# Evaluating the robustness of candidate management procedures in the BC sablefish (*Anoplopoma fibria*) FISHERY for 2019-2020.

## Context

Since 2008, Fisheries and Oceans Canada (DFO) and the British Columbia (BC) groundfish fishing industry have collaborated on a management strategy evaluation (MSE) process intended to maintain a transparent and sustainable harvest strategy for sablefish fisheries in BC. As part of the MSE, the performance of alternative harvest strategies is determined by simulation testing alternative management procedures (MPs) against operating models (OMs) that represent a range of hypotheses about uncertain sablefish stock status and productivity. The performance of MPs is measured against conservation and fishery objectives for the stock and fishery (DFO 2017). The sablefish MSE process has been reviewed in several Canadian Science Advisory Secretariat processes, Canadian Science Advisory Secretariat Science Responses, and independent peer-reviewed scientific journals and books since 2008 (Cox and Kronlund [2008](#ref-cox2008practical); Cox et al. [2011](#ref-cox2011management), [2013](#ref-cox2013roles), [2019](#ref-cox2019evaluating); DFO [2014](#ref-dfo2014performanc)). Canadian sablefish harvest advice derived from simulation-tested MPs has been adopted and subsequently approved by the Minister of Fisheries and Oceans every year since 2011.

The sablefish MSE aims to follow a 3-year cycle in which the operating model is re-fitted to updated fishery and survey biomass indices, catch-at-age, at-sea releases, and tag release-recoveries. Each 3-year update also offers an opportunity to revise the conservation and fishery objectives, as well as to propose new candidate MPs.

Previous BC sablefish assessment and MSE work demonstrated that low recruitment, on average over the past three decades, has contributed to a long-term decline in spawning stock biomass and harvest opportunities. Stakeholder and management consultations identified at-sea release mortality of sub-legal sablefish (i.e., fish smaller than 55 cm size limit) as a potential source of mortality that, if reduced or avoided, would improve production of over-55 cm sablefish, spawning stock biomass, and, ultimately, future harvest opportunities (Cox et al. [2019](#ref-cox2019evaluating)). While some management tactics aimed at reducing sub-legal mortality have been identified and implemented, to date management tactics aimed at reducing sub-legal mortality have not been formally evaluated through the sablefish MSE process. Indeed, closed-loop simulations suggest that both full avoidance and full retention of sub-legal sablefish may improve both average annual sablefish yield in directed fisheries as well as the probability of stock rebuilding to BMSY (Cox et al. 2011, 2019). Unfortunately, full avoidance may not be feasible, especially in trawl fisheries, which encounter sub-legal sablefish as part of fishing operations for other species, while full retention may involve lost fishing opportunities (particularly for the trawl sector) and lower profitability for directed fisheries, because sub-legal sablefish are worth less per-kilogram than legal-sized fish. In consultations, industry stakeholders suggested that an ideal solution would involve incentives that shift fishing behaviour toward higher avoidance of sub-legal sablefish.

The DFO Fisheries Management Branch has, therefore, requested that the Science Branch (i) update the sablefish operating model with the most recent data (up to 2018); (ii) provide an assessment of current stock status; (iii) re-evaluate expected performance of the current MP based on updated operating models; and (iv) evaluate alternative MPs involving sub-legal regulation options aimed at reducing sub-legal sablefish mortality caused by fishing. The key challenge in (iv) is identifying regulations that reduce sub-legal mortality for the least impact on fishing opportunities and profitability.

Advice arising from this Canadian Science Advisory Secretariat Science Response will be used to select a MP for BC Sablefish for years 2020-2022 that is compliant with the *DFO Sustainable Fisheries Framework* and *A fishery decision-making framework incorporating the Precautionary Approach* policy (Fisheries and Oceans Canada [2009](#ref-DFO2009)). In addition, this Science Response informs fishery managers and stakeholders about the potential biological and fishery implications of a limited set of sub-legal sablefish at-sea release regulations.

This Science Response Report results from the Science Response Process of September 2019 on evaluating the robustness of candidate management procedures in the BC sablefish (*Anoplopoma fibria*) fishery for 2019-2020.

## Background

## Analysis and response

This Science Response uses a closed-loop simulation approach to evaluate the relative performance of candidate MPs for the BC sablefish fishery, using identical methodology to that presented in the previous MSE cycle (Cox et al. [2019](#ref-cox2019evaluating)). The following sub-sections provide brief descriptions of the updated data that is used to condition the sablefish operating model, changes to the OM required to fit that data, and the new MP elements that were tested. Additional details of the simulation procedures, diagnostic checks, and performance measure calculations are given in Cox et al. ([2019](#ref-cox2019evaluating)).

### Objectives

The specific objectives of this Science Response are to:

1. Describe operating model fits and inferences after fitting (conditioning) to updated biomass indices, catch-at-age, and new catch-at-age data derived from length-composition sampling of sablefish in the trawl fishery;
2. Derive and weight a grid of 5 reference operating models based on uncertainties about sablefish stock status (for 2019) and productivity (reference OMs) and 5 robustness operating models that modify the reference grid OMs by replacing Year 2016 estimated recruitment with values simulated from the stock-recruitment relationship (robustness OMs);
3. Simulate and rank candidate MPs under the reference and robustness OMs based on weighted performance (across OMs) against Fishery Objectives (see below).

## Methods

### Updates to the operating model

Data updated to 2018 included biomass indices and catch-at-age for the stratifed random trap survey (StRS), catch-at-age for the commercial longline trap fishery, catch and total at-sea releases (in biomass units) for the commercial longline trap, longline hook, and trawl fisheries. New catch-at-age and catch-at-length datasets were obtained for the trawl fishery to help estimate trawl selectivity, which is the key determinant of sub-legal sablefish catch in trawl fisheries. The full trawl catch-at-age dataset (with some missing years) was derived from an age-length key given age and length data for years X and Y.

A series of small changes were made to the operating model as part of routine attempts to improve fits to various data. Specifically, these include (i) changing the functional form of trawl selectivity to a gamma density function, (ii) reducing the youngest model age class from age-3 to age-2 for all age composition series to better reflect range of age-composition observations, (iii) adding new commerical trawl age-composition data (Appendix A), (iv) adding an (optional) estimated recruitment deviation in 2016, rather than using the expected recruitment off the stock-recruit curve, (v) updating the ageing-error matrix to use a simpler normal approximation recommended in the previous CSAS review (Cox et al. 2019); and (vi) imposing a standard deviation of (on the log-scale) on trawl at-sea release observation errors to force a better fit to those data. Previous models avoided estimating recruitment in the 3 most recent years, mainly because (i) this would have been the first age-at-entry to the observations and the model and (ii) there is typically little information or catch to support those estimates because fish are too small to be selected by the fisheries or surveys. However, for this update, we made change (iv) because we needed to improve fits to recent (very high) trawl at-sea release observations. Otherwise, we would be simulating effects of at-sea releases based on a model that could not adequately fit historical at-sea releases. This change has a potentially large impact on simulated MP performance and, therefore, is a focus of the robustness OMs (described below).

### Operating model scenarios

Reference OMs

The reference OM was dervied using the same method as the previous MSE cycle (Cox et al. [2019](#ref-cox2019evaluating)). Briefly, we derive 5 OMs defined by the joint posterior distribution of 2018 spawning stock biomass (to reflect short-term risk) and stock-recruitment steepness (to reflect long-term stock productivity risk). The 5 combinations are chosen to represent the joint marginal mean of 2018 biomass and steepness and 4 outer points lying at the intersection of the mean of one variable, and the 10th and 90th percentiles of the marginal density of the other variable (Figure 1). For each of the 5 posterior points, the operating model was conditioned on a sample of 100 posterior draws constrained to lie within a Mahalanobis distance of 0.6 units from that point. We then used an empirical estimate of the posterior density at each of the 5 centres as a plausibility score for weighting MP performance across the 5 OMs within each of the reference and robustness sets (Table 2).

Robustness OMs

The robustness OMs were identical to the 5 reference OMs with the exception of how Year 2016 recruitment was treated in the OM historical conditioning and projections. The reference OM used draws from the joint posterior distribution (as defined above) for Year 2016 recruitment, which is approximately 12 million fish or about 5 times the historical average. For the robustness OMs, we simulated Year 2016 recruitment off the stock-recruitment relationship resulting in expected Year 2016 recruitment that was more similar to the long-term average (~2.3 million).

### Fishery Objectives

Objectives for the B.C. sablefish fishery have been developed iteratively via consultations between fishery managers, scientists, and industry stakeholders (Cox and Kronlund [2009](#ref-cox2009evaluation); Cox et al. [2011](#ref-cox2011management), [2019](#ref-cox2019evaluating); DFO [2014](#ref-dfo2014performanc)). The five primary objectives guiding the fishery are:

1. **P(fSSB > LRP)**: Maintain female spawning stock biomass (fSSB) above the limit reference point LRP = 0.4BMSY, where BMSY is the operating model fSSB at maximum sustainable yield (MSY), in 95% of years measured over two sablefish generations (36 years);
2. **P(decline)**: When female spawning stock biomass is between 0.4BMSY and 0.8BMSY, limit the probability of decline over the next 10 years from very low (5%) at the 0.4BMSY to moderate (50%) at 0.8BMSY. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between these probabilities;
3. **P(fSSB > BMSY)**: Maintain the female spawning biomass above a target level of (a) BMSY when inside the healthy zone, or (b) 0.8 BMSY when rebuilding from the Cautious zone, in the Year 2052 with a probability of 50%;
4. **P(Catch>1,992)**: Minimize probability that annual catch levels are below 1,992 tonnes measured over two sablefish generations.
5. **MaxCatch**: Maximize the average annual catch over 10 years subject to Objectives 1-4.

Performance measures corresponding to Objectives 1-4 (in bold) are read as "**Probability of (condition)"**. Performance measures are calculated for each simulation replicate, and the expected performance for a management procedure is summarized by the mean (or median) over the 100 replicates of each simulation. Full details of performance measures and calculations are given in Cox et al. (2019).

As noted above, there is a price premium for larger size classes of sablefish, which means that the same tonnage of landed catch may yield widely different dockside values if the underyling size distributions of individual fish are substantially different. This may have consequences for sub-legal regulation options that require landing small sablefish (e.g., full retention). Therefore, in addition to presenting catch performance statistics (e.g., Objective 5), we also computed cumulative landed value over 10 years and average landed value per tonne by fleet (because the size composition of the catch also differs by fleet).

### Management procedures

A management procedure (MP) represents a specific, repeatable algorithm for computing annual total allowable catches (TACs) in a fishery. In most cases, MPs involve monitoring data, assessment methods for processing data and estimating stock status, harvest control rules for translating assessment outputs into catch limits, and meta rules that may include constraints on TAC changes, as well as conditions (e.g., exceptional circumstances) for triggering deviations from the standard MP harvest advice.

The MP currently used to set annual sablefish TACs was initially developed in Year 2011 and revised in two subsequent MSE iterations. Generally, the MP consists of (i) 3 biomass indices; (ii) a surplus production model with observation and process errors for estimating stock biomass from the biomass indices; (iii) a 60:40 harvest control rule (HCR) in which the maximum target harvest rate is adjusted from 5.5% when estimated biomass is above 60% of estimated BMSY, and 0% when the estimated biomass is below 40% of BMSY; (iv) a meta rule stating that TAC increases are 0 unless the HCR recommended increase is more than 200 tonnes (TAC decreases are always adopted); and (v) a meta rule adjusting the maximum target fishing mortality rate from 9.5% in Year 2017 to 5.5% in Year 2021. The exact current MP specifications are given in Cox et al. (2019).

For this Science Response, we evaluated performance of the current MP for sablefish, a NoFishing reference case, and 13 variations of the current MP that only change at-sea release regulations. The MP variants are constructed by combining 3 features:

1. at-sea sub-legal release cap in which all at-sea releases below the cap may be released without penalty and amounts exceeding the cap go to overages. Caps are noCap, 0%, 50%, 100%, and 150% over the average (VALUE) at-sea releases that occurred between 2006 and 2018. The current MP involves no cap (unlimited at-sea releases without penalty), while a full retention (frt) case allows no at-sea releases (all fish brought on-board vessels must be landed and counted against the TAC).
2. fixed allocations of the total at-sea release cap to each fleet (i.e., trap, longline hook, trawl). Allocations are computed based on either recent (rct = 23%, 18%, 59%) or historical (hst = 30%, 37%, 33% ) average fleet-specific averages.
3. amortization period of either 5 (am5) or 10 (am10) years over which to spread at-sea release amounts that exceed the fleet-specific annual allowable totals (i.e, overages).

Our naming convention for MPs is a concatenation of ASSESSMENT\_CAP\_ALLOCATION\_AMORTIZATION settings. For example, the **SP\_cap.5\_hstAl\_am5** MP involves a surplus production model (**SP**), a total at-sea release cap that is 50% of the historical average (**cap.5**), a cap allocation among fleets that is computed from the historical, fleet-specific averages (**hstAl**), and a 5-year amortization period for at-sea release overages (**am5**). The two special cases are the current MP (SP\_noCap\_rctAl\_am5), which has no cap, and full retention (SP\_frt\_rctAl\_am5) – subsequent settings listed in these names do not apply and can be ignored.

Example at-sea release regulation for **SP\_cap.5\_hstAl\_am5**

In the computations below, the following notation applies: t is Year, g is fleet, and p(g) is allocation proportion for fleet g, and avgR is the average total (over all fleets) at-sea releases between 2006 and 2018.

* 1. Calculate 50% at-sea release CAP for year and fleet: CAP(t,g) = 0.5 x avgR x p(g)
  2. Run simulation for year t to get actual at-sea releases: R(t,g)
  3. Overage o(t,g) for the year is the difference between actual releases R(t,g) and the CAP(t,g): o(t,g) = R(t,g) - CAP(t,g)
  4. Amortization period is 5 years, so add 1/5th of this year's overage to accumulated overage account O(t,g) in each of the next 5 years: O[(t+1):(t+5),g] = O[(t+1):(t+5),g] + o(t,g)/5
  5. Get adjusted legal-sized sablefish TAC for next year by subtracting overage account for that year from initial TAC': TAC(t,g) = TAC'(t,g) - O(t,g), where TAC' is the initial TAC determined by the MP prior to at-sea release regulations.

Note that the overage account can never be less than zero, so that TACs cannot be increased above the initial TAC set by the first stage MP.

#### Management procedure tuning

There are five primary dimensions of MP performance against objectives. The first three represent biomass conservation performance against the LRP, short-term probability of decline, and achieving a long-term target near BMSY, while the fourth and fifth dimensions relate to maintaining catch levels above an industry-preferred floor and short-term average catch. It is rare that two MPs would have comparable performance across four of these objectives while only differing on one. If this were the case, then MP decisions would be straightforward – choose the MP with better performance on the fifth criterion. Unfortunately, MPs typically differ on all 5 dimensions simultaneously, which makes it difficult to compare performance without establishing some equivalency between conservation probabilities (performance dimensions 1-3) and short-term average catch (performance dimensions 5).

Management procedure tuning provides a means of establishing equivalent MP performance against objectives for which the values and probabilities are well-established. For example, maintaining the sablefish stock above the LRP (0.4BMSY) with high probability has not been openly debated since it is an overarching policy directive in the sablefish fishery context (at least not debated over the 10+ year history of the sablefish MSE). Similarly, maintaining a low probability of short-term decline has also not been debated, probably because avoiding further decline has been the key overriding objective of the sablefish fishing industry since the inception of the MSE process. Objective 3 – spawning biomass in the healthy zone within 2 generations – has been debated over the years for practical reasons. Specifically, there is concern that achieving Objective 3 would require severe short-term catch restrictions for highly uncertain long-term benefits. Over the past year, the sablefish industry and managers agreed to revise Objective 3 to achieve biomass in the healthy zone by a specific end-year (2052) with at least 50% probability, i.e., median fSSB at, or above, 0.8BMSY. As we demonstrate below, this objective is now feasible given sablefish dynamics and also achievable for a range of realistic MPs. However, this raises a new question: how much is it worth (i.e., in catch) to improve Objective 3 performance from to ? The probability difference of only 5 percentage points could mean a difference of several hundred tonnes in annual average catch, which would cumulatively added up to tens of millions of dollars in landed value. MPs that are better at Objective 3 do so at the expense of Objectives 4 and 5.

We aimed to simplify interpretation of MP performance by tuning all MPs to a standard , which ensures that all MPs under consideration meet all the stated conservation objectives and only differ in their catch performance. This simplification is valuable in the current context, because the at-sea regulations we evaluated have catch and fishing opportunity implications across fishing sectors.

Tuning was achieved by iteratively adjusting the 2022 phased-in maximum target fishing mortality rate until each MP met the lower limit of Objective 3, i.e., . We tuned the surplus production model management procedures separately to the reference OM (hiRec2016) and robustness OM (simRec2016) scenarios, leading to different values under each recruitment scenario.

Note that all candidate MPs continued to implement the 5-year phase-in to a maximum target fishing mortality of 5.5% by Year 2021 (Cox et al. 2019). Any adjustments to the maximum target fishing mortality rate (described below), therefore, only begin in Year 2022.

## Results

### Stock status

### Simulation model dynamics

We found that 2016 recruitment, estimated to be between X and Y, is a main driver of fishery outcomes in the simulations. The simulated dynamics over the next 10 years were markedly different under the two scenairos. Under the hiRec2016 scenario, we see the spawning biomass increasing rapidly over the first 5 years of the projection period, after which the large year class is recruited to the fishery and fished down (Figure 1). As the large 2016 year class is fished down, biomass trends towards under the feedback harvest MPs, or further up towards unfished, however at a reduced rate, under the No Fishing MP. In contrast, the biomass increases on average over the whole projection, albeit much more slowly, under the simRec2016 scenario (Figure 2). This less optimistic growth is a result of lower on average stochastic recruitment in 2016.

### Management Procedure Evaluation Results

We generated weighted ensemble predictions of MP performance by combing the results from the five reference set OMs and the five robustness set OMs where MP performance was weighted by posterior density estimates at the centres of their posterior samples (Table 2). We present the averaged MP performance from the weighted productivity and biomass scenarios only in the main body of the text, and only the MPs based on the tuned surplus production model AM.

Although the empirical and delay difference model MPs showed promising results, we did not tune them to meet fishery objectives. This was because MPs that used a surplus production model for the assessment method were able to meet all fishery objectives with minimal tuning, and extensive MP development was outside of the scope of this Science Response.

#### Reference set hiRec2016

Given the optimistic recruitment in the reference set of operating models, all MPs considered were predicted to meet conservation objectives 1 through 3 (Table 4). The probability of harvest being below the previous TAC floor of 1.992 kt over the next 10 years was at most 2.65 %, and the average catch over the next 10 years ranged from 3.70 kt to 4.51 kt.

#### Robustness set simRec2016

We found it was difficult to simultaneously meet objectives 2 and 3 under the robustness set of OMs. In these OMs, we found that most MPs failed to meet Objective 2, albeit only marginally so, when was adjusted to meet Objective 3 (Table 5).

As expected, catch performance under the robustness recruitment scenario was worse than the reference scenario. The probability of being below the TAC floor was around 16 - 25 %, except for the full retention MP at 7.6 %, while 10 year average catch ranged between 2.3 kt and 2.8 kt.

#### Sub-legal Discarding Behaviour

In general, more restrictive juvenile release regulations allowed for higher target fishing mortality rates (Tables 4 and 5, ). This was because the TAC was filled faster for each sector in each year, either by a TAC reduction through overages, or the removal of the size regulation. Faster TAC fulfillment meant that fleets were off the water earlier, and release induced mortality was reduced through reduced effort. Indeed, the MP with the highest 2022 mortality rate after tuning to Objective 3 was the full retention (**SP\_frt**) procedure, which counted sub-legal sized fish against the TAC.

Those MPs that had higher harvest rates also had higher total value over the next 10 years (Tables 6 and 7), corresponding to their higher average catch. Income per tonne of fish was very similar among MPs, with the exception of the full retention MP, which had a slightly lower value for direct trap and hook and line sablefish sectors, and a large decrease of about 6 % (approx $1400 per tonne) for the trawl sector. This decrease in income per tonne of fish reflects the larger proportion of juveniles in the trawl catch, given that the trawl fishery has higher selectivity of juvenile sized fish.

Little visual difference in aggregate dynamics between the different cap sizes, given an allocation and amortization period (Figures 3/4). More difference is seen in the discarded value and the overages as a percentage of TAC (Figures 5/6). As expected, overages drop with less restrictive caps, but landed value remains similar (Figures 5/6, tables 6/7). Counter-intuitively, the highest total value fisheries across all sectors are the full retention.

# Conclusions

Current MP does fine. No need to change the harvest rate or the estimation method, and could even increase the harvest rate to closely achieve Objective 3.

# Contributors

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# Appendices

# Appendix A: Updated operating model components

## Updated ageing error matrix

## Trawl Age-Length Key

We defined an empirical age-length key to convert commercial trawl length compositions to age compositions. The reason for this was to effectively increase the sample size of commercial trawl age composition data and improve estimates of selectivity for the commercial trawl fleet.