Fisheries and Oceans Canada | Pêches et Océans Canada
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# A MANAGEMENT PROCEDURE FRAMEWORK FOR GROUNDFISH IN BRITISH COLUMBIA

*Tiger Rockfish (*Sebastes nigrocinctus*) are one of the species caught in the British Columbia groundfish fisheries. (Image credit: Fisheries and Oceans Canada)*

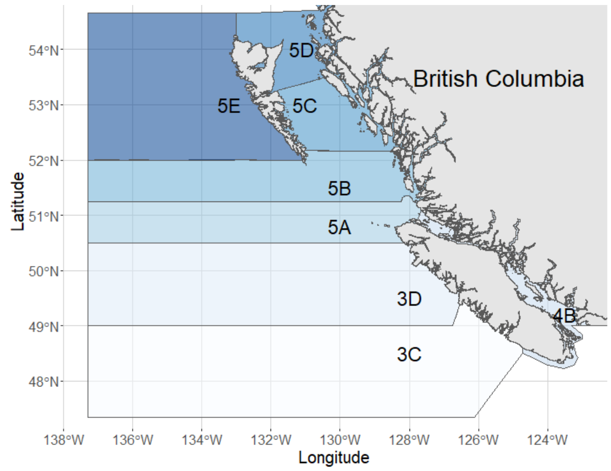


*Figure 1: Map of British Columbia showing the Pacific Marine Fisheries Commission (PMFC) major areas.*

## Context:

*The Pacific Region Groundfish Integrated Fisheries Management Plan lists approximately 80 species-area fish stocks for which annual total allowable catches are required. Most of these allowable catches are applied as individual transferable quotas within British Columbia (BC) groundfish fisheries. The majority of stocks encountered by the fishery are considered data-limited, defined as having insufficient data to reliably estimate stock status or to estimate abundance or productivity with conventional stock assessment methods (such as statistical catch-at-age models). In recent decades, groundfish stock assessments for BC have focused on data-rich stocks, resulting in some stocks with full stock assessments but leaving many data-limited stocks unassessed.*

*Fisheries and Oceans Canada's Sustainable Fisheries Framework, and the Fish Stocks provisions in the* Fisheries Act*, require that fish stocks be managed at or above the stock size necessary to promote sustainability of the stock, and above the Limit Reference Point (below which stocks are at risk of serious harm). However, for data-limited stocks, data are often insufficient to adequately account for uncertainty in such assessment of stock status. Instead of focusing on the explicit knowledge of current stock status, a management-oriented approach is proposed that emphasizes selecting management procedures that have specified probabilities of maintaining fish stocks above implicitly known reference points and of meeting other conservation and fishery objectives. This is done across multiple plausible states of nature, regardless of the quality and quantity of available data. Fisheries and Oceans Canada (DFO) Fisheries Management has requested that Science Branch develop a framework for applying a management procedure approach to data-limited groundfish stocks in BC.*

*This Science Advisory Report is from the June 8-9, 2020 meeting on A Management Procedure Framework for British Columbia Groundfish. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.*

# SUMMARY

- For data-limited stocks, data are often insufficient to use traditional stock assessments to determine stock status relative to biological reference points.
- Instead, a management procedure (MP) framework is proposed that emphasizes selecting MPs that have a specified probability of maintaining fish stocks above implicitly known reference points across multiple plausible states of nature.
- A reference point may not be explicitly known and so cannot be expressed as, for example, a spawning biomass of 10,000 t. Instead, the probability that the stock will remain above the reference point under a given MP can be calculated.
- The MP framework evaluates the performance of MPs with respect to attaining pre-defined objectives. Objectives are quantitatively expressed in terms of performance metrics; reference points can be implicit components of metrics.
- Worldwide there has been a movement towards MP (or management strategy evaluation) approaches to providing science advice on fish stocks via closed-loop simulation. Closed-loop simulation differs from conventional stock assessment because it simulates feedback between the implementation of MPs and the system representing the fish stock and its environment, described by one or more operating models (OMs).
- This document presents a methodology for developing appropriate OMs, testing suites of MPs, and identifying MPs that best meet the objectives of fisheries management, stakeholders and First Nations, specifically for British Columbia (BC) groundfish.
- The proposed MP framework is described according to how it aims to accomplish each of six best-practice steps for MP approaches: (1) defining the decision context, (2) setting objectives and performance metrics, (3) specifying OMs, (4) selecting candidate MPs, (5) conducting closed-loop simulations, and (6) presenting results to evaluate trade-offs.
- The framework includes (1) provisional conservation objectives, fishery objectives, and performance metrics based on policies of Fisheries and Oceans Canada's Sustainable Fisheries Framework, (2) a provisional library of data-limited MPs that are appropriate for BC groundfish stocks, and (3) provisional visualizations to help decision-makers evaluate performance of MPs and trade-offs among MPs.
- Steps 3 to 5 of the framework are the primary responsibility of the DFO Science Branch, though wider engagement at all steps will lead to greater credibility of the process and chances of its successful implementation. Ultimately, it is the role of Fisheries Management, with input from Science, stakeholders, and First Nations, to select the final MP that delivers a total allowable catch with acceptable tradeoffs.
- All code for implementing the MP Framework is publicly available in existing and custom-built R packages.
- Uncertainties inherent in the underlying system are represented in the OMs and may be related to the biology of the stock, the dynamics of the fleet, the observation process, and the implementation process. Estimates of commercial catches are considered reliable since 1996 for trawl-caught groundfish (due to 100% at-sea observer coverage) and since 2006 for line-caught species (due to 100% electronic monitoring).
- The framework provides a standardized and transparent approach across stocks, and should result in the provision of evidence-based catch advice for more stocks than at present.

# BACKGROUND

There are approximately 80 species-area fish stocks in British Columbia (BC; Figure 1) for which annual total allowable catches (TACs) are required for management. Many of the fish stocks encountered by the integrated groundfish fishery are considered data-limited, defined as those with insufficient data to: (1) reliably estimate stock status; or (2) estimate abundance or productivity with conventional stock assessment methods such as statistical catch-at-age models. Many of these stocks lack current assessment advice.

The Sustainable Fisheries Framework (SFF) lays the foundation for the precautionary approach to fisheries management in Canada (DFO 2009). The precautionary approach relies on the definition of biological reference points (BRPs), which define biomass targets as well as low biomass thresholds to be avoided with high probability. Recent amendments to Canada's *Fisheries Act* (in particular the Fish Stocks provisions) require that fish stocks be managed at sustainable levels, specifically at biomass levels above the limit reference point (LRP), which represents the spawning biomass below which serious harm may occur to the stock.

For data-limited stocks, data are generally insufficient to adequately account for uncertainty in development of BRPs and to subsequently assess stock status relative to BRPs. To improve compliance with the legal requirements identified in the Fish Stocks provisions for data-limited species, it is therefore necessary to develop defensible methods and a framework for setting catch limits that promote sustainability and maintain stocks above their LRP, recognizing that, in many cases, the LRP and stock status cannot be reliably estimated.

Worldwide there has been a movement towards management-oriented approaches to stock assessment and fisheries management (management strategy evaluation; MSE) via closed-loop simulation (Figure 2). Closed-loop simulation differs from conventional stock assessment because it simulates feedback between the implementation of management procedures (MPs) and a simulated system representing the fish stock and its environment, described by one or more operating models (OMs).

An OM can simulate (with uncertainties) the biology of the stock, the dynamics of the fleet, the data observation process and the management implementation process. Importantly, the simulations include feedback between the OM and the MP, where the OM generates data at each time step, which is used to apply the MP, which generates a catch recommendation, which is removed from the OM, which generates the next time step of data, and so forth until the projection period is complete (Figure 2). So while it may not be possible to reliably estimate the LRP (and state that it is, say, 10,000 t), this approach can calculate the probability that the stock will remain above the LRP under a given MP.

This document presents a methodology for developing appropriate OMs, testing suites of MPs, and identifying MPs that best meet the objectives of fisheries management, stakeholders, and First Nations for BC groundfish. The expected benefits of the framework are to:

- provide evidence-based catch advice for more stocks than at present;
- develop a standardized and transparent approach across stocks;
- test performance of data-limited MPs for providing catch advice with respect to meeting sustainability and fishery objectives;
- help build an understanding of the most important data needs and research priorities for reducing uncertainty in stock assessment advice; and
- improve capacity for DFO Science to provide catch advice consistent with Canada's Precautionary Approach Framework (DFO 2009) and compliant with the Fish Stocks provisions.

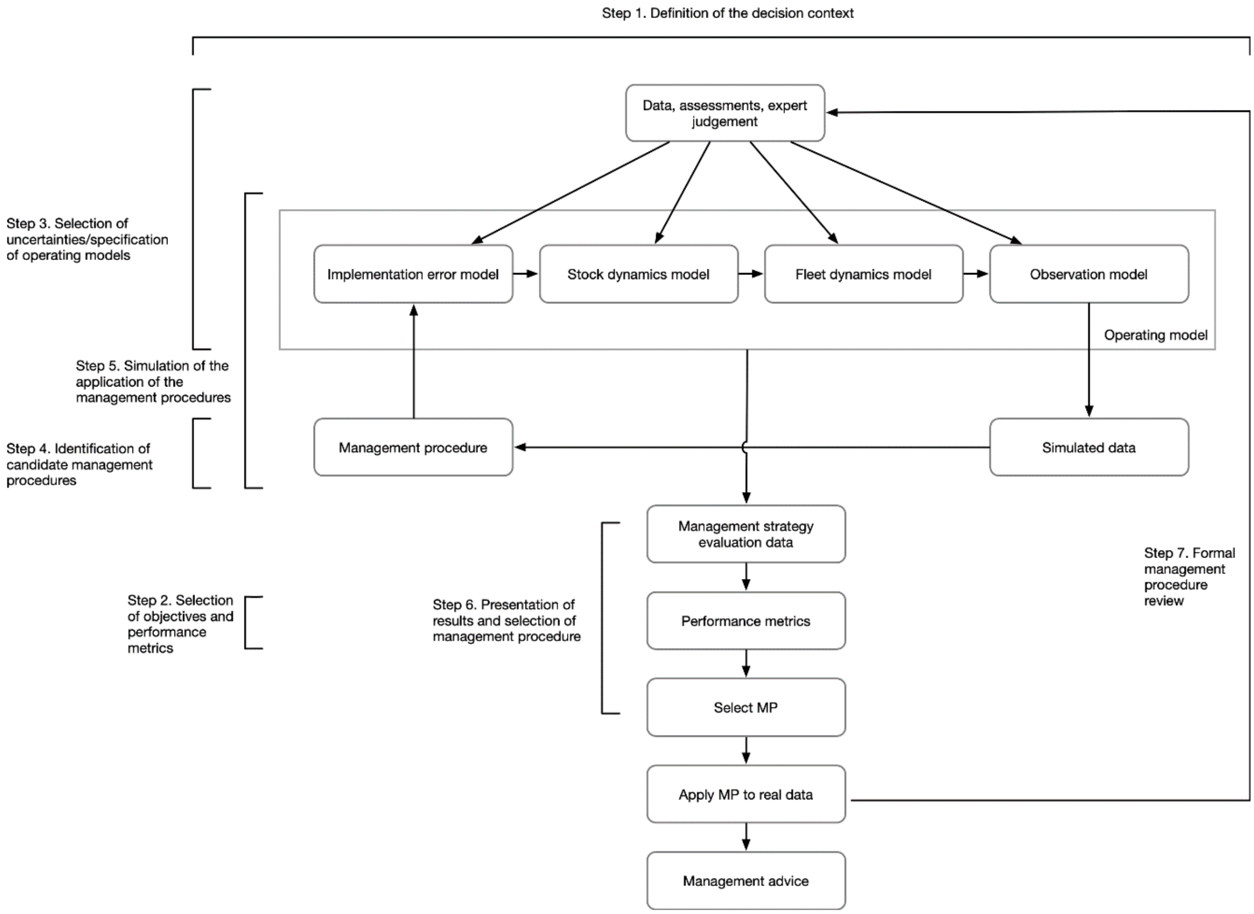


*Figure 2: The steps of the MSE process. Adapted from Carruthers and Hordyk (2018). Step 7 is not explicitly included in the MP Framework, but is discussed later.*

# ANALYSIS

The framework is organized along six best-practice steps for MSE (Figure 2) identified in the scientific literature (Gregory et al. 2012; Punt et al. 2016): (1) defining the decision context, (2) setting objectives and performance metrics, (3) specifying OMs, (4) selecting candidate MPs, (5) conducting closed-loop simulations, and (6) presenting results to evaluate trade-offs.

OM development and closed-loop simulations were implemented using the software package DLMtool (Carruthers and Hordyk 2018), although the framework itself is software agnostic. (i.e. software independent).

## Steps of the Management Procedure Framework

### Step 1: Define the decision context

Key questions to guide defining the decision context include:

- What is the decision to be made?
- What is the time frame for making the decision?
- How often will the decision be evaluated and updated?
- What are the boundaries on the project and decision?

- What are the legislative and policy requirements?
- What are specific roles and responsibilities of parties involved? Parties include DFO (Science, Fisheries Management, and Ecosystem Management Branches), First Nations, industry, academia, and/or non-governmental organizations.
- How will the final decision be made?
- How will the process be governed?

Definition of the decision context is the role of managers, stakeholders, First Nations, and other key interested parties. Engagement of these parties at all stages is critical, as it increases the likelihood that the process will be considered credible, objectives will reflect desired objectives, and MPs will be successfully implemented as planned.

**Step 2: Selection of objectives and performance metrics**

Clear management and fishery objectives must be identified, along with the performance metrics that measure them. Objectives may initially be high level and "strategic" (e.g., achieve sustainable fisheries, maintain economic prosperity, maintain cultural access) but these must be converted into operational "tactical" objectives that can be expressed as quantitative performance metrics. Fully quantified objectives include a metric, the desired probability of success, and a time frame to achieve the objective.

Objectives should be developed with the participation of managers, stakeholders, First Nations, and other interested parties. Objectives will largely fall into four categories: biological, economic, social and political. Within each of these categories, different interested parties will place value on different components, leading to inevitable trade-offs.

Five provisional objectives are proposed for BC groundfish, based on policy and precedent from other MSE processes. However, it is expected that objectives will be developed on a stock-by-stock basis and may reflect more diverse cultural, social, or economic objectives. They may also reflect a broader range of policy objectives such as those associated with rebuilding plans or species at risk. The provisional objectives are:

1. Maintain stock status above the LRP in the long term with an agreed upon probability.
2. Maintain stock status above the upper stock reference (USR) in the long term with an agreed upon probability.
3. Maintain a fishing exploitation rate below the rate at maximum sustainable yield with an agreed upon probability.
4. Given the above conservation objectives are achieved, maximize short- and long-term fisheries catch.
5. Given the above conservation objectives are achieved, minimize variability in fisheries catch from year to year.

The Framework suggests the provisional values of $0.4B_{\text{MSY}}$ for the LRP and $0.8B_{\text{MSY}}$ for the USR from DFO (2009), where $B_{\text{MSY}}$ is the spawning biomass at maximum sustainable yield. For Objective 1, international best practice suggests the probability of maintaining stocks above the LRP should be 90-95%, while the probability of reaching a target biomass (e.g., the USR or some pre-defined target above the USR) can be lower at around 50% (McIlgorm 2013).

The following provisional performance metrics are proposed to measure the performance of alternative MPs with respect to meeting the above objectives (LT: long term, ST: short term, C: catch):

1. LT LRP: Probability $B > 0.4B_{MSY}$ (over long-term year range)
2. LT USR: Probability $B > 0.8B_{MSY}$ (over long-term year range)
3. FMSY: Probability $F < F_{MSY}$ (over entire projection)
4. STC: Probability catch > reference catch (over years 1–10)
5. LTC: Probability catch > reference catch (over long-term year range)
6. AADC: Probability AADC (average absolute interannual difference in catch) < historical AADC (over entire projection)

It is suggested that "long-term" provisionally be the minimum of 1.5–2 generation times of the species (DFO 2009) or 50 years, whichever is longer. A time-frame of 50 years should lead to relatively stable behaviour of MPs for shorter-lived stocks such as flatfishes. The averaging of long-term performance metrics should be over a short window (e.g., 5–15 years) before the final year. "Short-term" should reflect some time period that is of near-term interest to current participants in the fishery, such as 1–10 years.

When performance metrics are calculated over a range of years, care needs to be taken to clearly report how summary statistics are calculated. The provisional suggestion is to calculate performance statistics across replicates and across the entire relevant time window (as defined for that metric). For example, for the FMSY metric the probability that $F < F_{MSY}$ is the proportion of replicate-year combinations for which $F < F_{MSY}$. Alternative options include calculating the performance statistics for a specific year of interest, calculating the proportion of years in which the performance metric is met, or ensuring that the performance metric threshold is met in *each and every year* or in *each and every replicate*.

#### Step 3: Selection of uncertainties and specification of operating models

Uncertainties inherent in the underlying system are represented in the OM and may be related to: the biology of the stock (e.g., growth, natural mortality, recruitment, migration); the dynamics of the fleet (e.g., targetting behaviour, selectivity of the fishing gear); the observation process (e.g., bias or imprecision in survey data or age/length composition data); and/or the implementation process (e.g., exceeding catch limits).

Development of OMs is principally the responsibility of DFO Science Branch, although input from stakeholders, First Nations, and other parties is desirable, especially with respect to identifying key uncertainties and ensuring plausibility of the OMs.

It is unlikely that the full range of uncertainties thought to influence the system can be captured in a single OM. Therefore, best practice recommends dividing MSE trials into a "reference set", using a core set of OMs that include the most important uncertainties (e.g., depletion of the stock or range of natural mortality values), and a "robustness set", representing other plausible OM formulations that represent alternative, but less plausible hypotheses. The purpose of the robustness set is to identify MPs that may perform well under the main sources of uncertainty but perform poorly when a wider range of uncertainty is considered. Reference and robustness set OMs may be selected through consultation of previous assessments, expert judgement, and/or by an iterative process examining the impact of uncertainties on the MSE performance.

Ideally, OMs should be conditioned on observed data to ensure they can reproduce historical observations. DLMtool's companion software package, MSEtool (Huynh et al. 2020), includes an efficient implementation of a stock reduction analysis (SRA) (Kimura and Tagart 1982; Walters et al. 2006) to condition the OMs on available data. For data-limited species, when key data streams are uncertain, it is recommended to include a broad set of uncertainties (including data uncertainties) in the set of OMs.

### Step 4: Identification of candidate management procedures

The scientific literature reports many MPs for data-limited fisheries. MPs for fisheries managed by catch limits are generally either model-based, where data are integrated into a stock assessment model and outputs are used to calculate catch limits, or empirical, where data are used in an algorithm to directly determine the catch limit (e.g., adjustment of catch based on changes in an index of abundance).

The MP Framework includes four main classes of empirical MPs, many of which can be customized via the MP tuning parameters:

1. Constant-catch MPs, which set the recommended catch to some fixed level, typically based on recent or historical catches.
2. Index-ratio MPs, which base their catch recommendation on a ratio of a population index in one time period compared to another time period – generally a recent period compared to a short period before that.
3. Index-slope MPs, which fit a regression of population index data over time and make a catch recommendation based on the slope of the regression.
4. Index-target MPs, which compare recent population index values to the value of the index at a fixed, agreed-upon historical time period to make a catch recommendation that aims to maintain the population index at the fixed historical value.

Other types of MPs that include input or output controls and other data types could also be considered. Model-based MPs fit a statistical population model (e.g., surplus production model) to observed data to estimate biological reference points and stock biomass. These are then incorporated into a harvest control rule to determine the catch limit for the following year. The MP Framework provisionally includes two surplus production model formulations, paired with three alternative harvest control rules.

In general, identification of available MPs is the role of Science. Managers, stakeholders and First Nations should be involved in identifying desirable MPs and provide input on feasibility of implementing some MPs and their likely success in terms of acceptance and compliance.

### Step 5: Simulation of the application of the management procedures

Once the OM and MPs are fully specified, the closed-loop simulation replicates can be run, following the process illustrated in Figure 2. Typically, a large number of replicate simulations are run for each OM-MP combination. Replicates differ in terms of OM process error, observation errors and random draws from ranges of OM parameters, meaning that each replicate provides a different set of simulated data to the MPs.

There may be a need to reduce the number of candidate MPs to a manageable set. Analysts can screen out MPs that do not meet a basic set of requirements for a broad range of stocks (e.g., MPs that result in a high probability of stocks being below the LRP), a procedure known as “satisficing”. Satisficing criteria may be used at the screening stage and can also be used at the final MP selection stage to help streamline the decision-making process.

Running the simulations is the role of Science. Feedback from managers, stakeholders and First Nations should be sought throughout the process, to enable iterative refinement of the models and outputs.

| | LT LRP | LT USR | FMSY | STC | LTC | AADC |
|---|---|---|---|---|---|---|
| MP-1 | >0.99 | >0.99 | >0.99 | 0.05 | 0.34 | 0.58 |
| MP-5 | >0.99 | >0.99 | >0.99 | <0.01 | 0.12 | 0.83 |
| MP-3 | >0.99 | >0.99 | >0.99 | <0.01 | 0.04 | 0.90 |
| MP-4 | >0.99 | >0.99 | >0.99 | <0.01 | 0.01 | 0.98 |
| MP-2 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | 0.99 |
| MP-ref | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-13 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-12 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-11 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-10 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-9 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-8 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-7 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-6 | >0.99 | >0.99 | >0.99 | <0.01 | <0.01 | >0.99 |
| MP-17 | >0.99 | 0.98 | >0.99 | 0.09 | 0.45 | 0.86 |
| MP-18 | >0.99 | 0.96 | 0.99 | 0.94 | 0.68 | 0.60 |
| MP-15 | 0.99 | 0.94 | 0.98 | >0.99 | 0.82 | 0.85 |
| MP-14 | 0.99 | 0.92 | 0.97 | 0.97 | 0.71 | 0.50 |
| MP-19 | 0.98 | 0.86 | 0.91 | 0.96 | 0.71 | 0.38 |
| MP-16 | 0.98 | 0.85 | 0.90 | 0.97 | 0.74 | 0.41 |

*Figure 3: Probability table illustrating performance metric values across a number of MPs. The various performance metrics (columns) are defined in the text. The MPs (rows) are ordered by decreasing performance metric values from top to bottom starting with the left-most performance metric and using columns from left to right to break any ties. The colour shading reflects the underlying numbers (yellow high, blue low). Outlined cells represent MPs that met a given satisficing criterion. MP names shaded grey represent reference MPs.*

### Step 6: Presentation of results and selection of management procedure

Selection of an MP involves addressing trade-offs (e.g., between conservation and economic performance metrics), and therefore is the purview of managers, stakeholders, First Nations, and interested parties. Ultimately, selection of the MP may be a subjective process, depending on the magnitude of trade-offs. It may be necessary to rank performance metrics in order of priority before the process starts. The role of Science in this step is to ensure that results are clearly presented to decision-makers. Ideally this should include presentation of graphical outputs that enable clear comparison of MPs with respect to performance metrics and trade-offs.

The framework presents a set of provisional visualizations that facilitate comparison of performance metrics across MPs and evaluation of trade-offs amongst them. The visualizations are intended to facilitate the selection of the MP. A publicly available R package for generating these visualizations has been developed (Anderson et al. 2020). The choice of visualizations can be decided on a stock-specific basis. It is expected that some or all of the visualizations will be refined over time as users gain familiarity and specific needs arise.

The first visualization is a graphical representation of a probability table (Figure 3) to visualize performance metric results. This visualization lends itself to a large number of MPs and works well for displaying results for all MPs, not necessarily just satisficed MPs. By shading the cells according to their underlying performance metric value, the visualization draws the eye to similarities and differences across MPs.

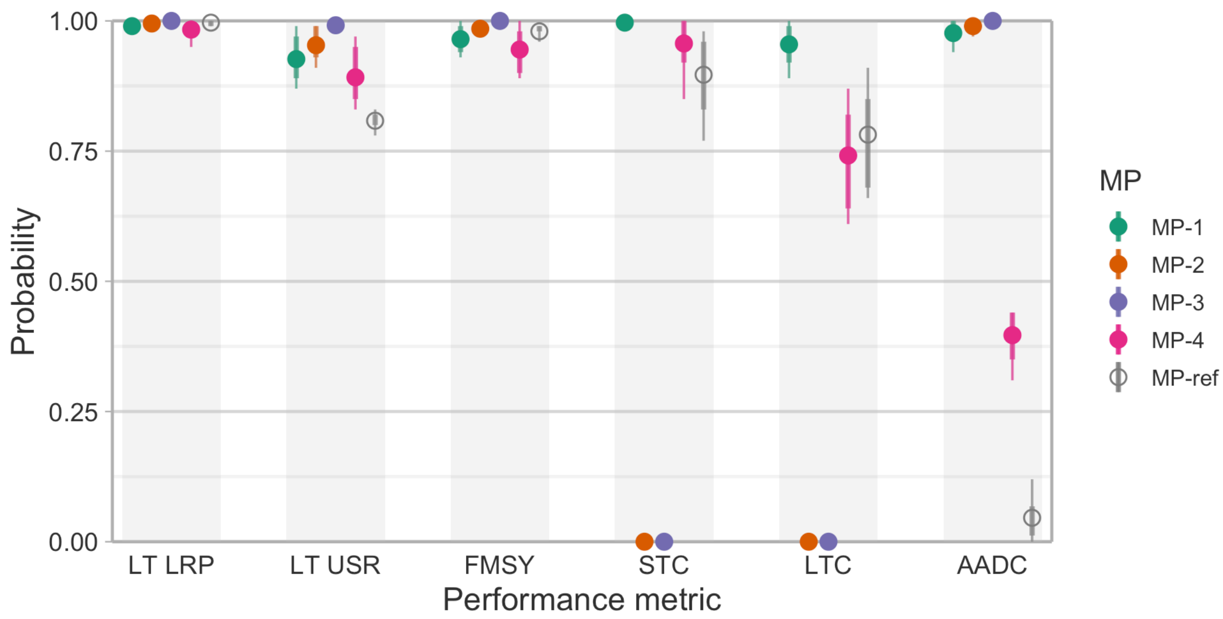


*Figure 4: Performance summary (probabilities of achieving performance metrics, see text for definitions) for a small number of MPs across OM scenarios. Dots represent mean performance across OM scenarios. Thin lines represent the range of performance across OM scenarios. Thicker lines represent the range of performance across OM scenarios after dropping the highest and lowest OM scenario within each performance metric. This visualization can also be used without the line segments to represent performance for individual OM scenarios (e.g., OM robustness scenarios). This example only has one reference management procedure (MP-ref, open circle).*

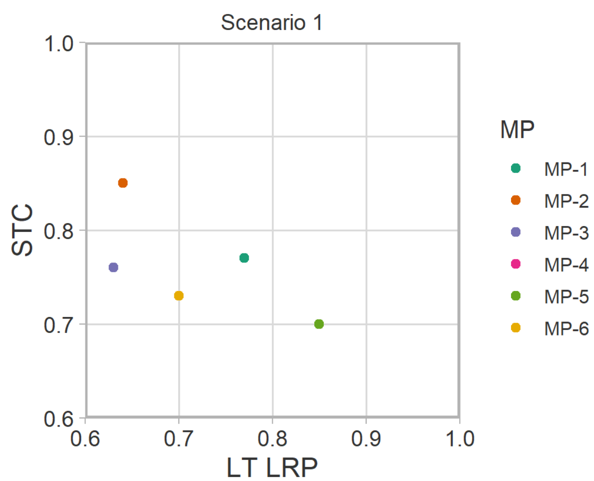


*Figure 5: Demonstration of bivariate trade-offs between two performance metrics (shown on axes) for a given OM scenario. Individual dots represent MPs.*

For some visualizations, it is recommended that the reference-set performance metrics are averaged across all OM reference-set scenarios. An exception is the table of performance metrics (e.g., Figure 3), which can be presented in two ways: (i) minimum value of the performance metric across all OM reference-set scenarios; and (ii) average value of the performance metric across all OM reference-set scenarios. The first is a "worst-case scenario" approach, whereas the second case integrates across the whole reference set. It is recommended that performance metrics from the individual OM robustness-set scenarios are presented separately. Figure 4 summarizes performance for a small set of satisficed MPs across OM reference-set scenarios. Figure 5 highlights trade-offs among performance metrics, allowing comparison of any two performance metrics (in this case LT LRP and STC).

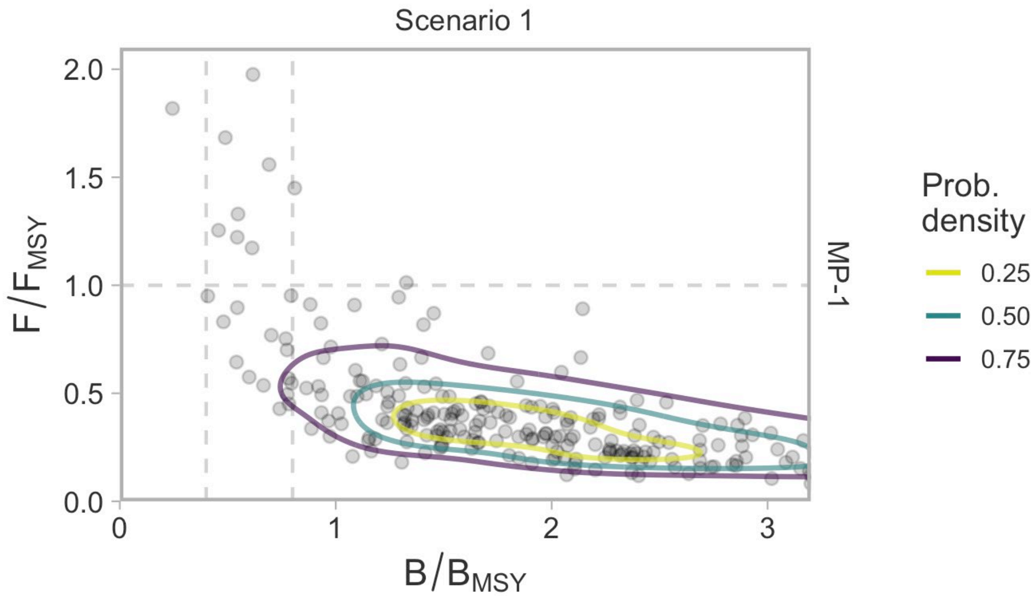


*Figure 6: Kobe plots for the final year of the projections across all replicates. The dots represent individual replicates. Contour lines indicate two-dimensional kernel-density-smoothed quantiles, calculated in log space. For example, the 0.50 contour lines encompass approximately 50% of the replicates. Vertical dashed lines show $B/B_{MSY}$ = 0.4 and 0.8, and the horizontal dashed line shows $F/F_{MSY}$ = 1, where $B/B_{MSY}$ and $F/F_{MSY}$ are, respectively, the spawning biomass and fishing mortality relative to their values at maximum sustainable yield. Replicates with values beyond the outer axis limits are shown on the axis limit with an open circle (e.g., bottom right corner).*

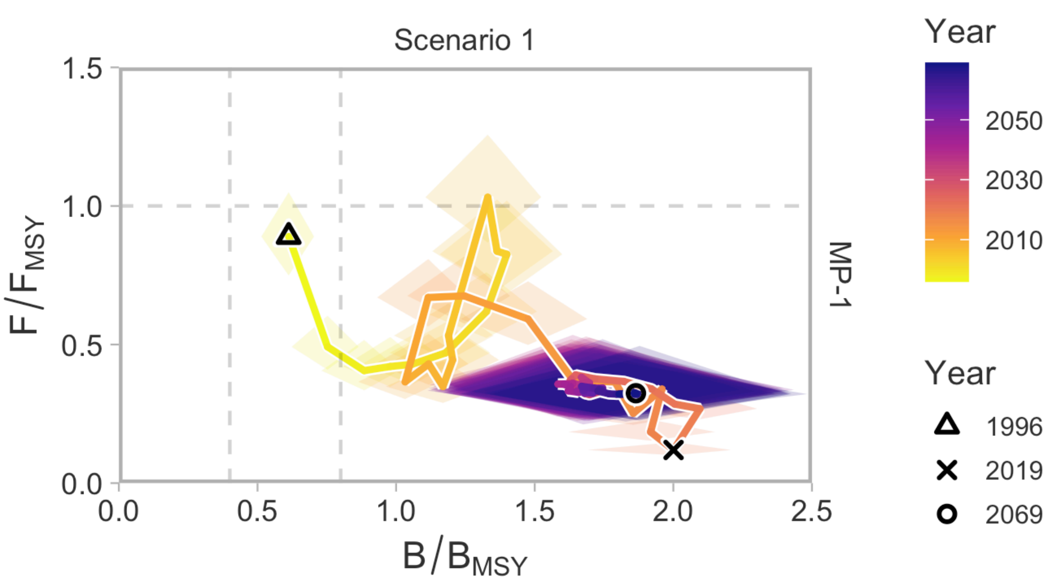


*Figure 7: Time trajectory of $B/B_{MSY}$ and $F/F_{MSY}$ values summarized across replicates. The solid line corresponds to the median value. Vertical dashed lines show $B/B_{MSY}$ = 0.4 and 0.8; horizontal dashed line shows $F/F_{MSY}$ = 1. Each diamond represents the 50% quantile of $B/B_{MSY}$ (horizontal) and $F/F_{MSY}$ (vertical).There is one diamond per year of the historical and projection period. The lines and diamonds change colour over time and specific points in time are illustrated with symbols.*

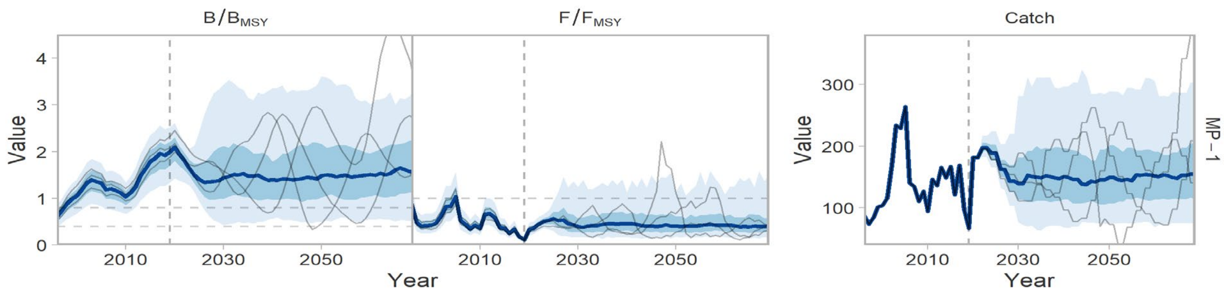


*Figure 8: This visualization illustrates historical and projected $B/B_{MSY}$, $F/F_{MSY}$, and catch for various MPs for a single OM (only one MP is shown here). Dark lines indicate the median value and the darker and lighter shaded ribbons indicate the 50% and 90% quantiles. Thin gray lines represent illustrative simulation replicates. The vertical dashed line indicates the last year of the historical period. The horizontal dashed lines indicate $B/B_{MSY}$ = 0.4 and 0.8, and $F/F_{MSY}$ = 1. Note that the simulations are mean-unbiased and so the median $B/B_{MSY}$ and $F/F_{MSY}$ are not expected to lie perfectly on the 1 line even if fishing perfectly at $F/F_{MSY}$.*

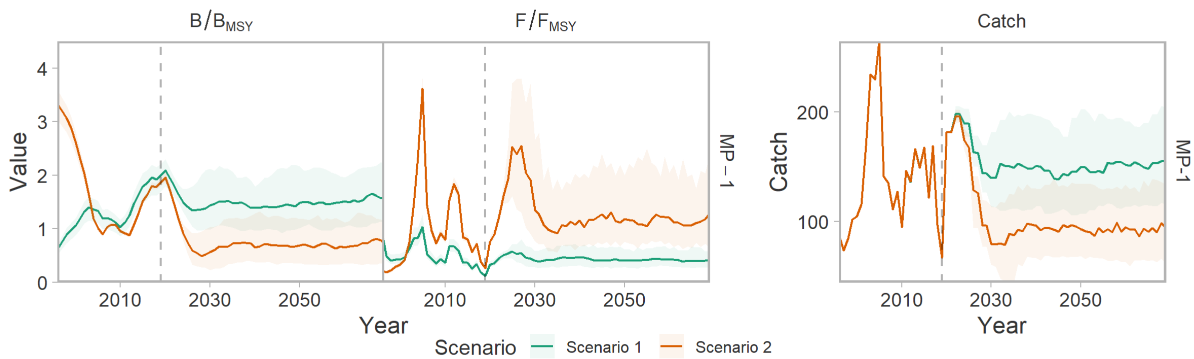


*Figure 9: This visualization highlights sensitivity of the historical conditioned and projected time series across OM scenarios for two hypothetical OM scenarios, though more than two can be included in this plot. Only one MP is shown here; in applications of the framework, all satisficed MPs would be shown as separate panels. The solid lines correspond to median values and the shaded ribbons correspond to 50% quantiles to indicate variability across replicates. The vertical dashed line indicates the last year of the historical period.*

Figures 6 and 7 illustrate the trade-off between $F/F_{MSY}$ and $B/B_{MSY}$ across replicates for the various MPs. Figure 6 shows a standard Kobe plot showing $F/F_{MSY}$ vs $B/B_{MSY}$ for the final year of the projection. This visualization highlights the parameter space with the highest probability density. Figure 7 shows the trajectory of $F/F_{MSY}$ vs $B/B_{MSY}$ through time. The final year of Figure 7 is an alternative representation of Figure 6. Figure 7 also presents a diagnostic check of the behaviour of MPs over time, for example by indicating how often the stock falls within the critical zone.

To understand the processes leading to the performance metrics, it is recommended that the results from the application of the MP framework should include visualizations of historical and projected $B/B_{MSY}$, $F/F_{MSY}$, and catch. Two versions are presented: Figure 8 provides careful inspection of individual OM scenarios and an understanding of individual replicate behavior, while Figure 9 compares the time series across OM scenarios. Inspection of these can improve understanding of the performance of MPs, and may lead to addition of new performance metrics if the existing set fails to capture some important behaviour. For example, if some MPs are creating highly variable TAC recommendations in the initial implementation years, this may suggest the need to specify a short-term TAC variability objective and performance metric. Alternatively, if some MPs are resulting in short-term declines in $B/B_{MSY}$ that eventually recover by the long-term window, this may suggest the need for a short-term conservation objective and performance metric.

It is the role of fishery managers, with input from stakeholders, First Nations and Science, to select the final MP.

To illustrate the MP framework, a Rex Sole (*Glyptocephalus zachirus*) case study (not shown here) included six OMs in the reference set. These represented uncertainty in: historical catch levels and initial depletion; natural mortality; steepness of the stock-recruit relationship; and selectivity. It included two OMs in the robustness set, representing further uncertainty in historical catch levels and initial depletion, and in time-varying natural mortality. MPs were screened out that did not achieve a long-term 90% probability [9 times out of 10, averaged across years and replicates] of keeping the stock above the LRP and a short-term 80% probability [8 times out of 10] of catch being above recent average catch.

### Sources of Uncertainty

As in all MP approaches, results of this framework will depend on the degree to which uncertainties within the real system are captured within the OMs. For this reason, it is recommended to develop multiple OMs to capture the key, most plausible hypotheses about the system in the reference set, and a wider range of uncertainties in the robustness set. However, it is inevitable that some uncertainties will not be considered, either because they are unknown or because including them would create unworkable complexity in the modelling and decision-making environment. For example, species for which spatial considerations are important (e.g., highly migratory species) or species with strong environmental drivers of productivity. Some considerations will inevitably be considered outside the scope of the process due to limitations in available data, time, or expertise. Therefore, it is important to evaluate the performance of selected MPs once they are implemented (Step 7 in Figure 2), either through informal or formal means (e.g., Butterworth 2008).

Outputs of the model used to condition the OMs (e.g., MSEtool's SRA) will rely on the quality of the available data, and also on the assumed distributions of its input parameters. In particular, assumptions about selectivity will be a key source of uncertainty for species with little or no age composition data. Therefore, selectivity should be treated as an axis of uncertainty in most applications. Furthermore, an SRA model assumes almost no observation error in historical catch data, so uncertainty may be underestimated in its outputs.

For trawl-caught BC groundfish, catch estimates are considered reliable since the 1996 introduction of 100% at-sea observer coverage. For line-caught species, catch data are considered reliable since the 2006 introduction of 100% electronic monitoring. For some species, especially those with low monetary value, catch data prior to these years may be more uncertain and it may be necessary to include alternative scenarios to account for uncertainty in catch.

## CONCLUSIONS AND ADVICE

The MP framework outlined here builds upon current scientific best practices, and is specifically tailored to BC groundfish. It provides a standardized and transparent approach across stocks, and should result in evidence-based catch advice for more stocks than at present. It also includes visualizations for communicating the results. Suggestions are given to help guide choices of details such as performance metrics, but these are provisional suggestions and are expected to be tailored to each individual application.

The first application of the MP Framework for decision making in Pacific Region is to support the re-evaluation of the current rebuilding plan for the inside population of Yelloweye Rockfish. The CSAS peer review meeting took place from June 10-11, 2020.

# OTHER CONSIDERATIONS

## Implicit versus explicit knowledge of reference points

MP frameworks differ from conventional assessments in two key ways: (1) reference points and stock status are not explicitly reported (or at least not emphasized); 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 – they are calculated in the 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 criteria can be established. The final decision point in this process is the MP that delivers a TAC that meets objectives, while ideally also achieving acceptable trade-offs among other objectives such as catch or variability in catch. Note that, for many stocks, especially data-limited stocks, it is not possible to reliably estimate biological reference points or estimate stock status; instead the probability of being above a reference point for a given MP is calculated. MP frameworks such as this one, where development of multiple OMs is integral, may be especially important for these stocks.

## Weight of evidence

Kronlund et al[1]. suggested a "weight of evidence" approach for determining whether rebuilding of a stock is required. This approach may include consideration of combined contributions of individual studies (totality of evidence), and expert-judgement-assigned weights for each line of evidence, where a line of evidence may consist of one or more studies. It is suggested that if conditioned OMs place a high probability of a fish stock being in the critical zone across a range of plausible OM assumptions, this could contribute to the lines of evidence used to trigger a rebuilding plan.

## Tuning MPs

Many of the MPs tested in this framework are characterized by one or more parameters that control how the TAC should change in response to changes in the survey index. In some applications of the framework it may be desirable to iteratively tune MPs on a fine scale to achieve desired performance outcomes. There is a trade-off between testing a larger set of generic MPs across a coarse array of tuning parameters and homing in on better-performing MPs via the satisficing step, versus focusing effort on a few MPs that are highly "tuned" to achieve desired outcomes. The latter approach may be preferred when generic MPs perform poorly or in more mature processes with strong stakeholder engagement where MPs can be tuned iteratively to meet a more refined set of objectives. Ultimately, the decision about whether to evaluate generic or finely tuned MPs will be made on a stock-by-stock basis. The process may start with more generic MPs and graduate to more finely tuned MPs as experience is gained with the performance of specific MPs.

[1] Kronlund, A.R., Marentette, J.R., Olmstead, M., Shaw, J., and Beauchamp, B. In prep. Considerations for the design of rebuilding strategies for Canadian fish stocks. DFO Can. Sci. Advis. Sec. Res. Doc.

### Reassessment frequency and triggers

In general, the purpose of an MP approach is to identify and select a robust MP that can be left in place for an agreed amount of time. A specific interval between assessments should be done on a stock-by-stock basis. The MP Framework itself can be used to test appropriate re-assessment intervals for individual fish stocks. Interim checks between assessments are also recommended to ensure the selected MP is performing as expected.

In addition to the best practice steps described above, Carruthers and Hordyk (2018) describe a final evaluation step, where performance of the selected MP is formally reviewed once it has been implemented (Step 7 in Figure 2). Departures from an MP's predicted performance have been termed "exceptional circumstances", where the observed system dynamics fall outside the range of OM scenarios specified in the OM(s), over which the MPs were demonstrated to be robust (Butterworth 2008). Exceptional circumstances can be caused either by misspecification of the original OM(s) or can be due to unforeseen changes in the real future system that were not captured in the original OM(s) (e.g., changes in natural mortality, growth, recruitment, or fishing dynamics). 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. An example of triggers for re-evaluation include observed data falling outside some confidence interval of the OM-predicted data (e.g., 90% or 95%). Regular evaluation of the performance of MPs recommended by this framework is advised (Step 7 of Figure 2).

### Extensions of the framework

Potential extensions of the framework could be used to inform:

1. Rebuilding plans, assessments for the Committee on the Status of Endangered Wildlife in Canada, Species at Risk processes, and recovery potential assessments;
2. Methods for an ecosystem approach to fisheries management;
3. Assessing the value of collecting more or less information (e.g. ageing more fish); and
4. Evaluating the performance of data-moderate and data-rich MPs.

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# SOURCES OF INFORMATION

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