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

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

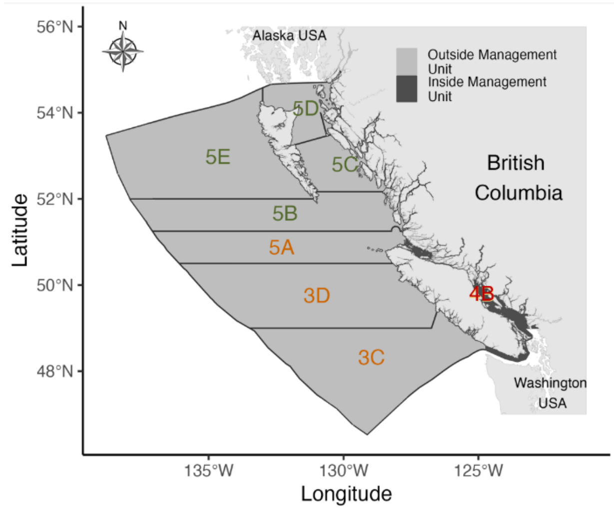

Figure 1. Map of Quillback Rockfish Management Units and Groundfish Management Areas.

Context:

*Quillback Rockfish (*Sebastes maliger*) are a wide-spread marine fish that occur in all of British Columbia's (BC's) coastal waters. Outside 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 outside Quillback Rockfish, and, if possible, to provide guidance and a rationale for 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 outside 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 used 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 was developed from the May 29-30, 2023 regional peer review on the Application of the Management Procedure Framework for Outside 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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Canada

SUMMARY

- The outside stock of Quillback Rockfish (*Sebastes maliger*, Outside Quillback Rockfish) occurs in all coastal waters outside of Groundfish Management Area 4B in British Columbia (BC).
- This analysis provides scientific advice for the sustainable management of Outside 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).
- The stock status was evaluated with regards 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 189% of B_{MSY} (standard deviation (SD) = 13%), and above both the LRP and USR with a 99% probability, averaged across three reference OMs.
- Since the current stock biomass is estimated to be above the LRP, the conservation objectives are to maintain the stock: (1) above the LRP during two generations (54 years) with a minimum probability of 75%, (2) above the USR with a minimum probability of 50%; and to (3) maintain fishing mortality below the removal reference, i.e., F_{MSY}, with a minimum probability of 50%. Other objectives include 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 27 years, based on the natural mortality value of 0.056 and 50% female maturity at 9.4 years. Natural mortality is based on the maximum observed age of 95 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) and the assumption that recreational catch is lower than estimates from the Internet Recreational Effort and Catch (iREC) survey. Two robustness OMs include an OM with lower steepness (h), and an OM that assumes lower average future recruitment.
- Environmental conditions affecting stock dynamics were considered with the alternative values of natural mortality, steepness, and lower recruitment OMs. Our understanding of the environment and stock productivity is not sufficient to model these relationships mechanistically.
- The Management Procedures (MPs) evaluated included three 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 (except one of the constant catch MPs, which did not meet the removal reference criterion) met all three conservation objectives under the OM reference set scenarios.
- Among the set of satisficed MPs, there is a trade-off between long-term biomass levels and long-term catches. While the MPs varied in the levels of long term catch, all maintained a high to very high probability of staying above the LRP and USR during the projections.
- The index-based management procedures were implemented biennially in the projections because the hard bottom longline (HBLL) survey requires two years to sample the full area. As such, catch advice from the index-based MPs can only be updated every two years.

- Exceptional circumstances that would trigger a re-evaluation of the OMs will be reviewed using the survey index, age and size-structure, and life history parameters. These data are presented in the Groundfish (GF) Synopsis report (e.g., DFO 2022).

BACKGROUND

Quillback Rockfish (*Sebastes maliger*) is a long-lived species (up to 95 years) commonly occurring in rocky marine habitats along the inner coast of British Columbia (BC) (Yamanaka et al. 2012). It is widely distributed in the Pacific Northeast, ranging north into the Gulf of Alaska and south into southern California. In BC, 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.

Outside Quillback Rockfish occur in all outer coast waters not including Groundfish Management Area 4B in BC (Figure 1). The stock has been proposed as a major fish stock for future prescription to 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 Outside stock was assessed to be 6,480 tonnes (with a coefficient of variation of 1.21), with a 81% 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 Outside Quillback Rockfish. 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 stock, its environment, and fishery dynamics. The underlying system (the fish stock and its environment) is described by one or more operating models (OMs). This approach is distinct from catch tables presented in conventional stock assessments 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 their 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).

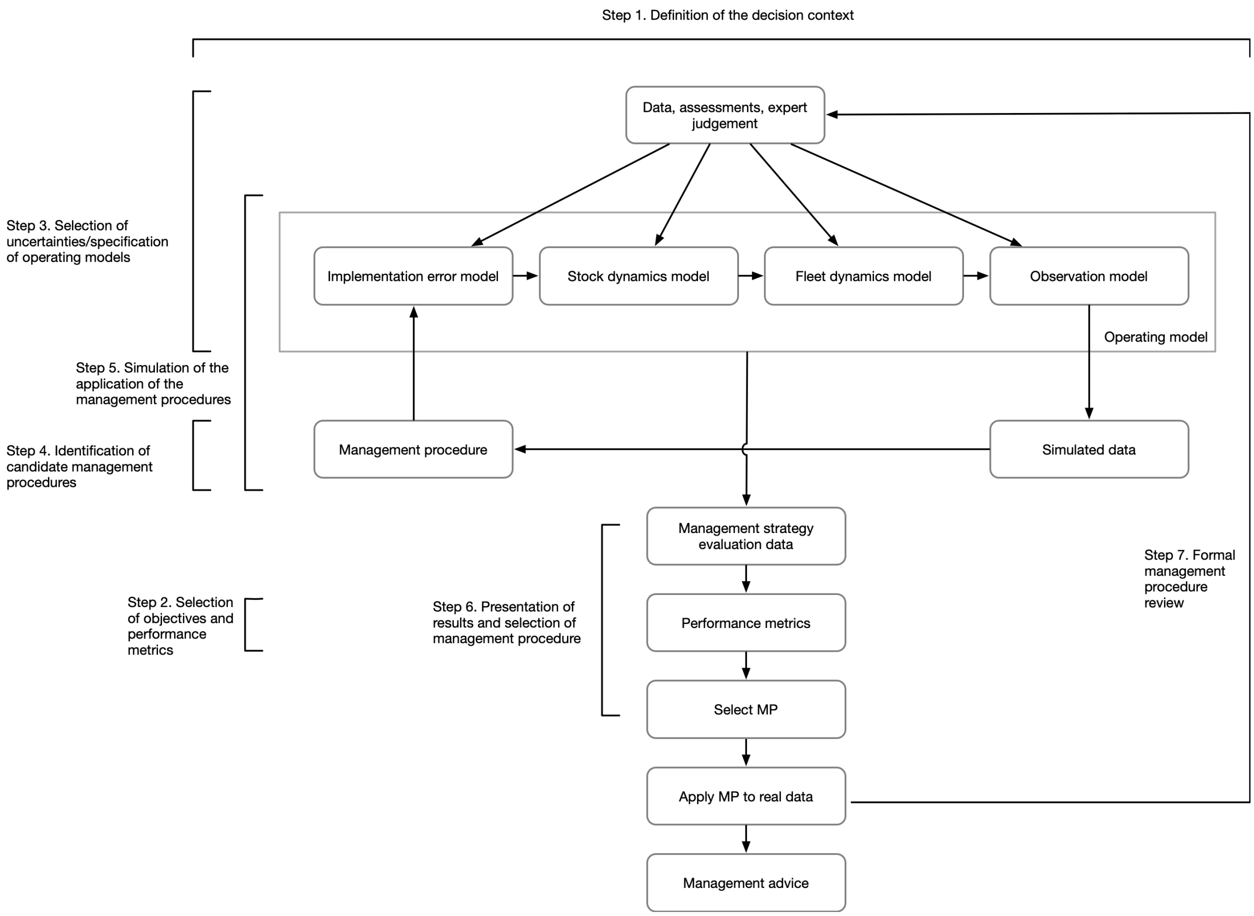

Figure 2. The steps of the MSE process following Punt et al. (2016), copied from Anderson et al. (2021) and adapted from Carruthers and Hordyk (2018).

The MP Framework (Anderson et al. 2021) was identified as a suitable tool for further assessment for Outside Quillback Rockfish since there was considerable uncertainty around the status estimate of the stock during the 2011 assessment (Yamanaka et al. 2012).

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 advice (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 Outside Quillback Rockfish stock (Haggarty et al. 2022a). 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 and spatial patterns in stock abundance, was taken into account in the MP Framework results for Outside Quillback Rockfish. Other sustainability objectives, e.g., spatial flexibility in fishery access, were identified as topics suited for groundfish management.

ANALYSIS

Approach

We followed the six steps laid out in the MP Framework in order to provide science advice for the management of Outside Quillback Rockfish.

Step 1: Decision Context

For this analysis, the decision context was to identify a management procedure to determine catch recommendations that achieve objectives. The operating models that we evaluated were used to determine stock status relative to the LRP, with consideration to 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 Outside 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. (2022a).

As informed by the guidelines of the implementation of the Fish Stocks Provisions, the proposed policy objectives were to:

1. Maintain the stock above the LRP during two generations (54 years) with at least 75% probability of success.
2. Maintain the stock above the USR during two generations with at least 50% probability of success.
3. Maintain fishing mortality below the reference removal during two generations with at least 50% probability of success. To be compliant with the United Nations Fish Stocks Agreement (from which the PA Policy was developed), the removal reference cannot exceed F_{MSY} (DFO 2009).

We also propose the following additional objective:

4. Maintain fishery access and catches both in the short-term (7 years) and in the long-term (2 generations).

No target probability is assigned to Objective 4 as it is used to evaluate trade-offs with Objectives 1-3. The short-term period of 7 years was chosen because it was identified by fishing representatives as a duration when changes in stock abundance may be noticeable in response to management actions (Haggarty et al. 2022a). This time period also closely corresponds to important biological traits such as the age of maturity.

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 2GT:** $P(B > 0.4\ B_{MSY})$ during 2 generations (2022-2075, years 1-54 of the projection period);
2. **USR 2GT:** $P(B > 0.8\ B_{MSY})$ during 2 generations;
3. **F_{MSY} 2GT:** $P(F < F_{MSY})$ during 2 generations;
4. **C ST:** Average catch during the short term (during 2022-2028, years 1-7 of the projection period); and
5. **C 2GT:** Average catch after 2 generations (in 2075, year 54 of the projection period).

Performance metrics 1-3, related to policy objectives, are probability based. The performance statistic was averaged across simulation replicates and years.

Additional performance metrics were calculated to inform comparison of candidate management procedures:

1. **IAV 2GT:** Average variability in catch during 2 generations. This metric calculates the absolute value of $(C_{y'} - C_{y'-k})/C_{y'-k}$, where C is catch, k is the update interval of 2 years, and y′ is the subset of projection years when the catch advice is updated in the management procedure. The mean is then taken across all update years and simulations and is reported as a proportion. Higher values imply that a management procedure is more likely to produce variable catch advice over time;
2. **B/B_0 2GT:** The median ratio of spawning biomass to average unfished biomass (B/B_0) after generations (in 2075);
3. **B/B_{MSY} 2GT:** The median ratio of B/B_{MSY} after 2 generations; and
4. **MA 2GT:** Mean age after 2 generations (median value across 200 simulations).

Predictability and flexibility in fishery access are both desirable objectives from the fishery standpoint (Haggarty et al. 2022a). A combination of catch magnitude and catch variability performance measures can inform selection of a management procedure that supports these strategic objectives. In addition to the probability that the stock remains above the LRP and USR, the ratios of B/B_0 and B/B_{MSY} are reported.

Population age structure provides a complementary perspective on stock abundance in addition to total biomass. Thus, we report the mean age after 2 generations (in 2075). The mean age is calculated with the selectivity of the hard-bottom longline survey (HBLL) to demonstrate predicted values from a fishery-independent survey. As a general rule of thumb, a depleted stock can be characterized by a truncated age structure (lower mean age) as fewer fish survive to old ages.

Step 3: Operating Models (OMs)

Outside Quillback Rockfish exhibit little to no population genetic structure. However, the northern (5BCDE) and southern (5A3CD) regions do exhibit different abundance trends. The HBLL index in the north has increased recently, while the index in the southern region has remained constant. Given this spatial heterogeneity, it was preferable to estimate historical population trends for the two regions. To model population connectivity, the coastwide recruitment is predicted from coastwide spawning biomass. The proportion of recruitment that is apportioned to each of the two areas is then estimated, with no movement after the recruitment phase of the life cycle.

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 Outside Quillback Rockfish, we established two reference set OMs that varied in the value of mean natural mortality, and one additional reference OM that assumes lower recreational catch than what is reported in the iREC survey [OM (1): M = 0.056; OM (2): M = 0.046; OM (3) M = 0.056, low rec catch]. Two robustness OMs include an OM with lower steepness in the stock-recruit relationship [OM (A): h = 0.5, reduced from 0.67), and an OM that assumes low future recruitment [OM (B)]. OM (A) tests the effect of assuming lower stock productivity, and OM (B) indirectly evaluates a change in the environment whereby future recruitment is negatively affected. Operating models were conditioned on historical catches, indices of abundance, age composition from the fishery and surveys, and commercial fishery mean weight.

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 Outside 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.

Annual catch of outside Quillback Rockfish by the recreational fishery is estimated from two sources. The creel survey utilizes aerial surveys to estimate recreational effort with a dockside interview to document catch composition. Spatial coverage of the creel survey is limited to the South Coast (Statistical Areas 11, 21-27 corresponding to Groundfish Management Area 3C, 3D, and 5A) for Outside Quillback Rockfish. While the creel survey started in 1981, coverage was limited to Statistical Area 23 (Barkley Sound) until the 1990s. There is currently no coverage for the North and Central Coast. In 2012, DFO established a coast-wide, internet-based survey of tidal water licence holders (iREC), which collects Quillback Rockfish data for the entire Outside region. The iREC survey includes catch estimates reported by anglers, with catch rate expansions by year and area to account for non-respondent license holders. Due to its more comprehensive coverage of Outside Quillback Rockfish catch, iREC was preferred over the creel survey for recreational catch.

The Outside Quillback Rockfish stock is indexed by two fishery-independent longline surveys: the outside HBLL survey and the International Pacific Halibut Commission (IPHC) longline survey. DFO also conducts four synoptic bottom trawl surveys, however, Quillback Rockfish are only caught in any significant quantities in the Hecate Strait trawl survey. They are caught in a limited amount in the West Coast Vancouver Island and Queen Charlotte Sound surveys, and have not been observed in the West Coast Haida Gwaii survey.

The HBLL survey data have been used to inform population trends since 2003. A geostatistical model was used to develop indices for the north and south regions. 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.

The IPHC survey generates a north and south index beginning in 1998. However, the IPHC survey does not target rockfish, and many survey stations have never caught a Quillback Rockfish.

Stock Synthesis 3 (SS3) was used to condition the OMs. The models were fitted to the various data sources to estimate historical recruitment and abundance, as well as fishery and survey selectivity. Fishery removals in the models are equal to the observed values. Three fisheries (hook and line, trawl, and recreational) were separately modeled with differing selectivity for the historical period. During the projection period, the HBLL index was used to calculate catch advice in index-based management procedures because it provides the best index for Outside Quillback Rockfish as it targets rocky habitat.

The model fits to the indices are shown in Figure 3.

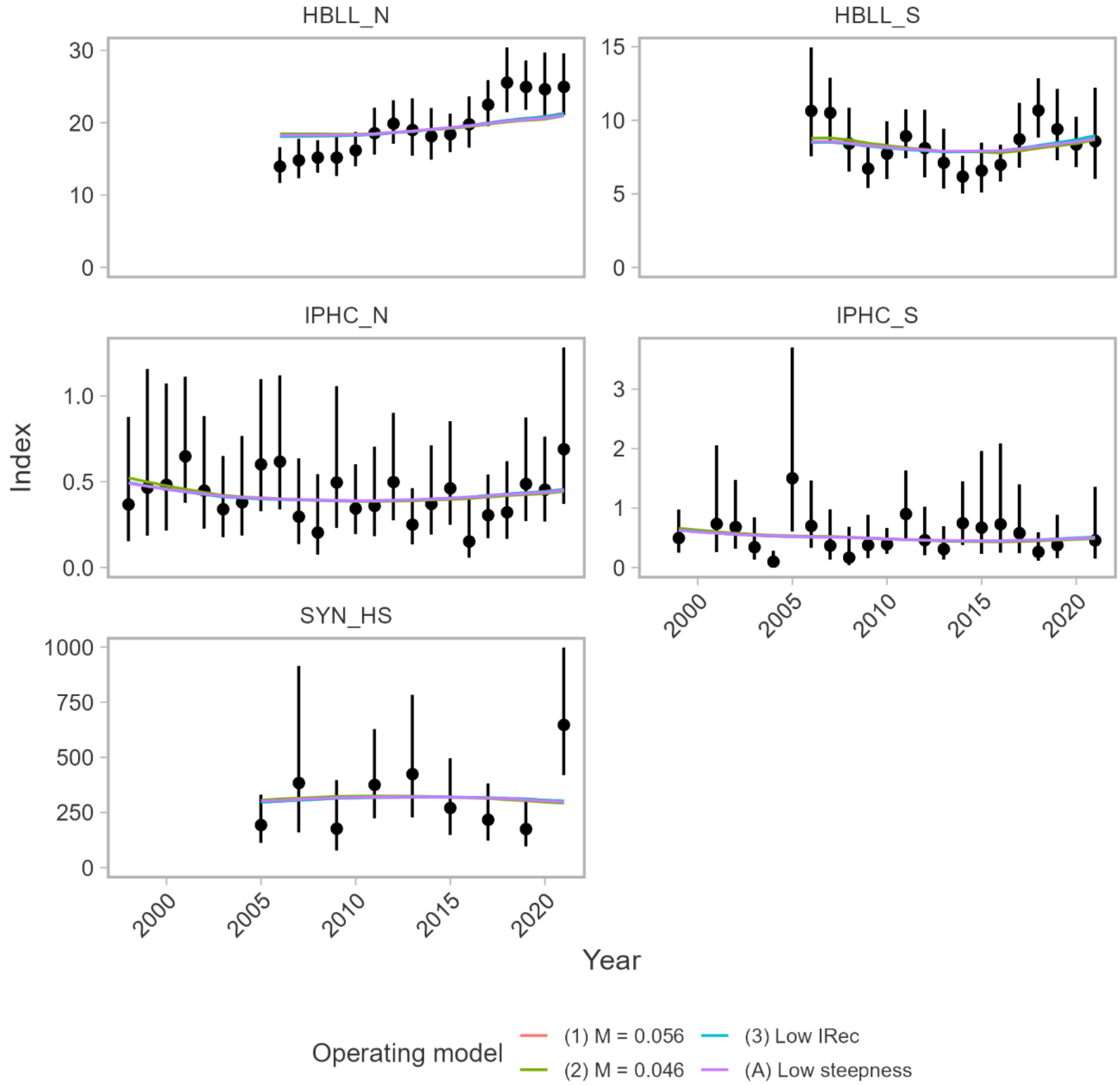

Figure 3. Indices of abundance from the HBLL survey (first row), IPHC survey (second row), and the Synoptic Trawl survey in Hecate Strait (SYN_HS). N & S indicate the index in the North (5BCDE) and South (5A3CD), respectively. Points indicate annual means in the index and the vertical lines span the 95% confidence interval in the annual index. Coloured lines are the predicted values in the operating models.

Operating Model Results

In all operating models, the spawning biomass in 2021 was above the LRP and USR with very high probability (Figure 4). The 2021 spawning biomass was also found to be above 0.2 and 0.4 B_0 with very high probability (Figure 4).

	0.4 BMSY	0.8 BMSY	0.2 B0	0.4 B0
(1) M = 0.056	>0.99	>0.99	>0.99	>0.99
(2) M = 0.046	>0.99	>0.99	>0.99	>0.99
(3) Low IRec	>0.99	>0.99	>0.99	>0.99
(A) Low steepness	>0.99	>0.99	>0.99	>0.99

Figure 4. Probability that the 2021 spawning biomass is above the LRP (40% B_{MSY}) and USR (80% B_{MSY}), and for values of 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 stock ranged from 1.64 B/B_{MSY} (0.48 B/B_0) in the low M operating model to 2.02 B/B_{MSY} (0.59 B/B_0) in the higher M operating model (Table 1). The estimated B/B_{MSY} and B/B_0 in 2021 is lower in operating models (2) and (A) when natural mortality and steepness are respectively lower. Absolute stock size is dependent on operating model, with a larger stock size inferred in operating models (1) and (A) (Figure 5). A slightly smaller stock is estimated for operating model (3) compared to (1). All models inferred similar trends in stock biomass over time, with the largest declines during the late 1980s-2000 followed by more stable and slightly increasing trend since then (Figure 5). The stock has not been estimated to be below B_{MSY} in its history (Figures 6a and 6b), nor below 0.4 B_0 (Figure 7). The large declines occurred during a period with high fishing (Figures 6a,b and 8).

Table 1. Estimates of MSY and unfished reference points, spawning biomass (B) and fishing mortality (F) in 2021, and corresponding ratios. Parameter values report the posterior mean and standard deviation, while status probabilities are calculated across 200 posterior samples. The Reference OM column reported the weighted average across the reference operating models (designated by numbers), with doubled weighting in OM (1) over the other two reference OMs.

Variable	(1) M = 0.056	(2) M = 0.046	(3) Low iREC	(A) Low steepness	Reference OM
B_{2021}/B_{MSY}	2.02 (0.15)	1.64 (0.11)	2.02 (0.15)	1.65 (0.12)	1.93
B_{2021}/B_0	0.59 (0.04)	0.48 (0.03)	0.59 (0.05)	0.59 (0.04)	0.57
B_{MSY}	1824.04 (125.32)	1600.34 (63.18)	1652.94 (123.38)	2368.76 (167.99)	1725.34
B_0	6195.5 (421.45)	5424.56 (210.1)	5634.01 (416.1)	6660.73 (469.04)	5862.39
B_{2021}	3696.77 (496.38)	2633.92 (267.25)	3363.03 (490.38)	3932.27 (559.29)	3347.62
F_{MSY}	0.064 (0.003)	0.055 (0.002)	0.063 (0.003)	0.039 (0.001)	0.062
F_{2021}/F_{MSY}	0.33 (0.04)	0.54 (0.05)	0.32 (0.04)	0.51 (0.07)	0.38
F_{2021}	0.021 (0.003)	0.03 (0.003)	0.02 (0.003)	0.02 (0.003)	0.023
MSY	126.73 (8.26)	92.46 (3.35)	115.16 (8.12)	98.64 (6.69)	115.27
LRP	729.62 (50.13)	640.14 (25.27)	661.18 (49.35)	947.5 (67.2)	690.14
USR	1459.23 (100.26)	1280.27 (50.55)	1322.36 (98.7)	1895.01 (134.39)	1380.27
LRP/B_0	0.12 (2e-04)	0.12 (2e-04)	0.12 (2e-04)	0.14 (1e-04)	0.12
USR/B_0	0.24 (3e-04)	0.24 (4e-04)	0.23 (3e-04)	0.28 (3e-04)	0.24
R_0	619.14 (42.12)	390.44 (15.12)	563.03 (41.58)	665.64 (46.87)	547.94
$P(B_{2021}>0.4B_{MSY})$	1	1	1	1	1
$P(B_{2021}>0.8B_{MSY})$	1	1	1	1	1
$P(B_{2021}>0.2_{B0})$	1	1	1	1	1
$P(B_{2021}>0.4_{B0})$	1	1	1	1	1
$P(F_{2021}<F_{MSY})$	1	1	1	1	1

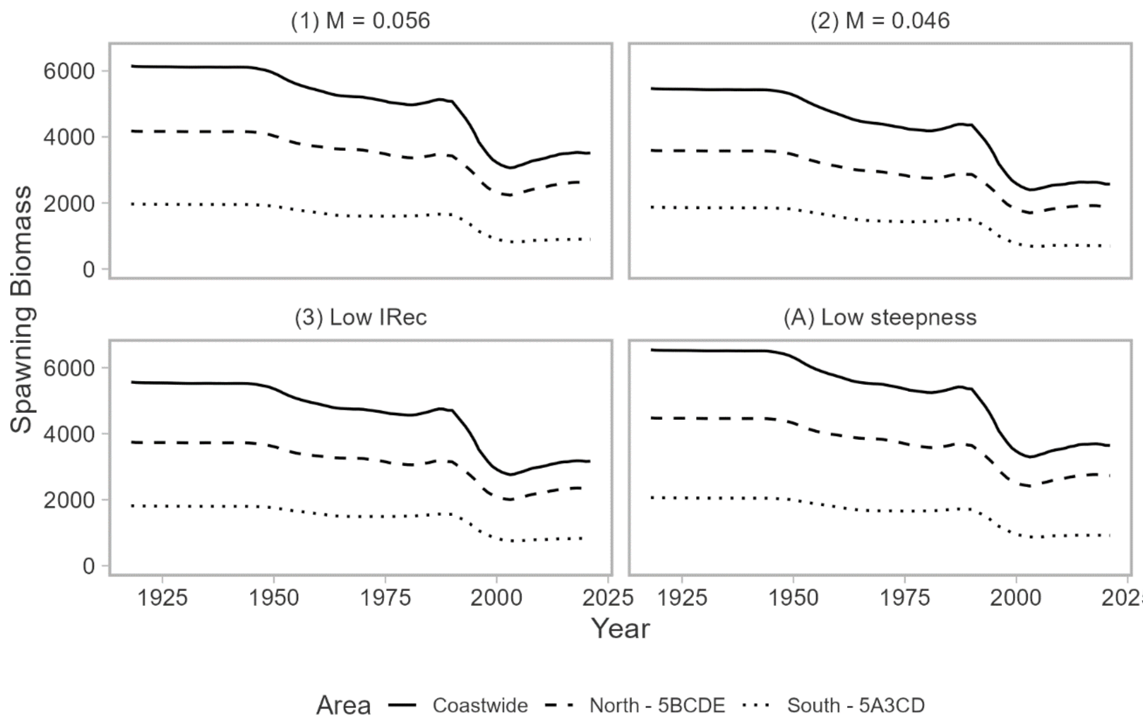

Figure 5. The modeled spawning biomass (tonnes) over time for the four OMs. OM (B) is not shown as it has the same historical pattern as OM (1). The three lines show the south and north regions separately and the combined coastwide biomass.

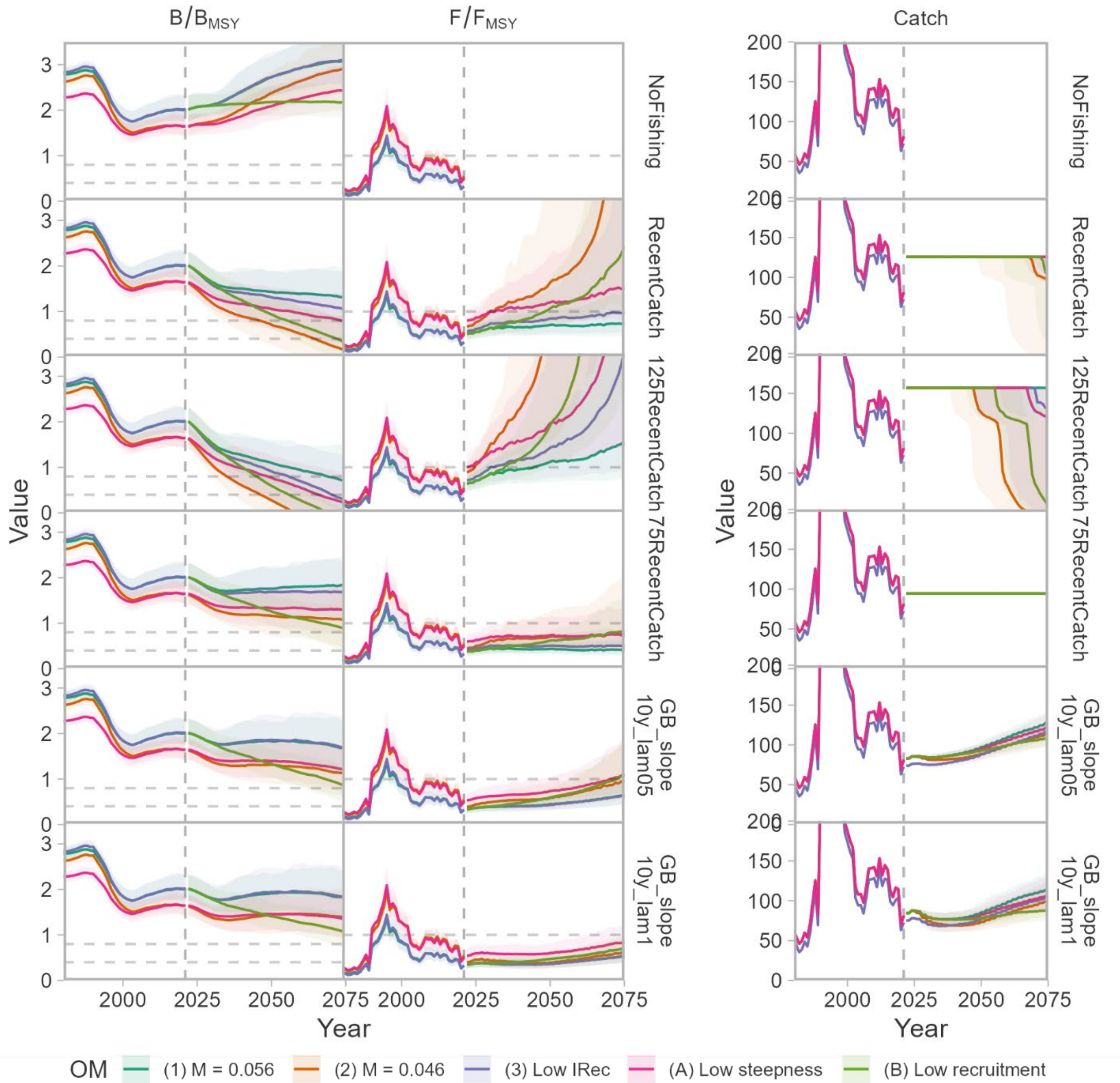

Figure 6a. Historical and projected time series of B/B_{MSY} (left column, with horizontal grey lines denoting 0.4 B_{MSY} and 0.8 B_{MSY}) F/F_{MSY}, (middle column, with horizontal grey line denoting F/F_{MSY} = 1) and catch (tonnes, right column) by operating model (colours) and management procedure (rows; set 1 of 2 figures). Lines indicate the median and the coloured bands span the 95% quantile across simulations. The historical period (prior to 2021, vertical dotted line) is truncated to 1980 and is identical among rows. The historical catch exceeded 200 tonnes during 1990-1998 and truncated in the right column. The projection period shows the resulting trajectories from implementation of the management procedures. Catches in the RecentCatch and 125RecentCatch MPs drop when the stock is not sufficiently large to catch the specified value.

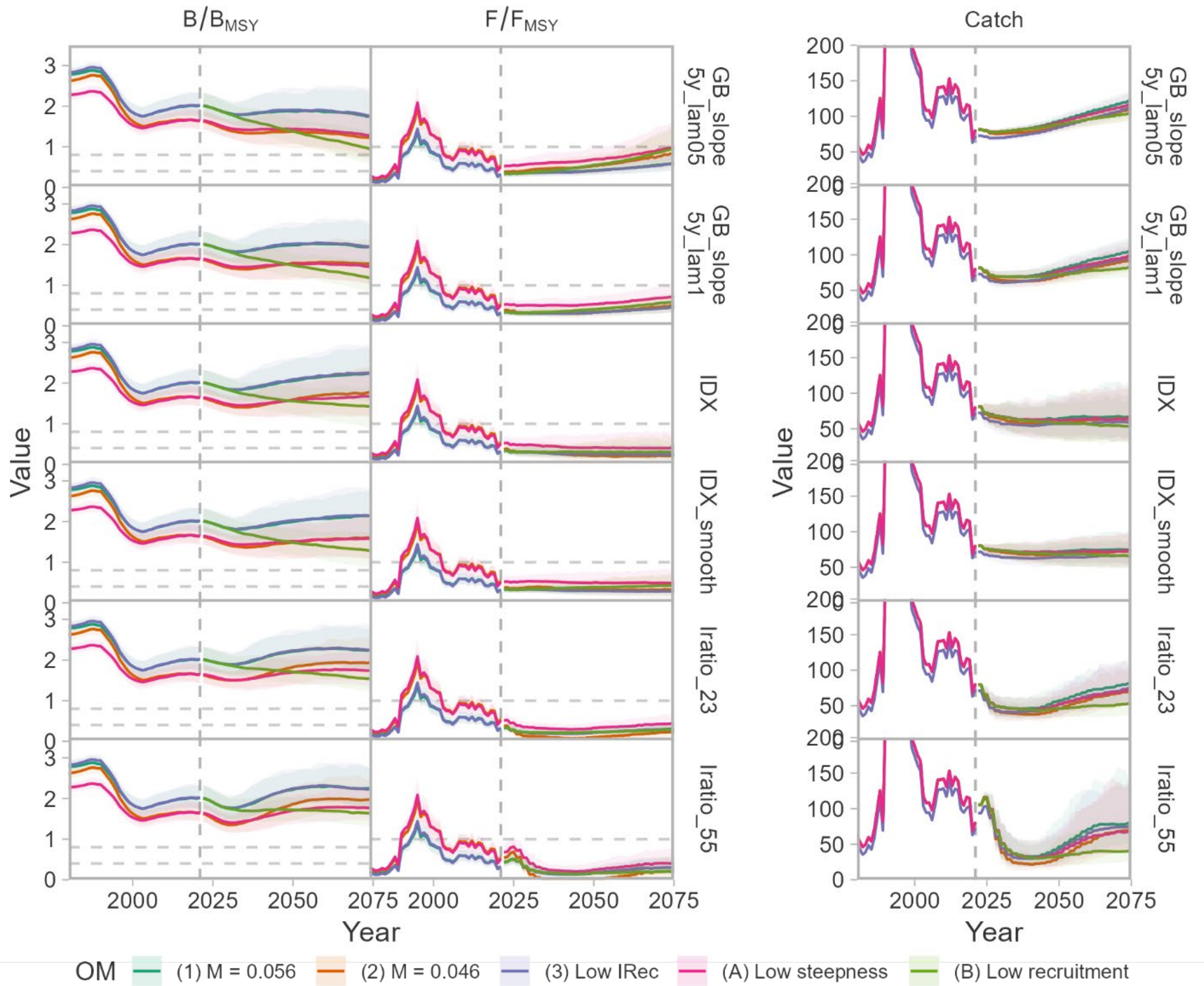

Figure 6b. Historical and projected time series of B/B_{MSY} (left column, with horizontal grey lines denoting 0.4 B_{MSY} and 0.8 B_{MSY}) F/F_{MSY}, (middle column, with horizontal grey line denoting F/F_{MSY} = 1) and catch (tonnes, right column) by operating model (colours) and management procedure (rows; set 2 of 2 figures). Lines indicate the median and the coloured bands span the 95% quantile across simulations. The historical period (prior to 2021, vertical dotted line) is truncated to 1980 and is identical among rows. The historical catch exceeded 200 tonnes during 1990-1998 and truncated in the right column. The projection period shows the resulting trajectories from implementation of the management procedures.

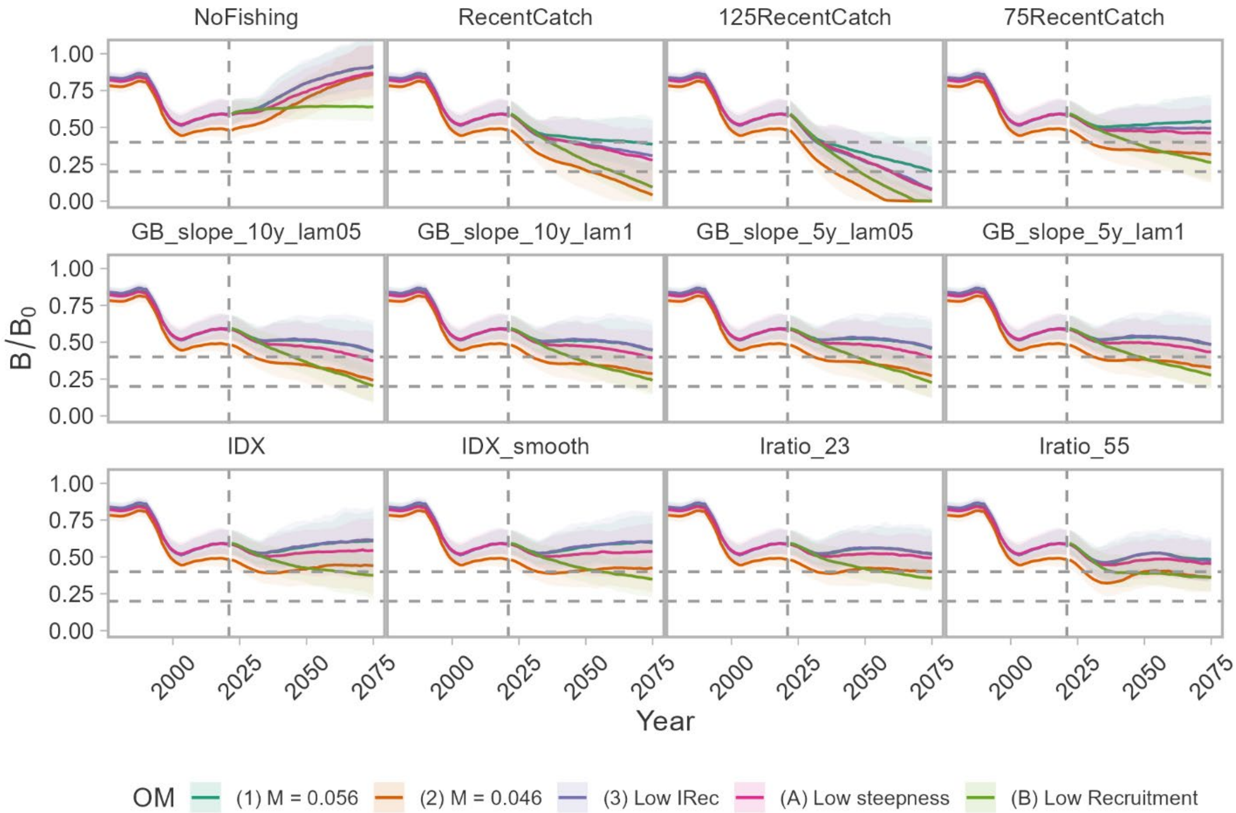

Figure 7. Historical and projected time series of B/B_0 by operating model (colours) and management procedure (panels). Lines indicate the median and the coloured bands span the 95% quantile across simulations. The historical period (prior to 2021, vertical dotted line) is truncated to 1980 and is identical among panels. The projection period shows the resulting trajectories from implementation of the management procedures. Horizontal, dotted grey lines denoting 0.2 B_0 and 0.4 B_0.

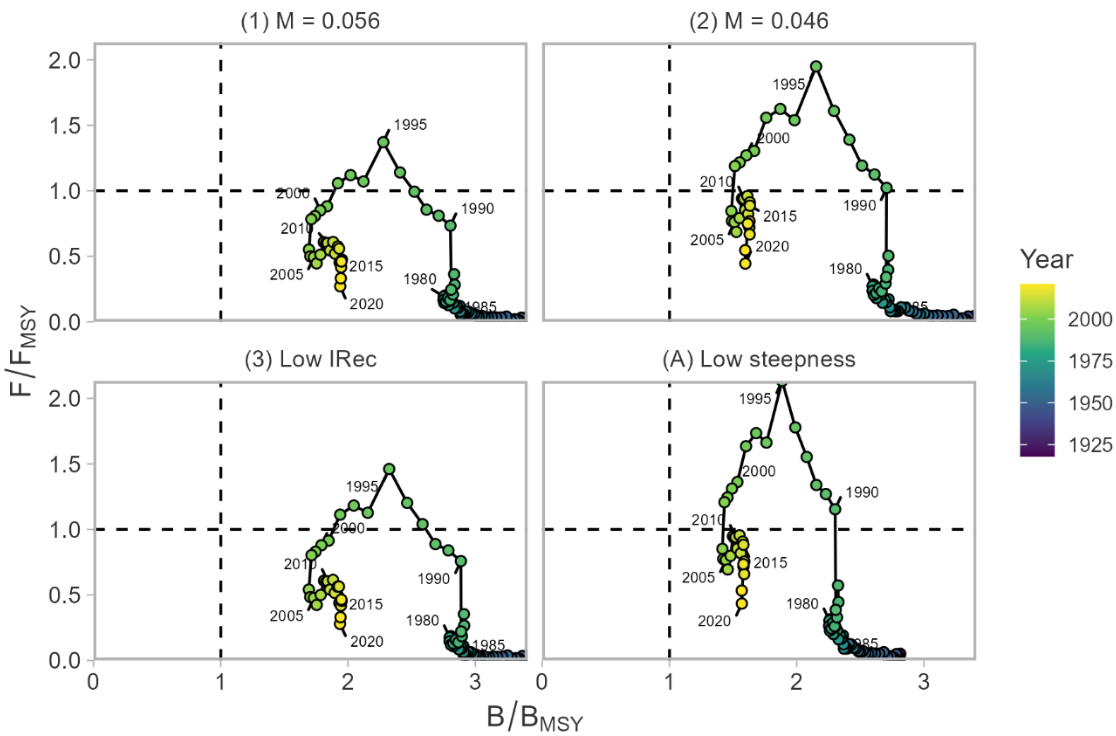

Figure 8. Kobe phase plot showing the historical stock trajectory in terms of B/ B_{MSY} and F/ F_{MSY}) for the reference and robustness set OMs at the maximum posterior density (MPD). Years are indicated color.

In equilibrium, the LRP is a low biomass state at which the age structure is expected to be severely truncated. The observed age composition in the HBLL and IPHC surveys for four OMs were compared to the expected equilibrium age structure at the LRP. The observed mean age in 2020 for the HBLL and IPHC surveys was 28.3 and 32.3, respectively. These ages are higher than the expected mean age of the equilibrium age composition given the population is at the LRP. While the LRP is defined with respect to biomass, the age structure analysis provides an additional insight on the conditions needed to conclude that the stock is 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 9).

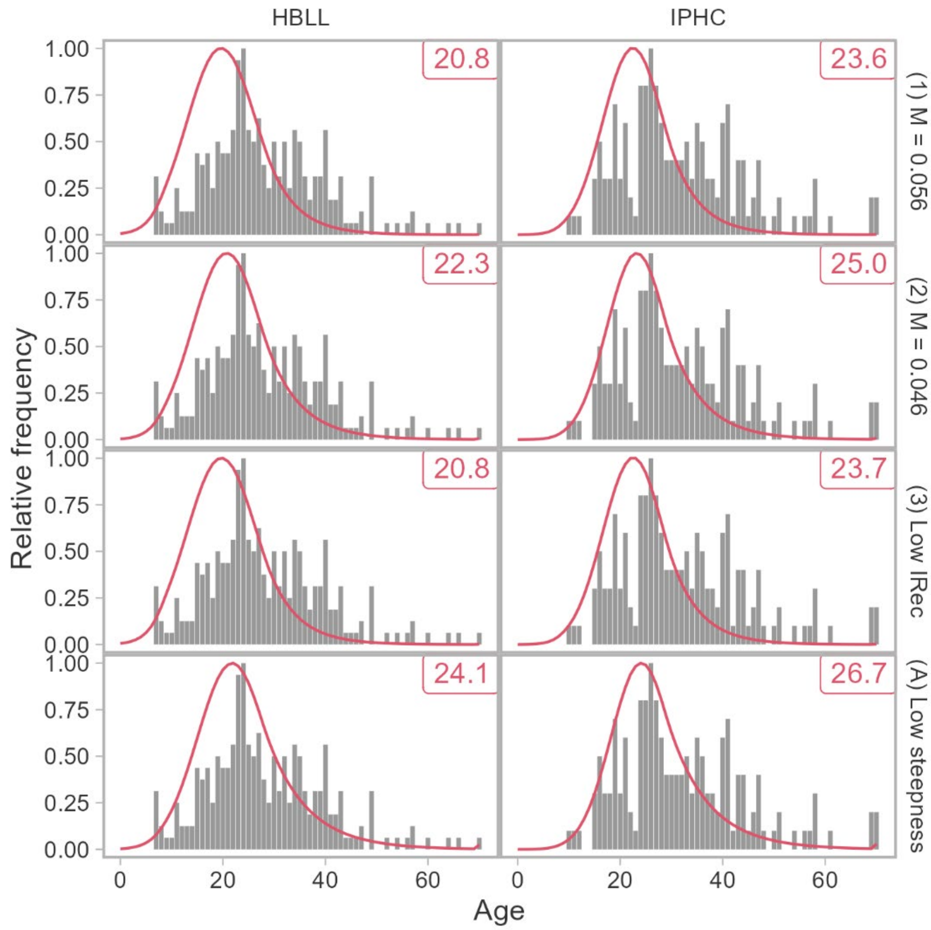

Figure 9. Age structure in the HBLL and IPHC surveys relative to the LRP. Bars represent observed proportions in the 2020 HBLL and 2019 IPHC surveys across all areas. The red line is the predicted equilibrium age distribution at the LRP, with red numbers in the corner of each panel reporting the corresponding mean age. The observed mean age of the age composition is 28.3 and 32.2 years from the 2020 HBLL and 2019 IPHC surveys, respectively. This figure is intended to serve as a rule of thumb for complementary perspectives on status inference with respect to the LRP, which is based on biomass.

The 2011 assessment used a surplus production model with a symmetric yield curve, i.e., B_{MSY} at 0.5 B/B_0 (Yamanaka et al. 2011). In contrast, yield curves are typically right-skewed in age structured models, i.e., with B_{MSY} at approximately 30% B/B_0 (Figure 10).

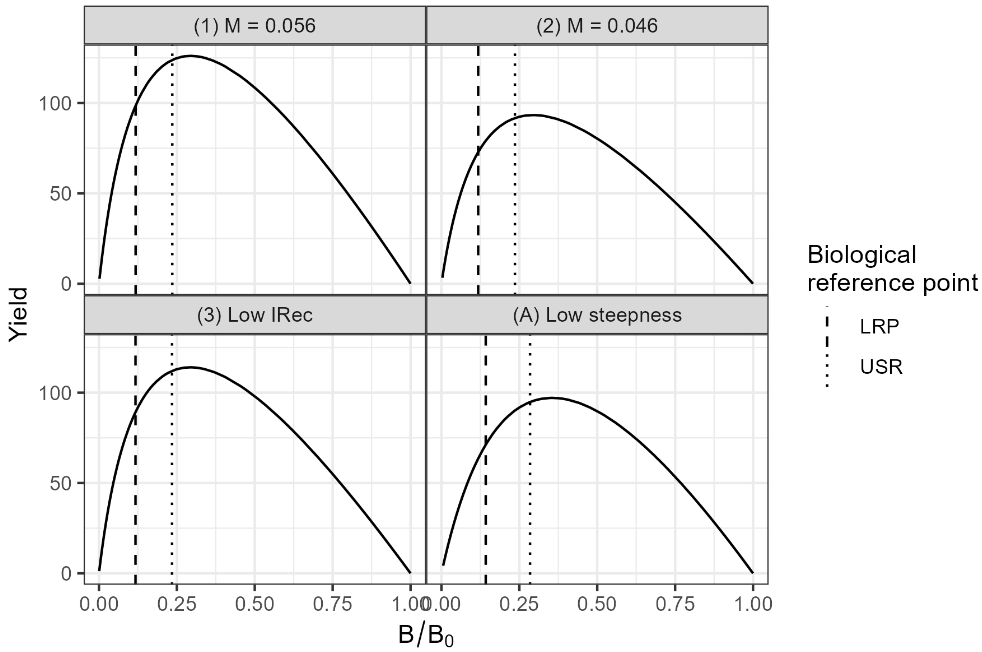

Figure 10. Yield curve as a function of depletion (B/ B_0) in the operating models, estimated at the maximum posterior density (MPD). Dashed and dotted vertical lines represent the value of 0.4 B_{MSY} (LRP) and 0.8 B_{MSY} (USR), respectively.

Step 4: Candidate Management Procedures

The MP Framework currently only considers MPs that make catch recommendations, because most catch for groundfish stocks are managed by quotas and commercial Total Allowable Catches (TACs). The catch recommendation specified in the management procedures would be inclusive of commercial, recreational, and Food, Social, and Ceremonial (FSC) catches. For comparison, the current commercial fishery TAC for Outside Quillback Rockfish is 4 tonnes (t) coastwide for the trawl sector, while for all other sectors, the TAC is 46 t for 5A3CD and 79 t for 5BCDE. In contrast, the recreational fishery is managed with a retention limit and seasonal closures.

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 three constant-catch MPs:

- RecentCatch: The average catch during 2012-2019 and is intended to reflect status quo conditions. Constant annual catch is 81.6 tonnes in the North (5BCDE) and 44 tonnes in the South (5A3CD);
- 125RecentCatch: Constant annual catch at 125 percent of the RecentCatch MP, i.e., 102 and 55 tonnes for the North and South, respectively; and
- 75RecentCatch: Constant annual catch at 75 percent of the RecentCatch MP, i.e., 61.2 and 33 tonnes for the North and South, respectively.

Index-based MPs, in general, adjust the catch based on changes in a population index over time. Within each family, various tuning parameters can be adjusted to alter (1) how the trend in the index is calculated, and/or (2) how the catch advice is calculated based on (1). For example, the change in catch advice can be some percentage of the change in the index, either with or without a maximum allowable percent change. The catch advice was calculated separately for the North and South based on the HBLL index in the corresponding area.

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. Management procedures can be tuned such that the catch recommendation can be moderately or highly responsive to changes in the index.

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.

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 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
NoFishing	Reference
RecentCatch	Constant catch
125RecentCatch	Constant catch
75RecentCatch	Constant catch
GB_slope_10y_lam05	Index slope
GB_slope_10y_lam1	Index slope
GB_slope_5y_lam05	Index slope
GB_slope_5y_lam1	Index slope
IDX	Index ratio
IDX_smooth	Index ratio
Iratio_23	Index ratio
Iratio_55	Index ratio

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 3.6.0 (Hordyk et al. 2022). The historical period of the operating model was replicated from the SS3 output in order to run the closed-loop projections. The length of the projection period was set at 54 years (2 generations for Outside Quillback Rockfish).

Performance Measures

Anderson et al. (2021) 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. Following the Guidelines for Implementing the Fish Stocks Provisions, the following criteria were used to determine which MPs are satisficed: LRP 2GT > 0.75, USR 2GT > 0.50, F_{MSY} 2GT > 0.50.

Almost all management procedures met the satisficing criteria, except for the 125RecentCatch management procedure in all operating models (Figure 11). While the RecentCatch MP met the satisficing criteria when averaged across the reference set, it did not perform well in the operating models with low productivity: OM (2) with low natural mortality and OM (A) with low steepness (Figures 12 and 13). These results illustrate the disadvantage of static management procedures in the long-term which are not responsive to changes in abundance. Static MPs frequently require lower catches, e.g., the 75RecentCatch MP which set catches at 75% of the recent historical mean, for better long-term performance in relation to biological risk.

All index-based management procedures met the three satisficing criteria for the reference set (Figure 11). Projected catches in the short term (C ST) were lower relative to the recent historical mean as a result of the operating model conditioning. Index-based MPs appear to produce lower short-term catch than the RecentCatch MP because the former adjusts catch from 2021 levels, which are lower than 2012-2019 average (Figure 14). The least reduction in the short term was seen in the Iratio_55 management procedure, but is accompanied with the highest variability in catch over time (Figures 12 and 13).

MP performance averaged across the three reference OMs is shown in Figure 15. OM (1) received twice the weighting as OM (2) and OM (3), per preference of the Technical Working Group.

Satisficed MPs

	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
NoFishing	1.00	1.00	1.00	0.00	0.00	0.02	0.90	3.09	34.01
IDX_smooth	1.00	1.00	1.00	78.21	79.53	0.03	0.56	1.90	30.06
Iratio_23	1.00	1.00	0.99	78.89	106.53	0.08	0.49	1.68	29.61
IDX	1.00	1.00	0.99	78.77	77.09	0.07	0.57	1.94	30.24
Iratio_55	1.00	1.00	0.93	118.28	104.28	0.12	0.45	1.53	28.97
GB_slope_5y_lam1	1.00	1.00	0.96	81.13	118.56	0.03	0.45	1.53	28.93
GB_slope_10y_lam1	1.00	0.99	0.91	87.09	126.16	0.02	0.41	1.40	28.36
GB_slope_5y_lam05	1.00	0.98	0.90	81.36	128.44	0.02	0.41	1.41	28.45
75RecentCatch	1.00	0.98	0.94	94.20	94.17	0.00	0.47	1.61	28.82
GB_slope_10y_lam05	1.00	0.97	0.87	84.32	133.34	0.02	0.39	1.33	28.07
RecentCatch	0.94	0.85	0.69	125.60	113.13	0.01	0.28	0.98	24.54

Figure 11. Satisficed MPs averaged across the OM reference set scenarios. MPs are ordered by decreasing performance metric values from top to bottom starting with the left-most performance metric (LRP 2GT) and using columns from left to right to break any ties. The colour shading reflect the probabilities. This figure excludes the FMSYref reference management procedure.

(1) M = 0.056

	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
75RecentCatch	1.00	1.00	1.00	94.20	94.20	0.00	0.54	1.84	29.38
IDX_smooth	1.00	1.00	1.00	80.46	82.70	0.03	0.60	2.04	30.16
NoFishing	1.00	1.00	1.00	0.00	0.00	0.02	0.91	3.13	33.67
Iratio_23	1.00	1.00	1.00	81.47	113.66	0.08	0.52	1.79	29.63
GB_slope_5y_lam1	1.00	1.00	1.00	83.49	125.84	0.03	0.48	1.66	29.12
IDX	1.00	1.00	1.00	81.24	80.84	0.07	0.61	2.06	30.26
GB_slope_10y_lam1	1.00	1.00	0.99	89.50	134.51	0.02	0.44	1.54	28.63
GB_slope_5y_lam05	1.00	1.00	0.99	83.62	135.51	0.02	0.46	1.57	28.80
Iratio_55	1.00	1.00	0.98	122.28	111.96	0.12	0.48	1.63	28.94
GB_slope_10y_lam05	1.00	1.00	0.98	86.60	140.94	0.02	0.43	1.50	28.51
RecentCatch	1.00	0.99	0.94	125.60	125.60	0.00	0.39	1.31	27.30
125RecentCatch	0.95	0.80	0.48	157.00	143.20	0.00	0.20	0.67	23.72

(2) M = 0.046

	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
75RecentCatch	1.00	0.93	0.78	94.20	94.09	0.00	0.32	1.07	27.79
IDX_smooth	1.00	1.00	0.98	80.56	79.96	0.04	0.42	1.46	29.70
NoFishing	1.00	1.00	1.00	0.00	0.00	0.02	0.86	2.93	35.18
Iratio_23	1.00	1.00	0.97	80.23	95.35	0.09	0.40	1.34	29.57
GB_slope_5y_lam1	1.00	0.98	0.83	83.15	107.77	0.03	0.33	1.11	28.36
IDX	1.00	1.00	0.97	81.02	76.02	0.07	0.44	1.52	30.09
GB_slope_10y_lam1	1.00	0.95	0.65	89.47	112.59	0.02	0.28	0.97	27.53
GB_slope_5y_lam05	1.00	0.94	0.63	83.58	119.18	0.02	0.27	0.93	27.38
Iratio_55	1.00	0.99	0.80	120.14	90.97	0.14	0.36	1.23	29.06
GB_slope_10y_lam05	0.99	0.90	0.54	86.73	122.84	0.02	0.24	0.83	26.72
RecentCatch	0.79	0.49	0.11	125.60	78.18	0.03	0.04	0.23	17.68
125RecentCatch	0.47	0.27	0.01	157.00	5.55	0.17	0.00	0.01	7.81

(3) Low IRec

	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
75RecentCatch	1.00	1.00	1.00	94.20	94.20	0.00	0.49	1.69	28.73
IDX_smooth	1.00	1.00	1.00	71.35	72.75	0.03	0.61	2.08	30.21
NoFishing	1.00	1.00	1.00	0.00	0.00	0.02	0.92	3.15	33.54
Iratio_23	1.00	1.00	1.00	72.39	103.45	0.08	0.52	1.79	29.61
GB_slope_5y_lam1	1.00	1.00	1.00	74.40	114.81	0.03	0.49	1.67	29.13
IDX	1.00	1.00	1.00	71.59	70.67	0.07	0.61	2.10	30.34
GB_slope_10y_lam1	1.00	1.00	0.99	79.88	123.03	0.02	0.45	1.55	28.65
GB_slope_5y_lam05	1.00	1.00	0.99	74.62	123.57	0.02	0.46	1.58	28.82
Iratio_55	1.00	1.00	0.98	108.41	102.22	0.12	0.47	1.63	28.95
GB_slope_10y_lam05	1.00	1.00	0.97	77.34	128.63	0.02	0.44	1.51	28.54
RecentCatch	0.99	0.92	0.75	125.60	123.16	0.00	0.31	1.05	25.87
125RecentCatch	0.84	0.65	0.30	157.00	105.63	0.03	0.08	0.40	18.52

Figure 12. Performance measures of all MPs in individual reference set operating models. MPs are ordered by decreasing performance metric values from top to bottom starting with the left-most performance metric (LRP 2GT) and using columns from left to right to break any ties. The colour shading reflect the probabilities. This figure excludes the FMSYref reference management procedure.

(A) Low steepness

	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
NoFishing	1.00	1.00	1.00	0.00	0.00	0.02	0.87	2.46	33.23
IDX_smooth	1.00	1.00	1.00	80.46	79.51	0.03	0.54	1.50	30.00
IDX	1.00	1.00	0.99	80.98	74.97	0.07	0.54	1.54	30.17
Iratio_23	1.00	1.00	0.98	80.88	100.99	0.08	0.49	1.39	29.83
Iratio_55	1.00	1.00	0.86	121.50	97.41	0.11	0.45	1.29	29.41
GB_slope_5y_lam1	1.00	0.99	0.88	83.38	116.10	0.03	0.44	1.23	29.17
75RecentCatch	1.00	0.99	0.93	94.20	94.20	0.00	0.46	1.28	29.19
GB_slope_10y_lam1	1.00	0.98	0.77	89.55	123.85	0.02	0.39	1.12	28.70
GB_slope_5y_lam05	1.00	0.98	0.77	83.65	128.46	0.02	0.40	1.13	28.75
GB_slope_10y_lam05	1.00	0.97	0.70	86.71	133.61	0.02	0.37	1.06	28.45
RecentCatch	0.98	0.83	0.36	125.60	122.19	0.00	0.28	0.78	26.90
125RecentCatch	0.82	0.55	0.05	157.00	100.53	0.03	0.08	0.29	19.94

(B) Low Recruitment

	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
NoFishing	1.00	1.00	1.00	0.00	0.00	0.01	0.64	2.20	35.17
IDX_smooth	1.00	1.00	1.00	80.46	72.13	0.03	0.35	1.19	30.44
IDX	1.00	0.99	1.00	81.23	63.04	0.07	0.38	1.27	30.84
Iratio_23	1.00	1.00	1.00	81.46	72.13	0.08	0.36	1.21	30.63
Iratio_55	1.00	1.00	0.99	122.27	64.10	0.11	0.36	1.23	30.45
GB_slope_5y_lam1	1.00	0.97	0.97	83.48	94.55	0.03	0.28	0.95	29.28
75RecentCatch	1.00	0.94	0.95	94.20	94.20	0.00	0.26	0.88	28.92
GB_slope_10y_lam1	1.00	0.92	0.91	89.50	99.28	0.02	0.24	0.83	28.50
GB_slope_5y_lam05	1.00	0.91	0.84	83.62	112.44	0.02	0.23	0.77	28.29
GB_slope_10y_lam05	0.99	0.88	0.78	86.60	116.60	0.02	0.20	0.69	27.69
RecentCatch	0.89	0.64	0.53	125.60	101.95	0.01	0.09	0.33	23.30
125RecentCatch	0.64	0.44	0.26	157.00	32.94	0.08	0.00	0.04	10.66

Figure 13. 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 2GT) and using columns from left to right to break any ties. The colour shading reflect the probabilities. This figure excludes the FMSYref reference management procedure.

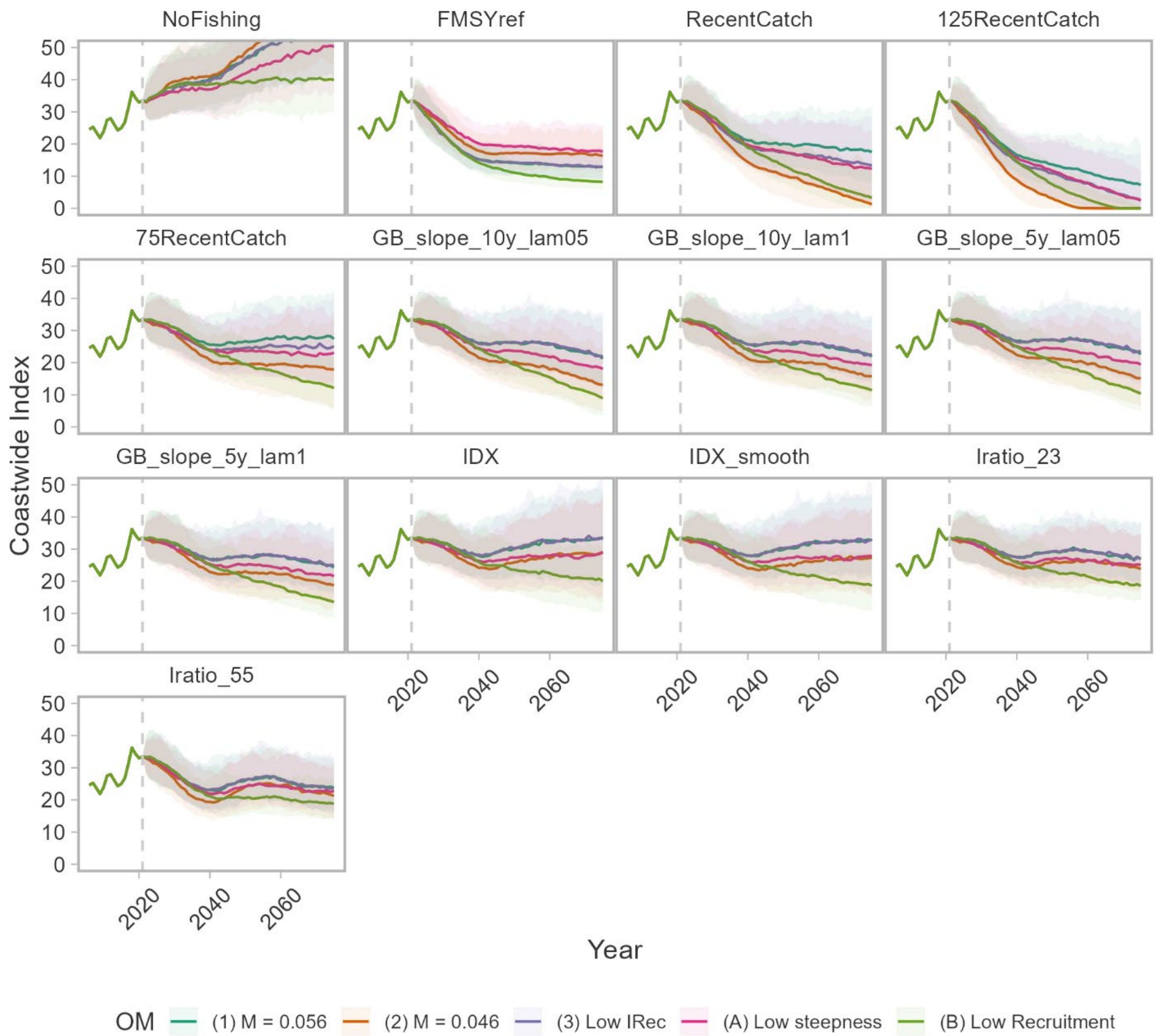

Figure 14. The coastwide index from the HBLL survey (prior to 2021 in vertical lines), with simulated values in the projections from 2022 and onward for each management procedure and operating model. Colored bands denote the 95% range of values simulated in the projections. Area-specific indices in 5BCDE and 5A3CD were used in the operating model conditioning and simulated in the closed-loop projections; the coastwide value is the sum over the two areas and is presented here as a stock-wide index. Upon implementation of a management procedure, simulated indices can be used in part to monitor whether the stock is responding as predicted and determine when a re-assessment is necessary.

	Reference OMs								
	LRP 2GT	USR 2GT	FMSY 2GT	C ST	C 2GT	IAV 2GT	B/B0 2GT	B/BMSY 2GT	MA 2GT
NoFishing	1.00	1.00	1.00	0.00	0.00	0.02	0.90	3.09	34.01
IDX_smooth	1.00	1.00	1.00	78.21	79.53	0.03	0.56	1.90	30.06
Iratio_23	1.00	1.00	0.99	78.89	106.53	0.08	0.49	1.68	29.61
IDX	1.00	1.00	0.99	78.77	77.09	0.07	0.57	1.94	30.24
Iratio_55	1.00	1.00	0.93	118.28	104.28	0.12	0.45	1.53	28.97
GB_slope_5y_lam1	1.00	1.00	0.96	81.13	118.56	0.03	0.45	1.53	28.93
GB_slope_10y_lam1	1.00	0.99	0.91	87.09	126.16	0.02	0.41	1.40	28.36
GB_slope_5y_lam05	1.00	0.98	0.90	81.36	128.44	0.02	0.41	1.41	28.45
75RecentCatch	1.00	0.98	0.94	94.20	94.17	0.00	0.47	1.61	28.82
GB_slope_10y_lam05	1.00	0.97	0.87	84.32	133.34	0.02	0.39	1.33	28.07
RecentCatch	0.94	0.85	0.69	125.60	113.13	0.01	0.28	0.98	24.54
125RecentCatch	0.81	0.63	0.32	157.00	99.39	0.05	0.12	0.43	18.44

Figure 15. Average performance of all MPs across the OM reference set scenarios, with operating model 1 receiving twice the weight relative to the other two reference OMs. MPs are ordered by decreasing performance metric values from top to bottom starting with the left-most performance metric (LRP 2GT) and using columns from left to right to break any ties. The 125RecentCatch MP does not meet the FMSY 2GT performance criterion. The colour shading reflect the probabilities. This figure excludes the FMSYref reference management procedure.

A guide on how to interpret the trade-off plots is provided in Figure 16, and trade-offs between catch and conservation objectives are shown in Figure 17.

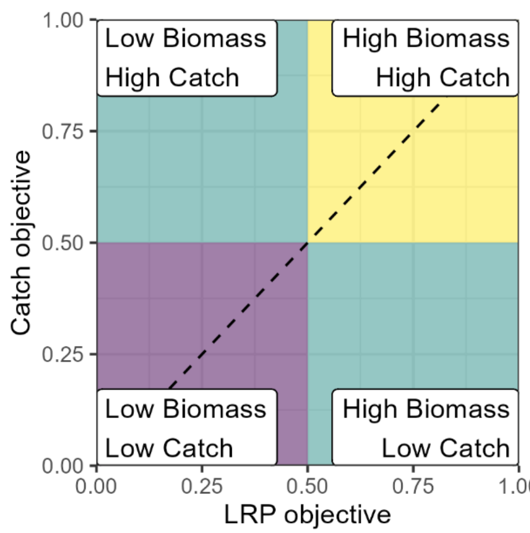

Figure 16. A schematic of a trade-off plot between the LRP objective (x-axis) and a catch objective (y-axis). It is desirable to find management procedures in the upper right corner of the figure, which have high probability of achieving both LRP and catch objectives. Management procedures that have low probability of achieving either objective are in the lower left corner and may not meet satisficing 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.

Among the set of satisficed MPs, there is no apparent trade-off between risk probability with respect to the LRP and USR and long-term catches (panels a-b of Figure 17). The MPs varied in the levels of long term catch, but all maintained a high to very high LRP and USR probability during the projections. From these panels, the best MPs are those that achieved the highest long-term catch (pending other trade-offs in catch variability, short-term catch, and long-term biomass). The RecentCatch MP (#2 in Figure 17) was not "efficient" because lower catch and lower risk probability were obtained relative to other MPs, i.e., the GB_slope MPs are superior in terms of both catch and risk probability (#4-7 in Figure 17).

The trade-off between long-term catches occurs ultimately with relative biomass levels after two generations, in terms of either B/B_{MSY} or B/B_0 (panels e-f of Figure 17). Broadly speaking, higher catches were achieved with a lower biomass among the set of MPs, and vice versa. Again, RecentCatch MP was not "efficient" because higher catches and higher biomass were achieved with the GB_slope family of MPs during the projections. With respect to long-term catch and long-term biomass, GB_slope MPs are preferable over the RecentCatch MP.

The trade-off with regards to short-term and long-term catch, i.e., after 2 generations, appears to be a choice between higher short-term catch in the RecentCatch and Iratio_55 MPs (right of the dotted one-to-one line in panel c of Figure 17) or higher long-term catch with the GB_slope family and Iratio_23 MPs (left of the dotted one-to-one line).Among the index-based MPs, catch variability over time was higher in the Iratio and IDX family of MPs compared to the GB_slope and IDX_smooth MPs (panel d of Figure 17). With respect to short-term catch, all index-based MPs appeared to produce relatively similar short-term catch, with the exception of higher short-term catch with Iratio_55.

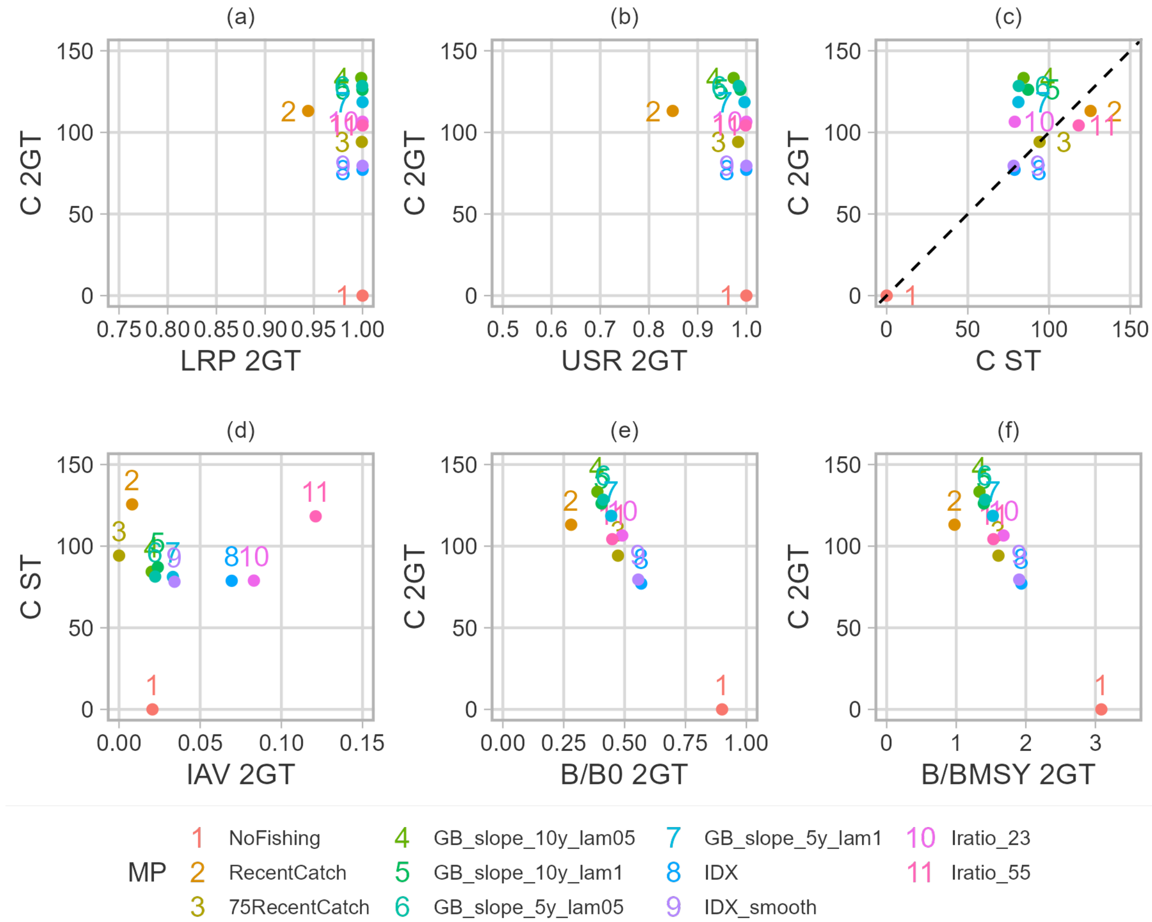

Figure 17. Trade-off plots (panels a-f) between various pairs of performance metrics (colored points with number legend) among the set of candidate management procedures that met the satisficing criteria. Values are averaged across the reference set of operating models. A trade-off (good performance of metric at the cost of another) in the management procedure set occurs when points are aligned along the top left to lower right corner of the panel, for example in panels (e) and (f). No trade-off occurs when management procedures are aligned from the bottom left to top right. The FMSYref reference management procedure is excluded here.

Stock Status

For Outside Quillback Rockfish, we identified three operating models for the reference set that differ in the natural mortality rate, and value of recreational catch. 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 and two values of total recreational catch assumed.

Averaging the resulting probabilities across the three reference OMs (giving OM (1) twice the weight as per Technical Working Group recommendations) equals a 99% probability that the stock in 2021 is above both the LRP and USR.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Metric A measures the decline across a three generation time span. Across the three reference OMs and robustness OM (A), we found a 98+% probability that the stock has declined by 30%, and less than a 1% probability the stock has declined by 70% (Figure 18). We found a 62% probability that the stock has declined by 50%, but only for OM (2), which assumes a lower value of natural mortality. For the three other OMs, there was only a 1% probability that the stock has declined by 50%.

	P70	P50	P30
(1) M = 0.056	<0.01	0.01	0.99
(2) M = 0.046	<0.01	0.62	>0.99
(3) Low IRec	<0.01	<0.01	0.98
(A) Low steepness	<0.01	0.01	0.98

Figure 18. Results for COSEWIC metric A, the probability that the spawning stock biomass in 2021 was below 70%, 50%, and 30% of B_{1941} (over three generations) for each operating model scenario. One generation is defined to be 27 years.

Sources of Uncertainty

Environmental Considerations

We have considered the uncertain effects of environmental conditions by constructing OMs that vary in natural mortality, recreational catch and by including an OM with a lower steepness [OM (A)] and 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 the effects of environmental conditions on stock productivity by evaluating MPs across OMs with a low recruitment scenario and OMs with varying rates of natural mortality-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 (Yamanaka and Logan 2010). Of the current 162 RCAs, there are 36 that occur in the outer waters that encompass over 3,000 square kilometers. Within those 3,000+ square kilometers, approximately 970 square kilometers are suitable rockfish habitat (Dunham et al. 2020). In total, about 14% of rockfish habitat in the outside waters is in an RCA. Additional habitat occurs in other protected areas and is not included in these numbers. In several studies (Haggarty et al. 2016, 2017; Frid et al. 2018), including remotely operated vehicle (ROV) and SCUBA surveys, results have been mixed whether or not RCAs support higher rockfish densities and older and larger age and size classes.

The RCAs have now been in place for 17 to 19 years, so we might expect to find more significant reserve effects such as increased densities and sizes of rockfish in RCAs in the near future. The extent that rockfish in RCAs can function as an unexploited source of recruitment to fisheries, however, has not yet been determined.

Catch

The other major source of uncertainty in our analyses is the magnitude of historical catch from all sectors, as well as the lack of a fishery-independent survey before and during the period of highest exploitation observed through the 1980s and early 1990s.

Uncertainty regarding commercial catch is due to 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 rockfish species 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 have not been collected from the commercial fishery since 2010. 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 (Haggarty et al. 2022b) and Inside Quillback Rockfish MP Framework application (DFO 2023), FSC catch is not explicitly included and remains uncertain for the Outside Quillback Rockfish. Some FSC catch, however, is part of the commercial catch because some Quillback Rockfish are 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.

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. Prioritizing collaborations will help DFO build mutually beneficial relationships that can help resolve uncertainties in FSC catch information. Ongoing work to develop and manage a database of existing data will also help.

CONCLUSIONS AND ADVICE

With the MP Framework, the acceptable risk of breaching reference points is established at the beginning of the process (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 emphasizes identification of status relative to the LRP and USR, following the PA Policy, as status also determines policy objectives going forward (DFO 2009).

Stock status was estimated by averaging the probabilities that the 2021 spawning biomass was above the LRP of 0.4 B_{MSY} and the USR of 0.8 B_{MSY} for the three reference OMs, which differ in the value of natural mortality, and the amount of recreational catch. OM (1) was given twice the weighting when averaging the probabilities to estimate stock status. The Outside Quillback Rockfish stock is estimated to be above both the LRP and USR with an average probability of 99%. There is also a 99% average probability that the 2021 spawning biomass is above 0.4 B_0.

A suite of management procedures were evaluated in their ability to achieve management objectives across five operating models. Trade-offs were observed in long-term catch and long-term ratios of biomass to B_{MSY} and B_0.

Amongst the satisficed MPs, fixed catch MPs provide more predictability, but require more oversight and diligence to ensure that fishing mortality does not increase rapidly and result in higher proportional catches than is anticipated. Index-based MPs are more responsive to changes in the index. The trade-off plots also provide information on how certain MPs may want to be eliminated from consideration. Within a plot, dominated MPs occur inside the arc of MPs that define the trade-off frontier. These dominated MPs would generally be less desirable, as a gain in one performance measure can be obtained without a corresponding trade-off in the other. For example, in panel F of Figure 17, the same catch (or even slightly more catch) that is generated with MP #2 can also be obtained in other MPs that achieve a higher conservation objective. If a subset of MPs are found to perform similarly across the set of reference OMs, their performance in the robustness OMs can be used to help managers evaluate which MPs may be more desirable than others.

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 from the survey, are proposed 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 (Figure 17). Informal procedures that use multiple lines of evidence are often preferable to a formal, predefined criterion for determining exceptional circumstances. Informal procedures allow for different types of information to be considered that may be difficult to operationalize within a formal protocol. For Outside Quillback Rockfish, the GF Synopsis report can be used as a reference for identifying exceptional circumstances (e.g., DFO 2022). The index presented in the GF Synopsis report will likely be updated every year, and can be visually inspected for any unexpected changes. Biological information, such as length frequencies and age bubble plots, as well as length-weight relationship and growth plots, are also presented in GF Synopsis, providing complementary information to the biomass trends shown in the index. The informal procedures approach also ensures that information such as fisher observations (if applicable) can be included in discussions regarding exceptional circumstances.

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SOURCES OF INFORMATION

This Science Advisory Report is from the May 29-30, 2023 regional peer review on the Application of the Management Procedure Framework for Outside 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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