The status of Vermilion Rockfish (*Sebastes miniatus*) and Sunset Rockfish (*Sebastes crocotulus*) in U.S. waters off the coast of California south of Point Conception in 2021

by
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Two fish of the vermilion/sunset rockfish cryptic species pair. Confirmation of species can only be determined via genetic analysis and species identification of these two fish caught in the Santa Barbara channel at approximately 250 ft depth is unknown. Photo courtesy of Sabrina Beyer (UCSC/NOAA).

Executive Summary

Stock

This assessment reports the combined status of the vermilion rockfish (*Sebastes miniatus*) and sunset rockfish (*Sebastes crocotulus*), referred to as “vermilion rockfish” throughout this document, in U.S. waters off the coast of California south of Point Conception ($34°27'N$) using data through 2020. Genetic evidence suggests overlapping distributions for the two species, with the majority of the sunset rockfish population occupying waters south of Point Conception. Alternative spatial structures for the vermilion rockfish assessment should be considered if additional data on stock structure and the distribution of the two species become available.

Catches

Over the past decade, vermilion rockfish in the assessed area off the coast of California have been primarily caught by the recreational fishery (Table i). Annual total mortality of catch and discards of vermilion rockfish have ranged between 106-260 mt, with total mortality (catch + discards) in 2020 of 110 mt. Vermilion and sunset rockfish landings from all sectors have historically been recorded as “vermilion rockfish” and sampling programs in California currently do not differentiate between the two species.

Recreational removals in California prior to 2004 were only estimated at large spatial scales (north and south of Point Conception) following the design of the Marine Recreational Fisheries Statistics Survey (MRFSS). Recent sampling (2004 – present) by the California Recreational Fisheries Survey (CRFS) produces estimates of vermilion rockfish landings and discard at a finer spatial resolution. Total removals south of Point Conception increased steadily following World War II, peaking in the late 1970s and 1980s with annual removals of 402 mt per year (Figure i). Recent years have seen a steady increase in landings, with recreational fleets accounting for the majority of total mortality.

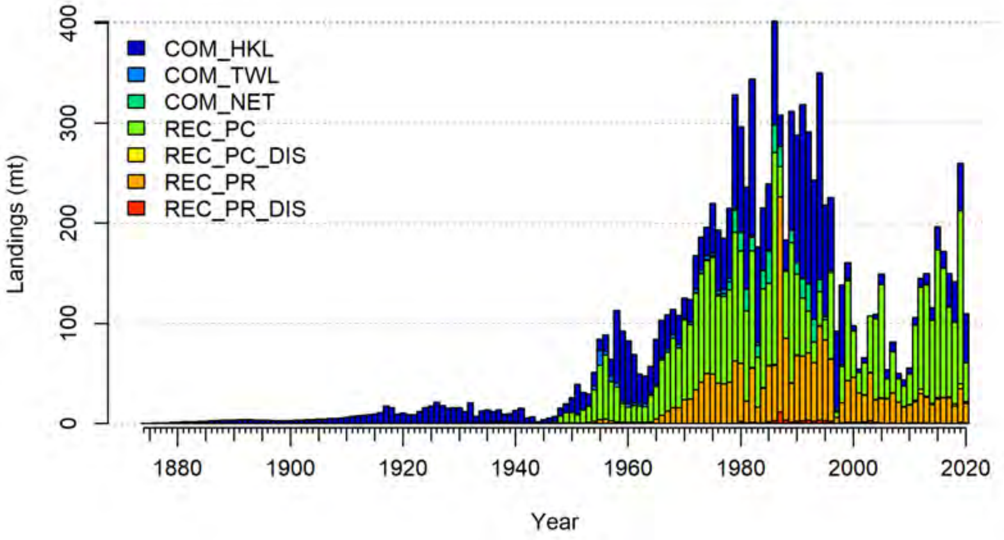

Figure i: Catch histories by fleet used in the base model (Commercial hook-and-line = COM_HKL, Commercial trawl = COM_TWL, Commercial net = COM_NET, Recreational party/charter retained = REC_PC, Recreational private/rental retained = REC_PR, Recreational party/charter dead discards = REC_PC_DIS, Recreational private/rental dead discards = REC_PR_DIS).

Table i: Recent mortality (mt) by fleet and total landings summed across all fleets in the model.

	Commercial			**Recreational**				
				Party/charter		Private/rental		
Year	Hook-and-Line	Trawl	Net	Retained	Dead Discards	Retained	Dead Discards	Total Mortality
2011	7.6	0.0	0.0	75.3	1.6	21.3	0.4	106.2
2012	8.5	0.0	0.0	102.6	4.4	29.1	0.6	145.3
2013	11.0	0.1	0.0	111.6	1.3	25.5	0.5	150.0
2014	12.7	0.1	0.0	83.3	1.2	18.6	0.3	116.1
2015	22.0	0.1	0.0	148.2	1.6	23.9	0.5	196.2
2016	16.1	0.2	0.1	129.4	0.8	25.3	0.3	172.1
2017	33.3	0.1	0.0	90.0	1.2	25.3	0.3	150.1
2018	40.2	0.0	0.0	82.3	1.9	17.2	0.4	142.1
2019	47.2	0.3	0.0	172.5	5.3	33.6	1.0	260.0
2020	48.8	0.1	0.1	38.9	1.6	19.8	0.5	109.7

Data and Assessment

A full assessment was attempted in 2005, but not accepted for management and a data-moderate assessment in 2013 was not reviewed. As such, this is the first benchmark assessment for vermilion and sunset rockfish. The 2021 assessment uses Stock Synthesis 3 (version V3.30.17.0). The assessment is a two-sex model, with the population spanning from the U.S./Mexico border to Point Conception ($34°27'N$). The model operates on an annual time step covering the period 1875 to 2020 (not including forecast years) and assumes an unfished population prior to 1875. Population dynamics are modeled for ages 0 through 70, with age-70 being the accumulator age.

The model is conditioned on catch from two sectors (commercial and recreational) divided among seven fleets, and is informed by four abundance indices (one fishery-independent survey, two CPUE indices from shore-based sampling programs, and one CPUE index using onboard party/charter observer data). The model is also fit to length composition data from fishery-independent and fishery-dependent sources, as well as age compositions conditioned on length. Discards for the commercial fleets are not included in the model. Commercial discards of vermilion rockfish are a small fraction of the total mortality and data on commercial discard length composition is limited. The recreational fishery is split into four fleets, one discard and one retained fish fleet each for the private/rental and the party/charter boat modes. The model also incorporates an updated length-weight relationship, length-based maturity schedule, and fecundity-at-length function.

The assessment estimates a single natural mortality rate for females and males, steepness of the Beverton-Holt stock-recruitment relationship, and sex-specific growth parameters. Year class strength is estimated as deviations from a Beverton-Holt expected stock-recruitment relationship beginning in 1965.

Stock Biomass

Spawning output of vermilion rockfish was estimated to be 471 million eggs in 2021 (95% asymptotic interval: 229 - 714 million eggs) or 48% (95% asymptotic interval: 26% - 71%) of unfished spawning output ("depletion," Table ii). Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output.

In southern California, spawning output declined rapidly in the 1970s and early 1980s, likely falling below the minimum stock size threshold in the early 1990s, followed by a steady recovery since the early 2000s (Figures ii and iii). The point estimate for spawning output in 2021 is above the management target (40% of unfished spawning output).

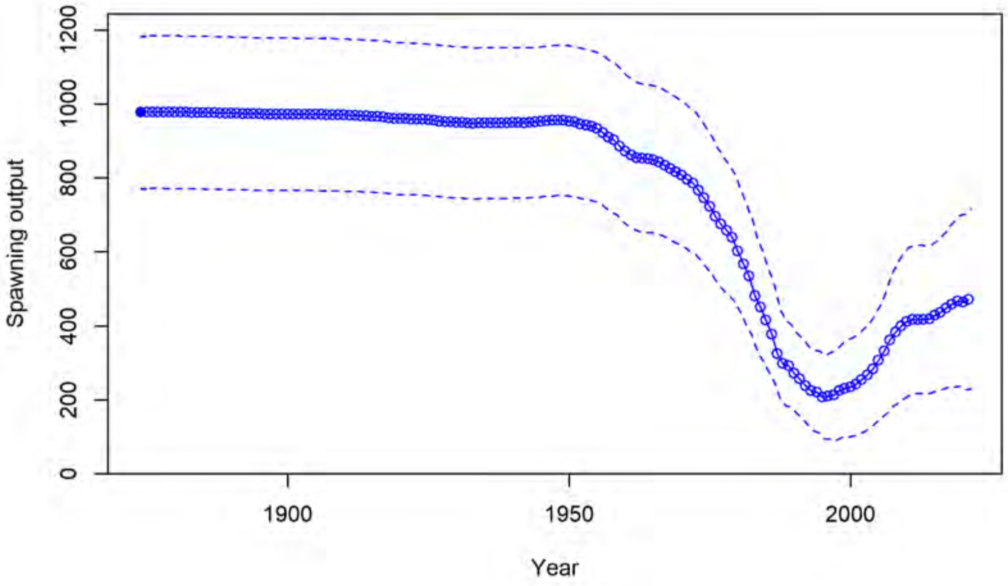

Figure ii: Estimated time series of spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

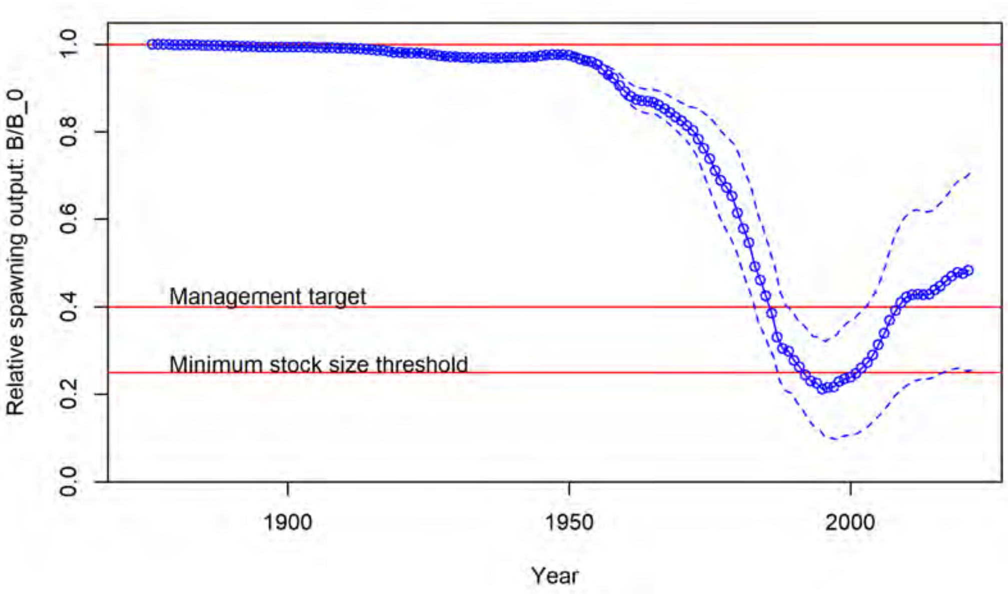

Figure iii: Estimated time series of spawning output relative to unfished spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

Table ii: Estimated recent trend in spawning output and the fraction unfished and the approximate 95% asymptotic confidence intervals.

	Spawning Output			**Fraction Unfished**		
Year	Estimate	Lower Interval	Upper Interval	Estimate	Lower Interval	Upper Interval
2011	417.626	216.763	618.489	0.427	0.232	0.622
2012	417.703	217.755	617.651	0.427	0.234	0.620
2013	416.626	217.570	615.682	0.426	0.235	0.617
2014	418.821	219.116	618.526	0.428	0.238	0.619
2015	428.176	225.337	631.015	0.438	0.245	0.631
2016	436.847	228.489	645.205	0.447	0.250	0.644
2017	448.412	232.930	663.894	0.459	0.255	0.662
2018	458.305	235.071	681.539	0.469	0.259	0.678
2019	466.811	236.253	697.369	0.477	0.261	0.693
2020	464.518	227.774	701.262	0.475	0.254	0.696
2021	471.178	228.525	713.831	0.482	0.256	0.708

Recruitment

Major recruitments (strong year classes) in southern California were consistently estimated by both primary sources of age data (NWFSC hook-and-line and trawl surveys), with a strong 1999 year class estimated even when either data set was removed (see sensitivity section) (Figure iv). Other years with relatively high estimates of recruitment were 1983-84, 1999, and 2016. These are consistent with estimates of strong year classes in other rockfish stock assessments. Recent recruitments (2011-2020) have above average in most years that are well-informed by data (Table iii), although extended periods of below-average recruitment (e.g. 2001-2006) have also occurred and future trends in recruitment are highly uncertain.

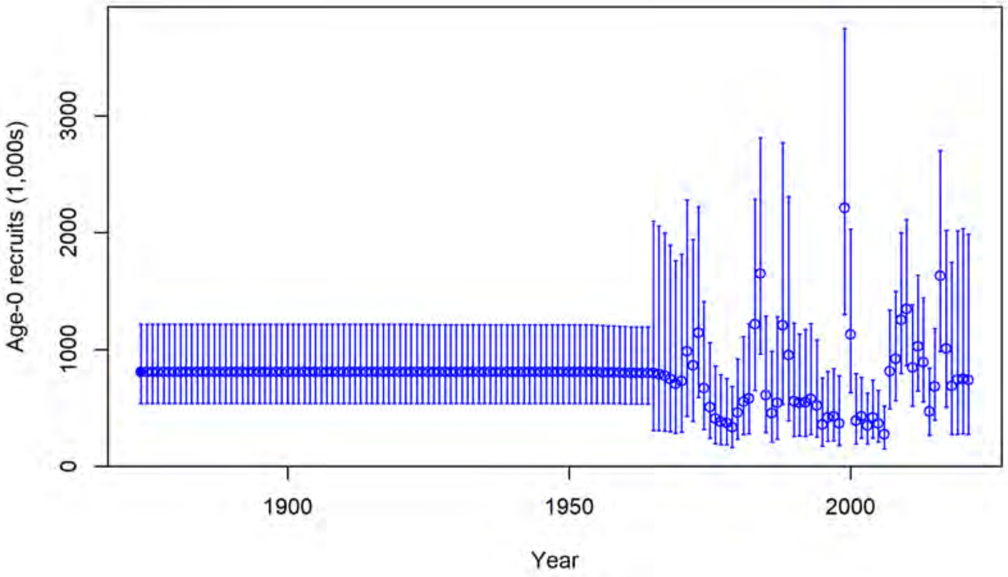

Figure iv: Age-0 recruits (1,000s) with approximate 95% asymptotic confidence intervals.

Table iii: Estimated recent trend in recruitment and recruitment deviations and the approximate 95% asymptotic confidence intervals.

	Recruitment			**Recruitment Deviations**		
Year	Estimate	Lower Interval	Upper Interval	Estimate	Lower Interval	Upper Interval
2011	846	517	1384	0.248	-0.082	0.577
2012	1025	644	1633	0.440	0.158	0.723
2013	892	550	1446	0.302	-0.001	0.604
2014	470	263	842	-0.340	-0.775	0.095
2015	683	396	1179	0.030	-0.347	0.407
2016	1629	982	2700	0.895	0.574	1.216
2017	1009	504	2018	0.405	-0.187	0.997
2018	688	271	1745	-0.039	-0.924	0.845
2019	743	274	2013	0.011	-0.955	0.978
2020	748	275	2033	0.018	-0.953	0.989
2021	736	273	1986	0.000	-0.980	0.980

Exploitation Status

The annual (equilibrium) spawning potential ratio (SPR) for vermilion rockfish in southern California has fluctuated around the management target for the past decade, with a recent spike in 2019 (Table iv, Figure v). Prior to 2011, the fishing intensity exceeded the target for a number of years in the 1980s and 1990s, regularly reaching levels 50% above target (Figure v). As with current estimates of spawning output, recent estimates of equilibrium SPR are highly uncertain, ranging from 45% to 104% of target in 2020, and 102% to 172% of target in 2019 (Table iv). As a percentage of biomass (ages 4+), southern California harvest rates peaked in the 1980s and 1990s, but have since declined to near-target levels for the past decade (Figure vi). Harvest rates in southern California in 2020 were below target, and the stock was above the target biomass (Figure vii). However, the harvest rate in 2019 was above target, and may be more representative of future catches, all else equal, given reductions in fishing activity during the 2020 pandemic. The equilibrium yield curve is shifted left, as expected from the Beverton-Holt steepness parameter estimated at 0.73 (Figure viii).

Table iv: Estimated recent trend in the relative fishing intensity ($\frac{1-SPR}{1-SPR_{50\%}}$, where SPR is the spawning potential ratio) and the exploitation rate, with approximate 95% asymptotic confidence intervals.

	Relative Fishing Intensity			Exploitation Rate		
Year	Estimate	Lower Interval	Upper Interval	Estimate	Lower Interval	Upper Interval
2011	0.935	0.632	1.237	0.119	0.068	0.169
2012	1.063	0.745	1.380	0.150	0.087	0.213
2013	1.000	0.686	1.313	0.130	0.075	0.184
2014	0.795	0.518	1.072	0.093	0.054	0.132
2015	1.134	0.805	1.464	0.154	0.088	0.221
2016	1.061	0.730	1.393	0.140	0.078	0.201
2017	0.992	0.660	1.323	0.124	0.068	0.180
2018	0.954	0.626	1.283	0.116	0.063	0.169
2019	1.371	1.018	1.724	0.224	0.119	0.328
2020	0.746	0.449	1.043	0.080	0.042	0.118

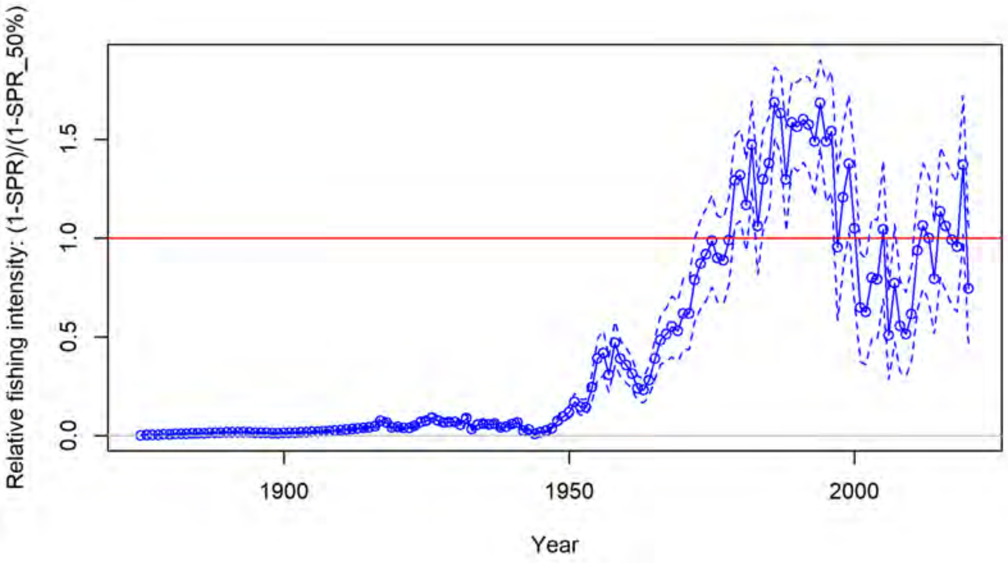

Figure v: Timeseries of relative fishing intensity ($\frac{1-SPR}{1-SPR_{50\%}}$ where SPR is the spawning potential ratio) with approximate 95% asymptotic confidence intervals (dashed lines).

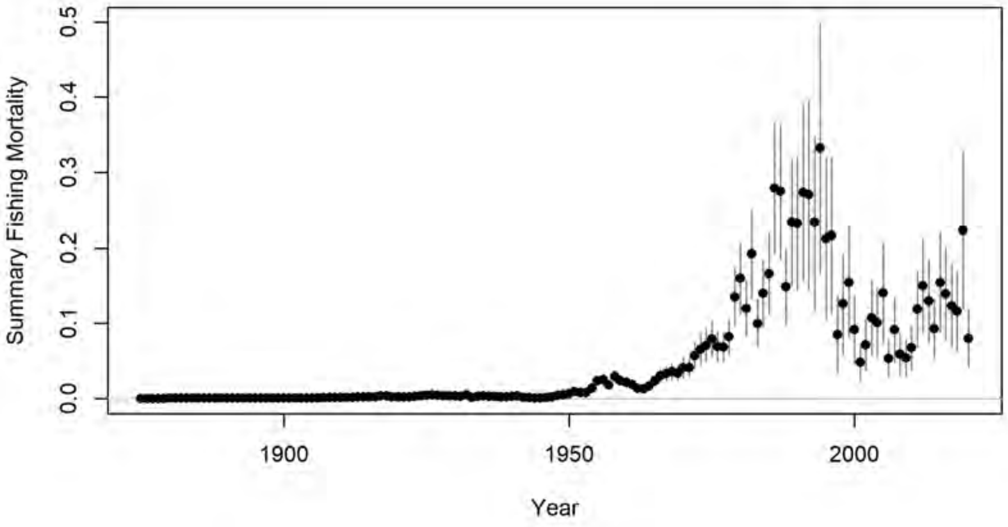

Figure vi: Time-series of estimated summary harvest rate (total catch divided by age-4 and older biomass) for the base case model with approximate 95% asymptotic confidence intervals (vertical lines).

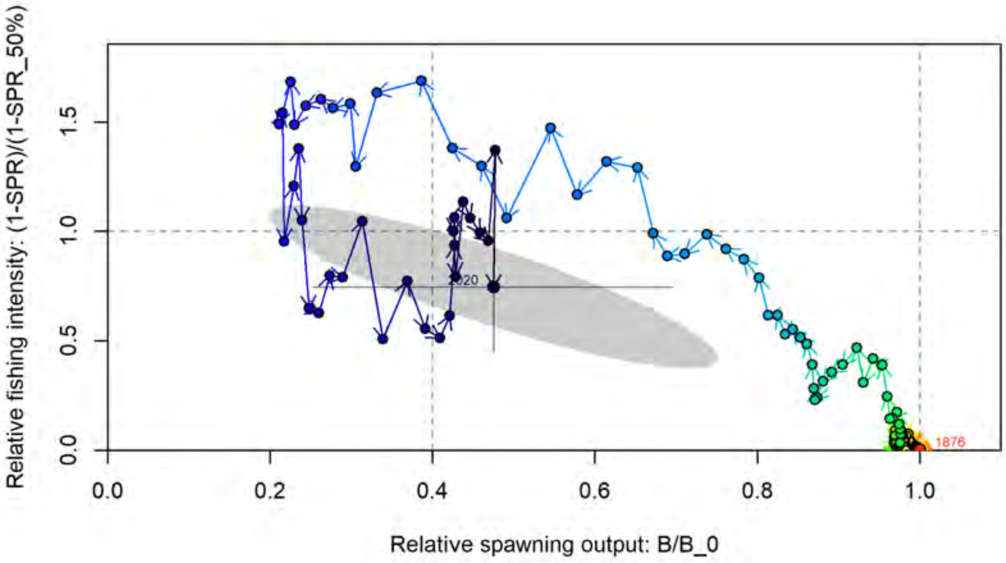

Figure vii: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point (representing 2020) show the 95% intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlations between the biomass ratio and SPR ratio. Fishing intensity in 2020 was reduced to due the pandemic.

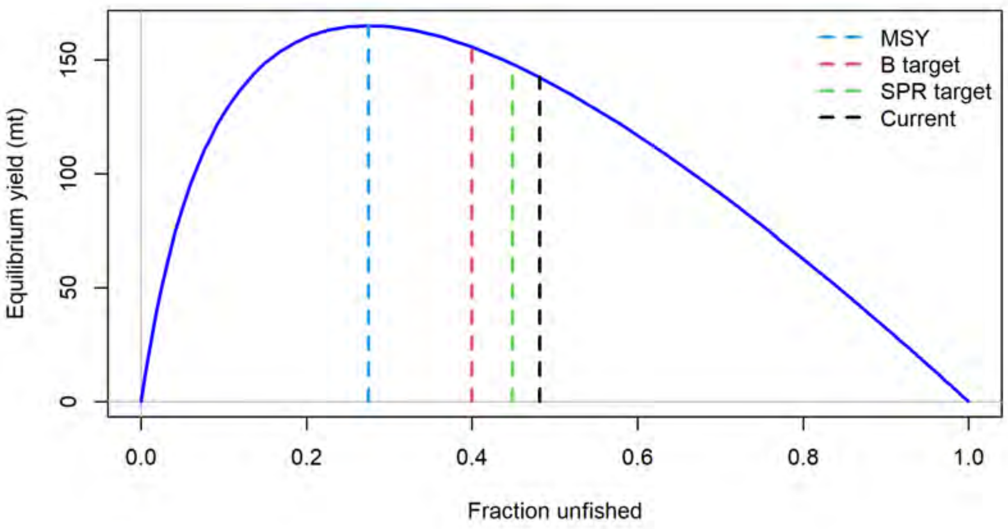

Figure viii: Equilibrium yield curve for the base case model with management quantities. Values are based on the 2020 fishery selectivities.

Ecosystem Considerations

In this assessment, ecosystem considerations were not explicitly included in analyses. This is primarily due to a lack of relevant data that could contribute ecosystem-related quantitative information for the assessment.

Vermilion/sunset rockfish are described as feeding on a wide range of both pelagic and benthic prey items, including forage fish species such as anchovies and mesopelagic fishes, squid, krill and octopus, as well as sporadically abundant pelagic organisms such as pyrosomes, salps and pelagic red crabs.

As with most other rockfish and groundfish in the California Current, recruitment, or cohort (year-class) strength appears to be highly variable for the vermilion/sunset rockfish complex, with only a modest apparent relationship to estimated levels of spawning output. Oceanographic and ecosystem factors are widely recognized to be key drivers of recruitment variability for most species of groundfish, as well as most elements of California Current food webs. With additional research, it may be feasible to incorporate ecosystem factors using results of pre-recruit surveys for co-occurring species or results from more data-rich groundfish assessments Such approaches would require more development and evaluation. Consequently, environmental factors are not explicitly considered in this assessment.

Reference Points

Reference point and management quantities for the vermilion rockfish base case model can be found in Table v. In 2021, spawning output relative to unfished spawning output ("depletion") is estimated at 48% (95% asymptotic interval: 26% - 71%). This stock assessment estimates that vermilion rockfish in the south is above the biomass target ($SB_{40\%}$), and well above the minimum stock size threshold ($SB_{25\%}$). Unfished age four-plus biomass is estimated to be 6011 mt in the base case model (95% asymptotic interval: 4805 - 7217 mt). The target spawning output ($SB_{40\%}$) is 391 million eggs (95% asymptotic interval: 311 - 471 million eggs). Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 148 mt (95% asymptotic interval: 121 - 176 mt, Table v and Figure viii).

Table v: Summary of reference points and management quantities including estimates of the approximate 95% asymtotic confidence intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	977.834	777.543	1178.125
Unfished Age 4+ Biomass (mt)	6010.980	4804.771	7217.189
Unfished Recruitment (R_0)	809.343	474.411	1144.275
Spawning Output (2021)	471.178	228.525	713.831
Fraction Unfished (2021)	0.482	0.256	0.708
Reference Points Based on $SB_{40\%}$			
Proxy Spawning Output $SB_{40\%}$	391.134	311.018	471.250
SPR Resulting in $SB_{40\%}$	0.456	0.380	0.531
Exploitation Rate Resulting in $SB_{40\%}$	0.139	0.106	0.172
Yield with SPR Based On $SB_{40\%}$ (mt)	155.763	124.738	186.788
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output ($SPR_{50\%}$)	439.020	356.091	521.949
$SPR_{50\%}$	0.500		
Exploitation Rate Corresponding to $SPR_{50\%}$	0.121	0.107	0.136
Yield with $SPR_{50\%}$ at SB_{SPR} (mt)	148.285	120.937	175.633
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB_{MSY})	268.898	136.620	401.176
SPR_{MSY}	0.342	0.163	0.521
Exploitation Rate Corresponding to SPR_{MSY}	0.195	0.092	0.298
MSY (mt)	165.171	124.402	205.940

Management Performance

Vermilion rockfish have been managed as part of the minor shelf rockfish complex in the Pacific Coast Groundfish Fishery Management Plan. North of $40°10'N$, total mortality of the minor shelf rockfish complex has exceeded the OFL since 2011. South of $40°10'N$, total mortality of the minor shelf rockfish complex has exceeded the OFL since 2015, and exceeded the ABC in most years since 2011. Total mortality estimates from the NWFSC are not yet available for 2020. A summary of these values as well as other base case summary results can be found in Tables vi and vii.

Results from post-STAR base models in all areas (southern California, northern California, Oregon, and Washington) are presented in Table viii. The fraction of the northern California model allocated to the northern management area (north of $40^{\circ}10'N$) is based on an Appendix in northern California assessment.

Table vi: Annual estimates of total mortality, overfishing limit (OFL), acceptable biological catch (ABC), annual catch limit (ACL) for vermilion rockfish in the minor shelf rockfish complex as reported in the GEMM report (NWFSC).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
North of 40°10' N												
OFL	11.127	11.127	9.717	9.717	9.717	9.717	9.720	9.720	9.720	9.720	9.700	9.700
ABC	5.564	5.564	8.104	8.104	8.104	8.104	8.104	8.104	8.104	8.104	7.547	7.547
Total landings	15.249	18.695	14.149	10.504	13.472	12.104	20.602	22.949	25.696			
CA rec. landings	4.209	4.867	2.657	2.950	5.018	4.549	6.490	7.631	7.884			
OR rec. landings	6.102	9.150	6.305	3.949	4.653	3.689	8.798	9.199	9.252			
WA rec. landings	1.001	0.911	1.279	0.960	1.141	0.997	0.731	1.151	2.497			
Commercial landings	3.935	3.767	3.906	2.644	2.661	2.799	4.557	4.966	6.063			
Research	0.002		0.002	0.002		0.069	0.026	0.002				
South of 40°10' N												
OFL	308.359	308.359	269.276	269.276	269.276	269.276	269.280	269.280	269.280	269.280	269.280	269.280
ABC	154.179	154.179	224.576	224.576	224.576	224.576	224.580	224.580	224.580	224.580	209.515	209.515
Total landings	210.310	235.216	237.074	197.043	334.984	292.375	341.207	344.454	484.967			
CA rec. landings	191.437	216.480	208.198	167.572	291.779	260.162	287.493	278.158	413.946			
Commercial landings	16.928	16.642	26.601	26.607	39.669	29.148	48.195	59.644	67.189			
Research	1.944	2.094	2.275	2.863	3.536	3.065	5.519	6.652	3.832			

Table vii: Summary of recent estimates and managment quantities for vermilion rockfish in the assessed area.

Quantity	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total catch (mt)	106.224	145.267	150.033	116.069	196.157	172.129	150.102	142.112	259.971	109.680	
$(1-SPR)/(1-SPR_{50\%})$	106.224	145.267	150.033	116.069	196.157	172.129	150.102	142.112	259.971	109.680	
Annual F	0.935	1.063	1.000	0.795	1.134	1.061	0.992	0.954	1.371	0.746	
Fill in F method	0.119	0.150	0.130	0.093	0.154	0.140	0.124	0.116	0.224	0.080	
Spawning Output (10^6)											
Estimate	2728.890	2792.570	2917.820	3082.180	3189.400	3249.510	3289.000	3242.810	3233.160	3321.640	6006.080
Spawning Output	417.626	417.703	416.626	418.821	428.176	436.847	448.412	458.305	466.811	464.518	471.178
Lower Interval	216.763	217.755	217.570	219.116	225.337	228.489	232.930	235.071	236.253	227.774	228.525
Recruits (1,000s)											
Estimate	618.489	617.651	615.682	618.526	631.015	645.205	663.894	681.539	697.369	701.262	713.831
Recruits	845.517	1025.460	892.128	470.136	683.215	1628.800	1008.840	688.065	743.171	747.805	736.076
Lower Interval	516.629	643.904	550.373	262.625	395.852	982.484	504.296	271.308	274.415	275.049	272.812
Fraction Unfished											
Estimate	1383.777	1633.113	1446.097	841.609	1179.184	2700.287	2018.176	1745.005	2012.658	2033.134	1986.015
Fraction Unfished	0.427	0.427	0.426	0.428	0.438	0.447	0.459	0.469	0.477	0.475	0.482
Lower Interval	0.232	0.234	0.235	0.238	0.245	0.250	0.255	0.259	0.261	0.254	0.256
Upper Interval	0.622	0.620	0.617	0.619	0.631	0.644	0.662	0.678	0.693	0.696	0.708

Table viii: Combined reference points for the four stock assessments conducted for vermilion and sunset rockfish in 2021. The fraction of the northern California stock that is estimated to be north of $40°10'N$ is 4.44% (see the appendix in the northern CA model for more details). The projected OFLs (2023-2032) assume full attainment of GMT-projected catches for 2021-22, and catches based on the PFMC harvest control rule given $p* = 0.45$ and $\sigma = 1$.

Description	CA South model	CA North model	$34°27'N$ to $40°10'N$	South of $40°10'N$	$40°10'N$ to CA/OR border	OR model	WA model	North of $40°10'N$
Unfished spawning output (10^6 eggs)	977.83	1145.18	1094.79	2072.63	50.39	29.20	2.80	82.39
Total Biomass (mt)	6263.31	6457.95	6173.80	12437.11	284.15	439.41	36.65	760.21
Unfished Recruitment (1000s of fish)	809.34	420.19	401.70	1211.04	18.49	16.30	2.50	37.29
Spawning Output (2021, 10^6 eggs)	471.18	489.44	467.90	939.08	21.54	21.40	1.50	44.44
Fraction Unfished (2021)	0.48	0.43				0.73	0.56	
Reference Points Based on $SPR_{50\%}$								
Proxy Spawning Output (10^6 eggs)	439.02	510.93	488.45	927.47	22.48	13.00	1.20	36.68
Proxy MSY, mt	148.28	138.99	132.88	281.16	6.12	7.90	0.80	14.82
GMT Projected Catch, 2021 (mt)	210.30	226.77	216.79	427.09	9.98	12.96	2.69	25.63
GMT Projected Catch, 2022 (mt)	210.30	226.77	216.79	427.09	9.98	12.96	3.26	26.20
OFL 2023 (mt)	159.36	154.24	147.45	306.82	6.79	13.48	0.71	20.97
OFL 2024 (mt)	158.81	157.36	150.44	309.25	6.92	13.38	0.71	21.01
OFL 2025 (mt)	158.80	158.58	151.60	310.40	6.98	13.16	0.71	20.85
OFL 2026 (mt)	159.01	158.48	151.50	310.52	6.97	12.89	0.72	20.58
OFL 2027 (mt)	159.28	157.61	150.67	309.96	6.93	12.60	0.73	20.26
OFL 2028 (mt)	159.58	156.40	149.52	309.09	6.88	12.31	0.74	19.93
OFL 2029 (mt)	159.90	155.12	148.29	308.19	6.83	12.03	0.75	19.60
OFL 2030 (mt)	160.25	153.92	147.15	307.40	6.77	11.76	0.76	19.29
OFL 2031 (mt)	160.64	152.91	146.18	306.82	6.73	11.51	0.77	19.00
OFL 2032 (mt)	161.06	152.08	145.39	306.45	6.69	11.27	0.78	18.74

Unresolved Problems and Major Uncertainties

The stratification of assessment areas was based on consideration of population structure identified in genetic analyses, differences in historical exploitation, differences in length composition within fleets, and availability of data sources. The STAR Panel discussed the potential for alternative stratifications such as north and south of Cape Mendocino depending on the results of future analyses of population structure.

Natural mortality remains the primary axis of uncertainty across assessment areas. Additional collection of otoliths from across the range of the stock and continued ageing of available otoliths may help reduce uncertainty in the future. In the relatively data-rich southern California model, steepness was estimated and uncertainties in both natural mortality and steepness were considered when determining alternative states of nature.

Decision Table and Forecasts

The forecasts of stock abundance and yield were developed using the post-STAR base model, with the forecast projections presented in Table ix. The total catches in 2021 and 2022 are set to the projected catch from the California Department of Fish and Wildlife (CDFW) by sector and model region, i.e., allocated north and south of $34°27'N$ in California.

Uncertainty in the decision table forecasts is based upon the three alternative states of nature agreed upon during the STAR panel, reflecting results of a bivariate likelihood profile over natural mortality and steepness. The low state of nature assumes $M = .1125$ and $h = 0.675$, and the high state of nature assumes $M = 0.1475$ and $h = 0.875$.

The buffers between OFL and ABC were calculated assuming a category 2 stock, with $\sigma = 1.0$ and a $p^* = 0.45$. For reference, the base model predicted σ is 0.258, calculated using the asymptotic standard error of the predicted OFL in 2021. Alternative catch streams (rows in the table) include $\sigma = 1.0$ with a $p^* = 0.4$, and removals of long-term equilibrium catch at the $F_{SPR=50\%}$ harvest rate with and without a buffer assuming $\sigma = 1.0$ and a $p^* = 0.45$. The buffer multiplier with $p^* = 0.45$ ranges from 0.874 in 2023 ramping to 0.803 in 2032.

The base model with the default harvest control rule catches (p*=0.45, σ=1) predicts an increasing stock over the period from 2023-2032. Forecasts based on the alternative catch streams project that the stock will remain above the target threshold of 40% through 2032 given either the base model or "high" states of nature (Table x). Given the low state of nature, the stock remains below the target threshold of 40% throughout the 12-year forecast under all four catch scenarios.

The STAT cautions that the GMT projections for catches in 2021-2022 (210 mt per year) exceed the maximum sustainable yield according to both proxies ($B_{40\%}$ and $SPR_{50\%}$) as well as the MSY value based on the estimated value of steepness (Table v). The southern California stock is above target biomass, so the GMT catch levels are unlikely to result in significant stock declines over a 2-year period. However, similar catch levels would exceed the overfishing limits (OFL) for 2023 and beyond (Table ix), and would be unsustainable in the long term. Given recent and projected near-term exploitation levels, and especially if vermilion and sunset rockfish continue to be managed as part of the minor shelf rockfish complex, the STAT recommends regular monitoring of total mortality for these two species to avoid excessive stock depletion and potential loss of yield. During the November 2021 Council meeting, additional projections with alternate catch assumptions for 2022 were conducted and provided for consideration.

Table ix: Projections of potential OFLs (mt), ABCs (mt), estimated age 4+ biomass (mt), estimated spawning output (10^6 eggs) and fraction unfished, assuming default harvest control rule catches with p* = 0.45 and $\sigma = 1.0$.

Year	Predicted OFL	ABC Catch	Age 4+ Biomass	Spawning Output	Fraction Unfished
2021			3450.76	471.178	0.481859
2022			3409.59	474.022	0.484767
2023	159.364	139.284	3351.20	476.977	0.487790
2024	158.813	137.373	3349.83	481.689	0.492608
2025	158.799	136.091	3349.31	485.152	0.496150
2026	159.011	135.000	3351.63	487.245	0.498290
2027	159.283	133.957	3354.79	488.421	0.499493
2028	159.578	132.928	3359.23	489.173	0.500261
2029	159.900	132.078	3365.10	489.835	0.500939
2030	160.252	131.086	3372.21	490.576	0.501696
2031	160.640	130.119	3380.61	491.499	0.502640
2032	161.063	129.334	3390.13	492.633	0.503800

Table x: Decision table summarizing 12-year projections (2021 to 2032) for vermilion rockfish based on three alternative states of nature spanning quantiles of spawning output in 2021. Columns range over low, medium, and high state of nature, and rows range over different assumptions of total catch levels corresponding to the forecast catches from each state of nature. Catches in 2021 and 2022 are fixed at catches provided by the CDFW.

				Low Productivity		Base Model		High Productivity	
				M = 0.1125		M = 0.1302		M = 0.1475	
				h = 0.675		h = 0.730		h = 0.875	
				NLL = 1015.23		NLL = 1013.02		NLL = 1014.72	
	Year	Buffer	Catch (mt)	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
$p^* = 0.45, \sigma = 1$	2021	1.000	210	406	0.355	471	0.482	581	0.642
	2022	1.000	210	407	0.357	474	0.485	585	0.646
	2023	0.874	139	408	0.358	477	0.488	589	0.651
	2024	0.865	137	411	0.360	482	0.493	595	0.658
	2025	0.857	136	413	0.361	485	0.496	599	0.662
	2026	0.849	135	413	0.362	487	0.498	601	0.664
	2027	0.841	134	413	0.362	488	0.499	601	0.664
	2028	0.833	133	413	0.362	489	0.500	600	0.663
	2029	0.826	132	414	0.362	490	0.501	599	0.661
	2030	0.818	131	415	0.363	491	0.502	597	0.659
	2031	0.810	130	417	0.365	491	0.503	594	0.657
	2032	0.803	129	419	0.367	493	0.504	592	0.654
$p^* = 0.40, \sigma = 1$	2021	1.000	210	406	0.355	471	0.482	581	0.642
	2022	1.000	210	407	0.357	474	0.485	585	0.646
	2023	0.762	121	408	0.358	477	0.488	589	0.651
	2024	0.747	119	413	0.362	484	0.495	598	0.660
	2025	0.733	118	418	0.366	490	0.501	604	0.667
	2026	0.719	116	421	0.368	495	0.506	608	0.672
	2027	0.706	115	424	0.371	499	0.510	611	0.675
	2028	0.693	114	427	0.374	503	0.514	613	0.677
	2029	0.680	112	432	0.378	506	0.518	614	0.678
	2030	0.667	111	437	0.382	510	0.522	615	0.679
	2031	0.654	109	442	0.387	515	0.526	616	0.680
	2032	0.642	108	448	0.392	519	0.531	617	0.681
Long-term Equil. Yield (MSY proxy, $SPR_{50\%}$), no buffer	2021	1.000	210	406	0.355	471	0.482	581	0.642
	2022	1.000	210	407	0.357	474	0.485	585	0.646
	2023	1.000	148	408	0.358	477	0.488	589	0.651
	2024	1.000	148	413	0.362	484	0.495	598	0.660
	2025	1.000	148	416	0.364	488	0.499	603	0.665
	2026	1.000	148	415	0.364	490	0.501	604	0.667
	2027	1.000	148	413	0.362	489	0.500	602	0.665
	2028	1.000	148	409	0.358	486	0.497	598	0.660
	2029	1.000	148	405	0.354	482	0.493	592	0.654
	2030	1.000	148	399	0.350	477	0.488	584	0.646
	2031	1.000	148	393	0.345	471	0.482	576	0.637
	2032	1.000	148	388	0.339	466	0.476	568	0.628
Long-term Equil. Yield (MSY proxy, $SPR_{50\%}$), with buffer	2021	1.000	210	406	0.355	471	0.482	581	0.642
	2022	1.000	210	407	0.357	474	0.485	585	0.646
	2023	0.874	130	408	0.358	477	0.488	589	0.651
	2024	0.865	128	415	0.364	486	0.497	599	0.662
	2025	0.857	127	420	0.368	493	0.504	607	0.670
	2026	0.849	126	423	0.370	497	0.508	611	0.675
	2027	0.841	125	424	0.372	500	0.511	612	0.676
	2028	0.833	124	425	0.372	501	0.512	611	0.675
	2029	0.826	123	425	0.372	501	0.512	609	0.673
	2030	0.818	122	424	0.371	500	0.511	606	0.669
	2031	0.810	121	424	0.371	499	0.510	602	0.665
	2032	0.803	120	423	0.371	498	0.509	598	0.660

Research and Data Needs

The following are high priority research and data needs for this assessment. Additional details for each topic can be found in the full assessment.

We recommend the following research be conducted before the next assessment:

- Develop a coastwide hook-and-line survey to provide indices of abundance and associated biological sampling providing representative data in untrawlable habitats.
- Examine the available tools more fully in cases when a survey's footprint is abruptly changed as a result of management action. These tools may include (but are not limited to), treating the "new" and "old" surveys as completely separate (aka breaking the survey), using selectivity blocks, or spatial/temporal modeling approaches. This avenue is important for many fishery-independent and -dependent indices, as they are subjected to numerous spatial management changes which in turn can affect the veracity of the data collected. Additional efforts are needed to investigate how fishery selectivity changes with management changes and how best to address the effects of management changes on length composition and indices.
- Expansion of the California Collaborative Fisheries Research Project into deeper depths outside and inside MPAs and to other closed areas to encompass the full depth distribution of vermilion and sunset rockfish or other shallow shelf rockfish species would provide valuable data for future assessments.
- Conduct additional investigations to resolve uncertainties in historical catch reconstructions would improve estimates of the scale of assessments and provide more representative removal estimates.
- Explore appropriate methods of including catches as numbers of fish vs. biomass.
- There is currently a very small amount of fishery-dependent age data collected in southern California such that none were included in the southern California stock assessment.
- Continue the NWFSC hook-and-line survey, which is a very important and informative source of data for the southern California stock assessment. Additional research into methods to standardize the hook-and line survey.

1 Introduction

Note to readers: Text in this section is the same in both California vermilion rockfish assessment documents.

1.1 Basic Information and Life History

Note: Prior to the identification of sunset rockfish as a separate species (Hyde, J.R.; Kimbrell, C. A.; Budrick, J. E.; Lynn, E. A.; Vetter 2008), historical studies of "vermilion" rockfish, particularly those conducted south of Point Conception ($34°27'N$), California, could have included a mixture of both species. Also, many current studies and data sets (e.g., landing statistics) do not distinguish between the species. In this document, we refer simply to "vermilion rockfish" when no species-specific information is available.

Vermilion rockfish (*Sebastes miniatus*) range from Prince William Sound, Alaska, to central Baja California at depths of 6 m to 436 m (Love et al. 2002). However, they are most commonly found from central Oregon to Punta Baja, Mexico (Hyde and Vetter 2009) at depths of 50 m to 150 m (Hyde and Vetter 2009). Hyde and Vetter (2009) describe vermilion rockfish as residents of shallower depths (<100 m) than their sibling species, sunset rockfish (*Sebastes crocotulus*). Adult fish tend to cluster on high relief rocky outcrops (Love et al. 2002) and kelp forests (Hyde and Vetter 2009). North of Point Conception, California, some adults reside in shallower water, living in caves and cracks (Love et al. 2002). Vermilion rockfish have shown high site fidelity (Hannah and Rankin 2011 (only tagged one vermilion rockfish), Lea et al. 1999), and low to average larval dispersal distance (Hyde and Vetter 2009). Lowe et al. (2009) suggested that vermilion rockfish have a lower site fidelity than previously believed, but acknowledged that their observations of movements to different depths may have been due to differences in depth distribution between the species. Vermilion rockfish have been aged to over 80 years, but few fish have been aged above 60 years, with females growing larger than their male counterparts. Fifty percent of females are mature at 5 years and about 37 cm, with males likely maturing at shorter lengths than females (Love et al. 2002).

Vermilion rockfish are viviparous, and females produce an estimated 63,000 to 2,600,000 eggs per brood, with larger fish releasing a substantially larger number of larvae. In southern California, vermilion rockfish larvae are released between July and March. In central and northern California, this release occurs in September, December, and April-June (Love et al. 2002). Hyde and Vetter (2009) suggest that low larval dispersal may be due to weak poleward flow of nearshore waters corresponding with peak vermilion rockfish larval release.

Young-of-the-year vermilion rockfish settle out of the water column during two primary recruitment periods per year, first from February to April and a second from August to October, and settlement has been observed in May off southern California (Love et al. 2002). Young-of-the-year vermilion and sunset rockfish are both mottled brown with areas of black, and older juveniles turn a mottled orange or red color (Love et al. 2012). Larvae measure about 4.3 mm and juvenile fish are found in depths of 6-36 m, living near sand and structure. After two months, juveniles travel deeper and live on low relief rocky outcrops and other structures (Love et al. 2002).

Adult vermilion rockfish predominantly eat smaller fish, though sometimes they pursue euphausiids and other various macroplankton (Phillips 1964). Love et al. (2002) noted their diet includes octopuses, salps, shrimps, and pelagic red crabs.

Population Structure and Multi-species Assessment Considerations

This assessment represents the aggregate population dynamics of the cryptic species pair vermilion rockfish and sunset rockfish. Hyde (2007) examined seven mitochondrial and two nuclear genes, which upon analysis suggested three species within the subgenus *Rosicola*. Hyde et al. (2008) described sunset rockfish as a distinct species noting depth separation of the adult populations of the two species using nine microsatellite loci. Adult sunset rockfish are mainly distributed at depths greater than 50 fm (100 m) and are predominantly located south of Point Conception ($34°27'N$). Hyde and Vetter (2009) and Budrick (2016) identified species using mtDNA assays and microsatellite loci, respectively.

Vermilion and sunset rockfish are morphologically very similar, with color being the most commonly cited differentiating feature. Hyde and Vetter (2009) noted differences in three of six morphological parameters examined, but none of them can readily be used for field identification.

In all historical and current recreational and commercial catches, sunset and vermilion rockfish are both recorded as vermilion rockfish. Future studies, such as the one described below will provide data needed to compare biological parameters between the two species as well as habitats and distributions.

Ongoing Population Structure Research (Provided by John Harms, NWFSC)

A group of researchers from the NWFSC and SWFSC is collaborating on a project to genotype tissue specimens collected from the vermilion and sunset rockfish cryptic pair captured during the West Coast Groundfish Bottom Trawl (WCGBT) Survey and the Southern California Shelf Rockfish Hook-and-Line Survey for the years 2004 - 2019. Funding for this project was obtained through the Saltonstall-Kennedy program for fiscal year 2020 through a proposal led by representatives from Pacific States Marine Fisheries Commission and the commercial passenger fishing vessel industry in southern California.

After combining with specimens obtained through other collection efforts along the West Coast, approximately 25,000 tissue specimens will be analyzed. Some earlier efforts to separate this cryptic pair to species used mitochondrial DNA (mtDNA) markers. However, due to a one-way mitochondrial introgression from the vermilion rockfish genome into the sunset rockfish genome (or incomplete lineage sorting), a portion of the sunset rockfish population contains mitochondrial DNA sequences consistent with vermilion rockfish resulting in incorrect species assignments for these introgressed individuals during the prior research project.

Once the collected specimens have been genotyped, any species-specific differences in spatial and depth distribution, size composition, weight-length relationships, and other biological characteristics will be identified. Using previously collected otoliths and ovaries, the demographics of the two species including age and growth and reproductive biology parameters such as length and age at 50% maturity and the prevalence of skip spawning will be explored and compared. These new genotyping results will be combined with data from the prior mtDNA work to evaluate whether introgressed (hybrid) sunset rockfish represent a biologically intermediate subform of the species complex. The effort also proposes to develop and test the efficacy of models to predict the relative proportion of the two species based upon explanatory variables including latitude, depth, species of co-occurrence, oceanographic parameters, habitat descriptors and/or other information. The anticipated completion of the genotyping of all specimens is approximately December 2021 with provision of final results by the end of FY 2022.

This research is aimed at providing information to support the successful stock assessment of this commercially and recreationally valuable cryptic species pair and is responsive to any data gaps identified by the assessment community. If successful, this research, conducted in close communication with stock assessors, may also assist the PFMC in establishing best practices for the assessment and management of cryptic species complexes. Though this project will only focus on nominal vermilion rockfish specimens collected through the 2019 survey field season, it may be advisable that tissue specimens collected aboard fishery-independent surveys as well as through fishery-dependent programs continue to be genotyped on an ongoing basis to support continued and timely monitoring of this economically and ecologically important species complex.

1.2 Map

A map showing the scope of the two California vermilion rockfish assessments and depicting a boundary at Point Conception ($34^{\circ}27'N$) that separates the two assessments is provided as Figure 1. The northern California model is bounded in the north by the California/Oregon border ($42^{\circ}00'N$) and the southern California model is bounded by the U.S./ Mexico border in the south (Figure 1). Cape Mendocino ($40^{\circ}10'N$) is also noted as it is a management boundary for the Pacific Fishery Management Council (PFMC) “minor shelf rockfish” stock complex.

1.3 Ecosystem Considerations

This stock assessment does not explicitly incorporate trophic interactions, habitat factors (other than as they inform relative abundance indices) or environmental factors into the assessment model, but a brief description of likely or potential ecosystem considerations are provided below.

Vermilion/sunset rockfish are described as feeding on a wide range of both pelagic and benthic prey items, including forage fish species such as anchovies and mesopelagic fishes, squid, krill and octopus, as well as sporadically abundant pelagic organisms such as pyrosomes, salps and pelagic red crabs (Phillips 1964, Love et al. 2002). Interestingly, other rockfishes (either juvenile or adult stages) have not been documented as prey for vermilion rockfish, as they have been for other large *Sebastes* species such as cowcod, bocaccio, and yelloweye rockfish. For the latter species, the idea of "cultivation effects," in which adults crop down forage species that are potential competitors/predators of their own juveniles (Walters and Kitchell 2001), has been suggested by Baskett et al. (2006). For example, Baskett et al. (2006) found that in such scenarios there could be alternative stable states in which either the overfished species or the smaller prey species could dominate. While the sparse diet data for vermilion/sunset rockfish do not suggest such a process for this species complex, food habits data for vermilion/sunset are not robust, and the larger community processes on these rocky reef communities may also influence productivity and community composition regardless of the direct predation interactions. Pelagic and benthic juvenile vermilion and sunset rockfish are likely preyed upon by the same wide range of predators that prey on juveniles and adults of other rockfish species, including seabirds, piscivorous fishes, and marine mammals.

As with most other rockfish and groundfish in the California Current, recruitment, or cohort (year-class) strength appears to be highly variable for the vermilion/sunset rockfish complex, with only a modest apparent relationship to estimated levels of spawning output. Oceanographic and ecosystem factors are widely recognized to be key drivers of recruitment variability for most species of groundfish, as well as most elements of California Current food webs. Empirical estimates of recruitment from pelagic juvenile rockfish surveys have been used to inform incoming year class strength for some of these stocks, however vermilion/sunset rockfish are rarely encountered in these surveys. Specifically, only 47 of nearly 300,000 total juvenile *Sebastes* encountered in juvenile surveys since 2001 were identified as vermilion/sunset rockfish (Field et al. 2021). Despite this, the results here suggest that at least a reasonable fraction of recruitment variability for sunset and vermilion rockfish is shared with other rockfish and groundfish stocks throughout the California Current, many of which also had strong year classes in 1984, 1999 and 2015-2016. Previous studies have demonstrated that large-scale oceanographic drivers, such as the relative transport of subarctic waters (typically indicated by relative sea level) tend to relate to a substantial fraction of overall groundfish recruitment trends and ecosystem productivity Schroeder et al. (2019). Although it is feasible that ecosystem factors, the results of pre-recruit surveys for co-occurring species, or the results of other groundfish assessments might ultimately be used to forecast recruitment for more data-limited stocks such as vermilion and sunset rockfish, as suggested by (Thorson and Ward 2014), such approaches would require more development and evaluation. Consequently, environmental factors are not explicitly considered in this assessment.

1.4 Historical and Current Fishery Information

Commercial Fishery

The commercial groundfish fishery off California developed in the late 19th century and consisted mainly of hook and line gear types (Figure 2). At the end of the 19th century, total rockfish landings were estimated to be between 2,000 to 3,500 tons statewide, with slightly over half of the catch during this period coming from waters south of Point Conception, and most of the remaining catch from central California ports (particularly San Francisco and Monterey). Catches declined through the 1930s as a result of the rapid expansion of the California sardine fishery, which tended to be more profitable (Love et al. 2002). The rockfish trawl fishery rapidly expanded into California in the early 1940s, after the introduction of the 'balloon trawl,' and when the United States became involved in World War II and wartime shortage of red meat created an increased demand for other sources of protein (Harry and Morgan 1961, Alverson et al. 1964, Lenarz 1987). Trawl landings have been restricted in most of southern California for decades (Frey 1971), and trawl gear north of Point Conception has not recently been a major component of the landings for vermilion rockfish, with the highest reported landings in the 1970s. The commercial setnet fishery has never been a large component of the vermilion rockfish landings and has essentially been non-existent for vermilion rockfish since 2002 when the state of California prohibited setnet gear in 60 fm or less. The largest net landings for vermilion rockfish were in the 1980s.

Vermilion rockfish have been landed in the commercial live-fish fishery that developed off the coast of California in the 1990s, but have not been a major target of that fishery due to their susceptibility to barotrauma. The fraction of the total catch from the live fish fleet is small, concentrated in northern California, and included in the commercial hook-and-line fleet in the northern California assessment models. The STAT also learned that vermilion rockfish landed dead (due to barotrauma) from a commercial trip landing live fish, remain valuable and may be sold dead. Separation of catch and size compositions for the live and dead catch is therefore less informative and was not pursued further.

Miller et al. (2014) described the spatial and temporal development of the California commercial groundfish fishery based on historical CDFW fish ticket and block summary data. They analyzed a spatially-explicit database of landings in California dating back to 1933, finding that groundfish fishing effort has shifted from shallow, coastal areas to deeper depths, greater distances from port, and in areas of more inclement weather over time. That general result was also found with limited data from recreational fisheries. Sampling of commercial species compositions in Southern California began in 1983, a time when the groundfish fleet was already fishing in deeper depths. Both historical reconstructions used these data to represent species compositions of total rockfish catch during earlier periods of the fishery. As a result, the reconstructions may overestimate the percentage of deep-water species in earlier fisheries that operated closer to port and in shallower depths.

Recreational Fishery

Vermilion rockfish are a targeted species in California's recreational fishery and have always ranked high in terms of catch among rockfish species, both in the party/charter boat and private/rental sectors. The Commercial Passenger Fishing Vessel (CPFV; aka 'party' and 'charter' boat) fleet began circa 1919 in California, although recreational fishing effort for fishes other than Tunas, other gamefish, and salmon was minimal until about 1930. The CPFV fleet numbered about 200 vessels in 1939 ((Croker 1940), cited in Young (1969)). After a hiatus in most operations during WWII, the fleet increased to about 590 vessels by 1953, then declined to approximately 256 vessels around 1963.

Onboard surveys of CPFV vessels in southern California ranked vermilion rockfish as the fifth and third most common rockfish species in the mid-1970s and mid-1980s, respectively (Ally et al. 1991, Collins and Crooke n.d.). Onboard CPFV observers in central California saw vermilion rockfish in over 27% of all observed drifts over the period 1987-1998, making vermilion rockfish fifth among rockfish species in terms of encounter rates per drift (Monk et al. 2016)

In southern California, harvest of vermilion rockfish from recreational fisheries, as a percentage of the total vermilion rockfish harvest, varied considerably from 1980 to 2000. After 2000, largely due to reduced commercial access to shelf habitat, recreational fisheries accounted for almost all the vermilion rockfish harvest in southern California, with relatively minor contributions from the commercial fleets. Similar patterns occurred north of Point Conception, with the majority of vermilion rockfish landings coming to ports in San Luis Obispo county.

1.5 Summary of Management History

Prior to the adoption of the Pacific Coast Groundfish Fishery Management Plan (FMP) in 1982, vermilion rockfish were managed through a regulatory process that included the California Department of Fish and Wildlife (CDFW) along with either the California State Legislature or the Fish and Game Commission (FGC) depending on the sector (recreation or commercial) and fishery. With implementation of the Pacific Coast Groundfish FMP, vermilion rockfish came under the management authority of the Pacific Fishery Management Council (PFMC), and were managed as part of the *Sebastes* complex. Because neither species had undergone rigorous stock assessment and did not compose a large fraction of the landings they were classified and managed as part of "Remaining Rockfish" under the larger heading of "Other Rockfish" (Pacific Fishery Management Council 2002, 2004).

Since the early 1980s a number of federal regulatory measures have been used to manage the commercial rockfish fishery including cumulative trip limits (generally for two- month periods) and seasons. Starting in 1994 the commercial groundfish fishery sector was divided into two components: limited entry and open access with specific regulations designed for each component. Other regulatory actions for the general rockfish categories have included area closures, gear restrictions, and cumulative bimonthly trip limits set for the four different commercial sectors: limited entry fixed gear, limited entry trawl, open access trawl, and open access non-trawl. Harvest guidelines are also used to regulate the annual harvest for both the recreational and commercial sectors.

In 2000, changes in the PFMC's rockfish management structure resulted in the discontinued use of the *Sebastes* complex, and was replaced with three species groups: nearshore, shelf, and slope rockfishes (January 4, 2000; 65 FR 221). Vermilion rockfish are managed in aggregate with other species in the minor shelf rockfish group, which is further divided into management areas north and south of Cape Mendocino, California ($40^{\circ}10'N$).

Since the enactment of California's Marine Life Management Act (MLMA), the Pacific Fishery Management Council and state of California developed and adopted various management specifications including seasonal and area closures (e.g. the CCAs; a closure of Cordell Banks to specific fishing), depth restrictions, gear restrictions, and bag limits to regulate the recreational fishery. Commercial fisheries were regulated through the use of license and permit regulations, finfish trap permits, gear restrictions, seasonal and area closures (e.g. the RCAs and CCAs; a closure of Cordell Banks to specific fishing), depth restrictions, trip limits, and minimum size limits (Wilson-Vandenberg et al. 2014).

Management of Recreational Fisheries

In March 1984 California adopted a general 20 aggregate daily bag limit that included a sub-bag limit of 10 fish for any given species. Significant regulatory changes in California's recreational sector began with a change from unlimited number of hooks and lines allowed prior to 2000 to no more than three hooks and one line per angler in 2000. Since 2001, the limit has been no more than two hooks and one line per angler and there is not a size limit on vermilion rockfish in the recreational fishery. Beginning January 1, 2021, the CDFW enacted a five-fish sub-bag limit for vermilion rockfish in the recreational fishery.

California also began spatial management, including area closures, and depth restrictions for the recreational fleet in 2000. In general, the recreational season north of Point Conception extends from April to December, and south of Point Conception from March to December. North of Point Conception vermilion rockfish in California are most commonly landed from Monterey to Morro Bay, where the maximum depth open to recreational fishing was between 30 and 40 fathoms until 2017. In 2017, the depth restrictions were eased by 10 fathoms, opening up 40-50 fm depths along the central California coast that had not been open consistently since 2002. In both 2017 and 2018, the deepest 10 fathoms was closed prior to the prescribed season in December due to high by-catch rates of yelloweye rockfish, which remains in an overfished status and is undergoing rebuilding. A full history of the recreational regulations relating to the spatial management of the fleet can be found in the Appendix.

Cowcod Conservation Areas (CCA) In 2001, two area closures "Cowcod Conservation Areas" were implemented to reduce fishing mortality of cowcod, originally prohibiting bottom-fishing deeper than 20 fm. Effective 2019, retention of nearshore and shelf rockfish (excluding cowcod) is allowed in depths shallower than 40 fm. The larger of the two areas (CCA West) is a 4200 square mile area west of Santa Catalina and San Clemente Islands. A smaller area (CCA East) is about 40 miles offshore of San Diego, and covers about 100 square miles.

Rockfish Conservation Areas (RCA) In 2002 the PFMC established trawl- and non-trawl area closures known as the Rockfish Conservation Areas. These closed areas are gear-specific, and have seasonally changing boundaries to help reduce fishing mortality.

1.6 Management Performance

The contribution of vermilion rockfish to the minor shelf rockfish Overfishing Limit (OFL) is currently derived from the data-poor Depletion-Based Stock Reduction Analysis (Dick and MacCall 2010). A 2005 vermilion rockfish stock assessment was not accepted for use in management and a 2013 data-moderate assessment was not reviewed by the STAR panel due to insufficient time.

Total mortality for vermilion rockfish was obtained from the Groundfish Expanded Mortality Multiyear GEMM report (Somers et al. 2020). The coastwide management of the shelf rockfish complex is split at Cape Mendocino ($40°10'N$). Therefore, the northern California vermilion rockfish model contains a portion of the management area from Cape Mendocino ($40°10'N$) to the California-Oregon border ($42°00'N$). The southern California vermilion rockfish model contains the area within the southern management area (south of $40°10'N$) that is south of Point Conception ($34°27'N$).

The total mortality of the shelf rockfish complex has been above the OFL in all years (2011-2019) north of $40°10'N$, and above the OFL south of $40°10'N$ from 2015-2019. Total mortality estimates from the NMFS NWFSC are not yet available for 2020 (Table vi). Vermilion rockfish total mortality was on average 59% (range 55%-66%) of the total shelf rockfish south of $40°10'N$ total mortality from 2011-2016. Vermilion rockfish decreased from 21% to 4% of the total contribution to the shelf rockfish complex north of $40°10'N$ from 2011-2019 with a noticeable decline from 16% to 6% from 2016 to 2017.

1.7 Foreign Fisheries

Sebastes spp. are not in the Fisheries National Chart (FNC, database containing species status) maintained by the Mexican Government, i.e., they are not commercially harvested in the northwest Mexican Pacific Ocean (E.M. Bojórquez, Centro de Investigaciones Biológicas del Noroeste, S.C., personal communication). Dr. Bojórquez also reached out to colleagues at the Fisheries National Institute who reported that vermilion rockfish are occasionally caught in the sport fishery in Ensenada City. However, there are no data available on vermilion rockfish fisheries off the coast of Mexico. Catches in Mexican waters by US fleets are not included in this assessment.

2 Data

The STAT presented proposed analyses and data sources for the 2021 vermilion rockfish assessment to the Council advisory bodies in Novemeber 2020, and again during the PFMC

Pre-Assessment Workshop for 2021 Vermilion/Sunset Rockfish and Lingcod Stock Assessments, hosted virtually on March 29, 2021. Topics addressed included progress on research priorities, data sources and types, stock structure, fleet structure, key model parameters (e.g. natural mortality), and potential challenges. Descriptions of each data source included in the model (Figure 3) and sources that were explored, but not included are included within this section.

2.1 Fishery-Dependent Data

A complete summary of estimated vermilion rockfish removals by each fleet in the commercial and recreational sectors modeled in this assessment is provided in Table 1. The data sources for landings varied by each fleet and a summary of each data source and the time period for which it was used is in Table 2. The commercial landings are in metric tons (mt) and the recreational landings are in numbers of fish (thousands of fish). Data and methods used to derive these estimates are described in this section.

2.1.1 Commercial Landings and Discards

Commercial Landings Prior to 1916

For landings estimates prior to 1916, we based our reconstruction on the total rockfish catches reported in a summary of early California fisheries landings by Sette and Fielder (1927) for the years 1888, 1892, 1895, 1899, 1904, 1908 and 1915. No rockfish were reported for 1888. We assumed no catches prior to 1875 and interpolated the catches between 0 mt and the 1892 catches (total of 834 tons) as reported. Similarly, catches between the reported years were interpolated assuming a straight linear trend between the years reported. We used a ratio-estimator derived from the catch reconstruction fraction of vermililion rockfish rockfish in total rockfish landings for the 1916 to 1919 period (the ratio for a comparable five year period was nearly identical). We apportioned the catches north and south of Point Conception based on ratio estimators that used the same assumptions used to apportion catches in the reconstruction time period (1916-1968). The catch reconstruction estimates indicated that vermililion rockfish made up slightly under 1% of the total rockfish catches during the early (1916-1919) time period, although the estimates indicate a slightly larger fraction (1.5%) of total catches south of Point Conception relative to the fraction of total catches to the north (0.9%). However, it is likely that the reconstruction is overestimating the fraction of smaller and/or more deeply distributed species relative to larger, shallower species as the reconstruction is based on the species composition data collected from market category samples in the late 1970s and early 1980s. The fishery has been shown to have progressed over time from a shallower, more nearshore distribution of effort to one in which deeper and more offshore waters were targeted (Miller et al. 2014). The notion that vermililion rockfish catches may have been greater is also consistent with the recognition by Roedel (1948) that during the 1930s and 1940s vermililion rockfish were “One of the more important commercial species, it is one of three leading species in southern California.” However, by the time of that report, vermililion rockfish represented five to eight percent of the southern California catch, based on Ralston et al. (2010), much more than at the beginning of the time series. This uncertainty is investigated more deeply in the model uncertainty and sensitivity section. Future efforts to improve historical catch reconstructions by accounting for the shift in effort over time to deeper waters should continue to be flagged as a research need.

Commercial Landings, 1916-2020

For commercial landings prior to 1969, we queried the SWFSC catch reconstruction database for estimates from the California Catch Reconstruction (Ralston and MacFarlane 2010). Landings in this database are divided into trawl, 'non-trawl,' and 'unknown' gear categories. Regions 7 and 8 as defined by Ralston et al. (2010) were assigned to southern California. Region 6 in Ralston et al. includes Santa Barbara County (mainly south of Point Conception), plus some major ports in San Luis Obispo County (north of Point Conception). To allocate catches from Region 6 to the areas north and south of Point Conception, we followed an approach used by Dick et al. (2007) for the assessment of cowcod. Specifically, port-specific landings of total rockfish from the CDFW Fish Bulletin series were used to determine the annual fraction of landings in Region 6 that was south of Point Conception (Table 3). Rockfish landings at that time were not reported at the species level. Although the use of total rockfish landings to partition catch in Region 6 is not ideal, we see this as the best available option in the absence of port-specific species composition data.

Years with no data were imputed using ratio estimates from adjacent years. Annual catches from unknown locations (Region 0) and unknown gear types were allocated proportional to the catches from known regions and gears. Catches from known regions, but unknown gears, were allocated proportional to catches by known gears within the same region. In this way, total annual removals in California were kept consistent with those reported by Ralston et al. (2010), and assigned to the assessment areas north and south of Point Conception, and either trawl or 'non-trawl' gear types. Since hook-and-line gears catch the majority of commercially-caught vermilion rockfish, we assigned estimated catch in the 'non-trawl' category to the hook and line fleet in the assessment model.

In September 2005, the California Cooperative Groundfish Survey (CCGS) incorporated newly acquired commercial landings statistics from 1969-77 into the CALCOM database. The data consisted of landing receipts ("fish tickets"), including mixed species categories for rockfish. In order to assign rockfish landings to individual species, the earliest available species composition samples were applied to the fish ticket data by port, gear, and quarter. These 'ratio estimator' landings are coded (internally) as market category 977 in the CALCOM database, and are used in this and past assessments as the best available landings for the time period 1969-1977 for all port complexes. Since commercial port sampling south of Point Conception started later, ratio estimates were used in some southern California port complexes through 1983. See Appendix A of Dick et al. (2007) and Pearson et al. (2008)(pp. 8 and 15-16) for further details.

Commercial catches from 1978-present were pulled from the CALCOM database, which is stratified using an identical design as the pre-1978 data described above and ensured consistency of the port complex and gear groupings over the entire time series (1969-2020). Although available strata definitions within PacFIN do not match the design of the California commercial catch expansion (Pearson and Erwin 1997), the STAT was able to manually aggregate data from PacFIN to almost exactly match the CALCOM estimates (Figure 4). The STAT recommends that port complex and gear group definitions used to expand California commercial catch estimates be incorporated into PacFIN lookup tables to facilitate future comparisons, ensure consistency between the two systems, and help identify potential errors.

Commercial length and age composition data

Biological data (lengths) from the commercial fisheries that landed vermilion rockfish were extracted from CALCOM. The CALCOM length composition data were "expanded" (catch-weighted by stratum, then aggregated by region, gear group, and year) to better represent the size composition of the landed catch. The length composition is available in Figure 5 for the commercial hook-and-line fleet, and Figure 6 for the commercial net fleet. Input sample sizes for commercial length compositions were based on the number of port samples and are in Tables 4 and 5. Length compositions with fewer than 30 measured fish in a region/gear/year combination were not included in the model likelihood.

Commercial discard length compositions from WCGOP were provided on 17 Nov 2020 by Andi Stephens (NWFSC). Only 224 vermililion rockfish were measured statewide from 2004-2018. The sparse discard length composition data were not considered for use in the model as discarded catch is a small fraction of the overall commercial landings.

Otoliths collected from commercial fisheries north of Point Conception were provided by the Pacific States Fisheries Commission and aged, but not used in the assessment due to low annual sample sizes.

2.1.2 Recreational Landings and Discard

Recreational Landings, 1928-1980

Recreational catch estimates prior to 1981 were based on the Ralston et al. (2010) catch reconstruction, which estimated catches by mode (CPFV and private vessel modes, where the latter included any shore-based catches) and estimated catches separately north and south of Point Conception. Party/Charter (PC mode) catches of all rockfish were based on logbook data (which do not report rockfish to the species level), scaled by compliance estimates, while total recreational catches from private/rental vessels (PR mode) catches were based on a combination of the relative catch rates observed in the PC fleet and a linear ramp between catch estimates in the early 1960s and those in the early 1980s (as described in Ralston et al. (2010)). The species composition of rockfish catches was estimated using a combination of the 1980s MRFS data as well as limited PC mode species composition data from onboard observer programs in the late 1970s (south of Point Conception) and dockside recreational creel surveys in the late 1950s and early 1960s (north of Point Conception). Vermilion (and sunset) rockfish have long been recognized as an important target of recreational fishers south of Point Conception, as well as those in the Morro Bay region, although they are less frequently encountered in recreational fisheries further north. As noted in Ralston et al. (2010) the catch reconstruction effort was intended to be an "iterative and multistage process," and there is considerable room for improvements in both the commercial and the recreational catch reconstruction estimates.

Marine Recreational Fishery Statistics Survey (MRFSS), 1980-2003

MRFSS estimates of California recreational landings from 1980-1989 and 1993-2003 were downloaded from the Recreational Fisheries Information Network (RecFIN). The MRFSS survey design included stratification by species (sunset rockfish were not recognized at the time), subregion (northern and southern California), 2-month 'wave,' water area (e.g. within or beyond three miles from shore), and fishing mode (party/charter (PC) and private/rental (PR) boats, plus various shore modes). The PC mode includes the Commercial Passenger Fishing Vessel fleet (CPFV).

Some known issues with the MRFSS estimates include 1) missing or imprecise estimates of catch in weight for some strata that reported catch in numbers, 2) a change in the spatial definition of California subregions after 1989, and 3) a hiatus in sampling from 1990-1992 (all modes) and also 1993-1995 in the party/charter mode north of Point Conception. The STAT attempted to address each of these issues, as described below. CRFS estimates from 2004 were also included in the MRFSS analysis, as they were not available on the current RecFIN website but are included with the MRFSS catch estimate tables.

The MRFSS estimated catch in numbers of fish and converted these to catch in weight using estimates of average fish weight [kg] from the same stratum. When a stratum contained an estimate of catch in numbers but was missing an average weight, the estimate of catch in weight for that stratum was omitted (or sometimes assigned a zero value) in the database. To correct these errors, the STAT first identified strata with positive catch in numbers but missing or zero values for catch in weight. Catch in weight for these strata was then estimated by imputing a value of average weight based on the mean of the reported average weights in the same year and subregion, which had a greater influence on average weight than boat mode (Figure 7). The effect of this data imputation was relatively minor for vermilion rockfish overall (~1% increase in total catch by weight, 1980-2004). However, 70% of missing catch in weight occurred over the years 2001-2004, with differences in individual year/mode/subregion combinations sometimes exceeding 10-20%.

MRFSS catch estimates for California were spatially stratified into two subregions, "Southern California" (subregion 1) and "Northern California" (subregion 2). During the 1990-1992 statewide hiatus in sampling, the definitions of these two subregions changed. Specifically, San Luis Obispo (SLO) County was included in the southern region prior to the hiatus (i.e. 1980-1989) (Witzig et al. 1992, Karpov et al. 1995), but moved to the northern subregion starting in 1993. In order to create a definition of spatial strata that is consistent and comparable over time, and one that is consistently divided near Point Conception, the STAT examined estimates of catch in numbers from a separate study (Albin and Karpov 1993) that used a finer spatial resolution in the northern subregion (including SLO County). Over the period 1981-1986, numbers of vermilion rockfish landed in SLO County were found to be roughly equal to the numbers of vermilion rockfish landed in all California counties north of SLO County (Table 6). Therefore, to approximate catches north and south of Point Conception from 1980-1989, the STAT reduced the 'southern' subregion annual catch (which included SLO County) from 1980-1989 by an amount equal to the northern subregion catch during the same period, and doubled the northern subregion catch. On average, this 'moves' the estimated SLO County catch from the southern region to the northern region from 1980-1989, creating a spatially consistent time series of landings over the entire time series.

Ultimately, the STAT chose to use recreational catch in numbers rather than catch in weight for the California assessment models. Since data from Albin (1993) were only available as catch in numbers, the ratios used to partition SLO County catch may not be consistent if applied to catch in weight due to differences in average weight between regions (Figure 7). Also, because missing weight estimates were concentrated over the period 2001-2004 rather than being spread over the entire time series, the method used to impute weights could have a greater influence on short-term stock dynamics.

As noted above, MRFSS sampling was halted from 1990-1992 due to funding issues. The survey resumed in 1993 in all modes, except for the PC boat mode which resumed in 1996 for counties north of Santa Barbara County. To produce catch estimates for the missing subregion/mode/year combinations, we used linear interpolation. Shore modes were a minor component of the vermilion rockfish catch and therefore combined with catches from the private (PR) boat mode into a single fleet. Specifically, catches were aggregated by subregion (adjusted as described above), year, and mode, and endpoints for the interpolations were defined as 2-year averages to reduce the effects of interannual variability in catch on interpolated estimates.

The MRFSS did not collect data on the size composition of discarded fish (except in the program's last year, 2003), although recent CRFS sampling shows that the mean size of discarded fish is smaller than retained catch. Since catch type "B1" is an angler-reported mixture of dead discards and landed fish which were unavailable to the sampler, the true size composition of B1 fish is unknown. To determine the effect of alternative assumptions about the size composition of discarded fish, the STAT separated B1 fish into a separate fleet in the model. This allowed us to apply discard size composition data from the more recent CRFS survey, and compare the result to a model that assumes B1 catch has the same size composition as the examined catch. Results are described in the model sensitivity section. Since the ratio of B1 catch to total catch (A+B1) was highly variable among years, an average B1/(A+B1) ratio was estimated for each subregion and boat mode. These average discard ratios were applied to the annual estimates of total catch to estimate annual discarded catch prior to 2005.

MRFSS estimates of catch and discard (1000s of fish) after adjustment for changes in subregion definition and sampling gaps are shown in Table 1.

California Recreational Fisheries Survey (CRFS), 2004-2020

Estimates of recreational landings and discard since 2004 have been produced by the CRFS. This survey improves upon the MRFSS sampling design, employing higher sampling rates and producing estimates with finer spatial and temporal resolution. The CRFS also employs onboard CPFV observers, providing spatially referenced, drift-level estimates of catch and discard for a subset of anglers on observed groundfish trips, as well as length composition data for discarded catch. These data are extremely valuable to stock assessment (see the CRFS Onboard Index of Abundance Index for further details).

CRFS mortality estimates for the period 2005-2020 were queried from RecFIN. Reported estimates were aggregated into subregion (north and south of Point Conception) and boat mode (PC and PR), and filtered to exclude fish caught in Mexican waters. Shore modes were a minor component of the recreational catch and were combined with the PR mode.

Discard mortality rates

Total recreational mortality estimates provided to RecFIN are adjusted using species- and depth-specific discard mortality rates. The discard mortality rates for vermilion rockfish that were endorsed by the SSC and adopted by the PFMC in March 2017 are 20% for 0-10 fm, 34% for 10-20 fm, 50% for 20-30 fm, and 100% for greater than 30 fm.

Similar to the MRFSS data, CRFS discard estimates were treated as a separate fleet to evaluate the effect of alternative size composition assumptions on model results. Estimates of retained and released dead fish (in numbers) by subregion and mode are available from the RecFIN website, and these were used in the model. Other than combining PR and shore modes, the estimates described above were used without modification.

Recreational length composition data

Length compositions were provided from the following sources:

- Recreational party/charter mode (PC)
  - Collins and Crooke CPFV onboard observer survey (1975-1978)
  - Ally et al. CPFV onboard observer survey (1986-1989)
  - MRFSS PC dockside survey (1980-2003)
  - CRFS PC onboard (discard only) survey (2004-2019)
  - CRFS PC dockside surveys (2004-2019)
- Recreational private/rental mode (PR)

  - Racine (1982) PR samples (1978)
  - MRFSS PR dockside survey (1980-2003)
  - CRFS PC dockside surveys (2004-2019)

The number of available fish by year and fleet as well as the method we used to calculate initial sample sizes are in Tables 4 and 5. Length composition data can be found in Figure 8 for the recreational PC retained fleet and Figure 9 for the recreational PC discard fleet, and Figure 10 for the recreational PR fleet.

Recreational age composition data

There are no recreational age composition data available for vermilion rockfish from California state sampling programs.

Recreational indices of abundance

A number of indices of abundance were explored for the recreational fleet (Figure 11), noting there were limited recreational index data from 2020 due to COVID-19. Discarded catch is available from onboard observer surveys, but was not included in indices. The STAT considered developing separate indices for discards, but sample sizes were not large enough to warrant modeling. The CDFW CPFV logbook data were not considered as an index of abundance due to the fact that vermilion rockfish may not be accurately reported to the species level. Indices developed for the assessment include:

- MRFSS era dockside survey of the PC fleet (1980-1999)
- CDFW CPFV onboard observer index (1999-2019)
- CRFS PR1 sites dockside survey (2004-2020)

2.2 Fishery-Independent Data

2.2.1 NWFSC West Coast Groundfish Bottom Trawl Survey

The West Coast Groundfish Bottom Trawl Survey (WCGBTS) is based on a random-grid design; covering the coastal waters from a depth of 55-1,280 m (Keller et al. 2017). 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’ off the coast of Washington, Oregon, and California. 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.

Vermilion rockfish are strongly associated with rocky habitat, i.e., untrawlable habitat, but can be found over soft bottom, especially as juveniles. This survey spans the entire West Coast and provided data for both the northern and southern California assessments. However, this survey does not sample most rocky habitats, nor does the survey conduct sampling within the Cowcod Conservation Areas (CCAs) or the California state Marine Protected Area (MPA) network.

Available Data

Age and Length Data. Vermilion rockfish are not found in high abundance in this survey, and in most cases lengths for the entire catch were available, i.e., few enough individuals were caught that all were measured. The assessment north of Point Conception includes 467 ages, which is the majority of the vermilion rockfish with available length information (587 total). South of Point Conception, 1,283 of the 1,962 vermilion rockfish observed and measured were also aged (Table 7). The length compositions by year of vermilion rockfish from the WCGBT survey are shown in Figure 13.

Maturity samples. Maturity samples were analyzed by by Melissa Head (NWFSC) and a description of the results is in the section on biological data.

Index of abundance. The index was considered, but not used in the pre-STAR base model. VAST-WestCoast was explored for standardization of the WCBTS data both north and south of Point Conception. Unfortunately, results were uncertain given the small number of tows that observed vermilion rockfish. Truncating the spatial distribution of the survey to less than 300 m, which only eliminated a small handful of positive tows, did not decrease the uncertainty such that spatially-explicit parameters were estimable. Model convergence was more of an issue south of Point Conception rather than north of the break. Changing the distributional assumptions of the positive model or changing to a tweedie-like distribution that combines the two models did not increase the likelihood that the model could estimate spatially-explicit parameters. It was decided that a non-spatial model, which is more easily accomplished outside of the VAST framework would be best for all areas where the survey samples this species. Future research could investigate correlation structures between areas and if shared information across small regions of overlap would stabilize parameter estimation.

The STAT also developed a delta-glm model for each area (north and south of Point Conception). Full details of the final index are in the Appendix, including sample sizes, model selection criteria, and model diagnostics.

2.2.2 NWFSC Hook and Line Survey

Since 2004, the NWFSC has conducted an annual hook and line survey targeting shelf rockfish in the genus *Sebastes* at fixed stations in the Southern California Bight. Key species of rockfish targeted by the survey are bocaccio (*S. paucispinis*), cowcod (*S. levis*), greenspotted (*S. chlorostictus*), and vermilion/sunset (*S. miniatus* and *S. crocotulus*) rockfishes, although a wide range of rockfish species have been observed by this survey. During each site visit, three deckhands simultaneously deploy 5-hook sampling rigs (this is referred to as a single drop) for a maximum of 5 minutes per line, but individual lines may be retrieved sooner at the angler's discretion (e.g., to avoid losing fish). Five drops are attempted at each site for a maximum possible catch of 75 fish per site per year (3 anglers x 5 hooks x 5 drops). Further details regarding the sample frame, site selection, and survey methodology are described by Harms et al. (2008).

Composition data from the hook-and-line survey are assigned to two different fleets in the southern California base model. The survey area expanded into the CCAs in 2014, and index selectivity is linked to the composition data from 2014-2019. Composition data prior to 2014 are assigned to a "dummy" fleet to account for potential changes in selectivity, and allow the early years of the survey to inform growth and recruitment. Further details are provided below, in the base model description and the appendix for the index standardization model.

Available Data

Age and Length Data. This survey provides a wealth of biological information for the stock assessment, including lengths of 22,720 vermilion and ages from 9,211 vermilion (Table 4). The length composition can be found in Figure 12 for the period 2014-2019 (sampling inside the CCAs) and Figure 15 for years 2004-2013, when sampling was limited to areas outside the CCAs.

Index of Abundance. The NWFSC hook-and-line survey has been used in a number of stock assessments.
Vermilion is one of the most common species encountered in the survey and is one of the only sources of information about the stock inside the CCAs, which have been closed to fishing since 2001. Details regarding the index of abundance, sample sizes and model selection can be found in the Appendices. Although it was not used in the assessment, the details related to the index of abundance are retained in the document for future reference.

2.2.3 California Department of Fish and Wildlife CPFV Survey

The CDFW conducted fishery-independent surveys in the Southern California Bight from 1976-1979 aboard research vessels. The purpose of the surveys was to capture *Sebastes* species and determine composition (species, size and age) of fish and to estimate size at maturity. The whereabouts of the majority of the data from these cruises is unknown. Bottom trawling in nearshore waters for juvenile rockfish was conducted, but those data are unavailable. This collection of survey data is also referred to as the "green binder" survey, as the data were discovered in green binders. The SWFSC keypunched the available data and also houses some of the otoliths collected during this study. It may be possible in the future to recover additional data from available cruise reports.

Available Data

Age and Length Data. A total of 389 vermilion otoliths that were matched to available data (including sex, when available) from 1976-1977 and contained information on sex were aged for the assessment. A total of 1,442 lengths spanning 1976-1979 were also included (Figure 14).

2.3 Additional Considered Data Sources

The STAT considered the following data sources, but found that vermilion rockfish were not well sampled and no further analysis was conducted.

NWFSC Triennial Survey

The Triennial Survey was first conducted by the Alaska Fisheries Science Center in 1977, and the survey continued until 2004 (Dark and Wilkins 1994). 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 US 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 $40^{\circ}10'N$ (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 m and surveyed south to $40^{\circ}10'N$. In 2004, the final year of the Triennial Survey series, the NWFSC Fishery Resource Analysis and Monitoring Division (FRAM) conducted the survey following similar protocols to earlier years.

Alaska Fisheries Science Center Slope Survey

The Alaska Fisheries Science Center Slope Survey operated during the months of October to November aboard the R/V *Miller Freeman*. Partial survey coverage of the US West Coast occurred during the years 1988-1996 and complete coverage (north of 34°30'S) during the years 1997 and 1999-2001. Typically, only these four years that are seen as complete surveys are included in assessments.

Partnership for Interdisciplinary Studies of Coastal Oceans

The Partnership for Interdisciplinary Studies of Coastal Oceans, PISCO-UCSC, conducts a number of surveys to monitor the kelp forests, one of which is a subtidal fish survey. PISCO has monitored fish population in the 0-20 m depth range as part of the Marine Life Protection Act (MLPA) since 1998. Paired sites inside and outside MPAs are surveyed to monitor the long-term dynamics of the kelp forest ecosystem and provide insight into the effect of MPAs on kelp forest species. PISCO conducts the fish surveys from late July through September. At each site, benthic, midwater, and canopy scuba transects are conducted at 5, 10, 15, and 20 m depth. All divers are trained in species identification. Along each 30 m transect, divers enumerate all identifiable non-cryptic fish, and estimate total length to the nearest centimeter. PISCO surveys are conducted by the University of California Santa Cruz (UCSC) in central California and the University of California Santa Barbara in southern California.

California Cooperative Oceanic Fisheries Investigations

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey began in 1951 and conducts quarterly cruises off southern and central California, collecting a suite of hydrographic and biological data at fixed stations and while underway; ichthyoplankon sampling with a paired bongo started in 1978. Data on larval abundance from the CalCOFI Ichthyoplankton survey have been used in stock assessments of several species, including bocaccio, cowcod and shortbelly rockfish. Although the long-term dataset is limited to a subset of species for which morphological identification of larvae has been possible, recent research has been successful at identifying a broader range of species based on genetic identification of larvae (Thompson et al. 2016). Vermilion rockfish cannot be identified morphologically in the ichthyoplankton samples. Of more than 20,000 larvae identified in the 1998-2013 time period, only nine were vermilion rockfish. Consequently, the data are insufficient at this time to use to inform relative abundance, although Thompson et al. (2017) do provide several relative abundance time series for other taxa, and future efforts may lead to better taxonomic resolution of historical or future collections.

Rockfish Recruitment and Ecosystem Survey

Since 1983, the SWFSC has conducted an annual midwater trawl survey for pelagic juvenile rockfish and other groundfish in the Central California region of the California Current (Ralston et al. (2013) and references therein). Due to concerns about mesoscale abundance patterns and a need for greater spatial representation in the data, including some apparent strong differences in spatial distribution patterns in the early 2000s (Hastie and Ralston 2007, Ralston et al. 2013), this survey was expanded to a broader spatial scale in the 2001-2004 period, and since 2004 most years have coastwide data from a combination of SWFSC, NWFSC and Cooperative Research surveys (see Field et al. (2021) for more complete details regarding coastwide pre-recruit data, and Sakuma et al. (2016) and Friedman et al. (2018) for additional details and alternative applications of survey data). Only 47 of nearly 300,000 total juvenile *Sebastes* encountered in the juvenile surveys since 2001 were identified as vermillion or sunset rockfish (Field et al. 2021). Despite this, the assessment results suggest that at least a reasonable fraction of recruitment variability for sunset and vermillion rockfish is shared with other rockfish and groundfish stocks throughout the California Current, many of which also had strong year classes in 1984, 1999 and 2015, and future investigations could lead to the development of multispecies-based recruitment indicators that could be helpful for future assessments.

California Collaborative Research Program

In 2017 the California Collaborative Research Program (CCFRP) expanded state-wide and now samples four MPAs and associated references sites in southern California.
Vermilion rockfish have been encountered at two of the MPAs (Carrington Point off Santa Rosa Island and South La Jolla) and observed in 27% of all drifts at these two locations. The STAT determined that the available data were too constrained spatially and temporally to be considered for an index of abundance. There are currently 262 lengths of vermilion available. With additional years of data, this data set can be considered for inclusion in a future southern California vermilion assessment.

Southern California Bight Publicly Owned Treatment Works

In the Southern California Bight, a number of monitoring programs exist to evaluate the potential consequences of effluent discharges from wastewater treatment facilities on the coastal marine environment. As over 20 million people live within an hour's drive of the ocean in this region, a major impact to this ecosystem includes a cumulative total of 1.5 billion liters of treated effluent released each day to the ocean, originating from 17 major wastewater treatment plants (Schiff et al. 2016). Most of these publicly owned treatment works support monitoring programs to evaluate the impacts on water and sediment quality, and associated ecological communities. For several, this includes bottom trawl surveys of coastal habitats, and data from the longest running trawl surveys, despite being limited spatially to waters closer to population centers, have previously been used in stock assessments of cowcod (*Sebastes levis*) (Dick and He 2019) and California scorpionfish (*Scorpaena guttata*) (Monk et al. 2017). Cowcod were rarely encountered in these surveys, occurring in 139 of the 1896 trawls conducted by the most rigorous of the surveys, and the development of a relative abundance index required pooling data into five year "blocks" in order to provide plausible estimates of year effects. The resulting index was not highly influential in the final assessment model (Dick and He 2019), and the lumping of years was only acceptable in that model because recruitments were not estimated. By contrast, California scorpionfish were frequently encountered in several of these surveys, with over 10,000 fish being observed (and measured) over the history of those surveys, and the resulting relative abundance index and length frequently data were very influential in the California scorpionfish assessment with respect to both trends and recruitment (Monk et al. 2017). As preliminary investigations suggested that vermilion rockfish are even rarer than cowcod in this survey, and because grouping years of data would be inappropriate where recruitments are being estimated, a more rigorous evaluation of these datasets was not developed for this assessment. However, it could be feasible to consider such an evaluation in future stock assessments.

2.4 Biology

2.4.1 Ageing Precision and Bias

Uncertainty in ageing error was estimated using a collection of 357 vermilion rockfish otoliths with two age reads between the NWFSC (reader 1, B. Kamikawa) and the SWFSC (reader 2, D. Watters) (Figure 16). Age-composition data used in the model were from a number of sources described above. The same readers aged otoliths for both California vermilion rockfish stock assessment models. Age reader 1 read all of the otoliths for the southern model and both readers read otoliths for the northern California model. In addition to the otoliths from these two regions, the same two readers aged fish for a Committee of Age Reading Experts (CARE) exchange among four ageing labs, initiated by the SWFSC.

Ageing error was estimated using publicly available software (Thorson et al. 2012). Reader 1 who was more experienced, was assumed to be unbiased. The ΔAIC among the top three models was less than two. The best fitting model selected curvilinear bias for reader 1 and curvilinear standard deviation for both readers. An analysis of ageing error after removing one fish aged at 88 by reader 1 and 78 by reader 2 selected the model with reader 2 as unbiased and curvilinear standard deviation (Figure 17). The reading of the oldest aged fish falls within the 95% confidence interval using this model (Figure 18). The latter model was selected for use in the assessment and the distribution of true age and observed age is in Figure 19.

The resulting estimates of ageing error indicated a standard deviation in age readings increasing from 0.001 years at age 0 to a standard deviation of 2.37 years at age 70, the first year of the plus group in the assessment model.

2.4.2 Maturity

Maturity at length of nominal vermilion rockfish was previously studied by Wyllie Echeverria (1987) from fish collected off central California. She found that 50% of females sampled were mature by 37 cm total length, and 50% of males were mature by 38 cm total length. Love et al. (1990) reported 37 cm total length for female size at 50% maturity, based on fish collected in southern California. Phillips (1964) reported a size at 50% maturity of 13 inches (33 cm) total length, although the sampling location of the fish used to determine maturity for that study was not specified within California.

For the current assessment, Melissa Head (NWFSC, pers. comm.) determined maturity for 545 female vermilion rockfish caught by recent fishery-independent surveys. Two types of maturity determinations were provided, 'biological maturity' and 'functional maturity.' The former category includes "juveniles exhibiting dummy runs (early vitellogenesis or yolk granules present in a small proportion of oocytes, some in early stages of cellular decay) and skip spawners (adults foregoing spawning in a given year)" (M. Head, pers. comm.), while the latter excludes such cases. A logistic regression was fit to the functional maturity determination as a function of fork length (Figure 20), estimating length at 50% maturity at 38.4 cm, with a slope of -0.312, based on the parameterization in Stock Synthesis. The samples available from areas north of Point Conception were smaller fish and did not allow for estimates of separate maturity curves. Both California vermilion rockfish assessments assumed the same maturity ogive (Figure 21).

2.4.3 Fecundity

Phillips (1964) reported fecundity for nominal "vermilion" rockfish collected in waters off California. Based on a sample of 12 fish ranging in size from 315-550 mm total length, he reported the minimum and maximum number of eggs as 63,300 and 1,625,600 per female, respectively. Love et al. (1990) estimated fecundity of fish in southern California, and reported an allometric fecundity - length relationship (eggs vs. total length, cm) with an exponent of 5.02, suggesting a significant increase in weight-specific fecundity with female size given a roughly cubic weight-length relationship. Dick et al. (2017) conducted a meta-analysis of *Sebastes* fecundity-length relationships. Insufficient data were available to model the subgenus *Rosicola*, but the predictive distribution of the fecundity-length exponent for the genus as whole centered around a value of four, supporting a general pattern of increasing weight-specific fecundity among the *Sebastes*. Analyses to date have not examined size-dependent changes in brood frequency for vermilion or sunset rockfish, i.e. current fecundity estimates represent brood fecundity.

For this assessment, new observations of fecundity at length were supplied by S. Beyer (UCSC / SWFSC, pers. comm.). These data were combined with digitized historical data sets used by Dick et al. (2017) to estimate a new fecundity-length relationship (Figure 22). The relationship between fecundity (millions of eggs) and fork length (cm) estimated from these data and used in the assessment was $F = 2.8e^{-9}L^{4.97}$

The resulting relationship between fecundity by female weight (kg) is illustrated in Figure 23, with spawning output at age (the product of maturity and fecundity) in Figure 24.

2.4.4 Natural Mortality

Natural mortality was not directly measured, so life-history based empirical relationships were used. The Natural Mortality Tool NMT, a Shiny-based graphical user interface allowing for the application of a variety of natural mortality estimators based on measures such as longevity, size, age and growth, and maturity, was used to obtain estimates of natural mortality. The NMT currently provides 19 options, including the Hamel (2015) method, which is a corrected form of the Then et al. (2018) functional regression model and is a commonly applied method for West Coast groundfish. The NMT also allows for the construction of a natural mortality prior weighted across methods by the user.

The STATs for the four vermilion rockfish assessment models all used the same prior for natural mortality across models. We assumed the age of 54 years to represent the practical longevity (i.e., 90% of the commonly seen maximum age of 60) for both females and males, though the absolute oldest age in Oregon was >60 years. In California, fish aged at 80+ were encountered. Empirical M estimators using the von Bertalanffy growth parameters were also considered, but they produced unreasonably high estimates (2-3 times higher than the longevity estimates). This is likely explained by the fact that vermilion rockfish have protracted longevity at L_∞. Additionally, the FishLife (Thorson and Barnett 2017) estimate was included, though, given the source of FishLife data is FishBase, there is a good chance the estimates of M are also from methods using longevity, though the actual source of longevity in FishLife was unknown. Both California vermilion rockfish assessments used the Hamel prior (2015), which is defined as a lognormal with log-scale mean = $ln\frac{5.4}{A_{max}}$ and SE = 0.438. Using a maximum age of 54 the point estimate and median of the prior is 0.1, which is used as a prior on M in the assessment model. We also explore sensitivity to these assumptions of natural mortality through likelihood profiling.

2.4.5 Sex Ratio

The sex ratio was assumed to be 50:50 in the assessment model. The majority of the recent age data in the assessment were collected from the NWFSC hook-and-line survey. There is a clear pattern of the sex ratio becoming skewed towards females in all years of the NWFSC hook-and-line survey beginning around 50 cm (Figures 25 and 26), as expected due to differences in male and female growth. There are no clear patterns in the sex ratio from the CDFW research fleet nor the WCGBTS (Figures 27, 28, and 29).

2.4.6 Weight-Length Relationship

In California, the weight(kg)-length(cm) relationship for vermilion rockfish was estimated external to the model using biological data available from fishery-independent data sources including the NWFSC hook-and-line survey and the WCGBTS. The estimated weight-length was assumed the same for males and females: W=1.744e-05L^3 (Figure 30).

2.4.7 Environmental or Ecosystem Data

As noted in Section 1.3, ecosystem data were not explicitly used in this assessment.

3 Assessment Model Description

3.1 History of Modeling Approaches

Current yield estimates for vermilion rockfish were estimated for the entire West Coast using Depletion-Based Stock Reduction Analysis (DB-SRA) (Dick and MacCall 2010). Average catch in 2008-2009 was 136.3 mt, and the median OFL in 2010 was 314.3 mt with a 28% probability that recent catch exceeded the OFL in 2010 (Dick and MacCall 2010).

A 2005 assessment was not accepted for management. From the September 2005 Briefing Book: "The SSC considers the assessment to be best available science, but at this stage does not endorse the results as being suitable for setting OYs." A 2013 data moderate assessment was prepared, but not reviewed. From the Pacific Coast Groundfish Stock Assessment Review (STAR) Panel Report for Data-Moderate Assessments (2013): "There was insufficient time during the review to evaluate all the assessments originally requested by the Council. Assessments for vermilion/sunset rockfish (*Sebastes miniatus* and *Sebastes crocotulus*) and yellowtail rockfish (south of $40°10'N$) were not presented by the Stock Assessment Team (STAT)."

3.1.1 Most Recent STAR Panel and SSC Recommendations

The 2005 STAR panel report compiled recommendations specific to vermilion rockfish, and also generic rockfish recommendations The generic rockfish recommendation are not presented here. The 2005 assessment was not accepted for management by the PFMC.

Vermilion Rockfish Recommendations

Investigation into the species composition of nominal vermilion rockfish is needed. It is not clear that separate assessments for the northern and southern areas are warranted for vermilion rockfish. Although there were differences in the estimated magnitude and timing of recruitment events, the estimated stock trends were similar in both areas. Pooling of data from northern and southern areas may permit a more robust assessment model to be obtained.

2021 STAT Response. Since the 2005 assessment, vermilion rockfish were speciated to vermilion and sunset rockfishes (Hyde and Vetter 2009). Sunset rockfish are more common south of Pt. Conception ($34°27'N$) and historical catches and length distributions between the two areas are different. The STAT discussed this at the Pre-Assessment Workshop and all participants agreed that modeling the areas separately was an appropriate decision.

3.1.2 Response to STAR Panel Requests

For the STAT responses to the STAR panel requests see the STAR panel report available on the PFMC's website.

3.2 Model Specifications

A decision was made by the STAT after discussions with the Pacific Fishery Management Council's Groundfish Management Team and Groundfish Advisory Panel to model the areas north and south of Point Conception independently for a number of reasons. These included a discussion of the evidence supporting higher densities of sunset rockfish south of Point Conception and the general decline in vermilion rockfish density as latitude increases. The preliminary exploration of length data also suggested that the size composition of landed fish north and south of Point Conception differed in a number of fleets. The STAT maintained consistency across the two models when the data supported the decisions, i.e., maintaining the same recreational and commercial fleet structures and sharing biological data from the more data-rich southern assessment.

The structure of the California models north and south of Point Conception are very similar. Population dynamics in both regions operate on an annual time step and are initialized from an unfished equilibrium condition in 1875. Sex-specific age and length structure is modeled from age 0 (recruitment age) to an accumulator age (plus group) of 70, with 1-cm population length bins ranging from 6-70 cm. Length data bins are 2-cm wide, and range from 8-70 cm in the south and 10-70 cm in the north. Expected recruitment is assumed to follow a Beverton-Holt function of spawning output, with lognormally-distributed recruitment deviations. Growth (male and female) is modeled using the Schnute parameterization of von Bertalanffy growth, with two estimated lengths (ages 0 and 30) and a growth rate coefficient (k). The major differences between the two models are the availability of fishery-independent data sources that are region-specific, and the parameterization of male growth and mortality parameters (details below).

The models in both regions are conditioned on catches from the commercial and recreational sectors. The commercial sector is divided into three fleets (hook-and-line, trawl, and net gears). Landings from minor commercial gears were a negligible component of the total harvest and were combined with the hook-and-line fleet. The recreational sector was divided into four fleets according to boat mode (party/charter or private/rental) and catch type (retained or discarded). This follows the same practice as a number of other recent rockfish stock assessments, where the ability to accurately estimate a retention curve is complicated by depth-dependent discard mortality rates.

Vermilion rockfish is a desirable species and discards are a small component of total fishing mortality in both the commercial and recreational sectors. The commercial catches do not include dead discards, which were estimated to be a small percent of the overall landings in both areas (averaging 7.4 mt coastwide since 2015, although increasing since 2017). In addition, there were very few observations available from WCGOP (fewer than 250 fish statewide). The size distribution of recreational discards from the CDFW and Cal Poly onboard observer programs represented larger fish from periods when the recreational shelf rockfish fishery closed versus smaller fish discarded when the fishery was open. Fish discarded during trips when vermilion rockfish were prohibited were removed from the recreational PC discard fleet length composition.

The southern California model is fit to three fishery-dependent indices of relative abundance: 1) MRFSS CPFV dockside, 2) CDFW onboard observer, and 3) CRFS PR1 dockside. The MRFSS CPFV dockside index is assumed to be proportional to changes in the relative abundance of the recreational party/charter fleet (retained fish only). The CDFW onboard observer index represents the same fleet (rec party/charter), but indexes change in abundance during recent years. The onboard index is specified as a separate "survey" fleet in the model because it overlaps in time with the MRFSS dockside time series. Both the MRFSS and onboard indices use the recreational party/charter fleet's selectivity curve to define vulnerable size classes. The CRFS PR1 dockside index is linked to the recreational private/rental boat fleet (retained fish), and uses the same selectivity curve. Recreational length measurements are included as marginal length compositions (proportions at length, sexes combined) by year starting in 1975 and 1978 for the PC and PR modes, respectively. Fishery-dependent length composition data are also included for the commercial hook-and-line and net fleets, but trawl length data were too sparse to be used for estimating trawl-specific selectivity parameters. Age structures from the commercial fleets were also sparse and not considered for the southern California assessment.

Fishery-independent data sources in the southern California model are organized into four fleets. The primary data source is the NWFSC hook-and-line survey. Data from this survey were used to create an index of relative abundance, marginal length compositions by sex and year, and conditional-age-at-length data by sex and year. Length and age data from the hook-and-line survey were broken into two fleets to better match assumptions in the index standardization methodology (see Appendix for details). The NWFSC trawl survey is the second fishery-independent data source in the southern model. An abundance index was developed for the trawl survey, but ultimately rejected due to high interannual variability, sparse data, and imprecise estimates. However, trawl survey conditional-age-at-length data and associated marginal length comps, both by sex and year, were retained in the model. The earliest available age and length composition data came from assorted CDFW research cruises which are collectively known as the "green binder" data (see data section for additional information).

Changes from the pre-STAR base model to the post-STAR base model Two suggestions from the STAR panel were incorporated into the final base model. These were 1) implement a time-block in 2017 to represent changes in selectivity for the commercial hook-and-line fishery resulting from regulatory changes, and 2) estimate steepness.

3.2.1 Additional Specifications

Length-based selectivity is modeled using the double normal parameterization within Stock Synthesis. Selectivity parameters were estimated for the commercial hook-and-line fleet and the commercial net fleet. The commercial trawl fleet is mirrored to the commercial hook-and-line fleet due to sparse sampling and the minor contribution of trawl landings to total harvest in southern California. Selectivity was estimated for the recreational PC fleet, recreational PC discard fleet and the Recreational PR fleet. There were no length data available for the recreational PR discard fleet, and it mirrors the selectivity of the recreational PC discard fleet. Selectivity for the recreational PC onboard index of abundance is mirrored to the recreational PC fleet as they share the same length composition. Length-based selectivity parameters were estimated for all fishery-independent data sources. Age-based selectivity was set equal to 1 for all ages in all fleets, except for the NWFSC trawl survey which has a selectivity of 0 for young-of-the-year (age 0) fish.

The length composition sample sizes for some years and fleets was small, and observations may not be representative of the total catch. Years with insufficient data were excluded from the likelihood, and initial sample sizes (prior to data weighting) for length composition data were set equal to a proxy such as the number or trips, hauls, or sampling events (as described in Tables 4 and 5).

3.2.2 Modeling Platform and Structure

The assessment was conducted using Stock Synthesis (SS) version 3.30.17.00 developed by Dr. Richard Methot (Methot and Wetzel 2013). The R package r4ss, version 1.38.0, along with R version 4.0.1 were used to investigate and plot model fits.

Electronic SS model input files including the data, control, starter, and forecast files can be found on the PFMC's website.

3.2.3 Model Parameters

The population dynamics model has many parameters, some estimated using the available data in the assessment and some fixed at values either determined external to the assessment or informed by the available data. Estimated and fixed parameter values, including associated properties (bounds, priors, asymptotic standard errors), are in Table 8.

A total of 115 parameters were estimated in the base model, including recruitment deviations. Time-invariant growth parameters (Brody growth coefficient, lengths at age 0 and age 30, and CV old/young) using the Schnute parameterization of the von Bertalanffy growth function were estimated for each sex, with male values parameterized as exponential offsets from female parameters. The CV of the distribution of length-at-age, CV(L), in the base model is estimated at the lower and upper ages specified in the Schnute parameterization of von Bertalanffy growth, and a linear interpolation between these 2 parameters is a function of age. This choice was based on visual inspection of the relationship between CV(L) and age, using the NWFSC hook-and-line survey data (Figure 31). Natural mortality was estimated using a parameter for both sexes and informed by a prior distribution. Natural mortality for males was assumed equal to female (exponential offset fixed at zero). Selectivity varied by fleet, and was assumed to be either asymptotic or domed for retained fleets, and forced to be domed for discard fleets with initial and final selectivity fixed at zero. Most selectivity parameters were assumed to be time-invariant, except time blocks were used to capture changes in selectivity associated with regulatory changes around 2001 (see regulations section). Recruitment deviations were estimated in the base model from 1965 – 2020. Initial (unifshed equilibrium) recruitment was also estimated. An extra standard deviation parameter was estimated for the PR mode abundance index, as the externally estimated CVs were small due to extremely large sample sizes (1000s of trips).

3.2.4 Priors

The Thorson-Dorn rockfish prior (developed for use West Coast rockfish assessments) conducted by James Thorson (personal communication, NWFSC, NOAA) and reviewed and endorsed by the Scientific and Statistical Committee (SSC) in 2017, has been a primary source of information on steepness for rockfish. This approach, however, was subsequently rejected for future analysis in 2019 when the new meta-analysis resulted in a mean value of approximately 0.95. In the absence of a new method for generating a prior for steepness the default approach reverts to the previously endorsed method, the 2017 prior for steepness (h; beta distribution with μ=0.72 and σ=0.16) is retained.

A prior for natural mortality was developed using the method of Hamel (2015). The STAT examined the distribution of ages from the NWFSC hook-and-line survey and found that roughly 99.9% of otoliths aged were in the mid-50s or younger. Therefore an approximate maximum age of 54 was selected, giving a median estimate of 0.1 yr^{-1} for the prior. The STAT notes that the recommended log-scale standard deviation of 0.438 for the prior makes it only weakly informative, so small changes to the prior's median value do not affect estimates of M and other assessment results.

3.2.5 Data Weighting

Length composition and conditional-age-at-length (CAAL) composition sample sizes for the base model were tuned by the "Francis method," based on equation TA1.8 in Francis (2011), and implemented in the r4ss package (Table 9).

As outlined in the Best Practices, a sensitivity run was conducted with length and conditional-age-at-length (CAAL) compositions were re-weighted using the McAllister-Ianelli harmonic mean method (McAllister, Murdoch K.; Ianelli 1997). See the model sensitivity section for a comparison of the Francis and McAllister-Ianelli results. Additionally, weighting using the Dirichlet-Multinomial likelihood, that includes and estimable parameter (theta) that scales the input sample size, was explored. However, all estimates of the ratio of $\theta/(1+\theta)$ were greater than 0.99, which indicates the models is trying to tune the sample sizes unchanged. Given this result, the STAT chose not to further explore the Dirichlet-Multinomial data weighting. As a note, there is a bug in SS Version 3.30.16.00 that prevents the number of estimated weights from being larger than the number of fleets. This was fixed in SS Version 3.30.16.01 and this version was only used for exploration of the Dirichlet-Multinomial data weighting.

3.2.6 Key Assumptions and Structural Choices

The STAT used sensitivity analyses to evaluate robustness of the pre-STAR base models to key assumptions and structural choices. The major structural choices in both California assessments were 1) the use of a single, stationary, and closed population model to describe the aggregate population dynamics and biological parameters of the cryptic species pair in each region, 2) density-dependence entirely characterized by a Beverton-Holt stock recruitment relationship, 3) that natural mortality rates can be adequately estimated from available data, and 4) time blocks based on major regulatory changes adequately characterize changes in size-selectivity of fishing gear over time. The catch histories of vermilion and sunset rockfishes are inseparable at this time, making estimation of species-specific fishing mortality rates impossible. Ongoing research may shed light on this issue, and help improve our understanding of potential differences between the species (e.g., vital rates) that could influence estimates of stock productivity and sustainable yield.

3.2.7 Convergence

Model convergence was examined by starting the minimization algorithm from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. "Jitter" is an option in SS that generates random starting values from a normal distribution logistically transformed into each parameter's range (Methot, R. D. et al. 2020). This was repeated 100 times and none of the runs converged to a lower negative log likelihood in the post-STAR base model (Figure 32). The model did not experience convergence issues, e.g., final gradient was below 0.0001, when reasonable starting values were used and there were no difficulties in inverting the Hessian to obtain estimates of variability.

4 Assessment Results

The base model parameter estimates along with approximate asymptotic standard errors are shown in Table 8. The full r4ss plotting output is available in the supplementary materials.

4.1 Fixed parameters

The following parameters were fixed in the post-STAR base model:

- M for males (set equal to estimated female value)
- Selectivity parameters estimated at the bounds during model exploration were fixed in the pre-STAR model

4.2 Parameter Estimates

The base model has a total of 115 estimated parameters (Table 8) that are described in more detail in the following sections:

4.3 Growth Estimation

The southern California base model estimated reasonable growth parameters for female and male k, lengths at age 30, and CVs of length at age (both young and old). The male growth parameters were modeled as exponential offsets to female growth, with the male $L_{age=0}$ and associated CV fixed to the estimates for females (7.7 cm and a CV of 0.09) because male estimates hit lower bounds. Female k was estimated at 0.16, slightly lower than the estimates for males of k of 0.18 (exponential offset of 0.13). Females reached a larger size at $L_{age=30}$ of 55 cm than males, which reached 52 cm at estimated $L_{age=30}$ (Figure 33). The CV's of the $L_{age=30}$ for females and males were 0.077 and 0.058, respectively.

Estimates of the vonBertalanffy parameters transformed from the Schnute parameterization used by SS are below. In both parameterizations of the growth equation, k has the same definition.

$$\text{Females } L_\infty = 55.8 \text{ cm; } k = 0.156; \; t_0 = \text{-1.07}$$

$$\text{Males } L_\infty = 52 \text{ cm; } k = 0.178; \; t_0 = \text{-1}$$

4.4 Natural Mortality Estimation

The southern California model estimates female natural mortality (M) and fixes male M at the same value. The estimated value of 0.130 (SE = 0.012) for both sexes is higher than the value estimated for northern California, but not inconsistent with the observed range of ages. Latitudinal gradients in natural mortality have been estimated for many species of rockfish, which is consistent with the lower estimates of M in the northern model.

4.5 Fits to Age Composition

The following plots show the Pearson residuals, mean age with Francis data weighting, and mean age and standard deviation in conditional age-at-length by fleet/survey:

- CDFW research survey: Figures 34, **??**, and 36
- Early NWFSC hook-and-line survey: Figures 37, 38, **??**, and 40 - 42

- NWFSC hook-and-line survey: Figures 43, **??**, and 45 - 46
- WCGBT survey: Figures 47 - 48, **??**, and 50 - 53

Fits to the marginal and conditional age at length data sets were best for the NWFSC hook-and-line survey, which is not surprising given that this survey accounted for the majority of age at length observations (over 9000). Similar to the northern model, the largest residuals were associated with infrequently encountered, older individuals, and no significant residual patterns were apparent. The model was able to reproduce interannual changes in mean age reasonably well, with the exception of 2009, when observed average age was unusually high (~5 years higher than surrounding years), but also had the largest variance.

4.6 Estimated Selectivity and Fits to Length Composition

The following plots show estimated selectivity (when not mirrored, Figures 54 - 68) and fits to the length composition (Figures 69 - 87) for each fleet/survey:

- Commercial hook-and-line: Figures 56, 60, 70, and 71
- Commercial net: Figures 61, 72, and 73
- Recreational retained PC: Figures 58, 62, 74 and 75
- Recreational discard PC: Figures 63, 76 and 77
- Recreational retained PR: Figures 64, 59, 78 and 79
- WCGBT survey: Figures 66, 82 and 83
- CDFW research survey: Figures 84 and 85
- NWFSC hook-and-line survey: Figure 80 and 81
- Early NWFSC hook-and-line survey: Figures 68, 86 and 87

Fits to the time-aggregated length comps were best for the commercial, recreational, and NWFSC survey fleets (Figure 69). The NWFSC trawl survey does not effectively sample primary adult habitat types, resulting in a multi-modal length frequency distribution that is difficult for the model to reproduce (Figure 69). Fits to the early CDFW research fleet are poor, but the data informing these years are relatively sparse in comparison to current sampling programs such as CRFS. Length composition data from the recreational fleets show evidence of modal progressions due to strong year classes (e.g., the 1999 year class showing up around 2002), there are no patterns in the pearson residual plots, and the model is able to track associated changes in mean length over time.

The commercial hook-and-line fleet (and mirrored commercial trawl fleet) were fit to time-varying asymptotic selectivity and the size at full selectivity shifts to smaller fish in the more recent time block (from 50 cm to 34 cm). The most likely change in selectivity for the commercial fleet is the implementation of the CCAs and additional regulatory changes in the early 2000s. Catches from the commercial net fishery declined prior to the CCAs. The length compositions from the net fishery did not support a dome shaped selectivity and parameters were fixed to have asymptotic selectivity (Figure 61).

Dome-shaped selectivity for the recreational PC and PR fleets are similar with the PR fleet encountering smaller fish than the PC fleet, whereas the recreational discards fleet rarely discards any fish larger than ~35 cm (Figures 62, 63, 64). A number of regulatory changes (e.g., establishment of the CCAs, depth restrictions) supported time blocks in both recreational retained fleets and resulted in narrower selectivity patterns in the 2000s.

Both fishery-independent hook-and-line surveys were fit to asymptotic selectivity because attempts to estimate dome-shaped selectivity resulted in poorly informed parameters (very large SEs) for terminal selectivity and the descending width. The length composition data from 2004-2013 for the NWFSC Hook-and-Line survey were fit as a ‘dummy’ fleet, and allowed to take a dome shape due to the lack of sampling inside the CCA where fish of larger size were observed.

Peak selectivity for the WCGBTS was fixed at the smallest length bin (Figure 66), and attempts to estimate other parameters (e.g., descending width) were unsuccessful, with the parameter hitting the lower bound near zero.

4.7 Fits to Indices

The following plots show log-scale fits to the indices and residuals by fleet/survey:

- MRFSS dockside PC survey: Figures 88 and 89
- CDFW dockside PR survey: Figures 90 and 91
- NWFSC hook-and-line survey: Figures 92 and 93
- CDFW onboard CPFV survey: Figures 94 and 95

Fits to the indices vary in quality. Two of the three recreational indices represented the PC fleet. The MRFSS era dockside interview index was fit moderately well given the uncertainty in some years, but the model was not able to adequately reproduce the first and last observations of the time series or the rate of decline in the late 1990s, as indicated by a short run of negative residuals (1995-1998) (Figures 88 and 89). The CDFW onboard index, which now contains 21 years of data was fit well and captures the trend from the standardized index; there was also not a strong pattern to the residuals (Figures 94 and 95).

An additional variance parameter was estimated for the recreational PR dockside index. The index was positively correlated with the base model predictions, but the relationship was not strong and most residuals shifted from positive to negative after 2011 (Figures 90 and 91). The NWFSC hook-and-line survey index was fit well through 2016, with the model capturing a general trend of increasing abundance, but the model did not capture the pattern of increased abundance in the last three years. Since the survey moved into the CCAs in 2014, the increase since 2017 does not appear to be related to the change in survey design (Figures 92 and 93).

4.8 Derived Quantities

Spawning output south of Point Conception declined rapidly throughout the 1970s, 1980s, and 1990s to a level below the Minimum Stock Size Threshold (MSST), but catches decreased enough in the 2000s for the stock to reach a stable level of spawning output (Table 10, Figure 96). Stock size is estimated to have been at the lowest level in the mid-1990s, but has since increased, in part due to an exceptionally strong recruitment in 1999, followed by several years of above-average recruitment. The stock is estimated to have been below the management target of (40% of unfished spawning output) from 1986-2007 (Figure 97. Relative exploitation rates ($\frac{1-SPR}{1-SPR_{50\%}}$) increased through time, exceeding target levels from the mid-1970s through the late 1990s. Exploitation over the past decade has fluctuated around target levels (Figure 98), with catches almost entirely landed by the recreational sector.

Vermilion spawning output in northern California was estimated to be 4471 million eggs in 2021 (95% asymptotic interval: 229 - 714 million eggs) or 48% (95% asymptotic interval: 26% - 71%) of unfished spawning output in 2021(“depletion,” Table ii and Figures 96 and 97). In 2021, vermilion biomass south of Point Conception is estimated to be above the target biomass level, while experiencing fishing intensity around the SPR fishing intensity target (Figure 98). The equilibrium yield curve is shifted left, as expected given the assumed value for the Beverton-Holt steepness parameter (h=0.72)(Figures 99 and 100). Harvest rates in southern California in 2020 were below target, and the stock was above the target biomass (Figure 101).

Estimates of derived reference points and approximate 95% asymptotic confidence intervals are shown in Table v. Estimates of stock size and status over time are shown in Table 10.

4.9 Recruitment Deviations

Major recruitments (strong year classes) in southern California were consistently estimated by the primary sources of age data (NWFSC hook-and-line and trawl surveys), with a strong 1999 year class estimated even when either data set is removed (see sensitivity section). Other years with relatively high estimates of recruitment were 1983-84, 1999, and 2016 (Figures 104, 105, 102, and 103). These are consistent with estimates of strong year classes in other rockfish stock assessments. Due to ageing error, years adjacent to strong (or weak) cohorts are sometimes estimated as having similar deviations.

4.9.1 Reference Points

Reference points were calculated using the estimated selectivities and catch distribution among fleets in the most recent year of the model, 2020. Sustainable yield (landings plus dead discards) was 148.28 mt when using an $SPR_{50\%}$ reference harvest rate. The spawning output equivalent to 40% of the unfished level ($SB_{40\%}$) was 391.13 million eggs.

The 2021 spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished levels (Figure 97). The estimated relative fishing intensity, $(1 - SPR)/(1 - SPR_{50\%})$, has fluctuated around the target level for the past decade, was above the management target in 2019 and below the management target in 2020 (Figures 98 and 101).

Table v shows the full suite of estimated reference points for the base model and Figures 99 and 100 show the equilibrium yield curve and net production based on a steepness value estimated at 0.73.

5 Assessment Model Diagnostics

5.1 Sensitivity to Assumptions, Data, and Weighting

All sensitivities in this section use the **pre-STAR** base model.

To better understand how data from individual fishery sectors or scientific surveys affected assessment results, we excluded data sets from the likelihood, one fleet at a time (referred to here as a "drop-one" analysis). "Fleet" in this sense refers to either a fishing fleet or a survey "fleet." To do this, we set "lambdas" (multipliers for each likelihood component) equal to zero. This is equivalent to removing the data from the model. When composition data were excluded, the selectivity parameters for that fleet were fixed at the base model estimates to standardize the size and age composition of harvested fish. When abundance indices were excluded, relevant catchability and 'extraSE' parameters associated with the index were not estimated. Composition data weights for the remaining fleets were kept consistent with the base model values. Results from all the 'drop-one' runs were compared to the base model using time series plots and tables containing likelihood components, parameter estimates and derived quantities.

For the southern California model, the NWFSC hook-and-line (HKL) survey is divided across two fleets (8 and 12; see survey description in the Fishery-Independent Data sources section). For consistency with other 'drop-one' runs, fleets 8 and 12 were excluded at the same time to remove all data associated with the hook-and-line survey. Removal of the HKL survey fleet (index, length comps, and age comps) resulted in larger estimates of unfished spawning output (Figure 106), and affected the trend in spawning biomass in recent years. Only removal of the REC_PC fleet had a noticeable effect on spawning output in the terminal year, but the difference was well within the estimated range of uncertainty from the base model. Relative spawning output ('depletion') estimates showed little change relative to the range of plausible outcomes predicted by the base model (Figure 107). Removal of the REC_PC fleet reduced the magnitude of negative recruitment deviations estimated in the 1970s, as well as the strength of the 1999 year class (Figure 108), but most general patterns in recruitment were consistent across the set of drop-one sensitivity tests. Changes in likelihoods, parameter estimates and derived quantities are recorded in Tables 11 and 12. Comparison of likelihoods among drop-one scenarios should be treated with caution due to changes in the data sets that were fit in each model run.

5.1.1 Sensitivity to Catch Uncertainty

To evaluate the influence of highly uncertain catch histories, we developed several sensitivity analyses. A "typical" sensitivity is to both halve and double historical catches, which tend to be far more uncertain than catches in the more recent and better documented era, particularly for rockfish (*Sebastes*). This is because historically most rockfish were landed in mixed stock market categories such as "unspecified rockfish" or "group red rockfish," and the species composition of these market categories were not sampled until the recent era (1978 in central and northern California, 1983 in the Southern California Bight). However, as described in the historical catch section, recent evaluations have suggested that historical catches in the Southern California Bight may be more uncertain than previously realized. Specifically, vermilion rockfish was explicitly described as "one of the most important commercial species, it is one of the three leading species (of rockfish) in"southern California" (Roedel 1948). The other two of the most important commercial species in southern waters were bocaccio, which is estimated to represented nine percent of total rockfish catch in southern waters between 1916 and 1950, and 20% between 1916 and 1968; and chilipepper, estimated to represent 11% of the catch between 1916 and 1950 and 14% between 1916 and 1968. However, the catch reconstruction estimated that vermilion rockfish catch to be less than five percent of the historical total for this region, while several species that were not described or described as "minor" importance were estimated to represent 10% or more of the catch (including bank, blackgill, bronzespotted and cowcod rockfish). The former two in particular are more deeply distributed slope species that were unlikely to represent a large fraction of catches in the 1920s and 1930s (Miller et al. 2014).

One partial explanation for the discrepancy is that market category 959, which is described as "group red" rockfish was rarely used until the late 1930s and early 1940s, but likely accounted for much of the vermilion rockfish catch from that period onward. Thus, vermilion rockfish would have been included in other market categories, such as market category 250, "unspecified rockfish," which accounted for half of the total rockfish catch early in the historical period. By the time species composition data were actually collected in the early 1980s, that market category would have very few vermilion rockfish, as most would have been sorted into "group red" or the "vermilion rockfish" (249) market categories. Consequently, when recent species composition data were applied to the historical market category catches, the fraction estimated to be vermilion rockfish would be biased low, and vermilion rockfish would be underrepresented in the earliest portion of the landings history. To evaluate a plausible alternative to the current estimates, we evaluated the consequences of assuming that both 10% and 20% of the total rockfish catches in the Southern California Bight were vermilion rockfish (comparable to the other two "leading species"). This effect would have likely been reduced from the late 1950s and early 1960s onward, thus for these sensitivities we only applied the higher catch levels to the pre-1969 time period (e.g., the time period of the historical reconstruction). These sensitivities were done in addition to both halving and doubling catches (both commercial and recreational) for the entire pre-1980 time period.

The halving and doubling of catches did lead to substantive differences in estimates of stock status, with a slightly more pessimistic perception in the doubling of historical catches and a slightly more optimistic perception in the halving (Figures 109 and 110). However, the treatment of only pre-1969 commercial catches did not lead to substantive changes in the perception of stock status, only a slight scaling of historical spawning output and an increase in historical harvest rates, resulted in a considerably earlier and more rapid stock decline relative to the base model. Associated with that increased scaling of historical spawning output was a slight increase in the equilibrium MSY level, by one to three tons depending on the scenario. The halving and doubling of all historical catches prior to 1980 had a more substantive effect on the estimated equilibrium MSY level, decreasing by approximately four tons and increasing by ~18 tons, respectively. However, there is less evidence to support a doubling of both relatively recent (60s through 70s) commercial catches and of recreational catches at this time. Given the relatively modest influence on the model results, and the need for more rigorous investigations and improvements to historical catch estimates (which are best done as an overarching effort on all historical catches), additional efforts to improve these estimates are likely more appropriate for future research recommendations.

5.1.2 Other Model Sensitivities

Results from the **pre-STAR** base model were compared to several alternative model specifications, as described below.

- Estimate the Beverton-Holt steepness parameter (h) rather than fixing it at the prior mean (h=0.72); estimate uncertainty intervals for comparison to base
- Start recruitment deviations 5 years earlier than the base model configuration
- Start recruitment deviations 5 years later than the base model configuration
- Compare results based on the McAllister-Ianelli data weighting method (for composition data) to the Francis method used for the base model.
- Mirror the recreational discard fleets' selectivity curves to the corresponding retained fleets (PC or PR) rather than fitting to discard length comps as in the base model.

Trends in spawning output for the southern California assessment model were generally robust to this set of sensitivities. However, recent estimates of spawning output were much lower when using McAllister-Ianelli data weights, relative to the Francis method used in the base model (Figure 111). The model tuned to McAllister-Ianelli weights was below target biomass, while the other models that used Francis weights showed similar trends in depletion and were above target biomass (Figure 112). The McAllister-Ianelli approach estimated a natural mortality rate that was about 20% lower than the Francis method (Tables 13). Best estimates from all runs were within the estimated range of uncertainty for the base model. Steepness in the southern region was estimated at a similar value than the prior mean (estimated at 0.77 vs. fixed at 0.72), and estimation of this parameter did not have a large effect on uncertainty in spawning output or recruitment deviations. The use of McAllister-Ianelli weights had the greatest impact on estimated recruitment deviations (Figure 113). This weighting method increased the variance of the estimated deviations as well as the estimated strength of the 1999 year class, relative to the models using the Francis approach. Changing the start date of the recruitment deviations had almost no effect. The McAllister-Ianelli method gives greater weight to the composition data for this model (Table 9).

During the STAR panel review, the STAT presented results from several sensitivity runs that were completed after distribution of the draft assessment document. All runs were conducted with the pre-STAR base models. These included:
- Fixing the natural mortality rate (M) to a value consistent with the observed maximum age when applying the Hamel prior (i.e., M = 5.4/80 = 0.07 yr^{-1})
- Assuming asymptotic (2-parameter) selectivity curves for all fleets, except for recreational discard and the NWFSC trawl survey)
- Estimating domed (4-parameter) selectivity curves for all fleets, but allowing for asymptotic shapes when supported by the data.
- Use of a 3-parameter, reparameterized Ricker stock-recruitment relationship instead of a standard, 2-parameter Beverton-Holt relationship.
- “Direct” estimation of male natural mortality and growth parameters, in contrast to the base model, which uses an exponential offset parameterization for male parameters and fixes male M = female M.
- Reduce the input variance of the NWFSC HKL index, forcing the model to fit the index better.

The STAT compared several results from these runs to the pre-STAR base model, including time series of spawning output, relative spawning output, and recruitment deviations (Figures 114, 115, and 116). Negative log likelihoods (total and by data type), parameter estimates, and derived quantities were also examined relative to the pre-STAR base (Table 14). Fixing M at 0.07 degraded the overall fit to the data, increasing the likelihood by more than 38 points. The model with forced asymptotic selectivity did not converge (parameters hit bounds), estimated a natural mortality rate that was inconsistent with the observed ages (M=0.26) and had a higher total negative likelihood. Estimating 4 selectivity parameters per fleet (excluding the discard and NWFSC trawl survey) produced results similar to the pre-base model. The STAT notes that the post-STAR base model allowed for greater flexibility in time-varying selectivity for the commercial hook-and-line fleet, relative to the pre-STAR base, so results from this sensitivity may differ if applied to the post-STAR base model. Parameters from a reparameterized Ricker stock-recruitment relationship were estimable (Table 14) with M fixed at 0.12, but produced results that were generally consistent with the Beverton-Holt relationship assumed in the base model. However, uncertainty in spawning output and relative stock status were greatly increased under the 3-parameter Ricker model (Figures 114 and 115). Sex-specific estimates of the natural mortality rate were similar to the combined estimate in the base model, and within one standard deviation based on reported asymptotic standard errors of the parameters. Lastly, reducing the input standard errors for the NWFSC hook-and-line survey had the expected effect of improving the fit to the index, but degraded the overall model fit (Table 14). The improved fit to the hook-and-line index was mainly accomplished through a reduction in the estimated natural mortality rate, slowing the rate of population increase to better match the index.

5.2 Likelihood Profiles

Likelihood profiles were conducted for natural mortality (M), steepness (h) and the log of R0 (unfished recruitment) by fixing these parameters across a range of values and continuing to estimate the remaining parameters assuming the base model framework. All models in this section use the **post-STAR** base models.

The profiles for natural mortality in the southern base model (Figures 117, 118, 119, 120, and 121) suggest that this parameter is reasonably well informed between a range of approximately 0.11 and 0.14. The profiles suggest a somewhat commonly observed phenomena of tension between the age data, which would suggest a lower natural mortality rate, and the length and index data, which tend to fit the data better with a higher value for M. The notable exceptions to these generalizations include the NWFSC hook and line survey index, which fits the data better with a considerably lower M, and the commercial fisheries data (hook-and-line, and setnet), which also fit the data better with a lower M. Intuitively, spawning output increased with lower natural mortality rate estimates, while the estimate of relative stock status was more pessimistic, while the converse was true (lower spawning output, more optimistic stock status estimates) with higher M values.

A profile of steepness was conducted on values ranging from 0.30 to 0.90 in 0.10 increments. The resulting likelihood profiles (by component, and by component and fleet) are shown as Figure 122, while model trajectories (spawning output, relative depletion, age-0 recruits and recruitment deviations) are shown as Figures 124, 123, 125, and 126. The likelihood profiles show that the overall best fit to the data is associated with high steepness values, although the data were generally uninformative above steepness values of 0.5. Overall the length data were not very informative, and there were some odd changes in the likelihood in some fleets at very low (0.3) steepness values. Similarly the age data were only marginally informative, and suggested higher steepness values in general. Most of the indices also suggested higher steepness values, particularly the NWFSC hook and line survey index, although the Rec PC index had a significantly better fit at lower steepness values. Predictably, spawning output scaled down with higher steepness values and up with lower values, however the estimate of stock status in 2021 varied relatively little across the range of values. Interestingly the most optimistic runs with respect to relative stock status were both the highest and the lowest values in the profile, although the overall difference was negligible for the ending year. The higher steepness runs were more pessimistic with respect to historical (late 1980s through the early 2000s) stock status.

A profile on the log of unfished recruitment (Ln R0) was conducted on values ranging from 6.2 to 6.9 (the base model estimate in base model was 6.66). In general, age data was better fit by the model with lower values of R0, survey data (as well as recruitment via likelihood penalties) were better fit by higher R0 values, and the cumulative fit to length data was best close to the base model estimate (Figure 127). The components by fleet were variable in the cases of length composition data, in which the commercial hook and line fishery and the Rec PC data fit better with lower R0 values, while the remaining fleets fit better with higher R0 values or were non-informative (Figures 128, 129, 130, and 131). Spawning output is estimated to be greater with the higher R0 values and lower with the lower R0 values, as a result of corresponding model changes in the estimate of the natural mortality rate (which is estimated to be much lower in the low R0 model). This results in the lower R0 runs also being more pessimistic, as the lower R0 runs were associated with considerably lower natural mortality rates. Additional profiles in which M is fixed may be helpful in evaluating model performance across many of the key model parameters.

5.3 Retrospective Analysis

All models in this section use the **post-STAR** base model.

A five year retrospective analysis was conducted on the southern base model by sequentially removing data, beginning with data from the year 2020. Figures 132, 133, 134, and 135 show the estimated spawning output, the estimated depletion, and recruitment deviation estimates. The greatest impact was the declining estimate of the strength of the 2016 year class, similar to the northern model, with the interesting result that with the loss of only 1-3 years of data the model attributes greater recruitment to 2015 relative to the base model, with variable responses among other recruitment estimates. This change is associated with an increasingly pessimistic perception of stock status, although the overall scaling of spawning output is relatively modest. This shift is understandably associated with the change in population trajectory as data supporting strong recent recruitment are removed. Beyond this shift, this analysis does not suggest that there are substantive retrospective patterns (Table 15). Note that all composition data weights were held constant at the base model values during each run.

5.4 Unresolved Problems and Major Uncertainties

Uncertainty around the magnitude of historical vermilion rockfish catches may be higher in this region, as some accounts suggest considerably higher historical catches than estimated in the 2010 catch reconstruction.

The primary fishery-independent survey for west coast groundfish, the NWC WCGBTS, does not sample rocky habitats where most vermilion rockfish are found, and thus does not provide a robust index of abundance (and was excluded from this assessment). The NWFSC hook and line survey provides demographic and relative abundance data throughout the Southern California Bight, with the exception of some state closed areas.

While recent age data are robust, based primarily on the NWFSC hook-and-line survey, historical age data (both fishery-dependent and fishery-independent) are very limited. The likelihood profiles suggest a somewhat commonly seen pattern of tension among data sources, with age data suggesting a lower natural mortality rate and length data (as well as most index data) suggesting a higher M. Natural mortality appears to be reasonably well estimated but is still uncertain, and seems to have the greatest influence on scaling the relative biomass and stock trajectory.

The model estimates a series of very low recruitment events through the late 1970s and early 1980s, a period in which many other rockfish in this region experienced high levels of recruitment. Recruitment patterns in more recent years generally follow those for other stocks. It is possible that selectivity patterns changed, data are biased, model misspecification, or unknown ecosystem interactions could be responsible for this pattern.

6 Harvest Projections and Decision Tables

The forecasts of stock abundance and yield were developed using the post-STAR base model, with the forecast projections presented in Table ix. The total catches in 2021 and 2022 are set to the projected catch from the California Department of Fish and Wildlife (CDFW) by sector and model region, i.e., allocated north and south of $34°27'N$ in California.

Uncertainty in the decision table forecasts is based upon the three alternative states of nature agreed upon during the STAR panel, reflecting results of a bivariate likelihood profile over natural mortality and steepness. The low state of nature assumes $M = .1125$ and $h = 0.675$, and the high state of nature assumes $M = 0.1475$ and $h = 0.875$.

The buffers between OFL and ABC were calculated assuming a category 2 stock, with $\sigma = 1.0$ and a $p^* = 0.45$. For reference, the base model predicted σ is 0.258, calculated using the asymptotic standard error of the predicted OFL in 2021. Alternative catch streams (rows in the table) include $\sigma = 1.0$ with a $p^* = 0.4$, and removals of long-term equilibrium catch at the $F_{SPR=50\%}$ harvest rate with and without a buffer assuming $\sigma = 1.0$ and a $p^* = 0.45$. The buffer multiplier with $p^* = 0.45$ ranges from 0.874 in 2023 ramping to 0.803 in 2032.

The base model with the default harvest control rule catches (p*=0.45, σ=1) predicts an increasing stock over the period from 2023-2032. Forecasts based on the alternative catch streams project that the stock will remain above the target threshold of 40% through 2032 given either the base model or “high” states of nature (Table x). Given the low state of nature, the stock remains below the target threshold of 40% throughout the 12-year forecast under all four catch scenarios.

The STAT cautions that the GMT projections for catches in 2021-2022 (210 mt per year) exceed the maximum sustainable yield according to both proxies ($B_{40\%}$ and $SPR_{50\%}$) as well as the MSY value based on the estimated value of steepness (Table v). The southern California stock is above target biomass, so the GMT catch levels are unlikely to result in significant stock declines over a 2-year period. However, similar catch levels would exceed the overfishing limits (OFL) for 2023 and beyond (Table ix), and would be unsustainable in the long term. Given recent and projected near-term exploitation levels, and especially if vermilion and sunset rockfish continue to be managed as part of the minor shelf rockfish complex, the STAT recommends regular monitoring of total mortality for these two species to avoid excessive stock depletion and potential loss of yield.

6.1 Regional Management and Spatial Management Considerations

Over the last several decades, spatially explicit management measures at both the state and federal/management council level have been implemented to achieve a wide range of marine resource and fishery management objectives. Depth restrictions to commercial and recreational fisheries in the Rockfish Conservation Areas (RCAs) and the Cowcod Conservation Areas (CCAs) are key among those, as are the suite of total and partial exclusion of commercial and recreational fishing activities in the California statewide network of Marine Protected Areas (MPAs). While the former are associated with explicit fisheries management objectives, the latter have a suite of ecological and economic objectives, most of which are not specific to, nor integrated across, the fisheries management arena. Despite this, both types of spatial management measures are expected to result in various biological, ecological, and socioeconomic effects within and adjacent to their boundaries. All of these effects have the potential to influence the nature and quality of the data used to inform stock assessments of species that reside in these areas, including vermilion rockfish.

Regardless of the management objective, spatial closures are expected to increase the spatial heterogeneity in abundance and size or age structure of fished stocks. This greater spatial variability can complicate the assumptions made in stock assessment models, particularly the assumption that the densities and demographic structure of assessed populations are relatively homogeneous, at least across predictable habitat types such as bathymetric gradients or substrate types (Punt and Methot 2004, Field et al. 2006, Berger et al. 2017). Although a wide range of factors above and beyond spatial management measures can also lead to violations of those assumptions, and the challenge is intuitively less problematic for populations with high movement rates and/or high population turnover, the challenge can be particularly important for longer lived populations with lower movement rates. The challenge can best be summarized by the result that the more effective MPAs or other closed areas are at protecting populations within them, the more likely it is that traditional assessment approaches will be biased or more uncertain.

If the spatial closures also prevent fisheries independent surveys from evaluating the relative abundance and demographic structure of managed populations, the challenges in developing robust population models, and thus robust management advice, become even more severe. While spatially explicit assessment models provide a means of more explicitly addressing these challenges, such models are computationally intensive, require robust data from the specific areas being modeled, and may also require detailed information regarding movement and dispersal rates (McGilliard et al. 2014, Berger et al. 2017, Cadrin 2020, Punt et al. 2020). Moreover, the complexity of these spatial models increases substantially if the size and location of closed areas changes over time, as many of the more "fisheries management based" closures (e.g., RCAs) have in California groundfish fisheries. Thus, such approaches may be less feasible for more data limited stocks, such as northern and southern vermilion rockfish, at least in the near term. However, the fact that both the northern and southern assessment models are informed by fishery-independent surveys that include habitats both inside and outside area closures provides some hope for greater recognition of spatial factors in future assessments.

7 Research and Data Needs

We recommend the following research be conducted before the next assessment:

- Investigate the structure of complex and contribution of each species to the vermilion/sunset rockfish complex. Investigate possible spatial differences in biological parameters within a single species and also between the two species. Little biological data for south of Point Conception or north of Point Arena were available for this assessment and is needed to better under biological parameters.
  - Conduct life history studies
  - Conduct research to identify the proportion of each species in population and in catches
- Take a closer look at historical catch reconstructions and all other historical data sources.
- Refine CCFRP survey index to look at alternative possible model structures, including a hierarchical structure and random effects. The CCFRP survey is the only fishery-independent survey available for nearshore rockfish sampling the nearshore rocky reef habitats. As of this assessment, only two years of coastwide data are available, and the index was limited to the site in central California that have been monitored since 2007.
- Continue to investigate the most appropriate model structure for the NWFSC HL survey index. The NWFSC HL survey is the only long-term fishery-independent

survey in rocky (untrawlable) habitat in the Southern California Bight. We also recommend evaluating how to structure the NWFSC Hook-and-Line survey index, given its expansion into the CCA, also independent analysis of information content in NWFSC Hook-and-Line survey. Increased spatiotemporal sampling around Point Conception would aid in identifying stock boundaries.

- Utilize existing ROV survey data sources
    - SWFSC Submersible Survey of the Cowcod Conservation Areas (Yoklavich et al. 2007).
    - This was a line-transect survey designed to estimate cowcod abundance in 2002 conducted from a submersible inside the CCAs. Originally, only cowcod were enumerated from the video footage. Over the last few years, the SWFSC has re-analyzed the video footage to enumerate other rockfish species.
    - The SWFSC Fishery Resource Division (FRD) conducted a survey of potential cowcod habitat between Point Conception and the U.S. – Mexico border from October through December of 2012 (Stierhoff and Cutter 2013).
    - SWFSC staff are submitting proposals to conduct an additional submersible survey in the Southern California Bight
    - CDFW ROV survey data
- Collection of length and age data are recommended for both the commercial and recreational fisheries. Very little age data are available from either fishery for vermilion and sunset rockfish.
- Investigate possible environmental drivers/co-variates for biological parameters, particularly for recruitment.
- Resolve differences between CalCOM and PacFIN expanded length composition data sets.

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Tables

Table 1: Landings of vermilion rockfish by fleet and year. All recreational fleet landings are in numbers (thousands of fish) and commercial fleets in biomass (mt). A description of the sources of the landings data are in the text and the next table.

Year	COM HKL(1)	COM TWL(2)	COM NET(3)	REC PC(4)	REC PC DIS(5)	REC PR(6)	REC PR DIS(7)	Total commerical	Total recreational
1875	0.222							0.222	
1876	0.443							0.443	
1877	0.665							0.665	
1878	0.886							0.886	
1879	1.108							1.108	
1880	1.329							1.329	
1881	1.551							1.551	
1882	1.772							1.772	
1883	1.994							1.994	
1884	2.215							2.215	
1885	2.437							2.437	
1886	2.658							2.658	
1887	2.880							2.880	
1888	3.101							3.101	
1889	3.323							3.323	
1890	3.544							3.544	
1891	3.766							3.766	
1892	3.988							3.988	
1893	3.763							3.763	
1894	3.539							3.539	
1895	3.315							3.315	
1896	3.131							3.131	
1897	2.946							2.946	
1898	2.761							2.761	
1899	2.576							2.576	
1900	2.850							2.850	
1901	3.124							3.124	
1902	3.398							3.398	
1903	3.672							3.672	
1904	3.946							3.946	
1905	4.217							4.217	
1906	4.487							4.487	
1907	4.758							4.758	
1908	5.028							5.028	
1909	5.658							5.658	

Table 1: Landings of vermilion rockfish by fleet and year. All recreational fle Landings of vermilion rockfish by fleet and year (continued).

Year	COM HKL(1)	COM TWL(2)	COM NET(3)	REC PC(4)	REC PC DIS(5)	REC PR(6)	REC PR DIS(7)	Total commerical	Total recreational
1910	6.288							6.288	
1911	6.918							6.918	
1912	7.547							7.547	
1913	8.177							8.177	
1914	8.807							8.807	
1915	9.437							9.437	
1916	10.719							10.719	
1917	17.300							17.300	
1918	15.775							15.775	
1919	9.432							9.432	
1920	10.247							10.247	
1921	8.953							8.953	
1922	8.808							8.808	
1923	11.798							11.798	
1924	15.818							15.818	
1925	17.356							17.356	
1926	21.537							21.537	
1927	17.872							17.872	
1928	15.233			0.102		0.009		15.233	0.111
1929	15.413			0.204		0.019		15.413	0.223
1930	15.701			0.306		0.028		15.701	0.334
1931	11.825			0.408		0.037		11.825	0.445
1932	20.048			0.510		0.047		20.048	0.557
1933	6.400			0.611		0.056		6.400	0.667
1934	11.678			0.713		0.065		11.678	0.778
1935	12.958			0.815		0.075		12.958	0.890
1936	11.356			0.815		0.075		11.356	0.890
1937	12.027			1.284		0.114		12.027	1.398
1938	7.770			1.359		0.103		7.770	1.462
1939	8.717			1.039		0.091		8.717	1.130
1940	12.105			0.839		0.067		12.105	0.906
1941	14.372			0.775		0.062		14.372	0.837
1942	4.971			0.412		0.033		4.971	0.445
1943	6.251			0.394		0.031		6.251	0.425
1944	1.566			0.323		0.026		1.566	0.349
1945	3.350			0.431		0.034		3.350	0.465
1946	4.516			0.742		0.059		4.516	0.801

Table 1: Landings of vermilion rockfish by fleet and year. All recreational fle Landings of vermilion rockfish by fleet and year (continued).

Year	COM HKL(1)	COM TWL(2)	COM NET(3)	REC PC(4)	REC PC DIS(5)	REC PR(6)	REC PR DIS(7)	Total commerical	Total recreational
1947	4.909			2.037		0.211		4.909	2.248
1948	7.594			6.572		0.503		7.594	7.075
1949	9.189			9.341		0.632		9.189	9.973
1950	14.356	0.008		9.529		0.762		14.364	10.291
1951	30.276	0.546		7.344		0.651		30.822	7.995
1952	17.110	0.123		11.905		0.821		17.233	12.726
1953	11.576	0.064		15.558		0.972		11.640	16.530
1954	13.386	3.832		29.359		2.200		17.218	31.559
1955	11.751	14.701		50.462		3.888		26.452	54.350
1956	16.141	3.989		59.738		4.534		20.130	64.272
1957	16.821	4.979		37.010		2.647		21.800	39.657
1958	72.113	4.619		32.439		1.786		76.732	34.225
1959	70.070	2.082		18.112		1.046		72.152	19.158
1960	62.396	3.710		14.579		1.079		66.106	15.658
1961	48.540	3.000		15.880		1.234		51.540	17.114
1962	29.570	2.666		15.702		1.195		32.236	16.897
1963	27.275	3.346		15.144		1.211		30.621	16.355
1964	27.331	1.925		25.382		1.704		29.256	27.086
1965	45.180	1.862		31.473		4.440		47.042	35.913
1966	37.854	1.990		52.645		8.860		39.844	61.505
1967	34.326	3.183		56.224		13.210		37.509	69.434
1968	25.103	3.576		66.690		16.724		28.679	83.414
1969	29.271	2.957	0.544	57.454		16.624		32.772	74.078
1970	19.930	1.486	0.363	75.982		25.467		21.779	101.449
1971	22.690	2.197	0.233	70.971		25.482		25.120	96.453
1972	34.002	3.191	0.184	91.772		35.461		37.377	127.233
1973	32.155	3.540	0.538	105.503		43.817		36.233	149.320
1974	27.650	3.772	1.442	113.447		54.612		32.864	168.059
1975	49.065	2.791	1.395	121.792		56.034		53.251	177.826
1976	60.215	3.596	1.628	91.611		46.437		65.439	138.048
1977	50.624	4.456	2.619	87.988		44.241		57.699	132.229
1978	69.492	3.441	8.211	87.677		43.492		81.144	131.169
1979	112.964	2.225	22.269	115.558		62.477		137.458	178.035
1980	104.687	0.399	18.404	97.673	1.647	55.657	15.233	123.490	170.210
1981	101.069	0.624	21.788	76.787	1.697	20.589	4.232	123.481	103.305
1982	156.830	1.552	12.795	101.130	2.236	51.795	10.646	171.177	165.807
1983	94.963	2.640	12.241	45.845	1.013	15.814	3.251	109.844	65.923

Table 1: Landings of vermilion rockfish by fleet and year. All recreational fle Landings of vermilion rockfish by fleet and year (continued).

Year	COM HKL(1)	COM TWL(2)	COM NET(3)	REC PC(4)	REC PC DIS(5)	REC PR(6)	REC PR DIS(7)	Total commerical	Total recreational
1984	61.866		18.664	98.154	2.170	37.676	7.744	80.530	145.744
1985	65.340	1.361	32.406	94.202	2.082	69.340	14.253	99.107	179.877
1986	103.427		28.150	289.555	6.401	80.749	16.598	131.577	393.303
1987	31.969		20.062	42.485	0.939	319.807	65.737	52.031	428.968
1988	29.383		1.601	85.182	1.883	111.696	22.959	30.984	221.720
1989	119.059		12.135	168.326	3.721	49.681	10.212	131.194	231.940
1990	127.440		11.312	103.909	2.297	85.407	17.555	138.752	209.168
1991	173.623		19.465	81.064	1.792	90.125	18.525	193.088	191.506
1992	151.701		27.151	58.219	1.287	94.843	19.495	178.852	173.844
1993	138.689		22.870	26.975	0.596	78.280	16.091	161.559	121.942
1994	206.471		12.040	43.773	0.968	120.841	24.839	218.511	190.421
1995	109.487	1.060	3.359	25.471	0.563	101.708	20.906	113.906	148.648
1996	72.081	0.052	2.165	107.198	2.370	76.621	15.749	74.298	201.938
1997	77.454	2.527	1.095	6.795	0.150	6.871	1.412	81.076	15.228
1998	79.312	2.214	0.264	41.589	0.919	23.702	4.872	81.790	71.082
1999	16.241	1.323	0.396	113.148	2.501	47.882	9.842	17.960	173.373
2000	5.183	0.108	0.082	52.550	1.162	52.718	10.836	5.373	117.266
2001	3.144	0.027	0.048	29.422	0.650	40.831	8.393	3.219	79.296
2002	4.594	0.079		71.110	1.572	46.901	9.641	4.673	129.224
2003	0.340	0.017		107.110	2.368	79.116	16.262	0.357	204.856
2004	4.296	0.007		131.057	2.897	32.588	6.698	4.303	173.240
2005	10.147		0.005	164.631	3.476	31.546	3.977	10.152	203.630
2006	9.346		0.013	27.315	2.379	29.149	2.106	9.359	60.949
2007	9.908			56.203	1.441	35.195	3.577	9.908	96.416
2008	5.790			32.090	0.565	24.471	2.332	5.790	59.458
2009	6.145			31.421	2.436	19.627	2.460	6.145	55.944
2010	6.192	0.084		53.679	1.906	24.707	4.506	6.276	84.798
2011	7.564			145.270	12.252	31.938	3.241	7.564	192.701
2012	8.533			202.896	29.536	45.931	4.124	8.533	282.487
2013	10.999	0.073		210.359	9.028	39.903	3.494	11.072	262.784
2014	12.651	0.051	0.013	148.321	8.318	27.725	1.994	12.715	186.358
2015	21.976	0.065	0.006	252.852	9.807	34.247	2.838	22.047	299.744
2016	16.099	0.171	0.056	207.393	5.633	34.706	2.274	16.326	250.006
2017	33.287	0.115	0.022	139.859	10.890	33.119	2.293	33.424	186.161
2018	40.246	0.034	0.039	141.229	14.013	23.196	2.605	40.319	181.043
2019	47.217	0.291	0.045	312.321	33.368	48.945	6.426	47.553	401.060
2020	48.764	0.075	0.096	67.263	10.370	28.887	3.037	48.935	109.557

Table 1: Landings of vermilion rockfish by fleet and year. All recreational fle Landings of vermilion rockfish by fleet and year (continued).

Year	COM HKL(1)	COM TWL(2)	COM NET(3)	REC PC(4)	REC PC DIS(5)	REC PR(6)	REC PR DIS(7)	Total commerical	Total recreational

Table 2: Sources of landings for the commercial and recreational fleets. The interpolated values were interpolated by J. Field (SWFSC). The reconstruction refers to the commercial and recreational catch recontructions in Ralston et al. (2010). Detailed descriptions of the sources are in the text.

Fleet	Interpolated	Reconstruction	CALCOM	MRFSS	CRFS
COM_HKL_1	1875-1915	1916-1968	1983-2020		
COM_TWL_2		1950-1968	1983-2020		
COM_NET_3			1983-2020		
REC_PC_4		1928-1980		1981-2003	2004-2020
REC_PC_DIS_5				1980-2003	2004-2020
REC_PR_6		1928-1980		1981-2003	2004-2020
REC_PR_DIS_7				1980-2003	2004-2020

Table 3: Re-apportionment of the Ralson et al. (2010) commercial catch reconstruction to north and south of Point Conception. San Luis Obispo county landings were assigned to southern California.

	FB 105	NMFS ERD live-access server				Major SLO Ports					
Year	Southern	San Diego	Los Angeles	Santa Barbara	Foreign catch landed in U.S.	Morro Bay	Avila	Source of SLO catch	Adjusted Santa Barbara	Ratio years	Percent Area 6 So. of Pt. Conc
1916	966.622	330.180	620.062		7.111			ratio	9.269	1928-33	0.328
1917	1559.699	532.764	1000.505		11.474			ratio	14.956	1928-33	0.328
1918	1422.288	485.827	912.360		10.463			ratio	13.638	1928-33	0.328
1919	850.462	290.502	545.548		6.257			ratio	8.155	1928-33	0.328
1920	923.717	315.525	592.540		6.796			ratio	8.857	1928-33	0.328
1921	806.935	275.634	517.627		5.936			ratio	7.738	1928-33	0.328
1922	793.996	271.214	509.327		5.841			ratio	7.614	1928-33	0.328
1923	1063.847	363.390	682.429		7.826			ratio	10.201	1928-33	0.328
1924	1426.244	487.178	914.897		10.492			ratio	13.676	1928-33	0.328
1925	1564.436	534.382	1003.544		11.509			ratio	15.001	1928-33	0.328
1926	1941.864	663.304	1245.654		14.286			ratio	18.620	1928-33	0.328
1927	1611.490	550.455	1033.728		11.855			ratio	15.452	1928-33	0.328
1928	1373.499	554.760	769.848	46.650	2.240	17.445	13.895	ratio	15.310	1949-51	0.328
1929	1389.528	641.799	687.264	44.600	15.864	16.678	13.285	ratio	14.637	1949-51	0.328
1930	1415.632	477.907	906.133	21.152	10.439	7.910	6.300	ratio	6.942	1949-51	0.328
1931	1617.811	400.302	1182.352	30.906	4.252	11.557	9.206	ratio	10.143	1949-51	0.328
1932	1135.482	298.471	797.365	34.762	4.885	12.999	10.354	ratio	11.408	1949-51	0.328
1933	907.472	252.635	588.304	46.540	19.993	17.404	13.863	ratio	15.274	1949-51	0.328
1934	857.005	129.533	510.376	127.600	89.495	47.716	38.007	ratio	41.877	1949-51	0.328
1935	741.225	77.847	373.921	177.653	111.805	66.434	52.916	ratio	58.303	1949-51	0.328
1936	424.053	69.717	122.803	181.882	49.651	68.015	54.176	ratio	59.691	1949-51	0.328

Table 3: Re-apportionment of the Ralson et al. (2010) commercial cat Re-apportionment of the commercial catch reconstruction (continued).

	FB 105	NMFS ERD live-access server				Major SLO Ports					
Year	Southern	San Diego	Los Angeles	Santa Barbara	Foreign catch landed in U.S.	Morro Bay	Avila	Source of SLO catch	Adjusted Santa Barbara	Ratio years	Percent Area 6 So. of Pt. Conc
1937	460.648	65.181	156.838	166.262	72.367	62.174	49.523	ratio	54.565	1949-51	0.328
1938	309.183	33.821	126.044	72.755	76.562	27.207	21.671	ratio	23.877	1949-51	0.328
1939	389.656	92.008	140.829	91.190	65.629	34.101	27.162	ratio	29.927	1949-51	0.328
1940	396.317	66.629	153.114	136.399	40.176	51.007	40.628	ratio	44.764	1949-51	0.328
1941	470.112	42.149	202.954	131.567	93.442	49.200	39.189	ratio	43.179	1949-51	0.328
1942	192.964	10.126	74.461	38.266	70.112	14.310	11.398	ratio	12.558	1949-51	0.328
1943	226.429	5.169	89.074	38.614	93.572	14.440	11.502	ratio	12.673	1949-51	0.328
1944	43.382	4.630	10.338	22.144	6.270	8.281	6.596	ratio	7.267	1949-51	0.328
1945	92.924	4.558	26.967	44.949	16.450	16.809	13.388	ratio	14.752	1949-51	0.328
1946	161.187	8.714	79.597	48.777	24.098	18.240	14.529	ratio	16.008	1949-51	0.328
1947	185.457	8.786	131.603	26.850	18.218	10.041	7.998	ratio	8.812	1949-51	0.328
1948	287.675	24.117	200.075	36.114	27.369	13.505	10.757	ratio	11.852	1949-51	0.328
1949	412.088	36.639	258.883	61.876	54.690	20.622	22.953	FB 80	18.301		0.296
1950	427.871	33.670	294.001	85.959	14.241	41.230	28.680	FB 86	16.049		0.187
1951	470.814	14.547	328.925	121.629	5.713	38.915	28.630	FB 89	54.084		0.445
1952	366.255	9.471	218.591	108.149	30.044	32.526	25.907	FB 95, ratio	49.716	1949-51	0.460
1953	298.737	14.706	179.438	88.656	15.937	56.383	4.399	FB 102, ratio	27.874	1954-57	0.314
1954	583.020	14.098	247.222	263.088	58.612	183.912	43.299	FB 102	35.877		0.136
1955	1810.387	48.451	199.073	1532.343	30.520	1393.824	119.727	FB 105	18.791		0.012

Table 3: Re-apportionment of the Ralson et al. (2010) commercial cat Re-apportionment of the commercial catch reconstruction (continued).

	FB 105	NMFS ERD live-access server				Major SLO Ports					
Year	Southern	San Diego	Los Angeles	Santa Barbara	Foreign catch landed in U.S.	Morro Bay	Avila	Source of SLO catch	Adjusted Santa Barbara	Ratio years	Percent Area 6 So. of Pt. Conc
1956	1481.432	35.073	257.455	1168.674	20.230	1026.897	69.943	FB 105	71.835		0.061
1957		32.080	227.864	1522.506		1298.195	71.549	FB 108	152.763		0.100
1958		141.032	228.887	1425.890		1136.077	88.642	FB 108, ratio	201.171	1954-57	0.141
1959		94.833	264.463	670.998		470.075	36.678	FB 111, ratio	164.245	1954-57	0.245
1960		89.909	238.784	1280.674		910.701	71.057	FB 117, ratio	298.916	1954-57	0.233
1961		98.523	174.942	1052.766		550.967	42.989	FB 121, ratio	458.809	1954-57	0.436
1962		70.086	172.422	916.793		602.720	56.922	FB 125	257.151		0.280
1963		112.154	220.538	1180.383		652.240	230.784	FB 129	297.359		0.252
1964		87.014	207.471	718.626		467.924	114.139	FB 132	136.564		0.190
1965		132.791	248.713	786.035		453.991	40.039	FB 135	292.005		0.371
1966		136.442	226.385	1026.923		666.109	82.682	FB 138	278.132		0.271
1967		167.066	250.557	1313.093		721.161	96.735	FB 144	495.197		0.377
1968		126.059	242.670	1187.506		612.312	34.805	FB 149	540.388		0.455

Table 4: Samples sizes of length composition data by year.

Source	Year	Fleet(#)	Number fish	Sample size	Trips
CALCOM	1983	COM_HKL(1)	23	1	1
CALCOM	1985	COM_HKL(1)	175	10	10
CALCOM	1986	COM_HKL(1)	309	22	22
CALCOM	1987	COM_HKL(1)	82	6	6
CALCOM	1988	COM_HKL(1)	101	5	5
CALCOM	1989	COM_HKL(1)	332	17	17
CALCOM	1990	COM_HKL(1)	40	2	2
CALCOM	1991	COM_HKL(1)	31	1	1
CALCOM	1992	COM_HKL(1)	102	6	5
CALCOM	1994	COM_HKL(1)	97	5	5
CALCOM	1995	COM_HKL(1)	486	26	26
CALCOM	1996	COM_HKL(1)	297	19	16
CALCOM	1997	COM_HKL(1)	568	31	31
CALCOM	1998	COM_HKL(1)	821	39	39
CALCOM	1999	COM_HKL(1)	79	3	3
CALCOM	2001	COM_HKL(1)	11	1	1
CALCOM	2002	COM_HKL(1)	96	4	3
CALCOM	2005	COM_HKL(1)	13	1	1
CALCOM	2006	COM_HKL(1)	95	7	7
CALCOM	2007	COM_HKL(1)	31	2	2
CALCOM	2008	COM_HKL(1)	58	3	3
CALCOM	2009	COM_HKL(1)	114	4	4
CALCOM	2010	COM_HKL(1)	42	2	2
CALCOM	2012	COM_HKL(1)	89	3	3
CALCOM	2013	COM_HKL(1)	127	3	3
CALCOM	2014	COM_HKL(1)	481	18	17
CALCOM	2015	COM_HKL(1)	470	18	18
CALCOM	2016	COM_HKL(1)	532	22	22
CALCOM	2017	COM_HKL(1)	336	16	15
CALCOM	2018	COM_HKL(1)	350	15	14
CALCOM	2019	COM_HKL(1)	381	16	16
CALCOM	2020	COM_HKL(1)	439	21	16
CALCOM	1985	COM_TWL(2)	18	1	1
CALCOM	1999	COM_TWL(2)	67	1	1
CALCOM	2016	COM_TWL(2)	34	1	1
CALCOM	1983	COM_NET(3)	81	3	3
CALCOM	1984	COM_NET(3)	94	6	6
CALCOM	1985	COM_NET(3)	103	8	8
CALCOM	1986	COM_NET(3)	116	7	7
CALCOM	1987	COM_NET(3)	22	2	2
CALCOM	1989	COM_NET(3)	13	1	1

Table 4: Samples sizes of length composition data by year. *(continued)*

Source	Year	Fleet(#)	Number fish	Sample size	Trips
CALCOM	1992	COM_NET(3)	34	2	2
CALCOM	1995	COM_NET(3)	26	2	2
CALCOM	1996	COM_NET(3)	37	2	2
CALCOM	1998	COM_NET(3)	20	1	1
CDFW	1975	REC_PC(4)	1341		180
CDFW	1976	REC_PC(4)	1520		203
CDFW	1977	REC_PC(4)	2063		171
CDFW	1978	REC_PC(4)	2099		162
MRFSS	1980	REC_PC(4)	87		50
MRFSS	1981	REC_PC(4)	223		74
MRFSS	1982	REC_PC(4)	281		94
MRFSS	1983	REC_PC(4)	207		112
MRFSS	1984	REC_PC(4)	374		191
MRFSS	1985	REC_PC(4)	313		145
MRFSS	1986	REC_PC(4)	608		225
MRFSS	1987	REC_PC(4)	45		28
MRFSS	1988	REC_PC(4)	179		74
MRFSS	1989	REC_PC(4)	27		26
CDFW	1986	REC_PC(4)	1147		141
CDFW	1987	REC_PC(4)	2098		162
CDFW	1988	REC_PC(4)	2509		142
CDFW	1989	REC_PC(4)	1950		162
MRFSS	1993	REC_PC(4)	77		50
MRFSS	1994	REC_PC(4)	132		87
MRFSS	1995	REC_PC(4)	42		32
MRFSS	1996	REC_PC(4)	202		107
MRFSS	1997	REC_PC(4)	13		12
MRFSS	1998	REC_PC(4)	283		140
MRFSS	1999	REC_PC(4)	1166		545
MRFSS	2000	REC_PC(4)	841		343
MRFSS	2001	REC_PC(4)	288		182
MRFSS	2002	REC_PC(4)	989		390
MRFSS	2003	REC_PC(4)	1086		443
CRFS	2004	REC_PC(4)	2036		360
CRFS	2005	REC_PC(4)	1978		149
CRFS	2006	REC_PC(4)	2041		153
CRFS	2007	REC_PC(4)	2381		179
CRFS	2008	REC_PC(4)	1848		139
CRFS	2009	REC_PC(4)	1694		127
CRFS	2010	REC_PC(4)	2212		166
CRFS	2011	REC_PC(4)	3883		292
CRFS	2012	REC_PC(4)	4751		357

Table 4: Samples sizes of length composition data by year. *(continued)*

Source	Year	Fleet(#)	Number fish	Sample size	Trips
CRFS	2013	REC_PC(4)	5544		417
CRFS	2014	REC_PC(4)	3688		308
CRFS	2015	REC_PC(4)	4210		267
CRFS	2016	REC_PC(4)	3724		248
CRFS	2017	REC_PC(4)	2348		234
CRFS	2018	REC_PC(4)	2357		215
CRFS	2019	REC_PC(4)	3804		255
CRFS	2020	REC_PC(4)	331		15
CRFS	2003	REC_PC_DIS(5)	1		
CRFS	2004	REC_PC_DIS(5)	1		
CRFS	2005	REC_PC_DIS(5)	3		
CRFS	2006	REC_PC_DIS(5)	2		
CRFS	2007	REC_PC_DIS(5)	2		
CRFS	2008	REC_PC_DIS(5)	4		
CRFS	2009	REC_PC_DIS(5)	13		
CRFS	2010	REC_PC_DIS(5)	31		
CRFS	2011	REC_PC_DIS(5)	22		
CRFS	2012	REC_PC_DIS(5)	42		
CRFS	2013	REC_PC_DIS(5)	24		
CRFS	2014	REC_PC_DIS(5)	19		
CRFS	2015	REC_PC_DIS(5)	13		
CRFS	2016	REC_PC_DIS(5)	10		
CRFS	2017	REC_PC_DIS(5)	5		
CRFS	2018	REC_PC_DIS(5)	2		
CRFS	2019	REC_PC_DIS(5)	2		
CDFW	1978	REC_PR(6)	560		
MRFSS	1980	REC_PR(6)	85		48
MRFSS	1981	REC_PR(6)	41		25
MRFSS	1982	REC_PR(6)	148		53
MRFSS	1983	REC_PR(6)	47		20
MRFSS	1984	REC_PR(6)	20		10
MRFSS	1985	REC_PR(6)	87		36
MRFSS	1986	REC_PR(6)	74		23
MRFSS	1987	REC_PR(6)	73		23
MRFSS	1988	REC_PR(6)	80		28
MRFSS	1989	REC_PR(6)	24		13
MRFSS	1993	REC_PR(6)	163		74
MRFSS	1994	REC_PR(6)	180		69
MRFSS	1995	REC_PR(6)	95		34
MRFSS	1996	REC_PR(6)	99		45
MRFSS	1997	REC_PR(6)	12		10
MRFSS	1998	REC_PR(6)	28		15

Table 4: Samples sizes of length composition data by year. *(continued)*

Source	Year	Fleet(#)	Number fish	Sample size	Trips
MRFSS	1999	REC_PR(6)	232		94
MRFSS	2000	REC_PR(6)	132		37
MRFSS	2001	REC_PR(6)	81		27
MRFSS	2002	REC_PR(6)	125		57
MRFSS	2003	REC_PR(6)	283		86
CRFS	2004	REC_PR(6)	1303		231
CRFS	2005	REC_PR(6)	1402		587
CRFS	2006	REC_PR(6)	1424		596
CRFS	2007	REC_PR(6)	1407		589
CRFS	2008	REC_PR(6)	1026		429
CRFS	2009	REC_PR(6)	762		319
CRFS	2010	REC_PR(6)	693		290
CRFS	2011	REC_PR(6)	671		281
CRFS	2012	REC_PR(6)	670		280
CRFS	2013	REC_PR(6)	975		408
CRFS	2014	REC_PR(6)	845		336
CRFS	2015	REC_PR(6)	765		284
CRFS	2016	REC_PR(6)	671		260
CRFS	2017	REC_PR(6)	573		263
CRFS	2018	REC_PR(6)	435		217
CRFS	2019	REC_PR(6)	769		340
CRFS	2020	REC_PR(6)	52		17
NWFSC	2004	NWFSC_HKL(8)	733	179	
NWFSC	2005	NWFSC_HKL(8)	830	210	
NWFSC	2006	NWFSC_HKL(8)	572	186	
NWFSC	2007	NWFSC_HKL(8)	901	202	
NWFSC	2008	NWFSC_HKL(8)	853	227	
NWFSC	2009	NWFSC_HKL(8)	1049	242	
NWFSC	2010	NWFSC_HKL(8)	1150	225	
NWFSC	2011	NWFSC_HKL(8)	1316	244	
NWFSC	2012	NWFSC_HKL(8)	1175	273	
NWFSC	2013	NWFSC_HKL(8)	1218	295	
NWFSC	2014	NWFSC_HKL(8)	1686	381	
NWFSC	2015	NWFSC_HKL(8)	1885	467	
NWFSC	2016	NWFSC_HKL(8)	1879	431	
NWFSC	2017	NWFSC_HKL(8)	2622	534	
NWFSC	2018	NWFSC_HKL(8)	2624	542	
NWFSC	2019	NWFSC_HKL(8)	2227	506	
NWFSC	2003	NWFSC_TWL(9)	41	9	
NWFSC	2004	NWFSC_TWL(9)	3	2	
NWFSC	2005	NWFSC_TWL(9)	42	12	
NWFSC	2006	NWFSC_TWL(9)	9	7	

Table 4: Samples sizes of length composition data by year. *(continued)*

Source	Year	Fleet(#)	Number fish	Sample size	Trips
NWFSC	2007	NWFSC_TWL(9)	119	17	
NWFSC	2008	NWFSC_TWL(9)	37	14	
NWFSC	2009	NWFSC_TWL(9)	15	9	
NWFSC	2010	NWFSC_TWL(9)	73	24	
NWFSC	2011	NWFSC_TWL(9)	25	4	
NWFSC	2012	NWFSC_TWL(9)	431	31	
NWFSC	2013	NWFSC_TWL(9)	355	17	
NWFSC	2014	NWFSC_TWL(9)	20	19	
NWFSC	2015	NWFSC_TWL(9)	221	21	
NWFSC	2016	NWFSC_TWL(9)	91	36	
NWFSC	2017	NWFSC_TWL(9)	179	26	
NWFSC	2018	NWFSC_TWL(9)	171	21	
NWFSC	2019	NWFSC_TWL(9)	130	9	
CDFW	1975	CDFW_RESEARCH(11)	510		
CDFW	1976	CDFW_RESEARCH(11)	755		
CDFW	1977	CDFW_RESEARCH(11)	143		
CDFW	1978	CDFW_RESEARCH(11)	24		
CDFW	1979	CDFW_RESEARCH(11)	10		

Table 5: Basis for initial input samples sizes by fleet and years for the length composition data in the table above.

Source	Fleet No.	Initial Sample Size Basis	Years
CALCOM	1	N_SAMPLES, YEARS WITH <30 FISH EXCLUDED	1983-2020
CALCOM	2	N_SAMPLES, YEARS WITH <30 FISH EXCLUDED	1985-2016
CALCOM	3	N_SAMPLES, YEARS WITH <30 FISH EXCLUDED	1983-1998
CDFW	4	N_TRIPS (ONBOARD CPFV)	1975-1989
CRFS	4	N_TRIPS	2014-2020
CRFS	4	N_TRIPS ESTIMATED FROM AVG. FISH/TRIP	2004-2013
MRFSS	4	N_TRIPS ESTIMATED FROM B. SOPER ALGORITHM	1980-2003
CRFS	5	N_FISH, YEARS WITH <10 FISH EXCLUDED	2003-2019
CDFW	6	N_FISH / 10	1978-1978
CRFS	6	N_TRIPS	2014-2020
CRFS	6	N_TRIPS ESTIMATED FROM AVG. FISH/TRIP	2004-2013
MRFSS	6	N_TRIPS ESTIMATED FROM B. SOPER ALGORITHM	1980-2003
NWFSC	8	N_SAMPLES (NUMBER OF POSITIVE DROPS)	2004-2019
NWFSC	9	EFFECTIVE N BASED ON STEWART & HAMEL (2014)	2003-2019
CDFW	11	N_FISH / 10	1975-1979

Table 6: Estimated ratio of SLO catch (in numbers) to catch in California counties north of SLO from Albin et al. (1993).

Species	Year	Area	Estimate	SE	CV	SLO/(Total-SLO)
Vermilion	1981	San_Luis_Obispo	16	9	58	1.7777778
Vermilion	1981	Total	25	10	39	
Vermilion	1982	San_Luis_Obispo	12	5	46	0.6315789
Vermilion	1982	Total	31	8	27	
Vermilion	1983	San_Luis_Obispo	17	12	67	1.1333333
Vermilion	1983	Total	32	12	38	
Vermilion	1984	San_Luis_Obispo	30	27	91	1.0714286
Vermilion	1984	Total	58	28	49	
Vermilion	1985	San_Luis_Obispo	15	8	54	0.7142857
Vermilion	1985	Total	36	10	27	
Vermilion	1986	San_Luis_Obispo	23	13	56	1.0454545
Vermilion	1986	Total	45	14	30	
					Average	1.0623098
					Catch-weighted Avg.	1.0360910

Table 7: Samples sizes of conditional age-at-length data by year.

Source	Year	Fleet(#)	Number of fish
NWFSC	2004	NWFSC_HKL(8)	604
NWFSC	2005	NWFSC_HKL(8)	535
NWFSC	2006	NWFSC_HKL(8)	545
NWFSC	2007	NWFSC_HKL(8)	554
NWFSC	2008	NWFSC_HKL(8)	588
NWFSC	2009	NWFSC_HKL(8)	598
NWFSC	2010	NWFSC_HKL(8)	631
NWFSC	2011	NWFSC_HKL(8)	577
NWFSC	2012	NWFSC_HKL(8)	590
NWFSC	2013	NWFSC_HKL(8)	842
NWFSC	2014	NWFSC_HKL(8)	532
NWFSC	2015	NWFSC_HKL(8)	547
NWFSC	2016	NWFSC_HKL(8)	529
NWFSC	2017	NWFSC_HKL(8)	514
NWFSC	2018	NWFSC_HKL(8)	530
NWFSC	2019	NWFSC_HKL(8)	495
NWFSC	2004	NWFSC_TWL(9)	2
NWFSC	2005	NWFSC_TWL(9)	21
NWFSC	2006	NWFSC_TWL(9)	9
NWFSC	2007	NWFSC_TWL(9)	55

Table 7: Samples sizes of conditional age-at-length data by year. *(continued)*

Source	Year	Fleet(#)	Number of fish
NWFSC	2008	NWFSC_TWL(9)	28
NWFSC	2009	NWFSC_TWL(9)	15
NWFSC	2010	NWFSC_TWL(9)	73
NWFSC	2011	NWFSC_TWL(9)	25
NWFSC	2012	NWFSC_TWL(9)	270
NWFSC	2013	NWFSC_TWL(9)	185
NWFSC	2014	NWFSC_TWL(9)	20
NWFSC	2015	NWFSC_TWL(9)	142
NWFSC	2016	NWFSC_TWL(9)	91
NWFSC	2017	NWFSC_TWL(9)	142
NWFSC	2018	NWFSC_TWL(9)	114
NWFSC	2019	NWFSC_TWL(9)	91
CDFW	1976	CDFW_RESEARCH(11)	251
CDFW	1977	CDFW_RESEARCH(11)	138

Table 8: 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 uniform Fem GP 1	0.130	2	(0.001, 0.4)	OK	0.0119792	Log Norm (-2.3026, 0.438)
L at Amin Fem GP 1	8.568	2	(4, 12)	OK	0.5192200	None
L at Amax Fem GP 1	55.378	2	(50, 58)	OK	0.5030420	None
VonBert K Fem GP 1	0.156	2	(0.12, 0.22)	OK	0.0050327	None
CV young Fem GP 1	0.089	2	(0.05, 0.2)	OK	0.0037273	None
CV old Fem GP 1	0.077	2	(0.05, 0.2)	OK	0.0069009	None
Wtlen 1 Fem GP 1	0.000	-2	(1.744e-05, 1.744e-05)			None
Wtlen 2 Fem GP 1	2.995	-2	(1, 3)			None
Mat50% Fem GP 1	38.400	-2	(38.4, 38.4)			None
Mat slope Fem GP 1	-0.312	-2	(-0.4, -0.2)			None
Eggs scalar Fem GP 1	0.000	-2	(0, 1)			None
Eggs exp len Fem GP 1	4.970	-2	(3, 6)			None
NatM uniform Mal GP 1	0.000	-2	(-2, 2)			None
L at Amin Mal GP 1	0.000	-2	(-4, 1)			None
L at Amax Mal GP 1	-0.062	2	(-0.5, 0.5)	OK	0.0096833	None
VonBert K Mal GP 1	0.137	2	(-0.5, 1)	OK	0.0307476	None
CV young Mal GP 1	0.000	-2	(-1, 1)			None
CV old Mal GP 1	-0.286	2	(-1, 1)	OK	0.1202960	None
Wtlen 1 Mal GP 1	0.000	-2	(0, 1)			None
Wtlen 2 Mal GP 1	2.995	-2	(1, 3)			None
CohortGrowDev	1.000	-1	(0.1, 10)			None
FracFemale GP 1	0.500	-1	(1e-06, 0.999999)			None
SR LN(R0)	6.696	1	(5, 9)	OK	0.2111420	None
SR BH steep	0.730	4	(0.201, 0.999)	OK	0.1368350	Full Beta (0.72, 0.16)
SR sigmaR	0.500	-2	(0, 2)			None
SR regime	0.000	-2	(-5, 5)			None
SR autocorr	0.000	-2	(0, 0)			None
Main RecrDev 1965	0.012	4	(-5, 5)	act	0.4832330	dev (NA, NA)
Main RecrDev 1966	0.006	4	(-5, 5)	act	0.4782160	dev (NA, NA)

Table 8: 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 1967	-0.003	4	(-5, 5)	act	0.4699440	dev (NA, NA)
Main RecrDev 1968	-0.034	4	(-5, 5)	act	0.4580990	dev (NA, NA)
Main RecrDev 1969	-0.088	4	(-5, 5)	act	0.4471390	dev (NA, NA)
Main RecrDev 1970	-0.050	4	(-5, 5)	act	0.4456950	dev (NA, NA)
Main RecrDev 1971	0.259	4	(-5, 5)	act	0.4066700	dev (NA, NA)
Main RecrDev 1972	0.136	4	(-5, 5)	act	0.3879450	dev (NA, NA)
Main RecrDev 1973	0.424	4	(-5, 5)	act	0.2985740	dev (NA, NA)
Main RecrDev 1974	-0.107	4	(-5, 5)	act	0.3493060	dev (NA, NA)
Main RecrDev 1975	-0.380	4	(-5, 5)	act	0.3463810	dev (NA, NA)
Main RecrDev 1976	-0.580	4	(-5, 5)	act	0.3467920	dev (NA, NA)
Main RecrDev 1977	-0.647	4	(-5, 5)	act	0.3387080	dev (NA, NA)
Main RecrDev 1978	-0.655	4	(-5, 5)	act	0.3243320	dev (NA, NA)
Main RecrDev 1979	-0.759	4	(-5, 5)	act	0.3344700	dev (NA, NA)
Main RecrDev 1980	-0.424	4	(-5, 5)	act	0.3219850	dev (NA, NA)
Main RecrDev 1981	-0.231	4	(-5, 5)	act	0.3276580	dev (NA, NA)
Main RecrDev 1982	-0.171	4	(-5, 5)	act	0.3520070	dev (NA, NA)
Main RecrDev 1983	0.588	4	(-5, 5)	act	0.2915630	dev (NA, NA)
Main RecrDev 1984	0.899	4	(-5, 5)	act	0.2569480	dev (NA, NA)
Main RecrDev 1985	-0.083	4	(-5, 5)	act	0.3638190	dev (NA, NA)
Main RecrDev 1986	-0.356	4	(-5, 5)	act	0.3772330	dev (NA, NA)
Main RecrDev 1987	-0.141	4	(-5, 5)	act	0.4236280	dev (NA, NA)
Main RecrDev 1988	0.678	4	(-5, 5)	act	0.4237960	dev (NA, NA)
Main RecrDev 1989	0.444	4	(-5, 5)	act	0.4363600	dev (NA, NA)
Main RecrDev 1990	-0.073	4	(-5, 5)	act	0.3704010	dev (NA, NA)
Main RecrDev 1991	-0.085	4	(-5, 5)	act	0.3342670	dev (NA, NA)
Main RecrDev 1992	-0.050	4	(-5, 5)	act	0.3461410	dev (NA, NA)
Main RecrDev 1993	0.017	4	(-5, 5)	act	0.3344870	dev (NA, NA)
Main RecrDev 1994	-0.078	4	(-5, 5)	act	0.3166410	dev (NA, NA)
Main RecrDev 1995	-0.434	4	(-5, 5)	act	0.3305140	dev (NA, NA)

Table 8: 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 1996	-0.291	4	(-5, 5)	act	0.2798050	dev (NA, NA)
Main RecrDev 1997	-0.267	4	(-5, 5)	act	0.2680160	dev (NA, NA)
Main RecrDev 1998	-0.434	4	(-5, 5)	act	0.3069930	dev (NA, NA)
Main RecrDev 1999	1.353	4	(-5, 5)	act	0.1536880	dev (NA, NA)
Main RecrDev 2000	0.678	4	(-5, 5)	act	0.2276690	dev (NA, NA)
Main RecrDev 2001	-0.404	4	(-5, 5)	act	0.3076860	dev (NA, NA)
Main RecrDev 2002	-0.319	4	(-5, 5)	act	0.2172940	dev (NA, NA)
Main RecrDev 2003	-0.546	4	(-5, 5)	act	0.2163860	dev (NA, NA)
Main RecrDev 2004	-0.367	4	(-5, 5)	act	0.1860630	dev (NA, NA)
Main RecrDev 2005	-0.525	4	(-5, 5)	act	0.1998320	dev (NA, NA)
Main RecrDev 2006	-0.834	4	(-5, 5)	act	0.2467080	dev (NA, NA)
Main RecrDev 2007	0.236	4	(-5, 5)	act	0.1495920	dev (NA, NA)
Main RecrDev 2008	0.347	4	(-5, 5)	act	0.1614880	dev (NA, NA)
Main RecrDev 2009	0.652	4	(-5, 5)	act	0.1412090	dev (NA, NA)
Main RecrDev 2010	0.717	4	(-5, 5)	act	0.1343260	dev (NA, NA)
Main RecrDev 2011	0.248	4	(-5, 5)	act	0.1680190	dev (NA, NA)
Main RecrDev 2012	0.440	4	(-5, 5)	act	0.1441650	dev (NA, NA)
Main RecrDev 2013	0.302	4	(-5, 5)	act	0.1544430	dev (NA, NA)
Main RecrDev 2014	-0.340	4	(-5, 5)	act	0.2219970	dev (NA, NA)
Main RecrDev 2015	0.030	4	(-5, 5)	act	0.1922640	dev (NA, NA)
Main RecrDev 2016	0.895	4	(-5, 5)	act	0.1637710	dev (NA, NA)
Main RecrDev 2017	0.405	4	(-5, 5)	act	0.3020210	dev (NA, NA)
Main RecrDev 2018	-0.039	4	(-5, 5)	act	0.4511170	dev (NA, NA)
Main RecrDev 2019	0.011	4	(-5, 5)	act	0.4932110	dev (NA, NA)
Main RecrDev 2020	0.018	4	(-5, 5)	act	0.4953620	dev (NA, NA)
LnQ base REC PC(4)	-9.778	-1	(-15, 0)			None
LnQ base REC PR(6)	-7.571	-1	(-15, 0)			None
Q extraSD REC PR(6)	0.136	1	(0, 0.4)	OK	0.0447306	None
LnQ base NWFSC HKL(8)	-10.198	-1	(-15, 0)			None

Table 8: 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 REC PC ONBOARD(10)	-10.544	-1	(-15, 0)			None
Size DblN peak COM HKL(1)	49.660	2	(15, 55)	OK	3.2092700	None
Size DblN top logit COM HKL(1)	-9.000	-2	(-12, 0)			None
Size DblN ascend se COM HKL(1)	4.511	2	(0.05, 9)	OK	0.4818970	None
Size DblN descend se COM HKL(1)	8.000	-2	(0.05, 9)			None
Size DblN start logit COM HKL(1)	-10.000	-2	(-11, -9)			None
Size DblN end logit COM HKL(1)	10.000	-2	(-10, 10)			None
Size DblN peak COM NET(3)	58.957	2	(10, 69)	OK	8.7500100	None
Size DblN top logit COM NET(3)	-6.000	-2	(-12, 0)			None
Size DblN ascend se COM NET(3)	5.177	2	(0.05, 10)	OK	0.6571650	None
Size DblN descend se COM NET(3)	8.000	-2	(0.05, 10)			None
Size DblN start logit COM NET(3)	-10.000	-2	(-11, -9)			None
Size DblN end logit COM NET(3)	10.000	-2	(-10, 10)			None
Size DblN peak REC PC(4)	28.209	2	(15, 40)	OK	0.9840960	None
Size DblN top logit REC PC(4)	-6.000	-2	(-12, 0)			None
Size DblN ascend se REC PC(4)	3.774	2	(0.05, 9)	OK	0.2436480	None
Size DblN descend se REC PC(4)	4.966	2	(0.05, 10)	OK	0.2220610	None
Size DblN start logit REC PC(4)	-10.000	-2	(-11, -9)			None
Size DblN end logit REC PC(4)	-4.549	2	(-10, 10)	OK	2.1342500	None
Size DblN peak REC PC DIS(5)	16.497	2	(10, 30)	OK	1.4170300	None
Size DblN top logit REC PC DIS(5)	-9.000	-2	(-12, 0)			None
Size DblN ascend se REC PC DIS(5)	3.159	2	(0.05, 9)	OK	0.8705430	None
Size DblN descend se REC PC DIS(5)	4.150	2	(2, 9)	OK	0.3501050	None
Size DblN start logit REC PC DIS(5)	-10.000	-2	(-11, -9)			None
Size DblN end logit REC PC DIS(5)	-10.000	-2	(-11, -9)			None
Size DblN peak REC PR(6)	31.455	2	(20, 40)	OK	0.4741960	None
Size DblN top logit REC PR(6)	-6.000	-2	(-12, 0)			None
Size DblN ascend se REC PR(6)	3.825	2	(2, 6)	OK	0.1063650	None
Size DblN descend se REC PR(6)	4.550	2	(2, 9)	OK	0.1347590	None

Table 8: 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 REC PR(6)	-10.000	-2	(-11, -9)			None
Size DblN end logit REC PR(6)	-3.015	2	(-10, 5)	OK	0.3787230	None
Size DblN peak NWFSC HKL(8)	51.554	2	(30, 60)	OK	2.1769700	None
Size DblN top logit NWFSC HKL(8)	-6.000	-2	(-12, 0)			None
Size DblN ascend se NWFSC HKL(8)	5.543	2	(2, 9)	OK	0.1548800	None
Size DblN descend se NWFSC HKL(8)	10.000	-2	(0.05, 10)			None
Size DblN start logit NWFSC HKL(8)	-10.000	-2	(-11, -9)			None
Size DblN end logit NWFSC HKL(8)	10.000	-2	(-11, 11)			None
Size DblN peak NWFSC TWL(9)	8.000	-2	(8, 60)			None
Size DblN top logit NWFSC TWL(9)	-10.000	-2	(-12, 0)			None
Size DblN ascend se NWFSC TWL(9)	10.000	-2	(2, 12)			None
Size DblN descend se NWFSC TWL(9)	0.050	-2	(0.05, 10)			None
Size DblN start logit NWFSC TWL(9)	10.000	-2	(9, 11)			None
Size DblN end logit NWFSC TWL(9)	-8.912	2	(-11, 10)	OK	1.0149200	None
Size DblN peak CDFW RESEARCH(11)	44.976	2	(10, 69)	OK	10.5382000	None
Size DblN top logit CDFW RESEARCH(11)	-6.000	-2	(-12, 0)			None
Size DblN ascend se CDFW RESEARCH(11)	5.854	2	(0.05, 9)	OK	1.0599500	None
Size DblN descend se CDFW RESEARCH(11)	10.000	-2	(0.05, 10)			None
Size DblN start logit CDFW RESEARCH(11)	-10.000	-2	(-11, -9)			None
Size DblN end logit CDFW RESEARCH(11)	10.000	-2	(-11, 11)			None
Size DblN peak EARLY HKL(12)	46.674	2	(30, 60)	OK	1.7997100	None
Size DblN top logit EARLY HKL(12)	-6.000	-2	(-12, 0)			None
Size DblN ascend se EARLY HKL(12)	5.051	2	(2, 9)	OK	0.1962900	None
Size DblN descend se EARLY HKL(12)	1.673	2	(0.05, 10)	OK	2.9650500	None
Size DblN start logit EARLY HKL(12)	-10.000	-2	(-11, -9)			None
Size DblN end logit EARLY HKL(12)	0.196	2	(-11, 11)	OK	0.5933010	None
minage@sel=1 NWFSC TWL(9)	1.000	-99	(0, 70)			None
maxage@sel=1 NWFSC TWL(9)	70.000	-99	(0, 70)			None
Size DblN peak COM HKL(1) BLK2repl 1875	52.015	3	(25, 65)	OK	3.5567700	None

Table 8: 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 peak COM HKL(1) BLK2repl 2002	30.366	3	(25, 65)	OK	2.8403800	None
Size DblN ascend se COM HKL(1) BLK2repl 1875	5.130	3	(0.05, 9)	OK	0.3224560	None
Size DblN ascend se COM HKL(1) BLK2repl 2002	3.006	3	(0.05, 9)	OK	1.0088800	None
Size DblN descend se COM HKL(1) BLK2repl 1875	8.000	-3	(0.05, 9)			None
Size DblN descend se COM HKL(1) BLK2repl 2002	8.000	-3	(0.05, 9)			None
Size DblN end logit COM HKL(1) BLK2repl 1875	10.000	-3	(-10, 10)			None
Size DblN end logit COM HKL(1) BLK2repl 2002	10.000	-3	(-10, 10)			None
Size DblN peak REC PC(4) BLK1repl 1875	27.773	3	(10, 40)	OK	1.8781600	None
Size DblN ascend se REC PC(4) BLK1repl 1875	3.634	3	(0.05, 9)	OK	0.4234370	None
Size DblN descend se REC PC(4) BLK1repl 1875	4.518	3	(0.05, 10)	OK	1.4244800	None
Size DblN end logit REC PC(4) BLK1repl 1875	-0.029	3	(-8, 9)	OK	0.4754130	None
Size DblN peak REC PR(6) BLK1repl 1875	28.924	3	(10, 40)	OK	1.6740400	None
Size DblN ascend se REC PR(6) BLK1repl 1875	3.697	3	(0.05, 9)	OK	0.4121980	None
Size DblN descend se REC PR(6) BLK1repl 1875	6.013	3	(0.05, 10)	OK	0.3664580	None
Size DblN end logit REC PR(6) BLK1repl 1875	-7.000	-3	(-8, 9)			None

Table 9: Suggested data-weighting for length and age composition data using the McAllister-Ianelli and Francis approaches, after five tuning iterations to the pre-STAR base model.

Method	Data Type	Fleet No.	Fleet Name	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Base Model
Francis	Length	1	COM_HKL	0.307	0.324	0.311	0.307	0.305	0.302
Francis	Length	3	COM_NET	1.562	1.661	1.740	1.754	1.756	1.756
Francis	Length	4	REC_PC	0.130	0.096	0.091	0.090	0.090	0.090
Francis	Length	5	REC_PC_DIS	0.285	0.312	0.316	0.317	0.317	0.319
Francis	Length	6	REC_PR	0.208	0.265	0.284	0.291	0.293	0.301
Francis	Length	8	NWFSC_HKL	0.259	0.275	0.271	0.269	0.268	0.264
Francis	Length	9	NWFSC_TWL	0.132	0.132	0.131	0.131	0.131	0.130
Francis	Length	11	CDFW_RESEARCH	0.260	0.292	0.291	0.293	0.293	0.292
Francis	Length	12	EARLY_HKL	0.098	0.110	0.116	0.118	0.119	0.119
Francis	Ages	8	NWFSC_HKL	0.326	0.304	0.290	0.285	0.283	0.273
Francis	Ages	9	NWFSC_TWL	0.103	0.090	0.083	0.081	0.081	0.080
Francis	Ages	11	CDFW_RESEARCH	0.096	0.036	0.025	0.023	0.023	0.023
Francis	Ages	12	EARLY_HKL	0.048	0.036	0.031	0.030	0.030	0.030
M-I	Length	1	COM_HKL	1.605	1.687	1.694	1.694	1.695	
M-I	Length	3	COM_NET	3.082	3.275	3.286	3.287	3.287	
M-I	Length	4	REC_PC	0.420	0.412	0.409	0.409	0.408	
M-I	Length	5	REC_PC_DIS	0.429	0.423	0.416	0.414	0.414	
M-I	Length	6	REC_PR	0.234	0.239	0.239	0.239	0.239	
M-I	Length	8	NWFSC_HKL	0.861	0.947	0.954	0.955	0.955	
M-I	Length	9	NWFSC_TWL	0.558	0.565	0.565	0.565	0.565	
M-I	Length	11	CDFW_RESEARCH	1.690	2.235	2.298	2.305	2.306	
M-I	Length	12	EARLY_HKL	1.031	1.155	1.171	1.173	1.173	
M-I	Ages	8	NWFSC_HKL	0.247	0.255	0.260	0.261	0.261	
M-I	Ages	9	NWFSC_TWL	0.071	0.044	0.038	0.037	0.036	
M-I	Ages	11	CDFW_RESEARCH	0.259	0.257	0.256	0.256	0.256	
M-I	Ages	12	EARLY_HKL	0.193	0.192	0.192	0.192	0.192	

Table 10: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Output (10^6 eggs)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	$\frac{1-SPR}{1-SPR_{50\%}}$	Exploitation Rate
1875	6263.31	977.834	6010.98	1.000	809.350	0.222	0.001	0.000
1876	6263.10	977.793	6010.78	1.000	809.347	0.443	0.002	0.000
1877	6262.71	977.714	6010.38	1.000	809.341	0.665	0.003	0.000
1878	6262.14	977.597	6009.81	1.000	809.332	0.886	0.004	0.000
1879	6261.41	977.446	6009.08	1.000	809.321	1.108	0.005	0.000
1880	6260.53	977.262	6008.21	0.999	809.307	1.329	0.006	0.000
1881	6259.53	977.050	6007.21	0.999	809.290	1.551	0.007	0.000
1882	6258.40	976.810	6006.08	0.999	809.272	1.772	0.008	0.000
1883	6257.16	976.545	6004.85	0.999	809.251	1.994	0.009	0.000
1884	6255.82	976.258	6003.52	0.998	809.229	2.215	0.010	0.000
1885	6254.40	975.951	6002.10	0.998	809.206	2.437	0.010	0.000
1886	6252.88	975.624	6000.59	0.998	809.181	2.658	0.011	0.000
1887	6251.30	975.281	5999.01	0.997	809.154	2.880	0.012	0.000
1888	6249.65	974.922	5997.37	0.997	809.127	3.101	0.013	0.001
1889	6247.93	974.550	5995.66	0.997	809.098	3.323	0.014	0.001
1890	6246.16	974.164	5993.90	0.996	809.068	3.544	0.015	0.001
1891	6244.34	973.767	5992.09	0.996	809.037	3.766	0.016	0.001
1892	6242.47	973.359	5990.23	0.995	809.006	3.988	0.017	0.001
1893	6240.56	972.942	5988.32	0.995	808.974	3.763	0.016	0.001
1894	6239.02	972.598	5986.80	0.995	808.947	3.539	0.015	0.001
1895	6237.83	972.324	5985.62	0.994	808.926	3.315	0.014	0.001
1896	6236.96	972.118	5984.76	0.994	808.910	3.131	0.013	0.001
1897	6236.35	971.966	5984.15	0.994	808.898	2.946	0.013	0.000
1898	6235.97	971.867	5983.78	0.994	808.891	2.761	0.012	0.000
1899	6235.81	971.815	5983.62	0.994	808.886	2.576	0.011	0.000
1900	6235.83	971.807	5983.65	0.994	808.886	2.850	0.012	0.000
1901	6235.61	971.753	5983.42	0.994	808.882	3.124	0.013	0.001
1902	6235.15	971.656	5982.97	0.994	808.874	3.398	0.015	0.001
1903	6234.47	971.515	5982.29	0.994	808.863	3.672	0.016	0.001
1904	6233.59	971.333	5981.41	0.993	808.849	3.946	0.017	0.001
1905	6232.53	971.111	5980.35	0.993	808.832	4.217	0.018	0.001
1906	6231.30	970.853	5979.13	0.993	808.812	4.487	0.019	0.001
1907	6229.93	970.562	5977.76	0.993	808.789	4.758	0.020	0.001
1908	6228.41	970.240	5976.25	0.992	808.764	5.028	0.022	0.001
1909	6226.78	969.891	5974.62	0.992	808.737	5.658	0.024	0.001
1910	6224.70	969.450	5972.55	0.991	808.703	6.288	0.027	0.001
1911	6222.21	968.922	5970.07	0.991	808.662	6.918	0.030	0.001
1912	6219.34	968.314	5967.21	0.990	808.614	7.547	0.032	0.001
1913	6216.13	967.631	5964.02	0.990	808.561	8.177	0.035	0.001
1914	6212.61	966.879	5960.51	0.989	808.502	8.807	0.038	0.001
1915	6208.80	966.063	5956.72	0.988	808.438	9.437	0.040	0.002
1916	6204.73	965.189	5952.67	0.987	808.370	10.719	0.046	0.002
1917	6199.83	964.142	5947.78	0.986	808.288	17.300	0.073	0.003
1918	6189.22	961.958	5937.19	0.984	808.115	15.775	0.067	0.003
1919	6180.88	960.181	5928.88	0.982	807.975	9.432	0.041	0.002
1920	6179.14	959.691	5927.18	0.981	807.936	10.247	0.044	0.002
1921	6176.88	959.121	5924.96	0.981	807.891	8.953	0.039	0.002
1922	6176.06	958.858	5924.17	0.981	807.870	8.808	0.038	0.001

Table 10: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output (10^6 eggs)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	$\frac{1-SPR}{1-SPR_{50\%}}$	Exploitation Rate
1923	6175.49	958.670	5923.61	0.980	807.855	11.798	0.051	0.002
1924	6172.21	957.971	5920.35	0.980	807.800	15.818	0.067	0.003
1925	6165.47	956.585	5913.61	0.978	807.689	17.356	0.074	0.003
1926	6157.83	954.999	5905.99	0.977	807.562	21.537	0.091	0.004
1927	6146.93	952.741	5895.11	0.974	807.382	17.872	0.076	0.003
1928	6140.31	951.291	5888.53	0.973	807.265	15.352	0.066	0.003
1929	6136.62	950.418	5884.88	0.972	807.195	15.651	0.067	0.003
1930	6133.00	949.584	5881.31	0.971	807.127	16.058	0.069	0.003
1931	6129.32	948.761	5877.67	0.970	807.061	12.301	0.054	0.002
1932	6129.44	948.707	5877.81	0.970	807.056	20.643	0.089	0.004
1933	6121.82	947.163	5870.21	0.969	806.931	7.113	0.032	0.001
1934	6127.33	948.193	5875.74	0.970	807.015	12.509	0.055	0.002
1935	6127.43	948.216	5875.84	0.970	807.016	13.909	0.061	0.002
1936	6126.17	947.992	5874.60	0.969	806.998	12.307	0.054	0.002
1937	6126.46	948.070	5874.88	0.970	807.005	13.521	0.060	0.002
1938	6125.52	947.941	5873.95	0.969	806.994	9.335	0.042	0.002
1939	6128.48	948.576	5876.91	0.970	807.046	9.925	0.044	0.002
1940	6130.64	949.050	5879.06	0.971	807.084	13.074	0.058	0.002
1941	6129.70	948.902	5878.12	0.970	807.072	15.268	0.067	0.003
1942	6126.79	948.343	5875.20	0.970	807.027	5.447	0.024	0.001
1943	6133.26	949.586	5881.65	0.971	807.127	6.706	0.030	0.001
1944	6138.14	950.549	5886.53	0.972	807.205	1.940	0.009	0.000
1945	6147.09	952.338	5895.48	0.974	807.349	3.848	0.017	0.001
1946	6153.59	953.696	5901.95	0.975	807.458	5.374	0.024	0.001
1947	6158.10	954.705	5906.43	0.976	807.539	7.314	0.034	0.001
1948	6160.24	955.340	5908.55	0.977	807.590	15.183	0.073	0.003
1949	6154.25	954.652	5902.62	0.976	807.535	19.895	0.096	0.003
1950	6143.52	953.136	5891.93	0.975	807.413	25.396	0.119	0.004
1951	6127.81	950.550	5876.24	0.972	807.205	39.376	0.172	0.007
1952	6100.02	945.285	5848.44	0.967	806.778	30.855	0.145	0.005
1953	6081.65	941.950	5830.20	0.963	806.506	29.331	0.143	0.005
1954	6065.38	939.145	5814.09	0.960	806.275	50.939	0.245	0.009
1955	6028.31	933.074	5777.41	0.954	805.772	84.460	0.389	0.015
1956	5959.18	921.865	5708.78	0.943	804.826	88.624	0.418	0.016
1957	5887.49	910.331	5637.44	0.931	803.832	63.963	0.309	0.011
1958	5843.54	902.228	5593.28	0.923	803.119	112.993	0.469	0.020
1959	5757.69	885.086	5507.63	0.905	801.573	92.316	0.392	0.017
1960	5699.41	871.895	5449.37	0.892	800.347	82.475	0.357	0.015
1961	5656.94	861.372	5407.14	0.881	799.344	69.359	0.314	0.013
1962	5631.81	854.388	5382.46	0.874	798.666	49.800	0.240	0.009
1963	5628.44	851.914	5379.42	0.871	798.424	47.608	0.230	0.009
1964	5628.77	850.538	5379.98	0.870	798.289	57.419	0.281	0.011
1965	5619.92	848.409	5371.47	0.868	797.673	84.168	0.391	0.016
1966	5585.65	842.189	5337.55	0.861	788.784	103.272	0.485	0.019
1967	5532.28	833.921	5285.13	0.853	776.980	108.758	0.516	0.021
1968	5472.93	825.035	5227.57	0.844	748.605	114.146	0.552	0.022
1969	5406.14	815.671	5165.07	0.834	704.615	108.503	0.530	0.021
1970	5342.99	806.667	5107.55	0.825	727.572	125.484	0.619	0.025

Table 10: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output (10^6 eggs)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	$\frac{1-SPR}{1-SPR_{50\%}}$	Exploita-tion Rate
1971	5260.53	795.707	5030.86	0.814	984.564	124.165	0.619	0.025
1972	5179.28	784.367	4948.81	0.802	864.626	168.145	0.790	0.034
1973	5069.89	765.959	4812.28	0.783	1143.970	186.223	0.870	0.039
1974	4955.92	744.479	4662.77	0.761	667.530	195.801	0.918	0.042
1975	4853.10	721.562	4571.22	0.738	503.119	219.924	0.986	0.048
1976	4728.85	695.090	4449.50	0.711	408.131	193.236	0.896	0.043
1977	4617.03	673.821	4437.73	0.689	378.159	185.066	0.886	0.042
1978	4485.35	657.332	4344.34	0.672	372.222	215.012	0.989	0.049
1979	4293.03	638.200	4172.04	0.653	332.286	328.485	1.291	0.079
1980	3963.63	600.995	3848.77	0.615	458.785	296.217	1.319	0.077
1981	3649.74	565.701	3536.90	0.579	551.992	236.123	1.166	0.067
1982	3396.81	533.571	3275.45	0.546	580.917	344.280	1.473	0.105
1983	3057.43	480.300	2898.40	0.491	1219.310	176.111	1.059	0.061
1984	2927.38	450.398	2723.26	0.461	1644.360	215.349	1.298	0.079
1985	2816.10	415.227	2548.24	0.425	606.764	239.304	1.380	0.094
1986	2762.29	377.635	2381.17	0.386	453.071	402.172	1.688	0.169
1987	2581.77	323.861	2238.95	0.331	542.885	308.459	1.633	0.138
1988	2482.26	298.463	2316.34	0.305	1207.750	182.994	1.297	0.079
1989	2494.54	291.922	2326.33	0.299	949.682	311.861	1.585	0.134
1990	2399.73	271.132	2164.72	0.277	555.826	288.279	1.564	0.133
1991	2349.59	257.093	2037.91	0.263	541.308	318.596	1.603	0.156
1992	2275.57	238.284	2043.28	0.244	548.148	291.455	1.574	0.143
1993	2219.19	224.794	2053.81	0.230	575.967	242.919	1.488	0.118
1994	2196.93	220.344	2032.52	0.225	520.904	350.523	1.684	0.172
1995	2052.65	206.646	1890.24	0.211	357.262	217.952	1.490	0.115
1996	2017.20	210.231	1859.38	0.215	414.777	225.508	1.541	0.121
1997	1947.28	212.333	1812.80	0.217	426.157	92.654	0.952	0.051
1998	1996.02	224.213	1879.12	0.229	366.684	138.692	1.206	0.074
1999	2008.39	230.193	1860.33	0.235	2207.040	161.219	1.377	0.087
2000	1997.05	234.265	1813.24	0.240	1130.090	98.073	1.049	0.054
2001	2121.04	242.567	1816.28	0.248	386.731	54.316	0.650	0.030
2002	2349.57	253.928	1847.62	0.260	426.554	65.716	0.628	0.036
2003	2571.55	266.980	2324.78	0.273	344.982	107.893	0.800	0.046
2004	2716.25	283.140	2596.80	0.290	419.019	109.471	0.792	0.042
2005	2803.32	306.822	2683.73	0.314	365.021	149.464	1.044	0.056
2006	2791.56	331.649	2681.83	0.339	272.994	53.976	0.509	0.020
2007	2842.76	361.043	2719.38	0.369	811.569	81.500	0.774	0.030
2008	2836.15	382.551	2713.56	0.391	917.223	50.286	0.555	0.019
2009	2869.68	399.931	2704.80	0.409	1256.540	43.581	0.514	0.016
2010	2943.09	411.689	2663.74	0.421	1348.870	55.787	0.616	0.021
2011	3054.06	417.626	2728.89	0.427	845.517	106.224	0.935	0.039
2012	3166.59	417.703	2792.57	0.427	1025.460	145.267	1.063	0.052
2013	3259.27	416.626	2917.82	0.426	892.128	150.033	1.000	0.051
2014	3348.92	418.821	3082.18	0.428	470.136	116.069	0.795	0.038
2015	3467.46	428.176	3189.40	0.438	683.215	196.157	1.134	0.062
2016	3480.25	436.847	3249.51	0.447	1628.800	172.129	1.061	0.053
2017	3490.94	448.412	3289.00	0.459	1008.840	150.102	0.992	0.046
2018	3546.80	458.305	3242.81	0.469	688.065	142.112	0.954	0.044

Table 10: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output (10^6 eggs)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	$\frac{1-SPR}{1-SPR_{50\%}}$	Exploita-tion Rate
2019	3630.29	466.811	3233.16	0.477	743.171	259.971	1.371	0.080
2020	3577.79	464.518	3321.64	0.475	747.805	109.680	0.746	0.033
2021	3665.87	471.178	3450.76	0.482	736.076	169.293	1.000	0.049
2022	3682.09	474.244	3457.17	0.485	736.908	168.096	1.000	0.049
2023	3685.49	479.835	3461.48	0.491	738.403	145.399	0.912	0.042
2024	3700.39	488.193	3477.53	0.499	740.585	143.410	0.905	0.041
2025	3708.57	495.306	3485.04	0.507	742.394	141.758	0.900	0.041
2026	3711.86	500.637	3487.73	0.512	743.722	140.186	0.894	0.040
2027	3712.12	504.314	3487.35	0.516	744.624	138.666	0.888	0.040
2028	3710.91	506.676	3485.62	0.518	745.197	137.198	0.882	0.039
2029	3709.38	508.092	3483.70	0.520	745.539	135.951	0.876	0.039
2030	3708.18	508.879	3482.23	0.520	745.728	134.590	0.870	0.039
2031	3707.98	509.328	3481.83	0.521	745.836	133.284	0.864	0.038
2032	3709.05	509.642	3482.77	0.521	745.911	132.194	0.859	0.038

Table 11: Likelihood components, parameter estimates and derived quantities from the leave one out analysis of the pre-STAR base model. Continued in the next table.

		Fleet Removed				
Label	pre-STAR base	COM HKL	COM NET	REC PC	REC PC DIS	REC PR
N.Parms	112.000	108.000	110.000	104.000	109.000	104.000
TOTAL	1036.430	1002.370	1026.030	961.680	1005.790	932.325
Survey	-42.870	-43.992	-43.190	-48.279	-43.172	-26.333
Length_comp	349.639	316.419	339.502	284.998	321.542	235.820
Age_comp	729.229	729.784	729.254	731.045	727.312	719.154
Recruitment	0.299	-0.005	0.333	-6.218	-0.007	3.634
Parm_priors	0.128	0.161	0.129	0.131	0.114	0.047
NatM_uniform_Fem_GP_1	0.125	0.128	0.125	0.125	0.123	0.114
L_at_Amin_Fem_GP_1	7.745	7.765	7.730	8.525	7.071	7.712
L_at_Amax_Fem_GP_1	55.222	55.253	55.169	55.302	54.936	55.143
VonBert_K_Fem_GP_1	0.161	0.161	0.162	0.158	0.167	0.163
CV_young_Fem_GP_1	0.089	0.089	0.089	0.088	0.086	0.088
CV_old_Fem_GP_1	0.077	0.077	0.076	0.076	0.080	0.078
L_at_Amax_Mal_GP_1	-0.061	-0.061	-0.060	-0.060	-0.058	-0.060
VonBert_K_Mal_GP_1	0.133	0.132	0.130	0.132	0.127	0.132
CV_old_Mal_GP_1	-0.289	-0.287	-0.289	-0.287	-0.294	-0.277
SR_LN(R0)	6.666	6.719	6.667	6.668	6.652	6.552
Q_extraSD_REC_PR(6)	0.129	0.124	0.129	0.138	0.130	
Bratio_2021	0.495	0.518	0.497	0.439	0.494	0.472
SSB_unfished	1053.330	1046.670	1048.350	1046.180	1064.390	1138.710
Totbio_unfished	6579.590	6613.590	6569.680	6578.540	6629.030	6849.680
Recr_unfished	785.502	827.605	786.146	787.085	774.097	700.631
Dead_Catch_SPR	140.632	144.823	140.624	140.838	140.465	135.190
OFLCatch_2023	159.972	171.060	160.235	143.898	158.941	152.523

Table 12: Likelihood components from the additional leave one out analysis of the pre-STAR base model. The column name is the fleet removed from the model.

Label	NWFSC HKL	NWFSC TWL	REC ONBOARD	GREEN BINDER
N.Parms	106.000	111.000	112.000	110.000
TOTAL	356.555	893.104	1050.940	1010.370
Survey	-36.334	-42.813	-28.402	-42.958
Length_comp	274.977	305.812	348.942	343.448
Age_comp	118.515	630.162	731.389	709.856
Recruitment	-0.639	-0.222	-1.155	-0.135
Parm_priors	0.032	0.162	0.163	0.161
NatM_uniform_Fem_GP_1	0.112	0.128	0.128	0.128
L_at_Amin_Fem_GP_1	9.067	9.464	7.851	7.823
L_at_Amax_Fem_GP_1	55.079	55.378	55.266	55.440
VonBert_K_Fem_GP_1	0.143	0.155	0.161	0.160
CV_young_Fem_GP_1	0.093	0.083	0.089	0.090
CV_old_Fem_GP_1	0.084	0.080	0.077	0.074
L_at_Amax_Mal_GP_1	-0.086	-0.063	-0.061	-0.061
VonBert_K_Mal_GP_1	0.174	0.151	0.133	0.133
CV_old_Mal_GP_1	-0.471	-0.270	-0.290	-0.294
SR_LN(R0)	6.616	6.707	6.700	6.706
Q_extraSD_REC_PR(6)	0.042	0.122	0.106	0.124
Bratio_2021	0.472	0.509	0.501	0.509
SSB_unfished	1155.340	1028.980	1024.850	1043.040
Totbio_unfished	6976.680	6592.750	6481.980	6558.330
Recr_unfished	746.921	817.909	812.305	817.161
Dead_Catch_SPR	135.527	144.098	140.701	143.005
OFLCatch_2023	148.056	168.603	152.997	164.373

Table 13: Likelihood components from additional sensitivity runs to estimating steepness, starting recruitment deviations in 1965 or 1975, McAllister-Ianelli data weighting and estimating discard selecitity for the pre-STAR base model.

Label	pre-STAR_base	est_h	dev_1960	dev_1970	M-I_wgts	disc_selex
N.Parms	112.000	113.000	117.000	107.000	112.000	109.000
TOTAL	1036.430	1036.340	1036.370	1037.190	2409.520	1005.660
Survey	-42.870	-43.005	-42.885	-42.789	-34.880	-43.206
Length_comp	349.639	349.744	349.650	349.627	1071.920	321.594
Age_comp	729.229	729.266	729.226	729.315	1355.140	727.143
Recruitment	0.299	0.290	0.250	0.895	17.342	0.007
Parm_priors	0.128	0.044	0.126	0.138	0.000	0.115
NatM_uniform_Fem_GP_1	0.125	0.123	0.125	0.126	0.099	0.123
L_at_Amin_Fem_GP_1	7.745	7.739	7.744	7.747	7.231	7.069
L_at_Amax_Fem_GP_1	55.222	55.226	55.222	55.227	53.337	54.936
VonBert_K_Fem_GP_1	0.161	0.161	0.161	0.161	0.174	0.167
CV_young_Fem_GP_1	0.089	0.089	0.089	0.089	0.093	0.086
CV_old_Fem_GP_1	0.077	0.077	0.077	0.077	0.096	0.080
L_at_Amax_Mal_GP_1	-0.061	-0.061	-0.061	-0.061	-0.050	-0.059
VonBert_K_Mal_GP_1	0.133	0.133	0.133	0.133	0.108	0.128
CV_old_Mal_GP_1	-0.289	-0.289	-0.289	-0.290	-0.334	-0.294
SR_LN(R0)	6.666	6.613	6.663	6.673	6.298	6.676
SR_BH_steep	0.720	0.777	0.720	0.720	0.720	0.720
Q_extraSD_REC_PR(6)	0.129	0.131	0.130	0.128	0.186	0.128
Bratio_2021	0.495	0.511	0.496	0.495	0.346	0.498
SSB_unfished	1053.330	1031.070	1054.590	1041.860	1058.190	1087.350
Totbio_unfished	6579.590	6397.360	6581.890	6530.880	6394.380	6777.110
Recr_unfished	785.502	744.570	783.240	790.861	543.230	793.229
Dead_Catch_SPR	140.632	139.486	140.449	140.611	116.556	149.178
OFLCatch_2023	159.972	158.981	160.003	158.893	107.972	169.255

Table 14: Likelihood components from additional sensitivity runs conducted after the draft document was submitted, and before the STAR panel. Descriptions of each run are in the text and all models are sensitivities using the pre-STAR base model.

Label	base	M=0.07	all_2asymp	all_4domed	ricker3p	MF_direct	HLsd=0.1	HLsd=0.05
N.Parms	112.000	111.000	103.000	120.000	113.000	115.000	112.000	112.000
TOTAL	1036.430	1074.980	1214.090	1030.850	1036.110	1017.590	1054.790	1127.720
Survey	-42.870	-38.073	-37.077	-43.342	-42.860	-43.480	-25.714	39.973
Length_comp	349.639	364.261	445.156	346.228	349.866	339.923	351.508	359.703
Age_comp	729.229	733.171	801.441	726.806	729.136	720.979	724.855	720.786
Recruitment	0.299	15.290	2.091	1.128	-0.200	-0.103	4.104	7.249
Parm_priors	0.128	0.332	2.455	0.014	0.167	0.272	0.032	0.008
NatM_uniform_Fem_GP_1	0.125	0.070	0.264	0.108	0.120	0.121	0.112	0.106
L_at_Amin_Fem_GP_1	7.745	7.322	10.713	7.724	7.731	9.494	7.727	7.601
L_at_Amax_Fem_GP_1	55.222	54.690	54.305	56.110	55.236	55.420	55.183	55.185
VonBert_K_Fem_GP_1	0.161	0.169	0.139	0.157	0.161	0.154	0.162	0.162
CV_young_Fem_GP_1	0.089	0.090	0.091	0.092	0.089	0.083	0.089	0.091
CV_old_Fem_GP_1	0.077	0.081	0.089	0.070	0.077	0.080	0.077	0.077
NatM_uniform_Mal_GP_1	0.000	0.000	0.000	0.000	0.000	0.130	0.000	0.000
L_at_Amin_Mal_GP_1	0.000	0.000	0.000	0.000	0.000	4.000	0.000	0.000
L_at_Amax_Mal_GP_1	-0.061	-0.058	-0.052	-0.063	-0.061	51.662	-0.061	-0.061
VonBert_K_Mal_GP_1	0.133	0.126	0.128	0.130	0.133	0.203	0.134	0.135
CV_young_Mal_GP_1	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.000
CV_old_Mal_GP_1	-0.289	-0.286	-0.323	-0.255	-0.289	0.062	-0.285	-0.284
SR_LN(R0)	6.666	6.024	9.000	6.464	6.495	6.689	6.553	6.474
SR_BH_steep	0.720	0.720	0.720	0.720		0.720	0.720	0.720
Q_extraSD_REC_PR(6)	0.129	0.188	0.147	0.106	0.138	0.127	0.219	0.301
SR_RkrPower_steep					0.720			
SR_RkrPower_gamma					1.112			
Bratio_2021	0.495	0.228	1.041	0.419	0.541	0.485	0.490	0.451
SSB_unfished	1053.330	1703.240	1161.430	1257.000	970.212	1153.660	1194.470	1243.530
Totbio_unfished	6579.590	8819.360	14699.600	7119.830	5948.650	6729.150	7118.530	7232.770
Recr_unfished	785.502	413.132	8103.080	641.451	662.130	803.217	701.139	648.001
Dead_Catch_SPR	140.632	114.974	609.874	128.501	148.832	139.081	137.663	133.860
OFLCatch_2023	159.972	77.479	1131.570	131.689	159.398	156.296	165.762	157.714

Table 15: Likelihood components from the retrospective analysis removing one to five years of data of the pre-STAR base model.

Label	base	retro-1	retro-2	retro-3	retro-4	retro-5
N.Parms	112.000	112.000	112.000	112.000	112.000	112.000
TOTAL	1036.430	1031.220	927.277	811.764	702.429	587.668
Survey	-42.870	-41.900	-38.577	-37.351	-37.240	-36.700
Length_comp	349.639	343.358	322.786	298.413	276.215	250.687
Age_comp	729.229	729.126	643.120	551.846	464.422	375.618
Recruitment	0.299	0.500	-0.198	-1.270	-1.056	-1.970
Parm_priors	0.128	0.136	0.143	0.122	0.086	0.031
NatM_uniform_Fem_GP_1	0.125	0.126	0.126	0.124	0.120	0.112
L_at_Amin_Fem_GP_1	7.745	7.761	8.646	8.809	8.808	8.885
L_at_Amax_Fem_GP_1	55.222	55.223	55.579	55.634	55.763	55.779
VonBert_K_Fem_GP_1	0.161	0.161	0.155	0.154	0.150	0.149
CV_young_Fem_GP_1	0.089	0.089	0.091	0.092	0.094	0.093
CV_old_Fem_GP_1	0.077	0.077	0.077	0.077	0.078	0.079
L_at_Amax_Mal_GP_1	-0.061	-0.061	-0.064	-0.067	-0.070	-0.066
VonBert_K_Mal_GP_1	0.133	0.133	0.142	0.151	0.160	0.159
CV_old_Mal_GP_1	-0.289	-0.288	-0.307	-0.296	-0.288	-0.310
SR_LN(R0)	6.666	6.675	6.667	6.627	6.554	6.461
Q_extraSD_REC_PR(6)	0.129	0.135	0.136	0.120	0.097	0.067
Bratio_2021	0.495	0.497	0.494	0.450	0.390	0.357
SSB_unfished	1053.330	1047.140	1037.550	1035.420	1033.270	1093.530
Totbio_unfished	6579.590	6561.790	6478.810	6408.070	6284.650	6479.950
Recr_unfished	785.502	792.722	785.702	755.247	702.293	639.422
Dead_Catch_SPR	140.632	140.703	137.118	134.012	127.521	121.555
OFLCatch_2023	159.972	162.411	146.525	135.081	117.671	99.172

Figures

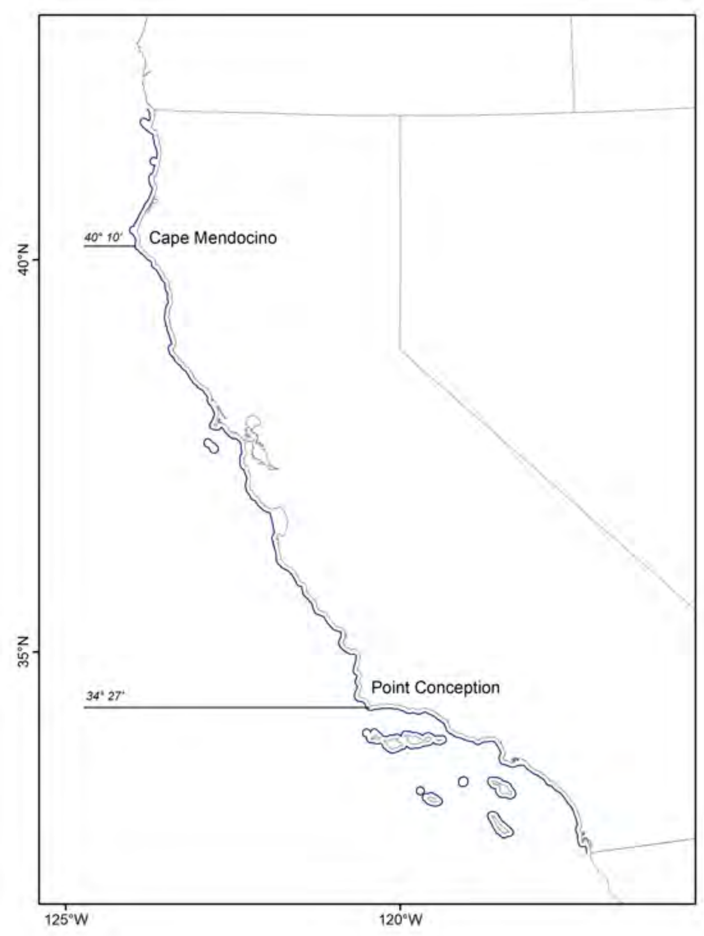

Figure 1: Map of the assssment area with the 3 nm California state water boundary. The northern California model includes areas from Point Conception to the California-Oregon border and the southern California assessment includes areas from Point Concpetion to the USA-Mexico border. The boundary at Cape Mendocino is a Pacific Fishery Management Council boundary for management of the stock complex, provided for reference.

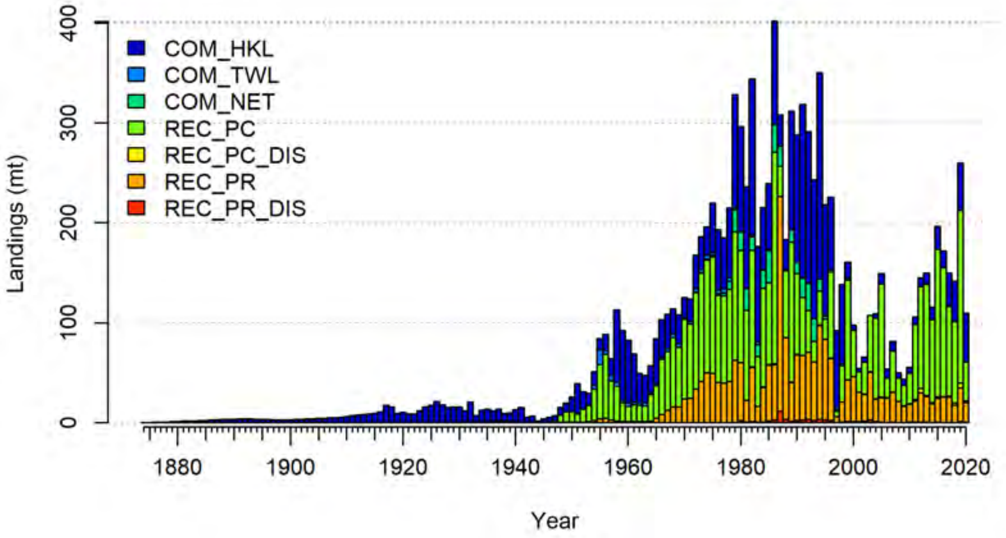

Figure 2: Catch histories by fleet used in the base model (Commercial hook-and-line = COM_HKL, Commercial trawl = COM_TWL, Commercial net = COM_NET, Recreational party/charter retained = REC_PC, Recreational private/rental retained = REC_PR, Recreational party/charter dead discards = REC_PC_DIS, Recreational private/rental dead discards = REC_PR_DIS).

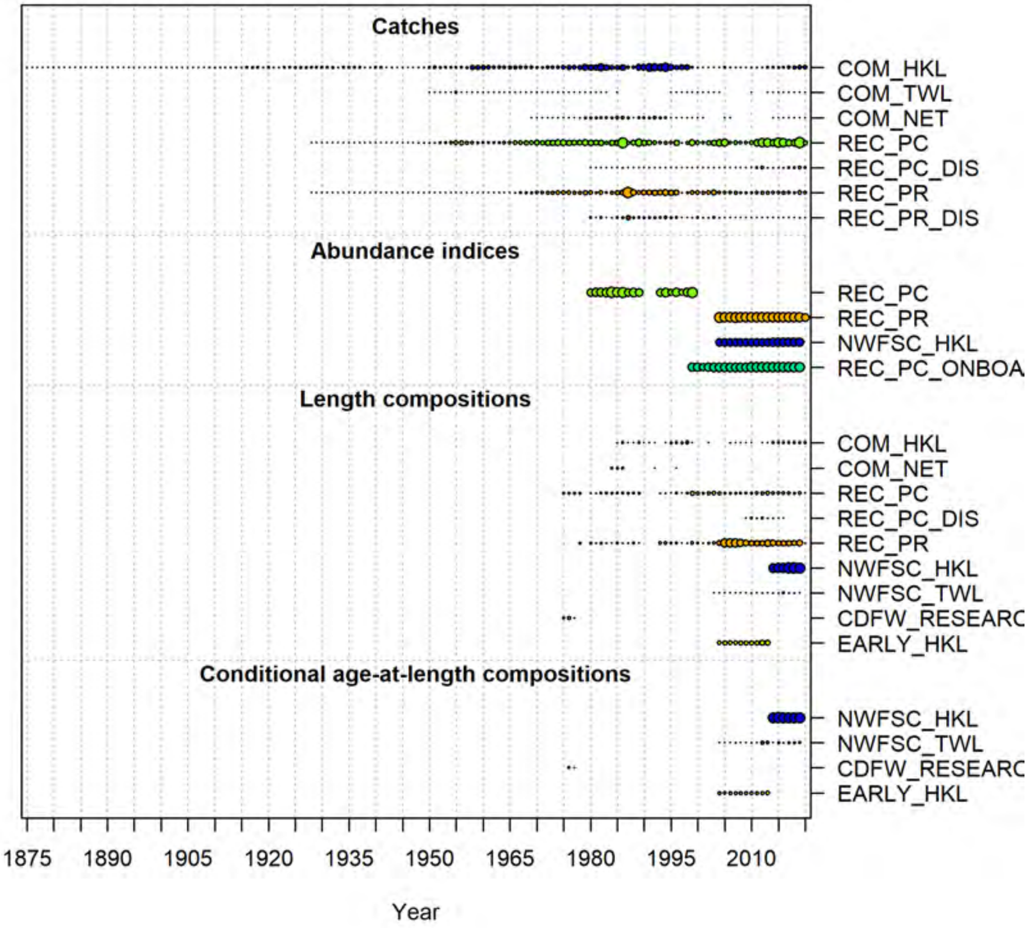

Figure 3: Summary of data sources used in the base model. See the text for fleet descriptions.

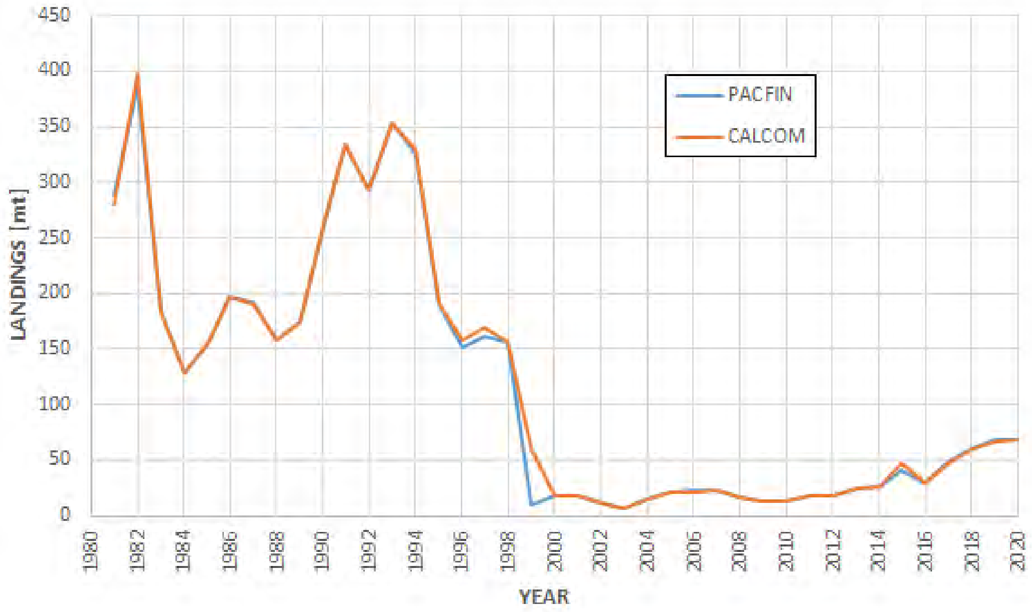

Figure 4: Comparison of total California landings from CALCOM and PacFIN.

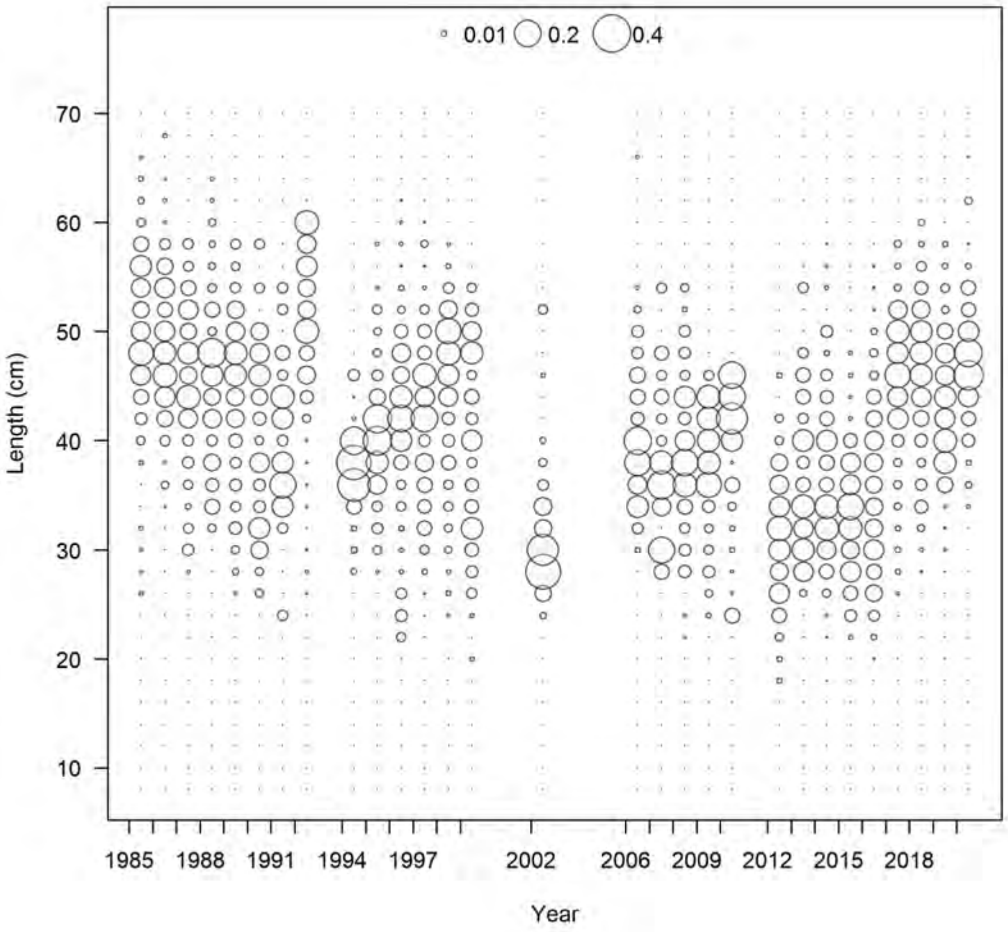

Figure 5: Length composition data from the commercial hook-and-line fishery.

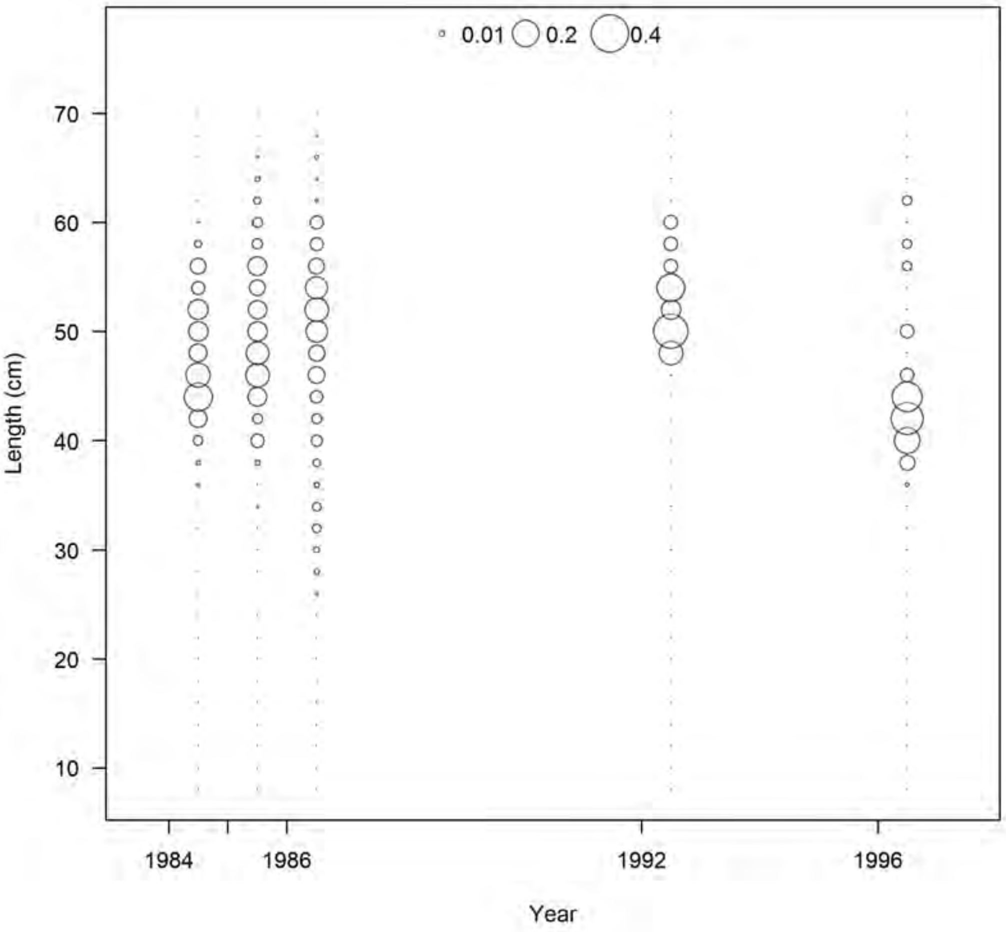

Figure 6: Length composition data from the commercial net fishery.

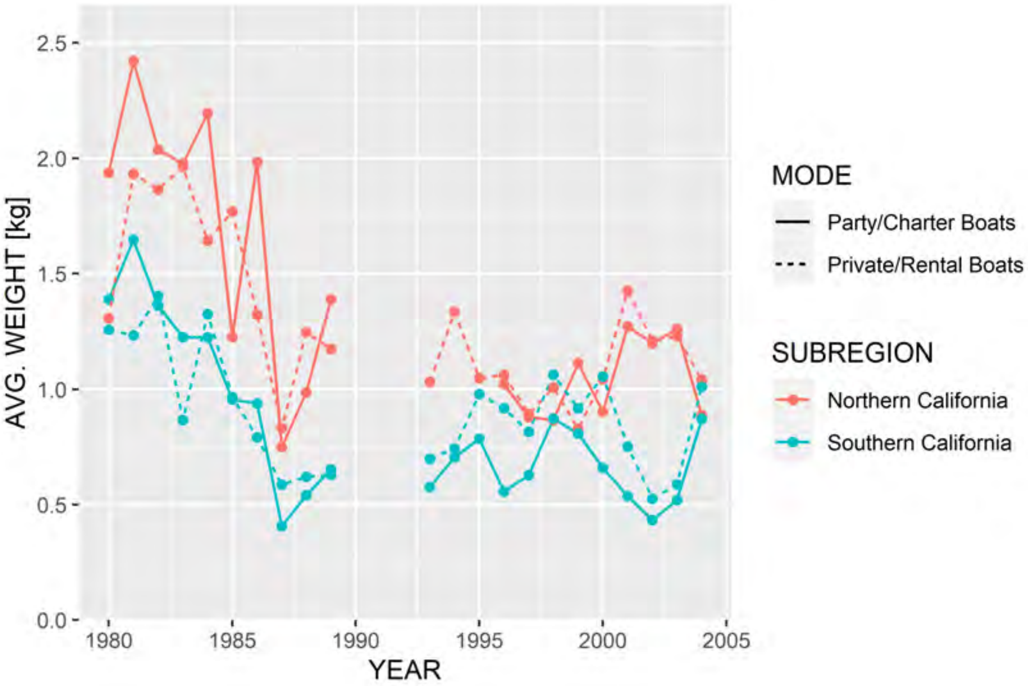

Figure 7: Average weights calculated from the recreational landings data on RecFIN.

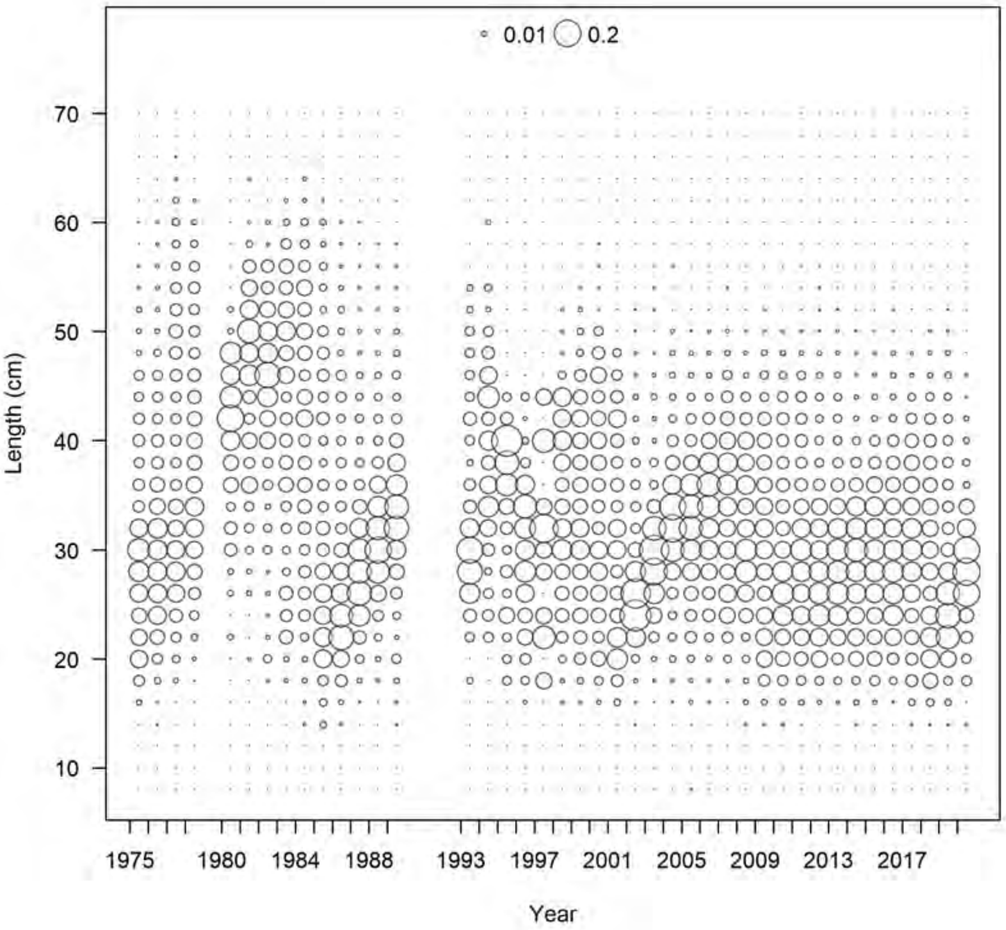

Figure 8: Length composition data from the recreational PC retained fishery.

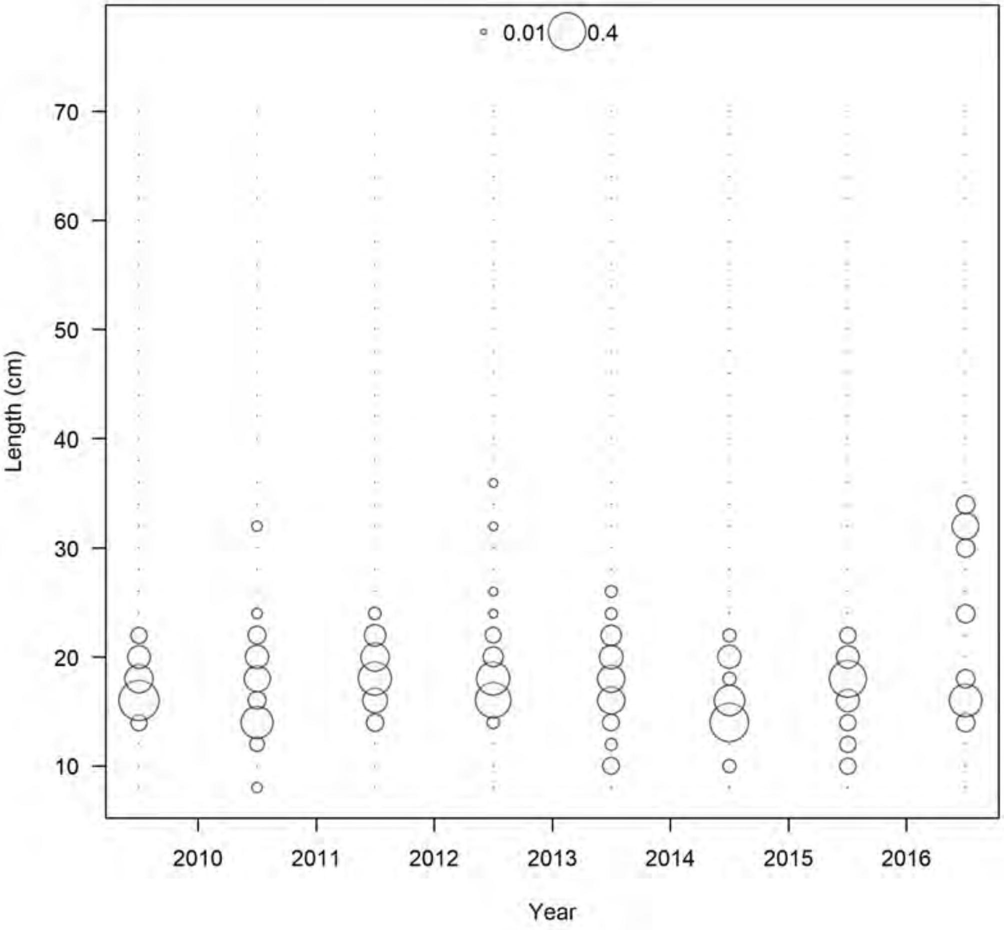

Figure 9: Length composition data from the recreational PC discard fishery.

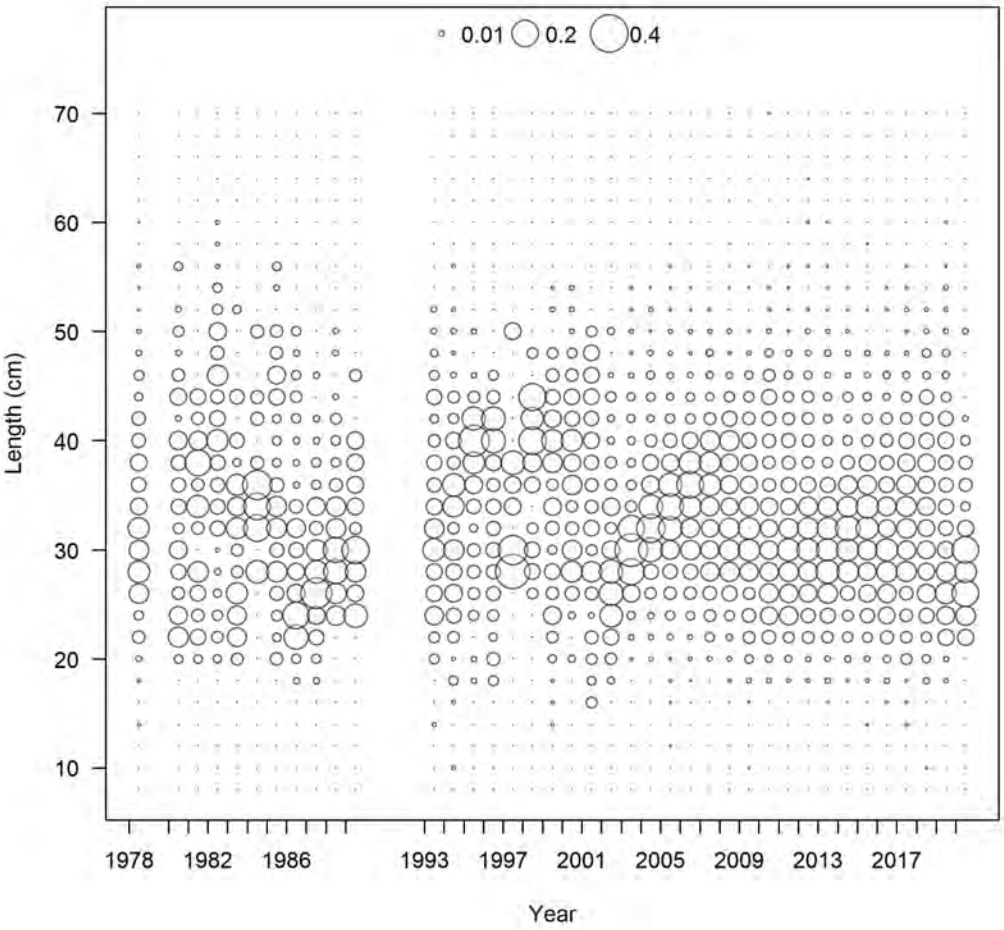

Figure 10: Length composition data from the recreational PR retained fishery.

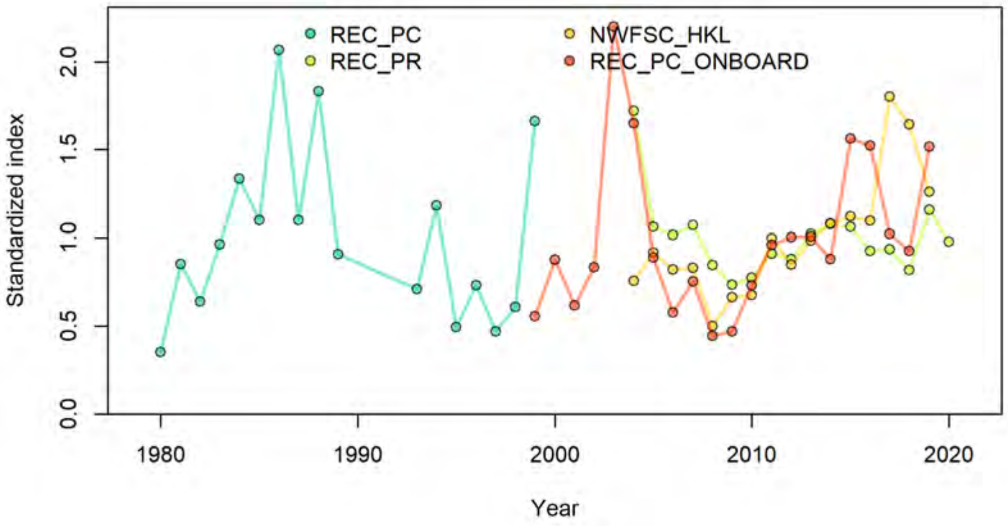

Figure 11: Standardized indices overlaid. Each index is rescaled to have mean observation = 1.0.

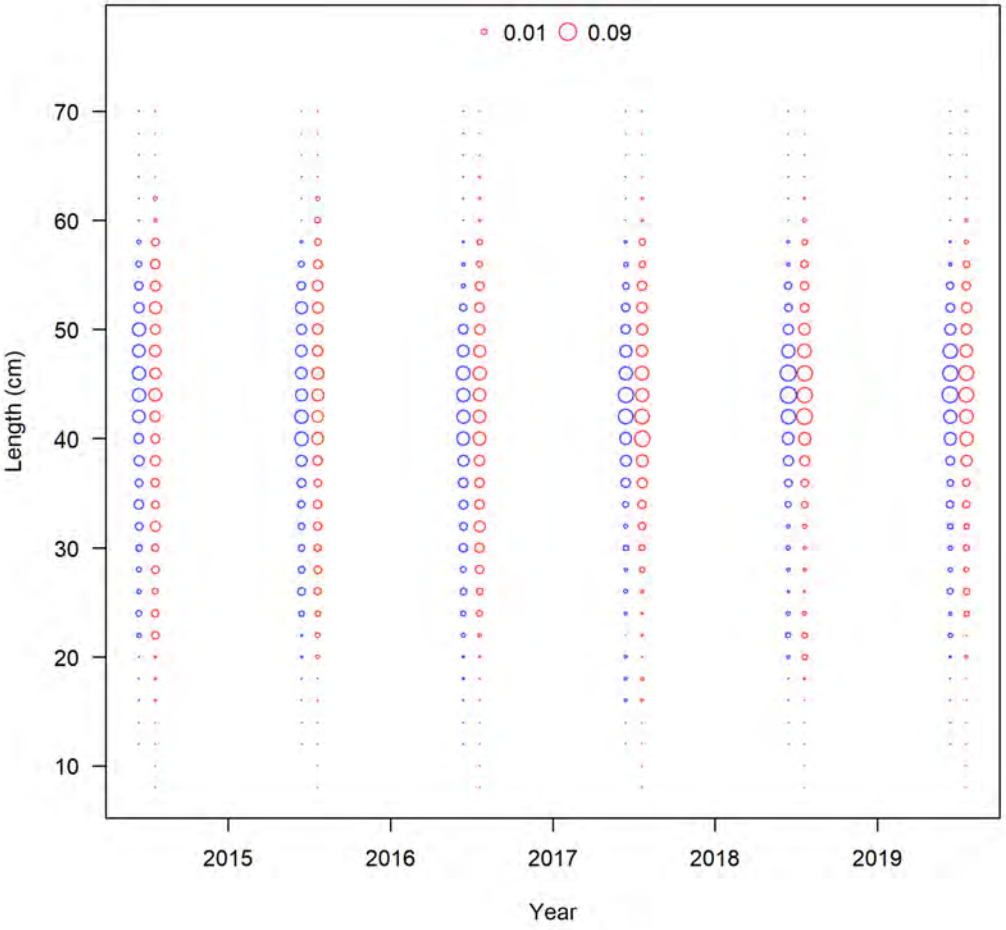

Figure 12: Length composition data from the NWFSC hook-and-line survey.

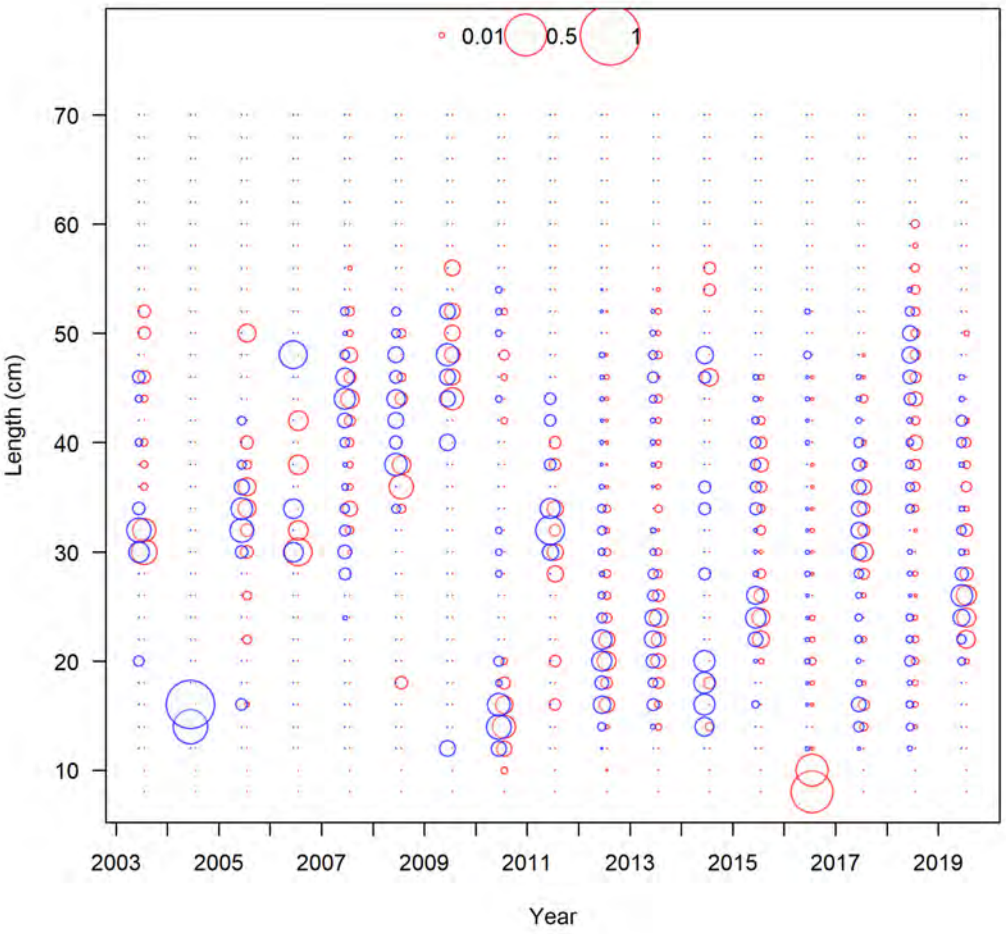

Figure 13: Length composition data from the West Coast Groundfish Bottomfish Trawl Survey.

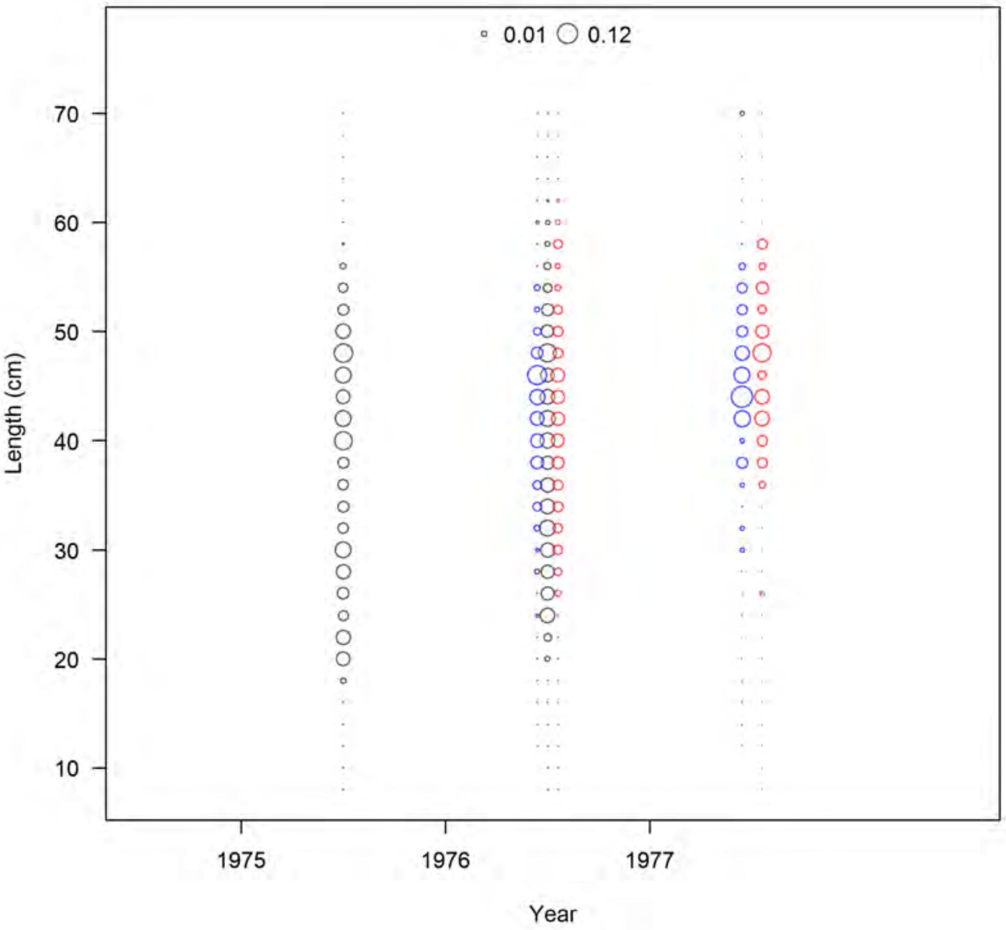

Figure 14: Length composition data from the CDFW research (aka green binder) survey.

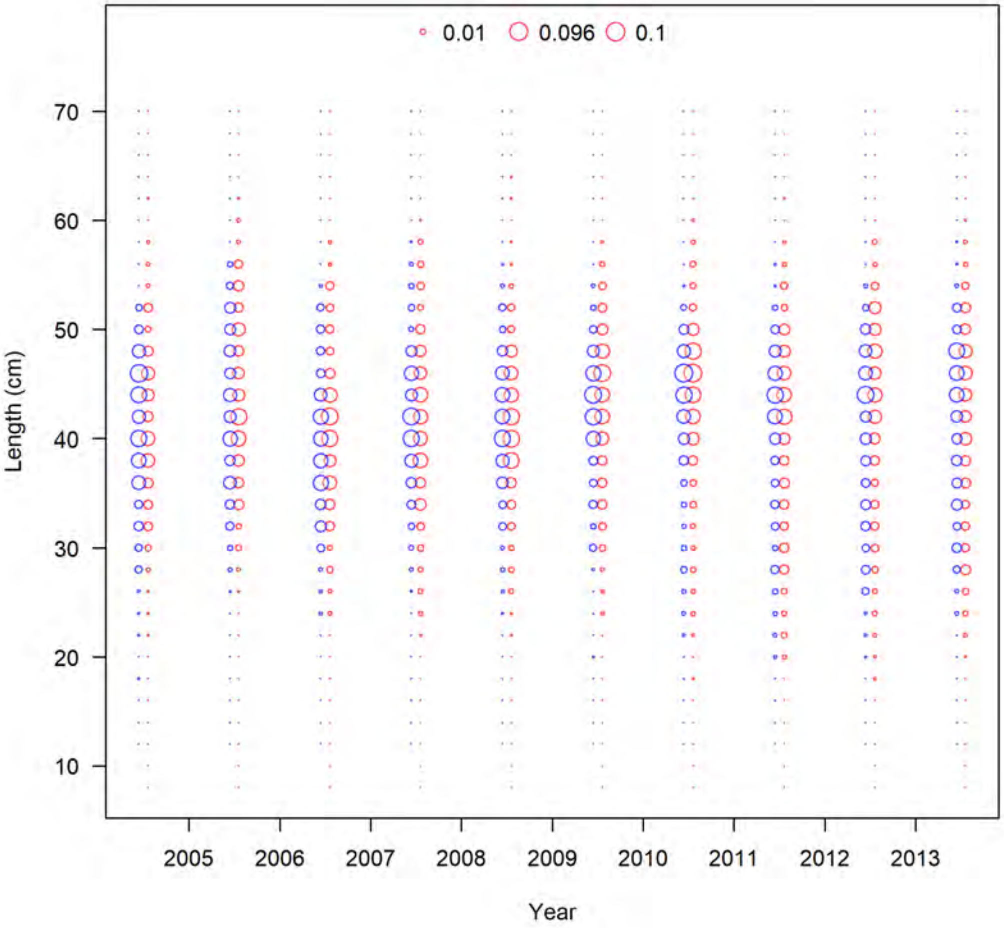

Figure 15: Length composition data from the NWFSC hook-and-line early years.

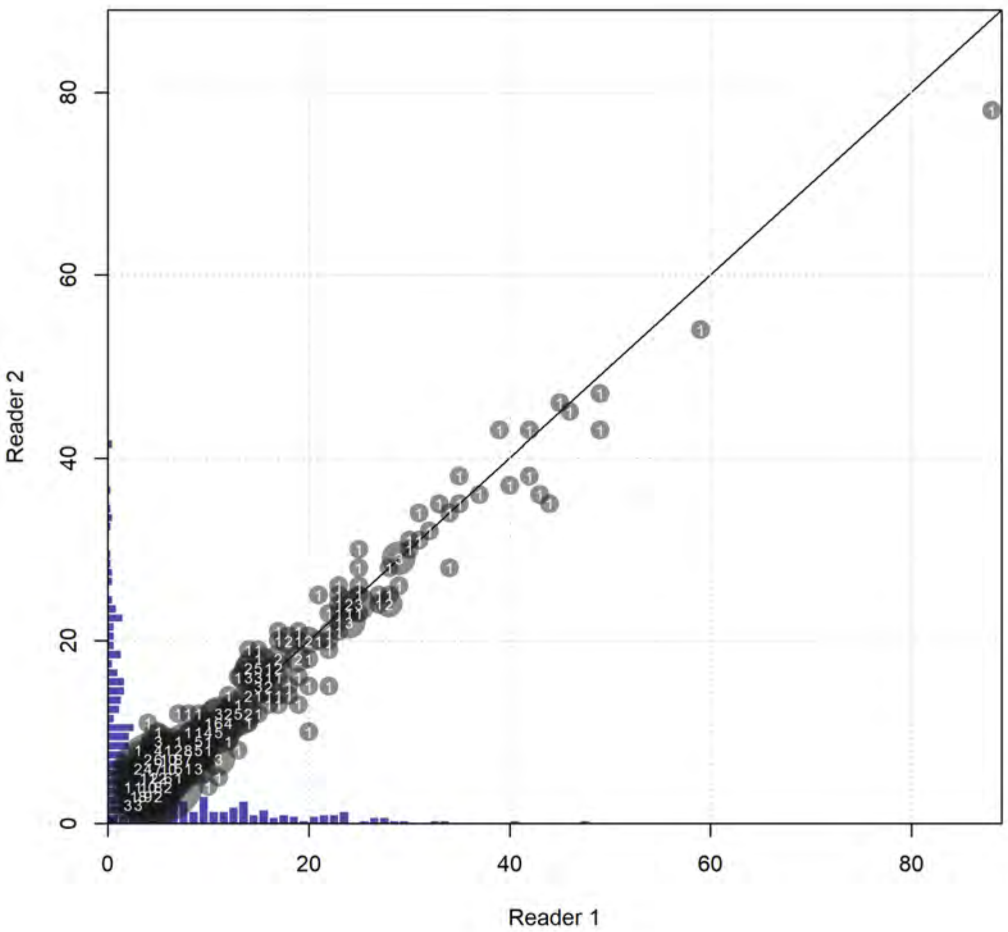

Figure 16: Aging precision between initial and blind double reads for vermilion rockfish. Numbers in the bubbles are the sample sizes of otoliths cross-read.

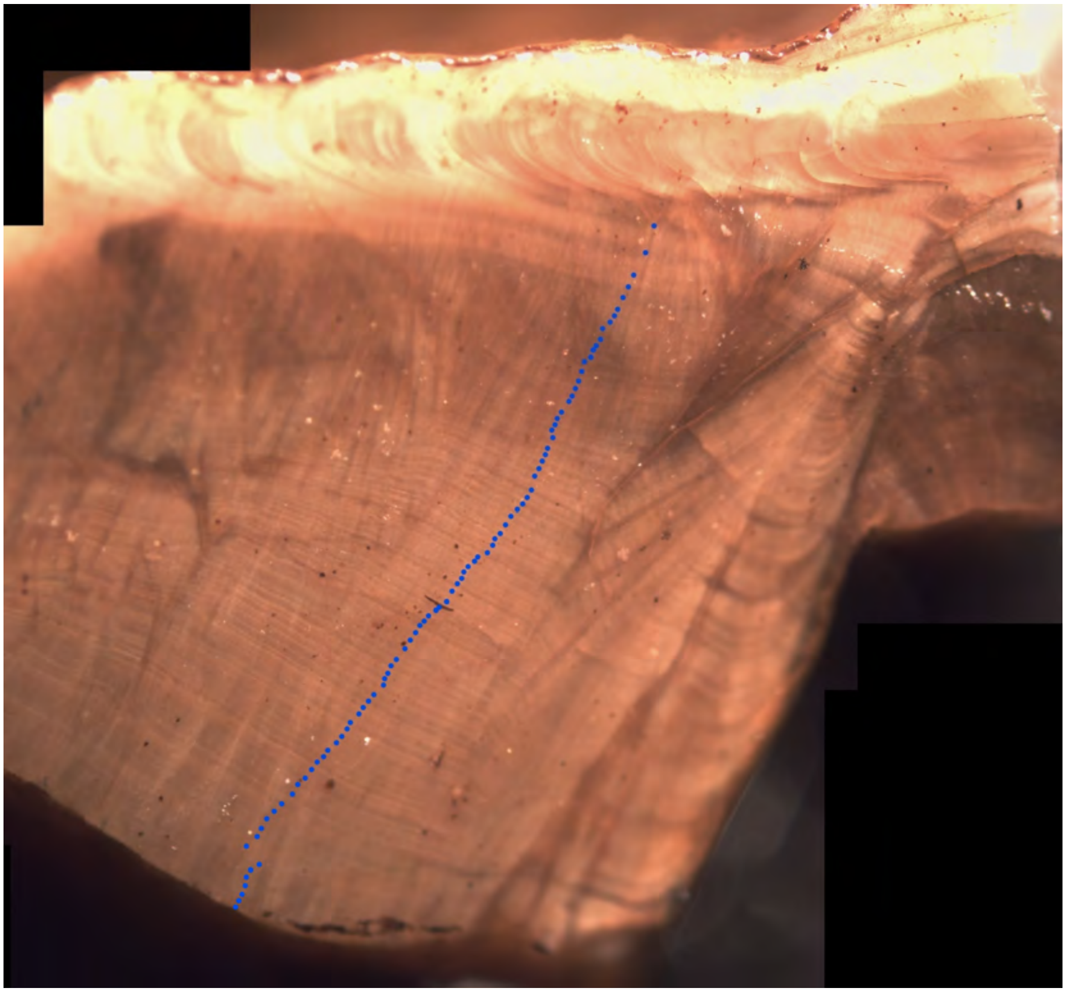

Figure 17: Photograph of the *oldest* aged fish used in the assessment with annuli marked by B. Kamikawa (NWFSC).

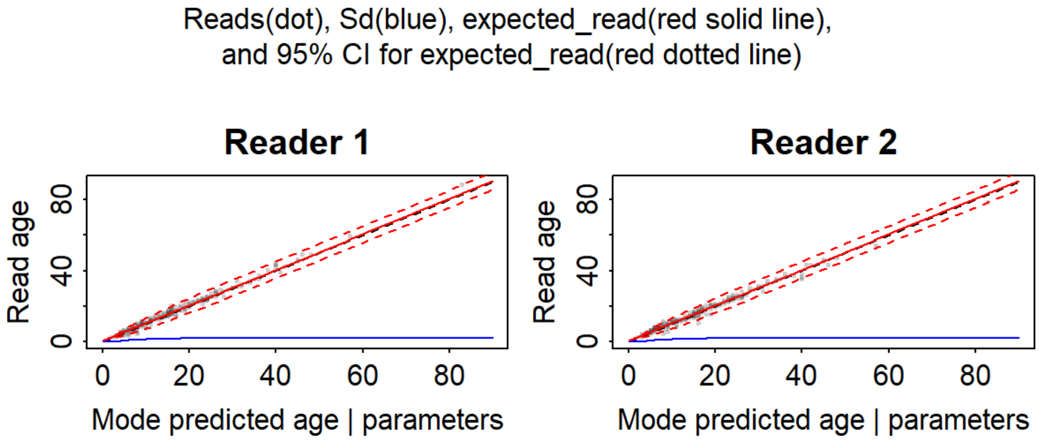

Figure 18: True versus predicted age for two current age readers at the NWFSC from the ageing error software with unbiased reads for reader 1 and curvilinear bias for reader 1 and curvilinear standard deviation for both readers.

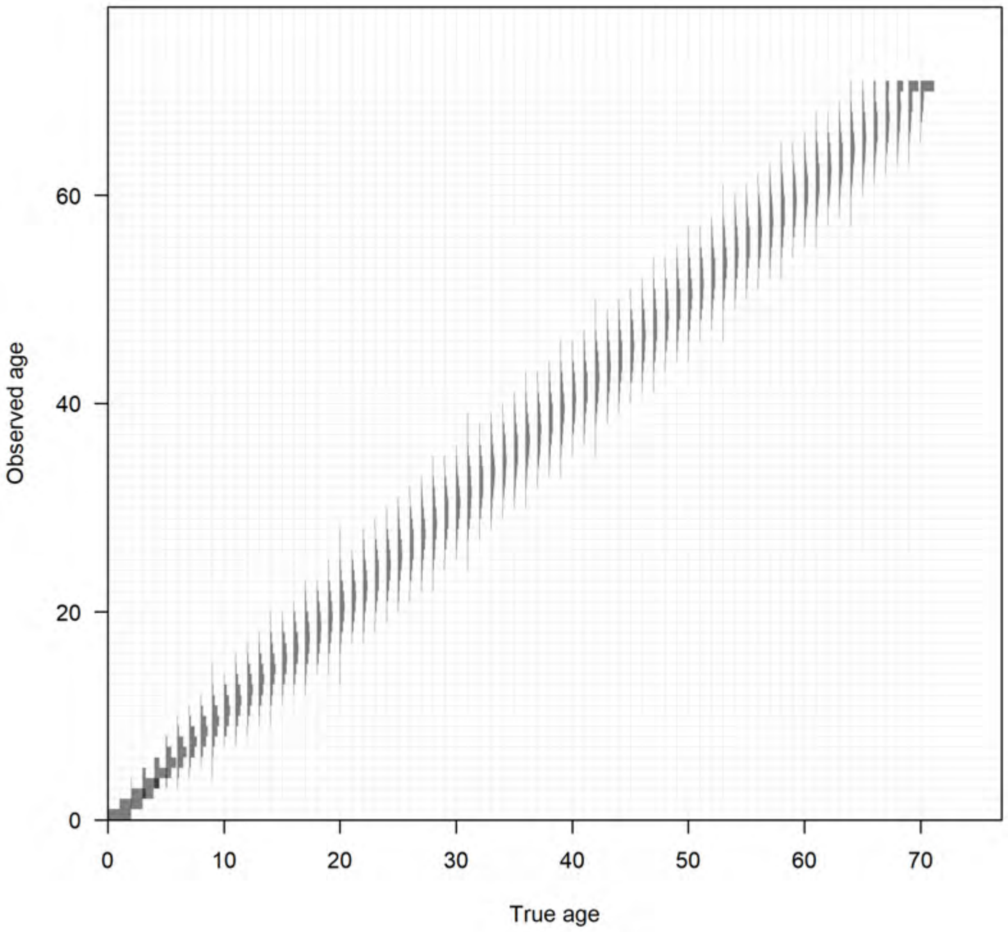

Figure 19: Distribution of observed age at true age for ageing error type 1.

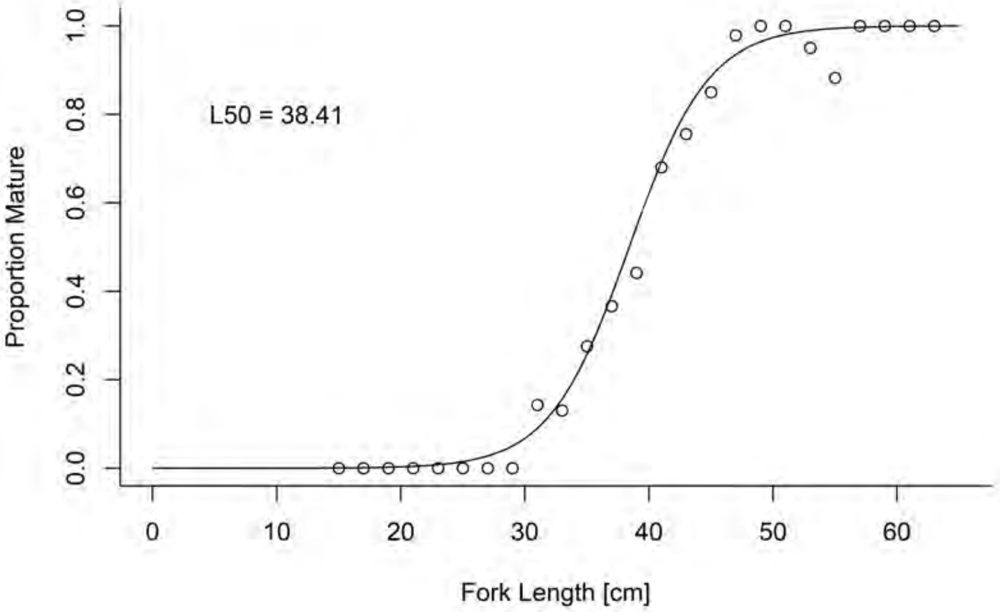

Figure 20: Fitted logistic regression of estimated functional maturity as a function of fork length for vermilion rockfish.

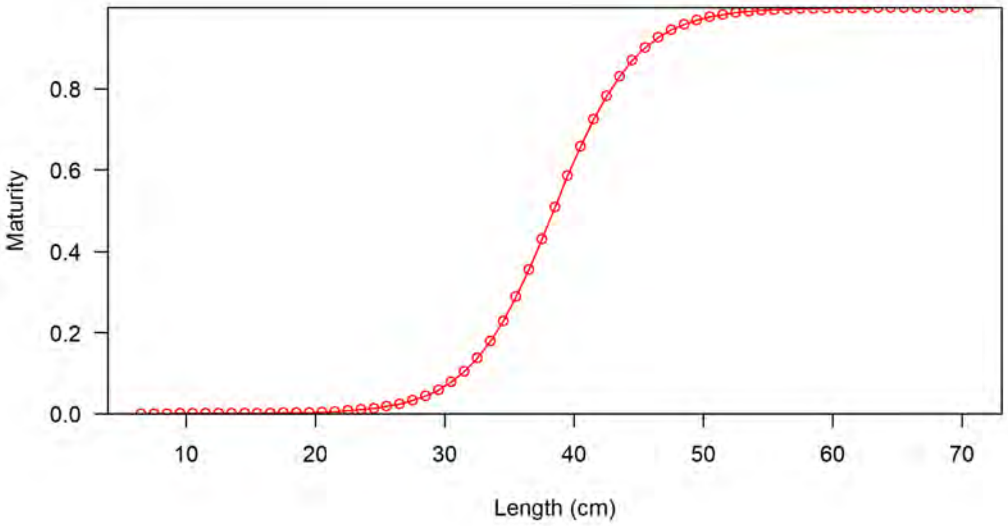

Figure 21: Maturity at length.

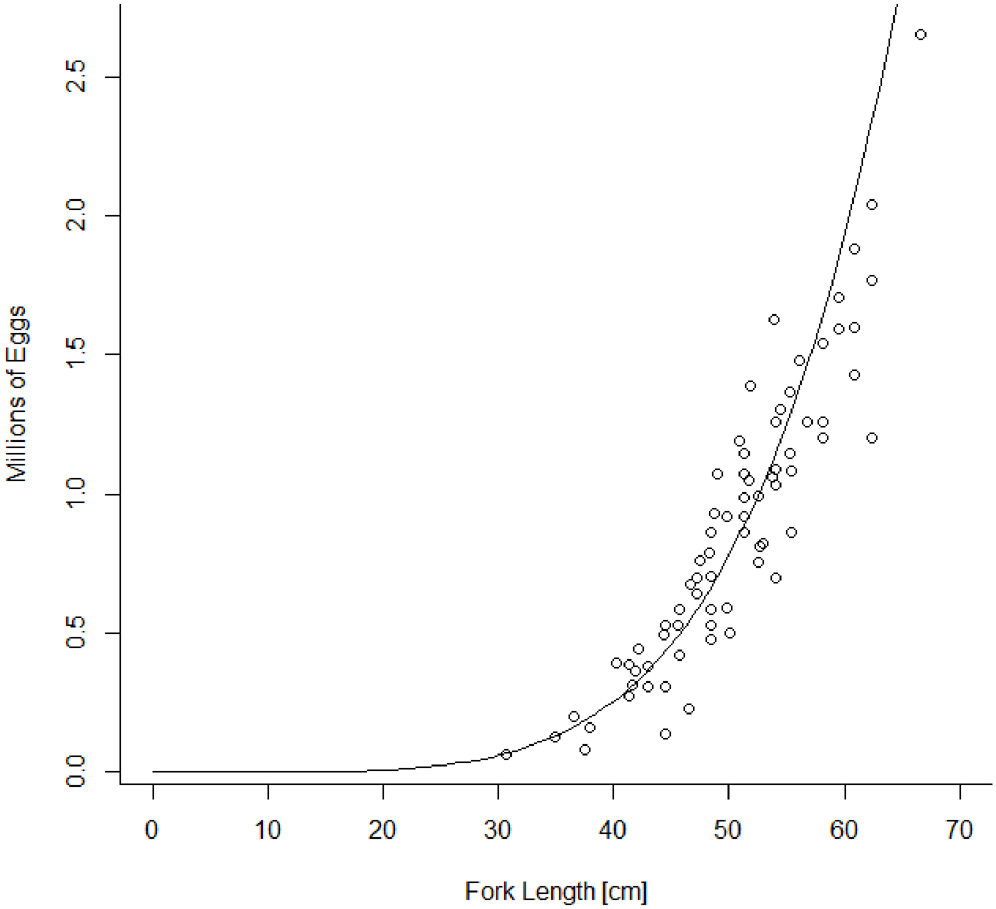

Figure 22: Fitted fecundity as a function of weight from samples of vermilion rockfish.

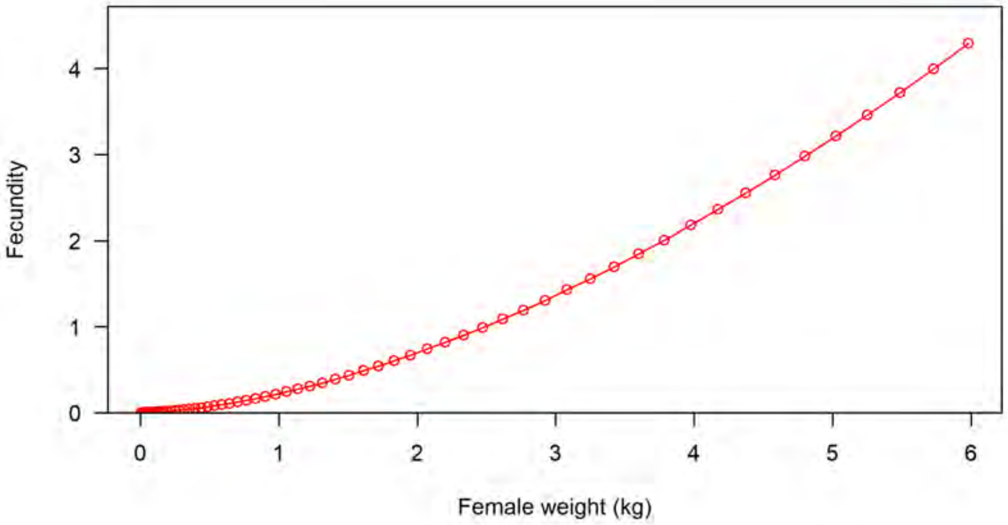

Figure 23: Fecundity as a function of weight.

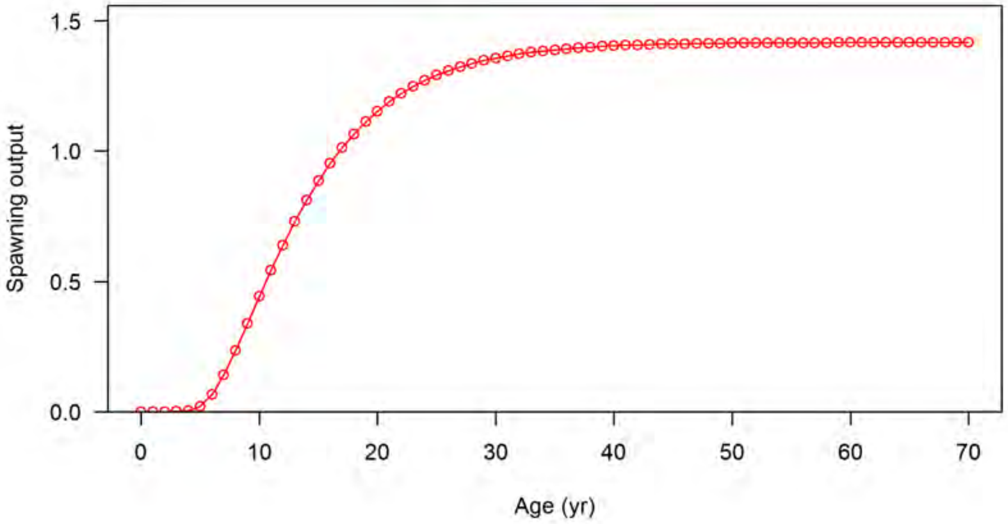

Figure 24: Spawning output at age. This is the product of maturity and fecundity. When these processes are length-based they are converted into the age dimension using the matrix of length at age.

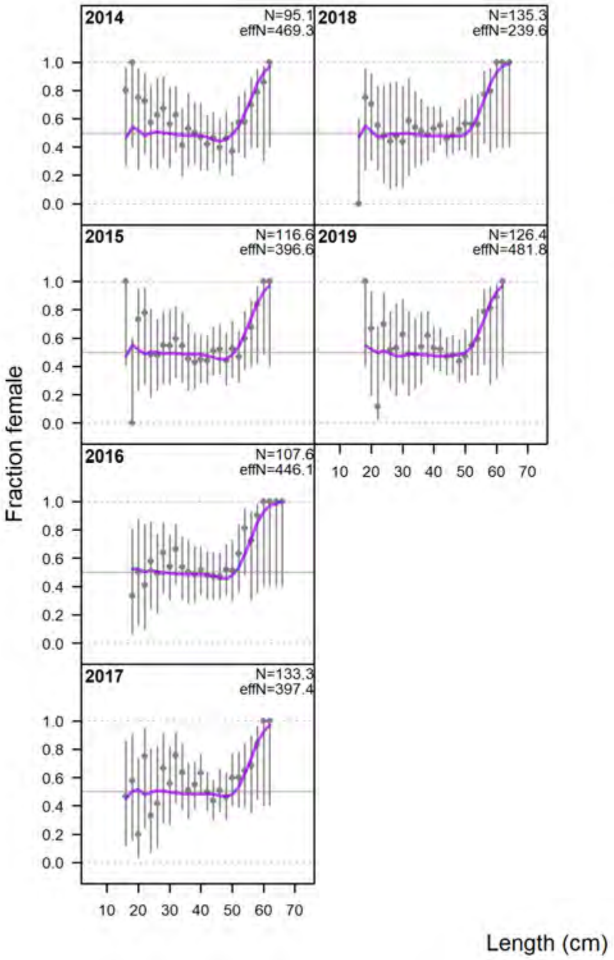

Figure 25: Sex ratios for length comps, whole catch, NWFSC hook-and-line survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

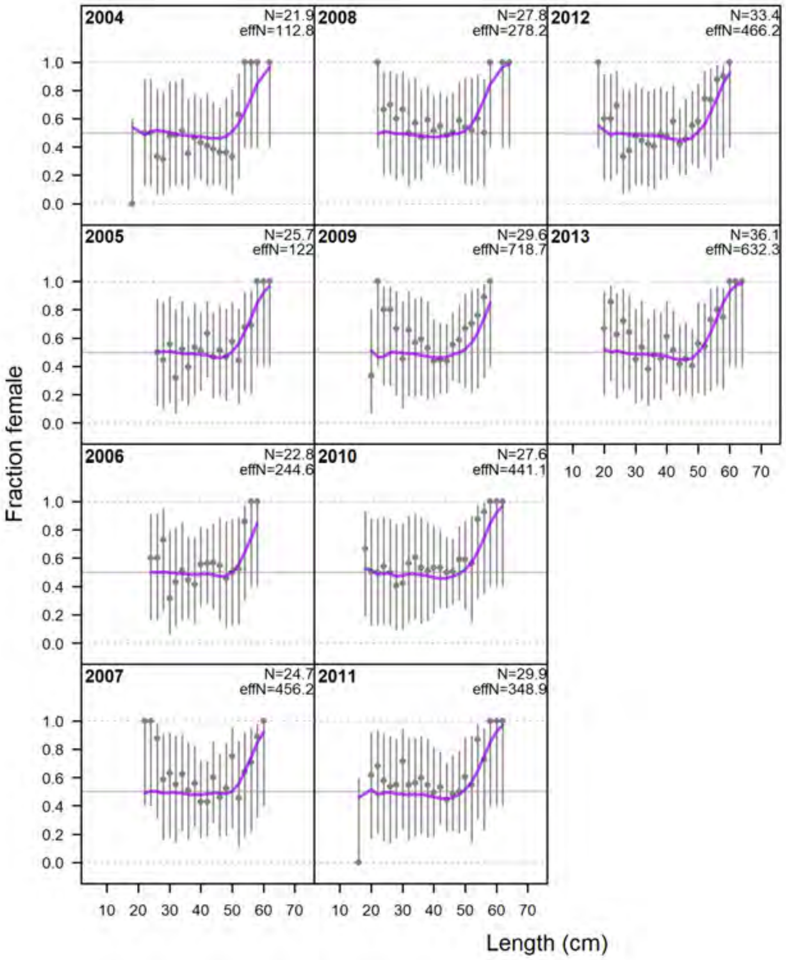

Figure 26: Sex ratios for length comps, whole catch, NWFSC hook-and-line early years. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

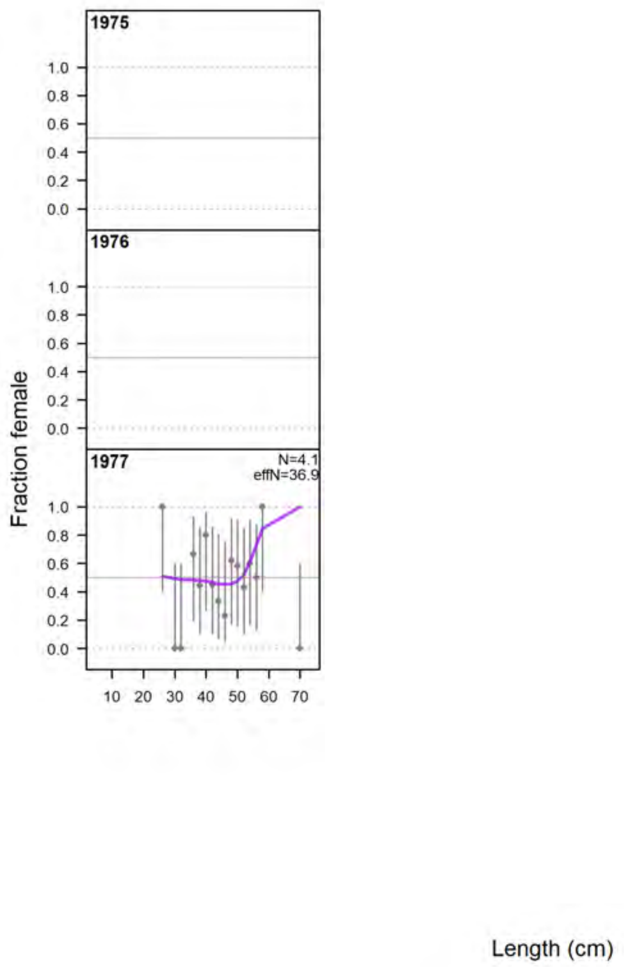

Figure 27: Sex ratios for length comps, whole catch, CDFW research (aka green binder) survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

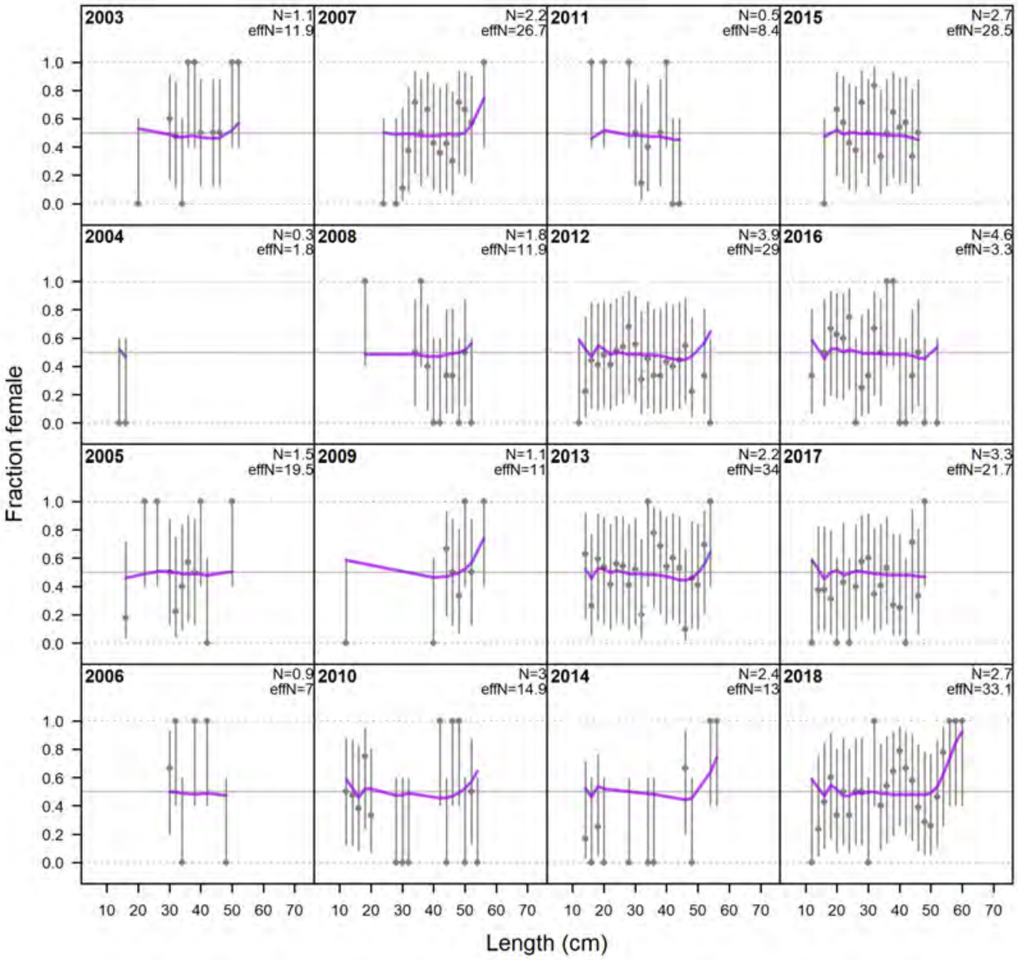

Figure 28: Sex ratios for length comps, whole catch, West Coast Groundfish Bottomfish Trawl Survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

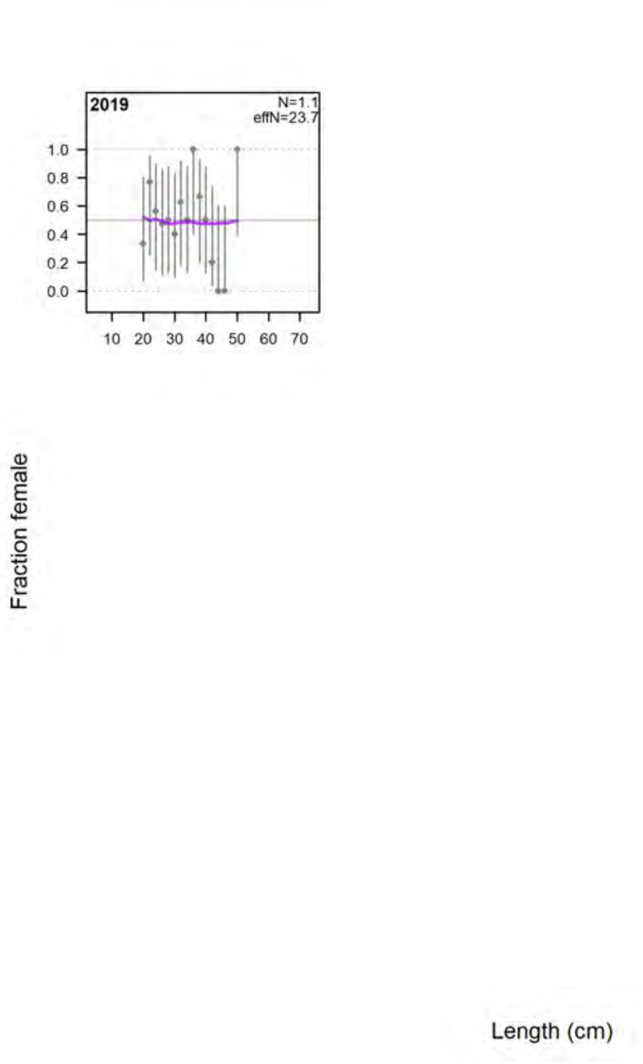

Figure 29: Sex ratios for length comps, whole catch, West Coast Groundfish Bottomfish Trawl Survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

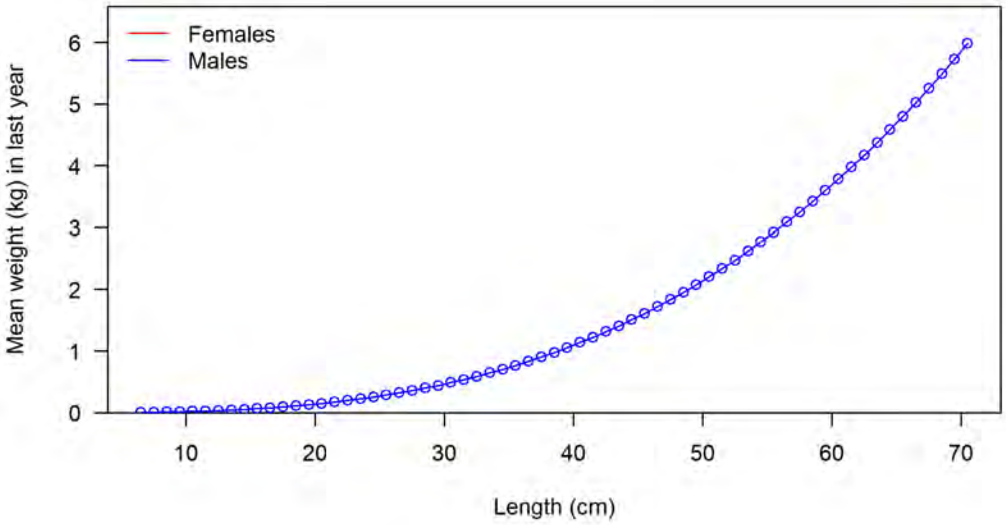

Figure 30: Weight-length relationship.

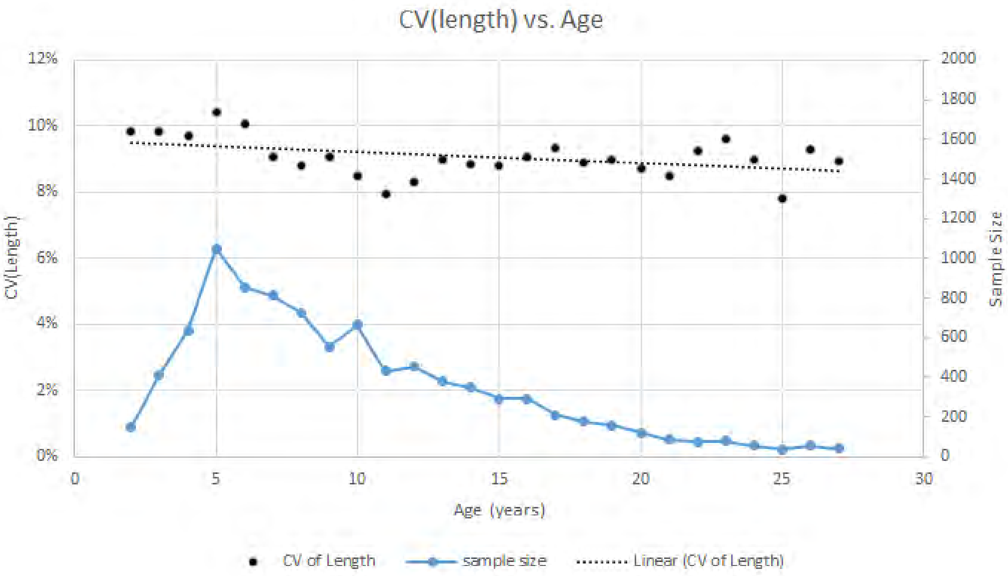

Figure 31: Coefficient of variation of length versus age for vermilion rockfish from the NWFSC hook-and-line survey.

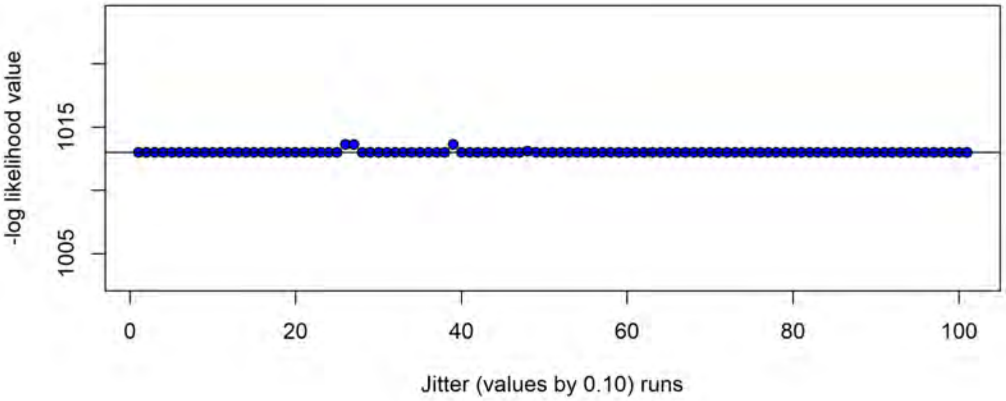

Figure 32: Results from 100 jittered runs of the post-STAR base model.

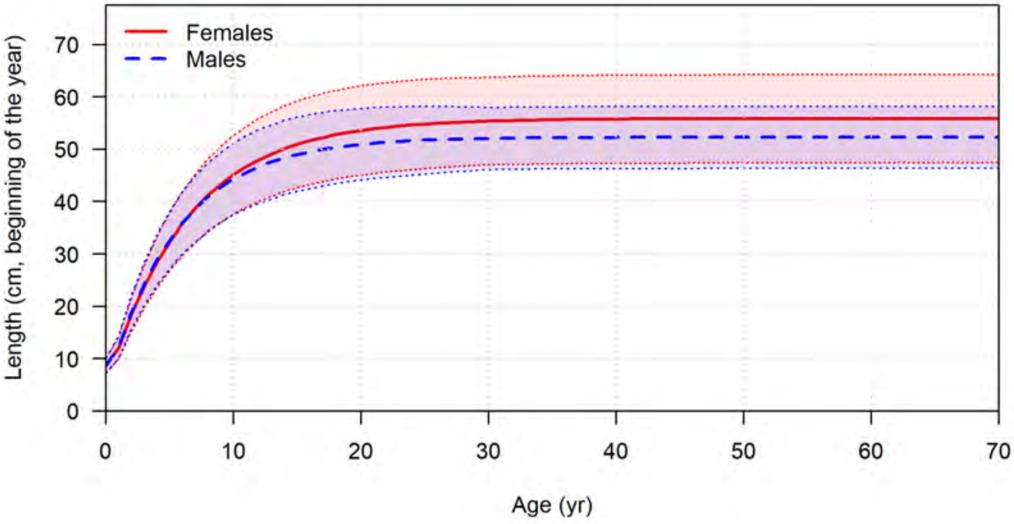

Figure 33: Length at age in the beginning of the year (or season) in the ending year of the model. Shaded area indicates 95% distribution of length at age around estimated growth curve.

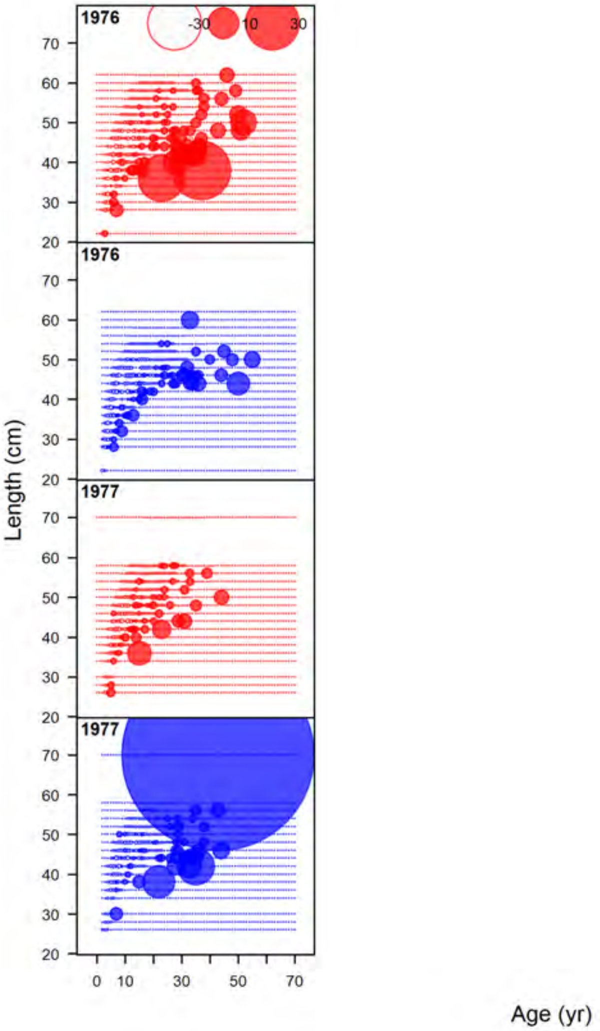

Figure 34: Pearson residuals, whole catch, CDFW_RESEARCH (max=375.72).

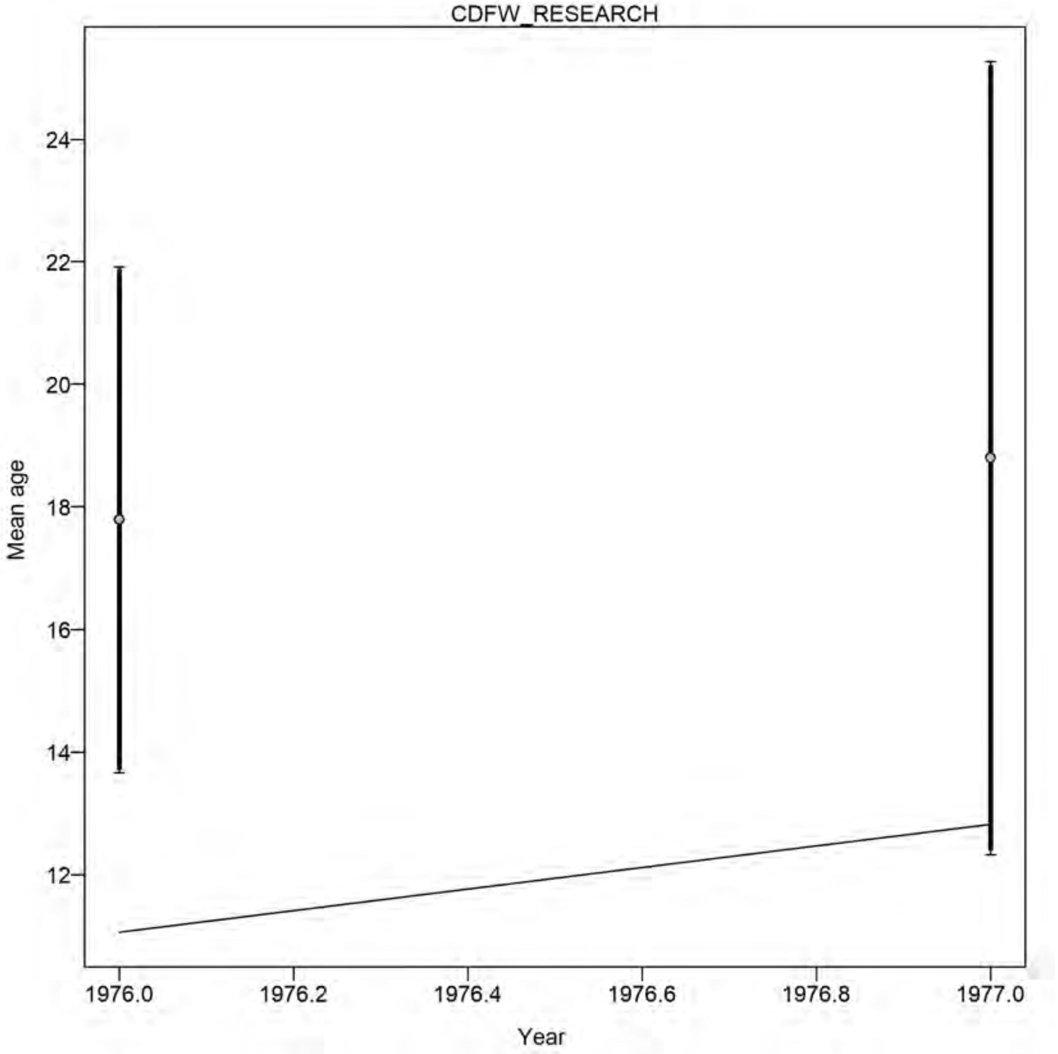

Figure 35: Mean age from conditional data (aggregated across length bins) for CDFW_RESEARCH with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from CDFW_RESEARCH: 0.9804 (0.9804-Inf).

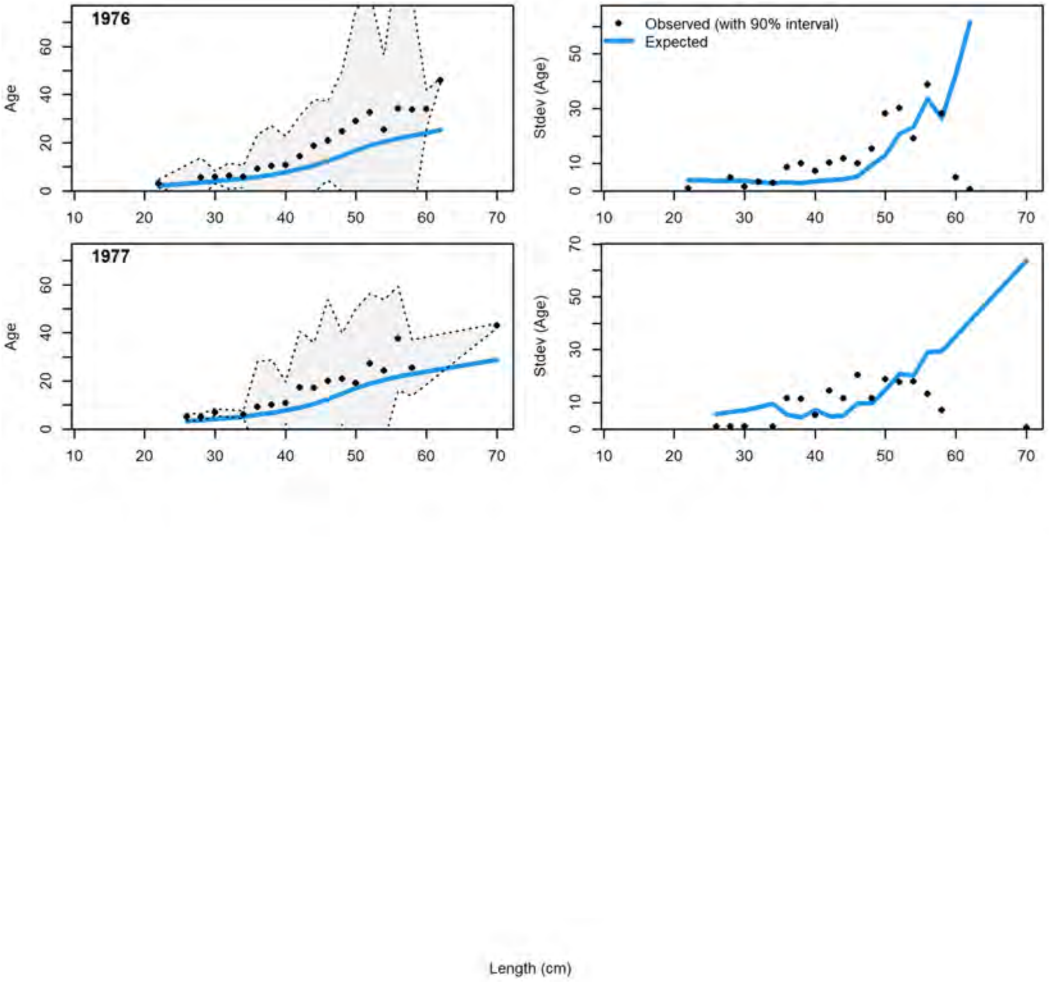

Figure 36: Conditional AAL plot, whole catch, CDFW_RESEARCH These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

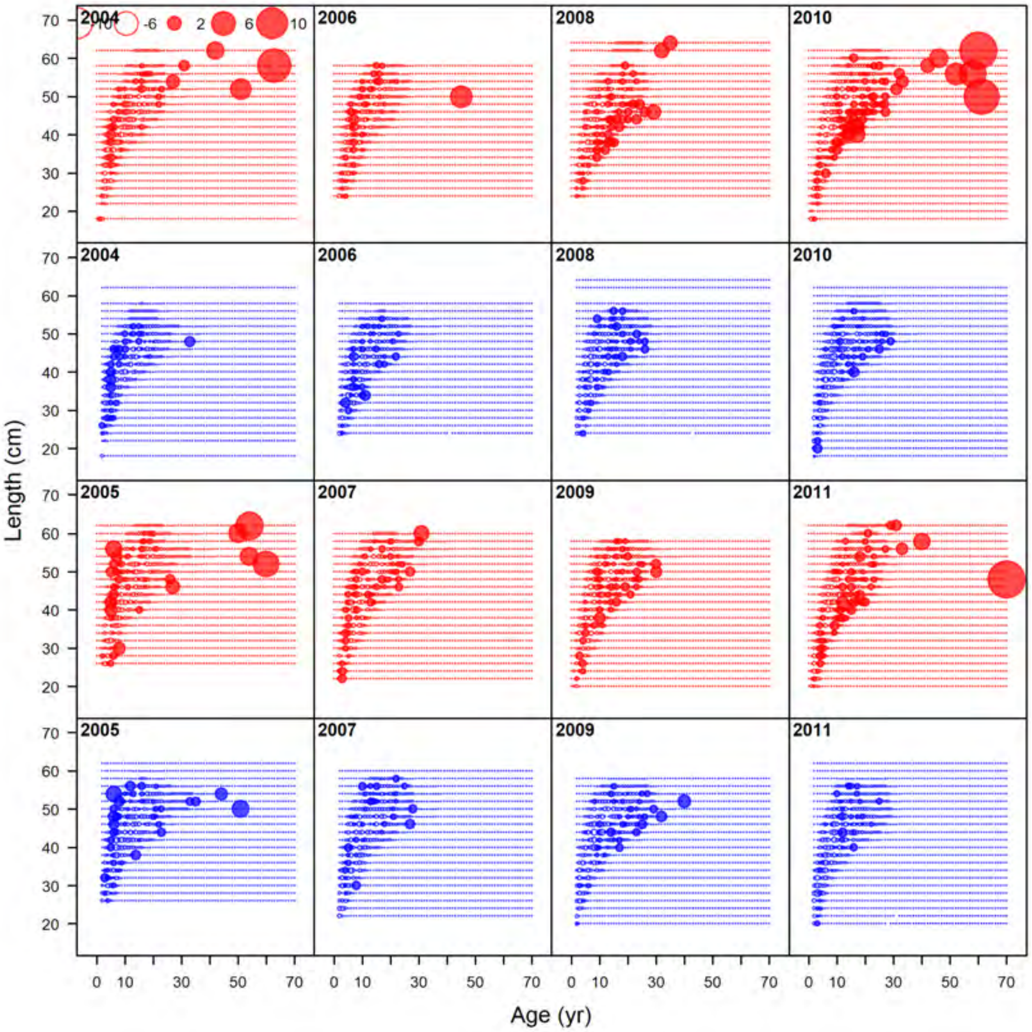

Figure 37: Pearson residuals, whole catch, EARLY_HKL (max=14.32) (plot 1 of 2).

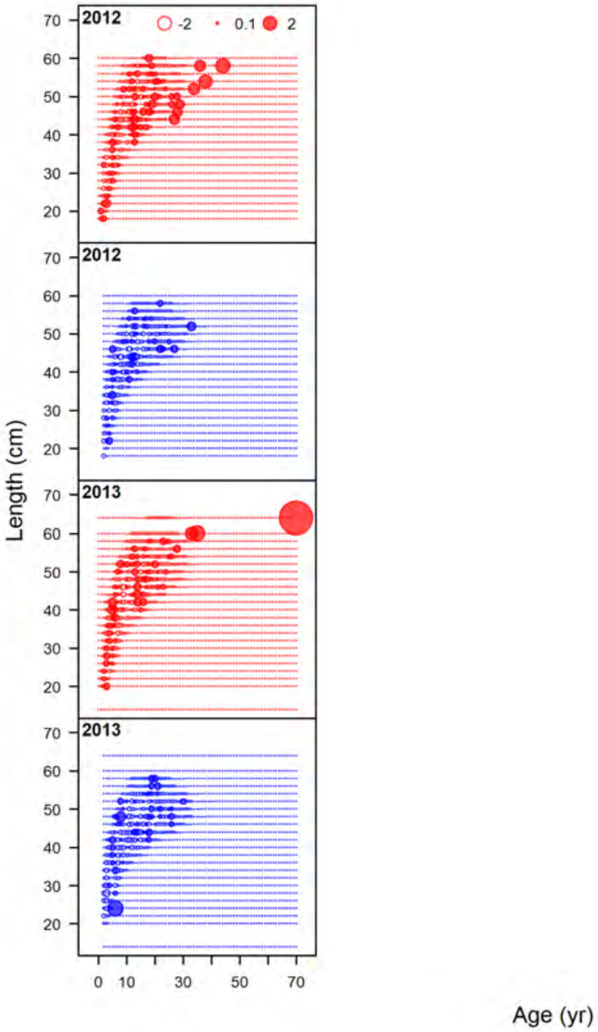

Figure 38: Pearson residuals, whole catch, EARLY_HKL (max=14.32) (plot 2 of 2).

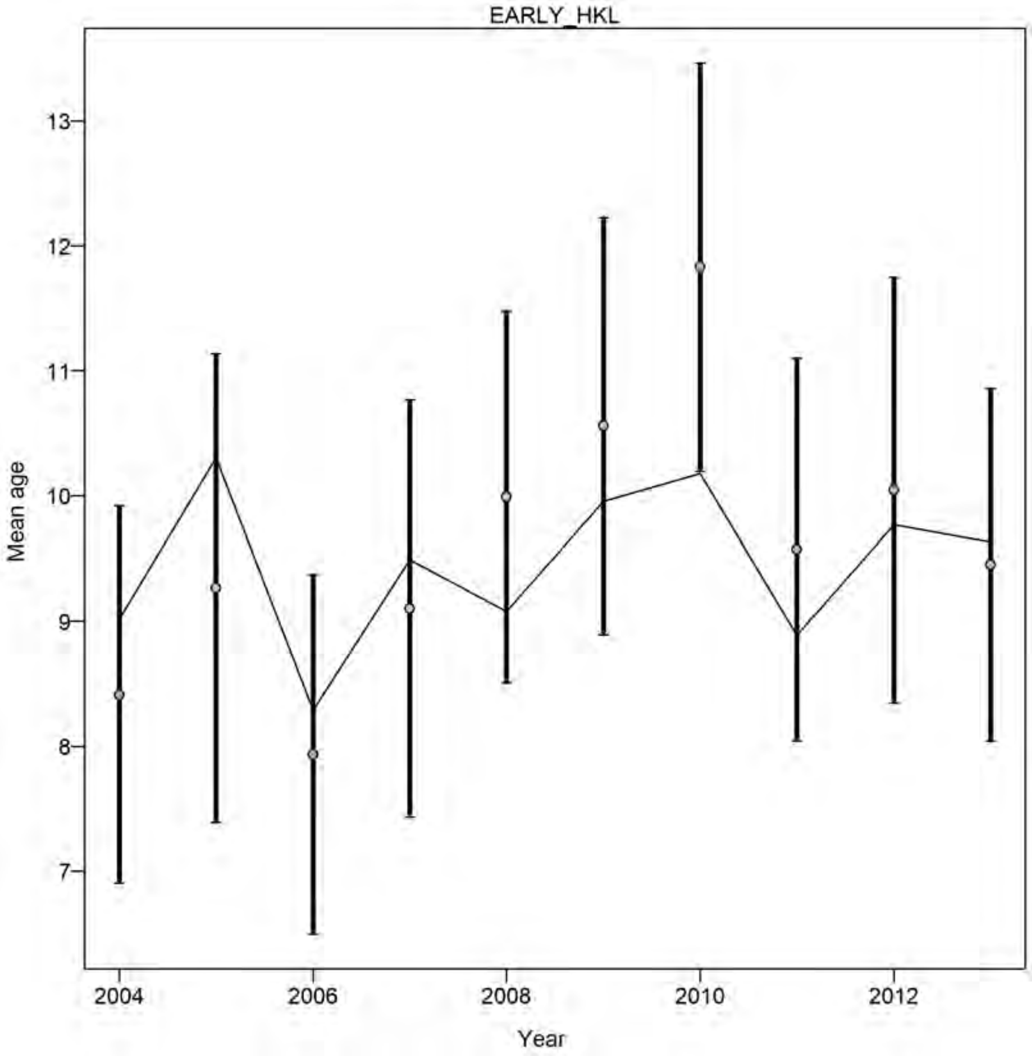

Figure 39: Mean age from conditional data (aggregated across length bins) for EARLY_HKL with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from EARLY_HKL: 0.9905 (0.6287-3.0507).

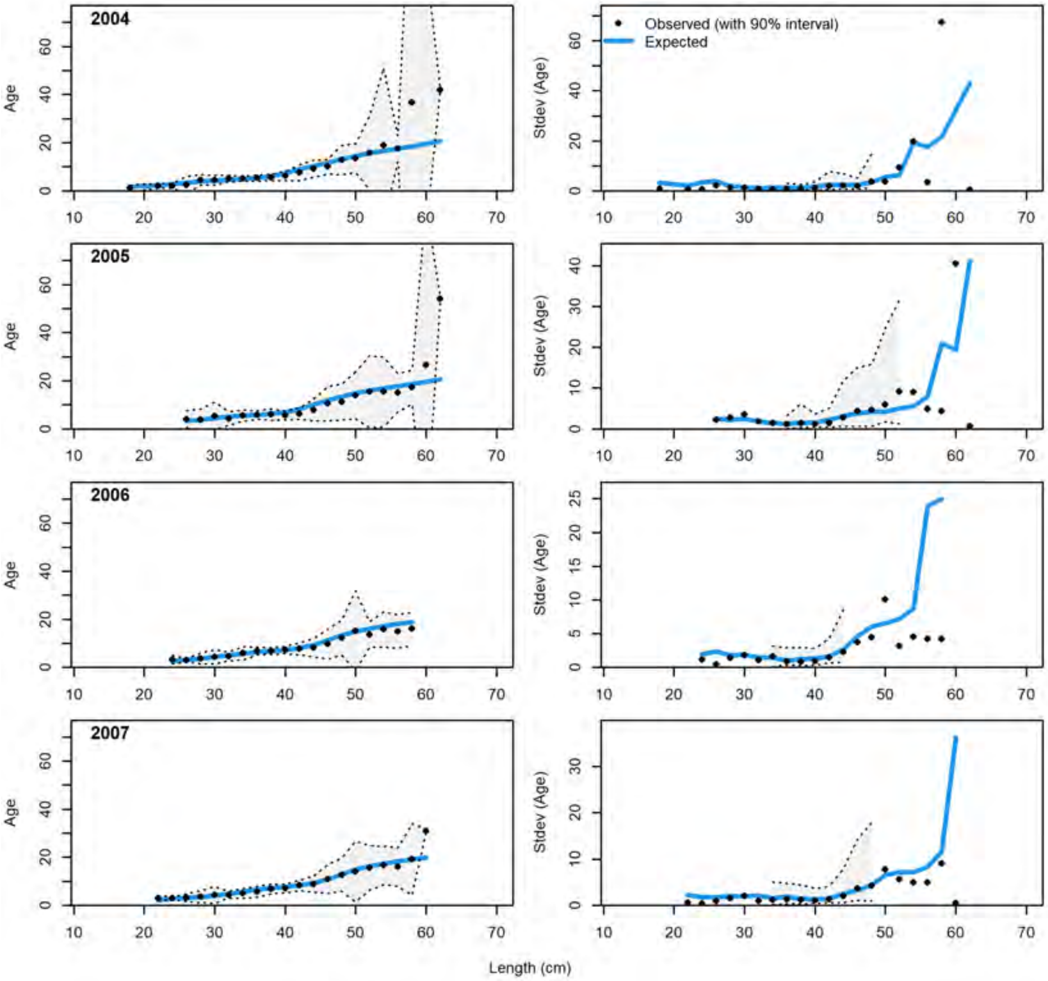

Figure 40: Conditional AAL plot, whole catch, EARLY_HKL (plot 1 of 3) These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

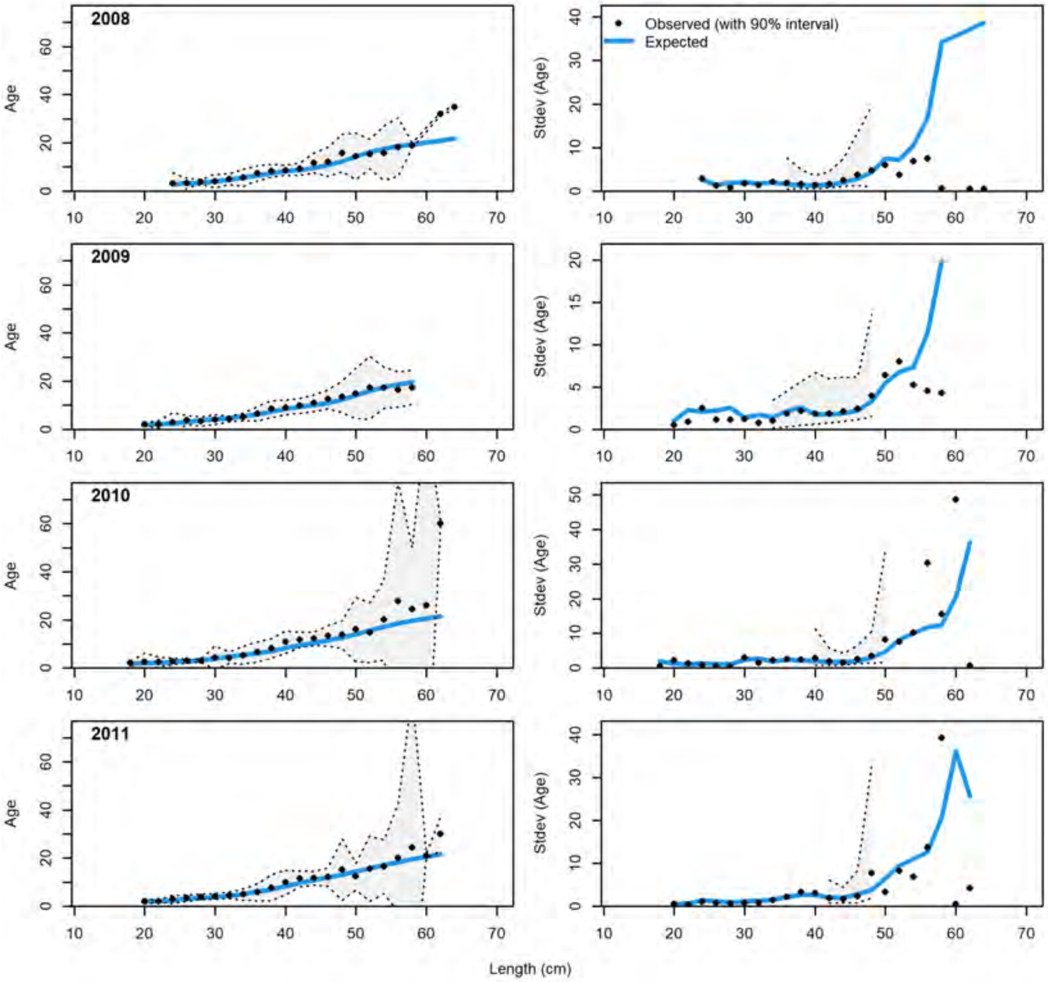

Figure 41: Conditional AAL plot, whole catch, EARLY_HKL (plot 2 of 3).

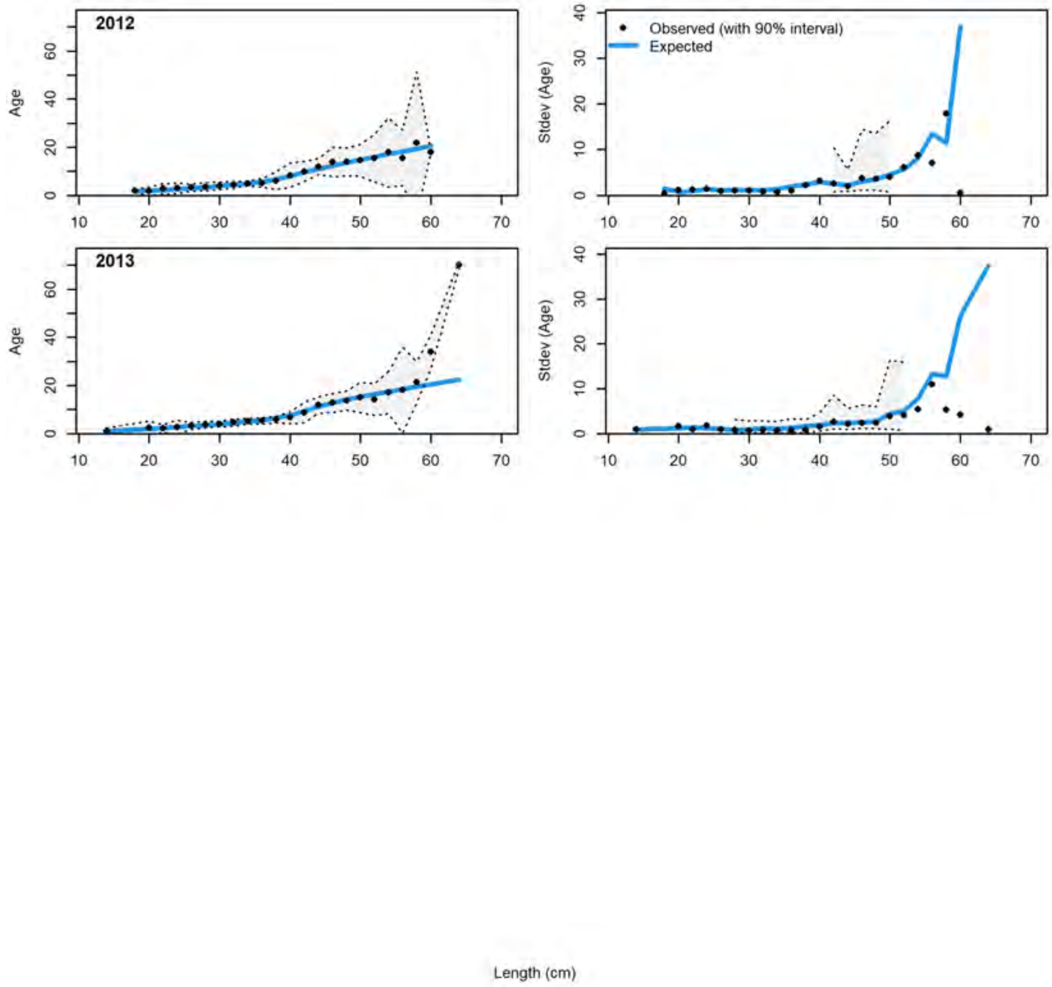

Figure 42: Conditional AAL plot, whole catch, EARLY_HKL (plot 3 of 3).

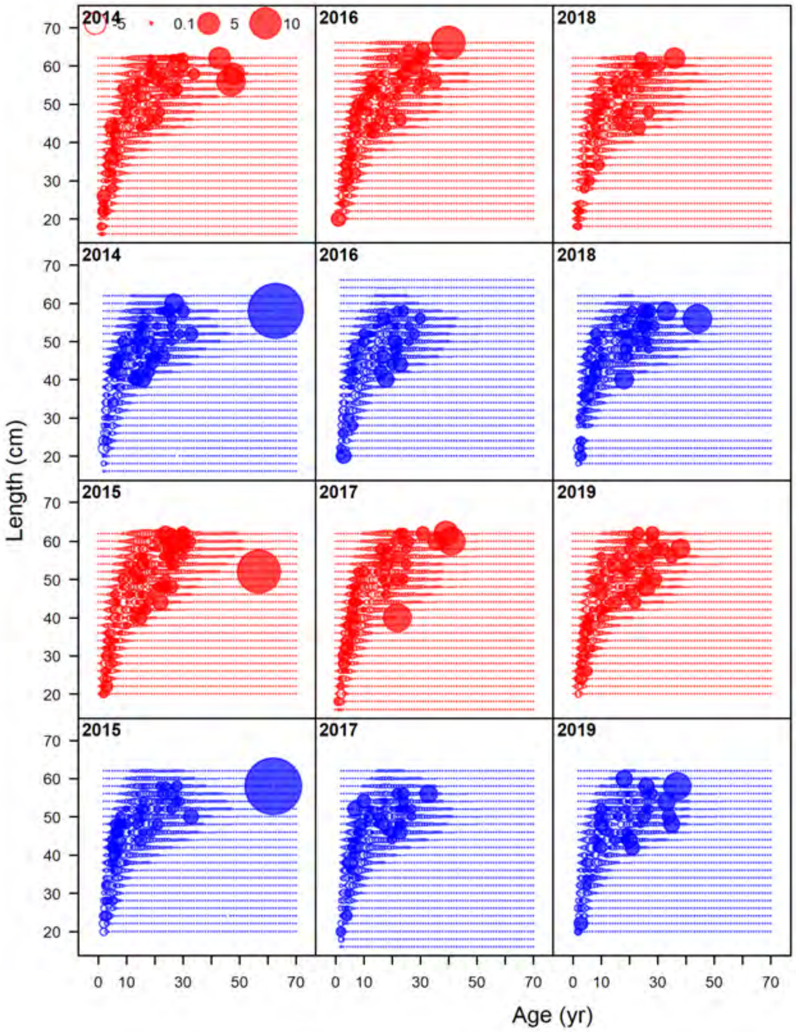

Figure 43: Pearson residuals, whole catch, NWFSC_HKL (max=32.76).

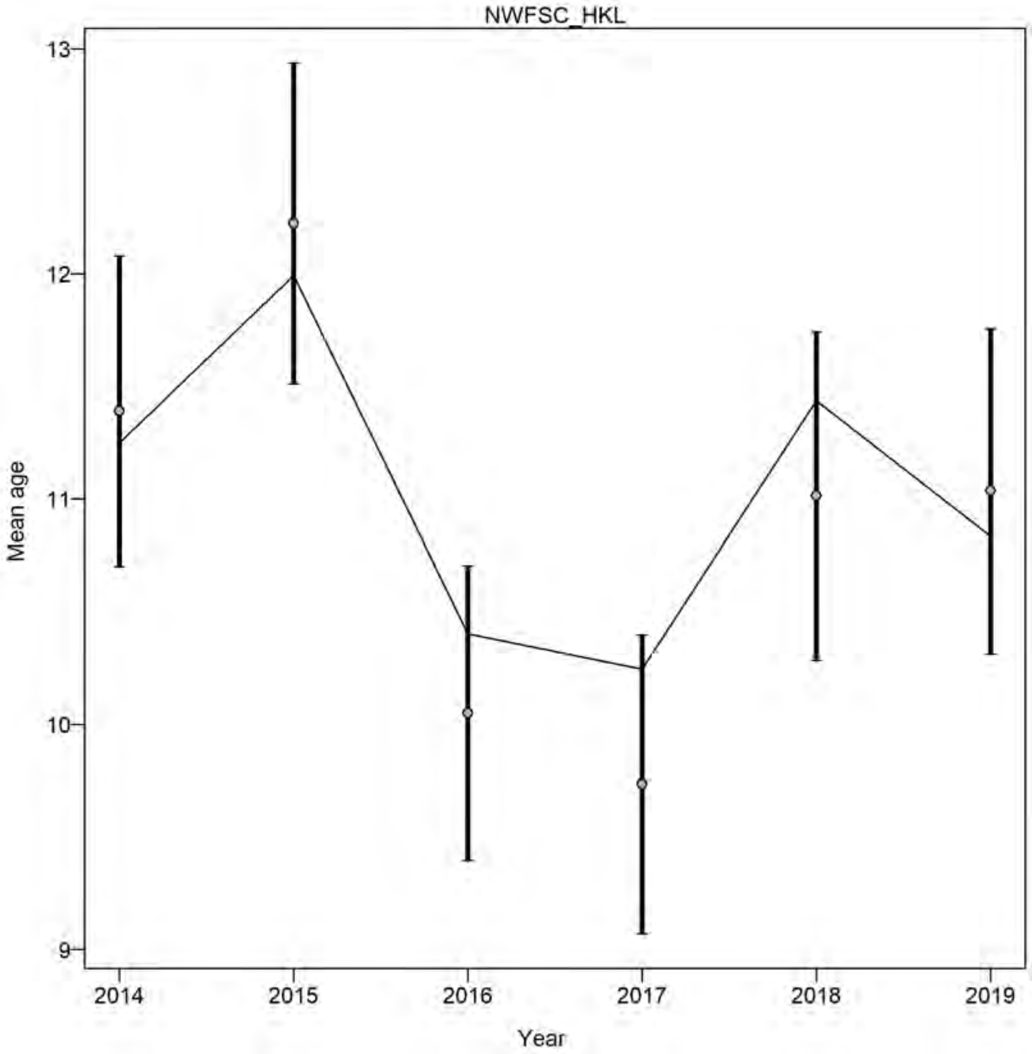

Figure 44: Mean age from conditional data (aggregated across length bins) for NWFSC_HKL with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from NWFSC_HKL: 0.9919 (0.8118-2.933).

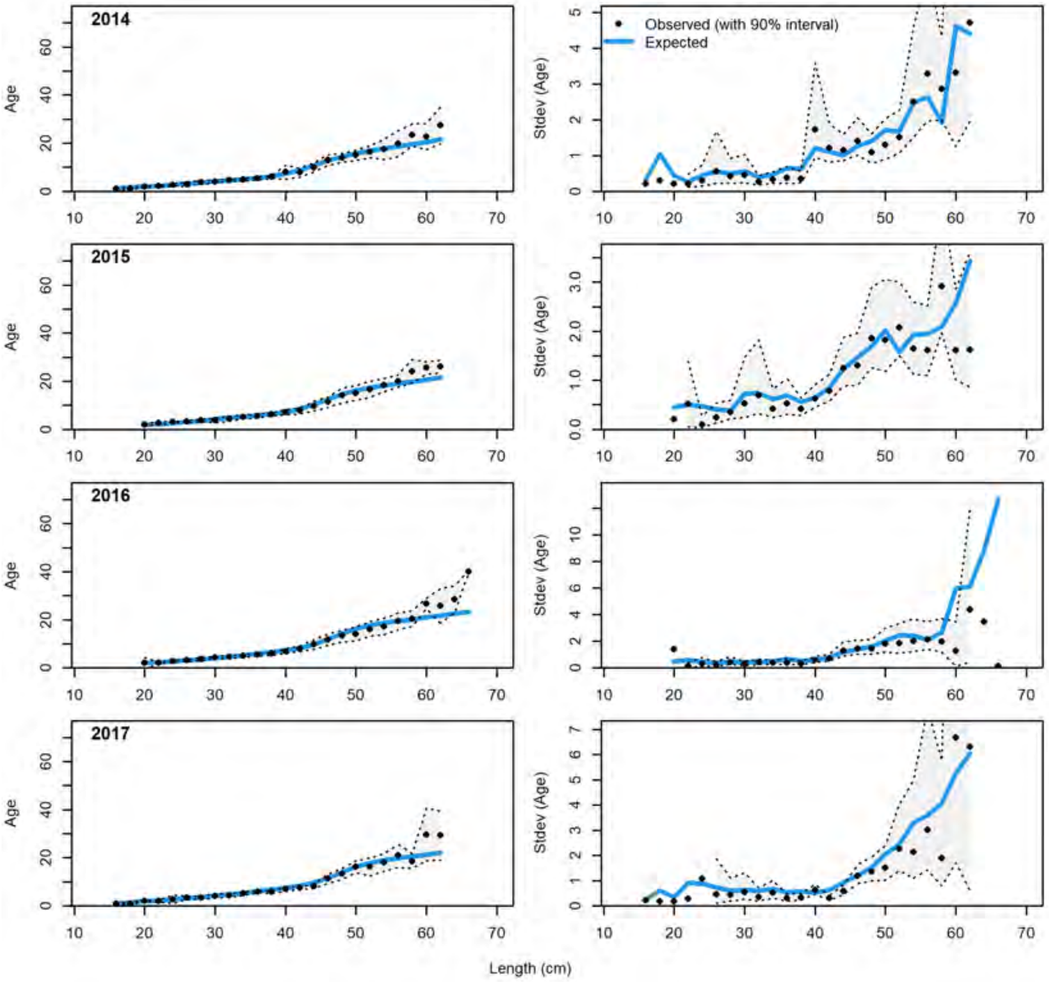

Figure 45: Conditional AAL plot, whole catch, NWFSC_HKL (plot 1 of 2) These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

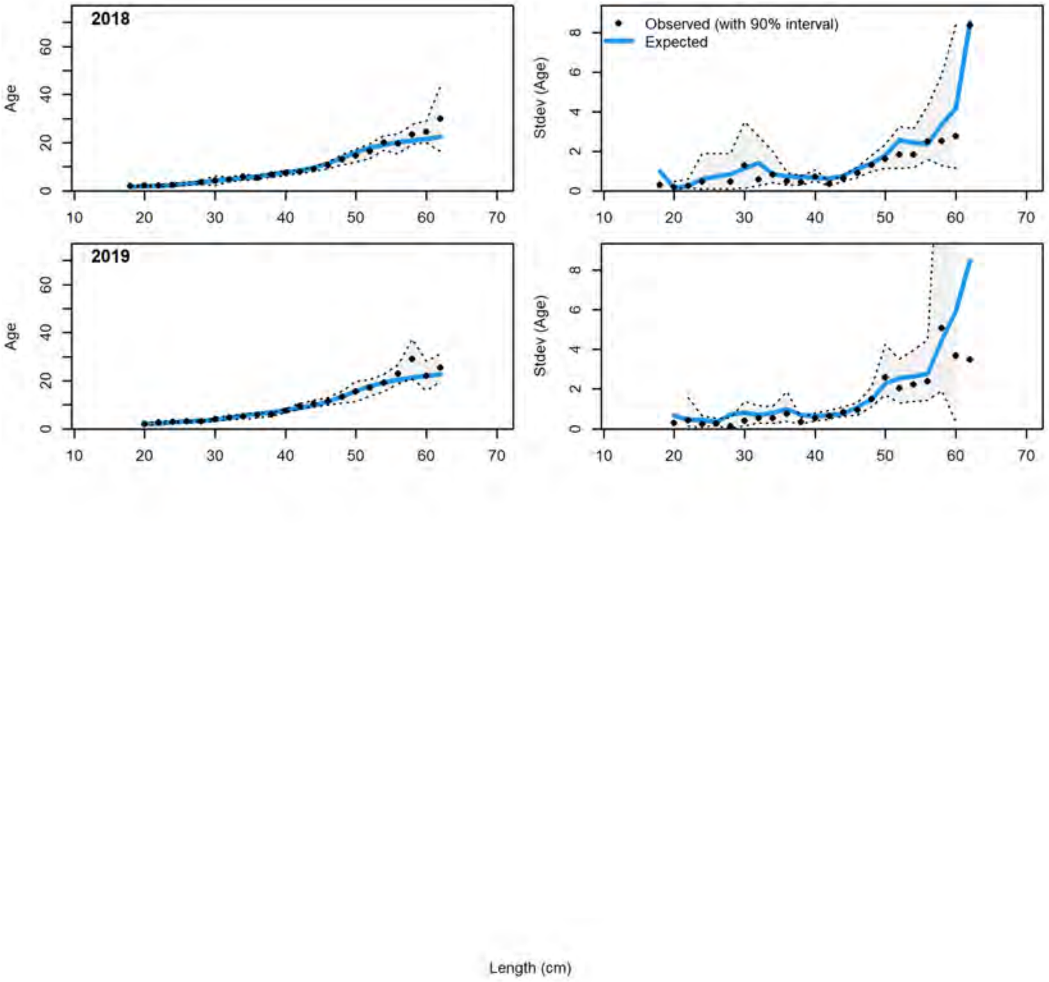

Figure 46: Conditional AAL plot, whole catch, NWFSC_HKL (plot 2 of 2).

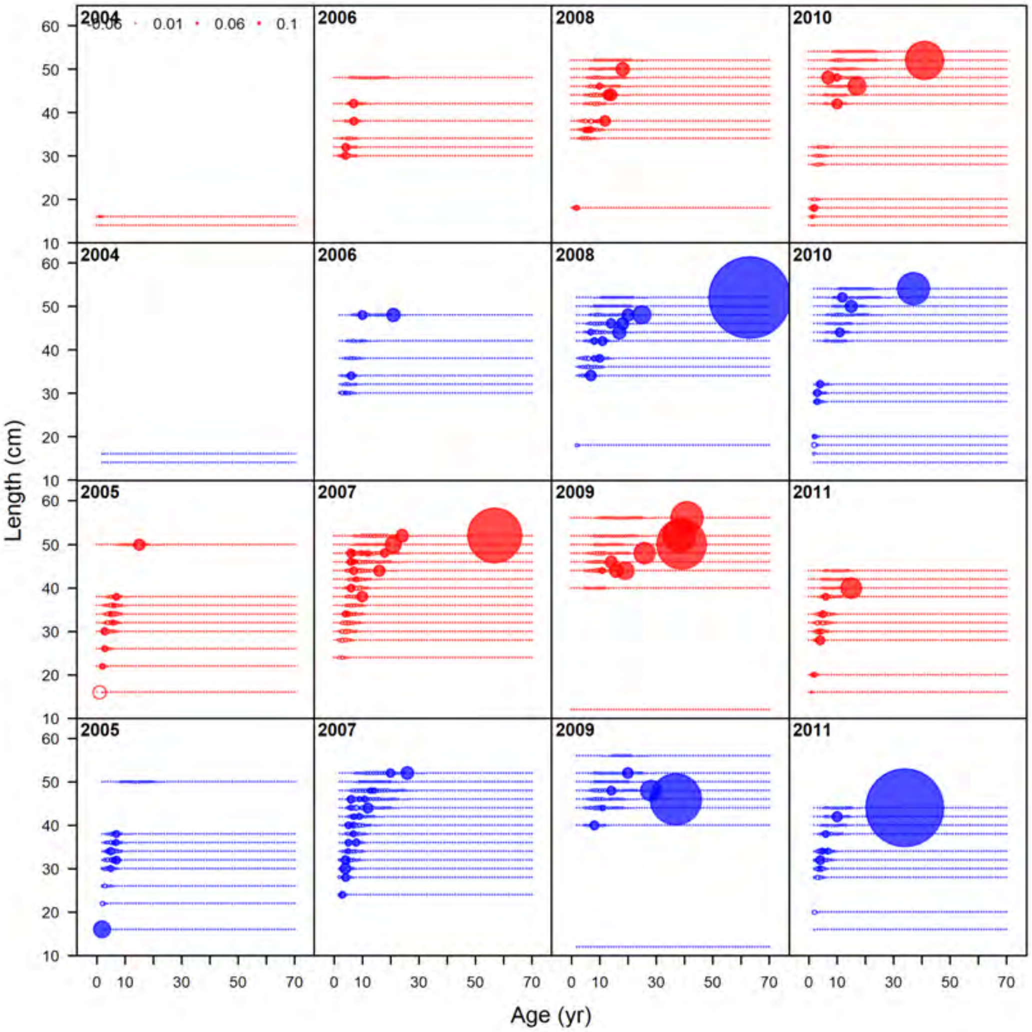

Figure 47: Pearson residuals, whole catch, NWFSC_TWL (max=68.79) (plot 1 of 2).

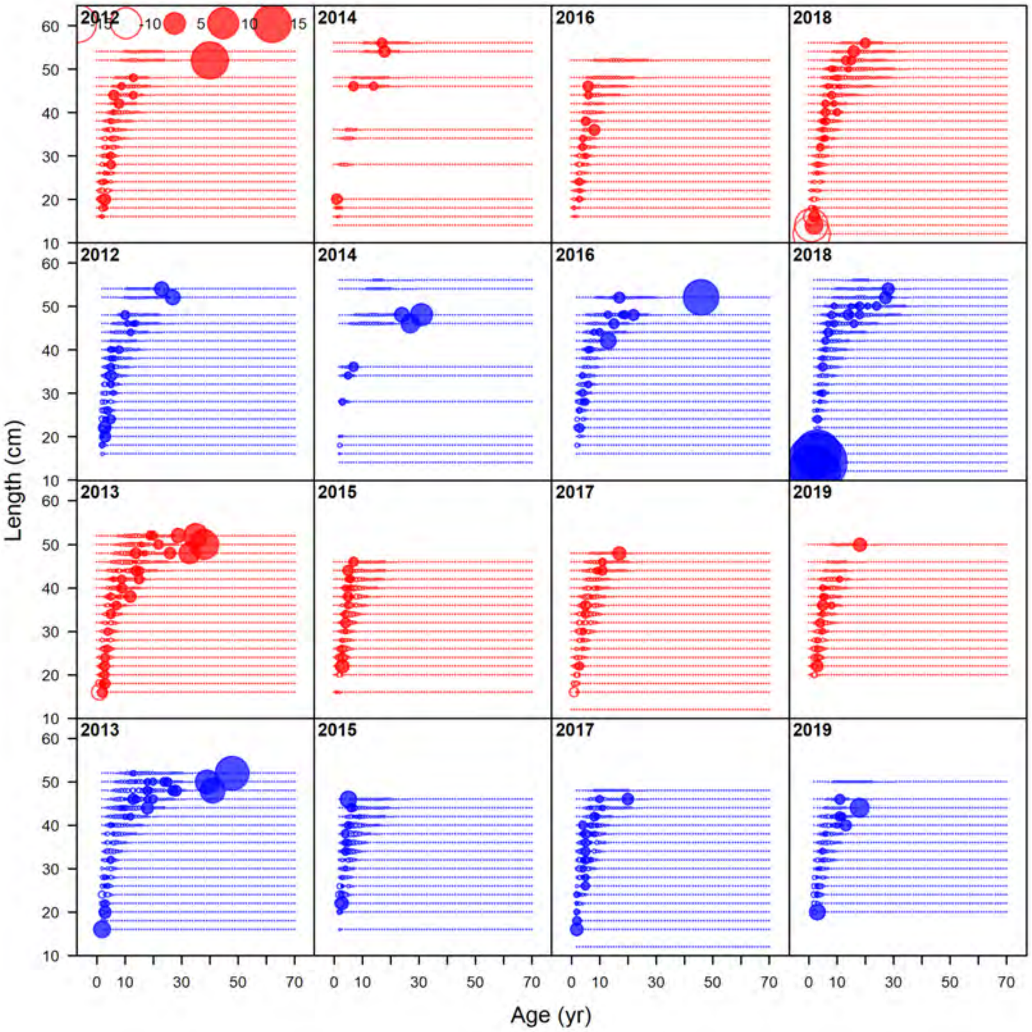

Figure 48: Pearson residuals, whole catch, NWFSC_TWL (max=68.79) (plot 2 of 2).

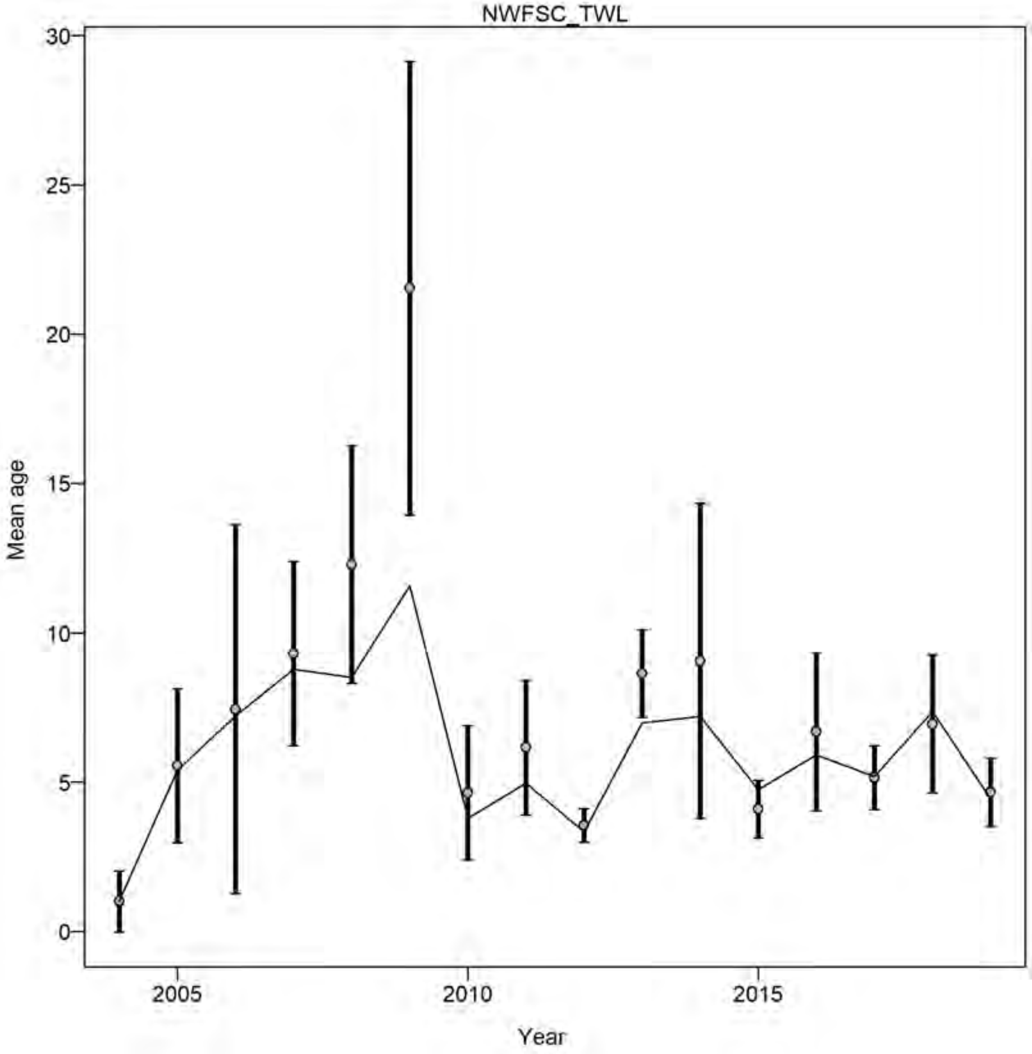

Figure 49: Mean age from conditional data (aggregated across length bins) for NWFSC_TWL with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from NWFSC_TWL: 0.9931 (0.5902-2.9955).

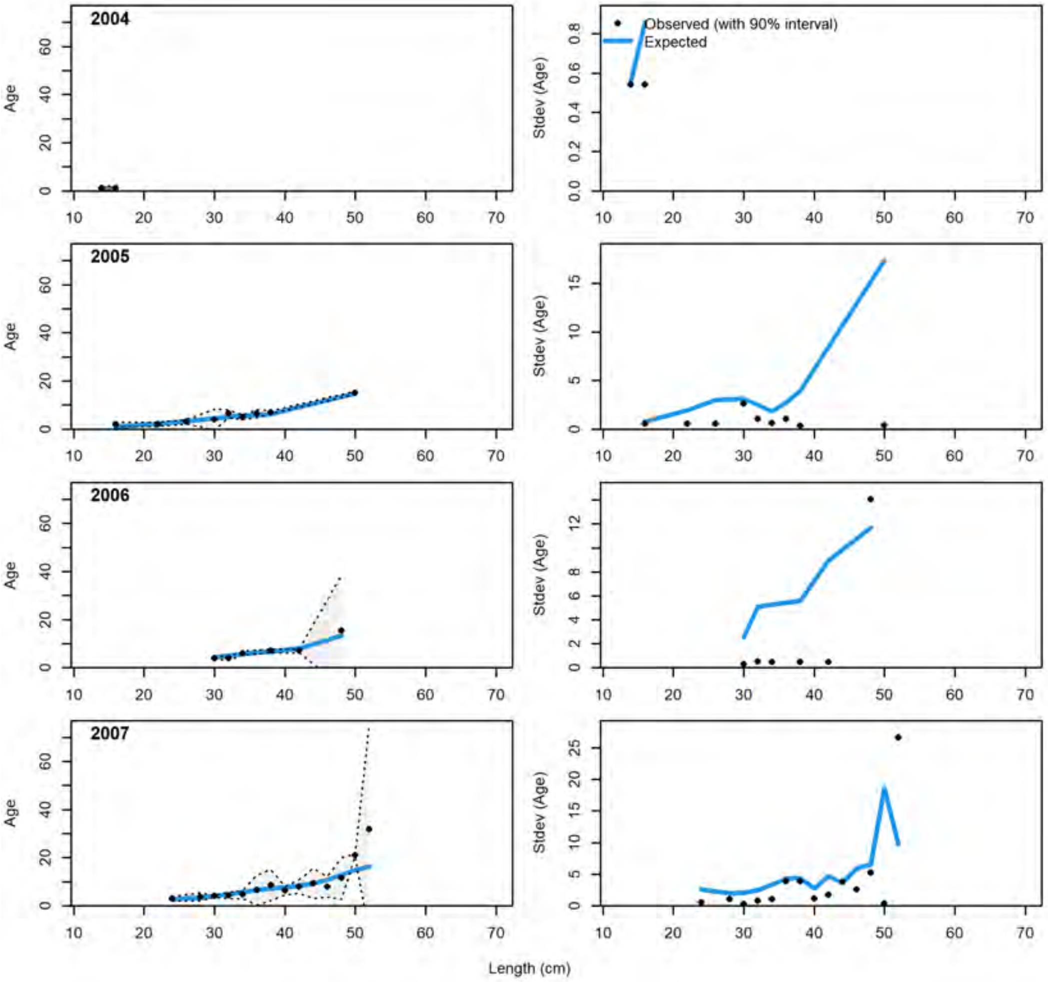

Figure 50: Conditional AAL plot, whole catch, NWFSC_TWL (plot 1 of 4) These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

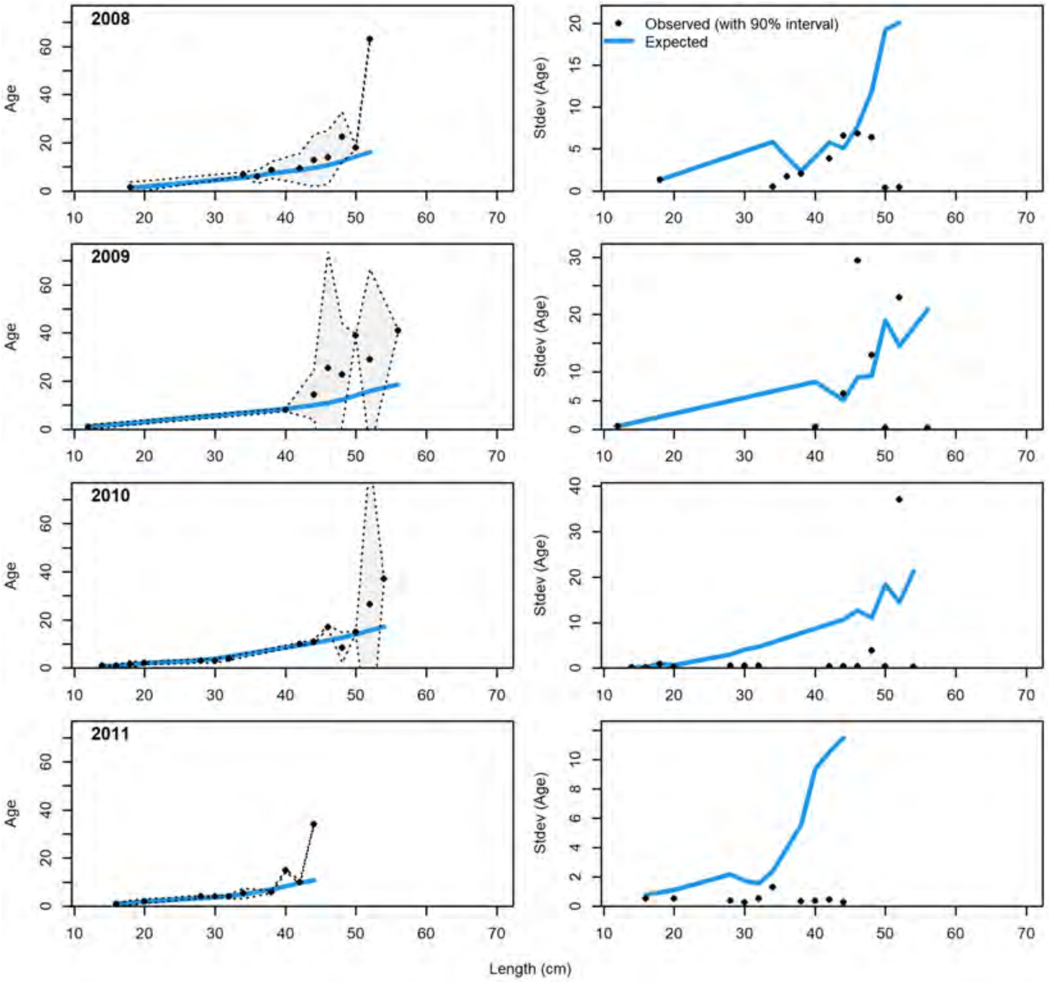

Figure 51: Conditional AAL plot, whole catch, NWFSC_TWL (plot 2 of 4).

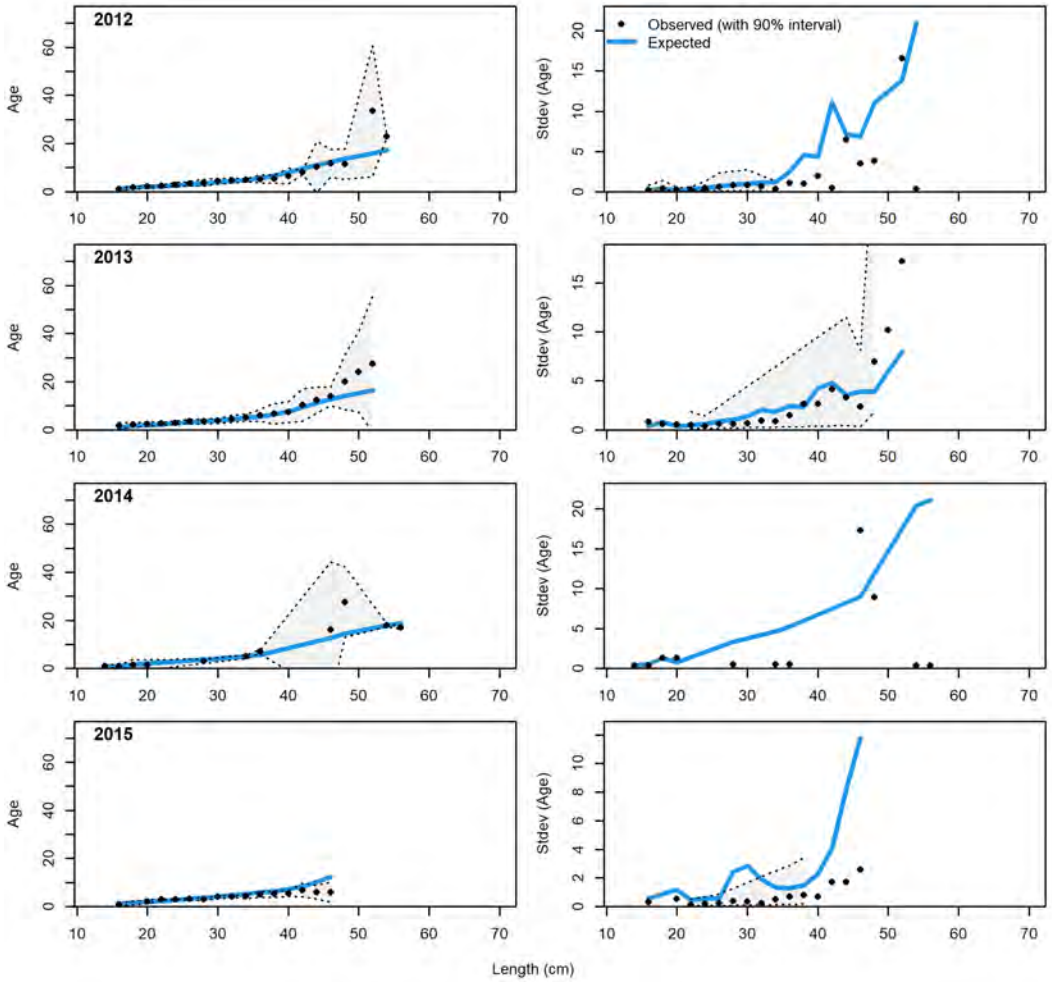

Figure 52: Conditional AAL plot, whole catch, NWFSC_TWL (plot 3 of 4).

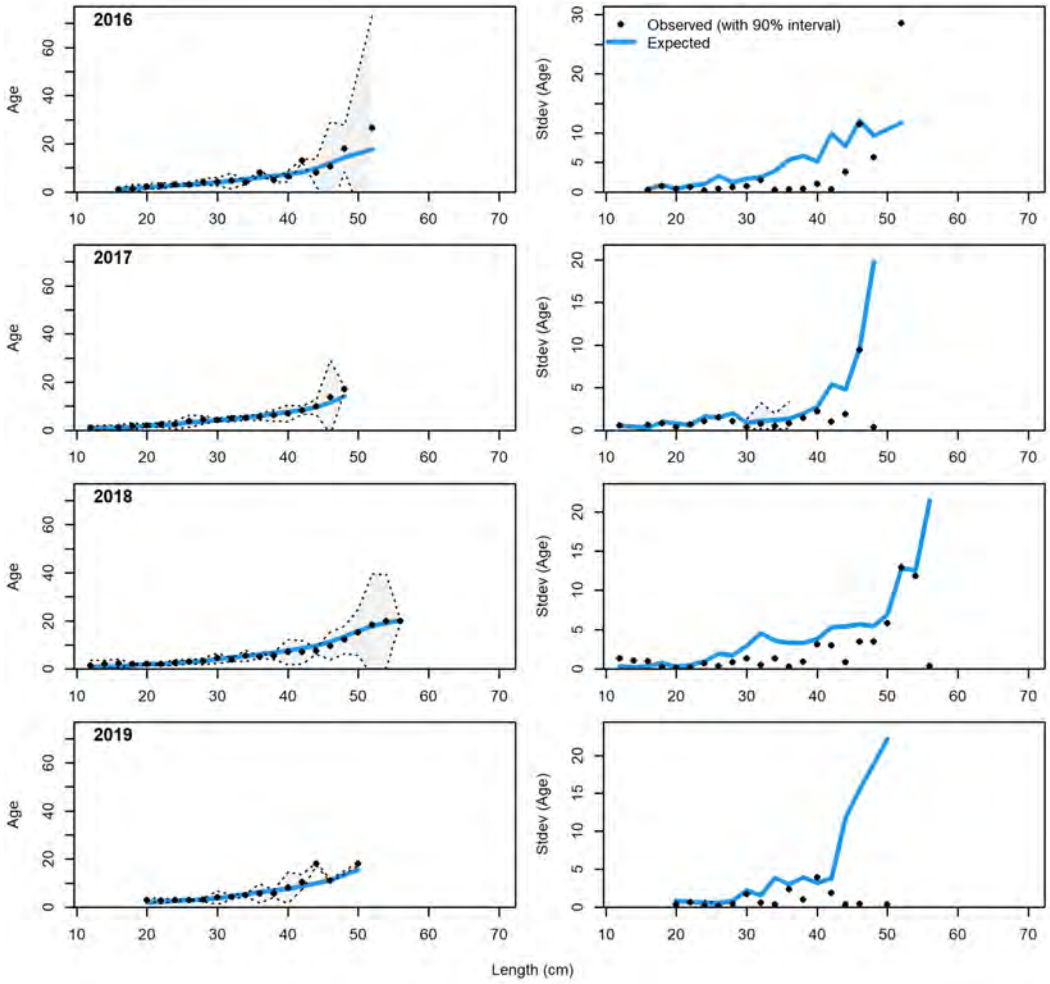

Figure 53: Conditional AAL plot, whole catch, NWFSC_TWL (plot 4 of 4).

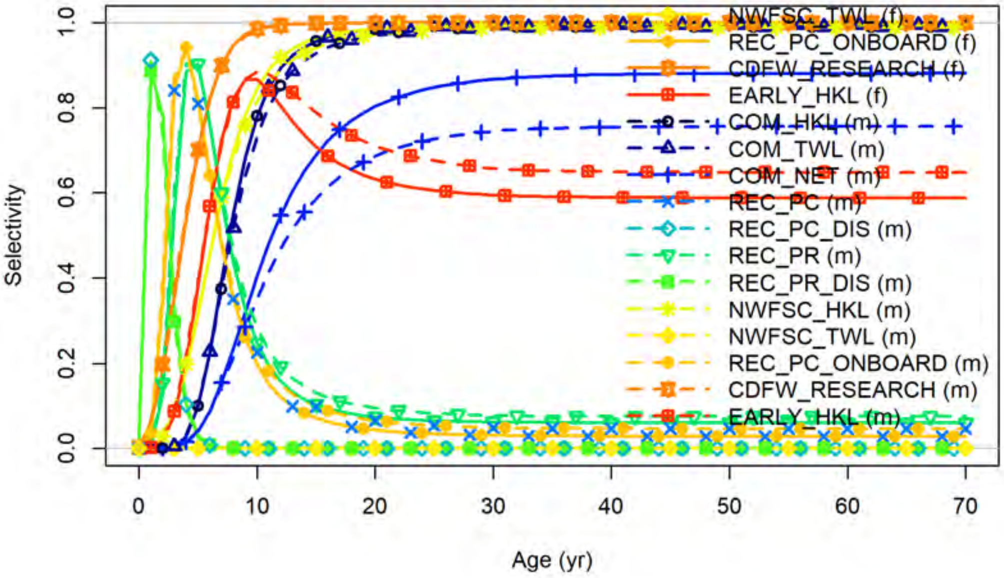

Figure 54: Selectivity at age derived from selectivity at length for multiple fleets.

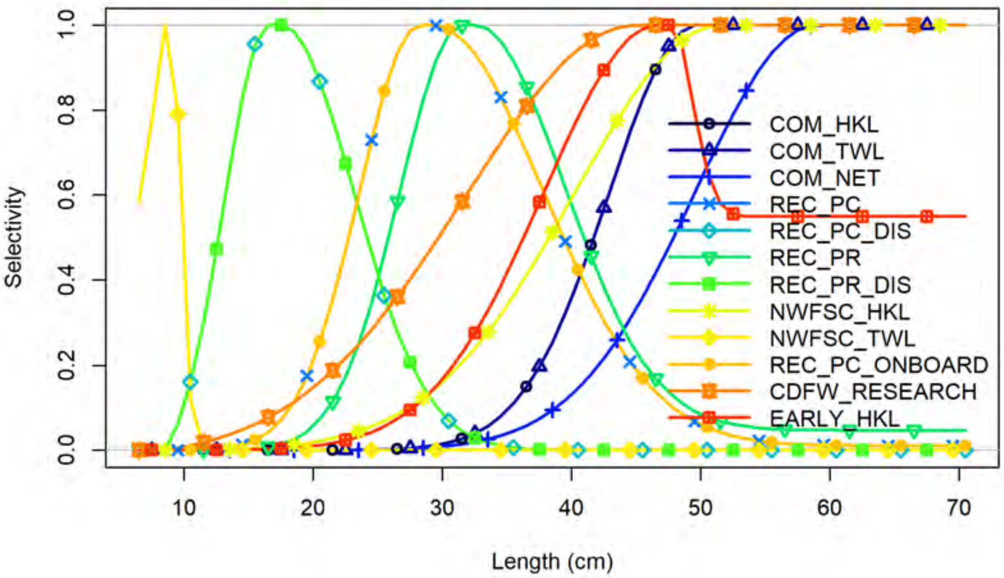

Figure 55: End year selectivity at length by fleet/survey.

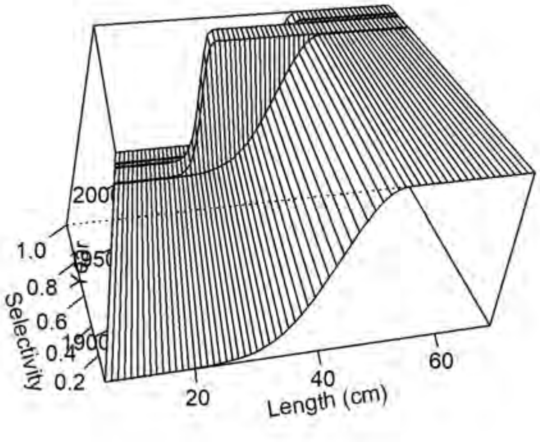

Figure 56: Surface plot of Female time-varying selectivity for COM_HKL.

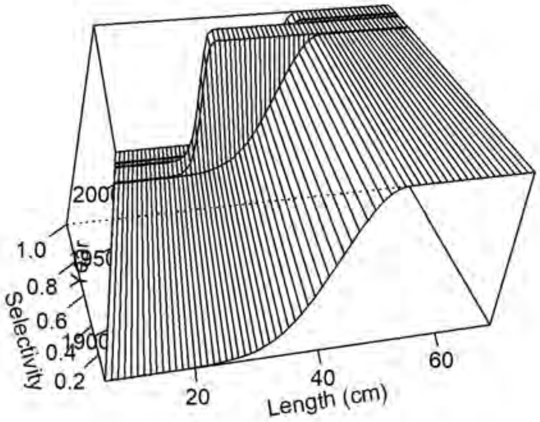

Figure 57: Surface plot of Female time-varying selectivity for COM_TWL.

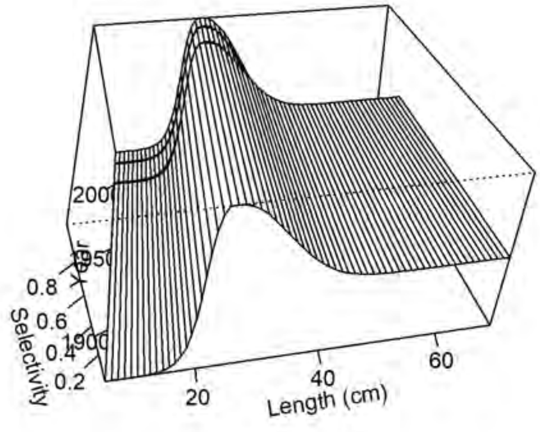

Figure 58: Surface plot of Female time-varying selectivity for REC_PC.

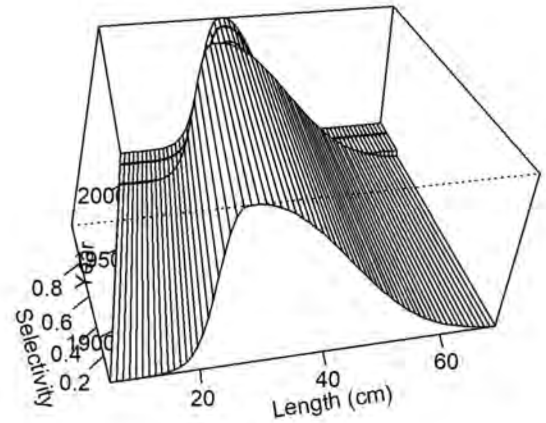

Figure 59: Surface plot of Female time-varying selectivity for REC_PR.

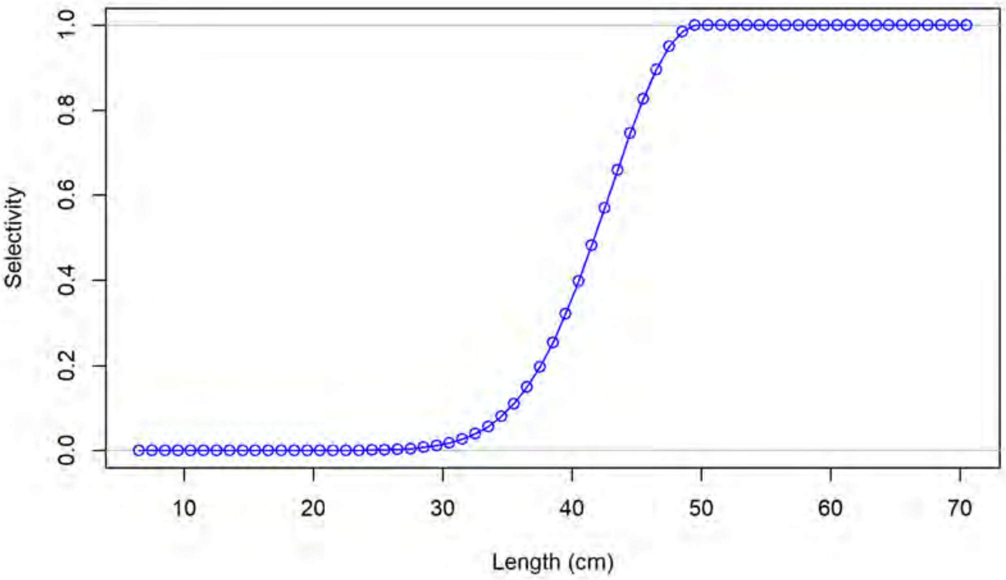

Figure 60: Female ending year selectivity for the commercial hook-and-line fishery.

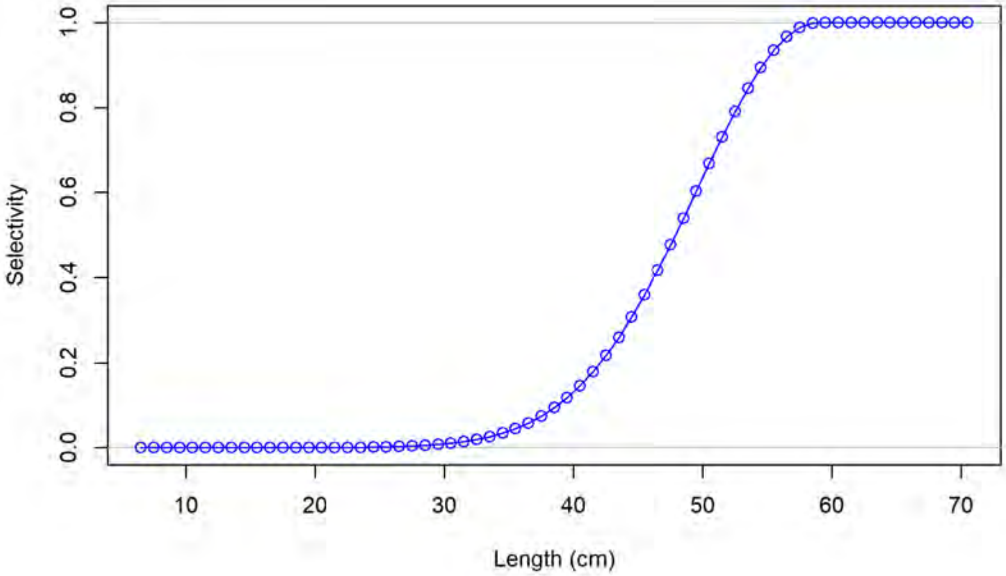

Figure 61: Female ending year selectivity for the commercial net fishery.

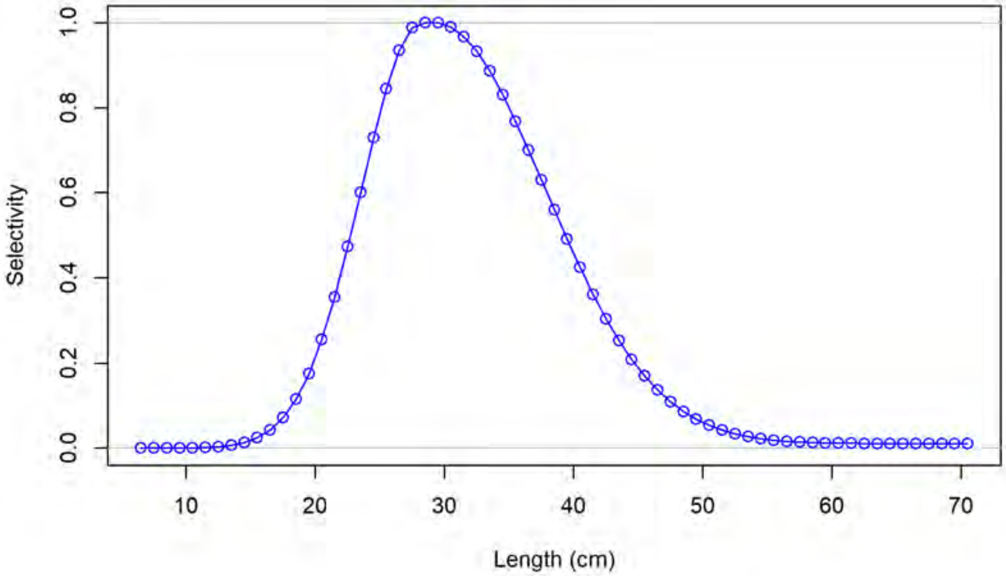

Figure 62: Female ending year selectivity for the recreational PC retained fishery.

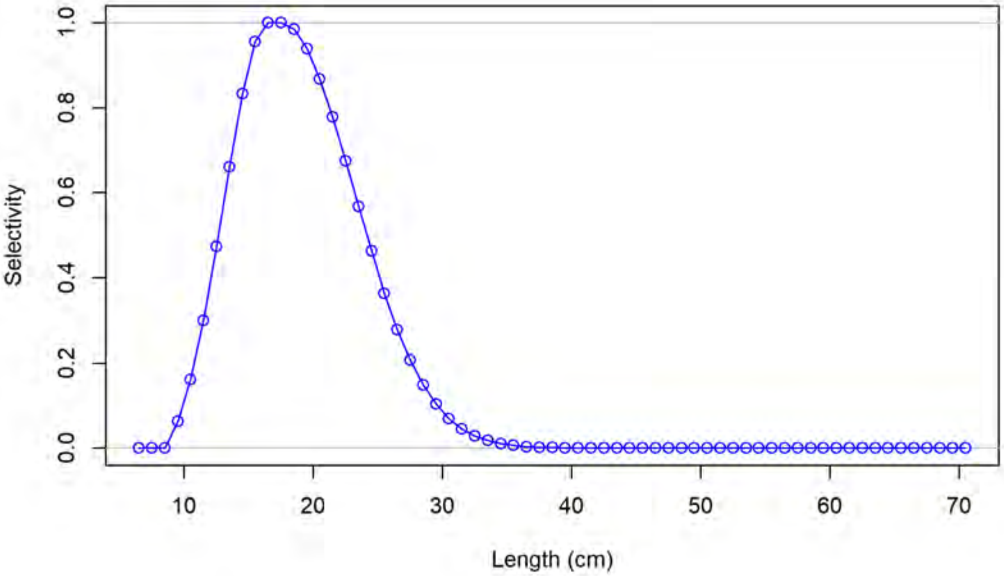

Figure 63: Female ending year selectivity for the recreational PC discard fishery.

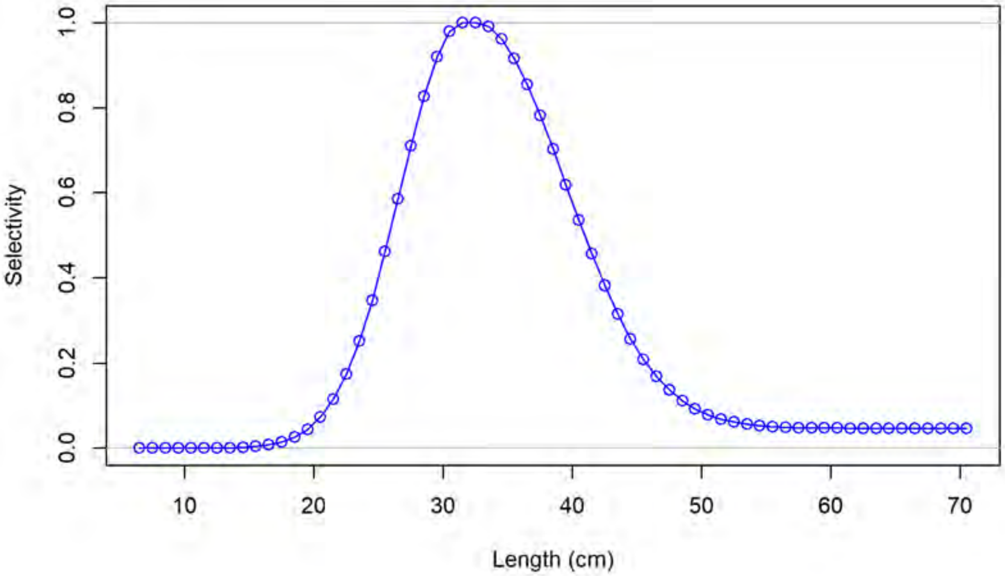

Figure 64: Female ending year selectivity for the recreational PR retained fishery.

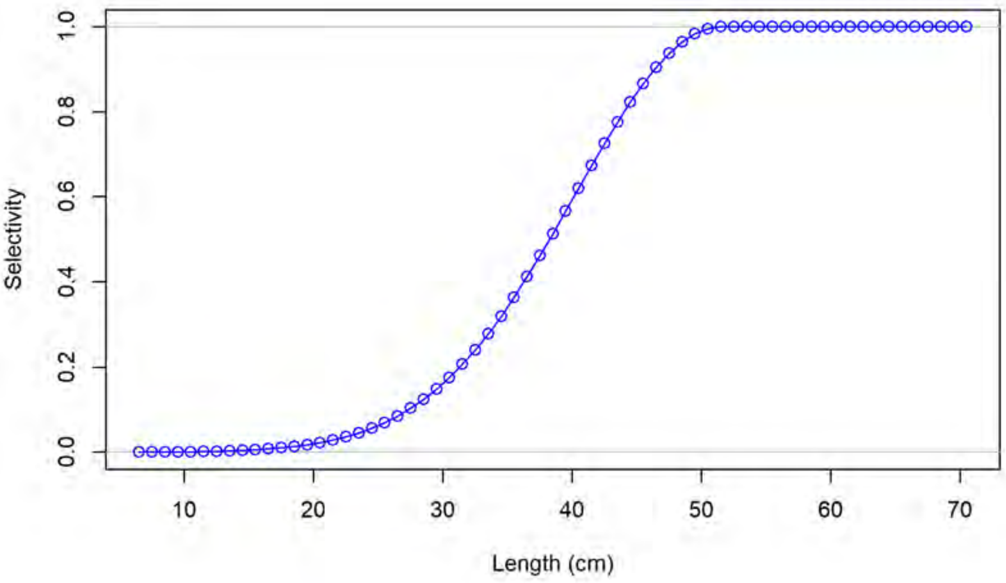

Figure 65: Female ending year selectivity for the NWFSC hook-and-line survey.

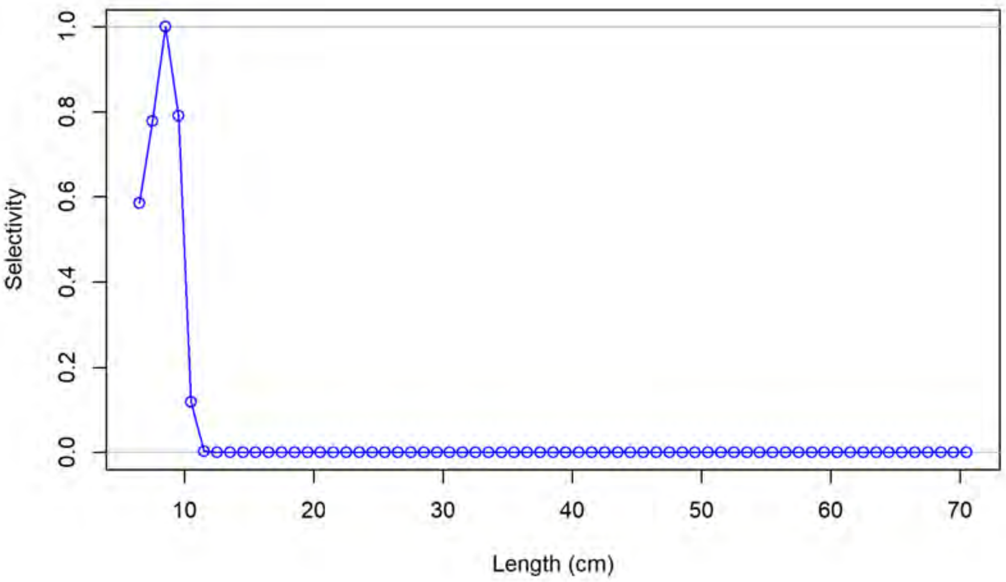

Figure 66: Female ending year selectivity for the West Coast Groundfish Bottomfish Trawl Survey.

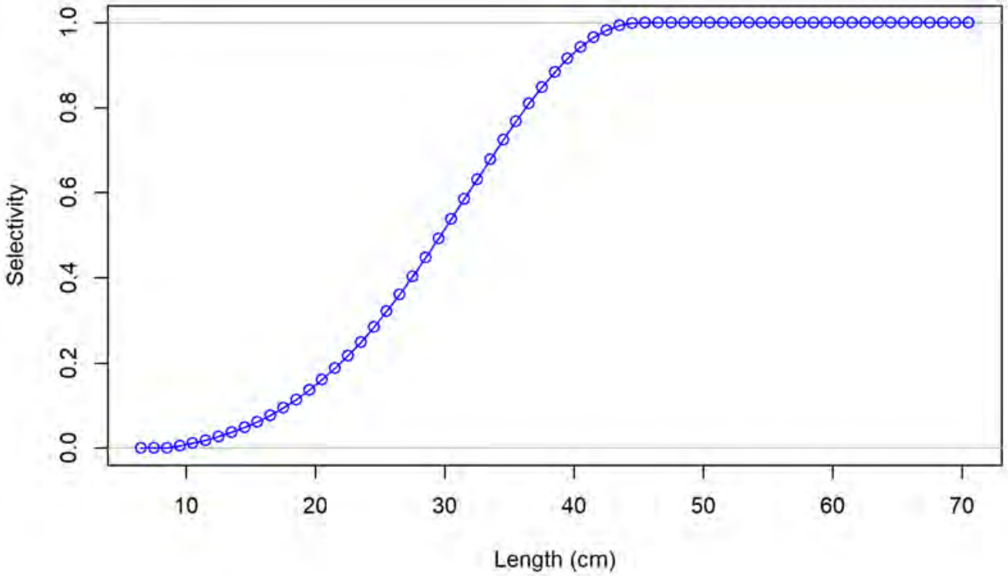

Figure 67: Female ending year selectivity for the CDFW research (aka green binder) survey.

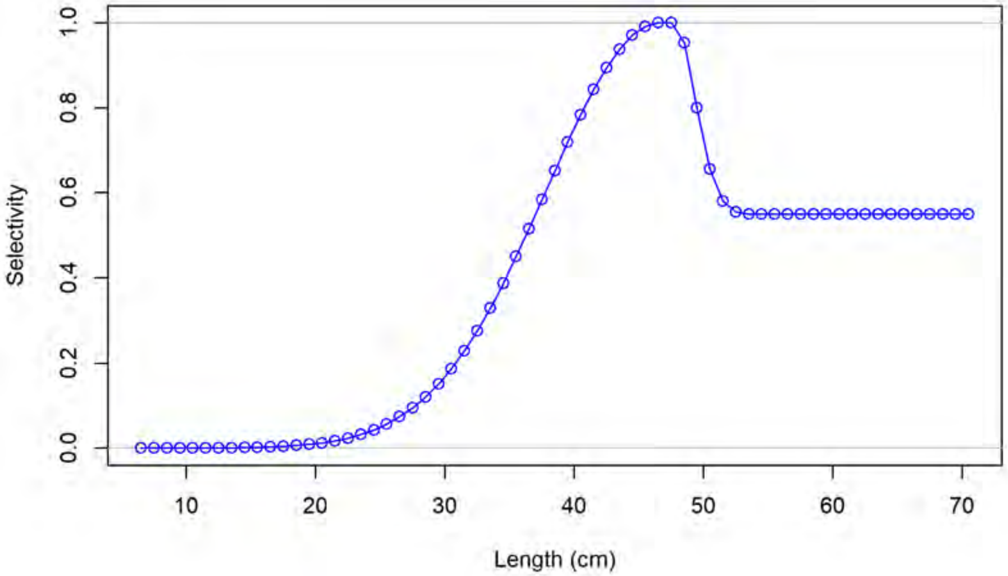

Figure 68: Female ending year selectivity for the NWFSC hook-and-line early years.

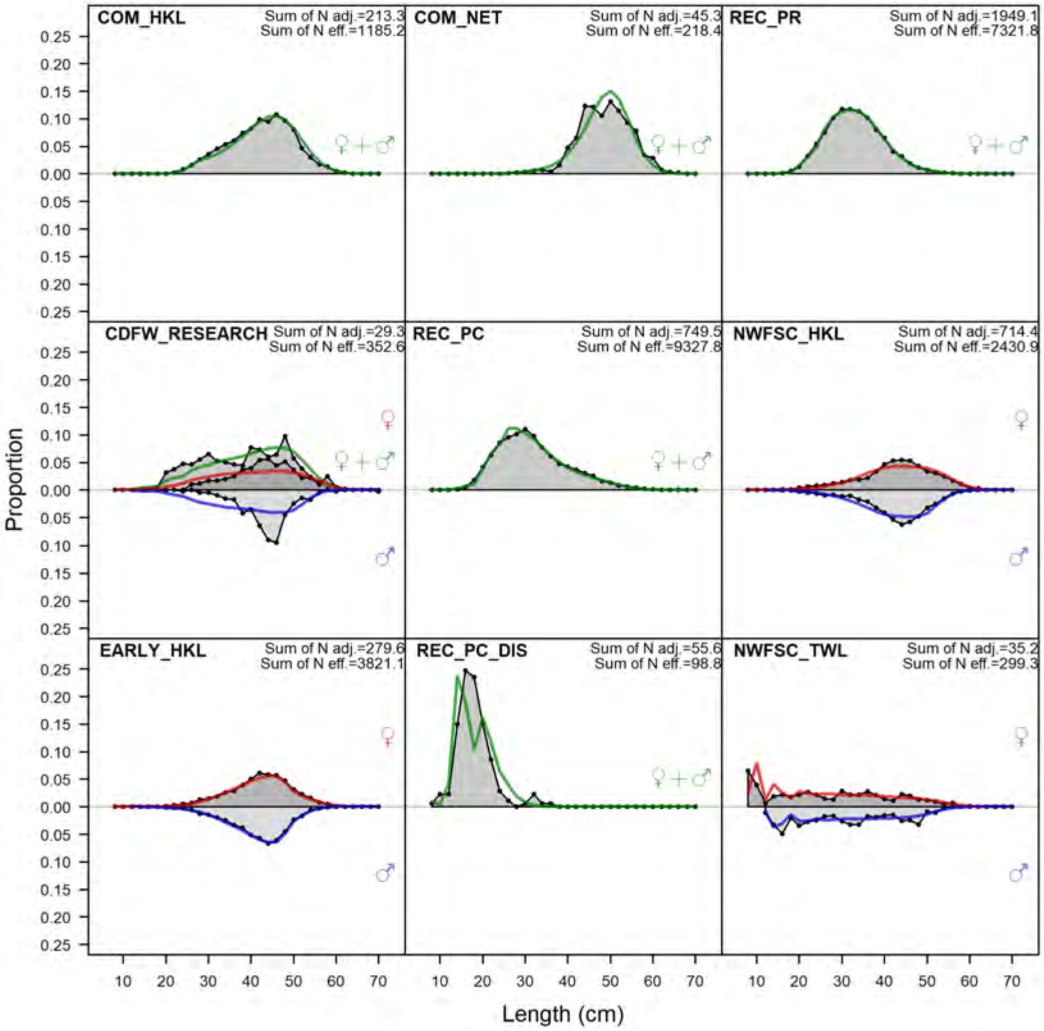

Figure 69: Length comps, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch.

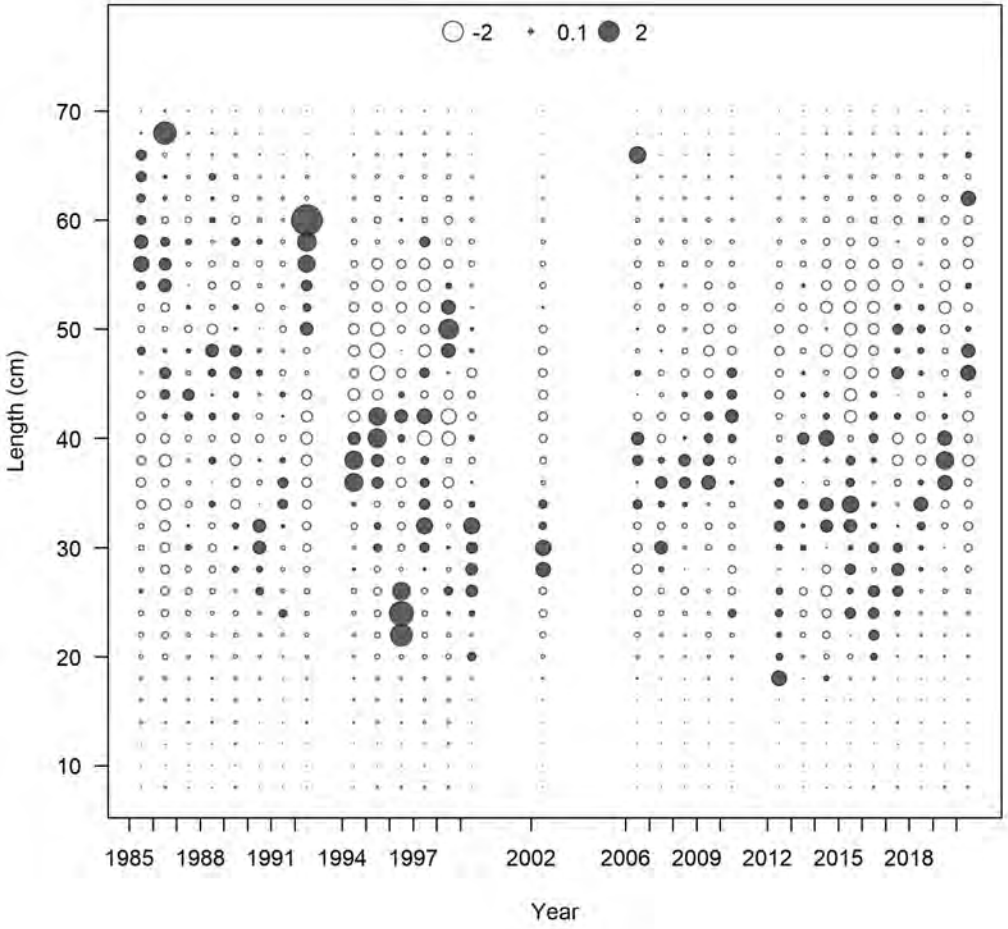

Figure 70: Pearson residuals for the commercial hook-and-line fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

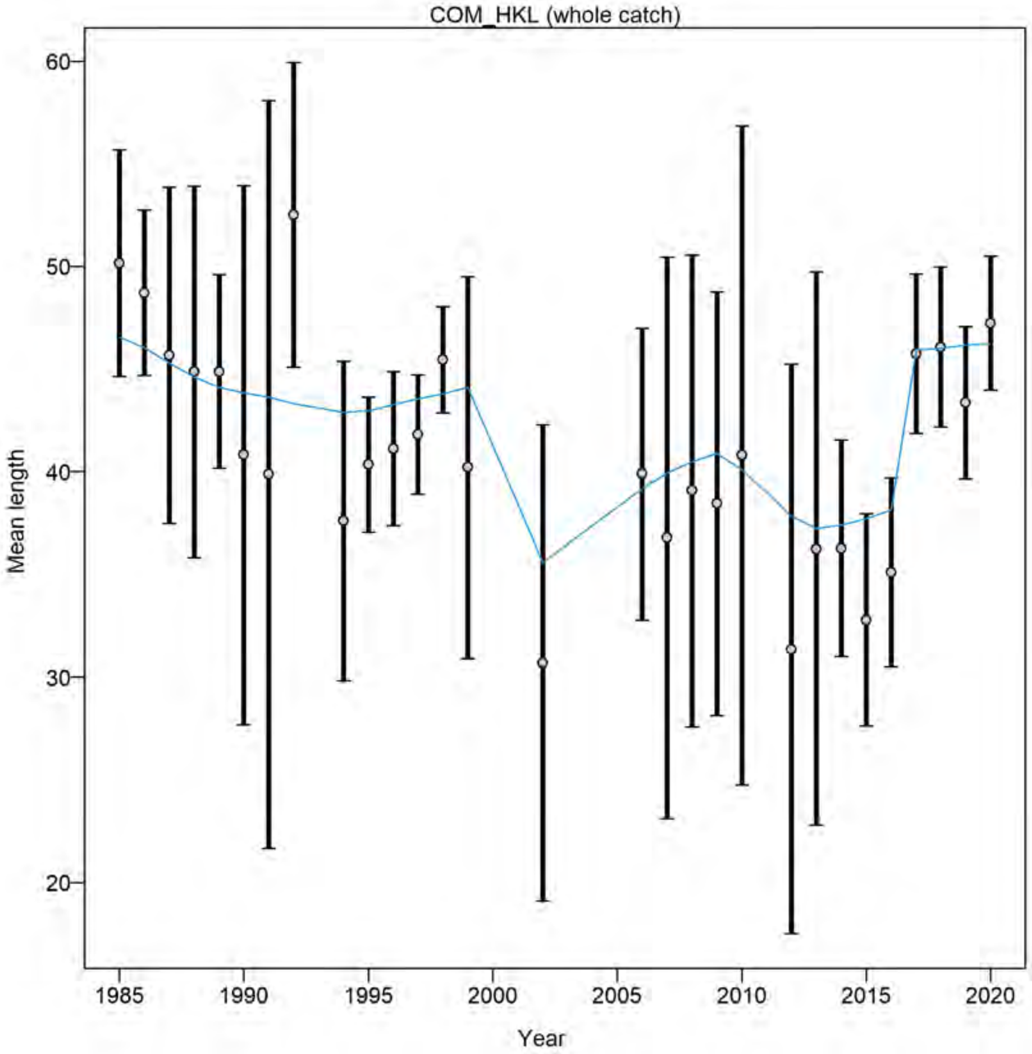

Figure 71: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the commercial hook-and-line fishery.

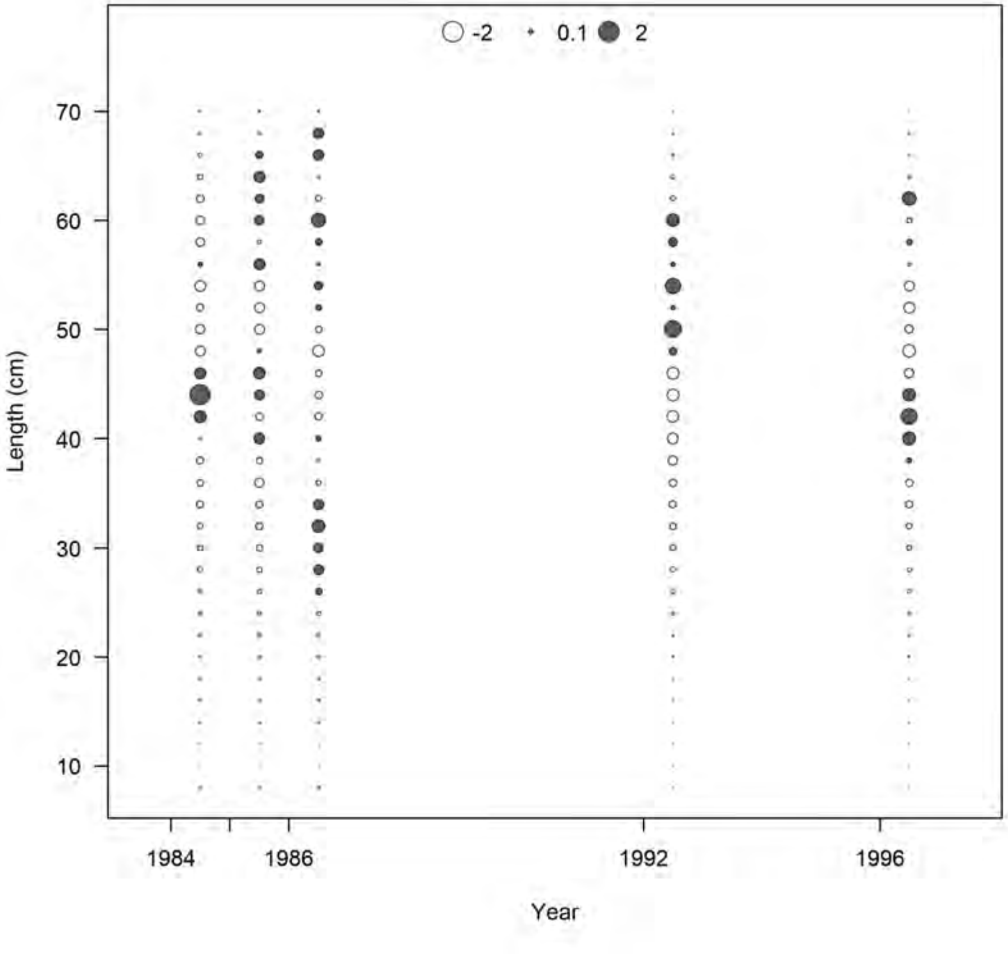

Figure 72: Pearson residuals for the commercial net fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

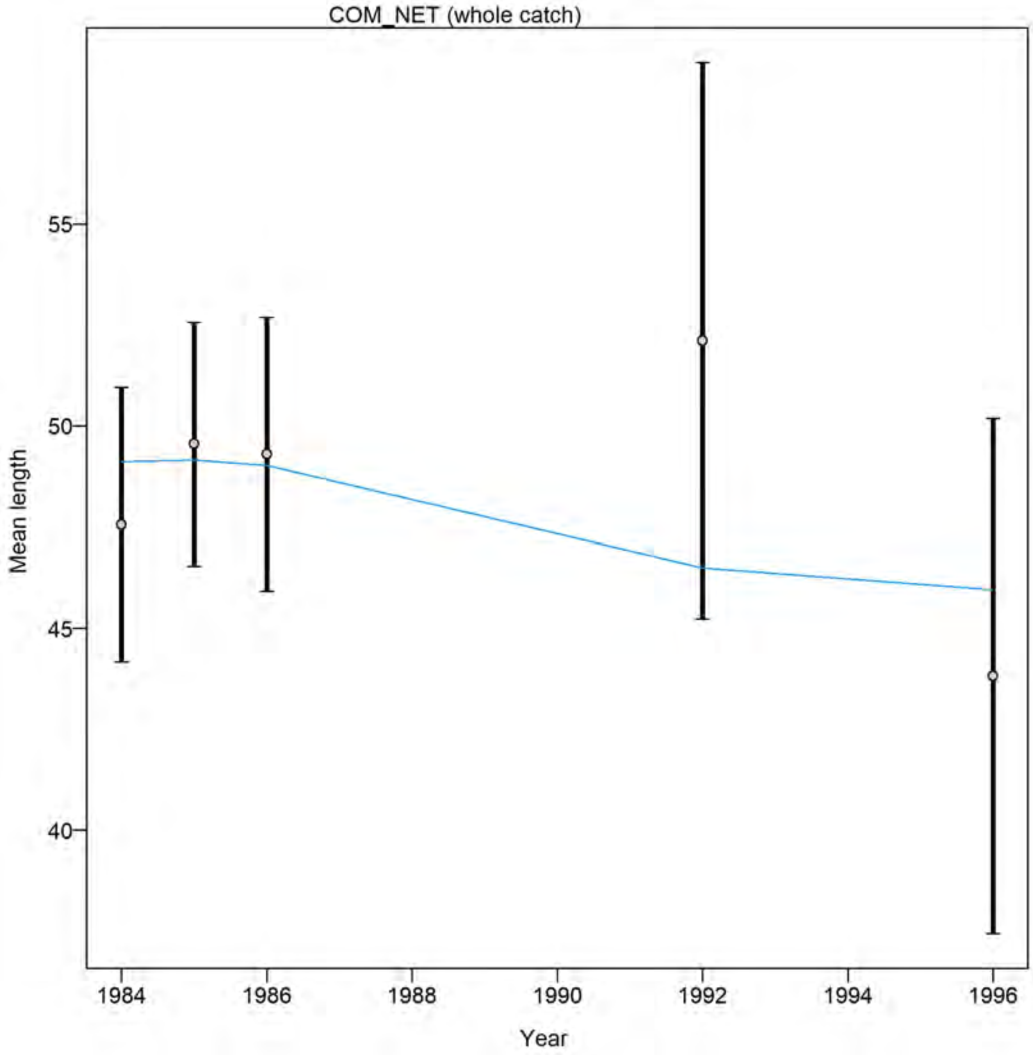

Figure 73: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the commercial net fishery.

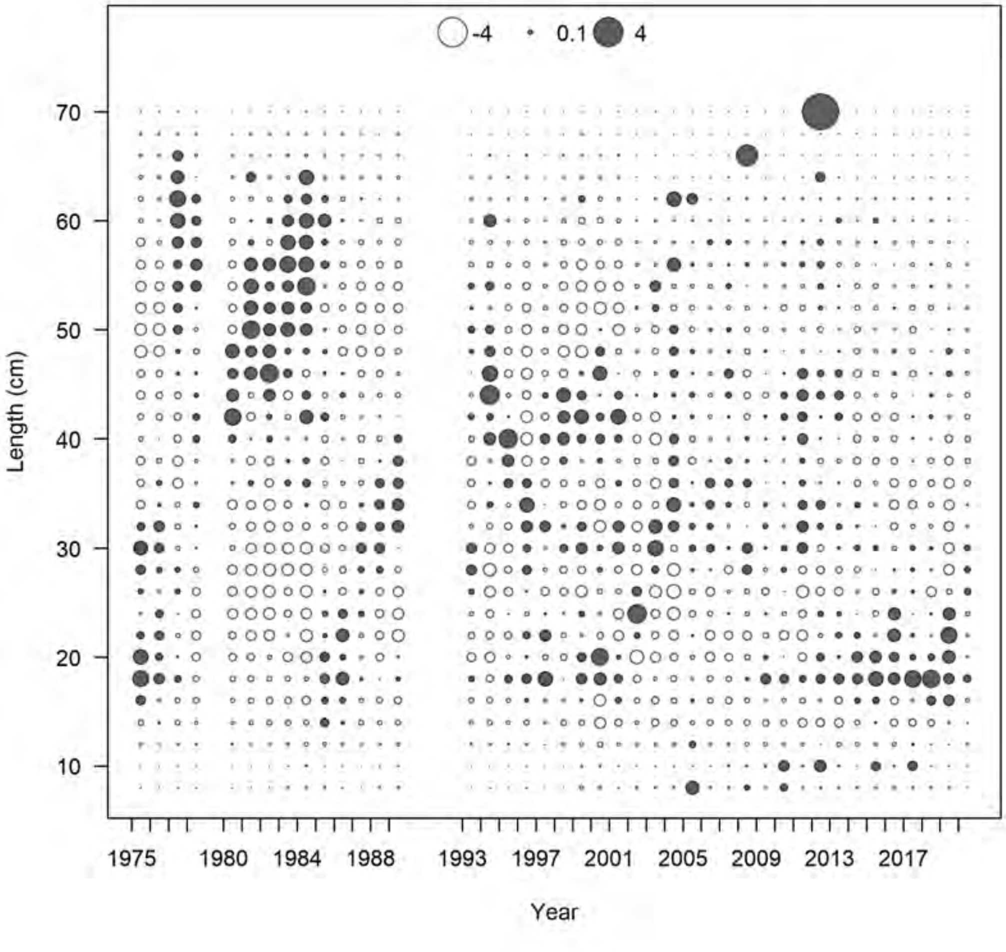

Figure 74: Pearson residuals for the recreational PC retained fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

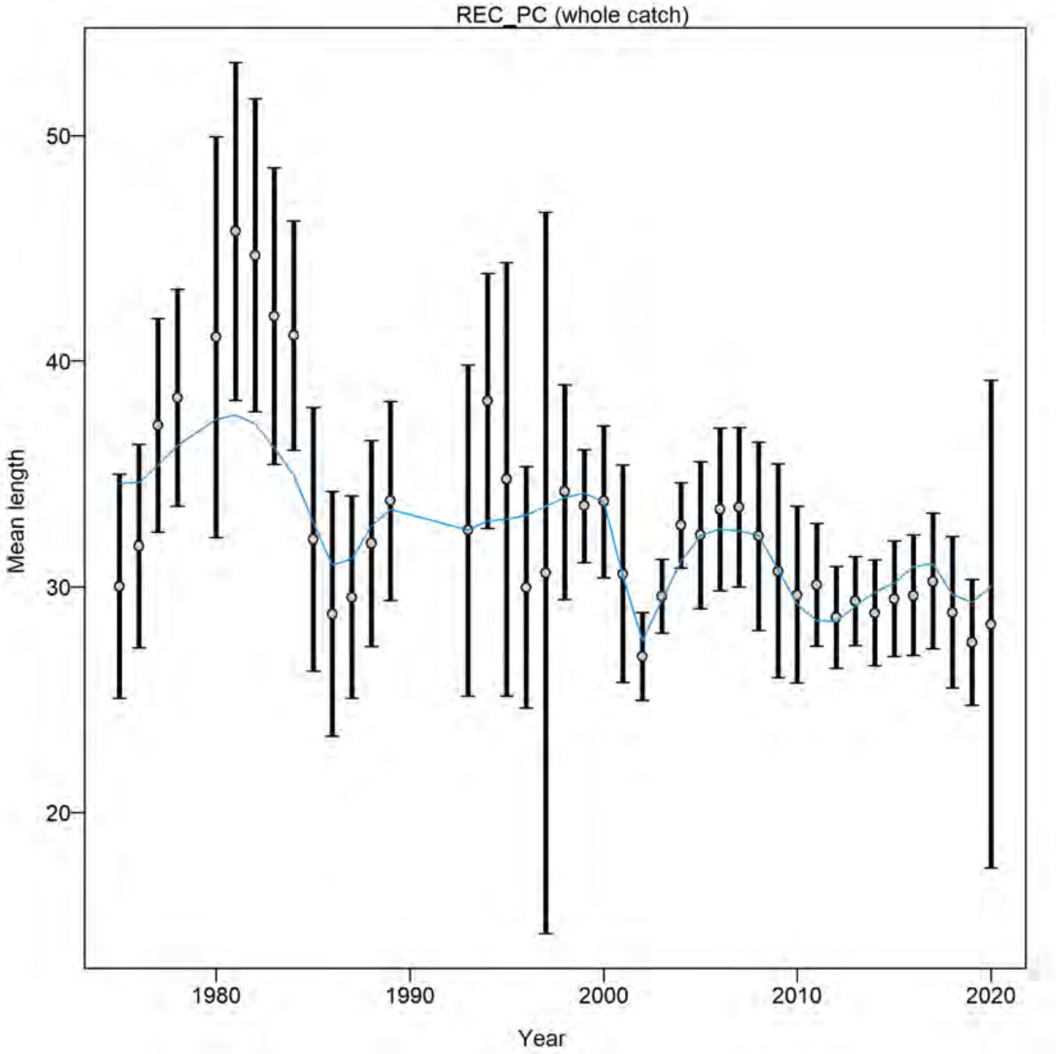

Figure 75: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the recreational PC retained fishery.

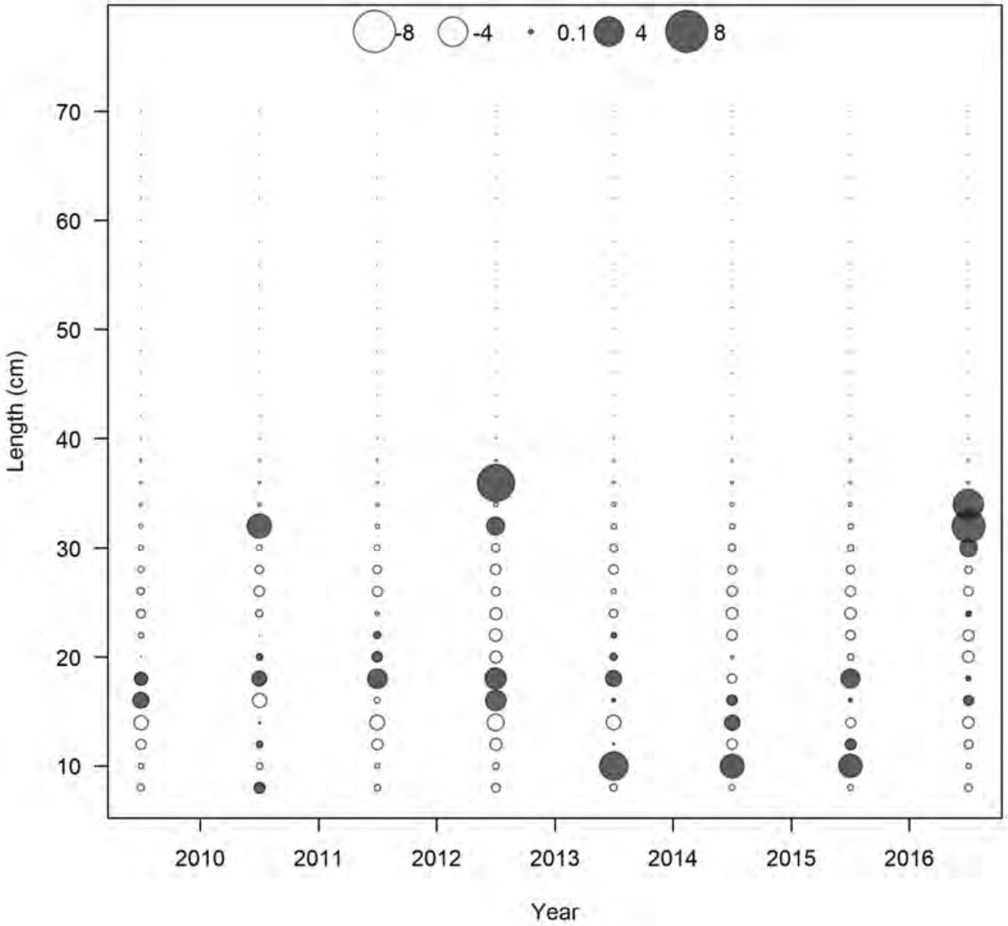

Figure 76: Pearson residuals for the recreational PC discard fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

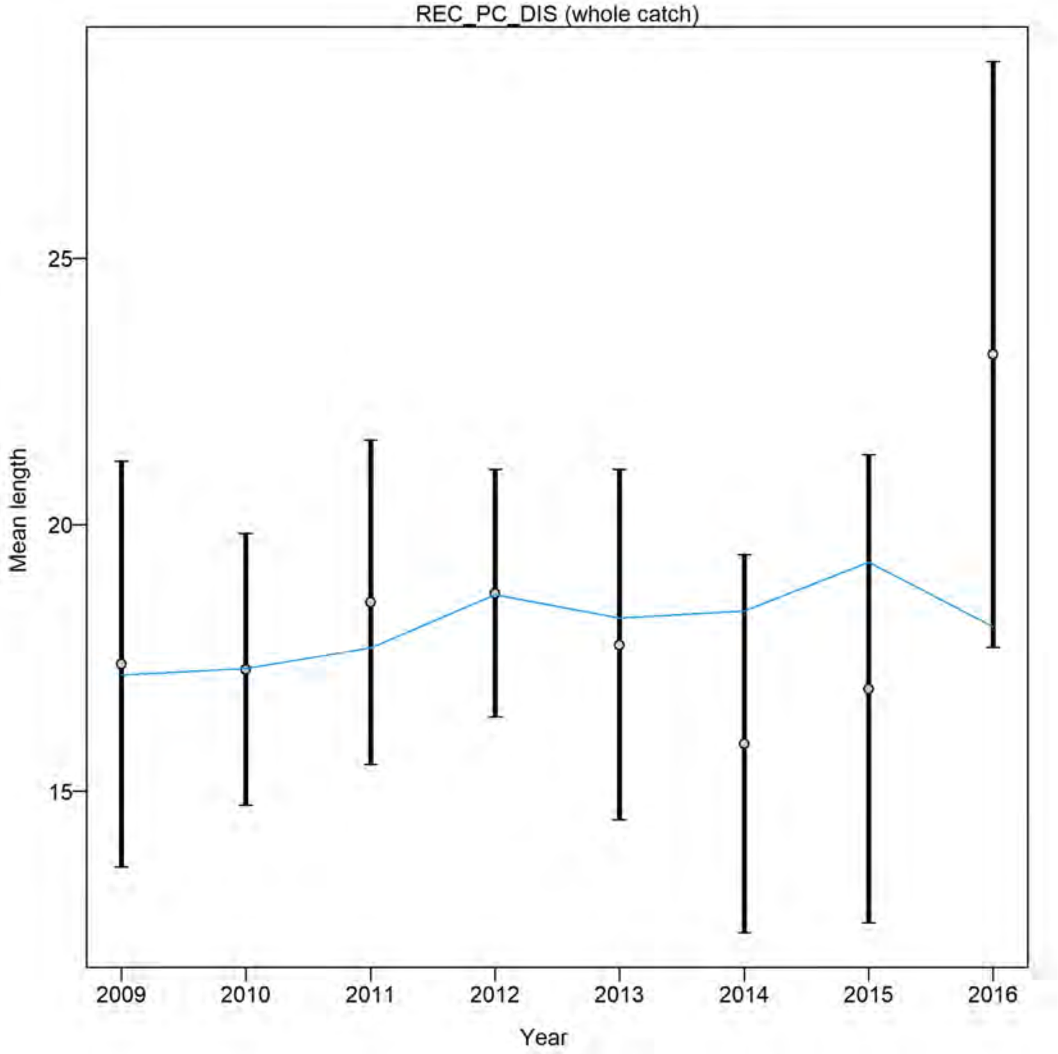

Figure 77: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the recreational PC discard fishery.

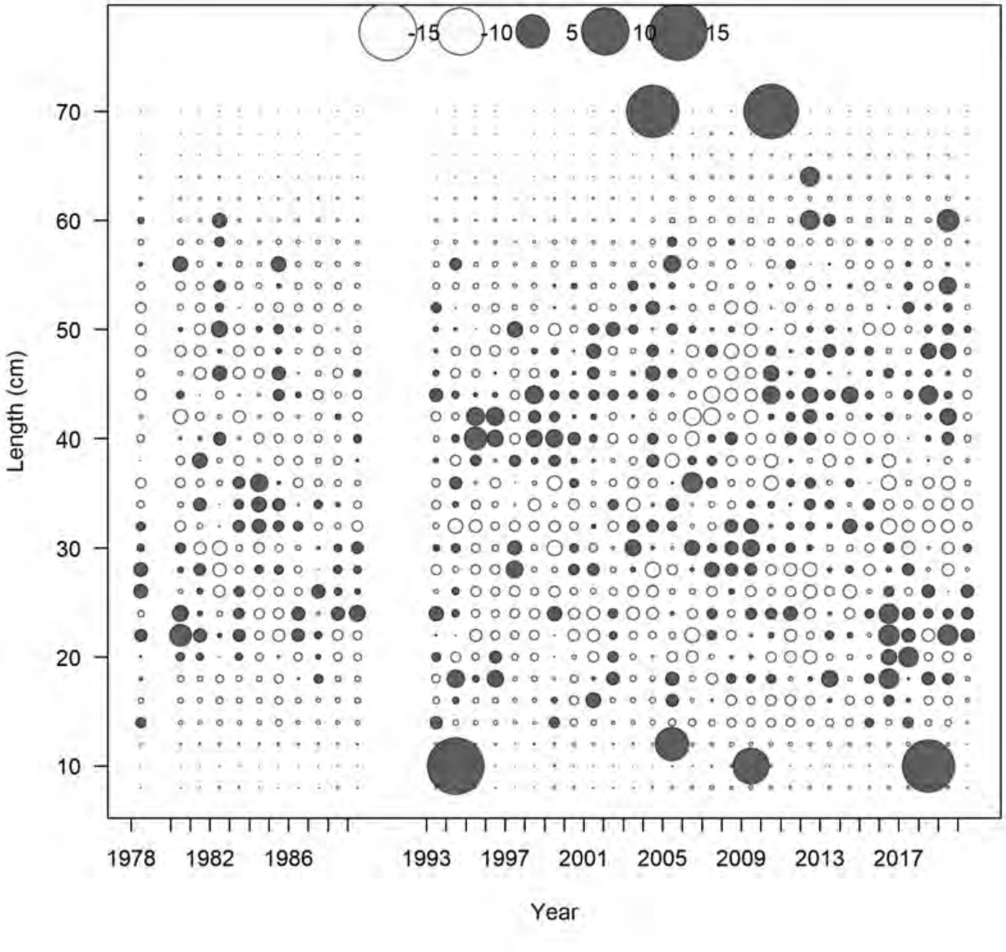

Figure 78: Pearson residuals for the recreational PR retained fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

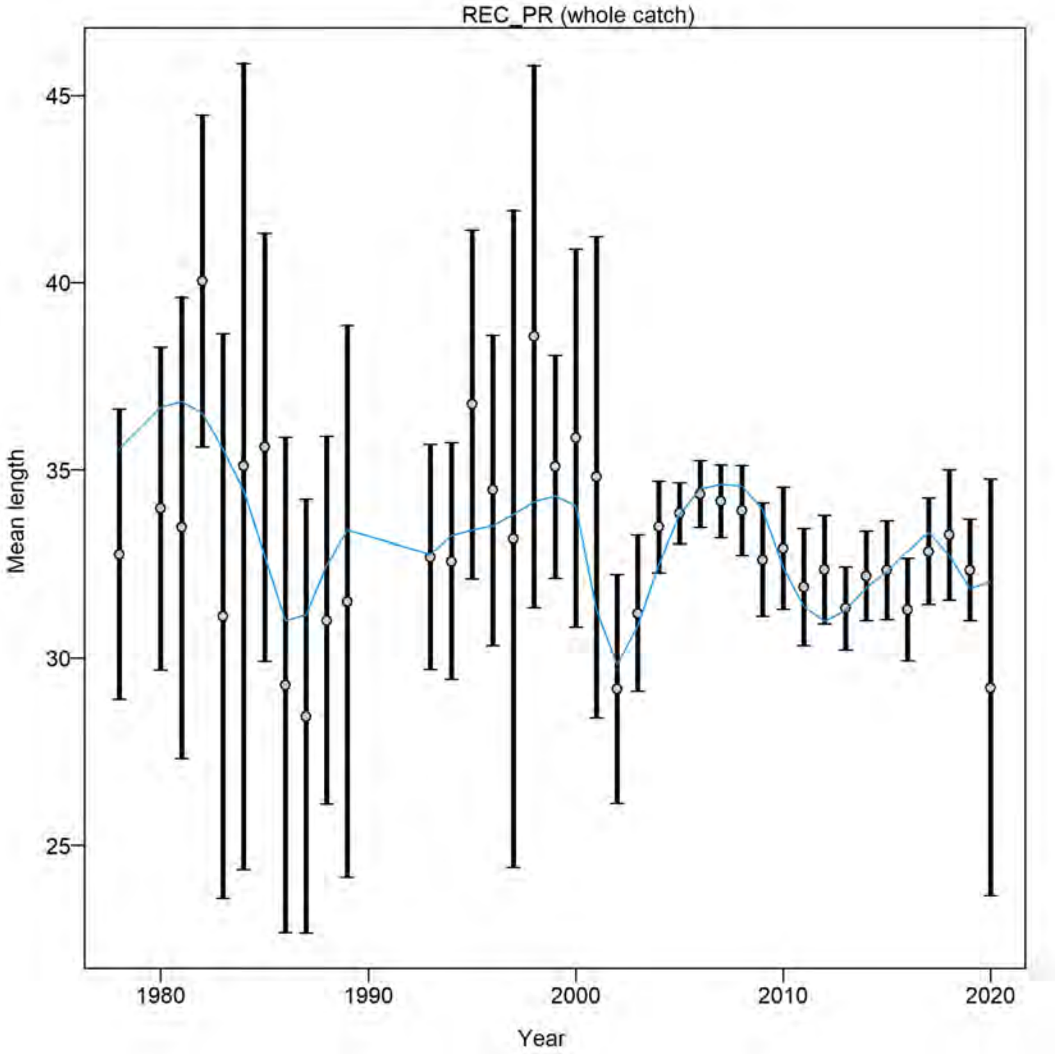

Figure 79: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the recreational PR retained fishery.

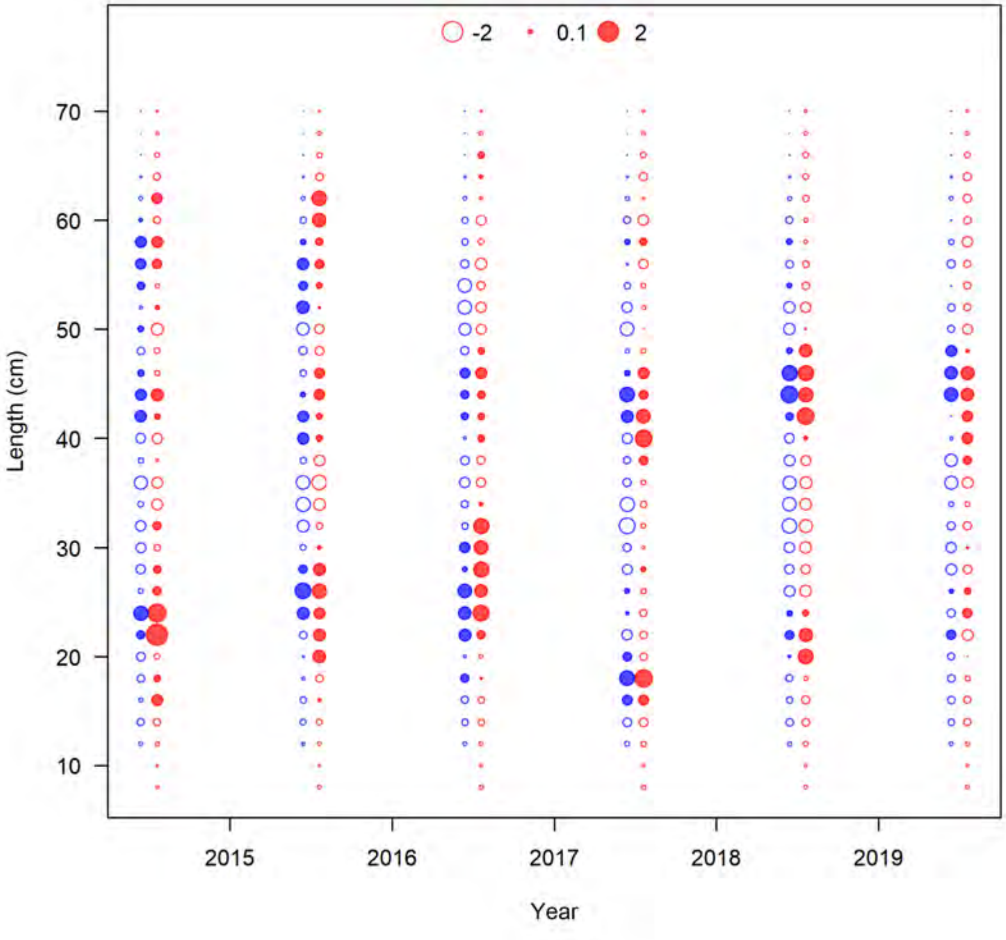

Figure 80: Pearson residuals for the NWFSC hook-and-line survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

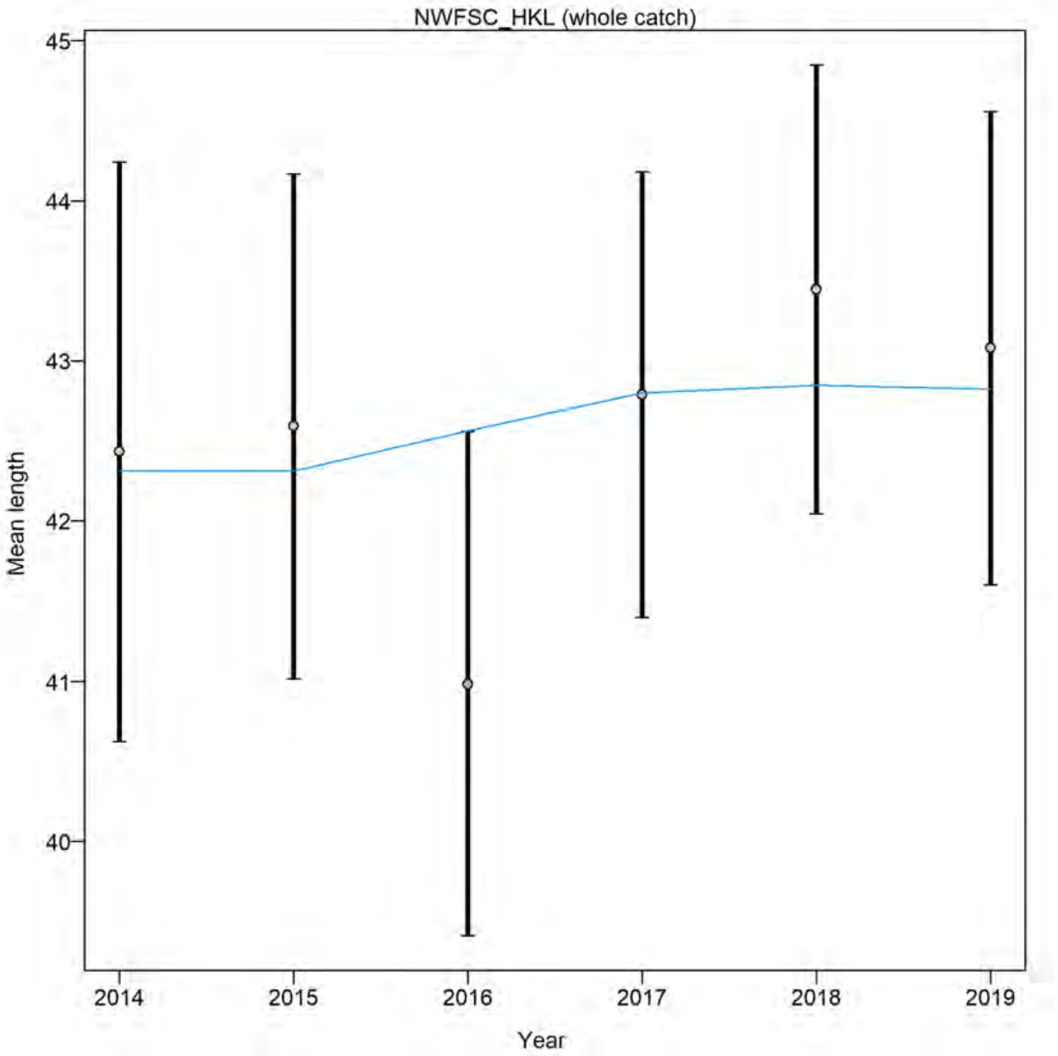

Figure 81: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the NWFSC hook-and-line survey.

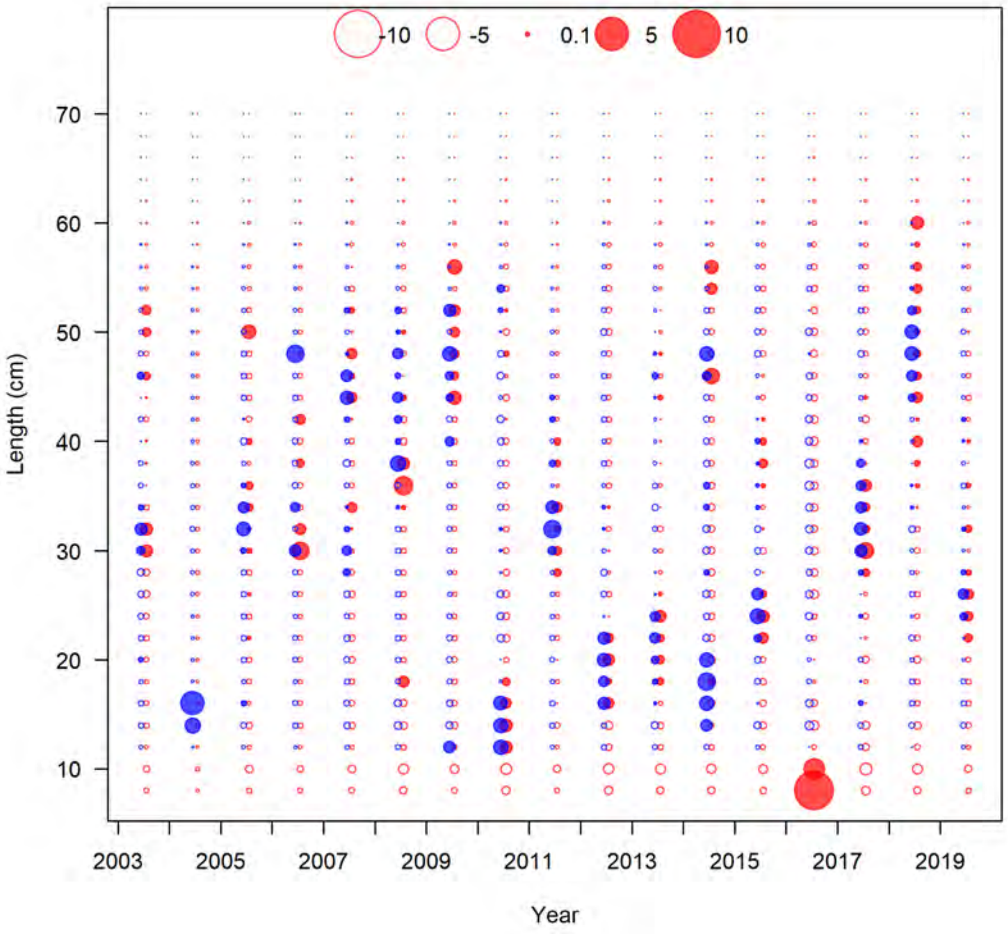

Figure 82: Pearson residuals for the West Coast Groundfish Bottomfish Trawl Survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

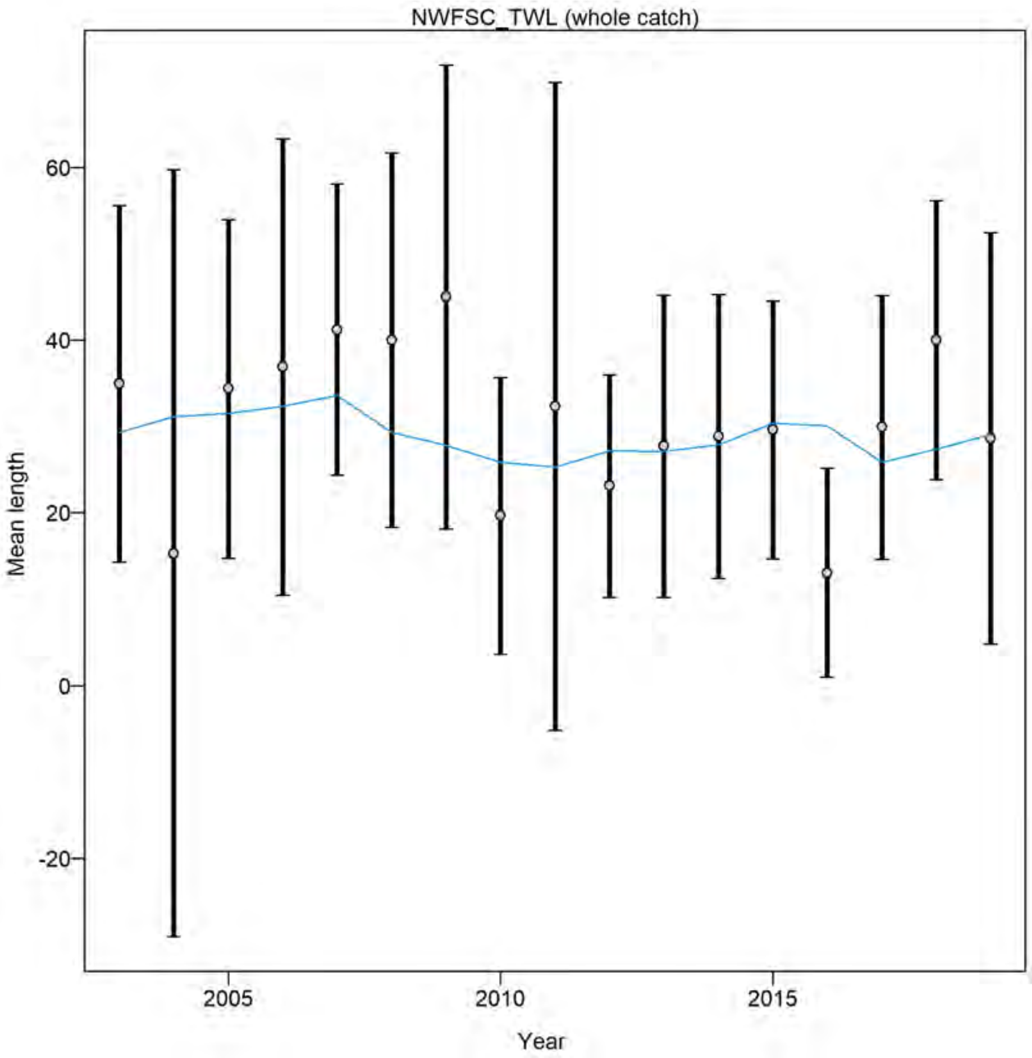

Figure 83: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the West Coast Groundfish Bottomfish Trawl Survey.

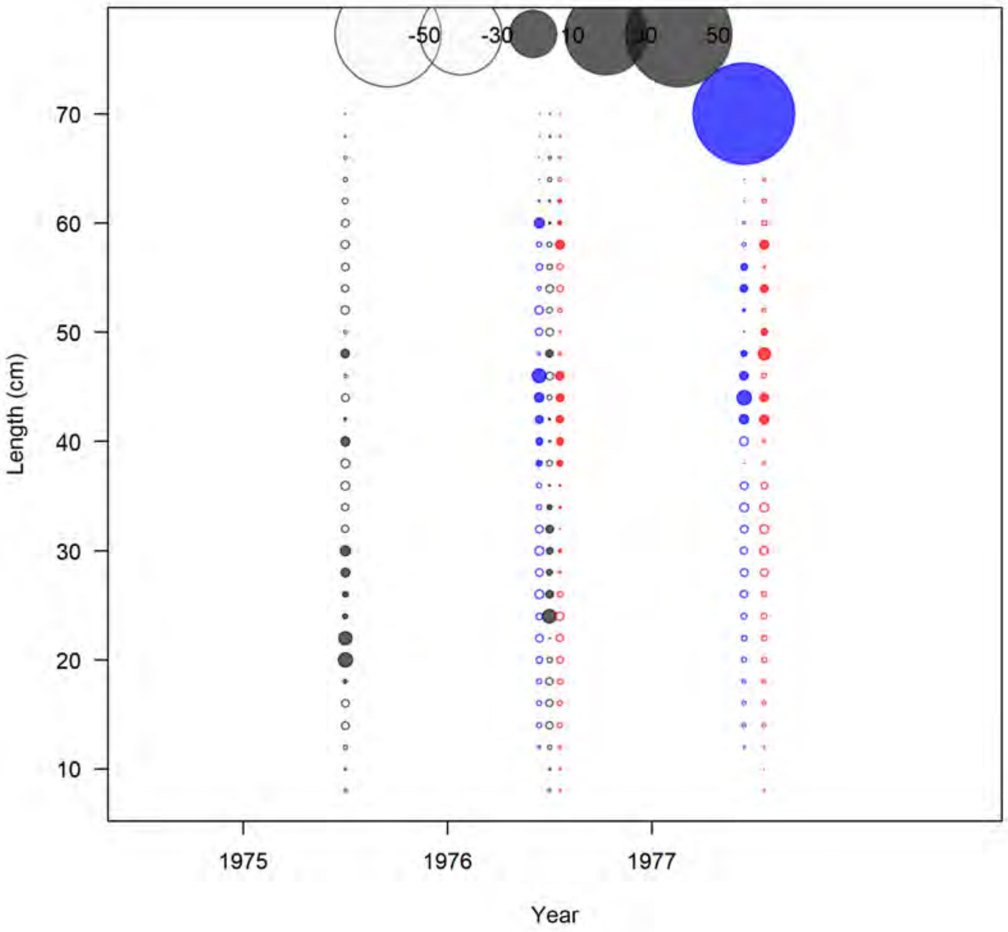

Figure 84: Pearson residuals for the CDFW research (aka green binder) survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

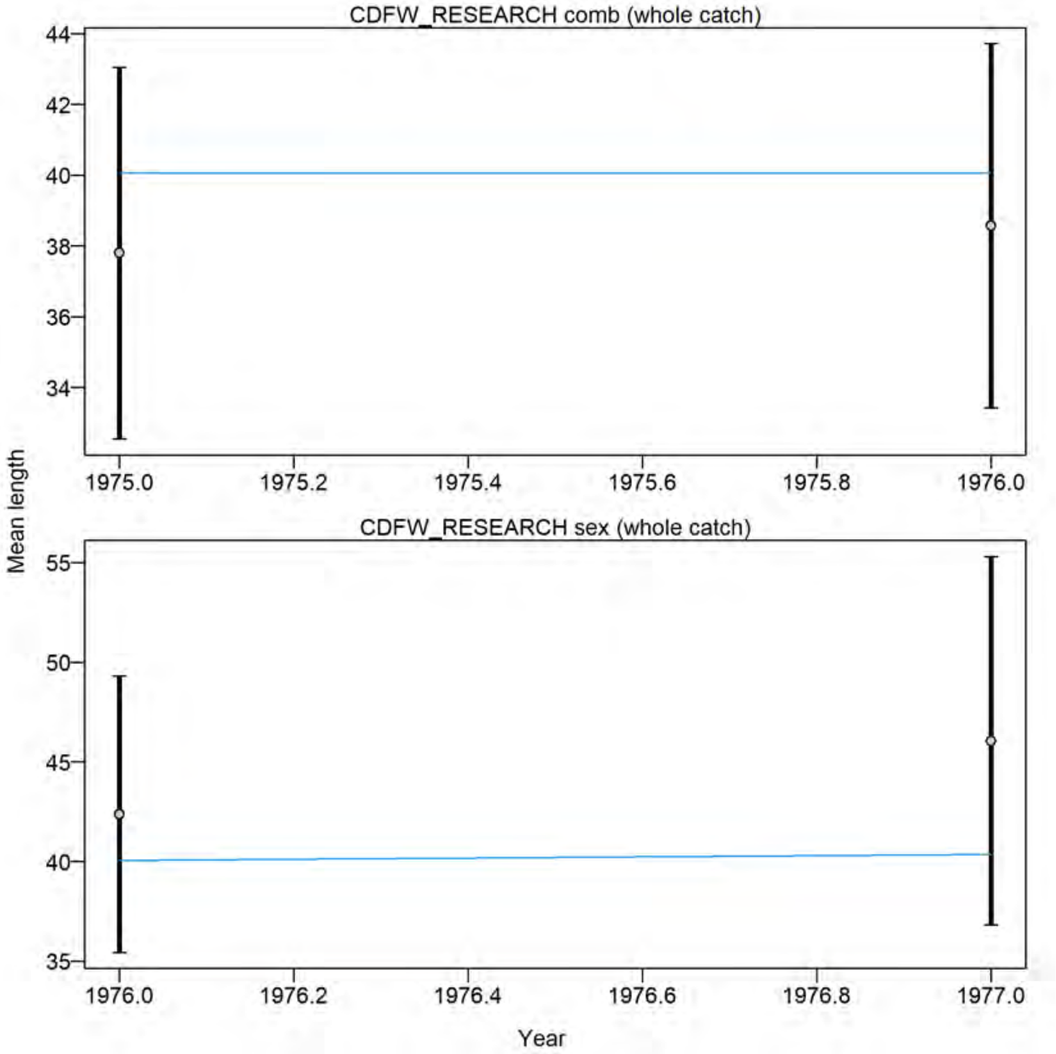

Figure 85: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the CDFW research (aka green binder) survey.

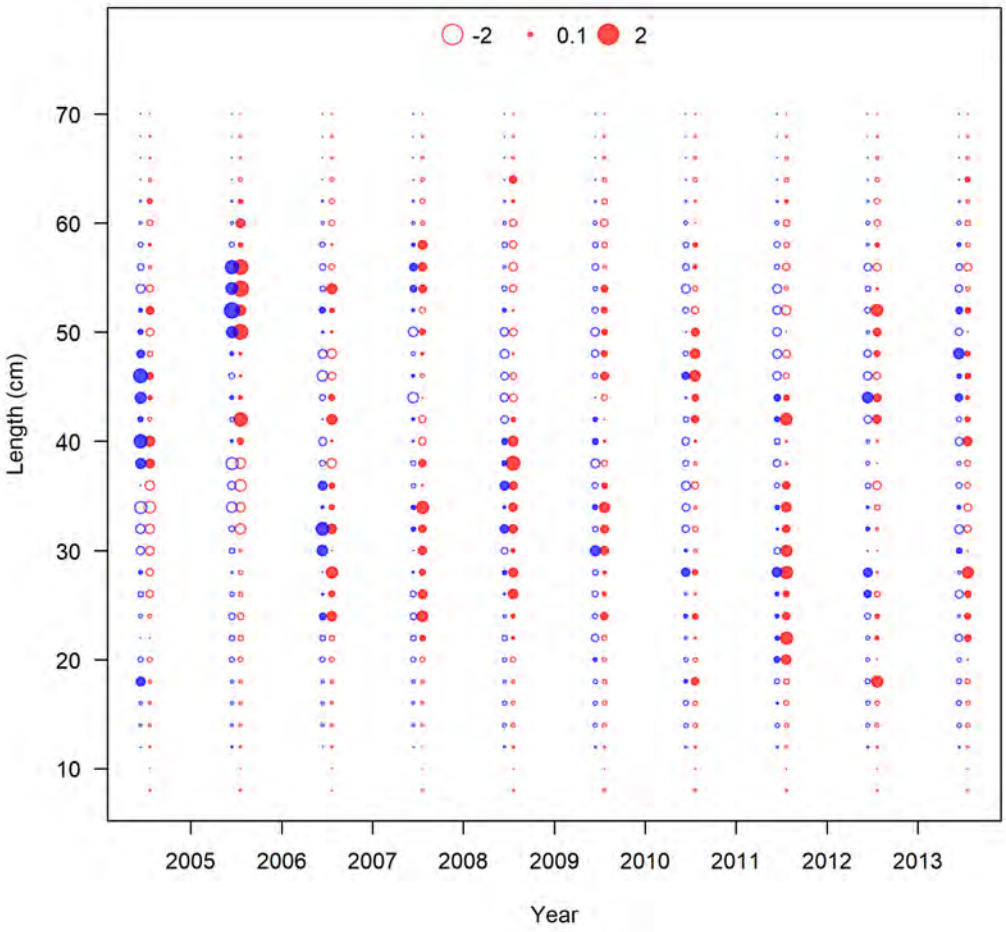

Figure 86: Pearson residuals for the NWFSC hook-and-line early years. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

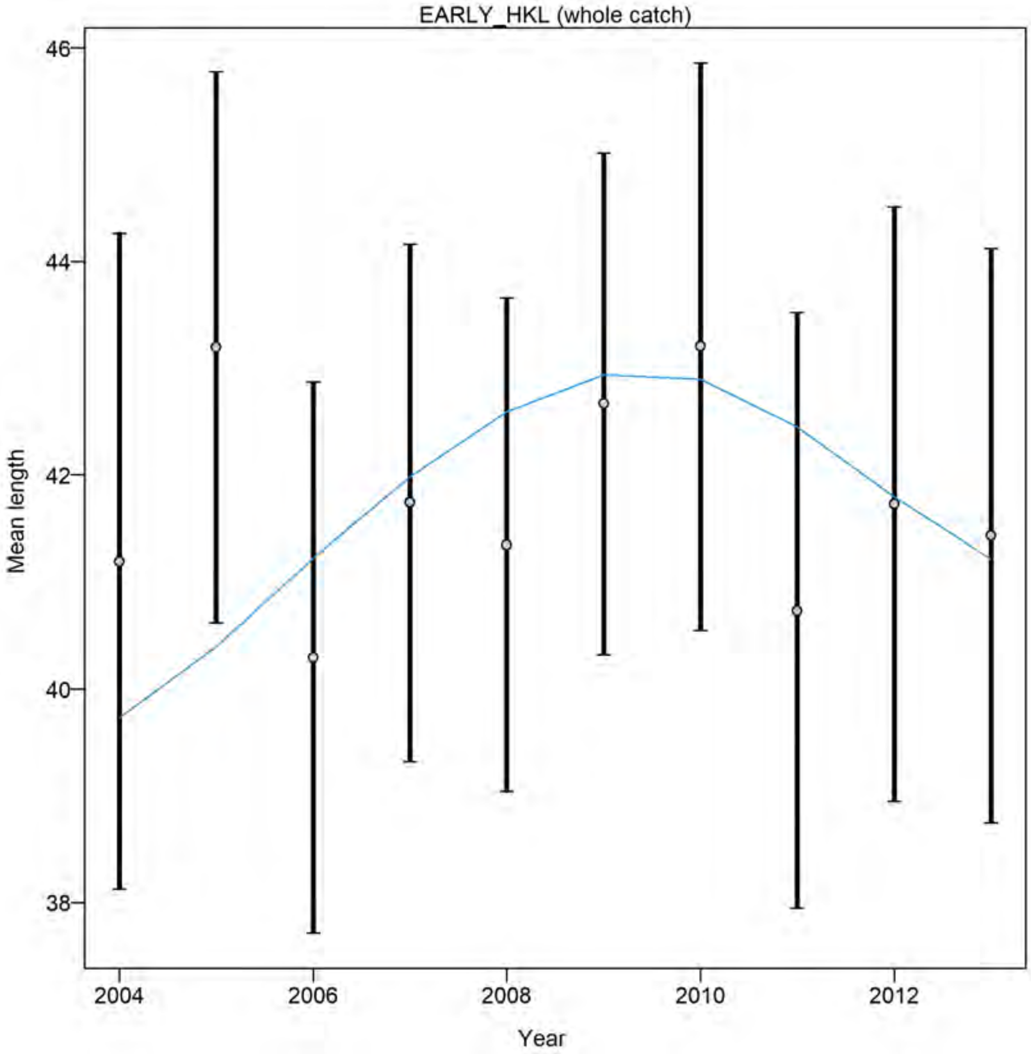

Figure 87: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the NWFSC hook-and-line early years.

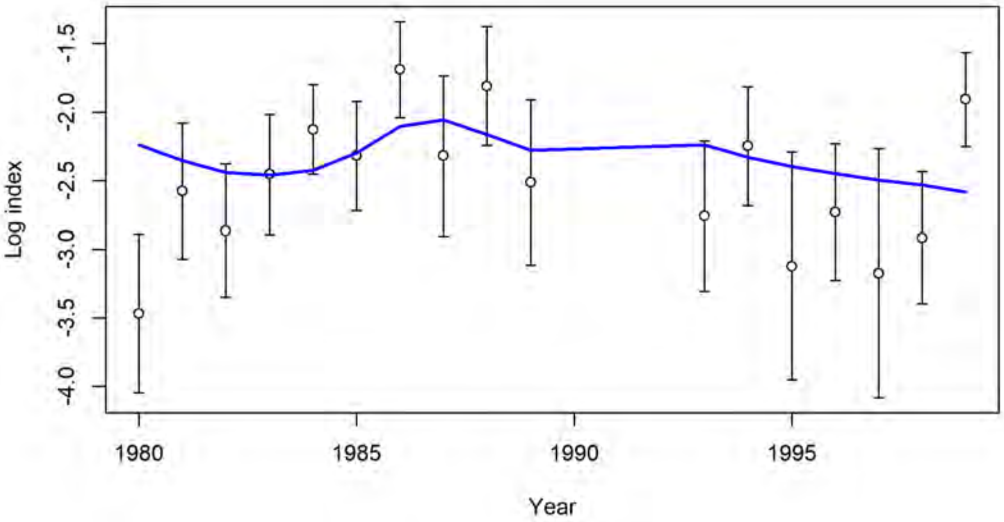

Figure 88: Fit to log index data on log scale for the recreational PC retained fishery. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

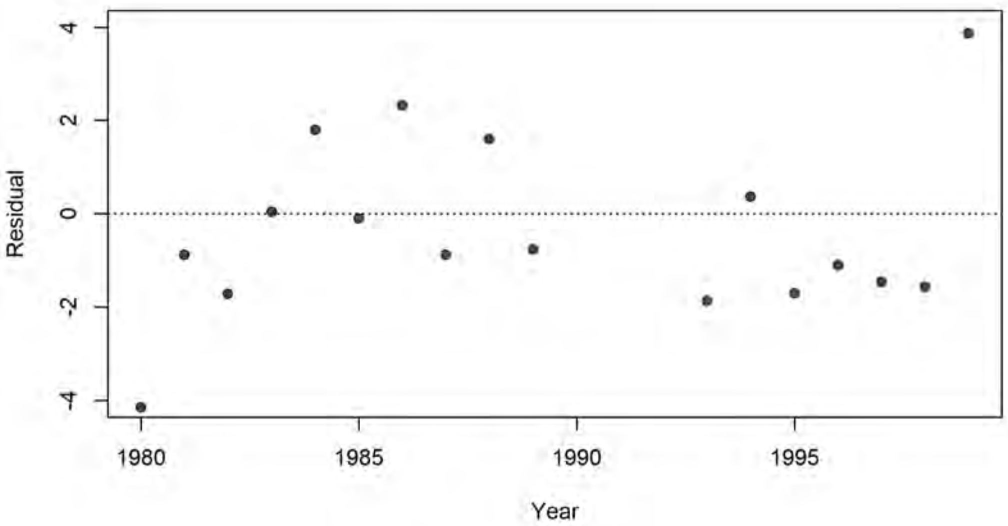

Figure 89: Residuals of fit to index for the REC_PC. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

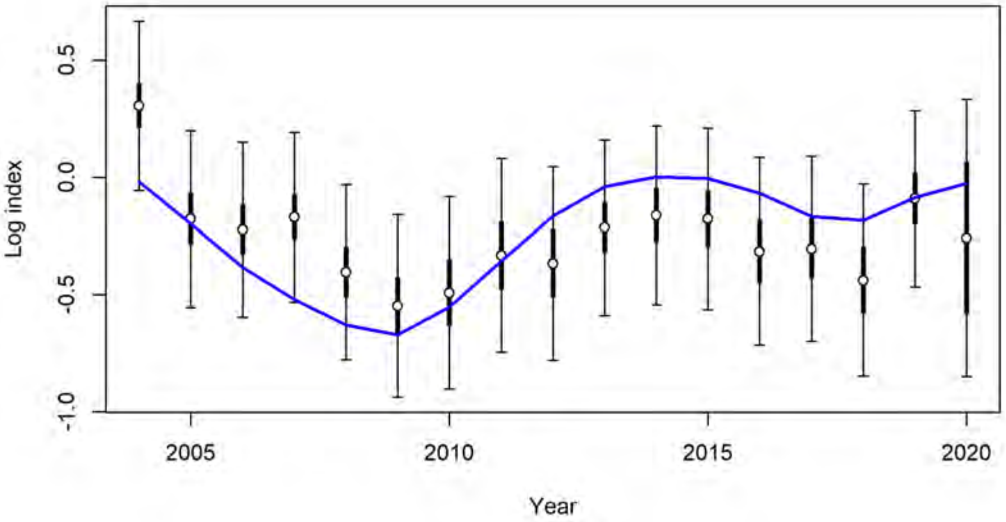

Figure 90: Fit to log index data on log scale for the recreational PR retained fishery. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

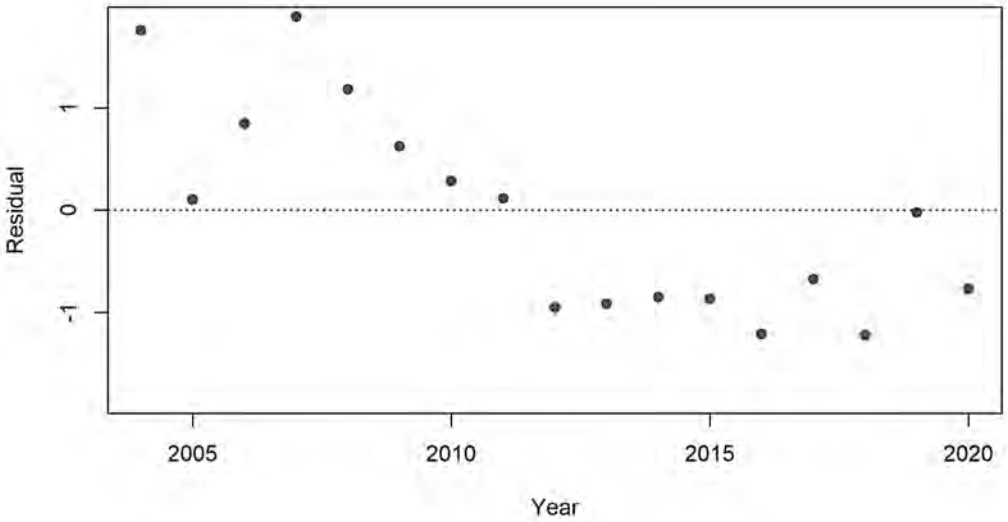

Figure 91: Residuals of fit to index for the REC_PR. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

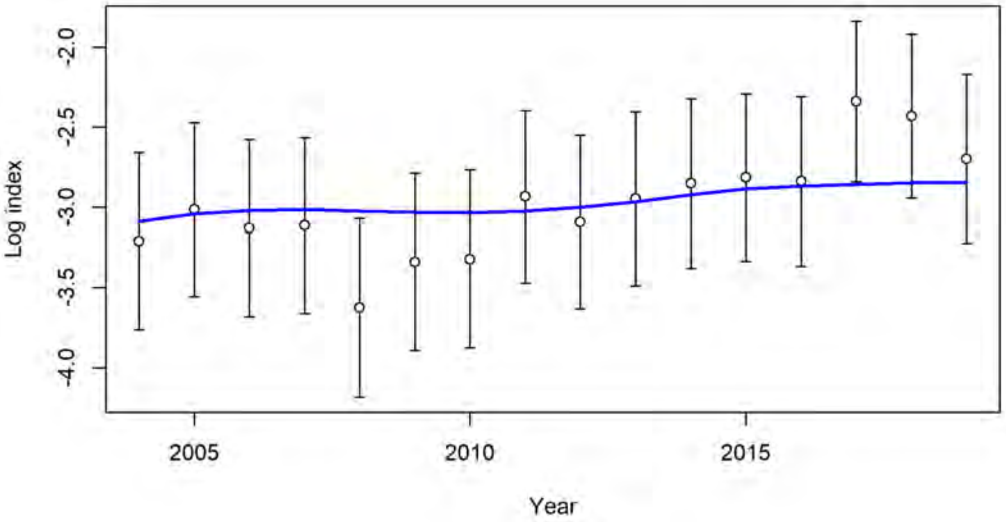

Figure 92: Fit to log index data on log scale for the NWFSC hook-and-line survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

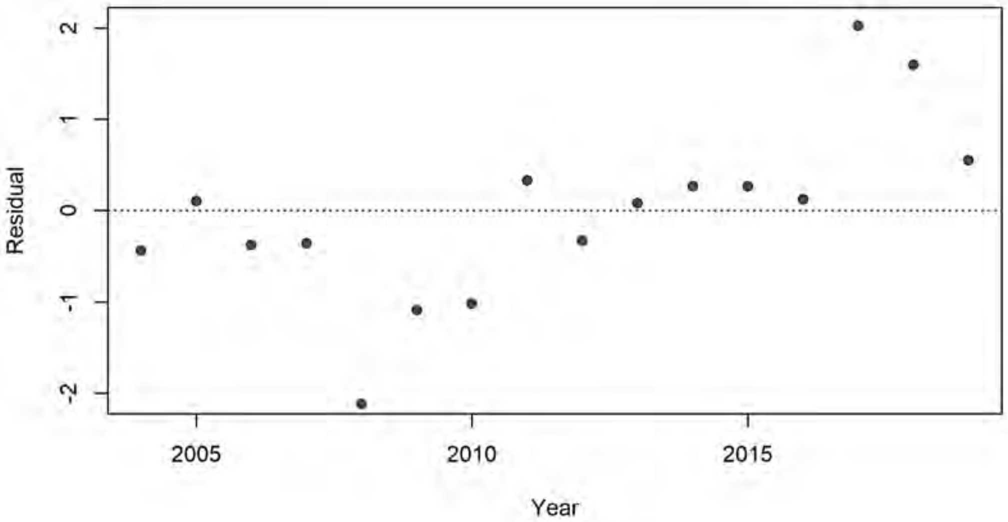

Figure 93: Residuals of fit to index for the NWFSC_HKL. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

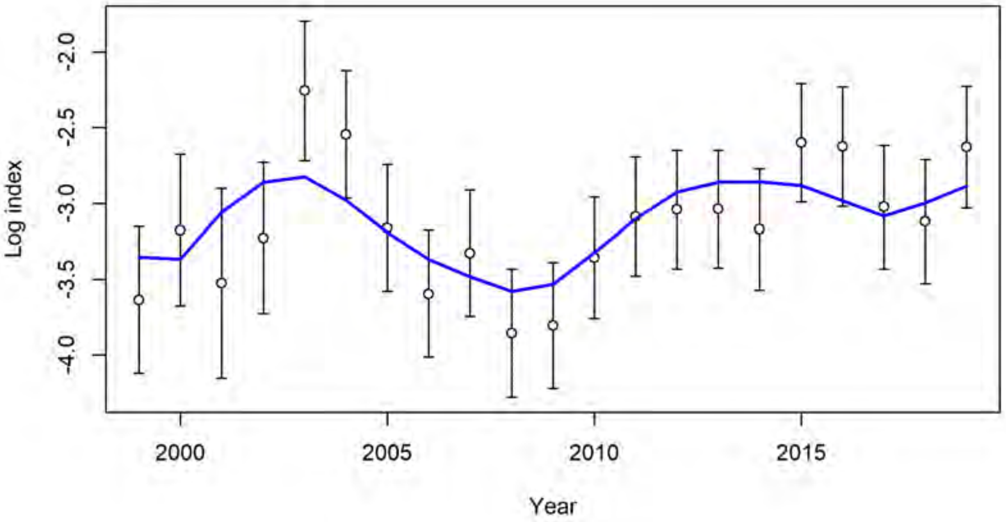

Figure 94: Fit to log index data on log scale for the recreational PC onboard survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

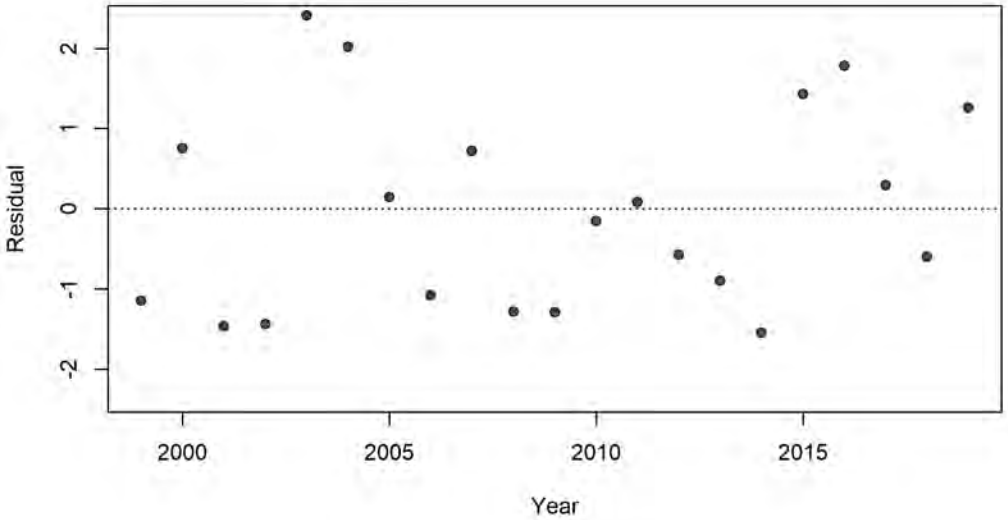

Figure 95: Residuals of fit to index for the REC_PC_ONBOARD. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

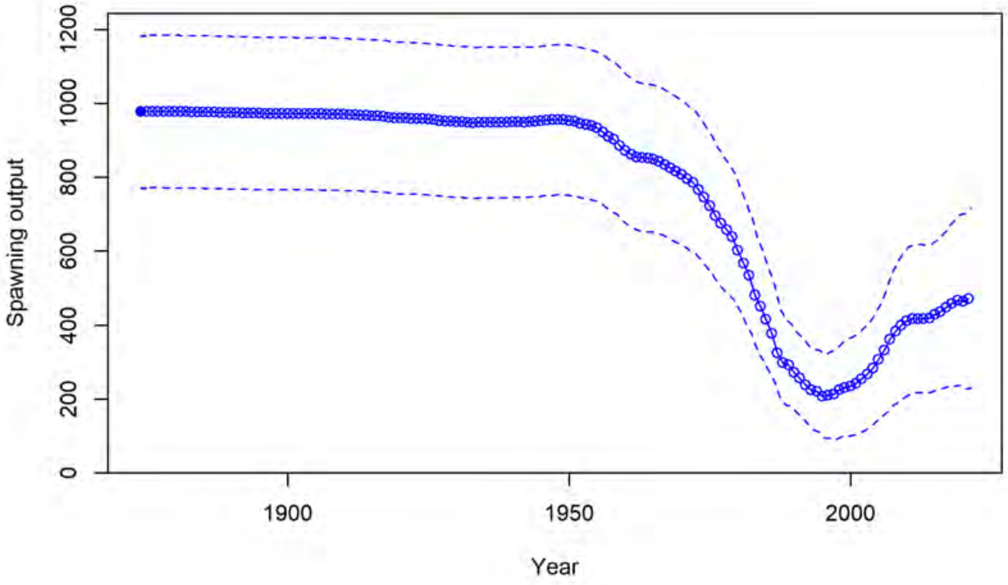

Figure 96: Estimated time series of spawning output.

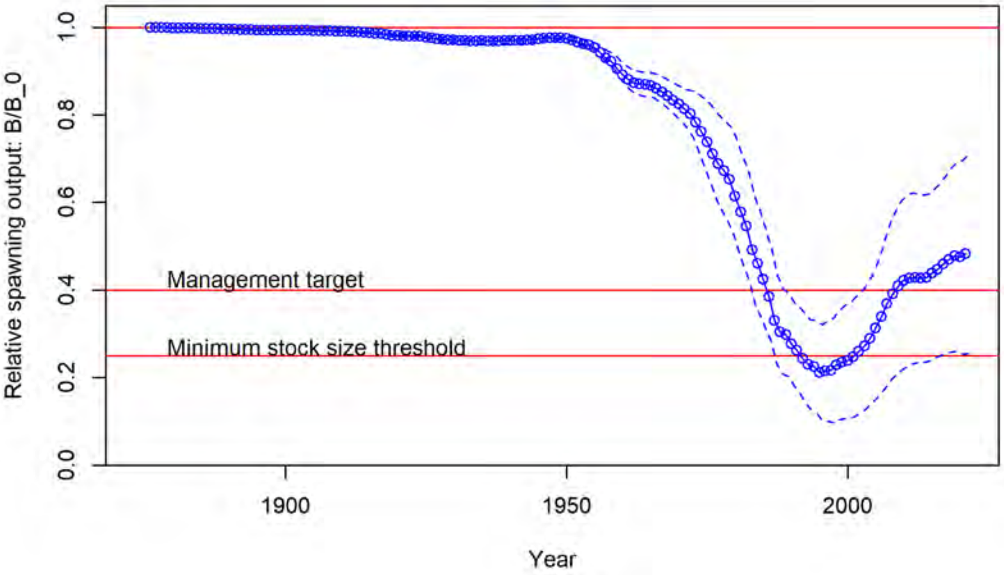

Figure 97: Estimated time series of relative spawning output.

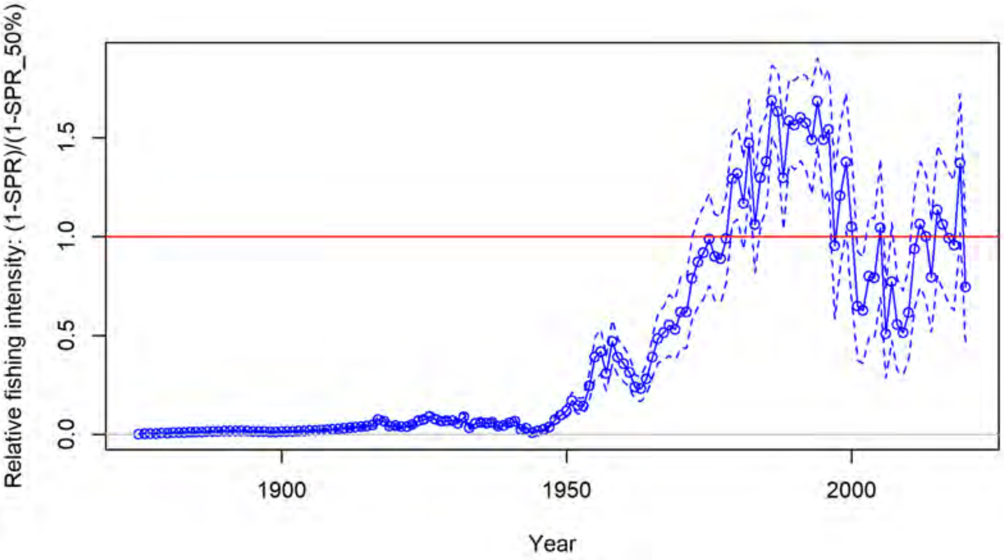

Figure 98: Timeseries of SPR ratio: (1-SPR)/(1-SPR_50%).

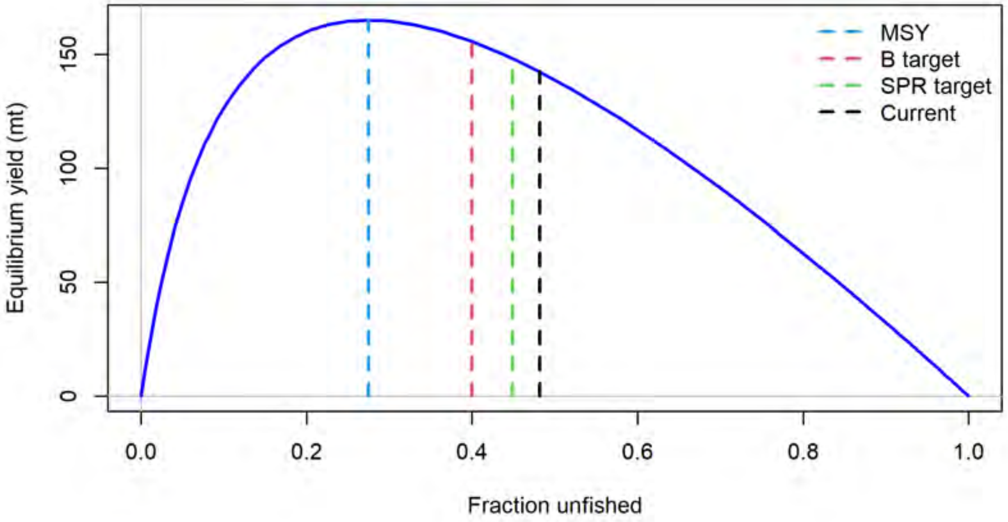

Figure 99: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivity and with steepness fixed at 0.72.

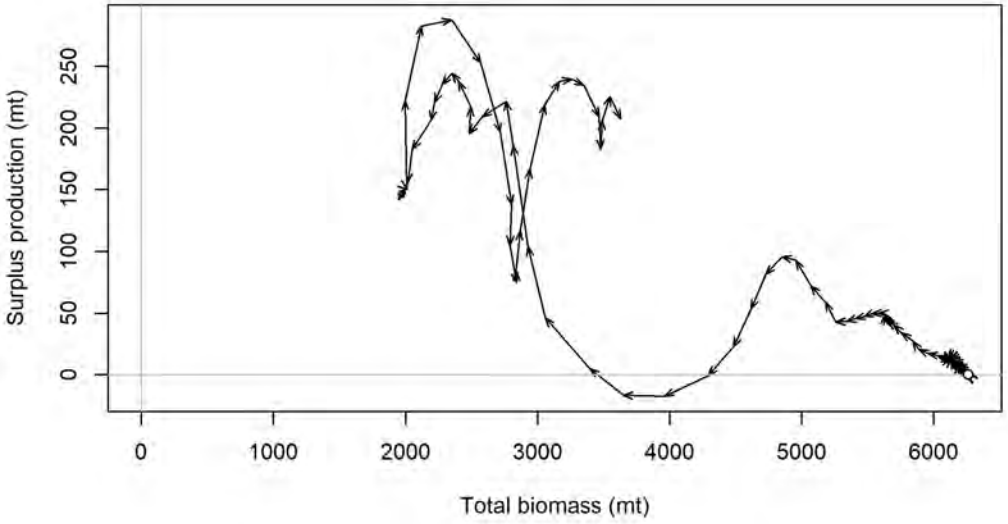

Figure 100: Surplus production vs. biomass plot.

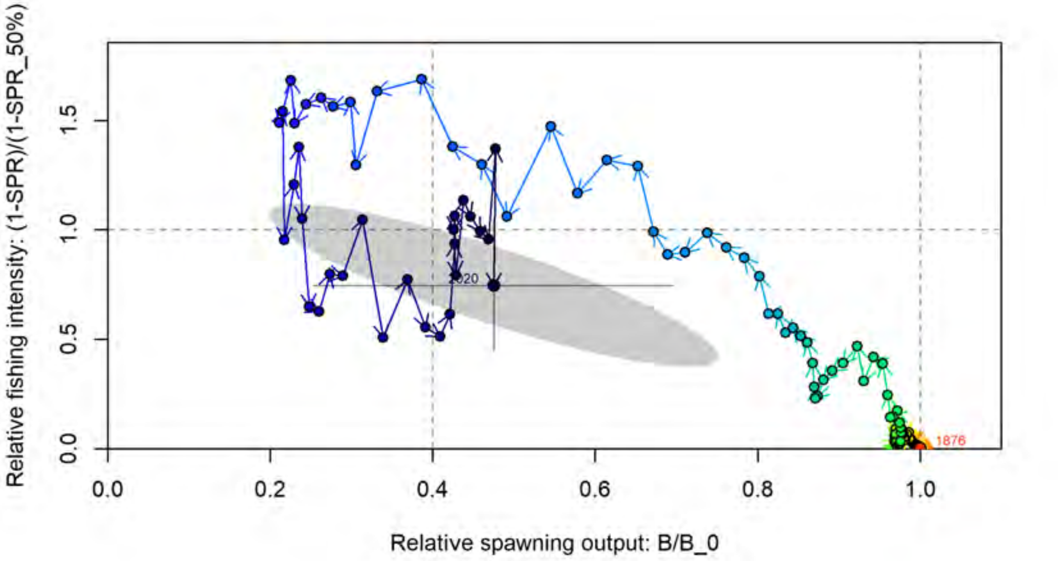

Figure 101: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show the 95 percent intervals based on 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.

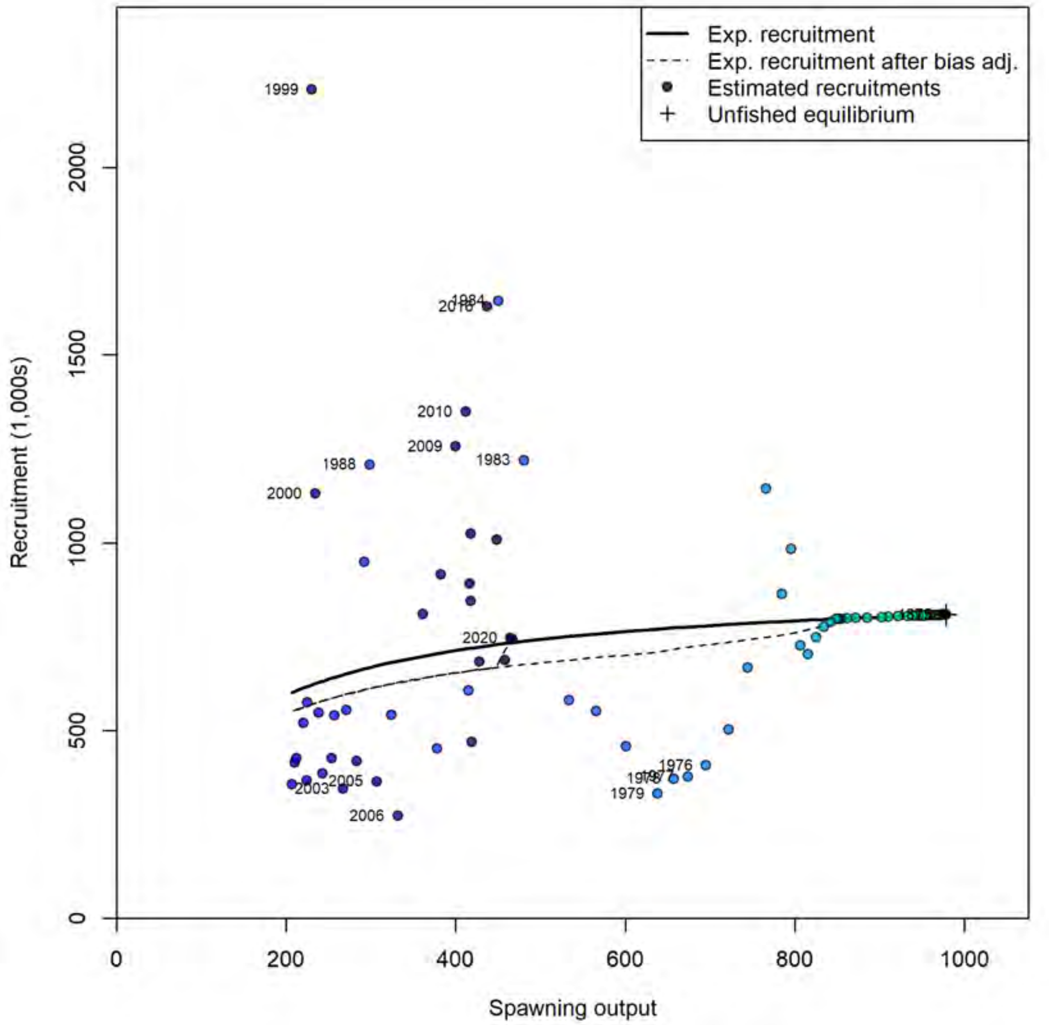

Figure 102: Stock-recruit curve with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

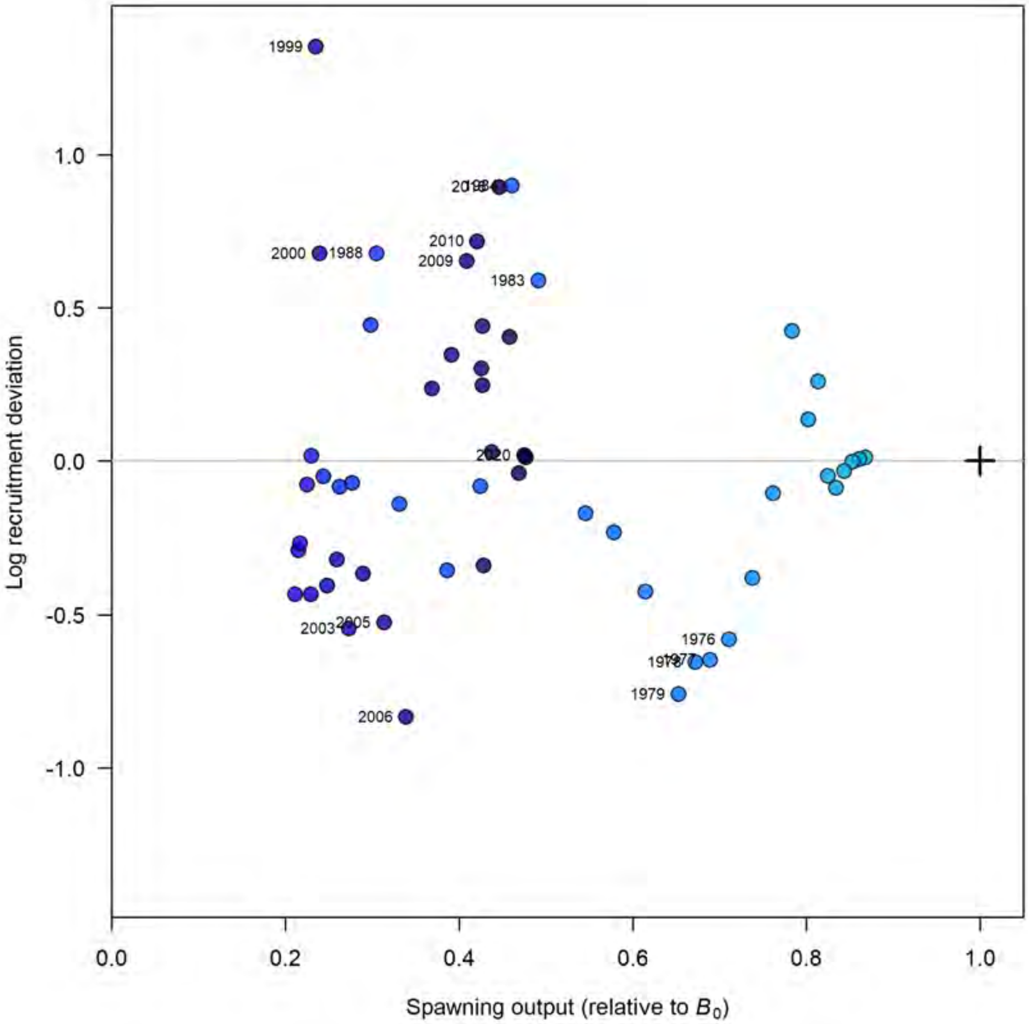

Figure 103: Deviations around the stock-recruit curve. Labels are on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

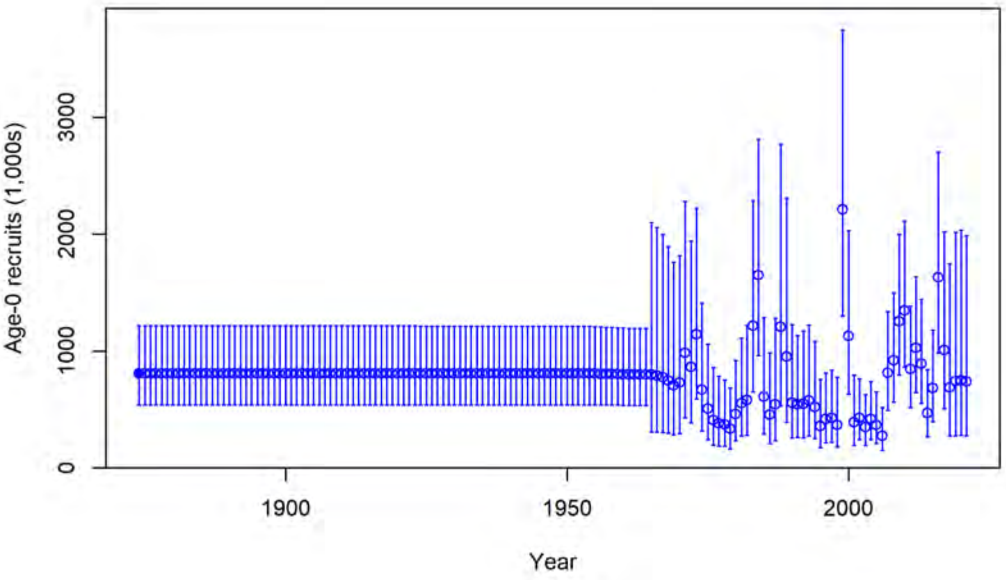

Figure 104: Age-0 recruits (1,000s) with ~95% asymptotic intervals.

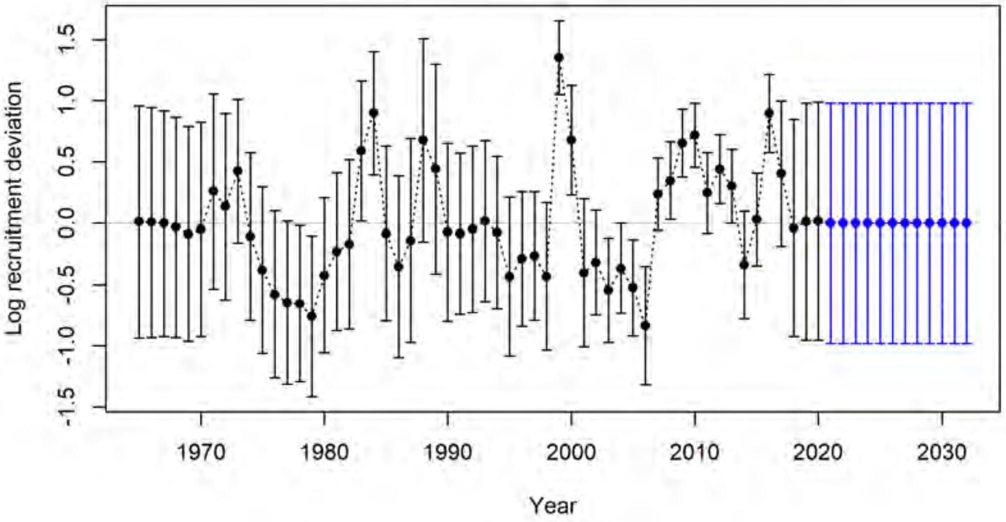

Figure 105: Estimated time series of recruitment deviations.

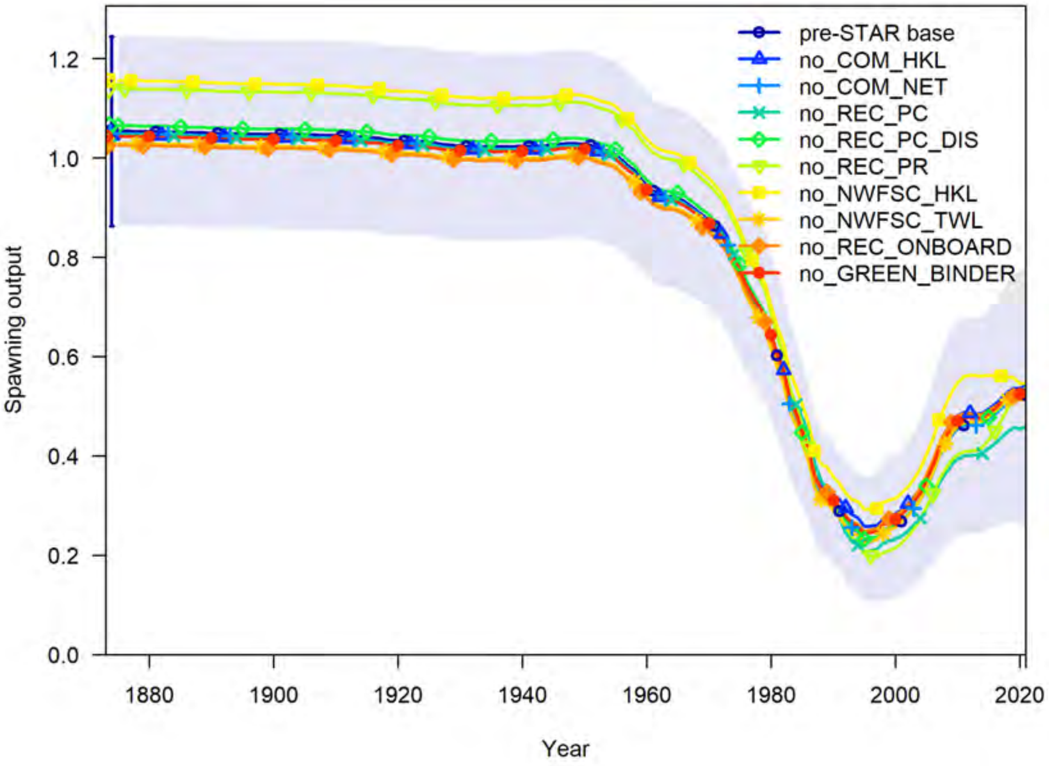

Figure 106: Change in the spawning output when a single fleet is removed from the model.

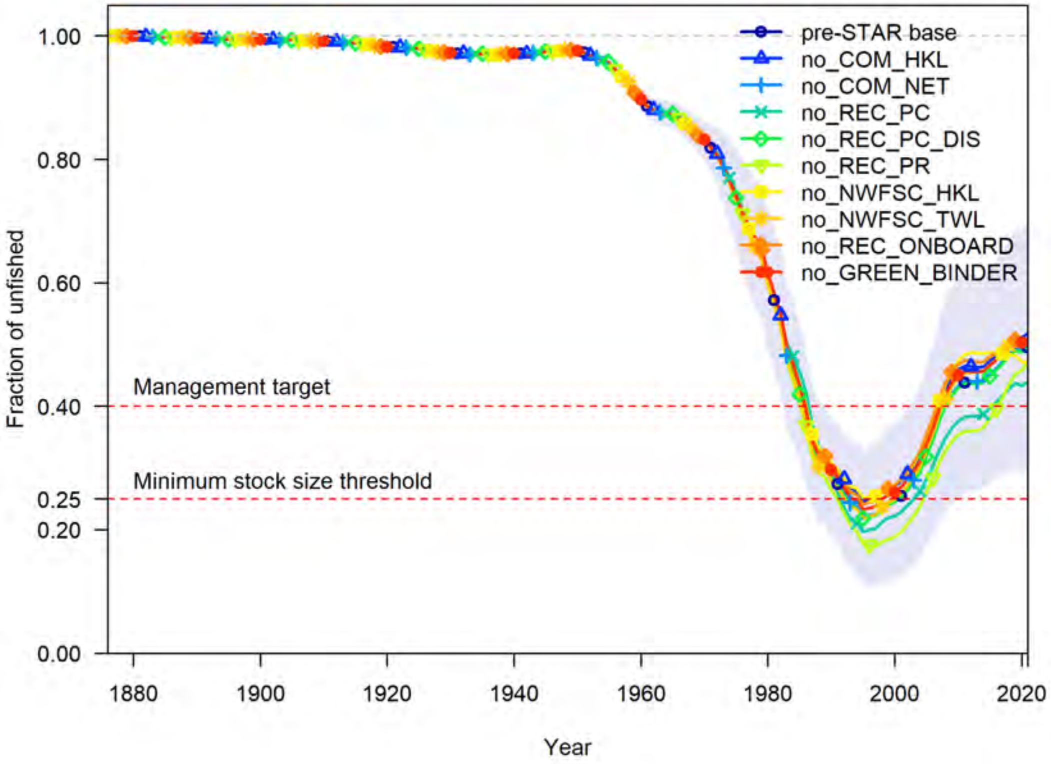

Figure 107: Change in the fraction of unfished biomass when a single fleet is removed from the model.

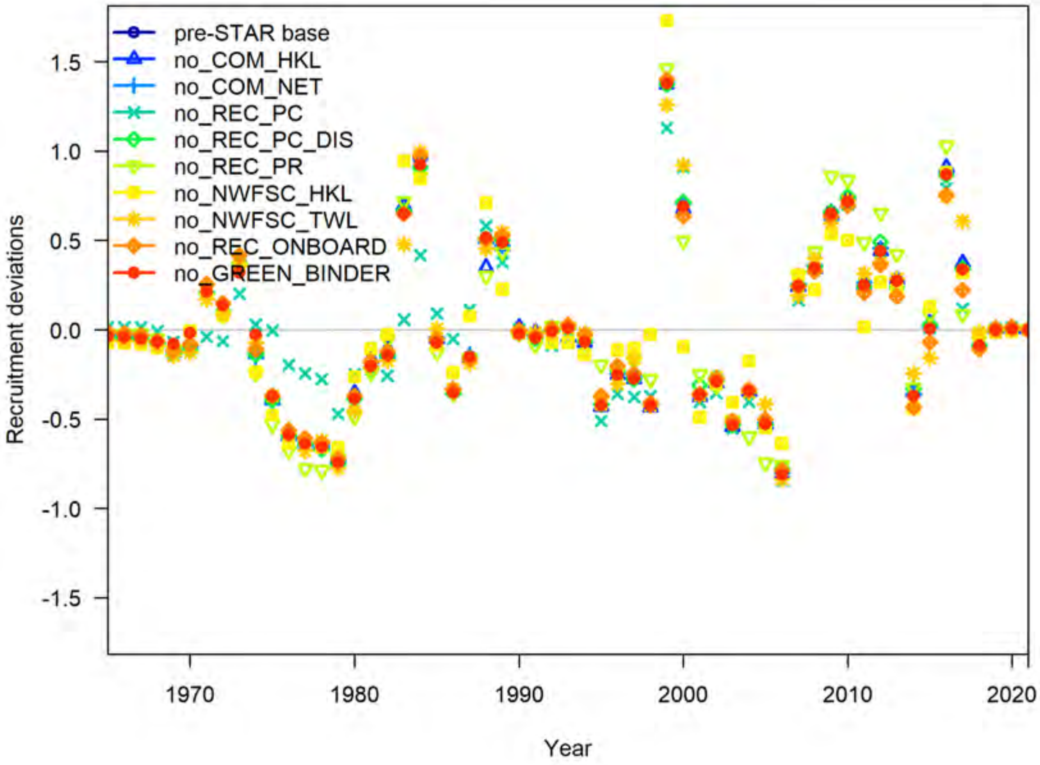

Figure 108: Change in the recruitment deviations when a single fleet is removed from the model.

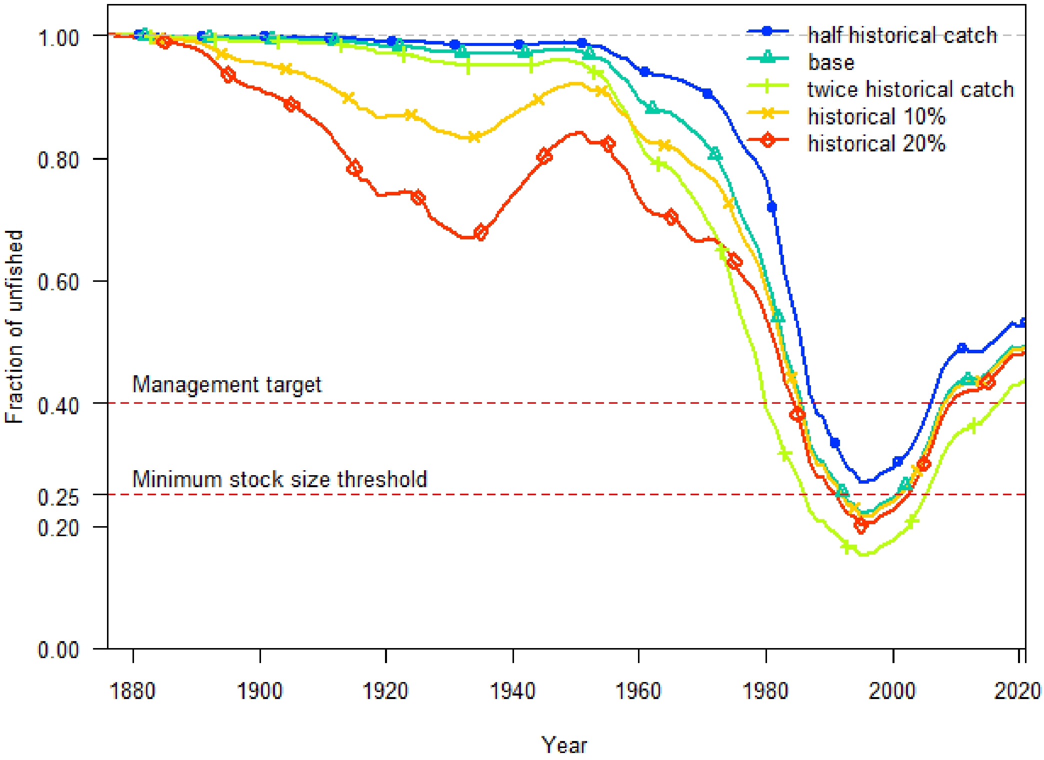

Figure 109: Change in depletion when historical catches are modified.

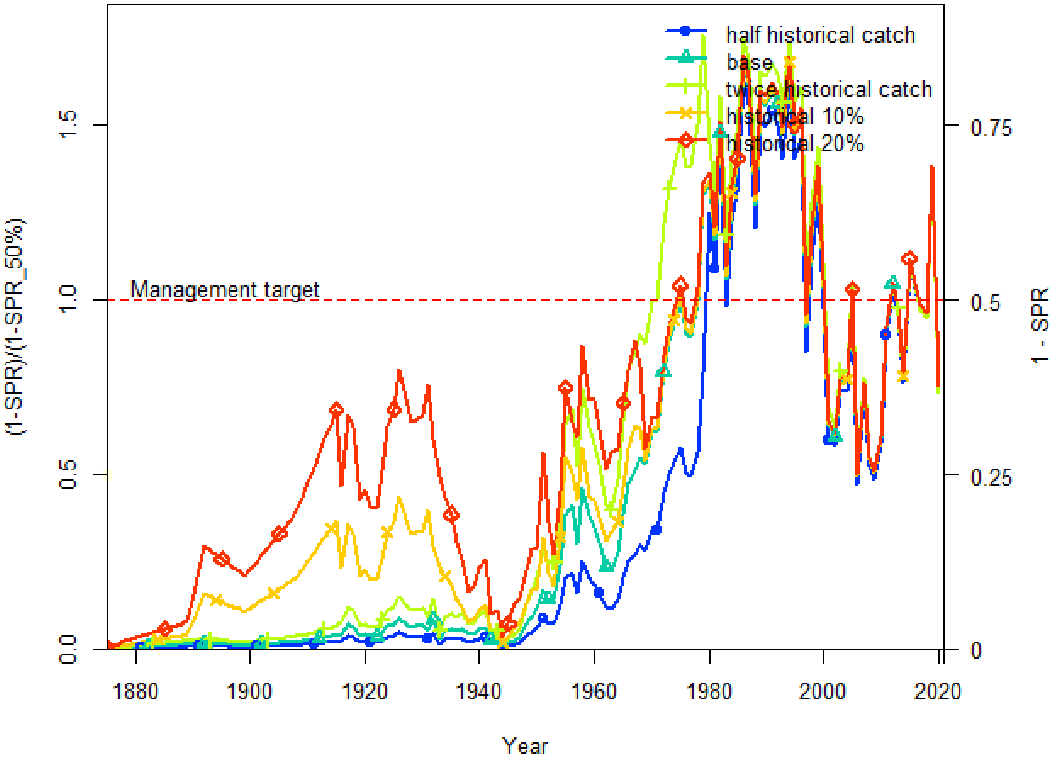

Figure 110: Change in the relative SPR when historical catches are modified.

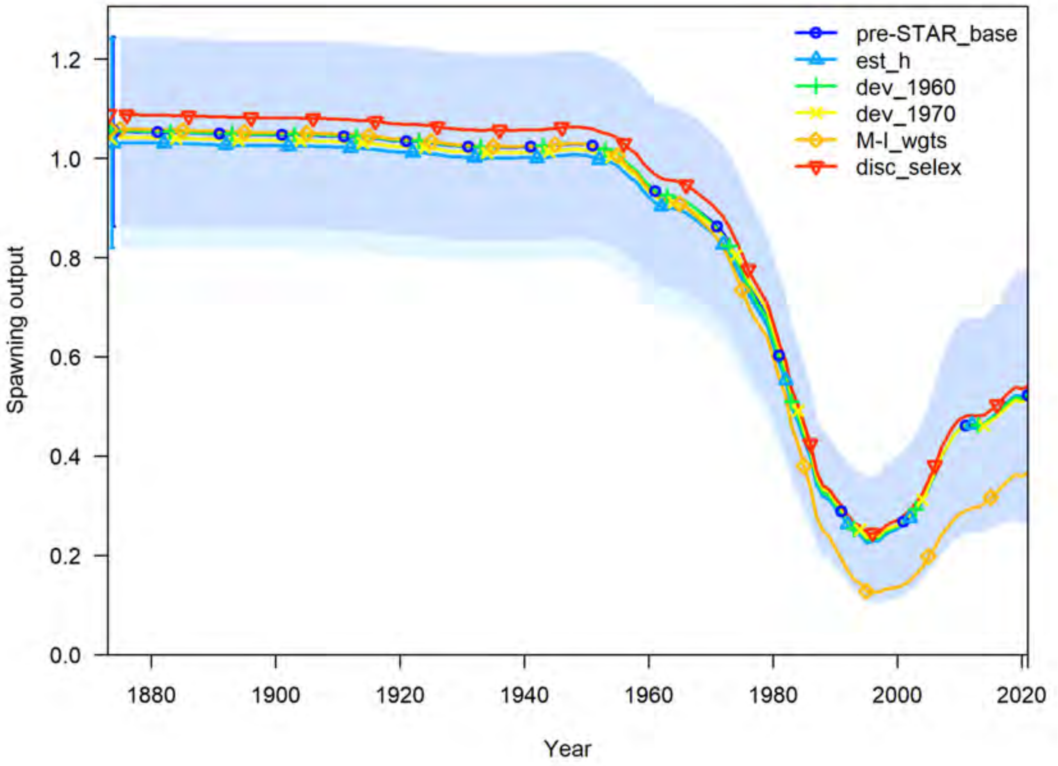

Figure 111: Change in the trajectory of spawning output to a series of model sensitivity runs.

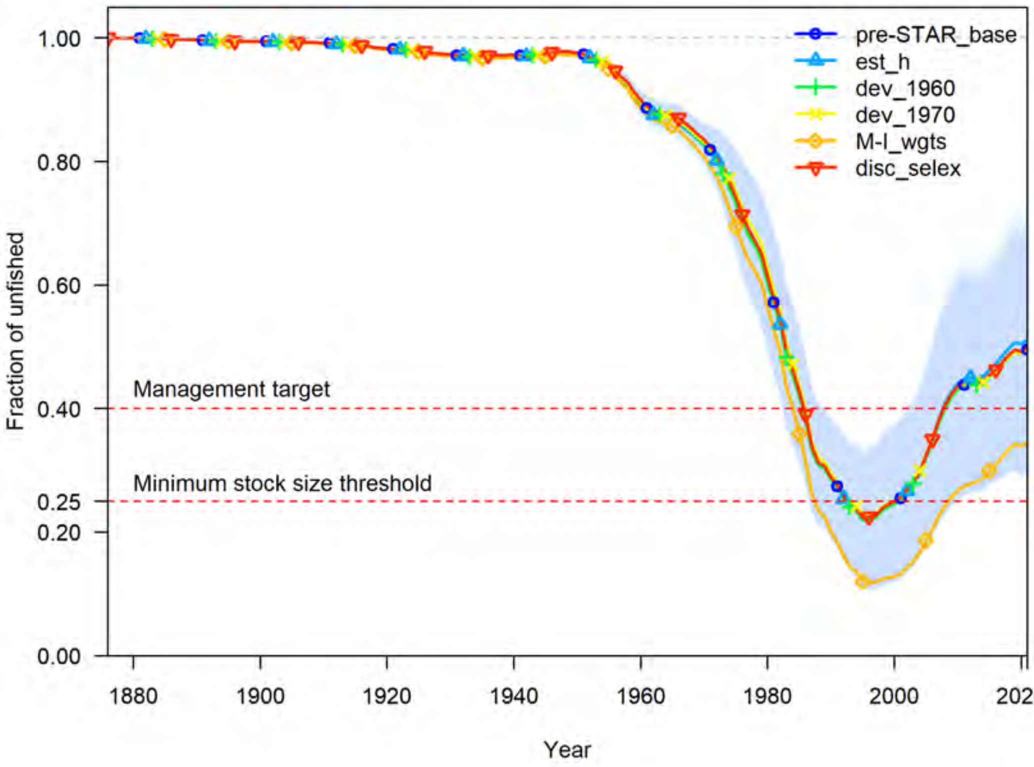

Figure 112: Change in the fraction of unfished biomass to a series of model sensitivity runs.

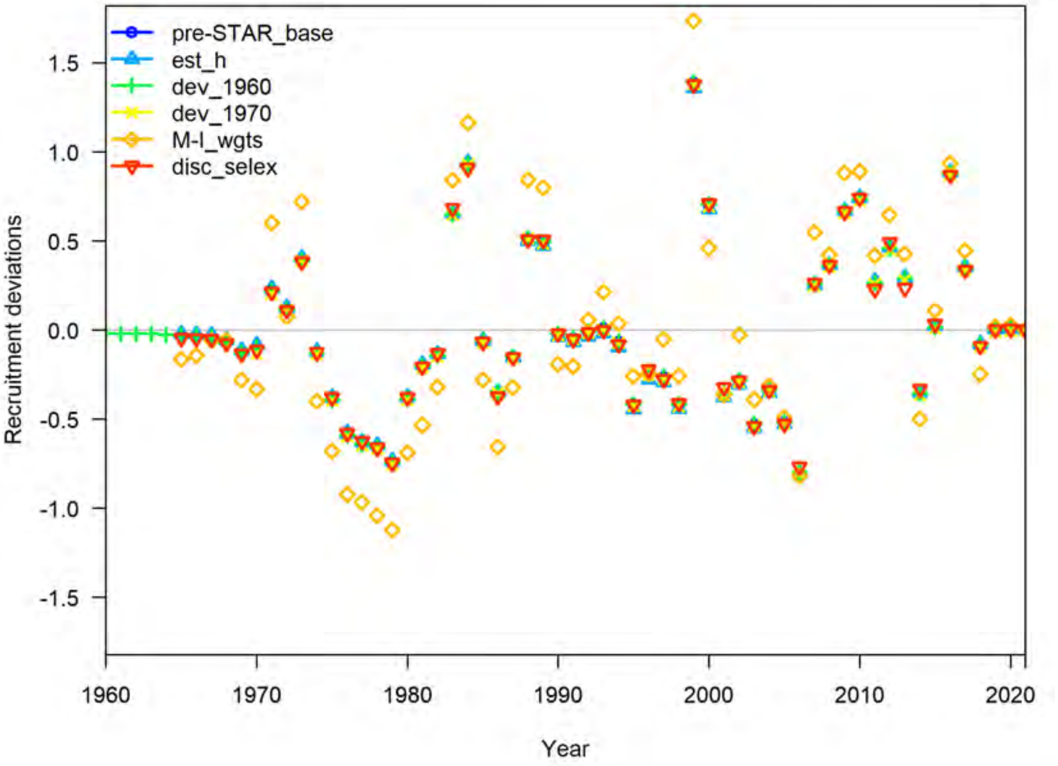

Figure 113: Change in the recruitment deviations to a series of model sensitivity runs.

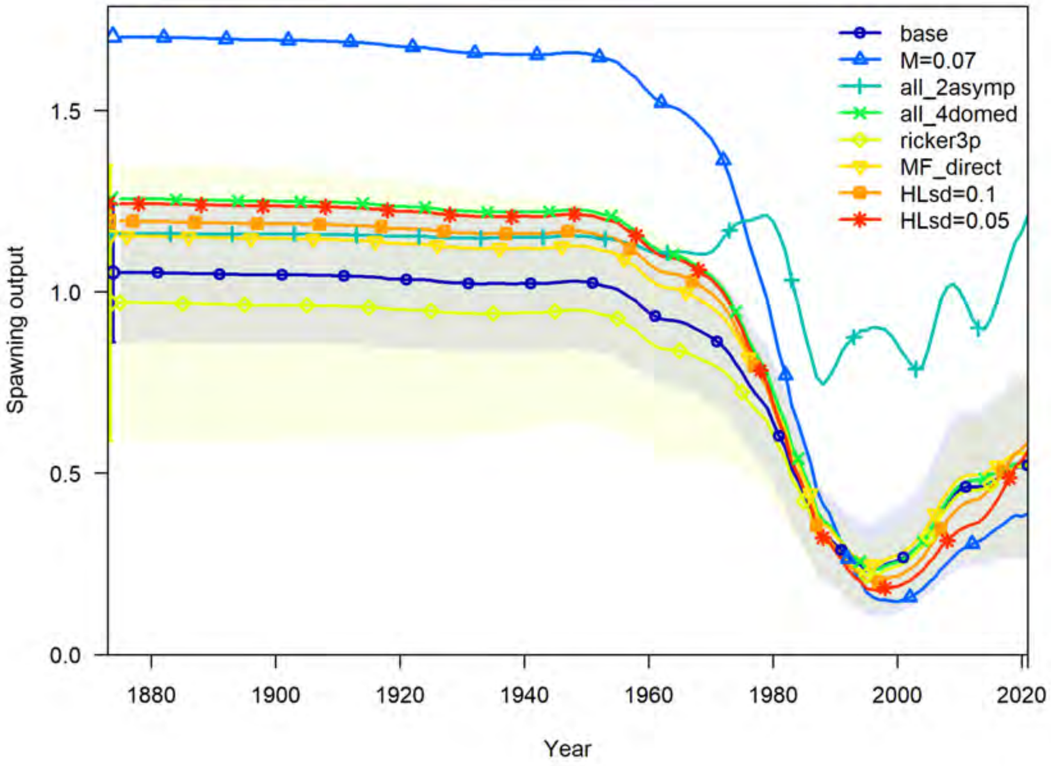

Figure 114: Change in the trajectory of spawning output to a series of model sensitivity runs.

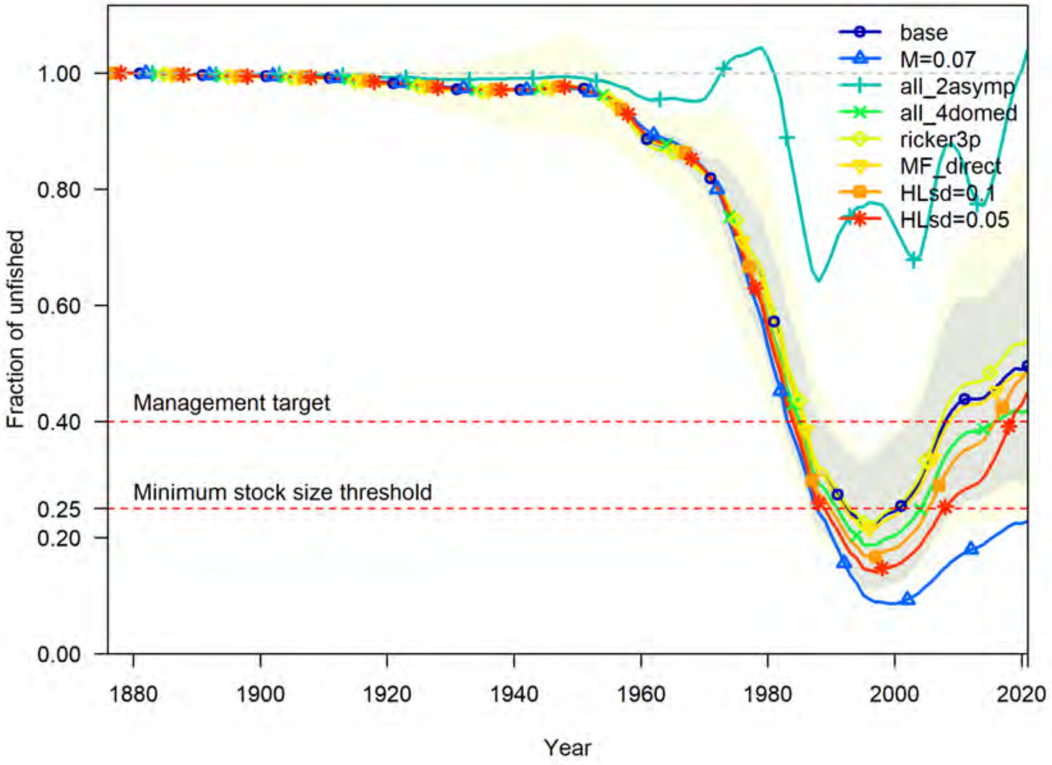

Figure 115: Change in the fraction of unfished biomass to a series of model sensitivity runs.

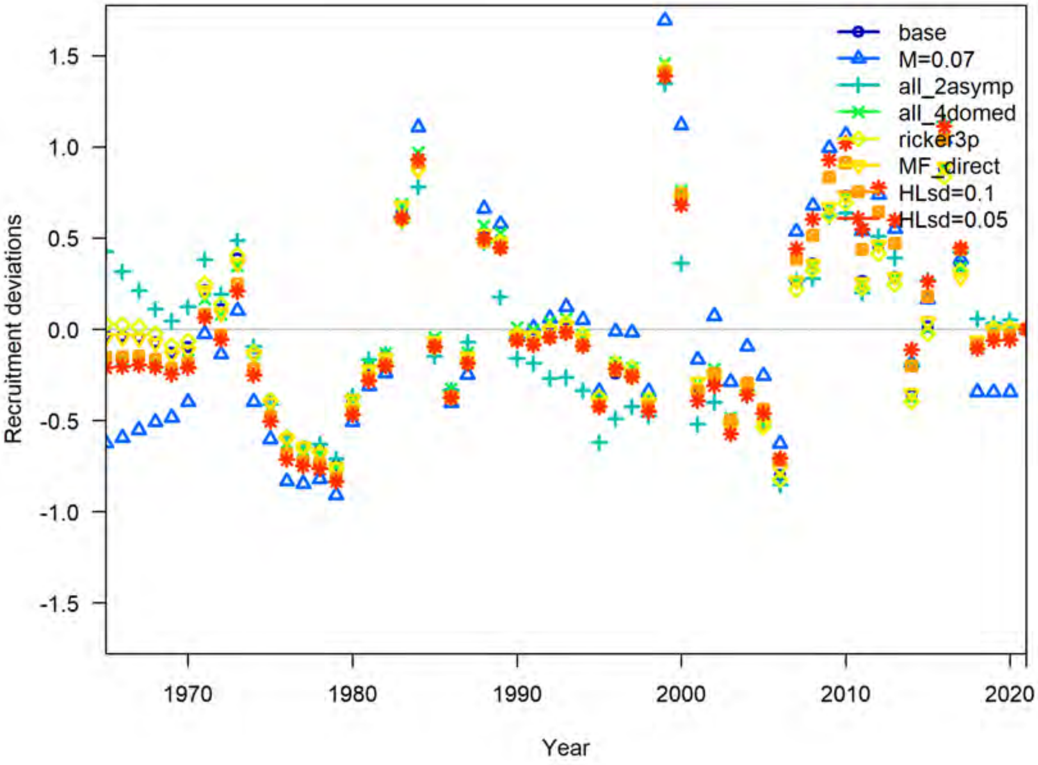

Figure 116: Change in the recruitment deviations to a series of model sensitivity runs.

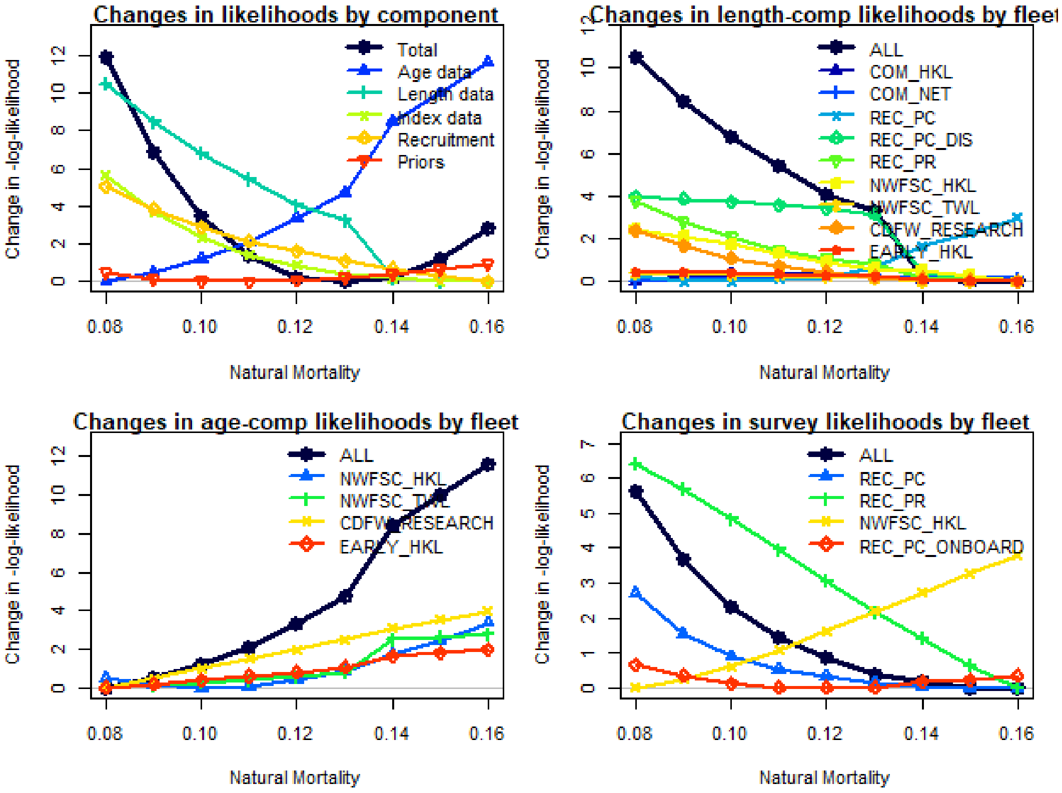

Figure 117: Likelihood profile across natural mortality values for each data type.

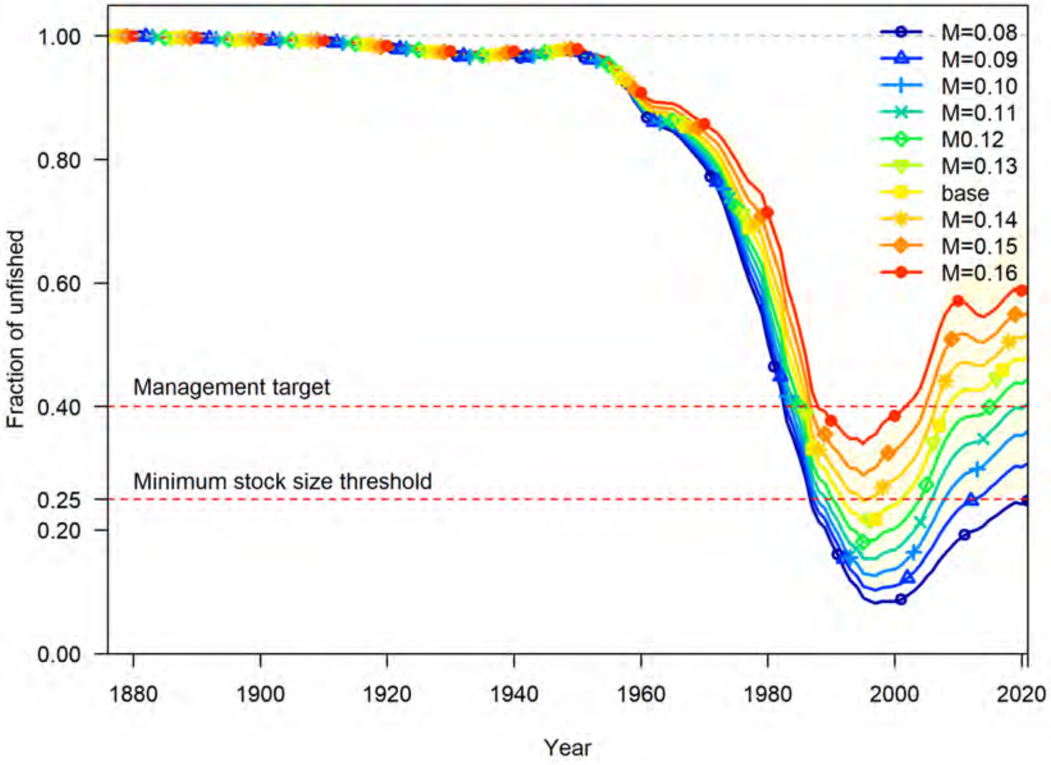

Figure 118: Trajectories of depletion across values of female natural mortality.

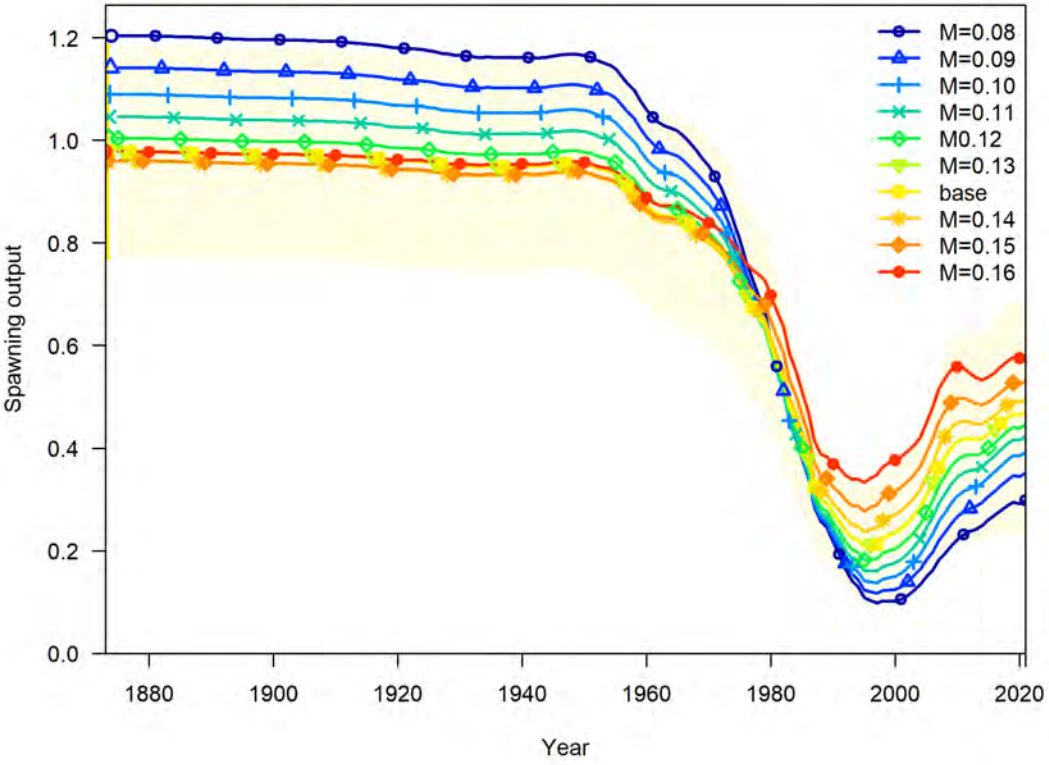

Figure 119: Trajectories of spawning output across values of female natural mortality.

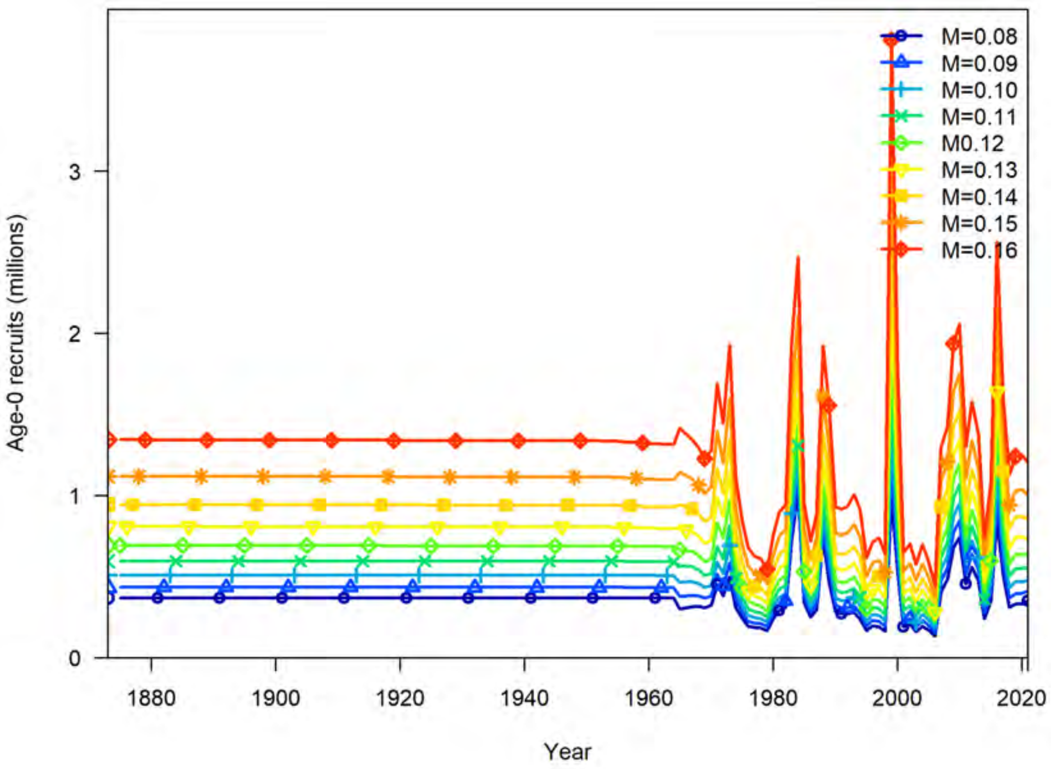

Figure 120: Trajectories of age-0 recruits across values of female natural mortality.

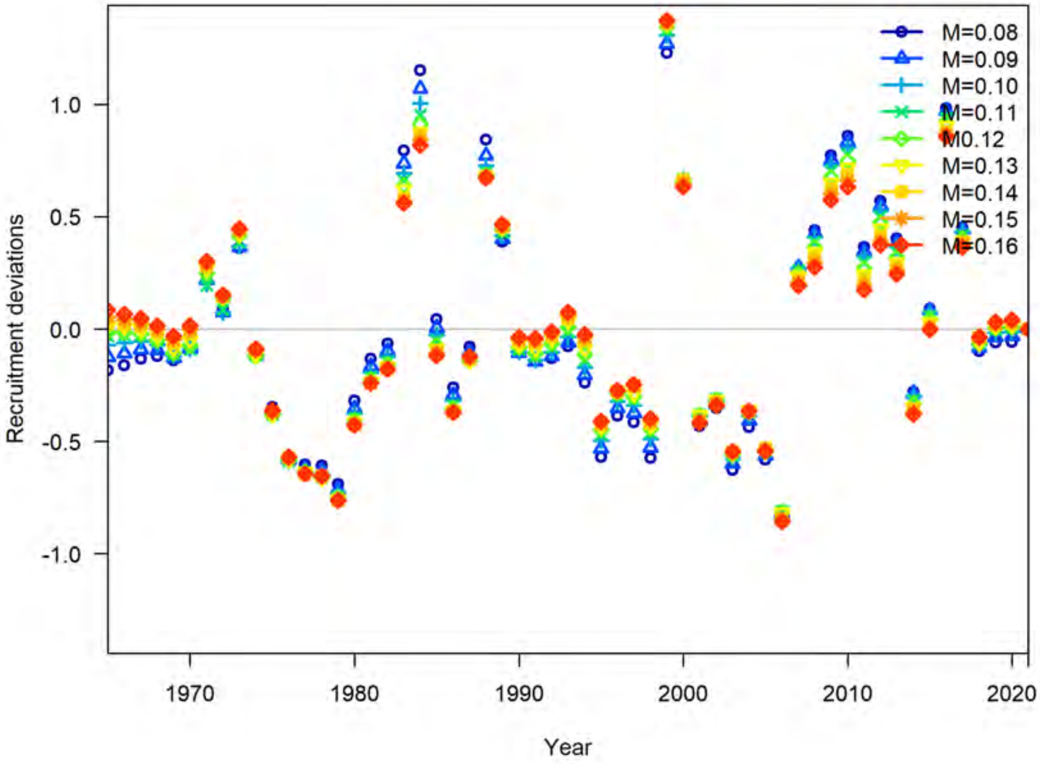

Figure 121: Trajectories of estimated recruitment deviations across values of female natural mortality.

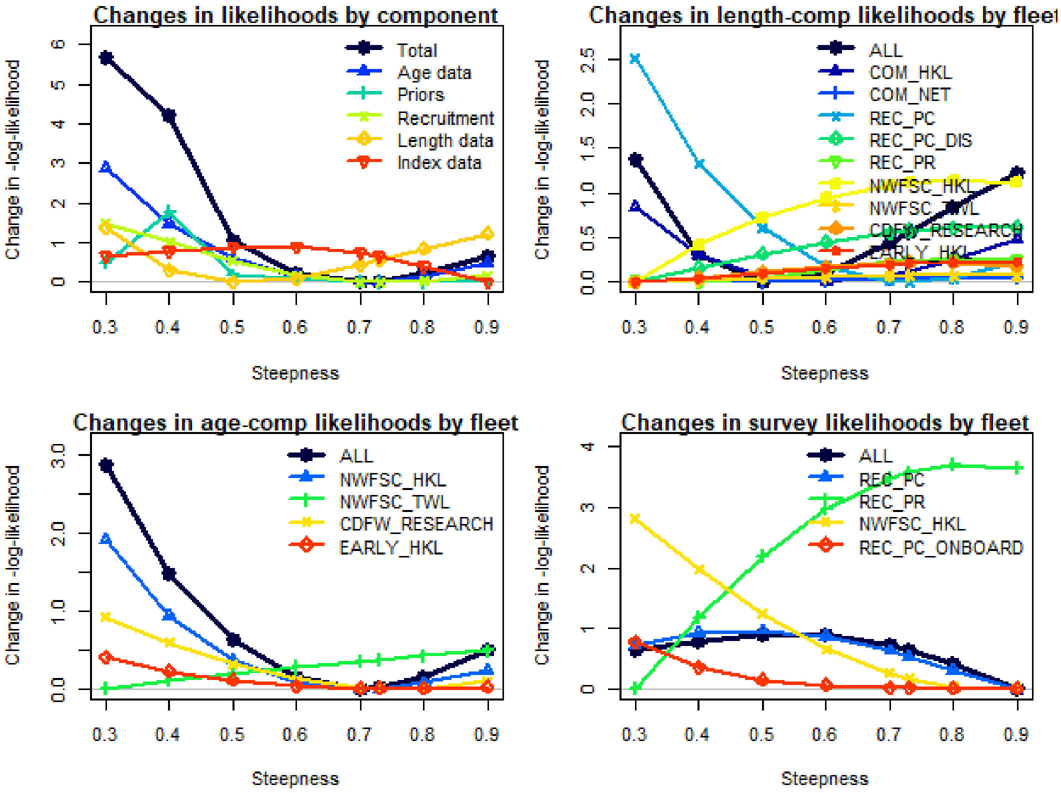

Figure 122: Likelihood profile across steepness values for each data type.

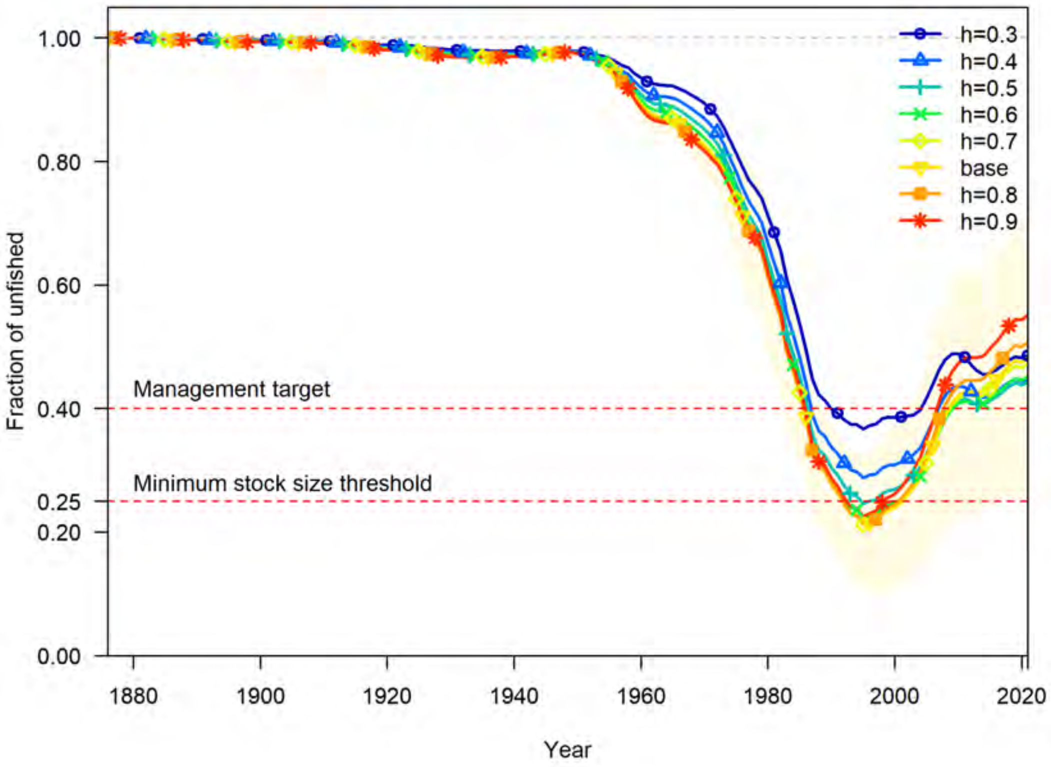

Figure 123: Trajectories of depletion across values of steepness.

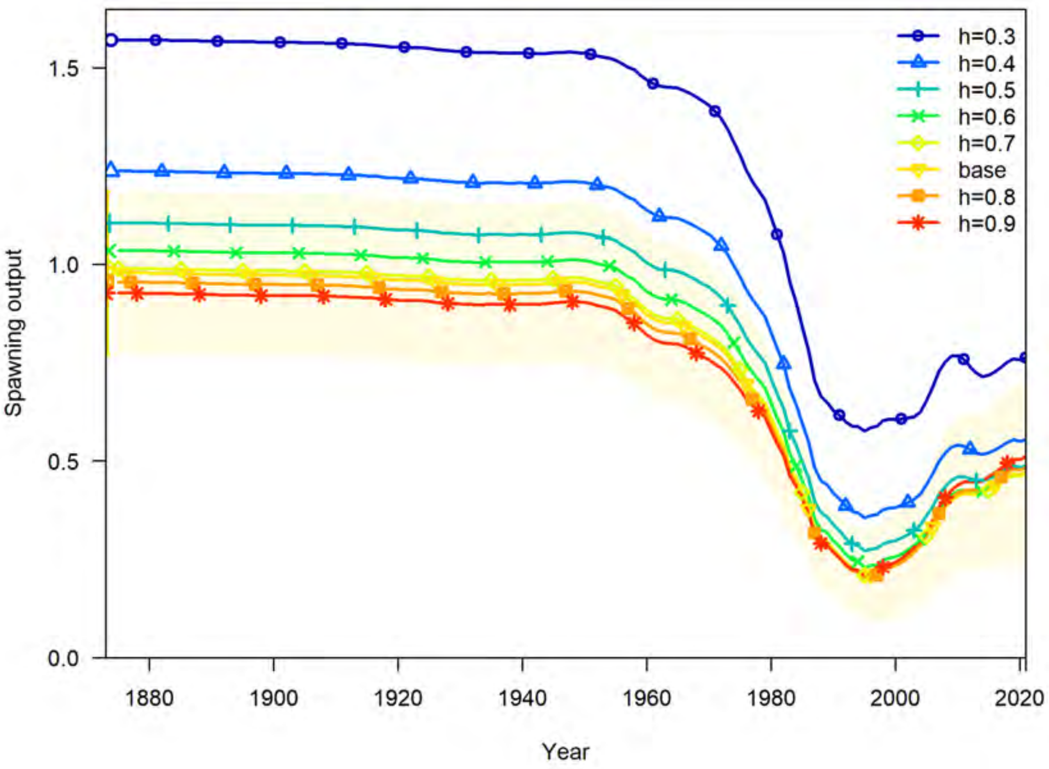

Figure 124: Trajectories of spawning output across values of steepness.

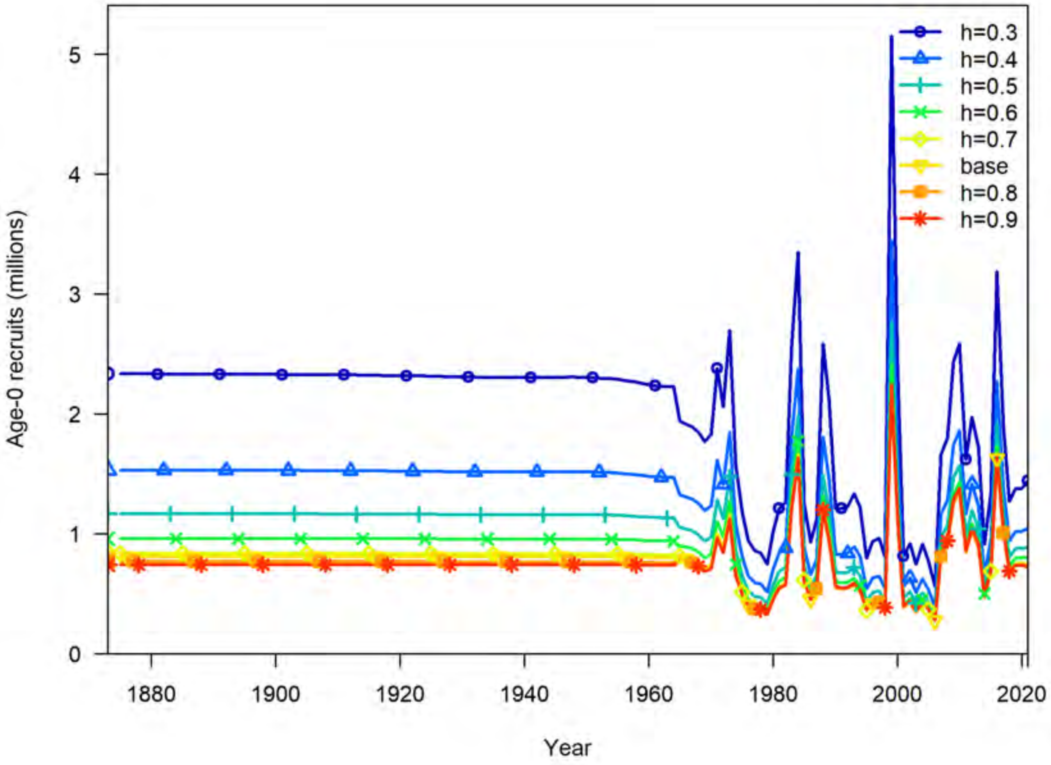

Figure 125: Trajectories of age-0 recruits across values of steepness.

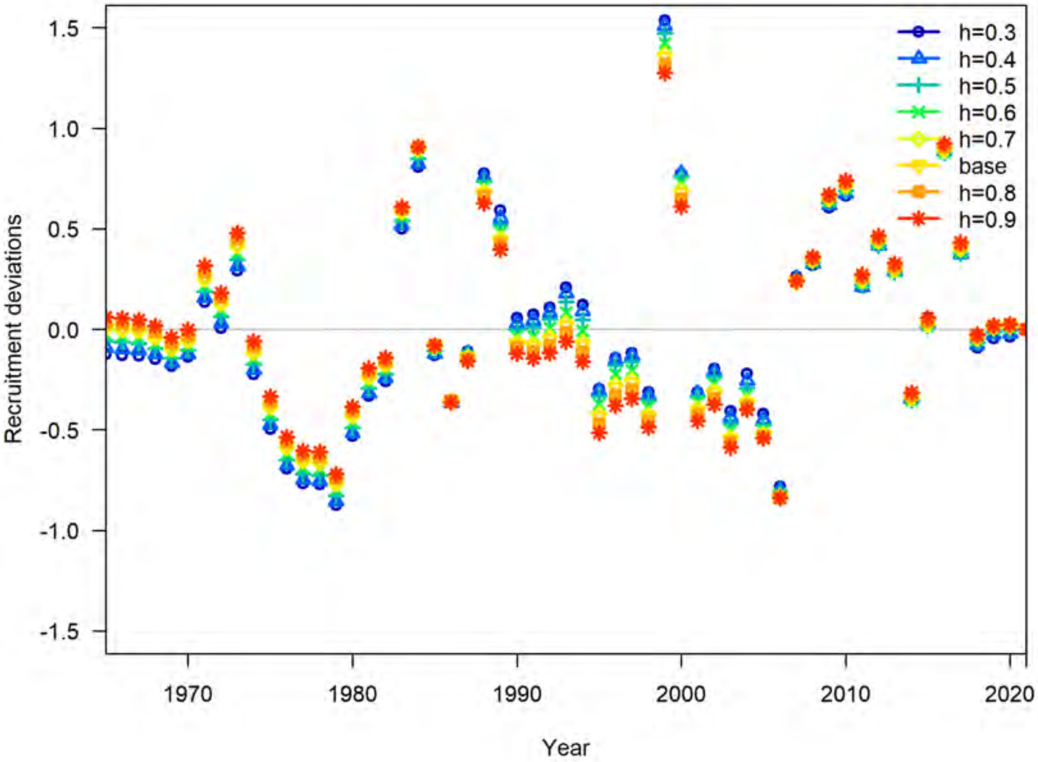

Figure 126: Trajectories of estimated recruitment deviations across values of steepness.

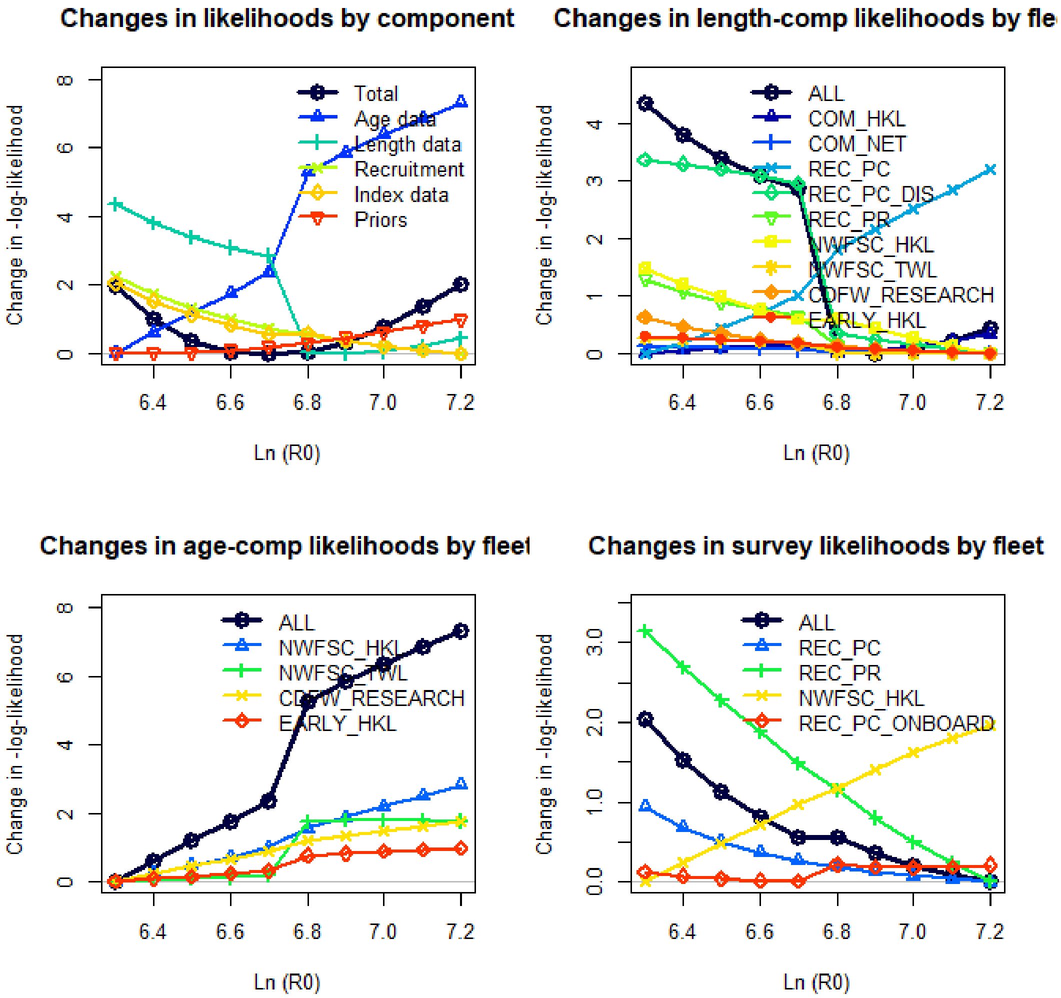

Figure 127: Likelihood profile across R0 values for each data type.

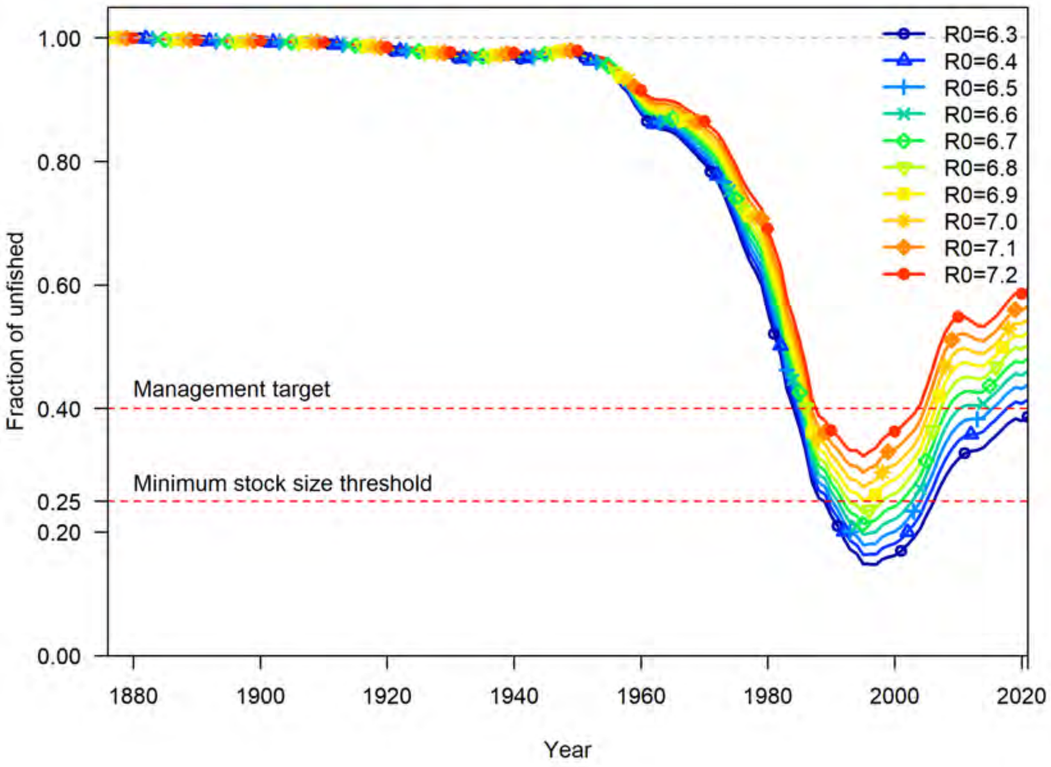

Figure 128: Trajectories of depletion across values of R0.

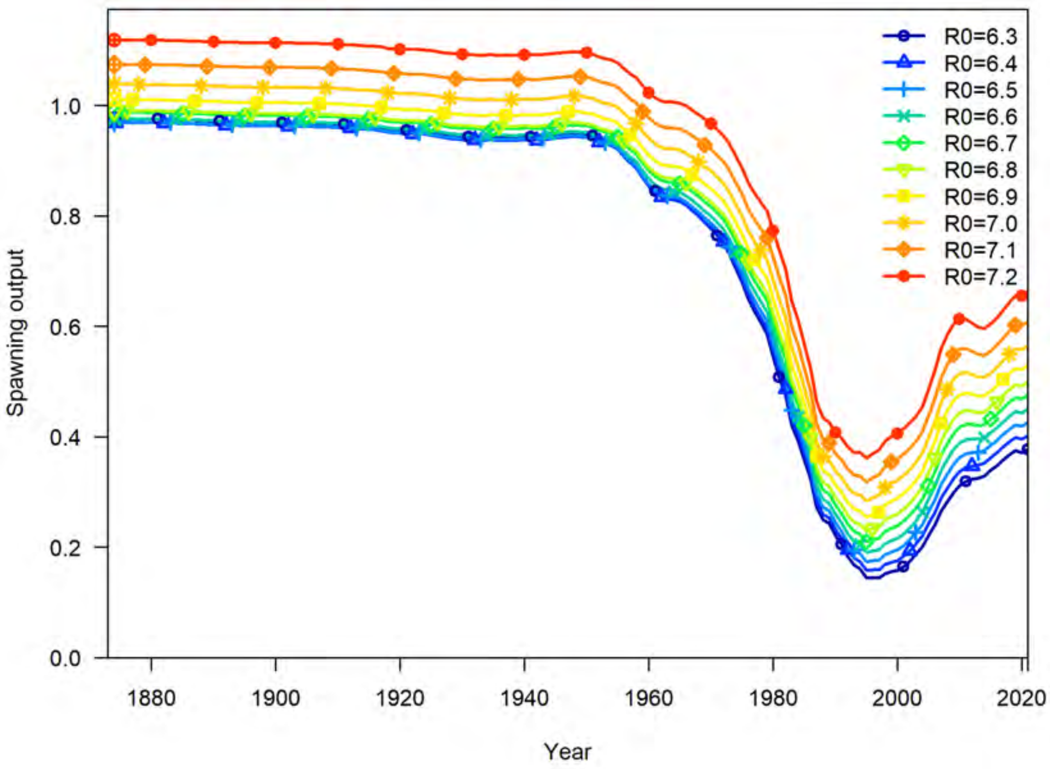

Figure 129: Trajectories of spawning output across values of R0.

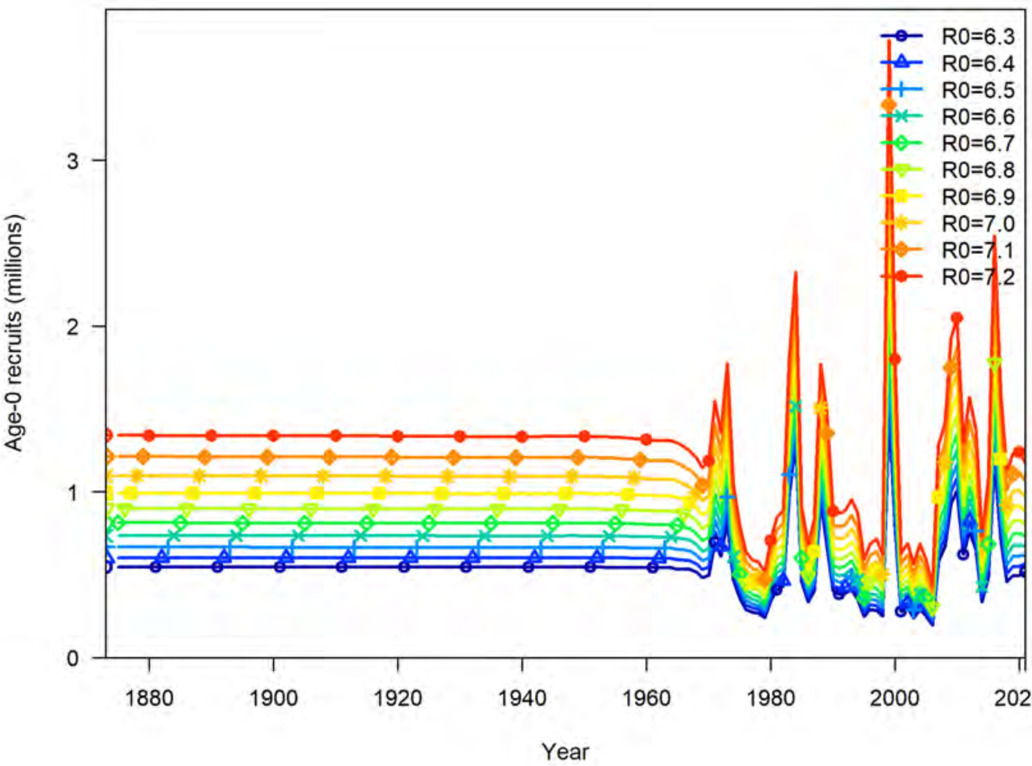

Figure 130: Trajectories of age-0 recruits across values of R0.

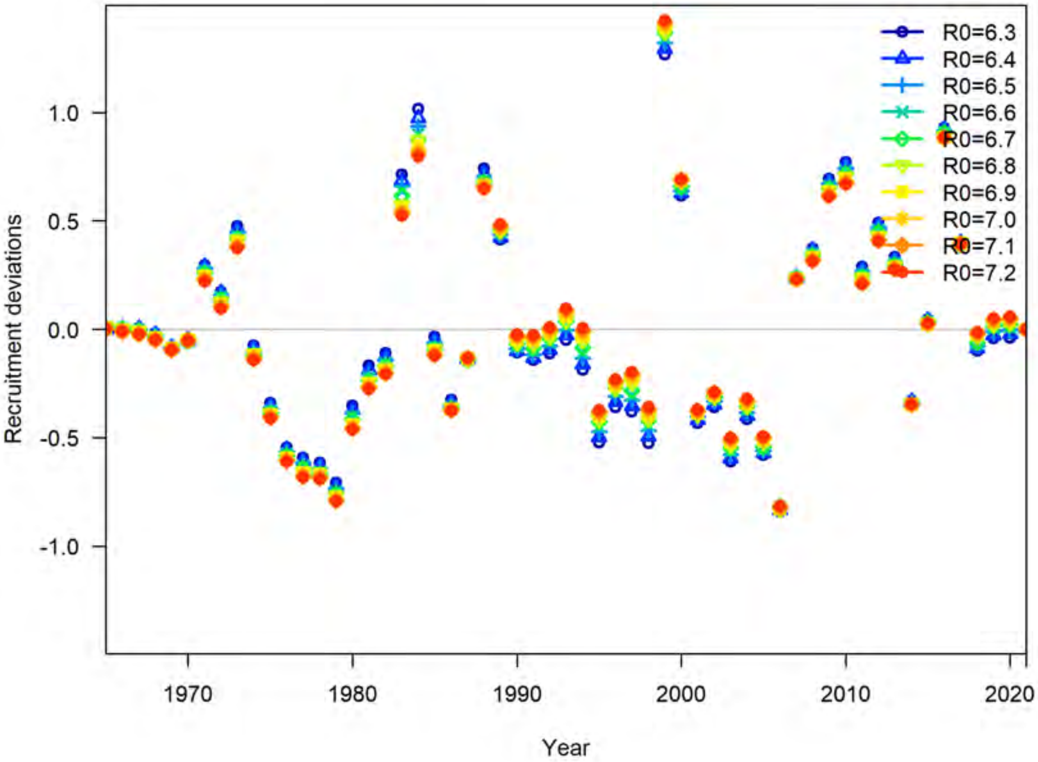

Figure 131: Trajectories of estimated recruitment deviations across values of R0.

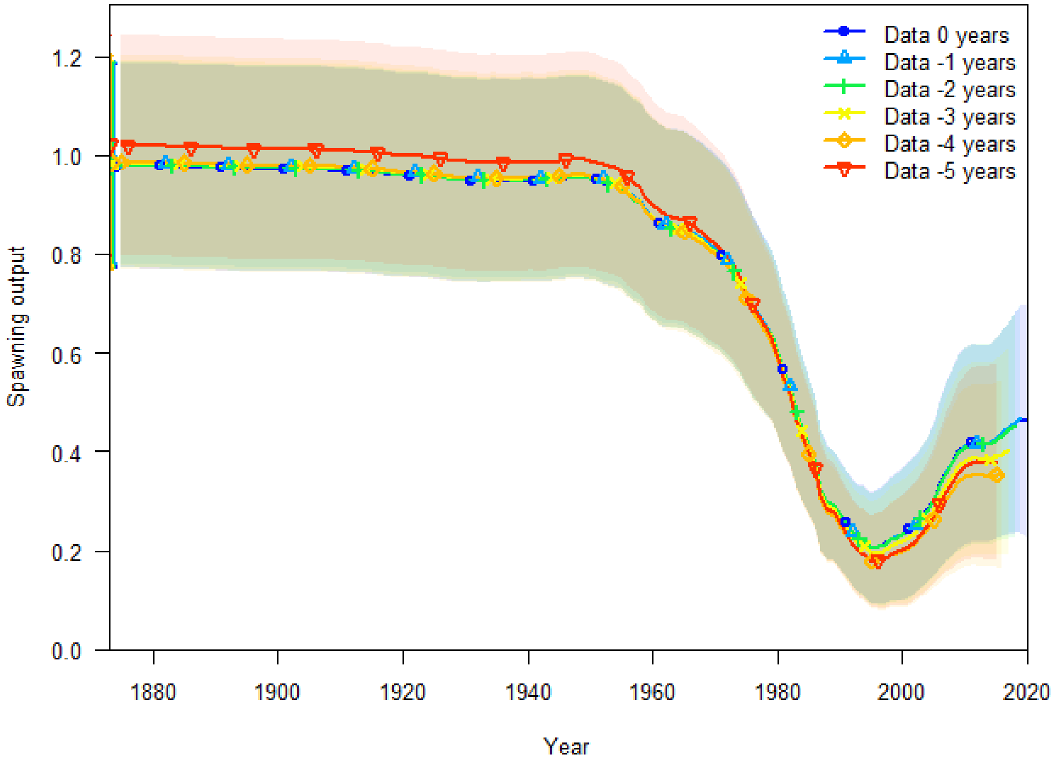

Figure 132: Change in the spawning output when the most recent 5 years of data area removed sequentially.

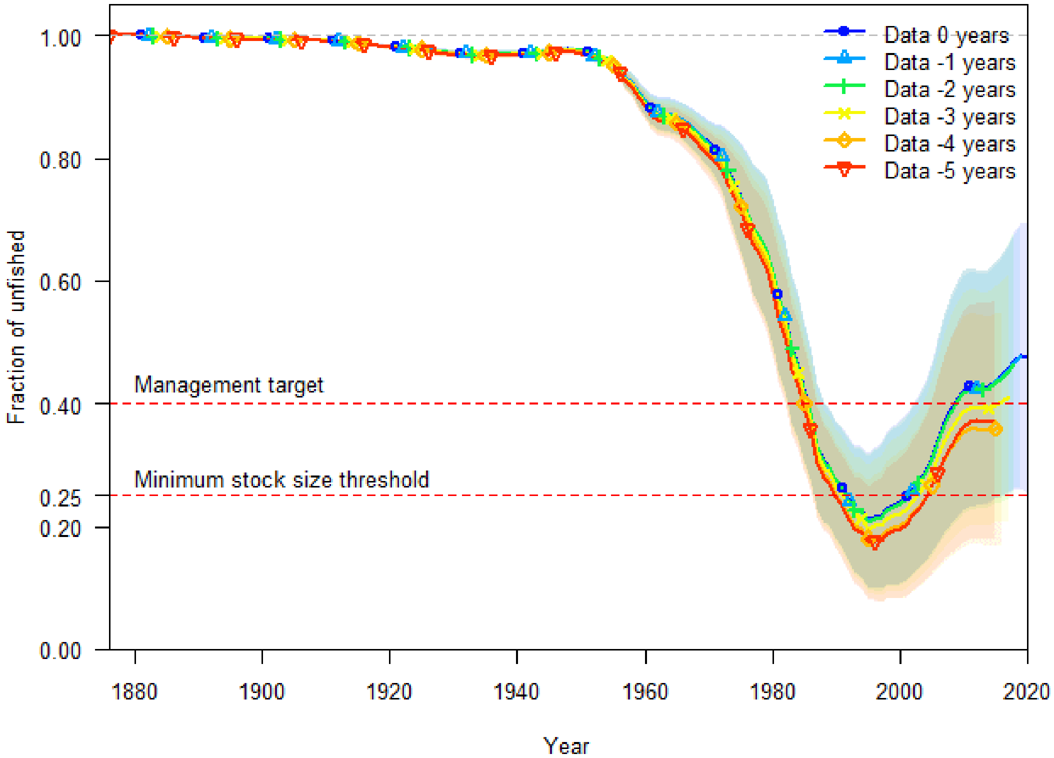

Figure 133: Change in the fraction of unfished biomass when the most recent 5 years of data area removed sequentially.

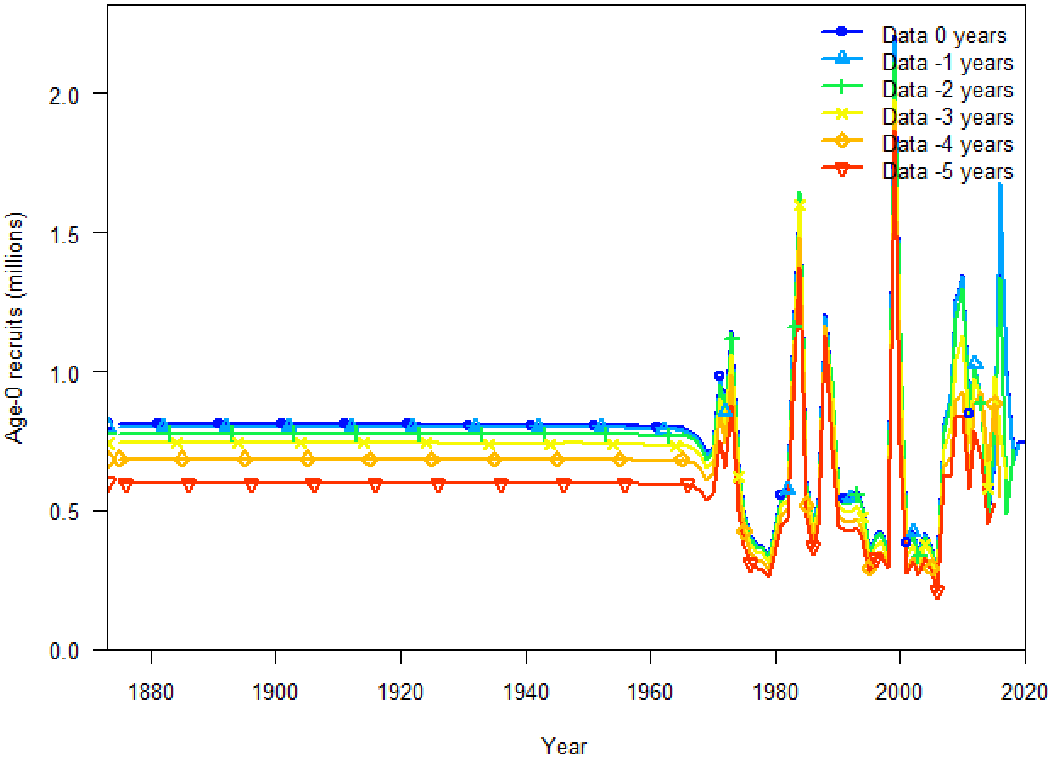

Figure 134: Trajectories of age-0 recruits when the most recent 5 years of data area removed sequentially.

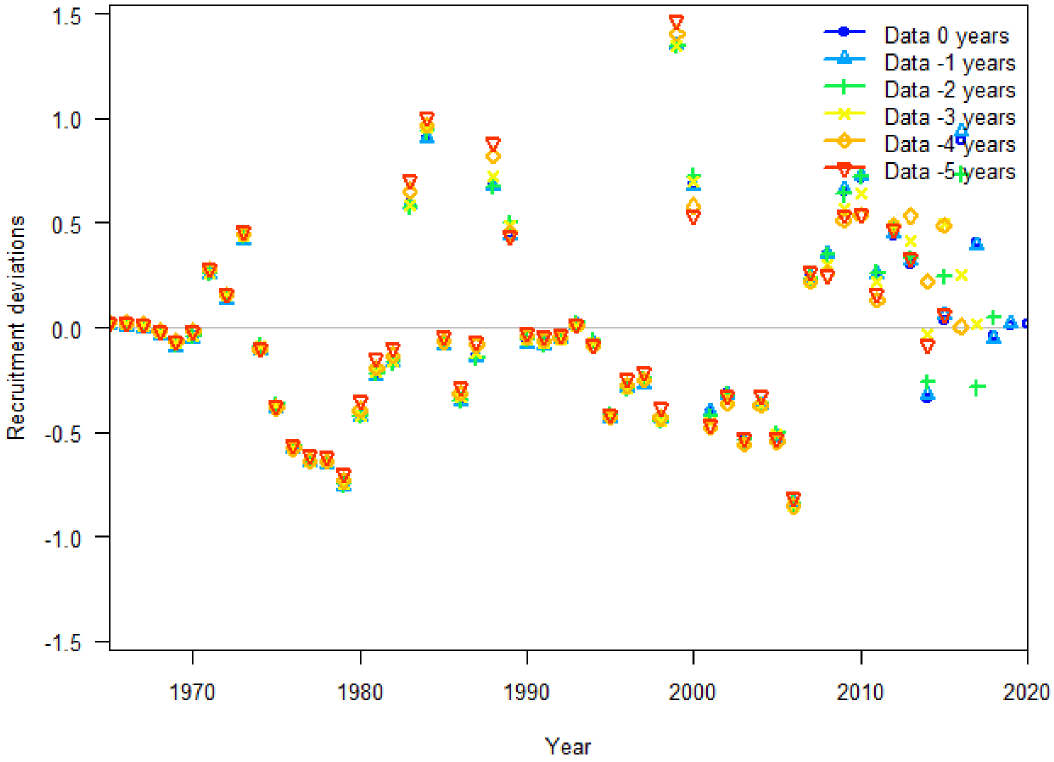

Figure 135: Change in the recruitment deviations when the most recent 5 years of data area removed sequentially.

Appendix A. Detailed Fit to Length Composition Data

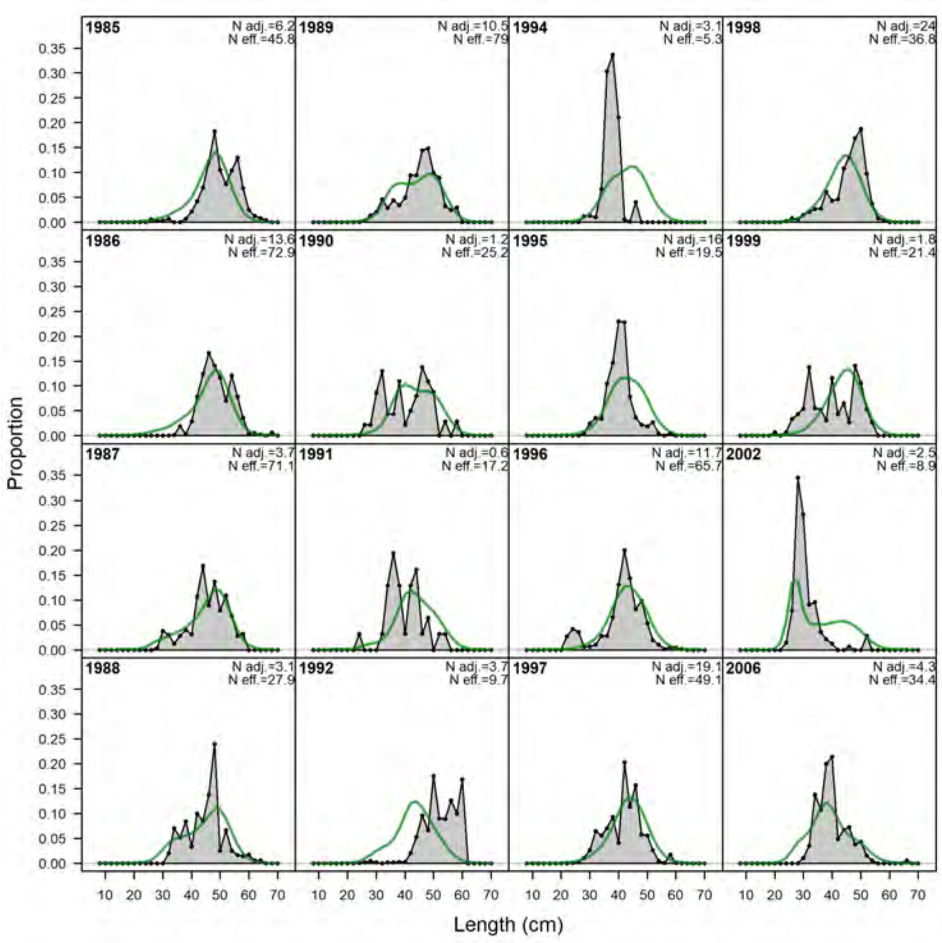

Figure A1: Length comps, whole catch, COM_HKL (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

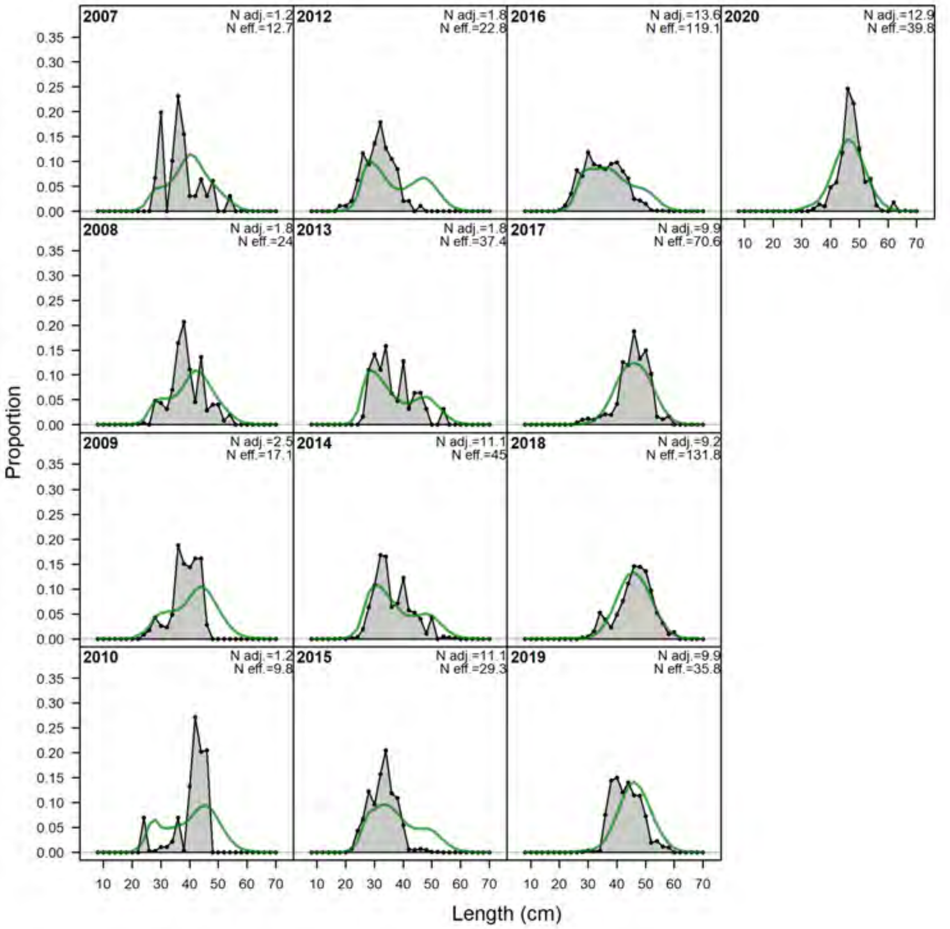

Figure A2: Length comps, whole catch, COM_HKL (plot 2 of 2).

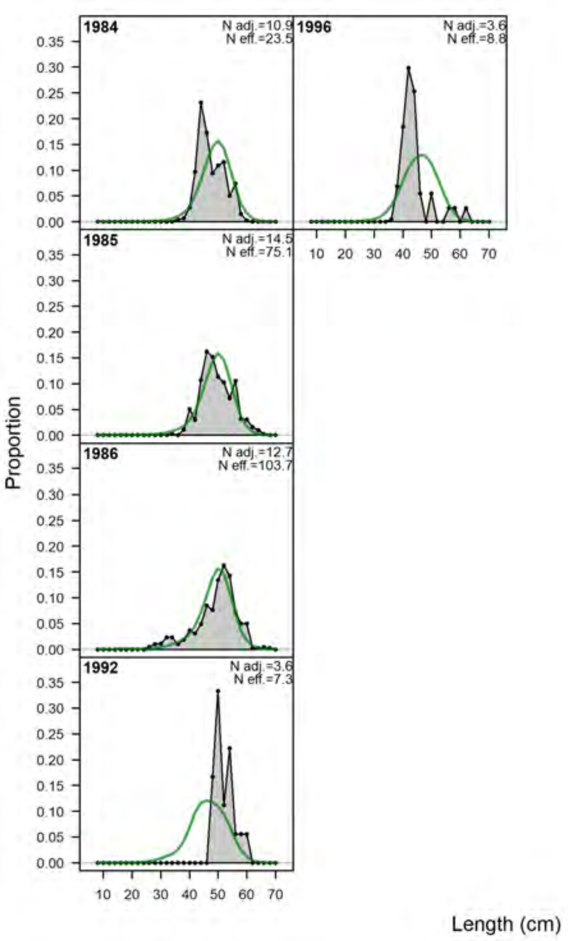

Figure A3: Length comps, whole catch, COM_NET.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

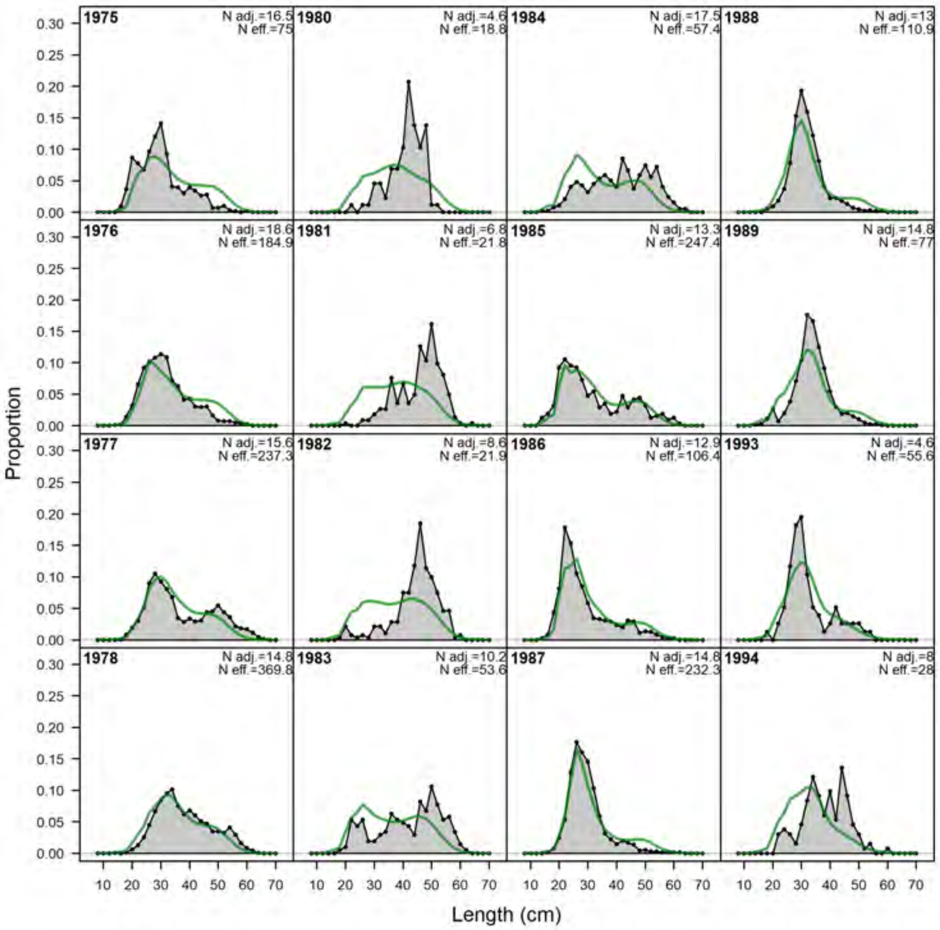

Figure A4: Length comps, whole catch, REC_PC (plot 1 of 3).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

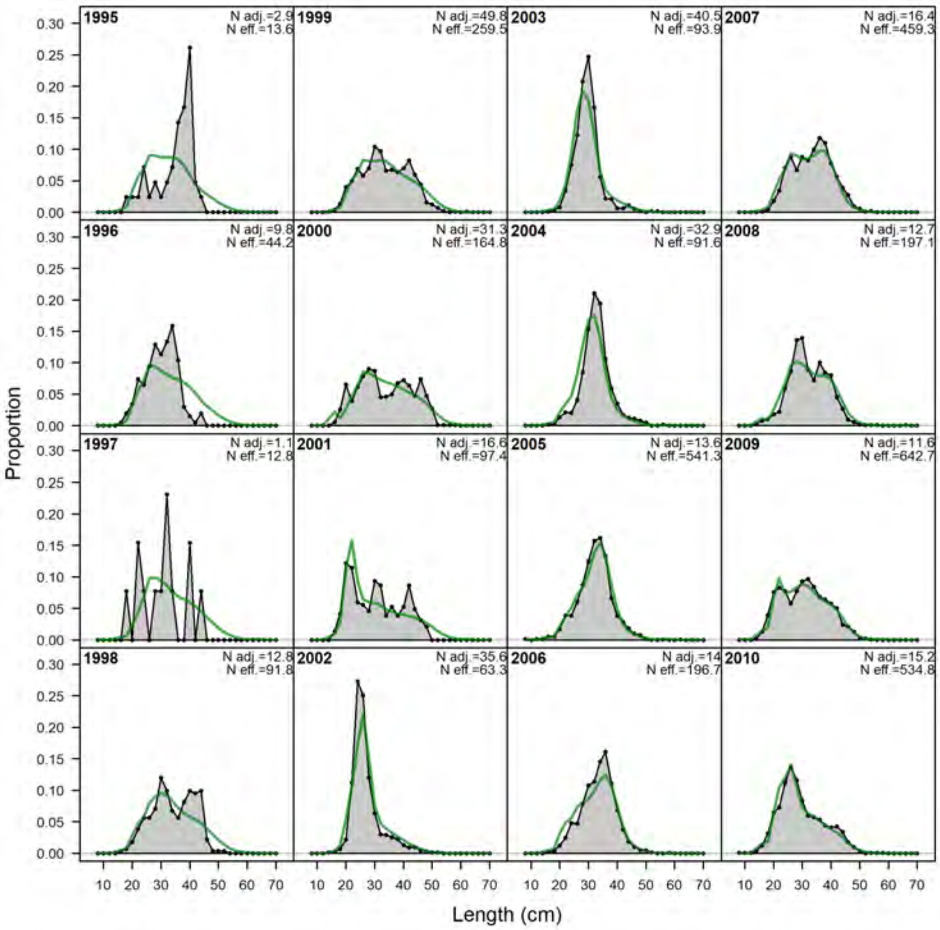

Figure A5: Length comps, whole catch, REC_PC (plot 2 of 3).

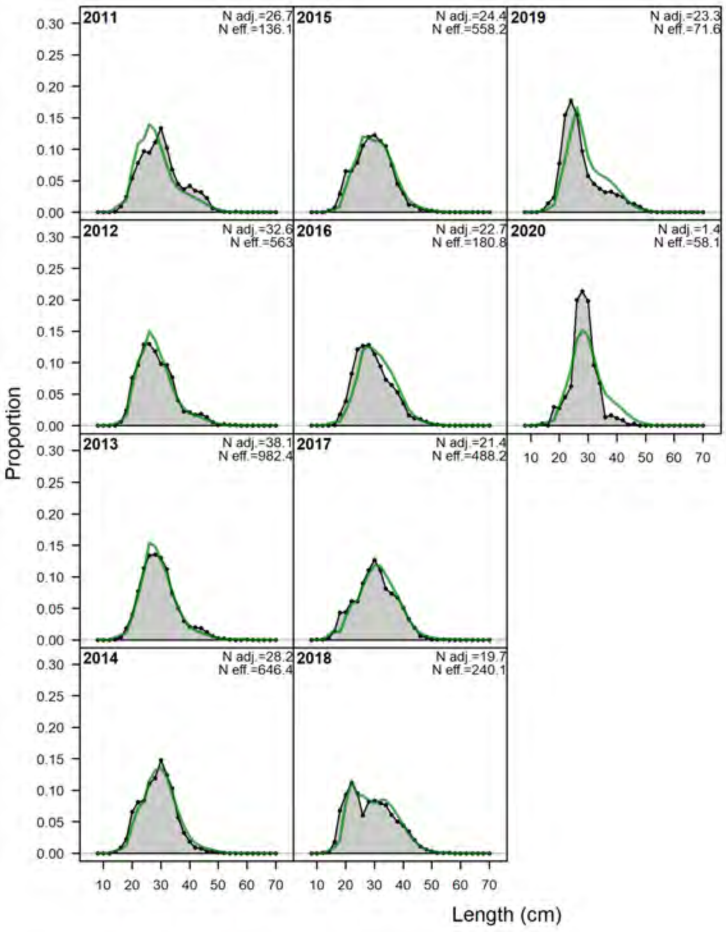

Figure A6: Length comps, whole catch, REC_PC (plot 3 of 3).

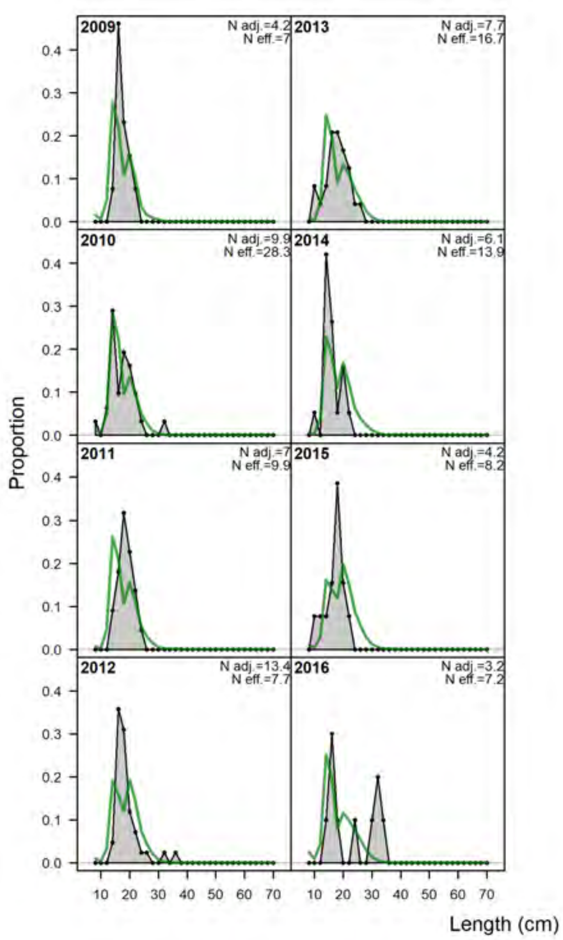

Figure A7: Length comps, whole catch, REC_PC_DIS.‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

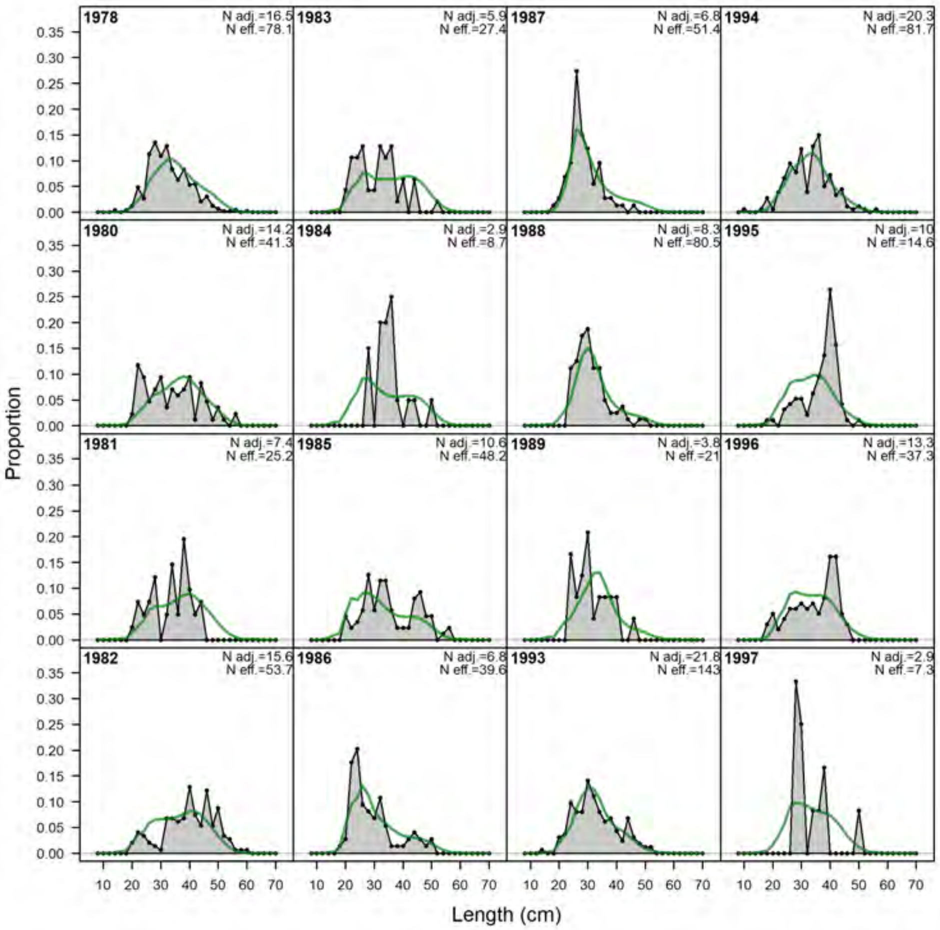

Figure A8: Length comps, whole catch, REC_PR (plot 1 of 3).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

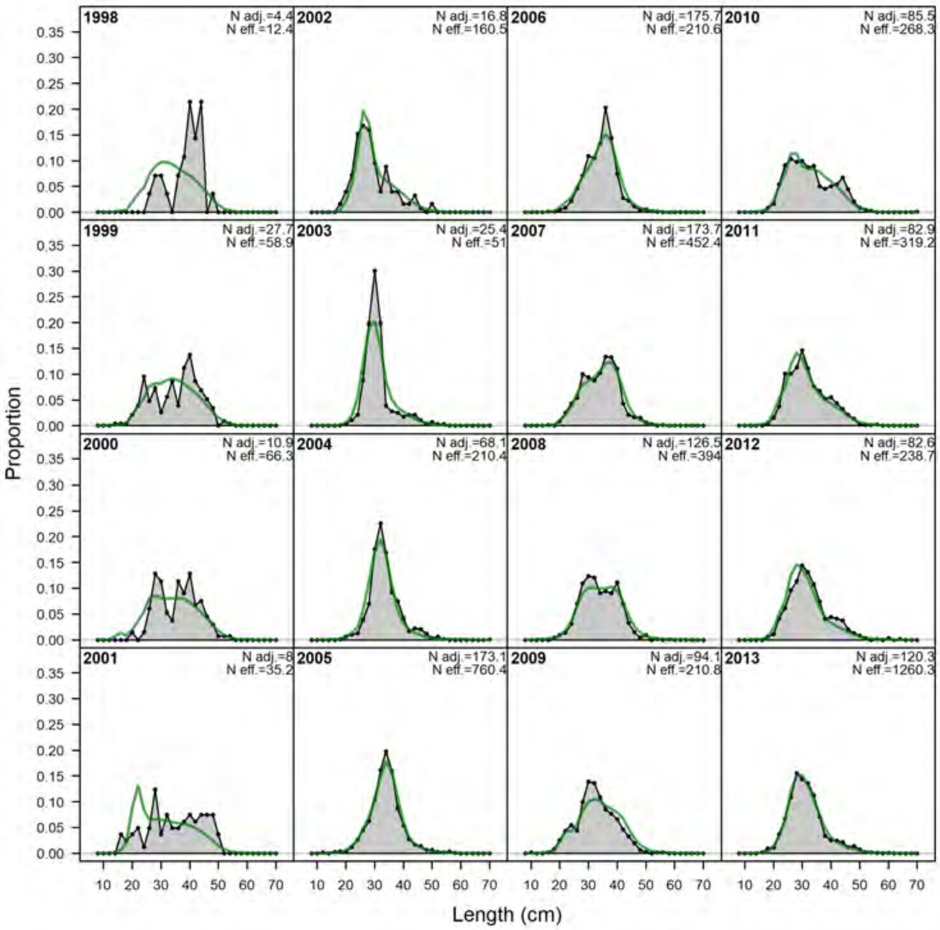

Figure A9: Length comps, whole catch, REC_PR (plot 2 of 3).

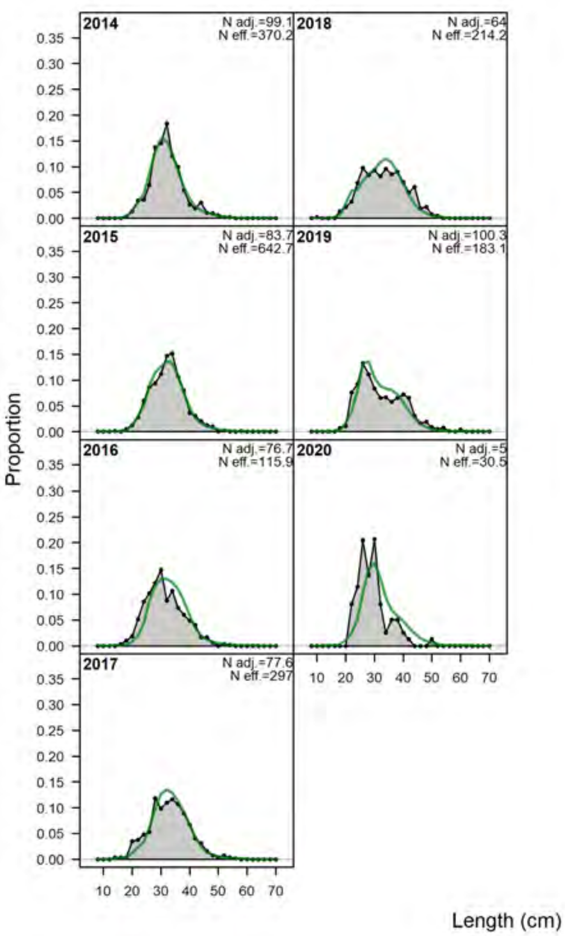

Figure A10: Length comps, whole catch, REC_PR (plot 3 of 3).

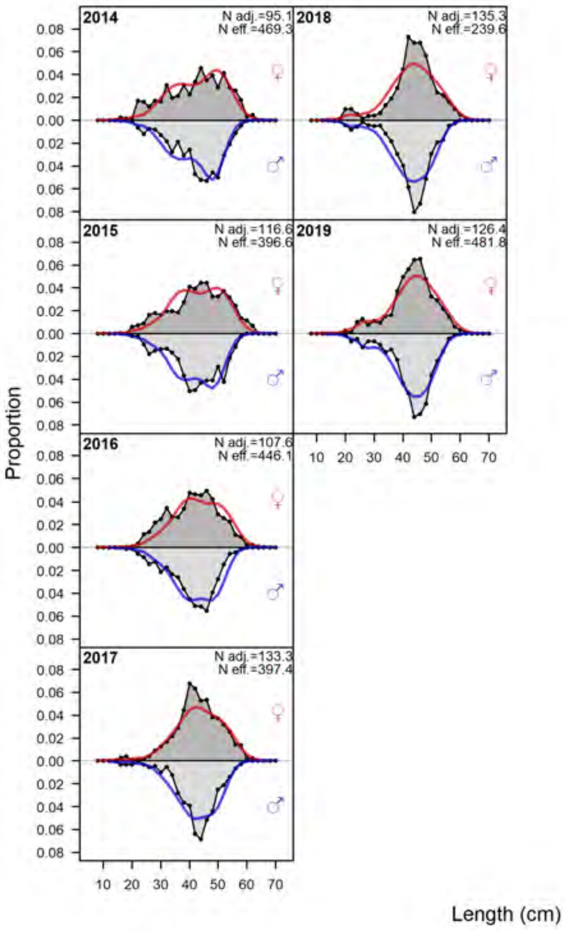

Figure A11: Length comps, whole catch, NWFSC_HKL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

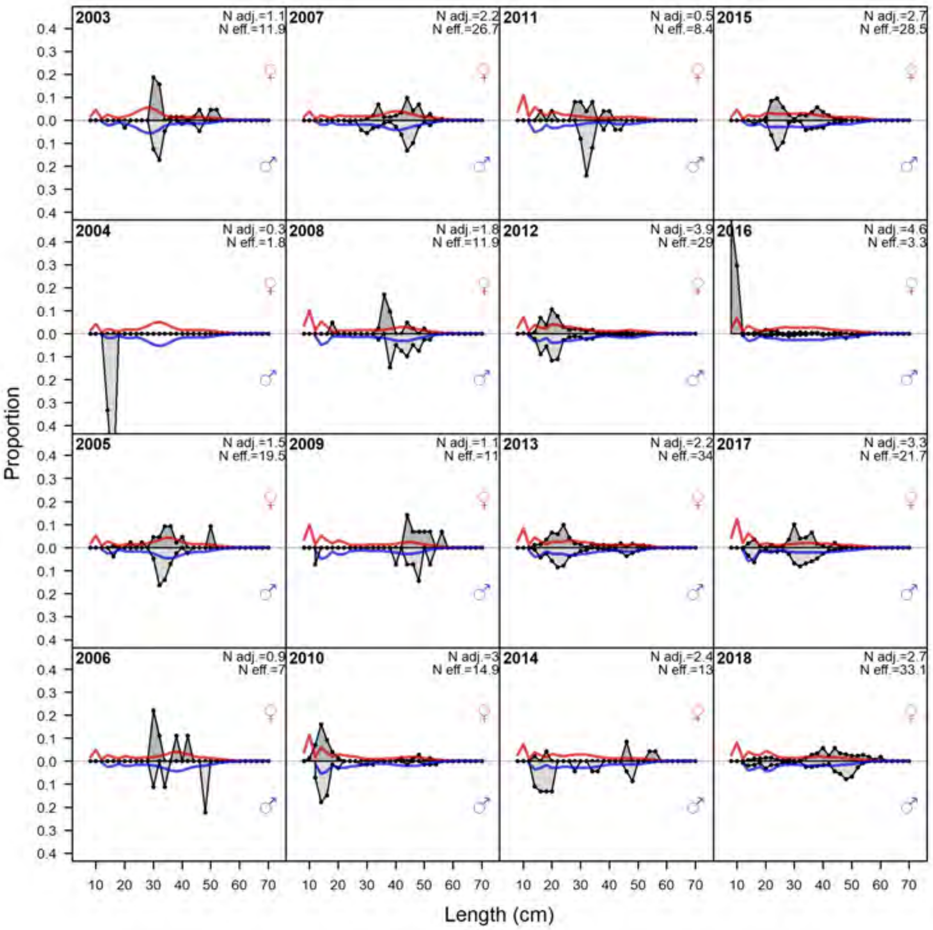

Figure A12: Length comps, whole catch, NWFSC_TWL (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

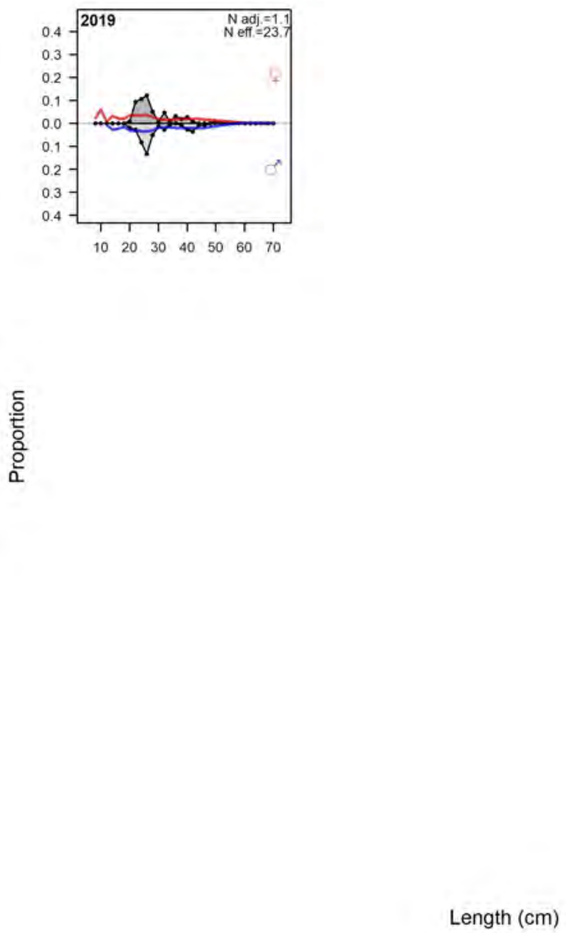

Figure A13: Length comps, whole catch, NWFSC_TWL (plot 2 of 2).

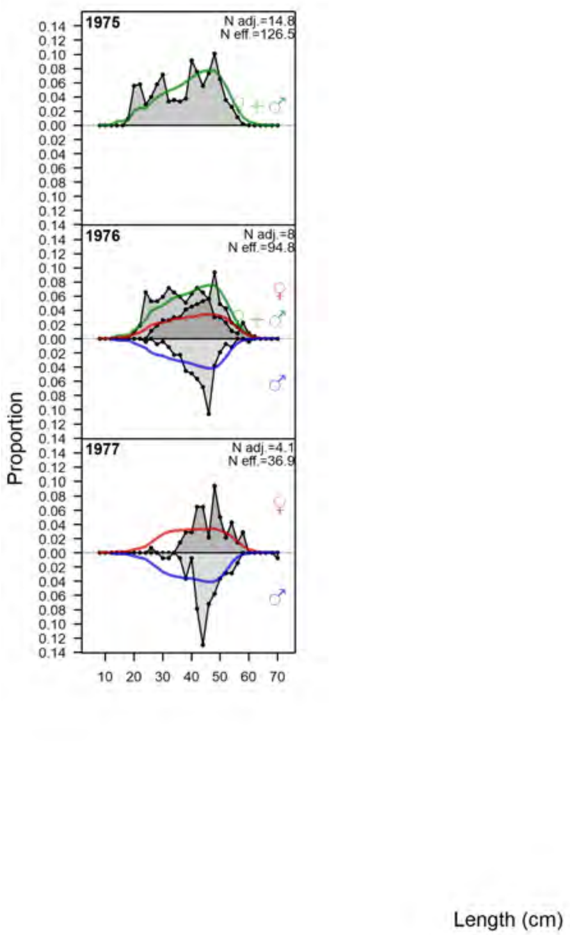

Figure A14: Length comps, whole catch, CDFW_RESEARCH.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

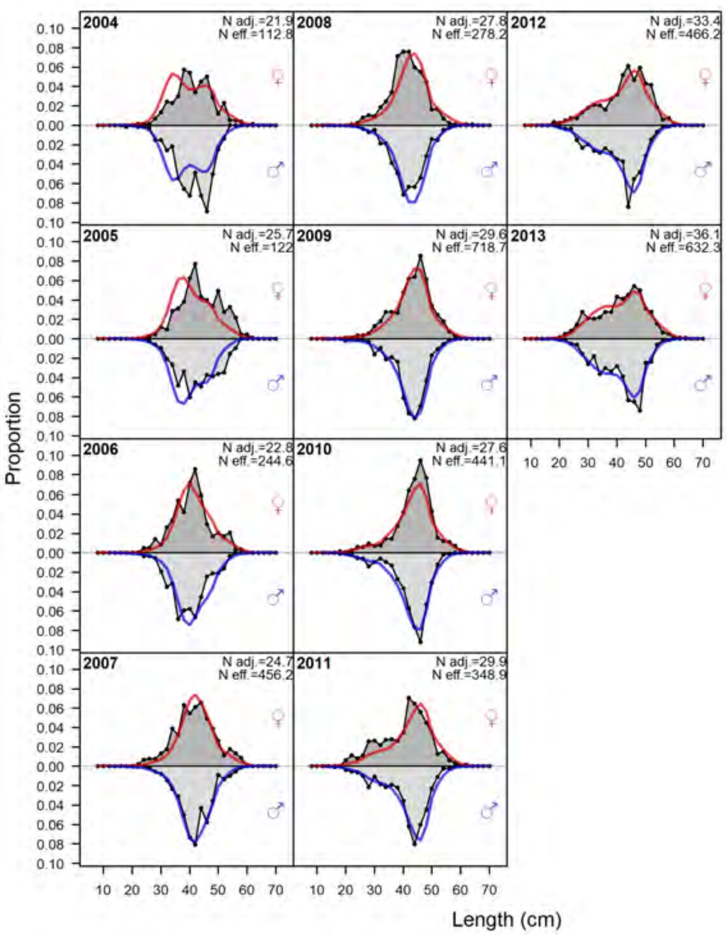

Figure A15: Length comps, whole catch, EARLY_HKL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

Appendix B. MRFSS Dockside Index of Abundance

MRFSS Dockside CPFV Index, 1980-1999

From 1980 to 2003 the MRFSS program conducted dockside intercept surveys of the recreational CPFV fishing fleet. No MRFSS CPUE data are available for the years 1990-1992, due to a hiatus in sampling related to funding issues. Sampling of California CPFVs north of Point Conception was further delayed, and CPFV samples in 1993 and 1994 are limited to San Luis Obispo County. For purposes of this assessment, the MRFSS time series was truncated at 1999 due to sampling overlap with the onboard observer program (i.e., the same observer samples the catch while onboard the vessel and also conducts the dockside intercept survey for the same vessel).

Each entry in the RecFIN Type 3 database corresponds to a single fish examined by a sampler at a particular survey site. Since only a subset of the catch may be sampled, each record also identifies the total number of that species possessed by the group of anglers being interviewed. The number of anglers and the hours fished are also recorded. The data, as they exist in RecFIN, do not indicate which records belong to the same boat trip. A description of the algorithms and process used to aggregate the RecFIN records to the trip level is outlined in the Supplemental Materials ("Identifying Trips in RecFIN").

MRFSS CPUE Index: Data Preparation, Filtering, and Sample Sizes

Trips recorded with a primary area fished in Mexico or in bays, e.g., San Francisco Bay, were excluded before any filtering on species composition. For indices representing only north of Point Conception, the years 1993-1994 were excluded due to limited spatial coverage.

The Stephens-MacCall (2004) filtering approach was used to predict the probability of catching vermilion rockfish, based on the species composition of the sampler examined catch in a given trip. Prior to applying the Stephens-MacCall filter, we identified potentially informative predictor species, i.e., species with sufficient sample sizes and temporal coverage (present in at least 5% of all trips) to inform the binomial model. The remaining 24 species all co-occurred with vermilion rockfish in at least one trip and were retained for the Stephens-MacCall logistic regression. Coefficients from the Stephens-MacCall analysis (a binomial GLM) are positive for species that are more likely to co-occur with vermilion rockfish, and negative for species that are less likely to be caught with vermilion rockfish (Figure B1). The top five species with high probability of co-occurrence with vermilion rockfish include copper, greenspotted, bocaccio, and olive rockfishes and ocean whitefish, all of which are associated with rocky reef and kelp habitats. The five species with the lowest probability of co-occurrence were kelp bass, Pacific bonito, white croaker, California sheephead, and barred sandbass.

While the filter is useful in identifying co-occurring or non-occurring species assuming all effort was exerted in pursuit of a single target, the targeting of more than one species or species complex ("mixed trips") can result in co-occurrence of species in the catch that do not truly co-occur in terms of habitat associations informative for an index of abundance. Stephens and MacCall (2004) recommended including all trips above a threshold where the false negatives and false positives are equally balanced. However, this does not have any biological relevance and for this data set, and we assume that if a vermilion rockfish was landed, the anglers fished in appropriate habitat, especially given vermilion rockfish is strongly associated with rocky habitat.

Stephens and MacCall (2004) proposed filtering (excluding) trips from the index standardization based on a criterion of balancing the number of false positives and false negatives. False positives (FP) are trips that are predicted to catch a vermilion rockfish based on the species composition of the catch, but did not. False negatives (FN) are trips that were not predicted to catch a vermilion rockfish, given the catch composition, but caught at least one. The Stephens-MacCall filtering method identified the probability of occurrence at which the rate of "false positives" equals "false negatives" of 0.31. The trips selected using this criteria were compared to an alternative method including all the "false positive" trips, regardless of the probability of encountering vermilion rockfish. This assumes that if vermilion rockfish were caught, the anglers must have fished in appropriate habitat during the trip. The catch included in this index is "sampler-examined" and the samplers are well trained in species identification.

The threshold probability that balances FP and FN excludes 5383 trips that did not catch a vermilion rockfish (84% of the trips), and 308 trips (5% of the data) that caught a vermilion rockfish. We retained the latter set of trips (FN), assuming that catching a vermilion rockfish indicates that a non-negligible fraction of the fishing effort occurred in habitat where vermilion rockfish occur. Only "true negatives" (the 5383 trips that neither caught vermilion rockfish, nor were predicted to catch them by the model) were excluded from the index standardization. The final dataset selected included 1043 trips, 70% of which encountered vermilion rockfish. Sample sizes by the factors selected to model are in Tables B1 and B2.

MRFSS CPUE Index: Model Selection, Fits, and Diagnostics

Initial exploration of negative binomial models for this dataset proved to be ill-fitting. The proportion of zeroes predicted by the Bayesian negative binomial models were different enough from the fraction of zeroes in the raw data, that a negative binomial model was not considered for model selection. We modeled catch per angler hour (CPUE; number of fish per angler hour) with a Bayesian delta-GLM model. Models incorporating temporal (year, 2-month waves) and geographic (region and primary area fished (inshore <3 nm, offshore >3 nm) factors were evaluated. For assessments north of Point Conception, two regions were defined based on counties, 1) Del Norte to Santa Cruz ("N") and 2) Monterey to San Luis Obispo ("C"). For assessment models south of Point Conception, the region represents individual counties. Note that Santa Barbara county spans north and south of Point Conception, but all accessible fishing ports in Santa Barbara county are south of Point Conception and vessels rarely (if ever) transit Point Conception. Indices with a year and area interaction were not considered in model selection; trends in the average CPUE by region were similar in the filtered data set (Figure B2).

The positive observations were modeled with a Lognormal distribution that was selected over a Gamma model by a ΔAIC of 51.8, and supported by Q-Q plots of the positive observations fit to both distributions (Figure B3). The delta-GLM method allows selection of differing linear predictors between the binomial and positive models. Based on AIC values from maximum likelihood fits, a main effects model including NA was fit for the binomial model and a main effects model including YEAR and CNTY and WAVE and AREA X was fit for the Lognormal model (Table B3). Models were fit using the “rstanarm” R package (version 2.21.1). Posterior predictive checks of the Bayesian model fit for the binomial model and the positive model were all reasonable (Figures B4 and B5). The binomial model generated data sets with the proportion zeros similar to the 30% zeroes in the observed data (Figure B6) and the predicted marginal effects from both the binomial and Lognormal models can be found in (Figures B7 and B8). The final index (Table B4) represents a similar trend to the arithmetic mean of the annual CPUE (Figure B9).

Table B1: Samples of vermilion rockfish in the southern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
37	163	242	67%
59	80	108	74%
73	131	209	63%
83	139	164	85%
111	217	320	68%

Table B2: Samples of vermilion rockfish in the southern model by year.

Year	Positive Samples	Samples	Percent Positive
1980	40	94	43%
1981	40	67	60%
1982	58	87	67%
1983	55	97	57%
1984	95	121	79%
1985	77	123	63%
1986	88	115	77%
1987	16	17	94%
1988	33	36	92%
1989	16	17	94%
1993	25	32	78%
1994	33	38	87%
1995	9	13	69%
1996	30	41	73%
1997	7	10	70%
1998	34	45	76%
1999	74	90	82%

Table B3: Model selection for the MRFSS dockside survey index for vermilion rockfish in the southern model.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	111.56	146.83
YEAR + CNTY	2.90	4.35
YEAR + CNTY + WAVE	6.40	0.00
YEAR + CNTY + WAVE + AREA X	2.82	1.85
YEAR + WAVE + AREA X	57.46	75.30
YEAR + AREA X	55.11	76.60
YEAR + CNTY + AREA X	0.00	6.19

Table B4: Standardized index for the MRFSS dockside survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the southern model.

Year	Index	logSE	lower HPD	upper HPD
1980	0.03	0.30	0.02	0.05
1981	0.08	0.25	0.04	0.12
1982	0.06	0.25	0.03	0.09
1983	0.09	0.22	0.05	0.13
1984	0.12	0.17	0.08	0.16
1985	0.10	0.20	0.06	0.14
1986	0.18	0.18	0.13	0.26
1987	0.10	0.30	0.05	0.17
1988	0.16	0.22	0.10	0.25
1989	0.08	0.31	0.04	0.14
1993	0.06	0.28	0.03	0.10
1994	0.11	0.22	0.07	0.16
1995	0.04	0.42	0.02	0.09
1996	0.07	0.25	0.04	0.10
1997	0.04	0.46	0.02	0.09
1998	0.05	0.25	0.03	0.08
1999	0.15	0.17	0.10	0.21

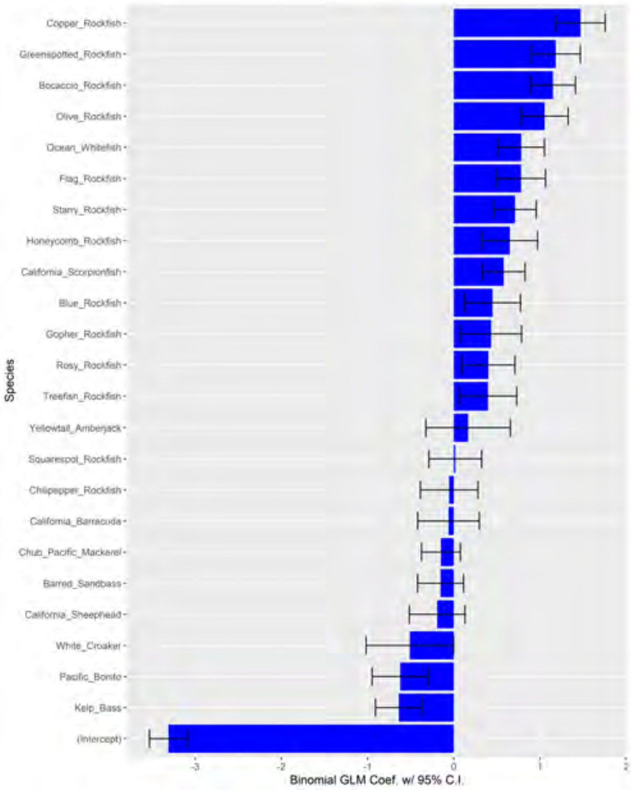

Figure B1: Species coefficients (blue bars) from the binomial GLM for presence/absence of vermilion rockfish in the CRFS private boat data. Horizontal black bars are 95% confidence intervals.

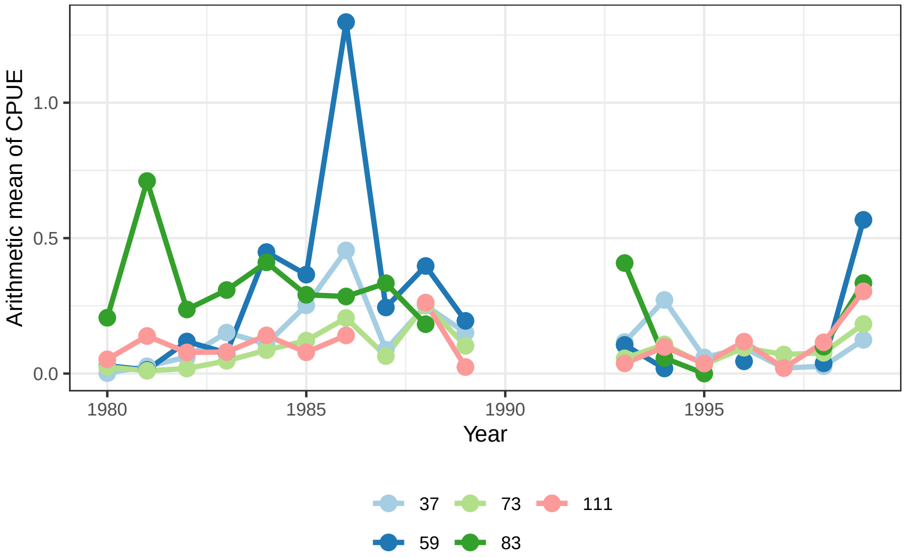

Figure B2: Arithmetic mean of CPUE by region for vermilion from the filtered data.

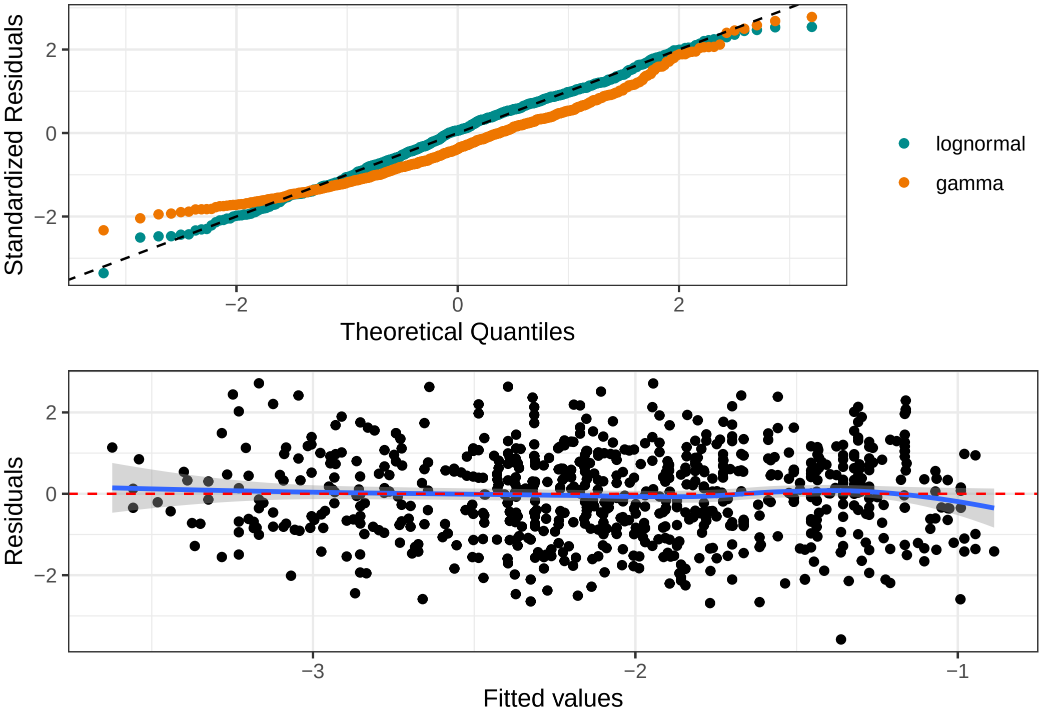

Figure B3: Q-Q plot (top) of the positive observations fit to lognormal and gamma distributions, and fitted values vs residuals for the Lognormal model (bottom).

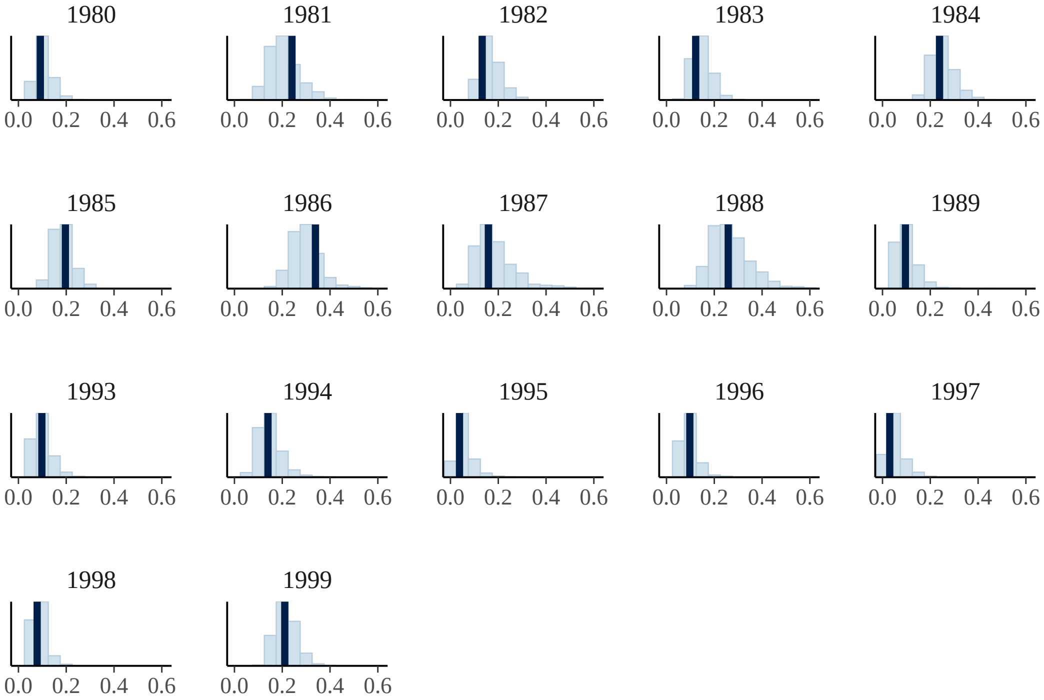

Figure B4: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

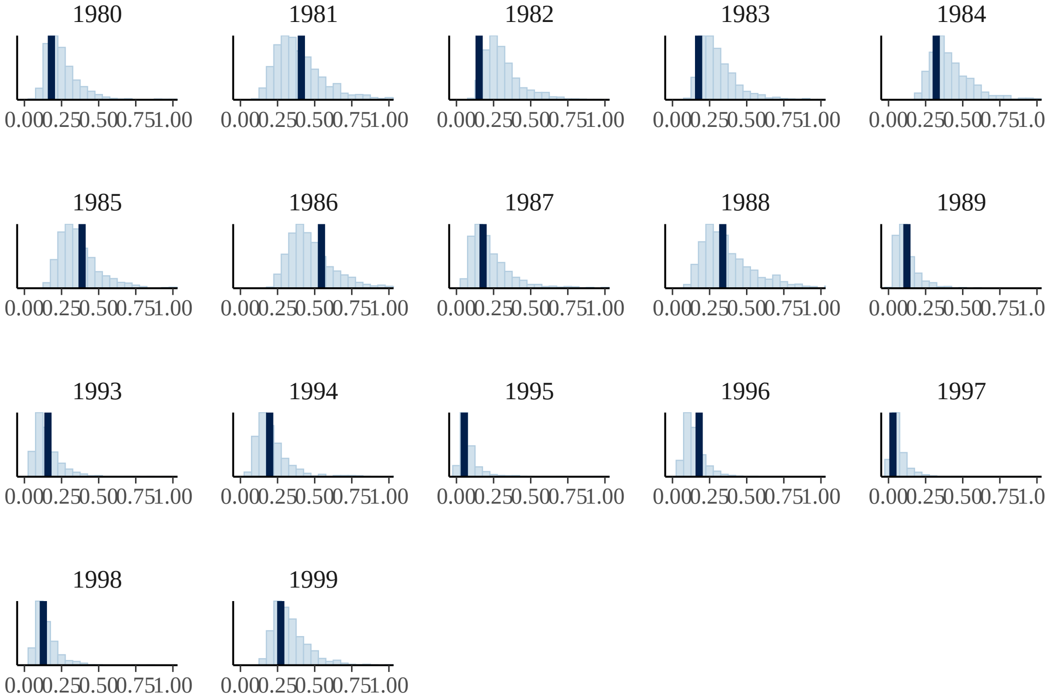

Figure B5: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

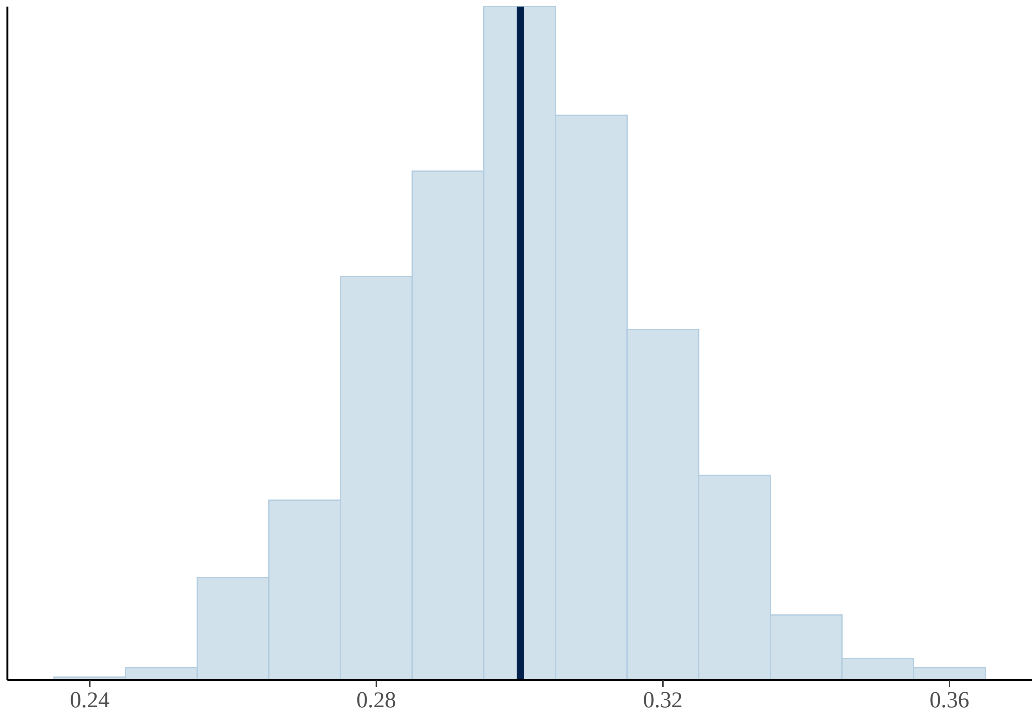

Figure B6: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

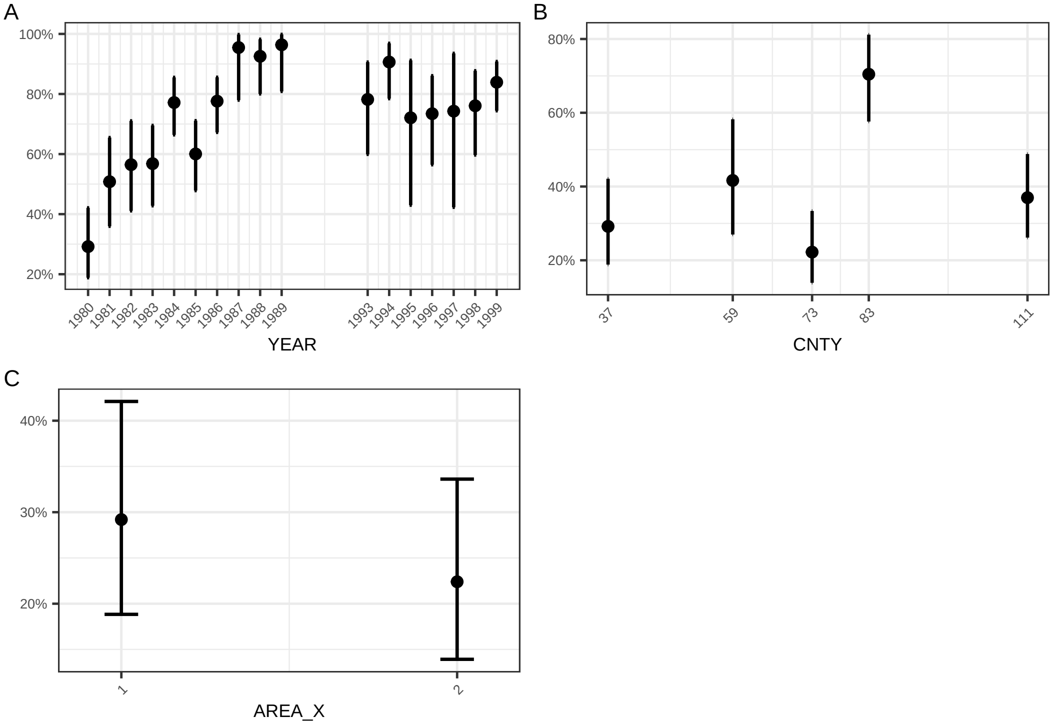

Figure B7: Binomial model marginal effects.

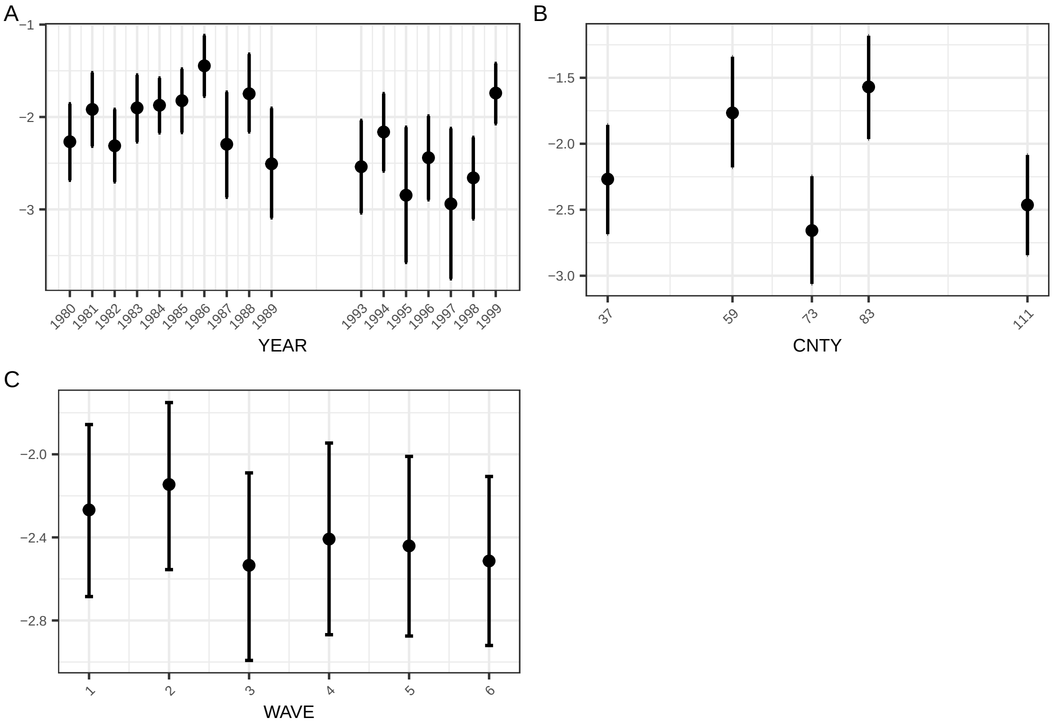

Figure B8: Positive model marginal effects.

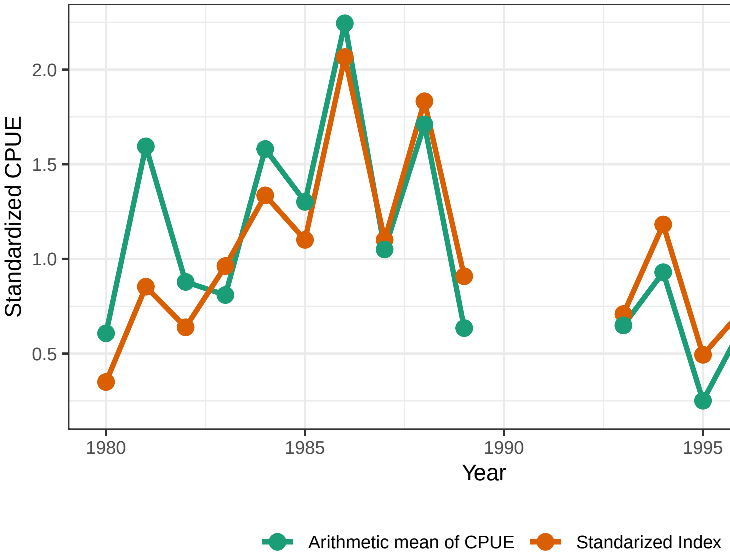

Figure B9: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

Appendix C. California Onboard CPFV Index of Abundance

California Onboard Observer Survey, 1999-2019

The state of California implemented a statewide onboard observer sampling program in 1999 (Monk et al. 2014). California Polytechnic State University (Cal Poly) has conducted an independent onboard sampling program as of 2003 for boats in Port San Luis and Morro Bay, and follows the protocols established in Reilly et al. (1998).

During an onboard observer trip the sampler rides along on the CPFV and records location-specific catch and discard information to the species level for a subset of anglers onboard the vessel. The subset of observed anglers is usually a maximum of 15 people the observed anglers change during each fishing stop.
The catch cannot be linked to an individual, but rather to a specific fishing location. The sampler also records the starting and ending time, number of anglers observed, starting and ending depth, and measures discarded fish. The fine-scale catch and effort data allow us to better filter the data for indices to fishing stops within suitable habitat for vermilion rockfish . Cal Poly has modified protocols reflect sampling changes that CDFW has also adopted, e.g., observing fish as they are encountered instead of at the level of a fisher's bag. Therefore, the Cal Poly data area incorporated in the same index as the CDFW data from 1999-2019. The only difference is that Cal Poly measures the length of both retained and discarded fish.

Due to the COVID-19 pandemic, there are no onboard observer samples from either CDFW or Cal Poly in 2020.

California CPFV CPUE Index: Data Preparation, Filtering, and Sample Sizes

As described above the CDFW and Cal Poly onboard observer programs are identical in that the same protocols are followed. The only difference is that Cal Poly measures both retained and discarded fish from the observed anglers and CDFW measures only discarded fish from the observed anglers. CDFW measures retained fish as part of the angler interview at the bag and trip level. This index selectivity is mirrored to the recreational fleet in the stock assessment model, which represent only retained (dead) fish. Therefore, only retained fish were modeled in this index. The length from CDFW sampling are contained in the RecFIN database and included in the length composition for the recreational fleet in the assessment model.

A number of filters are applied to these data. All of the Cal Poly data were QA/QC-ed once key-punched, whereas a number of errors remain in the data from CDFW. Data sheets from CDFW are not available prior to 2012 and staff constraints have also prevented a quality control review of the data.

Each drift was assigned to a reef (hard bottom). Hard bottom was extracted from the California Seafloor Mapping Project, with bathymetric data from state waters available at a 2 m resolution. Reefs were developed based on a number of factors described in the supplemental material ("Reef Delineation"). Depth restrictions in the recreational fishery were fairly consistent from 2004-2016. Starting in 2017, depth restrictions eased in districts north of Point Conception and the recreational fleet targeted these depths (Figure C1). The deeper waters (40-50 fm) are outside of the mapped hard bottom habitat, but could be assigend to the larger areas considered as a factor in the index.

We retained 14218 drifts for index standardization, with 5960 drifts encountering vermilion rockfish (Table C1).

Sample sizes by factors selected to model, excluding WAVE can be found in Tables C3, C2, and C4.

California CPFV CPUE Index: Model Selection, Fits, and Diagnostics

We modeled retained catch per angler hour (CPUE; number of fish per angler hour) a Bayesian delta-GLM model. Indices with a year and area interaction were not considered in model selection; trends in the average CPUE by region were similar in the filtered data set (Figure C2).

A Lognormal model was selected over a over a Gamma model for the positive observations by a ΔAIC of 919.67, and supported by Q-Q plots of the positive observations fit to both distributions (Figure C3). The delta-GLM method allows the linear predictors to differ between the binomial and positive models. Based on AIC values from maximum likelihood fits (Table C5), a main effects model including YEAR and WAVE and DEPTH bin was fit for the binomial model and a main effects model including YEAR and WAVE and DEPTH bin was fit for the Lognormal model. Models were fit using the "rstanarm" R package (version 2.21.1). Posterior predictive checks of the Bayesian model fit for the binomial model and the positive model were all reasonable (Figures C4 and C5). The binomial model generated data sets with the proportion zeros similar to the 58% zeroes in the observed data (Figure C6). The predicted marginal effects from both the binomial and Lognormal models can be found in Figures C8 and C9. The final index (Table C6) represents a similar trend to the arithmetic mean of the annual CPUE (Figure C7).

Table C1: Data filtering steps for theCA CPFV onboard survey index for vermilion rockfish in the southern model. The last row in the table represents the number of trips used to develop the index.

Filter	Desciption	Trip	Positive Trips	Percent drifts retained
All	Download from SQL; identifiable errors filtered	34151	6190	18%
Fishery closed	Removed samples when target fish fishery closed	29716	6187	21%
Ocean only	Removed samples from major bays	29661	6187	21%
Catch	Removed samples with zero catch of any species	27181	6187	23%
Depth	Removed samples in less than max depth of species	26489	6072	23%
Time fished	Removed upper two percent of time fished	25948	6015	23%
Percent groundfish in samples	Removed samples with fewer groundfish than when the target observed	14221	5960	42%

Table C2: Positive samples of vermilion rockfish in the southern model by depth (fm).

Year	Positive Samples	Samples	Percent Positive
(0,10]	51	665	8%
(10,20]	883	2460	36%
(20,30]	1568	3313	47%
(30,40]	1153	2556	45%
(40,50]	1816	4056	45%
(50,60]	489	1168	42%

Table C3: Samples of vermilion rockfish in the southern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
Los Angeles	1865	4319	43%
Orange	490	1238	40%
San Diego	1152	2408	48%
Santa Barbara	752	1581	48%
Ventura	1701	4672	36%

Table C4: Samples of vermilion rockfish in the southern model by year.

Year	Positive Samples	Samples	Percent Positive
1999	92	236	39%
2000	73	174	42%
2001	33	76	43%
2002	81	182	45%
2003	101	165	61%
2004	191	346	55%
2005	220	529	42%
2006	211	568	37%
2007	257	693	37%
2008	227	778	29%
2009	246	818	30%
2010	380	920	41%
2011	438	1046	42%
2012	512	1191	43%
2013	630	1410	45%
2014	396	1020	39%
2015	440	897	49%
2016	406	809	50%
2017	329	760	43%
2018	300	797	38%
2019	397	803	49%

Table C5: Model selection for the CA CPFV onboard survey index for vermilion rockfish in the southern model.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	725.28	568.97
YEAR + DISTRICT	494.00	124.13
YEAR + DISTRICT + WAVE	450.48	109.82
YEAR + DISTRICT + WAVE + DEPTH bin	0.00	0.00
YEAR + WAVE + DEPTH bin	41.38	132.83
YEAR + DEPTH bin	61.41	148.53
YEAR + DISTRICT + DEPTH bin	10.88	3.65

Table C6: Standardized index for the CA CPFV onboard survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the southern model.

Year	Index	logSE	lower HPD	upper HPD
1999	0.03	0.25	0.02	0.04
2000	0.04	0.26	0.02	0.07
2001	0.03	0.32	0.01	0.05
2002	0.04	0.25	0.02	0.06
2003	0.10	0.24	0.06	0.16
2004	0.08	0.22	0.05	0.12
2005	0.04	0.21	0.03	0.06
2006	0.03	0.21	0.02	0.04
2007	0.04	0.21	0.02	0.05
2008	0.02	0.22	0.01	0.03
2009	0.02	0.21	0.01	0.03
2010	0.03	0.20	0.02	0.05
2011	0.05	0.20	0.03	0.07
2012	0.05	0.20	0.03	0.07
2013	0.05	0.20	0.03	0.07
2014	0.04	0.20	0.03	0.06
2015	0.07	0.20	0.05	0.11
2016	0.07	0.20	0.05	0.11
2017	0.05	0.21	0.03	0.07
2018	0.04	0.21	0.03	0.06
2019	0.07	0.21	0.05	0.11

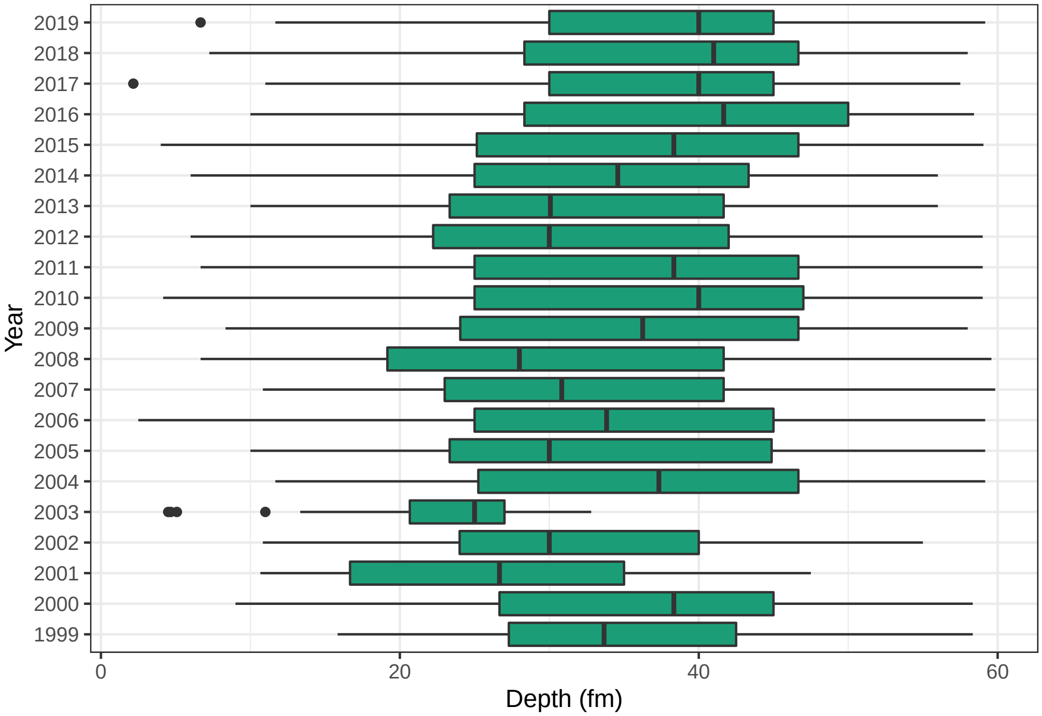

Figure C1: Boxplots of depths fished by year in the filtered data.

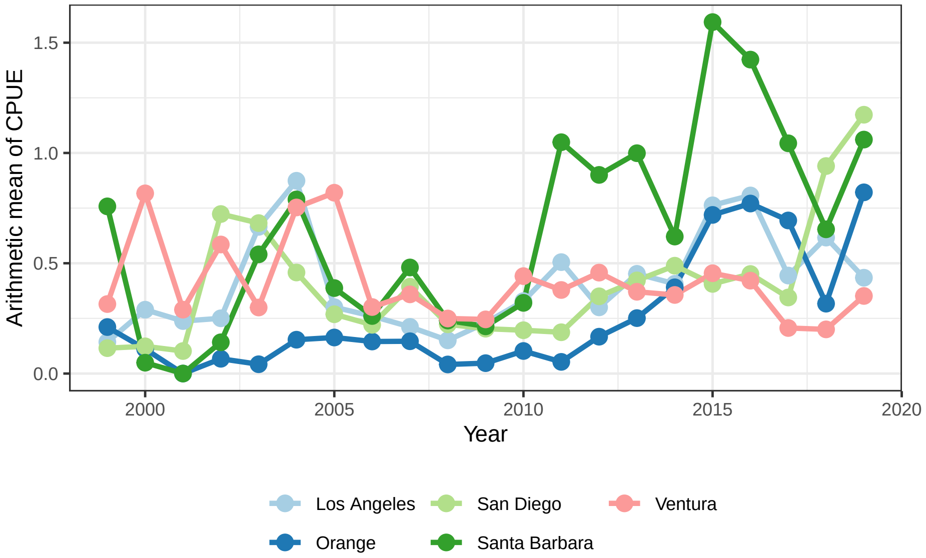

Figure C2: Arithmetic mean of CPUE by region for vermilion from the filtered data. The areas used are in the text.

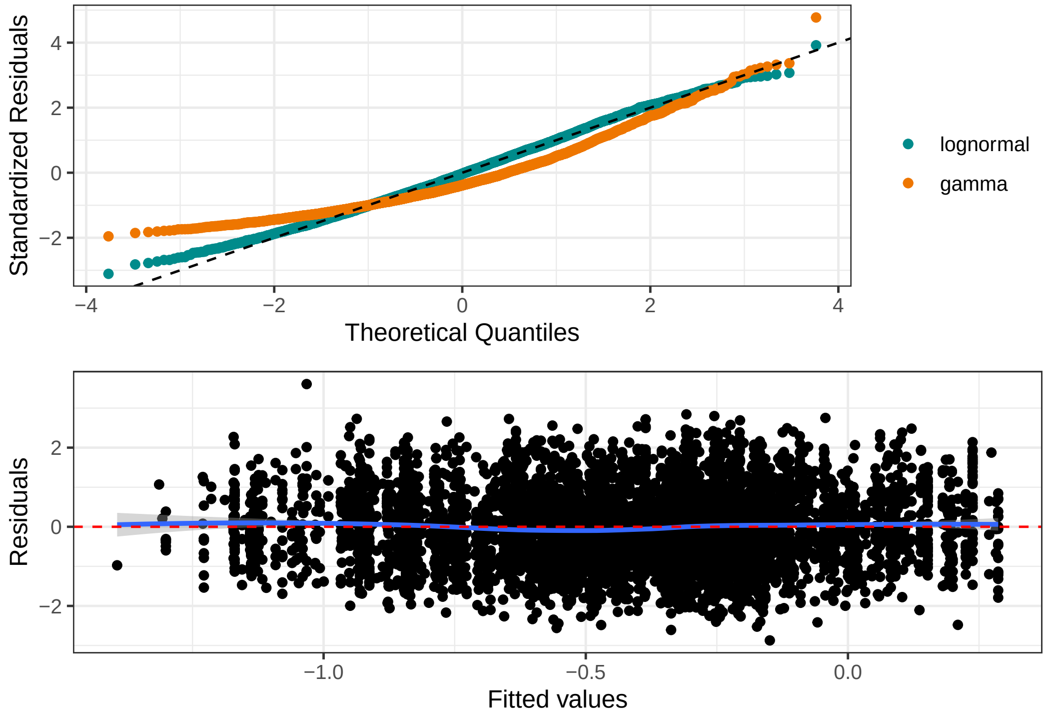

Figure C3: Q-Q plot (top) of the positive observations lognormal gamma distributions and fitted values vs residuals for the Lognormal model (bottom).

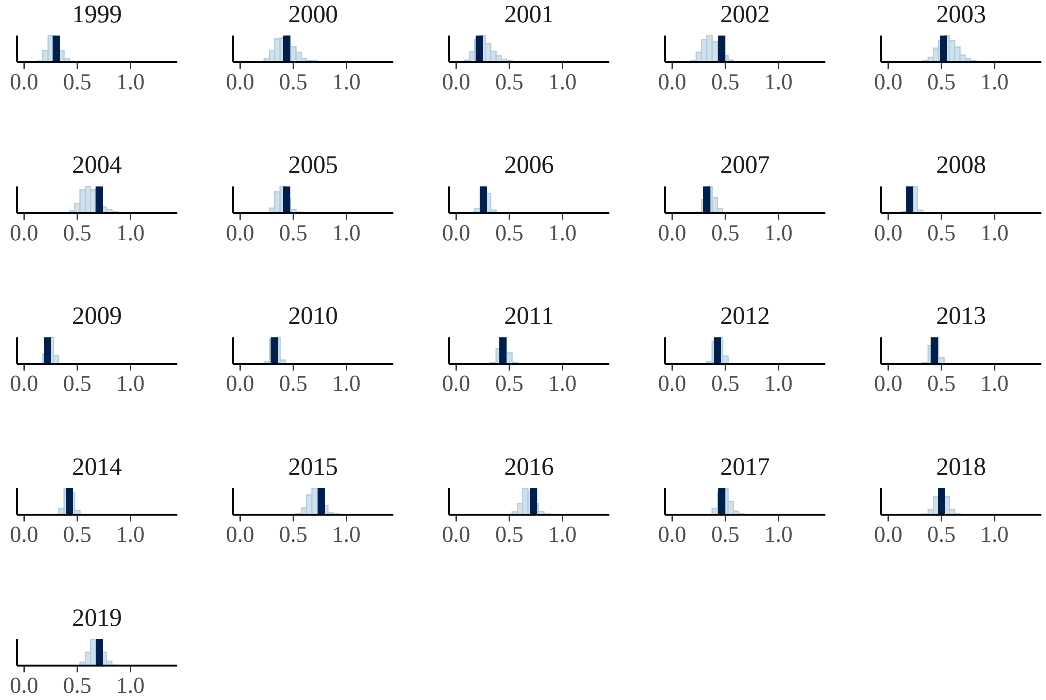

Figure C4: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

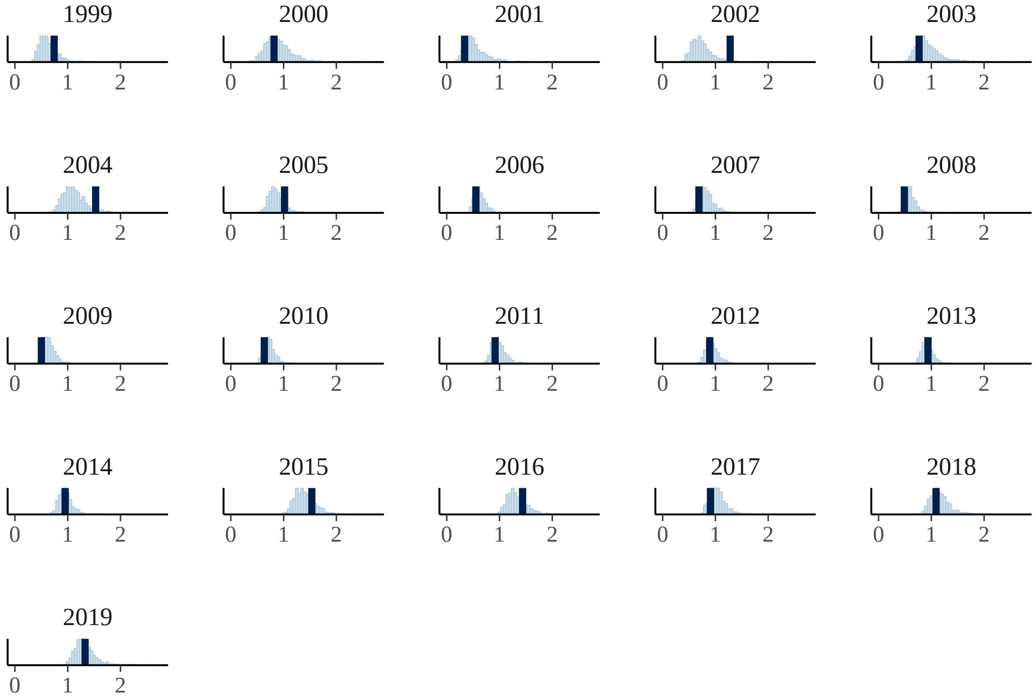

Figure C5: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

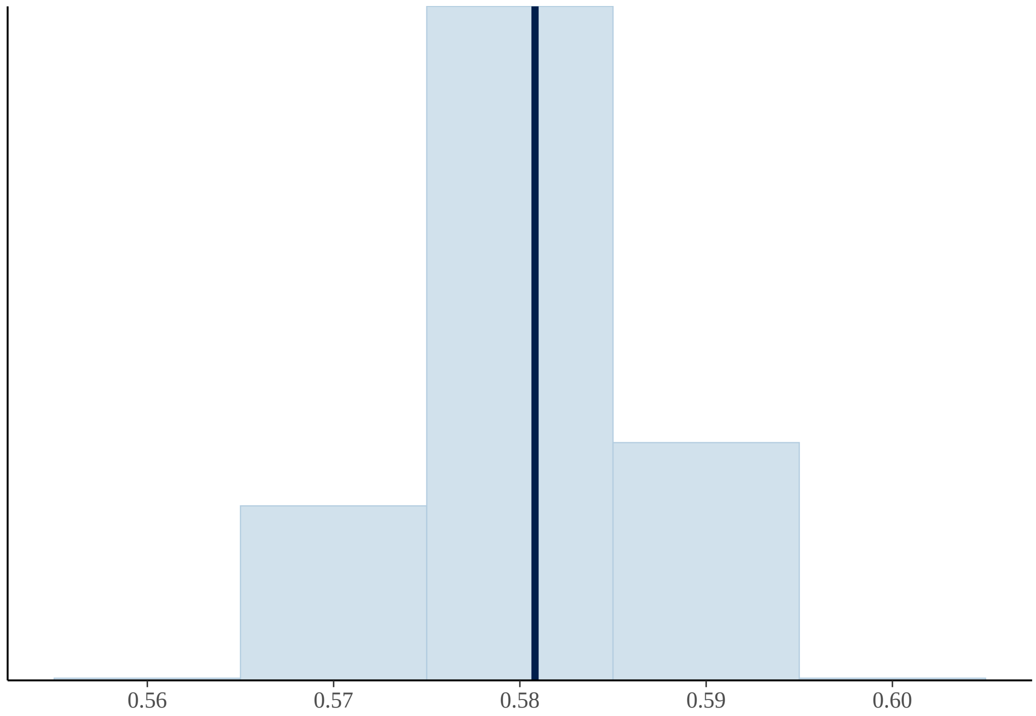

Figure C6: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

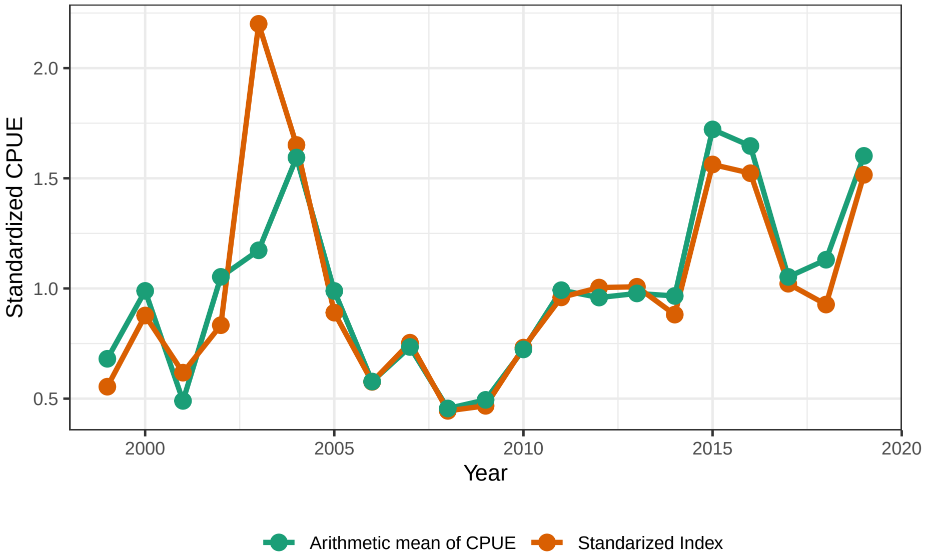

Figure C7: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective mean.

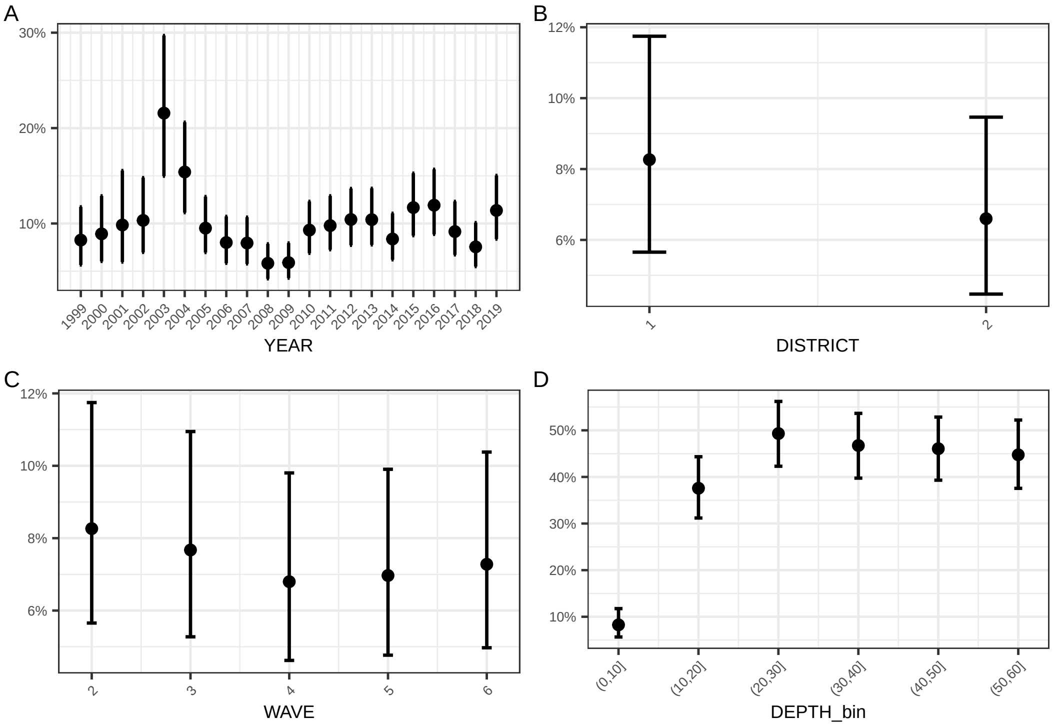

Figure C8: Marginal effects from the binomial model of the delta-GLM.

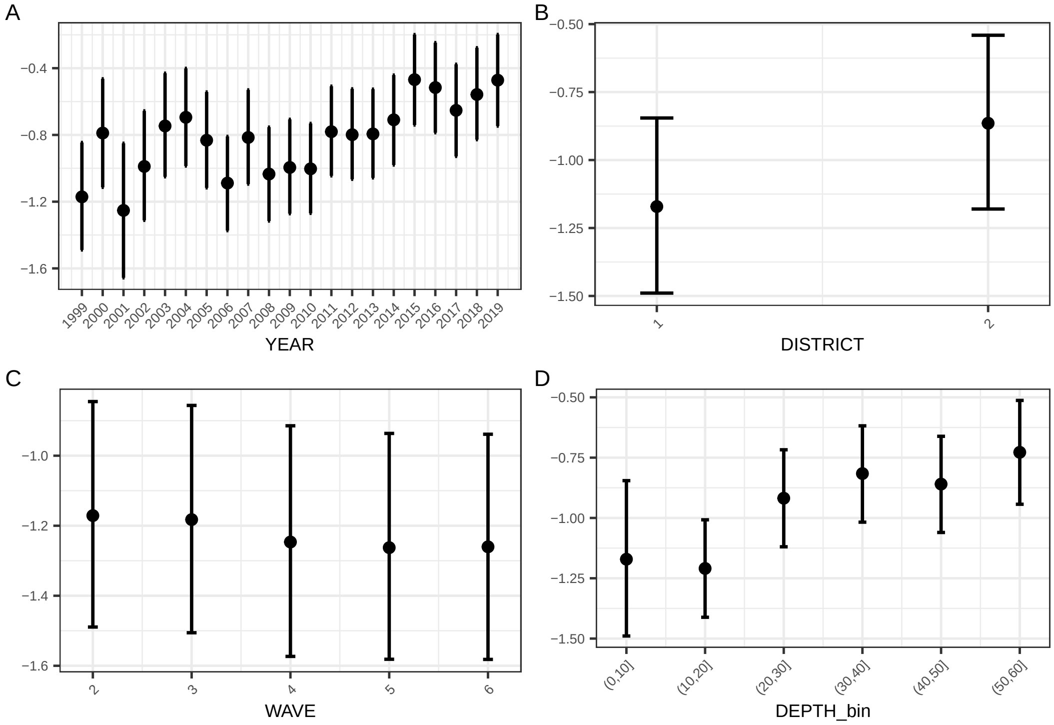

Figure C9: Marginal effects from the positive model of the delta-GLM.

Appendix D. CRFS PR Dockside Index of Abundance

CRFS Dockside Private Boat Index

Catch and effort data from CRFS dockside sampling of private boats, 2004-2018, were provided by CDFW for use in this assessment. The data include catch (number of fish) by species, number of anglers (i.e. effort units are angler trips), angler-reported distance from shore (Area X: inside/outside of 3 nm), county, port, interview site, year, month, and CRFS district. The sample size of the unfiltered private boat CPUE data is much larger than the crfspr CPFV data set, with 391,279 trips statewide, 120,655 in southern California (south of Point Conception), and 270,064 north of Point Conception.

CRFS Private Boat Index: Data Preparation, Filtering, and Sample Sizes Records were limited to "PR1" sites, and only the hook-and-line gear type (Table D1). Since this is a dockside index lacking precise fishing location information, we use the percent of groundfish within the catch from a trip as a proxy for retaining trips for index standardization. Similar to the CRFSS onboard index, we partitioned the data into areas north and south of Point Conception and applied the method separately to each data set.

Since 2005, the recreational fishery for shelf rockfish north of Point Conception has been closed from January through part of April and May.Angler reported distance from shore had no samples in the "outside 3 nm" category (Area X = 2) from 2004-2011, but was retained in the index standardization due to the relaxation of depth restrictions beginning in 2017. We retained 11953 drifts for index standardization, with 6768 drifts encountering vermilion (Table D1).

Northern California CRFS Private Boat Index: Model Selection, Fits, and Diagnostics

Sample sizes by factors selected to model, excluding WAVE can be found in Tables D2 and D3. We modeled retained catch per angler hour (CPUE; number of fish per angler hour) a Bayesian delta-GLM model. Indices with a year and area interaction were not considered in model selection; trends in the average CPUE by region were similar in the filtered data set (Figure D2).

A Lognormal model was selected for the positive observation GLM by a ΔAIC of 893.86 over a Gamma model and supported by Q-Q plots of the positive observations fit to both distributions (Figure D1). The delta-GLM method allows the linear predictors to differ between the binomial and positive models. Based on AIC values from maximum likelihood fits Table D4), a main effects model including YEAR and WAVE and AREA X was fit for the binomial model and a main effects model including YEAR and WAVE and AREA X was fit for the Lognormal model. Models were fit using the "rstanarm" R package (version 2.21.1). Posterior predictive checks of the Bayesian model fit for the binomial model and the positive model were all reasonable (Figures D3 and D4). The binomial model generated data sets with the proportion zeros similar to the 43% zeroes in the observed data (Figure

D5). The predicted marginal effects from both the binomial and Lognormal models can be found in (Figures D6 and D7). The final index (Table D5) represents a similar trend to the arithmetic mean of the annual CPUE (Figure D8).

Table D1: Data filtering steps for theCRFS PR dockside survey index for vermilion rockfish in the southern model. The last row in the table represents the number of trips used to develop the index.

Filter	Desciption	Trip	Positive Trips	Percent drifts retained
All data	Pre-filtered for drifts with marked for exclusion	54051	8654	16%
MOnths samples	Remove waves less than 2 due to small sample sizes and fishery closures.	51826	8565	17%
Groundfish	Removed trips with no observed groundfish	17827	8565	48%
HMS	Remove trips with more than half the catch composed of HMS species	17816	8564	48%
Final trips	Retained trips with at least 0.5 groundfish.	11953	6768	57%

Table D2: Samples of vermilion rockfish in the southern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
37	1515	2617	58%
59	243	443	55%
73	1718	2904	59%
83	1249	2017	62%
111	2043	3972	51%

Table D3: Samples of vermilion rockfish in the southern model by year.

Year	Positive Samples	Samples	Percent Positive
2004	583	843	69%
2005	446	738	60%
2006	498	871	57%
2007	616	1006	61%
2008	477	865	55%
2009	362	747	48%
2010	257	498	52%
2011	258	522	49%
2012	272	525	52%
2013	546	975	56%
2014	462	794	58%
2015	413	729	57%
2016	347	645	54%
2017	375	703	53%
2018	302	574	53%
2019	504	810	62%
2020	50	108	46%

Table D4: Model selection for the CRFS PR dockside survey index for vermilion rockfish in the southern model.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	328.75	168.29
YEAR + DISTRICT	209.71	39.02
YEAR + DISTRICT + WAVE	65.11	29.58
YEAR + DISTRICT + WAVE + AREA X	0.00	0.00
YEAR + WAVE + AREA X	2.48	5.11
YEAR + AREA X	149.97	14.04
YEAR + DISTRICT + AREA X	145.89	9.79

Table D5: Standardized index for the CRFS PR dockside survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the southern model.

Year	Index	logSE	lower HPD	upper HPD
2004	1.36	0.05	1.23	1.49
2005	0.84	0.06	0.75	0.93
2006	0.80	0.05	0.72	0.89
2007	0.84	0.05	0.77	0.93
2008	0.67	0.05	0.60	0.74
2009	0.58	0.06	0.51	0.65
2010	0.61	0.07	0.53	0.70
2011	0.72	0.07	0.62	0.83
2012	0.69	0.07	0.60	0.80
2013	0.81	0.06	0.72	0.90
2014	0.85	0.06	0.76	0.95
2015	0.84	0.06	0.74	0.94
2016	0.73	0.07	0.64	0.83
2017	0.74	0.07	0.65	0.84
2018	0.65	0.07	0.56	0.74
2019	0.91	0.06	0.82	1.02
2020	0.77	0.17	0.55	1.05

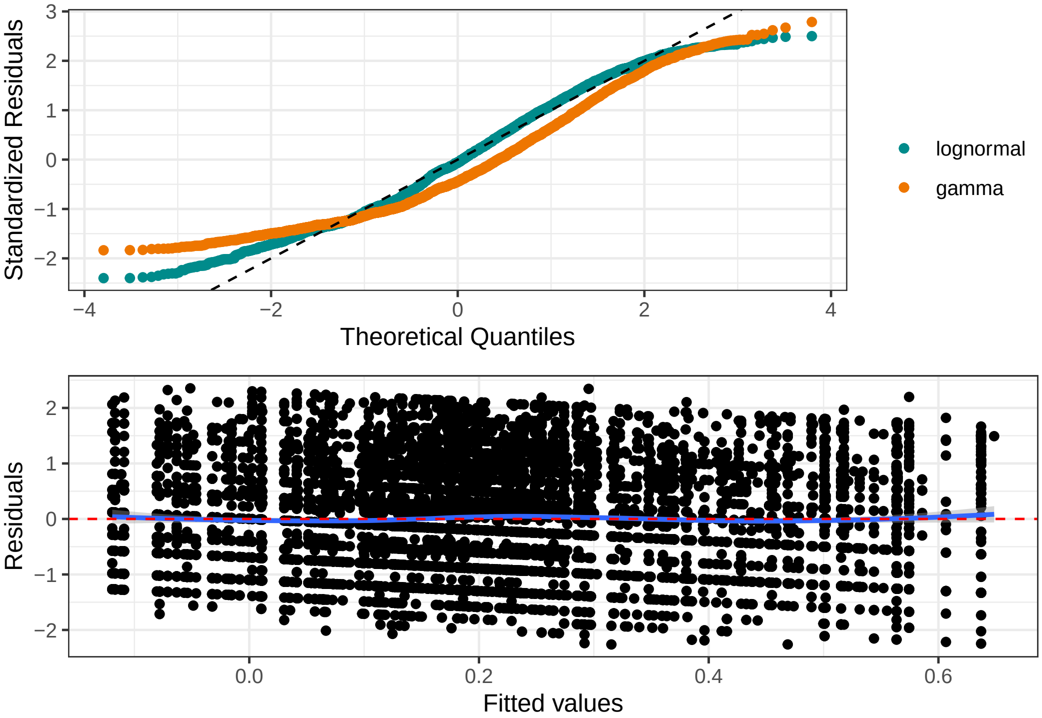

Figure D1: Q-Q plot (top) of the positive observations lognormal gamma distributions and fitted values vs residuals for the Lognormal model (bottom).

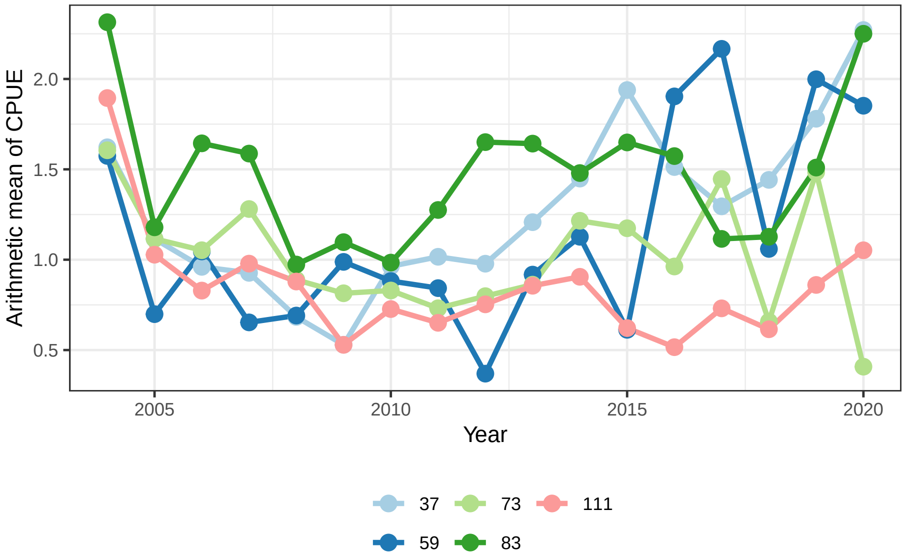

Figure D2: Arithmetic mean of CPUE by region for vermilion from the filtered data.

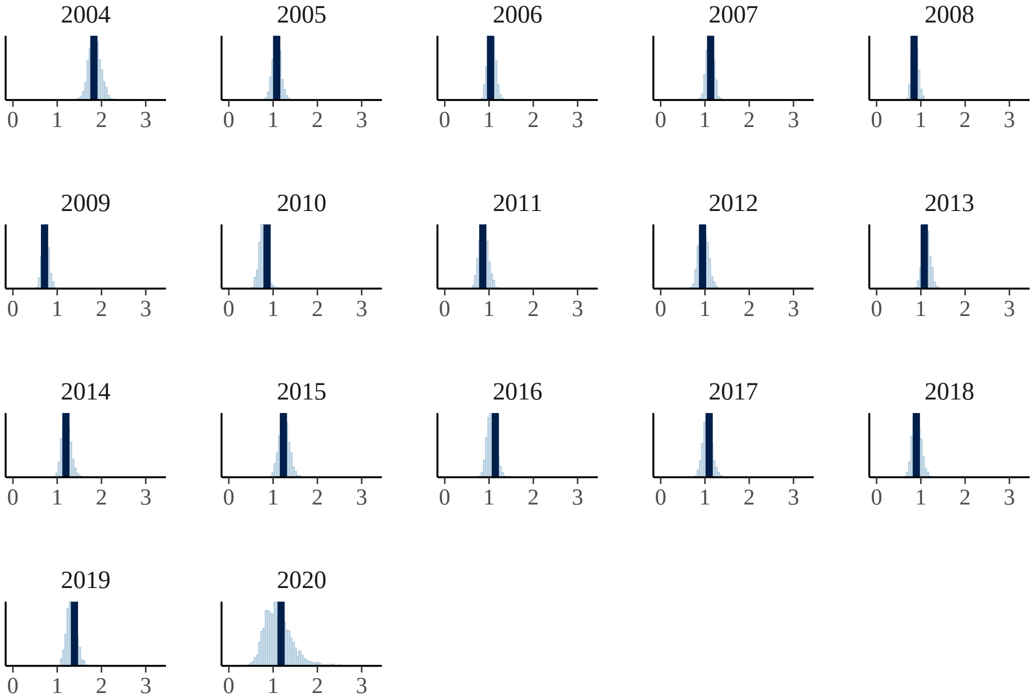

Figure D3: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

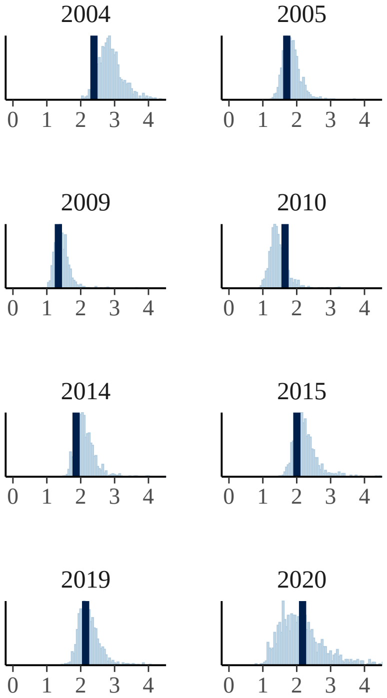

Figure D4: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

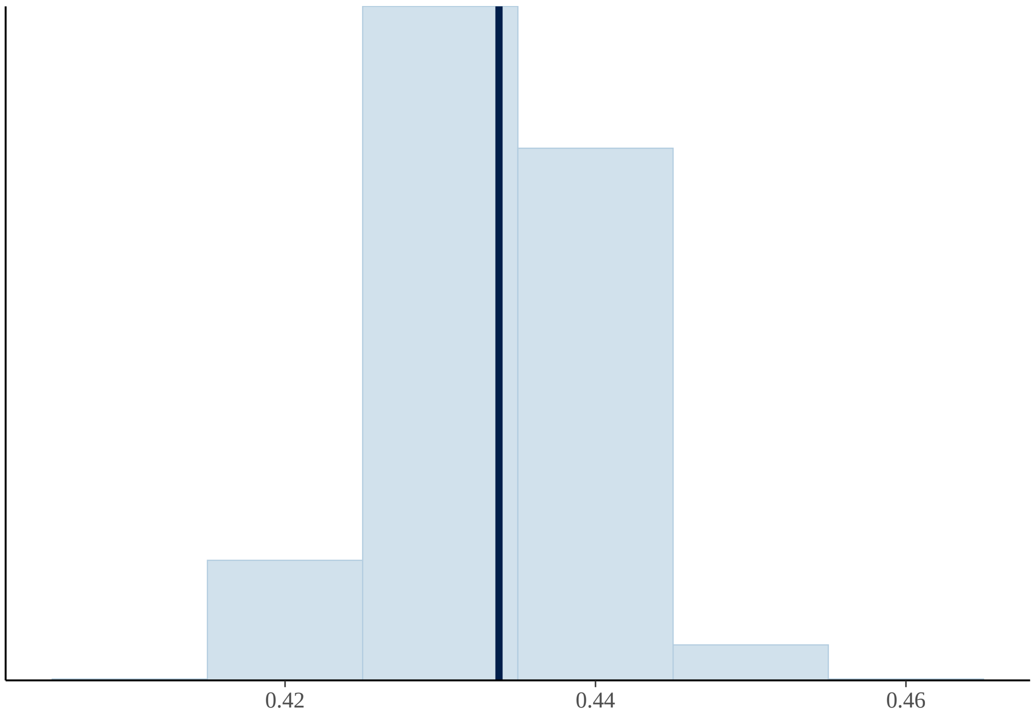

Figure D5: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

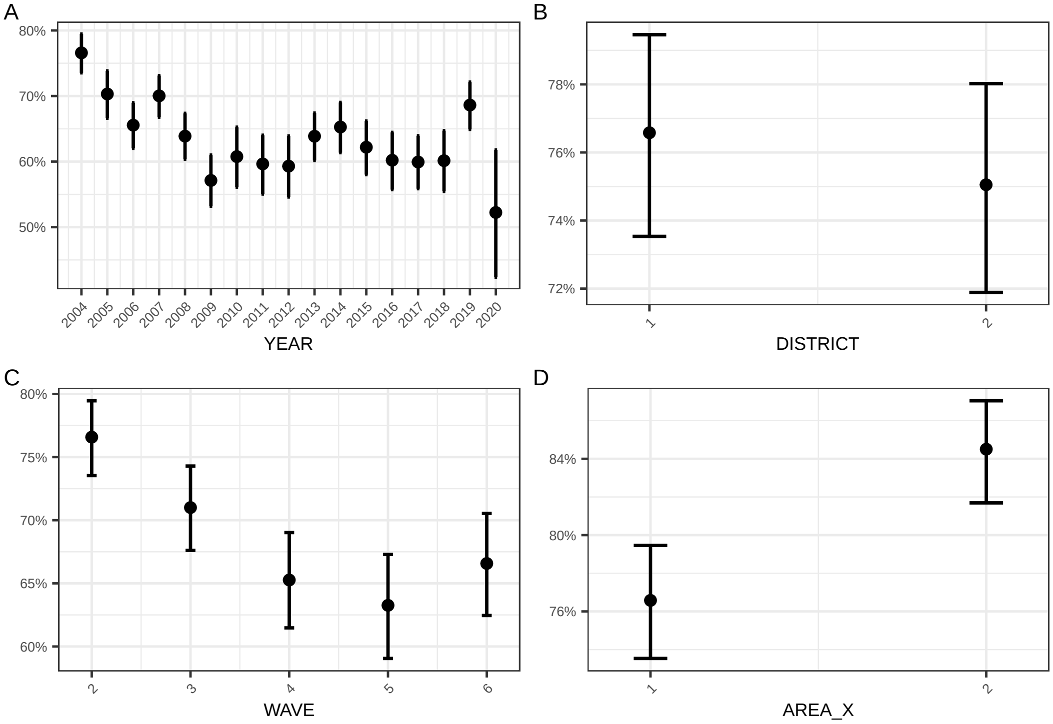

Figure D6: Binomial marginal effects from the final model.

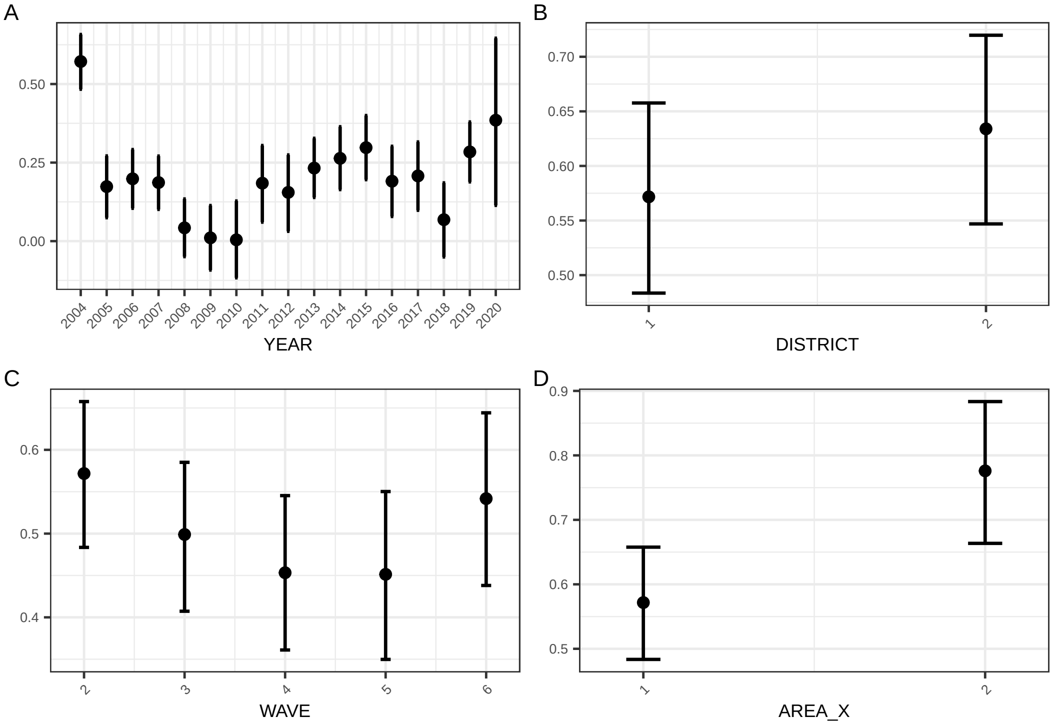

Figure D7: Positive model marginal effects from the final model.

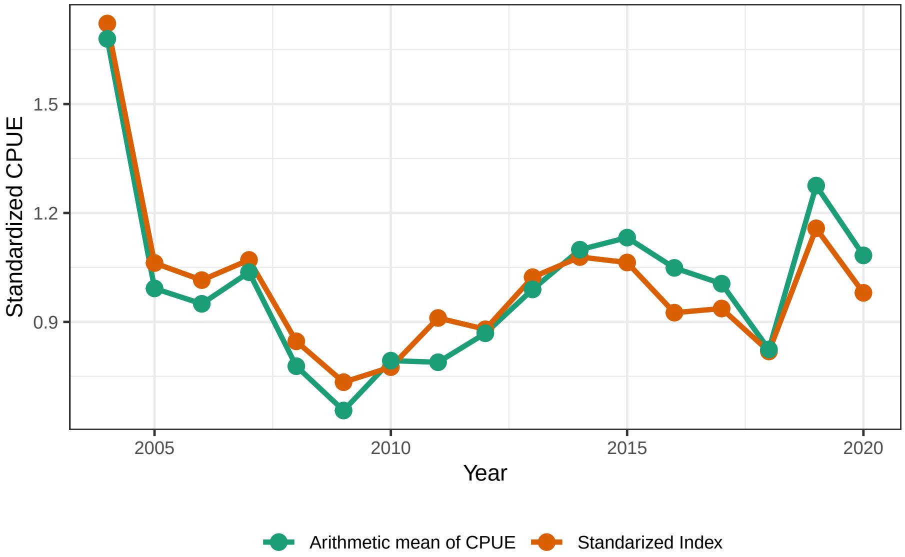

Figure D8: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

Appendix E. NWFSC Hook-and-Line Survey Index of Abundance

7.0.1 Northwest Fisheries Science Center Hook-and-Line Survey

Since 2004, the NWFSC has conducted an annual hook-and-line survey (NWFSC HL) targeting shelf rockfish at fixed stations ('sites') in the Southern California Bight (Figure E1). During each site visit, three deckhands simultaneously deploy 5-hook sampling rigs (this is referred to as a single 'drop') for a maximum of 5 minutes per line, but individual lines may be retrieved sooner at the angler's discretion (e.g. to avoid losing fish). Five drops are attempted at each site for a maximum possible catch of 75 fish per site per year (3 anglers × 5 hooks × 5 drops). Further details regarding the sampling frame, site selection, and survey methodology are described by Harms et al. (2008).

From 2004 through 2013, sampling was conducted only outside the Cowcod Conservation Areas (CCAs). Beginning in 2014, 40 sites inside the CCAs were sampled, and roughly another 40 sites have been added in subsequent years inside the CCAs. The survey currently has 201 sites (79 inside and 122 outside the CCAs).

Northwest Fisheries Science Center Hook-and-Line Survey Index: Data Preparation, Filtering, and Sample Sizes

Vermilion is one of the most commonly encountered species in the NWFSC hook-and-line survey (**Harms?**) (Figure E1). Sites considered for an abundance index were limited to those that have caught at least 1 vermilion rockfish over the period 2004-2018 (circles in Figure E1). Only 14 sites were identified as catching no vermilion over the entire sampling period. Sample sizes by depth and year can be found in Tables E1 and E3. Note that depth was used as a continuous variable (second-order polynomial) in the model, and depth bins were created for descriptive purposes and data exploration only.

Northwest Fisheries Science Center Hook-and-Line Survey Index: Model Selection, Fits, and Diagnostics

The STAT explored alternative model structures to generate a standardized index of relative abundance. This included alternative response variables (catch in weight, catch in numbers, presence/absence), levels of aggregation (hook, drop, or site), probability distributions (binomial, negative binomial, lognormal, delta-gamma, and logit-normal), and covariates (year, site number, depth, distance to port, area, inside/outside CCA). Preliminary analyses showed that trends in the annual proportion of positive hooks were very similar to trends in catch rate per drop or site. Posterior predictive checks of annual means and standard deviations identified the logit-normal model as the most appropriate error distribution. The final model included covariate terms for year, site number, drop number, a second-order depth term, and a normally-distributed random effect for each observation.

Models were fit using the “rstanarm” R package (version 2.21.1). Posterior predictive checks of the Bayesian model fit for the final logit model were all reasonable (Figures E2 and E3). The model generated data sets with the proportion zeros similar to the ~50% zeroes in the data (Figure E4). The predicted marginal effects from the final logit normal model can be found in Figure E6. The marginal depth effect represents the influence of depth on the proportion of vermilion after accounting for site effects. A model run without the site effect confirms that that depth follows the expected pattern observed in the data, i.e. a peak near 145 m (Figure E5). The final index (Table E4), when compared to the arithmetic mean of the annual CPUE, declines slightly more from 2008-2012, with a significant increase after 2016 (Figure E7).

The expansion of the survey area into the CCAs after 2014 limits exploration of year/area interactions in the model. The STAT adopted an approach similar to that used for the 2019 assessment of cowcod (Dick and He 2019). Specifically, because site effects (both inside and outside the CCA) are constant over time in the index, selectivity for the index is estimated using composition data that represents all areas (2014-2019, inside and outside the CCAs). Not wanting to lose length and age compositions prior to 2014, these data are moved to a ‘dummy’ fleet in the assessment model, and allowed to have a different selectivity curve due to differences in size composition inside and outside the CCAs (Keller et al. 2019). This treatment of the data, although not ideal, was seen as preferable to development of two separate indices.

Table E1: Positive samples of vermilion in the southern model by depth (fm).

Year	Positive Samples	Samples	Percent Positive
(0,50]	85	295	29%
(50,75]	226	815	28%
(75,100]	1697	3847	44%
(100,125]	1278	2156	59%
(125,150]	917	1594	58%
(150,175]	663	1155	57%
(175,200]	234	456	51%
(200,235]	75	122	61%

Table E2: Samples of vermilion in the NWFSC hook-and-line survey by area and depth bins (ft).

Area name	(0,50]	(50,75]	(75,100]	(100,125]	(125,150]	(150,175]	(175,200]	(200,235]
Fourteen Mile Bank			0%	7%	38%	32%	21%	
107 and 118 Banks							26%	10%
109 Bank						50%	71%	50%
43 Fathom Bank			22%	87%			4%	50%
Anacapa Island		0%	34%	18%	30%	9%	0%	
Catalina Island		13%	45%		67%	55%	21%	
Central Coast			34%	40%	8%	14%		
Cherry Bank			82%	77%	59%	72%	55%	
Cortez Bank		11%	50%	94%	79%	62%	100%	100%
Garrett Bank				100%	100%	58%	78%	89%
Harrison Reef			11%	53%	50%			
Hidden Reef				35%	80%			
Kidney Bank				82%	37%	58%		
Nine Mile Bank				38%	70%	25%		
Osborn Bank	0%	20%	10%			88%		
Point Conception/Arguello			93%	90%	85%	100%	100%	
Port Hueneme			66%					
Potato Bank			80%	46%	16%	80%	80%	
San Clemente Island	10%	0%	27%	52%	42%	51%	100%	
San Miguel Island		50%	77%	98%	100%			
San Nicolas Island East		50%	56%	33%		75%		
San Nicolas Island West		57%	61%	78%	90%	74%	82%	
San Pedro Bay		35%	31%					
Santa Barbara	24%	65%	66%					
Santa Barbara Channel			33%	43%	100%	54%	29%	
Santa Barbara Island			42%	85%	92%	65%	88%	67%
Santa Cruz Island		10%	32%		100%	83%	90%	96%
Santa Monica Bay	31%	17%	35%	14%	68%			
Santa Rosa Flats				66%	31%	82%	79%	23%
Santa Rosa Island		12%	64%	100%				
Sixty Mile Bank			30%	38%	61%	40%	20%	0%
South Coast	52%	12%	29%	23%	0%			
Tanner Bank			53%	62%	100%	100%	93%	100%

Table E3: Samples of vermilion in the southern model by year.

Year	Positive Samples	Samples	Percent Positive
2004	184	363	51%
2005	210	442	48%
2006	187	448	42%
2007	205	490	42%
2008	227	577	39%
2009	243	575	42%
2010	225	584	39%
2011	245	531	46%
2012	275	584	47%
2013	296	579	51%
2014	381	744	51%
2015	470	880	53%
2016	438	858	51%
2017	537	916	59%
2018	543	934	58%
2019	509	935	54%

Table E4: Standardized index for the NWFSC Hook-and-Line Survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the southern model.

Year	Mean	logSE	lower HPD	upper HPD
2004	0.0403	0.2824	0.0222	0.0666
2005	0.0491	0.2768	0.0272	0.0798
2006	0.0438	0.2817	0.0239	0.0719
2007	0.0445	0.2790	0.0244	0.0722
2008	0.0266	0.2843	0.0145	0.0444
2009	0.0355	0.2819	0.0195	0.0583
2010	0.0361	0.2825	0.0197	0.0599
2011	0.0532	0.2741	0.0295	0.0864
2012	0.0454	0.2756	0.0254	0.0739
2013	0.0526	0.2765	0.0290	0.0858
2014	0.0578	0.2697	0.0326	0.0931
2015	0.0599	0.2661	0.0339	0.0957
2016	0.0586	0.2697	0.0329	0.0950
2017	0.0963	0.2562	0.0559	0.1511
2018	0.0879	0.2606	0.0501	0.1392
2019	0.0674	0.2681	0.0381	0.1085

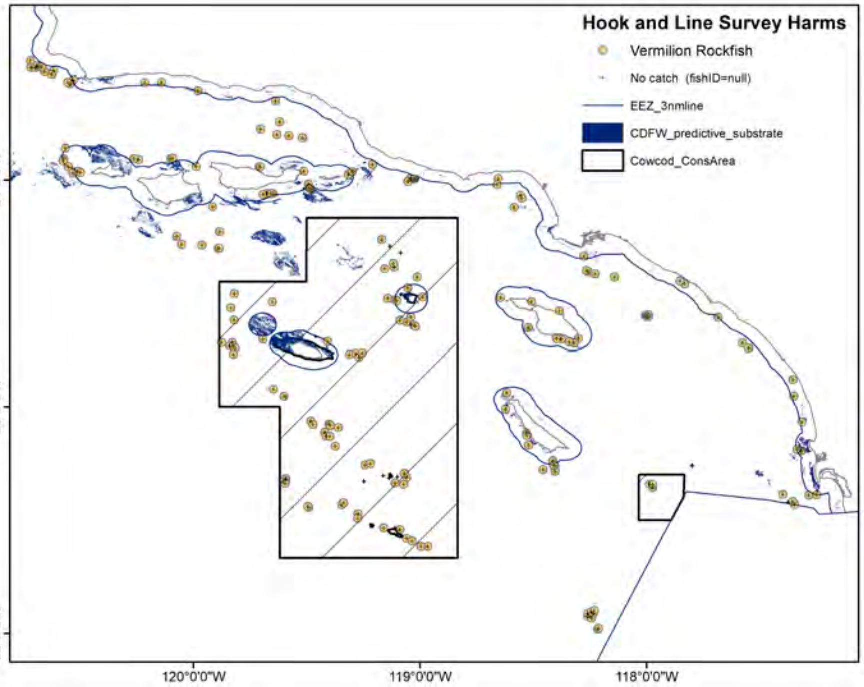

Figure E1: Map of the NWFSC hook-and-line survey site with circle indicating location at which vermilion rockfish were observed at least once.

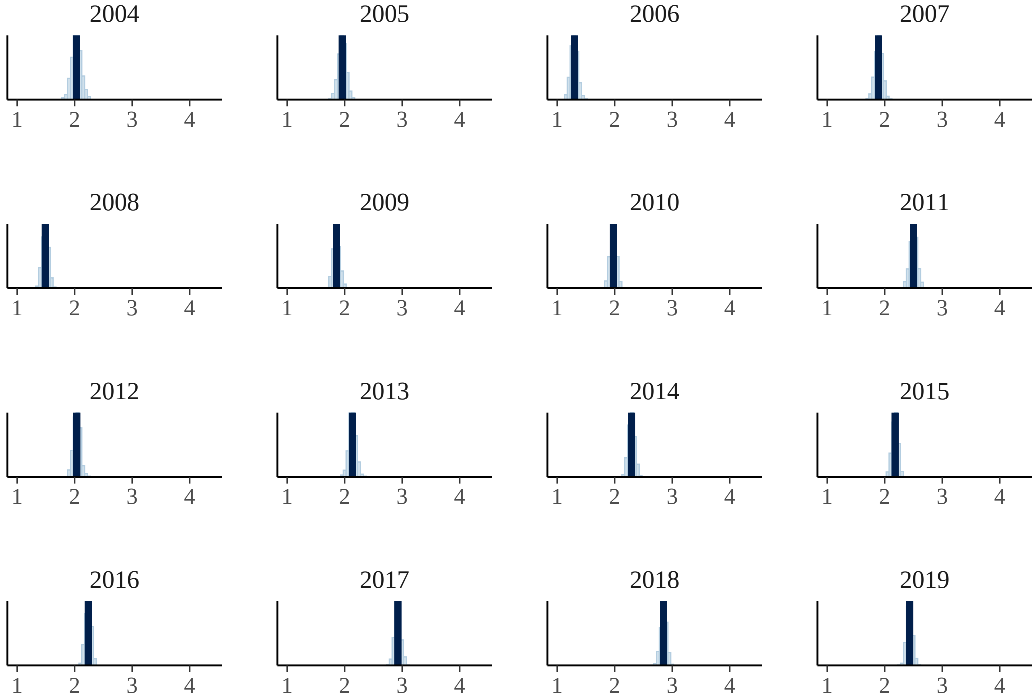

Figure E2: Posterior predictive draws of the mean by year with a vertical line of the raw data average.

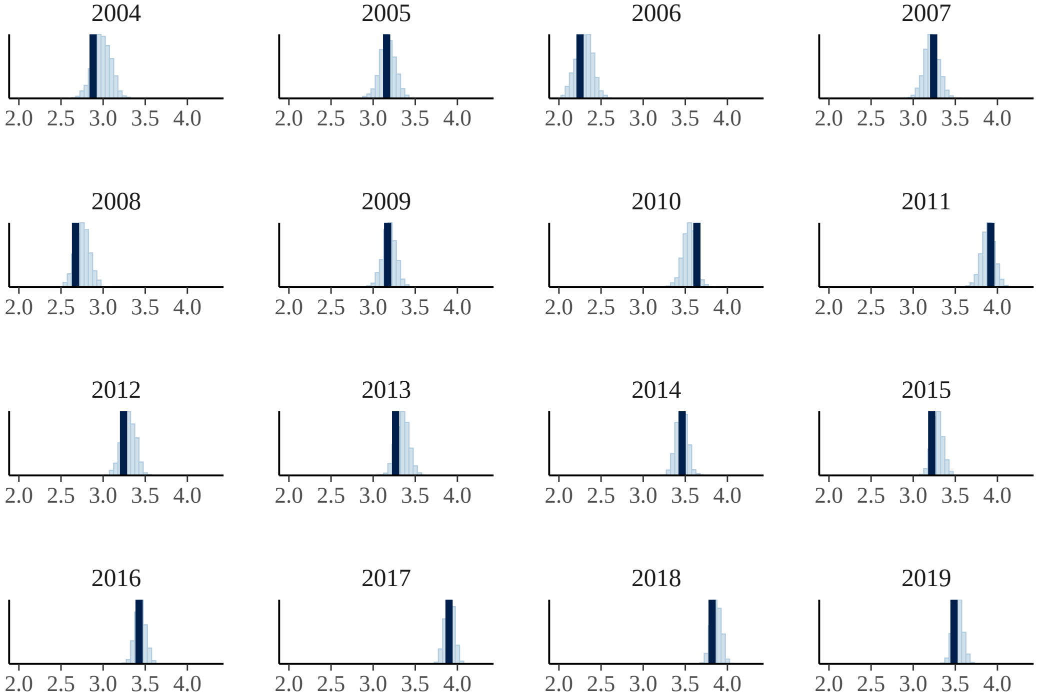

Figure E3: Posterior predictive draws of the standard deviation by year with a vertical line representing the observed average.

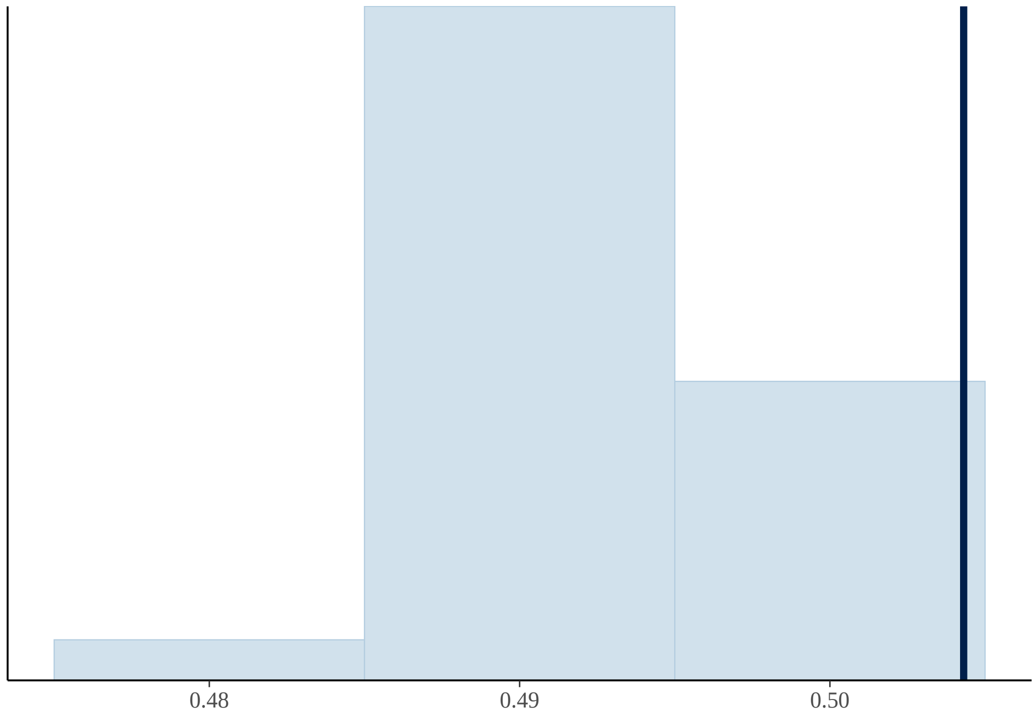

Figure E4: Posterior predictive distribution of the proportion of zero observations in replicate data sets generated by the logit normal model with a vertical line representing the observed average.

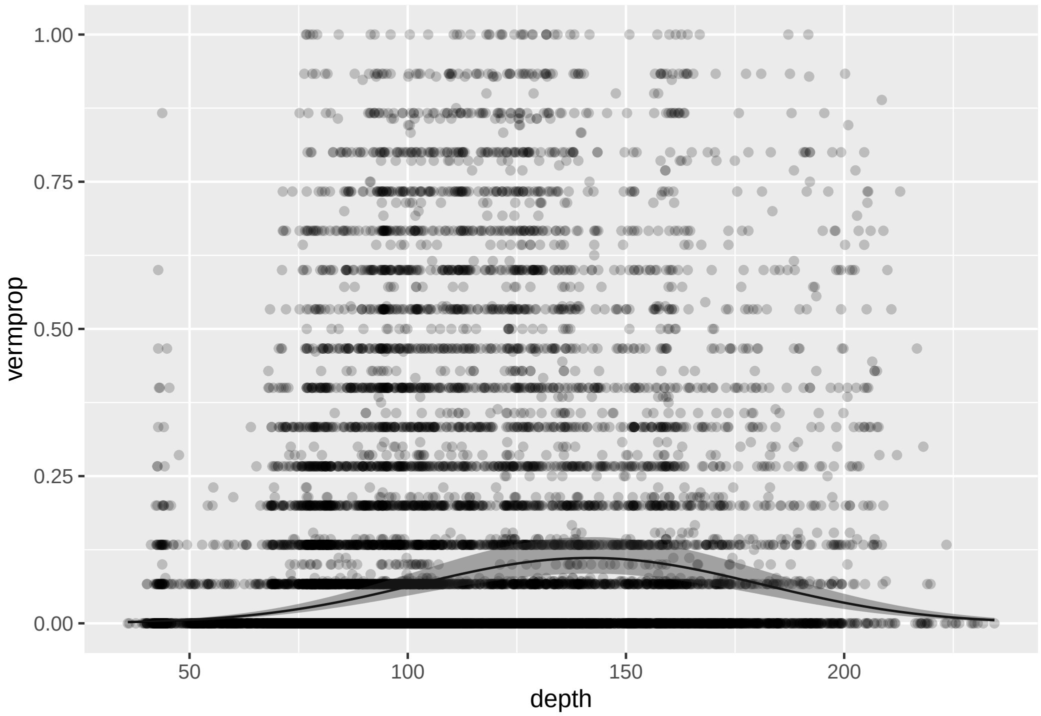

Figure E5: Marginal effect of depth from a logit normal model without site.

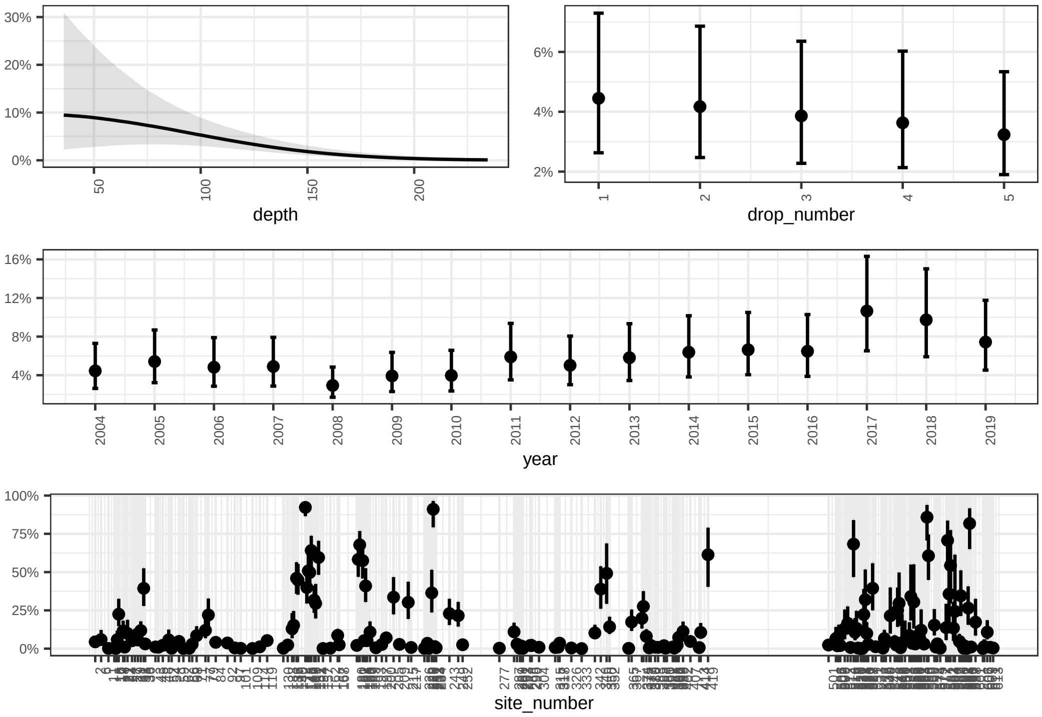

Figure E6: Marginal effects from the final model logit normal model.

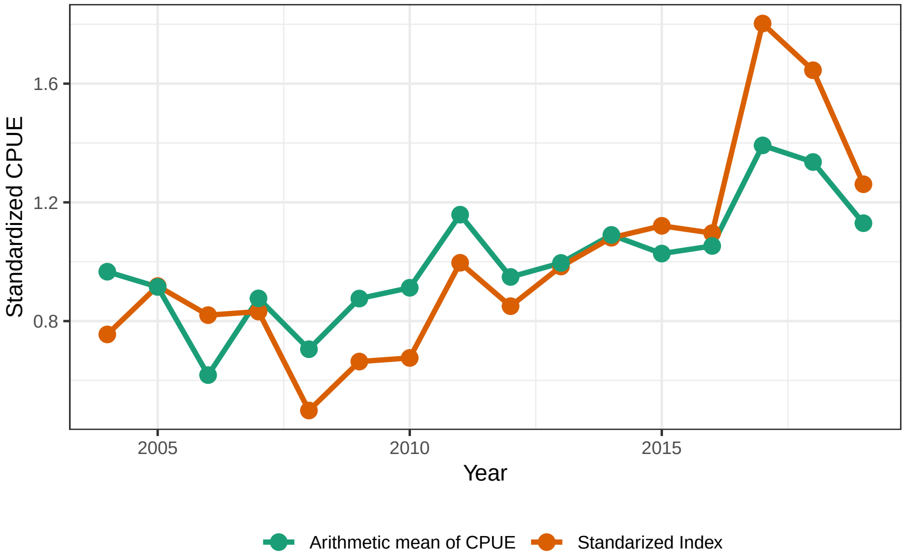

Figure E7: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

#Appendix F. WCGBTS Index of Abundance

In 2003, the NWFSC expanded the ongoing slope survey to include the continental shelf. This survey, referred to in this document as the West Coast Groundfish Bottom Trawl Survey (WCGBT Survey or WCGBTS), is conducted annually. It uses a r andom-grid design covering the coastal waters from a depth of 55 m to 1,280 m from late-May to early-October (Keller et al. 2017). Four chartered industry vessels are used in most years.

*WCGBTS Index: Data Preparation, Filtering, and Sample Sizes

Vermilion rockfish were found during the WCGBTS, mainly off the coast of California. Haul-level information collected during the survey was extracted from the Northwest Fisheries Science Center database using code within the `nwfscSurvey` package, providing information on catches (kg), vessel, year, latitude (decimal degrees), and area swept (hectares).

Just two records with positive tows were located north of the California-Oregon border and were excluded from this analysis. Most of the positive tows were found in waters less than 200 m depth (Table @ref{tab:ndepth}), and thus, this analysis was truncated to waters with a depth of 300 m or less. Positive tows were found south of 32.45 decimal degrees, which was used to represent the California-Mexico border. This left, fifty-eight positive tows north of 34.50 decimal degrees and one hundred twenty-three positive tows south of 34.50 decimal degrees. Positive encounters were just 7 and 15 percent of all tows for these two areas, respectively.

WCGBTS Index: Model Selection, Fits, and Diagnostics

Sample sizes by factors selected to model, excluding WAVE can be found in Tables F2 and F3. We modeled retained catch per angler hour (CPUE; number of fish per angler hour) a Bayesian delta-GLM model.

A Lognormal distribution was selected over a Gamma for the positive observation GLM. The delta-GLM method allows the linear predictors to differ between the binomial and positive models. Based on AIC values from maximum likelihood fits Table F4), a main effects model including YEAR and LAT bin was fit for the binomial model and a main effects model including YEAR and DEPTH bin and LAT bin was fit for the Lognormal model. Models were fit using the “rstanarm” R package (version 2.21.1). Posterior predictive checks of the Bayesian model fit for the binomial model and the positive model were all reasonable (Figures F2 and F3). The binomial model generated data sets with the proportion zeros similar to the 84% zeroes in the observed data (Figure F1). The predicted marginal effects from both the binomial and Lognormal models can be found in (Figures F5 and F6). The final index (Table F5) represents a similar trend to the arithmetic mean of the annual CPUE (Figure F4).

Table F1: Samples of vermilion rockfish in the southern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
32	14	64	22%
33	46	340	14%
34	58	339	17%

Table F2: Positive samples of vermilion rockfish in the southern model by depth (fm).

Year	Positive Samples	Samples	Percent Positive
[55,75]	28	87	32%
(75,100]	52	203	26%
(100,150]	31	156	20%
(150,200]	5	127	4%
(200,300]	2	170	1%

Table F3: Samples of vermilion rockfish in the southern model by year.

Year	Positive Samples	Samples	Percent Positive
2003	3	32	9%
2005	5	38	13%
2006	3	45	7%
2007	7	50	14%
2008	7	47	15%
2009	6	59	10%
2010	11	55	20%
2011	2	49	4%
2012	12	53	23%
2013	7	29	24%
2014	8	52	15%
2015	9	53	17%
2016	15	52	29%
2017	9	50	18%
2018	10	53	19%
2019	4	26	15%

Table F4: Model selection for the WCGBTS survey index for vermilion rockfish in the southern model.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	79.86	12.60
YEAR + PASS	88.32	12.30
YEAR + PASS + DEPTH bin	2.07	1.87
YEAR + PASS + DEPTH bin + LAT bin	1.97	0.00
YEAR + DEPTH bin + LAT bin	0.00	1.15
YEAR + LAT bin	86.61	11.82
YEAR + PASS + LAT bin	88.41	11.24

Table F5: Standardized index for the WCGBTS survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the southern model.

Year	Index	logSE	lower HPD	upper HPD
2003	0.78	1.26	0.03	4.10
2005	0.34	1.87	0.00	2.40
2006	0.13	1.16	0.01	0.62
2007	0.47	1.17	0.02	2.34
2008	0.83	1.01	0.07	3.58
2009	0.27	1.04	0.02	1.23
2010	0.19	1.01	0.02	0.79
2011	0.04	1.08	0.00	0.19
2012	1.81	1.46	0.04	10.72
2013	1.00	0.85	0.13	3.66
2014	3.72	1.01	0.30	16.34
2015	0.10	0.93	0.01	0.41
2016	0.22	0.88	0.03	0.82
2017	0.16	0.77	0.03	0.52
2018	0.61	0.91	0.07	2.34
2019	0.17	0.98	0.02	0.70

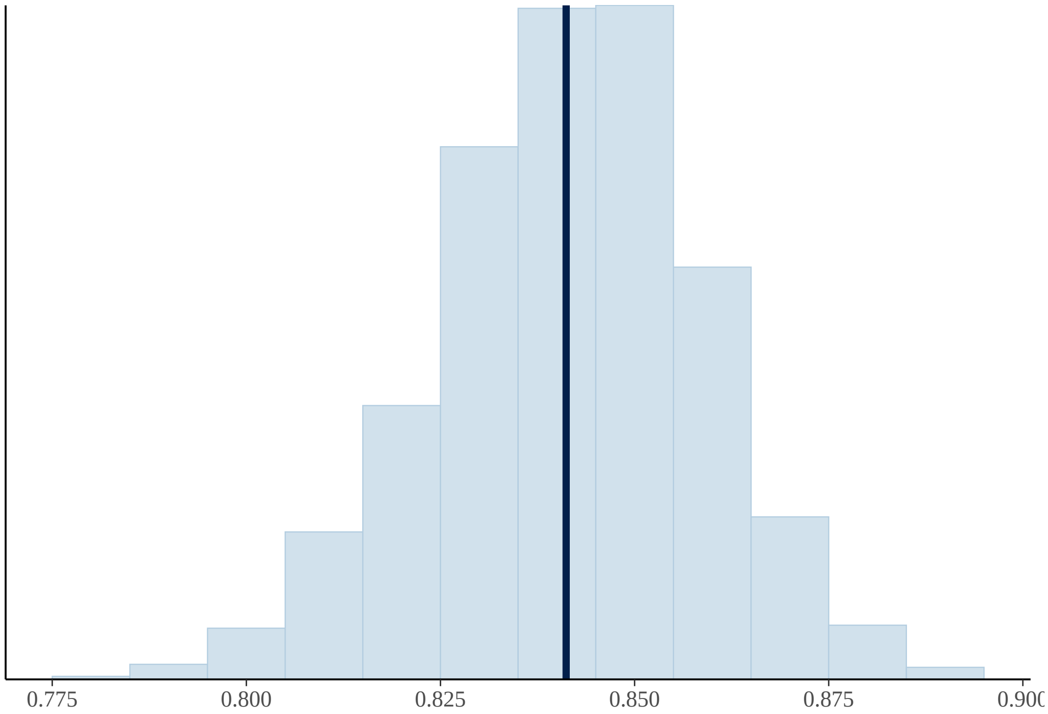

Figure F1: Posterior predictive distribution of the proportion of zero observations in replicate data sets generated by the delta model with a vertical line representing the observed average.

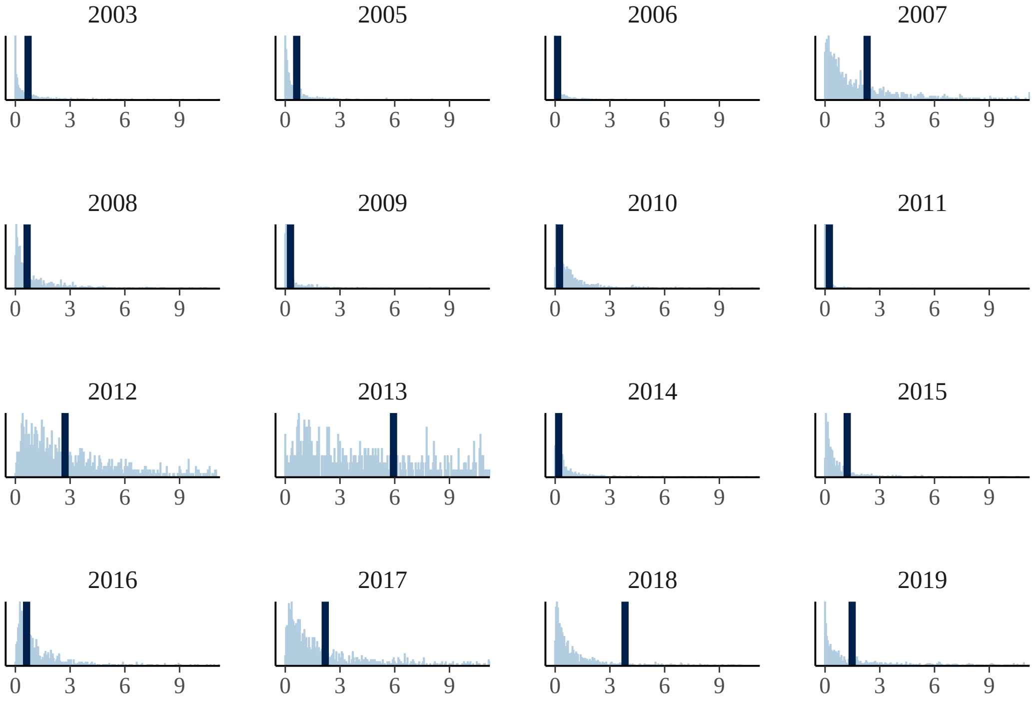

Figure F2: Posterior predictive draws of the mean by year with a vertical line of the raw data average.

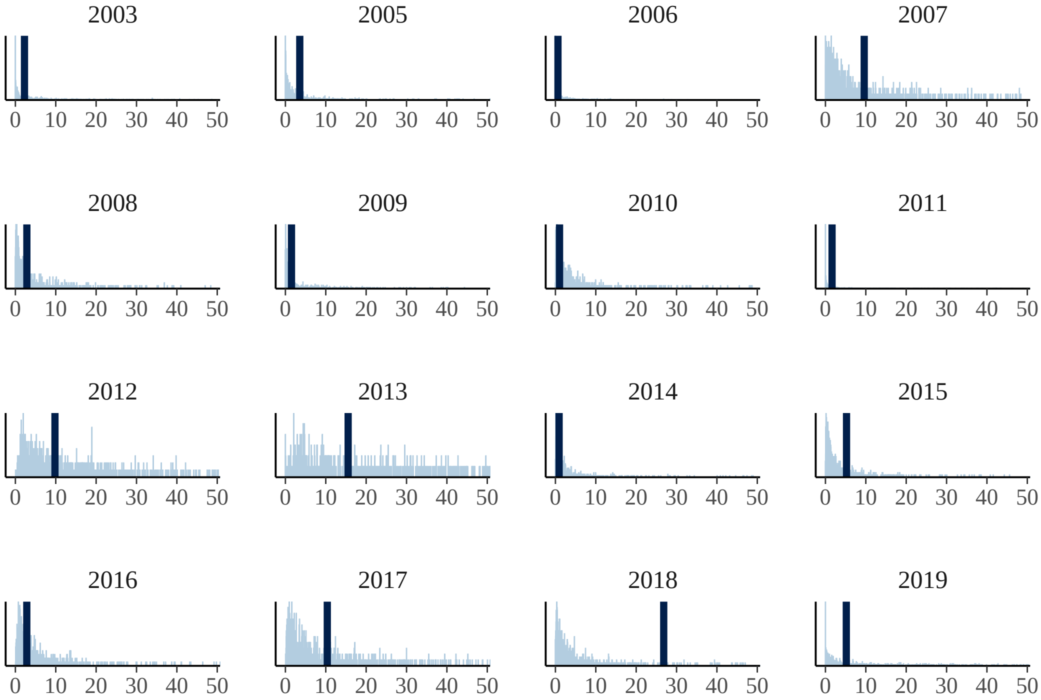

Figure F3: Posterior predictive draws of the standard deviation by year with a vertical line representing the observed average.

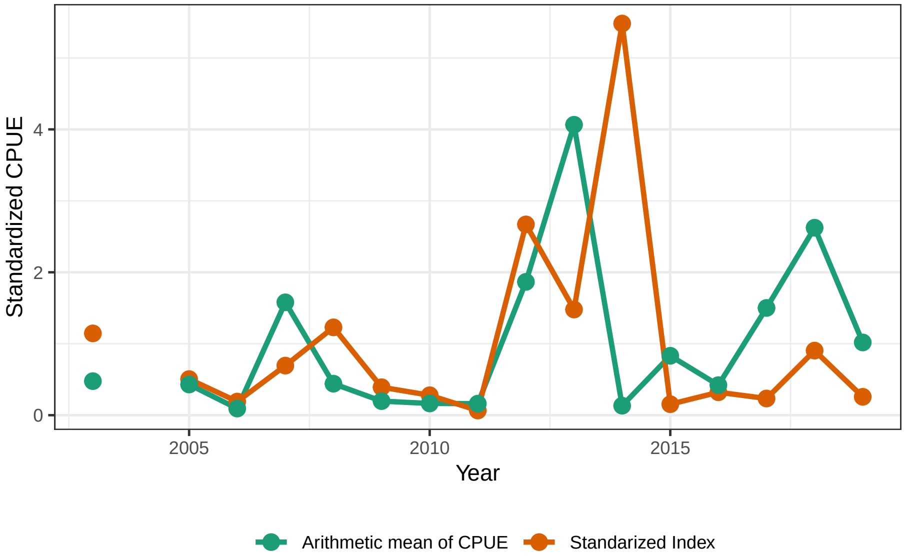

Figure F4: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

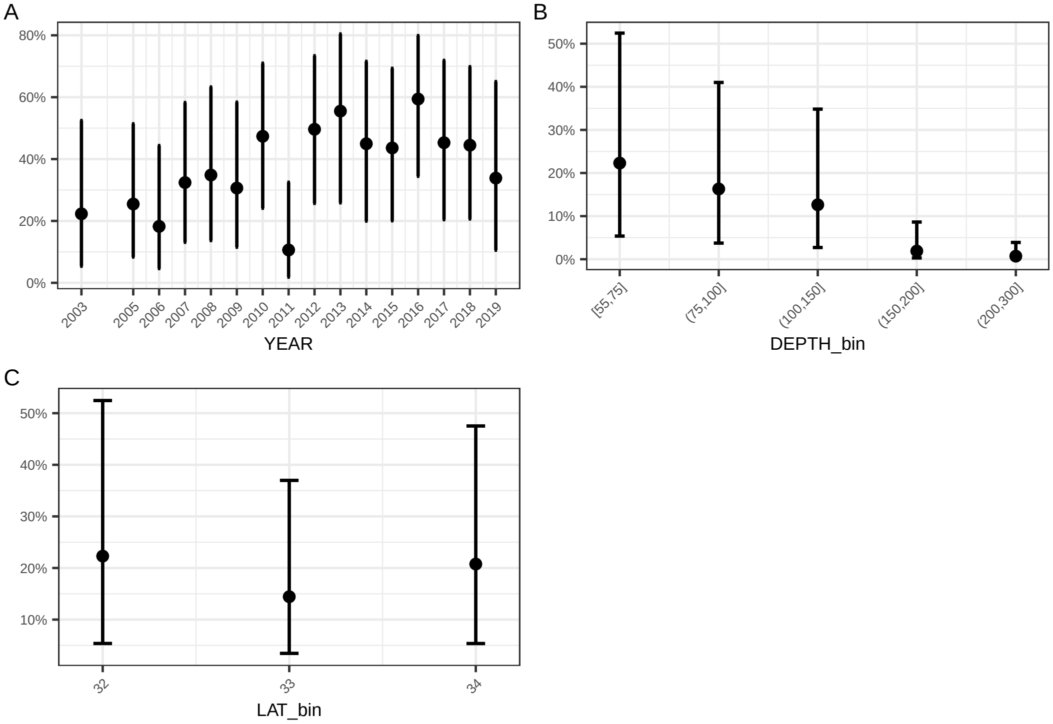

Figure F5: Binomial marginal effects from the final model

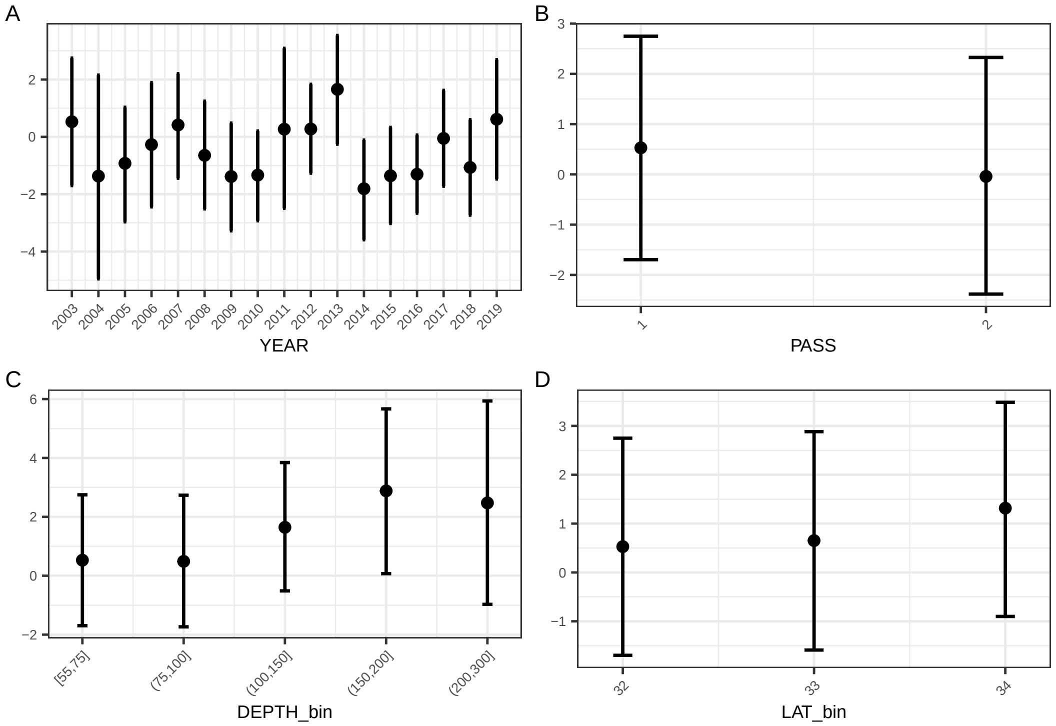

Figure F6: Positive model marginal effects from the final model.

Appendix G. Recreational Regulations

Figure G1: Recreational depth closures for shelf rockfish in the northern California management area.

Figure G2: Recreational depth closures for shelf rockfish in the north-central California management area.

Figure G3: Recreational depth closures for shelf rockfish in the central California management area.

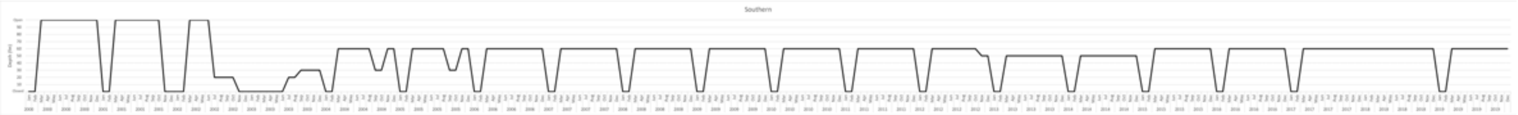

Figure G4: Recreational depth closures for shelf rockfish in the southern California management area.

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