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BOCACCIO (*SEBASTES PAUCISPINIS*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2019, INCLUDING GUIDANCE FOR REBUILDING PLANS

Bocaccio (Sebastes paucispinis).
Credit: RecFIN, USA.

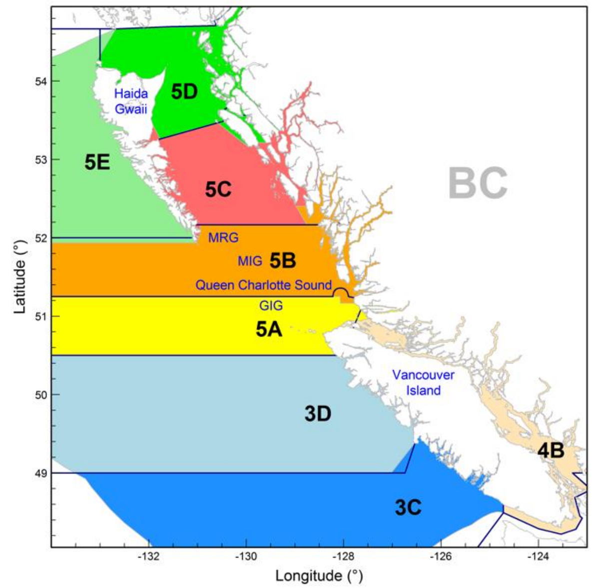

Figure 1. Bocaccio assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major areas outlined with solid lines and used in this assessment. The Groundfish Management Unit area boundaries, based on Pacific Fisheries Management Areas, are superimposed as coloured polygons for comparison. This assessment is for all offshore areas combined (3CD5ABCDE, excludes 4B).

Context:

Bocaccio rockfish (BOR) gets its name from the Italian translation for 'mouth', 'bocca', and is a moderately long-lived species (up to 50–60 years) found along the Pacific rim of North America. Historically, BOR was captured frequently by various gear types; however, since an updated Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status of 'Endangered' in 2013, the commercial fisheries have actively avoided this species and the average total annual catch has only been 69 tonnes from 2015-2019. This quantitative age-structured stock assessment treats the BC population of BOR as a single coastwide stock based on the absence of regional or gear-specific differences in biology. Harvest advice is provided showing that current and elevated harvest levels will be sustainable within 3-5 years once a very large 2016 cohort is anticipated to enter the spawning stock population. The harvest advice is expected to be compliant with DFO's Decision-making Framework Incorporating the Precautionary Approach.

This Science Advisory Report is from the December 17-18, 2019 regional peer review on the Bocaccio (Sebastes paucispinis) stock assessment for British Columbia in 2019, including guidance for rebuilding plans. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- A single Bocaccio rockfish (BOR) stock has been identified along the BC coast, based on no observable differences in mean weight, observed length, or growth models between North (5ABCDE) and South (3CD) and among three regional areas (5DE, 5ABC, 3CD). There were also no observable differences in BOR biology by trawl fishing gear type.
- The BOR stock was assessed using a two-fishery, annual two-sex catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated quantities. A composite base case that combined three models using three fixed values for natural mortality (*M*) to incorporate the uncertainty in this parameter was used to evaluate this stock.
- The median (with 5 and 95 percentiles of the Bayesian results) female spawning biomass at the beginning of 2020 (B_{2020}) is estimated to be 0.028 (0.013, 0.058) of unfished female spawning biomass (B_0). Also, B_{2020} is estimated to be 0.096 (0.042, 0.23) of the equilibrium spawning biomass at maximum sustainable yield, B_{MSY}.
- There is an estimated probability of <0.01 that $B_{2020} > 0.4B_{\mathrm{MSY}}$ and a probability of 0 that $B_{2020} > 0.8B_{\mathrm{MSY}}$ (i.e. of being in the Healthy zone). The probability that the exploitation rate in 2019 was below that associated with MSY is >0.99.
- There is evidence from the two most important trawl surveys and from the commercial fishery that a strong BOR cohort was spawned in 2016. This stock assessment estimates that this cohort is 44 times (5–95% range: 30–58) the average recruitment (1935-2019) estimated over the 85 year reconstruction period.
- Advice to management is presented in the form of decision tables using the provisional reference points from the DFO [Decision Making Framework Incorporating the Precautionary Approach] (DFO 2009). The decision tables provide ten-year projections across a range of constant catches up to 600 tonnes/year.
- The strong 2016 year class is projected to rebuild this stock above the limit reference point (LRP) ($0.4B_{\mathrm{MSY}}$) with a 0.95 probability by 2023 at catch levels up to 600 tonnes/year. Catch levels above 600 tonnes/year were not evaluated. It is projected to rebuild this stock above the Upper Stock Reference (USR) ($0.8B_{\mathrm{MSY}}$) with at least a 0.68 probability by 2023 over the same range of catch levels. Decision tables for stock rebuilding out to three generations (60 years) are presented in the Research Document.
- The size of the 2016 year class was a major source of uncertainty discussed during the review, this uncertainty was addressed with projections from the lowest 5th percentile of recruitment estimates. These projections extended the period to rebuild above the (USR) by 2 years.
- 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 0.2 and 0.4 of B_0 is also presented as alternative options in the Research Document.
- It is recommended that a stock status update be prepared biennially, with a full re-assessment occurring after 2025 or longer. Intermediate progress on rebuilding can be tracked by the two primary trawl surveys which sample this species as well as by the commercial trawl fishery.

INTRODUCTION

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the British Columbia (BC) population of Bocaccio rockfish (BOR) as "Threatened" in 2002. In November 2013, BOR was reassessed by COSEWIC as "Endangered". An endangered species is defined by the Species at Risk Act (SARA) as one that is facing imminent extirpation or extinction. In the absence of updated science advice, there is uncertainty about the risks posed to the BC BOR stock as catch levels will likely increase in response to an apparent strong recruitment event. This stock assessment provides an update on the stock status of BOR and also serves to inform DFO rebuilding plans for this species. Additional information is provided on COSEWIC indicators for assessment criterion A2b in the full Research Document.

BOR (*Sebastes paucispinis*) is ubiquitous along the BC coast, with most catches taken near the bottom in the depth range of 60-300 m. Catches appear to be greatest on the edge of the continental shelf where it slopes away, as well as along the edges of the main gullies in Queen Charlotte Sound and the more southern sections of Hecate Strait (Stanley et al. 2009). Stanley et al. (2009) noted that BOR is a schooling semi-pelagic species, leading to the observation that the adults likely do not occupy specific sites other than preferring high-relief boulder fields and rocks. The species appears to be a relatively short-lived compared to other *Sebastes* species such as Pacific Ocean Perch (*S. alutus*) or Rougheye Rockfish (*S. aleutianus*), a characteristic shared with other semi-pelagic *Sebastes* species (e.g., Widow Rockfish, *S. entomelas*). The available age data show that this species reaches maximum ages around 50-55 years, with one male specimen reaching age 70 and three specimens aged 60 or greater from a pool of nearly 4,000 age observations. This stock assessment evaluates a BC coastwide population harvested by two fisheries (1=commercial bottom and midwater trawl; 2=halibut longline, sablefish trap, lingcod longline, inshore longline, salmon troll, and recreational), each with pooled catches and with age data only available for the combined trawl fishery.

ASSESSMENT

The catch-at-age model used for the stock assessment was tuned to six fishery-independent trawl survey series (covering 1967-2019), a standardised commercial bottom trawl catch per unit effort (CPUE) series (1996-2012)[1], annual estimates of commercial catch from two fisheries, and age composition data from the combined commercial trawl fishery and four of the six surveys. Before the development of modern catch databases, historical landings of rockfish were aggregated: either as Pacific Ocean Perch (POP) or rockfish other than POP (ORF). Annual totals for Pacific Marine Fisheries Commission (PMFC) regions are available from eight different sources, although not in all years (see Haigh and Yamanaka 2011). All catches of BOR before 1996 for Trawl and 2006 for the "Other" fishery in this assessment have been reconstructed by applying contemporary ratios of BOR to ORF to annual historical landings by PFMC region. Discards were added to fishery-specific years based on average (trawl: 1997-2006, other: 2000:2004) observed rates of discarding relative to landings.

The model started from an assumed equilibrium state in 1935. Three component base runs using a two-sex model were implemented in a Bayesian framework (using the Markov Chain Monte Carlo procedure) under scenarios that fixed natural mortality (M) to three levels (0.07, 0.08, 0.09) using an accumulator age (A) of 50 years while estimating steepness of the stock-recruit function (h), catchability (q) for surveys and CPUE, and selectivity (μ) for four

[1] The series was truncated at 2012 on the advice of the BOR Technical Working Group (TWG); it was felt that avoidance behaviour by the fleet would bias the indices after TACs were considerably reduced in 2013 in response to the COSEWIC 'Endangered' designation.

surveys and the commercial trawl fleet. These three runs were combined into a composite base case which explored the major axes of uncertainty (M) in this stock assessment.

All calculations were made using the Bayesian Markov Chain Monte Carlo (MCMC) procedure to quantify parameter uncertainty. For each of the component base runs, six million simulations were sampled every 5000th to yield 1200 MCMC samples (reduced to 1000 after dropping the first 200 samples as 'burn-in') from the posterior distributions for estimated parameters. Estimates of various quantities were calculated from three pooled runs (3000 MCMC samples), and are presented as the median (with 5 and 95 percentiles to specify uncertainty). Calculated probabilities are based on the full MCMC posterior distributions.

The posterior parameter distributions for each component run of the composite base case were summed to create a composite posterior distribution of estimated parameters. This 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. Ten-year and three-generation projections were performed over a range of constant catches and harvest rates to estimate probabilities of breaching reference points. Advice to managers is presented as sets of decision tables that provide probabilities of exceeding reference points (consistent with the 2009 DFO Precautionary Approach: $0.4B_{\text{MSY}}$; $0.8B_{\text{MSY}}$) as well as remaining below the harvest rate at MSY (u_{MSY}) for 2020 through 2030 for a range of constant catch levels and harvest rates.

Figure 2 shows the estimated annual spawning biomass (mature females only) for the coastwide stock, together with the historical catches (males and females), for the composite base case. The coastwide BOR stock has experienced a nearly continuous decline from the start of the population reconstruction in 1935, interrupted only by a relatively level plateau spanning the years 1970-86 due to a few good recruitment events in 1969, 1976, and 1978. However, the decline continued from 1987 onwards until a very large recruitment event in 2016 (Figure 3), estimated to be 44 times the long-term average recruitment (5–95% range: 30–58).

The estimated median MSY is 1461 tonnes (703, 3623), compared to the average catch over the last five years (2015-2019) of 69 tonnes. The estimated current–year spawning biomass (B_{2020}) relative to equilibrium unfished biomass, B_{2020}/B_0 = 0.028 (0.013, 0.058), and to equilibrium spawning biomass that would support the MSY, B_{2020}/B_{MSY} = 0.096 (0.042, 0.23); neither of these estimates include the 2016 year class because it is assumed that the first four age classes do not have any mature females. In contrast, the equivalent ratio for the current biomass vulnerable to trawl gear (Table 1), V_{2020}/V_0 = 0.10 (0.050, 0.21), which is determined by the selectivity function, is greater than the spawning biomass ratio because it includes a small fraction of the 2016 cohort. The estimated exploitation rates (u_t) throughout the time series were low (maximum median $u \approx 0.06$, Figure 4), with the current-year exploitation rate relative to that at MSY estimated at u_{2019}/u_{MSY} = 0.29 (0.12, 0.66) for the trawl fishery and u_{2019}/u_{MSY} = 0.011 (0.0042, 0.026) for the 'other' fishery (Table 1, Figure 5).

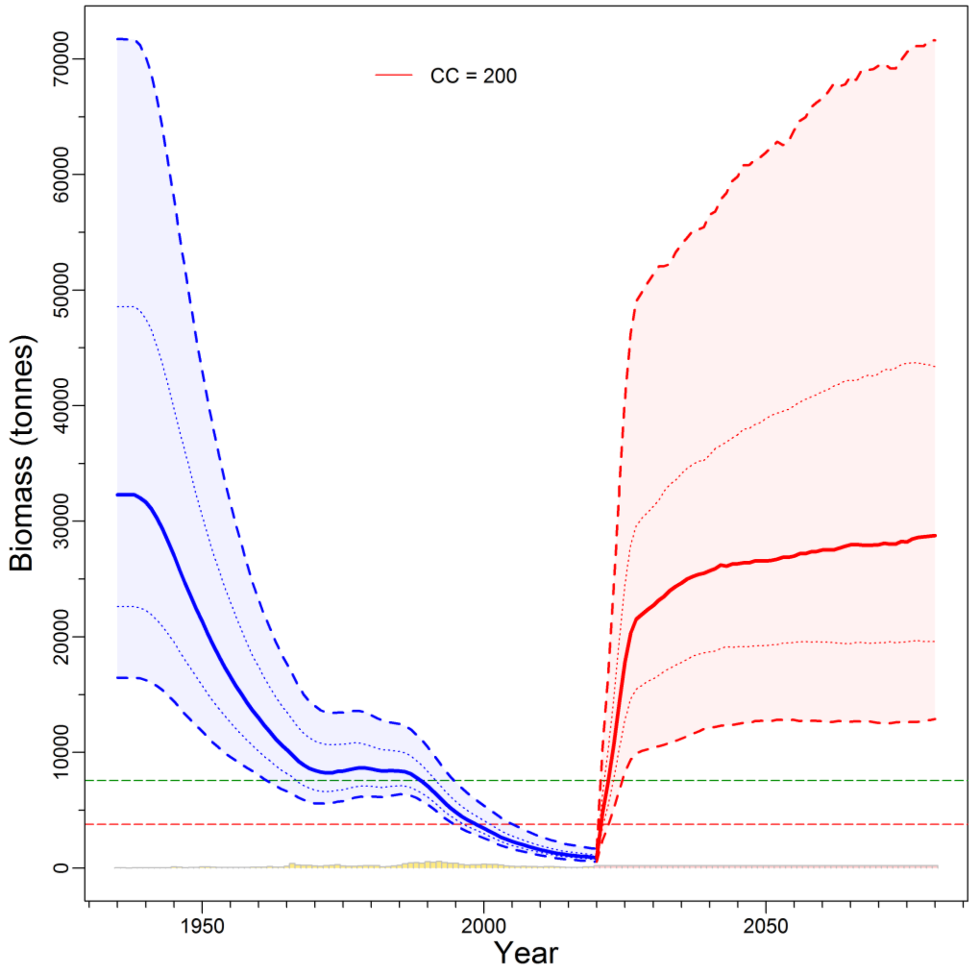

Figure 2. Estimates of spawning biomass B_t (tonnes) from the model posteriors of the composite base case (3000 MCMC samples). The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05, 0.95) in light blue and delimited by dashed lines for years t=1935-2020; projected biomass appears in light red for years t=2021-2080. Also delimited is the 50% credibility interval (quantiles: 0.25-0.75) delimited by dotted lines. The horizontal dashed lines show the median LRP (red: $0.4B_{MSY}$) and USR (green: $0.8B_{MSY}$). Catch and assumed catch policy (200 tonnes/year) are represented as bars along the bottom axis.

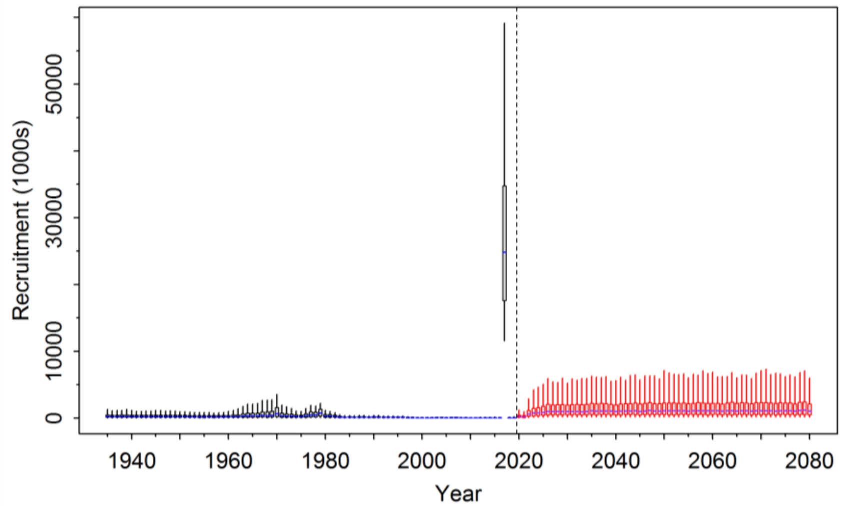

Figure 3. Composite base case: marginal posterior distribution of recruitment (in 1000s of age-1 fish) for reconstructed (1935-2020–in grey) and projected (2021-2080–in red) years. Boxplots give the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from 3000 MCMC results.

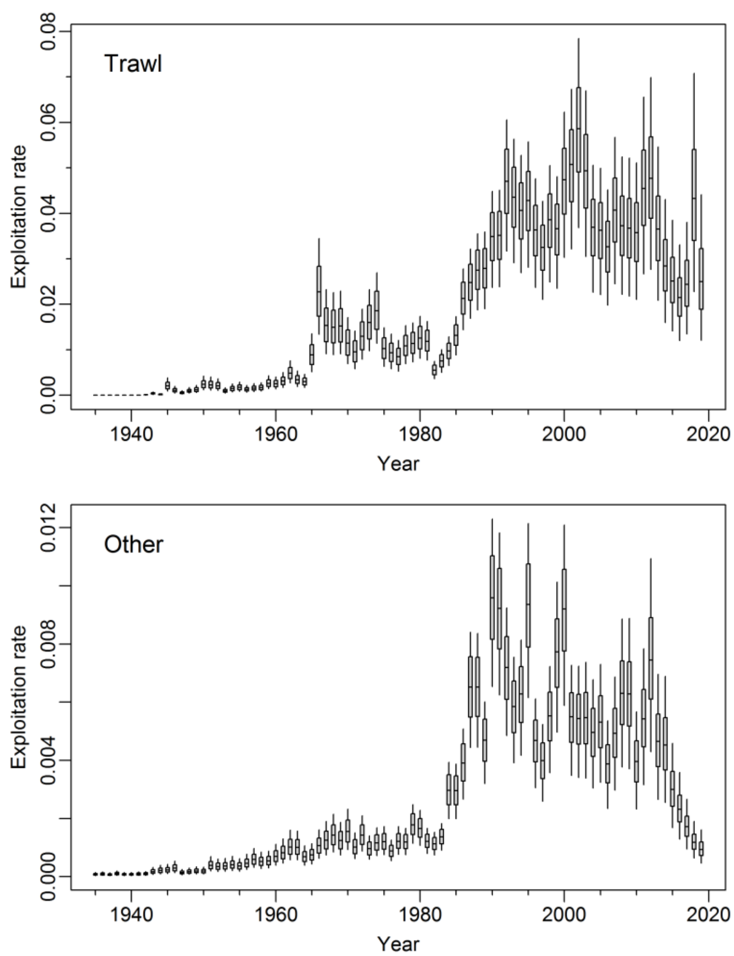

Figure 4. Composite base case: marginal posterior distributions of annual exploitation rate by year and fishery. Boxplots give the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from 3000 MCMC results.

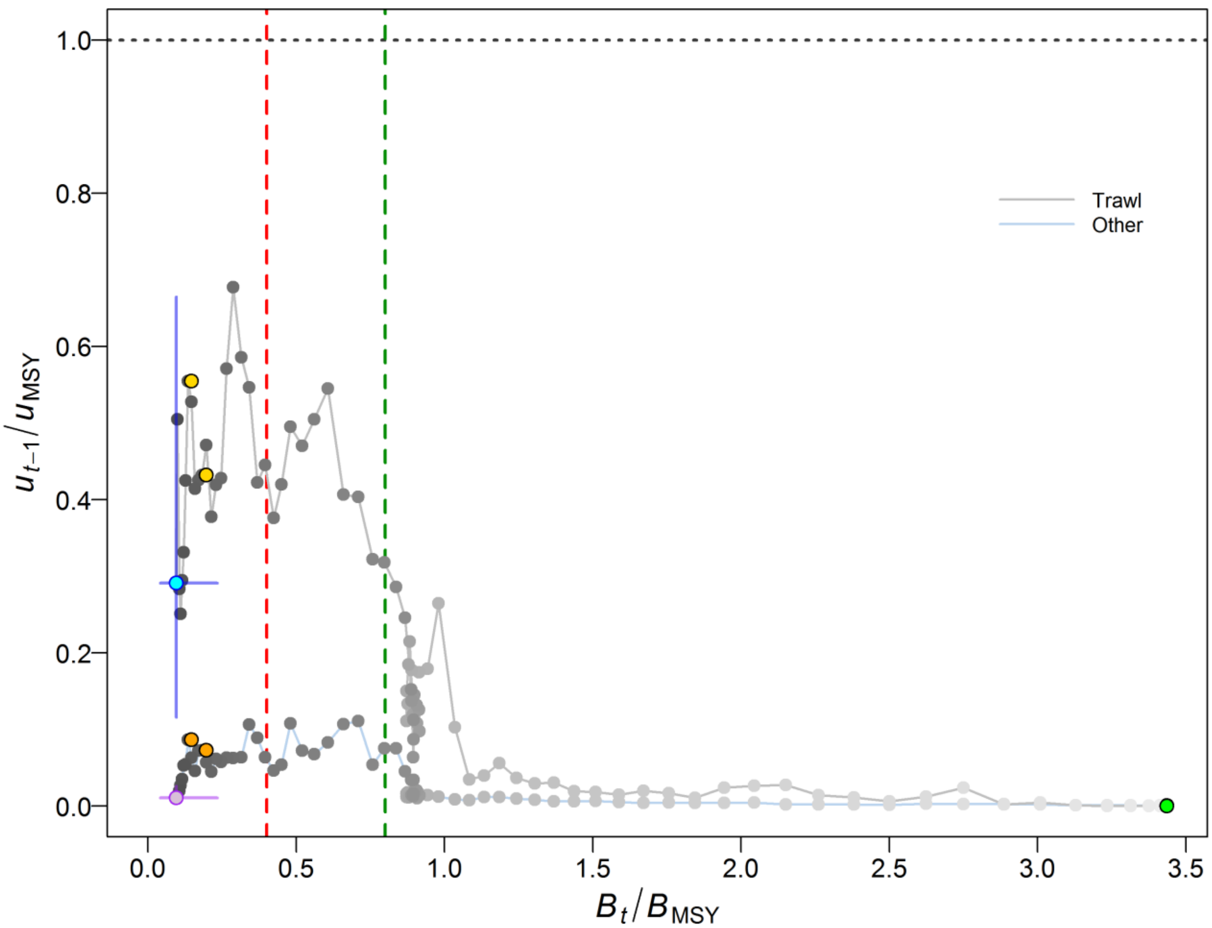

Figure 5. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass at the start of year t relative to B_{MSY}) and two measures of fishing pressure: trawl ($u_{t\text{-}1(trawl)}/u_{MSY}$: cyan dot) and 'other' ($u_{t\text{-}1(other)}/u_{MSY}$: purple dot) (both represent the exploitation rate in the middle of year t-1 relative to u_{MSY} for each fishery) for the composite base case. The filled green circle is the starting year (1935). Years then proceed from light grey through to dark grey with the final year (t=2020) as a filled cyan or purple circle, and the blue/purple lines represent the 0.05 and 0.95 quantiles of the posterior distributions for the final year. Previous assessment years (2008, 2012, Stanley et al. 2009, 2012) are indicated by gold/orange circles. 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}.

Table 1. Quantiles of MCMC-derived quantities from the 3000 samples of the MCMC posterior of the composite base case. Note that all vulnerable biomass definitions are provided using the respective fishery selectivity. Definitions: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B^{2020} – spawning biomass at the start of 2020, V_{2020} – vulnerable biomass in the middle of 2019, u_{2019} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2019, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2019), 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 (including MSY) are in tonnes. The average annual catch over the last 5 years (2015-19) was 69 tonnes.

From model output

Value	**5%**	**50%**	**95%**
B_0	16,460	32,289	71,710
V_0 (trawl)	27,930	55,089	123,319
V_0 (‘other’)	27,286	53,564	119,116
B_{2019}	552	899	1,655
V_{2020} (trawl)	3,046	5,703	12,273
V_{2020} (‘other’)	2,582	4,709	9,812
B_{2020} / B_0	0.0132	0.0278	0.0578
V_{2020} / V_0 (trawl)	0.0496	0.104	0.213
V_{2020} / V_0 (‘other’)	0.0426	0.0875	0.175
u_{2019} (trawl)	0.0121	0.025	0.0441
u_{2019} (‘other’)	0.000467	0.000930	0.00161
u_{max} (trawl)	0.0369	0.0588	0.0792
u_{max} (‘other’)	0.00654	0.00968	0.0124

MSY-based quantities

Value	**5%**	**50%**	**95%**
MSY	703	1,461	3,623
B_{MSY}	4,134	9,462	22,469
$0.4B_{MSY}$	1,653	3,785	8,988
$0.8B_{MSY}$	3,307	7,570	17,976
B_{2020} / B_{MSY}	0.0417	0.0963	0.2340
B_{MSY} / B_0	0.225	0.291	0.353
V_{MSY}	7,858	17,554	41,876
V_{MSY} / V_0 (trawl)	0.252	0.319	0.378
V_{MSY} / V_0 (‘other’)	0.253	0.328	0.396
u_{MSY}	0.054	0.085	0.133
u_{2019} / u_{MSY} (trawl)	0.116	0.291	0.664
u_{2019} / u_{MSY} (‘other’)	0.00421	0.0109	0.0258

Reference Points

Figure 6 shows the stock status for the composite base case as well as each component run relative to the provisional DFO (2009) limit and upper stock reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ respectively (see Table 1 for B_{MSY} reference points specific to BOR). These reference points define the ‘Critical’, ‘Cautious’ and ‘Healthy’ zones. The composite base case spawning biomass at the beginning of 2020 is estimated to be above the limit reference point (LRP) with probability $P(B_{2020} > 0.4B_{MSY}) < 0.01$, and above the upper stock reference (USR) point with probability $P(B_{2020} > 0.8B_{MSY}) = 0$ (i.e., no probability of being in the Healthy zone based on the set of MCMC posterior samples).

Starting in 2021, there is a quick rebound in spawning biomass because a small proportion of the 5-year old fish have become mature. Due to the large estimated size of the 2016 cohort, the recovery of the spawning stock biomass is rapid and the probability of this biomass exceeding the LRP, i.e. P(B_t > 0.4B_{MSY}), exceeds 95% in year t =2023 (Table 2). Figure 6 demonstrates the rapidity of this rebound by showing projected stock status in two years (at the beginning of 2022), assuming a constant catch of 200 tonnes/year or a harvest rate of 0.04/year. In this short time, spawning biomass has moved into the Cautious zone (i.e., the median lies near the USR of 0.8B_{MSY}).

MSY-based reference points estimated within a stock assessment model can be highly 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} (e.g., New Zealand Ministry of Fisheries 2011). Therefore, the reference points of 0.2B_0 and 0.4B_0 are also presented in Appendix F of the Research Document. These reference points 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 provisional 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. Because of the strong management measures in place to protect BOR, exploitation rates are already well below u_{MSY}, with the estimated ratio of $u_{2019}/u_{\mathrm{MSY}}$ = 0.29 (0.12, 0.66) (Table 1). The probability that the current exploitation rate is below that associated with MSY is P($u_{2019} < u_{\mathrm{MSY}}$) = 0.99 for the trawl fishery and 1 for the 'other' fishery. A phase plot of the time-evolution of spawning biomass and exploitation rate for the two modelled fisheries in MSY space (Figure 5) shows that the stock has been in the Cautious zone from 1989 to 1998 and in the Critical zone since 1999.

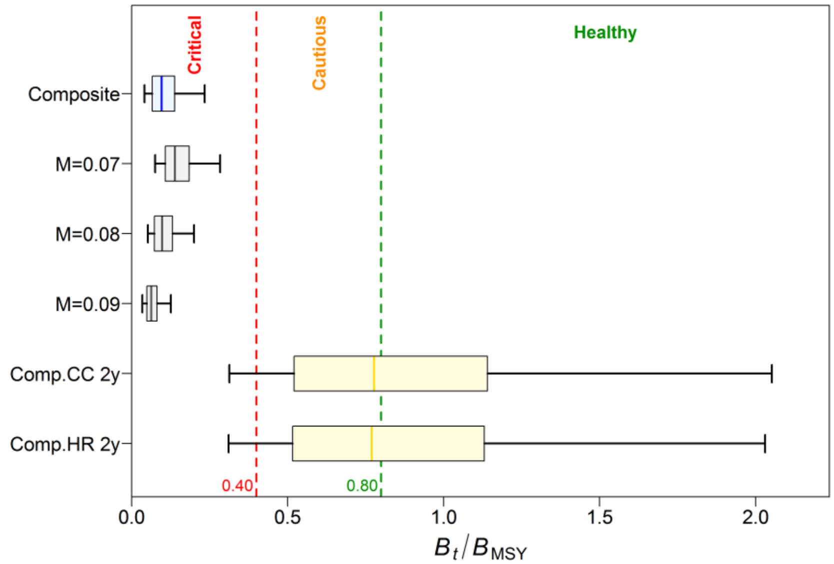

Figure 6. Status of the coastal BOR stock relative to the DFO Precautionary Approach (PA) provisional reference points of 0.4B_{MSY} and 0.8B_{MSY} for the t=2020 composite base case and the component base runs that are pooled to form the composite base case. Also shown are projected stock status for the composite base case at the beginning of 2022 after fishing at a constant catch=200 tonnes/year or a constant exploitation rate of 0.04/year. 2022 is the second year that the 2016 cohort is assumed to contribute to the spawning population. 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, starting with the biomass at the beginning of 2020, were made over a range of constant catch levels (0-600 tonnes in 50 tonne increments) and harvest rates (0-0.12/year in 0.01/year increments, available in the Research Document). This time frame was considered adequate for advice to managers before the next stock assessment of this species, especially given that these projections are dominated by the 2016 cohort, which is by far the primary contributor to any short-term biomass increase. Note that the uncertainty in rebuilding increases the further forward in time they are projected. While all projections should be treated with caution, projections beyond 10 years should be treated with additional caution. The decision table (Table 2) gives the probabilities of the spawning biomass exceeding the biomass reference points and of being below u_{MSY} 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.

At all levels of evaluated catch, Table 2 shows that a manager would be ≥ 99% certain that both B_{2025} and B_{2030} are above the LRP of 0.4B_{MSY}, ≥89% certain that B_{2025} and ≥93% certain that B_{2030} are above the USR of 0.8B_{MSY}, and ≥98% certain that u_{2025} and u_{2030} are below u_{MSY} for the composite base case. The preferred catch and risk levels used in managing the BOR stock are management choices. For example, it may be desirable to be 95% certain that B_{2025} exceeds an LRP whereas exceeding a USR might only require a 50% probability. Assuming this risk profile, all the catch policies in Table 2 would satisfy the specified LRP and USR constraints. Assuming that u_{MSY} is a limit exploitation rate, all the catch policies in Table 2 beginning in 2021 define harvest rates that would be less than u_{MSY} with a probability of at least 95%.

Table 2. Decision tables for the reference points 0.4B_{MSY}, 0.8B_{MSY}, and u_{MSY} for 1-10 year projections for a range of constant catch policies (in tonnes) using the composite base case. Values are the probability (proportion of 3000 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 annual catch over the last 5 years (2015-2019) was 69 tonnes.

P(B_t >0.4B_{MSY})

Catch										Projection year
policy	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
50	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
100	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
150	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
200	<0.01	0.65	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
250	<0.01	0.65	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
300	<0.01	0.65	0.87	0.96	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
350	<0.01	0.65	0.86	0.96	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
400	<0.01	0.64	0.86	0.96	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
450	<0.01	0.64	0.86	0.96	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	<0.01	0.64	0.86	0.96	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99
550	<0.01	0.64	0.85	0.96	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99
600	<0.01	0.64	0.85	0.95	0.98	0.99	0.99	>0.99	>0.99	0.99	0.99

P(B_t >0.8B_{MSY})

Catch										Projection year
policy	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0	0	0.21	0.49	0.73	0.87	0.94	0.96	0.97	0.97	0.97	0.98
50	0	0.20	0.49	0.73	0.87	0.93	0.96	0.97	0.97	0.97	0.97
100	0	0.20	0.49	0.73	0.86	0.93	0.96	0.97	0.97	0.97	0.97
150	0	0.20	0.48	0.72	0.85	0.93	0.96	0.96	0.96	0.97	0.97
200	0	0.20	0.48	0.72	0.85	0.92	0.95	0.96	0.96	0.96	0.97
250	0	0.20	0.48	0.72	0.85	0.92	0.95	0.96	0.96	0.96	0.96
300	0	0.20	0.48	0.71	0.85	0.92	0.94	0.95	0.96	0.96	0.96
350	0	0.20	0.47	0.71	0.84	0.91	0.94	0.95	0.95	0.96	0.96
400	0	0.19	0.47	0.70	0.84	0.91	0.94	0.95	0.95	0.95	0.95
450	0	0.19	0.46	0.70	0.83	0.90	0.93	0.94	0.94	0.95	0.95
500	0	0.19	0.46	0.70	0.83	0.90	0.93	0.94	0.94	0.94	0.94
550	0	0.19	0.46	0.69	0.82	0.89	0.93	0.93	0.93	0.93	0.94
600	0	0.19	0.45	0.68	0.82	0.89	0.92	0.93	0.93	0.93	0.93

P(u_t <u_{MSY})

Catch										Projection year
policy	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0	1	1	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1	1	1
100	>0.99	>0.99	1	1	1	1	1	1	1	1	1
150	0.98	>0.99	>0.99	1	1	1	1	1	1	1	1
200	0.95	0.99	>0.99	>0.99	>0.99	1	1	1	1	1	1
250	0.89	0.97	0.99	>0.99	>0.99	>0.99	1	1	1	1	1
300	0.81	0.94	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
350	0.72	0.91	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
400	0.63	0.86	0.96	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
450	0.56	0.82	0.93	0.97	0.99	0.99	0.99	>0.99	>0.99	0.99	0.99
500	0.49	0.76	0.91	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99
550	0.42	0.71	0.88	0.95	0.97	0.98	0.99	0.99	0.99	0.99	0.99
600	0.36	0.65	0.85	0.93	0.96	0.98	0.98	0.98	0.98	0.98	0.98

The associated Research Document (RD) also provides tables for rebuilding out to three generations; however, the current base case shows that a full recovery (with 95% probability) above the LRP will occur in three years and above the USR in six years, assuming catch policy does not exceed 250 tonnes/year (Table 2). Further, the stock will remain above the LRP for the next three generations under constant catch polices with a high probability (Table F.21, RD). Only under harvest rate scenarios greater than 0.08 does the spawning stock biomass begin to decline such that the probability of remaining above the LRP falls below 95% (Table F.22, RD).

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 across the three runs comprising the composite base case. The Bayesian approach also relies on the prior belief about each input parameter. In particular, the Technical Working Group noted that natural mortality (M) was a key uncertainty for this species, especially as it could not be estimated given the available data. Using a plausible range of M values helped to capture this uncertainty in model results.

Other uncertainties were explored through sensitivity runs. These included:

- productivity assumptions – changing standard deviation of recruitment residuals, using an alternative growth model;
- abundance – decreasing/increasing historical catch, removing the CPUE signal, dropping the historical surveys;
- composition – narrowing ageing error, using a full maturity ogive.

Most sensitivity runs remained primarily in the Critical zone. Explorations of alternative model runs that dropped abundance indices (CPUE, historical surveys) improved perceived stock status relative to B_0; however, these runs had either poor or unacceptable MCMC diagnostics. Using a full maturity ogive also increased perceived stock status, because small proportions of fish aged 1-4 were included in the spawning stock.

Uncertainty in the strength of the 2016 cohort was explored through a projection sensitivity run which used only the lowest 5th percentile of the 2016 recruitment posterior distribution to estimate future stock status. These projections extended the time required to rebuild biomass above the LRP and the USR by only 2 years.

Although the coastwide population of BOR might comprise multiple stocks, these could not be separated given the data available at the time of the stock assessment. Future assessments might adopt spatially distinct stocks if additional data support subdivision.

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 impacted by this fishery, including Bocaccio.

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, which 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, thus providing protection for areas frequented by juvenile groundfish of many species as well as juvenile and adult BOR. 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 dependant ecosystem and fishery monitoring, DFO, in collaboration with industry partners, conduct 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 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 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 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.

While occasional large recruitment events can be considered to be typical among species of *Sebastes*, such events tend to occur every 10 to 25 years in other species of this genus that have been assessed. Bocaccio appears to be an outlier species, with only one large cohort observed in over 60 years of potential data. While the existence of the large 2016 cohort is welcome information that is predicted to lead to recovery, it is noted that the southern California population of BOR has had several good recent recruitments that have led to recovery in that population.

There was considerable discussion amongst the peer review participants of possible linkages between environmental variables, BOR recruitment, and rockfish recruitment more generally as there have been a number of significant recruitment events for BOR as well as other rockfish species along the Pacific coast of North America over the last decade. Such recruitment events, while likely driven by environmental events, are difficult to evaluate because of their rarity and the indirect causality associated with these events. For example, it is possible that the coincident timing of a marine heat wave in the NE Pacific Ocean (2014-15), coined the 'The Blob', and the current strong BC BOR recruitment event are linked, but the intermediate causation steps are poorly understood

CONCLUSIONS AND ADVICE

In common with other BC rockfish stock assessments, this stock assessment depicts a slow-growing, low productivity stock. However, what is unusual about this stock assessment is that this stock appears to be even less productive than would be expected for the apparent rate of natural mortality suggested by the available ageing information. The exploitation rates estimated by the model, which reach their highest point at around 0.06/y, a level much lower than that seen in other recent rockfish stock assessments, should result in catches below replacement levels and allow the population to increase. But such increases had not been observed until evidence began to accumulate from the large 2016 cohort. The number of good recruitment events appear to be few for BOR, which has steadily declined over the period 1935–2020, in spite of the low exploitation rates stemming from management actions that have reduced recent removals to 100 tonnes or less per year. These results corroborate the findings in previous stock assessments of BOR. However, what distinguishes this stock assessment from the previous ones is the signal of new recruitment in the form of the strong 2016 year class, which is estimated by the composite base model to be 44 times (median estimate; 5-95% range: 30–58) the long-term average recruitment.

The RPR meeting participants recommended biennial updates of the current assessment to track progress of the strong 2016 cohort. The two-year interval is the minimum elapsed time required to obtain a complete cycle of bottom trawl survey results. This set of survey observations will provide a coast wide view of BOR abundance, which is needed to update this stock assessment, including revised decision tables.

Scheduling of the next full assessment depends on the actual strength of the recruiting 2016 year class, as it develops in the coming years. If it continues to show a strength consistent with the evaluation in this stock assessment, then coastal BOR should rebuild to levels above the USR in 3–5 years, and the need to re-evaluate this stock assessment can be postponed for a few years. The existing synoptic trawl surveys, particularly the Queen Charlotte Sound (QCS) and west coast Vancouver Island (WCVI) surveys, should provide adequate monitoring of this year class in the coming years. The next full stock assessment should be scheduled in 2025 (or possibly later), such that there will be at least two new indices from both the QCS and WCVI synoptic surveys. Regardless of when a new stock assessment is scheduled, technicians need 6-12 months to process and read new ageing structures before assessment scientists can begin the reconstruction of a population trajectory. Advice for interim years is explicitly included in the decision tables and managers can select another line on the table if stock abundance appears to have changed or if greater certainty of staying above the reference point is desired.

Advice to management is provided in the form of decision tables. These tables assume the composite base case model is valid and there will be no management interventions if stock status falls below accepted reference points at any level of constant catch.

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SOURCES OF INFORMATION

This Science Advisory Report is from the December 17-18, 2019 regional peer review on the Evaluation of Bocaccio rebuilding plan objectives. 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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