Status of Dover sole (*Microstomus pacificus*) along the U.S. West Coast in 2021

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Disclaimer

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One Page Summary

- This assessment for Dover sole incorporates a wide range of data sources: landings data and discard estimates; survey indices of abundance, length- and/or age-composition data for each fishery or survey (with conditional age-at-length data used for the surveys); information on weight-at-length, maturity-at-length, and fecundity-at-length; information on natural mortality and the steepness of the Beverton-Holt stock-recruitment relationship; and estimates of ageing error.
- The longest time series of fishery-independent information off the U.S. west coast arises from the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) that has been conducted annually from 2003 - 2019. The length and age data from this survey were highly influential on the model estimates of stock size and status. Additionally, these data were used to externally estimate starting parameter values by sex for length-at-age and the fixed values by sex for length-weight relationship.
- Dover sole off the U.S. west coast appear to have complex movement patterns, moving across depths, likely driven by season, spawning, and by size. Additionally, observations indicate possible sex-specific aggregations where a higher proportion of female fish are found in shallower (less than 300 m) and deeper waters (greater than 900 m), with higher proportion of males observed at intermediate depths (300 - 700 m).
- The model parameterization allowed for sex-specific selectivity with female Dover sole never fully selected (maximum selectivity less than 1.0). Large female Dover sole are observed at the deepest depth sampled (1,280 m) off the West Coast and likely extend into unobserved deeper depths. Lack of full selectivity of female Dover sole results in a fraction of unobserved spawning biomass in the population, increasing uncertainty in the estimate of the stock scale that the base model may not fully capture (via asymptotic error assumptions around estimated parameters).
- The model was highly sensitive to the assumed value of natural mortality. The base model fixed the instantaneous rate of natural mortality for females at the median of the prior, 0.108 per year, and estimated male natural mortality as an offset from the female value. When estimated, female natural mortality was well below the median of the prior, at 0.082 per year, which did not appear well supported by longevity information and resulted in estimates of survey catchability at or above 2.0. However, the relative difference in natural mortality by sex appeared to be well defined across reasonable ranges of natural mortality which informed the decision to only estimate male natural mortality parameterized as an offset from the fixed female value.
- The estimated spawning biomass at the beginning of 2021 was 232,065 mt ($\sim$95 percent asymptotic intervals: 154,153 to 309,977 mt), which when compared to unfished spawning biomass (294,070 mt) equates to a relative stock status level of 79 percent ($\sim$95 percent asymptotic intervals: 71 to 87 percent). The estimated scale of the stock (SB_0) from this assessment, 294,070 mt, is lower than the value estimated in the 2011 assessment of 469,866 mt but well within the 2011 $\sim$95 percent asymptotic interval (182,741 - 756,991 mt).
- Fishing intensity (1 - SPR) over the past decade has been well below the target $\text{SPR}_{30\%}$, ranging between 0.11 and 0.2. The estimated target spawning biomass based on the 25 percent management target is 73,518. Sustainable total yield, landings plus discards, using $\text{SPR}_{30\%}$ is estimated at 22,891 mt.

Executive Summary

Stock

This assessment reports the status of Dover sole (*Microstomus pacificus*) off the U.S. west coast using data through 2020. Dover sole are also harvested from the waters off the Canadian coast and in the Gulf of Alaska, and although those catches were not included in this assessment, it is not certain if those populations contribute to the biomass of Dover sole off the U.S. west coast. Dover sole exhibit complex seasonal and ontogenetic movement, moving to deeper waters based on size but also shifting seasonally, moving from shallower feeding grounds on the continental shelf during the summer months to deeper spawning habitat on the outer continental shelf and slope in the winter. However, the specific mechanisms that drive stock structure and related variability over space and time, are not well understood.

Landings

Dover sole were first landed in California in the early part of the 20th century with landings beginning in Oregon and Washington in the 1940's (Figure i). Landings remained relatively constant throughout the 1950s and 1960s before increasing rapidly into the early 1990s. Subsequently, the landings declined by nearly 60 percent in California and Oregon/Washington until 2007 when harvest guidelines increased the allowable catch leading to increased landings between 2007 - 2010. Since 2011, landings have been steadily decreasing, where the landings in 2020 is the lowest on record since the 1940s (Table i). There are multiple factors that have led to the recent low landings of Dover sole (e.g., co-occurrence with constraining stocks, market forces).

Groundfish trawl fisheries account for the majority of Dover sole landings off the West Coast, with fixed gears, shrimp trawls, and recreational fisheries collectively make up a very small amount of fishing mortality (less that 1 percent of the total). Some discarding of Dover sole has occurred in these fisheries, primarily prior to the implementation of the Individual Fishing Quota (IFQ) Catch Shares Program in 2011. Discard mortality was estimated within the model based on data of discarding rates and lengths across time. Landings and the estimates of total mortality are reported (Table i).

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

Year	CA	OR WA	Total Landings	Total Dead
2011	2401.08	5381.29	7782.37	7893.18
2012	2160.60	5167.29	7327.89	7429.72
2013	2217.77	5752.41	7970.18	8077.92
2014	1954.98	4494.25	6449.23	6543.10
2015	1892.58	4434.15	6326.73	6354.50
2016	1808.26	5510.11	7318.37	7349.81
2017	2196.85	5694.75	7891.60	7925.06
2018	1640.28	4780.99	6421.27	6447.41
2019	1397.44	4369.42	5766.86	5789.61
2020	1616.99	3070.65	4687.64	4706.57

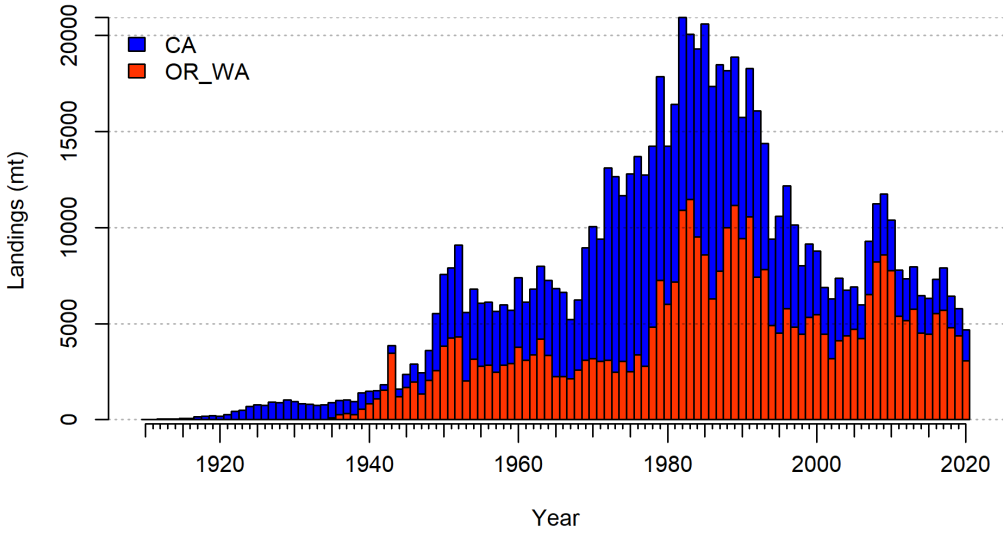


Figure i: Landings by fleet used in the base model where catches in metric tons by fleet are stacked.

Data and Assessment

This stock assessment for Dover sole off the west coast of the U.S. was developed using the length- and age-structured model Stock Synthesis (version 3.30.16). The previous stock assessment of Dover sole was conducted in 2011 and estimated the stock to be increasing with a stock status determination of 84 percent of virgin (or unfished) spawning biomass at the beginning of 2011. During the development of this assessment, model specifications including fleet structure, landings, data, and model structural assumptions were re-evaluated. Similar to the previous assessment, a single coastwide population was modeled allowing for area-specific fleets and separate growth and mortality parameters for each sex (i.e., a two-sex model). The model time domain is 1911 to 2020, with a 12 year forecast beginning in 2021.

All the data sources included in the base model for Dover sole have been re-evaluated for this assessment, including improvements and updates in the data (and associated analyses) that were used in the previous assessment. Estimate of landings prior to the mid-1980s have also been updated using the new historical catch reconstruction time series for Oregon. Survey data from the Alaska Fisheries Science Center (AFSC) and Northwest Fisheries Science Center (NWFSC) have been used to construct four sets of relative abundance indices, each spanning different time periods, were independently developed using a spatio-temporal delta-generalized linear mixed model (i.e., VAST).

The definition of fishing fleets changed in this assessment relative to those in the 2011 assessment. Two fishing fleets are now defined in the model: 1) a combined gear California fleet and 2) a combined gear Oregon/Washington fleet. The fleet grouping for Oregon and Washington was suggested by State representatives during the pre-assessment data meeting because of similarities in fishing across this region while also avoiding the inherent difficulties associated with separating data between Oregon and Washington due to the intermixing of fishing and landing locations across state boundaries.

This assessment integrates data and information from multiple sources into one modeling framework. Specifically, the assessment uses landings data and discard estimates; survey indices of abundance, length- and/or age-composition data for each fishery or survey (with conditional age-at-length data used for the Northwest Fisheries Science Center Slope Survey (NWFSC Slope Survey) and WCGBTS); information on weight-at-length, maturity-at-length, and fecundity-at-length; information on natural mortality and the steepness of the Beverton-Holt stock-recruitment relationship; and estimates of ageing error. The base model was tuned to account for the weighting of composition data as well as the specification of recruitment variance and recruitment bias adjustments. Estimates of recruitment at equilibrium spawning biomass (R_0), annual recruitment deviations, sex-specific length-based selectivity of the fisheries and surveys, retention for each of the fishery fleets, catchability of the surveys, sex-specific growth, the time series of spawning biomass, age and size structure, and current and projected future stock status are derived outputs of the model.

Multiple sources of uncertainty are explicitly included in this assessment, including parameter uncertainty using prior distributions, observational uncertainty through standard deviations of survey estimates, and model uncertainty through a comprehensive sensitivity analyses

to data source and model structural assumptions. A base model was selected that best fit the observed data while concomitantly balancing the desire to capture the central tendency across those sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model misspecification.

Stock Biomass

The terms "spawning output" and "spawning biomass" are used interchangeably in this document in reference to total female spawning biomass. For the purposes of this assessment, female spawning biomass is assumed to be proportional to egg and larval production (i.e., spawning output). The estimated spawning biomass at the beginning of 2021 was 232,065 mt (~95 percent asymptotic intervals: 154,153 to 309,977 mt, Table ii and Figure ii), which when compared to unfished spawning biomass (294,070 mt) equates to a relative stock status level of 79 percent (~95 percent asymptotic intervals: 71 to 87 percent, Figure iii). Overall, spawning stock biomass has steadily declined from near unfished levels in the 1940s to a time series low of 60 percent of unfished levels in 1994 following high landings in the 1980s and early 1990s. Over the past two decades, spawning stock biomass has generally been increasing as total landings have decreased. The stock is estimated to be well above the management target of $SB_{25\%}$ in 2021 and has remained well above the target throughout the time series (Table ii and Figure iii).

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

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2011	221913	145783.9	298042.1	0.75	0.67	0.84
2012	220118	144422.4	295813.6	0.75	0.67	0.83
2013	218371	143170.7	293571.3	0.74	0.66	0.82
2014	216973	142101.2	291844.8	0.74	0.66	0.82
2015	217507	142620.1	292393.9	0.74	0.66	0.82
2016	219403	144148.4	294657.6	0.75	0.67	0.82
2017	221755	145892.4	297617.6	0.75	0.68	0.83
2018	224177	147622.8	300731.2	0.76	0.68	0.84
2019	227036	149849.3	304222.7	0.77	0.69	0.85
2020	229626	151976.5	307275.5	0.78	0.70	0.86
2021	232065	154152.5	309977.5	0.79	0.71	0.87

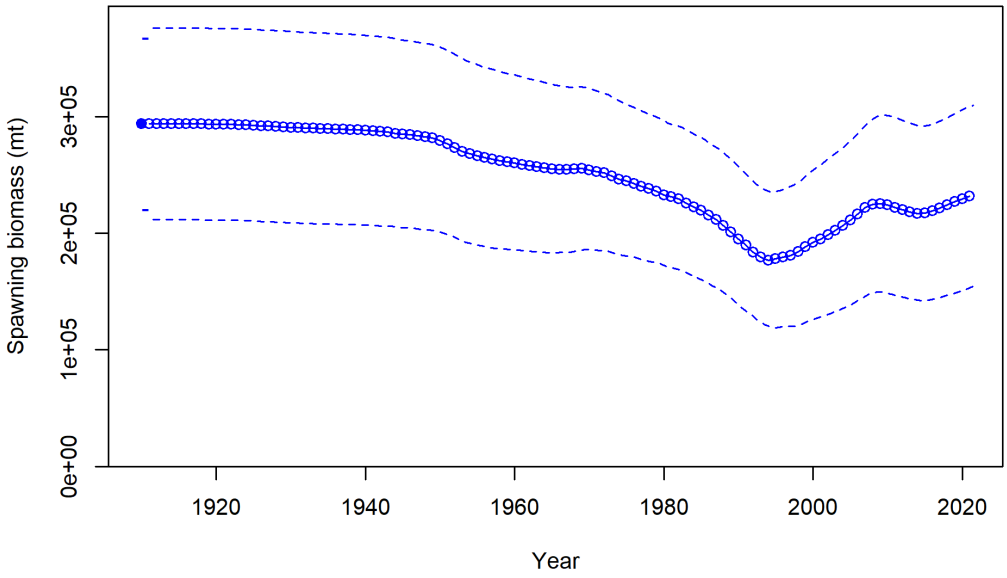


Figure ii: Estimated time series of spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

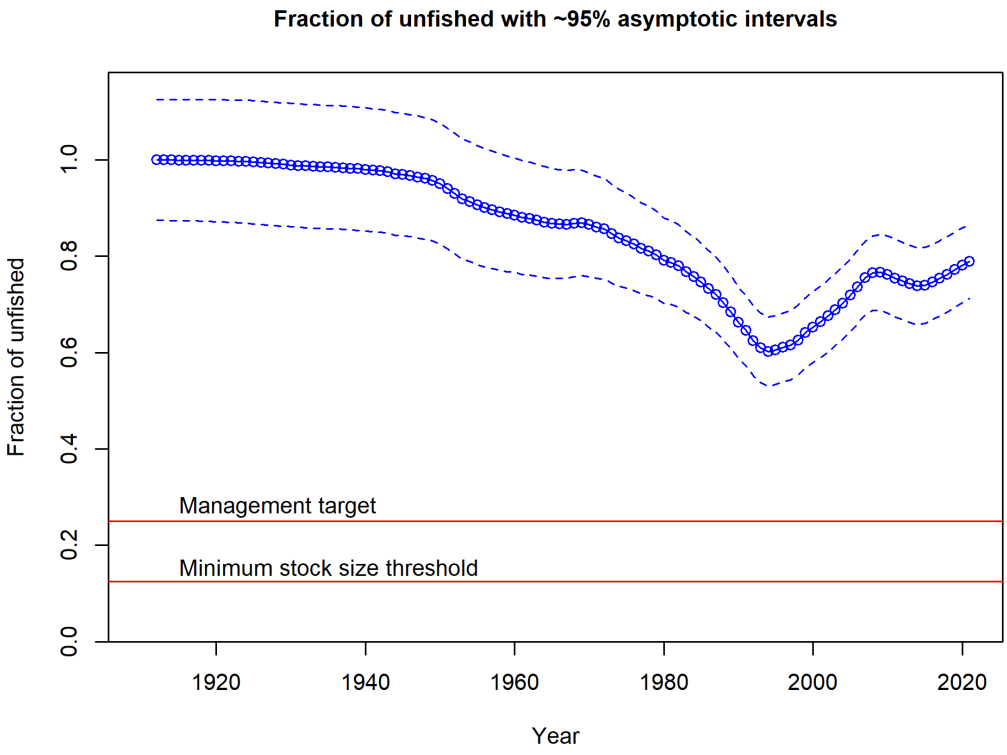


Figure iii: Estimated time series of fraction of unfished spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

Recruitment

There is large uncertainty associated with annual differences in recruitment across much of the time series due to a lack of informative data during the early period and little contrast in composition and index data in the later period to signal much variation in cohort strength (Table iii and Figure iv). Data were most informative from the early-2000s to the mid-2010s, where estimates showed periods of below average recruitment (2002-2006) and above average recruitment (2008-2010). The 2000 and 2009 year classes are estimated to be the largest across the time series and were well determined as being above average (i.e., ~95 percent asymptotic intervals did not span 0, Figure v). Overall, the Dover sole stock has not been reduced to levels that would provide considerable information on how recruitment changes with across spawning biomass levels (i.e., inform the steepness parameter). Thus, all recruitment is based on a fixed assumption about steepness ($h = 0.80$) and recruitment variability ($\sigma_R = 0.35$).

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

Year	Recruitment	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2011	204214	127585.52	326865.9	0.02	-0.37	0.41
2012	238648	154157.64	369445.6	0.18	-0.16	0.53
2013	161941	98865.06	265259.4	-0.21	-0.64	0.21
2014	166317	100364.16	275609.8	-0.19	-0.63	0.24
2015	199178	114941.63	345148.0	-0.02	-0.51	0.47
2016	205309	107885.30	390709.3	0.00	-0.61	0.61
2017	206028	103251.00	411110.2	-0.01	-0.67	0.66
2018	208863	103767.15	420400.4	0.00	-0.68	0.67
2019	209235	103020.66	424956.4	0.00	-0.69	0.69
2020	209423	103120.09	425309.9	0.00	-0.69	0.69
2021	209596	103213.09	425629.0	0.00	-0.69	0.69

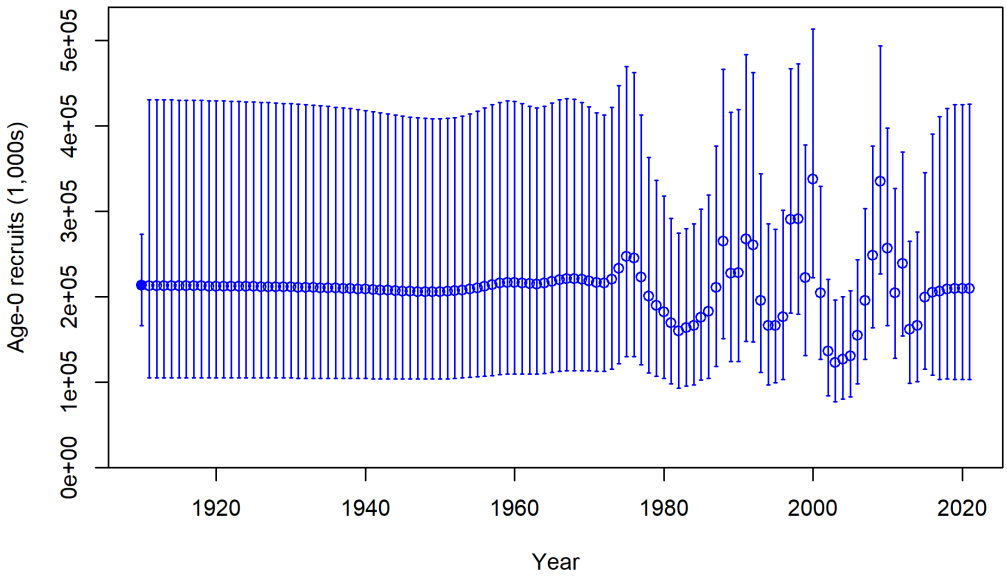


Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95 percent intervals.

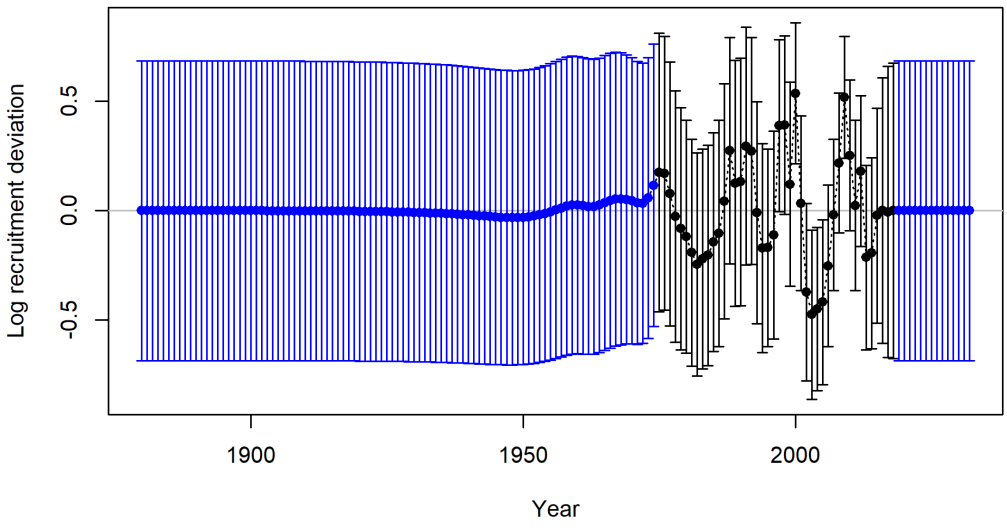


Figure v: Estimated time series of recruitment deviations.

Exploitation Status

Trends in fishing intensity (1 - SPR) largely mirrored that of landings given the relative lack of large variations in annual recruitment such that there was a steady increase from the 1940s to the mid to late 1980s before decreasing to current levels of 0.11 for 2020 (Figure vi). The maximum fishing intensity was 0.45 in 1991, well below the target harvest rate of 0.70 (1 - $SPR_{30\%}$). Fishing intensity over the past decade has ranged between 0.11 and 0.2 and the exploitation rate has been low (0.01 - 0.02, Table iv). Current estimates indicate that Dover sole spawning biomass is greater than 3 times higher than the target biomass level ($SB_{25\%}$), and fishing intensity remains well below the target harvest rate.

Table iv: Estimated recent trend in the 1-SPR where SPR is the spawning potential ratio the exploitation rate, and the 95 percent intervals.

Year	1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2011	0.18	0.13	0.24	0.02	0.01	0.02
2012	0.18	0.13	0.23	0.02	0.01	0.02
2013	0.20	0.14	0.25	0.02	0.01	0.02
2014	0.17	0.12	0.21	0.01	0.01	0.02
2015	0.16	0.11	0.21	0.01	0.01	0.02
2016	0.18	0.13	0.23	0.02	0.01	0.02
2017	0.19	0.14	0.24	0.02	0.01	0.02
2018	0.15	0.11	0.20	0.01	0.01	0.02
2019	0.14	0.10	0.18	0.01	0.01	0.02
2020	0.11	0.08	0.14	0.01	0.01	0.01

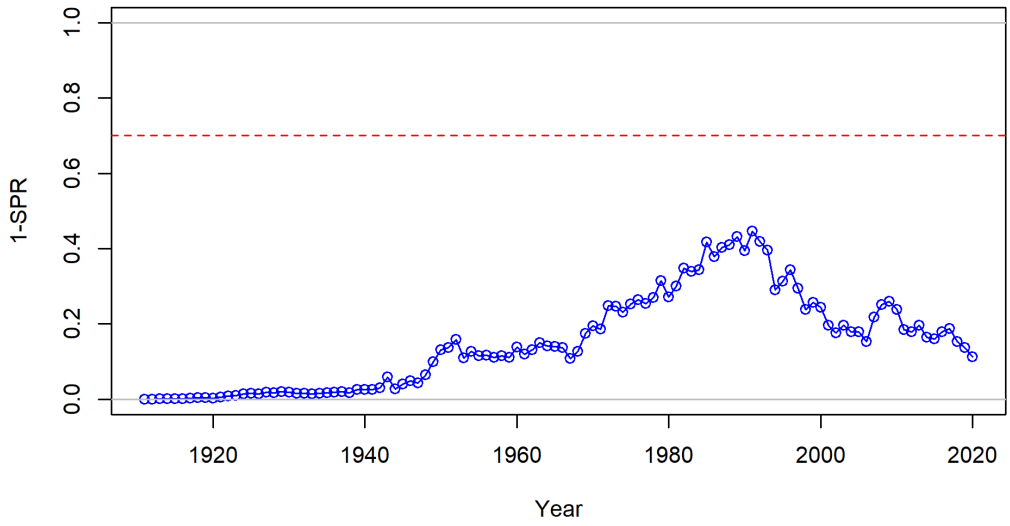


Figure vi: Estimated 1 - relative spawning ratio (SPR) by year for the base model. The management target is plotted as a red horizontal line and values above this reflect harvest in excess of the proxy harvest rate.

Ecosystem Considerations

Ecosystem factors have not been explicitly modeled in this assessment but there are several aspects of the California current ecosystem that may impact Dover sole population dynamics and warrant further research. Survival of Dover sole eggs and pelagic larvae that have a protracted pelagic phase are linked to water circulation patterns (King et al. 2011). The timing of settlement occurs typically between January and March and is correlated with Ekman transport, positive vertical velocity, and relatively warm bottom temperatures (Toole, Markle, and Donohoe 1997). Markle et al. (1992) hypothesized that juvenile Dover sole move inshore to nursery habitat by making vertical ascents during the night off bottom until they encounter suitable habitat. Tolimieri et al. (2020) identified multiple areas off the coast of southern California that had high densities of young Dover sole. This is consistent with the finding of Toole et al. (2011) that juvenile Dover sole 10 - 22 cm tended to move inshore during summer months. As Dover sole grow they generally move offshore into deep waters. Changing water temperature due to climate change may alter the winter onshore Ekman transport which could have impacts on juvenile survival and result in distributional shifts of favorable spawning grounds, or nursery habitats of Dover sole.

Reference Points

The 2021 spawning biomass relative to unfished equilibrium spawning biomass is well above the management target of 25 percent of unfished spawning biomass. The relative biomass compared to the ratio of the estimated SPR to the management target ($SPR_{30\%}$) across all model years are shown in Figure vii where warmer colors (red) represent early years and colder colors (blue) represent recent years. The relative biomass and estimated SPR have been well above the management biomass target (25 percent) and well below the SPR target across all model years. Figure viii shows the equilibrium curve based on a steepness value fixed at 0.8 with vertical dashed lines to indicate the estimate of fraction unfished at the start of 2021 (current) and the estimated management targets calculated based on the relative target biomass (B target), the SPR target, and the maximum sustainable yield (MSY).

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2020 (Table v). Sustainable total yield, landings plus discards, using an $SPR_{30\%}$ is 22,891 mt. The spawning biomass equivalent to 25 percent of the unfished spawning biomass ($SB_{25\%}$) calculated using the SPR target ($SPR_{30\%}$) was 74,498 mt. Recent removals have been below the point estimate of the potential long-term yields calculated using an $SPR_{30\%}$ reference point and the population scale has been relatively stable or increasing over the last decade.

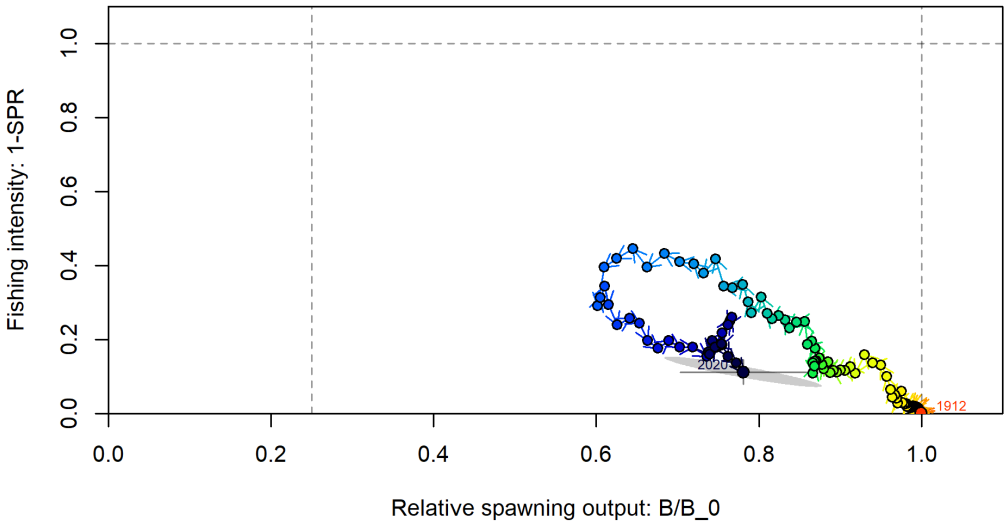


Figure vii: Phase plot of estimated 1-SPR versus fraction unfished for the base model.

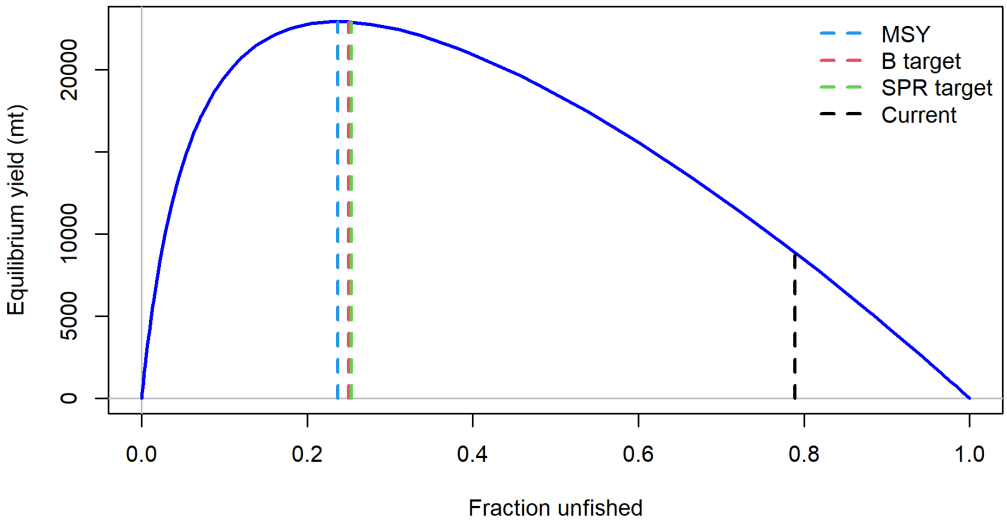


Figure viii: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities and with steepness fixed at 0.80.

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

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	294070	220699	367441
Unfished Age 3+ Biomass (mt)	594408	466269	722547
Unfished Recruitment (R0)	213096	159928	266264
Spawning Biomass (mt) (2021)	232065	154153	309977
Fraction Unfished (2021)	0.79	0.71	0.87
Reference Points Based SB25 Percent	-	-	-
Proxy Spawning Biomass (mt) SB25 Percent	73517	55175	91860
SPR Resulting in SB25 Percent	0.30	0.30	0.30
Exploitation Rate Resulting in SB25 Percent	0.12	0.12	0.12
Yield with SPR Based On SB25 Percent (mt)	22901	17705	28097
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Biomass (mt) (SPR30)	74498	55910	93085
SPR30	0.30	-	-
Exploitation Rate Corresponding to SPR30	0.12	0.12	0.12
Yield with SPR30 at SB SPR (mt)	22891	17697	28084
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Biomass (mt) at MSY (SB MSY)	69598	52425	86771
SPR MSY	0.28	0.28	0.29
Exploitation Rate Corresponding to SPR MSY	0.13	0.12	0.13
MSY (mt)	22919	17716	28122

Management Performance

Exploitation on Dover sole slowly increased starting around 1940 and reached a high in the early 1990s. After peaking in the 1990s exploitation rates declined steadily through 2006, increased from 2007 - 2010, but have steadily declined since. In the last ten years the annual catch limit (ACL) has been set well below the overfishing limit (OFL) and acceptable biological catch (ABC) (Table vi). Total mortality has ranged between 10 - 15 percent of the ACL in the most recent five years.

Table vi: The OFL, ABC, ACL, landings, and the estimated total mortality in metric tons.

Year	OFL	ABC	ACL	Landings	Est. Total Mortality
2011	44400	42436	25000	7782	7893
2012	44826	42843	25000	7328	7430
2013	92955	88865	25000	7970	8078
2014	77774	74352	25000	6449	6543
2015	66871	63929	50000	6327	6354
2016	59221	56615	50000	7318	7350
2017	89702	85755	50000	7892	7925
2018	90282	86310	50000	6421	6447
2019	91102	87094	50000	5767	5790
2020	92048	87998	50000	4688	4707

Unresolved Problems and Major Uncertainties

The base case model was developed with the goal of balancing parsimony with realism and fitting the data. To achieve parsimony, some simplification of model structure was assumed which may impact the interpretation and fit to specific data sets. The maturity-at-length or -at-age analysis conducted for this assessment identified possible differences in Dover sole south and north of Point Reyes. Currently, there is limited information on the movement of Dover sole by latitude or depth which could provide insights into the mechanisms behind these observed differences. Spatial estimates of biomass north and south of Point Reyes, using WCGBTS data averaged across the most recent five years, indicated that approximately 67 percent of the West Coast Dover sole biomass is estimated to be north of Point Reyes. Additionally, in recent years the majority of fishery data have been collected from ports north of Point Reyes, which limits the ability to support additional model complexity. Given the lack of information to inform the structure and parameterization of a spatial model, the base model assumed a single homogeneous population structure at this time. Future research into the biology and movement of Dover sole could facilitate future spatial modeling efforts if found to be the appropriate approach.

Uncertainty in natural mortality translates into uncertain estimates of both status and sustainable fishing levels for Dover sole. In the base model, a balance between fixing and

estimating this key parameter was achieved by fixing female natural mortality at the median of the prior while estimating the relative difference in male natural mortality. The difference between male and female natural mortality appeared to be well informed (likelihood profile) with estimates consistent with the data and biology of Dover sole across its range (U.S. west coast, Canada, U.S. Alaska waters). The likelihood profile across values of female natural mortality supported lower values, which were not expected *a priori* based on the available age data and were largely driven by length data from the AFSC slope survey. This could be due to limited information about maximum age for Dover sole in the data, the limited selection of female Dover sole by the fisheries and surveys or could indicate model misspecification. It is unclear what is driving this behavior in the model.

Dover sole life history exhibit strong relationships with depth that indicate the stock is more complex than the model assumes. Small fish are found in shallow water, with the median observed size increasing with depth. However, the variability of sizes observed by sex increases moving from deeper to shallower waters. Specifically, the WCGBTS observes large females at the deepest depths sampled but also observe some of the largest female Dover sole in waters less than 300 meters. In addition, there is a pattern of sex ratio by depth with more males being found in middle depths and more females found in shallow and deeper depths. These patterns are apparent in the summer fisheries and surveys. It is uncertain how the patterns affect the data (they may be a cause of the bi-modal length distributions seen in the slope surveys) and if these patterns can be effectively modeled to produce better fits to the data and better predictions of biomass while still preserving model parsimony.

Scientific Uncertainty

The model estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.17$ and the uncertainty around the OFL was $\sigma = 0.16$. This is likely an underestimate of overall uncertainty because of the necessity to fix several population dynamic parameters (e.g., steepness, recruitment variance, female natural mortality) and no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

Harvest Projections and Decision Table

The forecast of stock abundance and yield was developed using the base model. The total catches in 2021 and 2022 were set at 10,000 mt, well below the adopted 50,000 mt ACL for those year, based on recommendations from the Groundfish Management Team (GMT). These assumed removals are likely higher than what the true removals may be in 2021 and 2023 but have limited impact in the stock status and future removals during the projected period in the base model. The exploitation rate for 2023 and beyond is based upon an SPR of 30 percent and the 25:5 harvest control rule. The average exploitation rates, across recent years, by fleet were used to distribute catches during the forecast period. The ABC values were estimated using a category 1 time-varying σ_y starting at 0.50 combined with a P* value of 0.45. The catches in the base model during the projection period, 2023 - 2032 were set equal to the year-specific ABC using the current flatfish harvest control rule, 25:5 (Table vii).

The axes of uncertainty in the decision table are based on the uncertainty around female natural mortality. The default category 1 σ value of 0.50 was used to identify the low and high states of nature relative to the estimated 2021 spawning biomass (i.e., 1.15 standard deviations corresponding to the 12.5 and 87.5 percentiles). A search across female natural mortality values was done to identify the natural mortality value that resulted in current year spawning biomass values for the low and high states of nature based on the percentiles. The female natural mortality values that corresponded with the lower and upper percentiles were 0.084 yr^{-1} and 0.126 yr^{-1}.

Initial explorations were conducted using the model estimated uncertainty around 2021 spawning biomass of $\sigma = 0.17$ rather than the higher default category 1 σ value. However, the range of the low and high states of nature relative to the base model were determined to not adequately capture uncertainty based on feedback received during the STAR panel review. Model estimated uncertainty is an underestimate of the true uncertainty around the stock size since it only captures within model uncertainty and does not account for structural uncertainties. Applying a higher σ value allowed the low and high states of nature to capture a larger uncertainty range around the base model which may be more in line with the cumulative model and structural uncertainty. It was noted that the low and high states of nature results in catchability values (low state of nature catchability = 2.0 and high state of nature catchability = 0.56) for the WCGBTS that were factors higher or lower than the base model catchability (1.072). Catchability values could potentially provide understanding of the plausibility of alternative states; however, adequately interpreting values of catchability comes with inherent challenges due to changes in other key model parameters (e.g., selectivity).

Three alternative catch streams were created for the decision table (Table viii). The first option uses ABC values which are adjusted based on time-varying σ_y starting at 0.50 and increasing annually combined with a P^* value of 0.45. The two alternative catch streams assume fixed catches of either 7,000 or 20,000 mt for the 10 year projection period. All of these options assume full attainment of the catch values.

Across the low and high states of nature and across alternative future harvest scenarios the fraction of unfished ranges between 0.023 - 0.895 by the end of the 10 year projection period (Table viii). The low state of nature assuming full ABC removals results in a nearly depleted stock at the end of the time series. This is due to the assumption or removing the full ABC derived from the base model to the low state of nature which had an overall lower unfished spawning biomass associated with a low natural mortality value which results in a more depleted stock in 2021 relative to the base model.

Table vii: Projections of potential OFLs (mt), ABCs (mt), the buffer (ABC = buffer x OFL), estimated spawning biomass, and fraction unfished. The adopted OFL, ABC, and ACL for 2021 and 2022 reflect adopted management limits and the assumed removal is the removal assumptions applied for 2021 and 2022. The full ABC was assumed to be removed for 2023 - 2032

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed Removal (mt)	OFL (mt)	ABC (mt)	Buffer	Spawning Biomass (mt)	Fraction Unfished
2021	93547	84192	50000	10000	-	-	-	232065	0.79
2022	87540	78436	50000	10000	-	-	-	231642	0.79
2023	-	-	-	-	63834	59684	0.935	230918	0.79
2024	-	-	-	-	55859	51949	0.93	207333	0.71
2025	-	-	-	-	49608	45937	0.926	187284	0.64
2026	-	-	-	-	44769	41277	0.922	170449	0.58
2027	-	-	-	-	41053	37646	0.917	156459	0.53
2028	-	-	-	-	38217	34892	0.913	144943	0.49
2029	-	-	-	-	36050	32770	0.909	135500	0.46
2030	-	-	-	-	34389	31088	0.904	127779	0.43
2031	-	-	-	-	33108	29797	0.9	121483	0.41
2032	-	-	-	-	32100	28762	0.896	116323	0.40

Table viii: Decision table summary of 10 year projections beginning in 2023 for alternative states of nature based on an axis of uncertainty about female natural mortality for the base model. Columns range over low, mid, and high states of nature and rows range over different catch level assumptions. Values in italics indicate years where the stock size prevented the full catch removals.

			M = 0.084		M = 0.108		M = 0.126	
	Year	Catch	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished
	2021	10,000	130,402	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,406	0.578	231,642	0.788	410,978	0.899
	2023	7,000	130,187	0.577	230,918	0.785	409,093	0.895
	2024	7,000	130,897	0.58	231,425	0.787	408,497	0.894
	2025	7,000	131,593	0.583	231,923	0.789	408,020	0.892
7,000 mt	2026	7,000	132,315	0.586	232,460	0.790	407,746	0.892
	2027	7,000	133,080	0.59	233,048	0.792	407,685	0.892
	2028	7,000	133,889	0.593	233,681	0.795	407,810	0.892
	2029	7,000	134,732	0.597	234,344	0.797	408,079	0.893
	2030	7,000	135,595	0.601	235,020	0.799	408,451	0.893
	2031	7,000	136,465	0.605	235,695	0.801	408,888	0.894
	2032	7,000	137,331	0.609	236,358	0.804	409,361	0.895
	2021	10,000	130,357	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,358	0.578	231,642	0.788	410,978	0.899
	2023	20,000	130,139	0.577	230,918	0.785	409,093	0.895
	2024	20,000	125,188	0.555	225,521	0.767	402,630	0.881
	2025	20,000	120,142	0.533	220,194	0.749	396,479	0.867
20,000 mt	2026	20,000	115,118	0.51	215,059	0.731	390,789	0.855
	2027	20,000	110,193	0.488	210,181	0.715	385,612	0.843
	2028	20,000	105,413	0.467	205,591	0.699	380,946	0.833
	2029	20,000	100,799	0.447	201,293	0.685	376,756	0.824
	2030	20,000	96,356	0.427	197,281	0.671	372,999	0.816
	2031	20,000	92,080	0.408	193,539	0.658	369,624	0.809
	2032	20,000	87,958	0.39	190,049	0.646	366,588	0.802
	2021	10,000	130,402	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,406	0.578	231,642	0.788	410,978	0.899
	2023	59,685	130,187	0.577	230,918	0.785	409,093	0.895
	2024	51,949	106,617	0.473	207,333	0.705	384,636	0.841
ABC	2025	45,937	85,730	0.38	187,284	0.637	364,461	0.797
P* 0.45	2026	41,277	67,417	0.299	170,449	0.580	348,088	0.761
	2027	37,646	51,561	0.229	156,459	0.532	334,996	0.733
	2028	34,892	38,054	0.169	144,943	0.493	324,682	0.710
	2029	32,770	26,754	0.119	135,500	0.461	316,642	0.693
	2030	31,088	17,564	0.078	127,779	0.434	310,450	0.679
	2031	29,797	*10432*	*0.046*	121,483	0.413	305,756	0.669
	2032	28,762	*5289*	*0.023*	116,323	0.396	302,239	0.661

Research and Data Needs

Investigating and or addressing the following items could improve future assessments of Dover sole:

- Spatiotemporal distribution patterns with depth: There are patterns of length and sex ratios with depth which may indicate that the stock is more complex than currently modeled. Further research into the causes of these patterns as well as differences between seasons would help with understanding the stock characteristics such that a more realistic model could be built. This may also provide further insight into migration and help determine if there are localized populations.
- Stock boundaries: A common question in stock assessments is whether or not the entire stock is being represented. Dover sole live deeper than the range of the fisheries and surveys. The assessment model attempts to account for out of area biomass through catchability coefficients and selectivity curves, but that portion of the stock is unknown and can only be conjectured. Research into abundance in deep areas would be useful to verify that the assessment adequately predicts the entire spawning stock of Dover sole.
- Unavailable biomass: The distribution of Dover sole covers a wide-depth range off the West Coast. Dover sole are observed by the WCGBTS out to 1,280 m, the maximum depth sampled, where the majority of Dover sole observations at these depths are females. The sex-specific movement of Dover sole across depths results in the model estimating that females‘ are never fully selected (maximum selectivity well below 1.0 or dome-shaped) by the fisheries or the surveys. This results in an assumption that there is some portion of cryptic biomass that is unavailable for selection by the fisheries or observation by the surveys. Improved understanding about sex-specific availability across depths by season and the proportion of Dover sole biomass, particularly female biomass, at depths beyond the range of the survey would improve future estimates of stock size.
- California Sampling for Ages: Since 1990, nearly 60 percent of fish aged have been landed at the Crescent City port with some years all aged fish being landed there. In contrast, the majority of Dover sole landed in California occur at the Eureka port (approximately 67 percent over the last 10 years). Ensuring that sampling is spread across California ports and otoliths selected for ageing are spread across ports proportional to area removals may provide additional insights to area-specific population attributes.

1 Introduction

The Dover sole (*Microstomus pacificus*) is a flatfish belonging to the family Pleuronectidae and is called a sole although it is a flounder. Dover sole has also been known by several different common names including slippery sole, lemon sole, smear dab, rubber sole, short finned sole, slime sole, and tongue sole. Although there was little interest in Dover sole when the U.S. west coast trawl fishery first began in the late 19th century, the species is now commonly landed.

This is an assessment of the Dover sole population off of the U.S. west coast, including coastal waters of California, Oregon, and Washington from the U.S./Mexico border to the U.S./Canadian border (Figure 1). It does not include Canadian or Alaskan populations and assumes that these northern populations do not contribute to the stock being assessed here.

1.1 Life History

Dover sole range from Baja California to the Bering Sea and eastern Aleutian Islands (Kramer et al. 1995). Dover sole are generally found on mud or mud-sand bottom deeper than 20 fathoms (37 m) and out to below 1,500 m (Jacobson and Hunter 1993). They feed on polychaete worms, pink shrimp, brittle stars, gammarid amphipods, and small bivalves (Pearcy and Hancock 1978; Gabriel and Pearcy 1981). Dover sole exhibit dimorphic growth by sex with females off the West Coast reaching a maximum length around 48 cm, approximately 5 cm greater than males. Dover sole are estimated to live up to a maximum age of approximately 50 years.

Based on samples from the commercial fishery in northern California, Hagerman (1952) concluded that the spawning period for Dover sole is during November to March or April with heavy spawning during December to February. In contrast, a later study by Markle et al. (1992) concluded that Dover sole off the coast of Oregon appear to reach peak spawning in early spring. Spawning occurs in relatively deep water (Hagerman 1952) and prior to 1954 few Dover sole were caught during winter months because the fish were generally unavailable on the continental shelf during winter. Dover sole eggs and larvae are buoyant (Hagerman 1952) with an extended larval phase lasting at least one year (Pearcy, Hosie, and Richardson 1977; Markle, Harris, and Toole 1992; Butler, Dahlin, and Moser 1996). Additionally, Markle et al. (1992) postulate that Dover sole larvae may extend settlement by delaying metamorphosis to avoid unfavorable oceanographic conditions.

Based on research survey tows, Jacobson and Hunter (1993) found that the catches of Dover sole in a given area and depth zone were not randomly distributed by sex, with males and females tending to occur in separate patches. Furthermore, Dover sole appear to undergo ontogenetic shifts in their distribution with fish gradually moving to deeper water as they grow (Jacobson, Brodziak, and Rogers 2001). Westrheim et al. (1992) summarized the results from multiple tagging studies between 1948 - 1979 and indicated seasonal movements of Dover sole onto the continental shelf in the summer and off the shelf in the winter, but little

evidence of north-south movement or appreciable mixing between Pacific Marine Fisheries Commission (PMFC) statistical areas. However, a few tagged fish were observed to have moved long distances. For example, Westrheim and Morgan (1963) reported that a fish caught and tagged in the Willapa Deep area off Washington was subsequently recaptured off Humboldt Bay, California, 360 nautical miles south. Barss et al. (1977) reported having records for 13 tagged fish that were recaptured after 10 or more years at liberty. The longest time a fish was at liberty was 22 years and was recaptured within 1 nautical mile of its original release location. Although, Westrheim et al. (1992) found little observed movement movement north and south, they note that the majority of the tagging work was done prior to the development of the deepwater trawl fishery for Dover sole (except PFMC area 1C). Additionally, Dover sole larvae have an extensive pelagic period, greater than one year, which may allow larvae movement across the West Coast (Hagerman 1952).

Ono et al. (2016) examined movement patterns of Dover sole using WCGBTS data collected off the West Coast in early summer and early fall. They found that Dover sole displayed ontogenetic movement, moving to shallower and deeper water during summer months. Additionally, Dover sole appeared to move from areas southwest of San Francisco and northwest of Eureka to the northern or southern edges of the U.S. coast in late summer, aggregating along the Washington coast and south of Point Conception in California (Ono et al. 2016). This movement pattern identified by Ono et al. (2016) differs from the limited latitudinal movement identified by early tagging studies of Dover sole (Westrheim et al. 1992).

Stock structure is not well understood. Based on tagging study results that show limited adult movement, there may be multiple stocks of Dover sole due to limited intermingling adult populations, but larvae probably intermingle during their long pelagic life (Westrheim et al. 1992). Stepien (1999) used sequences of mitochondrial DNA extracted from Dover sole sampled at six sites ranging from southern California to the Gulf of Alaska and found phylogeographical structure in West Coast Dover sole with spatial clustering of genetically similar individuals. However, there were several unusual clusters of specimens having apparently similar genetic make-up although they were geographically separated (i.e., fish from Alaska with similar genetics as fish from San Diego).

1.2 Ecosystem Considerations

Ecosystem factors have not been explicitly modeled in this assessment but there are several aspects of the California current ecosystem that may impact Dover sole population dynamics and warrant further research. Survival of Dover sole eggs and pelagic larvae that have a protracted pelagic phase are linked to water circulation patterns (King et al. 2011). The timing of settlement occurs typically between January and March and is correlated with Ekman transport, positive vertical velocity, and relatively warm bottom temperatures (Toole, Markle, and Donohoe 1997). Markle et al. (1992) hypothesized that juvenile Dover sole move inshore to nursery habitat by making vertical ascents during the night off bottom until they encounter suitable habitat. Tolimieri et al. (2020) identified multiple areas off the coast of southern California that had high densities of young Dover sole. This is consistent with the finding of Toole et al. (2011) that juvenile Dover sole 10 - 22 cm tended to move inshore

during summer months. As Dover sole grow they generally move offshore into deep waters. Changing water temperature due to climate change may alter the winter onshore Ekman transport which could have impacts on juvenile survival and result in distributional shifts of favorable spawning grounds, or nursery habitats of Dover sole.

1.3 Historical and Current Fishery Information

Trawl fishing with boats powered by sail began in California waters in 1876 and caught many flatfishes, including Dover sole (Hagerman 1952). Even though there are reports of Dover sole being sold in summer markets in San Francisco as early as 1878 (Lockington (1880) as referenced by Hagerman (1952)), it was not until the early part of the 20th century that landings of Dover sole were recorded. In a 1936 biological report from the State of Washington Department of Fisheries Dover sole was described as "very slimy and is repulsive to handle" and "[i]t has no value as a commercial fish" (Smith 1936). It was not long after 1936 that Dover sole were being landed in significant quantities up and down the U.S. west coast.

Since Dover sole was considered a "repulsive" fish by some (Smith 1936) in the early years of the West Coast fishery development, it was likely discarded as bycatch when pursuing other more desirable species such as petrale sole (*Eopsetta jordani*) and English sole (*Parophrys vetulus*). However, markets were eventually developed and landings began steadily increasing in the 1940s. While early Dover sole landings were first recorded in California, fisheries for Dover sole had developed in Oregon and Washington by the 1930s (Table 1 and Figure 2). Landings remained relatively constant throughout the 1950s and 1960s before increasing rapidly into the early 1990s. Starting around 1980 landings in Oregon surpassed California landings, becoming the state with the highest landing of Dover sole. In recent years in California, the majority of removals of Dover sole have been landed in northern California ports (Eureka, Fort Bragg, and Crescent City). In Oregon, the majority of recent landings occur at Astoria and Newport followed by Coos Bay and Brookings. In Washington, ports in Bellingham and Westport, have the highest landings in recent years.

Over the last twenty years, the landings declined (mostly in California) until 2007 when harvest guidelines increased the allowable catch based on the 2005 assessment results (Sampson 2005). In 2015 the Annual Catch Limit (ACL) of Dover sole increased from 25,000 to 50,000 mt for Dover sole with 95 percent of the ACL allocated to the trawl fishery. However, attainment of Dover sole has been low (less than 15 percent). The reasons for low attainment of Dover sole are complex. Dover sole co-occur with sablefish (*Anoplopoma fimbria*) which has been a constraining species for Dover sole landings due to the lower ACLs of sablefish and allocation challenges among sablefish fishing sectors. Additionally, petrale sole (*Eopsetta jordani*), a highly targeted flatfish off the West Coast, was declared overfished in 2010 (Haltuch, Hicks, and See 2011), resulting in lower ACLs for petrale sole prior to the stock rebuilding in 2015 which could have limited opportunities for Dover sole landings. Finally, in recent years there has been increased competition in the whitefish markets with other inexpensive fish options (e.g., tilapia and catfish) which may have displaced U.S. wild caught species such as Dover sole (Norma-Lopez 2009).

Groundfish trawl fisheries land the majority of Dover sole (greater than 99 percent total landings) while fixed gears, shrimp trawls, and recreational fisheries make up a very small amount of fishing mortality. Shrimp trawls have been using excluders which have reduced bycatch of many species including Dover sole. The trawl fisheries typically catch Dover sole while targeting the deepwater complex consisting of Dover sole, sablefish, shortspine thornyhead (*Sebastolobus alascanus*), and longspine thornyhead (*Sebastolobus altivelis*, DTS deepwater complex) but also encounter Dover sole when targeting petrale sole or nearshore mix species. The fishery targets Dover sole across a range of depths (50 - 330 fathoms) depending upon the season (Scott Malvitch, personal communication, ODFW).

Historically, discarding of Dover sole occurred for a variety of reasons. Dover sole was discarded due to trip limits, small size, or even being too large. Dover sole of the largest size caught at deep depths become "jellied" where the tissue becomes soft and has little marketability (Mike Okoniewski, personal communication). Since the introduction of individual fishery quotas (IFQ) in 2011, the discarding of all quota species, including Dover sole, has dramatically declined across the IFQ trawl fleet.

1.4 Summary of Management History and Performance

Management restrictions for Dover sole came largely into place in the early 1980s with the implementation of trip limits and quotas on DTS species, which mostly limited catches of Dover sole because of more restrictive trip limits on the higher priced sablefish and thornyheads. Trip limits specific for Dover sole were implemented for portions of 1994, 1996, the start of 1997, and for years thereafter. Catches of the deepwater species during earlier years were controlled primarily by trip limits on the landings of sablefish and thornyheads, for which the fishers received much higher prices.

In studies of trawl logbook data from California (1985-91), Washington (1986-92), and Oregon (1987-93), Sampson (1997) tabulated how many trawl trips landed within 90 percent of the trip limits in effect at the time of each trip. Trips were sometimes constrained by the trip limits on sablefish (up to 43 percent of the trips landing in California, 32 percent of the trips landing in Oregon, and 27 percent of the trips landing in Washington). Trips were much less frequently constrained by the trip limits on the deepwater complex (up to 15 percent of the trips landing in California, 17 percent of the trips landing in Oregon, and 8 percent of the trips landing in Washington).

The introduction of the IFQ fishery in 2011 created an allocation system of quota pounds to vessels participating in the catch share program for species in the groundfish Fishery Management Plan. Overall, Dover sole removals have been well below the annual catch limits (ACLs, Table 2).

1.5 Fisheries off Canada and Alaska

Dover sole in Canadian waters are treated as two distinct stocks; a northern stock and a southern stock. The fishery in the north began in the 1970s while the fishery off of the West Coast of Vancouver Island started in the late 1980s. Area quotas were used to manage the two stocks until the introduction of individual based quotas in 1996. A 1999 assessment reported that the stocks were being exploited at levels near the maximum sustainable yield (Department of Fisheries and Ocean 1999). The stock has not been assessed since; however, was slated for assessment in 2020 (it is unknown if this was done according to schedule). For the two areas combined (3C/D), the total allowable catch in recent years has been set at 1,375 mt (Department of Fisheries and Ocean 2019).

In the Gulf of Alaska, the flatfish fishery has caught substantial quantities of Dover sole, with the peak of 9,740 mt in 1991 (Stockhausen, Turnock, and A'mar 2006). Gulf of Alaska catches or Dover sole have been well below the Total Allowable Catch (TAC) which was set at 9,501 mt in 2019 (The Plan Team for the Groundfish Fisheries of the Gulf of Alaska 2019). In 2020 the spawning biomass for Dover sole was estimated to be 27,935 mt, well above the biomass target for the Gulf of Alaska of 7,613 mt (The Plan Team for the Groundfish Fisheries of the Gulf of Alaska 2019).

2 Data

A description of each data source is provided below (Figure 3).

2.1 Fishery-Dependent Data

2.1.1 Recent Commercial Fishery Landings

The commercial removals were extracted from the Pacific Fisheries Information Network (PacFIN) database for 1981 - 2020 for California and Washington and 1987 - 2020 for Oregon on January 28, 2021. The majority of removals for Dover sole arise from trawl gear (i.e., greater than 99 percent). Commercial removals for all gear types were combined into two area-specific fleets: a California fleet and a combined Oregon/Washington fleet. The fleet grouping for Oregon and Washington was suggested by State representatives during the pre-assessment data meeting because of similarities in fishing across this region while also avoiding the inherent difficulties associated with separating data between Oregon and Washington due to the intermixing of fishing and landing locations across state boundaries.

2.1.1.1 Washington Landings Prior to 1981

Historical commercial landings of non-shrimp trawl gear were reconstructed for Dover sole landed in Washington for use in the 2011 assessment by Greg Lippert (Washington Department Fish and Wildlife, WDFW). Shrimp trawl, fixed gear, and recreational landings constitute a negligible amount of the total mortality for Dover sole. Historical landings of Dover sole landed in the state of Washington were determined from various data sources using era-specific understanding of fishing behavior. For details, please see Hicks and Wetzel (2011). The historical landings for Washington were revised slightly from those used in 2011 to include historical catches that were captured in Washington water but landed in California. See details below in Oregon Landings Prior to 1986.

2.1.1.2 Oregon Landings Prior to 1986

Historical commercial fishery landings of Dover sole in Oregon for the years 1911 - 1986 were obtained from Alison Whitman (Oregon Department of Fish and Wildlife, ODFW). A description of the historical reconstruction methods can be found in Karnowski et al. (2014). The California catch reconstruction (discussed below, Ralston et al. (2010)) excluded fish that were caught in Oregon or Washington waters and landed at a California port. In contrast, Oregon's historical catch reconstruction was based on the port of landing. This disconnect between methods applied by California and Oregon was brought to light during the 2016 Catch Reconstruction workshop. Landings estimates between 1948 - 1968 for Dover sole that were identified to have occurred in Oregon or Washington waters and excluded from the California reconstruction were provided by John Field (Southwest Fishery Science Center, SWFSC, NOAA). These landings of Dover sole were added to the Oregon/Washington fleet within the model (Table 3).

2.1.1.3 California Landings Prior to 1981

Historical commercial fishery landings of Dover sole from 1948 - 1980 were obtained directly from E.J. Dick (SWFSC, NOAA) who retrieved the data from the California Cooperative Groundfish Survey data system (CALCOM). The method of reconstructing California historical landings are described by Ralston et al. (2010).

At present, no landing for Dover sole before 1948 are available in CALCOM. For years prior to 1948, the landings from the 2005 assessment (Sampson 2005) were used (as was done in the 2011 assessment). The data from Sampson (2005) for the years of 1911 - 1947 include assumed discards of Dover sole from other fisheries operating at the time in California and represent total removals in comparison to the data from CALCOM account for only landed Dover sole. To account for this difference in the input catches for California a retention block was applied for 1911 - 1947 that assumed 100 percent retention (i.e., no additional discarding would be assumed since the removals during this period represent landings + discards).

2.1.2 Commercial Discards

Data on discards of Dover sole are available from a few different data sources. Multiple

historical discard studies were used in the model: estimates for the California trawl fishery discarding rate in 1992 (Humboldt State Study), Oregon at-sea discarding study between 1959 - 1961 (Hermann and Harry Jr. 1963), Pikitch discard study in Oregon and Washington between 1985 - 1987, 1974 discard rate analysis in Oregon (Methot et al. (1990) based on TenEyck and Demory (1975)), and discard observations from the West Coast Groundfish Observer Program (WCGOP).

Brodziak et al. (1997) described a discard study during 1989 - 1996 by researchers from Humboldt State University. Across 28 observed trips in California waters a total of 21,950 pounds of Dover sole were discarded from a total catch of 172,737 pounds. The authors did not specify what portions of the discards were due to the small size of the fish versus due to trip limits.

Hermann and Harry (1963) conducted a discard study in Oregon examining at-sea and landed length observation for multiple years between 1950 - 1961 (6 sampled years). The data consisted of length frequency measurements taken at-sea and comparable measurements taken at the docks, after sorting and discarding of small unmarketable fish. Retained and discarded fish were estimated by converting observations to pounds using average weights. Estimates of the total length distribution measured at-sea and landed fish were used in previous assessments of Dover sole (Sampson 2005; Hicks and Wetzel 2011); however, these data were not available for evaluation in this assessment and were only included as 'ghost' observations (allows to see the implied data fits without being incorporated in the model likelihood estimation). Hermann and Harry (1963) report did include estimates of at-sea catches and landed Dover sole for each year. Discard rates for well sampled years, 1959 - 1961, were retained for use in this assessment. The discarding rate per year ranged from 0.112 - 0.232.

Based on sampling at-sea during summer 1974 in Oregon waters, TenEyck and Demory (1975) estimated age-specific retention rates and reported age-at-50-percent-retention of 7.4 years for male Dover sole and 6.9 years for females, equivalent to lengths at 50 percent retention around 33 cm. Based on data from the 1974 study, Methot et al. (1990) reported that the fraction discarded on a weight basis was 0.167.

A trawl discard study conducted in 1985 - 1987, referred to as the Pikitch study, organized by Ellen Pikitch resulted in discard rates and length observations for various groundfish species including Dover sole (Pikitch, Erickson, and Wallace 1988). The northern and southern boundaries of the study were $48^{\circ}42'$ N. latitude and $42^{\circ}60'$ N. latitude respectively, which is primarily within the Columbia INPFC area, falling within Oregon/Washington waters (Pikitch, Erickson, and Wallace 1988; Rogers and Pikitch 1992). Participation in the study was voluntary and included vessels using bottom, midwater, and shrimp trawl gears. Observers on commercial vessels collected the data, estimated the total weight of the catch by tow, and recorded the weight of species retained and discarded in the sample. Results of the Pikitch discard study were processed and provided by John Wallace (personal communication, Northwest Fishery Science Center, NWFSC, NOAA) in the form of ratios of discard weight to retained weight of Dover sole and sex-specific length frequencies. The observed discard length observations by year and sex for Dover sole from the Pikitch study were limited. In

order to reduce the noise in these data sex-specific observations were combined based on the assumption that discarding of small fish was not sex-specific (there was no indication of this in the data).

The final data for discard rate and length observations is from the WCGOP. This program is part of the NWFSC and has been recording discard observations starting in 2003. Since 2011, when the IFQ program was implemented, observer coverage rates increased to nearly 100 percent for all the limited entry trawl vessels in the program and discard rates declined compared to pre-2011 rates. Discard rates were obtained for both the IFQ catch-share (observed and electronic monitored vessels) and the non-catch share sector for Dover sole. A single discard rate was calculated by weighting discard rates based on the commercial landings by each sector. Coefficient of variations were calculated for the non-catch shares sector and pre-catch share years by bootstrapping vessels within ports because the observer program randomly chooses vessels within ports to be observed. Post trawl rationalization, all catch-share vessels have 100 percent observer coverage and discarding is assumed to be known.

The discard rates across all data sources for the California and the Oregon/Washington fleets are shown in Table 4 and Figures 4 - 10. The mean weights of discarded Dover sole from WCGCOP data are shown in Figures 6 and 7. The discard length observations from the Pikitch study (Oregon/Washington only) and WCGOP are shown in Figures 8 and 10. The observed lengths discarded and the overall discard rate by the California fleet in recent years appeared to have roughly two periods: 2011 - 2014 and 2015 - 2019. The discard rates from 2015 - 2019 were lower than the earlier IFQ years (Figure 4) with a higher proportion of smaller fish discarded (Figure 8, except 2017). The number of discard length observations in California in recent years (2015 - 2019, samples ranged from 82 - 733 per year) was lower than the earlier years (2011 - 2014, samples ranged from 618 - 1310 per year). This may be due to both a decrease in discarding of Dover sole and increase in the number of vessels using electronic monitoring (EM) where EM vessels only carry observers 20 percent of the time. There was a similar decline in length discard samples from WCGOP for the 2015 - 2019 period for Washington/Oregon but not to the extent observed in California. However, the discard rates and length discarded in Oregon/Washington appeared relatively consistent across the IFQ period.

2.1.3 Commercial Fishery Length and Age Data

The PacFIN Biological Data System (BDS) contains data for Dover sole from ODFW (1987-present) and WDFW (1967- present), but only 1989 - present data from California Department of Fish and Game (CDFG). In contrast for California, the CALCOM database contains earlier length (1969 - 1988) and age samples (1981 - 1989) that are not currently available in PacFIN. Expanded length and age data from CALCOM for all years available were provided by E.J. Dick (personal communication, SWFSC, NOAA). Since there were early samples that were available in CALCOM and not PacFIN, the CALCOM expanded length and ages were used in this assessment. Early model sensitivities conducted reflected little difference in model estimates for Dover sole, a well sampled species with large landings, when the same years of data were used between PacFIN or CALCOM.

Commercial length-frequency distributions based on the fishing year were developed for each state for years where observations were available. For each fleet, the raw observations (compiled from the PacFIN and CALCOM databases) 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. The expanded length observations were then expanded by the landings in each state. Post-expanded length data were combined into a single fleet for Oregon/Washington. Age frequencies were computed in the same manner.

Length and age data collected from commercial landings for each state are summarized by the number of trips and fish sampled by year (Tables 5 and 6). The lengths sampled by port for California are shown in Figure 11 based on port information in PacFIN. While the model used length data from CALCOM due to the early years of data available, the years where CALCOM and PacFIN overlap the samples should be the same. Length observations in California generally range between 30 - 50 cm with females consisting of a higher proportion of the larger sizes due to dimorphic growth (Figure 12). Observed average size had high large variance prior to 1988, due to lower input sample sizes, with the variance of observations in recent years being low (Figure 13). The length composition data aggregated across years for the California fishery shows that a higher proportion of males are selected relative to females and the peak length of males selected is lower than the female peak size (Figure 14).

The age samples by port in California are shown in Figure 15 based on data in PacFIN. Due to limited ageing capacity no otoliths collected in California between 2010 - 2020 were read for this assessment. The majority of read ages for California were sampled from otoliths from fish landed at the Crescent City port, followed by samples from the Eureka and Fort Bragg ports. The mean age of sampled fish fluctuated between 11 and 17 years of age across years with available age data from California (Figures 16 and 17). The peak age observed in aged fish for males and females were around 10 years of age (Figure 18).

Length and age data collected from commercial landings for Oregon and Washington are summarized by the number of trips and fish sampled by year (Tables 5 and 6). The length samples by port for Oregon and Washington are shown in Figure 19 and 20. The observed range of lengths by sex (and unsexed) combined between Oregon and Washington primarily range between 35 - 45 cm prior to 1985 then slightly shift to a larger range of selected fish from 1985 - present (Figure 21). The mean lengths observed across available data years also show the increased variance in early year samples and the lower mean size observed, around 35 cm in recent years (Figure 22). The length composition data aggregated across years for the Oregon/Washington fishery shows a higher proportion of males are selected relative to females, similar to that observed in California, but even more extreme with a sharp peak for males selected around 30 cm (Figure 14). For clarity, the aggregated length figure shows both female and unsexed lengths plotted in the top section of the fleet specific panel where the unsexed lengths are plotted behind the female lengths. There unsexed length compositions from Oregon/Washington were primarily from early data years.

The otoliths read by port of collection for Oregon and Washington are shown in Figures 23 and 24. There are a reduced number of otoliths read from Oregon and Washington since the

last assessment in 2011 due to limited ageing capacity (Table 6). The mean age of sampled fish across all years ranged between 11 and 14 years of age in Oregon and Washington (Figures 25 and 26). The peak age observed in aged fish for males and females was around 10 years of age similar to the California fleet observations (Figure 18).

The input sample sizes for each fleet in the model were calculated via the Stewart method (Ian Stewart, personal communication):

$$\text{Input effN} = N_{\text{trips}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is} < 44$$
$$\text{Input effN} = 7.06 * N_{\text{trips}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is} \geq 44$$

To avoid double use of the length and age data from individual fish, the length and age data sources were each given 0.50 weight in the likelihood calculations when model fitting.

2.2 Fishery-Independent Data

Data from four research surveys have been used in this assessment to provide fishery-independent information about the abundance, distribution, and biological characteristics of Dover sole. The longest time series of fishery-independent data arises from the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) which began in 2003. This survey samples the shelf and slope off the U.S. West Coast covering depths from 30 - 700 fathoms (55 - 1,280 meters) on an annual basis (excluding 2020 due to COVID-19). This assessment also used data from three additional fishery-independent surveys: AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey), Alaska Fisheries Science Center Slope Survey (AFSC Slope Survey), and NWFSC Slope Survey. The Triennial Survey began in 1980 and repeated every three years through 2004. The AFSC Slope Survey conducted tows on the U.S. West Coast slope area using the research vessel R/V *Miller Freeman* sampling subsets of the coastline starting in 1984, with full sampling coverage between 1997 - 2001. The final survey, NWFSC Slope Survey, was a cooperative survey using commercial fishing vessels which began in 1998 as a survey for deepwater species (Dover sole, longspine thornyhead, shortspine thornyhead, and sablefish) survey and was expanded to other groundfish in 1999.

2.2.1 NWFSC 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, Keller, and Horness 2011). This design generally uses four industry-chartered vessels per year assigned to a roughly equal number of randomly selected grid cells and divided into two 'passes' of the coast. Two vessels fish from north to south during each pass between late May to early October. 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.

Dover sole are observed across a wide depth range with the largest and oldest individuals often being found in deeper depths (Figures 27, 28, and 29). The majority of tows between 100 - 700 m observed Dover sole (Figure 30). The sex ratio across depths varied with greater than 50 percent of the fish sampled between 200 - 800 m being male Dover sole, with observations of females dominating deeper depths.

The data from the WCGBTS was analyzed using a spatio-temporal delta-model (Thorson et al. 2015), implemented as an R package, VAST (Thorson and Barnett 2017), which is publicly available online. Spatial and spatio-temporal variation is specifically included in both encounter probability and positive catch rates, a logit-link for encounter probability and a log-link for positive catch rates. Vessel-year effects 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, Punt, and Methot 2004; Thorson and Ward 2014). Spatial variation was approximated using 500 knots, and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016).

Data collected by the WCGBTS were used to generate an index of abundance from 2003 - 2019. The estimated index of abundance is shown in Table 7 and Figure 33. The gamma distribution with random strata-year, pass, and vessel effects had the lowest AIC and was chosen as the final model. The Q-Q plot does not show meaningful departures from the assumed distribution (Figure 31) with no clear pattern in residuals (Figure 32). The indices for the WCGBTS show a generally flat trend with a possible slight dip around 2010. A comparison between the VAST and design-based indices of abundance are shown in Figure 34. The area stratification used in the design-based index calculation is shown in Table 8.

Length compositions were expanded based upon the stratification and the age data were used as conditional age-at-length data. The number of tows that collected length measurements of Dover sole ranged between 400 - 600 tows per year (Table 9) with ages collected for Dover sole in nearly every tow length data were collected (Table 10). The reduced number of tows with lengths or age data collected in 2019 was due to a reduction in survey effort in that year alone (2 vessels vs. 4 vessels used for all other years).

The expanded length frequencies by sex are shown in Figure 35. The mean length by year decreased between 2003-2005, increased until approximately 2012, and has been stable at a lower mean size from 2013-2019 (Figure 36). The age frequencies by sex are shown in Figure 37 and the mean age across years are shown in Figure 38. The length data aggregated across years shows a peak in the length observations of males between 30 - 35 cm (Figure 14). There was a wide range of female lengths observed and no clear peak.

Fish with ages also have an associated length and each type of data have been used in the model. Age data from the WCGBTS were used as conditional-age-at-length data within the model, which avoids double use of fish with length and an age observation by explicitly stating the length associated with each aged fish. Hence, the length and conditional-age-at-length data from the WCGBTS were given full weight in likelihood calculations when model fitting.

The input sample sizes for length and marginal age-composition data for all fishery-independent surveys were calculated according to Stewart and Hamel (2014), which determined that the approximate realized sample size for flatfish species was $3.09 * N_{\text{tow}}$. The effective sample size of conditional-age-at-length data was set at the number of fish at each length by sex and by year. The conditional-age-at-length data were not expanded and were binned according to length, age, sex, and year.

2.2.2 AFSC/NWFSC West Coast Triennial Shelf Survey

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

Haul depths ranged from 91 - 457 m during the 1977 survey with no hauls shallower than 91 m. Due to haul performance issues and truncated sampling with respect to depth, the data from 1977 were omitted from this analysis. The surveys in 1980, 1983, and 1986 covered the U.S. west coast south to 36.8°N. latitude and a depth range of 55 - 366 m. The surveys in 1989 and 1992 covered the same depth range but extended the southern range to 34°50′ N. latitude (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55 - 500 m and surveyed south to 34°50′ N. latitude. In 2004, the final year of the Triennial Survey series, the NWFSC Fishery Resource and Monitoring division (FRAM) conducted the survey following similar protocols to earlier years. Due to changes in survey timing, the Triennial Survey data have been split into independent early (1980 - 1992) and late (1995 - 2004) survey time series. The split of the time series was done in the base model via a shift in catchability (Q) between the 1992 and 1995 survey years.

Data collected by the Triennial Survey were used to generate indices of abundance using VAST, described above in Section 2.2.1. Spatial variation was approximated using 500 knots and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). The indices of abundance were estimated using VAST separately for the early and late periods of the survey. The estimated early and late indices of abundance are shown in Table 7 and Figures 39 and 40. The lognormal distribution with random strata-year and vessel effects had the lowest AIC and was chosen as the final model. The Q-Q plots examining potential departure from the assumed distribution are shown in Figures 41 and 42. The Q-Q plot for the early period did not show meaningful departures from the assumed distribution; however, the late period Q-Q plot had some departures from expected but there was no clear pattern in residuals (Figures 43 and 44).

The indices for the early and late periods of the Triennial Survey were generally flat with a slight increase in 2001 and a sharp increase in 2004. The 2004 data point increased at a rate beyond what may be anticipated for a longer lived flatfish life history such as Dover sole. A similar spike in abundance in 2004 has been observed for other species sampled (e.g., petrale sole) observed in the Triennial Survey which may be indicative of a change in the application of the survey rather than an increase in biomass. A comparison between the VAST and design based indices of abundance are shown in Figure 34. The area stratification used in the design-based index calculation are shown in Tables 11 and 12.

Length bins from 8 to 60 cm in 2 cm increments were used to summarize the length frequency of the survey catches in each year. Tables 13 and 14 shows the number of lengths taken by the survey per year. The length frequency distributions for the Triennial Survey from 1980 - 2004 are shown in Figure 45. The stratifications for length data expansions are provided in Tables 11 and 12. The mean length observed by year is show in Figure 46. The lengths aggregated by sex are shown in Figure 14.

There are no Dover sole age data from the Triennial Survey.

The input sample sizes for length data were calculated using the same approach for the WCGBTS data described in Section 2.2.1.

2.2.3 AFSC Slope Survey

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

Data collected by the AFSC Slope Survey were used to generate an index of abundance using VAST, described above in Section 2.2.1. Spatial variation was approximated using 500 knots, and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). The estimated index of abundance is shown in Table 7 and Figure 47. The gamma distribution with random strata-year and vessel effects had the lowest AIC and was chosen as the final model. The Q-Q plots do not show any meaningful departures from the assumed distribution (Figure 48) with no clear pattern in residuals (Figure 49). The index for the AFSC Slope Survey was generally flat with a slight increase in 2001. A comparison between the VAST and design-based indices of abundance are shown in Figure 34. The area stratification used in the design-based index calculation is shown in Table 15.

Length bins from 8 to 60 cm in 2 cm increments were used to summarize the length frequency of the survey catches in each year. Table 16 shows the number of lengths taken by the survey

per year. The length frequency distributions for the AFSC Slope Survey are shown in Figure 50. The stratifications for length data expansions are provided in Table 15. The mean length observed by year is show in Figure 50. The lengths aggregated by sex show a peak in males observed around 30 cm with a wide range of female lengths being observed with a slight peak around 30 cm and a second peak around 40 - 45 cm (Figure 14)

During the 2011 STAR panel review, an issue with the AFSC Slope Survey age data was identified. Aged fish for Dover sole did not appear to be a representative sample of the lengths observed and these data were not used in the 2011 assessment. Additional explorations were conducted examining these data for use in this assessment and a similar conclusion was reached that the length of aged fish did not appear to be a random representative sample of all observed lengths. These data were not used in this assessment.

The input sample sizes for length data were calculated using the same approach for the WCGBTS data described in Section 2.2.1.

2.2.4 NWFSC Slope Survey

The NWFSC Slope Survey covered waters throughout the summer from 183 m to 1,280 m north of 34°30′ N. latitude, which is near Point Conception, from 1999 and 2002. The survey sampled 80 fixed east - west transects of latitude, separated by 10 minutes of latitude. Five stations in each transect were selected from two depth categories: shallow strata (184 - 549 m) and deep strata (550 - 1,280 m). There were a total of 400 possible stations to sample from each year, with 302 - 327 successful tows on average per year. The survey was conducted from mid-August to mid-October in 1998 but was somewhat earlier in 1999 and 2000 (late-June to late- September).

Data collected by the NWFSC Slope Survey were used to generate an index of abundance using VAST, described above in Section 2.2.1. Spatial variation was approximated using 500 knots, and the model used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). The estimated index of abundance is shown in Table 7 and Figure 52. The gamma distribution with random strata-year and vessel effects had the lowest AIC and was chosen as the final model. The Q-Q plots do not show any meaningful departures from the assumed distribution (Figure 53) with no clear pattern in residuals (Figure 54). The index for the NWFSC Slope Survey was generally flat with a slight increase in 2002. A comparison between the VAST and design-based indices of abundance are shown in Figure 34. The area stratification used in the design-based index calculation is shown in Table 17.

Length bins from 8 to 60 cm in 2 cm increments were used to summarize the length frequency of the survey catches in each year. Table 18 shows the number of lengths taken by the survey per year. The length frequency distributions for the NWFSC Slope Survey are shown in Figure 55. The stratifications for length data expansions are provided in Table 17. The mean length observed by year ranged between 33 - 36 cm and is show in Figure 56. The

selected lengths aggregated across years by the NWFSC Slope Survey was similar to the lengths observed by the other slope survey AFSC Slope Survey (Figure 14).

Age data from the NWFSC Slope Survey were used as conditional age-at-length age data within the model. Table 19 show the number of ages taken by the survey per year. The age frequency observed by the NWFSC Slope Survey ranged between 2-60 years of age with a median age of 13 and 10 years for females and males, respectively (Figures 57 and 58).

The input sample sizes for length data were calculated using the same approach for the WCGBTS data described in Section 2.2.1. The effective sample size of conditional-age-at-length data was set at the number of fish at each length by sex and by year. The conditional-age-at-length data were not expanded and were binned according to length, age, sex, and year.

2.2.5 Summary of Fishery-Independent Indices of Abundance

The indices from each fishery-independent source were standardized for comparison. Each index of abundance was rescaled relative its mean index value (i.e., each index centered around 1.0). The four indices of abundance were relatively consistent, with the notable exception of the late Triennial Survey 2001 and 2004 data points which were well above the Triennial Survey mean value (Figure 59).

2.3 Biological Data

2.3.1 Natural Mortality

Natural mortality is a parameter that is often highly uncertain in fish stocks. There are no current published estimates of natural mortality for Dover sole, aside from what has been used in previous assessments which were based upon maximum ages. Assessments of Dover sole off the West Coast in 1997 and 2005 both fixed this parameter at 0.09 yr^{-1} for both males and females (Brodziak, Jacobson, and Wilkins 1997; Sampson 2005). The 2011 assessment estimated natural mortality at 0.117 yr^{-1} for females and 0.142 yr^{-1} for males (Hicks and Wetzel 2011).

The current method for developing a prior on natural mortality for West Coast groundfish stock assessments is based on Hamel (2015), a method for combining meta-analytic approaches relating the M rate to other life-history parameters such as longevity, size, growth rate, and reproductive effort to provide a prior on M. This approach modifies work done by Then et al. (2015) who estimated M and related life history parameters across a large number of fish species from which to develop an M estimator for fish species in general. They concluded by recommending M estimates be based on maximum age alone, based on an updated

Hoenig non-linear least squares estimator $M = 4.899A_{\max}^{-0.916}$. Hamel (2015) re-evaluated the data used by Then et al. (2015) by fitting the one-parameter $A_{\max}$ model under a log-log transformation (such that the slope is forced to be -1 in the transformed space (Hamel 2015)), the point estimate and median of the prior for M is:

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

where $A_{\max}$ is the maximum age. The prior is defined as a lognormal distribution with mean $ln(5.4/A_{\max})$ and standard error = 0.438. The maximum age for Dover sole was selected based on available age data from all West Coast data sources (Figure 60). The oldest aged Dover sole was 69 years, captured by the commercial fishery in 1989, not accounting for potential ageing error. Examining all aged fish, a maximum age of 50 was selected. Across all data sources there were limited observation greater than 50 years of age (79 observations in total). In the fish that have been aged from the WCGBTS there have been 41 observations of fish greater than 50 years old (25 females and 16 males). There was little support for a sex-specific differences in maximum age. However, age data are subject to ageing error which could impact this estimate of longevity. Using a maximum age of 50, the median of the prior was 0.108 yr^{-1} with a standard error of 0.438.

2.3.2 Maturation and Fecundity

Estimates of maturity at length and age for Dover sole have been variable across historical studies. Hagerman (1952) reported that 50 percent of 35 cm female Dover sole were mature with 100 percent maturity-at-length of 45 cm. Yoklavich and Pikitch (1989) reported a smaller size at 50 percent maturity. Hunter et al. (1992) reported that different collection times and methods of analysis resulted in different estimates of maturity at length and suggest that differences reported between Hagerman (1952) and Yoklavich and Pikitch (1989) may have been due to these differences rather than changes in maturity. Brodziak and Mikus (2000) found significant north-south differences in maturity curves derived for International North Pacific Fisheries Commission (INPFC) areas, with fish maturing at smaller sizes in the north. Their estimate of length at 50 percent maturity was less than 34.3 cm, as reported by Hagerman (1952).

The maturity-at-length assumed in this assessment was based on new Dover sole maturity reads conducted by Melissa Head (NWFSC, NOAA) examining a total of 428 from the WCGBTS (N = 309) and ODFW State sampling (N = 119). The coastwide 50 percent size-at-maturity was estimated at 32.8 cm and a slope of -0.28 with maturity asymptoting to 1.0 for larger fish. The shape of the new maturity-at-length curve and a comparison to the maturity curve used in the 2011 assessment is shown in Figure 61. The new maturity-at-length curve was based on the estimate of functional maturity, an approach that classifies maturity with developing oocytes as mature or immature based on the proportion of vitellogenin in the cytoplasm and the measured frequency of atretic cells (Melissa Head, personal communication, NWFSC, NOAA).

Spatial difference in life history traits is commonly observed in groundfish species off the West Coast. Maturity-at-length was examined spatially splitting Dover sole samples into north and south of Point Reyes off the California coast (approximately 38°0′ N. lat.). The latitudinal split was selected prior to examining the data and in a somewhat arbitrary fashion, with the decision driven by the number of samples available by area and based on work by Tolimieri et al. (2020) which identified areas of high age-1 Dover sole density. The northern group had 334 maturity samples and the southern group had 94 maturity samples. The estimated length at 50 percent maturity was significantly different for fish in the north and south, with fish in the south maturing at larger sizes (39.84 cm) relative to fish in the north (31.23 cm, Figure 62). These results are consistent in trend with those from Brodziak and Mikus (2000) who also determined that fish in the north appear to mature at smaller sizes relative to fish in the south. However, the measured variation in maturity-at-length by area in Brodziak and Mikus (2000) was less extreme (Coastwide: 33.4 cm, Vancouver: 28.2 cm, Columbia: 32.0 cm, Eureka: 34.6 cm, Monterrey: 35.3 cm) compared to the current estimates north and south of Point Reyes. Spatial estimates of biomass north and south of Point Reyes, using WCGBTS data averaged across the most recent five years, indicated that approximately 67 percent of the West Coast Dover sole biomass is estimated to be north of Point Reyes.

The size and age of fish observed in shallower depths (less than 400 m) varies between the north and south (Figure 63). In the north a wide range of sizes and ages are observed at shallower depths, while only younger and smaller fish are observed at shallower depths in the south. This pattern in sizes and age are also apparent when looking at all observations of Dover sole by the WCGBTS (Figure 64) with a distinct break in observations around San Francisco, just south of Point Reyes. The mechanisms leading to these differences across the coast are unclear. Future work should be done to determine if maturity-at-length or -age slowly change across latitudes or if there are distinct changes by area.

This assessment did not account for these spatial differences in maturity and assumed a homogeneous population structure for Dover sole off the West Coast due to challenges in the ability to split data by area combined with the uncertain spatial migration patterns of Dover sole off the West Coast. The new maturity-at-length estimates were concluded approximately two months prior to the assessment deadline which provided time to incorporate the new estimates in the base model. However, the time was not sufficient to adequately evaluate the viability of creating a spatial model for Dover sole. Future analysis should be conducted to further understand potential patterns in life history traits across the coast combined with tagging studies which could provide insight in movement.

Fecundity is related to body size of Dover sole. Yoklavich and Pikitch (1989) estimated fecundity of Dover sole off the Oregon coast reporting that a 40 cm female produces about 40,000 oocytes and a 55 cm female produces about 160,000 oocytes. Hunter et al. (1992) estimated the fecundity of Dover sole samples off the coasts of Oregon and California and found no statistical difference in the fecundity by area and estimated no statistical difference in Oregon between their results and those from Yoklavich and Pikitch (1989).

The relationship of fecundity to weight concluded by Yoklavich and Pikitch (1989) was nearly linear when translated from length to weight. Based on the work of Yoklavich and Pikitch

(1989) fecundity was assumed to be equal to body weight in this assessment (e.g., spawning output equal to spawning biomass).

2.3.3 Length-Weight Relationship

Weight-at-length data collected by the WCGBTS were used to externally estimate a weight-length relationship for both sexes of Dover sole. Weight-at-length was generally similar between females and males (Figure 65). Males were estimated to marginally weigh more at the larger lengths (> 50 cm) compared to females. However, the majority of observations of fish greater than 50 cm are predominated by female fish because males generally do not tend to grow as large in comparison. The following estimate of the weight-at-length relationship was used by sex in this assessment:

$$\text{Females: } \alpha = 2.97\text{e-}06;\ \beta = 3.33$$
$$\text{Males: } \alpha = 2.6\text{e-}06;\ \beta = 3.37$$

where weight is measured in grams and length in cm.

2.3.4 Growth (Length-at-Age)

The length-at-age was estimated for male and female Dover sole using data collected from the WCGBTS survey. Figure 66 shows the lengths and ages for all years and all data as well as predicted von Bertalanffy fits to the data. Females grow larger reaching a maximum around 48 cm, while males reach maximum size around 43 cm. However, there is considerable variation in length-at-age for both sexes.

Brodziak and Mikus (2000) reported differences in growth curves between some INPFC areas using data collected on the continental slope (183 - 1,280 m). Using data collected during the WCGBTS (55 - 1,280 m) variation in length-at-age was investigated for four different regions along the coast: south of Point Conception, north of Point Conception to the California/Oregon border, Oregon, and Washington. Figure 67 shows the differences between female and male growth curves in each of these areas. The L_∞ for males south of Point Conception was the largest of the areas, although the differences in maximum size were relatively small. The difference in sizes for females was also minimal, with females generally reaching larger sizes in the northern areas.

Coastwide sex-specific growth parameters were initially estimated external to the model at the following values:

$$\text{Females } L_\infty = 48.5;\ L1 = 11.1 \text{ cm};\ k = 0.117 \text{ per year}$$
$$\text{Males } L_\infty = 43.1 \text{ cm};\ L1 = 15.5 \text{ cm};\ k = 0.106 \text{ per year}$$

These values were used as starting parameter values within the base model prior to estimating each parameter for male and female Dover sole.

The WCGBTS was used to examine the variation in length-at-age by year. The base model assumes that length-at-age and weight-at-age were static across the modeled years. However, if there are significant variations in growth by year that are not accounted for in the model, this could result in bias parameter and model estimates due to the model attributing patterns in the data to other sources (e.g., recruitment, growth parameters). Variations in growth by year could result from annual recruitment strength or positive and negative oceanographic conditions. The WCGBTS data did not indicate large meaningful variations in observed length-at-age or weight-at-age across the survey years (Figures 68 and 69).

2.3.5 Sex Ratio

The sex ratio observed by depth showed interesting patterns. First, because males grow to a smaller size, the proportion of females at intermediate lengths is less than 50 percent, and is 100 percent at larger lengths (Figure 70). This inter-plays with the pattern of larger fish in deeper water and results in fewer females at intermediate depths (250-750 m) and nearly all females in the deepest depths (Figure 71). Sex ratio was slightly variable over latitude but showed no specific pattern (Figure 71). The assessment assumed a sex ratio of 50:50 at the time of settlement.

2.3.6 Ageing Precision and Bias

Uncertainty surrounding the age-reading error process for Dover sole was incorporated by estimating ageing error by age. Age composition data used in the model were from break-and-burn otolith reads. In the early years of data, ages were based on scale reads. However, after examining the distribution of ages by length, there were concerns about the potential bias in these data (Figure 72). These age reads were not used in the base model and were not used in the 2005 or 2011 assessments of Dover sole.

Aged Dover sole used in the assessment were aged by either the Cooperative Ageing Project (CAP) in Newport, Oregon or the California Department of Fish and Wildlife (CDFW). Otoliths collected by each survey, Oregon fishery, and Washington fishery data were read by the CAP ageing lab. Otoliths collected from the California fishery were aged by CDFW. Within-lab ageing error was estimated for both CAP and CDFW. Break-and-burn double reads of more than 8,000 otoliths were provided by the CAP lab (unpublished data) and 160 double reads from CDFW (unpublished data). An ageing error estimate was made based on these double reads using a computational tool specifically developed for estimating ageing error (Punt et al. 2008) and using release 1.1.0 of the R package nwfscAgeingError (Thorson, Stewart, and Punt 2012) for input and output diagnostics. A linear standard error was estimated by age where there is more variability in the age of older fish (Figure 73). Sensitivities to alternative ageing error estimates (curvilinear relationship with age) were

conducted during model development and the model was relatively insensitive to alternative ageing error assumptions.

2.4 Environmental and Ecosystem Data

This assessment did not explicitly incorporate environmental data.

3 Assessment Model

3.1 Summary of Previous Assessments and Reviews

3.1.1 History of Modeling Approaches

The previous assessment of Dover sole conducted in 2011 (Hicks and Wetzel 2011) estimated the fraction unfished of Dover sole off the U.S. west coast at 84 percent, well above the target biomass (25 percent of unfished). The 2011 assessment modeled the Dover sole using three state-specific fishing fleets with four fishery-independent surveys. The model estimated sex-specific natural mortality, growth, and selectivity. The 2011 assessment of Dover sole included some new concepts, mainly new features of Stock Synthesis at the time. Selectivity curves for both slope surveys were modeled using cubic splines which allows for greater flexibility in the shape of selectivity. The sex-specific selectivities were estimated where female selectivity was not forced to asymptote at 1.0, allowing for the possibility of differential maximum selection by sex. The estimate of spawning biomass of 393,507 mt in 2011 was highly uncertain, with the 95 percent confidence interval ranging between 81,000 - 705,000 mt. This estimated stock size was considerably higher than the final year spawning biomass from the 2005 assessment of 188,987 mt.

The 2005 assessment of Dover sole also concluded that the biomass of Dover sole off of the U.S. west coast was well above the target biomass (40 percent, the management target at that time), at 63 percent of unfished biomass (Sampson 2005). The 2005 assessment assumed a different fishery fleet structure from that used in 2011. Two fisheries fleets, a southern fleet from Eureka to Conception and a northern fleet from U.S. Vancouver to Columbia based on INPFC areas was assumed, with sex-specific, domed selection curves based on length for each fleet. This assessment used three survey time-series with dome-shaped sex-specific selectivity with female Dover sole never being fully selected (maximum selectivity less than 1.0).

3.1.2 Response to the 2011 STAR Panel Recommendations and SSC

General Research Recommendations

Recommendation: Complete and review the Washington catch reconstruction and review the California and Oregon catch reconstructions. The accuracy and wide availability of consistent basic information is essential to the development of Pacific coast assessments. In addition to the raw data, the reliability and availability of more spatially dis-aggregated forms of the data should be investigated to determine if they could be used to develop more spatially explicit models without causing sacrifices in accuracy.

Response: In 2016 a groundfish historical catch reconstruction workshop was held to review catch reconstructions (landings prior to 1981) for California, Oregon, and Washington. During this workshop, a divergence in approaches between California and Oregon catch reconstructions was identified. The California catch reconstruction did not include fish caught north of the California/Oregon border by trawlers that landed at ports in California between 1948 - 1968 and these fish were not accounted in the Oregon catch reconstruction. Flatfish (petrale sole and Dover sole) were approximately 75 percent of these landings. Estimates of these landings attributed to Dover sole were provided by Dr. John Field and were added to historical catches for the Oregon/Washington fleet in this assessment. Additionally, while California has created catch reconstruction for many species going back to the early 1900s, Dover sole historical catches are not available prior to 1948. Future assessments of Dover sole would benefit from extending the catch reconstruction to earlier years, especially for species that have experienced a long time series of exploitation. WDFW is still undertaking efforts to develop historical catch reconstructions for groundfish species landed in Washington's waters and significant progress has been made. After discussions with WDFW it was determined that the historical catches used in the 2011 assessment still represented the best estimates of Dover sole removals.

Recommendation: The difficulties encountered in the Dover sole assessment and some other flatfish assessments with respect to the linkage between selectivities require addressing. Although in many instances sized based selectivity may be appropriate, when sexes separate spatially there is a requirement for models to at least be able to investigate complete independence between genders. It is important that this be implemented in an updated version of Stock Synthesis.

Response: Stock Synthesis now provides additional flexibility in the parameterization of sex-specific selectivity curves for both the double normal and logistic selectivity functions. To take advantage of this new flexibility fleets in this assessment assumed double normal selectivity parameterization. The new approach in Stock Synthesis allows the user to specify a sex (male or female) to apply the main parameter lines with the other sex being estimated as offsets from the main selectivity curve. The offset selectivity estimates sex-specific parameters for the peak, ascending width, descending with, final selectivity, and a scale parameter.

Recommendation: The panel investigated the use of age-specific natural mortality in both assessments presented during the STAR panel. In each case, one of the reasons for exploring different mortality schedules was the difficulty in fitting the imbalanced abundance at age information (as seen through residuals to fits), either in the sex ratio at older ages (Dover sole) or the ratio of young to old fish (sablefish). The use of Lorenzen M based on a decline

in natural mortality by the inverse of the growth rate implies a link with predation; however, wider use and development of some guidance on the appropriateness of the implementation in other stock assessments should be investigated.

Response: Alternative parameterization of natural mortality by age and sex were explored during model development. Assuming either Lorenzen natural mortality or linear changes in natural mortality at age had limited impact in model estimates and generally did not result in large improvements in the fits to data. Estimating natural mortality for Dover sole was challenging in general due to variable observations by sex, size, and age resulting from complex ontogenetic movement patterns.

Recommendation: Currently the only available error distribution for age information is the multinomial probability function. It appears that this may have some impact with respect to underestimating strong year classes and it would be desirable to explore the use of alternative error assumptions in order to analyze survey information, in particular where variance estimates in catches-at-age may be less than independent on abundance.

Response: The current version of Stock Synthesis now allows for either multinomial or a Dirichlet Multinomial error distribution (linear or saturation). Both of the Dirichlet Multinomial parameterizations were explored during model development. The Dirichlet Multinomial approach in Stock Synthesis incorporates data weighting via an estimated parameter in the error distribution. The estimated parameter for data weight for each data source and type had issues of hitting the upper data weight bound (1.0). This method does not appear to work as intended for Dover sole.

Recommendation: There should be new studies of maturity by length and age based on more comprehensive coastwide and depth-based sampling and using histological techniques for determining maturity stage. Given that there is uncertainty regarding the temporal stability of maturity schedules, there should be periodic monitoring to explore for changes in maturity.

Response: A new coastwide estimate of functional maturity was developed for use in this assessment. The new functional maturity estimate of length at 50 percent maturity was similar to the assumed maturity in the 2011 assessment; however, the new slope reflected a more gradual increase in maturity-at-length. This new analysis also identified large spatial differences in maturity-at-length and -age spatially north and south of Point Reyes in California. This assessment did not explicitly account for this potential difference in maturity-at-length due to limited information on Dover sole movement patterns (latitudinal or/and water depth). Additionally, the fine scale information of historical data (catches, lengths, and age) creates challenges from splitting data by area. Additional, research should be conducted to evaluate movement and the variation in life history traits in Dover sole off the West Coast to improve future assessments.

Recommendation: Update the STAR Terms of Reference (TOR) to ensure that assessment documents include standard plots (or tables) of likelihood profiles that include likelihood

components by data source and fleet. Such plots are an important diagnostic tool for displaying tensions among data sources profiles.

Response: The groundfish assessment TOR now requires standardized tables and figures and are provided in this assessment. Likelihood tables with the contribution by data type for the base model and each sensitivity are provided.

Recommendations Specific to Dover sole

Recommendation: Researching ageing error, particularly aging bias, is important for Dover sole given the current base models difficulty with reconciling some tensions between different data sources regarding the sex ratio at the oldest ages. In addition, the ability of the model to track cohorts accurately would be significantly disrupted if there were severe size-based bimodality in cohorts caused by vastly different times of settlement (Dover sole are thought to have a larval period of 6 - 18 months). Consequently, larval period should also be examined.

Response: A new ageing analysis was conducted for otoliths read by the CAP lab and CDFW. The ageing error analysis for otoliths read by the CAP lab consisted of over 8,000 double reads of Dover sole otoliths. The ageing error analysis for otoliths read by CDFW used the same data that were available in 2011. In regard to age at settlement, Stock Synthesis now provides the ability to account for this explicitly. A range of alternative age at settlement and timing were explored during model development. Model fits to data did not appreciably improve across these sensitivities. Additionally, estimates across models were similar to the base model, where the main difference appeared to be the years associated with a particular recruitment deviation.

Recommendation: For the WCGBTS, raw age and length information appeared to imply persistently different sex ratios when viewed in isolation. The concern is that there is some unrepresentative sampling occurring in the age distribution as ages are sub-sampled from length. The sampling procedure should be investigated more closely and potentially improved.

Response: Examinations of the WCGBTS data were conducted examining the observations by sex across depths and examining potential non-representative sampling by sex, length, and age. The sex ratio across depths for Dover sole are approximately 50:50 at shallower depths sampled by the survey, shifting to a higher proportion of males observed in mid-depths (300 - 800 m), and then shifting to a higher proportion of females at the deepest depths. This sex ratio pattern was observed across all of the four surveys used in this assessment implying a biological mechanism rather than non-representative sampling.

Recommendation: The conclusions of the NMFS workshop on developing priors on catchability were not available to the Panel. These should be made available and the information reconsidered specifically with respect to Dover sole, in an attempt to reconcile the relatively low catchability estimates for the surveys, particularly the WCGBTS which is thought to cover the majority of the stock distribution.

Response: Unfortunately, there is still limited guidance regarding what catchability values by survey and species would be considered reasonable or expected. The derived catchability in this base model for the WCGBTS was greater than the 2011 value (0.69). The catchability for the WCGBTS fluctuated above and below 1.0 within models explored during development of the base model. This change in the catchability was not driven by a single change in the model structure but due to an aggregate of minor changes (i.e., combine Oregon and Washington into a single fleet, update and reprocess data based on current methodologies, if natural mortality was estimated).

Recommendation: Having simplified the model compared to previous assessments, especially with respect to uniform growth, it is important to continue investigating if this is likely to introduce undesirable levels of bias into the assessment process as more information becomes available. Spatial information on the distribution by age/size of females, particularly in the southern part of the range, particularly across the stratification boundaries of the survey as well as between stocks, should be the primary focus of this work.

Response: This is an area of needed ongoing research.

3.2 Model Structure and Assumptions

3.2.1 Modeling Platform and Structure

The assessment was conducted used Stock Synthesis version 3.30.16 developed by Dr. Richard Methot at the NOAA, NWFSC (Methot and Wetzel 2013). This most recent version was used because it included improvements and corrections to older model versions. The previous assessment of Dover sole also used Stock Synthesis but an earlier version, 3.21f; model bridging was performed between both versions of Stock Synthesis and discussed below. The R package r4ss, version 1.38.0, along with R version 4.0.1 were used to investigate and plot model fits.

3.2.2 Model Selection and Evaluation

The base assessment model for Dover sole was developed to balance parsimony and realism, and the goal was to estimate a spawning output trajectory for the population of Dover sole off the west coast of the U.S. 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.

3.2.3 Model Changes from the Last Assessment

The assessment model structure was similar to that used in 2011, but there were a few meaningful changes to the model structure.

First, in 2011 the options for estimating sex-specific selectivity were more restrictive than those available for use in this assessment. This assessment used the double normal selectivity parameterization for both fishery, Triennial Survey, and WCGBTS fleets in the model where the female sex-specific selectivity parameters were estimated as full offsets with a scale parameter relative to the male selectivity (offset parameters for the peak, ascending width, descending width, final selectivity, and a scale parameter). In contrast, the option used in the 2011 assessment (the only available option in Stock Synthesis at the time) allowed for offset sex-selectivity estimation; however, the scaling of selectivities by sex were linked based on user inputs (i.e., referred to as "dogleg" parameterization where two parameters estimate the relative difference in log-space for male selectivity). Male Dover sole were generally determined to have a higher selectivity likely due their shallower depth distribution compared to females. After model exploration, selectivity of both slope surveys, NWFSC Slope Survey and AFSC Slope Survey, were modeled using a cubic spline selectivity form, same as was done in the 2011 assessment. The use of the cubic spline selectivity allowed better fits to the length composition data which appeared to have bimodality across female Dover sole sampled. Both of these surveys observed a higher frequency of females compared to the other data sources, likely related to the deep water sampling design of these surveys, and male selectivity was estimated relative to female selectivity (i.e., estimated via dogleg parameterization).

This assessment simplified the fleet structure by collapsing data and catches from Oregon and Washington into a single fleet. Vessels fishing out of Oregon and Washington often fish across state lines where the landed state port may not accurately reflect the area of removals. During the pre-assessment data webinar state representatives from WDFW and ODFW supported the aggregation of data from these states into a single fishing fleet within the model.

A minor change in parameterization from the 2011 assessment was the change in estimating male biological parameters (natural mortality, growth) as offsets from the female parameters. The 2011 assessment STAR panel expressed concerns regarding potential confounding between the estimation of sex-specific selectivity and natural mortality. Switching to a biological offset parameterization creates a linkage between parameters by sex. The 2011 assessment determined that the estimates of natural mortality by sex were highly uncertain; however, joint likelihood profiles showed that the difference in natural mortality by sex was well defined. An offset parameterization provides the flexibility to estimate all sex-specific natural mortality and growth parameters or to fix a parameter by sex (typically females) and only estimate the relative difference to the fixed parameter for the other sex.

Data weighting approaches and application have evolved considerably since 2011 when the last assessment of Dover sole was conducted. Currently, there are three alternative approaches for data weighting that have been approved for West Coast groundfish stock assessments: 1)

Francis method, 2) McAllister Ianelli Harmonic Mean method, or 3) Dirichlet-Multinomial method. The base model was weighted using the "Francis method", which was based on equation TA1.8 in Francis (2011). This formulation looks at the mean length or age and the variance of the mean to determine if across years, the variability is explained by the model. If the variability around the mean does not encompass the model predictions, then that data source should be down-weighted. This method accounts for correlation in the data (i.e., the multinomial distribution). Sensitivities were performed examining the difference in weighting using McAllister Ianelli Harmonic Mean Weighting (1997) and the Dirichlet Multinomial Weighting (2017).

The final major changes relative to the 2011 assessment was the treatment of select biological parameters: natural mortality and the maturity-at-length. The maturity-at-length was updated based on new research conducted by Melissa Head (NOAA, NWFSC). The new estimate was based on a relatively new concept of functional maturity, an approach that classifies maturity with developing oocytes as mature or immature based on the proportion of vitellogenin in the cytoplasm and the measured frequency of atretic cells.

The method of developing a natural mortality prior has changed since the last assessment conducted in 2011. The current approach used for stock assessments of West Coast groundfish is based on Hamel (2015). Additionally, this assessment did not estimate female natural mortality and fixed the parameter at the median of the prior, 0.108 yr^{-1}. During model development the estimate of female natural mortality was deemed to be unrealistic due to low parameter estimates (around 0.08 yr^{-1}) which did not appear to be supported by the data. However, the relative difference in the natural mortality between male and female Dover sole appeared to be well defined. Using the offset parameterization allowed for the estimation of male natural mortality only in the base model. The 2011 assessment freely estimated (no offsets) sex specific natural mortality values (female = 0.116 yr^{-1} and male = 0.143 yr^{-1}).

3.2.4 Bridging Analysis

The exploration of models began by bridging from the 2011 assessment to Stock Synthesis version 3.30.16, which produced minor differences in scale but a similar status (Figures 74 and 75). The data bridging process, where data were updated through 2010, were updated in a step-wise additive fashion where the fleet structure was first modified (e.g., change to two fleets compared to three state-specific fleets used in 2011), then catches, indices, discard rates and mean weights, lengths, and ages were updated in that order. The model that included all updated data, labeled "Age" in Figure 74, also included data weighting according to the McAllister Ianelli method. The estimated stock scale dropped relative to the 2011 bridge model when the fleet structure was revised, declined further when discard rates were updated, but increased when lengths and ages were updated with the final scale and status similar to the 2011 model (Figures 76 and 77).

The next step in the model bridging analysis was to update all data sources through 2020 and apply a current data weighting method. The catches, indices, lengths, ages, and discard

data (rates, mean weights, and discarded length observations) through 2020 were all added to the model in an additive step-wise fashion. The length and age data for the California fleet reflect the data available in PacFIN because CALCOM data used in the final model were not available at the time. The estimated spawning output had large fluctuations, below and above, the 2011 estimated time series, based on each updated data set (Figure 78). The model with all data extended through 2020 and data weighted estimated a slightly higher scale but was relatively similar with the 2011 assessment estimate. The estimated relative stock status across models ended up with similar final estimates in 2011 (Figure 79), although showed alternative trajectory patterns during the interim years.

The final step in the model bridging evaluated the impact of updated biological parameter starting values, updated prior value for natural mortality, switching to estimating female biological parameters as offsets from males, and updating all fishery and survey selectivity parameterization using the double-normal selectivity pattern with females estimated as offsets from males (this included both slope surveys which assumed a cubic spline selectivity in the base model). All changes were done in an additive fashion. Updating the starting biological parameters and prior for natural mortality resulted in limited changes in the model relative to the "Update - 2020 All Data" model (Figures 80 and 81). Switching to estimate male biological parameters as offset from the female parameters resulted in a down-ward shift in the estimated scale of the stock. The final model bridging comparison updated the parameterization of sex-specific selectivity resulted in a significant decrease in the uncertainty of the estimated stock scale, and with the relative stock status more depleted compared to previous model updates (Figure 80 and 81). The selectivity form used in this model bridging reflects the initial parameterization with females estimated as offsets for all fleets and maximum female selectivity being less the 1.0. The final model was updated from this initial parameter structure based on numerous model explorations but this comparisons shows the general impact of the initial switch to the new selectivity assumptions.

3.2.5 Key Assumptions and Structural Choices

The specifications of the assessment are listed in Table 20. The model is a two-sex, age-structured model starting in 1911 with an accumulated age group at 60 years. Growth and natural mortality were assumed time invariant with constant growth estimated and female natural mortality fixed at the median of the prior and the relative offset of male natural mortality was estimated. The lengths in the population were tracked by 1 cm intervals and the length data were binned into 2 cm intervals. Stock Synthesis estimates growth in the age and size plus group. To avoid issues with additional estimated growth in the plus groups, the selection of the maximum age and length bins were selected to ensure that the numbers of fish in the plus group would be low.

Time blocks on selectivity and retention parameters were used to allow for shifts in selectivity and retention curves. Time blocks for the peak of the selectivity parameter for the California and Oregon/Washington fleet were 1911 - 1984, 1985 - 1995, and 1996 - 2021. These blocks were based on what seemed to be large scale management changes to the DTS fishery but were also influenced by choices in previous Dover sole assessments (Sampson 2005; Hicks and Wetzel 2011). Time blocks for the fishery retention in Oregon/Washington were 1911 -

1988, 1989 - 2003, 2004 - 2010, and 2011 - 2021. California did not have as much historical discard data, thus the time blocks on retention for this fleet were defined as 1911 - 2003, 2004 - 2010, 2011 - 2014, and 2015 - 2021. The 2011 - 2014 and 2015 - 2021 retention blocks for the California fleet were based on observed changes in the discard rates and lengths from WCGOP between the early IFQ and recent IFQ years.

The specification of when to estimate recruitment deviations is an assumption that affects the estimate of early model uncertainty around stock scale and status. Recruitment deviations were estimated from 1880 - 2018 to appropriately quantify uncertainty in the early model years. The earliest length-composition data occur in 1967 and the earliest age data were in 1981. The most informed years for estimating recruitment deviations were from about the mid-1990s to 2014. The period from 1880 - 1974 was fit using an early series with little or no bias adjustment, the main period of recruitment deviates occurred from 1975 - 2018 with an upward and downward ramping of bias adjustment, and 2019 onward were fit using forecast recruitment deviates with no bias adjustment. Methot and Taylor (2011) summarize the reasoning behind varying levels of bias adjustment based on the information available to estimate the deviates. The standard deviation of recruitment variability was assumed to be 0.35 based on the estimated variation in recruitment from the base model.

The following distributions were assumed for data fitting: survey indices were lognormal, total discards applied a t-distribution with 30 degrees of freedom, and the compositional data had a multinomial error structure.

3.2.6 Priors

Priors were applied only to parameters for steepness (h) and natural mortality (M). The steepness prior is based on the Myers (1999) meta-analysis of flatfish steepness and the natural mortality prior is based on a meta-analysis completed by Hamel (2015). The prior for steepness assumed a beta distribution with a mean equal to 0.80 and a standard deviation of 0.09 (Figure 82).

The prior distribution for natural mortality was based on the Hamel (2015) meta-analytic approach with an assumed maximum age of 50 years for both males and females. The prior assumed a log normal distribution for natural mortality with a median of 0.108 yr^{-1} and a standard error of 0.438 (Figure 83).

3.2.7 Data Weighting

Length data from the four surveys, conditional age-at-length compositions from the WCGBTS and NWFSC Slope Survey, and length and marginal age compositions from the fishery fleets were fit and appropriately weighted within the model. Length and marginal age data started with a sample size determined from the equation listed in Section 2.1.3 for both fishing fleets

in the model. Input sample sizes for survey length data were calculated according to the method described in Section 2.2.1. It was assumed for age-at-length data that each age was a random sample within the length bin and the model started with a sample size equal to the number of fish in that length bin.

Extra variability parameters were estimated and added to the input variance for the indices of abundance for three surveys in the model; 1) Triennial Survey both early and late, 2) NWFSC Slope Survey, and 3) AFSC Slope Survey. Estimating additional variance for the WCGBTS was explored and determined to not be required. WCGOP discard rate data during the pre-IFQ period (prior to 2011) were bootstrapped to provide uncertainty of the total discard rate estimates. The IFQ fishery starting in 2011 has 100 percent observer coverage and a low default uncertainty of 0.05 was assumed for discard rates from 2011 - 2021.

The base assessment model was weighted using the Francis method, which was based on equation TA1.8 in Francis (Francis and Hilborn 2011). Sensitivities were performed examining the difference between the McAllister Ianelli (McAllister and Ianelli 1997) method (Harmonic Mean weighting) and the Dirichlet Multinomial Weighting (2017) approaches. The weights applied to each length and age data set for the base model are shown in Table 25 under the Francis method column.

3.2.8 Estimated and Fixed Parameters

There were 229 estimated parameters in the base model. These included one parameter for R_0, 10 parameters for growth, 1 parameter for male natural mortality, 3 parameters for extra variability for the survey indices, 61 parameters for length-based selectivity, retention, and time blocking of the fleets and the surveys, 141 recruitment deviations (including 31 pre-model estimates), and 12 forecast recruitment deviations (Table 21).

Fixed parameters in the model were as follows. Steepness was fixed at 0.80, the mean of the prior. A sensitivity analysis and a likelihood profile were performed for steepness. Natural mortality was fixed at 0.108 yr^{-1} for females, the median of the prior. Estimation of female natural mortality was explored during model development. The estimate of female natural mortality was low (around 0.082 yr^{-1}) relative to the median of the prior which was based on maximum age; however, well within the prior distribution (SE = 0.438). There were limited observations of fish greater than 50 years of age, so a natural mortality that would be associated with a maximum around 65 years of age did not seem well supported. The 99th percentile of age data from West Coast surveys ranged between 45 - 50 years of age. Assumptions regarding Dover sole maximum age from other regions appear to have similar observations with a maximum age of 45 listed for British Columbia, Canada and the oldest age observed in the U.S. Gulf of Alaska of 59 years. Additionally, the population scale with female natural mortality estimated appeared low, where the catchability for the NWFSC Slope Survey and WCGBTS were above 2.0. The decision to fix natural mortality in the base model was based on each of these factors combined.

The standard deviation of recruitment deviates was fixed at 0.35 (σ_R). Maturity-at-length was fixed as described above in Section 2.3.2. Length-weight parameters were fixed at external estimates based on WCGBTS length-weight observations (Figure 65).

Sex-specific and dome-shaped selectivity was explored for all fleets within the model. Older Dover sole, particularly females, are often found in deeper waters and may move into areas that limit their availability to fishing gear.

3.3 Base Model Results

The base model parameter estimates along with approximate asymptotic standard errors (SD column) are shown in Table 21 and the likelihood components are shown in Table 22. Estimates of derived reference points and approximate 95 percent asymptotic confidence intervals are shown in Table 23. Estimates of stock size over time are shown in Table 24.

3.3.1 Parameter Estimates

The male natural mortality parameter was estimated as a relative offset from the fixed female value within the model. Male natural mortality was estimated to be 0.114 yr^{-1} and the female natural mortality was fixed at 0.108 yr^{-1}. The female value was fixed at the median of the prior.

The estimates of growth parameters by sex varied relative to the externally estimated starting values. The length at age 1 and the maximum length estimates for both sexes was slightly less than the external estimates but were well within the 95 percent confidence interval given the estimated uncertainty (Table 21 and Figure 84). The estimated k for female and male fish were greater than the values estimated externally using only available survey data (0.132 yr^{-1} for females and 0.138 yr^{-1} for males). The majority of female and male Dover sole growth occurs at younger ages, reaching near maximum length by age 20-25, depending upon sex, with female Dover sole reaching larger maximum lengths (Figure 84).

Length-based selectivity curves were estimated for the fishery and survey fleets by sex. The estimated selectivities are shown in Figure 85. The selectivity for both commercial fleets (California and Oregon/Washington) were parameterized using the double-normal selectivity where female selectivity was estimated as an offset from males. Dome-shape selectivity was explore for each of these fleets by sex during model development. The best fit to the California length data by sex was achieved with an asymptotic male selectivity and a dome-shaped selectivity for females with maximum selection estimated less than 1.0. The selectivity for the Oregon/Washington fleet was estimated to be dome-shaped for both sexes with maximum female selectivity less than 1.0. The selectivity for both commercial fleets shifted rightward or leftward by blocked year period, likely driven by management or fishery changes across time.

The selectivity of the Triennial Survey and the WCGBTS in the base model were estimated using the double-normal parameterization, allowing for dome-shaped selectivity. Female selectivity parameters were estimated as offsets from the male parameters. The Triennial Survey which surveyed depths 55 - 549 meters, only a subset of the depth range of Dover sole, had peak selectivity for both sexes around 30 cm and reduced selectivity for larger sizes where maximum female selectivity was less than 1.0. The WCGBTS which samples a wide range of depths (55 -1,280 m) had the highest female selectivity across sizes but maximum selectivity was still less than 1.0. The two slope surveys, AFSC Slope Survey and NWFSC Slope Survey, which focused sampling at deeper depths were parameterized using a cubic spline function, which allows for bi-modal selectivity peaks across size.

Retention curves were assumed to be asymptotic. The estimated curves for each commercial fleet based on the historical time blocks and discarded length composition data are shown in Figure 86. The earliest retention curve for California, 1911-1947, was fixed left skewed for full retention since the input catches for this period included estimates of discard mortality. The retention curves for both commercial fleets since the start of the IFQ fishery have shifted leftward indicating very limited discarding of Dover sole. The model estimated coastwide discard and landings by fleet are shown in Figure 87.

The catchability for each of the surveys was analytically solved comparing observed to expected vulnerable biomass across all years. The catchability for the Triennial Survey was 0.219 and 0.467 for the early and late periods, respectively. The catchability for the AFSC Slope Survey and the NWFSC Slope Survey was and , respectively. The WCGBTS catchability was 1.072.

Additional survey variability, process error added directly to each year's input standard deviation for the Triennial Survey, applied to both the early and late period of the survey, the AFSC Slope Survey, and the NWFSC Slope Survey was estimated within the model. The model estimated a large added variance of 0.317 for the Triennial Survey. The added variance estimate for both of the slope surveys was similar at 0.042 and 0.044. No added variance was estimated for the WCGBTS.

The time series of estimated recruitments and annual recruitment deviations are shown in Figures 88 and 89. Years with the highest recruitment deviations were estimated to have occurred in 2000 and 2009 with the lowest between 2003 - 2005. There is little information regarding recruitment prior to 1970 but are estimated in the base model to account for uncertainty around the unfished condition. Estimated recruitment deviations during years with the majority of the compositional data, after 1980, have relatively high uncertainty intervals indicating lack of support for clear strong or poor recruitment years across data sources. Recruitment deviations after 2015 are relatively uninformed with estimated deviations near zero where recruitment is estimated primarily based on the spawner-recruit curve (Figure 90). The recruitment bias adjustment applied within the model across years is shown in Figure 91.

3.3.2 Fits to the Data

There are numerous types of data for which the fits are discussed: survey abundance indices, discard data (rates, mean body weights, and length compositions), length composition data for the fisheries and surveys, marginal age compositions for the fisheries, and conditional age-at-length observations for the WCGBTS and NWFSC Slope Survey.

The fits to the survey indices are shown in Figures 92 - 95. The WCGBTS is the longest index of abundance for West Coast groundfish and was fit reasonably well for Dover sole with no estimated added variance (Figure 92). The index was variable with a slight dip around 2011 - 2013 but was relatively flat across years. The index of abundance for the Triennial Survey was fit as two periods, early 1980 - 1992 and late 1995 - 2004 using a shift in catchability. The year specific standard deviation estimated by VAST (thick black bars) was low compared to the large added variance (thin black lines) estimated within the model in order to fit each period of the index of abundance (Figure 93). Even with the large estimated added variance the model did not fit the sharp peak in the 2004 estimate from the Triennial Survey. The indices from both slope surveys, AFSC Slope Survey and NWFSC Slope Survey, were generally flat and fit by the base model (Figures 94 and 95). For both surveys the estimated added variance allowed better fits to specific year values from each of these surveys: AFSC Slope Survey 2001 estimate and NWFSC Slope Survey values in 2000 and 2002.

The observed WCGOP discard rates were fit by each fleet in the model using time blocks (Figures 96 - 97). The discard rates were fit well for the California fleet based on the retention blocks in the model. The fits to the discard rates for the Oregon/Washington fleet were more variable compared to the California fleet (Figure 97). The estimated discard rate for the early block 1910 - 2001 were driven by fits to the Pikitch discard rates, which had low uncertainty in the annual discard rate, compared to the earlier discard rates which were more uncertain. Additionally, the Pikitch discard lengths were the sole source of discard size observations for this period. The WCGOP data between 2002 - 2010 had equally split years of higher and lower discard rate observations with the model fitting the lower discard rates well due to the low uncertainty intervals on years with low discard rates (i.e., there were similar standard deviations across years but result in tighter intervals on lower discard rates). The fit to the mean weight of discarded Dover sole was good for both fishing fleets in the model (Figures 98 and 99).

The WCGOP discard lengths by the California fleet were relatively well fit, except for the most recent years where the observed lengths were quite variable (Figures 100 and 101). The period of variable lengths in recent years coincides with a decline in the number of observations by year. The fits to the WCGOP discard lengths for the Oregon/Washington fleet fit well (Figures 102 - 104). The Pikitch discard lengths had little variability across size and the estimated model fit encapsulated the peak in the lengths but not the sharpness in observed discarding (1985 -1987 in Figure 102).

Fits to the length data are shown based on the proportions of lengths observed by year and the Pearson residuals-at-length for all fleets. Detailed fits to the length data by year and fleet are provided in Appendix A. Length composition aggregated fits by fleet are reasonably well fit

and are shown in Figure 105. The poorest fit was for unsexed length compositions from either the discard observations and the early year unsexed lengths from the Oregon/Washington fleet. There was little evidence for patterns of poor fits to the California length data Pearson residuals (Figure 101). The Pearson residuals for the Oregon/Washington fleet were relatively small (maximum residual size = 1.66) similar to the California data but there was some evidence of the observations being greater than the predicted values (filled circles) for males around 36 cm (Figure 107). The Oregon/Washington fleet had a high proportion of males observed at this size, greater than the proportion observed in the California fleet (Figure 105). There was evidence of a slight female residual pattern around the largest sizes observed for Oregon/Washington, although the size of the residual was small. During model development increasing the selectivity of large female fish did not improve the fit to these data. The mean length observed by year for both the California and Oregon/Washington fleet had larger mean lengths during the early years of available data (Figures 108 and 109). The mean of lengths observed in recent years by the California fleet ranged between 38 - 42 cm and ranged between 35-40 cm for the Oregon/Washington fleet.

The observed ages aggregated across years for the California and Washington/Oregon fleet are shown in Figure 110. The maximum size of the Pearson residuals for both fleets was generally small (maximum = 2.66, Figures 111 and 112). The mean age by year for California ranged between 12 - 18 years of age and the Oregon/Washington mean age was slightly lower ranging between 11 - 15 years of age (Figures 113 and 114).

The length data from each survey were generally fit well (Figure 105. The Pearson residuals for each survey show little evidence for model misfit to the data (Figures 115 - 118). The Triennial Survey observed the lowest mean length across years (less than 32 cm excluding 1980) and both slope surveys observed mean lengths ranging between 32 - 35.5 cm (Figures 119 - 121). The mean length observed by the WCGBTS showed a slight pattern of increasing mean length between 2004 - 2012 and then a drop in mean length in 2013 which remained relatively constant around 33 - 34 cm for subsequent years (Figure 122).

The ages from the NWFSC Slope Survey and WCGBTS were used as conditional-age-at-length data in the base model. The Pearson residuals by year for both data sets are available in the Appendix. The fits to the conditional age-at-length data across ages and lengths each year are shown in Figures 123 - 128 where the expected fit (blue line) generally matches the observations except at the largest lengths where the number of observations by age, length, and year are limited. The observed mean age by year from the NWFSC Slope Survey was either above or below the model predicted mean age by year but within the confidence interval by year (Figure 130). The observed mean age and the model predictions were reasonably consistent until 2010 for the WCGBTS (Figure 131). However, the recent years observed mean age (between 12 - 14 years of age) by year were greater compared to the model predicted mean age (approximately 11.5 - 12 years of age).

3.3.3 Population Trajectory

The predicted spawning biomass is given in Table 24 and plotted in Figure 132. The predicted spawning biomass time series shows a slow decline in spawning biomass from the 1950s

through the mid-1990s as catches increased between 1940 and the late 1980s (Figure 2). The predicted spawning biomass begins to slowly increase around 2000 through the final model year 2020 likely driven by a decrease in removals over the last 25 years. The estimated total biomass follows the same general trend as observed in the spawning biomass (Figure 133). The estimated spawning biomass relative to unfished equilibrium spawning biomass has remained relatively high, never dropping below 0.60, and well above the current management target of 0.25 (Figure 134). The relative biomass at the start of 2021 is estimated at 0.79.

Female Dover sole were never fully selected by either fishery or any survey since the largest females tend to move to deeper depths that extend beyond the maximum depth sampled. This behavior results in a subset of the spawning biomass that is unobserved and unavailable. The model predicted available and unavailable spawning biomass is shown in Figure 135. The estimates of the unavailable spawning biomass are based on the catch by fleet, the model estimated numbers-at-age, and the derived age-specific selectivity all by year. The estimated unavailable spawning biomass is shown broken out by small and large fish where small fish are defined as fish less than the age of derived peak selectivity. The sharp increase in small fish reflected in the upper right panel is primarily an artifact of the Oregon/Washington fleet beginning around this time, later than the California fleet, and then drops when selectivity and retention changes during the mid-1980s. There is a large portion of the female spawning biomass estimated to be unavailable relative to the available spawning biomass.

Recruitment deviations were estimated for the entire time series that was modeled (Figure 89 and discussed in Section 3.3.1). Recruitment deviations were estimated to be above average in the late 1990s, below average in the early 2000s, and then generally above average between 2008 - 2012. The stock-recruit curve resulting from a value of steepness fixed at 0.8 is shown in Figure 136 with estimated recruitments also shown. The stock is predicted to have never fallen to low enough levels that the effects of steepness are obvious. Steepness was not estimated in this model, but a likelihood profile across steepness values is shown in Section 3.4.3.

3.4 Model Diagnostics

3.4.1 Convergence

Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. Starting parameters were jittered using the jitter function built into Stock Synthesis, using jitter input of 0.05. This was repeated 100 times with only 1 out of 100 runs returning to the base model likelihood. However, a better, lower negative log-likelihood, model fit was not found. In the jittering analysis models with similar log-likelihood values (difference < 0.50 units) were often found with little difference in overall model estimates indicating a relatively flat likelihood surface around the maximum likelihood estimate. Additionally, jitters using a smaller jitter value yielded an increased frequency of runs returning to the base model with no models finding a better fit to the data. Through the jittering done as explained and

likelihood profiles, we are confident that the base model as presented represents the best fit to the data given the assumptions made. There were no difficulties in inverting the Hessian to obtain estimates of variability, although much of the early model investigation was done without attempting to estimate a Hessian.

3.4.2 Sensitivity Analyses

Sensitivity analyses were conducted to examine the relative influence of specific changes to data inputs and model structural assumptions to further address uncertainty associated with the base model estimates and derived management quantities. The majority of the sensitivity models are the result of a single change relative to base model (i.e., they are not the result of cumulative changes such as the modeling approach used with the bridging analysis). Comparisons of likelihood values and estimates of key parameters from the sensitivity analysis are shown in Tables 26 and 27. Many additional sensitivity runs were explored during development and testing of the base model. This section focuses on the main data and structural sensitivity model runs and includes the following:

Data Sensitivities

1. Remove California commercial length data
2. Remove Oregon/Washington commercial length data
3. Remove AFSC Slope Survey length data
4. Remove Triennial Survey length data
5. Remove NWFSC Slope Survey length data
6. Remove WCGBTS length data
7. Remove California commercial age data
8. Remove Oregon/Washington commercial age data
9. Remove NWFSC Slope Survey age data
10. Remove WCGBTS age data
11. Remove AFSC Slope Survey index
12. Remove Triennial Survey index
13. Remove NWFSC Slope Survey index
14. Remove WCGBTS index

Structural Sensitivities

1. Estimate Lorenzen natural mortality (M) by sex with the change of M occurring at approximately age-at-50-percent maturity of 10 years old

2. Allow the model to estimate female M
3. Fix M values by sex at the estimates from the 2011 assessment of Dover sole
4. Fix M values for each sex at the median of the prior distribution (0.108)
5. Mirror the selectivity by sex for the California and Oregon/Washington fishing fleets
6. Assume the 2011 parameterization of fishery selectivity
7. Assume the 2011 parameterization of survey selectivity
8. Fix the NWFSC Slope Survey female selectivity to asymptote at 1.0
9. Assume the 2011 length-at-maturity estimate
10. No estimation of recruitment deviations
11. Use of the McAllister and Ianelli method for data-weighting (Table 25)
12. Use of the Dirichlet Multinomial method for data-weighting (Table 25) and
13. Fix the extra standard deviation parameters for the AFSC Slope Survey, NWFSC Slope Survey, and Triennial Survey at a near negligible level (0.01)

In general, the base model was the most sensitive (i.e., spawning biomass estimates beyond the 95 percent confidence interval for the base model) to models that applied alternative approaches to estimating or fixing natural mortality parameters and when the largest source of survey age data (WCGBTS) was removed (Figures 140 and 141). Fixing sex-specific M at the 2011 assessment estimates (i.e., higher than the base model) resulted in an increase in overall spawning stock biomass and the fraction of unfished biomass (i.e., stock status), while adding the estimation of female M or sex-specific Lorenzen M (i.e., lower estimates than the base model) resulted in decreases relative to the base model (Table 27; Figures 148 and 149). In general, natural mortality (fixed or estimated) ranged from 0.082 to 0.116 for females and 0.082 to 0.142 for males across sensitivity runs. The total negative log likelihood was slightly less for the models that estimated female M and sex-specific Lorenzen M, suggesting a slightly better fit to the available data. However, natural mortality is often a difficult parameter to estimate in stock assessment such that model misspecification is always a concern. These two alternative M models were not chosen as the base model for the following reasons. First, estimates near the lower range of M values relate to a longevity of about 65 years (following from Hamel (2015)), which is not well supported by the observed data (i.e., few observations more than 50 years old). Second, the scale of the population was considerably reduced to the point where catchability doubled for the surveys, which for the WCGBTS and NWFSC Slope Survey meant unrealistically high (at or above 2) catchability coefficients (Figure 150). Third, the lack of contrast in data and in the population trajectory through time, as seen with Dover sole, are often limitations to estimating M reliably without auxiliary information (e.g., tagging data) due to the inability of the model to decipher otherwise confounding causes of demographic change (Wang 1999; Lee et al. 2011).

The removal of ages from the WCGBTS, which represent a considerable amount of the total available age data since 2009, resulted in lower estimates of spawning biomass and the fraction of unfished biomass compared to the inclusion of these data in the base model (Figures 144 and 145). This result is not surprising given that these age data suggest a higher population scale (Figure 155) compared to other sources of age information. Whereas the

removal of the Oregon/Washington commercial age data had the opposite effect (increase spawning biomass), though not quite as large of an effect as the removal of the WCGBTS age data. The removal of other sources of age data led to largely insensitive results relative to the base model, as did the removal on any one source of length data (Figures 142 and 143) or survey index (Figures 146 and 147).

Other changes in model structure that led to moderately sensitive results (i.e., divergent from, but within the 95 percent confidence interval of, the base model) include assumptions based upon selectivity (Figures 151 and 152) and the method for weighting data (Figures 153 and 154). While the McAllister and Ianelli approach to data weighting led to an 11 percent, on average, decline in spawning biomass across the time series compared to the base model, it had less of an impact on overall stock status (76 percent compared to 79 percent in 2021, respectively). In general, the Francis approach to data weighting used in the base model applied less weight relative to input sample sizes compared to the McAllister and Ianelli approach (Table 25). The Dirichlet multinomial approach to data weighting was abandoned due to inconsistent results relative to input sample sizes and parameters hitting bounds (Table 25). Specifying survey selectivity patterns to match that used in the 2011 assessment was the most sensitive among alternative selectivity scenarios examined in terms of overall stock size and was also the most plausible of these in terms of the lowest total likelihood (Table 27), though not lower than the base model. This difference in stock size is largely explained by the increase in the male natural mortality estimate for this sensitivity model (Table 27).

3.4.3 Likelihood Profiles

Likelihood profiles were conducted for R_0, steepness, and sex-specific natural mortality values separately. These likelihood profiles were conducted by fixing the parameter at specific values and estimated the remaining parameters based on the fixed parameter value.

In regard to values of $\log(R_0)$, the negative log-likelihood was minimized at approximately $\log(R_0)$ of 12.27 (Figure 155). The estimate of $\log(R_0)$ was informed by a relatively consistent signal from length data across all sources. While the length data across sources supported $\log(R_0)$ values around 12.0, the age data primarily informed by the WCGBTS supported higher values. The stock scale was highly sensitive to values with the final stock status ranging between 0.60 to 1.0 (Figures 156 and 157.

For steepness, the negative log-likelihood supported values between 0.40 - 1.0 (Figure 155). Likelihood components by data source show that the age data from the WCGBTS support lower steepness values while the length data across most fleets in the model were relatively flat. The survey indices generally provide very little information concerning steepness but tend to support higher values of steepness. The estimated spawning biomass for Dover sole diverges most at the start of the time series (estimates of $SB0$) and across the final 25 years of the model (Figure 159) The stock was estimated to be most depleted at the end of the time series with lower values of steepness (Figure 160).

The negative log-likelihood was minimized at a female natural mortality value around 0.08 with values from 0.07 - 0.09 supported based on the total negative-log-likelihood (Figure 161). The profile was run under the base model assumption that the offset of male natural mortality was estimate based on the fixed female natural mortality. The length data was generally uninformative across fleets and surveys except for the AFSC Slope Survey that supported lower natural mortality values. The age data from this WCGBTS supported lower female natural mortality values. The stock scale and status was highly variable across natural mortality values where lower values resulted in lower stock scale and status (Figures 162 and 163).

The negative log-likelihood was minimized at a male natural mortality offset value at approximately 0.05 (a value of 0.114 yr^{-1} converted into regular space) with offset values from 0.0 - 0.1 supported based on the total negative-log-likelihood (Figure 164). The profile was run under the base model assumption that the female natural mortality was fixed at 0.108. The length data generally supported offset values of -0.1 - 0.1 (0.098 - 0.119 yr^{-1}). The age data from this WCGBTS supported higher male offset natural mortality values. The stock scale and status was highly variable across male natural mortality values where lower values resulted in lower stock scale and status (Figures 165 and 166).

3.4.4 Retrospective Analysis

A ten-year retrospective analysis was conducted by successively removing years of data ranging from 2010 - 2019 (i.e., "Data -1 Years" corresponds to data through 2019). The estimated spawning output was generally consistent with the base model when recent years of data were removed (Figures 167). Although, when the most recent 9 or 10 years of data was removed (i.e., data available through 2010 and 2011) the estimate of stock scale dropped relative to the base model and other retrospective runs. The estimates of fraction unfished were fairly consistent with the base model (Figure 168), except the retrospective run with 10 years of data removed estimated a slightly more depleted stock relative to the base model.

3.4.5 Historical Analysis

The estimated spawning biomass from previous assessments since 2001 are shown in Figure 169. The estimate of stock scale from the base model is considerably lower relative to the 2011 assessment estimate, which was highly uncertain. The base model SB_0 was similar to the value estimated by the 2005 assessment, the stock trajectory from the base model diverged between 1960-2005 in comparison to the 2005 estimate. The relative stock status of the base model was relatively consistent in trend with the estimate from the 2011 assessment, although slightly less optimistic but still well above the management target.

A comparison between the estimate of spawning biomass and fraction unfished including the uncertainty intervals from the 2011 and the base model are shown in Figures 170 and 171. The 2001 and 2005 assessments were not included because they were conducted in early version of Stock Synthesis which did not facilitate easy comparison of uncertainty estimates.

4 Management

4.1 Reference Points

The 2021 spawning output relative to unfished equilibrium spawning output is well above the management target of 25 percent of unfished spawning output. The fishing intensity has been below the current management harvest rate limit ($SPR_{30\%}$) across all modeled years (Figure 137). The relative biomass compared to the ratio of the estimated SPR to the management target ($SPR_{30\%}$) across all model years are shown in Figure 138 where warmer colors (red) represent early years and colder colors (blue) represent recent years. The relative biomass and estimated SPR has been well above the management biomass target (25 percent) and well below the SPR target across all model years. Figure 139 shows the equilibrium curve based on a steepness value fixed at 0.8 with vertical dashed lines to indicate the estimate of fraction unfished at the start of 2021 (current) and the estimated management targets calculated based on the relative target biomass (B target), the SPR target, and the maximum sustainable yield (MSY).

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2020 (Table 23). Sustainable total yield, landings plus discards, using an $SPR_{30\%}$ is 22,891 mt. The spawning output equivalent to 25 percent of the unfished spawning output ($SB_{25\%}$) calculated using the SPR target ($SPR_{30\%}$) was 74,498 millions of eggs. Recent removals have been below the point estimate of the potential long-term yields calculated using an $SPR_{30\%}$ reference point and the population scale has been relatively stable in recent years.

4.2 Unresolved Problems and Major Uncertainties

The base case model was developed with the goal of balancing parsimony with realism and fitting the data. To achieve parsimony, some simplification of model structure was assumed which may impact the interpretation and fit to specific data sets. The maturity-at-length or -at-age analysis conducted for this assessment identified possible differences in Dover sole south and north of Point Reyes. Currently, there is limited information on the movement of Dover sole by latitude or depth which could provide insights into the mechanisms behind these observed differences. Spatial estimates of biomass north and south of Point Reyes, using WCGBTS data averaged across the most recent five years, indicated that approximately 67 percent of the West Coast Dover sole biomass is estimated to be north of Point Reyes. Additionally, in recent years the majority of fishery data have been collected from ports north of Point Reyes, which limits the ability to support additional model complexity. Given the lack of information to inform the structure and parameterization of a spatial model, the base model assumed a single homogeneous population structure at this time. Future research into the biology and movement of Dover sole could facilitate future spatial modeling efforts if found to be the appropriate approach.

Uncertainty in natural mortality translates into uncertain estimates of both status and sustainable fishing levels for Dover sole. In the base model, a balance between fixing and estimating this key parameter was achieved by fixing female natural mortality at the median of the prior while estimating the relative difference in male natural mortality. The difference between male and female natural mortality appeared to be well informed (likelihood profile) with estimates consistent with the data and biology of Dover sole across its range (U.S. west coast, Canada, U.S. Alaska waters). The likelihood profile across values of female natural mortality supported lower values, which were not expected *a priori* based on the available age data and were largely driven by length data from the AFSC slope survey. This could be due to limited information about maximum age for Dover sole in the data, the limited selection of female Dover sole by the fisheries and surveys or could indicate model misspecification. It is unclear what is driving this behavior in the model.

Dover sole life history exhibit strong relationships with depth that indicate the stock is more complex than the model assumes. Small fish are found in shallow water, with the median observed size increasing with depth. However, the variability of sizes observed by sex increases moving from deeper to shallower waters. Specifically, the WCGBTS observes large females at the deepest depths sampled but also observe some of the largest female Dover sole in waters less than 300 meters. In addition, there is a pattern of sex ratio by depth with more males being found in middle depths and more females found in shallow and deeper depths. These patterns are apparent in the summer fisheries and surveys. It is uncertain how the patterns affect the data (they may be a cause of the bi-modal length distributions seen in the slope surveys) and if these patterns can be effectively modeled to produce better fits to the data and better predictions of biomass while still preserving model parsimony.

4.3 Harvest Projections and Decision Tables

The forecast of stock abundance and yield was developed using the base model. The total catches in 2021 and 2022 were set at 10,000 mt, well below the adopted 50,000 mt ACL for those year, based on recommendations from the Groundfish Management Team (GMT). These assumed removals are likely higher than what the true removals may be in 2021 and 2023 but have limited impact in the stock status and future removals during the projected periord in the base model. The exploitation rate for 2023 and beyond is based upon an SPR of 30 percent and the 25:5 harvest control rule. The average exploitation rates, across recent years, by fleet were used to distribute catches during the forecast period. The ABC values were estimated using a category 1 time-varying σ_y starting at 0.50 combined with a P* value of 0.45. The catches during the projection period, 2023 - 2032 were set equal to the year-specific ABC using the current flatfish harvest control rule, 25:5 (Table vii).

The axes of uncertainty in the decision table is based on the uncertainty around female natural mortality. Uncertainty in the forecasts is based upon the category 1 default uncertainty of $\sigma = 0.50$. The default σ value was used to identify the 12.5 and 87.5 percentiles of the asymptotic standard deviation for the current year, 2021, spawning biomass from the base model to identify the low and high states of nature (i.e., 1.15 standard deviations

corresponding to the 12.5 and 87.5 percentiles). Once the 2021 spawning biomass for the low and high states of nature were identified a search across female natural mortality values were done to attain the current year spawning biomass values. The female natural mortality values that corresponded with the lower and upper percentiles were 0.084 yr^{-1} and 0.126 yr^{-1}.

Initial explorations were conducted using the model estimated uncertainty around 2021 spawning biomass of $\sigma = 0.17$ rather than the higher default σ value. However, the range of the low and high states of nature relative to the base model were determined to not adequately capture uncertainty based on feedback received during the STAR panel review. The model estimated σ around the 2021 spawning biomass only captures model uncertainty which is an underestimate of the true uncertainty around the stock size. Applying a higher σ value allowed the low and high states of nature to capture a larger uncertainty which may be more in line with the cumalative model and structural uncertainty. It was noted that the low and high states of nature results in catchability values (low state of nature catchability = 2.0 and high state of nature catchability = 0.56) for the WCGBTS that were factors higher or lower than the base model catchability (1.072). Interpreting values of catchability comes with inherent challenges due to changes in other key model parameters (e.g., selectivity).

Three alternative catch streams were created for the decision table. The first option uses ABC values based on a category 1 σ_y starting at 0.50 and increasing annually combined with a P^* value of 0.45. The two alternative catch streams assume fixed catch of either 7,000 or 20,000 mt for the 10 year projection period. All of these options assume full attainment of the catch values.

Across the low and high states of nature and across alternative future harvest scenarios the fraction of unfished ranges between 0.023 - 0.895 by the end of the 10 year projection period (Table 29). The low state of nature assuming full ABC removals results in a nearly depleted stock at the end of the time series. This is due to the assumption or removing the full ABC derived from the base model to the low state of nature which had an overall lower unfished spawning biomass associated with a low natural mortality value which results in a more depleted stock in 2021 relative to the base model.

4.4 Evaluation of Scientific Uncertainty

The model estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.17$ and the uncertainty around the OFL was $\sigma = 0.16$. This is likely an underestimate of overall uncertainty because of the necessity to fix several population dynamic parameters (e.g., steepness, recruitment variance, female natural mortality) and no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

4.5 Regional Management Considerations

Currently Dover sole are managed using coastwide harvest specifications; therefore, this assessment does not provide a recommended method for allocating harvests regionally. There

is currently no genetic evidence that there are distinct biological stocks of Dover sole off the U.S. west coast. The limited historical tagging data available describing adult movement suggests that there may be significant movement across depth but limited movement across latitude.

4.6 Research and Data Needs

Investigating and or addressing the following items could improve future assessments of Dover sole:

- Spatiotemporal distribution patterns with depth: There are patterns of length and sex ratios with depth which may indicate that the stock is more complex than currently modeled. Further research into the causes of these patterns as well as differences between seasons would help with understanding the stock characteristics such that a more realistic model could be built. This may also provide further insight into migration and help determine if there are localized populations.
- Stock boundaries: A common question in stock assessments is whether or not the entire stock is being represented. Dover sole live deeper than the range of the fisheries and surveys. The assessment model attempts to account for out of area biomass through catchability coefficients and selectivity curves, but that portion of the stock is unknown and can only be conjectured. Research into abundance in deep areas would be useful to verify that the assessment adequately predicts the entire spawning stock of Dover sole.
- Unavailable biomass: The distribution of Dover sole covers a wide-depth range off the West Coast. Dover sole are observed by the WCGBTS out to 1,280 m, the maximum depth sampled, where the majority of Dover sole observations at these depths are females. The sex-specific movement of Dover sole across depths results in the model estimating that females‘ are never fully selected (maximum selectivity well below 1.0 or dome-shaped) by the fisheries or the surveys. This results in an assumption that there is some portion of cryptic biomass that is unavailable for selection by the fisheries or observation by the surveys. Improved understanding about sex-specific availability across depths by season and the proportion of Dover sole biomass, particularly female biomass, at depths beyond the range of the survey would improve future estimates of stock size.
- California Sampling for Ages: Since 1990, nearly 60 percent of fish aged have been landed at the Crescent City port with some years all aged fish being landed there. In contrast, the majority of Dover sole landed in California occur at the Eureka port (approximately 67 percent over the last 10 years). Ensuring that sampling is spread across California ports and otoliths selected for ageing are spread across ports proportional to area removals may provide additional insights to area-specific population attributes.

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6 References

Barss, W. H., R. L. Demory, and N. TenEyck. 1977. "Marine Resource Surveys on the Continental Shelf and Upper Slope Off Washington, 1975-76: Completion Report July 1, 1975 to September 30, 1977." *Oregon Department of Fish and Wildlife* Unpublished project completion report to NMFS.

Bradburn, M. J., A. A Keller, and B. H. Horness. 2011. "The 2003 to 2008 US West Coast Bottom Trawl Surveys of Groundfish Resources Off Washington, Oregon, and California: Estimates of Distribution, Abundance, Length, and Age Composition." US Department of Commerce, National Oceanic; Atmospheric Administration, National Marine Fisheries Service.

Brodziak, J., Larry D. Jacobson, and M. E. Wilkins. 1997. "Assessment of the Dover Sole Stock for 1997." Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220: Pacific Fishery Management Council.

Brodziak, J., and Robert Mikus. 2000. "Variation in Life History Parameters of Dover Sole, *Microstomus Pacificus*, Off the Coasts of Washington, Oregon, and Northern California." *Fish Bulletin* 98: 661–73.

Butler, John L, Katherine A Dahlin, and H Geoffrey Moser. 1996. "Growth and Duration of the Planktonic Phase and a Stage Based on Population Matrix of Dover Sole, *Microstomus Pacificus*." *Bulletin of Marine Science* 58: 29–53.

Department of Fisheries and Ocean. 1999. "Dover Sole West Coast Vancouver Island (Areas 3C, D) to Queen Charlotte Islands (Areas 5A-E)." DFO Science Stock Status Report A6-04 (1999).

———. 2019. "Pacific Region: Integrated Fisheries Management Plan - Groundfish." Fisheries; Oceans Canada.

Francis, R. I. C. Chris, and R. Hilborn. 2011. "Data Weighting in Statistical Fisheries Stock Assessment Models." *Canadian Journal of Fisheries and Aquatic Sciences* 68 (6): 1124–38. https://doi.org/10.1139/f2011-025.

Gabriel, W. L., and W. G. Pearcy. 1981. "Feeding Selectivity of Dover Sole, *Microstomus Pacificus*, Off Oregon." *Fish Bulletin* 79: 749–63.

Hagerman, F. B. 1952. "The Biology of Dover Sole, *Microstomus Pacificus*." Fish Bulletin No. 85: State of California Department of Fish; Game Bureau of Marine Fisheries.

Haltuch, Melissa A., Allan C. Hicks, and Kevin See. 2011. "Status of the U.S. Petrale Sole Resource in 2010." 7700 Ambassador Place NE, Suite 200, Portland, OR: Pacific Fishery Management Council.

Hamel, Owen S. 2015. "A Method for Calculating a Meta-Analytical Prior for the Natural Mortality Rate Using Multiple Life History Correlates." *ICES Journal of Marine Science: Journal Du Conseil* 72 (1): 62–69. https://doi.org/10.1093/icesjms/fsu131.

Helser, T. E., A. E. Punt, and R. D. Methot. 2004. "A Generalized Linear Mixed Model Analysis of a Multi-Vessel Fishery Resource Survey" 70: 251–64.

Hermann, R. B., and G. Y. Harry Jr. 1963. "Results of a Sampling Program to Determine Catches of Oregon Trawl Vessels." *Pacific Marine Fisheries Commission Bulletin* 6: 40–61.

Hicks, Allan C., and Chantel R. Wetzel. 2011. "The Status of Dover Sole (*Microstomus Pacificus*) Along the U.S. West Coast in 2011." 7700 Ambassador Place NE, Suite 200, Portland, OR 97220: Pacific Fishery Management Council.

Hunter, Roe. 1992. "Fecundity, Spawning, and Maturity of Female Dover Sale Microstomus Pacificus, with an Evaluation of Assumptions and Precision." *Fish Bulletin*, no. 93: 101–28.

Jacobson, Larry D., J. Brodziak, and J. B. Rogers. 2001. "Depth Distributions and Time-Varying Bottom Trawl Selectivities for Dover Sole (*Microstomus Pacificus*), Sablefish (*Anoplopoma Fimbria*), and Thornyheads (*Sebastolobus Alascanus and S. Altivelis*) in a Commercial Fishery." *Fish Bulletin* 99: 309–27.

Jacobson, Larry D., and J. R. Hunter. 1993. "Bathymetric Demography and Management of Dover Sole." *North American Journal of Fisheries Management* 93: 405–20.

Karnowski, M., V. V. Gertseva, and Andi Stephens. 2014. "Historical Reconstruction of Oregon's Commercial Fisheries Landings." Oregon Department of Fish; Wildlife, Salem, OR.

King, Jacquelynne R., Vera N. Agostini, Christopher J. Harvey, Gordon A. McFarlane, Michael G. G. Foreman, James E. Overland, Emanuele Di Lorenzo, Nicholas A. Bond, and Kerim Y. Aydin. 2011. "Climate Forcing and the California Current Ecosystem." *ICES Journal of Marine Science* 68 (6): 1199–1216. https://doi.org/10.1093/icesjms/fsr009.

Kramer, D. E., W. H. Barss, B. C. Paust, and B. E. Bracken. 1995. *Guide to Northeast Pacific Flatfishes: Families Bothidae, Cynoglossidae, and Pleuronectidae*. Vol. 47. AK and Alaska Fisheries Development Foundation, AK. Marine Advisory Bull. Alaska Sea Grant, University of Alaska Fairbanks.

Kristensen, Kasper, A. Nielsen, Casper W Berg, H. J. Skaug, and B. M. Bell. 2016. "TMB: Automatic Differentiation and Laplace Approximation." *Journal of Statistical Software* 70: 1–21.

Lee, H-H., M. N. Maunder, K. R. Piner, and R. D Methot. 2011. "Estimating Natural Mortality Within a Fisheries Stock Assessment Model: And Evaluation Using Simulation Analysis Based on Twelve Stock Assessments." *Fisheries Research* 109: 89–94.

Lockington, W. N. 1880. "Report on the Food Fish of San Francisco." 1878-1879. Calif. Comm. of Fish.,

Markle, Douglas F, Phillip M Harris, and Christopher L Toole. 1992. "Metamorphosis and an Overview of Early-Life-History Stages in Dover Sole Microstomus Pacificus." *Fish Bulletin* 90: 285–301.

McAllister, M. K., and J. N. Ianelli. 1997. "Bayesian Stock Assessment Using Catch-Age Data and the Sampling - Importance Resampling Algorithm." *Canadian Journal of Fisheries and Aquatic Sciences* 54: 284–300.

Methot, R. D., I. G. Taylor, and Y. Chen. 2011. "Adjusting for Bias Due to Variability of Estimated Recruitments in Fishery Assessment Models." *Canadian Journal of Fisheries and Aquatic Sciences* 68 (10): 1744–60. https://doi.org/10.1139/f2011-092.

Methot, R. D., and C. R. Wetzel. 2013. "Stock Synthesis: A Biological and Statistical Framework for Fish Stock Assessment and Fishery Management." *Fisheries Research* 142 (May): 86–99. https://doi.org/10.1016/j.fishres.2012.10.012.

Methot Jr, Richard D., R. Demory, F. Henry, and J. Turnock. 1990. "Assessment of West Coast Dover Sole in 1990 and Recommendations to Management in 1991." Pacific Fishery Management Council.

Myers, Ransom A, Keith G. Bowen, and Nicholas Barrowman. 1999. "Maximum Reproductive Rate of Fish at Low Population Sizes." *Canadian Journal of Fisheries and Aquatic Sciences* 56: 2404–19. http://www.nrcresearchpress.com/doi/pdf/10.1139/f99-201.

Norma-Lopez, Ana. 2009. "Is Tilapia the Same Product Worldwide or Are Markets Segmented?" *Aquaculture Economics and Management* 13 (2): 138–54.

Ono, Kotaro, Andrew O. Shelton, Eric J. Ward, James T. Thorson, Blake E. Feist, and Ray Hilborn. 2016. "Space-Time Investigation of the Effects of Fishing on Fish Populations." *Ecological Applications* 26 (2): 392–406. http://onlinelibrary.wiley.com/doi/10.1890/14-1874.1/full.

Pearcy, W. G., and D. Hancock. 1978. "Feeding Habit of Dover Sole, *Microstomus Pacificus*; Rex Sole, *Glyptocephalus Zachirus*; Slender Sole, *Lyopsetta Exilis*; and Pacific Sanddab, *Citharichthys Sordidus*; in a Region of Diverse Sediments and Bathymetry Off Oregon." *Fish Bulletin* 76: 641–51.

Pearcy, W. G., M. J. Hosie, and S. L. Richardson. 1977. "Distribution and Duration of Pelagic Life of Larvae of Dover Sole, *Microstomus Pacificus*; Rex Sole, *Glyptocephalus Zachirus*, and Petrale Sole, *Eopsetta Jordani*, in Waters Off Oregon." *Fish Bulletin* 75: 173–83.

Pikitch, Ellen K., Daniel L. Erickson, and John R. Wallace. 1988. "An Evaluation of the Effectiveness of Trip Limits as a Management Tool." 88-27. Northwest; Alaska Fisheries Center, National Marine Fisheries Service NWAFC Processed Report. https://www.afsc.noaa.gov/Publications/ProcRpt/PR1988-27.pdf.

Punt, A. E., D. C. Smith, K. KrusicGolub, and S. Robertson. 2008. "Quantifying Age-Reading Error for Use in Fisheries Stock Assessments, with Application to Species in Australia's Southern and Eastern Scalefish and Shark Fishery." *Canadian Journal of Fisheries and Aquatic Sciences* 65 (9): 1991–2005. https://doi.org/10.1139/F08-111.

Ralston, Stephen, Don E. Pearson, John C. Field, and Meisha Key. 2010. "Documentation of the California Catch Reconstruction Project." US Department of Commerce, National Oceanic; Atmospheric Administration, National Marine.

Rogers, Jean Beyer, and Ellen K. Pikitch. 1992. "Numerical Definition of Groundfish Assemblages Caught Off the Coasts of Oregon and Washington Using Commercial Fishing Strategies." *Canadian Journal of Fisheries and Aquatic Sciences* 49 (12): 2648–56.

Sampson, D. B. 1997. "Effective Fishing Effort in the Oregon Groundfish Trawl Fishery." Final Report to the Oregon Trawl Commission. Astoria, OR.

———. 2005. "The Status of Dover Sole Off the U.S. West Coast in 2005." Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR 97220.

Smith, R. T. 1936. "Report on the Puget Sound Otter Trawl Investigation." State of Washington Division of Scientific Research Department of Fisheries Biological Report No. 36B.

Stepien, C. 1999. "Phylogeographical Structure of the Dover Sole Microstomus Pacificus: The Larval Retention Hypothesis and Genetic Divergence Along the Deep Continental Slope of the Northeastern Pacific Ocean." *Molecular Ecology* 8 (6): 923–39. https://doi.org/10.1046/j.1365-294x.1999.00643.x.

Stewart, Ian J., and Owen S. Hamel. 2014. "Bootstrapping of Sample Sizes for Length- or Age-Composition Data Used in Stock Assessments." *Canadian Journal of Fisheries and Aquatic Sciences* 71 (4): 581–88. https://doi.org/10.1139/cjfas-2013-0289.

Stockhausen, W. T., B. J. Turnock, and Z. T. A'mar. 2006. "Gulf of Alaska Dover Sole." https://apps-afsc.fisheries.noaa.gov/refm/docs/2006/GOAdover.pdf.

TenEyck, N., and R. L. Demory. 1975. "Utilization of Flatfish Caught by Oregon Trawlers in 1974." 75-3. Oregon Department of Fish; Wildlife.

Then, A. Y., J. M. Hoenig, N. G. Hall, and D. A. Hewitt. 2015. "Evaluating the Predictive Performance of Empirical Estimators of Natural Mortality Rate Using Information on over 200 Fish Species." *ICES Journal of Marine Science* 72 (1): 82–92. https://doi.org/10.1093/icesjms/fsu136.

The Plan Team for the Groundfish Fisheries of the Gulf of Alaska. 2019. "Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska." North Pacific Fishery Management Council 605 W 4th Avenue, Suite 306, Anchorage, AK 99501.

Thorson, James T., and Lewis A. K. Barnett. 2017. "Comparing Estimates of Abundance Trends and Distribution Shifts Using Single- and Multispecies Models of Fishes and Biogenic Habitat." *ICES Journal of Marine Science: Journal Du Conseil* 74 (5): 1311–21. https://doi.org/10.1093/icesjms/fsw193.

Thorson, James T., Kelli F. Johnson, R. D. Methot, and I. G. Taylor. 2017. "Model-Based Estimates of Effective Sample Size in Stock Assessment Models Using the Dirichlet-Multinomial Distribution." *Fisheries Research* 192: 84–93. https://doi.org/10.1016/j.fishres.2016.06.005.

Thorson, James T., and Kasper Kristensen. 2016. "Implementing a Generic Method for Bias Correction in Statistical Models Using Random Effects, with Spatial and Population Dynamics Examples." *Fisheries Research* 175 (March): 66–74. https://doi.org/10.1016/j.fishres.2015.11.016.

Thorson, James T., and Eric J. Ward. 2014. "Accounting for Vessel Effects When Standardizing Catch Rates from Cooperative Surveys." *Fisheries Research* 155 (July): 168–76. https://doi.org/10.1016/j.fishres.2014.02.036.

Thorson, J. T., A. O. Shelton, E. J. Ward, and H. J. Skaug. 2015. "Geostatistical Delta-Generalized Linear Mixed Models Improve Precision for Estimated Abundance Indices for West Coast Groundfishes." *ICES Journal of Marine Science* 72 (5): 1297–1310. https://doi.org/10.1093/icesjms/fsu243.

Thorson, J. T., Ian J. Stewart, and A. E. Punt. 2012. "nwfscAgeingError: A User Interface in R for the Punt *et Al.* (2008) Method for Calculating Ageing Error and Imprecision." *Available from: Http://Github.com/Nwfsc-Assess/nwfscAgeingError/.*

Tolimieri, Nick, John Wallace, and Melissa Haltuch. 2020. "Spatio-Temporal Patterns in Juvenile Habitat for 13 Groundfishes in the California Current Ecosystem." Edited by George Tserpes. *PLOS ONE* 15 (8): e0237996. https://doi.org/10.1371/journal.pone.0237996.

Toole, C. L., R. D. Brodeur, C. J. Donohoe, and D. F. Markle. 2011. "Seasonal and Interannual Variability in the Community Structure of Small Demersal Fishes Off the Central Oregon Coast." *Marine Ecology Progress Series* 428 (May): 201–17. https://doi.org/10.3354/meps09028.

Toole, C. L., D. F. Markle, and C. J. Donohoe. 1997. "Settlement Timing, Distribution, and Abundance of Dover Sole (Microstomus Pacificus) on an Outer Continental Shelf

Nursery Area." *Canadian Journal of Fisheries and Aquatic Sciences* 54 (3): 531–42. https://doi.org/10.1139/f96-304.

Wang, Y-G. 1999. "A Maximum-Likelihood Method for Estimating Natural Mortality and Catchability Coefficient from Catch-and-Effort Data." *Marine Freshwater Research* 50: 307–11.

Weinberg, K. L., M. E. Wilkins, F. R. Shaw, and M. Zimmermann. 2002. "The 2001 Pacific West Coast Bottom Trawl Survey of Groundfish Resources: Estimates of Distribution, Abundance and Length and Age Composition." NOAA Technical Memorandum NMFS-AFSC-128. U.S. Department of Commerce.

Westrheim, S. J., W. H. Barss, Ellen K. Pikitch, and L. F. Quirollo. 1992. "Stock Delineation of Dover Sole in the California-British Columbia Region, Based on Tagging Studies Conducted During 1948-1979." *North American Journal of Fisheries Management* 12: 172–81.

Westrheim, S. J., and A. R. Morgan. 1963. "Results from Tagging a Spawning Stock of Dover Sole, *Microstomus Pacificus*." *Pacific Marine Fisheries Commission Bulletin* 6: 14–21.

Yoklavich, M., and Ellen K. Pikitch. 1989. "Reproductive Status of Dover Sole, *Microstomus Pacificus*, Off Northern Oregon." *Fish Bulletin* 87: 988–95.

7 Tables

Table 1: Removals (mt) by state, the summed total landings across states (mt), and the estimated total mortality (mt) summed by year. Oregon and Washington were combined into a single fleet in the model

Year	California	Oregon	Washington	Total Landings	Est. Total Mortality
1911	10	0	0	10	10
1912	20	0	0	20	20
1913	30	0	0	30	30
1914	40	0	0	40	40
1915	50	0	0	50	50
1916	56	0	0	56	56
1917	152	0	0	152	152
1918	184	0	0	184	184
1919	193	0	0	193	193
1920	166	0	0	167	167
1921	255	0	0	255	255
1922	430	0	0	430	430
1923	494	0	0	494	494
1924	693	0	0	693	693
1925	764	0	0	764	764
1926	754	0	0	754	754
1927	913	0	0	913	913
1928	896	0	0	896	896
1929	1020	1	0	1021	1021
1930	952	1	0	953	953
1931	820	1	0	821	821
1932	775	10	0	785	786
1933	724	5	0	729	730
1934	768	3	0	770	771
1935	785	5	95	886	895
1936	719	19	244	982	1007
1937	726	97	211	1034	1064
1938	680	5	260	946	971
1939	862	294	246	1401	1453
1940	656	528	297	1480	1560
1941	412	625	468	1505	1610
1942	274	1037	501	1811	1959
1943	409	2748	697	3854	4186
1944	418	681	499	1598	1712
1945	683	1176	501	2360	2522
1946	945	1431	527	2903	3092
1947	1104	910	434	2448	2578
1948	1555	1398	639	3592	3935
1949	2978	2034	514	5526	6054
1950	3732	3338	484	7554	8277

Table 1: Removals (mt) by state, the summed total landings across states (mt), and the estimated total mortality (mt) summed by year. Oregon and Washington were combined into a single fleet in the model *(continued)*

Year	California	Oregon	Washington	Total Landings	Est. Total Mortality
1951	3662	3866	379	7907	8664
1952	4797	3747	553	9097	9966
1953	3545	1601	421	5567	6098
1954	3638	2408	741	6787	7435
1955	3268	1659	1130	6057	6636
1956	3286	1906	932	6125	6711
1957	3159	2104	365	5629	6167
1958	3136	2196	642	5974	6545
1959	2784	2494	424	5702	6247
1960	3620	2676	1092	7388	8095
1961	3046	2367	717	6130	6716
1962	3407	2649	733	6789	7439
1963	3809	3213	969	7991	8756
1964	3898	2807	546	7252	7946
1965	4564	1757	497	6819	7470
1966	4383	1925	314	6622	7254
1967	3091	1902	227	5220	5720
1968	3647	2101	492	6240	6837
1969	5860	2622	461	8942	9797
1970	6877	2591	597	10065	11026
1971	6383	2633	394	9411	10310
1972	10016	2728	370	13114	14366
1973	10199	2076	384	12659	13867
1974	8658	2579	441	11678	12793
1975	10291	2071	428	12791	14012
1976	10322	2296	1073	13691	15000
1977	9944	1861	928	12734	13950
1978	9421	3384	1422	14227	15589
1979	10612	5065	2186	17863	19574
1980	8232	4025	1990	14247	15612
1981	9262	5250	1911	16423	17998
1982	10054	8083	2804	20941	22952
1983	8579	8454	3023	20057	21984
1984	9781	6102	3415	19298	21151
1985	12020	5691	2888	20599	22865
1986	11052	4772	1525	17348	19248
1987	10761	6057	1671	18489	20501
1988	8197	7677	2310	18184	20156
1989	7723	8908	2249	18880	20931
1990	6320	7509	1925	15753	17474
1991	7721	8813	1740	18273	20289
1992	8643	6075	1356	16074	17877
1993	6547	6483	1341	14371	16008

Table 1: Removals (mt) by state, the summed total landings across states (mt), and the estimated total mortality (mt) summed by year. Oregon and Washington were combined into a single fleet in the model *(continued)*

Year	California	Oregon	Washington	Total Landings	Est. Total Mortality
1994	4488	3871	1030	9388	10470
1995	6098	3535	959	10593	11823
1996	6405	4688	1095	12187	13480
1997	5309	3965	852	10125	11199
1998	3584	3800	639	8023	8869
1999	3826	4513	806	9145	10101
2000	3315	4707	758	8780	9691
2001	2441	3738	711	6890	7604
2002	3126	2722	453	6301	6772
2003	3245	3644	467	7356	7888
2004	2389	3802	554	6745	7204
2005	2206	3973	723	6902	7360
2006	1743	3526	701	5970	6354
2007	2761	5555	963	9279	9869
2008	3004	7265	957	11227	11909
2009	3163	7457	1127	11747	12451
2010	2620	6885	886	10392	10999
2011	2401	4741	641	7782	7893
2012	2161	4450	717	7328	7430
2013	2218	5146	606	7970	8078
2014	1955	4242	252	6449	6543
2015	1893	4174	260	6327	6354
2016	1808	5164	346	7318	7350
2017	2197	5203	492	7892	7925
2018	1640	4372	409	6421	6447
2019	1397	4067	303	5767	5790
2020	1617	3033	38	4688	4707

Table 2: The OFL, ABC, ACL, landings, and the estimated total mortality in metric tons.

Year	OFL	ABC	ACL	Landings	Est. Total Mortality
2011	44400	42436	25000	7782	7893
2012	44826	42843	25000	7328	7430
2013	92955	88865	25000	7970	8078
2014	77774	74352	25000	6449	6543
2015	66871	63929	50000	6327	6354
2016	59221	56615	50000	7318	7350
2017	89702	85755	50000	7892	7925
2018	90282	86310	50000	6421	6447
2019	91102	87094	50000	5767	5790
2020	92048	87998	50000	4688	4707

Table 3: Historical removals in metric tons that were caught in Oregon or Washington waters and landed in California that were excluded from the California historical catch reconstruction. These landings were added to the Oregon and Washington historical catch reconstructions

Year	Oregon (mt)	Washington (mt)
1948	70	0
1949	600	2
1950	587	13
1951	263	0
1952	511	21
1953	487	0
1954	863	4
1955	441	0
1956	457	0
1957	445	0
1958	502	0
1959	540	0
1960	546	0
1961	496	8
1962	484	2
1963	630	0
1964	305	0
1965	317	0
1966	294	0
1967	182	0
1968	225	0

Table 4: Discard rates by source used in the base model.

Fleet	Year	Observation	Std. Dev.	Source
CA	1992	0.127	0.200	Humboldt State University
CA	2002	0.140	0.168	WCGOP
CA	2003	0.070	0.188	WCGOP
CA	2004	0.078	0.232	WCGOP
CA	2005	0.067	0.208	WCGOP
CA	2006	0.144	0.203	WCGOP
CA	2007	0.136	0.139	WCGOP
CA	2008	0.078	0.219	WCGOP
CA	2009	0.107	0.311	WCGOP
CA	2010	0.115	0.152	WCGOP
CA	2011	0.050	0.050	WCGOP
CA	2012	0.029	0.050	WCGOP
CA	2013	0.037	0.050	WCGOP
CA	2014	0.057	0.050	WCGOP
CA	2015	0.019	0.050	WCGOP
CA	2016	0.004	0.050	WCGOP
CA	2017	0.010	0.050	WCGOP
CA	2018	0.002	0.050	WCGOP
CA	2019	0.004	0.050	WCGOP
OR/WA	1959	0.232	0.200	Hermann and Harry 1963
OR/WA	1960	0.112	0.200	Hermann and Harry 1963
OR/WA	1961	0.131	0.200	Hermann and Harry 1963
OR/WA	1974	0.167	0.200	Methot et al. 1990
OR/WA	1985	0.093	0.095	Pikitch Study
OR/WA	1986	0.092	0.095	Pikitch Study
OR/WA	1987	0.090	0.089	Pikitch Study
OR/WA	2002	0.137	0.130	WCGOP
OR/WA	2003	0.108	0.164	WCGOP
OR/WA	2004	0.035	0.147	WCGOP
OR/WA	2005	0.102	0.208	WCGOP
OR/WA	2006	0.146	0.166	WCGOP
OR/WA	2007	0.080	0.200	WCGOP
OR/WA	2008	0.034	0.271	WCGOP
OR/WA	2009	0.049	0.167	WCGOP
OR/WA	2010	0.035	0.186	WCGOP
OR/WA	2011	0.006	0.050	WCGOP
OR/WA	2012	0.002	0.050	WCGOP
OR/WA	2013	0.003	0.050	WCGOP
OR/WA	2014	0.001	0.050	WCGOP
OR/WA	2015	0.001	0.050	WCGOP
OR/WA	2016	0.005	0.050	WCGOP
OR/WA	2017	0.008	0.050	WCGOP
OR/WA	2018	0.006	0.050	WCGOP
OR/WA	2019	0.003	0.050	WCGOP

Table 5: Summary of the number of trips and fish sampled per year for the commercial length data used in the assessment.

Year	CA Trips	CA Fish	OR Trips	OR Fish	WA Trips	WA Fish
1967	0	0	0	0	1	225
1968	0	0	0	0	5	1554
1969	18	857	0	0	1	334
1970	14	671	0	0	10	2392
1971	29	725	0	0	5	1066
1972	47	1174	0	0	6	1358
1973	36	900	0	0	2	430
1974	32	799	0	0	1	216
1975	40	1358	0	0	3	539
1976	39	1475	0	0	6	1696
1977	0	0	0	0	2	576
1978	68	2702	0	0	0	0
1979	38	1583	0	0	0	0
1980	115	4324	0	0	0	0
1981	97	3561	0	0	0	0
1982	68	3336	0	0	0	0
1983	105	5146	0	0	0	0
1984	87	4224	0	0	0	0
1985	121	5140	0	0	11	1100
1986	100	4068	0	0	11	1099
1987	114	5700	39	3926	18	950
1988	94	4654	52	3090	22	1100
1989	17	673	64	3165	20	999
1990	92	4070	64	3250	16	800
1991	133	5646	91	4687	18	900
1992	130	5081	88	4124	17	849
1993	84	3294	33	1608	17	850
1994	70	2929	36	1888	17	850
1995	97	3536	31	1702	21	1050
1996	94	3620	26	1242	20	1000
1997	88	3553	37	1795	20	1000
1998	90	3659	49	2129	19	952
1999	82	3374	46	2197	24	1199
2000	73	2873	46	2138	23	1150
2001	78	2844	42	1684	19	950
2002	113	4144	49	2264	18	901
2003	109	3974	65	2789	23	1131
2004	72	3198	63	2889	19	950
2005	86	3273	68	2928	17	850
2006	67	2514	86	3792	12	1150
2007	60	2285	101	3060	22	2150
2008	72	2684	134	4005	23	2134
2009	61	2271	106	3146	10	1000
2010	37	1153	114	3192	12	1200

Table 5: Summary of the number of trips and fish sampled per year for the commercial length data used in the assessment. *(continued)*

Year	CA Trips	CA Fish	OR Trips	OR Fish	WA Trips	WA Fish
2011	42	1443	107	3099	14	1400
2012	68	2399	109	3173	8	800
2013	74	2515	107	2825	15	1551
2014	59	1965	111	2716	5	500
2015	49	1472	97	2488	15	1450
2016	34	1080	110	3099	8	749
2017	15	517	123	3302	24	1872
2018	18	669	112	2470	27	1071
2019	17	645	107	2093	36	808
2020	25	864	69	1417	5	107

Table 6: Summary of the number of trips and fish sampled per year for the commercial age data used in the assessment.

Year	CA Trips	CA Fish	OR Trips	OR Fish	WA Trips	WA Fish
1981	80	2388	0	0	0	0
1982	28	694	0	0	0	0
1983	38	939	0	0	0	0
1984	54	1308	0	0	0	0
1985	80	1891	0	0	6	585
1986	75	1863	0	0	7	687
1987	79	1975	39	3706	13	686
1988	71	1772	50	2990	17	827
1989	105	2621	62	3062	12	547
1990	26	859	62	3096	12	590
1991	0	0	91	4675	9	433
1992	43	1562	87	4018	17	834
1993	29	1105	33	1602	15	738
1994	25	1083	36	1875	17	840
1995	35	1353	30	1614	21	1044
1996	40	1649	26	1227	20	989
1997	42	1742	34	1643	8	394
1998	48	1979	40	1715	18	300
1999	42	1710	41	1920	24	307
2000	65	2483	39	1705	23	300
2001	61	2084	40	309	12	595
2002	67	2396	33	347	18	439
2003	65	2178	52	2156	21	628
2004	8	388	53	1187	19	916
2005	11	486	28	623	7	344
2006	10	423	52	747	12	573
2007	22	836	60	899	22	636
2008	6	269	52	782	0	0
2009	7	324	76	741	0	0
2015	0	0	58	218	0	0
2016	0	0	0	0	3	147
2017	0	0	75	202	4	197
2018	0	0	20	49	17	380
2019	0	0	71	205	0	0

Table 7: Summary of the fishery-independent biomass/abundance time series observartions (Obs.) and input standard error (SE) used in the stock assessment.

	AFSC Slope		Triennial		NWFSC Slope		NWFSC WCGBT	
Year	Obs	SE	Obs	SE	Obs	SE	Obs	SE
1980	-	-	30994	0.13	-	-	-	-
1983	-	-	37978	0.1	-	-	-	-
1986	-	-	54304	0.13	-	-	-	-
1989	-	-	30906	0.1	-	-	-	-
1992	-	-	21842	0.12	-	-	-	-
1995	-	-	46452	0.08	-	-	-	-
1997	99447	0.09	-	-	-	-	-	-
1998	-	-	39074	0.07	156030	0.09	-	-
1999	93871	0.09	-	-	159304	0.09	-	-
2000	101506	0.08	-	-	200112	0.09	-	-
2001	132550	0.08	90035	0.07	151752	0.08	-	-
2002	-	-	-	-	207126	0.07	-	-
2003	-	-	-	-	-	-	268401	0.07
2004	-	-	165516	0.09	-	-	286776	0.08
2005	-	-	-	-	-	-	302273	0.07
2006	-	-	-	-	-	-	292839	0.07
2007	-	-	-	-	-	-	358496	0.07
2008	-	-	-	-	-	-	305036	0.07
2009	-	-	-	-	-	-	280014	0.07
2010	-	-	-	-	-	-	243716	0.06
2011	-	-	-	-	-	-	247505	0.07
2012	-	-	-	-	-	-	253490	0.07
2013	-	-	-	-	-	-	302184	0.08
2014	-	-	-	-	-	-	300312	0.07
2015	-	-	-	-	-	-	288817	0.07
2016	-	-	-	-	-	-	299068	0.07
2017	-	-	-	-	-	-	346079	0.07
2018	-	-	-	-	-	-	325884	0.07
2019	-	-	-	-	-	-	307556	0.09

Table 8: Stratification for the WCGBTS used for the design-based index and length composition expansion.

Strata	Area	Depth m.1	Depth m.2	Latitude dd.1	Latitude dd.2
shallow 45 49	11787.26	55	183	45.0	49.0
shallow 405 45	11255.12	55	183	40.5	45.0
shallow 345 405	10687.86	55	183	34.5	40.5
shallow 32 345	5812.34	55	183	32.0	34.5
mid 45 49	5828.87	183	549	45.0	49.0
mid 405 45	6210.90	183	549	40.5	45.0
mid 345 405	6951.65	183	549	34.5	40.5
mid 32 345	9955.26	183	549	32.0	34.5
mid deep 45 49	4023.61	549	900	45.0	49.0
mid deep 405 45	5264.06	549	900	40.5	45.0
mid deep 345 405	7801.30	549	900	34.5	40.5
mid deep 32 345	15683.99	549	900	32.0	34.5
deep 405 49	9258.57	900	1280	40.5	49.0
deep 345 405	8058.58	900	1280	34.5	40.5
deep 32 345	15788.73	900	1280	32.0	34.5

Table 9: Summary of the number of tows, fish sampled, and the calculated input sample size for the WCGBTS length data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
2003	440	22898	22866	32	1359
2004	402	17349	17309	40	1242
2005	547	17664	17659	5	1690
2006	528	13519	13496	23	1631
2007	577	11265	11255	10	1782
2008	553	6234	6230	4	1708
2009	541	3573	3566	7	1671
2010	600	3239	3206	33	1854
2011	570	8423	8396	27	1761
2012	559	8776	8761	15	1727
2013	413	7328	7316	12	1276
2014	576	10177	10152	25	1779
2015	567	10070	10010	60	1752
2016	580	10160	10126	34	1792
2017	586	6223	6210	13	1810
2018	592	6031	6015	16	1829
2019	291	3034	3033	1	899

Table 10: Summary of the number of tows, fish sampled, and the calculated input sample size for the WCGBTS age data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
2003	383	957	956	1	957
2004	207	952	950	2	639
2005	519	989	986	3	989
2006	505	970	967	3	970
2007	550	984	980	4	984
2008	541	948	945	3	948
2009	534	1034	1029	5	1034
2010	575	996	986	10	996
2011	563	1075	1068	7	1075
2012	555	1088	1086	2	1088
2013	409	809	805	4	809
2014	572	1123	1110	13	1123
2015	563	1088	1083	5	1088
2016	576	1120	1119	1	1120
2017	584	1141	1139	2	1141
2018	590	1161	1156	5	1161
2019	288	487	487	0	487

Table 11: Stratification for the early Triennial Survey used for the design-based index and length composition expansion.

Strata	Area	Depth m.1	Depth m.2	Latitude dd.1	Latitude dd.2
shallow north	11787.26	55	183	45.0	49.0
shallow central	11255.12	55	183	40.5	45.0
shallow south	8905.66	55	183	36.5	40.5
mid north	3800.61	183	400	45.0	49.0
mid central	3867.20	183	400	40.5	45.0
mid south	1843.70	183	400	36.5	40.5

Table 12: Stratification for the late Triennial Survey used for the design-based index and length composition expansion.

Strata	Area	Depth m.1	Depth m.2	Latitude dd.1	Latitude dd.2
shallow north	11787.26	55	183	45.0	49.0
shallow central	11255.12	55	183	40.5	45.0
shallow south	8905.66	55	183	36.5	40.5
mid north	5356.73	183	500	45.0	49.0
mid central	5427.27	183	500	40.5	45.0
mid south	2712.25	183	500	36.5	40.5

Table 13: Summary of the number of tows, fish sampled, and the calculated input sample size for the early Triennial survey length data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1980	27	1563	1563	0	83
1983	35	3221	3221	0	108
1986	125	7754	7754	0	386
1989	323	13715	13715	0	998
1992	243	8617	8614	3	750

Table 14: Summary of the number of tows, fish sampled, and the calculated input sample size for the late Triennial survey length data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1995	296	19522	19521	1	914
1998	374	24974	24871	103	1155
2001	454	32422	32226	196	1402
2004	371	33388	33113	275	1146

Table 15: Stratification for the AFSC Slope Survey used for the design-based index and length composition expansion.

Strata	Area	Depth m.1	Depth m.2	Latitude dd.1	Latitude dd.2
shallow north	5828.87	183	549	45.0	49.0
shallow central	6210.90	183	549	40.5	45.0
shallow south	6951.65	183	549	34.5	40.5
mid north	4023.61	549	900	45.0	49.0
mid central	5264.06	549	900	40.5	45.0
mid south	7801.30	549	900	34.5	40.5
deep north	9258.57	900	1280	40.5	49.0
deep south	8058.58	900	1280	34.5	40.5

Table 16: Summary of the number of tows, fish sampled, and the calculated input sample size for the AFSC Slope survey length data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1997	162	11645	11644	1	500
1999	166	10498	10496	2	512
2000	176	12346	12346	0	543
2001	179	12586	12586	0	553

Table 17: Stratification for the NWFSC Slope Survey used for the design-based index and length and age composition expansion.

Strata	Area	Depth m.1	Depth m.2	Latitude dd.1	Latitude dd.2
shallow north	5828.87	183	549	45.0	49.0
shallow central	6210.90	183	549	40.5	45.0
shallow south	6951.65	183	549	34.5	40.5
mid north	4023.61	549	900	45.0	49.0
mid central	5264.06	549	900	40.5	45.0
mid south	7801.30	549	900	34.5	40.5
deep north central	9258.57	900	1280	40.5	49.0
deep south	8058.58	900	1280	34.5	40.5

Table 18: Summary of the number of tows, fish sampled, and the calculated input sample size for the NWFSC Slope survey length data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1998	272	18855	18518	337	840
1999	282	21510	21233	277	871
2000	291	19998	19990	8	899
2001	293	18996	18970	26	905
2002	367	24822	24821	1	1134

Table 19: Summary of the number of tows, fish sampled, and the calculated input sample size for the NWFSC Slope survey age data used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1998	139	1283	1274	9	429
1999	131	502	502	0	404
2000	126	522	522	0	389
2001	143	961	961	0	441
2002	140	1787	1787	0	432

Table 20: Specifications and structure of the base model.

Model Structure	Base Model
Starting year	1911
Population characteristics	
Maximum age	60
Gender	2
Population lengths	5-60 cm by 1 cm bins
Summary biomass (mt)	Age 3+
Data characteristics	
Data lengths	8-60 cm by 2 cm bins
Data ages	1-60 ages
Minimum age for growth calculations	1
Maximum age for growth calculations	60
First mature age	0
Starting year of estimated recruitment in main period	1975
Fishery characteristics	
Fishing mortality method	Hybrid F
Maximum F	3.5
Catchability	Analytical estimate
CA Trawl Selectivity	Double Normal, Female Offset
OR/WA Trawl Selectivity	Double Normal, Female Offset
AFSC Slope Survey	Cubic Spline, Male Offset
Triennial Survey	Double Normal, Female Offset
NWFSC Slope Survey	Cubic Spline, Male Offset
NWFSC WCGBT Survey	Double Normal, Female Offset
Fishery time blocks	
CA Trawl Selectivity	1911-1984, 1985-1995, 1996-2020
CA Trawl Retention	1911-1947, 1948-2010, 2011-2014, 2015-2020
OR/WA Trawl Selectivity	1911-1984, 1985-1995, 1996-2020
OR/WA Trawl Retention	1911-2001, 2002-2010, 2011-2020

Table 21: 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 (mean and SD).

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
NatM p 1 Fem GP 1	0.108	-2	(0.05, 0.2)	NA	NA	Log Norm (-2.226, 0.48)
L at Amin Fem GP 1	7.994	2	(3, 25)	OK	0.6519700	None
L at Amax Fem GP 1	48.052	3	(35, 60)	OK	0.3001350	None
VonBert K Fem GP 1	0.132	2	(0.03, 0.2)	OK	0.0041634	None
CV young Fem GP 1	0.156	3	(0.01, 1)	OK	0.0117583	None
CV old Fem GP 1	0.080	4	(0.01, 1)	OK	0.0034354	None
Wtlen 1 Fem GP 1	0.000	-99	(0, 0.1)	NA	NA	None
Wtlen 2 Fem GP 1	3.332	-99	(2, 4)	NA	NA	None
Mat50Mat slope Fem GP 1	-0.278	-99	(-1, 0)	NA	NA	None
Eggs/kg inter Fem GP 1	1.000	-99	(-3, 3)	NA	NA	None
Eggs/kg slope wt Fem GP 1	0.000	-99	(-3, 3)	NA	NA	None
NatM p 1 Mal GP 1	0.054	3	(-1, 1)	OK	0.0359919	Normal (0, 0.2)
L at Amin Mal GP 1	0.258	3	(-1, 1)	OK	0.0946283	None
L at Amax Mal GP 1	-0.135	4	(-1, 1)	OK	0.0094279	None
VonBert K Mal GP 1	0.046	3	(-1, 1)	OK	0.0454348	None
CV young Mal GP 1	-0.122	4	(-1, 1)	OK	0.1162650	None
CV old Mal GP 1	-0.026	5	(-1, 1)	OK	0.0665667	None
Wtlen 1 Mal GP 1	0.000	-99	(0, 0.1)	NA	NA	None
Wtlen 2 Mal GP 1	3.371	-99	(2, 4)	NA	NA	None
CohortGrowDev	1.000	-4	(0, 1)	NA	NA	None
FracFemale GP 1	0.500	-99	(1e-06, 0.999999)	NA	NA	None
SR LN(R0)	12.270	1	(6, 17)	OK	0.1273000	None
SR BH steep	0.800	-7	(0.22, 1)	NA	NA	Normal (0.8, 0.09)
SR sigmaR	0.350	-99	(0.15, 0.55)	NA	NA	None
SR regime	0.000	-99	(-2, 2)	NA	NA	None
SR autocorr	0.000	-99	(0, 0)	NA	NA	None
Early InitAge 31	0.000	2	(-5, 5)	act	0.3499870	dev (NA, NA)
Early InitAge 30	0.000	2	(-5, 5)	act	0.3499850	dev (NA, NA)

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Early InitAge 29	0.000	2	(-5, 5)	act	0.3499840	dev (NA, NA)
Early InitAge 28	0.000	2	(-5, 5)	act	0.3499820	dev (NA, NA)
Early InitAge 27	0.000	2	(-5, 5)	act	0.3499800	dev (NA, NA)
Early InitAge 26	0.000	2	(-5, 5)	act	0.3499770	dev (NA, NA)
Early InitAge 25	0.000	2	(-5, 5)	act	0.3499750	dev (NA, NA)
Early InitAge 24	0.000	2	(-5, 5)	act	0.3499720	dev (NA, NA)
Early InitAge 23	0.000	2	(-5, 5)	act	0.3499690	dev (NA, NA)
Early InitAge 22	0.000	2	(-5, 5)	act	0.3499660	dev (NA, NA)
Early InitAge 21	0.000	2	(-5, 5)	act	0.3499620	dev (NA, NA)
Early InitAge 20	0.000	2	(-5, 5)	act	0.3499580	dev (NA, NA)
Early InitAge 19	0.000	2	(-5, 5)	act	0.3499530	dev (NA, NA)
Early InitAge 18	0.000	2	(-5, 5)	act	0.3499480	dev (NA, NA)
Early InitAge 17	0.000	2	(-5, 5)	act	0.3499430	dev (NA, NA)
Early InitAge 16	0.000	2	(-5, 5)	act	0.3499370	dev (NA, NA)
Early InitAge 15	0.000	2	(-5, 5)	act	0.3499300	dev (NA, NA)
Early InitAge 14	0.000	2	(-5, 5)	act	0.3499230	dev (NA, NA)
Early InitAge 13	0.000	2	(-5, 5)	act	0.3499150	dev (NA, NA)
Early InitAge 12	-0.001	2	(-5, 5)	act	0.3499060	dev (NA, NA)
Early InitAge 11	-0.001	2	(-5, 5)	act	0.3498970	dev (NA, NA)
Early InitAge 10	-0.001	2	(-5, 5)	act	0.3498860	dev (NA, NA)
Early InitAge 9	-0.001	2	(-5, 5)	act	0.3498750	dev (NA, NA)
Early InitAge 8	-0.001	2	(-5, 5)	act	0.3498640	dev (NA, NA)
Early InitAge 7	-0.001	2	(-5, 5)	act	0.3498510	dev (NA, NA)
Early InitAge 6	-0.001	2	(-5, 5)	act	0.3498370	dev (NA, NA)
Early InitAge 5	-0.001	2	(-5, 5)	act	0.3498220	dev (NA, NA)
Early InitAge 4	-0.001	2	(-5, 5)	act	0.3498050	dev (NA, NA)
Early InitAge 3	-0.001	2	(-5, 5)	act	0.3497870	dev (NA, NA)
Early InitAge 2	-0.001	2	(-5, 5)	act	0.3497680	dev (NA, NA)
Early InitAge 1	-0.001	2	(-5, 5)	act	0.3497460	dev (NA, NA)

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Early RecrDev 1911	-0.002	2	(-5, 5)	act	0.3497230	dev (NA, NA)
Early RecrDev 1912	-0.002	2	(-5, 5)	act	0.3496970	dev (NA, NA)
Early RecrDev 1913	-0.002	2	(-5, 5)	act	0.3496690	dev (NA, NA)
Early RecrDev 1914	-0.002	2	(-5, 5)	act	0.3496390	dev (NA, NA)
Early RecrDev 1915	-0.002	2	(-5, 5)	act	0.3496050	dev (NA, NA)
Early RecrDev 1916	-0.002	2	(-5, 5)	act	0.3495690	dev (NA, NA)
Early RecrDev 1917	-0.003	2	(-5, 5)	act	0.3495280	dev (NA, NA)
Early RecrDev 1918	-0.003	2	(-5, 5)	act	0.3494840	dev (NA, NA)
Early RecrDev 1919	-0.003	2	(-5, 5)	act	0.3494360	dev (NA, NA)
Early RecrDev 1920	-0.004	2	(-5, 5)	act	0.3493830	dev (NA, NA)
Early RecrDev 1921	-0.004	2	(-5, 5)	act	0.3493250	dev (NA, NA)
Early RecrDev 1922	-0.004	2	(-5, 5)	act	0.3492610	dev (NA, NA)
Early RecrDev 1923	-0.005	2	(-5, 5)	act	0.3491920	dev (NA, NA)
Early RecrDev 1924	-0.005	2	(-5, 5)	act	0.3491160	dev (NA, NA)
Early RecrDev 1925	-0.005	2	(-5, 5)	act	0.3490320	dev (NA, NA)
Early RecrDev 1926	-0.006	2	(-5, 5)	act	0.3489410	dev (NA, NA)
Early RecrDev 1927	-0.007	2	(-5, 5)	act	0.3488400	dev (NA, NA)
Early RecrDev 1928	-0.007	2	(-5, 5)	act	0.3487300	dev (NA, NA)
Early RecrDev 1929	-0.008	2	(-5, 5)	act	0.3486090	dev (NA, NA)
Early RecrDev 1930	-0.008	2	(-5, 5)	act	0.3484800	dev (NA, NA)
Early RecrDev 1931	-0.009	2	(-5, 5)	act	0.3483390	dev (NA, NA)
Early RecrDev 1932	-0.010	2	(-5, 5)	act	0.3481850	dev (NA, NA)
Early RecrDev 1933	-0.011	2	(-5, 5)	act	0.3480160	dev (NA, NA)
Early RecrDev 1934	-0.012	2	(-5, 5)	act	0.3478300	dev (NA, NA)
Early RecrDev 1935	-0.013	2	(-5, 5)	act	0.3476260	dev (NA, NA)
Early RecrDev 1936	-0.014	2	(-5, 5)	act	0.3474010	dev (NA, NA)
Early RecrDev 1937	-0.015	2	(-5, 5)	act	0.3471540	dev (NA, NA)
Early RecrDev 1938	-0.017	2	(-5, 5)	act	0.3468820	dev (NA, NA)
Early RecrDev 1939	-0.018	2	(-5, 5)	act	0.3465840	dev (NA, NA)

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Early RecrDev 1940	-0.020	2	(-5, 5)	act	0.3462580	dev (NA, NA)
Early RecrDev 1941	-0.022	2	(-5, 5)	act	0.3459050	dev (NA, NA)
Early RecrDev 1942	-0.024	2	(-5, 5)	act	0.3455280	dev (NA, NA)
Early RecrDev 1943	-0.026	2	(-5, 5)	act	0.3451410	dev (NA, NA)
Early RecrDev 1944	-0.028	2	(-5, 5)	act	0.3447570	dev (NA, NA)
Early RecrDev 1945	-0.029	2	(-5, 5)	act	0.3443810	dev (NA, NA)
Early RecrDev 1946	-0.031	2	(-5, 5)	act	0.3440340	dev (NA, NA)
Early RecrDev 1947	-0.032	2	(-5, 5)	act	0.3437420	dev (NA, NA)
Early RecrDev 1948	-0.033	2	(-5, 5)	act	0.3435200	dev (NA, NA)
Early RecrDev 1949	-0.032	2	(-5, 5)	act	0.3433990	dev (NA, NA)
Early RecrDev 1950	-0.031	2	(-5, 5)	act	0.3434180	dev (NA, NA)
Early RecrDev 1951	-0.029	2	(-5, 5)	act	0.3435870	dev (NA, NA)
Early RecrDev 1952	-0.025	2	(-5, 5)	act	0.3439230	dev (NA, NA)
Early RecrDev 1953	-0.020	2	(-5, 5)	act	0.3444390	dev (NA, NA)
Early RecrDev 1954	-0.014	2	(-5, 5)	act	0.3451440	dev (NA, NA)
Early RecrDev 1955	-0.006	2	(-5, 5)	act	0.3459740	dev (NA, NA)
Early RecrDev 1956	0.002	2	(-5, 5)	act	0.3468460	dev (NA, NA)
Early RecrDev 1957	0.011	2	(-5, 5)	act	0.3476500	dev (NA, NA)
Early RecrDev 1958	0.019	2	(-5, 5)	act	0.3481720	dev (NA, NA)
Early RecrDev 1959	0.024	2	(-5, 5)	act	0.3481670	dev (NA, NA)
Early RecrDev 1960	0.025	2	(-5, 5)	act	0.3474870	dev (NA, NA)
Early RecrDev 1961	0.023	2	(-5, 5)	act	0.3462650	dev (NA, NA)
Early RecrDev 1962	0.019	2	(-5, 5)	act	0.3449250	dev (NA, NA)
Early RecrDev 1963	0.018	2	(-5, 5)	act	0.3440230	dev (NA, NA)
Early RecrDev 1964	0.024	2	(-5, 5)	act	0.3438290	dev (NA, NA)
Early RecrDev 1965	0.035	2	(-5, 5)	act	0.3440890	dev (NA, NA)
Early RecrDev 1966	0.046	2	(-5, 5)	act	0.3440780	dev (NA, NA)
Early RecrDev 1967	0.052	2	(-5, 5)	act	0.3430640	dev (NA, NA)
Early RecrDev 1968	0.053	2	(-5, 5)	act	0.3408960	dev (NA, NA)

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Early RecrDev 1969	0.051	2	(-5, 5)	act	0.3377750	dev (NA, NA)
Early RecrDev 1970	0.045	2	(-5, 5)	act	0.3339940	dev (NA, NA)
Early RecrDev 1971	0.036	2	(-5, 5)	act	0.3302760	dev (NA, NA)
Early RecrDev 1972	0.034	2	(-5, 5)	act	0.3277400	dev (NA, NA)
Early RecrDev 1973	0.058	2	(-5, 5)	act	0.3277570	dev (NA, NA)
Early RecrDev 1974	0.116	2	(-5, 5)	act	0.3299830	dev (NA, NA)
Main RecrDev 1975	0.175	1	(-5, 5)	act	0.3249090	dev (NA, NA)
Main RecrDev 1976	0.170	1	(-5, 5)	act	0.3194670	dev (NA, NA)
Main RecrDev 1977	0.077	1	(-5, 5)	act	0.3079680	dev (NA, NA)
Main RecrDev 1978	-0.027	1	(-5, 5)	act	0.2940390	dev (NA, NA)
Main RecrDev 1979	-0.083	1	(-5, 5)	act	0.2825360	dev (NA, NA)
Main RecrDev 1980	-0.119	1	(-5, 5)	act	0.2722570	dev (NA, NA)
Main RecrDev 1981	-0.192	1	(-5, 5)	act	0.2652520	dev (NA, NA)
Main RecrDev 1982	-0.246	1	(-5, 5)	act	0.2607530	dev (NA, NA)
Main RecrDev 1983	-0.221	1	(-5, 5)	act	0.2564420	dev (NA, NA)
Main RecrDev 1984	-0.204	1	(-5, 5)	act	0.2571300	dev (NA, NA)
Main RecrDev 1985	-0.144	1	(-5, 5)	act	0.2559530	dev (NA, NA)
Main RecrDev 1986	-0.104	1	(-5, 5)	act	0.2641320	dev (NA, NA)
Main RecrDev 1987	0.043	1	(-5, 5)	act	0.2750120	dev (NA, NA)
Main RecrDev 1988	0.275	1	(-5, 5)	act	0.2644450	dev (NA, NA)
Main RecrDev 1989	0.125	1	(-5, 5)	act	0.2870610	dev (NA, NA)
Main RecrDev 1990	0.131	1	(-5, 5)	act	0.2892640	dev (NA, NA)
Main RecrDev 1991	0.295	1	(-5, 5)	act	0.2775250	dev (NA, NA)
Main RecrDev 1992	0.273	1	(-5, 5)	act	0.2650400	dev (NA, NA)
Main RecrDev 1993	-0.010	1	(-5, 5)	act	0.2590830	dev (NA, NA)
Main RecrDev 1994	-0.170	1	(-5, 5)	act	0.2439250	dev (NA, NA)
Main RecrDev 1995	-0.170	1	(-5, 5)	act	0.2305950	dev (NA, NA)
Main RecrDev 1996	-0.111	1	(-5, 5)	act	0.2425970	dev (NA, NA)
Main RecrDev 1997	0.390	1	(-5, 5)	act	0.2005750	dev (NA, NA)

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Main RecrDev 1998	0.391	1	(-5, 5)	act	0.2083130	dev (NA, NA)
Main RecrDev 1999	0.121	1	(-5, 5)	act	0.2380310	dev (NA, NA)
Main RecrDev 2000	0.537	1	(-5, 5)	act	0.1646990	dev (NA, NA)
Main RecrDev 2001	0.034	1	(-5, 5)	act	0.2040620	dev (NA, NA)
Main RecrDev 2002	-0.374	1	(-5, 5)	act	0.2074260	dev (NA, NA)
Main RecrDev 2003	-0.476	1	(-5, 5)	act	0.1978180	dev (NA, NA)
Main RecrDev 2004	-0.450	1	(-5, 5)	act	0.1907800	dev (NA, NA)
Main RecrDev 2005	-0.419	1	(-5, 5)	act	0.1924790	dev (NA, NA)
Main RecrDev 2006	-0.252	1	(-5, 5)	act	0.1885100	dev (NA, NA)
Main RecrDev 2007	-0.019	1	(-5, 5)	act	0.1767170	dev (NA, NA)
Main RecrDev 2008	0.218	1	(-5, 5)	act	0.1632500	dev (NA, NA)
Main RecrDev 2009	0.517	1	(-5, 5)	act	0.1423250	dev (NA, NA)
Main RecrDev 2010	0.253	1	(-5, 5)	act	0.1761350	dev (NA, NA)
Main RecrDev 2011	0.024	1	(-5, 5)	act	0.1993930	dev (NA, NA)
Main RecrDev 2012	0.181	1	(-5, 5)	act	0.1762300	dev (NA, NA)
Main RecrDev 2013	-0.214	1	(-5, 5)	act	0.2153530	dev (NA, NA)
Main RecrDev 2014	-0.195	1	(-5, 5)	act	0.2233590	dev (NA, NA)
Main RecrDev 2015	-0.023	1	(-5, 5)	act	0.2512550	dev (NA, NA)
Main RecrDev 2016	-0.001	1	(-5, 5)	act	0.3100570	dev (NA, NA)
Main RecrDev 2017	-0.006	1	(-5, 5)	act	0.3393210	dev (NA, NA)
Main RecrDev 2018	-0.001	1	(-5, 5)	act	0.3446800	dev (NA, NA)
Late RecrDev 2019	0.000	6	(-5, 5)	act	0.3500000	dev (NA, NA)
Late RecrDev 2020	0.000	6	(-5, 5)	act	0.3500000	dev (NA, NA)
LnQ base AFSC Slope(3)	-0.514	-1	(-25, 25)	NA	NA	None
Q extraSD AFSC Slope(3)	0.042	3	(0, 2)	OK	0.0440172	None
LnQ base Triennial(4)	-1.519	1	(-10, 2)	OK	0.2239780	None
Q extraSD Triennial(4)	0.317	3	(0, 2)	OK	0.0962624	None
LnQ base NWFSC Slope(5)	0.129	-1	(-25, 25)	NA	NA	None
Q extraSD NWFSC Slope(5)	0.044	3	(0, 2)	OK	0.0388581	None

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
LnQ base NWFSC WCGBT(6)	0.070	-1	(-25, 25)	NA	NA	None
LnQ base Triennial(4) BLK4add 1995	0.756	3	(-15, 15)	OK	0.2799050	None
Size DblN peak CA(1)	37.419	1	(15, 50)	OK	0.6528580	None
Size DblN top logit CA(1)	-15.000	-3	(-15, 7)	NA	NA	None
Size DblN ascend se CA(1)	3.473	3	(-10, 10)	OK	0.1418580	None
Size DblN descend se CA(1)	6.000	-4	(-10, 10)	NA	NA	None
Size DblN start logit CA(1)	-20.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit CA(1)	10.000	-4	(-10, 10)	NA	NA	None
Retain L infl CA(1)	25.682	2	(10, 40)	OK	1.1243100	None
Retain L width CA(1)	1.389	3	(0.1, 5)	OK	0.3298070	None
Retain L asymptote logit CA(1)	5.767	3	(-10, 10)	OK	0.2175330	None
Retain L maleoffset CA(1)	0.000	-9	(-10, 10)	NA	NA	None
SzSel Fem Peak CA(1)	0.858	2	(-20, 20)	OK	0.6002580	None
SzSel Fem Ascend CA(1)	0.000	-4	(-5, 5)	NA	NA	None
SzSel Fem Descend CA(1)	0.000	-4	(-10, 10)	NA	NA	None
SzSel Fem Final CA(1)	-11.283	3	(-20, 10)	OK	1.0255000	None
SzSel Fem Scale CA(1)	0.669	3	(0.01, 1)	OK	0.0697448	None
Size DblN peak OR WA(2)	36.462	2	(15, 50)	OK	0.0656806	None
Size DblN top logit OR WA(2)	-11.469	-3	(-15, 5)	NA	NA	None
Size DblN ascend se OR WA(2)	3.183	3	(-10, 10)	OK	0.0470625	None
Size DblN descend se OR WA(2)	-9.977	-4	(-10, 10)	NA	NA	None
Size DblN start logit OR WA(2)	-20.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit OR WA(2)	-0.524	2	(-10, 10)	OK	0.1895980	None
Retain L infl OR WA(2)	23.601	2	(15, 40)	OK	0.6895470	None
Retain L width OR WA(2)	1.561	3	(0.1, 5)	OK	0.1746760	None
Retain L asymptote logit OR WA(2)	6.273	3	(-10, 10)	OK	0.1758390	None
Retain L maleoffset OR WA(2)	0.000	-9	(-10, 10)	NA	NA	None
SzSel Fem Peak OR WA(2)	5.067	2	(-20, 20)	OK	0.1074580	None
SzSel Fem Ascend OR WA(2)	1.242	-4	(-5, 5)	NA	NA	None

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
SzSel Fem Descend OR WA(2)	-0.888	-4	(-10, 10)	NA	NA	None
SzSel Fem Final OR WA(2)	-0.654	3	(-20, 10)	OK	0.2386450	None
SzSel Fem Scale OR WA(2)	0.534	3	(0.1, 1)	OK	0.0424478	None
SizeSpline Code AFSC Slope(3)	0.000	-9	(0, 2)	NA	NA	None
SizeSpline GradLo AFSC Slope(3)	0.413	3	(-0.001, 10)	OK	0.0495267	None
SizeSpline GradHi AFSC Slope(3)	-0.123	3	(-1, 1)	OK	0.0876719	None
SizeSpline Knot 1 AFSC Slope(3)	20.000	-99	(8, 60)	NA	NA	None
SizeSpline Knot 2 AFSC Slope(3)	34.000	-99	(8, 60)	NA	NA	None
SizeSpline Knot 3 AFSC Slope(3)	38.000	-99	(8, 60)	NA	NA	None
SizeSpline Knot 4 AFSC Slope(3)	48.000	-99	(8, 60)	NA	NA	None
SizeSpline Val 1 AFSC Slope(3)	-2.101	2	(-9, 7)	OK	0.1740300	None
SizeSpline Val 2 AFSC Slope(3)	0.462	2	(-9, 7)	OK	0.0763358	None
SizeSpline Val 3 AFSC Slope(3)	0.000	-99	(-9, 7)	NA	NA	None
SizeSpline Val 4 AFSC Slope(3)	0.444	2	(-9, 7)	OK	0.1727740	None
SzSel MaleDogleg AFSC Slope(3)	45.000	-4	(-10, 60)	NA	NA	None
SzSel MaleatZero AFSC Slope(3)	0.000	-5	(-10, 10)	NA	NA	None
SzSel MaleatDogleg AFSC Slope(3)	0.874	5	(-10, 10)	OK	0.1192610	None
SzSel MaleatMaxage AFSC Slope(3)	-3.003	-5	(-10, 10)	NA	NA	None
Size DblN peak Triennial(4)	31.124	2	(15, 55)	OK	0.4219320	None
Size DblN top logit Triennial(4)	-9.119	-3	(-10, 5)	NA	NA	None
Size DblN ascend se Triennial(4)	4.007	3	(-10, 10)	OK	0.1225830	None
Size DblN descend se Triennial(4)	2.992	-4	(-10, 10)	NA	NA	None
Size DblN start logit Triennial(4)	-20.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit Triennial(4)	-2.566	3	(-10, 10)	OK	0.6052600	None
SzSel Fem Peak Triennial(4)	0.000	-4	(-20, 20)	NA	NA	None
SzSel Fem Ascend Triennial(4)	0.000	-4	(-5, 5)	NA	NA	None
SzSel Fem Descend Triennial(4)	0.000	-4	(-10, 10)	NA	NA	None
SzSel Fem Final Triennial(4)	1.166	4	(-20, 20)	OK	0.6189130	None
SzSel Fem Scale Triennial(4)	0.698	3	(0.01, 1)	OK	0.0749704	None

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
SizeSpline Code NWFSC Slope(5)	0.000	-9	(0, 2)	NA	NA	None
SizeSpline GradLo NWFSC Slope(5)	0.770	3	(-0.001, 10)	OK	0.2628160	None
SizeSpline GradHi NWFSC Slope(5)	-0.199	3	(-1, 1)	OK	0.1431560	None
SizeSpline Knot 1 NWFSC Slope(5)	20.000	-99	(8, 60)	NA	NA	None
SizeSpline Knot 2 NWFSC Slope(5)	34.000	-99	(8, 60)	NA	NA	None
SizeSpline Knot 3 NWFSC Slope(5)	38.000	-99	(8, 60)	NA	NA	None
SizeSpline Knot 4 NWFSC Slope(5)	48.000	-99	(8, 60)	NA	NA	None
SizeSpline Val 1 NWFSC Slope(5)	-4.012	2	(-9, 7)	OK	0.8145320	None
SizeSpline Val 2 NWFSC Slope(5)	0.317	2	(-9, 7)	OK	0.1373030	None
SizeSpline Val 3 NWFSC Slope(5)	0.000	-99	(-9, 7)	NA	NA	None
SizeSpline Val 4 NWFSC Slope(5)	0.375	2	(-9, 7)	OK	0.2689290	None
SzSel MaleDogleg NWFSC Slope(5)	45.000	-4	(-10, 60)	NA	NA	None
SzSel MaleatZero NWFSC Slope(5)	0.000	-5	(-10, 10)	NA	NA	None
SzSel MaleatDogleg NWFSC Slope(5)	0.880	5	(-10, 10)	OK	0.1660520	None
SzSel MaleatMaxage NWFSC Slope(5)	-5.624	-5	(-10, 10)	NA	NA	None
Size DblN peak NWFSC WCGBT(6)	33.691	2	(15, 55)	OK	0.2174900	None
Size DblN top logit NWFSC WCGBT(6)	-2.968	-3	(-15, 5)	NA	NA	None
Size DblN ascend se NWFSC WCGBT(6)	4.077	3	(-10, 10)	OK	0.0445981	None
Size DblN descend se NWFSC WCGBT(6)	-0.815	-4	(-10, 10)	NA	NA	None
Size DblN start logit NWFSC WCGBT(6)	-10.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit NWFSC WCGBT(6)	1.049	3	(-10, 10)	OK	0.2704930	None
SzSel Fem Peak NWFSC WCGBT(6)	0.000	-4	(-15, 15)	NA	NA	None
SzSel Fem Ascend NWFSC WCGBT(6)	0.000	-4	(-5, 5)	NA	NA	None
SzSel Fem Descend NWFSC WCGBT(6)	3.013	-4	(-10, 10)	NA	NA	None
SzSel Fem Final NWFSC WCGBT(6)	-0.952	4	(-20, 20)	OK	0.3046470	None
SzSel Fem Scale NWFSC WCGBT(6)	0.649	4	(0.01, 1)	OK	0.0371037	None
Size DblN peak CA(1) BLK1repl 1910	39.938	4	(15, 55)	OK	0.7448700	None
Size DblN peak CA(1) BLK1repl 1985	35.578	4	(15, 55)	OK	0.7699650	None
Retain L infl CA(1) BLK2repl 1910	10.000	-4	(10, 40)	NA	NA	None

Table 21: 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 (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
Retain L infl CA(1) BLK2repl 1948	28.901	5	(15, 40)	OK	0.5102720	None
Retain L infl CA(1) BLK2repl 2011	25.233	5	(15, 40)	OK	1.4874500	None
Retain L width CA(1) BLK2repl 1910	0.100	-4	(0.1, 5)	NA	NA	None
Retain L width CA(1) BLK2repl 1948	0.992	5	(0.1, 5)	OK	0.2835660	None
Retain L width CA(1) BLK2repl 2011	1.055	5	(0.1, 5)	OK	0.5451350	None
Retain L asymptote logit CA(1) BLK2repl 1910	10.000	-4	(-10, 10)	NA	NA	None
Retain L asymptote logit CA(1) BLK2repl 1948	2.375	5	(-10, 10)	OK	0.0839036	None
Retain L asymptote logit CA(1) BLK2repl 2011	3.265	5	(-10, 10)	OK	0.0539576	None
SzSel Fem Peak CA(1) BLK1repl 1910	0.978	4	(-50, 50)	OK	0.8112050	None
SzSel Fem Peak CA(1) BLK1repl 1985	1.007	4	(-50, 50)	OK	0.8754770	None
Size DblN peak OR WA(2) BLK1repl 1910	42.434	4	(15, 55)	OK	0.5659470	None
Size DblN peak OR WA(2) BLK1repl 1985	35.499	4	(15, 55)	OK	0.0149884	None
Retain L infl OR WA(2) BLK3repl 1910	27.904	5	(15, 40)	OK	0.6798150	None
Retain L infl OR WA(2) BLK3repl 2002	27.172	5	(15, 40)	OK	0.6943230	None
Retain L width OR WA(2) BLK3repl 1910	0.843	5	(0.1, 5)	OK	0.3719160	None
Retain L width OR WA(2) BLK3repl 2002	1.378	5	(0.1, 5)	OK	0.3438220	None
Retain L asymptote logit OR WA(2) BLK3repl 1910	2.340	5	(-10, 10)	OK	0.0859856	None
Retain L asymptote logit OR WA(2) BLK3repl 2002	3.286	5	(-10, 10)	OK	0.1054710	None
SzSel Fem Peak OR WA(2) BLK1repl 1910	10.066	4	(-50, 50)	OK	0.5665890	None
SzSel Fem Peak OR WA(2) BLK1repl 1985	4.841	4	(-50, 50)	OK	0.2462730	None

Table 22: Likelihood components by source.

Label	Total
TOTAL	1028.95
Catch	0.00
Equil catch	0.00
Survey	-49.59
Discard	-72.22
Mean body wt	-81.24
Length comp	338.18
Age comp	909.45
Recruitment	-15.67
InitEQ Regime	0.00
Forecast Recruitment	0.00
Parm priors	0.04
Parm softbounds	0.01
Parm devs	0.00
Crash Pen	0.00

Table 23: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	294070	220699	367441
Unfished Age 3+ Biomass (mt)	594408	466269	722547
Unfished Recruitment (R0)	213096	159928	266264
Spawning Biomass (mt) (2021)	232065	154153	309977
Fraction Unfished (2021)	0.79	0.71	0.87
Reference Points Based SB25 Percent	-	-	-
Proxy Spawning Biomass (mt) SB25 Percent	73517	55175	91860
SPR Resulting in SB25 Percent	0.30	0.30	0.30
Exploitation Rate Resulting in SB25 Percent	0.12	0.12	0.12
Yield with SPR Based On SB25 Percent (mt)	22901	17705	28097
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Biomass (mt) (SPR30)	74498	55910	93085
SPR30	0.30	-	-
Exploitation Rate Corresponding to SPR30	0.12	0.12	0.12
Yield with SPR30 at SB SPR (mt)	22891	17697	28084
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Biomass (mt) at MSY (SB MSY)	69598	52425	86771
SPR MSY	0.28	0.28	0.29
Exploitation Rate Corresponding to SPR MSY	0.13	0.12	0.13
MSY (mt)	22919	17716	28122

Table 24: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1911	598660	293971	594150	1.00	212749	10.03	0.00	0.00
1912	598624	293956	594114	1.00	212717	20.03	0.00	0.00
1913	598578	293936	594069	1.00	212682	30.03	0.00	0.00
1914	598521	293910	594012	1.00	212644	40.03	0.00	0.00
1915	598453	293879	593945	1.00	212602	50.04	0.00	0.00
1916	598376	293844	593869	1.00	212556	55.84	0.00	0.00
1917	598293	293806	593787	1.00	212505	152.14	0.00	0.00
1918	598121	293722	593616	1.00	212448	183.73	0.00	0.00
1919	597926	293626	593422	1.00	212386	192.73	0.00	0.00
1920	597728	293529	593225	1.00	212318	166.53	0.00	0.00
1921	597560	293447	593059	1.00	212245	254.63	0.01	0.00
1922	597316	293326	592816	1.00	212164	429.64	0.01	0.00
1923	596919	293126	592421	1.00	212073	493.94	0.01	0.00
1924	596481	292905	591985	1.00	211974	692.85	0.01	0.00
1925	595881	292599	591387	0.99	211862	763.55	0.02	0.00
1926	595247	292274	590755	0.99	211741	753.74	0.01	0.00
1927	594654	291969	590165	0.99	211611	913.15	0.02	0.00
1928	593946	291604	589459	0.99	211468	895.94	0.02	0.00
1929	593290	291266	588805	0.99	211315	1020.69	0.02	0.00
1930	592552	290885	588070	0.99	211150	952.71	0.02	0.00
1931	591912	290555	587435	0.99	210976	821.09	0.02	0.00
1932	591422	290304	586948	0.99	210792	785.89	0.02	0.00
1933	590982	290082	586511	0.99	210594	729.75	0.01	0.00
1934	590603	289894	586137	0.99	210380	770.66	0.02	0.00
1935	590191	289693	585729	0.99	210145	895.23	0.02	0.00
1936	589674	289449	585217	0.98	209889	1007.46	0.02	0.00
1937	589073	289175	584620	0.98	209608	1064.20	0.02	0.00
1938	588434	288887	583987	0.98	209302	971.38	0.02	0.00
1939	587890	288646	583449	0.98	208971	1452.81	0.03	0.00
1940	586923	288210	582489	0.98	208603	1559.82	0.03	0.00
1941	585905	287767	581478	0.98	208210	1610.02	0.03	0.00
1942	584890	287343	580471	0.98	207795	1959.34	0.03	0.00
1943	583613	286816	579202	0.98	207372	4185.90	0.06	0.01
1944	580470	285461	576068	0.97	206924	1711.57	0.03	0.00
1945	579630	285109	575237	0.97	206543	2522.08	0.04	0.00
1946	578088	284432	573705	0.97	206196	3091.50	0.05	0.01
1947	576098	283537	571722	0.96	205924	2578.03	0.04	0.00
1948	574620	282851	570251	0.96	205769	3935.33	0.06	0.01
1949	571990	281611	567626	0.96	205739	6054.22	0.10	0.01
1950	567587	279466	563226	0.95	205874	8276.65	0.13	0.01
1951	561499	276492	557137	0.94	206197	8664.11	0.14	0.02
1952	555490	273523	551124	0.93	206780	9966.47	0.16	0.02

Table 24: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1953	548728	270098	544353	0.92	207633	6098.22	0.11	0.01
1954	545852	268473	541463	0.91	208904	7435.39	0.13	0.01
1955	542090	266431	537680	0.91	210420	6635.61	0.12	0.01
1956	539392	264873	534954	0.90	212149	6710.68	0.12	0.01
1957	536949	263406	532477	0.90	213959	6166.85	0.11	0.01
1958	535317	262289	530808	0.89	215591	6545.32	0.12	0.01
1959	533684	261150	529138	0.89	216648	6247.45	0.11	0.01
1960	532681	260301	528105	0.89	216828	8094.69	0.14	0.02
1961	530387	258799	525795	0.88	216128	6716.37	0.12	0.01
1962	529731	258081	525139	0.88	215261	7438.84	0.13	0.01
1963	528738	257221	524162	0.87	214869	8756.46	0.15	0.02
1964	526894	256004	522333	0.87	215807	7945.76	0.14	0.02
1965	526059	255304	521497	0.87	217861	7470.02	0.14	0.01
1966	525813	254892	521225	0.87	219947	7254.44	0.14	0.01
1967	525939	254719	521309	0.87	221049	5719.50	0.11	0.01
1968	527614	255375	522946	0.87	221120	6836.99	0.13	0.01
1969	528376	255591	523691	0.87	220378	9796.99	0.18	0.02
1970	526608	254493	521927	0.87	218722	11026.27	0.20	0.02
1971	524000	252927	519340	0.86	216415	10310.37	0.19	0.02
1972	522326	251836	517704	0.86	215660	14366.49	0.25	0.03
1973	517175	248945	512587	0.85	220557	13867.00	0.25	0.03
1974	512832	246444	508222	0.84	233091	12793.47	0.23	0.03
1975	509910	244723	505151	0.83	246829	14012.20	0.25	0.03
1976	506323	242520	501305	0.82	245278	14999.74	0.26	0.03
1977	502571	240092	497369	0.82	222977	13950.26	0.25	0.03
1978	500473	238286	495421	0.81	200709	15588.70	0.27	0.03
1979	497512	236117	492922	0.80	189447	19574.24	0.31	0.04
1980	491350	232610	487166	0.79	182286	15612.31	0.27	0.03
1981	488758	231347	484795	0.79	169110	17997.86	0.30	0.04
1982	483581	229417	479801	0.78	159973	22952.00	0.35	0.05
1983	473527	225725	469992	0.77	163622	21983.59	0.34	0.05
1984	463822	222644	460408	0.76	165981	21151.00	0.34	0.05
1985	454071	219558	450581	0.75	175888	22865.04	0.42	0.05
1986	440096	215359	436516	0.73	182538	19247.86	0.38	0.04
1987	428912	211749	425121	0.72	210898	20501.29	0.40	0.05
1988	416244	206720	412164	0.70	265069	20156.44	0.41	0.05
1989	404319	201165	399574	0.68	227495	20931.34	0.43	0.05
1990	392828	194781	387424	0.66	227938	17474.30	0.39	0.05
1991	386352	189805	381492	0.65	267623	20289.00	0.45	0.05
1992	378944	183752	373893	0.62	260568	17877.18	0.42	0.05
1993	375973	179389	370399	0.61	195731	16007.57	0.40	0.04
1994	376514	176891	371387	0.60	166273	10469.82	0.29	0.03
1995	383372	177991	379391	0.61	166252	11823.09	0.31	0.03

Table 24: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1996	388939	179527	385406	0.61	176224	13479.59	0.34	0.03
1997	392516	180940	388832	0.62	290696	11198.98	0.29	0.03
1998	397766	184079	393378	0.63	291381	8869.41	0.24	0.02
1999	405154	188473	399051	0.64	222475	10100.94	0.26	0.03
2000	411776	191987	405889	0.65	337650	9691.04	0.24	0.02
2001	419411	195100	414160	0.66	204146	7604.29	0.20	0.02
2002	429805	198709	423470	0.68	135916	6772.29	0.18	0.02
2003	441080	202667	437153	0.69	122924	7888.08	0.20	0.02
2004	450234	206544	447424	0.70	126399	7203.97	0.18	0.02
2005	458040	211334	455411	0.72	130619	7360.29	0.18	0.02
2006	463096	216476	460371	0.74	154568	6353.83	0.15	0.01
2007	466390	221929	463448	0.75	195658	9868.99	0.22	0.02
2008	463974	224940	460416	0.76	248259	11908.80	0.25	0.03
2009	458266	225547	453741	0.77	334902	12451.17	0.26	0.03
2010	452032	224168	446346	0.76	256930	10999.29	0.24	0.02
2011	448433	221913	441826	0.75	204214	7893.18	0.18	0.02
2012	449540	220118	444363	0.75	238648	7429.72	0.18	0.02
2013	452497	218371	448041	0.74	161941	8077.92	0.20	0.02
2014	455790	216973	451164	0.74	166317	6543.10	0.17	0.01
2015	460857	217507	457370	0.74	199178	6354.50	0.16	0.01
2016	465743	219403	462025	0.75	205309	7349.81	0.18	0.02
2017	469043	221755	464785	0.75	206028	7925.06	0.19	0.02
2018	471179	224177	466820	0.76	208863	6447.41	0.15	0.01
2019	474186	227036	469803	0.77	209235	5789.61	0.14	0.01
2020	477349	229626	472920	0.78	209423	4706.57	0.11	0.01
2021	481200	232065	476764	0.79	209596	10000.00	0.22	0.02
2022	479656	231642	475216	0.79	209566	10000.00	0.22	0.02
2023	478100	230918	473658	0.79	209515	59684.50	0.68	0.13
2024	428939	207333	424499	0.71	207666	51948.90	0.68	0.12
2025	389618	187284	385189	0.64	205764	45937.20	0.68	0.12
2026	358333	170449	353944	0.58	203856	41277.20	0.68	0.12
2027	333523	156459	329174	0.53	201992	37645.80	0.68	0.11
2028	313889	144943	309580	0.49	200221	34892.40	0.68	0.11
2029	298274	135500	294004	0.46	198572	32769.90	0.67	0.11
2030	285783	127779	281550	0.43	197067	31087.50	0.67	0.11
2031	275741	121483	271541	0.41	195718	29796.91	0.67	0.11
2032	267559	116323	263391	0.40	194519	28761.72	0.67	0.11

Table 25: Data weights applied by each alternative data weighting method. Weights for the Dirichlet multinomial are undetermined due to inconsistent results relative to input sample sizes and parameters hitting bounds.

Data	Francis	McAllister Ianelli	Dirichlet Multinomial
California Lengths	0.082	0.182	0.972
Oregon/Washington Lengths	0.093	0.084	0.951
AFSC Slope Lengths	1.856	3.117	1.000
Triennial Lengths	0.243	0.618	1.000
NWFSC Slope Lengths	0.286	1.395	1.000
NWFSC WCGBT Lengths	0.409	1.115	1.000
California Ages	0.119	0.505	1.000
Oregon/Washington Ages	0.189	0.563	1.000
NWFSC Slope Ages	0.034	0.184	1.000
NWFSC WCGBT Ages	0.111	0.157	1.000

Table 26: Sensitivities to changes in input data relative to the base model. The data source listed has been removed for the sensitivity run.

	Base Model	CA lengths	OR/WA lengths	AFSC slope lengths	Trien-nial lengths	NWFSC slope lengths	NWFSC WCGBT lengths	CA ages	OR/WA ages	NWFSC slope ages	NWFSC WCGBT ages	AFSC slope index	Trien-nial index	NWFSC slope index	NWFSC WCGBT index
Total Likel.	1028.95	947.16	919.32	994.62	1003.82	1016.99	894.56	976.48	937.84	956.94	299.75	1035.26	1032.46	1036.89	1059.93
Survey Like.	-49.59	-49.76	-49.35	-53.26	-50.74	-50.14	-56.41	-49.44	-49.26	-49.78	-51.87	-43.25	-46.02	-41.62	-17.68
Length Like.	338.180	263.290	258.270	310.390	315.490	327.750	223.750	339.420	334.960	335.680	308.970	338.230	338.130	338.260	338.230
Age Like.	909.450	903.150	881.650	907.480	908.250	908.700	897.130	855.690	822.750	840.020	211.960	909.350	909.420	909.330	908.160
Recruitment Like.	-15.67	-15.59	-15.13	-16.43	-15.77	-15.84	-16.89	-15.53	-16.30	-15.55	-15.02	-15.66	-15.68	-15.67	-15.29
Forecast Recr. Like.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Parameter Priors Like.	0.040	0.020	0.030	0.010	0.040	0.030	0.130	0.030	0.070	0.020	0.010	0.040	0.040	0.040	0.050
log(R0)	12.270	12.260	12.310	12.250	12.290	12.270	12.370	12.300	12.470	12.210	11.920	12.270	12.270	12.270	12.270
SB Virgin	294070	291602	303687	288621	300864	292973	321119	301414	358182	279583	209686	293663	293919	293800	294391
SB 2020	232065	230181	243389	225894	239043	230776	265527	238940	299632	216992	144993	231472	231681	231610	228349
Fraction Unfished 2021	0.790	0.790	0.800	0.780	0.790	0.790	0.830	0.790	0.840	0.780	0.690	0.790	0.790	0.790	0.780
Total Yield - SPR 50	22891	22574	23919	22654	23354	22850	24624	23509	28092	21812	17030	22858	22876	22867	22791
Steepness	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
M - Female	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
Length at Amin - Female	7.990	7.950	8.000	8.270	7.970	8.070	7.660	8.080	7.940	7.920	4.380	7.990	7.990	7.990	7.990
Length at Amax - Female	48.050	48.060	47.710	48.160	48.060	48.080	47.760	48.050	47.720	48.150	47.580	48.050	48.050	48.050	48.010
Von Bert. k - Female	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.150	0.130	0.130	0.130	0.130
CV young - Female	0.160	0.160	0.160	0.150	0.160	0.160	0.170	0.160	0.160	0.160	0.130	0.160	0.160	0.160	0.160
CV old - Female	0.080	0.080	0.080	0.080	0.080	0.080	0.070	0.080	0.080	0.080	0.090	0.080	0.080	0.080	0.080
M - Male	0.114	0.113	0.114	0.112	0.114	0.113	0.120	0.114	0.116	0.113	0.106	0.114	0.114	0.114	0.115
Length at Amin - Male	10.350	10.380	10.280	10.130	10.340	10.310	10.910	10.450	10.070	10.340	6.190	10.340	10.340	10.340	10.360
Length at Amax - Male	41.970	42.040	41.840	42.120	41.980	42.010	42.180	41.960	41.590	42.020	40.490	41.970	41.970	41.970	41.950
Von Bert. k - Male	0.140	0.140	0.140	0.140	0.140	0.140	0.130	0.140	0.140	0.140	0.170	0.140	0.140	0.140	0.140
CV young - Male	0.140	0.140	0.140	0.150	0.140	0.140	0.160	0.140	0.140	0.140	0.060	0.140	0.140	0.140	0.140
CV old - Male	0.080	0.080	0.080	0.080	0.080	0.080	0.070	0.080	0.080	0.080	0.100	0.080	0.080	0.080	0.080

Table 27: Sensitivities to changes in structural assumptions relative to the base model.

	Base Model	Est. Fem M	Est. Lorenz. M	Fix M median prior	Fix M 2011 est.	2011 Fish. Sel.	2011 Surv. Sel.	Mirror Com. Sel.	NWFSC slope Asympt. Sel.	2011 Matu-rity	No recdevs	No add Surv. SD	MI Data Weight
Total Likelihood	1028.950	1021.860	1023.040	1030.190	1040.700	1088.030	1036.920	1124.550	1046.820	1029.560	1185.130	1087.700	2336.390
Survey Likelihood	-49.590	-51.560	-51.400	-49.880	-47.340	-50.090	-49.830	-50.560	-49.940	-49.560	-46.260	3.390	-48.910
Length Likelihood	338.180	334.470	336.030	337.450	346.840	381.710	340.100	383.260	352.730	338.550	429.950	341.340	720.840
Age Likelihood	909.450	907.370	906.690	911.840	909.300	932.420	914.770	940.100	913.270	909.630	950.650	911.760	1826.860
Recruitment Likelihood	-15.670	-15.070	-14.720	-15.730	-15.160	-15.330	-15.460	-15.770	-15.770	-15.660	0.000	-14.850	-12.070
Forecast Recruitment Likelihood	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Parameter Priors Likelihood	0.040	0.160	0.070	0.000	0.490	0.100	0.430	0.040	0.010	0.050	0.040	0.040	0.030
log(R0)	12.270	11.430	12.430	12.150	13.130	12.280	12.440	12.170	12.120	12.270	12.290	12.300	12.160
SB Virgin	294070	223732	228088	260613	589087	295670	352136	265539	253263	291038	299686	304691	263056
SB 2020	232065	125501	126385	197555	542320	231480	292196	201692	190444	227949	235221	248301	200191
Fraction Unfished 2021	0.790	0.560	0.550	0.760	0.920	0.780	0.830	0.760	0.750	0.780	0.780	0.810	0.760
Total Yield - SPR 50	22891	13246	13619	20746	46952	22769	25540	21301	20379	22268	23216	23721	20531
Steepness	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
Natural Mortality - Female	0.108	0.082	0.097	0.108	0.116	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
Length at Amin - Female	7.990	8.040	8.030	7.970	8.060	7.960	8.220	8.380	7.700	7.990	8.020	8.040	8.240
Length at Amax - Female	48.050	47.950	47.950	48.080	48.050	47.990	48.410	48.000	48.100	48.050	48.140	48.120	48.000
Von Bert. k - Female	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130
CV young - Female	0.160	0.150	0.160	0.160	0.160	0.160	0.150	0.150	0.160	0.160	0.160	0.160	0.150
CV old - Female	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
Natural Mortality - Male	0.114	0.082	0.103	0.108	0.142	0.118	0.130	0.115	0.104	0.115	0.115	0.114	0.113
Length at Amin - Male	10.350	10.540	10.030	10.470	9.950	10.370	11.280	9.980	10.690	10.360	10.510	10.420	10.140
Length at Amax - Male	41.970	42.000	41.980	41.960	42.000	41.240	42.010	41.440	41.970	41.970	42.000	41.970	41.790
Von Bert. k - Male	0.140	0.140	0.140	0.140	0.140	0.140	0.130	0.140	0.140	0.140	0.140	0.140	0.140
CV young - Male	0.140	0.140	0.140	0.140	0.140	0.120	0.130	0.130	0.130	0.140	0.140	0.140	0.130
CV old - Male	0.080	0.080	0.080	0.080	0.080	0.090	0.080	0.080	0.080	0.080	0.080	0.080	0.080

Table 28: Projections of potential OFLs (mt), ABCs (mt), the buffer (ABC = buffer x OFL), estimated spawning biomass, and fraction unfished. The adopted OFL, ABC, and ACL for 2021 and 2022 reflect adopted management limits and the assumed removal is the removal assumptions applied for 2021 and 2022. The full ABC was assumed to be removed for 2023 - 2032

Year	Adopted OFL (mt)	Adopted ABC (mt)	Adopted ACL (mt)	Assumed Removal (mt)	OFL (mt)	ABC (mt)	Buffer	Spawning Biomass (mt)	Fraction Unfished
2021	93547	84192	50000	10000	-	-	-	232065	0.79
2022	87540	78436	50000	10000	-	-	-	231642	0.79
2023	-	-	-	-	63834	59684	0.935	230918	0.79
2024	-	-	-	-	55859	51949	0.93	207333	0.71
2025	-	-	-	-	49608	45937	0.926	187284	0.64
2026	-	-	-	-	44769	41277	0.922	170449	0.58
2027	-	-	-	-	41053	37646	0.917	156459	0.53
2028	-	-	-	-	38217	34892	0.913	144943	0.49
2029	-	-	-	-	36050	32770	0.909	135500	0.46
2030	-	-	-	-	34389	31088	0.904	127779	0.43
2031	-	-	-	-	33108	29797	0.9	121483	0.41
2032	-	-	-	-	32100	28762	0.896	116323	0.40

Table 29: Decision table summary of 10 year projections beginning in 2023 for alternative states of nature based on an axis of uncertainty about female natural mortality for the base model. Columns range over low, mid, and high states of nature and rows range over different catch level assumptions. Values in italics indicate years where the stock size prevented the full catch removals.

			M = 0.084		M = 0.108		M = 0.126	
	Year	Catch	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished
	2021	10,000	130,402	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,406	0.578	231,642	0.788	410,978	0.899
	2023	7,000	130,187	0.577	230,918	0.785	409,093	0.895
	2024	7,000	130,897	0.58	231,425	0.787	408,497	0.894
	2025	7,000	131,593	0.583	231,923	0.789	408,020	0.892
7,000 mt	2026	7,000	132,315	0.586	232,460	0.790	407,746	0.892
	2027	7,000	133,080	0.59	233,048	0.792	407,685	0.892
	2028	7,000	133,889	0.593	233,681	0.795	407,810	0.892
	2029	7,000	134,732	0.597	234,344	0.797	408,079	0.893
	2030	7,000	135,595	0.601	235,020	0.799	408,451	0.893
	2031	7,000	136,465	0.605	235,695	0.801	408,888	0.894
	2032	7,000	137,331	0.609	236,358	0.804	409,361	0.895
	2021	10,000	130,357	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,358	0.578	231,642	0.788	410,978	0.899
	2023	20,000	130,139	0.577	230,918	0.785	409,093	0.895
	2024	20,000	125,188	0.555	225,521	0.767	402,630	0.881
	2025	20,000	120,142	0.533	220,194	0.749	396,479	0.867
20,000 mt	2026	20,000	115,118	0.51	215,059	0.731	390,789	0.855
	2027	20,000	110,193	0.488	210,181	0.715	385,612	0.843
	2028	20,000	105,413	0.467	205,591	0.699	380,946	0.833
	2029	20,000	100,799	0.447	201,293	0.685	376,756	0.824
	2030	20,000	96,356	0.427	197,281	0.671	372,999	0.816
	2031	20,000	92,080	0.408	193,539	0.658	369,624	0.809
	2032	20,000	87,958	0.39	190,049	0.646	366,588	0.802
	2021	10,000	130,402	0.578	232,065	0.789	412,460	0.902
	2022	10,000	130,406	0.578	231,642	0.788	410,978	0.899
	2023	59,685	130,187	0.577	230,918	0.785	409,093	0.895
	2024	51,949	106,617	0.473	207,333	0.705	384,636	0.841
ABC	2025	45,937	85,730	0.38	187,284	0.637	364,461	0.797
P* 0.45	2026	41,277	67,417	0.299	170,449	0.580	348,088	0.761
	2027	37,646	51,561	0.229	156,459	0.532	334,996	0.733
	2028	34,892	38,054	0.169	144,943	0.493	324,682	0.710
	2029	32,770	26,754	0.119	135,500	0.461	316,642	0.693
	2030	31,088	17,564	0.078	127,779	0.434	310,450	0.679
	2031	29,797	*10432*	*0.046*	121,483	0.413	305,756	0.669
	2032	28,762	*5289*	*0.023*	116,323	0.396	302,239	0.661

8 Figures

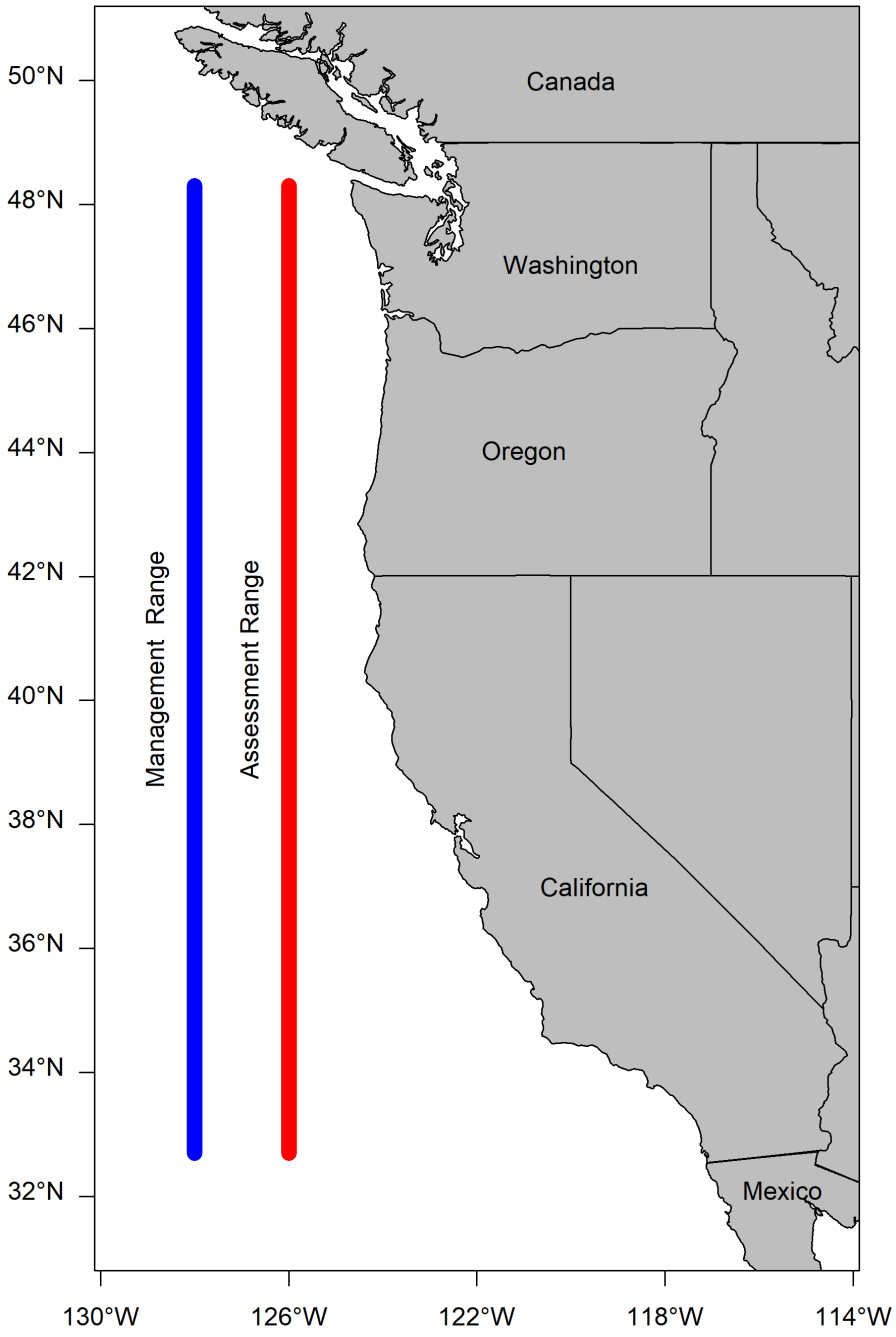


Figure 1: Map of the assessment area.

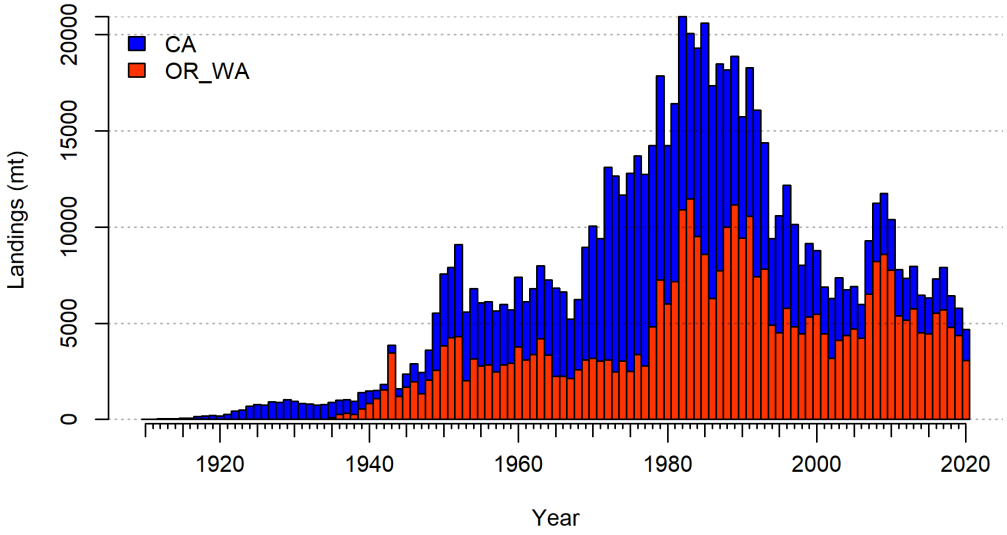


Figure 2: Landings by fleet used in the base model where catches in metric tons by fleet are stacked.

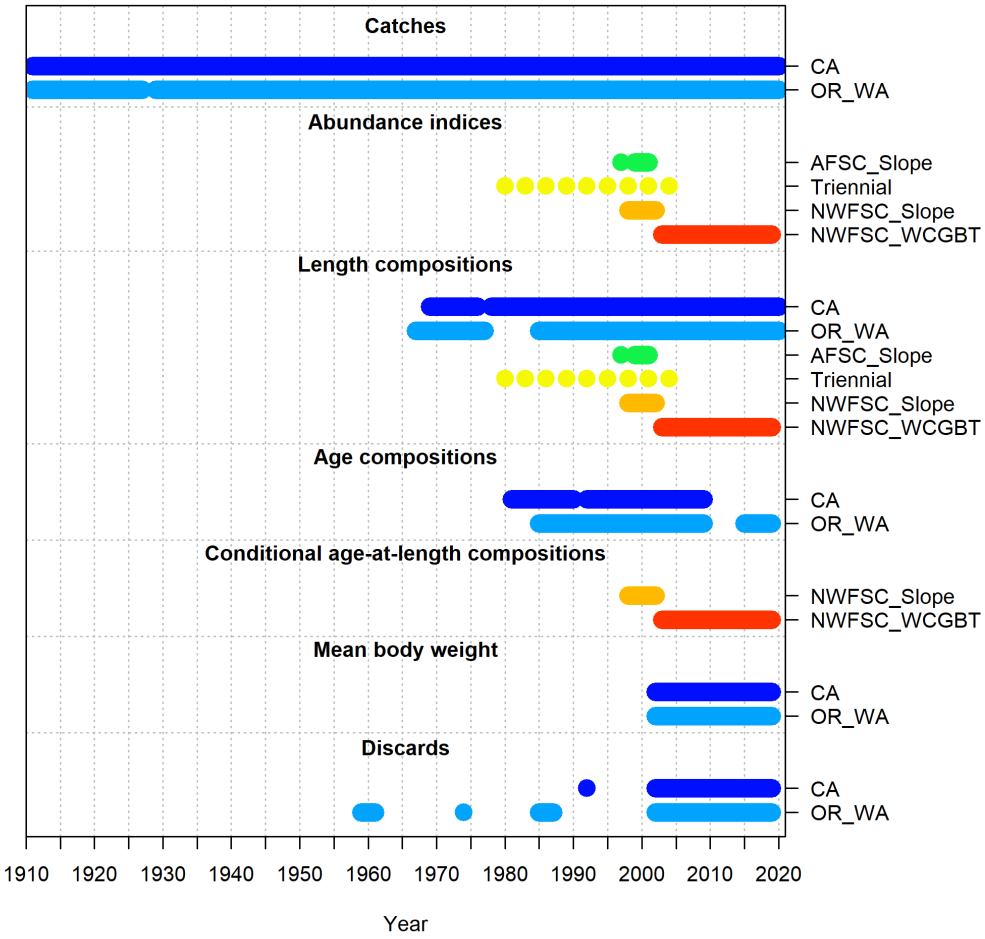


Figure 3: Summary of data sources used in the base model.

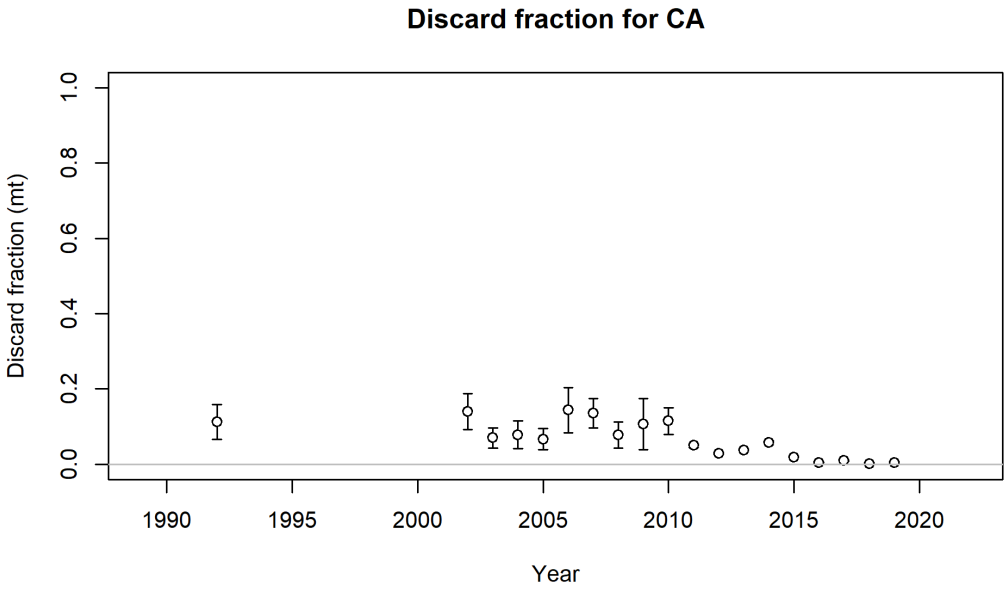


Figure 4: Observed discard rates for the California fleet.

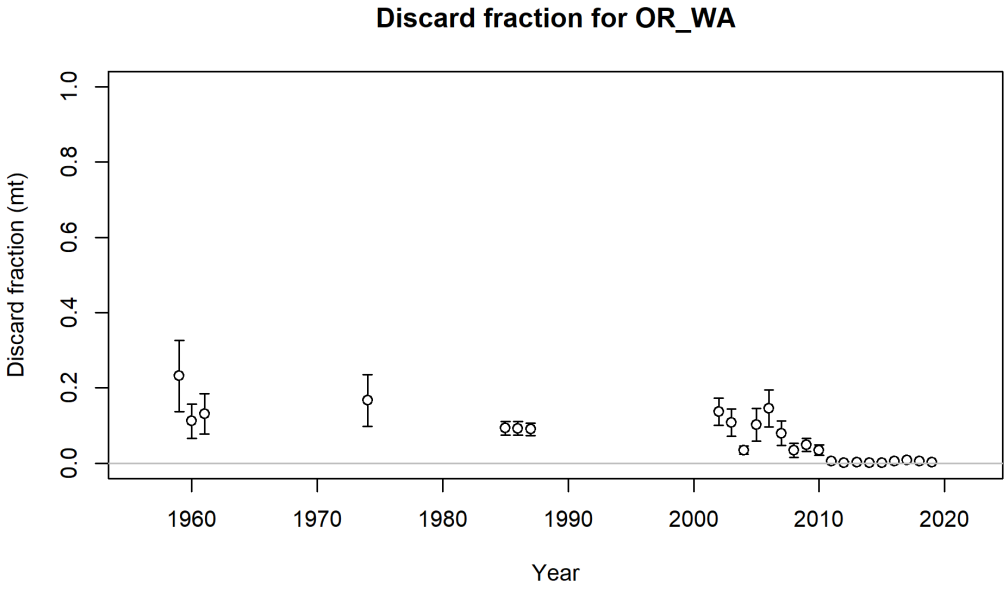


Figure 5: Observed discard rates for the Oregon/Washington fleet.

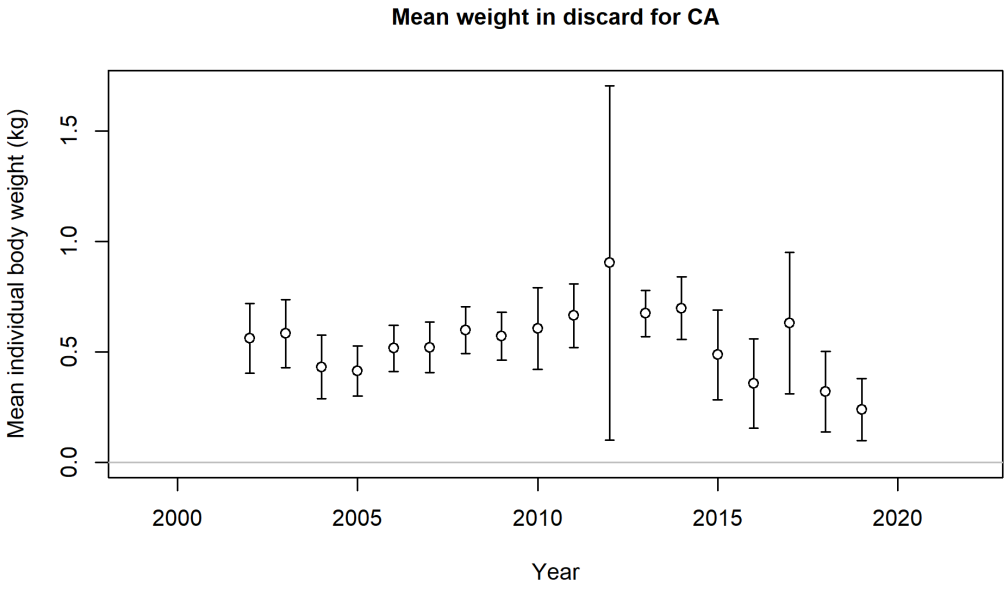


Figure 6: Observed discard mean weights for the California fleet.

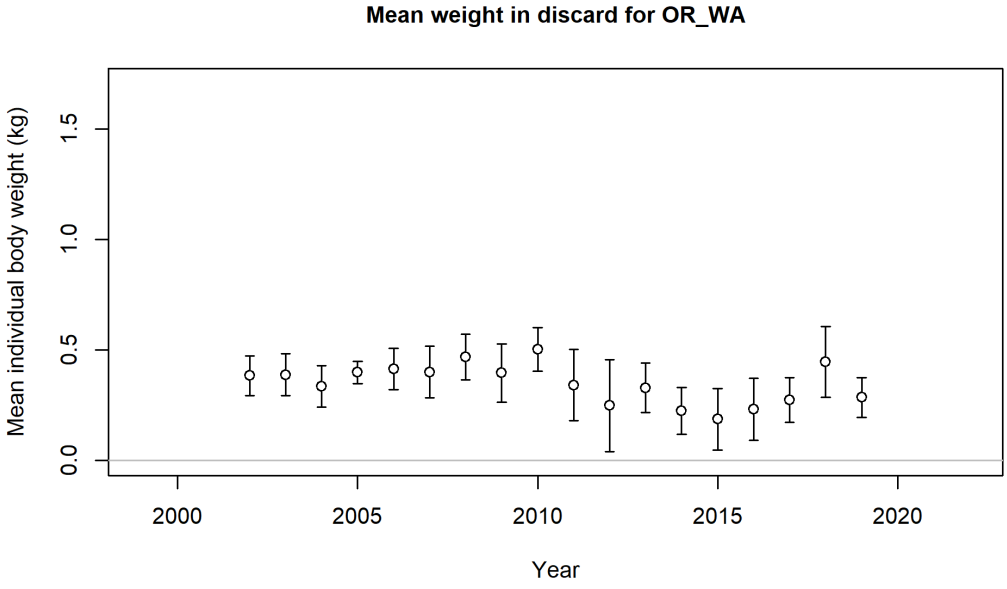


Figure 7: Observed discard mean weights for the Oregon/Washington fleet.

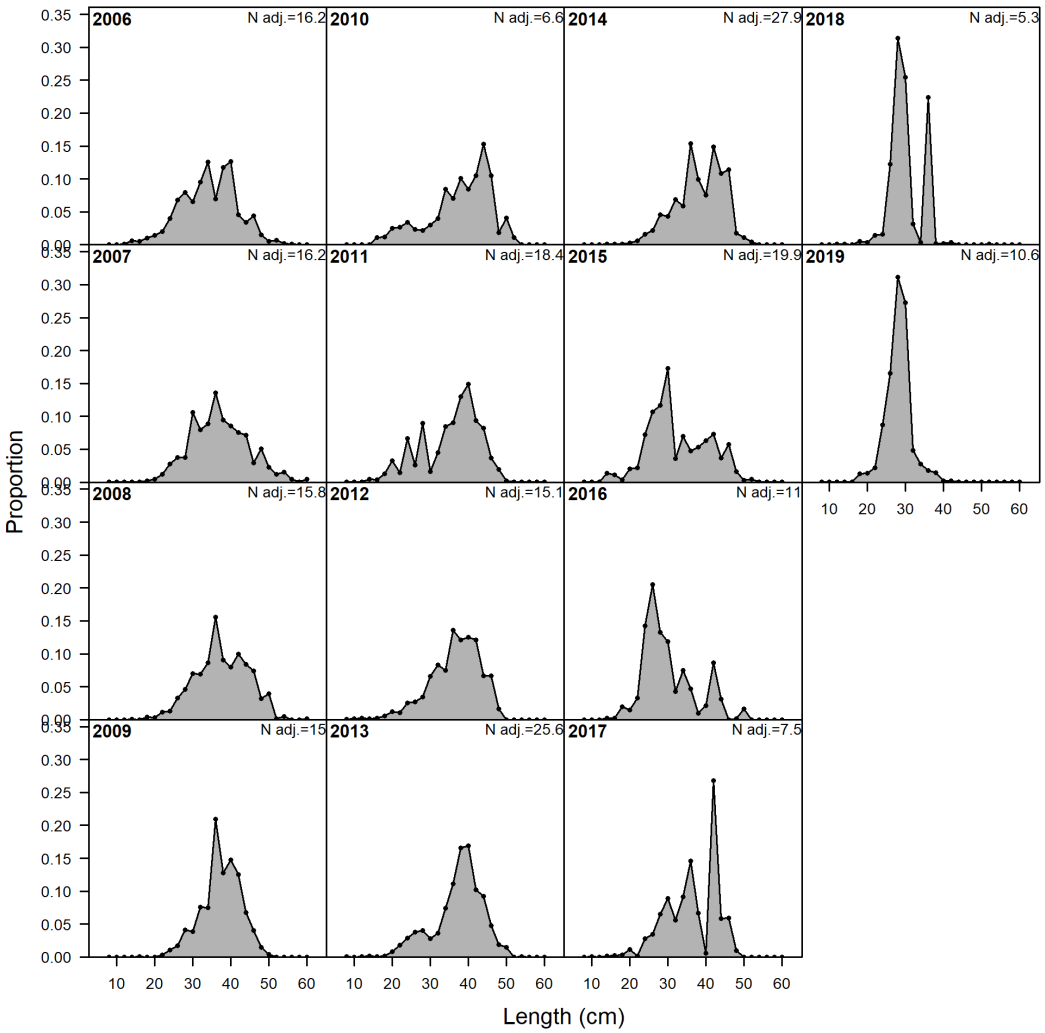


Figure 8: Observed discard lengths for the California fleet.

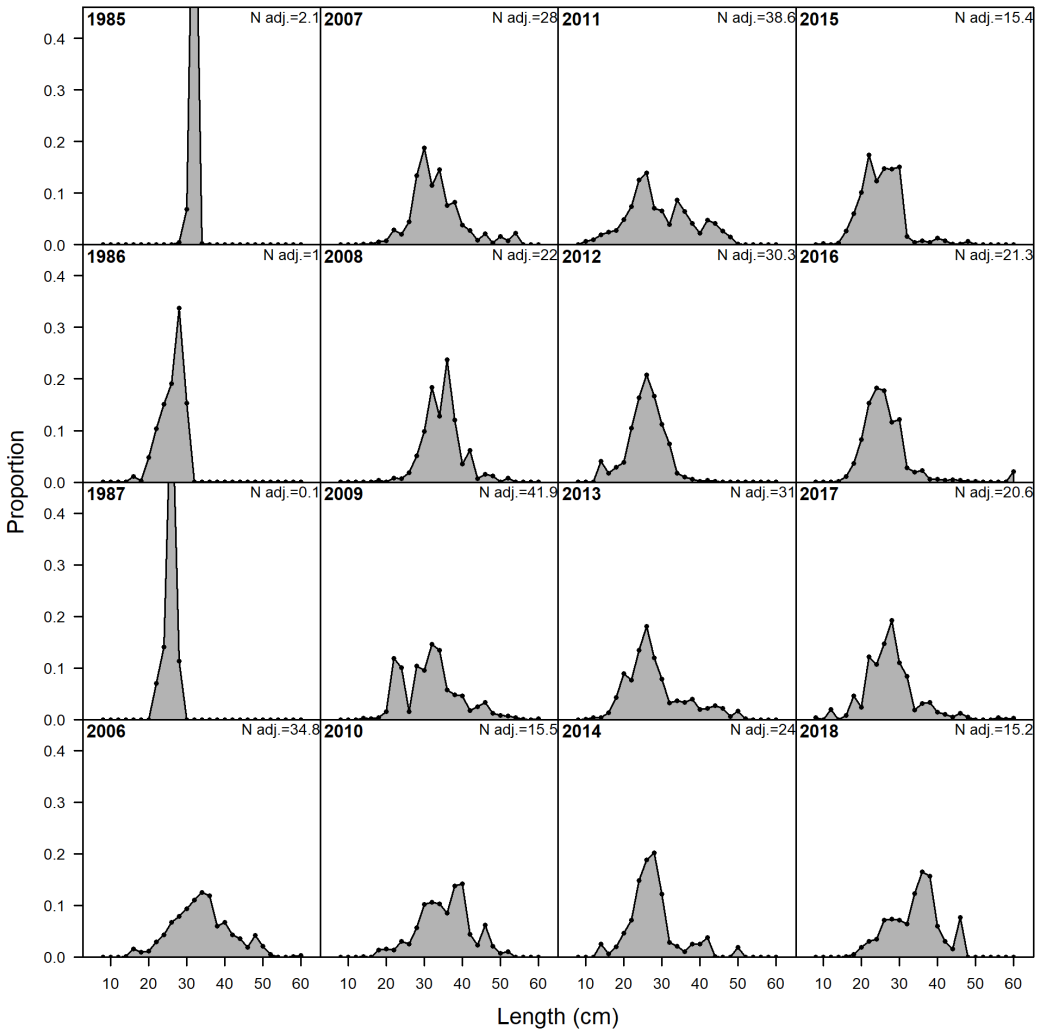


Figure 9: Observed discard lengths for the Oregon/Washington fleet.

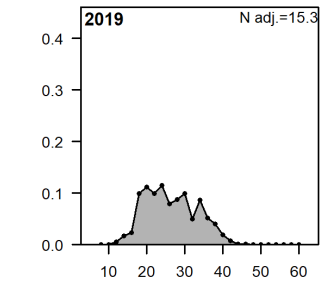


Figure 10: Observed discard lengths for the Oregon/Washington fleet.

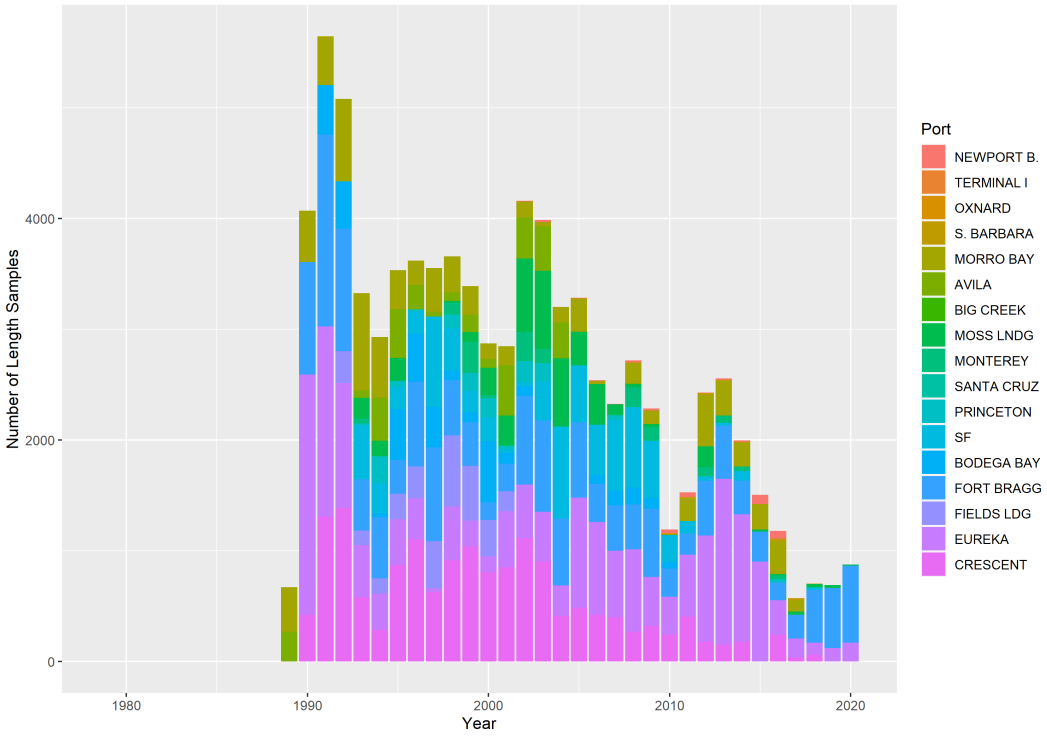


Figure 11: The number of length samples by port and year from California.

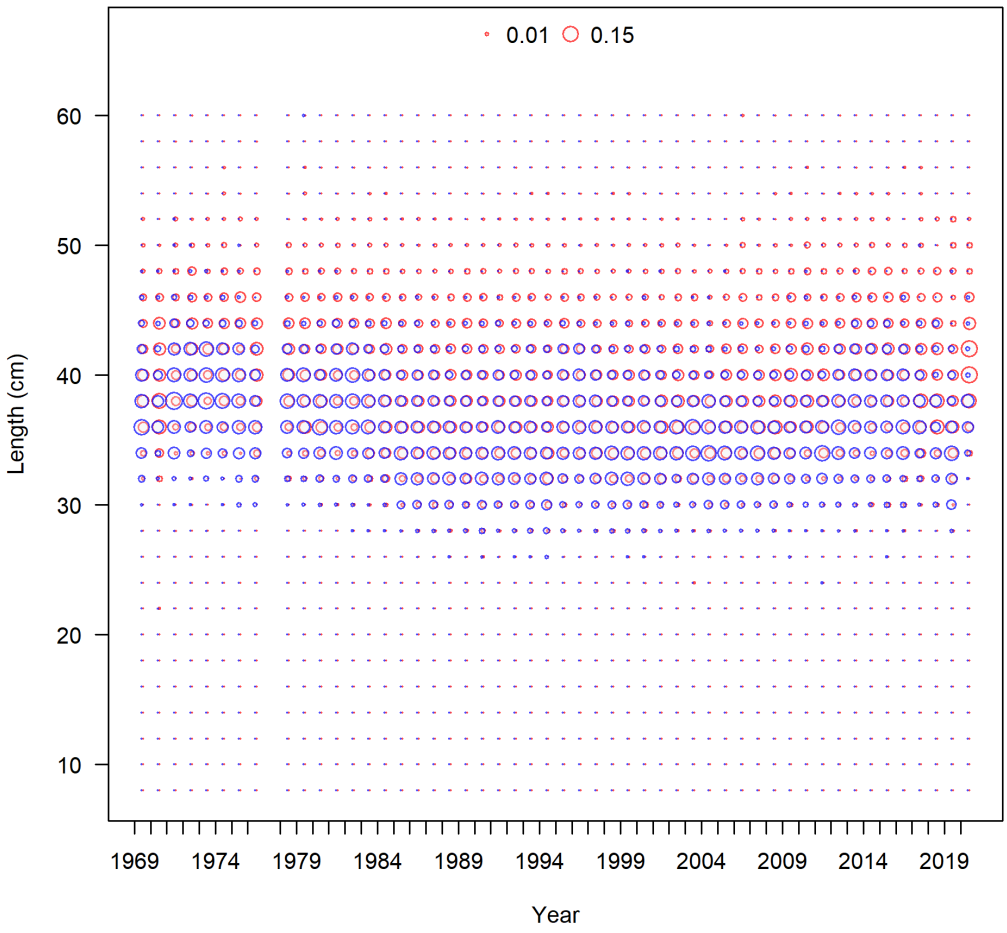


Figure 12: Length composition data from the California commercial fleet.

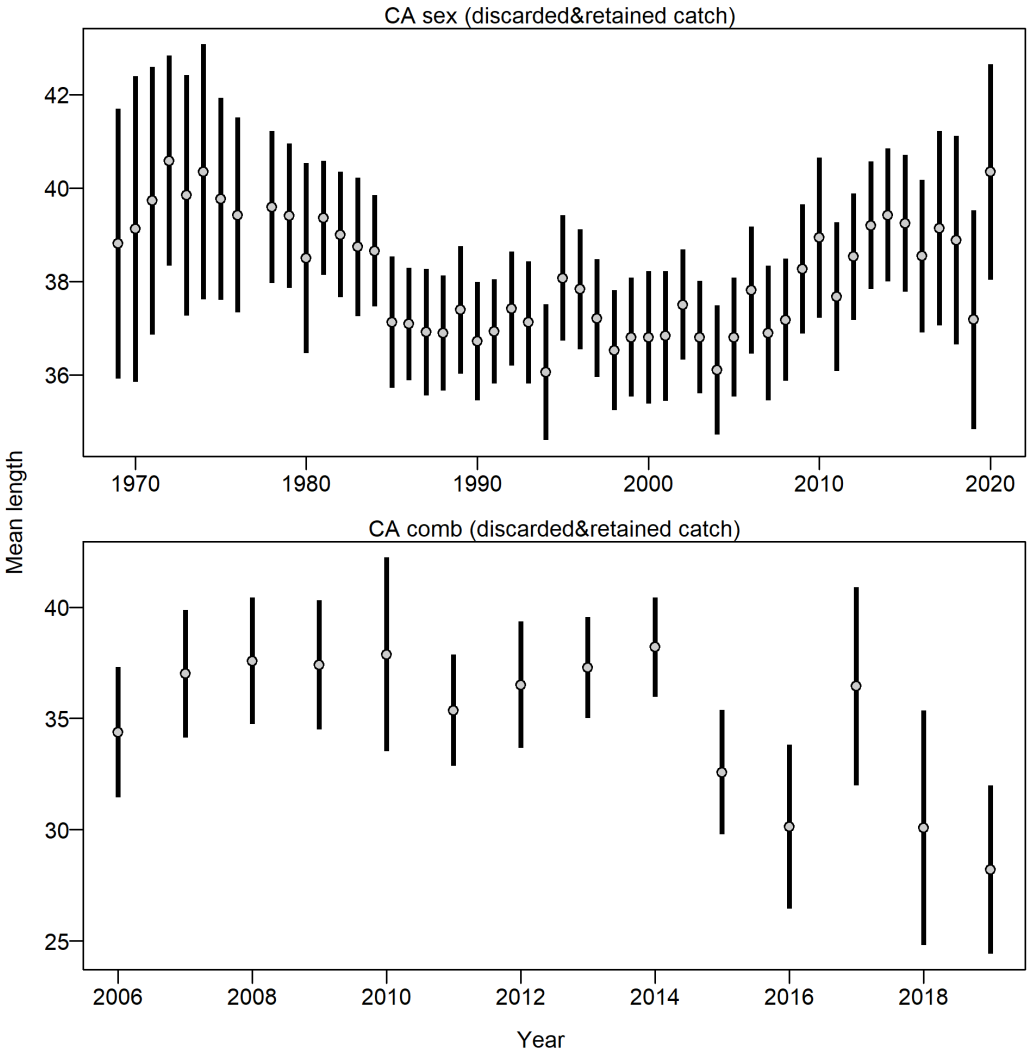


Figure 13: Mean length for California commercial fleet with 95 percent confidence intervals.

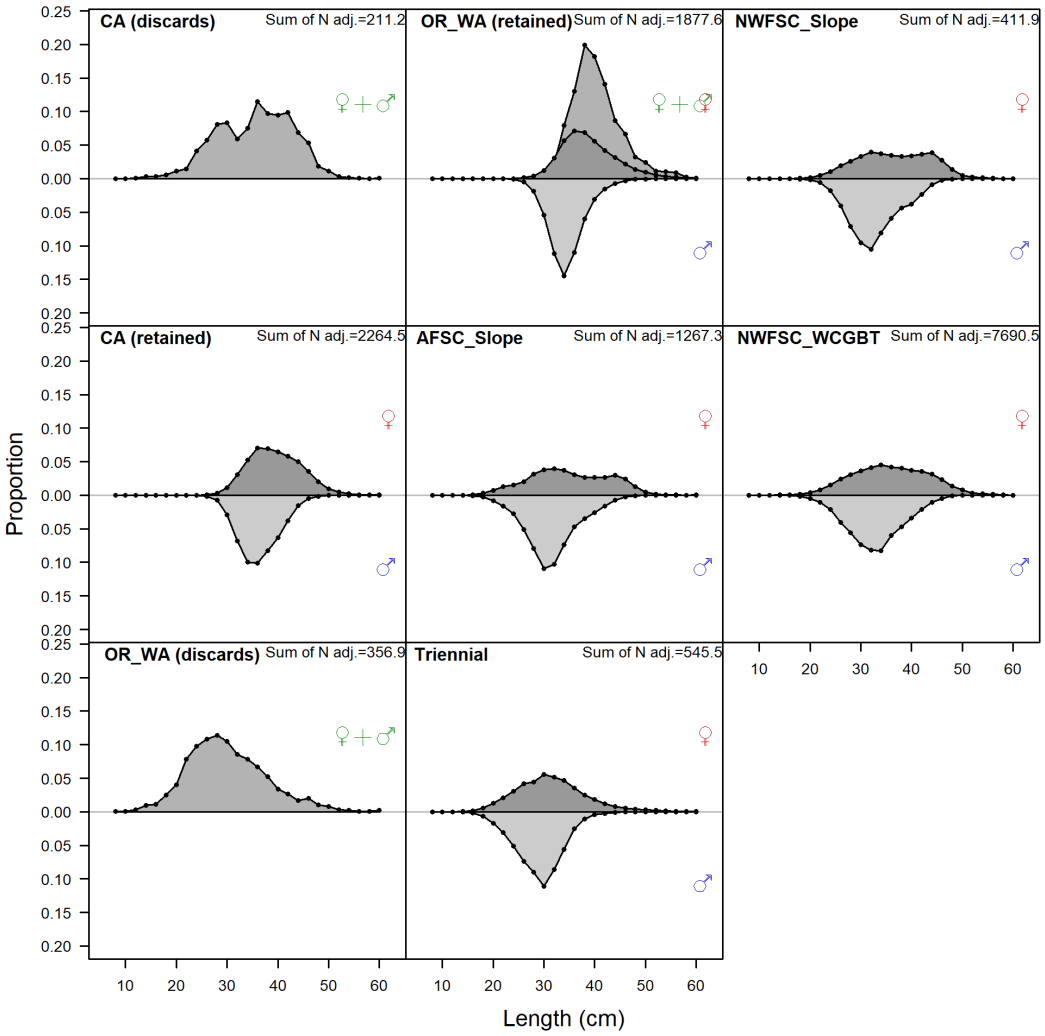


Figure 14: Length composition data aggregated across years by fleet.

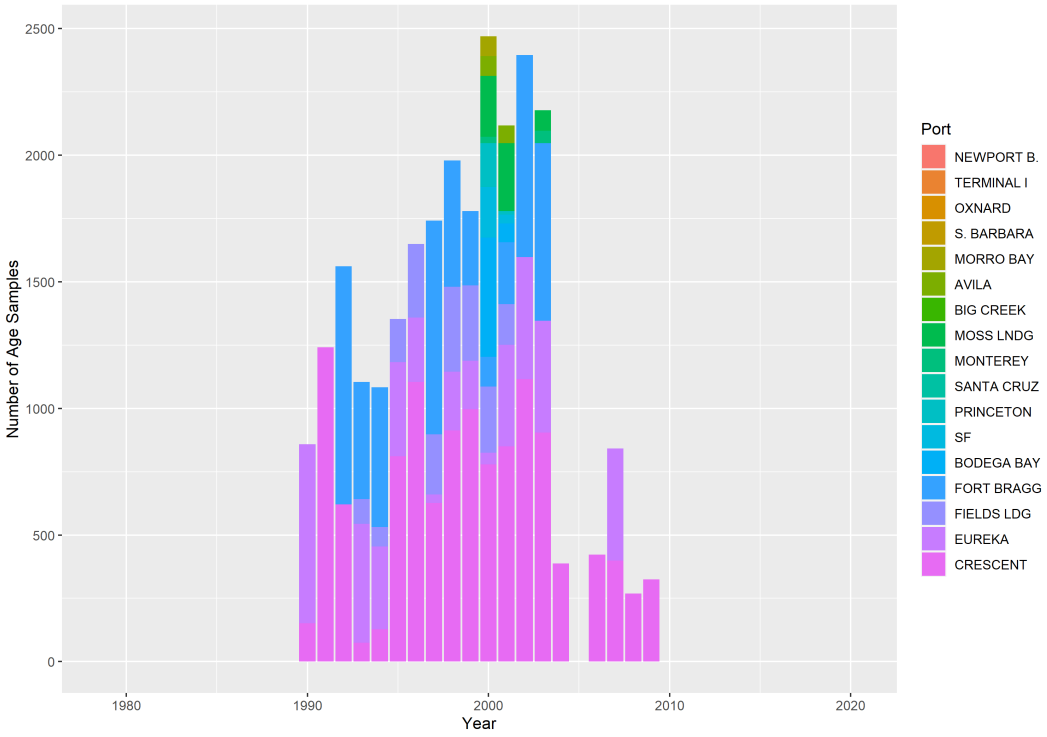


Figure 15: The number of read otoliths samples by port and year from California.

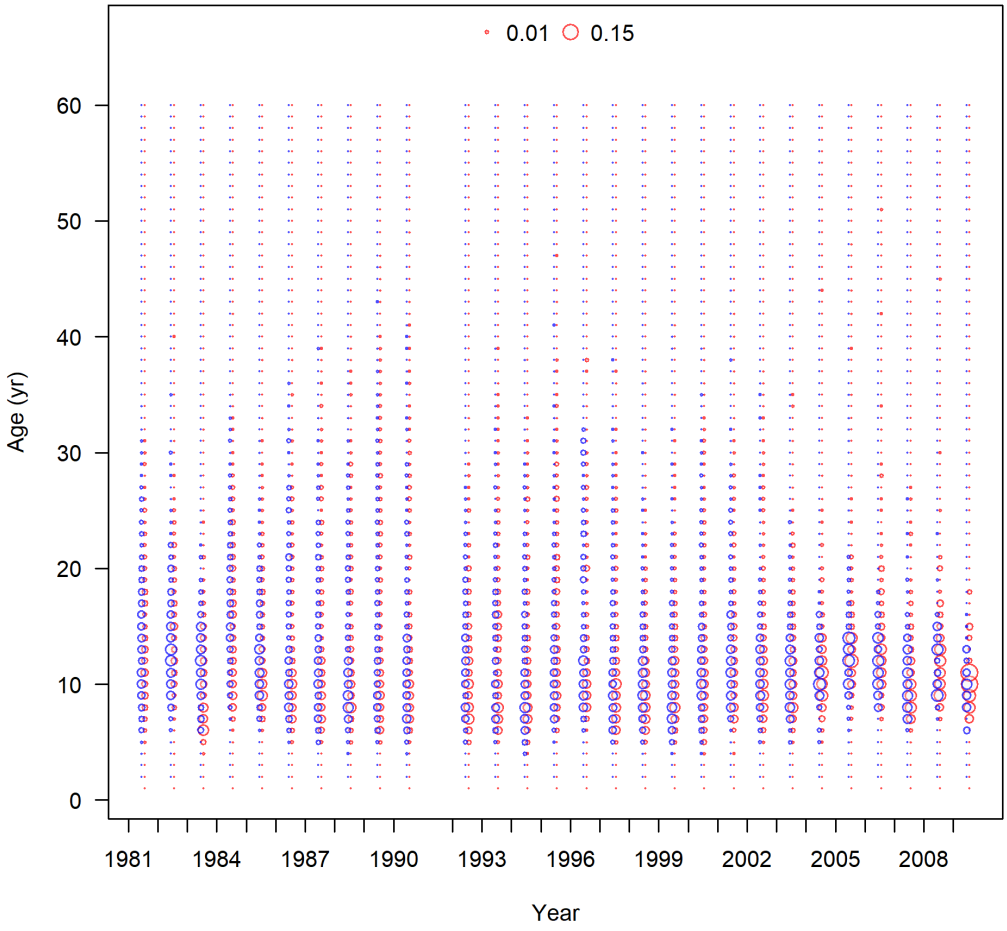


Figure 16: Age composition data from the California commercial fleet.

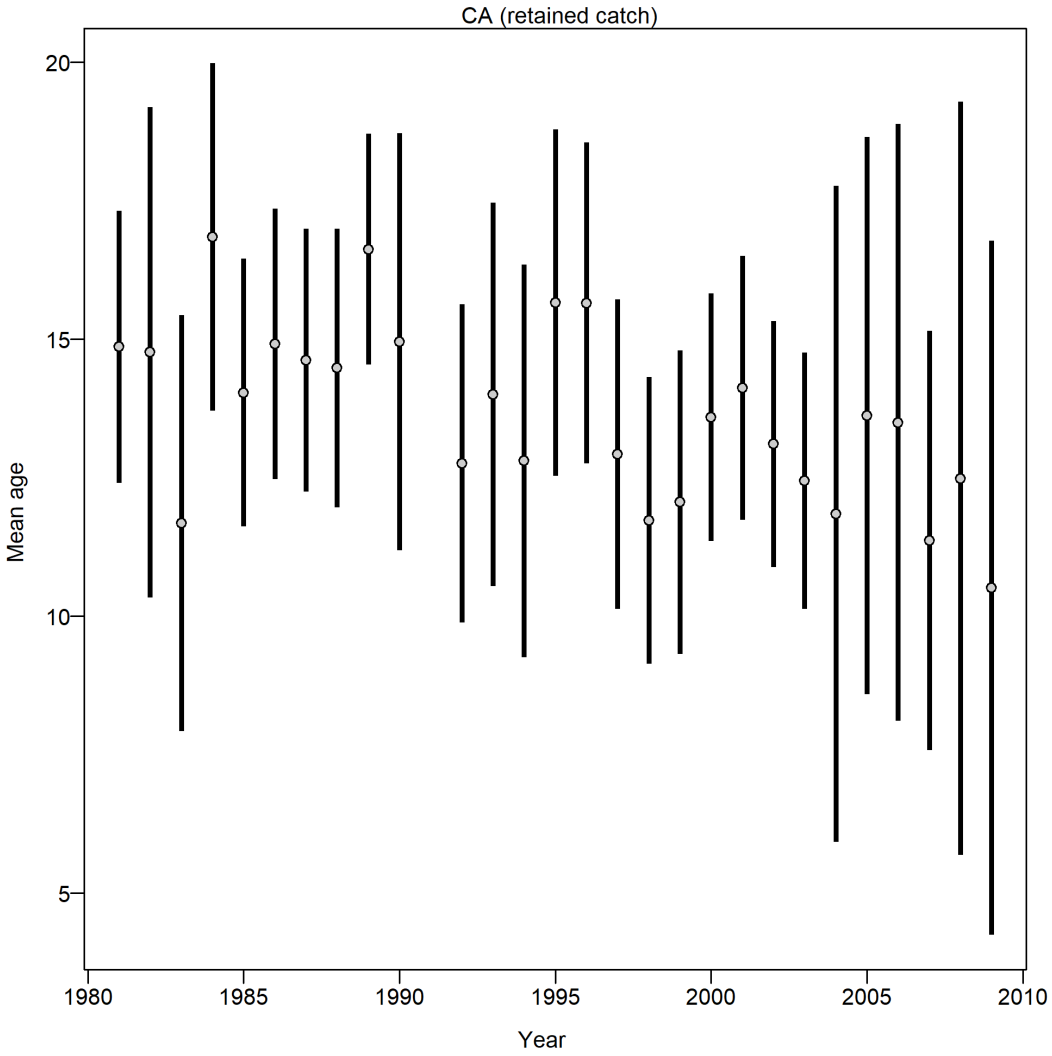


Figure 17: Mean age for California commercial fleet with 95 percent confidence intervals.

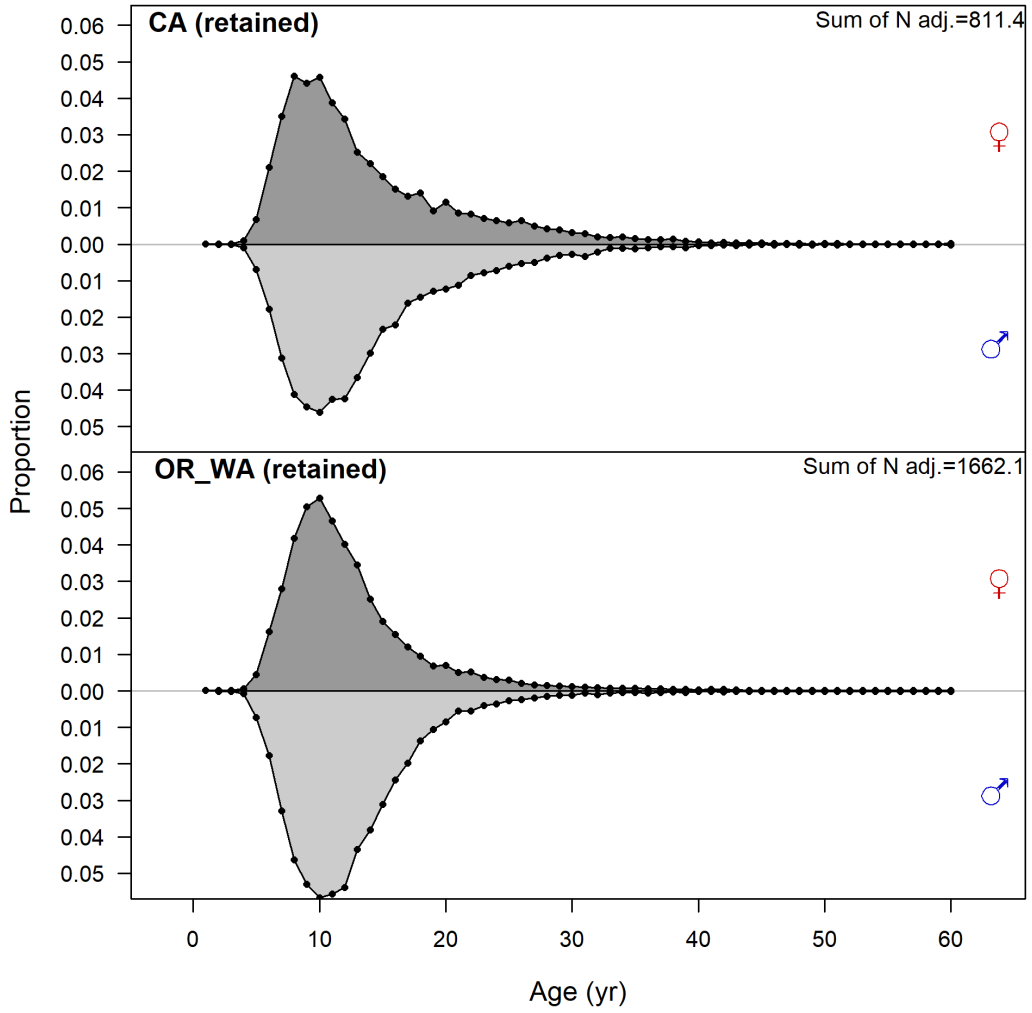


Figure 18: Age composition data aggregated across years by fleet.

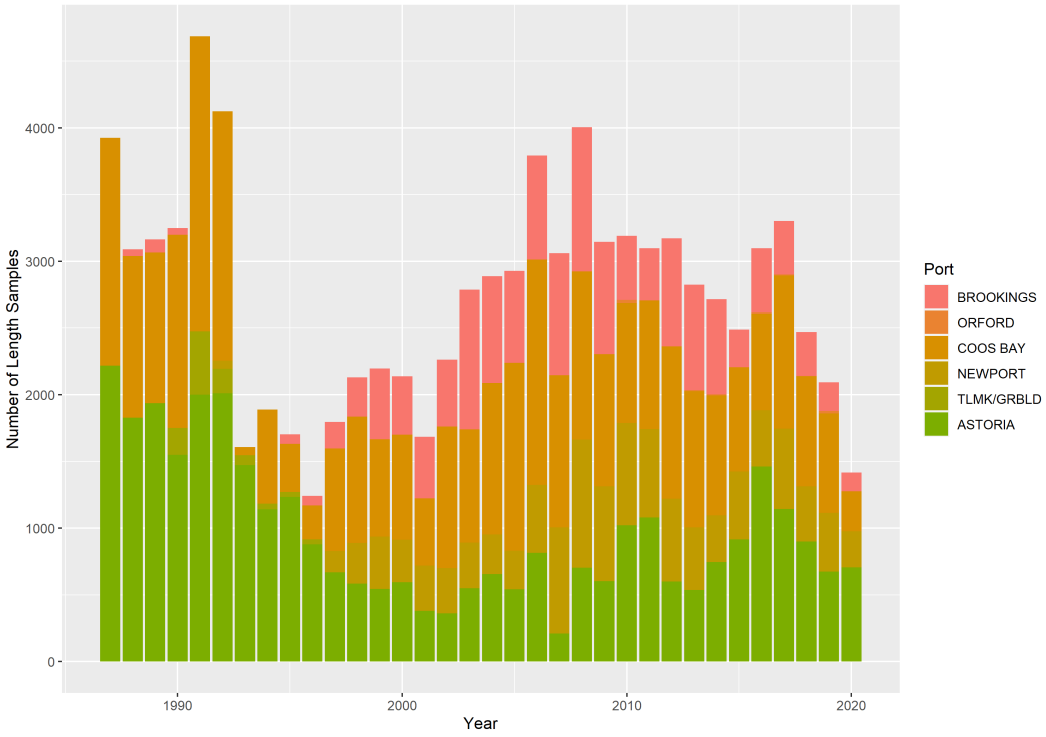


Figure 19: The number of length samples by port and year from Oregon.

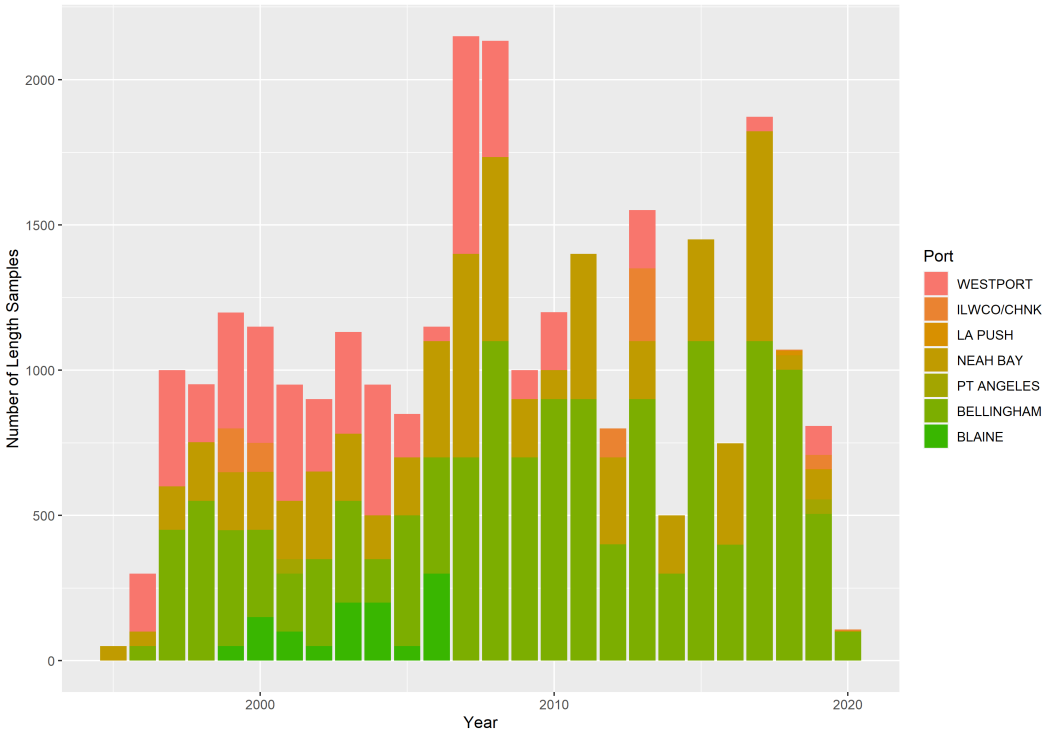


Figure 20: The number of length samples by port and year from Washington.

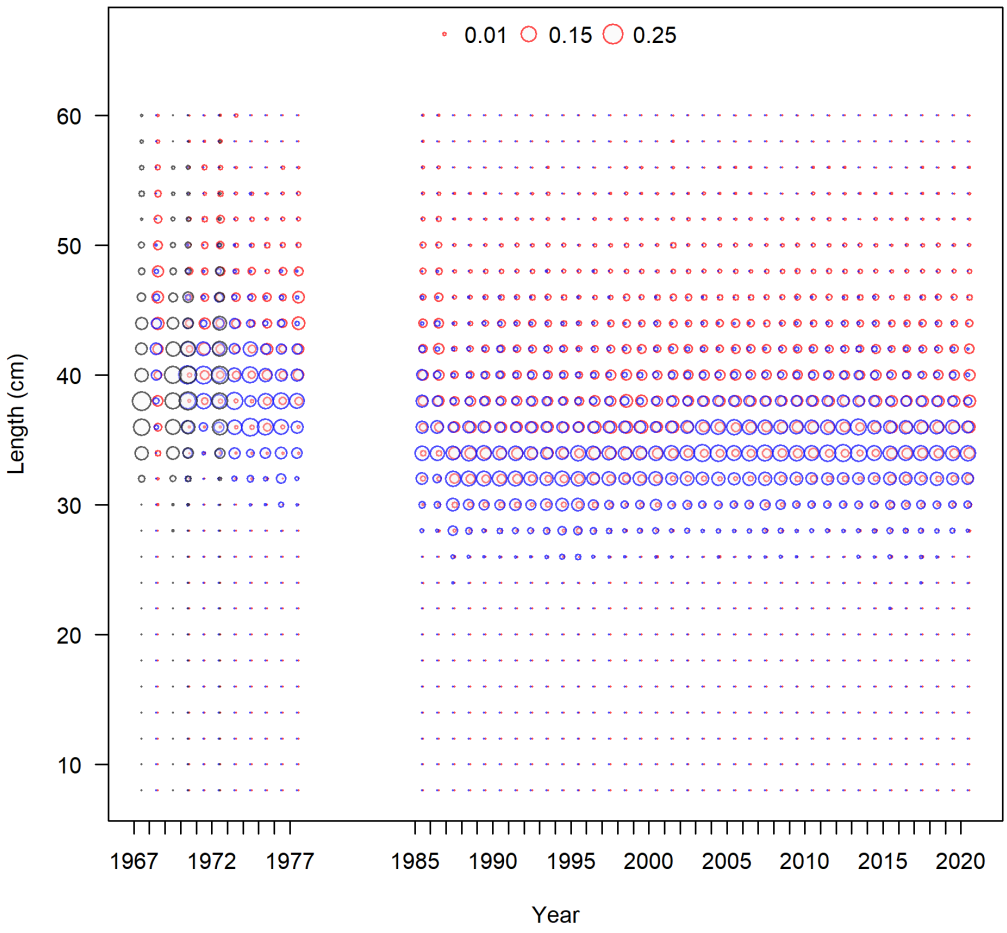


Figure 21: Length composition data from the Oregon/Washington commercial fleet.

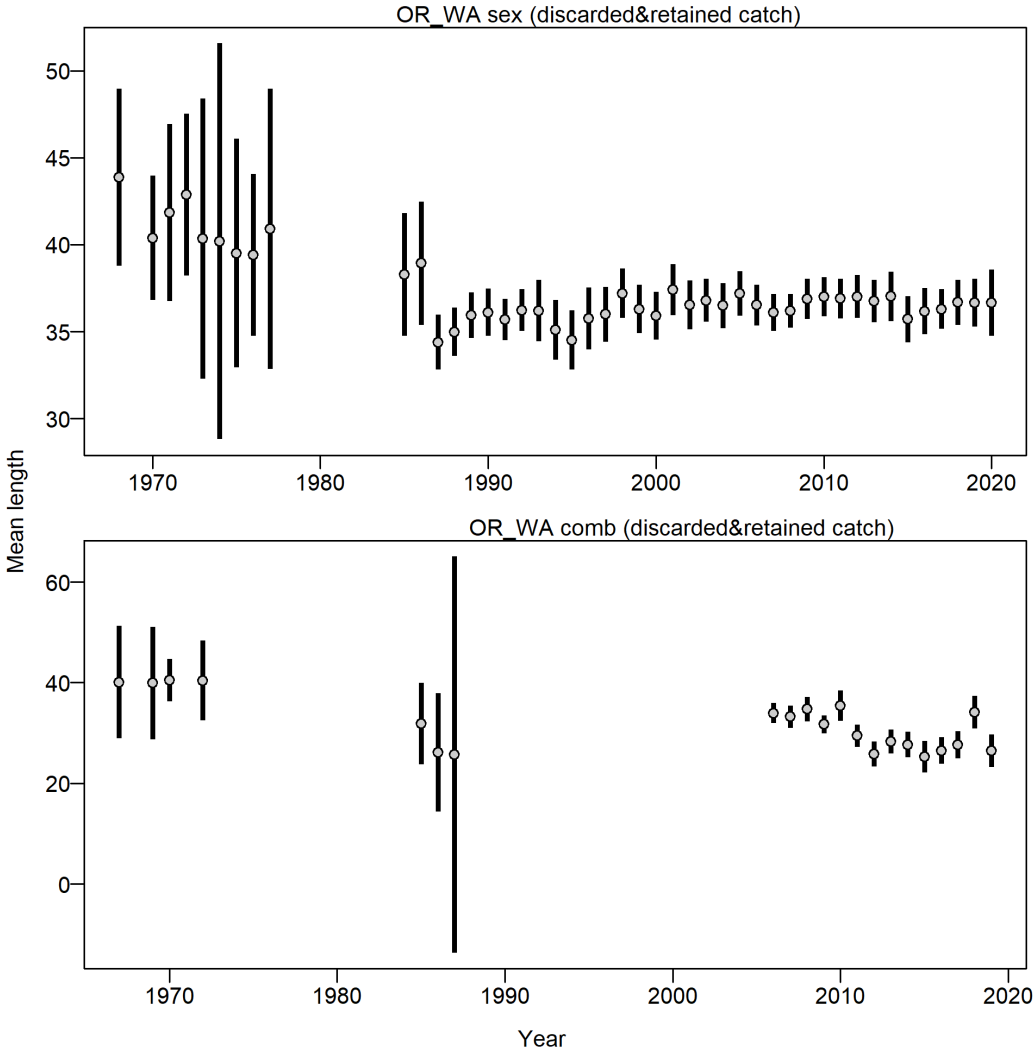


Figure 22: Mean length for Oregon/Washington commercial fleet with 95 percent confidence intervals.

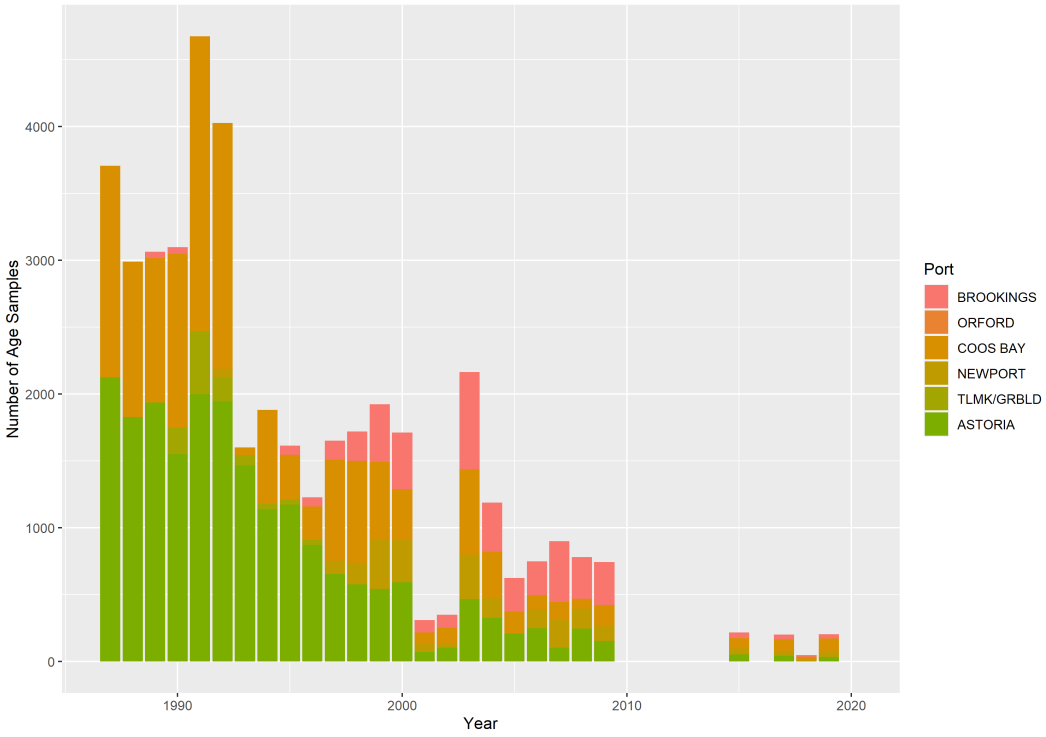


Figure 23: The number of read otoliths samples by port and year from Oregon.

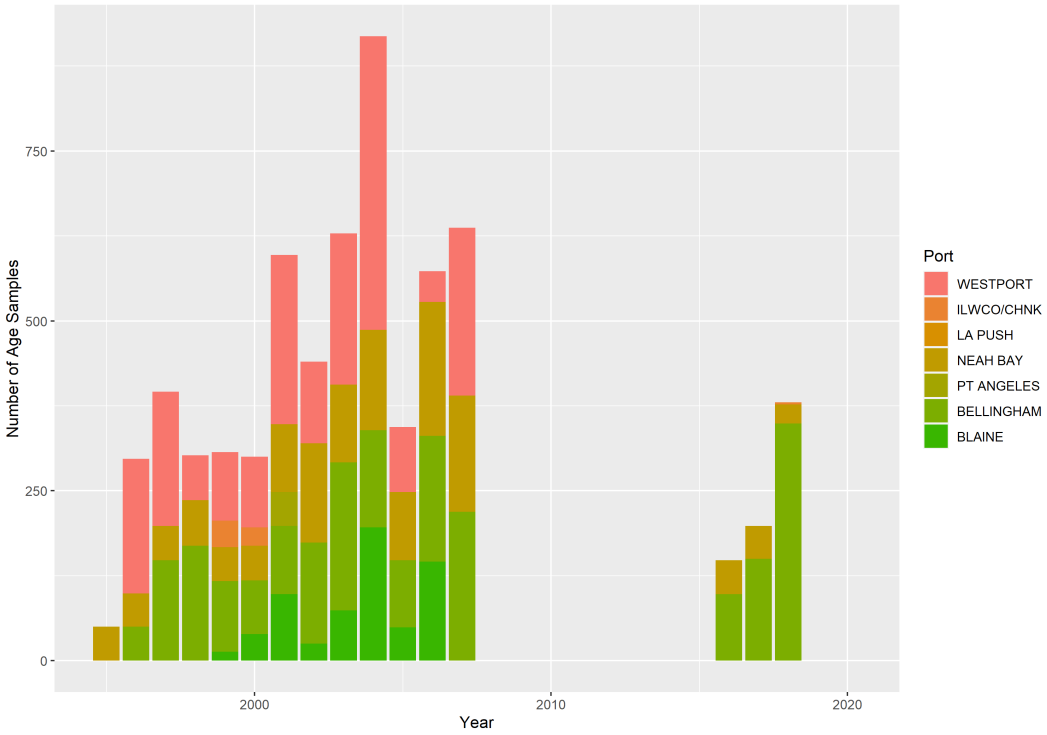


Figure 24: The number of read otoliths samples by port and year from Washington.

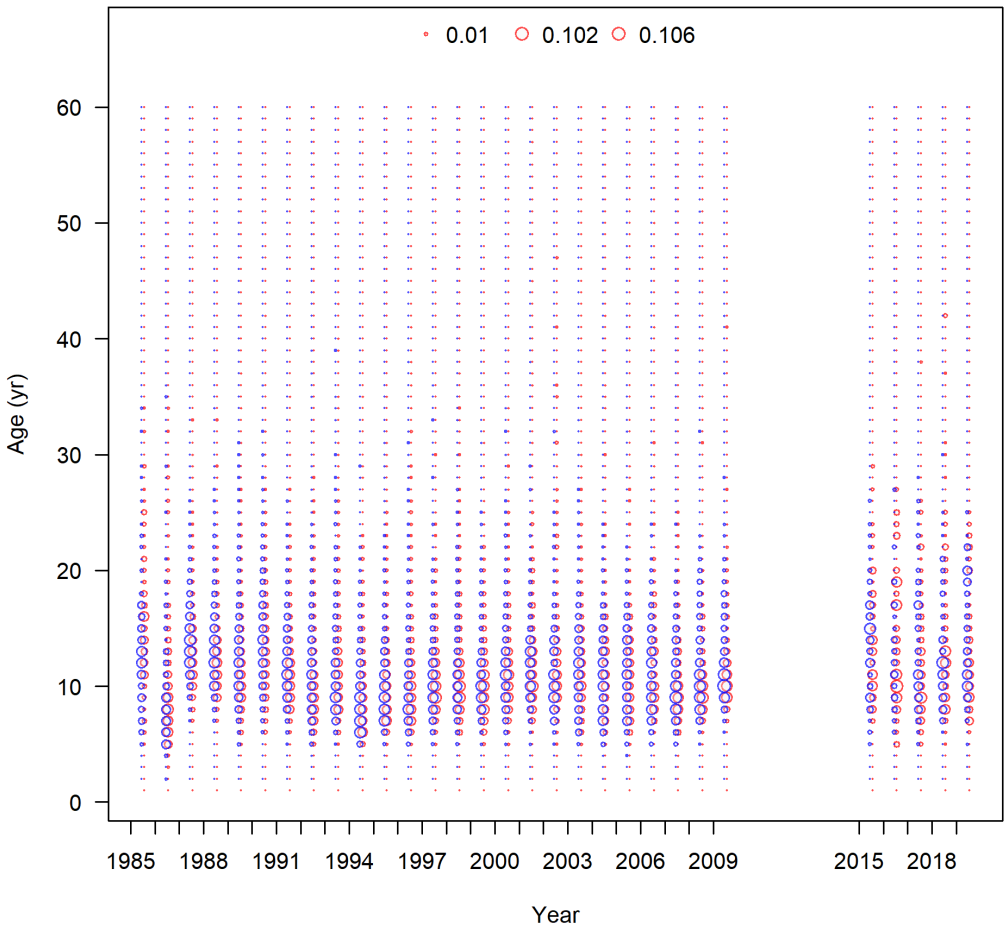


Figure 25: Age composition data from the Oregon/Washington commercial fleet.

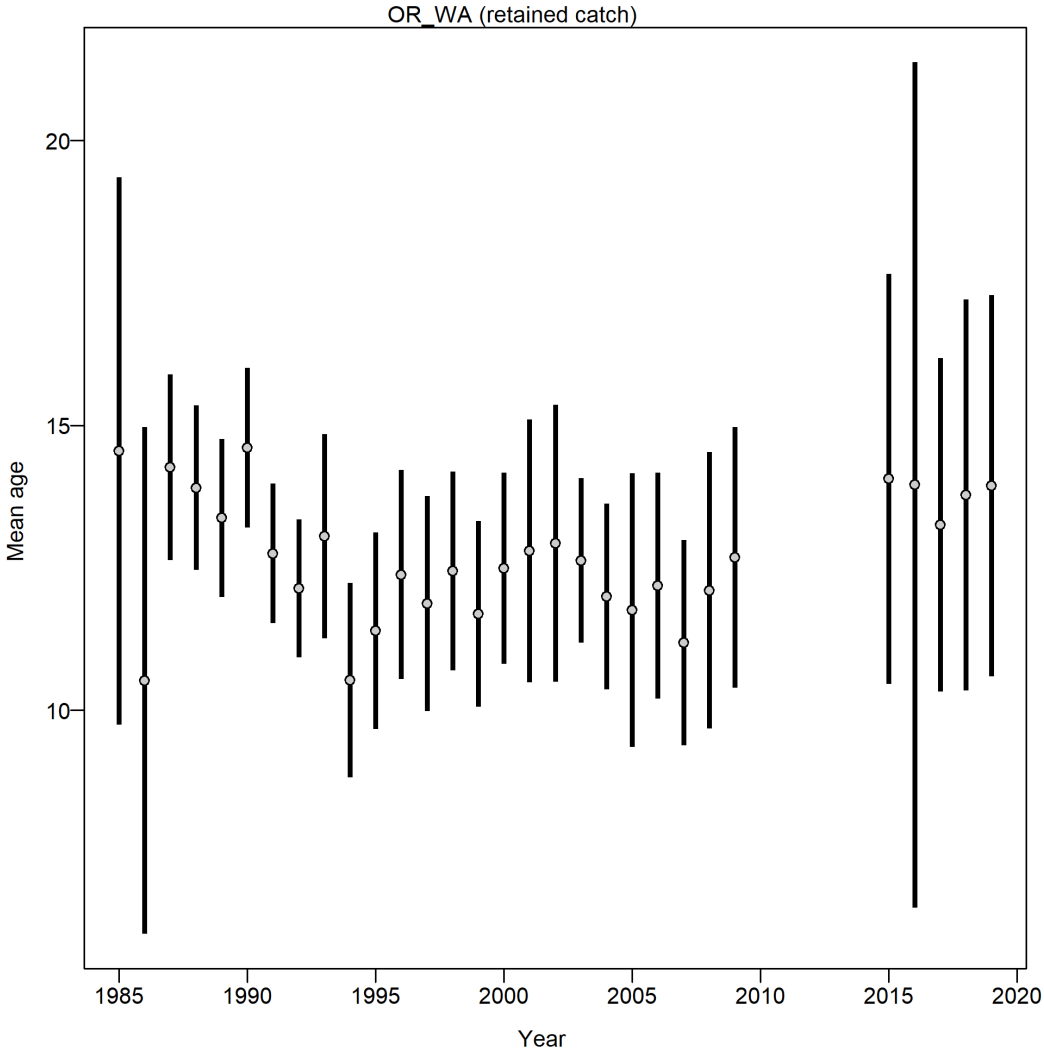


Figure 26: Mean age for Oregon/Washington commercial fleet with 95 percent confidence intervals.

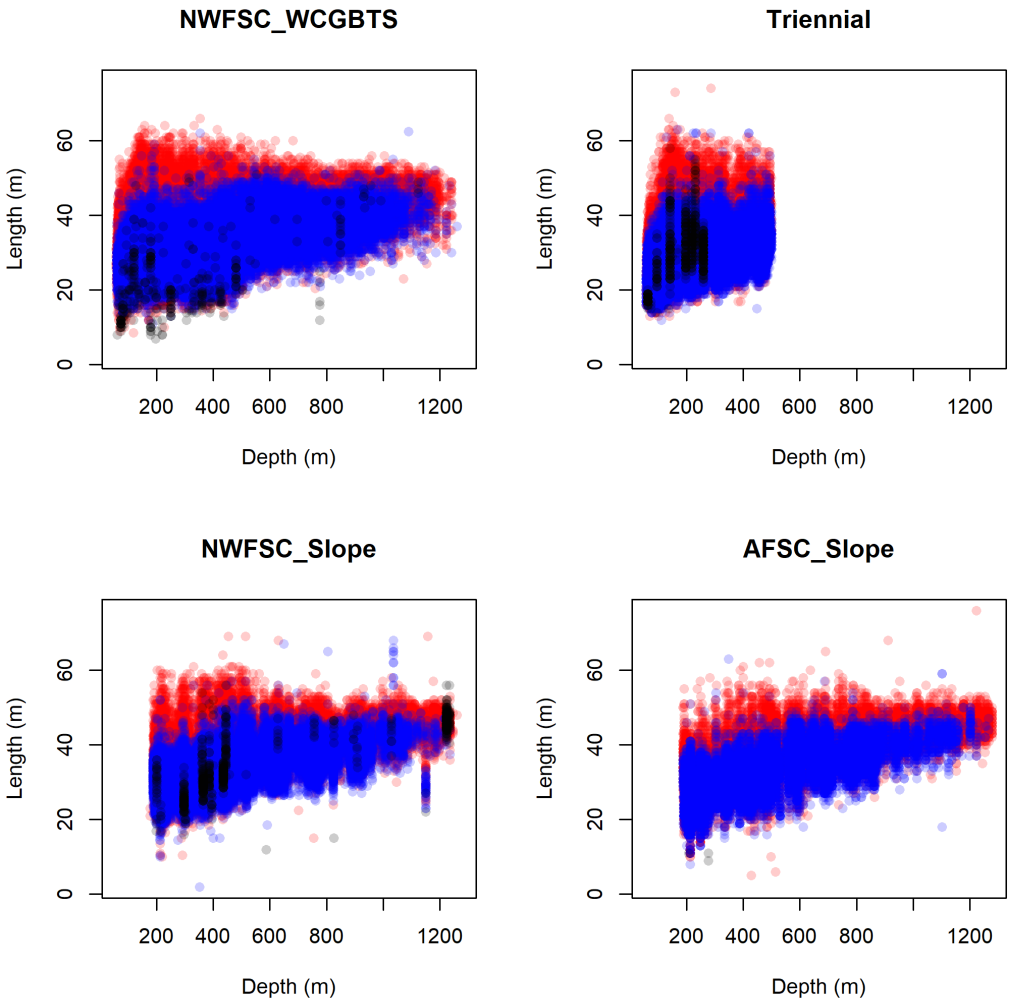


Figure 27: Observed length by depth from each survey by sex (red - females, blue - males) .

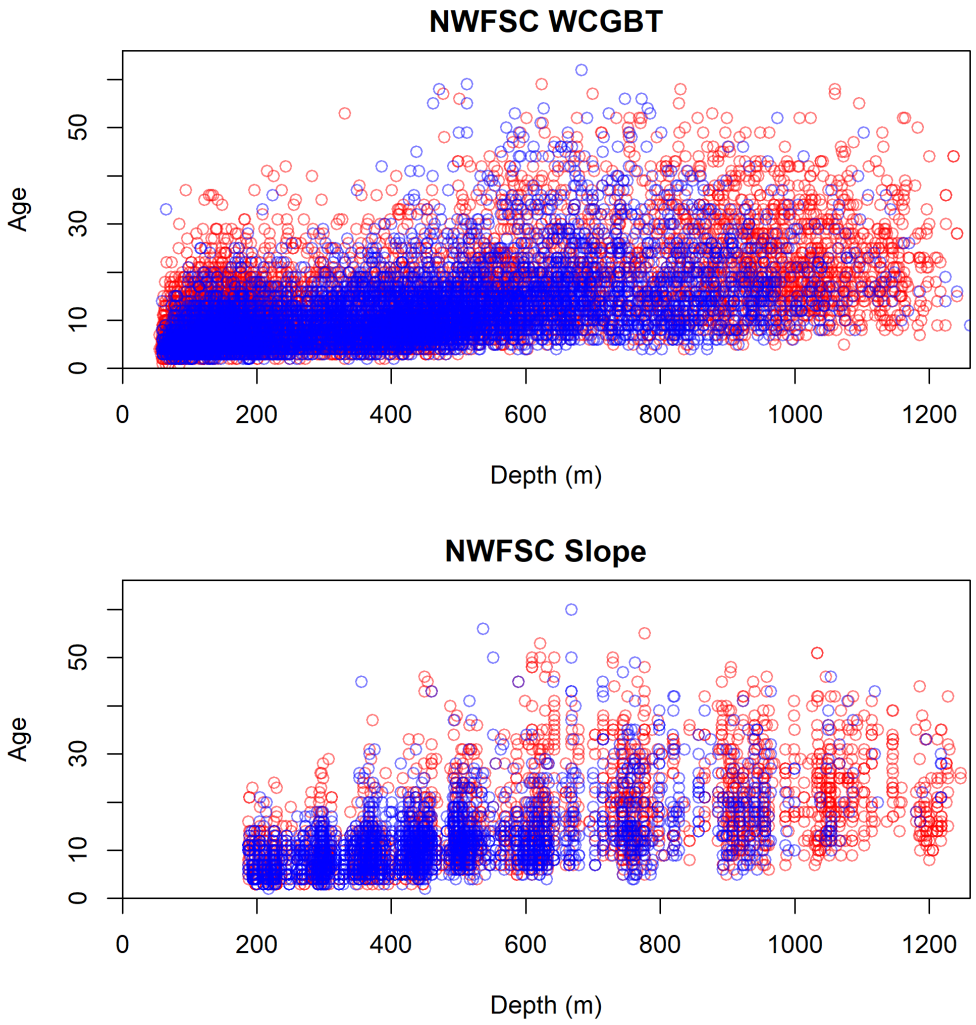


Figure 28: Observed age by depth from the NWFSC Slope Survey and WCGBTS by sex (red - females, blue - males).

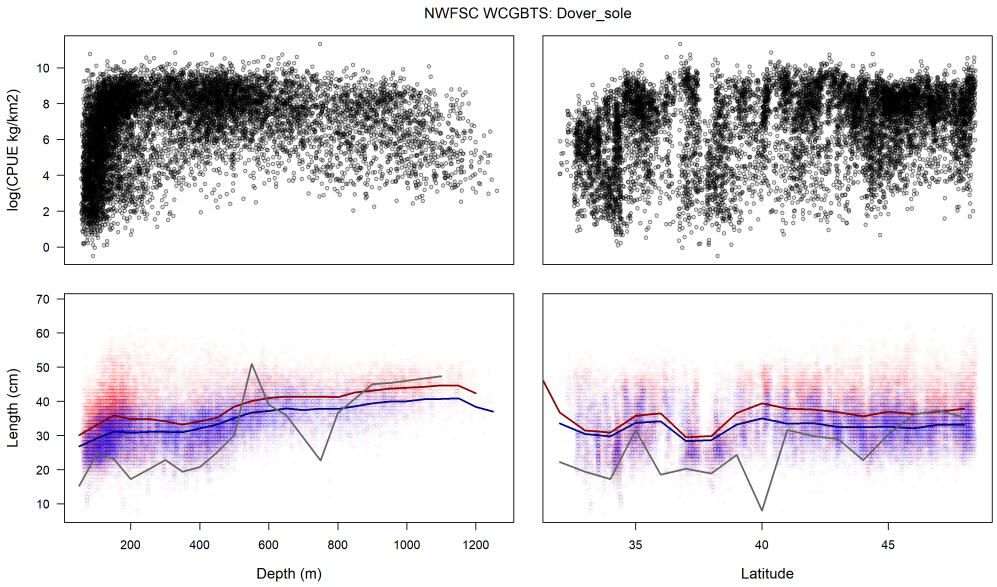


Figure 29: The catch-per-unit-effort (log-scale), lengths by sex observed by depth and latitude for the WCGBTS. The solid lines indicate the average length by depth or latitude by sex (red - females, blue - males, grey - unsexed).

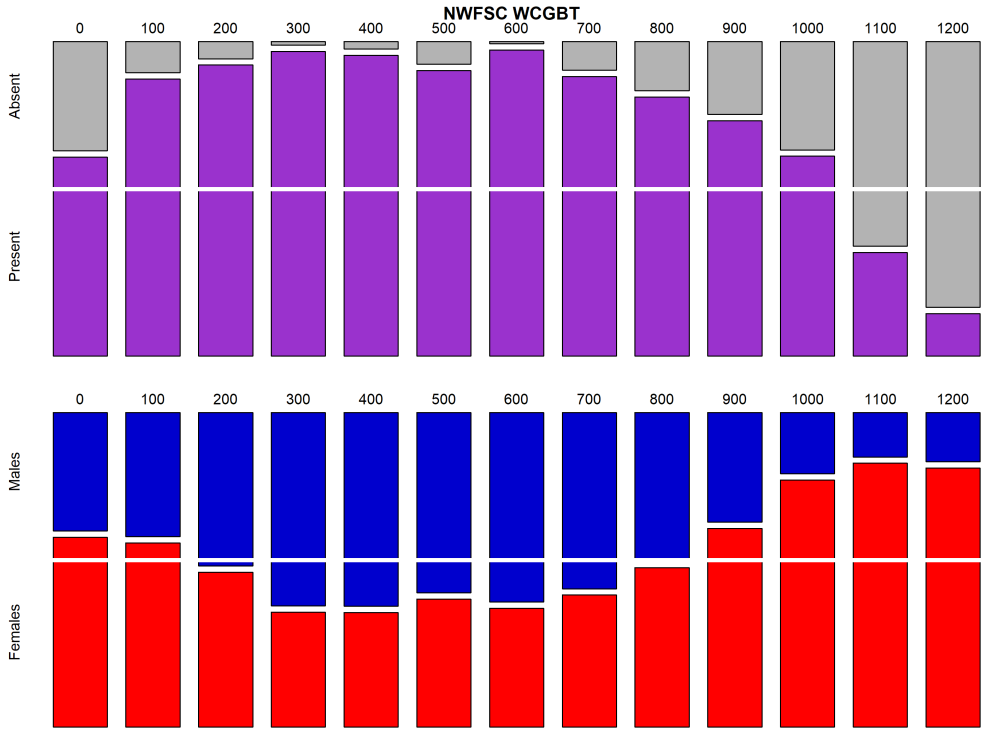


Figure 30: Observed proportion of positive tows (tows that observed Dover sole, top panel) where positive tows are purple and negative tows are grey and sex ratio (red - females, blue - males, bottom panel) by depth bins (m) from the WCGBTS where the horizontal while line indicates 0.50.

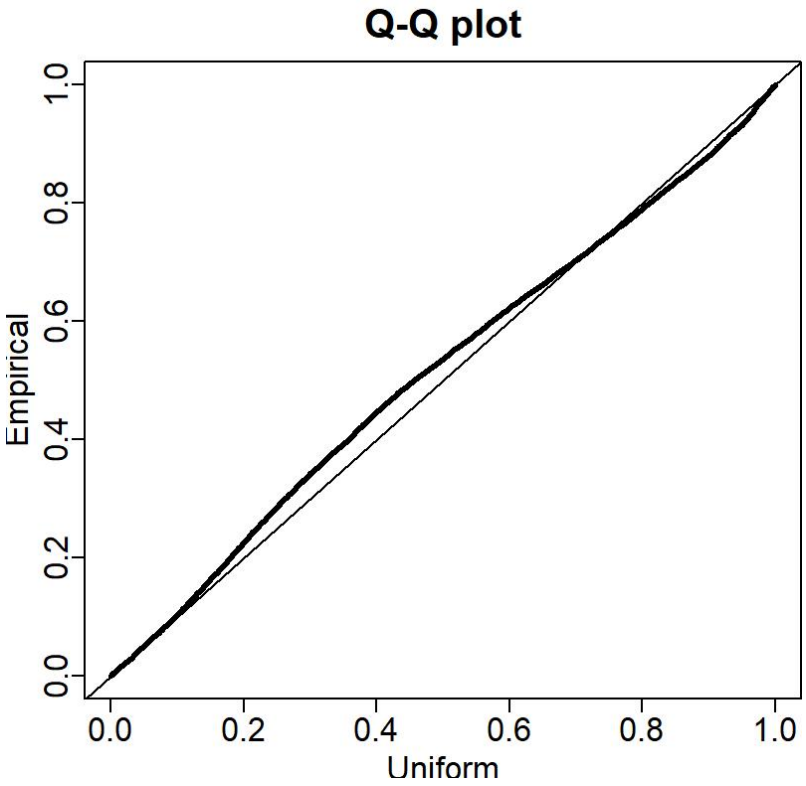


Figure 31: Q-Q and diagnostics for the WCGBTS.

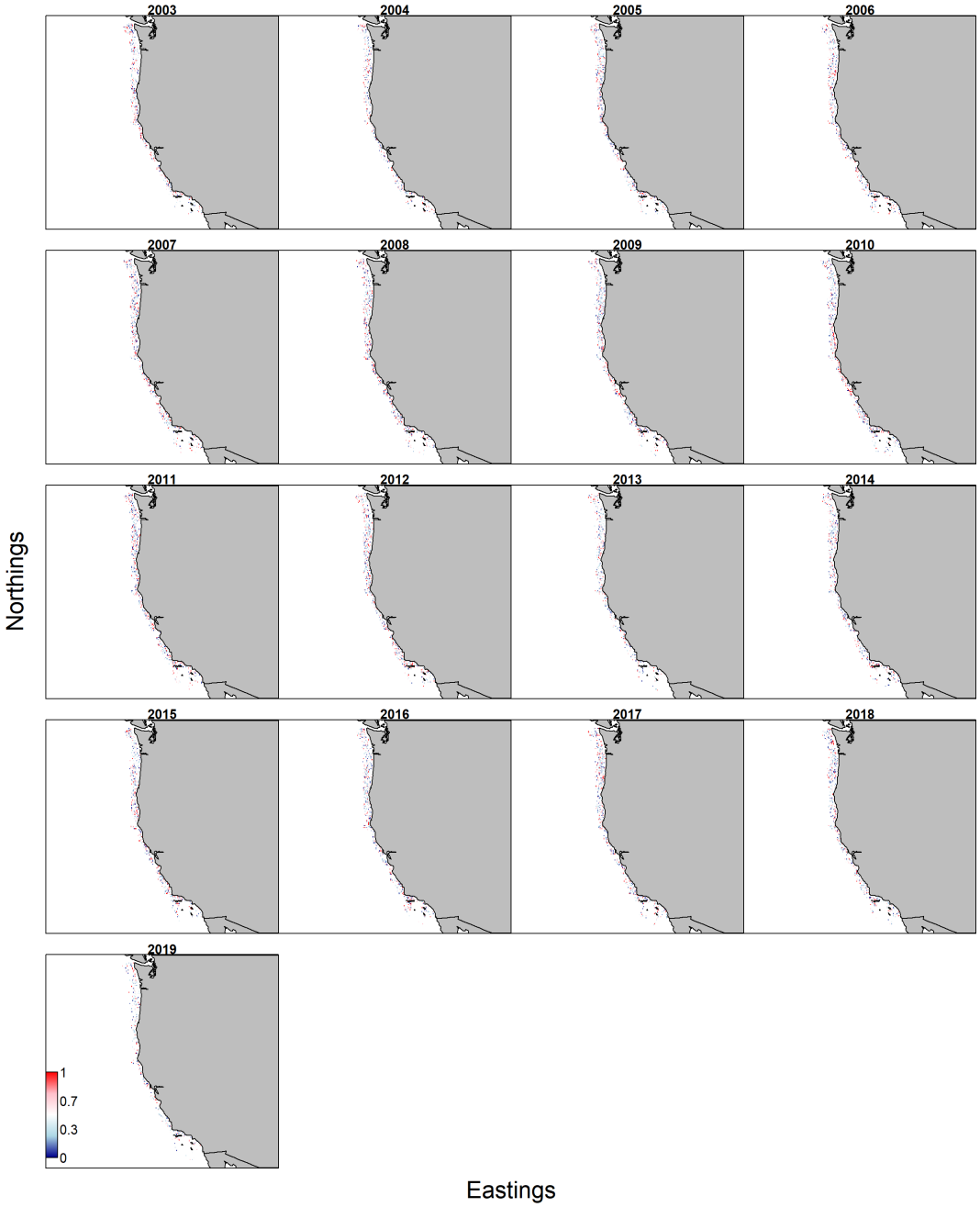


Figure 32: Residuals for the WCGBTS index.

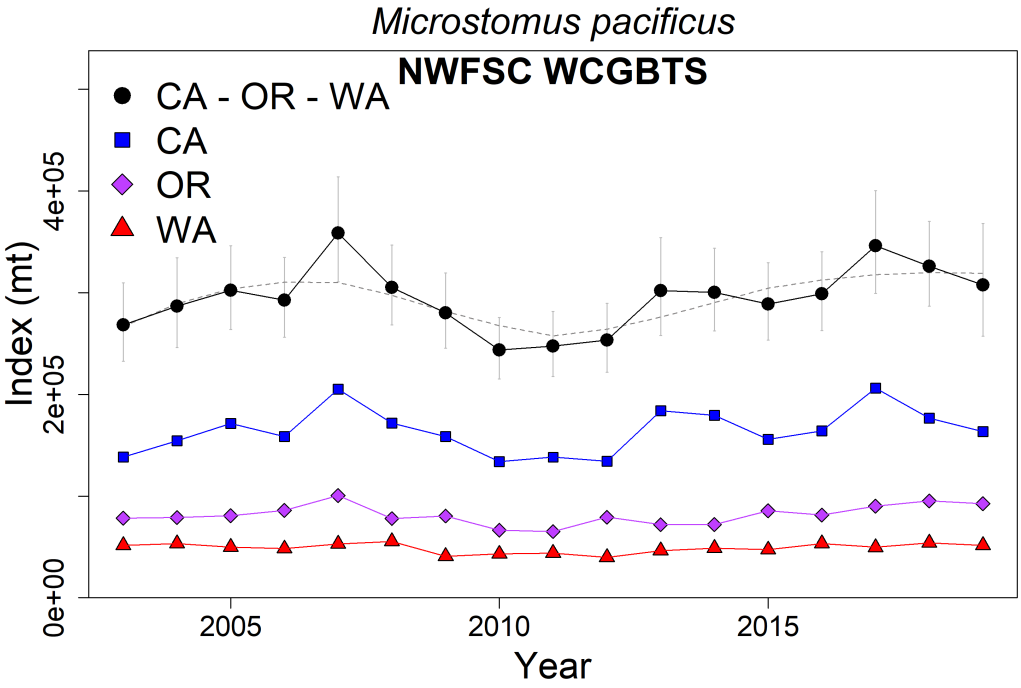


Figure 33: The estimated index of abundance for the WCGBTS (coastwide - black line with circles). A loess soother line was fit to the data series and is denoted by the grey dashed line.

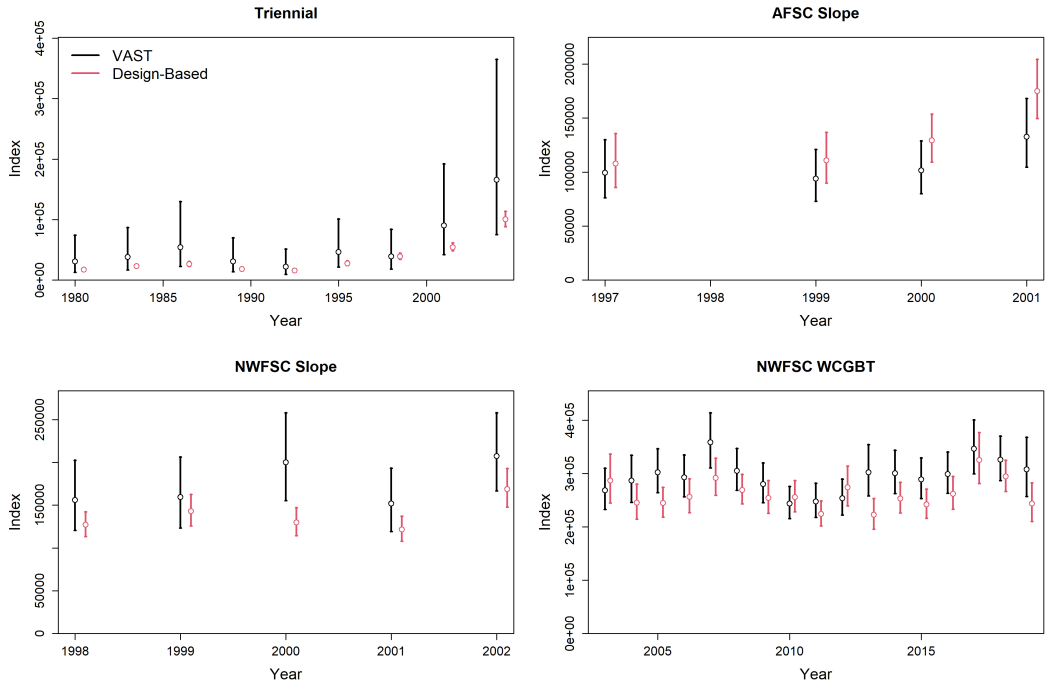


Figure 34: VAST based indices compared to the design-based indices for each fleet.

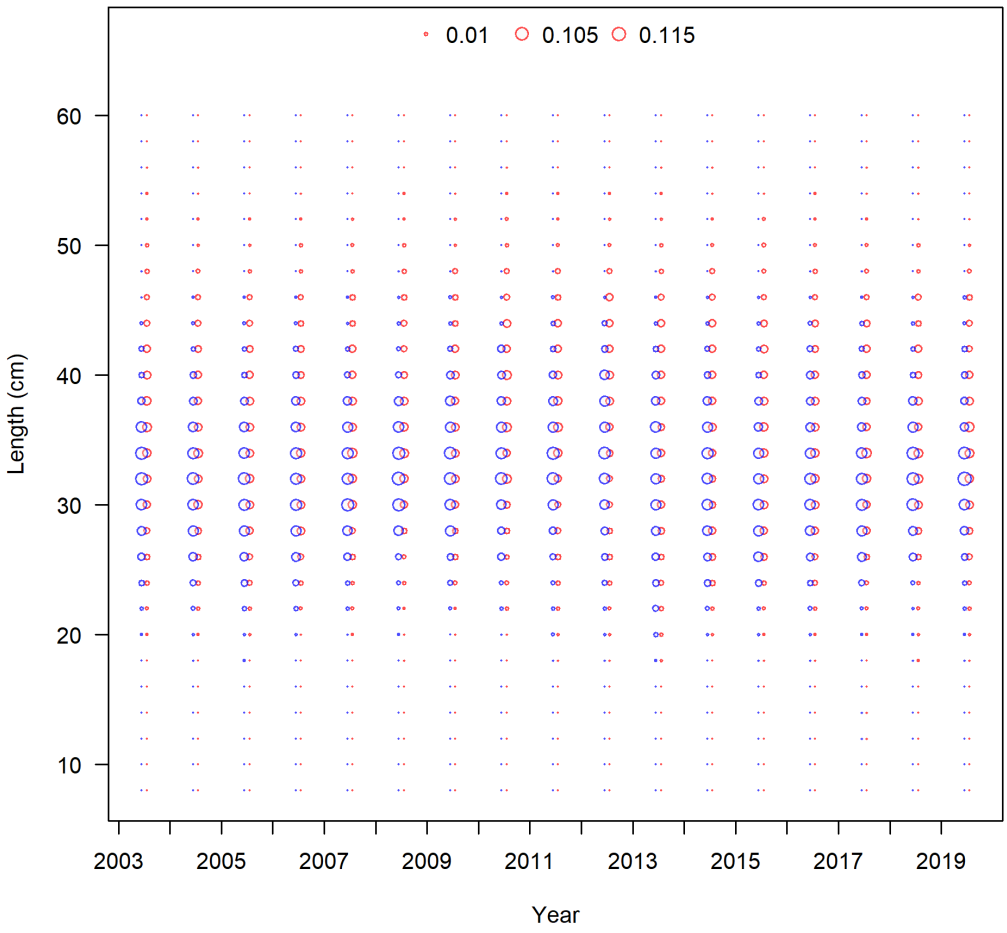


Figure 35: Length composition data from the WCGBTS.

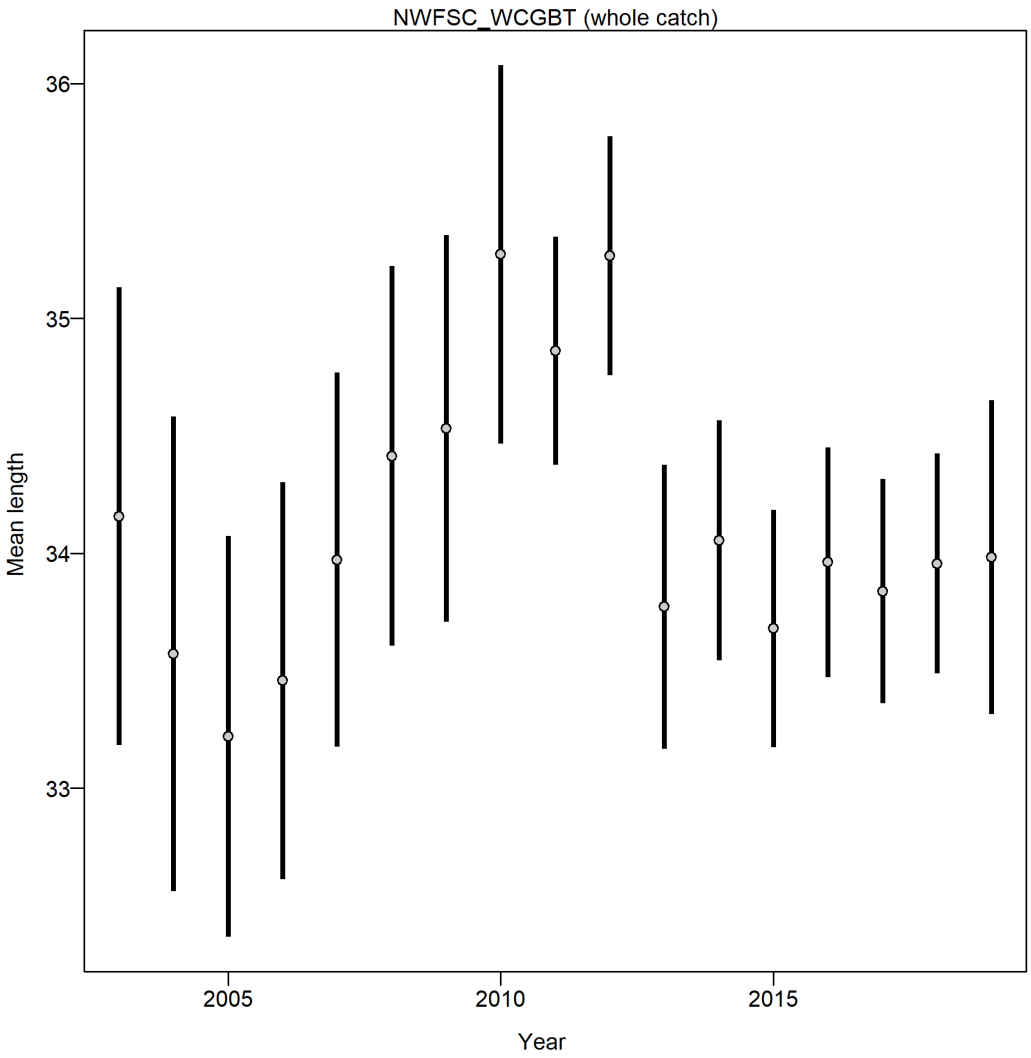


Figure 36: Mean length for WCGBTS with 95 percent confidence intervals.

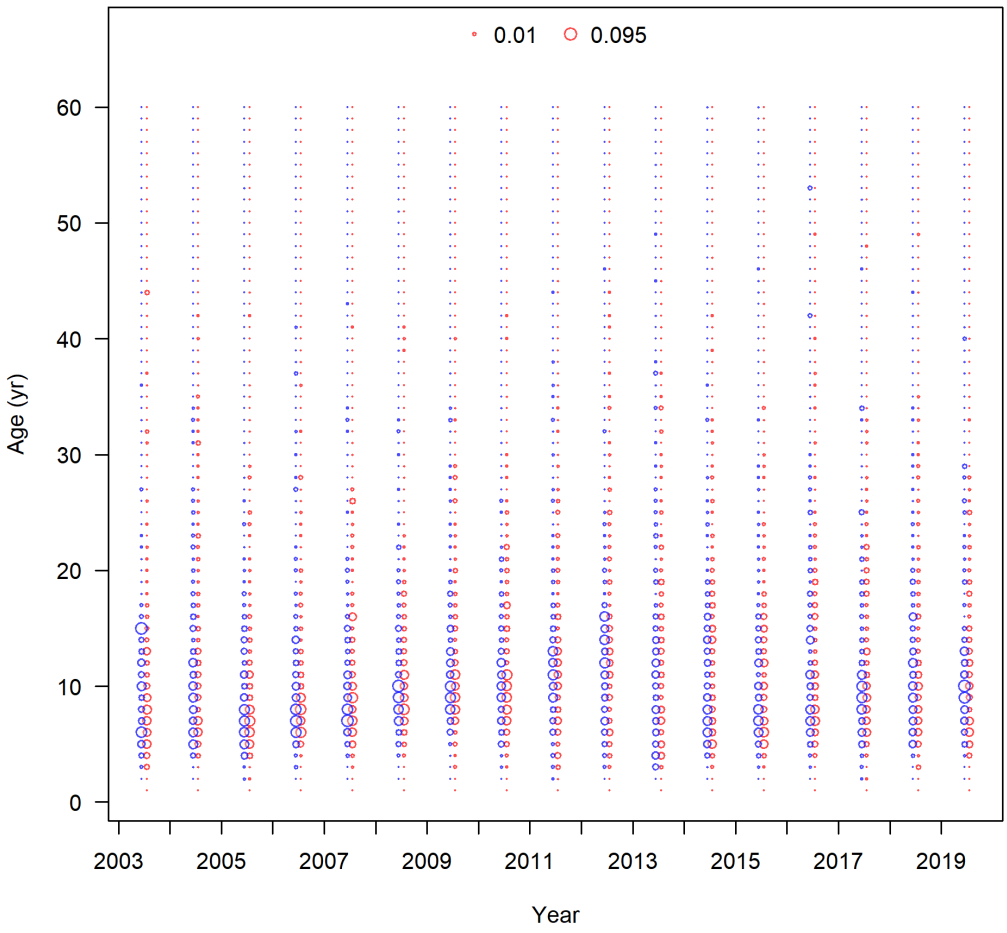


Figure 37: Age composition data from the WCGBTS.

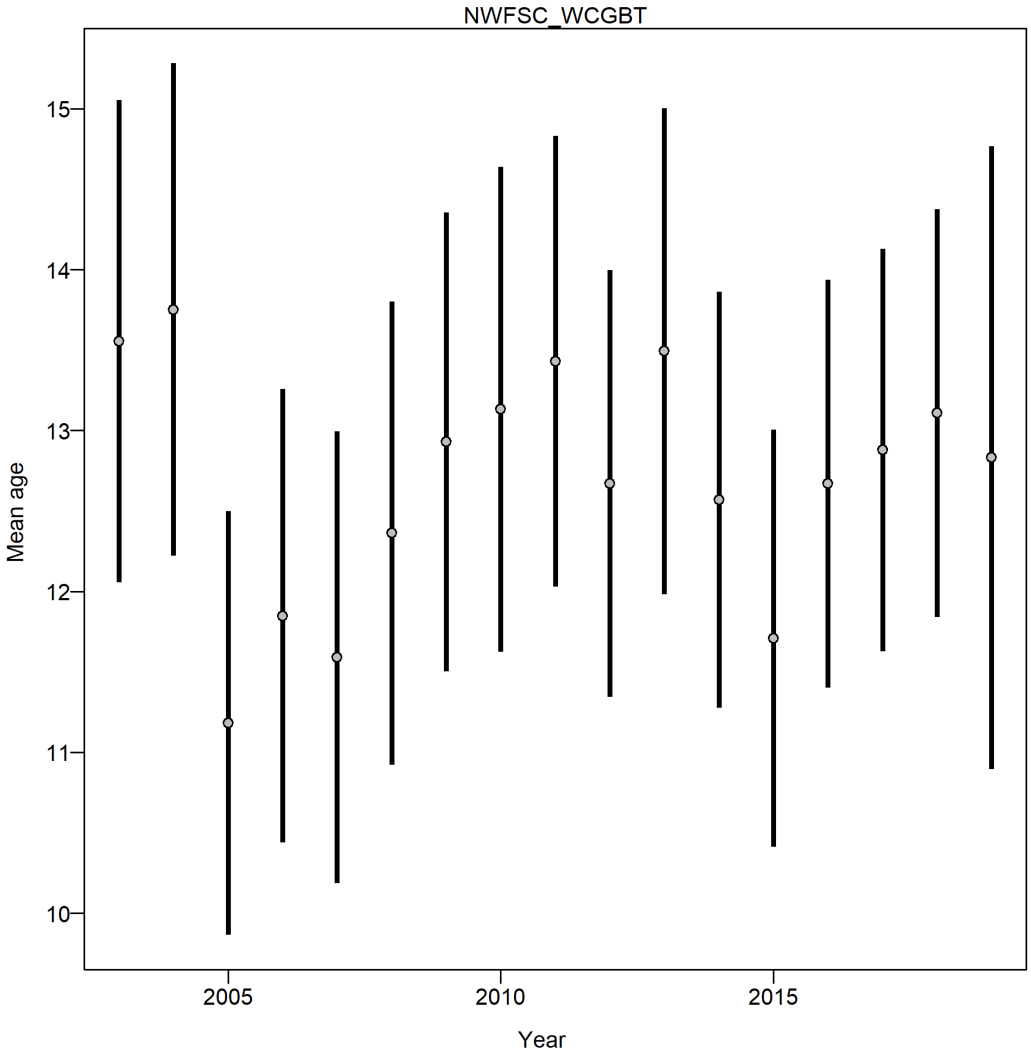


Figure 38: Mean age for WCGBTS with 95 percent confidence intervals.

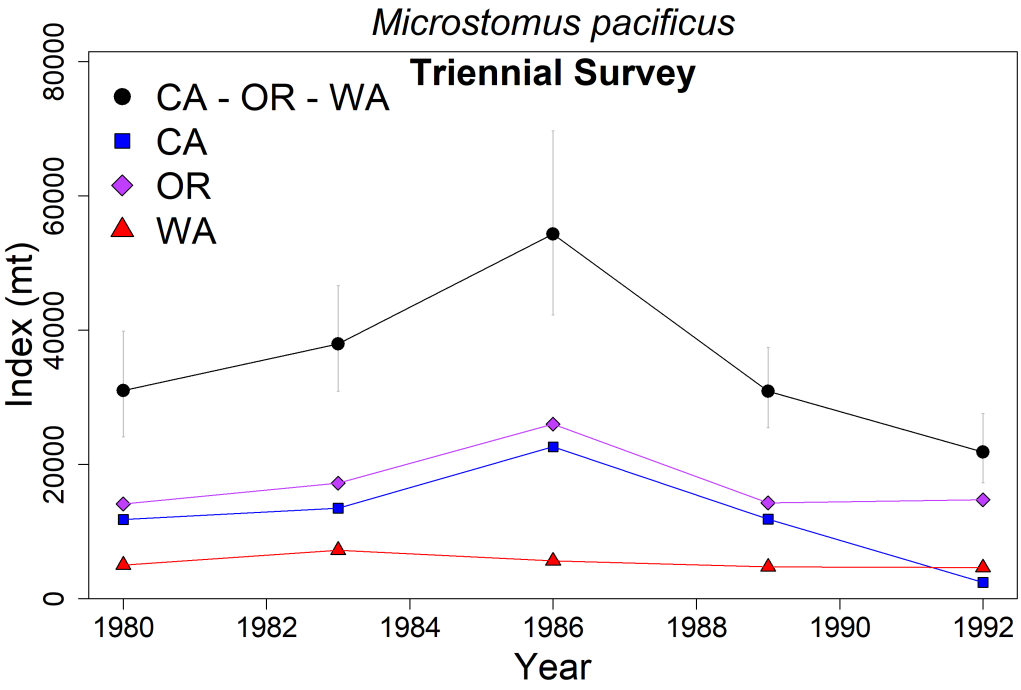


Figure 39: The estimated index of abundance for the early Triennial survey (coastwide - black line with circles). A loess soother line was fit to the data series and is denoted by the grey dashed line.

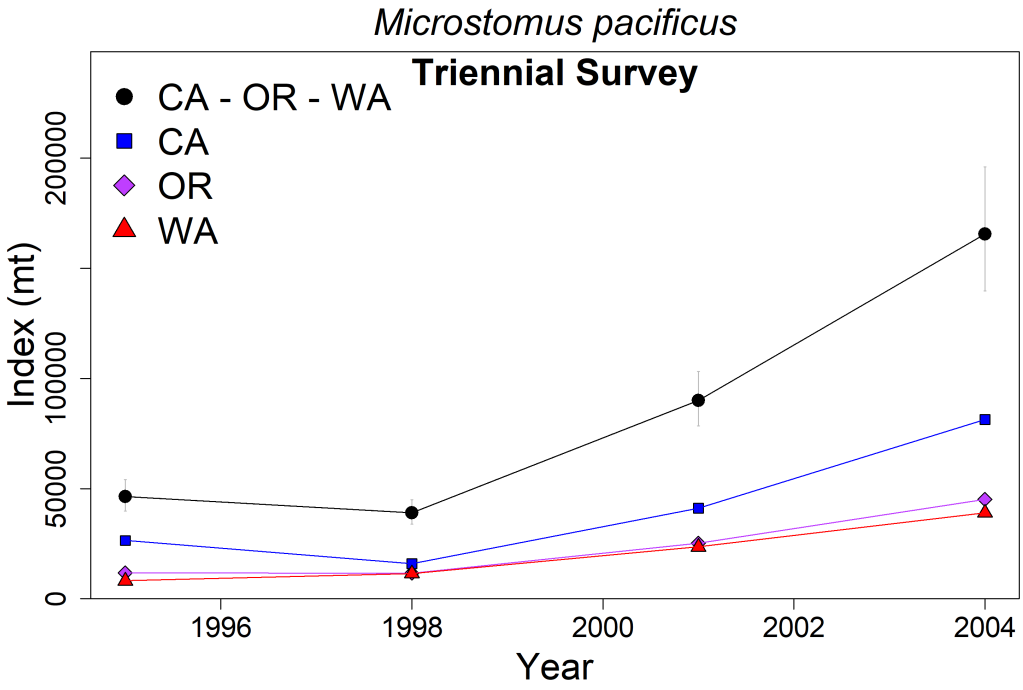


Figure 40: The estimated index of abundance for the late Triennial survey (coastwide - black line with circles). A loess soother line was fit to the data series and is denoted by the grey dashed line.

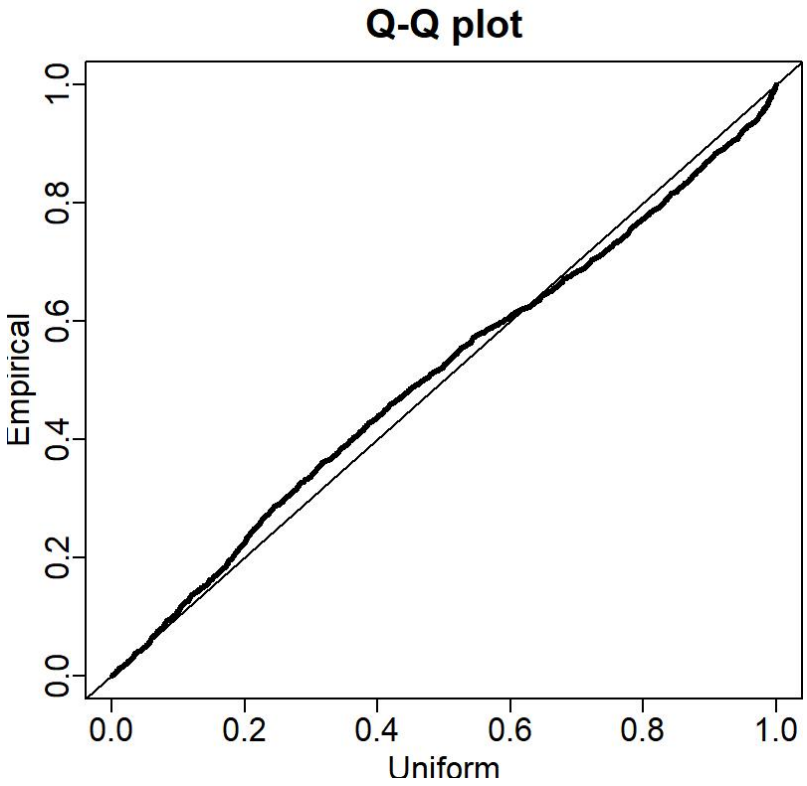


Figure 41: Q-Q and diagnostics for the early Triennial survey (1980 - 1992).

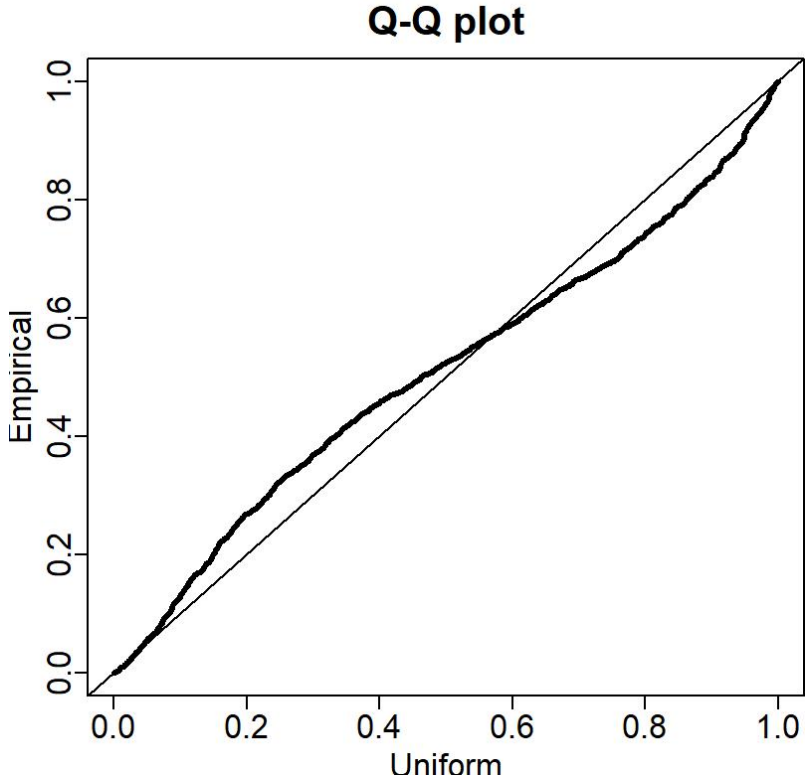


Figure 42: Q-Q and diagnostics for the late Triennial survey (1995 - 2004).

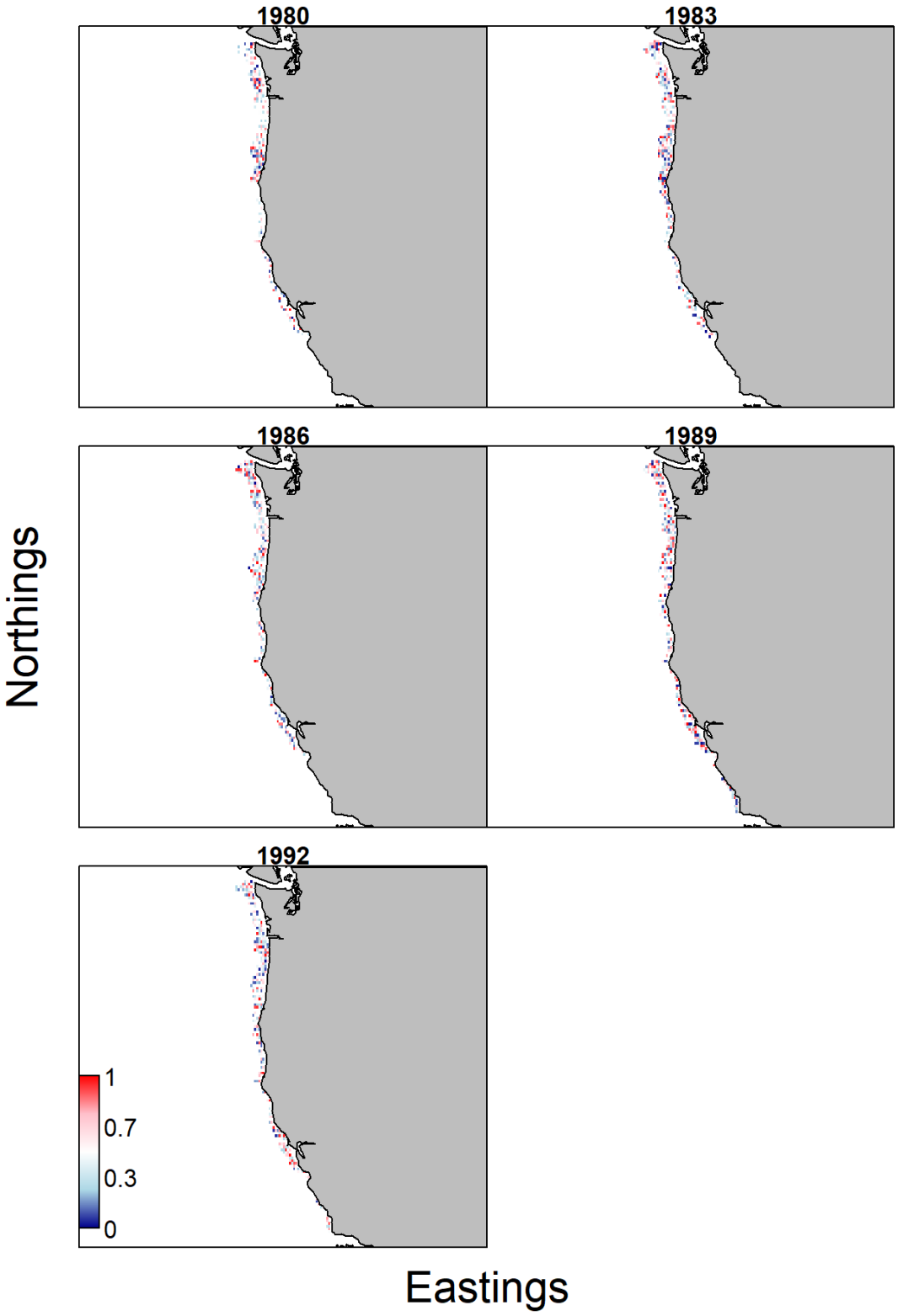


Figure 43: Residuals for the early Triennial survey.

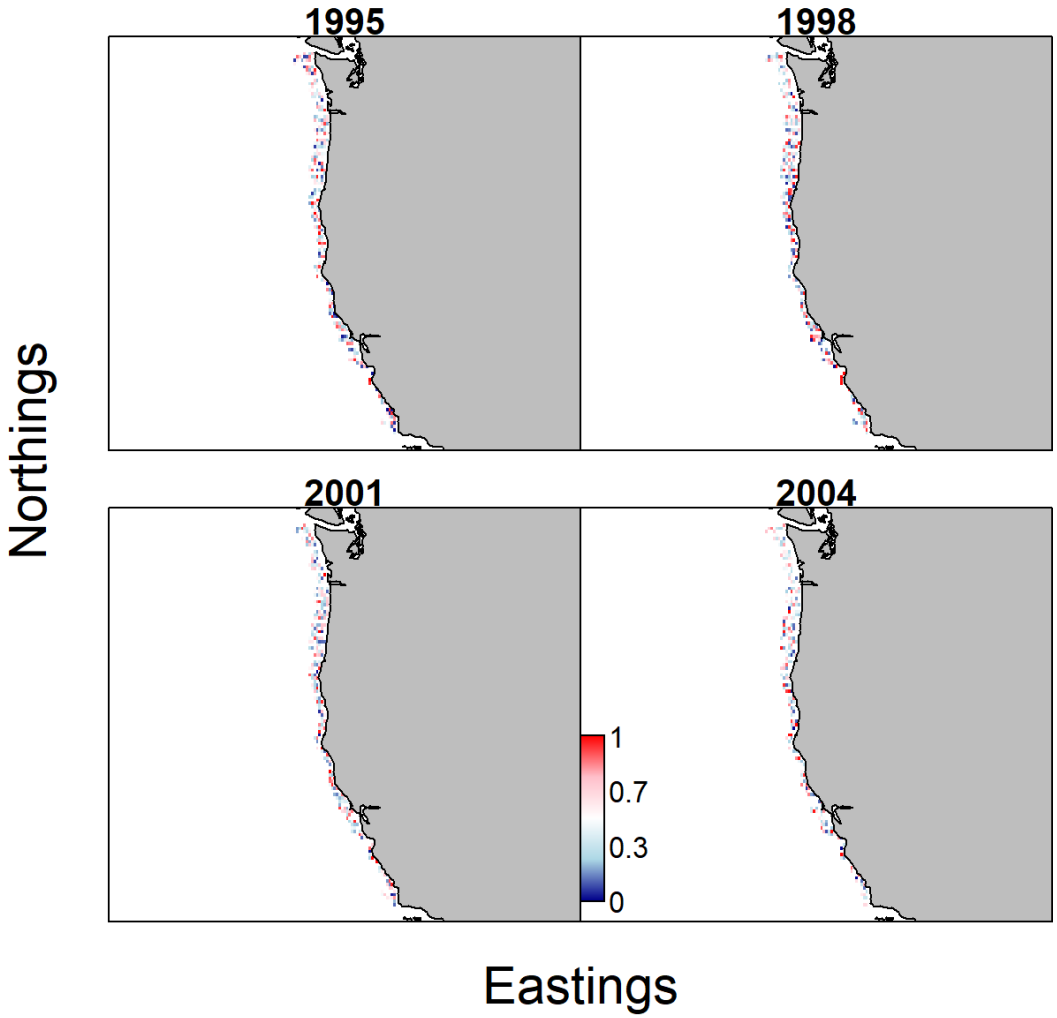


Figure 44: Residuals for the late Triennial survey.

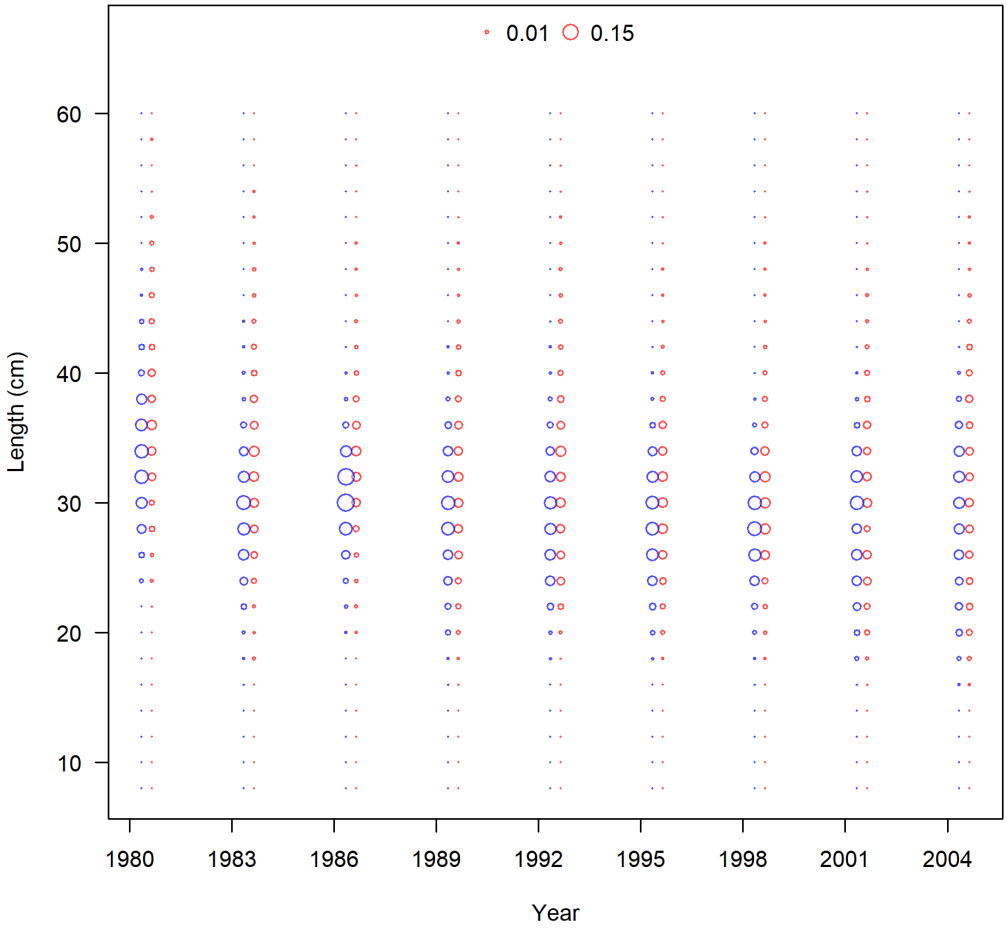


Figure 45: Length composition data from the Triennial survey.

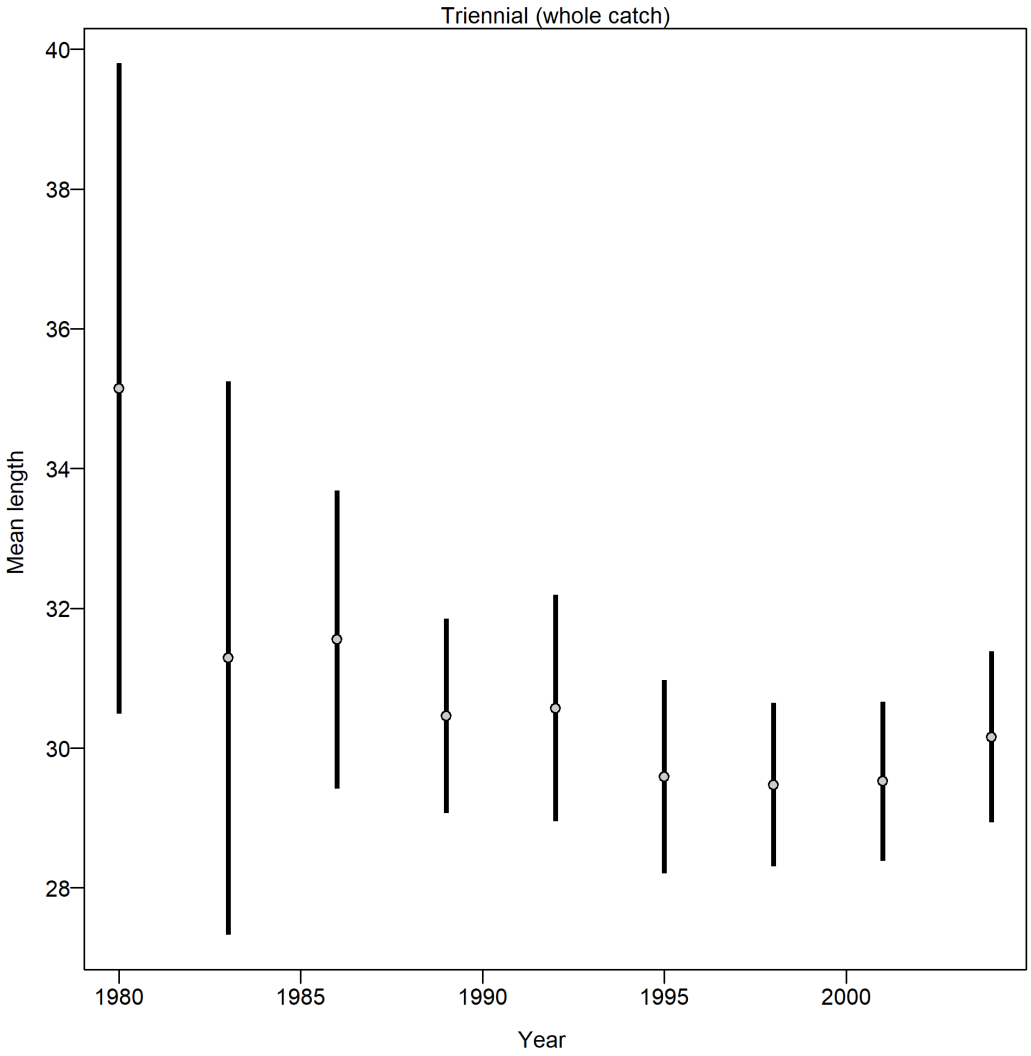


Figure 46: Mean length for Triennial with 95 percent confidence intervals.

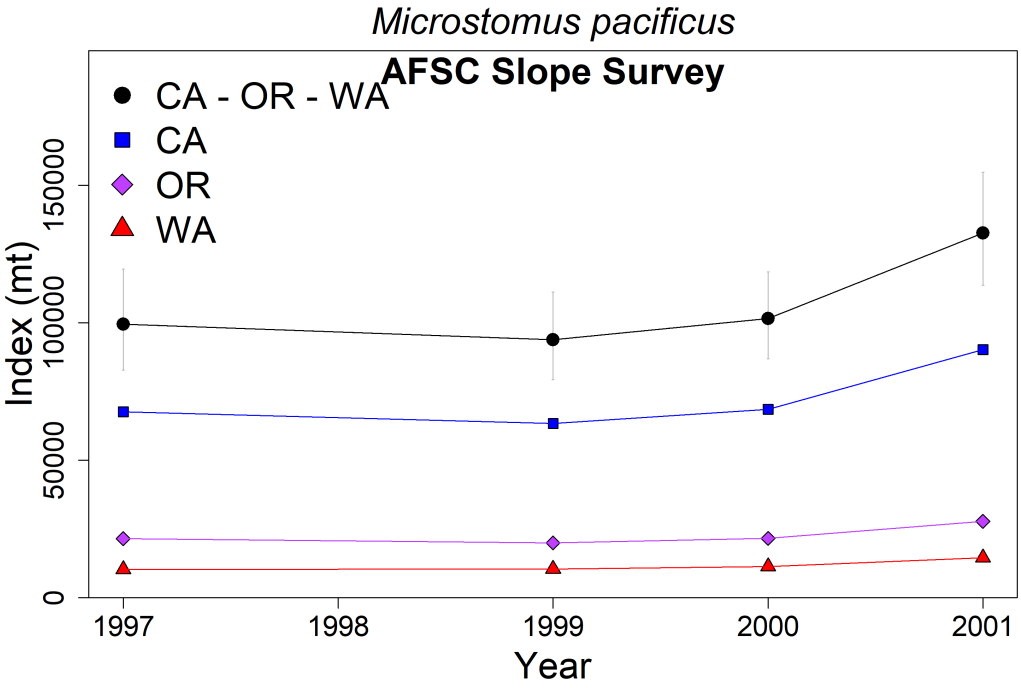


Figure 47: The estimated index of abundance for the AFSC Slope survey (coastwide - black line with circles). A loess soother line was fit to the data series and is denoted by the grey dashed line.

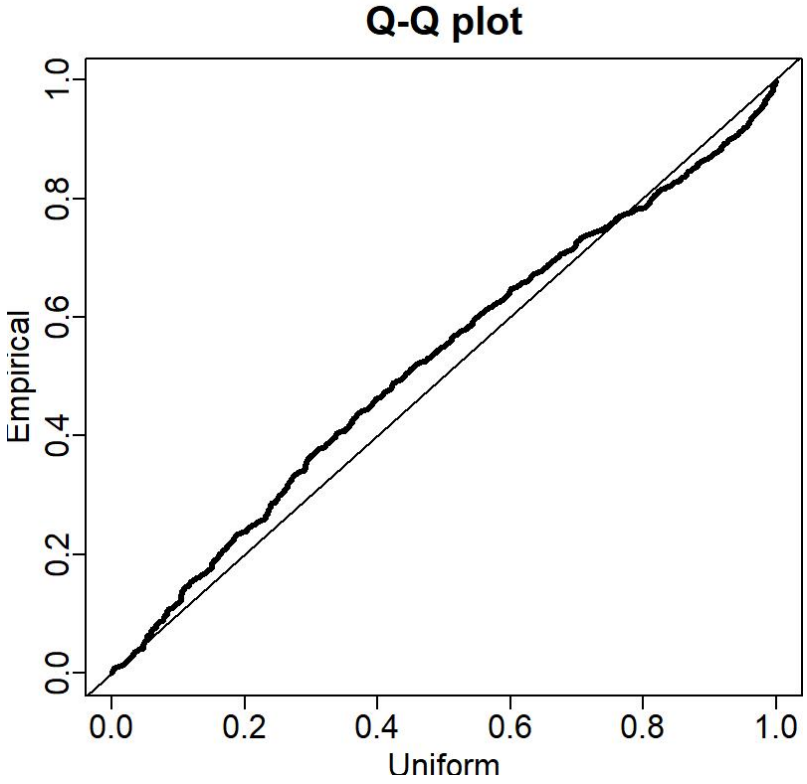


Figure 48: Q-Q and diagnostics for the AFSC Slope survey .

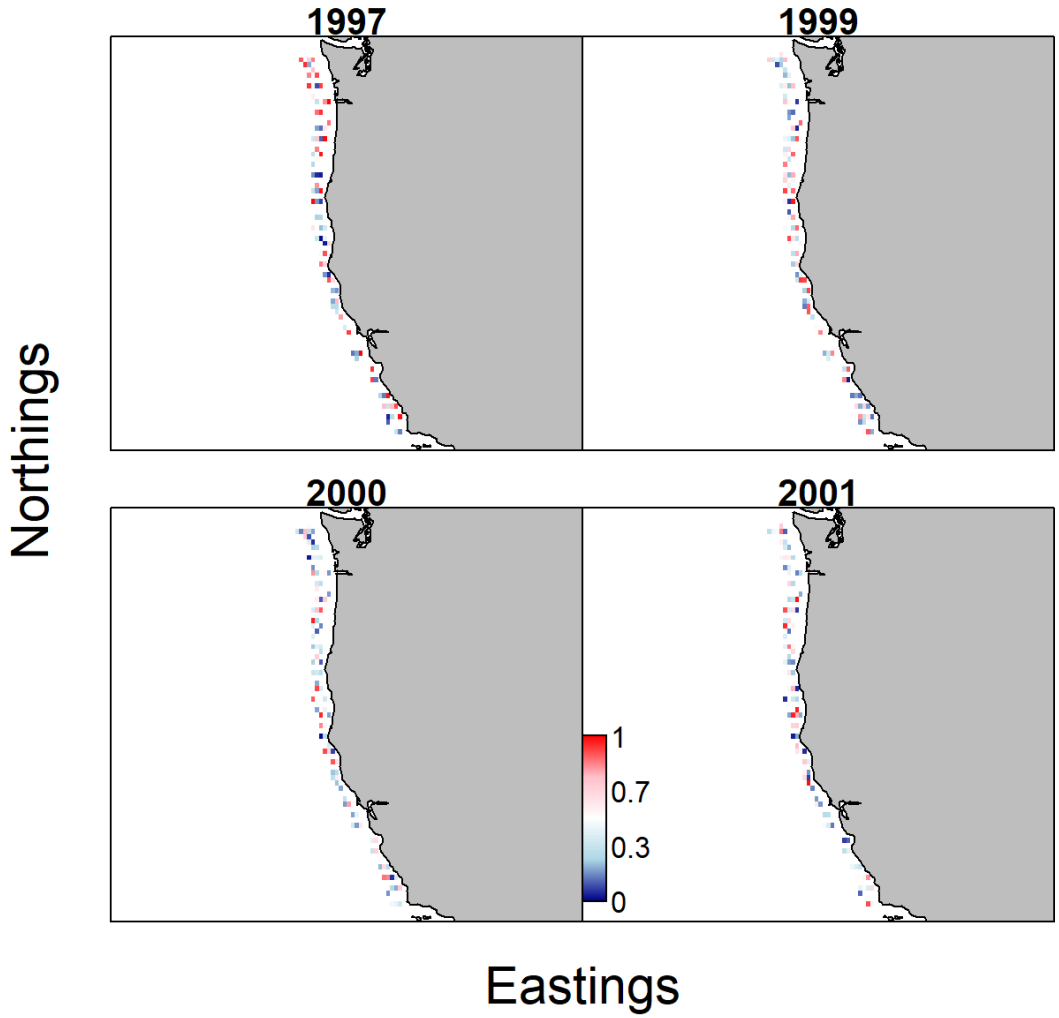


Figure 49: Residuals for the AFSC Slope survey.

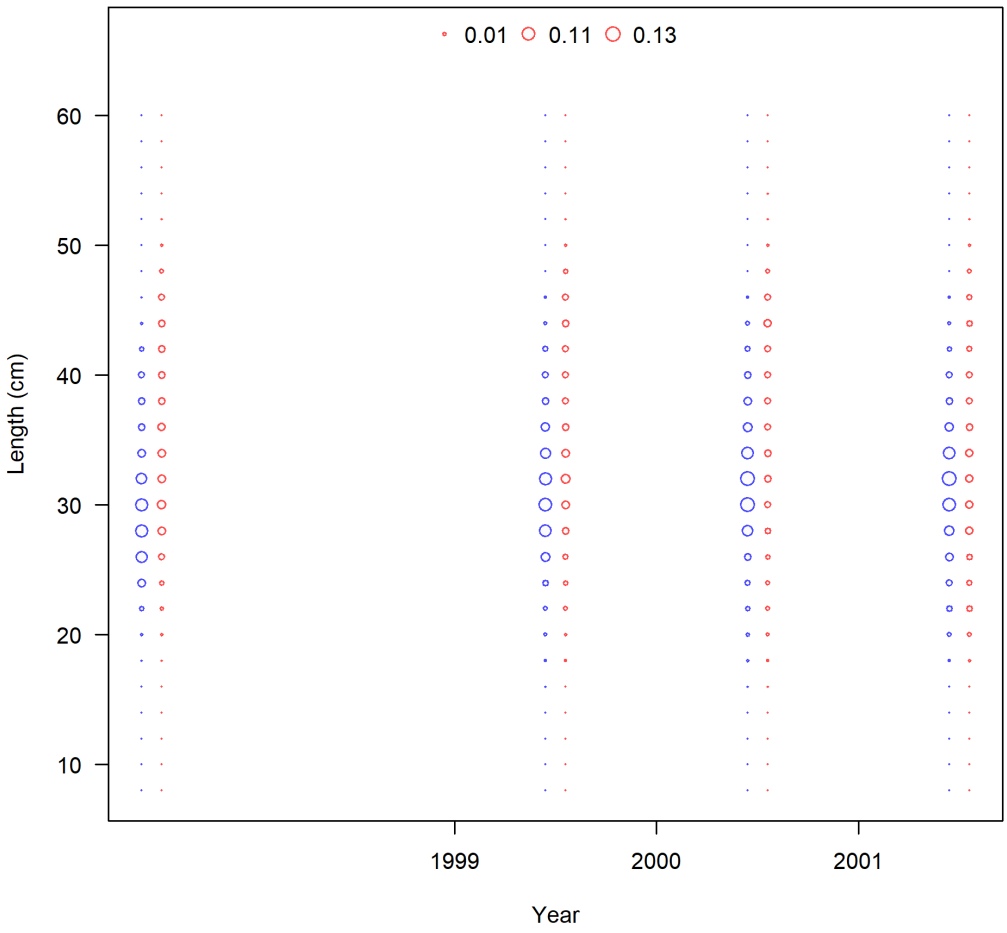


Figure 50: Length composition data from the AFSC Slope survey.

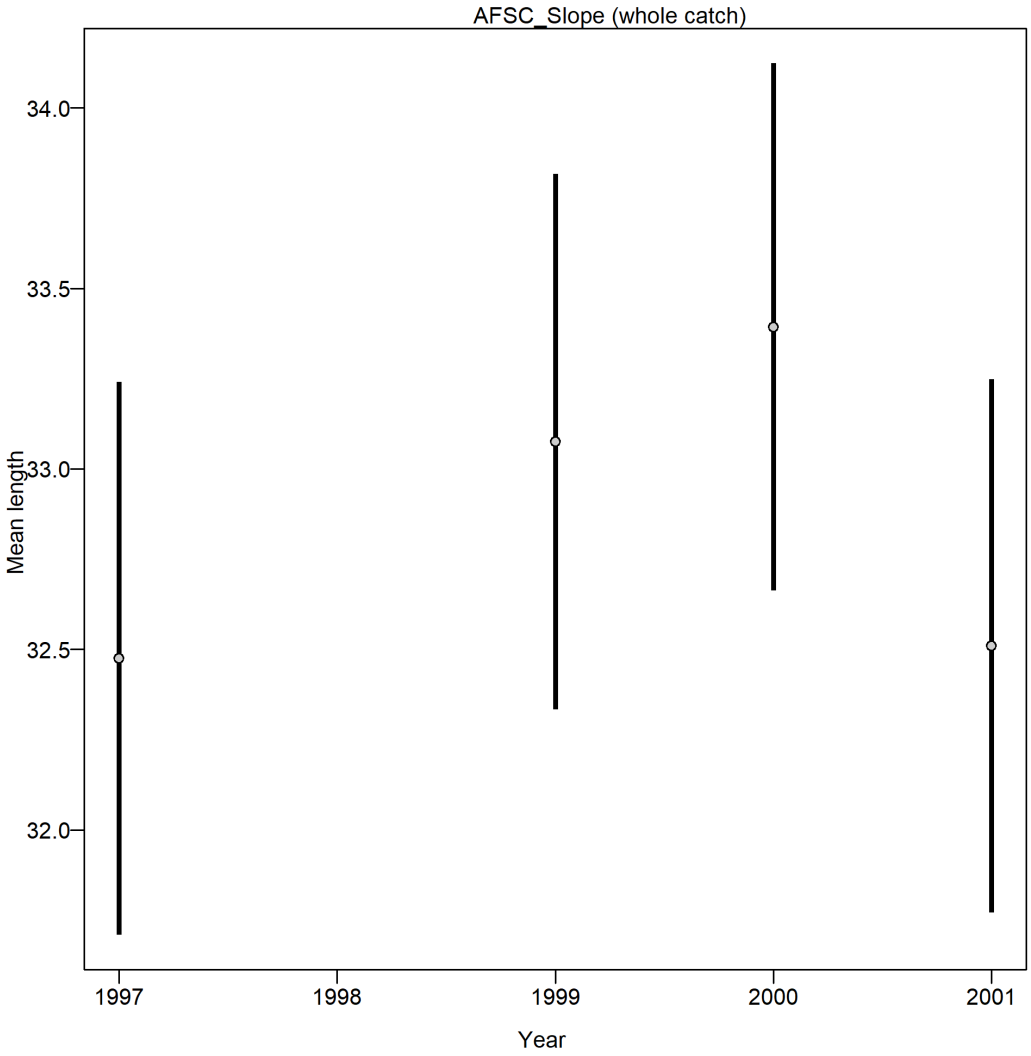


Figure 51: Mean length for AFSC Slope survey with 95 percent confidence intervals.

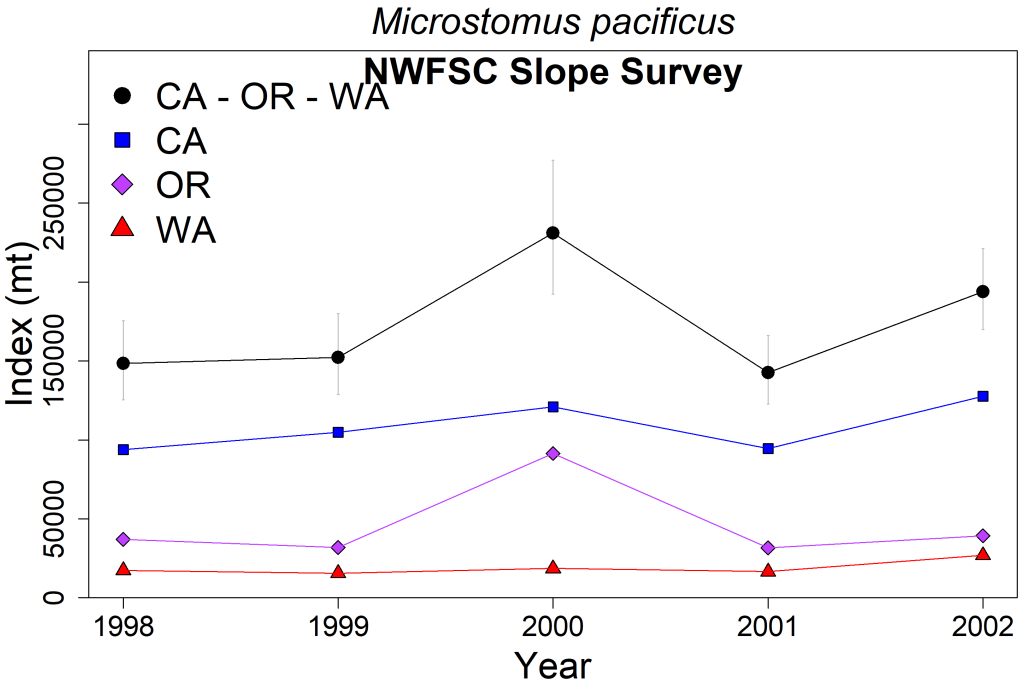


Figure 52: The estimated index of abundance for the NWFSC Slope survey (coastwide - black line with circles). A loess soother line was fit to the data series and is denoted by the grey dashed line.

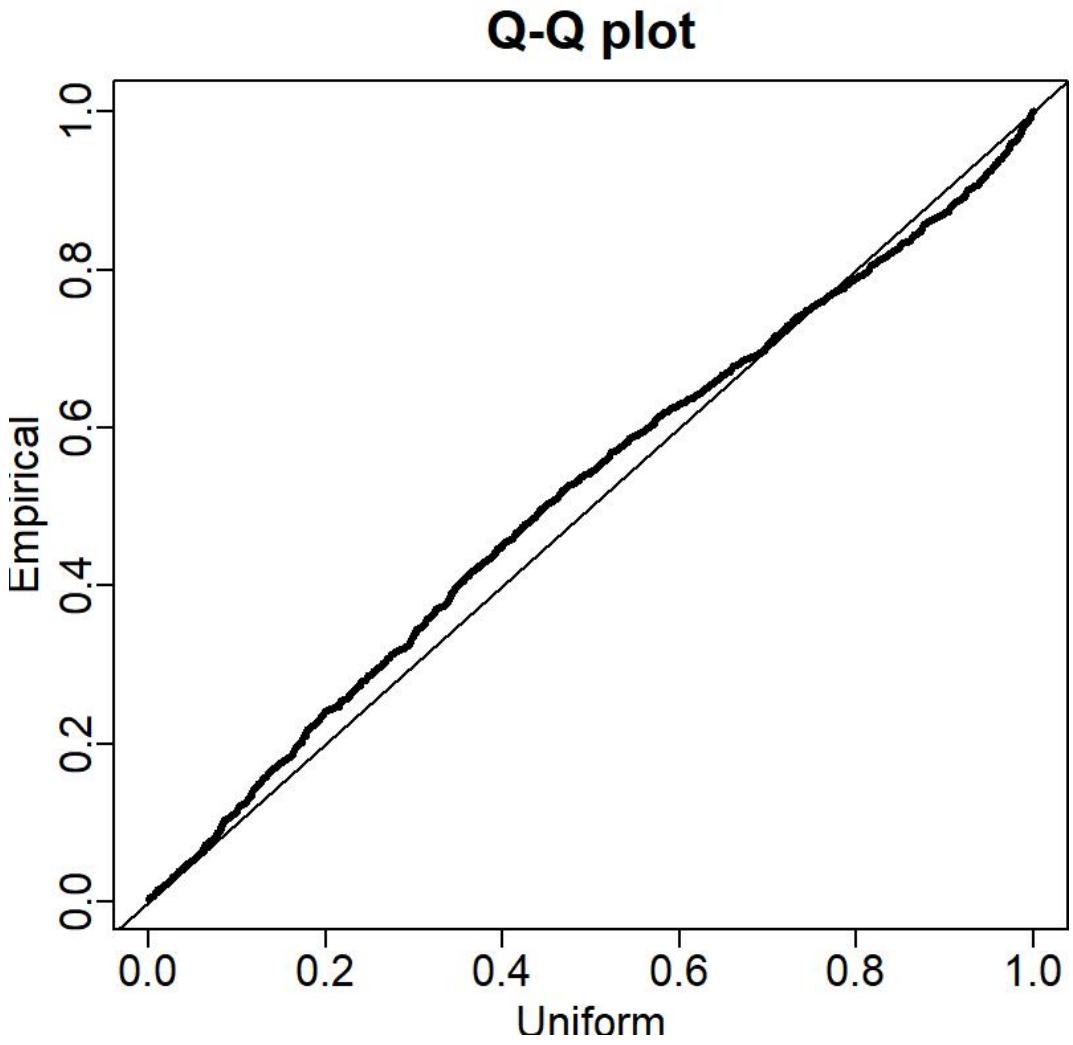


Figure 53: Q-Q and diagnostics for the NWFSC Slope survey.

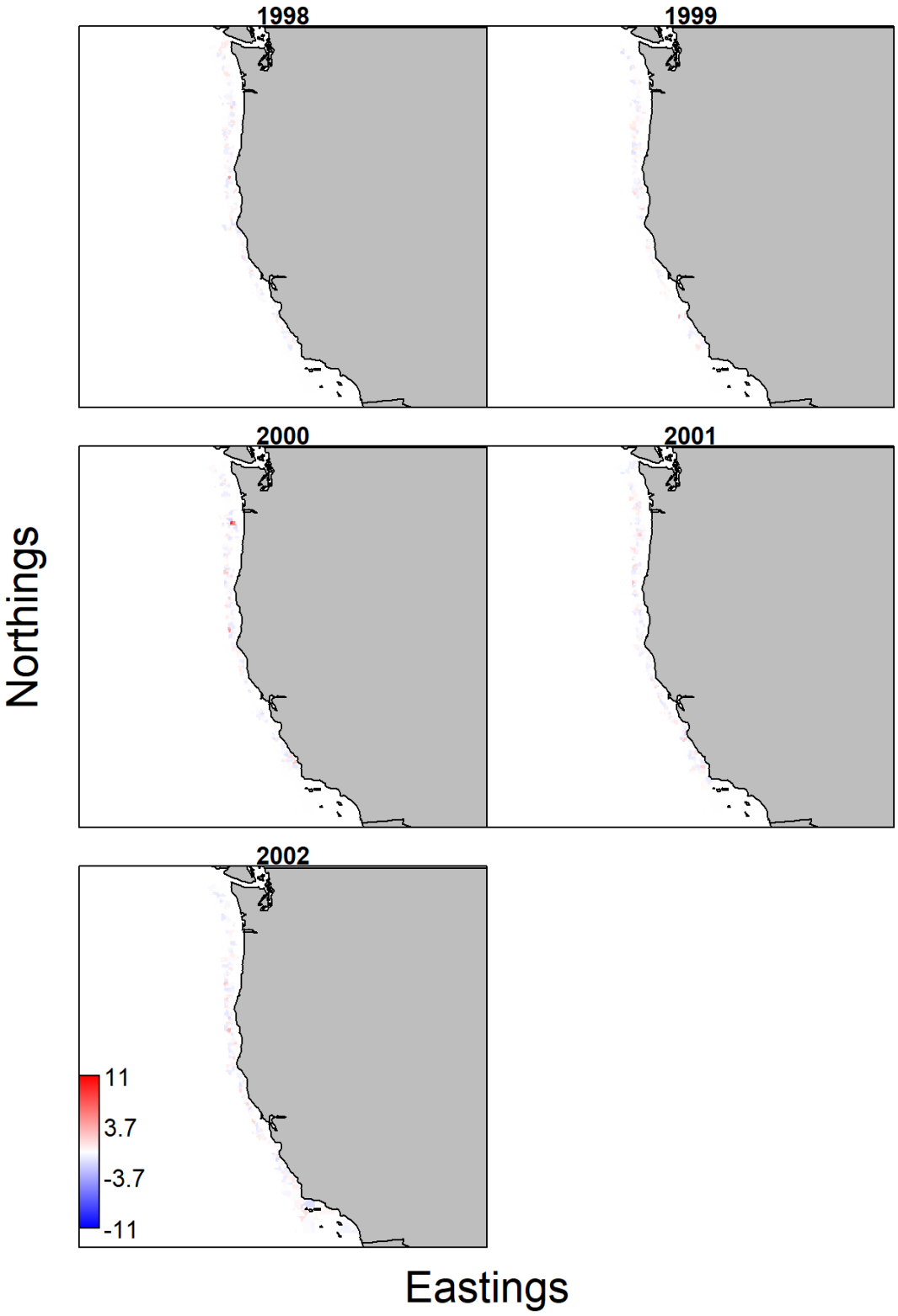


Figure 54: Residuals for the NWFSC Slope survey.

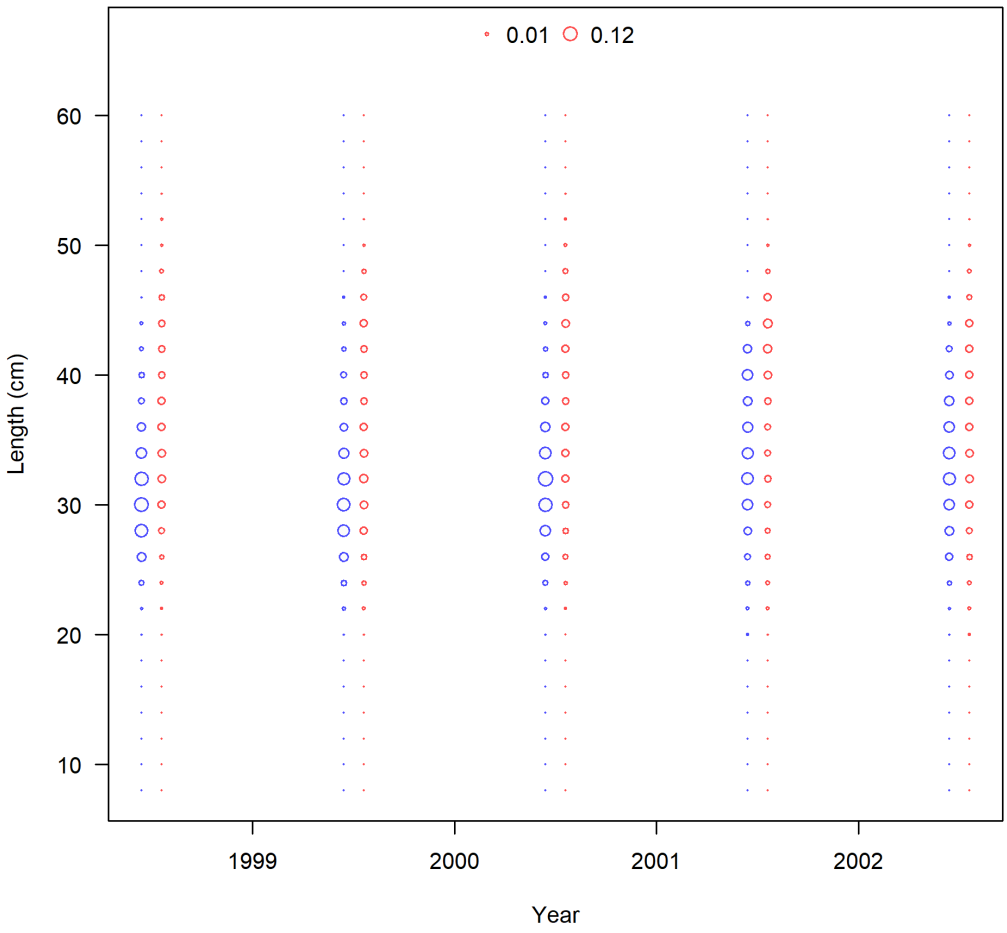


Figure 55: Length composition data from the NWFSC Slope survey.

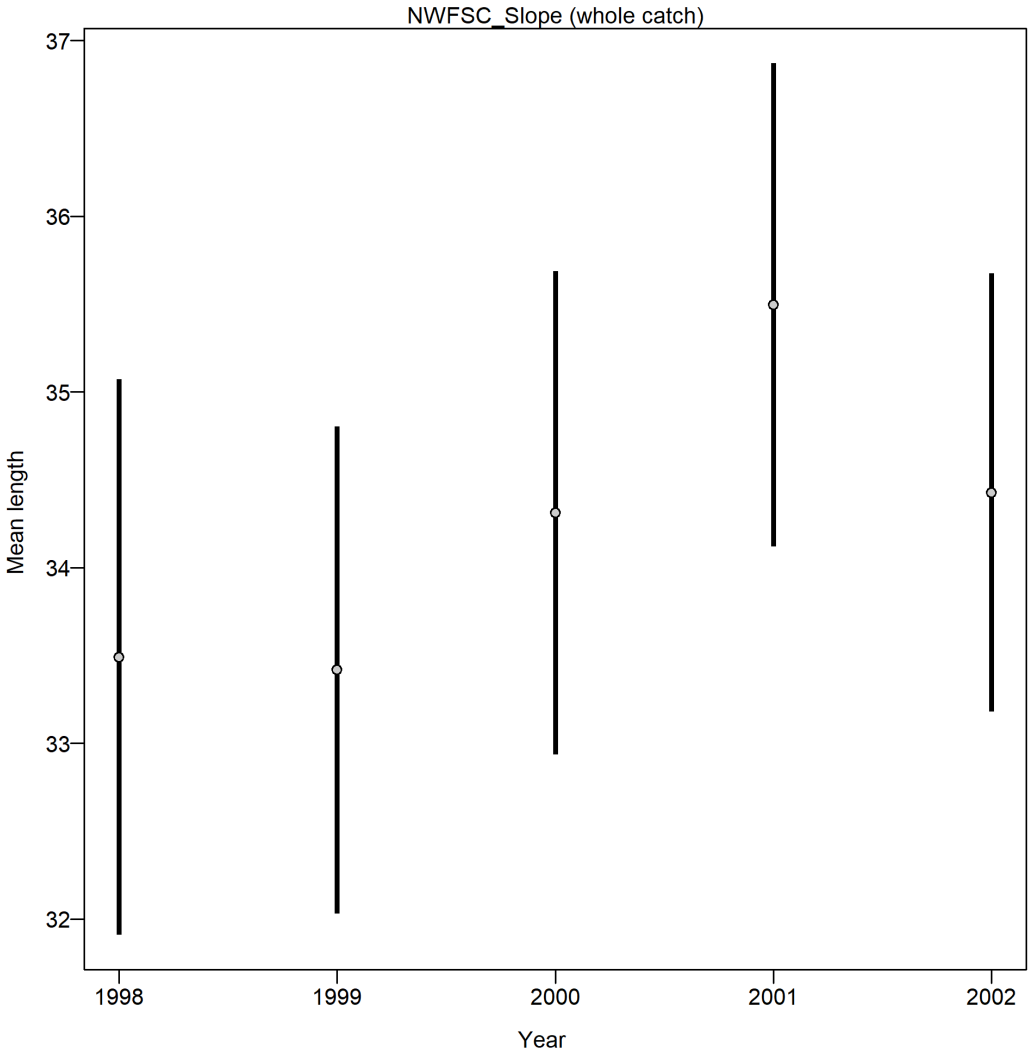


Figure 56: Mean length for NWFSC Slope survey with 95 percent confidence intervals.

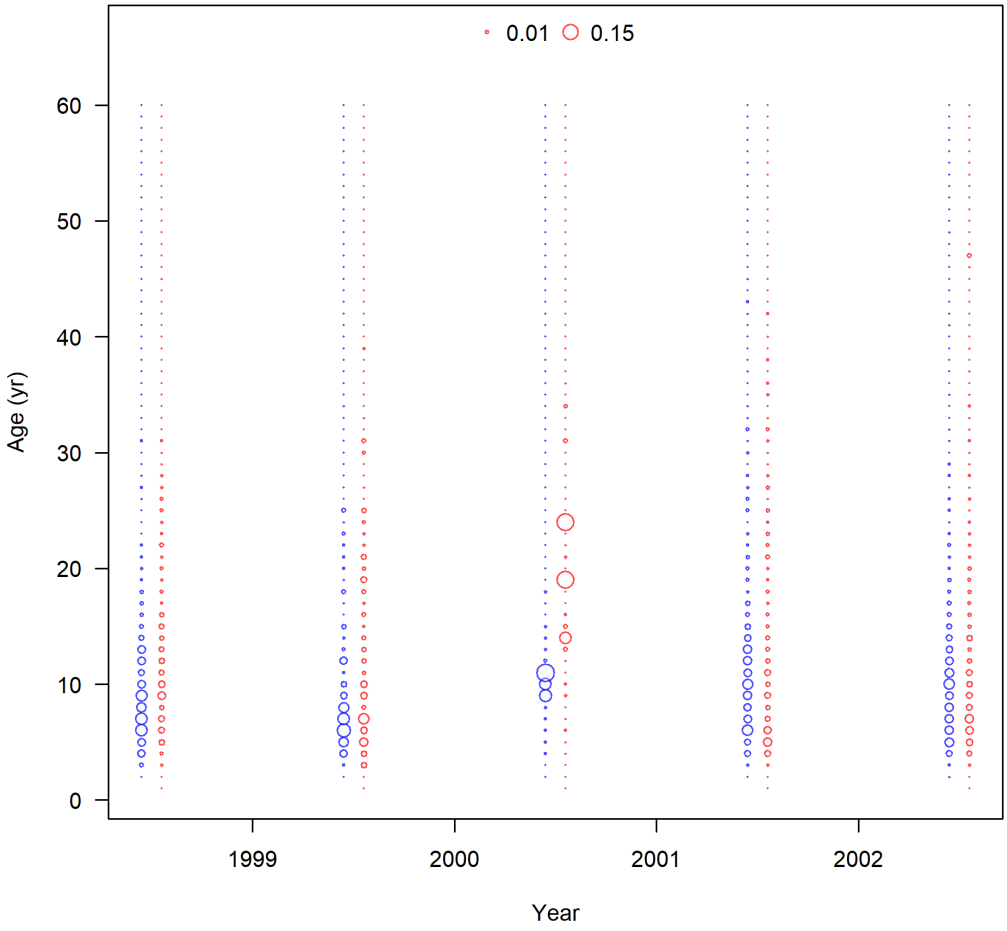


Figure 57: Age composition data from the NWFSC Slope survey.

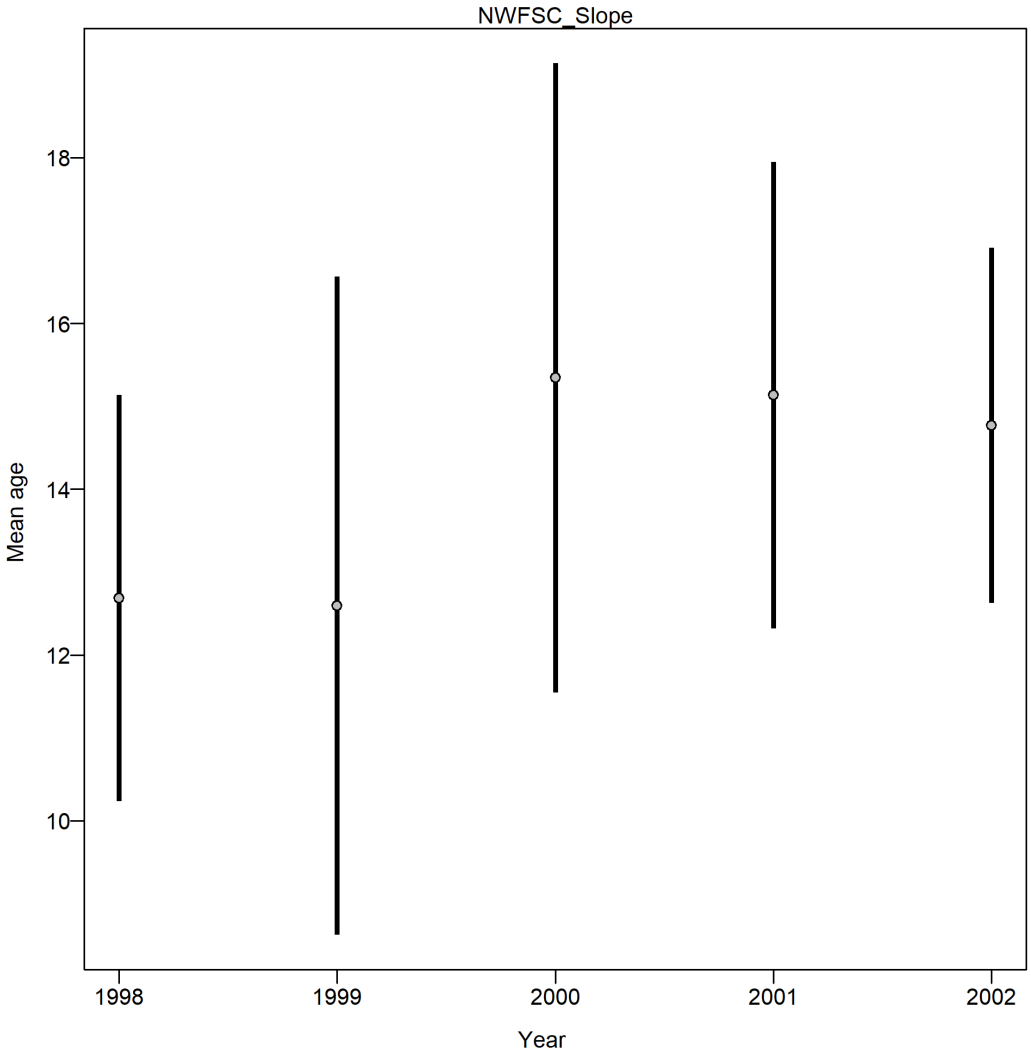


Figure 58: Mean age for NWFSC Slope survey with 95 percent confidence intervals.

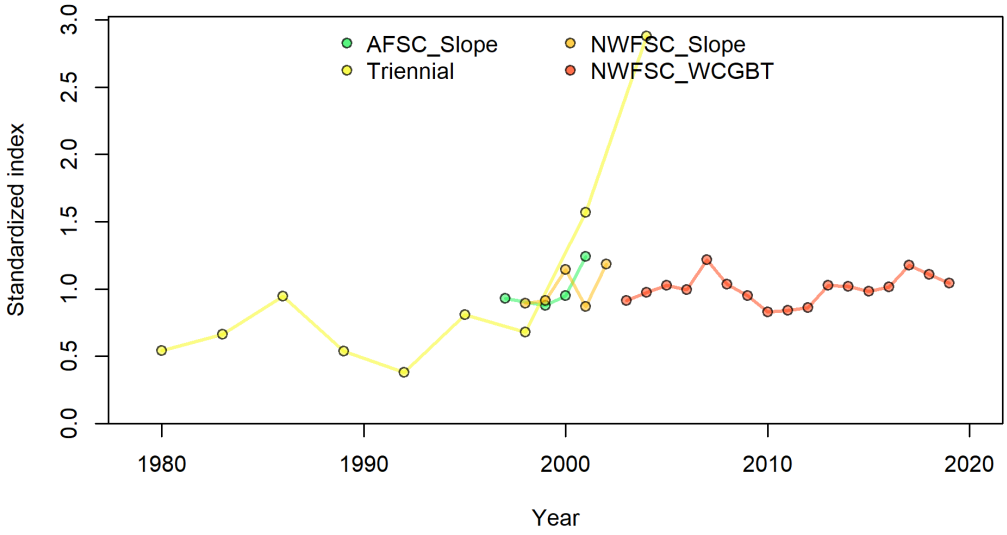


Figure 59: Standardized indices overlaid. Each index is rescaled to have mean observation = 1.0.

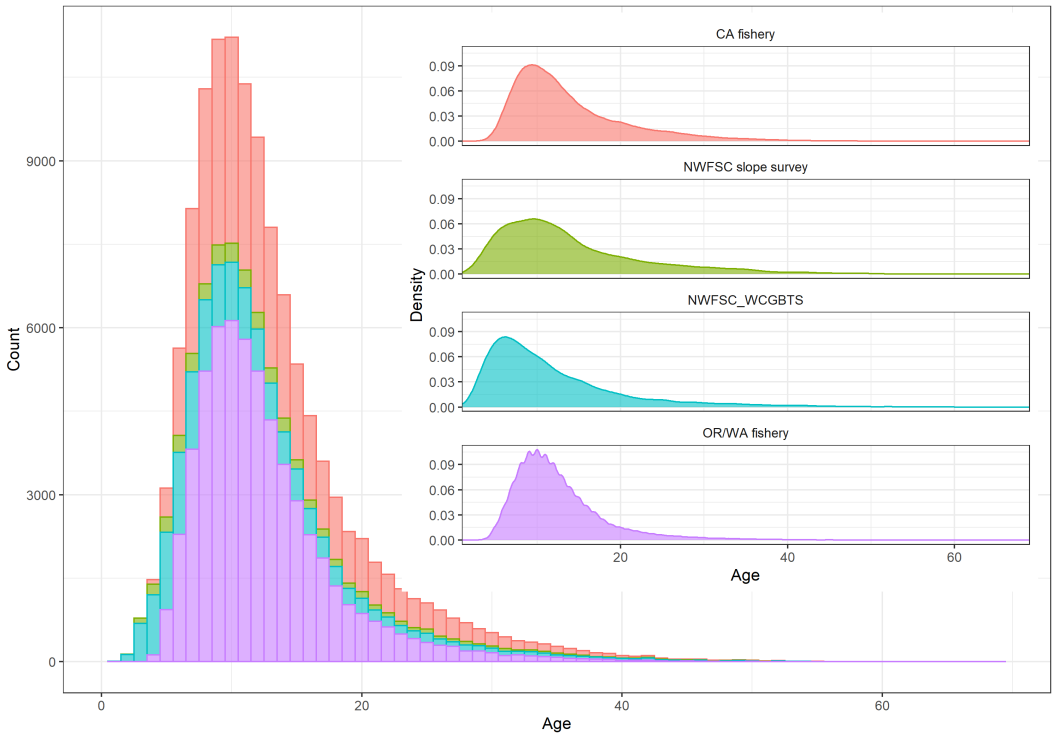


Figure 60: Stacked distribution of observed ages across data sources summed across all years.

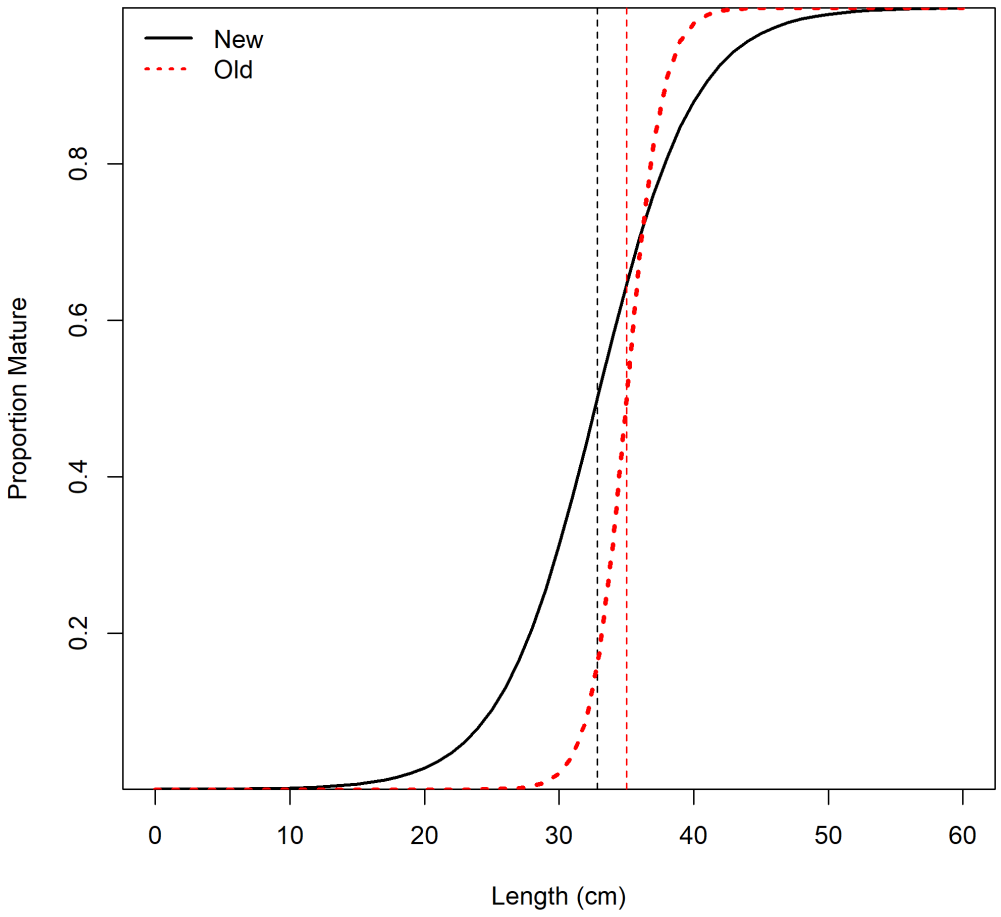


Figure 61: Comparison of the maturity-at-length assumed in the 2011 assessment and the new estimate used in the base model where the vertical dashed lines indicates length-at-50-percent-maturity associated with each estimate.

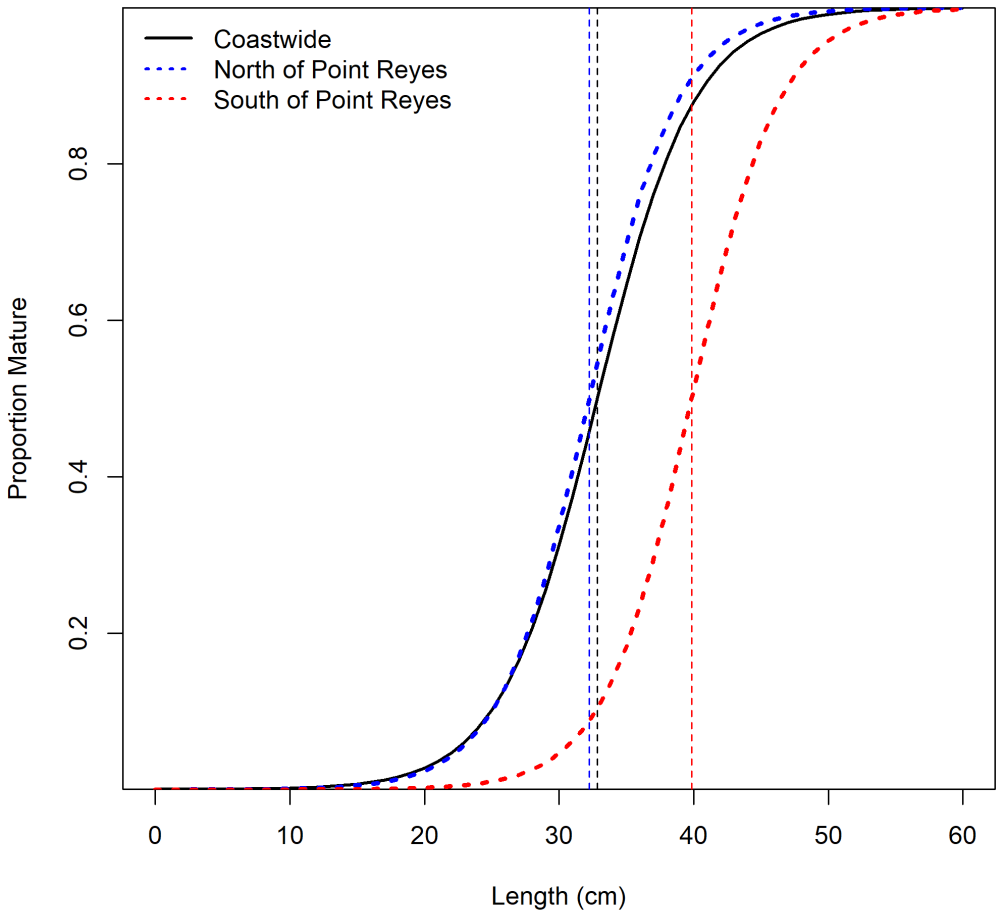


Figure 62: Comparison of the maturity-at-length between fish sample north (N = 334) and south of Point Reyes (N = 94) where dashed vertical lines indicate the length-at-50-percent maturity associated with each estimate.

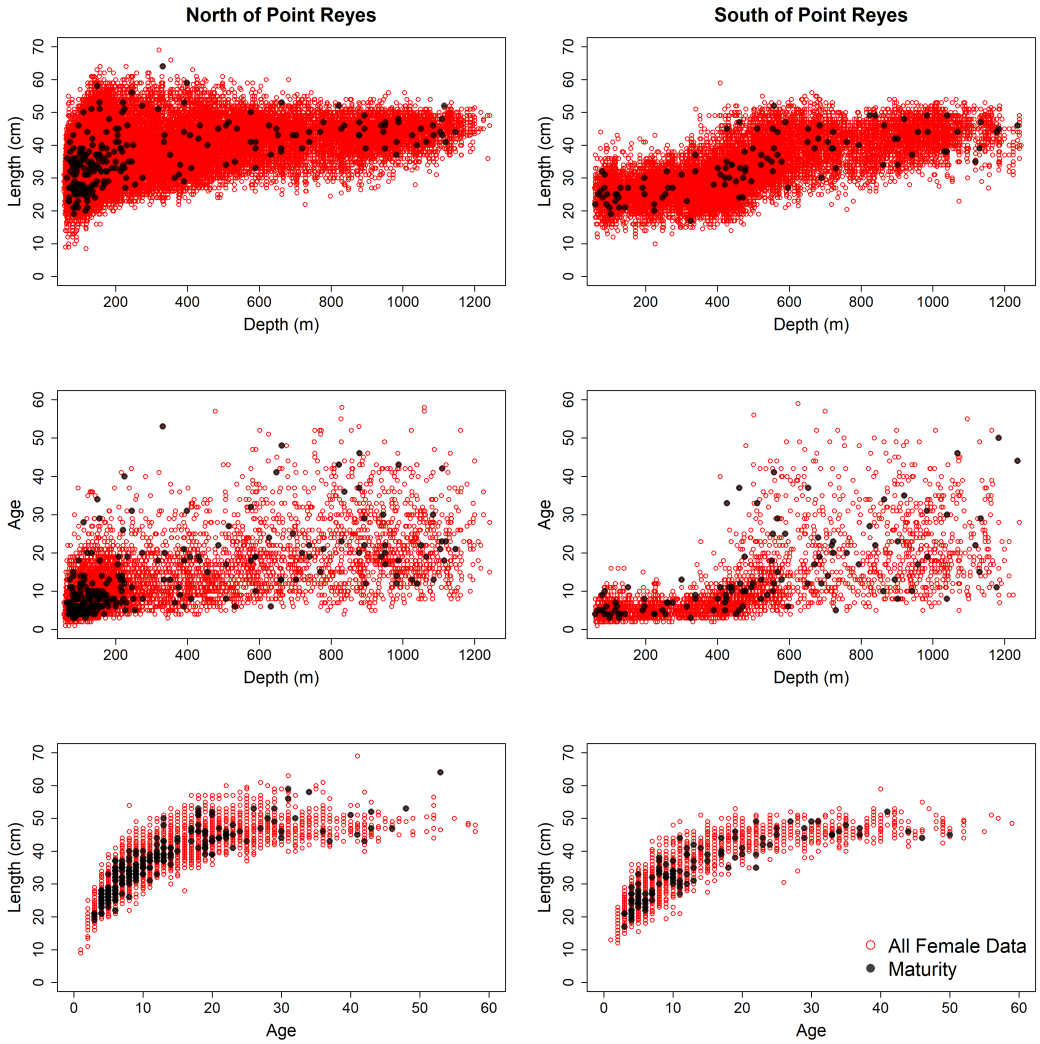


Figure 63: Comparison of the observed sizes and ages by depth between fish sample north and south of Point Reyes for maturity (black circles) and all female observations (open red circles) by the WCGBTS.

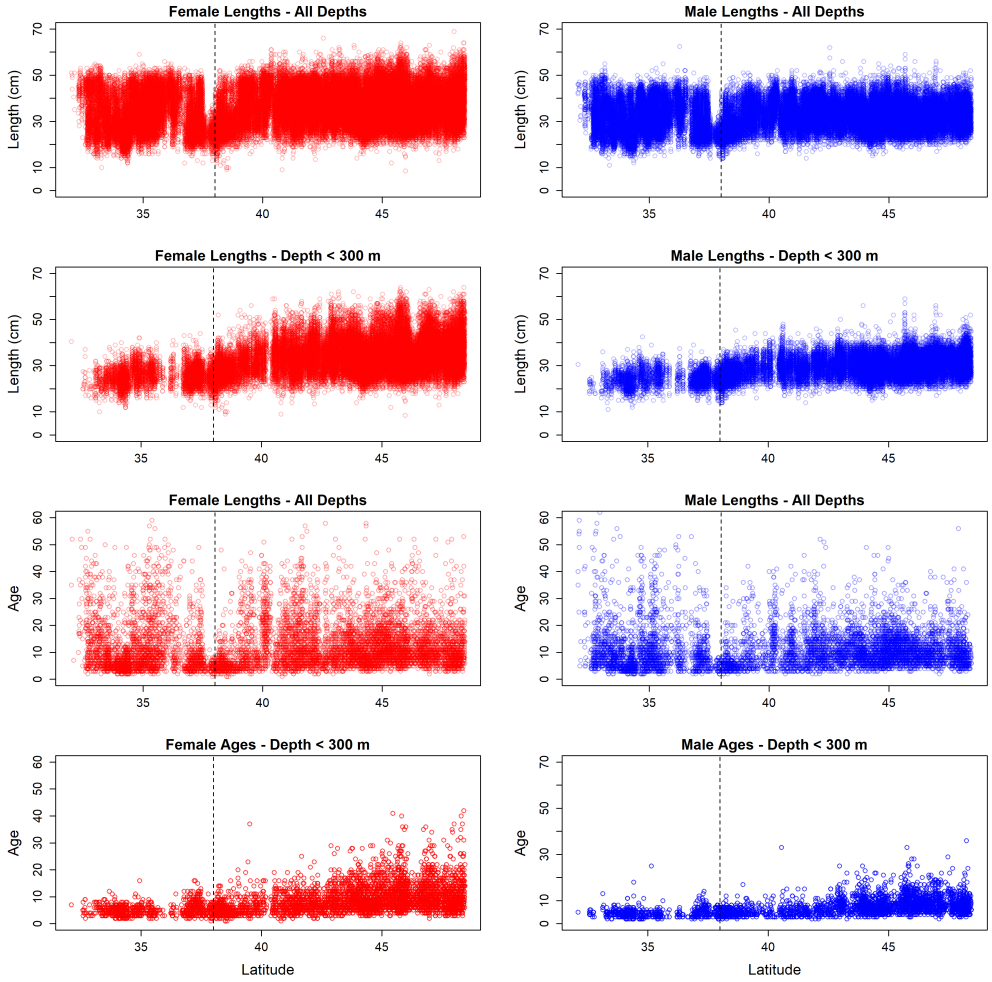


Figure 64: Comparison of the observed sizes and ages by latitude where the vertical black dashed line at Point Reyes.

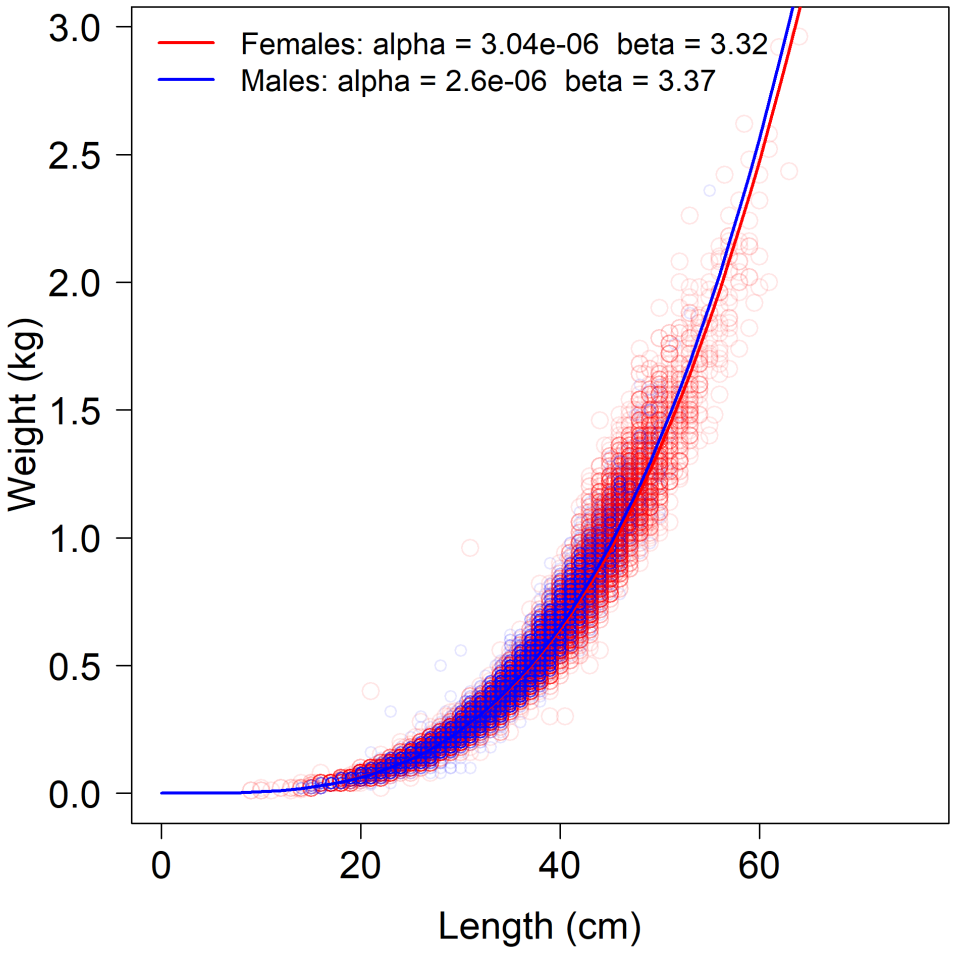


Figure 65: Externally estimated length-weight by sex.

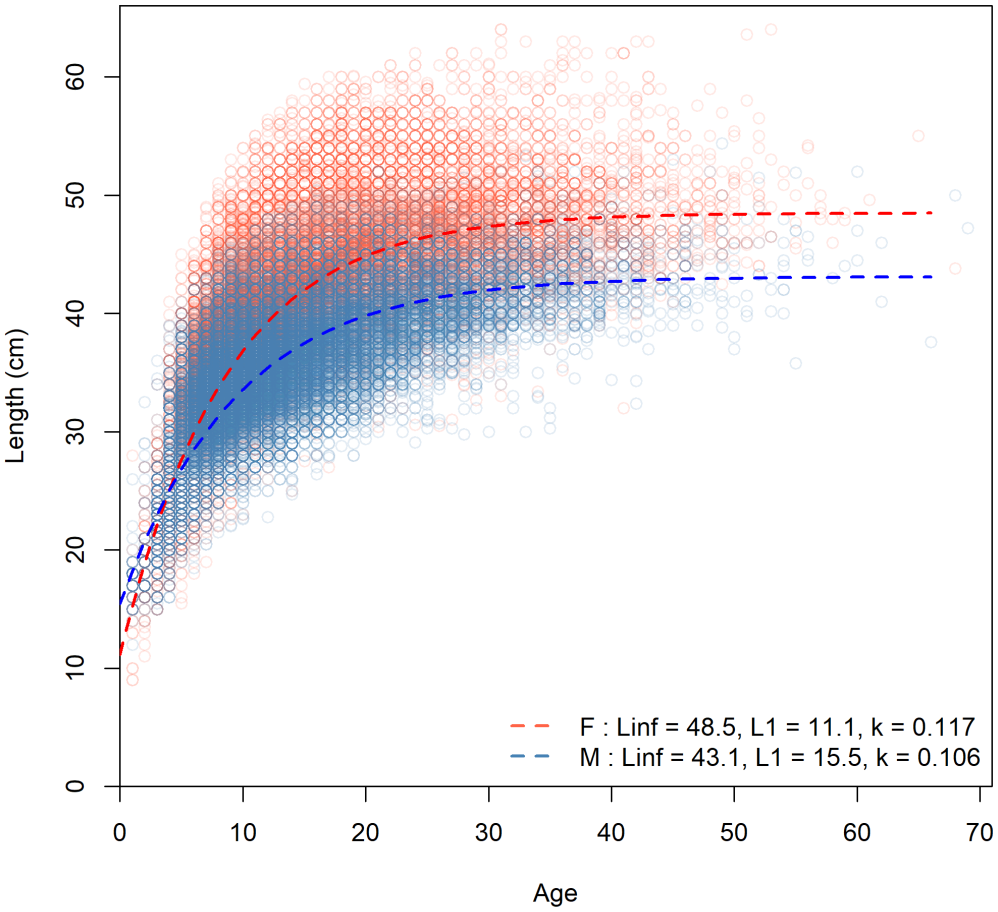


Figure 66: Externally estimated length-at-age by sex.

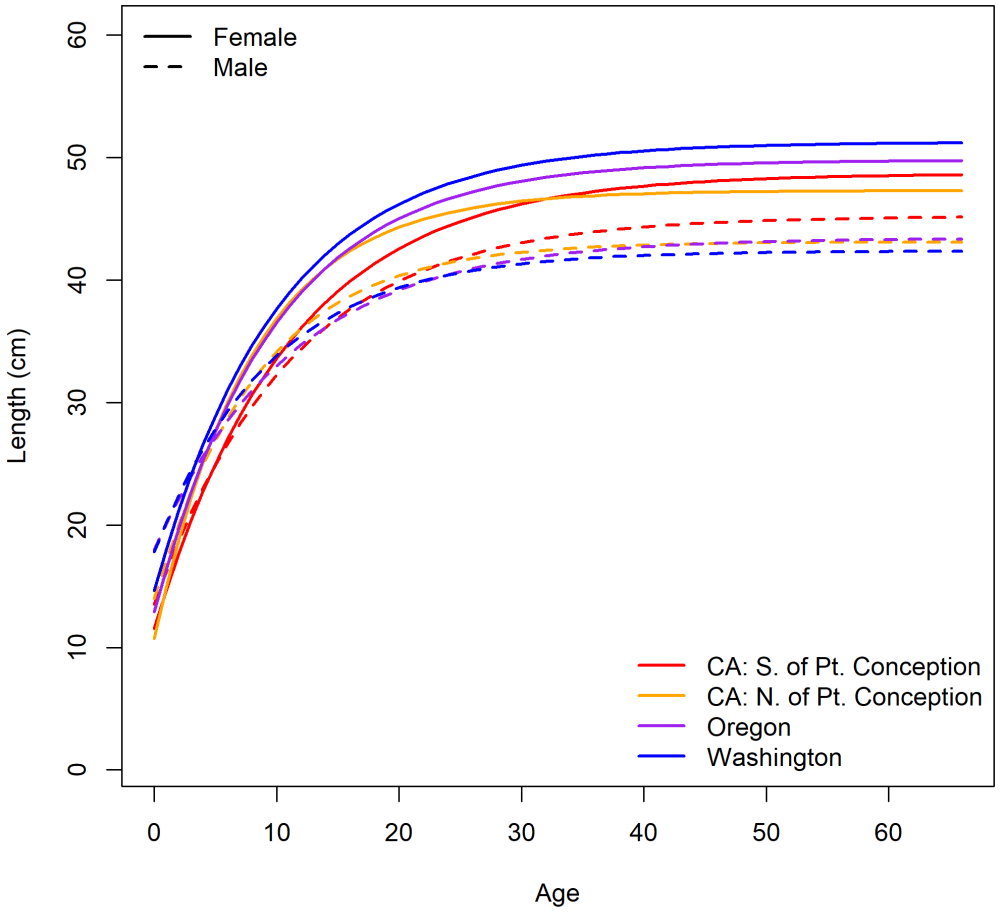


Figure 67: Externally estimated length-at-age by sex for four regions off the West Coast.

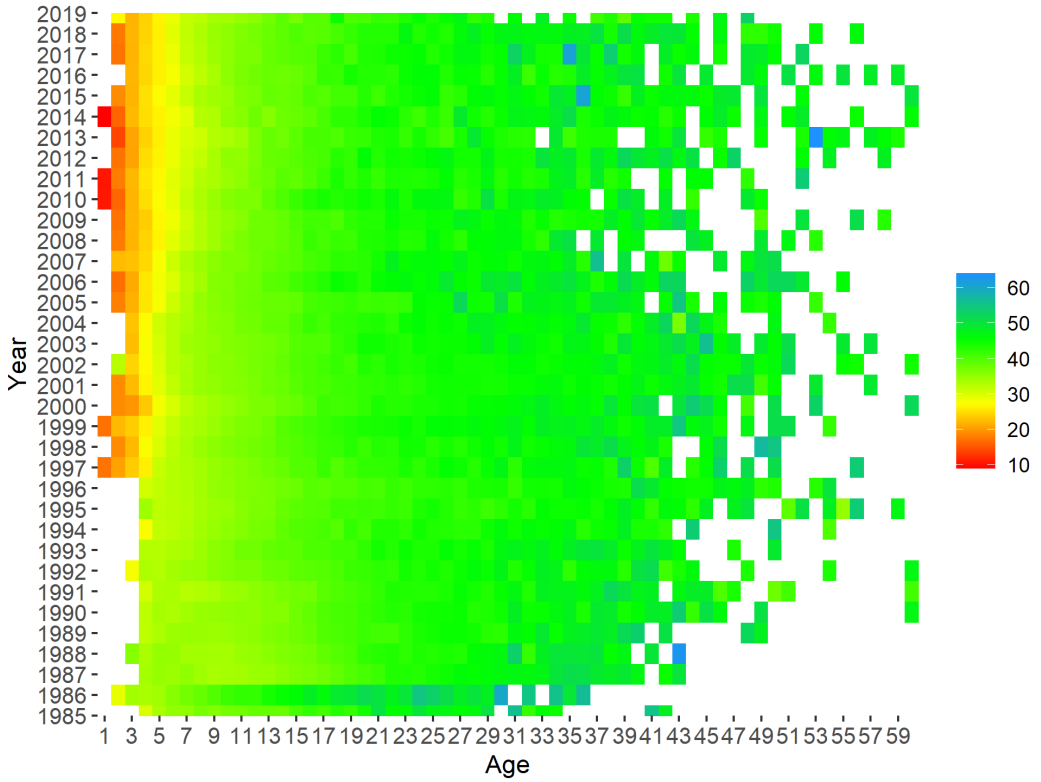


Figure 68: Temporal patterns in mean length-at-age (cm) data. Colors correspond to different length-at-age values as shown in the legend, with red being the smallest fish (across all years and ages) and blue being the largest fish.

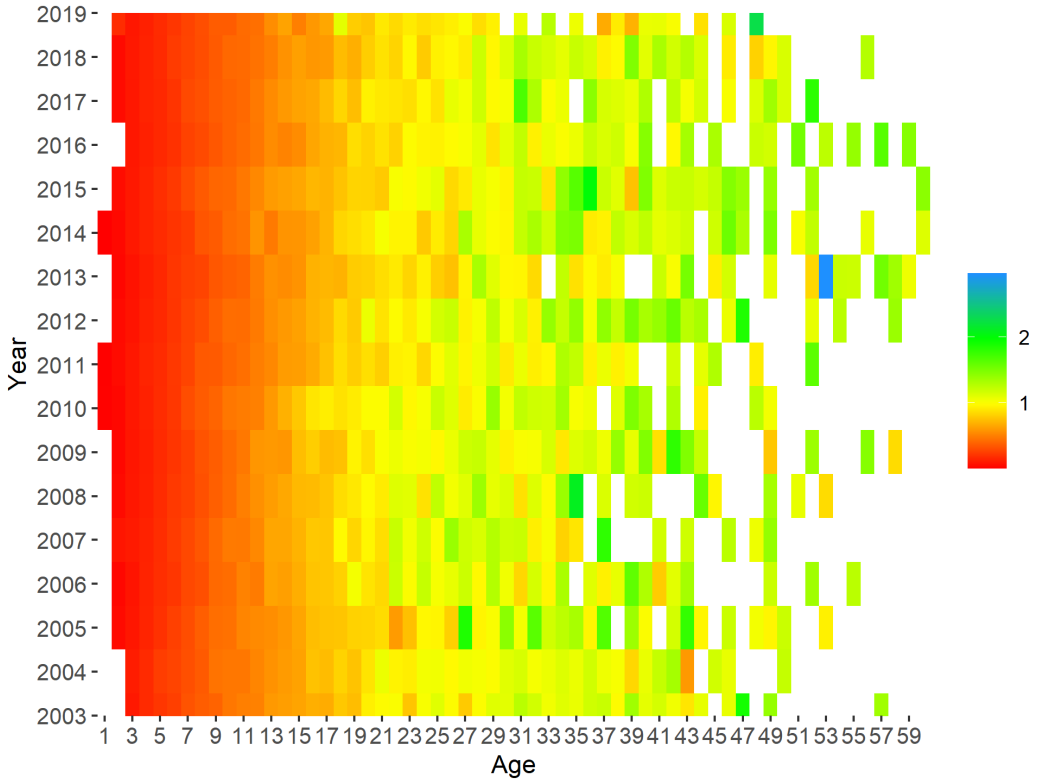


Figure 69: Temporal patterns in mean weight-at-age (kg) data. Colors correspond to different weight-at-age values as shown in the legend, with red being the lightest fish (across all years and ages) and blue being the heaviest fish.

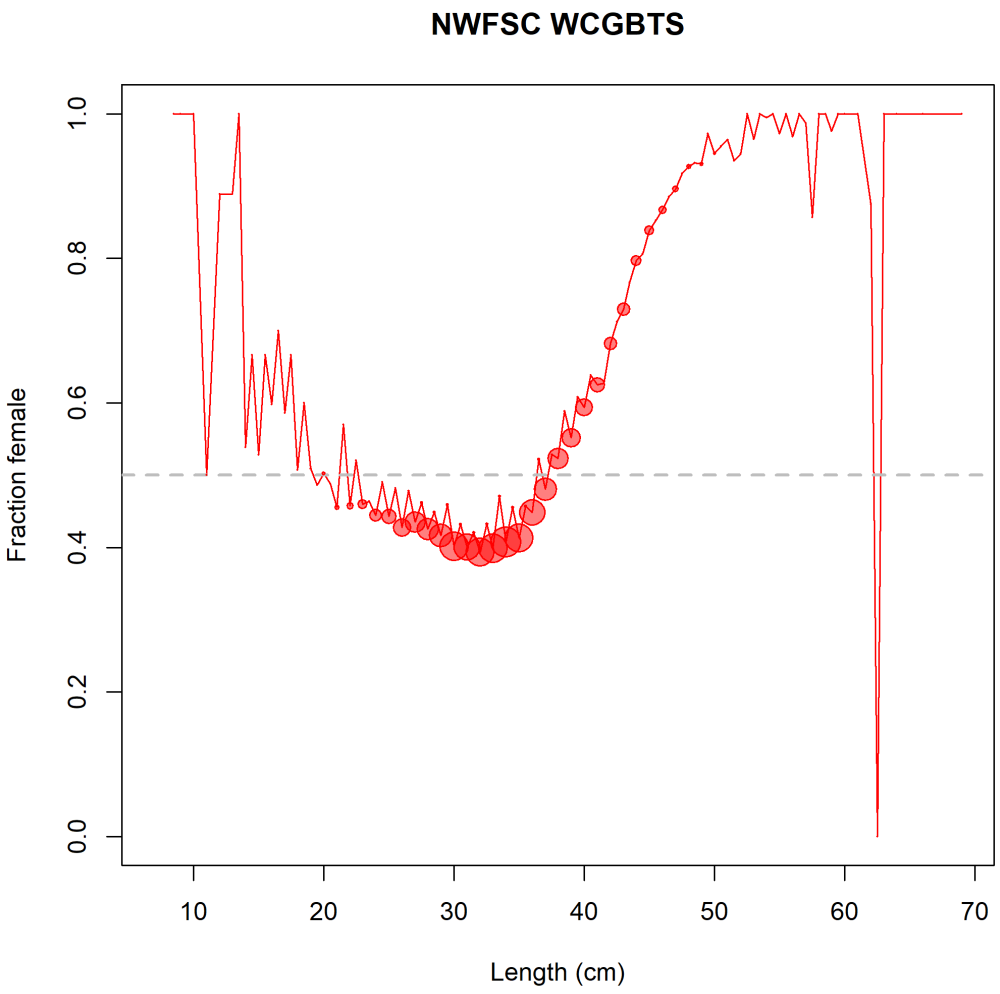


Figure 70: Fraction female by length observed by the WCGBTS.

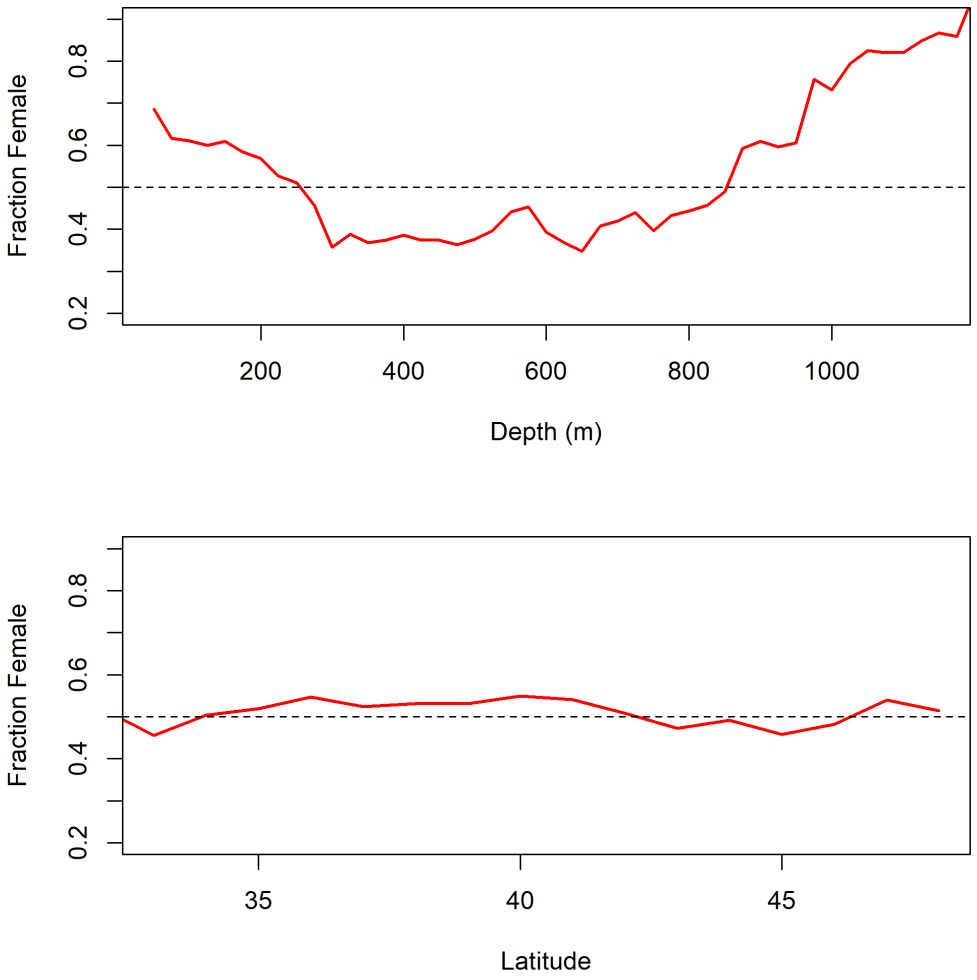


Figure 71: Fraction female observations by depth and latitude from the WCGBTS.

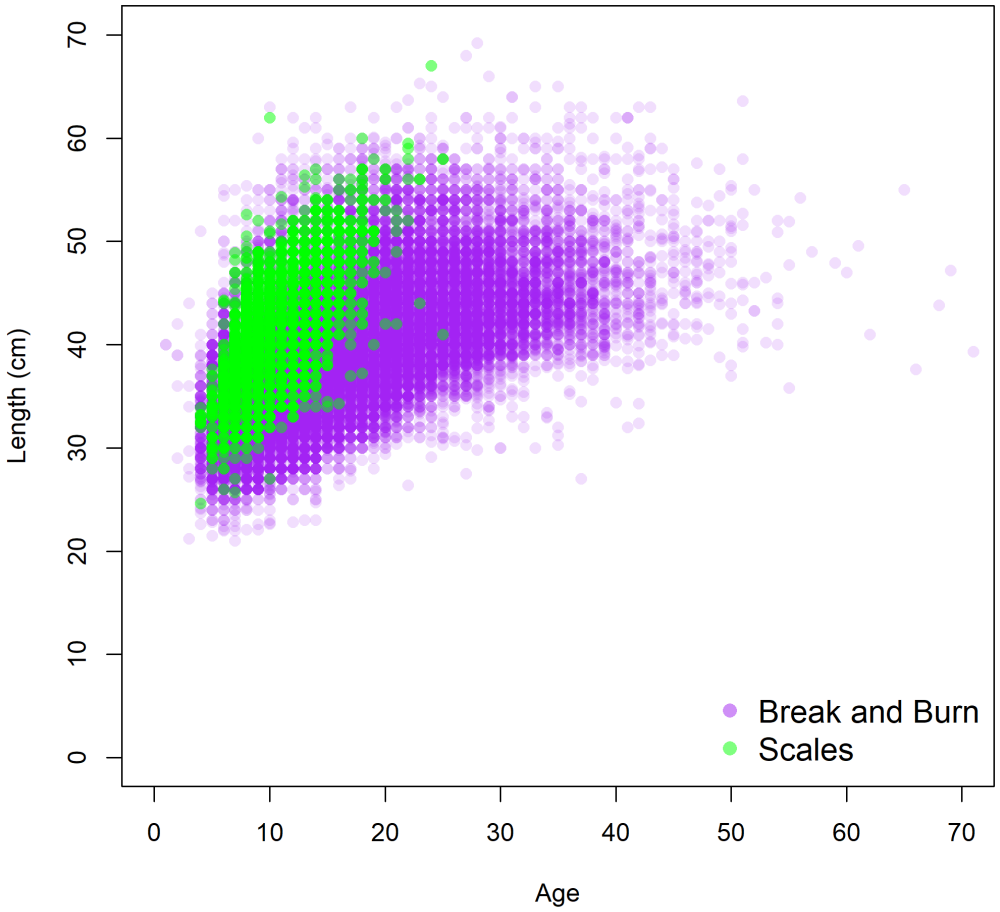


Figure 72: Comparison between break-and-burn versus scale age reads.

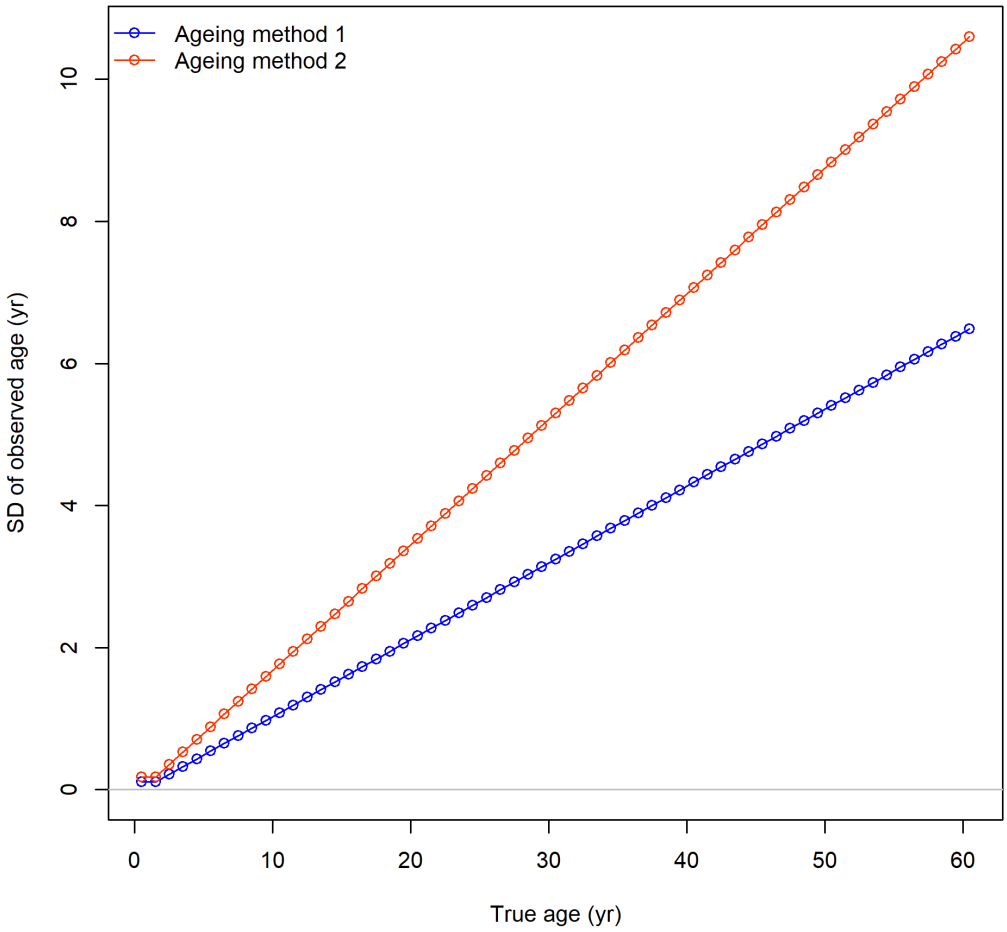


Figure 73: The standard deviation by age for two ageing error applied to age data in the base model (method 1: CAP Lab, method 2: CDFW).

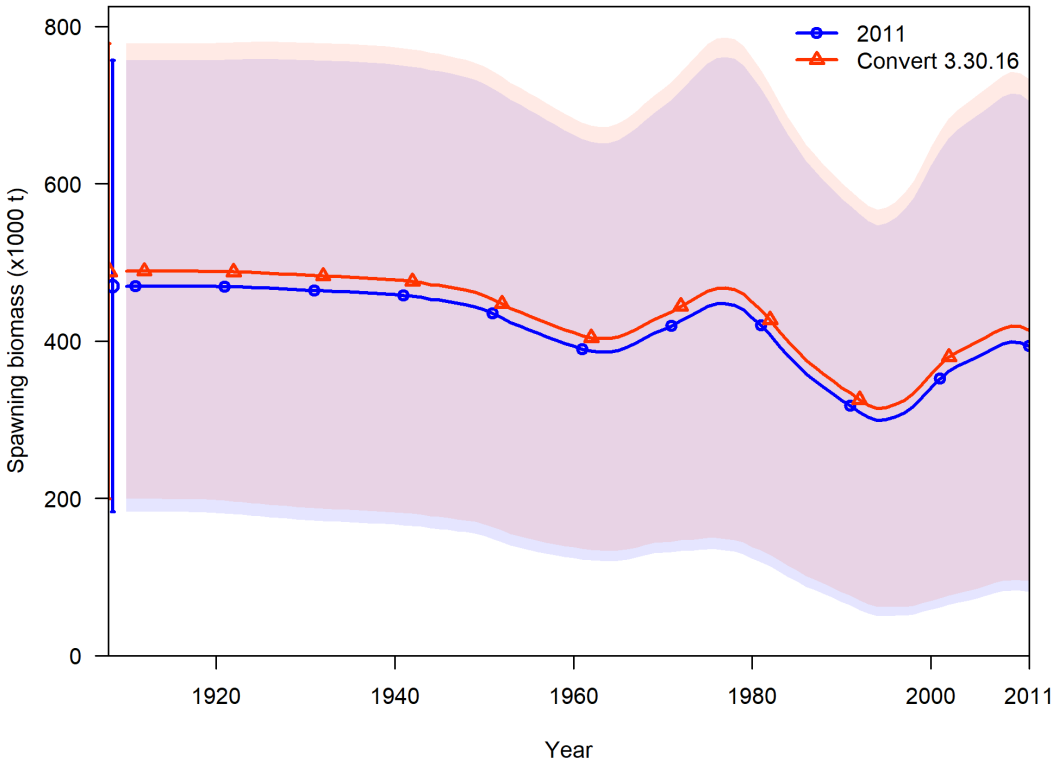


Figure 74: Model version bridge comparison of estimated spawning biomass.

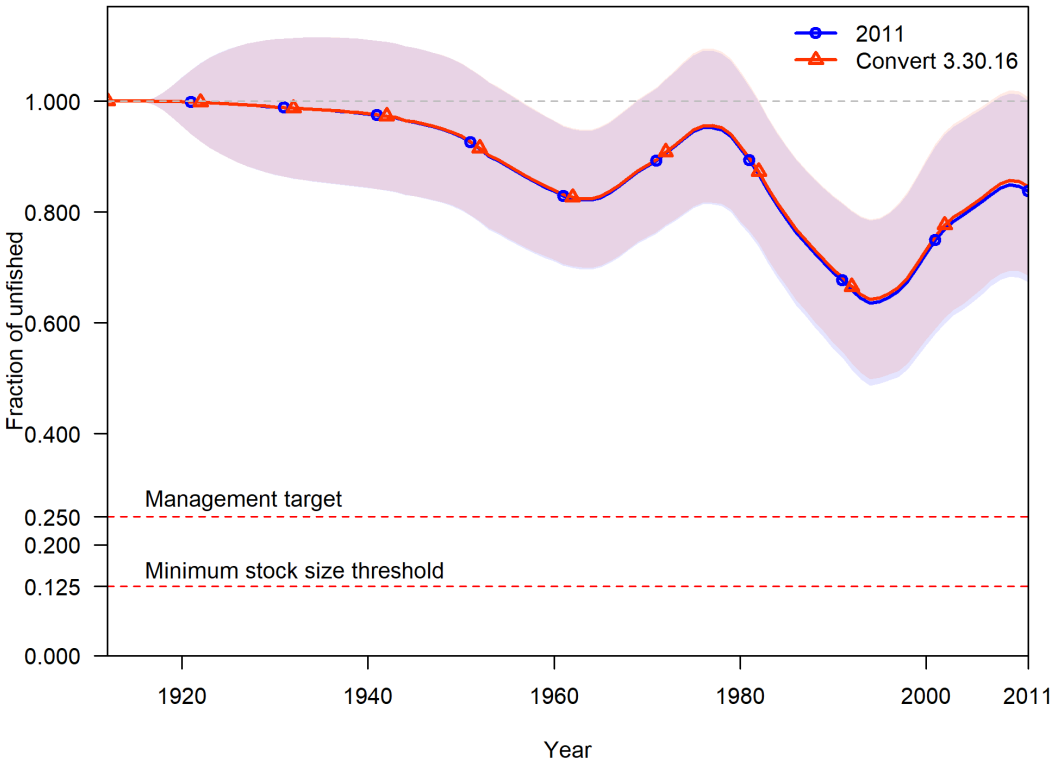


Figure 75: Model version bridge comparison of estimated fraction unfished.

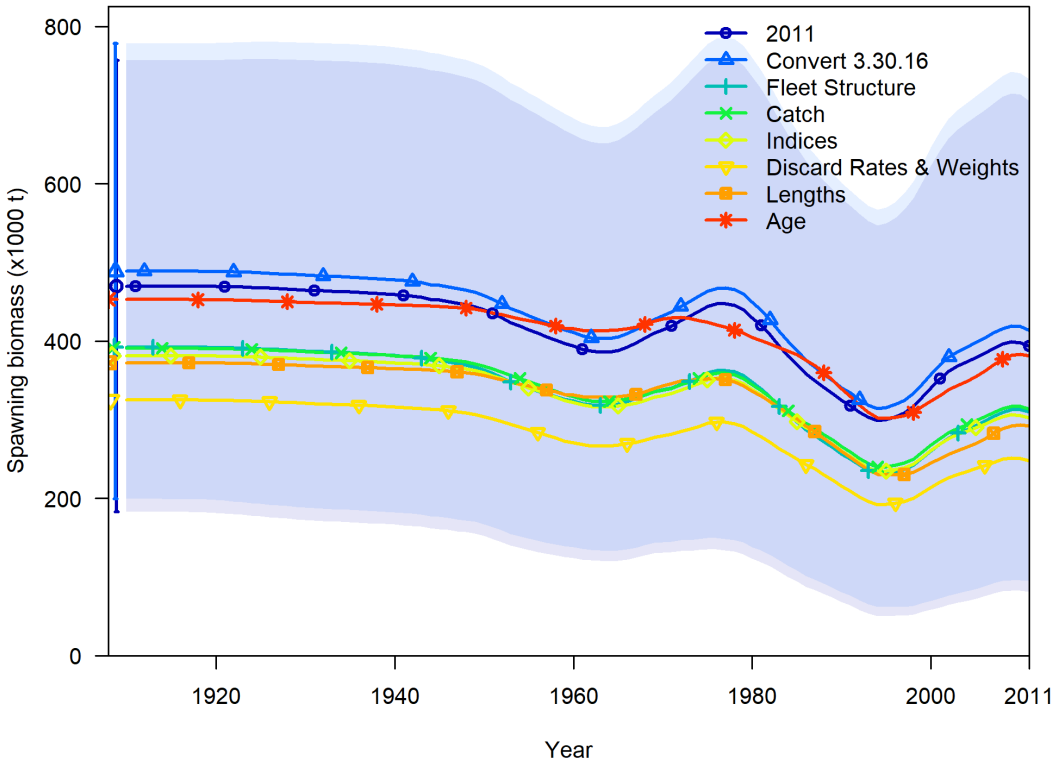


Figure 76: Data updated through 2010 bridge comparison of estimated spawning biomass.

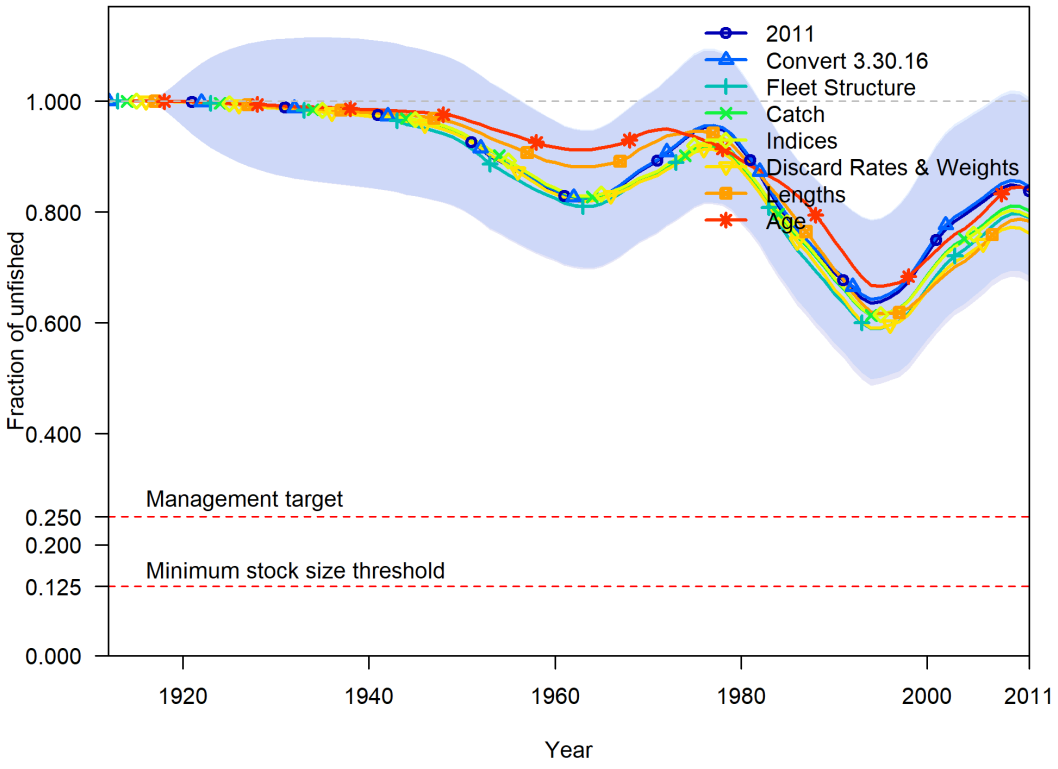


Figure 77: Data updated through 2010 bridge comparison of estimated fraction unfished.

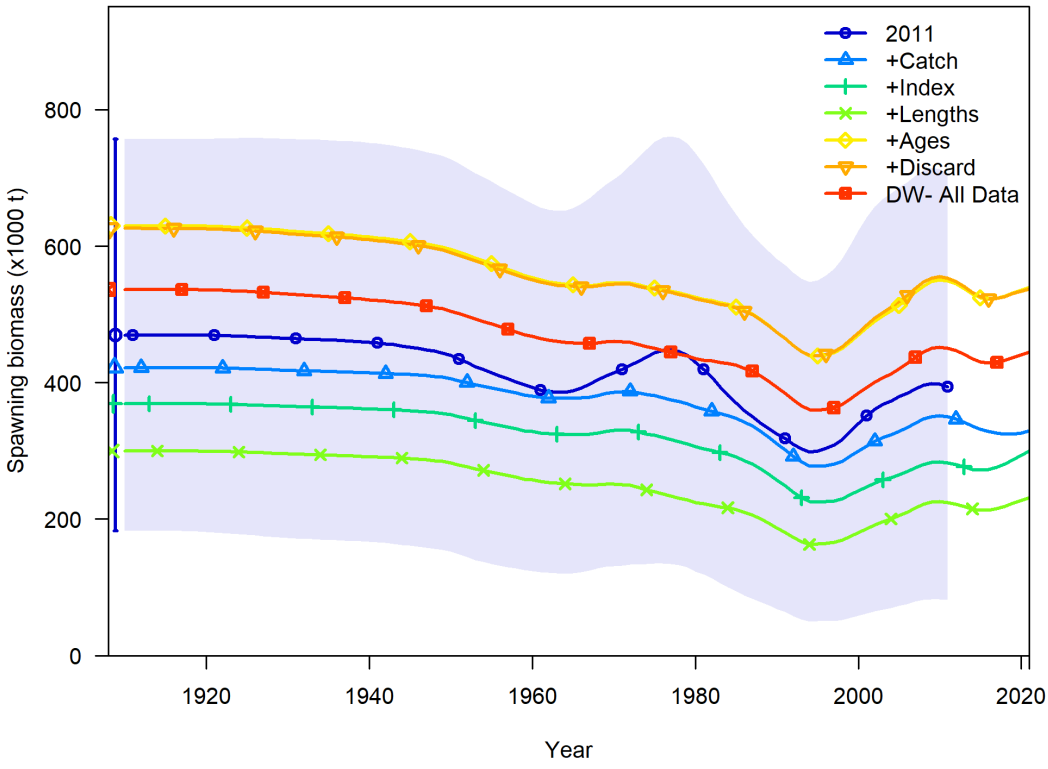


Figure 78: All data updated through 2020 bridge comparison of estimated spawning biomass.

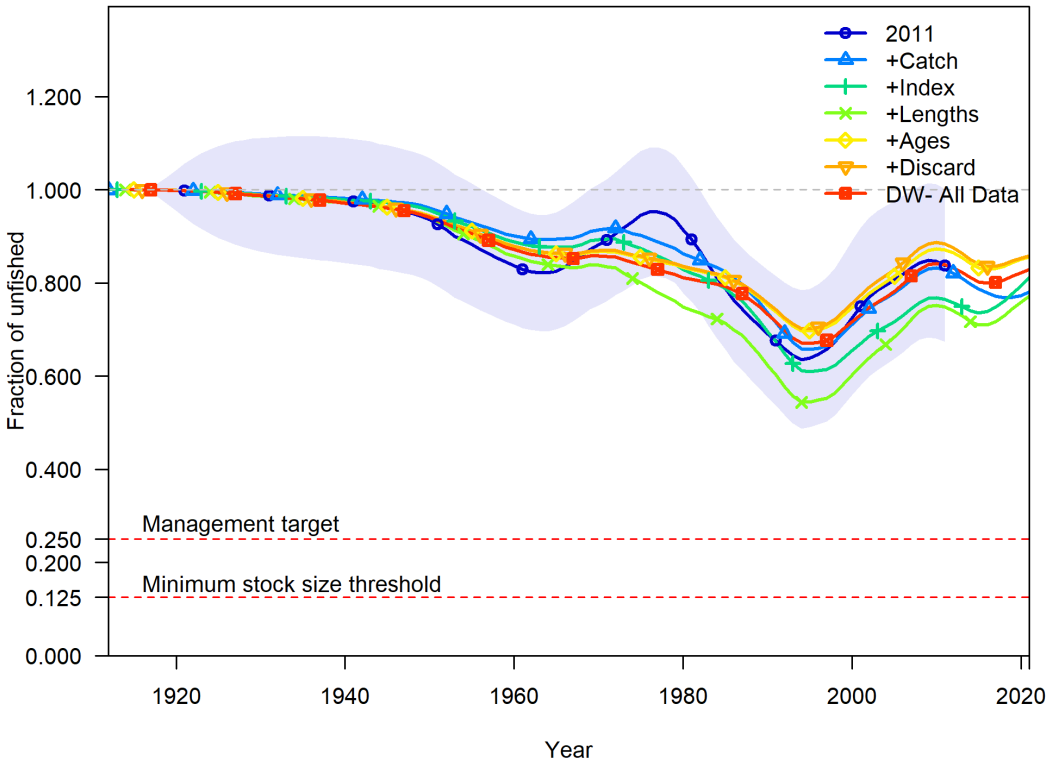


Figure 79: All data updated through 2020 bridge comparison of estimated fraction unfished.

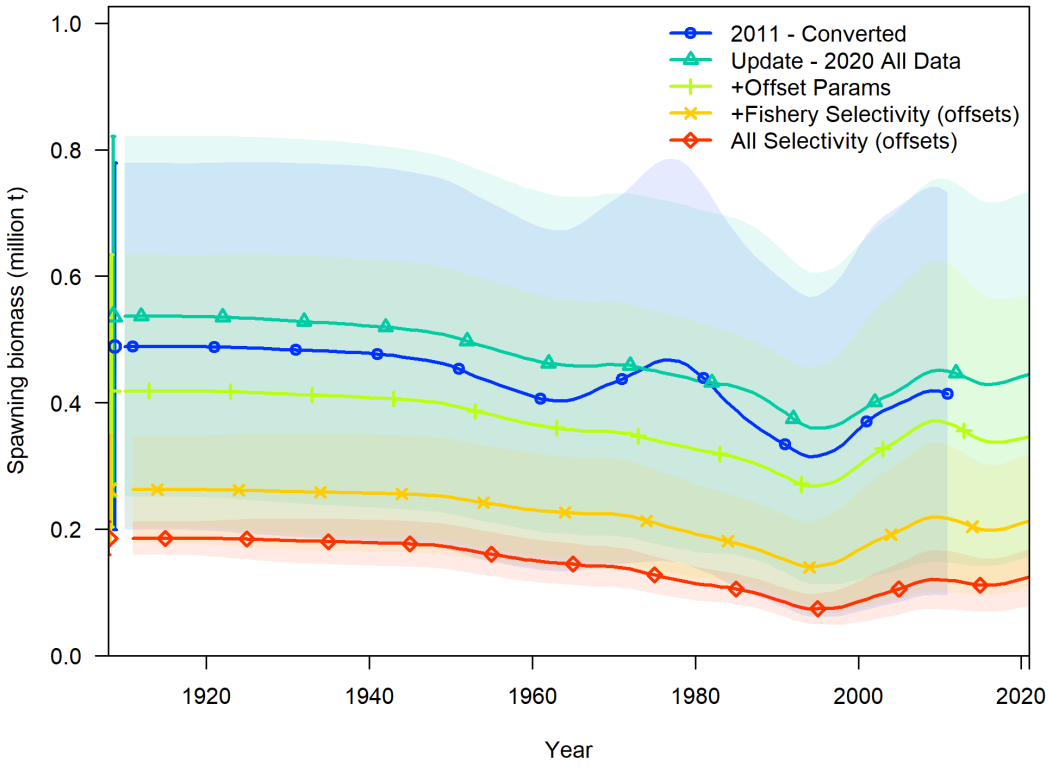


Figure 80: Estimated spawning biomass based on select structural changes and parameter updates.

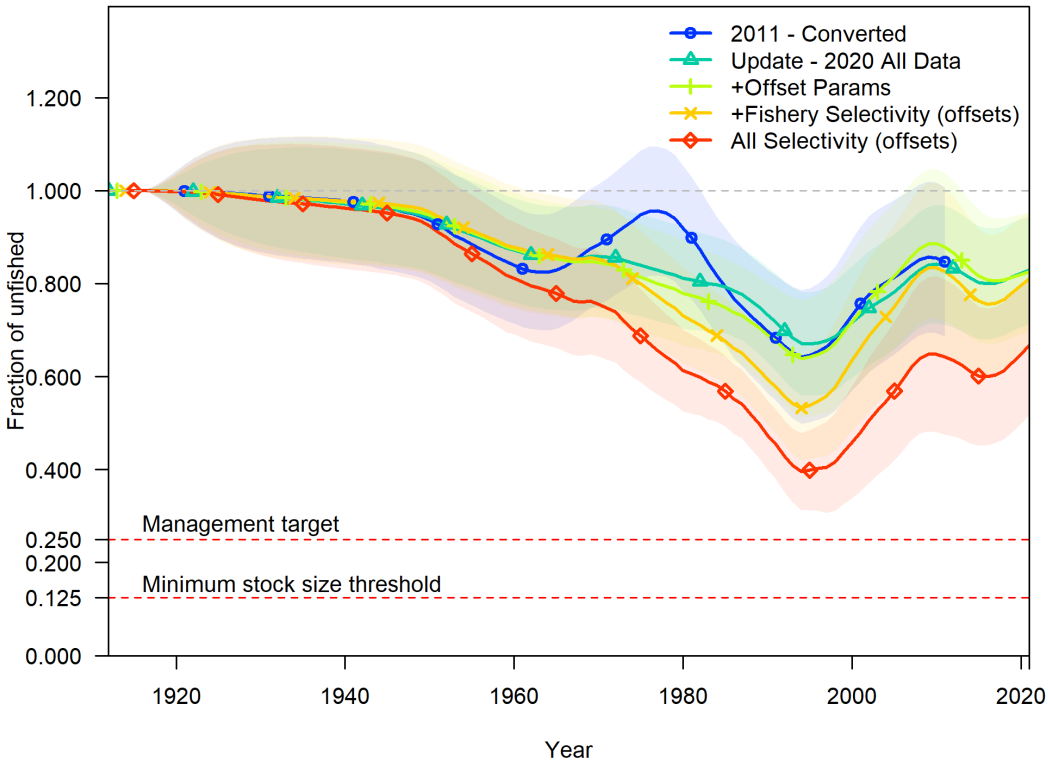


Figure 81: Estimated fraction of unfished based on select structural changes and parameter updates.

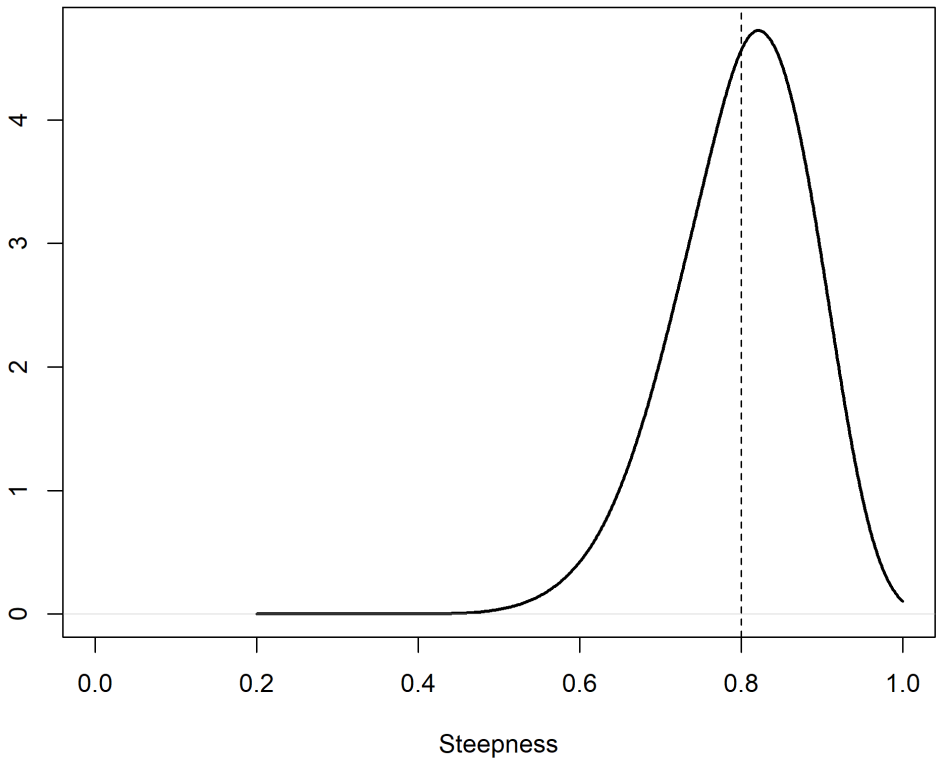


Figure 82: Prior distribution for steepness.

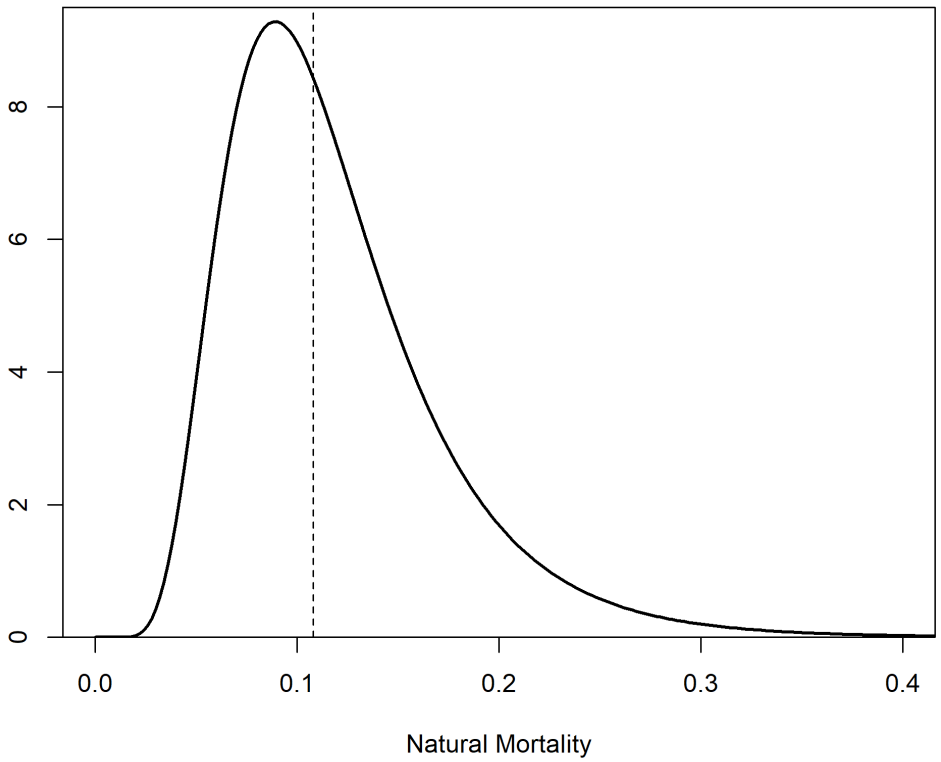


Figure 83: Prior distribution for natural mortality.

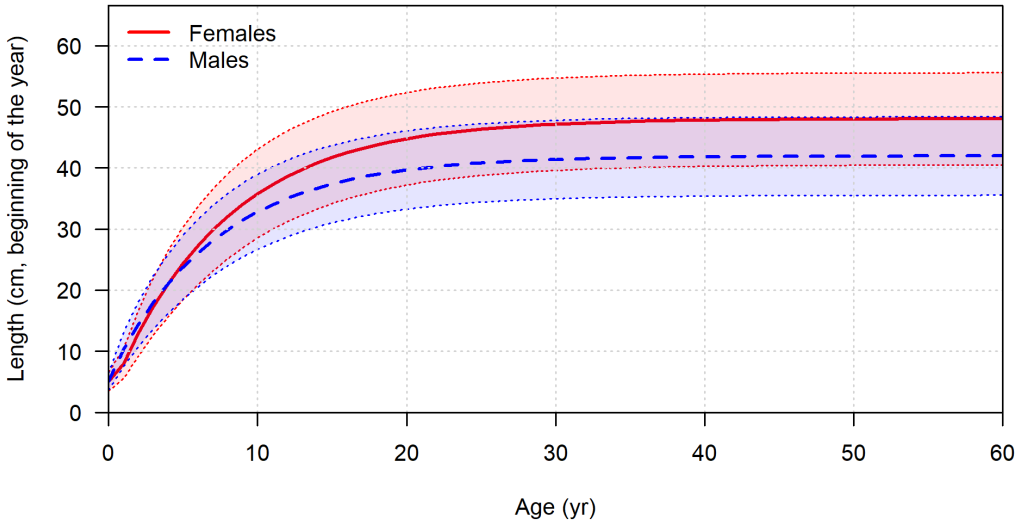


Figure 84: Model estimated length-at-age in the beginning of the year. Shaded area indicates 95 percent distribution of length-at-age around the estimated growth curve.

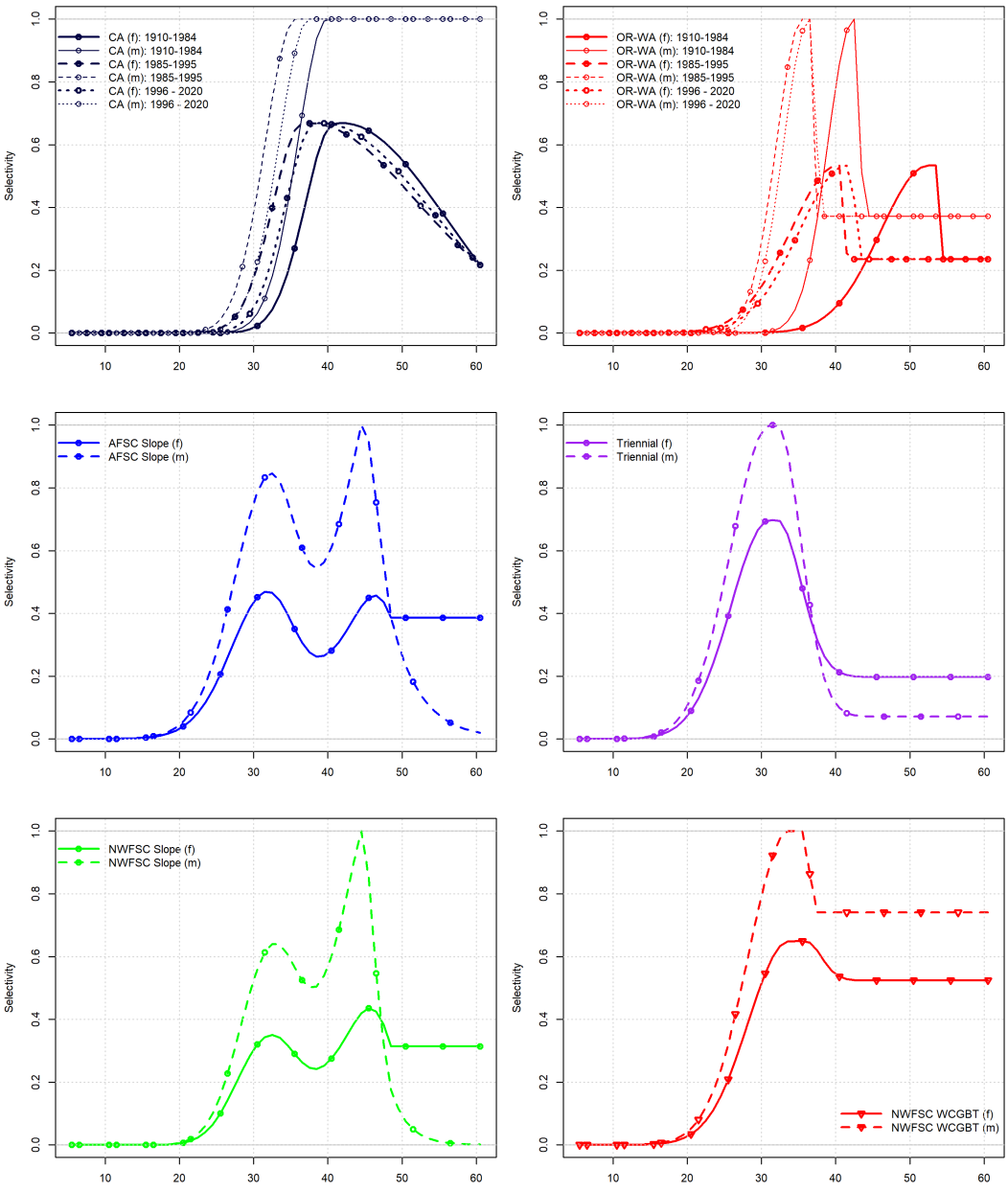


Figure 85: Selectivity by fleet.

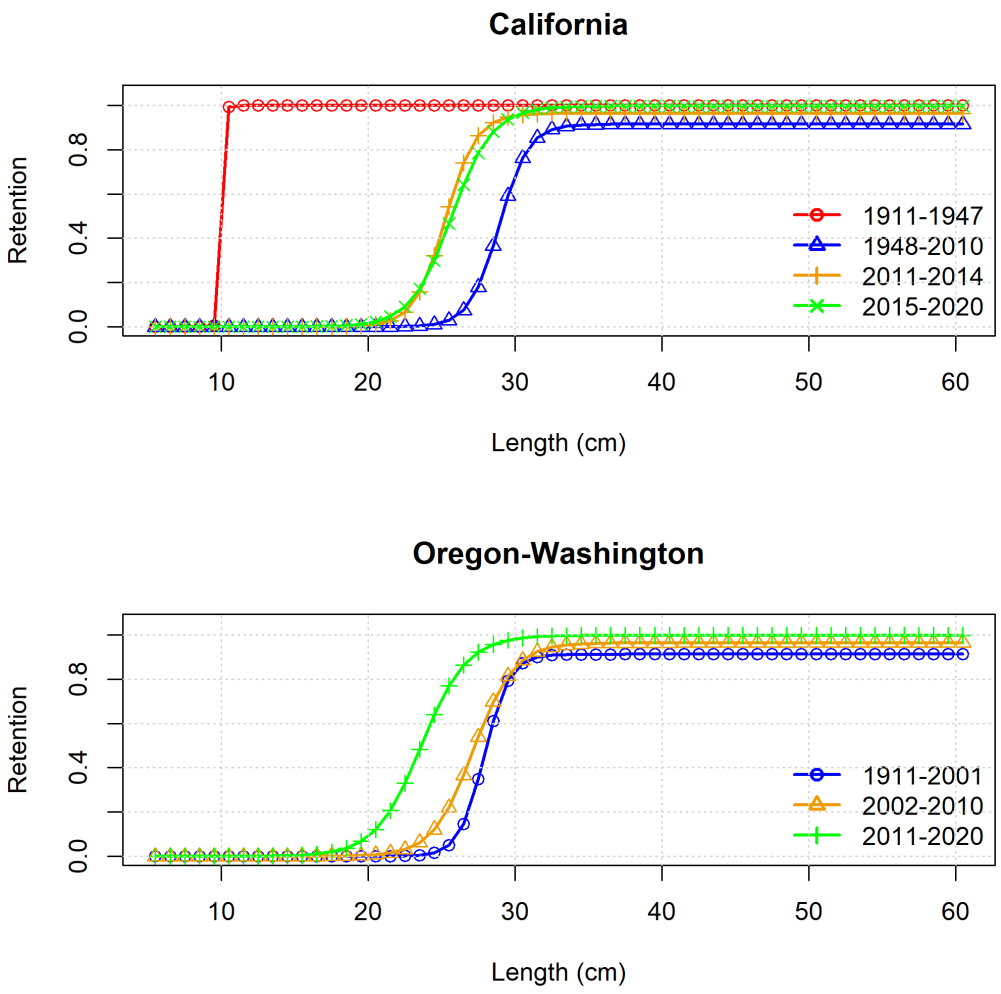


Figure 86: Estimated retention curves by time block.

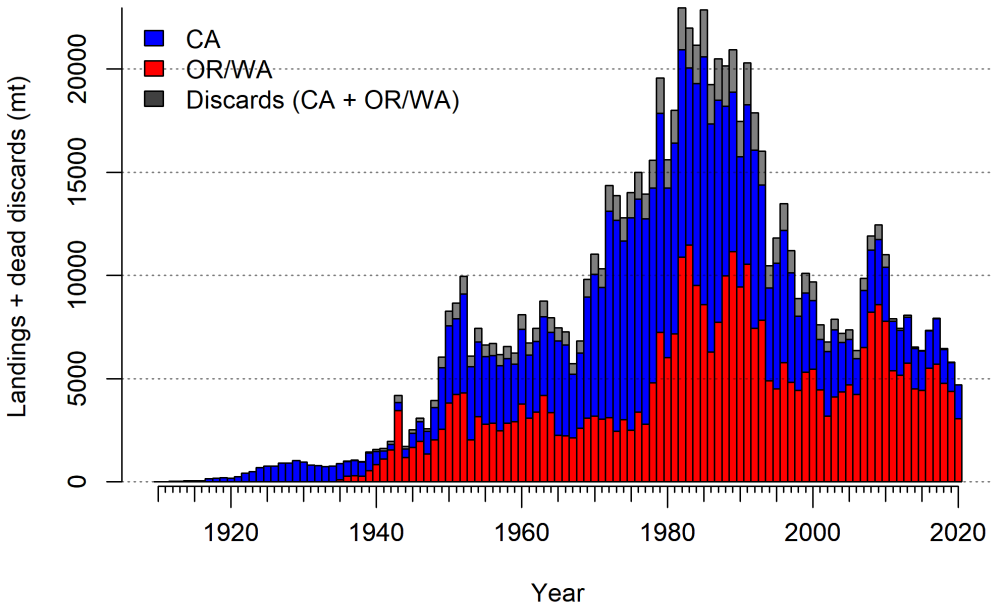


Figure 87: Landings plus estimated discards in metric tons.

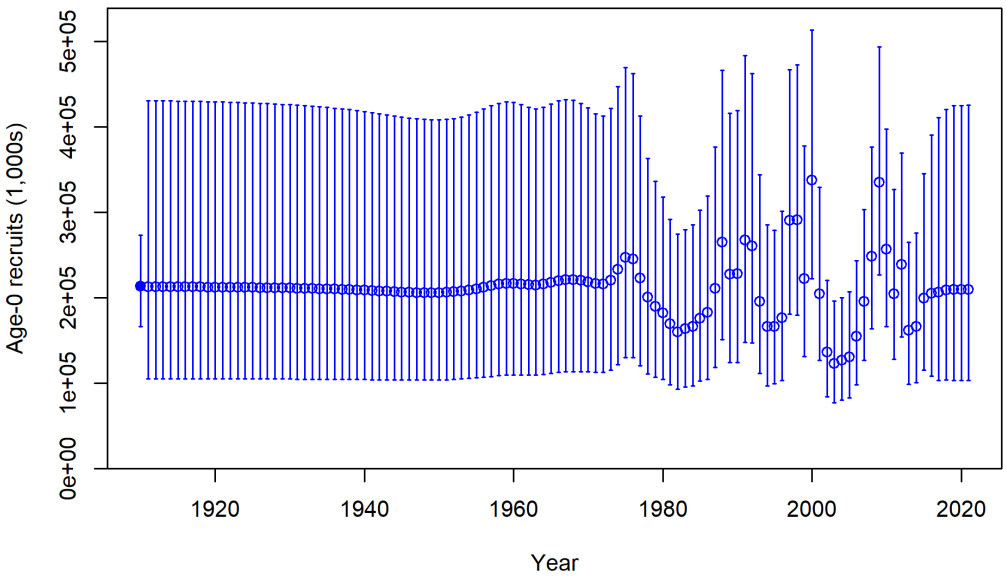


Figure 88: Estimated time series of age-0 recruits (1000s).

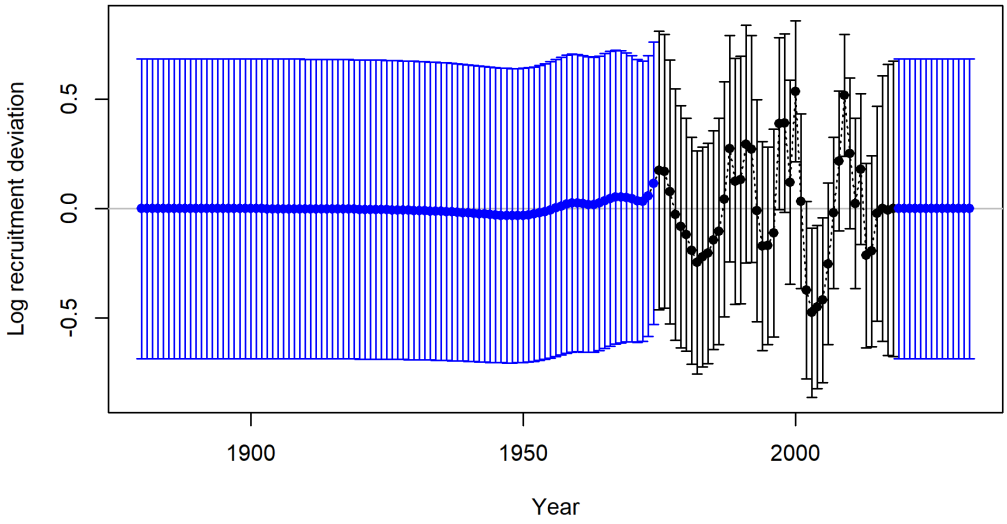


Figure 89: Estimated time series of recruitment deviations.

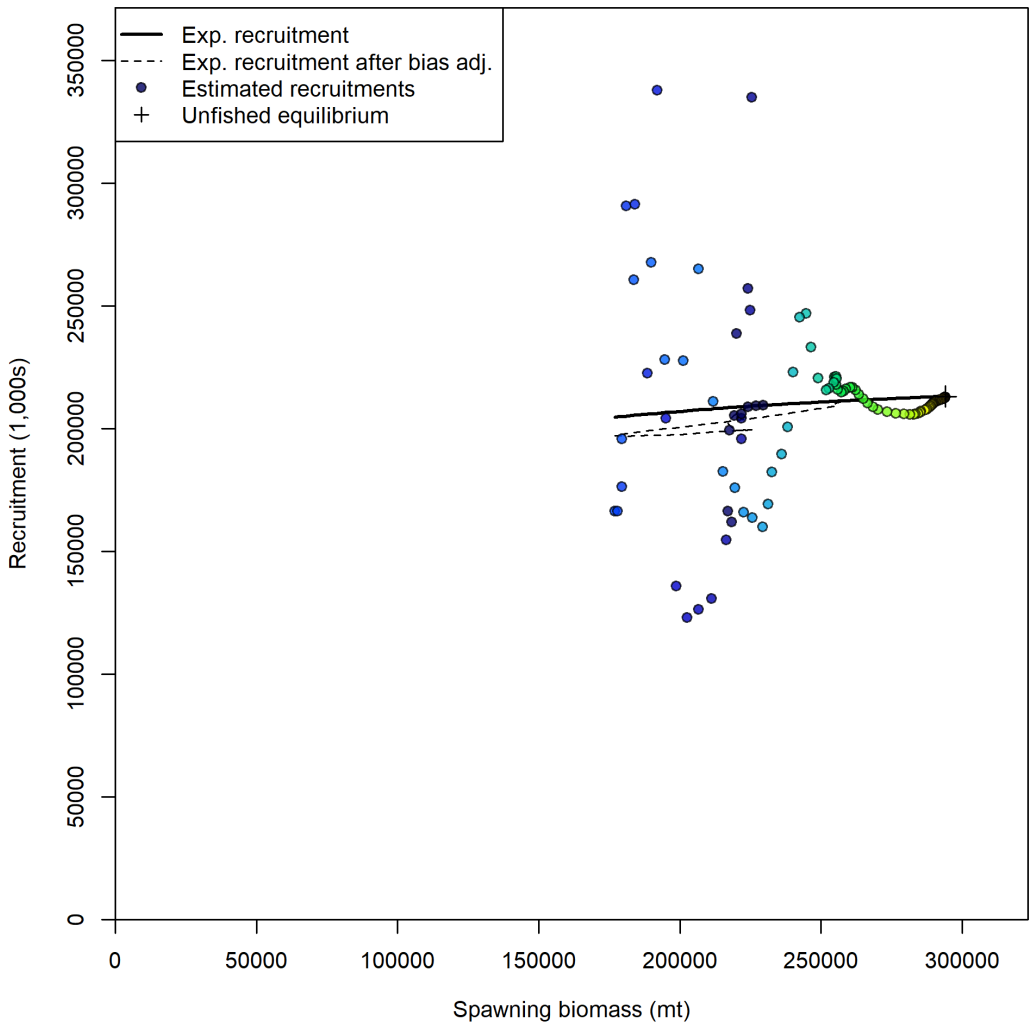


Figure 90: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

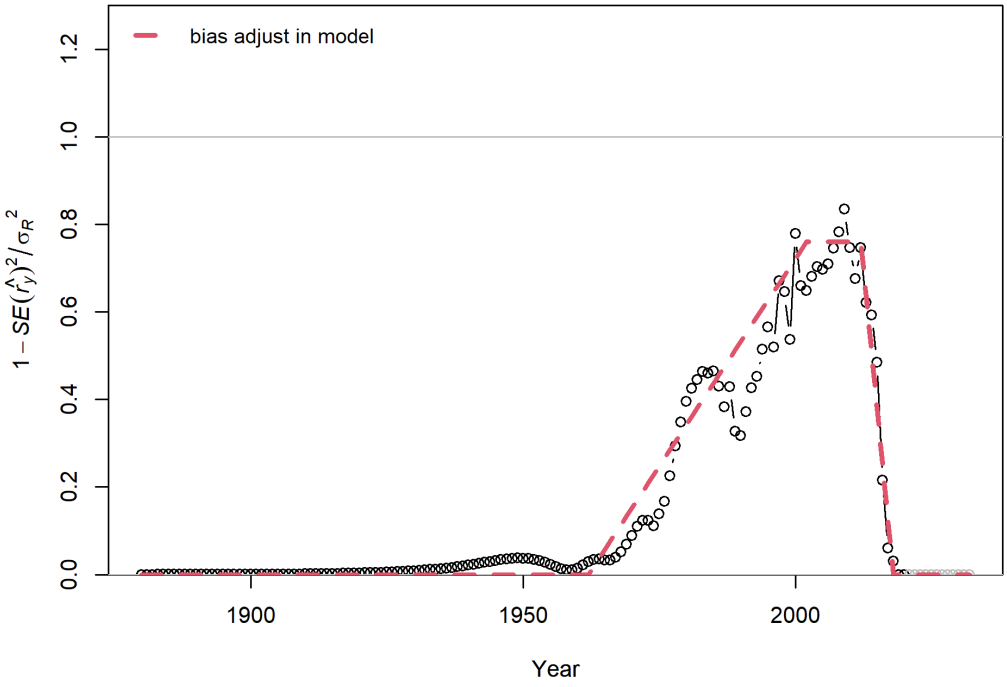


Figure 91: Recruitment bias adjustment applied in the base model.

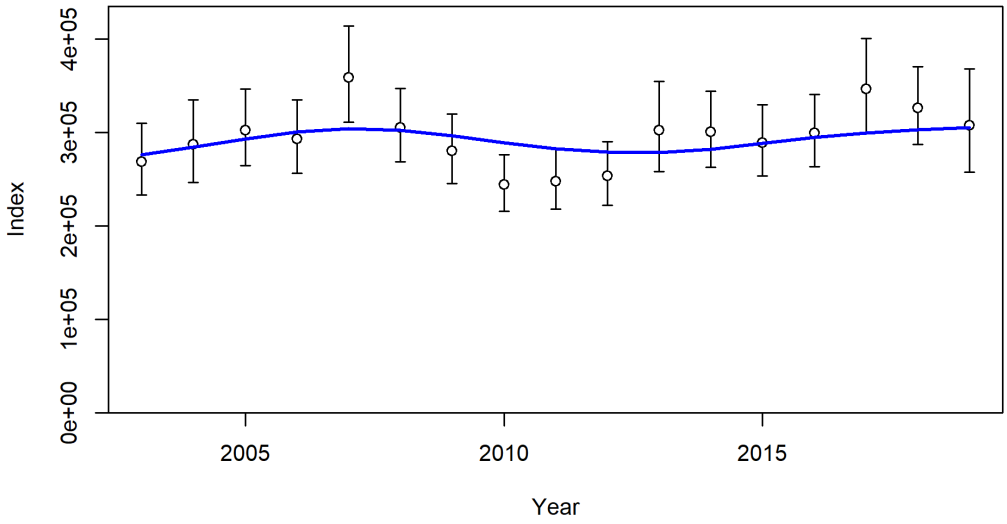


Figure 92: Fit to the NWFSC WCGBTS index of abundance.

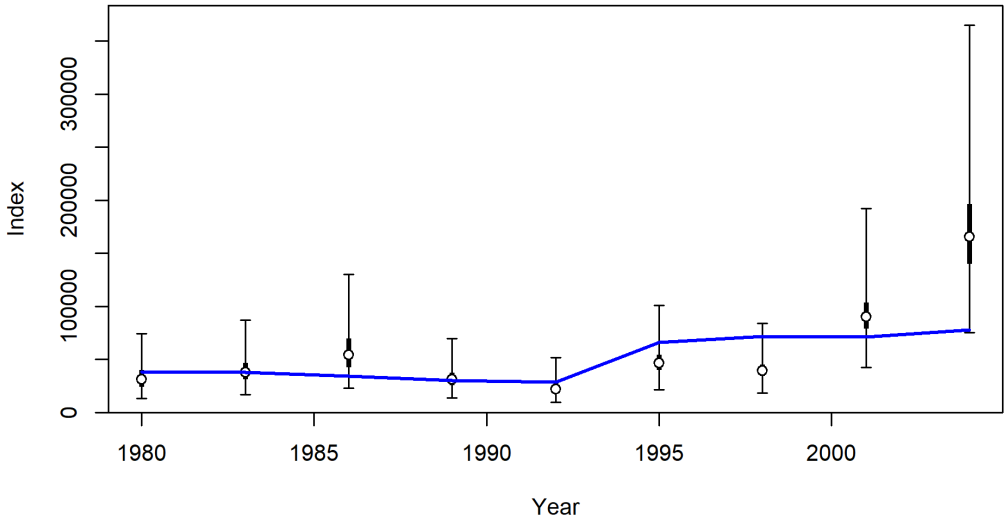


Figure 93: Fit to the Triennial survey index of abundance. Thicker lines indicate input uncertainty before the addition of estimated additional uncertainty parameter.

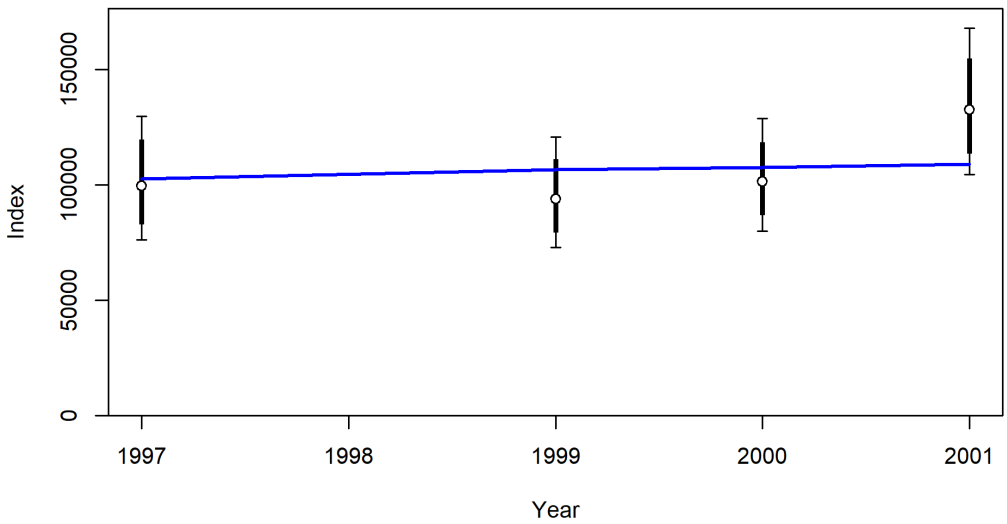


Figure 94: Fit to the AFSC Slope survey index of abundance. Thicker lines indicate input uncertainty before the addition of estimated additional uncertainty parameter.

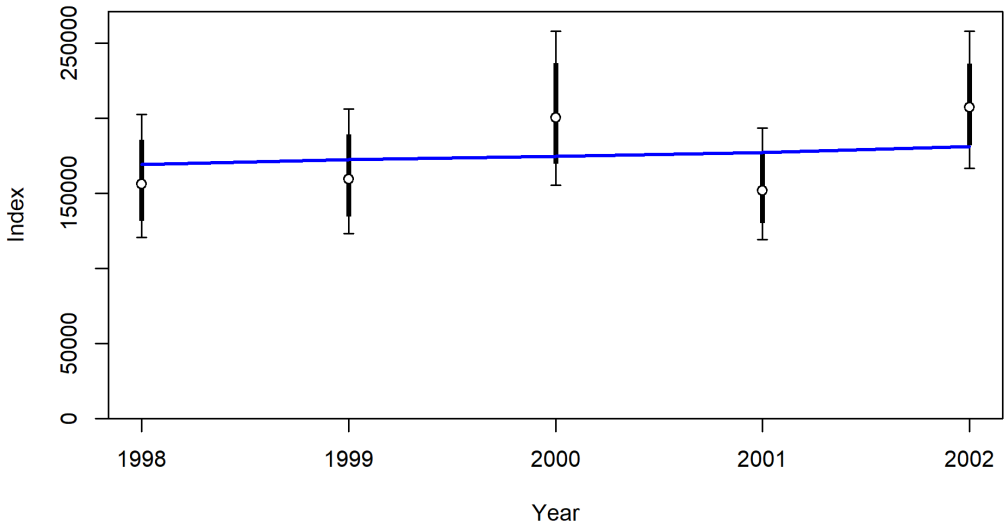


Figure 95: Fit to the NWFSC Slope survey index of abundance. Thicker lines indicate input uncertainty before the addition of estimated additional uncertainty parameter.

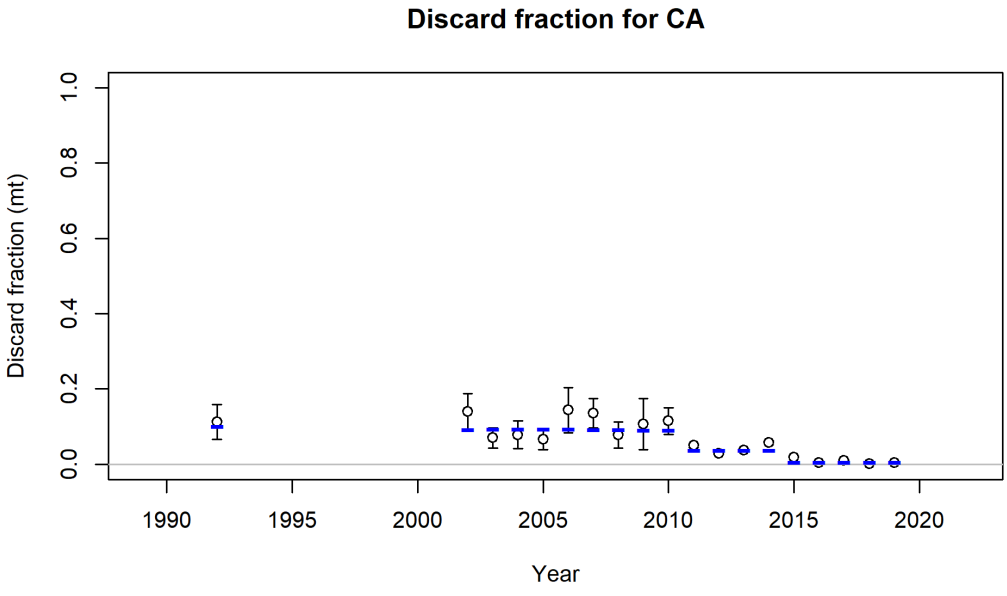


Figure 96: Fit to the annual discard rates for the California fleet.

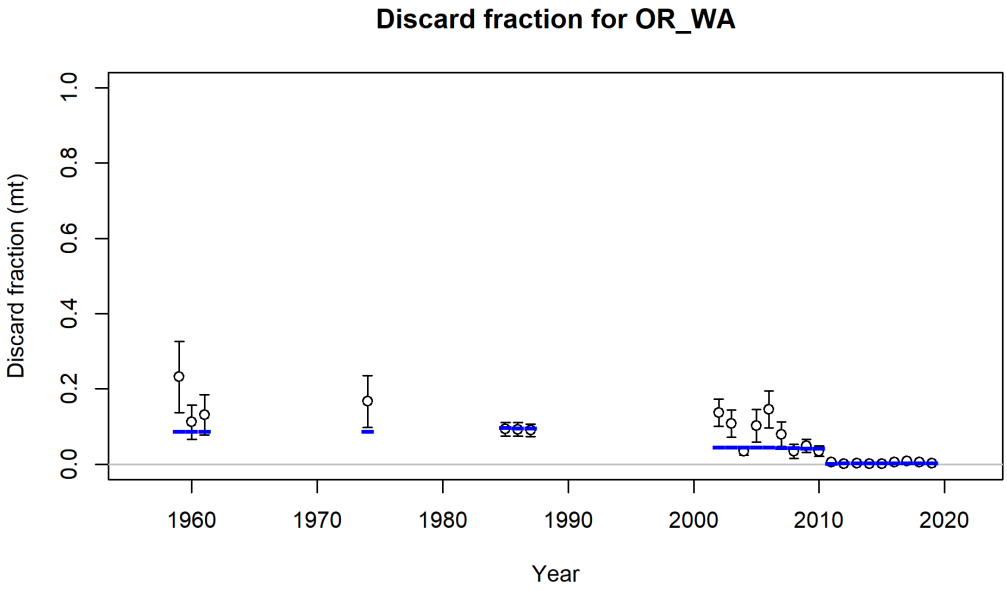


Figure 97: Fit to the annual discard rates for the Oregon/Washington fleet.

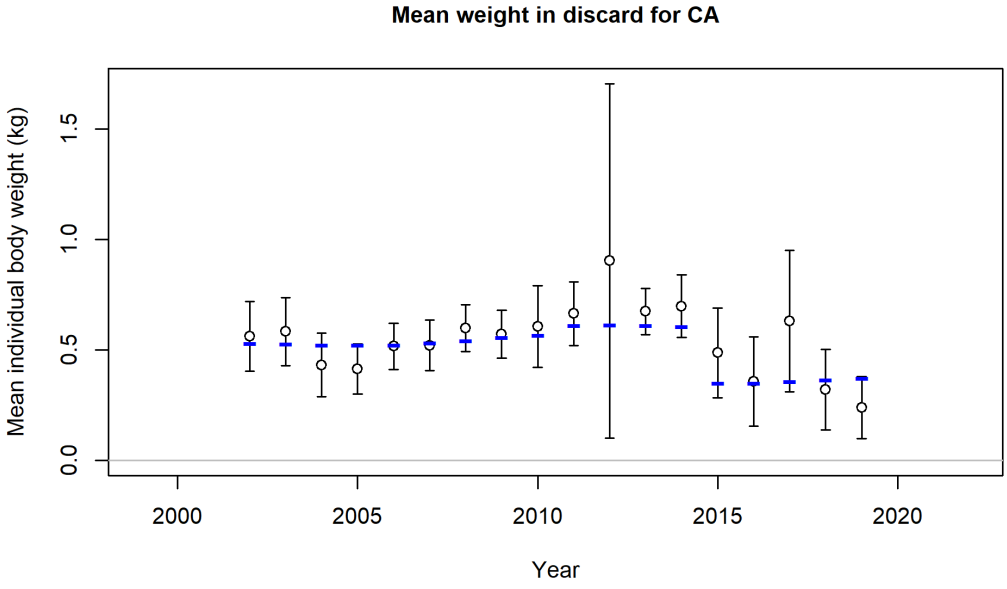


Figure 98: Fit to the annual mean body weight observations for the California fleet.

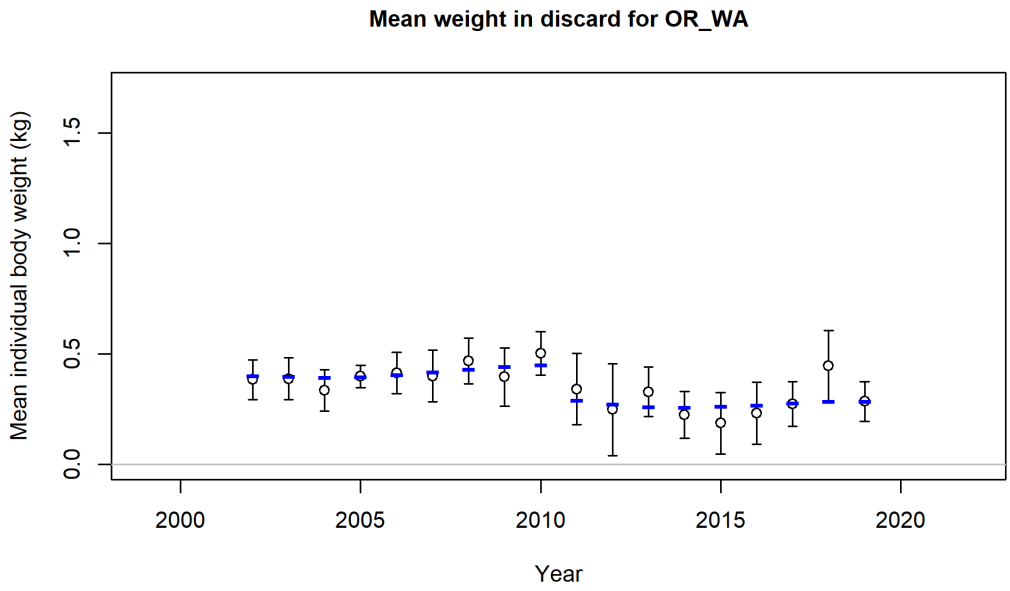


Figure 99: Fit to the annual mean body weight observations for the Oregon/Washington fleet.

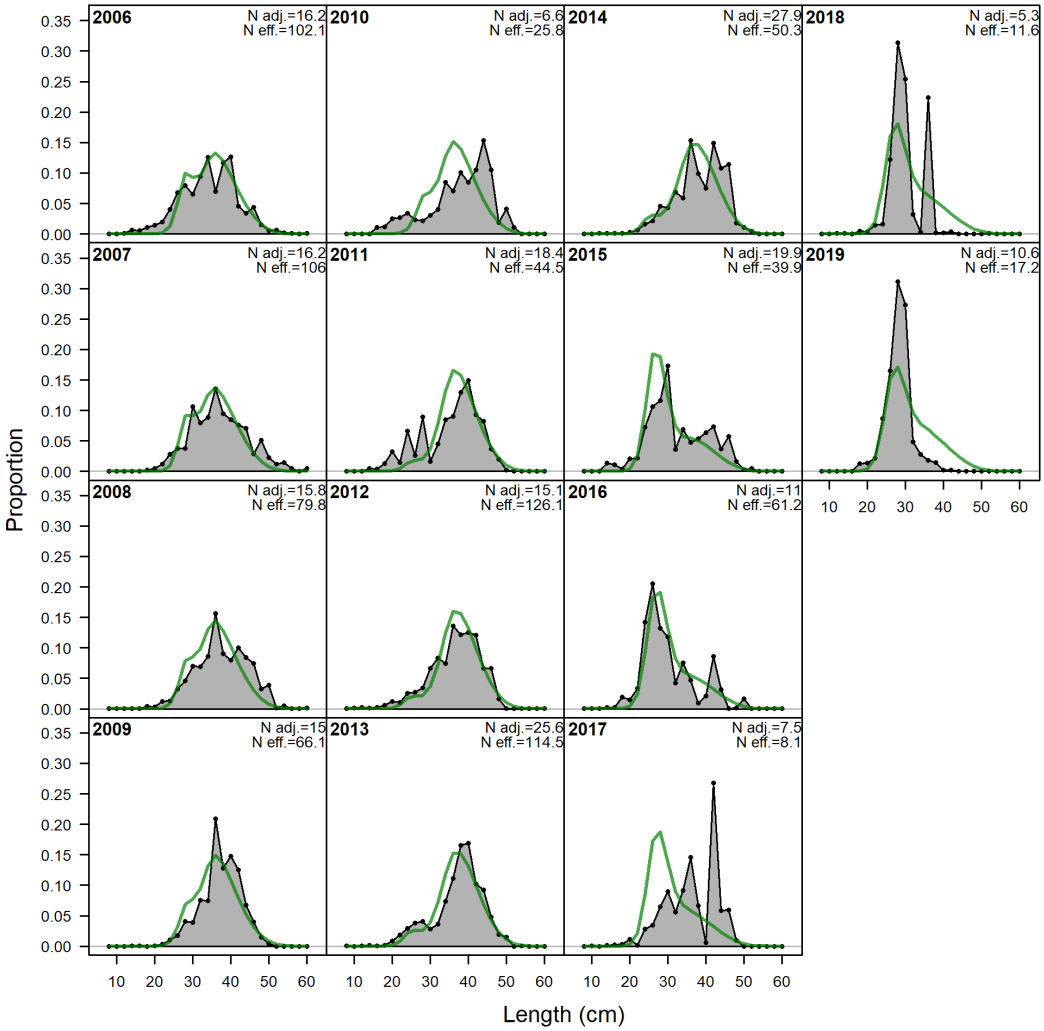


Figure 100: Fit to the annual length composition of discarded fish for the California fleet.

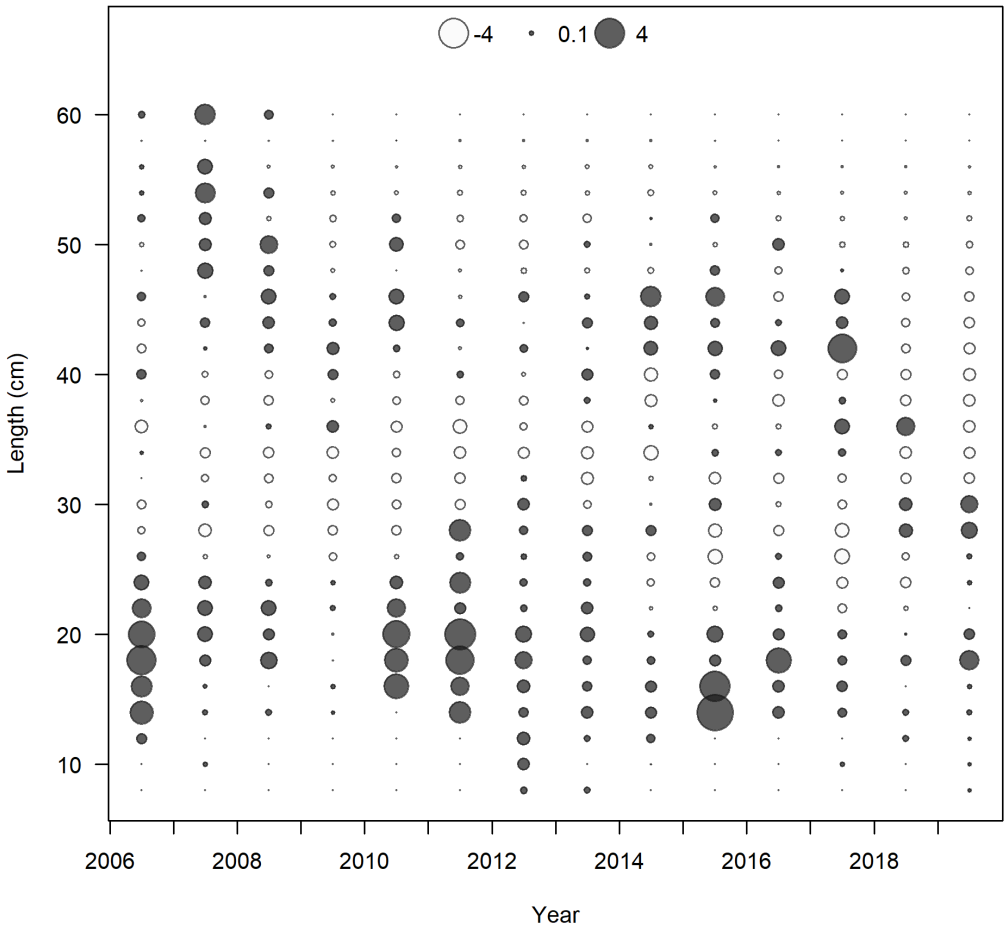


Figure 101: Pearson residuals to annual length composition of discarded fish for the California fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

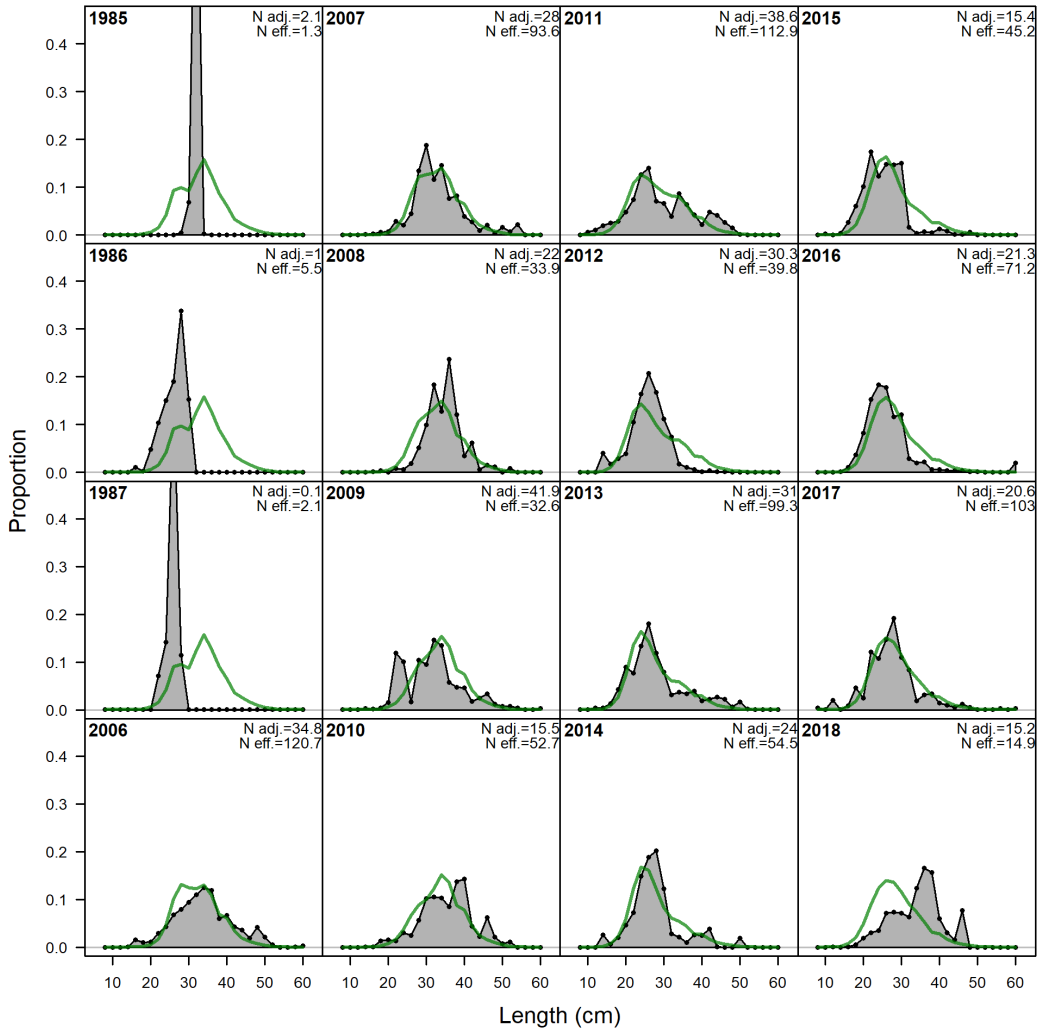


Figure 102: Fit to the annual length composition of discarded fish for the Oregon/Washington fleet.

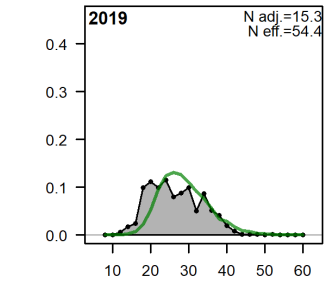


Figure 103: Fit to the annual length composition of discarded fish for the Oregon/Washington fleet.

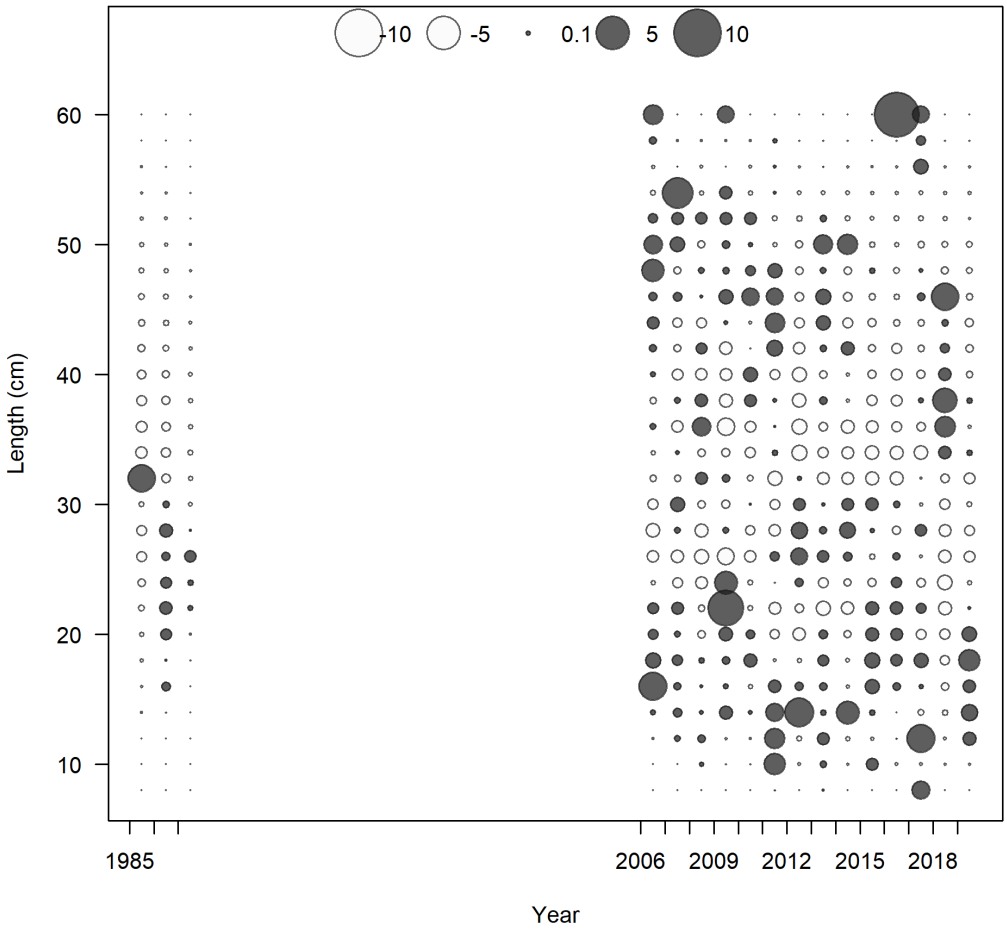


Figure 104: Pearson residuals to annual length composition of discarded fish for the Oregon/Washington fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

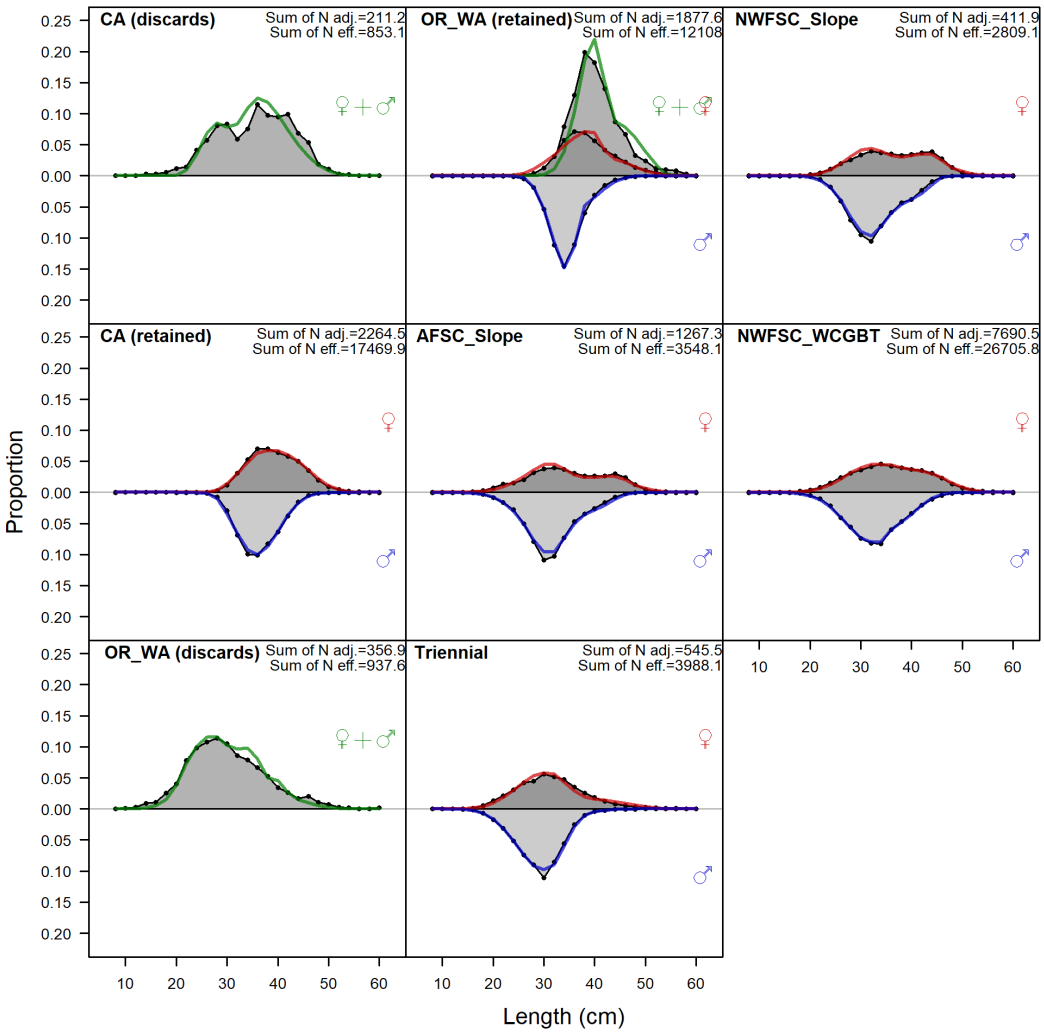


Figure 105: Aggregated length composition fit across time by fleet.

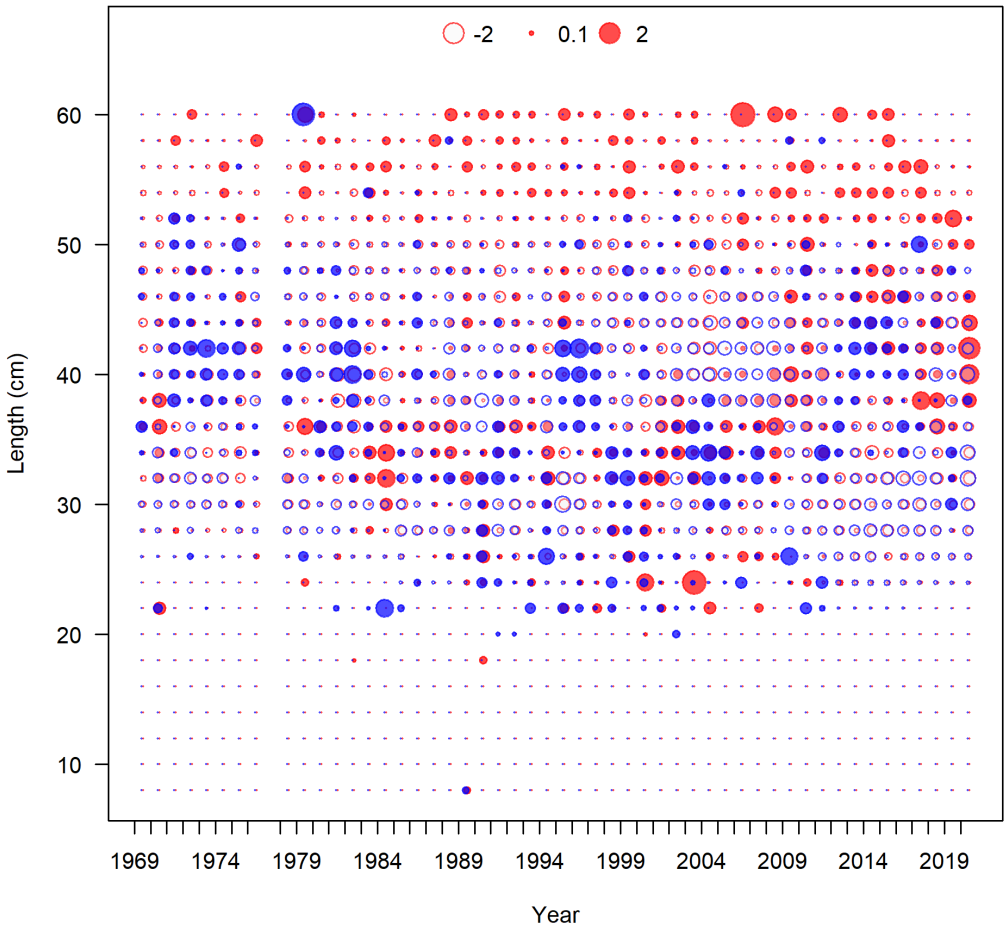


Figure 106: Pearson residuals to annual length composition for the California fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

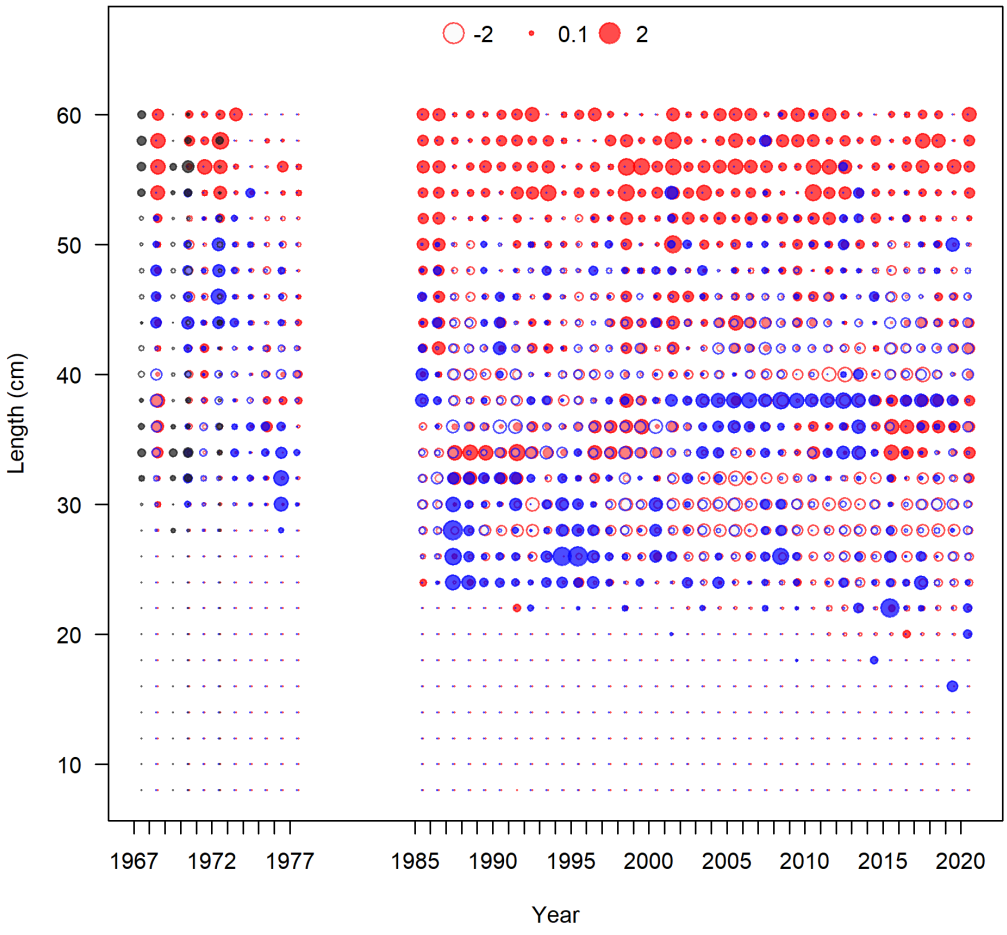


Figure 107: Pearson residuals to annual length composition for the Oregon/Washington fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

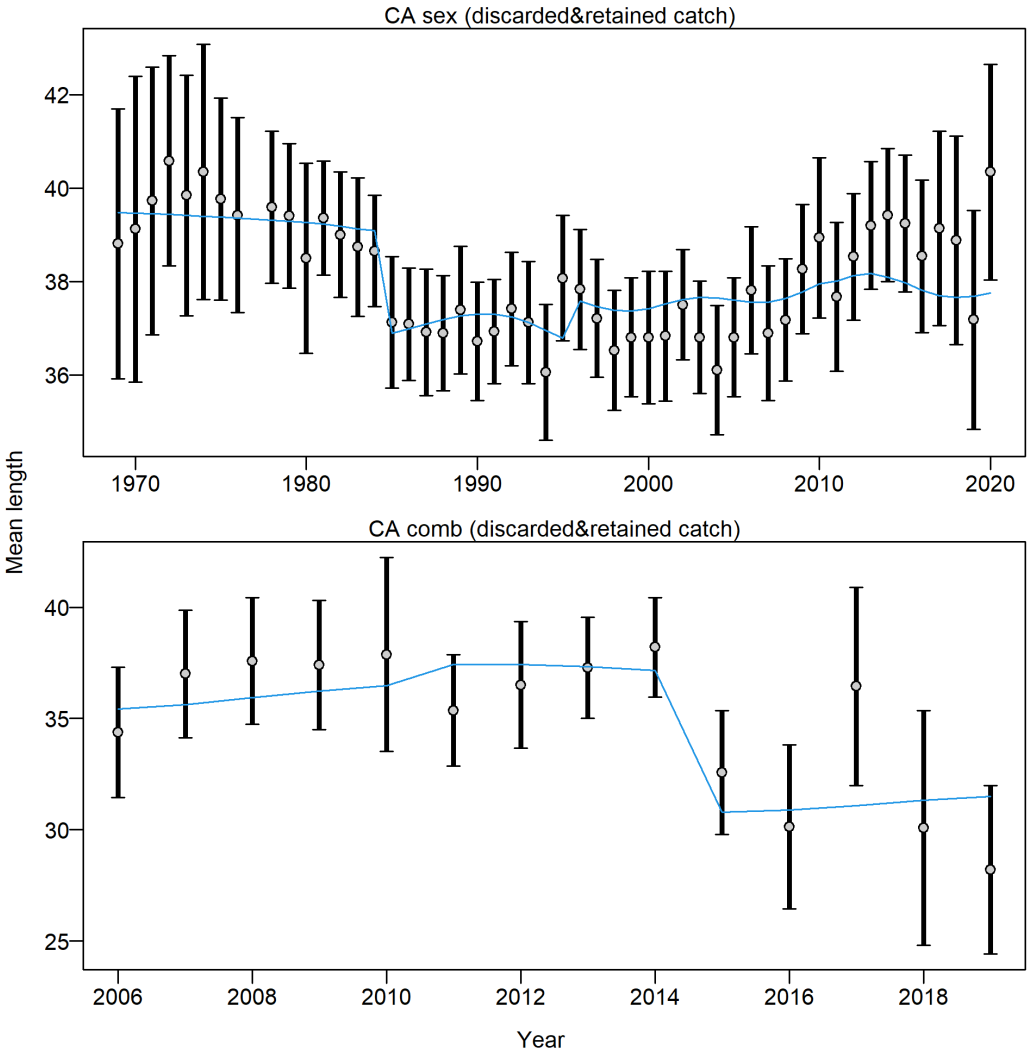


Figure 108: Mean length observations for the California fleet.

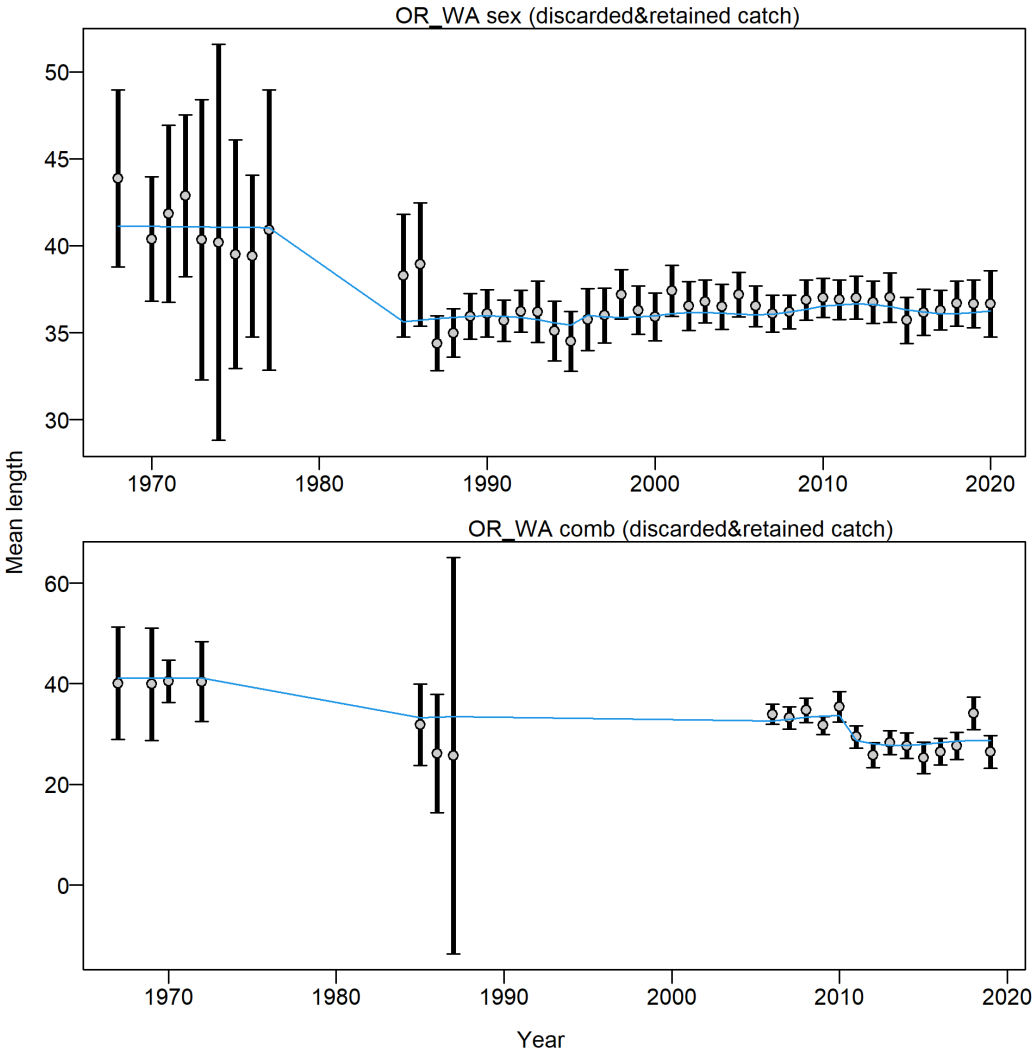


Figure 109: Mean length observations for the Oregon/Washington fleet.

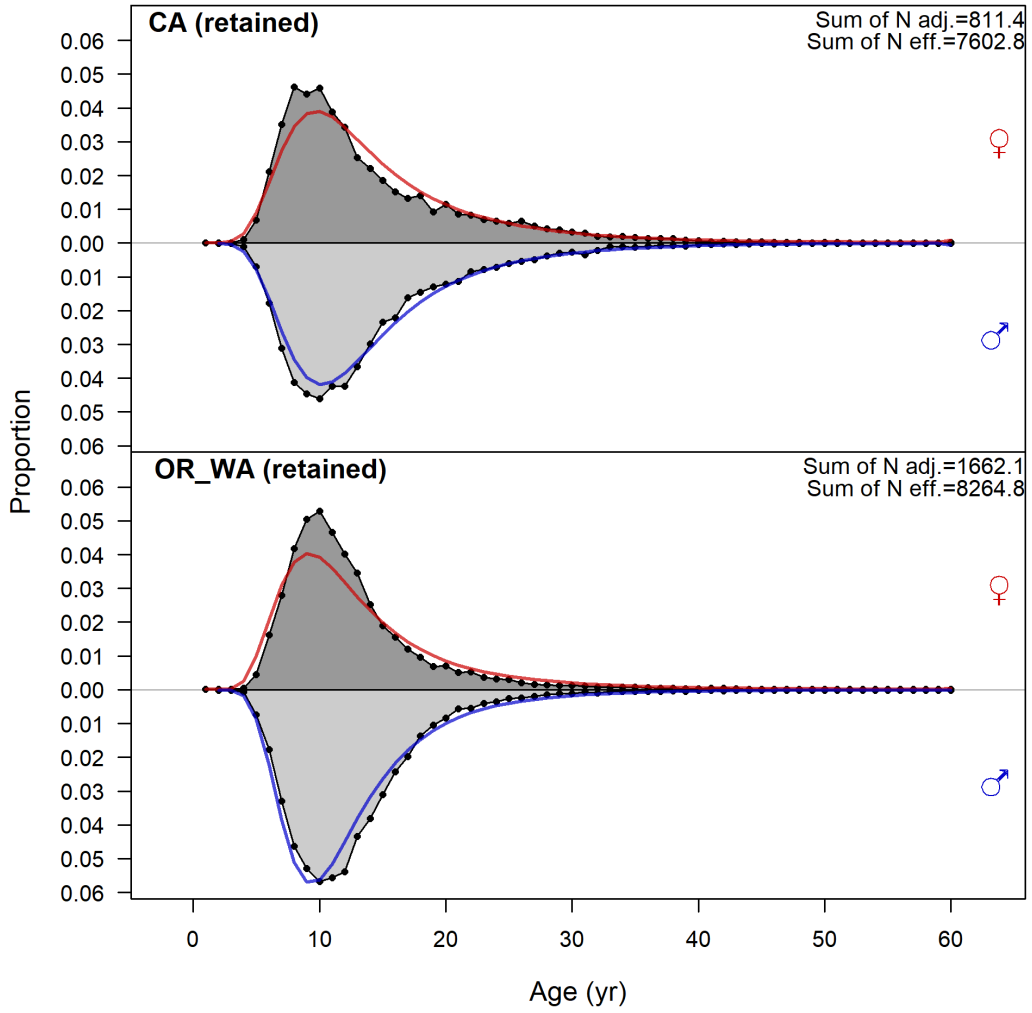


Figure 110: Aggregated age composition fit across time by fleet.

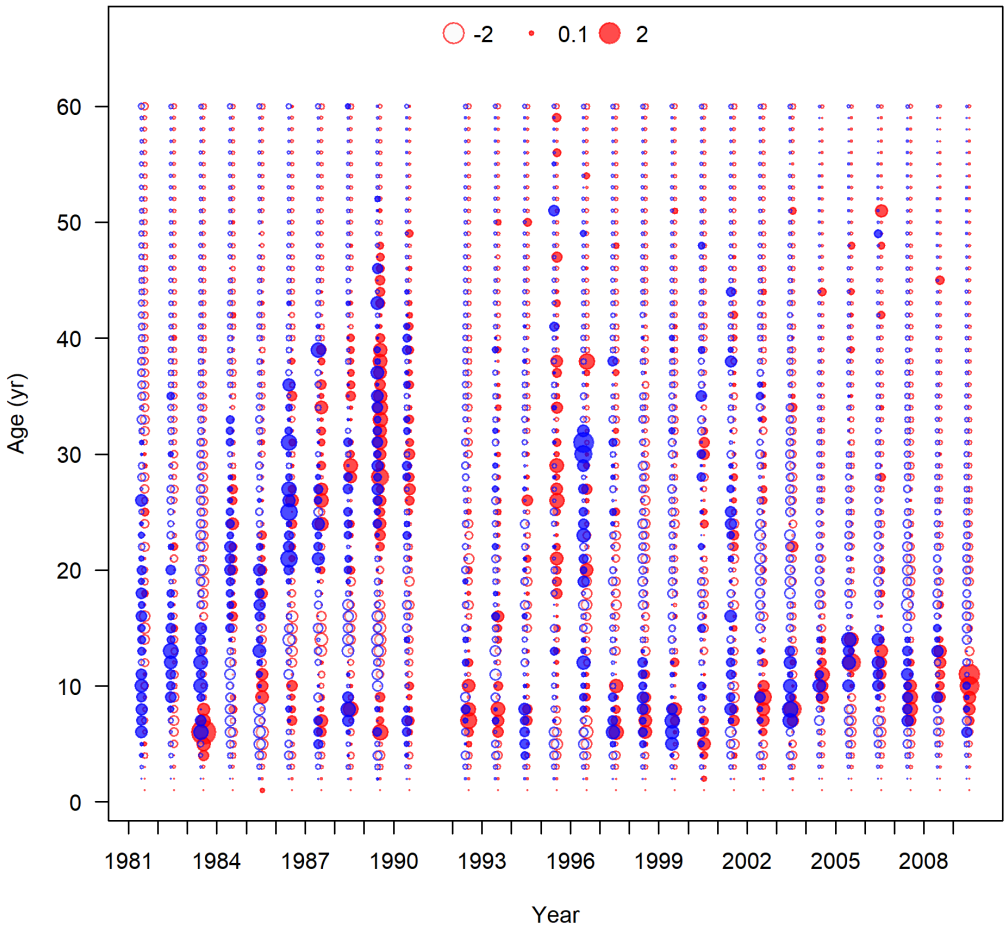


Figure 111: Pearson residuals to annual age composition for the California fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

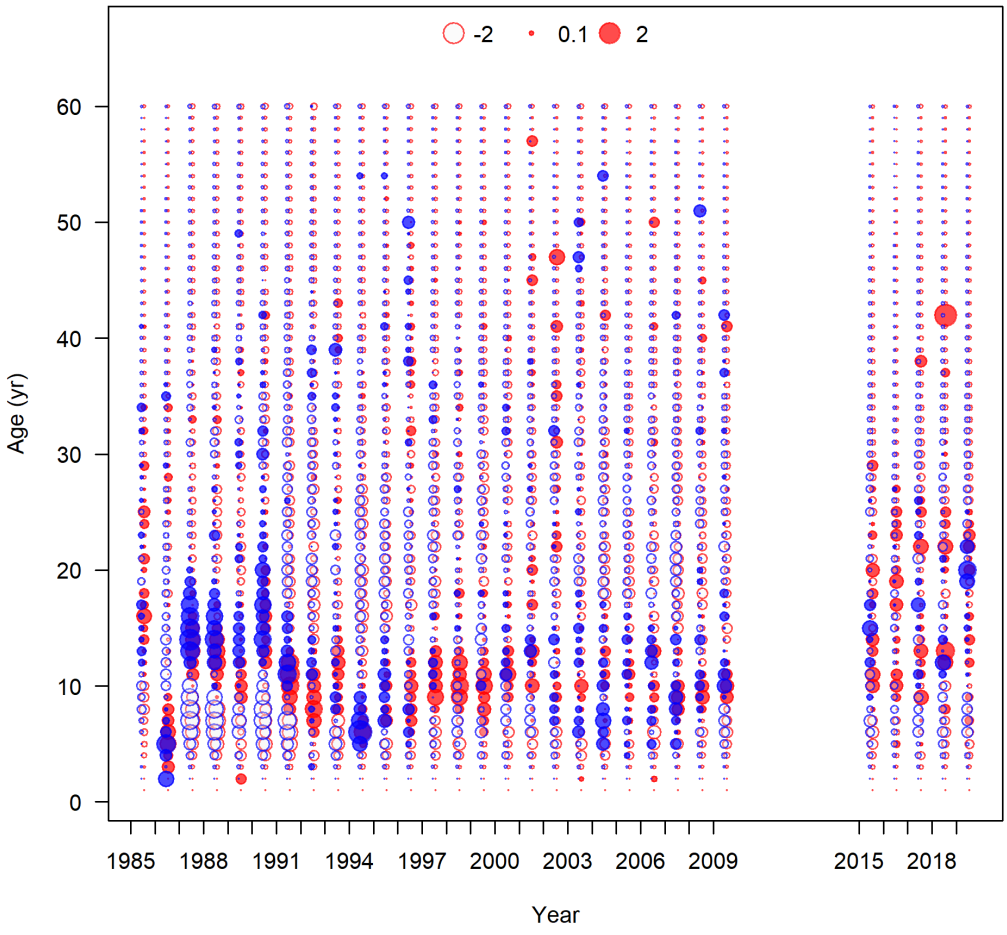


Figure 112: Pearson residuals to annual age composition for the Oregon/Washington fleet. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

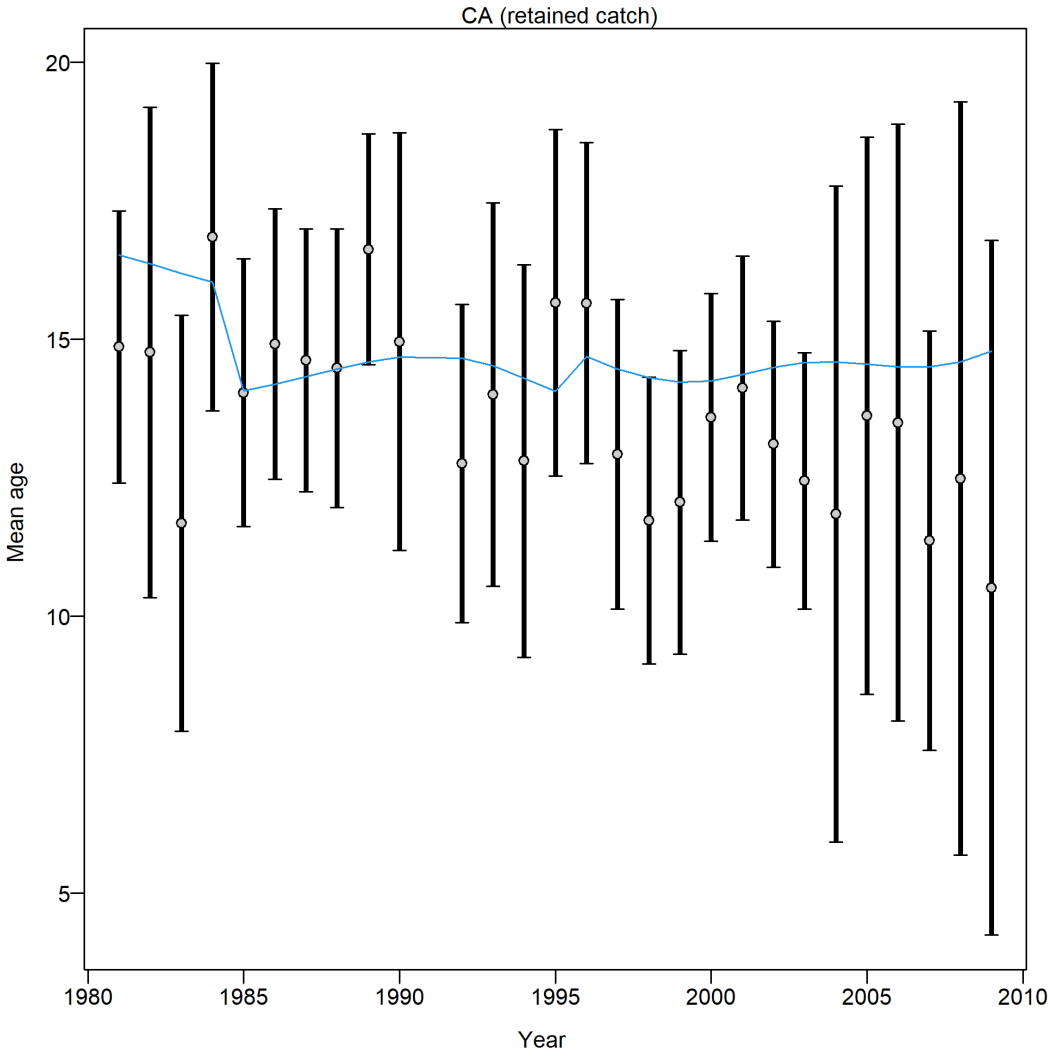


Figure 113: Mean age observations for the California fleet.

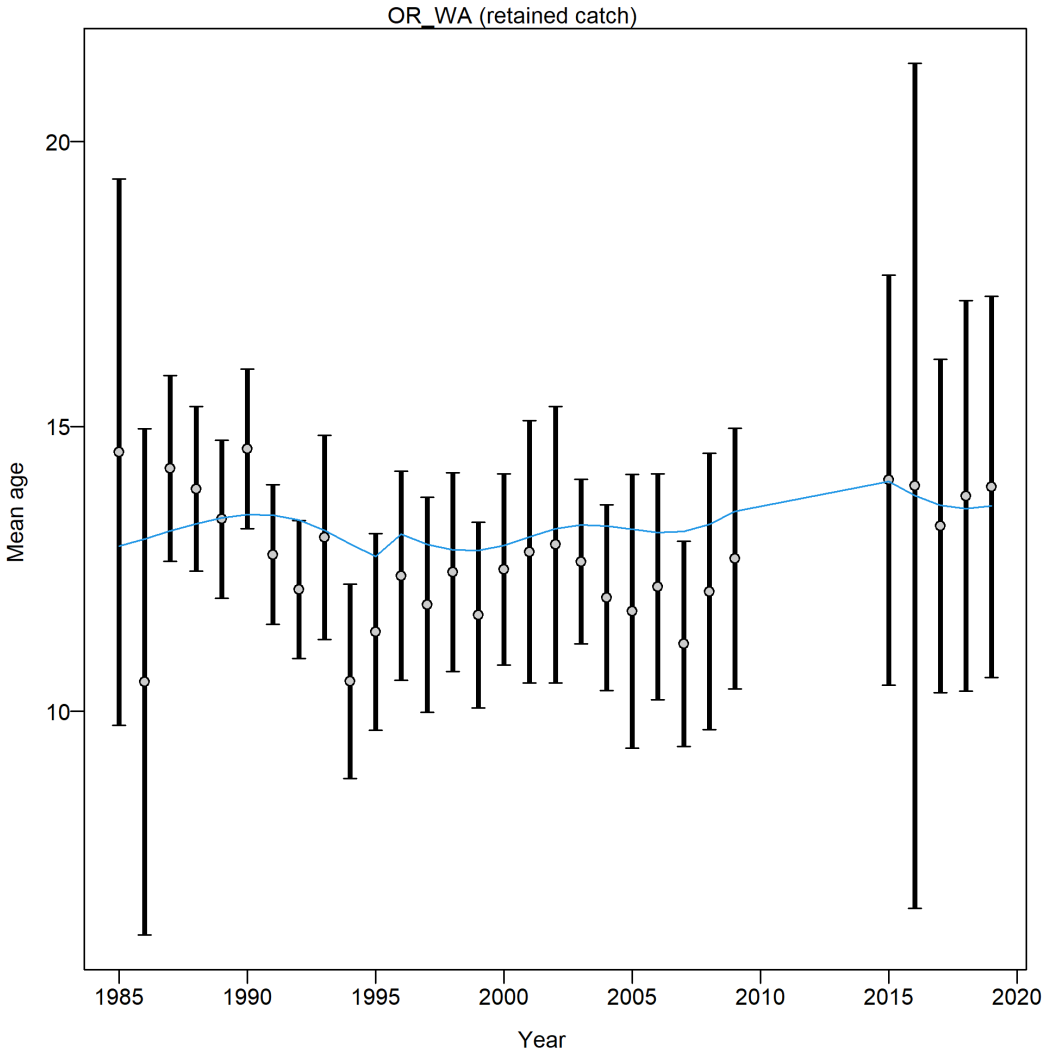


Figure 114: Mean age observations for the Oregon/Washington fleet.

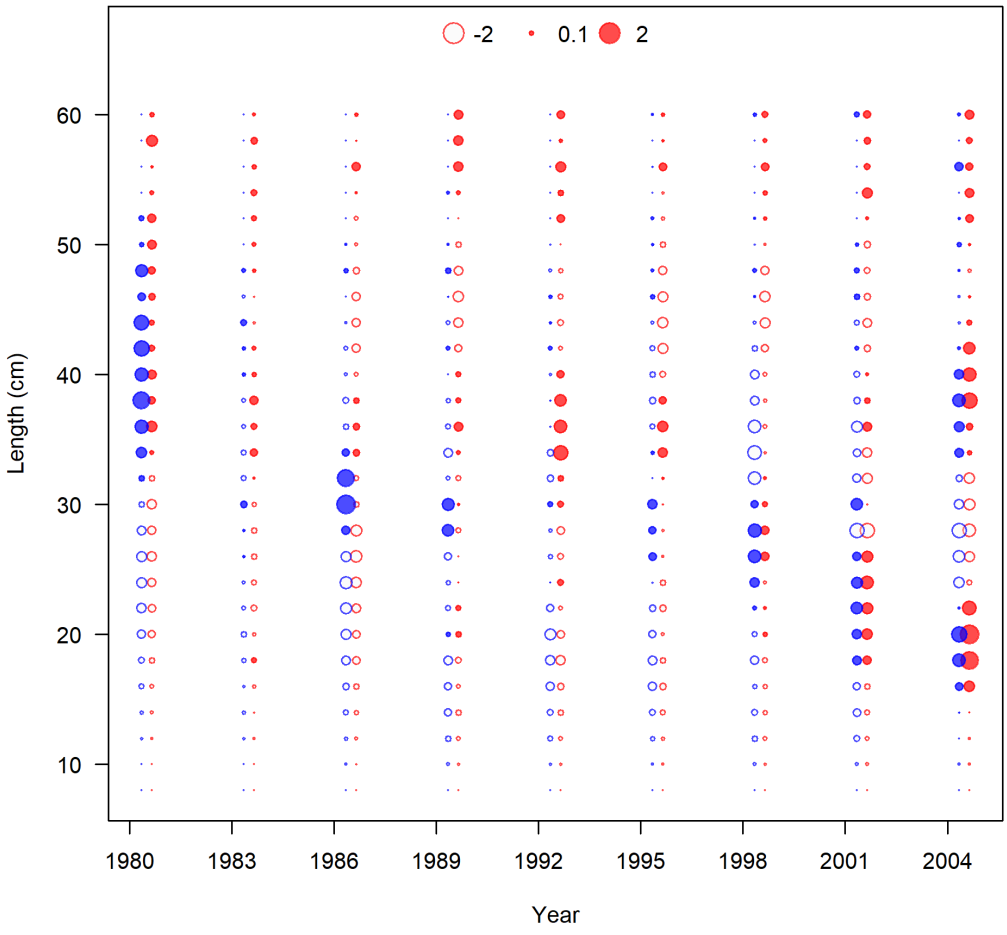


Figure 115: Pearson residuals to annual length composition for the Triennial survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

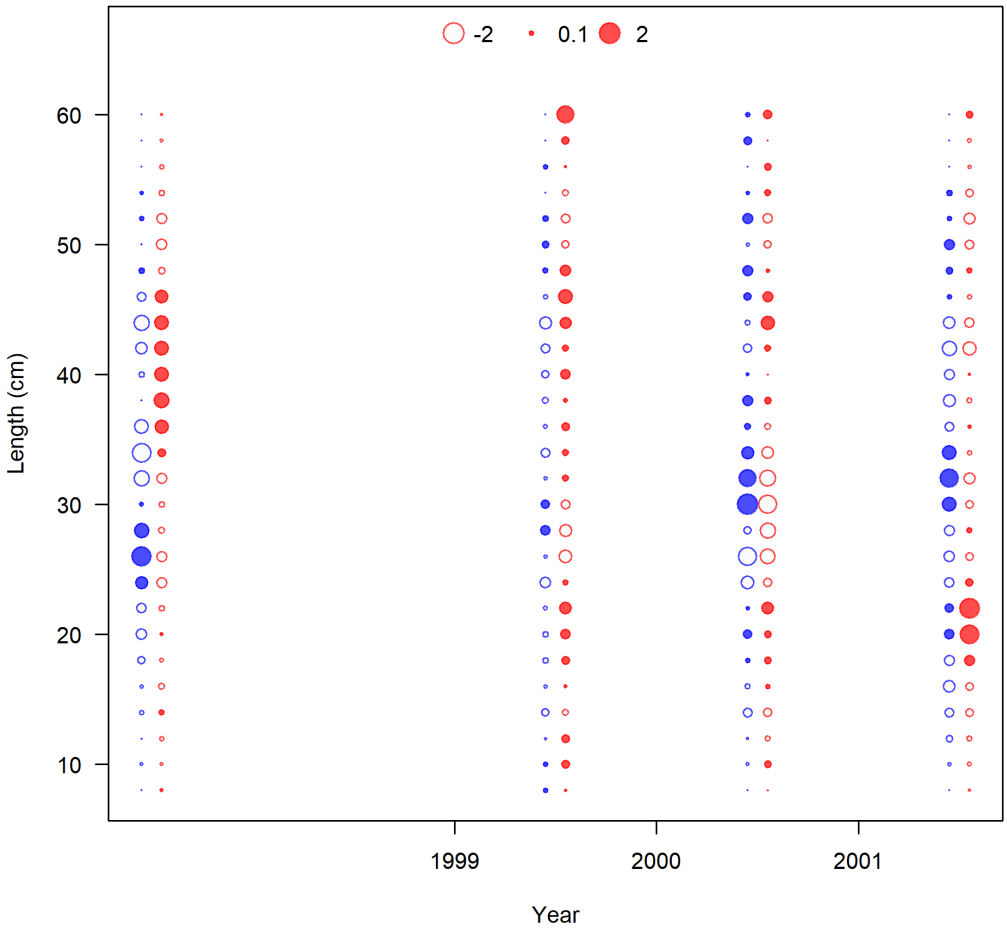


Figure 116: Pearson residuals to annual length composition for the AFSC Slope survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

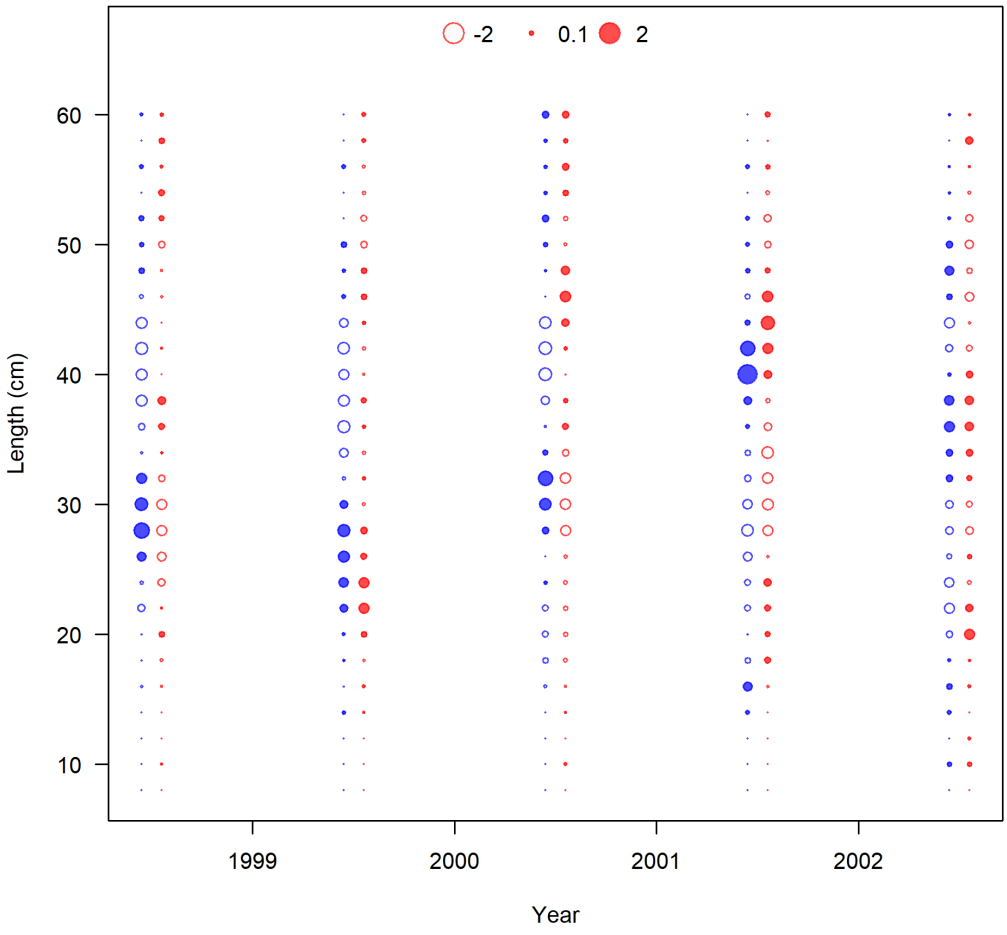


Figure 117: Pearson residuals to annual length composition for the NWFSC Slope survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

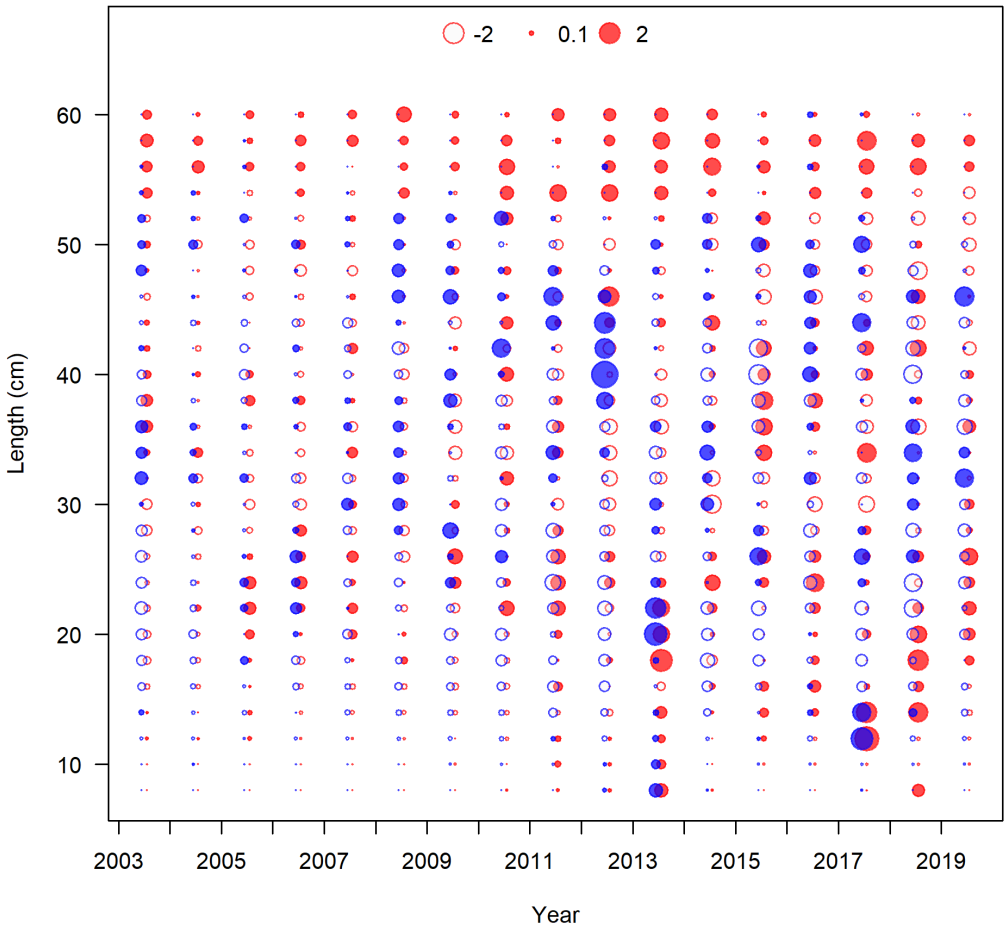


Figure 118: Pearson residuals to annual length composition for the NWFSC WCGBTS. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

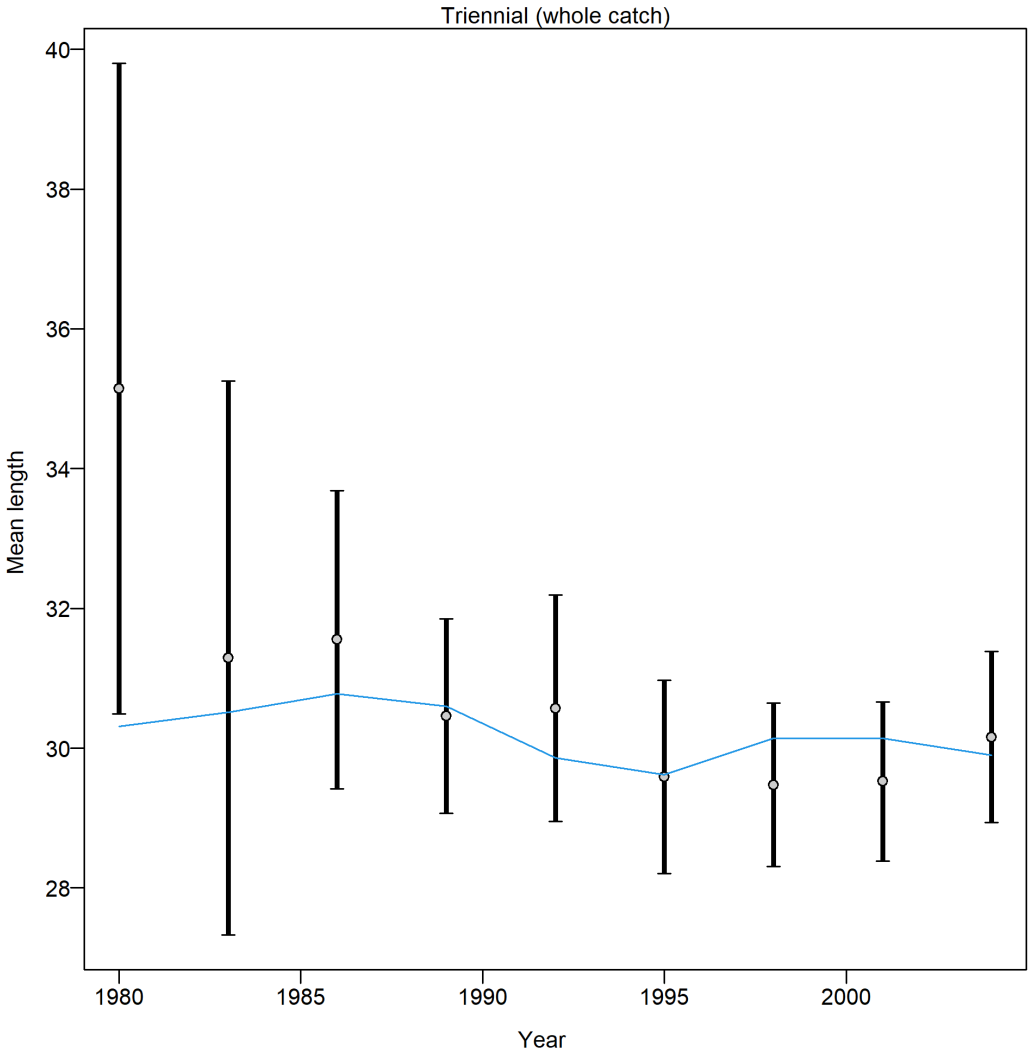


Figure 119: Mean length observations for the Triennial.

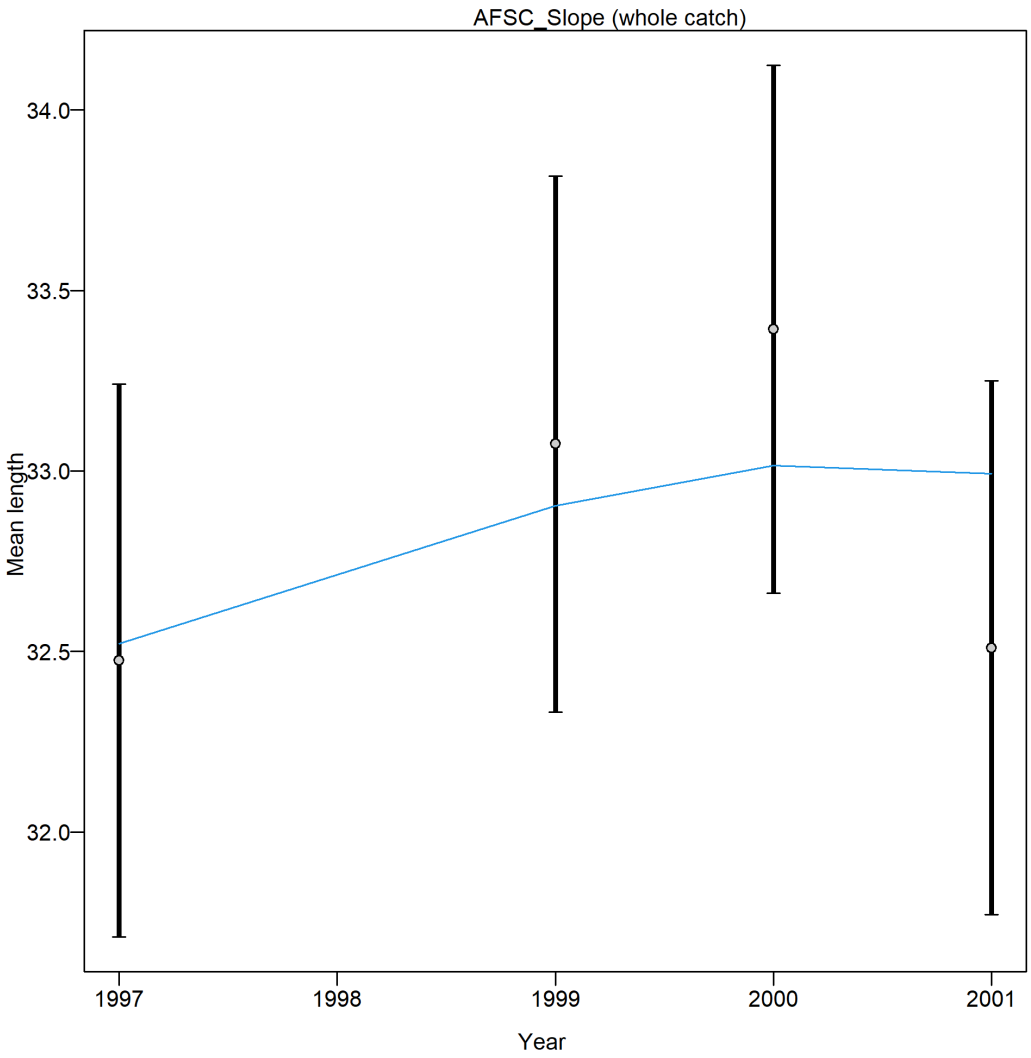


Figure 120: Mean length observations for the AFSC Slope survey.

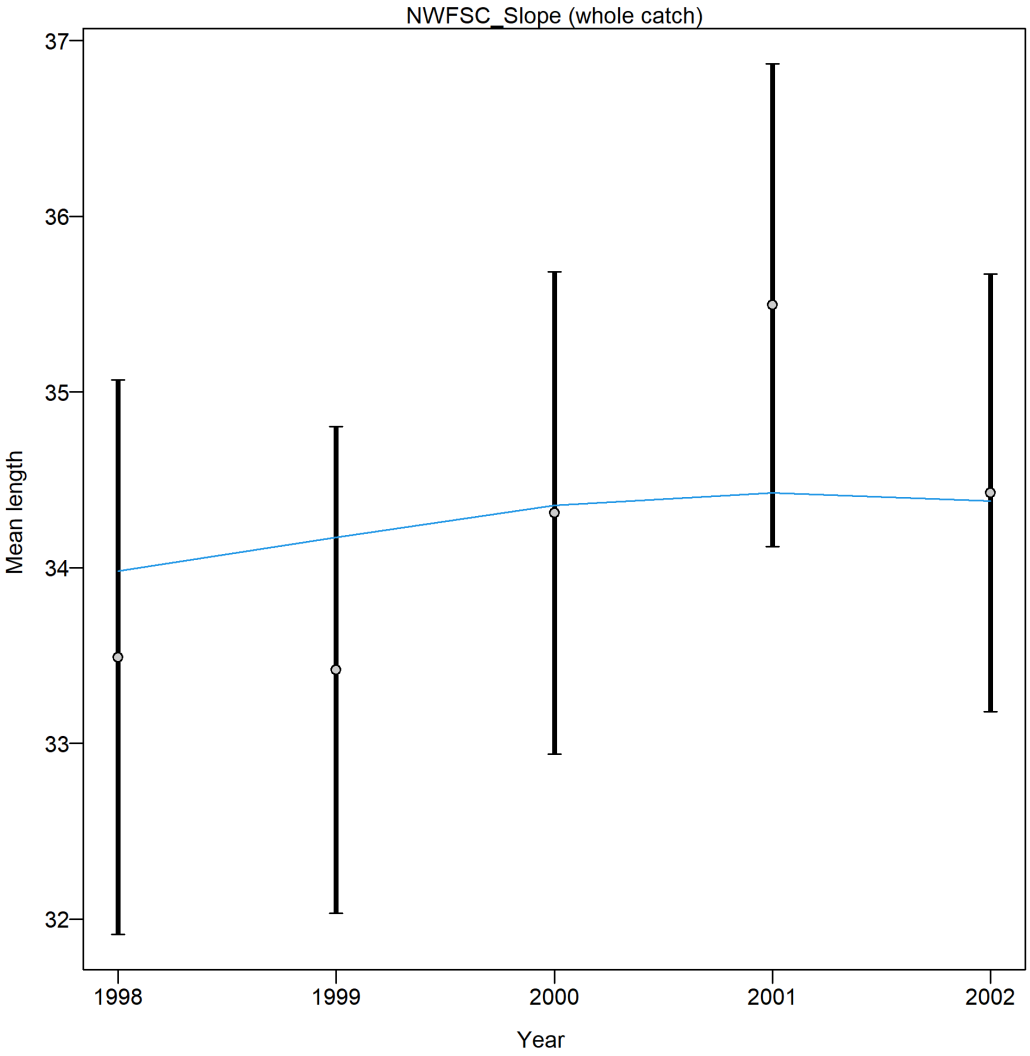


Figure 121: Mean length observations for the NWFSC Slope survey.

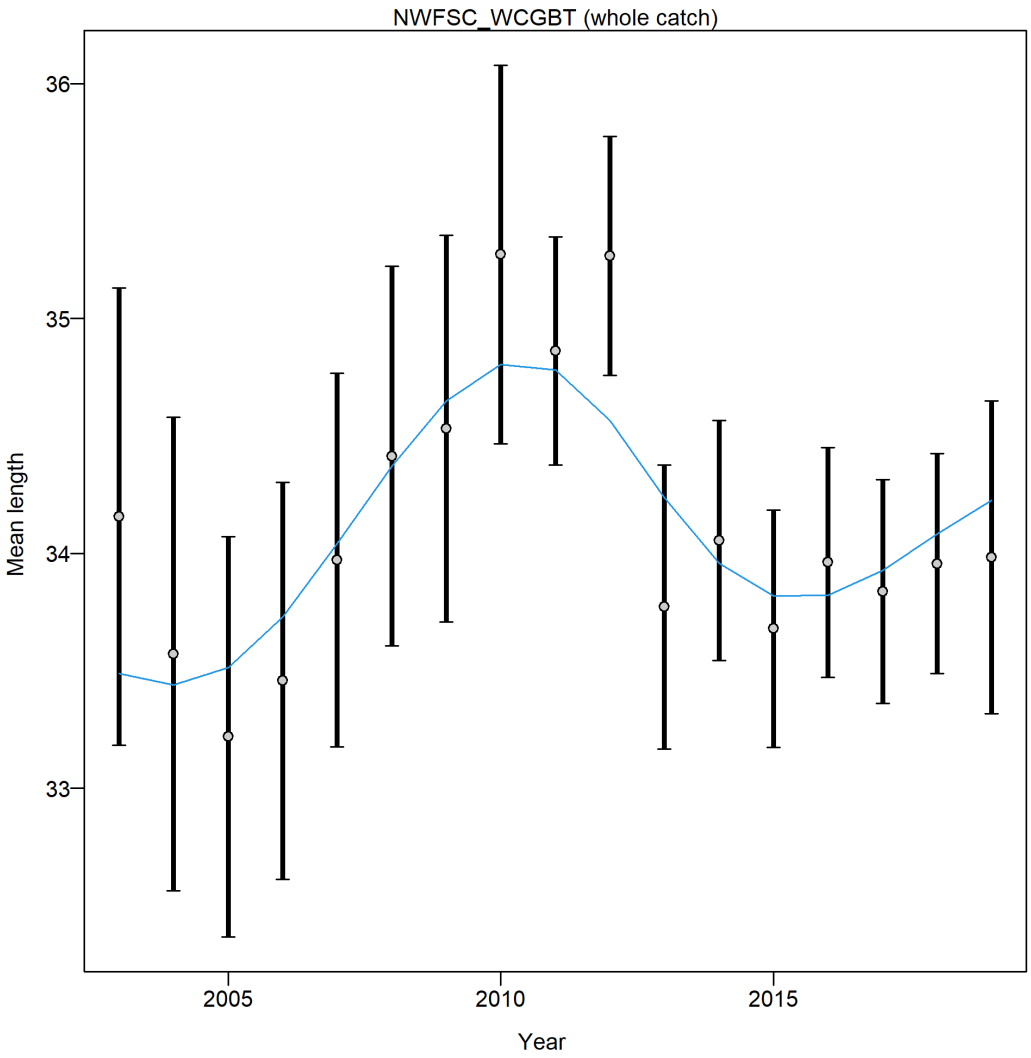


Figure 122: Mean length observations for the NWFSC WCGBTS.

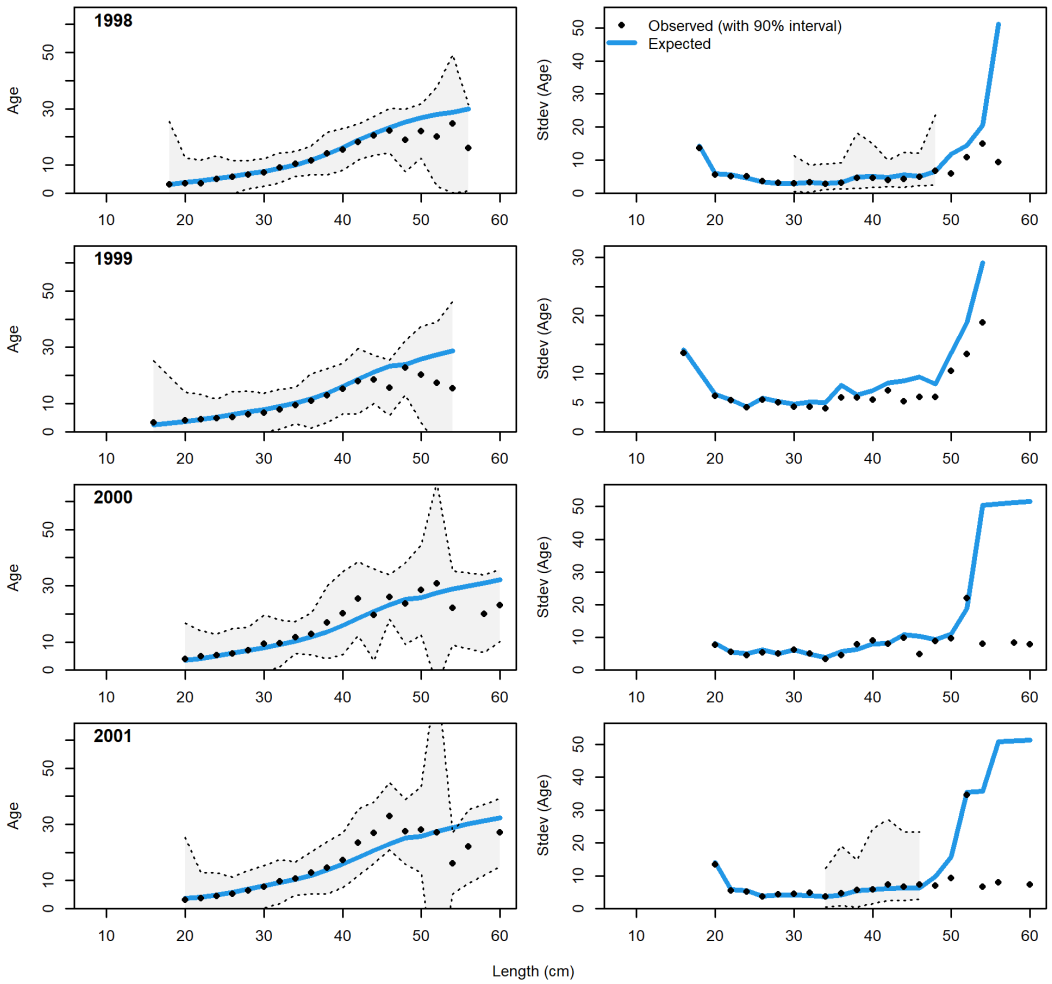


Figure 123: Conditional age-at-length for mean age and standard deviation for the NWFSC Slope survey (plot 1 of 2) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervals based on the chi-square distribution.

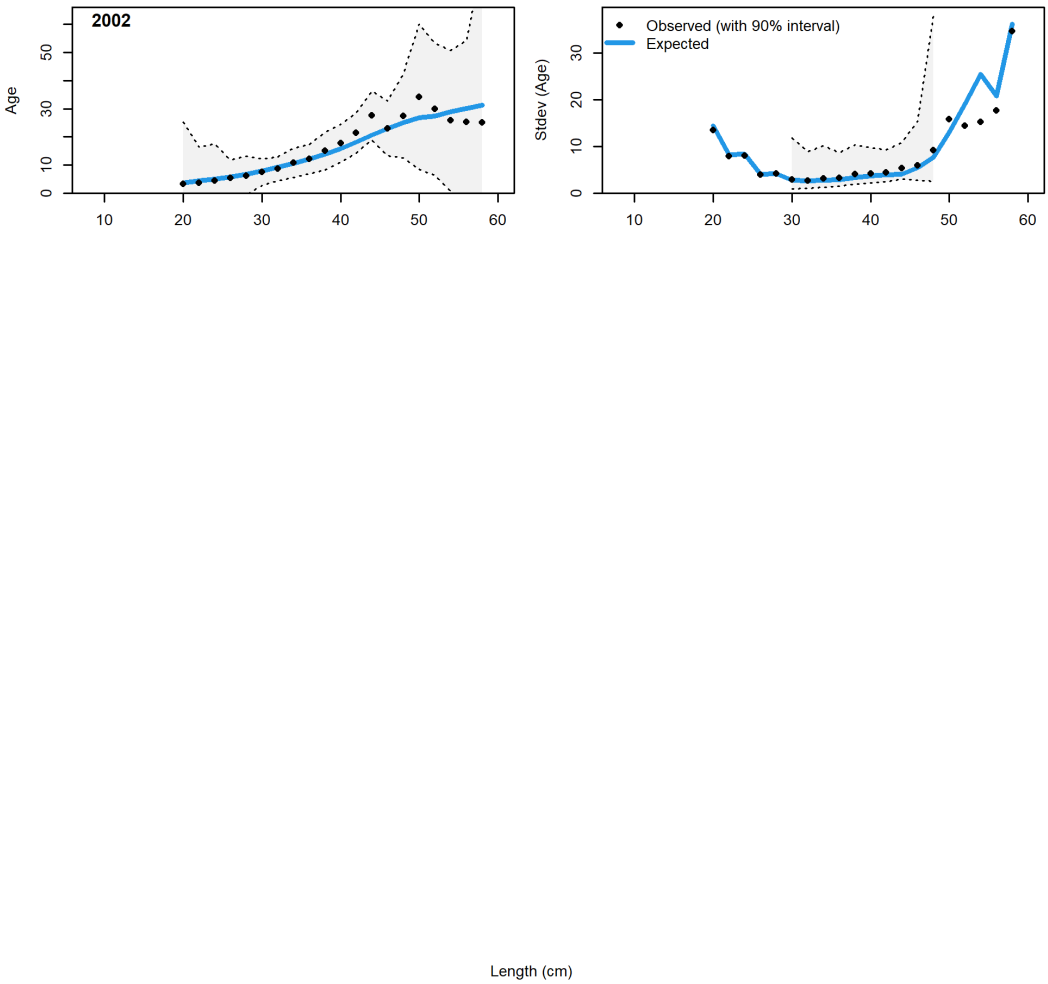


Figure 124: Conditional age-at-length for mean age and standard deviation for the NWFSC Slope survey (plot 2 of 2) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervals based on the chi-square distribution.

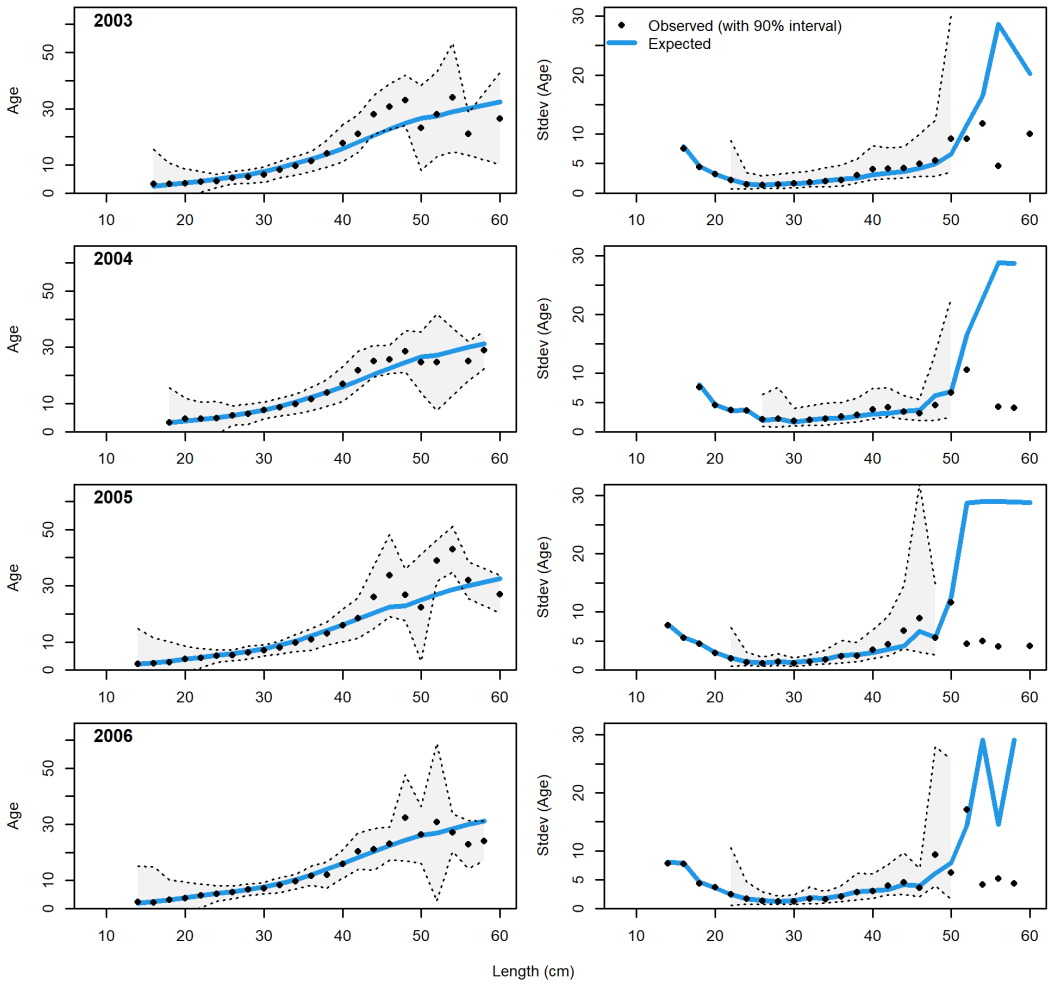


Figure 125: Conditional age-at-length for mean age and standard deviation for the NWFSC WCGBT (plot 1 of 5) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervals based on the chi-square distribution.

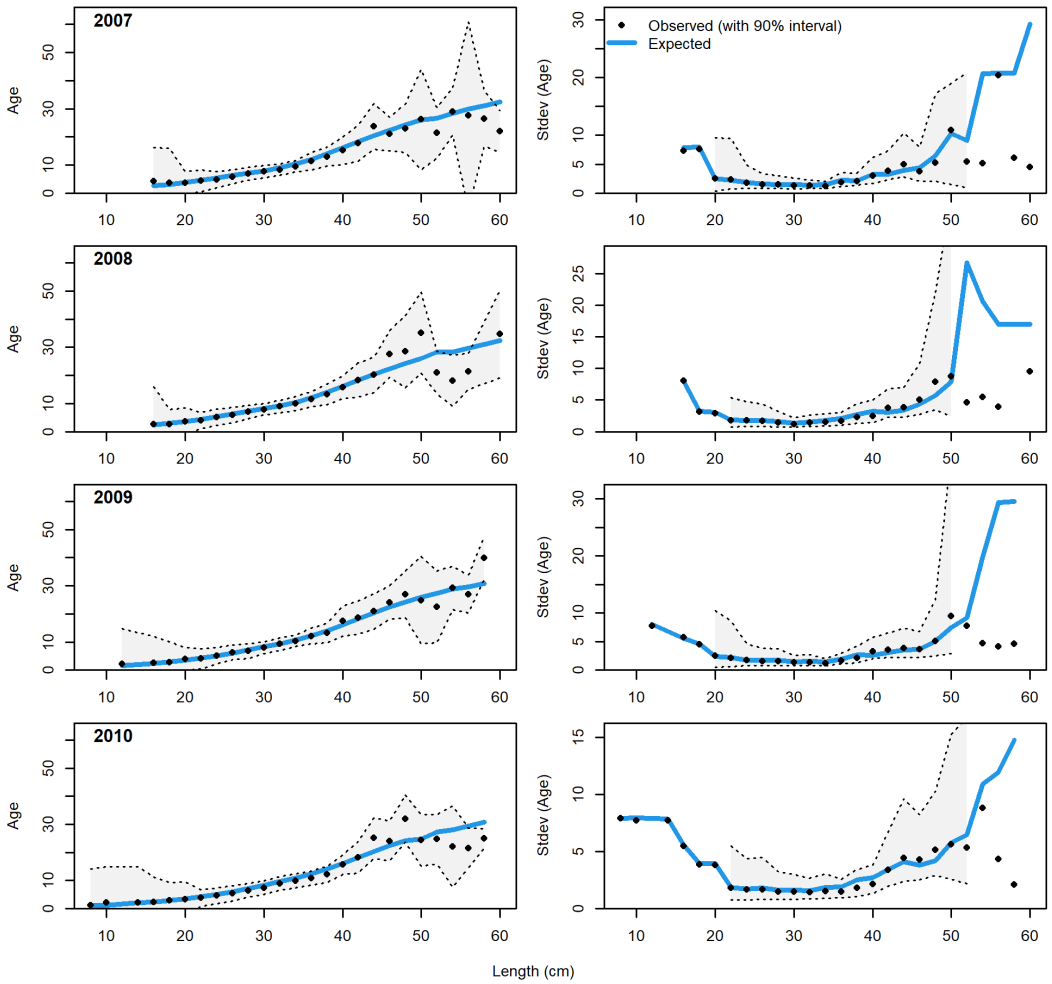


Figure 126: Conditional age-at-length for mean age and standard deviation for the WCGBTS (plot 2 of 5) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervalss based on the chi-square distribution.

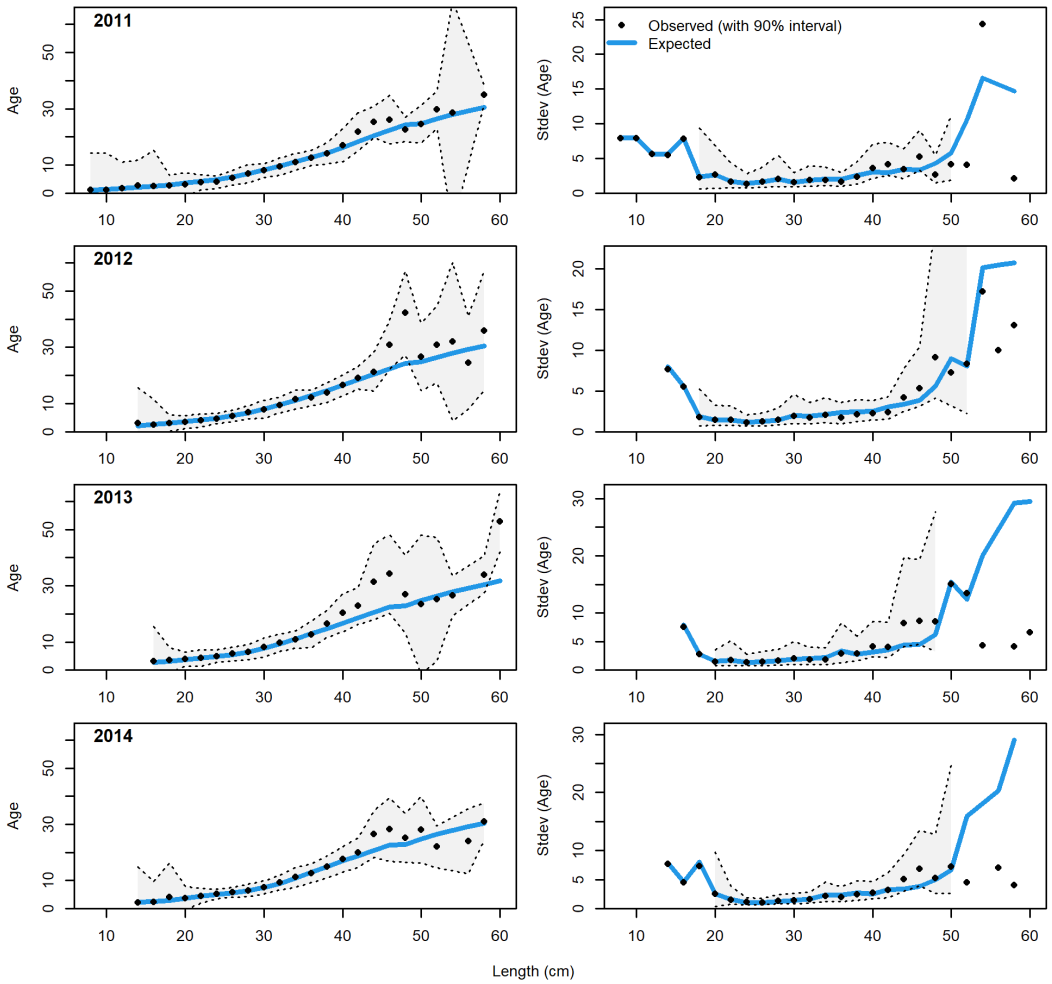


Figure 127: Conditional age-at-length for mean age and standard deviation for the WCGBTS (plot 3 of 5) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervals based on the chi-square distribution.

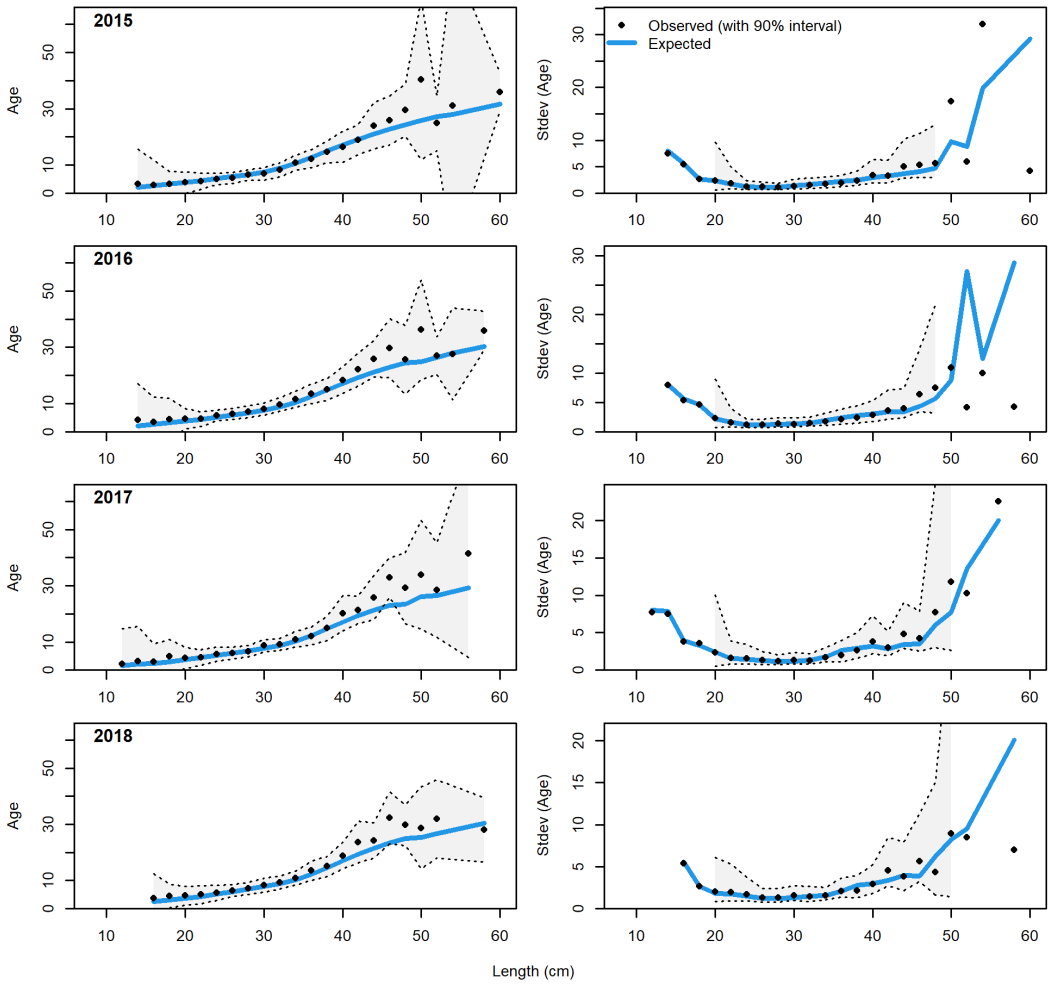


Figure 128: Conditional age-at-length for mean age and standard deviation for the WCGBTS (plot 4 of 5) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervals based on the chi-square distribution.

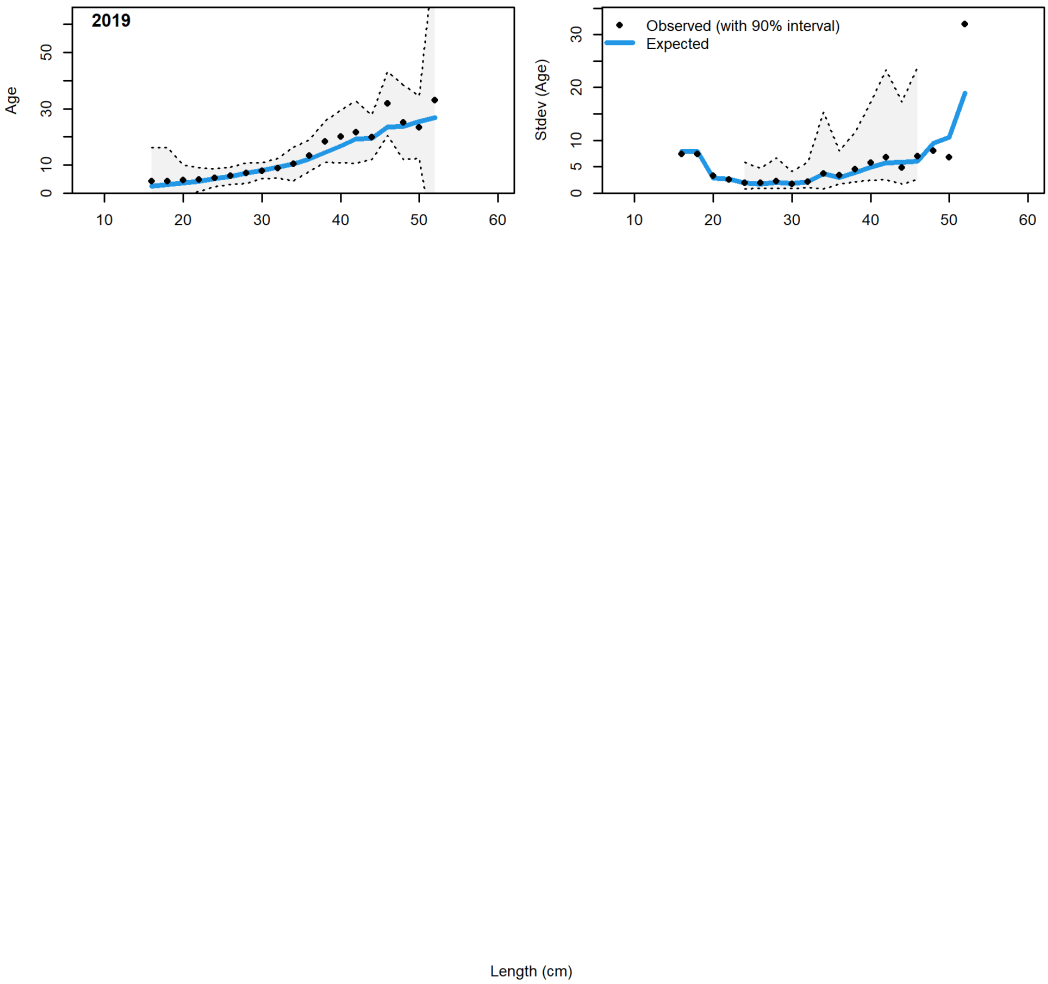


Figure 129: Conditional age-at-length for mean age and standard deviation for the WCGBTS (plot 5 of 5) Left plots are mean conditional age-at-length by size-class (observed and expected) with 90 percent confidence intervals based on adding 1.64 standard error of mean to the data. Right plots in each pair are standard error of mean age-at-length (observed and expected) with 90 percent confidence intervals based on the chi-square distribution.

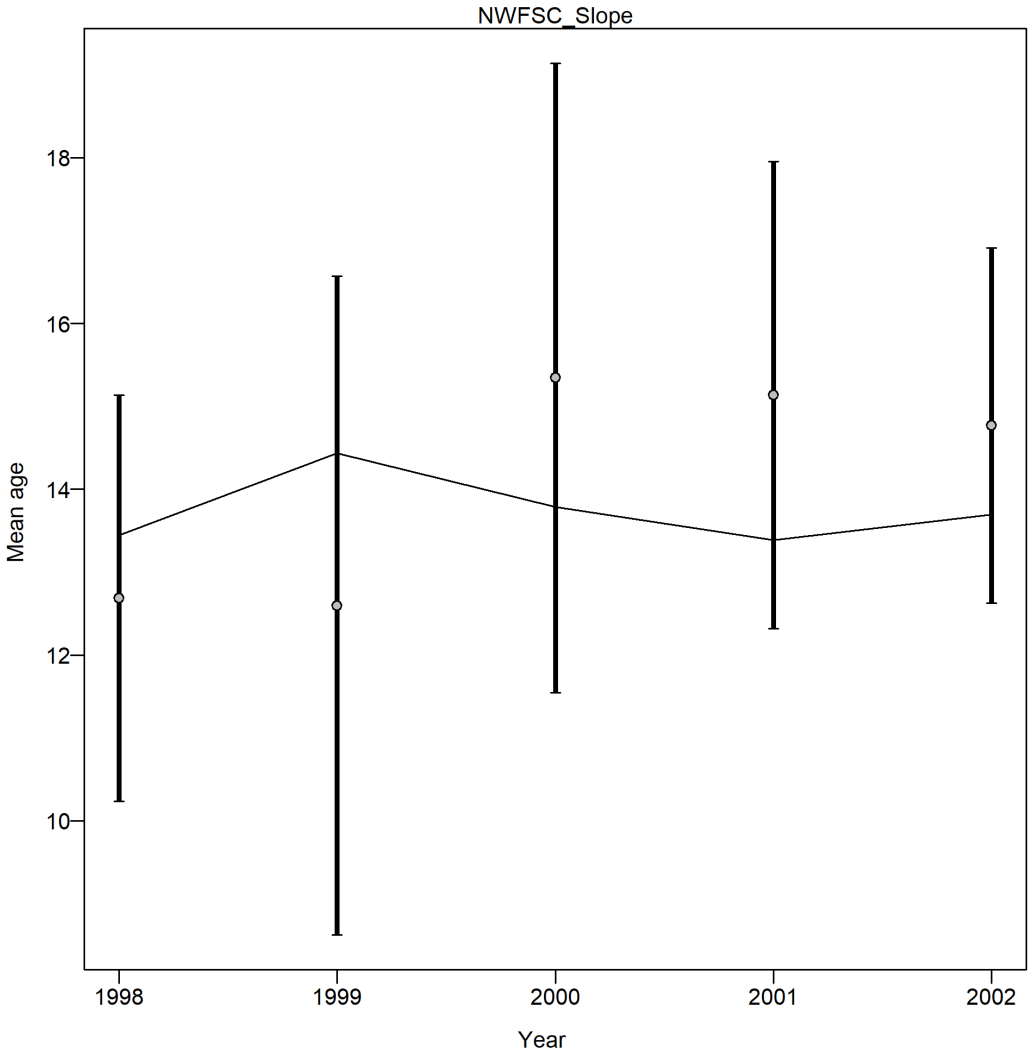


Figure 130: Mean age from conditional age-at-length data for the NWFSC Slope survey.

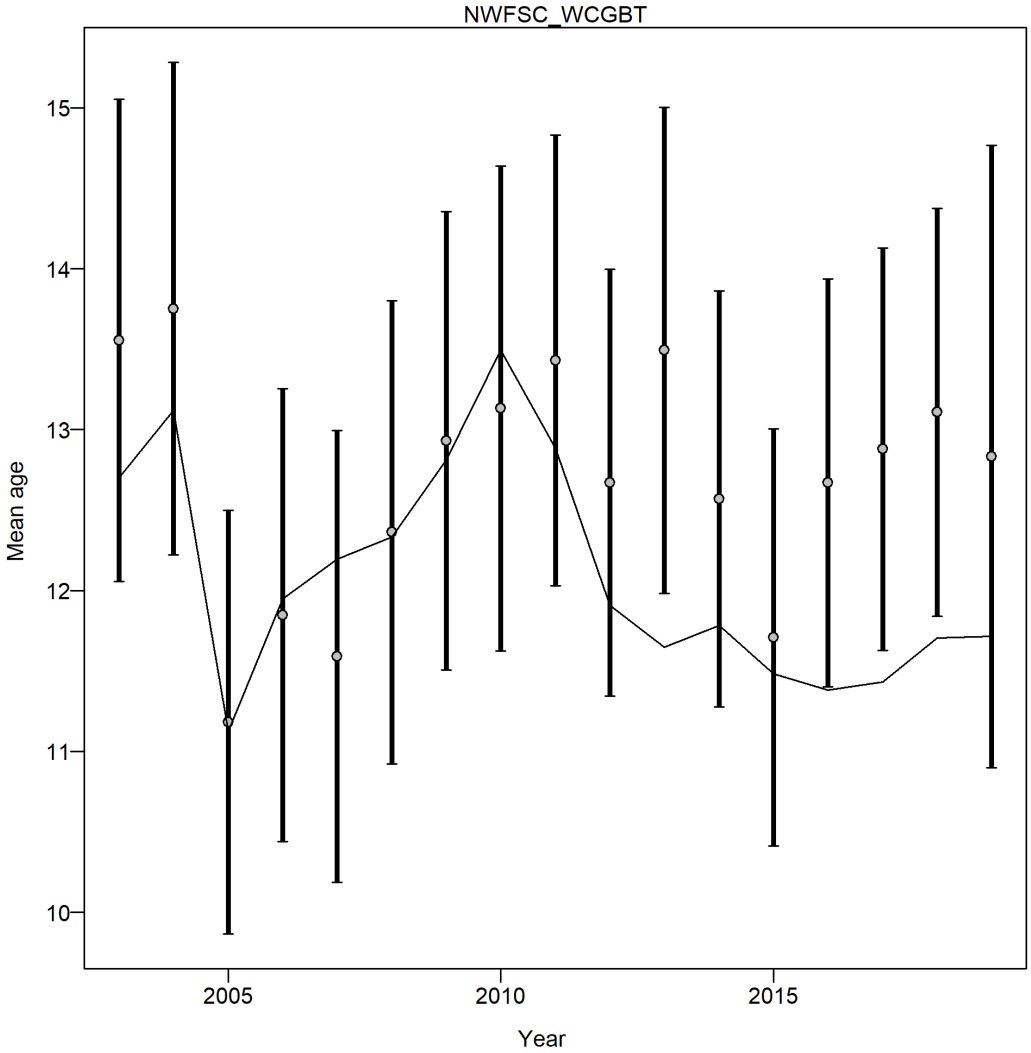


Figure 131: Mean age observations from the conditional age-at-length data from the WCGBTS.

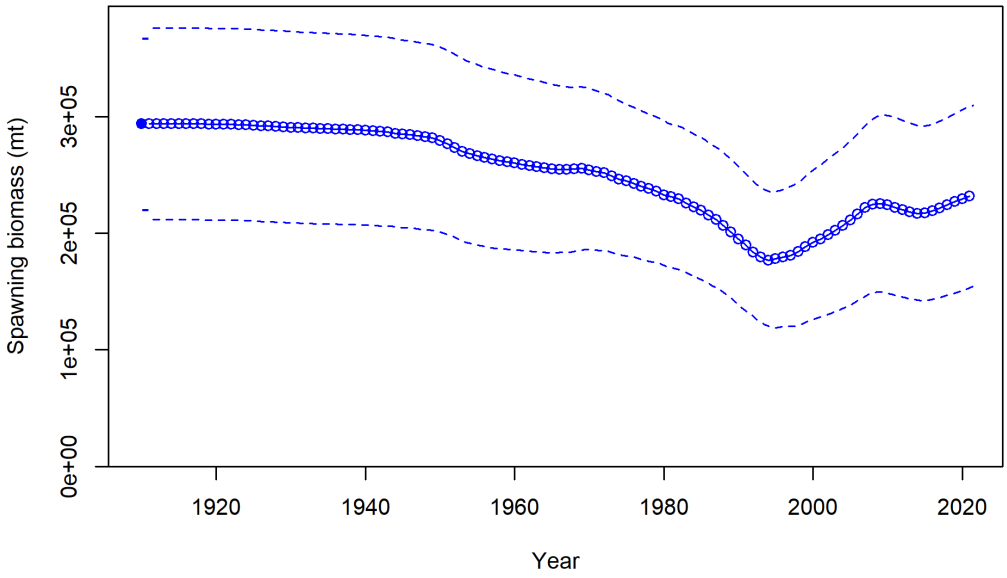


Figure 132: Estimated time series of spawning biomass.

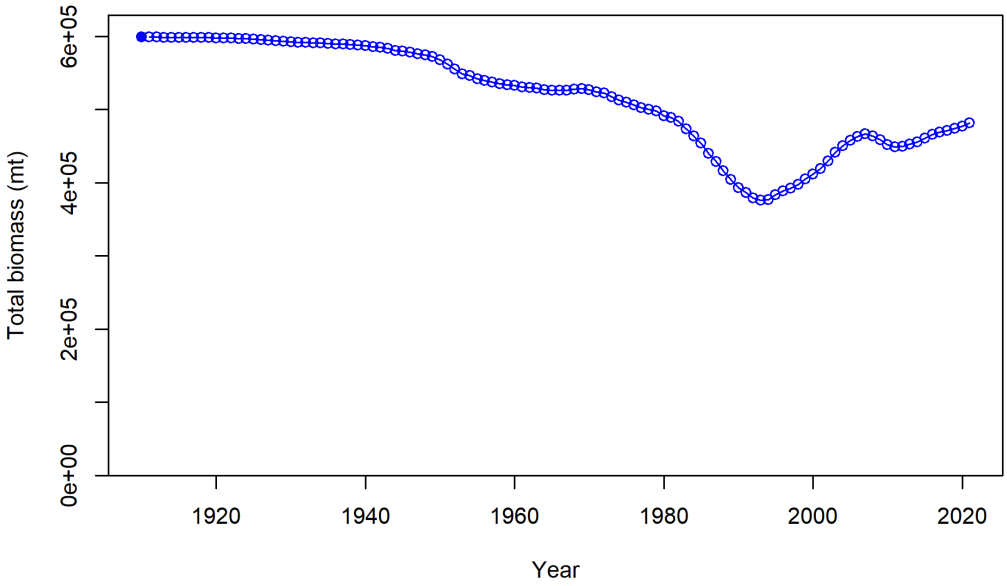


Figure 133: Estimated time series of total biomass.

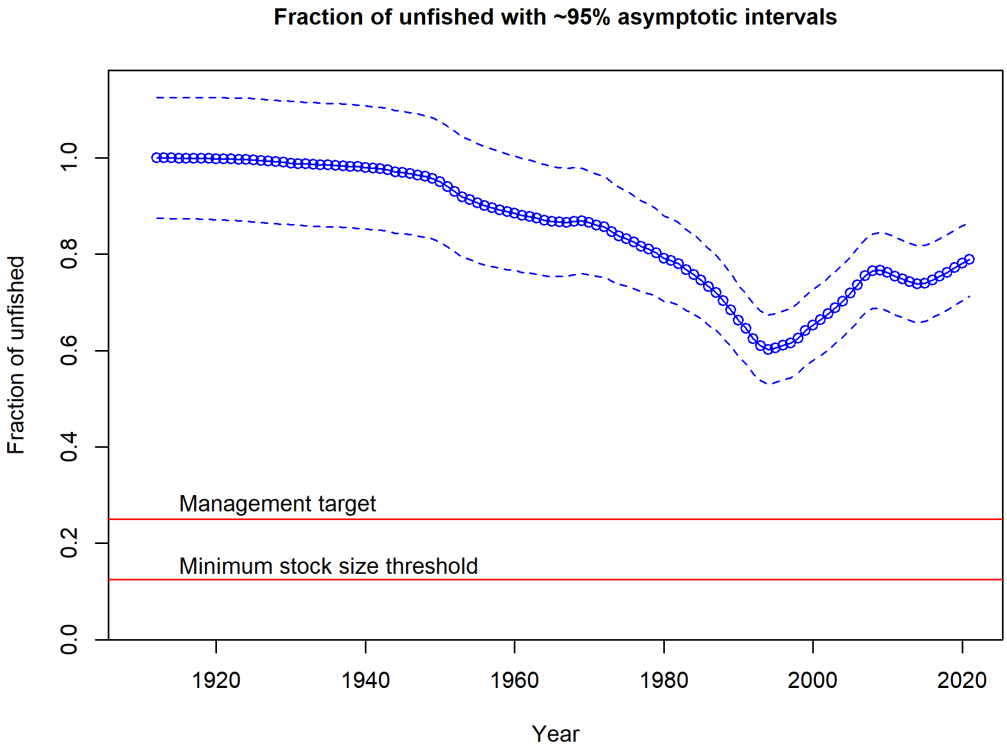


Figure 134: Estimated time series of fraction of unfished spawning biomass.

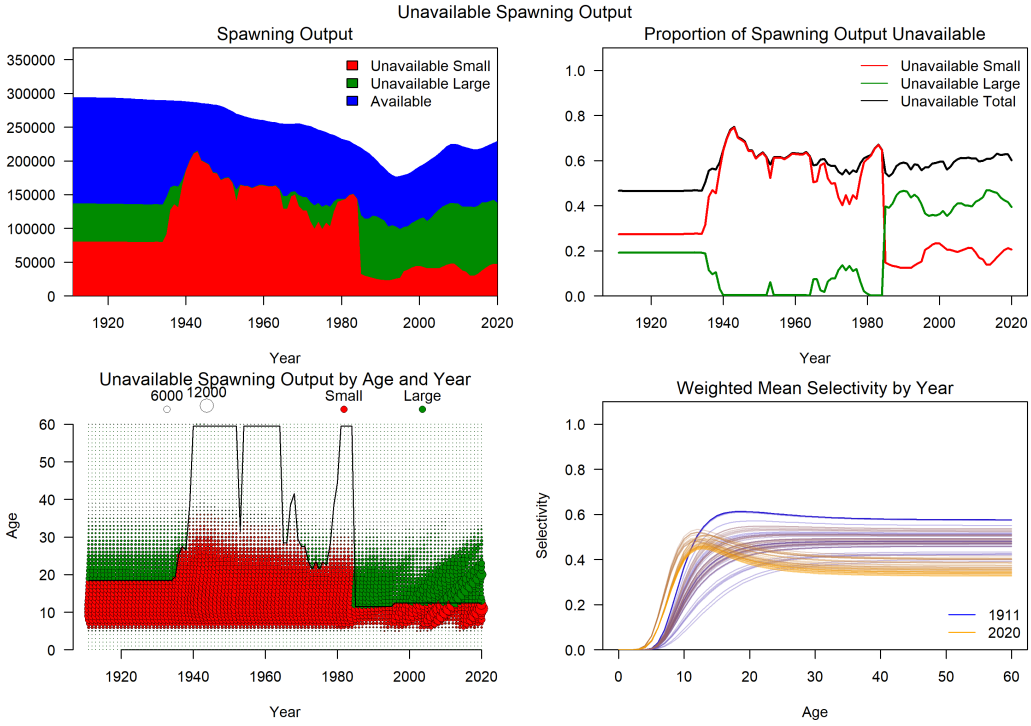


Figure 135: Proportion of biomass unavailable due to selectivity for small and large fish.

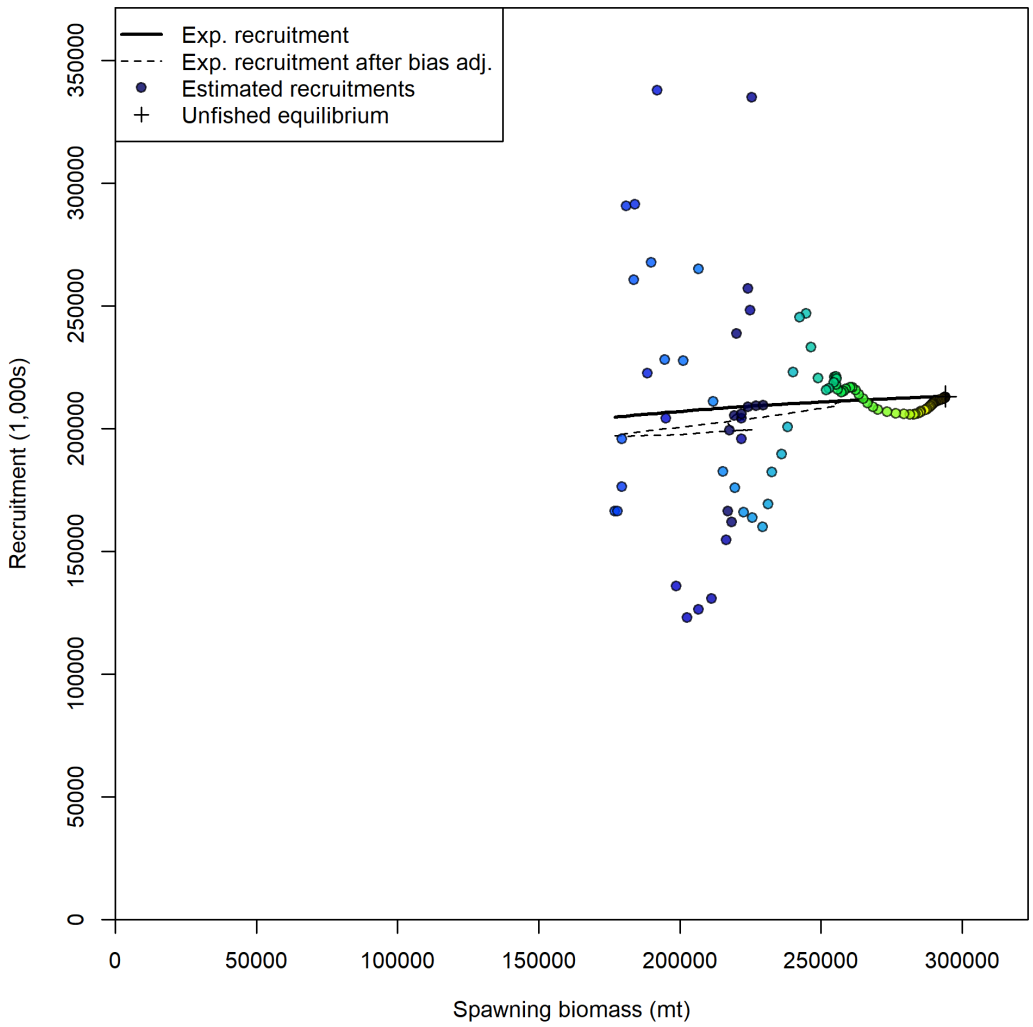


Figure 136: Stock recruit curve where point color indicate year, with warmer colors (yellow to green) indicating earlier years and cooler colors (blue) showing later years.

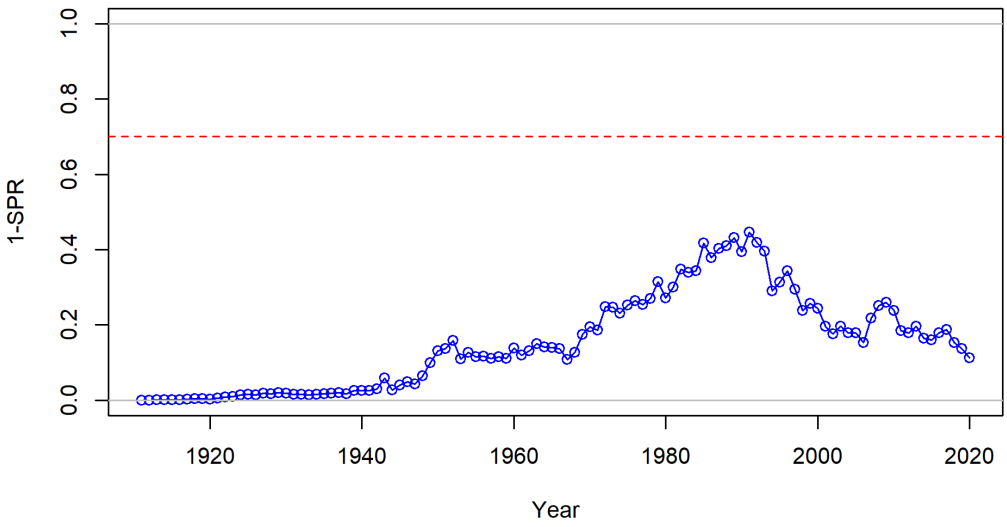


Figure 137: Estimated 1 - relative spawning ratio (SPR) by year.

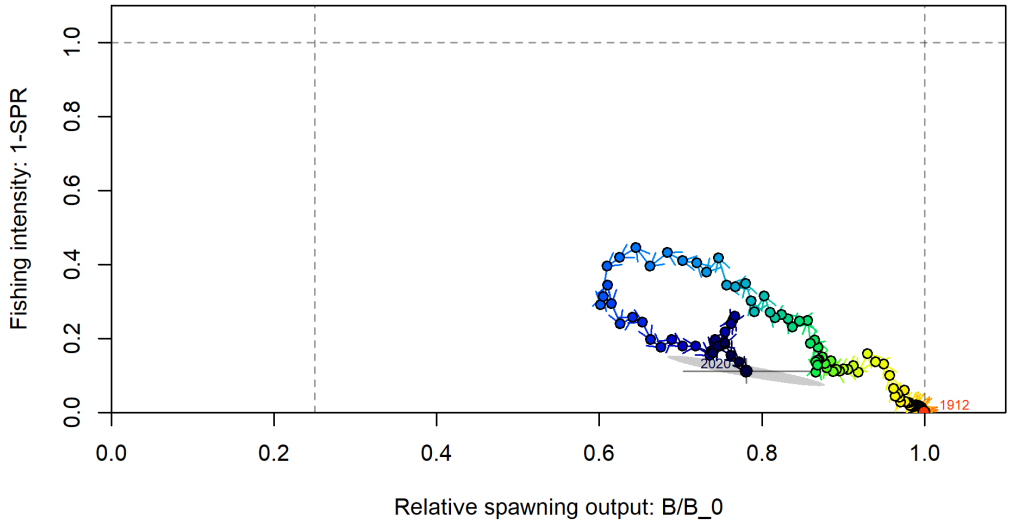


Figure 138: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show the 95 percent intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95 percent region which accounts for the estimated correlations between the biomass ratio and SPR ratio.

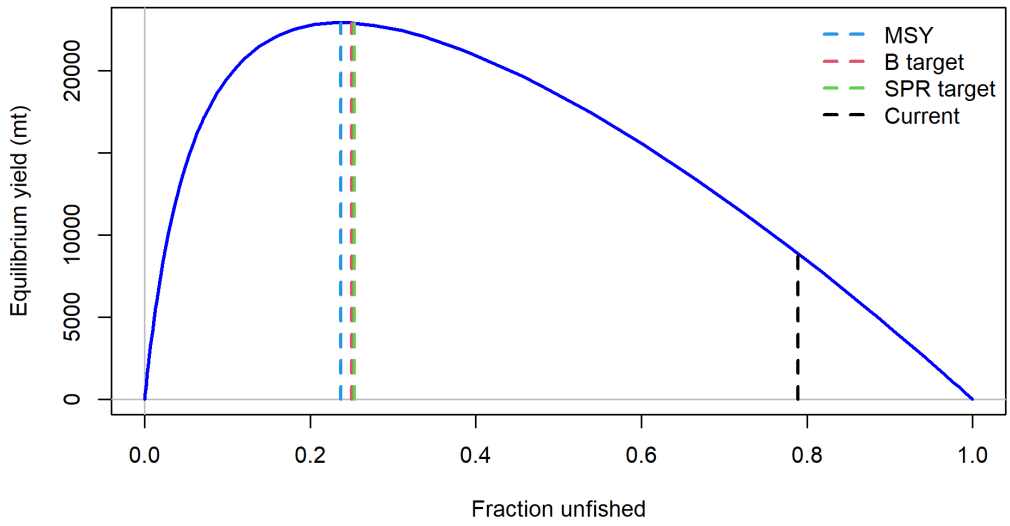


Figure 139: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities and with steepness fixed at 0.80.

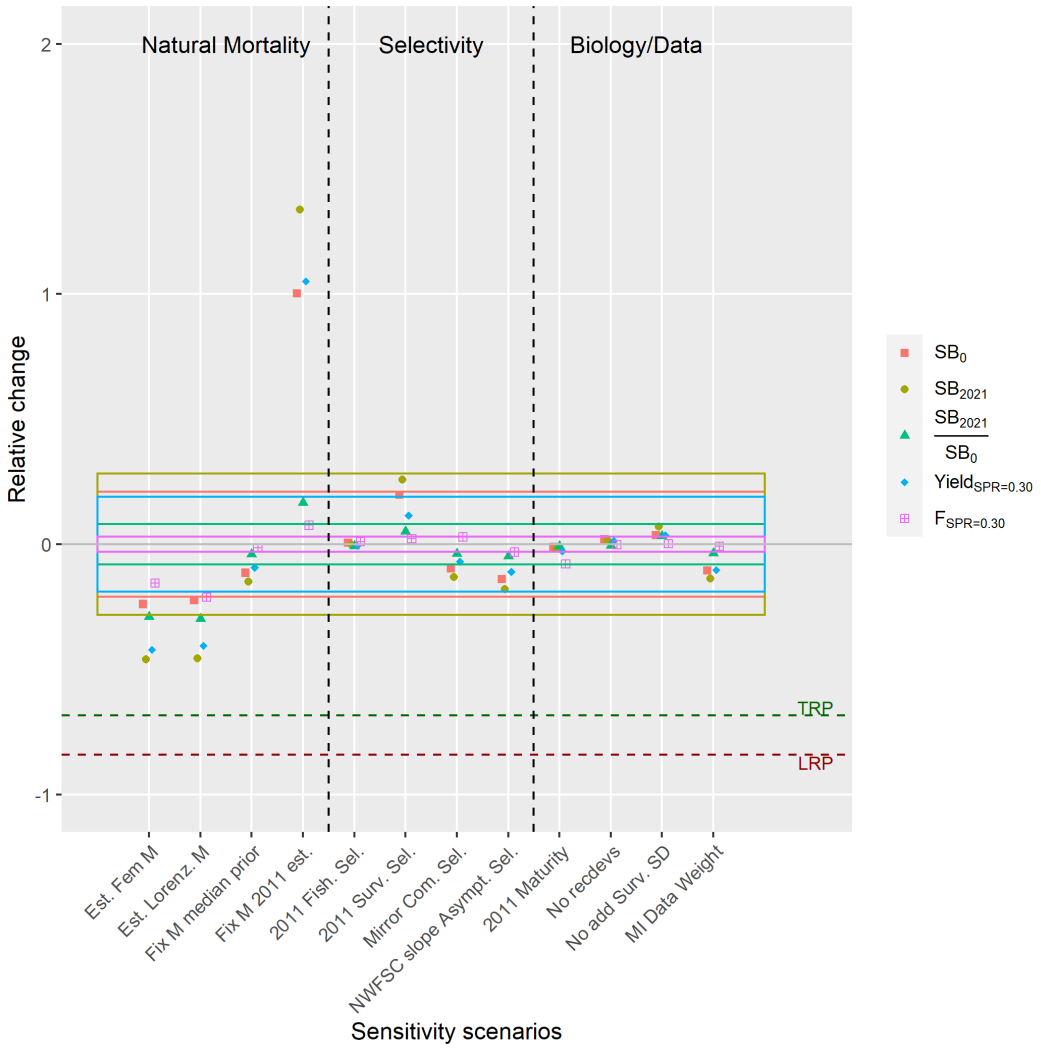


Figure 140: Relative change in derived quantities (SB0: unfished spawning biomass, SB2021: spawning biomass in 2021, SB2021/SB0: fraction unfished in 2021, Yield SPR=0.30: Yield at the the target SPR, and F SPR=0.30: the exploitation rate at the target SPR) by structural sensitivities compared to the base model. A relative change value of 0.0 would indicate the same estimates from the sensitivity as the base model. Positive relative changes values would indicate that the estimates from the sensitivity were greater than the base model. The target reference point (TRP) and limit reference point (LRP) only apply to the fraction unfished (SB2021/SB0).

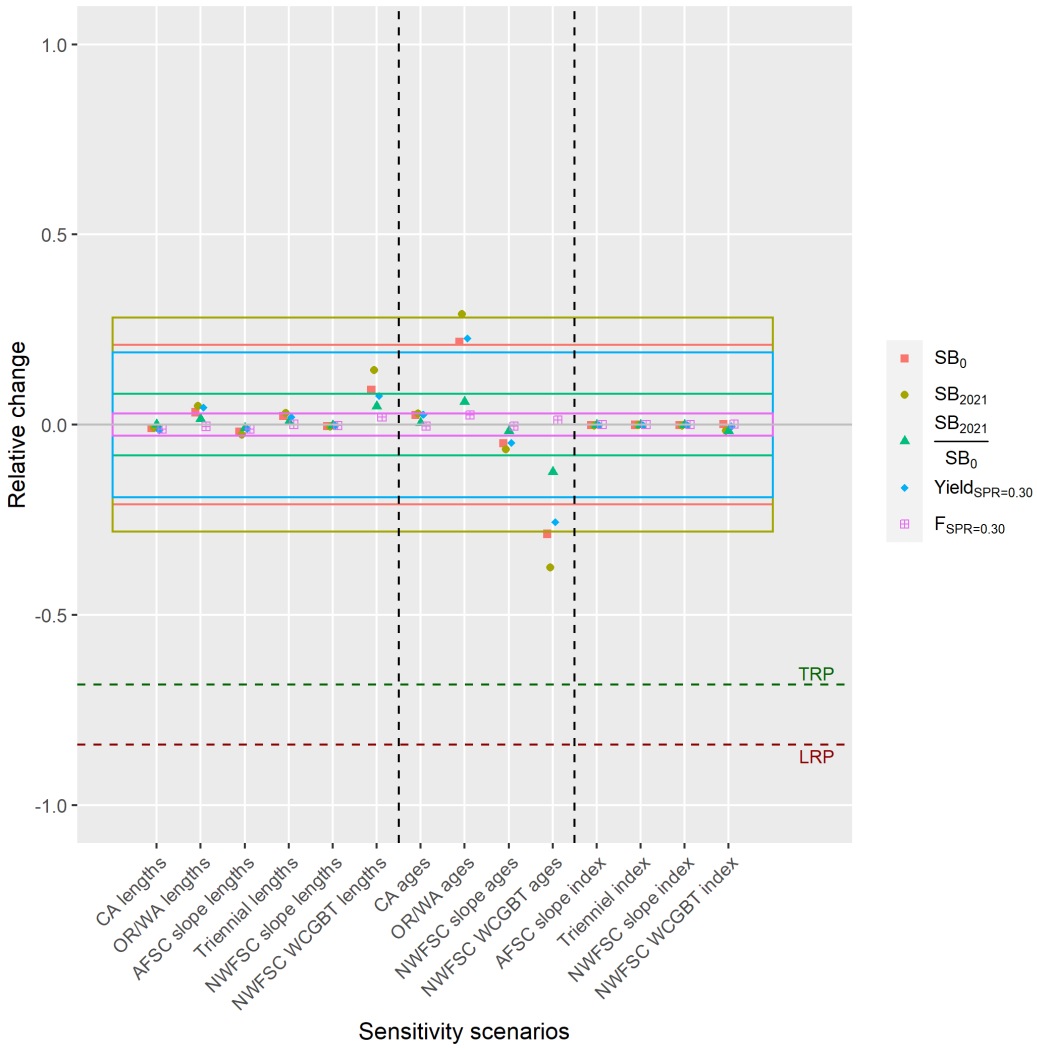


Figure 141: Relative change in derived quantities (SB0: unfished spawning biomass, SB2021: spawning biomass in 2021, SB2021/SB0: fraction unfished in 2021, Yield SPR=0.30: Yield at the the target SPR, and F SPR=0.30: the exploitation rate at the target SPR) by data sensitivities compared to the base model. A relative change value of 0.0 would indicate the same estimates from the sensitivity as the base model. Positive relative changes values would indicate that the estimates from the sensitivity were greater than the base model. The target reference point (TRP) and limit reference point (LRP) only apply to the fraction unfished (SB2021/SB0).

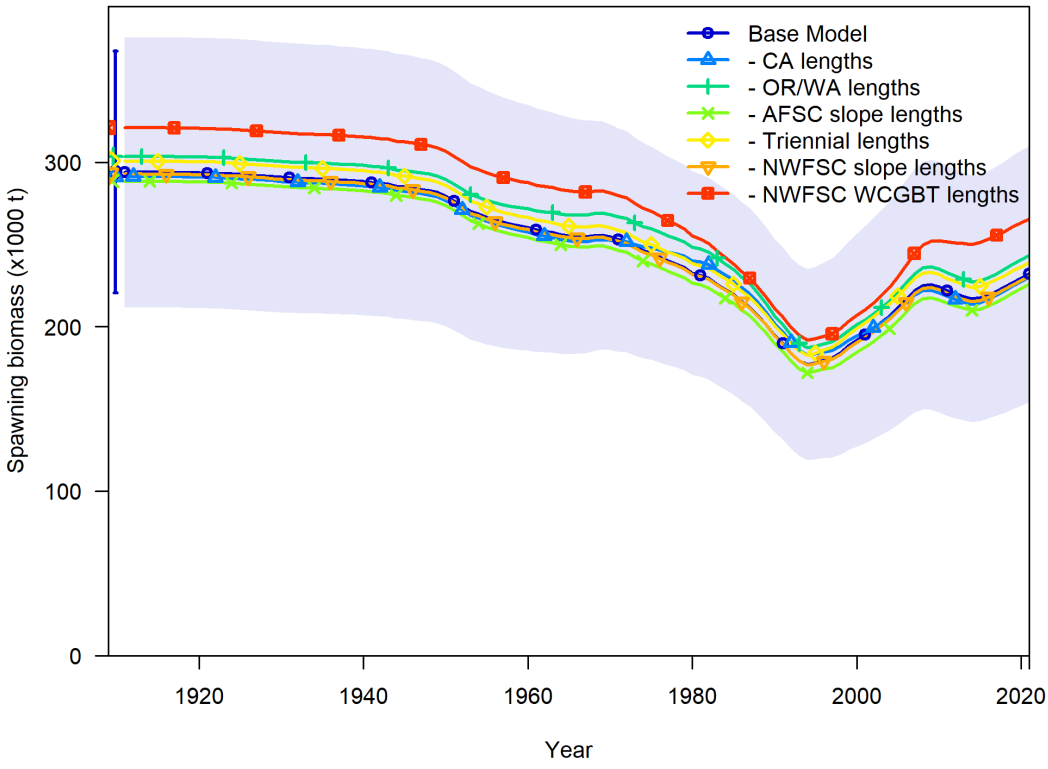


Figure 142: Estimates of spawning biomass for the base model and alternative sensitivity models that remove (-) sources of length data.

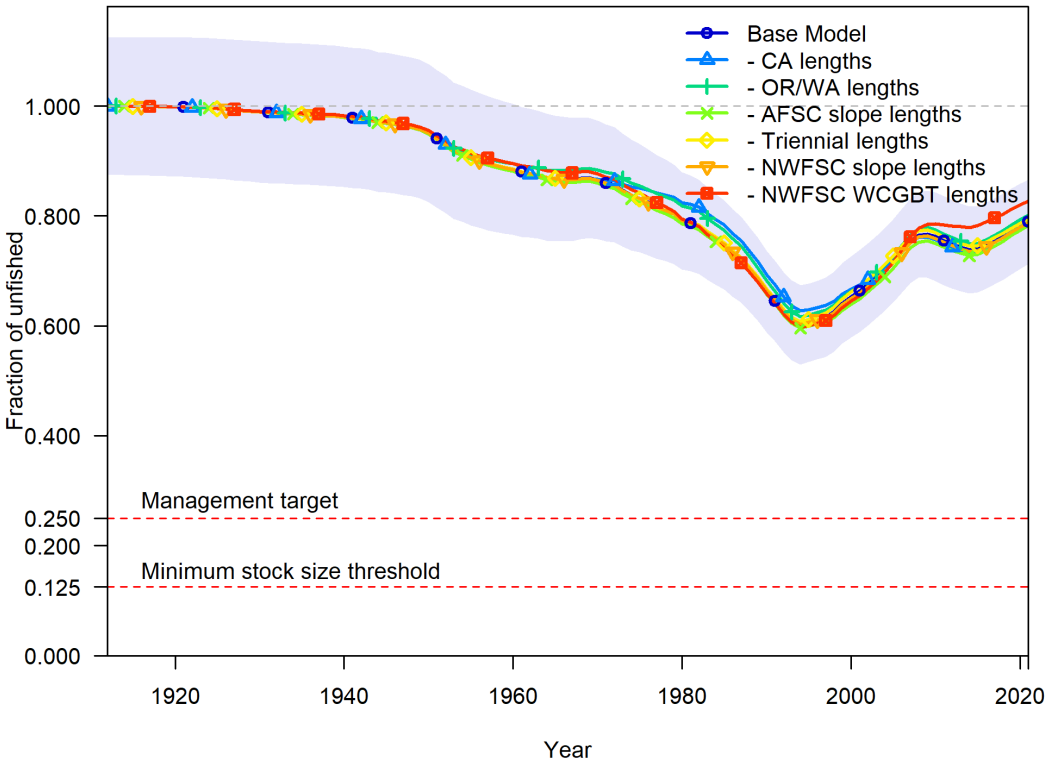


Figure 143: Estimates of relative spawning biomass for the base model and alternative sensitivity models that remove (-) sources of length data.

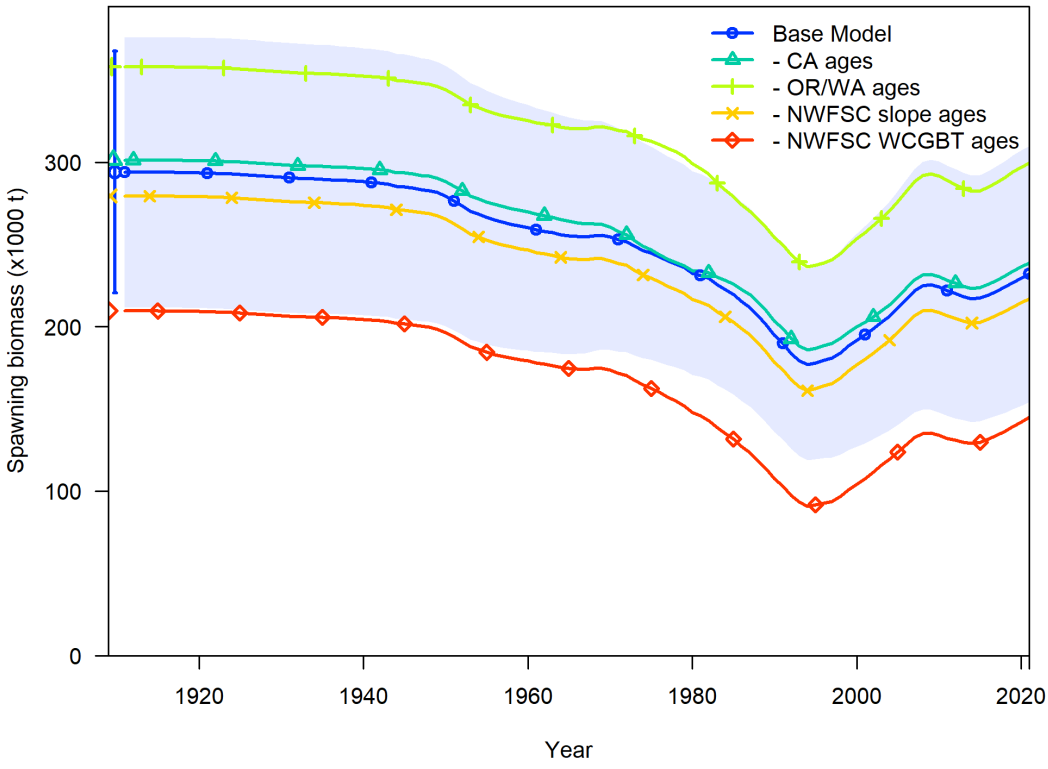


Figure 144: Estimates of spawning biomass for the base model and alternative sensitivity models that remove (-) sources of age data.

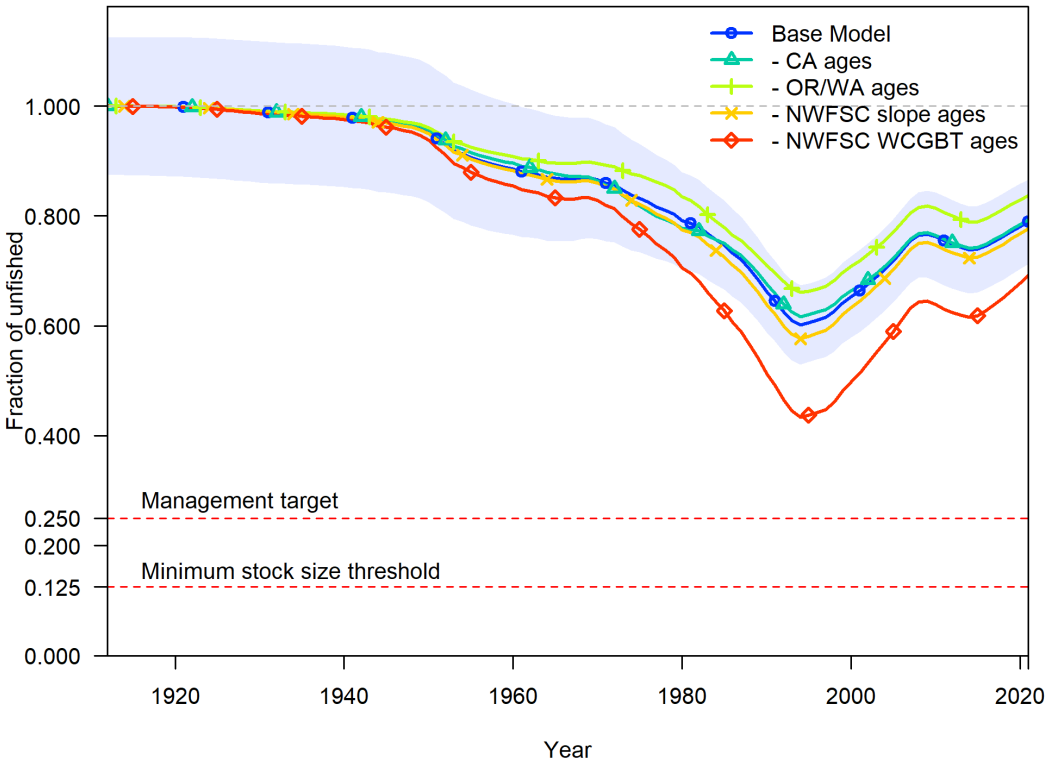


Figure 145: Estimates of relative spawning biomass for the base model and alternative sensitivity models that remove (-) sources of age data.

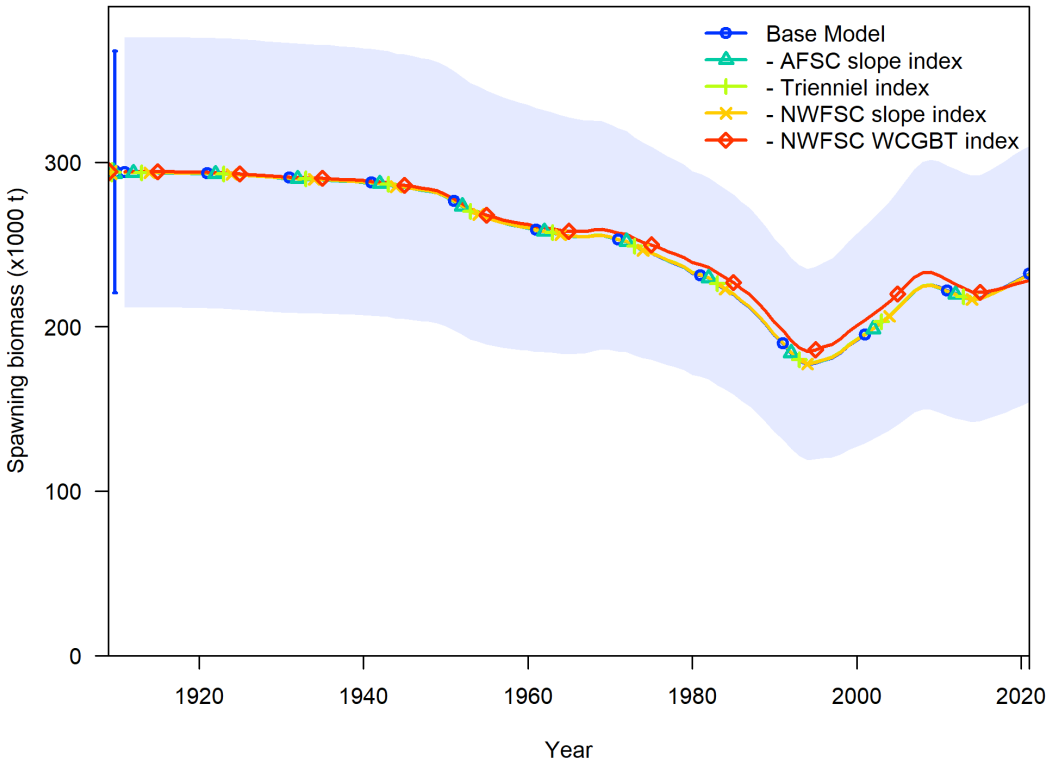


Figure 146: Estimates of spawning biomass for the base model and alternative sensitivity models that remove (-) sources of index data.

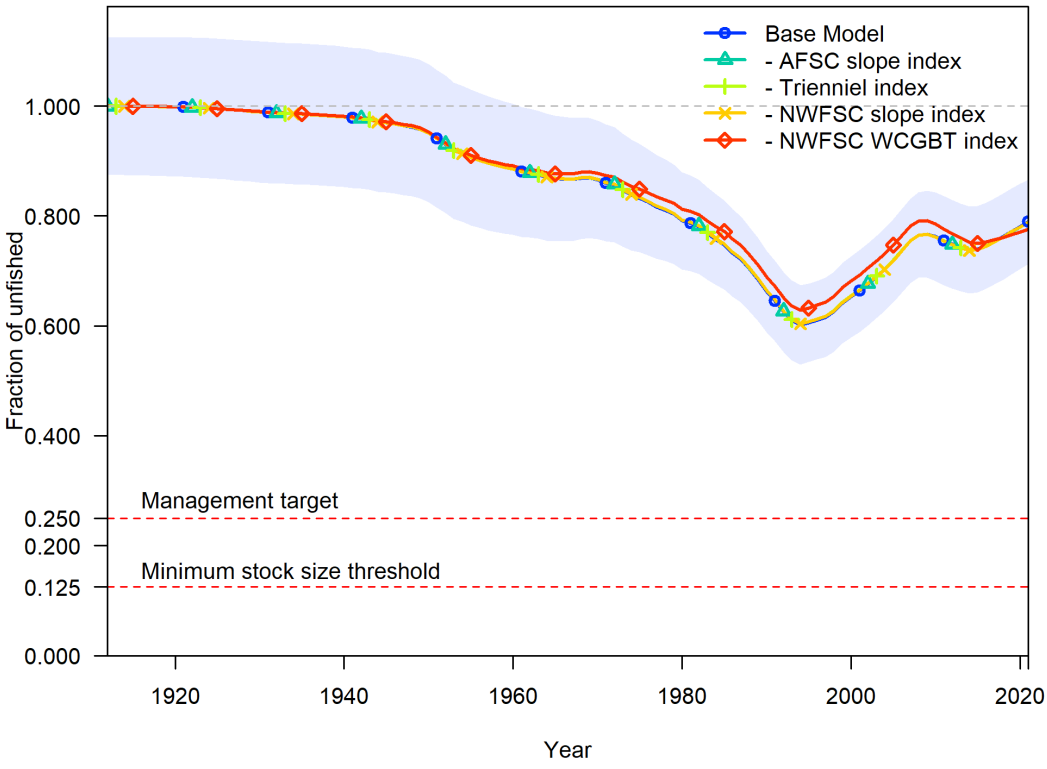


Figure 147: Estimates of relative spawning biomass for the base model and alternative sensitivity models that remove (-) sources of index data.

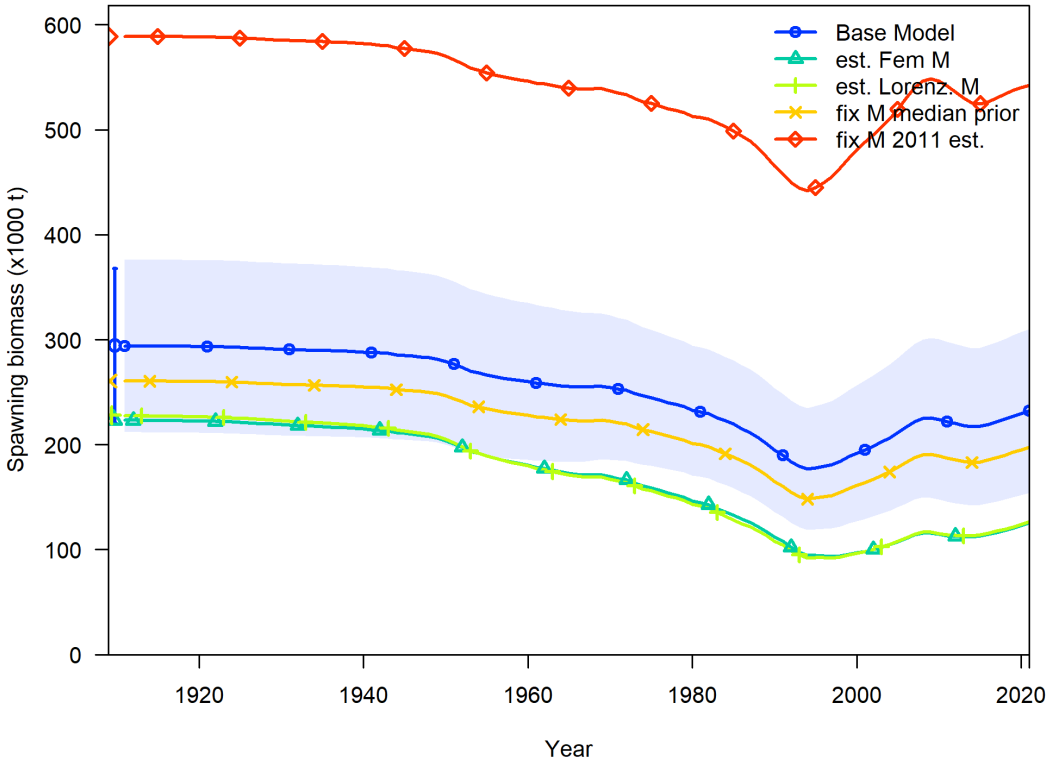


Figure 148: Estimates of spawning biomass for the base model and alternative sensitivity models to natural mortality including estimating females, estimating an age-specific Lorenzen relationship for males and females, fixing male and female parameters at the median of the prior, and fixing natural mortality at estimates from the 2011 assessment.

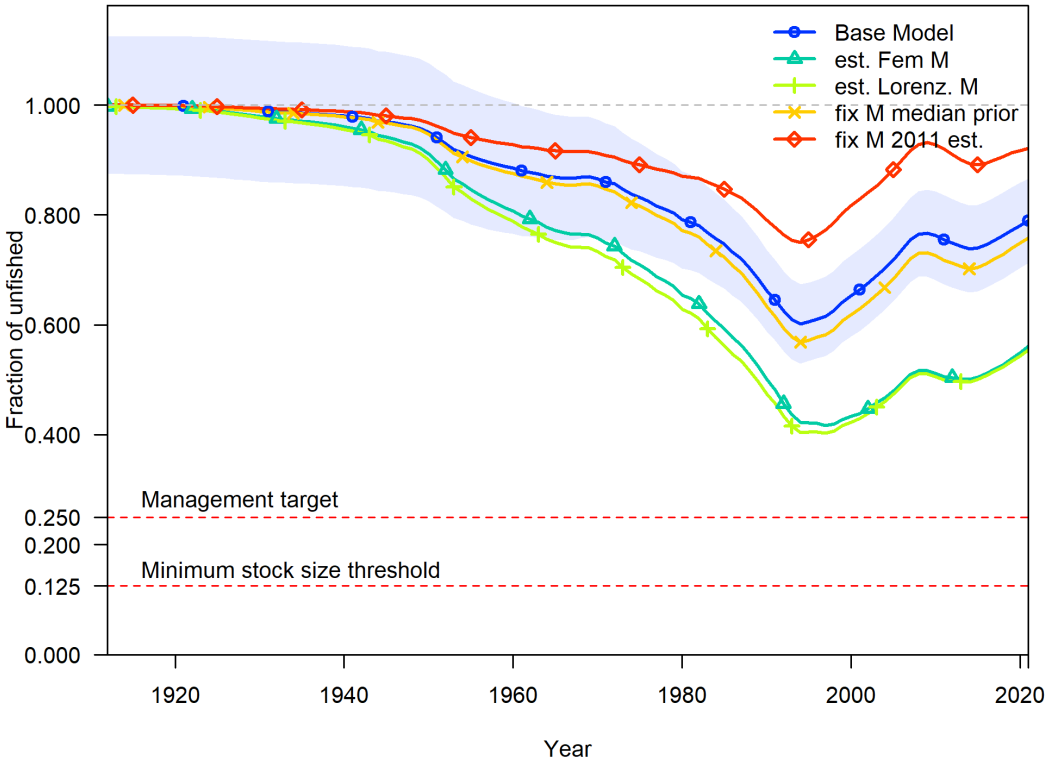


Figure 149: Estimates of relative spawning biomass for the base model and alternative sensitivity models to natural mortality including estimating females, estimating an age-specific Lorenzen relationship for males and females, fixing male and female parameters at the median of the prior, and fixing natural mortality at estimates from the 2011 assessment.

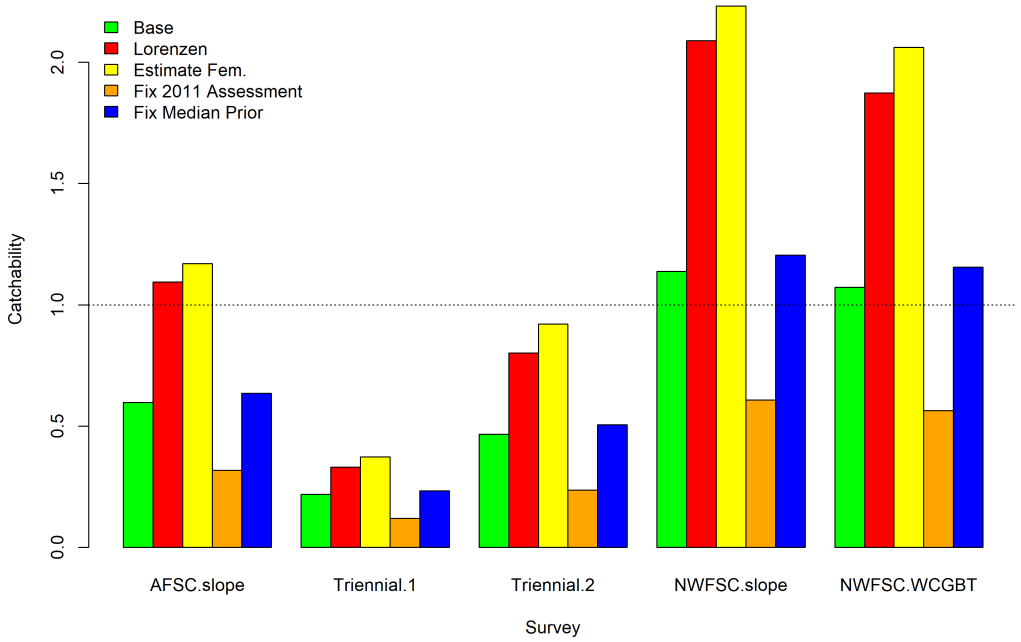


Figure 150: Survey catchability estimates for the base model and alternative natural mortality sensitivity runs.

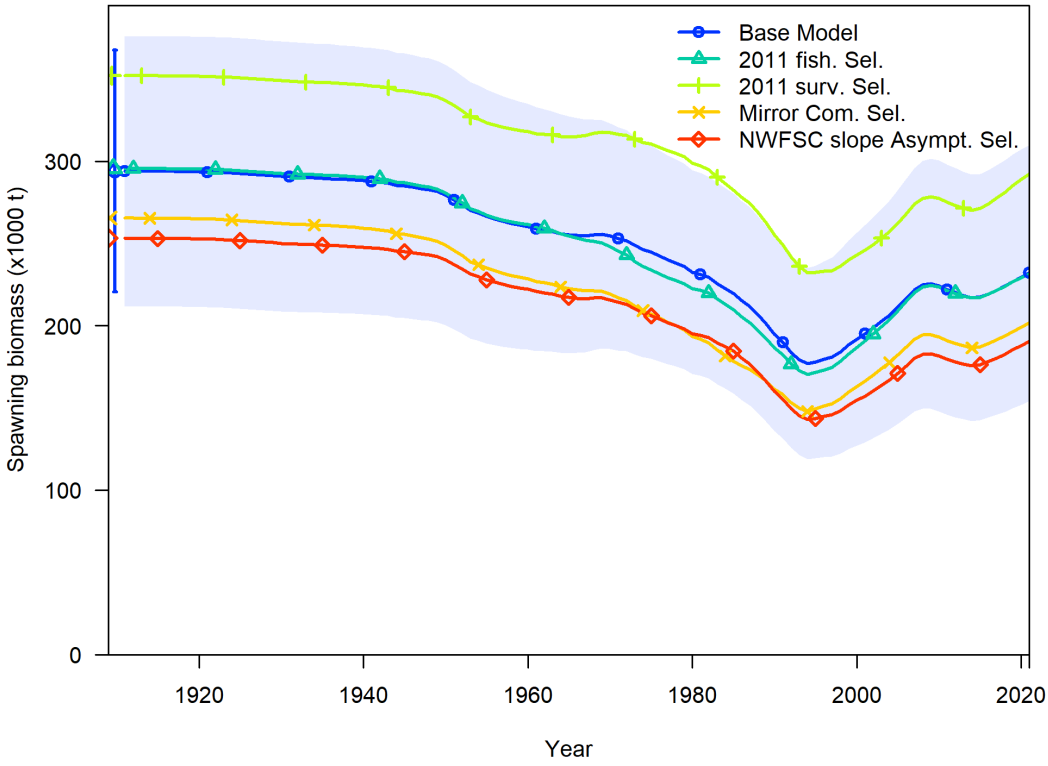


Figure 151: Estimates of spawning biomass for the base model and alternative sensitivity models to selectivity including the parameterization of fishery selectivity following the 2011 assessment, the parameterization of survey selectivity following the 2011 assessment, mirroring California and Oregon/Washington commercial selectivity, and forcing one index (the NWFSC slope survey) to be asymptotic.

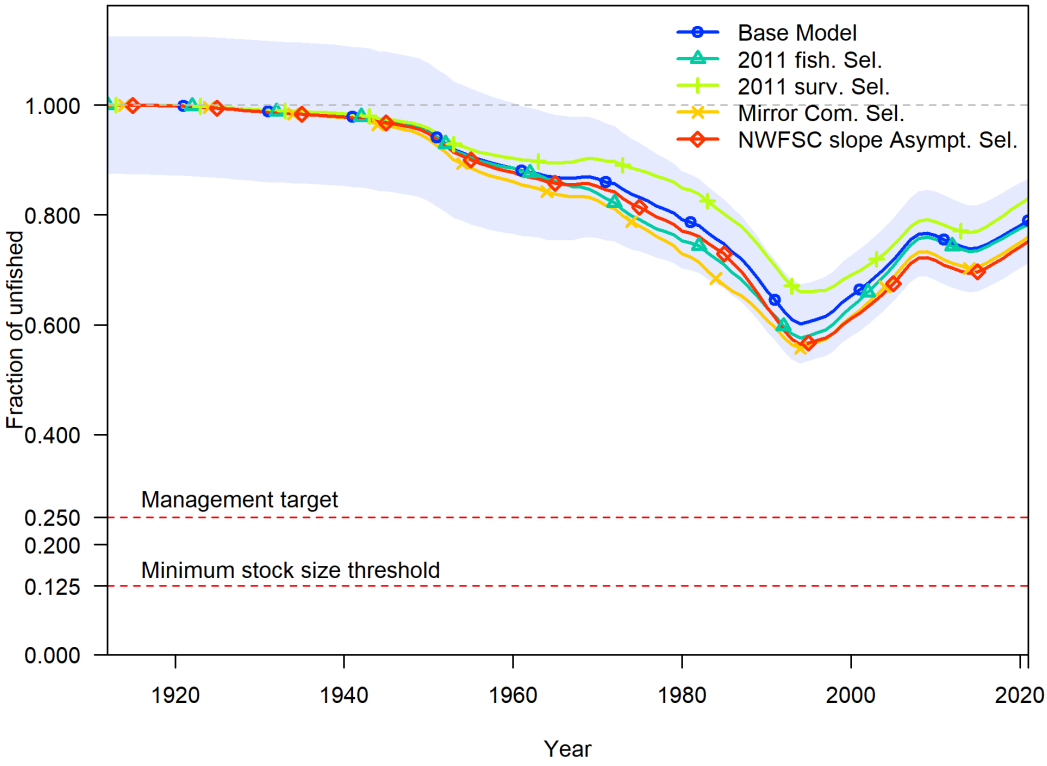


Figure 152: Estimates of relative spawning biomass for the base model and alternative sensitivity models to selectivity including the parameterization of fishery selectivity following the 2011 assessment, the parameterization of survey selectivity following the 2011 assessment, mirroring California and Oregon/Washington commercial selectivity, and forcing one index (the NWFSC slope survey) to be asymptotic.

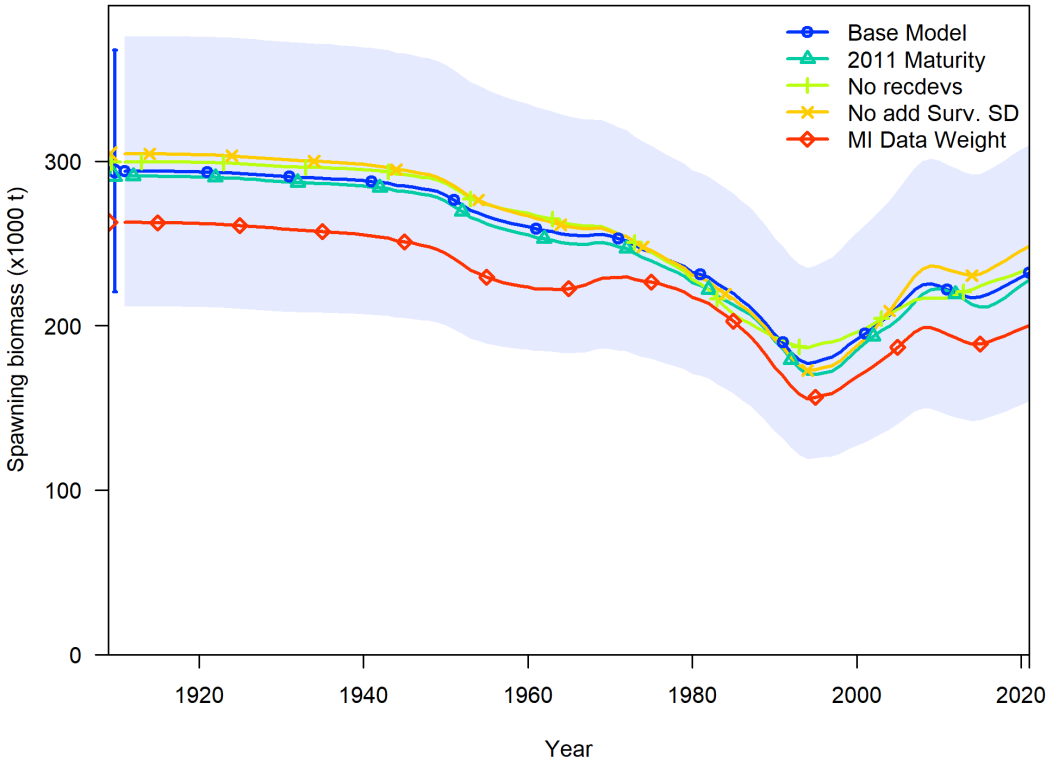


Figure 153: Estimates of spawning biomass for the base model and alternative sensitivity models including using the maturity ogive from the 2011 assessment, estimating no recruitment deviations, effectively not allowing extra survey variance (standard deviation), and applying the McAllister and Ianelli approach to data weighting.

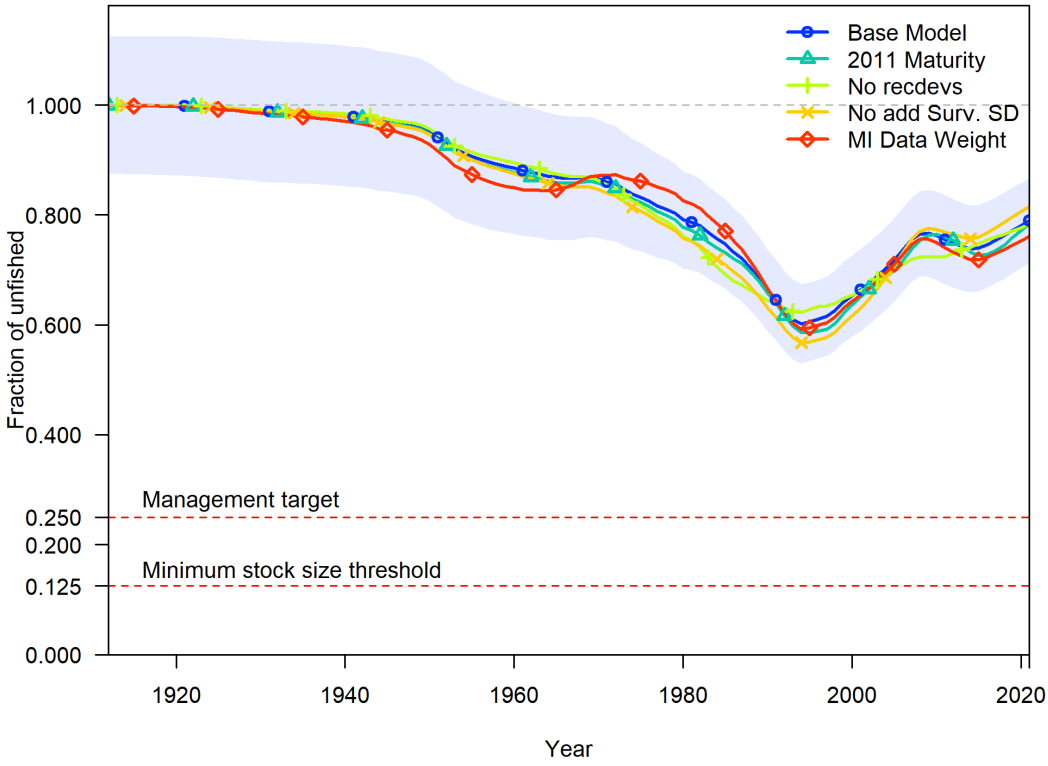


Figure 154: Estimates of relative spawning biomass for the base model and alternative sensitivity models including using the maturity ogive from the 2011 assessment, estimating no recruitment deviations, effectively not allowing extra survey variance (standard deviation), and applying the McAllister and Ianelli approach to data weighting.

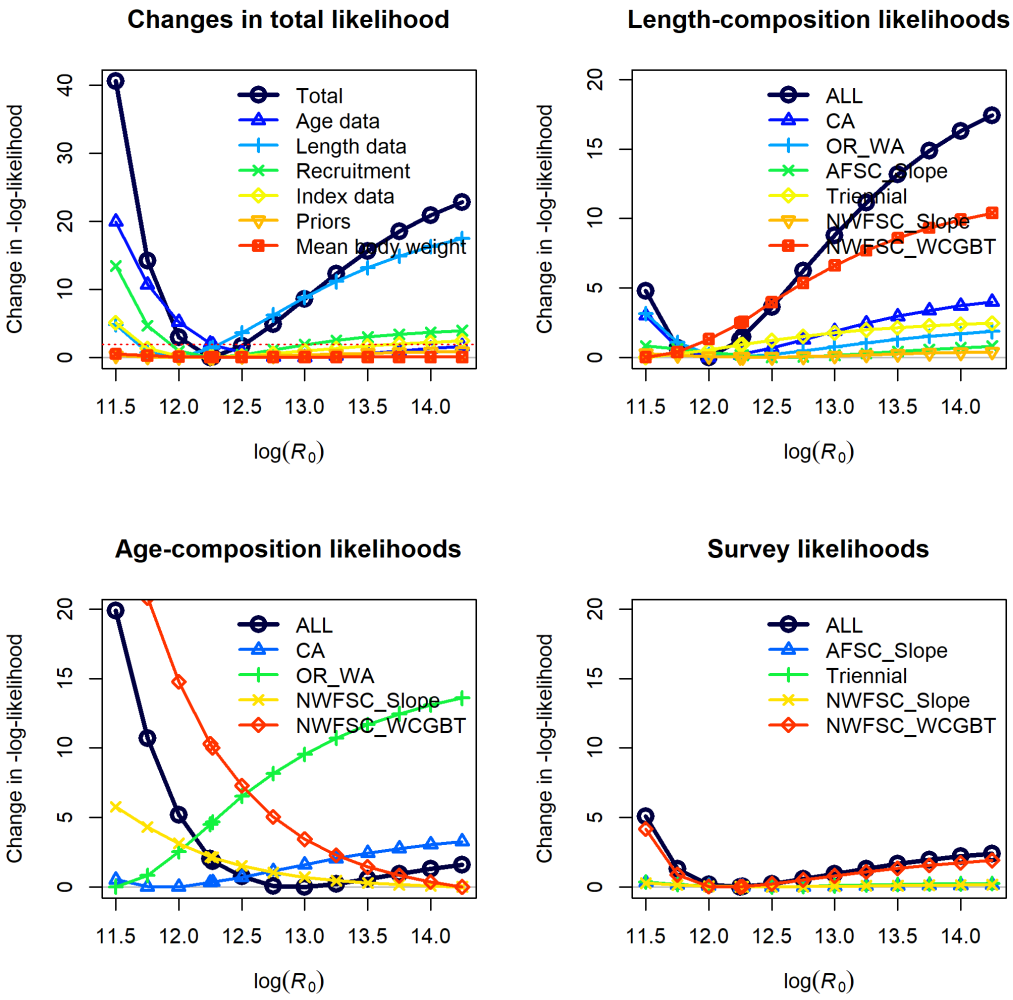


Figure 155: Change in the negative log-likelihood across a range of log(R0) values.

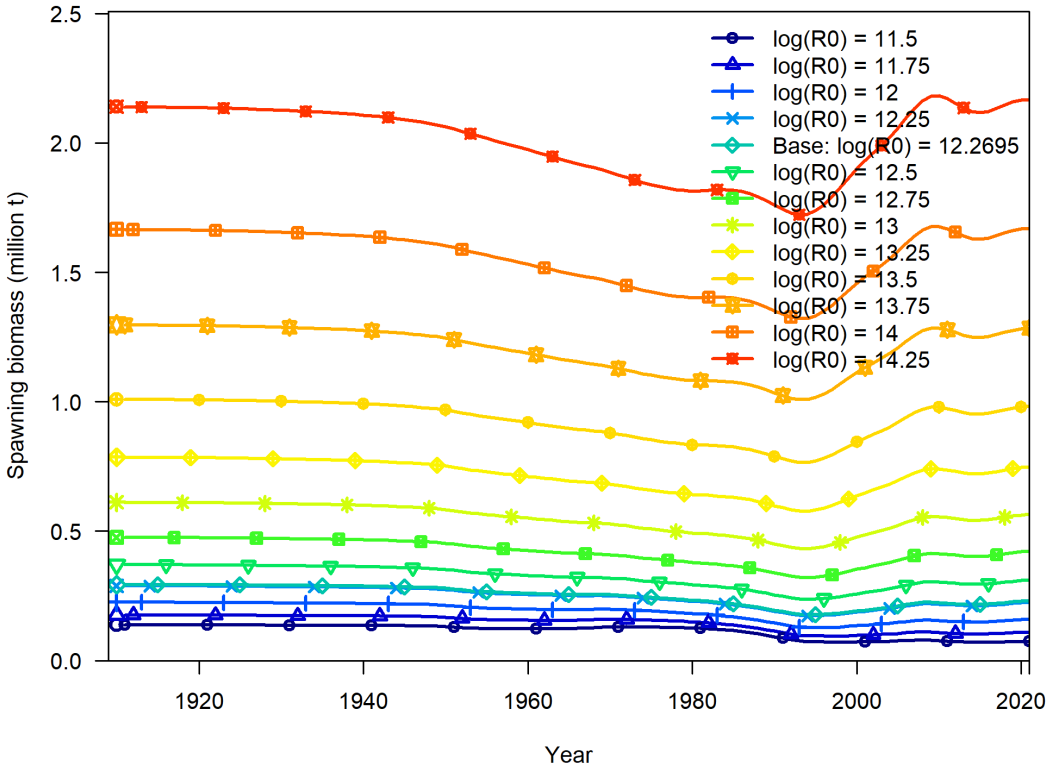


Figure 156: Change in the estimate of spawning biomass across a range of log(R0) values.

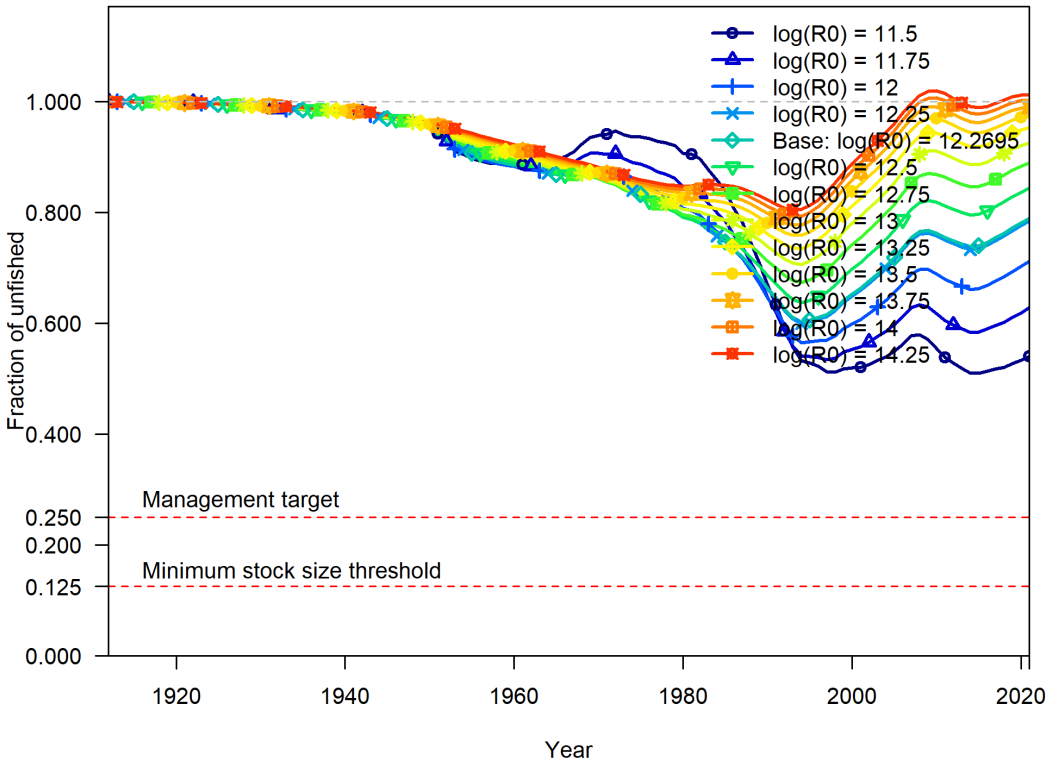


Figure 157: Change in the estimate of fraction unfished across a range of log(R0) values.

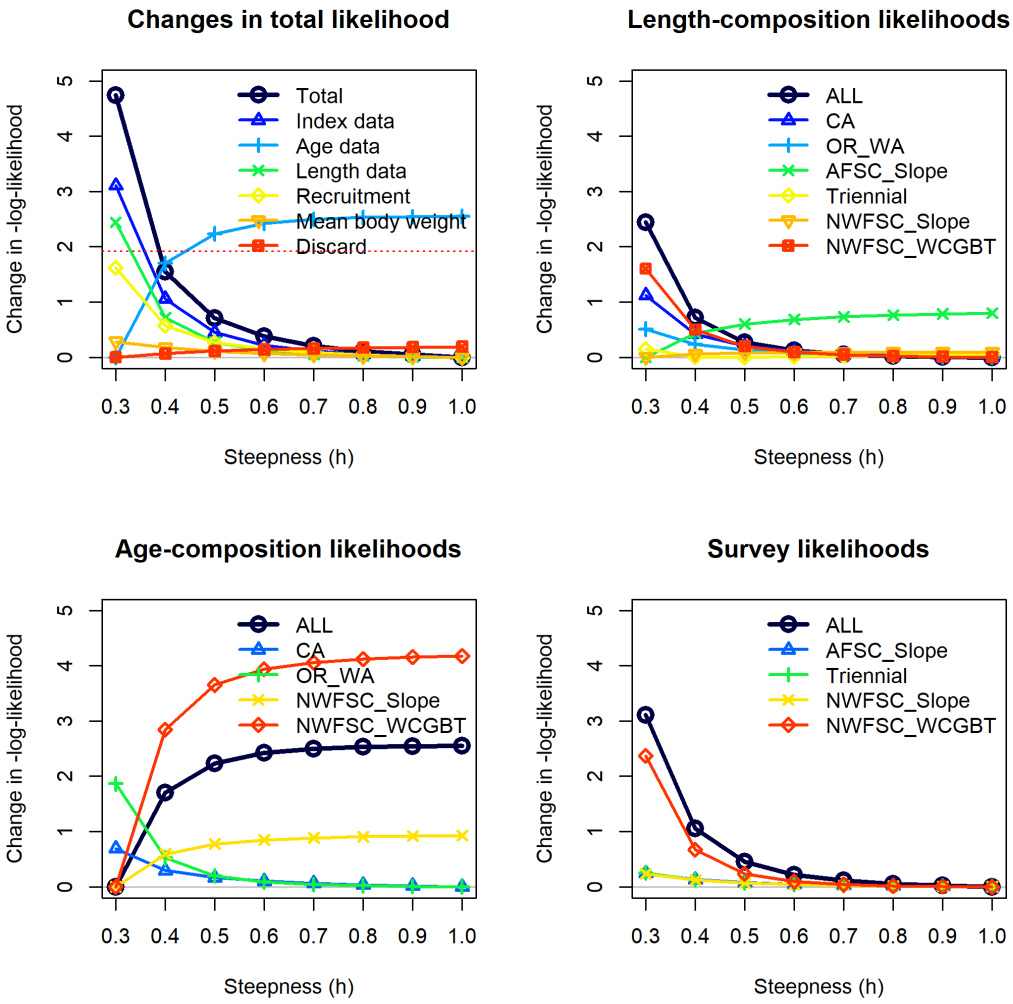


Figure 158: Change in the negative log-likelihood across a range of steepness values.

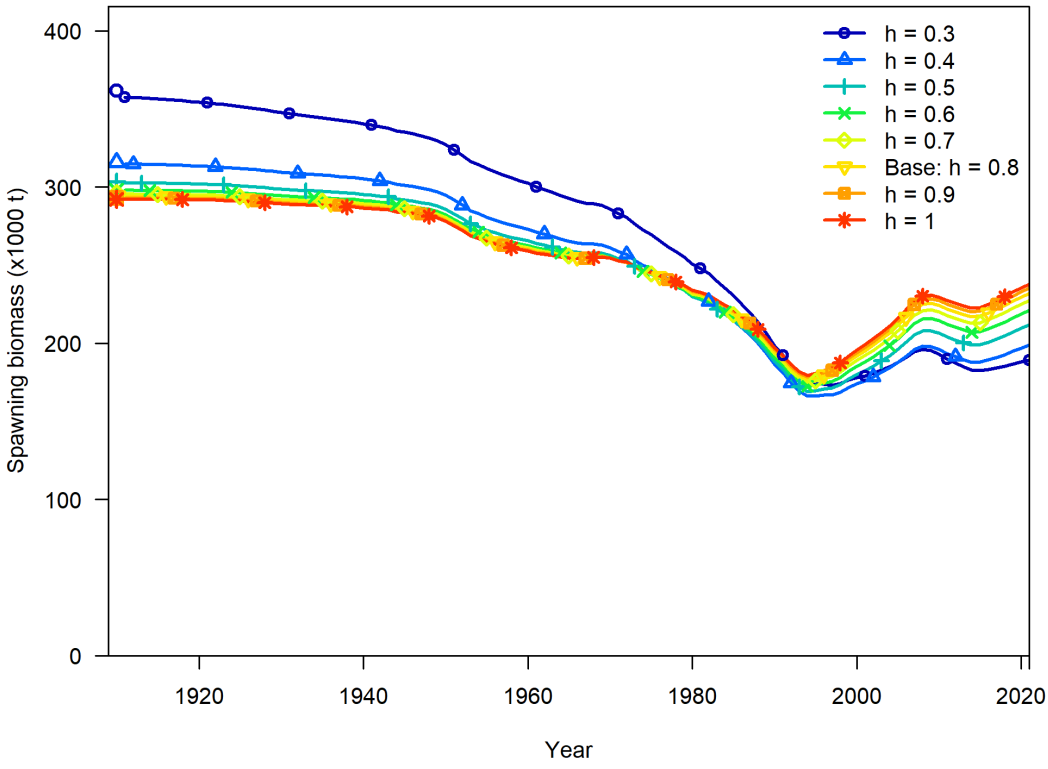


Figure 159: Change in the estimate of spawning biomass across a range of steepness values.

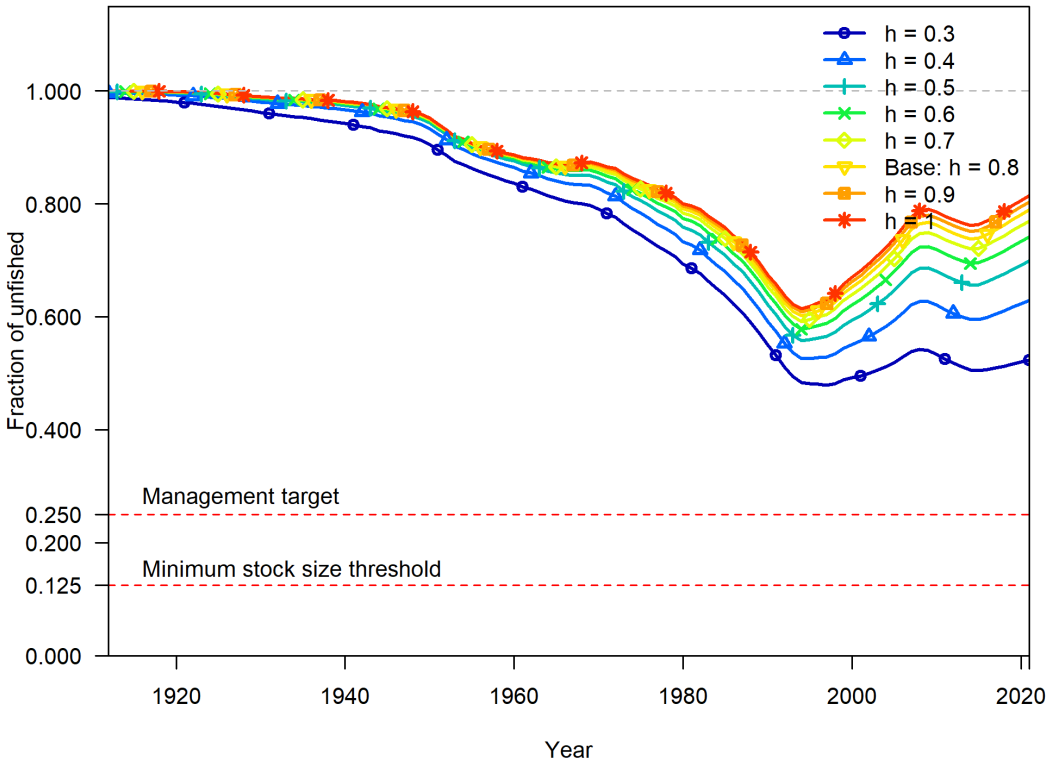


Figure 160: Change in the estimate of fraction unfished across a range of steepness values.

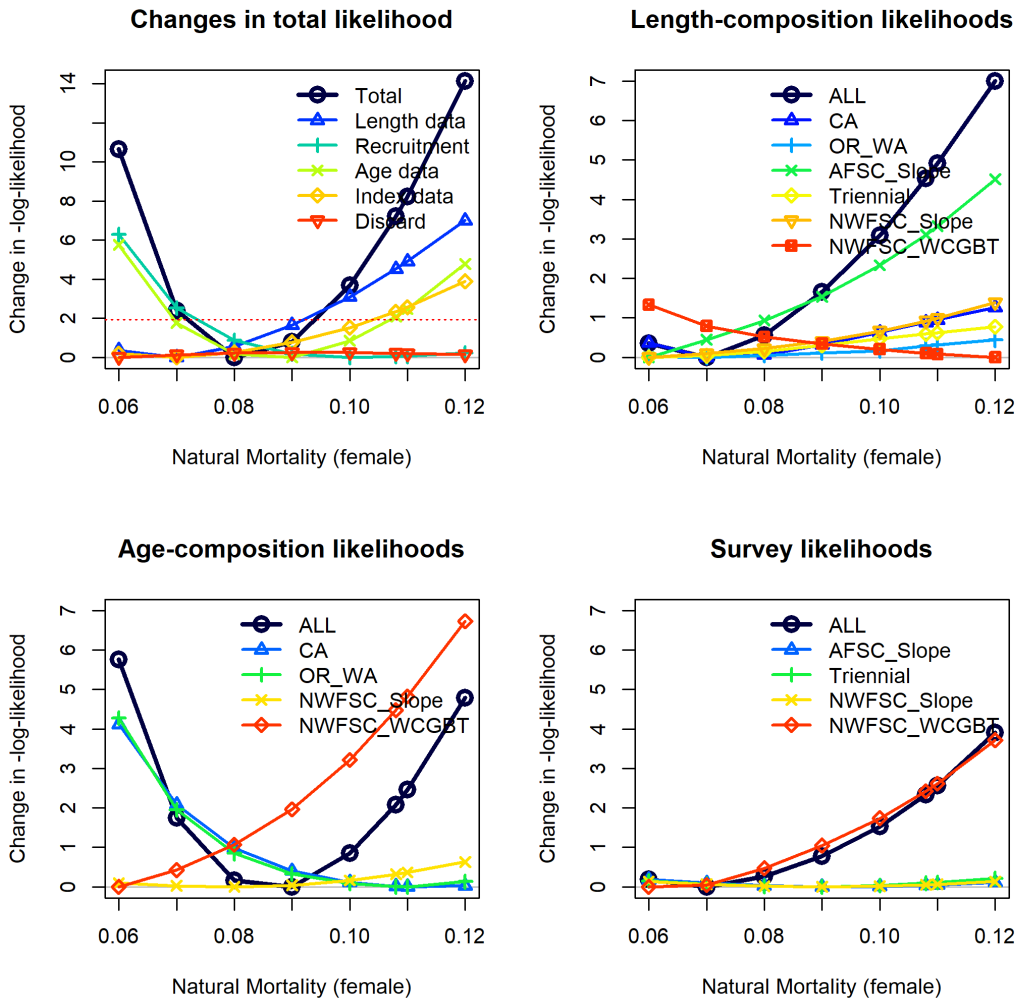


Figure 161: Change in the negative log-likelihood across a range of female natural mortality values.

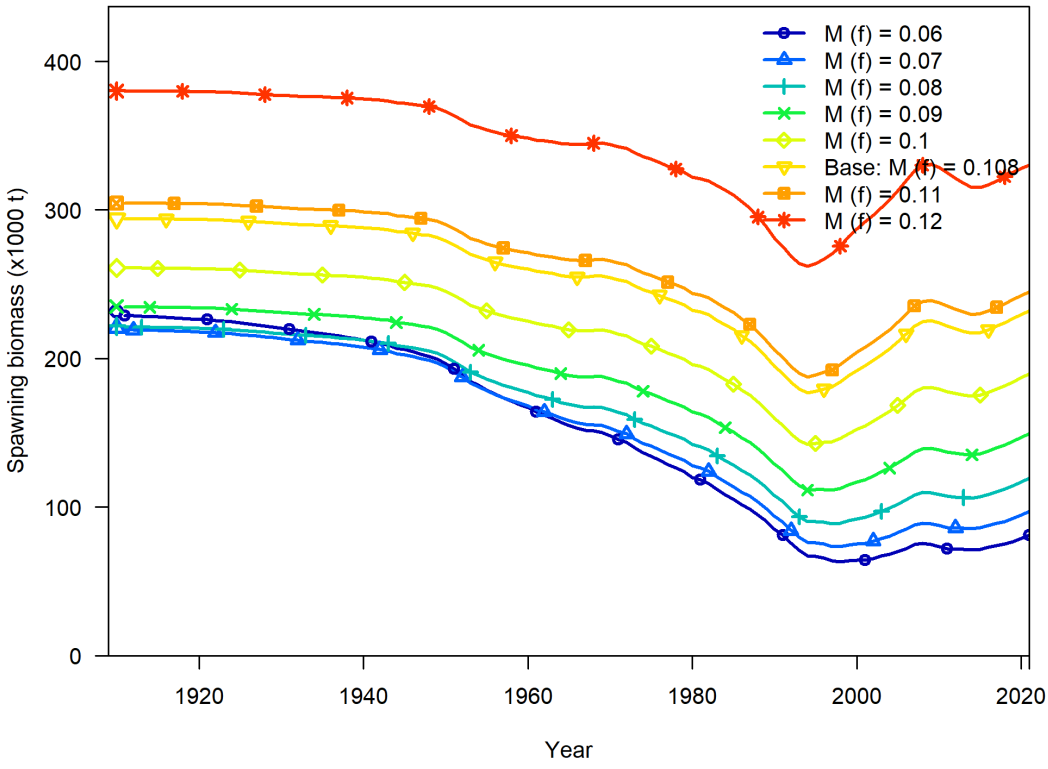


Figure 162: Change in the estimate of spawning biomass across a range of female natural mortality values.

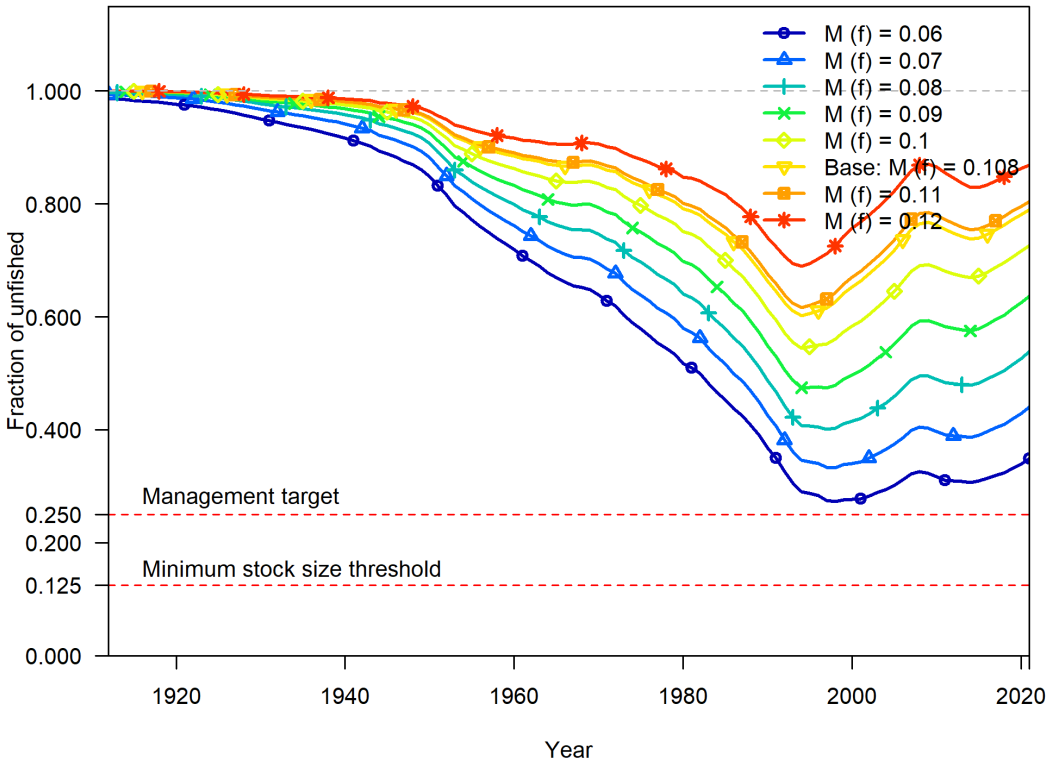


Figure 163: Change in the estimate of fraction unfished across a range of female natural values.

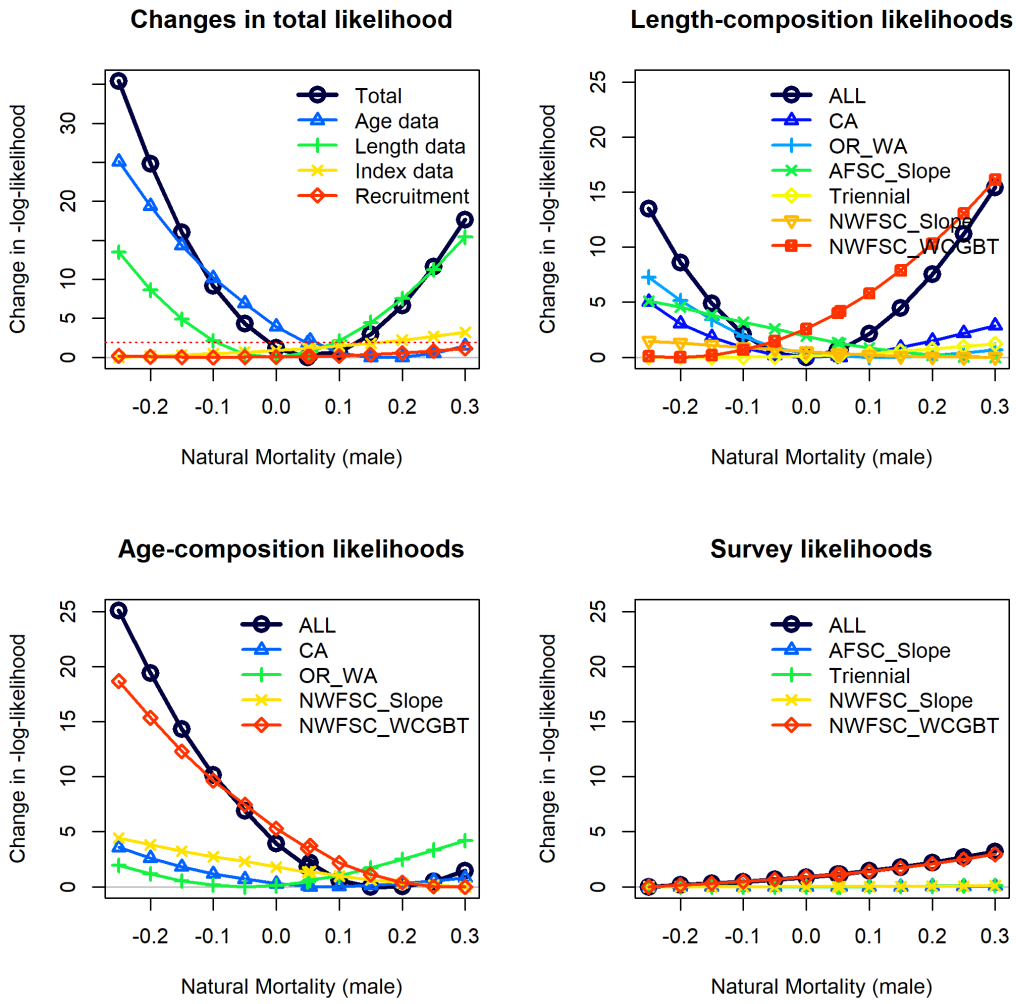


Figure 164: Change in the negative log-likelihood across a range of offset male natural mortality values.

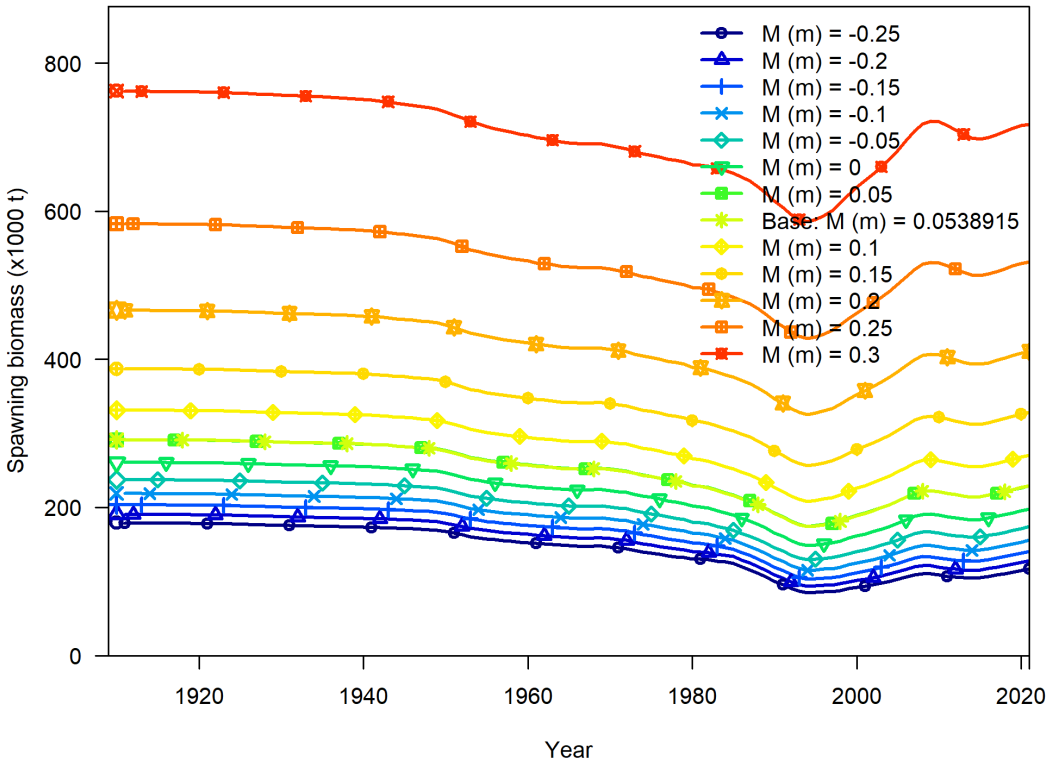


Figure 165: Change in the estimate of spawning biomass across a range of offset male natural mortality values.

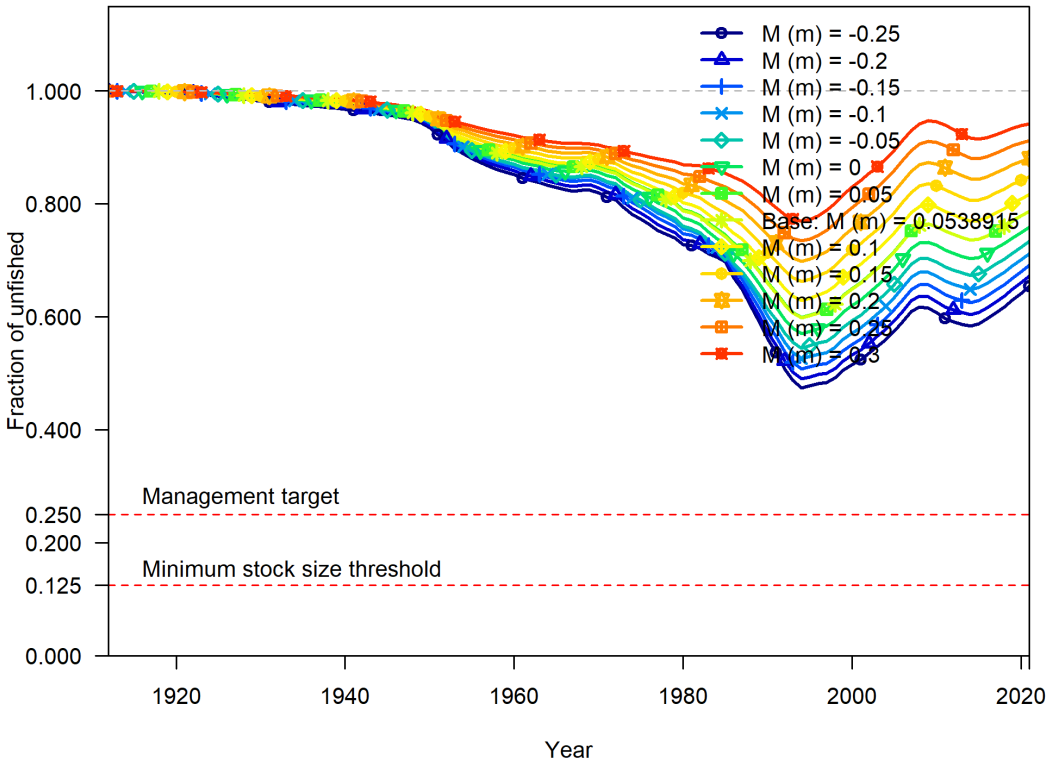


Figure 166: Change in the estimate of fraction unfished across a range of male natural values.

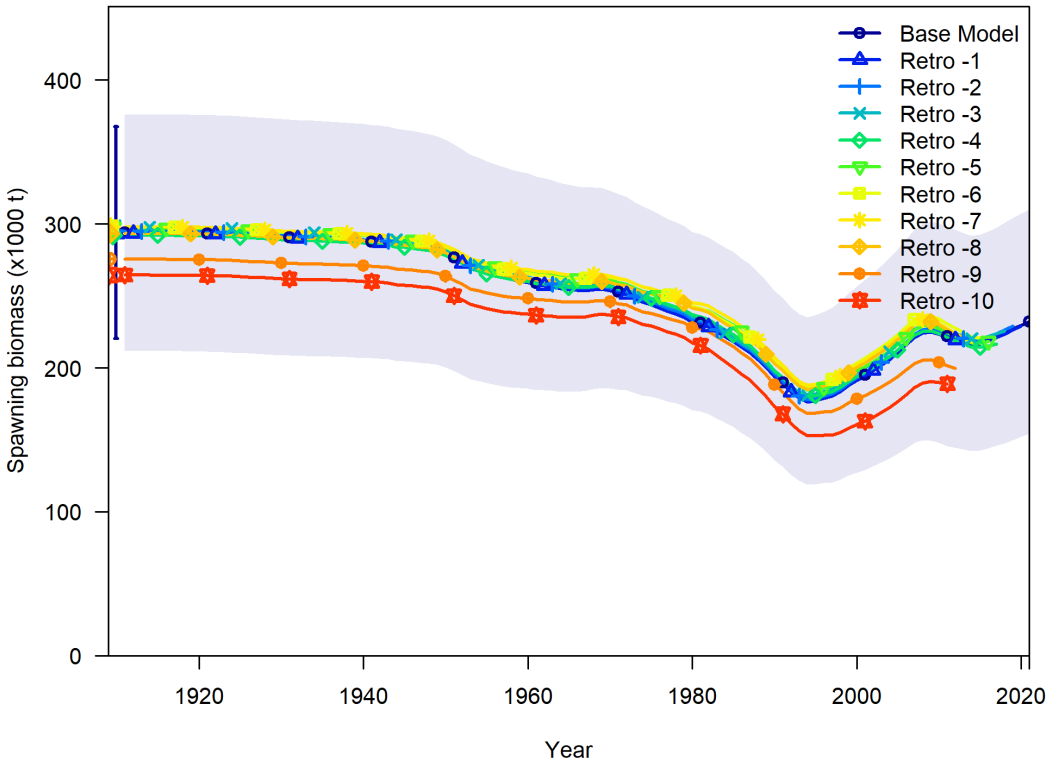


Figure 167: Change in the estimate of spawning biomass when the most recent 10 years of data area removed sequentially.

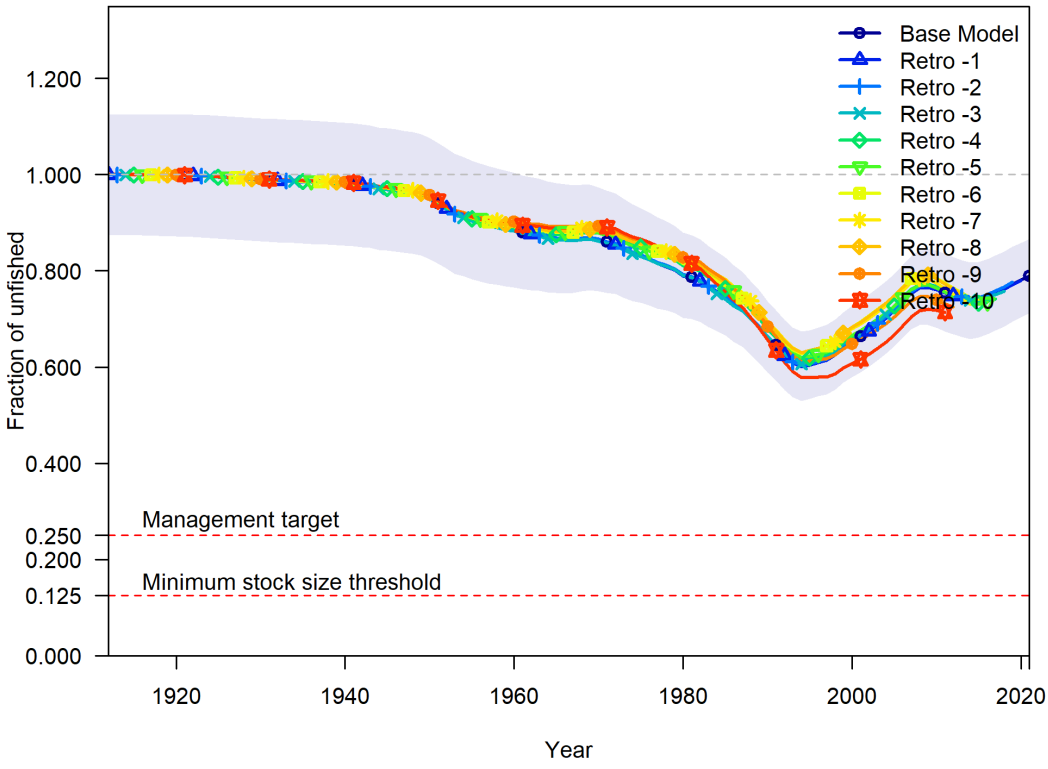


Figure 168: Change in the estimate of fraction unfished when the most recent 10 years of data area removed sequentially.

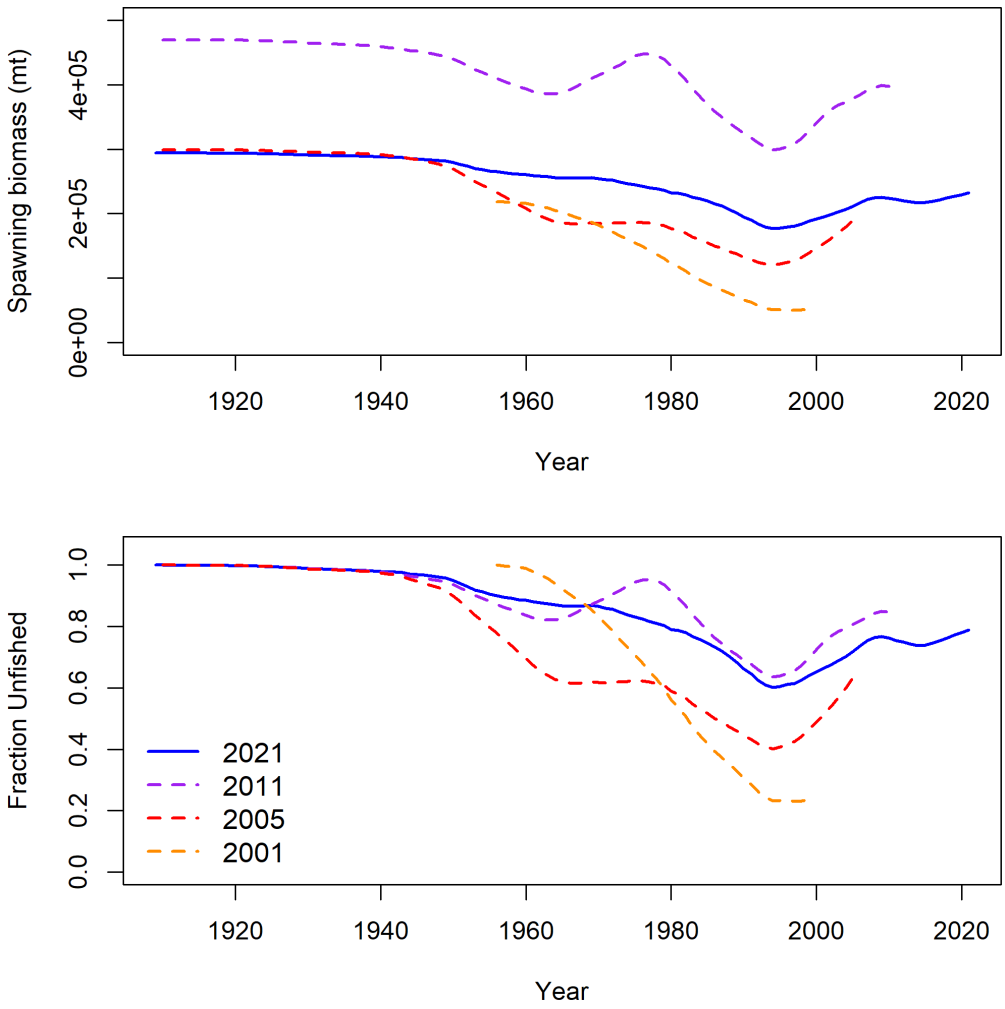


Figure 169: Estimates of spawning biomass across the base model and previous assessments of Dover sole.

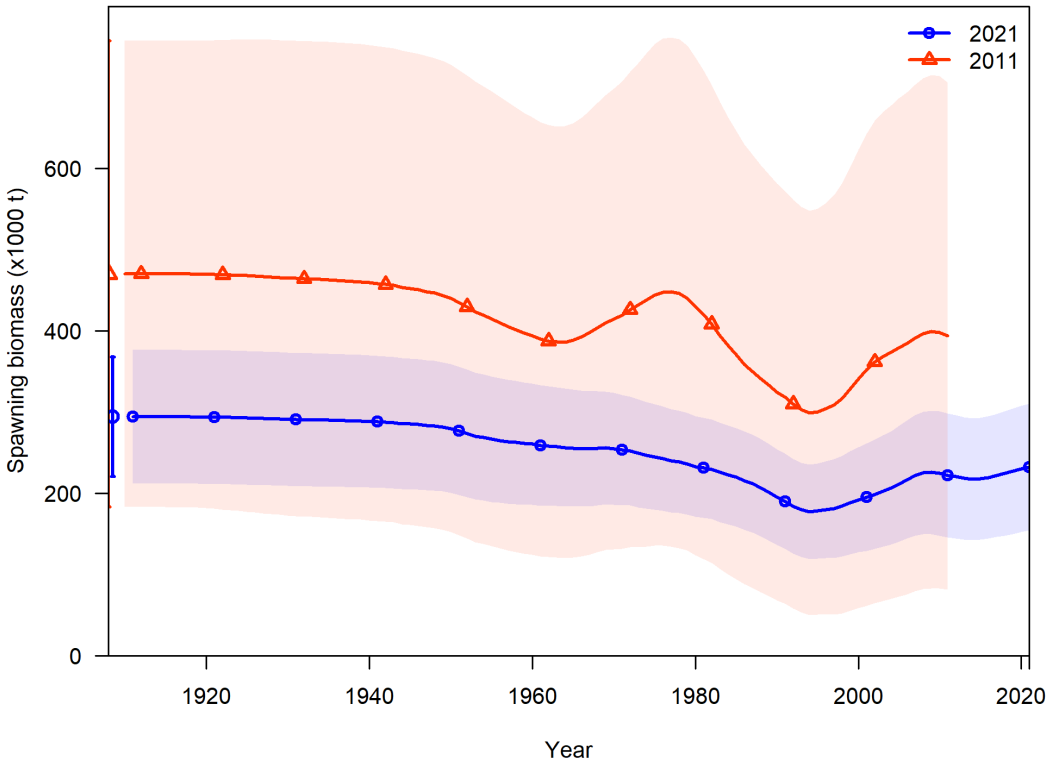


Figure 170: Estimates of spawning biomass with uncertainty intervals between the base model and the 2011 assessment.

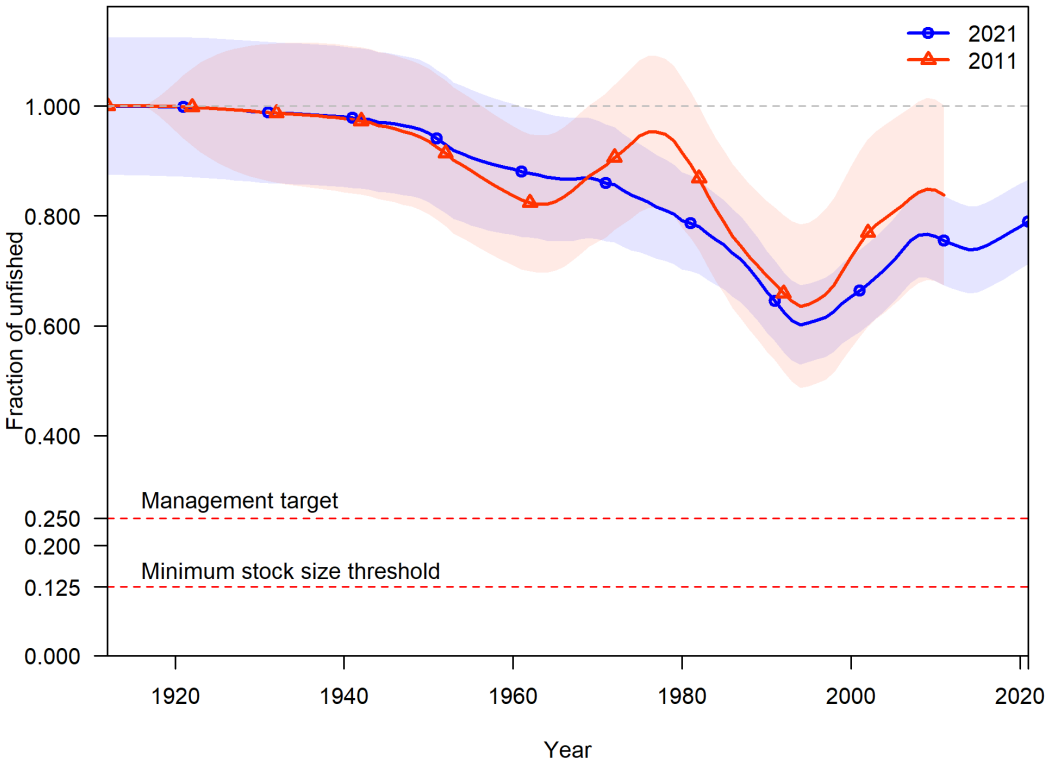


Figure 171: Estimates of fraction unfished with uncertainty intervals between the base model and the 2011 assessment.

9 Appendix A

9.1 Detailed Fit to Length Composition Data

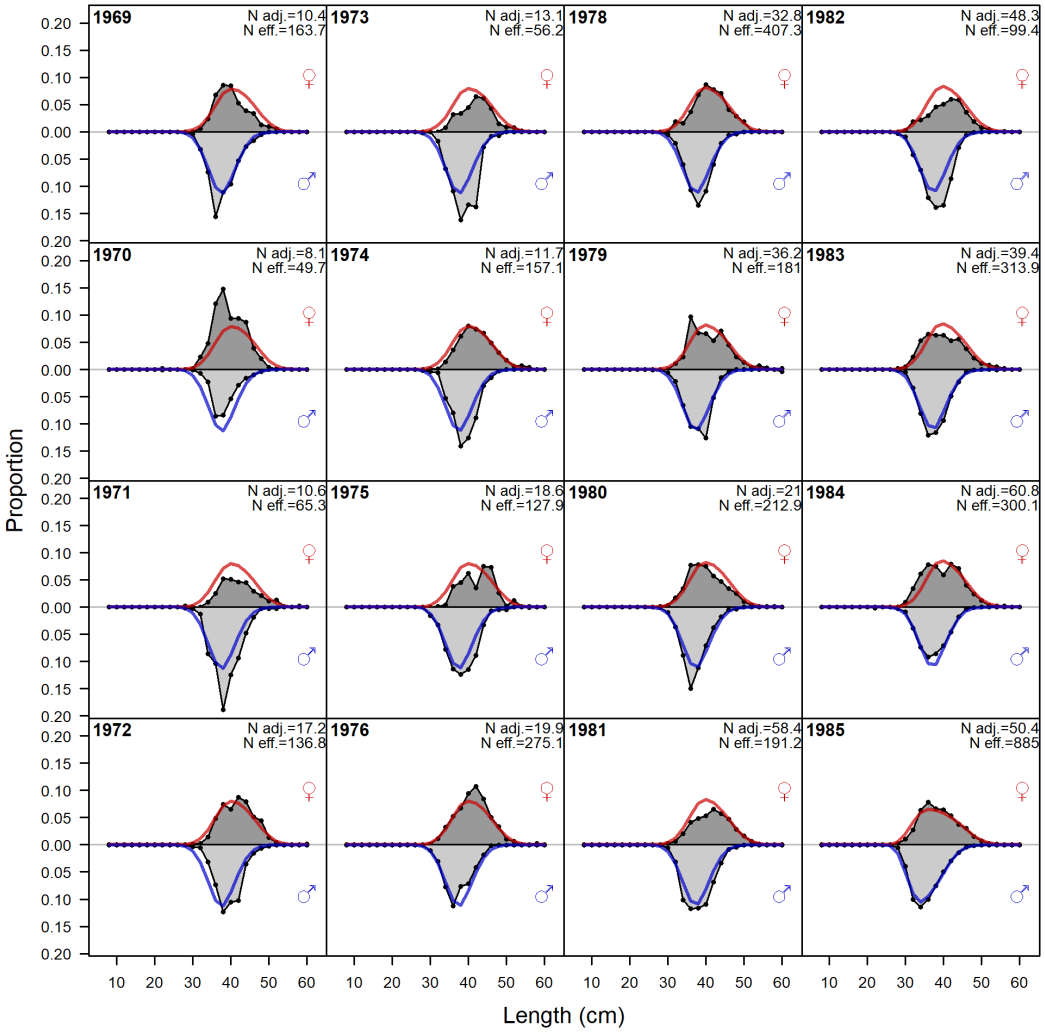


Figure 172: Length comps, retained, CA (plot 1 of 4).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

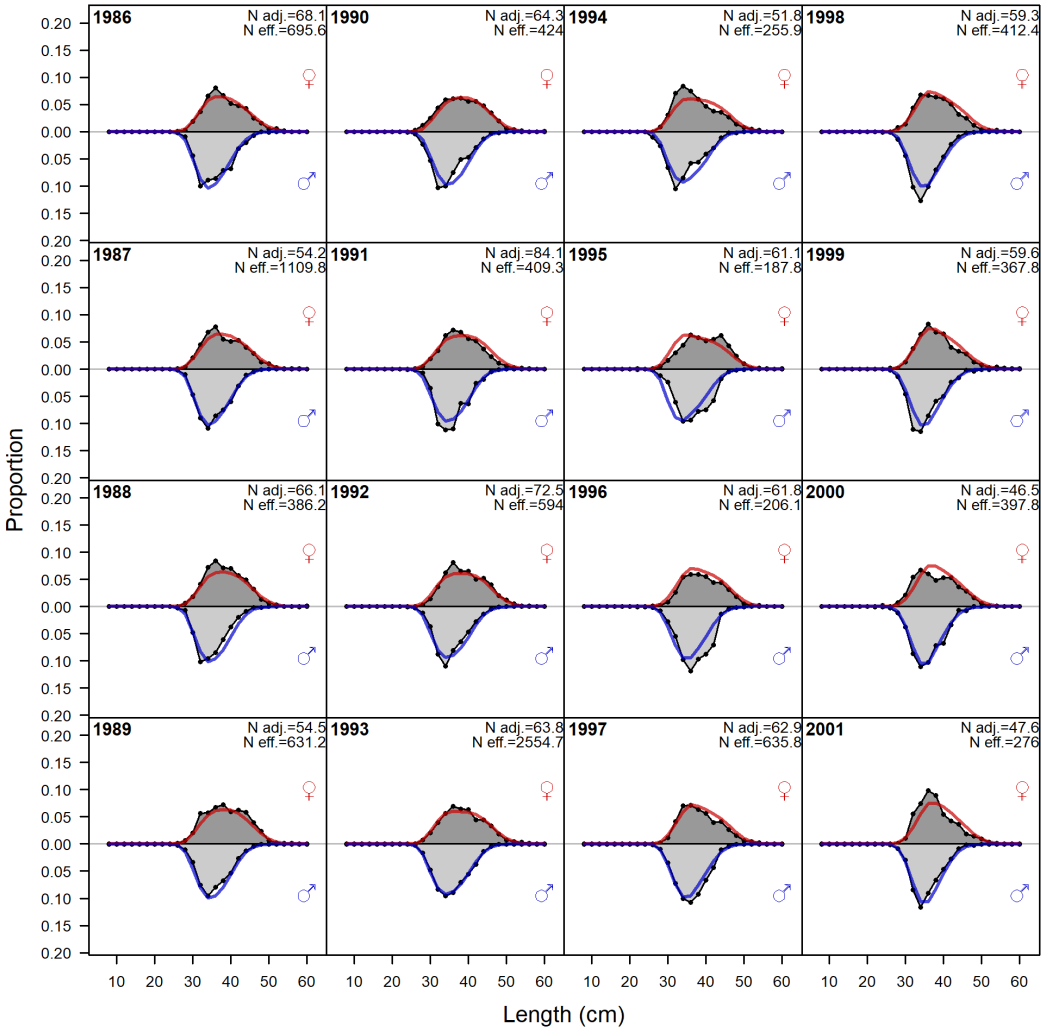


Figure 173: Length comps, retained, CA (plot 2 of 4).

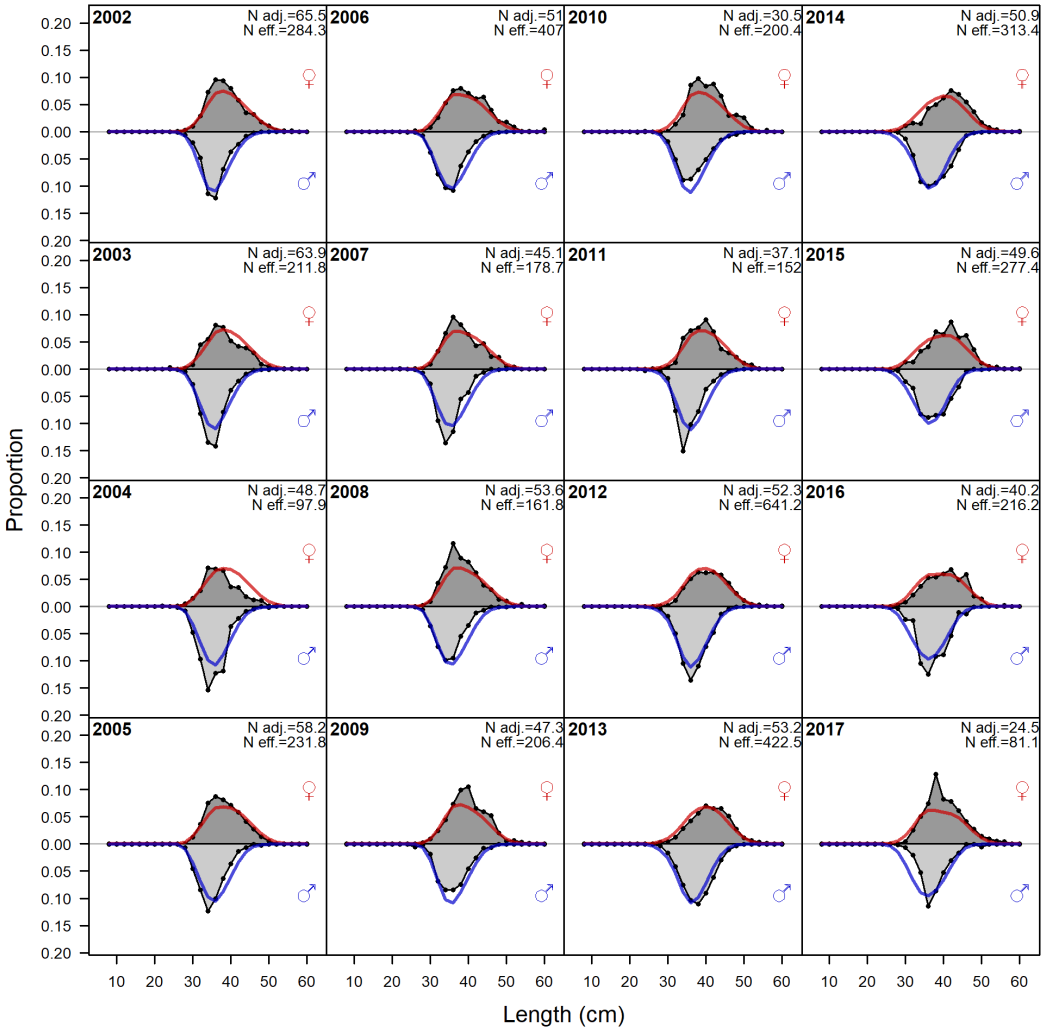


Figure 174: Length comps, retained, CA (plot 3 of 4).

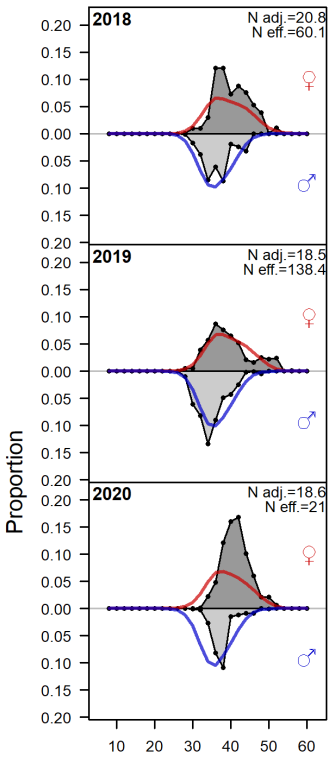


Figure 175: Length comps, retained, CA (plot 4 of 4).

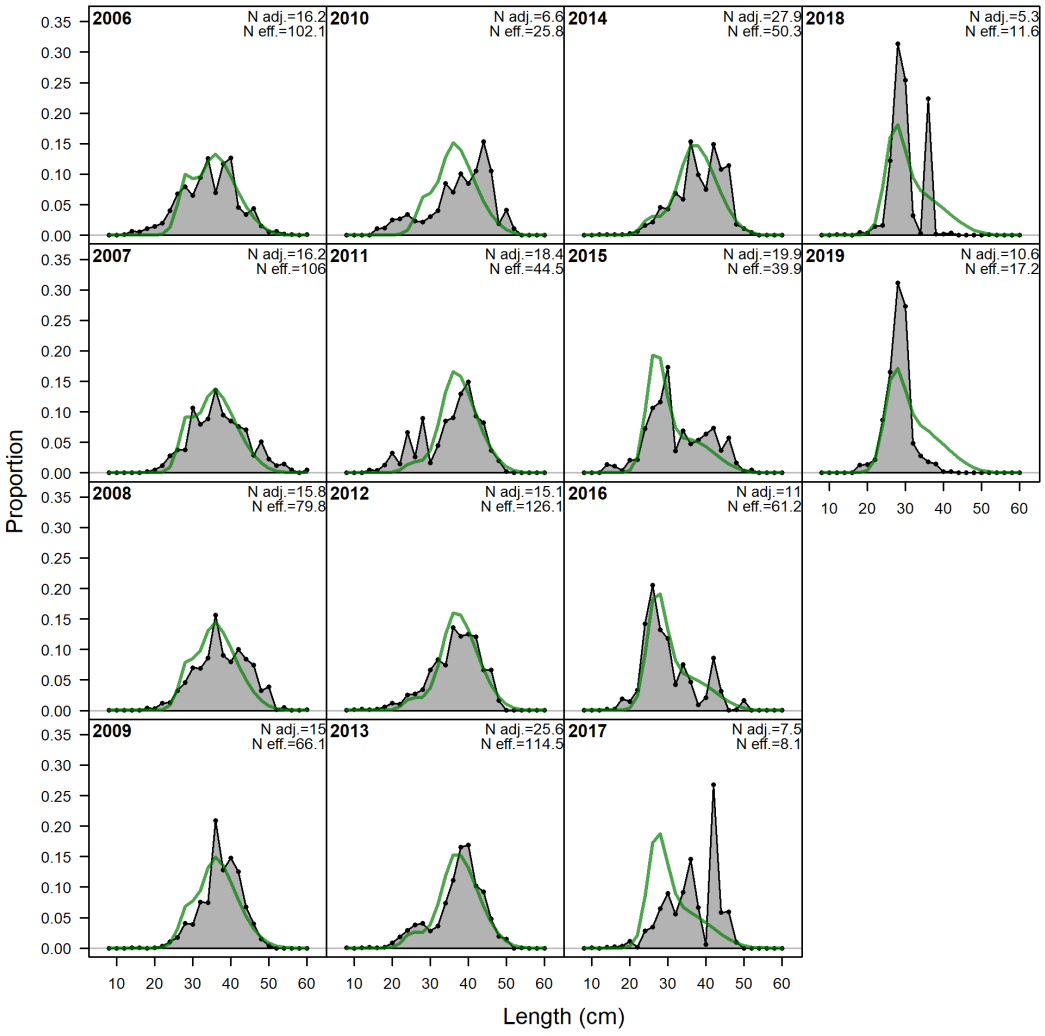


Figure 176: Length comps, discard, CA.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

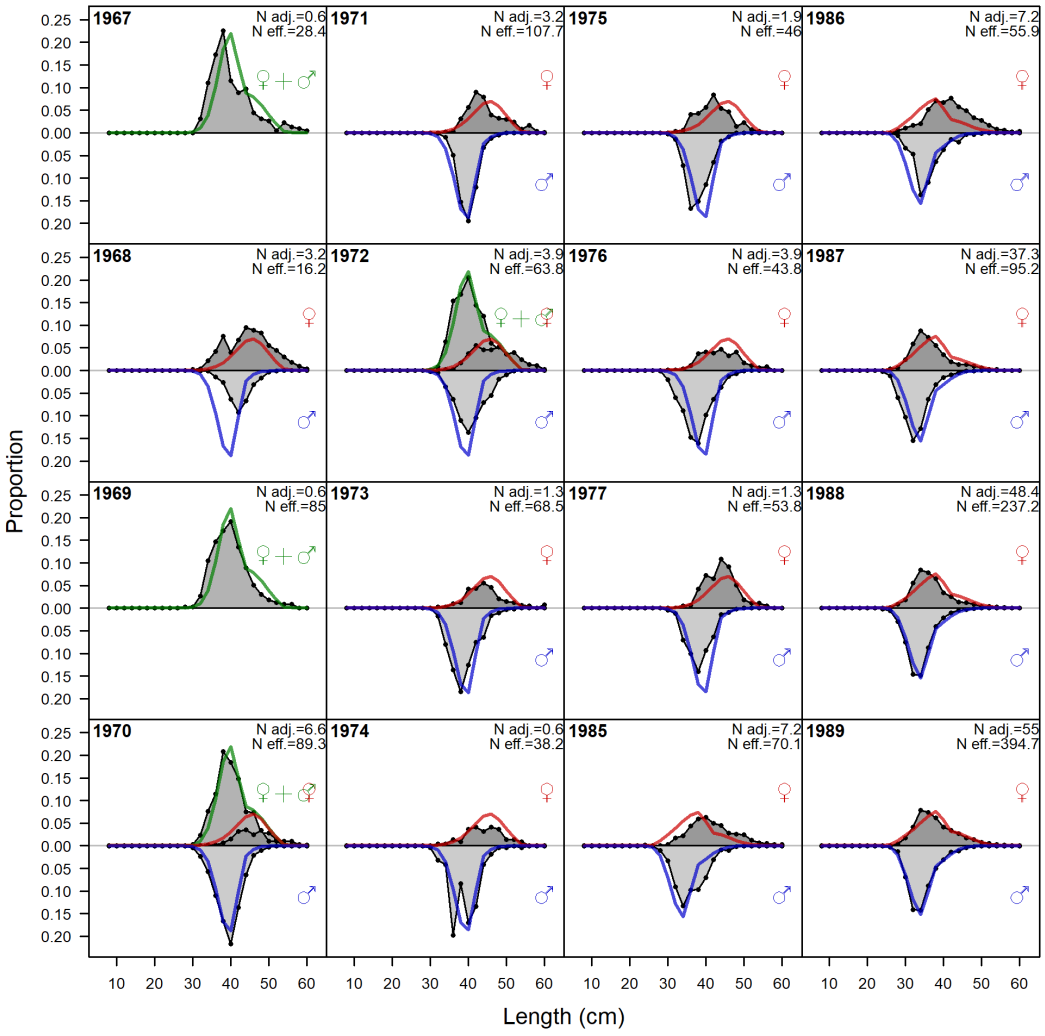


Figure 177: Length comps, retained, OR_WA (plot 1 of 3).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

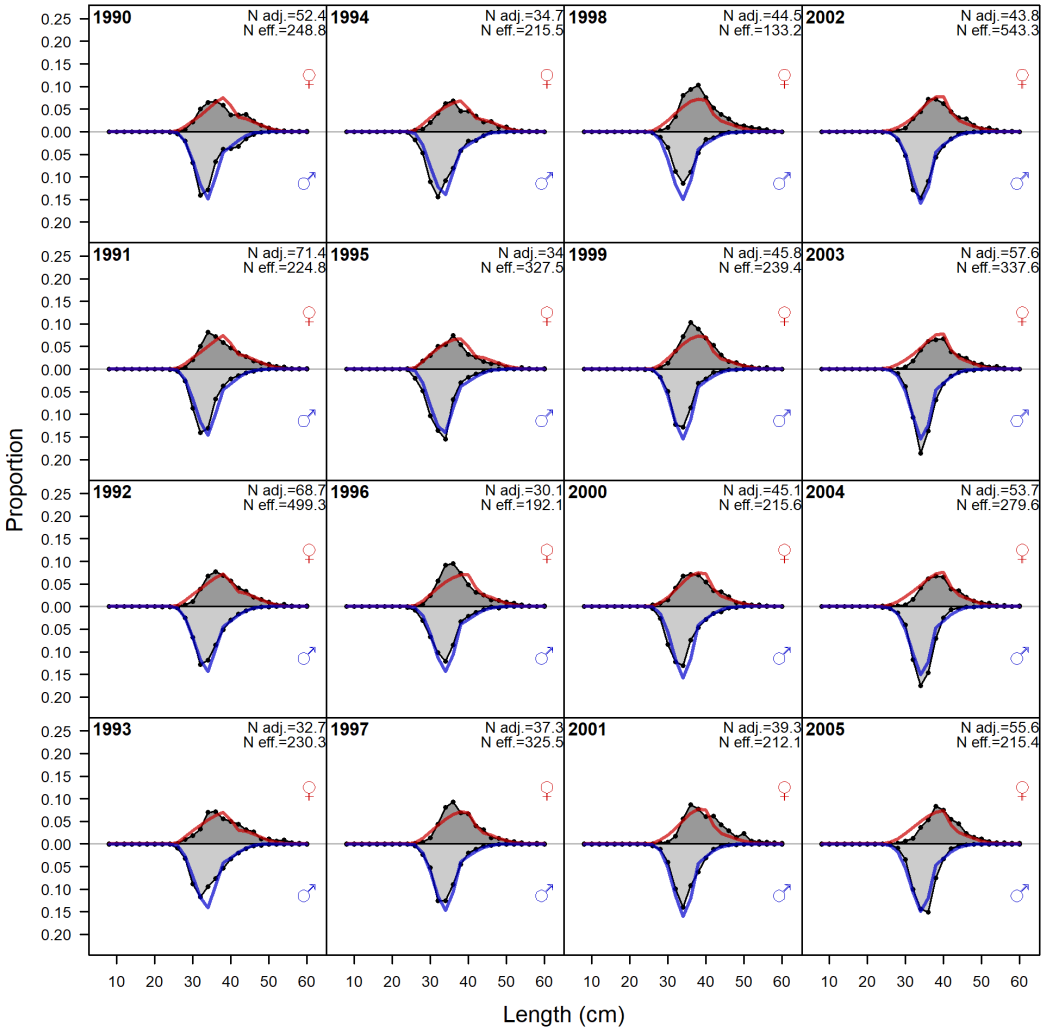


Figure 178: Length comps, retained, OR_WA (plot 2 of 3).

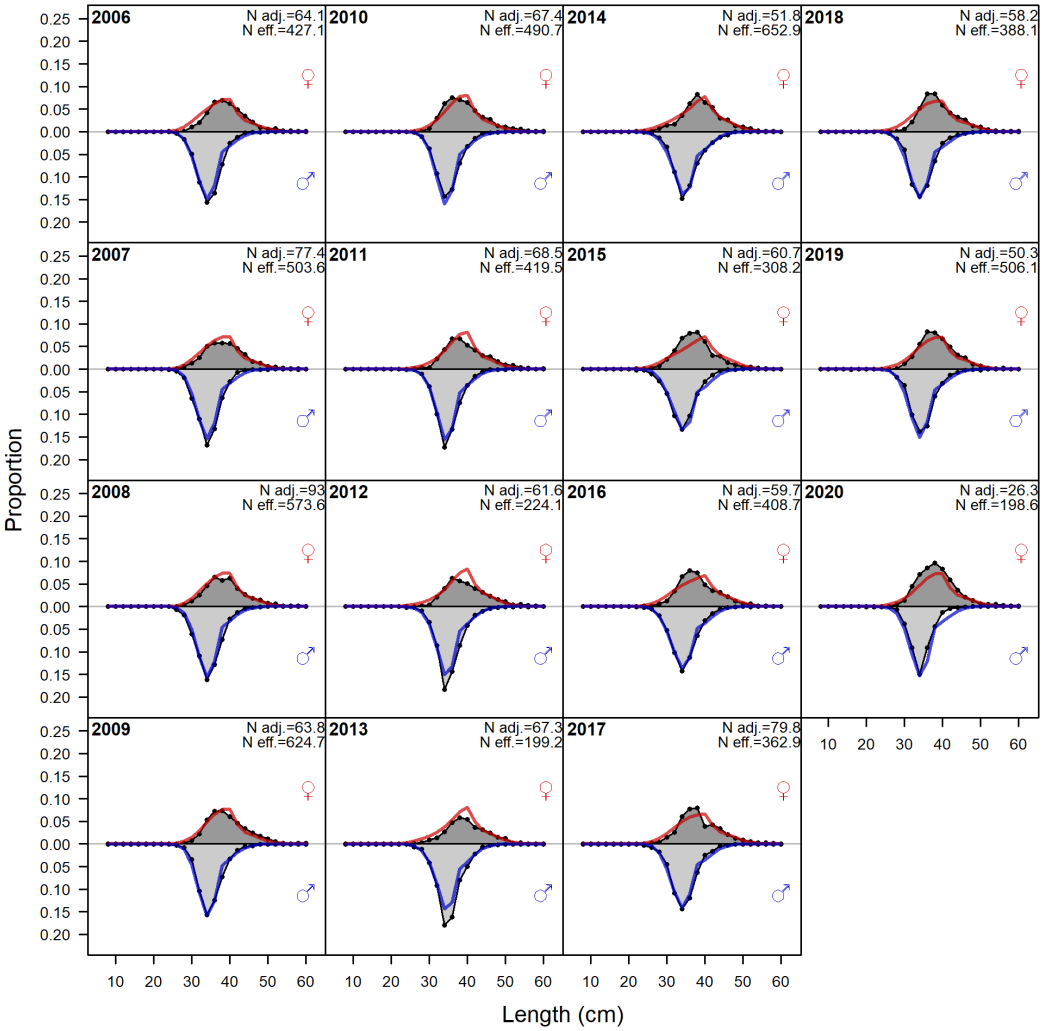


Figure 179: Length comps, retained, OR_WA (plot 3 of 3).

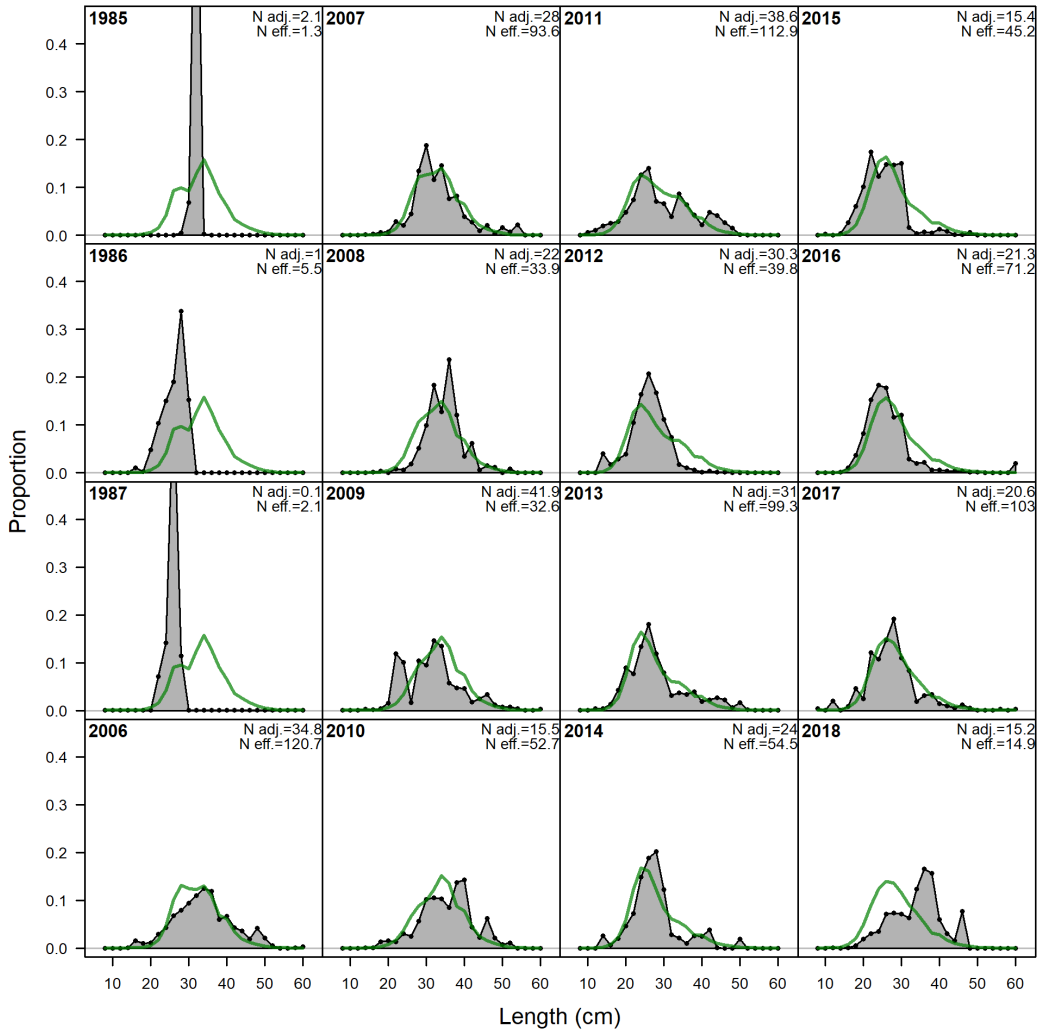
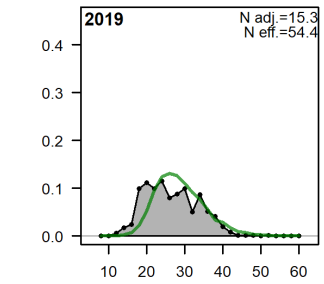


Figure 180: Length comps, discard, OR_WA (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..



Proportion

Length (cm)

Figure 181: Length comps, discard, OR_WA (plot 2 of 2).

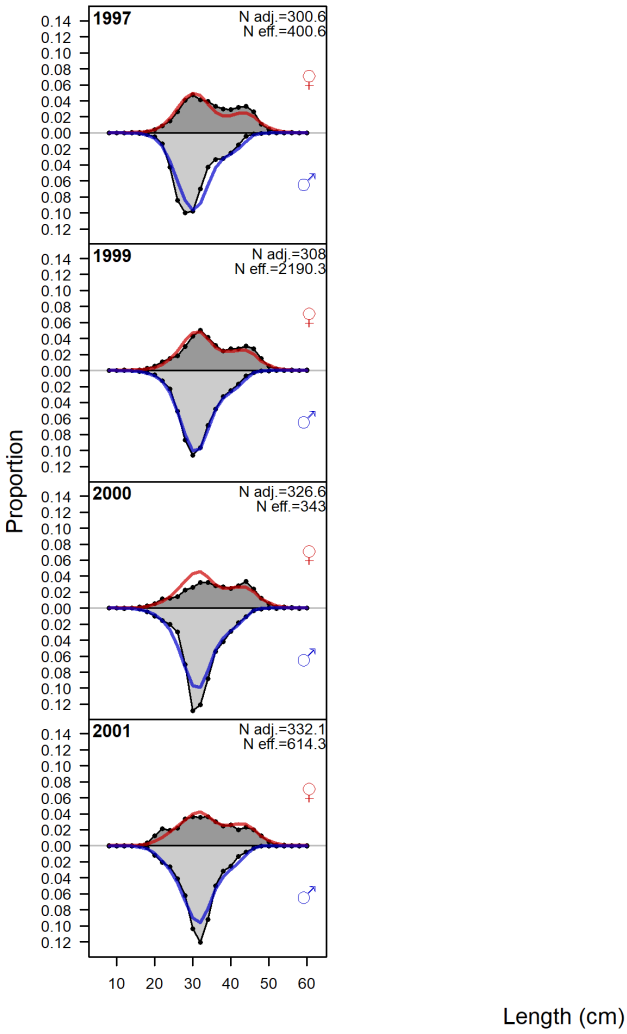


Figure 182: Length comps, whole catch, AFSC_Slope.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

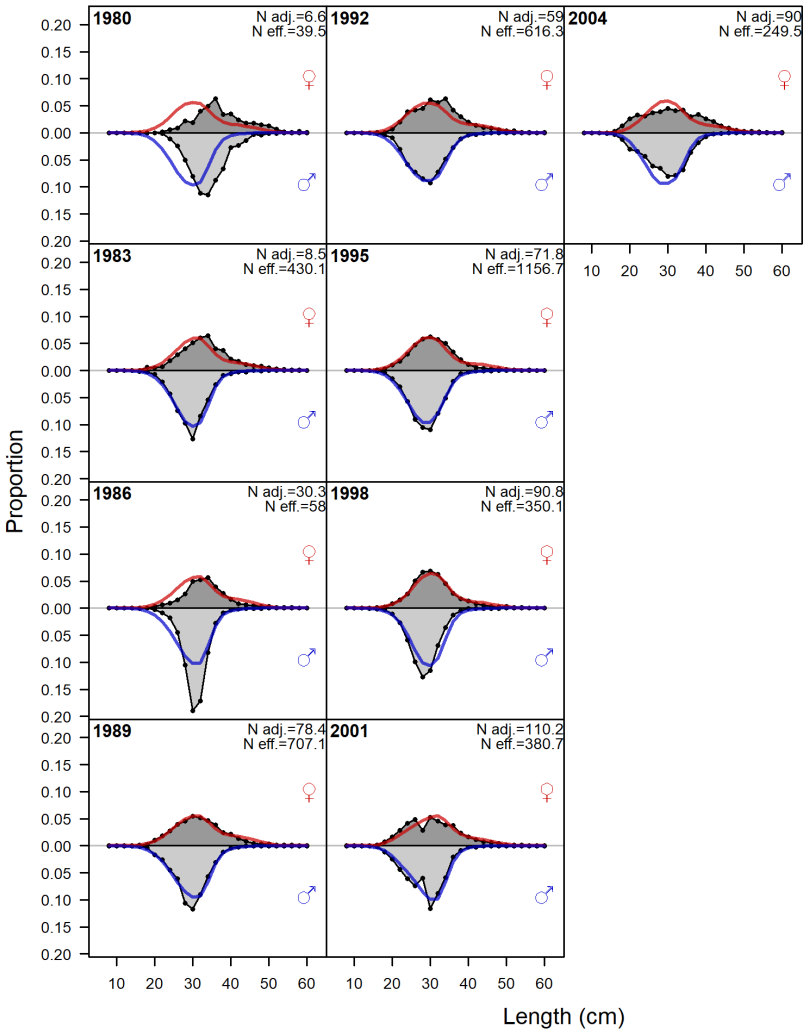


Figure 183: Length comps, whole catch, Triennial.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

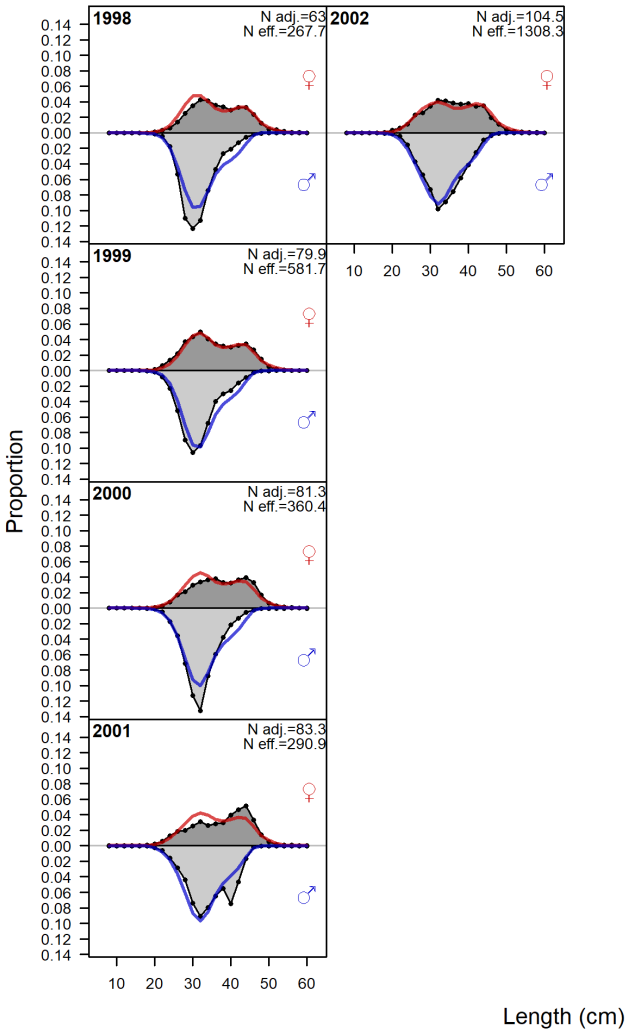


Figure 184: Length comps, whole catch, NWFSC_Slope.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

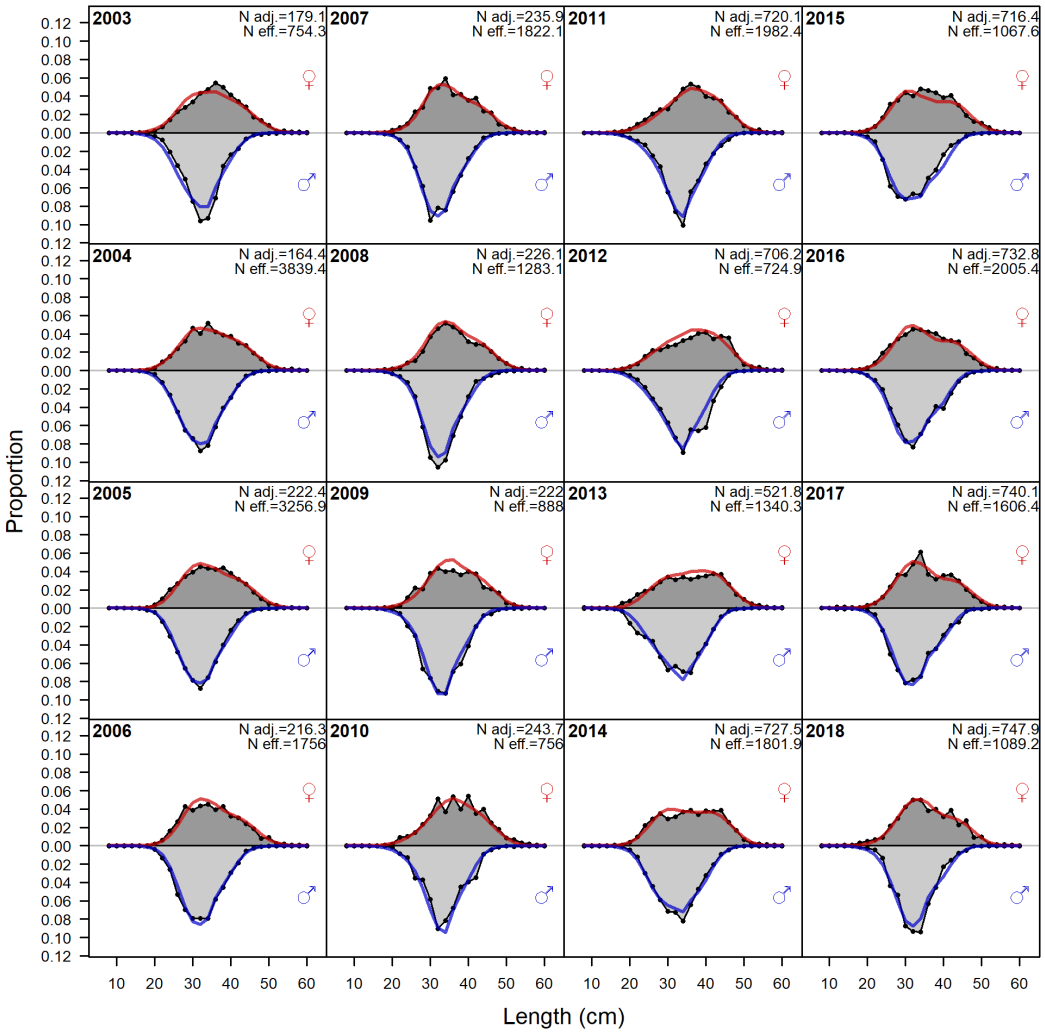


Figure 185: Length comps, whole catch, NWFSC_WCGBT (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

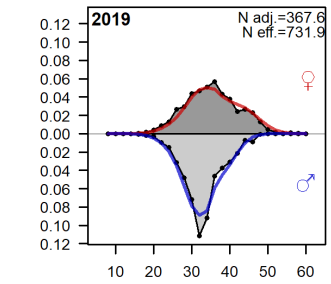


Figure 186: Length comps, whole catch, NWFSC_WCGBT (plot 2 of 2).

9.2 Detailed Fit to Age Composition Data

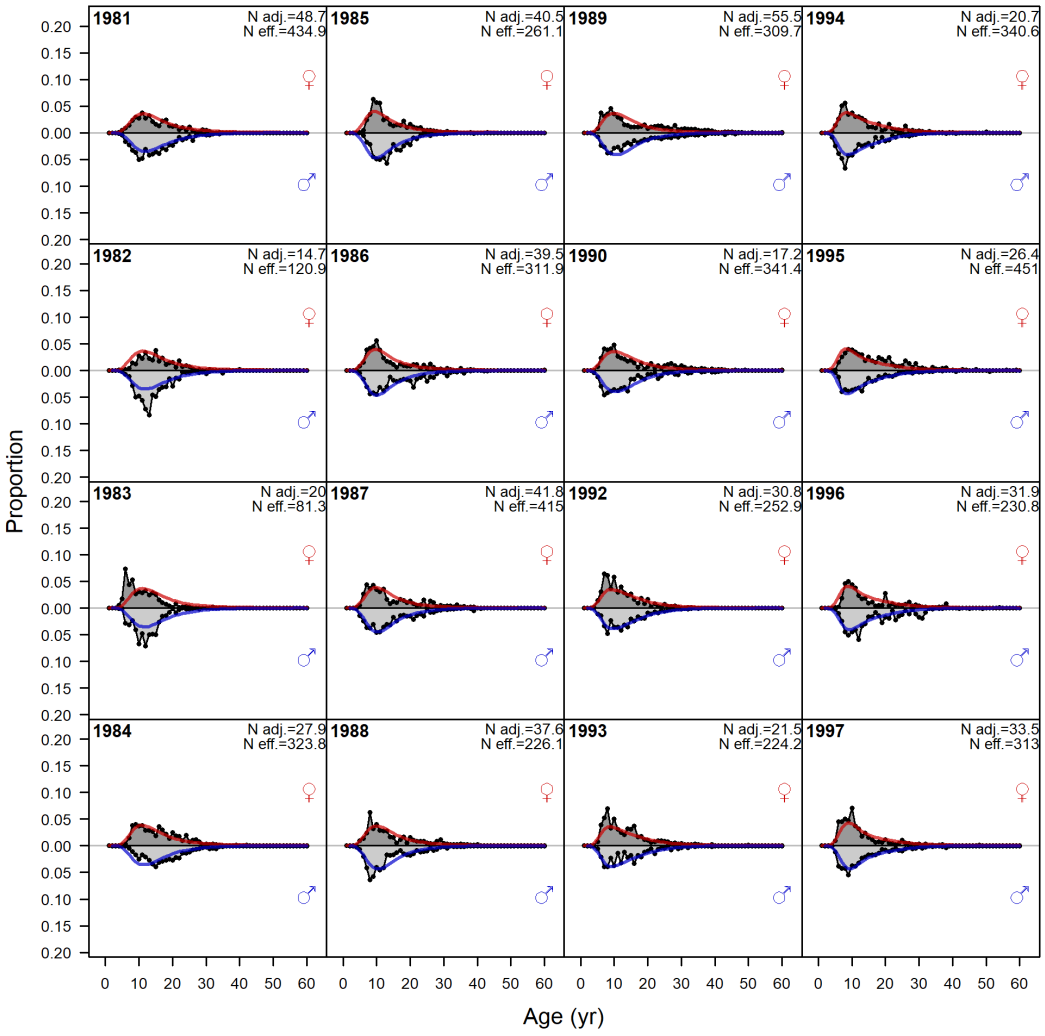


Figure 187: Age comps, retained, CA (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

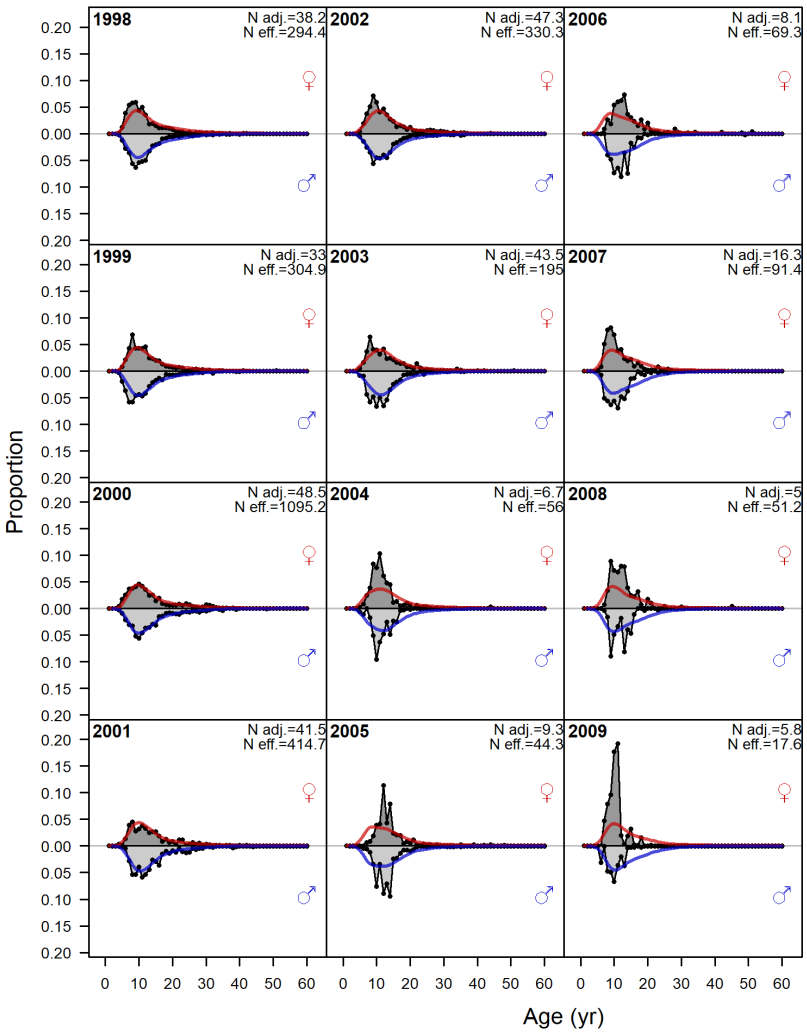


Figure 188: Age comps, retained, CA (plot 2 of 2).

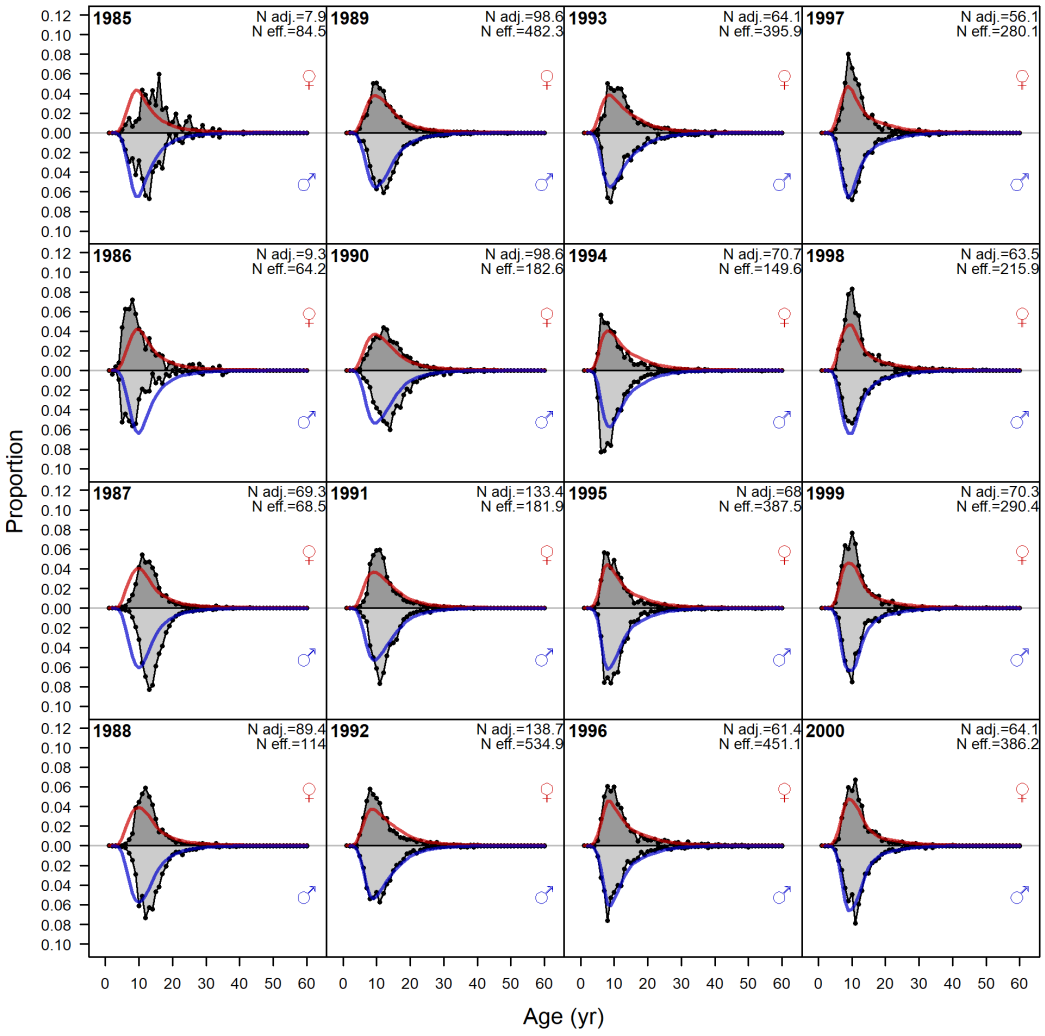


Figure 189: Age comps, retained, OR_WA (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

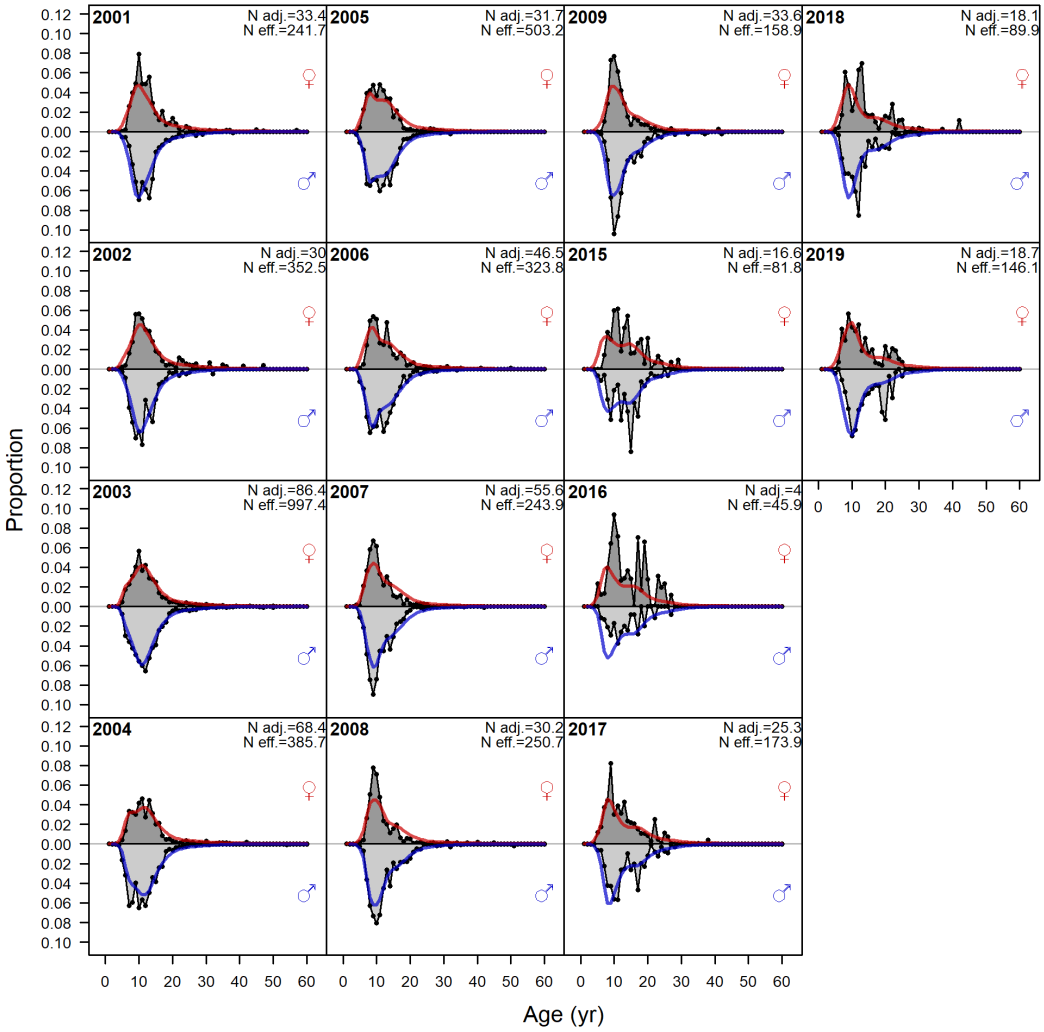


Figure 190: Age comps, retained, OR_WA (plot 2 of 2).

9.3 Detailed Fit to Conditional-Age-at-Length Composition Data

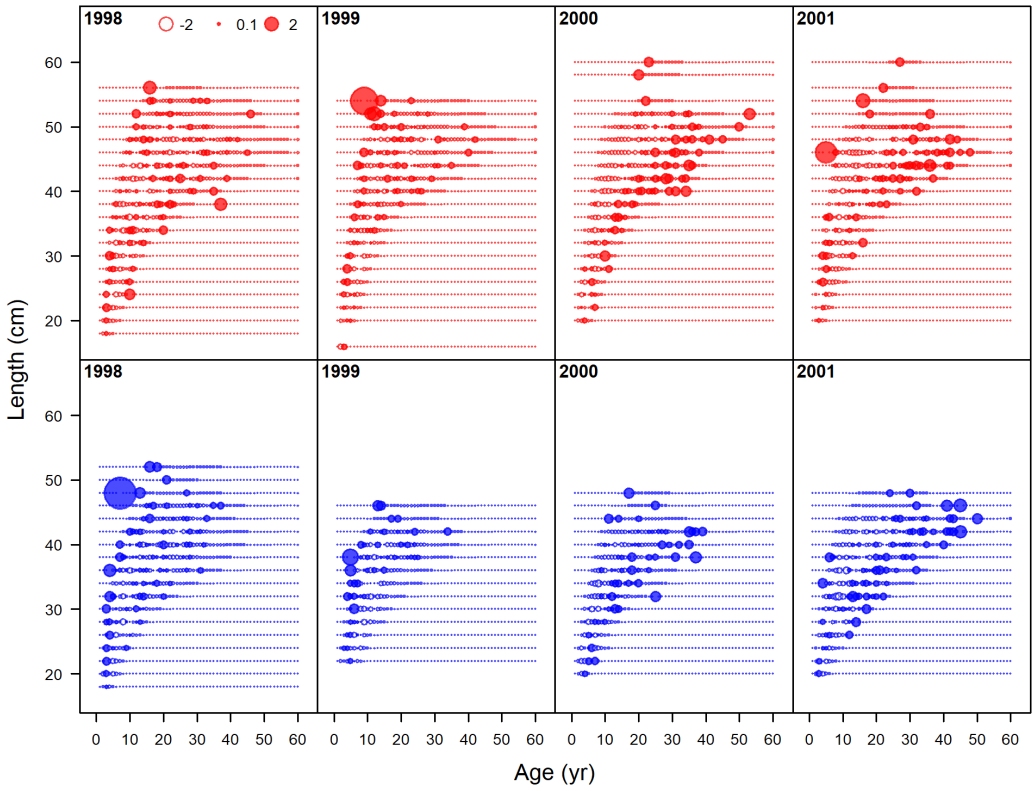


Figure 191: Pearson residuals, whole catch, NWFSC_Slope (max=10.43) (plot 1 of 2).

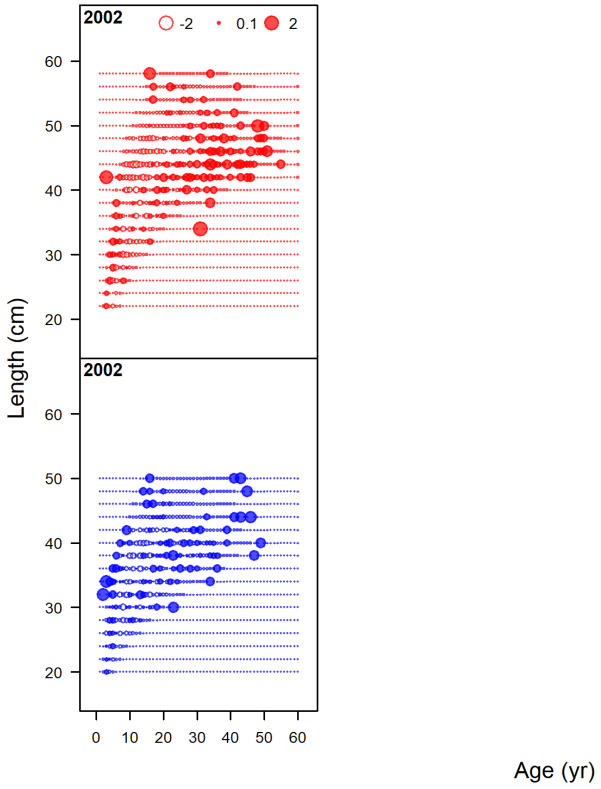


Figure 192: Pearson residuals, whole catch, NWFSC_Slope (max=10.43) (plot 1 of 2) (plot 2 of 2).

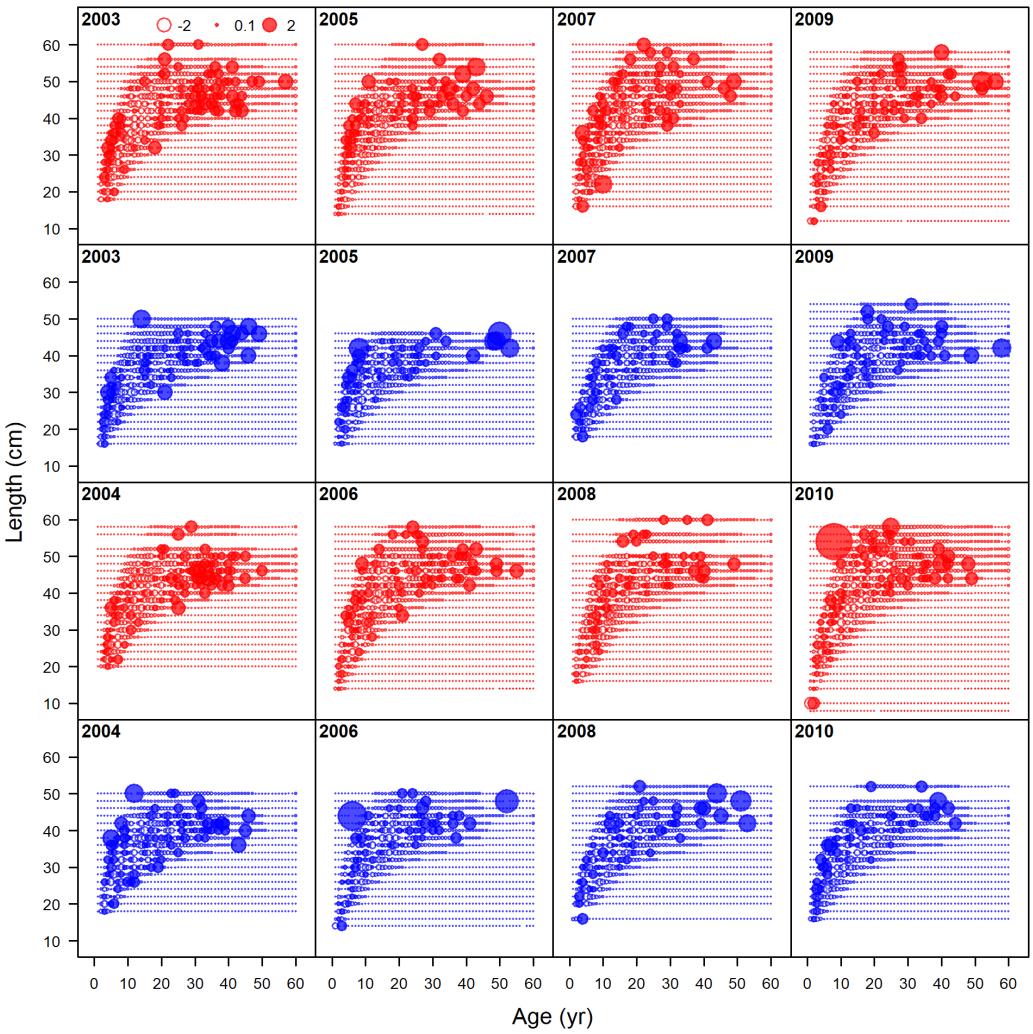


Figure 193: Pearson residuals, whole catch, NWFSC_WCGBT (max=13.53) (plot 1 of 3).

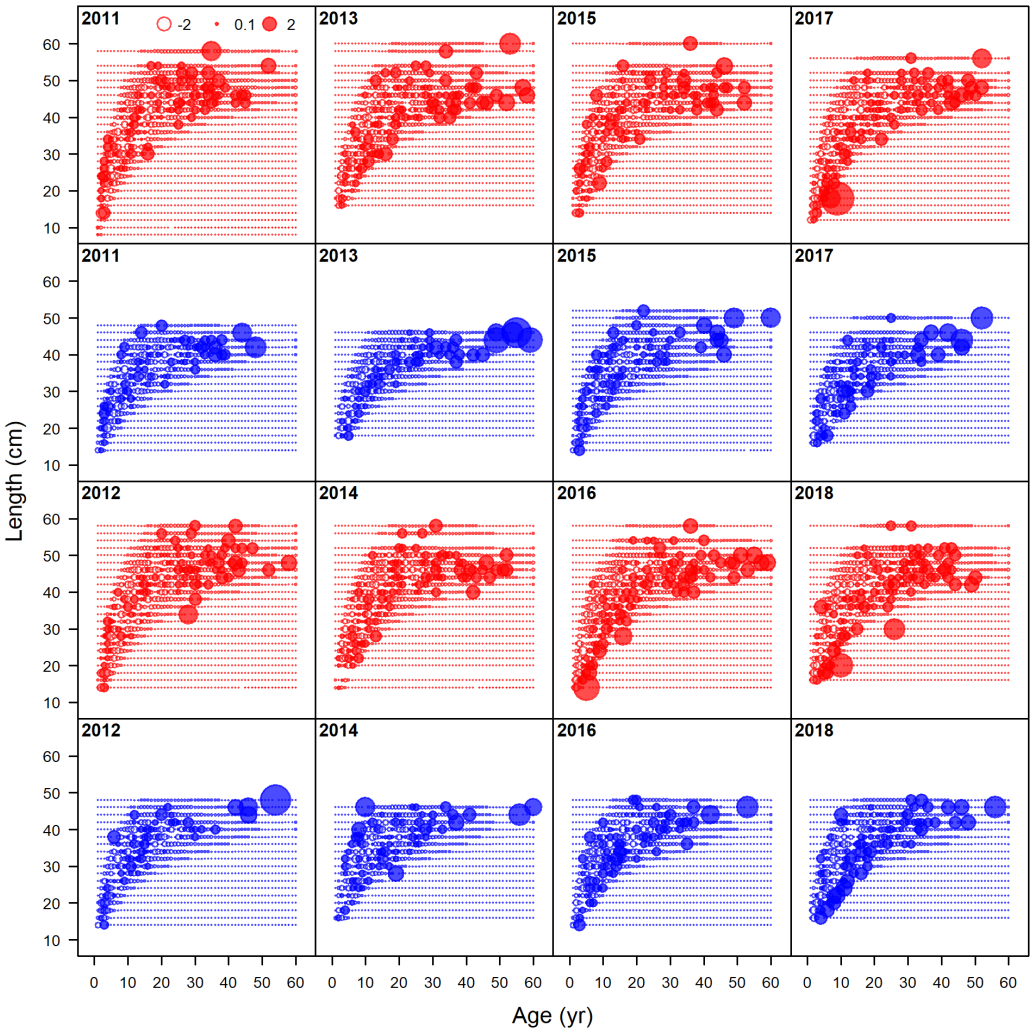


Figure 194: Pearson residuals, whole catch, NWFSC_WCGBT (max=13.53) (plot 1 of 3) (plot 2 of 3).

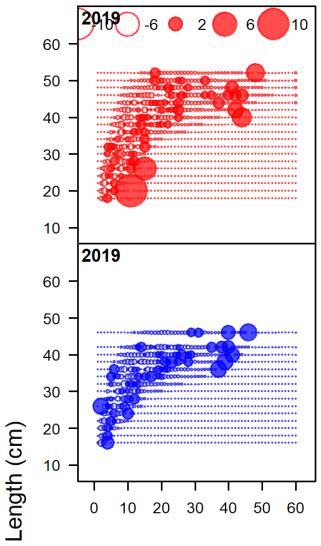


Figure 195: Pearson residuals, whole catch, NWFSC_WCGBT (max=13.53) (plot 1 of 3) (plot 2 of 3) (plot 3 of 3).

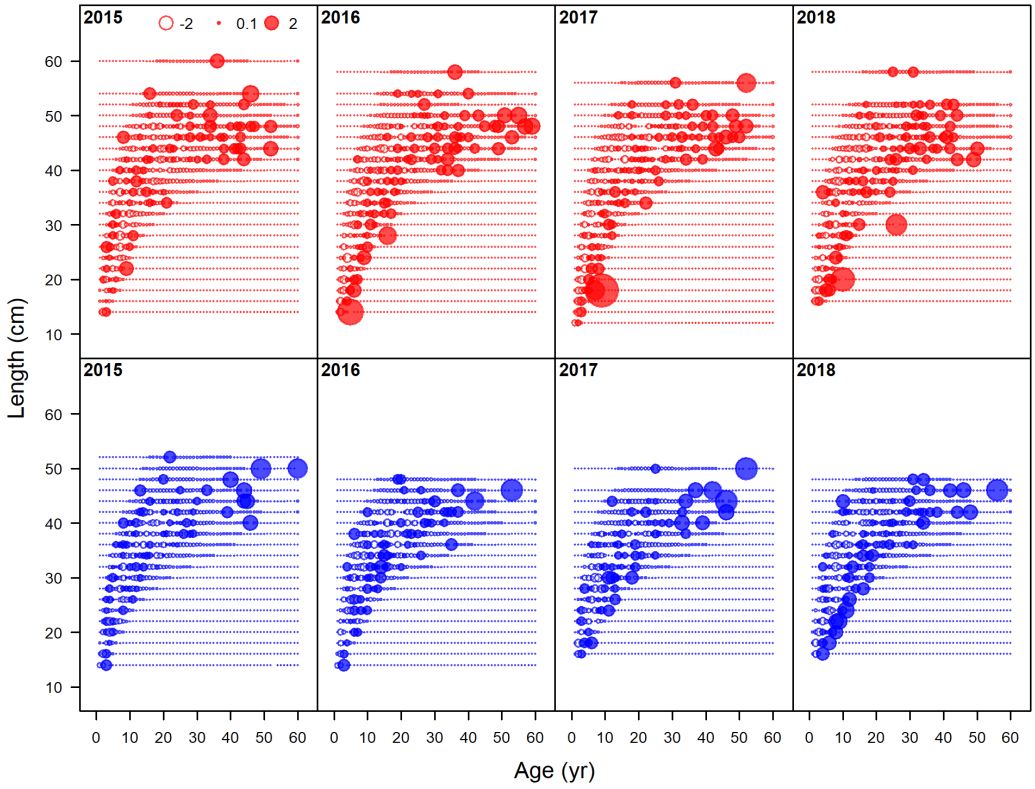


Figure 196: Pearson residuals, whole catch, NWFSC_WCGBT (max=13.53) (plot 1 of 5) (plot 2 of 5) (plot 3 of 5) (plot 4 of 5).

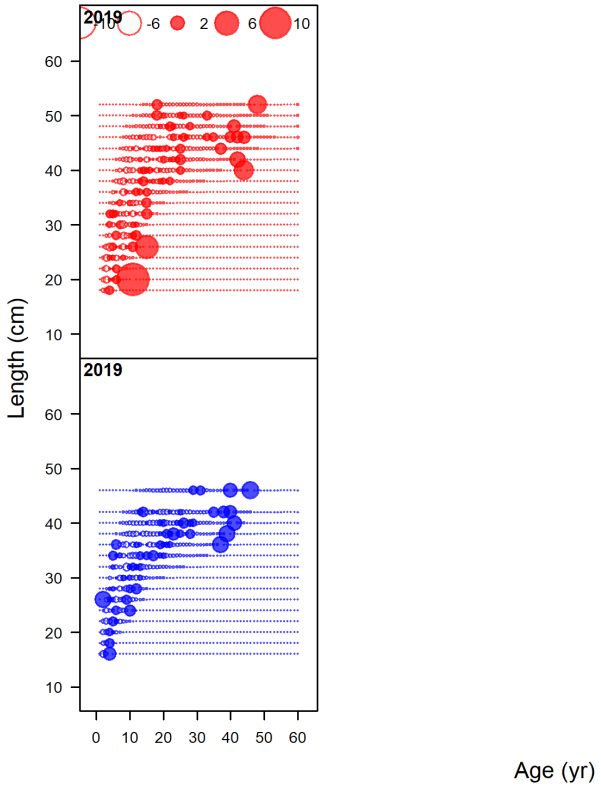


Figure 197: Pearson residuals, whole catch, NWFSC_WCGBT (max=13.53) (plot 1 of 5) (plot 2 of 5) (plot 3 of 5) (plot 4 of 5) (plot 5 of 5).