Agenda Item C.6
Attachment 6
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Status of Vermilion rockfish (*Sebastes miniatus*) along the US West - Oregon coast in 2021

by
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Contents

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Executive Summary

Stock

This assessment reports the status of vermilion rockfish (*Sebastes miniatus*) off Oregon state using data through 2020. Vermilion rockfish are also found in California (their core range) and Washington waters of the U.S. West Coast, and those are treated in separate stock assessments given different mangement considerations and exploitation histories. There is substantial biogeographic separation in the populations off Oregon and Washington, thus justifying separation of those populations into different management units and stock assessments.

Landings

Vermilion rockfish have been caught mainly by hook and line gear in commercial and recreational fisheries (Figure i). Commercial catches ramped up in the late 1960s followed by decreasing catches since the mid-1980s. Recreational catches started to increase in the 1980s, fluctuating over time, with high catches over the last several years (Table i).

Table i: Recent landings by fleet and total landings summed across fleets.

Year	Commercial	Recreational	Total Landings
2011	2.95	6.10	9.05
2012	2.79	9.15	11.94
2013	3.42	6.30	9.73
2014	2.28	3.95	6.23
2015	1.47	4.65	6.12
2016	2.02	3.69	5.71
2017	3.26	8.80	12.06
2018	3.09	9.20	12.29
2019	3.86	9.25	13.11
2020	3.05	8.24	11.29

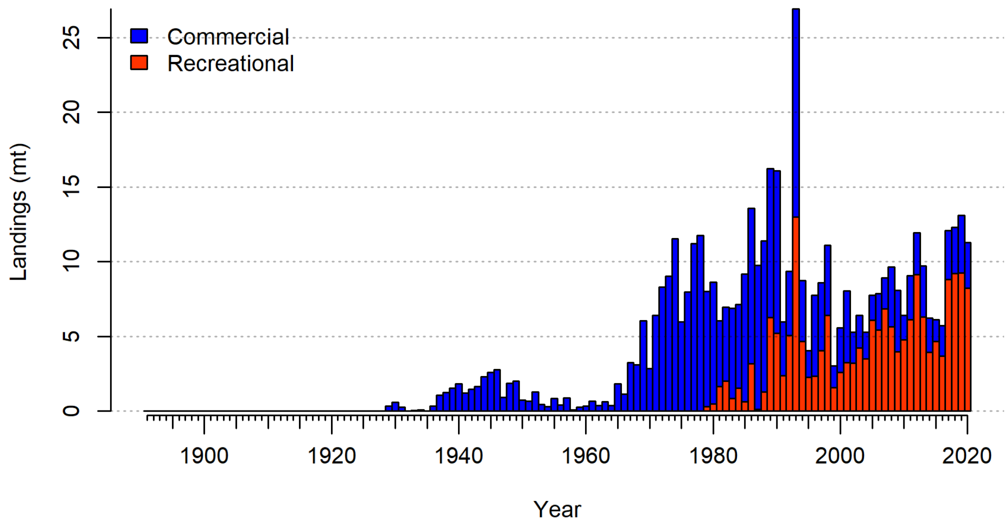

Figure i: Landings by fleet used in the reference model where catches in metric tons by fleet are stacked.

Data and Assessment

The stock assessment for vermilion rockfish off Oregon was developed using the length- and age-structured model Stock Synthesis (version 3.30.16). No previous stock assessment for vermilion rockfish off Oregon has been conducted. Model structure included two fleets (commercial and recreational) and one fishery-based index of abundance. Life history parameters were sex-specific (i.e., a two-sex model) with natural mortality and growth parameters estimated, along with recruitment. The model covers the years 1892 to 2020, with a 12 year forecast beginning in 2021.

This assessment integrates data and information from multiple sources into one modeling framework. Specifically, the assessment uses landings data, length and conditional age-at-length composition data (using ageing error matrices to incorporate ageing imprecision) for each fishery, and one index of abundance based on the recreational fishery; fixed parameterizations of weight-at-length, maturity-at-length, and fecundity-at-length, the Beverton-Holt stock-recruitment steepness value and recruitment variability. Estimated values include initial population scale (lnR_0), natural mortality and growth for each sex, asymptotic selectivity and recruitment deviations. The base model was tuned to account for the weighting of the length and age data and index variances (which was estimated), as well as the specification of recruitment variance and recruitment bias adjustments. Derived quantities include the time series of spawning biomass, age and size structure, and current and projected future stock status.

Within model uncertainty is explicitly included in this assessment by parameter estimation uncertainty, while among model uncertainty is explored through sensitivity analyses addressing alternative input assumptions such as data treatment and weighting, and model specification sensitivity to the treatment of life history parameters, selectivity, and recruitment. A reference model was selected that best fit the observed data while concomitantly balancing the desire to capture the central tendency across those sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model misspecification.

Stock Biomass

Spawning output (in millions of eggs; meggs) instead of spawning biomass is used to report the mature population scale because fecundity is nonlinearly related to body female weight. The estimated spawning output at the beginning of 2021 was 21 meggs (~95 percent asymptotic intervals: 10 to 33 meggs, Table ii and Figure ii), which when compared to unfished spawning output (29) meggs gives a relative stock status level of 73 percent (~95 percent asymptotic intervals: 48 to 98 percent, Figure iii). Overall, spawning output declined with the onset of increasing commercial removals in the 1960s and continued to decline with the increase in recreational catches through the 1990s, even dropping below the target relative stock size. The largest of the estimated recruitment pulses since the mid 1990s (that are supported by each of the data sets) caused a sharp increase in spawning output through the mid 2010s, followed by another decline. The minimum relative stock size of 34 percent of unfished levels is estimated to have occurred in 1995. Currently the stock is estimated well above the management target of $SB_{40\%}$ in 2021 and is estimated to have remained above the target since 2000 (Table ii and Figure iii).

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

Year	Spawning Output	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2011	27.41	14.59	40.23	0.94	0.65	1.22
2012	27.04	14.33	39.75	0.92	0.65	1.20
2013	26.42	13.82	39.02	0.90	0.63	1.18
2014	25.87	13.42	38.32	0.88	0.61	1.16
2015	25.47	13.23	37.70	0.87	0.61	1.14
2016	24.94	12.97	36.92	0.85	0.59	1.11
2017	24.38	12.69	36.07	0.83	0.58	1.08
2018	23.26	11.85	34.67	0.80	0.55	1.04
2019	22.25	11.05	33.45	0.76	0.52	1.00
2020	21.47	10.34	32.60	0.73	0.49	0.98
2021	21.35	10.06	32.65	0.73	0.48	0.98

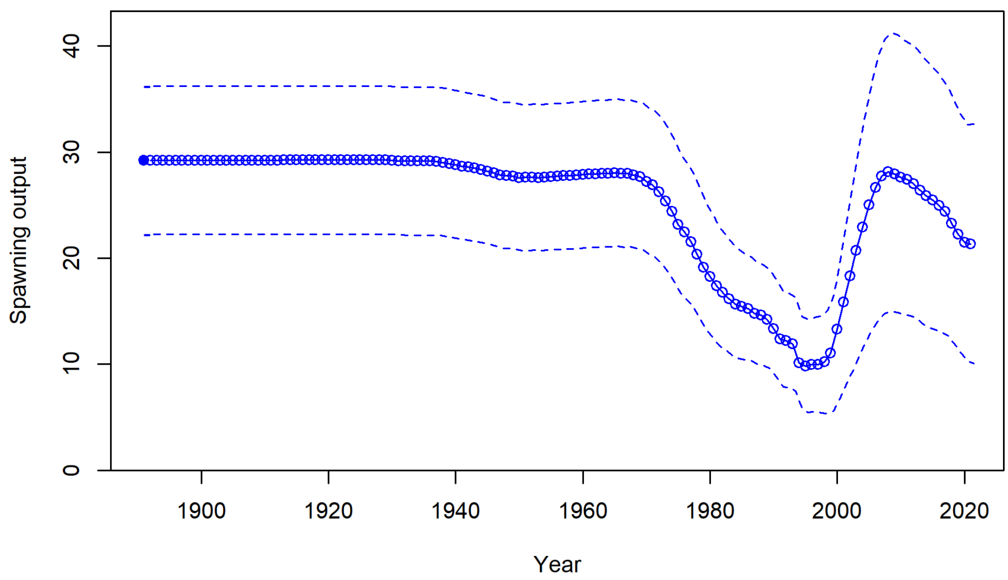

Figure ii: Estimated time series of spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

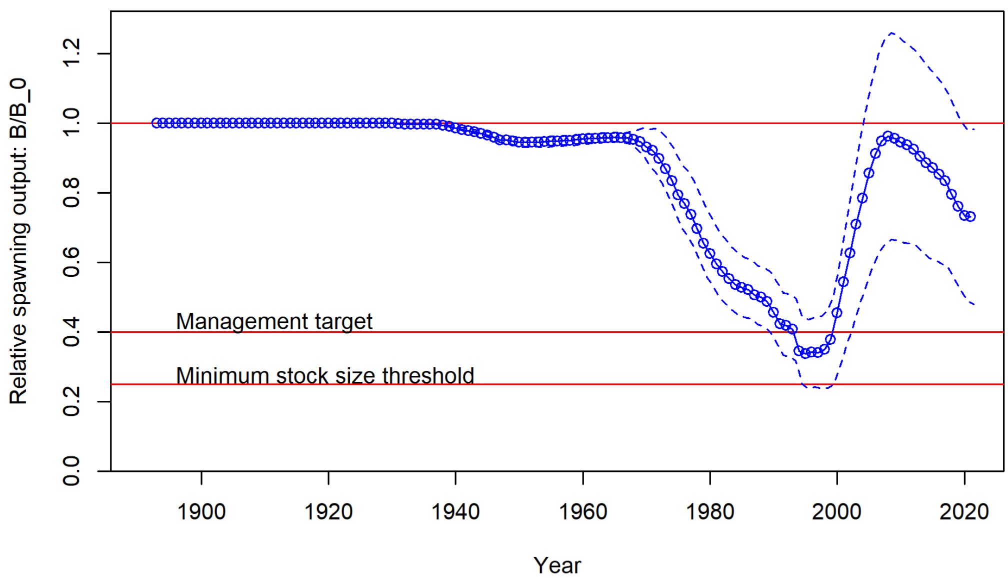

Figure iii: Estimated time series of fraction of unfished spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

Recruitment

Informative recruitment begins in the 1960s and peaks in the 1990s (Table iii and Figure iv). Data were most informative from the the 1990s to the mid-2010s. Peaks years of recruitments are found in years 1993, 1994, 1998, 2005 and 2015 (Figure v). Overall, the vermilion rockfish stock has not been reduced to levels that would provide considerable information on how recruitment compensation changes across spawning biomass levels (i.e., inform the steepness parameter). Thus, all recruitment is based on a fixed assumption about steepness (h = 0.72) and recruitment variability ($\sigma_R = 0.6$).

Table iii: Estimated recent trend in recruitment (1000s of fish) and recruitment deviations and the 95 percent intervals.

Year	Recruitment	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2011	6.69	3.07	14.55	-0.73	-1.34	-0.12
2012	23.17	12.48	43.01	0.51	0.15	0.87
2013	9.65	4.34	21.42	-0.36	-1.00	0.28
2014	31.41	15.11	65.28	0.82	0.29	1.36
2015	78.28	36.66	167.13	1.74	1.16	2.31
2016	11.62	3.82	35.39	-0.32	-1.39	0.74
2017	15.03	4.59	49.17	-0.06	-1.23	1.11
2018	14.79	4.53	48.24	-0.07	-1.24	1.09
2019	14.71	4.51	48.02	-0.07	-1.24	1.09
2020	14.64	4.48	47.84	-0.07	-1.24	1.09
2021	15.77	4.89	50.88	0.00	-1.18	1.18

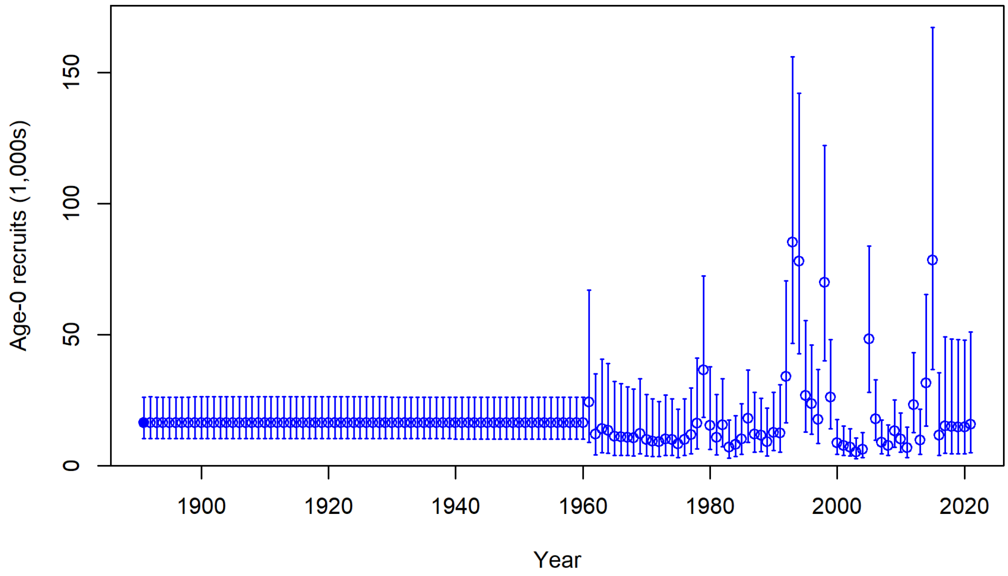

Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95 percent intervals.

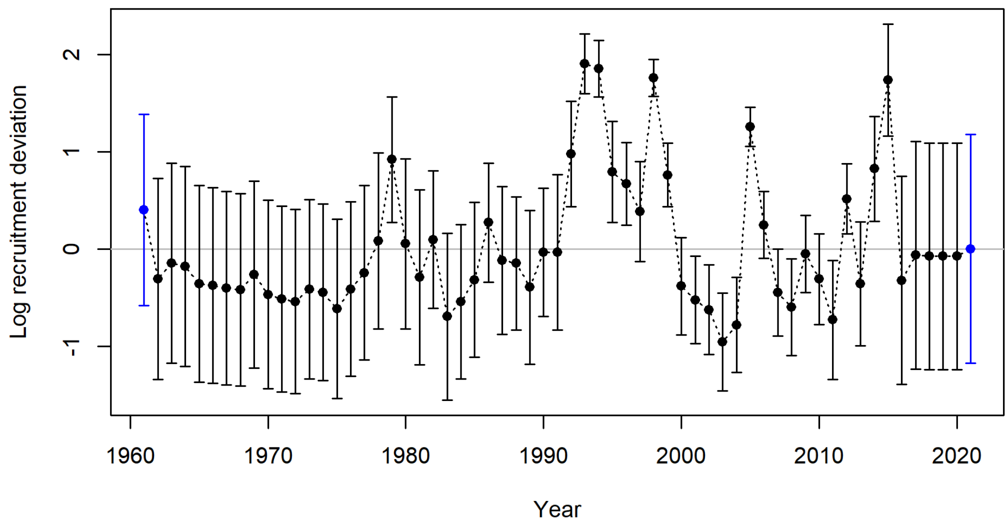

Figure v: Estimated time series of recruitment deviations.

Exploitation Status

Trends in fishing intensity (1 - SPR) largely mirrored that of landings until the 1990s when recruitment pulses overcame the catches to lower overall fishing intensity (Figure vi). The maximum fishing intensity was 0.84 in 1993, above the target SPR-based harvest rate of 0.50 (1 - $SPR_{50\%}$). Current levels of 0.47 for 2020 are near the fishing limit. Fishing intensity over the past decade has ranged between 0.27 and 0.51 and the exploitation rate has been high (0.02 - 0.05, Table iv). Current estimates indicate that vermilion rockfish spawning output is much greater than than the target biomass level ($SB_{40\%}$), though fishing intensity remains near target F_{MSY} proxy harvest rate.

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

Year	1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2011	0.35	0.20	0.50	0.03	0.02	0.04
2012	0.43	0.26	0.59	0.04	0.02	0.06
2013	0.38	0.22	0.53	0.03	0.02	0.05
2014	0.28	0.15	0.41	0.02	0.01	0.03
2015	0.28	0.15	0.41	0.02	0.01	0.03
2016	0.27	0.15	0.40	0.02	0.01	0.03
2017	0.47	0.30	0.63	0.05	0.02	0.07
2018	0.48	0.31	0.65	0.05	0.03	0.07
2019	0.51	0.33	0.69	0.05	0.03	0.08
2020	0.47	0.29	0.64	0.05	0.02	0.07

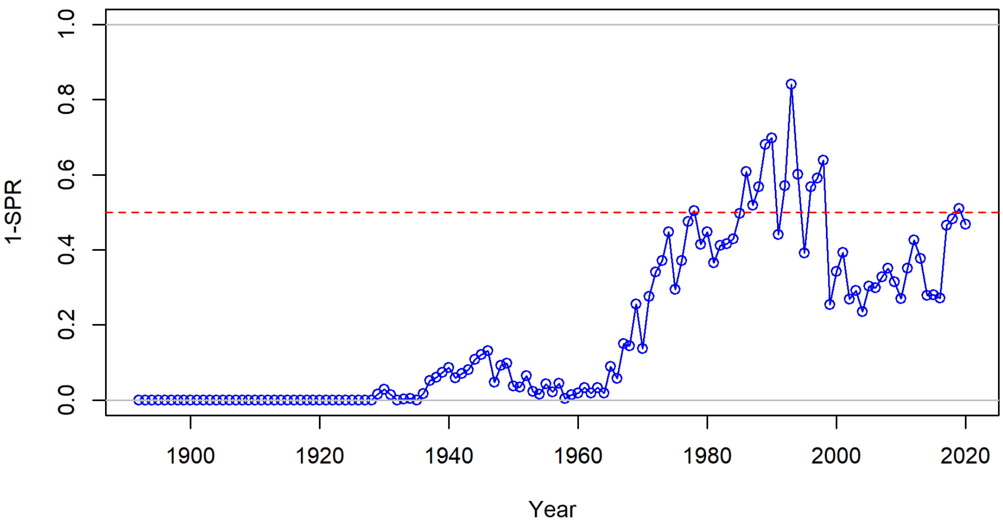

Figure vi: Estimated 1 - relative spawning ratio (SPR) by year for the base model. The management target is plotted as a red horizontal line and values above this reflect harvest in excess of the proxy harvest rate.

Ecosystem Considerations

This stock assessment does not explicitly incorporate trophic interactions, habitat factors or environmental factors into the assessment model. More predation, diet and habitat work, and mechanistic linkages to environmental conditions would be needed to incorporate these elements into the stock assessment.

Reference Points

The 2021 spawning biomass relative to unfished equilibrium spawning biomass is well above the management target of 40 percent of unfished spawning biomass. The relative biomass and the ratio of the estimated SPR to the management target ($SPR_{50\%}$) across all model years are shown in Figure vii where warmer colors (red) represent early years and colder colors (blue) represent recent years. There have been periods where the stock status has decreased below the target and fishing intensity has been higher than the target fishing intensity based on $SPR_{50\%}$. Figure viii shows the equilibrium curve based on a steepness value fixed at 0.72 with vertical dashed lines to indicate the estimate of fraction unfished at the start of 2021 (current) and the estimated management targets calculated based on the relative target biomass (B target), the SPR target, and the maximum sustainable yield (MSY).

Reference points were calculated using the estimated selectivities and catch distributions among fleets in the most recent year of the model, 2020 (Table v). Sustainable total yield, removals, using an $SPR_{50\%}$ is 7.95 mt. The spawning output equivalent to 40 percent of the unfished spawning output ($SO_{40\%}$) calculated using the SPR target ($SPR_{50\%}$) was 13.04 meggs. Recent removals have been close to the point estimate of potential long-term yields calculated using an $SPR_{50\%}$ reference point and the population size has been relatively decreasing toward the target over the past few years.

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

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	29.24	22.19	36.29
Unfished Age 3+ Biomass (mt)	354.37	278.67	430.07
Unfished Recruitment (R0)	16.33	8.52	24.13
Spawning Output (2021)	21.35	10.06	32.65
Fraction Unfished (2021)	0.73	0.48	0.98
Reference Points Based SB40%			
Proxy Spawning Output SB40%	11.70	8.88	14.51
SPR Resulting in SB40%	0.46	0.46	0.46
Exploitation Rate Resulting in SB40%	0.06	0.05	0.07
Yield with SPR Based On SB40% (mt)	8.32	5.57	11.07
Reference Points Based on SPR Proxy for MSY			

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

	Estimate	Lower Interval	Upper Interval
Proxy Spawning Output (SPR50)	13.04	9.90	16.19
SPR50	0.50		
Exploitation Rate Corresponding to SPR50	0.05	0.04	0.06
Yield with SPR50 at SB SPR (mt)	7.95	5.32	10.57
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB MSY)	8.04	6.28	9.81
SPR MSY	0.35	0.34	0.35
Exploitation Rate Corresponding to SPR MSY	0.09	0.07	0.11
MSY (mt)	8.82	5.89	11.76

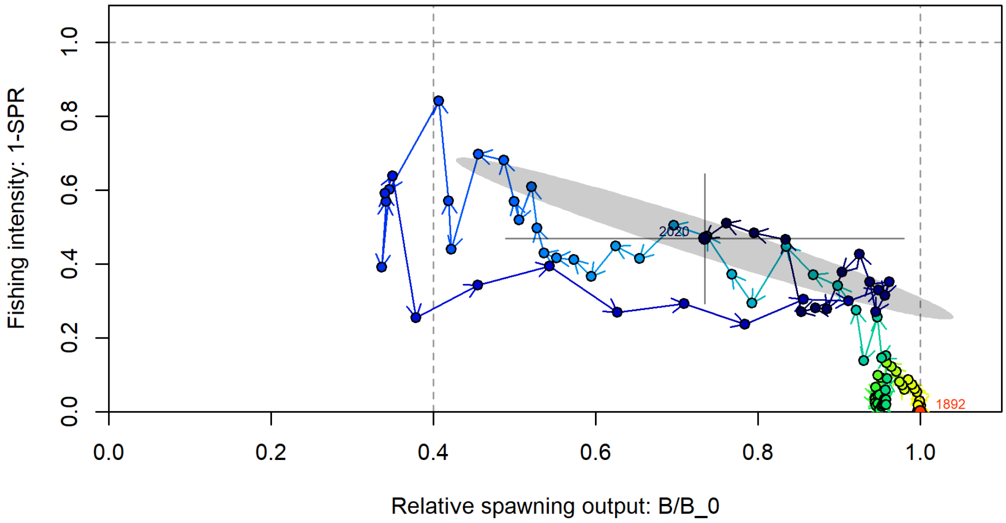

Figure vii: Phase plot of estimated 1-SPR versus fraction unfished for the base model.

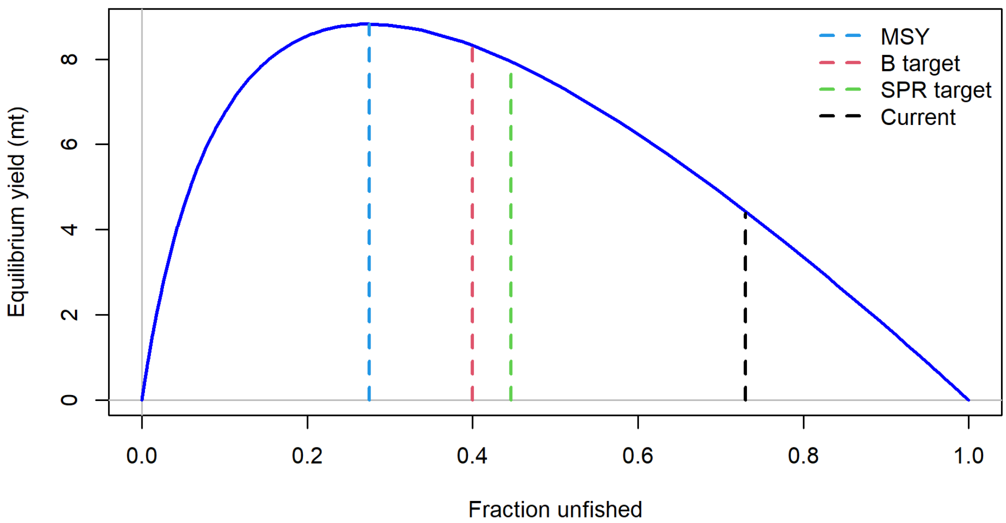

Figure viii: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities and with steepness fixed at 0.80.

Management Performance

Exploitation on vermilion rockfish increased starting around 1960 and reached a high in the early 1990s. Since that time, catch has mostly fluctuated between 5 and 10 mt per year, with some years exceeding 10 mt, particularly in the last 4 years. The last ten years of the vermilion rockfish component acceptable biological catch (ABC) and annual catch limit (ACL) (which are equivalent) of the Minor Shelf Rockfish North Complex has been set, by definition, below the overfishing limit (OFL) (Table vi). The vermilion rockfish component OFL for this Complex has been exceeded by the Oregon removals in the most recent 4 years.

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

Year	OFL	ABC	ACL	Landings	Est. Total Mortality
2011	11.1	5.6	5.6	9.1	9.1
2012	11.1	5.6	5.6	11.9	11.9
2013	9.7	8.1	8.1	9.7	9.7
2014	9.7	8.1	8.1	6.2	6.2
2015	9.7	8.1	8.1	6.1	6.1
2016	9.7	8.1	8.1	5.7	5.7
2017	9.7	8.1	8.1	12.1	12.1
2018	9.7	8.1	8.1	12.3	12.3
2019	9.7	8.1	8.1	13.1	13.1
2020	9.7	8.1	8.1	11.3	11.3

Unresolved Problems and Major Uncertainties

Natural mortality (M) was estimated by the model, though vermilion rockfish longevity is not well understood in Oregon. While the estimated sex-specific M values seem well within reason, the model remains sensitive to the choice of this parameter, and therefore improving the M prior (the prior used in this model may be centered on the higher end) while continuing to collect age data for future estimation within the model is important. This also plays through the collection of lengths to go with ages to continue to improve the estimation of age and growth. Future work on improving point estimates and possibly investigate time-varying life history parameters could improve model fits.

Functional maturity is an emerging concept in reproductive biology capturing physiological behaviors such as delayed maturity, skipped spawning and atresia and correcting for them in the length at maturity relationship. Investigating functional maturity could improve the application of maturity in the model.

Fishery-independent surveys would add additional support for those trends seen using fishery-based data.

Scientific Uncertainty

The model-estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.27$ and the uncertainty around the OFL was $\sigma = 0.31$. This is likely an underestimate of overall uncertainty because of the necessity to fix some parameters such as steepness, as well as a lack of explicit incorporation of model structural uncertainty.

Harvest Projections and Decision Table

A ten year (2023-2032) projection of the reference model with removals in 2021 and 2022 provided by the Groundfish Management Team for each fleet under the category 1 (sigma=0.5) time-varying buffer using $P^* = 0.45$ and 40-10 ABC control rule is provided in Table vii.

Table vii: Projections of potential OFLs (mt), ABCs (mt), the buffer (ABC = buffer x OFL), estimated spawning biomass, and fraction unfished. The North of 40°10'N OFL and ABC for 2021 and 2022 are included for comparison.

Year	OFL 40°10'N	ACL 40°10'N	Predicted OFL	ABC Catch	Buffer	Spawning Output	Fraction Unfished
2021	9.70	8.10	13.01	12.96	1.00	21.37	0.73
2022	9.70	8.10	13.35	12.96	1.00	21.53	0.73
2023	-	-	13.41	12.54	0.94	21.75	0.74
2024	-	-	13.29	12.36	0.93	21.85	0.75
2025	-	-	13.03	12.06	0.93	21.74	0.74
2026	-	-	12.72	11.73	0.92	21.46	0.73
2027	-	-	12.41	11.38	0.92	21.08	0.72
2028	-	-	12.10	11.05	0.91	20.65	0.71
2029	-	-	11.82	10.74	0.91	20.20	0.69
2030	-	-	11.56	10.45	0.90	19.75	0.68
2031	-	-	11.31	10.18	0.90	19.33	0.66
2032	-	-	11.08	9.94	0.90	18.92	0.65

The decision table (Table viii) was constructed using female and male natural mortality to define the low and high states of nature. The multi-parameter likelihood profile was used to find the low (Female M = 0.07092; Male M= 0.06525) and high (Female M = 0.08527; Male M = 0.07845) female and male natural mortality values that produce -log likeliehood values +0.66 units from the reference -log likelihood value. These correspond to the 12.5% and 87.5% quantiles (standard quantiles used in west coast decision tables). The catch rows in the table were based on three proposed catch streams: 1. P* = 0.45, sigma = 0.5 2. P* = 0.40, sigma = 0.5 3. An equilibrium catch based on the F_{MSY} proxy using SPR = 0.5.

Across all states of natures and catch streams, vermilion rockfish relative stock size never falls below the target relative stock size of 40%. Both P* approaches lower the stock status from the high relative stock size values, while the F_{MSY} proxy does not. The mismatch in the corresponding steepness value ($h = 0.6$) that matches MSY at SPR = 0.5 with the steepness value in the stock assessment ($h = 0.72$) that correpsonds to an MSY SPR of 0.35 explains why this constant catch will maintain the stock at very high relative stock status levels.

Table viii: Decision table summary of 10 year projections beginning in 2023 for alternative states of nature based on an axis of uncertainty about female and male natural mortality for the reference model. Columns range over low (12.5 quantile), mid (reference model), and high states (87.5 quantile) of nature and rows range over different catch level assumptions. Values in italics indicate years where the stock size prevented the full catch removals.

			Female M = 0.071; Male =0.065		Female M = 0.079; Male =0.073		Female M = 0.085; Male =0.079	
	Year	Catch	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
	2021	12.96	17.70	0.62	21.37	0.73	24.46	0.79
	2022	12.96	17.76	0.62	21.53	0.73	24.68	0.80
	2023	12.60	17.89	0.63	21.79	0.74	25.01	0.81
	2024	12.45	17.93	0.63	21.92	0.75	25.20	0.82
	2025	12.19	17.81	0.63	21.85	0.74	25.16	0.82
P*=0.45	2026	11.89	17.56	0.62	21.63	0.74	24.93	0.81
sigma=0.5	2027	11.56	17.23	0.60	21.29	0.72	24.58	0.80
	2028	11.24	16.86	0.59	20.90	0.71	24.16	0.78
	2029	10.93	16.46	0.58	20.48	0.70	23.70	0.77
	2030	10.63	16.06	0.56	20.04	0.68	23.23	0.75
	2031	10.36	15.67	0.55	19.62	0.67	22.76	0.74
	2032	10.10	15.29	0.54	19.21	0.65	22.31	0.72
	2021	12.96	17.70	0.62	21.37	0.73	24.46	0.79
	2022	12.96	17.76	0.62	21.53	0.73	24.68	0.80
	2023	11.77	17.89	0.63	21.79	0.74	25.01	0.81
	2024	11.60	18.00	0.63	21.99	0.75	25.27	0.82
	2025	11.34	17.96	0.63	21.99	0.75	25.30	0.82
P*=0.4	2026	11.04	17.78	0.62	21.84	0.74	25.14	0.82
sigma=0.5	2027	10.72	17.53	0.62	21.58	0.73	24.87	0.81
	2028	10.41	17.22	0.60	21.25	0.72	24.51	0.79
	2029	10.10	16.89	0.59	20.89	0.71	24.11	0.78
	2030	9.82	16.56	0.58	20.52	0.70	23.70	0.77
	2031	9.55	16.23	0.57	20.15	0.69	23.29	0.76
	2032	9.29	15.91	0.56	19.80	0.67	22.89	0.74
	2021	12.96	17.70	0.62	21.37	0.73	24.46	0.79
	2022	12.96	17.76	0.62	21.53	0.73	24.68	0.80
	2023	7.95	17.89	0.63	21.79	0.74	25.01	0.81
	2024	7.95	18.32	0.64	22.30	0.76	25.58	0.83
FMSY proxy	2025	7.95	18.59	0.65	22.62	0.77	25.92	0.84
SPR=0.5	2026	7.95	18.72	0.66	22.75	0.77	26.05	0.84
	2027	7.95	18.73	0.66	22.75	0.77	26.03	0.84
	2028	7.95	18.66	0.66	22.65	0.77	25.89	0.84
	2029	7.95	18.53	0.65	22.47	0.76	25.67	0.83
	2030	7.95	18.36	0.64	22.25	0.76	25.39	0.82
	2031	7.95	18.16	0.64	21.99	0.75	25.09	0.81
	2032	7.95	17.94	0.63	21.71	0.74	24.76	0.80

Research and Data Needs

1. Resolution in stock structure. Continued sampling of vermilion rockfish in Oregon would allow for more genetic understanding of population structure. In addition, consideration of fishery similarities between northern California (north of Cape Menodcino) and southern Oregon may be worth further consideration to see if that is a better grouping of stocks compared to combining central and northern California.

2. Continued quantification of ageing error. The CARE exchange has high value in general to further our ability to understand the inherent variability of reading ageing structures, and should be strongly supported.

3. The life history parameters are all assumed constant through time. This assumption of stationarity is one of convenience and parsimony. Any insight into the changing of life history values or differing productivity regimes could help refine these assumptions.

4. Natural mortality proved the source of greatest uncertainty in the model. While empirical methods can help define priors for natural mortality, good sampling of age structure or direct measures (e.g., tagging) are preferred. Oregon's robust sampling program may include ways to collect data that can directly improve natural mortality estimation and reduce model uncertainty.

5. Ongoing sampling of biological data will remain a core component of information in the stock assessment and needs to be continued and supported.

6. A fishery-independent index of abundance would be a welcome inclusion in this assessment, along with the ongoing development of the ORBS index (e.g., the appropriateness of applying the Stephens-MacCall filtering method to fisheries data; how to treat months with different management measures).

7. The large uncertainty estimated in this stock assessment was limited given the asymptotic, symmetric variance estimation from the maximum likelihood estimation method. While a Bayesian model was considered and even explored for this model, it was not included due to challenges in implementation and lack of enough time to achieve a converged model. Continuted development of Bayesian approaches to characterizing uncertainty are strongly encouraged.

8. Ensemble modelling may be another potential tool to incorporate model uncertainty beyond within model variance estimation that should be considered.

9. Fishery selectivity continues to be challenging to represent, and are key parameters in the model. Blocks in selectivity and whether there are *apriori* reasons to expect any dome-shaped selectivity deserve continued thought. The change of selectivity within a year (e.g., some seasons have depth restriction, others do not) should also be a topic of discussion.