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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2020/047

ROUGHEYE/BLACKSPOTTED ROCKFISH (*SEBASTES ALEUTIANUS/MELANOSTICTUS*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2020

Rougheye Rockfish (Sebastes aleutianus) Credit: RecFIN, USA

Blackspotted Rockfish (Sebastes melanostictus) Credit: RecFIN, USA.

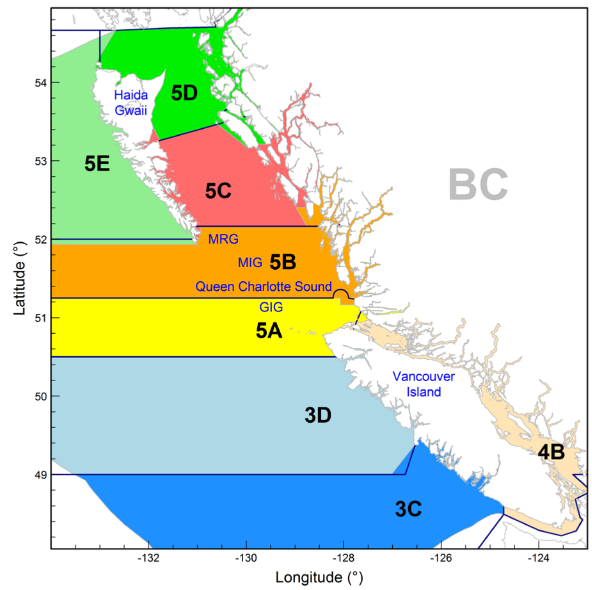


Figure 1. Rougheye/Blackspotted Rockfish assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major areas outlined with solid lines and used in this assessment. The Groundfish Management Unit area boundaries, based on Pacific Fisheries Management Areas, are superimposed as coloured polygons for comparison. This assessment is for PMFC areas 5DE and 3CD5AB (excludes 5C and 4B).

Context

This is the first formal assessment for the Rougheye/Blackspotted (REBS) Rockfish complex (Sebastes aleutianus/melanostictus). REBS has historically been assessed, fished (trawl, longline, trap) and managed as a single species, Rougheye Rockfish. In 2009, the existence of two distinct species within the species complex was confirmed with the identification of Blackspotted Rockfish (previously Rougheye Rockfish Type I), and Rougheye Rockfish (previously Rougheye Rockfish Type II). Rougheye Rockfish gets its name from the ten or so spines found on the lower rim of the orbit of the eye socket. Blackspotted Rockfish gets its name from black spots on the body. Although both species are distributed throughout the north Pacific (northern Japan to southern California), for the purposes of this assessment, data for the REBS complex have been partitioned into northern (REBS north) and southern (REBS south) stocks. The northern stock in PMFC Areas (Figure 1) 5D and 5E (5DE) is predominantly comprised of Blackspotted Rockfish, the southern stock in PMFC Areas 3C, 3D, 5A and

5B (3CD5AB) is largely comprised of Rougheye Rockfish. Both species (REBS) can be very long-lived: in British Columbia (BC), REBS north aged up to 147y, REBS south up to 125y.

Fisheries and Oceans Canada (DFO) Fisheries Management has requested that DFO Science Branch assess both stocks 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 for the two stocks over the next 10 years.

This Science Advisory Report is from the May 26-27, 2020 regional peer review on Blackspotted / Rougheye Rockfish (Type I and Type II) stock assessment for British Columbia in 2020. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Two spatial stocks of the Rougheye/Blackspotted (REBS) Rockfish complex have been identified along the BC coast, based loosely on the spatial distribution of genetically confirmed specimens from surveys: the northern stock in 5DE is predominantly comprised of Blackspotted Rockfish or REBS north (previously Rougheye Rockfish Type I). The southern stock in 3CD5AB is largely comprised of Rougheye Rockfish (Type II) or REBS south.
- The REBS stocks were assessed using a two-fishery, annual two-sex catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated quantities. For each stock, a composite base case that combined nine models for REBS north and six for REBS south, using three fixed values for natural mortality (M), to incorporate the uncertainty in this parameter, and three values of catch per unit effort (CPUE) process error, were used to evaluate stock status.
- For REBS north, the median (with 5th and 95th percentiles) female spawning biomass at the beginning of 2021 (B_{2021}) is estimated to be 0.595 (0.405, 0.840) of unfished female spawning biomass (B_0). Also, B_{2021} is estimated to be 2.21 (1.50, 3.15) times the equilibrium spawning biomass at maximum sustainable yield, B_{MSY}.
- For REBS south, the median (with 5th and 95th percentiles) female spawning biomass at the beginning of 2021 (B_{2021}) is estimated to be 0.286 (0.155, 0.680) of unfished female spawning biomass (B_0). Also, B_{2021} is estimated to be 1.07 (0.582, 2.61) times the equilibrium spawning biomass at maximum sustainable yield, B_{MSY}.
- For REBS north, there is an estimated probability of 1 that $B_{2021} > 0.4B_{MSY}$ and a probability of 1 that $B_{2021} > 0.8B_{MSY}$ (i.e., of being in the Healthy zone). The probability that the exploitation rate in 2020 was below that associated with MSY is 1 for both groundfish trawl and commercial non-trawl (Other) fisheries.
- For REBS south, there is an estimated probability of >0.99 that $B_{2021} > 0.4B_{MSY}$ and a probability of 0.74 that $B_{2021} > 0.8B_{MSY}$ (i.e., of being in the Healthy zone). The probability that the exploitation rate in 2020 was below that associated with MSY is 0.42 for the groundfish trawl fishery and 0.64 for the combined commercial non-trawl (Other) fisheries.
- 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 1200 tonnes/year for REBS north and up to 600 t/y for REBS south.

- It is projected that the REBS north stock will remain above the 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 (600 t/y). For REBS south , it is projected that the stock will remain above the LRP with a probability of 0.85 and above the USR with a probability of 0.53 over the next 10 years at current levels of catch (300 t/y). For the REBS south stock, this catch strategy is not sustainable over the long-term (1.5 generations or 75 years).
- 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 is also presented as alternative options in the Research Document.
- It is recommended that a full re-assessment occur in 10 years or less, subject to the availability of new information. During intervening years, the trend in abundance can be tracked by surveys which sample this species, as well as by commercial fishery CPUE.

INTRODUCTION

In April 2007, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the Rougheye/Blackspotted Rockfish (REBS, *Sebastes aleutianus/melanostictus*) species complex, comprising a pair of sympatric species, as 'Special Concern'. At the time of the COSEWIC assessment, the taxonomy was emerging and these species were named Rougheye Rockfish Type I and Type II, where Type I corresponded to Blackspotted Rockfish (*Sebastes melanostictus*) and Type II denoted Rougheye Rockfish (*Sebastes aleutianus*). Although the taxonomy separating the two species is clearer now using genetic analyses and various biomarkers, species allocation methodologies for historical data still need to be developed. In 2009, both Rougheye Rockfish Type I and II were added to Canada's *Species at Risk Act* (SARA) Schedule 1 as Special Concern. Since then, no changes have been made to the status of the species, and a management plan was developed in 2012.

Both Rougheye and Blackspotted Rockfish are ubiquitous along the BC coast and most catches are taken close to the bottom over depths of 200 to 800+ m along the shelf break. They range from northern Japan to southern California. Fisheries using trawl gear see highest densities off Northwest (NW) Haida Gwaii, at the mouths of Moresby and Mitchell's Gullies, and off the NW coast of Vancouver Island. Fisheries using hook and line gear catch REBS along the 500 m isobath, with the highest densities occurring off NW Haida Gwaii. REBS occur mainly on soft substrata in sloping areas with frequent boulders.

Rougheye and Blackspotted Rockfish are among the longest lived *Sebastes*, with maximum recorded ages of 147 years (Blackspotted Rockfish, *Sebastes melanostictus*) and 125 years (Rougheye Rockfish, *Sebastes aleutianus*) in BC waters, and 205 years in Southeast Alaska (Munk 2001, most likely a *Sebastes melanostictus* specimen). In BC, abundance information for REBS is derived from synoptic surveys and from the commercial fishery. The two species are intercepted by trawl nets, hook and line gear, and the Sablefish trap fishery, and are key species caught in the BC multi-species integrated groundfish fishery.

In this stock assessment, two spatial stocks of the REBS complex have been defined, based loosely on the spatial distribution of genetically confirmed specimens from surveys (Creamer 2016). Using Pacific Marine Fisheries Commission areas as boundaries, the northern stock (REBS north) in 5DE is predominantly comprised of Blackspotted Rockfish, and the southern stock (REBS south) in 3CD5AB is largely comprised of Rougheye Rockfish. REBS data from area 5C were considered to be in a zone of hybridisation and consequently were omitted from the stock assessment except to proportionately distribute by year the 5C catch between the two species (~65–70% in favour of Blackspotted Rockfish). It is recognised that this spatial definition only approximates the true species distribution but was adopted in the absence of a more reliable methodology.

ASSESSMENT

This stock assessment evaluates two stocks along the BC coast, REBS north 5DE and REBS south 3CD5AB, which are harvested by multiple fisheries. The assessment uses an annual catch-at-age model tuned to one fishery-independent trawl survey series for REBS north and three surveys for REBS south, a commercial bottom trawl CPUE series for both, annual estimates of commercial catch since 1935, and age composition data from survey series (spanning 1997–2016) and commercial fisheries (spanning 1978–2018). Two fisheries are modelled: one a combined bottom and midwater 'Trawl' fishery and an 'Other' fishery, which combines commercial hook and line and trap fisheries. The second fishery is a compromise that acknowledges other methods of capturing this species while keeping the complexity to a minimum, given the lack of good information from these additional fisheries.

The model starts from an assumed equilibrium state in 1935. Nine component base runs using a two-sex model were implemented in a Bayesian framework under scenarios that fixed natural mortality (M) to three levels (0.035, 0.045, 0.055) using an accumulator age (A) of 80 years and added three sets of process error (c_p) to the CPUE index (0.1, 0.28, 0.4 for REBS north and 0.1, 0.25, 0.4 for REBS south). Steepness (h) of the stock-recruit function was fixed at 0.7; catchability (q) for the surveys and CPUE, and selectivity (μ) for three of the four surveys and the commercial trawl fleet were estimated. For REBS north the respective nine component runs were combined into a composite base case, for REBS south only six of the nine components runs were used as three had poor convergence characteristics. These component runs explored the two major axes of uncertainty in this stock assessment, namely, the parameter M and CPUE process error. Sensitivity analyses were performed to test the effect of additional alternative model assumptions.

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 pooled runs (9000 MCMC samples for REBS north, 6000 for REBS south), and are presented as the median (with 5th and 95th percentiles to specify uncertainty). Calculated probabilities are based on the pooled 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 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 and 1.5-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 2021 through 2031 for a range of constant catch levels and harvest rates.

Figure 2 shows the estimated annual spawning biomass (mature females only) for the coastwide stocks of REBS north and REBS south, each for the composite base case. Both stocks have experienced a nearly continuous decline from the start of the population reconstruction in 1935, interrupted only by occasional recruitment events (Figure 3). The 1.5-generation (75-year) projections at catches close to current harvest rates (BSR: 600 t/y, RER: 300 t/y) show that REBS north will remain fairly stable, with median stock levels well above $0.8B_{\text{MSY}}$, whereas REBS south will eventually crash in the absence of high-recruitment events.

For REBS north, the estimated median MSY is 636 tonnes (474, 1115) (Table 1), compared to the average catch over the last five years (2015-2019) of 548 tonnes. The estimated current-year spawning biomass (B_{2021}) relative to equilibrium unfished biomass, B_{2021}/B_0 = 0.60 (0.41, 0.84), and to equilibrium spawning biomass that would support the MSY, B_{2021}/B_{MSY} = 2.21 (1.50, 3.15). Median exploitation rates in 2020 for the two fisheries are low (Trawl: 0.016/y, Other: 0.023/y, Table 1, Figure 4). The estimated current-year exploitation rate relative to that at MSY is u_{2020}/u_{MSY} = 0.06 (0.02, 0.14) for the Trawl fishery and u_{2020}/u_{MSY} = 0.11 (0.03, 0.32) for the Other fishery (Table 1, Figure 5).

For REBS south, the estimated median MSY is 193 tonnes (152, 495) (Table 1), compared to the average catch over the last five years (2015-2019) of 291 tonnes. The estimated current-year spawning biomass (B_{2021}) relative to equilibrium unfished biomass, B_{2021}/B_0 = 0.29 (0.16, 0.68), and to equilibrium spawning biomass that would support the MSY, B_{2021}/B_{MSY} = 1.07 (0.58, 2.61). Median exploitation rates in 2020 for the two fisheries are moderate (Trawl: 0.072/y, Other: 0.044/y, Table 1, Figure 4). The estimated current-year exploitation rate relative to that at MSY is u_{2020}/u_{MSY} = 1.17 (0.19, 2.59) for the Trawl fishery and u_{2020}/u_{MSY} = 0.72 (0.13, 1.77) for the Other fishery (Table 1, Figure 5).

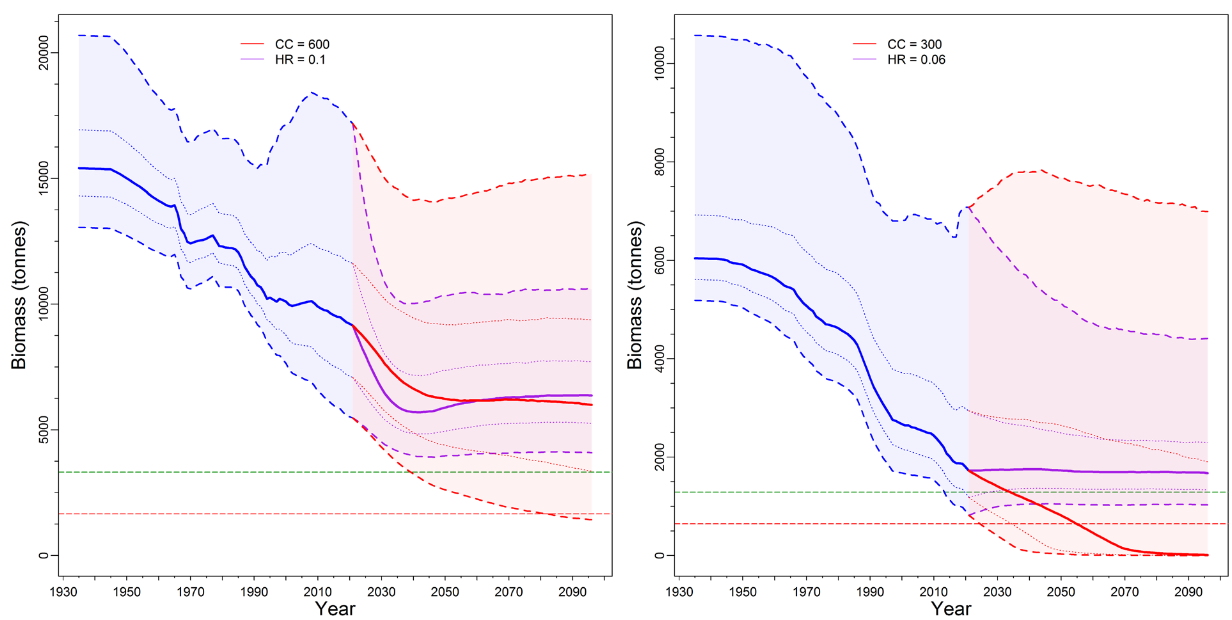


Figure 2. Estimates of spawning biomass B_t (tonnes) from the model posteriors of the REBS north (left, 9000 samples) and REBS south (right, 6000 samples) composite base cases. The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05, 0.95) in blue and delimited by dashed lines for years t=1935–2021; projected biomass appears in light red (constant catch) and purple (harvest rate) for years t=2022-2096 (1.5 generations). 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: $0.4B_{\text{MSY}}$) and USR (green: $0.8B_{\text{MSY}}$).

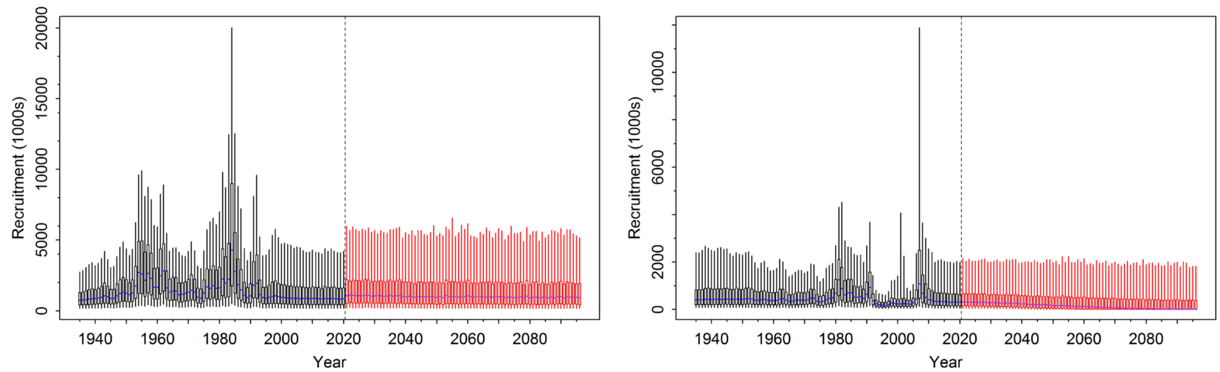


Figure 3. Composite base case (REBS north on left, REBS south on right): marginal posterior distribution of recruitment (in 1000s of age-1 fish) for reconstructed (1935–2021–in grey) and projected (2022–2096–in red) years. Boxplots give the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from pooled MCMC results.

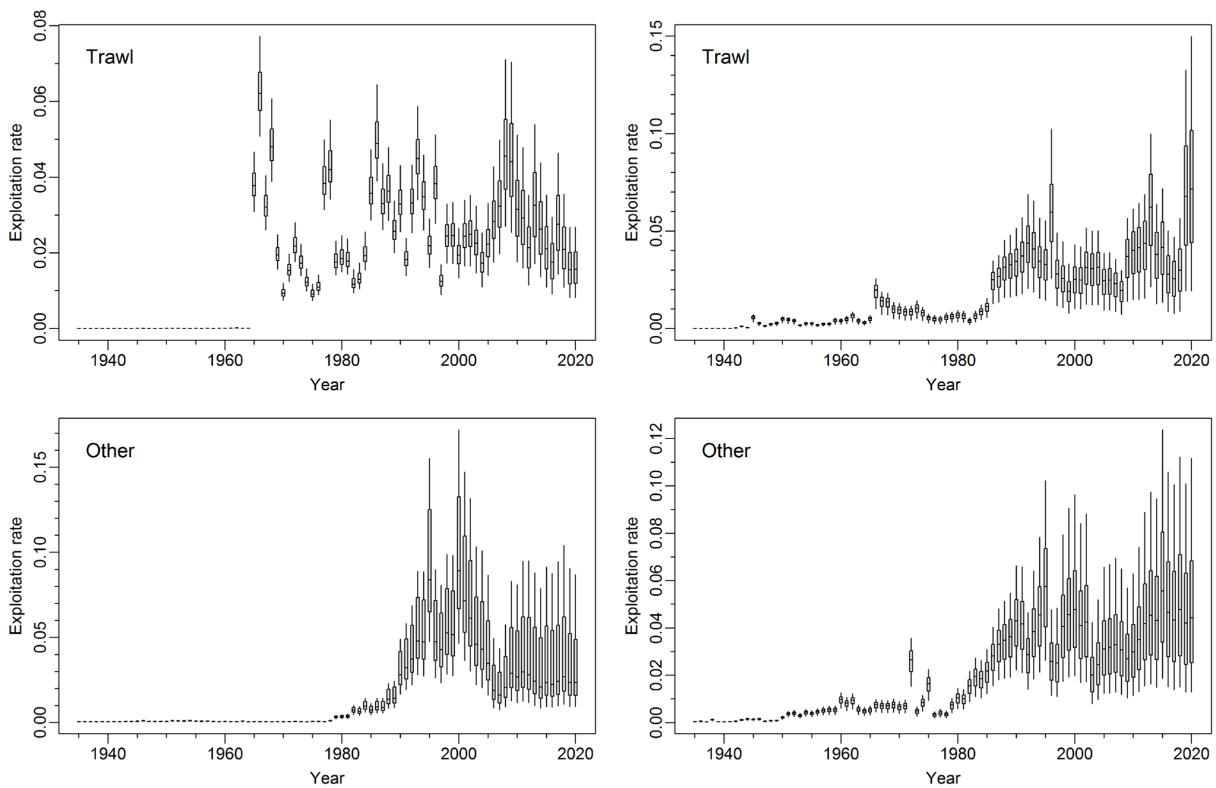


Figure 4. Composite base case (REBS north on left, REBS south on right): marginal posterior distributions of annual exploitation rate by year and fishery. Boxplots give the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from pooled MCMC results.

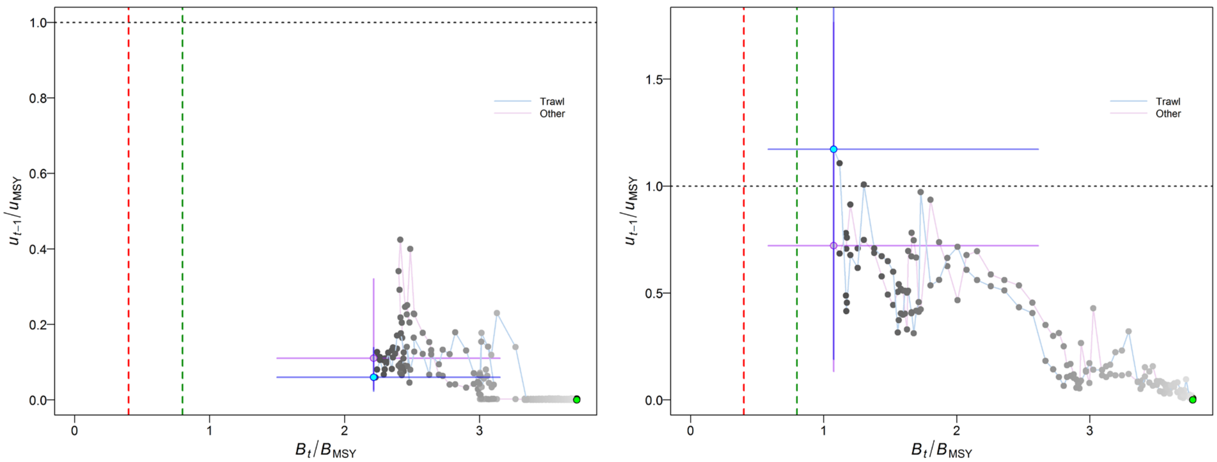


Figure 5. Phase plot through time (REBS north on left, REBS south on right) of the medians of the ratios B_t/B_{MSY} (the spawning biomass at the start of year t relative to B_{MSY}) and two measures of fishing pressure: trawl ($u_{t-1(trawl)}/u_{MSY}$: cyan dot) and 'other' ($u_{t-1(other)}/u_{MSY}$: 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 cases. The filled green circle is the starting year (1935). Years then proceed from lighter shades through to darker with the final year (t=2021) as a filled cyan or purple circle, and the blue/purple cross lines represent the 0.05 and 0.95 quantiles of the posterior distributions for the final year. 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 pooled samples (9000 for REBS north, 6000 for REBS south) of the MCMC posterior of the composite base cases for each stock. 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_{2021} – spawning biomass at the start of 2021, V_{2021} – vulnerable biomass in the middle of 2020, u_{2020} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2020, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2020), 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 548 tonnes for REBS north and 291 tonnes for REBS south.

	REBS north Model Output			REBS south Model Output		
Value	5%	50%	95%	5%	50%	95%
B_0	13,058	15,413	20,693	5,187	6,045	10,574
V_0 (trawl)	22,056	27,588	34,360	10,927	13,136	23,704
V_0 (other)	15,965	19,483	27,661	6,813	8,643	13,292
B_{2021}	5,475	9,153	17,176	818	1,725	7,078
V_{2021} (trawl)	9,242	15,963	30,283	1,772	3,964	15,566
V_{2021} (other)	2,493	8,970	22,357	752	2,037	7,289
B_{2021} / B_0	0.405	0.595	0.840	0.155	0.286	0.680
V_{2021} / V_0 (trawl)	0.387	0.59	0.903	0.159	0.304	0.666
V_{2021} / V_0 (other)	0.153	0.455	0.833	0.104	0.239	0.572
u_{2020} (trawl)	0.00823	0.0157	0.0269	0.0193	0.0716	0.150
u_{2020} (other)	0.00939	0.0234	0.087	0.0130	0.0442	0.112
u_{max} (trawl)	0.0508	0.0622	0.078	0.0259	0.0717	0.150
u_{max} (other)	0.0479	0.0894	0.173	0.0264	0.0592	0.125

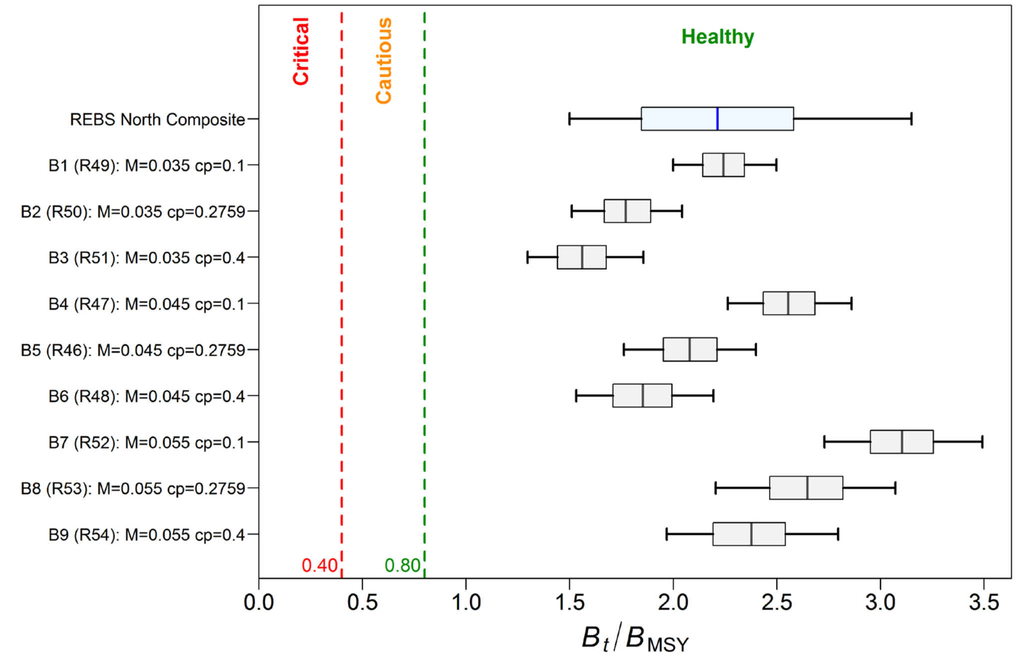
Value	REBS north MSY Values 5%	50%	95%	REBS south MSY Values 5%	50%	95%
MSY	474	636	1,115	152	193	495
B_{MSY}	3,519	4,140	5,519	1,380	1,611	2,739
$0.4B_{MSY}$	1,408	1,656	2,208	552	644	1,095
$0.8B_{MSY}$	2,815	3,312	4,415	1,104	1,289	2,191
B_{2021} / B_{MSY}	1.5	2.21	3.15	0.582	1.07	2.61
B_{MSY} / B_0	0.26	0.269	0.276	0.258	0.265	0.272
V_{MSY}	1,577	2,675	4,150	2,418	3,213	5,130
V_{MSY} / V_0 (trawl)	0.0558	0.101	0.153	0.184	0.239	0.289
V_{MSY} / V_0 (other)	0.0926	0.130	0.178	0.326	0.369	0.426
u_{MSY}	0.164	0.268	0.400	0.050	0.062	0.106
u_{2020} / u_{MSY} (trawl)	0.0234	0.0602	0.138	0.191	1.17	2.59
u_{2020} / u_{MSY} (other)	0.0281	0.110	0.321	0.134	0.721	1.77

Reference Points

Figure 6 shows the stock status for the REBS north and REBS south composite base cases, 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). These reference points define the ‘Critical’, ‘Cautious’ and ‘Healthy’ zones. The REBS north composite base case spawning biomass at the beginning of 2021 is estimated to be above the limit reference point (LRP) with probability $P(B_{2021} > 0.4B_{MSY}) = 1$, and above the upper stock reference (USR) point with probability $P(B_{2021} > 0.8B_{MSY}) = 1$ (i.e., no probability of being in the Cautious or Critical zones based on the set of MCMC posterior samples). The REBS south composite base case spawning biomass at the beginning of 2021 is estimated to be above the LRP with probability $P(B_{2021} > 0.4B_{MSY}) > 0.99$, and above the USR point with probability $P(B_{2021} > 0.8B_{MSY}) = 0.74$ (i.e., 0.26 probability of being in the Cautious zone based on the set of MCMC posterior samples).

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. Phase plots of the time-evolution of spawning biomass and exploitation rate for the two modelled fisheries in MSY space (Figure 5) show that both stocks have been in the Healthy zone from 1935 to the present, with only the REBS south stock showing a median exploitation rate by the Trawl fishery exceeding u_{MSY} in the current year.



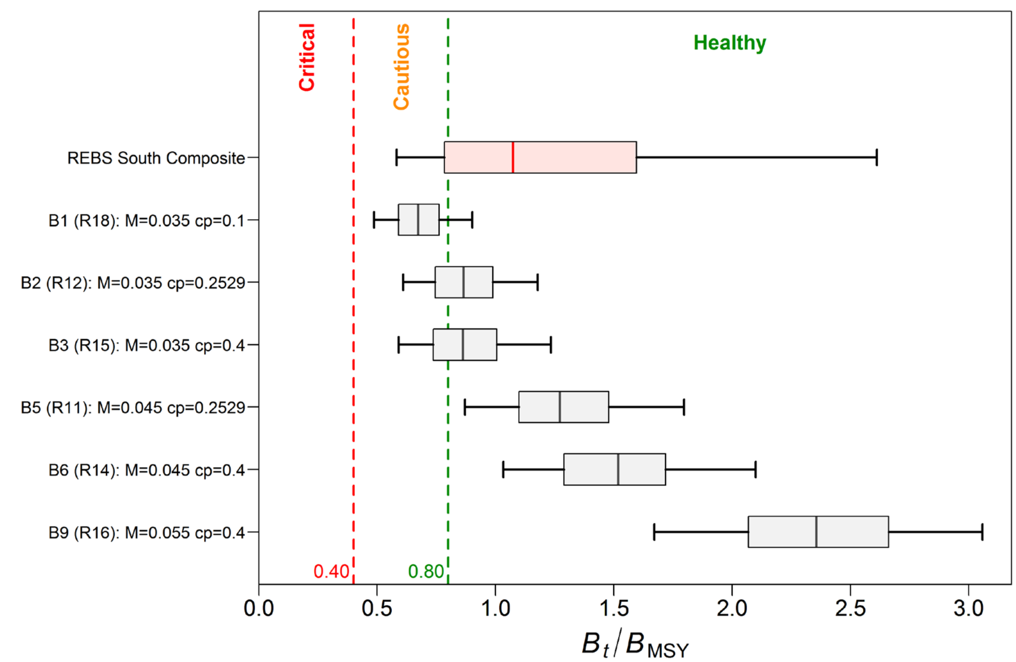


Figure 6. Status of the REBS north 5DE (top) and REBS south 3CD5AB (bottom) stocks relative to the DFO Precautionary Approach (PA) provisional reference points of 0.4B_{MSY} and 0.8B_{MSY} for the t=2021 composite base cases and the component base runs that are pooled to form the composite base cases. 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 2021, were made over a range of constant catch levels (0–1200 tonnes in 100 tonne increments for REBS north, 0–600 tonnes in 50 tonne increments for REBS south) 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 these species. 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 tables (Table 2, Table 3) give 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 REBS north catch, Table 2 shows that a manager would be ≥ 99% certain that both B_{2026} and B_{2031} are above the LRP of $0.4B_{\mathrm{MSY}}$, ≥99% certain that B_{2026} and ≥82% certain that B_{2031} are above the USR of $0.8B_{\mathrm{MSY}}$, and ≥74% certain that u_{2026} and ≥54% certain that u_{2031} are below u_{MSY} for the composite base case. The preferred catch and risk levels used in managing the REBS north stock are management choices. For example, it may be desirable to be 95% certain that B_{2026} 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 target 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 50%.

At all levels of evaluated REBS south catch, Table 3 shows that a manager would be ≥66% certain that B_{2026} and ≥44% certain that B_{2031} are above the LRP of $0.4B_{\mathrm{MSY}}$, ≥41% certain that B_{2026} and ≥30% certain that B_{2031} are above the USR of $0.8B_{\mathrm{MSY}}$, and ≥14% certain that u_{2026} and u_{2031} are below u_{MSY} for the composite base case. The preferred catch and risk levels used in managing the REBS south stock are management choices. For example, it may be desirable to be 95% certain that B_{2026} exceeds an LRP whereas exceeding a USR might only require a 50% probability. Assuming this risk profile, the 300 t/y catch policy in Table 3 would satisfy the specified LRP and USR constraints. Assuming that u_{MSY} is a target exploitation rate, only the 200 t/y catch policy in Table 3 would yield harvest rate in 2026 that would be less than u_{MSY} with a probability of at least 50%.

The associated Research Document also estimates stock status over 1.5 generations to be consistent with DFO policy (DFO, 2009). At current catch levels, the median spawning stock biomass of REBS north is projected to remain in the Healthy zone for the next 75 years. In contrast, the REBS south median spawning stock biomass is projected to decline steadily until it reaches the Critical zone some time after 2050 if current catch levels are maintained. These projections are based on average stock recruitment over the next 75 years; however, if large episodic recruitment events occur, the spawning biomass may avoid falling into the Cautious and Critical zones.

Table 2. REBS north decision tables for the reference points 0.4B_{MSY}, 0.8B_{MSY}, and u_{MSY} for projections through 2031 for a range of constant catch policies (in tonnes/year) using the composite base case. Values are the probability (proportion of 9000 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 of REBS north over the last 5 years (2015–2019) was 548 tonnes.

P(B_t >0.4B_{MSY})

Catch policy	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
										Projection year	
0	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1
400	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
600	1	1	1	1	1	1	1	1	1	1	1
700	1	1	1	1	1	1	1	1	1	1	1
800	1	1	1	1	1	1	1	1	1	1	1
900	1	1	1	1	1	1	1	1	1	1	1
1000	1	1	1	1	1	1	1	1	1	1	>0.99
1100	1	1	1	1	1	1	1	1	1	>0.99	>0.99
1200	1	1	1	1	1	1	1	1	1	>0.99	>0.99

P(B_t >0.8B_{MSY})

Catch policy	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
										Projection year	
0	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1
400	1	1	1	1	1	1	1	1	1	1	>0.99
500	1	1	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99
600	1	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
700	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
800	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98
900	1	1	1	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.97	0.96
1000	1	1	1	>0.99	>0.99	>0.99	0.99	0.98	0.97	0.95	0.93
1100	1	1	>0.99	>0.99	>0.99	>0.99	0.99	0.97	0.95	0.92	0.88
1200	1	1	>0.99	>0.99	>0.99	0.99	0.98	0.95	0.92	0.88	0.82

P(u_t <u_{MSY})

Catch policy	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
										Projection year	
0	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1
400	1	1	1	1	1	1	1	1	1	1	1
500	1	1	>0.99	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
600	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99
700	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.95
800	>0.99	0.99	0.99	0.99	0.98	0.97	0.95	0.94	0.91	0.89	0.87
900	0.99	0.98	0.97	0.96	0.95	0.93	0.9	0.87	0.84	0.81	0.78
1000	0.97	0.96	0.95	0.93	0.9	0.87	0.83	0.79	0.75	0.72	0.69
1100	0.95	0.93	0.91	0.88	0.85	0.80	0.76	0.72	0.68	0.65	0.62
1200	0.93	0.89	0.86	0.82	0.78	0.74	0.69	0.65	0.62	0.58	0.54

Table 3. REBS south decision tables for the reference points 0.4B_{MSY}, 0.8B_{MSY}, and u_{MSY} for projections through 2031 for a range of constant catch policies (in tonnes/year) using the composite base case. Values are the probability (proportion of 6000 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 of REBS south over the last 5 years (2015–2019) was 291 tonnes.

P(B_t >0.4B_{MSY})

Catch policy	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
											Projection year
0	>0.99	>0.99	>0.99	>0.99	1	1	1	1	1	1	1
50	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1	1
100	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
150	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
200	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.98
250	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.96	0.95	0.94	0.93
300	>0.99	>0.99	0.99	0.98	0.97	0.96	0.94	0.91	0.89	0.88	0.85
350	>0.99	>0.99	0.99	0.97	0.94	0.91	0.89	0.85	0.82	0.79	0.76
400	>0.99	>0.99	0.98	0.95	0.91	0.87	0.82	0.78	0.74	0.70	0.66
450	>0.99	0.99	0.97	0.93	0.87	0.82	0.76	0.71	0.66	0.62	0.58
500	>0.99	0.99	0.96	0.90	0.83	0.76	0.70	0.64	0.59	0.56	0.52
550	>0.99	0.99	0.94	0.86	0.79	0.70	0.64	0.58	0.54	0.51	0.48
600	>0.99	0.98	0.92	0.83	0.74	0.66	0.59	0.54	0.50	0.47	0.44

P(B_t >0.8B_{MSY})

Catch policy	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
											Projection year
0	0.74	0.78	0.83	0.87	0.91	0.94	0.96	0.98	0.99	>0.99	>0.99
50	0.74	0.77	0.80	0.83	0.86	0.89	0.91	0.94	0.95	0.97	0.98
100	0.74	0.76	0.77	0.79	0.81	0.83	0.85	0.87	0.88	0.89	0.91
150	0.74	0.74	0.75	0.75	0.76	0.77	0.78	0.79	0.79	0.80	0.81
200	0.74	0.73	0.72	0.72	0.71	0.71	0.70	0.70	0.70	0.70	0.69
250	0.74	0.72	0.70	0.68	0.66	0.65	0.64	0.63	0.62	0.61	0.60
300	0.74	0.70	0.67	0.65	0.62	0.60	0.58	0.57	0.55	0.54	0.53
350	0.74	0.69	0.65	0.62	0.59	0.56	0.54	0.52	0.50	0.49	0.48
400	0.74	0.68	0.63	0.59	0.55	0.53	0.50	0.48	0.47	0.45	0.44
450	0.74	0.67	0.61	0.56	0.53	0.49	0.47	0.45	0.43	0.41	0.40
500	0.74	0.65	0.59	0.54	0.50	0.47	0.44	0.41	0.40	0.38	0.36
550	0.74	0.64	0.57	0.52	0.47	0.44	0.41	0.39	0.36	0.35	0.33
600	0.74	0.63	0.55	0.50	0.45	0.41	0.38	0.36	0.34	0.32	0.30

P(u_t <u_{MSY})

Catch policy	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
											Projection year
0	1	1	1	1	1	1	1	1	1	1	1
50	>0.99	>0.99	>0.99	>0.99	1	1	1	1	1	1	1
100	0.87	0.88	0.89	0.91	0.93	0.94	0.96	0.97	0.98	0.98	0.98
150	0.63	0.63	0.63	0.64	0.65	0.67	0.68	0.7	0.72	0.73	0.74
200	0.49	0.49	0.49	0.49	0.50	0.50	0.51	0.51	0.52	0.52	0.52
250	0.40	0.40	0.40	0.40	0.40	0.41	0.41	0.42	0.42	0.42	0.43
300	0.34	0.33	0.33	0.33	0.33	0.33	0.34	0.34	0.34	0.34	0.34
350	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28	0.28	0.27
400	0.24	0.23	0.23	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.22
450	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.19
500	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17
550	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15
600	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14

Sources of Uncertainty

Two spatial stocks of the REBS complex have been identified along the BC coast, based loosely on the spatial distribution of genetically confirmed specimens from surveys: the northern stock in 5DE is predominantly comprised of Blackspotted Rockfish. The southern stock in 3CD5AB is largely comprised of Rougheye Rockfish. Although the populations of Blackspotted Rockfish and Rougheye Rockfish have some broad-scale regional separation, genetic analyses show that the two species comingle along the BC coast (Creamer 2016). The genetic-based stocks could not be separated given the data available at the time of the stock assessment. Catch allocation methods to identify catch as either Blackspotted Rockfish or Rougheye Rockfish need to be developed before future assessments and management can replace the REBS complex with genetically-distinct stocks.

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 comprising the composite base cases. 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 values based on the longevity of these sympatric species. Using a plausible range of M values helped to capture this uncertainty in model results.

Another axis of uncertainty explicitly incorporated into the base composite cases was that of weighting the commercial CPUE indices. This was done by using three values of process error added to the CPUE CV values during the reweighting procedure (Francis 2011). Lower process error informed the model to fit the CPUE indices closely, while higher process error relaxed this constraint to the point that the CPUE signal was mostly ignored. Removing CPUE from the model entirely caused instability in data fitting and parameter estimation.

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

- productivity assumptions – changing natural mortality;
- abundance – decreasing/increasing historical catch;
- composition – widening ageing error.

Most sensitivity runs remained primarily in the Healthy zone. Explorations of alternative model runs that reduce/increase catches show diversions from the central runs but routinely end up with similar depletion status (B_{2021}/B_0). This has been noted by previous stock assessments for offshore rockfish. Explorations using a wider ageing error matrix showed that this third axis of uncertainty was not as great as the two adopted in the assessment (M and CPUE process error).

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.

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. 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 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 these 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.

CONCLUSIONS AND ADVICE

In common with other BC rockfish stock assessments, this stock assessment depicts two slow-growing, low productivity stocks. However, there is reasonable evidence that there is sufficient productivity to maintain a strong (mostly target) fishery in 5DE and a lesser bycatch fishery in 3CD5AB. Due to a presumed high level of hybridization in 5C, the 5C catches were allocated to REBS north and REBS south based on annual catch proportions between 5DE and 3CD5AB. Consequently, catch from 5C was not explicitly included in the harvest advice. Given the low level of catch from 5C, it was agreed that the inclusion or exclusion of this area from either analysis would have little consequence to stock status to REBS. There are three sets of fishery independent surveys which are used to monitor these two stocks and two CPUE series were developed that seem credible and helped facilitate the modelling. There is a reasonable amount of age data from the 5DE commercial fishery but much less from the 3CD5AB commercial fishery. All three primary synoptic surveys have a commendable amount of age data from most years. There are two main problems with this stock assessment. One is that this species complex is difficult to age, apparently more so than many of the other BC rockfish species. This ageing difficulty results in variable ageing that is hard to fit without introducing substantial ageing error. This was less of a problem for the REBS north stock assessment because there were sufficient age data which led to stability in the MCMC simulations. But the REBS south assessment runs tended to be unstable, requiring fixing the survey selectivity parameters to the MPD estimates and introducing strong priors on the commercial selectivities to obtain even moderate MCMC convergence.

The other problem is the species complex itself. The assessment approximated the stock split by using spatial definitions to define each species. All data from the west coast of Haida Gwaii and Dixon Entrance were assigned to the REBS north complex. The balance of the BC data, excluding the biological data from the lower part of Hecate Strait and the upper Moresby Gully (5C), were assigned to the REBS south complex. The lower Hecate Strait/upper Moresby Gully data were discarded except to split the catch proportionally between the two stocks. This approximation worked reasonably well and has resulted in a credible stock assessment for REBS north and a less reliable stock assessment for REBS south.

There was an expectation when this project was first initiated in 2018 that it would be possible to construct models to predict the species split based on information associated with the catch. While such models exist, they require high quality relevant data which do not appear to be available for REBS. Creamer (2016) constructed such a model which was used to predict the species split in the commercial fishery, beginning in 1996. This model used a suite of survey events as the training data set and then applied a form of the resulting predictive model to the commercial fishery. Because the commercial data available to Creamer were aggregated for confidentiality reasons, the final species split was based on 0.5° grids with the only parameter available being the spatial location of the grid. In effect, the Creamer species split was a finer scale version of the split used in this stock assessment. What would be preferable is for the species information to be collected directly from the commercial fishery to better understand the distribution of the component species in the fishery before the survey data can be used to reliably split the commercial data. While the use of survey data to develop a procedure that will predict the speciation in the commercial catch is potentially a valid approach, these predictions should be validated from data in the target fishery. Alternatively, the collected commercial fishery data can be used in the predictive model. In either case, such sampling programs should span several years in order to understand the level of interannual variability that is bound to exist in this species complex. Given the uncertainties associated with division of the REBS complex into two spatial stocks, a review of this division prior to or as part of future stock assessments is essential.

The REBS north stock assessment appears to be robust to a range of assumptions, including M, CPUE inclusion/exclusion, catch history and the uncertainty width of the ageing error matrix. The credible model fits to the data and the well-converged MCMC simulation behaviour for nearly every run attempted to give this stock assessment a high level of credibility. This stock appears to be at fairly high relative biomass levels in spite of the long history of fishing and the projections indicate that there is little short-term concern. On the other hand, the REBS south stock assessment is much less definitive, with the runs using M=0.035 nearing or entering the Cautious Zone and many of the runs, particularly those using M=0.055, have poor fits to the data with evidence of non-convergence in the MCMC simulations. That this stock is possibly at low levels is credible, given the long run of declining CPUE observations since 2010. The surveys are less clear, although the 2018 WCVI survey index is the lowest in the series and both the 2017 and 2019 QCS survey indices are also low. While it is likely that this stock is at a low level, it is not clear how low that might be.

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

It is recommended that a full re-assessment occur in 10 years or less, subject to the availability of new information. During intervening years the trend in abundance can be tracked by surveys which sample this species, as well as by commercial fishery CPUE.

It is further recommended that future assessments explore methods for incorporating alternative size-fecundity relationships in assessments. In the current REBS assessment, spawning stock biomass is assumed to be proportional to egg production and fecundity is assumed to be proportional to the female body weight. For rockfishes, however, there is evidence that fecundity-length exponents may be greater than cubic (i.e., larger than fecundity-weight exponents) and larger females consequently contribute disproportionately more to egg production than smaller females (Dick et al. 2017). This difference could lead to biased estimates of stock depletion if the size-fecundity relationship is strong but not incorporated into assessment models (He et al. 2015). Length-dependent fecundity has been explicitly incorporated into rockfish assessments conducted by US agencies (see Table 1 of He et al. 2015), and future assessments for REBS or other rockfishes in Canada could do similarly.

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SOURCES OF INFORMATION

This Science Advisory Report is from the May 26-27, 2020 regional peer review on Blackspotted / Rougheye Rockfish (Type I and Type II) stock assessment for British Columbia in 2020. 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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ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2020. Rougheye/Blackspotted Rockfish (*Sebastes aleutianus/melanostictus*) Stock Assessment for British Columbia in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/047.

Aussi disponible en français :

MPO. 2020. Évaluation des stocks du complexe des sébastes à œil épineux et à taches noires (Sebastes aleutianus/melanostictus) de la Colombie-Britannique en 2020. Secr. can. de consult. sci. du MPO, Avis sci. 2020/047.