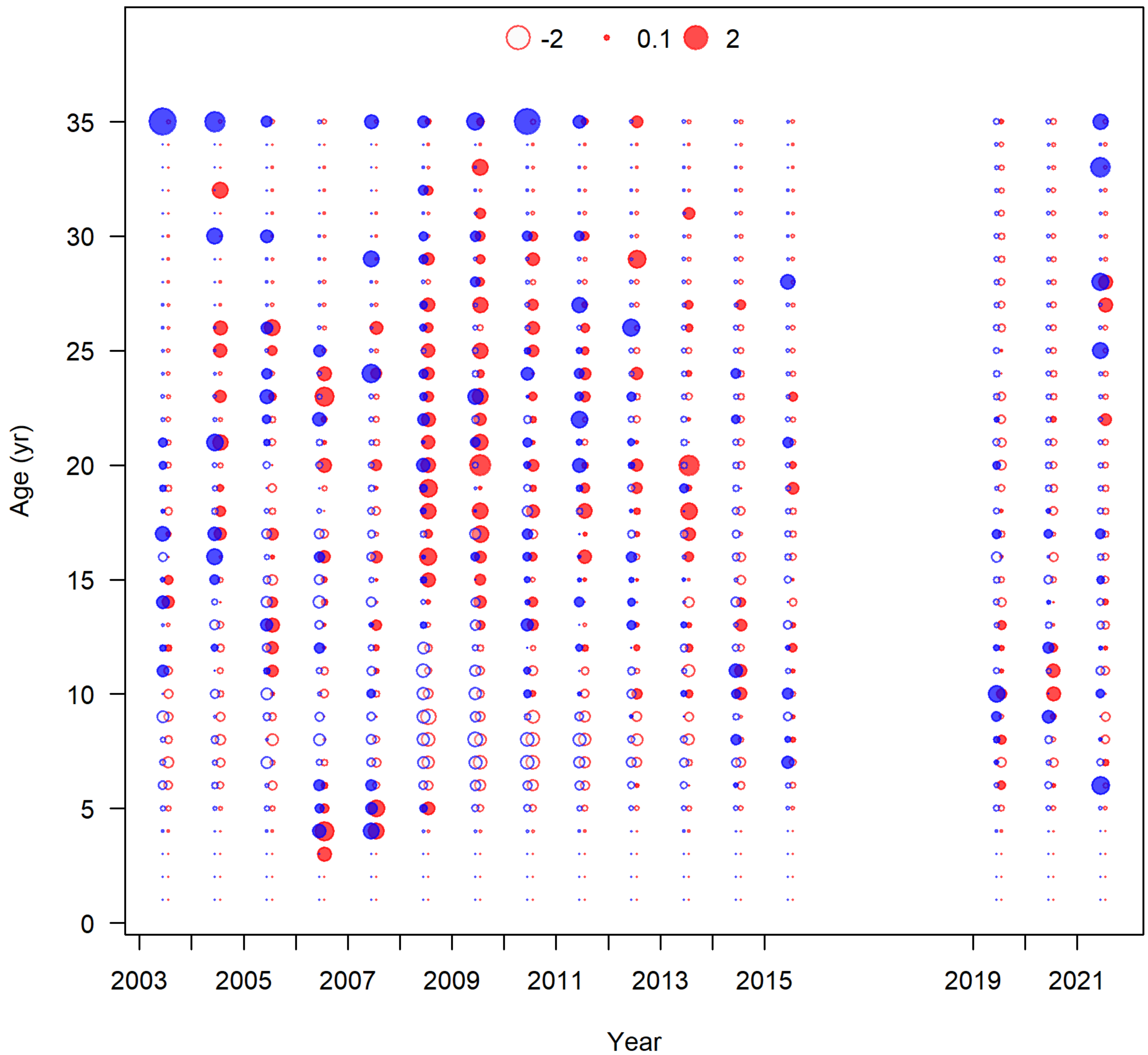

Figure 106: Pearson residuals for ages in the Washington at-sea hake fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) for females (red) and males (blue).

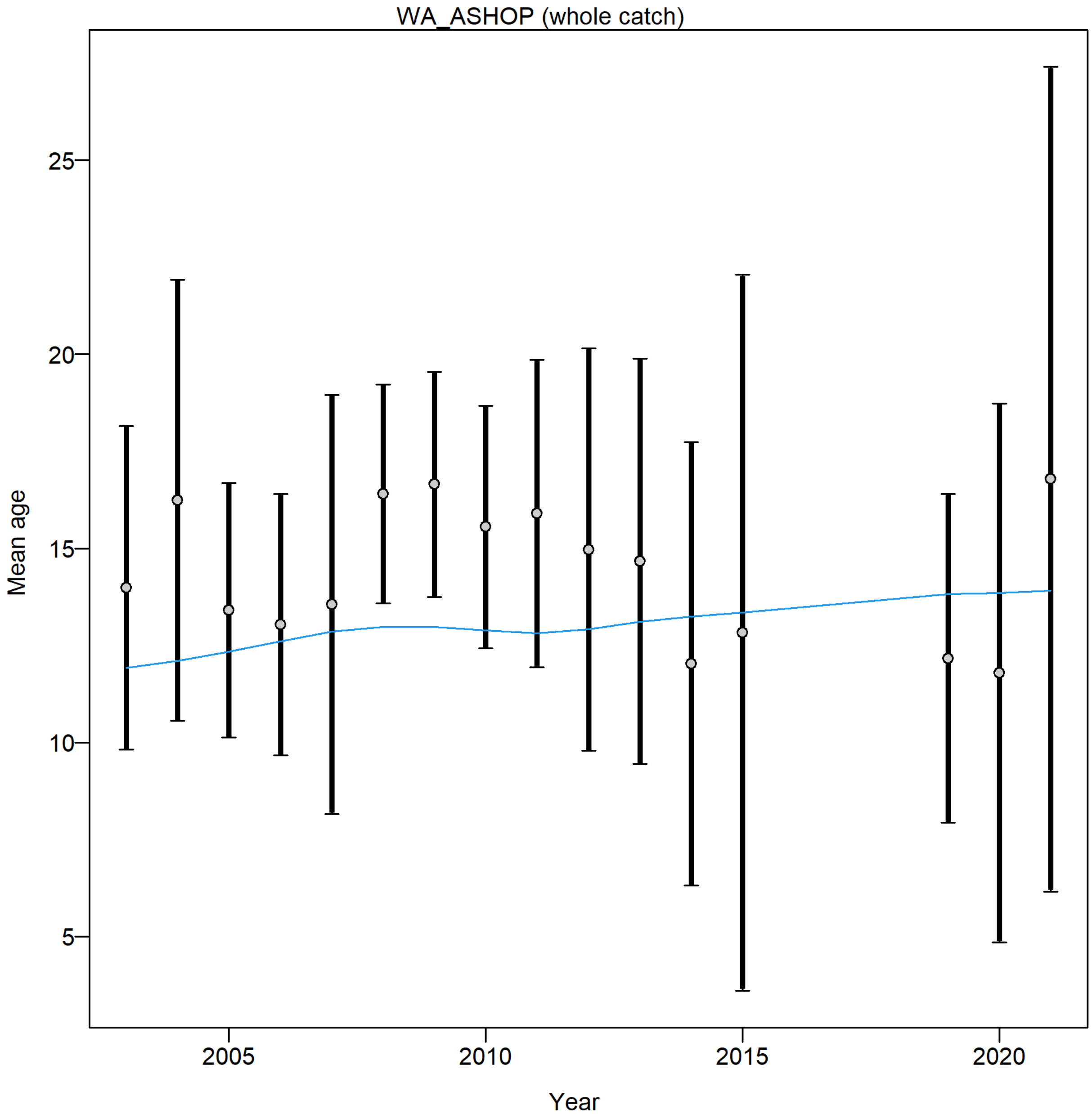

Figure 107: Mean age for the Washington at-sea hake fleet with 95 percent confidence intervals based on current samples sizes.

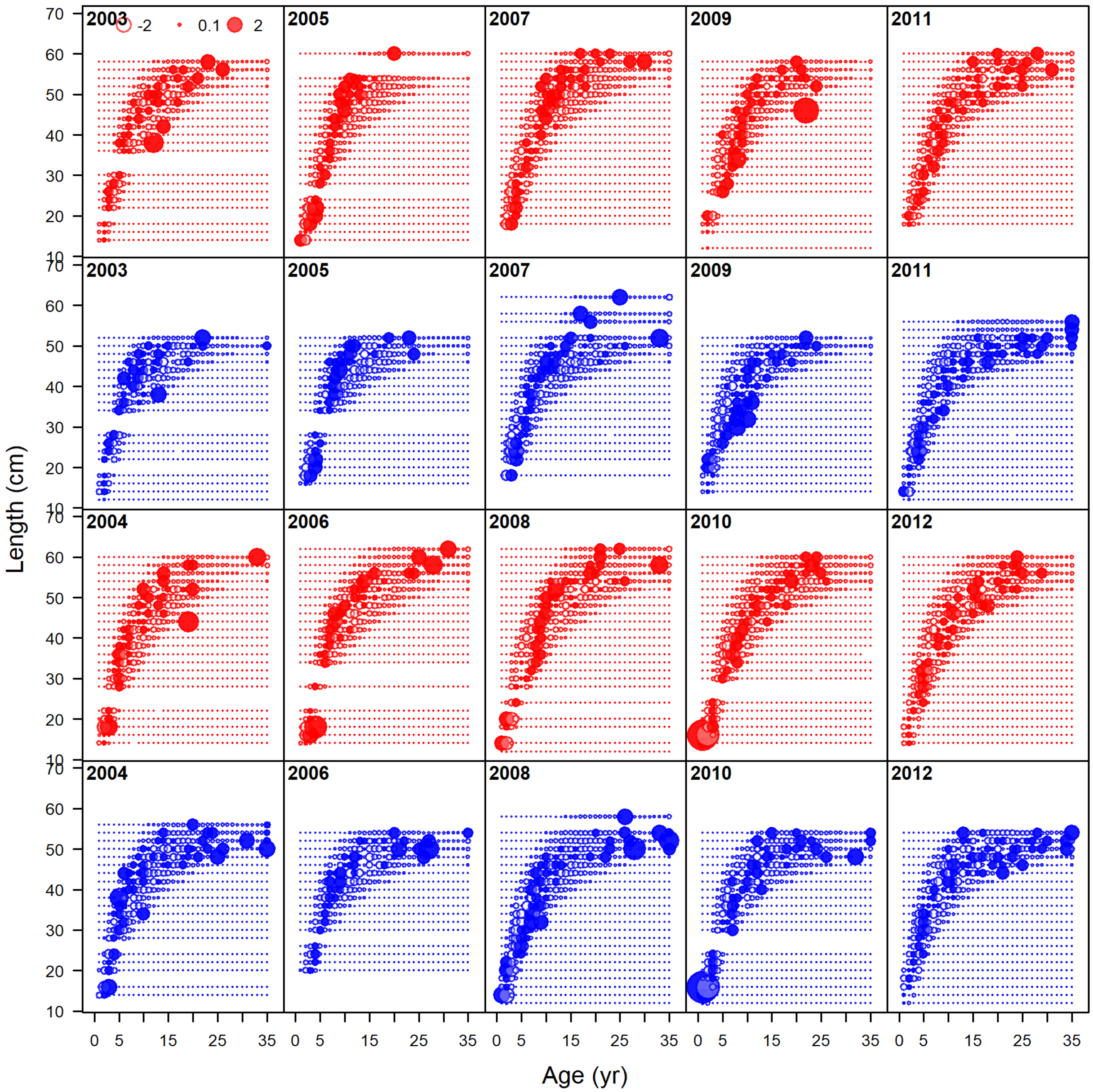

Figure 108: Pearson residuals for conditional age-at-length in the West Coast Groundfish Bottomtrawl Survey (plot 1 of 2). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) and are separate for each sex (red female, and blue male).

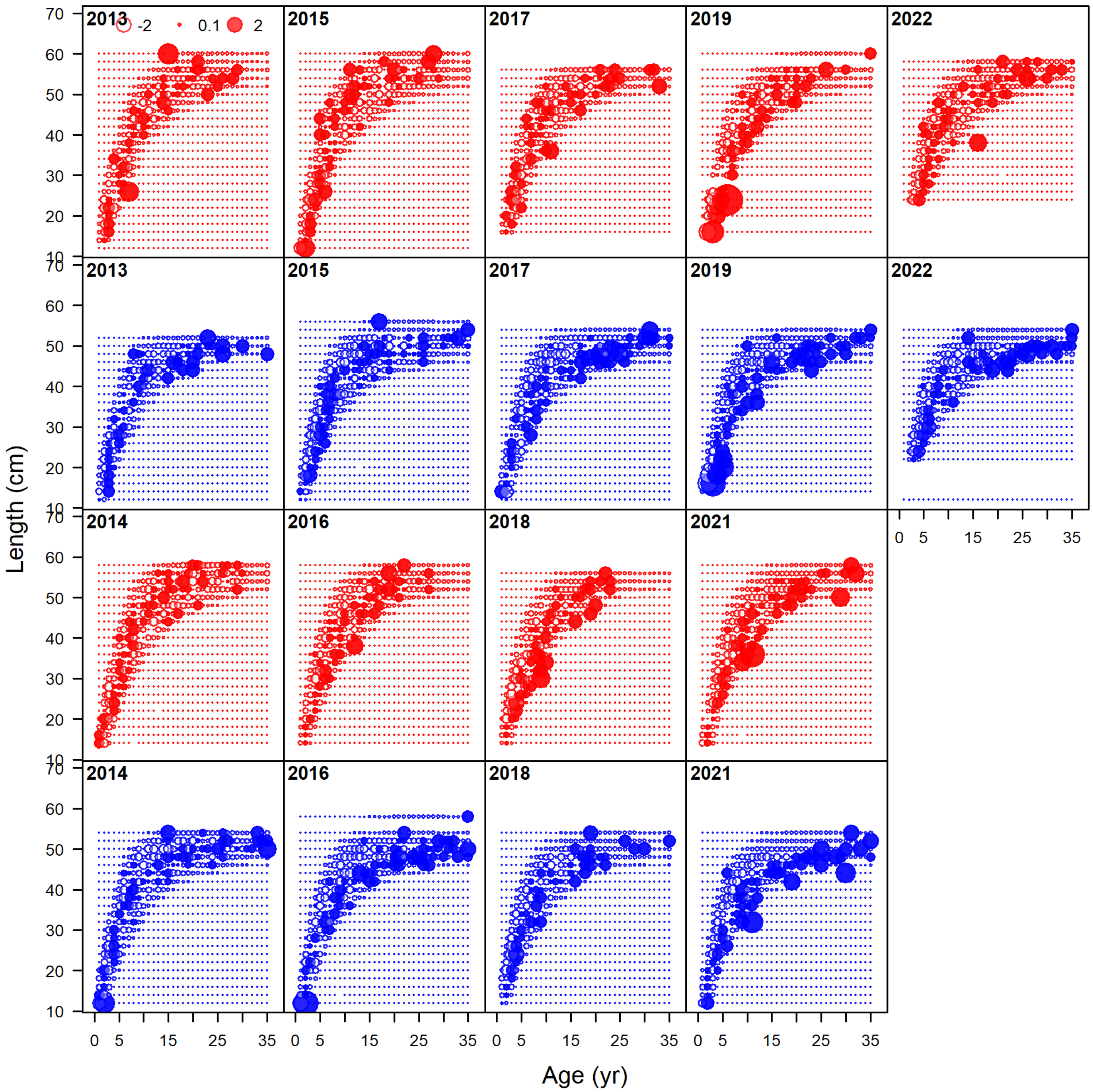

Figure 109: Pearson residuals for conditional age-at-length in the West Coast Groundfish Bottomtrawl Survey (plot 2 of 2). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) and are separate for each sex (red female, and blue male).

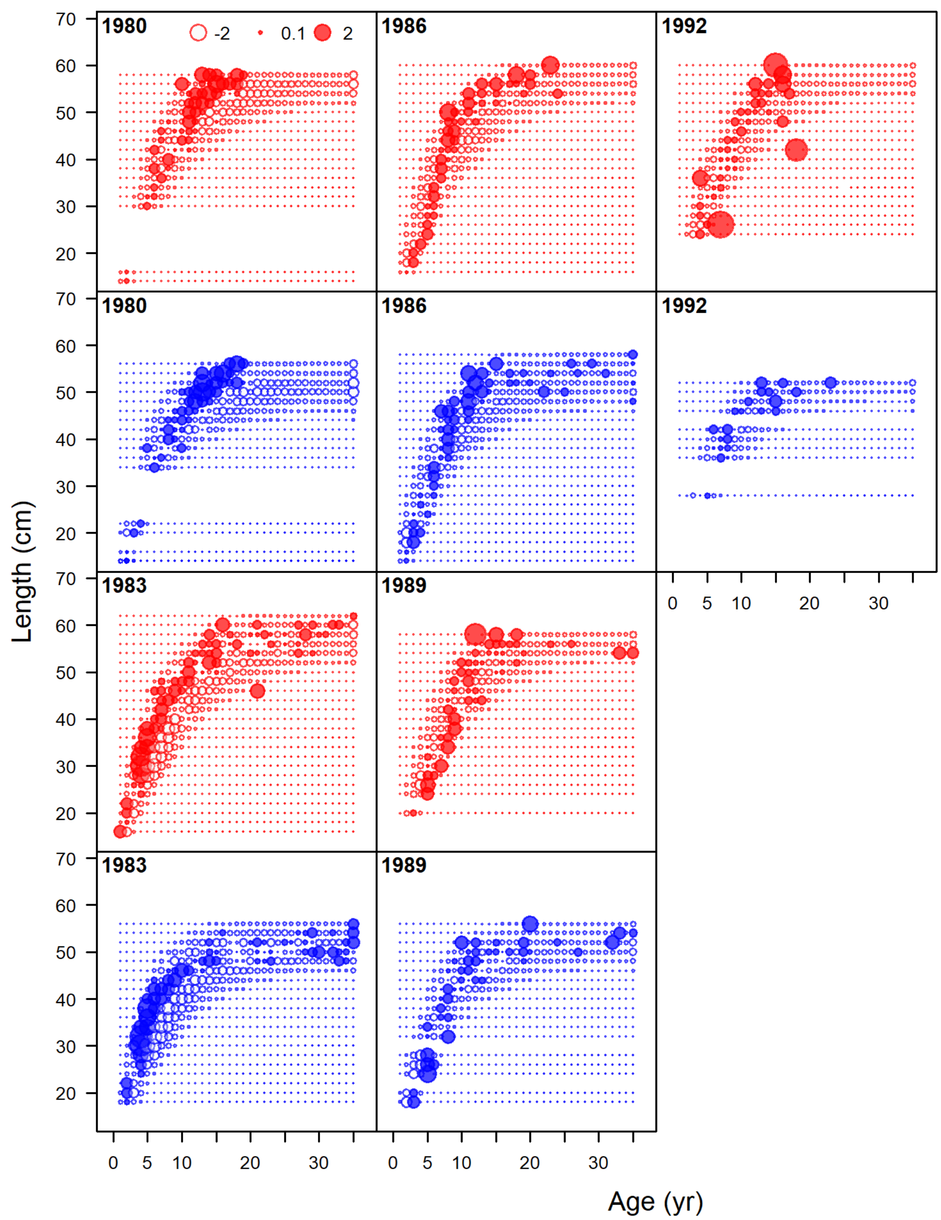

Figure 110: Pearson residuals for conditional age-at-length in the early Triennial survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) and are separate for each sex (red female, and blue male).

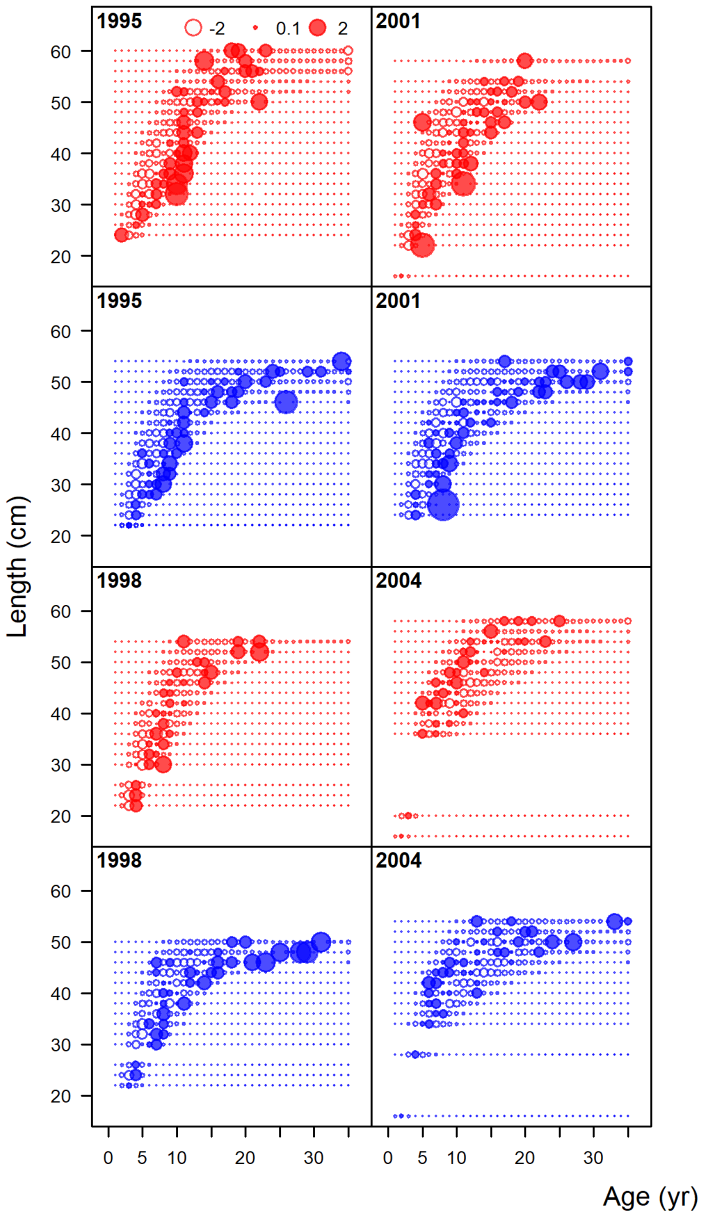

Figure 111: Pearson residuals for conditional age-at-length in the late Triennial survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected) and are separate for each sex (red female, and blue male).

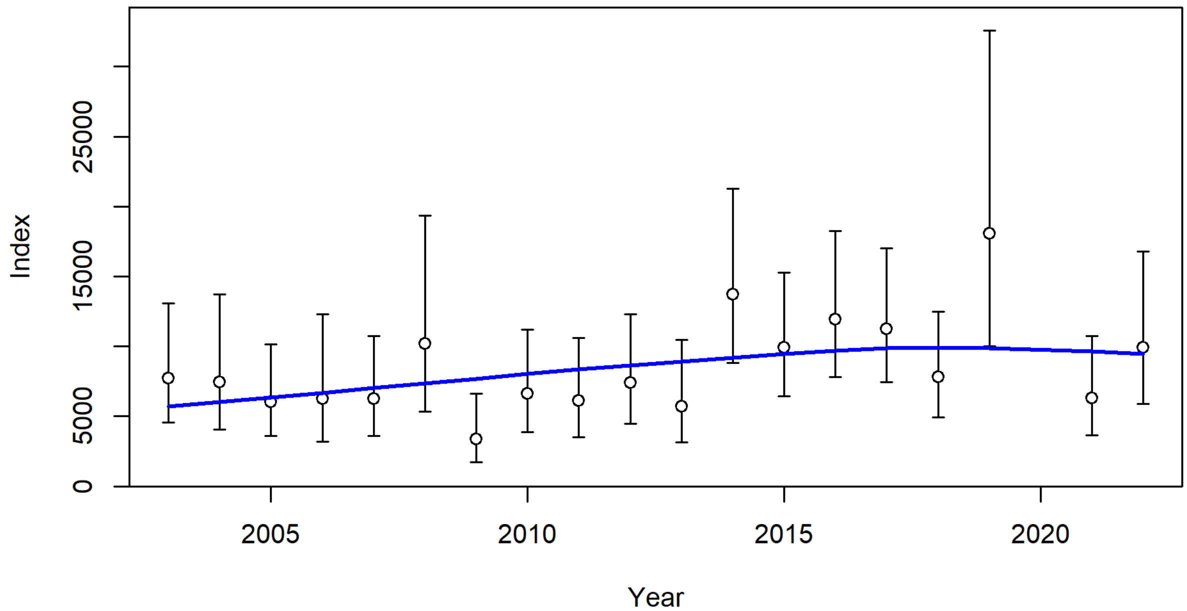

Figure 112: Fit of model to WCGBTS. Lines represent input 95 percent confidence interval of survey index.

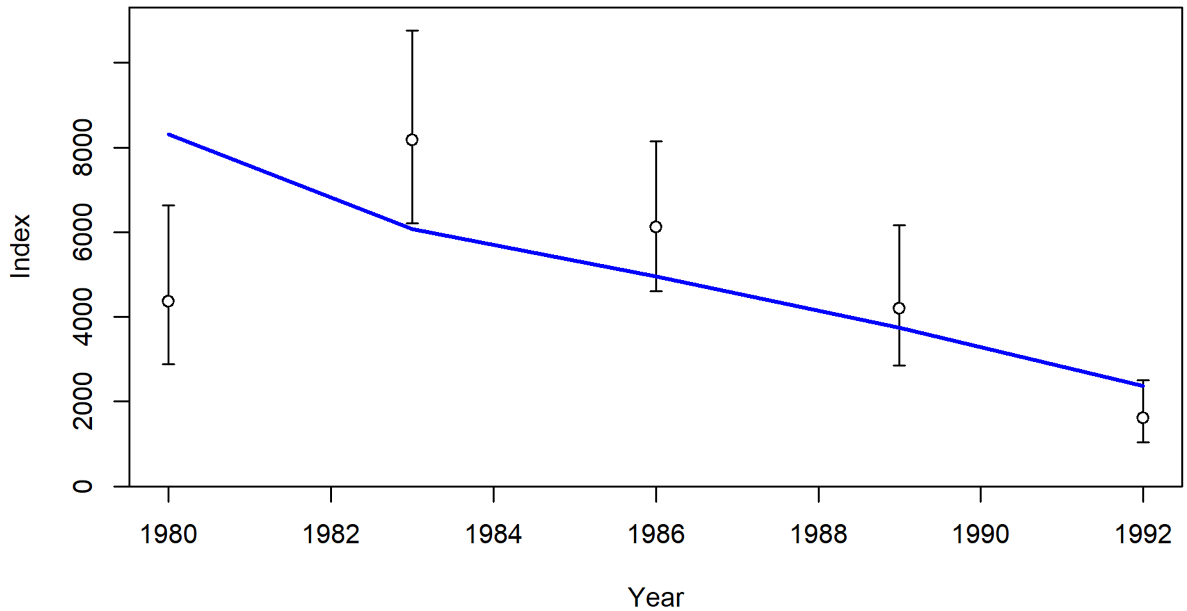

Figure 113: Fit of model to early Triennial Survey. Lines represent input 95 percent confidence interval of survey index.

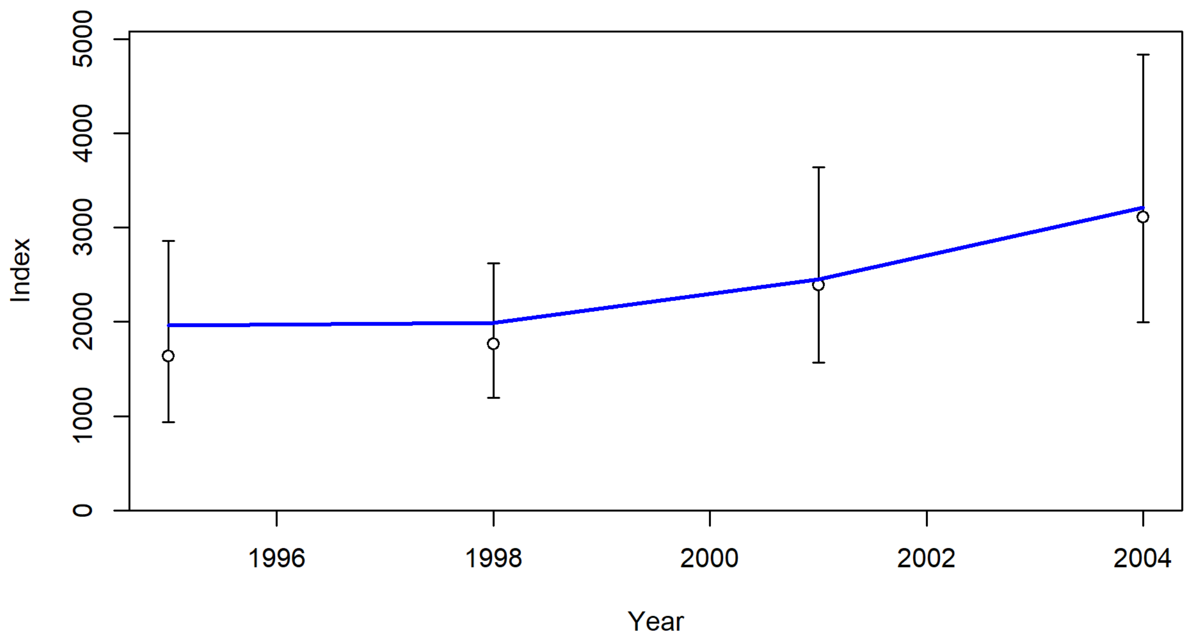

Figure 114: Fit of model to late Triennial Survey. Lines represent input 95 percent confidence interval of survey index.

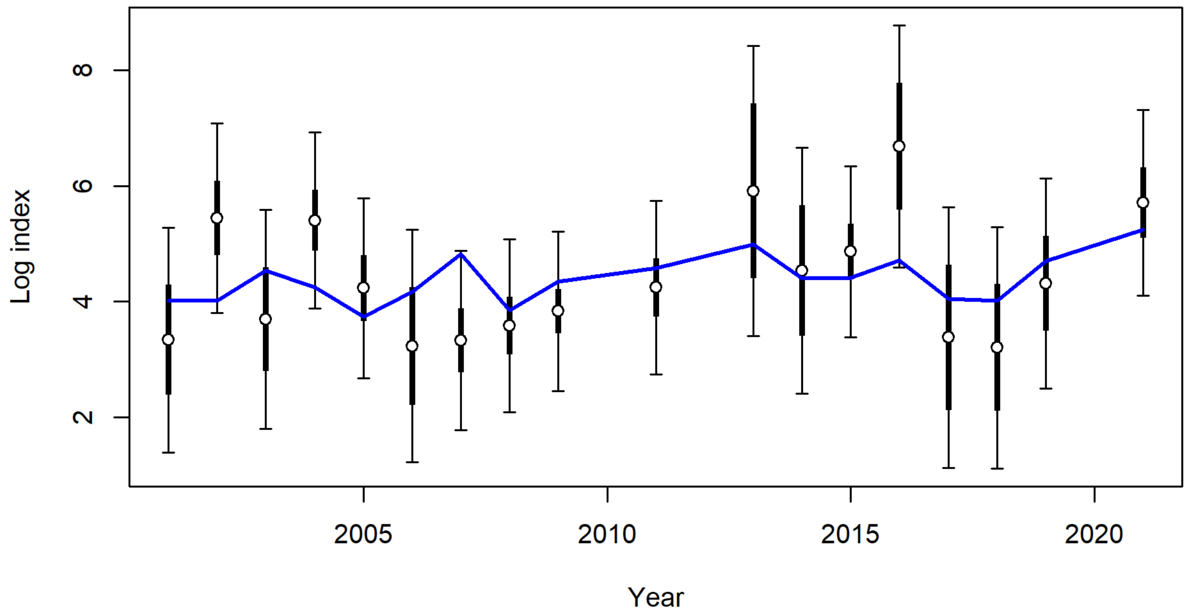

Figure 115: Fit of model to log of pre-recruit survey index. Log scale is shown because model fits were difficult to evaluate on absolute index scale. Thick lines represent input 95 percent confidence intervals. Thin lines are 95 percent confidence intervals including estimated added survey standard deviation.

8.3.5 Time series

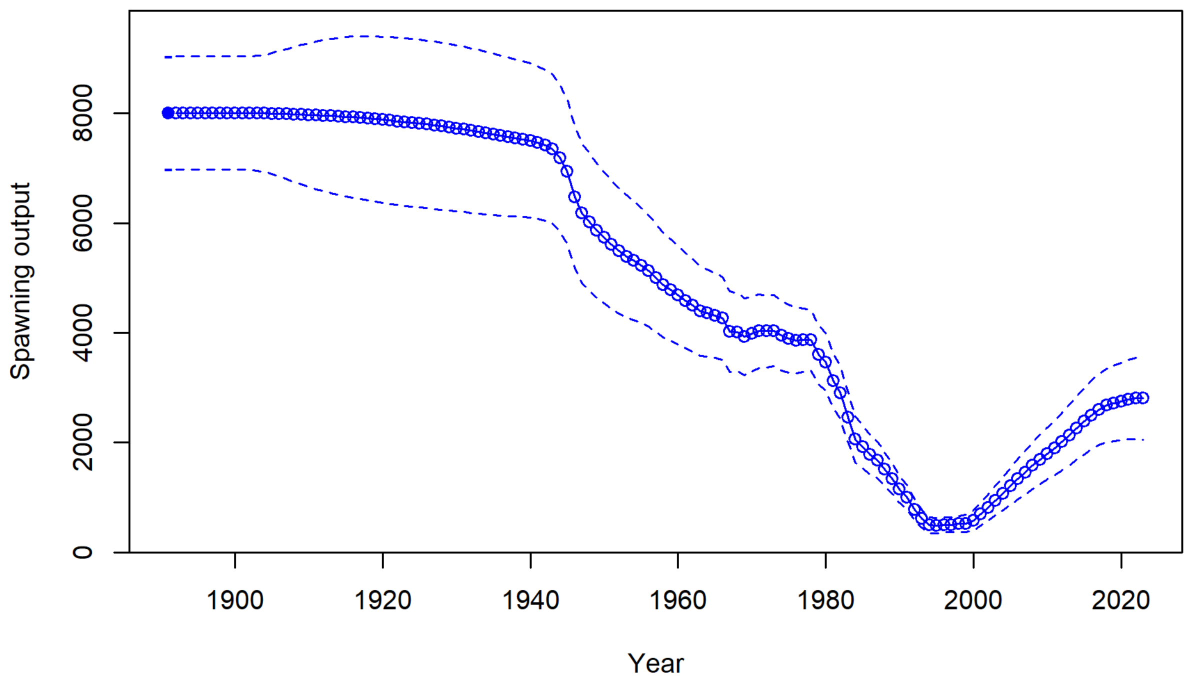

Figure 116: Estimated time series of spawning output in million of eggs with 95 percent confidence interval.

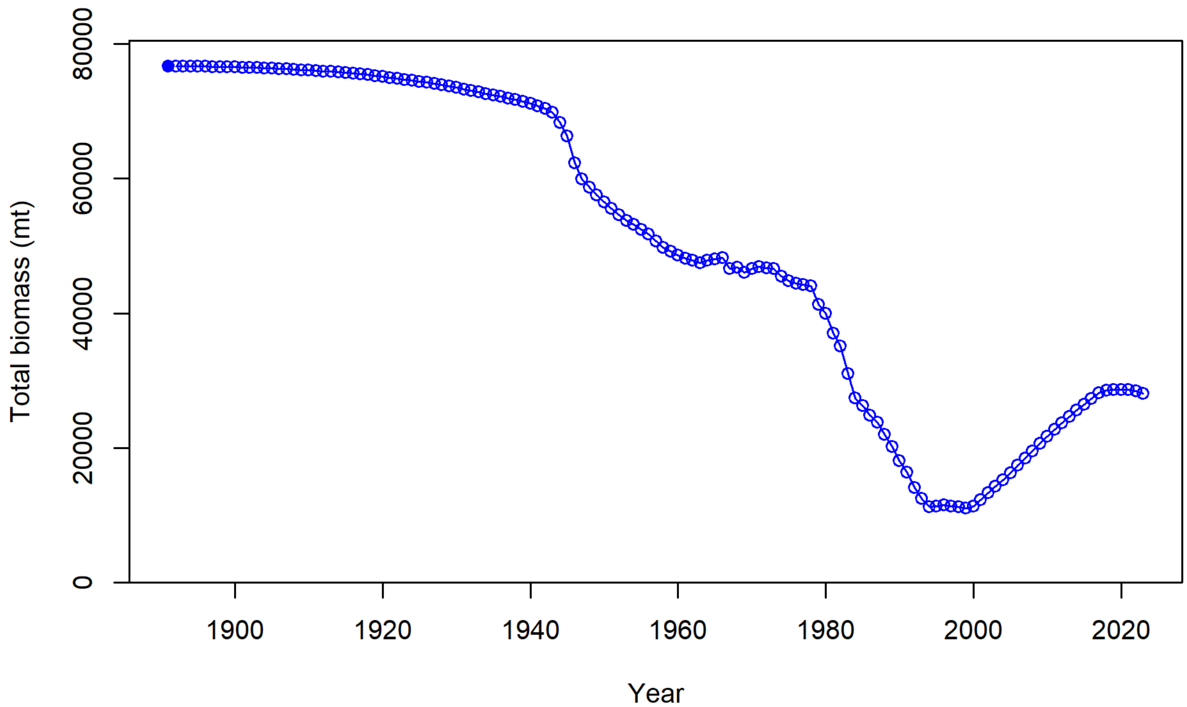

Figure 117: Estimated time series of total biomass in mt.

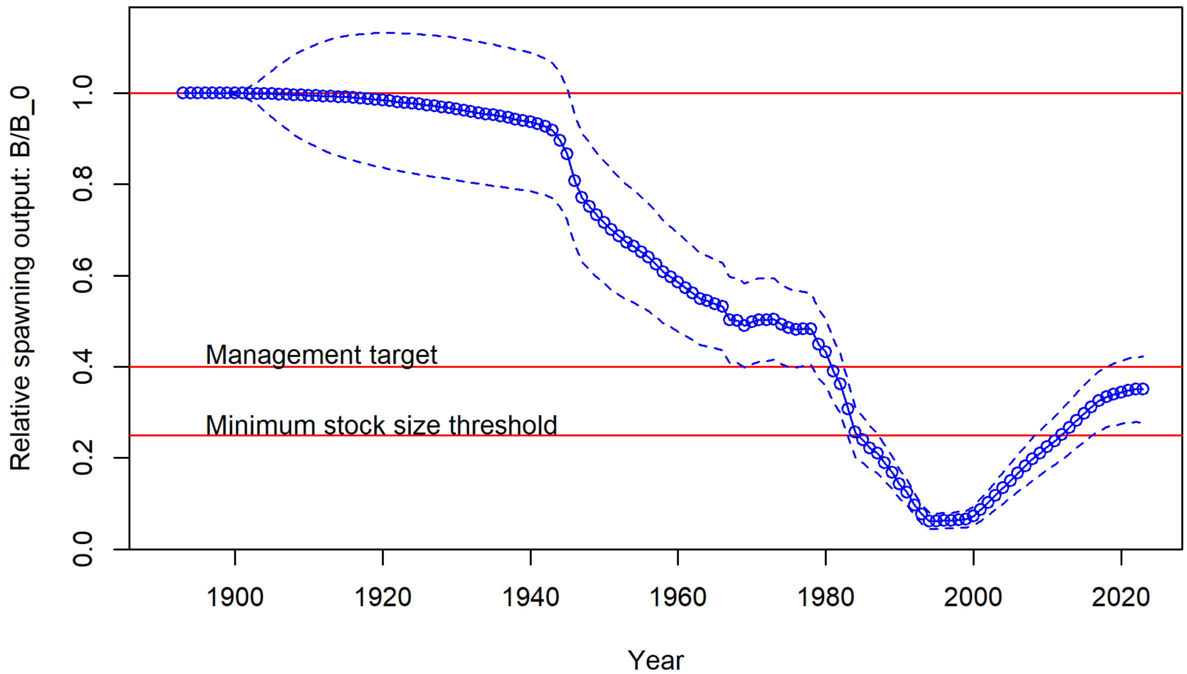

Figure 118: Estimated time series of spawning output relative to unfished with 95 percent confidence interval.

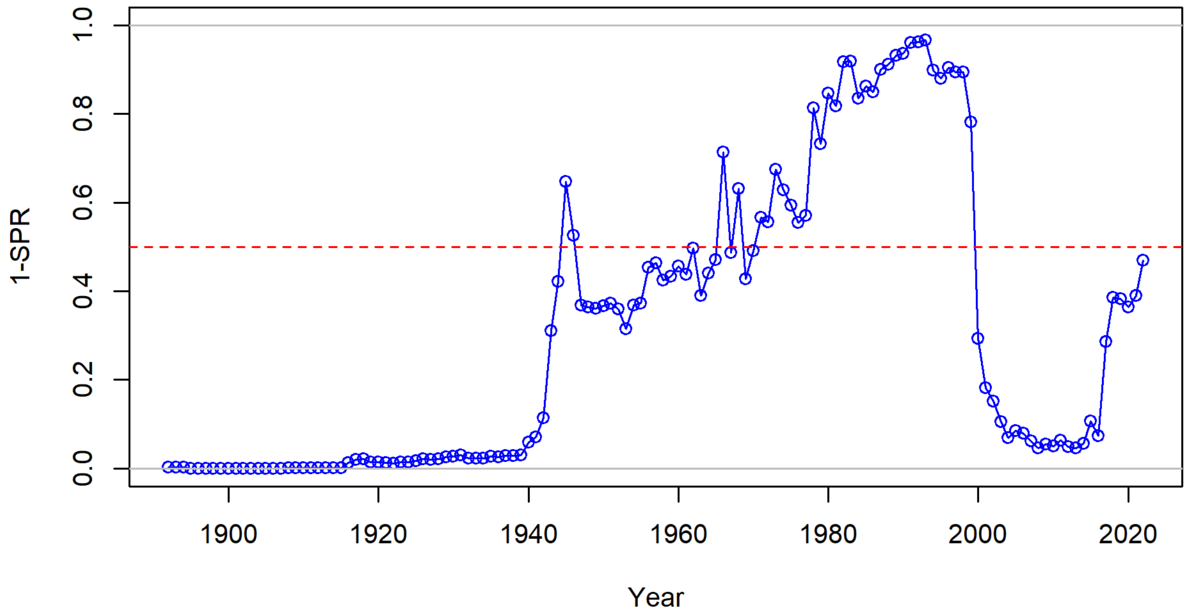

Figure 119: Estimated time series of fishing intensity (1-SPR).

8.4 Diagnostics

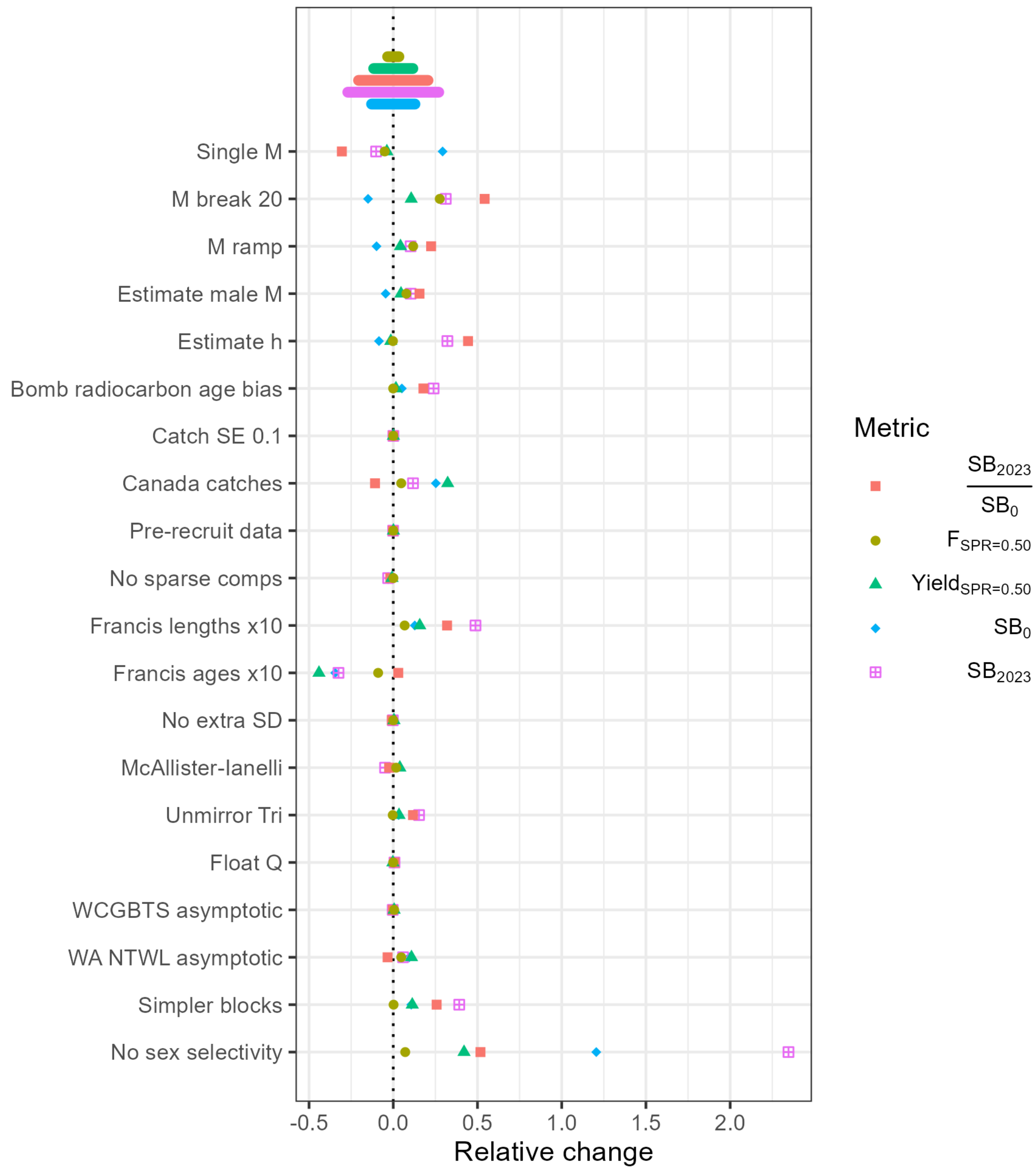

Figure 120: Comparison of the relative change in estimated management quantities as compared to the base model for structural sensitivities. The quantities compared are 1) the estimate of unfished spawning output (SB_0), spawning output in 2023 (SB_{2023}), the relative spawning output in 2023 (SB_{2023}/SB_0), the yield resulting in a population at a spawning potential ratio of 0.5 ($Yield_{SPR=0.50}$), and the fishing mortality associated with that yield ($F_{SPR=0.50}$). The thick lines at the top indicate the 95 percent confidence interval around the point estimate of the quantity from the base model, where each color corresponds with a specific quantity in the legend. Values to the right of the vertical dashed line indicate the quantity was estimated higher than in the base model, whereas values to the left indicate the quantity was estimated lower.

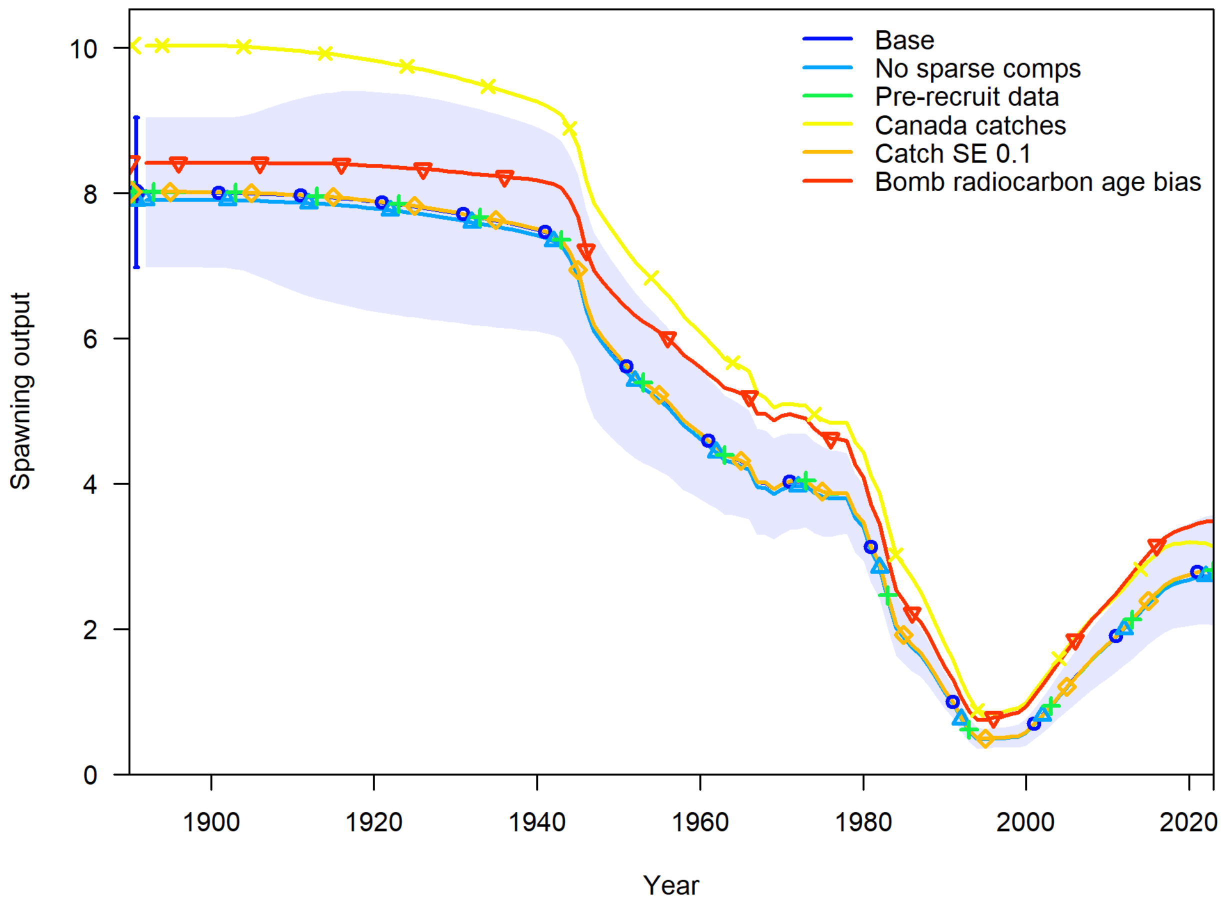

Figure 121: Comparison of spawning output for data sensitivities. Scenarios are described in section 3.5.2.1. Blue band represents 95 percent confidence interval from the base model.

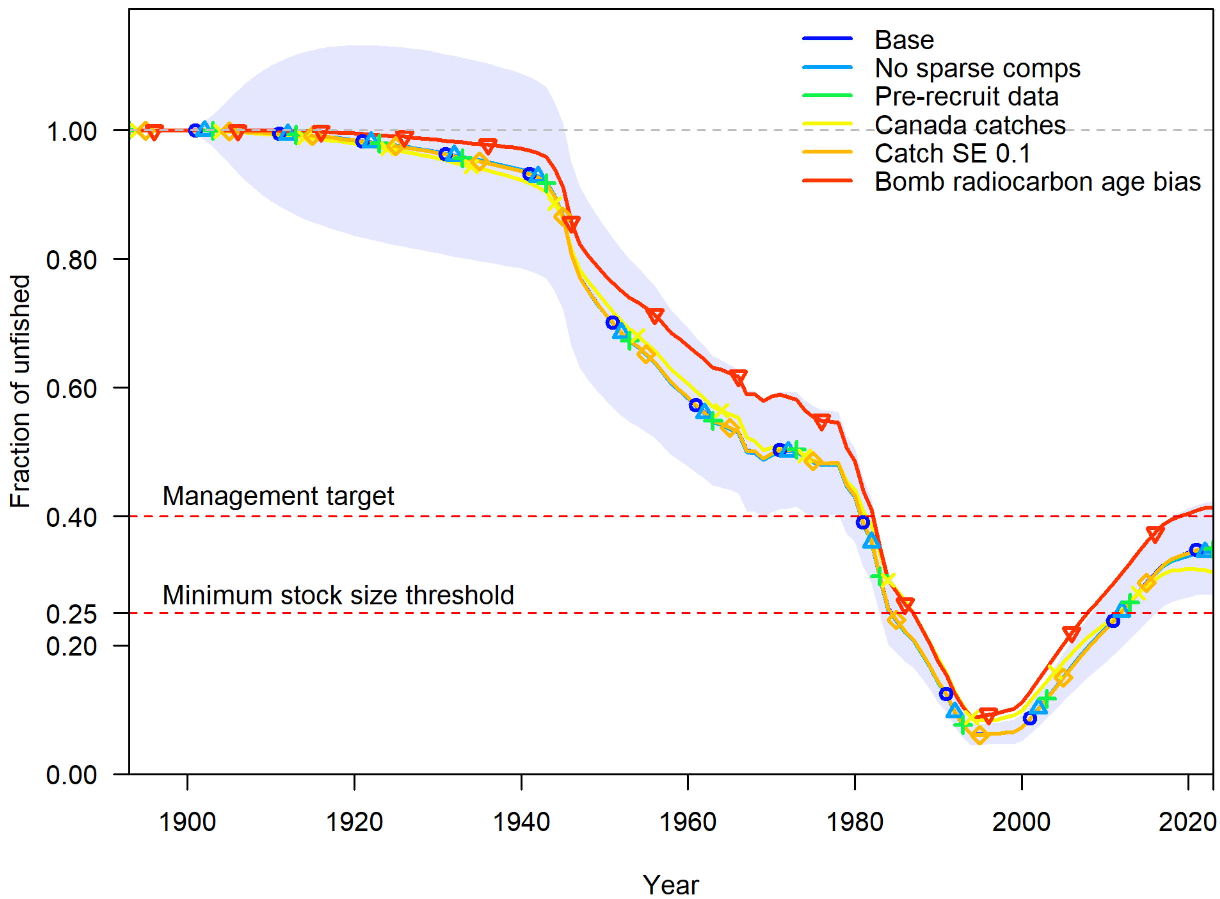

Figure 122: Comparison of spawning output relative to unfished for data sensitivities. Scenarios are described in section 3.5.2.1. Blue band represents 95 percent confidence interval from the base model.

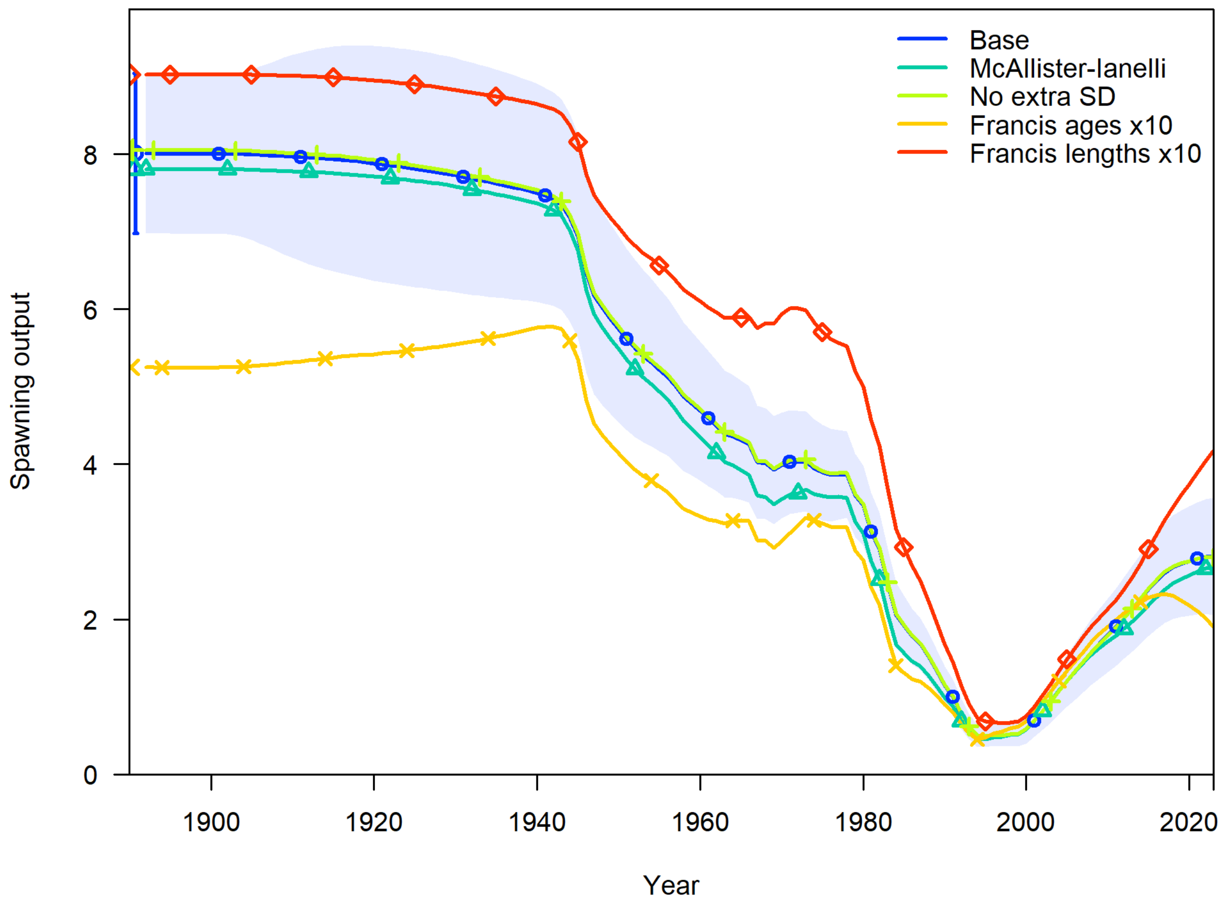

Figure 123: Comparison of spawning output for data weighting sensitivities. Scenarios are described in section 3.3.6.2. Blue band represents 95 percent confidence interval from the base model.

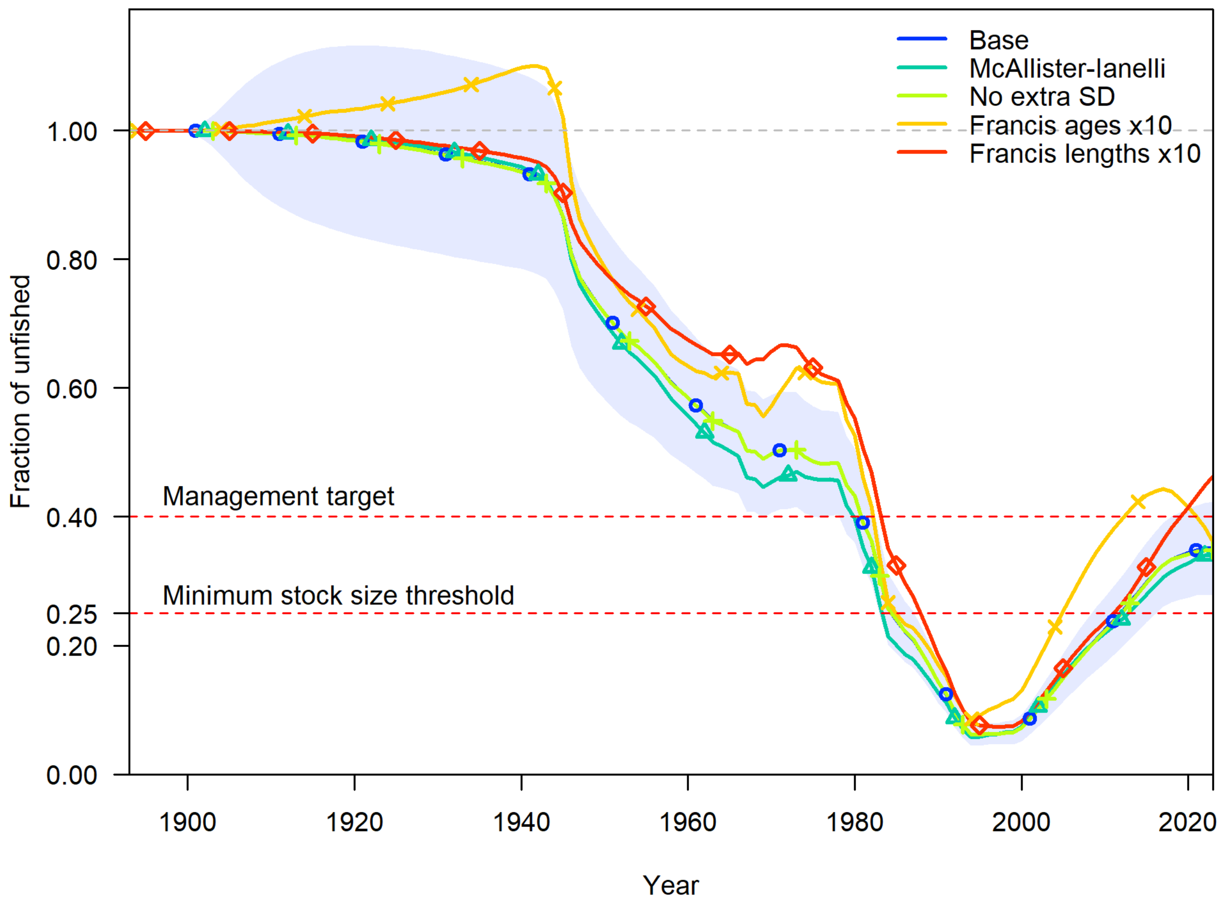

Figure 124: Comparison of spawning output relative to unfished for data weighting sensitivities. Scenarios are described in section 3.3.6.2. Blue band represents 95 percent confidence interval from the base model.

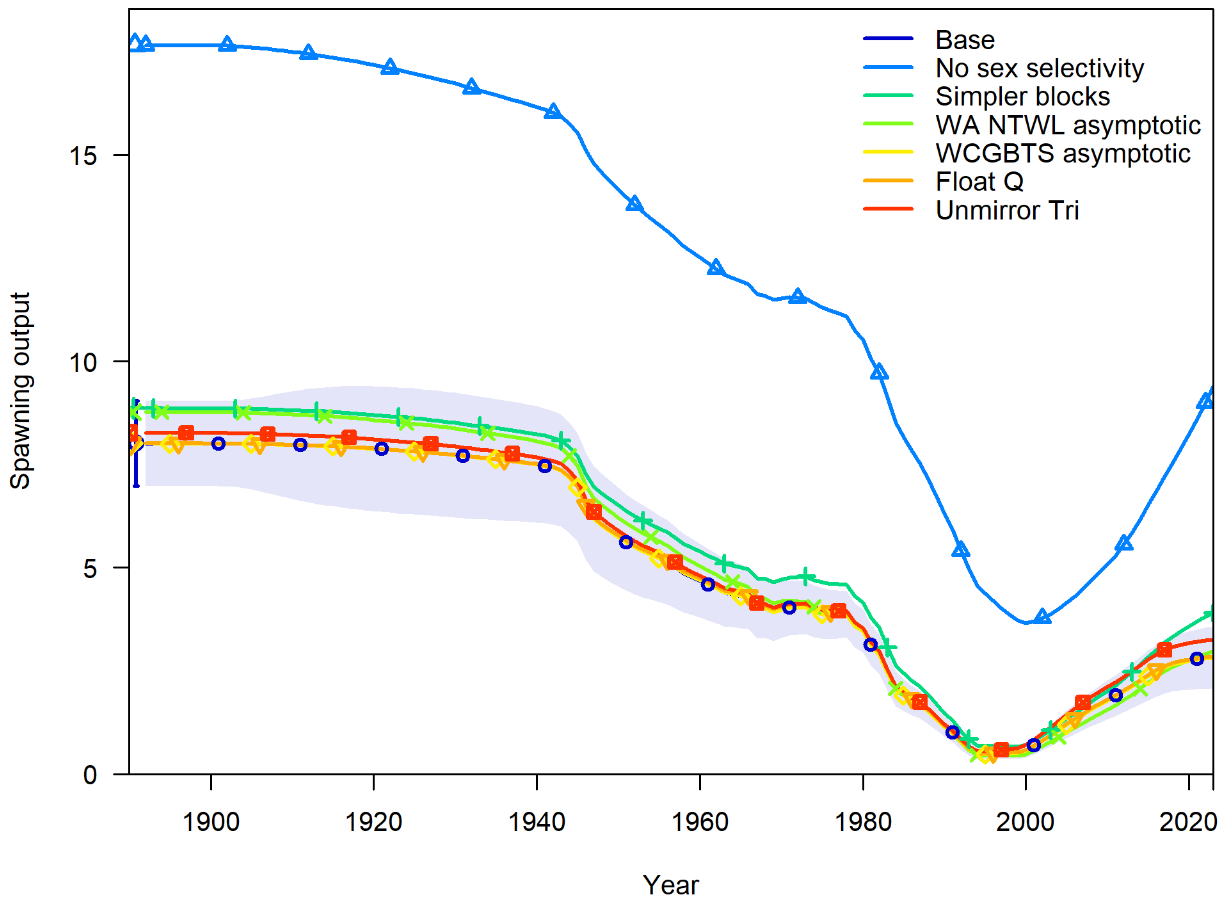

Figure 125: Comparison of spawning output for selectivity and catchability sensitivities. Scenarios are described in section 3.5.2.3. Blue band represents 95 percent confidence interval from the base model.

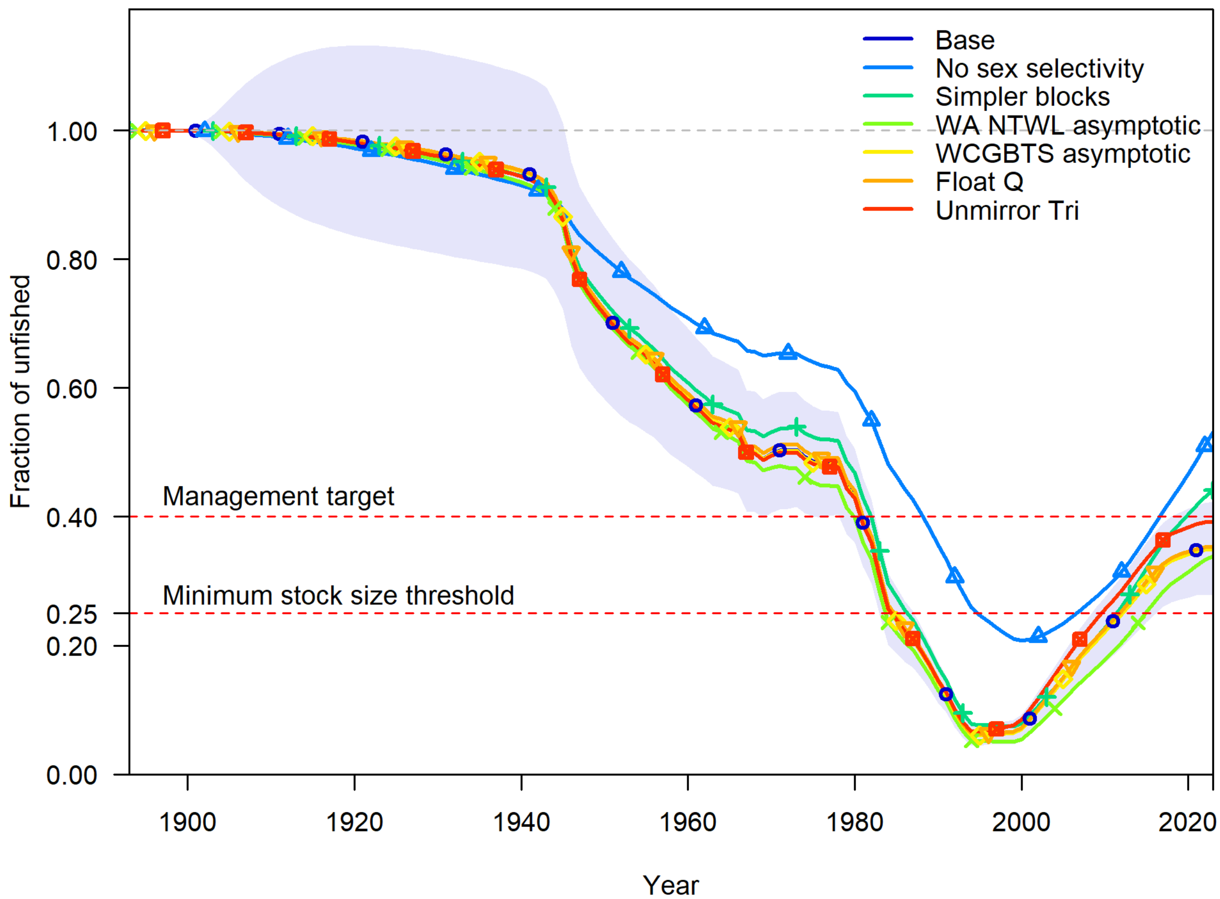

Figure 126: Comparison of spawning output relative to unfished for selectivity and catchability sensitivities. Scenarios are described in section 3.5.2.3. Blue band represents 95 percent confidence interval from the base model.

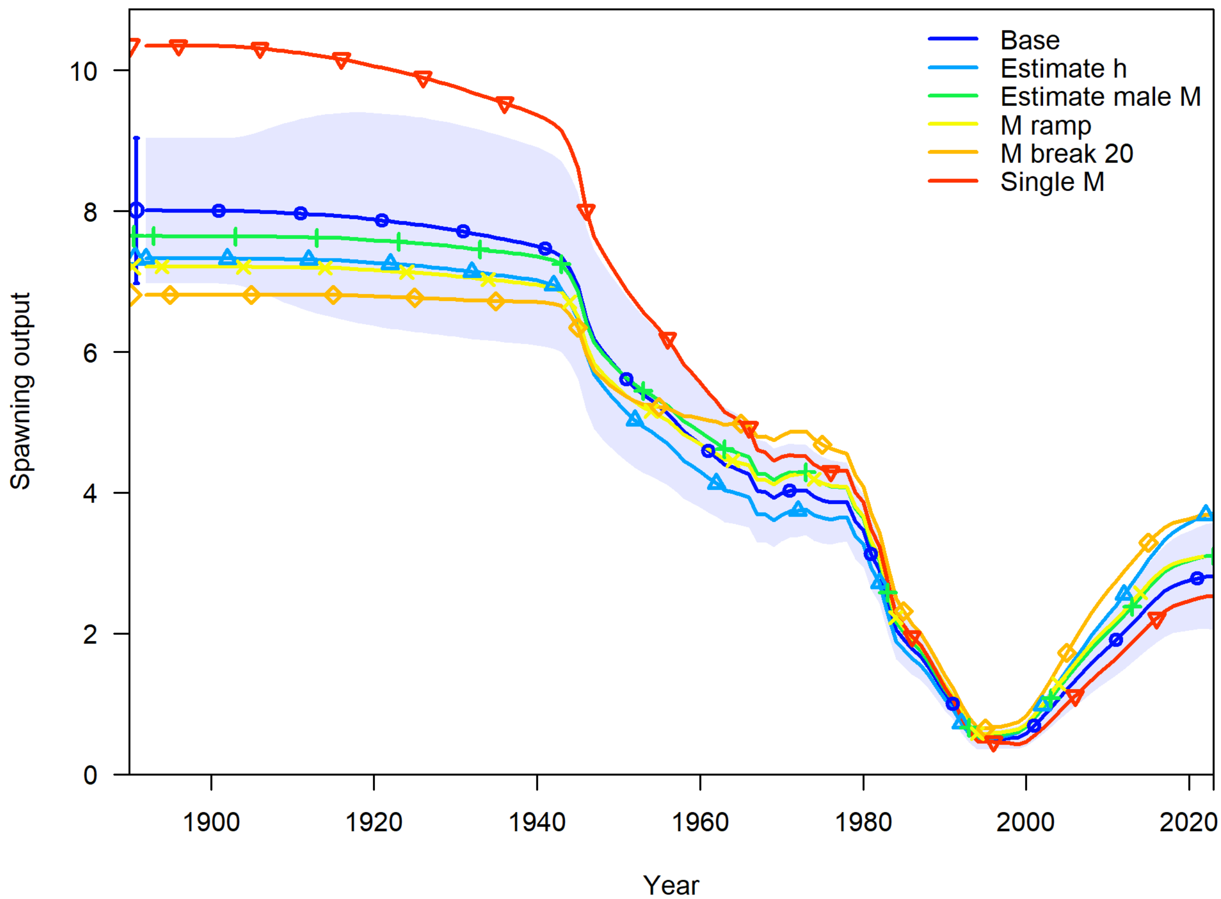

Figure 127: Comparison of spawning output for productivity sensitivities. Scenarios are described in section 3.5.2.4. Blue band represents 95 percent confidence interval from the base model.

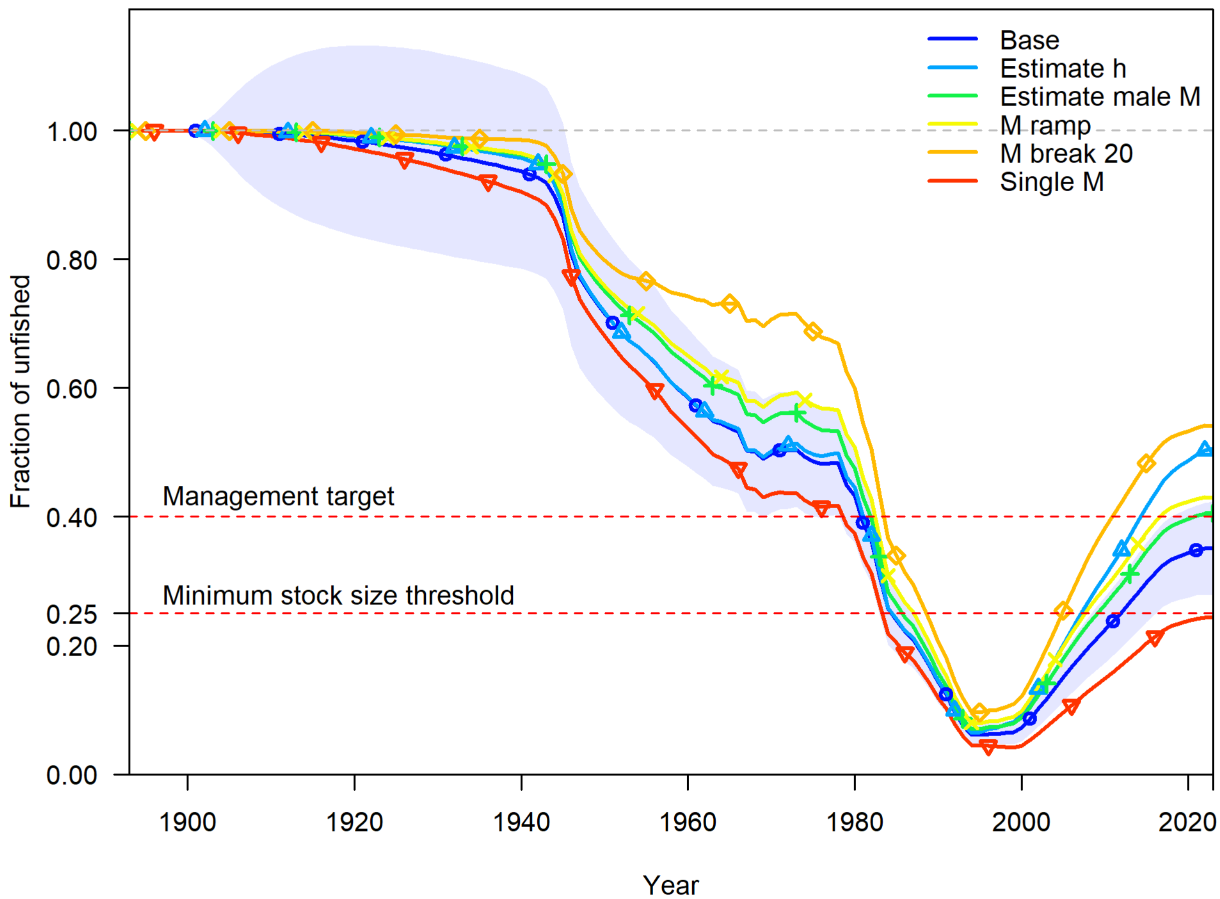

Figure 128: Comparison of spawning output relative to unfished for productivity sensitivities. Scenarios are described in section 3.5.2.4. Blue band represents 95 percent confidence interval from the base model.

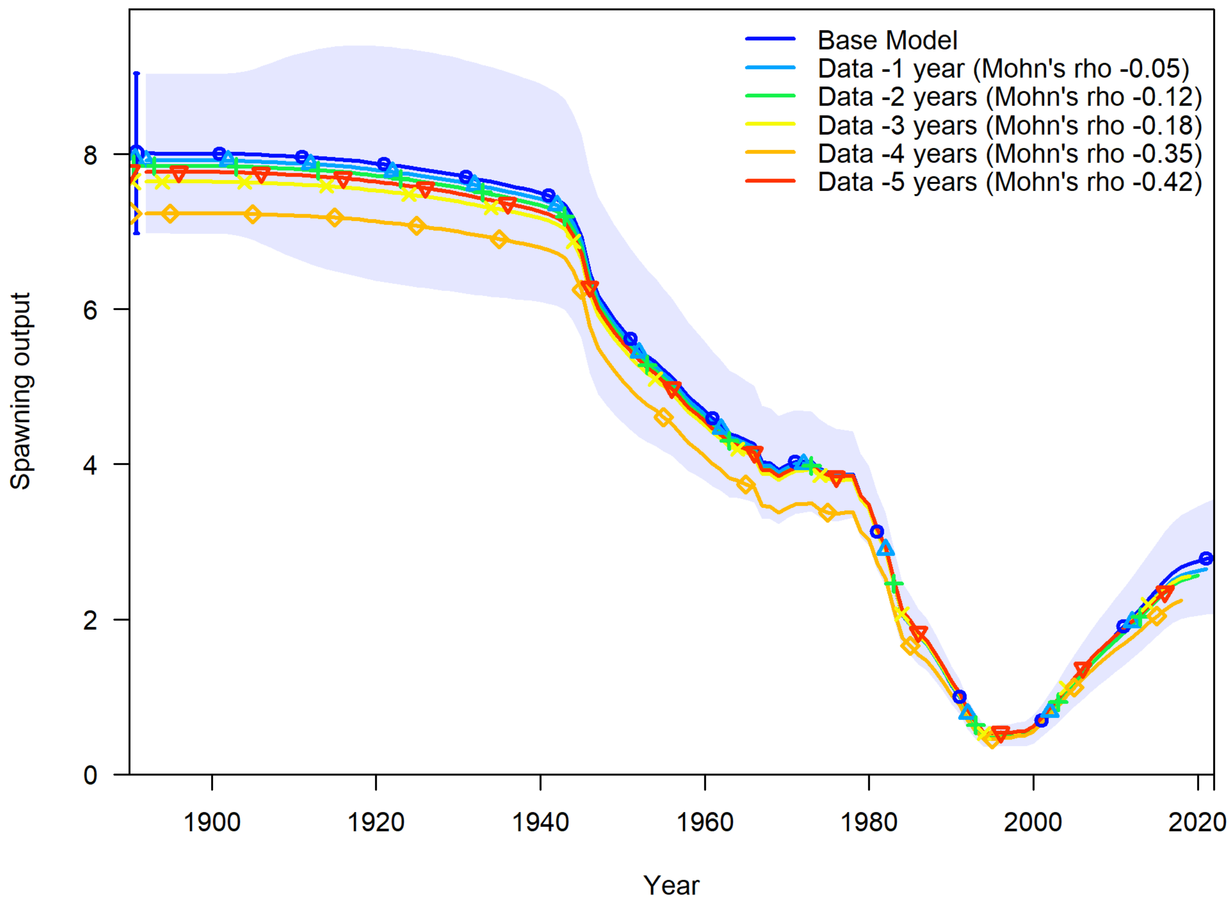

Figure 129: Change in spawning output when the most recent five years of data are sequentially removed from the model.

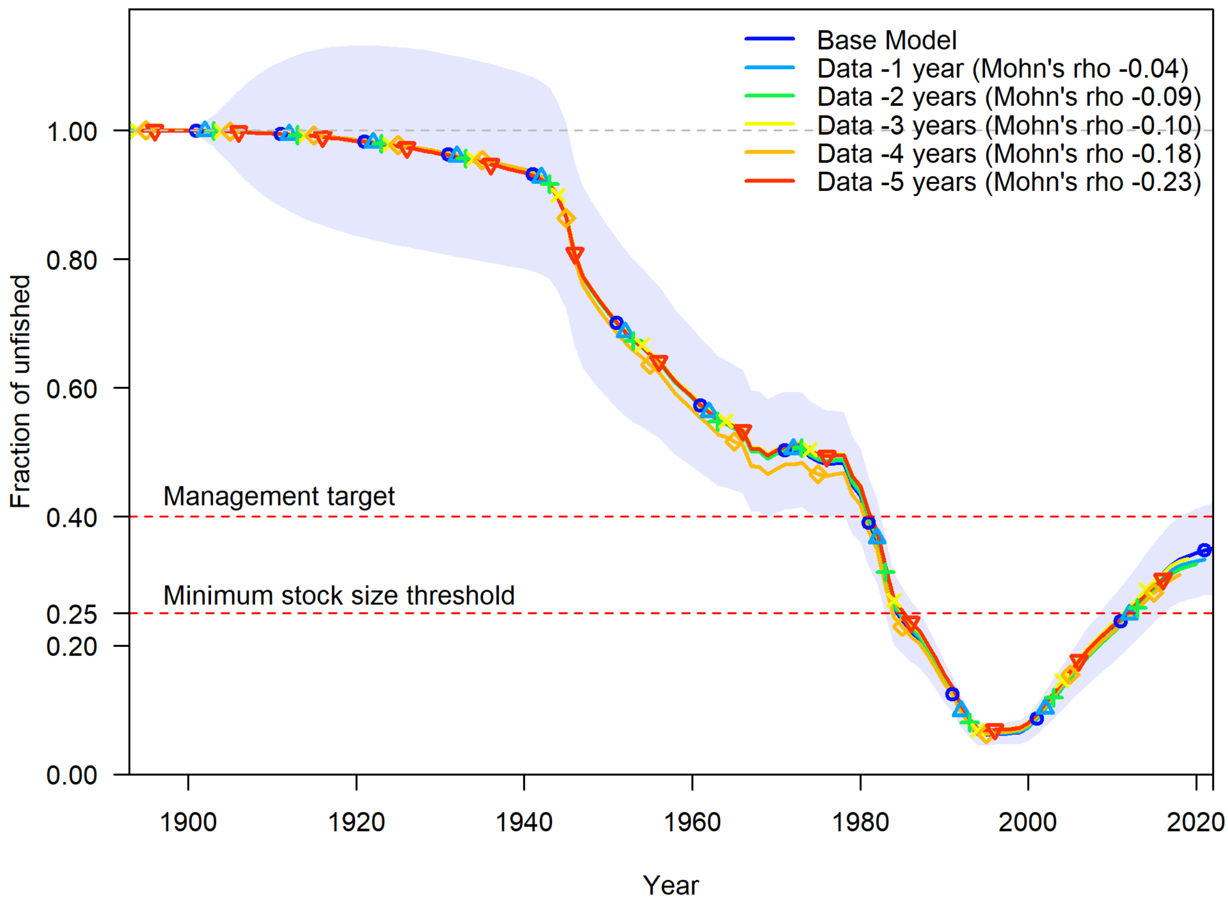

Figure 130: Change in spawning output relative to unfished when the most recent five years of data are sequentially removed from the model.

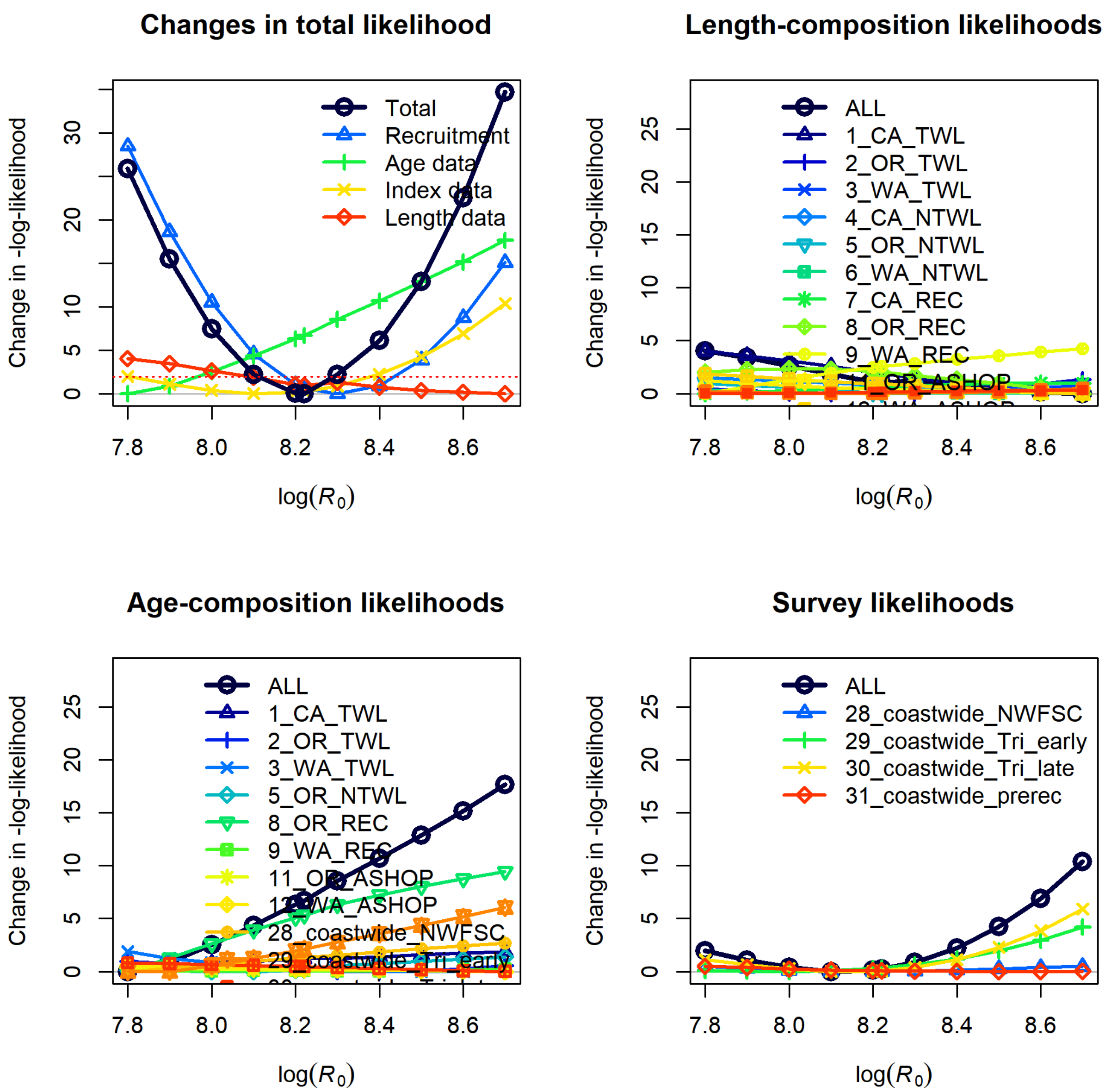

Figure 131: Likelihood profile showing support from various data sources for different values of $\ln(R_0)$, the natural logarithm of unfished recruitment, relative to the base model. Values associated with likelihoods that fall below the red dashed line are within the 95 percent chi-squared confidence interval.

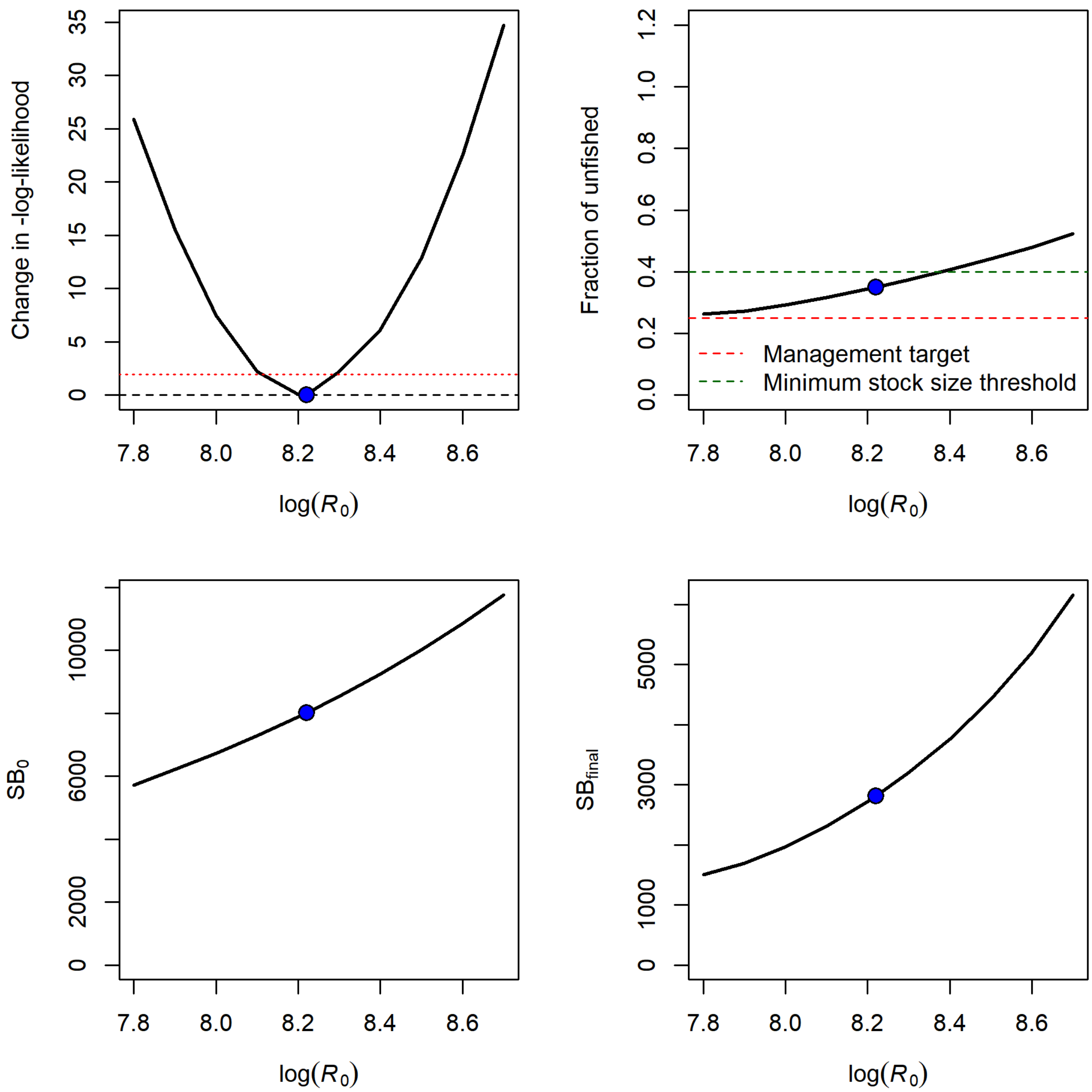

Figure 132: Likelihood profile of $\ln(R_0)$, and impact of changing $\ln(R_0)$ values from the base model (blue dot) on depletion (top right), unfished spawning output (lower left), and terminal year spawning output (lower right).

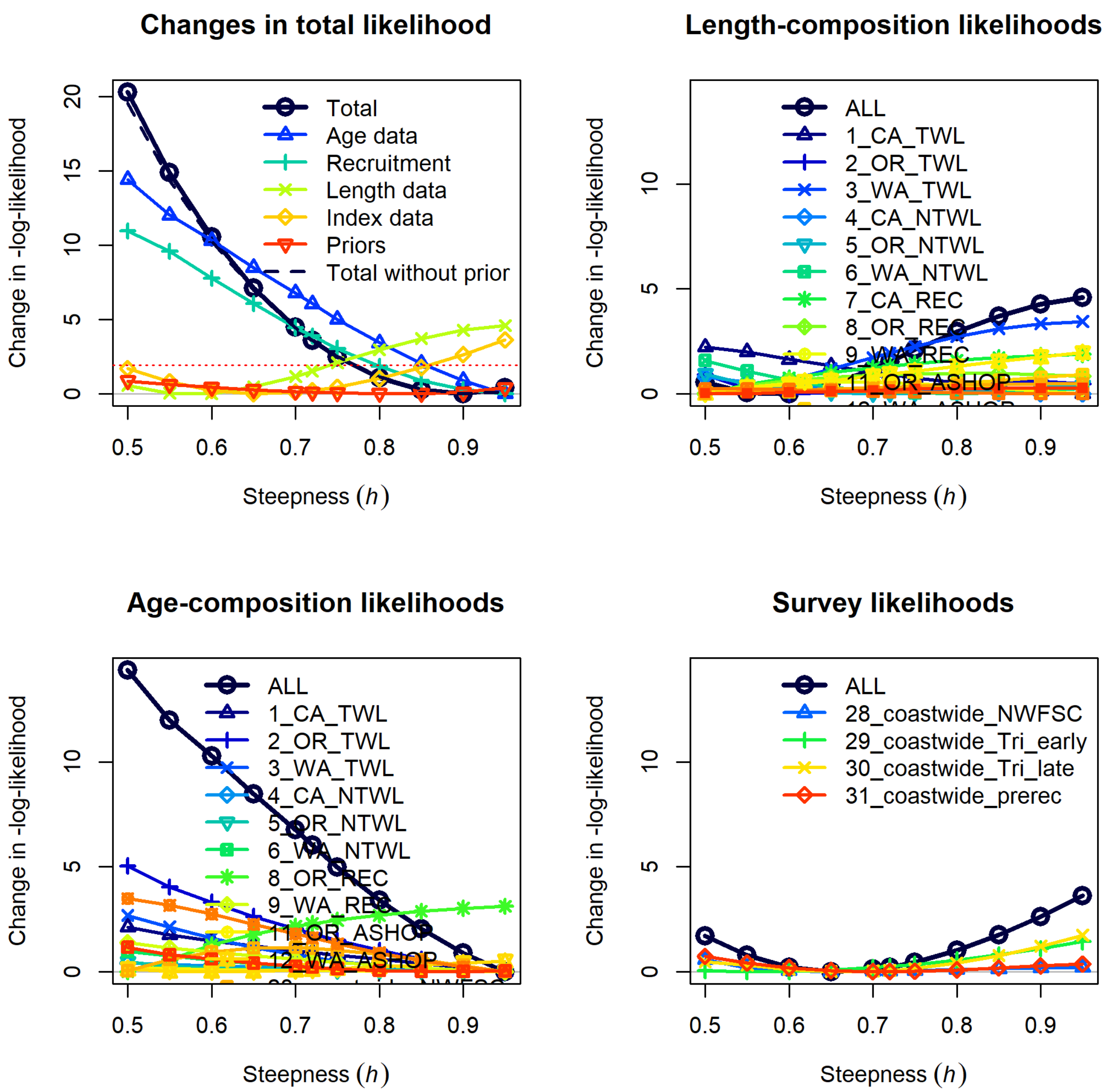

Figure 133: Likelihood profile showing support from various data sources for different values of steepness, relative to the base model. Change in log-likelihood is relative to the base model. Values associated with likelihoods that fall below the red dashed line are within the 95 percent chi-squared confidence interval.

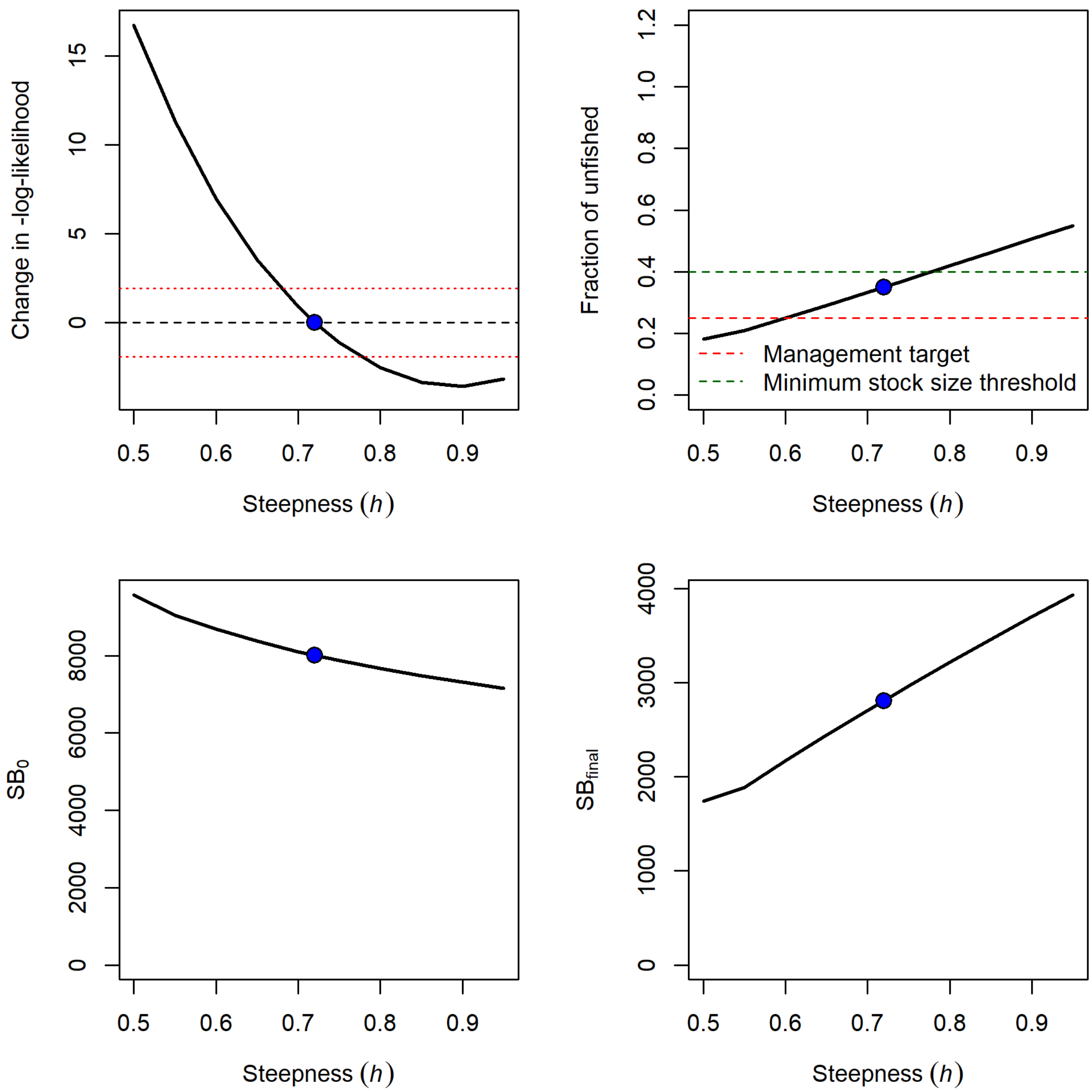

Figure 134: Likelihood profile of steepness, and impact of changing steepness values from the base model (blue dot) on depletion (top right), unfished spawning output (lower left), and terminal year spawning output (lower right).

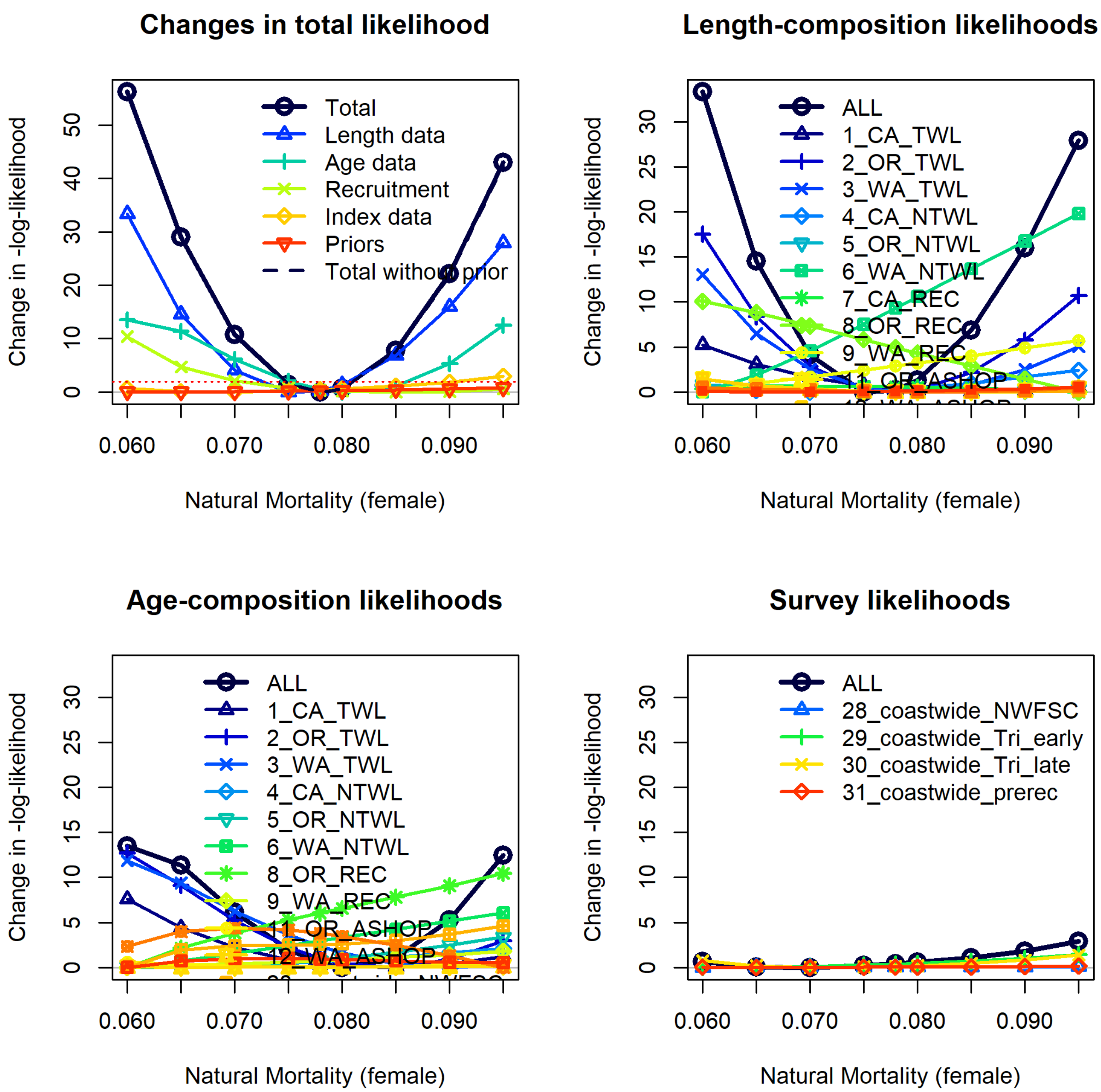

Figure 135: Likelihood profile showing support from various data sources for different values of female natural mortality. Change in log-likelihood is relative to the base model. Values associated the likelihoods that fall below the red dashed line are within the 95 percent chi-squared confidence interval.

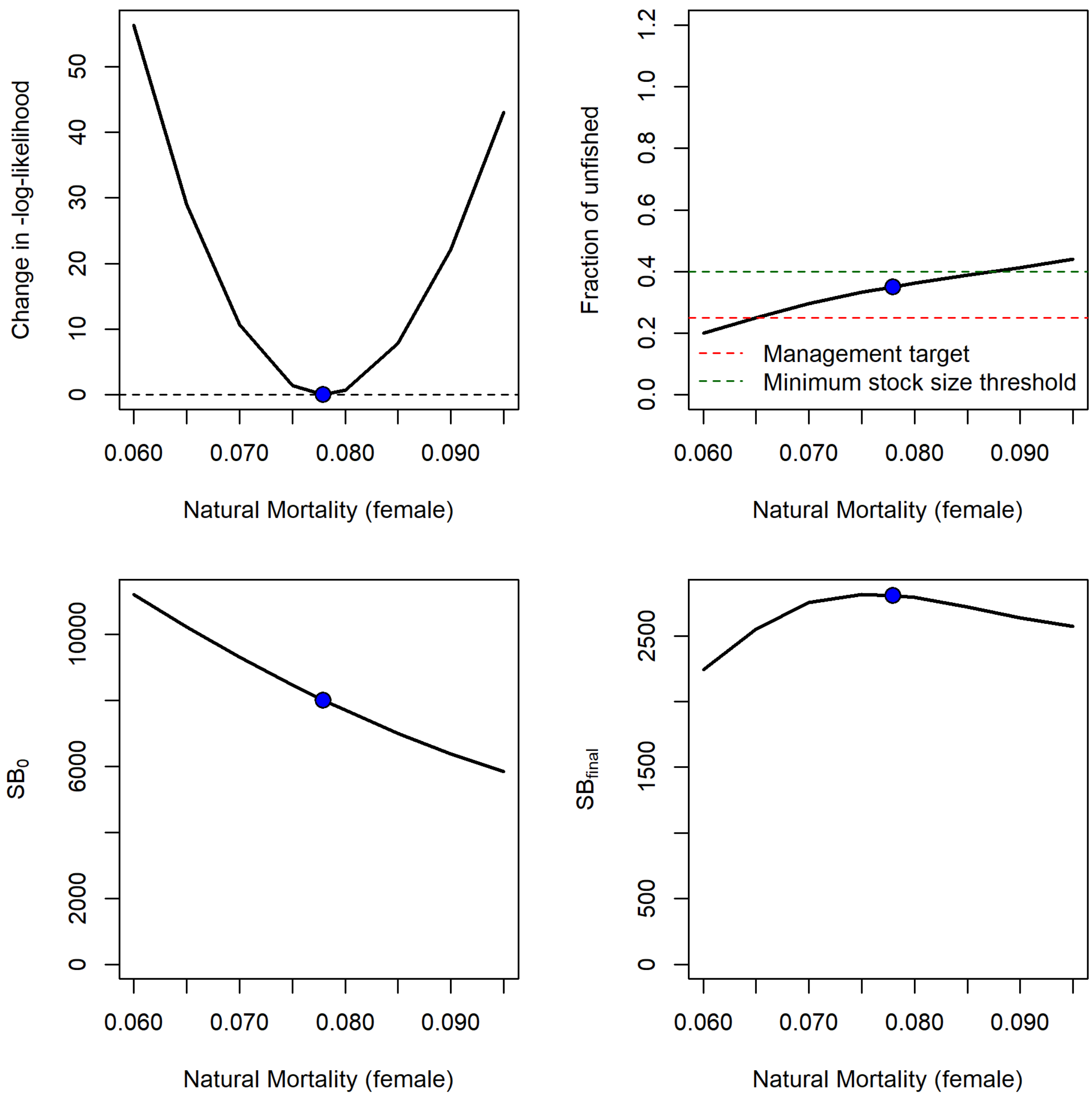

Figure 136: Likelihood profile of female natural mortality, and impact of changing female natural mortality values from the base model (blue dot) on depletion (top right), unfished spawning output (lower left), and terminal year spawning output (lower right).

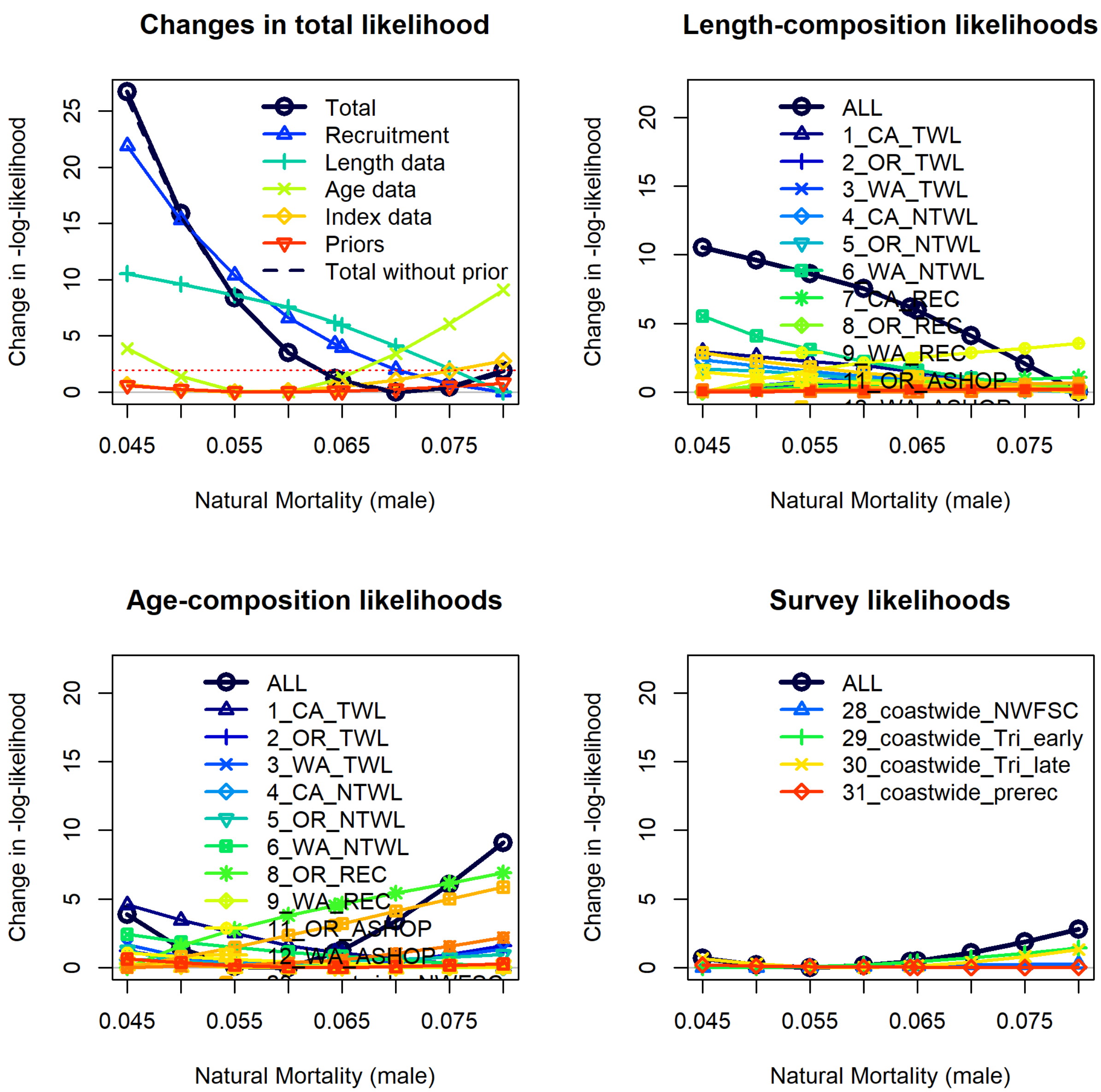

Figure 137: Likelihood profile showing support from various data sources for different values of male natural mortality. Change in log-likelihood is relative to the base model. Values associated the likelihoods that fall below the red dashed line are within the 95 percent chi-squared confidence interval.

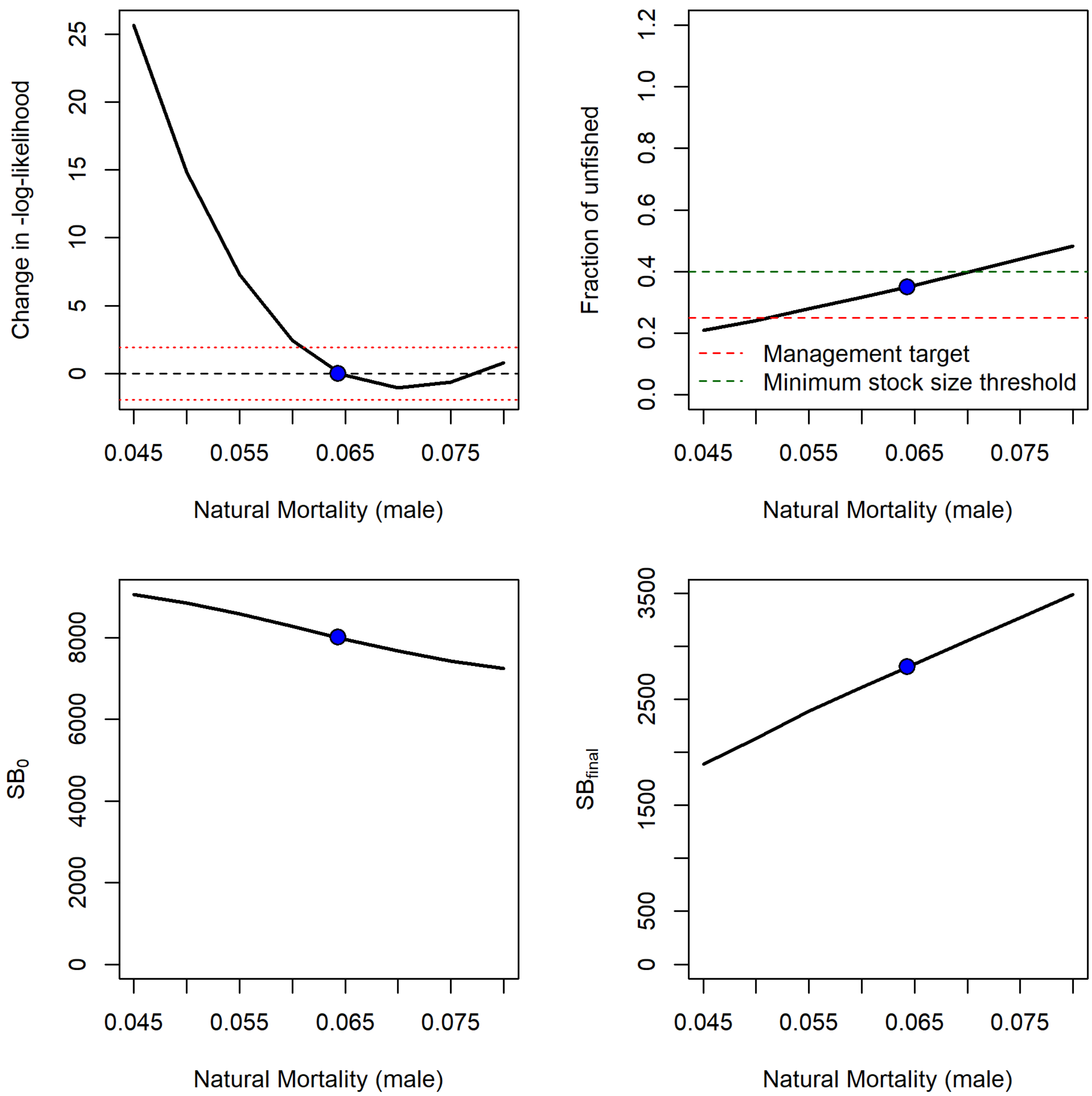

Figure 138: Likelihood profile of male natural mortality, and impact of changing male natural mortality values from the base model (blue dot) on depletion (top right), unfished spawning output (lower left), and terminal year spawning output (lower right).

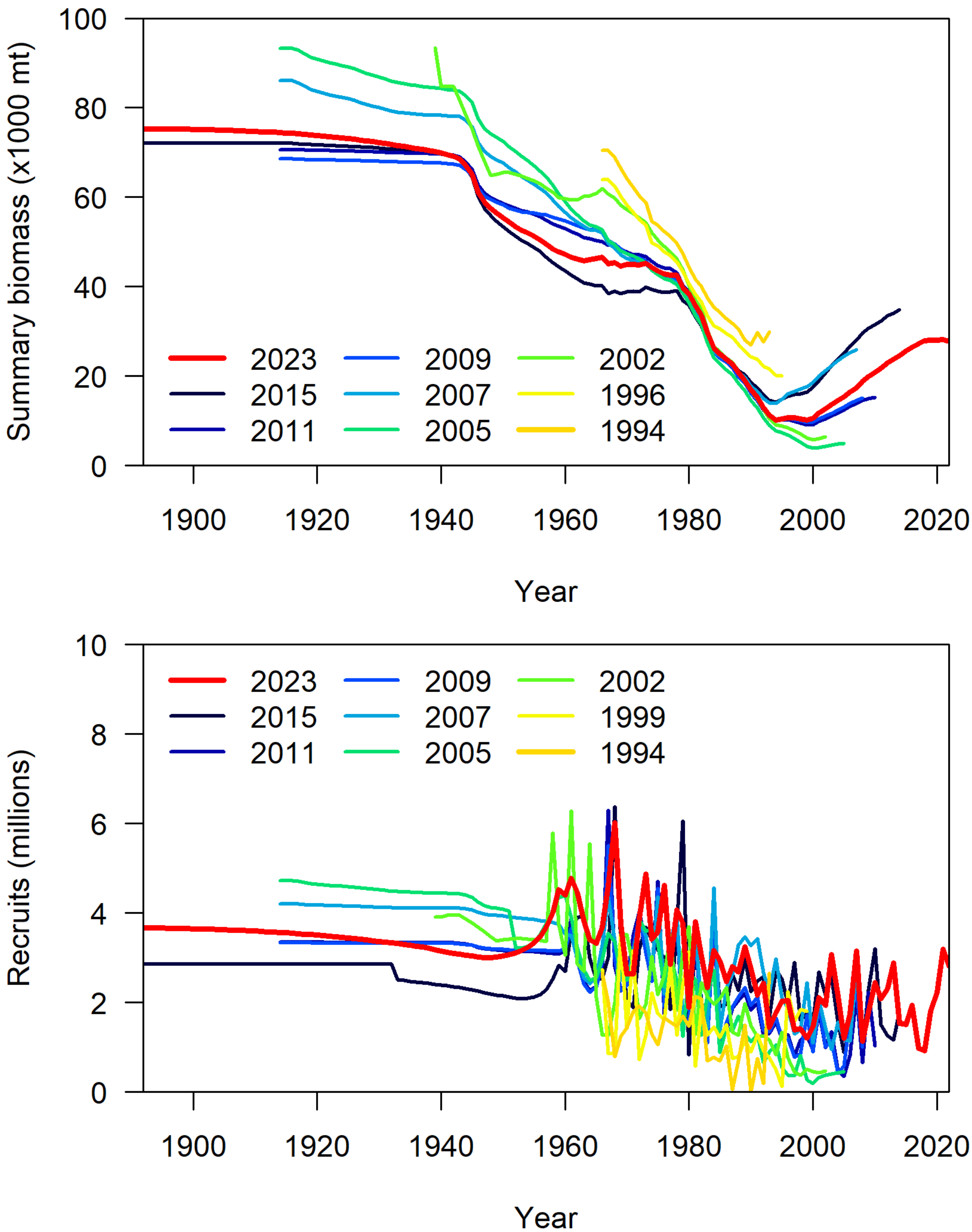

Figure 139: Summary biomass (1000s of mt) and age-0 recruitment (millions of fish) of current and past full and update assessments. Summary biomass shows age 5+ canary rockfish with the exception of the 2002 update, which provided summary biomass for age 3+ canary rockfish.

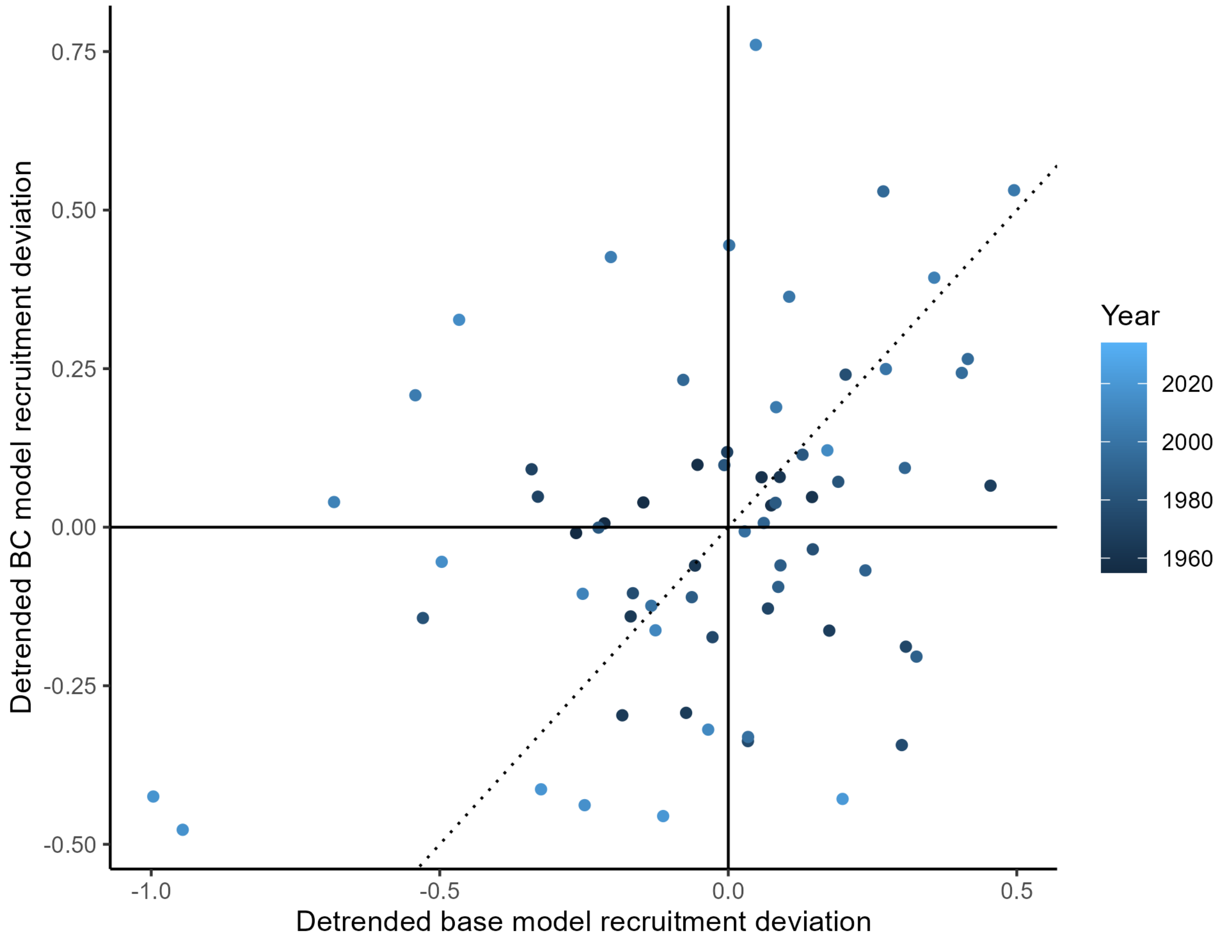

Figure 140: Comparison of recruitment deviations estimated in DFO (2022) and this model. Deviations are detrended using standard linear regression to account for opposite long-term recruitment trends in the two models. Dashed line is the 1:1 line. Points that fall on this line have perfect correspondence between the two models.

8.5 Management

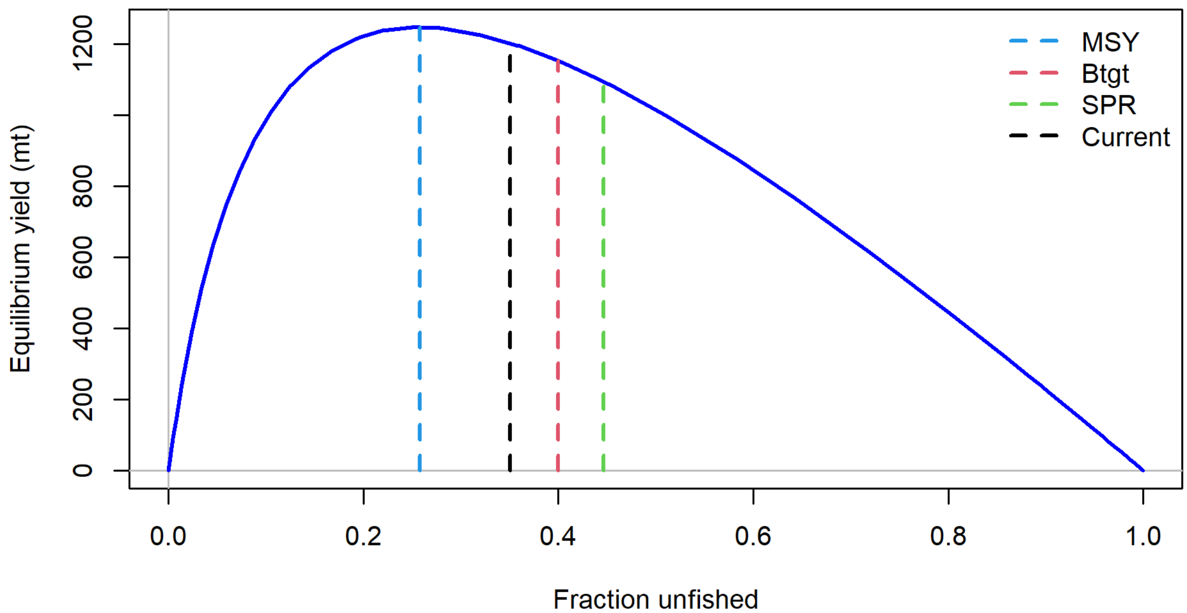

Figure 141: Estimated yield curve with various reference point proxies.

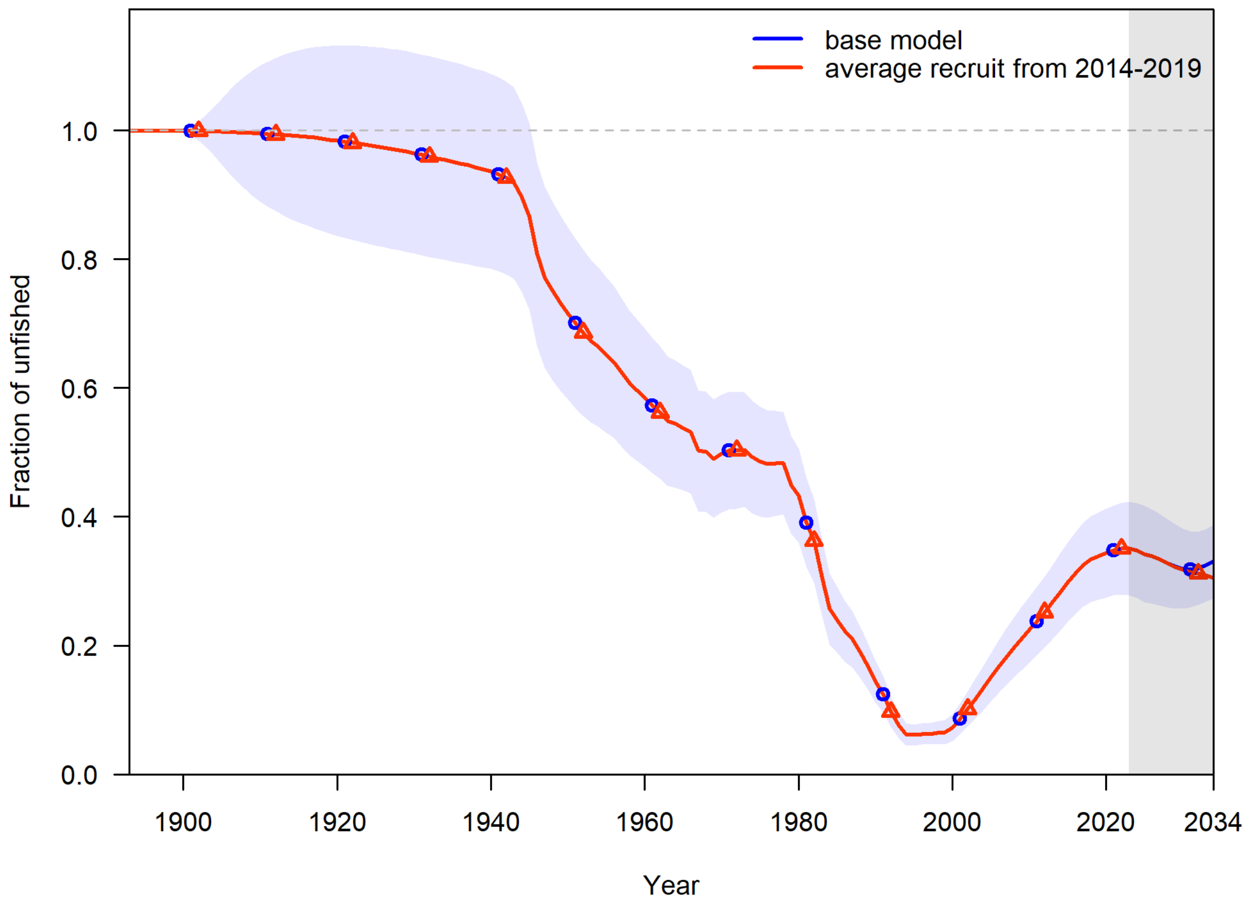

Figure 142: Comparison of spawning output relative to unfished for projections with P*=0.45 under average recruitment assumptions (blue line) and when applying the base projected catch values to a model assuming low recruitment (average recruitment from 2014-2019; red line). Blue band represents 95 percent confidence interval from the base model. Shaded block indicates the projection period (2023-2034).