REDSTRIPE ROCKFISH (*SEBASTES PRORIGER*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2018

Redstripe Rockfish (Sebastes proriger). Credit: Terri Bonnet, DFO.

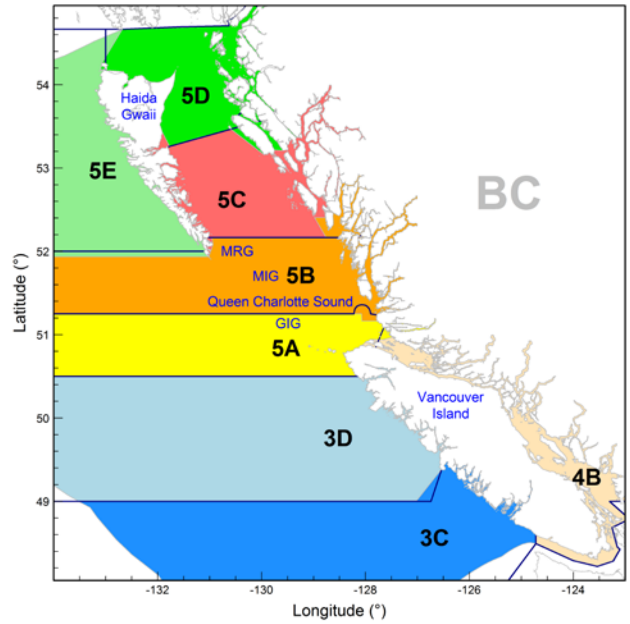

Figure 1. Redstripe Rockfish assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major areas outlined with solid lines are used in this assessment. The Groundfish Management Unit area boundaries, based on [Pacific Fisheries Management Areas](), are superimposed as coloured polygons for comparison. This assessment is for areas called 'BC North' (5DE, green) and 'BC South' (3CD5ABC, red through blue).

Context

Redstripe Rockfish (Sebastes proriger) is a long-lived, commercially important species of rockfish found along the Pacific rim of North America. Its commercial attractiveness stems from the bright red colour and long shelf life when properly processed. Redstripe Rockfish supports the sixth largest rockfish fishery (based on the 2017 management harvest plan) in BC with an annual coastwide TAC (total allowable catch) in 2017 of 1,564 t and an average annual catch of 842 t from 2013-2017. This quantitative age-structured stock assessment has split the BC population of Redstripe Rockfish into two stocks based on a persistent difference in relative size at age. Harvest advice is provided showing that current harvest levels are sustainable and compliant with DFO's Decision-making Framework Incorporating the Precautionary Approach.

This Science Advisory Report is from the June 13-14, 2018 Regional Peer Review on Stock Assessment for British Columbia Redstripe Rockfish (Sebastes proriger) in 2018. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule]() as they become available.

SUMMARY

- Two stocks of Redstripe Rockfish were identified along the British Columbia (BC) coast based on observable, consistent differences in mean length and growth models between the areas. The two stocks are called BC North (or BCN) in Pacific Marine Fisheries Commission (PMFC) 5DE and BC South (or BCS) in PMFC 3CD5ABC.
- Both Redstripe Rockfish stocks were assessed using a single fishery, annual two-sex catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated quantities.
- The median (and 5 and 95 percentiles of the Bayesian results) female spawning biomass at the beginning of 2018 (B_{2018}) is estimated to be 0.91 (0.69-1.13) of unfished female spawning biomass (B_0) in BCN and 0.62 (0.47-0.81) of B_0 in BCS. Also, B_{2018} is estimated to be 3.16 (2.02-4.00) of the equilibrium spawning biomass at maximum sustainable yield, B_{MSY}, in BCN and 2.43 (1.51-3.79) of B_{MSY} in BCS.
- At current catch levels, there is an estimated probability of >0.99 that both $B_{2018} > 0.4B_{MSY}$ and $B_{2018} > 0.8B_{MSY}$ for both stocks (i.e. of being in the healthy zone). The probability that the exploitation rate in 2017 was below that associated with MSY is also >0.99 for both stocks
- Advice to management is presented in the form of decision tables using the provisional reference points from the Fisheries and Oceans Canada Sustainable Fisheries Framework (SFF) Precautionary Approach. The decision tables provide five-year projections across a range of constant catches (Table 5, Table 6).
- The appropriateness of the MSY based reference points for long lived low productivity species is uncertain, consequently advice to management relative to reference points based on 0.4 and 0.2 of B_0 (unfished spawning biomass) is also presented as an alternative option.(Appendix F Tables: F11, F12, F25, F26).
- It is recommended that the next assessment occur in 2023, with three new indices available from each of the four biennial synoptic trawl surveys and five additional years of ageing and catch data. No appropriate indicators for this stock are recommended that would trigger an assessment earlier than scheduled. Advice for the interim years is explicitly included in the decision tables.
- Recommended future work includes the investigation of alternate reference points due to the sensitivity of B_{MSY} based reference points to assumptions about model parameters and functions, including: catchability (q), natural mortality (M), recruitment variability (σ_R), and commercial and survey selectivities. It is also recommended that future assessors review the informative priors used in this stock assessment and investigate alternatives with the intent of developing more appropriate priors.

INTRODUCTION

Redstripe Rockfish (*Sebastes proriger*) occurs along the Pacific rim of North America, ranging from the Aleutian Islands (Alaska) southward through BC down to central Baja California (Love et al. 2002). In BC, hotspots of catch per unit effort (CPUE) from bottom trawl tows summed over 22 years (1996-2017), occur off Rennell Sound (west of Graham Is., Haida Gwaii), along the canyon walls of the three main gullies in Queen Charlotte Sound, NW off Vancouver Island, and SW off Barkley Sound, WCVI. Most of the commercial captures along the BC coast lie between depths 91 m and 380 m. Catches are continuous in BC from the lower part of Hecate Strait all the way to the BC border with Washington state. Another continuous stretch of

Redstripe Rockfish catches occurs along the west coast of Graham Island into the western part of Dixon Entrance. These stretches of continuous catch coincide with the separation of Redstripe Rockfish into two stocks – BC North (BCN) and BC South (BCS).

The Pacific Marine Fisheries Commission (PMFC) major areas used in stock assessments are similar to the groundfish management areas (GMAs) used by the Fisheries and Oceans Canada (DFO) Groundfish Management Unit (GMU) to set TACs (Figure 2). Exact GMU area boundaries were not used in the assessment because reporting from them has only been available since 1996 and there is no available procedure to alter historical landings to conform to these boundaries. Therefore, areas refer to PMFC areas unless otherwise specified.

The trawl TACs by GMU area have remained unchanged since 2001: 173 t in 3C, 772 t in 3D5AB, 330 t in 5CD, and 246 t in 5E. The hook and line TACs have remained unchanged since 2006: 5 t in 3C, 22 t in 3D5AB, 9 t in 5CD, and 7 t in 5E. The mean catch from 2013-2017 coastwide from all fisheries was 842 t (109 t in BCN, 732 t in BCS). Ninety-eight percent of the commercial captures of Redstripe Rockfish were made in the depth range 113-427 m for BCN and 82-444 m in BCS.

ASSESSMENT

This report summarises the key results from the 2018 quantitative stock assessment for two stocks of Redstripe Rockfish. A single-fishery annual two-sex, catch-at-age model was tuned to fishery-independent trawl survey data (from historical survey data and the ongoing synoptic bottom trawl surveys), annual fishery-dependent catch-per-unit-effort (CPUE) abundance indices, annual estimates of commercial trawl catch since 1940, and age composition data from the commercial fishery and from survey series. Sensitivity analyses (four in BCN, five in BCS) were conducted to explore sensitivity to a subset of assumptions and data sources used in the base case.

Each stock assessment model estimates the steepness parameter of the stock-recruitment relationship (which represents one component of stock productivity), natural mortality (M) (independently for females and males), catchability coefficients (q) for the survey series and CPUE, and selectivity parameters for the commercial fishery and each survey series (four in BCS and two in BCN).

The models reconstruct the time series of vulnerable biomass (total of male and female biomass that is vulnerable to capture by the fishery) and spawning stock biomass (mature females only), given the model assumptions and parameter estimates. The estimated parameters are then used to calculate maximum sustainable yield (MSY) and reference points. Five-year projections are performed over a range of constant catches to estimate probabilities of the spawning biomass being greater than the reference points. All calculations are made using the Bayesian Markov Chain Monte Carlo (MCMC) method to quantify parameter the uncertainty. This procedure yielded 1,000 MCMC samples (after dropping a 200 sample ‘burn-in’) from the posterior distributions for estimated parameters. Estimates of various quantities were calculated from these samples, and are presented as the median (with 5-95% quantiles to specify uncertainty). Calculated probabilities are also based on the MCMC posterior distributions.

Advice to managers is presented as sets of decision tables that provide probabilities of exceeding reference points (consistent with the DFO SFF Precautionary Approach: $0.4B_{\text{MSY}}$; $0.8B_{\text{MSY}}$ as well as remaining below u_{MSY} (the exploitation rate producing MSY) for 2018 through 2023 for a range of constant catch levels for each stock.

Figure 2 shows the posterior distributions of the estimated annual vulnerable biomass for each stock, together with the historical catches. Figure 3 compares trajectories for each stock of the estimated medians of vulnerable and spawning (mature females only) biomasses relative to their unfished equilibrium values.

The BCN stock shows long periods of relatively stable standing stock punctuated by periodic declines, e.g., after 1966 during the foreign fleet activity and in the 1990s during an emergent domestic trawl fleet ([left panel] Figure 2). There are also periods of population increases generated by major recruitment events in 1982 and 1996 ([left panel] Figure 4). Fishing pressure by foreign fleets ([left panel] Figure 5) from 1965-70 caused a decline in biomass followed by a period of stability to the mid-1980s. The BCN stock declined again to its lowest point around 1990, after which the large 1982 recruitment entered the vulnerable biomass, causing a biomass increase to the mid-1990s. Biomass then declined steadily to the mid-2000s, when another recruitment event combined with lowered catches resulted in an increasing biomass to the present.

The BCS stock shows a long steady declining trend in the population from 1940 to the mid-1970s, followed by a 10-y rise to levels above B_0 by 1985, likely due to above-average recruitment in the 1970s ([right panel] Figure 4). This increasing trend was also aided by the cessation of offshore foreign fishing, which is evidenced by the decreasing trend in exploitation rate after 1977 ([right panel] Figure 5). Another steady decline, steeper this time due to higher catches and increasing exploitation rates as the domestic fleet entered the fishery ([right panel] Figure 5) continued for 20 years and reached its lowest point around 2006. An above –average recruitment event in the early 2000s ([right panel] Figure 4) occurred to produce a 5-y increase followed by a stable standing stock until the most recent year.

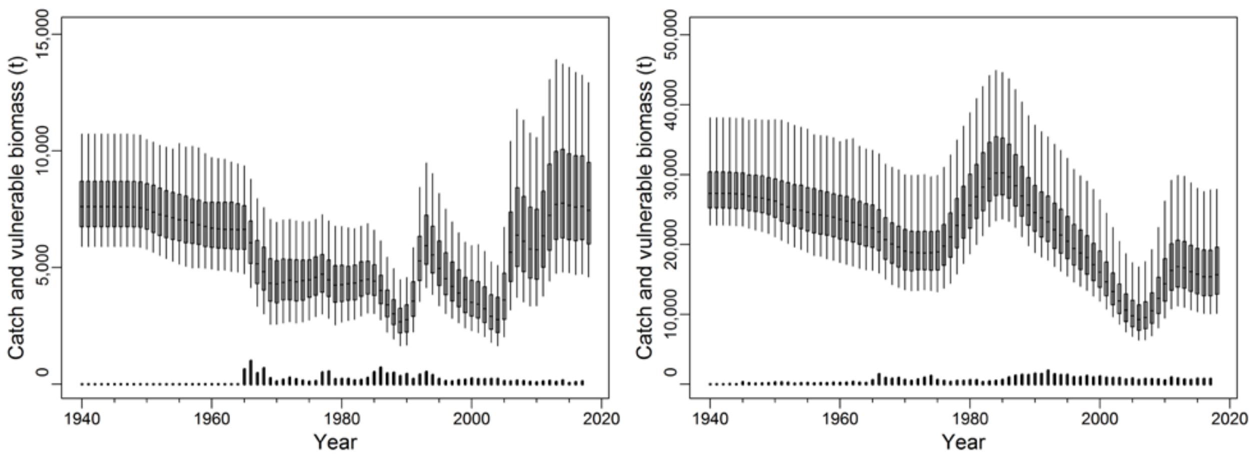

Figure 2. Annual commercial catch (vertical bars) and vulnerable biomass (boxplots showing 5, 25, 50, 75 and 95 percentiles of the MCMC results). Left: BC North, Right: BC South.

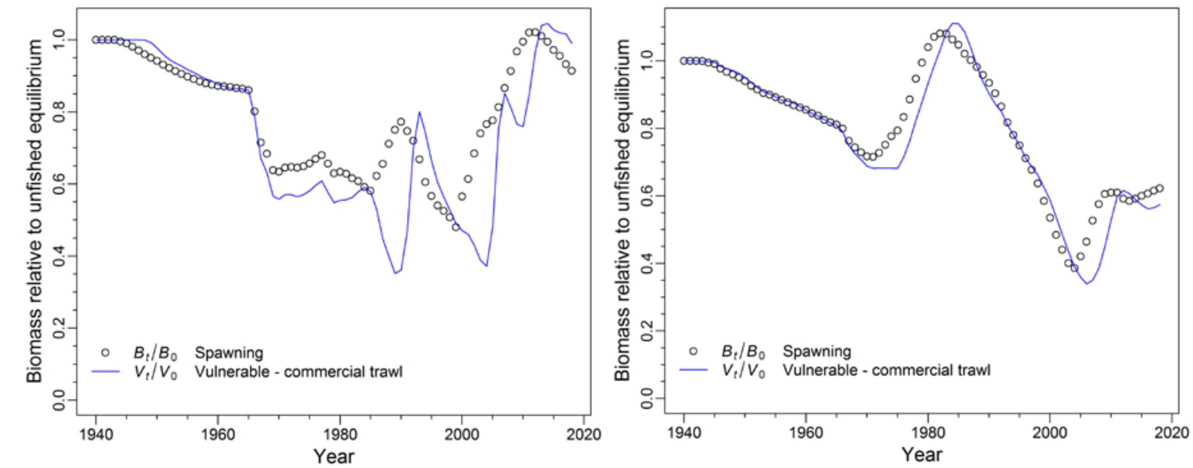

Figure 3. Trajectories of spawning and vulnerable biomass relative to unfished equilibrium levels, B_t / B_0 and V_t / V_0 respectively, shown as MCMC medians. Left: BC North, Right: BC South.

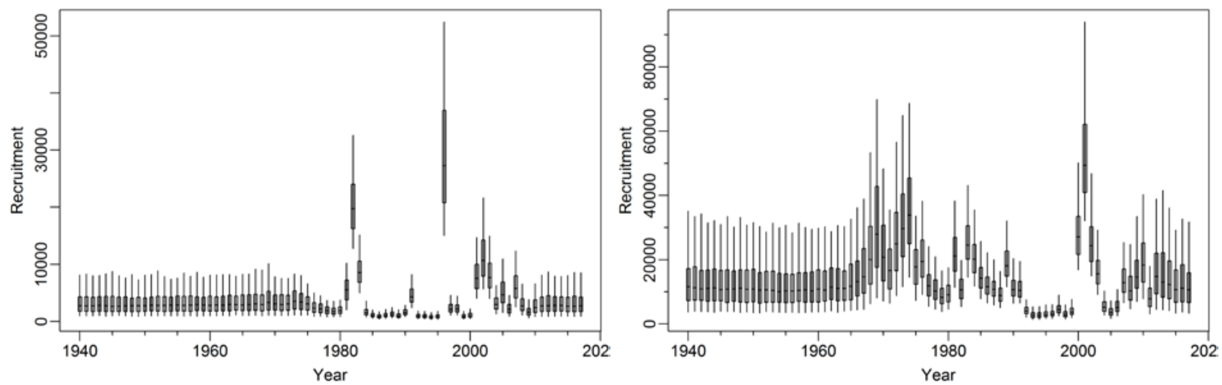

Figure 4. Marginal posterior distribution of recruitment (in 1000s of age-1 fish) for each year. Boxplots give the 5, 25, 50, 75 and 95 percentiles from the MCMC results. Left: BC North, Right: BC South.

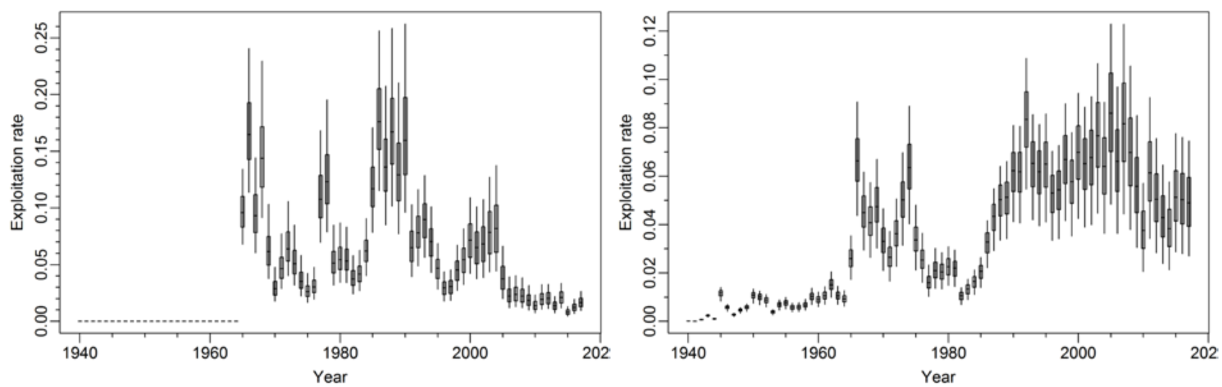

Figure 5. Marginal posterior distributions of annual exploitation rate by year. Boxplots give the 5, 25, 50, 75 and 95 percentiles from the MCMC results. Left: BC North, Right: BC South.

Both BC stocks of Redstripe Rockfish show long periods of below average recruitment punctuated by periodic strong recruitment events (Figure 4). Above-average recruitment in the BCN stock is evident in the early 1980s and the mid-1990s. The BCS stock also shows above-average recruitment in the early 1980s but the later above-average recruitment is delayed to the early 2000s. There is also some evidence of above-average BCS recruitment in the 1970s which is informed from age sample data from 1979 and possibly from the early 1990s.

The estimated BCN annual exploitation rate (ratio of total catch to the vulnerable biomass in the middle of the year) peaked in the mid-1960s ([left panel] Figure 5) due to foreign catches, and then peaked again in the late 1980s due to increased domestic exploitation combined with lowered vulnerable biomass levels. Similarly, BCS exploitation rates were high in the 1960s and early 1970s due to foreign fleet catches and increased again in the 1990s, where they remained until around 2010 ([right panel] Figure 5). Estimated BCN 2017 exploitation rate, u_{2017}, is 0.016 (0.009-0.027, Table 1) while the BCS 2017 exploitation rate, u_{2017}, is 0.049 (0.027-0.075, Table 1).

Table 1. Quantiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2018} – spawning biomass at the start of 2018, V_{2018} – vulnerable biomass in the middle of 2018, u_{2017} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2017, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1940-2017), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last 5 years (2013-2017) is 109 t in BCN and 732 t in BCS.

	BC North			BC South		
Value	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_0	5,611	7,216	10,083	21,925	26,149	36,390
V_0	5,910	7,606	10,733	22,780	27,318	38,172
B_{2018}	4,193	6,500	11,079	10,700	16,235	28,967
V_{2018}	4,605	7,455	12,935	10,142	15,665	27,905
B_{2018} / B_0	0.692	0.914	1.129	0.469	0.622	0.810
V_{2018} / V_0	0.718	0.990	1.267	0.424	0.574	0.764
u_{2017}	0.009	0.016	0.027	0.027	0.049	0.075
$u_{\max}$	0.127	0.187	0.281	0.056	0.089	0.125
MSY	281	497	787	946	1467	2481
B_{MSY}	1,488	2,135	3,411	4,553	6,830	10,701
$0.4B_{MSY}$	595	854	1,364	1821	2732	4,280
$0.8B_{MSY}$	1,190	1,708	2,728	3,643	5,464	8,561
B_{2018} / B_{MSY}	2.015	3.156	3.999	1.509	2.429	3.768
B_{MSY} / B_0	0.250	0.293	0.379	0.190	0.256	0.344
V_{MSY}	474	848	2,578	2466	5043	9,080
V_{MSY} / V_0	0.073	0.107	0.293	0.088	0.183	0.302
u_{MSY}	0.120	0.638	0.990	0.115	0.300	0.800
u_{2017} / u_{MSY}	0.011	0.025	0.154	0.049	0.160	0.496

The estimated ratio of current spawning biomass (B_{2018}) to equilibrium unfished spawning biomass (B_0) is 0.91 (0.69-1.13) in BCN and 0.62 (0.47-0.81) in BCS (Table 1). The estimated median MSY is 497 t (281-787 t) in BCN and 1,467 t(946-2,481 t) in BCS, compared to the average catches over the last five years (2013-2017) of 109 t and 732 t, respectively. The estimated value of B_{2018}/B_{MSY}, where B_{MSY} is the equilibrium spawning biomass that would support the MSY, is 3.16 (2.02-4.00) in BCN and 2.43 (1.51-3.77) in BCS.

Reference Points

Figure 6 shows the stock status relative to the provisional DFO (2009) limit reference point (LRP) and upper stock reference point (USP) of $0.4B_{MSY}$ and $0.8B_{MSY}$, respectively. These reference points define the critical, cautious and healthy zones. For both stocks, the spawning biomass at the beginning of 2018 is estimated to be above the limit reference point with probability $P(B_{2018} > 0.4B_{MSY}) > 0.99$, and above the upper stock reference point with probability $P(B_{2017} > 0.8B_{MSY}) > 0.99$. The BCN and BCS models both estimate that biomass has remained relatively constant since 2012 (Figure 2).

There was some reservation regarding the appropriateness of MSY-based reference points for long-lived species. This concern is particularly true for the northern stock where MSY was poorly determined. Consequently, alternative reference points relative to B_0 were also provided.

A second component of the provisional harvest rule of 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 estimated ratio of u_{2017}/u_{MSY}, which the harvest rule specifies should be ≤1, is 0.03 (0.01-0.15) in BCN and 0.16 (0.05-0.50) in BCS (Table 1). The probability that the current exploitation rate is below that associated with MSY is $P(u_{2017} < u_{MSY}) = 0.99$ for both stocks.

Both stocks are estimated to have been in the healthy zone (above $0.8B_{MSY}$) since the start of fishing in 1940 (based on median values) and the median exploitation rate is estimated to have never been greater than u_{MSY} during this period.

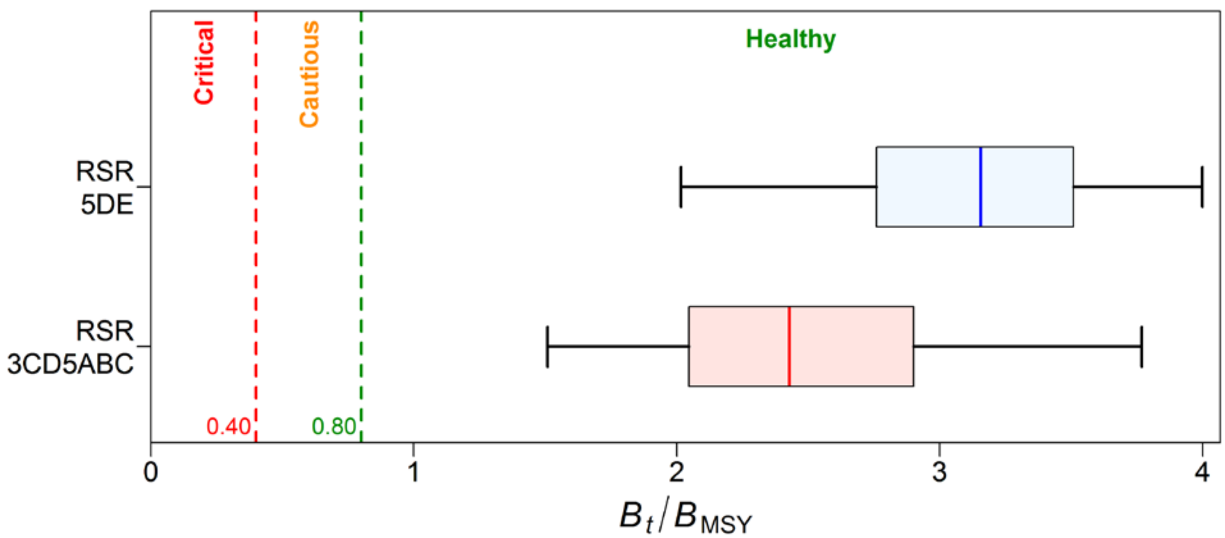

Figure 6. Current status of the two Redstripe Rockfish stocks relative to the DFO Precautionary Approach provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$. The probability that B_{2018} lies in the critical zone is 0, in the cautious zone is 0, and in the healthy zone is 1. Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

Projection Results and Decision Tables

Five-year projections, starting with the biomass at the beginning of 2018, were made over a range of constant catch levels (0-2,000 t in 100 t increments). This time frame was considered adequate for long-term advice and short enough for projections to be mainly based on individuals spawned before 2010 (and therefore explicitly estimated by the assessment model). Decision tables (Table 2 and Table 3) give the probabilities of the spawning biomass exceeding the reference points in each projected year for each catch level. Note that these tables assume that catches are held constant, so there is no consequent reduction of the exploitation rate in the projections if a stock reaches the cautious or critical zones.

Generally, it is up to managers to choose the preferred catch levels and the preferred risk levels. For example, it may be desirable to be 95% certain that B_t exceeds a LRP whereas exceeding an USR might only require a 50% probability. Assuming this risk profile, all catch policies in Table 2 and Table 3 could be adopted to be 95% certain that the spawning biomass would remain above $0.4B_{\mathrm{MSY}}$ at the start of 2023. Similarly, all catch policies in Table 2 and Table 3 could be adopted to be 50% certain that the spawning biomass is above $0.8B_{\mathrm{MSY}}$ at the start of 2023. These tables also show that there is at least a 95% probability that harvest rates will be less than u_{MSY} in 2023 at annual catches of 500 t or less in the north and 1300 t or less in the south. The harvest reference removal rate guidance of the SFF is potentially the only reference point for the two Redstripe Rockfish stocks that provides contrasting harvest advice for managers.

Table 2. BC North – Decision tables for the reference points $0.4B_{MSY}$, $0.8B_{MSY}$, and u_{MSY} for 1-5 year projections for a range of constant catch strategies (in tonnes) using the base case model. Values are the probability (proportion of 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 being less than the u_{MSY} reference point. For reference, the average catch over the last 5 years (2013-2017) is 109 t.

	$P(B_t > 0.4B_{\mathrm{MSY}})$						$P(B_t > 0.8B_{\mathrm{MSY}})$						$P(u_t < u_{\mathrm{MSY}})$					
Catch	2018	2019	2020	2021	2022	2023	2018	2019	2020	2021	2022	2023	2018	2019	2020	2021	2022	2023
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.99	0.99	0.99	0.99
400	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.99	0.98	0.98	0.97	0.97
500	1	1	1	1	1	1	1	1	1	1	1	1	0.98	0.97	0.97	0.97	0.96	0.95
600	1	1	1	1	1	1	1	1	1	1	1	1	0.97	0.96	0.95	0.94	0.93	0.92
700	1	1	1	1	1	1	1	1	1	1	1	0.99	0.96	0.95	0.94	0.92	0.90	0.88
800	1	1	1	1	1	1	1	1	1	1	0.99	0.98	0.95	0.94	0.92	0.89	0.86	0.82
900	1	1	1	1	1	1	1	1	1	0.99	0.98	0.97	0.94	0.92	0.89	0.86	0.81	0.75
1000	1	1	1	1	1	1	1	1	1	0.99	0.98	0.95	0.93	0.90	0.87	0.82	0.76	0.68
1100	1	1	1	1	1	0.99	1	1	1	0.99	0.97	0.92	0.91	0.88	0.84	0.78	0.69	0.58
1200	1	1	1	1	1	0.99	1	1	0.99	0.98	0.95	0.88	0.90	0.86	0.82	0.72	0.61	0.49
1300	1	1	1	1	0.99	0.99	1	1	0.99	0.98	0.93	0.85	0.89	0.85	0.79	0.67	0.54	0.42
1400	1	1	1	1	0.99	0.99	1	1	0.99	0.97	0.90	0.81	0.88	0.83	0.73	0.62	0.47	0.35
1500	1	1	1	1	0.99	0.99	1	1	0.99	0.95	0.87	0.79	0.87	0.81	0.70	0.56	0.40	0.27
1600	1	1	1	1	0.99	0.99	1	1	0.99	0.94	0.84	0.76	0.85	0.79	0.66	0.51	0.35	0.22
1700	1	1	1	0.99	0.99	0.99	1	1	0.98	0.92	0.80	0.73	0.84	0.77	0.63	0.44	0.28	0.18
1800	1	1	1	0.99	0.99	0.99	1	1	0.98	0.89	0.78	0.72	0.83	0.74	0.59	0.39	0.23	0.13
1900	1	1	1	0.99	0.99	0.99	1	1	0.98	0.88	0.76	0.70	0.82	0.70	0.54	0.34	0.20	0.10
2000	1	1	1	0.99	0.99	0.99	1	1	0.97	0.84	0.74	0.68	0.80	0.68	0.51	0.29	0.16	0.08

Table 3. BC South – Decision tables for the reference points 0.4B_{MSY}, 0.8B_{MSY}, and u_{MSY} for 1-5 year projections for a range of constant catch strategies (in tonnes) using the base case model. See Table 2 caption for details. For reference, the average catch over the last 5 years (2013-2017) is 732 t.

	$P(B_t > 0.4B_{MSY})$						$P(B_t > 0.8B_{MSY})$						$P(u_t < u_{MSY})$					
Catch	2018	2019	2020	2021	2022	2023	2018	2019	2020	2021	2022	2023	2018	2019	2020	2021	2022	2023
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
400	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
600	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
700	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
800	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
900	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.99	0.99	0.99	0.99	0.99
1000	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.99	0.99	0.99	0.99	0.98
1100	1	1	1	1	1	1	1	1	1	1	1	1	0.99	0.98	0.98	0.98	0.98	0.97
1200	1	1	1	1	1	1	1	1	1	1	1	1	0.98	0.98	0.97	0.97	0.97	0.97
1300	1	1	1	1	1	1	1	1	1	1	1	1	0.97	0.97	0.97	0.96	0.95	0.95
1400	1	1	1	1	1	1	1	1	1	1	1	1	0.96	0.96	0.95	0.95	0.94	0.93
1500	1	1	1	1	1	1	1	1	1	1	1	1	0.95	0.94	0.94	0.93	0.92	0.91
1600	1	1	1	1	1	1	1	1	1	1	1	0.99	0.94	0.93	0.92	0.91	0.90	0.89
1700	1	1	1	1	1	1	1	1	1	1	1	0.99	0.93	0.92	0.91	0.90	0.89	0.86
1800	1	1	1	1	1	1	1	1	1	1	1	0.99	0.92	0.90	0.89	0.88	0.86	0.84
1900	1	1	1	1	1	1	1	1	1	1	0.99	0.98	0.91	0.89	0.88	0.86	0.83	0.81
2000	1	1	1	1	1	1	1	1	1	1	0.99	0.98	0.90	0.88	0.86	0.83	0.81	0.78

Sources of Uncertainty

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. The Bayesian approach also relies on the modeller's prior belief about each input parameter. In particular, it was noted that the selection of a prior distribution on *M* was a key uncertainty in the assessment model that is not represented in the set of sensitivity analyses presented. Explorations of alternative model runs that used different prior distributions for *M* produced different estimates of stock status relative to reference points; however, these differences were not large enough to change the perception that stock status was in the healthy zone relative to BMSY-based reference points.

Other uncertainties were explored through sensitivity runs which investigated alternative assumptions to the base case run. It is acknowledged that the range of sensitivity analyses was not exhaustive, however several major uncertainties were explored including the influence of excluding commercial CPUE, using an alternative (lower) catch history, using only unsorted age samples, excluding some older survey series (south only) and an alternate (higher) value for recruitment variability (σ_R). In all cases estimates of stock status remained in the healthy zone.

MSY-based reference points are considered highly uncertain because they are poorly estimated and assume constant fishing conditions over time.

Both assessment models assumed that northern and southern stocks were closed populations, which may not be the case. This assumption is especially uncertain for the northern stock, which given its small geographic coverage, may be at the edge of a larger stock that extends up into Alaska. Similarly, the southern stock may be part of a population that extends into Washington State and Oregon.

Ecosystem Considerations

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 for individual trawl tows when the combined coral and sponge catch exceeds 20 kg. These measures have been incorporated into DFO's Pacific Region Groundfish Integrated Fisheries Management Plan (Pacific Region Integrated Fisheries Management Plan, Groundfish, Effective February 21, 2017).

The fishery is also 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).

While assessments and harvest options for groundfish species in the Pacific region are 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.

CONCLUSIONS AND ADVICE

The assessment depicts a slow-growing, low-productivity stock which experienced commercial fishing by foreign and domestic fleets before the implementation of individual vessel quotas in 1997. Exploitation rates have since declined, with very low exploitation in BCN (median u_{2017}=0.02) and moderate exploitation in BCS (median u_{2017}=0.05). Estimated exploitation rates are well below modelled estimates of natural mortality for both stocks.

Advice to management is provided in the form of decision tables. The tables assume the model to be valid and no future management interventions would occur if stock status changes for each level of constant catch.

It is recommended that the next assessment occur in 2023, with three new indices from each of the four synoptic surveys and five additional years of commercial fleet ageing and catch data. No appropriate indicators are recommended that could be used to trigger an assessment earlier than scheduled during the interim years. The most suitable potential indicator, the Queen Charlotte Sound synoptic survey, provides biennial estimates of relative biomass with error and likely requires at least two observations to trigger a new assessment, and assessment of ageing structures collected from surveys would require an additional 6-8 months. Advice for interim years is explicitly included in the decision tables.

OTHER CONSIDERATIONS

It is not known how the global warming trend associated with climate change will affect this species and the conclusions made by this stock assessment. Although there is agreement that warmer temperature regimes will affect marine species, the exact nature of these effects is poorly understood. Previous attempts at incorporating climate variables into stock assessments such as this one have proved unsuccessful, largely because of 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 a more complex modelling approach.

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SOURCES OF INFORMATION

This Science Advisory Report is from the June 13-14, 2018 Regional Peer Review on Stock Assessment for British Columbia Redstripe Rockfish (*Sebastes proriger*) in 2018. 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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