Status of copper rockfish (*Sebastes caurinus*) along the Washigton US West coast in 2020

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December 2020

Correct citation for this publication:

Wetzel, C.R., B.J. Langseth, J.M. Cope, T. Tsou, K.E. Hinton. 2020. Status of copper rockfish (*Sebastes caurinus*) along the Washigton US West coast in 2020. Pacific Fisheries Management Council, Portland, Oregon. 69 p.

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1 Introduction

1.1 Basic Information

This assessment reports the status of copper rockfish (*Sebastes caurinus*) off the US West coast using data through 2020. Copper rockfish is a medium- to large-sized nearshore rockfish found from Mexico to Alaska. The core range is comparatively large, from northern Baja Mexico to the Gulf of Alaska, as well as in Puget Sound. Copper rockfish have historically been a part of both commercial (mainly in the live-fish fishery) and recreational fisheries throughout its range.

1.2 Life History

Copper rockfish are commonly found in waters less than 130 meters in depth in nearshore kelp forests and rocky habitat (Love 1996). The diets of copper rockfish consist primarily of crustaceans, mollusks, and fish (Lea, McAllister, and VenTresca 1999; Bizzarro, Yoklavich, and Wakefield 2017). The body coloring or copper rockfish varies across the coast with northern fish often exibiting dark brown to olive with southern fish exibiting yellow to olive-pink variations in color (Miller and Lea 1972) which initially led to them being designated as two seperate species (*caurinus* and *vexillaris*).

Numerous genetic studies have been performed looking for genetic variation in copper rockfish with variable outcomes. Genetic work has revealed significant differences between Puget Sound and coastal stocks of copper rockfish (Dick, Shurin, and Taylor 2014). Stocks along the West Coast have not been deteremined to be genetically distinct populations but significant population sub-division has been detected along the indicating limited oceanographic exchange among geographically proximate locations (Buonaccorsi et al. 2002; Johansson et al. 2008). A specific study examining copper rockfish populations off the coast of Santa Barbara and Monterey California identified a genetic break between the north and south with moderate differentiation (Sivasundar and Palumbi 2010).

Copper rockfish is a relatively long-lived rockfish and have been estimated to live at least 50 years (Love 1996). Copper rockfish was determined to have the highest vulnerability (V = 2.27) of any West Coast groundfish based on recent productivity susceptibility analaysis (Cope et al. 2011).

1.3 Ecosystem Considerations

Replace text.

1.4 Historical and Current Fishery Information

Off the coast of Washington copper rockfish is primarily caught in the recreational/sport fishery with very little mortaltiy from commercial fishing. Copper rockfish has been a target of recreational fishing as early as 1934 with catches stabilizing around 2,500 - 3,000 fish per year starting around 1980 with the exception of selected years with high (2005) or low catches (2015).

1.5 Summary of Management History and Performance

Copper rockfish is managed by the Pacific Fishery Management Council (PFMC) using annual catch limits (ACLs) and overfished limits (OFLS) split North and South of N. 40° 10' Lat. N. off the West Coast. Copper rockfish was most recently assessed in 2013 as two stocks, one South of Pt. Conception in California and North to the Washington/Canadian border. The 2013 assessed estimated both areas to be above the management target of 40% of unfished conditions with the southern area being assessed at 75% and the northern population at 48%. The OFLs and the ACLs from each assessed area were modified to match the management boundery of North and South of N. 40° 10' Lat. N.

2 Data

A description of each data source is provided below (Figure 2).

2.1 Fishery-Dependent Data

2.1.1 Recreational / Sport Data

Table 1 and Table 2

2.1.2 Commercial Data

Table 1

2.2 Fishery-Independent Data

There were no fishery-independent data sources available for copper rockfish off the Washington coast to be considered for this assessment.

2.3 Biological Data

2.3.1 Natural Mortality

Hamel (2015) developed 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. In that same issue of *ICES Journal of Marine Science*, Then et al. (2015) provided an updated data set of estimates of 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 $M = 4.899A_{max}^{-0.916}$. The approach of basing M priors on maximum age alone was one that was already being used for West Coast rockfish assessments. However, in fitting the alternative model forms relating M to A_{max}, Then et al. (2015) did not consistently apply their transformation. In particular, in real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of M to A_{max}. Therefore, it would be reasonable to fit all models under a log transformation. This was not done. Re-evaluating the data used in 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 for M is:

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

The above is also the median of the prior. The prior is defined as a lognormal distribution with mean $ln(5.4/A_{\max})$ and SE = 0.438. Using a maximum age of 50, the point estimate and median of the prior is 0.108 per year The maximum age was selected based on available age data from all West Coast data sources and literature values. The oldest aged rockfish was 51 years with two observations, off the coast of Washington and Oregon in 2019. However, age data are subject to ageing error which could impact this estimate of longevity. The selection of 50 years was based on the range of other ages available with multiple observations of fish between 44 and 51 years of age and literature examining the longevity of `spp` (Love 1996).

2.3.2 Length-Weight Relationship

The length-weight relationship for copper rockfish was estimated outside the model using all coastwide biological data available from fishery-independent data sources (Figure 5). The estimated length-weight for female fish was 9.56e-06$L^{3.19}$ and males at 1.08e-05$L^{3.15}$ where L is length in cm (Figures 6).

2.3.3 Growth (Length-at-Age)

The length-at-age was estimated for male and female copper rockfish using data collected from fishery-dependent data sources off the coast of Oregon and Washington that were collected from 1998-2019 (Table 3 and Figure 7). Figure 8 shows the lengths and ages for all years by data source as well as predicted von Bertalanffy fits to the data. Females grow larger than males and sex-specific growth parameters were estimated at the following values:

$$\text{Females } L_\infty = 49.7 \text{ cm; } k = 0.151$$

$$\text{Males } L_\infty = 48.1 \text{ cm; } k = 0.178$$

These values were fixed within the base model for male and female copper rockfish. In contrast, the length-at-age values cited in the 2013 data-moderate assessment (Cope et al. 2013) for copper rockfish (although not directly used by XDB-SRA), were from Lea (1999). The L_{∞} from the Lea study were quite a bit larger for both sexes than those estimated for this assessment using recent length and age data off the coast of Oregon and Washington. However, the data presented in Lea (1999) reflected fish sampled off the coast of California and showed very few fish sampled that were greater than 12 years of age.

2.3.4 Maturation and Fecundity

Maturity-at-length based on the work of Hannah (2014) which estimated the 50% size-at-maturity of 34.83 cm off the coast of Oregon with maturity asymptoting to 1.0 for larger fish (Figure 9).

The fecundity-at-length was based on research Dick et al. (2017). The fecundity relationship for copper rockfish was estimated equal to 3.362e-07$L^{3.68}$ in millions of eggs where L is length in cm. Fecundity-at-length is shown in Figure 10.

2.3.5 Sex Ratio

There was limited sex specific observations by length or age for all biological data sources (Figures 11 and 12). The sex ratio of young fish was assumed to be 1:1.

3 Assessment Model

3.1 Summary of Previous Assessments

Copper rockfish was last assesseed in 2013 (Cope et al. 2013). The stock was assessed using extended depletion-based stock reduction analysis (XDB-SRA) a data-moderate approach which incorporated catch and index data with prior on select parameters (natural mortality, stock status in a specified year, productivity, and the relative status of maximum productivity). Copper rockfish was assessed as two separated stocks, the area South of Pt. Conception off the California coast and the area North of Pt. Conception to the Washington Canada border. The 2013 assessment estimated the stock South of Pt. Conception at 75% of unfished spawning output North of Pt. Conception at 48% of unfished spawning output.

3.1.1 Bridging Analysis

A direct bridging analysis was not conducted because the previous assessment was structured to include the area from North of Pt. Conception to the Washington/Canadian border.

3.2 Model Structure and Assumptions

The Washington copper rockfish area assessed using a two-sex model with sex specific life history parameters. The model assumed two fleets: 1) recreational and 2) commercial fleets with recreational removals beginning in 1935. Selectivity was specified using the double normal parameterization within SS for the recreational fleet where selectivity was fixed to be asymptotic with the ascending slope and size of maximum selectivity parameters estimated. The commercial fleet selectivity was assumed to be the same as the recreational fleet due to a lack of length data to estimate a fleet specific selectivity curve. Recruitment was specified to be deterministic due to limited composition data.

3.2.1 Modeling Platform and Structure

Stock Synthesis version 3.30.16 was used to estimate the parameters in the model. 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 Priors

A prior distribution was developed for natural mortality (M) using the Hamel (2015) meta-analytic approach with an assumed maximum age of 50 years. The prior assumed a lognormal distribution for natural mortality. The lognormal prior has a median of 0.108 and a standard error of 0.438.

The prior for steepness (h) assumed a beta distribution with μ=0.72 and σ=0.15.
The prior parameters are based on the Thorson-Dorn rockfish prior (commonly used in past West Coast rockfish assessments) conducted by James Thorson (personal communication, NWFSC, NOAA) which was reviewed and endorsed by the Scientific and Statistical Committee (SSC) in 2017. However, this approach was subsequently rejected for future analysis in 2019 when the new meta-analysis resulted in a mean value of approximately 0.95. In the absense of a new method for generating a prior for steepness the default approach reverts to the previously endorsed method, the 2017 value.

3.2.3 Data Weighting

Length compositions from the recreational fleet were fit in the model. In the absense of index or or commercial composition data, no data weighting was performed in the base model. Sensitivities were performed using the three data weighting approaches that are commonly applied for West Coast groundfish stock assessments; Francis method (Francis and Hilborn 2011), McAllister and Ianelli method (also known as Harmonic Mean weighting) (McAllister and Ianelli 1997), and the Dirichlet method (Thorson et al. 2017).

3.2.4 Estimated and Fixed Parameters

There were 3 estimated parameters in the base model. These included one parameter for R_0 and 2 parameters for selectivity (Table 6).

Fixed parameters in the model were as follows. Steepness was fixed at the mean of the prior. Natural mortality was fixed at 0.108 yr^{-1} for females and males, which is the median of the prior. The standard deviation of recruitment deviates was fixed at 0 and recruitment was assumed deterministic. Maturity-at-length was fixed as described above in Section 2.3.4. Length-weight parameters were fixed at estimates using all length-weight observations described above in Section 2.3.2. The length-at-age was fixed at sex-specific externally estimated values described above in Section 2.3.3.

Dome-shaped selectivity was explored for the recreational fleet. Older and larger copper rockfish may be found deeper waters and may move into areas that limit their availability to fishing gear. However, limited support for dome-shaped selectivity for the recreational fleet was found and the selectivity was fixed to be asmptotic. The commercial selectivity was set equal to the recreational selectivity due to a lack of composition data to support fleet specific estimation.

3.3 Model Selection and Evaluation

The base assessment model for copper rockfish was developed to balance parsimony and realism, and the goal was to estimate a spawning output trajectory for the population of copper rockfish off the Washington coast. The model contains many assumptions to achieve parsimony and uses many different sources of data to estimate reality. A series of investigative model runs were done to achieve the final base model.

3.4 Base Model Results

The base model parameter estimates along with approximate asymptotic standard errors are shown in Table 6 and the likelihood components are shown in Table [XX add table xx]. Estimates of derived reference points and approximate 95 percent asymptotic confidence intervals are shown in Table 9. Estimates of stock size and status over time are shown in Table 7.

3.4.1 Parameter Estimates

Selectivity curves were estimated for the recreational fleet. The estimated selectivity for the recreational fleet is shown in Figure 13. Selectivities were fixed to be asymptotic, reaching maximum selectivity for fish between 35 and 40 cm. The selectivity for the commercial fleet was assumed to be equal to the recreational fleet selectivity.

ADD R0 parameter estimates

3.4.2 Fits to the Data

Figure 16 Figure 17 Figure 18

3.4.3 Population Trajectory

The predicted spawning output (in millions of eggs) is given in Table 7 and plotted in Figure 19. The predicted spawning output from the base model generally showed a slow decline over the timeseries with the spawning output stabilizing in recent years.

The 2020 spawning output relative to unfished equilibrium spawning output is above the target of 40% of unfished spawning output (Figure 21). Approximate confidence intervals based on the asymptotic variance estimates show that the uncertainty in the estimated spawning output is limited. The standard deviation of the log of the spawning output in 2020 is 0.11.

The stock-recruit curve resulting from a value of steepness fixed at is shown in Figure 22. The estimated annual recruitment is shown in Figure 14

3.4.4 Reference Points

Reference points were calculated using the estimated selectivity and catch distributions among fleets in the most recent year of the model (2019). Sustainable total yields were mt when using an $SPR_{50\%}$ reference harvest rate. The spawning output equivalent to 40% of the unfished spawning output ($SB_{40\%}$) was millions of eggs.

UPDATE – The recent catches (landings plus discards) have been below the point estimate of potential long-term yields calculated using an $SPR_{50\%}$ reference point and the population has been increasing sharply over the last 15 years.

The 2020 spawning output relative to unfished equilibrium spawning output is above the target of 40% of unfished spawning output (Figure 21). The fishing intensity, $1 - SPR$, has bounced above and blow the harvest rate limit ($SPR_{50\%}$) in recent years (Table 7 and Figure 36).

Table 9 shows the full suite of estimated reference points for the base model and Figure 37 shows the equilibrium curve based on a steepness value fixed at 0.72.

3.5 Model Diagnostics

3.5.1 Convergence

Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. Starting parameters were jittered by 5%. This was repeated 100 times and a better minimum was not found (Table XXX). The model did not experience convergence issues when provided reasonable starting values. Through the jittering done as explained above 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.

3.5.2 Sensitivity Analyses

A number of sensitivity analyses were conducted. The majoirty of the sensitivities conducted was a single exploration from the base model assumptions and/or data, and were not performed in a cumulative fashion.

1. Fix natural mortality 10 percent lower at a value of 0.097 per year for both sexes.
2. Fix natural mortality 10 percent higher at a value of 0.119 per year for both sexes.
3. Fix L_∞ 5 percent higher at a value of 52.2 cm for females and 50.5 for males.
4. Assume platoons within Stock Synthesis where there are 5 platoons consisting of slower, average, and faster growing fish assumed.
5. Estimate annual recruitment deviations.
6. Data weighting according to the McAllister-Ianelli method using the weighting values shown in Table XX.
7. Data weighting according to the Francis method using the weighting values shown in Table XX.
8. Data weighting according to the Dirichlet method where the estimated parameters are shown in Table XX.

Likelihood values and estimates of key parameters from each sensitivity are available in Table {tab:sensitivities}. Plots of the estimated time-series of spawning biomass and relative spawning biomass are shown in Figures 23 and 24.

A sensitivity of assuming a lower L_∞ was also conducted but not presented here. Assuming the L_∞ to be lower than the input value resulted in a dramatic and unrealistic shift in stock scale.

3.5.3 Retrospective Analysis

A five-year retrospective analysis was conducted by running the model using data only through 2015, 2016, 2017, 2018, 2019 and 2020. The estimated spawning output was consistent with the base model when recent year's data were removed up until 4 and 5 years of data were removed (Figures 25 and 26). Removing this amount of data resulted in a downward shift in stock scale and status.

3.5.4 Likelihood Profiles

Likelihood profiles were conducted for R_0, steepness, maximum length, and female 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 regards to values of R_0, the negative log-likelihood was minimized at approximately $\log(R_0)$ of 2.17 (Figure 28, 29, 27).

For steepness, the negative log-likelihood supported values at the upper bound of 1.0 (Figure 30). ADD TEXT ABOUT SUPPORT Figure 31 and Figure 32

MAXIMUM LENGTH PROFILE

NATURAL MORTALITY PROFILE Figure 33 and Figure 34 and Figure 35

3.5.5 Unresolved Problems and Major Uncertainties

4 Management

4.1 Reference Points

4.2 Unresolved Problems and Major Uncertainties

4.3 Harvest Projections and Decision Tables

4.4 Evaluation of Scientific Uncertainty

4.5 Research and Data Needs

5 Acknowledgments

Here are all the mad props!

Merit McCrea, Gerry Richter, Louis Zimm, Daniel Platt

6 Tables

Table 1: Catches (mt) by fleet for all years and total catches (mt) by year summed by year.

Year	WA Recreational	WA Commercial	Total Catch
1935	0.02	0.00	0.02
1936	0.05	0.00	0.05
1937	0.08	0.00	0.08
1938	0.12	0.00	0.12
1939	0.15	0.00	0.15
1940	0.19	0.00	0.19
1941	0.22	0.00	0.22
1942	0.26	0.00	0.26
1943	0.29	0.00	0.29
1944	0.32	0.00	0.32
1945	0.36	0.00	0.36
1946	0.39	0.00	0.39
1947	0.43	0.00	0.43
1948	0.46	0.00	0.46
1949	0.49	0.00	0.49
1950	0.53	0.00	0.53
1951	0.56	0.00	0.56
1952	0.59	0.00	0.59
1953	0.63	0.00	0.63
1954	0.66	0.00	0.66
1955	0.69	0.00	0.69
1956	0.73	0.00	0.73
1957	0.76	0.00	0.76
1958	0.79	0.00	0.79
1959	0.82	0.00	0.82
1960	0.86	0.00	0.86
1961	0.89	0.00	0.89
1962	0.92	0.00	0.92
1963	0.95	0.00	0.95
1964	0.99	0.00	0.99
1965	1.02	0.00	1.02
1966	1.05	0.00	1.05
1967	1.08	0.00	1.08
1968	1.11	0.00	1.11
1969	1.15	0.00	1.15
1970	1.18	0.00	1.18
1971	1.21	0.00	1.21
1972	1.24	0.00	1.24
1973	1.27	0.00	1.27
1974	1.30	0.00	1.30
1975	1.33	0.00	1.33

Table 1: Catches (mt) by fleet for all years and total catches (mt) by year summed by year. *(continued)*

Year	WA Recreational	WA Commercial	Total Catch
1976	0.96	0.00	0.96
1977	0.59	0.00	0.59
1978	1.10	0.00	1.10
1979	1.47	0.00	1.47
1980	0.86	0.00	0.86
1981	1.92	0.00	1.92
1982	2.01	0.00	2.01
1983	1.23	0.00	1.23
1984	1.95	0.00	1.95
1985	1.68	0.20	1.88
1986	2.02	0.19	2.21
1987	2.43	0.93	3.36
1988	2.27	0.25	2.51
1989	2.30	0.00	2.30
1990	2.93	0.03	2.96
1991	2.15	0.00	2.15
1992	3.49	0.00	3.49
1993	2.72	0.01	2.73
1994	1.90	0.00	1.90
1995	2.44	0.00	2.44
1996	2.83	0.00	2.83
1997	2.68	0.00	2.68
1998	2.74	0.00	2.74
1999	2.78	0.00	2.78
2000	2.91	0.00	2.91
2001	2.93	0.00	2.93
2002	1.89	0.00	1.89
2003	2.23	0.00	2.23
2004	2.20	0.00	2.20
2005	6.16	0.00	6.16
2006	2.86	0.00	2.86
2007	2.88	0.00	2.88
2008	3.03	0.00	3.03
2009	2.72	0.00	2.72
2010	2.12	0.00	2.12
2011	2.63	0.00	2.63
2012	1.75	0.00	1.75
2013	2.55	0.00	2.55
2014	2.34	0.00	2.34
2015	1.31	0.00	1.31
2016	1.85	0.00	1.85
2017	1.29	0.01	1.30
2018	3.02	0.00	3.02
2019	4.26	0.00	4.26

Table 1: Catches (mt) by fleet for all years and total catches (mt) by year summed by year. *(continued)*

Year	WA Recreational	WA Commercial	Total Catch
2020	2.76	0.00	2.76

Table 2: Input numbers of fish removals converted to metric tons (mt) within the model.

Year	Numbers of Fish	Metric Tons
1934	0	0.00
1935	10	0.02
1936	32	0.05
1937	53	0.08
1938	75	0.12
1939	96	0.15
1940	118	0.19
1941	139	0.22
1942	161	0.26
1943	182	0.29
1944	204	0.32
1945	225	0.36
1946	246	0.39
1947	268	0.43
1948	289	0.46
1949	311	0.49
1950	332	0.53
1951	354	0.56
1952	375	0.59
1953	397	0.63
1954	418	0.66
1955	440	0.69
1956	461	0.73
1957	482	0.76
1958	504	0.79
1959	525	0.82
1960	547	0.86
1961	568	0.89
1962	590	0.92
1963	611	0.95
1964	633	0.99
1965	654	1.02
1966	676	1.05
1967	696	1.08
1968	718	1.11
1969	740	1.15
1970	761	1.18
1971	783	1.21
1972	804	1.24
1973	826	1.27
1974	847	1.30
1975	868	1.33
1976	628	0.96
1977	387	0.59

Table 2: Input numbers of fish removals converted to metric tons (mt) within the model. *(continued)*

Year	Numbers of Fish	Metric Tons
1978	719	1.10
1979	957	1.47
1980	563	0.86
1981	1253	1.92
1982	1317	2.01
1983	805	1.23
1984	1280	1.95
1985	1105	1.68
1986	1335	2.02
1987	1608	2.43
1988	1506	2.27
1989	1534	2.30
1990	1966	2.93
1991	1449	2.15
1992	2359	3.49
1993	1850	2.72
1994	1296	1.90
1995	1675	2.44
1996	1948	2.83
1997	1853	2.68
1998	1897	2.74
1999	1932	2.78
2000	2027	2.91
2001	2053	2.93
2002	1327	1.89
2003	1573	2.23
2004	1551	2.20
2005	4359	6.16
2006	2038	2.86
2007	2066	2.88
2008	2183	3.03
2009	1972	2.72
2010	1544	2.12
2011	1916	2.63
2012	1277	1.75
2013	1858	2.55
2014	1699	2.34
2015	955	1.31
2016	1339	1.85
2017	932	1.29
2018	2173	3.02
2019	3073	4.26
2020	2000	2.76

Table 3: Summary of the number of samples by year and source used to estimate length-at-age parameters.

	OR PacFIN	OR RecFIN MRFSS	WA PacFIN	WA RecFIN MRFSS
1998	0	0	0	46
1999	0	0	0	136
2000	0	0	0	26
2001	0	0	0	32
2002	1	0	0	19
2003	9	0	0	0
2004	26	0	0	188
2005	0	58	0	225
2006	1	150	0	65
2007	1	188	0	86
2008	1	217	0	65
2009	0	156	0	35
2010	6	273	0	24
2011	0	235	0	27
2012	11	216	0	35
2013	31	158	0	8
2014	25	121	0	123
2015	10	0	0	74
2016	25	0	0	169
2017	40	177	1	101
2018	44	175	0	176
2019	102	174	0	274

Table 4: Summary of the recreational length samples used in the stock assessment.

Year	All Fish	Sexed Fish	Unsexed Fish
1979	8	0	8
1981	4	0	4
1982	5	0	5
1983	3	0	3
1995	141	0	141
1996	221	0	221
1997	63	0	63
1998	202	46	156
1999	194	136	58
2000	26	26	0
2001	32	32	0
2002	83	61	22
2003	46	18	28
2004	244	201	43
2005	443	265	178
2006	169	96	73
2007	152	110	42
2008	91	71	20
2009	71	52	19
2010	57	38	19
2011	127	27	100
2012	81	37	44
2013	71	14	57
2014	136	130	6
2015	84	81	3
2016	179	155	24
2017	212	108	104
2018	315	188	127
2019	463	273	190
2020	59	58	1

Table 5: Summary of the recreational age samples. These ages were not directly used in the stock assessment.

Year	All Fish	Sexed Fish	Unsexed Fish
1998	46	46	0
1999	136	136	0
2000	26	26	0
2001	32	32	0
2002	19	19	0
2004	188	186	2
2005	225	225	0
2006	65	65	0
2007	86	86	0
2008	65	65	0
2009	35	35	0
2010	24	24	0
2011	27	26	1
2012	35	34	1
2013	8	8	0
2014	123	121	2
2015	74	71	3
2016	169	152	17
2017	101	99	2
2018	176	175	1
2019	274	272	2

Table 6: 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, 0.4)	NA	NA	Log Norm (-2.2256, 0.48)
L at Amin Fem GP 1	16.600	-2	(3, 25)	NA	NA	None
L at Amax Fem GP 1	49.700	-2	(35, 60)	NA	NA	None
VonBert K Fem GP 1	0.151	-2	(0.03, 0.3)	NA	NA	None
CV young Fem GP 1	0.100	-2	(0.01, 0.3)	NA	NA	None
CV old Fem GP 1	0.100	-2	(0.01, 0.3)	NA	NA	None
Wtlen 1 Fem GP 1	0.000	-9	(0, 0.1)	NA	NA	None
Wtlen 2 Fem GP 1	3.190	-9	(2, 4)	NA	NA	None
Mat50Mat slope Fem GP 1	-0.600	-9	(-1, 0)	NA	NA	None
Eggs scalar Fem GP 1	0.000	-9	(-3, 3)	NA	NA	None
Eggs exp len Fem GP 1	3.679	-9	(-3, 3)	NA	NA	None
NatM p 1 Mal GP 1	0.108	-2	(0.05, 0.4)	NA	NA	Log Norm (-2.2256, 0.48)
L at Amin Mal GP 1	14.900	-2	(3, 25)	NA	NA	None
L at Amax Mal GP 1	48.100	-2	(35, 60)	NA	NA	None
VonBert K Mal GP 1	0.178	-2	(0.03, 0.3)	NA	NA	None
CV young Mal GP 1	0.100	-2	(0.01, 0.3)	NA	NA	None
CV old Mal GP 1	0.100	-2	(0.01, 0.3)	NA	NA	None
Wtlen 1 Mal GP 1	0.000	-9	(0, 0.1)	NA	NA	None
Wtlen 2 Mal GP 1	3.150	-9	(2, 4)	NA	NA	None
FracFemale GP 1	0.500	-9	(0.01, 0.99)	NA	NA	None
SR LN(R0)	2.170	1	(1, 20)	OK	0.0497768	None
SR BH steep	0.720	-7	(0.22, 1)	NA	NA	Normal (0.72, 0.09)
SR sigmaR	0.900	-99	(0.15, 1)	NA	NA	None
SR regime	0.000	-99	(-2, 2)	NA	NA	None
SR autocorr	0.000	-99	(0, 0)	NA	NA	None
Size DblN peak WA Recreational(1)	38.113	1	(15, 50)	OK	0.4906010	None
Size DblN top logit WA Recreational(1)	-0.505	-2	(-7, 7)	NA	NA	None
Size DblN ascend se WA Recreational(1)	3.801	3	(-10, 10)	OK	0.1022150	None
Size DblN descend se WA Recreational(1)	-0.413	-4	(-10, 10)	NA	NA	None

Table 6: 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)
Size DblN start logit WA Recreational(1)	-20.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit WA Recreational(1)	10.000	-3	(-10, 10)	NA	NA	None

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

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3 (mt)	Fraction Unfished	Age-0 Recruits	Total Catch (mt)	1-SPR	Exploitation Rate
1935	80.77	8.04	79.11	1.00	8.77	0.02	0.00	0.00
1936	80.76	8.04	79.10	1.00	8.77	0.05	0.01	0.00
1937	80.71	8.03	79.05	1.00	8.77	0.08	0.01	0.00
1938	80.63	8.03	78.98	1.00	8.77	0.12	0.02	0.00
1939	80.53	8.01	78.87	1.00	8.77	0.15	0.03	0.00
1940	80.40	8.00	78.74	0.99	8.77	0.19	0.03	0.00
1941	80.25	7.98	78.59	0.99	8.76	0.22	0.04	0.00
1942	80.07	7.96	78.41	0.99	8.76	0.26	0.04	0.00
1943	79.87	7.94	78.22	0.99	8.76	0.29	0.05	0.00
1944	79.66	7.91	78.00	0.98	8.76	0.32	0.06	0.00
1945	79.42	7.88	77.76	0.98	8.75	0.36	0.06	0.00
1946	79.17	7.86	77.51	0.98	8.75	0.39	0.07	0.01
1947	78.90	7.82	77.25	0.97	8.75	0.43	0.07	0.01
1948	78.62	7.79	76.97	0.97	8.74	0.46	0.08	0.01
1949	78.33	7.76	76.67	0.96	8.74	0.49	0.08	0.01
1950	78.02	7.72	76.37	0.96	8.74	0.53	0.09	0.01
1951	77.70	7.68	76.05	0.96	8.73	0.56	0.09	0.01
1952	77.37	7.65	75.72	0.95	8.73	0.59	0.10	0.01
1953	77.03	7.61	75.38	0.95	8.72	0.63	0.11	0.01
1954	76.69	7.56	75.03	0.94	8.72	0.66	0.11	0.01
1955	76.33	7.52	74.68	0.94	8.71	0.69	0.12	0.01
1956	75.97	7.48	74.32	0.93	8.71	0.73	0.12	0.01
1957	75.60	7.44	73.95	0.92	8.70	0.76	0.13	0.01
1958	75.22	7.39	73.58	0.92	8.70	0.79	0.13	0.01
1959	74.84	7.35	73.20	0.91	8.69	0.82	0.14	0.01
1960	74.46	7.30	72.81	0.91	8.69	0.86	0.15	0.01
1961	74.06	7.26	72.42	0.90	8.68	0.89	0.15	0.01
1962	73.67	7.21	72.02	0.90	8.68	0.92	0.16	0.01
1963	73.27	7.16	71.63	0.89	8.67	0.95	0.16	0.01
1964	72.86	7.12	71.22	0.89	8.66	0.99	0.17	0.01
1965	72.46	7.07	70.82	0.88	8.66	1.02	0.17	0.01
1966	72.05	7.02	70.41	0.87	8.65	1.05	0.18	0.01
1967	71.63	6.97	69.99	0.87	8.64	1.08	0.18	0.02
1968	71.22	6.92	69.58	0.86	8.64	1.11	0.19	0.02
1969	70.80	6.88	69.16	0.86	8.63	1.15	0.20	0.02
1970	70.38	6.83	68.74	0.85	8.62	1.18	0.20	0.02
1971	69.95	6.78	68.32	0.84	8.62	1.21	0.21	0.02
1972	69.53	6.73	67.90	0.84	8.61	1.24	0.21	0.02
1973	69.10	6.68	67.47	0.83	8.60	1.27	0.22	0.02
1974	68.67	6.63	67.04	0.82	8.60	1.30	0.22	0.02
1975	68.24	6.58	66.61	0.82	8.59	1.33	0.23	0.02
1976	67.81	6.53	66.18	0.81	8.58	0.96	0.18	0.01

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

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3 (mt)	Fraction Unfished	Age-0 Recruits	Total Catch (mt)	1-SPR	Exploitation Rate
1977	67.76	6.52	66.14	0.81	8.58	0.59	0.11	0.01
1978	68.08	6.55	66.45	0.81	8.59	1.10	0.20	0.02
1979	67.90	6.53	66.28	0.81	8.58	1.47	0.25	0.02
1980	67.38	6.47	65.76	0.81	8.57	0.86	0.16	0.01
1981	67.47	6.48	65.85	0.81	8.57	1.92	0.31	0.03
1982	66.55	6.38	64.93	0.79	8.56	2.01	0.32	0.03
1983	65.58	6.27	63.96	0.78	8.54	1.23	0.22	0.02
1984	65.42	6.25	63.80	0.78	8.54	1.95	0.32	0.03
1985	64.58	6.16	62.96	0.77	8.52	1.88	0.31	0.03
1986	63.86	6.07	62.24	0.76	8.51	2.21	0.36	0.04
1987	62.85	5.96	61.24	0.74	8.49	3.36	0.48	0.05
1988	60.81	5.73	59.20	0.71	8.45	2.51	0.40	0.04
1989	59.68	5.60	58.07	0.70	8.42	2.30	0.39	0.04
1990	58.82	5.50	57.22	0.68	8.40	2.96	0.46	0.05
1991	57.39	5.34	55.79	0.66	8.37	2.15	0.38	0.04
1992	56.81	5.27	55.22	0.66	8.36	3.49	0.52	0.06
1993	55.00	5.07	53.41	0.63	8.31	2.73	0.46	0.05
1994	53.99	4.95	52.42	0.62	8.28	1.90	0.36	0.04
1995	53.85	4.93	52.28	0.61	8.28	2.44	0.43	0.05
1996	53.21	4.86	51.64	0.60	8.26	2.83	0.48	0.05
1997	52.24	4.75	50.67	0.59	8.23	2.68	0.47	0.05
1998	51.46	4.66	49.90	0.58	8.21	2.74	0.48	0.05
1999	50.66	4.57	49.11	0.57	8.19	2.78	0.49	0.06
2000	49.87	4.48	48.32	0.56	8.16	2.91	0.51	0.06
2001	49.00	4.38	47.45	0.55	8.13	2.93	0.51	0.06
2002	48.15	4.29	46.61	0.53	8.10	1.89	0.40	0.04
2003	48.33	4.30	46.79	0.54	8.11	2.23	0.44	0.05
2004	48.19	4.29	46.66	0.53	8.10	2.20	0.44	0.05
2005	48.09	4.27	46.56	0.53	8.10	6.16	0.73	0.13
2006	44.23	3.87	42.70	0.48	7.97	2.86	0.54	0.07
2007	43.63	3.80	42.11	0.47	7.94	2.88	0.55	0.07
2008	43.06	3.73	41.55	0.46	7.91	3.03	0.56	0.07
2009	42.37	3.65	40.87	0.45	7.88	2.72	0.54	0.07
2010	42.02	3.61	40.52	0.45	7.87	2.12	0.47	0.05
2011	42.25	3.63	40.76	0.45	7.87	2.63	0.53	0.06
2012	42.00	3.60	40.52	0.45	7.86	1.75	0.42	0.04
2013	42.60	3.67	41.11	0.46	7.89	2.55	0.52	0.06
2014	42.42	3.65	40.93	0.45	7.88	2.34	0.49	0.06
2015	42.45	3.65	40.95	0.45	7.88	1.31	0.34	0.03
2016	43.45	3.76	41.95	0.47	7.92	1.85	0.42	0.04
2017	43.91	3.81	42.41	0.47	7.94	1.30	0.33	0.03
2018	44.87	3.91	43.37	0.49	7.98	3.02	0.55	0.07
2019	44.17	3.84	42.66	0.48	7.96	4.26	0.65	0.10

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

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3 (mt)	Fraction Unfished	Age-0 Recruits	Total Catch (mt)	1-SPR	Exploitation Rate
2020	42.28	3.65	40.77	0.45	7.88	2.76	0.54	0.07
2021	41.87	3.60	40.37	0.45	7.86	1.38	0.35	0.03
2022	42.80	3.69	41.31	0.46	7.90	1.38	0.35	0.03
2023	43.72	3.78	42.23	0.47	7.93	2.47	0.50	0.06
2024	43.57	3.77	42.08	0.47	7.93	2.47	0.50	0.06
2025	43.43	3.76	41.93	0.47	7.93	2.46	0.50	0.06
2026	43.30	3.75	41.79	0.47	7.92	2.45	0.50	0.06
2027	43.17	3.74	41.67	0.46	7.92	2.44	0.50	0.06
2028	43.06	3.72	41.56	0.46	7.91	2.43	0.50	0.06
2029	42.96	3.71	41.46	0.46	7.91	2.43	0.50	0.06
2030	42.87	3.70	41.37	0.46	7.90	2.42	0.50	0.06
2031	42.78	3.69	41.29	0.46	7.90	2.42	0.50	0.06
2032	42.71	3.68	41.22	0.46	7.90	2.41	0.50	0.06

Table 8: Sensitivities relative to the base model.

	Base Model	Low M	High M	Platoons	High Linf	Estimate Rec. Devs.	Francis Data Weighting	MI Data Weighting	Dirichlet Data Weighting
Total Likelihood	1132.240	1160.080	1110.870	1105.530	1254.970	611.654	72.464	184.895	1098.570
Survey Likelihood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Length Likelihood	1132.240	1160.030	1110.830	1105.530	1254.970	591.824	72.463	184.895	1098.420
Age Likelihood	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Recruitment Likelihood	0.000	0.000	0.000	0.000	0.000	19.745	0.000	0.000	0.000
Forecast Recruitment Likelihood	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000	0.000
Parameter Priors Likelihood	0.000	0.050	0.041	0.000	0.000	0.000	0.000	0.000	0.149
log(R0)	2.170	1.982	2.367	2.286	1.821	1.544	2.170	2.170	2.073
SB Virgin	8.041	8.200	8.053	8.954	6.868	4.299	8.041	8.041	7.296
SB 2020	3.601	3.154	4.114	4.459	1.541	0.183	3.601	3.601	2.832
Fraction Unfished 2021	0.448	0.385	0.511	0.498	0.224	0.042	0.448	0.448	0.388
Total Yield - SPR 50	2.355	2.143	2.620	2.527	1.912	1.424	2.355	2.355	2.160
Steepness	0.720	0.720	0.720	0.720	0.720	0.720	0.720	0.720	0.720
Natural Mortality - Female	0.108	0.097	0.119	0.108	0.108	0.108	0.108	0.108	0.108
Length at Amin - Female	16.600	16.600	16.600	16.600	16.600	16.600	16.600	16.600	16.600
Length at Amax - Female	49.700	49.700	49.700	49.700	52.200	49.700	49.700	49.700	49.700
Von Bert. k - Female	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151
CV young - Female	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
CV old - Female	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Natural Mortality - Male	0.108	0.097	0.119	0.108	0.108	0.108	0.108	0.108	0.108
Length at Amin - Male	14.900	14.900	14.900	14.900	14.900	14.900	14.900	14.900	14.900
Length at Amax - Male	48.100	48.100	48.100	48.100	50.500	48.100	48.100	48.100	48.100
Von Bert. k - Male	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178
CV young - Male	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
CV old - Male	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100

Table 9: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	8.04	7.26	8.83
Unfished Age 3+ Biomass (mt)	79.11	71.40	86.83
Unfished Recruitment (R0)	8.76	7.91	9.61
Spawning Output (2021)	3.60	2.80	4.40
Fraction Unfished (2021)	0.45	0.39	0.50
Reference Points Based SB40 Percent	NA	NA	NA
Proxy Spawning Output(SB40 Percent	3.22	2.90	3.53
SPR Resulting in SB40 Percent	0.46	0.46	0.46
Exploitation Rate Resulting in SB40 Percent	0.07	0.07	0.07
Yield with SPR Based On SB40 Percent (mt)	2.47	2.24	2.70
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Output (SPR50)	3.59	3.24	3.94
SPR50	50.00	NA	NA
Exploitation Rate Corresponding to SPR50	0.06	0.06	0.06
Yield with SPR50 at SB SPR (mt)	2.35	2.14	2.57
Reference Points Based on Estimated MSY Values	NA	NA	NA
Spawning Output at MSY (SB MSY)	2.17	1.96	2.38
SPR MSY	0.34	0.34	0.34
Exploitation Rate Corresponding to SPR MSY	0.10	0.10	0.10
MSY (mt)	2.64	2.39	2.88

Table 10: Projections of potential OFLs (mt), ABCs (mt), estimated spawning output and fraction unfished.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 3+ Biomass (mt)	Spawning Output	Fraction Unfished
2021	2.36	1.38	40.37	3.60	0.45
2022	2.41	1.38	41.31	3.69	0.46
2023	2.47	2.47	42.23	3.78	0.47
2024	2.47	2.47	42.08	3.77	0.47
2025	2.46	2.46	41.93	3.76	0.47
2026	2.45	2.45	41.79	3.75	0.47
2027	2.44	2.44	41.67	3.74	0.46
2028	2.43	2.43	41.56	3.72	0.46
2029	2.43	2.43	41.46	3.71	0.46
2030	2.42	2.42	41.37	3.70	0.46
2031	2.42	2.42	41.29	3.69	0.46
2032	2.41	2.41	41.22	3.68	0.46

7 Figures

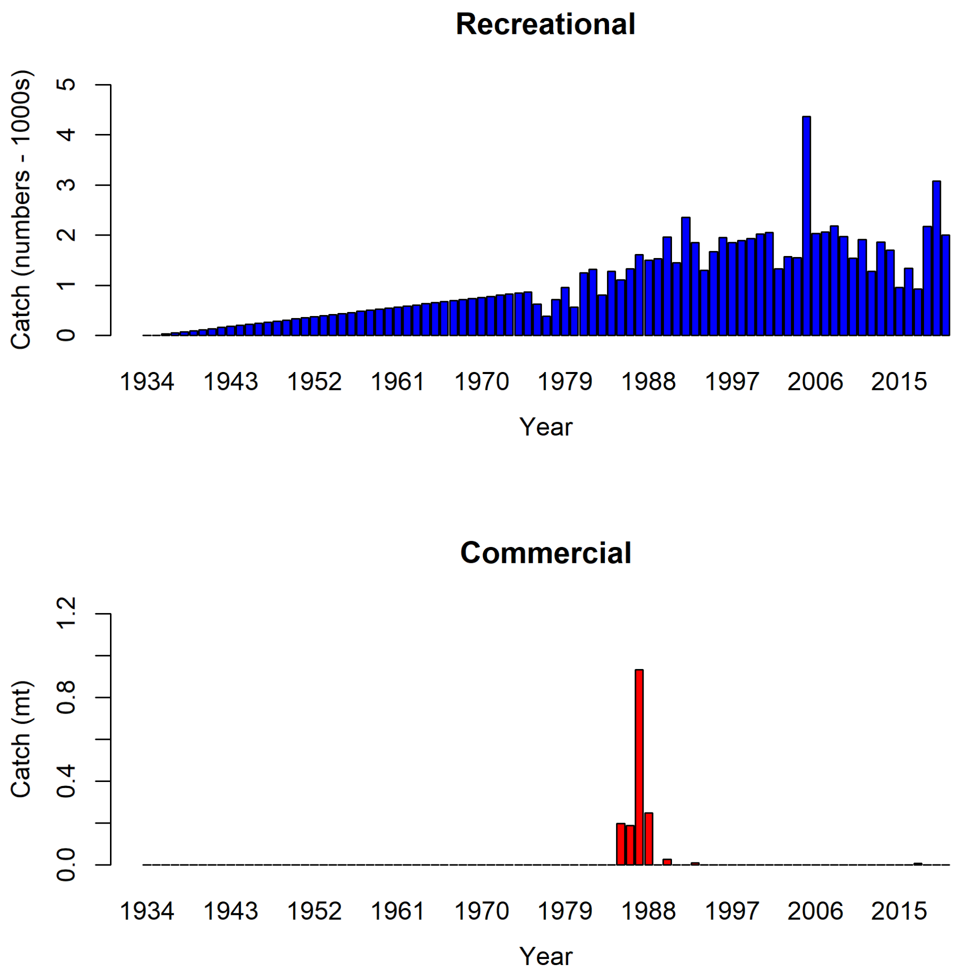

Figure 1: Catches by year for the recreational and commercial fleets in the model.

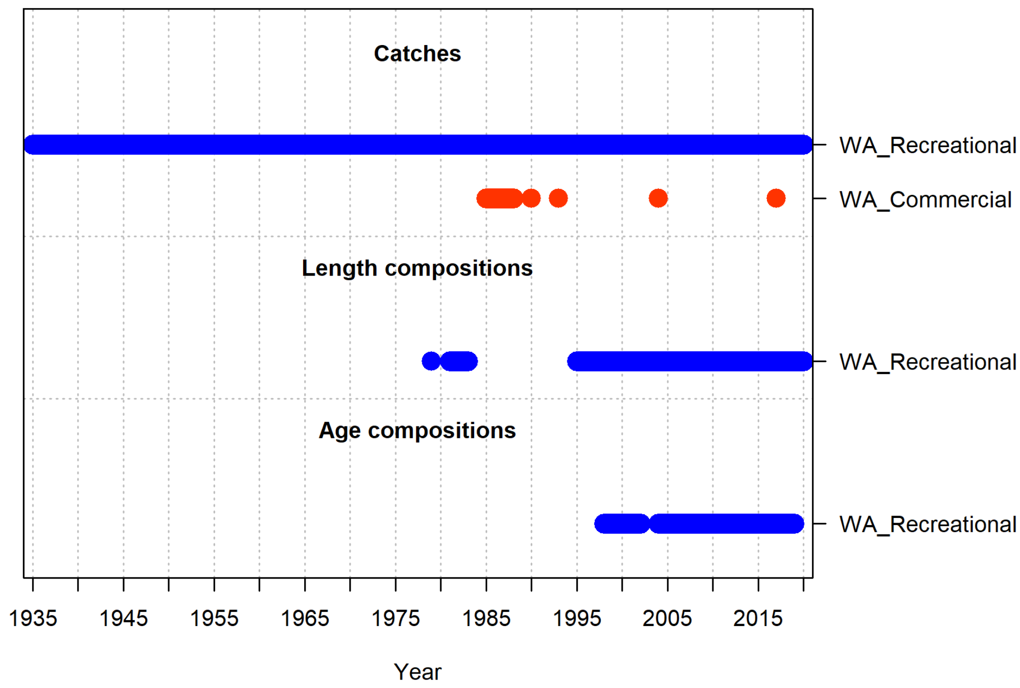

Figure 2: Summary of data sources used in the base model.

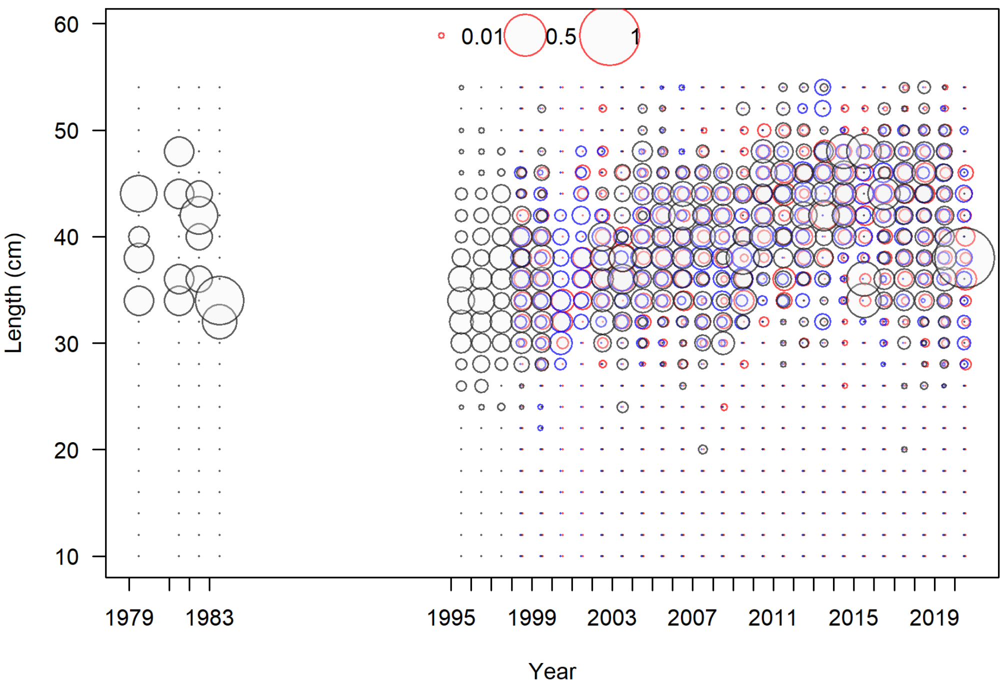

Figure 3: Length composition data from the recreational fleet.

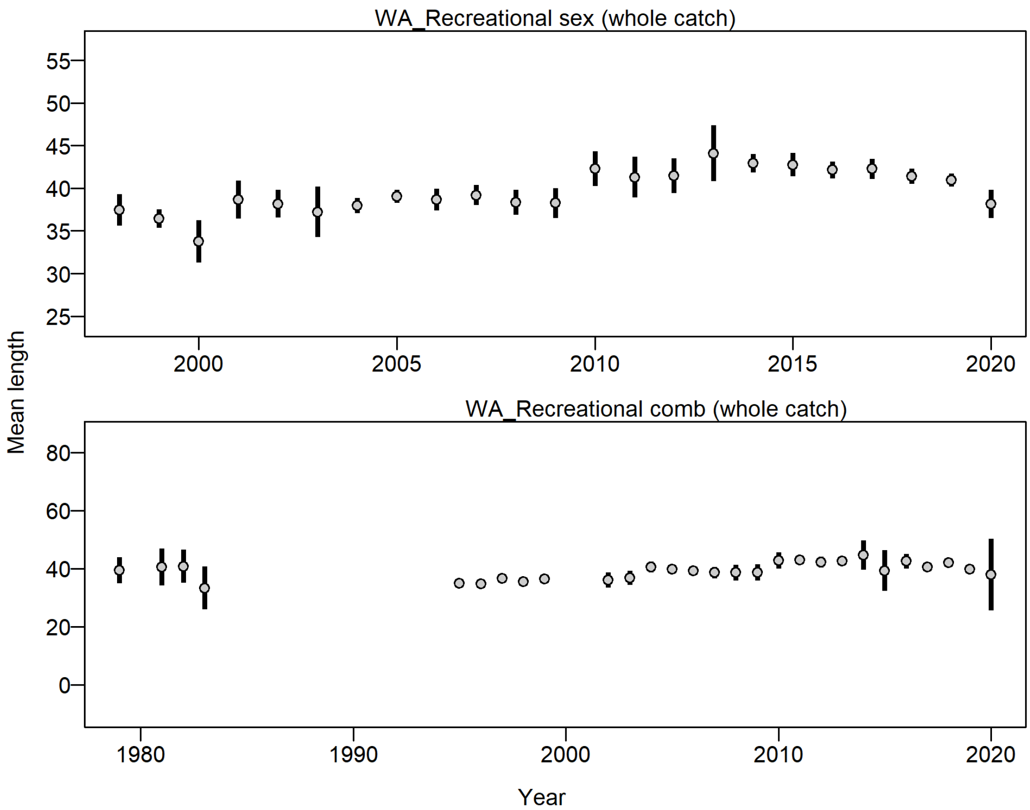

Figure 4: Mean length for recreational fleet with 95 percent confidence intervals.

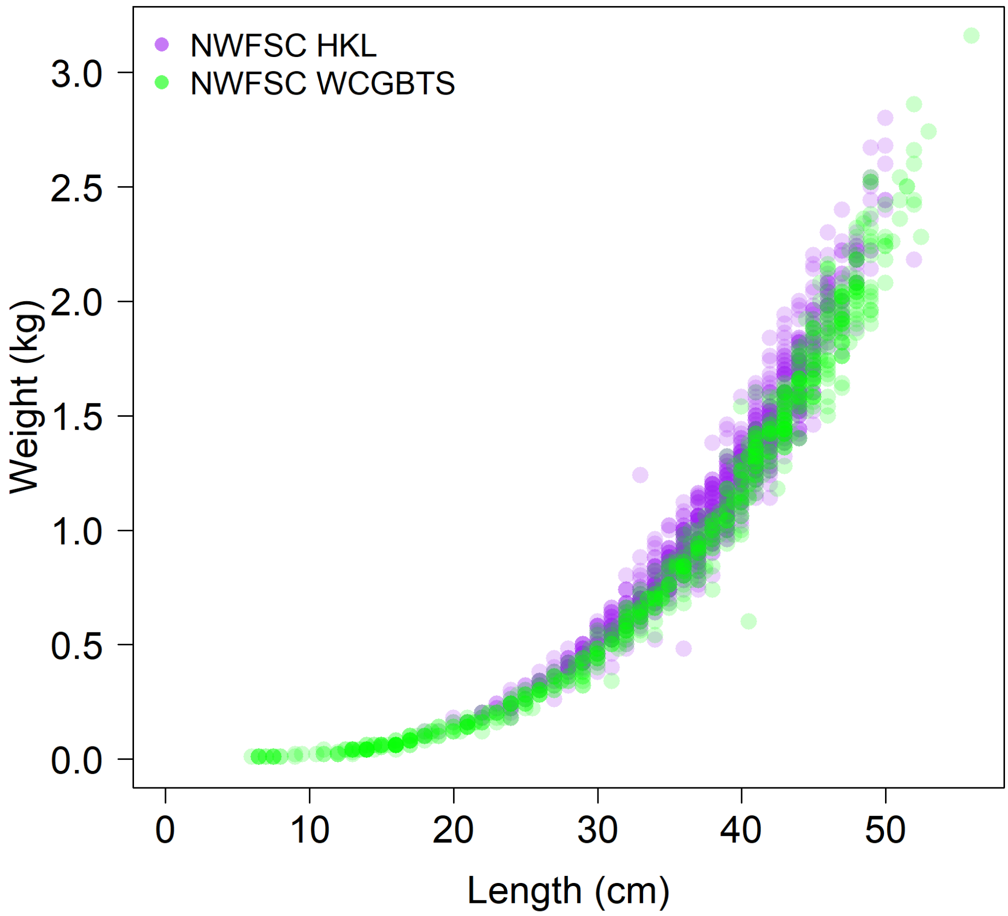

Figure 5: Comparison of the length-at-weight data from the NWFSC Hook and Line and the NWFSC WCGBT surveys.

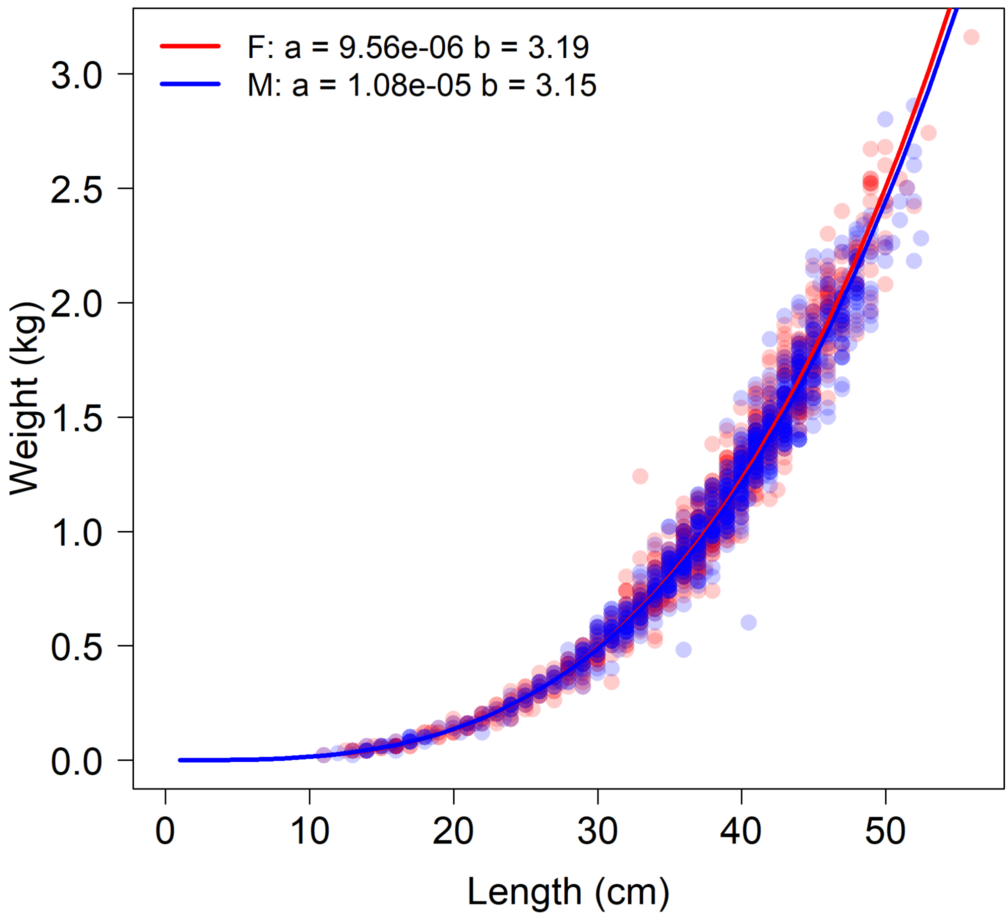

Figure 6: Survey length-at-weight data with sex specific estimated fits.

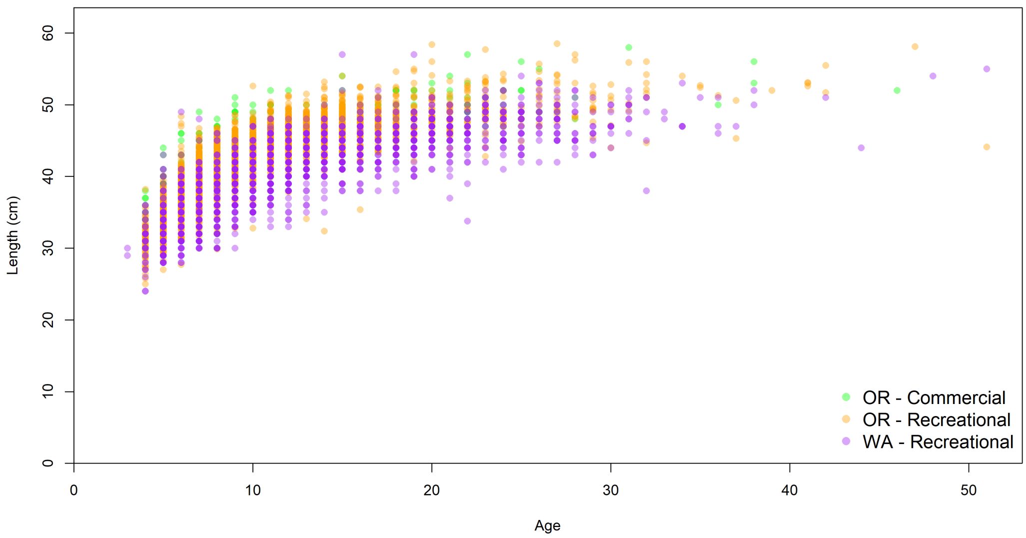

Figure 7: Observed length-at-age by data source.

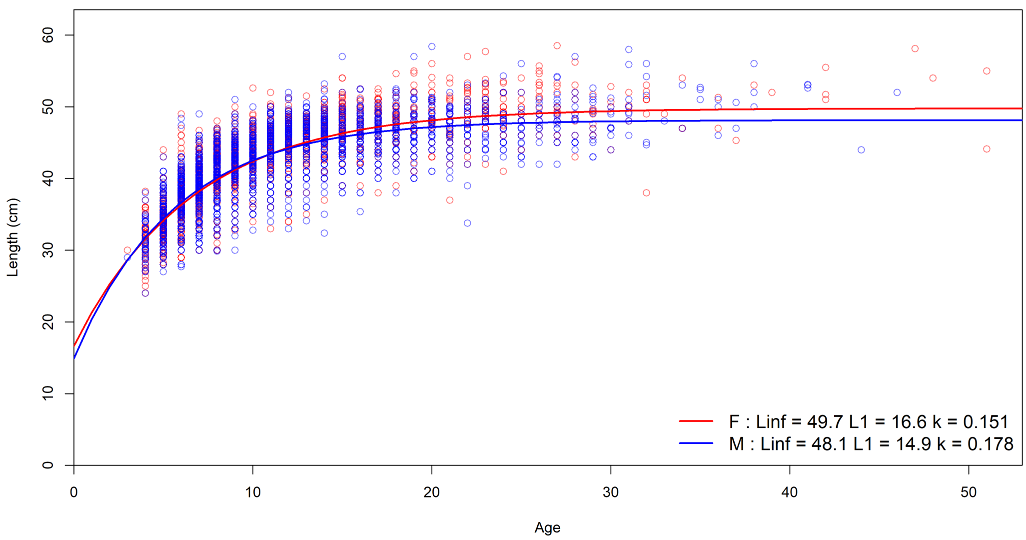

Figure 8: Length-at-age data from the with sex specific estimated growth.

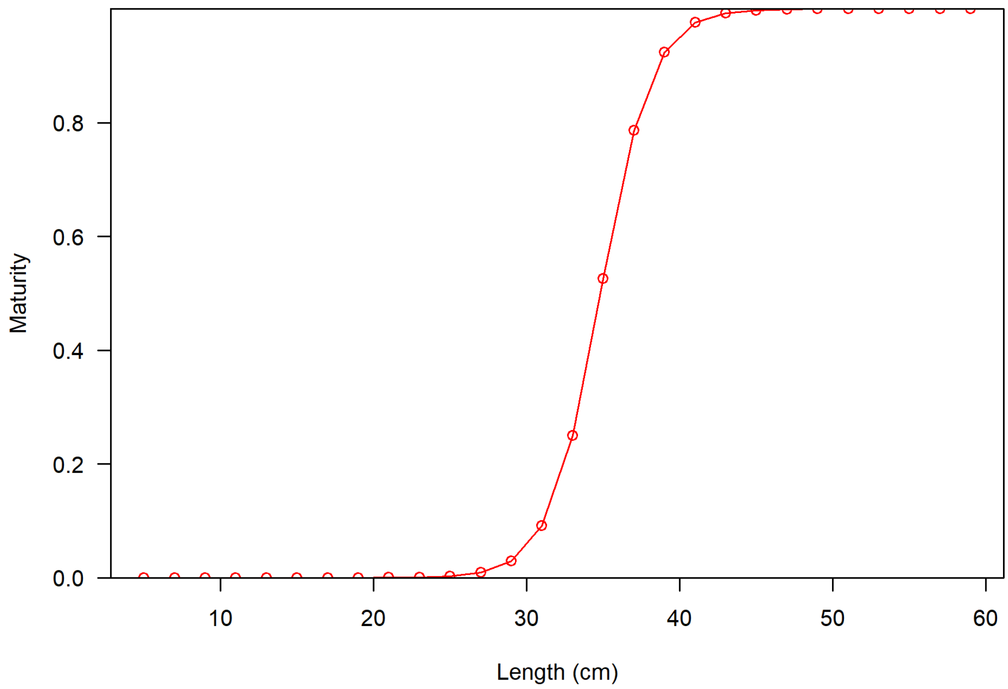

Figure 9: Maturity as a function of length.

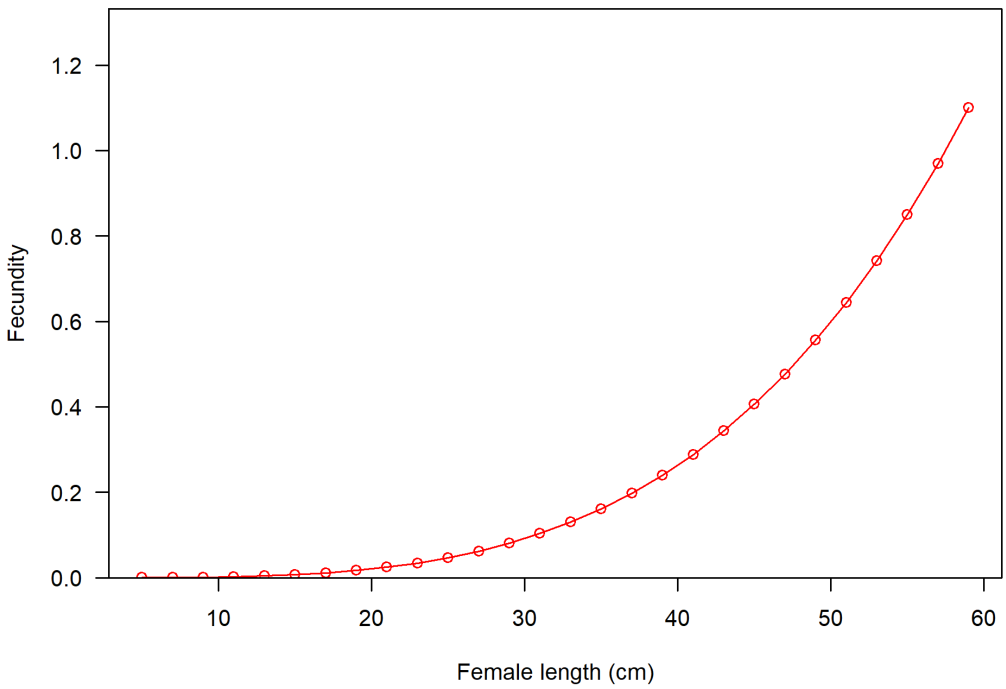

Figure 10: Fecundity as a function of length.

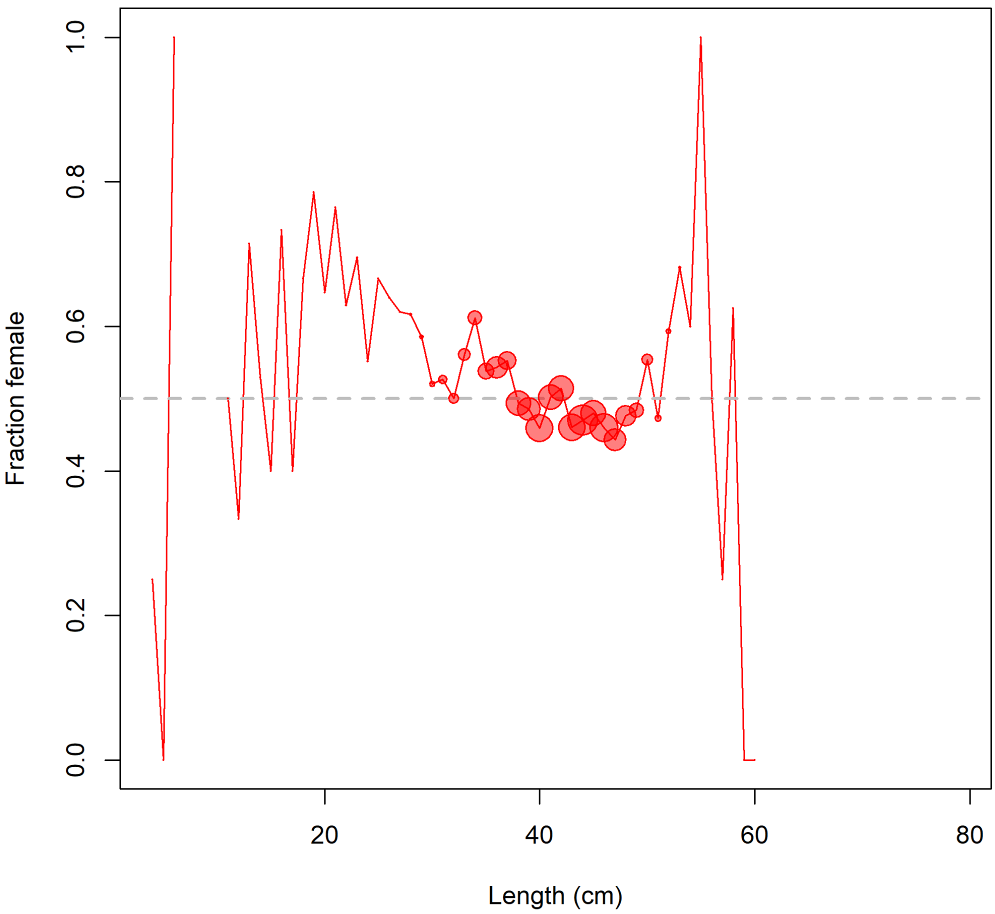

Figure 11: Fraction female by length across all available data sources.

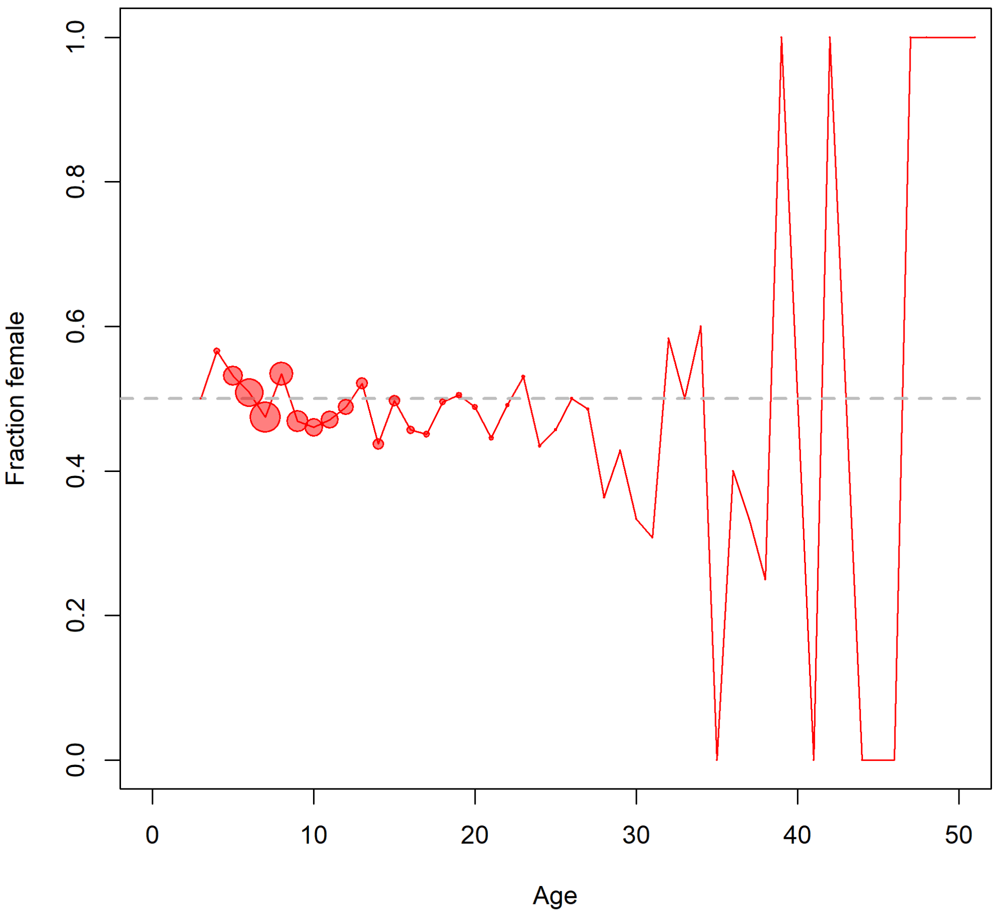

Figure 12: Fraction female by age across all available data sources.

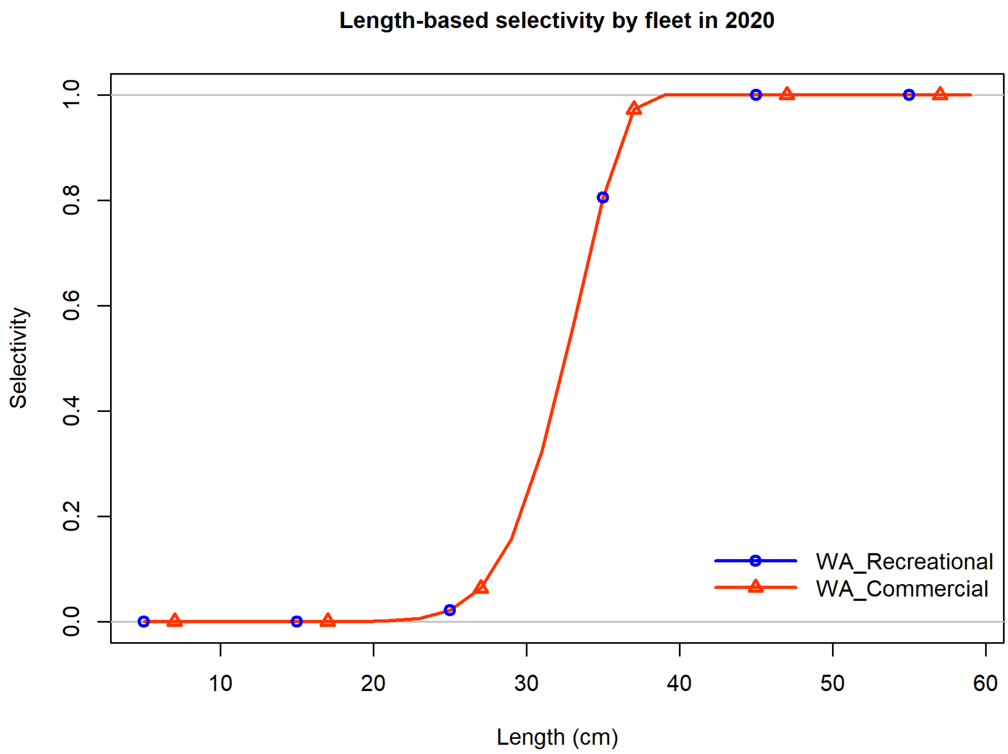

Figure 13: Selectivity at length by fleet.

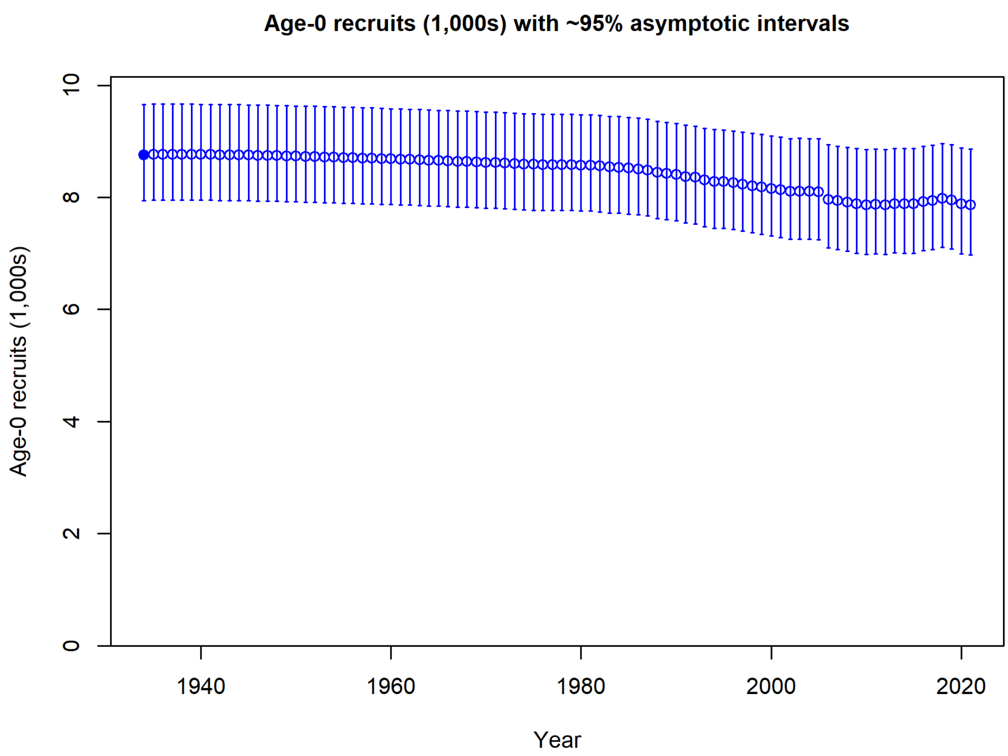

Figure 14: Estimated time series of age-0 recruits (1000s).

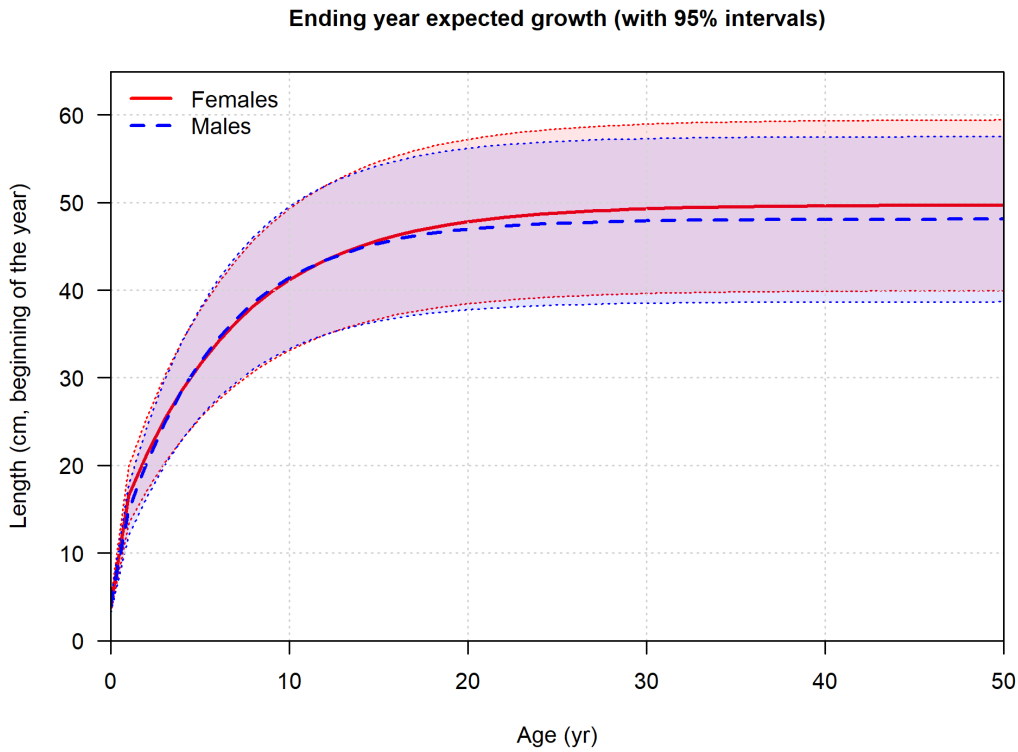

Figure 15: Length at age in the beginning of the year in the ending year of the model.

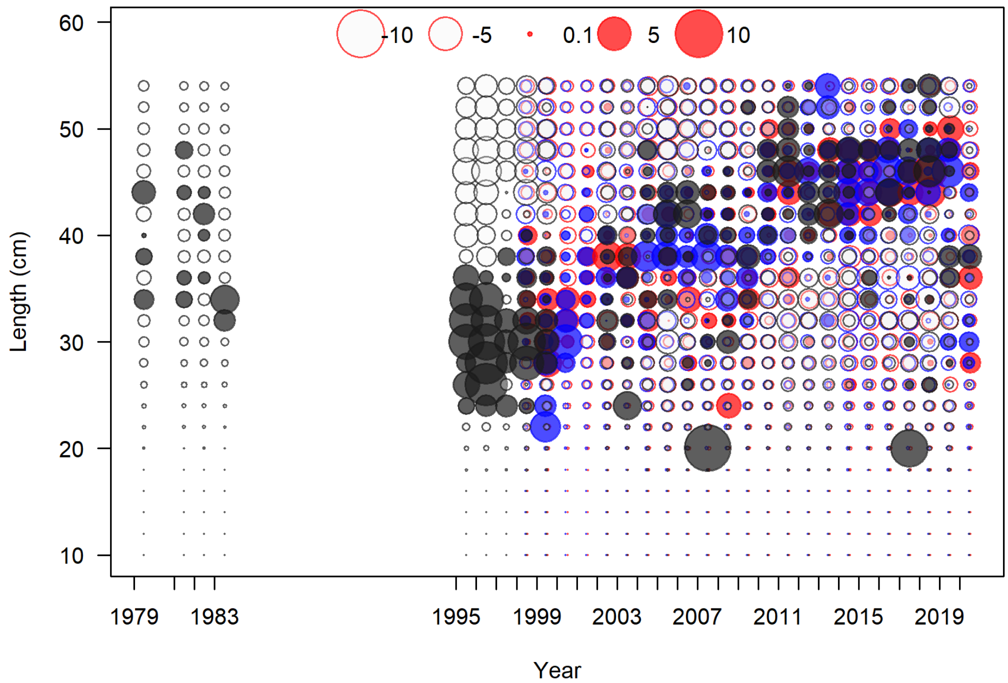

Figure 16: Pearson residuals for recreational fleet. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

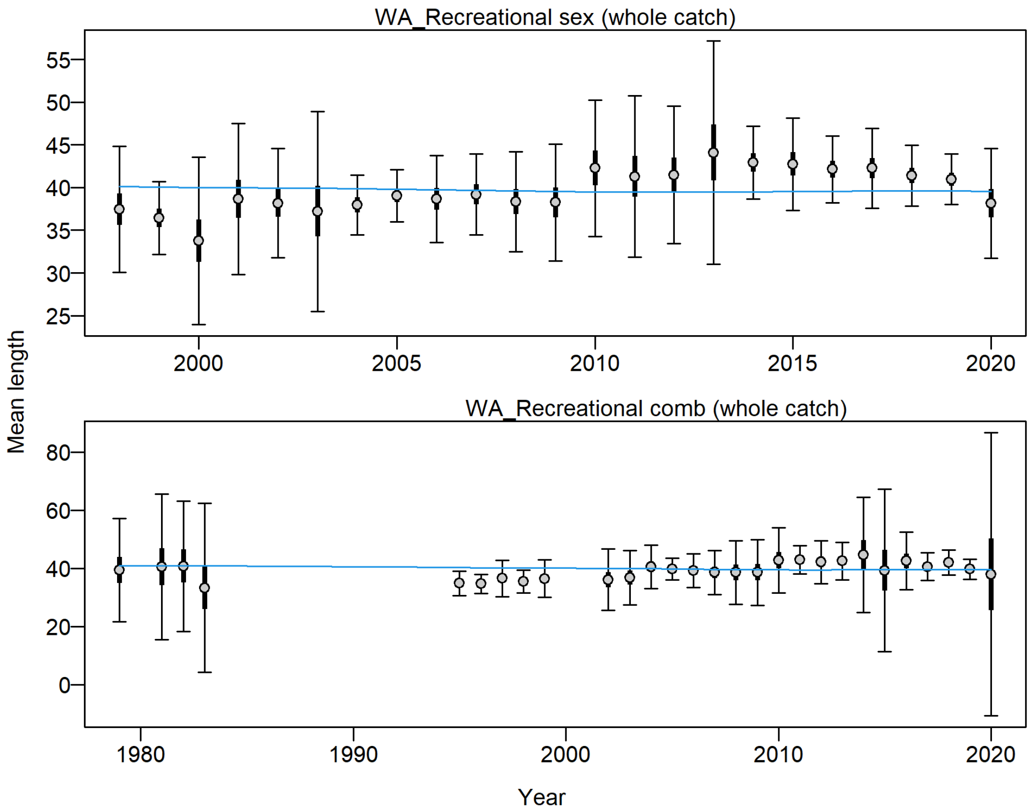

Figure 17: Mean length for recreational with 95 percent confidence intervals based on current samples sizes.

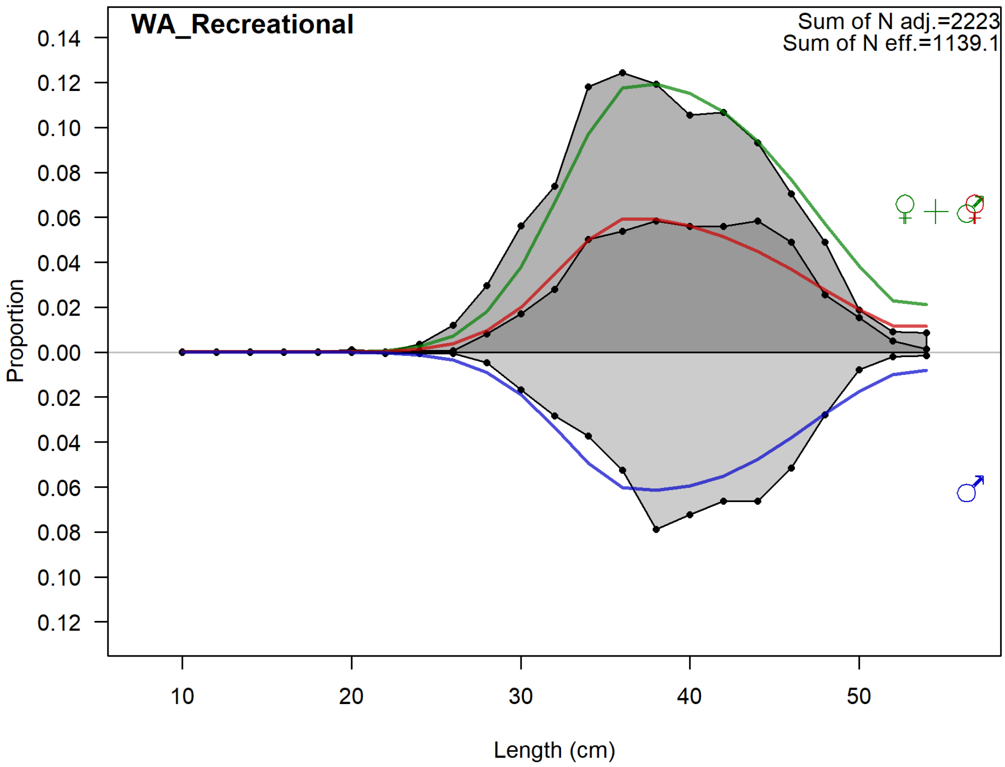

Figure 18: Aggregated length comps over all years.

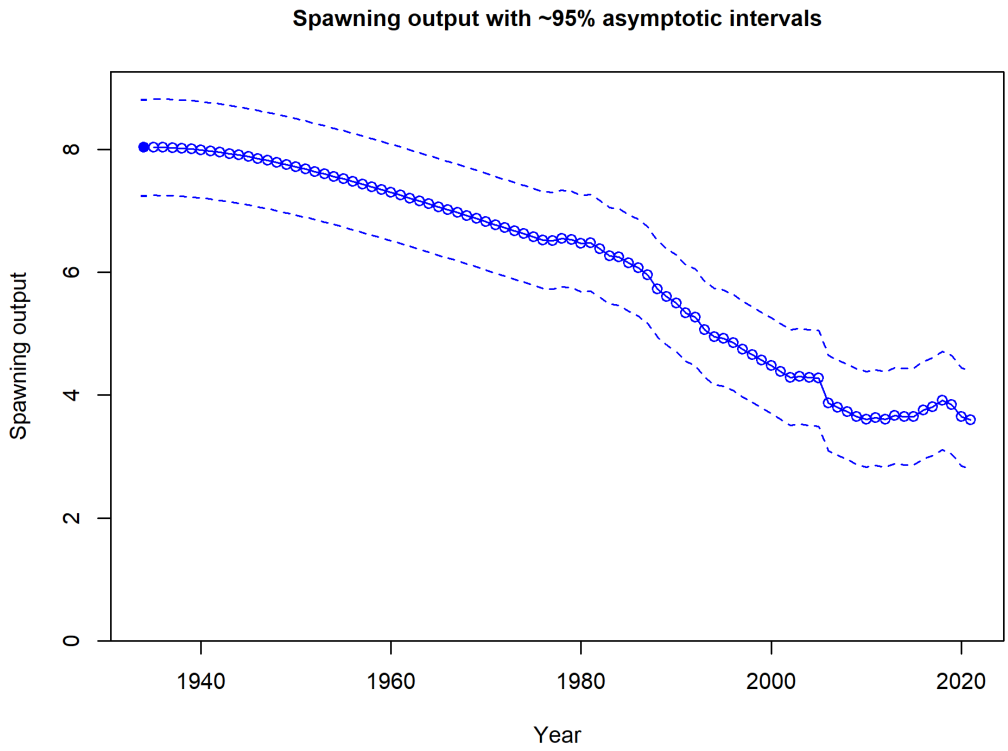

Figure 19: Estimated time series of spawning output.

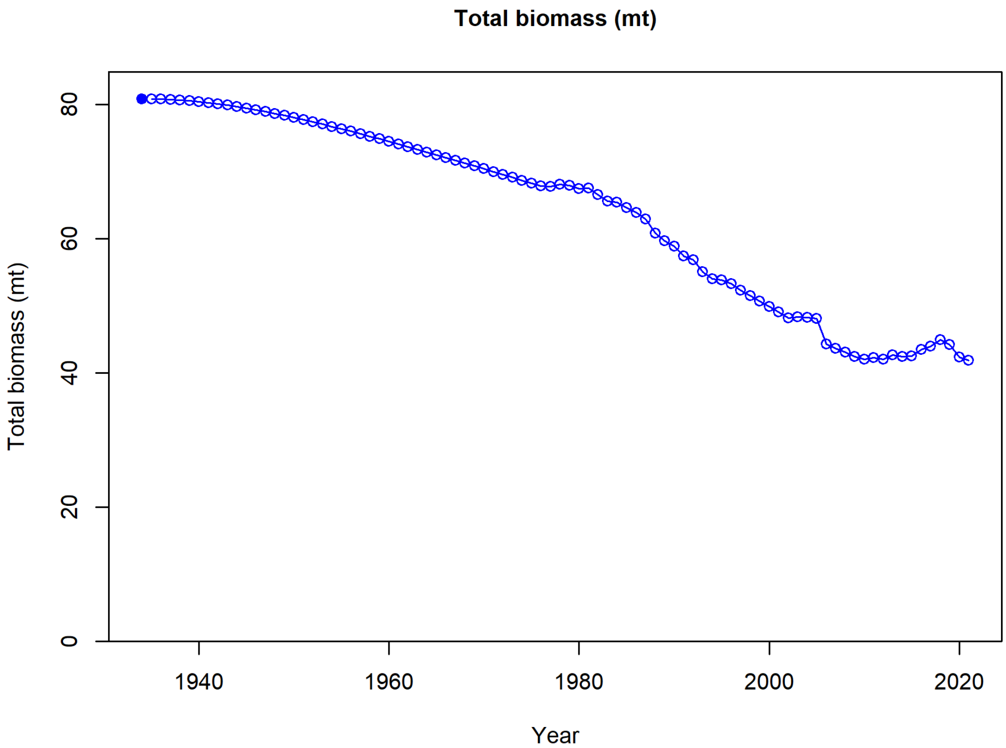

Figure 20: Estimated time series of total biomass.

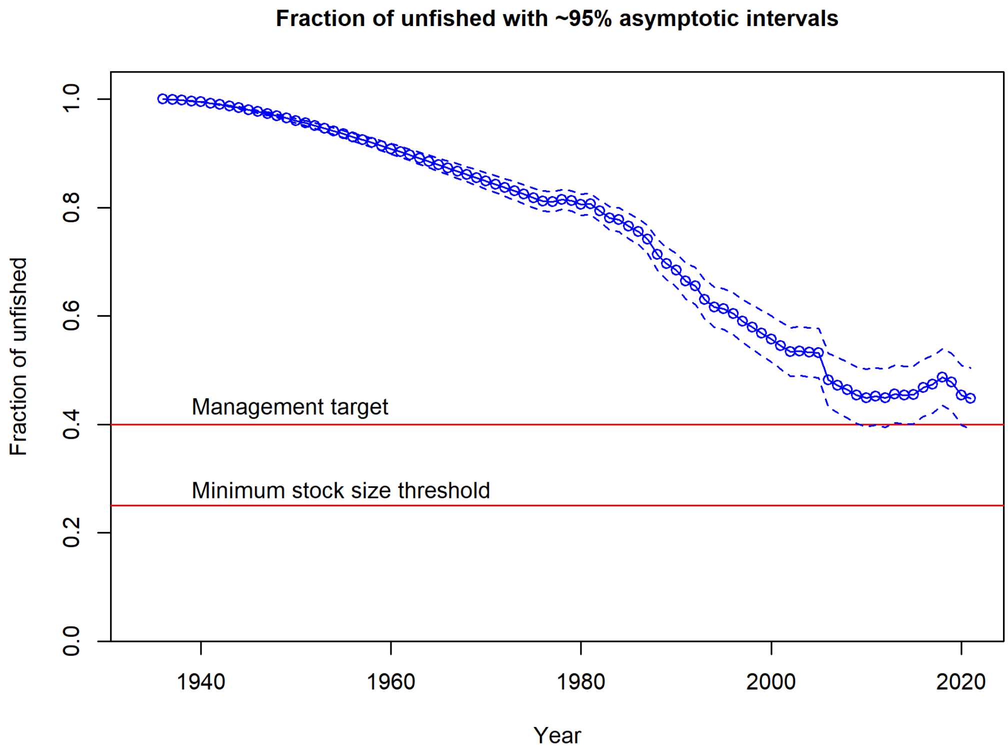

Figure 21: Estimated time series of fraction of unfished spawning output.

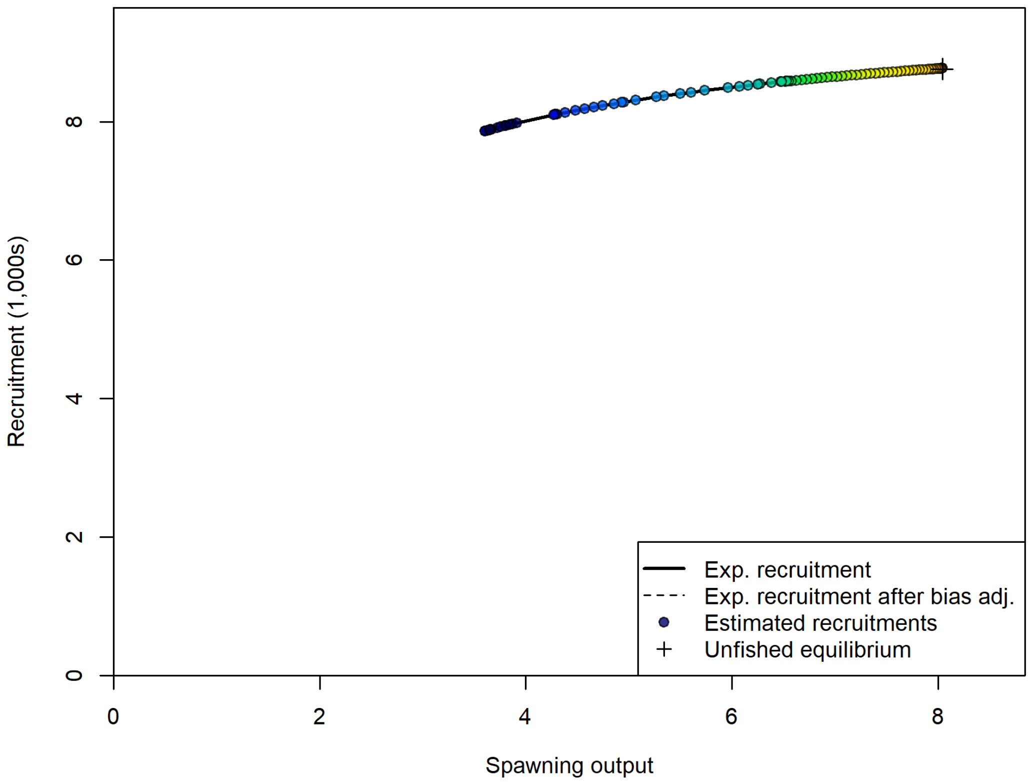

Figure 22: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

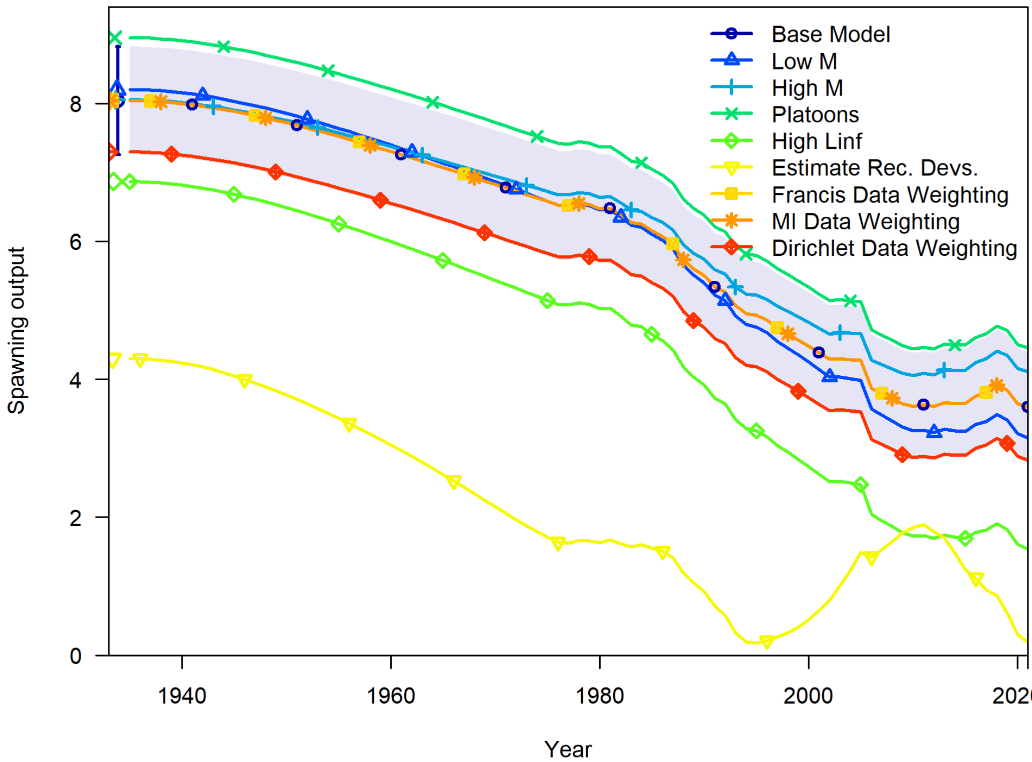

Figure 23: Change in estimated spawning output by sensitivity.

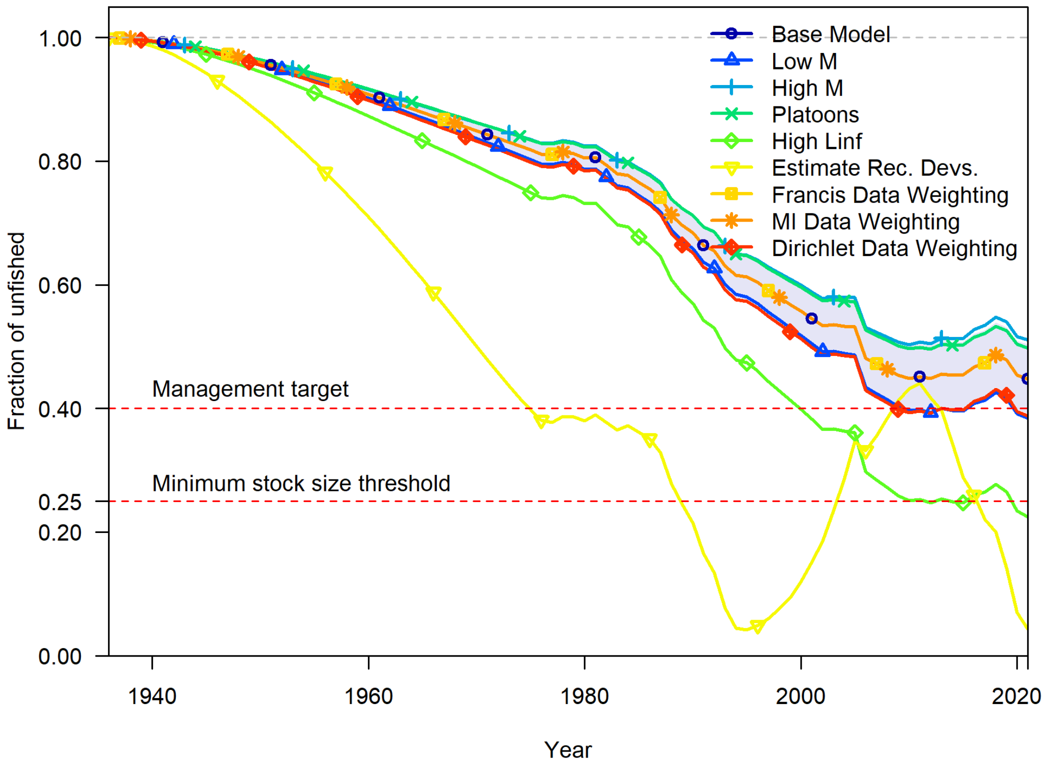

Figure 24: Change in estimated fraction unfished by sensitivity.

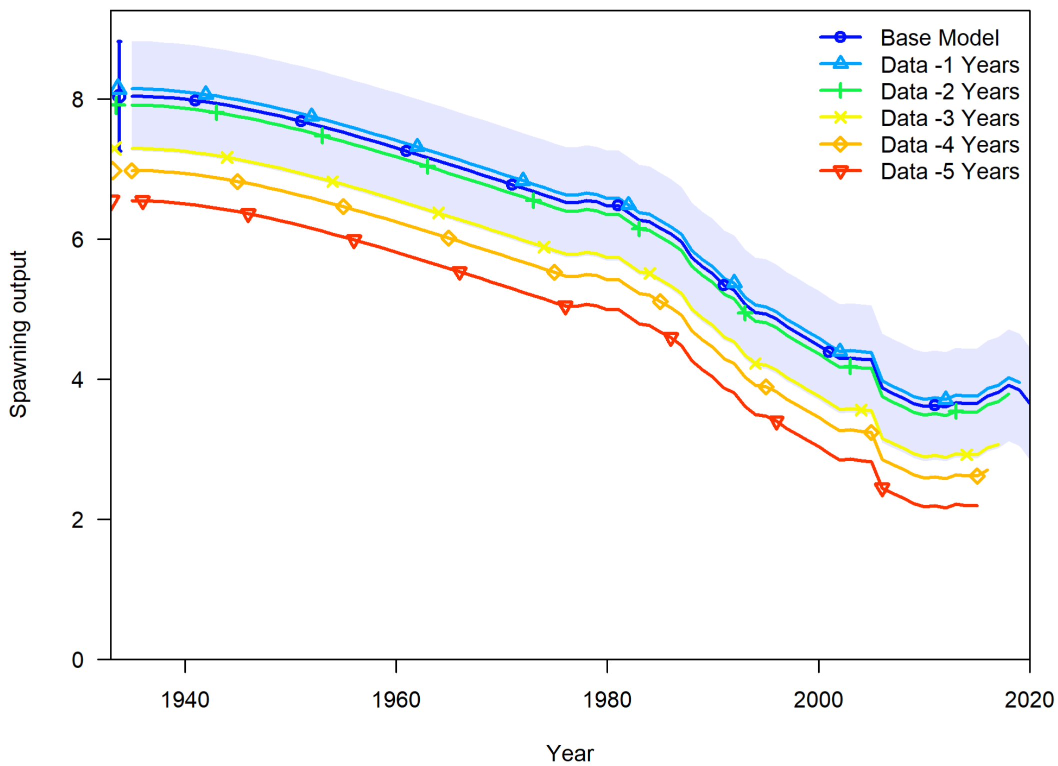

Figure 25: Change in the estimate of spawning output when the most recent 5 years of data area removed sequentially.

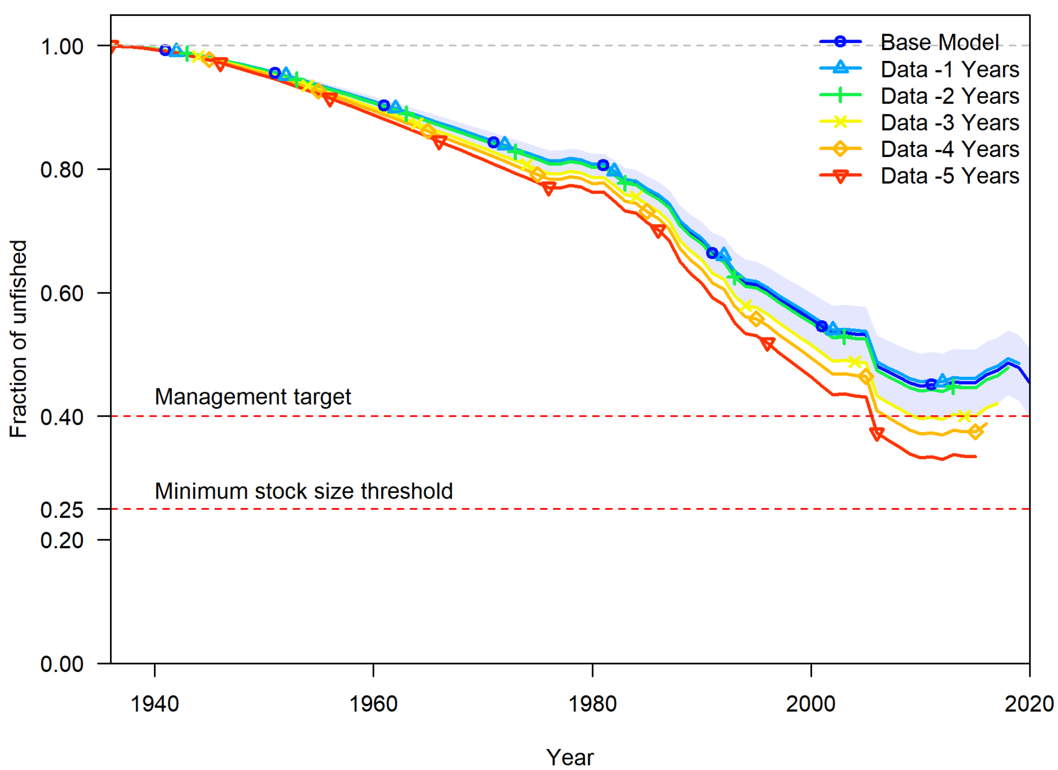

Figure 26: Change in the estimate of fraction unfished when the most recent 5 years of data area removed sequentially.

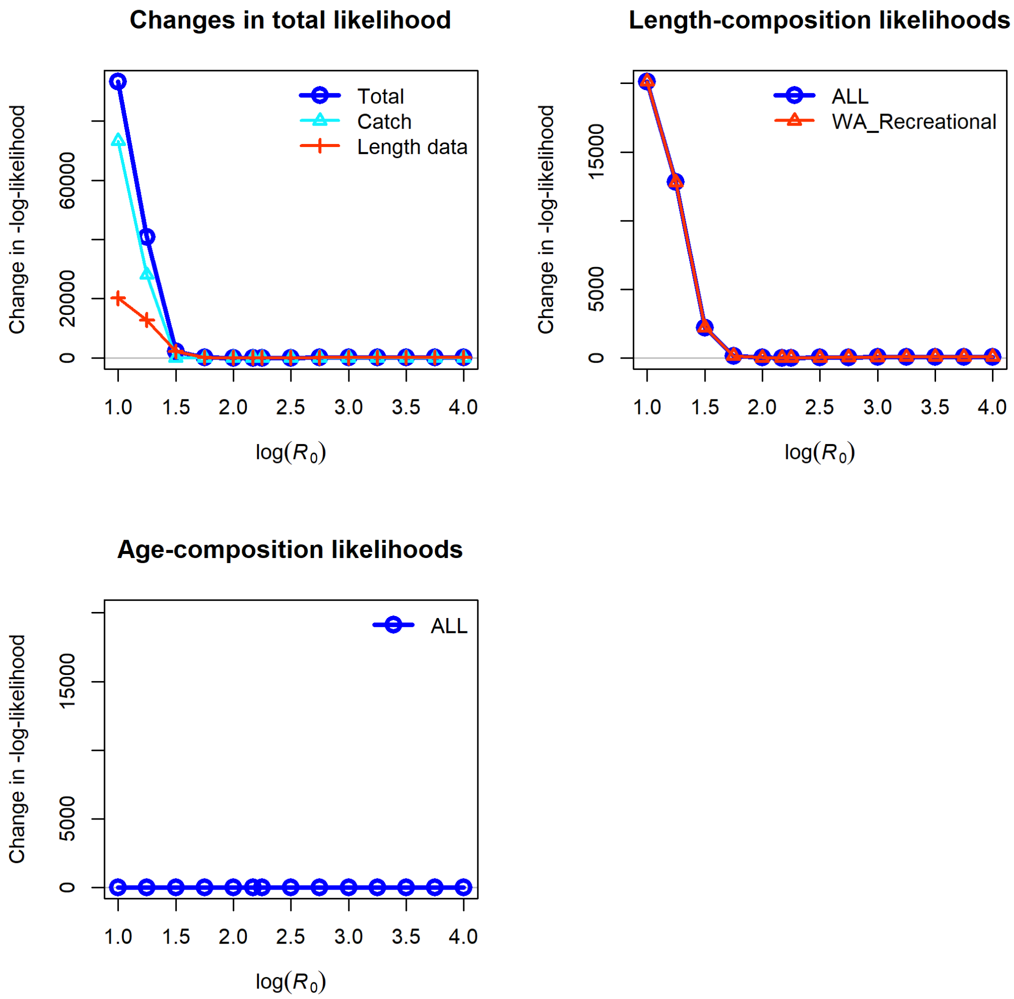

Figure 27: Change in the negative log-likelihood across a range of log(R0) values.

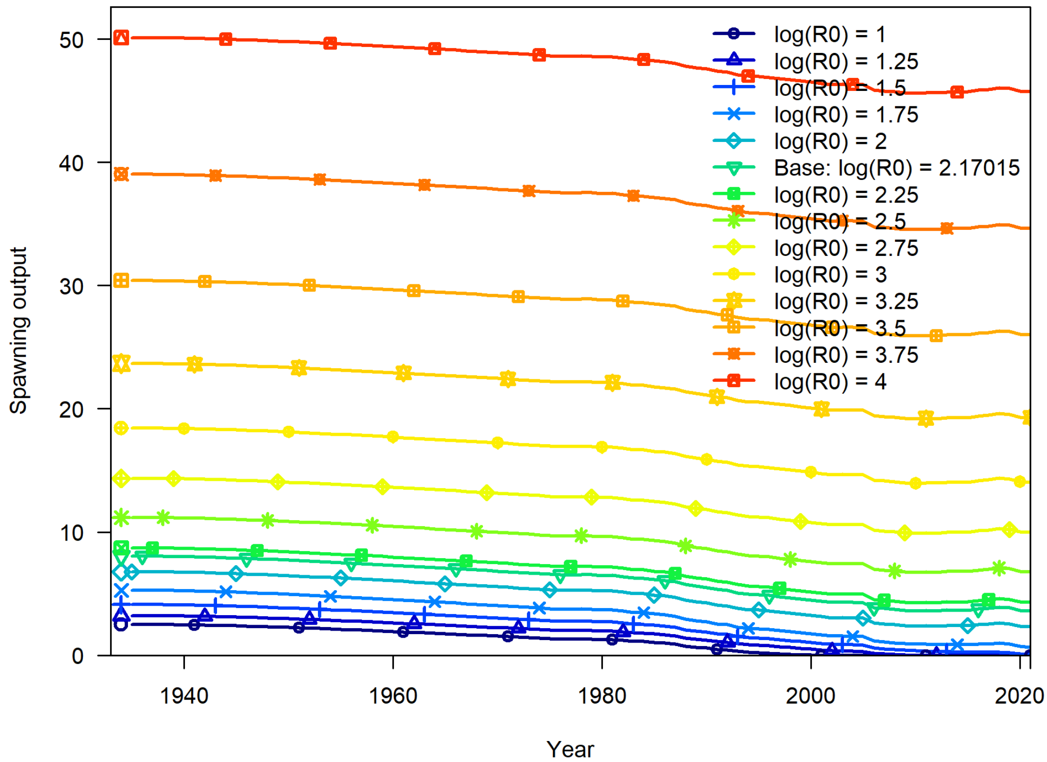

Figure 28: Change in the estimate of spawning output across a range of log(R0) values.

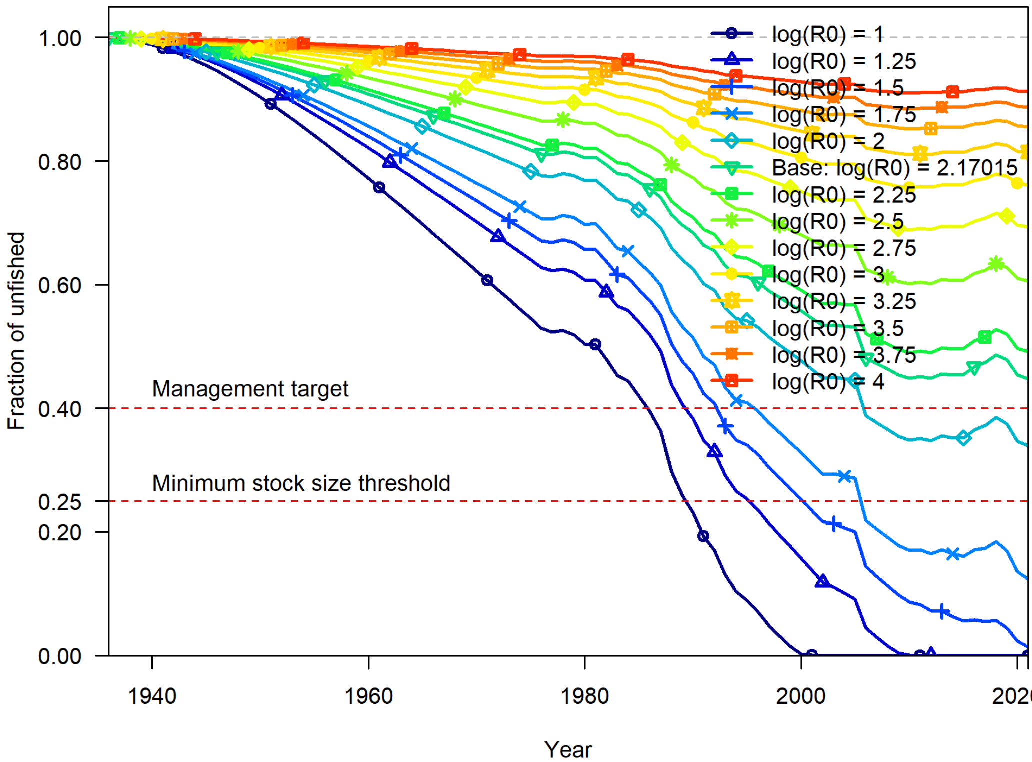

Figure 29: Change in the estimate of fraction unfished across a range of log(R0) values.

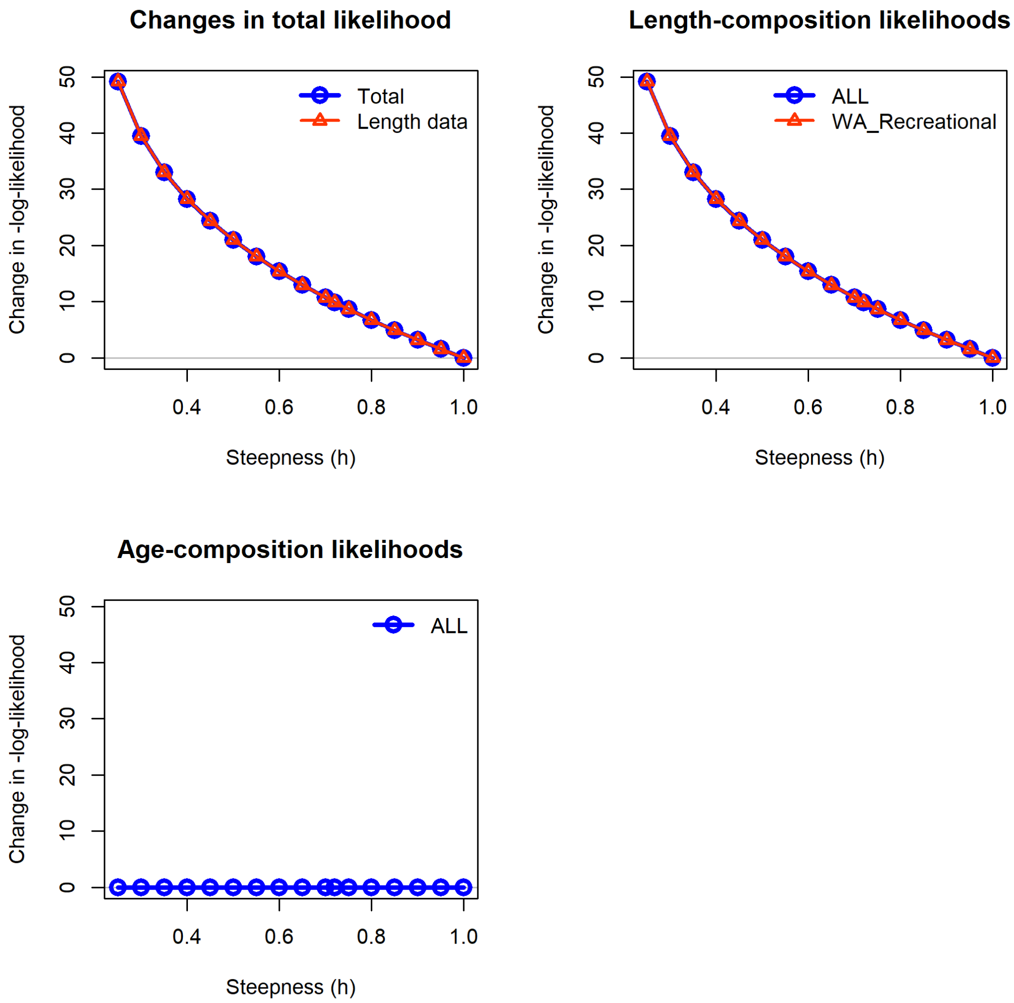

Figure 30: Change in the negative log-likelihood across a range of steepness values.

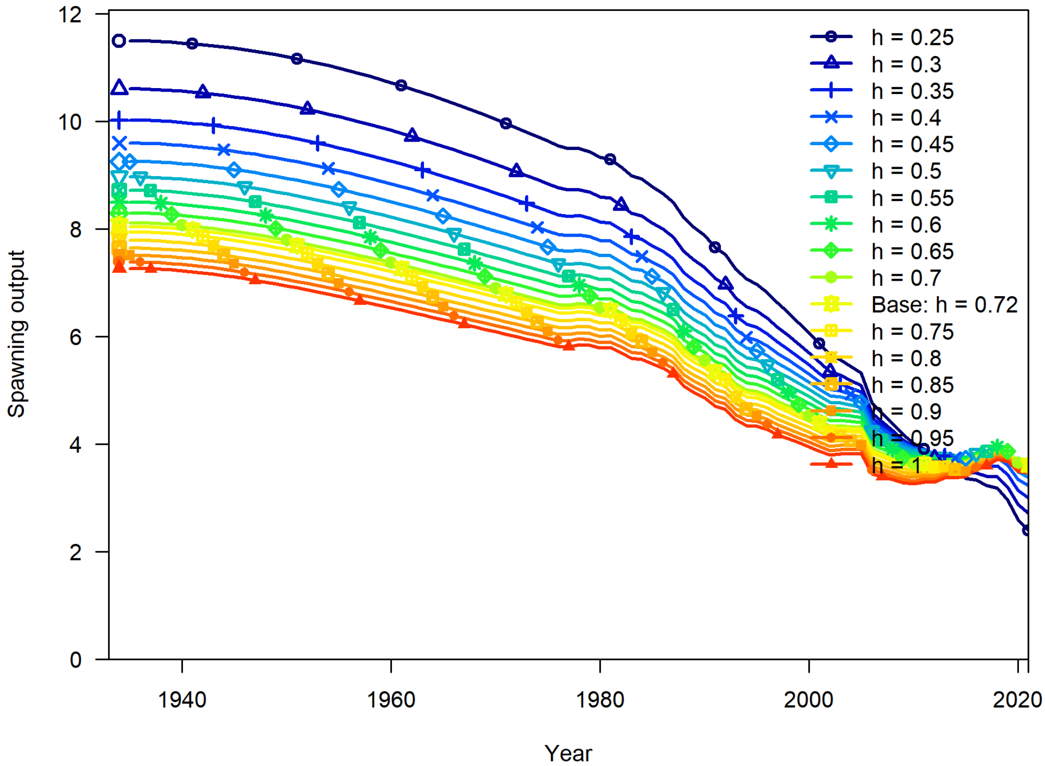

Figure 31: Change in the estimate of spawning output across a range of steepness values.

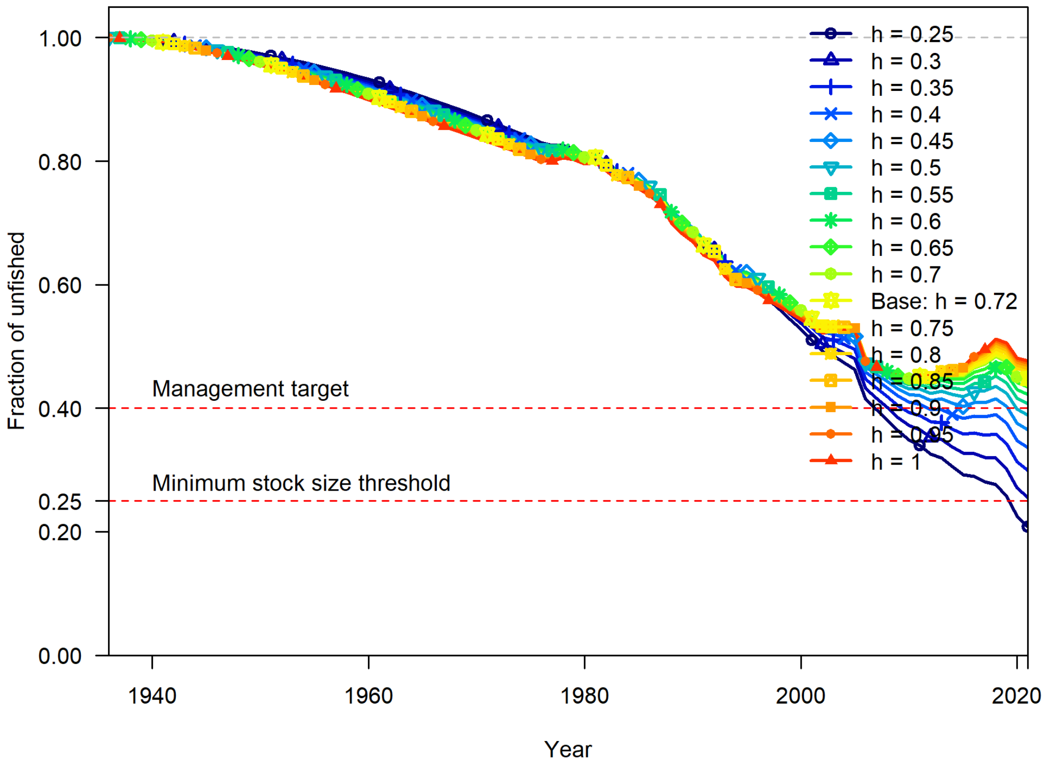

Figure 32: Change in the estimate of fraction unfished across a range of steepness values.

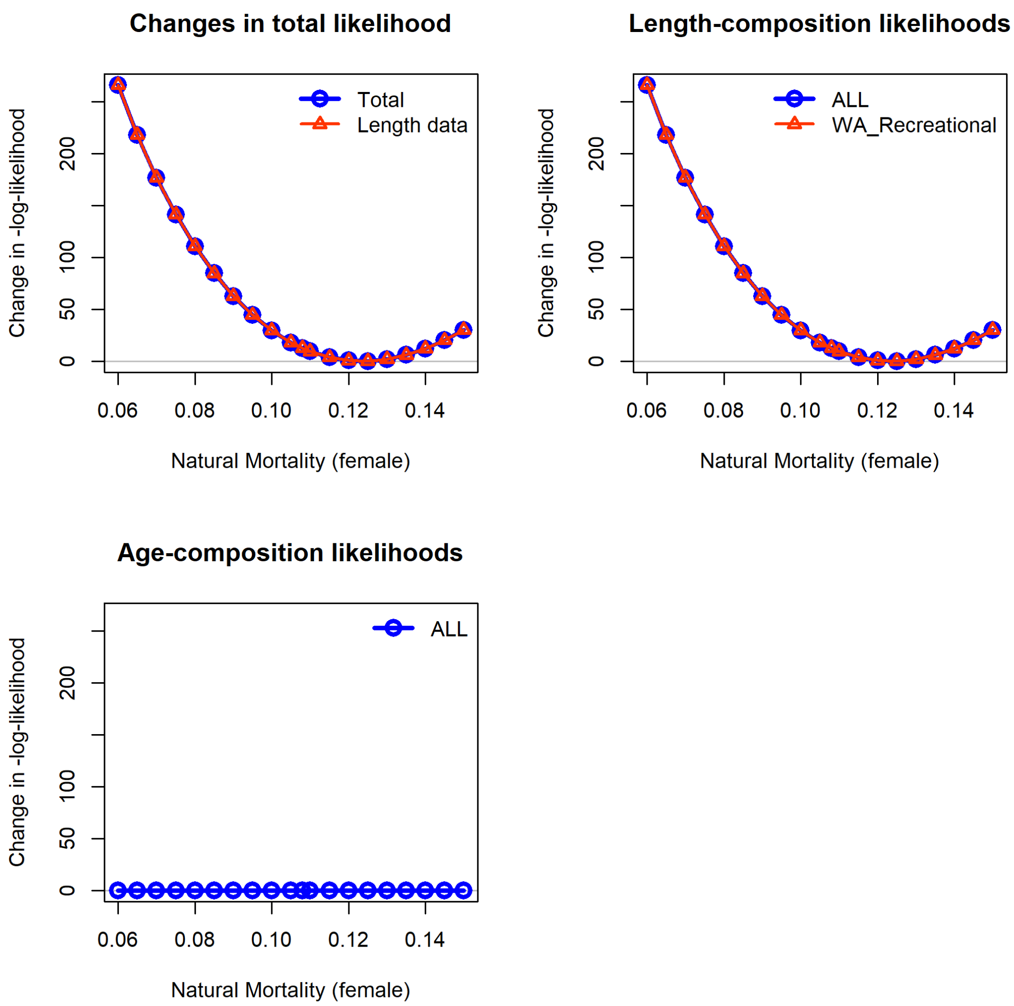

Figure 33: Change in the negative log-likelihood across a range of female natural mortality values.

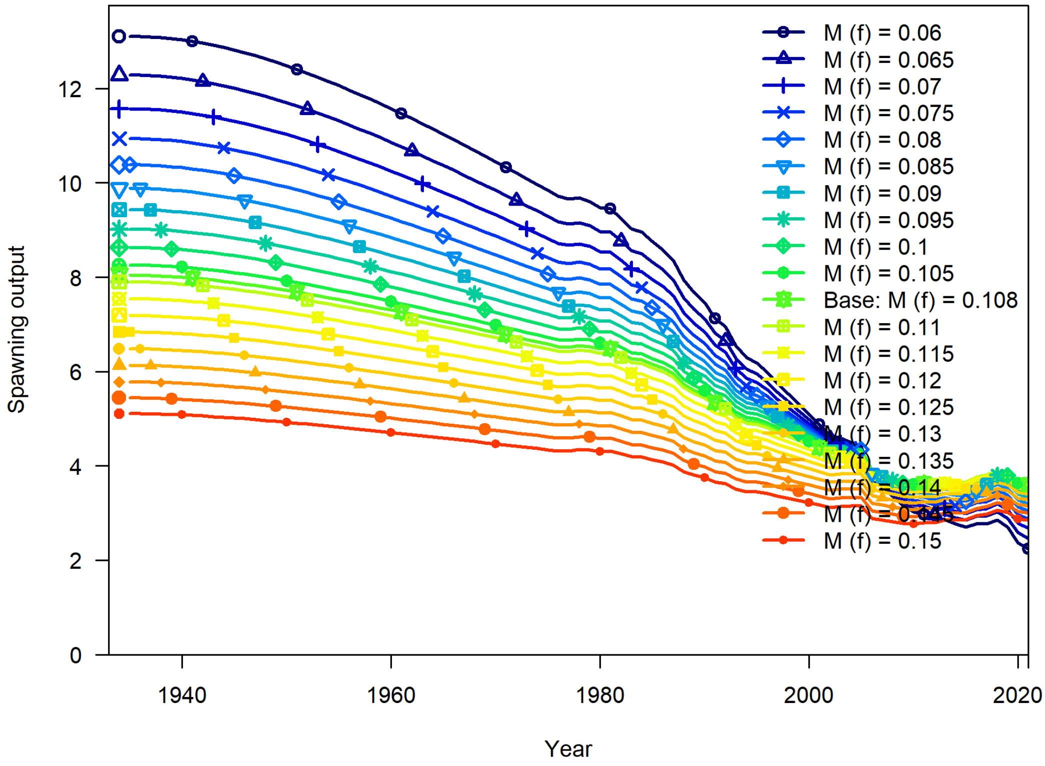

Figure 34: Change in the estimate of spawning output across a range of female natural mortality values.

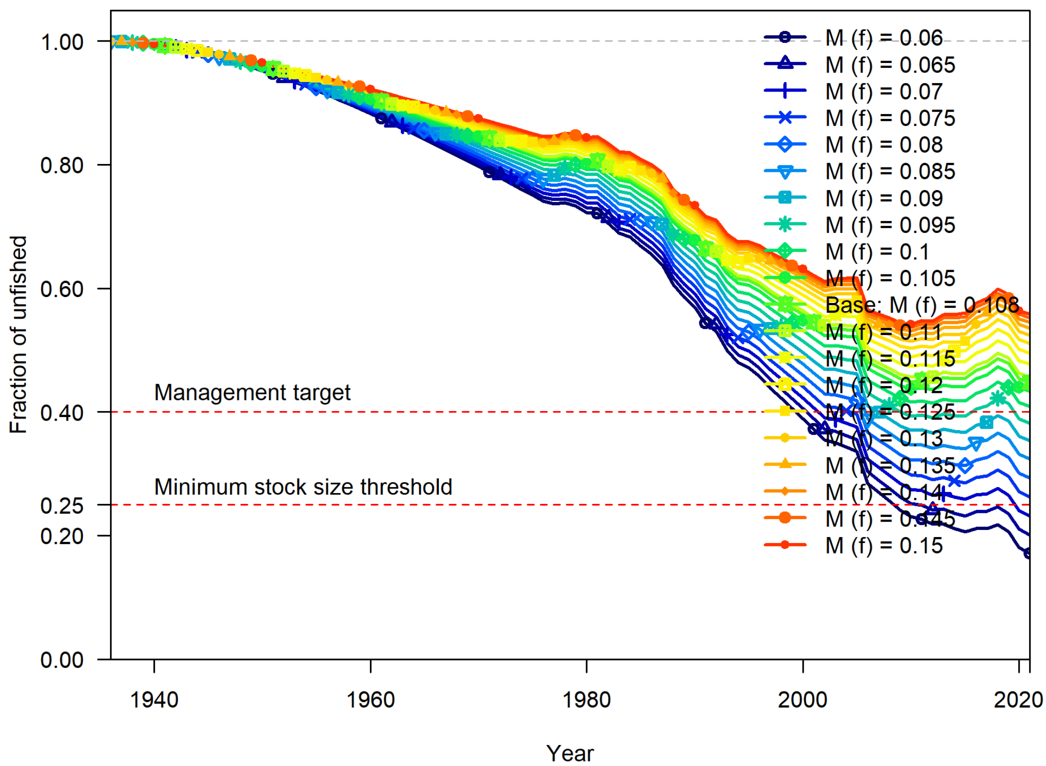

Figure 35: Change in the estimate of fraction unfished across a range of female natural values.

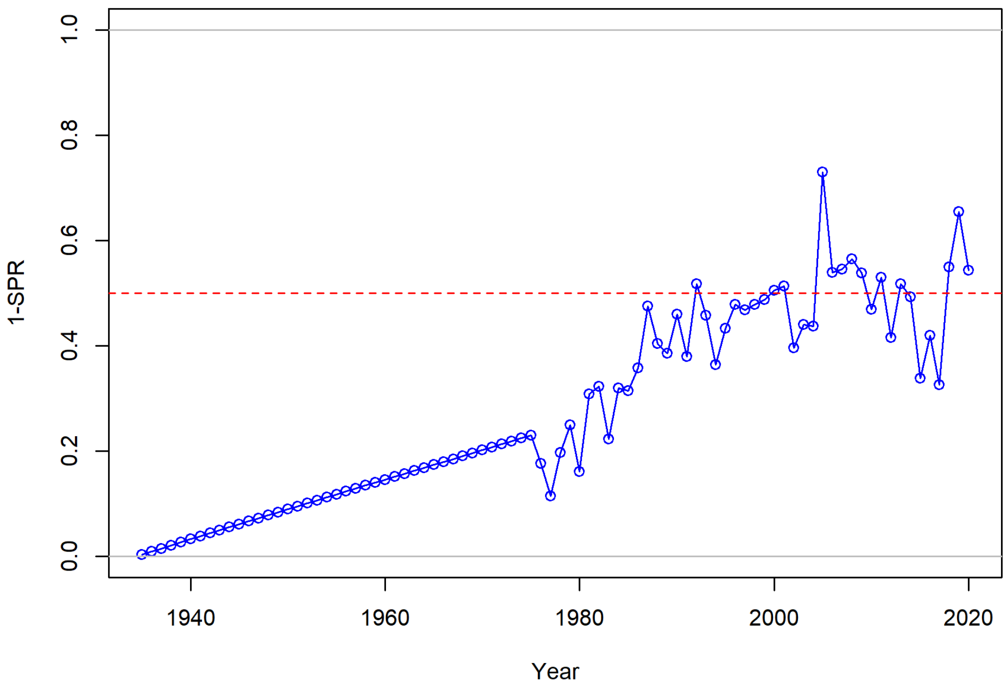

Figure 36: Estimated 1 - relative spawning ratio (SPR) by year.

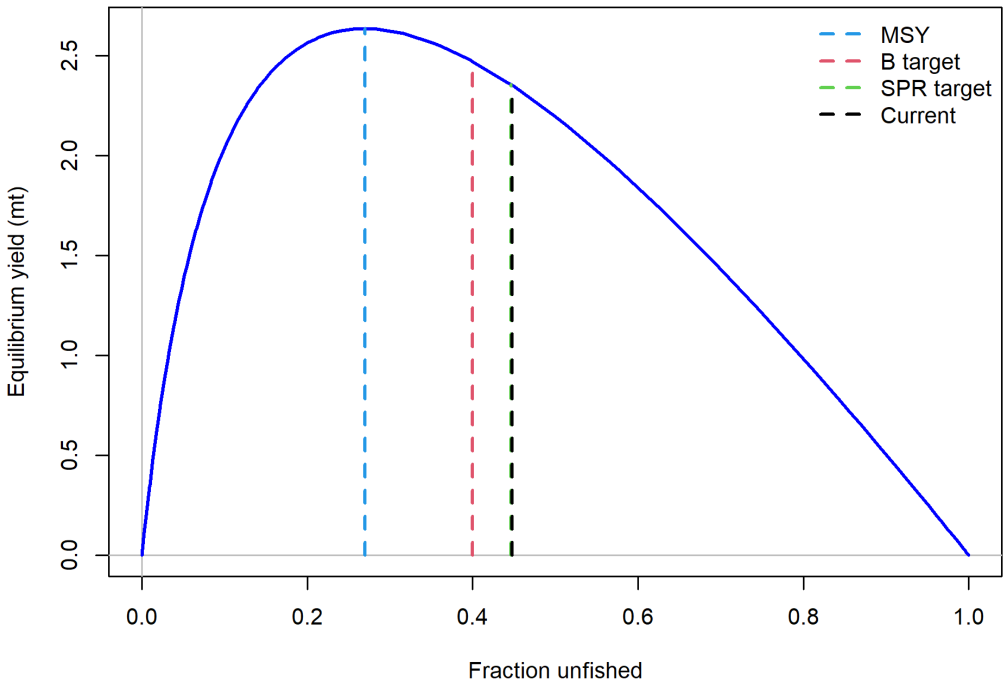

Figure 37: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivity and with steepness fixed at 0.72.

8 Appendix A. Detailed Fit to Length Composition Data

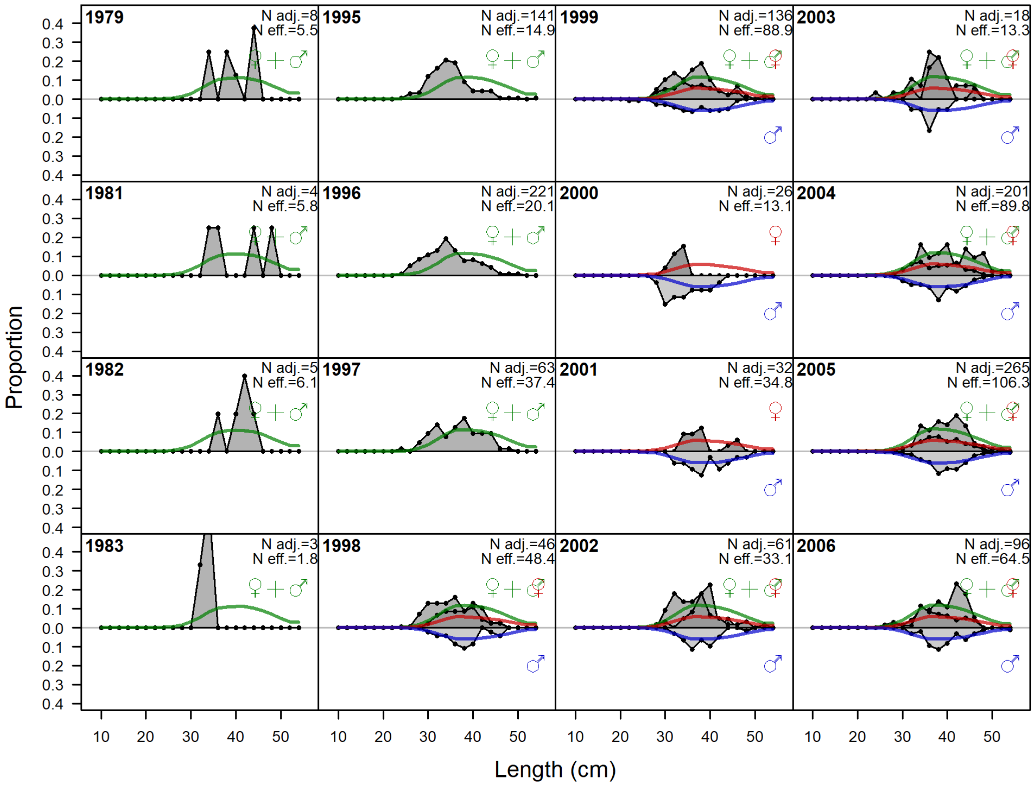

Figure 38: Length comps, whole catch, WA_Recreational (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method..

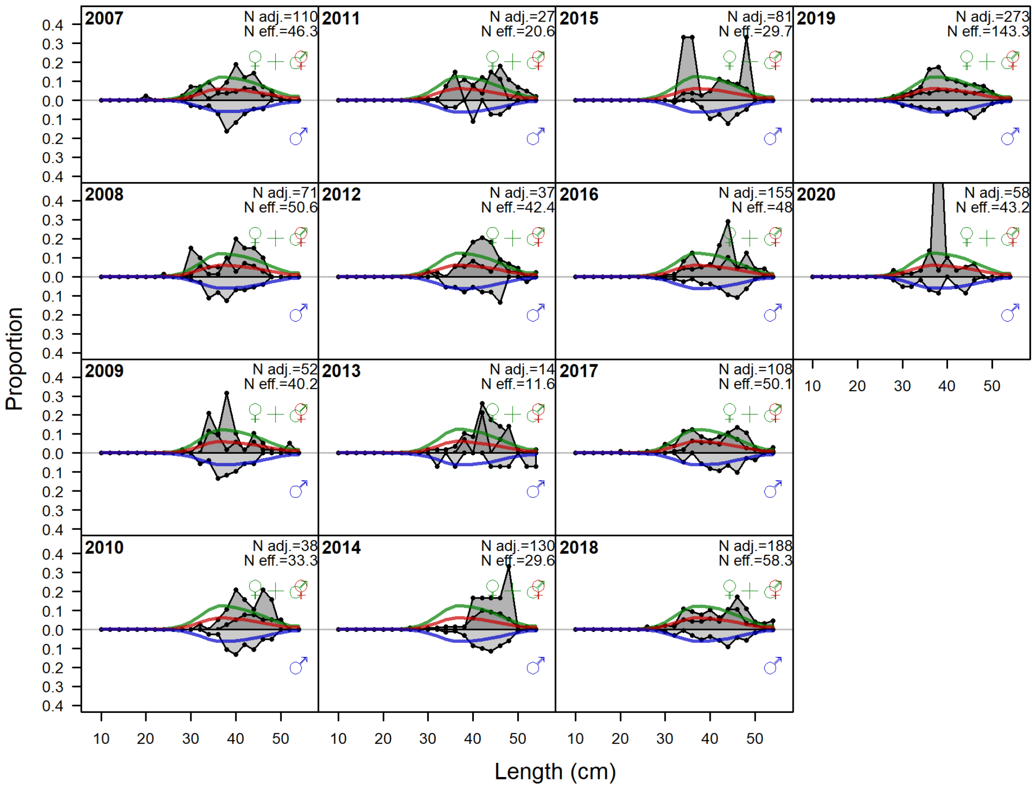

Figure 39: Length comps, whole catch, WA_Recreational (plot 2 of 2).

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