Agenda Item C.6
Attachment 7
September 2021

Status of Vermilion rockfish (*Sebastes miniatus*) along the US West - Washington State coast in 2021

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August 2021

Correct citation for this publication:

Cope, J.M., T.-. Tsou, K. Hinton, C. Niles. 2021. Status of Vermilion rockfish (*Sebastes miniatus*) along the US West - Washington State coast in 2021. Pacific Fishery Management Council, Portland, Oregon. 0 p.

Contents

Disclaimer

Executive Summary

Stock

This assessment reports the status of vermilion rockfish (*Sebastes miniatus*) off Washington state using data through 2020. Vermilion rockfish are also found in California and Oregon waters, but those are treated separately in other stock assessments. The core range of vermilion rockfish are in California, thus outside Washington waters; this assessment thus considers a very small population at the limit of the species range under different mangement considerations and exploitation histories than vermilion rockfish stocks in either California or Oregon. 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. Vermilion in Canadian waters are also rare and not included in this assessment.

Landings

Vermilion rockfish are mainly caught in recreational fisheries by hook and line gear (Figure i). Recreational catches are generally low, but in relative terms increased in mid-1980s and have fluctuated since to a peak catch in 2019 (Table i). Vermilion are not targets in the Washington recreational fishery and are considered rare.

Table i: Recent fishery and total landings (in 1000s of fish).

Year	Fishery	Total Landings
2011	0.518	0.518
2012	0.489	0.489
2013	0.538	0.538
2014	0.534	0.534
2015	0.673	0.673
2016	0.416	0.416
2017	0.491	0.491
2018	0.621	0.621
2019	1.294	1.294
2020	0.325	0.325

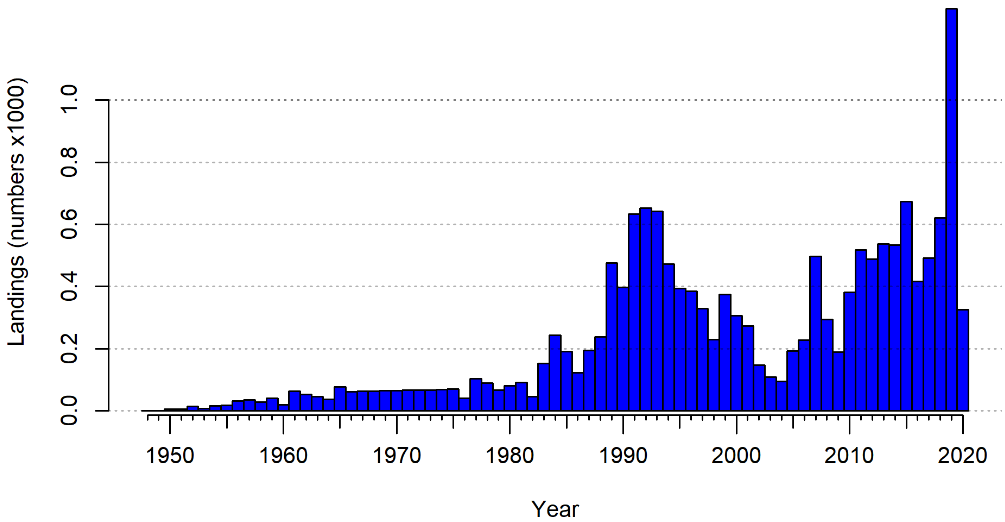

Figure i: Landings (1000s of fish) used in the reference model.

Data and Assessment

The stock assessment for vermilion rockfish off Washington state was developed using the length- and age-structured model Stock Synthesis (version 3.30.16). No previous stock assessment for vermilion rockfish off Washington has been conducted. Model structure included one recreational fleet. 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 1949 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 recreational landings data, and length and conditional age-at-length composition data (using ageing error matrices to incorporate ageing imprecision); 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), sex-specific natural mortality and growth, asymptotic selectivity and recruitment deviations. The base model was tuned to account for the weighting of the length and age data, as well as the specification of recruitment variance and recruitment bias adjustments. Derived quantities include the time series of spawning output, age and size structure, and current and projected future stock status.

Uncertainty is explicitly included in this assessment through variances of all estimated parameters, while among model uncertainty is explored through sensitivity analyses 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 female body weight. The estimated spawning output at the beginning of 2021 was 2 meggs (~95 percent asymptotic intervals: -1 to 4 meggs, Table ii and Figure ii), which when compared to unfished spawning biomass (3) meggs gives a relative stock status level of 56 percent (~95 percent asymptotic intervals: 6 to 107 percent, Figure iii). Overall, spawning output declined with the onset of increasing recreational removals in the mid-1980s and continued to decline with the increase in recreational catches through the 1990s. The largest of the estimated recruitment pulses since the late 1990s (that are supported by each of the data sets) caused a small increase in the spawning output through the early 2010s, after which a very small decline is observed. The minimum relative stock size of 55 percent of unfished levels is estimated to have occurred in 2002. Currently the stock is estimated to be above the management target of $SB_{40\%}$ in 2021 and has never dropped below the target throughout the time series (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	1.82	<0.01	3.89	0.66	0.36	0.97
2012	1.82	<0.01	3.94	0.66	0.34	0.99
2013	1.81	<0.01	3.98	0.66	0.32	1.00
2014	1.81	<0.01	4.02	0.66	0.30	1.02
2015	1.80	<0.01	4.06	0.66	0.28	1.04
2016	1.77	<0.01	4.08	0.64	0.24	1.05
2017	1.77	<0.01	4.13	0.65	0.23	1.07
2018	1.76	<0.01	4.15	0.64	0.20	1.08
2019	1.72	<0.01	4.14	0.62	0.17	1.08
2020	1.56	<0.01	3.99	0.57	0.07	1.07
2021	1.55	<0.01	4.00	0.56	0.06	1.07

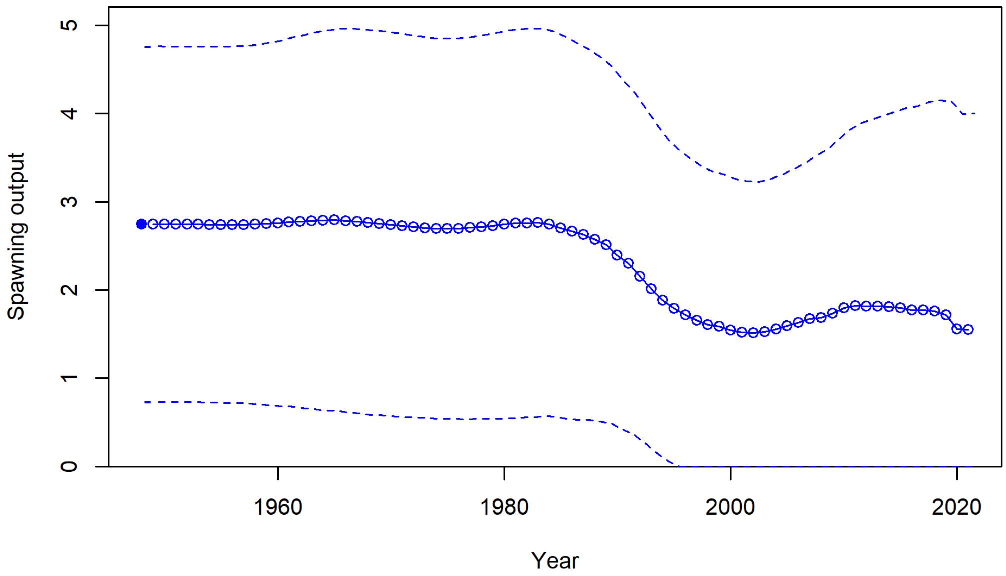

Figure ii: Estimated time series of spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

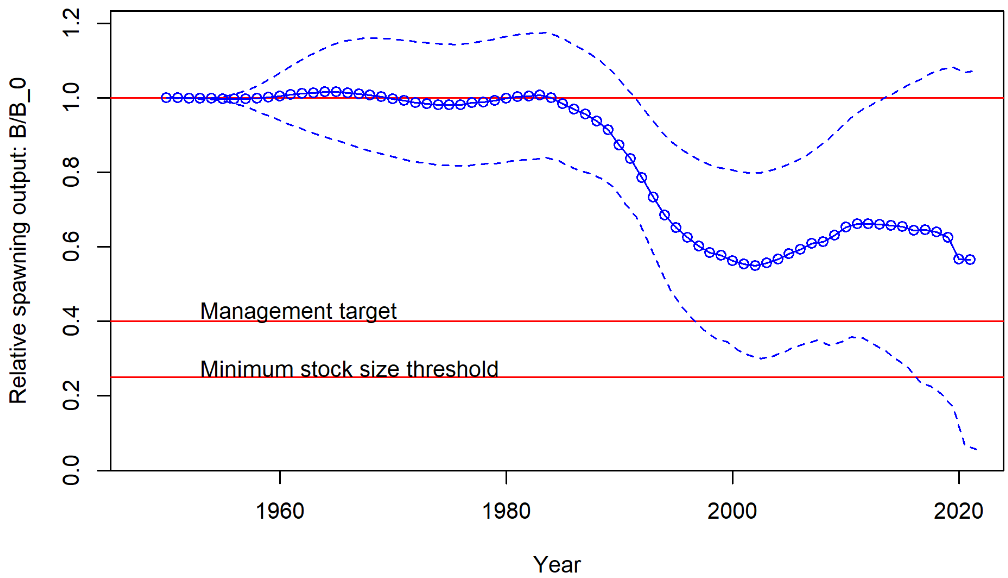

Figure iii: Estimated time series of fraction of unfished spawning output (circles and line: median; light broken lines: 95 percent intervals) for the base model.

Recruitment

Recruitment information is overall weak for this model; informative recruitments start to appear in the 1980s and peak in early 2000s (Table iii and Figure iv). Data were most informative from the 1990s to the mid-2010s. Peak years of recruitments are found in years 1995-1996, 1999-2000, 2006, and 2011 (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 (σ_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	2.97	0.72	12.36	0.30	-0.56	1.15
2012	1.77	0.42	7.56	-0.23	-1.20	0.74
2013	1.63	0.38	6.93	-0.33	-1.32	0.66
2014	1.81	0.42	7.77	-0.24	-1.28	0.81
2015	1.94	0.45	8.47	-0.18	-1.28	0.92
2016	2.24	0.50	9.95	-0.04	-1.19	1.10
2017	2.35	0.53	10.53	-0.01	-1.17	1.16
2018	2.35	0.52	10.56	-0.01	-1.17	1.16
2019	2.35	0.52	10.56	-0.01	-1.17	1.16
2020	2.32	0.51	10.55	-0.01	-1.17	1.16
2021	2.33	0.51	10.55	0.00	-1.18	1.18

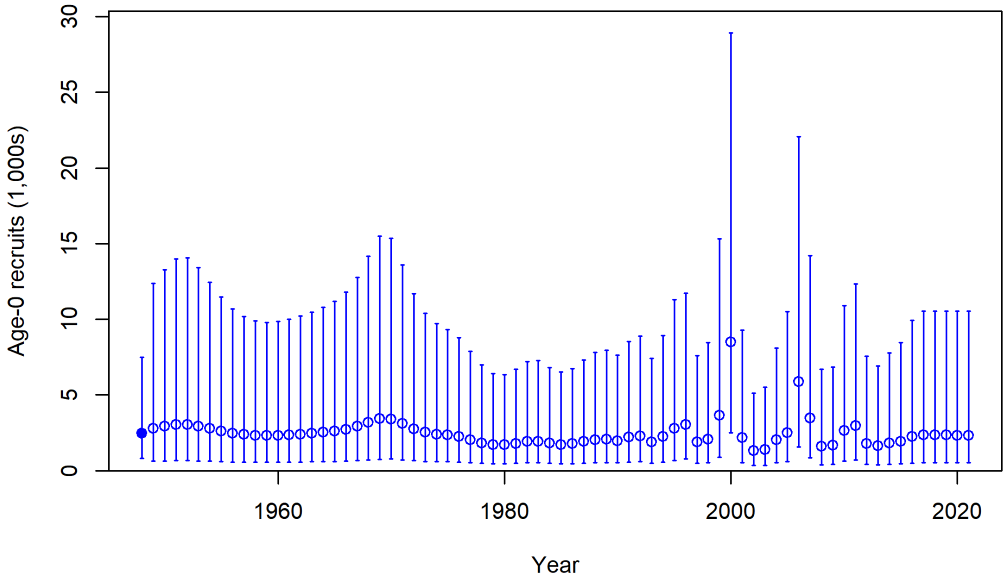

Figure iv: Estimated time series of age-0 recruits (1000s) for the base model with 95 percent intervals.

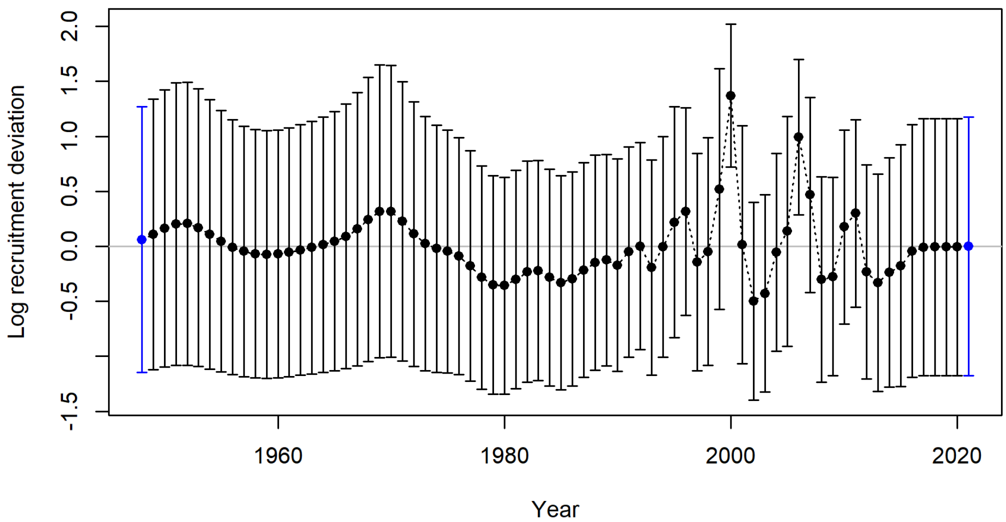

Figure v: Estimated time series of recruitment deviations.

Exploitation Status

Trends in fishing intensity (1 - SPR) largely mirrored that of landings (Table iv; Figure vi). The maximum fishing intensity was 0.75 in 2019, above the target SPR-based harvest rate of 0.50 (1 - $SPR_{50\%}$). Current levels of 0.4 for 2020 are below the retrospectively estimated fishing limit, but 2019 was the highest on record. Fishing intensity over the past decade has ranged between 0.4 and 0.75 and the exploitation rate has been moderate (0.04 - 0.14, Table iv). Current estimates indicate that vermilion rockfish spawning output is greater than than the target biomass level ($SB_{40\%}$), though fishing intensity has fluctuated 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	0.47	0.09	0.84	0.05	0.00	0.10
2012	0.45	0.08	0.83	0.04	0.00	0.10
2013	0.48	0.09	0.87	0.05	0.00	0.11
2014	0.48	0.08	0.88	0.05	0.00	0.11
2015	0.55	0.14	0.96	0.06	0.00	0.14
2016	0.42	0.02	0.82	0.04	0.00	0.09
2017	0.47	0.05	0.89	0.05	0.00	0.11
2018	0.54	0.10	0.98	0.06	0.00	0.14
2019	0.75	0.38	1.12	0.14	0.00	0.33
2020	0.40	0.00	0.84	0.04	0.00	0.09

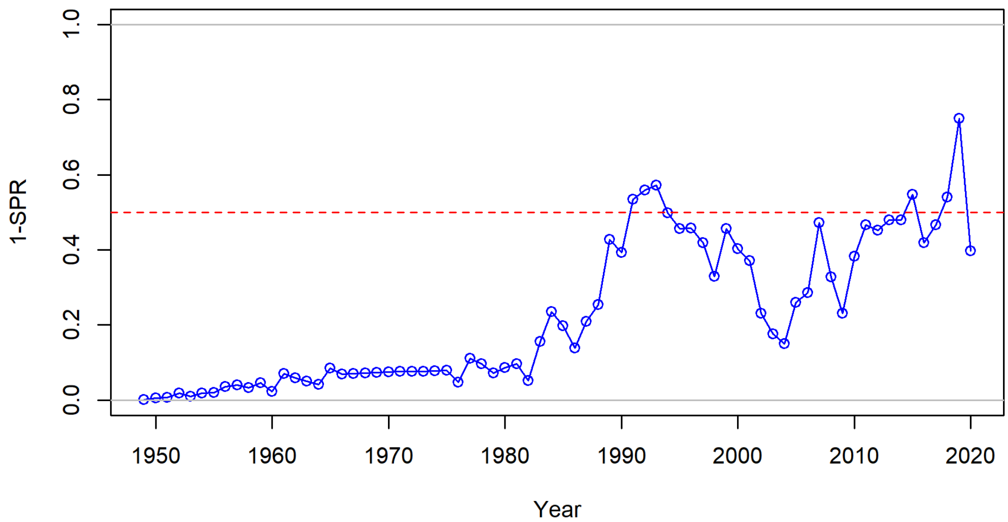

Figure vi: Estimated 1 - relative spawning ratio (SPR) by year for the base model. The management target is plotted as a red horizontal line and values above this reflect harvest in excess of the proxy harvest rate.

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 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 fishing intensity has been higher than the target fishing intensity based on $SPR_{50\%}$, but the stock status has always been above the target. 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 selectivity and catch distribution for the recreational fleet in the most recent year of the model, 2020 (Table v). Sustainable total yield, removals, using a $SPR_{50\%}$ is 0.771 mt. The spawning output equivalent to 40 percent of the unfished spawning biomass ($SB_{40\%}$) calculated using the SPR target ($SPR_{50\%}$) was 1.225 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 fluctuating, but consistently above 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	2.75	0.74	4.75
Unfished Age 3+ Biomass (mt)	36.04	8.49	63.60
Unfished Recruitment (R0)	2.48	0.00	5.46
Spawning Output (2021)	1.55	0.00	4.00
Fraction Unfished (2021)	0.56	0.06	1.07
Reference Points Based SB40%			
Proxy Spawning Output SB40%	1.10	0.30	1.90
SPR Resulting in SB40%	0.46	0.46	0.46
Exploitation Rate Resulting in SB40%	0.06	0.04	0.08
Yield with SPR Based On SB40% (mt)	0.81	0.05	1.57
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (SPR50)	1.23	0.33	2.12

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

	Estimate	Lower Interval	Upper Interval
SPR50	0.50		
Exploitation Rate Corresponding to SPR50	0.05	0.04	0.07
Yield with SPR50 at SB SPR (mt)	0.77	0.05	1.49
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB MSY)	0.75	0.28	1.22
SPR MSY	0.34	0.32	0.37
Exploitation Rate Corresponding to SPR MSY	0.09	0.06	0.13
MSY (mt)	0.87	0.05	1.70

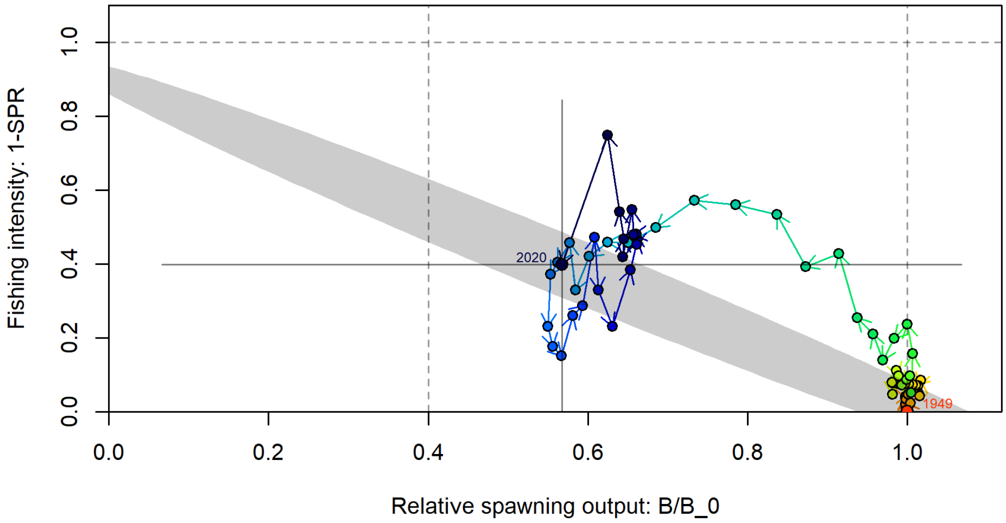

Figure vii: Phase plot of estimated 1-SPR versus fraction unfished for the base model.

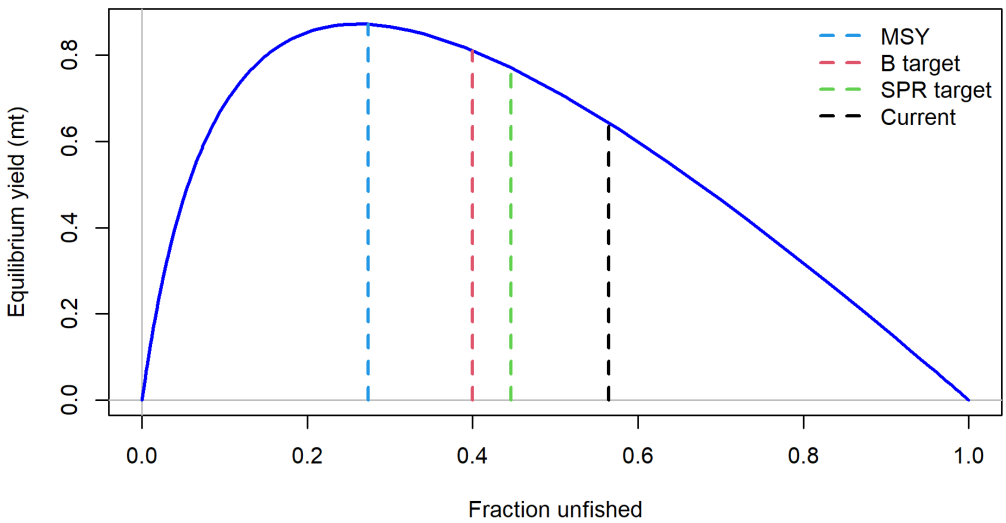

Figure viii: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities and with steepness fixed at 0.80.

Management Performance

Exploitation on vermilion rockfish increased starting around the mid-1980s and reaching relatively high levels in the early 1990s. Since that time, catch has mostly fluctuated between 100 and 700 fish a year, with a peak of >1200 fish in 2019. The last ten years of the vermilion component acceptable biological catch (ABC) and annual catch limit (ACL) (which are equivalent) of the Minor Shelf Rockfish North Complex are by definition set below the overfishing limit (OFL) (Table vi). The Washington contribution to the component ACL has not exceeded the colletitve vermilion rockfish component ACL for this complex, and is a very minor portion of the overall coastwide take of vermilion rockfish.

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	1.01	1.01
2012	11.1	5.6	5.6	0.95	0.95
2013	9.7	8.1	8.1	1.05	1.05
2014	9.7	8.1	8.1	1.04	1.04
2015	9.7	8.1	8.1	1.32	1.32
2016	9.7	8.1	8.1	0.82	0.82
2017	9.7	8.1	8.1	0.97	0.97
2018	9.7	8.1	8.1	1.24	1.24
2019	9.7	8.1	8.1	2.60	2.60
2020	9.7	8.1	8.1	0.66	0.66

Unresolved Problems and Major Uncertainties

This assessment, while having multiple years of length and age data, has low samples sizes for each data source. The growth estimates seem reasonable and do not tend to add a large amount of variability to the model outputs, the major source of uncertainty stems from the uncertainty in natural mortality. This uncertainy seems larger than even among model uncertainty in the treatments of data or alternative model specifications. The ability to decrease the uncertainty in this parameter would then bring attention back to alternative model specifications.

The structure of this model is simple– one non-target fleet and stationary productivity and selectivity with recruitment deviations allowing to add non-deterministic changes to the population, yet there is an observable retrospective pattern. This would suggest some sort of bias in the data and/or model misspecification. The limited data and simple model structure makes the latter difficult to explore. It may also be inherent in the fact that this is a small population sensitive to perturbations. Attention to this restrospective pattern should be maintained in future assessments as data increases.

The large ageing error seen in the Committee of Age Reading Experts (CARE) exchange was untenable for use in a reference model, but should be revisited with further exchanges to figure out why the Washington Depatment of Fish and Wildlife ageing was such an outlier to the other laboratories. Further work on the age and growth of vermilion rockfish in Washington would help improve the ageing error and overall growth estimates.

Historical catches are roughly estimated, though little additional information is available to improve this estimate. While historical catches are very uncertain, the levels are so small compared to the population that is makes little difference in model results, though remains an area of uncertainty.

Scientific Uncertainty

The model-estimated uncertainty around the 2021 spawning biomass was $\sigma = 0.71$ and the uncertainty around the OFL was $\sigma = 0.76$. 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 2 (sigma=1.0) 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	9.7	8.1	0.94	2.69	1.00	1.55	0.56
2022	9.7	8.1	0.84	3.26	1.00	1.37	0.50
2023	-	-	0.70	0.61	0.87	1.15	0.42
2024	-	-	0.70	0.61	0.87	1.14	0.42
2025	-	-	0.70	0.61	0.86	1.13	0.41
2026	-	-	0.71	0.61	0.85	1.13	0.42
2027	-	-	0.72	0.61	0.84	1.13	0.42
2028	-	-	0.73	0.61	0.83	1.13	0.43
2029	-	-	0.74	0.62	0.83	1.14	0.43
2030	-	-	0.75	0.62	0.82	1.14	0.43
2031	-	-	0.76	0.62	0.81	1.15	0.44
2032	-	-	0.77	0.62	0.80	1.16	0.44

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 = 1.0
2. P* = 0.40, sigma = 1.0
3. An equilibrium catch based on the F_{MSY} proxy using SPR = 0.5

Vermilion rockfish stock assessments in California had category 2 designations with more data, but also more uncertainty given the mixed species (sunset and vermilion rockfishes) nature of the fishery. It is believed only vermilion are caught in Washington state, but the category 2 sigma = 1.0 used in the decision tables was based on high model uncertainty.

Catch is modelled as numbers in the assessment, which necessitated conversion of biomass based estimates into numbers for projections. This means that while biomass-based catch streams within each row are static, the numbers associated with those biomass estimates change across the states of nature given age and length structures of varying among states of nature. This requires conversion of biomass to numbers in every year of all low and high states of nature in order to maintain the biomass estimates at expected values. A check was made for each scenario of the decision table to make sure inputted removals in numbers match the expected removals in biomass.

The fixed values for 2021-2022 are very high catches compared to the historical take of vermilion rockfish in Washington state. This has a notable effect on the stock size and status of the low M state of nature. While the reference and high state of nature runs keeps the population near or well above the target stock status for all catch streams, the low state of nature falls well below the overfished limit. The catch streams also show a large drop in catch after the fixed values of 2021-2022, highlighting how each catch control rule will lead to large reductions in future vermilion rockfish catch.

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 = 0.067; Male =0.069		Female M = 0.084; Male =0.086		Female M = 0.099; Male =0.100	
	Year	Catch	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
P*=0.45 sigma=1.0	2021	2.69	0.68	0.31	1.55	0.56	3.62	0.81
	2022	3.26	0.50	0.23	1.38	0.50	3.44	0.77
	2023	0.62	0.28	0.13	1.16	0.42	3.21	0.72
	2024	0.61	0.26	0.12	1.15	0.42	3.20	0.72
	2025	0.61	0.25	0.11	1.15	0.42	3.19	0.72
	2026	0.61	0.24	0.11	1.15	0.42	3.18	0.72
	2027	0.61	0.24	0.11	1.16	0.42	3.18	0.72
	2028	0.62	0.24	0.11	1.17	0.43	3.19	0.72
	2029	0.62	0.24	0.11	1.18	0.43	3.20	0.72
	2030	0.62	0.24	0.11	1.20	0.44	3.21	0.72
	2031	0.63	0.24	0.11	1.21	0.44	3.23	0.73
	2032	0.63	0.24	0.11	1.23	0.45	3.24	0.73
P*=0.4 sigma=1.0	2021	2.69	0.68	0.31	1.55	0.56	3.62	0.81
	2022	3.26	0.50	0.23	1.38	0.50	3.44	0.77
	2023	0.54	0.28	0.13	1.16	0.42	3.21	0.72
	2024	0.53	0.27	0.12	1.16	0.42	3.20	0.72
	2025	0.53	0.26	0.12	1.16	0.42	3.20	0.72
	2026	0.53	0.26	0.12	1.17	0.43	3.20	0.72
	2027	0.53	0.26	0.12	1.18	0.43	3.21	0.72
	2028	0.53	0.27	0.12	1.20	0.44	3.22	0.72
	2029	0.53	0.27	0.12	1.22	0.44	3.24	0.73
	2030	0.53	0.28	0.13	1.24	0.45	3.26	0.73
	2031	0.52	0.29	0.13	1.26	0.46	3.28	0.74
	2032	0.52	0.30	0.13	1.28	0.47	3.30	0.74
FMSY proxy SPR=0.5	2021	2.69	0.68	0.31	1.55	0.56	3.62	0.81
	2022	3.26	0.50	0.22	1.38	0.50	3.44	0.77
	2023	0.77	0.28	0.13	1.15	0.42	3.21	0.72
	2024	0.77	0.25	0.11	1.14	0.41	3.18	0.72
	2025	0.77	0.23	0.10	1.12	0.41	3.16	0.71
	2026	0.77	0.21	0.09	1.11	0.40	3.15	0.71
	2027	0.77	0.19	0.09	1.11	0.40	3.14	0.71
	2028	0.77	0.18	0.08	1.11	0.40	3.13	0.70
	2029	0.77	0.17	0.08	1.11	0.40	3.13	0.70
	2030	0.77	0.16	0.07	1.11	0.40	3.13	0.70
	2031	0.77	0.15	0.07	1.12	0.41	3.14	0.71
	2032	0.77	0.14	0.06	1.12	0.41	3.15	0.71

Research and Data Needs

1. Resolution in stock structure. The Washington population of vermilion rockfish seems to have a large degree of separation from the core population and even the main population found in Oregon. Washington state has begun sampling tissue from landed vermilion rockfish in order to add more resolution to the genetic relatedness among vermilion found in U.S. waters.

2. The degree of ageing error between otoliths read in the Washington Department of Fish and Wildlife agein lab and others in the CARE exchange highlights the need for further exchanges to determine why these differences exist, as they do not within the WDFW ageing lab, nor among the reads from the other labs. 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. While the small size and rare occurrence of vermilion rockfish off Washington state makes these direct methods a challenge to do, improved data collection may help with natural mortality estimation and reduce model uncertainty.

5. Sample sizes for biological data are small in this assessment, so increases in samples could help reduce model uncertainty. The practicality of this suggestion is questionable as the limited number of vermilion rockfish encountered makes it difficult to increase sample sizes.

6. A fishery-independent index of abundance would be a welcome inclusion in this assessment. Again, such a rarely encountered fish may be hard to monitor via an index of abundance, but the possibility of a nearshore/shallow shelf survey is welcome.

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, though again it is especially challenging given the rarity of occurrence and non-target nature of vermilion rockfish.