Evaluating the robustness of candidate management procedures in the BC sablefish (*Anoplopoma fibria*) 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. Transparency and potential sustainability of candidate management procedures (MPs) are demonstrated by simulating MP performance against a set of pre-agreed conservation and socio-economic objectives. Operating models underlying the simulations are intended to represent key uncertainties related to sablefish stock status and productivity. 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; Cox et al. 2013; Cox et al. [2011](#ref-cox2011management), [2019](#ref-cox2019evaluating)) **SDNJ to add (DFO 2014, 2016)**. Canadian Sablefish harvest advice derived from simulation-tested MPs has been adopted and subsequently approved by the Minister of Fisheries 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 demonstrates that low recruitment, on average over the past three decades, has contributed to a long-term decline in spawning stock biomass and harvest opportunities. Extensive 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 "leakage" in sablefish production that, if avoided, could help to increase both spawning stock biomass and future harvest opportunities (Cox at al. 2019).

The DFO Fisheries Management Branch has, therefore, requested that the Science Branch (i) update the Sablefish operating model to include the most recent data available (up to 2018); (ii) update advice about expected performance of the current MP; and (iii) evaluate alternative MP and/or regulation options aimed at reducing productivity losses to sub-legal mortality. The key issue in (iii) is identifying MPs that minimize the impact of such regulations on fishing opportunities in non-directed fisheries (i.e., bottom trawl) where sub-legal sablefish are captured incidentally.

Advice arising from this Canadian Science Advisory Secretariat Science Response will be used to select a new 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, the paper informs fishery managers and stakeholders about the fishery implications of limiting productivity losses due to sub-legal sablefish releases at-sea.

## Mandatory paragraph

*The meeting date and title must be exactly as they appear on the Fisheries and Oceans Science Advisory Schedule. Be sure to use the default text in the French template for the translation as well as the meeting information on the French version of the schedule. Edit the following sentence as necessary.*

This Science Response Report results from the Science Response Process Month Day, Year on the Title of Process Here.

*Add the following sentence if there are other associated publications that will be posted on the schedule.*

Additional publications from this meeting will be posted on the as they become available.

# Background

## Description of the fishery

# Analysis and response

This paper 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 provided for conditioning the sablefish operating model, the changes required to fit that data, and the new management procedure 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 a grid of 5 reference operating models and 5 robustness trial operating models based on uncertainties about Sablefish stock status and productivity (reference OMs) and year 2016 recruitment (robustness OMs);
3. Quantify and rank the relative performance of alternative MPs against updated Sablefish MSE Objectives (see Fishery Objectives section). Management procedure elements to be combined are given in Table 1.

## 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.

A series of small changes were made to the operating model as part of routine attempts to improve fits to various data. Specifically, we (i) changed the functional form of trawl selectivity to a gamma distribution function; (ii) reduced the youngest observed age class from age-3 to age-2 for all age composition series to better reflect age-composition observations; (iii) added new commercial trawl age-composition data (Appendix A); (iv) added an estimated recruitment deviation in 2016 (rather than using the expected recruitment off the stock-recruit curve); (v) updated the ageing-error matrix to use a simpler normal approximation recommended in the previous CSAS review; and (vi) imposed a standard deviation of (on the log scale) on trawl at-sea release observation errors to force a better fit to that data.

### Operating model scenarios

We defined 10 operating model scenarios in total, consisting of 5 reference case scenarios and 5 robustness scenarios. The reference OM set included the operating model estimated recruitment for 2016 year class, which is very large, while the robustness OM set used random draws to simulate the 2016 recruitment.

Reference and robustness OM parameter sets were both derived from the joint posterior distribution of the reference OM fit (except the 2016 recruitment for the robustness OMs) using the same approach as Cox et al. ([2019](#ref-cox2019evaluating)). Specifically, parameter sets were chosen from the joint marginal posterior of 2018 spawning stock biomass (stock status dimension of uncertainty) and stock-recruit steepness (productivity dimension). The 5 reference scenarios were obtained by sampling around the joint marginal mean and 4 outer points arranged uniformly around the edge of a central posterior density defined by a Mahalanobis distance of 0.57 from the joint marginal mean. These outer points define the boundary of the joint 80% credibility interval on stock status and productivity. We attempted to avoid idiosyncratic draws at these 5 specific points (also recommended from previous CSAS review) by sampling 100 posterior draws constrained to lie within a Mahalanobis distance of *0.75 - this should be tested/ plotted* of that point. Simulated MP performance was aggregated over the 5 scenarios via weighted-averaging results based on the empirical estimate of the posterior density at each of the 5 points.

### 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); DFO [2014](#ref-dfo2014performanc)). The five primary objectives guiding this 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 female spawning biomass 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 (as defined by the operating model), limit the probability of decline over the next 10 years from very low (5%) at 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): Achieve at least 50% probability of female spawning biomass being above 0.8 BMSY by Year 2054;
4. P(Catch>1,992): Maximize probability that annual catch levels remain above 1,992 tonnes measured over two sablefish generations;
5. MaxCatch: Maximize the average annual catch over 10 years subject to Objectives 1-4.

### Management procedures

We tested a grid of 43 management procedures, made up of a no fishing procedure and 42 combinations of MP components varied across 4 main axes given by (Table 1) (i) the method used to estimate current biomass and stock status; (ii) the biomass of Under-55 cm sablefish allowed to be released at-sea without penalty; (iii) the allocation of total allowable at-sea releases among sectors; and (iv) the number of years over which at-sea release overages are amortized by subtracting from future Over-55 catch limits. All 42 MPs followed the current management procedure's schedule for reducing the maximum target harvest rate from 9.5% to 5.5% in 0.8% steps over 5 years starting from 2017.

We defined two new estimation procedures in addition to the original Surplus Production model used in the current management procedure for estimating stock status. The first was an empirical index based method, which generates feedback directly from the stratified random survey and the second was a Deriso-Schnute delay-difference model (Deriso [1980](#ref-deriso1980harvesting); Schnute [1985](#ref-schnute1985general)). The details of the estimation models are given in Appendix B. While the delay difference assessment uses the same harvest control rule as the surplus production model, the empirical rule uses a control rule given in Appendix B. The empirical MP was added in an attempt to simplify the annual TAC advice, as well as to further improve transparency.

The 5 schemes for setting total allowable at-sea releases of Under-55 cm sablefish included no limit (the status quo), three limits given as percentages of the historical average total at-sea releases (based on either long-term 2006-2018 or more recent 2016-2018 periods), and full retention (i.e., 0% allowed) where the 55 cm size limit was removed and all sablefish catch was counted against the Over-55 cm TAC, regardless of whether the fish were Under-55 or Over-55. At-sea releases in excess of sector-specific limits for a given year were equally divided among years within the amortization period (5 or 10 years) and then added to sector-specific "overage" accounts. Over-55 TACs in a given future year were then adjusted by subtracting the accumulated overage in that year from the Over-55 TAC on a one-to-one basis (i.e., ignoring the conversion from Under-55 to Over-55 equivalents). When at-sea releases were below the sector-specific limits in a given year, the overage account was reduced by the difference between the realised releases and the allowable limit, down to a floor of 0. The floor, in this case, allocates the benefits of avoidance to future improvements in biomass and subsequent increases in Over-55 TACs, rather than compensating for previous year's TAC losses.

## Results

### Management Procedure Evaluation Results

We combined the results from the five reference set OMs and the five robustness set OMs according to the density estimates at the centres of their posterior samples.

#### Reference set

#### Robustness set

### Sub-legal Discarding Behaviour

# Conclusions

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# Contributors

Mandatory section and title.

|  |  |
| --- | --- |
| Name | Affiliation |
| Sean Cox | Simon Fraser University, BC |
| Sam Johnson | Simon Fraser University, BC |
| Brendan Connors | DFO Science, Pacific Region |

# Sources of information

Cox, S., Holt, K., and Johnson, S. 2019. Evaluating the robustness of management procedures for the Sablefish (*Anoplopoma fimbria*) fishery in British Columbia, Canada for 2017-18. Can. Sci. Adv. Sec. Res. Doc (032): vi + 79 p.

Cox, S., and Kronlund, A. 2009. Evaluation of interim harvest strategies for sablefish (anoplopoma fimbria) in british columbia, canada for 2008/09. DFO Can. Sci. Advis. Sec. Res. Doc 42.

Cox, S., Kronlund, A., and Lacko, L. 2011. Management procedures for the multi-gear sablefish (anoplopoma fimbria) fishery in british columbia, canada. Can. Sci. Advis. Secret. Res. Doc 62.

Deriso, R.B. 1980. Harvesting strategies and parameter estimation for an age-structured model. Canadian Journal of Fisheries and Aquatic Sciences 37(2): 268–282. NRC Research Press.

DFO. 2014. Performance of a revised management procedure for sablefish in british columbia. Can. Sci. Adv. Sec. Res. Doc (025).

Fisheries and Oceans Canada. 2009. Summary of historic catch vs available weight. Pacific region fisheries management: Groundfish.

Schnute, J. 1985. A general theory for analysis of catch and effort data. Canadian Journal of Fisheries and Aquatic Sciences 42(3): 414–429. NRC Research Press.

# Tables

Table 1. Components of candidate management procedures.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **1.Assessment model** | **2. *U*MAX in harvest control rule** | **3. Under-55 release cap[[1]](#footnote-1)** | **4. Allocation of Under-55 release cap** | **5. Overage rule amortization period for Under-55 releases4** |
| 1. Surplus production (status quo) 2. Delay-difference | 1. Continue to 5.5% by 2021 (status quo) 2. Re-tune to meet Objectives 1-3 | 1. No cap (status quo) 2. 0% (full retention) 3. 50% 4. 100% 5. 150% | 1. Recent average (2016-2018) percentages of total Under-55 releases[[2]](#footnote-2) 2. Long-term average (2006-2018) percentages of Under-55 releases3 | 1. 5 years 2. 10 years |

1 as a percentage of historical average total releases across all fleets

2 59%, 23%, and 18% for trawl, trap and hook and line, respectively

3 37%, 30%, and 33% for trawl, trap and hook and line, respectively

4 number of years that overage is amortized; that is, paid back in Over-55 TAC, for example, via reduction in subsequent year’s Over-55 TAC, purchase of Over-55 TAC from other sectors but not fished. Specific details of how these rules work may not be required for simulation, assuming the intended effect of Under-55 caps are realized). For 2019, it may be necessary to simply assume a one-for-one conversion of Sub-55 to Over-55 TAC. Further research and consultation is needed to determine a mutually acceptable conversion rate.

Table 2: Operating model conditioning

Table 3: OM/MP grids

Table 4: Juvenile discarding MP equations

Table 4: Selected results?

We’re going to have to be careful about how we choose tables to show. Will all 43 MPs fit on a page?

# Figures

Figure 1: Show the joint marginal posterior of h and SSB, with 5 scenario centres picked out. Also add colour coding for posterior density within a given Mahalanobis distance of each centre

Figure 2: Not sure yet

# 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.

# Appendix B: New Management Procedures

## Empirical MP

We developed a new empirical MP to test for estimating sablefish stock status and determing TACs. This MP was based on comparing two consecutive 3-year moving averages of the stratified random survey, and calculating the proportional difference between those two smoothed estimates. So, for a given year , we calculated

This proportional change was then used to adjust the relative harvest rate in the most recent year of fishing, which was calculated as the TAC in year divided by the moving average of the index in the final year

The adjustment to the relative harvest rate was dependent on the direction of the proportional change. For increases in the moving average index, the relative harvest rate was increased at the rate , up to a maximum increase of 20% in the relative harvest rate; for decreases in the moving average index, the relative harvest rate was decreased at the rate , down to a floor of a 0% removal rate when . This rule gives the piecewise continuous function

$$

This form of rule is designed to have a fast decrease () in relative harvest rates, and a slow increase in relative harvest rates ().

Finally, the target harvest rate was calculated as the average of the adjusted relative harvest rate, and an overall target harvest rate scaled by a tuning scalar . This was then multipled by the final year’s moving average index to provide a TAC.

Averaging the relative harvest rate and the scaled target rate is meant to stop the harvest rate dropping to zero in response to a large negative change in observations, which could be caused either by a large negative observation error. The scalar is meant to tune the target absolute harvest rate to a relative harvest rate.

This MP has multiple options for tuning parameters. First, the number of points used in the moving average could be used to reduce the influence of year to year noise. Second, the , , and parameters in the harvest control rule can be used to adjust the rate at which harvest rates are changed and the scale of the target harvest rate. Finally, the value of the target harvest rate can be changed to increase or decrease the level of precaution in the MP.

We used tuning parameters , , and , corresponding to a slow-up and fast down MP, with set close to the posterior mean value of the StRS catchability parameter . We then chose as the target absolute harvest rate.

Add example tuning??

## Delay Difference Assessment Model

Our delay difference stock assessment model

Table 1: Unfished and fished equilibrium quantities for the delay-difference population dynamics.

|  |  |
| --- | --- |
| Description | Equation |
| Survivorship |  |
| Average Weight |  |
| Unfished Numbers |  |
| Unfished Recruitment |  |
| Stock-Recruit | , |
| Biomass |  |
| Recruitment |  |
| Yield |  |

Table 2: Process and observation model components of the delay difference stock assessment model used in BC Sablefish management procedures.

|  |  |
| --- | --- |
| X | Model.Equations |
| NA | . |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA |  |
| NA | {Expected biomass indices} |
| NA |  |
| NA |  |
| NA | Observation model deviations |
| NA |  |
| NA | Recruitment deviations |
| NA |  |

1. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)