Agenda Item C.6
Attachment 4
September 2021

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

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Two fish of the vermilion/sunset 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, in U.S. waters off the coast of California south of Point Conception ($34°27'N$) using data through 2020. Genetic evidence suggests overlapping distributions for the two species, with the majority of the sunset rockfish population occupying waters south of Point Conception. Alternative spatial structures for the vermilion rockfish assessment should be considered if additional data on stock structure and the distribution of the two species become available.

Catches

Over the past decade, vermilion rockfish in the assessed area off the coast of California in have been primarily caught by the recreational fishery (Table i). Annual total mortality of catch and discards of vermilion rockfish have ranged between 106-260 mt, with total mortality (catch + discards) in 2020 of 110 mt. Vermilion and sunset rockfishes 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 landings and discard at a finer spatial resolution. Total removals south of Point Conception increased steadily following World War II, peaking in the late 1970s and 1980s with annual removals exceeding 398 mt per year (Figure i). Recent years have seen a steady increase in landings, with recreational fleets accounting for the majority of landings.

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

	Commercial			Recreational				
				Party/charter		Private/rental		
Year	Hook-and-line	Trawl	Net	Retained	Dead discards	Retained	Dead discards	Total Mortality
2011	7.564	0.000	0.000	75.329	1.574	21.340	0.416	106.224
2012	8.533	0.000	0.000	102.566	4.422	29.128	0.617	145.267
2013	10.999	0.073	0.000	111.629	1.300	25.528	0.503	150.033
2014	12.651	0.051	0.013	83.283	1.205	18.577	0.289	116.069
2015	21.976	0.065	0.006	148.152	1.617	23.873	0.468	196.157
2016	16.099	0.171	0.056	129.384	0.813	25.279	0.328	172.129
2017	33.287	0.115	0.022	89.956	1.189	25.282	0.250	150.102
2018	40.246	0.034	0.039	82.319	1.909	17.211	0.355	142.112
2019	47.217	0.291	0.045	172.463	5.296	33.640	1.020	259.971
2020	48.764	0.075	0.096	38.880	1.576	19.828	0.461	109.680

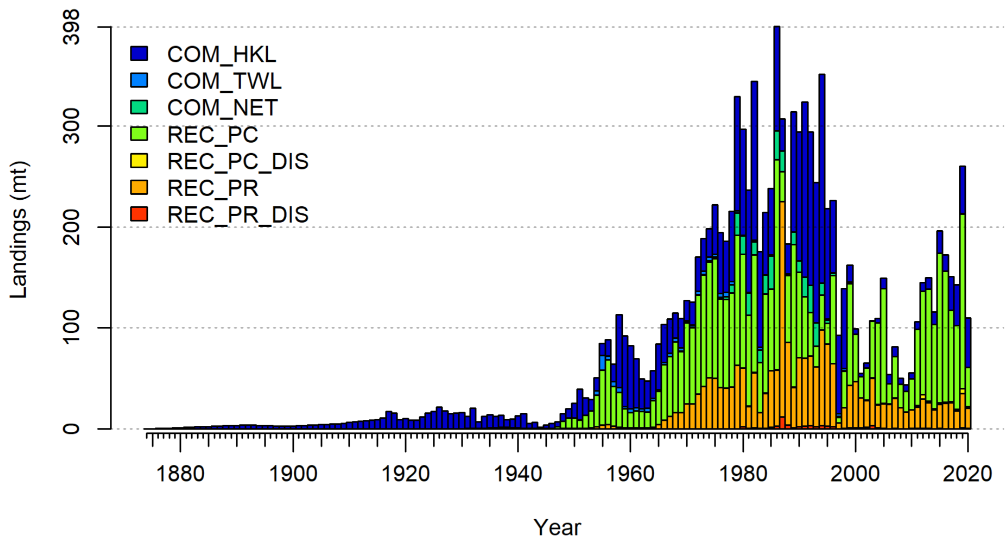

Figure i: Catch histories by fleet used in the base model (Commercial hook-and-line = COM_HKL, Commercial trawl = COM_TWL, Commercial net = COM_NET, Recreational party/charter retained = REC_PC, Recreational private/rental retained = REC_PR, Recreational party/charter dead discards = REC_PC_DIS, Recreational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

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 rockfishes. The 2021 assessment uses Stock Synthesis 3 (version V3.30.17.0). The assessment is a two-sex model, with the population spanning from the U.S./Mexico border to Point Conception ($34°27'N$). The model operates on an annual time step covering the period 1875 to 2020 (not including forecast years) and assumes an unfished population prior to 1875. Population dynamics are modeled for ages 0 through 70, with age-70 being the accumulator age.

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

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

Stock Biomass

Spawning output of vermilion rockfish was estimated to be 978 million eggs in 2021 (95% asymptotic interval: 778 - 1178 million eggs) or 48% (95% asymptotic interval: 26% - 71% million eggs) of unfished spawning output ("depletion," Table ii). Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output.

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

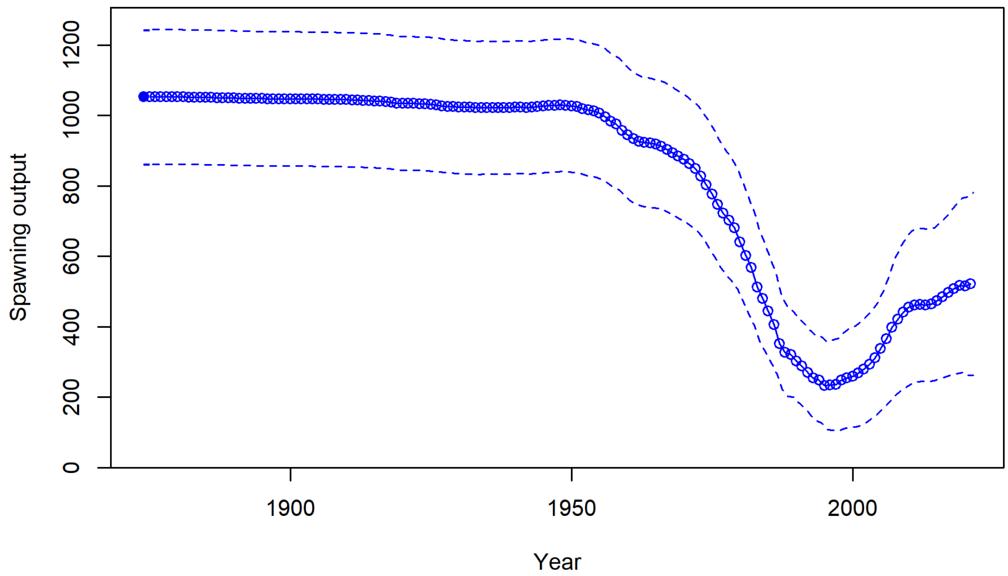

Figure ii: Estimated time series of spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

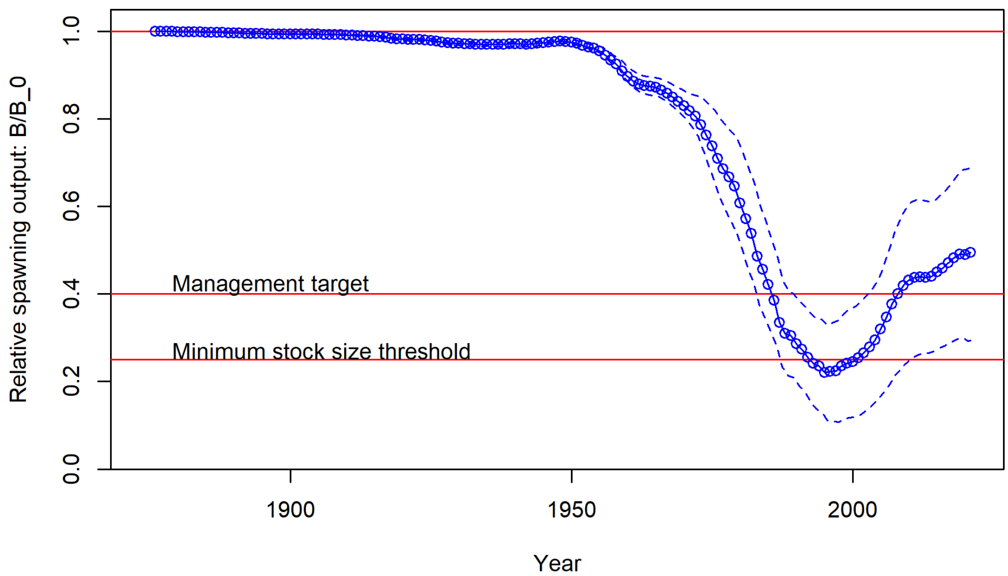

Figure iii: Estimated time series of spawning output relative to unfished spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

Table ii: Estimated recent trend in spawning output and the fraction unfished and the approximate 95% asymtotic 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

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

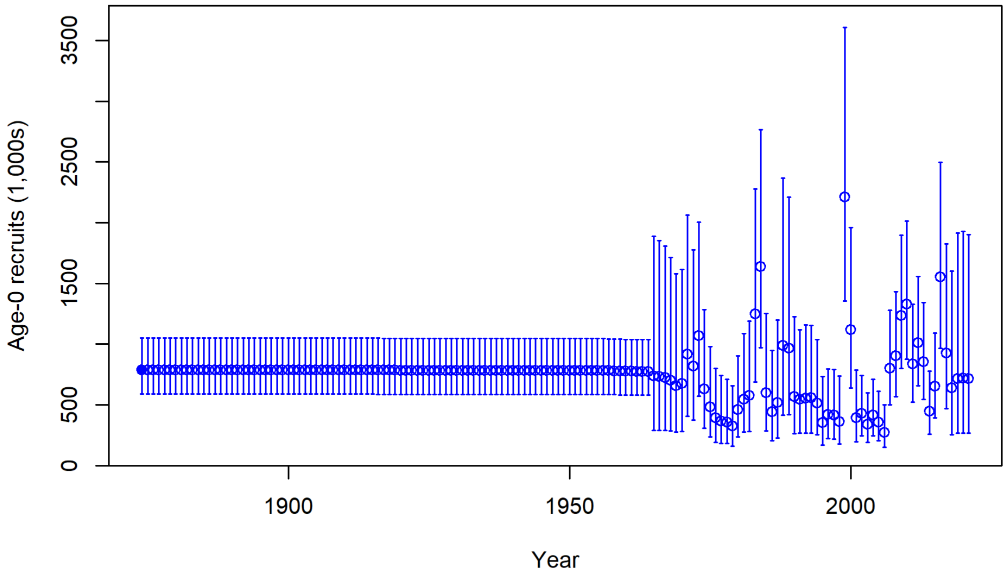

Figure iv: Age-0 recruits (1,000s) with approximate 95% asymptotic confidence intervals.

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

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

Exploitation Status

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

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

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

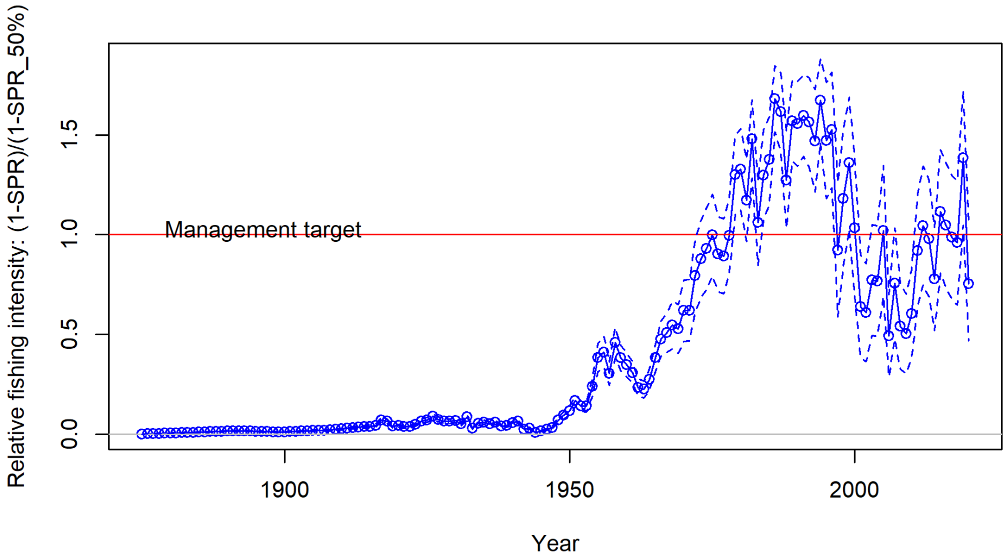

Figure v: Timeseries of relative fishing intensity ($\frac{1-SPR}{1-SPR_{50\%}}$ where SPR is the spawning potential ratio) with approximate 95% asymptotic confidence intervals (dashed lines).

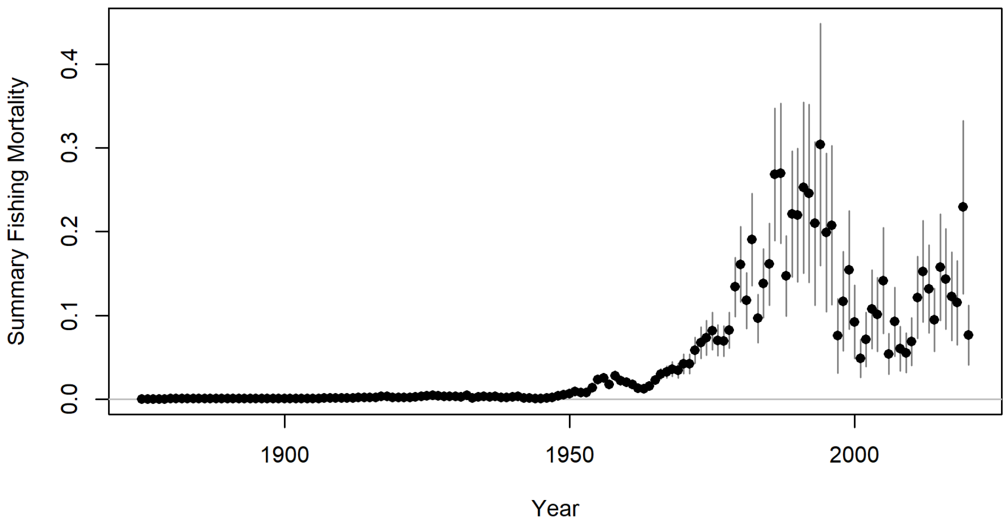

Figure vi: Time-series of estimated summary harvest rate (total catch divided by age-4 and older biomass) for the base case model with approximate 95% asymptotic confidence intervals (veritcal lines).

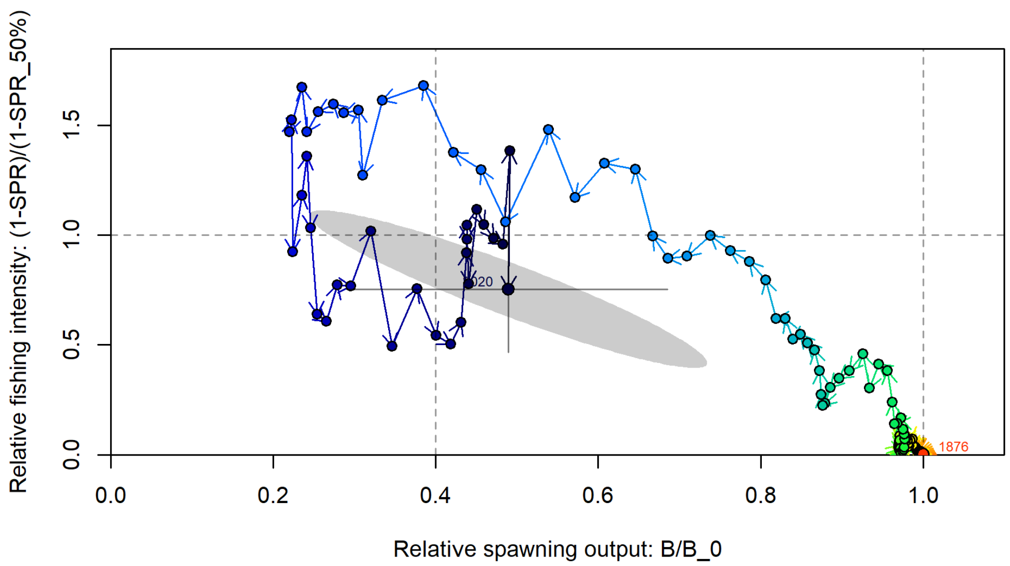

Figure vii: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show the 95% intervals based on the asymptotic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

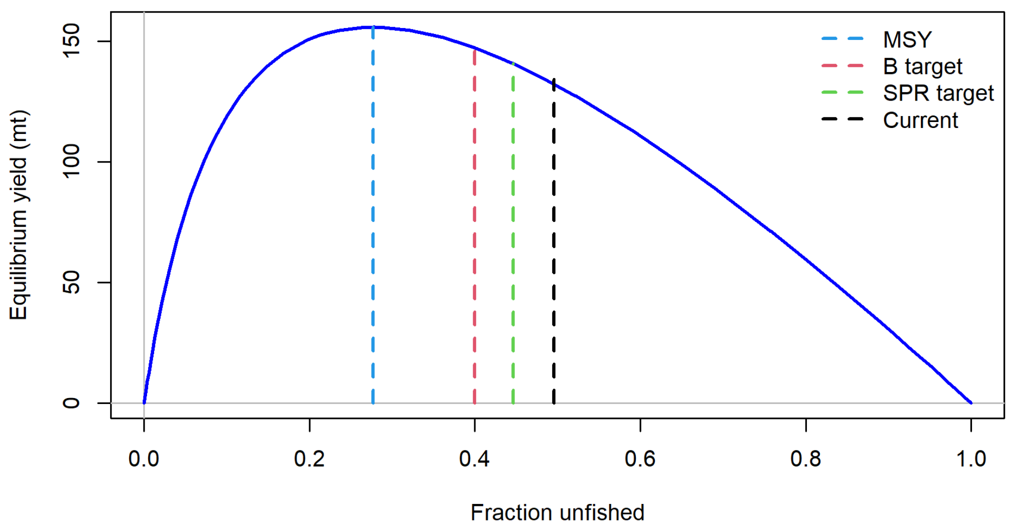

Figure viii: Equilibrium yield curve for the base case model with management quantities. Values are based on the 2020 fishery selectivities.

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. 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/sunset. Such approaches would require more development and evaluation. Consequently, environmental factors are not explicitly considered in this assessment.

Reference Points

Reference point and management quantities for the vermilion rockfish base case model can be found in Table v. In 2021, spawning output relative to unfished spawning output ("depletion") is estimated at 48% (95% asymptotic interval: 26% - 71%). This stock assessment estimates that vermilion rockfish in the south is above the biomass target ($SB_{40\%}$), and well above the minimum stock size threshold ($SB_{25\%}$). Unfished age four-plus biomass is estimated to be 6011 mt in the base case model (95% asymptotic interval: 4805 - 7217 mt). The target spawning output ($SB_{40\%}$) is 391 million eggs (95% asymptotic interval: 311 - 471 million eggs), which corresponds with an equilibrium yield of 156 mt (95% asymptotic interval: 125 - 187 mt). Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 148 mt (95% asymptotic interval: 121 - 176 mt), Table v and Figure viii).

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

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

Management Performance

Vermilion rockfish have been managed as part of the minor shelf rockfish complexes in the Pacific Coast Groundfish Fishery Management Plan. North $40°10'N$ 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 2019-2020. 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 CA model allocated to the northern management area (north of $40°10'N$) is based on an Appendix in northern CA assessment.

Table vi: Summary of recent estimates and managment quantities for vermilion rockfish.

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

Table vii: Annual estimates of total mortality, overfishing limit (OFL), acceptable biological catch (ABC), annual catch limit (ACL) for vermilion 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 viii: Combined reference points for the four stock assessments conducted for vermilion and sunset rockfishes 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)	977.8	1145.2	1094.8	2072.6	50.4	29.2	2.8	82.4
Total Biomass, mt	6263.3	6458.0	6173.8	12437.1	284.1	439.4	36.6	760.2
Unfished Recruitment (1000s of fish)	809.3	420.2	401.7	1211.0	18.5	16.3	2.5	37.3
Spawning Output (2021, 10^6 eggs)	471.2	489.4	467.9	939.1	21.5	21.4	1.5	44.4
Fraction Unfished (2021)	0.5	0.4				0.7	0.6	
Reference Points Based on $SPR_{50\%}$								
Proxy Spawning Output (10^6 eggs)	439.0	510.9	488.4	927.5	22.5	13.0	1.2	36.7
Proxy MSY, mt	148.3	139.0	132.9	281.2	6.1	7.9	0.8	14.8
GMT Projected Catch, 2021, mt	210.3	226.8	216.8	427.1	10.0	13.0	2.7	25.6
GMT Projected Catch, 2022, mt	210.3	226.8	216.8	427.1	10.0	13.0	3.3	26.2
OFL 2023, mt	159.4	154.2	147.4	306.8	6.8	13.5	0.7	21.0
OFL 2024, mt	158.8	157.8	150.9	309.7	6.9	13.4	0.7	21.0
OFL 2025, mt	158.8	159.5	152.5	311.3	7.0	13.2	0.7	20.9
OFL 2026, mt	159.0	159.9	152.8	311.8	7.0	12.9	0.7	20.6
OFL 2027, mt	159.3	159.4	152.4	311.7	7.0	12.6	0.7	20.3
OFL 2028, mt	159.6	158.7	151.7	311.3	7.0	12.3	0.7	20.0
OFL 2029, mt	159.9	157.8	150.8	310.7	6.9	12.0	0.7	19.7
OFL 2030, mt	160.3	157.0	150.1	310.3	6.9	11.8	0.8	19.4
OFL 2031, mt	160.6	156.3	149.5	310.1	6.9	11.5	0.8	19.2
OFL 2032, mt	161.1	155.9	149.0	310.1	6.9	11.3	0.8	18.9

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 Panel discussed the potential for alternative stratifications such as north and south of Cape Mendocino depending on the results of future analysis of population structure under the Saltonstall/Kennedy grant.

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 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 $34°27'N$.

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

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

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

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

Table ix: Projections of potential OFLs (mt), ABCs (mt), estimated age 4+ biomass (mt), estimated spawning output (10^6 eggs) and fraction unfished.

Year	Predicted OFL	ABC Catch	Age 4+ Biomass	Spawning Output	Fraction Unfished
2021	169.293	169.293	3450.76	471.178	0.481859
2022	168.096	168.096	3457.17	474.244	0.484994
2023	166.360	145.399	3461.48	479.835	0.490712
2024	165.792	143.410	3477.53	488.193	0.499260
2025	165.412	141.758	3485.04	495.306	0.506534
2026	165.119	140.186	3487.73	500.637	0.511986
2027	164.882	138.666	3487.35	504.314	0.515746
2028	164.704	137.198	3485.62	506.676	0.518161
2029	164.590	135.951	3483.70	508.092	0.519610
2030	164.536	134.590	3482.23	508.879	0.520414
2031	164.548	133.284	3481.83	509.328	0.520873
2032	164.625	132.194	3482.77	509.642	0.521195

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

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

Research and Data Needs

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

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

- Develop a coastwide hook-and-line survey to provide indices of abundance and associated biological sampling providing representative data in untrawlable habitats.
- Examine the available tools more fully in cases when a survey's footprint is abruptly changed as a result of management action. These tools may include (but are not limited to), treating the "new" and "old" surveys as completely separate (aka breaking the survey), using selectivity blocks, or spatial/temporal modeling approaches. This avenue is important for many fishery-independent and -dependent indices, as they are subjected to numerous spatial management changes which in turn can affect the veracity of the data collected. Additional efforts are needed to investigate how fishery selectivity changes with management changes and how best to address the effects of management changes on length composition and indices.
- Expansion of the California Collaborative Fisheries Research Project from the current 120 ft depth or starting similar surveys that sample in deeper waters outside, if not inside MPAs and other closed areas to encompass the full depth distribution of vermilion and sunset rockfish or other shallow shelf rockfish species would provide valuable data for future assessments.
- Conduct additional investigations to resolve uncertainties in historical catch reconstructions would improve estimates of the scale of assessments and provide more representative removal estimates.
- Explore appropriate methods of including catches as numbers of fish vs. biomass.
- There is currently a very small amount of fishery-dependent age data collected in Southern California such that none were included in the Southern California stock assessment.
- Continue the NWFSC hook-and-line survey, which is a very important and informative source of data for the Southern California stock assessment. Additional research into methods to standardize the hook-and line survey.