Fisheries and Oceans Canada

Pêches et Océans Canada

Ecosystems and Oceans Science

Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat

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Science Advisory Report 2022/001

YELLOWMOUTH ROCKFISH (*SEBASTES REEDI*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2021

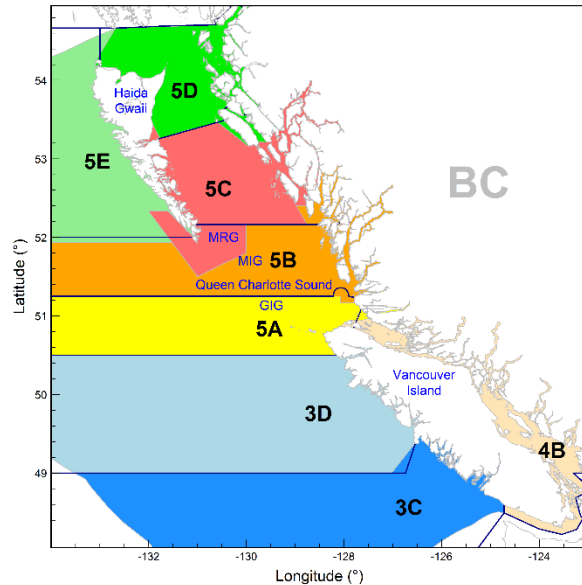Yellowmouth Rockfish (Sebastes reedi)
Credit: Terri Bonnet, DFO

Figure 1. Yellowmouth Rockfish assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major areas outlined with solid lines and used in this assessment. The Groundfish Management Unit area boundaries, based on *Pacific Fisheries Management Areas*, are superimposed as coloured polygons for comparison. This assessment is for PMFC areas 3CD+5ABCDE (excludes 4B).

Context

This is the second model-based stock assessment for Yellowmouth Rockfish (YMR, Sebastes reedi) after an initial assessment in 2011, which also provided a recovery potential analysis. YMR is almost exclusively fished by the commercial trawl fleet (84% bottom and 16% midwater), with minor amounts (<1%) caught by the other gear types (hook & line, trap). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the species as 'Threatened' in 2010, but the 2011 stock assessment determined the coastwide stock status to be in the Fisheries and Oceans Canada (DFO) Healthy zone. The species ranges from the Gulf of Alaska southward to northern California near San Francisco. In British Columbia (BC), the apparent area of highest concentration occurs in Queen Charlotte Sound with isolated hotspots west of Haida Gwaii and at the northern end of Vancouver Island. This species occurs along the west coast of Vancouver Island, but its density appears to be low south of Brooks Peninsula. YMR has been aged up to 90 years old, but ages higher than 60 years are uncommon in the biological data (<1%).

DFO Fisheries Management requested that DFO Science Branch assess YMR relative to reference points that are consistent with Decision-making Framework Incorporating the Precautionary Approach

(DFO 2009), and provide advice on the implications of various harvest strategies on projected stock status. These quantitative age-structured stock assessments generate harvest advice over the next 10 years.

*This Science Advisory Report is from the September 8-9, 2021 regional peer review on Yellowmouth Rockfish (*Sebastes reedi*) stock assessment for British Columbia in 2021. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.*

SUMMARY

- The Yellowmouth Rockfish (YMR) stock assessment evaluates a British Columbia (BC) coastwide population harvested by a single fishery dominated by bottom trawl. Midwater trawl catches (16% by weight over the period 1996 to 2020) of YMR were combined with bottom trawl for the purposes of this stock assessment. YMR catches by capture methods other than trawl were negligible, averaging less than 1% over the same period. Analyses of biology and distribution did not support separate regional stocks for YMR.

- The YMR stock was assessed using an annual two-sex catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated and derived parameters. The model framework adopted was National Oceanic and Atmospheric Administration's (NOAA) Stock Synthesis 3, a change from the platform used for the 2011 YMR stock assessment. A composite base case, consisting of five models covering a plausible range of fixed values for natural mortality (M), was used to evaluate stock status because M could not be reliably estimated using the model platform.

- This stock assessment was primarily informed by the catch per unit effort (CPUE) abundance series and the commercial fishery age frequencies. The YMR abundance indices from the fishery independent surveys had too much relative error to reliably monitor abundance while the associated survey age frequency data showed inadequate continuity for use in estimating year class strength.

- The median (with 5th and 95th percentiles) female spawning biomass at the beginning of 2022 (B_{2022}) was estimated to be 0.69 (0.44, 1.08) of the equilibrium unfished female spawning biomass (B_0). Also, B_{2022} was estimated to be 2.39 (1.54, 3.73) times the equilibrium spawning biomass at maximum sustainable yield, B_{MSY}.

- There was an estimated probability of 1 that $B_{2022} > 0.4B_{MSY}$ and a probability of 1 that $B_{2022} > 0.8B_{MSY}$ (i.e., of being in the Healthy zone). The probability that the exploitation rate in 2021 was below that associated with MSY was 0.95 for the commercial fishery.

- Advice to managers was presented in the form of decision tables using the provisional reference points from Fisheries and Oceans Canada's (DFO) [Decision Making Framework Incorporating the Precautionary Approach](#) (DFO 2009). The decision tables provided ten-year projections across a range of constant catches up to 3000 tonnes/year.

- The YMR stock was projected to remain above the limit reference point (LRP) ($0.4B_{MSY}$) and USR ($0.8B_{MSY}$) with a probability of >0.99 over the next 10 years at current levels of catch (1000-1250 t/y). Catches >1500 t/y were predicted to exceed the harvest rate limit (u_{MSY}) in 10 years with probability >50%.

- The appropriateness of the MSY-based reference points for long-lived, low productivity species is uncertain; consequently, advice relative to reference points based on 0.2 and 0.4 of B_0 was also presented as alternative options.

- It is recommended that a full re-assessment occurs in no more than 10 years, subject to the availability of new information. During intervening years, the trend in abundance can be tracked by commercial fishery CPUE and, less reliably (because of the high relative error), by the fishery independent surveys used in this stock assessment.

INTRODUCTION

Yellowmouth Rockfish (*Sebastes reedi*, YMR) ranges from the Gulf of Alaska southward to northern California near San Francisco. In BC, the apparent area of highest concentration occurs in Queen Charlotte Sound with isolated hotspots west of Haida Gwaii and at the northern end of Vancouver Island. This species occurs along the west coast of Vancouver Island, but its density appears to be low south of Brooks Peninsula.

In 2010, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the coastal population of YMR in British Columbia as 'Threatened', based on a decline in abundance and the threat from commercial fishing. As a result, the species was considered for legal listing under the *Species at Risk Act* (SARA). In a 2011 stock assessment (also acting as a recovery potential assessment, Edwards et al. 2012) put forward two base case runs ('Estimate *M*' and *M*=0.047), which both estimated that the B_{2011} stock status was well above the upper stock reference level, denoting a healthy stock in the DFO Sustainable Fisheries Framework (DFO 2009). In 2017, a decision was made not to list Yellowmouth Rockfish under Schedule 1 of the SARA. In 2019, Bill C-68 was enacted to amend the Fisheries Act with the Fish Stocks Provisions (FSP), prompting a national review of the approximately 180 stocks with Sustainability Surveys. Coastal BC Yellowmouth Rockfish is one of 18 groundfish stocks in the Pacific Region being considered for prescription under the new FSP regulations. The purpose of this YMR stock assessment was to evaluate the current stock status and provide advice suitable for input to a sustainable fisheries management plan.

This assessment covered all of the BC outer coast, including Pacific Marine Fisheries Commission (PMFC) major areas (3CD and 5ABCDE, Figure 1). The available biological data were examined for evidence of stock separation between the most northerly component of the YMR stock (west coast Haida Gwaii and western Dixon Entrance) and the remaining more southerly sections of the population. This potential split was chosen as the scenario with the greatest potential to show population differences based on observed differences found in other BC finfish populations. While some differences (growth, size, and composition taken by gear type) between areas were found, the differences were generally small and not always consistent across years or sexes. Furthermore, YMR data from the west coast of Haida Gwaii were sparse and this part of the coast only accounted for a relatively small proportion of the catch (12% mean from 1996–2020). Consequently, the authors elected to make the same single stock assumption that had been made by Edwards et al. (2012).

ASSESSMENT

The stock assessment used an annual catch-at-age model tuned to four fishery-independent trawl survey series, a bottom trawl CPUE series, annual estimates of commercial catch (Figure 2) since 1935, and age composition data from survey series (25 years of data from four surveys) and the commercial fishery (28 years of data). The model started from an assumed equilibrium state in 1935, the survey data covered the period 1967 to 2020 (although not all years were represented), and the CPUE series provided an annual index from 1996 to 2020.
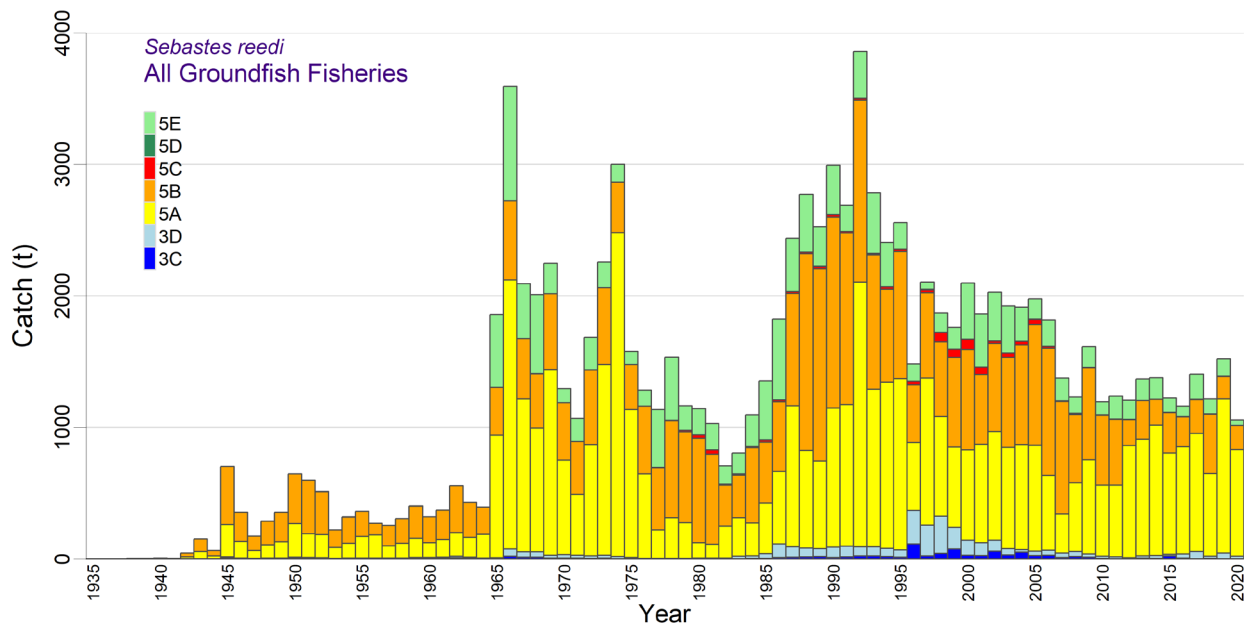
Figure 2. Catch reconstruction of Yellowmouth Rockfish from 1935 to 2020 used in the stock assessment model. The 2021 catch was assigned the same value (1057 t) as the 2020 catch.

A two-sex model was implemented in a Bayesian framework (using the Markov Chain Monte Carlo [MCMC] 'No U-Turn Sampling' procedure) to estimate five models which fixed natural mortality to each of five levels (0.04, 0.045, 0.05, 0.055, 0.06), spanning a range that was considered plausible and which returned acceptable MCMC diagnostics. The parameters estimated by these models included average recruitment and annual year class deviations over the period 1950–2012, and selectivities for the four surveys and the commercial trawl fleet. These five model runs were combined into a composite base case which covered the plausible range of the major axis of parameter uncertainty in this stock assessment. Fourteen sensitivity analyses were performed relative to the central run (M=0.05) of the composite base case to test the effect of alternative model assumptions.

The posterior parameter distributions for each component run of the base case were combined to create a composite posterior distribution of estimated parameters. This composite posterior distribution was then used to calculate a distribution of maximum sustainable yield (MSY) and associated reference points that reflected the assumed range of uncertainty in M and the relative weight given to the commercial CPUE. Ten-year projections were performed over a range of constant catches to estimate probabilities of breaching reference points. Advice to managers was presented as decision tables that provided probabilities of exceeding reference points (consistent with the 2009 DFO Precautionary Approach: $0.4B_{MSY}$; $0.8B_{MSY}$) as well as remaining below the harvest rate at MSY (u_{MSY}) for 2022 through 2032 for a range of constant catch levels.

Figure 3 shows the estimated annual spawning biomass (mature females only) relative to spawning biomass at MSY for the coastwide YMR stock depicted by the composite base case. The stock has fluctuated based on four good recruitment years (1952, 1962, 1982 and 2006, Figure 4), increasing to a level above the equilibrium biomass associated with average recruitment (B_0) over four decades (1965-2005) before declining to a low point in 2014. Thereafter, the spawning biomass increased to approximately 15,000 tonnes.

Estimated quantities from the MCMC posterior of the composite base case can be found in Table 1. The estimated median equilibrium MSY was 1039 tonnes (696, 1919), compared to the average catch over the last five years (2016-2020) of 1272 tonnes. The estimated current-year spawning biomass (B_{2022}) relative to equilibrium unfished biomass, $B_{2022}/B_0 = 0.69$ (0.44, 1.08), and to equilibrium spawning biomass that would support the MSY, $B_{2022}/B_{MSY} = 2.39$ (1.54, 3.73). Median exploitation rate in 2021 was low at 0.024 (0.010, 0.042). The estimated current-year exploitation rate relative to that at MSY was $u_{2021}/u_{MSY} = 0.51$ (0.20, 1.00) for the commercial fishery (Figure 5).
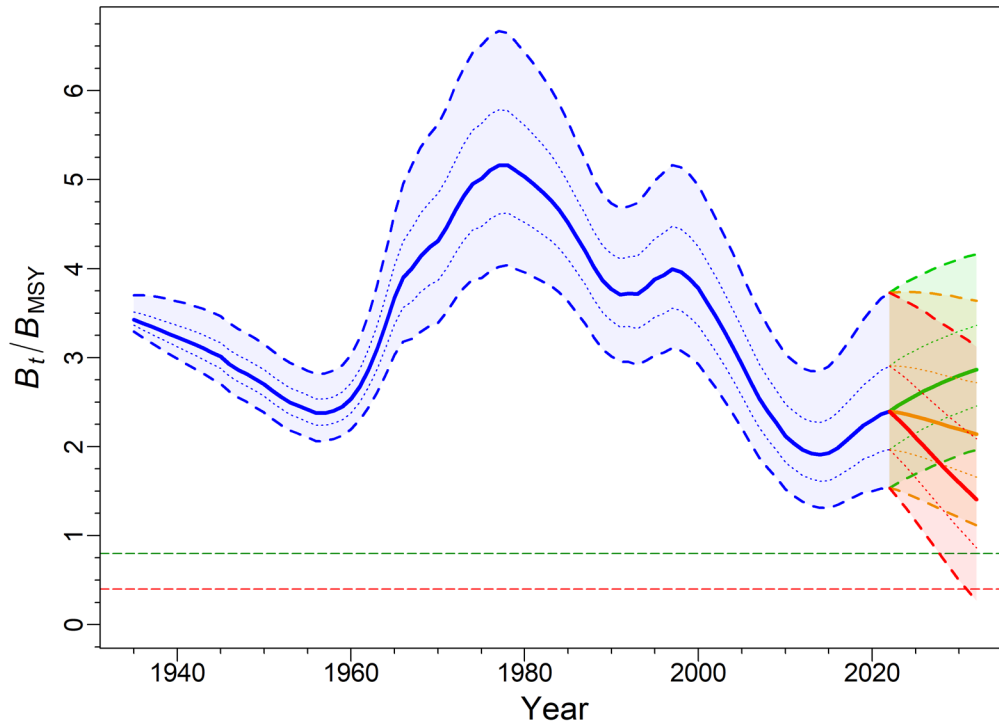

Figure 3. Estimates of spawning biomass B_t relative to B_{MSY} from the model posteriors (10,000 samples) of the YMR composite base case. The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05, 0.95) in blue and delimited by dashed lines for years t=1935–2022; projected biomass using constant catch appears in green (no catch), orange (1250 t/y), and red (2500 t/y) for years t=2023-2032 (10 years). Also shown is the 50% credibility interval (quantiles: 0.25–0.75) delimited by dotted lines.
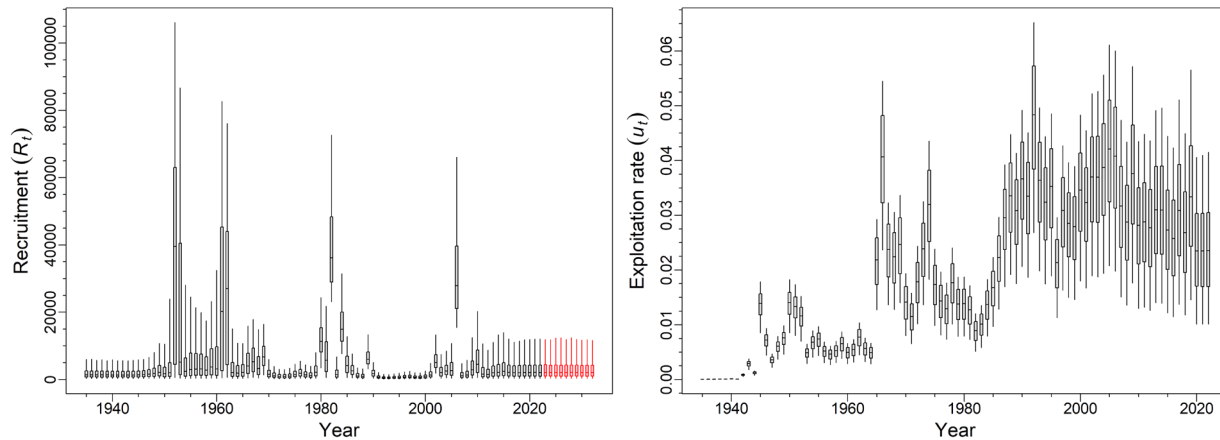
Figure 4. Composite base case marginal posterior distributions of annual recruitment (age-0 fish, left, including projected recruitment in red) and exploitation rate (right) for YMR. Boxplots give the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from pooled MCMC results.

Table 1. Quantiles of MCMC-derived quantities from 10,000 samples pooled from five component runs for the base case. Definitions: B_0 – unfished equilibrium spawning biomass (mature females), B_{2022} – spawning biomass at the start of 2022, u_{2021} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2021, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2021), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY. All biomass values (including MSY) are in tonnes. The average catch over the last 5 years (2016-20) was 1272 t.

| Quantity	5%	25%	50%	75%	95%
B_0	20,898	23,707	26,386	30,528	41,314
B_{2022}	10,070	13,848	18,001	24,978	42,533
B_{2022} / B_0	0.4446	0.5708	0.6922	0.8417	1.08
u_{2021}	0.01012	0.01697	0.02357	0.03048	0.04154
u_{max}	0.02686	0.03845	0.04837	0.0573	0.06531
MSY	695.7	845.4	1,039	1,327	1,919
B_{MSY}	6,063	6,894	7,656	8,810	11,938
$0.4B_{MSY}$	2,425	2,758	3,063	3,524	4,775
$0.8B_{MSY}$	4,850	5,515	6,125	7,048	9,550
B_{2022} / B_{MSY}	1.535	1.969	2.394	2.905	3.727
B_{MSY} / B_0	0.2702	0.2847	0.2917	0.2971	0.3036
u_{MSY}	0.04063	0.04356	0.04636	0.04893	0.05117
u_{2021} / u_{MSY}	0.2019	0.3471	0.5082	0.7066	1.001
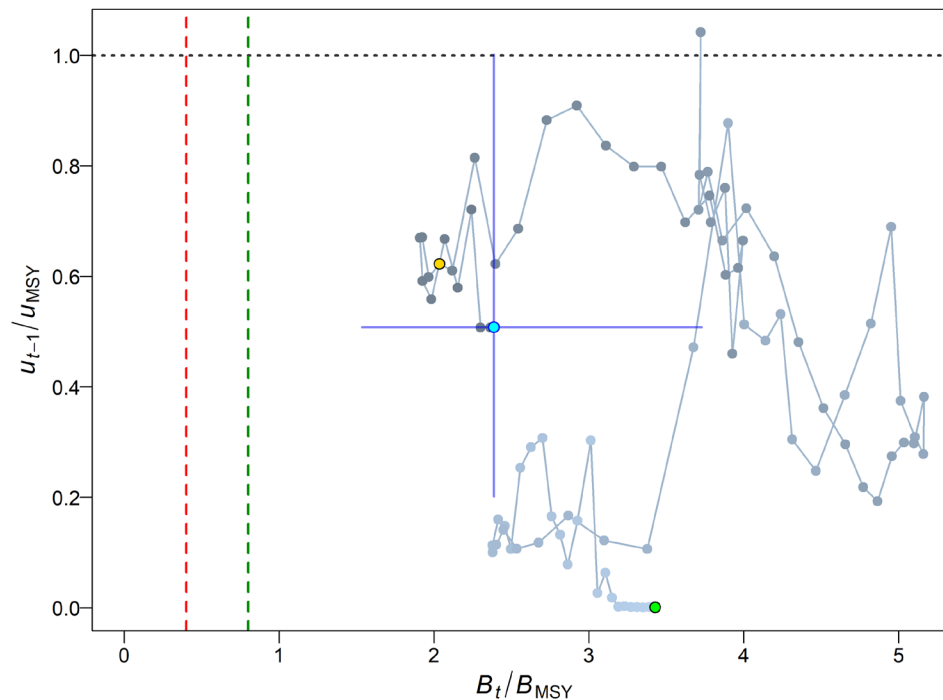
Figure 5. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass at the start of year t relative to B_{MSY}) and fishing pressure u_{t-1}/u_{MSY}: (representing the exploitation rate in the middle of year t-1 relative to u_{MSY}) for one fishery (trawl+) for the YMR composite base case. The filled green circle is the equilibrium starting year (1935). Years then proceed from lighter shades through to darker with the final year (t=2022) as a filled cyan circle, with the blue cross lines representing the 0.05 and 0.95 quantiles of the posterior distributions for the final year. Previous assessment year (2011) is indicated by gold circle. Red and green vertical dashed lines indicate the PA provisional LRP = $0.4B_{MSY}$ and USR = $0.8B_{MSY}$, and the horizontal grey dotted line indicates u_{MSY}.

Reference Points

Figure 6 shows the stock status for the YMR composite base case, as well as each base component run, relative to the provisional DFO (2009) limit and upper stock reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$, respectively. These reference points define the 'Critical', 'Cautious' and 'Healthy' zones. The YMR composite base case spawning biomass at the beginning of 2022 was estimated to be above the limit reference point (LRP) with probability $P(B_{2022} > 0.4B_{MSY})$ = 1, and above the upper stock reference (USR) point with probability $P(B_{2022} > 0.8B_{MSY})$ = 1 (i.e., no probability of being in the Cautious or Critical zones based on the set of MCMC posterior samples).

MSY-based reference points estimated within a stock assessment model can be sensitive to model assumptions about natural mortality and stock recruitment dynamics (Forrest et al. 2018). As a result, other jurisdictions use reference points that are expressed in terms of B_0 rather than B_{MSY} (Edwards et al., 2012, New Zealand Ministry of Fisheries 2011). Therefore, the reference points of $0.2B_0$ and $0.4B_0$ are also presented in Table 3. These reference points, for example, are default values used in New Zealand respectively as a 'soft limit', below which management action needs to be taken, and a 'target' biomass for low productivity stocks, a mean around which the biomass is expected to vary. The 'soft limit' is equivalent to the Upper Stock

Reference (USR, 0.8B_{MSY}) in the DFO Sustainable Fisheries Framework while a 'target' biomass is not specified.

A second component of the provisional harvest rule (DFO 2009) concerns the relationship of the exploitation rate relative to that associated with MSY under equilibrium conditions (u_{MSY}). The rule specifies that the exploitation rate should not exceed u_{MSY} when the stock is in the Healthy zone. Catches should be reduced when in the Cautious zone, and be kept to the lowest level possible when in the Critical zone. The phase plot of the time-evolution of spawning biomass and exploitation rate for the modelled fishery in MSY space (Figure 5) shows that the stock has been in the Healthy zone from 1935 to the present, with one excursion of median exploitation rate above u_{MSY} in 1992.
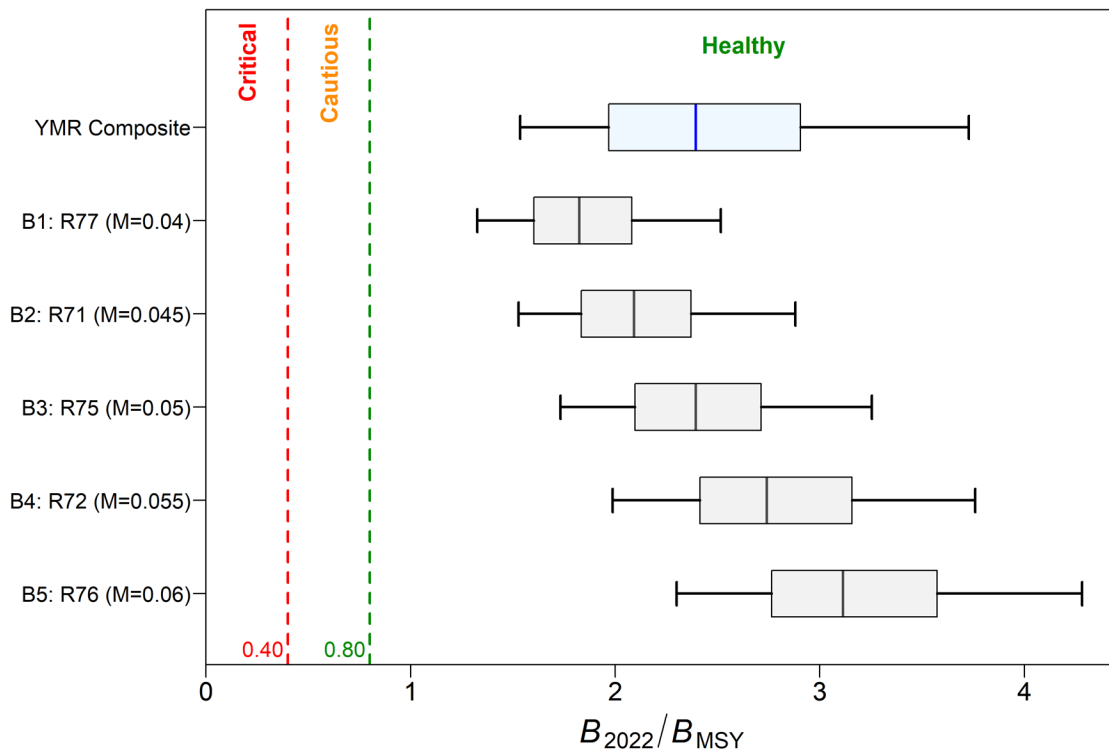

Figure 6. Stock status of the YMR base case and its component base runs relative to the DFO Precautionary Approach (PA) provisional reference points of 0.4B_{MSY} and 0.8B_{MSY} for t=2022. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior.

Projection Results and Decision Tables

Ten-year projections with the first projection year labelled 2023 (reported as the biomass at the beginning of 2023 – which is the same as the biomass at the end of 2022 in the tables and figures), were made over a range of constant catch levels (0-3000 tonnes in 250/500 t increments; Table 2 and Table 3). This time frame was considered adequate for advice to managers before the next stock assessment of this species. Note that the projection uncertainty increases as the number of projection years increase. While all projections should be treated with caution, projections for rockfish beyond 10 years should be treated with additional caution because they assume recruitment to vary about the average while Figure 4 shows that historical YMR recruitments were generally low but punctuated by occasional large recruitments. Consequently, simple average recruitment is not an accurate representation of recruitment for

this species (see projected recruitment in Figure 4). The short-term (up to 10 years) projections in Table 2 are largely determined from year classes estimated during the model reconstruction and are more reliable, particularly in the first years.

The decision tables (Table 2 and Table 3) give the probabilities of the spawning biomass exceeding the biomass reference points or of being below u_{MSY} in each projected year for each catch level. These tables assume that catches will be held constant, with no consequent reduction of the exploitation rate even if a stock reaches the Cautious or Critical zones.

Assuming that a catch of 1250 t (close to the recent 5-year mean) will be taken each year for the next 10 years, Table 2 indicates that a manager would be >99% certain that both B_{2027} and B_{2032} lie above the LRP of $0.4B_{MSY}$, >99% certain that B_{2027} and 99% certain that B_{2032} lie above the USR of $0.8B_{MSY}$, and 83% certain that u_{2026} and 78% certain that u_{2031} lie below u_{MSY} for the composite base case. Generally, it is up to managers to choose the preferred catch levels or harvest levels (if available) using risk levels acceptable to stakeholders. For example, it may be desirable to be 95% certain that B_{2032} exceeds an LRP whereas exceeding a USR might only require a 50% probability. Assuming this risk profile, a catch policy of <=2000 t/y satisfies the LRP constraint in Table 2. Assuming that u_{MSY} is a target exploitation rate, only catch policies <=750 t/y have a probability greater than 95% of the harvest rate remaining below u_{MSY} in 10 years, whereas catch policies <=1500 t/y would have a probability greater than 50%.

Table 2. Decision tables for the reference points 0.4B$_{MSY}$, 0.8B$_{MSY}$, and u$_{MSY}$ for current year (labelled as 2022) and 10-year projections for a range of constant catch policies (in tonnes) using the composite base case. Values are the probability (proportion of 10,000 MCMC samples) of the female spawning biomass at the start of year t being greater than the B$_{MSY}$ reference points, or the exploitation rate of vulnerable biomass in the middle of year t-1 being less than the u$_{MSY}$ reference point. For reference, the average catch over the last 5 years (2016-2020) was 1272 t.

$P(B_t > 0.4B_{MSY})$

Catch policy	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
750	1	1	1	1	1	1	1	1	1	1	1
1000	1	1	1	1	1	1	1	1	1	1	1
1250	1	1	1	1	1	1	1	1	1	1	1
1500	1	1	1	1	1	1	1	1	>0.99	>0.99	>0.99
2000	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99	0.99	0.98
2500	1	1	1	1	>0.99	>0.99	>0.99	0.99	0.97	0.95	0.92
3000	1	1	1	1	>0.99	0.99	0.98	0.95	0.91	0.87	0.81

$P(B_t > 0.8B_{MSY})$

Catch policy	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
750	1	1	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99
1000	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1250	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
1500	1	1	1	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98
2000	1	1	>0.99	>0.99	>0.99	0.99	0.98	0.97	0.95	0.92	0.90
2500	1	1	>0.99	>0.99	0.99	0.97	0.94	0.91	0.87	0.82	0.78
3000	1	1	>0.99	0.99	0.97	0.93	0.88	0.82	0.76	0.70	0.64

$P(u_t < u_{MSY})$

Catch policy	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.95	1	1	1	1	1	1	1	1	1	1
500	0.95	1	1	1	1	1	1	1	1	1	1
750	0.95	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
1000	0.95	0.96	0.96	0.96	0.95	0.95	0.94	0.94	0.94	0.93	0.93
1250	0.95	0.87	0.86	0.85	0.84	0.83	0.82	0.81	0.80	0.79	0.78
1500	0.95	0.74	0.73	0.71	0.70	0.69	0.67	0.66	0.65	0.64	0.62
2000	0.95	0.52	0.50	0.48	0.47	0.45	0.43	0.42	0.41	0.39	0.38
2500	0.95	0.36	0.35	0.33	0.31	0.29	0.28	0.27	0.25	0.24	0.23
3000	0.95	0.25	0.23	0.22	0.20	0.19	0.18	0.16	0.15	0.14	0.13

Table 3. Decision tables for the reference points 0.2B₀ and 0.4B₀ for current year (labelled as 2022) and 10-year projections for a range of constant catch policies (in tonnes) using the composite base case. Values are the probability (proportion of 10,000 MCMC samples) of the female spawning biomass at the start of year t being greater than the B₀ reference points. For reference, the average catch over the last 5 years (2016-2020) was 1272 t.

P(B_t >0.2B_0)

Catch policy	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
750	1	1	1	1	1	1	1	1	1	1	1
1000	1	1	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99
1250	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1500	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
2000	1	1	1	>0.99	>0.99	>0.99	0.99	0.98	0.97	0.95	0.93
2500	1	1	1	>0.99	>0.99	0.98	0.96	0.94	0.9	0.87	0.82
3000	1	1	>0.99	>0.99	0.98	0.96	0.92	0.86	0.81	0.75	0.69

P(B_t >0.4B_0)

| Catch policy	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.98	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
750	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97
1000	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95	0.94	0.93	0.93
1250	0.98	0.98	0.97	0.96	0.95	0.94	0.93	0.91	0.90	0.89	0.87
1500	0.98	0.97	0.96	0.95	0.93	0.92	0.89	0.87	0.85	0.83	0.81
2000	0.98	0.97	0.95	0.92	0.88	0.85	0.81	0.77	0.73	0.69	0.66
2500	0.98	0.96	0.92	0.88	0.82	0.77	0.71	0.66	0.60	0.55	0.51
3000	0.98	0.95	0.9	0.83	0.76	0.69	0.61	0.54	0.49	0.44	0.40
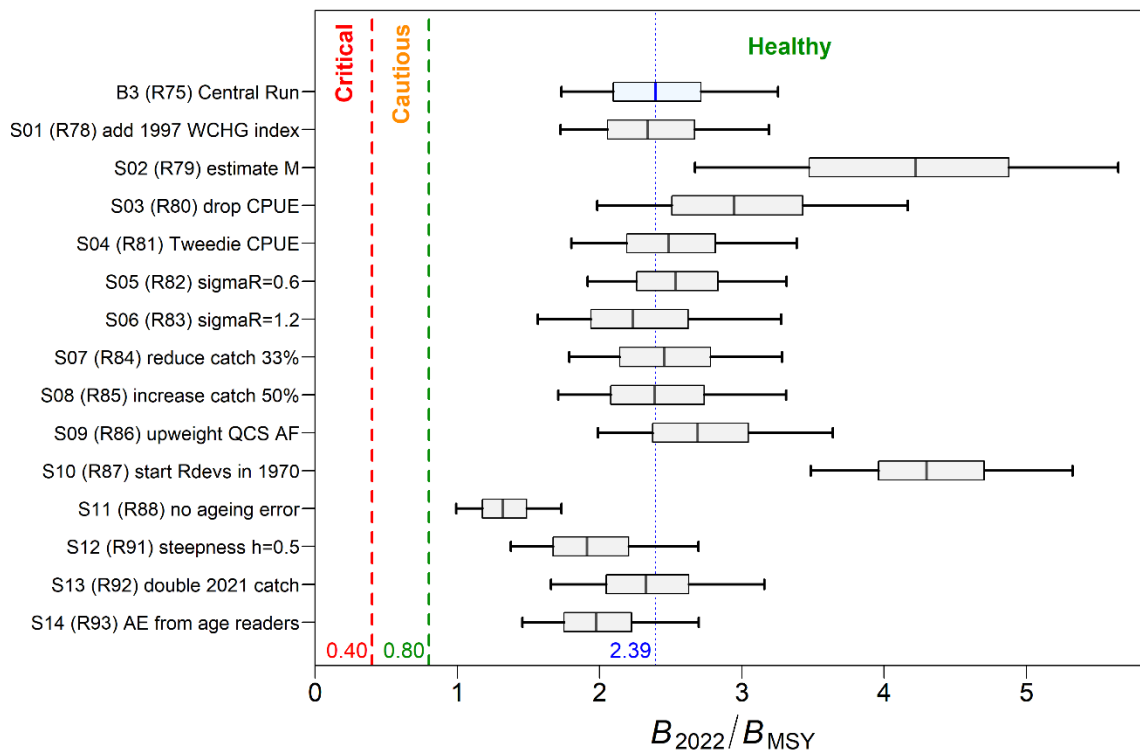
Figure 7. Stock status of the YMR sensitivity runs compared to the central run (B3) relative to the DFO Precautionary Approach (PA) provisional reference points of 0.4B$_{MSY}$ and 0.8B$_{MSY}$ for t=2022. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior. The vertical dotted blue line depicts the median of B3.

Sources of Uncertainty

Only one spatial stock of YMR has been identified along the BC coast, based on data that show small differences in biology (lengths, growth rate) among gear types and regional areas, but this may change with the accumulation of more data. Only one trawl fishery was modelled, but, because selectivities may differ between the bottom and midwater trawl fisheries, these fisheries may need to be modelled separately in future stock assessments. However, this two fishery approach was not possible in this stock assessment because there were inadequate data to do so reliably.

Uncertainty in the estimated parameters is explicitly addressed using a Bayesian approach, with credibility intervals and probabilities provided for all quantities of interest. These intervals and probabilities are only valid for the specified model using the weights assigned to the various data components across the pooled runs forming the composite base case. The Bayesian approach also relies on the prior belief about each input parameter. In particular, the authors noted that natural mortality (*M*) was a key uncertainty for this species, especially as its estimation gave non-credible biomass values. Using a plausible range of *M* values constrained population sizes to levels consistent with estimates from previous YMR and Pacific Ocean Perch assessments.

In the past, the use of commercial CPUE as an index of abundance has been generally avoided in BC rockfish stock assessments (primarily due to uncertainty in vessel behaviour in response to regulations). Despite this, CPUE of the bottom trawl fishery has been successfully used in

several recent stock assessments. However, unlike these analyses, where the CPUE analyses were presumed to be based on catch/effort data collected from a passive bycatch fishery, YMR is frequently a target species as well as a bycatch species. The lack of real abundance information in the survey data required the inclusion of CPUE to provide a usable abundance series. A sensitivity analysis, which dropped DFO localities with the highest catch rates, returned CPUE series which were consistent with the total analysis, indicating that the CPUE trend in the localities with lower catch rates was consistent with the overall trend.

Other uncertainties were explored through sensitivity runs (S) based on the central run. These included:

- productivity assumptions – estimating natural mortality (S02), changing σ_R (standard deviation of recruitment; S05, S06), changing the period over which mean recruitment was estimated (S10), changing steepness h of the stock-recruit relationship (S12);

- abundance – addition/removal of abundance indices (S01, S03, S04), decreasing/increasing historical catch (S07, S08), doubling the final catch in 2021 (S13);

- composition – upweighting QCS survey age frequency (AF) data (S09), removing ageing error (S11), using ageing error based on otolith readers' precision estimates (S14).

All sensitivity runs remained in the Healthy zone (Figure 7). Most sensitivities followed the trajectory of the central run with some variation, while three scenarios departed markedly (S02, S10, S11). Although estimating M (S02) followed the trajectory of the central run, it remained consistently above the latter and was one of the most optimistic scenarios. However, it is likely that this run did not converge and these results should be interpreted with caution. The run that estimated recruitment deviations starting in 1970 rather than 1950 (S10) followed a path well below the central run before trending up to an estimate for current (2022) stock status that was similar to that of the run that estimated M (S02). The most pessimistic run was the one without ageing error corrections (S11), suggesting that accounting for ageing error is important to remove bias, in this case negative bias.

Three additional runs requested by the RPR process were added to the sensitivity analysis (Figure 7) to explore the effects of lower steepness (h=0.5, S12), doubling the 2021 catch (S13), and using an alternative ageing error structure based on otolith readers' precision estimates of observed ages (S14). All three runs were more pessimistic than the central run; however, the current stock status for all three was estimated to remain in the Healthy zone.

The use (or lack) of ageing error (AE), showed that this assumption had an important impact on model results. The model with no ageing error (S11) estimated recruitment peaks spread broadly across adjacent years, while a strong AE assumption (B3, central run) concentrated recruitment into single years. The intermediate AE assumption (S14) lay in between the two extremes of S11 and B3, with the first two recruitment peaks spread less broadly across years than in S11. This issue emerged as a potential axis of uncertainty during the RPR review and should be explored in future assessments. The authors chose the strong AE assumption because the single-year recruitment events were more in line with expected rockfish life history patterns.

Foreign fleet effort in 1965-76 along the BC coast targeted Pacific Ocean Perch, and YMR catch for these years was estimated as an assumed bycatch; therefore, the magnitude of the foreign fleet removals of YMR is uncertain. Another source of uncertainty in the catch series comes from domestic landings from the mid-1980s to 1995 (pre-observer coverage), which may have misreported lesser rockfish species to bypass quota restrictions on more desirable species like Pacific Ocean Perch. However, the sensitivity runs on catch (S07 and S08) show that catch

uncertainty did not have a major effect on the model's biomass trajectory or on the estimates of the relative stock size at the end of 2021 (Figure 6).

This rockfish stock assessment marks a departure from those conducted since 2009 by adopting the Stock Synthesis 3 (SS) generic stock assessment platform maintained by NOAA (Methot and Wetzel 2013). This platform provides more flexibility than models used in past BC rockfish assessments, but a time-consuming learning curve precluded the use of some features (e.g., retrospective analysis) in this stock assessment.

The 2011 YMR stock assessment (using the Awatea software platform) estimated a larger initial stock size (B_0) than in this assessment. Even the 2011 fixed M base case (M=0.047) had a median estimate for B_0 of 37,300 t which was 43% higher than the median composite base case estimate of B_0. The larger 2011 biomass resulted in a larger estimated MSY at 1,700 t, which is 65% greater than the MSY estimate for the composite base case. Model run updates using the Awatea platform and incorporating most of the changes implemented for this SS stock assessment (including ageing error, CPUE series, additional data up to 2021) resulted in stock size and stock status estimates that were consistent with those obtained by the 2011 stock assessment. Additionally, the updated Awatea model (analogous to the central run, fixing M=0.05 and h=0.7) estimated B_{2022} to be ~17,200 t vs. the SS estimate of ~18,000 t, with remarkably similar trajectories after 1980. Unlike SS, Awatea was able to obtain a good model fit to the data while estimating both M and h. These results indicated that the different distributional assumptions used to fit the age frequency data (multinomial in SS vs. robust normal in Awatea) were the primary sources for the differences in model predictions across the two software platforms. The SS model estimated a lower overall stock size (and consequently lower long-term productivity) and larger punctuated recruitments compared to the Awatea model. However, both models estimated equivalent absolute biomass trajectories beginning around 1980 and current stock status to be well within the Healthy zone.

Ecosystem Considerations and Climate Change

DFO groundfish fisheries managers have worked in consultation with science, industry and non-government organisations to implement measures in the commercial trawl fishery to protect bottom habitat, foster biodiversity, and ensure that these fisheries remain sustainable. These actions, described below, will benefit all species affected by this fishery.

In 2012, measures were introduced to reduce and manage the bycatch of corals and sponges by the BC groundfish bottom trawl fishery. These measures were developed jointly by industry and environmental non-governmental organisations, and include limiting the footprint of groundfish bottom trawl activities to manage the trawl fishery impacts on significant ecosystem components such as corals and sponges, establishing a combined bycatch conservation limit for corals and sponges, and establishing an encounter protocol. These measures also restrict access by bottom trawling to less than one-half of the available benthic habitat (stratified by area and depth) on the BC coast. These measures have been incorporated into DFO's Pacific Region Groundfish Integrated Fisheries Management Plan.

To further mitigate ecosystem risk, all BC commercial groundfish fisheries are subject to the following management measures: 100% at-sea monitoring, 100% dockside monitoring, individual vessel accountability for all retained and released catch, individual transferable quotas, and reallocation of these quotas between vessels and fisheries to cover catch of non-directed species (see aforementioned Management Plan). These measures ensure that impacts on non-target species, 'Endangered, Threatened and Protected' (ETP) species, and biogenic habitat components (coral and sponge) are well monitored.

In addition to the fishery dependent ecosystem and fishery monitoring, DFO, in collaboration with industry partners, conducts a suite of fishery independent random depth-stratified surveys (using bottom trawl, demersal hook and line, and trap gears), which provide comprehensive coast wide coverage biennially of most offshore benthic habitats between the depths of 50 and 500 m. This suite of surveys provides an important layer of information with very high specificity ensuring that ecosystem components vulnerable to fishing gears are monitored.

While assessments and harvest options for groundfish species in the Pacific region are primarily provided on a single species basis, the fishery is managed in a multi-species context wherein many single species quotas are managed simultaneously. Additionally, freezing the footprint of the trawl fishery reduces the likelihood of impacts from the activities of the commercial bottom trawl fleet expanding into new benthic habitats.

It is not known how climate change will affect this species or the conclusions made by this stock assessment. Although there is agreement that warmer temperature regimes and changes to other environmental variables such as dissolved oxygen will likely affect marine species, the exact nature of these effects is poorly understood. Previous attempts at incorporating climate variables into stock assessments (Haigh at al. 2019) have proved unsuccessful, largely due to low contrast in the introduced series, a too-short time series, or overly simplistic (or unrealistic) functional models. Warmer temperatures may affect recruitment processes, natural mortality, and growth, any of which may affect stock resilience, productivity, and status relative to reference points which may in turn alter the perception of consequences associated with varying harvest levels relative to stock status. As well, reference points which rely on equilibrium conditions will shift because changing temperature regimes imply a change in productivity and consequently a different equilibrium level. Understanding the effect of climate change in a marine context will require additional monitoring and analyses.

CONCLUSIONS AND ADVICE

One of the biggest challenges for the YMR stock assessment was the lack of information provided by the survey abundance indices. Adding a CPUE index series provided some contrast across a range of abundance levels which helped stabilise the model, but did not prevent some unrealistically high biomass estimates at higher fixed values of M. This model gets most of its information from the commercial fishery age frequencies and CPUE. To achieve credible model results (good MCMC diagnostics), the commercial age frequency data were deliberately upweighted. The upweighting was roughly three times stronger than that using the initially adopted Francis (2011) method of adjusting sample sizes based on mean age, and was necessary to avoid the estimation of unrealistically high R_0 values resulting from SS' multinomial age error fitting.

This stock assessment depicts a slow-growing, low productivity stock. Natural mortality (M) could not be credibly estimated using the new model platform, largely due to the lack of contrast and the high relative errors in the survey biomass indices. The alternative approach followed in this stock assessment was to identify a range of plausible M values which were used as fixed estimates to construct five separate models. These were then combined into a composite base case to provide management advice. None of the M values used in the composite base case indicated that there was a sustainability issue with this stock. Even the lowest investigated value of M=0.04 returned a median estimate for B_{2022}/B_0 of 0.53 (0.38, 0.73) and for B_{2022}/B_{MSY} of 1.8 (1.3, 2.5). Consequently, the authors were reasonably confident that the YMR stock lies in the Healthy zone and is likely to stay there for 5-10 years at current levels of catch (around 1000 to 1250 t/y). Unfortunately, the stock assessment's estimate of absolute stock size is uncertain, as is long-term yield. The median B_0 estimate from the composite base case (~26,000 t), along

with the corresponding estimate of MSY (~1,000 t), is simply an average across five plausible values of *M* that were somewhat arbitrarily chosen. However, alternative model formulations that make different mathematical assumptions (such as ageing error vectors or choice of distributions used to fit the age data) can result in differing absolute stock size estimates while still fitting the available data. These alternative models generally agree that current stock status lies in the Healthy zone but will differ with respect to the long-term yield from the population. Short-term projections (up to 10 years) should be relatively similar because they would be based on estimated recent recruitments.

The decision tables provide guidance to the selection of short-term catch recommendations and describe the range of possible future outcomes over the projection period at fixed levels of annual catch. The accuracy of the projections is predicated on the model being correct. Uncertainty in the parameters is explicitly addressed using a Bayesian approach but reflects only the specified model and weights assigned to the various data components.

It is recommended that a full re-assessment occur in no more than 10 years, subject to the availability of new information. During intervening years the trend in abundance can be tracked by commercial fishery CPUE and, less reliably (because of the high relative error), by the fishery independent surveys used in this stock assessment. The groundfish synopsis report (Anderson et al. 2019), which will be periodically updated as a Science Response, summarises these trends and can be used as a tracking tool.

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SOURCES OF INFORMATION

This Science Advisory Report is from the September 8-9, 2021 regional peer review on Yellowmouth Rockfish (*Sebastes reedi*) stock assessment for British Columbia in 2021. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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