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EVALUATION OF MANAGEMENT PROCEDURES FOR THE INSIDE POPULATION OF YELLOWEYE ROCKFISH REBUILDING PLAN IN BRITISH COLUMBIA



Yelloweye Rockfish, *Sebastes ruberrimus* (DFO ROV team, 2011).

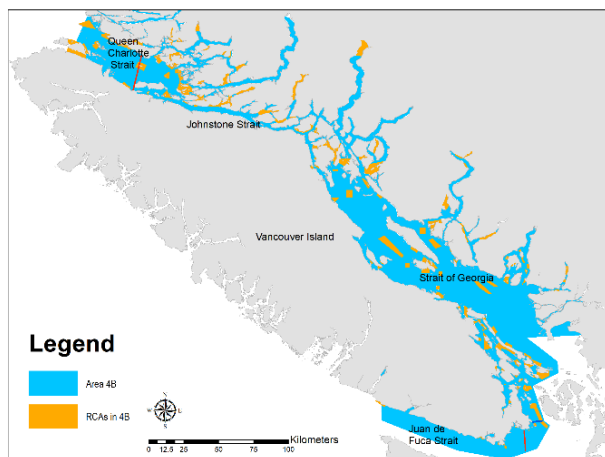


Figure 1. Map of Groundfish Management Area 4B showing Rockfish Conservation Areas (RCAs) and the presumed extent of the Inside Yelloweye Rockfish population (area bounded by red lines).

Context:

Under Canadian policy and legislation, fish stocks that have been assessed as being below the Limit Reference Point (LRP) require a rebuilding plan to grow the stock above the LRP. Rebuilding plans should be based upon objectives characterized by: (1) a target; (2) a desired time to reach the target; and (3) an acceptable probability of reaching the target. Rebuilding plans should also include planned management measures or management procedures (MPs), milestone objectives, and undergo regular evaluation. The inside stock of Yelloweye Rockfish (*Sebastes ruberrimus*, Inside Yelloweye Rockfish) is a data-limited stock, occurring in Groundfish Management Area 4B (Queen Charlotte Strait, Strait of Georgia, and Strait of Juan de Fuca) in British Columbia (BC) (Figure 1). The stock was assessed as being below the LRP in 2010, resulting in a published rebuilding plan. It is also listed under the Species at Risk Act (SARA) as a Species of Special Concern. The current MP for rebuilding is a fixed annual total allowable catch (TAC) of 15 metric tonnes, which has not been re-evaluated since the last assessment. Fisheries and Oceans Canada (DFO) Fisheries Management Branch has requested that Science Branch develop advice to inform a rebuilding plan consistent with the DFO (2013) guidance document. This project applies the Management Procedure Framework (peer reviewed June 8-9, 2020), which emphasizes selecting MPs that have a high likelihood of meeting objectives across multiple plausible states of nature, to evaluate rebuilding of the Inside Yelloweye Rockfish stock.

This Science Advisory Report is from the June 10-11, 2020 regional peer review on the Evaluation of Management Procedures for the Inside Population of Yelloweye Rockfish Rebuilding Plan. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada \(DFO\) Science Advisory Schedule](#) as they become available.

SUMMARY

- The inside stock of Yelloweye Rockfish (*Sebastes ruberrimus*, Inside Yelloweye Rockfish) is a data-limited stock, occurring in Groundfish Management Area 4B (Queen Charlotte Strait, Strait of Georgia, and Strait of Juan de Fuca) in British Columbia (BC).
- The stock was assessed as being below the Limit Reference Point (LRP) in 2010, resulting in a published rebuilding plan.
- This assessment provides scientific advice through application of a new management strategy evaluation framework recently developed for BC groundfishes (the Management Procedure [MP] Framework) (Anderson et al. 2021). The MP Framework evaluates the performance of alternative data-limited MPs to support re-evaluation of the current rebuilding plan for Inside Yelloweye Rockfish.
- The MP Framework was used to evaluate the ability of 34 data-limited MPs to meet the proposed principal objective of rebuilding the stock above the LRP ($0.4 B_{MSY}$) over 1.5 generations (56 yrs) with at least a 95% (19 times out of 20) probability of success.
- Performance of MPs was also evaluated for two additional conservation metrics based on $LRP=0.4B_{MSY}$ and Upper Stock Reference ($USR=0.8B_{MSY}$), three average-catch objectives, and one catch-variability objective.
- Natural mortality, selectivity, and historical catch were identified as major sources of uncertainty. Uncertainty in these parameters was accounted for by evaluating performance of the MPs across six alternative Operating Models (OM) scenarios based on different model and data assumptions. Four OMs, representing the most important and plausible uncertainties, were allocated to a “reference set”; two OMs, representing a broader range of uncertainties, were allocated to a “robustness set”.
- None of the reference set OMs estimated the median stock biomass to be below the LRP in 2019. Differences in estimates of Inside Yelloweye Rockfish stock status between the current OMs and previous assessment were attributable to model structure choices.
- Closed-loop simulation screened out MPs that did not meet basic performance criteria, resulting in five remaining candidate MPs: two annual constant-catch MPs (10 and 15 tonnes), and three MPs that adjust the total allowable catch (TAC) based on a survey index of abundance. All five final MPs met the principle performance metric with greater than 0.98 probability (49 times out of 50), across all four OM reference set scenarios.
- The constant catch policy MPs resulted in a greater short-term fishery yield and higher catch stability than the index-based MPs. Index-based MPs resulted in greater long-term yield.
- MP performance was most challenged under the lower productivity robustness scenario (Low M), where none of the five MPs were able to achieve the principle performance metric. The highest-ranking MP for this scenario (a constant catch of 10 tonnes) resulted in a 90% probability of rebuilding the stock to above the LRP over 1.5 generations.
- Based on performance relative to the objectives, the rank order of the five candidate MPs was consistent among reference set scenarios with the highest ranking MP consistently being the constant annual catch of 10 t. This was also the highest ranking MP for both robustness set scenarios.
- Major uncertainties associated with assessing stock status for Inside Yelloweye Rockfish highlight the importance of using an MP framework for decision-making.

- For the five final candidate MPs, the catch advice from the index-based MPs should be updated annually. Prospective performance of all MPs should be re-evaluated at least every three years.
- Establishing formal “exceptional circumstance” detection protocols to trigger earlier reevaluation of performance of the chosen MP is recommended.
- The flexibility of the MP Framework to inform different information needs was demonstrated using results structured to allow evaluation of two additional assessment criteria for the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).
- This was the first implementation of the MP Framework for decision making. Future collaborative work is recommended to identify further management objectives for Inside Yelloweye Rockfish.

INTRODUCTION

The purpose of this peer review is to provide scientific advice to support revision of the rebuilding plan for the inside stock of Yelloweye Rockfish (*Sebastes ruberrimus*) (DFO 2018), consistent with national policy guidance (DFO 2009, 2013). The project applies a closed-loop simulation framework (Anderson et al. 2021) to evaluate the performance of alternative management procedures (MPs) with respect to meeting rebuilding objectives for the inside stock of Yelloweye Rockfish (hereafter Inside Yelloweye Rockfish). This project provides scientific advice through application of a new management strategy evaluation (MSE) framework recently developed for BC groundfishes, called the Management Procedure (MP) Framework, (Anderson et al. 2021).

The MP Framework differs from conventional stock assessments in the way science advice is delivered. In most BC groundfish stock assessments, catch advice is presented in the form of decision tables, where probabilities of breaching reference points (e.g., probability of the stock falling below the Limit reference Point [LRP]) are presented over a range of possible future total allowable catch (TAC) levels. This approach places consideration of risk at the final step of the decision-making process and may not always be transparent or related to pre-agreed objectives. MP frameworks differ from conventional assessments in two key ways: (1) reference points and stock status are not necessarily explicitly reported; and (2) 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 therefore still an integral component of the framework, but they are calculated in the Operating Models (OMs) and are built into the performance metrics. Critically, agreement on acceptable risk (e.g., acceptable probabilities of breaching reference points) must be reached at the beginning of the process so that performance metrics and satisficing (screening) criteria can be established. Frameworks such as these are particularly important for data-limited stocks.

Yelloweye Rockfish are a long-lived species (up to 121 years in B.C., Keppel and Olsen 2019), occurring in rocky benthic habitats that have a patchy, discontinuous distribution along BC's inner coast (Yamanaka et al. 2011). These life history traits make the species vulnerable to overexploitation by fisheries. The inside stock is considered to be data-limited, as there is sparse availability of age-composition data; a lack of biological data from commercial, recreational, and First Nations' fisheries; and uncertainty in the magnitude of historical catches.

Inside Yelloweye Rockfish occur in Groundfish Management Area 4B in British Columbia (BC) (Figure 1). Note that Management Area 4B is larger than the extent of the genetic population and designatable unit used by COSEWIC (Figure 1). The stock is expected to be designated as

a major fish stock in the fall of 2020, at which time its management will be legislated under the Fish Stocks provisions of the *Fisheries Act*. The stock was assessed as being below the LRP in 2010 (Yamanaka et al. 2011; DFO 2012). In response, a rebuilding plan was developed and published in Appendix 9 of the Pacific Region Integrated Fishery Management Plan (IFMP) for Groundfish (DFO 2018). Inside Yelloweye are also listed under the Species at Risk Act (SARA) as a Species of Special Concern (COSEWIC 2008), and anticipated to be reassessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2020. Results from this project may inform the COSEWIC reassessment and a revised SARA management plan, should one be required.

The current rebuilding plan objective is to “rebuild the stock above the LRP over 80 years with 56% probability of success.” The milestone objective is to “achieve positive trends within each 10-year period.” The current MP for Inside Yelloweye Rockfish aims to keep the total annual catch (commercial, recreational, First Nations food, social and ceremonial [FSC], and survey) below 15 tonnes (see Appendix 9 of DFO [2018] for details). The guidance for rebuilding plans in Canada states that there should be a high probability of rebuilding fish stocks out of the critical zone within the stated time-frame (DFO 2013). Part of the motivation for this project was concern, expressed by fisheries managers, that the 56% probability of success stated in the current rebuilding plan (DFO 2018) is inconsistent with the definition of high probability. The current rebuilding plan implements an annual fixed TAC of 15 metric tonnes (DFO 2018), which has not been simulation-tested.

The guidance document also identifies some recommended management measures, which include: keeping removals from all sources to the lowest possible level; development of a harvest control rule (HCR); and application of management strategy evaluation (MSE) to evaluate, via simulation, the performance of alternative management measures with respect to meeting rebuilding objectives for the stock (DFO 2013).

Objectives and Milestones

We present a set of refined conservation and catch objectives and associated performance metrics for the rebuilding plan for Inside Yelloweye Rockfish. Key provisional conservation objectives are guided by the PA Framework (DFO 2006, 2009), the rebuilding plan guidance document (DFO 2013), and regional precedents (DFO 2020).

The proposed core conservation objective is:

1. Rebuild the stock above the LRP over 56 years (1.5 generations) with at least 95% [19 times out of 20] probability of success.

We also propose the following additional objectives:

2. Rebuild the stock above the USR over 56 years (1.5 generations).
3. Rebuild the stock above the LRP over 38 years (1 generation).
4. Given the above conservation objectives are achieved, maintain an average target catch in the short and long term.
5. Given the above conservation objectives are achieved, minimize variability in fisheries catch from year to year.

In addition to the above objectives, we propose refining the milestones identified in the original rebuilding plan (DFO 2018) with the italicized text as follows:

6. Achieve positive biomass trends within each 10 year period *for as long as the stock remains below the LRP*.

ANALYSIS

Closed Loop Simulation

The Management Procedure (MP) Framework evaluates the performance of alternative data-limited MPs to support re-evaluation of the current rebuilding plan for Inside Yelloweye Rockfish. The MP Framework follows six best-practice steps for MSE: (1) defining the decision context; (2) setting objectives and performance metrics; (3) specifying operating models (OMs) to represent the underlying system and calculate performance metrics; (4) selecting candidate MPs; (5) conducting closed-loop simulations to evaluate performance of the MPs; and (6) presenting results to facilitate evaluation of trade-offs (Figure 2).

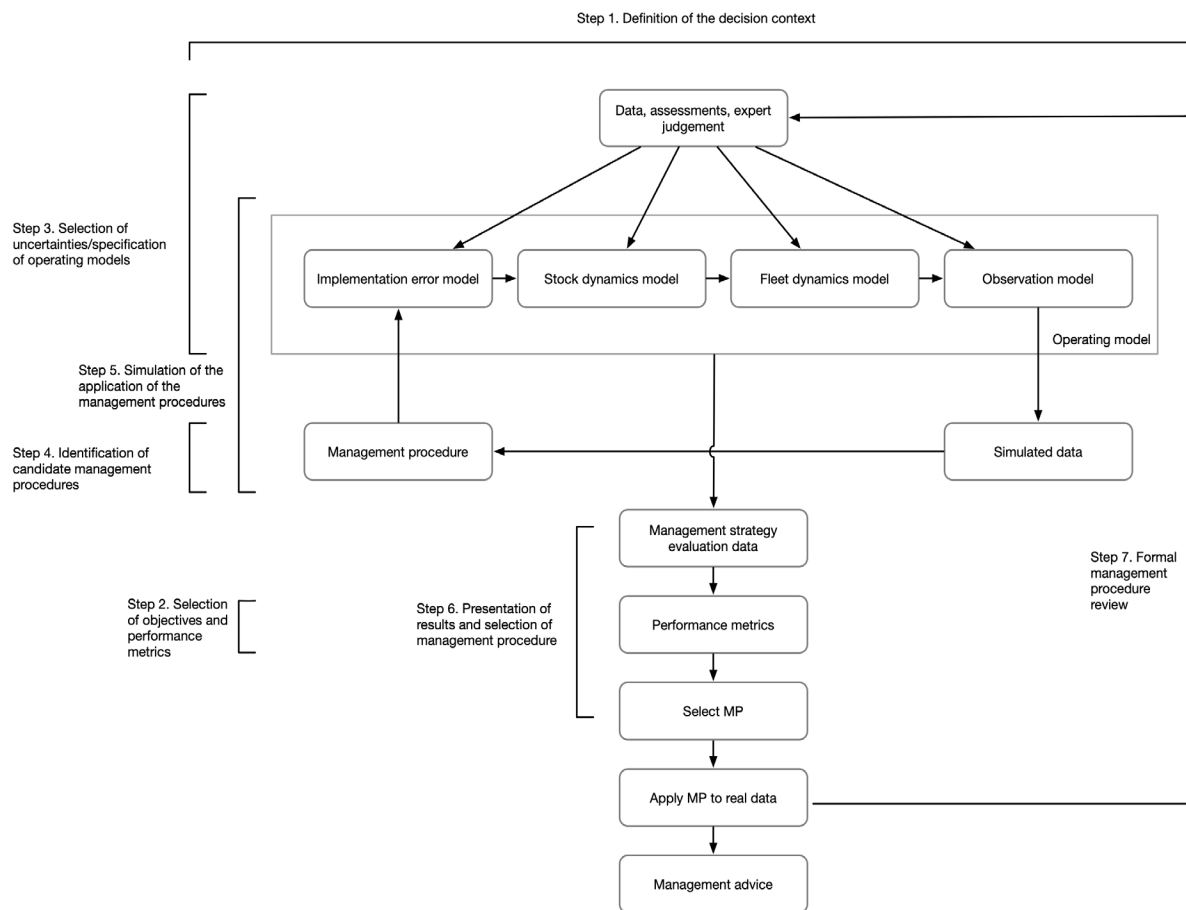


Figure 2. The steps of the MSE process following Punt et al. (2016) as implemented in DLMtool. Copied from Anderson et al. (2020) and adapted from Carruthers and Hordyk (2018a).

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 (Step 7) is to periodically monitor and evaluate the performance of the MP (DFO 2013; Dowling et al. 2015; Carruthers and Hordyk 2018a). This may be done through informal means, e.g., via feedback from fishers and survey information (e.g., Cox and Kronlund 2008), 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 (Butterworth 2008; Carruthers and Hordyk 2018b; discussed in Anderson et al. 2020).

Performance Metrics

Performance metrics allow us to quantitatively assess the ability of different MPs to meet the specified conservation and fishery objectives. In the closed-loop simulations, all reference points and performance metrics are calculated in the OM. Raw performance metrics are calculated in each of the 100 years of the projection period and summarized according to the time-frame of interest. GT represents generation time, ST and LT refer to short- and long-term respectively, and AADC stands for average absolute deviation in catch over some period of time:

- **LRP 1.5GT:** $P(B > 0.4 \text{ BMSY})$ after 1.5 GT (in 2075, year 56 of the projection period)
- **USR 1.5GT:** $P(B > 0.8 \text{ BMSY})$ after 1.5 GT (in 2075, year 56 of the projection period)
- **LRP 1GT:** $P(B > 0.4 \text{ BMSY})$ after 1 GT (in 2057, year 38 of the projection period)
- **ST C10:** $P(\text{average catch} > 10 \text{ t})$ during 2020–2029, years 1–10 of the projection period
- **ST C15:** $P(\text{average catch} > 15 \text{ t})$ during 2020–2029, years 1–10 of the projection period
- **LT C20:** $P(\text{average catch} > 20 \text{ t})$ after 1 GT (in 2057, year 38 of the projection period)
- **ST AADC:** $P(\text{AADC}_{2020-2029} < \text{AADC}_{2012-2019})$

Performance statistics were calculated across replicates and years for the entire defined time window. For example, short-term catch metrics were averaged over replicates and the years 2020–2029.

Operating Models

Two open-source software packages for MSE were used for this analysis: the Data Limited Methods toolkit (DLMtool) (Carruthers and Hordyk 2018a, 2018b) and the Management Strategy Evaluation toolkit (MSEtool) (Huynh et al. 2019). DLMtool OMs have four main components representing the real fished system: population dynamics, fishery dynamics, observation processes, and management implementation. To isolate the effects of specific sources of uncertainty on performance of MPs, we developed alternative OMs that change the value (or distribution) of one or more parameters and/or data sources of interest. OMs are calibrated or conditioned with observed data, so they can reproduce historical observations. The OMs are developed using stock reduction analysis (SRA) (Kimura and Tagart 1982; Walters et al. 2006), which is effectively a statistical catch-at-age model that estimates the combinations of historical fishing mortality and recruitment that would be consistent with the observed data. MSE best practice recommends dividing MSE trials into 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 (Rademeyer et al. 2007).

For Inside Yelloweye Rockfish, we established four reference set OMs: (1) a baseline OM; (2) an OM reflecting an alternative assumption about the magnitude of historical catch during the period 1986–2005; (3) an OM allowing for episodic (rare but large) future recruitment events; and (4) an OM estimating selectivity in the Inside Hard Bottom Longline Survey (HBLL) survey (Table 1). We further established two robustness set OMs: (A) an OM that assumes lower

natural mortality than the other OMs; and (B) an OM that assumes a higher coefficient of variation (CV) in the future HBLL survey (Table 1).

Table 1: Inside Yelloweye Rockfish OM scenarios.

OM Scenario name	Set type
(1) Base	Reference
(2) Low catch	Reference
(3) Episodic recruitment	Reference
(4) Estimate HBLL selectivity	Reference
(A) Low M	Robustness
(B) High HBLL CV	Robustness

For all OM scenarios, except scenario (A), the median spawning biomass in 2019 was estimated to be above the LRP (Figure 3). OM Scenario (A) estimated median spawning biomass to have been below the LRP for most years after 2000 and less than 50% probability of being above the LRP in 2019. OM Scenario (2) and OM Scenario (4) also had a small probability of being below the LRP in the current year. Therefore, according to all the reference set OM scenarios and one robustness set OM scenario, the stock can already be considered to have rebuilt above the LRP. The median spawning biomass is estimated to be above the USR in OM Scenarios (1), (2), (3), and (B); and estimated to be below the USR in OM Scenarios (4) and (A). OM fits to the surveys and three commercial CPUE series are shown in Figure A.1.

	LRP	USR
(1) Base	0.98	0.71
(2) Low catch	0.93	0.61
(3) Episodic recruitment	0.98	0.71
(4) Estimate HBLL selectivity	0.93	0.37
(A) Low M	0.44	0.04
(B) High HBLL CV	0.98	0.71

Figure 3. Probability that the 2019 spawning biomass is above the LRP and USR for the six operating models. The colour shading reflects the underlying numbers and is included to make the differences in the values more readily apparent, yellow (high probability) to purple (low probability).

Management Procedures

Anderson et al. (2021) evaluated all MPs that were available in DLMtool as of November 2019. DLMtool includes a comprehensive set of data-limited MPs that make different types of management recommendations, including adjustments to TAC, effort, or spatial allocation of catch or effort. The MP Framework only considers MPs that make TAC recommendations,

because most groundfish stocks are managed by quotas and TACs. Thirty-four data-limited MPs were evaluated to see if they would meet the Inside Yelloweye Rockfish objectives.

Two main types of MPs were evaluated: empirical (data-based) and model-based MPs. Three reference MPs were also evaluated. The empirical MPs included constant catch and index-based MPs. Constant-catch MPs set the recommended catch to a fixed level, of 5t, 10t, and 15t (the current MP used for Inside Yelloweye Rockfish). Index-based MPs adjust the TAC based on changes in a population index over time, increasing or decreasing the TAC in accordance with some variable associated with an index (e.g., with the estimated slope in the index over a recent period of time). The time intervals for updates used were annual or five-year. The model-based MPs used a surplus production model, paired with two alternative harvest control rules (HCRs): 80% B_{MSY} and 40% B_{MSY} as the USR and LRP, respectively; and 40% B_0 and 10% B_0 as the USR and LRP, respectively.

Closed-loop simulations were run for 250 stochastic replicates with a projection period of 100 years. 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 (Miller and Shelton 2010; see Anderson et al. 2021). We set the initial satisficing criteria of LRP 1.5GT > 0.9 and assessed average and minimum performance across all candidate MPs for the reference set of OMs. All MPs met the satisficing criterion, both in individual OM reference set scenarios and averaged across all four reference OMs. Since many MPs also generated low catches, we applied an additional satisficing filter, retaining only MPs where average ST C10 > 0.50 (where the probability of average catch greater than 10 t during 2020-2029 was greater than 0.50). Applying the two criteria resulted in only five satisficed MPs. Two constant catch MPs of 10 and 15 t (CC_10t and CC-15t) and three index-slope MPs (Islope_10_lambda04, Islope_10_lambda08, and Islope_5_lambda04). These index-slope MPs vary in how the TAC advice changes relative to the magnitude of the slope in the index. Performance with the reference set of OMs differed across satisficed MPs and performance metrics (Figures 4 and 5). The index-slope MPs achieved between 0.59 and 0.88 for ST C10. Within the reference set there was virtually no trade-off between LRP 1.5GT and ST C10, since all MPs were able to achieve LRP 1.5 GT > 0.99. There is also a trade-off between short-term and long-term catches. Notably, ST C10 is lowest and LT C20 is highest for the Islope_10_lambda08 MP in all OMs. All other MPs generate higher ST C10 but lower LT C20. All MPs achieved continuous growth throughout the projection period, albeit at different rates.

OM Scenario (A), low natural mortality, reduced the probability of achieving the LRP 1.5GT performance metric to a range of 0.75-0.90, compared to > 0.99 across the reference set (Figure 4). OM Scenario (A) demonstrated a trade-off between ST C10 and LRP 2GT (Figure 6). Across MPs, catches would have to be lower in OM Scenario (A) than in the reference set OMs to achieve similar conservation outcomes. By comparing the projections across OM scenarios on the same figure, it is clear that F/F_{MSY} , B/B_{MSY} , and catch were most sensitive to the OM Scenario (A) assumptions (Figure 7). Note that the rank order of MPs, which is likely more important in a decision context, differed under OM Scenario (A) compared to the OM reference set scenarios.

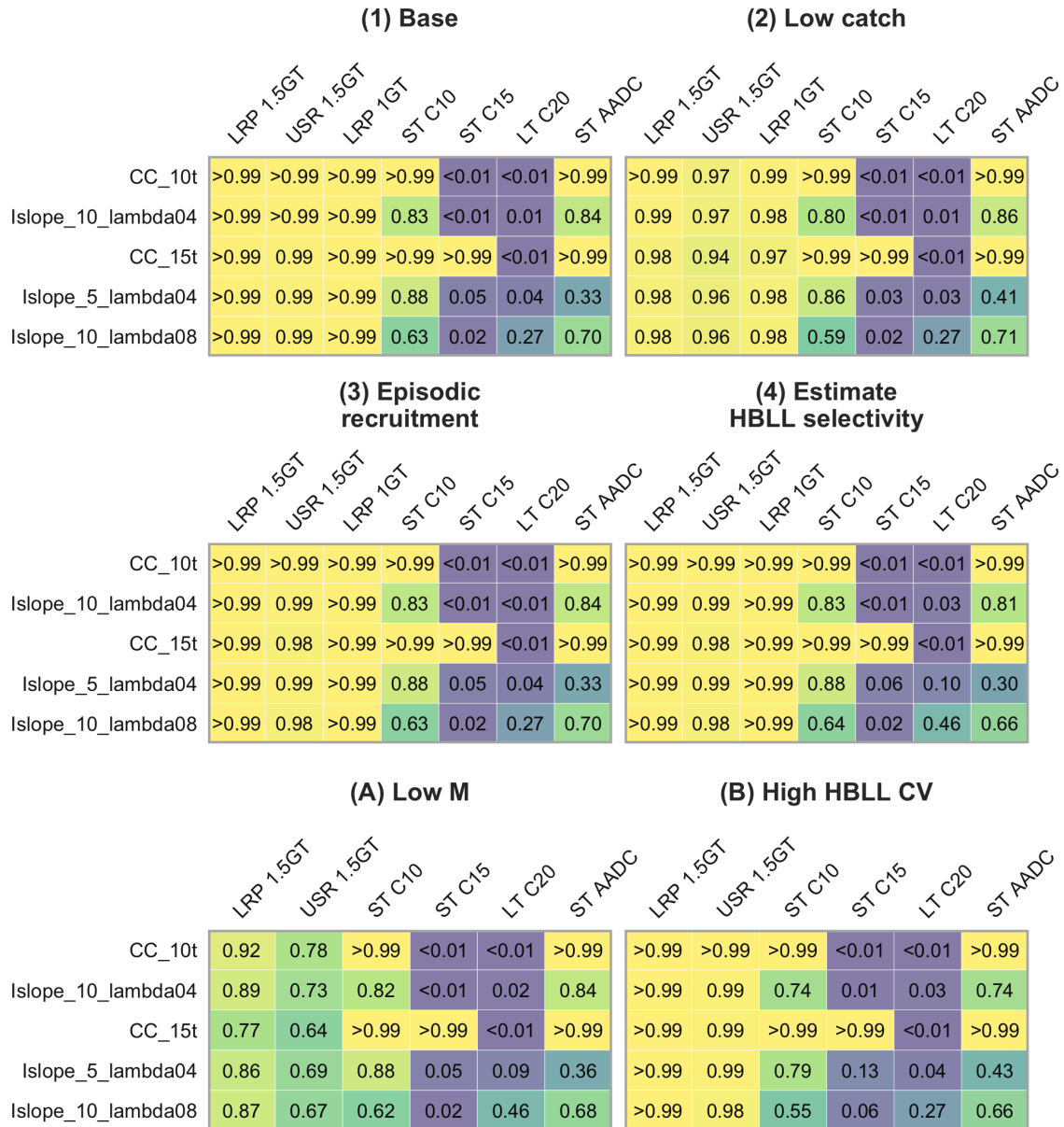


Figure 4. Performance of satisfied MPs for the OM reference (1-4) and robustness (A, B) set scenarios. MPs are ordered by decreasing performance metric values from the averaged reference set. The colour shading reflects the underlying numbers and is included to make the differences in the values more readily apparent, yellow (high probability) to purple (low probability).

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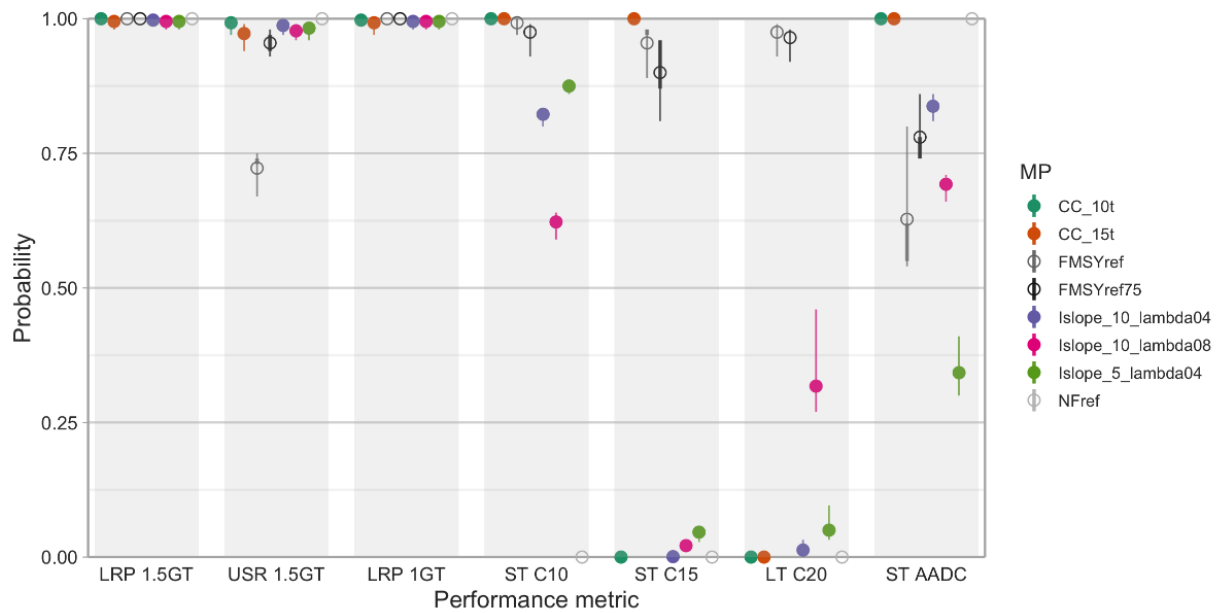


Figure 5. Dot-and-line plot of performance metrics across OM scenarios. Dots represent average performance metric values and thin lines represent the range of values across OM scenarios. Thick lines represent the range of values across OM scenarios after dropping the high and low values. Reference MPs are indicated by open circles. Non-reference MPs are indicated by closed circles.

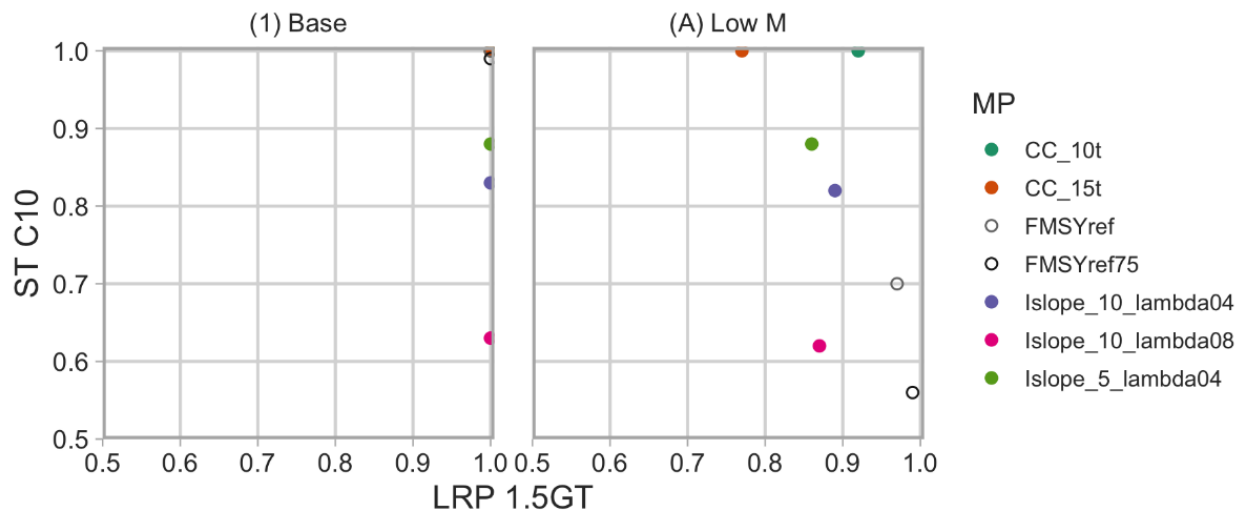


Figure 6. Trade-off plot between LRP 1.5GT and ST C10 performance metric values for satisfied MPs for the reference set OM 1 (Base) and robustness set OM A (Low M). The trade-off plots for OMs not shown are similar to OM 1. Reference MPs are indicated by open circles. Non-reference MPs are indicated by closed circles.

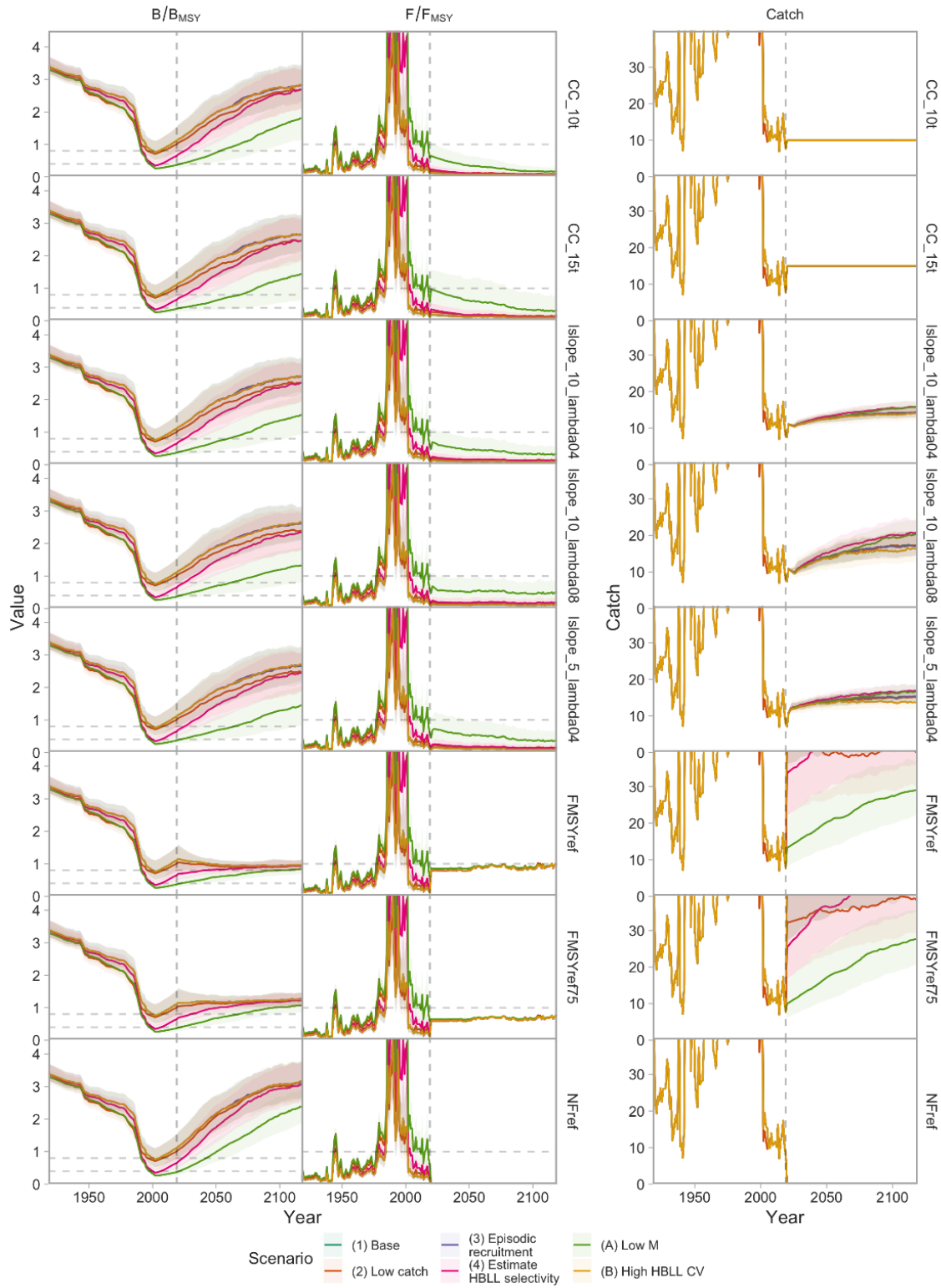


Figure 7. B/B_{MSY} , F/F_{MSY} , and catch from the historical and projected time periods (B =Biomass, F =Fishing Pressure, MSY =at Maximum Sustainable Yield). The LRP and USR are shown with dashed lines.

COSEWIC Considerations

COSEWIC and DFO have different criteria for assessing the status of marine fish stocks. DFO focuses on current status relative to some reference state or threshold, while COSEWIC criteria are focused on the decline over past generations and the probability of continued declines in the future (COSEWIC 2015). COSEWIC applies a set of quantitative assessment criteria and guidelines to develop and assign a status to the stock in question. To inform the reassessment of Inside Yelloweye Rockfish, we report results for two of COSEWIC's quantitative assessment criteria that may be applicable to this stock, Metric A and Metric E.

COSEWIC Metric A

COSEWIC's Metric A measures the probability that the stock has declined by 70%, 50%, or 30% after three generations, where one generation for Inside Yelloweye Rockfish is defined as 38 years. Note that three generations under this definition is 114 years but since our historical period (1918-2019) is 102 years, we use this as an approximation of three generations. These decline thresholds are used to assign status designations of endangered, threatened, and species of special concern, respectively, although other factors, such as cause of decline, are also considered (COSEWIC 2015). To inform the COSEWIC re-assessment of Inside Yelloweye Rockfish, we report the following for each OM (Figure 8):

- P70 - Probability that, on average, the stock declined more than 70% of B_{1918} over three generations, where generation time is 38 years and probability is calculated as $P[1 - B_{2019}/B_{1918} > 0.7]$.
- P50 - Probability that, on average, the stock declined more than 50% of B_{1918} over three generations.
- P30 - Probability that, on average, the stock declined more than 30% of B_{1918} over three generations.

	P70	P50	P30
(1) Base	0.43	0.87	0.98
(2) Low catch	0.53	0.86	0.97
(3) Episodic recruitment	0.43	0.87	0.98
(4) Estimate HBLL selectivity	0.82	0.94	0.99
(A) Low M	0.99	>0.99	>0.99
(B) High HBLL CV	0.43	0.87	0.98

Figure 8. Results for COSEWIC metric A, the probability that the stock on average declined more than 70%, 50%, and 30% of B_{1918} over the past three generations, for each OM scenario, where one generation is defined as 38 years. The colour shading reflects the underlying numbers and is included to make the differences in the values more readily apparent, purple (high probability) to yellow (low probability).

Extinction Risk - COSEWIC Metric E

COSEWIC Metric E measures the probability of future extinction of the stock. A stock is designated as endangered if the probability of extinction is 20% within 20 years (or five generations, whichever is longer) and threatened if there is a 10% probability of extinction within 10 years. Criteria E is seldom applied to marine fishes, due to heavy reliance on data and assumptions about parameters required as inputs to population viability analyses (Ross Claytor, COSEWIC, pers. com., January 29, 2020).

In order to evaluate the probability of future extinction under candidate MPs, stock-specific extinction thresholds must be assigned. Two candidate extinction thresholds of $2\%B_0$ and $5\%B_0$ were examined. These arbitrary thresholds were informed by precedents in the literature (e.g., Forrest et al. 2015 used $5\%B_0$) and historical depletion estimates for other species in the Strait of Georgia, e.g., Lingcod in the Strait of Georgia have been estimated to be depleted to as low as $2\%B_0$ but are recovering (Logan et al. 2005). In the future, simulation-testing of alternative thresholds could be used to identify stock-specific extinction thresholds.

Using a projection period of 100 years, the probability was calculated that, on average throughout the whole 100-year projection period, the stock remains above 2% and 5% B_0 under the five satisfied MPs and the no fishing reference MP for each OM scenario individually. The average probability that the stock remains above each threshold under these MPs across all OM reference set scenarios was also calculated. The two additional performance metrics are:

- $2\%B_0 = P[B_y > 0.02B_0]$ on average during the whole projection period, where B_0 is the initial biomass and B_y refers to the biomass in a given year.
- $5\%B_0 = P[B_y > 0.05B_0]$ on average during the whole projection period

The probability that the Inside Yelloweye Rockfish stock remains above 2% and 5% of B_0 , averaged across reference set OMs, was greater than 0.99, and all OM-MP combinations had at least 0.90 probability of remaining above these thresholds, indicating a low risk of extinction.

Sources of Uncertainty

The MP Framework is specifically designed to identify management procedures that are robust in closed-loop simulations despite uncertainties associated with data, our understanding of the species and its environment, as well as observation, estimation, and implementation error (Anderson et al. 2021). Furthermore, the robustness set OMs explore formulations that represent alternative hypotheses to those in the reference set (Rademeyer et al. 2007; Punt et al. 2016). Candidate MPs should perform well across both OM reference and robustness scenarios. Despite this, major sources of uncertainty associated with Inside Yelloweye Rockfish have been identified.

Two OM robustness set scenarios performed differently from the OM reference set scenarios, especially OM Scenario (A). This low mortality/low productivity scenario ($M \sim \text{Lognormal}(0.025, 0.2)$), based on a lower estimate of M used for Yelloweye Rockfish in Alaska (Wood 2019), was the only one where the median biomass was estimated to be in the critical zone at the start of the projection period. For all other OM scenarios, we sampled from a probability distribution for M with mean 0.045 y^{-1} , which matched that used in the previous stock assessment (Yamanaka et al. 2011). The rate of natural mortality of fish populations is one of the most important, yet most difficult, parameters to estimate.

A major source of uncertainty in our analyses is the magnitude of historical catch. We followed the same approach to reconstructing historical recreational catch data and estimating current

recreational catch data as Yamanaka et al. (2011). We evaluated the effect of doubling the nominal commercial catch for the period 1986–2005 in OM Scenario (2) but performance of the MPs was not appreciably different from other OM reference set scenarios. FSC catches were not explicitly included in this model except for reported FSC catch landed on “Dual Fishing” trips, which were included in the commercial catch. FSC catch from small boats are partially included in the recreational effort estimates from the creel overflights because an FSC fisher cannot be distinguished from a recreational fisher in that case. 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.

Selectivity was another major source of uncertainty in our OMs. There are no available age-composition data for commercial or recreational fisheries, and none from the Dogfish survey, so the selectivity for all these gears was fixed. Selectivity for the commercial and recreational fisheries were set to match those reported for the outside Yelloweye Rockfish stock (Cox et al. 2020). However, it was noted during the Outside Yelloweye Rebuilding process that additional biological sampling is needed to better estimate the selectivity of commercial, recreational, and FSC fisheries (DFO 2020). This recommendation is also made for the inside population. Selectivity for the Dogfish survey was set to mirror the value used for the HBLL survey, despite differences in gear and design between the two surveys. DFO has begun to collect rockfish biological data on the Dogfish survey and to compare it to the HBLL survey in order to reduce this uncertainty in future analyses for Inside Yelloweye.

The 2010 assessment used a surplus production (SP) model, with fundamentally different structural assumptions to the SRA used for conditioning OMs in our analysis. As a check, an SP model was fit, similar to that used by Yamanaka et al. (2011) and obtained much lower biomass and stock status estimates than from the reference set SRA OMs. Furthermore, the estimate of B_{MSY} was higher for the SP model than for OM Scenario (1), while the F_{MSY} estimate from the SP model was lower than those from the reference set SRA models, indicating lower productivity in the SP model. The fact that the SP model had lower estimated productivity and biomass, and higher B_{MSY} lead to a more pessimistic assessment of stock status. The SP-fitting exercise suggests that model structure, rather than the addition of ten years of new data since the last assessment, was a major factor contributing to different perceptions of stock status between the current OMs and the previous assessment. During the regional peer review process, it was noted that the SP model is expected to be a poor choice of model for a long-lived stock that has long lags between recruitment and fishable biomass. In the previous assessment, an SP model was deemed necessary, given the lack of composition data and uncertainty over selectivity. Although selectivity is still very uncertain, some composition data are now available and were incorporated into this analysis.

In a recent evaluation of the outside stock of Yelloweye Rockfish, Cox et al. (2020) found similar differences between their age-structured OMs, which estimated stock status to be above the LRP, and the 2014 SP model-based assessment (Yamanaka et al. 2018), which found the stock to be below the LRP, triggering a rebuilding plan. Cox et al. (2020) noted that structural differences between SP and age-structured models would be expected to produce different results, particularly due to differences in the formulation of productivity. OM Scenario (A), the scenario with lower productivity, mimicked the stock status estimates of Yamanaka et al. (2011), albeit with a lower mean value of M than was used in Yamanaka et al.’s (2011) SP model. Cox et al. (2020) noted that age-structured models allow for lags in recruitment to fisheries, surveys, and the spawning stock, characteristics that can promote resilience and are more realistic for a long-lived species like Yelloweye Rockfish. These differences are controlled by fishery selectivity-at-age, survey selectivity-at-age, and maturity-at-age, respectively, in age-structured

models and can be over-simplified in aggregate SP models. Cox et al. (2020) also noted that their SP-based MPs tended to underestimate biomass, which we also found in the current study (i.e., the SP MPs generated no catch in the first decade of the projections).

During the peer review meeting, additional analysis was requested of the authors to elucidate what was driving the positive stock trajectory in most of the OMs. The authors tried up-weighting, down-weighting, and excluding the 2019 data from the Dogfish survey but the biomass still trended upwards. The conclusion drawn was that the positive biomass trajectory was a result of increased recruitment and decreased catches over the last two decades, and the fact that fish select to the fishery after they are mature, so some spawning can take place before they are caught. OM Scenario (4), where survey selectivity-at-age was estimated, resulted in lower estimates of stock status, implying that assumptions about selectivity were a contributing factor to perceptions of stock status. This most likely results from impacts on other parameter estimates, such as R_0 , and autocorrelation in recruitment.

Despite differences in perception of stock status among some of our OMs, and between this and the previous stock assessment, the MP Framework provides a method for integrating across the major uncertainties in stock status and reference points that are prevalent for this stock. In particular, the inclusion of OM Scenario (A) in the robustness set provides decision-makers with an alternative view of stock status and performance of MPs.

CONCLUSIONS AND ADVICE

We applied a new MP Framework for Pacific groundfishes (Anderson et al. 2021) to evaluate the ability of alternative MPs to meet rebuilding objectives for Inside Yelloweye Rockfish. This is the first application of the MP Framework for decision-making purposes.

For many stocks, especially data-limited stocks like Inside Yelloweye Rockfish, it is not possible to reliably estimate biological reference points or estimate stock status. MP frameworks differ from traditional stock assessments in that reference points and stock status are not necessarily 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, but they are calculated in the OMs and are built into the performance metrics. Evaluation of the OMs used suggests that the differences in estimates of Inside Yelloweye Rockfish stock status between the current and previous assessments may be attributable to model structure choices. However, despite uncertainties in the stock status, MPs that were able to achieve the objectives were still identified.

We evaluated the performance of 31 data-limited MPs (and three reference MPs) with respect to meeting the rebuilding objectives. We screened out MPs that did not meet both the LRP 1.5GT > 0.9 and ST C10 > 0.50 criteria across the OM reference set scenarios, resulting in five remaining MPs. Satisficed MPs in the current analyses included constant catch MPs and annual Islope MPs. These MPs achieved the conservation metrics LRP 1.5 GT, USR 1.5GT and LRP 1GT with greater than 0.98 probability (49 times out of 50) across all four OM reference set scenarios. This was largely because none of the reference set OMs estimated the stock to be in the critical zone in 2020—the start of the projection period. All the index-based MPs were also evaluated at five-year intervals. While all of these MPs met the LRP 1.5GT criteria, none of them met the ST C10 criteria. Therefore, if an index-based MP is selected, we recommend annual updates.

Within the two OM robustness set scenarios, OM Scenario (B), which simulated higher variability in the future HBLL survey, performed similarly to the OM reference set scenarios. However, under OM Scenario (A), the Low M scenario, the probabilities of meeting the

performance metric LRP 1.5GT ranged from 0.75 (75 times out of 100) to 0.9 (nine times out of 10), with the current MP (CC_15t) having the lowest probability in this range.

Whereas the rebuilding plan guidance (DFO 2013) only describes objectives related to rebuilding, we also evaluated performance of MPs with respect to three average-catch objectives and one catch-variability objective. The CC_10t and CC_15t MPs, by definition, met their respective ST C10 and ST C15 performance metrics. The Islope MPs showed some contrast across MPs within the reference set for ST C10 and ST C15, depending on the MP configuration and the OM scenario. The OM robustness set scenarios generally produced lower probabilities of meeting the ST C10 metric.

Generally, there were no significant trade-offs apparent between conservation and catch objectives for the different Management Procedures applied to the reference set OMs. However, there was a trade-off between short-term and long-term catch in all OMs; one MP (Islope_10_lambda08) notably generated lower short-term catch for larger long-term catch. In the Low *M* scenario of the robustness set, none of the MPs could achieve the core conservation objective. In this scenario the closest result was achieved by a 10 tonne constant catch MP but with an unacceptably low likelihood of 90% probability. 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 (Carruthers and Hordyk 2018b). In line with guidance for rebuilding plans in Canada (DFO 2013), we recommend re-evaluation of the performance of the selected MP at least every three years.

OTHER CONSIDERATIONS

Ecosystem considerations and climate change were not explicitly included in this analysis; however, differences in productivity amongst areas may be driven by ecosystem and or environmental effects. The impact or benefit of Rockfish Conservation Areas (RCAs) on stock growth could also not be evaluated or included in this work as a result of a lack of monitoring data available within RCAs; however, recent data have been collected and will be incorporated in future projects. It is expected that as RCAs mature and size-age structures stabilize within RCAs, that they will begin to have a positive effect on Inside Yelloweye Rockfish biomass.

Although the scope of this project was to see if we could meet the objectives related to biomass, future work could include analyses about spatial, age-structured distributions and other aspects of a healthy rebuilt stock. Future management and rebuilding objectives could be strengthened by explicitly addressing the restoration of large size and old age structures. Moving towards a management strategy evaluation offers a way to consider or operationalize an Ecosystem Approach to Fisheries Management by incorporating ecosystem considerations, climate uncertainty, and other conservation measures into MP selection.

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SOURCES OF INFORMATION

This Science Advisory Report is from the June 10-11, 2020 regional peer review on the Evaluation of Management Procedures for the Inside Population of Yelloweye Rockfish Rebuilding Plan. 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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APPENDIX

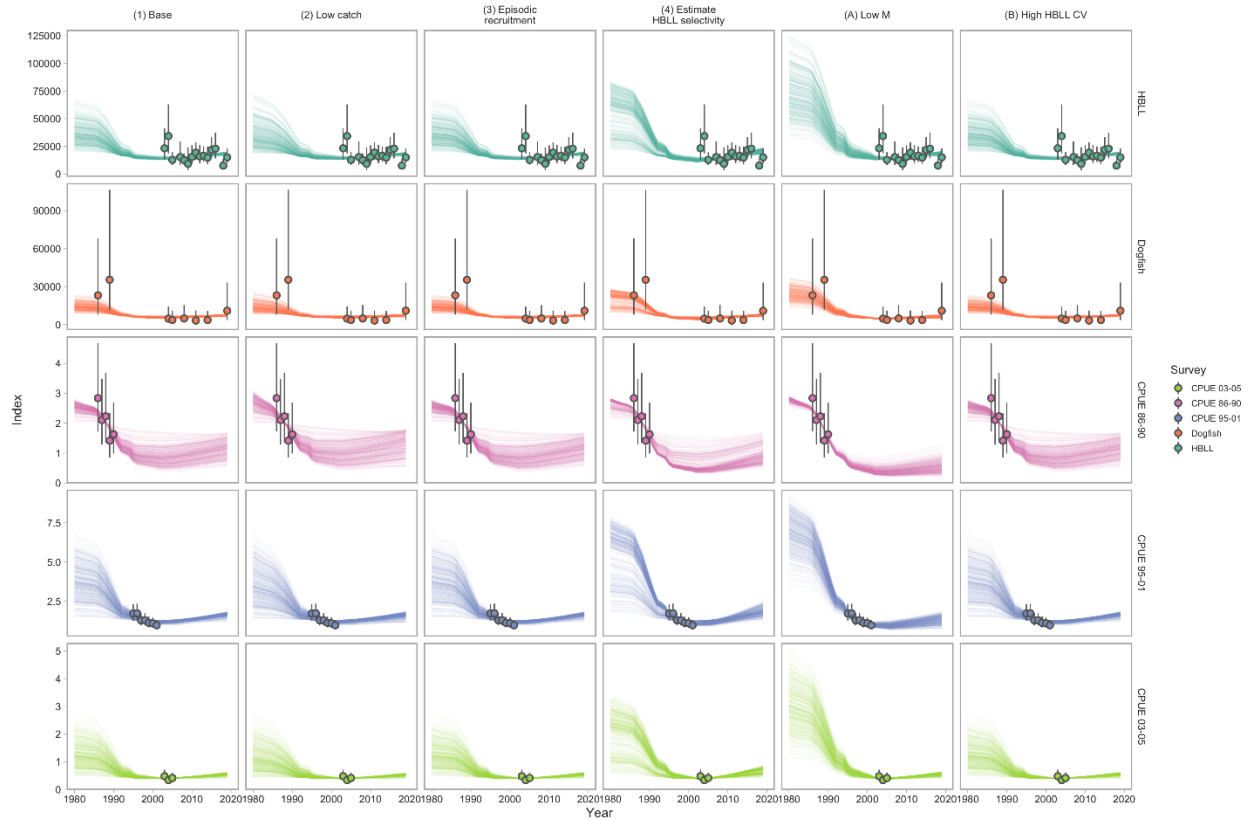


Figure A.1. SRA model fits to the HBL, Dogfish, and three commercial CPUE relative indices. Panels from left to right represent OM scenarios. Thin lines represent individual SRA model fits across stochastic draws from the various OM parameters. Dots represent index mean and line segments represent 2 times the standard errors as entered into the SRA models.

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