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APPLICATION OF THE MANAGEMENT PROCEDURE FRAMEWORK FOR INSIDE QUILLBACK ROCKFISH (*SEBASTES MALIGER*) IN BRITISH COLUMBIA IN 2021

Quillback Rockfish, Sebastes maliger *(Photo credit: N. McDaniel)*

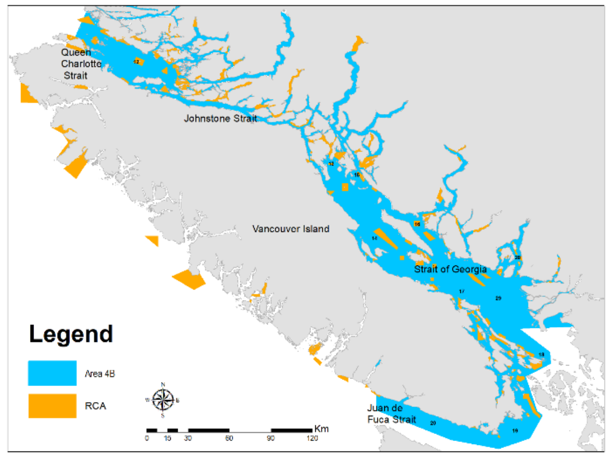

Figure 1. Map of Groundfish Management Area 4B showing Rockfish Conservation Areas (RCAs).

Context:

*Quillback Rockfish (*Sebastes maliger*) are a wide-spread marine fish that occur in all of British Columbia's (BC's) coastal waters. Inside Quillback Rockfish are targeted in hook and line commercial fisheries, Food, Social and Ceremonial fisheries, and recreational fisheries. Fisheries and Oceans Canada (DFO) Fisheries Management (Groundfish Management Unit, GMU) requested that Science Branch review existing fishery, biological and survey data to recommend candidate reference points for inside Quillback Rockfish, and, if possible, to provide guidance and rationale on alternative reference points to the provisional maximum sustainable yield (MSY) based reference points. Advice arising from this Canadian Science Advisory Secretariat (CSAS) regional peer review will be used by GMU to inform harvest advice for the inside Quillback Rockfish fishery in accordance with the DFO Precautionary Approach, and the legislated Fish Stock Provisions of the* Fisheries Act. *To provide the GMU with the best advice, Science will be following the Management Procedure (MP) Framework for groundfish. The MP Framework uses closed-loop simulation to evaluate the robustness of management procedures to achieve fishery and conservation objectives across plausible states of nature. This approach is particularly well-suited for data limited stocks with major uncertainties in stock dynamics.*

This Science Advisory Report is from the December 6-7, 2022 regional peer review on the Application of the Management Procedure Framework for Inside Quillback Rockfish in British Columbia in 2021. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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SUMMARY

- The inside stock of Quillback Rockfish (*Sebastes maliger*, Inside Quillback Rockfish) occurs in Groundfish Management Area 4B (Queen Charlotte Strait, Strait of Georgia, and Strait of Juan de Fuca) in British Columbia (BC).
- This analysis provides scientific advice for the sustainable management of Inside Quillback Rockfish consistent with the Precautionary Approach (PA) Policy through application of the Management Procedure (MP) Framework developed for BC groundfishes (Anderson et al. 2021). The MP Framework evaluates the performance of MPs across alternative plausible states of nature explored in different operating models (OMs).
- Current stock status partly determines management actions related to policy requirements. The stock status was evaluated with regard to a Limit Reference Point (LRP) and Upper Stock Reference (USR) of 0.4 B_{MSY} and 0.8 B_{MSY}, respectively. The 2021 spawning biomass was estimated to be 88% of B_{MSY} (with an interquartile range of 46-147% credible interval (CI)), above the LRP with a 79% probability, and above the USR with a 52% probability, averaged across three OMs.
- Since the current stock biomass is estimated to be above the LRP, the conservation objective is to maintain the stock above the LRP after one generation (24 years) with a minimum probability of 75%. Other objectives include maintaining the stock above the USR, and maintaining fishery access and catch. These objectives follow strategic objectives identified in workshops held in 2021 (see Haggarty et al. 2022).
- The generation time was estimated to be 24 years, based on the natural mortality value of 0.067 and 50% maturity at 8.7 years. Natural mortality is based on the maximum observed age of 80 years. Since the previous assessment, the relationship between natural mortality and maximum observed age has been updated based on meta-analyses in the scientific literature.
- Five total OMs were explored. Three reference OMs differ in values of mean natural mortality (M = 0.067, 0.055, 0.088). Two robustness OMs include an OM that excludes Area 12 jig survey data, and an OM that assumes low future recruitment.
- Environmental conditions affecting stock dynamics were considered with the alternative values of natural mortality and low recruitment OMs. Our understanding of the environment and stock productivity, however, is not sufficient to model these relationships mechanistically.
- The Management Procedures (MPs) evaluated included two constant catch MPs, eight MPs based on an index of survey abundance, and a “no fishing” and “fishing at F_{MSY}” reference MP. All MPs met the conservation objective of being above the LRP after one generation with 75% probability under the OM reference set scenarios.
- A trade-off between maintaining the stock above the LRP after one generation, and maximizing catch over one generation was identified across the candidate MPs. Minimal trade-off between catch after one generation and catch after three generations was observed. MPs that advise high catches after one generation continue to do so after three generations.
- Since index-based management procedures were implemented biennially in the projections, we recommend updating the catch advice from the selected MP (if index-based) every two years.

- Exceptional circumstances that would trigger a re-evaluation of the OMs should be reviewed on a regular basis.

BACKGROUND

Quillback Rockfish is a long-lived species (up to 80 years for the Inside stock), commonly occurring in rocky marine habitats along the inner coast of British Columbia (Yamanaka et al. 2012). It is widely distributed in the Pacific Northeast, ranging in the north up into the Gulf of Alaska and south into southern California. In British Columbia, Quillback Rockfish are found at shallow depths (<20 m) to depths around 150 m. Juveniles settle in shallow, benthic habitat, and migrate deeper as individuals age.

Inside Quillback Rockfish occur in Groundfish Management Area 4B in British Columbia (BC) (Figure 1). The stock has been proposed as a major fish stock in Batch 2, at which time its sustainable management will be legislated under the Fish Stocks Provisions in the *Fisheries Act* as described in the Guidelines for Implementing the Fish Stocks Provisions. In 2011, the median biomass of the Inside stock was assessed to be 2,668 tonnes (with a coefficient of variation of 0.60), with a 70% probability of being above the LRP of 0.4 B_{MSY} (Yamanaka et al. 2012). The stock was designated to be in the “Cautious” zone.

The purpose of this project is to provide scientific advice to support management of Inside Quillback Rockfish (*Sebastes maliger*). This analysis applied the Management Procedure (MP) Framework (Anderson et al. 2021), recently developed for BC groundfish, to evaluate the performance of index-based and constant catch MPs, with respect to meeting policy and fishery objectives. This approach follows a Management Strategy Evaluation (MSE) approach, using closed-loop simulation to simulate the interaction between the stock, its environment, and fishery dynamics. The underlying system (the fish stock and its environment) is described by one or more operating models (OMs). The MP Framework is distinct from conventional stock assessment approaches that do not incorporate the feedback between management advice and the operating model in projections. The closed-loop simulation approach takes into account the effect of the MPs on the system, as well as the future data collected from the system and its use in the MPs. The MP framework focuses on testing management procedures in a “closed-loop” simulation environment to identify those that meet and satisfy agreed-upon policy and fishery objectives (Figure 2).

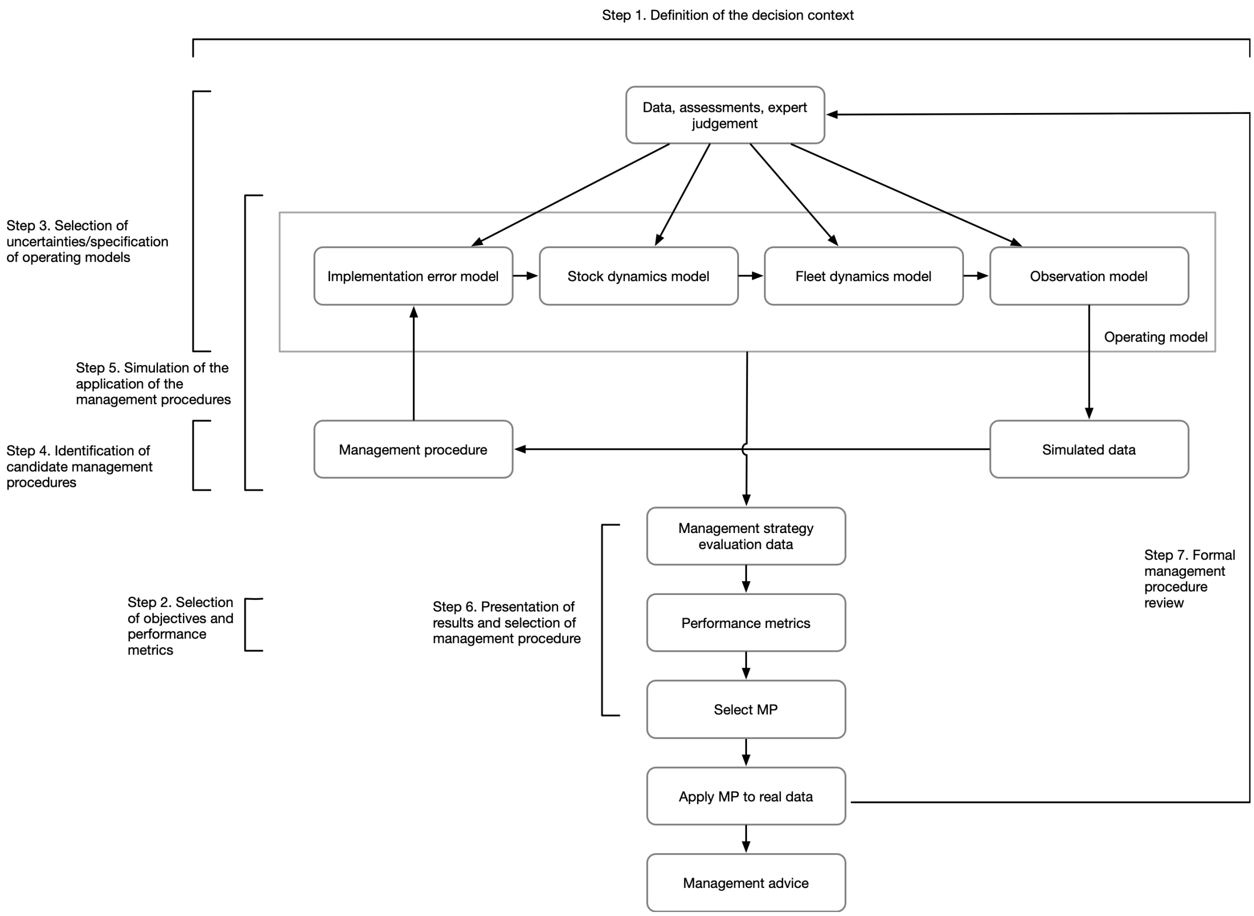

Figure 2. The steps of the MSE process following Punt et al. (2016), copied from Anderson et al. (2021) and adapted from Carruthers and Hordyk (2018).

ANALYSIS

Approach

In 2020, the Management Procedure Framework (MP Framework) for Groundfish in British Columbia (Anderson et al. 2021) was developed to demonstrate its use to evaluate MPs for data-limited groundfish species. The MP Framework uses the functionality of openMSE (consisting of the DLMtool, MSEtool, and SAMtool R packages), with additional supporting code and visualization tools in the ggmse R package (Anderson et al. 2021). The MP Framework was identified as a suitable tool for further assessment for Inside Quillback Rockfish since there was considerable uncertainty around the status estimate of the stock during the 2011 assessment (Yamanaka et al. 2012).

The MP Framework was followed for selecting MPs to provide catch advice for Inside Quillback Rockfish. The framework follows six best practice steps described below and in greater detail in Anderson et al. (2021). The best practice steps are based on a review by Punt et al. (2016), who identified five key steps in the MSE process (Steps 2–6 below, Figure 2).

The six steps are as follows:

- Step 1. Definition of the decision context.

- Step 2. Selection of objectives and performance metrics.
- Step 3. Selection of uncertainties/specification of operating models.
- Step 4. Identification of candidate management procedures.
- Step 5. Simulation of the application of the management procedures.
- Step 6. Presentation of results and selection of management procedure.

After selection and implementation of the MP for setting the catch limit (e.g., applying the selected MP algorithm to the observed survey index), a final necessary step is to periodically monitor and evaluate the performance of the MP. This may be done through informal means, e.g., via feedback from fishers and survey information, or through more formal statistical measures, where observed data are compared to predictions from the OMs to test whether the system is performing as expected.

Objectives Workshop

In support of the MP Framework, DFO hosted a series of workshops in early 2021, bringing together Fisheries and Oceans Canada (DFO) scientists and managers, Indigenous representatives and knowledge-holders, commercial and recreational (public) fishing representatives, non-governmental organizations (NGOs), and external scientists, to identify strategic objectives for the Inside Quillback Rockfish stock (Haggarty et al. 2022). Information gathered at the workshops was used to identify operational objectives and performance measures for this analysis. Additional objectives and feedback, for example, the desire to consider age structure, was taken into account in the MP Framework results for Inside Quillback Rockfish. Other sustainability objectives were identified as topics suited for groundfish management.

Step 1: Decision Context

For this analysis, the decision context was identifying a management procedure to determine catch recommendations that achieve objectives. The operating models we evaluated to determine stock status relative to the LRP and consideration of environmental conditions to meet the requirements of the Fish Stocks Provisions. The scientific content of the advice (including the structure and content of the operating models), and consideration of the relative performance of the MPs and trade-offs among performance metrics, supported discussions by the regional peer review participants.

Step 2: Objectives and Performance Measures

A set of objectives and associated performance metrics for Inside Quillback Rockfish were presented. Key policy objectives are guided by the PA Framework and the previous stock assessment by Yamanaka et al. (2012). Additional objectives related to fisheries yield were considered based on broad strategic objectives identified in Haggarty et al. (2022).

The proposed conservation objective was:

1. Maintain the stock above the LRP after one generation (24 years) with at least 75% probability of success.

Following general international practice and DFO policy guidance, the desired probability of success was set at 75% to ensure there is high probability that the stock would be above the LRP in the simulation projections.

We also proposed the following additional objectives:

2. Maintain the stock above the USR after one generation (24 years).
3. Maintain fishing mortality below that at maximum sustainable yield during one generation (24 years). To be compliant with the United Nations Fish Stocks Agreement (from which the DFO PA Policy was developed), the removal reference should not exceed F_{MSY}.
4. Maintain fishery access and catches both in the short-term (7 years) and in the long-term (1 generation and 3 generations). This long time period evaluates whether or not there is inter-generational access to the fishery (Haggarty et al. 2022).

We did not assign target probabilities to Objectives 2-4 as they are provided for the purpose of evaluating trade-offs with Objective 1.

We proposed the following performance metrics to measure the objectives, where B represents spawning biomass, MSY refers to maximum sustainable yield, B_{MSY} refers to equilibrium spawning biomass at MSY, GT represents generation time, and ST represents short term.

We defined the LRP and USR as 0.4 B_{MSY} and 0.8 B_{MSY}, respectively, following definitions in the PA Framework, as used in the 2011 stock assessment (Yamanaka et al. 2012). In the closed-loop simulations, all reference points and performance metrics are calculated in the operating model. Raw performance metrics are calculated in each year of the projection and summarized according to the time-frame of interest:

1. **LRP 1GT**: P(B > 0.4 B_{MSY}) after 1 generation (in 2045, year 24 of the projection period)
2. **LRP ST**: P(B > 0.4 B_{MSY}) after 7 years (in 2028, year 7 of the projection period)
3. **USR 1GT**: P(B > 0.8 B_{MSY}) after 1 generation
4. **F_{MSY}**: P(F < F_{MSY}) during the first generation (during 2022-2045, years 1-24 of the projection period)
5. **C ST**: Average catch during the short term (during 2022-2028, years 1-7 of the projection period)
6. **C 1GT**: Average catch after 1 generation
7. **C 3GT**: Average catch after 3 generations (in 2093, year 72 of the projection period)

In cases where performance metrics are calculated over a range of years, the mean performance statistic was calculated across replicates and years for the defined time window (Anderson et al. 2021).

Step 3: Operating Models (OMs)

Best practice recommends identification of a “reference set” of core OMs that include the most important uncertainties (e.g., depletion of the stock or range of natural mortality values), and a “robustness set”, to capture a wider range of uncertainties that may be less plausible but should nonetheless be explored. Anderson et al. (2021) recommended that reference set performance metrics should be averaged together (an ensemble approach to integrate across OM uncertainties) but that performance metrics from individual OM robustness set scenarios should be presented separately. Presenting robustness results separately allows managers to see how MPs that performed well in the reference set perform under a set of more diverse assumptions.

Since natural mortality has not been directly estimated for Inside Quillback Rockfish, we established three reference set OMs which varied by the mean of the distribution for natural mortality (M): (1) M = 0.067; (2) M = 0.055; and (3) M = 0.088. These means were based on various predictors that use maximum age to indirectly predict M. We further established two robustness set OMs encompassing additional sources of uncertainty: (A) an OM that excludes the jig survey from the historical conditioning; and (B) an OM that assumes lower than average recruitment in the projection. OM (A) tests the effect of including spatially restricted information from an additional survey, and OM (B) indirectly evaluates a change in the environment whereby future recruitment is negatively affected. Operating models were developed to reflect historical catches, indices of abundance, and age composition to ensure these empirical data were satisfactorily modeled (model conditioning).

Data Sources

Rockfish commercial catch data can be grouped into three time periods: historic (1918-1950), early electronic (1951-2005), and modern (2006 onwards). There are two major sources of uncertainty in the historical and early electronic periods for Inside Quillback Rockfish. The first uncertainty is that rockfish catch, other than Pacific Ocean Perch (*Sebastes alutus*), was reported as an aggregate (other rockfish, ORF) in the historic period. To reconstruct historical catches, an algorithm was developed by Haigh and Yamanaka (2011, see their Section 1) that applies a ratio calculated from a period with credible landings data from the hook and line dockside monitoring program (1997-2005) to generate a time series of catch by species, year, fishery sector, and management area. “Credible” landings data are taken from reference years where catch knowledge was considered high quality and stable, beginning in 1997 with the start of observer trawl coverage and the individual vessel quota system (Haigh and Yamanaka 2011).

The second major source of uncertainty is the magnitude of unreported catch that was released or discarded at sea, prior to the introduction of 100% observer coverage in 2006. The catch reconstruction of Haigh and Yamanaka (2011) assumes no discarding prior to 1986, when the ZN license was instituted. Prior to that it is assumed all rockfish were kept. Discards are assumed to be fully reported in DFO databases since 2006 and the introduction of 100% observer coverage. Non-retained Quillback Rockfish catch (releases or discards) was estimated for each fishery using the ratio of Quillback Rockfish (d) discarded by a fishery to fishery-specific landed targets using data from 2000-2004 hook and line observer logs. The estimated historical unreported catch was then incorporated into the catch reconstruction, giving a final annual total.

Recreational catch was estimated from the creel survey (1982-2021), with linear interpolation needed to model the development of the recreational fishery after World War II (1945-1981). Dockside interviews also informed the length distribution of Inside Quillback Rockfish caught in the recreational fishery.

The Inside Quillback Rockfish stock is indexed by two fishery-independent surveys: the inside Hard Bottom Longline (HBLL) survey and the jig surveys. The HBLL survey informs population trends since 2003, while the jig survey informs earlier population trends (1986-2004). For this analysis, the jig survey from Area 12 was used. Electronic records used to develop indices were not available for survey data collected in other Areas in recent years, i.e., 2004 and 2005 surveys in the Strait of Georgia, at the time of this analysis. While the Area 12 survey does not explicitly index all of Area 4B, similar reductions in catch rates have been observed from jig surveys in other statistical areas in Area 4B. Therefore, it is believed that the Area 12 index is representative of the population trends of the inside stock during 1986-2004. Age samples are also available from both surveys. No HBLL age samples were available from 2020 as the survey was cancelled due to the COVID-19 pandemic. Age samples from the 2021 HBLL survey were also not available for this analysis.

Operating Model Results

In all operating models, the spawning biomass in 2021 was likely above the LRP (with greater than 50% probability, Figure 3). All models inferred similar trends in stock biomass over time, with biomass declines during the 1980s-2000 followed by more stable conditions since then (Figures 4-6). The probability was higher in the operating models with a higher natural mortality rate (OM 1 and 3) and when the Jig Area 12 index was excluded (OM A). The operating model with mean M = 0.055 (the lowest mean in the reference set) produced the lowest probability of being above the LRP.

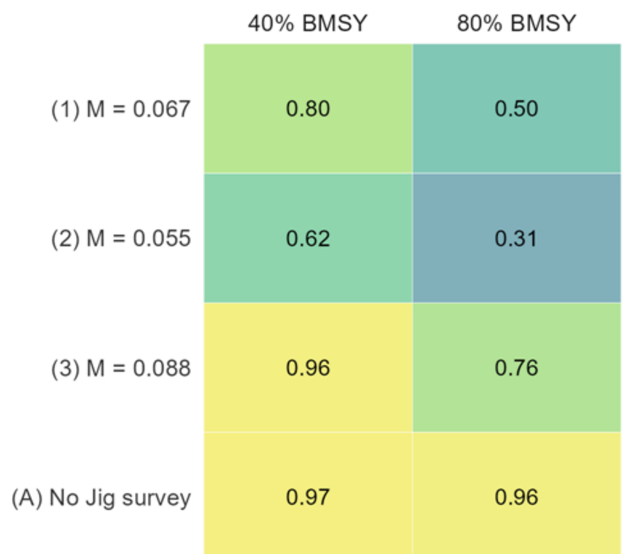

Figure 3. Probability that the 2021 spawning biomass is above the LRP (40% B_{MSY}) and USR (80% B_{MSY}) for the four operating models. Operating model (B) is not shown as its historical estimates are identical for OM (1), and only differs in the projection years.

In 2021, the credible intervals of B/B_{MSY} and B/B_0 in all OM scenarios varied based on the value of natural mortality and steepness of the stock-recruit relationship. Within each operating model, the status relative to the LRP and USR was primarily driven by the value of steepness. While population declines were estimated for Inside Quillback Rockfish, the stock was estimated to be above the LRP in all operating models.

With respect to unfished biomass, the stock was likely to be above 20% B_0 in all reference OMs except OM 2 (Figure 4). The 2011 assessment used a Bayesian state-space surplus production model with a symmetric yield curve, i.e., B_{MSY} at 0.5 B/B_0 (Yamanaka et al. 2012). In contrast, yield curves are typically right-skewed in age-structured models, i.e., B_{MSY} is less than 0.5 B/B_0. The status of the stock relative to 0.2 and 0.4 B_0, which reflect a potential threshold for recruitment overfishing (Myers et al. 1994) and are used in other jurisdictions, is shown in Figure 4.

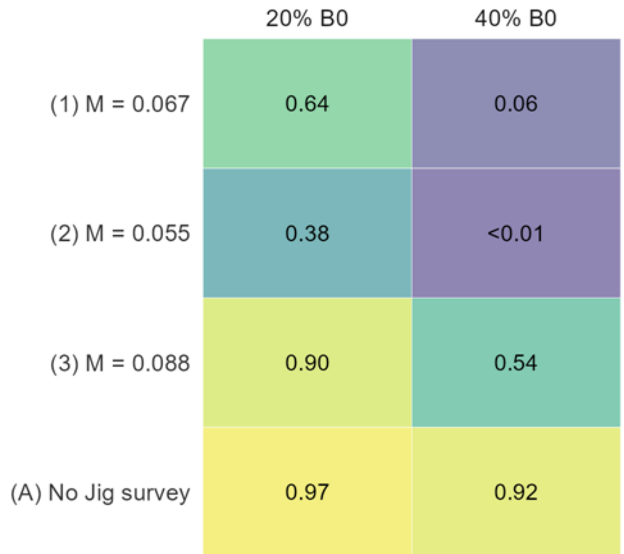

Figure 4. Probability that the 2021 spawning biomass is above 0.2 and 0.4 B_0 for the four operating models. Operating model (B) is not shown as its historical estimates are identical for OM (1), and only differs in the projection years.

The LRP is a low biomass state at which the age structure is expected to be severely truncated. The observed HBLL age composition was compared to the expected equilibrium age structure at the LRP. The observed age structure in the survey in 2019 and the estimated age structure in 2021 within the operating models contained more older fish (20+ years) than expected at the LRP. The mean age of the HBLL survey in 2019 was 23.3 years, larger than the equilibrium mean age at the LRP in our operating models. While the LRP is defined with respect to biomass, the age structure analysis provides an additional insight on the conditions needed to identify the stock to be below the LRP. The age structure at the LRP would need to be further truncated beyond what is currently observed in the HBLL survey (Figure 5).

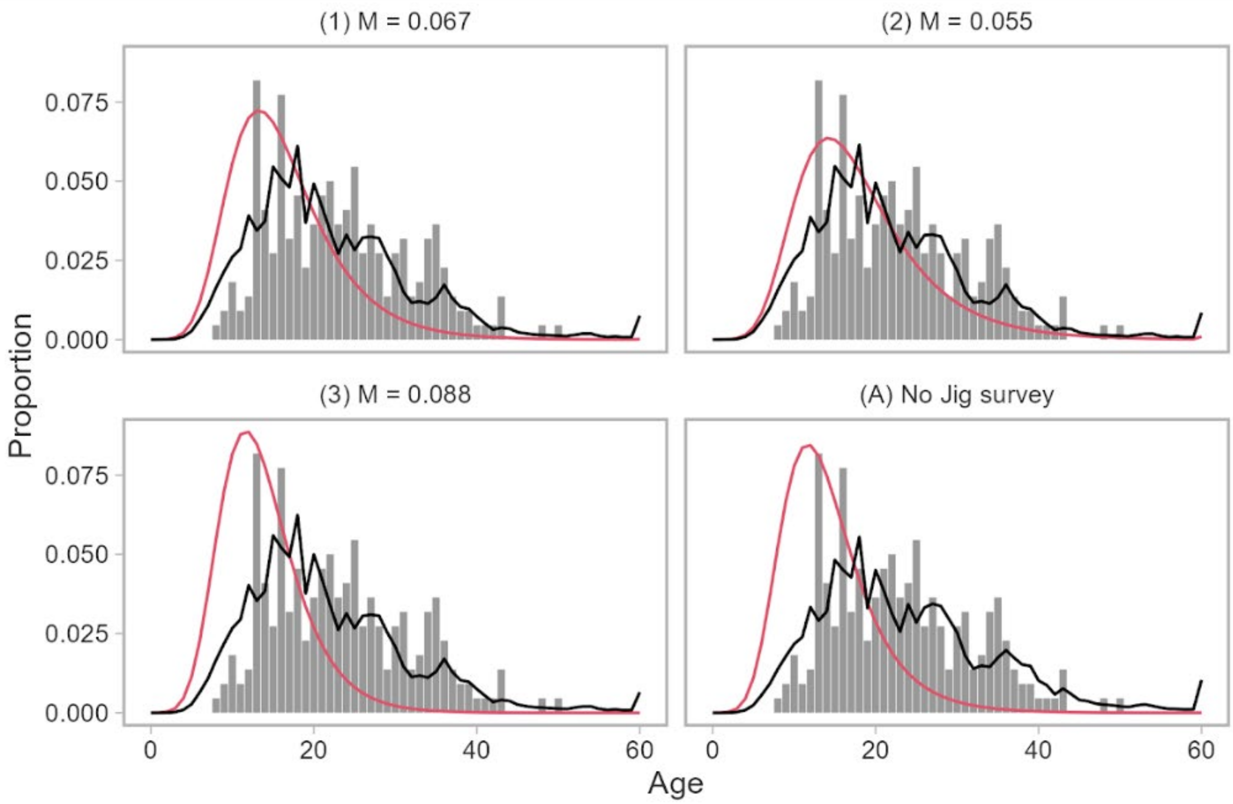

Figure 5. The modeled equilibrium age structure across the three reference OMs and the robustness OM (A) are shown in the black lines. The grey bars are the raw age data. The red line is the expected equilibrium age structure if the population is below the limit reference point. The surplus of older individuals observed (difference between black and red line) provides some additional support that the population is above the LRP.

Step 4: Candidate Management Procedures

The MP Framework currently only considers MPs that make catch recommendations, because most groundfish stocks are managed by quotas and commercial total allowable catches (TACs). The catch recommendation specified in the management procedures is inclusive of commercial, recreational, and Food, Social and Ceremonial (FSC) catches, i.e., it does not inform allocation decisions amongst fishery sectors. In comparison, the current commercial fishery TAC for Inside Quillback Rockfish is 24 tonnes (t). We evaluated two main types of MPs: constant catch and index-based MPs, and also evaluated two reference MPs (Table 2).

Constant-catch MPs set the recommended catch to some fixed level, typically based on recent or historical catches. Constant-catch MPs do not incorporate feedback between the management system and the population—they make the same catch recommendation regardless of trends in the population index. We considered two constant-catch MPs of 33 t and 41 t. Thirty-three tonnes is the average catch during 2012-2019 and is intended to reflect status quo conditions. Forty-one tonnes corresponds to 125% of the 2012-2019 average.

Index-based MPs, in general, adjust the catch based on changes in a population index over time. Index-ratio MPs increase or decrease the catch in accordance with the ratio of the index from two different time periods. Index-slope MPs increase or decrease the catch in accordance with the estimated slope in the index over a recent period of time.

We evaluated index-based MPs with biennial updates with fixed catch between updates, i.e., the most recent catch recommendation. The two-year update cycle is the minimum time period needed to process survey data to update the HBLL index. All index-based MPs set a minimum catch floor of 0.5 t, the approximate catch required for scientific surveys.

In addition to the empirical candidate MPs, we included the following reference MPs:

1. No fishing (NFref)
2. Fishing at F_{MSY} (FMSYref; results not presented here, please see the accompanying Research Document)

The purpose of reference MPs is not to explore viable management strategies but to bound the range of possible performance and determine whether or not differences among MPs are meaningful (Punt et al. 2016). For example, the "no fishing" reference MP provides information on maximum possible stock levels and the rate of population growth in the absence of fishing. The fishing at MSY ("FMSYref") MP can not be implemented in practice because it has perfect information about the true state of nature, and has perfect implementation. It exists only within the simulations, and is programmed to have perfect information and implementation. "FMSYref" implements different levels of fishing mortality for each operating model and simulation. This management procedure is mainly used to compare MPs within a single operating model.

Table 2. Candidate management procedures. (Please see the accompanying Research Document for the FMSYref MP results.)

Management procedure	MP type
CC_33	Constant catch
CC_41	Constant catch
IDX	Index ratio
IDX_smooth	Index ratio
Iratio_23	Index ratio
Iratio_55	Index slope
GB_slope_5y_lam1	Index slope
GB_slope_5y_lam05	Index slope
GB_slope_10y_lam1	Index slope
GB_slope_10y_lam05	Reference
NFref	Reference

Steps 5 and 6: Application of Candidate Management Procedures and Presentation of Results

We ran the closed-loop simulations across 200 stochastic replicates using MSEtool version 3.5.0 and the simulation random seed set to 1. The length of the projection period was set at 72 years (3 generations for Inside Quillback Rockfish).

Performance Measures

Anderson et al. (2020) recommended filtering MPs with a "satisficing" step, where trial simulations are run to screen out MPs that do not meet a basic set of performance criteria. The following criterion was set to determine which MPs are satisficed: LRP 1GT > 0.75.

Almost all management procedures met the satisficing criterion, except for the 41 t constant catch MP in OM (2) (Figure 6 and Figure 7). However, this MP did meet the satisficing criterion when the performance measure was averaged across the reference operating models (Figure 8).

With respect to the LRP, USR, and F_{MSY} performance measures, MP performance was better when the natural mortality rate was higher. Performance of MPs was higher in OM (A) than in OM (1) because OM (A) represented a more productive state of nature. On the other hand, performance was slightly worse in OM (B) than in OM (1). However, these management procedures still met the satisficing criterion despite the lower recruitment modeled in projections for OM (B).

(1) M = 0.067

	LRP 1GT	LRP ST	USR 1GT	FMSY	C ST	C 1GT
*NFref **	0.98	0.93	0.87	1.00	0.00	0.00
CC_33	0.90	0.84	0.75	0.84	33.00	33.00
GB_slope_10y_lam1	0.89	0.83	0.75	0.81	35.00	43.00
GB_slope_10y_lam05	0.88	0.83	0.75	0.81	36.00	39.00
GB_slope_5y_lam1	0.88	0.82	0.75	0.80	37.00	46.00
GB_slope_5y_lam05	0.88	0.82	0.75	0.80	37.00	41.00
IDX_smooth	0.88	0.82	0.74	0.80	37.00	42.00
IDX	0.88	0.82	0.74	0.79	38.00	47.00
Iratio_55	0.87	0.84	0.70	0.77	29.00	91.00
CC_41	0.86	0.82	0.74	0.79	41.00	41.00
Iratio_23	0.85	0.82	0.72	0.76	38.00	65.00

(2) M = 0.055

	LRP 1GT	LRP ST	USR 1GT	FMSY	C ST	C 1GT
*NFref **	0.97	0.82	0.79	1.00	0.00	0.00
CC_33	0.82	0.70	0.61	0.71	33.00	33.00
GB_slope_10y_lam1	0.78	0.70	0.57	0.68	35.00	42.00
GB_slope_10y_lam05	0.78	0.69	0.57	0.68	36.00	39.00
GB_slope_5y_lam1	0.76	0.69	0.55	0.64	36.00	45.00
GB_slope_5y_lam05	0.77	0.69	0.56	0.66	36.00	40.00
IDX_smooth	0.76	0.69	0.56	0.64	37.00	41.00
IDX	0.76	0.69	0.55	0.62	37.00	46.00
Iratio_55	0.77	0.72	0.46	0.59	29.00	83.00
CC_41	0.74	0.67	0.56	0.62	41.00	40.00
Iratio_23	0.74	0.69	0.50	0.56	37.00	60.00

(3) M = 0.088

	LRP 1GT	LRP ST	USR 1GT	FMSY	C ST	C 1GT
*NFref **	1.00	1.00	0.97	1.00	0.00	0.00
CC_33	0.97	0.98	0.92	0.96	33.00	33.00
GB_slope_10y_lam1	0.97	0.98	0.90	0.96	35.00	43.00
GB_slope_10y_lam05	0.97	0.97	0.90	0.96	36.00	39.00
GB_slope_5y_lam1	0.97	0.97	0.90	0.95	37.00	46.00
GB_slope_5y_lam05	0.97	0.97	0.90	0.95	37.00	41.00
IDX_smooth	0.97	0.97	0.90	0.95	37.00	42.00
IDX	0.97	0.97	0.90	0.95	38.00	48.00
Iratio_55	0.97	0.98	0.87	0.96	29.00	90.00
CC_41	0.97	0.96	0.90	0.95	41.00	41.00
Iratio_23	0.97	0.97	0.88	0.94	38.00	65.00

Figure 6. Performance measures of all MPs in individual reference set operating models. The colour shading reflect the probabilities. Italicized MPs with asterisks indicate reference MPs. Only the average catch during the short term and after one generation (24 years) are presented here.

(A) No Jig survey

	LRP 1GT	LRP ST	USR 1GT	FMSY	C ST	C 1GT
NFref *	1.00	0.98	0.97	1.00	0.00	0.00
CC_33	0.98	0.97	0.96	0.97	33.00	33.00
GB_slope_10y_lam1	0.98	0.97	0.96	0.97	35.00	38.00
GB_slope_10y_lam05	0.98	0.97	0.96	0.97	35.00	37.00
GB_slope_5y_lam1	0.98	0.97	0.96	0.97	36.00	40.00
GB_slope_5y_lam05	0.98	0.97	0.96	0.97	36.00	38.00
IDX_smooth	0.98	0.97	0.96	0.97	37.00	39.00
IDX	0.98	0.97	0.96	0.97	37.00	42.00
Iratio_55	0.98	0.97	0.97	0.97	28.00	51.00
CC_41	0.98	0.97	0.96	0.97	41.00	41.00
Iratio_23	0.98	0.97	0.96	0.97	37.00	49.00

(B) Future low recruitment

	LRP 1GT	LRP ST	USR 1GT	FMSY	C ST	C 1GT
NFref *	0.95	0.88	0.78	1.00	0.00	0.00
CC_33	0.80	0.79	0.64	0.79	33.00	33.00
GB_slope_10y_lam1	0.78	0.79	0.62	0.78	35.00	37.00
GB_slope_10y_lam05	0.78	0.79	0.63	0.78	35.00	36.00
GB_slope_5y_lam1	0.78	0.79	0.62	0.77	36.00	39.00
GB_slope_5y_lam05	0.78	0.79	0.62	0.77	36.00	37.00
IDX_smooth	0.78	0.79	0.62	0.77	37.00	38.00
IDX	0.78	0.79	0.62	0.76	37.00	40.00
Iratio_55	0.80	0.80	0.60	0.81	28.00	50.00
CC_41	0.76	0.78	0.60	0.74	41.00	40.00
Iratio_23	0.78	0.79	0.61	0.76	37.00	44.00

Figure 7. Performance measures of all MPs in individual robustness set operating models. MPs are ordered by decreasing performance metric values from top to bottom starting with the left-most performance metric (LRP 1GT) and using columns from left to right to break any ties. The colour shading reflect the probabilities. Italicized MPs with asterisks indicate reference MPs. Only the average catch during the short term and after one generation (24 years) are presented here.

	LRP 1GT	LRP ST	USR 1GT	FMSY	C ST	C 1GT
NFref *	0.98	0.92	0.88	1.00	0.00	0.00
CC_33	0.90	0.84	0.76	0.84	33.00	33.00
GB_slope_10y_lam1	0.88	0.84	0.74	0.82	35.00	42.67
GB_slope_10y_lam05	0.88	0.83	0.74	0.82	36.00	39.00
GB_slope_5y_lam05	0.87	0.83	0.74	0.80	36.67	40.67
Iratio_55	0.87	0.85	0.68	0.77	29.00	88.00
IDX_smooth	0.87	0.83	0.73	0.80	37.00	41.67
GB_slope_5y_lam1	0.87	0.83	0.73	0.80	36.67	45.67
IDX	0.87	0.83	0.73	0.79	37.67	47.00
CC_41	0.86	0.82	0.73	0.79	41.00	40.67
Iratio_23	0.85	0.83	0.70	0.75	37.67	63.33

Figure 8. Average performance of all MPs across the OM reference set scenarios.

Looking at the performance measures averaged across reference OMs, the Iratio_55 MP generated the lowest short-term catch, and the highest catch after one generation (Figure 8).. On the other hand, the 41 t constant catch MP provided the highest short-term catch. The four GB_slope MPs differed in tuning parameters, but slightly higher catches were generated with λ=1 than with λ=0.5 (λ is the ratio of the change in the catch advice relative to that in the index). The performance of most index-based MPs (IDX, GB_slope, and Iratio MPs) with respect to LRP 1GT and C STwas in between that for the 31 t and 41 t constant catch MPs. All index-based MPs generated higher catch after one generation compared to the 33 t constant catch MP.

The following trade-off plots show the performance of MPs relative to two objectives. An example on how to interpret the trade-off plots is provided in Figure 9.

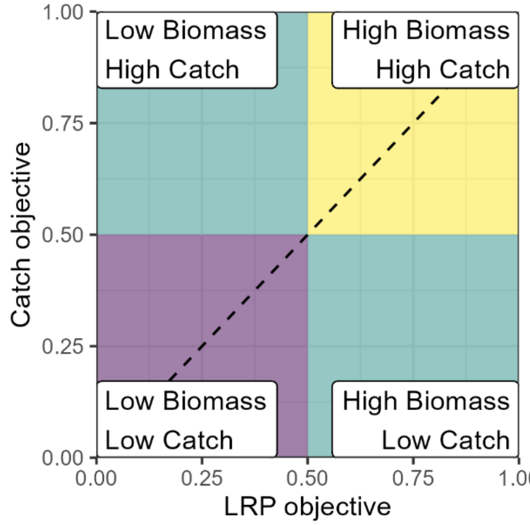

Figure 9. A schematic of a trade-off plot between the LRP objective (x-axis) and a catch objective (y-axis). It is desirable to find management procedures in the upper right corner of the figure, which have high probability of achieving both LRP and catch objectives. Management procedures that have low probability of achieving either objective are in the lower left corner and may not meet satifisficing criteria. Candidate management procedures often have a trade-off of meeting one objective at the expense of the other, and would be plotted in the off-diagonal of this figure, i.e., top left or bottom right. The trade-off plot shows the compromise between the two objectives for choosing one management procedure over another. No trade-off exists if the set of management procedures fall on the one-to-one line (dotted horizontal line), in which case, the best management procedure, relative to the two objectives, is the one at the top right.

We observed a trade-off between LRP 1GT and C 1GT across the candidate MPs (Figure 10). While CC_33 generated the lowest catch and high probability above the LRP, the Iratio MPs generated the highest catch and lowest LRP probabilities. All other MPs appeared to be clustered in between the two ends of the trade-off frontier. Overall, all MPs had similar C ST, but the two Iratio MPs generated the highest catch after one generation (C 1GT performance measure, Figure 11). Catch trade-offs diminished when comparing over three generations (Figure 12). MPs that advise high catches after one generation continue to do so after three generations.

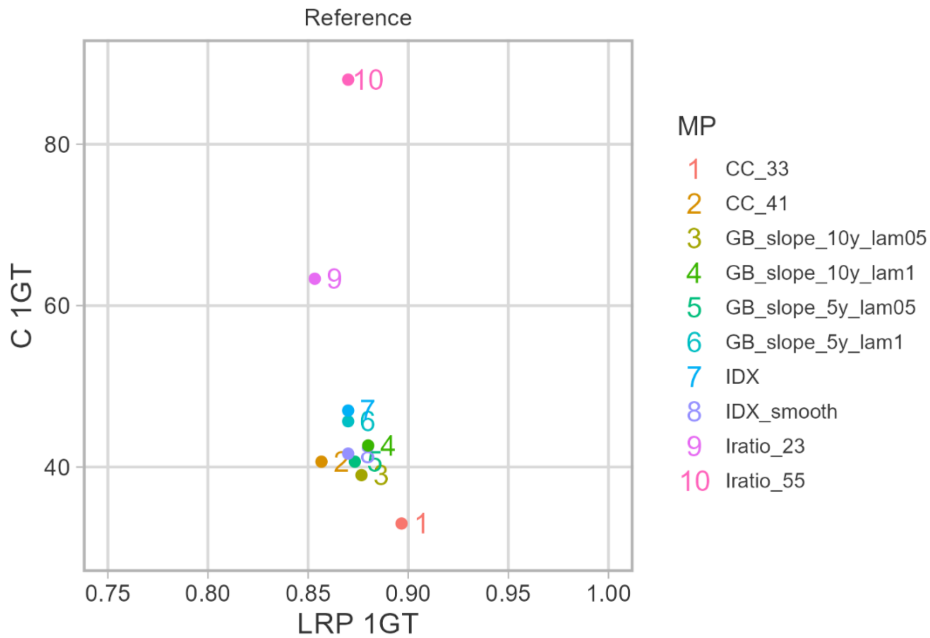

Figure 10. Trade-off between LRP 1GT and C 1GT performance metrics (averaged across the OM reference set) among the candidate management procedures. A trade-off between the LRP objective and catch after one generation appears as the management procedures create a "frontier" in the off-diagonal of the figure (top left to bottom right corner). Thus, selection of a management procedure with high probability of one objective will have a lower probability of meeting the other objective, compared to other candidate management procedures.

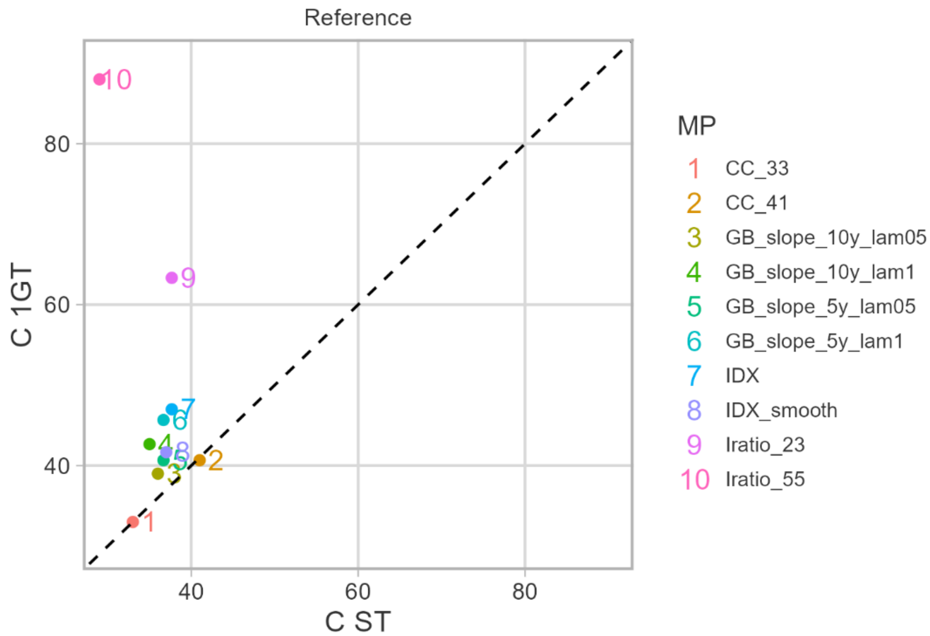

Figure 11. Trade-off between C 1GT and C ST performance metrics (averaged across the OM reference set) among the candidate management procedures. There appears to be no trade-off between short term catch and catch after one generation in this set of management procedures because the performance measures all fall on one side of the one-to-one dotted line. All index-based MPs generate higher catch after one generation compared to in the short-term. Constant catch MPs by definition land on the one-to-one line.

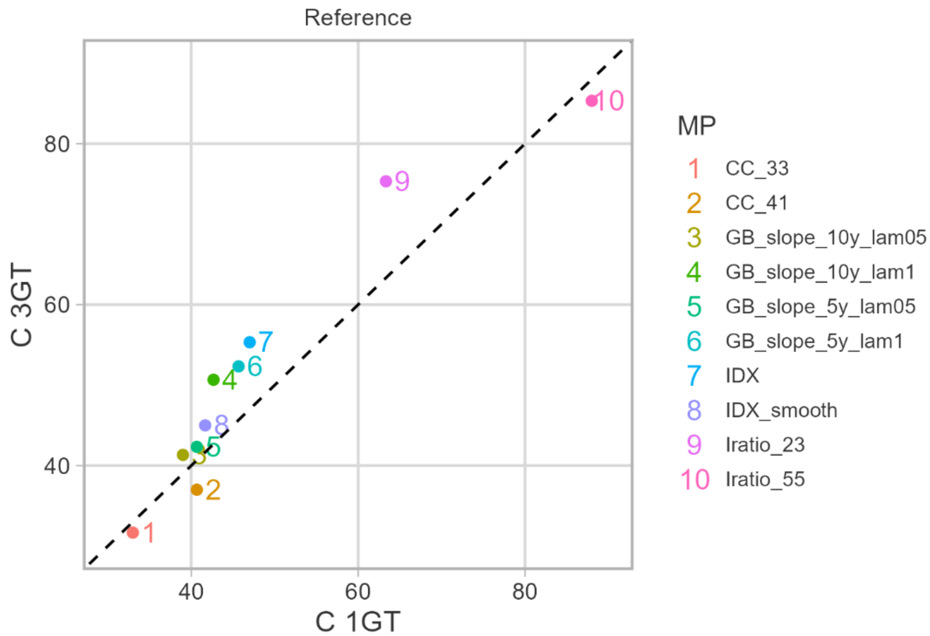

Figure 12. Trade-off between C 1GT and C 3GT performance metrics (averaged across the OM reference set) among the candidate management procedures. The management procedures do not fall on the one-to-one line. Management Procedures in the top-left half of the figure generate more catch after three generations compared to after one generation. Similarly, MPs in the bottom-right half generate more catch after one generation compared to after three generations. Otherwise, no strong trade-off in catch after one vs. three generation is observed because the performance measures do not form a distinct frontier line in the off-diagonal.

Projection Trajectories

The time-series trajectories of B/B_{MSY} and catch in the first generation (24 years) of the projection demonstrate performance all MPs and OMs.

While there is broad range in the confidence interval for B/B_{MSY} at the beginning of the projection, all candidate MPs (excluding the reference MPs) maintained the stock at similar levels to 2021 or achieved continuous stock growth over the first generation of the projection period (Figure 13).The rate of stock growth was dependent on individual operating model, with the most responsive changes in the stock observed when the natural mortality rate was high (OM 3). Annual probabilities that the stock is above the LRP and USR in the simulation are reported in Figure 14.

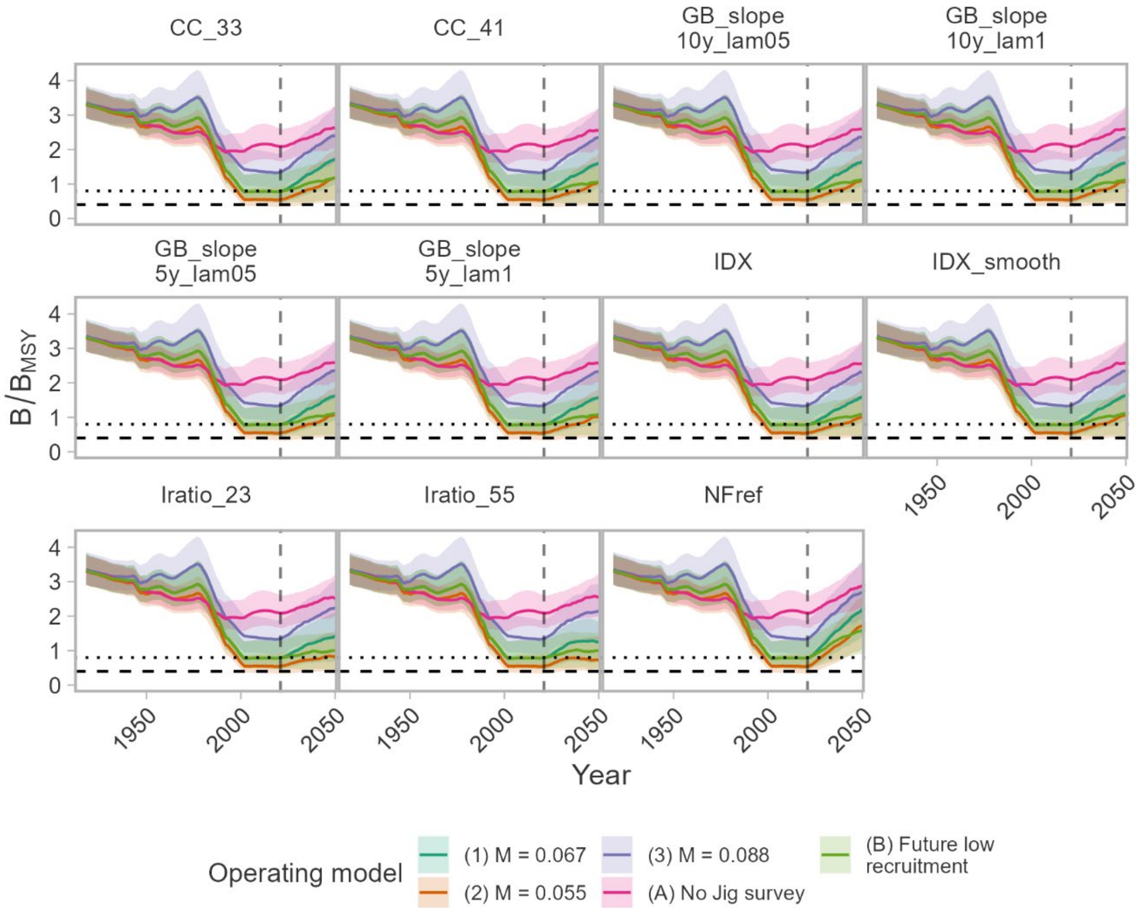

Figure 13. B/B_{MSY} from the historical and projected (one generation) time periods for each management procedure (panel) and operating models (colors). Solid line indicates the median value and the darker and grey ribbons indicate the 95% coverage interval. The vertical dashed line indicates the last year of the historical period (2021). The horizontal dashed and dotted line indicate B/B_{MSY} = 0.4 and 0.8, respectively.

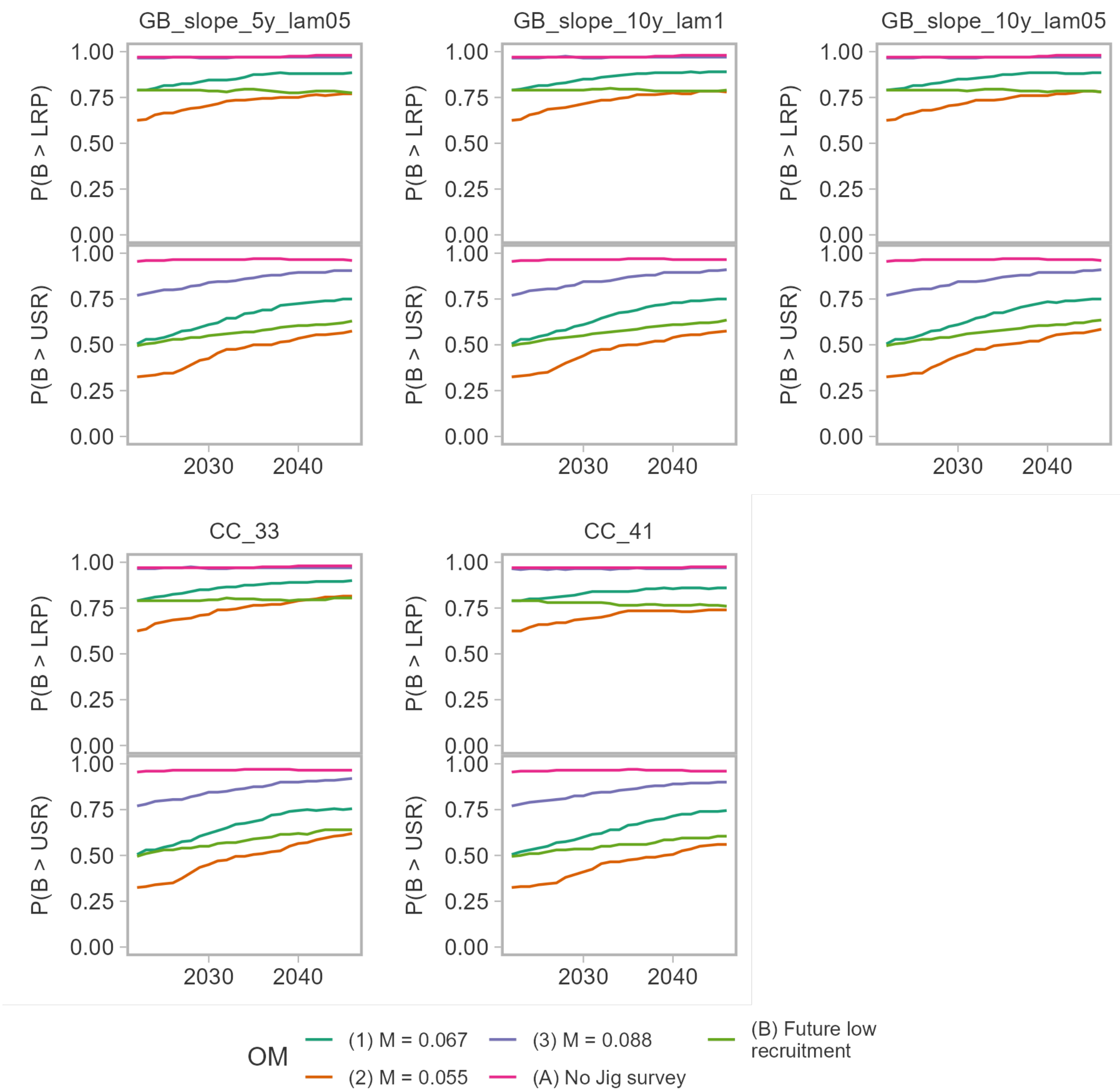

Figure 14a. Annual probability that the stock is above the LRP and USR in the first generation of the projections. Panels are organized by MP and colors donate probabilities in individual OMs (set 1 of 2 figures).

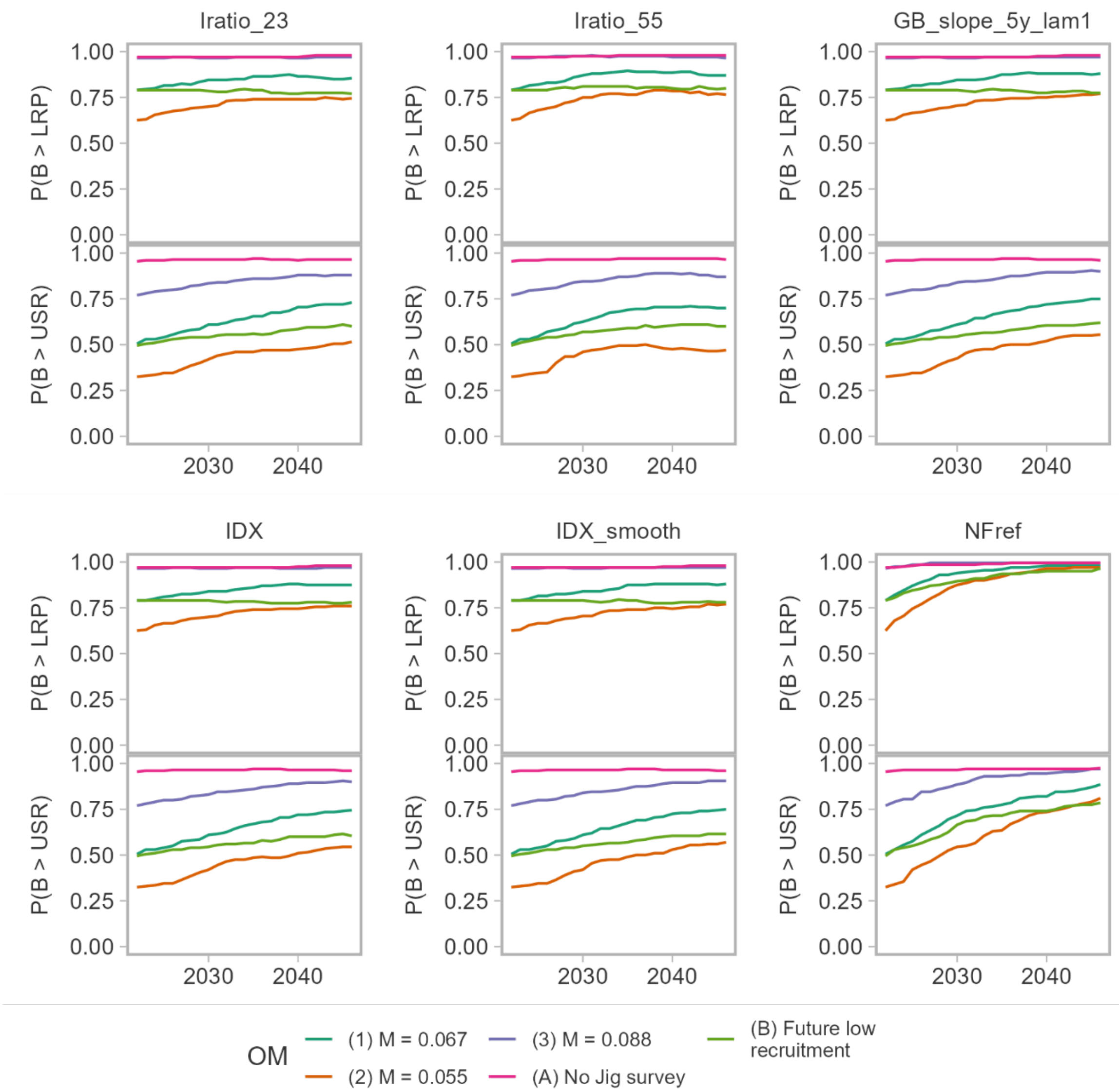

Figure 14b. Annual probability that the stock is above the LRP and USR in the first generation of the projections. Panels are organized by MP and colors donate probabilities in individual OMs (set 2 of 2 figures).

Stock Status

The MP Framework was developed with the intention of using reference points implicitly in the science advice, in contrast to a conventional stock assessment, where stock status is explicitly reported and decision tables are presented. Such tables present probabilities of breaching reference points (e.g., probability of the stock falling below the LRP) over a range of future catch levels. Consideration of risk occurs at the final step of the decision-making process.

With the MP Framework, the acceptable risk of breaching reference points is established at the beginning of the process, i.e., Step 2 of the best practices, and reference points and stock status need not be explicitly reported (Anderson et al. 2021). Reference points are built into the performance metrics as outcomes of management procedures, i.e., the probability of breaching the reference point with a certain MP in the projections.

The Fish Stocks Provisions emphasize identification of status relative to the limit reference point, following the PA Policy. To meet the requirements of the Fish Stocks Provisions, best use of the MP Framework for BC groundfish should consider whether the conditioned operating models are sufficient for identifying status. These operating models are classified in the reference set. Operating models can also be developed with the primary intention of testing management procedures and studying their behavior across various scenarios rather than identifying status. These operating models are in the robustness set. On the other hand, operating models for very data-limited species, e.g., those with few data, such as size or age data or representative indices of abundance, may not be defensible for identifying status, in which case, there would be no operating models in the reference set. The MP Framework was developed for a data-limited context, but it can accommodate the data more elegantly than a piecemeal approach of stock assessment models.

For Inside Quillback Rockfish, we identified three operating models for the reference set that differed in the natural mortality rate. The first OM used a “base” mean value for M based on the most recent scientific information available for predicting the parameter, with alternative means including a continuity scenario from the 2011 assessment in the other two OMs. The status of the stock in 2021 relative to the LRP was robust to the value of M (with distribution means ranging from 0.055 to 0.088). The stock was more likely than not above the LRP, with probabilities of being above the LRP differing based on M.

Averaging the resulting probabilities across the three reference OMs equals a 79% probability that the stock in 2021 is above the LRP. There is a 52% corresponding probability, averaged across the three reference OMs, that the stock is above the USR.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Metric A measures the decline across a three generation time span. When the three reference OMs are averaged, our analysis shows that there is a high probability that the population has declined by 30% and 50% (with 99% and 86% percent probability, respectively), and a lower probability (48%) that the population had declined more than 70% in 2021.

Sources of Uncertainty

Environmental Considerations

In anticipation of Inside Quillback Rockfish being included in the second batch of major stocks prescribed in regulation under the Fish Stock Provisions, we have considered the uncertain effects of environmental conditions by constructing OMs that vary in natural mortality and by including an OM with reduced recruitment (OM B).

Establishing a mechanistic relationship between environmental variables (EVs) and aspects of population productivity (e.g., growth, maturity, recruitment, natural mortality) is notoriously difficult for marine fishes. Even establishing correlations can be difficult, and these relationships may not even hold over time. Furthermore, incorporating environmental effects into assessments may bias advice depending on how well the environment-productivity relationship is understood.

Here, we do not directly model any individual environmental variable (e.g., temperature or oxygen) as we do not have any a priori hypotheses on the relationship between an EV and productivity. Rather, we consider environmental conditions on stock productivity by evaluating MPs across OMs with a low recruitment scenario and OMs with varying rates of natural mortality. Numerous methods have been developed to estimate *M* from available life history parameters. The Barefoot Ecologist’s Toolbox provides a convenient Shiny App that indirectly estimates *M* using various published empirical methods. Estimates of *M* for Inside Quillback

Rockfish ranged from 0.02 to 0.25, depending on the empirical method. However, the high values were estimated from growth parameters and are unlikely for this stock given the high maximum observed age. Other Quillback Rockfish assessments, such as those on the U.S. West Coast, have also used *M* values in the lower range.

In this way, we assume that any number of environmental effects may be acting on the stock, resulting in different rates of natural mortality or reduced recruitment. In lieu of understanding any relationships between EVs and productivity, we are still able to test MPs considering these uncertainties.

Rockfish Conservation Areas

As part of the rockfish conservation strategy, 164 Rockfish Conservation Areas (RCAs), in which fisheries targeting or catching rockfish as bycatch are prohibited, were established in BC waters between 2004-2006. There are 128 RCAs in Area 4B that protect an estimated 267 square kilometers of rockfish habitat, amounting to 19% of available rockfish habitat in inside waters (Dunham et al. 2020). Remotely Operated Vehicle (ROV) surveys of RCAs in inside waters found that there was no difference in the abundance or size of Yelloweye Rockfish inside RCAs at the time of study (3-7 years after RCA establishment). Additional data collected on a 2018 ROV survey have also shown little difference between RCA and non-RCA sites (D. Haggarty, DFO, unpublished data). The results from the 2018 survey, however, were not available in time to be included in this project.

It is expected that, given the longevity of rockfishes, it will take upwards of 20 years for populations to show responses to closed areas. The RCAs in the inside waters have now been in place for 16 to 18 years, so we might expect to find increased densities and sizes of rockfish in RCAs in the near future. The extent to which rockfish in RCAs can function as an unexploited source of recruitment to fisheries, however, has not yet been determined.

Historical Catch

The other major source of uncertainty in our analyses is the magnitude of historical catch. Uncertainty regarding commercial catch is due to the reporting of rockfishes other than Pacific Ocean Perch in an aggregate category before 1950, and the magnitude of unreported catch during 1986-2005. A reconstruction of historical catch data to 2005 was done by Haigh and Yamanaka (2011), which attempted to parse out Quillback Rockfish from the aggregated rockfish category and to account for discarded fish. The reconstructed catches were used in the previous stock assessment (Yamanaka et al. 2012). Reconstruction remains the best available time series of historical catches. We therefore followed the same approach to reconstructing historical recreational catch data and estimating current recreational catch data as Yamanaka et al. (2012).

Biological samples from Inside Quillback Rockfish have not been collected from the commercial fishery since 2001. Thus, it was not explicitly known how the age distribution of fish caught in the commercial fishery has changed over time. Mean weight reported since 100% at-sea and dockside monitoring requirements were introduced in 2006 was used to indirectly ascertain that fishing practices have not significantly changed over time. Developing a biological sampling protocol for a live fishery would fill in this information gap for future assessments.

As in the Inside Yelloweye Rockfish rebuilding plan review, FSC catch is not explicitly included and remains uncertain for the Inside Quillback Rockfish. Some FSC catch, however, is part of the commercial catch because some Quillback Rockfish will be caught and landed on “dual fishing” trips upon which both commercial and FSC fishing is conducted. The fish are landed and subject to dock-side monitoring so the data are included in DFO commercial databases.

Dual fishing trips mostly occur in the northern part of the inside waters. Similarly, some FSC effort will also be captured in the creel survey effort data because FSC fishing that occurs from small vessels will appear like a recreational fishing boat and be counted on DFO creel survey overflights and will enter into the estimate of recreational effort.

Future applications of the MP Framework for this stock would benefit from more detailed collaborative work with First Nations to quantify contemporary and historical FSC catch in Area 4B. Prioritizing collaborations will help DFO build mutually beneficial relationships that can help resolve uncertainties in FSC catch information.

CONCLUSIONS AND ADVICE

MP frameworks differ from traditional stock assessments in that reference points and stock status need not be explicitly reported, and objectives related to the probability of breaching reference points must be agreed upon at the beginning of the process. Reference points and stock status are still an integral component of the framework; they are calculated in the OMs and are built into the performance metrics.

Stock status was estimated by averaging the probabilities that the 2021 spawning biomass was above the LRP of 0.4 B_{MSY} for the three reference OMs, which differ in the value of natural mortality. The Inside Quillback Rockfish stock is estimated to be above the LRP with an average probability of 79%, and a 52% average probability that it is above the USR. There is a 64% average probability that the 2021 spawning biomass is above 0.2 B_0.

A suite of management procedures were evaluated in their ability to achieve management objectives across five operating models. All but the constant catch of 41 tonnes MP achieved meeting the LRP after one generation objective with greater than 90% probability. The two Iratio MPs were able to achieve the LRP after one generation objective with greater than 95% probability, but this came with a trade-off in catch.

Evidence for exceptional circumstances, occurring within the recommended assessment interval, would trigger a review of the OM(s) and MP, possibly resulting in a new OM, or an adjustment to the selected MP. In this analysis, the HBLL index and associated mean age and mean weight are presented as indicators for future re-assessment. These indicators were simulated in the projection as the corresponding real data are expected to be available in the future as the HBLL survey continues. An example of a trigger for re-evaluation could be the observed index of abundance falling outside the 90% confidence interval of the index simulated in this analysis.

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SOURCES OF INFORMATION

This Science Advisory Report is from the December 6-7, 2022 regional peer review on the Application of the Management Procedure Framework for Inside Quillback Rockfish in British Columbia in 2021. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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