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

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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 north 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 76-204 mt, with total mortality (catch + discards) in 2020 of 139 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 north of Point Conception increased steadily following World War II, peaking in the late 1970s and 1980s with annual removals of 365 mt per year (Figure i). Recent years have seen a steady increase in landings, with recreational fleets accounting for the majority of total mortality.

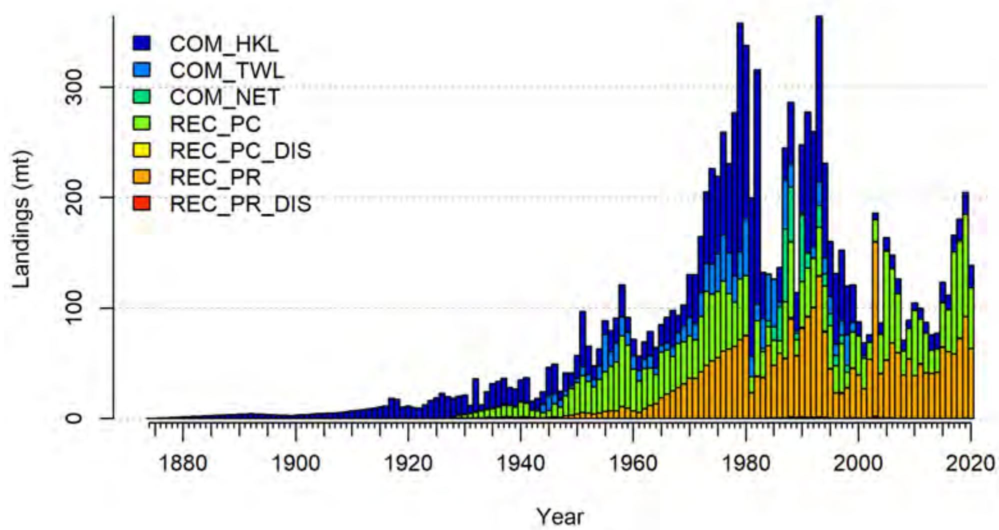

Figure i: Catch histories by fleet used in the base model (Commercial hook-and-line = COM_HKL, Commercial trawl = COM_TWL, Commercial net = COM_NET, Recreational party/charter retained = REC_PC, Recreational private/rental retained = REC_PR, Recreational party/charter dead discards = REC_PC_DIS, Recreational 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	10.0	0.0	0	40.3	0.3	49.4	0.1	100.1
2012	9.4	0.0	0	36.0	0.2	41.2	0.2	87.1
2013	13.8	0.0	0	21.1	0.1	40.6	0.1	75.8
2014	14.1	0.0	0	21.1	0.0	41.7	0.2	77.2
2015	18.2	0.4	0	40.0	0.1	64.6	0.2	123.5
2016	13.3	0.1	0	38.0	0.2	60.3	0.3	112.1
2017	14.2	0.1	0	92.3	0.4	58.3	0.3	165.6
2018	19.0	0.6	0	88.0	0.1	72.4	0.2	180.5
2019	19.6	0.0	0	92.0	0.3	91.9	0.6	204.4
2020	19.9	0.0	0	55.4	0.2	63.3	0.3	139.0

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 Point Conception ($34°27'N$) to the California/Oregon border ($42°00'N$). The assessment 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 five abundance indices (one fishery-independent survey, two CPUE indices from shore-based recreational fishery sampling programs, and two CPUE indices from recreational onboard party/charter boat observer programs). 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 parameters for natural mortality of females and males, and sex-specific growth parameters. Year class strength is estimated as deviations from a Beverton-Holt stock-recruitment relationship beginning in 1970. Steepness of the Beverton-Holt stock-recruitment relationship is fixed at the mean of the prior ($h = 0.72$).

Stock Biomass

Spawning output of vermilion rockfish was estimated to be 489 million eggs in 2021 (95% asymptotic interval: 263 - 716 million eggs) or 43% (95% asymptotic interval: 25% - 61%) 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 northern California, spawning output declined rapidly in the 1970s and early 1980s, likely falling below the minimum stock size threshold for a number of years in the 1990s and early 2000s, followed by a steady recovery since the late 2000s (Figures ii and iii). The point estimate for spawning output in 2021 is just above the management target (40% of unfished spawning output).

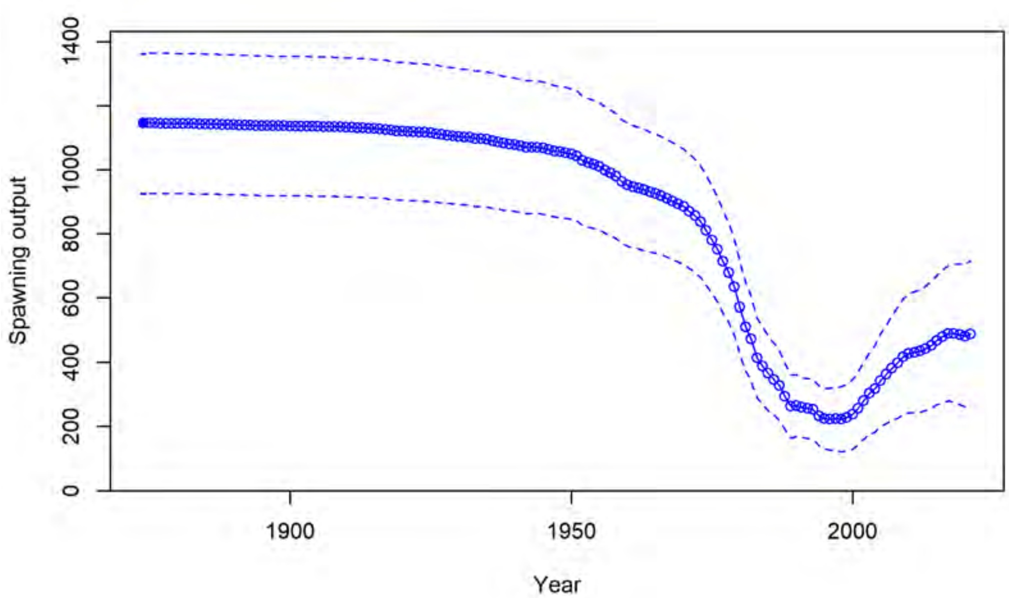

Figure ii: Estimated time series of spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

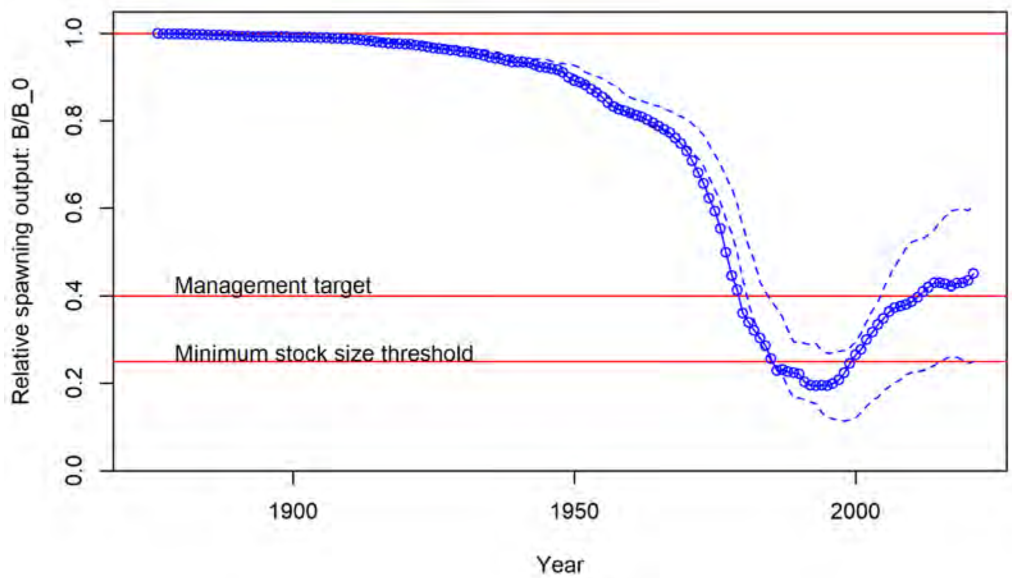

Figure iii: Estimated time series of spawning output relative to unfished spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

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	431.973	244.002	619.944	0.377	0.227	0.527
2012	435.431	244.955	625.907	0.380	0.229	0.531
2013	442.395	249.226	635.564	0.386	0.234	0.539
2014	454.034	257.314	650.754	0.396	0.241	0.552
2015	469.146	267.897	670.395	0.410	0.251	0.568
2016	479.639	273.578	685.700	0.419	0.257	0.581
2017	490.602	279.902	701.302	0.428	0.263	0.594
2018	490.707	275.944	705.470	0.428	0.260	0.597
2019	487.751	269.376	706.126	0.426	0.254	0.598
2020	482.178	260.377	703.979	0.421	0.246	0.596
2021	489.439	263.228	715.650	0.427	0.249	0.606

Recruitment

Recruitment deviations were estimated from 1970-2020 with a recent, strong recruitment in 2016 that has contributed to the recent increase in vermilion rockfish biomass in northern California (Table iii; Figure iv). The second highest estimated recruitment occurred in 1985 and is more certain than the estimated 2016 recruitment.

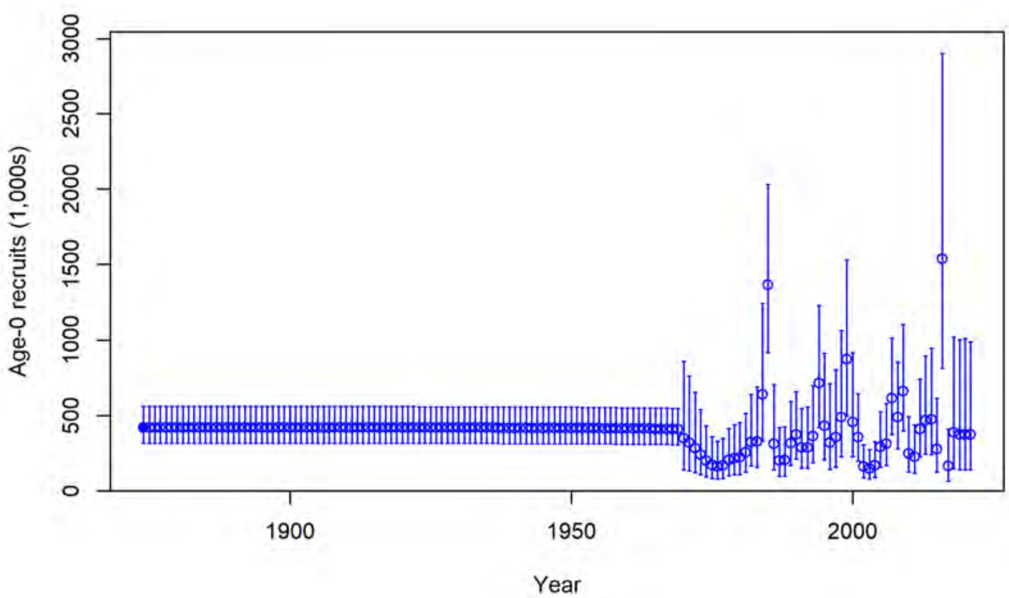

Figure iv: Age-0 recruits (1,000s) with approximate 95% asymptotic confidence intervals.

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	225	116	437	-0.397	-0.956	0.163
2012	408	224	741	0.196	-0.279	0.672
2013	466	242	896	0.326	-0.220	0.872
2014	476	239	946	0.341	-0.248	0.930
2015	277	125	616	-0.215	-0.937	0.506
2016	1536	814	2901	1.472	0.963	1.980
2017	163	65	409	-0.800	-1.680	0.081
2018	387	147	1022	0.048	-0.892	0.988
2019	373	138	1004	0.003	-0.964	0.970
2020	374	138	1010	0.009	-0.961	0.978
2021	372	140	991	0.000	-0.980	0.980

Exploitation Status

The annual (equilibrium) spawning potential ratio (SPR) for vermilion rockfish was above target from 2017-2019 (Table iv, Figure v). Prior to 2011, the fishing intensity exceeded the target for a number of years, regularly reaching levels 50% above target in the 1980s and 1990s (Figure v). As with current estimates of spawning output, recent estimates of equilibrium SPR are highly uncertain, ranging from 68% to 129% of target in 2020 (Table iv). As a percentage of total biomass (ages 4+), California harvest rates peaked in the 1980s and 1990s, but have since declined to levels below 10% for the past decade (Figure vi). Harvest rates in northern California were near target in 2020, but above target in the three previous years (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 fixed at 0.72 (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	0.939	0.653	1.224	0.061	0.037	0.085
2012	0.826	0.558	1.094	0.051	0.031	0.071
2013	0.715	0.469	0.961	0.041	0.025	0.056
2014	0.701	0.461	0.941	0.040	0.024	0.055
2015	0.966	0.684	1.249	0.062	0.038	0.087
2016	0.905	0.629	1.181	0.058	0.035	0.080
2017	1.108	0.808	1.408	0.077	0.045	0.108
2018	1.164	0.861	1.467	0.081	0.047	0.115
2019	1.248	0.943	1.554	0.094	0.054	0.133
2020	0.990	0.684	1.296	0.061	0.035	0.088

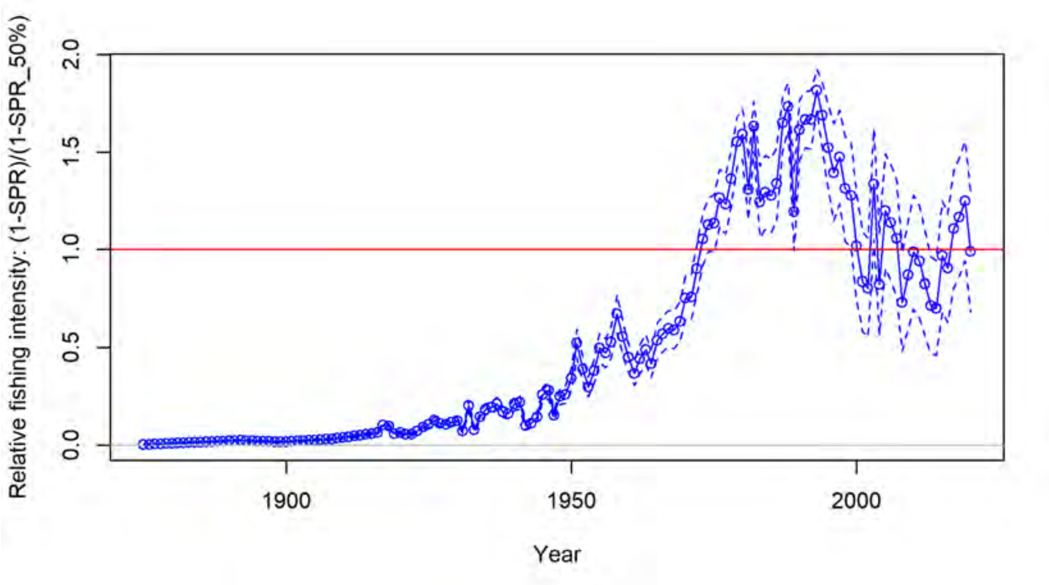

Figure v: Timeseries of relative fishing intensity ($\frac{1-SPR}{1-SPR_{50\%}}$ where SPR is the spawning potential ratio) with approximate 95% asymptotic confidence intervals (dashed lines).

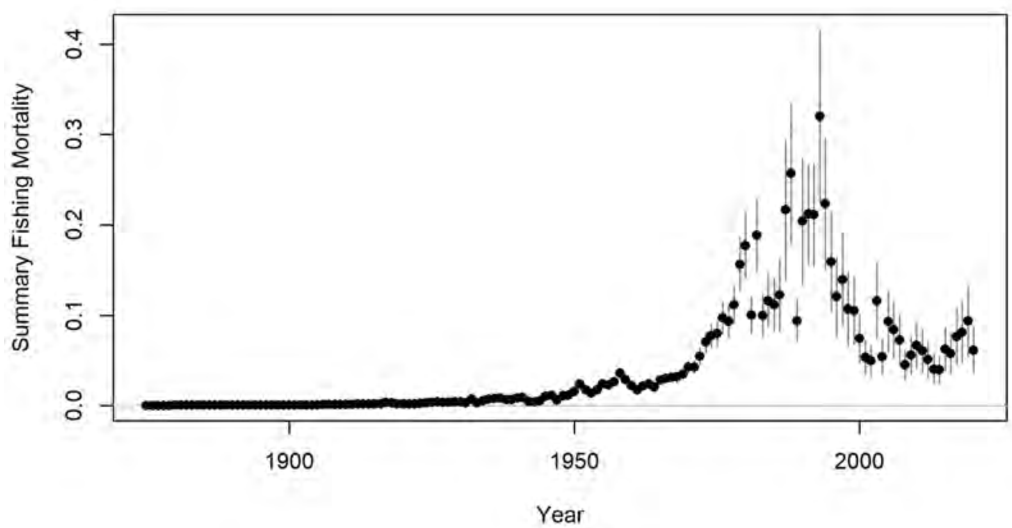

Figure vi: Time-series of estimated summary harvest rate (total catch divided by age-4 and older biomass) for the base case model with approximate 95% asymptotic confidence intervals (vertical lines).

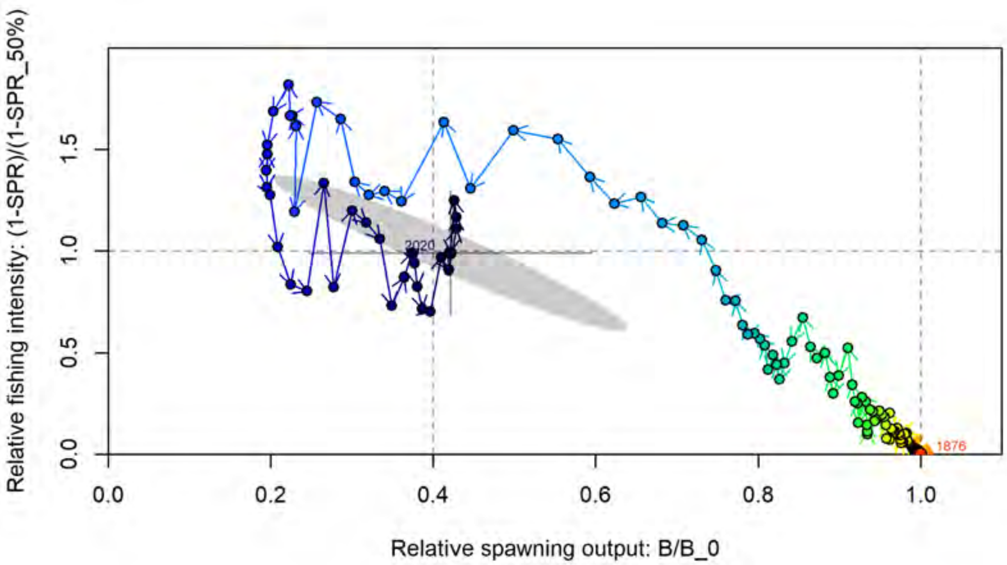

Figure vii: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point (representing 2020) show the 95% intervals 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.

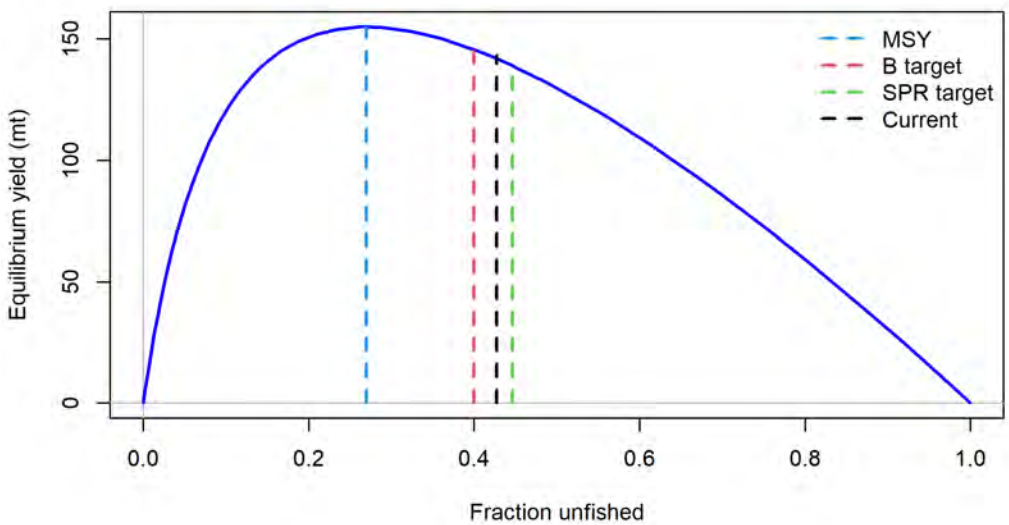

Figure viii: Equilibrium yield curve for the base case model with management quantities. Values are based on the 2020 fishery selectivities.

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 43% (95% asymptotic interval: 25% - 61%). This stock assessment estimates that vermilion rockfish in the north 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 6342 mt in the base case model (95% asymptotic interval: 5667 - 7017 mt). The target spawning output ($SB_{40\%}$) is 458 million eggs (95% asymptotic interval: 366 - 550 million eggs). Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 139 mt (95% asymptotic interval: 118 - 160 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	1145.180	914.835	1375.525
Unfished Age 4+ Biomass (mt)	6341.790	5666.596	7016.984
Unfished Recruitment (R_0)	420.186	299.040	541.332
Spawning Output (2021)	489.439	263.228	715.650
Fraction Unfished (2021)	0.427	0.249	0.606
Reference Points Based on $SB_{40\%}$			
Proxy Spawning Output $SB_{40\%}$	458.073	365.935	550.211
SPR Resulting in $SB_{40\%}$	0.458	0.458	0.458
Exploitation Rate Resulting in $SB_{40\%}$	0.071	0.060	0.083
Yield with SPR Based On $SB_{40\%}$ (mt)	145.614	123.238	167.990
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output ($SPR_{50\%}$)	510.928	408.159	613.697
$SPR_{50\%}$	0.500		
Exploitation Rate Corresponding to $SPR_{50\%}$	0.062	0.052	0.073
Yield with $SPR_{50\%}$ at SB_{SPR} (mt)	138.992	117.750	160.234
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB_{MSY})	308.931	249.480	368.382
SPR_{MSY}	0.341	0.332	0.349
Exploitation Rate Corresponding to SPR_{MSY}	0.104	0.087	0.121
MSY (mt)	155.029	130.706	179.352

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)	100.124	87.083	75.837	77.220	123.528	112.080	165.560	180.495	204.445	139.006	
$(1-SPR)/(1-SPR_{50\%})$	0.939	0.826	0.715	0.701	0.966	0.905	1.108	1.164	1.248	0.990	
Annual F	0.061	0.051	0.041	0.040	0.062	0.058	0.077	0.081	0.094	0.061	
Age 4+ Biomass (mt)	2741.110	2813.220	2961.290	3037.340	3087.710	3118.040	3173.250	3184.580	3135.420	3393.480	6335.880
Spawning Output (10^6)											
Estimate	431.973	435.431	442.395	454.034	469.146	479.639	490.602	490.707	487.751	482.178	489.439
Lower Interval	244.002	244.955	249.226	257.314	267.897	273.578	279.902	275.944	269.376	260.377	263.228
Upper Interval	619.944	625.907	635.564	650.754	670.395	685.700	701.302	705.470	706.126	703.979	715.650
Recruits (1,000s)											
Estimate	224.973	407.824	465.847	475.537	277.184	1536.160	162.592	387.483	372.609	373.837	371.777
Lower Interval	115.906	224.497	242.276	238.986	124.805	813.510	64.605	146.879	138.265	138.332	139.533
Upper Interval	436.670	740.858	895.729	946.231	615.609	2900.748	409.194	1022.226	1004.144	1010.280	990.579
Fraction Unfished											
Estimate	0.377	0.380	0.386	0.396	0.410	0.419	0.428	0.428	0.426	0.421	0.427
Lower Interval	0.227	0.229	0.234	0.241	0.251	0.257	0.263	0.260	0.254	0.246	0.249
Upper Interval	0.527	0.531	0.539	0.552	0.568	0.581	0.594	0.597	0.598	0.596	0.606

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 forecasts is based upon the three states of nature agreed upon at the STAR panel, reflecting three different natural mortality rates. The steepness parameter of the Beverton-Holt stock-recruit curve was fixed in the base model and in all of the forecasts. The northern California model is not data rich and while there is uncertainty in steepness, it was not well estimated in the base model when natural mortality was also estimated. The alternative states of nature maintain the female to male natural mortality rate ratio from the base model. To capture the 75% interval around the negative log-likelihood, alternate states were identified within 0.66 negative log-likelihood points from the base model where female $M = 0.0856$ and male $M = 0.0805$. The high state of nature fixes female $M = 0.0956$ and male $M = 0.08989$. For the low state of nature, female $M = 0.0769$ and male $M = 0.07231$.

For reference, the base model predicted $\sigma = 0.246$. The buffers between the OFL and ABC were calculated assuming a category 1 stock, with $\sigma = 0.5$ and a $p^* = 0.45$. The alternative catch stream (rows in the table) include $\sigma = 0.5$ with a $p^* = 0.4$ for a category 1 stock. Additional runs assuming a category 2 stock, conducted prior to the decision of a category 1 designation are in an appendix.

Current forecasts based on the alternative states of nature and requested catch streams project that the stock will remain above the target threshold of 40% in 2032 (Table x). In all of the scenarios of the low state of nature, the stock remains below the target threshold of 40% until 2026 or 2027. The base model with the base catches results in an increasing stock over the period from 2023-2032. In all scenarios the catch significantly decreases from 2022 to 2023; projected catch in 2022 is 227 mt, and 2023 catches from the base model range from 118-139 mt. The base model includes a portion of the stock within the northern management unit (north of $40°10'N$). An analysis based on the private/rental mode index through 2019 suggests that 4.44% of the catches from this model should be apportioned to the northern management unit for vermilion rockfish.

The STAT cautions that the GMT projections for catches in 2021-2022 (227 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 northern California stock is just above target biomass in 2021 (43% of unfished spawning ouptut), so these catch levels are unlikely to result in significant stock declines over a short period of time. However, similar catch levels would exceed the overfishing limits (OFL) if carried forward for 2023 and beyond (Table viii), 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			3459.01	489	0.427
2022			3459.21	491	0.429
2023	154.2	144	3436.92	497	0.434
2024	157.4	146	3480.14	515	0.450
2025	158.6	147	3505.64	530	0.463
2026	158.5	146	3517.70	542	0.474
2027	157.6	145	3520.37	552	0.482
2028	156.4	143	3517.50	558	0.487
2029	155.1	141	3511.45	562	0.491
2030	153.9	139	3503.96	565	0.493
2031	152.9	138	3496.35	566	0.494
2032	152.1	136	3489.16	567	0.495

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	
				Female M = 0.0769 Male M = 0.0723 NLL = 1031.36		Female M = 0.0856 Male M = 0.0805 NLL = 1030.7		Female M = 0.0956 Male M = 0.0899 NLL = 1031.36	
	Year	Buffer	Catch (mt)	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
$p^* = 0.45, \sigma = 0.5$	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.935	144	438	0.363	497	0.434	568	0.519
	2024	0.930	146	452	0.375	515	0.450	589	0.539
	2025	0.926	147	464	0.385	530	0.463	608	0.556
	2026	0.922	146	474	0.393	542	0.474	623	0.569
	2027	0.917	145	480	0.398	552	0.482	634	0.579
	2028	0.913	143	485	0.402	558	0.487	641	0.586
	2029	0.909	141	488	0.405	562	0.491	646	0.590
	2030	0.904	139	490	0.407	565	0.493	648	0.592
	2031	0.900	138	492	0.408	566	0.494	649	0.593
	2032	0.896	136	493	0.409	567	0.495	648	0.592
$p^* = 0.40, \sigma = 0.5$	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.873	135	438	0.363	497	0.434	568	0.519
	2024	0.864	136	453	0.376	516	0.451	591	0.540
	2025	0.856	137	467	0.387	533	0.466	612	0.559
	2026	0.848	136	477	0.396	547	0.478	629	0.575
	2027	0.840	134	485	0.402	558	0.487	642	0.587
	2028	0.832	132	491	0.407	566	0.495	652	0.595
	2029	0.824	130	496	0.411	572	0.500	658	0.602
	2030	0.817	128	499	0.414	577	0.504	663	0.606
	2031	0.809	127	502	0.416	580	0.507	666	0.608
	2032	0.801	125	505	0.418	583	0.509	667	0.610

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.
- Connectedness of this stock with southern California (south of Point Conception) is an unresolved uncertainty as outlined in the STAT report and elsewhere in this report. Further studies on larval/juvenile/adult movement via tagging or other methods are warranted. Additionally population substructure investigations, particularly north and south of Cape Mendocino are also recommended.
- Development of a more comprehensive fishery-independent index is a priority for this region. This could involve expansion of the CCFRP across depths and latitudes or expansion of the NWFSC hook-and-line survey northward.

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 ($34°27'N$) that separates the two assessments is provided as Figure 1. The northern California model is bounded in the north by the California/Oregon border ($42°00'N$) and the southern California model is bounded by the U.S./ Mexico border in the south (Figure 1). Cape Mendocino ($40°10'N$) 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 ($40°10'N$).

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 ($40^{\circ}10'N$). Therefore, the northern California vermilion rockfish model contains a portion of the management area from Cape Mendocino ($40^{\circ}10'N$) to the California-Oregon border ($42^{\circ}00'N$). The southern California vermilion rockfish model contains the area within the southern management area (south of $40^{\circ}10'N$) that is south of Point Conception ($34^{\circ}27'N$).

The total mortality of the shelf rockfish complex has been above the OFL in all years (2011-2019) north of $40^{\circ}10'N$, and above the OFL south of $40^{\circ}10'N$ 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 $40^{\circ}10'N$ total mortality from 2011-2016. Vermilion rockfish decreased from 21% to 4% of the total contribution to the shelf rockfish complex north of $40^{\circ}10'N$ 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, Figure 6 for the commercial trawl fleet and Figure 7 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 8). 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 8). 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:

There are no available recreational length composition data available for 2020 north of Point Conception in RecFIN and sparse sampling was confirmed by J. Budrick (CDFW, pers. comm.). Data collected during the Miller and Gotshall study was also used by Karpov (1995) to compare MRFSS and historical estimates. Some sections of the assessment refer to the Miller and Gotshall dataset as "Karpov" data.

- Recreational party/charter mode (PC)
    - Miller and Gotshall dockside PC survey (1959-1960)

  - PC samples collected by commercial port samples (1978-1979)
  - MRFSS dockside PC survey (1980-2003)
  - CRFS dockside PC survey (2004-2019)
  - CRFS onboard (discard only) and dockside (retained only surveys 2004-2019)
  - Deb Wilson-Vandenberg onboard CPFV survey (1988-1998)
- Recreational private/rental mode (PR)
  - Miller and Gotshall dockside PR survey (1959)
  - MRFSS dockside PR (1980-2003)
  - CRFS dockside PR (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 9 for the recreational PC retained fleet and Figure 10 for the recreational PC discard fleet, Figure 11 for the recreational PR fleet, and Figure 12 for the Deb Wilson-Vandenberg CPFV onboard survey.

Recreational age composition data

There are no recreational age composition data available for vermilion rockfish from California state sampling programs. Otoliths are available from SWFSC collaborative study with Cal Poly to investigate the precision of back-calculating whole fish length from filleted fish in the CPFV fleet. These otoliths were not aged for this assessment.

Recreational indices of abundance

A number of indices of abundance were explored for the recreational fleet (Figure 13), 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)
- Deb Wilson Vandenberg's CPFV onboard observer survey (1988-1998)
- CDFW/Cal Poly CPFV onboard observer index (1999-2019)
- CRFS PR1 sites dockside survey (2004-2019)

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 14.

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 J. Abrams thesis data

For his master's thesis work at Humboldt State University, Jeff Abrams conducted fishery-independent hook-and-line surveys in 2010 and 2011 off of California's North Coast (Abrams 2014). Sites were randomly sampled from areas of known rocky habitat within six depth by distance-from-port strata out of three ports: Crescent City Harbor, Trinidad Bay and Noyo River Harbor. The otoliths collected as part of this study are valuable stock assessments of recreationally-important groundifsh species that are often lacking biological samples, especially from the North Coast. This collection resides at the SWFSC Santa Cruz lab.

Available Data

Age and Length Data. All 81 vermilion rockfish collected during the survey were aged and represent the most northern biological samples in the northern California model. The available length compositions for males and females, 2010-2011, are shown in Figure 15.

2.2.3 SWFSC Groundfish Ecology Cruises

Don Pearson (SWFSC, retired) conducted a series of groundfish surveys (hook-and-line and trawl) from 2003 - 2005 along the coast of California. Surveys were conducted onboard chartered commercial vessels and NOAA research vessels.

Even though samples were collected via multiple gear types, the the majority were collected using commercial hook-and-line hear, and data from all gears were combined for use in the assessment.

Available Data

Age and Length Data. A total of 229 vermilion rockfish otoliths were aged from this survey from samples in 2004-2005. The length composition includes 355 vermilion rockfish from these surveys (Figure 16).

2.2.4 California Collaborative Fisheries Research Project

Since 2007, the California Collaborative Fisheries Research Program (CCFRP) has monitored several areas in California to evaluate the performance of MPAs and understand nearshore fish populations (Wendt and Starr 2009, Starr et al. 2015). In 2017, the survey expanded beyond the four MPAs in central California (Año Nuevo, Point Lobos, Point Buchon, and

Piedras Blancas) to include the entire California coast. Fish are collected by volunteer anglers aboard CPFVs guided by one of the following academic institutions based on proximity to fishing location: Humboldt State University; Bodega Marine Laboratories; Moss Landing Marine Laboratories; Cal Poly San Luis Obispo; University of California, Santa Barbara; and Scripps Institution of Oceanography.

Surveys consist of fishing with hook-and-line gear for 30-45 minutes within randomly chosen 500 by 500 m grid cells within and outside MPAs. Prior to 2017, all fish were measured for length and released or descended to depth; since then, some have been retained for biological collections including otoliths and fin clips. This is the only long-term fisheries-independent data series that spans the entire California coast (although coastwide coverage is limited to recent years) and provides relative abundance and demographic data on fish stocks within California's network of MPAs.

Available Data

Age and Length Data. A total of 48 otoliths from the CCFRP survey were available, but not included in the assessment model due to annual sample sizes of fewer than in the CCFRP survey is in Figure 17.

Index of Abundance The index of abundance in the pre-STAR base model is based on a Bayesian negative binomial model, and the posterior predictions were weighted with the assumption that 20% of the available habitat within California state waters (0-3 nm) is within MPAs (Figure 13). The SWFSC has worked extensively on quantifying area of rocky habitat from high resolution bathymetric data collected as part of the Seafloor Mapping Program. This method of habitat area quantification has been used in a number of stock assessments to weight indices of abundance since 2013. This is the first time the habitat data are utilized to weight an inside/outside MPA effect within an index of abundance. Full details on the observed data, model selection and modeling methods 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.

2.3 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 $40°10'N$ (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 m and surveyed south to $40°10'N$. 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.

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 18). 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 19). The reading of the oldest aged fish falls within the 95% confidence interval using this model (Figure 20). The latter model was selected for use in the assessment and the distribution of true age and observed age is in Figure 21.

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 22), 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 23).

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. (2017b) 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. (2017b) to estimate a new fecundity-length relationship (Figure 24). 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 25, with spawning output at age (the product of maturity and fecundity) in Figure 26.

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 at birth was assumed to be 50:50 and plots of the sex ratio by year for data with sex-specific CAAL data are available in Figure 27, Figure 28, and Figure 29 along with 75% intervals calculated as Jeffreys intervals based on adjusted input sample sizes from Francis weighting (Brown et al. 2001). The WCGBTS provided the majority of age data to the assessment and no clear patterns can be seen in the sex ratios. For years with fish larger than 50 cm, the sex ratio is skewed towards females, which is consistent with the observation that females grow larger than males, on average.

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 31).

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 northern California model is fit to four fishery-dependent indices of relative abundance: 1) MRFSS CPFV dockside, 2) two onboard observer surveys, and 3) CRFS PR1 dockside. The MRFSS CPFV dockside index is assumed to be proportional to changes in the abundance of fish vulnerable to the recreational party/charter fleet (retained fish only). The onboard observer indices represent the same fleet (rec party/charter), but indices change in abundance during recent years. The onboard indices are specified as separate “survey” fleets in the model because they 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 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 1980 for both the PC and PR modes. Fishery-dependent length composition data are also included for the three commercial fleets. Age structures from the commercial fleets were also sparse and not considered for the northern California assessment.

Fishery-independent data sources in the northern California model are organized into four fleets. Data from the CCFRP survey were used to create an index of relative abundance and marginal length compositions by year. The WCGBTS is the second fishery-independent data source in the northern model. An abundance index was developed for the WCGBT 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. Additional age and length composition data came from the SWFSC groundfish ecology cruises and Jeff Abrams thesis collections (see data section for additional information).

Changes from the pre-STAR base model to the post-STAR base model
During the STAR panel two changes to the base model were agreed STAT proposed a modifications to the pre-STAR base that included 1) a time block on the CCFRP index in 2017 after the survey was expanded from central California to the entire California coast, as explored in Request 1 of the STAR panel report, 2) CCFRP length compositions re-weighted to reflect the weighting used in the index, and 3) removal of 2020 from the PR dockside index of abundance due to sampling constraints during COVID. The final base model was approved by both the STAT and the Panel.

3.2.1 Additional Specifications

Selectivity was specified using the double normal parameterization within Stock Synthesis for all fleets. Selectivity parameters were estimated for the commercial hook-and-line fleet, commercial trawl fleet, and the commercial net fleet, as well as 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. The Abrams dataset was too sparse to estimate its own selectivity parameters and was only collected over a two year period. The Abrams research selectivity mirrors the commercial hook-and-line fleet. The STAT explored mirroring this data set to the recreational PC fleet, but the length composition was more representative of the commercial fleet. Hook-and-line gear was the dominant collection method for the SWFSC groundfish ecology survey and is mirrored to the commercial hook-and-line fleet.

Selectivity parameters were estimated for the CCFRP fleet. Note that the post-STAR base model includes a time block on selectivity for CCFRP in 2017 when the survey expanded statewide.

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 118 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. 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, by sex, using the NWFSC hook-and-line survey data (Figure 32). Natural mortality was estimated for both females and males, and informed by a prior distribution. 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 in 2002 and 2017 (see regulations section). Recruitment deviates were estimated in the base model from 1970 – 2020. Initial (unfished equilibrium) recruitment was also estimated. An extra standard deviations were 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 33). 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 material on the Council's website.

4.1 Fixed parameters

The following parameters were fixed in the post-STAR base model:
* h controlling the steepness of the stock-recruit relationship * Selectivity parameters estimated at the bounds during model exploration

4.2 Parameter Estimates

The base model has a total of 118 estimated parameters (Table 8) that are described in more detail in the following sections:

4.3 Growth Estimation

The northern California base model estimated reasonable growth parameters for k and lengths at age 0 and age 30. Internal estimates of growth were estimated directly for both females and males, and not as an offset. An offset for male growth was explored, but the CV of length at $L_{age=30}$ was estimated around 2-3%. When the male CV was fixed to equal the female CV, the assessment model shrunk the CV of females at $L_{age=30}$, which the STAT did not find reasonable. Therefore, the male CV at $L_{age=30}$ was fixed at the CV estimated for females of 0.07 (Figure 34).

The direct estimation of male $L_{age=0} = 6.02$ cm was reasonable compared to female $L_{age=0} = 7.8$. While k was estimated larger for males (0.19) than females (0.15), female $L_{age=30}$ of 55 cm was larger than males at 49 cm. These results are consistent with other studies that have looked at sex-specific growth in vermilion rockfish.

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

Females L_∞ = 55.8 cm; k = 0.147; t_0 = -0.99

Males L_∞ = 50 cm; k = 0.199; t_0 = -0.63

4.4 Natural Mortality Estimation

The northern California model directly estimated male growth and natural mortality (M) parameters due to the above-mentioned issue with estimation of CVs for length at age 30 when using the offset parameterization. Female natural mortality was estimated at 0.09 (SE = 0.0083) and male natural mortality was estimated at 0.08 (SE = 0.0088), which the STAT considered reasonable given that observed maximum ages for both sexes are similar. Latitudinal gradients in natural mortality have been estimated for many species of rockfish, which is consistent with the higher estimates of M in the southern model.

4.5 Fits to Age Composition

The following plots show fits to the conditional age-at-length composition for each fleet/survey:
- Abrams research survey: Figures 35, **??** and 37
- WCGBT survey: Figures 38 - 40, **??**, and 42 - 45
- SWFSC groundfish ecology survey: Figures 46, **??** and 48

Fits to the conditional age-at-length data sets seemed reasonable, with no evidence of strong residual patterns. The largest residuals were mainly associated with the infrequently encountered, oldest individuals. The model was able to reproduce interannual changes in mean age for the NWFSC trawl and Abrams thesis research data, but tended to slightly overestimate average age (by about 1 year) in three of the four years for the SWFSC groundfish ecology data set.

4.6 Estimated Selectivity and Fits to Length Composition

Fits to the time-aggregated length comps were best for the commercial, recreational, and CCFRP fleets Figure (61). The following plots show estimated selectivity (when not mirrored, Figures 49 - 60) and fits to the length composition (Figures 61 - 83) for each fleet/survey:

- Commercial hook-and-line: Figures 53, 62, and 63
- Commercial trawl: Figures 54, 64, and 65
- Commercial net: Figures 55, 66, and 67
- Recreational retained PC: Figures 51, 56, 68, and 69
- Recreational discard PC: Figures 57, 70 and 71
- Recreational retained PR: Figures 52, 58, 72 and 73
- Deb Wilson-Vandenberg onboard CPFV survey: Figure 74 and 75
- WCGBT survey: Figures 59, 59, 76 and 77
- Abrams research survey: Figures 78 and 79
- SWFSC groundfish ecology survey: Figures 80 and 81
- CCFRP: Figures 60, 82 and Figure 83

The WCGBTS does not sample primary adult habitat types, resulting in a length frequency distribution that appears bimodal and is difficult for the model to reproduce (Figure 61), and also reflected in the descending limb of the selectivity around 0.42 for any fish larger than 20 cm (Figure 59). Fits to the two short-term research fleets (SWFSC groundfish ecology surveys and Abrams thesis research) are adequate, but ultimately based on mirrored selectivity curves (details in selectivity section, below). Fits to length composition data from the recreational fleets show evidence of modal progressions due to strong year classes (e.g., the 1984-1985 year classes entering the fishery a few years later), do not show evidence of strong patterns in the pearson residual plots, and the model is able to track associated changes in mean length over time.

The Abrams research fleet and SWFSC groundfish ecology selectivity curves were mirrored to the commercial hook-and-line fleet, which was fixed to an asymptotic selectivity (Figure 53). Initial estimation of the commercial trawl selectivity resulted in large terminal estimates with large standard errors. Therefore, it was fixed to be asymptotic and the peak size and the ascending width were estimated (Figure 54). The historic net fishery selectivity was estimated with four parameters including a descending limb; fish were fully selected by around 43 cm and by around 47 cm selectivity decreased to 0.6 (Figure 55).

All three selectivities for recreational fleets were estimated as domed selectivities (Figures 56, 57, 58). A number of regulatory changes in the recreational fleets prompted selectivity time blocks, and both recreational retained fleets estimated a large length at full selectivity in the later time block, from 2017-2020, which is consistent with relaxation of depth restrictions. Peak selectivity of the discard fleet is around 20 cm, and once fish reach 40 cm, they are no longer selected by the discard fleet. There is no size limit on vermilion rockfish and this is assumed to represent angler preference.

The CCFRP fishes within 150 ft of water to reduce barotrauma-induced mortality and does not observe the larger fish that are seen in the recreational fleets fishing in deeper waters (especially once depth restrictions were relaxed in 2017) and further offshore (Figure 60). The estimated length composition fits vary by year, with the early years expecting larger fish than were observed and the more recent years (2015-2020) expecting smaller fish, likely from the larger 2013-2014 year classes.

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 84 and 85
- CDFW dockside PR survey: Figures 86 and 87
- Deb Wilson-Vandenberg onboard CPFV survey: Figures 88 and 89

- CDFW/Cal Poly onboard CPFV survey: Figures 90 and 91
- CCFRP survey: Figures 92 and 93

Fits to the indices vary in quality. Three of the four recreational indices represented the PC fleet, covering the years 1980-2019. The MRFSS era dockside interview index was fit reasonably well except for the first few years of the index (Figures 84). The Deb Wilson-Vandenberg onboard survey from 1988-1998 was fairly flat and uninformative, and the model was not able to reproduce a spike in 1990 when an increased CPUE was estimated in the standardized index (Figures 88 and 89). However, it is unclear whether the increase in CPUE for one year is an artifact of the data or represents an actual short-term increase in abundance. The CDFW and Cal Poly onboard index, which now contains 21 years of data provided an uninformative fit to the data. Both the beginning (1999-2001) and ending (2017-2019) years represent time periods when the fishery had access to deeper water. Even with selectivity time blocks for these periods, the index was not fit to the decrease in observed CPUE from 1999-2001 or the slight increase from 2017-2019. There is some pattern in the residuals with groups of alternating positive and negative years (Figures 90 and 91). The recreational PR index was not well fit, even with additional error added within the model and residual patterns also indicate a poor fit (Figures 86 and 87). Residuals for the first part of the survey are positive and negative for the second half of the survey. The only fishery-independent index, CCFRP, fit reasonably well to the increasing trend from 2016-2020 (Figures 92 and 93). All of the indices (recreational and CCFRP) indicated an increasing trend from 2008 to 2010 and then a decrease with lows in all indices in 2013 that was not fit in any of the indices. CCFRP is the only index sampling within the MPAs, and starting in 2017 the index represents the entire coast north of Point Conception.

4.8 Derived Quantities

Spawning output north 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 late 1990s and 2000s for the stock to reach a stable level of spawning output (Table 10, Figure 95). Stock size is estimated to have been at the lowest level during the 1990s, but has since increased, in part due to strong recruitments in 1999 and 2016. The stock is estimated to have been below the management target of B40% since the early 1980s (Figure 95), recently returning to levels near the target biomass. Relative exploitation rates ($\frac{1-SPR}{1-SPR_{50\%}}$) increased through time, exceeding target levels from the 1970s through the 1990s. Exploitation over the past decade has fluctuated around target levels (Figure 96), with most catches landed by the recreational sector.

Vermilion rockfish spawning output in northern California was estimated to be 4489 million eggs in 2021 (95% asymptotic interval: 263 - 716 million eggs) or 43% (95% asymptotic interval: 25% - 61%) of unfished spawning output in 2021("depletion," Table ii) and Figure 95). In 2021, vermilion rockfish biomass north of Point Conception is estimated to be near the target biomass level, while experiencing fishing intensity around the SPR fishing intensity target (Figure 99). The equilibrium yield curve is shifted left, as expected from the fixed Beverton-Holt steepness parameter h=0.72 (Figures 97 and 98). Harvest rates in northern California were near target in 2020, but above target in the three previous years (Figure 99).

4.9 Recruitment Deviations

Model estimates of recruitment for the 1970-2018 period indicated an extended period of below-average recruitment throughout the 1970s and early 1980s, which is generally inconsistent with strong recruitment trends for many years in the 1970s and in 1980 for other species of rockfish. As this time period is only weakly informed by length data, this may indicate some potential for model misspecification. Major recruitments (strong year classes) estimated in the northern California model include strong 1984, 1985, 1999, and 2016 year classes (Figures 100, 101, 102, and 103). These are consistent with estimates of strong year classes in other rockfish stock assessments, nearly all of which suggest very high recruitment in 1999. More recently, strong year classes have been estimated in 2016 for widow rockfish, sablefish and Pacific hake, observations that are consistent with observations of high juvenile rockfish abundance in the California Current during the 2015-2016 large marine heatwave (Schroeder et al. 2019). Due to ageing error, years adjacent to strong (or weak) cohorts are sometimes estimated as having similar deviations.

4.10 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 total yield (landings plus discards) was 138.99 mt when using an $SPR_{50\%}$ reference harvest rate. The spawning output equivalent to 40% of the unfished level ($SB_{40\%}$) was 458 million eggs.

The 2020 spawning biomass relative to unfished equilibrium spawning biomass is just below the target of 40% of unfished levels (Figure 95). The relative fishing intensity, $(1 - SPR)/(1 - SPR_{50\%})$, was near the management target in 2020, and has fluctuated around the target level for the past decade (Figure 96 and 99).

Table v shows the full suite of estimated reference points for the base model and Figures 97 and 98 show the equilibrium yield curve and net production based on a steepness value fixed at 0.72.

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.

Drop-one analysis of the northern California assessment revealed slightly larger variability in spawning output trends relative to the south, but all runs were still within the range of uncertainty estimated by the base model (Figure 104). Removal of most fleets had little effect on terminal stock status, with best estimates in the vicinity of target biomass levels (Figure 105). An exception was removal of the REC_PC fleet, which caused the best estimate of terminal depletion to drop just above the minimum stock size threshold. This suggests that the REC_PC data sets, together, favor a less-depleted stock relative to data from the other fleets. The strength of the 2016 year class is sensitive to the removal of fleet-specific data sets (Figure 106). Removal of the REC_PR fleet produces the largest estimates of 2016 cohort size, and removal of the NWFSC_TWL fleet estimates a 2016 deviation that is less than half as large (but still positive). Uncertainty in the strength of this recent year class should be taken into consideration for short-term forecasts of stock abundance and yield. Changes in likelihoods, parameter estimates and derived quantities are recorded in Table 11. 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, the we both halved and doubled the historical catches in the pre-STAR base model. The historical catches tend to be far more uncertain than catches in the more recent and better documented era for rockfish (*Sebastes* spp.), as historically most rockfish were landed in mixed stock market categories. However, relative to the somewhat elevated uncertainties described in the historical catch sensitivity analysis for southern California vermilion rockfish, there is less evidence for substantive bias in historical catches of vermilion rockfish north of Point Conception, where there is better evidence that vermilion rockfish made up a relatively modest fraction of the total catch.

The halving and doubling of historical catches in the northern model did lead to substantial differences in estimates of stock status (Figures 107 and 108). A doubling of historical catches restuled in a stock slightly above the MSST, and a substantially larger predicted biomass when historical catches were halved. Equilibrium MSY estimates were also larger with greater historical catches (by approximately 32 tons) and reduced with lower historical catches. The relative change in model fit, as reflected by the total negative log likelihood, was modest, with a slightly improved fit in the lower historical catch scenario, and a slightly poorer fit in the higher historical catch scenario.

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 northern California assessment model were generally robust to this set of sensitivities (Figure 109). Best estimates from all runs were within the estimated range of uncertainty for the base model. Steepness was estimated at a higher value than the prior mean (estimated at 0.94 vs. fixed at 0.72). Similarly, stock status did not vary greatly among this set of sensitivity runs, with only a minor increase in 2021 relative spawning output when using McAllister-Ianelli weights and a slight decrease when estimating steepness (Figure 110). The use of McAllister-Ianelli weights had the greatest impact on estimated recruitment deviations (Figure 111). This weighting method significantly reduced the magnitude of the 2016 year class, and generally increased the variance of the estimated deviations. The McAllister-Ianelli method gives greater weight to the composition data for this model (Table 9), and resulted in lower estimates of the male and female natural mortality rates (Table 13).

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.

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 112, 113, and 114). 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 about 3 points. The model with forced asymptotic selectivity estimated a slightly higher natural mortality rates (female $M = 0.11$, male $M = 0.10$) and had a total negative likelihood that was over 30 points higher than the pre-STAR base model. Estimating 4 selectivity parameters per fleet (excluding the discard and NWFSC trawl survey) produced results similar to the pre-base model, with a slightly larger population scale. Parameters from a reparameterized Ricker stock-recruitment relationship were estimable (Table 14) with M fixed at base model values, but produced point results and a total likelihood that were generally consistent with the Beverton-Holt relationship assumed in the base model.

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 northern model (Figures 115, 116, 117, 118, and 119) suggest that this parameter is reasonably well informed between a range of approximately 0.07 and 0.11, a somewhat lower range of values than was estimated for the southern model. Interestingly, profiles for natural mortality in the north indicated that the length data were better fit by the model with a lower natural mortality rate, and the age data were better fit by a higher rate, a result that is in contrast to that observed in the southern model. Most of the indices were also better fit by a higher natural mortality rate, although the Deb Wilson-Vandenberg Index and the onboard observer index were better fit with lower natural mortality rates. As is typical, spawning output increased with decreasing natural mortality, such that the model estimate with $M = 0.05$ was 1.5 times that of the model estimate when M was assumed to be 0.12. Similarly, the model estimated depletion in 2020 was well above the target level, close to 70%, for the M=0.12 model, while the ending depletion was just barely over the minimum stock size threshold of 25% of the unfished level in the M=0.05 model (Figure 116).

A profile of steepness was conducted on values ranging from 0.30 to 0.90 in 0.10 increments. The likelihood profiles (by component, and by component and fleet) are shown as Figure 120, and the resulting model trajectories (spawning output, relative depletion, age-0 recruits, and recruitment deviations) are shown as Figures 122, 121, 123, and 124. 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 was some odd jumps 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 was actually more optimistic with lower steepness values and more pessimistic with higher steepness values. The higher steepness runs were also more pessimistic with respect to historical (late 1980s through the early 2000s) stock status.

A profile on the log of unfished recruitment was conducted on values ranging from 5.7 to 6.4 (the base model estimate was 6.07), and is shown as Figure 125. In general, age data was better fit by the model with higher values of R0, as was most of the survey data (as well as recruitment via likelihood penalties). The DWV_onboard survey index and the Rec_PR were both somewhat better fit by the lower R0 values. All length data were either better fit to lower R0 values or were uninformative. As with the southern model, spawning output is estimated to be greater with the higher R0 values, although the overall difference in scaling was minimal for early years. Also consistent with the southern model result, the northern model result was more pessimistic with the lower R0 values, with the low R0 values being below the MSST and higher R0 values suggesting that relative spawning output is well above target levels (Figures 126, 127, 128, and 129). As with the southern model, this is 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), such that the R0 profile is in many ways simply providing the same information as the profile on the natural mortality rate.

Additional profiles in which M is fixed may be helpful in evaluating model performance.

5.3 Retrospective Analysis

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

A five year retrospective analysis was conducted on the northern base model by sequentially removing data, beginning with data from the year 2020. Figures 130, 131, 132, and 133 show the estimated spawning output, the estimated depletion, the recruitment deviation estimates and the estimated fit to the CCFRP index (which was the index most affected by the analysis). The greatest impact of sequentially removing recent data was the declining estimate of the strength of the 2016 year class, a result similar to the southern model, as the length composition and index data that informed those year classes were removed. There was also a slightly lesser reduction in the strength of the 2013 and 2014 year classes. However, aside from a modest rescaling upwards of recruitment deviations, the spawning output and depletion estimates did not change by any significant measure, suggesting no concerning 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

This assessment treats populations north and south of Point Conception as separate, but there is likely larval or juvenile dispersal, and potentially some adult movement, among these areas. Dispersal and movement rates are not well known.

The primary fishery-independent survey for West Coast groundfish, the NWFSC WCGBTS, does not sample rocky habitats where most vermilion rockfish are found, and thus does not provide a robust index of abundance. An alternative survey, the CCFRP hook-and-line survey, provides a good signal for vermilion rockfish, including relative abundance and demographic structure inside and outside a number of MPAs. In addition to not including data from closed areas, many of the fishery-dependent indices are noisy, and some are not particularly well fit, such as the recreational PR dockside index.

Age data are limited and consequently growth and natural mortality estimates are uncertain. There is an unusual pattern of tension among data sources inferred by the likelihood profiles, with age data suggesting a higher natural mortality rate and length data suggesting a lower M. This is opposite the pattern seen in the southern assessment, and (very generally speaking) many other west coast groundfish assessments.

The model estimates a series of very low recruitment events throughout most of the 1970s, 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 forecasts is based upon the three states of nature agreed upon at the STAR panel, reflecting three different natural mortality rates. The steepness parameter of the Beverton-Holt stock-recruit curve was fixed in the base model and in all of the forecasts. The northern California model is not data rich and while there is uncertainty in steepness, it was not well estimated in the base model when natural mortality was also estimated. The alternative states of nature maintain the female to male natural mortality rate ratio from the base model. To capture the 75% interval around the negative log-likelihood, alternate states were identified within 0.66 negative log-likelihood points from the base model where female $M = 0.0856$ and male $M = 0.0805$. The high state of nature fixes female $M = 0.0956$ and male $M = 0.08989$. For the low state of nature, female $M = 0.0769$ and male $M = 0.07231$.

For reference, the base model predicted $\sigma = 0.246$. The buffers between the OFL and ABC were calculated assuming a category 2 stock, with $\sigma = 1.0$ and a $p^* = 0.45$. Alternative catch streams (rows in the table) include $\sigma = 1.0$ with a $p^* = 0.4$, and removals of long-term equilibrium catch with and without a buffer assuming $\sigma = 1.0$ with a $p^* = 0.45$. The buffer multiplier with $p^* = 0.45$ ranges from 0.874 in 2023 ramping to 0.803 in 2032.

Current forecasts based on the alternative states of nature and requested catch streams project that the stock will remain above the target threshold of 40% in 2032 (Table x). In all of the scenarios of the low state of nature, the stock remains below the target threshold of 40% until 2026 or 2027. The base model with the base catches results in an increasing stock over the period from 2023-2032. In all scenarios the catch significantly decreases from 2022 to 2023; projected catch in 2022 is 227 mt, and 2023 catches from the base model range from 118-139 mt. The base model includes a portion of the stock within the northern management unit (north of $40°10'N$). An analysis based on the private/rental mode index through 2019 suggests that 4.44% of the catches from this model should be apportioned to the northern management unit for vermilion rockfish.

The STAT cautions that the GMT projections for catches in 2021-2022 (22 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 northern California stock is just above target biomass in 2021 (43% of unfished spawning ouptut), so these catch levels are unlikely to result in significant stock declines over a short period of time. However, similar catch levels would exceed the overfishing limits (OFL) if carried forward for 2023 and beyond (Table viii), 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	0.240							0.240	
1876	0.481							0.481	
1877	0.721							0.721	
1878	0.961							0.961	
1879	1.201							1.201	
1880	1.442							1.442	
1881	1.682							1.682	
1882	1.922							1.922	
1883	2.163							2.163	
1884	2.403							2.403	
1885	2.643							2.643	
1886	2.884							2.884	
1887	3.124							3.124	
1888	3.364							3.364	
1889	3.604							3.604	
1890	3.845							3.845	
1891	4.085							4.085	
1892	4.325							4.325	
1893	4.082							4.082	
1894	3.839							3.839	
1895	3.596							3.596	
1896	3.396							3.396	
1897	3.195							3.195	
1898	2.995							2.995	
1899	2.794							2.794	
1900	3.091							3.091	
1901	3.389							3.389	
1902	3.686							3.686	
1903	3.983							3.983	
1904	4.281							4.281	
1905	4.574							4.574	
1906	4.867							4.867	
1907	5.161							5.161	
1908	5.454							5.454	
1909	6.137							6.137	

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	6.820							6.820	
1911	7.504							7.504	
1912	8.187							8.187	
1913	8.870							8.870	
1914	9.553							9.553	
1915	10.236							10.236	
1916	11.401	0.078						11.479	
1917	18.423	0.121						18.544	
1918	17.339	0.141						17.480	
1919	10.214	0.098						10.312	
1920	11.101	0.100						11.201	
1921	9.792	0.083						9.875	
1922	9.512	0.072						9.584	
1923	12.425	0.077						12.502	
1924	16.444	0.044						16.488	
1925	18.531	0.038						18.569	
1926	22.856	0.108						22.964	
1927	19.433	0.199						19.632	
1928	16.629	0.237		0.968		0.129		16.866	1.097
1929	16.687	0.415		1.936		0.258		17.102	2.194
1930	17.743	0.351		2.225		0.297		18.094	2.522
1931	6.901	0.372		2.967		0.396		7.273	3.363
1932	29.852	0.400		3.709		0.494		30.252	4.203
1933	4.689	0.662		4.450		0.593		5.351	5.043
1934	15.902	0.538		5.192		0.692		16.440	5.884
1935	22.085	0.516		5.934		0.791		22.601	6.725
1936	22.880	0.361		6.676		0.890		23.241	7.566
1937	23.651	0.642		7.913		1.055		24.293	8.968
1938	15.579	0.683		7.783		1.037		16.262	8.820
1939	15.410	0.964		6.806		0.907		16.374	7.713
1940	19.535	0.711		9.802		1.307		20.246	11.109
1941	22.414	0.575		9.059		1.208		22.989	10.267
1942	8.129	0.205		4.812		0.641		8.334	5.453
1943	8.953	2.123		4.602		0.613		11.076	5.215
1944	11.685	6.952		3.779		0.504		18.637	4.283
1945	25.632	13.081		5.038		0.672		38.713	5.710
1946	26.460	9.621		8.672		1.156		36.081	9.828

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	8.080	6.436		6.860		0.914		14.516	7.774
1948	15.948	4.601		13.691		1.825		20.549	15.516
1949	11.403	3.289		17.744		2.365		14.692	20.109
1950	20.761	3.513		21.624		2.883		24.274	24.507
1951	50.232	8.231		24.697		4.297		58.463	28.994
1952	25.828	6.312		21.489		3.739		32.140	25.228
1953	12.207	6.873		18.300		3.184		19.080	21.484
1954	15.970	11.603		22.750		3.958		27.573	26.708
1955	12.291	33.959		27.121		4.719		46.250	31.840
1956	18.960	13.532		30.283		5.269		32.492	35.552
1957	22.741	16.798		33.760		5.140		39.539	38.900
1958	29.220	17.213		48.275		8.438		46.433	56.713
1959	13.554	11.745		43.326		7.054		25.299	50.380
1960	14.338	12.582		28.609		5.462		26.920	34.071
1961	13.131	9.555		21.774		4.127		22.686	25.901
1962	15.768	8.377		27.549		6.925		24.145	34.474
1963	22.174	10.624		25.949		9.265		32.798	35.214
1964	18.474	6.040		20.317		10.292		24.514	30.609
1965	18.676	6.526		31.612		14.553		25.202	46.165
1966	23.120	6.256		30.545		17.182		29.376	47.727
1967	33.441	8.818		23.824		19.300		42.259	43.124
1968	15.824	9.849		30.533		21.820		25.673	52.353
1969	18.957	14.557		29.109		24.365		33.514	53.474
1970	38.364	17.340		29.796		28.201		55.704	57.997
1971	44.496	14.437		27.202		28.446		58.933	55.648
1972	50.334	21.573		38.963		32.994		71.907	71.957
1973	64.800	24.939		51.944		37.561		89.739	89.505
1974	86.226	26.708		46.594		40.375		112.934	86.969
1975	69.642	34.322		45.448		42.019		103.964	87.467
1976	93.143	41.767		47.441		45.682		134.910	93.123
1977	80.740	36.816		36.765		46.300		117.556	83.065
1978	147.227	24.299		28.583		46.998		171.526	75.581
1979	207.084	24.304		39.460		50.204		231.388	89.664
1980	156.720	51.306		38.464	1.793	52.516	0.675	208.026	93.448
1981	143.396	17.770	0.011	10.442	0.648	16.625	0.789	161.177	28.504
1982	212.016	14.963	0.002	37.100	2.302	27.914	1.325	226.981	68.641
1983	42.209	26.913	3.068	17.704	1.098	28.437	1.350	72.190	48.589

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	0.569	41.934	5.704	13.350	0.828	52.799	2.506	48.207	69.483
1985	0.823	42.702	12.506	18.446	1.144	40.652	1.930	56.031	62.172
1986	30.693	4.154	31.418	10.063	0.624	53.422	2.536	66.265	66.645
1987	29.064	44.472	65.800	50.415	3.128	55.851	2.651	139.336	112.045
1988	55.941	21.304	49.169	77.850	4.830	107.405	5.098	126.414	195.183
1989	34.448	2.654	6.120	16.690	1.036	68.454	3.249	43.222	89.429
1990	61.399	1.485	60.728	45.553	2.826	91.362	4.337	123.612	144.078
1991	126.397	0.561	13.817	43.835	2.720	94.794	4.499	140.775	145.848
1992	103.910	10.272	0.328	42.118	2.613	98.227	4.662	114.510	147.620
1993	150.587	21.365	19.802	40.401	2.507	125.643	5.964	191.754	174.515
1994	85.276	14.598	10.992	38.684	2.400	77.675	3.687	110.866	122.446
1995	49.647	15.606	10.994	36.967	2.294	44.727	2.123	76.247	86.111
1996	63.809	10.343	9.314	24.106	1.496	23.840	1.132	83.466	50.574
1997	64.022	13.592	7.143	46.393	2.878	25.198	1.196	84.757	75.665
1998	44.000	27.858	6.333	15.063	0.935	31.625	1.501	78.191	49.124
1999	34.011	8.816	0.012	34.743	2.156	50.273	2.386	42.839	89.558
2000	12.629	0.460	0.017	35.685	2.214	42.306	2.008	13.106	82.213
2001	11.286	2.752	0.103	27.561	1.710	28.825	1.368	14.141	59.464
2002	6.487	0.160		16.260	1.009	49.219	2.336	6.647	68.824
2003	5.829	0.176		20.646	1.281	148.420	7.045	6.005	177.392
2004	10.123	0.154		36.496	2.264	36.835	1.748	10.277	77.343
2005	11.476	0.090	0.007	94.576	1.242	46.584	1.067	11.573	143.469
2006	12.101	0.001		59.900	0.029	56.800	1.474	12.102	118.203
2007	13.314			45.292	0.096	46.542	0.779	13.314	92.709
2008	9.778	0.164		17.789	0.063	29.531	2.392	9.942	49.775
2009	7.058	0.029		23.383	1.247	40.157	1.430	7.087	66.217
2010	6.939	0.010		52.499	0.620	29.975	1.284	6.949	84.378
2011	10.047			38.094	1.250	40.223	0.618	10.047	80.185
2012	9.400	0.006		35.352	0.853	35.099	0.798	9.406	72.102
2013	13.845	0.005		20.502	0.402	35.159	0.409	13.850	56.472
2014	14.139	0.015	0.023	19.670	0.163	35.302	0.833	14.177	55.968
2015	18.172	0.410	0.010	36.213	0.457	52.952	0.945	18.592	90.567
2016	13.271	0.094		34.281	0.786	48.712	1.071	13.365	84.850
2017	14.226	0.062	0.002	62.594	1.528	42.352	1.110	14.290	107.584
2018	19.041	0.619		60.220	0.734	53.136	1.250	19.660	115.340
2019	19.593	0.039		64.423	1.118	69.455	2.273	19.632	137.269
2020	19.930	0.017		39.824	0.531	49.817	0.882	19.947	91.054

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	1978-2020		
COM_TWL_2		1916-1968	1978-2020		
COM_NET_3			1981-2017		
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).

Year	FB 105	NMFS ERD live-access server				Major SLO Ports					
	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	1978	COM_HKL(1)	25	1	1.00
CALCOM	1979	COM_HKL(1)	464	14	14.00
CALCOM	1980	COM_HKL(1)	770	19	19.00
CALCOM	1981	COM_HKL(1)	898	23	23.00
CALCOM	1982	COM_HKL(1)	407	10	10.00
CALCOM	1983	COM_HKL(1)	89	3	3.00
CALCOM	1986	COM_HKL(1)	17	1	1.00
CALCOM	1990	COM_HKL(1)	10	1	1.00
CALCOM	1991	COM_HKL(1)	70	4	4.00
CALCOM	1992	COM_HKL(1)	219	15	15.00
CALCOM	1993	COM_HKL(1)	924	50	49.00
CALCOM	1994	COM_HKL(1)	309	20	20.00
CALCOM	1995	COM_HKL(1)	163	10	10.00
CALCOM	1996	COM_HKL(1)	394	23	23.00
CALCOM	1997	COM_HKL(1)	289	14	14.00
CALCOM	1998	COM_HKL(1)	203	9	9.00
CALCOM	1999	COM_HKL(1)	264	16	16.00
CALCOM	2000	COM_HKL(1)	15	1	1.00
CALCOM	2001	COM_HKL(1)	20	2	2.00
CALCOM	2002	COM_HKL(1)	28	2	2.00
CALCOM	2005	COM_HKL(1)	34	4	3.00
CALCOM	2006	COM_HKL(1)	68	4	4.00
CALCOM	2007	COM_HKL(1)	74	4	4.00
CALCOM	2008	COM_HKL(1)	22	3	2.00
CALCOM	2009	COM_HKL(1)	45	4	4.00
CALCOM	2011	COM_HKL(1)	22	1	1.00
CALCOM	2012	COM_HKL(1)	12	1	1.00
CALCOM	2013	COM_HKL(1)	12	1	1.00
CALCOM	2014	COM_HKL(1)	116	9	9.00
CALCOM	2015	COM_HKL(1)	29	2	2.00
CALCOM	2016	COM_HKL(1)	15	1	1.00
CALCOM	2017	COM_HKL(1)	45	4	4.00
CALCOM	2018	COM_HKL(1)	11	1	1.00
CALCOM	2019	COM_HKL(1)	108	6	6.00
CALCOM	2020	COM_HKL(1)	61	4	4.00
CALCOM	1979	COM_TWL(2)	14	1	1.00
CALCOM	1983	COM_TWL(2)	22	2	2.00
CALCOM	1984	COM_TWL(2)	76	5	5.00
CALCOM	1985	COM_TWL(2)	18	1	1.00
CALCOM	1987	COM_TWL(2)	13	1	1.00
CALCOM	1992	COM_TWL(2)	13	1	1.00

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

Source	Year	Fleet(#)	Number fish	Sample size	Trips
CALCOM	1993	COM_TWL(2)	35	3	3.00
CALCOM	1994	COM_TWL(2)	12	1	1.00
CALCOM	1996	COM_TWL(2)	44	2	2.00
CALCOM	1997	COM_TWL(2)	42	3	3.00
CALCOM	1999	COM_TWL(2)	21	1	1.00
CALCOM	2015	COM_TWL(2)	18	1	1.00
CALCOM	2016	COM_TWL(2)	15	1	1.00
CALCOM	2017	COM_TWL(2)	26	1	1.00
CALCOM	2018	COM_TWL(2)	47	2	2.00
CALCOM	1987	COM_NET(3)	28	2	2.00
CALCOM	1988	COM_NET(3)	21	1	1.00
CALCOM	1990	COM_NET(3)	110	7	7.00
CALCOM	1993	COM_NET(3)	66	3	3.00
CALCOM	1994	COM_NET(3)	42	2	2.00
CALCOM	1995	COM_NET(3)	80	6	6.00
CALCOM	1996	COM_NET(3)	36	2	2.00
CALCOM	1997	COM_NET(3)	34	2	2.00
CALCOM	1998	COM_NET(3)	70	3	3.00
KARPOV	1959	REC_PC(4)	506		
KARPOV	1960	REC_PC(4)	1042		
SWFSC	1978	REC_PC(4)	30	26	
SWFSC	1979	REC_PC(4)	82	31	
MRFSS	1980	REC_PC(4)	73		51.00
MRFSS	1981	REC_PC(4)	33		27.00
MRFSS	1982	REC_PC(4)	37		34.00
MRFSS	1983	REC_PC(4)	37		30.00
MRFSS	1984	REC_PC(4)	86		62.00
MRFSS	1985	REC_PC(4)	139		93.00
MRFSS	1986	REC_PC(4)	127		84.00
MRFSS	1987	REC_PC(4)	223		73.00
MRFSS	1988	REC_PC(4)	154		89.00
MRFSS	1989	REC_PC(4)	234		94.00
MRFSS	1993	REC_PC(4)	59		40.00
MRFSS	1994	REC_PC(4)	81		45.00
MRFSS	1995	REC_PC(4)	88		65.00
MRFSS	1996	REC_PC(4)	315		208.00
MRFSS	1997	REC_PC(4)	1209		156.00
MRFSS	1998	REC_PC(4)	210		91.00
MRFSS	1999	REC_PC(4)	571		295.00
MRFSS	2000	REC_PC(4)	129		81.00
MRFSS	2001	REC_PC(4)	200		134.00
MRFSS	2002	REC_PC(4)	378		235.00

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

Source	Year	Fleet(#)	Number fish	Sample size	Trips
MRFSS	2003	REC_PC(4)	577		361.00
CRFS	2004	REC_PC(4)	995		176.00
CRFS	2005	REC_PC(4)	1627		288.00
CRFS	2006	REC_PC(4)	1444		256.00
CRFS	2007	REC_PC(4)	1805		319.00
CRFS	2008	REC_PC(4)	690		122.00
CRFS	2009	REC_PC(4)	884		156.00
CRFS	2010	REC_PC(4)	1630		288.00
CRFS	2011	REC_PC(4)	1426		252.00
CRFS	2012	REC_PC(4)	1234		218.00
CRFS	2013	REC_PC(4)	917		162.00
CRFS	2014	REC_PC(4)	563		159.00
CRFS	2015	REC_PC(4)	734		190.00
CRFS	2016	REC_PC(4)	742		166.00
CRFS	2017	REC_PC(4)	1082		175.00
CRFS	2018	REC_PC(4)	1190		150.00
CRFS	2019	REC_PC(4)	1357		163.00
CRFS	2003	REC_PC_DIS(5)	38		
CRFS	2004	REC_PC_DIS(5)	78		
CRFS	2005	REC_PC_DIS(5)	67		
CRFS	2006	REC_PC_DIS(5)	49		
CRFS	2007	REC_PC_DIS(5)	9		
CRFS	2008	REC_PC_DIS(5)	9		
CRFS	2009	REC_PC_DIS(5)	40		
CRFS	2010	REC_PC_DIS(5)	70		
CRFS	2011	REC_PC_DIS(5)	13		
CRFS	2012	REC_PC_DIS(5)	6		
CRFS	2013	REC_PC_DIS(5)	6		
CRFS	2014	REC_PC_DIS(5)	7		
CRFS	2015	REC_PC_DIS(5)	6		
CRFS	2016	REC_PC_DIS(5)	5		
CRFS	2017	REC_PC_DIS(5)	6		
CRFS	2018	REC_PC_DIS(5)	2		
CRFS	2019	REC_PC_DIS(5)	13		
KARPOV	1959	REC_PR(6)	499		
MRFSS	1980	REC_PR(6)	89		62.00
MRFSS	1981	REC_PR(6)	55		36.00
MRFSS	1982	REC_PR(6)	109		65.00
MRFSS	1983	REC_PR(6)	83		60.00
MRFSS	1984	REC_PR(6)	176		117.00
MRFSS	1985	REC_PR(6)	137		93.00
MRFSS	1986	REC_PR(6)	158		102.00

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

Source	Year	Fleet(#)	Number fish	Sample size	Trips
MRFSS	1987	REC_PR(6)	97		45.00
MRFSS	1988	REC_PR(6)	79		46.00
MRFSS	1989	REC_PR(6)	94		51.00
MRFSS	1993	REC_PR(6)	510		269.00
MRFSS	1994	REC_PR(6)	285		147.00
MRFSS	1995	REC_PR(6)	152		85.00
MRFSS	1996	REC_PR(6)	119		73.00
MRFSS	1997	REC_PR(6)	92		50.00
MRFSS	1998	REC_PR(6)	124		79.00
MRFSS	1999	REC_PR(6)	255		135.00
MRFSS	2000	REC_PR(6)	197		101.00
MRFSS	2001	REC_PR(6)	71		45.00
MRFSS	2002	REC_PR(6)	240		126.00
MRFSS	2003	REC_PR(6)	494		187.00
CRFS	2004	REC_PR(6)	2098		371.00
CRFS	2005	REC_PR(6)	4068		1784.21
CRFS	2006	REC_PR(6)	5036		2208.77
CRFS	2007	REC_PR(6)	3889		1705.70
CRFS	2008	REC_PR(6)	2600		1140.35
CRFS	2009	REC_PR(6)	1994		874.56
CRFS	2010	REC_PR(6)	1938		850.00
CRFS	2011	REC_PR(6)	2210		969.30
CRFS	2012	REC_PR(6)	1917		840.79
CRFS	2013	REC_PR(6)	2409		1056.58
CRFS	2014	REC_PR(6)	2117		1058.00
CRFS	2015	REC_PR(6)	3492		1620.00
CRFS	2016	REC_PR(6)	3315		1406.00
CRFS	2017	REC_PR(6)	2963		1384.00
CRFS	2018	REC_PR(6)	3225		1350.00
CRFS	2019	REC_PR(6)	3426		1329.00
CDFW	1988	DWV_ONBOARD(8)	674		100.00
CDFW	1989	DWV_ONBOARD(8)	1274		134.00
CDFW	1990	DWV_ONBOARD(8)	583		48.00
CDFW	1991	DWV_ONBOARD(8)	388		62.00
CDFW	1992	DWV_ONBOARD(8)	1173		145.00
CDFW	1993	DWV_ONBOARD(8)	1079		162.00
CDFW	1994	DWV_ONBOARD(8)	753		112.00
CDFW	1995	DWV_ONBOARD(8)	964		147.00
CDFW	1996	DWV_ONBOARD(8)	582		137.00
CDFW	1997	DWV_ONBOARD(8)	1278		177.00
CDFW	1998	DWV_ONBOARD(8)	662		118.00
NWFSC	2003	NWFSC_TWL(9)	21	4	

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

Source	Year	Fleet(#)	Number fish	Sample size	Trips
NWFSC	2004	NWFSC_TWL(9)	6	4	
NWFSC	2005	NWFSC_TWL(9)	7	2	
NWFSC	2006	NWFSC_TWL(9)	18	4	
NWFSC	2007	NWFSC_TWL(9)	1	1	
NWFSC	2008	NWFSC_TWL(9)	37	14	
NWFSC	2009	NWFSC_TWL(9)	208	21	
NWFSC	2010	NWFSC_TWL(9)	33	12	
NWFSC	2011	NWFSC_TWL(9)	3	2	
NWFSC	2012	NWFSC_TWL(9)	40	4	
NWFSC	2013	NWFSC_TWL(9)	50	9	
NWFSC	2014	NWFSC_TWL(9)	17	12	
NWFSC	2015	NWFSC_TWL(9)	5	5	
NWFSC	2016	NWFSC_TWL(9)	9	9	
NWFSC	2017	NWFSC_TWL(9)	64	12	
NWFSC	2018	NWFSC_TWL(9)	26	7	
NWFSC	2019	NWFSC_TWL(9)	42	7	
J_ABRAMS	2010	ABRAMS_RE-SEARCH(11)	25		
J_ABRAMS	2011	ABRAMS_RE-SEARCH(11)	56		
SWFSC	2002	SWFSC_GF_ECOL(12)	71	13	
SWFSC	2003	SWFSC_GF_ECOL(12)	110	22	
SWFSC	2004	SWFSC_GF_ECOL(12)	118	18	
SWFSC	2005	SWFSC_GF_ECOL(12)	25	9	
SWFSC	2010	SWFSC_GF_ECOL(12)	12	3	
SWFSC	2016	SWFSC_GF_ECOL(12)	19	3	
CCFRP	2007	CCFRP(13)	140	57	
CCFRP	2008	CCFRP(13)	230	74	
CCFRP	2009	CCFRP(13)	226	65	
CCFRP	2010	CCFRP(13)	320	86	
CCFRP	2011	CCFRP(13)	282	75	
CCFRP	2012	CCFRP(13)	294	90	
CCFRP	2013	CCFRP(13)	172	73	
CCFRP	2014	CCFRP(13)	272	92	
CCFRP	2015	CCFRP(13)	168	56	
CCFRP	2016	CCFRP(13)	387	87	
CCFRP	2017	CCFRP(13)	366	107	
CCFRP	2018	CCFRP(13)	482	115	
CCFRP	2019	CCFRP(13)	558	130	
CCFRP	2020	CCFRP(13)	447	111	

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	1978-2020
CALCOM	2	N_SAMPLES, YEARS WITH <30 FISH EXCLUDED	1979-2018
CALCOM	3	N_SAMPLES, YEARS WITH <30 FISH EXCLUDED	1987-1998
CRFS	4	N_TRIPS	2014-2019
CRFS	4	N_TRIPS ESTIMATED FROM AVG. FISH/TRIP	2004-2013
KARPOV	4	N_FISH / 10	1959-1960
MRFSS	4	N_TRIPS ESTIMATED FROM B. SOPER ALGORITHM	1980-2003
SWFSC	4	N_SAMPLES	1978-1979
CRFS	5	N_FISH, YEARS WITH <10 FISH EXCLUDED	2003-2019
CRFS	6	N_TRIPS	2014-2019
CRFS	6	N_TRIPS ESTIMATED FROM AVG. FISH/TRIP	2004-2013
KARPOV	6	N_FISH / 10	1959-1959
MRFSS	6	N_TRIPS ESTIMATED FROM B. SOPER ALGORITHM	1980-2003
CDFW	8	N_TRIPS (UNIQUE ASSIGNMENT NUMBERS)	1988-1998
NWFSC	9	EFFECTIVE N BASED ON STEWART & HAMEL (2014)	2003-2019
J_ABRAMS	11	N_FISH	2010-2011
SWFSC	12	N_SAMPLES (NUMBER OF HAULS)	2002-2016
CCFRP	13	N_SAMPLES (UNIQUE ID.CELL.PER.TRIP)	2007-2020

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_TWL(9)	6
NWFSC	2005	NWFSC_TWL(9)	7
NWFSC	2006	NWFSC_TWL(9)	18
NWFSC	2007	NWFSC_TWL(9)	1
NWFSC	2008	NWFSC_TWL(9)	37
NWFSC	2009	NWFSC_TWL(9)	111
NWFSC	2010	NWFSC_TWL(9)	33
NWFSC	2011	NWFSC_TWL(9)	2
NWFSC	2012	NWFSC_TWL(9)	40
NWFSC	2013	NWFSC_TWL(9)	50
NWFSC	2014	NWFSC_TWL(9)	16
NWFSC	2015	NWFSC_TWL(9)	5
NWFSC	2016	NWFSC_TWL(9)	9
NWFSC	2017	NWFSC_TWL(9)	64
NWFSC	2018	NWFSC_TWL(9)	26
NWFSC	2019	NWFSC_TWL(9)	42
J_ABRAMS	2010	ABRAMS_RESEARCH(11)	25
J_ABRAMS	2011	ABRAMS_RESEARCH(11)	56
SWFSC	2002	SWFSC_GF_ECOL(12)	44
SWFSC	2003	SWFSC_GF_ECOL(12)	58
SWFSC	2004	SWFSC_GF_ECOL(12)	108
SWFSC	2005	SWFSC_GF_ECOL(12)	19

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	0.086	2	(0.001, 0.4)	OK	0.0082872	Log Norm (-2.3026, 0.438)
L at Amin Fem GP 1	7.592	2	(1, 15)	OK	0.6175560	None
L at Amax Fem GP 1	55.184	2	(45, 65)	OK	0.6960840	None
VonBert K Fem GP 1	0.147	2	(0.05, 0.25)	OK	0.0079037	None
CV young Fem GP 1	0.099	2	(0.01, 0.3)	OK	0.0097941	None
CV old Fem GP 1	0.074	2	(0.01, 0.3)	OK	0.0094818	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	0.080	2	(0.001, 0.4)	OK	0.0087910	Log Norm (-2.3026, 0.438)
L at Amin Mal GP 1	5.898	2	(1, 15)	OK	0.5581020	None
L at Amax Mal GP 1	49.940	2	(45, 65)	OK	0.5173370	None
VonBert K Mal GP 1	0.199	2	(0.05, 0.25)	OK	0.0085385	None
CV young Mal GP 1	0.077	2	(0.01, 0.3)	OK	0.0053649	None
CV old Mal GP 1	0.070	-2	(0.01, 0.3)			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)	6.041	1	(5, 8)	OK	0.1471020	None
SR BH steep	0.720	-2	(0.201, 0.999)			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 1970	-0.134	4	(-5, 5)	act	0.4521630	dev (NA, NA)
Main RecrDev 1971	-0.215	4	(-5, 5)	act	0.4352040	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 1972	-0.327	4	(-5, 5)	act	0.4153930	dev (NA, NA)
Main RecrDev 1973	-0.477	4	(-5, 5)	act	0.3937230	dev (NA, NA)
Main RecrDev 1974	-0.651	4	(-5, 5)	act	0.3731320	dev (NA, NA)
Main RecrDev 1975	-0.798	4	(-5, 5)	act	0.3566460	dev (NA, NA)
Main RecrDev 1976	-0.850	4	(-5, 5)	act	0.3464360	dev (NA, NA)
Main RecrDev 1977	-0.791	4	(-5, 5)	act	0.3461600	dev (NA, NA)
Main RecrDev 1978	-0.590	4	(-5, 5)	act	0.3420630	dev (NA, NA)
Main RecrDev 1979	-0.521	4	(-5, 5)	act	0.3449060	dev (NA, NA)
Main RecrDev 1980	-0.473	4	(-5, 5)	act	0.3462160	dev (NA, NA)
Main RecrDev 1981	-0.316	4	(-5, 5)	act	0.3461750	dev (NA, NA)
Main RecrDev 1982	-0.053	4	(-5, 5)	act	0.3347880	dev (NA, NA)
Main RecrDev 1983	-0.015	4	(-5, 5)	act	0.3737700	dev (NA, NA)
Main RecrDev 1984	0.673	4	(-5, 5)	act	0.3220940	dev (NA, NA)
Main RecrDev 1985	1.445	4	(-5, 5)	act	0.2003400	dev (NA, NA)
Main RecrDev 1986	-0.022	4	(-5, 5)	act	0.4117670	dev (NA, NA)
Main RecrDev 1987	-0.452	4	(-5, 5)	act	0.3692650	dev (NA, NA)
Main RecrDev 1988	-0.401	4	(-5, 5)	act	0.3647980	dev (NA, NA)
Main RecrDev 1989	0.073	4	(-5, 5)	act	0.3084210	dev (NA, NA)
Main RecrDev 1990	0.235	4	(-5, 5)	act	0.2723070	dev (NA, NA)
Main RecrDev 1991	-0.021	4	(-5, 5)	act	0.3063500	dev (NA, NA)
Main RecrDev 1992	-0.010	4	(-5, 5)	act	0.3095030	dev (NA, NA)
Main RecrDev 1993	0.220	4	(-5, 5)	act	0.3014960	dev (NA, NA)
Main RecrDev 1994	0.935	4	(-5, 5)	act	0.2268070	dev (NA, NA)
Main RecrDev 1995	0.443	4	(-5, 5)	act	0.3528520	dev (NA, NA)
Main RecrDev 1996	0.142	4	(-5, 5)	act	0.3822650	dev (NA, NA)
Main RecrDev 1997	0.251	4	(-5, 5)	act	0.3901180	dev (NA, NA)
Main RecrDev 1998	0.566	4	(-5, 5)	act	0.3653510	dev (NA, NA)
Main RecrDev 1999	1.139	4	(-5, 5)	act	0.2375850	dev (NA, NA)
Main RecrDev 2000	0.476	4	(-5, 5)	act	0.3120040	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 2001	0.198	4	(-5, 5)	act	0.2527550	dev (NA, NA)
Main RecrDev 2002	-0.621	4	(-5, 5)	act	0.2759890	dev (NA, NA)
Main RecrDev 2003	-0.742	4	(-5, 5)	act	0.2616310	dev (NA, NA)
Main RecrDev 2004	-0.604	4	(-5, 5)	act	0.2766190	dev (NA, NA)
Main RecrDev 2005	-0.093	4	(-5, 5)	act	0.2425840	dev (NA, NA)
Main RecrDev 2006	-0.028	4	(-5, 5)	act	0.2511420	dev (NA, NA)
Main RecrDev 2007	0.635	4	(-5, 5)	act	0.1721730	dev (NA, NA)
Main RecrDev 2008	0.398	4	(-5, 5)	act	0.2123430	dev (NA, NA)
Main RecrDev 2009	0.692	4	(-5, 5)	act	0.1806370	dev (NA, NA)
Main RecrDev 2010	-0.298	4	(-5, 5)	act	0.3026240	dev (NA, NA)
Main RecrDev 2011	-0.397	4	(-5, 5)	act	0.2854350	dev (NA, NA)
Main RecrDev 2012	0.196	4	(-5, 5)	act	0.2424730	dev (NA, NA)
Main RecrDev 2013	0.326	4	(-5, 5)	act	0.2785740	dev (NA, NA)
Main RecrDev 2014	0.341	4	(-5, 5)	act	0.3003230	dev (NA, NA)
Main RecrDev 2015	-0.215	4	(-5, 5)	act	0.3681840	dev (NA, NA)
Main RecrDev 2016	1.472	4	(-5, 5)	act	0.2595480	dev (NA, NA)
Main RecrDev 2017	-0.800	4	(-5, 5)	act	0.4491540	dev (NA, NA)
Main RecrDev 2018	0.048	4	(-5, 5)	act	0.4795330	dev (NA, NA)
Main RecrDev 2019	0.003	4	(-5, 5)	act	0.4931920	dev (NA, NA)
Main RecrDev 2020	0.009	4	(-5, 5)	act	0.4945830	dev (NA, NA)
LnQ base REC PC(4)	-9.529	-1	(-15, 0)			None
LnQ base REC PR(6)	-7.818	-1	(-15, 0)			None
Q extraSD REC PR(6)	0.163	1	(0, 0.5)	OK	0.0431518	None
LnQ base DWV ONBOARD(8)	-10.817	-1	(-15, 0)			None
LnQ base REC PC ONBOARD(10)	-10.665	-1	(-15, 0)			None
LnQ base CCFRP(13)	-8.617	-1	(-15, 0)			None
Size DblN peak COM HKL(1)	46.184	2	(30, 60)	OK	1.8247300	None
Size DblN top logit COM HKL(1)	-9.000	-2	(-12, 0)			None
Size DblN ascend se COM HKL(1)	4.731	2	(2, 8)	OK	0.2392430	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 descend se COM HKL(1)	10.000	-2	(1, 10)			None
Size DblN start logit COM HKL(1)	-10.000	-2	(-11, -9)			None
Size DblN end logit COM HKL(1)	10.000	-2	(-11, 11)			None
Size DblN peak COM TWL(2)	47.816	2	(25, 65)	OK	3.4986700	None
Size DblN top logit COM TWL(2)	-9.000	-2	(-12, 0)			None
Size DblN ascend se COM TWL(2)	4.153	2	(0.05, 10)	OK	0.6224990	None
Size DblN descend se COM TWL(2)	10.000	-2	(0.05, 10)			None
Size DblN start logit COM TWL(2)	-10.000	-2	(-11, -9)			None
Size DblN end logit COM TWL(2)	10.000	-2	(-10, 10)			None
Size DblN peak COM NET(3)	42.706	2	(25, 65)	OK	2.6409800	None
Size DblN top logit COM NET(3)	-9.000	-2	(-12, 0)			None
Size DblN ascend se COM NET(3)	3.303	2	(0.05, 10)	OK	0.8105430	None
Size DblN descend se COM NET(3)	0.226	2	(0.05, 10)	OK	4.6011900	None
Size DblN start logit COM NET(3)	-10.000	-2	(-11, -9)			None
Size DblN end logit COM NET(3)	0.332	2	(-10, 10)	OK	1.5862600	None
Size DblN peak REC PC(4)	46.582	2	(20, 60)	OK	2.6591600	None
Size DblN top logit REC PC(4)	-9.000	-2	(-12, 0)			None
Size DblN ascend se REC PC(4)	5.132	2	(0.5, 8)	OK	0.3535910	None
Size DblN descend se REC PC(4)	4.037	2	(1, 10)	OK	0.9537990	None
Size DblN start logit REC PC(4)	-10.000	-2	(-11, -9)			None
Size DblN end logit REC PC(4)	-10.000	-2	(-11, 11)			None
Size DblN peak REC PC DIS(5)	18.728	2	(10, 50)	OK	1.5126900	None
Size DblN top logit REC PC DIS(5)	-9.000	-2	(-10, 10)			None
Size DblN ascend se REC PC DIS(5)	1.740	2	(1, 10)	OK	0.9218750	None
Size DblN descend se REC PC DIS(5)	4.470	2	(2, 8)	OK	0.2767100	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)	40.022	2	(10, 50)	OK	2.2625100	None
Size DblN top logit REC PR(6)	-9.000	-2	(-12, 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)
Size DblN ascend se REC PR(6)	4.416	2	(1, 10)	OK	0.3324090	None
Size DblN descend se REC PR(6)	5.522	2	(1, 10)	OK	0.5701240	None
Size DblN start logit REC PR(6)	-10.000	-2	(-11, -9)			None
Size DblN end logit REC PR(6)	-10.000	-2	(-11, 11)			None
Size DblN peak NWFSC TWL(9)	16.300	2	(10, 60)	OK	0.8883540	None
Size DblN top logit NWFSC TWL(9)	-9.000	-2	(-12, 0)			None
Size DblN ascend se NWFSC TWL(9)	0.977	2	(0.05, 10)	OK	1.0706500	None
Size DblN descend se NWFSC TWL(9)	0.070	-2	(0.05, 10)			None
Size DblN start logit NWFSC TWL(9)	-10.000	-2	(-11, -9)			None
Size DblN end logit NWFSC TWL(9)	-0.433	2	(-10, 10)	OK	1.0731400	None
Size DblN peak CCFRP(13)	40.886	2	(20, 60)	OK	1.8257500	None
Size DblN top logit CCFRP(13)	-9.000	-2	(-12, 0)			None
Size DblN ascend se CCFRP(13)	4.986	2	(1, 8)	OK	0.2970620	None
Size DblN descend se CCFRP(13)	4.716	2	(1, 8)	OK	0.5171640	None
Size DblN start logit CCFRP(13)	-10.000	-2	(-11, -9)			None
Size DblN end logit CCFRP(13)	-8.000	-2	(-10, 10)			None
Size DblN peak REC PC(4) BLK1repl 1875	34.896	3	(20, 50)	OK	1.4011300	None
Size DblN peak REC PC(4) BLK1repl 2002	34.171	3	(20, 50)	OK	1.5347700	None
Size DblN ascend se REC PC(4) BLK1repl 1875	4.236	3	(1, 8)	OK	0.2511310	None
Size DblN ascend se REC PC(4) BLK1repl 2002	4.224	3	(1, 8)	OK	0.3016690	None
Size DblN descend se REC PC(4) BLK1repl 1875	4.416	3	(0.05, 10)	OK	0.6250990	None
Size DblN descend se REC PC(4) BLK1repl 2002	5.390	3	(0.05, 10)	OK	0.4656160	None
Size DblN end logit REC PC(4) BLK1repl 1875	-0.589	3	(-8, 9)	OK	0.4286590	None
Size DblN end logit REC PC(4) BLK1repl 2002	-2.097	3	(-8, 9)	OK	1.2891700	None
Size DblN peak REC PR(6) BLK1repl 1875	34.377	3	(20, 50)	OK	1.2105900	None
Size DblN peak REC PR(6) BLK1repl 2002	36.471	3	(20, 50)	OK	0.7783140	None
Size DblN ascend se REC PR(6) BLK1repl 1875	4.259	3	(0.05, 9)	OK	0.2307990	None
Size DblN ascend se REC PR(6) BLK1repl 2002	4.105	3	(0.05, 9)	OK	0.1512450	None
Size DblN descend se REC PR(6) BLK1repl 1875	2.778	3	(0.05, 10)	OK	0.8692620	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 descend se REC PR(6) BLK1repl 2002	5.253	3	(0.05, 10)	OK	0.3040040	None
Size DblN end logit REC PR(6) BLK1repl 1875	-0.398	3	(-8, 9)	OK	0.3136130	None
Size DblN end logit REC PR(6) BLK1repl 2002	-1.752	3	(-8, 9)	OK	0.7407420	None
Size DblN peak CCFRP(13) BLK2repl 1875	35.330	3	(20, 60)	OK	1.0697500	None
Size DblN ascend se CCFRP(13) BLK2repl 1875	4.745	3	(1, 8)	OK	0.1936110	None
Size DblN descend se CCFRP(13) BLK2repl 1875	4.082	3	(1, 8)	OK	0.2258800	None
Size DblN end logit CCFRP(13) BLK2repl 1875	-8.000	-3	(-10, 10)			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	0.428	0.385	0.348	0.329	0.319	0.304
Francis	Length	2	COM_TWL	4.310	4.941	4.630	4.543	4.489	4.388
Francis	Length	3	COM_NET	0.596	0.615	0.603	0.598	0.595	0.590
Francis	Length	4	REC_PC	0.207	0.156	0.148	0.144	0.142	0.140
Francis	Length	5	REC_PC_DIS	0.196	0.192	0.193	0.195	0.196	0.196
Francis	Length	6	REC_PR	0.166	0.113	0.103	0.097	0.095	0.093
Francis	Length	8	DWV_ONBOARD	0.260	0.222	0.220	0.218	0.217	0.215
Francis	Length	9	NWFSC_TWL	0.202	0.229	0.246	0.247	0.247	0.246
Francis	Length	11	ABRAMS_RESEARCH	0.961	1.408	1.729	1.918	2.018	2.161
Francis	Length	12	SWFSC_GF_ECOL	0.511	0.480	0.456	0.438	0.427	0.411
Francis	Length	13	CCFRP	0.120	0.057	0.049	0.047	0.047	0.046
Francis	Ages	9	NWFSC_TWL	1.110	0.565	0.585	0.578	0.575	0.577
Francis	Ages	11	ABRAMS_RESEARCH	1.060	0.922	0.893	0.880	0.876	0.869
Francis	Ages	12	SWFSC_GF_ECOL	0.388	0.287	0.280	0.275	0.273	0.269
M-I	Length	1	COM_HKL	0.991	0.985	0.983	0.982	0.982	
M-I	Length	2	COM_TWL	6.483	6.669	6.700	6.705	6.706	
M-I	Length	3	COM_NET	3.619	3.689	3.691	3.692	3.692	
M-I	Length	4	REC_PC	0.622	0.610	0.607	0.606	0.606	
M-I	Length	5	REC_PC_DIS	0.302	0.302	0.303	0.303	0.303	
M-I	Length	6	REC_PR	0.208	0.185	0.180	0.179	0.179	
M-I	Length	8	DWV_ONBOARD	1.007	1.283	1.330	1.336	1.337	
M-I	Length	9	NWFSC_TWL	0.647	0.644	0.643	0.643	0.642	
M-I	Length	11	ABRAMS_RESEARCH	0.812	0.791	0.783	0.781	0.780	
M-I	Length	12	SWFSC_GF_ECOL	1.897	2.036	2.055	2.058	2.059	
M-I	Length	13	CCFRP	0.792	0.861	0.886	0.894	0.896	
M-I	Ages	9	NWFSC_TWL	0.425	0.408	0.408	0.409	0.409	
M-I	Ages	11	ABRAMS_RESEARCH	0.521	0.524	0.524	0.524	0.524	
M-I	Ages	12	SWFSC_GF_ECOL	0.432	0.433	0.433	0.433	0.433	

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	6457.95	1145.180	6341.79	1.000	420.189	0.240	0.001	0.000
1876	6457.72	1145.140	6341.55	1.000	420.188	0.481	0.003	0.000
1877	6457.27	1145.050	6341.10	1.000	420.184	0.721	0.004	0.000
1878	6456.60	1144.910	6340.43	1.000	420.180	0.961	0.005	0.000
1879	6455.74	1144.730	6339.57	1.000	420.173	1.201	0.007	0.000
1880	6454.68	1144.510	6338.52	0.999	420.165	1.442	0.008	0.000
1881	6453.45	1144.250	6337.28	0.999	420.156	1.682	0.010	0.000
1882	6452.04	1143.960	6335.88	0.999	420.146	1.922	0.011	0.000
1883	6450.48	1143.630	6334.32	0.999	420.134	2.163	0.012	0.000
1884	6448.77	1143.260	6332.61	0.998	420.121	2.403	0.014	0.000
1885	6446.92	1142.870	6330.77	0.998	420.107	2.643	0.015	0.000
1886	6444.94	1142.440	6328.79	0.998	420.091	2.884	0.016	0.000
1887	6442.83	1141.990	6326.68	0.997	420.075	3.124	0.018	0.000
1888	6440.61	1141.510	6324.47	0.997	420.058	3.364	0.019	0.001
1889	6438.28	1141.000	6322.14	0.996	420.040	3.604	0.020	0.001
1890	6435.84	1140.470	6319.71	0.996	420.021	3.845	0.022	0.001
1891	6433.32	1139.920	6317.19	0.995	420.001	4.085	0.023	0.001
1892	6430.70	1139.350	6314.57	0.995	419.980	4.325	0.025	0.001
1893	6428.00	1138.760	6311.88	0.994	419.959	4.082	0.023	0.001
1894	6425.68	1138.250	6309.57	0.994	419.941	3.839	0.022	0.001
1895	6423.74	1137.810	6307.63	0.994	419.925	3.596	0.020	0.001
1896	6422.16	1137.440	6306.05	0.993	419.912	3.396	0.019	0.001
1897	6420.87	1137.140	6304.77	0.993	419.901	3.195	0.018	0.001
1898	6419.87	1136.890	6303.77	0.993	419.892	2.995	0.017	0.000
1899	6419.13	1136.710	6303.04	0.993	419.885	2.794	0.016	0.000
1900	6418.64	1136.580	6302.55	0.992	419.880	3.091	0.018	0.000
1901	6417.91	1136.400	6301.83	0.992	419.874	3.389	0.019	0.001
1902	6416.94	1136.190	6300.86	0.992	419.866	3.686	0.021	0.001
1903	6415.74	1135.930	6299.66	0.992	419.857	3.983	0.023	0.001
1904	6414.32	1135.620	6298.24	0.992	419.846	4.281	0.024	0.001
1905	6412.69	1135.280	6296.62	0.991	419.833	4.574	0.026	0.001
1906	6410.87	1134.890	6294.79	0.991	419.819	4.867	0.028	0.001
1907	6408.86	1134.460	6292.79	0.991	419.804	5.161	0.029	0.001
1908	6406.67	1133.990	6290.60	0.990	419.787	5.454	0.031	0.001
1909	6404.32	1133.490	6288.26	0.990	419.768	6.137	0.035	0.001
1910	6401.44	1132.880	6285.38	0.989	419.746	6.820	0.039	0.001
1911	6398.05	1132.160	6281.99	0.989	419.720	7.504	0.043	0.001
1912	6394.18	1131.340	6278.13	0.988	419.690	8.187	0.046	0.001
1913	6389.85	1130.420	6273.81	0.987	419.657	8.870	0.050	0.001
1914	6385.10	1129.410	6269.07	0.986	419.620	9.553	0.054	0.002
1915	6379.94	1128.300	6263.92	0.985	419.579	10.236	0.058	0.002
1916	6374.41	1127.120	6258.39	0.984	419.536	11.479	0.065	0.002
1917	6367.97	1125.740	6251.97	0.983	419.485	18.544	0.103	0.003
1918	6355.07	1123.070	6239.08	0.981	419.387	17.480	0.098	0.003
1919	6343.82	1120.690	6227.84	0.979	419.298	10.312	0.059	0.002
1920	6340.07	1119.770	6224.11	0.978	419.264	11.201	0.064	0.002
1921	6335.77	1118.750	6219.84	0.977	419.227	9.875	0.056	0.002
1922	6333.05	1118.060	6217.13	0.976	419.201	9.584	0.055	0.002

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	6330.82	1117.490	6214.92	0.976	419.180	12.502	0.071	0.002
1924	6325.96	1116.420	6210.07	0.975	419.140	16.488	0.093	0.003
1925	6317.54	1114.640	6201.65	0.973	419.073	18.569	0.104	0.003
1926	6307.53	1112.530	6191.65	0.971	418.994	22.964	0.128	0.004
1927	6293.79	1109.670	6177.92	0.969	418.886	19.632	0.110	0.003
1928	6283.95	1107.540	6168.10	0.967	418.806	18.350	0.105	0.003
1929	6275.80	1105.800	6159.98	0.966	418.740	20.069	0.116	0.003
1930	6266.32	1103.850	6150.52	0.964	418.666	21.504	0.124	0.003
1931	6255.85	1101.720	6140.08	0.962	418.584	11.819	0.072	0.002
1932	6255.12	1101.550	6139.37	0.962	418.578	35.932	0.201	0.006
1933	6231.08	1096.840	6115.36	0.958	418.397	12.164	0.077	0.002
1934	6230.87	1096.810	6115.16	0.958	418.396	24.388	0.145	0.004
1935	6218.79	1094.490	6103.10	0.956	418.306	31.681	0.184	0.005
1936	6200.04	1090.870	6084.39	0.953	418.165	33.450	0.195	0.005
1937	6180.24	1087.010	6064.60	0.949	418.015	36.386	0.212	0.006
1938	6158.28	1082.730	6042.67	0.945	417.847	28.148	0.170	0.005
1939	6145.17	1080.110	6029.60	0.943	417.743	26.763	0.161	0.004
1940	6134.13	1077.790	6018.60	0.941	417.651	35.201	0.210	0.006
1941	6115.25	1074.110	5999.77	0.938	417.504	36.802	0.218	0.006
1942	6095.66	1070.180	5980.20	0.935	417.346	15.666	0.099	0.003
1943	6097.81	1070.210	5982.37	0.935	417.347	18.086	0.112	0.003
1944	6098.00	1069.860	5982.60	0.934	417.333	24.392	0.144	0.004
1945	6092.61	1068.370	5977.24	0.933	417.273	46.379	0.259	0.008
1946	6066.56	1062.850	5951.19	0.928	417.049	49.264	0.280	0.008
1947	6038.62	1057.190	5923.27	0.923	416.817	24.937	0.153	0.004
1948	6035.50	1056.290	5920.19	0.922	416.780	41.344	0.250	0.007
1949	6016.16	1052.710	5900.92	0.919	416.632	41.637	0.258	0.007
1950	5996.61	1049.340	5881.42	0.916	416.492	57.103	0.341	0.010
1951	5962.08	1043.210	5846.92	0.911	416.234	97.256	0.523	0.017
1952	5889.33	1029.570	5774.23	0.899	415.652	65.834	0.388	0.011
1953	5849.64	1021.890	5734.59	0.892	415.319	47.731	0.297	0.008
1954	5829.43	1017.640	5714.47	0.889	415.132	63.144	0.379	0.011
1955	5795.16	1010.820	5680.34	0.883	414.830	88.583	0.498	0.016
1956	5737.76	999.421	5623.03	0.873	414.316	79.676	0.471	0.014
1957	5690.69	990.309	5576.04	0.865	413.897	91.083	0.527	0.016
1958	5634.15	979.363	5519.61	0.855	413.386	121.435	0.674	0.022
1959	5548.86	963.632	5434.50	0.841	412.633	91.794	0.556	0.017
1960	5495.17	953.454	5380.92	0.833	412.134	71.784	0.449	0.013
1961	5464.32	946.547	5350.20	0.827	411.789	56.711	0.367	0.011
1962	5450.96	942.553	5337.00	0.823	411.588	69.341	0.441	0.013
1963	5426.52	936.985	5312.70	0.818	411.306	78.880	0.489	0.015
1964	5394.49	929.991	5280.75	0.812	410.946	64.498	0.417	0.012
1965	5378.50	925.931	5264.82	0.809	410.735	85.459	0.536	0.016
1966	5342.24	918.924	5228.67	0.802	410.368	91.600	0.569	0.018
1967	5301.05	911.001	5187.58	0.796	409.946	98.364	0.596	0.019
1968	5255.18	901.738	5141.79	0.787	409.445	93.686	0.591	0.018
1969	5214.97	894.004	5101.69	0.781	409.019	102.856	0.635	0.020
1970	5166.83	884.693	5054.09	0.773	346.965	130.721	0.755	0.026

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
1971	5092.18	870.471	4981.02	0.760	317.689	130.677	0.760	0.026
1972	5016.08	856.438	4910.74	0.748	282.120	164.526	0.902	0.034
1973	4900.84	837.002	4809.39	0.731	241.104	205.261	1.053	0.043
1974	4736.19	810.859	4653.67	0.708	200.838	226.049	1.125	0.049
1975	4540.43	780.610	4468.21	0.682	171.651	219.141	1.136	0.049
1976	4338.58	751.211	4277.19	0.656	161.263	259.520	1.264	0.061
1977	4083.33	713.366	4031.27	0.623	169.023	230.890	1.232	0.057
1978	3844.81	678.980	3798.14	0.593	204.136	276.837	1.362	0.073
1979	3553.55	633.680	3507.25	0.553	215.419	358.233	1.551	0.102
1980	3181.04	571.196	3130.40	0.499	220.993	337.873	1.592	0.108
1981	2835.44	510.402	2777.92	0.446	252.470	199.414	1.308	0.072
1982	2640.15	472.735	2578.95	0.413	323.285	315.991	1.633	0.123
1983	2343.47	413.522	2277.67	0.361	326.166	132.770	1.243	0.058
1984	2249.88	389.422	2170.86	0.340	640.086	131.391	1.293	0.061
1985	2184.84	367.228	2082.72	0.321	1364.890	126.880	1.276	0.061
1986	2164.33	347.128	2029.06	0.303	310.434	136.868	1.338	0.067
1987	2207.34	327.946	1983.22	0.286	198.765	245.180	1.648	0.124
1988	2191.75	293.898	1931.71	0.257	202.897	286.600	1.733	0.148
1989	2148.83	262.807	2074.96	0.229	314.940	114.534	1.193	0.055
1990	2265.37	264.830	2206.98	0.231	371.258	247.955	1.614	0.112
1991	2230.42	259.567	2162.19	0.227	285.484	277.263	1.666	0.128
1992	2143.36	256.142	2053.77	0.224	287.513	259.934	1.666	0.127
1993	2052.02	254.118	1959.34	0.222	360.886	364.615	1.817	0.186
1994	1844.78	232.480	1762.71	0.203	715.994	231.089	1.687	0.131
1995	1765.66	224.142	1671.85	0.196	432.086	160.390	1.521	0.096
1996	1775.17	222.943	1646.89	0.195	319.144	131.419	1.394	0.080
1997	1835.33	224.090	1671.14	0.196	356.441	152.875	1.474	0.091
1998	1887.00	223.131	1778.34	0.195	487.581	120.203	1.311	0.068
1999	1981.63	227.935	1883.77	0.199	872.018	121.399	1.275	0.064
2000	2082.04	238.541	1962.76	0.208	456.099	87.959	1.019	0.045
2001	2236.81	257.370	2073.76	0.225	354.237	68.729	0.837	0.033
2002	2426.16	280.246	2234.09	0.245	160.435	75.965	0.804	0.034
2003	2608.49	304.085	2498.83	0.266	145.627	185.721	1.335	0.074
2004	2655.77	317.366	2579.41	0.277	169.288	86.888	0.822	0.034
2005	2768.19	343.800	2724.26	0.300	288.417	163.640	1.198	0.060
2006	2763.10	363.725	2717.26	0.318	312.414	148.195	1.139	0.055
2007	2743.71	382.850	2681.88	0.334	613.925	126.823	1.057	0.047
2008	2729.68	399.411	2640.45	0.349	489.007	71.262	0.731	0.027
2009	2780.98	417.505	2665.12	0.365	662.871	89.049	0.870	0.033
2010	2829.01	427.774	2671.22	0.374	247.817	105.254	0.988	0.039
2011	2883.10	431.973	2741.11	0.377	224.973	100.124	0.939	0.037
2012	2952.51	435.431	2813.22	0.380	407.824	87.083	0.826	0.031
2013	3032.45	442.395	2961.29	0.386	465.847	75.837	0.715	0.026
2014	3120.45	454.034	3037.34	0.396	475.537	77.220	0.701	0.025
2015	3205.37	469.146	3087.71	0.410	277.184	123.528	0.966	0.040
2016	3250.53	479.639	3118.04	0.419	1536.160	112.080	0.905	0.036
2017	3307.80	490.602	3173.25	0.428	162.592	165.560	1.108	0.052
2018	3359.55	490.707	3184.58	0.428	387.483	180.495	1.164	0.057

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
2019	3419.45	487.751	3135.42	0.426	372.609	204.445	1.248	0.065
2020	3461.79	482.178	3393.48	0.421	373.837	139.006	0.990	0.041
2021	3564.40	489.439	3459.01	0.427	371.777	148.994	1.000	0.043
2022	3642.30	501.884	3539.37	0.438	373.641	156.383	1.000	0.044
2023	3693.75	518.613	3590.72	0.453	376.032	141.065	0.916	0.039
2024	3741.37	538.451	3638.45	0.470	378.712	142.518	0.909	0.039
2025	3770.44	555.898	3666.95	0.485	380.939	142.328	0.904	0.039
2026	3785.58	569.855	3681.40	0.498	382.641	140.918	0.898	0.038
2027	3791.16	580.383	3686.31	0.507	383.879	138.819	0.892	0.038
2028	3790.77	587.989	3685.38	0.513	384.751	136.434	0.886	0.037
2029	3787.10	593.289	3681.30	0.518	385.348	134.186	0.881	0.036
2030	3781.90	596.847	3675.80	0.521	385.743	131.889	0.875	0.036
2031	3776.60	599.185	3670.30	0.523	386.001	129.775	0.870	0.035
2032	3771.99	600.698	3665.54	0.525	386.167	128.020	0.864	0.035

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 TWL	COM NET	REC PC	REC PC DIS
N.Parms	115.000	113.000	113.000	111.000	104.000	112.000
TOTAL	910.571	886.431	887.894	903.309	853.962	887.799
Survey	-55.121	-55.341	-55.069	-54.993	-46.506	-55.296
Length_comp	370.792	347.782	348.279	363.172	314.154	348.598
Age_comp	581.647	581.938	582.039	581.783	577.342	581.765
Recruitment	13.129	11.972	12.545	13.221	8.811	12.612
Parm_priors	0.116	0.072	0.092	0.121	0.153	0.113
NatM_uniform_Fem_GP_1	0.089	0.091	0.090	0.088	0.087	0.089
L_at_Amin_Fem_GP_1	7.786	7.754	7.788	7.773	7.941	7.798
L_at_Amax_Fem_GP_1	55.383	55.347	55.414	55.315	55.480	55.359
VonBert_K_Fem_GP_1	0.145	0.146	0.145	0.146	0.143	0.146
CV_young_Fem_GP_1	0.096	0.096	0.096	0.096	0.097	0.095
CV_old_Fem_GP_1	0.075	0.076	0.076	0.075	0.069	0.075
NatM_uniform_Mal_GP_1	0.084	0.087	0.085	0.084	0.082	0.084
L_at_Amin_Mal_GP_1	6.025	5.992	5.984	6.019	6.134	6.073
L_at_Amax_Mal_GP_1	49.896	49.861	49.835	49.873	49.931	49.897
VonBert_K_Mal_GP_1	0.199	0.200	0.200	0.199	0.197	0.198
CV_young_Mal_GP_1	0.076	0.076	0.076	0.075	0.075	0.075
SR_LN(R0)	6.072	6.130	6.093	6.065	6.001	6.078
Q_extraSD_REC_PR(6)	0.184	0.185	0.182	0.185	0.165	0.184
Bratio_2021	0.391	0.427	0.397	0.386	0.276	0.394
SSB_unfished	1114.670	1111.270	1100.150	1104.010	1056.010	1116.470
Totbio_unfished	6264.570	6302.200	6219.740	6240.070	6008.800	6279.770
Recr_unfished	433.531	459.429	442.736	430.575	403.752	436.042
Dead_Catch_SPR	140.884	145.028	141.881	140.347	134.758	141.325
OFLCatch_2023	168.686	184.428	171.247	166.356	127.785	170.296

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	REC PR	DWV ON-BOARD	NWFSC TWL	REC ON-BOARD	ABRAMS RE-SEARCH	SWFSC GF ECOL	CCFRP
N.Parms	103.000	115.000	112.000	115.000	115.000	115.000	112.000
TOTAL	842.732	901.725	453.806	915.877	723.727	815.093	903.442
Survey	-41.896	-45.539	-53.087	-49.159	-55.803	-55.071	-47.274
Length_comp	296.000	355.090	317.016	370.117	298.109	352.340	357.127
Age_comp	573.202	582.738	185.839	581.878	468.925	504.841	584.196
Recruitment	15.378	9.408	3.887	12.928	12.300	12.815	9.221
Parm_priors	0.041	0.020	0.146	0.105	0.189	0.160	0.165
NatM_uniform_Fem_GP_1	0.094	0.096	0.082	0.089	0.090	0.087	0.086
L_at_Amin_Fem_GP_1	7.873	7.894	2.665	7.858	7.907	8.042	7.682
L_at_Amax_Fem_GP_1	55.398	55.461	54.476	55.475	55.895	55.465	55.360
VonBert_K_Fem_GP_1	0.143	0.144	0.177	0.144	0.142	0.141	0.147
CV_young_Fem_GP_1	0.103	0.097	0.054	0.097	0.103	0.094	0.095
CV_old_Fem_GP_1	0.058	0.074	0.091	0.075	0.085	0.075	0.075
NatM_uniform_Mal_GP_1	0.090	0.092	0.087	0.085	0.078	0.082	0.082
L_at_Amin_Mal_GP_1	6.125	5.987	5.661	6.075	6.293	6.198	6.015
L_at_Amax_Mal_GP_1	49.932	49.806	48.895	49.911	51.341	49.814	49.986
VonBert_K_Mal_GP_1	0.197	0.200	0.223	0.198	0.186	0.196	0.198
CV_young_Mal_GP_1	0.076	0.076	0.050	0.076	0.082	0.076	0.075
SR_LN(R0)	6.167	6.261	6.054	6.065	6.022	6.048	5.998
Q_extraSD_REC_PR(6)		0.183	0.190	0.186	0.184	0.189	0.156
Bratio_2021	0.461	0.475	0.350	0.367	0.387	0.374	0.381
SSB_unfished	1062.550	1138.850	1258.060	1097.050	1075.040	1116.830	1105.680
Totbio_unfished	6200.400	6546.320	6381.090	6147.110	6464.640	6307.160	6117.130
Recr_unfished	476.663	523.510	425.995	430.385	412.280	423.416	402.527
Dead_Catch_SPR	146.545	156.489	141.986	139.694	140.130	139.100	139.307

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_1965	dev_1975	M-I_wgts	disc_selex
N.Parms	115.000	116.000	120.000	110.000	115.000	112.000
TOTAL	910.571	907.729	910.111	916.042	1459.840	887.696
Survey	-55.121	-53.639	-55.143	-53.784	-23.580	-55.272
Length_comp	370.792	368.226	370.773	374.478	975.367	348.521
Age_comp	581.647	581.438	581.650	582.166	481.182	581.739
Recruitment	13.129	10.601	12.711	13.134	25.981	12.583
Parm_priors	0.116	1.096	0.111	0.041	0.879	0.118
NatM_uniform_Fem_GP_1	0.089	0.071	0.089	0.094	0.072	0.089
L_at_Amin_Fem_GP_1	7.786	7.816	7.787	7.723	6.787	7.798
L_at_Amax_Fem_GP_1	55.383	55.380	55.382	55.411	54.076	55.357
VonBert_K_Fem_GP_1	0.145	0.145	0.145	0.146	0.164	0.146
CV_young_Fem_GP_1	0.096	0.096	0.096	0.097	0.103	0.095
CV_old_Fem_GP_1	0.075	0.075	0.075	0.075	0.099	0.076
NatM_uniform_Mal_GP_1	0.084	0.066	0.084	0.090	0.062	0.084
L_at_Amin_Mal_GP_1	6.025	6.032	6.024	5.981	5.335	6.075
L_at_Amax_Mal_GP_1	49.896	49.896	49.893	49.929	49.751	49.897
VonBert_K_Mal_GP_1	0.199	0.199	0.199	0.199	0.203	0.198
CV_young_Mal_GP_1	0.076	0.076	0.076	0.076	0.083	0.075
SR_LN(R0)	6.072	5.646	6.077	6.109	5.748	6.082
SR_BH_steep	0.720	0.949	0.720	0.720	0.720	0.720
Q_extraSD_REC_PR(6)	0.184	0.204	0.184	0.170	0.291	0.184
Bratio_2021	0.391	0.354	0.392	0.403	0.450	0.395
SSB_unfished	1114.670	1122.630	1112.830	1039.250	1171.900	1124.530
Totbio_unfished	6264.570	5886.500	6262.020	5915.060	6674.760	6332.760
Recr_unfished	433.531	283.081	435.707	450.010	313.684	437.870
Dead_Catch_SPR	140.884	122.568	141.190	139.207	121.059	142.990
OFLCatch_2023	168.686	134.232	169.016	166.763	122.969	172.726

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
N.Parms	115.000	113.000	102.000	120.000	115.000
TOTAL	910.571	913.403	941.375	903.410	910.344
Survey	-55.121	-54.362	-47.772	-56.047	-55.068
Length_comp	370.792	367.419	391.825	366.576	371.412
Age_comp	581.647	583.641	583.745	580.208	581.194
Recruitment	13.129	16.033	13.533	12.433	10.747
Parm_priors	0.116	0.663	0.040	0.231	2.050
NatM_uniform_Fem_GP_1	0.089	0.070	0.112	0.082	0.089
L_at_Amin_Fem_GP_1	7.786	7.654	8.164	7.813	7.826
L_at_Amax_Fem_GP_1	55.383	54.861	54.327	56.252	55.492
VonBert_K_Fem_GP_1	0.145	0.149	0.145	0.142	0.144
CV_young_Fem_GP_1	0.096	0.095	0.099	0.100	0.096
CV_old_Fem_GP_1	0.075	0.076	0.083	0.072	0.075
NatM_uniform_Mal_GP_1	0.084	0.070	0.104	0.080	0.084
L_at_Amin_Mal_GP_1	6.025	5.875	6.145	6.192	6.066
L_at_Amax_Mal_GP_1	49.896	49.672	49.159	50.399	49.958
VonBert_K_Mal_GP_1	0.199	0.203	0.202	0.193	0.198
CV_young_Mal_GP_1	0.076	0.076	0.076	0.076	0.075
SR_LN(R0)	6.072	5.808	6.351	6.000	6.155
SR_BH_steep	0.720	0.720	0.720	0.720	
Q_extraSD_REC_PR(6)	0.184	0.181	0.227	0.173	0.194
SR_RkrPower_steep					0.756
SR_RkrPower_gamma					2.091
Bratio_2021	0.391	0.272	0.447	0.374	0.399
SSB_unfished	1114.670	1299.090	812.554	1296.250	1216.720
Totbio_unfished	6264.570	6638.840	5455.100	6635.630	6818.550
Recr_unfished	433.531	332.940	573.138	403.454	470.973
Dead_Catch_SPR	140.884	126.330	149.426	138.704	141.940
OFLCatch_2023	168.686	117.583	192.884	164.012	185.183

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	115.000	115.000	115.000	115.000	115.000	115.000
TOTAL	910.571	906.994	867.262	822.588	788.220	777.922
Survey	-55.121	-55.766	-53.996	-51.246	-48.585	-46.604
Length_comp	370.792	368.179	359.674	349.063	339.825	332.774
Age_comp	581.647	582.287	548.815	520.694	493.187	488.214
Recruitment	13.129	12.155	12.593	3.888	3.656	3.391
Parm_priors	0.116	0.131	0.168	0.181	0.126	0.139
NatM_uniform_Fem_GP_1	0.089	0.088	0.086	0.085	0.088	0.086
L_at_Amin_Fem_GP_1	7.786	7.755	7.631	8.810	8.088	7.758
L_at_Amax_Fem_GP_1	55.383	55.333	55.203	55.622	55.859	55.750
VonBert_K_Fem_GP_1	0.145	0.146	0.149	0.142	0.142	0.144
CV_young_Fem_GP_1	0.096	0.096	0.099	0.075	0.076	0.079
CV_old_Fem_GP_1	0.075	0.075	0.076	0.081	0.082	0.080
NatM_uniform_Mal_GP_1	0.084	0.083	0.081	0.081	0.084	0.084
L_at_Amin_Mal_GP_1	6.025	6.010	5.935	7.013	6.981	6.850
L_at_Amax_Mal_GP_1	49.896	49.898	49.780	49.883	49.926	49.829
VonBert_K_Mal_GP_1	0.199	0.199	0.201	0.199	0.197	0.199
CV_young_Mal_GP_1	0.076	0.075	0.076	0.066	0.065	0.063
SR_LN(R0)	6.072	6.060	6.011	6.005	6.027	6.012
Q_extraSD_REC_PR(6)	0.184	0.163	0.155	0.160	0.166	0.165
Bratio_2021	0.391	0.398	0.372	0.349	0.376	0.375
SSB_unfished	1114.670	1120.050	1102.160	1142.560	1115.090	1128.810
Totbio_unfished	6264.570	6284.820	6181.330	6280.630	6109.090	6102.100
Recr_unfished	433.531	428.271	407.856	405.568	414.364	408.450
Dead_Catch_SPR	140.884	139.496	134.971	132.663	114.791	113.918
OFLCatch_2023	168.686	161.477	150.481	114.336	105.421	101.855

Figures

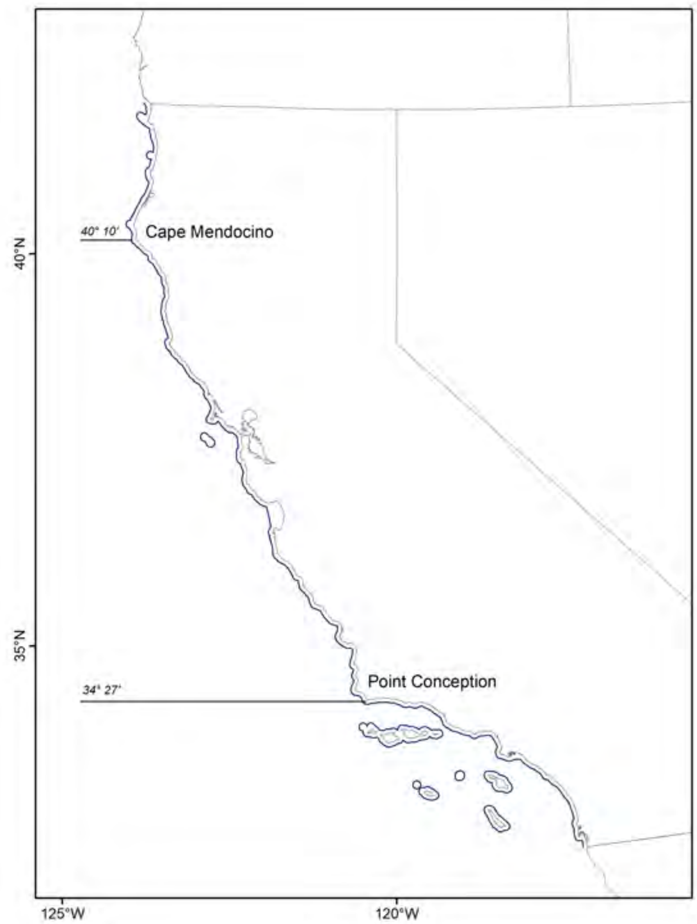

Figure 1: Map of the assssment area with the 3 nm California state water boundary. The northern California model includes areas from Point Conception to the California-Oregon border and the southern California assessment includes areas from Point Concpetion to the USA-Mexico border. The boundary at Cape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

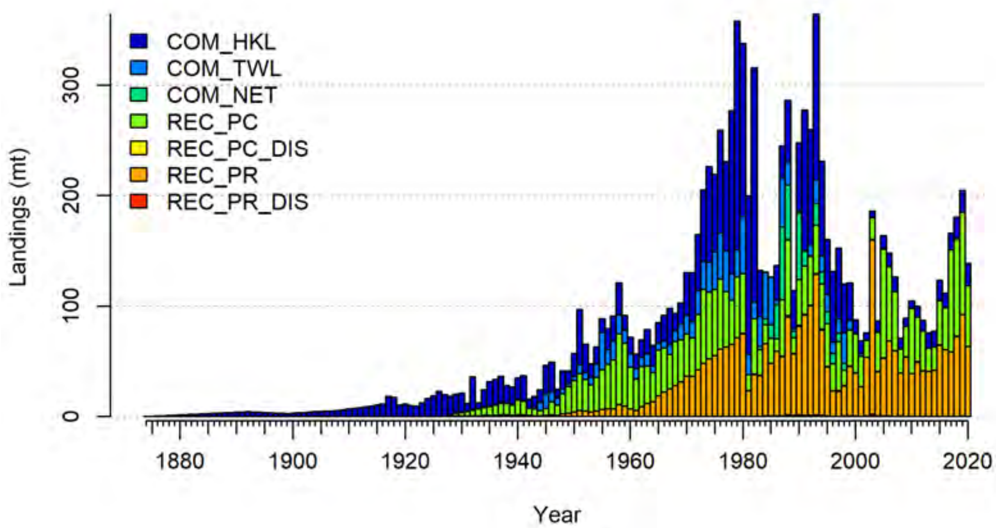

Figure 2: Catch histories by fleet used in the base model (Commercial hook-and-line = COM_HKL, Commercial trawl = COM_TWL, Commercial net = COM_NET, Recreational party/charter retained = REC_PC, Recreational private/rental retained = REC_PR, Recreational party/charter dead discards = REC_PC_DIS, Recreational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

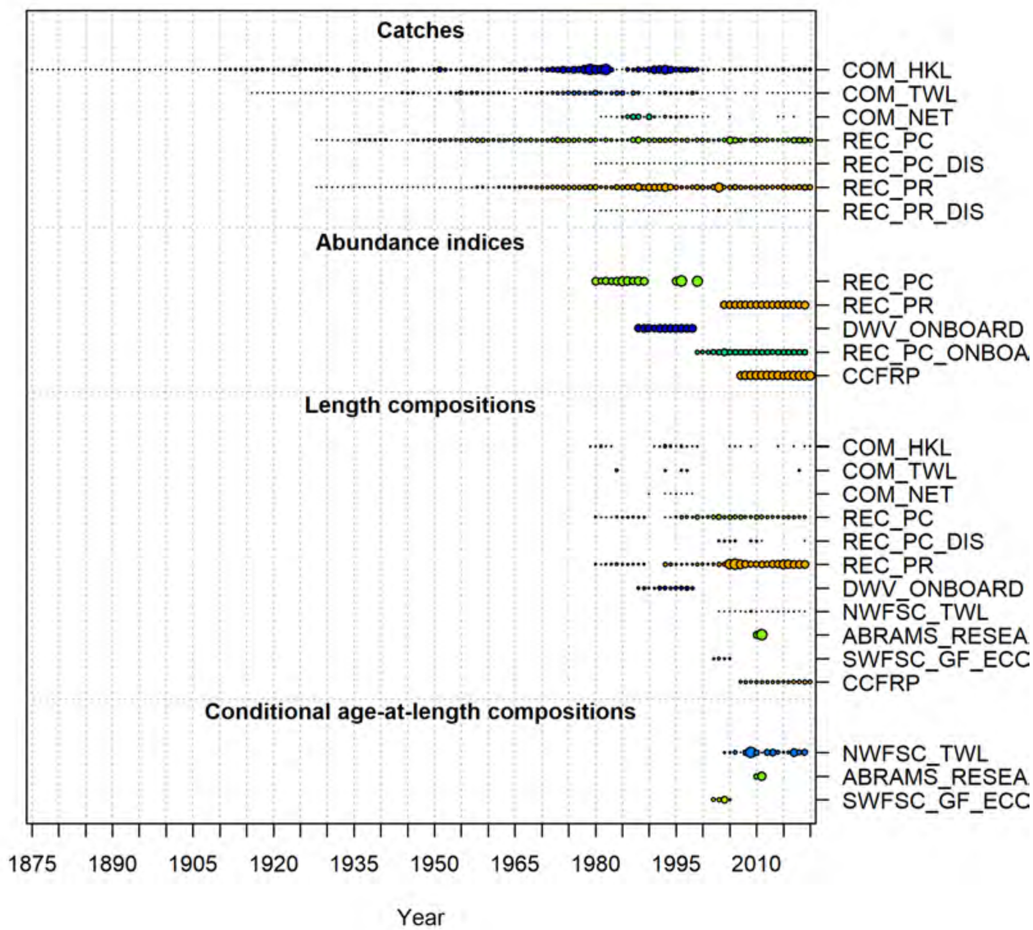

Figure 3: Summary of data sources used in the base model. See the text for fleet descriptions.

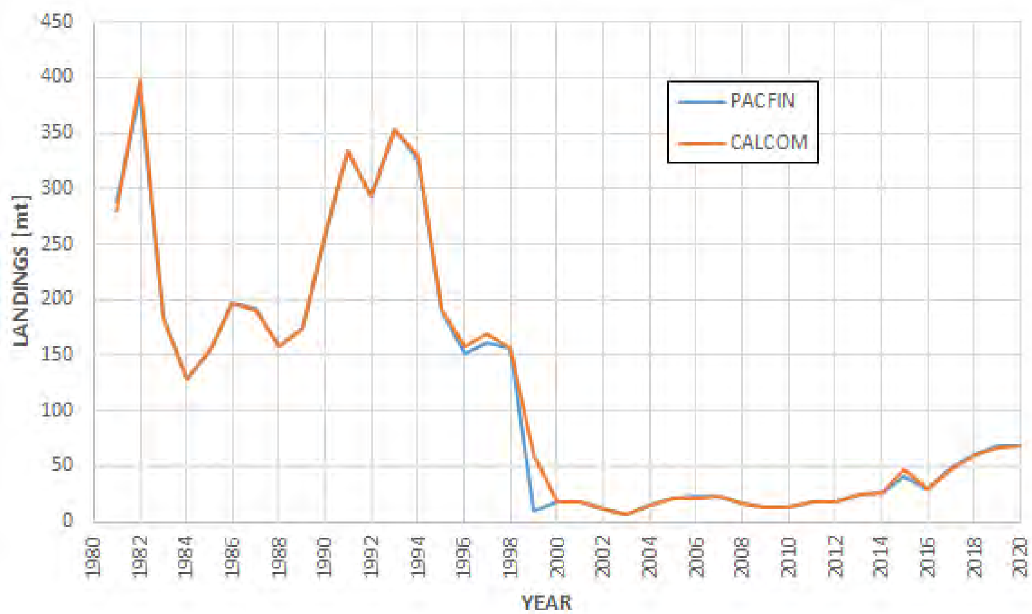

Figure 4: Comparison of total California landings from CALCOM and PacFIN.

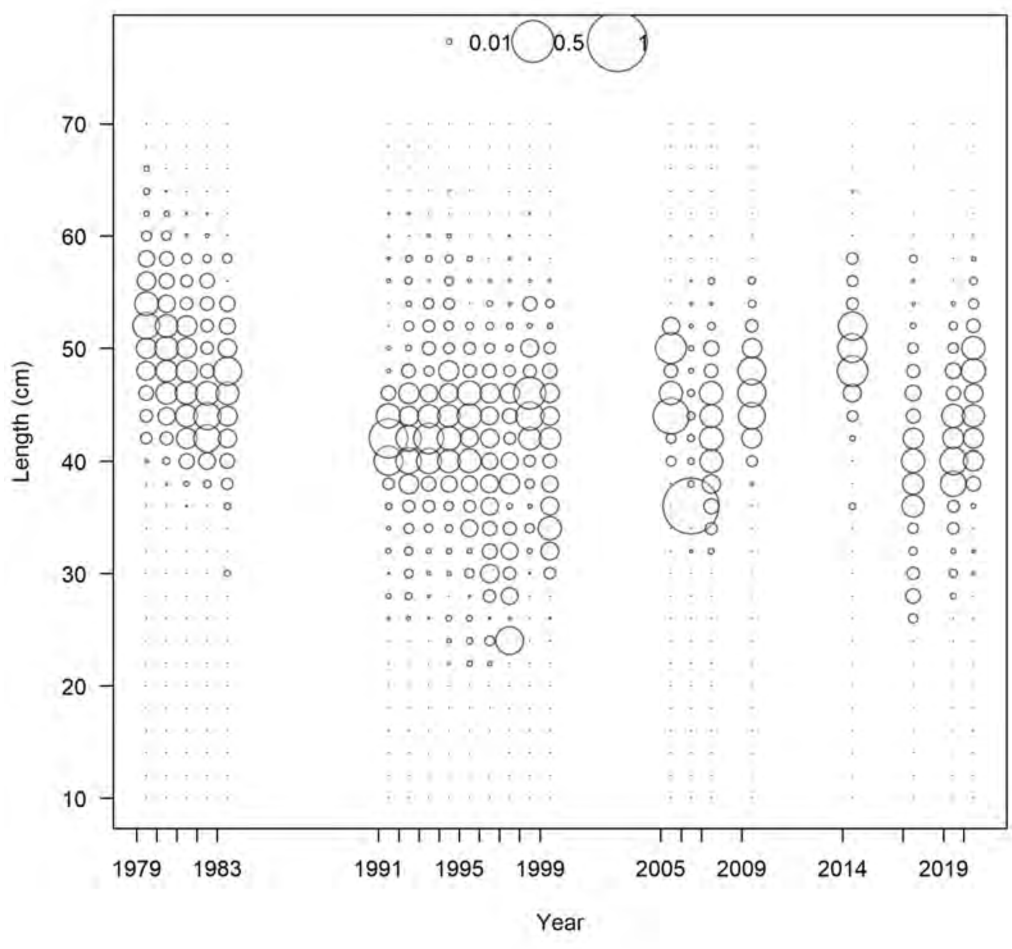

Figure 5: Length composition data from the commercial hook-and-line fishery.

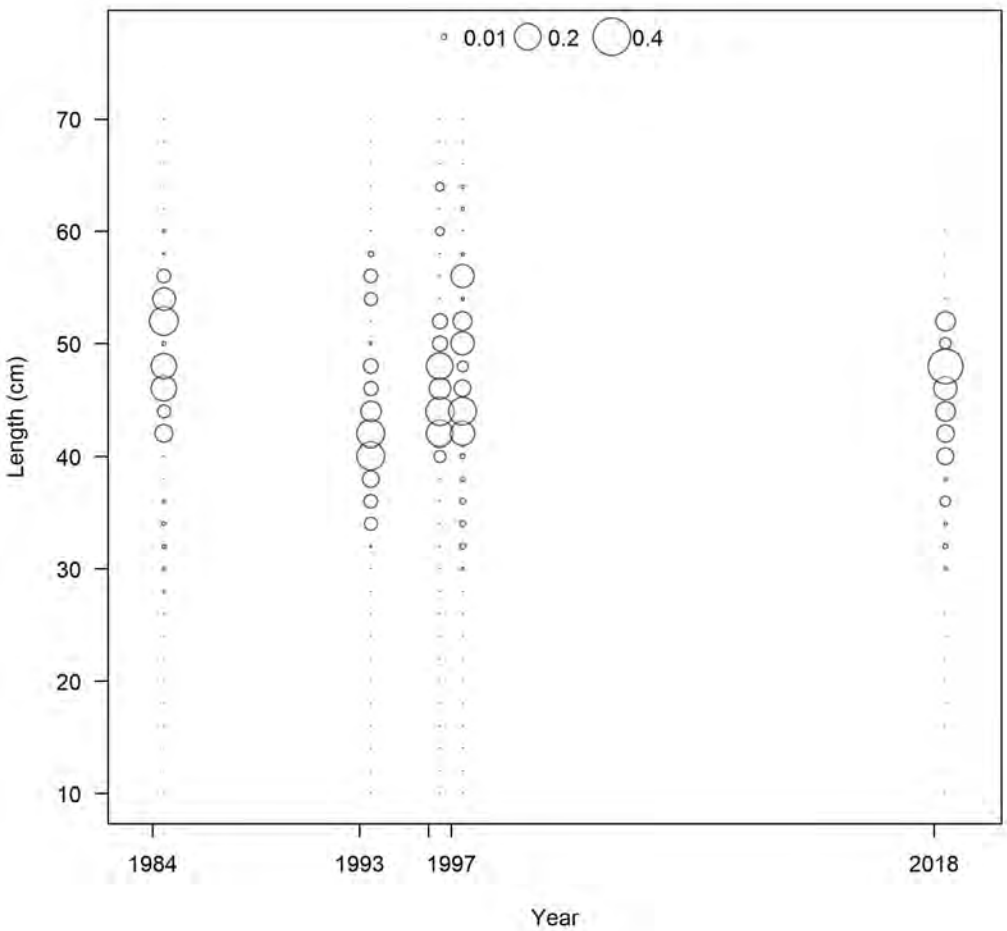

Figure 6: Length composition data from the commercial trawl fishery.

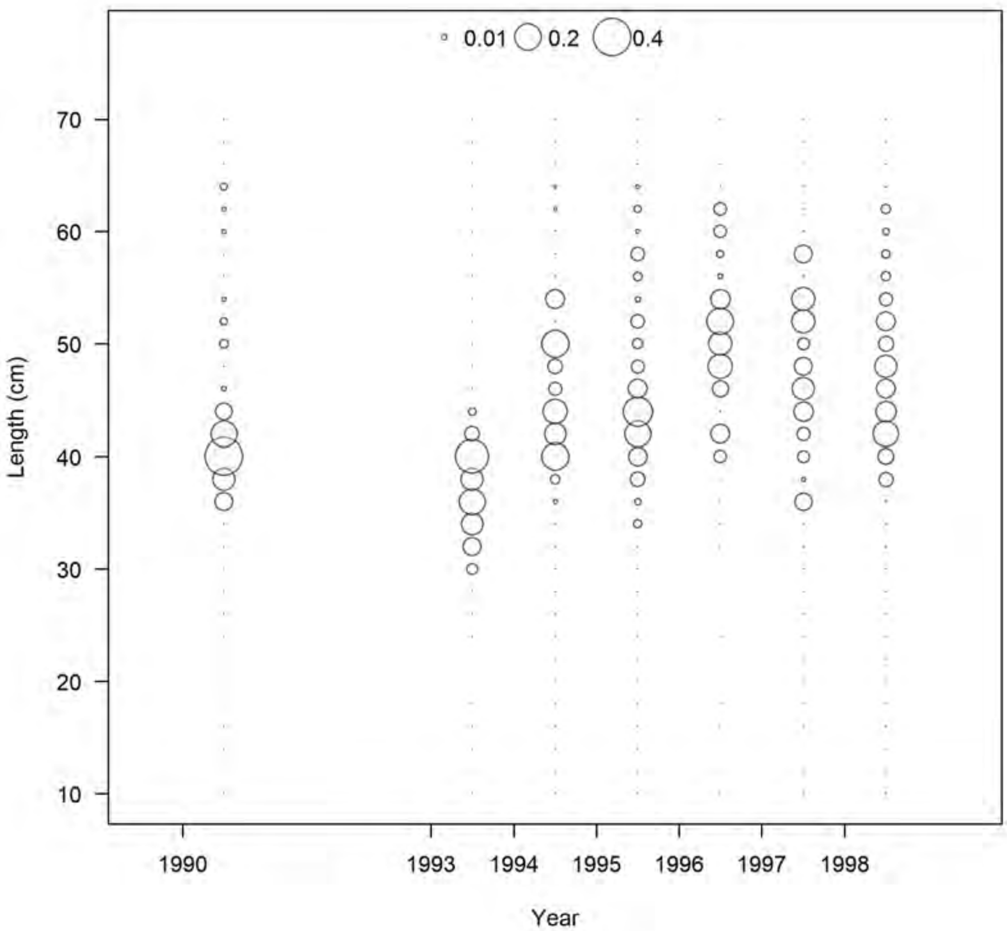

Figure 7: Length composition data from the commercial net fishery.

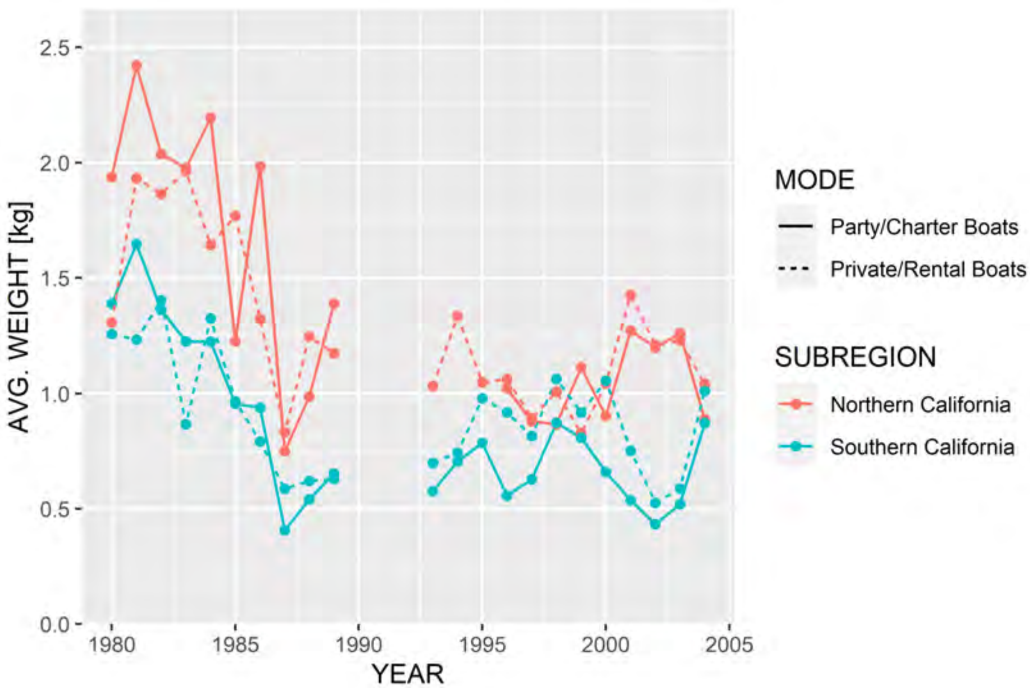

Figure 8: Average weights calculated from the recreational landings data on RecFIN.

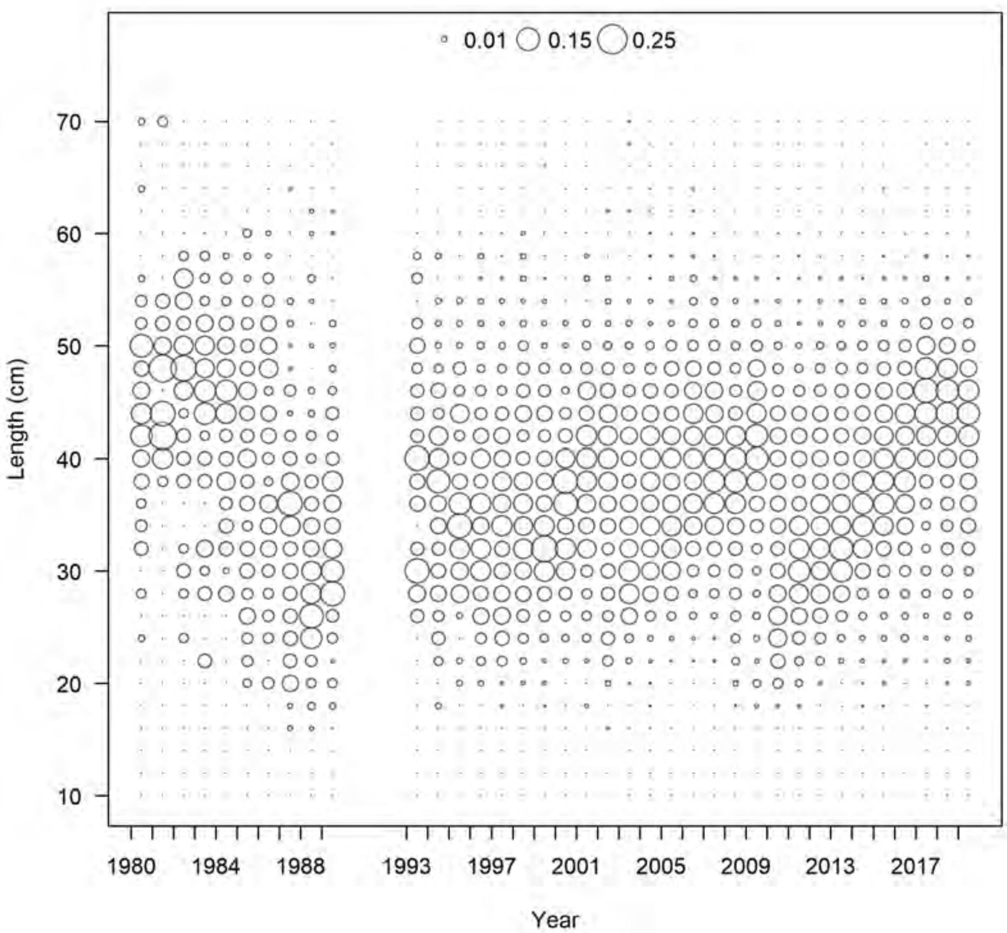

Figure 9: Length composition data from the recreational PC retained fishery.

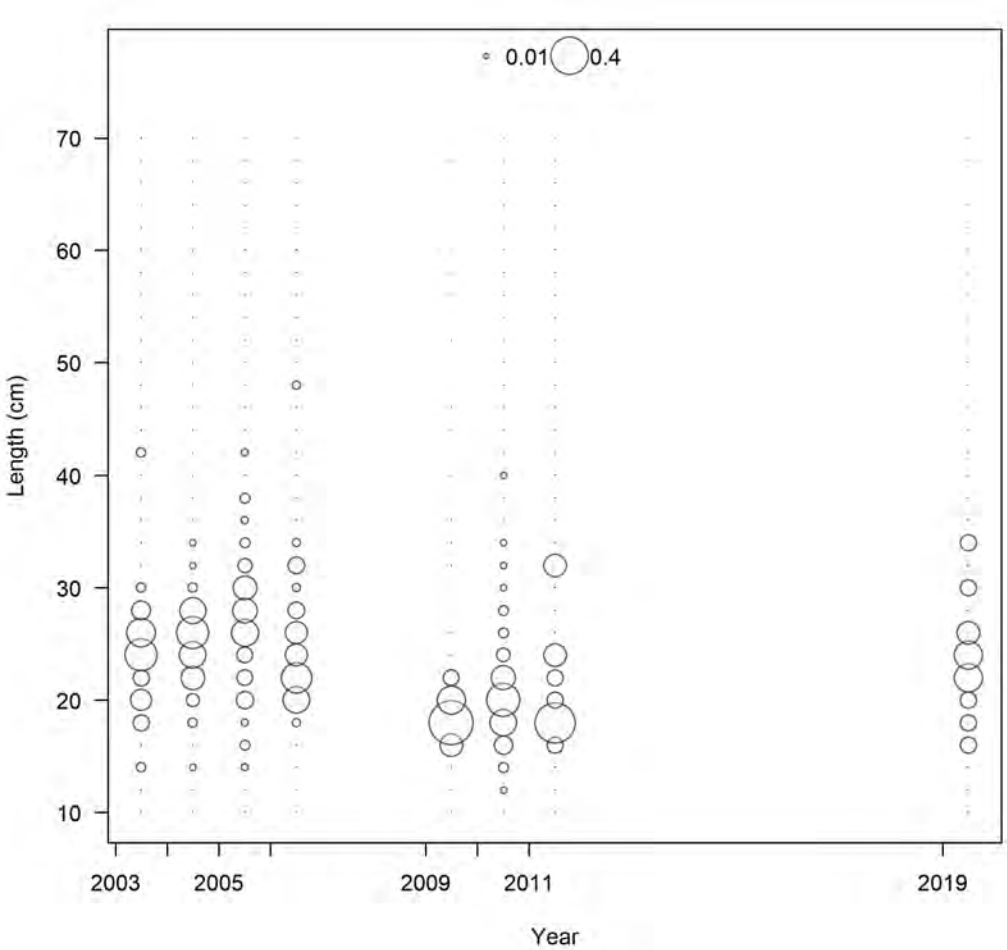

Figure 10: Length composition data from the recreational PC discard fishery.

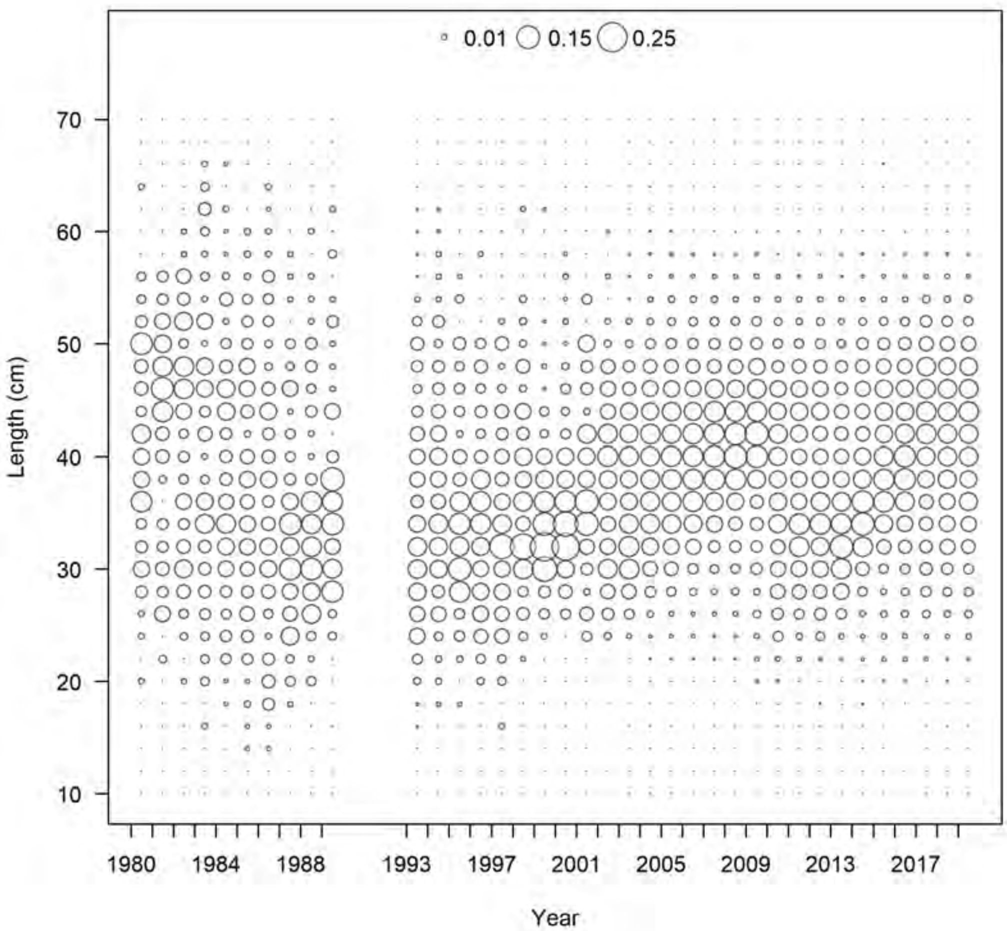

Figure 11: Length composition data from the recreational PR retained fishery.

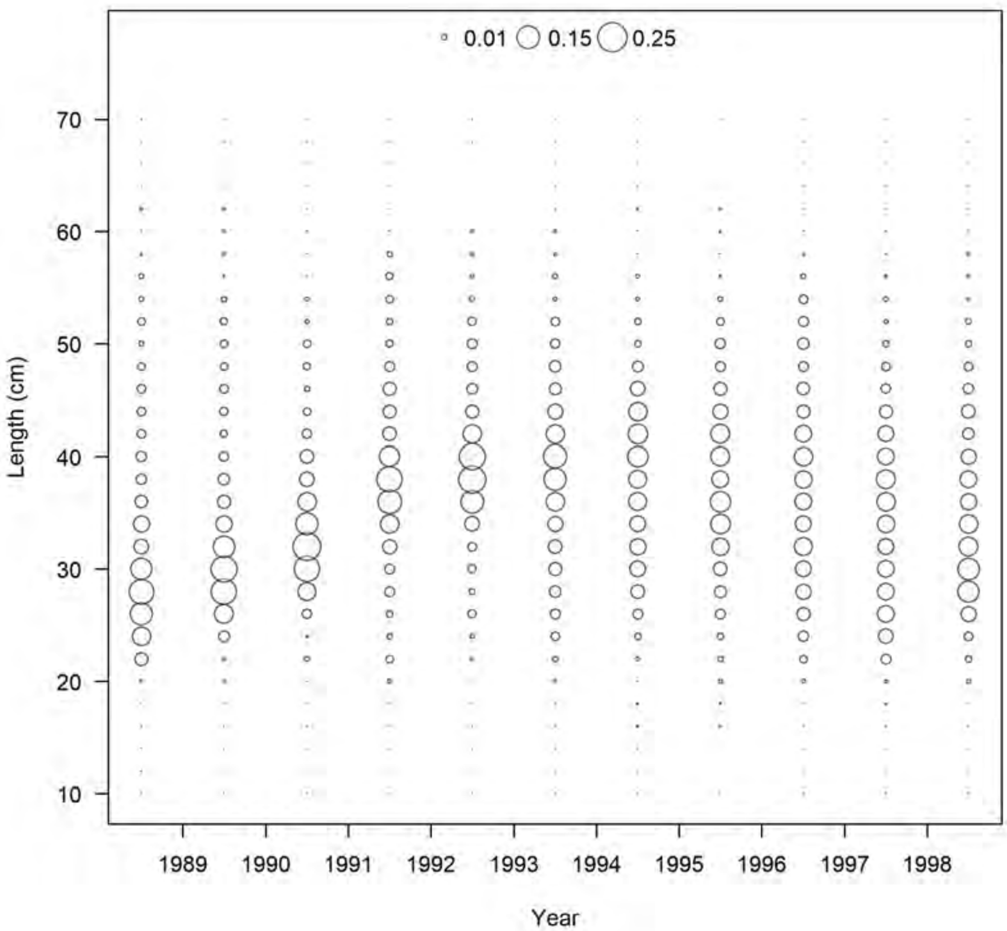

Figure 12: Length composition data from the Deb Wilson-Vandenberg onboard survey.

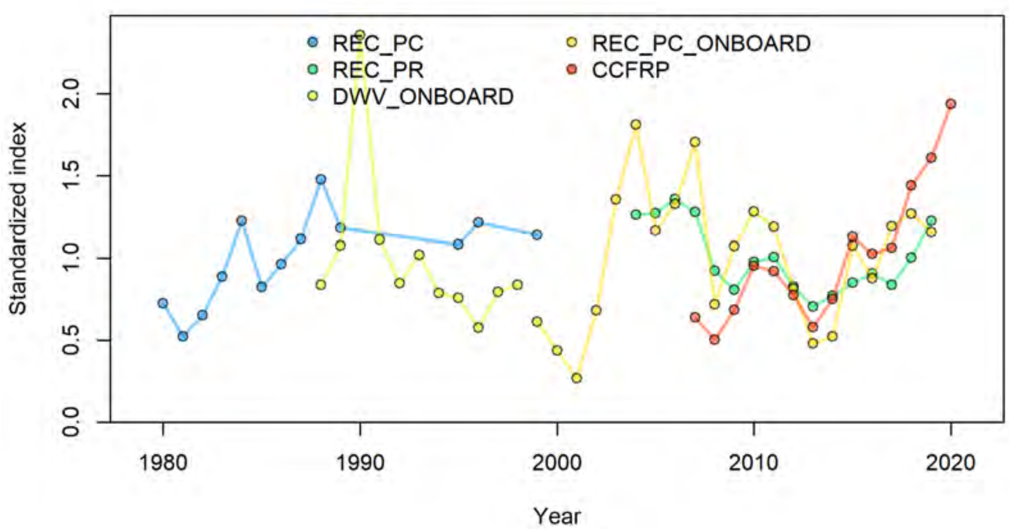

Figure 13: Standardized indices overlaid. Each index is rescaled to have mean observation = 1.0.

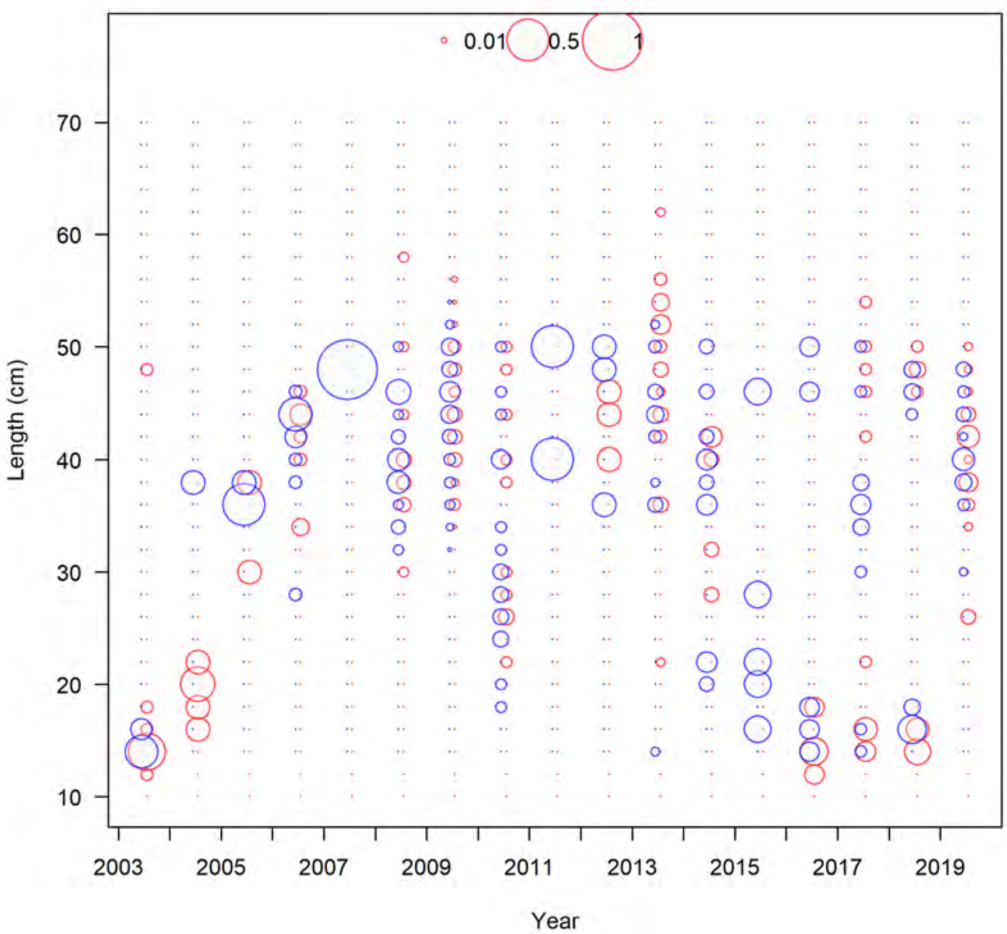

Figure 14: Length composition data from the West coast groundfish bottomfish trawl survey.

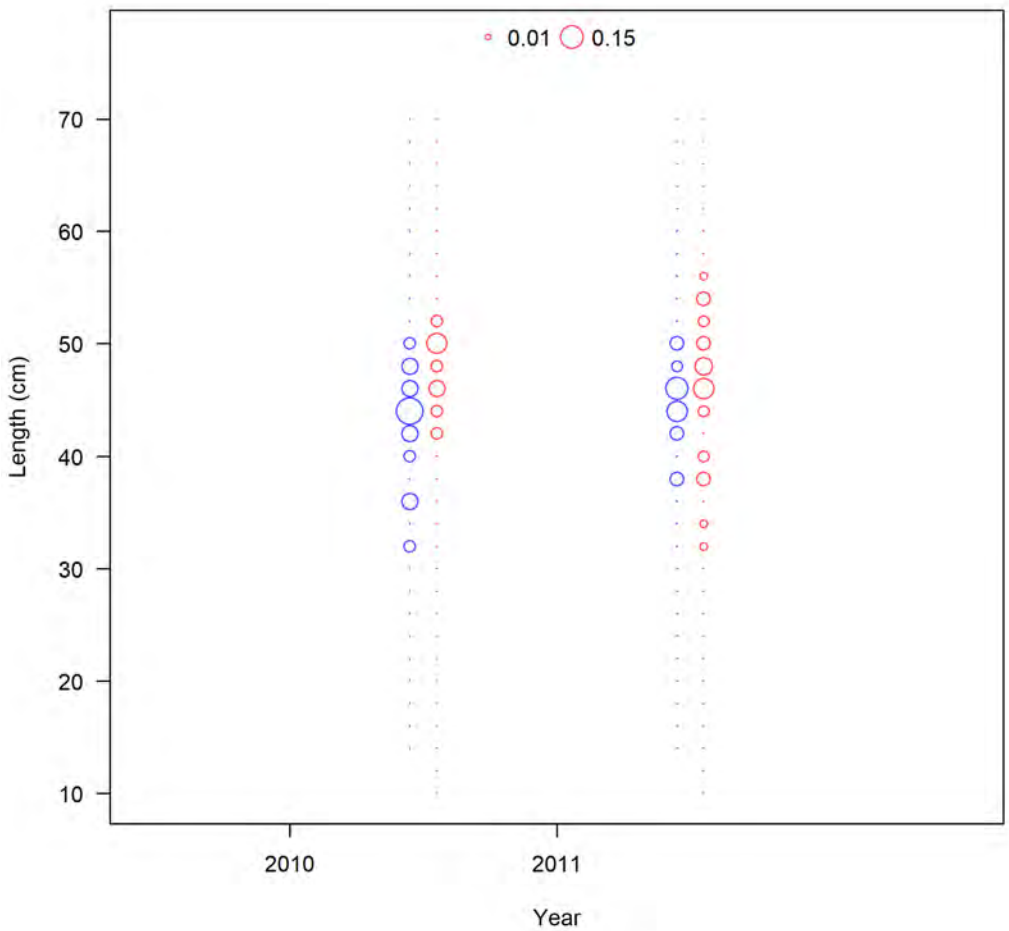

Figure 15: Length composition data from the Abrams thesis research survey.

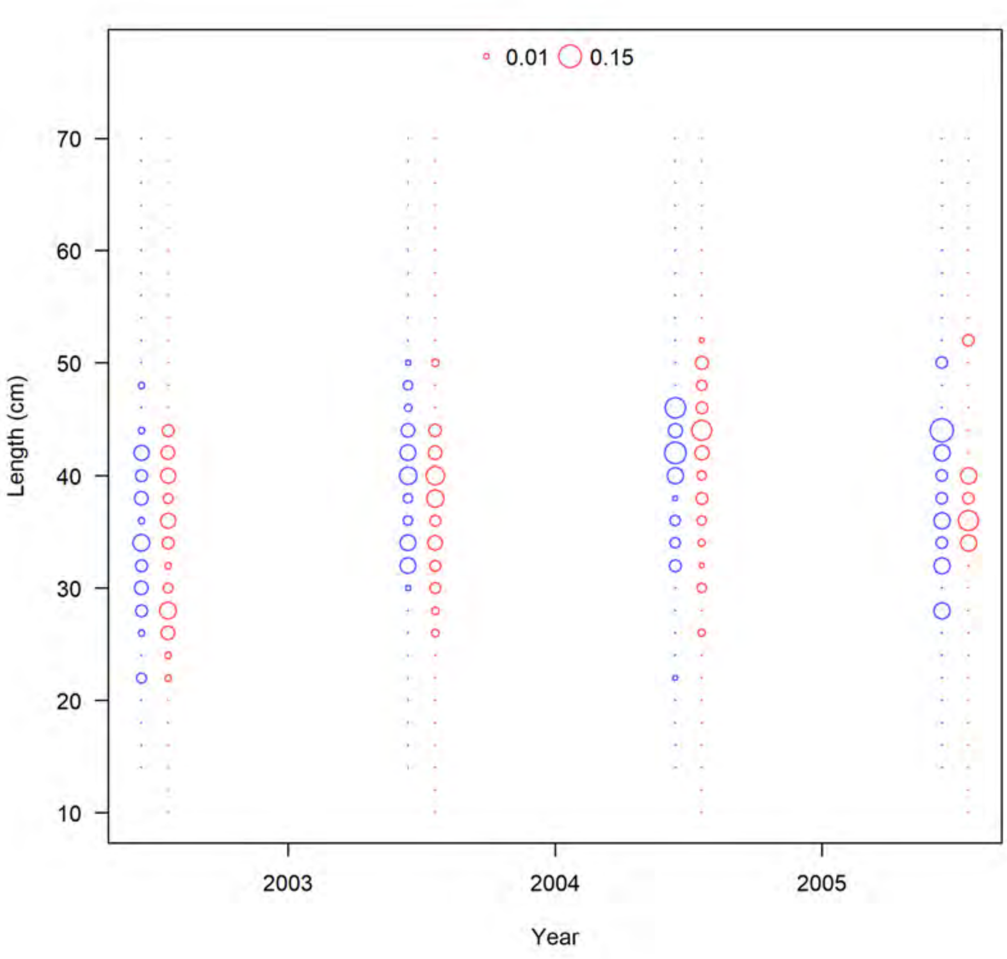

Figure 16: Length composition data from the SWFSC groundfish ecology survey.

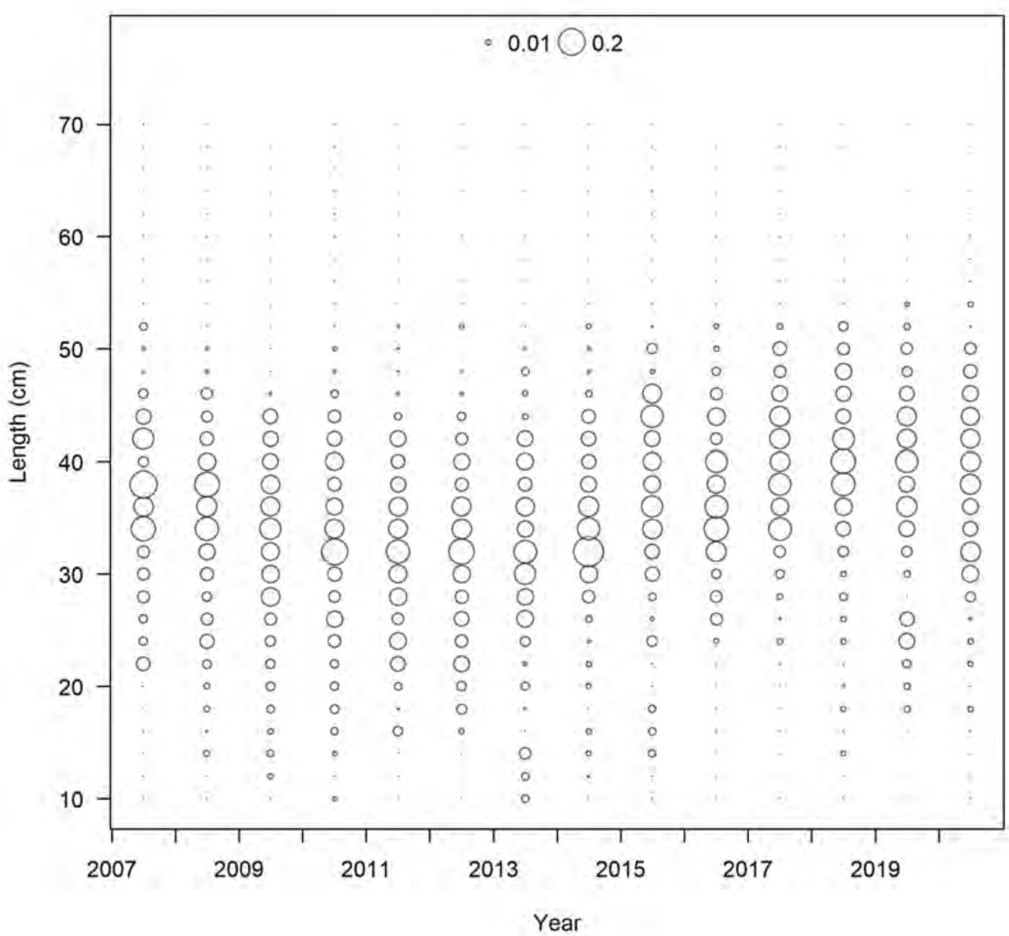

Figure 17: Length composition data from the California Collaborative Fisheries Research Program survey.

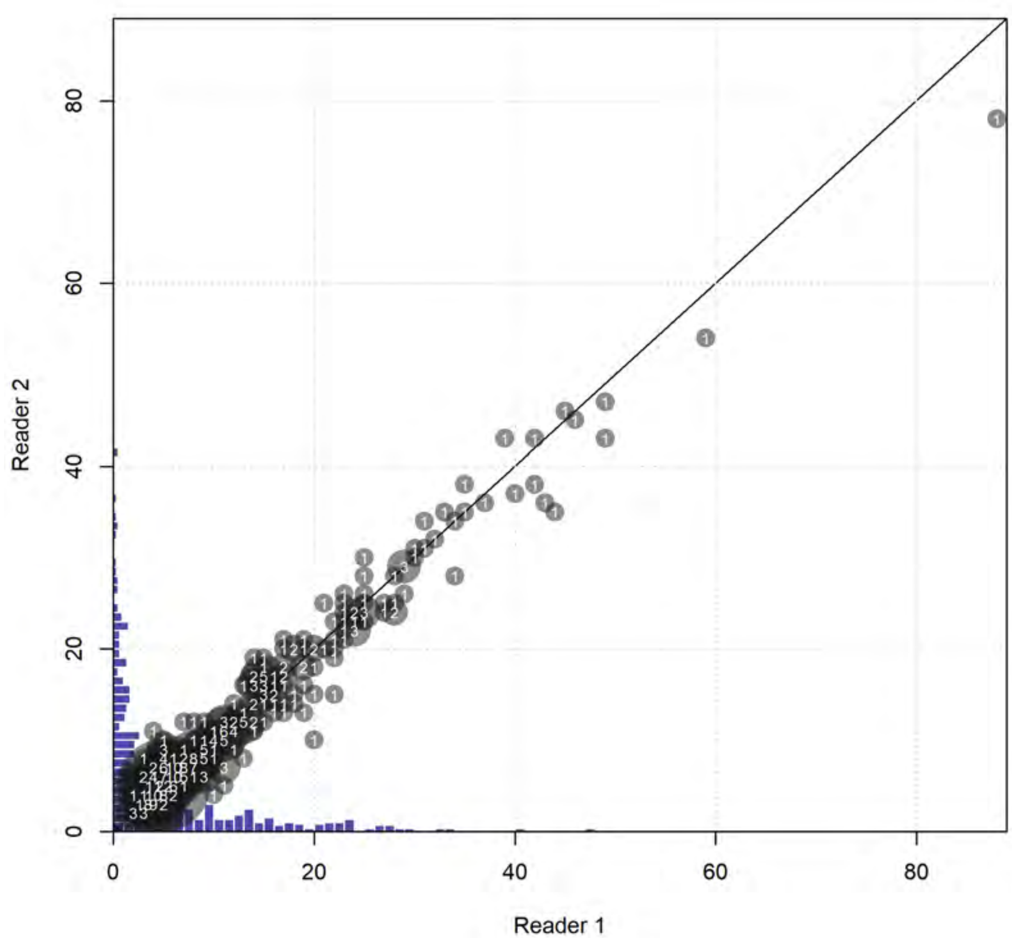

Figure 18: Aging precision between initial and blind double reads for vermilion rockfish. Numbers in the bubbles are the sample sizes of otoliths cross-read.

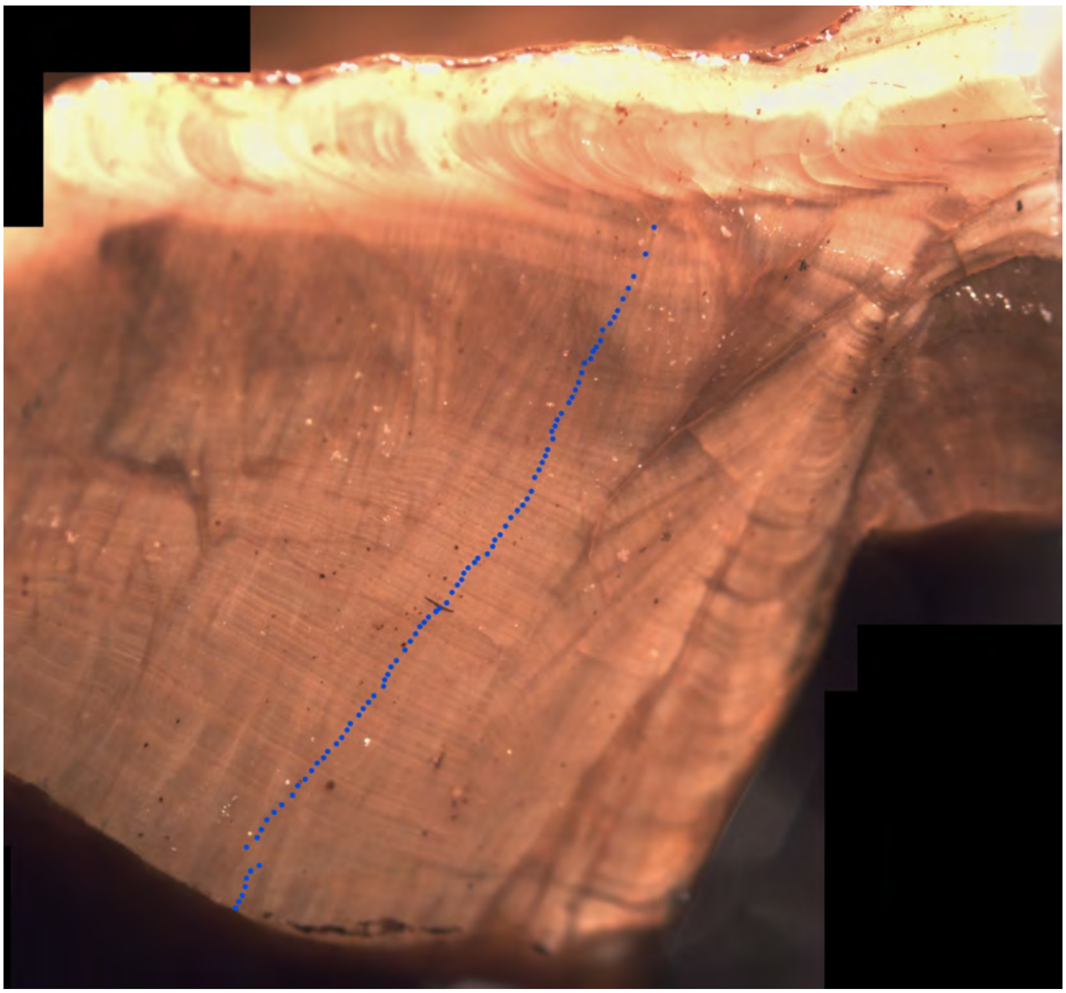

Figure 19: Photograph of the *oldest* aged fish used in the assessment with annuli marked by B. Kamikawa (NWFSC).

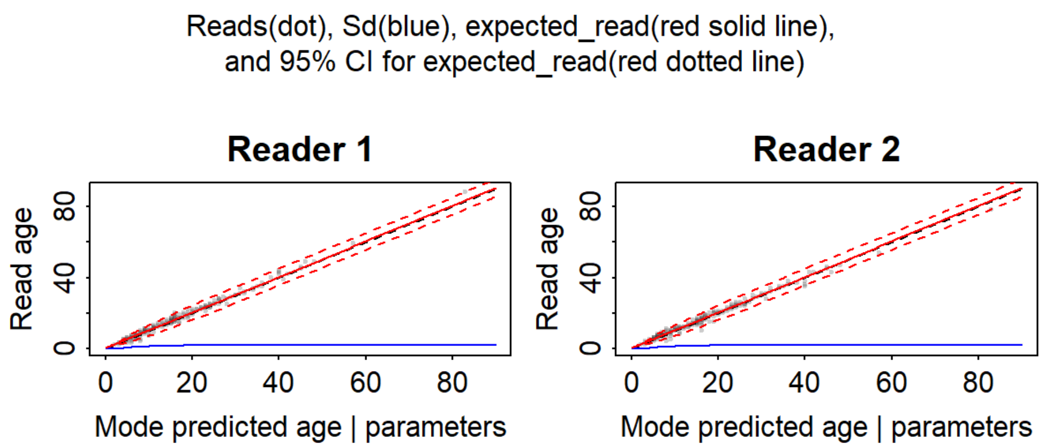

Figure 20: True versus predicted age for two current age readers at the NWFSC from the ageing error software with unbiased reads for reader 1 and curvilinear bias for reader 1 and curvilinear standard deviation for both readers.

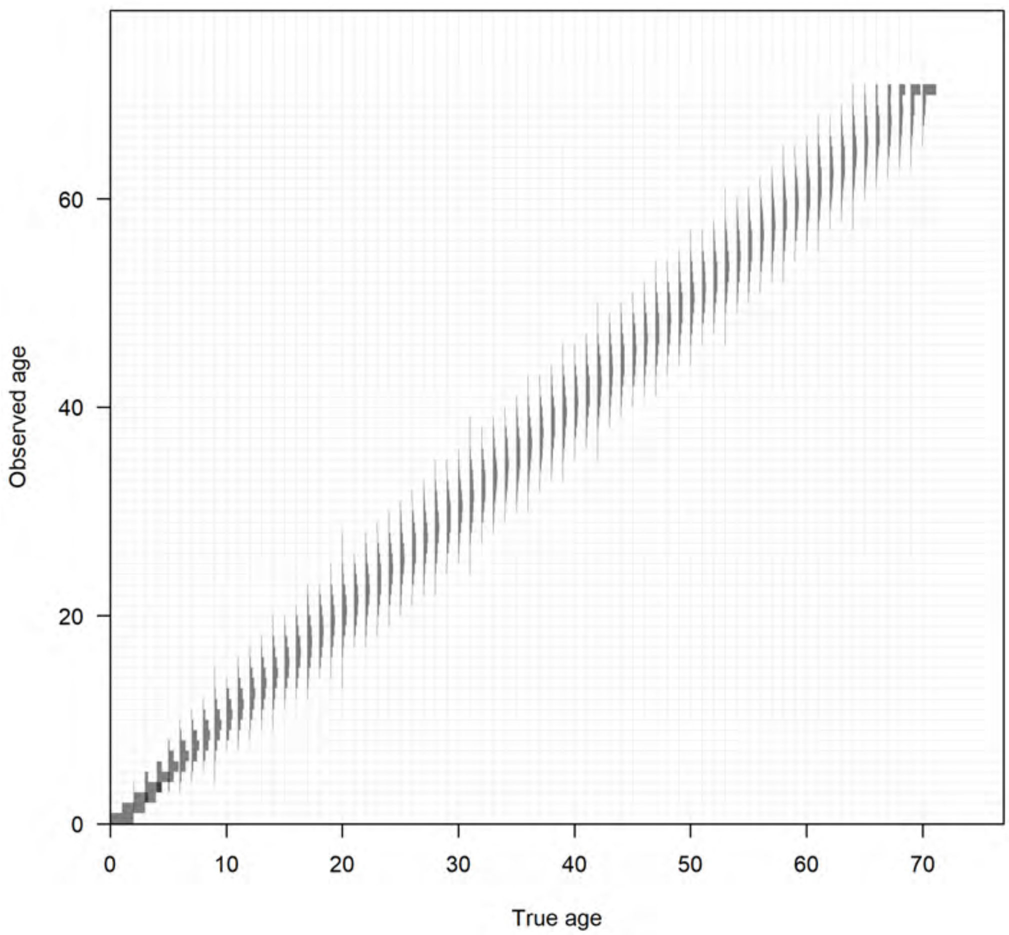

Figure 21: Distribution of observed age at true age for ageing error type 1.

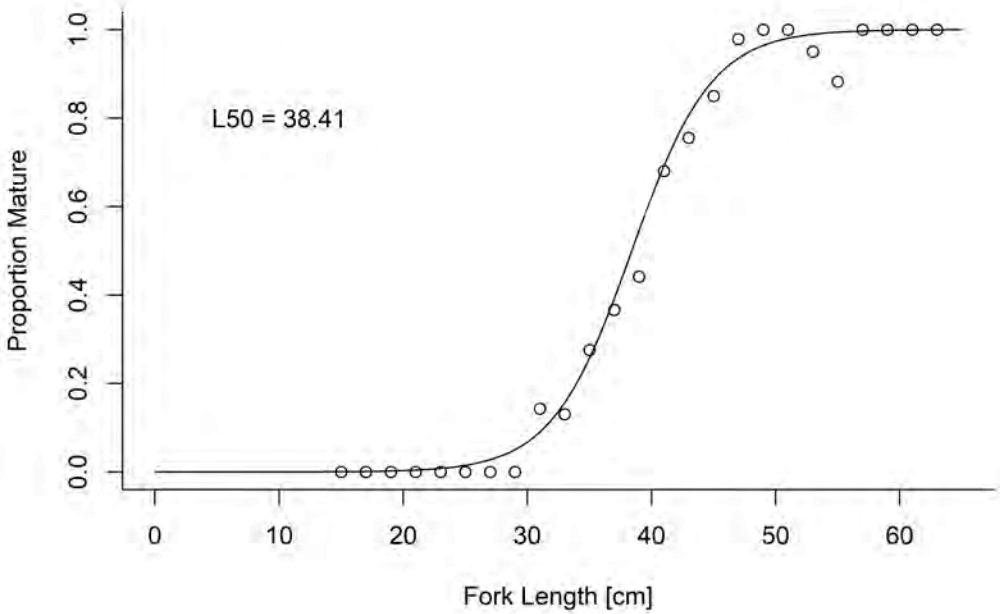

Figure 22: Fitted logistic regression of estimated functional maturity as a function of fork length for vermilion rockfish.

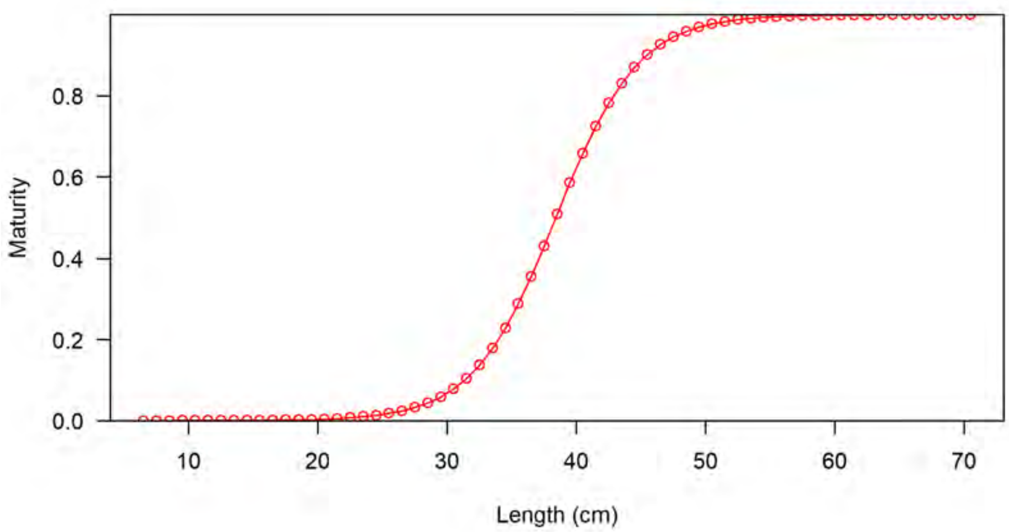

Figure 23: Maturity at length.

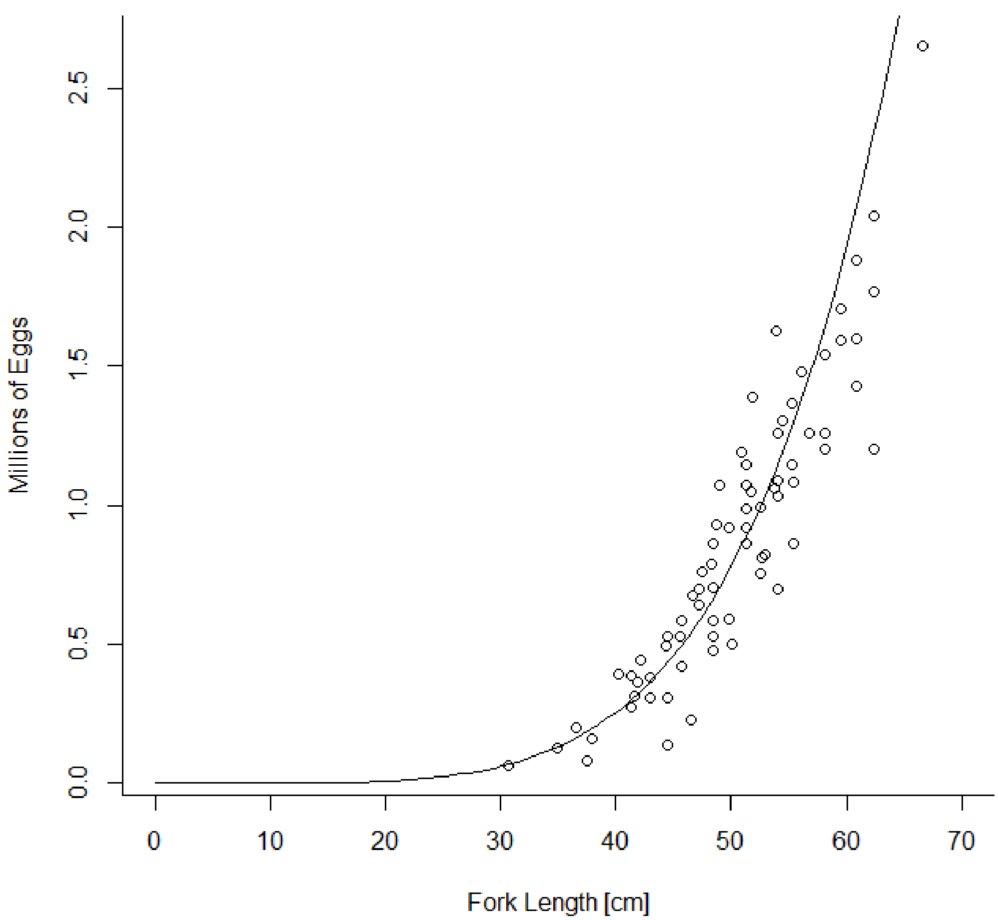

Figure 24: Fitted fecundity as a function of weight from samples of vermilion rockfish.

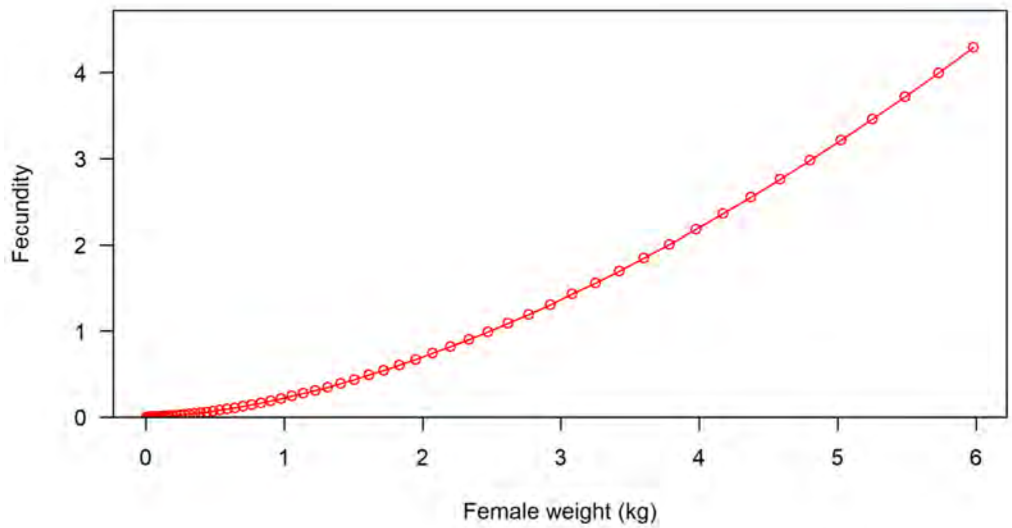

Figure 25: Fecundity as a function of weight.

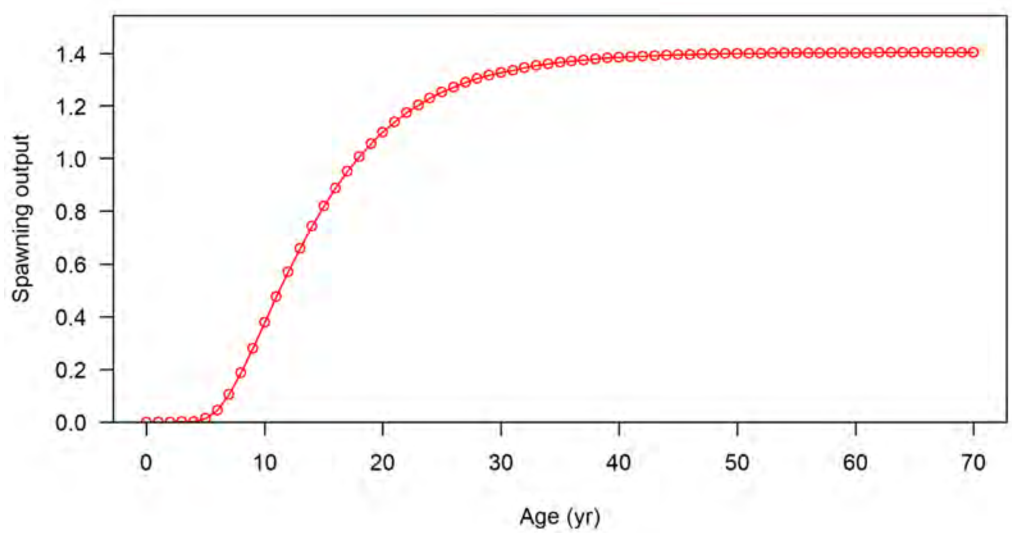

Figure 26: Spawning output at age. This is the product of maturity and fecundity. When these processes are length-based they are converted into the age dimension using the matrix of length at age.

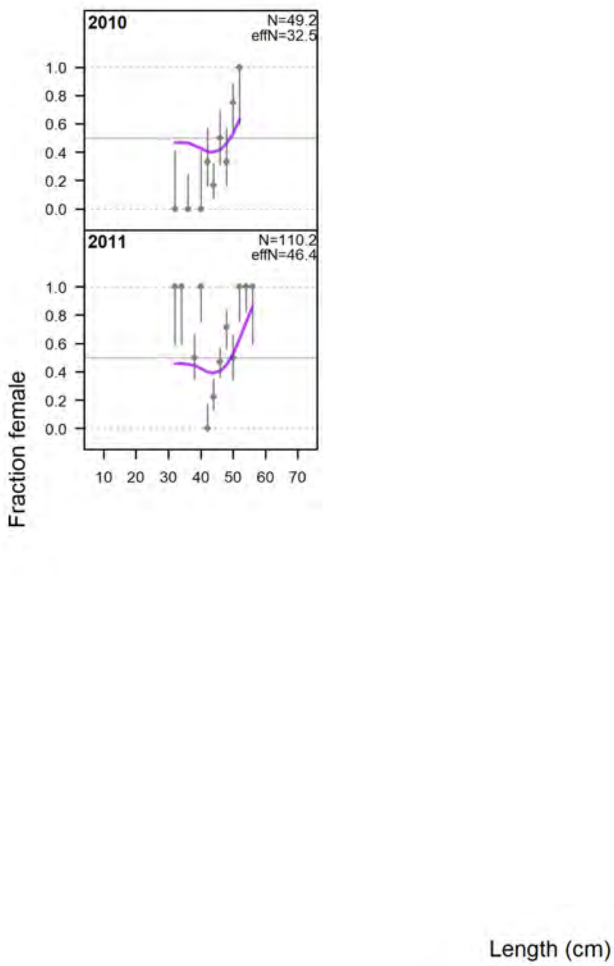

Figure 27: Sex ratios for length comps, whole catch, Abrams thesis research survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

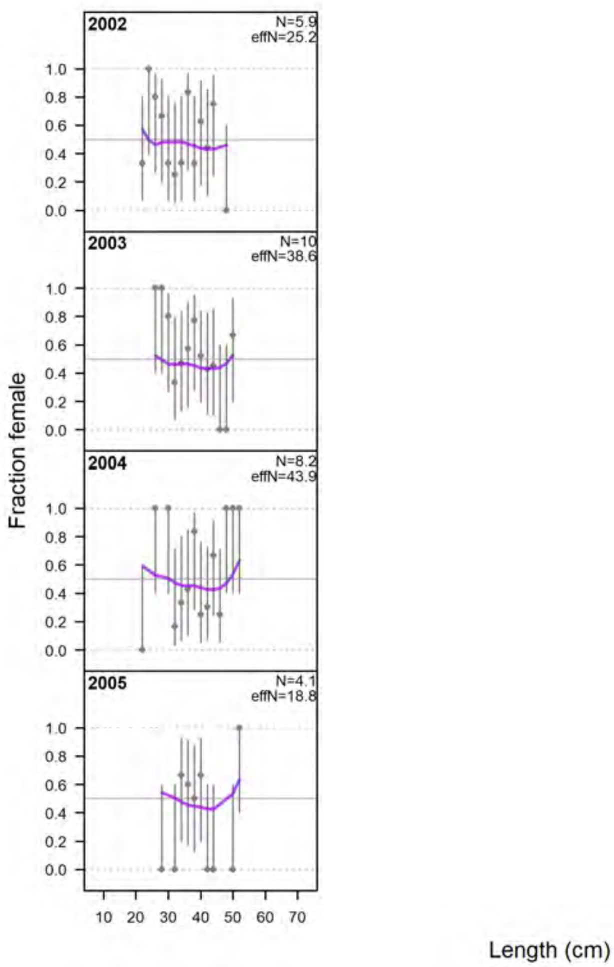

Figure 28: Sex ratios for length comps, whole catch, SWFSC groundfish ecology survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

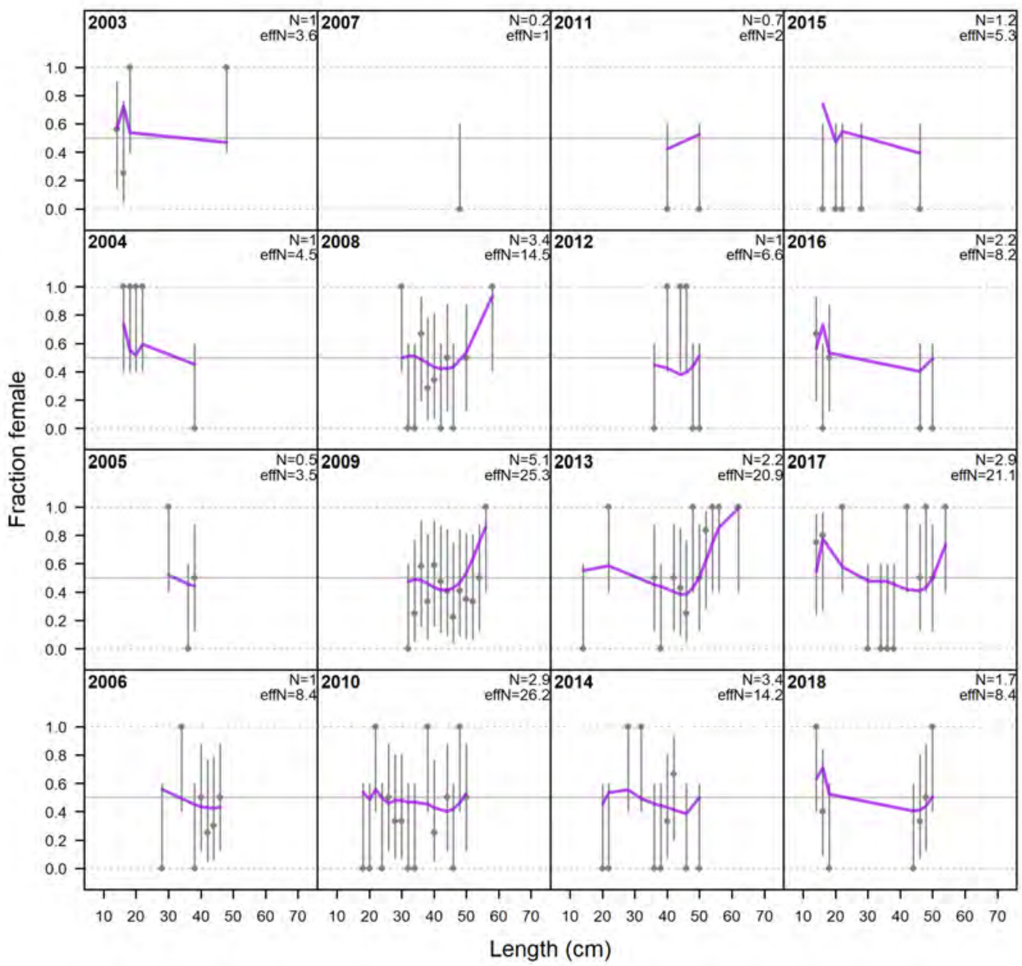

Figure 29: Sex ratios for length comps, whole catch, West coast groundfish bottomfish trawl survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

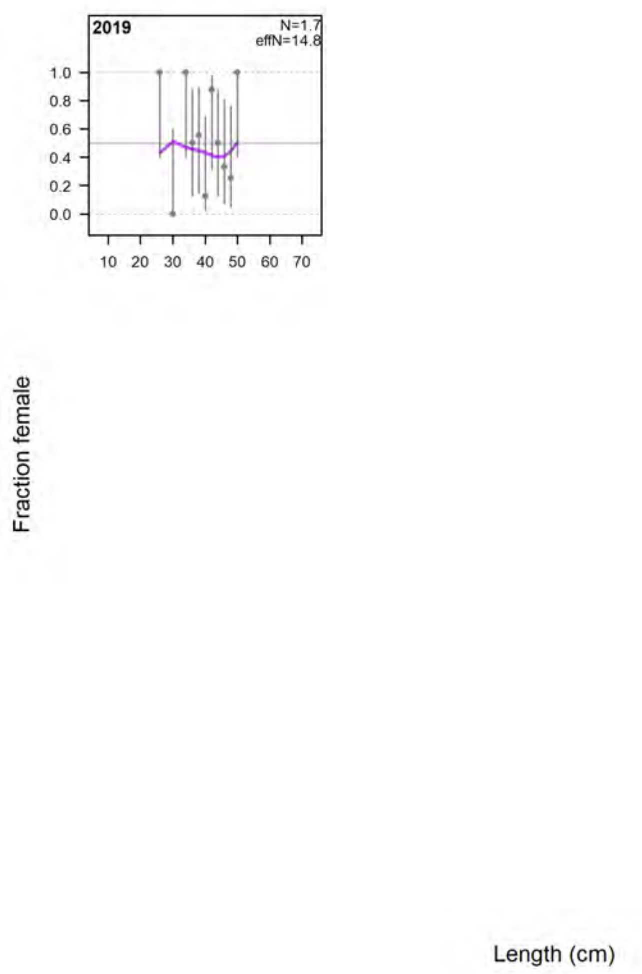

Figure 30: Sex ratios for length comps, whole catch, West coast groundfish bottomfish trawl survey. Observed sex ratios (points) with 75% intervals (vertical lines) calculated as a Jeffreys interval based on the adjusted input sample size. The model expectation is shown in the purple line.

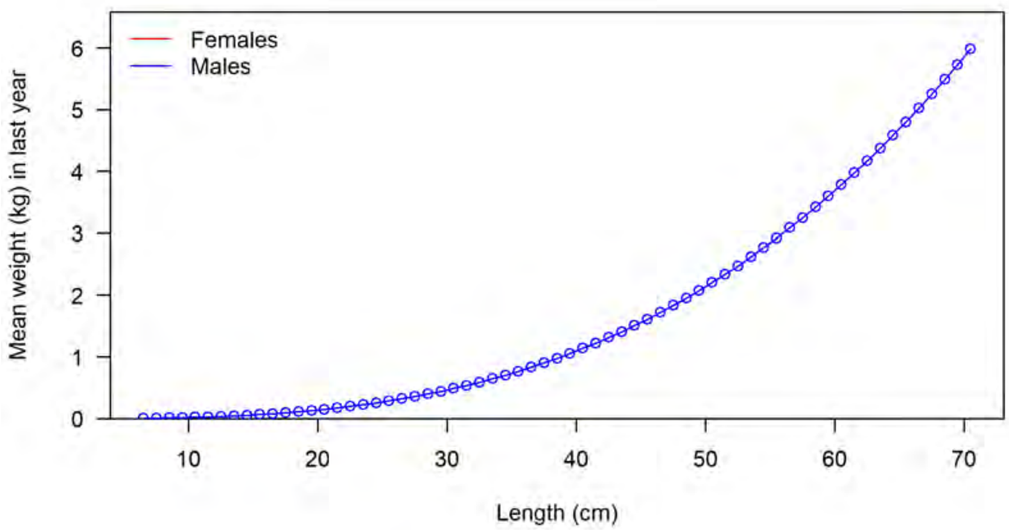

Figure 31: Weight-length relationship.

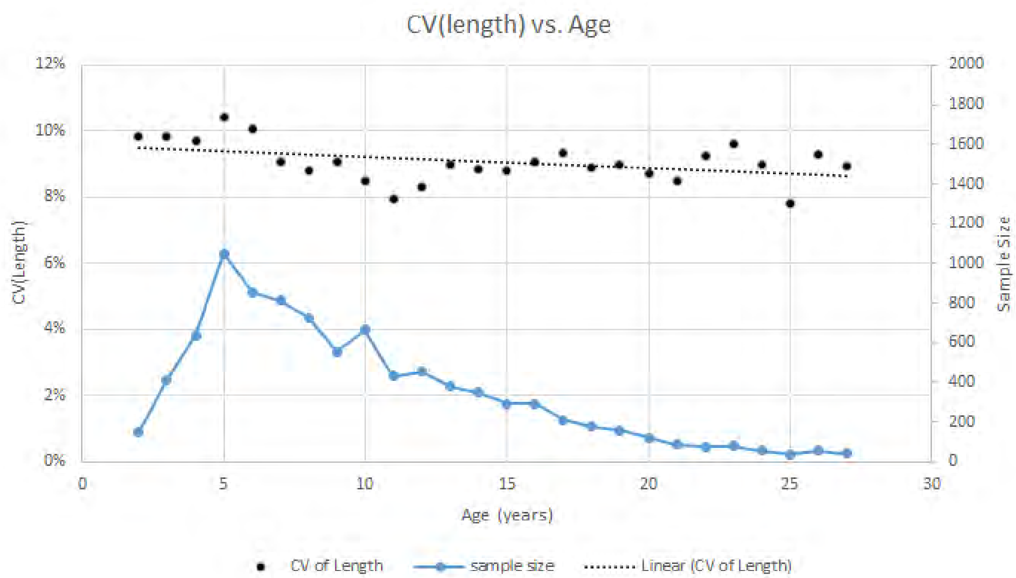

Figure 32: Coefficient of variation of length versus age for vermilion rockfish from the NWFSC hook-and-line survey.

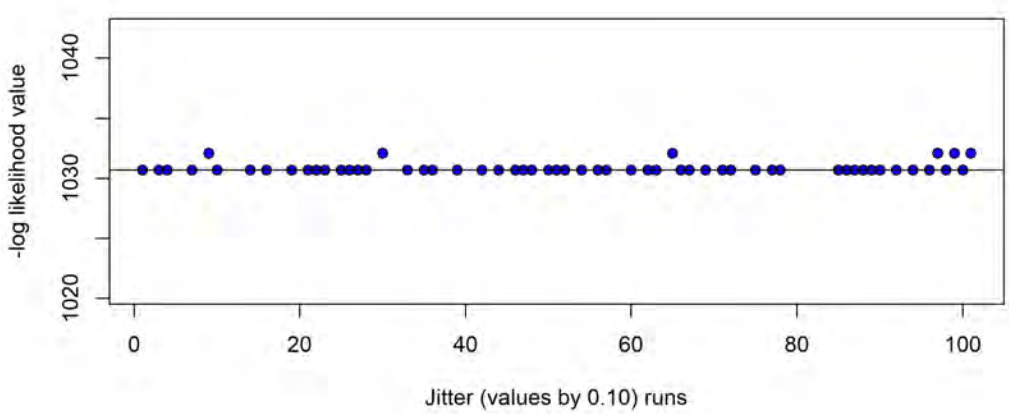

Figure 33: Results from 100 jittered runs of the post-STAR base model. Missing values indicate the 43 runs that did not converge.

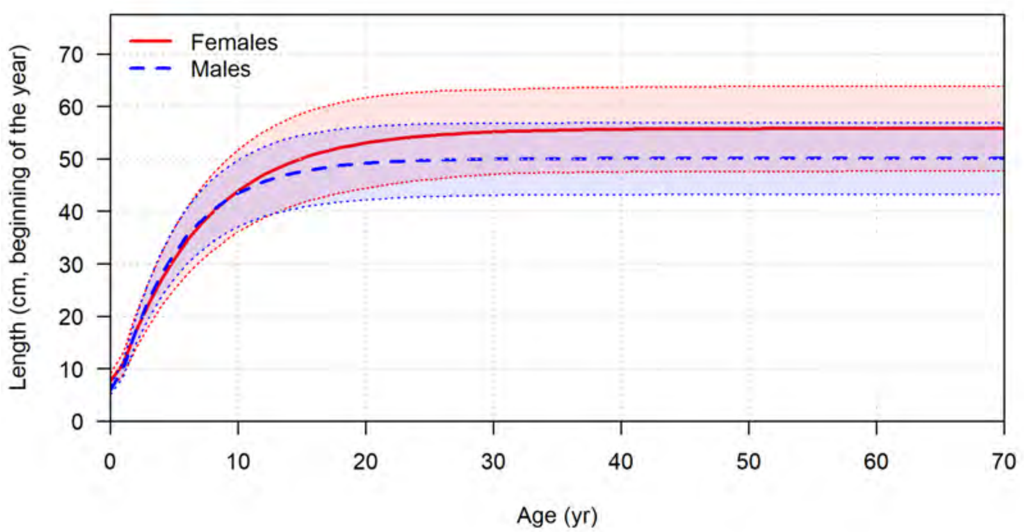

Figure 34: Length at age in the beginning of the year (or season) in the ending year of the model. Shaded area indicates 95% distribution of length at age around estimated growth curve.

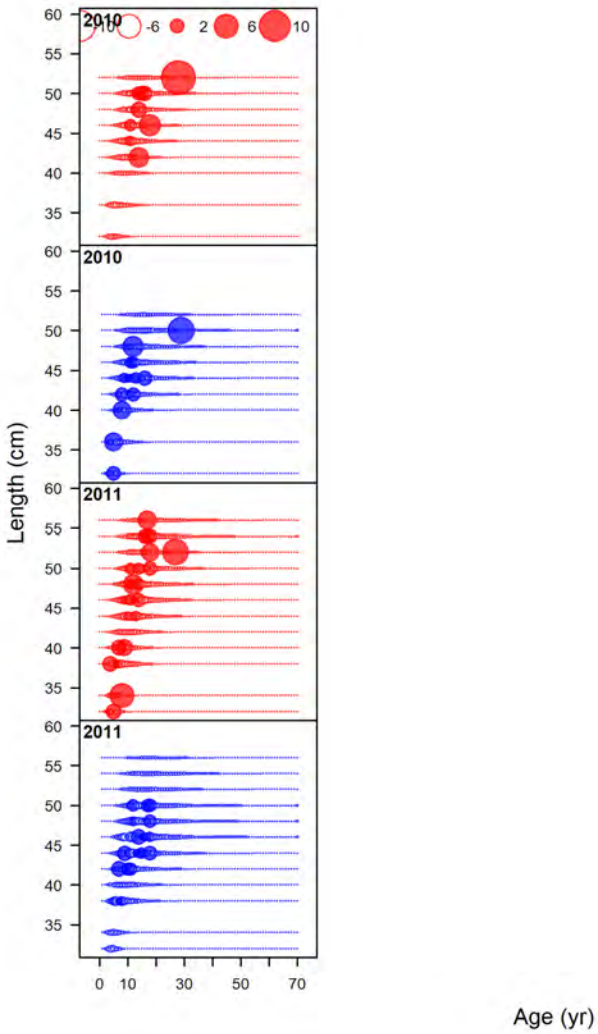

Figure 35: Pearson residuals, whole catch, ABRAMS_RESEARCH (max=11.91).

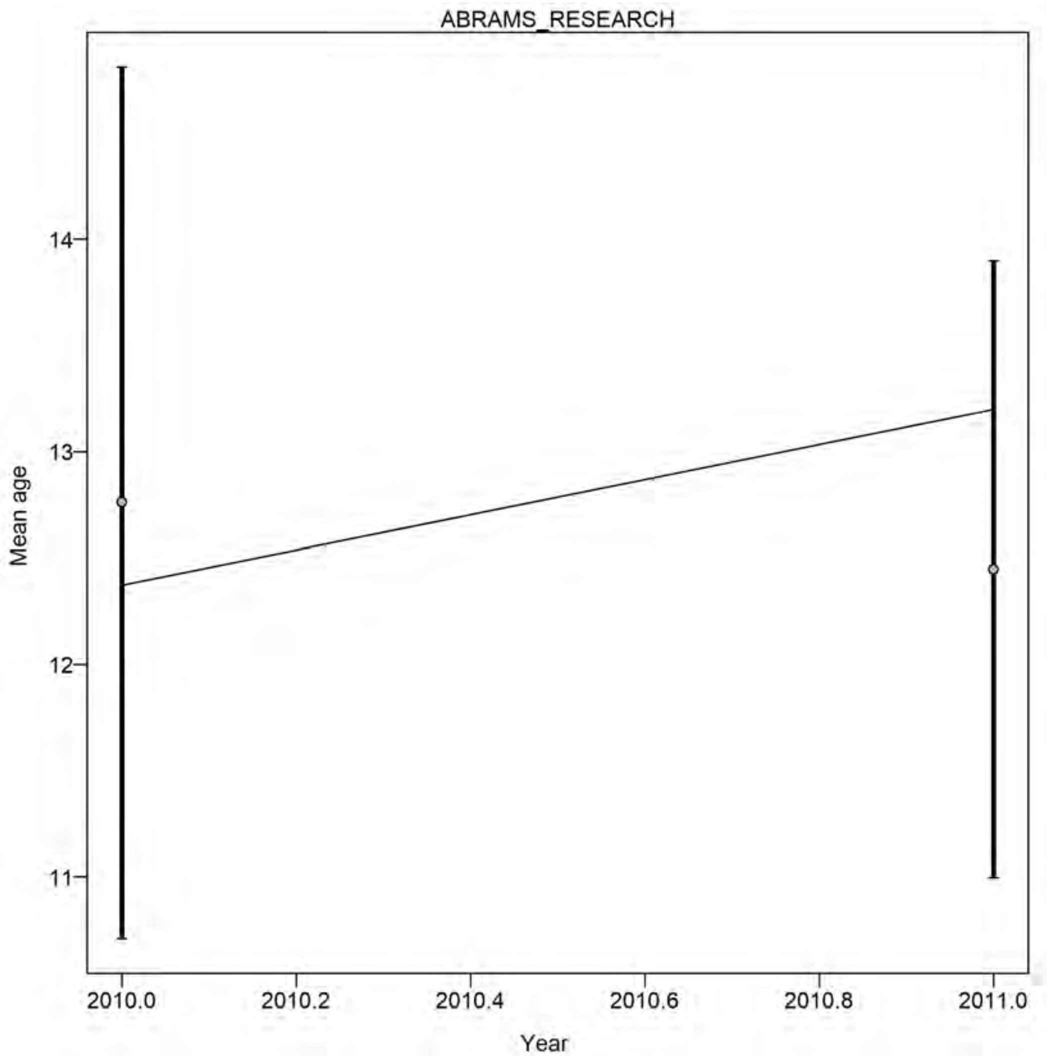

Figure 36: Mean age from conditional data (aggregated across length bins) for ABRAMS_RESEARCH with 95% confidence intervals based on current samples sizes.Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from ABRAMS_RESEARCH:0.9942 (0.9942-Inf) For more info, see

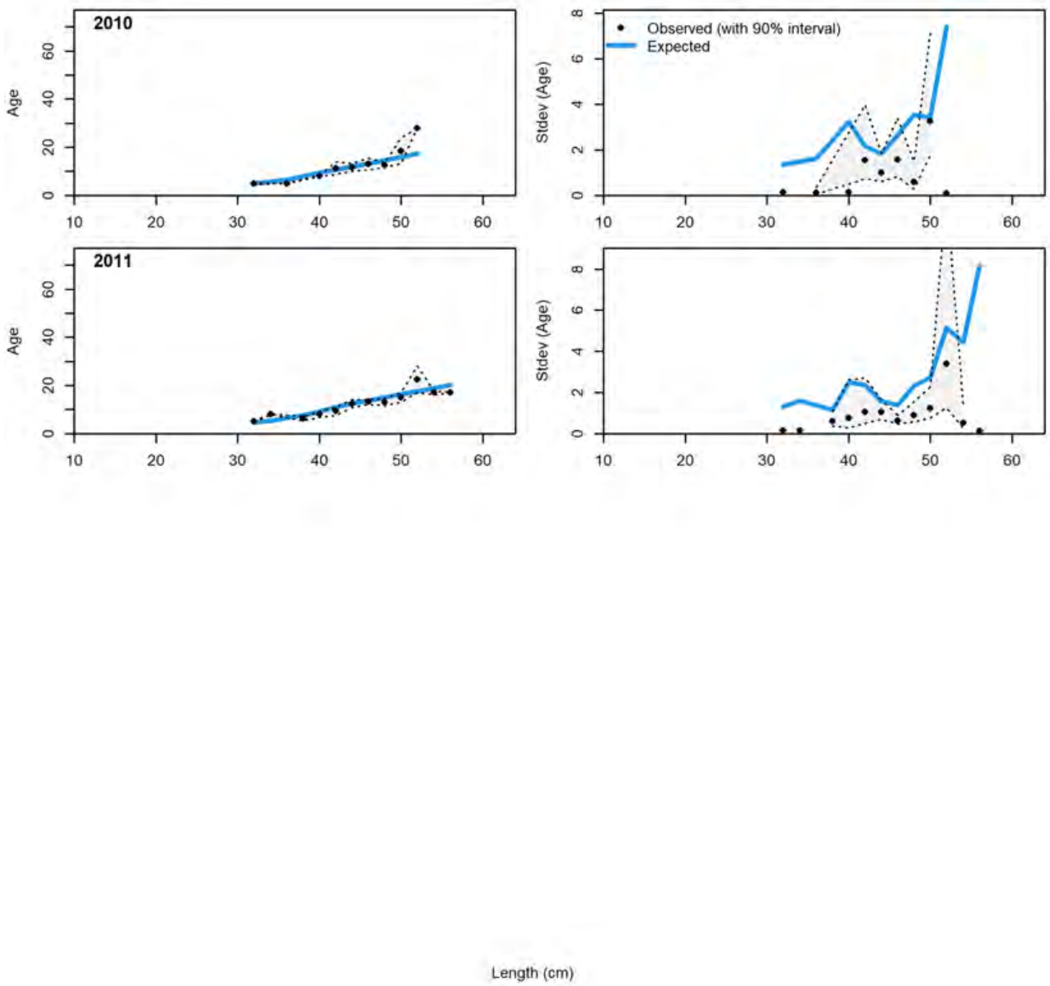

Figure 37: Conditional AAL plot, whole catch, ABRAMS_RESEARCH These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

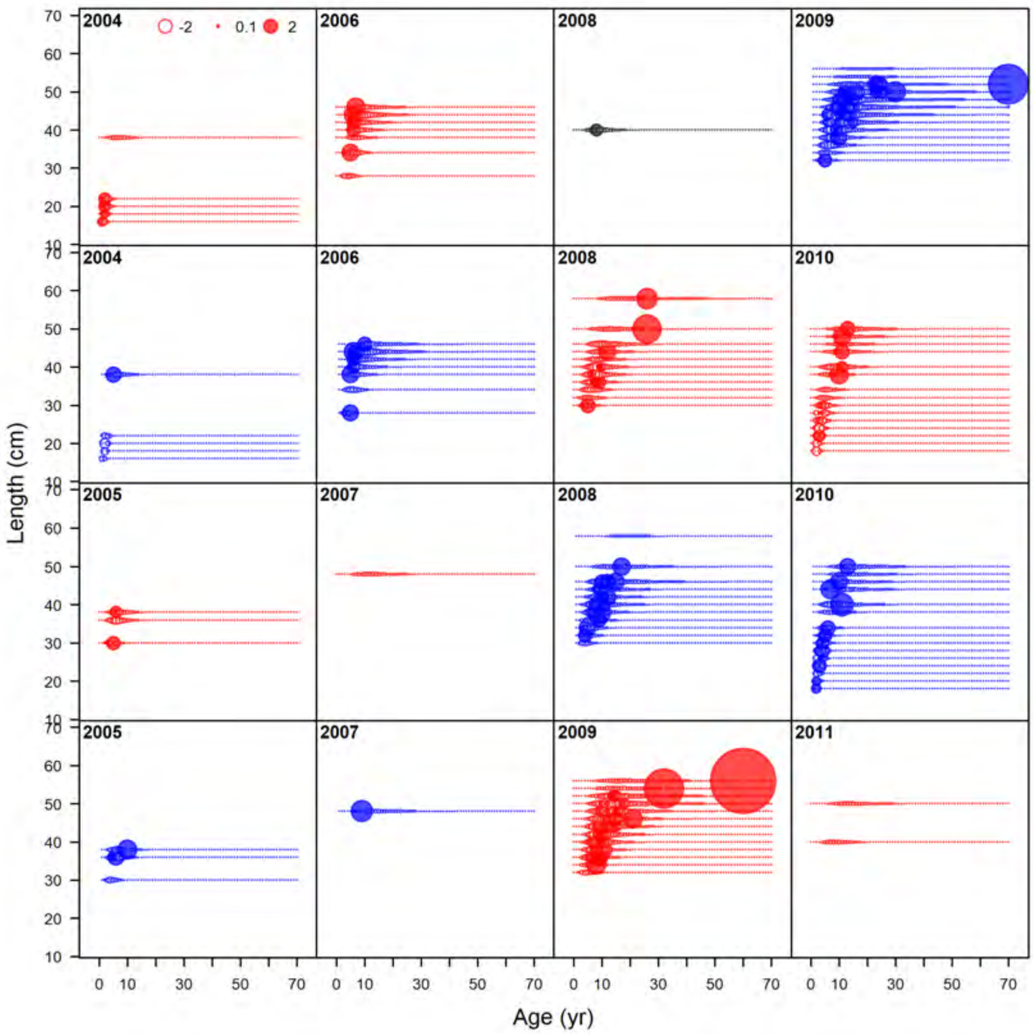

Figure 38: Pearson residuals, whole catch, NWFSC_TWL (max=43.61) (plot 1 of 3).

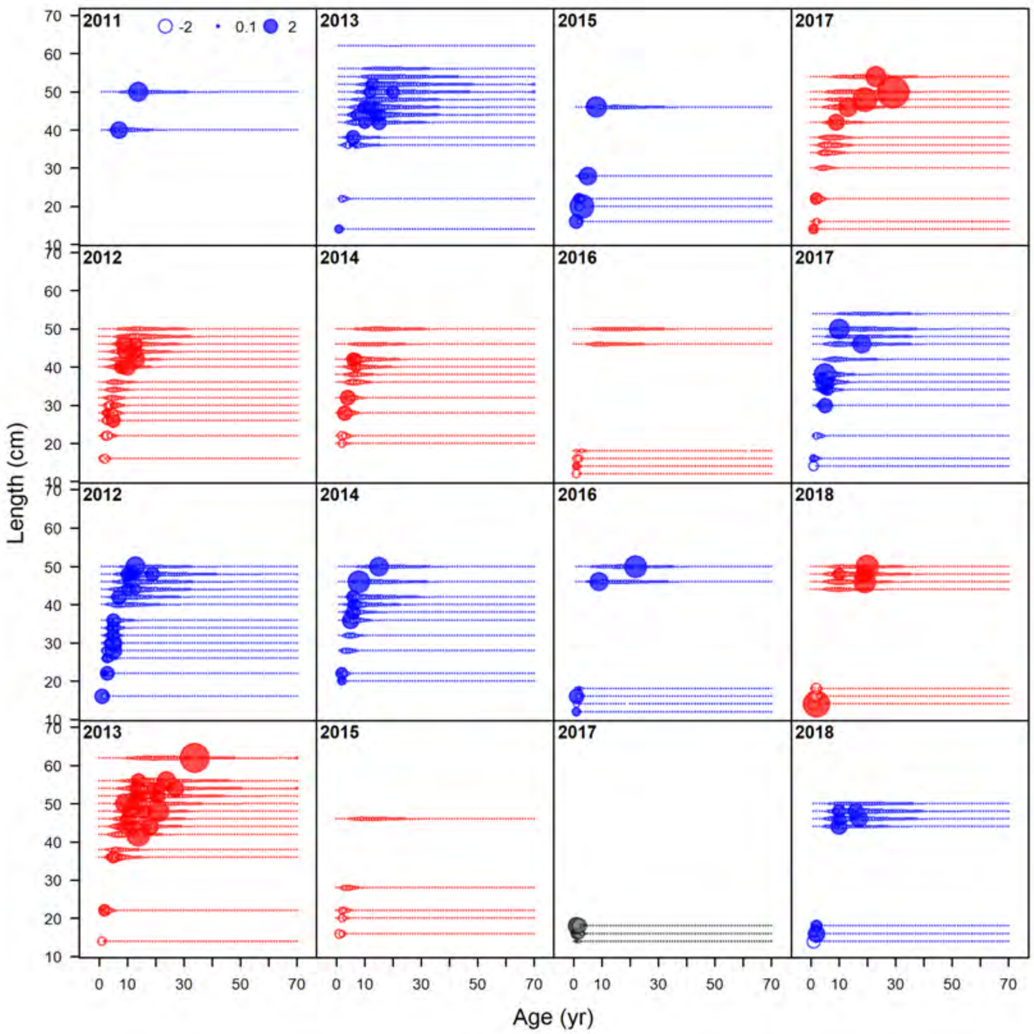

Figure 39: Pearson residuals, whole catch, NWFSC_TWL (max=43.61) (plot 2 of 3).

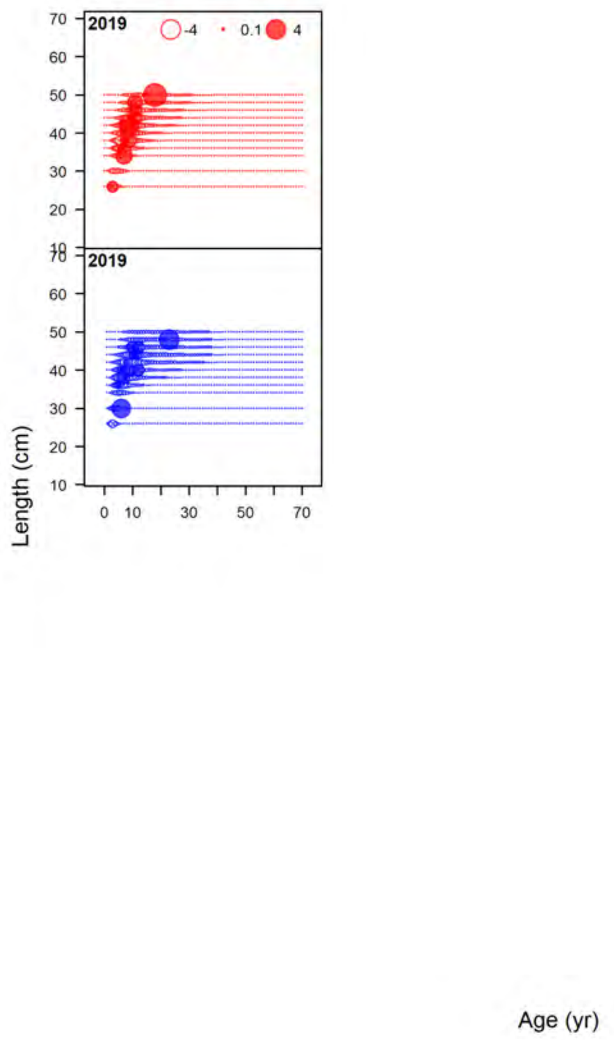

Figure 40: Pearson residuals, whole catch, NWFSC_TWL (max=43.61) (plot 3 of 3).

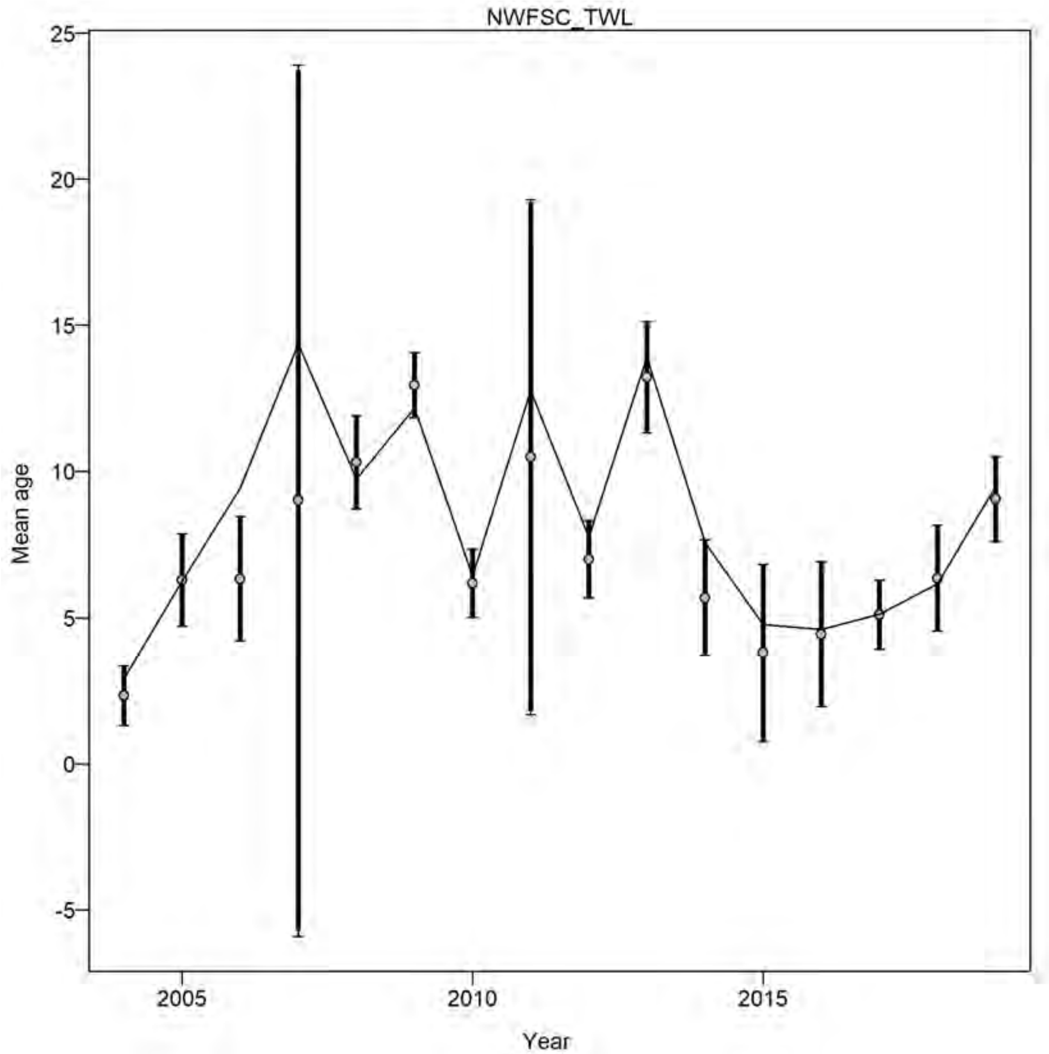

Figure 41: Mean age from conditional data (aggregated across length bins) for NWFSC_TWL with 95% confidence intervals based on current samples sizes.Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from NWFSC_TWL:0.9764 (0.5421-3.1871) For more info, see

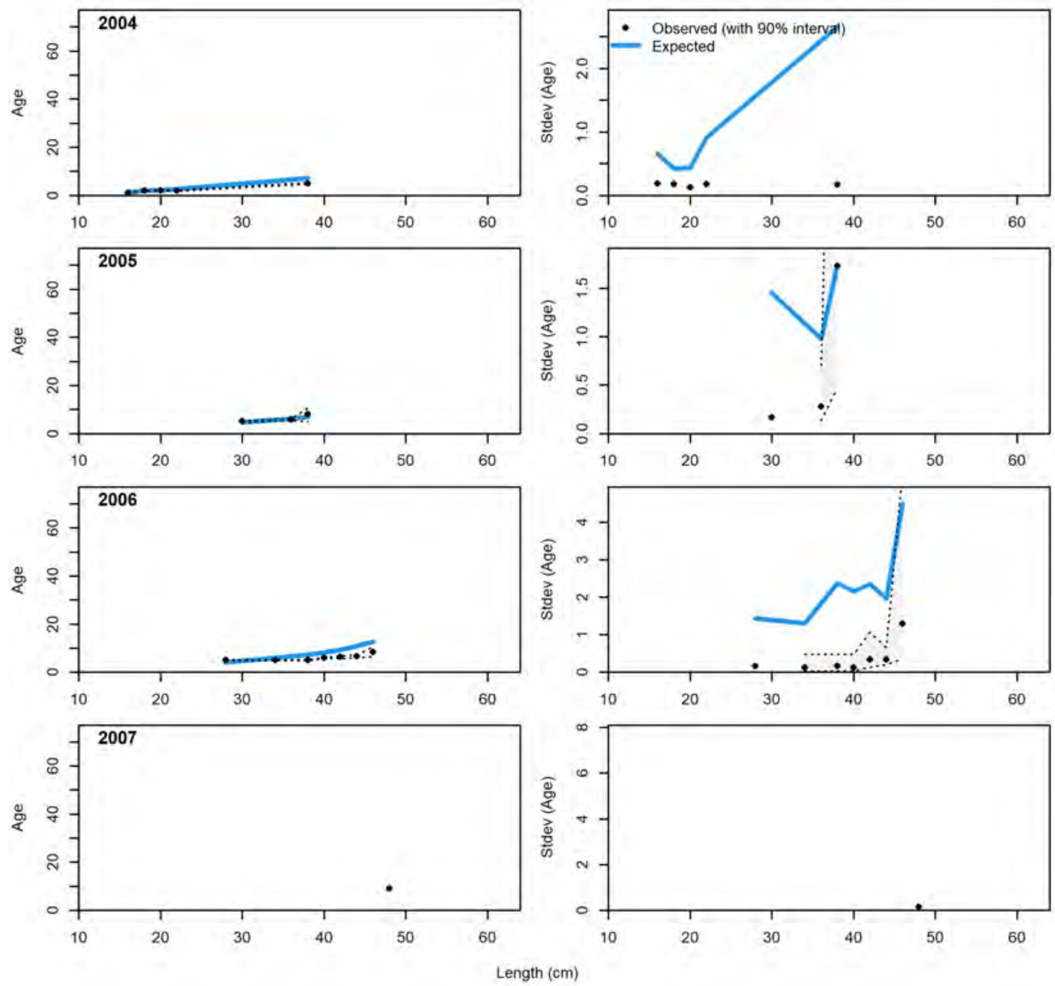

Figure 42: Conditional AAL plot, whole catch, NWFSC_TWL (plot 1 of 4) These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

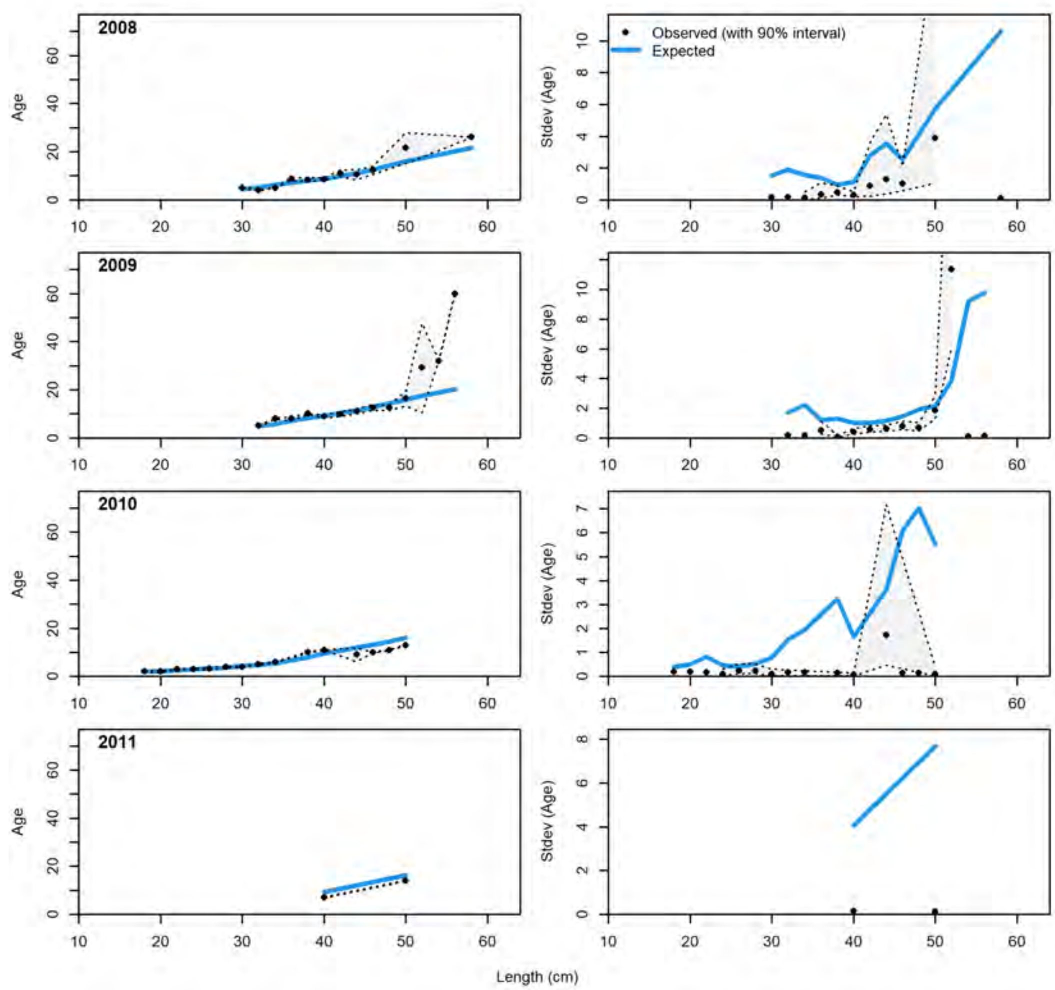

Figure 43: Conditional AAL plot, whole catch, NWFSC_TWL (plot 2 of 4).

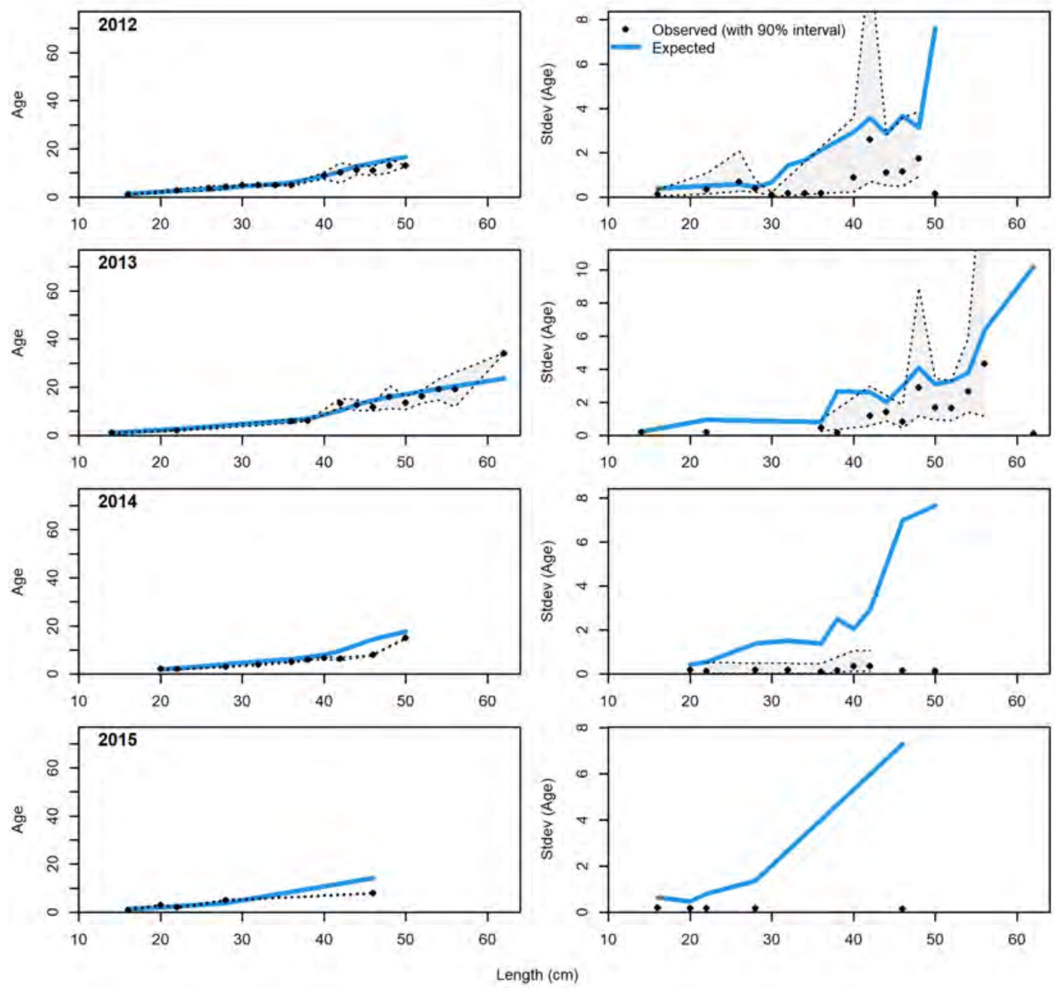

Figure 44: Conditional AAL plot, whole catch, NWFSC_TWL (plot 3 of 4).

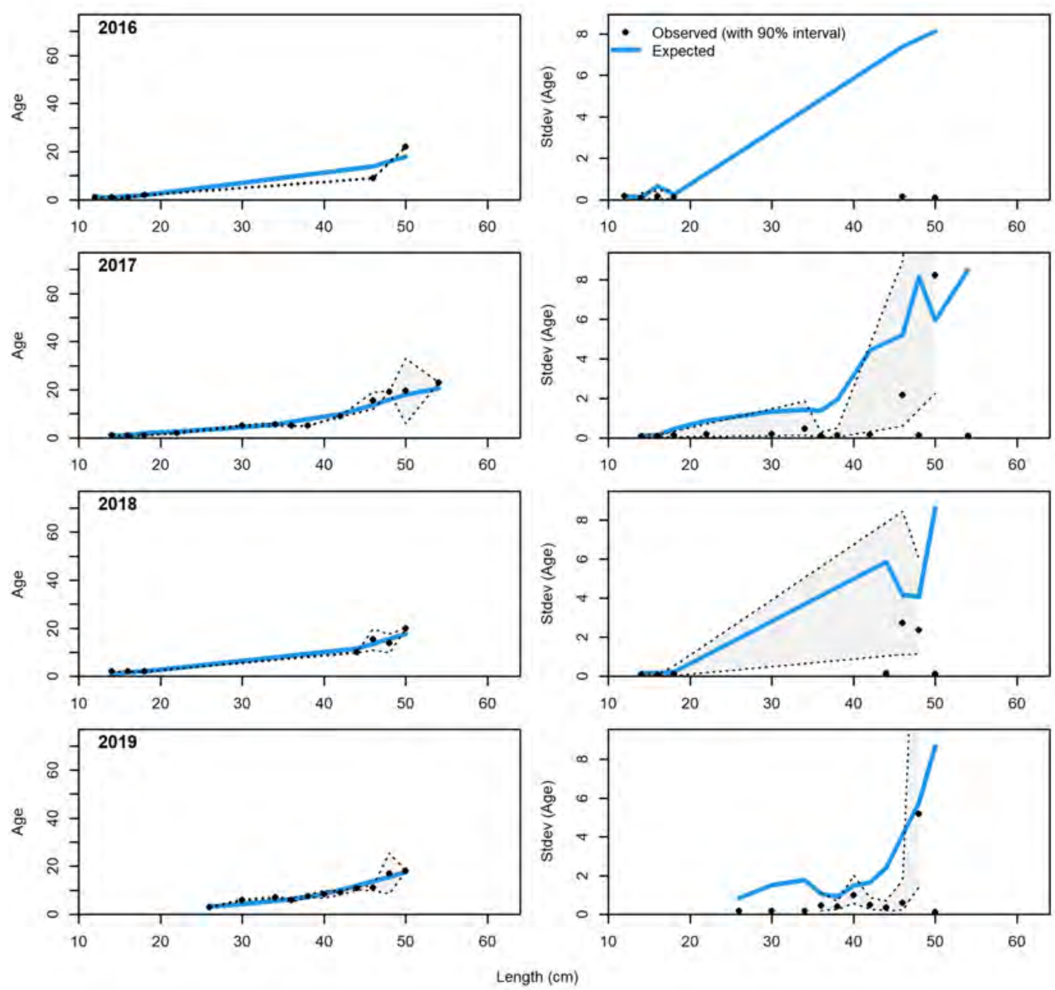

Figure 45: Conditional AAL plot, whole catch, NWFSC_TWL (plot 4 of 4).

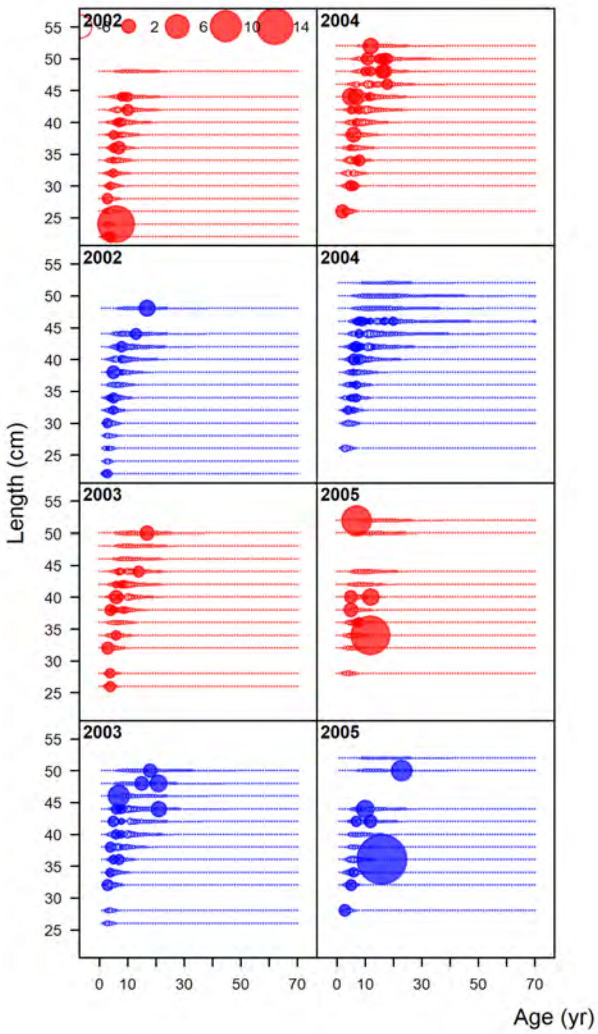

Figure 46: Pearson residuals, whole catch, SWFSC_GF_ECOL (max=25.1).

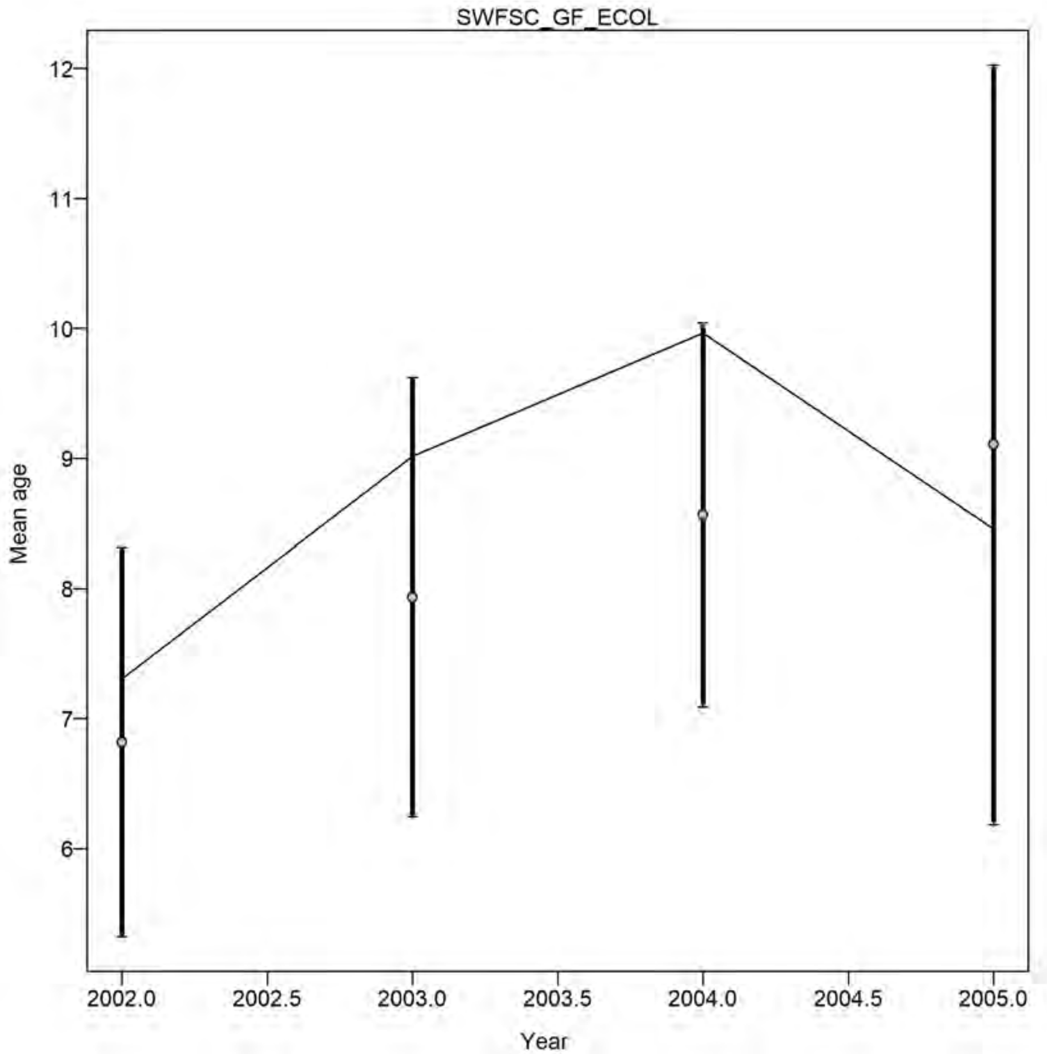

Figure 47: Mean age from conditional data (aggregated across length bins) for SWFSC_GF_ECOL with 95% confidence intervals based on current samples sizes.Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data from SWFSC_GF_ECOL:0.9874 (0.6839-10.5598) For more info, see

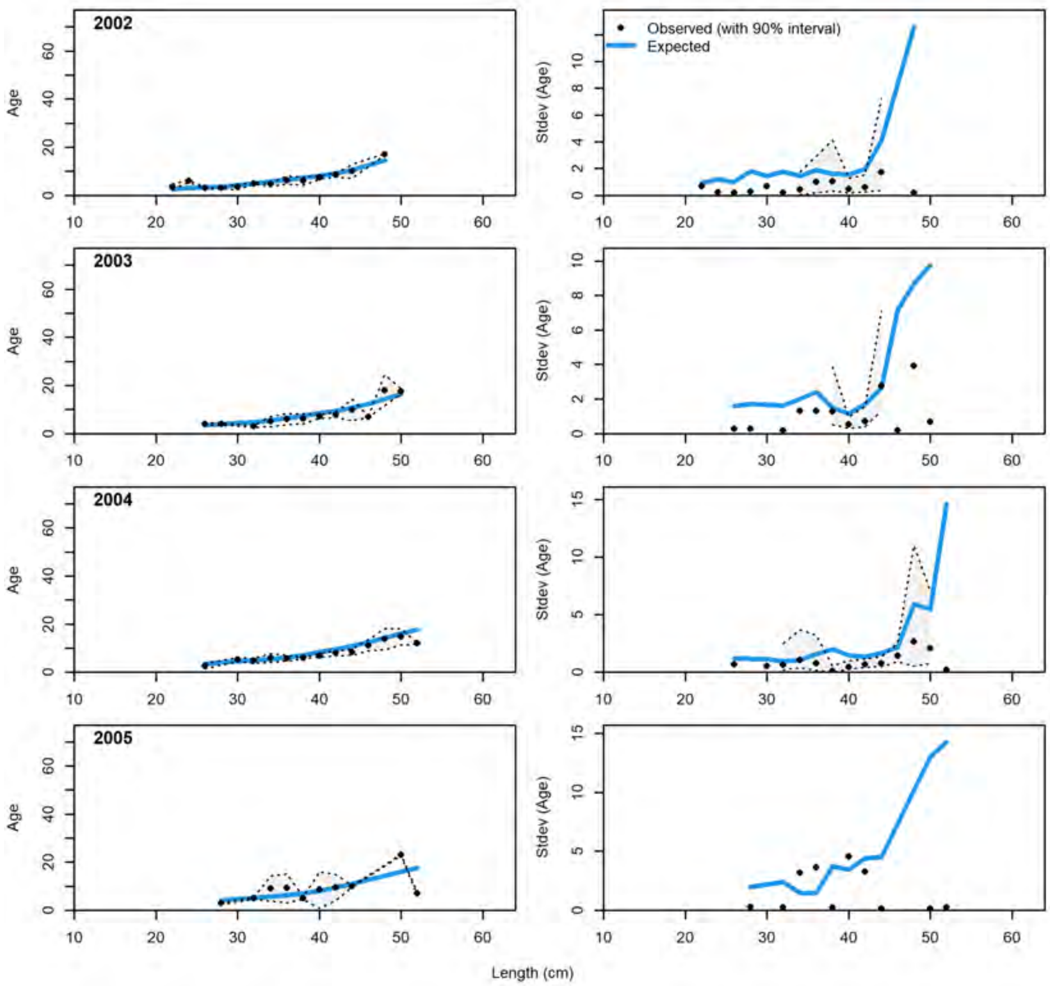

Figure 48: Conditional AAL plot, whole catch, SWFSC_GF_ECOL These plots show mean age and std. dev. in conditional A@L.Left plots are mean A@L by size-class (obs. and exp.) with 90% CIs based on adding 1.64 SE of mean to the data.Right plots in each pair are SE of mean A@L (obs. and exp.) with 90% CIs based on the chi-square distribution.

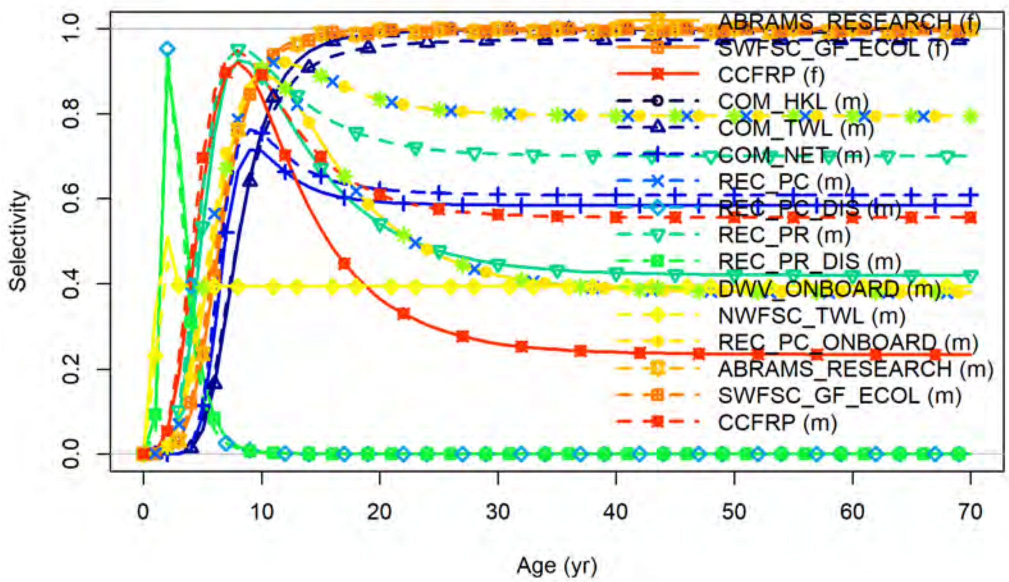

Figure 49: Selectivity at age derived from selectivity at length for multiple fleets.

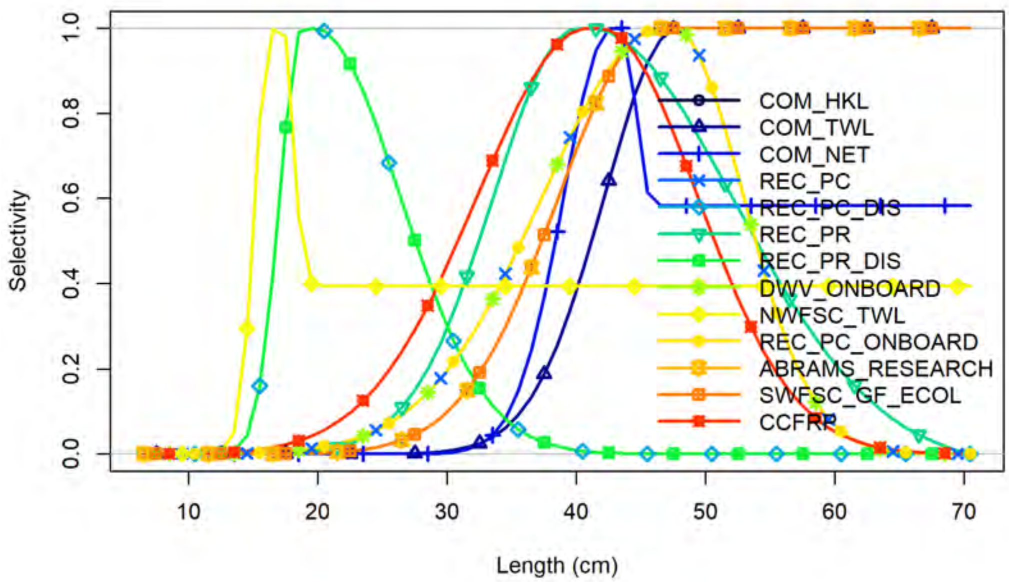

Figure 50: End year selectivity at length by fleet/survey.

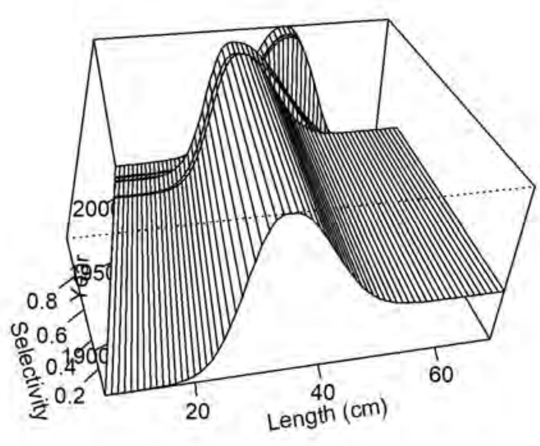

Figure 51: Surface plot of Female time-varying selectivity for REC_PC.

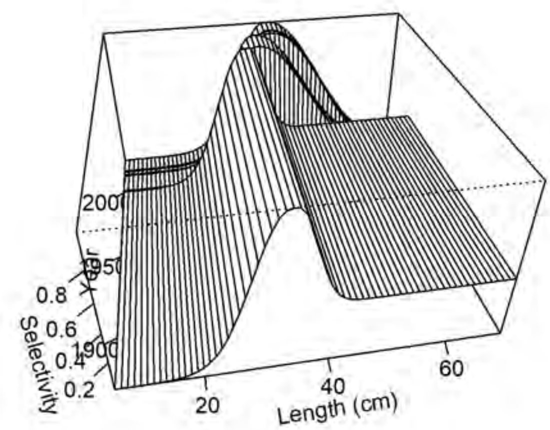

Figure 52: Surface plot of Female time-varying selectivity for REC_PR.

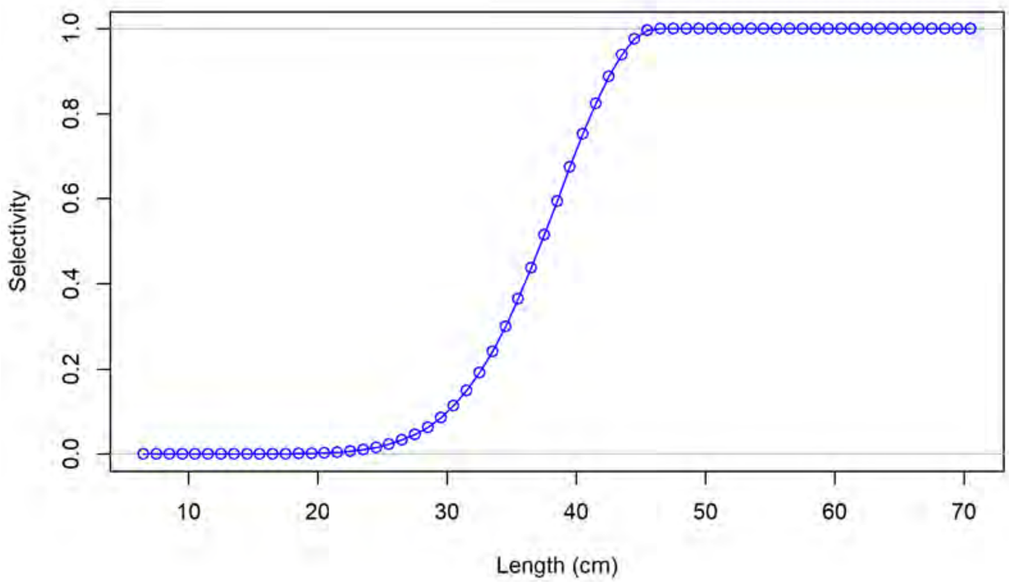

Figure 53: Female ending year selectivity for the commercial hook-and-line fishery.

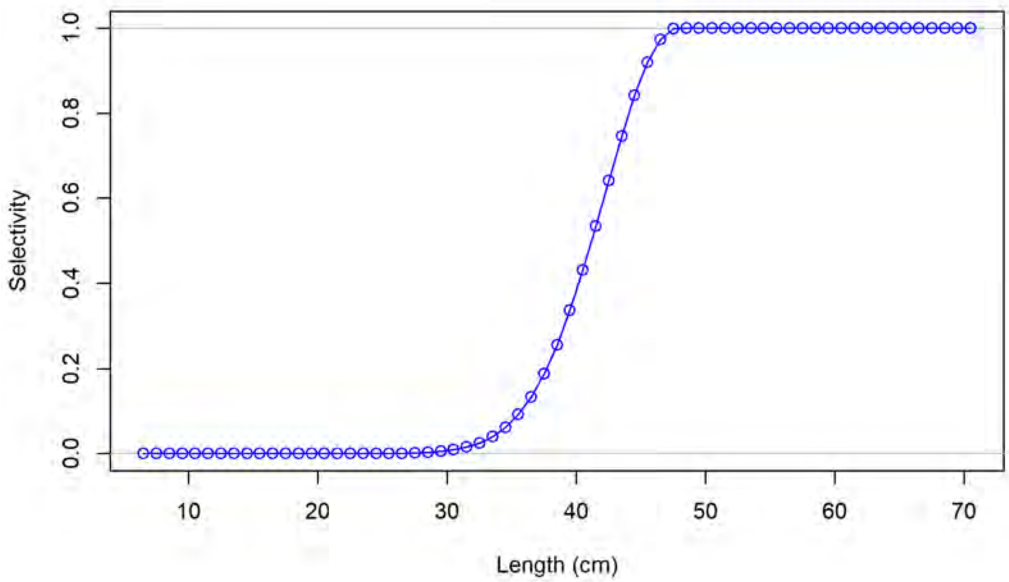

Figure 54: Female ending year selectivity for the commercial trawl fishery.

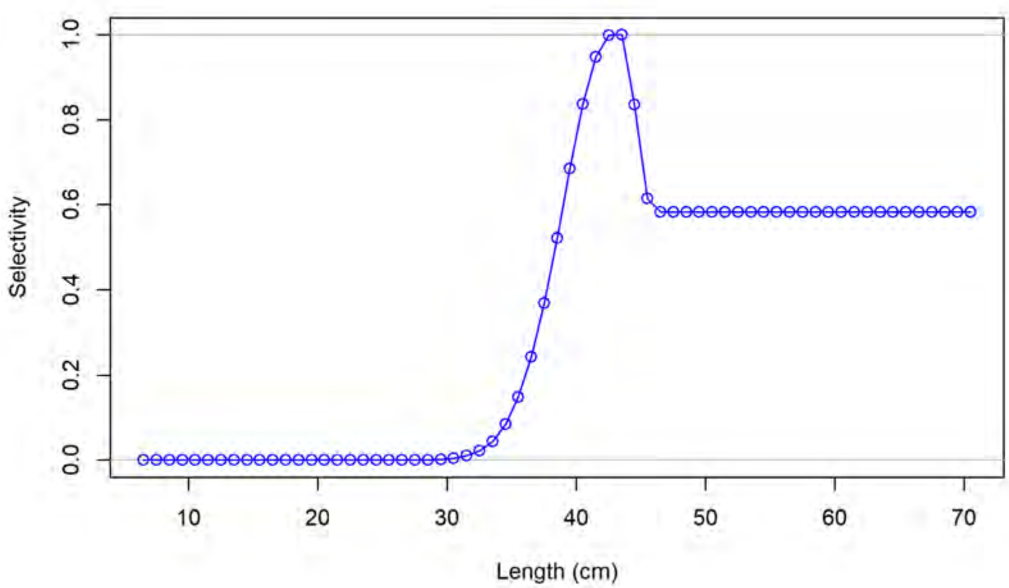

Figure 55: Female ending year selectivity for the commercial net fishery.

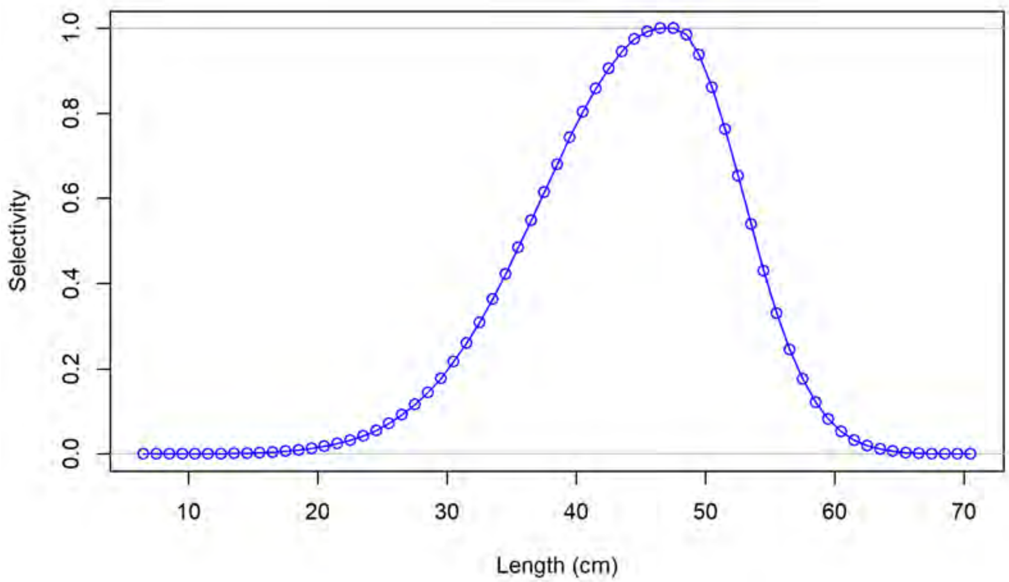

Figure 56: Female ending year selectivity for the recreational PC retained fishery.

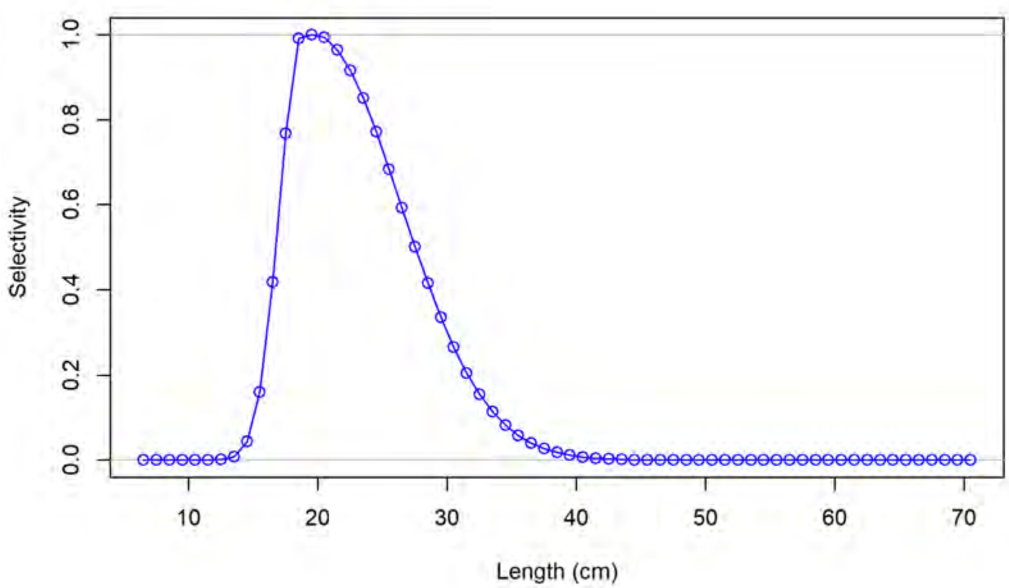

Figure 57: Female ending year selectivity for the recreational PC discard fishery.

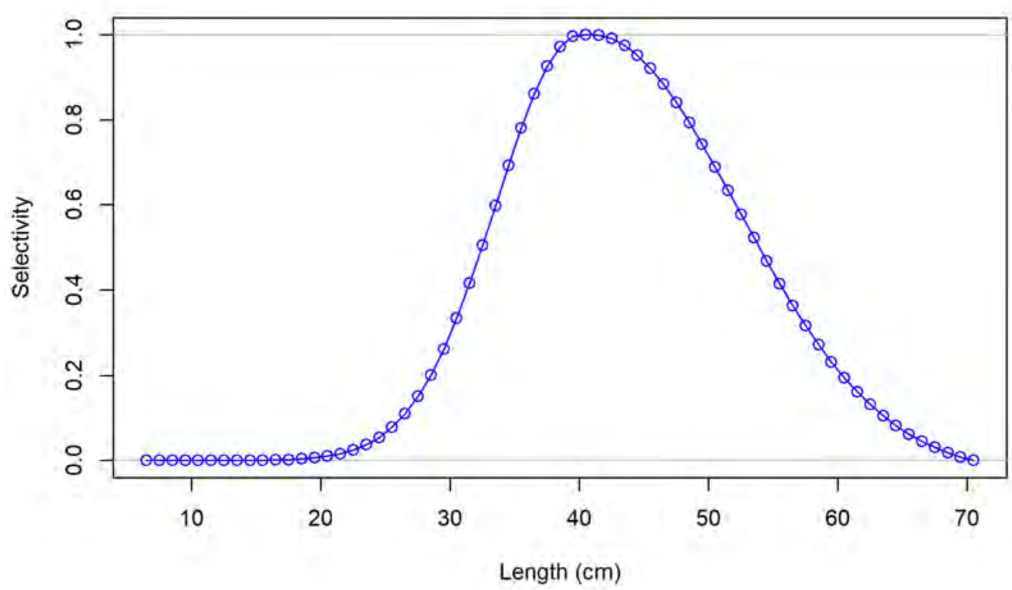

Figure 58: Female ending year selectivity for the recreational PR retained fishery.

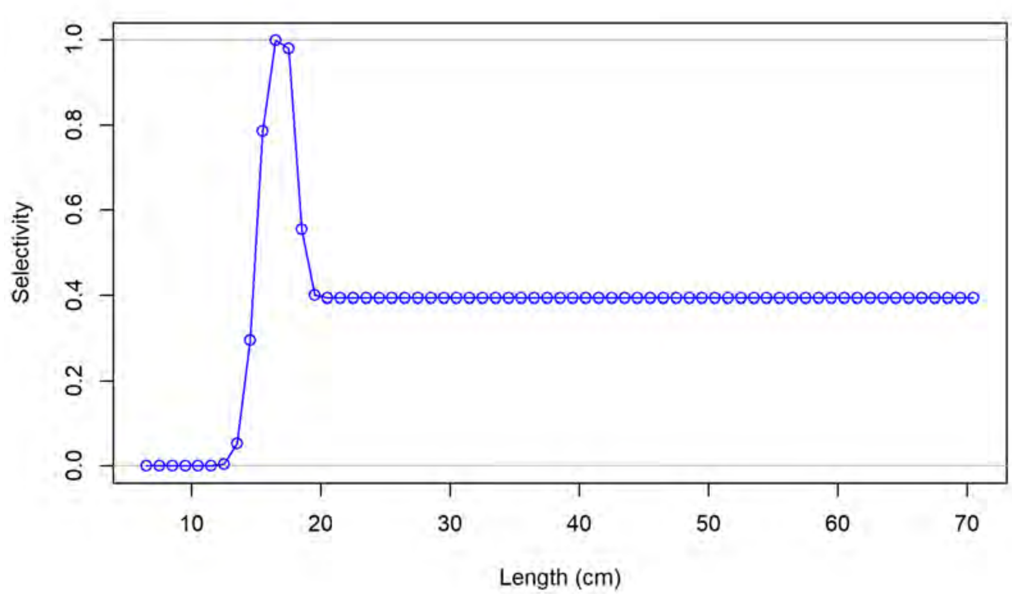

Figure 59: Female ending year selectivity for the West coast groundfish bottomfish trawl survey.

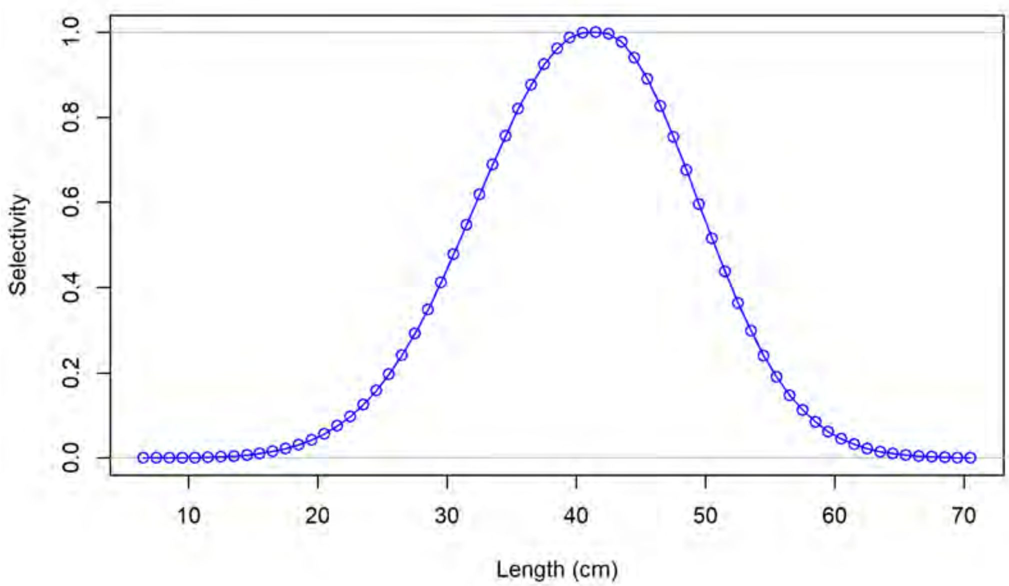

Figure 60: Female ending year selectivity for the California Collaborative Fisheries Research Program survey.

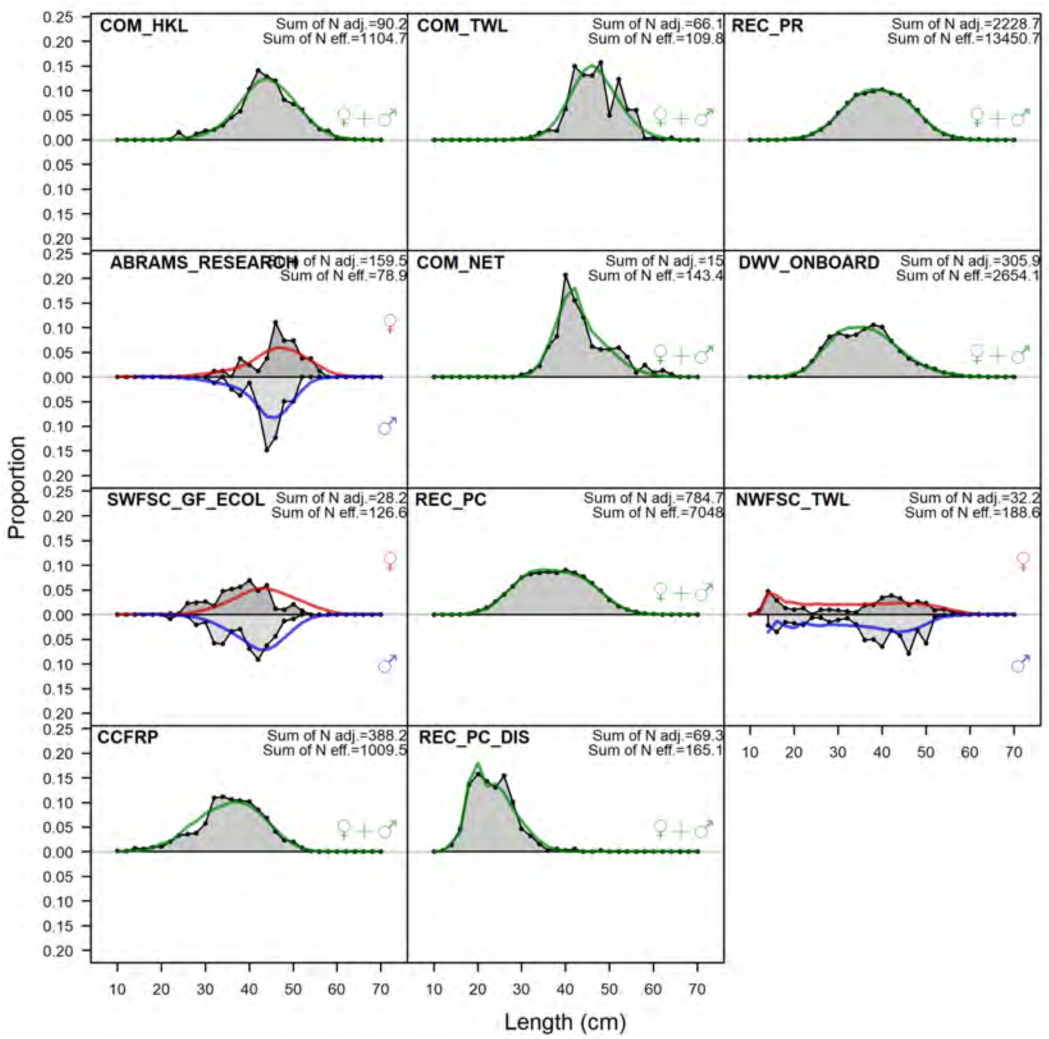

Figure 61: Length comps, aggregated across time by fleet. Labels 'retained' and 'discard' indicate discarded or retained sampled for each fleet. Panels without this designation represent the whole catch.

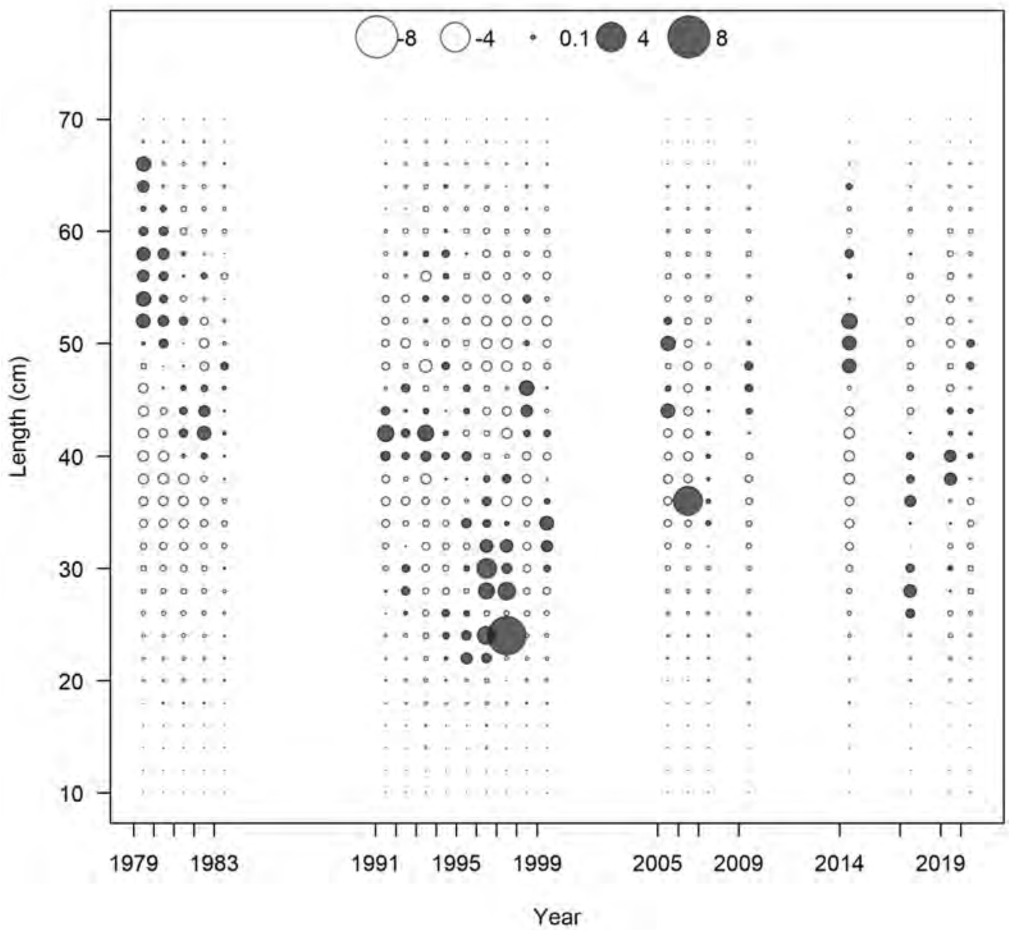

Figure 62: Pearson residuals for the commercial hook-and-line fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

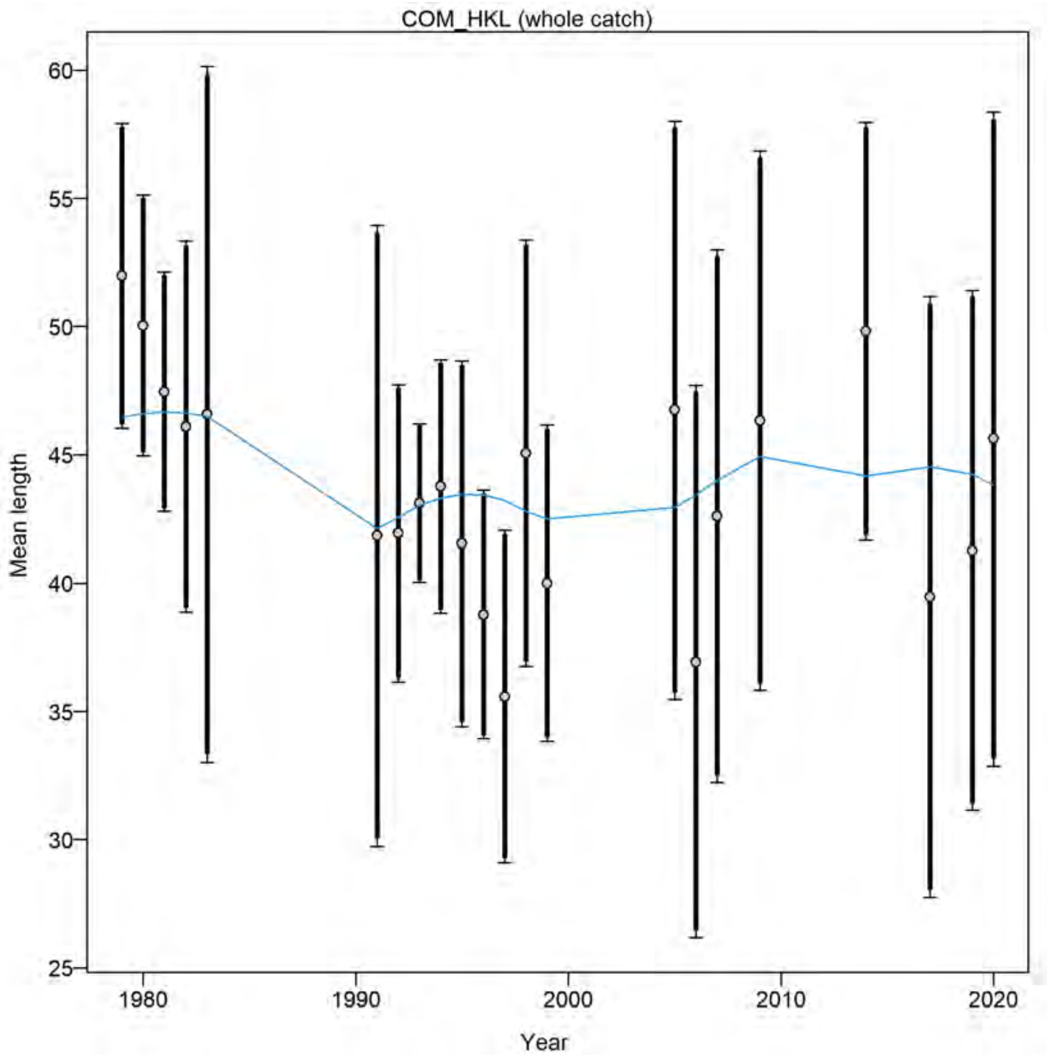

Figure 63: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the commercial hook-and-line fishery.

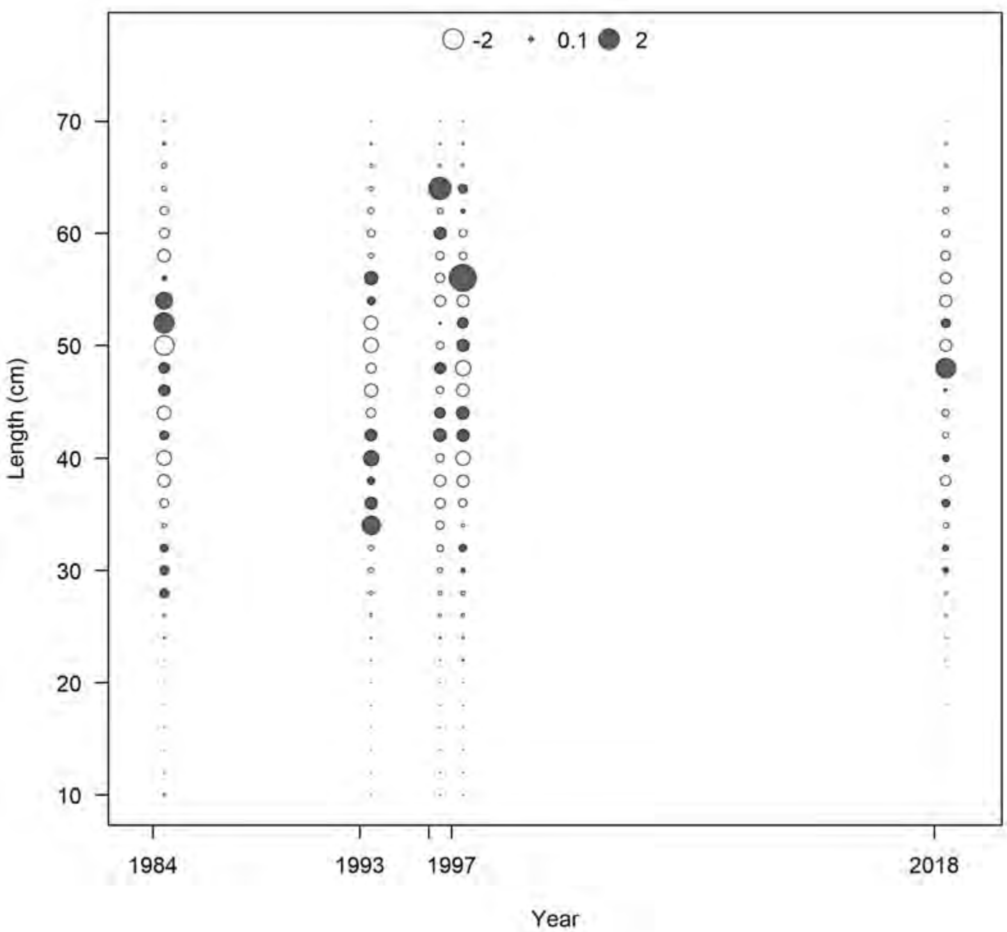

Figure 64: Pearson residuals for the commercial trawl fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

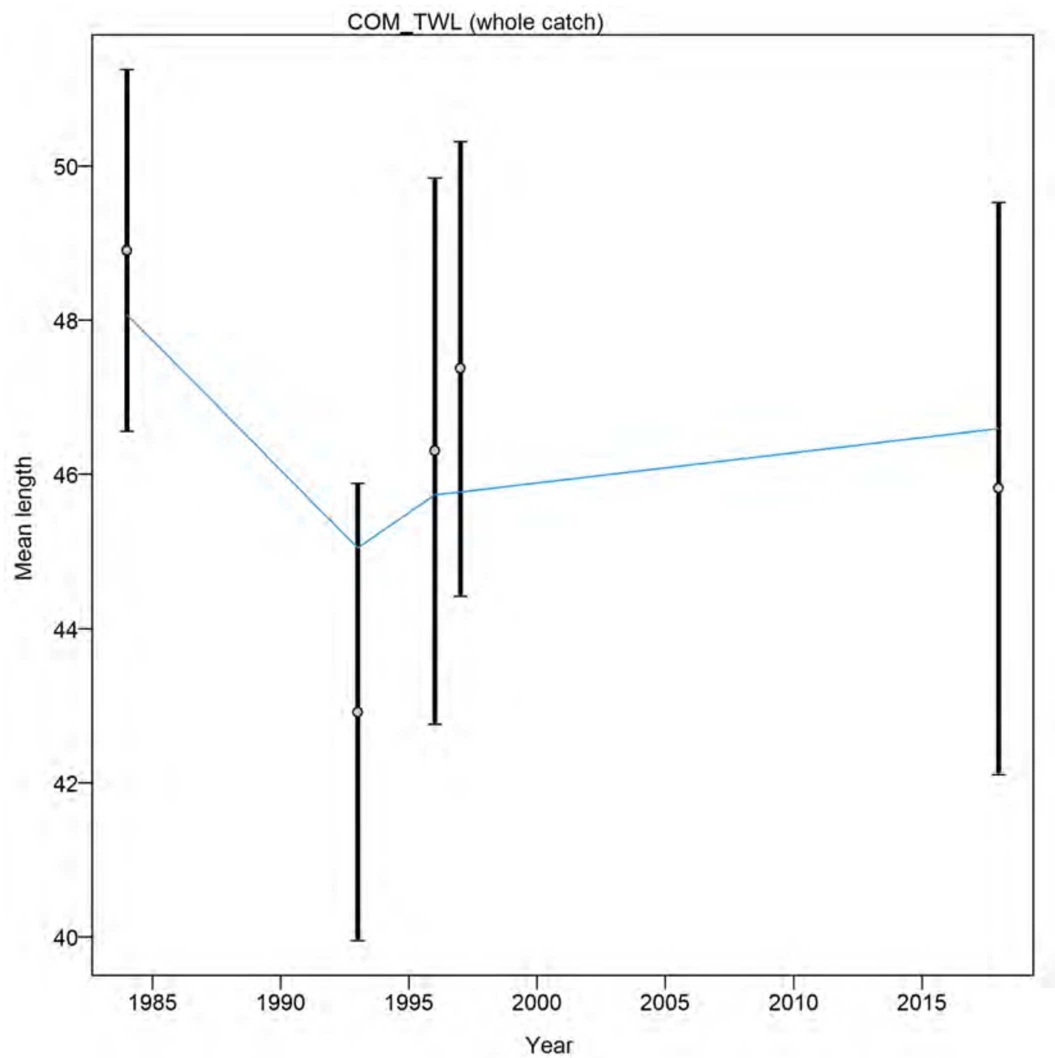

Figure 65: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the commercial trawl fishery.

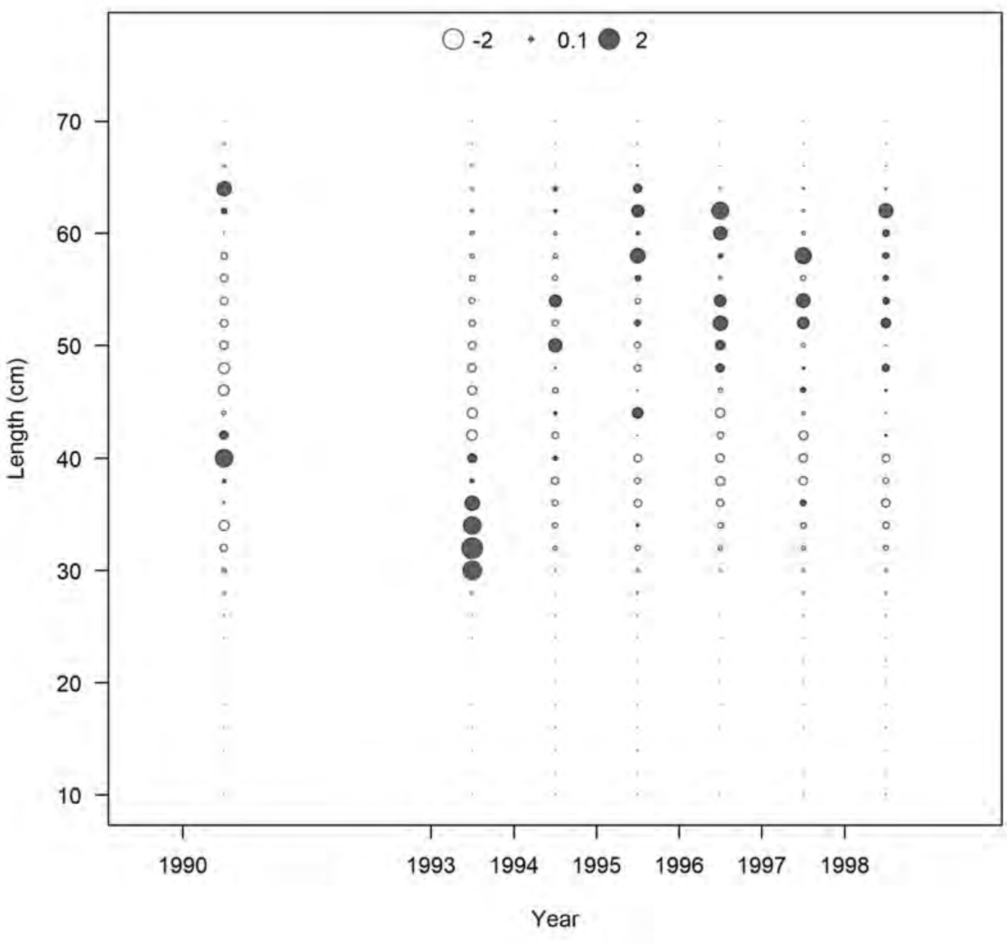

Figure 66: Pearson residuals for the commercial net fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

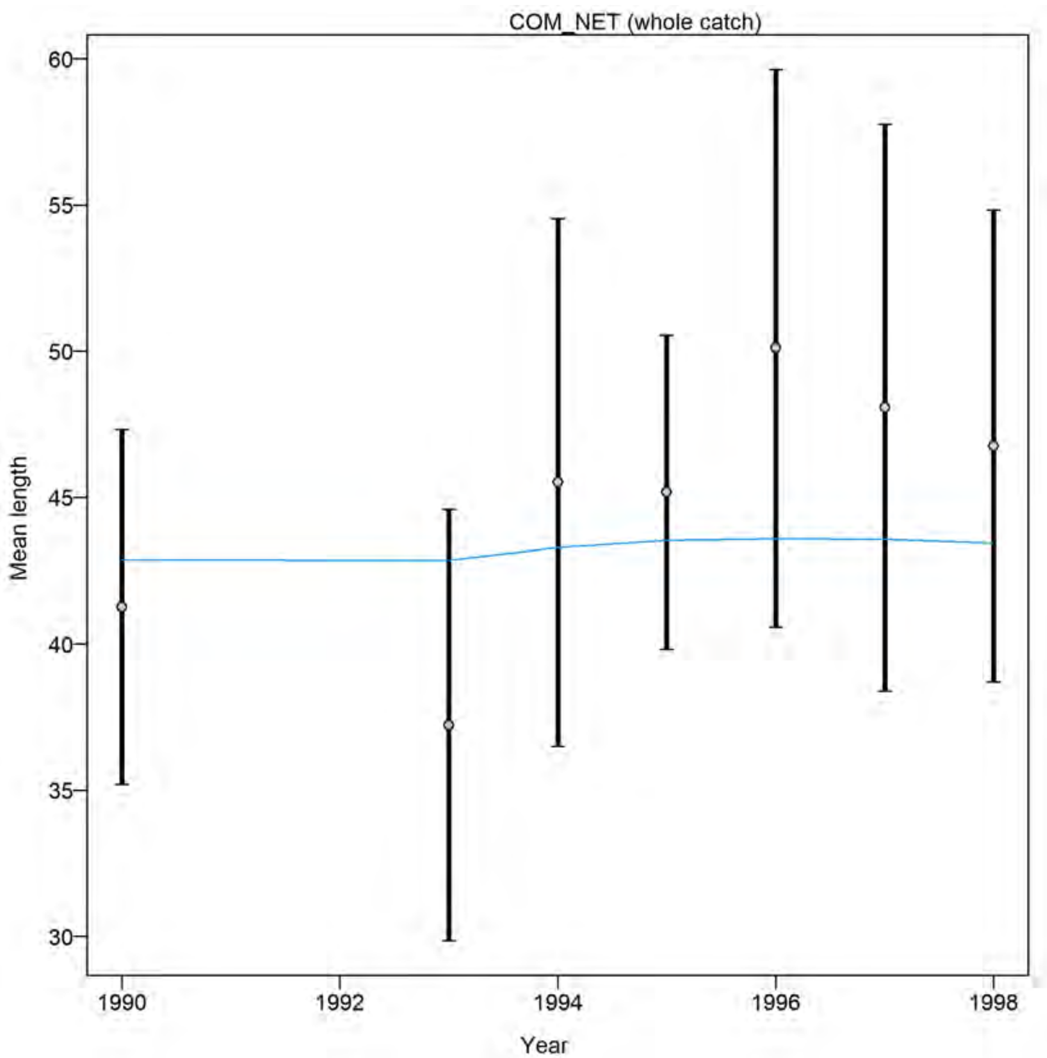

Figure 67: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the commercial net fishery.

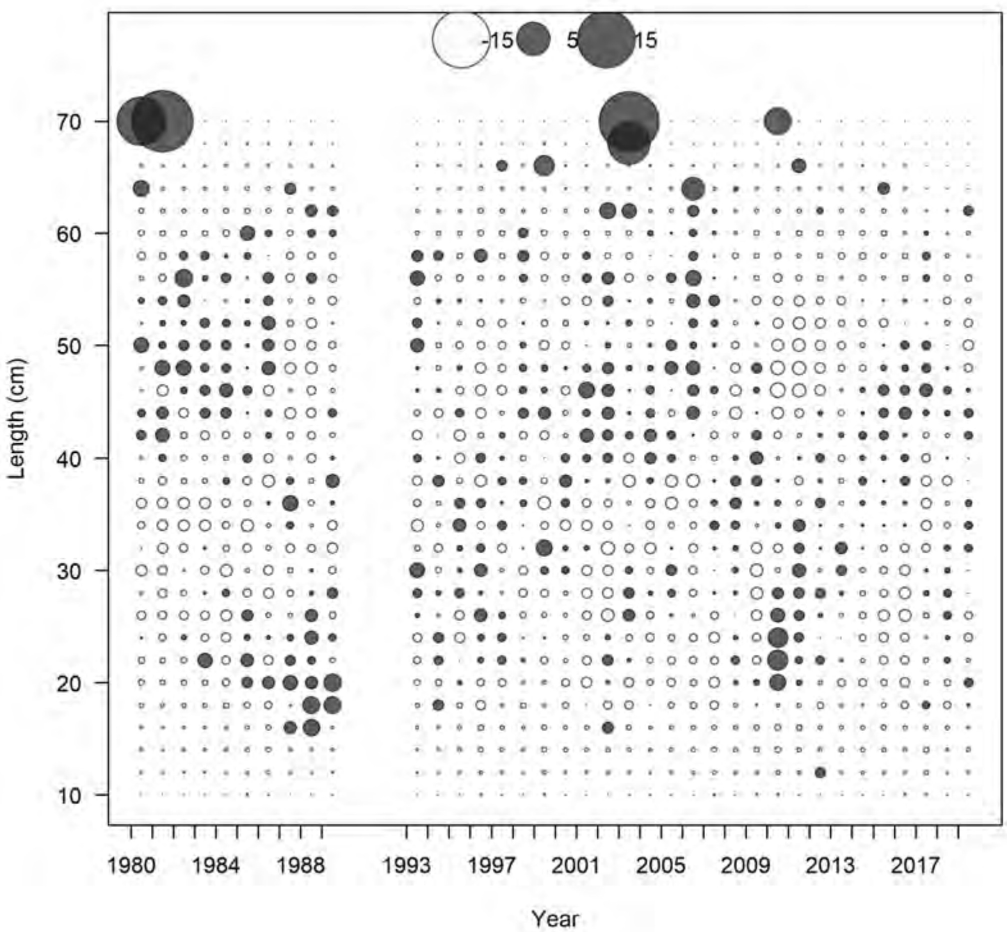

Figure 68: Pearson residuals for the recreational PC retained fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

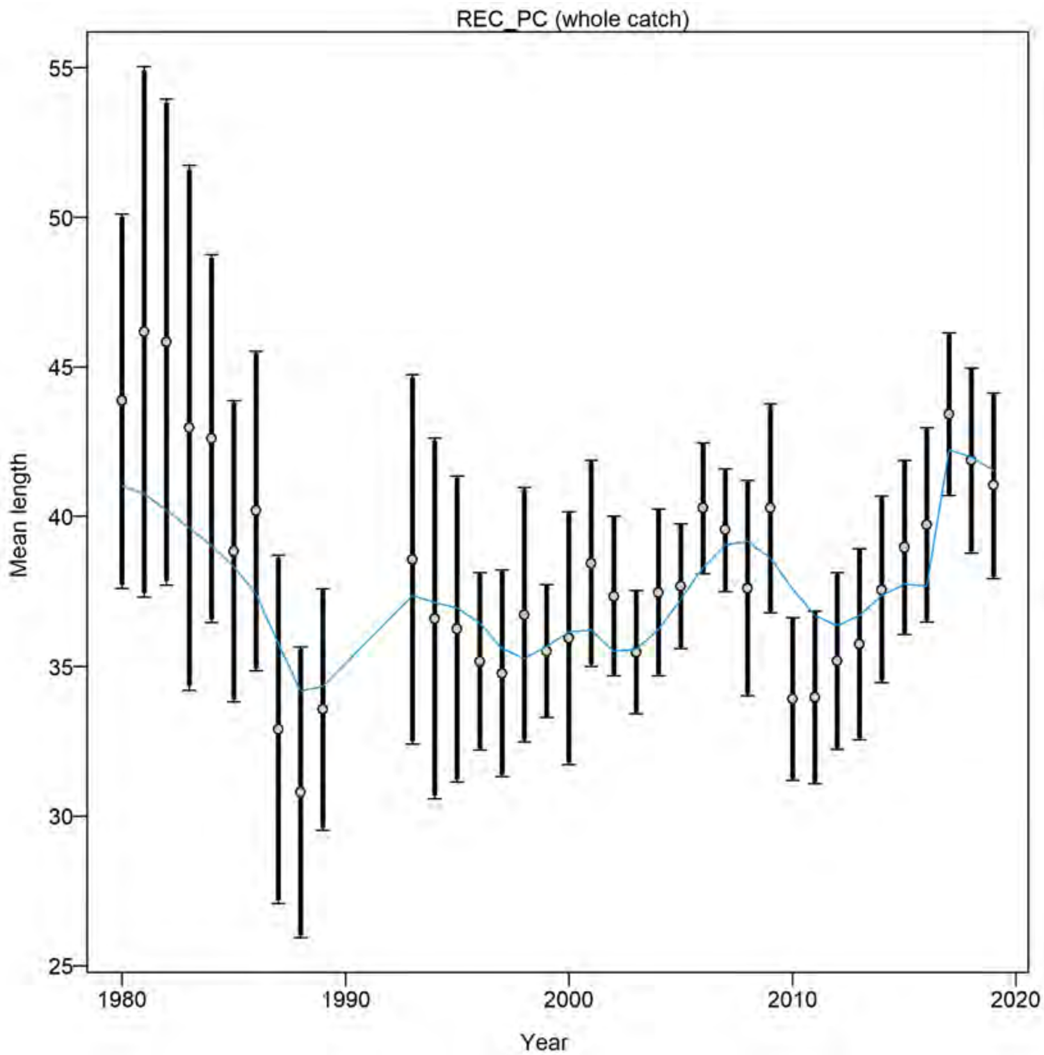

Figure 69: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the recreational PC retained fishery.

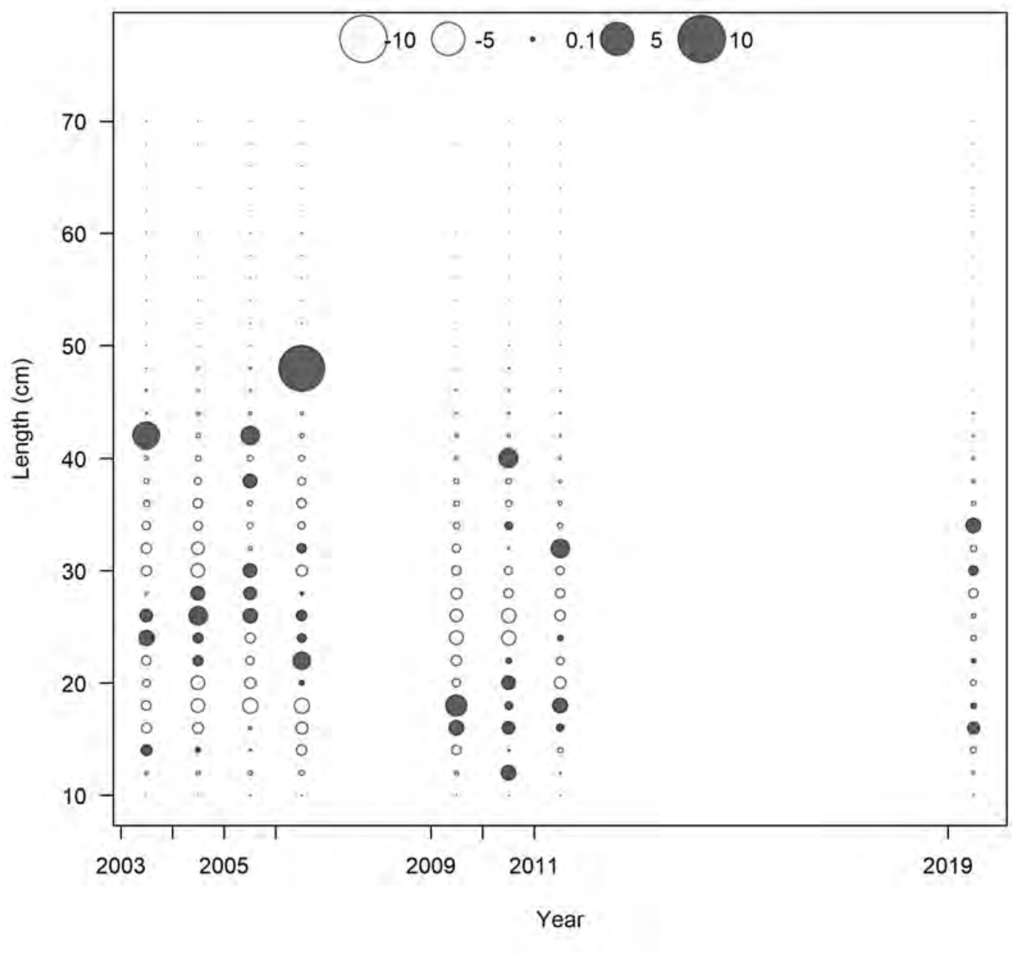

Figure 70: Pearson residuals for the recreational PC discard fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

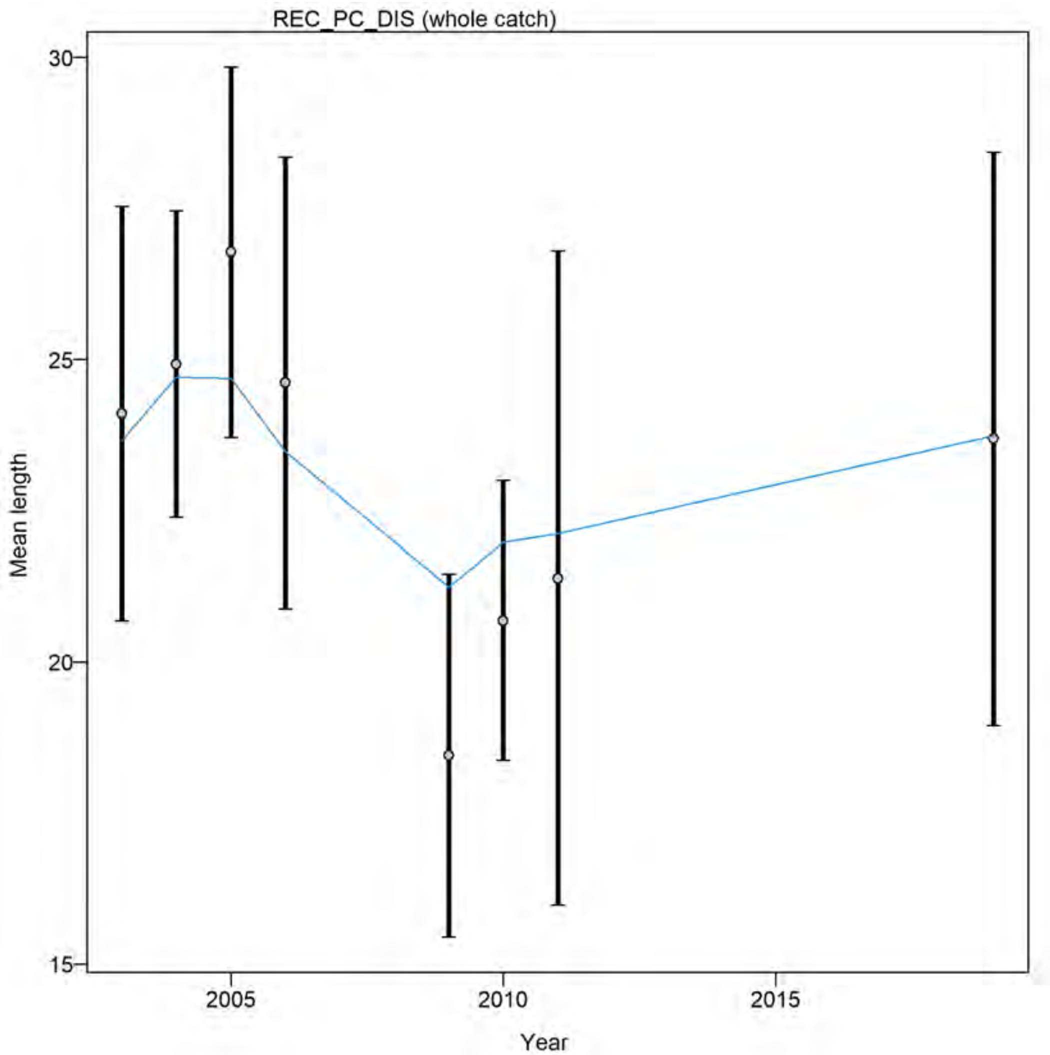

Figure 71: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the recreational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

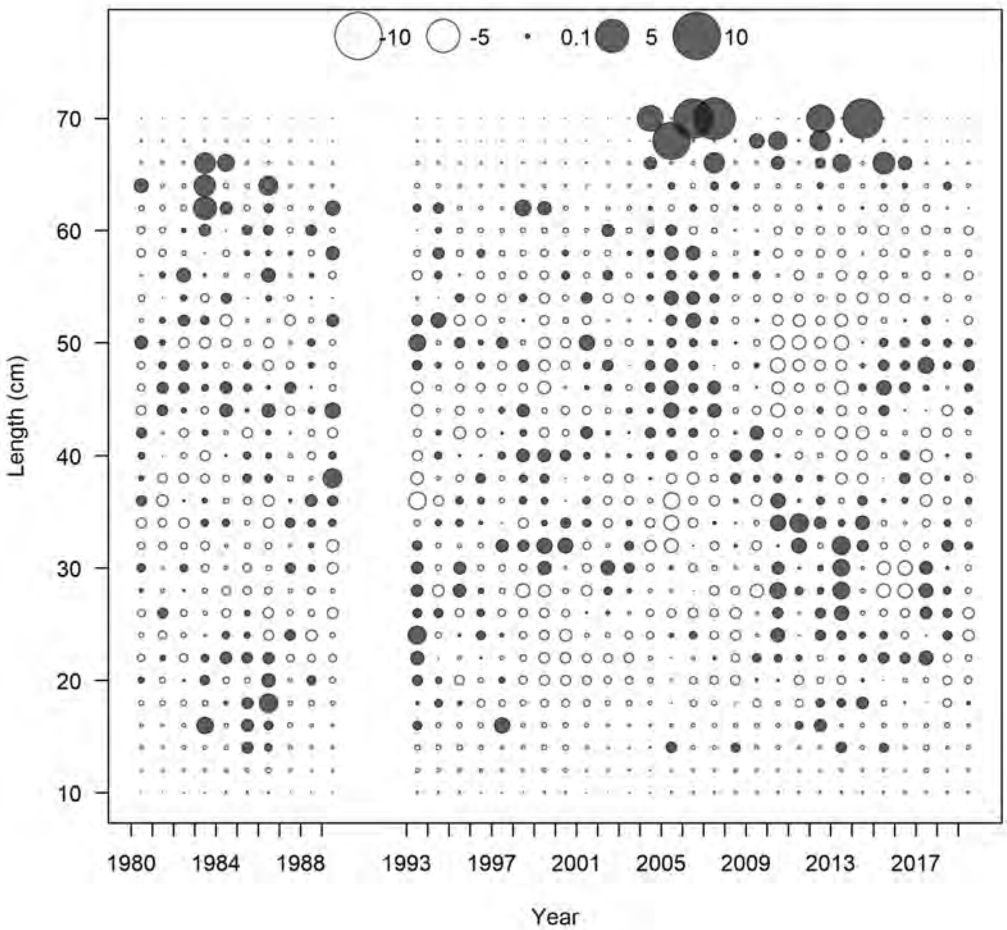

Figure 72: Pearson residuals for the recreational PR retained fishery. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

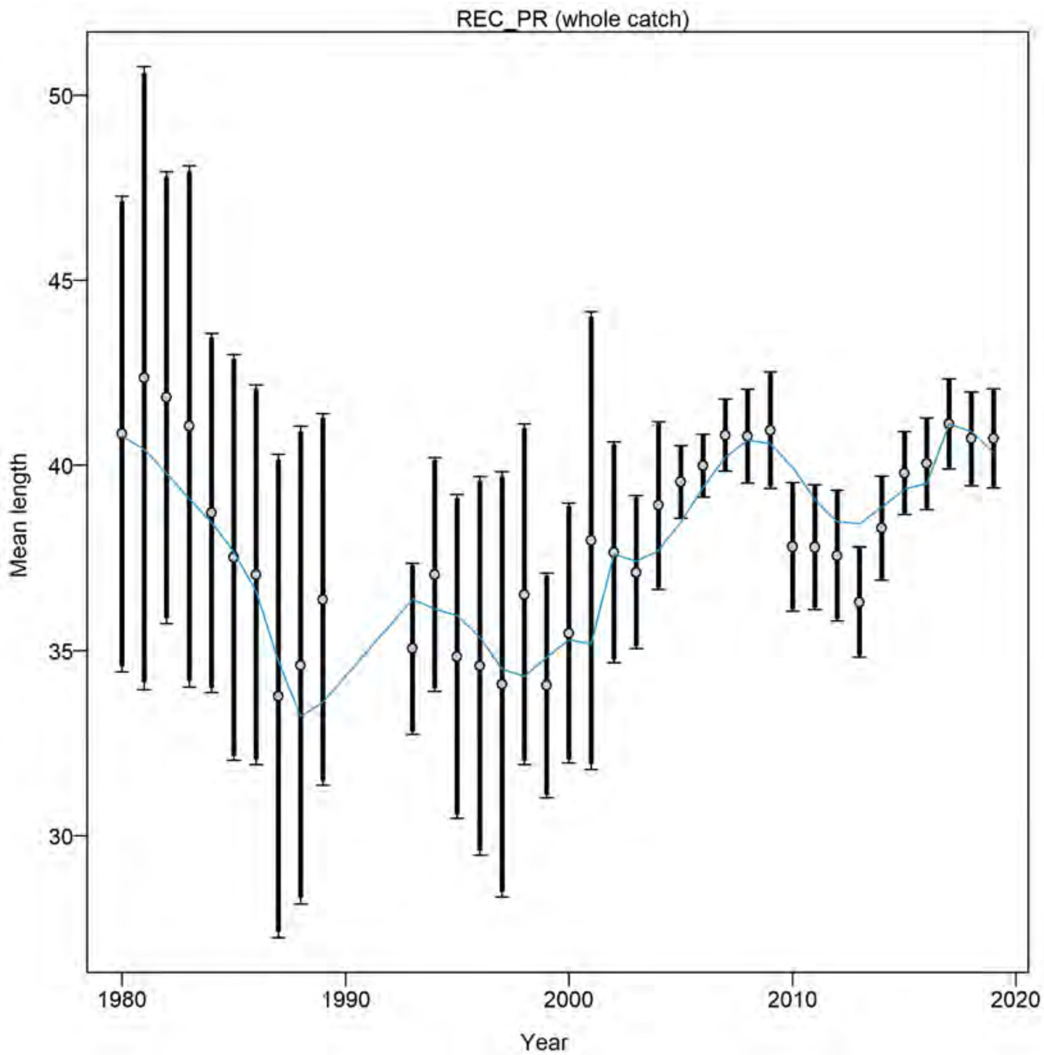

Figure 73: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the recreational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

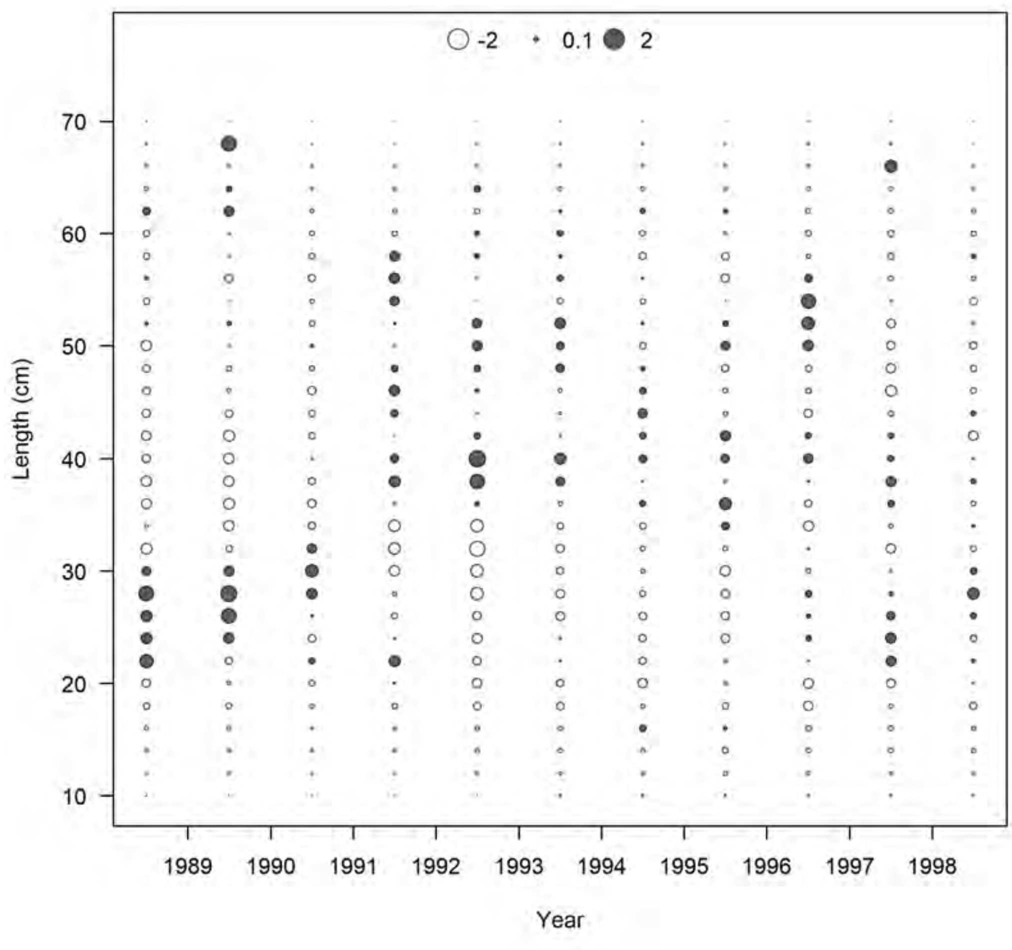

Figure 74: Pearson residuals for the Deb Wilson-Vandenberg onboard survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

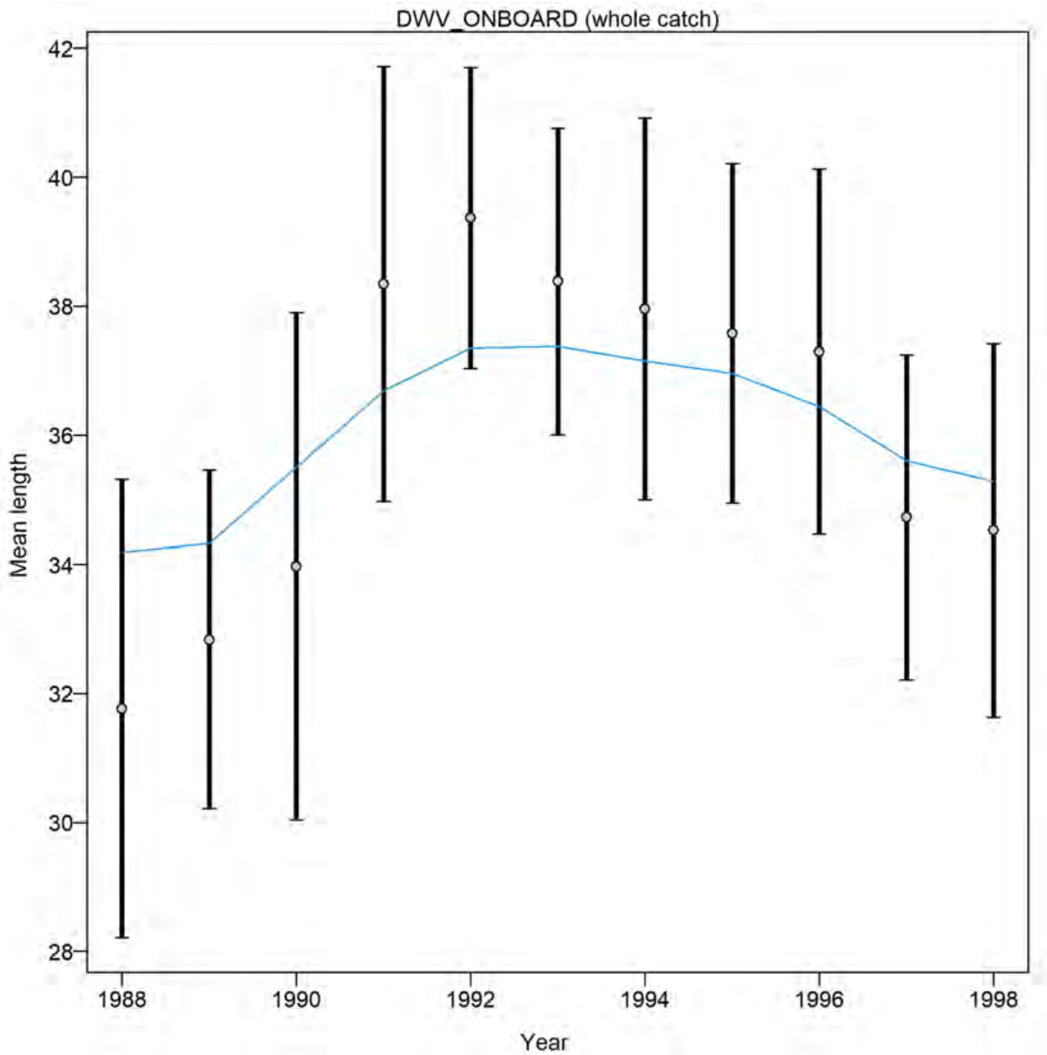

Figure 75: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the Deb Wilson-Vandenberg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

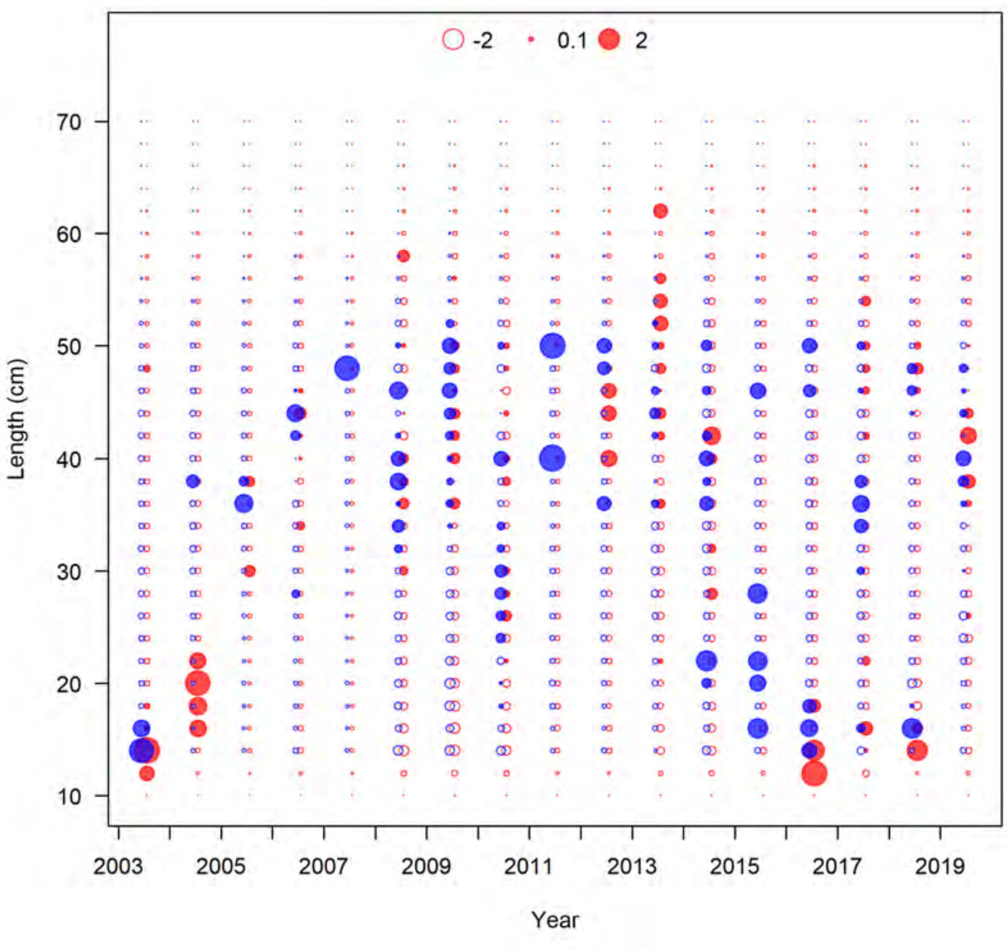

Figure 76: Pearson residuals for the West coast groundfish bottomfish trawl survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

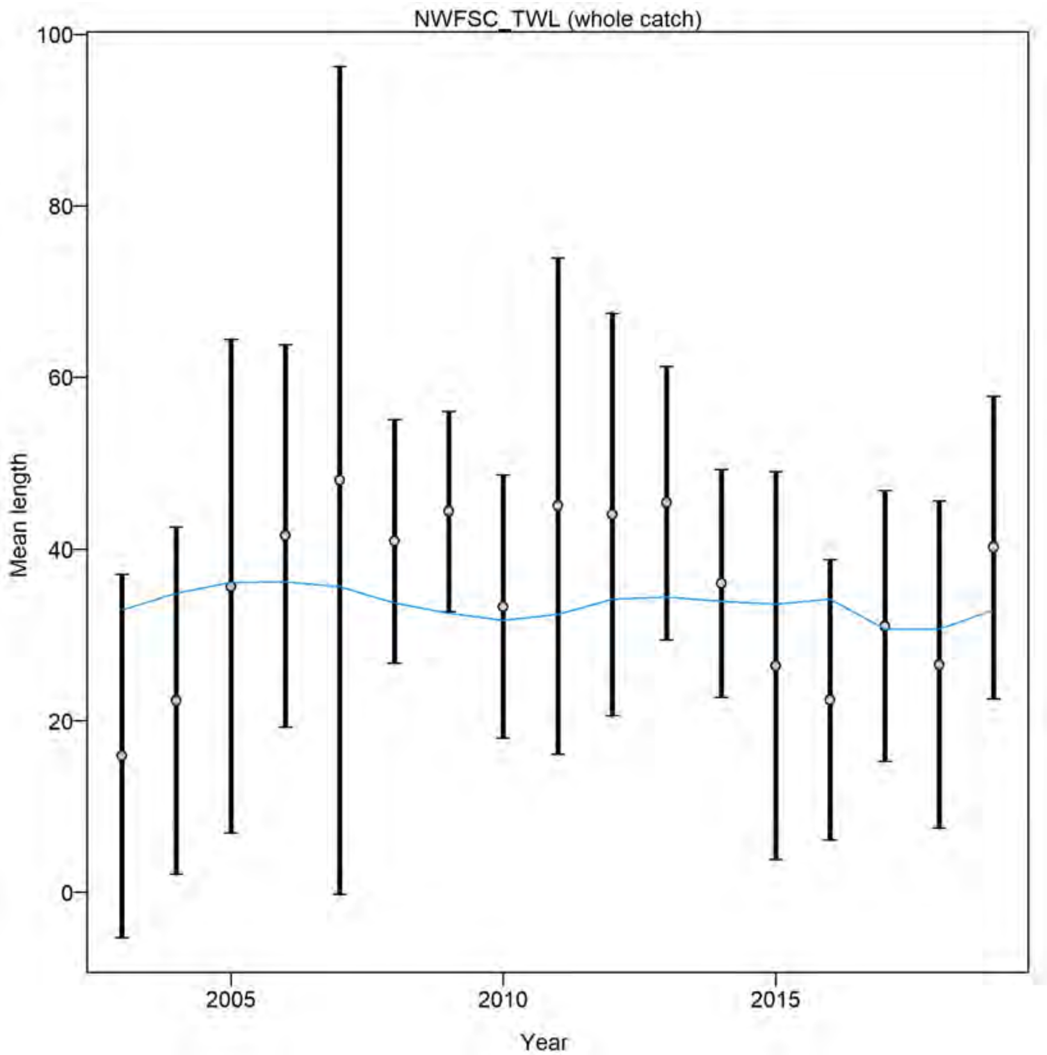

Figure 77: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the West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

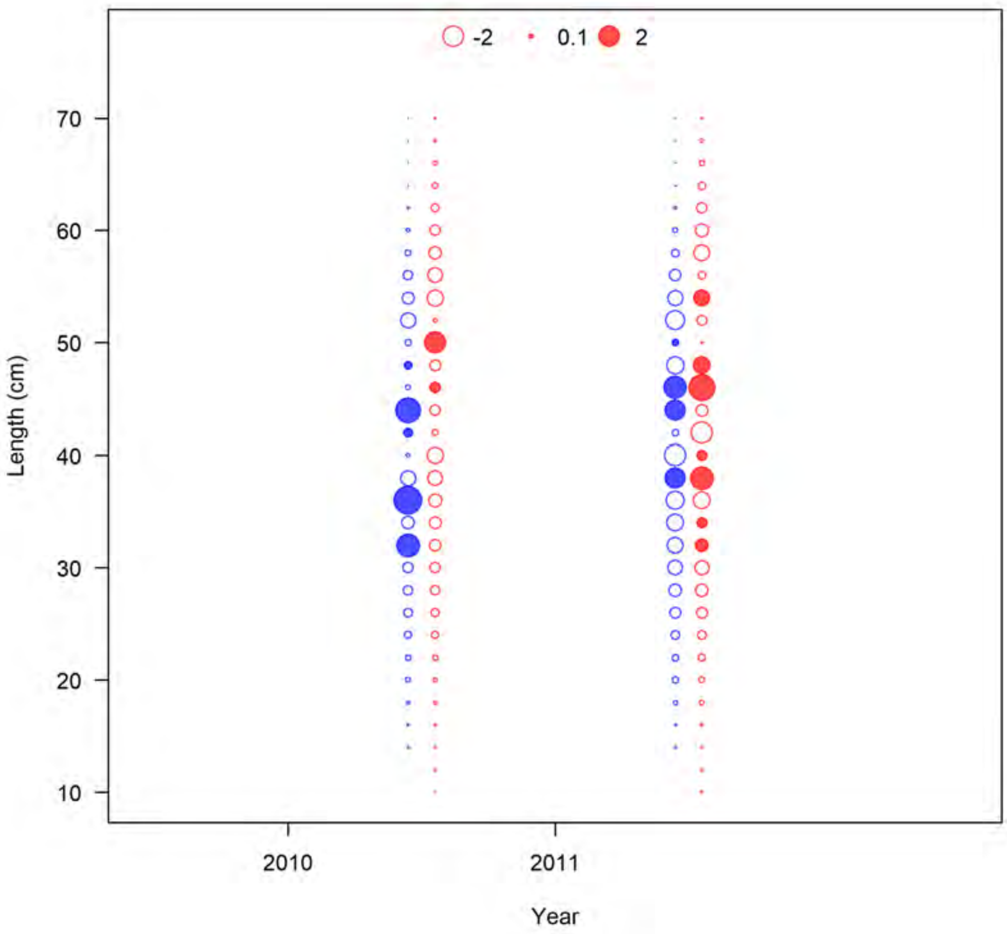

Figure 78: Pearson residuals for the Abrams thesis research survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

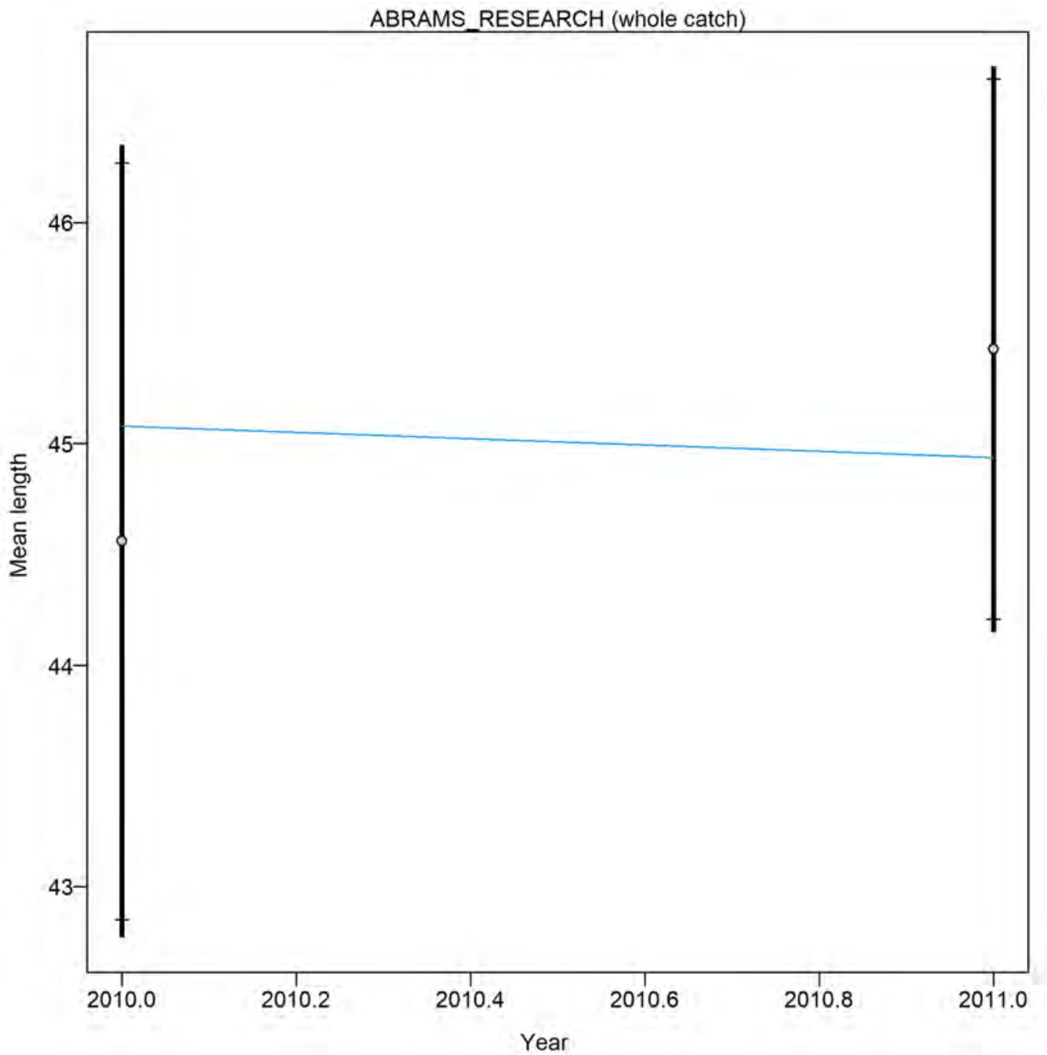

Figure 79: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the Abrams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

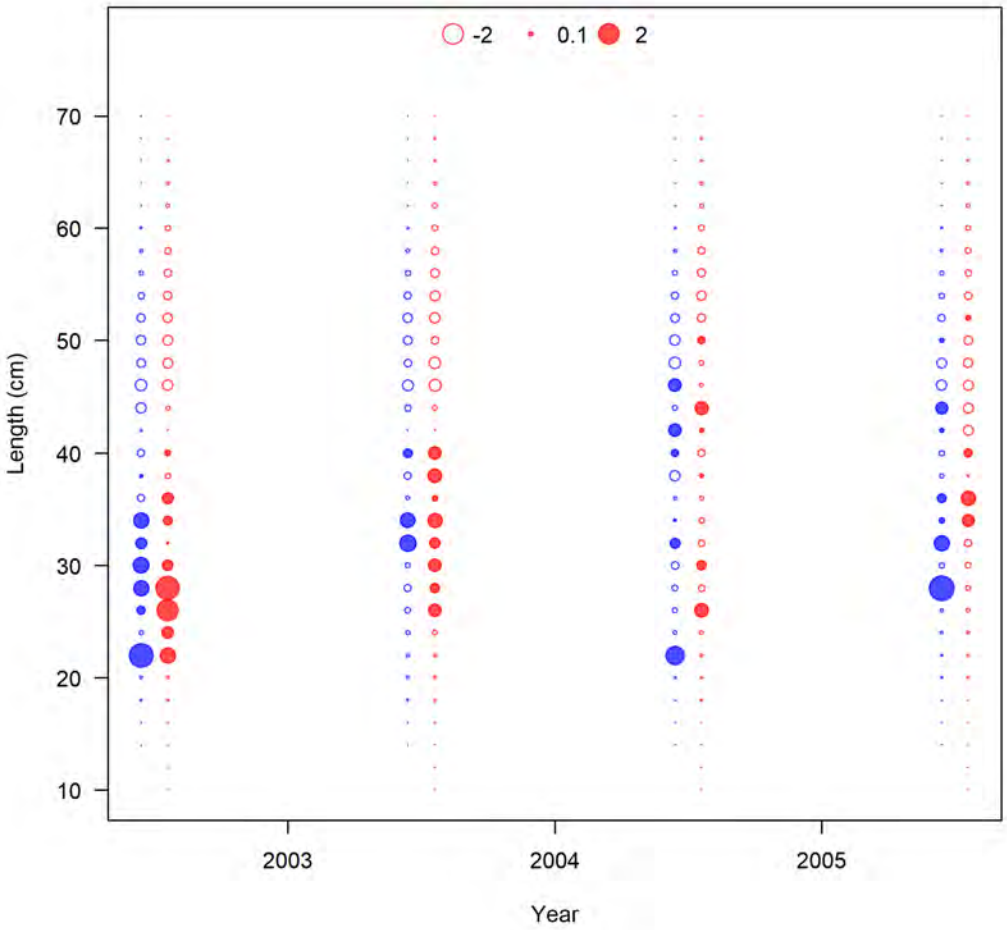

Figure 80: Pearson residuals for the SWFSC groundfish ecology survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

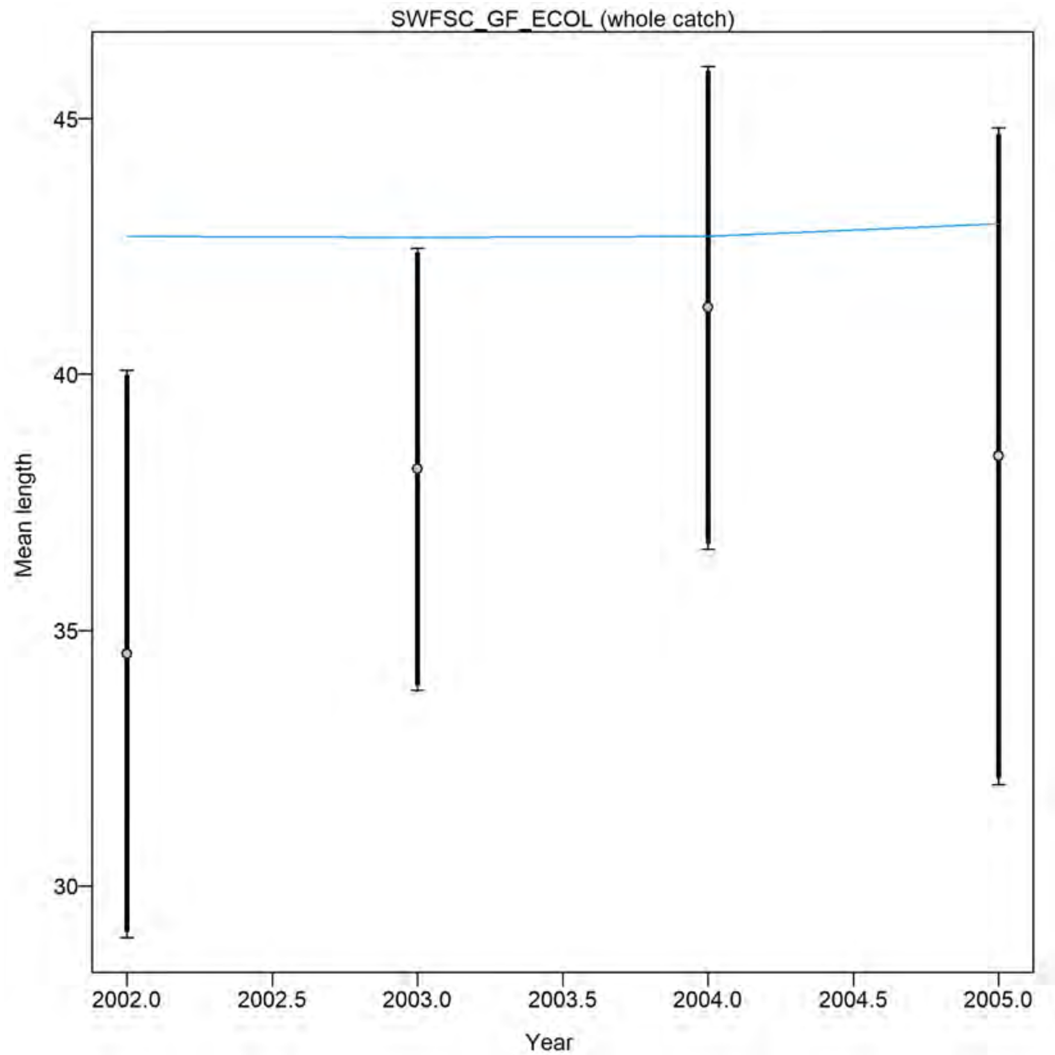

Figure 81: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the SWFSC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

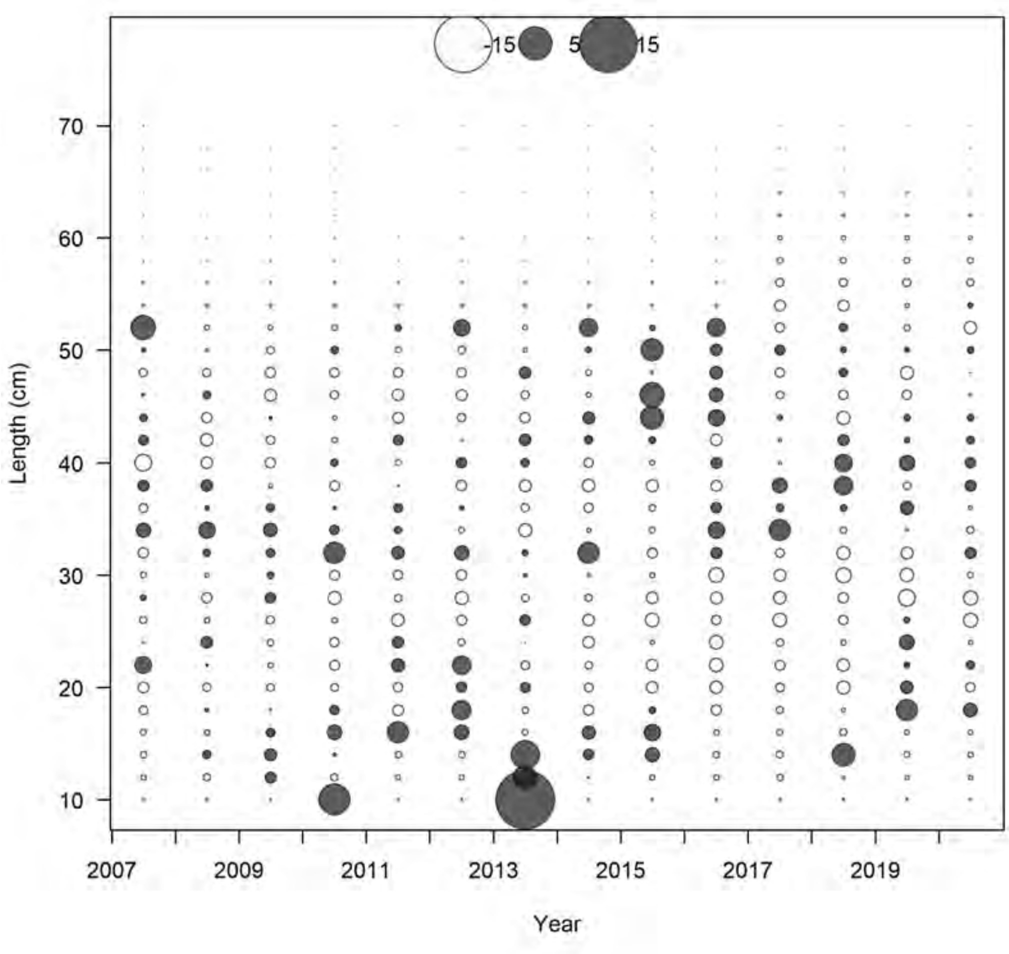

Figure 82: Pearson residuals for the California Collaborative Fisheries Research Program survey. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

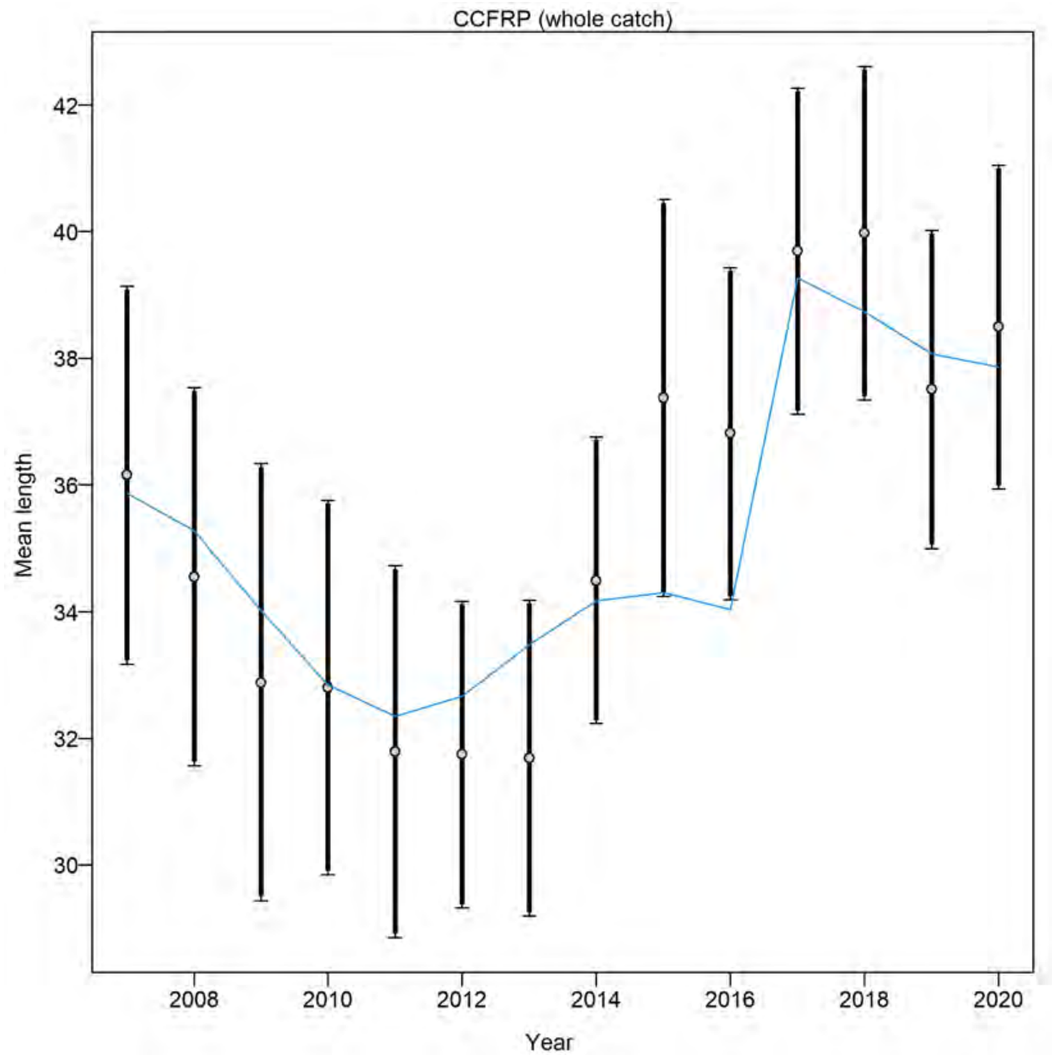

Figure 83: Mean length (cm) for REC_PR with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data from the California Collaborative Fisheries Research Program survey.

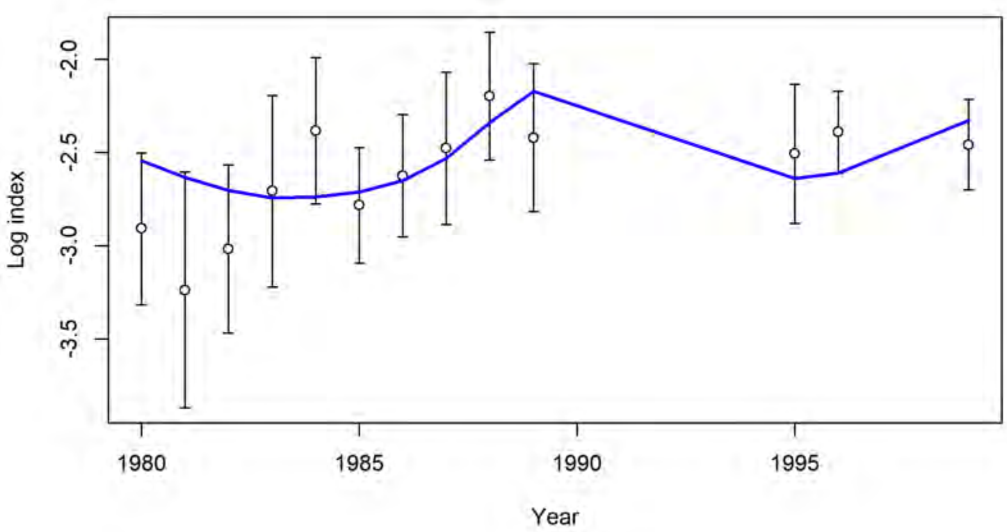

Figure 84: Fit to log index data on log scale for the recreational PC retained fishery. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

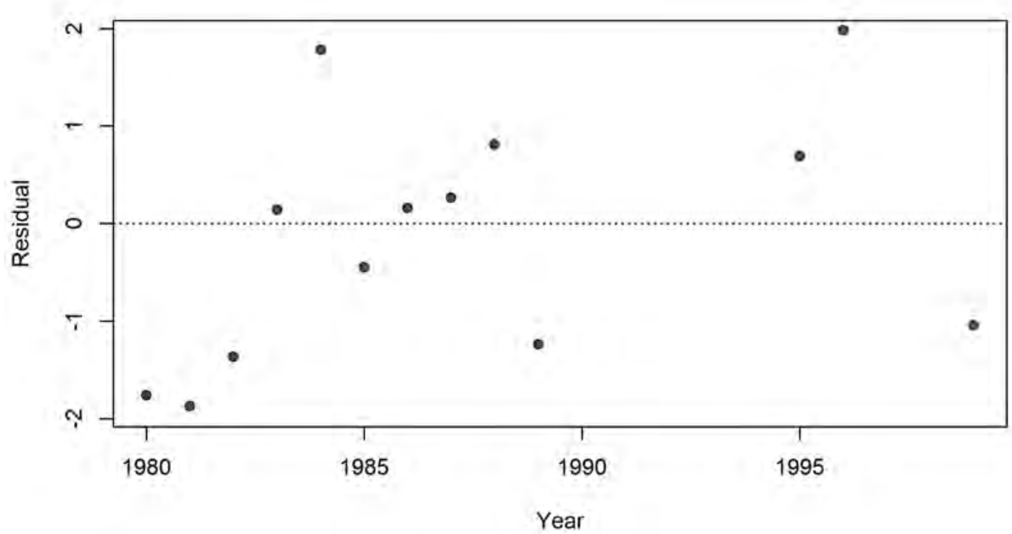

Figure 85: Residuals of fit to index for the REC_PC. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

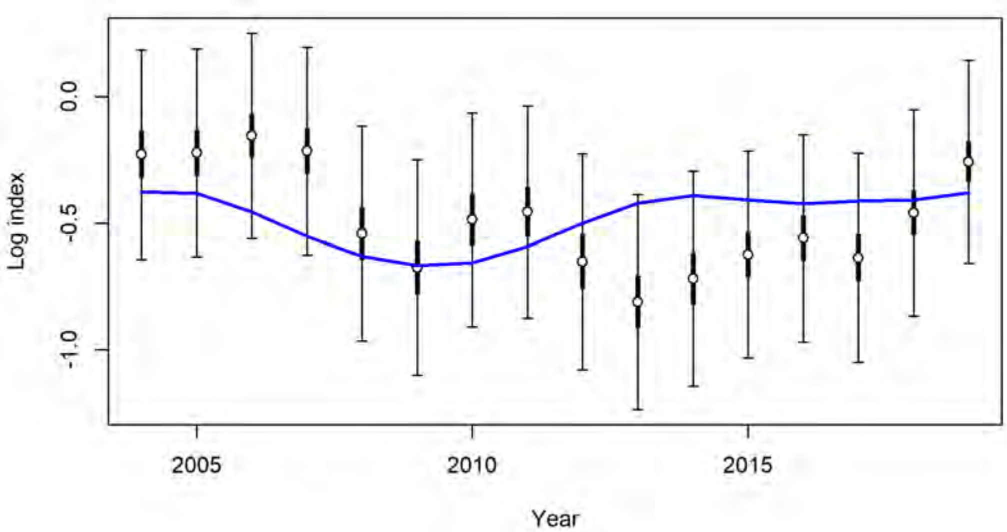

Figure 86: Fit to log index data on log scale for the recreational PR retained fishery. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

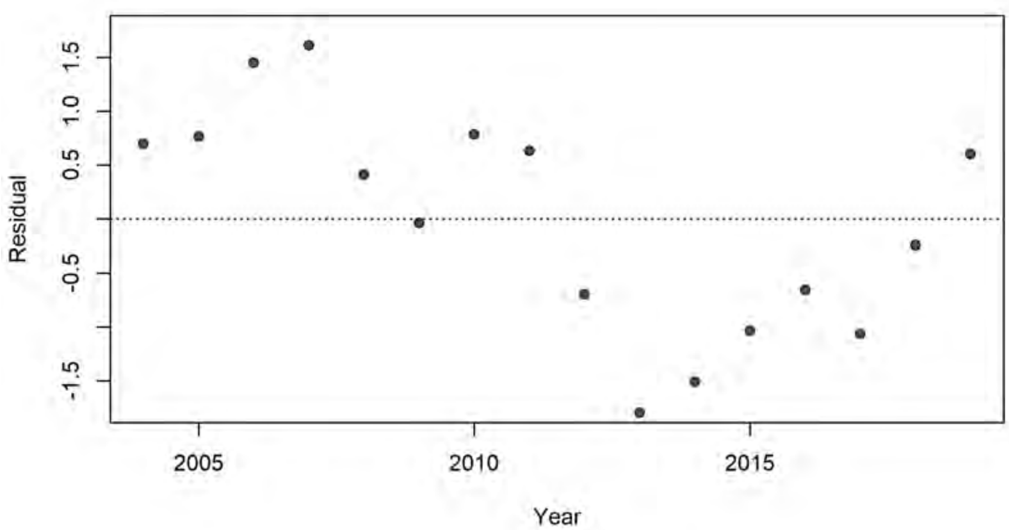

Figure 87: Residuals of fit to index for the REC_PR. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

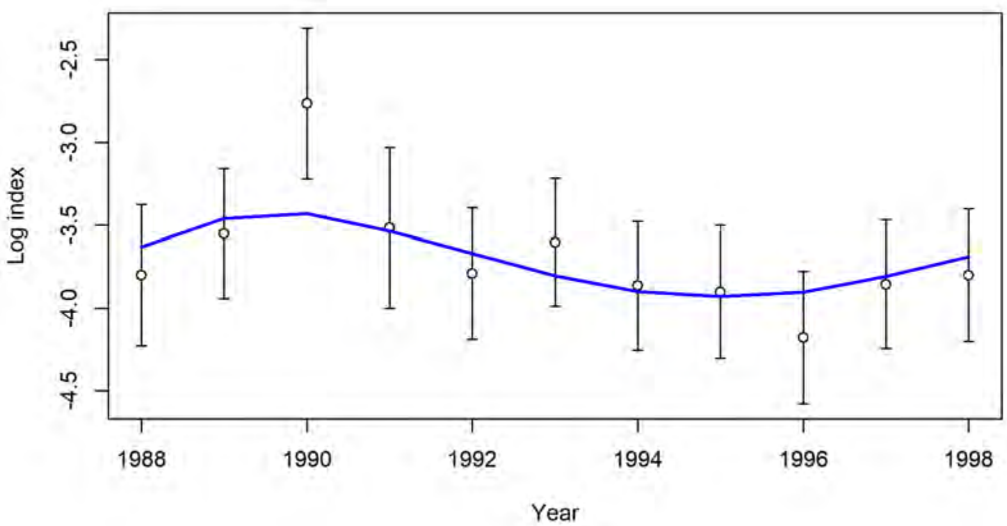

Figure 88: Fit to log index data on log scale for the Deb Wilson-Vandenberg onboard survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty parameter.

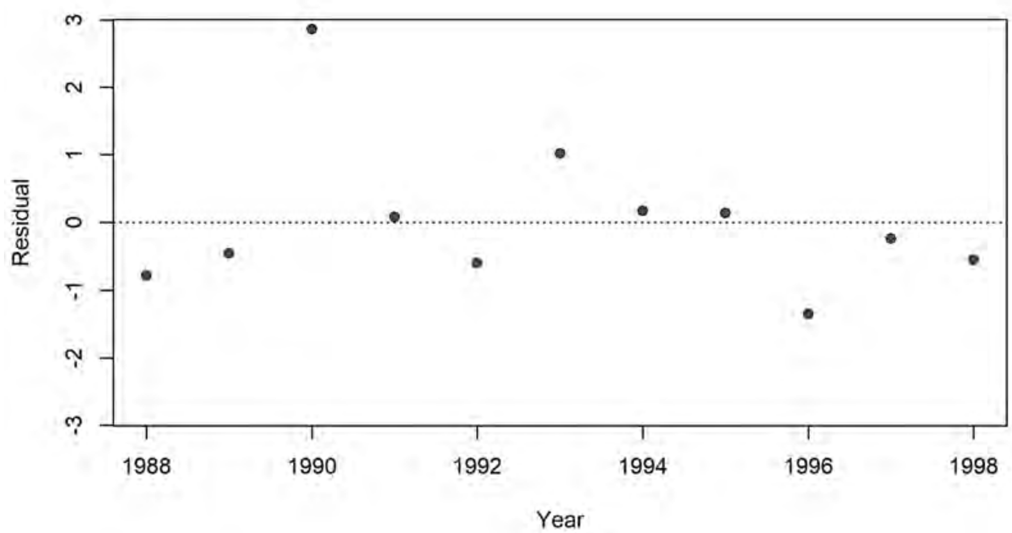

Figure 89: Residuals of fit to index for the DWV_ONBOARD. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

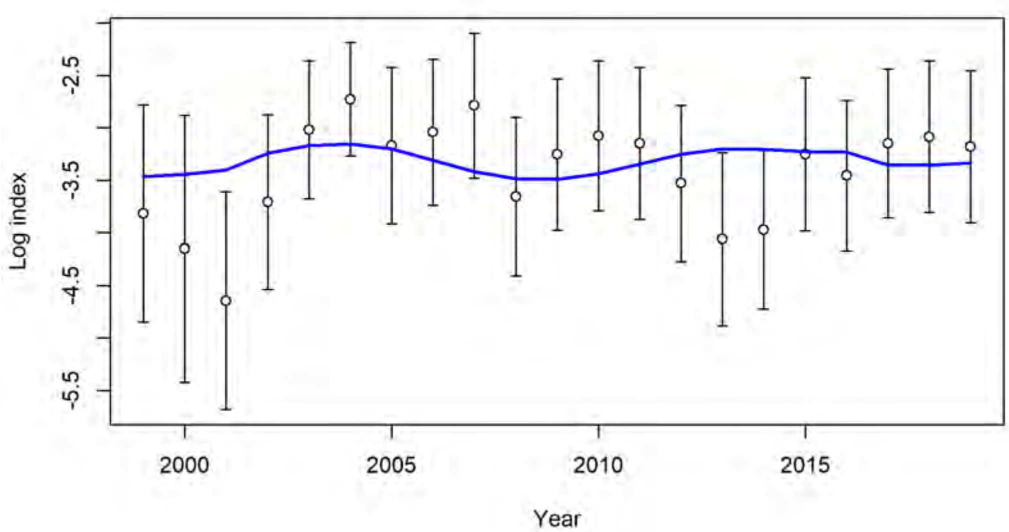

Figure 90: Fit to log index data on log scale for the recreational PC onboard survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated additional uncertainty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

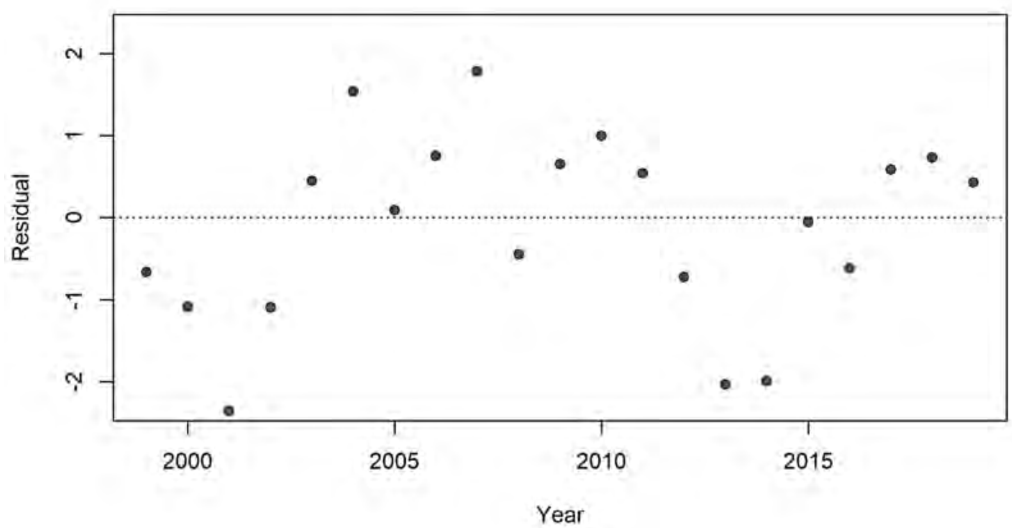

Figure 91: Residuals of fit to index for the REC_PC_ONBOARD. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

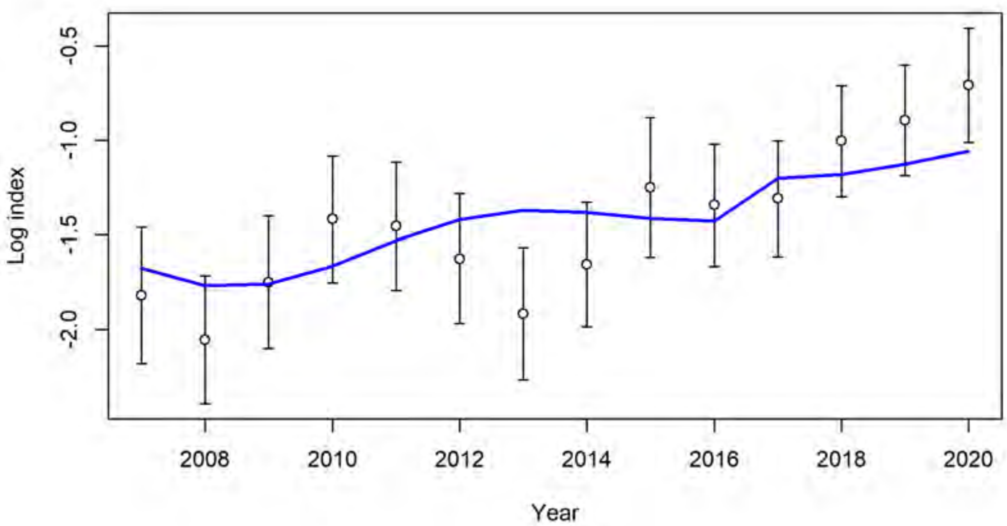

Figure 92: Fit to log index data on log scale for the California Collaborative Fisheries Research Program survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines (if present) indicate input uncertainty before addition of estimated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

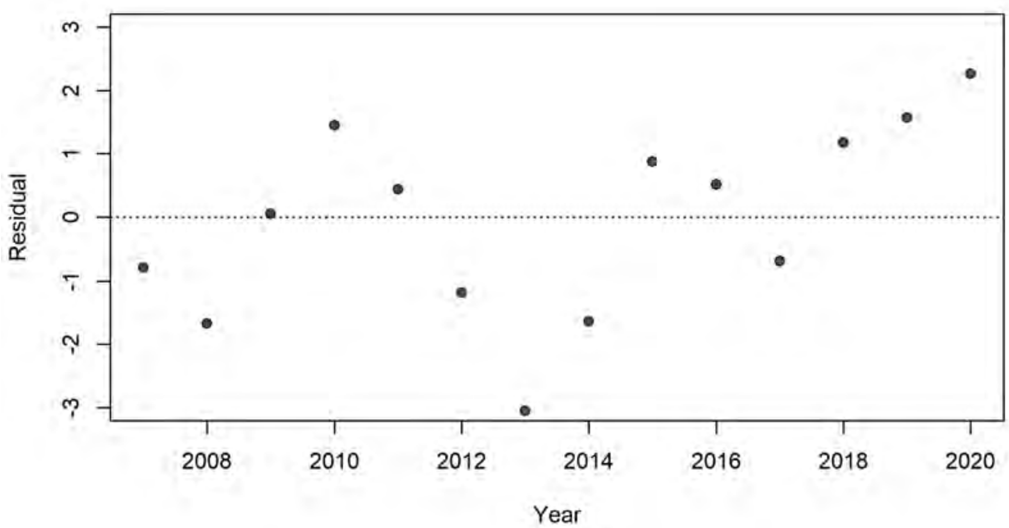

Figure 93: Residuals of fit to index for the CCFRP. Values are (log(Obs) - log(Exp))/SE where SE is the total standard error including any estimated additional uncertainty.

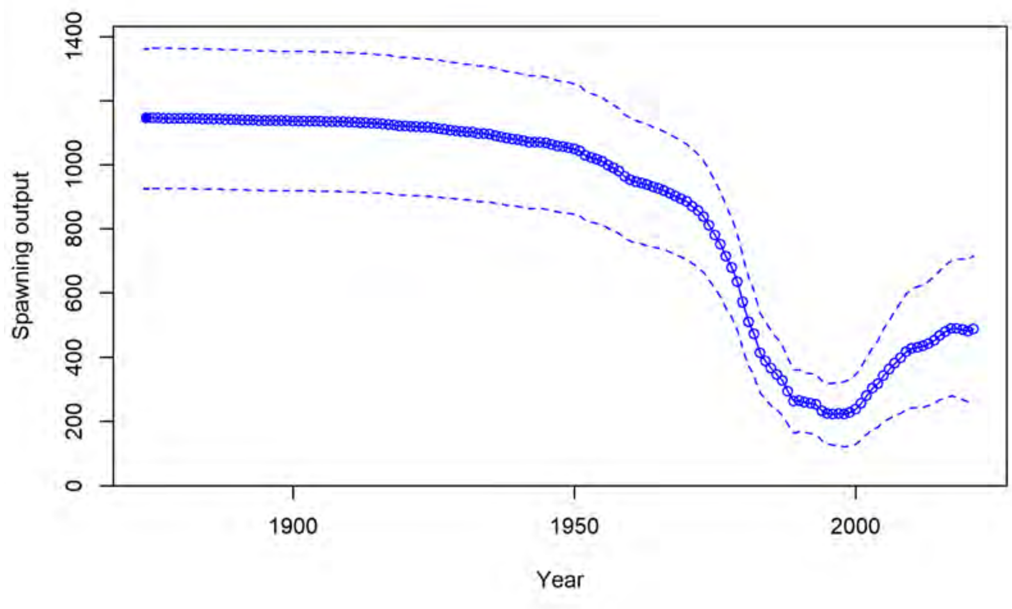

Figure 94: Estimated time series of spawning output.

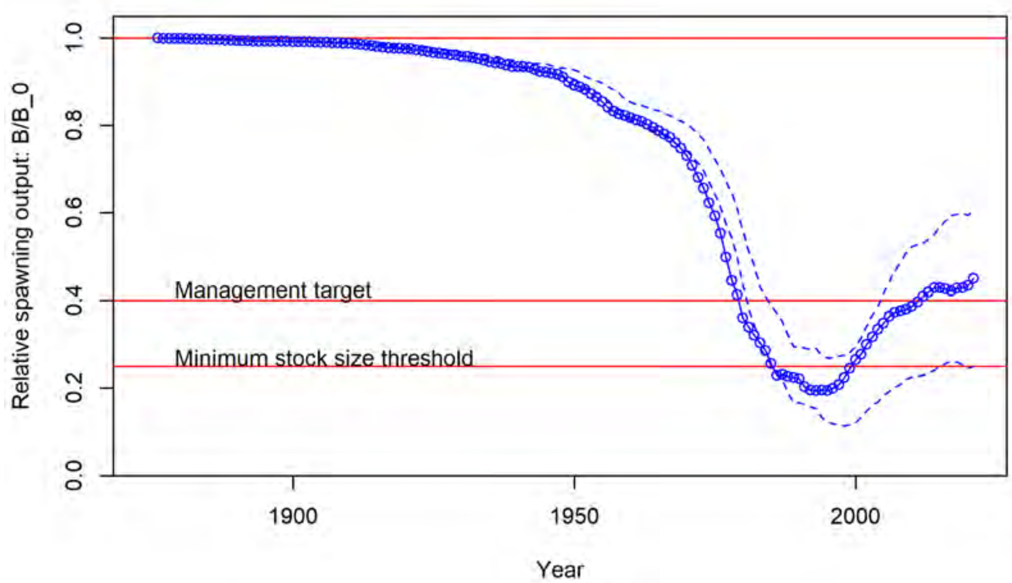

Figure 95: Estimated time series of relative spawning output.

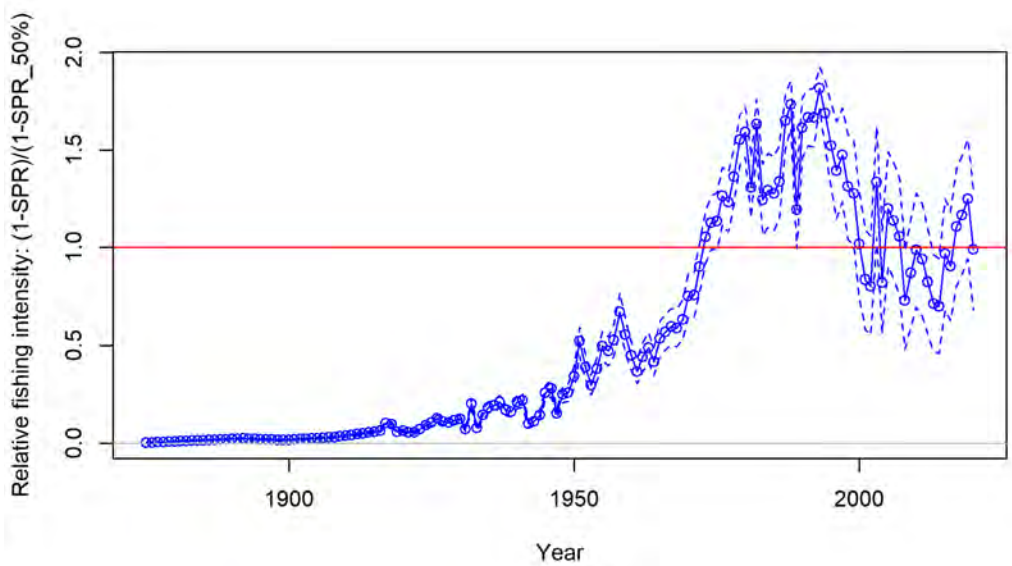

Figure 96: Timeseries of SPR ratio: (1-SPR)/(1-SPR_50%).

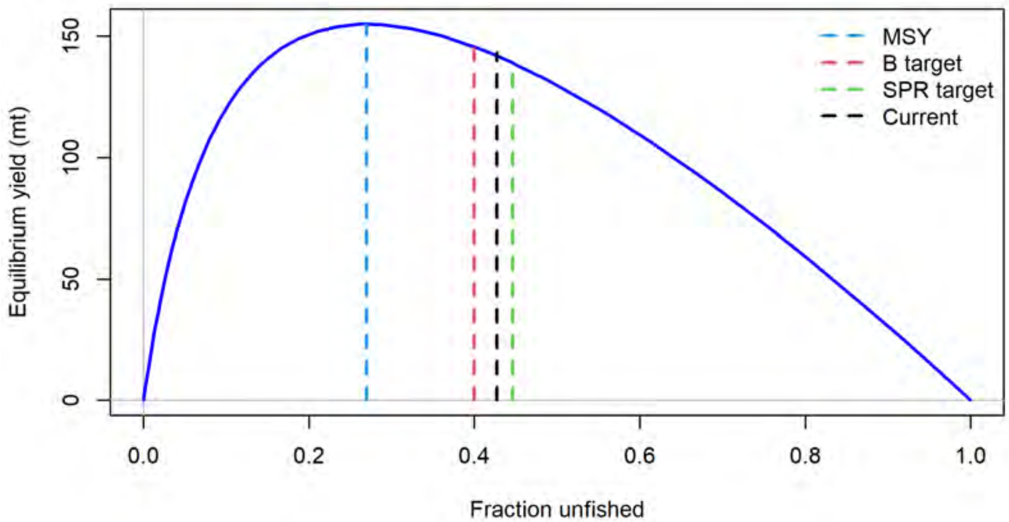

Figure 97: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivity and with steepness fixed at 0.72.

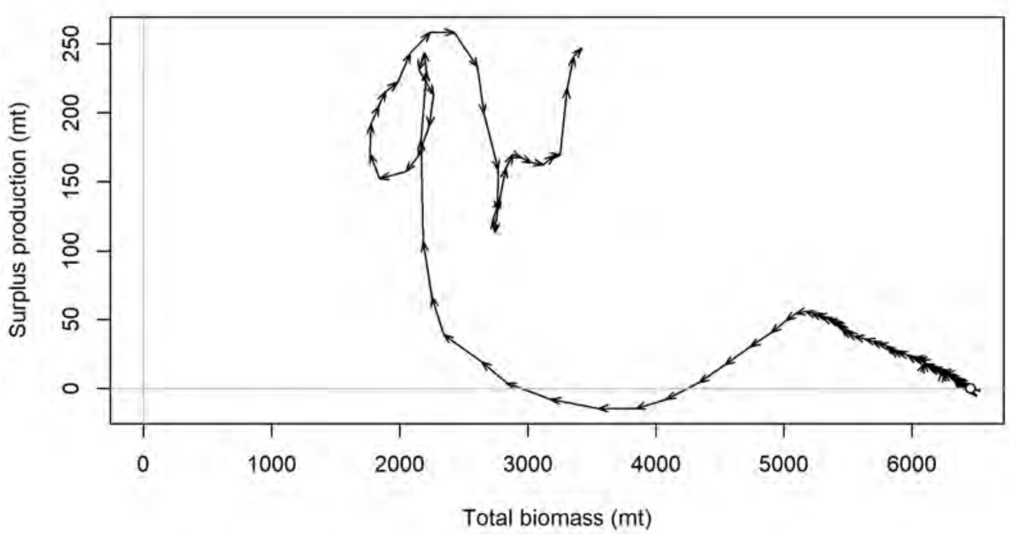

Figure 98: Surplus production vs. biomass plot.

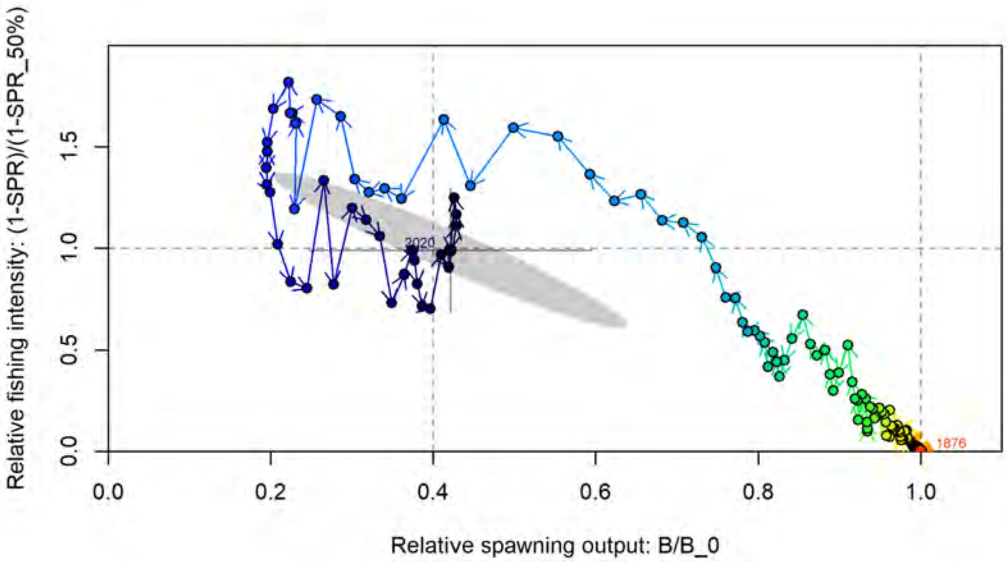

Figure 99: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show the 95 percent intervals based on 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.

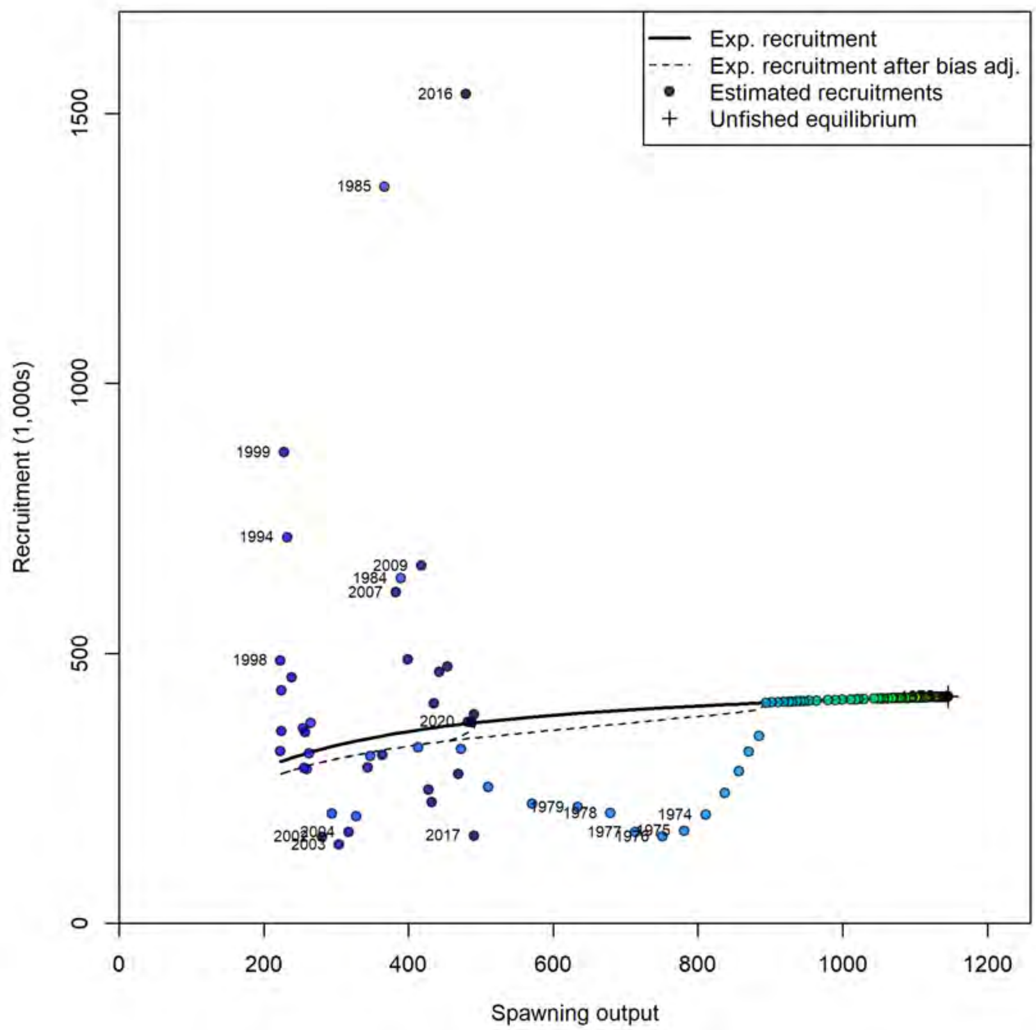

Figure 100: Stock-recruit curve with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

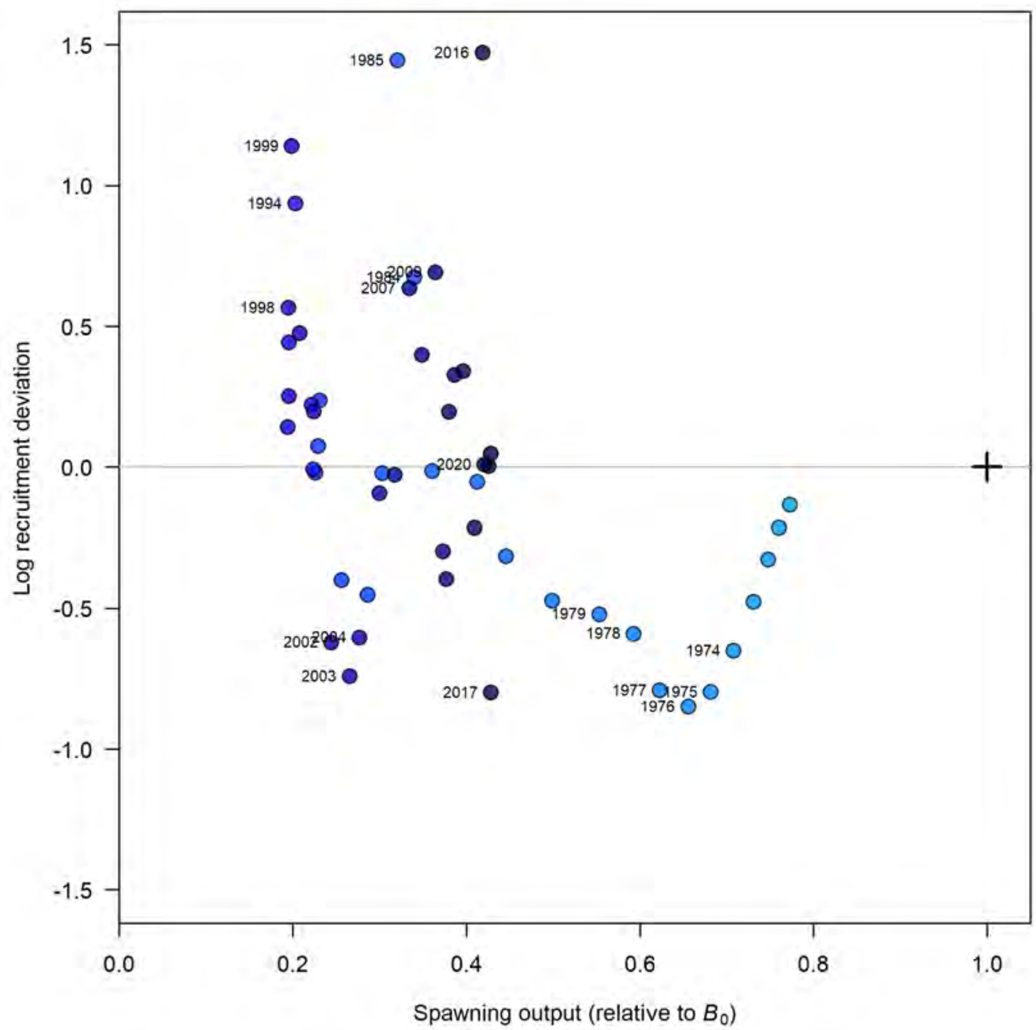

Figure 101: Deviations around the stock-recruit curve. Labels are on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

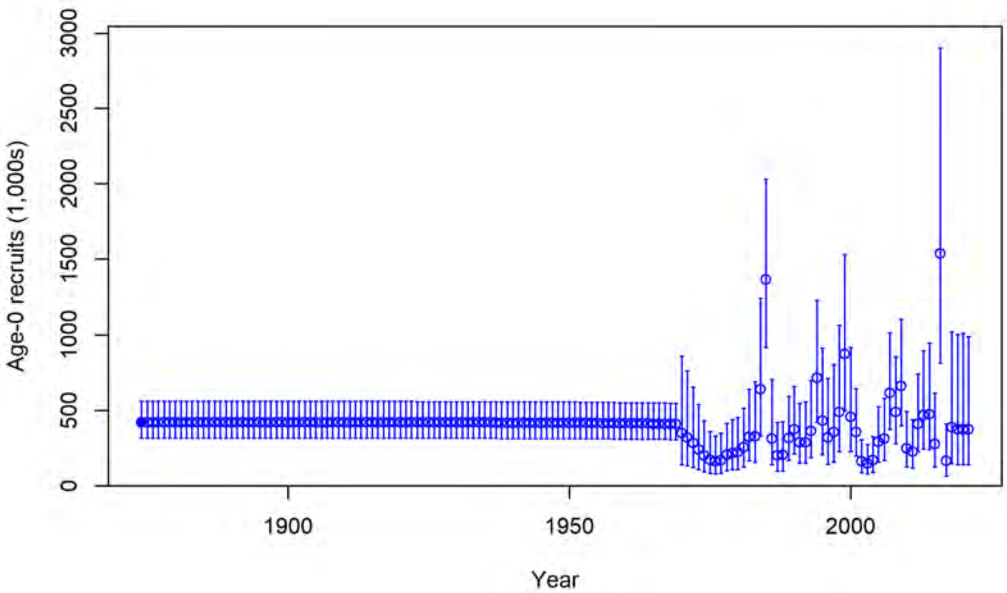

Figure 102: Age-0 recruits (1,000s) with ~95% asymptotic intervals.

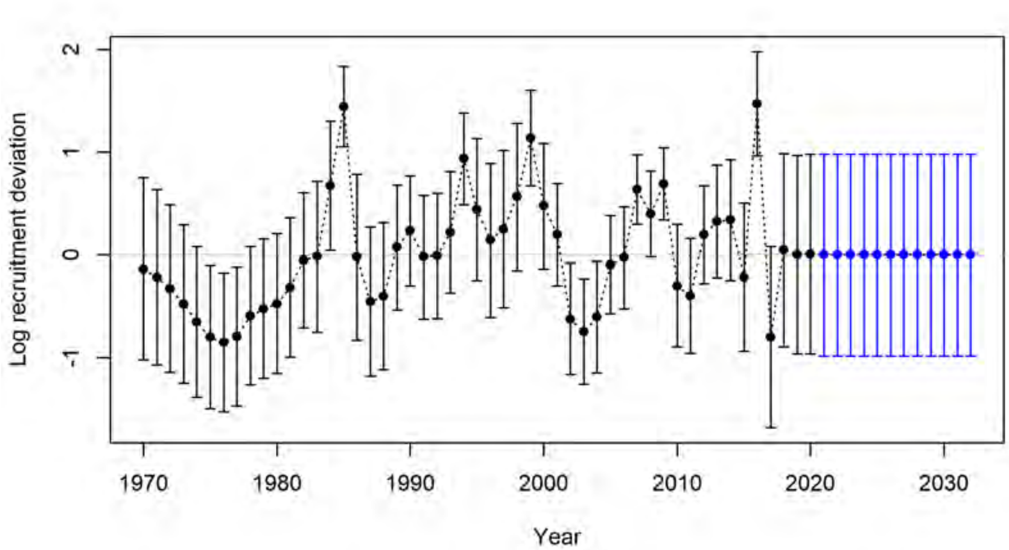

Figure 103: Estimated time series of recruitment deviations.

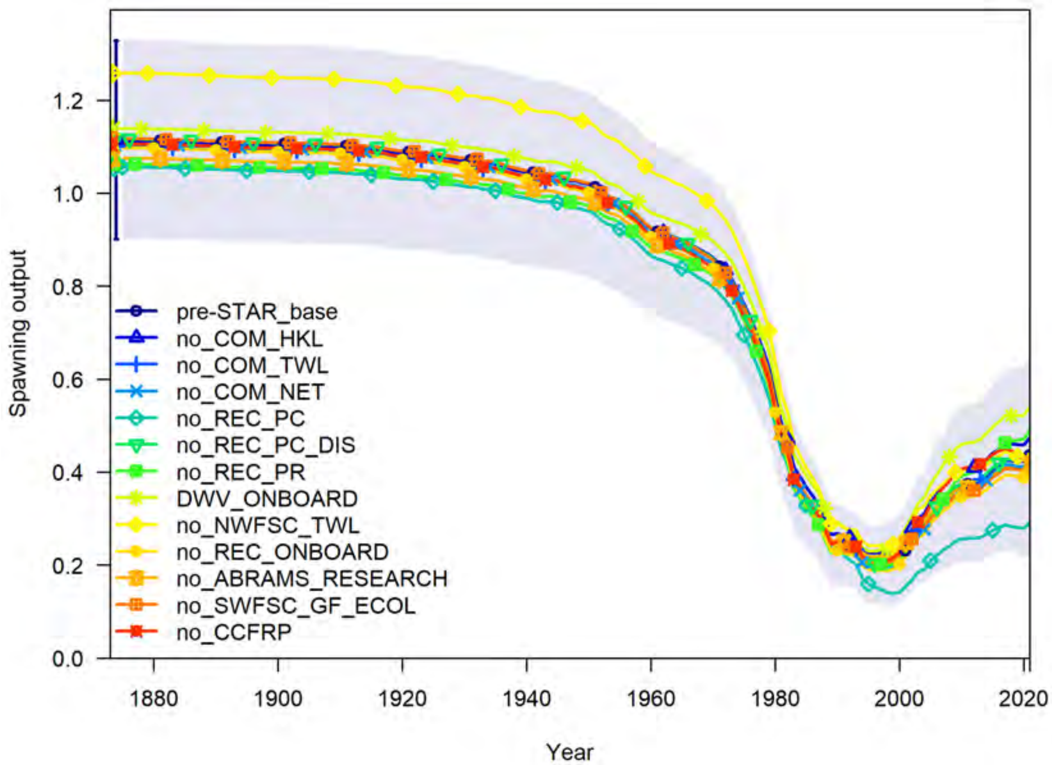

Figure 104: Change in the spawning output when a single fleet is removed from the model.

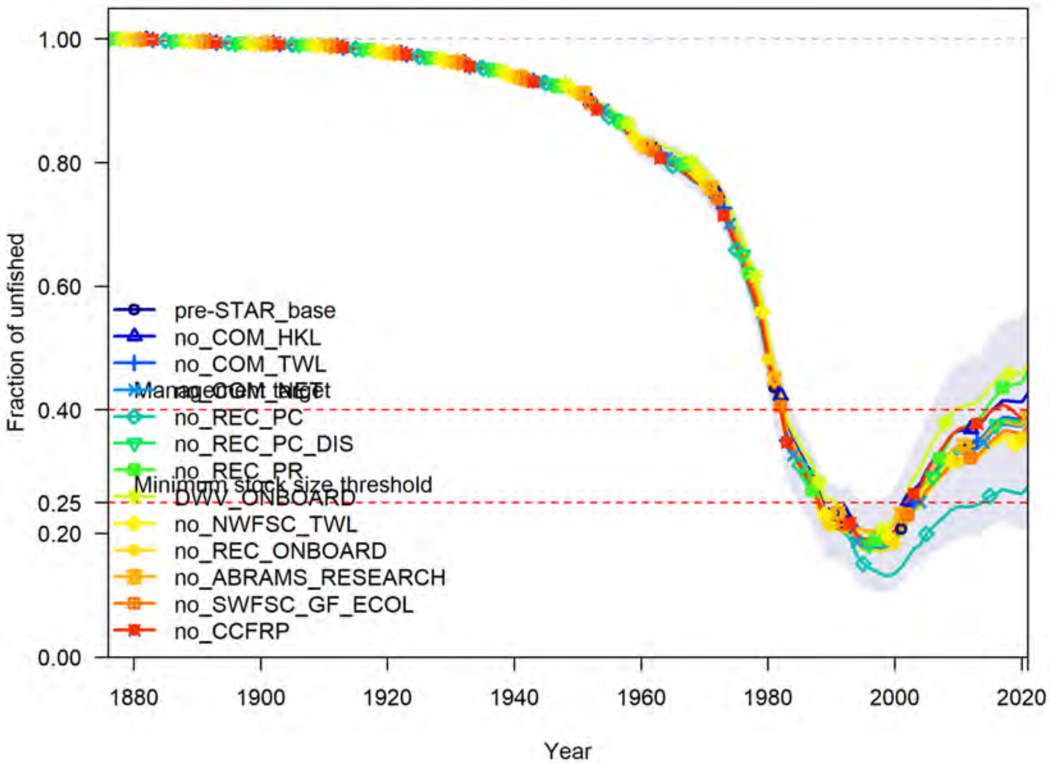

Figure 105: Change in the fraction of unfished biomass when a single fleet is removed from the model.

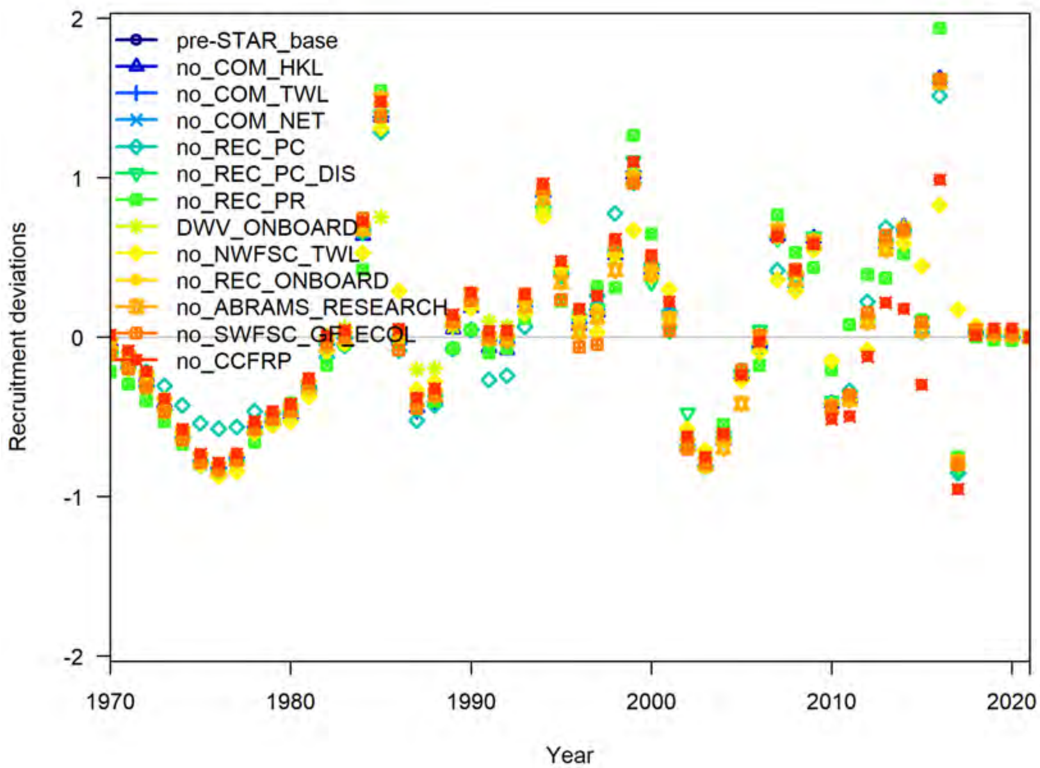

Figure 106: Change in the recruitment deviations when a single fleet is removed from the model.

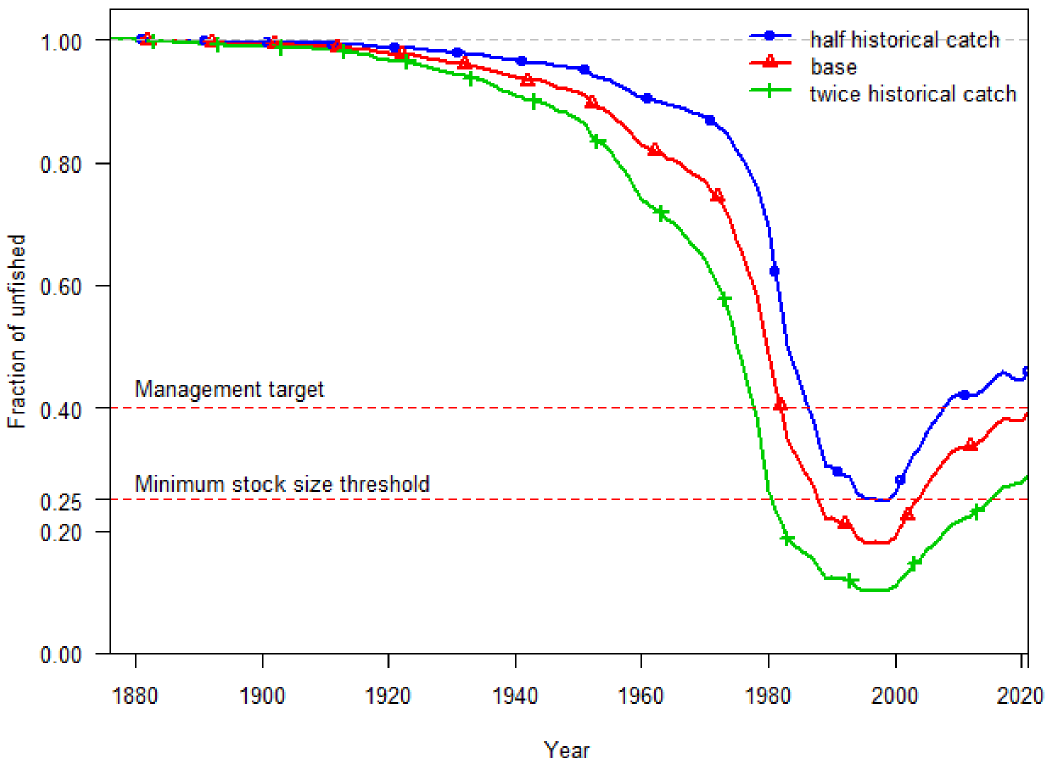

Figure 107: Change in depletion when historical catches are modified.

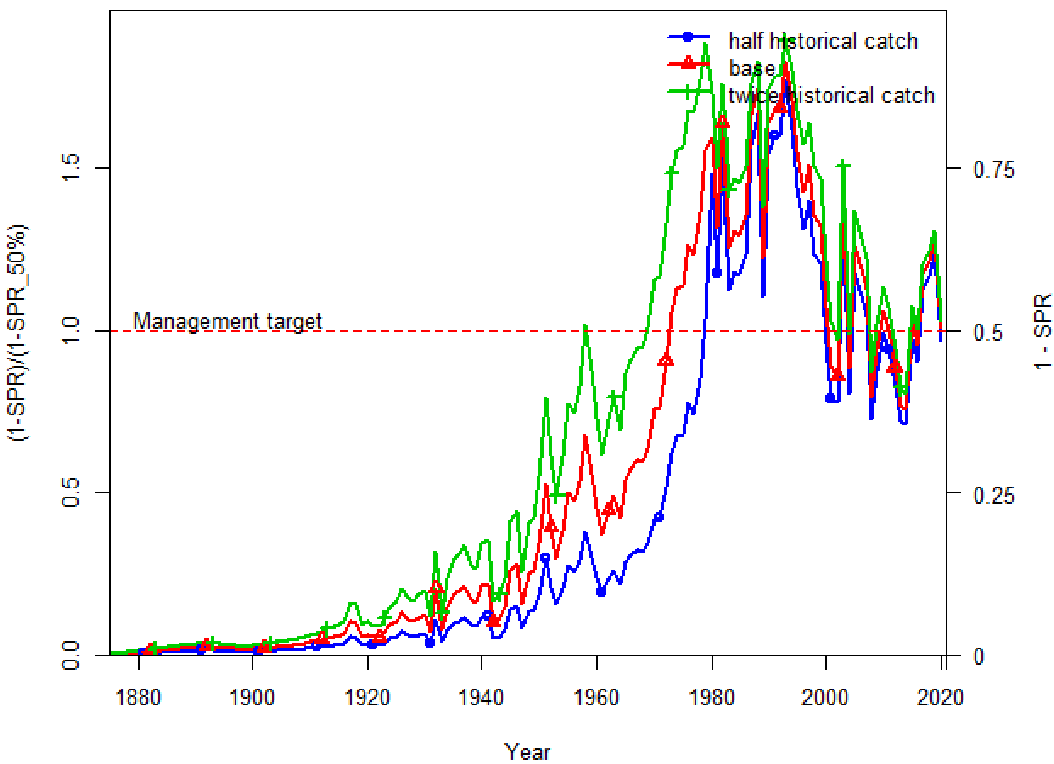

Figure 108: Change in the relative SPR when historical catches are modified.

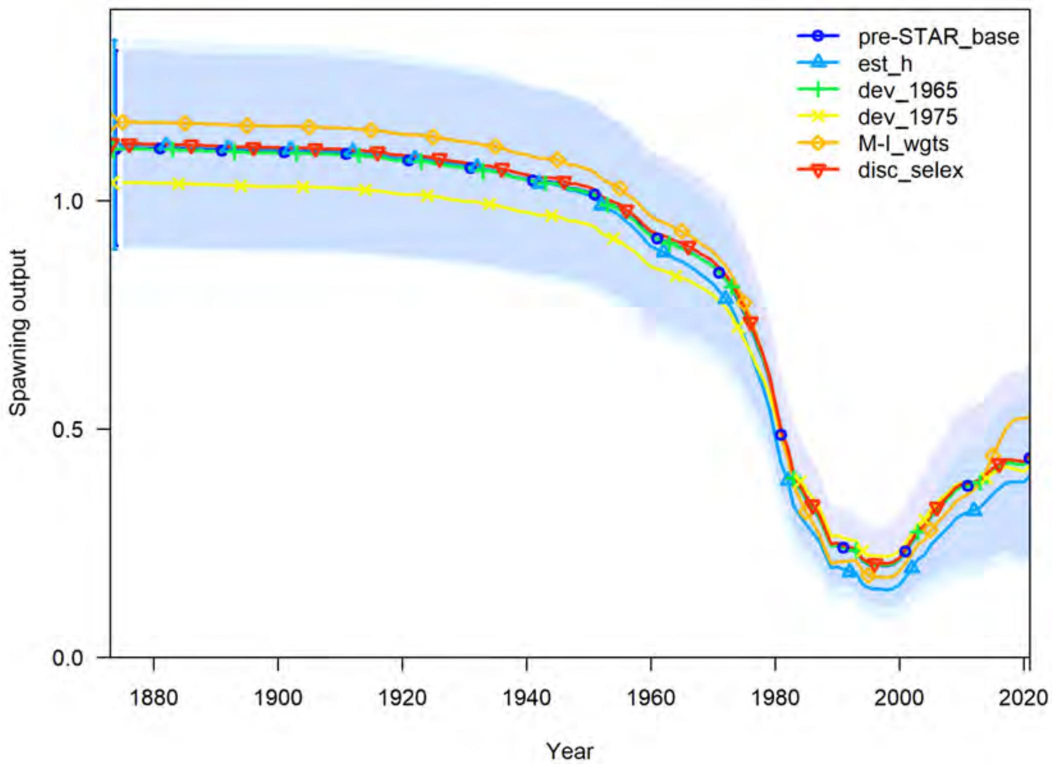

Figure 109: Change in the trajectory of spawning output to a series of model sensitivity runs.

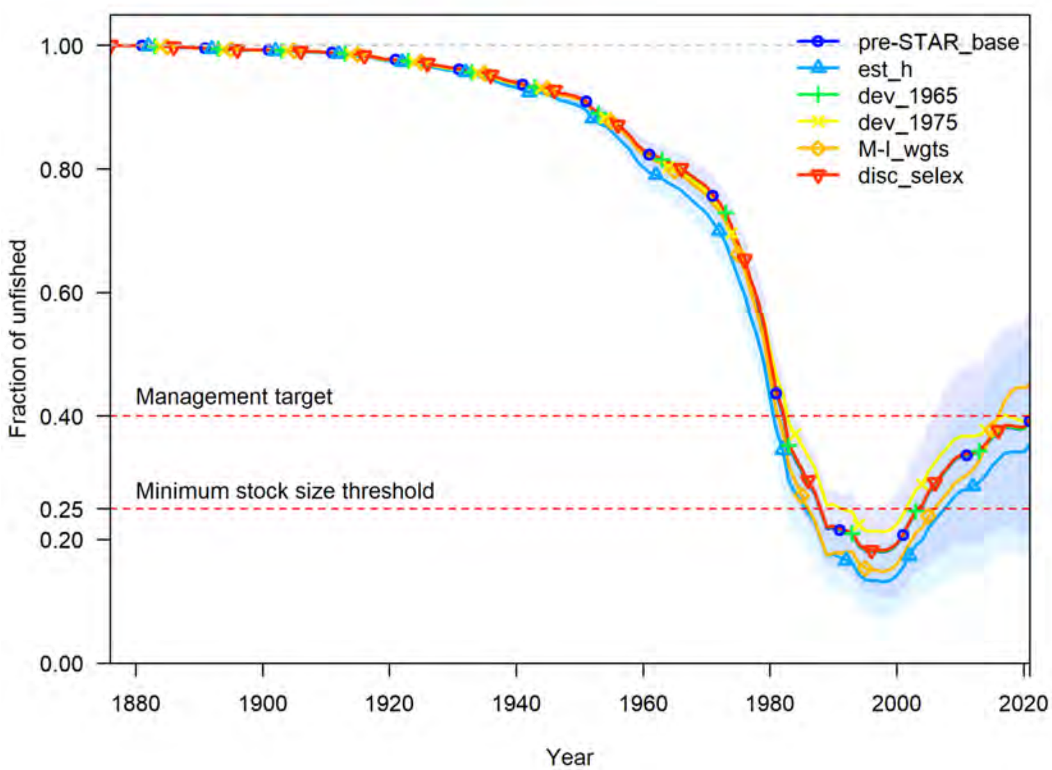

Figure 110: Change in the fraction of unfished biomass to a series of model sensitivity runs.

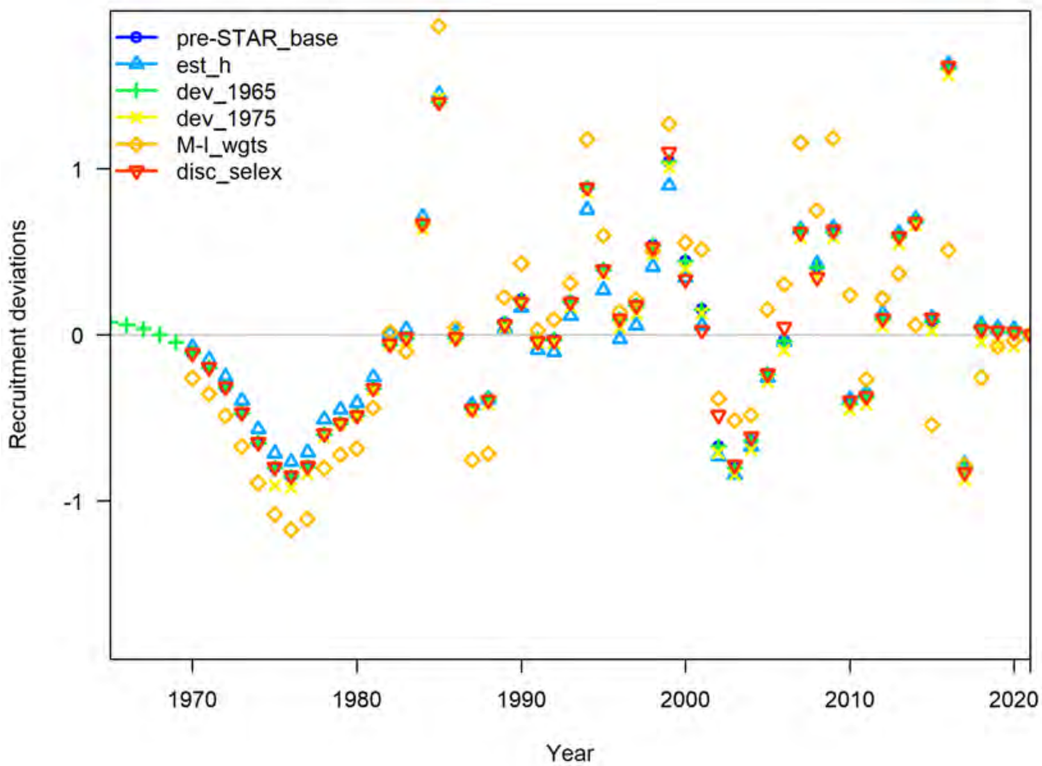

Figure 111: Change in the recruitment deviations to a series of model sensitivity runs.

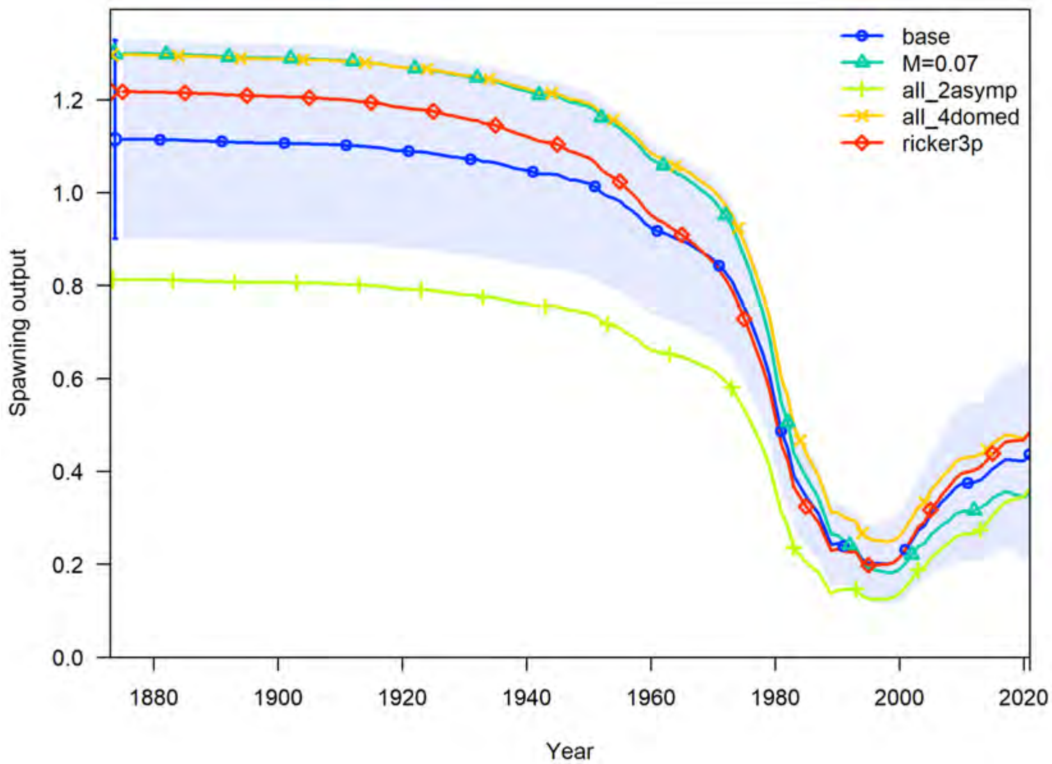

Figure 112: Change in the trajectory of spawning output to a series of model sensitivity runs.

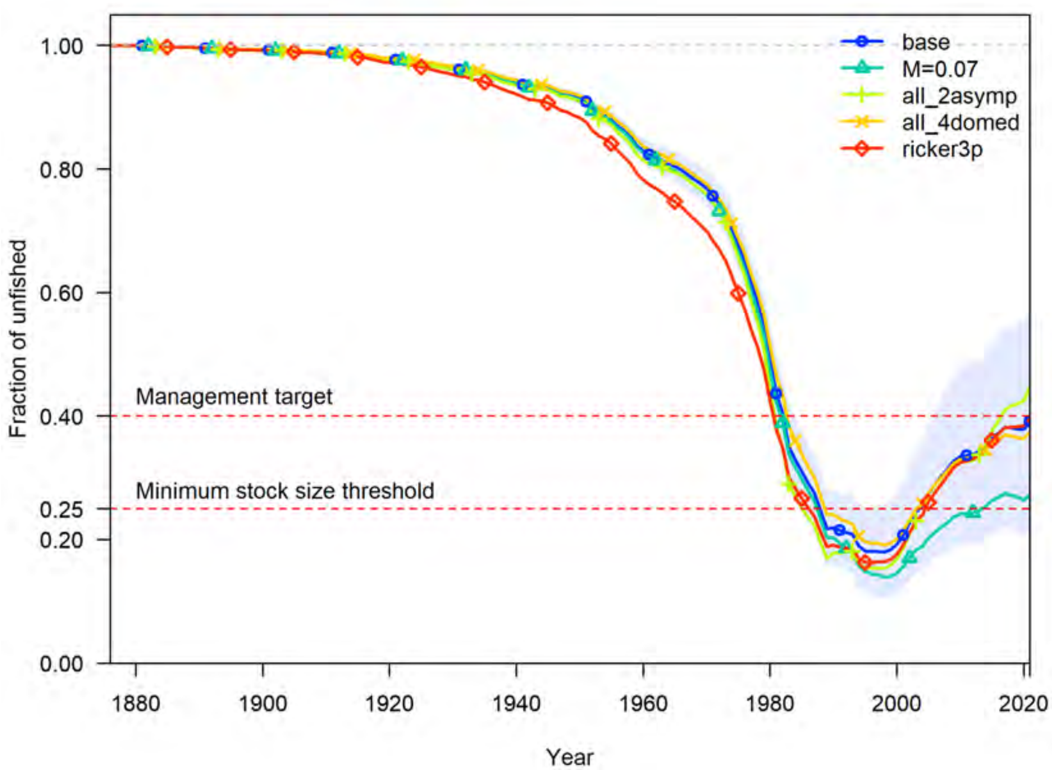

Figure 113: Change in the fraction of unfished biomass to a series of model sensitivity runs.

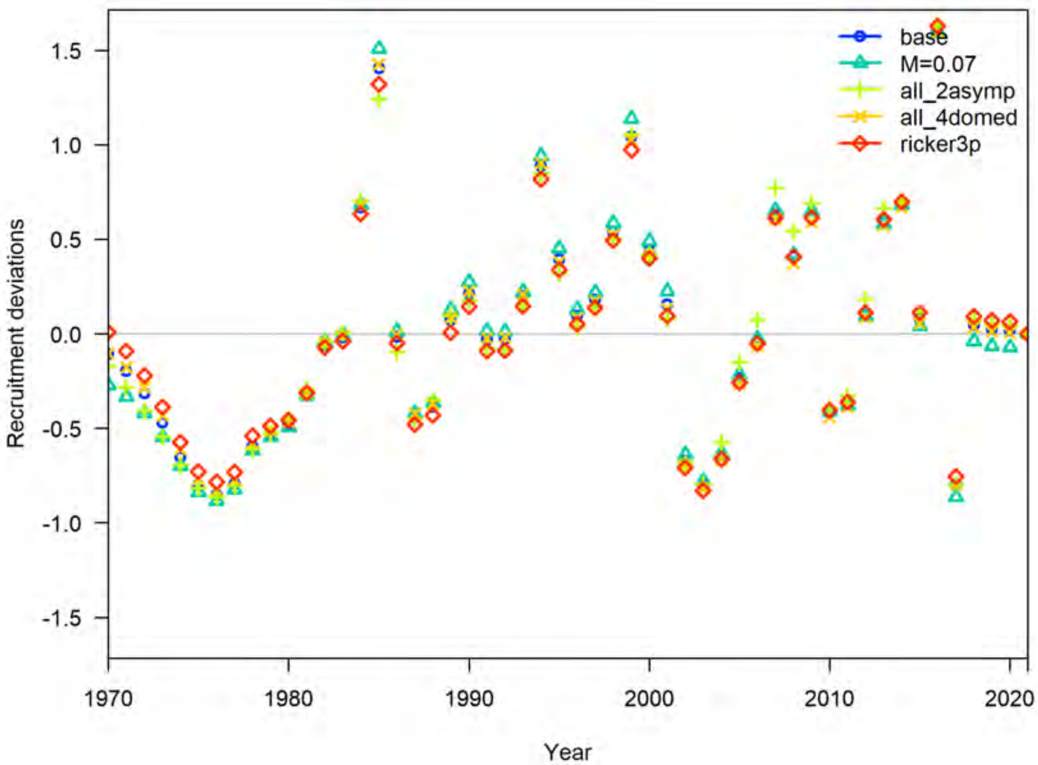

Figure 114: Change in the recruitment deviations to a series of model sensitivity runs.

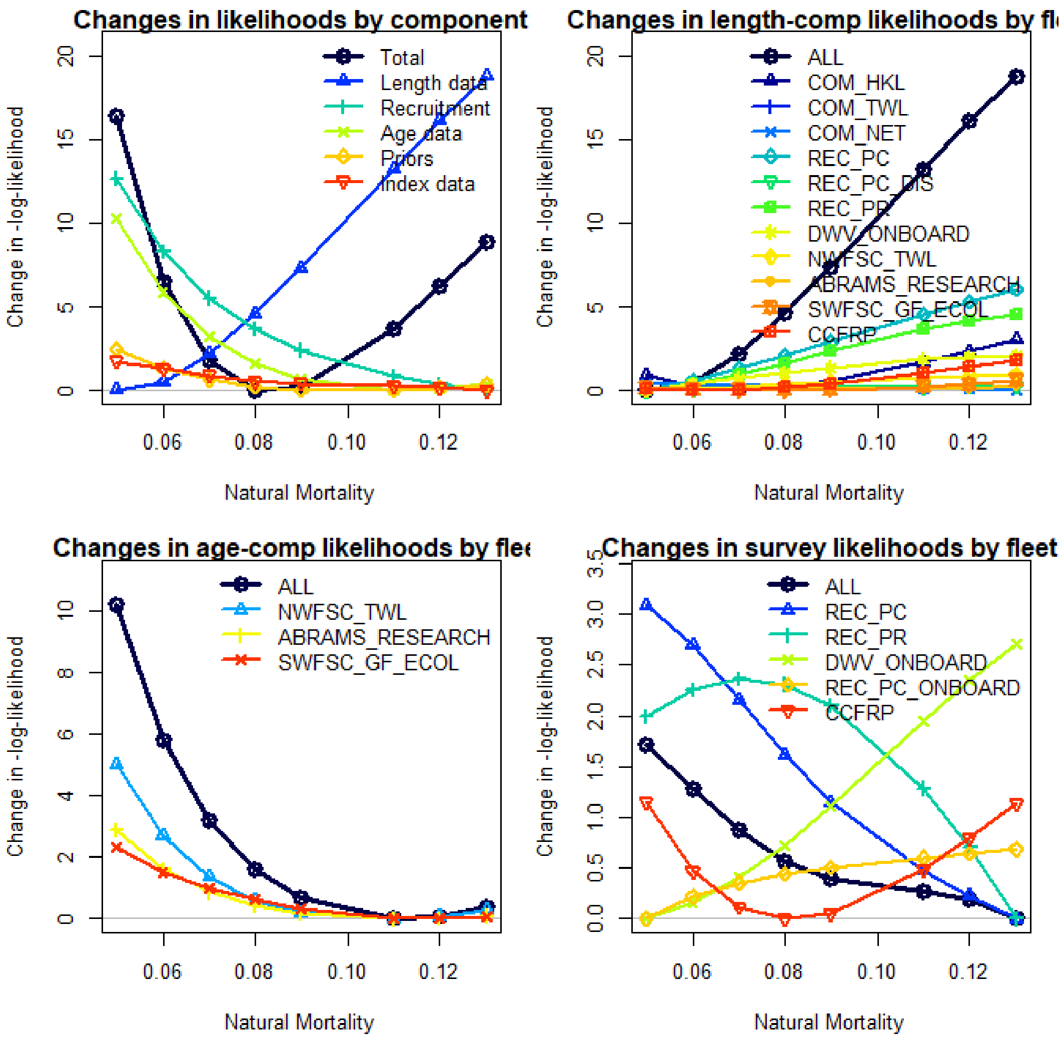

Figure 115: Likelihood profile across natural mortality values for each data type.

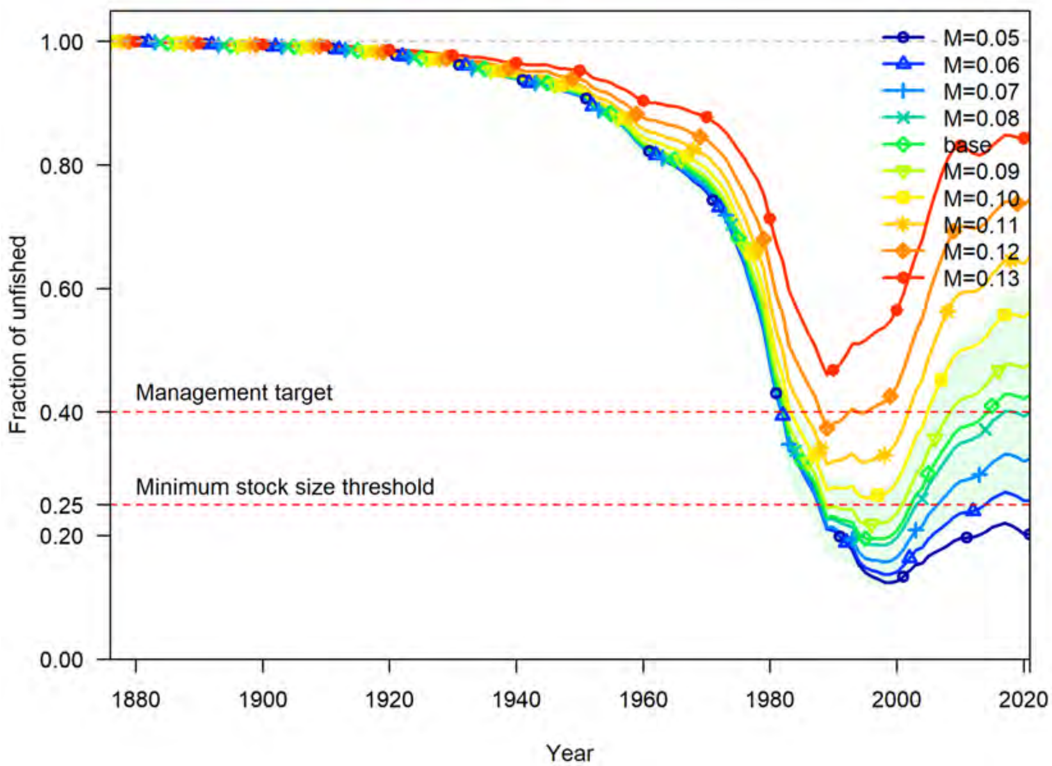

Figure 116: Trajectories of depletion across values of female natural mortality.

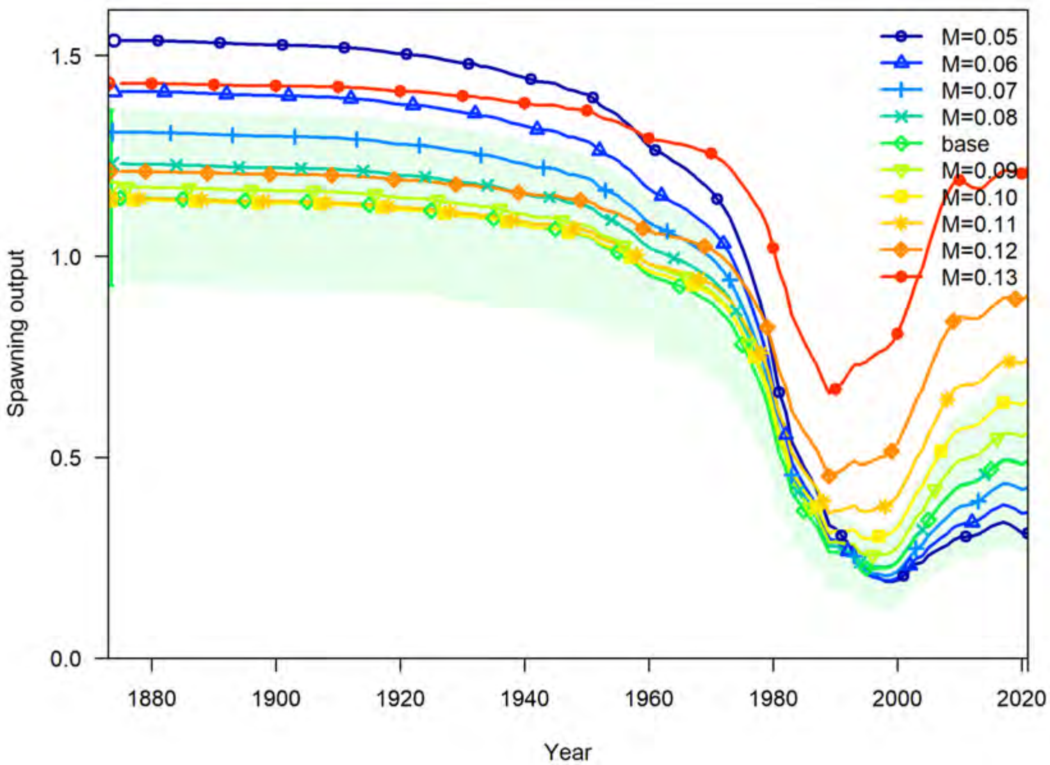

Figure 117: Trajectories of spawning output across values of female natural mortality.

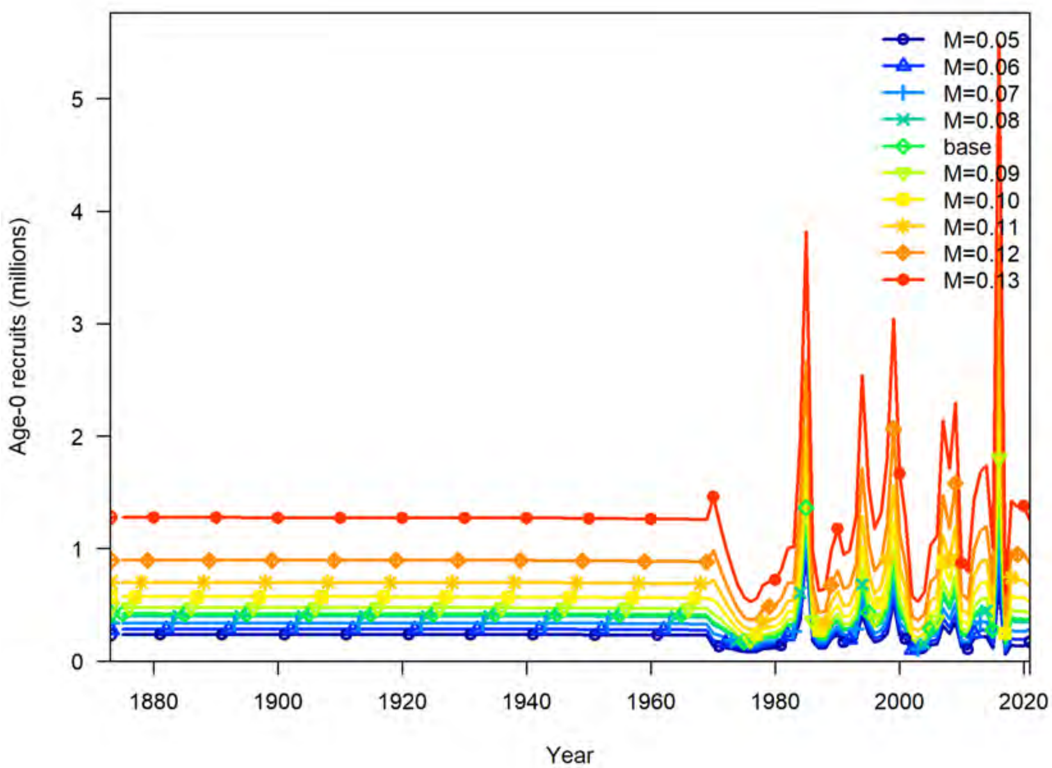

Figure 118: Trajectories of age-0 recruits across values of female natural mortality.

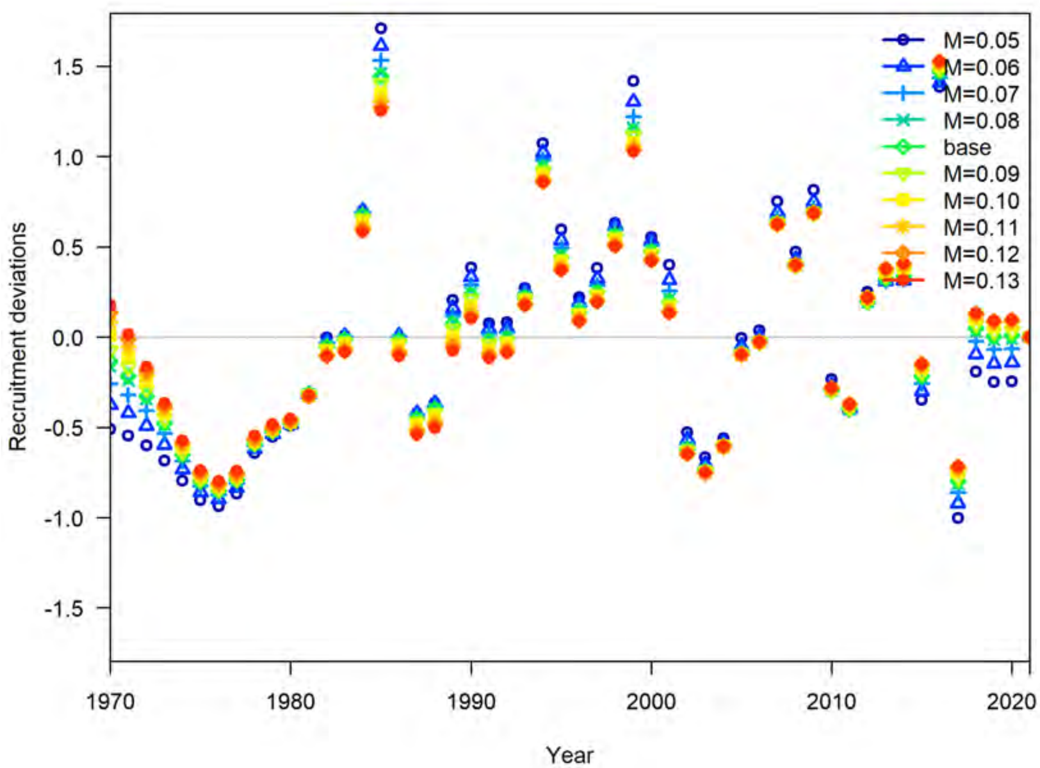

Figure 119: Trajectories of estimated recruitment deviations across values of female natural mortality.

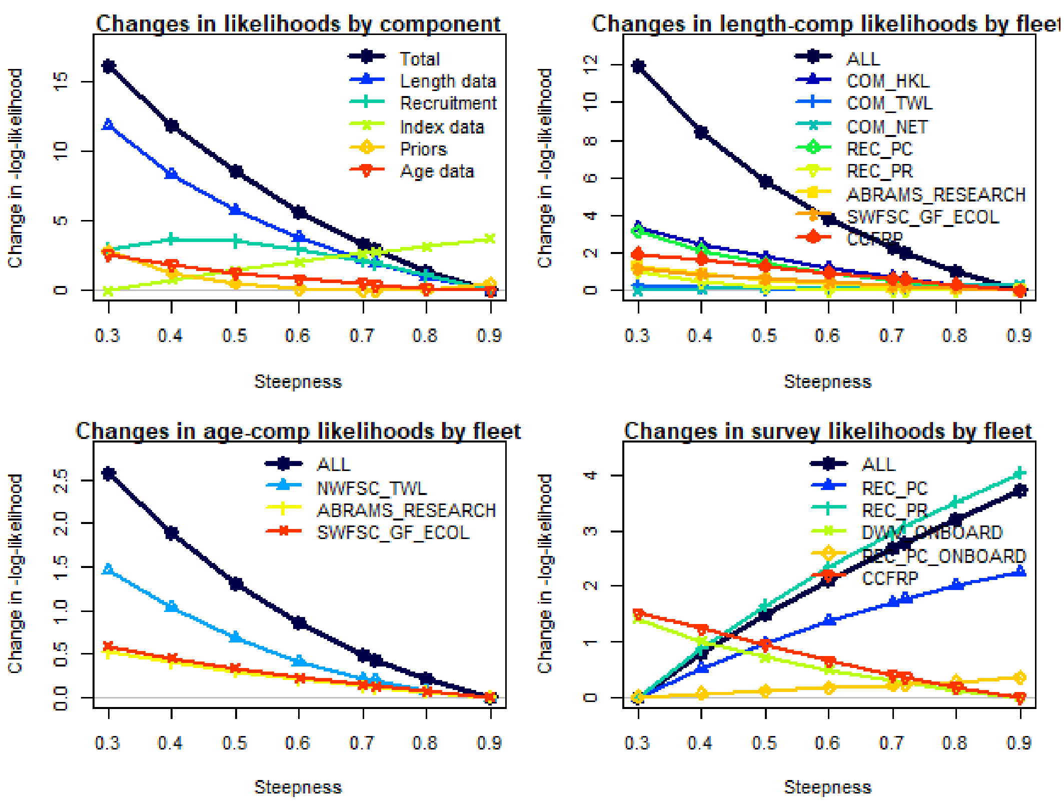

Figure 120: Likelihood profile across steepness values for each data type.

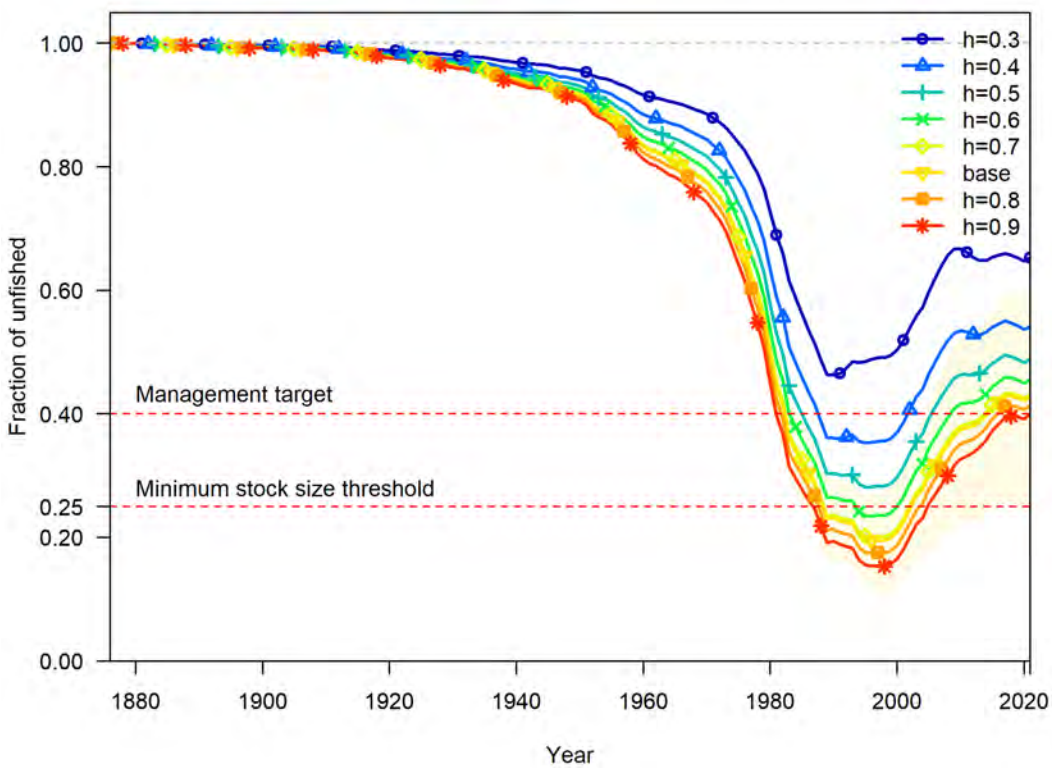

Figure 121: Trajectories of depletion across values of steepness.

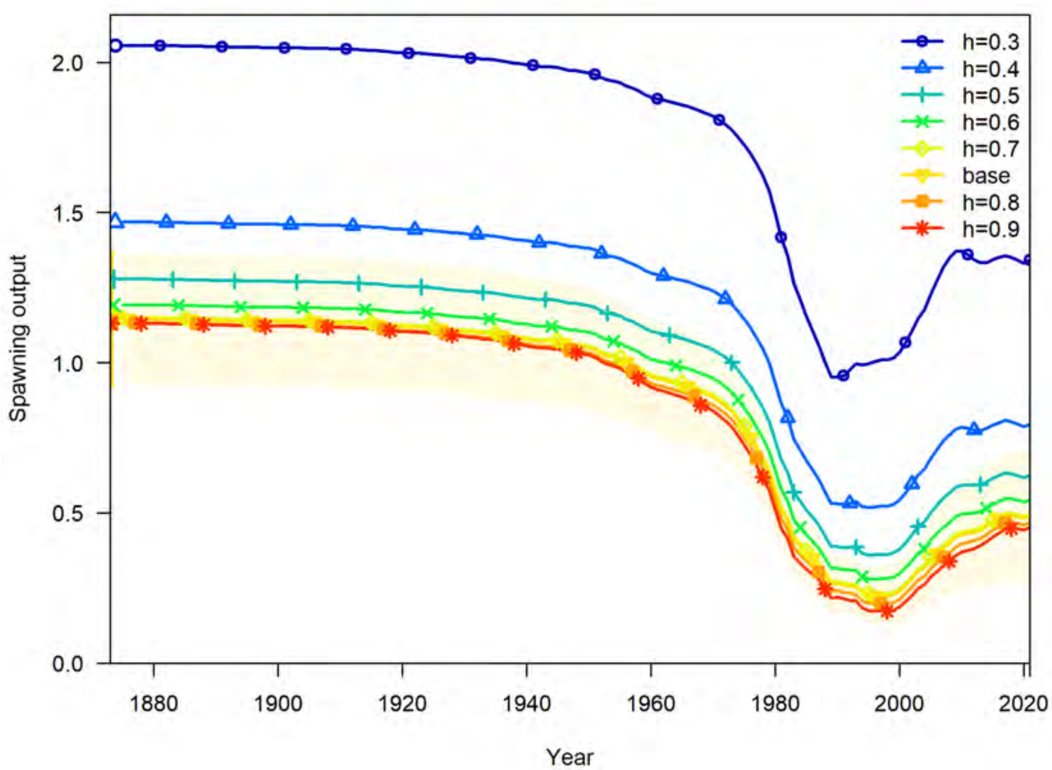

Figure 122: Trajectories of spawning output across values of steepness.

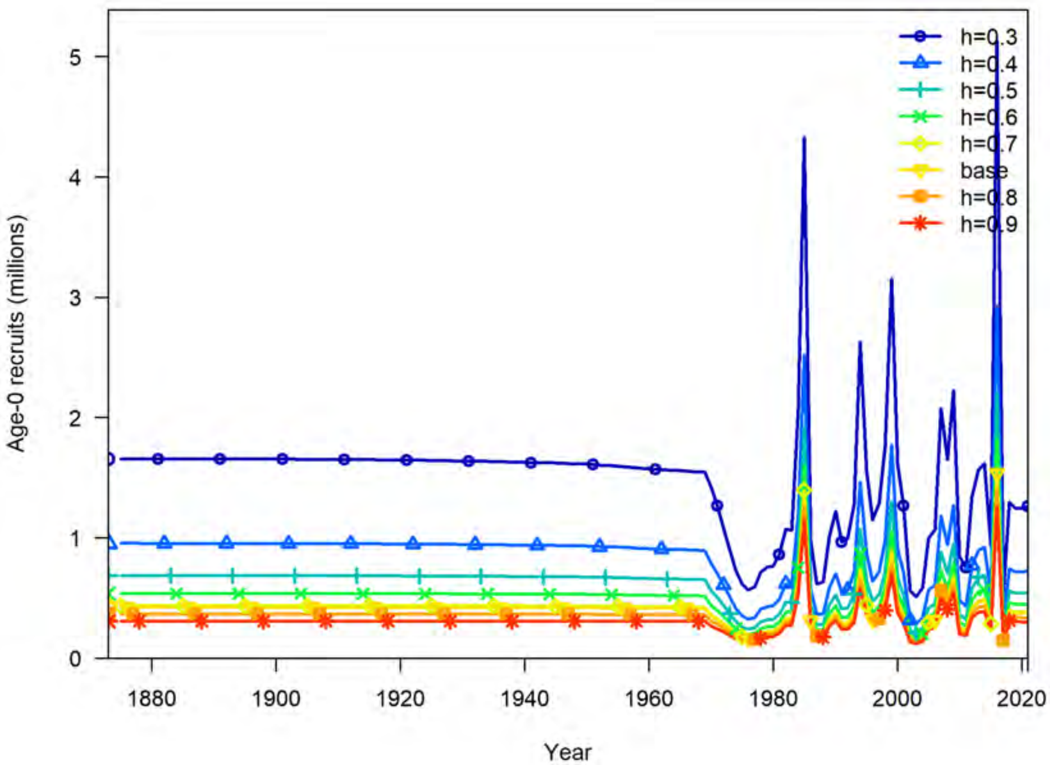

Figure 123: Trajectories of age-0 recruits across values of steepness.

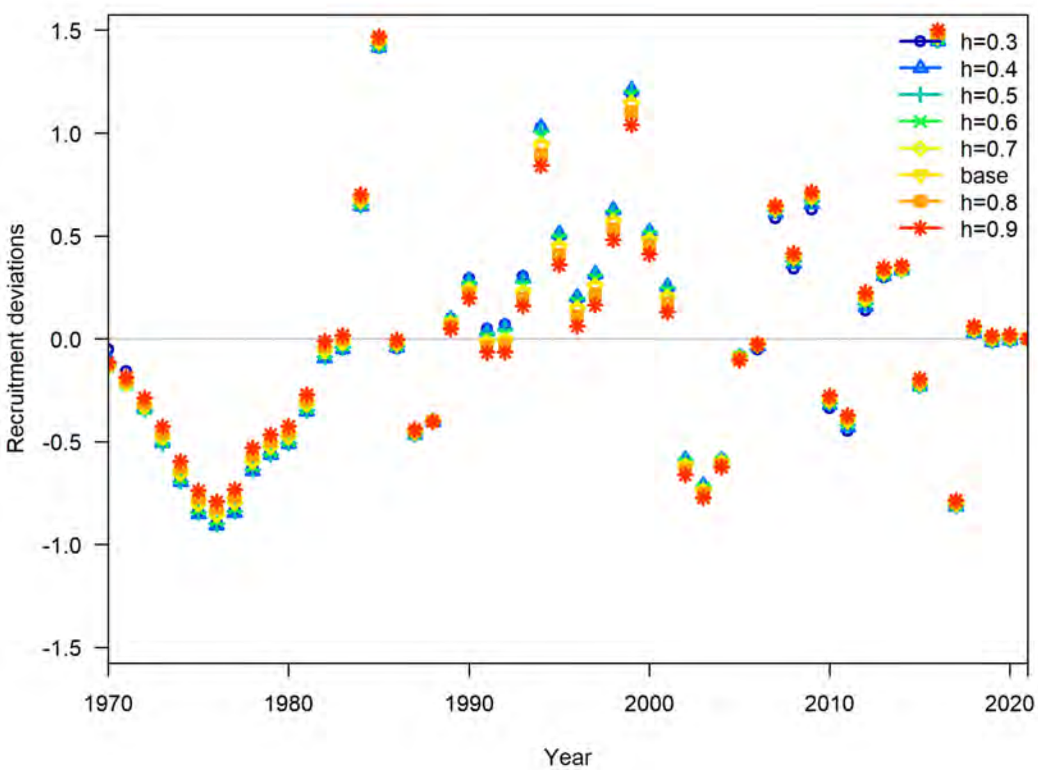

Figure 124: Trajectories of estimated recruitment deviations across values of steepness.

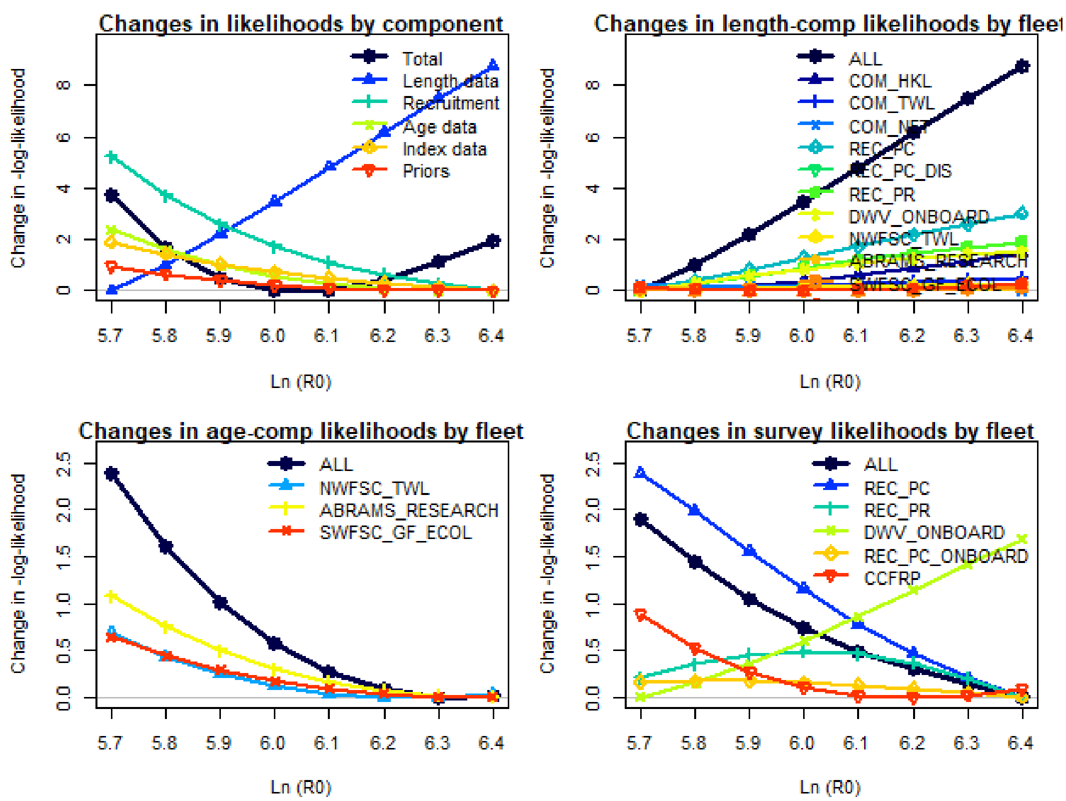

Figure 125: Likelihood profile across R0 values for each data type.

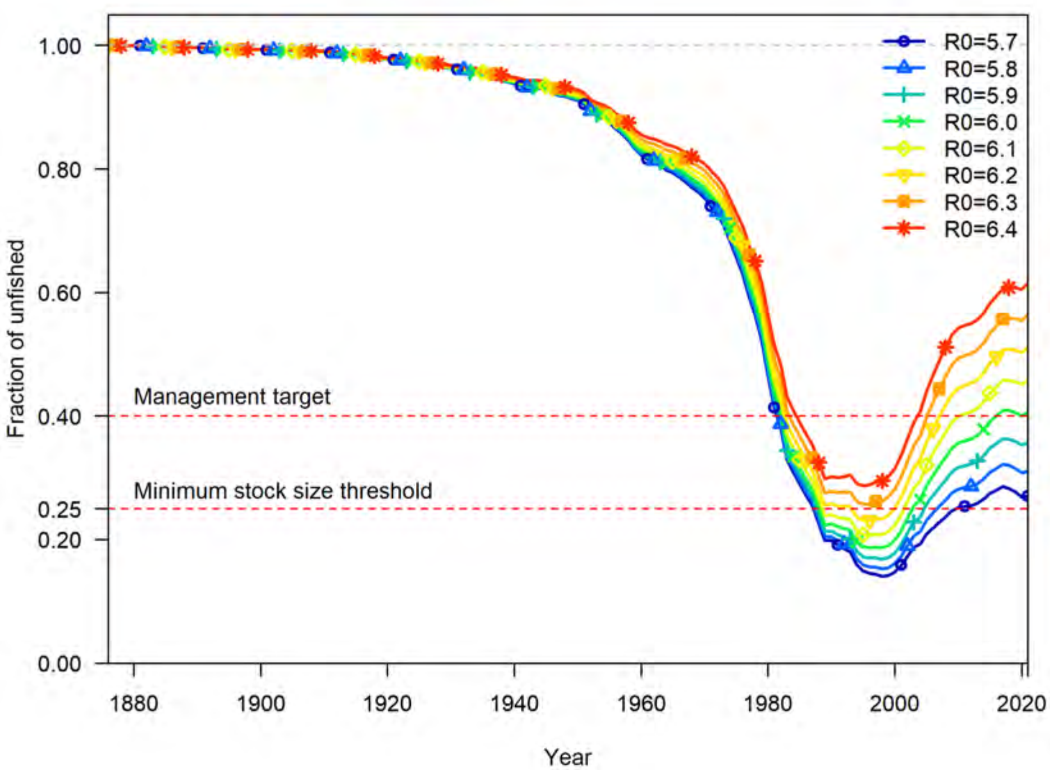

Figure 126: Trajectories of depletion across values of R0.

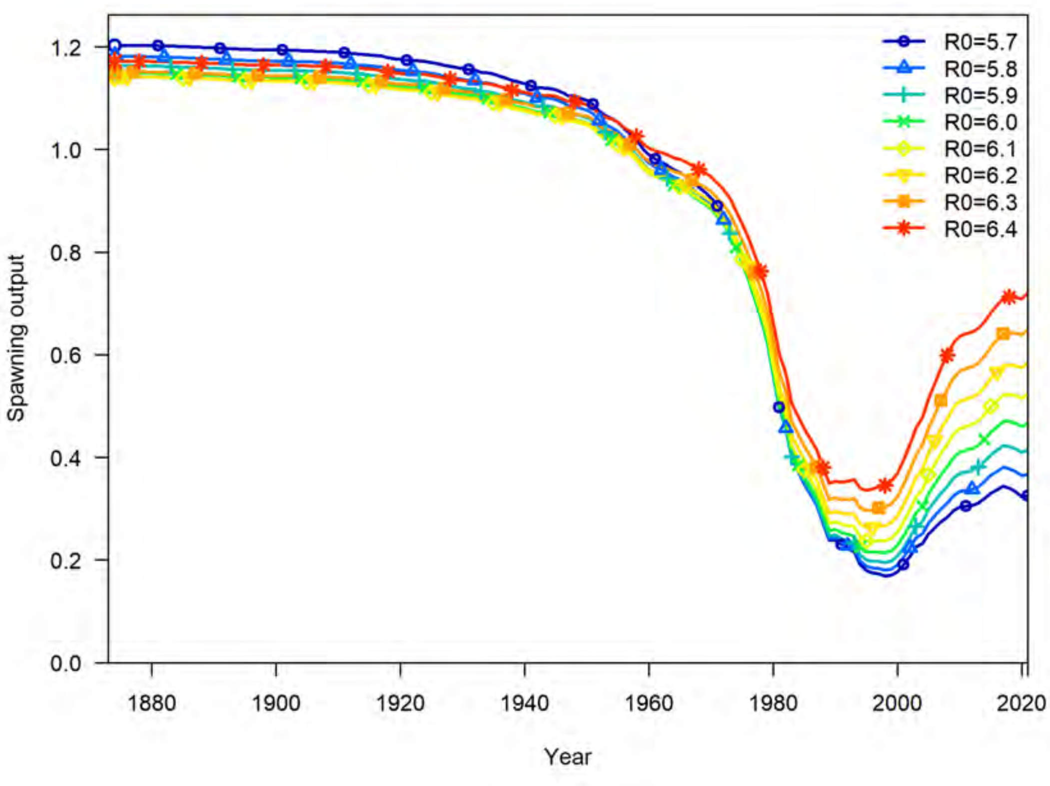

Figure 127: Trajectories of spawning output across values of R0.

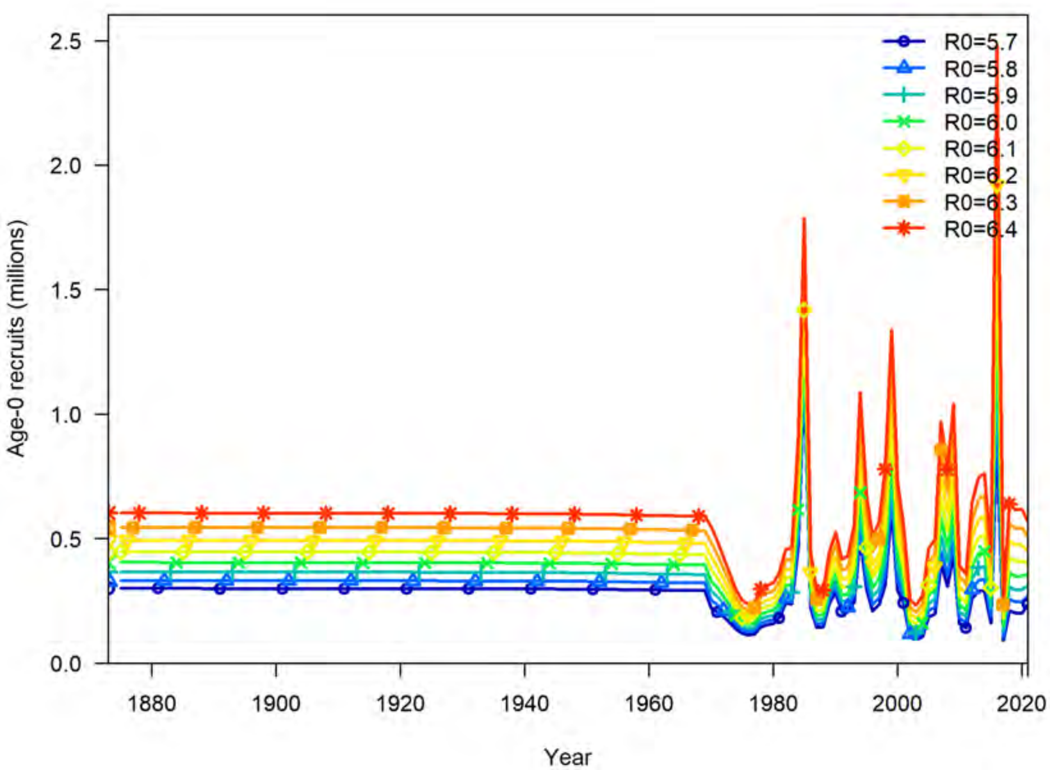

Figure 128: Trajectories of age-0 recruits across values of R0.

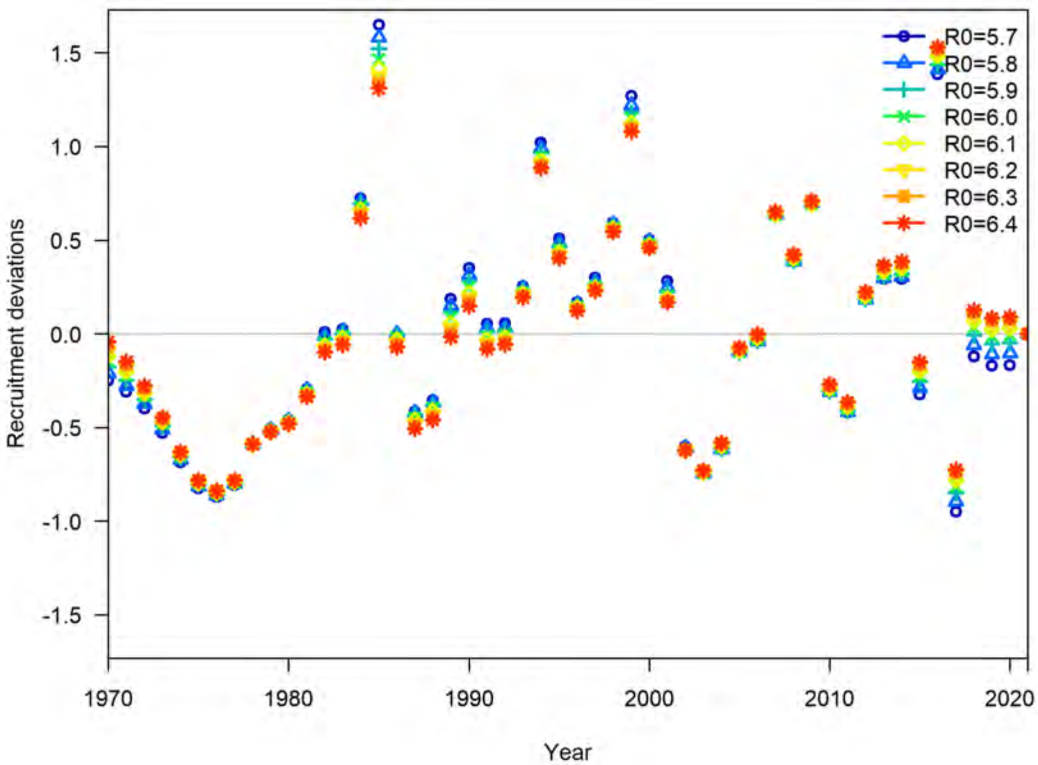

Figure 129: Trajectories of estimated recruitment deviations across values of R0.

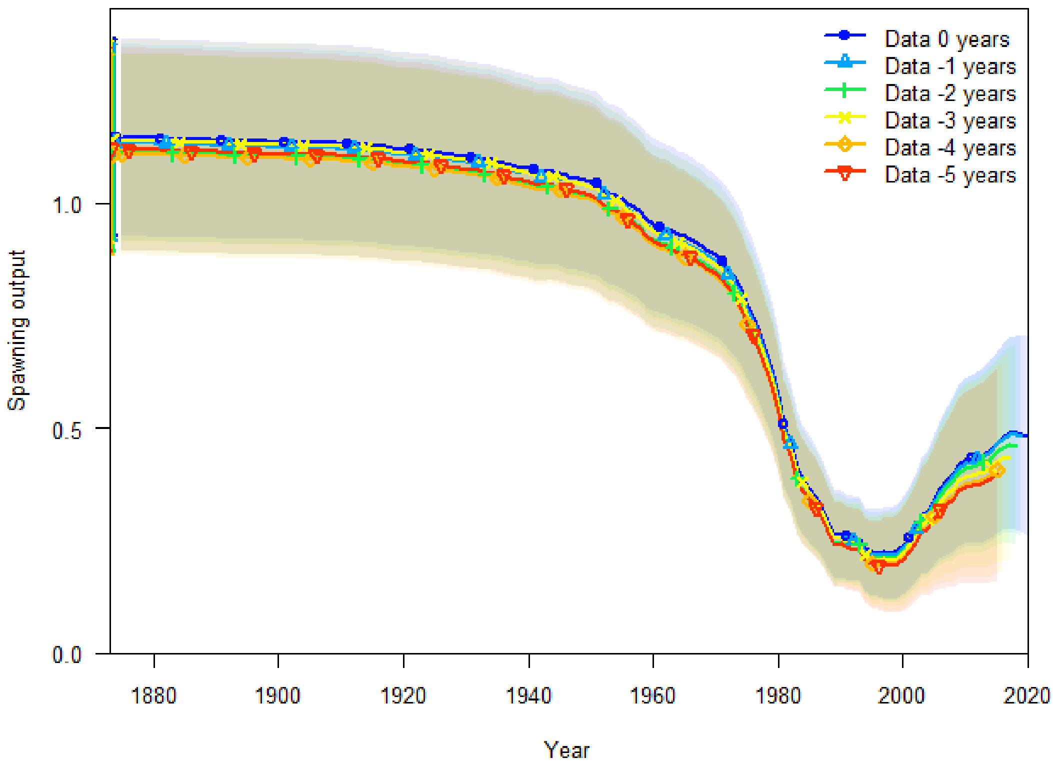

Figure 130: Change in the spawning output when the most recent 5 years of data area removed sequentially.

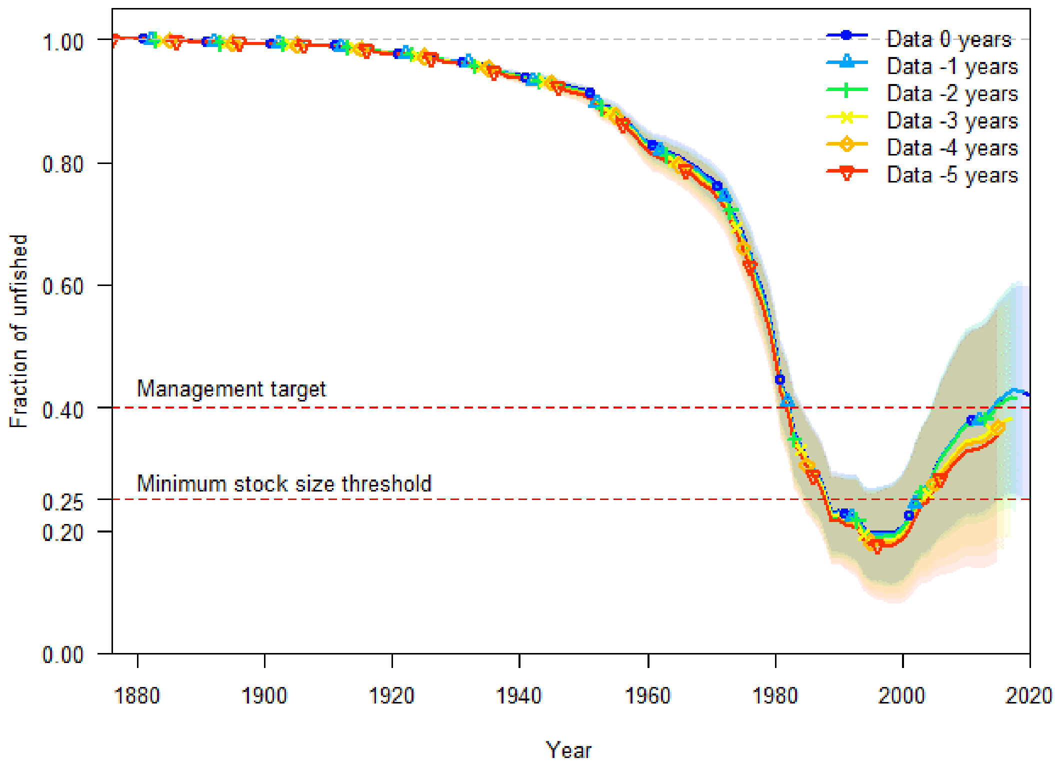

Figure 131: Change in the fraction of unfished biomass when the most recent 5 years of data area removed sequentially.

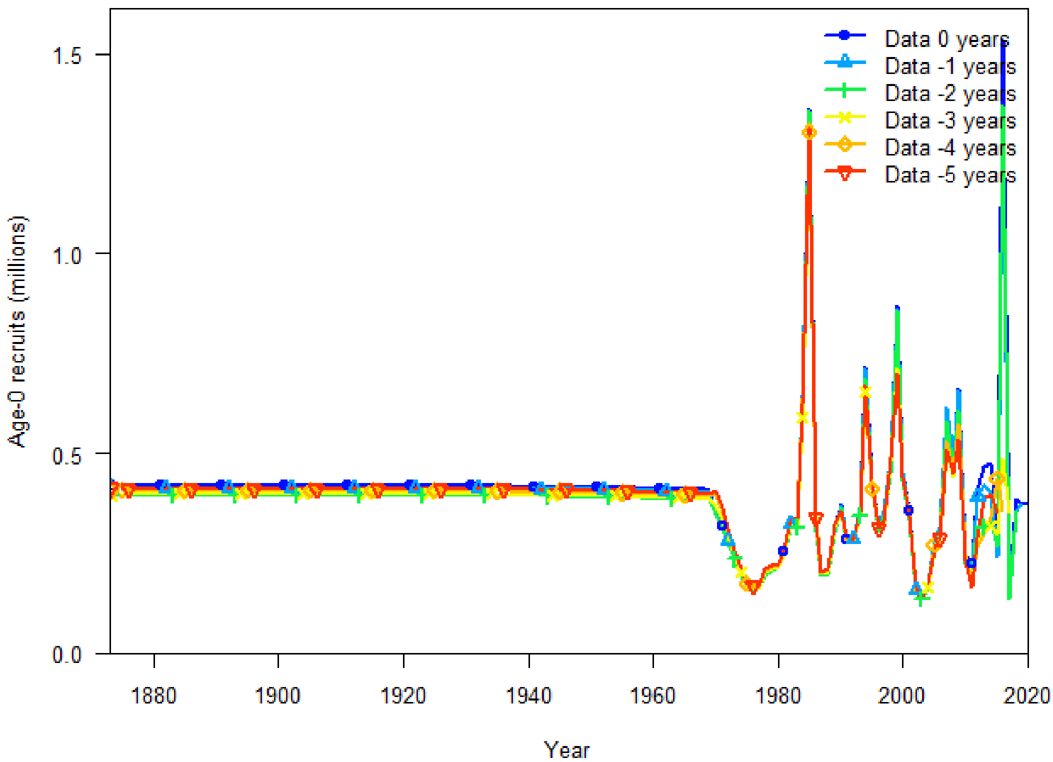

Figure 132: Trajectories of age-0 recruits when the most recent 5 years of data area removed sequentially.

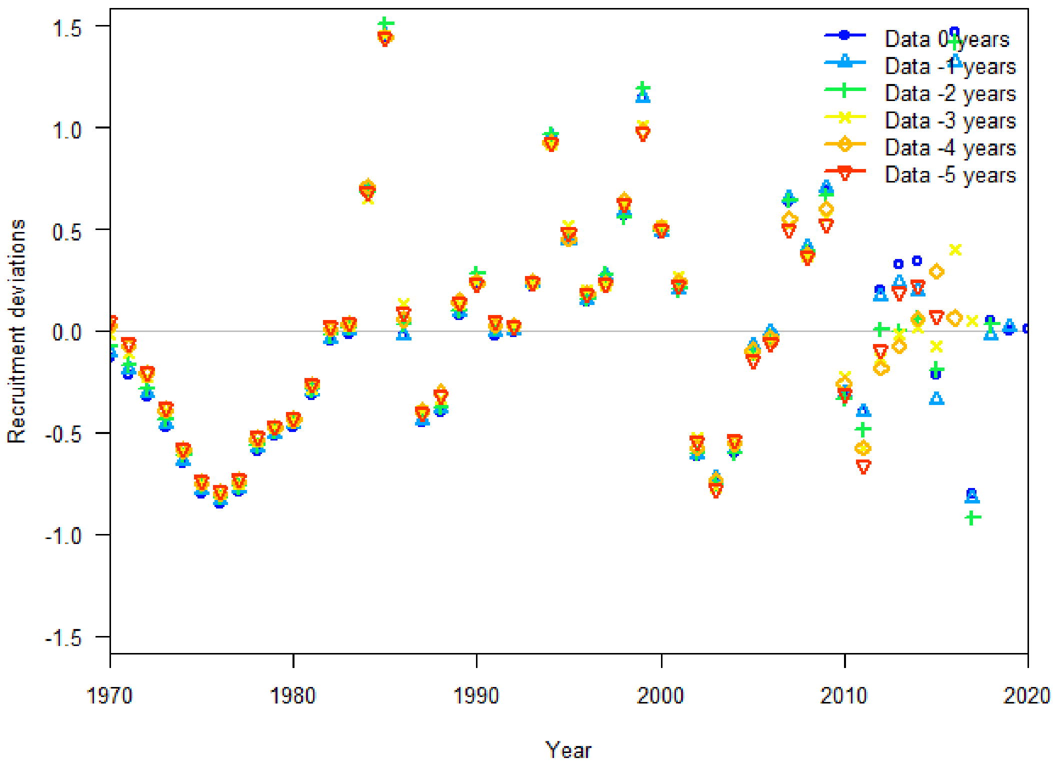

Figure 133: Change in the recruitment deviations when the most recent 5 years of data area removed sequentially.

Appendix A. Detailed Fit to Length Composition Data

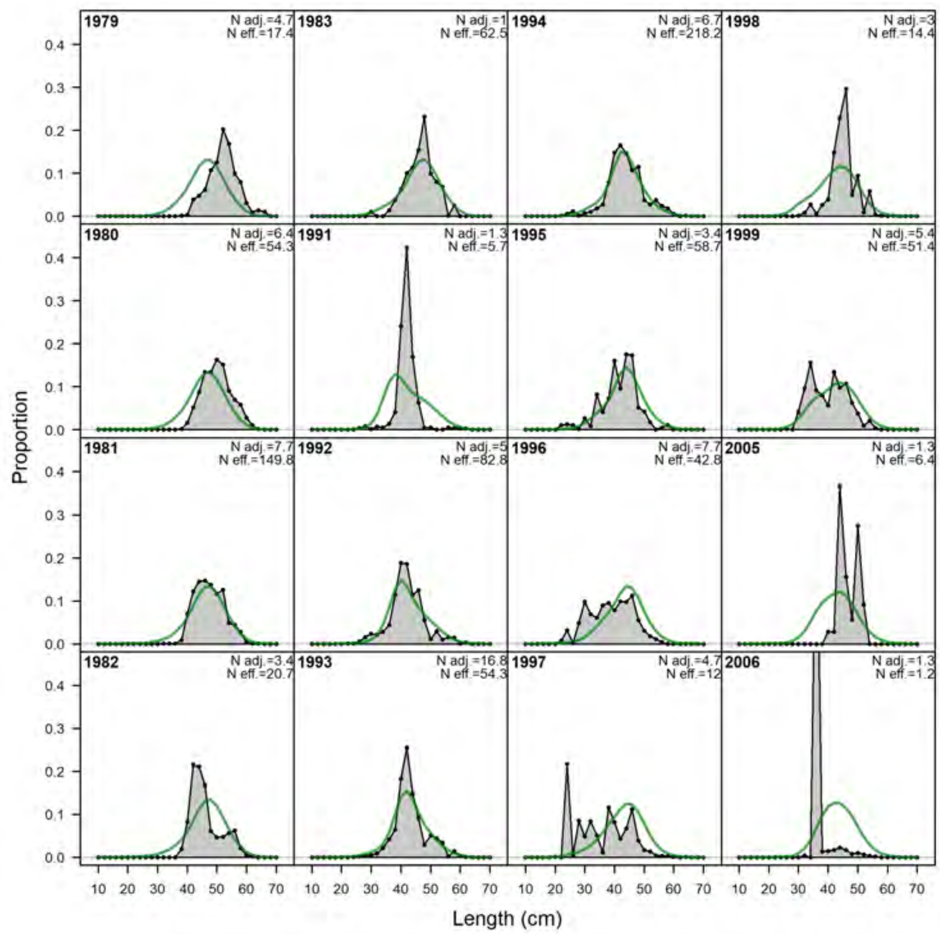

Figure A1: Length comps, whole catch, COM_HKL (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

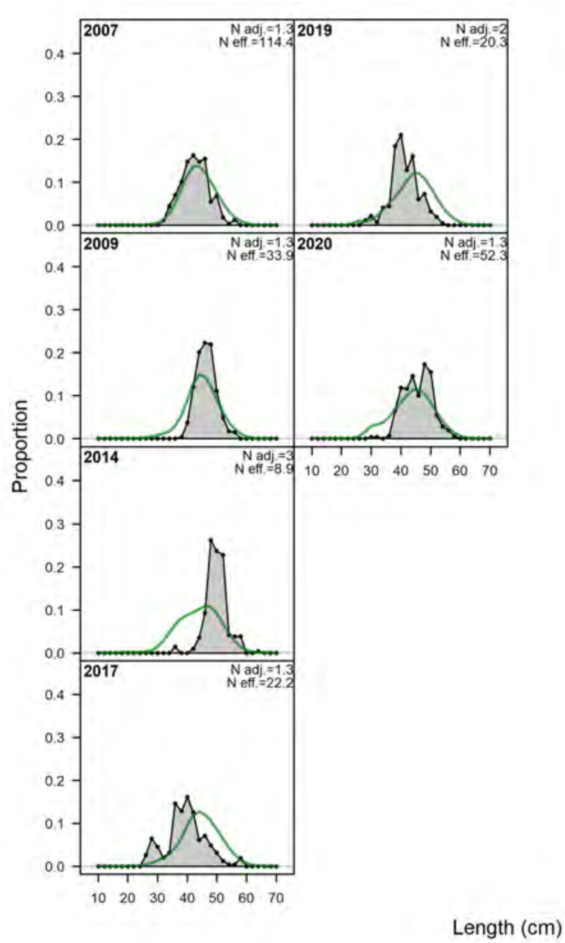

Figure A2: Length comps, whole catch, COM_HKL (plot 2 of 2).

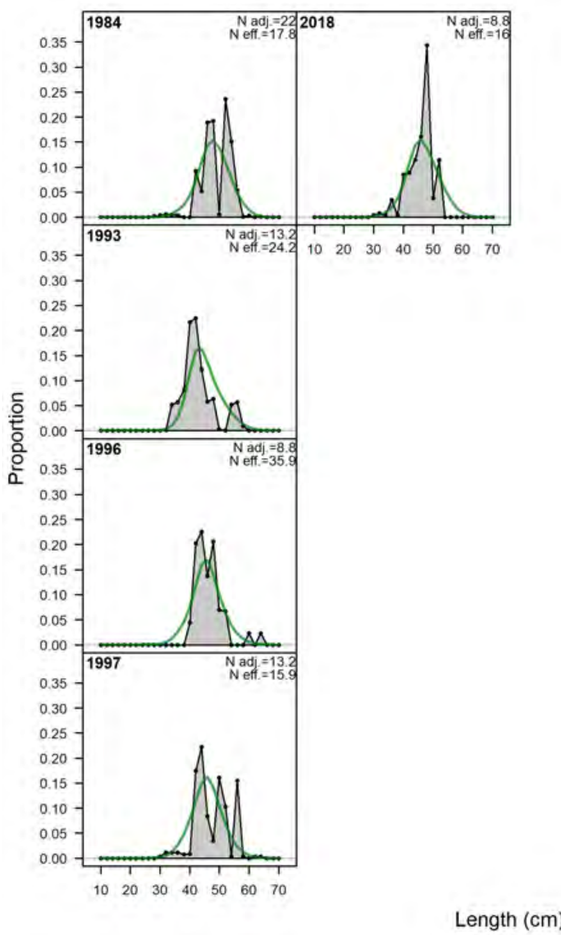

Figure A3: Length comps, whole catch, COM_TWL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

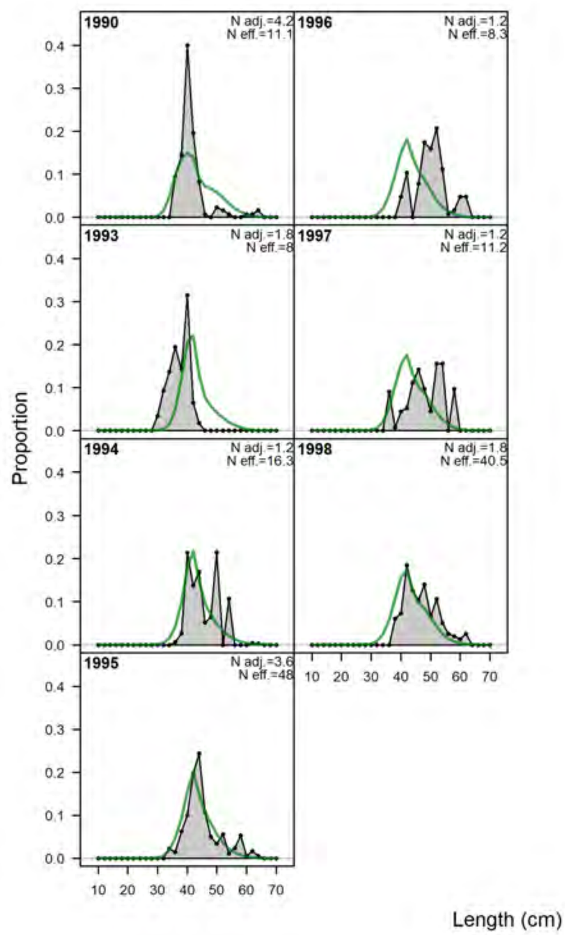

Figure A4: Length comps, whole catch, COM_NET.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

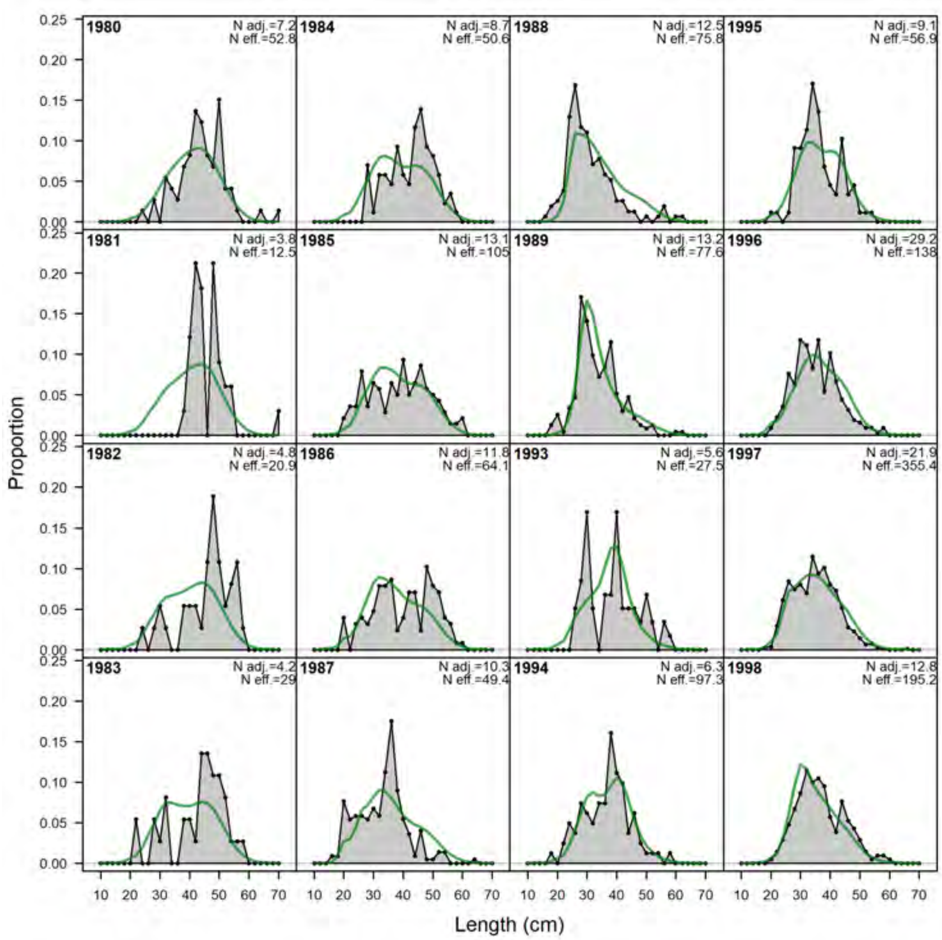

Figure A5: Length comps, whole catch, REC_PC (plot 1 of 3).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

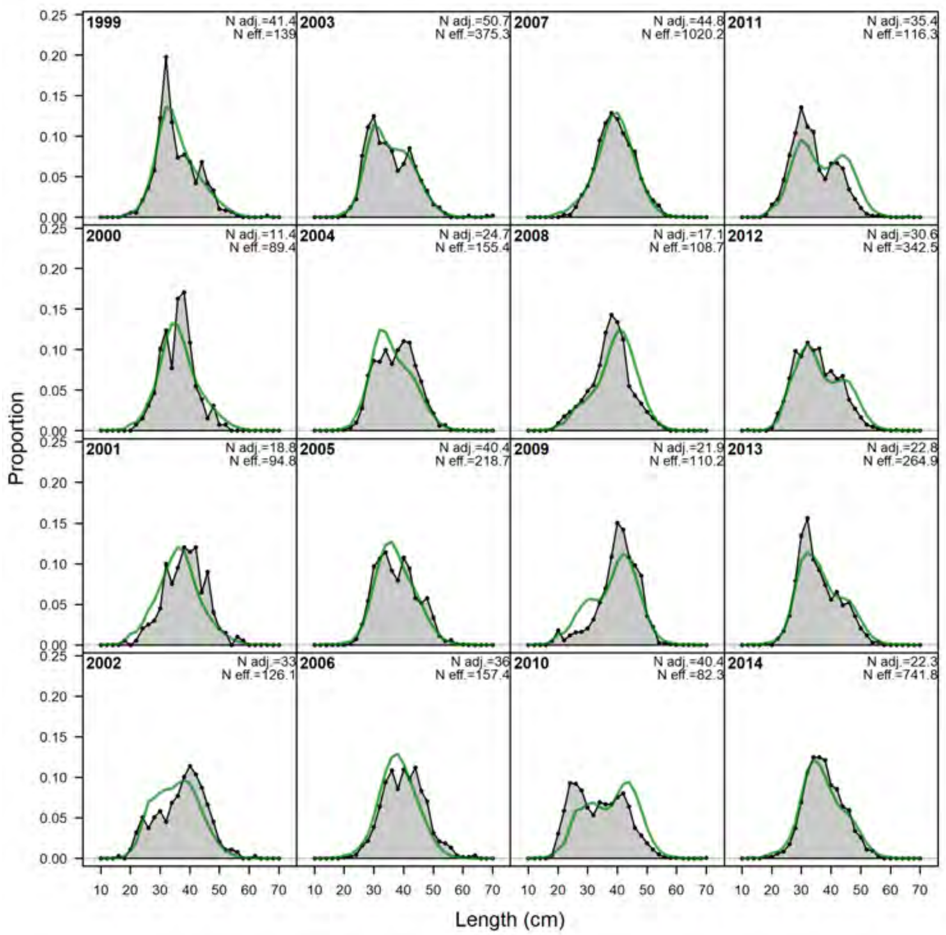

Figure A6: Length comps, whole catch, REC_PC (plot 2 of 3).

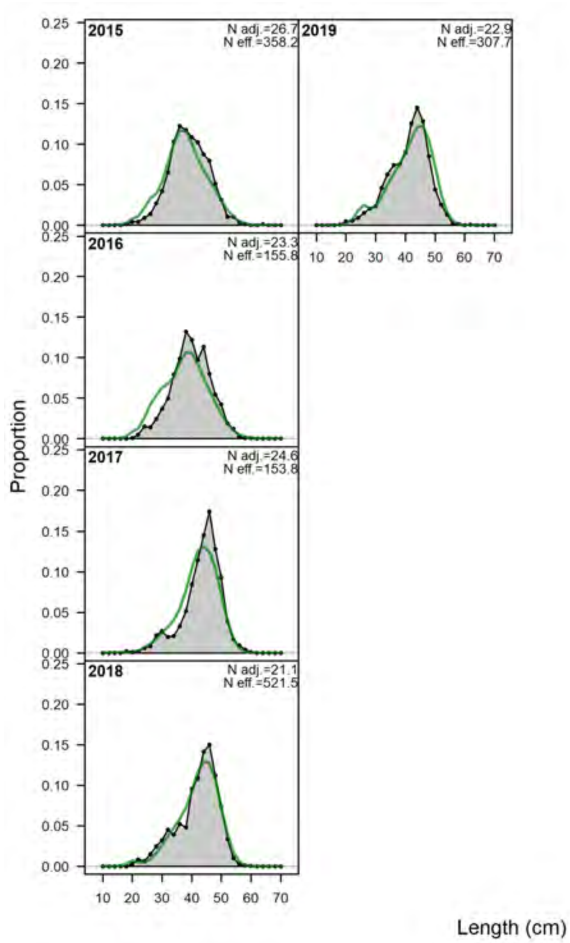

Figure A7: Length comps, whole catch, REC_PC (plot 3 of 3).

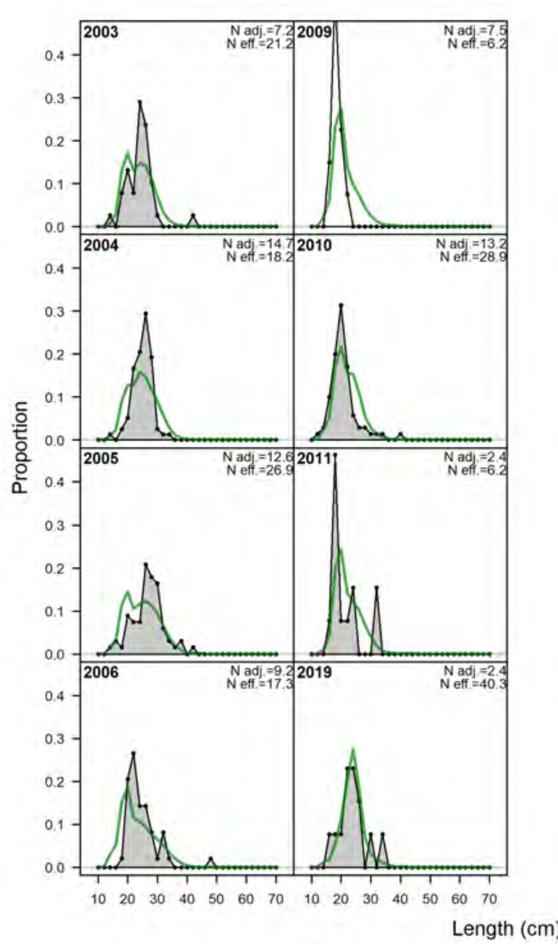

Figure A8: Length comps, whole catch, REC_PC_DIS.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

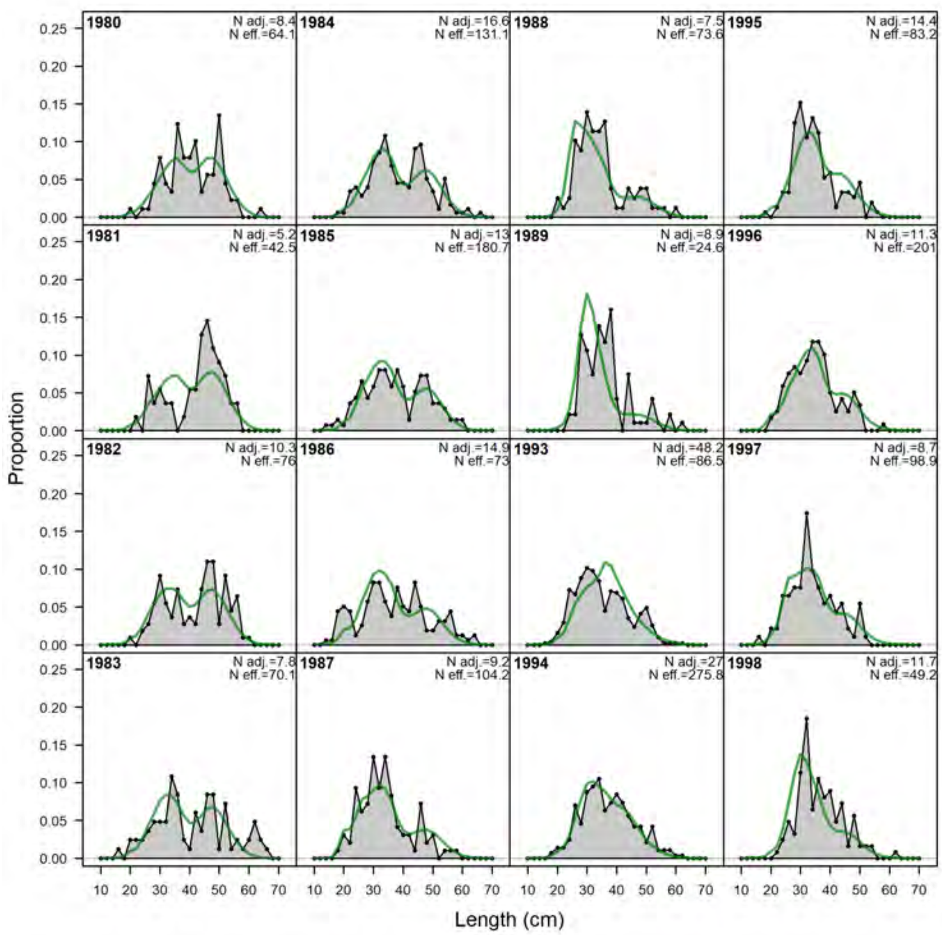

Figure A9: Length comps, whole catch, REC_PR (plot 1 of 3).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

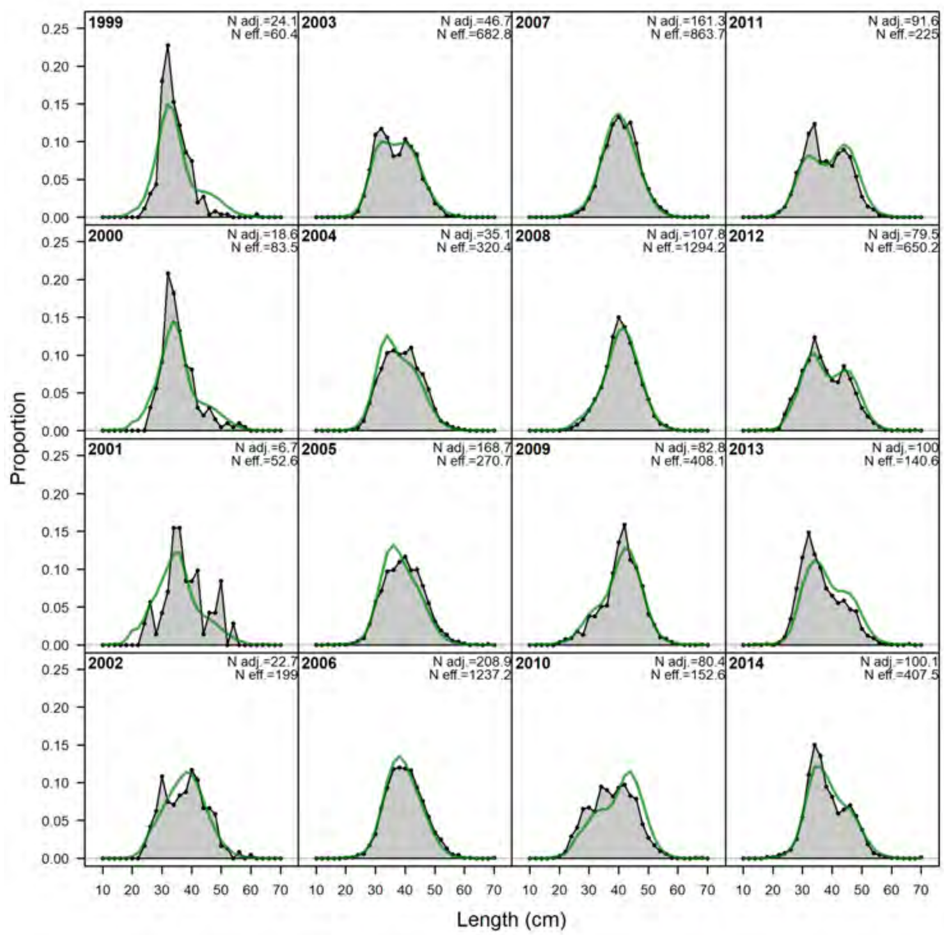

Figure A10: Length comps, whole catch, REC_PR (plot 2 of 3).

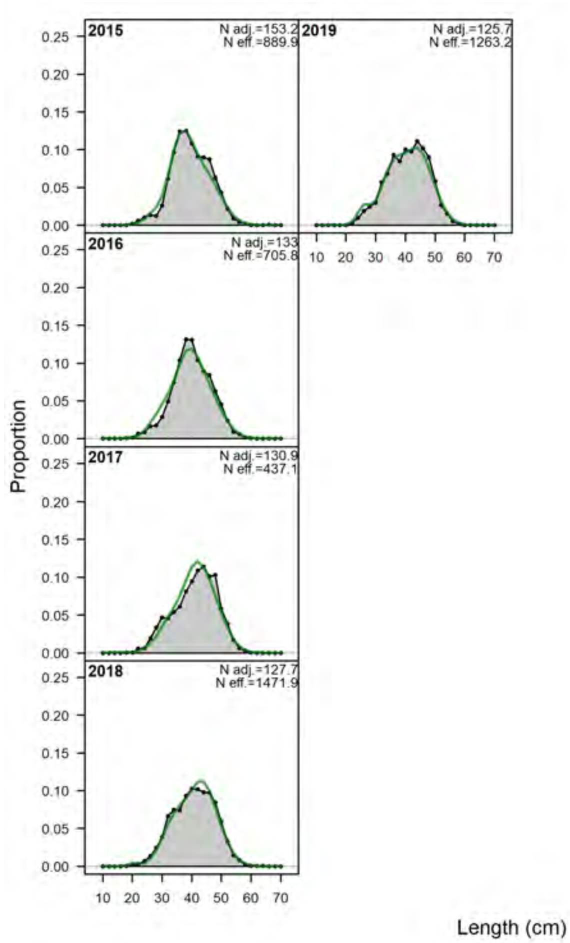

Figure A11: Length comps, whole catch, REC_PR (plot 3 of 3).

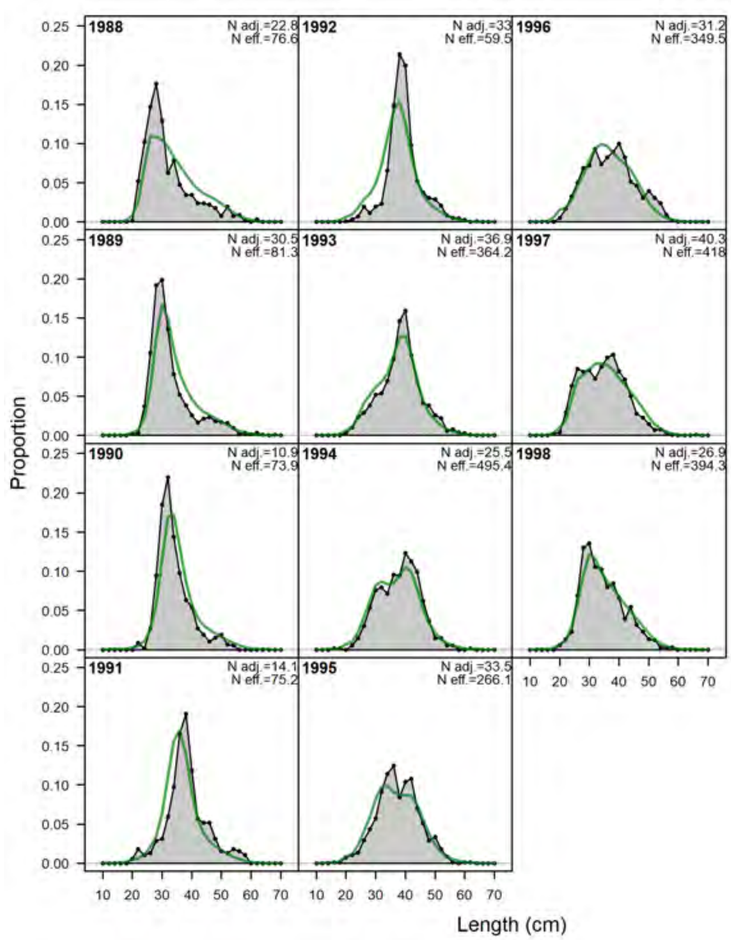

Figure A12: Length comps, whole catch, DWV_ONBOARD.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

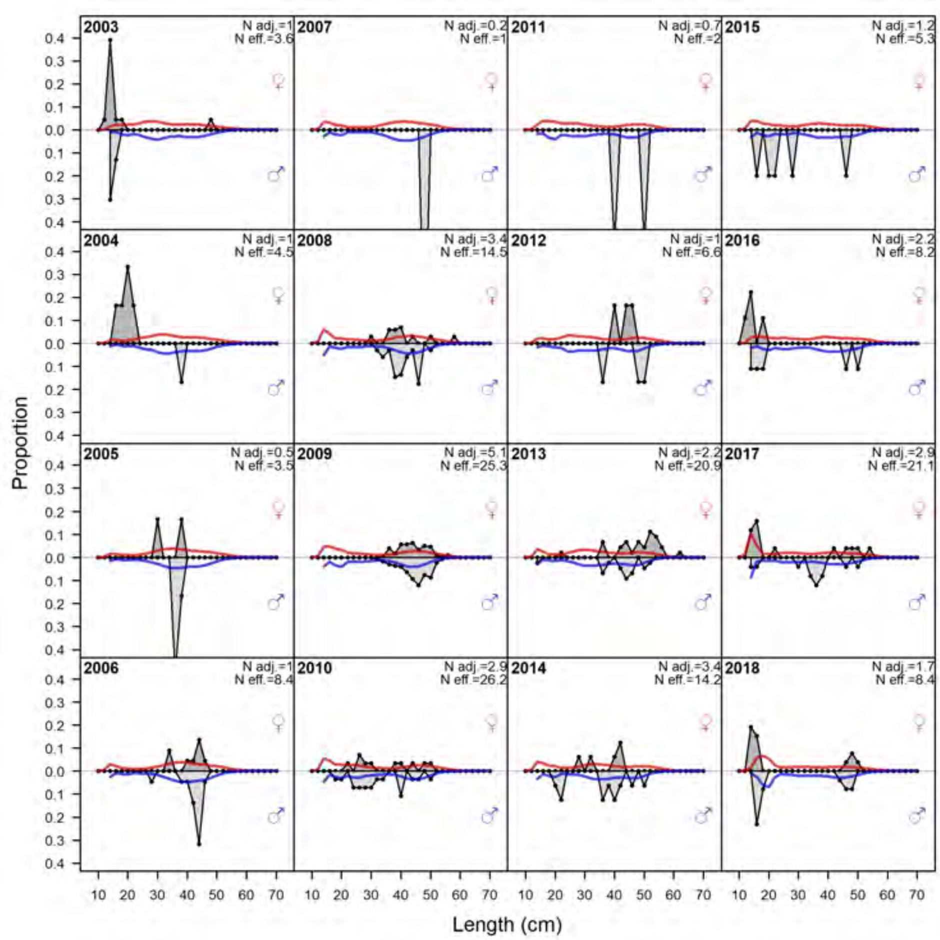

Figure A13: Length comps, whole catch, NWFSC_TWL (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

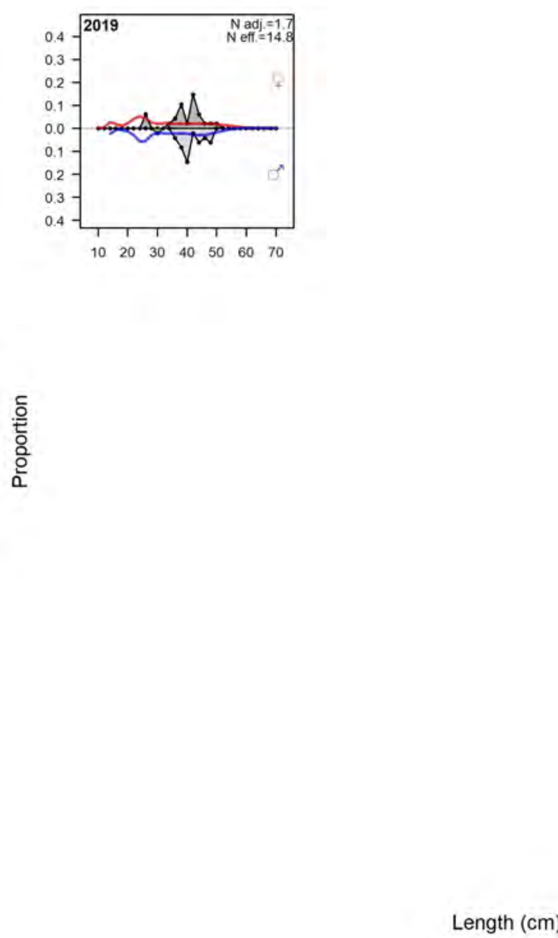

Figure A14: Length comps, whole catch, NWFSC_TWL (plot 2 of 2).

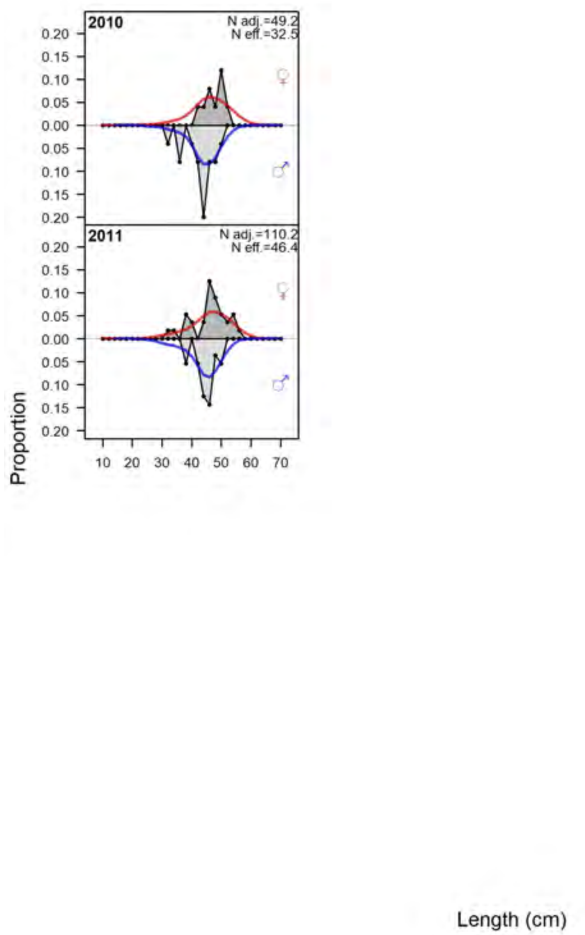

Figure A15: Length comps, whole catch, ABRAMS_RESEARCH.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

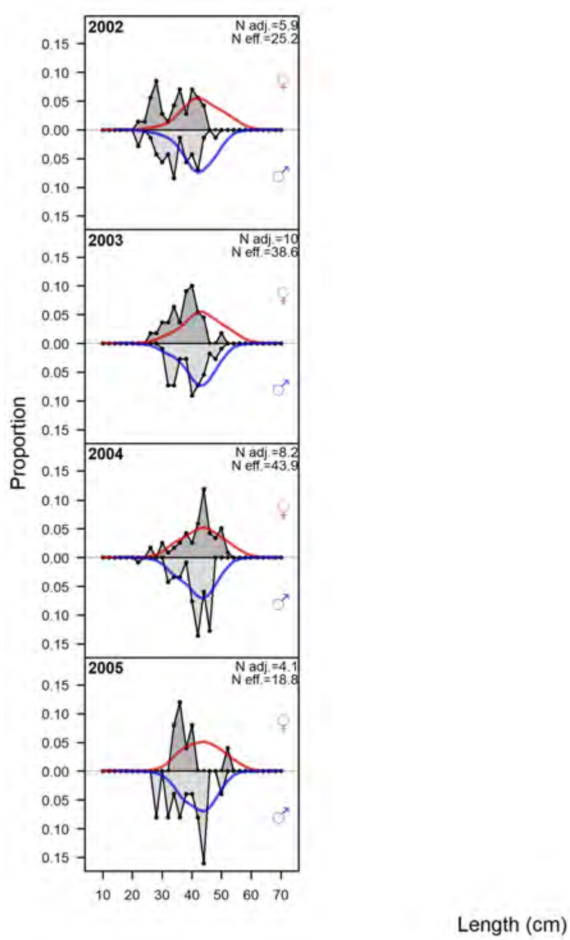

Figure A16: Length comps, whole catch, SWFSC_GF_ECOL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

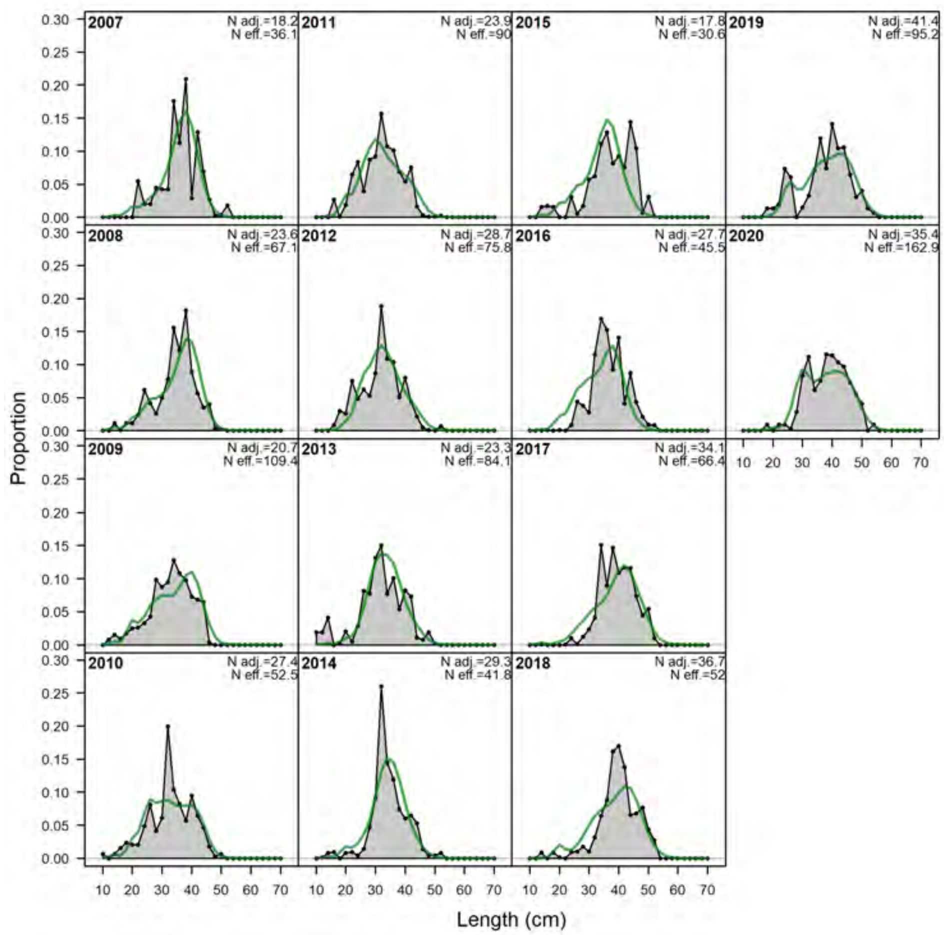

Figure A17: Length comps, whole catch, CCFRP.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

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 25 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 gopher, flag, copper, canary, and starry rockfishes, all of which are associated with rocky reef and kelp habitats. The five species with the lowest probability of co-occurrence were chinook salmon, widow and greenspotted rockfishes, chub mackerel and rosy rockfish.

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 0.35. 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 1182 trips that did not catch a vermilion rockfish (52% of the trips), and 188 trips (8% 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 1182 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 1083 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 62.35, 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 YEAR and SubRegion was fit for the binomial model and a main effects model including YEAR and SubRegion 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 northern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
C	442	585	76%
N	320	498	64%

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

Year	Positive Samples	Samples	Percent Positive
1980	31	57	54%
1981	14	32	44%
1982	24	41	59%
1983	19	33	58%
1984	34	59	58%
1985	54	98	55%
1986	50	87	57%
1987	27	36	75%
1988	38	48	79%
1989	29	42	69%
1995	31	41	76%
1996	104	129	81%
1997	127	162	78%
1998	98	119	82%
1999	82	99	83%

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

Model	Binomial ΔAIC	Lognormal ΔAIC
1	65.99	106.17
YEAR + SubRegion	0.00	0.89
YEAR + SubRegion + WAVE	1.77	3.03
YEAR + SubRegion + WAVE + AREA X	3.76	1.85
YEAR + WAVE	22.05	21.16
YEAR + AREA X	20.13	14.44
YEAR + WAVE + AREA X	22.67	16.13
YEAR + SubRegion + AREA X	2.00	0.00

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 northern model.

Year	Index	logSE	lower HPD	upper HPD
1980	0.05	0.21	0.03	0.08
1981	0.04	0.32	0.02	0.07
1982	0.05	0.23	0.03	0.07
1983	0.07	0.26	0.04	0.11
1984	0.09	0.20	0.06	0.13
1985	0.06	0.16	0.04	0.08
1986	0.07	0.16	0.05	0.10
1987	0.08	0.21	0.05	0.12
1988	0.11	0.17	0.08	0.15
1989	0.09	0.21	0.06	0.13
1995	0.08	0.20	0.05	0.12
1996	0.09	0.11	0.07	0.11
1997	0.23	0.11	0.19	0.29
1998	0.17	0.12	0.13	0.21
1999	0.09	0.12	0.07	0.11

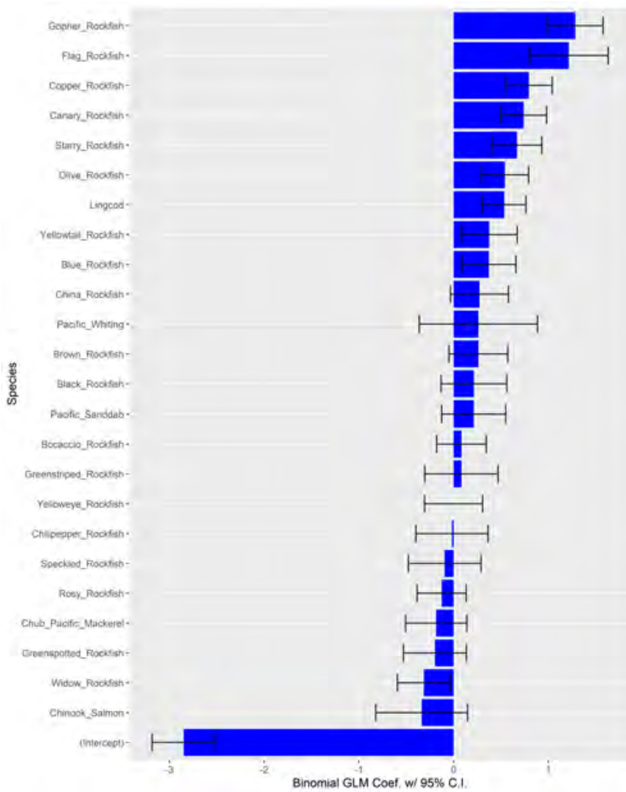

Figure B1: Species coefficients (blue bars) from the binomial GLM for presence/absence of vermilion rockfish in the CRFS private boat data. Horizontal black bars are 95% confidence intervals.

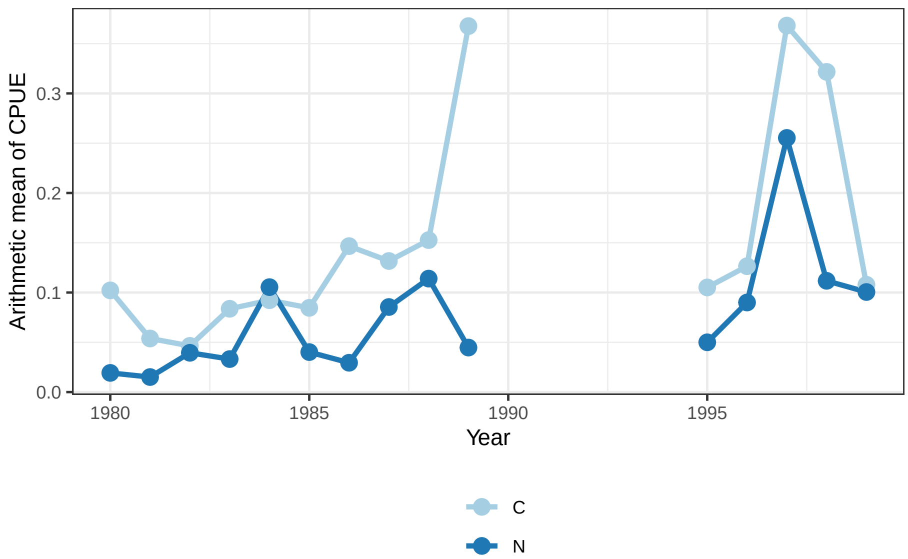

Figure B2: Arithmetic mean of CPUE by region for vermilion from the filtered data.

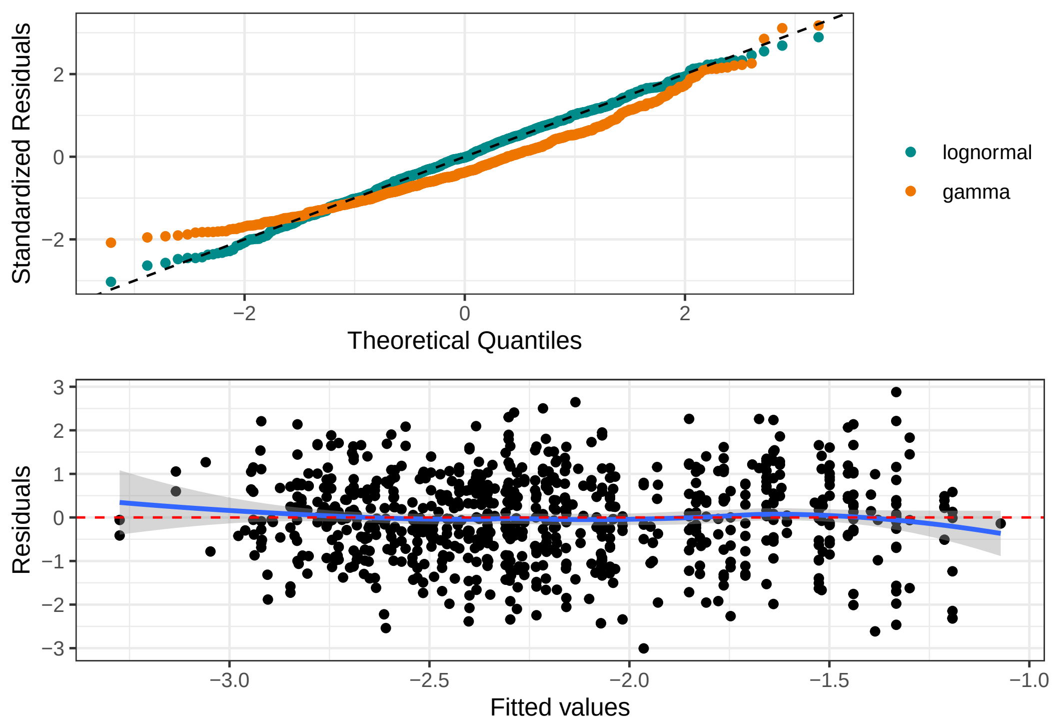

Figure B3: Q-Q plot (top) of the positive observations fit to lognormal and gamma distributions, and fitted values vs residuals for the Lognormal model (bottom).

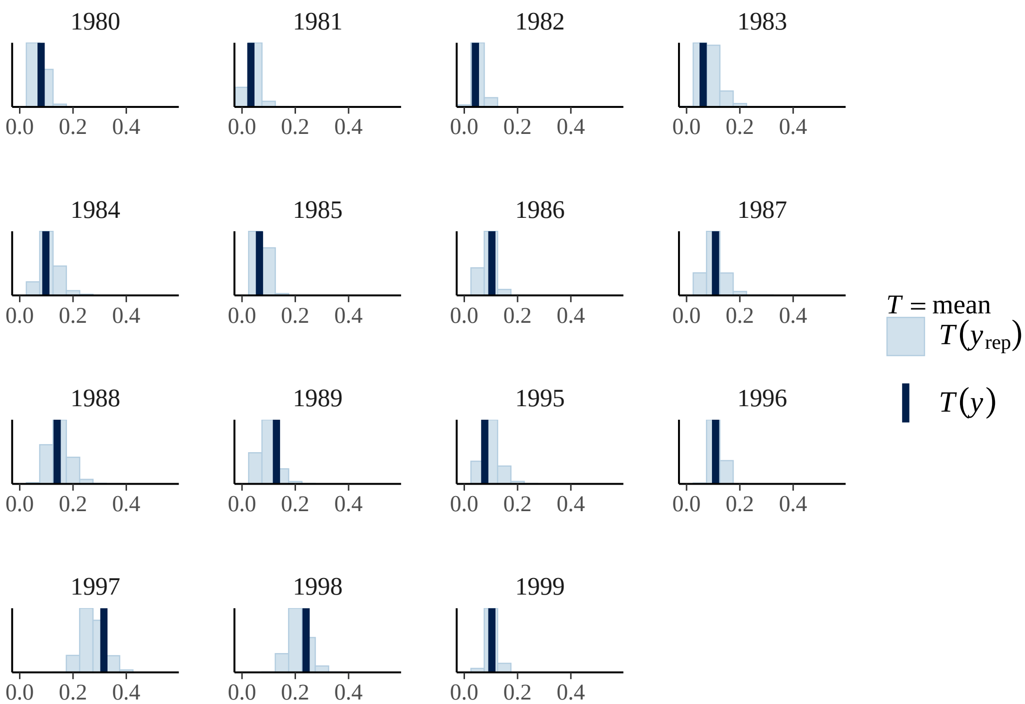

Figure B4: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

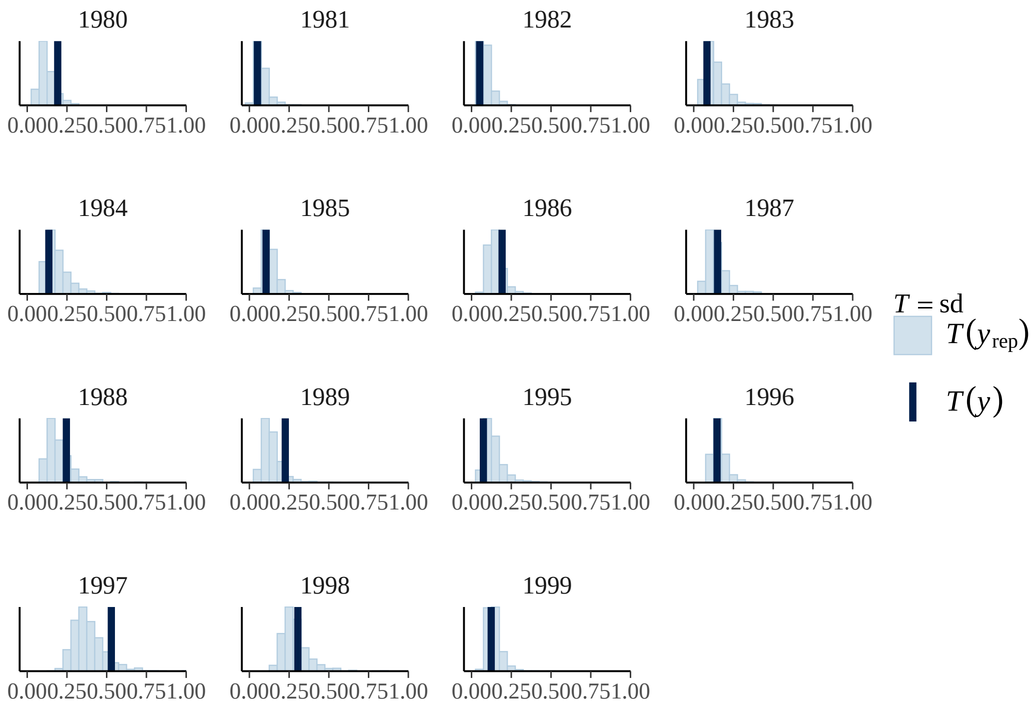

Figure B5: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

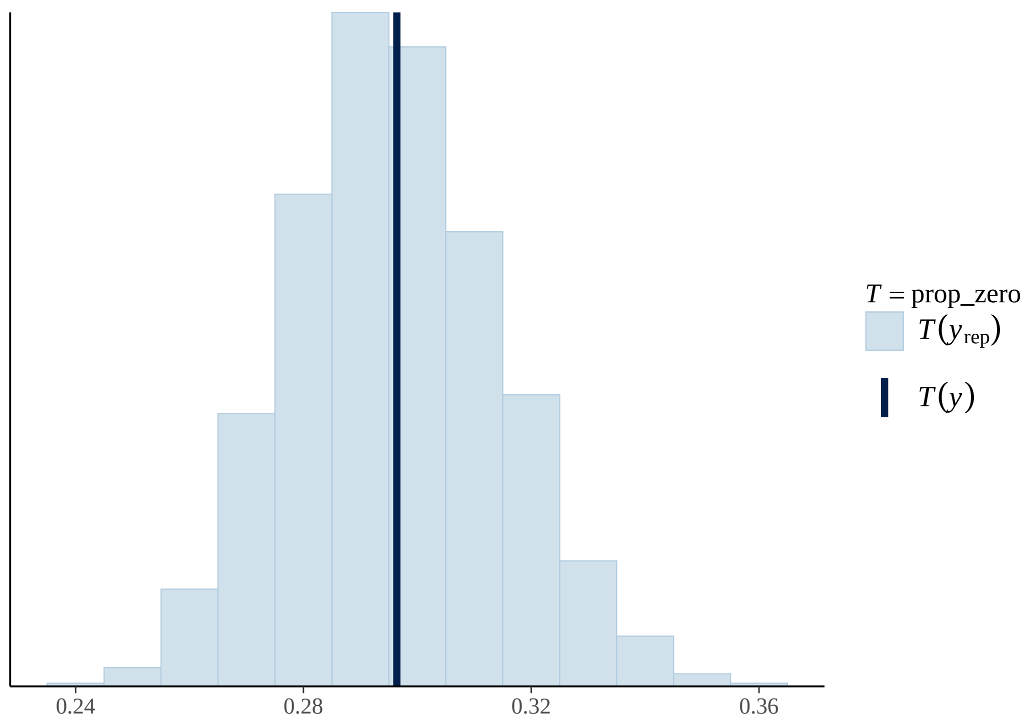

Figure B6: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

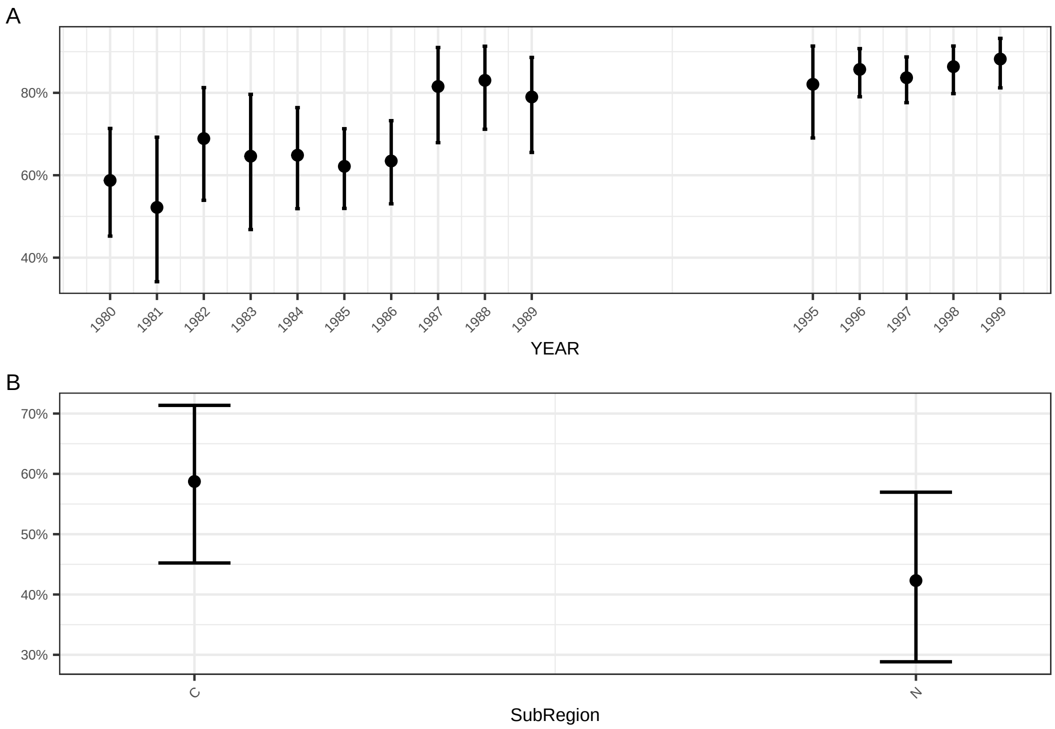

Figure B7: Binomial model marginal effects.

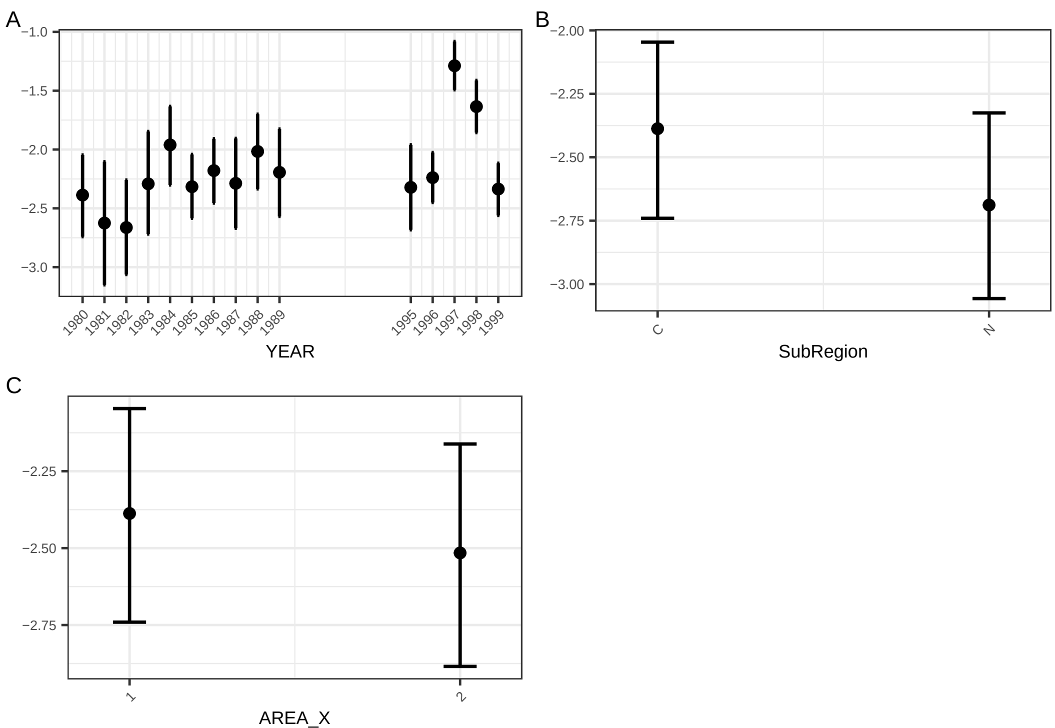

Figure B8: Positive model marginal effects.

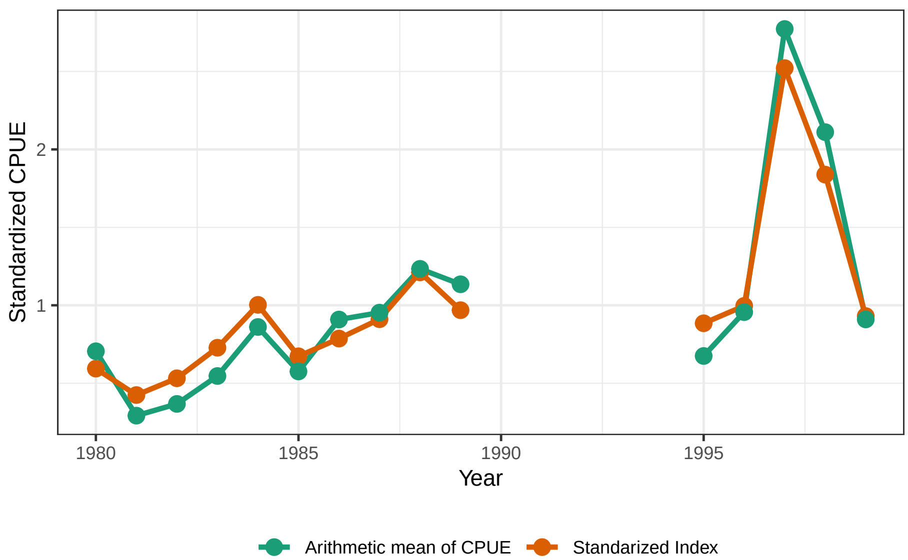

Figure B9: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

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 4481 drifts for index standardization, with 1706 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 122.41, 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 62% 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 northern 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	6901	1755	25%
Fishery closed	Removed samples when target fish fishery closed	5922	1736	29%
Ocean only	Removed samples from major bays	5780	1736	30%
Catch	Removed samples with zero catch of any species	5335	1736	33%
Depth	Removed samples in less than max depth of species	5287	1736	33%
Time fished	Removed upper two percent of time fished	5180	1722	33%
Percent groundfish in samples	Removed samples with fewer groundfish than when the target observed	4481	1706	38%

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

Year	Positive Samples	Samples	Percent Positive
(0,10]	40	346	12%
(10,15]	139	559	25%
(15,20]	279	808	35%
(20,25]	226	588	38%
(25,30]	219	601	36%
(30,35]	159	373	43%
(35,40]	216	450	48%
(40,65]	428	756	57%

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

Subregion	Positive Samples	Samples	Percent Positive
CA/OR border to Santa Cruz (V1)	238	1213	20%
Moss Landing to Big Sur (V2)	146	511	29%
San Luis Obsipso to Morro Bay (V3)	591	1044	57%
South Morro Bay to Point Conception (V4)	643	1180	54%
Offshore (V5)	88	533	17%

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

Year	Positive Samples	Samples	Percent Positive
1999	13	60	22%
2000	6	38	16%
2001	11	71	15%
2002	17	60	28%
2003	117	276	42%
2004	192	400	48%
2005	67	153	44%
2006	121	265	46%
2007	126	268	47%
2008	47	155	30%
2009	54	198	27%
2010	79	193	41%
2011	62	182	34%
2012	66	220	30%
2013	29	160	18%
2014	47	221	21%
2015	75	219	34%
2016	79	321	25%
2017	226	426	53%
2018	146	295	49%
2019	126	300	42%

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

Model	Binomial ΔAIC	Lognormal ΔAIC
1	797.52	436.25
YEAR + SubRegion	129.05	60.03
YEAR + SubRegion + WAVE	120.54	58.72
YEAR + SubRegion + WAVE + DEPTH bin	0.00	0.00
YEAR + WAVE + DEPTH bin	285.69	66.16
YEAR + DEPTH bin	316.83	74.00
YEAR + SubRegion + DEPTH bin	10.87	6.06

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 northern model.

Year	Index	logSE	lower HPD	upper HPD
1999	0.02	0.53	0.01	0.05
2000	0.02	0.65	0.00	0.04
2001	0.01	0.53	0.00	0.02
2002	0.02	0.42	0.01	0.05
2003	0.05	0.33	0.02	0.09
2004	0.07	0.28	0.04	0.11
2005	0.04	0.38	0.02	0.08
2006	0.05	0.36	0.02	0.09
2007	0.06	0.35	0.03	0.11
2008	0.03	0.38	0.01	0.05
2009	0.04	0.37	0.02	0.07
2010	0.05	0.37	0.02	0.09
2011	0.04	0.37	0.02	0.08
2012	0.03	0.38	0.01	0.06
2013	0.02	0.42	0.01	0.04
2014	0.02	0.38	0.01	0.04
2015	0.04	0.37	0.02	0.07
2016	0.03	0.37	0.01	0.06
2017	0.04	0.36	0.02	0.08
2018	0.05	0.37	0.02	0.09
2019	0.04	0.37	0.02	0.08

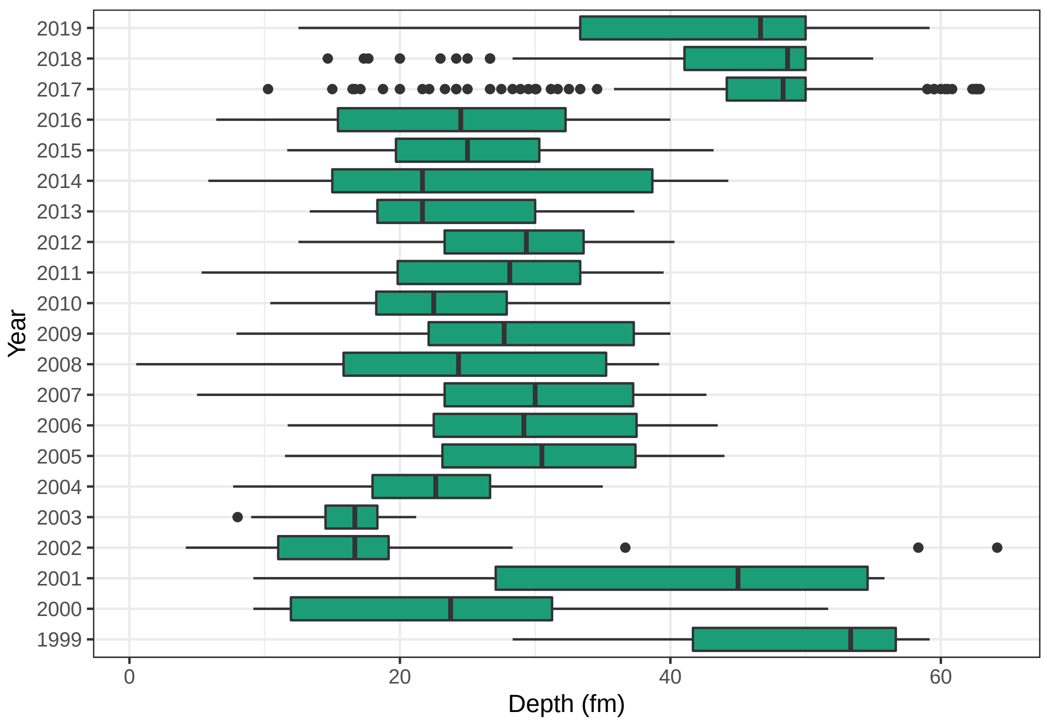

Figure C1: Boxplots of depths fished by year in the filtered data.

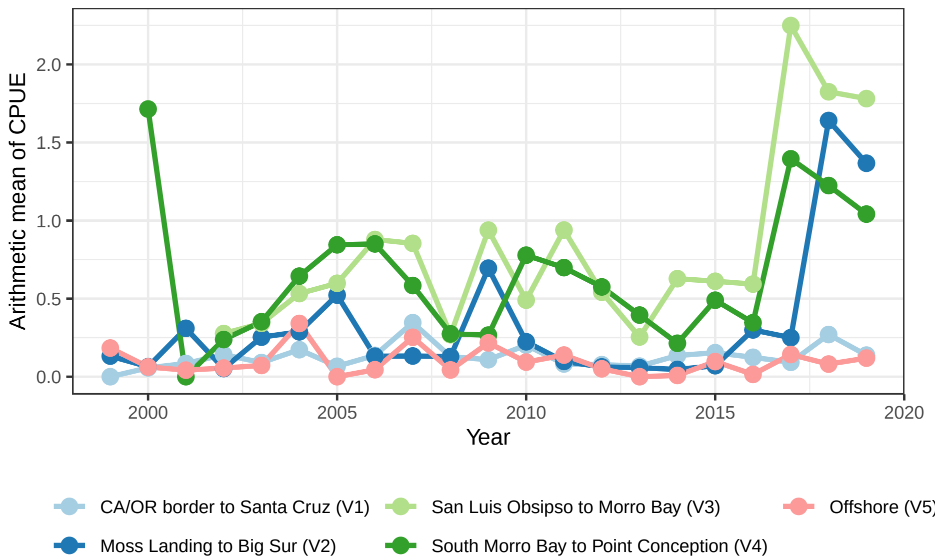

Figure C2: Arithmetic mean of CPUE by region for vermilion from the filtered data. The areas used are in the text.

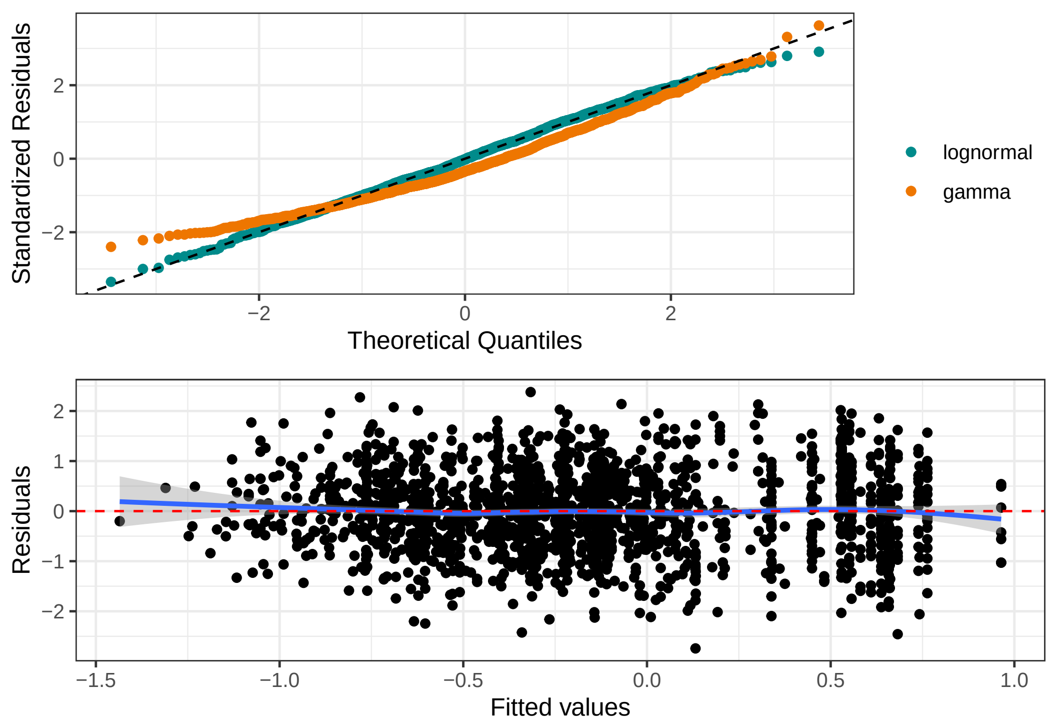

Figure C3: Q-Q plot (top) of the positive observations lognormal gamma distributions and fitted values vs residuals for the Lognormal model (bottom).

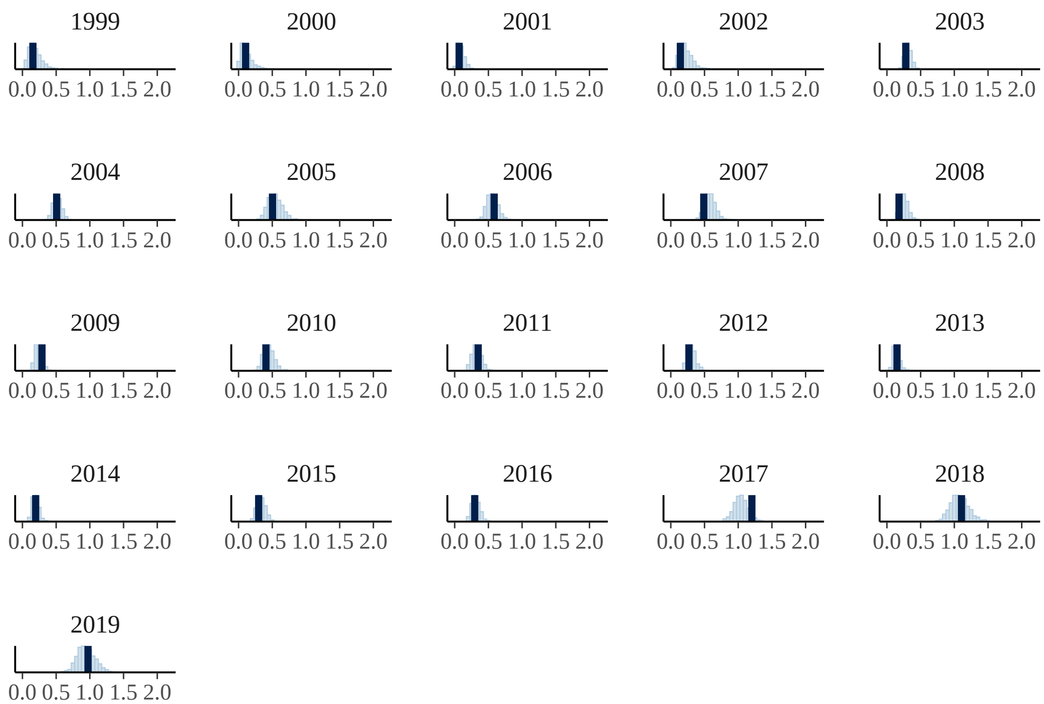

Figure C4: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

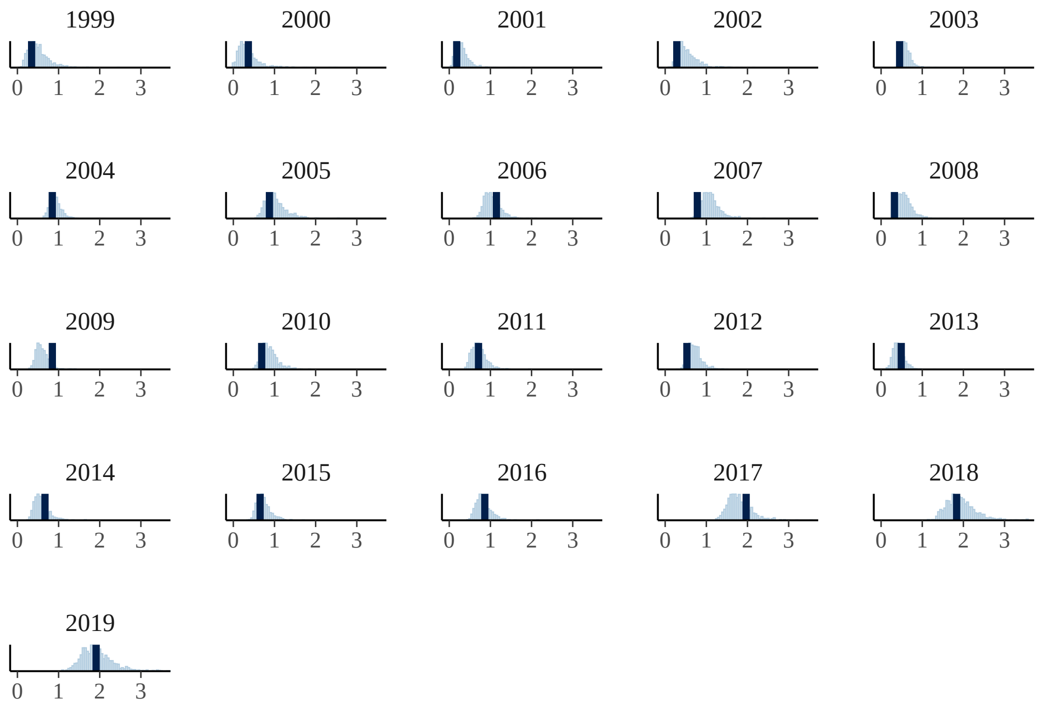

Figure C5: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

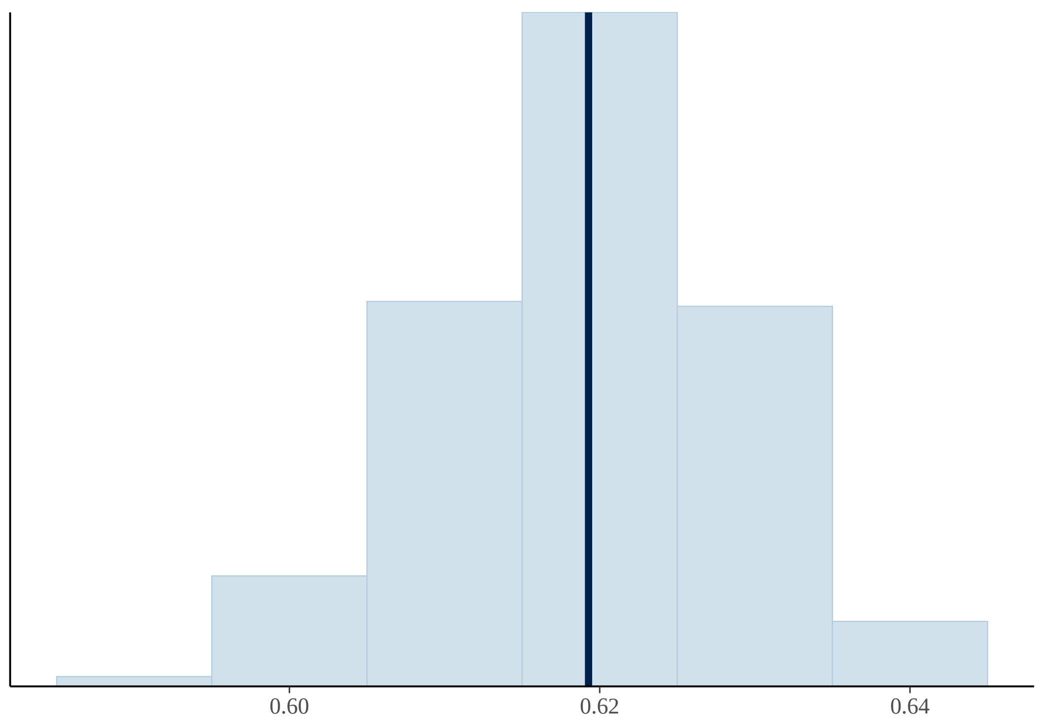

Figure C6: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

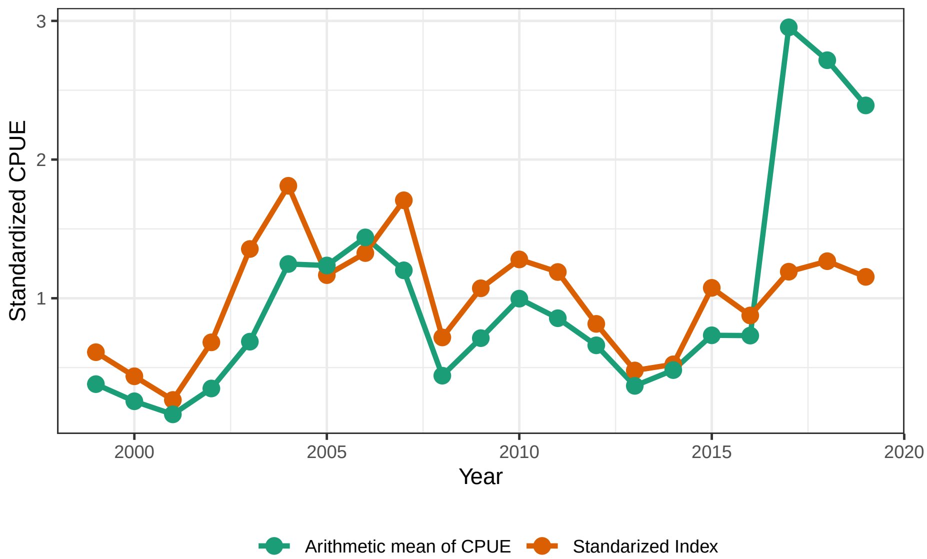

Figure C7: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective mean.

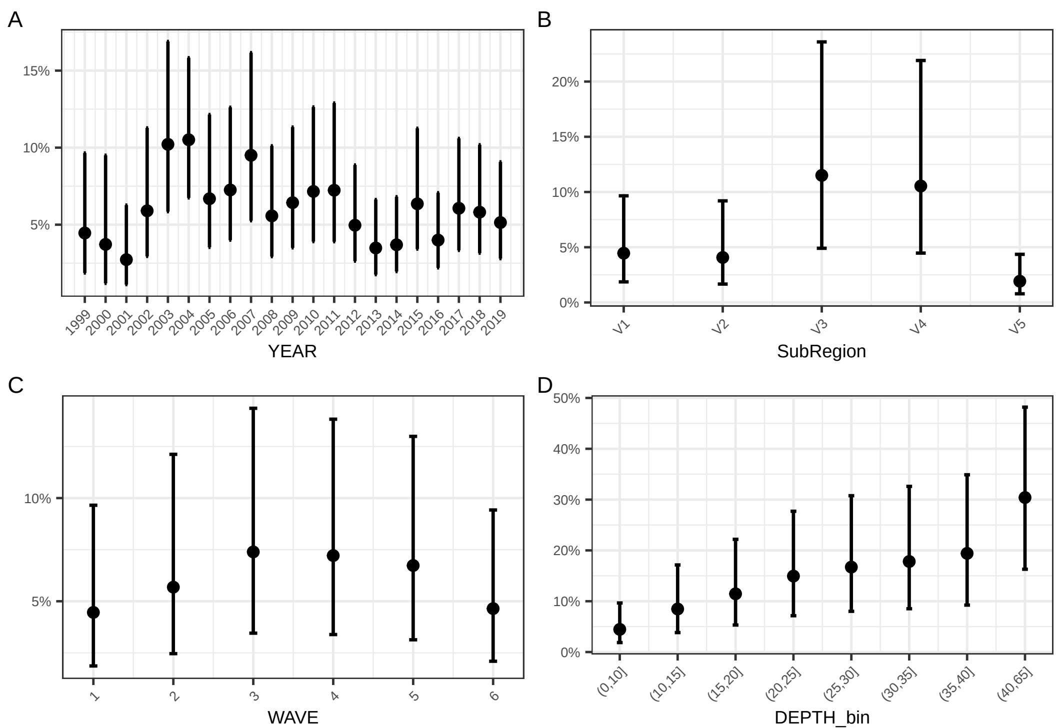

Figure C8: Marginal effects from the binomial model of the delta-GLM.

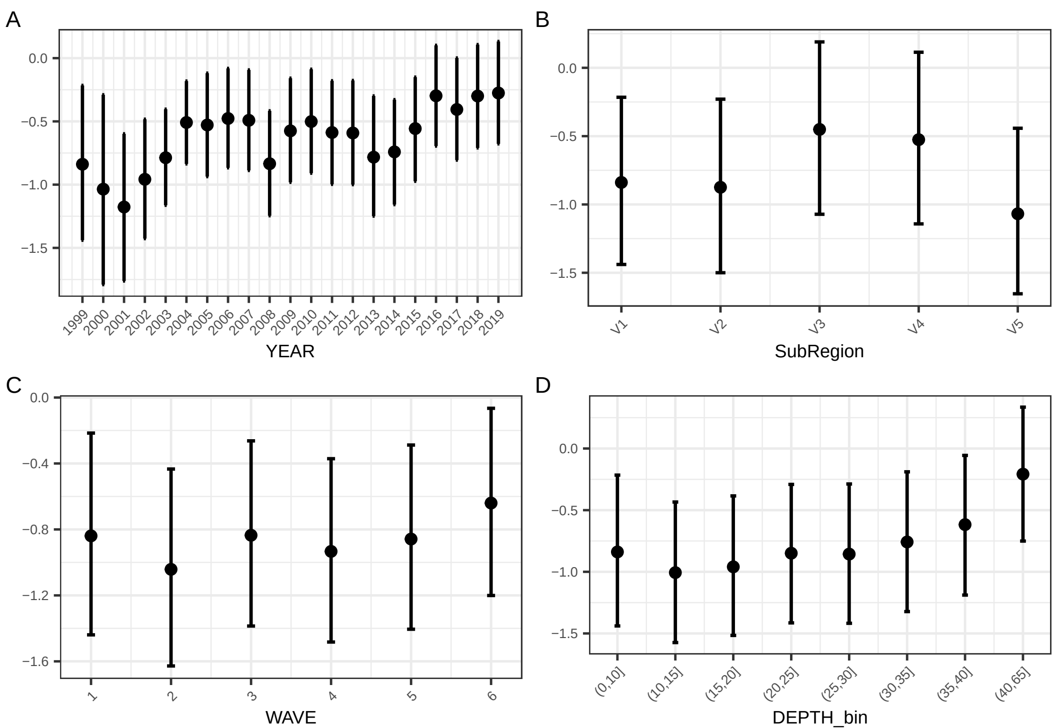

Figure C9: Marginal effects from the positive model of the delta-GLM.

Appendix D. Deb Wilson-Vandenberg Onboard CPFV Index of Abundance

Deb Wilson-Vandenberg Index

The Deb Wilson-Vandenberg data set is an onboard observer survey data conducted by CDFW survey in central California from 1987-1998 and referred to as the Deb Wilson-Vandenberg onboard observer survey, (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 the target species.

Deb Wilson-Vandenberg Index: Data Preparation, Filtering, and Sample Sizes

A large effort was made by the SWFSC to recover data from the original data sheets for this survey and developed into a relational database (Monk et al. 2016). The specific fishing locations at each fishing stop were recorded at a finer scale than the catch data for this survey. We aggregated the relevant location information (time and number of observed anglers) to match the available catch information. Between April 1987 and July 1992 the number of observed anglers was not recorded for each fishing stop, but the number of anglers aboard the vessel is available. We imputed the number of observed anglers using the number of anglers aboard the vessel and the number of observed anglers at each fishing stop from the August 1992-December 1998 data (see Supplemental materials for details). In 1987, trips were only observed in Monterey, CA and were therefore excluded from the analysis (Table D1). Sampling targeted areas of central California. Of the 2,256 trips observed, only 12 of those launched from port in District 6, which was removed from the analysis.

Each fishing location was assigned to a reef based on the on the bathymetric maps and interpretation of hard bottom was extracted from the California Seafloor Mapping Project. Reefs were aggregated to four regions produce adequate sample sizes; Ft. Bragg to Santa Cruz (V1), Moss Landing to Big Sur (V2), San Luis Obispo to Pt. Conception (V3), and Offshore (deeper) locations including the Farallon Islands and reefs of Half Moon Bay and Monterey Bay (V4). The ports in San Luis Obispo county were sampled more frequently than other regions and the arithmetic mean of CPUE by year was higher also higher in this area (Figure D1)

We retained 6597 drifts for index standardization, with 2016 fishing location encountering vermilion rockfish.

Tables of the number of samples and positive observervervations by factors depth, region and year, can be found in Tables D2, D3, and D4.

Deb Wilson-Vandenberg Index: Model Selection, Fits, and Diagnostics

A Lognormal model was over a Gamma model selected for the positive observations by a ΔAIC of 313.12 and supported by Q-Q plots of the positive observations fit to both distributions (Figure D2). 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 D5), 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 D3 and D4). The binomial model generated data sets with the proportion zeros similar to the 69% 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 D6) represents a similar trend to the arithmetic mean of the annual CPUE (Figure D8).

Table D1: Data filtering steps for theDebWV onboard survey index for vermilion rockfish in the northern 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	None	7566	2593	34%
No catch	Remove no catch trips	7041	2068	29%
Sparse data	Remove District 6 and 1987	6697	2022	30%
Time fished	Remove drifts fished less than 6 minutes	6597	2016	31%

Table D2: Positive samples of vermilion rockfish in the northern model by depth (fm).

Year	Positive Samples	Samples	Percent Positive
(0,10]	113	478	24%
(10,20]	455	1344	34%
(20,30]	410	1198	34%
(30,40]	465	1331	35%
(40,50]	347	1067	33%
(50,60]	172	617	28%
(60,70]	36	263	14%
(70,118]	18	299	6%

Table D3: Samples of vermilion rockfish in the northern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
V1	362	1317	27%
V2	322	1448	22%
V3	924	1668	55%
V4	408	2164	19%

Table D4: Samples of vermilion rockfish in the northern model by year.

Year	Positive Samples	Samples	Percent Positive
1988	136	422	32%
1989	170	446	38%
1990	65	122	53%
1991	73	135	54%
1992	168	467	36%
1993	196	485	40%
1994	189	555	34%
1995	247	791	31%
1996	238	963	25%
1997	323	1312	25%
1998	211	899	23%

Table D5: Model selection for the DebWV onboard survey index for vermilion rockfish in the northern model.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	1011.38	422.42
YEAR + MegaReef	169.08	52.50
YEAR + MegaReef + WAVE	120.32	42.13
YEAR + MegaReef + WAVE + DEPTH bin	0.00	0.00
YEAR + WAVE + DEPTH bin	611.73	260.44
YEAR + DEPTH bin	642.50	272.83
YEAR + MegaReef + DEPTH bin	55.30	7.28

Table D6: Standardized index for the DebWV onboard survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the northern model.

Year	Index	logSE	lower HPD	upper HPD
1988	0.02	0.22	0.01	0.03
1989	0.03	0.20	0.02	0.04
1990	0.06	0.23	0.04	0.10
1991	0.03	0.25	0.02	0.05
1992	0.02	0.20	0.01	0.03
1993	0.03	0.20	0.02	0.04
1994	0.02	0.20	0.01	0.03
1995	0.02	0.20	0.01	0.03
1996	0.02	0.20	0.01	0.02
1997	0.02	0.20	0.01	0.03
1998	0.02	0.20	0.01	0.03

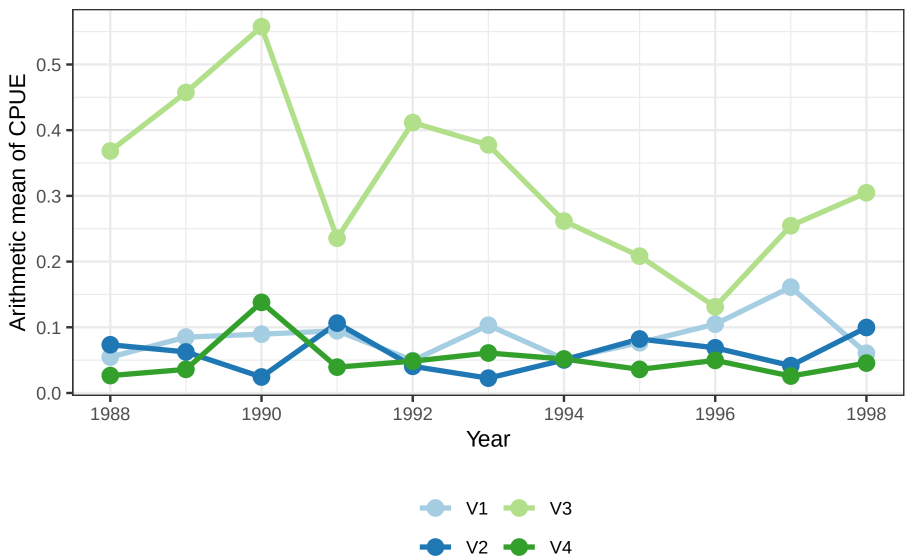

Figure D1: Arithmetic mean of CPUE by region for vermilion from the filtered data.

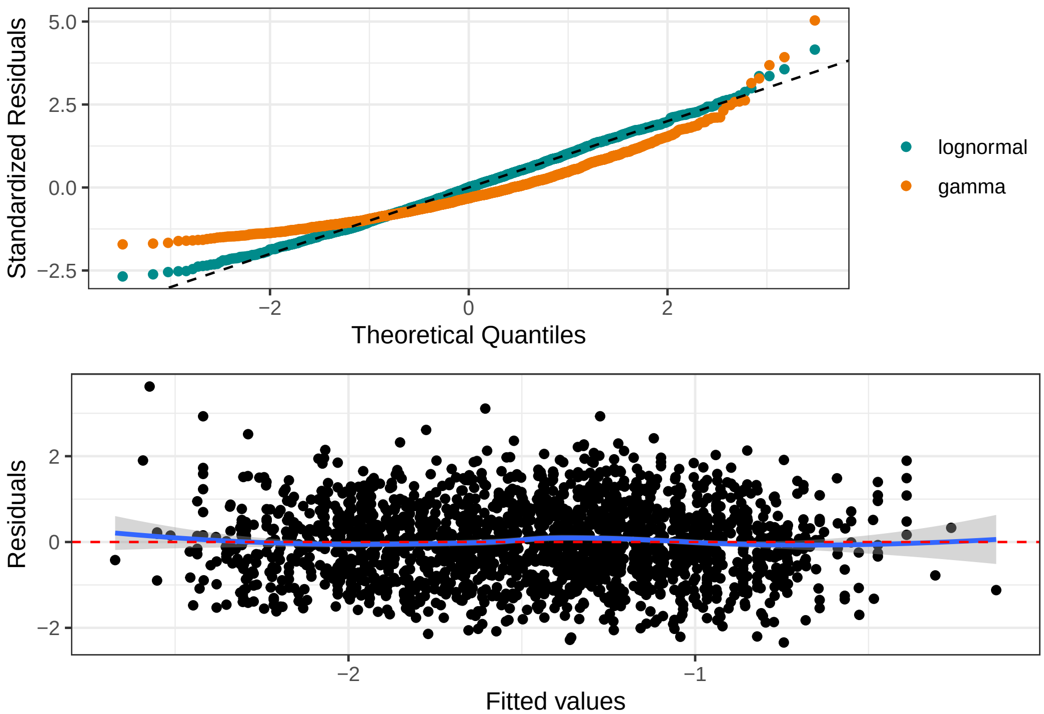

Figure D2: Q-Q plot (top) of the positive observations lognormal gamma distributions and fitted values vs residuals for the Lognormal model (bottom).

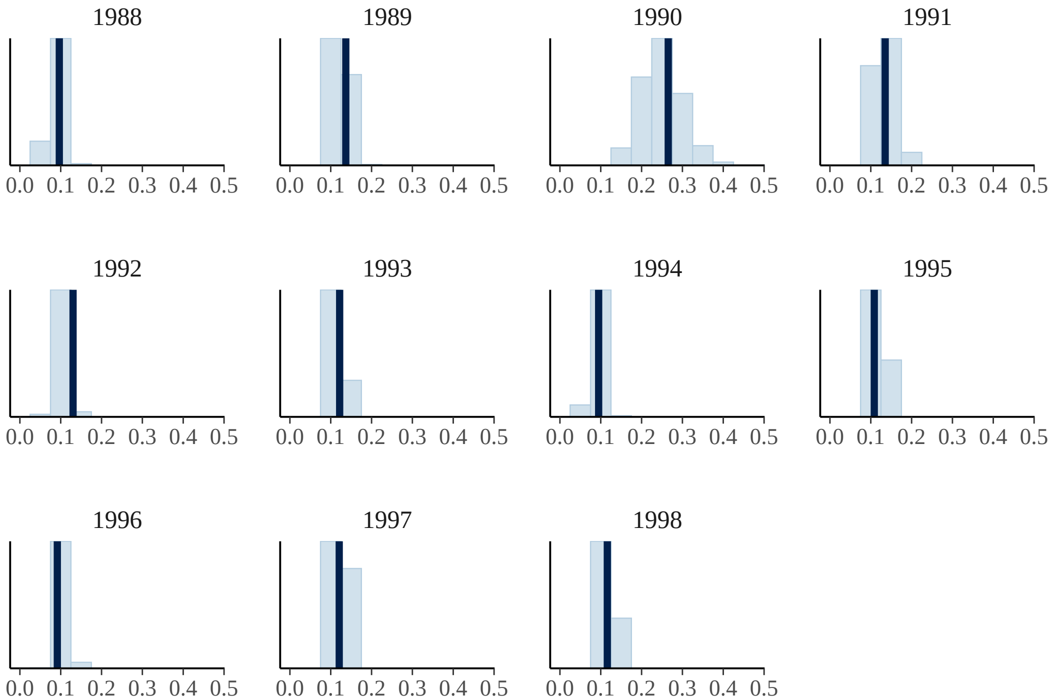

Figure D3: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

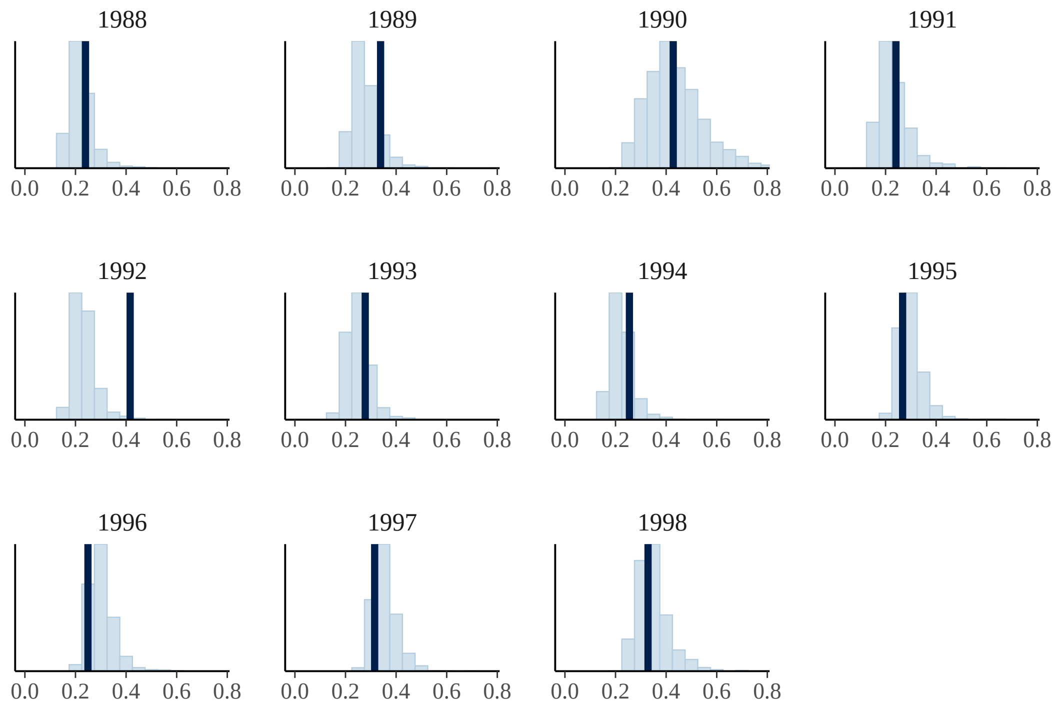

Figure D4: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

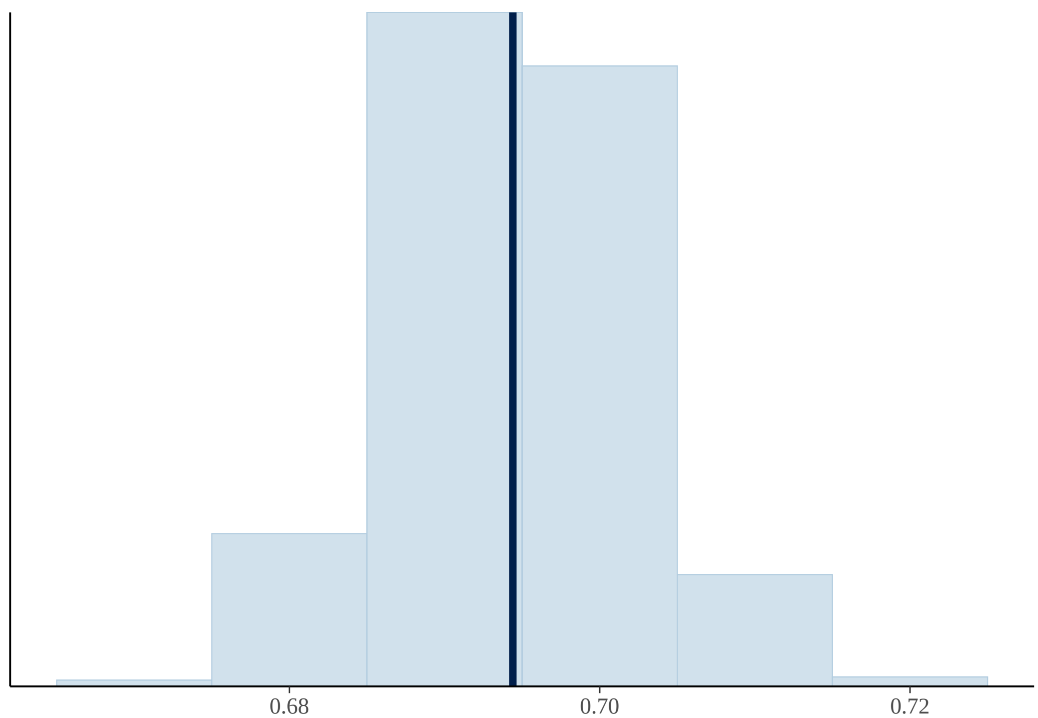

Figure D5: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

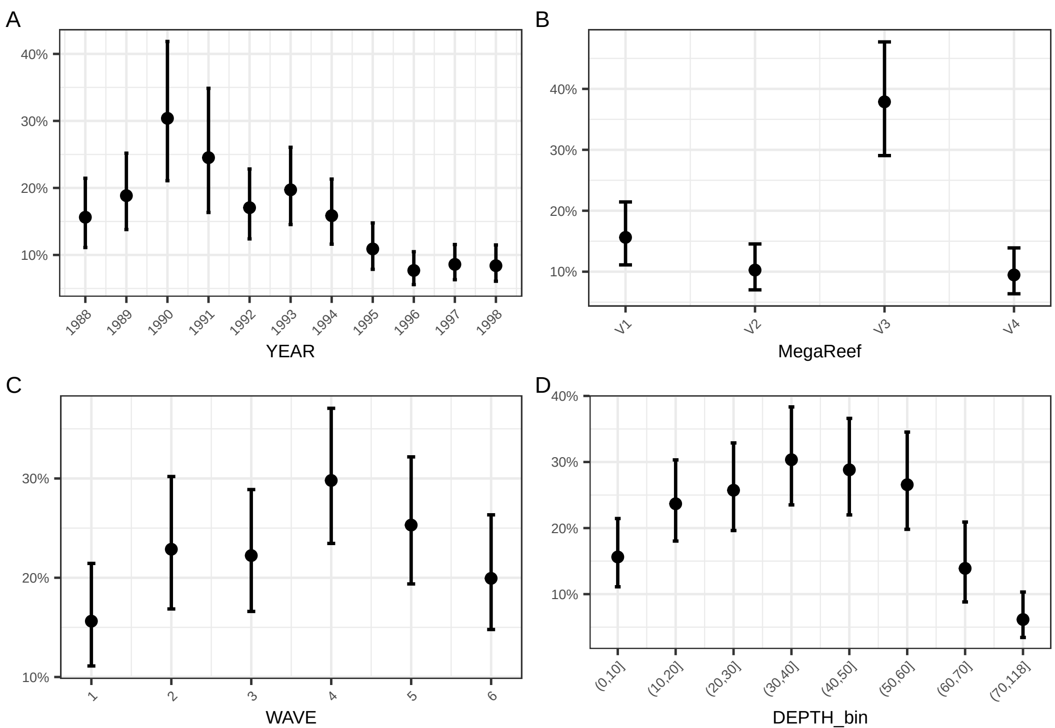

Figure D6: Binomial marginal effects from the final model

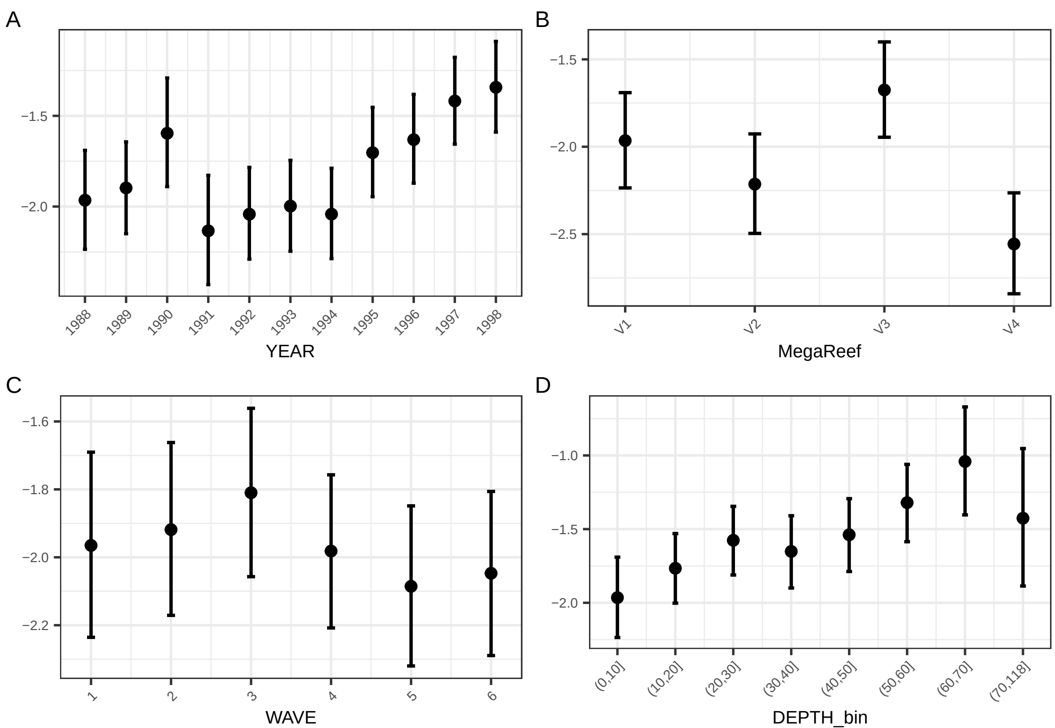

Figure D7: Positive model marginal effects from the final model.

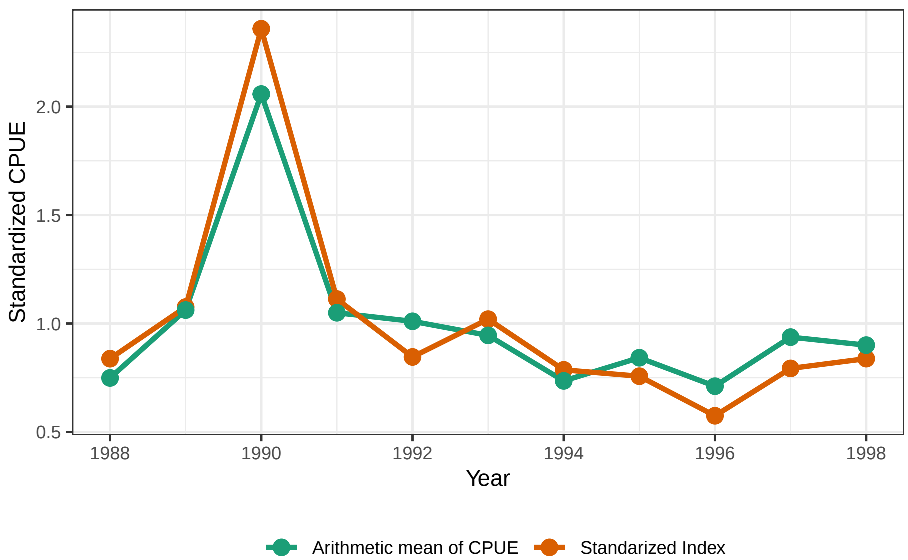

Figure D8: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

Appendix E. 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 E1). 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 57647 drifts for index standardization, with 21464 drifts encountering vermilion (Table E1).

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 E2 and E3. 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 E2).

A Lognormal model was selected for the positive observation GLM by a ΔAIC of 3457.72 over a Gamma model and supported by Q-Q plots of the positive observations fit to both distributions (Figure E1). 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 E4), a main effects model including YEAR and DISTRICT and WAVE and AREA X was fit for the binomial model and a main effects model including YEAR and DISTRICT 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 E3 and E4). The binomial model generated data sets with the proportion zeros similar to the 63% zeroes in the observed data (Figure E5). The predicted marginal effects from both the binomial and Lognormal models can be found in (Figures E6 and E7). The final index (Table E5) represents a similar trend to the arithmetic mean of the annual CPUE (Figure E8).

Table E1: Data filtering steps for theCRFS PR dockside survey index for vermilion rockfish in the northern 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	78855	24932	32%
Year 2020	Remove 2020 due to decreased sampling.	77109	24404	32%
Months samples	Remove waves less than 2 due to small sample sizes and fishery closures.	76979	24344	32%
Groundfish	Removed trips with no observed groundfish	66621	24344	37%
HMS	Remove trips with more than half the catch composed of HMS species	66609	24341	37%
Final trips	Retained trips with at least 0.95 groundfish.	57647	21464	37%

Table E2: Samples of vermilion rockfish in the northern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
3	12234	24086	51%
4	4504	11933	38%
5	1706	4527	38%
6	3020	17101	18%

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

Year	Positive Samples	Samples	Percent Positive
2004	1076	2487	43%
2005	1433	3568	40%
2006	1934	4508	43%
2007	1342	3328	40%
2008	1023	3414	30%
2009	1004	3722	27%
2010	883	2442	36%
2011	1037	2831	37%
2012	920	2785	33%
2013	1134	3380	34%
2014	1271	4065	31%
2015	1802	4924	37%
2016	1658	4357	38%
2017	1567	4122	38%
2018	1638	3954	41%
2019	1742	3760	46%

Table E4: Model selection for the CRFS PR dockside survey index for vermilion rockfish in the northern model.

Model	Binomial ΔAIC	Lognormal ΔAIC
1	6137.96	1832.84
YEAR + DISTRICT	469.50	83.21
YEAR + DISTRICT + WAVE	425.71	34.01
YEAR + DISTRICT + WAVE + AREA X	0.00	0.00
YEAR + WAVE	5198.73	1446.58
YEAR + AREA X	5353.08	1527.86
YEAR + WAVE + AREA X	5024.99	1440.38
YEAR + DISTRICT + AREA X	42.53	47.71

Table E5: 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 northern model.

Year	Index	logSE	lower HPD	upper HPD
2004	0.80	0.05	0.72	0.87
2005	0.80	0.05	0.73	0.88
2006	0.86	0.04	0.78	0.93
2007	0.81	0.05	0.73	0.88
2008	0.58	0.05	0.52	0.65
2009	0.51	0.05	0.46	0.56
2010	0.62	0.05	0.55	0.68
2011	0.63	0.05	0.57	0.70
2012	0.52	0.05	0.47	0.58
2013	0.44	0.05	0.40	0.49
2014	0.49	0.05	0.44	0.54
2015	0.54	0.05	0.49	0.58
2016	0.57	0.05	0.52	0.62
2017	0.53	0.05	0.48	0.58
2018	0.63	0.04	0.58	0.69
2019	0.77	0.04	0.71	0.84

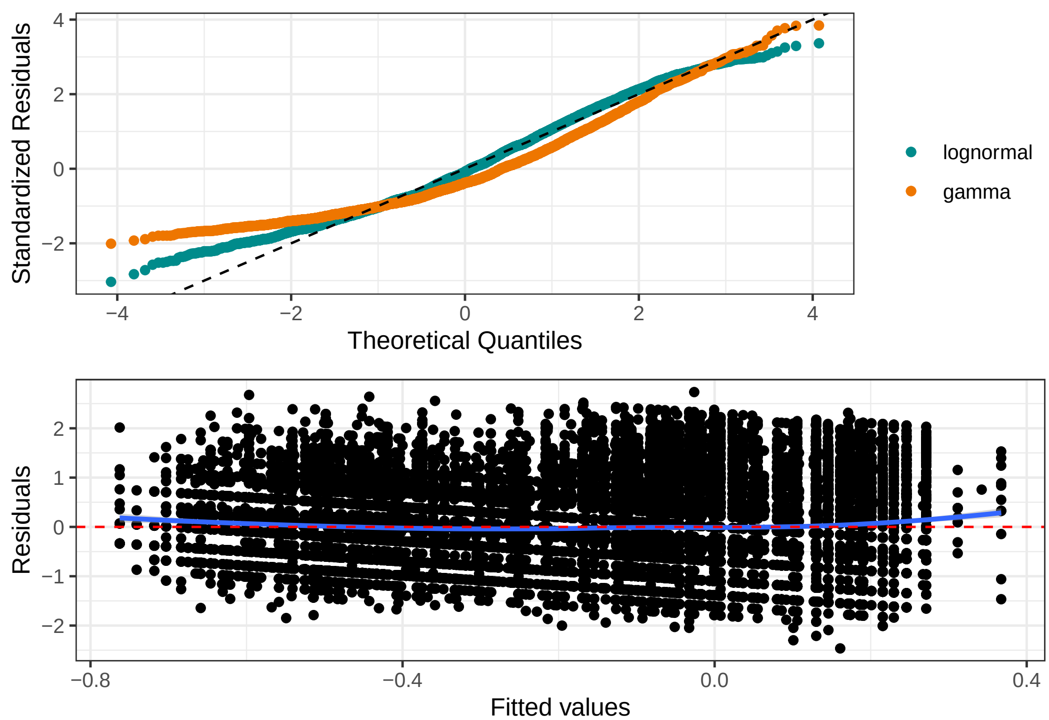

Figure E1: Q-Q plot (top) of the positive observations lognormal gamma distributions and fitted values vs residuals for the Lognormal model (bottom).

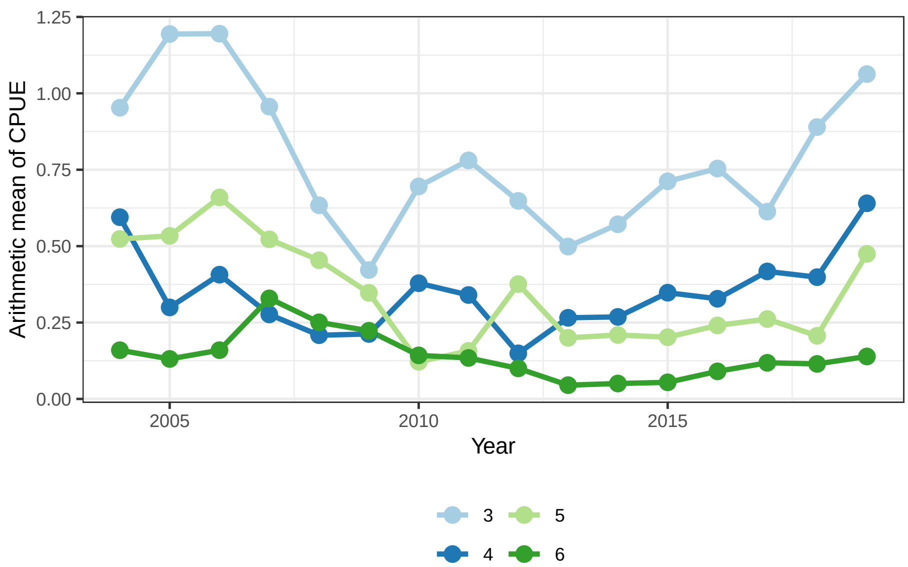

Figure E2: Arithmetic mean of CPUE by region for vermilion from the filtered data.

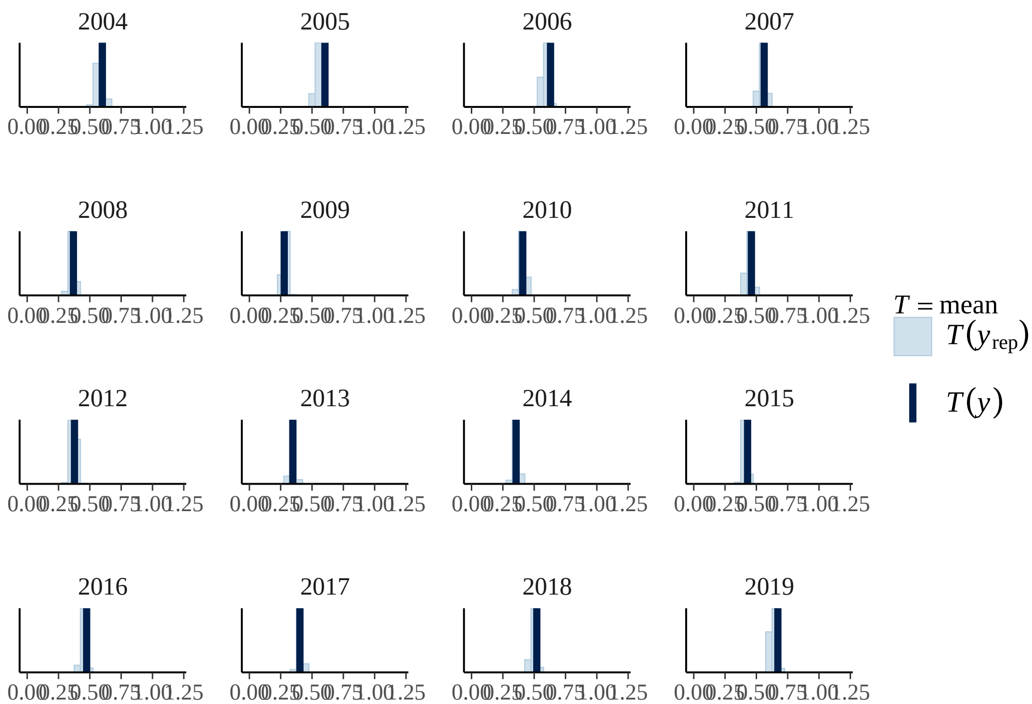

Figure E3: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the delta model with a vertical line representing the observed mean in the data.

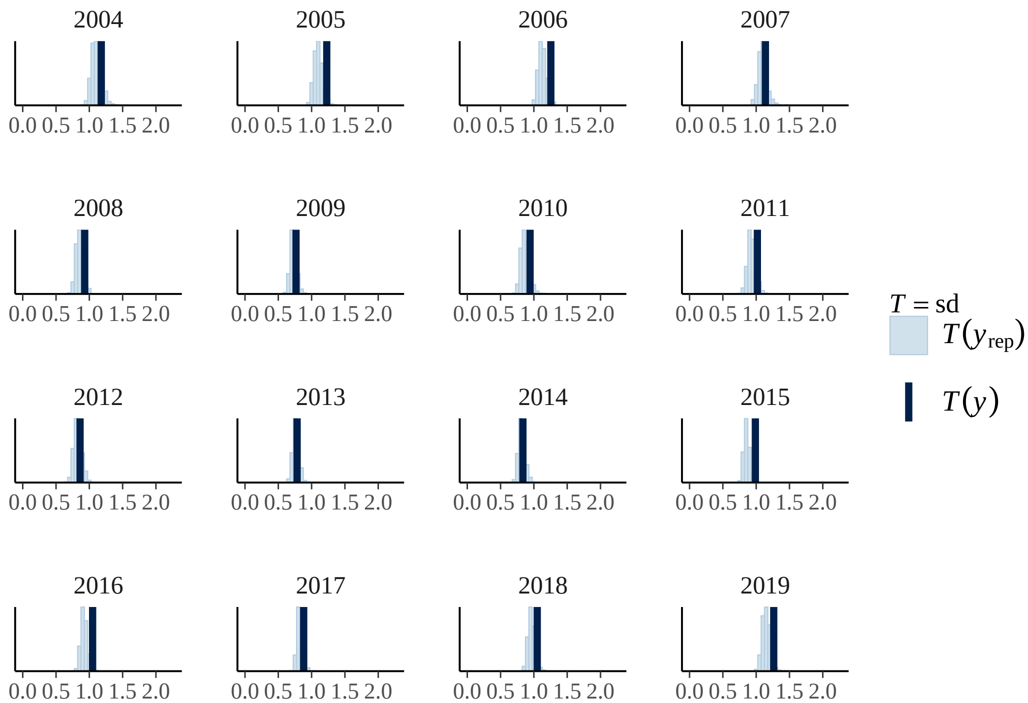

Figure E4: Posterior predictive draws of the standard deviation by year (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed standard deviation in the data.

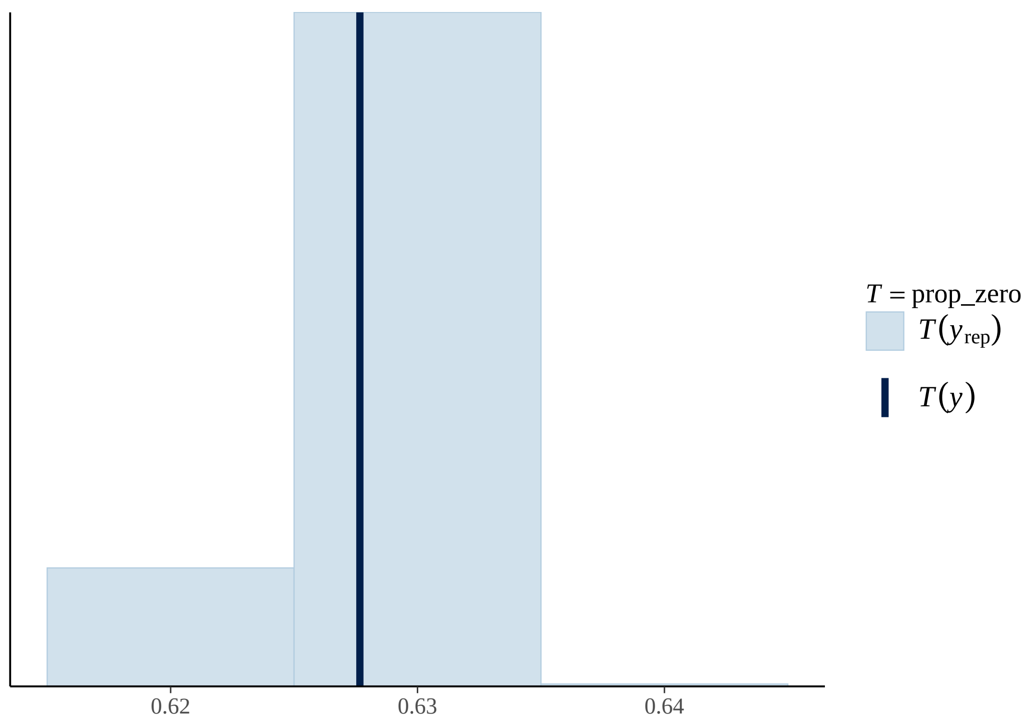

Figure E5: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average proportion of zeros in the data.

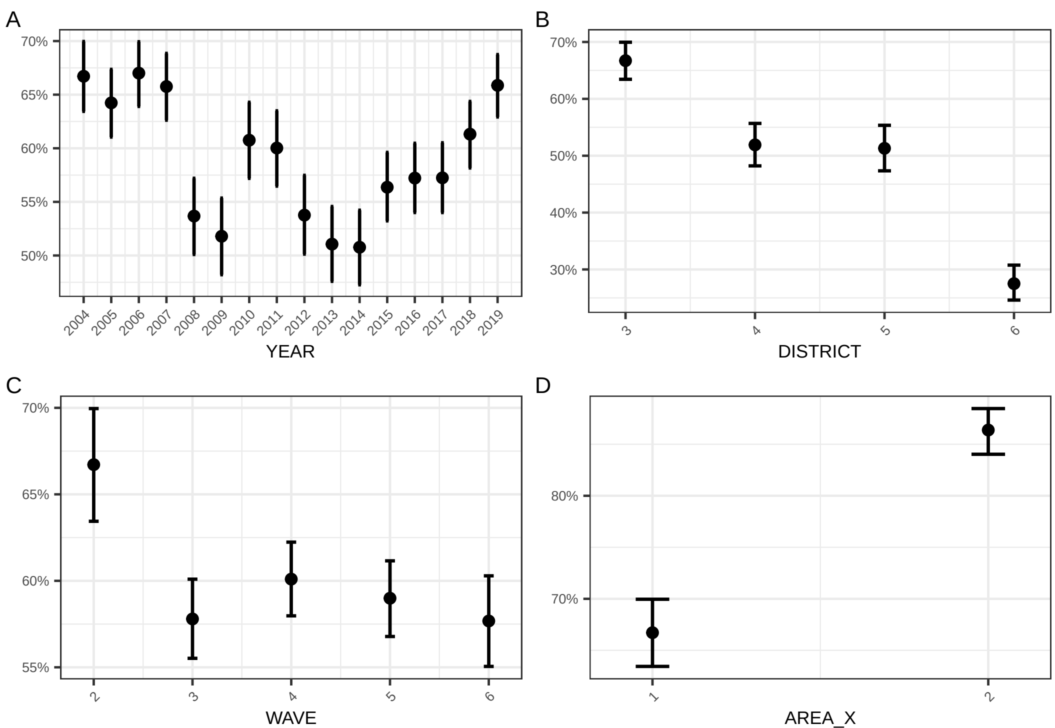

Figure E6: Binomial marginal effects from the final model.

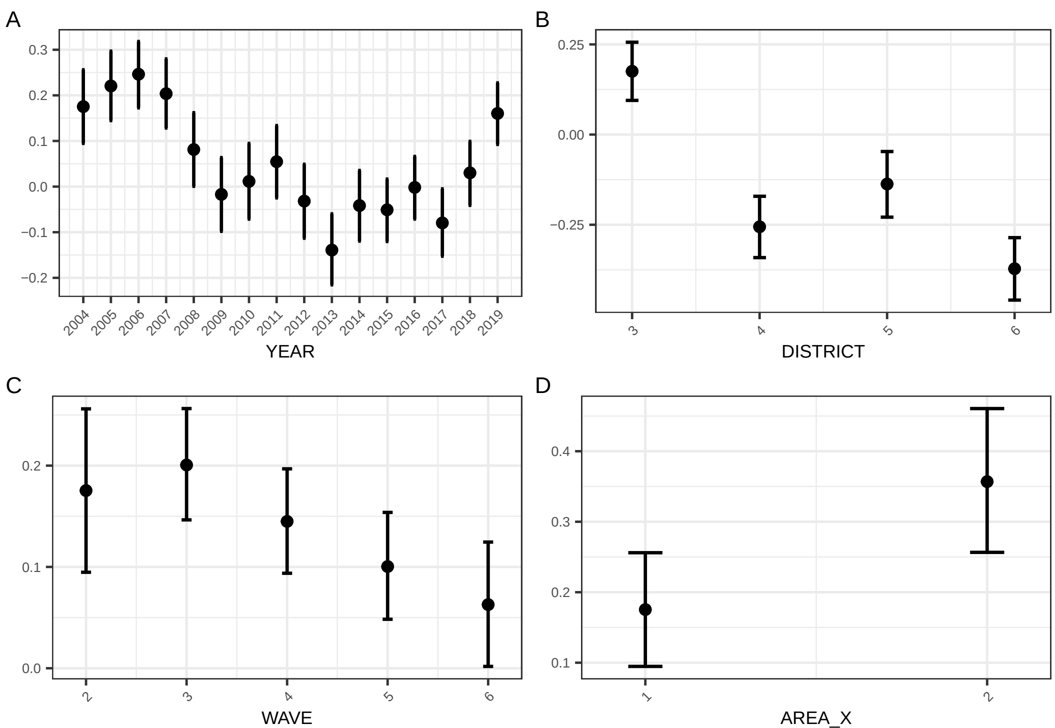

Figure E7: Positive model marginal effects from the final model.

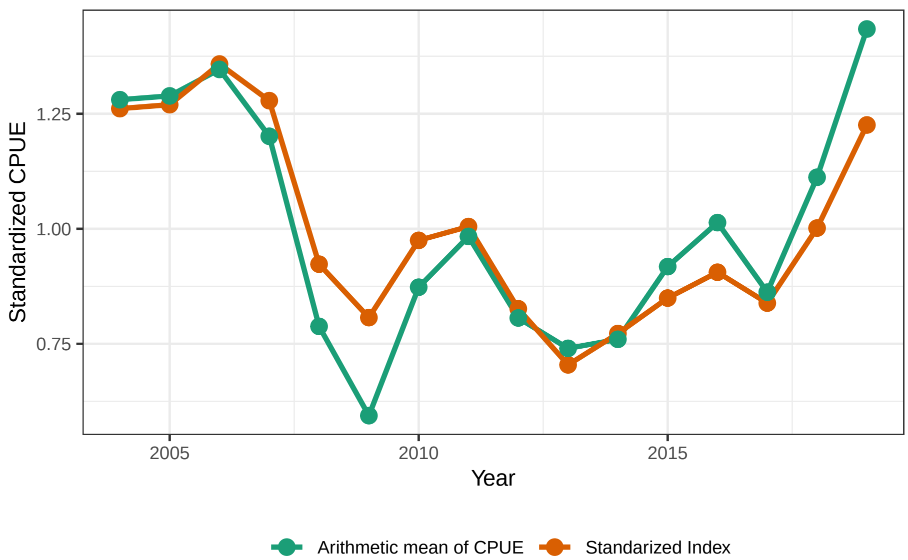

Figure E8: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

Appendix F. CCFRP Index of Abundance

California Collaborative Fisheries Research Program Index

The California Collaborative Fisheries Research Program, CCFRP, is a fishery-independent hook-and-line survey designed to monitor nearshore fish populations at a series of sampling locations both inside and adjacent to MPAs along the central California coast (Wendt and Starr 2009, Starr et al. 2015). The CCFRP survey began in 2007 and was originally designed as a statewide program in collaboration with NMFS scientists and fishermen. From 2007-2016 the CCFRP project was focused on the central California coast, and has monitored four MPAs consistently. In 2017, the program was expanded coastwide within California. The index of abundance was developed from the four MPAs sampled consistently (Año Nuevo and Point Lobos by Moss Landing Marine Labs; Point Buchon and Piedras Blancas by Cal Poly).

The survey design for CCFRP consists a number 500 x 500 m cells both within and outside each MPA. On any given survey day site cells are randomly selected within a stratum (MPA and/or reference cells). CPFVs are chartered for the survey and the fishing captain is allowed to search within the cell for a fishing location. During a sampling event, each cell is fished for a total of 30-45 minutes by volunteer anglers. Each fish encountered is recorded, measured, and can be linked back to a particular angler, and released (or descended to depth). Starting in 2017, a subset of fish have been retained to collect otoliths and fin clips that provide needed biological information for nearshore species. For the index of abundance, CPUE was modeled at the level of the drift, similar to the fishery-dependent onboard observer survey described above.

CCFRP Index: Data Preparation, Filtering, and Sample Sizes

The CCFRP data are quality controlled at the time they are key punched and little filtering was needed for the index. Cells not consistently sampled over time were excluded as well as cells that never encountered vermilion rockfish. CCFRP samples shallower depths to avoid barotrauma-induced mortality. We retained 5444 drifts for index standardization, with 1927 drifts encountering vermilion rockfish.

CCFRP Index: Model Selection, Fits, and Diagnostics

Sample sizes by factors selected to model, excluding WAVE can be found in Tables F1 and F3. 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 F1). Plots of the arithmetic mean by inside (MPA) and outside (REF) MPAs over time is in Figure F2.

A negative binomial model was fit to the drift-level data (catch with a log offset for angler hours). Because the averaged observed CPUE inside MPAs and in the reference sites exhibited differing trends, we explored a YEAR:SITE interaction, which was selected as the best fit model by AIC Table F4), The final model included YEAR and AREA and SITE and DEPTH_bin and YEAR:SITE and offset(logEffort). The model was 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 F4 and F5). The negative binomial model generated data sets with the proportion zeros similar to the 65% zeroes in the observed data (Figure F3). The predicted marginal effects from the model can be found in (Figures F6).

Based on work completed at the SWFSC, we estimate that the percent of rocky reef habitat from Point Conception to the California border within California state waters is 892 km^2, of which approximately 23% is in MPAs that prohibit the harvest of groundfish (pers comm. Rebecca Miller, UCSC). There is recreational fishing outside of state waters, but habitat maps are not available at the same 2-m resolution and do not allow for direct comparisons. High-resolution habitat maps are not available for the state waters south of Point Conception.

The final index was weighted, giving 20% of the model weight to MPAs and 80% of model weight to the "open" areas within the state. The CCFRP index includes all of the MPAs currently sampled from 2017-2020 and the core central California sampling sites from 2007-2016. Trends among all of the MPAs sampled increased along the entire coast from 2017-2020. The final index (Table F5) represents a similar trend to the arithmetic mean of the annual CPUE (Figure F7).

To visualize the affect of weighting on the index, Figure (F8) shows the unweighted index and the index with 10-60% of the weight given to MPAs versus open areas. Each of these indices are scaled to their means to allow for direct comparison.

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

Subregion	Positive Samples	Samples	Percent Positive
South Cape Mendocino	474	1854	26%
Ten Mile	364	1343	27%
Stewarts Point	599	932	64%
Bodega Head	490	1315	37%

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

Year	Positive Samples	Samples	Percent Positive
(0,10]	356	1589	22%
(10,15]	925	2438	38%
(15,20]	646	1417	46%

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

Year	Positive Samples	Samples	Percent Positive
2007	92	539	17%
2008	123	563	22%
2009	113	366	31%
2010	163	416	39%
2011	139	366	38%
2012	161	394	41%
2013	109	426	26%
2014	161	448	36%
2015	98	224	44%
2016	168	411	41%
2017	155	366	42%
2018	148	301	49%
2019	164	306	54%
2020	133	318	42%

Table F4: Model selection for the CCFRP survey index for vermilion rockfish in the northern model.

Model	ΔAIC
1 + offset(logEffort)	1191.26
YEAR + AREA + offset(logEffort)	653.34
YEAR + AREA + SITE + offset(logEffort)	188.88
YEAR + AREA + SITE + DEPTH bin + offset(logEffort)	62.28
YEAR + SITE + offset(logEffort)	579.86
YEAR + DEPTH bin + offset(logEffort)	760.91
YEAR + SITE + DEPTH bin + offset(logEffort)	397.53
YEAR + AREA + DEPTH bin + offset(logEffort)	478.98
YEAR + AREA + SITE + DEPTH bin + YEAR:SITE + offset(logEffort)	0.00

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

Year	Index	logSE	lower HPD	upper HPD
2007	0.11	0.13	0.09	0.14
2008	0.10	0.11	0.08	0.12
2009	0.16	0.11	0.13	0.19
2010	0.19	0.10	0.15	0.23
2011	0.16	0.10	0.13	0.19
2012	0.16	0.10	0.13	0.19
2013	0.08	0.12	0.06	0.10
2014	0.14	0.10	0.11	0.17
2015	0.19	0.13	0.14	0.24
2016	0.14	0.10	0.11	0.17
2017	0.14	0.10	0.11	0.17
2018	0.18	0.10	0.15	0.22
2019	0.22	0.10	0.18	0.26
2020	0.24	0.11	0.19	0.29

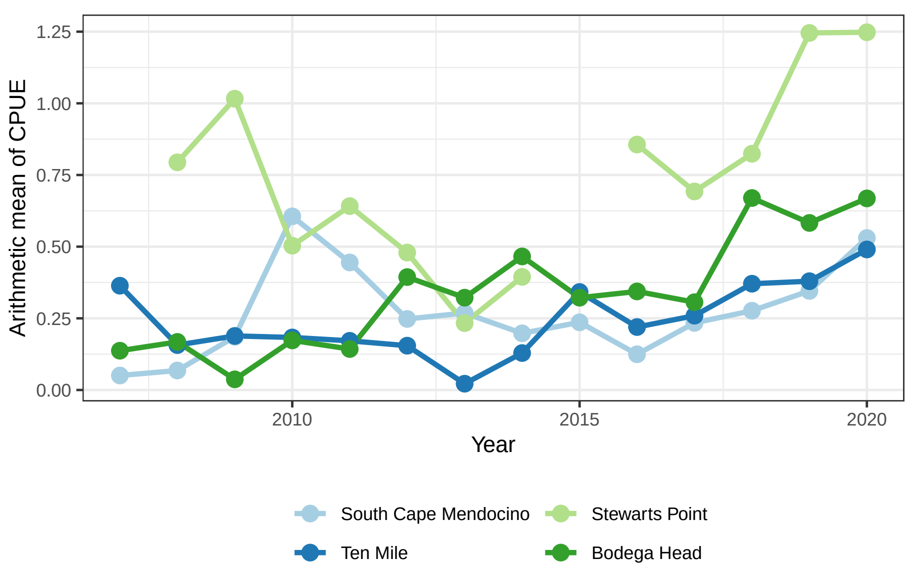

Figure F1: Arithmetic mean of CPUE by region for vermilion from the filtered data. The areas used are in the text.

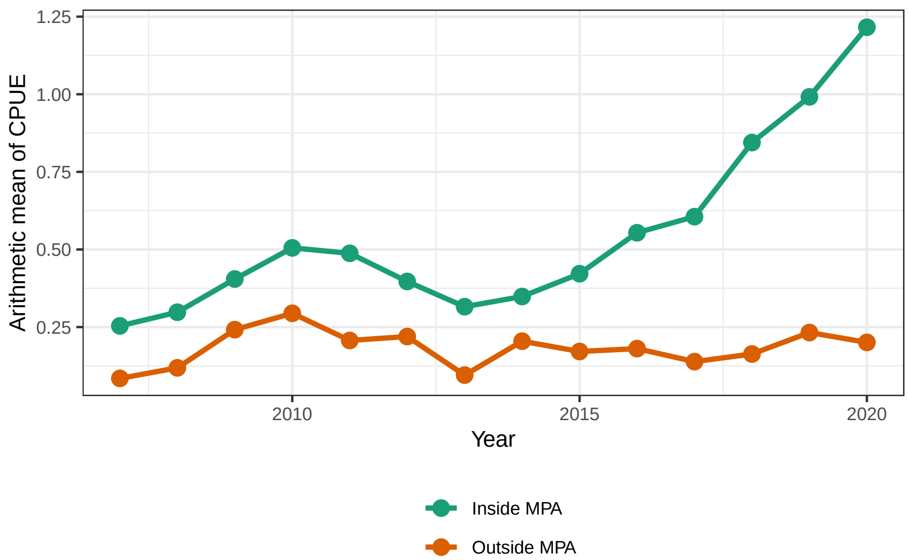

Figure F2: Arithmetic mean of CPUE by inside/outside MPAs for vermilion from the filtered data. The areas used are in the text.

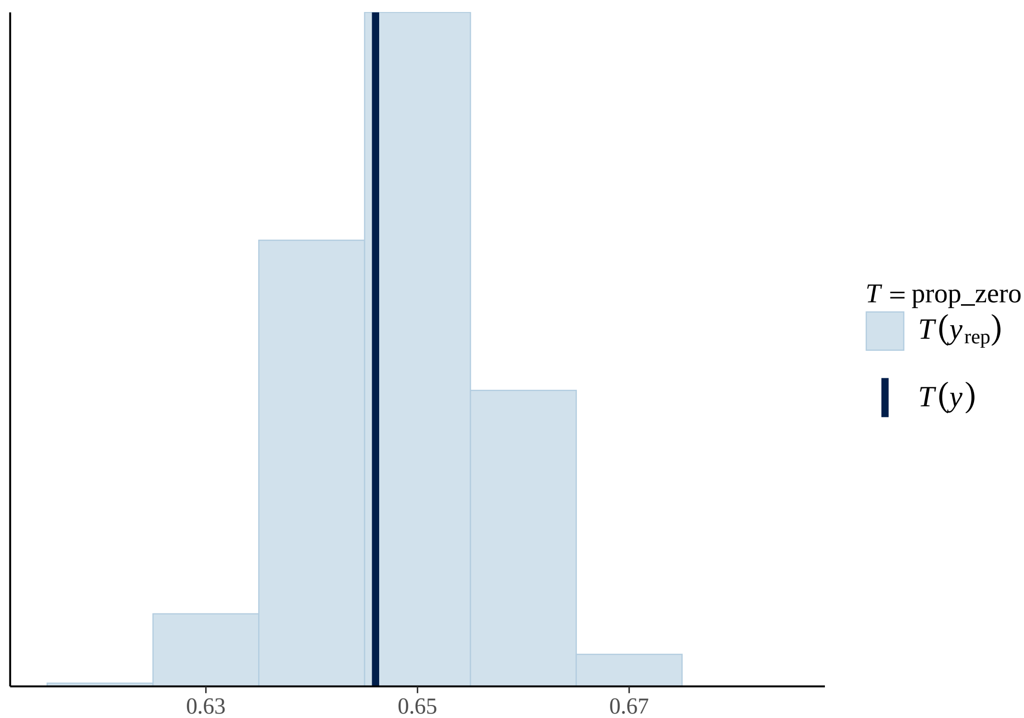

Figure F3: Posterior predictive distribution of the proportion of zero observations (x-axis) in replicate data sets generated by the delta model with a vertical line representing the observed average in the data.

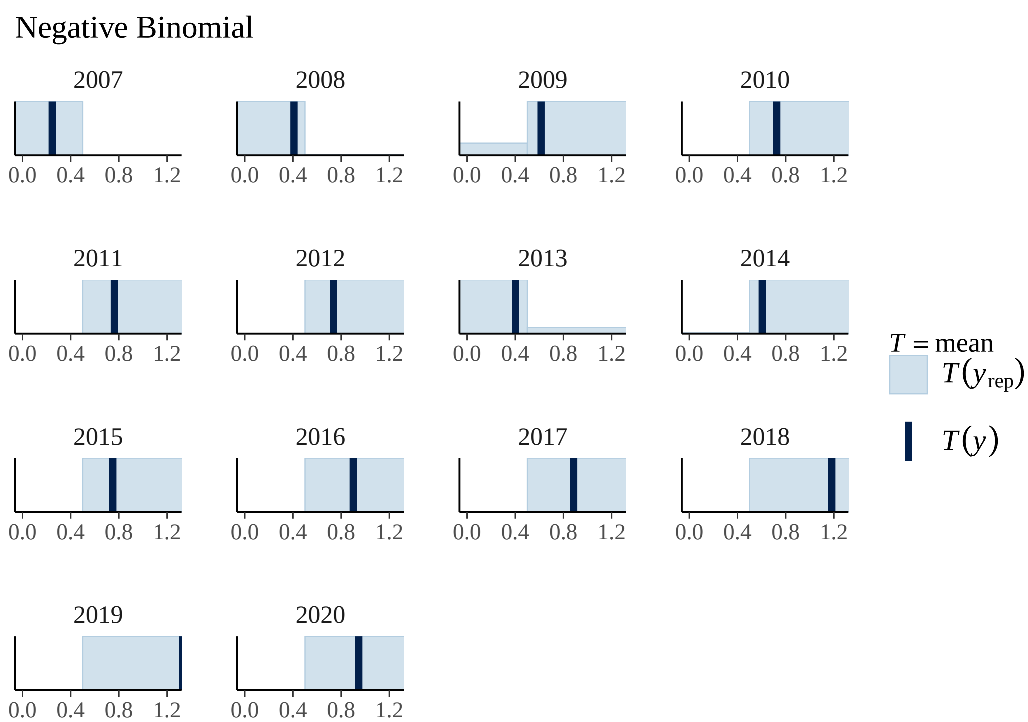

Figure F4: Posterior predictive draws of the mean (x-axis) by year in replicate data sets generated by the negative binomial model with a vertical line representing the observed mean in the data.

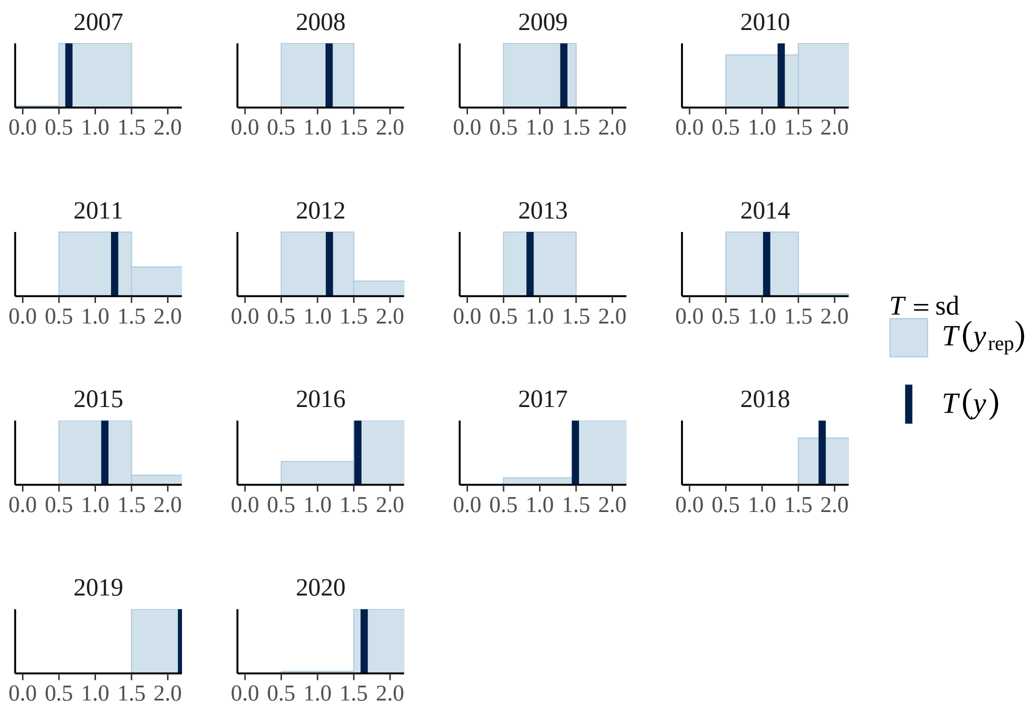

Figure F5: Posterior predictive draws of the standard deviation (x-axis) in replicate data sets generated by the negative binomial model with a vertical line representing the observed mean in the data.

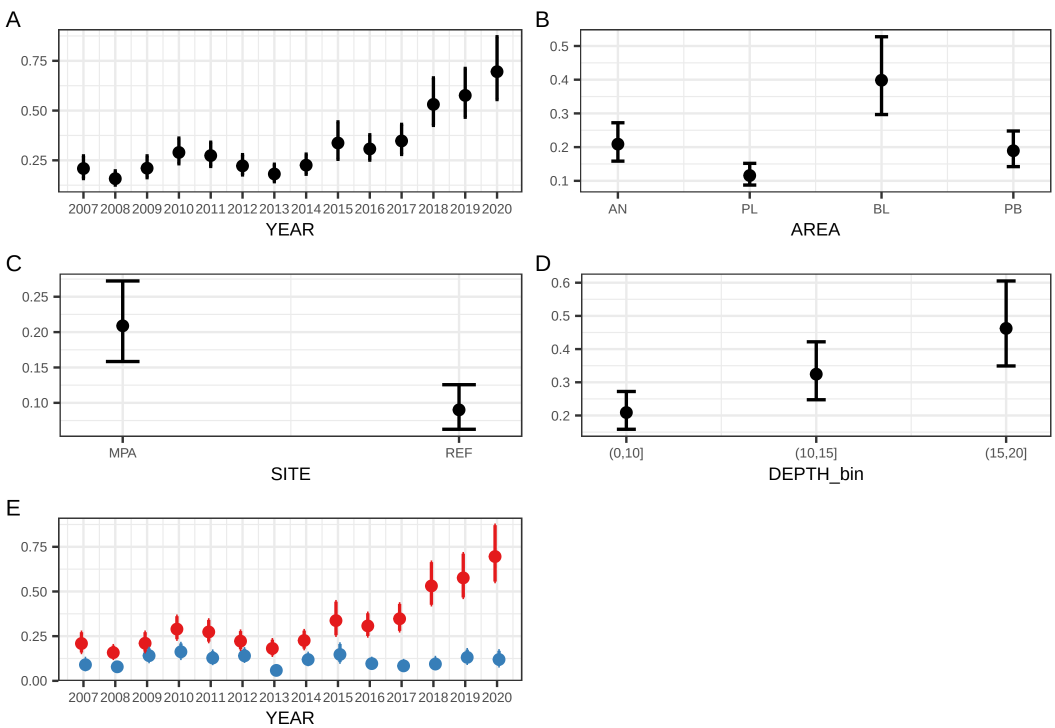

Figure F6: Negative ninomial marginal effects from the unweighted model.

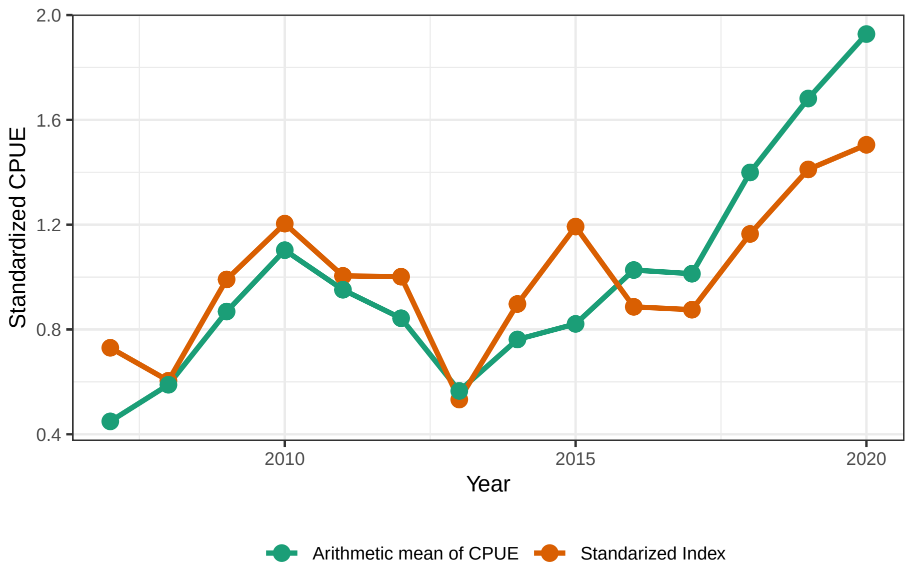

Figure F7: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

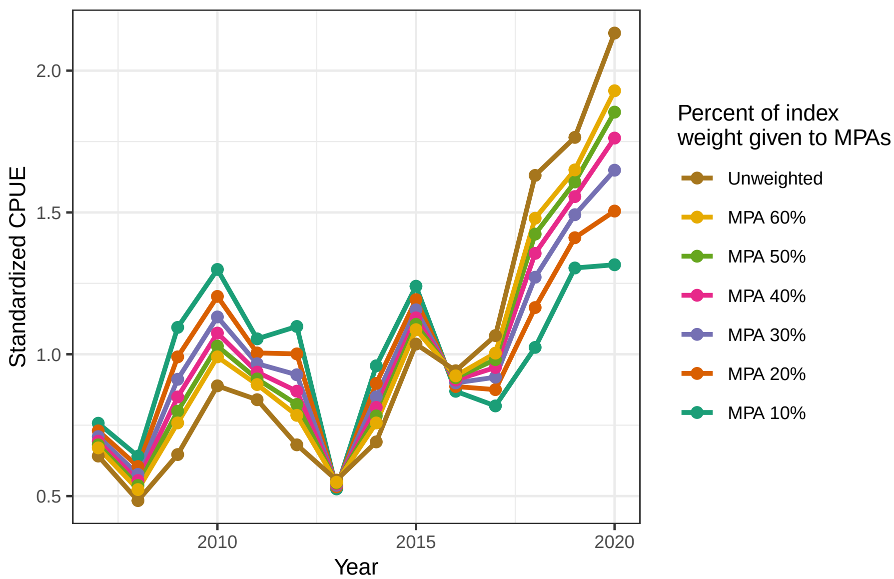

Figure F8: Standardized index with differing weighting to the MPAs from 10% to 60%. Each index is scaled to its respective means.

Appendix G. 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 G2 and G3. We modeled retained catch per angler hour (CPUE; number of fish per angler hour) a Bayesian delta-GLM model.

A Gamma distribution was selected over a Lognormal 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 G4), a main effects model including YEAR and DEPTH bin and LAT bin was fit for the binomial model and a main effects model including YEAR and PASS and DEPTH bin and LAT bin was fit for the Gamma 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 G2 and G3). The binomial model generated data sets with the proportion zeros similar to the 92% zeroes in the observed data (Figure G1). The predicted marginal effects from both the binomial and Gamma models can be found in (Figures G5 and G6). The final index (Table G5) represents a similar trend to the arithmetic mean of the annual CPUE (Figure G4).

Table G1: Samples of vermilion rockfish in the northern model by subregion used in the index.

Subregion	Positive Samples	Samples	Percent Positive
34	12	125	10%
35	15	132	11%
36	13	113	12%
37	16	313	5%

Table G2: Positive samples of vermilion rockfish in the northern model by depth (fm).

Year	Positive Samples	Samples	Percent Positive
[55,75]	10	121	8%
(75,100]	16	170	9%
(100,150]	23	214	11%
(150,200]	4	67	6%
(200,300]	3	111	3%

Table G3: Samples of vermilion rockfish in the northern model by year.

Year	Positive Samples	Samples	Percent Positive
2003	2	38	5%
2004	2	42	5%
2006	2	45	4%
2008	6	58	10%
2009	8	65	12%
2010	5	59	8%
2012	3	64	5%
2013	4	30	13%
2014	5	56	9%
2015	3	48	6%
2016	5	58	9%
2017	5	48	10%
2018	3	45	7%
2019	3	27	11%

Table G4: Model selection for the WCGBTS survey index for vermilion rockfish in the northern model.

Model	Binomial ΔAIC	Gamma ΔAIC
1	0.00	67.52
YEAR + PASS	15.66	48.80
YEAR + PASS + DEPTH bin	15.59	0.00
YEAR + PASS + DEPTH bin + LAT bin	7.42	4.40
YEAR + DEPTH bin + LAT bin	12.04	10.96
YEAR + LAT bin	16.79	67.52
YEAR + PASS + LAT bin	12.89	53.13

Table G5: Standardized index for the WCGBTS survey index with log-scale standard errors and 95% highest posterior density (HPD) intervals for vermilion in the northern model.

Year	Index	logSE	lower HPD	upper HPD
2003	0.20	1.08	0.01	0.91
2004	0.00	1.29	0.00	0.02
2006	0.39	1.41	0.01	2.23
2008	0.66	0.95	0.07	2.91
2009	0.33	1.44	0.01	1.89
2010	0.06	0.83	0.01	0.23
2012	0.13	0.93	0.01	0.48
2013	0.05	0.88	0.01	0.17
2014	0.07	1.37	0.00	0.36
2015	0.10	1.02	0.01	0.42
2016	0.21	0.83	0.03	0.75
2017	0.03	0.92	0.00	0.11
2018	0.01	0.99	0.00	0.05
2019	0.02	0.85	0.00	0.06

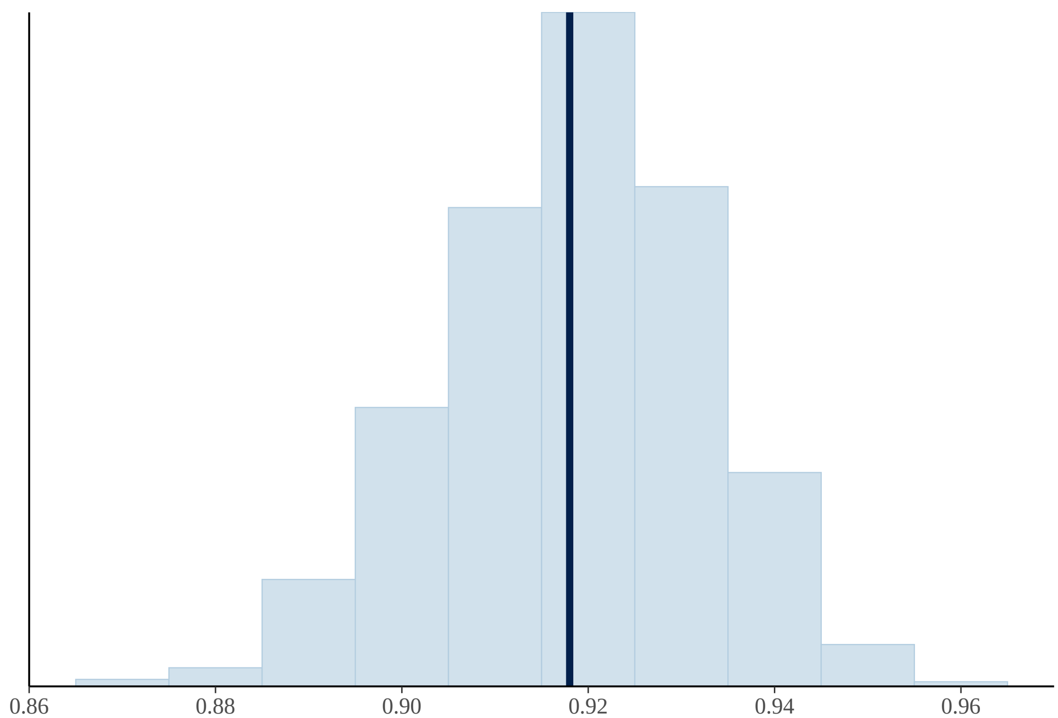

Figure G1: Posterior predictive distribution of the proportion of zero observations in replicate data sets generated by the delta model with a vertical line representing the observed average.

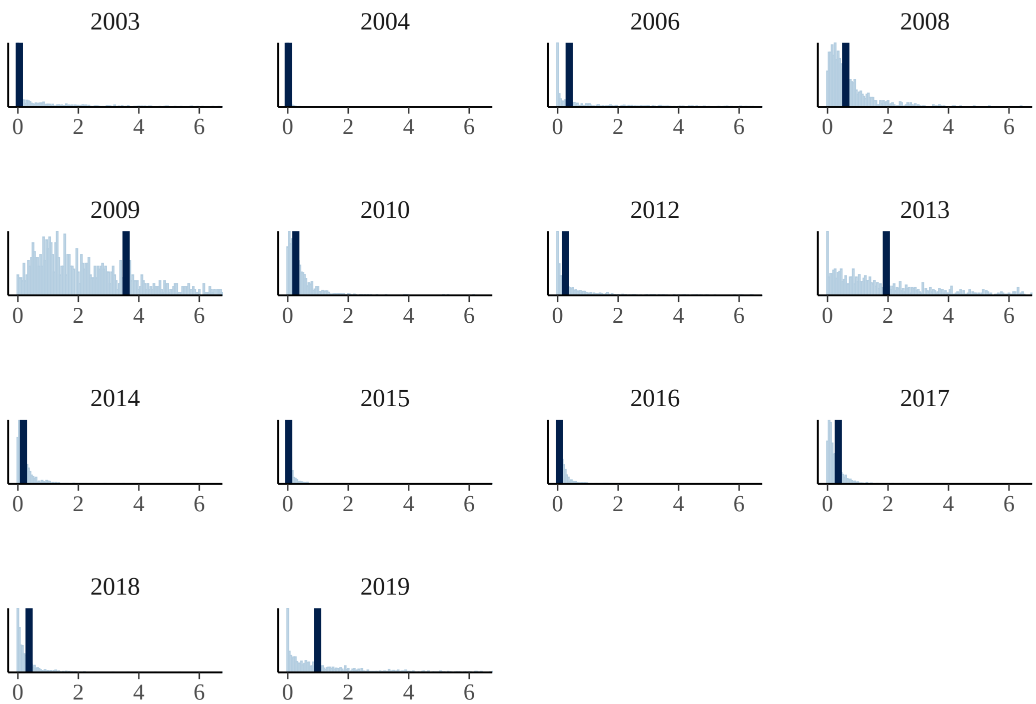

Figure G2: Posterior predictive draws of the mean by year with a vertical line of the raw data average.

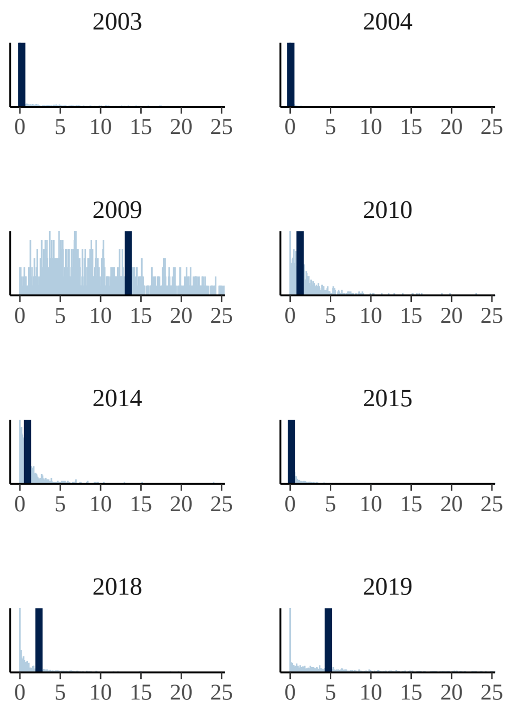

Figure G3: Posterior predictive draws of the standard deviation by year with a vertical line representing the observed average.

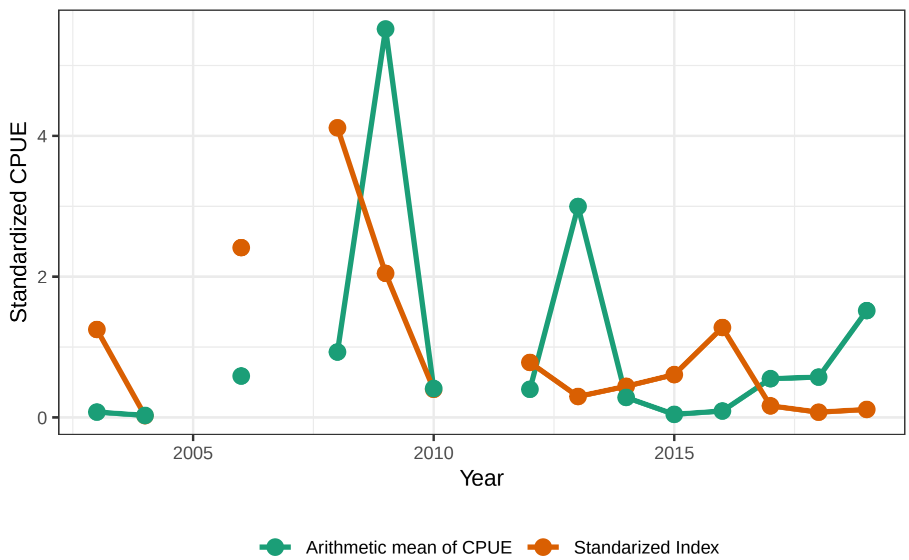

Figure G4: Standardized index and arithmetic mean of the CPUE from the filtered data. Each timeseries is scaled to its respective means.

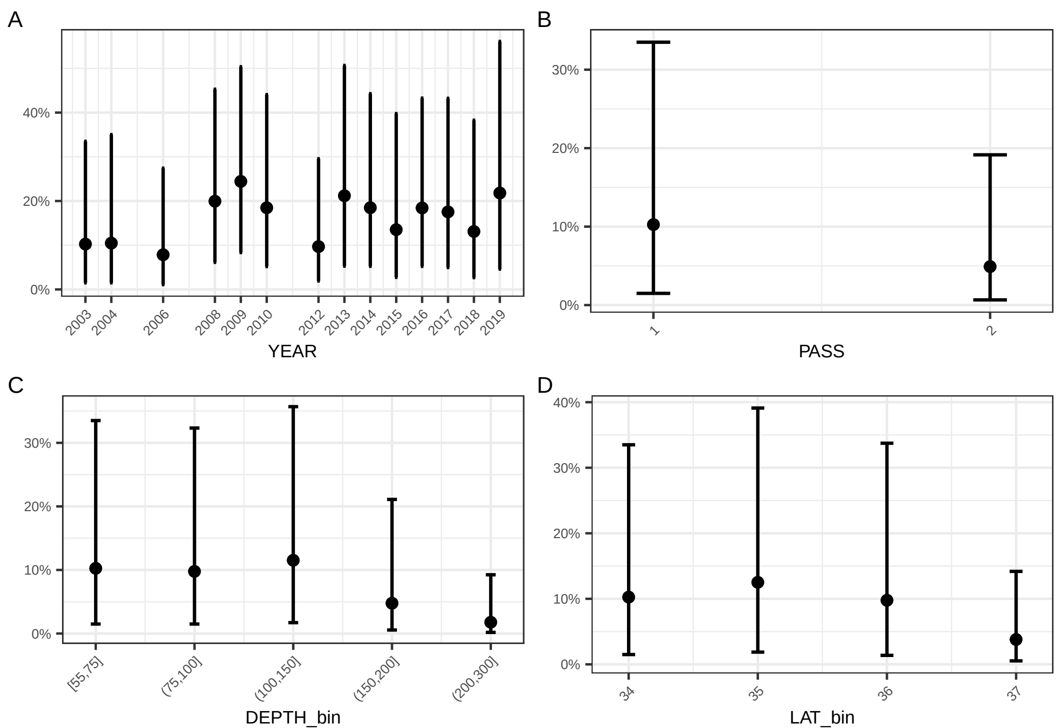

Figure G5: Binomial marginal effects from the final model

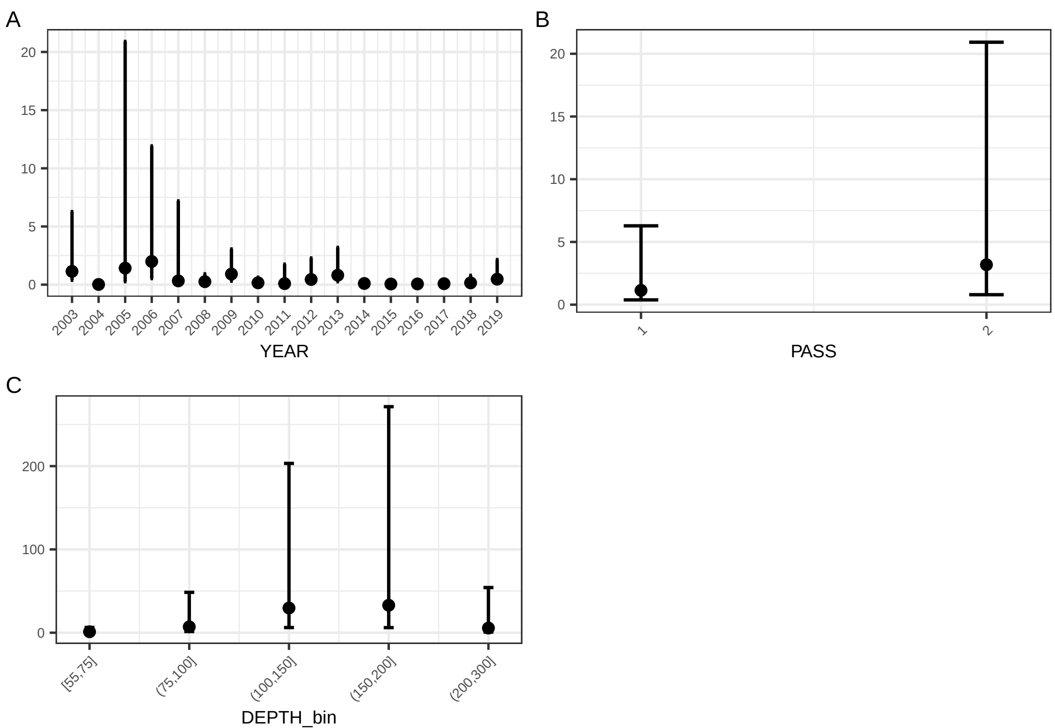

Figure G6: Positive model marginal effects from the final model.

Appendix H. Recreational Regulations

Figure H1: Recreational depth closures for shelf rockfish in the northern California management area.

Figure H2: Recreational depth closures for shelf rockfish in the north-central California management area.

Figure H3: Recreational depth closures for shelf rockfish in the central California management area.

Figure H4: Recreational depth closures for shelf rockfish in the southern California management area.

Appendix I. Management Boundary Analysis

The 2021 northern California base model for vermilion rockfish represents U.S. waters between $34°27'N$ and the California-Oregon border $42°00'N$. Federal management of the minor shelf rockfish, which includes vermilion rockfish, is based on areas north and south of $40°10'N$, near Cape Mendocino. Therefore, yield estimates from the northern California base model must be divided between the northern and southern management areas in order to determine the contribution of vermilion rockfish to the minor nearshore rockfish overfishing limit (OFL).

Allocation of the OFL could, ideally, be based on a fishery-independent survey of abundance, but lacking that information several alternatives exist. Previous allocations have used catch as a proxy for abundance when no other information was available (Dick and MacCall 2010, Dick and Maccall 2011). Recent catches of vermilion rockfish in the recreational and commercial sectors suggest that roughly 4.8% and 2.8%, respectively, of catches in these sectors are landed north of Cape Mendocino (Tables I1 and I2). Removals for the recreational fleet are in numbers of fish and removals from the commercial fleet are in mt, to be consistent with the assessment inputs.

Recent advances in habitat mapping allow us to estimate the relative amount of reef habitat within state waters (0-3 nm) in each area, e.g., the California Seafloor Mapping Project. If we assumed that average density of vermilion rockfish is constant over the assessed area, the fraction of vermilion rockfish occurring north of Cape Mendocino would be equal to the fraction of habitat in the same area: approximately 18% (pers. comm. Rebecca Miller, UCSC). However, the assumption of equal density may not be accurate, and no direct estimates of density are available from a fishery-independent survey with adequate spatial coverage.

As was proposed in the 2017 blue/deacon rockfish complex stock assessment (Dick et al. 2017a) we combined existing habitat information with a proxy for fish density – catch per unit effort. Although data from the CRFS onboard CPFV observer program are more precise in terms of total catch, effort, and location, relatively few samples are available north of Cape Mendocino. Sampling coverage for the dockside survey is spatially more complete, in that numerous samples exist in the northern management area. We therefore used the private boat (PR1) CPUE data to develop a spatial index (with CPUE assumed proportional to density), and multiplied the area-specific CPUE estimates by the amount of habitat to produce a spatial index of relative abundance. Data were filtered using the same methods detailed in the assessment for the CRFS private boat dockside index. Years prior to 2016 were subsequently dropped as well as 2020 due to reduced sampling during COVID-19, to create an index that is representative of recent catch rates in each area. Sample sizes (number of trips) for the final data set are shown in Table I3.

Vermilion rockfish is a shelf species and we recognize that there is a fraction of the population and rocky habitat outside of state waters. However, due to depth closures that began in 2002, samples from deeper waters are not available, nor is the associated habitat data. This method assumes the same proportion of habitat outside state waters north and south of Cape Mendocino. We explored limiting the data to only angler-reported trips inside state waters. However, the accuracy of the angler-reported trip location is unknown and the trip may represent catch from both inside and outside state waters. Filtering based on angler-reported area fished did not affect the final result, so we retained all data for this analysis.

We modeled CPUE (vermilion rockfish per angler trip) using a Bayesian negative binomial regression with subregion (defined as CRFS districts, see Table I3) as a qualitative covariate and pooling data across years 2016-2019. Including the subregion covariate reduced AIC by 2270 points relative to the null (intercept-only) model. CPUE in the Wine District subregion was lower than the other subregions in the model (Table I4). When CPUE is multiplied by the percentage of habitat area north of $40^{\circ}10'N$ latitude, the expected percentage of the stock that occurs north of Cape Mendocino is 4.4% (Table I4).

Table I1: California recreational total mortality (1000s of fish) for vermilion rockfish by CRFS district, 2016-2019. The Redwood district occurs mainly north of Cape Mendocino. Source:RecFIN

Year	CENTRAL	BAY	WINE	REDWOOD	Percent mortality in Redwood District
2016	63.382	15.480	3.888	2.099	2.47%
2017	79.042	20.795	4.891	2.858	2.66%
2018	89.937	17.996	4.192	3.214	2.79%
2019	96.274	29.016	8.616	3.363	2.45%

Table I2: Commercial landings (mt) of vermilion rockfish in California port complexes located north (CRS+ERK) and south (MRO-BRG) of Cape Mendocino, 2016-2019. Source: CALCOM.

Year	MRO-BRG	CRS+ERK	Percent landings in CRS+ERK
2016	12.477	0.888	1.33%
2017	12.738	1.550	2.32%
2018	17.650	2.010	3.00%
2019	16.579	3.052	4.56%

Table I3: Number of trips sampled in the PR1 mode by year and CRFS District.

YEAR	Central	Bay	Wine	Redwood
2016	2175	795	279	1108
2017	1782	800	392	1148
2018	1783	677	345	1149
2019	1724	681	204	1151

Table I4: Estimated CPUE, percent habitat area, and relative abundance by CRFS District.

CRFS District	CPUE	Area	Percent of Area	CPUExAREA	Relative Abundance
Central	0.833	315.912	35.56%	0.296	59.32%
Bay	0.448	271.279	30.54%	0.137	27.45%
Wine	0.286	136.937	15.42%	0.044	8.82%
Redwood	0.122	164.193	18.48%	0.022	4.41%

Appendix J. Decision Table Assuming Category 2

Uncertainty in the forecasts is based upon the three states of nature agreed upon at the STAR panel, reflecting three different natural mortality rates. The steepness parameter of the Beverton-Holt stock-recruit curve was fixed in the base model and in all of the forecasts. The northern California model is not data rich and while there is uncertainty in steepness, it was not well estimated in the base model when natural mortality was also estimated. The alternative states of nature maintain the female to male natural mortality rate ratio from the base model. To capture the 75% interval around the negative log-likelihood, alternate states were identified within 0.66 negative log-likelihood points from the base model where female $M = 0.0856$ and male $M = 0.0805$. The high state of nature fixes female $M = 0.0956$ and male $M = 0.08989$. For the low state of nature, female $M = 0.0769$ and male $M = 0.07231$.

For reference, the base model predicted $\sigma = 0.246$. The buffers between the OFL and ABC were calculated assuming a category 2 stock, with $\sigma = 1.0$ and a $p^* = 0.45$. The alternative catch stream (rows in the table) include $\sigma = 1.0$ with a $p^* = 0.4$ for a category 2 stock.

Current forecasts based on the alternative states of nature and requested catch streams project that the stock will remain above the target threshold of 40% in 2032 (Table J1). In all of the scenarios of the low state of nature, the stock remains below the target threshold of 40% until 2026 or 2027. The base model with the base catches results in an increasing stock over the period from 2023-2032. In all scenarios the catch significantly decreases from 2022 to 2023; projected catch in 2022 is 227 mt, and 2023 catches from the base model range from 118-139 mt. The base model includes a portion of the stock within the northern management unit (north of $40°10'N$). An analysis based on the private/rental mode index through 2019 suggests that 4.44% of the catches from this model should be apportioned to the northern management unit for vermilion rockfish.

Table J1: 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	
				Female M = 0.0769 Male M = 0.0723 NLL = 1031.36		Female M = 0.0856 Male M = 0.0805 NLL = 1030.7		Female M = 0.0956 Male M = 0.0899 NLL = 1031.36	
	Year	Buffer	Catch (mt)	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
$p^* = 0.45, \sigma = 1$	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.874	135	438	0.363	497	0.434	568	0.519
	2024	0.865	136	453	0.376	516	0.451	591	0.540
	2025	0.857	137	467	0.387	533	0.466	612	0.559
	2026	0.849	136	477	0.396	547	0.478	629	0.575
	2027	0.841	134	485	0.402	558	0.487	642	0.587
	2028	0.833	132	491	0.407	566	0.494	652	0.595
	2029	0.826	130	496	0.411	572	0.500	658	0.602
	2030	0.818	128	499	0.414	577	0.504	663	0.606
	2031	0.810	127	502	0.416	580	0.507	666	0.608
	2032	0.803	125	505	0.418	583	0.509	667	0.610
$p^* = 0.40, \sigma = 1$	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.762	118	438	0.363	497	0.434	568	0.519
	2024	0.747	118	456	0.378	519	0.453	593	0.542
	2025	0.733	118	472	0.392	539	0.470	616	0.563
	2026	0.719	117	487	0.404	556	0.485	636	0.581
	2027	0.706	115	499	0.414	570	0.498	652	0.595
	2028	0.693	113	509	0.422	581	0.508	664	0.607
	2029	0.680	111	518	0.429	591	0.516	674	0.615
	2030	0.667	108	525	0.436	599	0.523	681	0.622
	2031	0.654	106	533	0.442	606	0.529	686	0.627
	2032	0.642	105	539	0.447	612	0.534	691	0.631
Long-term Equil. Yield (MSY proxy, $SPR_{50\%}$), no buffer	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	1.000	139	438	0.363	497	0.434	568	0.519
	2024	1.000	139	453	0.376	516	0.451	590	0.539
	2025	1.000	139	467	0.387	533	0.465	610	0.558
	2026	1.000	139	477	0.396	546	0.477	627	0.573
	2027	1.000	139	485	0.402	557	0.486	639	0.584
	2028	1.000	139	491	0.407	564	0.493	647	0.591
	2029	1.000	139	495	0.410	569	0.497	652	0.596
	2030	1.000	139	497	0.412	572	0.499	654	0.598
	2031	1.000	139	98	0.413	573	0.500	655	0.598
	2032	1.000	139	499	0.414	573	0.501	654	0.597
Long-term Equil. Yield (MSY proxy, $SPR_{50\%}$), with buffer	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.874	122	438	0.363	497	0.434	568	0.519
	2024	0.865	120	456	0.378	518	0.453	593	0.542
	2025	0.857	119	472	0.392	538	0.470	616	0.563
	2026	0.849	118	486	0.403	555	0.485	635	0.580
	2027	0.841	117	498	0.413	569	0.497	651	0.595
	2028	0.833	116	508	0.421	580	0.507	663	0.606
	2029	0.826	116	516	0.428	589	0.515	672	0.614
	2030	0.818	115	522	0.433	596	0.521	678	0.620
	2031	0.810	114	528	0.438	602	0.526	682	0.624
	2032	0.803	113	533	0.442	606	0.529	685	0.626

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